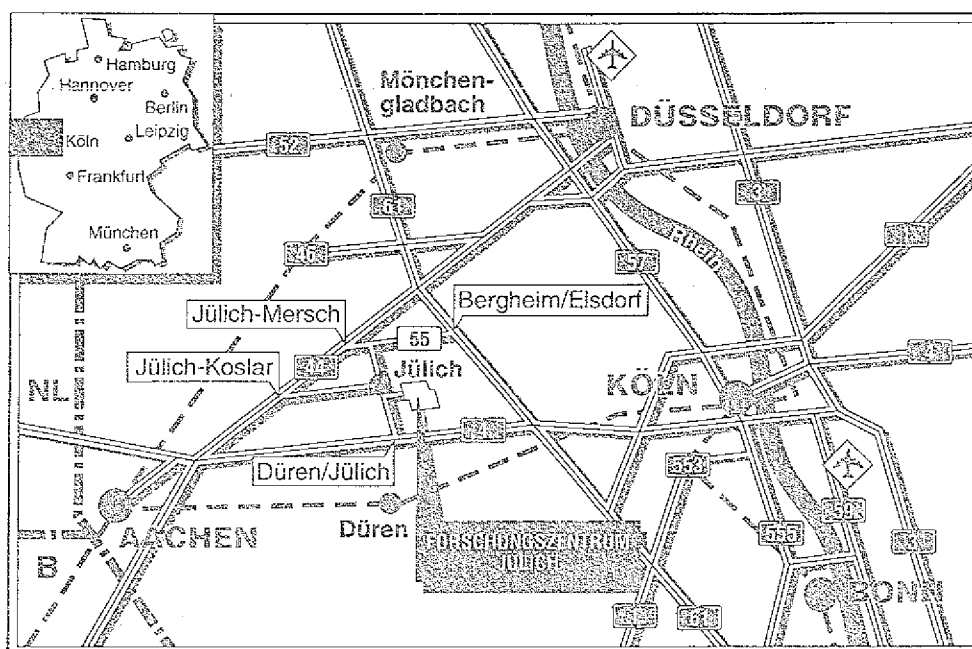


Institut für Kernphysik

**Workshop on
Mesons and Mesonic States
up to slightly above 1 GeV/c²**

Jülich, February 19-20, 1990

Edited by
W. Oelert and Th. Seifick



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**Workshop on
Mesons and Mesonic States
up to slightly above 1 GeV/c²**

Jülich, February 19-20, 1990

Edited by
W. Oelert and Th. Sefzick

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WORKSHOP
on
MESONS and MESONIC STATES
up to slightly above 1 GeV/c²

The new accelerator COSY-Jülich will provide protons with momenta up to 3.3 GeV/c. Thus an effective mass slightly above 1 GeV/c² can be produced in the pp-interaction. Employing higher mass targets also heavier mesons can be observed. The production of single mesons and of mesonic states with and without strangeness can be investigated at COSY.

The structure of some mesons in the mass range of 950 MeV/c² to 1020 MeV/c² is still not well understood. While the $\phi(1020)$ at the upper limit of this range is believed to be of rather pure $s\bar{s}$ nature the content of the $\eta'(958)$ meson at the lower limit of this range is still under discussion. New results suggest that what is called the f_0 meson (former notation S^*) consists in reality of two close and narrow states; one of them being a $s\bar{s}$ - quarks configuration while the other should be a flavour singlet which couples to $\pi\pi$ and $K\bar{K}$ with similar strengths. Also the discussion on possible gluonium candidates is still alive. It is speculated that some of these mesons - till now supposed to have widths of 30 to 50 MeV/c² - could rather be an overlay of structures with much smaller widths. Another feature of resonances in this region is their partial decay into the $K\bar{K}$ channel if their actual mass is large enough. Strong decays in $K\bar{K}$ could be a signal of a $K\bar{K}$ "molecular" nature of the resonances. In particular the atomic K^+K^- structure should exist.

In order to have a review of the physics related to these problems there was a workshop held on :

MESONS and MESONIC STATES up to slightly above 1 GeV/c²
at the ZEL - Forschungszentrum - Jülich
February 19 to 20, 1990

The following contains copies of the shown transparencies and short write-ups as far as available.

We would like to thank the "Vorstand des Forschungszentrums Jülich", especially Professor Dr. J. Treusch, for supporting this workshop and our research.

We appreciate the hospitality of the Zentrallabor für Elektronik (ZEL) letting us use their lecture hall and taking care of lots of details.

Finally we would like to thank all people contributing with presentations and for aid in organizing the workshop.

All this allowed us to have two days of stimulating discussions.

Jülich, September 1990

Workshop on
Mesons and Mesonic States
up to slightly above 1 GeV/c²

at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich - KFA
February 19. - 20. 1990

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I)

W. Oelert

Introductory Remarks

COSY-COoler-Synchrotron

an dem FORSCHUNGSZENTRUM JÜLICH
KFA
IKP

mit Phasen - Raum - Kühlung

für Protonen

Eigenschaften :

*

Hohle Strahl = Dichte

*

großer dynamischer Bereich :

bis

40 MeV
2.5 GeV

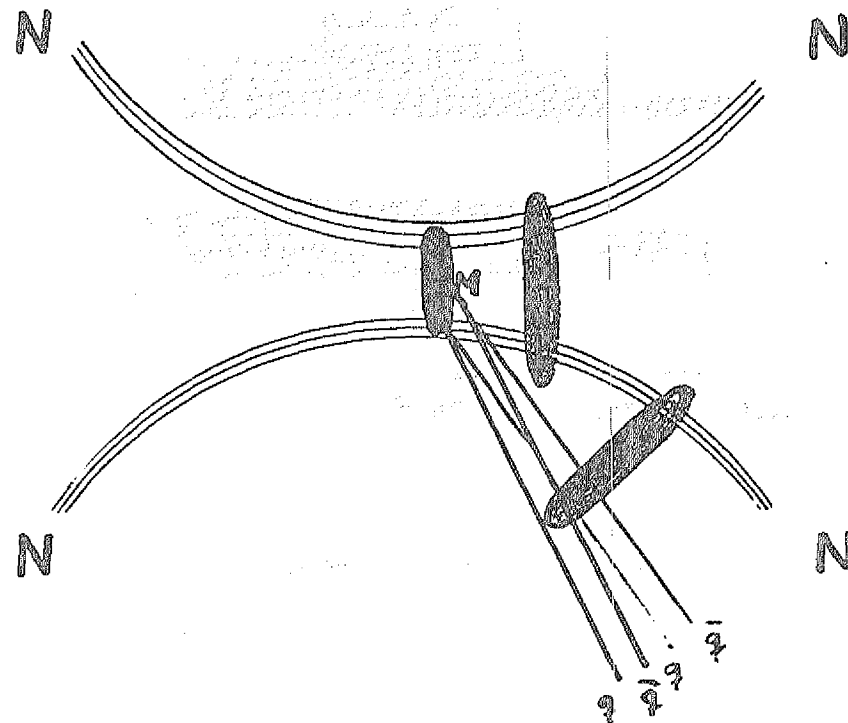
Injektion

*

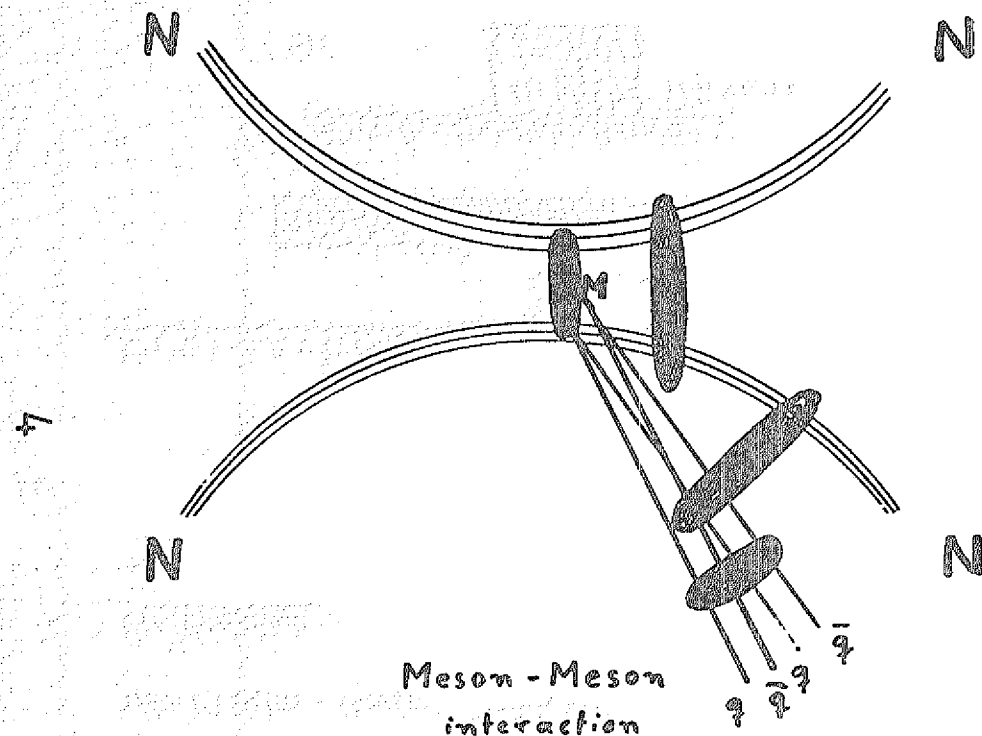
Experimente am internen
wie am externen Strahl

*

Flexible Ionen-Optik durch große
gerade Sektionen mit Teleskopstruktur



$$\text{cosy: } M \leq \sim 16 \frac{\text{GeV}}{c^2}$$



COSY: $M \leq \sim 1.6 \text{ GeV}$

COSY Proposals :

- 1) Spectroscopy of Light Hyper-Nuclei
Ernst
- 2) A Production at Rest by Means of the $^4\text{He} (p, ^4\text{He}K^+) A$ Reaction at 1 GeV
Ernst
- 3) Study of the Parity-Violation in the Proton - Proton Scattering at 230 MeV and 1500 MeV
Eversheim
- 4) Extensions to the Experimental Facilities of COSY by a Polarized Proton- and Deuteron - Beam
Eversheim
- 5) A Study of $p-p$ Excitation Function and Search for Dibaryonic Resonances
Hinterberger
- 6) A Precision Study of Near-Threshold Two-Meson Production via the Reactions

$p + d$	$\rightarrow$	$^3\text{He} + \pi^+\pi^-$
	$\rightarrow$	$^3\text{He} + K^+K^-$

Jahn
- 7) Proton Induced Deuteron Break-Up
Jarczyk, Strzalkowski

8) **Study of Neutral Mesons in Nuclei with a Two Arm Photon Spectrometer**
Koch

9) Investigation of Proton-Proton Bremsstrahlung
Kuhlmann, Morsch

10) Experimental Investigation of Low-Lying States of Pionic Atoms at COSY- Jülich
Machner

11) **Threshold Meson Production at the Internal COSY Beam in the Range of Scalar Mesons Involving Strangeness**
Oelert

12) **Study of η and η' Production and Interaction**
Roderburg

13) Production of Very Heavy Λ -Hypernuclei at Energies Below the Nucleon-Nucleon Threshold
Schult

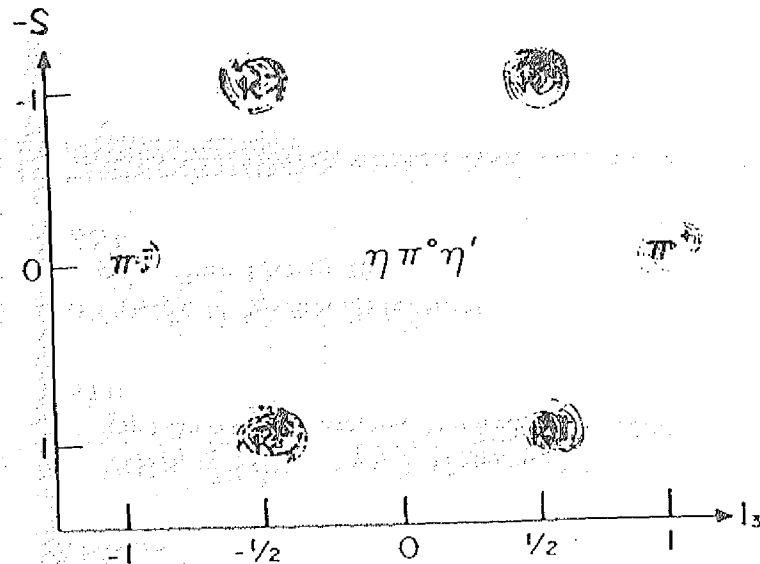
14) Systematics of Double Differential $\Lambda(p, xn)$ Cross Sections in the Medium Energy Range
Scobel

15) **Associated Strangeness Production in pp - Reactions**
Turek

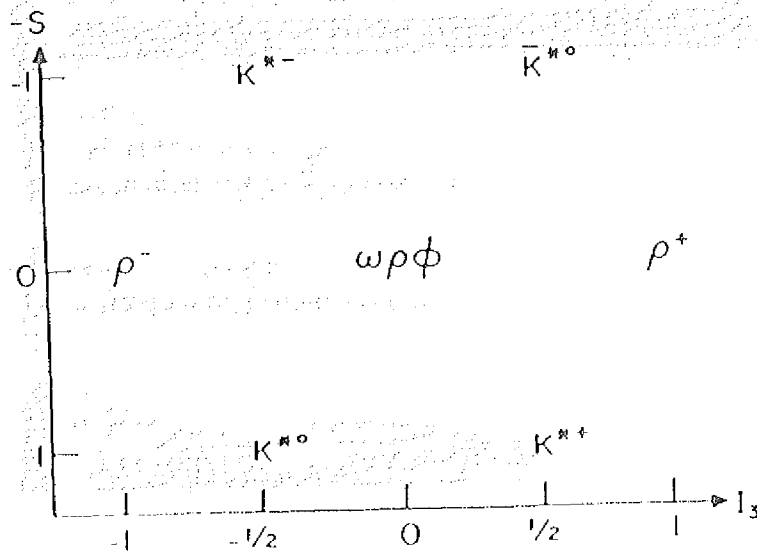
16) **Study of Selective Excitations of Baryon Resonances**
Morsch

17) Measurements of Electromagnetic Moments of the Δ - Resonance
Morsch

18) **Threshold Physics Facility at TP2 in COSY**
Sistemich



ein Nonet mit
antiparalleler Spinstellung der Quarks
 $J^P = 0^-$; pseudoscalare Mesonen

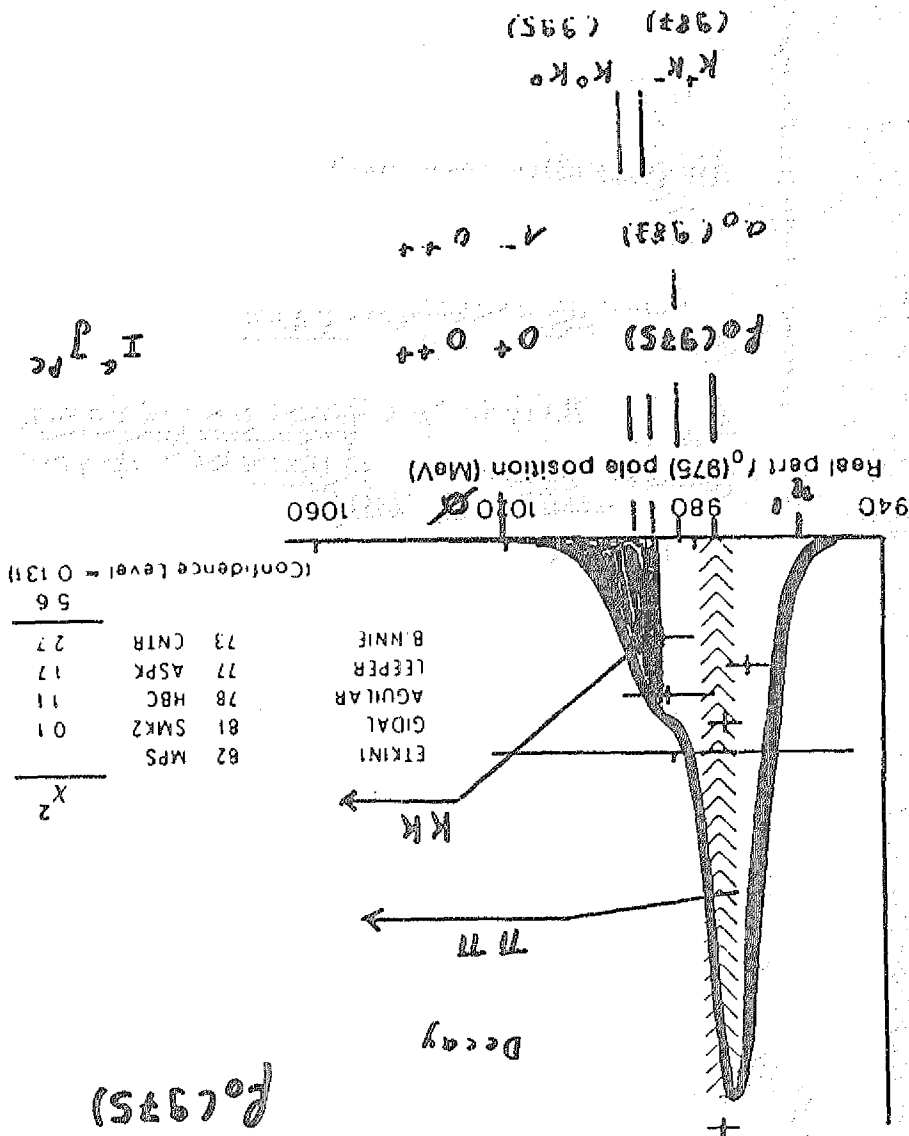


ein Nonet mit
paralleler Spinstellung der Quarks
 $J^P = 1^-$; Vektormesonen

PP → PP M

M meson	mass (GeV/c ²)	threshold	
		P_{beam} (GeV/c)	E_{beam} (GeV)
π^0	0.135	0.777	0.280
$\pi^\pm$	0.140	0.792	0.290
$\pi^+\pi^-$	0.279	1.219	0.600
$\pi^+\pi^-\pi^0$	0.419	1.617	0.931
η	0.549	1.986	1.258
$\pi^+\pi^-\pi^+\pi^-$	0.558	2.012	1.283
$\eta \pi$	0.688	2.390	1.629
$\pi^+\pi^-\pi^+\pi^-\pi^0$	0.698	2.418	1.655
ρ	0.770	2.632	1.856
ω	0.783	2.670	1.892
$\eta \pi \pi$	0.828	2.807	2.021
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$	0.837	2.836	2.048
$\rho \pi$	0.905	3.043	2.246
$\omega \pi$	0.918	3.084	2.285
η'	0.958	3.208	2.404
f_0	0.975	3.263	2.457
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-\pi^0$	0.977	3.269	2.463
a_0	0.983	3.288	2.481
K^+K^-	0.987	3.302	2.494
$K^0\bar{K}^0$	0.995	3.327	2.519
ϕ	1.020	3.404	2.593

976.4 = 3.7 (ERROR SCALED BY 1.4)



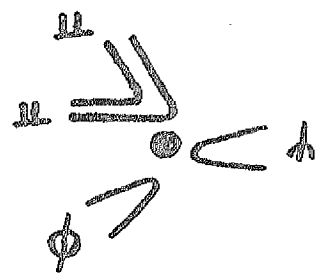
These summarizes the situation in the 1 GeV mass range:

"circumstantial evidence for gluonic component have recently emerged:

$\psi \rightarrow \phi \pi^+ \pi^-$ doubly forbidden (OZI rule)

good glueball signal:

$\psi \rightarrow \phi G; G \rightarrow \pi^+ \pi^-$.



$S^*(975)$ (f_0) a sharp and clear bump here.

Data on $pp \rightarrow pp + \pi\pi$:

clear indication of the S^* presence as a shoulder in the data.

two signals in the S^* region:

$S(988)$ contains $s\bar{s}$ quarks

whereas $S(993)$ is a flavour singlet

(coupling to $\pi\pi$ and KK with similar strengths)

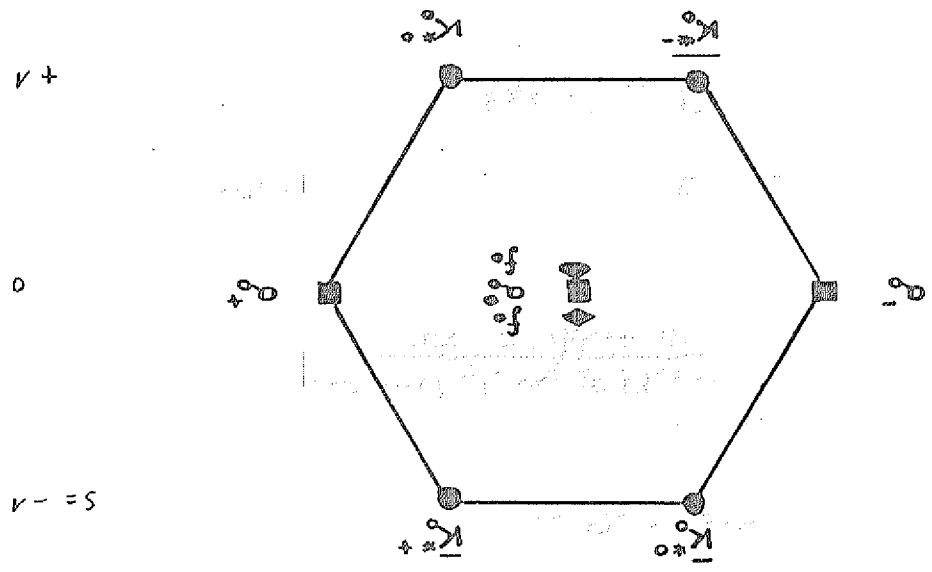
and a possible gluonium candidate."

In qualitative agreement
 Allow :

f_0 two close and narrow states

(988) is likely to be a bound state of kaons,
(991) couples equally to pion and kaon pairs,
as expected for a glueball.

Issue : Number of $I=0$ states
in a given mass region



O^{++} Multiplet

$S = -1$

0

$+1$

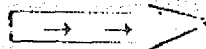
J. Weinstein

N. Isgur

1989 :



simple $q\bar{q}$ mesons unlikely



$K\bar{K}$ molecule interpretation of f_0 a_0
in a $q q \bar{q} \bar{q}$ system

What would be the signature of

GLUE ?

Quantumnumbers

$0^{++} > 0^{-+} > 2^{++}$ | ggg

$0^{--} > 1^{-+} > 2^{--}$ | ggg

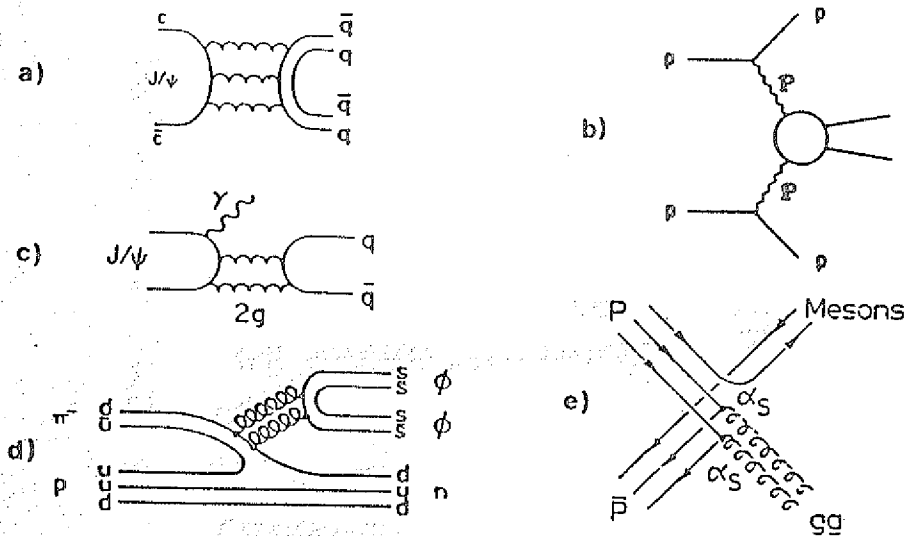


Figure 2: Dynamical configurations used, at present, to study light hadron spectroscopy in a search for glueball states.

$$pp \rightarrow ppX$$

hadronic interactions $\rightarrow \pi\pi$ and KK systems

four quark structures vs. two meson model
gluonic contributions

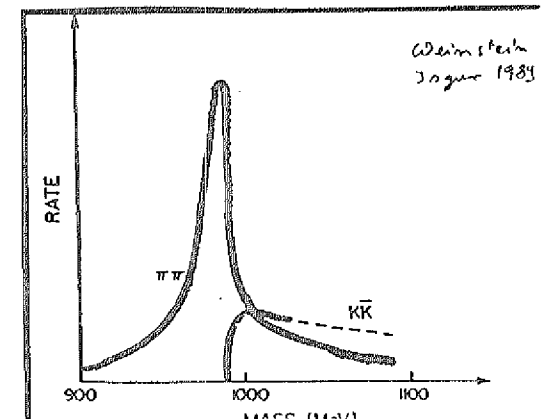
electromagnetic interactions $\rightarrow \pi\pi$ and KK systems
 $\rightarrow \pi - N$ and $K - N$ systems

rather sharp and sharp resonances
the onset behaviour and the width

$\rightarrow \rightarrow$ necessary:

threshold measurements (small angles)
with
high precision

$X =$ two mesons
effects of these
two mesons
in
 $pp - \gamma$ system visible



$pp \rightarrow ppX$

hadronic interactions $\rightarrow \pi\pi$ and KK systems

four quark structures vs. two meson model

phonic contributions

electromagnetic interactions $\rightarrow \pi\pi$ and KK systems

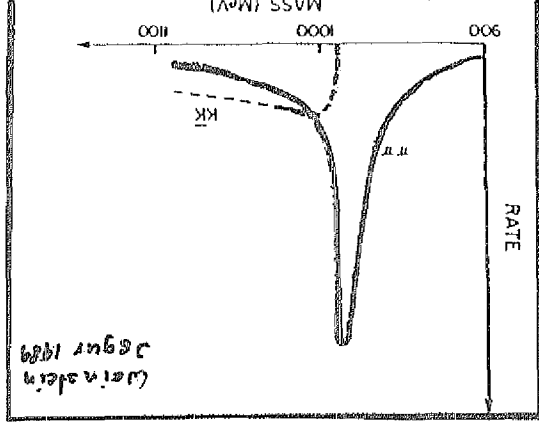
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two mesons
in
 pp -system visible



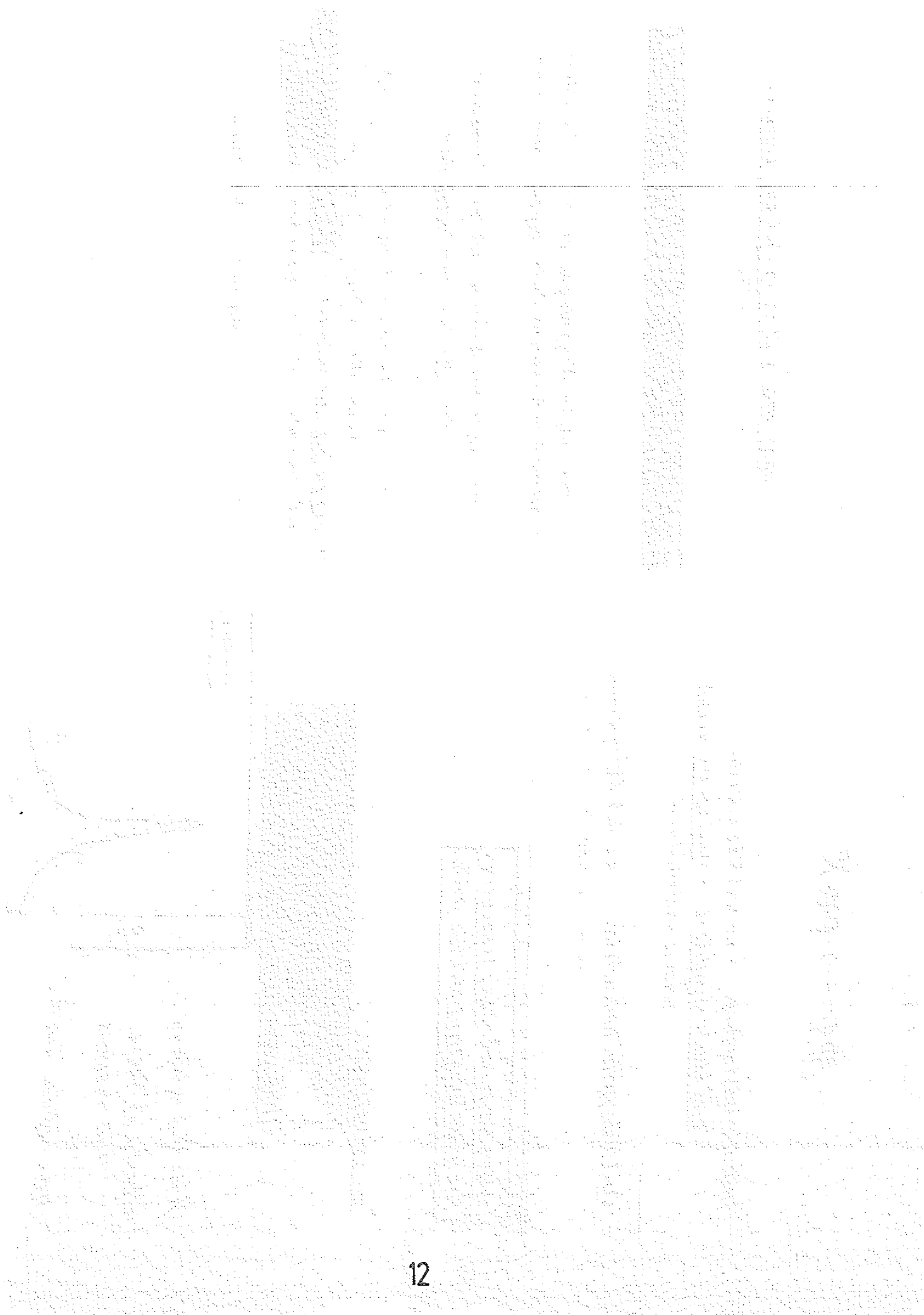
Thank you to those helping to make things go well

Thank you to the board of directors of the KFA
especially to Prof. J. Treusch
for supporting our activities in intermediate energies
and especially now for supporting this workshop

Thank you to all speakers for taking the effort
to prepare and present their research and results.
Thank you to the director and the administration
of the ZEL for their hospitality.

Workshop on Mesons and Meson States

Thank you to all of you for participation
at the



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II)

S. Martin

Beam Properties of COSY



- o HISTOR. REMARK
- o EXP. - MACHINE
- o MAIN PARAMETERS
- o Experiments, Luminosities, Exp. Areas
- o Experiment Planning
- o int. targets
- o (Extraction)
- o MODES , LIMITS

1982

Bad Honnef Workshop Summary

Purpose. - regional plan for 1985-1995...
- must agree on energy and particle and ΔE
EXP + CANU compromises! keep talking together!

Resources - people - possible spallation source
- Big Karl - ideas!

KFA

Cooling Technology - proven: $20 < T_p < 200 \text{ MeV} \rightarrow (400)$
LEAR - CELSIUS - TSR - ESR - INS - good R+D to build on

6Tm A Cooled Synchrotron? $< 30 \text{ nA} >$ thrupt 20% Df

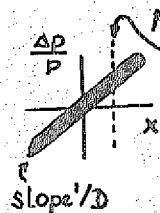
LEAR - ESR Same ring can cool and accelerate Lattice?
Better with separated rings? resolving Limit

2Tm An Uncooled Recirculator? assist + encourage!
quick way to get selective improvement + design experience

H_2^+

better brightness allows higher data rate
at given resolution in principle accel.?
coul.?

15



More Questions

fibre targets?

slit-free cleanup with e. beam edges?

heavy ion cooling?

500 eV with high luminosity?

xtraction of cooled beam?

stacking

small angles

variable dispersion
lattice?

Remarks on Workshop Environment
an excellent meeting

experiment

machine

stripp. injection $\rightarrow \beta_x \times \beta_y \rightarrow \min.$
recirculation at stripping foil

exp. areas for $\rightarrow$ straight sections
internal targets open c-magnets

fiber targets $\rightarrow \beta_x, \beta_y \rightarrow \max.$
 0° -measurement

mom. resolution $\rightarrow D/\sqrt{\beta}$ vary

e-cooling $\rightarrow D$ small $D = \sigma$
 β large β small

int. target $\rightarrow$ stoch. cooling
heating

duty cycle for $\rightarrow$ stochastic
extracted beams extraction

(1) .. 5 - 10 sec

COSY

Main parameters of COSY

circumference	183.47 m
bending radius of dipoles	7.0 m
dipole-field	
at injection of 40 MeV protons	0.13 T
at max. energie of 2.5 GeV protons	158 T
field ramp	1 T/s
length of cooling section	8.0 m
length of internal target TP 1	4.0 m
β -function at target TP 1	
horizontal:	$0.3 \text{ m} < x < 80.0 \text{ m}$ (5)
vertical:	$0.4 \text{ m} < z < 80.0 \text{ m}$ (6.7)
dispersion at target TP 1	$0.0 \text{ m} < D < 60.0 \text{ m}$
cooled emittance	$x \text{ and } z < 0.2 \text{ mm mrad}$
	$dp/p < 0.1\%$ 5
acceleration frequency ($h=1$)	0.46 MHz-1.6 MHz
vacuum	$< 10^{-10} \text{ mbar}$

ASI COSY

ccmainpara

Beam Parameters

COSY ring:	
periodicity:	6 (FDDF or DFFD) 0.3/4.3
horiz./vert. tune:	3.87/4.12
Q_{tr} :	2.39
aperture radius:	
horiz./vert.:	70/30 mm
horiz./vert. acceptance:	
(FDDF)	50/16 $\pi \text{ mm mrad}$
(DFFD)	180/36 $\pi \text{ mm mrad}$
$\Delta p/p$:	
(FDDF)	$\pm 0.53\%$
(DFFD)	$\pm 0.42\%$
β_x/β_y at TP1 ($D=0\text{m}$):	
(FDDF)	5/6.7 m
(DFFD)	1/2.2 m
β_x/β_y at TP2 ($D=0\text{m}$):	
(FDDF)	2/4.4 m
(DFFD)	8/1.4 m

Date: 1-March-1989

COSY - Jülich

beamparam22p

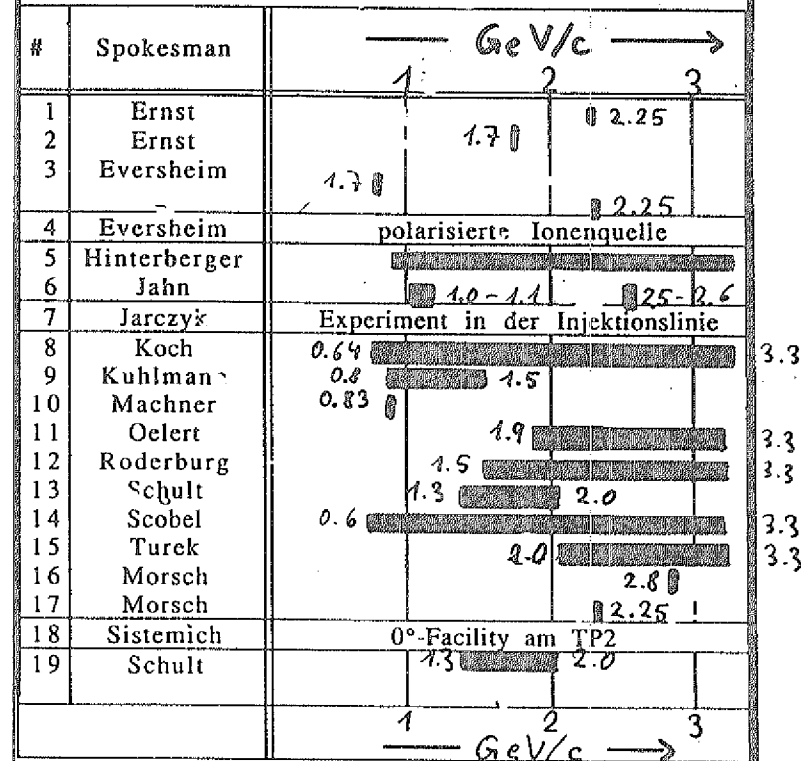
Experiment-Anforderungen

an den COSY-Strahl

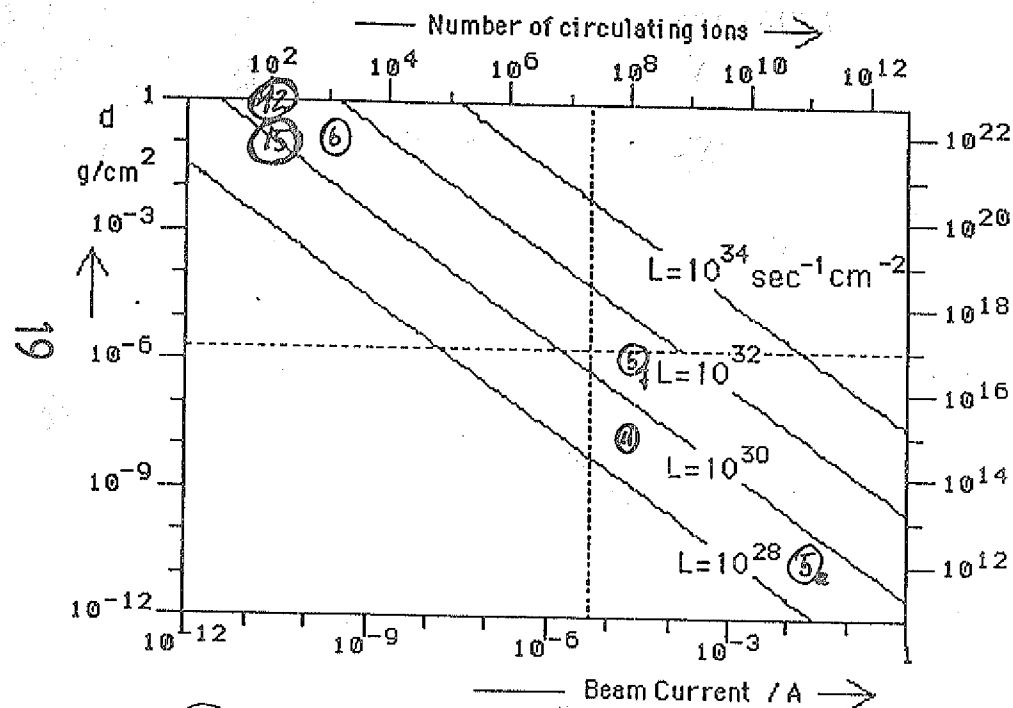
#	Spokesman	int.	ext.	Intens. [pps]	cool	ε	$\Delta p/p$
1	Ernst		BK	$2 \cdot 10^9 - 10^{10}$	(s)	1π	10^{-4}
2	Ernst		BK	$2 \cdot 10^8 - 10^9$	(s)	1π	10^{-4}
3	Eversheim		Pol.	$6 \cdot 10^{10}$	---	8π	
4	Eversheim		polarisierte Ionenquelle				
5	Hinterberger	TP2		$10^6 - 10^7$ $- 10^{11}$	(s)	$< 5 \pi$	
6	Jahn		BK	$10^9 - 5 \cdot 10^9$	s	$< 1 \pi$	
7	Jarczyk		Experiment in der Injektionslinie				
8	Koch			$10^{10} - 10^{12}$	---		
9	Kuhlmann		TOF	$10^7 - 10^9$	(e)		
10	Machner		BK	$5 \cdot 10^8 - 10^{10}$	e		10^{-4}
11	Oelert	TP3		10^9	s	0.7π	10^{-4}
12	Roderburg		TOF	$10^7 - 10^9$	s		
13	Schult	TP2		$10^9 - 10^{11}$	---		
14	Scobel		"TOF"	$10^8 - 10^{10}$	---		
15	Turek		TOF	$10^8 - 10^9$	c+s		10^{-4}
16	Morsch		BK+TOF	$10^9 - 10^{10}$	---		
17	Morsch		TOF	$5 \cdot 10^9$	---		
18	Sistemich	TP2			---		
19	Schult	TP2		$10^9 - 10^{11}$	---		

COSY - Jülich

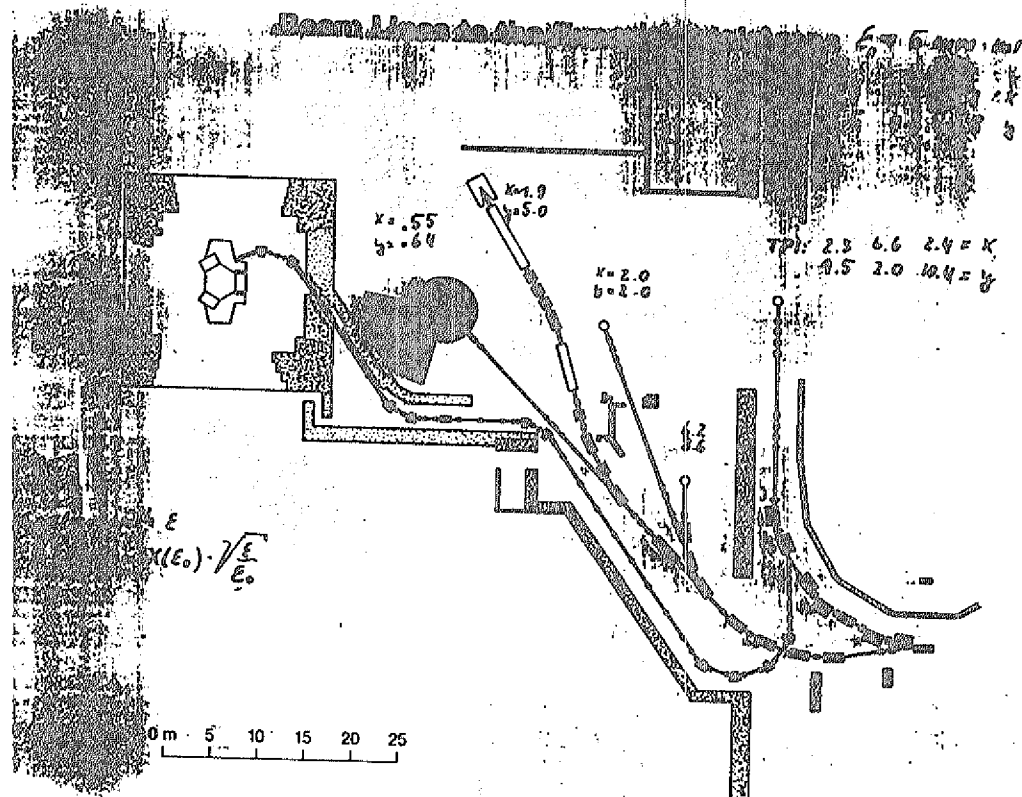
Von den Experimenten gewünschte Strahlimpulse



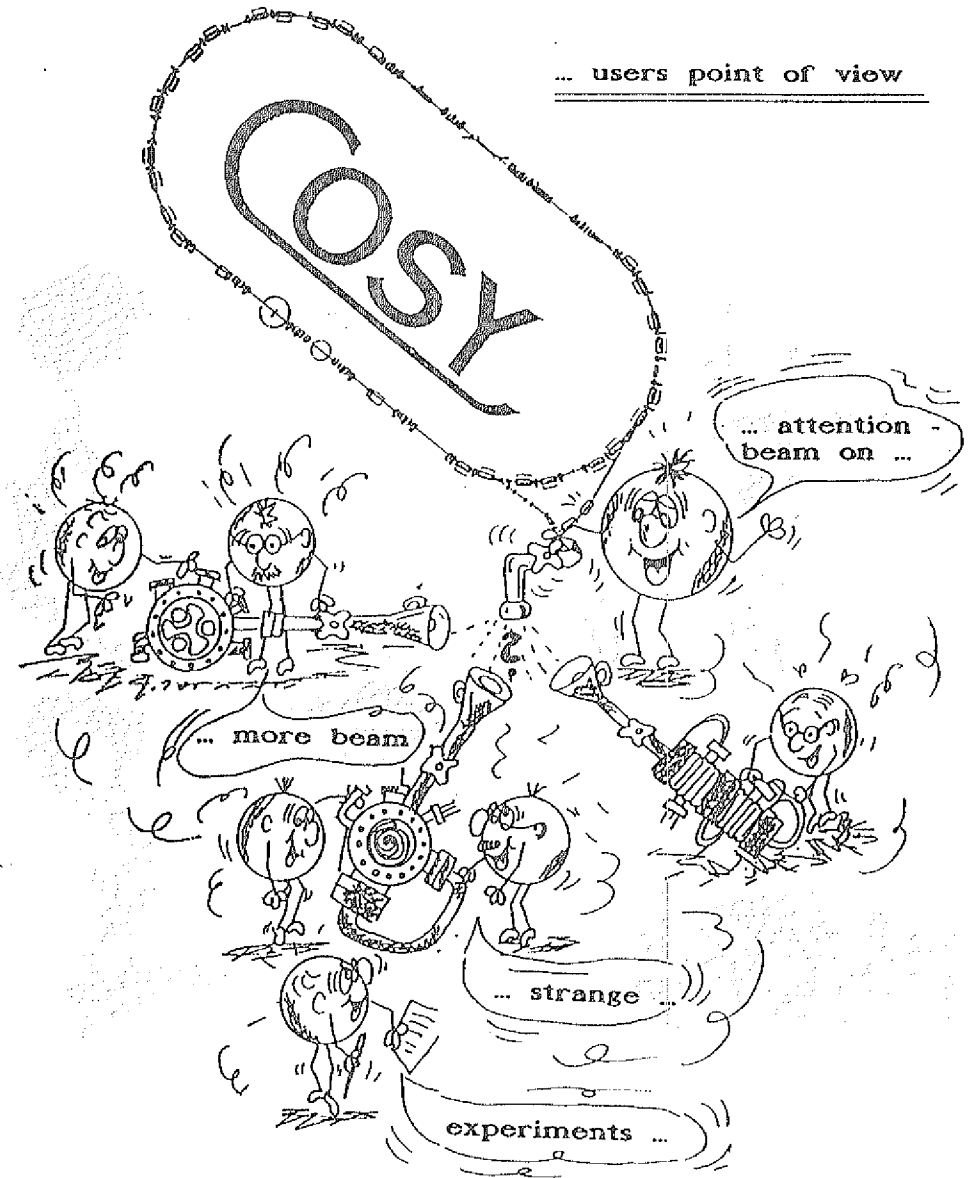
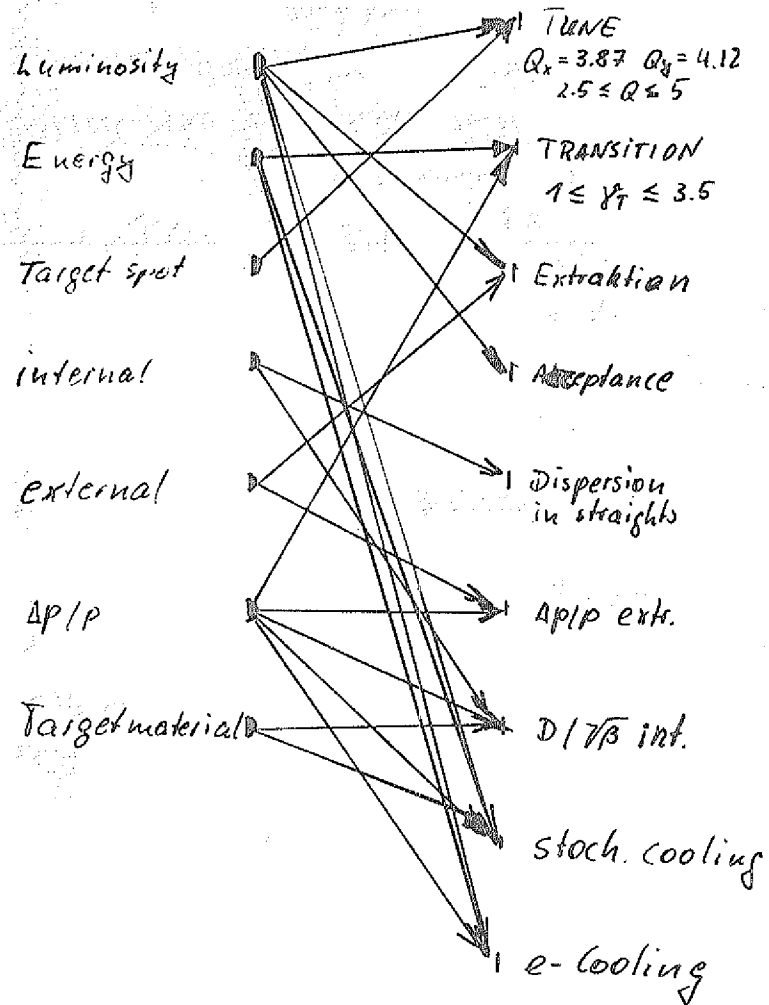
COSY - Jülich



- (12) Thresh. meson production Oelert
- (5_f) (p,p) excitation, fiber Winterberger
- (5_a) " " atomic beam "
- (12) ($\gamma \gamma'$) production Roderburg
- (15) Associated Strangeness Turck
- (6) $p+d \rightarrow {}^3\text{He} + \pi^+ \pi^-$
 $K^+ K^-$ Jahn



how to find a working point



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III)

M. Pennington

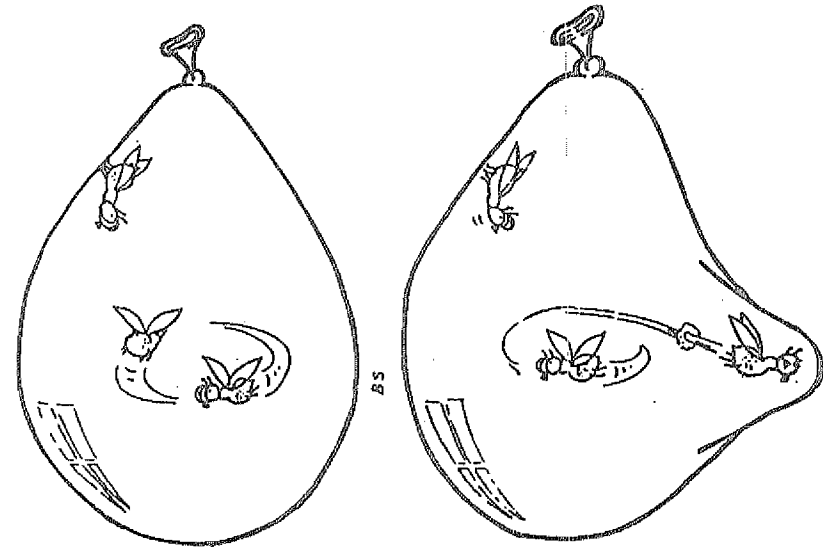
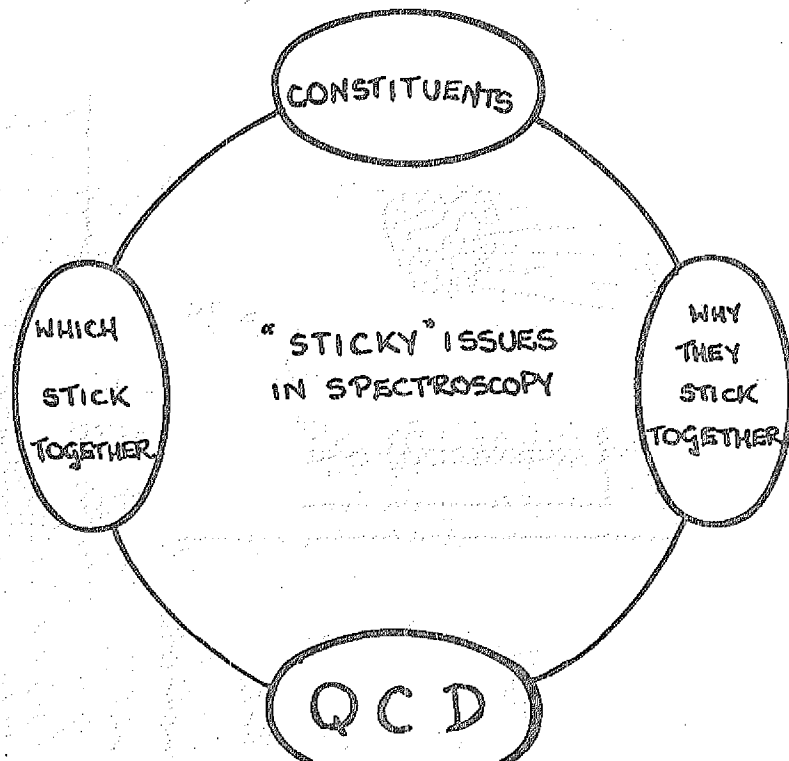
Search for Light Scalar Mesons

COSY

SEARCH FOR
SCALAR MESONS
IN 1 GeV REGION

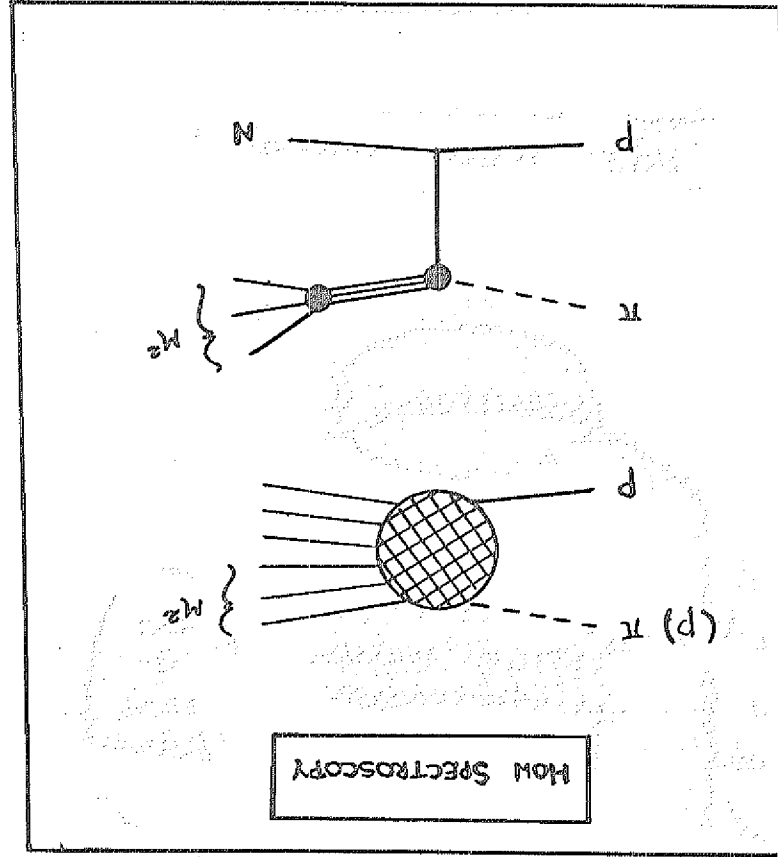
WHY SPECTROSCOPY

23

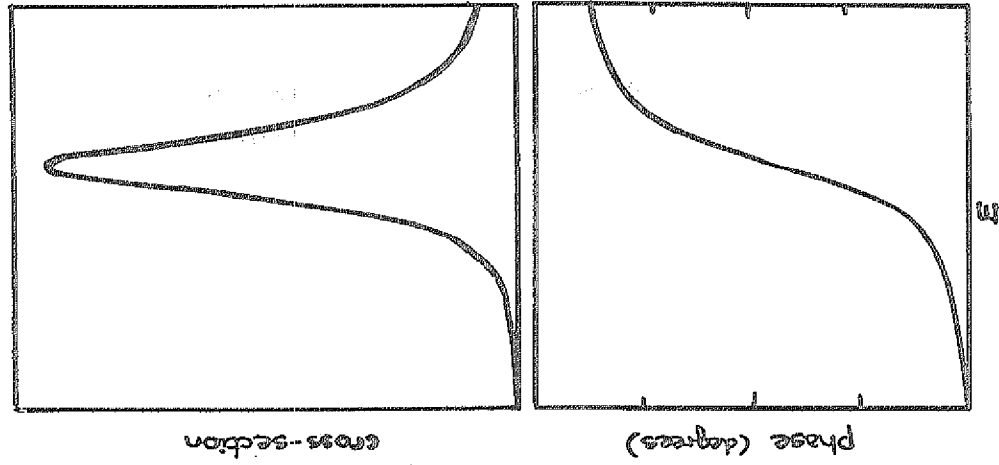
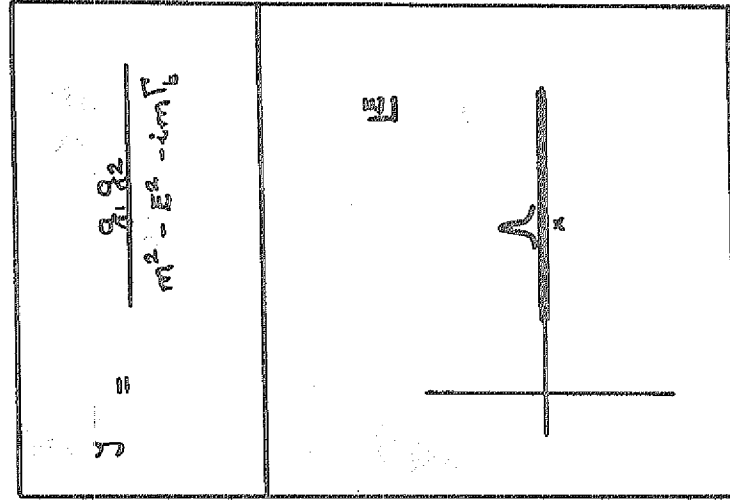


New technology

the theory
of the

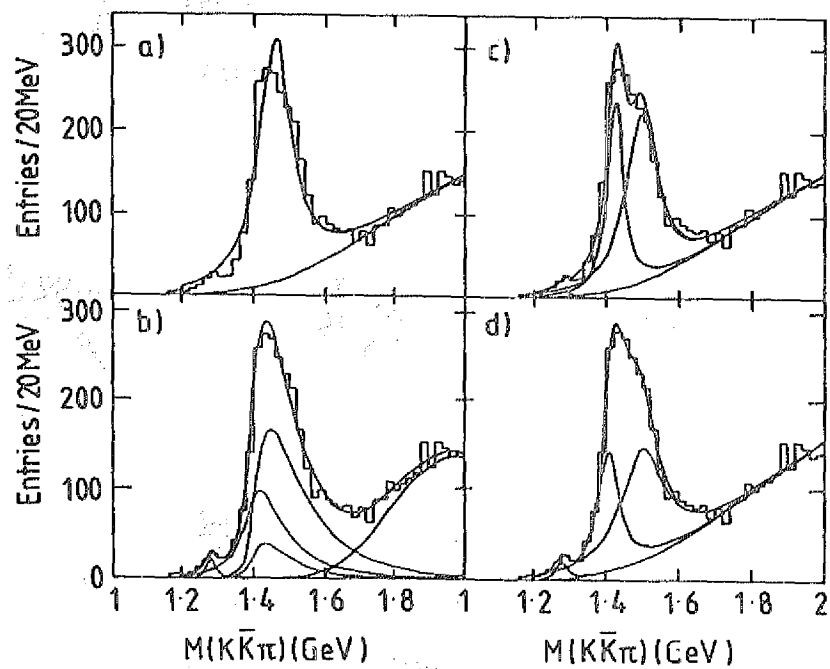


24



Resonances plus background

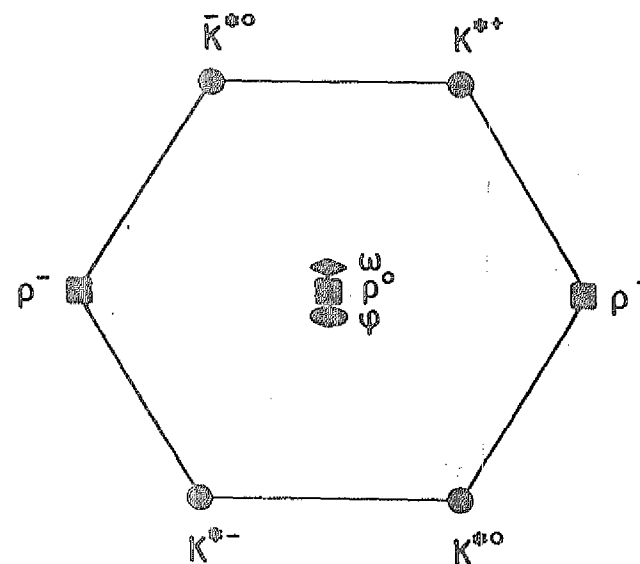
How many states?



$I \quad J^{PC}$

$(q\bar{q}) \quad L=0, S=1$

1^{--} Multiplet



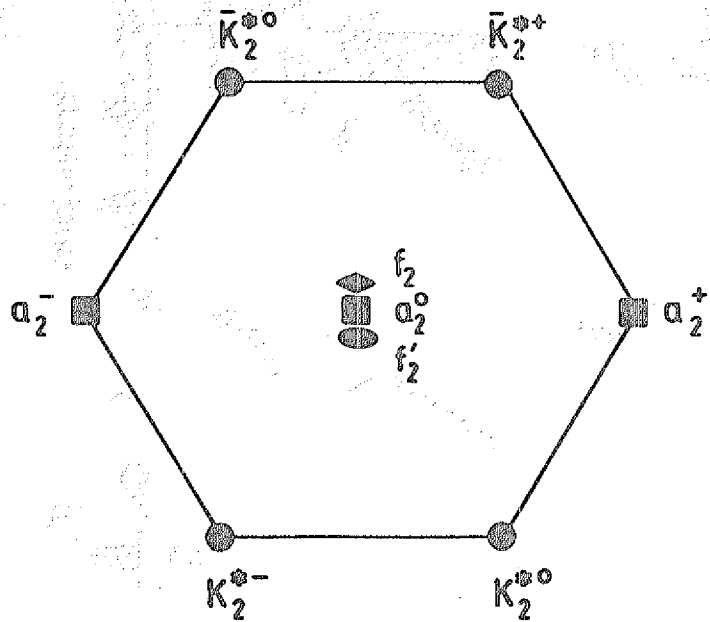
$I=0$

$$\omega = \frac{1}{\sqrt{2}} (u\bar{u} + d\bar{d})$$

$$\phi = s\bar{s}$$

$(q\bar{q}) \quad L=1, S=1$

2^{++} Multiplet

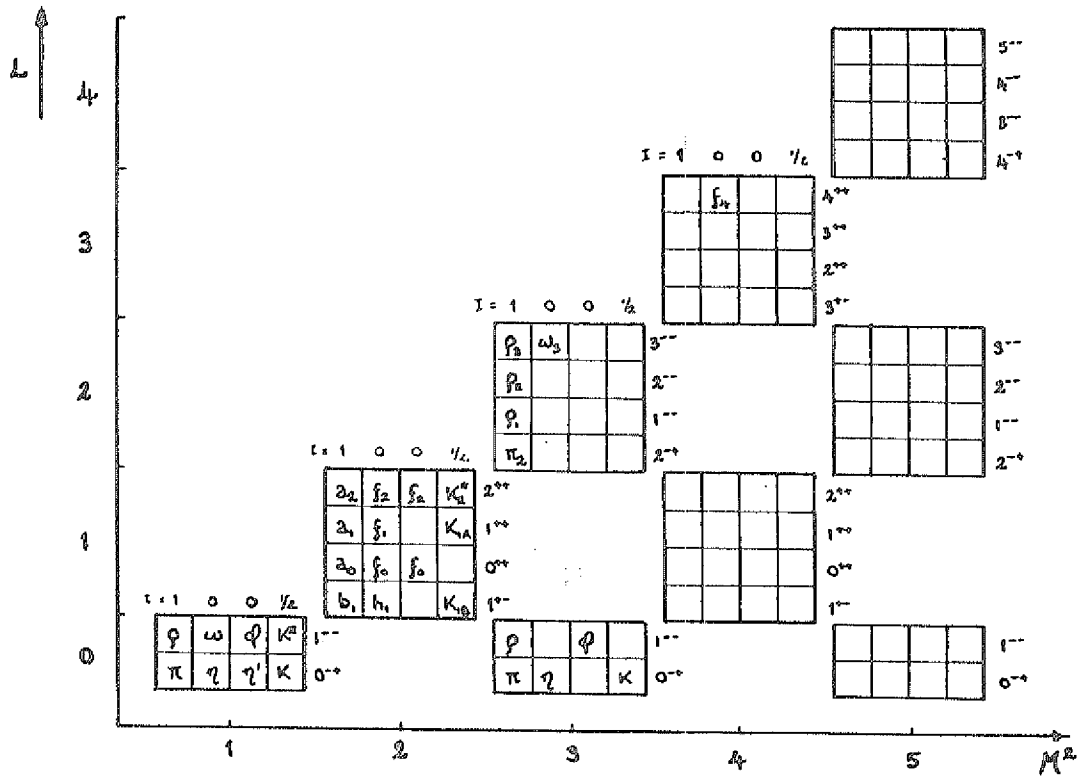


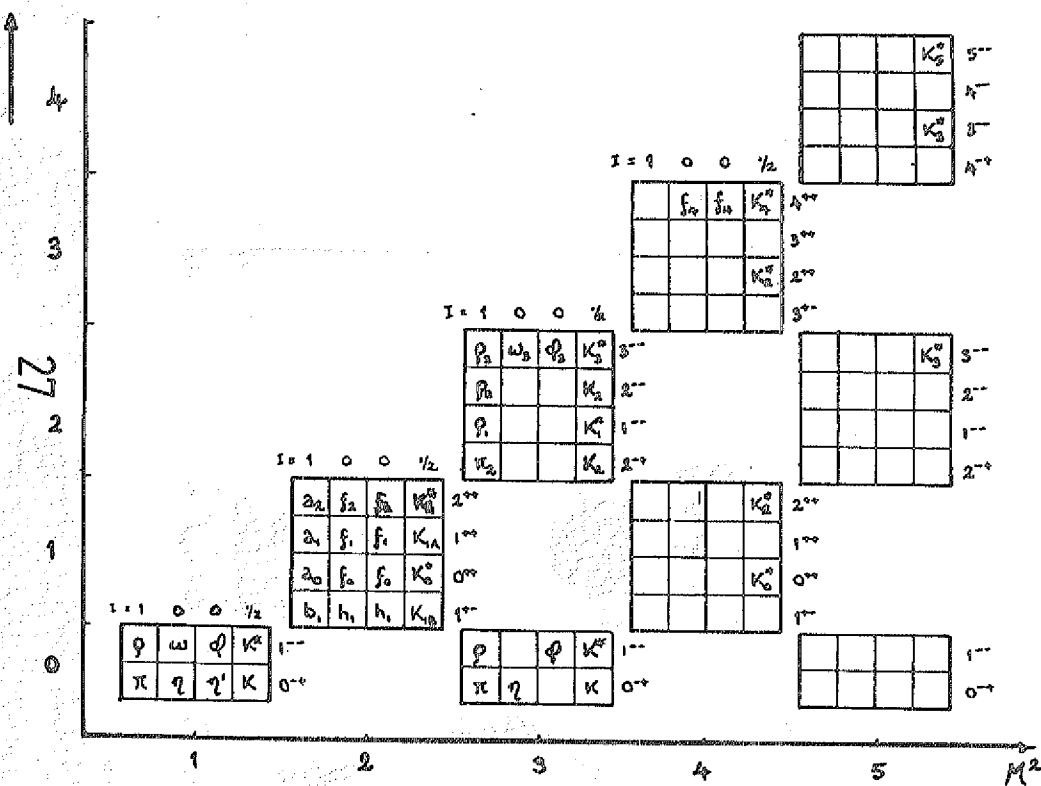
$I=0$

$$f_2(1270) = \frac{1}{\sqrt{2}} (u\bar{u} + d\bar{d})$$

$$f_2(1525) = s\bar{s}$$

Gell-Mann Okubo : $m_{K^*} - m_{a_2} = m_{f_2'} - m_{K^*} \quad \checkmark$





Hadrons - Colour Singlets

9

1000

3

1000

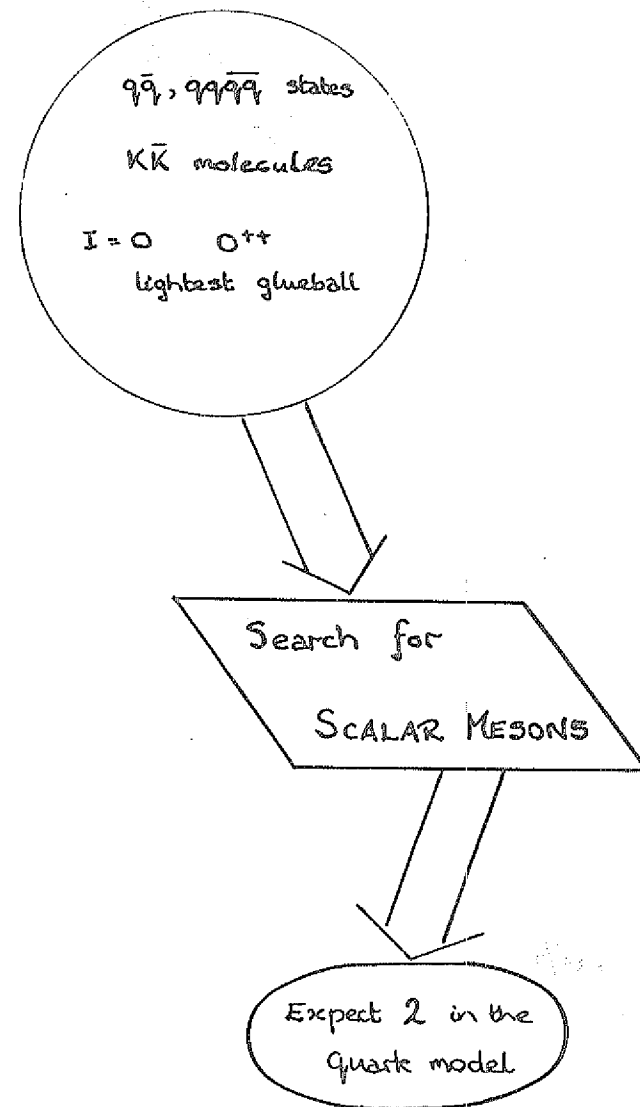
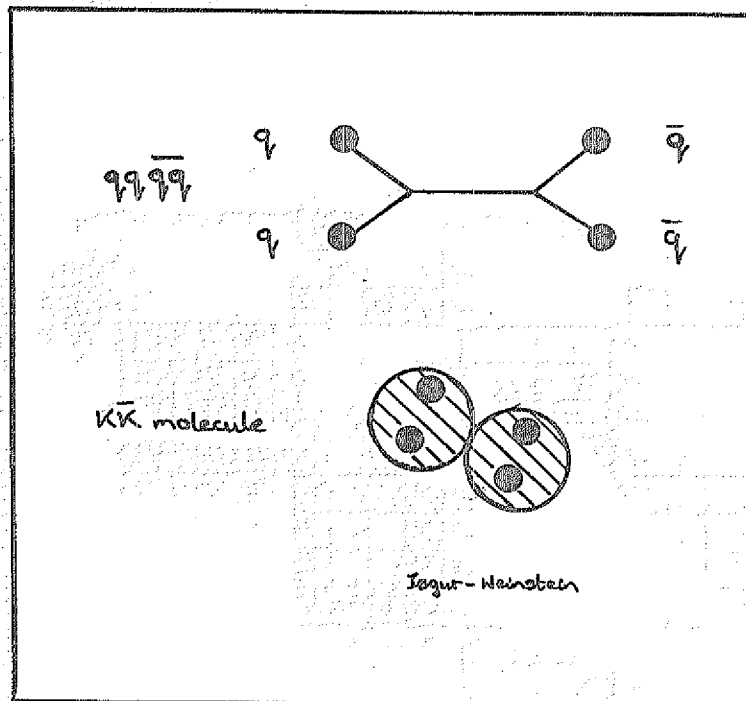
Mesons: $\bar{q}q = \bar{3} \otimes 3 = 8 \oplus 1$

Baryons: $9 \otimes 9 \otimes 9 = \underline{3} \otimes \underline{3} \otimes \underline{3} = \underline{10} \oplus \underline{8} \oplus \underline{8} \oplus 1$

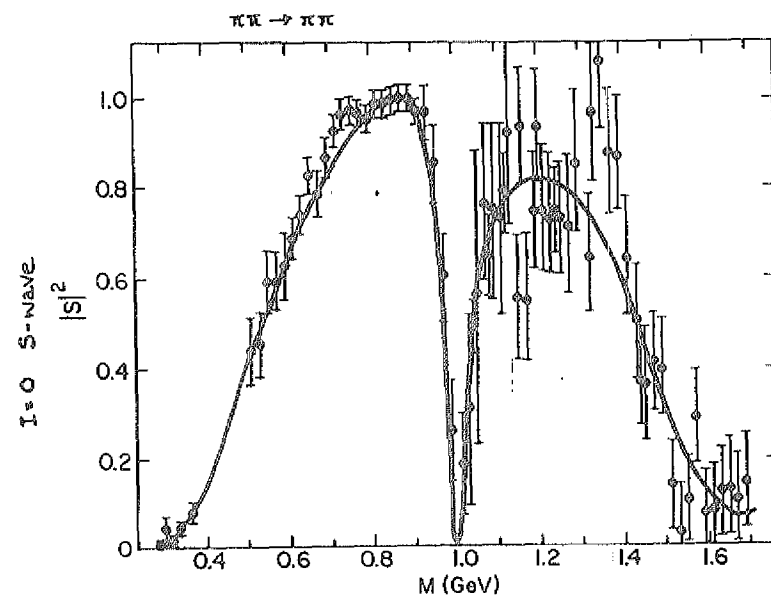
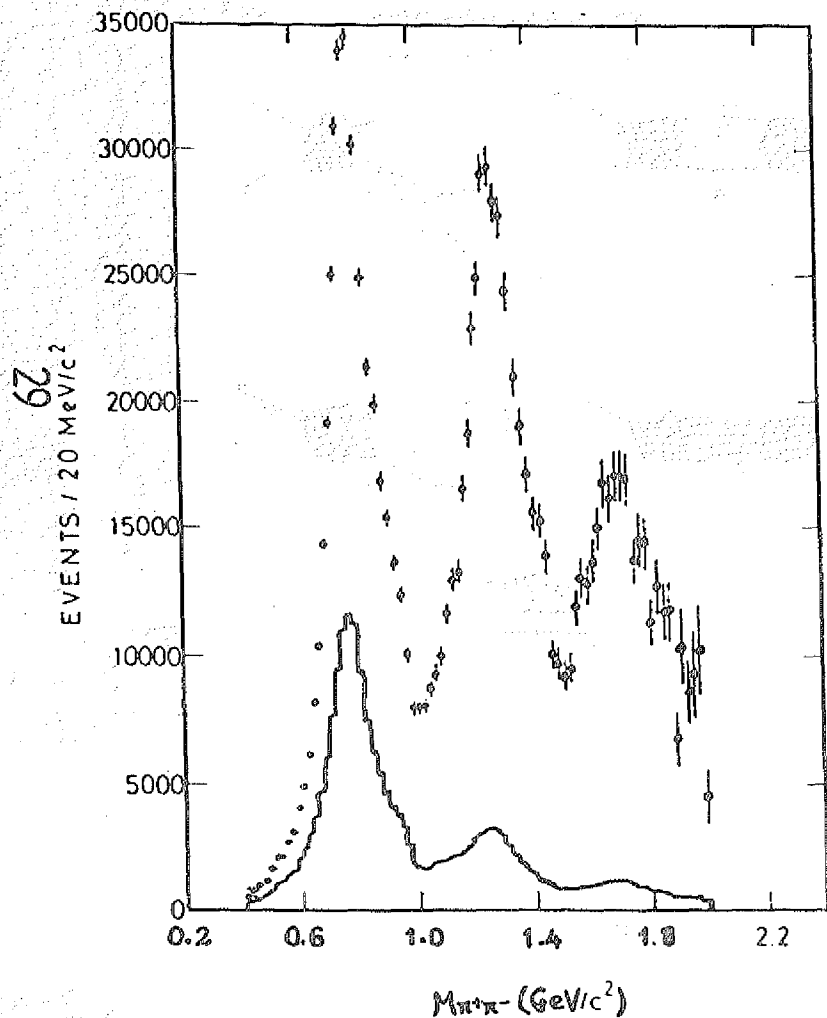
$\frac{9}{10} \cdot \frac{9}{10}$ $\frac{1}{10} \cdot \frac{1}{10}$

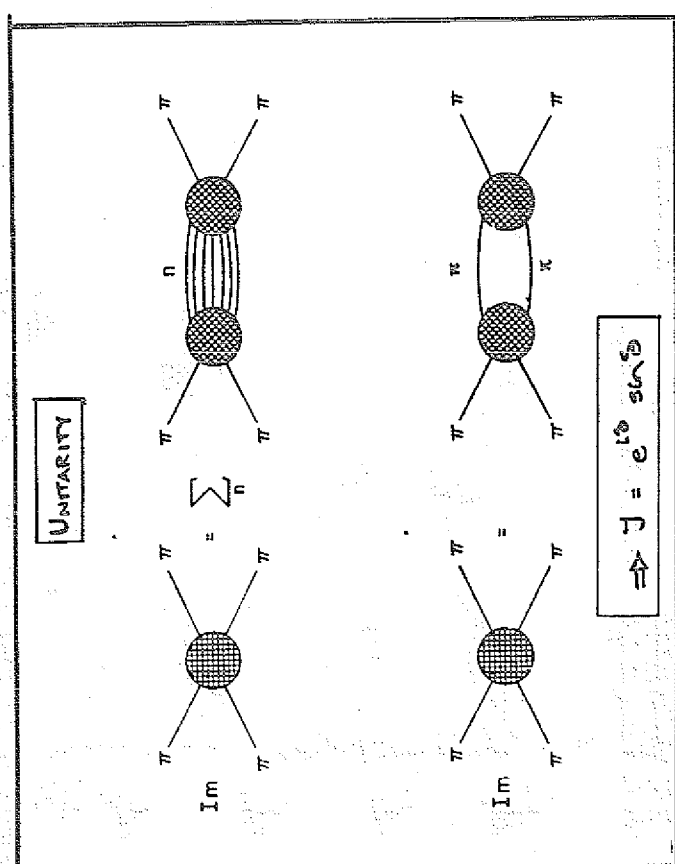
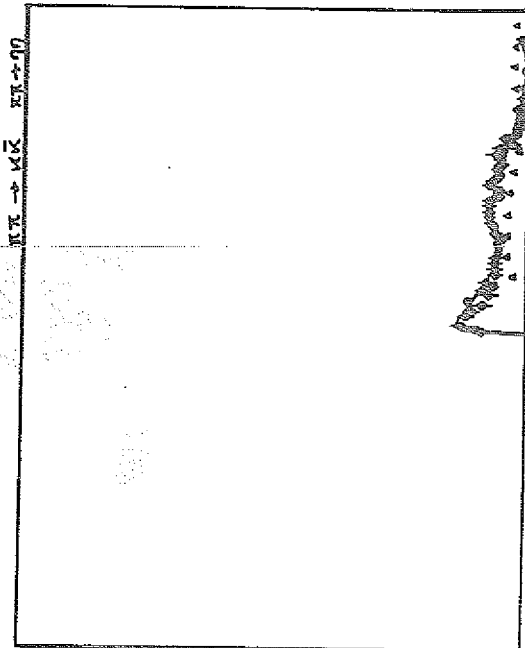
$$99 \quad \pi \quad \dots \oplus 1$$

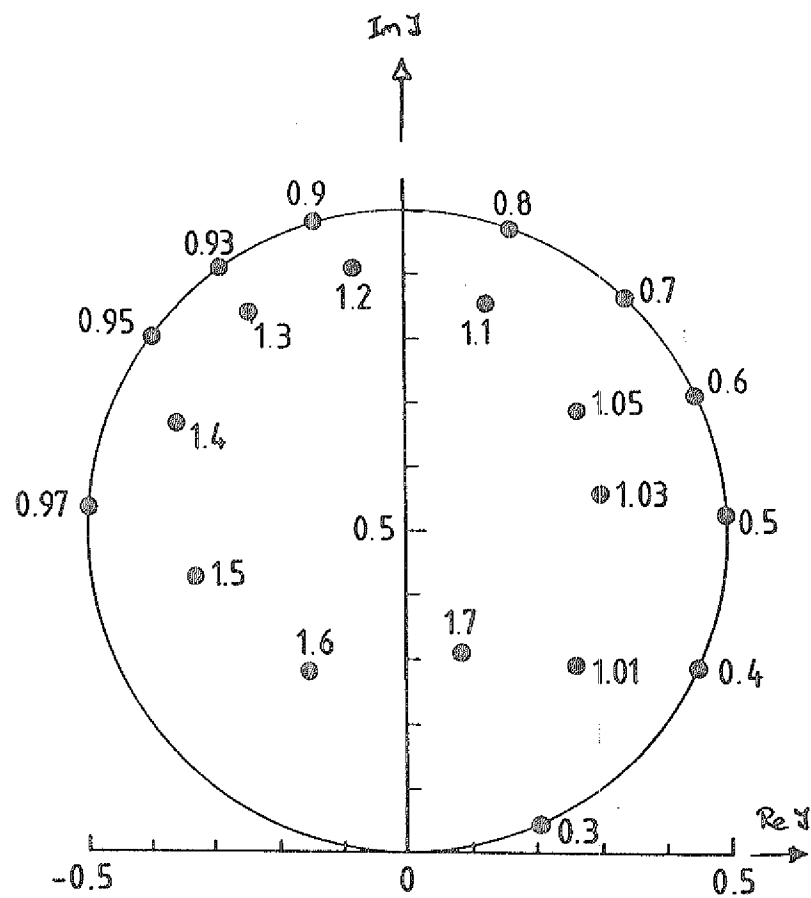
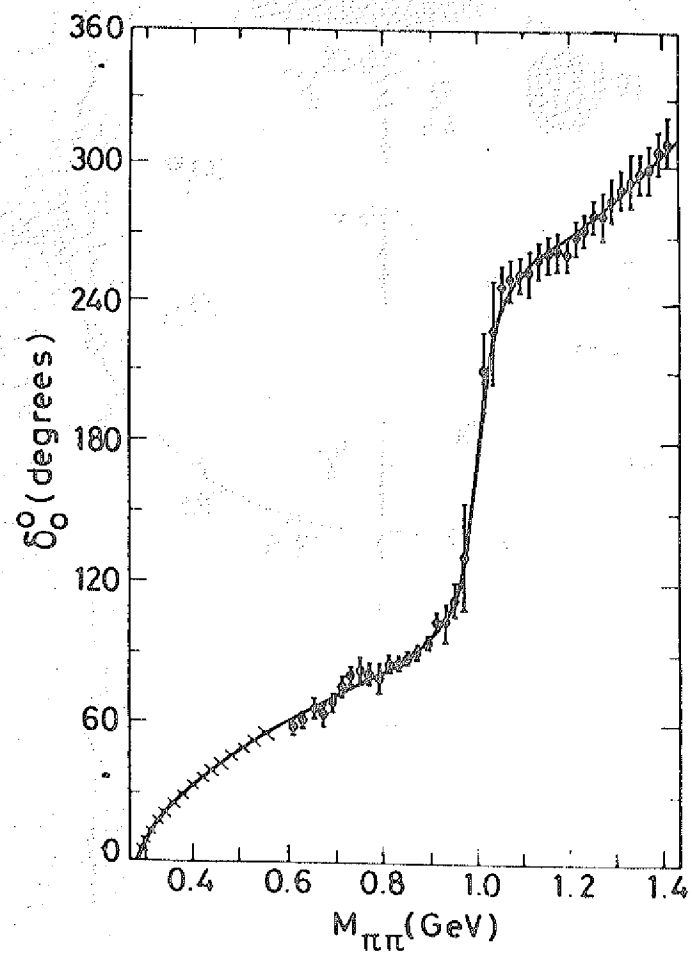
QCD suggests

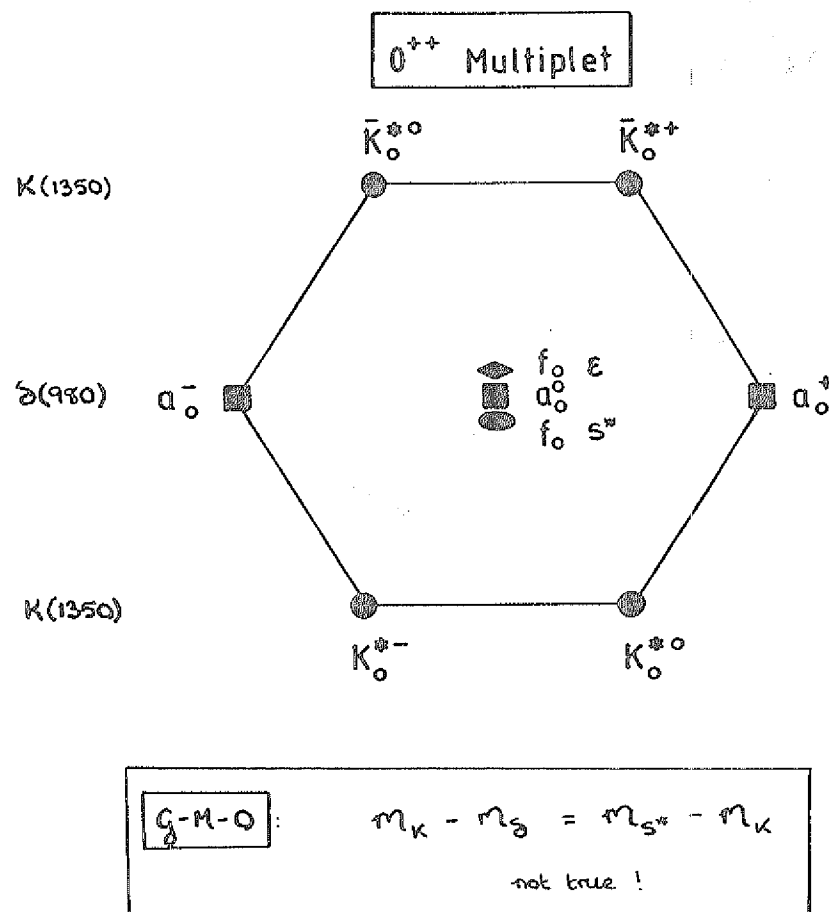


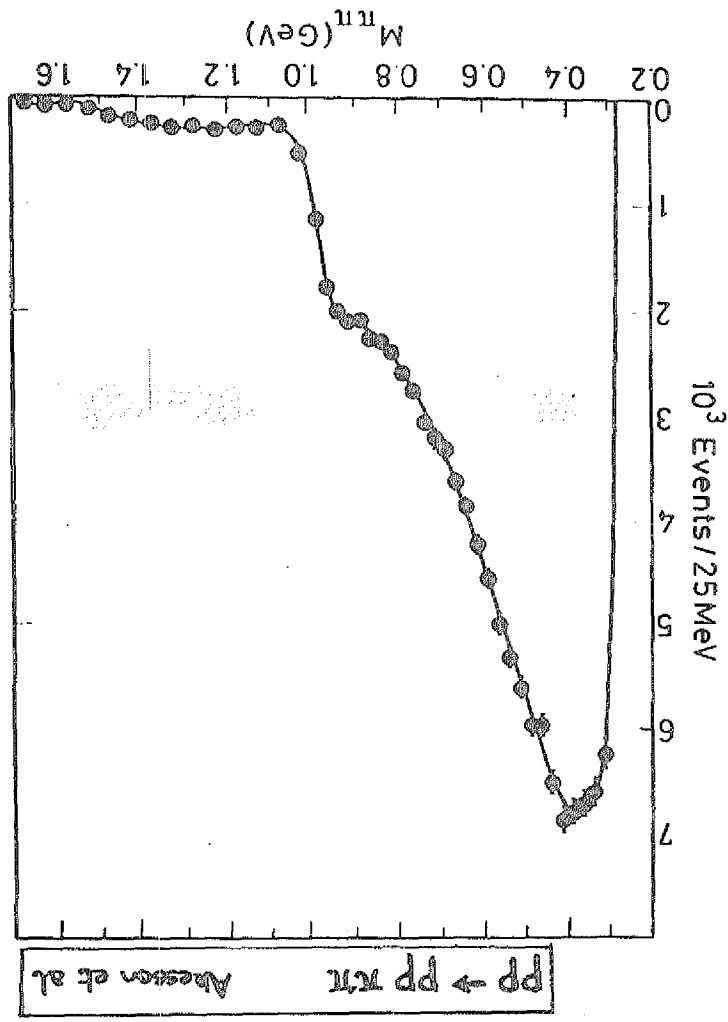
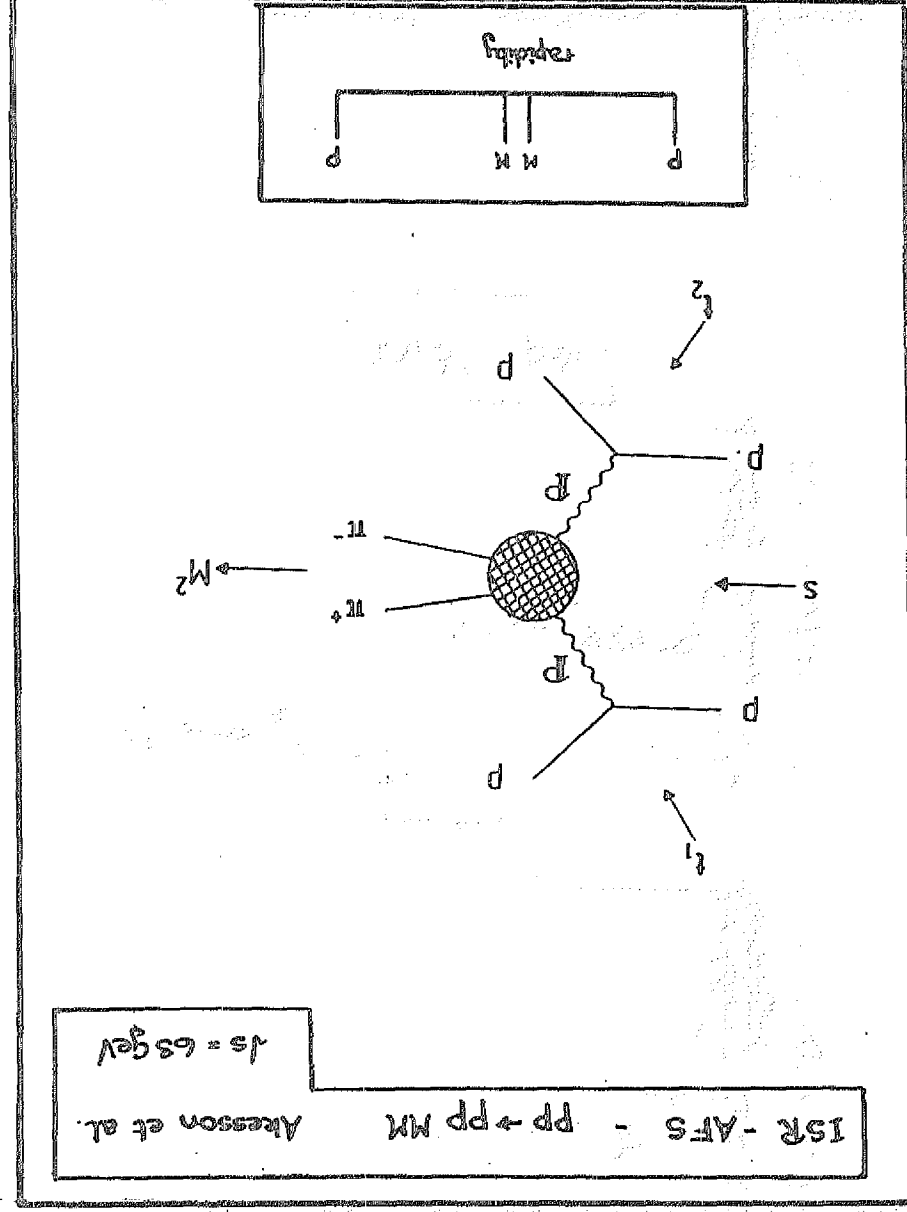
$\pi^- p \rightarrow \pi^- \pi^+ n$ CERN-Munich

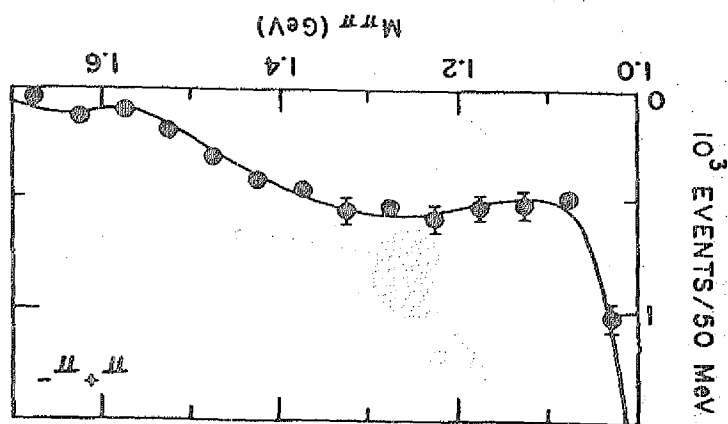
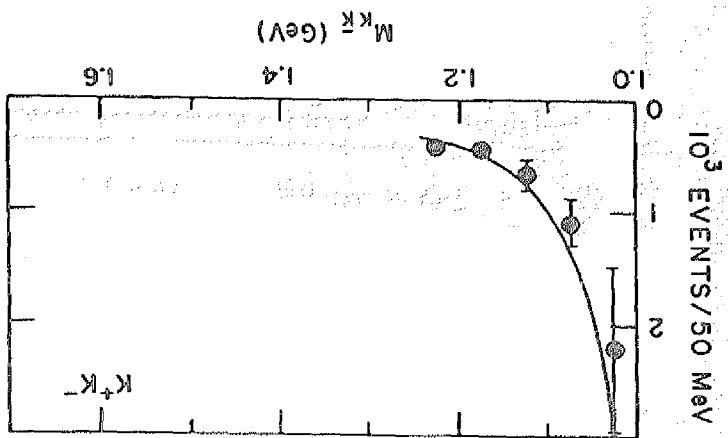




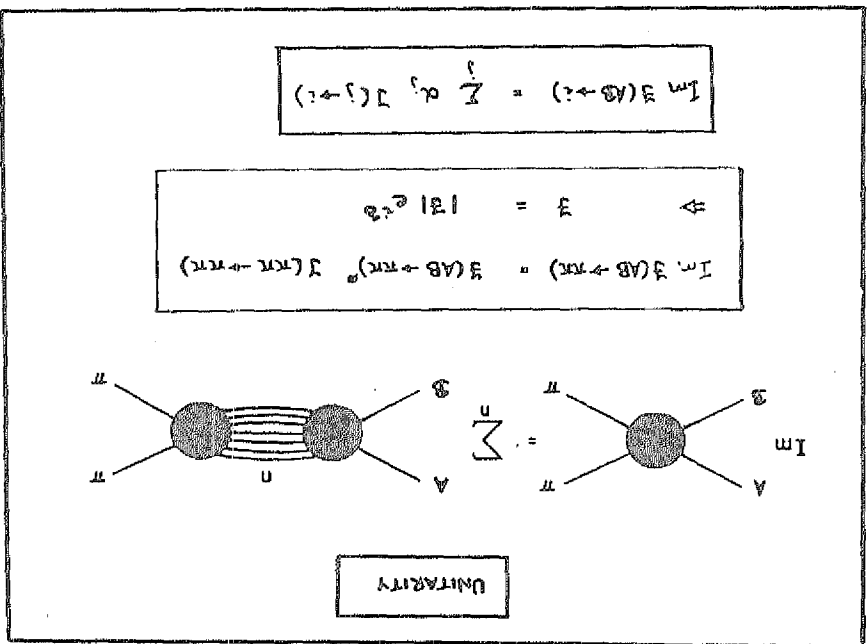


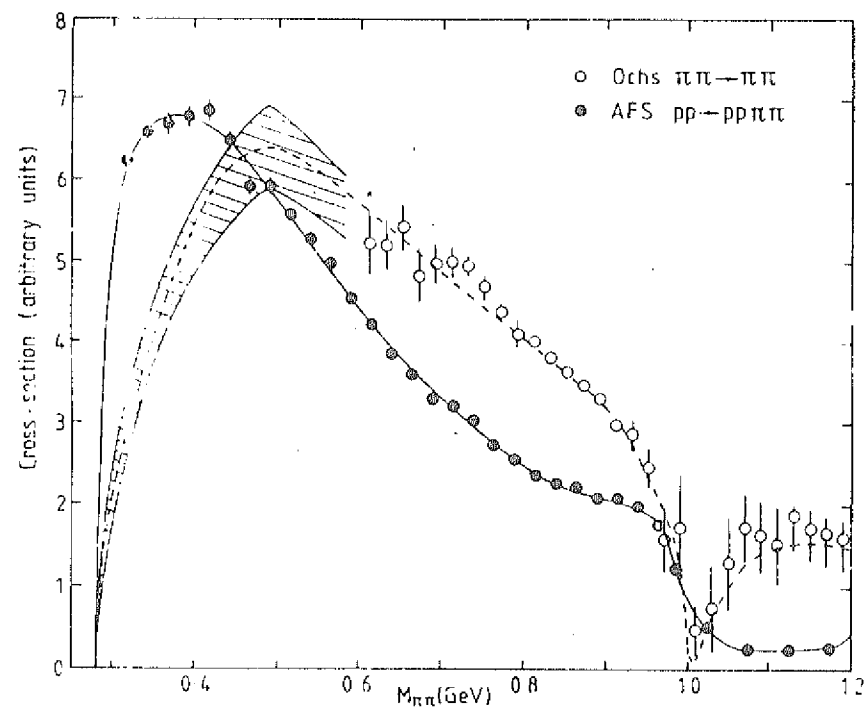
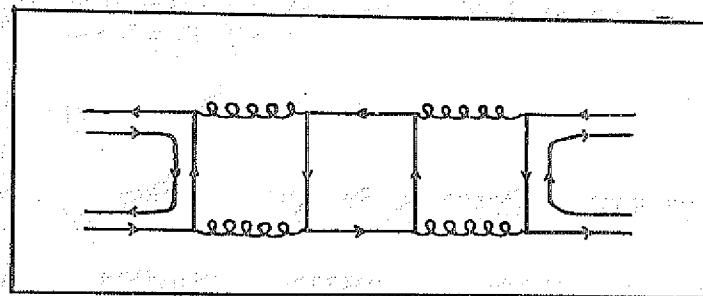






$pp \rightarrow pp\pi\pi$





AMP Analysis

[K.L. Au, D. Morgan & MRP]

Aim

FIT ESSENTIALLY ALL HIGH STATISTICS DATA*

WITH $\pi\pi$, $K\bar{K}$ FINAL STATES WITH

0^{++} QUANTUM NUMBERS IN TERMS OF AMPLITUDES

THAT SATISFY COUPLED-CHANNEL UNITARITY, IN

WHICH

- (1) the parametrisation does NOT prejudge the number of dynamical entities,
- (2) with as many different parametrisations as possible.

Resonance f_0	Poles	E_R (GeV)	g_π (GeV)	g_K (GeV)	$ g_\pi/g_K $
$S_1(991)$	A,C	0.991 ± 0.021	0.22	0.23	0.8
$S_2(988)$	B	0.988	0.02	0.35	0.06
$E(900)$	D,E	0.91 ± 0.35	0.52	0.21	1.9

AMP results

DATA

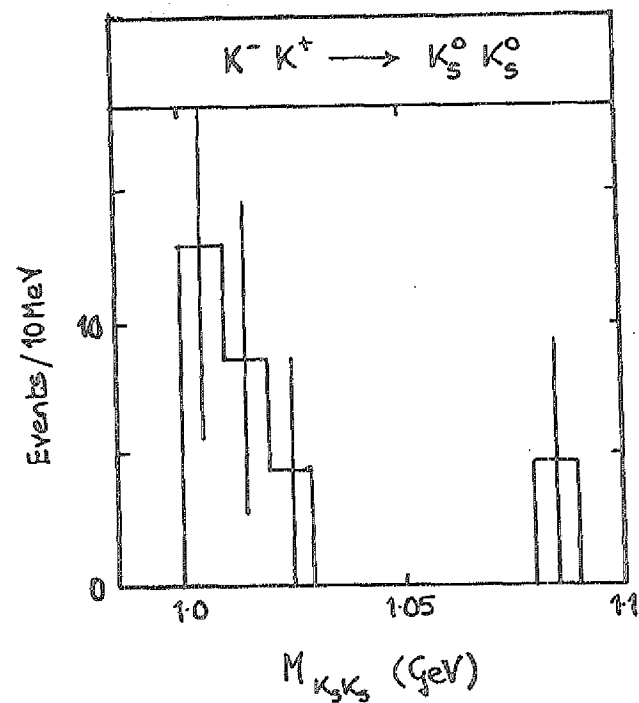
Ochs, Hyams et al
Cason et al I
Ellis et al
Cohen et al
Cason et al II
Netzel et al, Costa et al
Polychronakos et al
Alexander et al
Gidel et al

Scalar Mesons

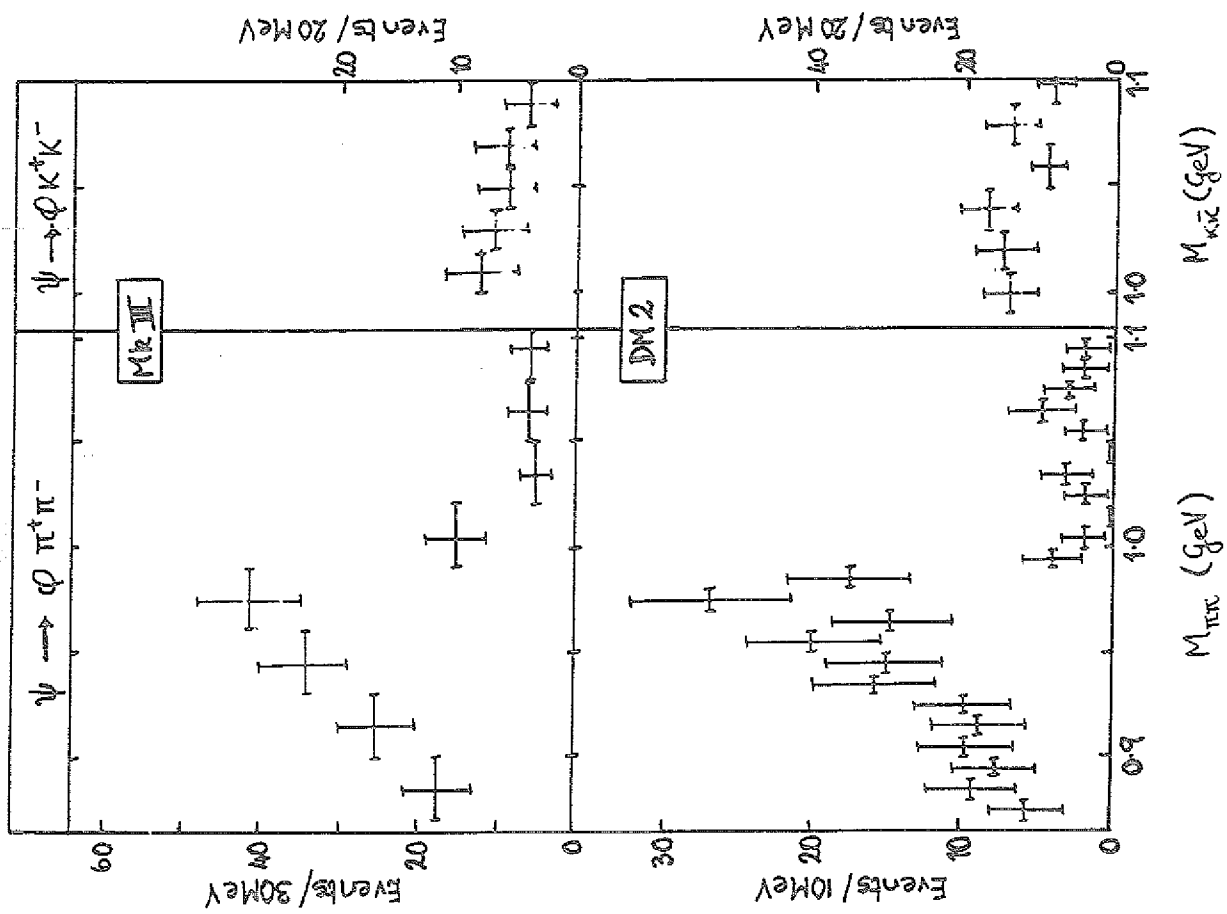
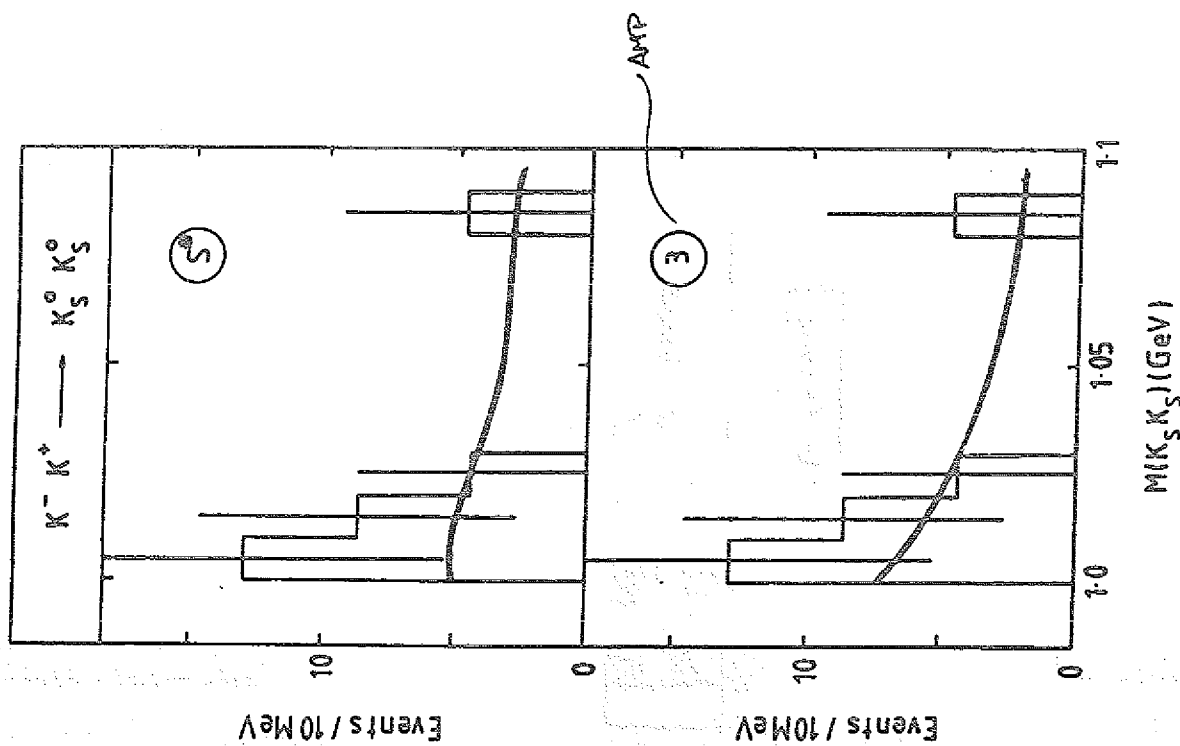
CONFIRMATION
NATURE

} requires new data

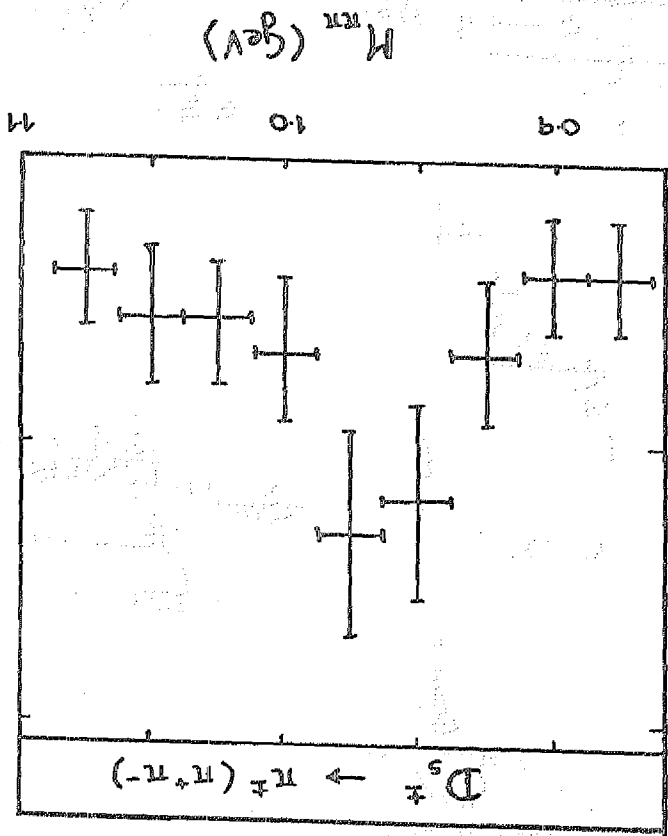
" ϕ " $\rightarrow \pi\pi, K\bar{K}$



LASS : ASTON ET AL.

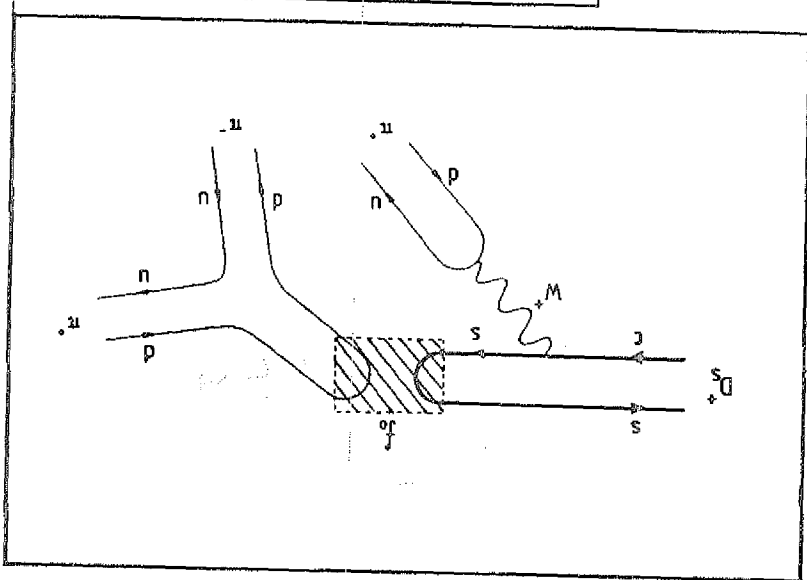


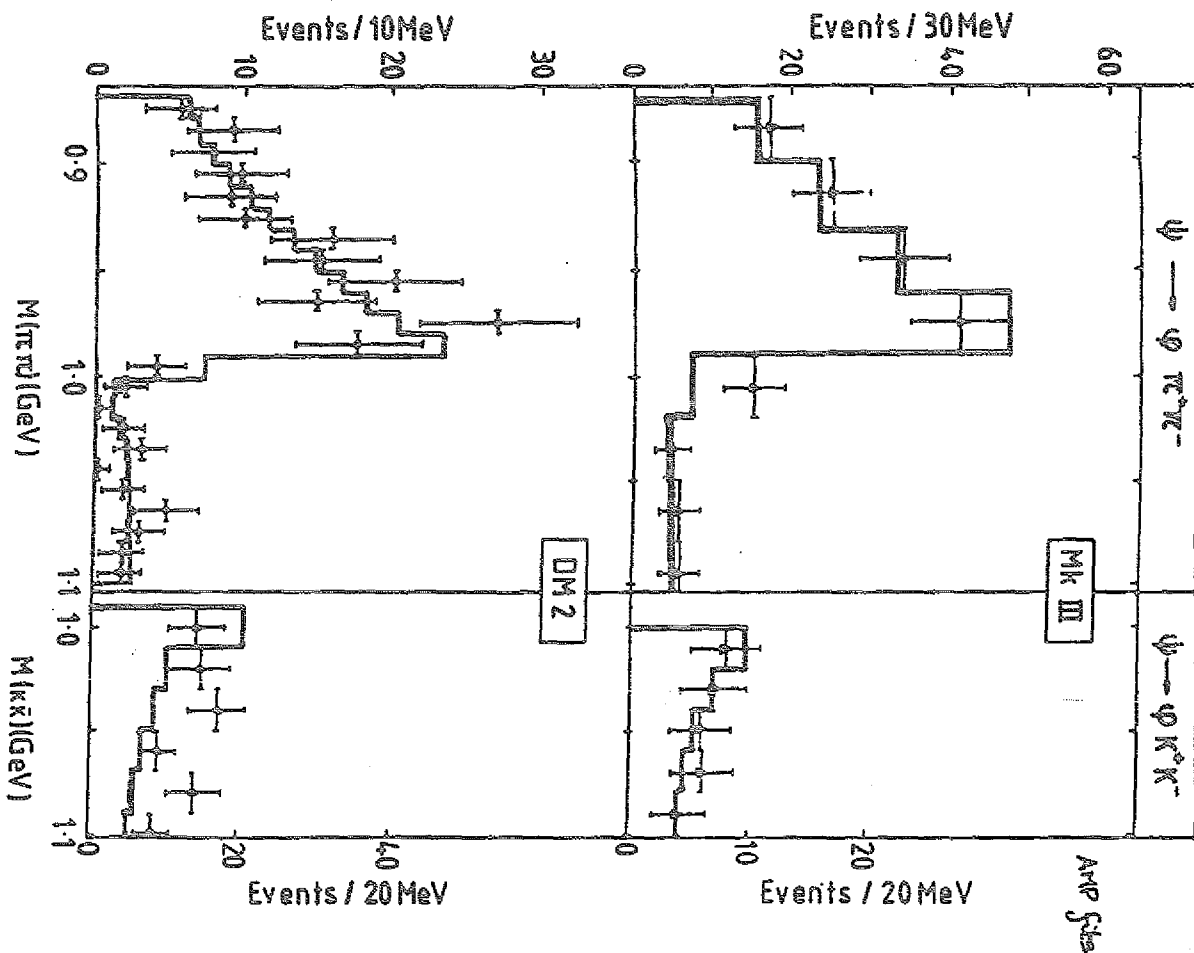
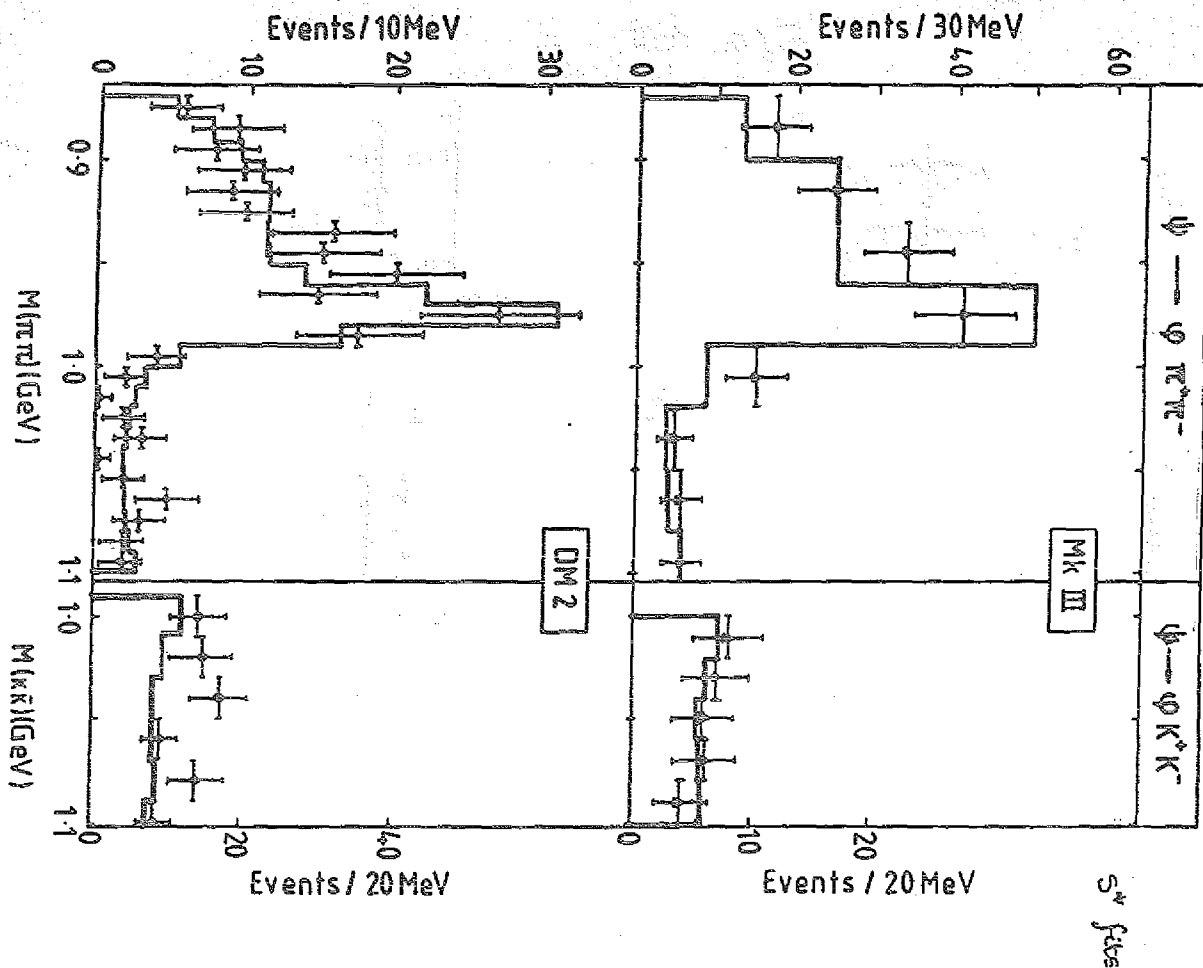
Events / 25 MeV

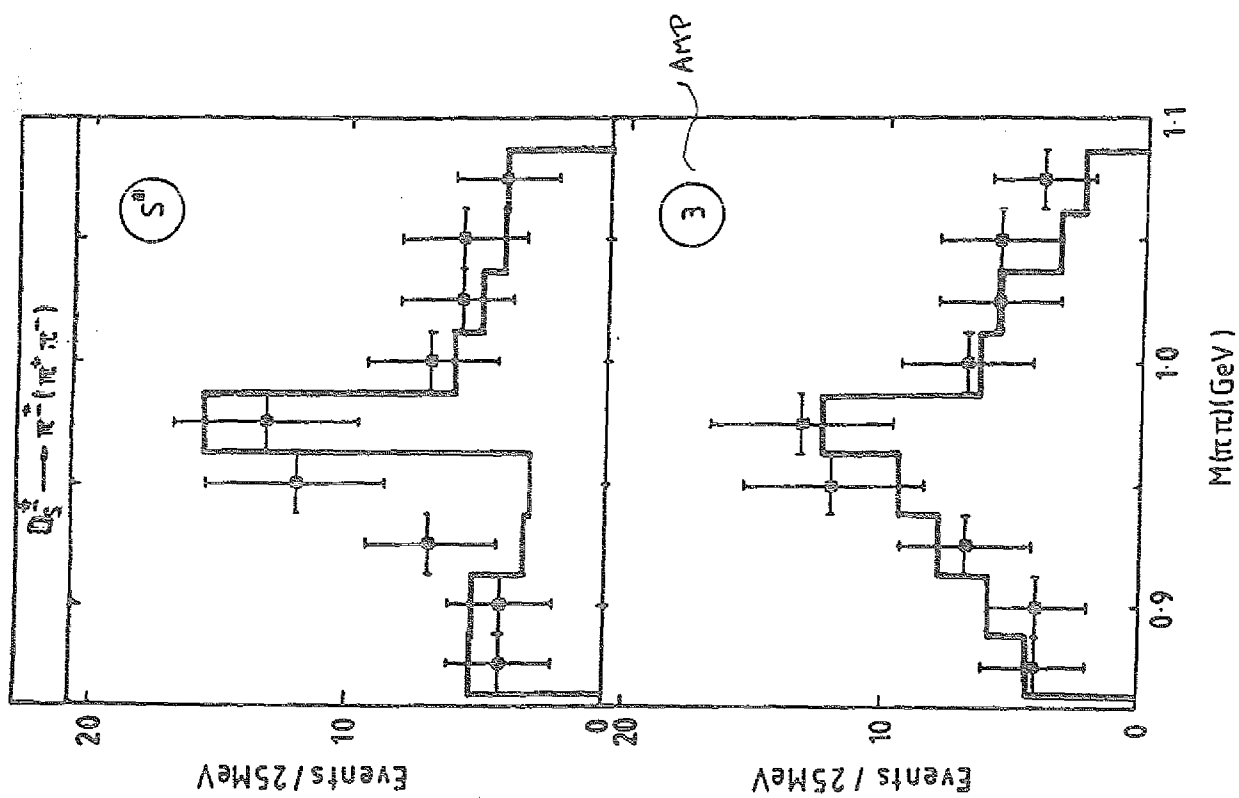
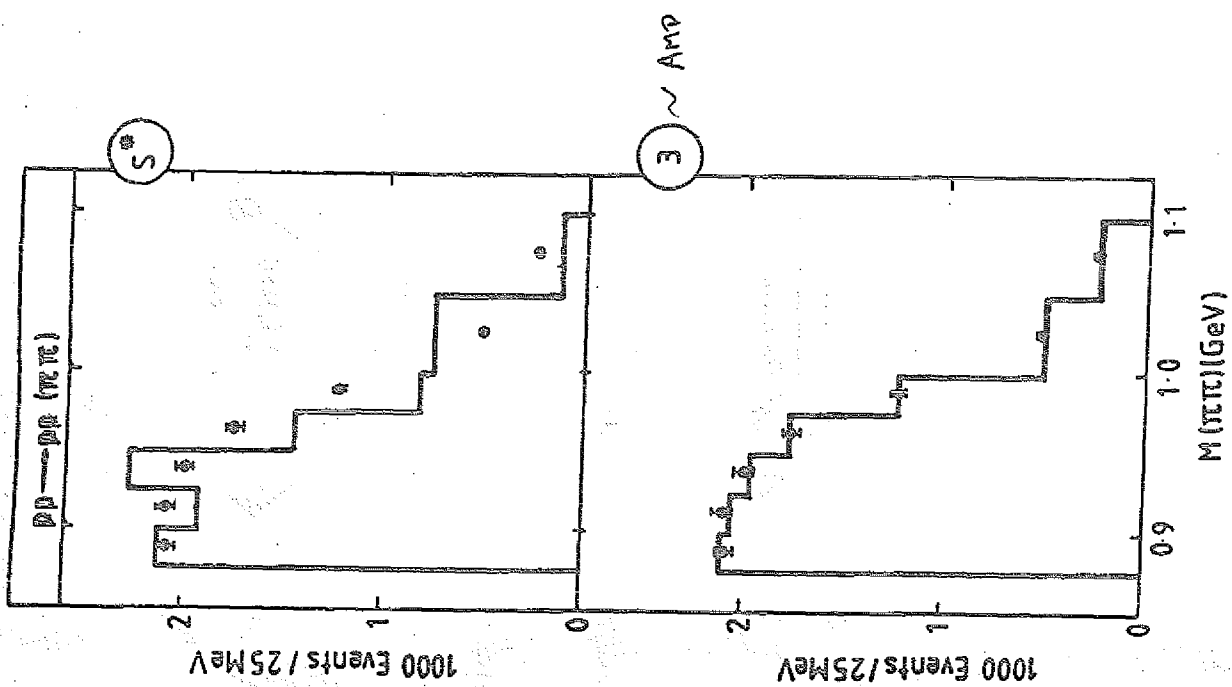


Angos et al

FERMILAB E691 Angos et al







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SCALAR RESULTS

update Feb 90

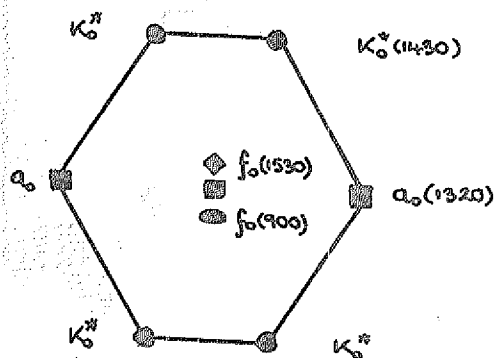
 $K\bar{K}$ molecules $f_0(52)$ $a_0(980)$

?

glueball

 $f_0(137)$

?

 $q\bar{q}$
lowest
scalar
multiplet

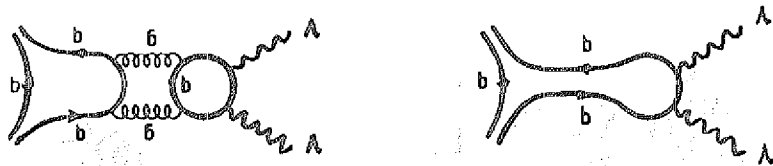
?

Need Confirmation

TESTS

1. Improved classic meson-meson reactions unlikely
2. Even more precise data on
 $K^-p \rightarrow K\bar{K}\Lambda(\Sigma)$ near $K\bar{K}$ threshold
 of LASS
3. Very high statistics data on
 K^+K^- , $K_S K_S$ production
 close to threshold in very
 fine bins COSY
4. Even more data on $\eta \rightarrow \pi\pi$
 $\eta \rightarrow K_S K_S$
 $\eta \rightarrow K^+ K^-$
 with angular separation
 of ≈ 3 BEPC?
5. $\gamma\gamma \rightarrow \pi\pi, K\bar{K}$

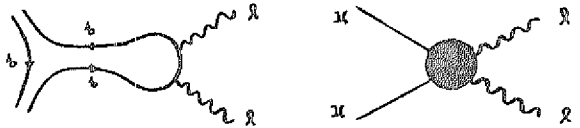
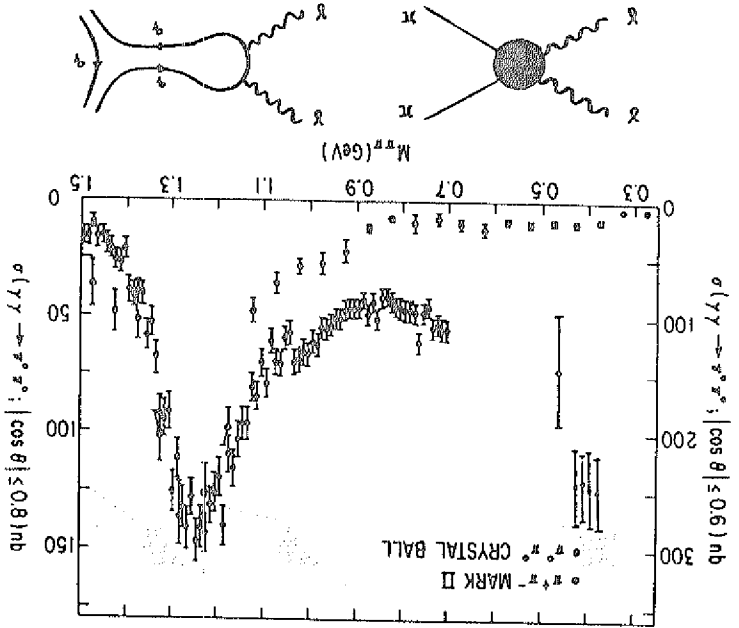
$\gamma\gamma$ Couplings

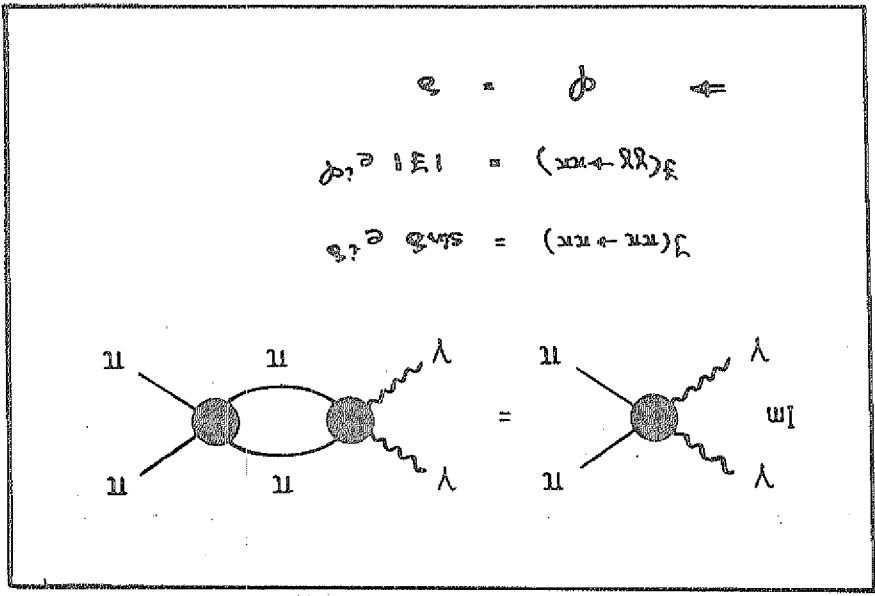
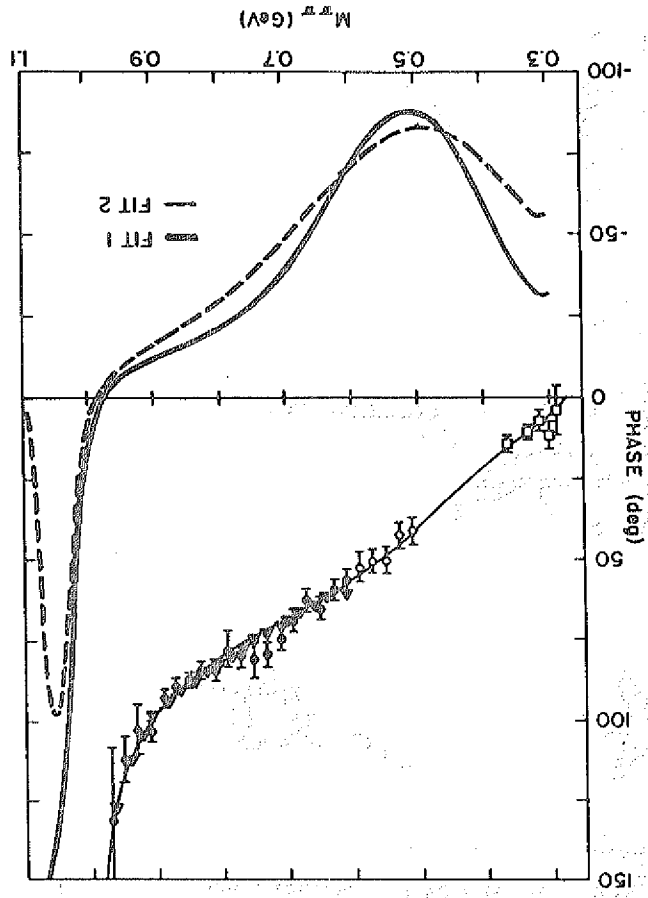


$$\Gamma(f_0(q\bar{q}) \rightarrow \gamma\gamma) \approx \frac{4}{15} \left(\frac{m_0}{m_b}\right)^2 \Gamma(f_0(q\bar{q}) \rightarrow \gamma\gamma)$$

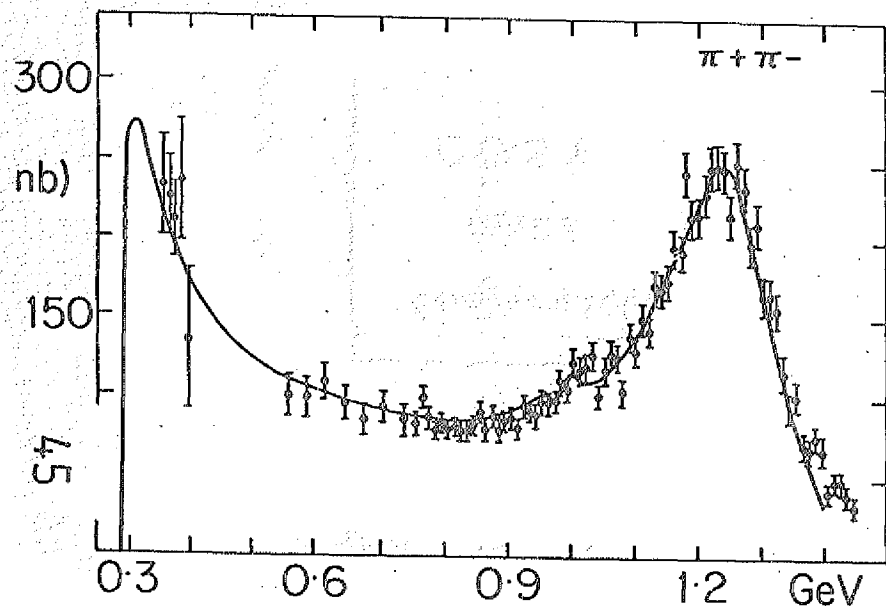
$$\Gamma(f_0(K\bar{K}) \rightarrow \gamma\gamma) = \frac{\pi\alpha^2}{m_K^2} |f_0(K\bar{K})|^2$$

Standard for
gg matrix



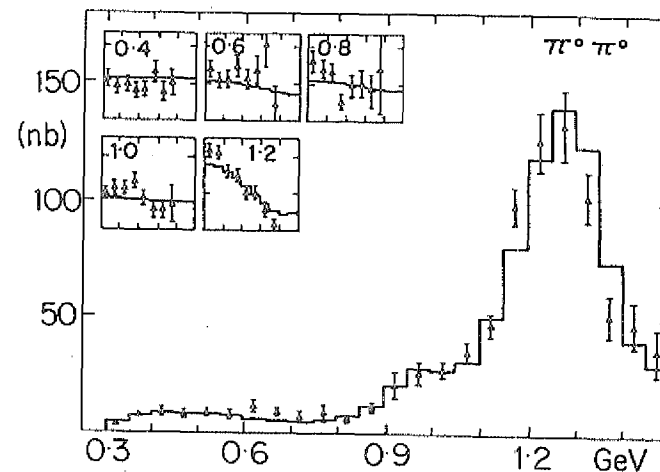


Mark II $\gamma\gamma \rightarrow \pi^+\pi^-$

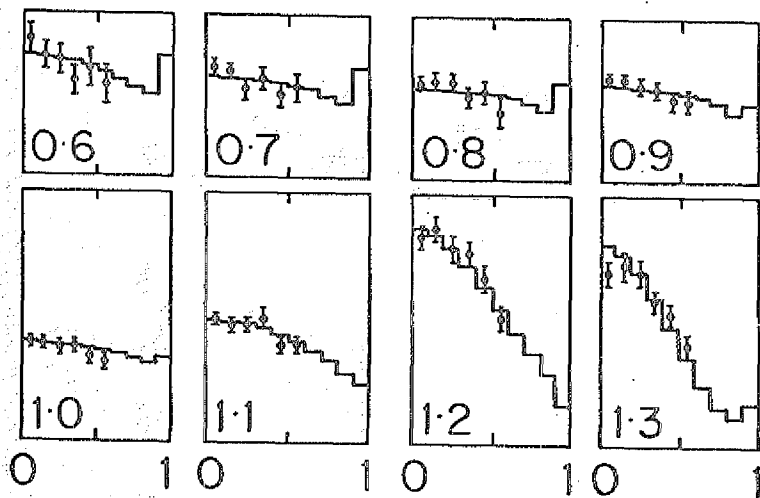


(a)

Crystal Ball $\gamma\gamma \rightarrow \pi^0\pi^0$



D. Morgan - KRP
find
 $\Gamma(5^0 \rightarrow \gamma\gamma) \sim 0.5 \text{ keV}$
 $\Gamma(2^- \rightarrow \gamma\gamma) \sim 6 \text{ keV}$



(b)

Confirmation
Needs
COSY

Evidence for dynamics
beyond the quark model

Scalar Mesons

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1. D. Morgan and M.R. Pennington, Physics Letters 137B (1984) 411.
2. K.L. Au, D. Morgan and M.R. Pennington, Physics Letters 167B (1986) 229.
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4. M.R. Pennington, Proceedings of the VIII International Workshop on Photon-photon collisions, Shresh, Jerusalem Hills, Israel (World Scientific), ed. U. Karshon (1988) pp 297.
5. M.R. Pennington, Proceedings of the BNL Workshop on Glueballs, Hybrids and Exotic Hadrons, (American Institute of Physics) ed. S.U. Chung (1989) pp 145.
6. D. Morgan and M.R. Pennington, Proceedings of the 3rd International Conference on Hadron Spectroscopy, Ajaccio, France, 1989 (to be published).
7. D. Morgan and M.R. Pennington, "Amplitude analysis of $\gamma\gamma \rightarrow \pi\pi$ from threshold to 1.4 GeV", (RAL-90-030, DTP-90-24, April 1990)
Submitted to Zeitschrift fur Physik C.
8. T.H. Burnett and S.R. Sharpe, "Non-Quark-Model Mesons "
Submitted to Ann. Rev. Nucl and Particle Science (March 1990).

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Workshop on
Mesons and Mesonic States

up to slightly above $1 \text{ GeV}/c^2$

at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich
February 19. - 20. 1990

IV)

P. Kroll

**Meson - Nucleon Coupling Constants
from Nucleon - Nucleon Scattering**

MESON-NUCLEON COUPLING CONSTANTS

from

NUCLEON-NUCLEON SCATTERING

Motivation:

P. Kroll, Jülich 1979

two indications for a large $s, \bar{s}$ component in the proton wave fun.

$$\pi N \Sigma \text{ term} \Rightarrow \frac{\langle p | \bar{s} s | p \rangle}{\frac{1}{2} \langle p | u + \bar{u} + d + \bar{d} | p \rangle} \approx 0.2$$

polarized structure fct. of the proton (EMC) $\langle \sigma \rangle \approx 0$

fraction of proton spin carried by s and $\bar{s}$ $\bar{\Delta}_s = \Delta_s - \frac{a_s}{2\pi} \Delta G \approx -0.24$
correction from pol. gluons

Consequence: bag rule does not apply to baryons?

strong spin? (Ellis et al - despite many $s, \bar{s}$ $g_{NN} \approx 0$)

Interpretation of spin effect - generalized versions of Goldberger-Treiman relation

axialvector form factor may be related to η pole at $q^2 = 0$

debate is controversial

(Ellis et al, Friedrich, Veneziano, Efremov et al, ...)

in any case it seems to be important

to determine precisely the c.c. of $\eta, \eta', \phi, \dots$

What do we know about these coupling?

• isoscalar electromagnetic form factor of the nucleon

Höhler et al 3 pole fit

$$g_{\eta}^2/4\pi = 24 \pm 12 \quad g_{\eta\omega}/g_{\eta\pi} \approx 0.2 \quad \text{very L-type w/}$$

$$g_{\phi}^2/4\pi = 5.1 \quad = 0.2 \quad \text{compared with}$$

$$SU(6) : 4.8$$

Jaffe: evidence for strong s content in the nucleon

(but $F \sim 1/4$ made by conspiracy of the three pole residues - imagine "pure $SU(2)$ world $m(s) \rightarrow \infty$ ")

Grari + Krümpelmann: only ω pole + continuum contribution
no need for a ϕ

$$g_{\eta\omega}^2/4\pi = 8.8 \quad g_{\eta\omega}/g_{\eta\pi} = 0.16$$

• NN Potentials

energy independent potentials from static approximations of pole terms
coupling constants fixed at $t=0$

Bonn	$g_{\eta}^2/4\pi = 4.22$	$g_{\eta'}^2/4\pi = 0$	$g_{\eta\omega}^2/4\pi = 13.96$	$g_{\eta\phi} = 0$	$g_{\phi}^2/4\pi = 1.22$	$g_{\eta\eta'} = 0$
Nijmegen	3.68	4.23	7.3	0.43	0.04	0

discontinuity of UPC is built up by: (unitarity) ¹⁵

$$I_m \langle N\bar{N} | T | N\bar{N} \rangle = \langle N\bar{N} | T^\dagger T | N\bar{N} \rangle + \langle N\bar{N} | T^\dagger | \text{intermediate states} \rangle + \dots$$

most important contr. to low energy NN (nearest singularities)

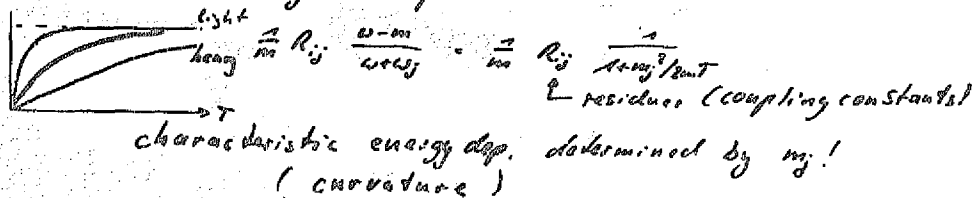
$|n\pi\rangle$ continuum (uncorrelated π 's) and $(n\pi)$ resonances (meson poles)

$|3\pi\rangle$ classified in terms of $\pi\pi$ (S : $\pi\pi$ S-wave, $I=0$) and $\pi\pi$ (S : $\pi\pi$ P-wave $I=1$)

discrepancy function	intermediate state	sign of contribution	remarks
$\Delta_s(I=1)$	$\pi\pi$ (S-wave) $\pi\rho$ (P-wave)	- -	π subtracted out no 2π next important meson: $b_1(1235)$
$\Delta_s(I=0)$	$\eta(549), \eta(958)$ $\pi\rho$ (S-wave)	- +	no 2π
$\Delta_s(I=1)$	$f_1^{1,2,3-}(NN \rightarrow \pi\pi)$ $\pi\rho$ (D-wave) $a_0(980)$	- + +	f_1^2 contains the ρ
$\Delta_s(I=0)$	$f_0^{2,3-}(NN \rightarrow \pi\pi)$ $\pi\rho$ (P-wave) $\omega(783)$ $\phi(1020)$ $f_0(975)$	- + - - +	f_0^2 contains the ϵ next important meson: $f_2(1270)$
$\Delta_m(I=1)$	$f_1^{1,2,3-}(NN \rightarrow \pi\pi)$ $\pi\rho$ (P-wave) $\pi\rho$ (S-wave) $a_1(1270)$	- + + +	f_1^2 contains the ρ next important meson: $a_2(1320)$
$\Delta_m(I=0)$	$f_0^{2,3-}(NN \rightarrow \pi\pi)$ $\pi\rho$ (P-wave) $\omega(783)$ $\phi(1020)$	- - - -	next important meson: $f_2(1270)$

Table 1: Contributions from the UPC to the NN discrepancy functions (only masses $< 1200\text{MeV}$ are considered)

contributions of meson pole terms to Δ_i 's:



2π contribution

$\pi N \rightarrow \pi N$ analytically continued to $N\bar{N} \rightarrow \pi\pi$
lowest $N\bar{N} \rightarrow \pi\pi$ PWA S_2^0 ($J \leq 3$)
large J : nucleon exchange

$\Rightarrow$ contributions to discontinuity of UPC
(taken as known)

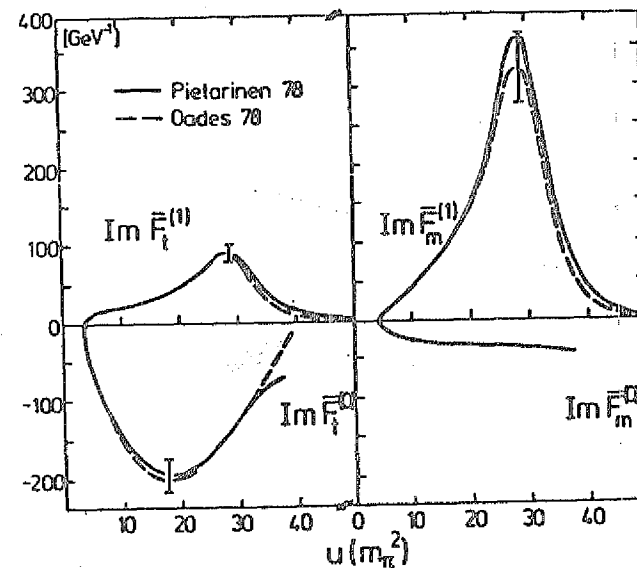
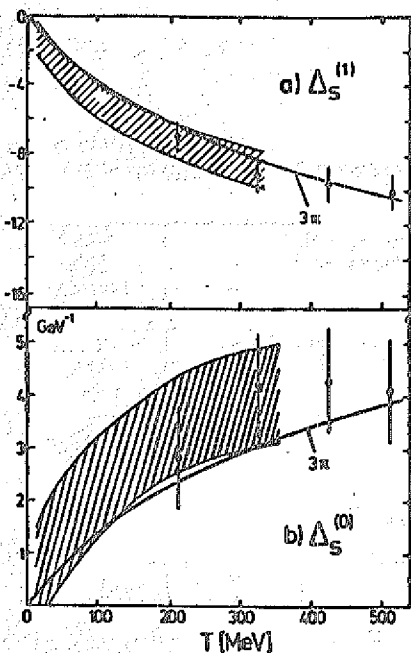


Fig. 1

Höller and Pietarinen
Gustafson, Nielsen and Oades

I from BASQUE phase shifts

III all other phase shifts



< 0

> 0

η, η' contributions < 0!!

energy dependence requires contributions with effective mass below 1000 MeV!!

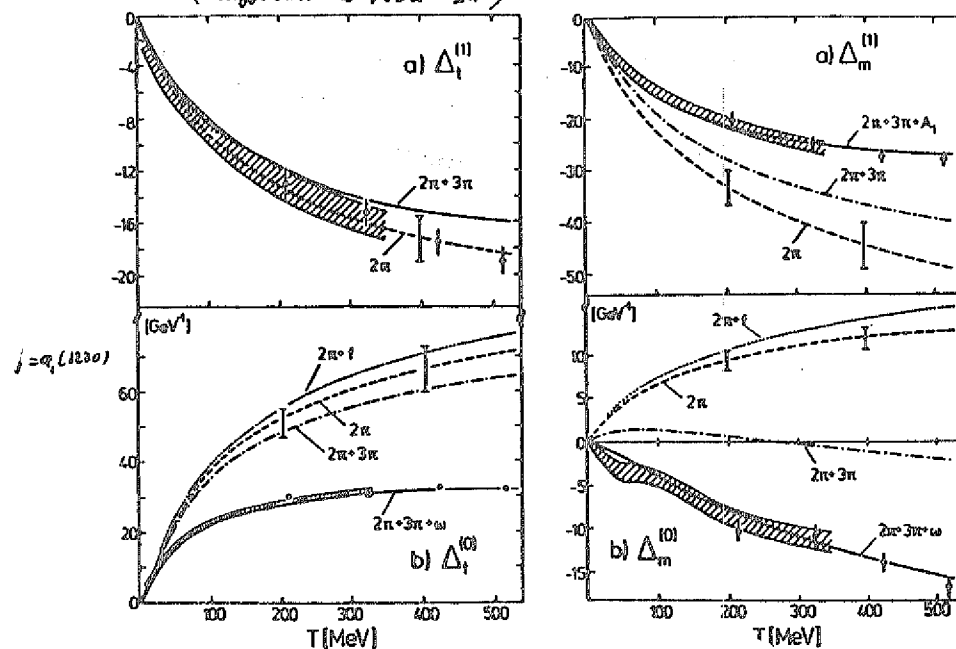
evidence for 3π continuum

I=1: $\pi\pi$ (S wave), $\pi\pi$ (P wave) < 0
I=0: $\pi\pi$ (S wave) > 0

Note: $\Delta_S^{(I)} + \Delta_S^{(II)} < 0$ (pp analysis)
may be misidentified with η (fit: $g_\eta^2/4\pi \approx 4.7!$)
as found in many pol. studies

* $\Delta_S^{(I)}$ saturated by 2π contribution
(consistent since 3π starts with a $\pi\pi$ S wave)

* $\Delta_m^{(I)}$ 2π contribution very strong; 3π and A_1 can fill the gap between it and the photo.
(difficult without 3π)



* $\Delta_{\pi, \pi}^{(I)}$ ignoring 3π just the ω pole with
 $g_{\omega\pi\pi}^2/4\pi \approx 20$ $g_{\omega\pi\pi}/g_{\omega\pi\pi} = 0$
would lead to $\Delta_S^{(I)} = 0!$
ignoring 3π : $g_{\omega\pi\pi}^2/4\pi \approx 8$ but $g_\pi/g_\omega = 0.7!$
too large

With 2π and 3π - reasonable values

Quantitative analysis of the UPC

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3π continuum approximated by $\pi\pi$ and $\pi\pi$
and $N\bar{N} \rightarrow \pi\pi, \pi\pi$ estimated from
nucleon exchange

$$\text{Diagram} = \text{Diagram}_1 + \text{Diagram}_2 + \sum_j \text{Diagram}_j$$

(GNO) $j = \eta, \omega, A_1$

resulting meson-nucleon coupling constants

$$g_\eta^2/4\pi = g_{\eta'}^2/4\pi = 0 \quad (< 1.0)$$

$$\omega: \quad g_\omega^2/4\pi = 8.1 \pm 1.5 \quad g_\pi/g_\omega = 0.14 \pm 0.20$$

$$A_1: \quad g_{A_1}^2/4\pi = 7.3 \pm 3.0$$

$$\eta_1(1270) (\delta): \quad g_{\eta_1}^2/4\pi = 2.2 \pm 0.9; \quad g_{\eta_1}/g_\pi = 0.6 \pm 0.9 \quad \text{fixed Bonn-Klein}$$

remarks: ω and ϕ contributions add (different from
elm. form factor analysis)
a small ϕ contr. cannot be
separated from the ω (new analysis?)

• no hint at $a_0(980) (\delta)$ and $f_0(975) (5^+)$
strong ss content? $K\bar{K}$ molecule?

• contr. from heavy mesons negligible (example ϕ)
(new analysis with extended energy region?)

Conclusions

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• clear evidence for contributions from
 3π continuum

• meson-nucleon coupling constants can only
be determined when 3π continuum is taken
into account; otherwise misleading results

• no hints at strong η, η', ϕ (and a_0, f_0)
contributions

• new analysis in progress

Δ_i 's will have smaller error bars
and be determined over a larger range
of energy (≈ 1000 MeV instead of 500 MeV)

• expected: main results of previous analyses
will be confirmed

• better determination of coupling constants
(smaller errors)

• from extended energy range

(hopefully) coupling constants

of ϕ and some heavier
mesons

• future: further improvements can be obtained
from data on $\Delta_{\pi\pi}, \Delta_{\pi\pi}$ (pn) at higher energies
 S_2, S_3 (COSY?)

IS THE POLE APPROXIMATION TO THE UNPHYSICAL PART OF THE LEFT HAND CUT SUFFICIENT ?

P. Kroll

Department of Physics - University of Wuppertal

1. Introduction

In any application of dispersion relations to kaon-nucleon and nucleon-nucleon scattering the existence of an unphysical part of the left hand cut (LHC) is a challenge. If one is, for example, interested in predictions of real parts of scattering amplitudes or more generally if one uses dispersion relations as constraints in phase shift or amplitude analyses in order to resolve ambiguities, one has to assume something about the contributions from the unphysical part of the LHC which clearly weakens the power of the dispersion relations. On the other hand, if an amplitude, that is real as well as imaginary part, for a given t value and for a given energy range is known one may turn around the procedure and use the dispersion relation as a tool to obtain information on the discontinuity of the LHC. The easiest and often used method to exploit this idea is to approximate the discontinuity by a sum of poles and to determine their coupling constants and eventually also their masses. In nucleon-nucleon scattering this method has been applied for example by Bugg (1) and by Verwest et al. (2). With the advent of total cross-section data in pure spin states, however, it turned out by a detailed study performed by us (3) that this pole approximation is not sufficient. We found clear evidence for contributions from the 3π continuum. In the following I will report on that investigation. I will start with a description of the available information on the discrepancy functions and will proceed with a qualitative discussion of the physics of the LHC. Thereafter the discontinuity of the LHC will be discussed quantitatively. I will end up with some conclusions.

2. The NN discrepancy functions

Forward nucleon-nucleon scattering is described by three invariant functions F_i . By unitarity their imaginary parts are related to the total cross-sections in pure spin states.

i) spin averaged cross section

$$\sigma_{\text{tot}} = \frac{1}{2} \left\{ \sigma(\vec{\uparrow}) + \sigma(\vec{\downarrow}) \right\} = 2\sqrt{\pi} \operatorname{Im} (\phi_1 + \phi_3) \Big|_{t=0} = \frac{4\pi}{p_L} \operatorname{Im} F_1 \quad (1.a)$$

ii) transversely polarized nucleons

$$\Delta\sigma_T = \sigma(\uparrow\uparrow) - \sigma(\uparrow\downarrow) = -4\sqrt{\pi} \operatorname{Im} \phi_2 \Big|_{t=0} = -\frac{4\pi}{p_L} \operatorname{Im} F_2 \quad (1.b)$$

iii) longitudinally polarized nucleons

$$\Delta\sigma_L = \sigma(\vec{\uparrow}) - \sigma(\vec{\downarrow}) = 4\sqrt{\pi} \operatorname{Im} (\phi_1 - \phi_3) \Big|_{t=0} = \frac{4\pi}{p_L} \operatorname{Im} F_3 \quad (1.c)$$

where for comparison the relations to the s-channel helicity amplitudes ϕ_i are also given.

The (singly subtracted) forward dispersion relations for proton-nucleon scattering read

$$\begin{aligned} \operatorname{Re} F_{ipN}(\omega) &= \operatorname{Re} F_{ipN}(m) + \frac{1}{m} \tau_{pN;l} R_{i\pi} \frac{\omega - m}{\omega + \omega_\pi} \\ &+ f_{ipN}^d \frac{\omega - m}{\omega_d - \omega} - \beta_i \frac{\omega - m}{\pi} \int_{\omega(2m_\pi)}^{\infty} d\omega' \frac{\operatorname{Im} F_{ipN}(\omega')}{(\omega' + \omega)(\omega' + m)} \\ &+ \frac{\omega - m}{\pi} \int_m^{\infty} d\omega' \frac{\operatorname{Im} F_{ipN}(\omega')}{(\omega' - \omega)(\omega' + m)} \end{aligned} \quad (2)$$

Hereby the following notations are used:

$\omega(p_L)$ lab. energy (momentum);

$m_\pi(m)$ pion (nucleon) mass;

$\beta_1 = \beta_2 = -\beta_3 = 1$; $\omega(2m_\pi) = -m + 2m_\pi^2/m$; $\omega_\pi = -m + m_\pi^2/2m$;

$\operatorname{Re} F_{ipN}(m)$ subtraction constants;

f_{ipN}^d , $R_{i\pi}$ are the residues of the deuteron (4) and pion poles respectively (compare table 1).

Table 1 - Meson-nucleon coupling constants

meson	coupling constant	remark
π	$g_\pi^2/4\pi = 14.24$	fixed
η, η'	$g_\eta^2/4\pi = g_{\eta'}^2/4\pi = 0 (< 1.0)$	
ω	$g_{\omega}^2/4\pi = 8.1 \pm 1.5$ $g_{\omega\omega}/g_{\omega\eta} = 0.14 \pm 0.20$	
A_1	$g_{A_1}^2/4\pi = 7.3 \pm 3.0$	
ρ	$g_{\rho}^2/4\pi = 2.2 \pm 0.9$ $g_{\rho\rho}/g_{\rho\pi} = 0.6 \pm 0.9$	taken from ref. 14

τ is the isospin crossing (s-u) matrix defined by

$$\begin{pmatrix} F_{ipp} \\ F_{ipn} \end{pmatrix} = \begin{pmatrix} 1/2 & 1/2 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} F_i^{(I_u=1)} \\ F_i^{(I_u=0)} \end{pmatrix} \quad (3)$$

where I_u denotes the isospin of the NN system. The discrepancy functions are defined by

$$\Delta_{ipN} = \text{Re } F_{ipN}^{\text{exp}} - \text{Re } F_{ipN}^{\text{DR}} = -\beta_i \frac{\omega - m}{\pi} \int_{\omega(2m_\pi)}^{\bar{\omega}} d\omega' \frac{\text{Im } F_{ipN}^-(\omega')}{(\omega' + \omega)(\omega' + m)} \quad (4)$$

where the $\text{Re } F_{ipN}^{\text{exp}}$ are the real parts of F_{ipN} which are either reconstructed from phase shifts or taken from Coulomb interference measurements and the $\text{Re } F_{ipN}^{\text{DR}}$ collect all known parts of the dispersion relation (2). $\omega_1 = m$, $\omega_2 = \omega_3 = 3$ GeV as determined by our knowledge on the $\text{Im } F_{ipN}^-$ (compare in figure 1).

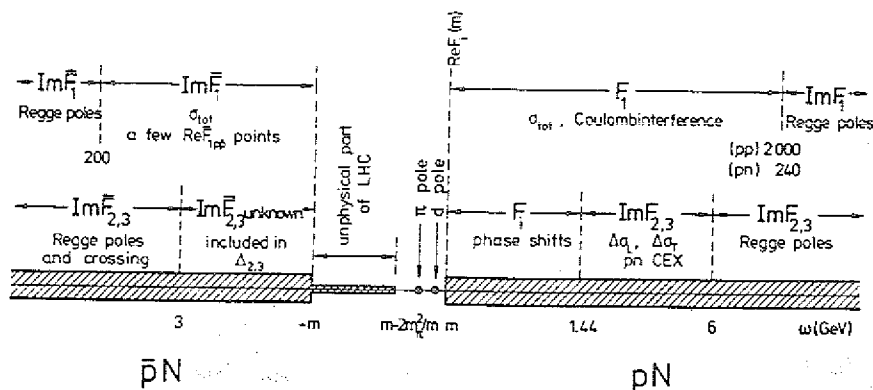


Figure 1 - The singularity structure of the pN forward amplitudes in the ω plane and the input used in our analysis

Since we are aiming at a study of the NN cut, it is convenient to form combinations of the discrepancy functions with definite u-channel

quantum numbers :

$$i) \Delta_s^{(I_u)} = \frac{1}{2} \left\{ \Delta_{1pN}^{(I_u)} - \Delta_{2pN}^{(I_u)} - \frac{1}{2} \Delta_{3pN}^{(I_u)} \right\} = - \frac{\omega-m}{\pi} \int_{\omega(2m_\pi)}^{\bar{\omega}} d\omega' \frac{\text{Im } \bar{F}_3^{(I_u)}(\omega')}{(\omega'+\omega)(\omega'+m)} \quad (5)$$

Only spin singlet partial waves ($\bar{f}_s^J$) contribute to the NN amplitude $\bar{F}_s$, that is only states with unnatural parity ($J^P=A$).

$$ii) \Delta_t^{(I_u)} = \frac{1}{2} \left\{ \Delta_{1pN}^{(I_u)} + \Delta_{2pN}^{(I_u)} - \frac{1}{2} \Delta_{3pN}^{(I_u)} \right\} = - \frac{\omega-m}{\pi} \int_{\omega(2m_\pi)}^{\bar{\omega}} d\omega' \frac{\text{Im } \bar{F}_t^{(I_u)}(\omega')}{(\omega'+\omega)(\omega'+m)} \quad (6)$$

Here, only coupled triplet partial waves ($\bar{f}_{11}^J$) with $J^P=N$ contribute.

$$iii) \Delta_m^{(I_u)} = \Delta_{1pN}^{(I_u)} + \frac{1}{2} \Delta_{3pN}^{(I_u)} = - \frac{\omega-m}{\pi} \int_{\omega(2m_\pi)}^{\bar{\omega}} d\omega' \frac{\text{Im } \bar{F}_m^{(I_u)}(\omega')}{(\omega'+\omega)(\omega'+m)} \quad (7)$$

to which coupled triplet waves $\bar{f}_{22}^J$ ($J^P=N$) and uncoupled triplet waves $\bar{f}_1^J$ ($J^P=A$) contribute.

In figure 1 I compile the input we used in the actual calculation of the discrepancy functions. I want to point out that because of lack of $\Delta\sigma_T(pn)$ data, we made use of forward pn charge exchange differential cross-sections. Details of the calculations are given in refs. 3, 5, 6. Our analysis provides us with :

$\Delta_{2,3pp}$, $\Delta_{2,3pn}$ from threshold up to $\omega = 1.44$ GeV

Δ_{1pp} up to 2000 GeV

Δ_{1pn} up to 70 GeV

The high energy parts of the latter two functions are important for any model of the LHC since they keep the high mass contributions under control. The same holds for the pp discrepancy function Δ_{1pp} for which we have also some information from the rare $p\bar{p}$ Coulomb interference data.

3. The physics of the LHC

By unitarity the discontinuity of the LHC is built up by the contributions from the allowed intermediate states

$$\text{Im} \langle N\bar{N} | T | N\bar{N} \rangle = \sum_n \langle N\bar{N} | T^\dagger | n \rangle \langle n | T | N\bar{N} \rangle$$

$$= \langle N\bar{N} | T^+ | \pi\pi \rangle \langle \pi\pi | T | N\bar{N} \rangle + \langle N\bar{N} | T^+ | 3\pi \rangle \langle 3\pi | T | N\bar{N} \rangle + \dots \quad (8)$$

The most important contributions to the unitarity sum certainly come from the 2π intermediate states (nearest singularities). We have at our disposal independent information on these contributions which we may check by comparison with the discrepancy functions. In case that they pass this test we can make use of them in the further analysis.

Two groups, Gustafson et al. (7) and Höhler et al. (8) have calculated the lowest $N\bar{N} \rightarrow \pi\pi$ partial waves $f_{\pm}^J$ ($J \leq 1$ and $J \leq 3$ respectively) from the πN amplitudes (9) by analytic continuation. Approximating for larger J the partial waves by the Born term i.e. nucleon exchange, we obtain, from unitarity, the imaginary parts of the $N\bar{N}$ amplitudes for u less than $50 m_{\pi}^2$ for $I_u = 1$ and $40 m_{\pi}^2$ for $I_u = 0$. The results from the two groups agree very well. Inserting the imaginary parts into eqs. (5-7), we find the contributions of the 2π cut to the discrepancy functions.

For the other contributions (from the 2π cut for $u > 50 (40) m_{\pi}^2$ and from the other cuts) no independent informations from other sources are available. The usual procedure is to approximate these contributions by a sum over meson pole terms, each of which produces a term

$$\frac{1}{m} R_{ij} \frac{\omega - m}{\omega + \omega_j} = \frac{1}{m} R_{ij} \frac{1}{1 + m_j^2 / 2mT} \quad (9)$$

in the discrepancy function $\Delta_i(I_u)$ ($\omega_j(m_j)$ is the position (mass) of the pole j and R_{ij} its residue, T is the kinetic energy in the lab. system). Each pole has a characteristic energy dependence determined by its mass. Heavy mesons (mass ≥ 1.1 GeV) play only a minor role in the energy range under consideration because the curvature of their pole terms is much weaker than what we observe in the discrepancy functions.

However, as I will demonstrate in a moment, the discrepancy functions show clear evidence for contributions from the 3π continuum. All contributions needed for a sufficiently accurate approximation to the discontinuity of the LHC are graphically represented by

$$\text{Im} \begin{array}{c} \diagup \quad \diagdown \\ \text{---} \text{---} \text{---} \text{---} \end{array} \approx \begin{array}{c} \text{---} \pi \text{---} \\ \diagup \quad \diagdown \\ \text{---} \pi \text{---} \end{array} + \begin{array}{c} \text{---} \pi \text{---} \\ \diagup \quad \diagdown \\ \text{---} \pi \text{---} \end{array} + \sum_j \begin{array}{c} \diagup \quad \diagdown \\ \text{---} \text{---} \end{array} \quad \begin{array}{l} u < 50(40)m_{\pi}^2 \\ \text{continuum only} \\ j = \eta, \omega, A_1, \dots \end{array}$$

In table 2 the most important contributions to the various discrepancy functions are compiled whereby, for convenience, the lowest angular momentum states of the 3π continuum are classified in terms of $\pi\pi$ and $\pi\rho$ states. ϵ stands for a $\pi\pi$ S wave ($I = 0$) and ρ for a $\pi\pi$ P wave ($I = 1$).

Comparison of the table with figures 2-4 shows that

Table 2 - Contributions from LHC to the NN discrepancy functions (only masses ≤ 1.1 GeV are considered)

discrepancy function	intermediate state	sign of contribution	remark
$\Delta_s^{(1)}$	$\pi\pi$ (S wave) $\pi\rho$ (P wave)	- -	π subtracted out no 2π lightest meson : B (1235)
$\Delta_s^{(0)}$	η (549), η' (958) $\pi\rho$ (S wave)	- +	no 2π
$\Delta_t^{(1)}$	$f_+^{1,3,\dots}$ ($N\bar{N} \rightarrow \pi\pi$) $\pi\rho$ (D Wave) δ (980)	- + +	f_+^1 contains the ρ } probably Zweig for- } bidden ($u\bar{d}$ $s\bar{s}$) next important pole : A_2 (1310)
$\Delta_t^{(0)}$	$f_+^{0,2,\dots}$ ($N\bar{N} \rightarrow \pi\pi$) $\pi\rho$ (P wave) ω (783) ϕ (1020) S^* (980)	+ - - - +	$f_+^{(0)}$ contains the ϵ next important pole: f (1271) } probably Zweig for- } bidden ($s\bar{s}$; $s\bar{s}$ ($u\bar{u} + d\bar{d}$))
$\Delta_m^{(1)}$	$f_-^{1,3,\dots}$ ($N\bar{N} \rightarrow \pi\pi$) $\pi\pi$ (P wave) $\pi\rho$ (S wave) A_1 (1100)	- + + +	f_-^1 contains the ρ next important pole : A_2 (1310)
$\Delta_m^{(0)}$	$f_-^{2,4,\dots}$ ($N\bar{N} \rightarrow \pi\pi$) $\pi\rho$ (P wave) ω (783) ϕ (1020)	+ - - -	next important pole : f (1271)

- i) the negative sign of $\Delta_s^{(1)}$ and the positive one of $\Delta_s^{(0)}$ require contributions from the 3π continuum. The energy dependences of the discrepancy functions call for contributions with effective masses considerably below 1000 MeV. Thus heavy mesons cannot be responsible for the signs of $\Delta_s^{(0,1)}$.
- ii) $\Delta_t^{(1)}$ is completely saturated by the 2π term, there is no need for other contributions. This is in agreement with the 3π continuum idea since its lowest angular momentum state contributing to $\Delta_t^{(1)}$ is a $\pi\rho$ D wave which should be small.
- iii) the 2π contribution to $\Delta_m^{(1)}$, essentially the flip P wave f_-^1 , dramatically exceeds the data, calling again for the 3π continuum. The lowest angular momentum states have the right sign to fill the gap between the 2π term and the data. Neglect of the 3π contribution would force us to conclude that the 2π term is in severe disagreement with the NN data.

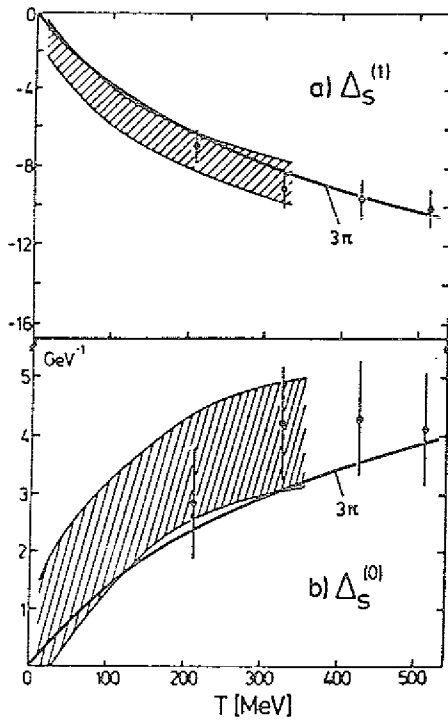


Figure 2 - The discrepancy functions $\Delta_S^{(1)}$ (a) and $\Delta_S^{(0)}$ (b) as a function of the kinetic energy. The hatched band indicates the experimental data (10), only the BASQUE results (11) are shown separately ($\bullet$). The solid line is the 3π contribution (compare section 4)

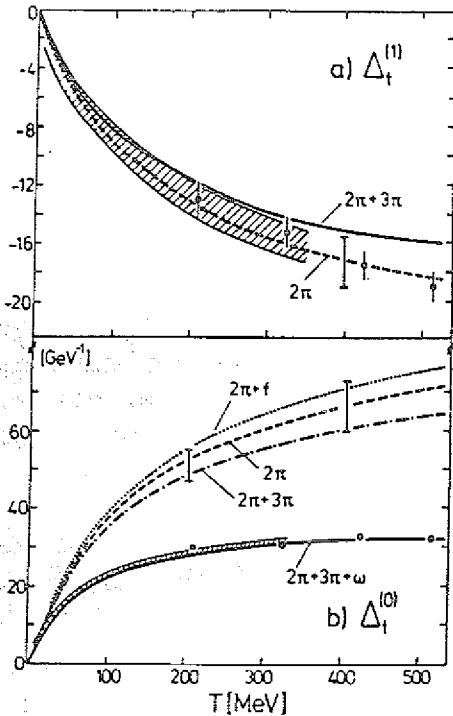


Figure 3 - The discrepancy functions $\Delta_t^{(1)}$ (a) and $\Delta_t^{(0)}$ (b) as a function of T . Various cut and OBE contributions are shown (compare section 4). The 2π contributions are calculated from $NN \rightarrow \pi\pi$ partial waves of ref. 7. Typical (systematic) errors of them are indicated. The f couplings are those given in table 1. For further notations compare figure 2.

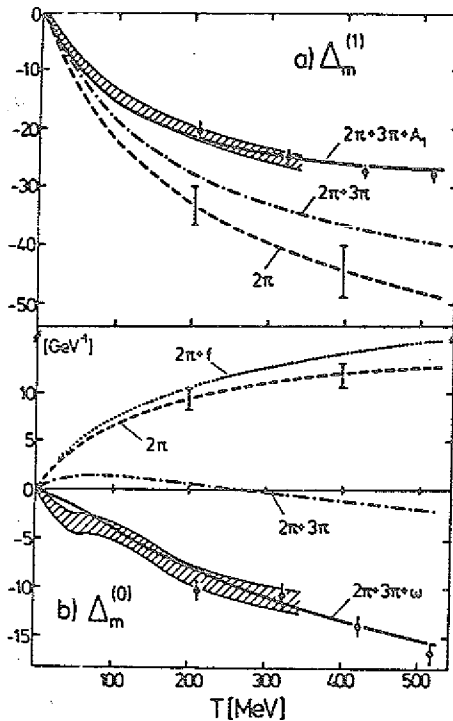
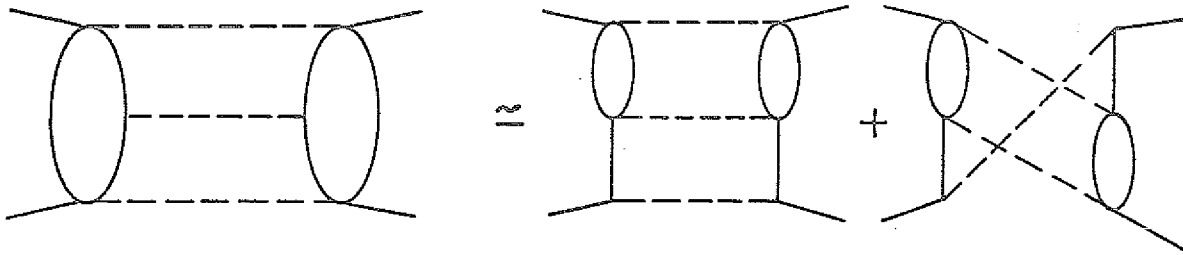


Figure 4 - The discrepancy functions $\Delta_m^{(1)}$ (a) and $\Delta_m^{(0)}$ (b) as a function of T . For notations compare figure 3.

- iv) describing the difference between $\Delta_{t,m}^{(0)}$ and the 2π term solely by the ω pole, one obtains for the ω vector coupling the value $g_{V\omega}/4\pi = 7.7$ and the rather large ratio $g_{T\omega}/g_{V\omega} = 0.7$ in contrast to pure pole models where the tensor coupling comes out very small. The reason for the large tensor coupling in our description lies in the 2π contribution to $\Delta_m^{(0)}$ to which no low mass meson pole corresponds. However, part of the difference between $\Delta_{t,m}^{(0)}$ and the 2π term may come from the 3π continuum which starts with a $\pi\rho$ P wave.

4. A quantitative study of the LHC

From the preceding discussion it should be clear that we obtain a qualitative understanding of the NN discrepancy functions only if the 3π continuum is taken into account. A quantitative investigation, however, i.e. a check for consistency of the $NN \rightarrow \pi\pi$ partial waves and a determination of coupling constants requires a detailed dynamical model for the 3π discontinuity which, of course, is hard to perform. As a first step the 3π continuum is assumed to be determined by $\pi\epsilon$ and $\pi\rho$ and the dynamics of the reactions $NN \rightarrow \pi\epsilon$, $\pi\rho$ is approximated by nucleon exchange. Exploiting unitarity the 3π discontinuity can then be calculated in a similar fashion as that of the 2π cut from the $NN \rightarrow \pi\pi$ amplitudes. In order to take into account the finite width of the ρ and the ϵ the discontinuities are averaged over the contribution of the $NN \rightarrow \pi\pi$ S and P waves. Graphically the model is described by



With this averaging procedure the model discontinuity really starts at the 3π threshold instead than at the $\pi\pi(\rho)$ threshold. Furthermore, it has the advantage that the results do not depend on the approximations one has to make in going from the partial waves to masses and coupling constants.

At each vertex of the graphs shown above a form factor is introduced. In the actual calculation all form factors are set equal and the then only parameter of the model is adjusted such that $\Delta_S^{(I)}$ is well reproduced.

As can be seen from figures 2-4 the model removes most of the difficulties in the discrepancy functions discussed above. $\Delta_S^{(0)}$ is solely saturated by the 3π term, nothing is left for pole terms. One, therefore, has to conclude that the coupling constants of both the η and the η' are zero within the errors. On the other hand, in $\Delta_t^{(0)}$, $\Delta_m^{(0,1)}$ there are still gaps left to other contributions for which by inspection of table 2, the ω and the A_1 poles are the most important candidates. Fitting the pole terms to the data, one ends up with a good description of all $K\bar{K}$ discrepancy functions and with reasonable coupling constants (results are given in table 1). Also the high energy behaviour of our model for the LHC is correct as can be seen from figure 5 where Δ_{1pp} and Δ_{1pn} are plotted.

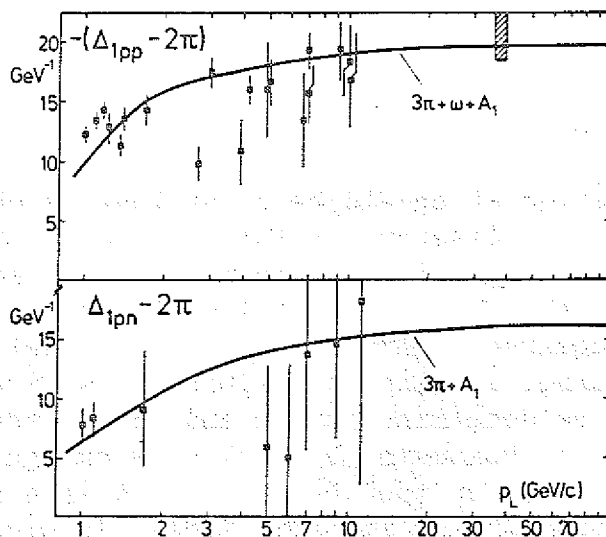


Figure 5 - The high energy behaviour of the discrepancy functions Δ_{1pp} and Δ_{1pn} . The 2π contribution has been subtracted out. The solid lines are our fits. The hatched bar is the average of the pp data from 15 to 2000 GeV/c.

I want to end this section with a few remarks concerning the contributions from other pole terms.

- i) There is no way to separate a small ϕ contribution from that of the ω . The values of the ω couplings quoted in table 1 are obtained under the neglect of the ϕ .
- ii) There are no hints at contributions from the δ and S^* . Nowadays these mesons are interpreted as cryptoexotics (12) with a $s\bar{s}$ quark content (compare table 1). Their weak coupling to nucleons may be then taken as evidence that the low energy NN interaction obeys the Zweig rule. This justifies the neglect of the ϕ . According to Lovas (13) the validity of Zweig's rule may be also the reason why there is no hint at contributions from the 4 (or more) π continuum in the data.
- iii) Contributions from heavy mesons are negligible. In the case of the f meson for which the coupling constants have been computed from πN hyperbolic dispersions relations (14) (compare table 1) one can, however, demonstrate the effect of such a pole term. As is seen from figures 3 and 4 the contributions of the f lie within the error bars. Similar (or smaller) effects are expected from other heavy mesons.

5. Conclusions

Exploiting the experimentally available information on forward nucleon-nucleon scattering in terms of discrepancy functions one can clearly demonstrate the need for contributions from the 3π continuum which are not included in the usual pole approximation. The 3π term is sufficiently well described by a conventional nucleon exchange model. Having done this, one finds a surprisingly perfect agreement of the 2π contribution as calculated from the available $NN \rightarrow \pi\pi$ partial waves and the NN scattering data.

In addition to the 2π and 3π contributions effects of the ω and the A_1 pole terms are seen in the discrepancy functions, allowing us to fix their coupling constants.

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DISCUSSION

- C.B. Dover:

I was struck by the implications of your remarks (on the role of the three-pion continuum) for conventional one-boson-exchange models of the nucleon-nucleon potential. Some of the OBE models, for instance the very successful one due to the Nijmegen group, have a sizeable coupling to η and η' as well as a large value $f/g \approx 0.7$ for the ω exchange. As I understand it, this could be an artifact of having treated three-pion-exchange improperly. Do you agree?

- P. Kroll :

Yes, I agree. As an example, let me explain how one can arrive at a large η coupling in the dispersion theoretic approach. Let us assume that we would not have at our disposal the $\Delta\sigma_L(pn)$ data. Then we could only compute $\Delta_S(pp)$ but not separate the isospins. $\Delta_S(pp)$ is negative (compare figure 2) and we would take this as the η and not call for 3π contributions. Fitting a pole term to $\Delta_S(pp)$, we would obtain $g_{\eta/4\pi}^2 \approx 4.7$.

- G. Violini :

Could you make some comment on the quality of the input data for the three forward contributing amplitudes? And did you make any attempt to study by your method also the two non-forward contributing ones?

- P. Kroll :

Our analysis is based on σ_{tot} , $\Delta\sigma_L$ data for pp and pn scattering as well as $\Delta\sigma_T(pp)$ and the pn charge exchange forward $d\sigma/dt$. Apart from $\Delta\sigma_L(pn)$ the quality of the data is good, the statistical errors are less than 5%. $\Delta\sigma_L(pn)$, obtained from proton-deuteron data, has statistical errors of about 10% and in addition it suffers from the uncertainties of the Glauber corrections which amount to a systematical error of about 1 mb for $P_L = 1$ to 2 GeV/c. At higher energies the systematical error drops down rapidly.

We have not attempted an investigation of non-forward amplitudes since above the phase shift region there is no input available.

1. The first part of the report is a general introduction to the subject.

2. The second part of the report is a detailed description of the methods used in the study.

3. The third part of the report is a discussion of the results of the study.

4. The fourth part of the report is a conclusion and a list of references.

5. The fifth part of the report is a summary of the findings of the study.

6. The sixth part of the report is a list of references.

7. The seventh part of the report is a list of references.

Workshop on
Mesons and Mesonic States

up to slightly above $1 \text{ GeV}/c^2$

at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich
February 19. - 20. 1990

v)

K. Koenigsmann

η , η' , f_0 and a_0
in Two-Photon Interactions

2-photon production of η' & a_0

71

- Introduction to $\gamma\gamma$ -scattering
Formalism & what we learn
Constituents in mesons

- $\gamma\gamma \rightarrow$ Pseudoscalars

Experiments

Mixing angle
Gluon content

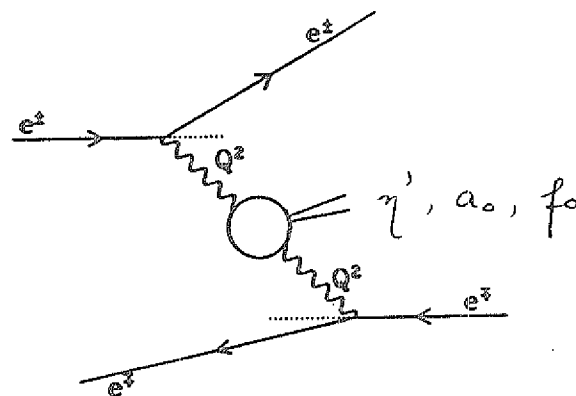
- $\gamma\gamma \rightarrow$ Scalars

Experiments

$q\bar{q}$ vs $q\bar{q}q\bar{q}$ vs $K\bar{K}$

K. Königsmann: Workshop on Mesons &
Mesonic States Tübingen, 1990

Two-Photon Production



Unique conditions:

- initial state calculable

QED 2nd order

- final state with

$C = +$ and $J \neq 1$ ('no-tag')

- $\sigma(e^+e^- \rightarrow e^+e^- R) \propto \langle e_q^2 \rangle_R^2$

$\rightarrow$ test of Quark / Gluon
constituents

$$\sigma(e^+e^- \rightarrow e^+e^- R)$$

with 'equivalent-photon approx.'

calculated by Low 1960 for π^0

$$\sigma(e^+e^- \rightarrow e^+e^- R) = \eta^2 \int \frac{d\omega^2}{\omega^2} f\left(\frac{\omega}{2E_e}\right) \sigma_{\gamma\gamma \rightarrow R}(\omega^2)$$

$$\eta = \frac{\alpha}{\pi} \ln \frac{E_e}{2m_e}$$

$$\omega_{\gamma\gamma} = 2 \sqrt{(E_1 - E'_1)(E_2 - E'_2)}$$

$$f\left(\frac{\omega}{2E_e}\right) \approx 8 \ln \frac{\omega}{2E_e} - 6$$

$$\sigma(\gamma\gamma \rightarrow R) = 8\pi(2j+1) \frac{\Gamma_{\text{tot}} \Gamma_{\gamma\gamma}}{(\omega^2 - M^2)^2 + \Gamma^2 M^2}$$

$$\xrightarrow{\Gamma \ll M} 8\pi^2(2j+1) \frac{\Gamma_{\gamma\gamma}}{M_R} \delta(\omega^2 - M^2)$$

$$\sigma(e^+e^- \rightarrow e^+e^- R) = \eta^2 f\left(\frac{M}{2E}\right) 8\pi^2(2j+1) \frac{\Gamma_{\gamma\gamma}}{M_R^2}$$

$$\approx 0.5 \text{ nb} \frac{\Gamma_{\gamma\gamma} / \text{keV}}{M_R^2 / \text{GeV}}$$

at DORIS

Measurement of $\sigma(e^+e^- \rightarrow e^+e^- R)$

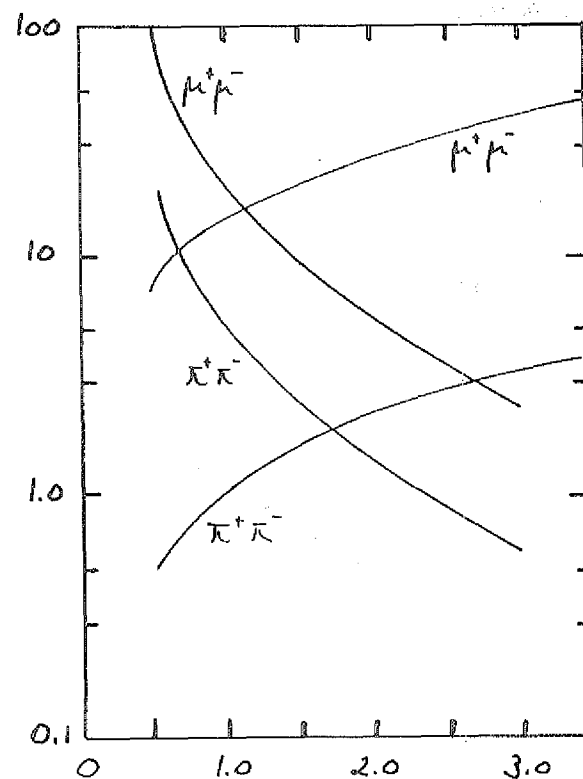
allows determination of $\Gamma_{\gamma\gamma}$

$$e^+e^- \rightarrow e^+e^- X$$

vs.

$$e^+e^- \rightarrow X$$

$$\frac{\sigma(e^+e^- \rightarrow e^+e^- X)}{\sigma(e^+e^- \rightarrow X)}$$



E_e / GeV

Statistics

is still a problem in
 $\gamma\gamma$ -scattering

with $\mathcal{L}_{ee} \approx 100 \text{ pb}^{-1} / \text{yr}$

$$\sigma_{ee \rightarrow e e h} \approx 0.5 \text{ nb}$$

$$\epsilon \approx 1\%$$

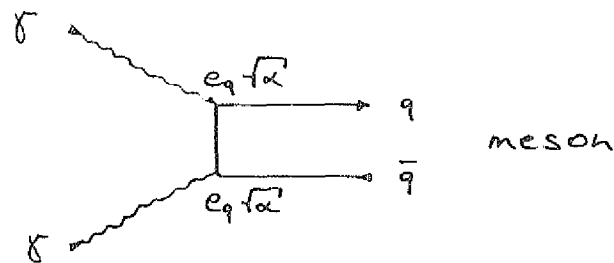
$$\Rightarrow N_R \approx 500 \text{ events / yr}$$

ok for M_R , Γ_R , Γ_{RR}

but not for PWA!

need complementing experiments!

Γ_{RR} of Mesons



$$|m\rangle = a |u\bar{u}\rangle + b |d\bar{d}\rangle + c |s\bar{s}\rangle$$

$$\text{with } a^2 + b^2 + c^2 = 1$$

$$\langle \gamma\gamma | m \rangle \propto \langle e_q^2 \rangle_m$$

$$\propto a \cdot \frac{4}{9} + b \cdot \frac{1}{9} + c \cdot \frac{1}{9}$$

$$\Gamma_{\gamma\gamma} \propto |\langle \gamma\gamma | m \rangle|^2$$

$$\propto \langle e_q^2 \rangle_m^2$$

- large sensitivity to $u\bar{u}$ contents
- although $\langle \gamma\gamma | gg \rangle = 0$
sensitivity to gluon contents
via $a^2 + b^2 + c^2 < 1$

Physical Mesons

$$SU(3) \quad \pi^0 = (d\bar{d} - u\bar{u}) / \sqrt{2}$$

$$\eta_1 = (d\bar{d} + u\bar{u} + s\bar{s}) / \sqrt{3}$$

$$\eta_8 = (d\bar{d} + u\bar{u} - 2s\bar{s}) / \sqrt{6}$$

η_1 & η_8 with same quantum # mix

$$\eta = \eta_8 \cos \theta - \eta_1 \sin \theta$$

$$\eta' = \eta_8 \sin \theta + \eta_1 \cos \theta$$

'ideal mixing' with $\tan \theta = 1/\sqrt{2}$

$$\eta = s\bar{s}$$

$$\eta' = (u\bar{u} + d\bar{d}) / \sqrt{2}$$

but annihilations $d\bar{d} \leftrightarrow 2g \leftrightarrow s\bar{s}$

yields $\theta \approx -20^\circ$

$$\eta \approx 0.6 u\bar{u} + 0.6 d\bar{d} - 0.6 s\bar{s}$$

$$\eta' \approx 0.4 u\bar{u} + 0.4 d\bar{d} + 0.8 s\bar{s}$$

another set of basis states
better suited for later discussion

$$n\bar{n} = (u\bar{u} + d\bar{d}) / \sqrt{2}$$

$$s\bar{s} = s\bar{s} \quad \text{Rosner}$$

$$(gg = \text{gluonium})$$

then

$$\eta = x_\eta \cdot n\bar{n} + y_\eta \cdot s\bar{s}$$

$$\eta' = x_{\eta'} \cdot n\bar{n} + y_{\eta'} \cdot s\bar{s}$$

$$\text{with } x_\eta = y_{\eta'} = \sqrt{\frac{1}{3}} \cos \theta - \sqrt{\frac{2}{3}} \sin \theta$$

$$y_\eta = -x_{\eta'} = -\sqrt{\frac{1}{3}} \cos \theta - \sqrt{\frac{2}{3}} \sin \theta$$

$$\text{or } \tan \theta = \frac{-\sqrt{2} x_\eta - y_\eta}{x_\eta - \sqrt{2} y_\eta} = \frac{x_{\eta'} - \sqrt{2} y_{\eta'}}{\sqrt{2} x_{\eta'} + y_{\eta'}}$$

Predictions for $\Gamma_{\pi\pi}$

$$\begin{aligned}\Gamma_{\pi\pi}(\pi^0) &= \frac{9\alpha^2}{32\pi^3} m_\pi^3 \frac{\langle e_q^2 \rangle_\pi^2}{f_\pi^2} \\ &= \frac{\alpha^2}{64\pi^3} \cdot \frac{m_\pi^3}{f_\pi^2}\end{aligned}$$

Adler-Bell-Jackiw ('69)

in the quark model expect:

$$\frac{\langle e_q^2 \rangle_\pi}{f_\pi} \rightarrow \frac{\langle e_q^2 \rangle_{1/8}}{f_{1/8}}$$

SU(3) symmetry : $f_\pi = f_8$

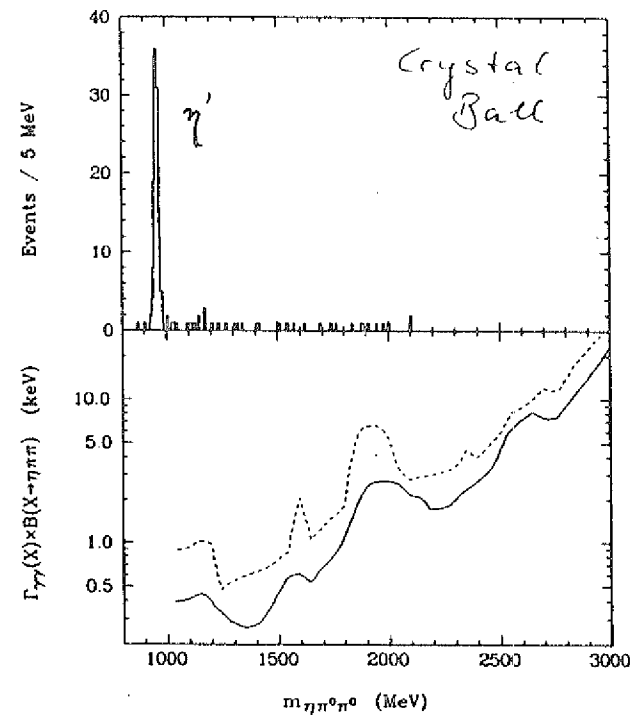
SU(3) broken : $f_\pi \approx 0.8 f_8$
Donoghue ... (86), Grunberg

f_8 / f_1 unknown

$$\frac{\Gamma_{\pi\pi}(\eta)}{\Gamma_{\pi\pi}(\pi^0)} = \frac{1}{3} \cdot \frac{m_\eta^3}{m_\pi^3} \left\{ \frac{f_\pi}{f_8} \cos\theta - \sqrt{8} \frac{f_\pi}{f_1} \sin\theta \right\}$$

$$\frac{\Gamma_{\pi\pi}(\eta')}{\Gamma_{\pi\pi}(\pi^0)} = \frac{1}{3} \cdot \frac{m_{\eta'}^3}{m_\pi^3} \left\{ \frac{f_\pi}{f_8} \sin\theta + \sqrt{8} \frac{f_\pi}{f_1} \cos\theta \right\}$$

$\gamma\gamma \rightarrow \gamma\gamma\gamma\gamma\gamma\gamma$



$$\Gamma_{\pi\pi}(\eta') = 4.6 \pm 0.7 \text{ keV}$$

All Experiments on $\Gamma_{\pi\pi}(\pi^0, \eta, \eta')$

$\Gamma_{\pi\pi}(\pi^0)$

$\Gamma_{\pi\pi}(\pi^0)$ (eV)	mode	Experiment
7.9 ± 0.5	various	previous average ($S = 1.9$) [7]
$7.25 \pm 0.18 \pm 0.11$	decay distance	Atherton <i>et al.</i> [83]
$7.7 \pm 0.5 \pm 0.5$	$\gamma\gamma \rightarrow \gamma\gamma$	Crystal Ball [84]
7.5 ± 0.3	all	average ($S = 1.7$)
$\Gamma_{\pi\pi}(\eta)$ (keV)	mode	Experiment
1.00 ± 0.22	Primakoff	Bemporad <i>et al.</i> [85]
0.324 ± 0.046	Primakoff	Browman <i>et al.</i> [86]
$0.56 \pm 0.12 \pm 0.10$	$\gamma\gamma \rightarrow \gamma\gamma$	Crystal Ball (SPEAR) [87]
$0.53 \pm 0.04 \pm 0.04$	$\gamma\gamma \rightarrow \gamma\gamma$	JADE [88]
$0.64 \pm 0.14 \pm 0.13$	$\gamma\gamma \rightarrow \gamma\gamma$	TPC/2 γ [89]
$0.514 \pm 0.017 \pm 0.035$	$\gamma\gamma \rightarrow \gamma\gamma$	Crystal Ball [84]
0.52 ± 0.03	$\gamma\gamma \rightarrow \gamma\gamma$	average

76

$\Gamma_{\pi\pi}(\eta)$

$\Gamma_{\pi\pi}(\eta') \times E$ (keV)	$\Gamma_{\pi\pi}(\eta')$ (keV)	mode	Experiment
$1.74 \pm 0.33 \pm 0.34$	$5.8 \pm 1.1 \pm 1.2$	$\rho\gamma$	Mark II [17]
$1.50 \pm 0.15 \pm 0.27$	$5.0 \pm 0.5 \pm 0.9$	$\rho\gamma$	JADE [90]
$1.86 \pm 0.33 \pm 0.24$	$6.2 \pm 1.1 \pm 0.8$	$\rho\gamma$	CELLO [91]
$1.14 \pm 0.08 \pm 0.11$	$3.80 \pm 0.26 \pm 0.43$	$\rho\gamma$	PLUTO [92]
$1.53 \pm 0.12 \pm 0.19$	$5.1 \pm 0.4 \pm 0.7$	$\rho\gamma$	TASSO [93]
$1.35 \pm 0.09 \pm 0.19$	$4.5 \pm 0.3 \pm 0.7$	$\rho\gamma$	TPC/2 γ [94]
$1.38 \pm 0.33 \pm 0.27$	$4.6 \pm 1.1 \pm 0.9$	$\rho\gamma$	MD-1 (prel.) [95]
$1.13 \pm 0.04 \pm 0.13$	$3.76 \pm 0.13 \pm 0.47$	$\rho\gamma$	ARGUS [96]
$1.28 \pm 0.08 \rightarrow$	4.25 ± 0.34	$\rho\gamma$	average
0.074 ± 0.017	4.0 ± 0.9	$\gamma\gamma$	JADE [88]
$0.104 \pm 0.011 \pm 0.007$	$4.5 \pm 0.5 \pm 0.5$	$\gamma\gamma$	Crystal Ball [84]
$0.093 \pm 0.015 \rightarrow$	4.17 ± 0.75	$\gamma\gamma$	average ($S = 1.4$)
$2.04 \pm 0.26 \pm 0.39$	$4.7 \pm 0.6 \pm 0.9$	$\eta\pi^+\pi^-$	Mark II [57]
$1.65 \pm 0.06 \pm 0.22$	$3.80 \pm 0.13 \pm 0.50$	$\eta\pi^+\pi^-$	JADE (prel.) [1]
$1.03 \pm 0.08 \pm 0.11$	$4.6 \pm 0.4 \pm 0.6$	$\eta\pi^0\pi^0$	Crystal Ball [36]
$2.77 \pm 0.25 \rightarrow$	4.43 ± 0.41	$\eta\pi\pi$	average
	4.30 ± 0.25	all	average

$\Gamma_{\pi\pi}(\eta')$

World average values

$$\Gamma_{\pi\pi}(\pi^0) = 7.5 \pm 0.3 \text{ eV}$$

$$\Gamma_{\pi\pi}(\eta) = 0.52 \pm 0.03 \text{ keV}$$

$$\Gamma_{\pi\pi}(\eta') = 4.30 \pm 0.25 \text{ keV}$$

this yields:

$$\Theta = -22^\circ \pm 1^\circ$$

$$f_K/f_1 = 0.95 \pm 0.03$$

check for gg -contents in η' (only)

$$\eta' = (\eta_8 \sin\Theta + \eta_1 \cos\Theta) \cos\varphi + gg \sin\varphi$$

$$\text{with } \Gamma_{\pi\pi}(gg) = 0 !$$

$$\text{set } f_K/f_8 = 0.8 \quad \& \quad f_K/f_1 = 1.0$$

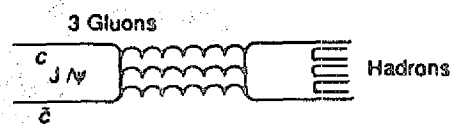
$$\sim \Theta = -21^\circ \pm 2^\circ$$

$$|\varphi| = 25^\circ \pm 5^\circ$$

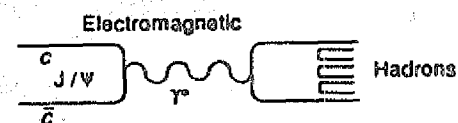
$$|\sin\varphi| = 0.42 \pm 0.08$$

i.e. $0.42^2 = 18\%$ gg -contents in η'

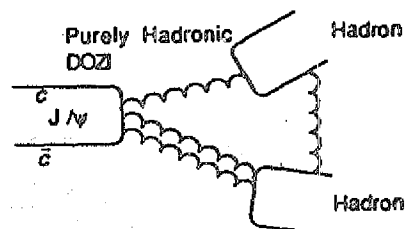
J/ψ Decays



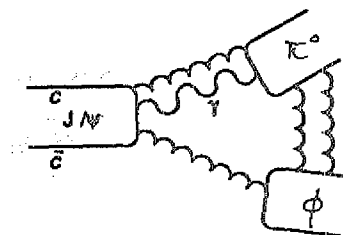
$$I = 0$$



$$I = 0, 1$$



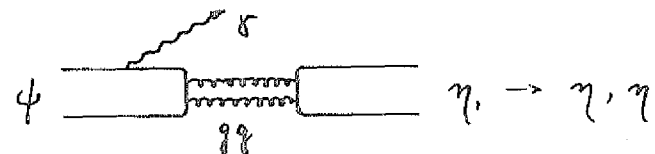
$$I = 0$$



$$I = 0, 1$$

Other exp^t determinations of Θ

$$\phi \rightarrow \delta(\gamma, \gamma')$$



$$\frac{\Gamma(\phi \rightarrow \delta \gamma')}{\Gamma(\phi \rightarrow \delta \gamma)} = \frac{k_{\gamma'}^2}{k_{\gamma}^2} \times \frac{1}{4\pi^2 \Theta}$$

$$= 4.8 \pm 0.2$$

PDG

$$\sim \Theta = -22^\circ \pm 1^\circ$$

$$\phi \rightarrow V + P$$

$$V = \{\rho, \omega, \phi; K^*\}$$

$$P = \{\pi, \eta, \eta'; K\}$$

involves 4 decay diagrams

$$\sim \Theta = -19^\circ \pm 1^\circ$$

$$X_\eta = 0.814 \pm 0.014$$

Mark 3 (88)

- M1 radiative transitions
Gilman (87)

$$\phi \rightarrow \gamma \eta \quad \rightarrow \quad x_\eta = 0.52 \pm .05$$

$$\eta' \rightarrow \gamma \rho \quad \rightarrow \quad x_\eta = 0.57 \pm .05$$

$$\rightarrow \theta \approx 20^\circ$$

$$\eta' \rightarrow \gamma \omega \quad \rightarrow \quad x_{\eta'} = 0.65 \pm 0.07$$

$$\rho \rightarrow \gamma \eta \quad \rightarrow \quad x_\eta = 0.76 \pm 0.06$$

$$\rightarrow \theta \approx -15^\circ$$

- $\pi \rho$ scattering Gilman (87)

$$\frac{\sigma(\pi^- \rho \rightarrow \eta' n)}{\sigma(\pi^- \rho \rightarrow \eta n)} = \left| \frac{x_{\eta'}}{x_\eta} \right|^2$$

$$\rightarrow \theta \approx -16^\circ \pm 2^\circ$$

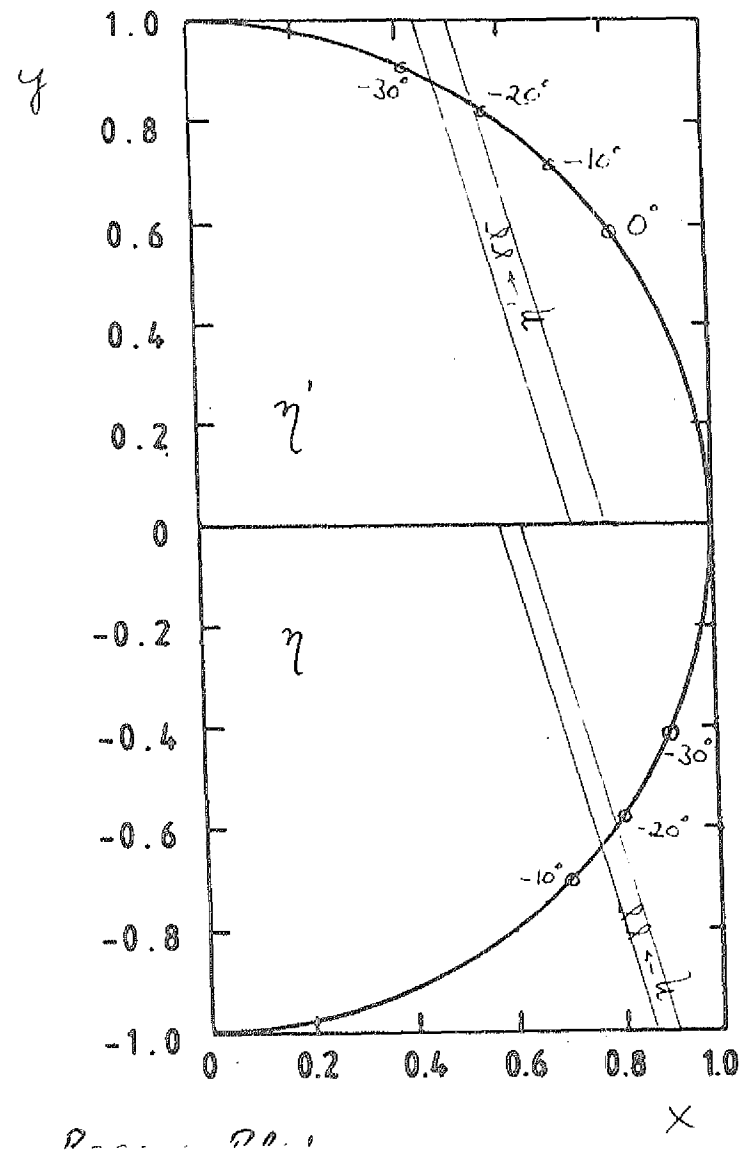
- Quadratic mass matrix

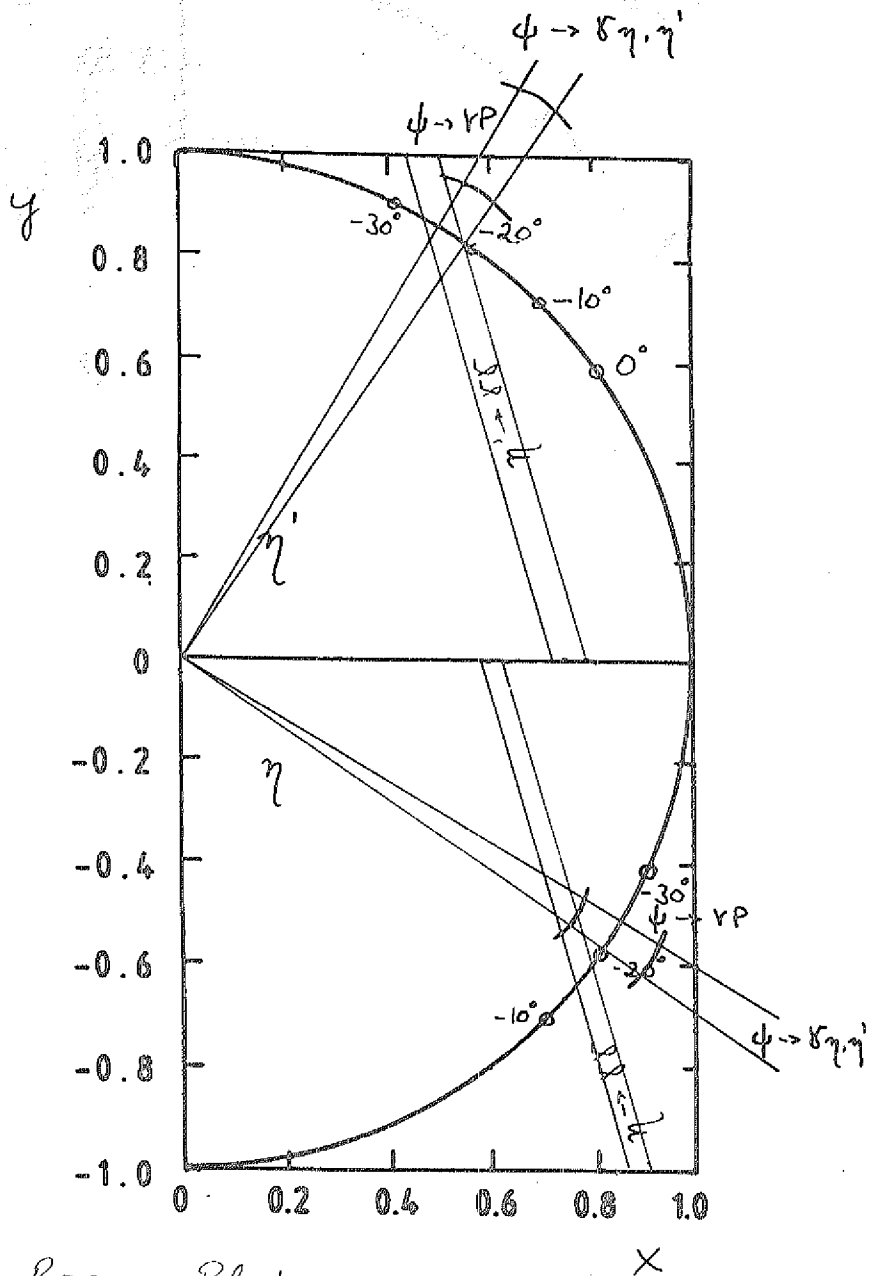
Gell-Mann - Okubo +

1 loop chiral corrections

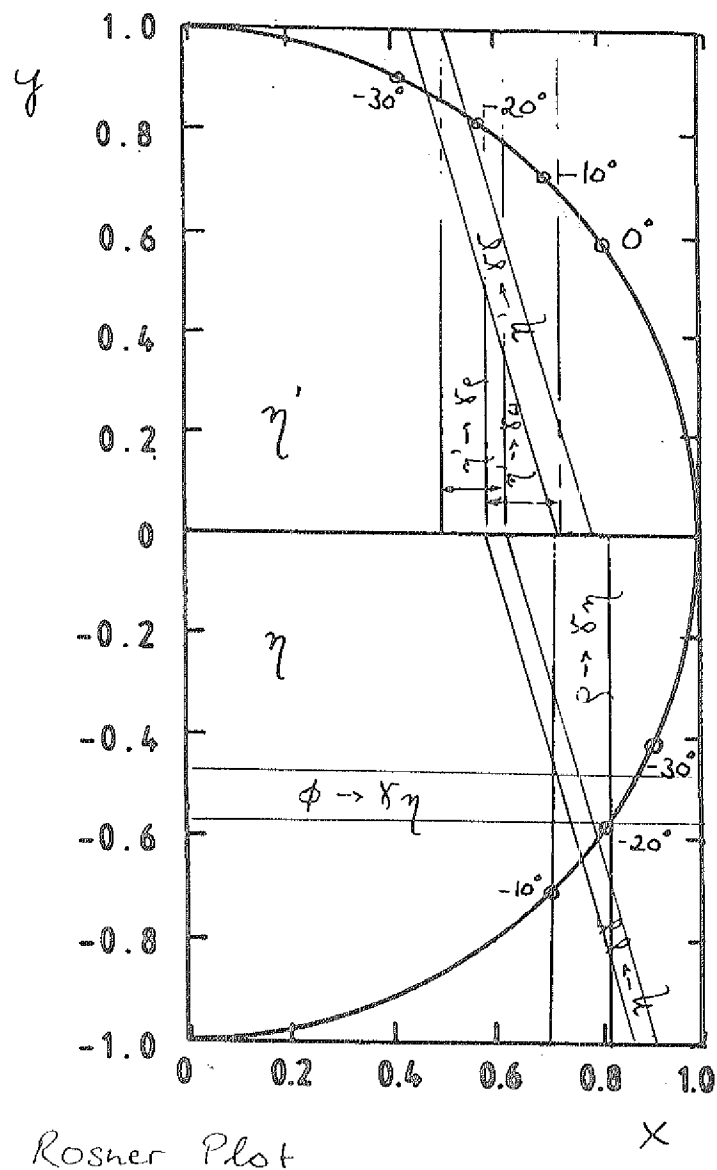
$$\rightarrow \theta \approx -20^\circ \pm 4^\circ$$

Donoghue (85)

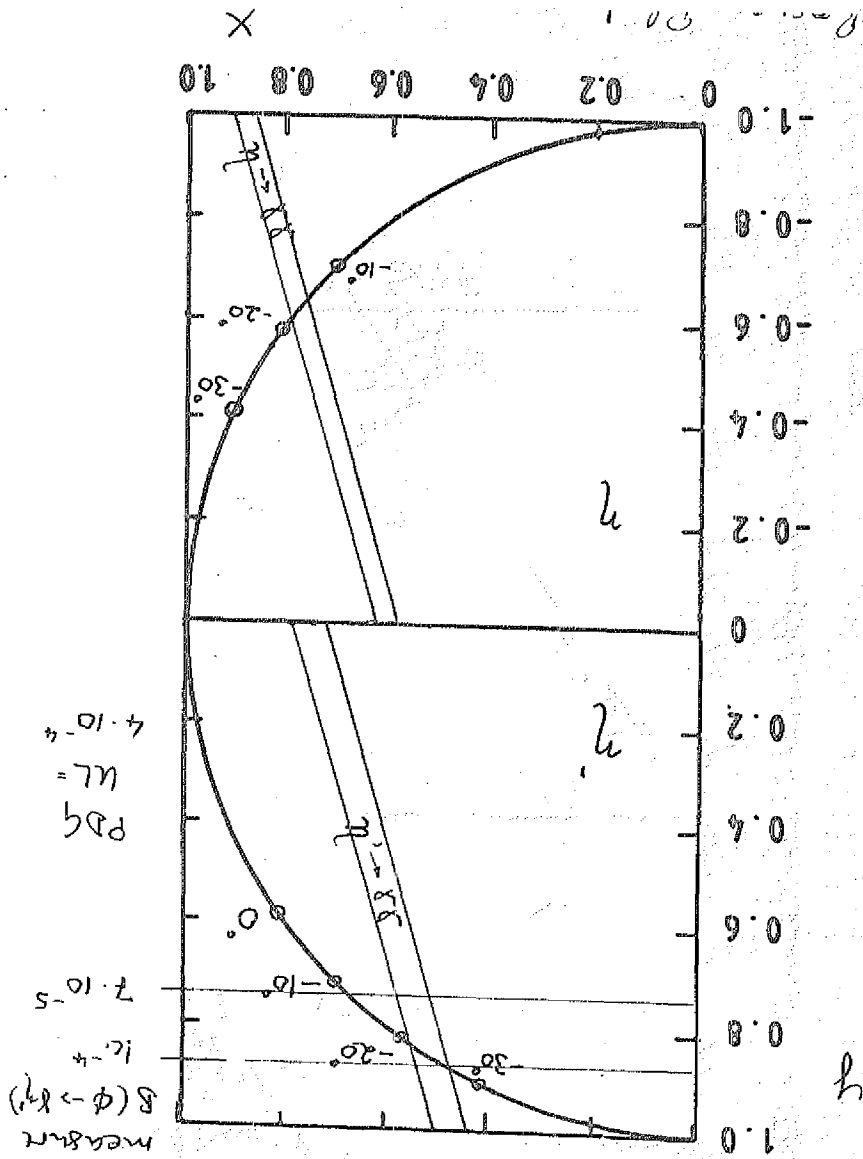




Rosner Plot



Rosner Plot



$\eta \rightarrow$ Scalar Mesons

in contrast to $L=1$ $3P_2$ states
 at $L=1$ $3P_0$ states problematic
 $f_0(1975)$ & $a_0(980)$
 too light
 $m(f_2, a_2) \approx 200$ MeV
 $a_0(1090)$ $f_0(1090)$ Godfrey-Jagun (1985)

- too narrow
 $\Gamma_{a_0} \approx 300$ MeV $\Gamma_{f_0} \approx 850$ MeV $q \neq$

- too strongly coupled to $K\bar{K}$

$1.3 \leq g_{\eta K} / g_{\eta \pi} \leq 2.5$ Morgan (77)

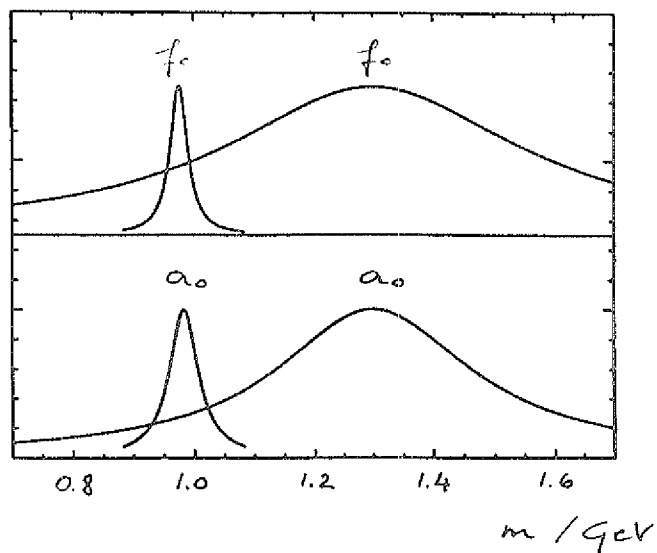
$\phi \rightarrow \eta f_0$ but $\phi \rightarrow \phi f_0$ Marks (92)

- too many $3P_0$ states

in the 1-2 GeV region

9 candidate states

4 needed!



Comparison of ρ - ω -
line shapes of

$f_0(975)$ with $\Gamma_{f_0} = 34 \text{ MeV}$

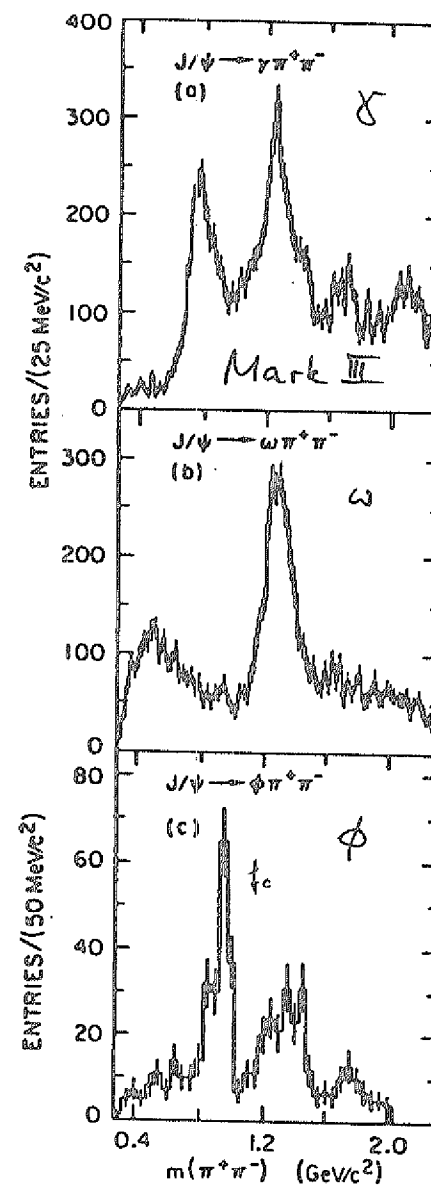
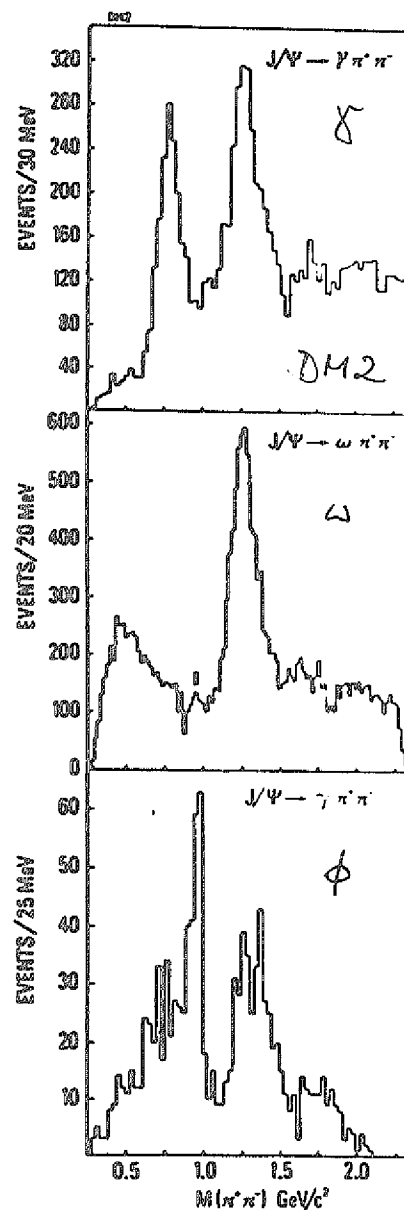
$f_0(1300)$ with $\Gamma_{f_0} = 600 \text{ MeV}$

and $a_0(980)$ with $\Gamma_{a_0} = 57 \text{ MeV}$

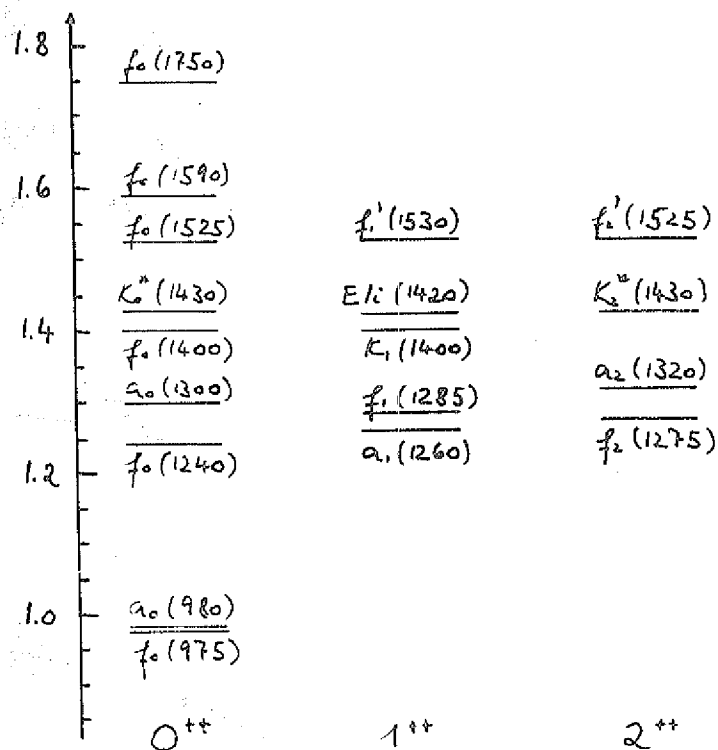
$a_0(1300)$ with $\Gamma_{a_0} = 400 \text{ MeV}$

Gieseler '89

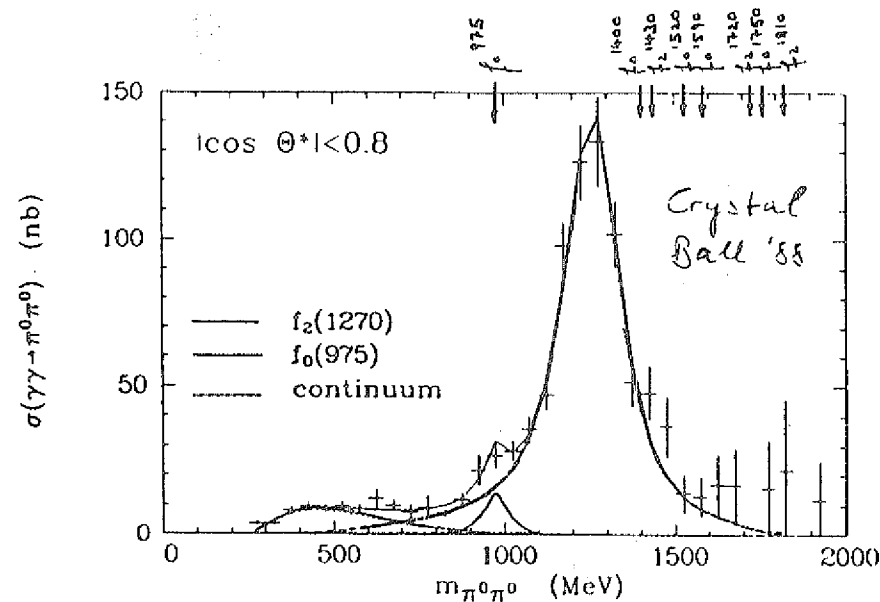
$$J/\psi \rightarrow (\rho, \omega, \phi) \pi^+ \pi^-$$



GeV / m



$$\gamma\gamma \rightarrow \pi^+\pi^- \rightarrow \gamma\gamma\gamma\gamma$$



$$f_2(1270) : \Gamma_{\gamma\gamma} = 3.3 \pm 0.3 \text{ keV}$$

$$f_0(975) : \Gamma_{\gamma\gamma} = 0.31 \pm 0.17 \text{ keV} \quad 2.2\sigma$$

Vorhersage : $f_0 = S^*$

$$f_0 = q\bar{q}$$

$$= q\bar{q}q\bar{q}$$

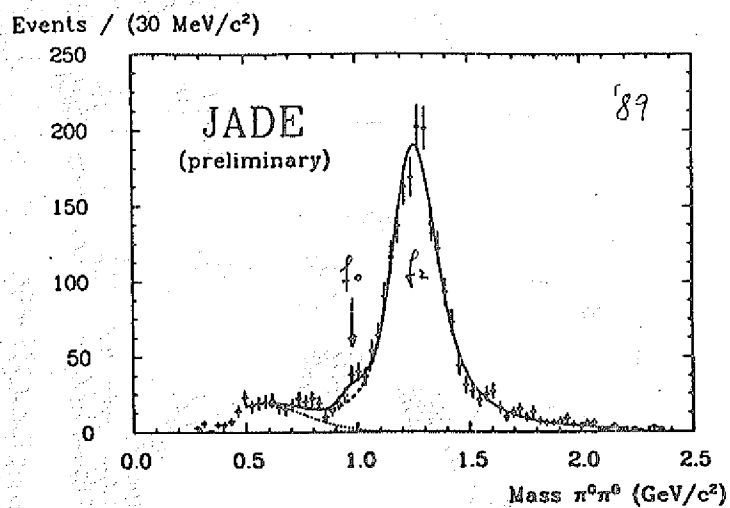
$$= K\bar{K} \text{ molecule}$$

$$\Gamma_{\gamma\gamma} \sim 5 \text{ keV} \sim 4 \Gamma_{\gamma\gamma}^{f_2(1270)}$$

$$\sim 0.3 \text{ keV}$$

$$\sim 0.6 \text{ keV}$$

$$\gamma\gamma \rightarrow 2\pi^0 \rightarrow \gamma\gamma\gamma\gamma$$

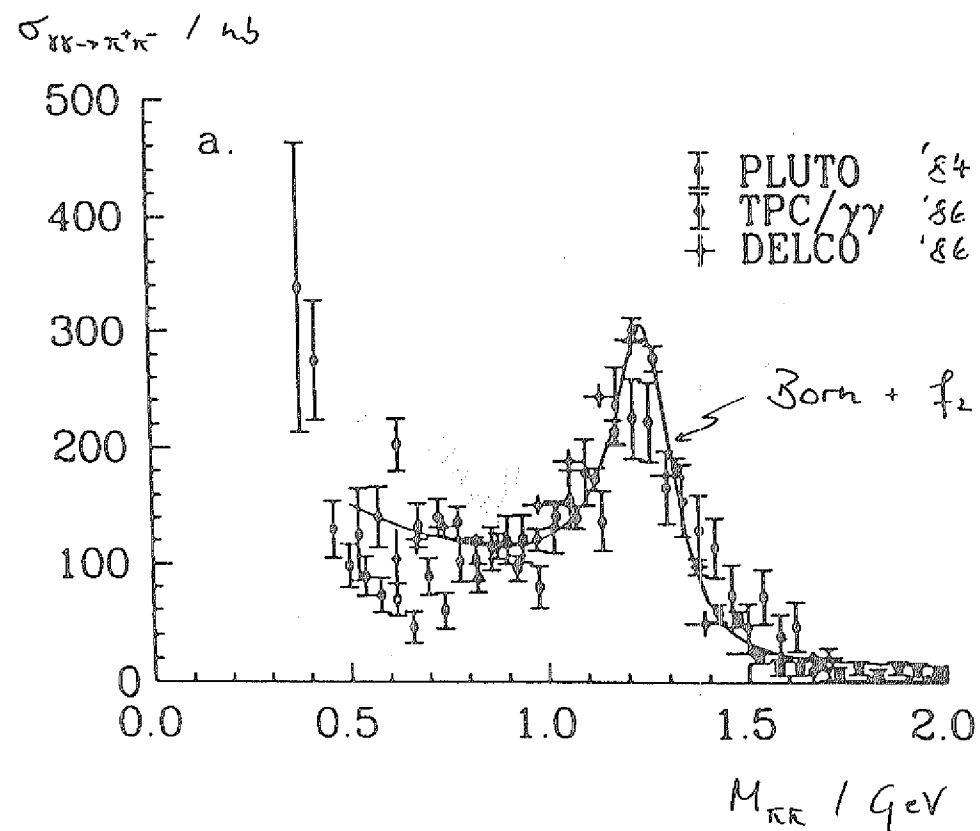


$$f_2(1270) : \Gamma_{\gamma\gamma} = 3.1 \pm 0.4 \text{ keV}$$

$$f_0(975) : \Gamma_{\gamma\gamma} < 0.6 \text{ keV} \quad 90\% \text{ CL}$$

$$45 \pm 7 \text{ events} : 65$$

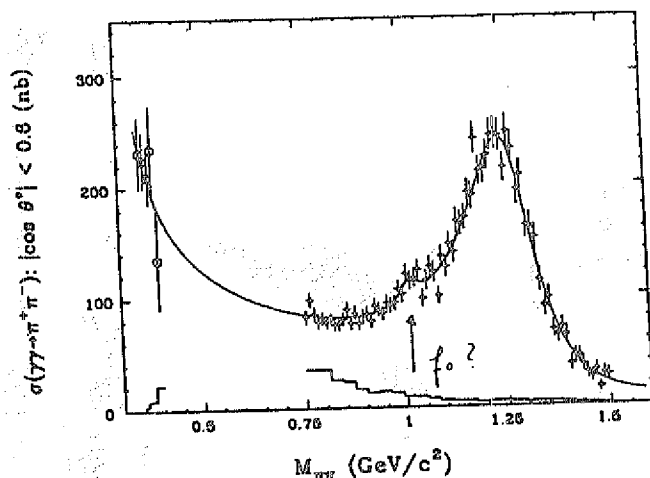
$$\gamma\gamma \rightarrow \pi^+ \pi^-$$



from S. Cartwright, Chicago 86

$$\gamma\gamma \rightarrow \pi^+\pi^-$$

Mark II (88)



Thesis
Boyer

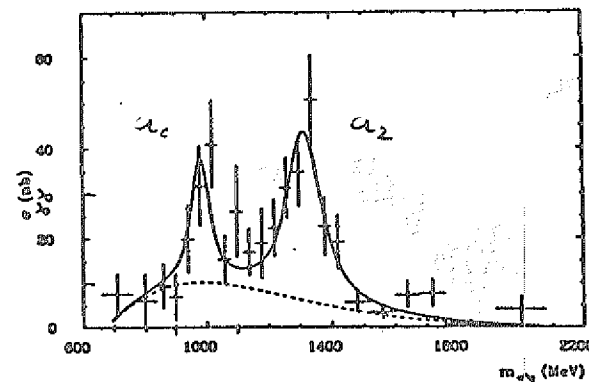
$$f_2(1275) : \Gamma_{\gamma\gamma} = 3.2 \pm 0.1 \text{ keV}_{\text{stat}}$$

$$f_0(975) : m(f_0) = 1012 \pm 7 \text{ MeV} \\ = m(975) + 5\sigma !$$

$$\Gamma(f_0) = 52 \pm 20 \text{ MeV}$$

$$\Gamma_{\gamma\gamma} = 0.29 \pm 0.11 \text{ keV}_{\text{stat}} \\ 2.6 \sigma$$

$$\gamma\gamma \rightarrow \pi^0\eta \rightarrow \gamma\gamma\gamma\gamma$$



Crystal
Ball '86

$$a_2(1320) : \Gamma_{\gamma\gamma} = 1.1 \pm 0.3 \text{ keV}$$

$$a_0(980) : \Gamma_{\gamma\gamma} = (0.19 \pm .12) \text{ keV} / B_{\gamma\pi}^{\frac{1}{2} \approx 0.9} \\ \approx 0.2 \pm 0.1 \text{ keV} \quad 2.7\sigma$$

Vorhersage :

$$a_0 = q\bar{q}$$

$$= q\bar{q}q\bar{q}$$

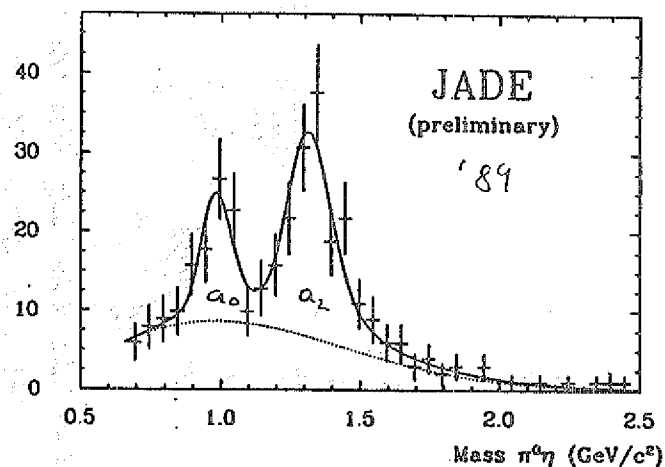
$$= K\bar{K} \text{ molecule}$$

$$\Gamma_{\gamma\gamma} \approx 2 \text{ keV} = 4 \Gamma_{\gamma\gamma}^{a_2}$$

$$\approx 0.3 \text{ keV}$$

$$\approx 0.6 \text{ keV}$$

$$\gamma\gamma \rightarrow \gamma \pi^0 \rightarrow \gamma\gamma\gamma\gamma$$

Events / (50 MeV/c²)

$$a_2(1320) : \Gamma_{\text{rr}} = 1.1 \pm 0.3 \text{ keV}$$

$$a_0(980) : \Gamma_{\text{rr}} = (0.29 \pm 0.15 \text{ keV}) / B_{\eta\pi} \\ \approx 0.3 \pm 0.16 \text{ keV}$$

Experiment vs. Theory for O^+ mesons

source	$\Gamma_{\text{rr}}(f_0)$ [keV]	$\Gamma_{\text{rr}}(a_0)$
Experiments	0.30 ± 0.09	0.25 ± 0.10
$q\bar{q}$	~ 5	~ 1.5
$s\bar{s}$	~ 0.3	
Achasov $q\bar{q}q\bar{q}$	~ 0.3	~ 0.3
Barnes $K\bar{K}$	~ 0.6	~ 0.6

$\rightarrow f_0$ & a_0 difficult to
accommodate as $q\bar{q}$ states

most likely

• $q\bar{q}q\bar{q}$ state

Jeff '77

• $K\bar{K}$ 'molecule'

Weinstein - Isgur '82

$K\bar{K}$ is special configuration
of $(u\bar{u} + d\bar{d})s\bar{s}$ state

maybe the only one ?!

WI

in particular

U-E
Barnes

$K\bar{K}$ molecule explains:

- $m(f_0, a_0) = 2m_K - E_b$
 $\approx 990 - 10 \text{ MeV}$
- $\Gamma(f_0 \rightarrow \pi\pi) \approx 15 \text{ MeV}$ (27 PDG)
- $\Gamma(a_0 \rightarrow \eta\pi) \approx 40 \text{ MeV}$ (~50 PDG + Barnes)
- $\Gamma_{\gamma\gamma}(a_0, f_0) \approx 0.6 \text{ keV}$
- $\psi \rightarrow \phi f_0$
 $\rightarrow \omega f_0$

98

added complication by Pennington

3! scalars below 1 GeV:

$S_1(991) = \text{glueball} ?!$

$S_2(988) = s\bar{s} \text{ or } K\bar{K}$

$E(900) = u\bar{u} + d\bar{d}$

How to prove $f_0 = K\bar{K}$?

measure $E1$ δ -transition

$f_0 \rightarrow \delta\eta$

$f_0 \rightarrow \delta\omega$

$\phi \rightarrow \delta f_0$

$\phi \rightarrow \delta a_0$

$B \sim 10^{-5}$

close

high statistics production expt
with

$f_0 \rightarrow K\bar{K}, \pi\pi$

$\delta \rightarrow K\bar{K}, \eta\pi$

maybe additional evidence
from

$i(1420) = K^* \bar{K}$

$E(1420) = K^* \bar{K}$

2

Workshop on
Mesons and Mesonic States

up to slightly above $1 \text{ GeV}/c^2$

at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich
February 19. - 20. 1990

VI)

J. Weinstein

$K\bar{K}$ - Boundstates

$K\bar{K}$ Bound. States

John Weinstein, Tennessee

KFA Workshop

February 19-21, 1990

Nathan Isgur
Ted Barnes

Eric Swanson
Greg Gordin
Kevin Dudley
J.S. Wu
Kim Maltman

A study of $qq\bar{q}\bar{q}$ systems

Motivations: Bag Model Predictions

Truncated Potential Model Predictions

→ Quark Model Predictions?

* Extend Quark Model from

Energies $\leftrightarrow$ Spectroscopy

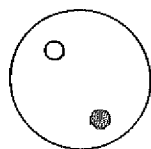
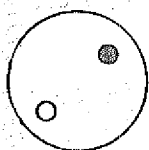
Wavefunctions $\leftrightarrow$ dynamics

Conclusions: S^* and δ are $K\bar{K}$ Molecules

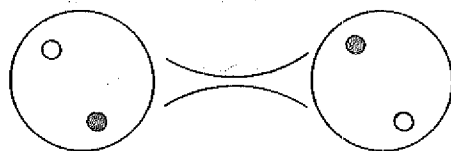
$\left\{ \begin{array}{l} \text{Final State} \\ \text{Coupled Channel} \end{array} \right\}$ Interactions

Lots of physics (before glue?)

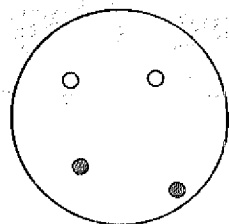
Possible $qq\bar{q}\bar{q}$ Ground States



$\updownarrow$ NRQM $\updownarrow$



$B \leftrightarrow \bar{B} \Leftrightarrow$ quark. exch.
↓
annihilation mixing



MIT Bag

Model: Coupled Channel, ^{radial} Schrödinger eqⁿ

$$\left[\begin{matrix} K \\ \approx \\ \approx \end{matrix} + \begin{matrix} M \\ \approx \\ \approx \end{matrix} + \begin{matrix} V \\ \approx \\ \approx \end{matrix} \right] \underline{u} = \sqrt{s} \underline{u}$$

$$\underline{u}_{I=0} = \begin{bmatrix} \pi\pi \\ K\bar{K} \\ q\bar{q} \\ q\bar{q}' \\ \pi\pi' \\ \eta\eta' \\ f_0 f_0' \end{bmatrix}$$

$$\underline{u}_{I=1} = \begin{bmatrix} \pi\eta \\ K\bar{K}' \\ \pi\eta' \\ a_0 \end{bmatrix}$$

$$\underline{u}_{I=2} = \begin{bmatrix} \pi\pi' \end{bmatrix}$$

$$\underline{u}_{I=3/2} = \begin{bmatrix} K\pi \end{bmatrix}$$

$$\underline{u}_{I=1/2} = \begin{bmatrix} K\pi \\ K\eta \\ K\eta' \\ \eta \end{bmatrix}$$

$$\left[\begin{matrix} K \\ \approx \\ \approx \end{matrix} \right]_{ij} = \frac{1}{2\mu_{ij}} P_i^2 \delta_{ij}$$

$$\left[\begin{matrix} M \\ \approx \\ \approx \end{matrix} \right]_{ij} = (m_{1i} + m_{2i}) \delta_{ij}$$

$$\left[\begin{matrix} V \\ \approx \\ \approx \end{matrix} \right]_{ij} = \begin{bmatrix} V[(P\bar{P})_i \rightarrow (P\bar{P})_j] & V[(P\bar{P})_i \leftrightarrow ({}^3P_0 q\bar{q})_i] \\ \hline & V[({}^3P_0 q\bar{q})_i \leftrightarrow ({}^3P_0 q\bar{q})_j] \end{bmatrix}$$

$\sqrt{s}' =$ invariant mass (non-relativistic)

the 3 types of rotations

3

$$V[(pp)_i \leftrightarrow (pp)_j]$$

- obtain from NRAM

of variational principle

of $qqq\bar{q}$ trial wfn

- dependent on hyperfine interactions



$$021 \leftrightarrow \eta - \eta', \text{ mixing}$$

$$V[(pp)_i \leftrightarrow ({}^3P_0 qq)_j]$$



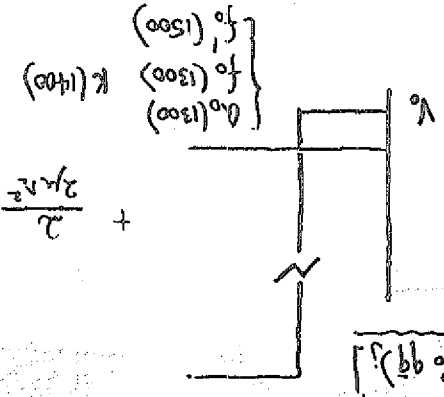
$\propto$ Haseen Clebsch Gordon

* kinematic factor

* SS suppression factor (=1)

* $SU(3)$ constant $\neq \Theta(a-n)$

[Hybrids at ~2.6 GeV]



16

NRQM

" QCD inspired model "

$$H = \sum_i m_i + \sum_i \frac{p_i^2}{2m_i} + \sum_{ij} \frac{c_{ij}}{r_{ij}} + H_{A=0} + \text{const}$$

where

$$H_{ij} = b_{ij} \vec{F}_i \cdot \vec{F}_j + \frac{\alpha_{EM}}{\alpha_s} H_{ij}^{QED} \vec{F}_i \cdot \vec{F}_j$$

and

$$F_i^a = \begin{cases} +\frac{1}{2}\lambda_i^a & i = \text{quark} \\ -\frac{1}{2}\lambda_i^a & i = \text{antiquark} \end{cases}$$

> Clearly incomplete.

> Reproduces much of the known exp data on mesons & baryons with ~ 10 "free" parameters.

> Testable.

3

qqq̄q̄ in NRQM

$$|SS_{\pm}\rangle = \frac{N_{SS\pm}}{\sqrt{2}} \left[\overset{\text{space}}{\psi_{SS\pm}(\vec{a}, \vec{y}, \vec{x})} \overset{\text{color}}{\boxed{q_1 q_2 \bar{q}_3 \bar{q}_4}} \overset{\text{Spin}}{\left| 1_{13} 1_{24} \right\rangle} \right. \\ \left. \mp \psi_{SS\pm}(\vec{a}, \vec{x}, \vec{y}) \left| 1_{14} 1_{23} \right\rangle \right] |S_{12} S_{34}\rangle$$

$$|AA_{\pm}\rangle = \frac{N_{AA\pm}}{\sqrt{2}} \left[\psi_{AA\pm}(\vec{a}, \vec{y}, \vec{x}) \left| 1_B 1_{24} \right\rangle \right. \\ \left. \pm \psi_{AA\pm}(\vec{a}, \vec{x}, \vec{y}) \left| 1_{14} 1_{23} \right\rangle \right] |\vec{A}_{12} \cdot \vec{A}_{34}\rangle$$

{upper} states are {symmetric} under 1↔2 or 3↔4,
{lower} states are {antisymmetric}

Couple with {antisymmetric 3×3 "cryptoexotic"} flavor.
{symmetric 6×6 "exotic"}

Minimize Energy in $H + \sum_{i<j} \frac{1}{2} \in R_{ij}^2$ with
 $\cos \alpha_{\pm} |SS_{\pm}\rangle + \sin \alpha_{\pm} |AA_{\pm}\rangle$.

H is constrained by q̄q̄ spectroscopy

Find O^+ is mostly $O^- O^-$ w almost no $|\bar{l} l$ comp.

Define

$$\psi_{\text{eff}}(\vec{r}) = \langle (q\bar{q})_1 (q\bar{q})_2 \delta(\vec{r}_1 - \vec{r}_2 + \vec{r}_2) | qq\bar{q}\bar{q} \rangle$$

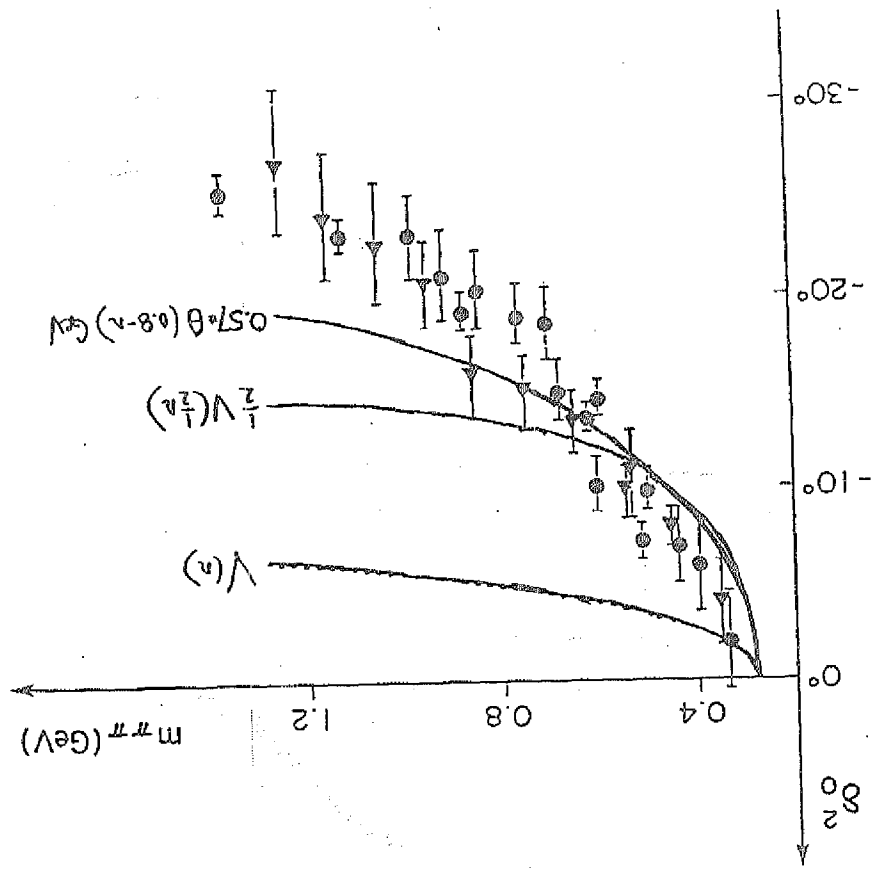
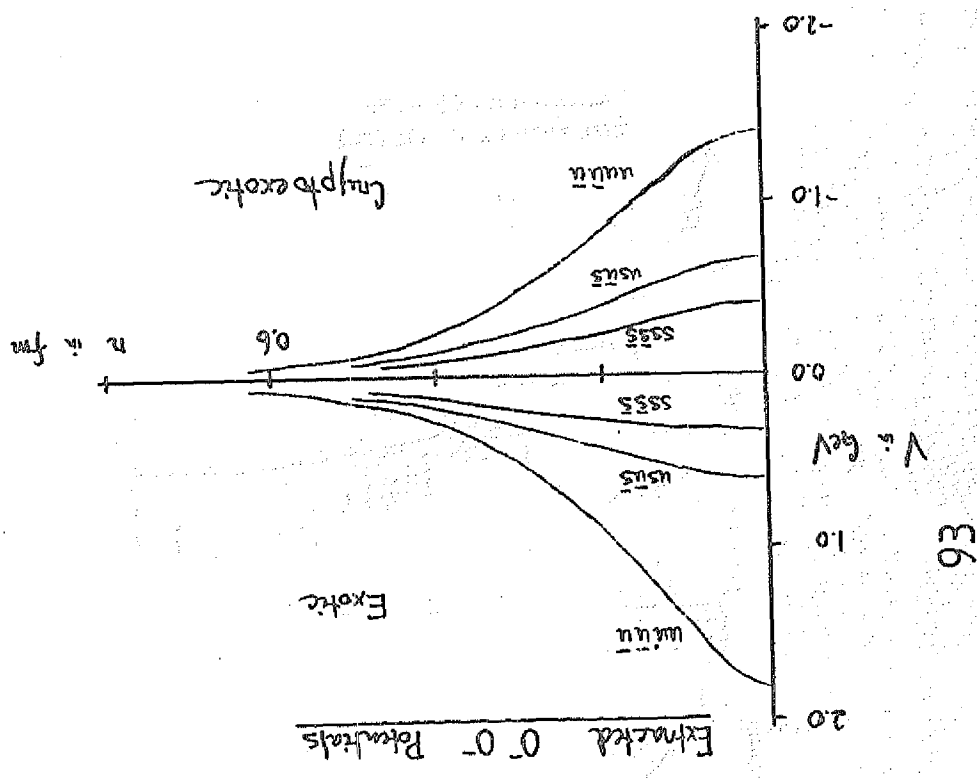
and

$$V_{\text{eff}}(\vec{r}) = E_{qq\bar{q}\bar{q}} - E_1 - E_2 + \frac{1}{2\mu} \frac{\nabla^2 \psi_{\text{eff}}}{\psi_{\text{eff}}} - \left(\frac{1}{2} \epsilon \pi^2 \right)$$

weak potential
to keep mesons
~15 fm apart
(unless they bind)

Extract 6 potentials:

$$\begin{cases} V_{u\bar{u}t\bar{t}}^C & \leftarrow E_{qq\bar{q}\bar{q}} - E_1 - E_2 < 0 \\ V_{u\bar{u}t\bar{t}}^E & \\ * \begin{cases} V_{us\bar{u}\bar{s}}^C & \leftarrow " \\ V_{us\bar{u}\bar{s}}^E & \\ \begin{cases} V_{ss\bar{s}\bar{s}}^C & \leftarrow " \\ V_{ss\bar{s}\bar{s}}^E & \end{cases} \end{cases} \end{cases}$$

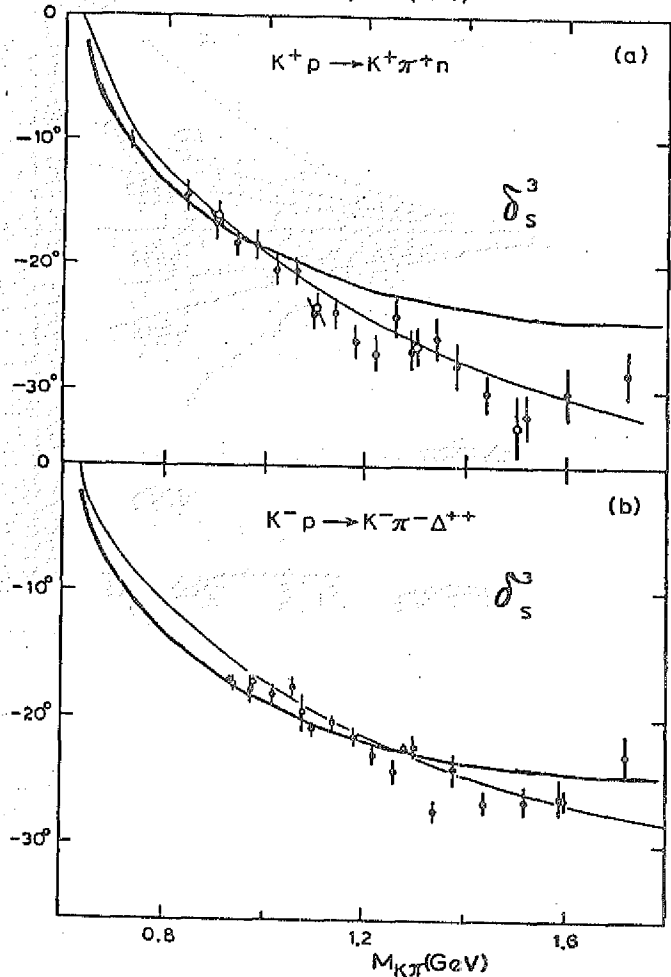


Date: F. Dörmann, J. Frank, D. Cohen, D. Hoogland

$(\pi\pi)_{I=2}$ Phase Shift

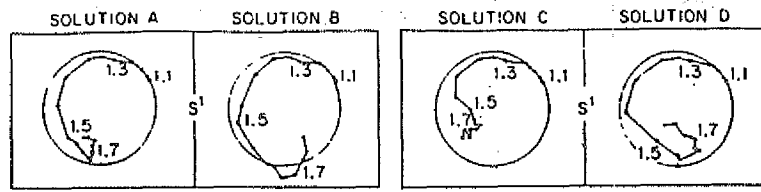
P. Estabrooks et al. / $K^+p \rightarrow K^+\pi^+n, K^+\pi^-\Delta^{++}$
 NUCLEAR PHYSICS B133, 490 (1978)

$$(K\pi)^{I=3/2}$$

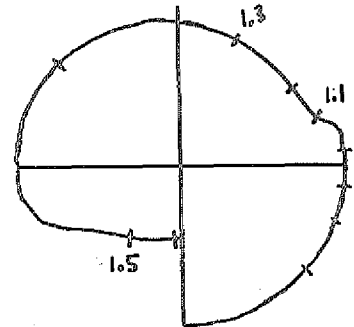


$$V = 0.43 \theta(0.8-n) \text{ GeV}$$

ESTABROOKS ET AL. NUCLEAR PHYSICS B133 (1978)

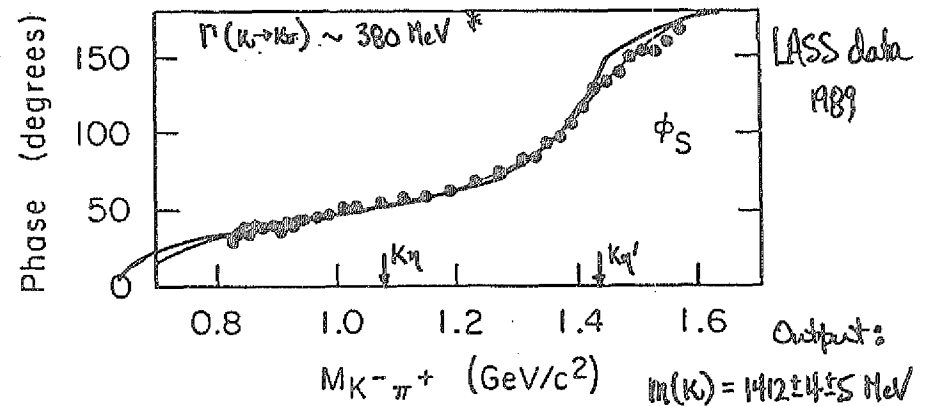


elastic $K\pi$ to 1.5



Coupled Channel Results.

Input: $m(K) \sim 1470 \text{ MeV}$

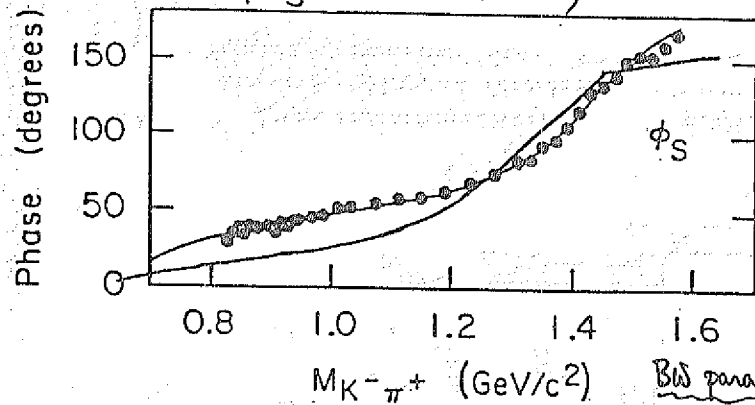


* In $K\pi \leftrightarrow K$

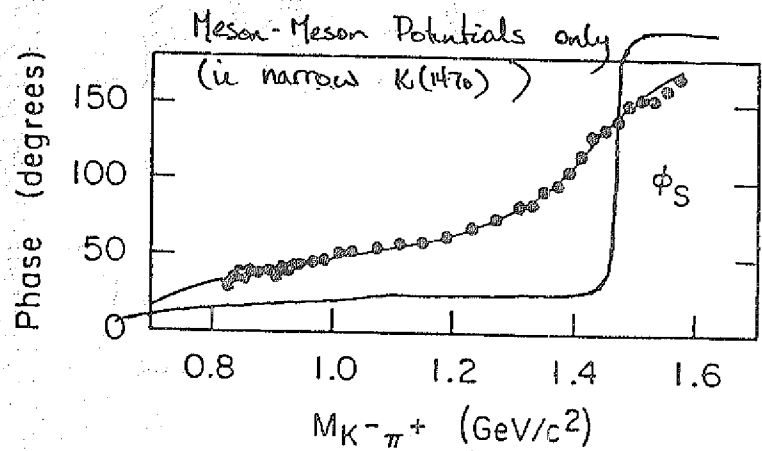
Output: $m(K) = 1412 \pm 4 \pm 5 \text{ MeV}$
 $\Gamma(K) = 294 \pm 10 \pm 21 \text{ MeV}$

What if...

Couplings to $K(1470)$ only



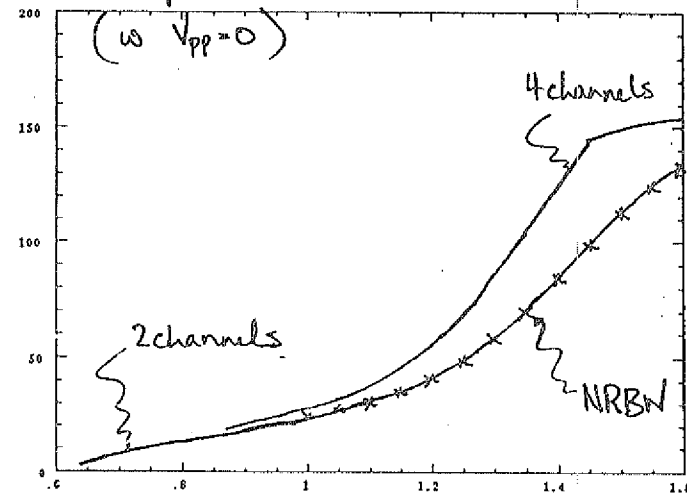
BW parameters
 $m \approx 1.3 \text{ GeV}$
 $\Gamma \approx 0.31 \text{ GeV}$



Background!

What if...

Compare 2 channel $K\pi \leftrightarrow K(1470)$



with a Breit Wigner of $m = 1.420$
 $\Gamma = 0.380$

and the 4 channel $V_{pp}=0$ result.
 (from previous page)

Shows: • 2 channel system is Breit Wigner like
 • $K\eta$ and $K\eta'$ channels change phase shifts

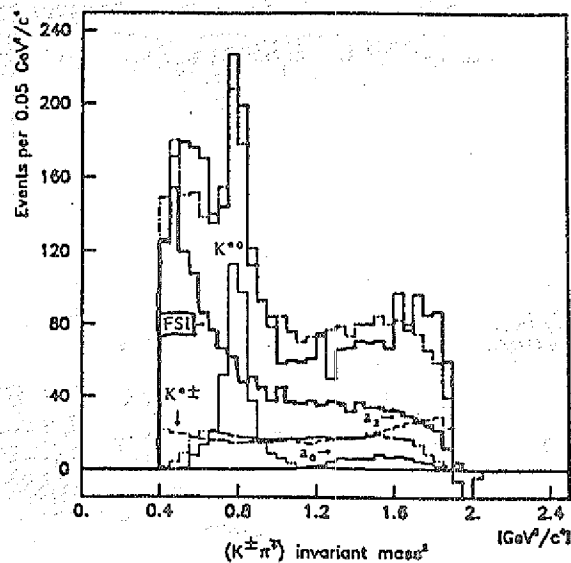
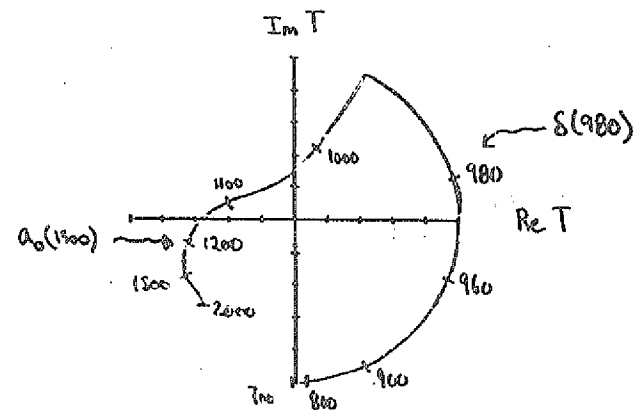
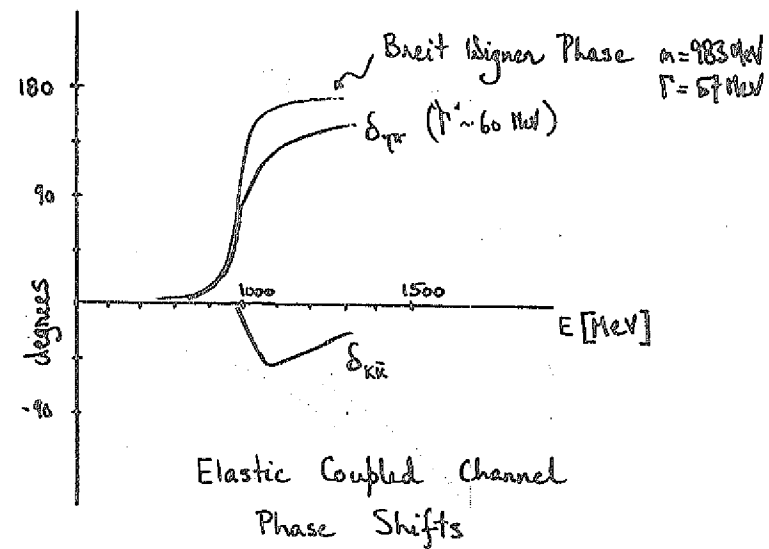


Abbildung 41: Quadrat der invarianten Masse ($K^\pm \pi^\mp$) für die 3073 Ereignisse nach Abzug der Kontrollregionen. Die dicke strich-punktierte Linie stellt das Ergebnis der S-parametrischen Anpassung dar. Die einzelnen Beiträge sind ebenfalls eingezeichnet.

$$V_{K\pi} = -0.8 \text{ GeV} \times 1 \text{ fm}$$

$$p\bar{p} \rightarrow K_S^0 K^\pm \pi^\mp \text{ @ ASTERIX}$$

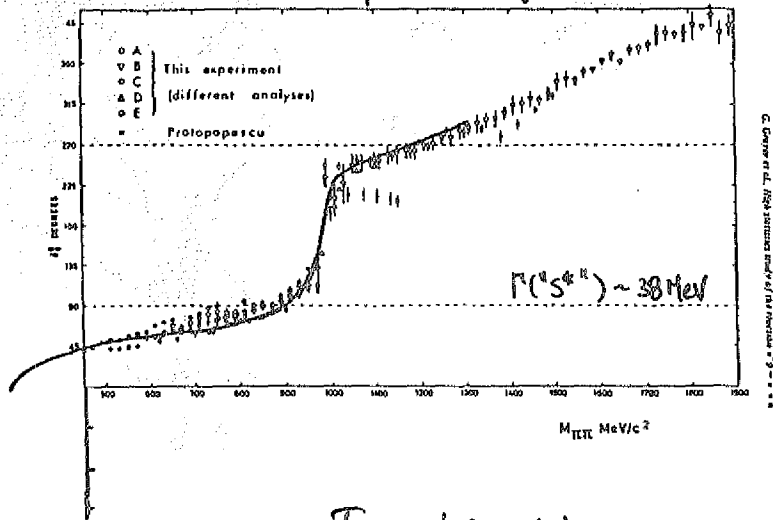
Friederike Feld-Dahne PhD Thesis



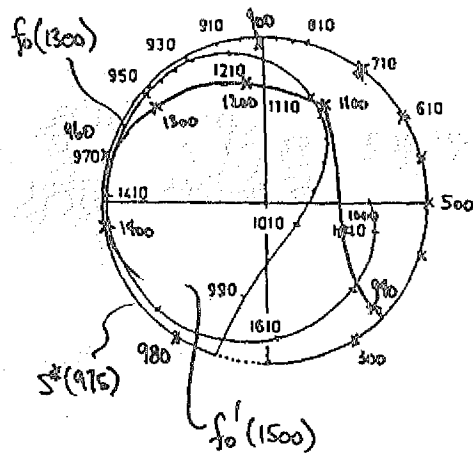
$\pi\eta \rightarrow \pi\eta$ Transition Matrix from Coupled Channels

97

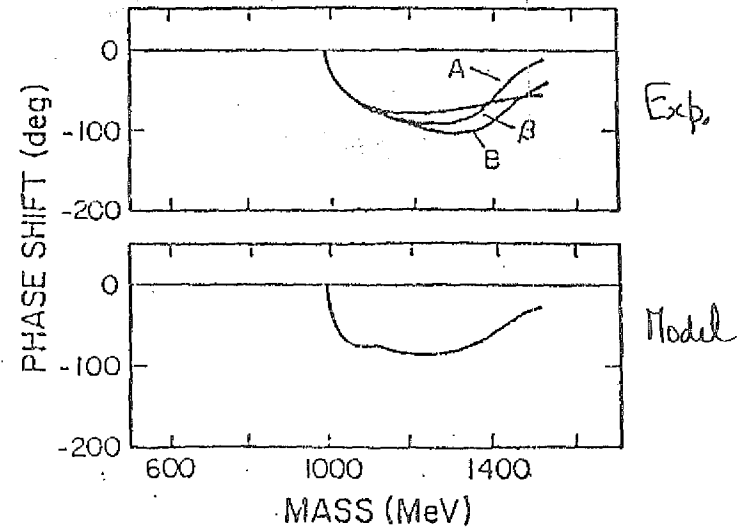
$\pi\pi$ elastic phase shift



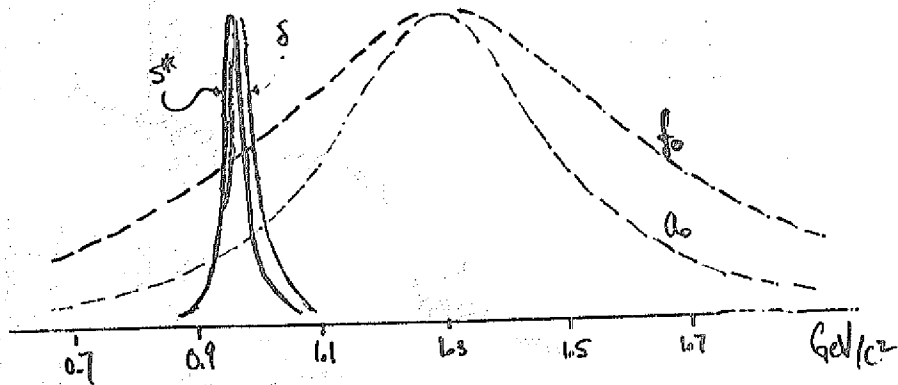
$\pi\pi \rightarrow \pi\pi$ Transition Matrix



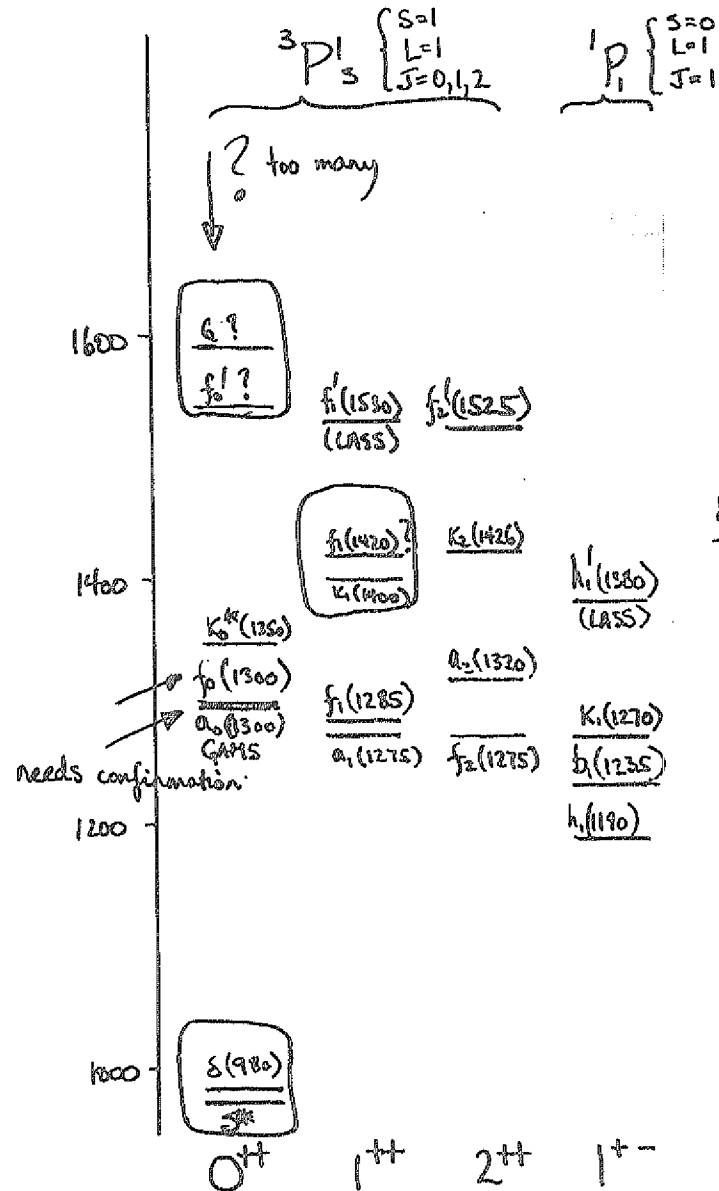
$$S(K\bar{K} \rightarrow K\bar{K}) \text{ in } I=0$$



Breit Wigner comparison
of naive $q\bar{q}$ $^3P_0$, $K\bar{K}$ Molecules
and Experiment.



	$M_{I=1}$	$\Gamma_{I=1}$	$M_{I=0}$	$\Gamma_{I=0}$
$q\bar{q}$:	~ 1300	~ 400	~ 1300	$400-1000$
$K\bar{K}$:	~ 980	~ 50	~ 980	~ 30
exp:	983 ± 2	54 ± 4	975 ± 4	33 ± 7



Quark Model:

$$s\bar{s}$$

$$s\bar{u}, s\bar{d}, d\bar{s}, u\bar{s}$$

$$\frac{1}{2}(u\bar{u} + d\bar{d})$$

$$d\bar{u}, \frac{1}{2}(u\bar{u} - d\bar{d}), u\bar{d}$$

$$\frac{1+4+1+3}{9} = 3 \times 3$$

$$\langle \vec{L} \cdot \vec{S} \rangle \sim 100 \text{ MeV}$$

$3P_0$ $q\bar{q}$ states vs: $K\bar{K}$ Molecules

• $m_{S^*} \sim m_S \Rightarrow$ no $s\bar{s}$ in S^*

$$\Rightarrow \Gamma(S^* \rightarrow \pi\pi) \sim 4 \Gamma(S \rightarrow \eta\pi)$$

$$\uparrow \text{exp} \sim 0.6 \pm 0.2$$

$$\text{if } K\bar{K} \sim 0.6$$

$$\bullet \frac{\Gamma(S^* \rightarrow K\bar{K})}{\Gamma(S^* \rightarrow \pi\pi)} \sim \frac{1}{3} \frac{P_K}{P_\pi}$$

$\uparrow$ not exp. observation

not $K\bar{K}$ prediction.

Two photon widths (Ted Barnes PL165B 1985)

$$\underline{I=1} \quad \Gamma(S^0 \rightarrow \gamma\gamma) = \begin{cases} 1.5 \text{ keV} & \text{for } S = \frac{1}{2}(u\bar{u} - d\bar{d}) \\ 0.6 \text{ keV} & \text{for } S = K\bar{K} \end{cases}$$

$$\underline{\text{Exp:}} \quad \Gamma \cdot B(\eta\pi) = \begin{cases} 0.19 \pm 0.07 \pm 0.10 \text{ keV} & (\text{CBEL}) \\ 0.21 \pm 0.05 \pm 0.14 \text{ keV} & (\text{JADE}) \end{cases}$$

$$\underline{I=0} \quad \Gamma(S^* \rightarrow \gamma\gamma) = \begin{cases} 4.5 \text{ keV} & \text{for } S^* = \frac{1}{2}(u\bar{u} + d\bar{d}) \\ 0.33 \text{ keV} & \text{for } S^* = s\bar{s} \\ 0.6 \text{ keV} & \text{for } S^* = K\bar{K} \end{cases}$$

$$\underline{\text{Exp:}} \quad \Gamma \cdot BR(\pi\pi) = 0.19 \pm 0.05 \pm 0.12 \text{ keV} \quad (\text{Mark II})$$

$$\text{Ratio:} \quad \frac{\Gamma(S^* \rightarrow \gamma\gamma)}{\Gamma(S^0 \rightarrow \gamma\gamma)} = \begin{cases} \frac{25}{9} & \text{if } \frac{1}{2}(u\bar{u} \pm d\bar{d}) \\ 1 & \text{if } K\bar{K} \end{cases}$$

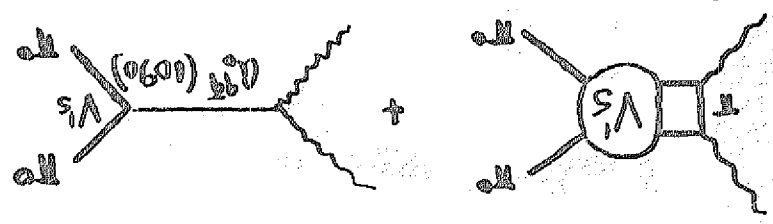
$$2\gamma \rightarrow \pi^+\pi^- \rightarrow \pi^0\pi^0$$

$$\pi^+\pi^- = \left[\frac{2}{3} \pi\pi^{I=0} + \left[\frac{1}{3} \pi\pi^{I=2} \right] \right]$$

enhanced by $V_{\pi\pi}^{I=0}$
suppressed by repulsive $V_{\pi\pi}^{I=2}$

$|f(0)|^2$ enhancements (subtractions)

produce too much $\pi^0\pi^0$ signal.



These two processes "can" reproduce data.

DM1 & DM2, LAL (Onsay) Preprint 81-15, Aghajani et al
Casper, Ball, Proulx, BLM Int. Conf. on High Energy Physics, 86, Houston
An Onsay & Livingston, Durham Preprint DMT 87/22
Rosen & Livingston, RAL preprint 87-076
Rosen & Livingston, RAL preprint 87-076
Rosen & Livingston, RAL preprint 87-076

: "Explains" decay paradox

$$L \rightarrow \delta\pi \rightarrow K\bar{K}\pi$$

$$\neq \eta\pi\pi$$

Final state interactions are shown

to alter the decay chain

$$L \rightarrow [a(K^*\bar{K} + K\bar{K}^*) + b(K\bar{K}\pi)] \xrightarrow{R\pi} K\bar{K}\pi$$

- K^* signal washes out
- δ "signal" induced

Frank, Isgur,
Donnell, JD
PRD 32 (85)

N.B. may also lead to "flat-topped" isht.

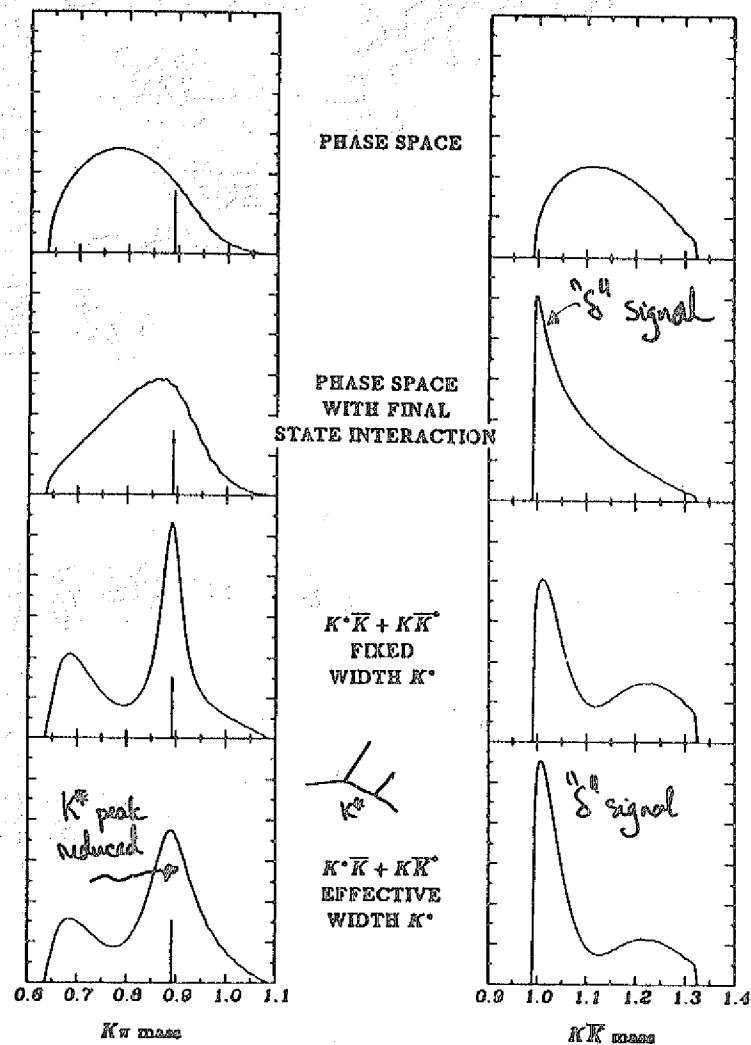
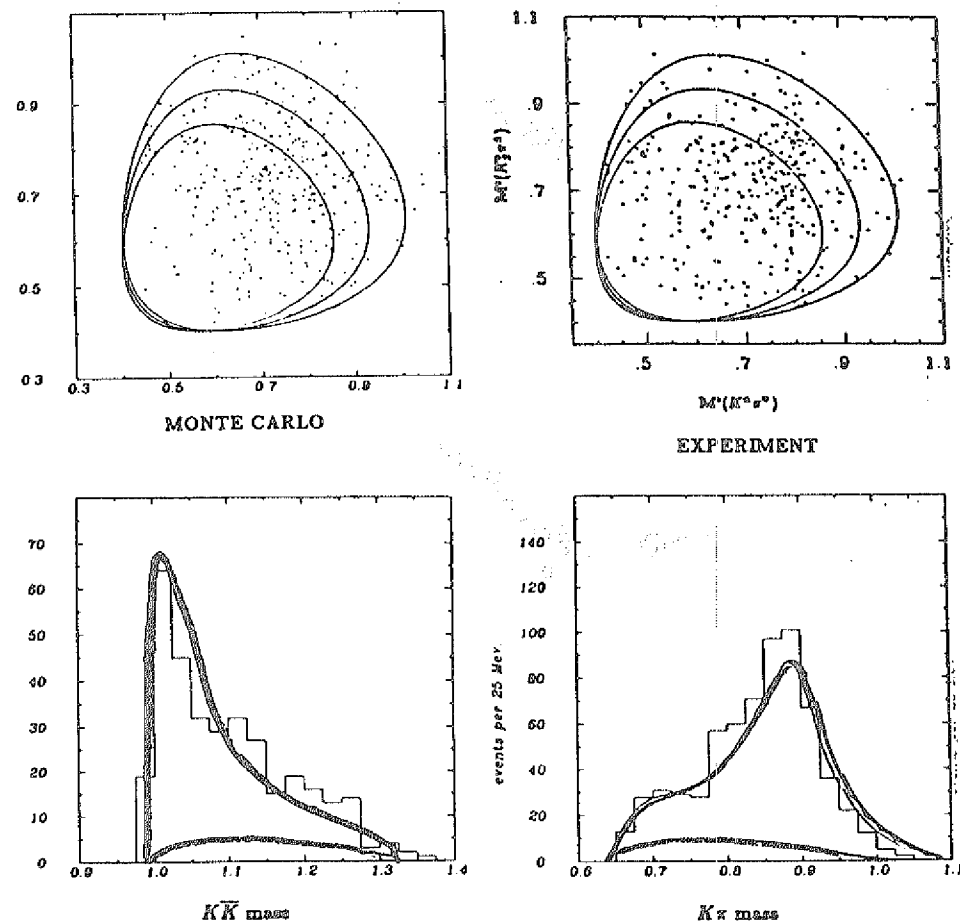


FIG 6. EFFECTIVE MASS DISTRIBUTION SUMMARY, MARK III CUTS

FIG 7. THEORETICIANS FIT WITH MARK III DATA
($K\bar{K}\pi + K\bar{K}^* + K^*\bar{K}$) with interactions and 15% background.

"Production" Model

$$\underline{J/\psi \rightarrow V X}$$

$$V = \rho, \omega, \phi$$

X "flavor tagged"

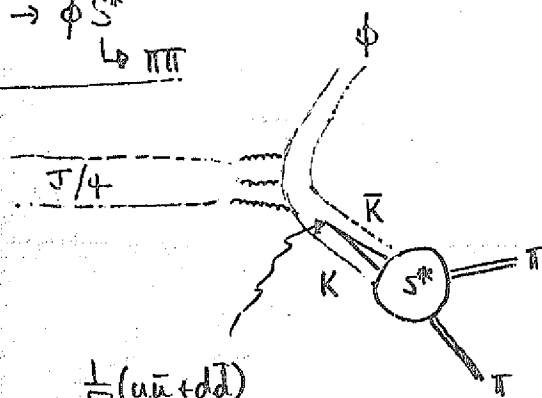
$$\begin{cases} \Gamma(J/\psi \rightarrow \omega S^*) \ll \Gamma(J/\psi \rightarrow \omega f_2(1270)) \\ \Gamma(J/\psi \rightarrow \rho \delta) \ll \Gamma(J/\psi \rightarrow \rho a_2(1320)) \end{cases}$$

↑
unpicked for $^3P_0$ partner of $^3P_2$

For $K\bar{K}$?

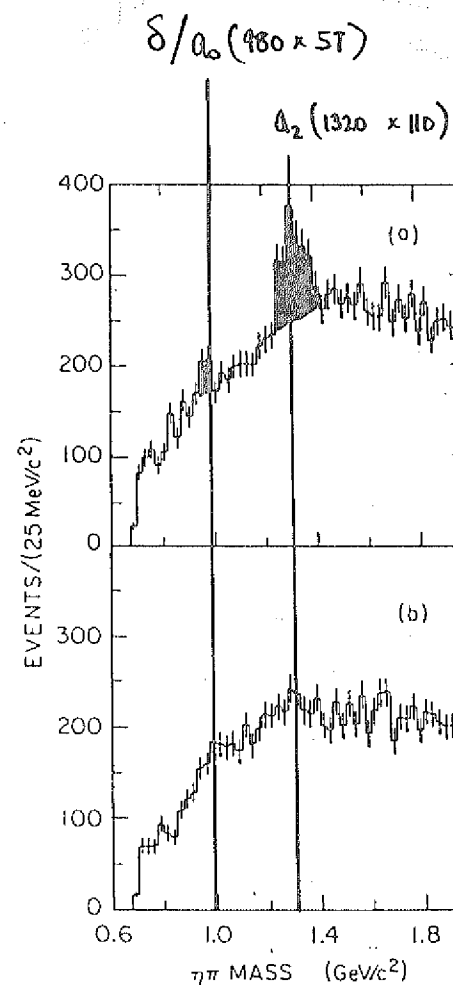
$$\underline{J/\psi \rightarrow \phi S^*}$$

$\hookrightarrow \pi\pi$



$$\frac{1}{12} (u\bar{u} + d\bar{d})$$

$$\frac{1}{12} (u\bar{u} + d\bar{d} + s\bar{s})$$



$$J/\psi \rightarrow \begin{cases} \pi\pi \\ \rho X \\ \eta\pi \end{cases}$$

$$J/\psi \rightarrow \pi\pi \eta\pi$$

MARK III Data

"Production" Model

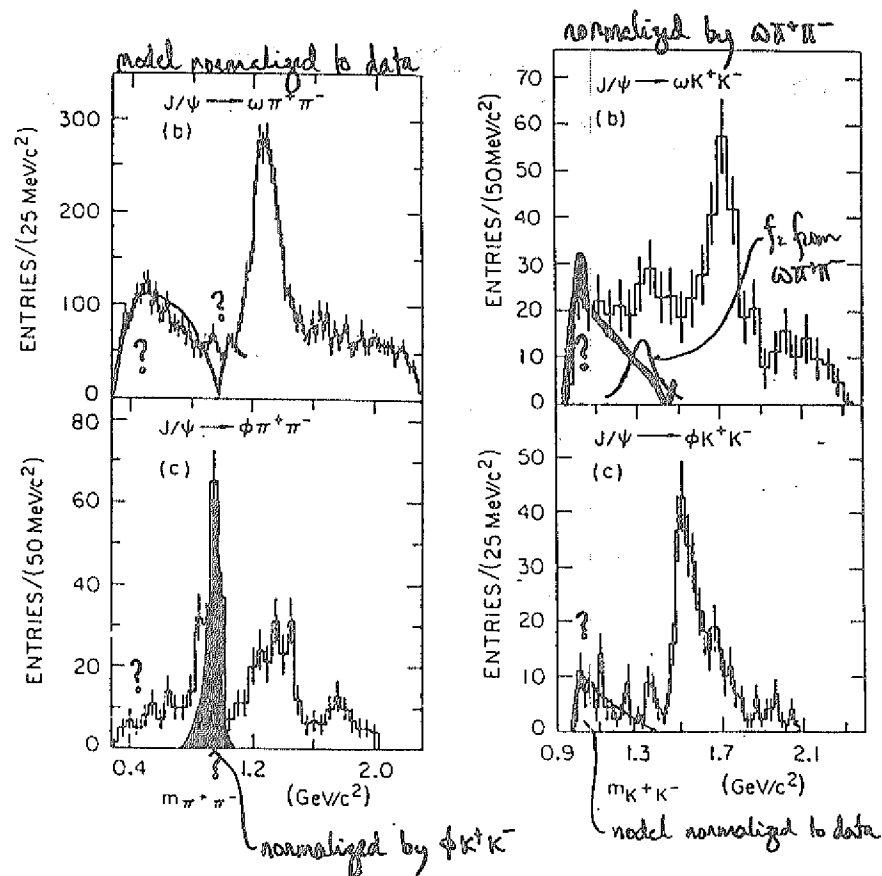
$$\left[\begin{matrix} K \\ \approx \\ M \\ \approx \\ V \\ \approx \end{matrix} \right] \underline{u} = E \underline{u} + \underline{s} \delta(3)$$

$$\left\{ \begin{array}{l} \underline{s} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} \text{ drives } K\bar{K} \text{ in } [2] \\ \text{allows } u_{K\bar{K}}^{I=1}(0) \neq 0 \end{array} \right.$$

$$\left\{ \begin{array}{l} \underline{u}_{inhomo} + \alpha \underline{u}_{homo} = \underline{u}_{production} \\ \text{"no incoming waves"} \end{array} \right.$$

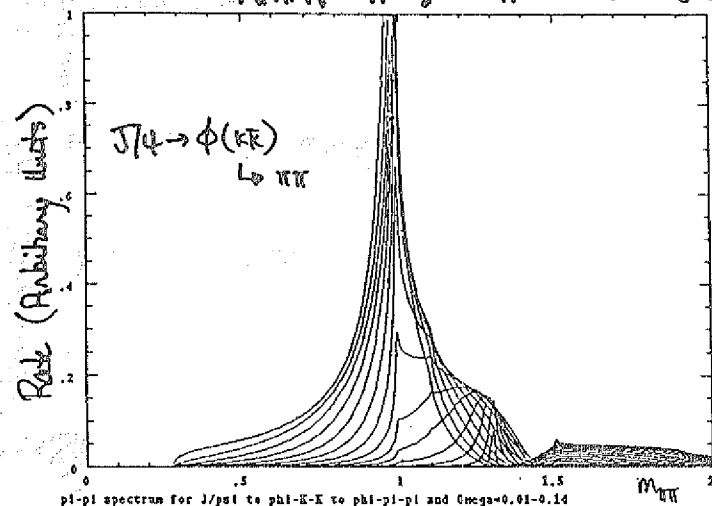
$$|u_i(0)|^2 \text{ phase space} = \text{production rate}$$

Preliminary Production Results

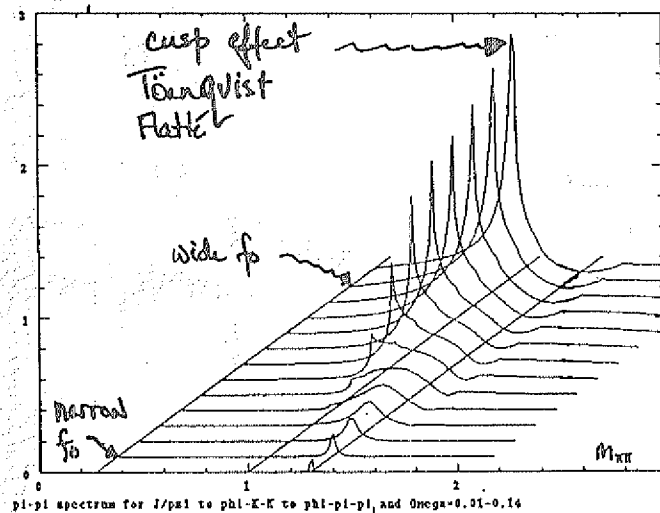


Some $J/\psi \rightarrow VPP$ problems resolved?

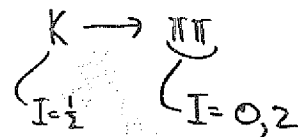
WHAT IF! $V_{pp} = 0 \neq \Gamma(f_0) = \dots$



same curves



Application to weak interactions



Naive Standard Model: $\left[\frac{\Gamma_{\Delta I = \frac{1}{2}}(K \rightarrow \pi\pi)}{\Gamma_{\Delta I = \frac{3}{2}}(K \rightarrow \pi\pi)} \right]^{\frac{1}{2}} \sim \sqrt{2}$

Experiment: $\left[\frac{\Gamma(K_S^0 \rightarrow \pi\pi)}{\Gamma(K^+ \rightarrow \pi^+\pi^0)} \right]^{\frac{1}{2}} \sim 2.5$

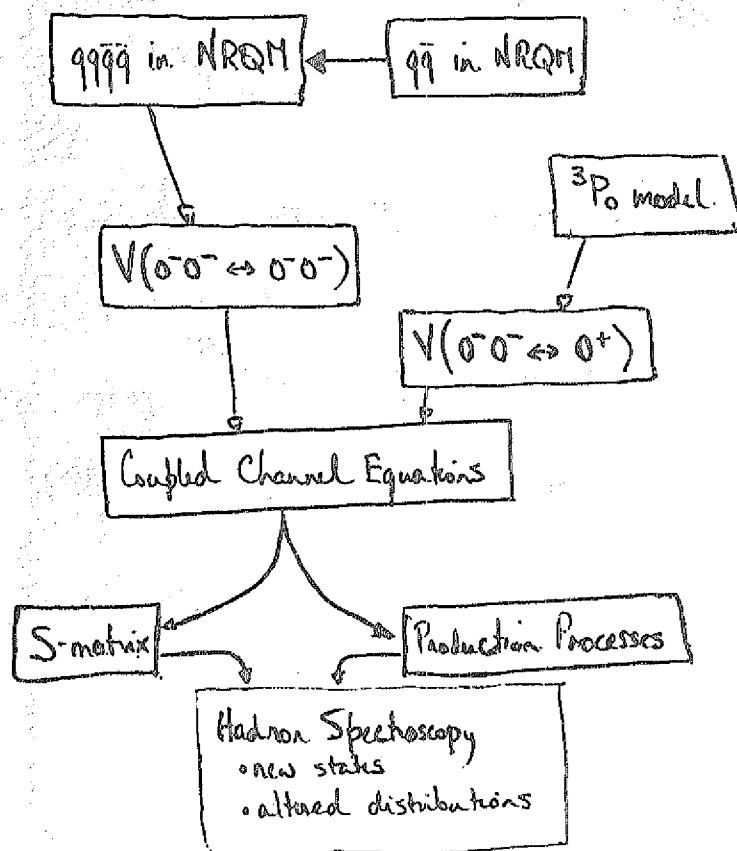
$\Rightarrow \Delta I = \frac{1}{2}$ enhanced & $\Delta I = \frac{3}{2}$ suppressed

$$FSI \Rightarrow \frac{\langle (\pi\pi)_{I=0} | H_W^{(\frac{1}{2})} | K \rangle}{\langle (\pi\pi)_{I=2} | H_W^{(\frac{1}{2})} | K \rangle} = \left[\frac{4_{\pi\pi}^{I=0}(0)}{4_{\pi\pi}^{I=2}(0)} \right] \cdot \frac{\langle f_{\pi\pi}^{I=0} | a | K \rangle}{\langle f_{\pi\pi}^{I=2} | a | K \rangle}$$

$$\left[\frac{4_{\pi\pi}^{I=0}(0)}{4_{\pi\pi}^{I=2}(0)} \right]_{M_{\pi\pi} = M_K} \approx 4$$

Isgur, Maltman, Barnes, JW; UTP-89-10

Overview / Summary



Conclusions

- S^* and δ are not $q\bar{q}$ $^3P_0$ s but $K\bar{K}$ Molecules
- This "explains"
 - extra scalars - $(K\pi)^{I=1/2 \neq 3/2}$
 - mass and width of S^* and δ
 - $\Gamma(S^* \rightarrow \pi\pi) : \Gamma(\delta \rightarrow \eta\pi)$
 - $\Gamma(S^* \rightarrow K\bar{K}) : \Gamma(S^* \rightarrow \pi\pi)$
 - $\Gamma(S^* \rightarrow \gamma\gamma) \neq \Gamma(\delta \rightarrow \gamma\gamma)$
 - $\Delta I = 1/2$ enhancement in $K \rightarrow \pi\pi$
 - $B(\phi \rightarrow \gamma S^*) \neq B(\phi \rightarrow \gamma \delta)$ FEC & NI
 - $\gamma\gamma \rightarrow \pi^0\pi^0$ KD TB NI JW
 - $L \rightarrow \pi\delta$ but $\delta \not\rightarrow \eta\pi$ JW NI
 - threshold effect in $K\pi$ in $p\bar{p} \rightarrow K_S^0 K^\pm \pi^\mp$ JW NI
 - $\Gamma(J/\psi \rightarrow \omega S^*) : \Gamma(J/\psi \rightarrow \omega f_2)$
 - $\Gamma(J/\psi \rightarrow \rho \delta) : \Gamma(J/\psi \rightarrow \rho a_2)$
 - S^* in $J/\psi \rightarrow \phi \pi\pi$ but not $J/\psi \rightarrow \omega \pi\pi$
 - threshold effects in $\omega \pi\pi$ but not $\phi \pi\pi$ in J/ψ
 - threshold effects in $\omega K\bar{K}$ and $\phi K\bar{K}$ in J/ψ
 - why MIT Baryonia does not exist.

If Coupled Channel Interactions alter 00^-
what about

↖ Lots of data, but no theory.

- $[1^- 1^-]_{J=2,1,0}$

- $[0^- 1^-]$ and the $E/f_1(1420)$

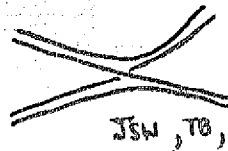
- $D\bar{D}$

- 3 body interactions

- $\Lambda(1405)$

- EMC?

$TB \neq QQ$



JSW, TB, JW

Monte Carlo Techniques and Born Approximation

will be used to evaluate some of the $(q\bar{q})-(q\bar{q})$
potentials in sections which are difficult for
the variational techniques to access.

- Relativistic corrections.

Not an "exciting" solution, i.e.

- no hybrids, glueballs, new hadrons, ...
- no "new" physics
- based on Schrödinger eqn

Exciting to have a solution

- intuitive
- wide ranging

The 0^+ Nonet Is Respectable *

Invited Talk presented at Hadron 89
International Conference on Hadron Spectroscopy
Ajaccio, Corsica, France
23-27 September, 1989
To be published in the Proceedings

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Abstract

We discuss a simple model which resolves long standing problems associated with the S^* and δ scalar mesons, the systematics of the $4 L = 1$ $q\bar{q}$ nonets (the scalar nonet in particular), scalar resonances observed in $J/\psi \rightarrow$ vector-pseudoscalar-pseudoscalar, and the $\Delta I = \frac{1}{2}$ rule in $K \rightarrow \pi\pi$. The model is based on meson-meson interactions which enter through quark exchange processes and pair annihilation and creation processes. In our picture the S^* and δ scalar mesons are not $^3P_0$ $q\bar{q}$ scalars but are instead $I = 0$ and 1 S -wave " $K\bar{K}$ Molecules" created by the coupled channel interplay of individual meson-meson interactions. The other light pseudoscalar-pseudoscalar systems are affected in observable ways but they do not form bound states.

* This work was supported by the U.S. Department of Energy, Division of High Energy Physics, under Contract DE-AS05-76ER03956.

Introduction

The $S^*(975)$ and $\delta(980)$ scalar mesons have remained problematical as $q\bar{q}$ quark model states despite many attempts to understand them.¹⁾ Among other difficulties they are too light, too narrow, and too strongly coupled to $K\bar{K}$ final states to be naïve quark model $(2S+1)L_J = {}^3P_0$ $q\bar{q}$ states (figs. 1 and 2). There are also more than 9 candidates in the scalar nonet (fig. 2).

Our quark model study of the light (u, d , and s) $qq\bar{q}\bar{q}$ systems has led us to the conclusion that the S^* and δ scalar mesons are $K\bar{K}$ bound states analogous to the deuteron.²⁾ In this talk I will discuss that analysis and show how the $K\bar{K}$ molecule picture enters. I will then show how it resolves the four problems noted above as well as several others involving the properties of the S^* and δ . As mentioned in the abstract, the coupled channel analysis which leads to the $K\bar{K}$ molecule affects other pseudoscalar-pseudoscalar systems even though they do not bind. These effects will be discussed and experimental evidence for them will be given. Finally I will show how the model, initially constructed to study scattering states, can be modified to describe the creation of pseudoscalar-pseudoscalar S -wave states by decay processes. Preliminary results for $J/\psi \rightarrow \phi\pi\pi$, $\phi K\bar{K}$, $\omega\pi\pi$, and $\omega K\bar{K}$ will be compared with the predictions. An application to the weak decay $K \rightarrow \pi\pi$ will also be presented.

The Coupled Channel Model

If one considers the ground or metastable states of the $qq\bar{q}\bar{q}$ system it is clear that there are at least three qualitatively different configurations: one is "baryonium", in which all four particles comprise a single hadronic structure, a second is a system of two lightly bound mesons, and a third is two free pseudoscalar mesons (fig. 3). The baryonium states have been predicted in several models³⁾ but no clear evidence confirming their existence has been established.

Our nonrelativistic quark model analysis concludes that the $qq\bar{q}\bar{q}$ ground state is usually two free mesons. There are, however, two important exceptions; weakly bound S -wave systems consisting of a kaon-antikaon pair are formed in the model just below $K\bar{K}$ threshold in both $I = 0$ and 1 .⁴⁾ We identify the S^* and δ as these states.

It is clear that two mesons can bind only if there are attractive interactions between the constituents of one meson and the constituents of the other meson. A natural interaction mechanism to consider is one gluon exchange between the mesons. This will change two color singlet mesons into two color octet mesons in an overall color singlet state. This octet-octet state is, however, a linear combination of pseudoscalar-pseudoscalar and vector-vector meson pairs in each of the two singlet-singlet combinations $(\bar{13}) \cdot (24)$ and $(14) \cdot (2\bar{3})$.

From this we see that one gluon exchange and quark exchange are related, both can lead to transitions between pseudoscalar-pseudoscalar pairs (fig. 4a). As an example, quark exchange will transform an initial $K\bar{K}^{I=0}$ system into an $\eta\eta$, $\eta\eta'$ or $\eta'\eta'$ pair, or an initial $K\bar{K}^{I=1}$ system into an $\eta\pi$ or $\eta'\pi$ pair. Furthermore, since the physical η and η' states are $\approx \sqrt{\frac{1}{2}}(\eta_{n\bar{n}} - \eta_{s\bar{s}})$ and $\sqrt{\frac{1}{2}}(\eta_{n\bar{n}} + \eta_{s\bar{s}})$ respectively (where $\eta_{n\bar{n}} \equiv \sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d})$ and $\eta_{s\bar{s}} \equiv s\bar{s}$), second order transitions such as $K\bar{K} \rightarrow \eta\eta \rightarrow \pi\pi$ in which all OZI-violating processes occur inside the η and η' wavefunctions are possible. Diagonal transitions such as $\pi\pi \rightarrow \pi\pi$ are generated by the quark exchange mechanism in all pseudoscalar-pseudoscalar channels except for $K\bar{K} \rightarrow K\bar{K}$.

We have extracted from our nonrelativistic quark model analysis of the $qq\bar{q}\bar{q}$ system strong, short-range and gaussian-like potentials which are due to these quark exchange interactions.²⁾ They are found to depend on wavefunction symmetries and the $\vec{S}_i \cdot \vec{S}_j$ hyperfine interaction. We find it useful to convert these extracted potentials into square well potentials which give similar low energy phase shifts and have a common range a . Given the uncertainties inherent in our analysis we believe that this is a reasonable substitution.

In principle the quark exchange processes also transform pseudoscalar pairs into $J = 0$ vector pairs. In our quark model analysis, however, the vector-vector amplitudes in the ground state $qq\bar{q}\bar{q}$ wavefunction are very small and we neglect these channels in this paper.

Transitions between pseudoscalar-pseudoscalar pairs can also go through $q\bar{q}$ annihilation to a $^3P_0$ $q\bar{q}$ scalar meson followed by $q\bar{q}$ creation (fig. 4b). The S -channel mesons in this process are the $I = 1$ $a_0(1300)$, $I = 1/2$ $\kappa(1440)$, $I = 0$ $n\bar{n}$ $f_0(1300)$ and $I = 0$ $s\bar{s}$ $f'_0(1500)$.

Each vertex is modelled by a square well potential of range a (as above) and depth set by the product of the channel dependent flavor Clebsch-Gordon coefficient, a kinematic factor, and an SU(3) constant. This isospin independent SU(3) constant is taken from the decay analysis of Kokoski and Isgur⁵⁾ and gives the known $f_0(1300) \rightarrow \pi\pi$ width in a two channel approximation.

We require a third type of (diagonal) potential which determines the masses of the free $q\bar{q}$ scalar mesons. We model these with a P -wave core added to a square well potential of range a and a depth chosen to fix the a_0 at 1300 MeV, the f_0 at 1300 MeV, the κ at 1440 MeV, and the f'_0 at 1500 MeV. Quark confinement is imposed in these channels by an infinite potential in the exterior region $r > a$.

From this discussion it is clear that, unless the off-diagonal potentials are negligible, one cannot consider a pseudoscalar-pseudoscalar system in isolation from accessible 0^-0^- ($q\bar{q})(q\bar{q})$ and $0^+ q\bar{q}$ systems; a coupled channel approach is required.⁶⁾ To model these interactions

at low energies we use the radial coupled channel Schrödinger equation with the potential matrix V as discussed above:

$$(K + M + V) u(r) = E u(r). \quad (1)$$

The elements of the kinetic energy matrix K are $(K)_{ij} = -\delta_{ij} \frac{1}{2\mu_i} \frac{\partial^2}{\partial r^2}$. M is a diagonal matrix whose entries are the rest mass energies of the mesons in the pseudoscalar-pseudoscalar channels or the constituent quark masses in the $0^+ q\bar{q}$ channels. E is the total energy of the asymptotic scattering states.

The radial wavefunction $u(r)$ in equation (1) is an n -component vector whose entries represent all the interacting states; it has the form

$$u^{I=0}(r) = \begin{pmatrix} u_{\pi\pi I=0} \\ u_{KR I=0} \\ u_{\eta\eta} \\ u_{\eta\eta'} \\ u_{\eta'\eta'} \\ u_{f_0(1300)} \\ u_{f'_0(1500)} \end{pmatrix}, \quad u^{I=1/2}(r) = \begin{pmatrix} u_{K\pi I=1/2} \\ u_{K\eta} \\ u_{K\eta'} \\ u_{\kappa(1440)} \end{pmatrix}, \quad u^{I=1}(r) = \begin{pmatrix} u_{\eta\pi} \\ u_{KR I=1} \\ u_{\eta'\pi} \\ u_{a_0(1300)} \end{pmatrix},$$

$$u^{I=3/2}(r) = (u_{K\pi I=3/2}), \quad \text{or} \quad u^{I=2}(r) = (u_{\pi\pi I=2}),$$

according to the isospin channel of interest.

With all operators in equation (1) specified we integrate numerically to find the wavefunctions $u(r)$ at each scattering energy E . Knowing the wavefunctions enables us to find the S -matrix for pseudoscalar-pseudoscalar scattering.²⁾

The Coupled Channel S -Matrix

A simple system for which experimental phase shift data is available is the single channel $I = 2 \pi\pi$ system.⁷⁾ In fig. 5 we compare the experimental $I = 2 \pi\pi$ phase shift with the phase shift generated from the extracted $I = 2 \pi\pi$ potential. Observe that it clearly misses the data. The nonrelativistic quark model is known, however, to underestimate meson radii by a factor of about 2. As the ranges of the quark exchange potentials and annihilation potentials are largely determined by the meson radii we have allowed ourselves the freedom to expand the (common) range of all potentials by the factor 2 and scale down the strength of the modified quark exchange potentials by a second common factor which, from the threshold $\pi\pi^{I=2}$ phase shift data (fig. 5), is determined to be 0.5 (with an estimated error of about ± 0.1).

While this rescaling is perhaps the weakest part of our analysis we note that the repulsive character of the extracted $I = 2 \pi\pi$ potential is a natural but nontrivial consequence of the

model. We consider the signs and relative strengths of the potentials to be predictions of the model and rescale all exchange potentials with the same factors. Thus the rescaling represents one new parameter in the model. When the depths of the $0^-0^- \rightarrow 0^+$ and $0^+ \rightarrow 0^+$ potentials are redetermined according to their doubled range by the criterion discussed above we can generate the scattering matrices for the much more complicated coupled channel $I = 1, 1/2$, and 0 systems with no free parameters. Before turning to these predictions we note that the $K\pi^{I=3/2}$ phase shift (not shown) also reflects an underlying repulsive potential.⁸⁾

We now consider the 4-channel $I = 1$ version of equation (1) with the rescaled potentials. The elastic $\eta\pi$ phase shift found by solving equation (1) is shown in fig. 6a. As data on elastic $\eta\pi$ scattering is not available we compare this with the phase shift of an elastic Breit-Wigner $\eta\pi$ resonance with mass 983 MeV and width 57 MeV, the parameters of the $\delta(980)$. From this comparison we see that the coupled channel interactions produce a phase shift which closely follows the Breit-Wigner form below $K\bar{K}$ threshold but deviates from it above threshold. This is consistent with the observed properties of the δ . The $^3P_0$ $q\bar{q}$ $a_0(1300)$ does not stand out in the phase shift diagram but can be associated with the "loop" in the complex $\eta\pi \rightarrow \eta\pi$ transition matrix between about 1200 and 1400 MeV (fig. 6b). This is consistent with the known difficulty in observing the a_0 .⁹⁾ We identify the rapid fall of $\delta_{K\bar{K}}$ at $K\bar{K}$ threshold (fig. 6a) with an effective $K\bar{K}$ binding potential and the $K\bar{K}$ bound state with the $\delta(980)$. The rapid change in the $\eta\pi$ elastic phase shift around 980 MeV is due to $\eta\pi$ coupling to the $K\bar{K}$ molecule. It is well known that threshold effects can make broad resonances appear lighter and narrower; thus one could argue that the structure at 980 MeV is actually a highly modified $a_0(1300)$.¹⁰⁾ In the $K\bar{K}$ molecule picture, however, the δ is an extra non- $q\bar{q}$ $I = 1$ scalar state created by coupled channel interactions and the $a_0(1300)$ exists as a separate state. The confirmation of the $a_0(1300)$ is therefore a critical test of our picture.

Detailed information on $\pi\pi^{I=0}$ elastic scattering already exists and we can compare our 7-channel elastic $\pi\pi$ phase shift directly with the data (fig. 7a). Given the many approximations in our model we are very encouraged by this result. The major features of the $\pi\pi$ phase shift are reproduced by the coupled channel interactions below ≈ 1400 MeV. The slow increase in the phase shift below about 900 MeV is due mainly to the attractive $\pi\pi^{I=0}$ potential and the wide $f_0(1300)$; the slow increase above 1000 MeV is due mainly to the $f_0(1300)$. Above about 1400 MeV the model will be less reliable; relativistic dynamics, $\pi\pi'$ and related channels, and $J = 0$ vector-vector channels (eg. $\rho\rho$) are some of the factors missing from our analysis. The narrow S^* effect seen around 980 MeV is due to the $\pi\pi$ system coupling to a $K\bar{K}$ bound state that is created by the coupled channel interactions. We identify this state with the $S^*(975)$ scalar meson. This state also seen as a falling elastic $K\bar{K}$ phase shift, indicative of a binding $K\bar{K}^{I=0}$ potential (figs. 7b and 7c).

In figs. 7d and 7e we compare the experimental $I = 0$ $\pi\pi \rightarrow \pi\pi$ transition matrix with that of the coupled channel model, noting that the experimental errors in the phase (for example, at $K\bar{K}$ threshold) are not shown in the corresponding Argand curve. Although there are minor differences in detail between the experiment and the model they are in very good qualitative agreement. The loop in the Argand diagram between ≈ 1200 and 1400 MeV is due to the $f_0(1300)$ and a small loop just above 1500 MeV (not shown because of the questionable validity of the model above ≈ 1400 MeV) is due to the $f'_0(1500)$.

In figs. 8a and 8b we show the $K\pi^{I=1/2}$ and $K\eta$ elastic phase shifts and the $K\pi \rightarrow K\pi$ transition matrix for the 4-channel $I = 1/2$ component of the strange $qq\bar{q}\bar{q}$ sector obtained from equation (1). We find neither a $K\pi$ nor a $K\eta$ bound state. The narrowing of the $\kappa(1440)$ from the naïve quark model width of ≈ 400 MeV to ≈ 130 MeV is consistent with LASS data, as is the elasticity of the $K\pi \rightarrow K\pi$ transition matrix element below the $K\eta'$ threshold.¹²⁾ The elastic $K\pi$ phase shift at low $K\pi$ invariant mass indicates a strongly attractive $K\pi^{I=1/2}$ potential, for which there is some experimental evidence from ASTERIX.¹³⁾ A complete analysis of this sector is underway.⁸⁾

The S^* and δ as $K\bar{K}$ Molecules

As noted in the first section the assignment of the S^* and δ to the $q\bar{q}$ scalar nonet is problematical. Here we discuss evidence supporting our claim that the $K\bar{K}$ molecule interpretation of the S^* and δ resolves these problems.

The narrow widths of the S^* and δ disagree with the expectations of the naïve $^3P_0$ $q\bar{q}$ model^{5,14)} (fig. 1). A comparison of the $\pi\pi$ and $\eta\pi$ phase shifts immediately below the $K\bar{K}$ threshold with Breit-Wigner phase shifts indicates that the coupled channel widths of the S^* and δ are ≈ 38 and ≈ 60 MeV respectively. These values are consistent with the observed widths of 34 ± 6 and 57 ± 11 MeV.⁸⁾

In fig. 2, we show the established and candidate states for the $^3P_{0,1,2}$ and $^1P_1$ nonets. The $^3P_0$ and $^3P_1$ nonets are overpopulated. The S^* and δ are nearly degenerate in mass, just below $K\bar{K}$ threshold, and very light relative to the other scalars. They are also too light to fit into the expected pattern of weak spin-orbit splittings which predicts that the $^3P_0$, $^3P_1$, and $^3P_2$ mesons which have the same flavor wavefunctions should differ in mass by less than ≈ 100 MeV. If the S^* and δ are weakly bound $K\bar{K}$ molecules then masses just below $K\bar{K}$ threshold are expected. If the $a_0(1300)$ is confirmed the $^3P_0$ $n\bar{n}$ states will agree with quark model expectations in both mass and number. The properties of the f'_0 $^3P_0$ ¹⁵⁾ and the nature of the $E/f_1(1420)$ $^3P_1$ ¹⁶⁾ still need to be established. The very small $\bar{L} \cdot \bar{S}$

splittings in these reassigned ${}^3P_J$ nonets are consistent with those observed in the baryon sector.¹⁷⁾

There are other properties of the S^* and δ which are problematical for a $q\bar{q}$ assignment but are natural in the $K\bar{K}$ picture. We will discuss a few of these problems before applying the model to pseudoscalar-pseudoscalar production dynamics.

If $q\bar{q}$, the near degeneracy of the S^* and δ constrains the S^* to have almost no $s\bar{s}$ content. With $\sqrt{\frac{1}{2}}(u\bar{u} \pm d\bar{d})$ states one has the SU(3) prediction $\Gamma(S^* \rightarrow \pi\pi)/\Gamma(\delta \rightarrow \eta\pi) \approx 4$. In the coupled channel $K\bar{K}$ molecule picture we find ≈ 0.6 in agreement with the observed value of 0.6 ± 0.2 (figs. 6a and 7a).

Another SU(3) $q\bar{q}$ prediction is that $\Gamma(S^* \rightarrow K\bar{K})/\Gamma(S^* \rightarrow \pi\pi) \approx p_K/3p_\pi$, where $p_K(p_\pi)$ is the kaon(pion) kinetic energy. The data does not support this expectation; above $K\bar{K}$ threshold the S^* decays predominantly to $K\bar{K}$, as expected for the high mass tail of a $K\bar{K}$ bound state. Similar remarks apply to the ratio $\Gamma(\delta \rightarrow \eta\pi)/\Gamma(\delta \rightarrow K\bar{K})$.

The two photon widths of the S^* and δ^0 have been calculated,¹⁸⁾ assuming both $q\bar{q}$ and $K\bar{K}$ assignments, with the results

$$\Gamma(S^* \rightarrow \gamma\gamma) = \begin{cases} 4.5 & \text{KeV for } \sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d}) \\ 0.33 & \text{KeV for } s\bar{s} \\ 0.6 & \text{KeV for } K\bar{K} \end{cases}$$

and

$$\Gamma(\delta^0 \rightarrow \gamma\gamma) = \begin{cases} 1.5 & \text{KeV for } \sqrt{\frac{1}{2}}(u\bar{u} - d\bar{d}) \\ 0.6 & \text{KeV for } K\bar{K} \end{cases}$$

The latest experimental measurements are $\Gamma(S^* \rightarrow \gamma\gamma) BR(\pi\pi) = 0.19 \pm 0.05 \pm .12$ KeV (Mark II) and $\Gamma(\delta^0 \rightarrow \gamma\gamma) BR(\eta\pi) = 0.19 \pm 0.07 \pm_{-0.07}^{+0.10}$ KeV (Crystal Ball) or $0.29 \pm 0.05 \pm 0.14$ KeV (Jade),¹⁹⁾ consistent with $K\bar{K}$ but not $\sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d})$ content. The $s\bar{s}$ assignment for the S^* , which is favored by this measure, must be rejected due to the near degeneracy of the S^* and δ masses as discussed above. Although the absolute widths for the $K\bar{K}$ molecule interpretation are larger than experiment by a factor of about 3 for both the S^* and δ^0 , the ratio of the $\gamma\gamma$ widths is predicted to be exactly 1: the S^* and δ are $\sqrt{\frac{1}{2}}(K^+K^- \pm K^0\bar{K}^0)$ and the $\gamma\gamma$ widths depend only on the K^+K^- content. The ratio is independent of the details of the wavefunctions in both these models and is therefore a crucial test:

$$\frac{\Gamma(S^* \rightarrow \gamma\gamma)}{\Gamma(\delta^0 \rightarrow \gamma\gamma)} = \begin{cases} \frac{25}{9} \approx 2.8 & \text{for } \sqrt{\frac{1}{2}}(u\bar{u} \pm d\bar{d}) \\ 1 & \text{for } K\bar{K} \end{cases}$$

Since $BR(S^* \rightarrow \eta\pi)$ and $BR(\delta \rightarrow \eta\pi)$ are both ≈ 0.8 ²⁰⁾ they approximately cancel in the experimental ratio. Thus the data favors the $K\bar{K}$ picture, although a definitive measurement would be of great interest.

A puzzle in J/ψ decays which casts still more doubt on the $q\bar{q}$ interpretation of the S^* and δ is summarized by the observations (figs. 9, 10a) that²¹⁾

$$\begin{aligned}\Gamma(J/\psi \rightarrow \omega S^*) &\ll \Gamma(J/\psi \rightarrow \omega f_2) \\ \Gamma(J/\psi \rightarrow \rho \delta) &\ll \Gamma(J/\psi \rightarrow \rho a_2).\end{aligned}$$

If the S^* and δ are the $^3P_0$ $q\bar{q}$ partners of the $^3P_2$ $q\bar{q}$ $f_2(1275)$ and $a_2(1320)$ then these inequalities are unexpected. If the $q\bar{q}$ partners of the f_2 and a_2 are instead the nearly degenerate $f_0(1300)$ and $a_0(1300)$ a high statistics partial wave analysis should observe them. We do not expect the production dynamics of the $K\bar{K}$ molecule S^* and δ to be similar to those of the $q\bar{q}$ scalars and, in the next section, we will investigate the effects of coupled channel interactions on these decays.

A Production Model and Two Applications

To discuss the effect of the coupled channel interactions on pseudoscalar pair production we consider the decay $J/\psi \rightarrow \omega\pi\pi$, which has a strong, wide enhancement at ≈ 500 MeV in the $\pi\pi$ invariant mass distribution and no S^* signal (fig. 10a).²¹⁾ The ω is a narrow $\sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d})$ resonance and one expects to find a $\sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d})$ pair recoiling from it. Following $\sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d})$ pair creation within the non- ω $\sqrt{\frac{1}{2}}(u\bar{u} + d\bar{d})$ pair a $\pi\pi$ pair can be created. (We neglect $s\bar{s}$ pair creation for the present.) The $\pi\pi$ pair undergoes coupled channel interactions as it propagates from the origin to the asymptotic region. This is not $\pi\pi$ scattering because the $\pi\pi$ pair is created inside the potentials. It is clear, however, that the production dynamics must be related to the scattering dynamics.

We use the inhomogeneous coupled channel equations based on equation (1) to solve this "production problem":

$$(K + M + V) u_S(r) = E u_S(r) + S \delta(r) \quad (2)$$

The solutions $u_S(r)$ have the same form as the solutions $u(r)$ of equation (1). The "source" vector S is chosen to be nonzero in one entry only and models the "creation" of a particular channel of u_S by giving that channel a nonzero radial wavefunction at the origin. A linear combination of $u_S(r)$ and the homogeneous solutions $u(r)$ of equation (1) can be constructed to form a solution $u_+(r)$ which has only outgoing waves. The amplitude to find a given

system in the asymptotic region, after a given channel is created at the origin, is determined from the outgoing solution $u_+(r)$ and is interpreted as the probability amplitude for the process. Phase space times the modulus of the probability amplitude squared is proportional to the rate for the process. We can generate the probability amplitude, and hence the rate, as a function of the invariant mass of the system, resulting in a spectrum which should be proportional to the experimental invariant mass distribution. If the energy rises above the threshold for two or more open channels then the relative rate from a common initial channel into each asymptotic channel is fixed by the outgoing solution $u_+(r)$.

To illustrate this procedure we again consider the decay $J/\psi \rightarrow \omega\pi\pi$ and the related decay $J/\psi \rightarrow \omega K\bar{K}$. We assume the creation of a $\pi\pi$ pair at the origin, although we anticipate that both $K\bar{K}$ and $f_0(1300)$ production at the origin will also contribute and that the details of the production spectra will change when these contributions are added.²³⁾ The unknown relative normalization of the experimental and model spectra can be determined by fitting the model rate to the experimental rate at any arbitrary energy. For $J/\psi \rightarrow \omega\pi\pi$ we constrain the low mass enhancement in the model to have the same area as the experimental spectrum. This normalization is then used to predict the absolute $K\bar{K}$ spectrum in $J/\psi \rightarrow \omega K\bar{K}$. Thus, recoiling against the ω , we predict the shape of the $\pi\pi$ spectrum and both the shape and normalization of the $K\bar{K}$ spectrum.

Some previously unresolved problems with these spectra are the $\pi\pi$ threshold effect in $\omega\pi\pi$,^{21,22)} the absence of an S^* signal in $\omega\pi\pi$, and the $K\bar{K}$ threshold effect in $\omega K\bar{K}$. As seen in figs. 10a and 10b, the model qualitatively fits the data and suggests that these decays may be better understood if the coupled channel interactions are taken into account.

In the related decays $J/\psi \rightarrow \phi\pi\pi$ and $J/\psi \rightarrow \phi K\bar{K}$ we assume the creation of a $K\bar{K}$ pair at the origin and find the amplitude for $\pi\pi$ or $K\bar{K}$ to appear in the asymptotic region. We expect that $\eta\eta$, $\eta\eta'$, $\eta'\eta'$ and $f'_0(1500)$ production at the origin will also contribute and that the details of the production spectra will change when these contributions are added. The unknown overall normalization is determined by fitting the $K\bar{K}$ threshold effect ($m_{K\bar{K}} < 1.2$ GeV) from the model to the experimental spectrum (fig. 10c). This normalization is then used to predict the $\pi\pi$ spectrum (fig. 10d). Thus, recoiling against the ϕ , we predict the shape of the $K\bar{K}$ spectrum and both the shape and normalization of the $\pi\pi$ spectrum.

Some apparent inconsistencies with these spectra are the lack of a $\pi\pi$ threshold enhancement in $\phi\pi\pi$ (given the enhancement seen in $\omega\pi\pi$ and elsewhere), the strong S^* signal in $\phi\pi\pi$ (which seems to violate the OZI rule), and the $K\bar{K}$ threshold effect in $\phi K\bar{K}$. As seen in figs. 10c and 10d the model qualitatively fits all the above mentioned data, demonstrating the importance of the coupled channel interactions and stressing the need to include them in data analysis.

Coupled channel interactions are also found to play a major role in the $\Delta I = 1/2$ rule in the weak decay $K \rightarrow \pi\pi$.²⁴⁾ The $\pi\pi$ system can be created in either $I = 0$ or 2 , corresponding to $\Delta I = 1/2$ or $\Delta I = 3/2$. Experimentally one finds the ratio of amplitudes

$$\left[\frac{\Gamma(K_s^0 \rightarrow \pi^0 \pi^0)}{\Gamma(K^+ \rightarrow \pi^0 \pi^+)} \right]^{\frac{1}{2}} \approx 25$$

which is far from the naïve standard model prediction of

$$\left[\frac{\Gamma_{\Delta I=1/2}}{\Gamma_{\Delta I=3/2}} \right]^{\frac{1}{2}} = \sqrt{2}.$$

A comparison of these ratios reveals that $I = 2$ $\pi\pi$ production is suppressed relative to the $I = 0$ $\pi\pi$ state. From the $\pi\pi$ phase shifts at the kaon mass one infers that $I = 0$ $\pi\pi$ pairs have an attractive interaction (fig. 7a) and $I = 2$ $\pi\pi$ pairs have a repulsive interaction (fig. 5), leading respectively to the enhancement and the suppression of the wavefunction at the origin. Our production solutions for $\pi\pi$ creation at the kaon mass predict an additional factor of ≈ 4 in the expected amplitude ratios. When included with other perturbative QCD corrections the long standing problem of the $\Delta I = 1/2$ rule is largely resolved.

Summary and Conclusions

Given that the proton and neutron are known to interact strongly enough to bind as (qqq) clusters, it is not surprising that mesons should also have strong “nuclear” forces and form similar bound states.

To investigate the $q\bar{q}q\bar{q}$ systems we have used the nonrelativistic quark model to find the ground states and from these have extracted S -wave pseudoscalar-pseudoscalar potentials. A model for the couplings between pseudoscalar pairs and scalar $q\bar{q}$ mesons provides additional interactions which also lead to meson-meson potentials. The coupled channel Schrödinger equation is used to study the low-energy effects of these meson-meson interactions. The solutions of these equations in $I = 0$ and 1 lead to the prediction that mesonic analogues of the deuteron should exist; $K\bar{K}$ systems form bound states which we identify with the S^* and δ scalar resonances.

With this assignment many of the properties of the S^* and δ are clarified. These include their masses, widths, branching fractions both below and above $K\bar{K}$ threshold and two photon widths. The systematics of the $^3P_0$ $q\bar{q}$ sector are also improved by the $K\bar{K}$ molecule assignment since there were too many scalar candidates and now the masses of the remaining states are consistent with quark model predictions and the $^3P_1$ and $^3P_2$ $q\bar{q}$ masses.

In addition to creating the S^* the $I = 0$ coupled channel interactions reproduce the $\pi\pi$ elastic scattering phase shift data from threshold to ≈ 1400 MeV. In $I = 1$ these interactions lead to predictions about the elastic $\eta\pi$ phase shifts. In $K\pi^{I=1/2}$ attractive potentials are predicted but there are no $K\pi$ or $K\eta$ bound states, in agreement with observations. Both the $K\pi^{I=3/2}$ and $\pi\pi^{I=2}$ systems are found to be repulsive.

The same model can be applied to production processes where problems in certain $J/\psi \rightarrow VPP$ channels may be resolved. A long standing puzzle of the $\Delta I = 1/2$ rule in the nonleptonic weak decay $K \rightarrow \pi\pi$ is largely resolved.

The wide-ranging successes of this model in the scalar sector are most encouraging. At present we are continuing our study of the $I = 1/2$ and $3/2$ pseudoscalar-pseudoscalar systems and of the dynamics of coupled channels in pseudoscalar pair production in all isospin channels. We plan to improve the model by incorporating relativistic kinematics in a coupled channel Klein-Gordon equation, and also to apply it to other sectors such as vector-vector in $J = 0, 1$, and 2 (There are unexplained threshold effects seen in $\gamma\gamma \rightarrow VV^{J=2}$), the vector-pseudoscalar systems (Is the $E(1420)$ a KK^* threshold effect?), and meson-baryon systems (Is the $\Lambda(1405)$ a $\bar{K}N$ molecule?). An analysis of the charmed $qq\bar{q}\bar{q}$ systems and a three-body coupled channel equation to study the $K\bar{K}\pi$ and $\eta\pi\pi$ decays of the E , ι , and D mesons are two less straightforward but interesting extensions of this research.

It is possible that many of the present problems in 1-2 GeV spectroscopy may be artifacts of our neglect of hadron-hadron coupled channel interactions, and that the correct classification and identification of the $q\bar{q}$ states, glueballs, and hybrids in this mass region may prove extremely difficult until we have sorted out these details.

I would like to thank David Morgan whose paper, "Is the 0^+ Nonet Respectable?", provided the inspiration for the title of this paper. I would also like to thank my collaborators, Nathan Isgur and Ted Barnes, for their many important contributions to this study, and Frank Close, Joe Macek, and George Condo for their useful discussions and suggestions.

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- 7) The data of Fig. 5 are a combination of the compilation of F. Wagner in Proceedings of the XVII Int. Conf. on High Energy Physics, London, 1974 (Rutherford Lab, Chilton, Didcot, England, 1974), p. II-27 and the data of J. Prukop *et al.*, Phys. Rev. D10, 2055 (1974). See also D. Cohen *et al.*, Phys. Rev. D7, 661 (1973); W. Hoogland *et al.*, Nucl. Phys. B126, 109 (1977); W. Hoogland *et al.*, Nucl. Phys. B69, 109 (1974).
- 8) " $I=1/2$ and $3/2$ $qq\bar{q}\bar{q}$ Systems", J. Weinstein and N. Isgur, work in progress.
- 9) M. Boutemour, these proceedings.
- 10) S.M. Flatté, Phys. Lett. 63B, 224 (1976).

- 11) For $\pi\pi$ phase shifts we use the measurements of G. Grayer *et al.*, Nucl. Phys. B75, 189 (1974). For other measurements see A.A. Belkov *et al.*, JETP Lett. 29, 597 (1979); L. Rosselet *et al.*, Phys. Rev. 15, 574 (1977); V. Srinivasan *et al.*, Phys. Rev. D12, 681 (1975); N.M. Cason *et al.*, Phys. Rev. D28, 1586 (1983).
- 12) B. Ratcliff, these proceedings.
- 13) F. Feld-Dahme, Ludwig-Maximilians-Universität Ph.D. thesis, Munich (1987).
- 14) S. Godfrey and N. Isgur, Phys. Rev. D32, 189 (1985).
- 15) J.P. Stroot, Proc. APS Meeting, Sante Fe, N.M. (1984); Yu.Z. Prokoshkin, these proceedings; see also 12).
- 16) There have been many suggestions that the E(1420) is not a $q\bar{q}$ meson. See, for example M. Feindt; E. Klempt and K. Peters; R. Longacre; K. Yamada, these proceedings.
- 17) S. Capstick and N. Isgur, Phys. Rev. D34, 2809 (1986).
- 18) T. Barnes, Phys. Lett. 165B, 434 (1985), and Proceedings of the VIIth Int. Workshop on Photon-Photon Collisions, Paris (1986), ed. A. Courau and P. Kessler (World Scientific, Singapore, 1986), p. 25.
- 19) G. Gidal, Proc. VIII Int. Workshop on $\gamma\gamma$ Collisions, Shresh, Israel, 1988.
- 20) PDG, Phys. Lett B204 (1988).
- 21) L. Kopke and N. Wermes, CERN-EP/88-93.
- 22) The threshold effect in $\pi\pi$ has a long history, see, for example, N. Booth and A. Abashian, Phys. Rev. 132, 2314 (1963); see also 2,21) and references therein; H.G. Dosch and D. Gromes, Z. Phys. C34, 554 (1987).
- 23) "Coupled Channel Effects in Pseudoscalar Pair Production", J. Weinstein and N. Isgur, work in progress.
- 24) N. Isgur, K. Maltman, J. Weinstein and T. Barnes, UTPT-89-10, to appear in Phys. Rev. Lett.

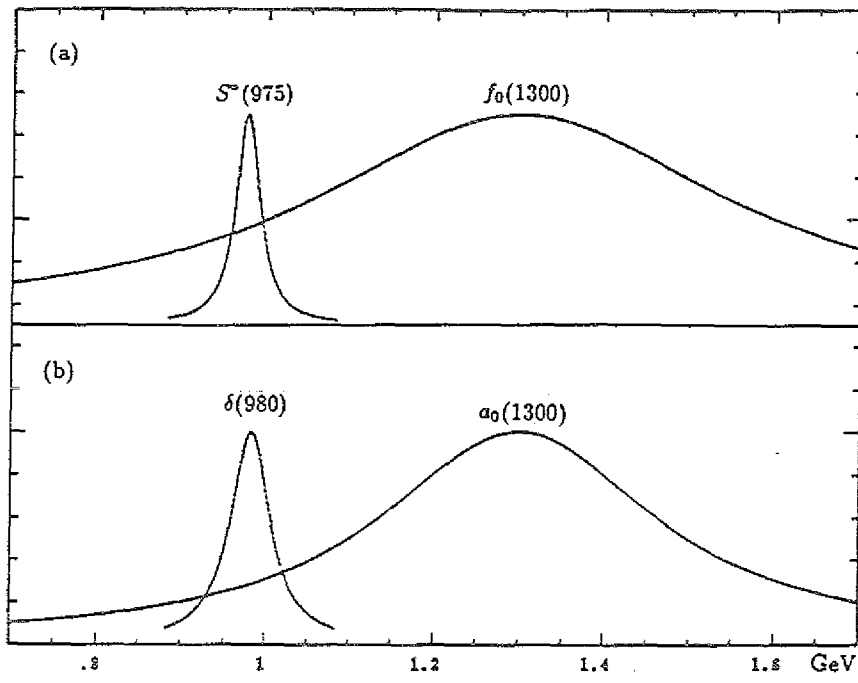


Figure 1: We compare the Breit-Wigner line shapes of a 600 MeV wide $f_0(1300)$ with the 34 MeV wide $S^*(975)$ in (a) and a 400 MeV wide $a_0(1300)$ with the 57 MeV wide $\delta(980)$ in (b). The discrepancies between the naïve quark model predictions and the S^* and δ are clear.

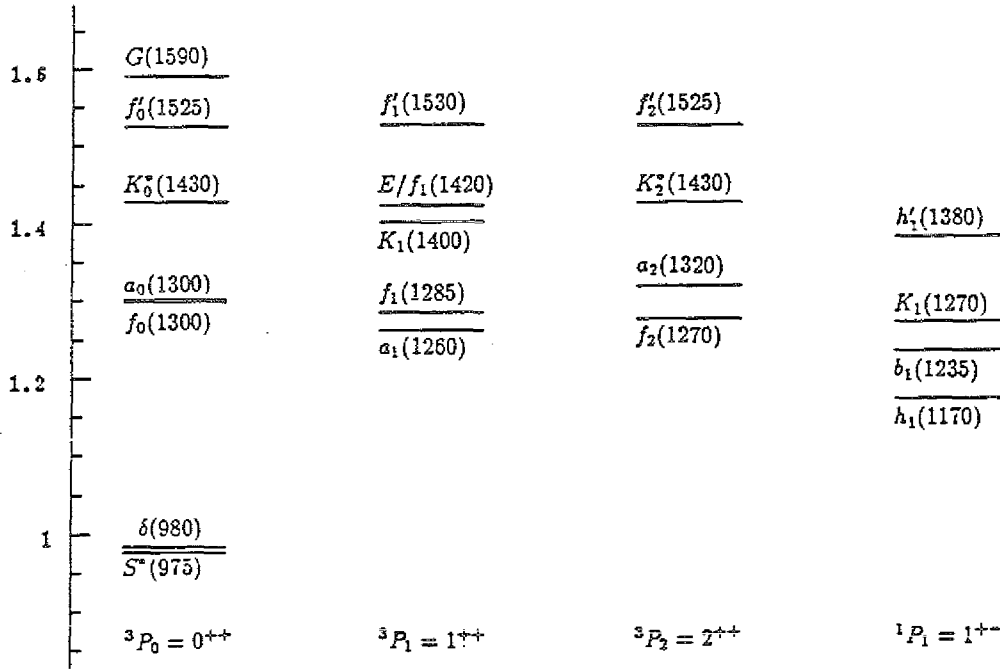


Figure 2: The candidate states for the four $L = 1$ nonets are located by mass and quantum numbers. The S^* and δ , just below $K\bar{K}$ threshold, are too light for the ≈ 100 MeV wide ${}^3P_0 - {}^3P_1 - {}^3P_2$ spin-orbit splittings predicted by the naïve quark model. The ${}^3P_0$ and ${}^3P_1$ sectors are also overpopulated.

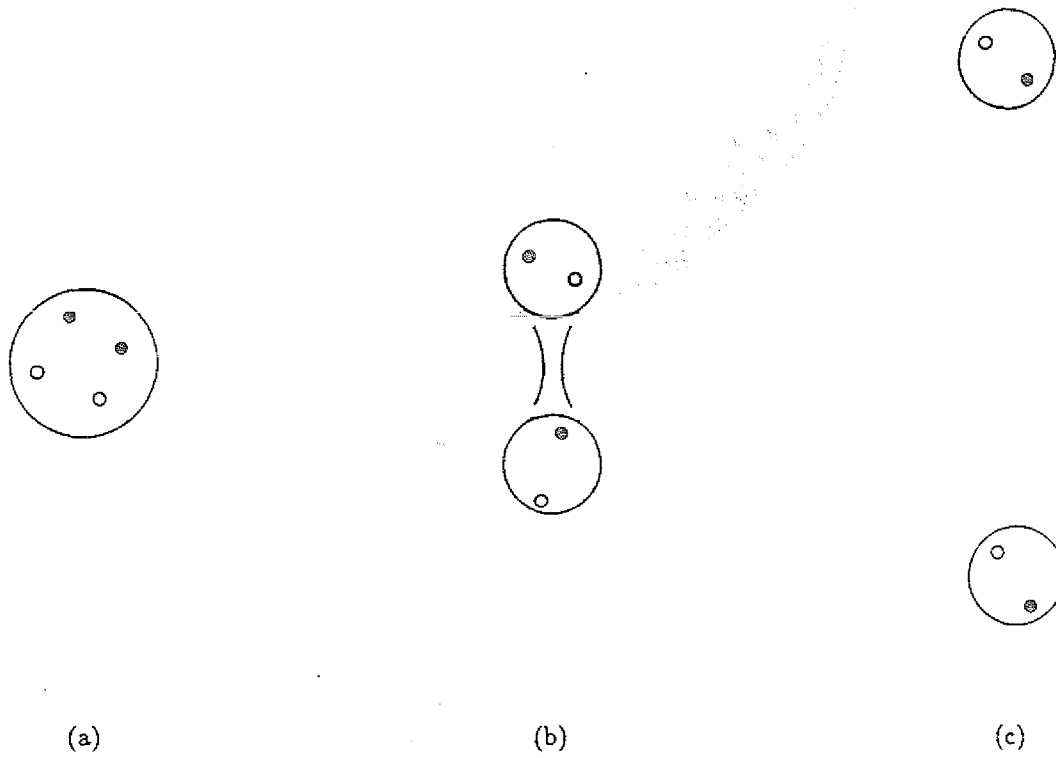


Figure 3: Three possible ground and metastable states of the $qq\bar{q}\bar{q}$ system: (a) a single hadron (baryonium), (b) two bound mesons, or (c) two free mesons.

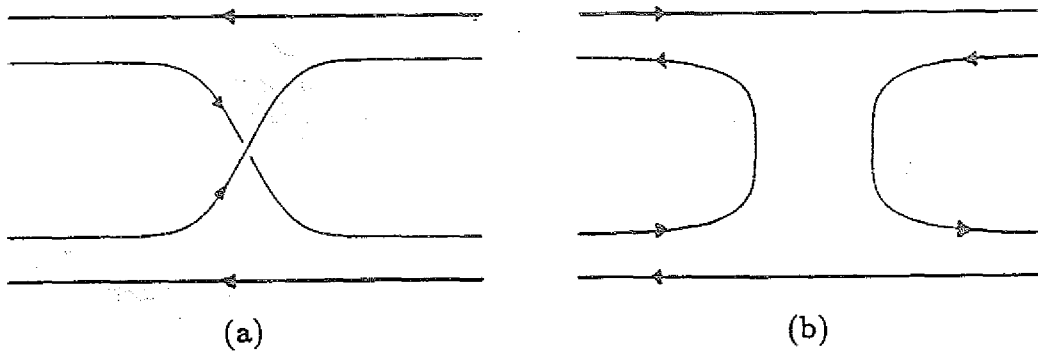


Figure 4: Two sources of the pseudoscalar-pseudoscalar potentials are (a) the quark exchange interaction and (b) the $q\bar{q}$ pair annihilation and creation interaction through ordinary S -channel ${}^3P_0$ $q\bar{q}$ scalars.

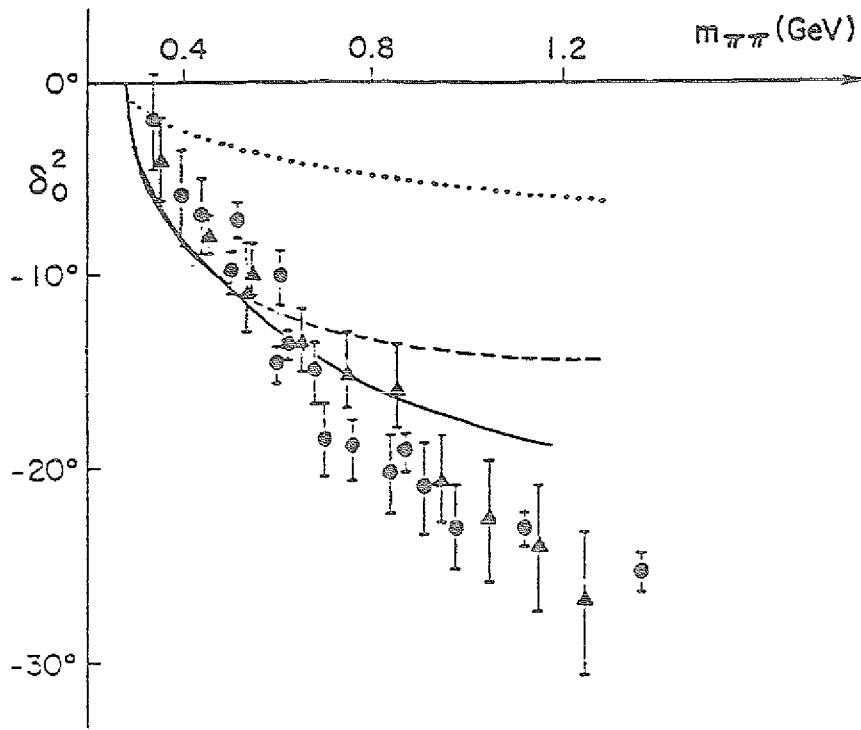


Figure 5: Three $I = 2$ $\pi\pi$ phase shifts and the experimental data. The dotted curve follows from the extracted potential $V_{\pi\pi}^{I=2}(r)$, the dashed curve from $\tilde{V}_{\pi\pi}^{I=2}(r) = 0.5 V_{\pi\pi}^{I=2}(\frac{r}{2})$, and the solid curve from the "equivalent" square well potential.

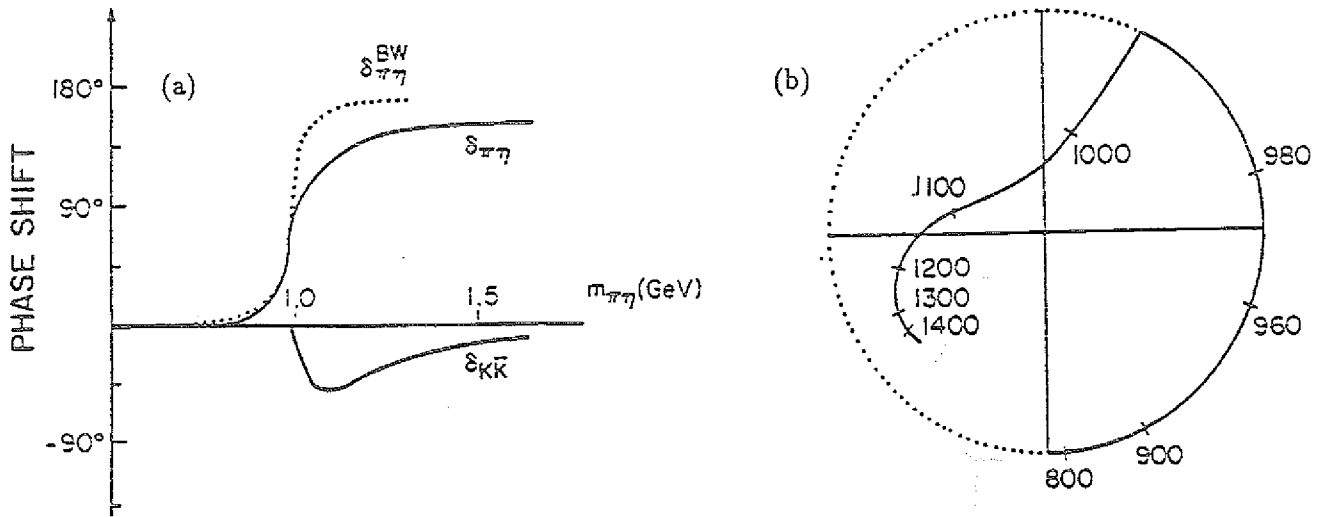


Figure 6: (a) The phase shift from the coupled channel solution to equation (1) for elastic $\eta\pi$ scattering (solid curve) is compared to the phase shift obtained from $\eta\pi$ scattering through a Breit-Wigner resonance with the parameters of the $\delta(980)$ (dotted curve). Also shown in (a) is the elastic $K\bar{K}$ phase shift obtained from equation (1). The drop in $\delta_{K\bar{K}}$ at $K\bar{K}$ threshold is due to the binding $I = 1$ $K\bar{K}$ potential. In (b) the elastic $\eta\pi$ transition matrix element is shown.

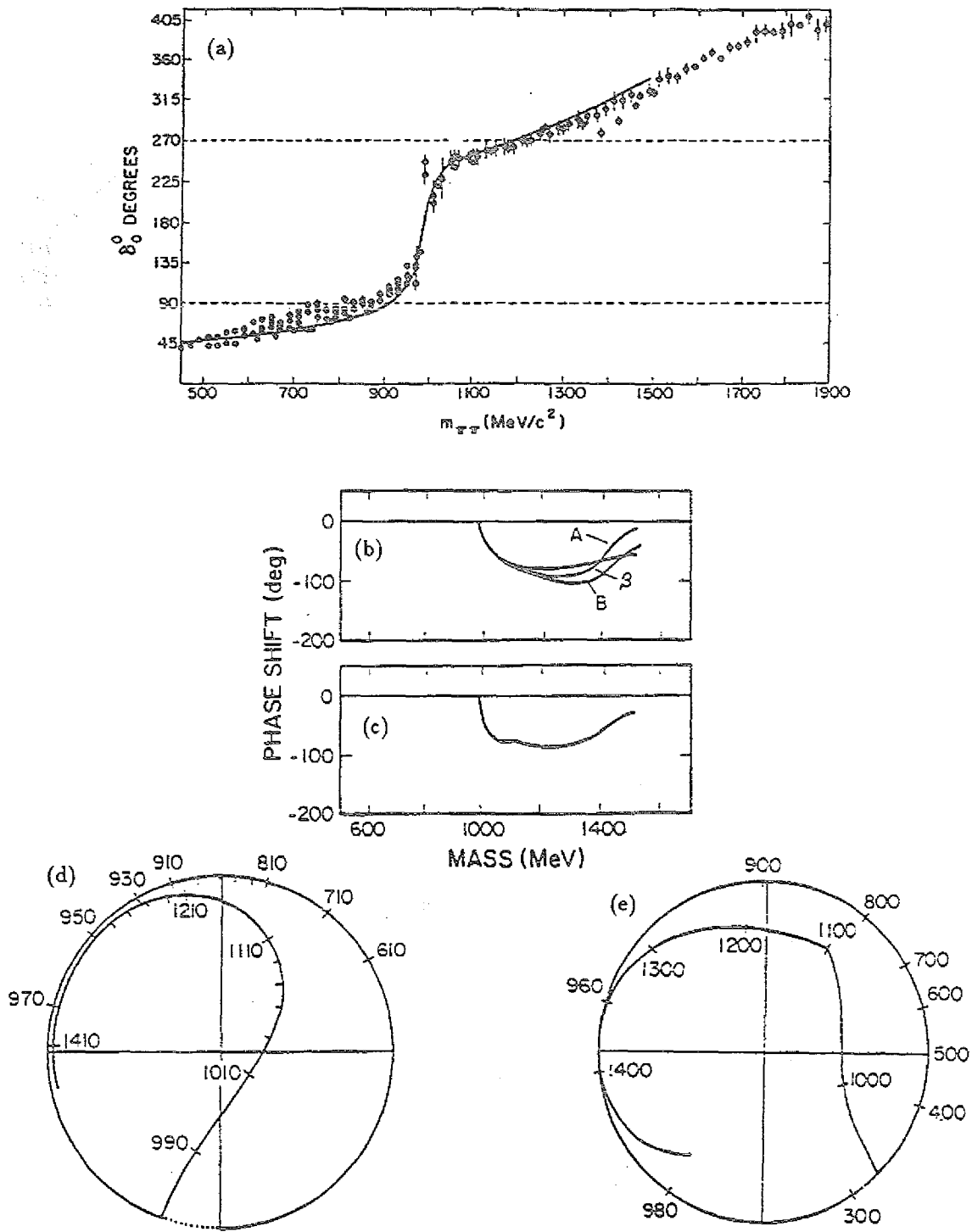


Figure 7: (a) The elastic $I = 0$ $\pi\pi$ phase shift from the coupled channel equation is shown with experimental data.¹¹⁾ The major features of the data below ≈ 1400 MeV are reproduced. The elastic $K\bar{K}$ phase shift from the experiment (b) and the model (c) are similar. The drop in $\delta_{K\bar{K}}$ at $K\bar{K}$ threshold is due to the $I = 0$ binding $K\bar{K}$ potential. We also show the experimental (d) and model (e) $\pi\pi \rightarrow \pi\pi$ transition matrix element.

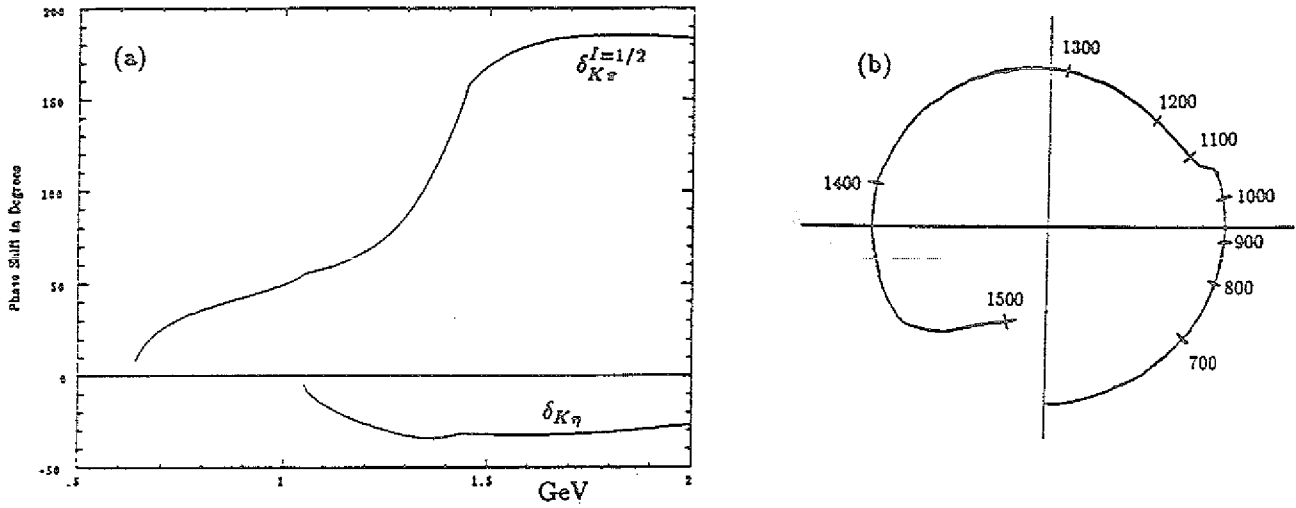


Figure 8: In (a) we show the $I = 1/2$ elastic $K\pi$ and $K\eta$ scattering phase shifts from the model. Neither a $K\pi$ nor $K\eta$ bound state exists although there is a strongly attractive $K\pi$ potential indicated by the threshold behavior of the phase shift. In (b) we show the transition matrix element for $K\pi \rightarrow K\pi$ scattering.

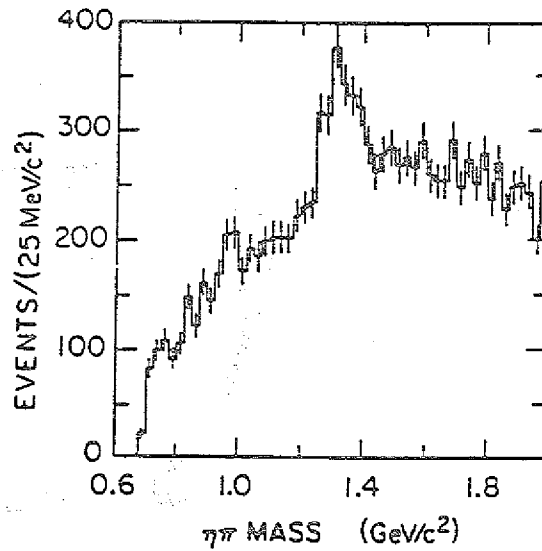


Figure 9: This is the experimental $\eta\pi$ invariant mass distribution²¹⁾ from the reaction $J/\psi \rightarrow \rho(\eta\pi)$. While the $a_2(1320)$ signal is clear there is no significant signal at 980 MeV where there should be an enhancement if the δ were the $^3P_0$ $q\bar{q}$ partner of the $^3P_2$ a_2 .

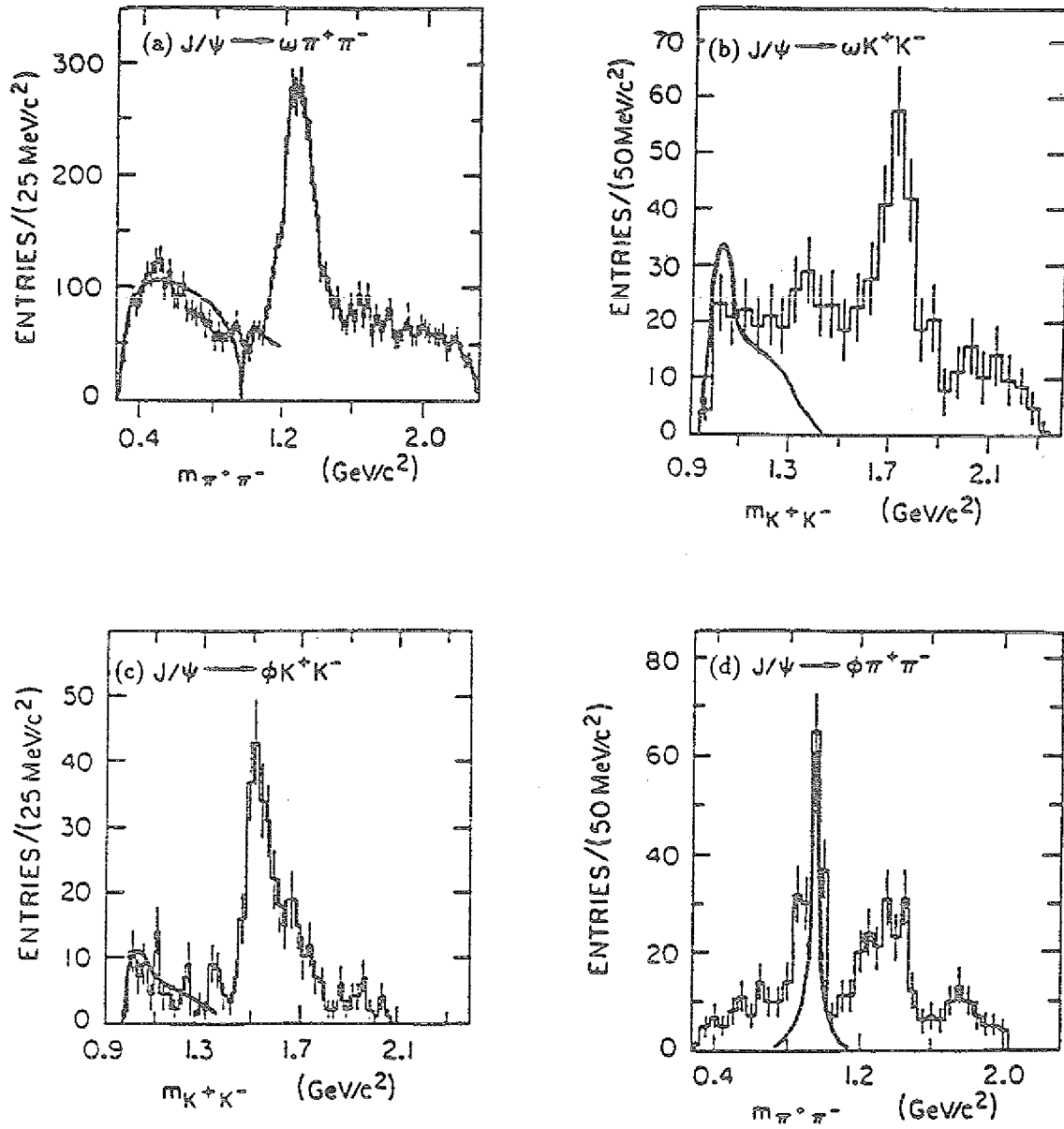


Figure 10: Some puzzles in J/ψ decay may be resolved by coupled channel interactions: the predicted spectra are the solid curves which show

- the $\pi\pi$ threshold peak in $\omega\pi\pi$ (a) but not in $\phi\pi\pi$ (d)
- no S^* peak in $\omega\pi\pi$ (a) but a strong S^* peak in $\phi\pi\pi$ (d)
- a threshold enhancement in both $\omega K\bar{K}$ (b) and $\phi K\bar{K}$ (c)

The shape of these spectra are predicted by the model, and the normalizations of (b) and (d) are determined by (a) and (c) respectively. These are preliminary spectra; not all production mechanisms are included.

1. The first part of the report deals with the general situation of the country and the position of the various groups of the population. It is a very interesting and informative part of the report.

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Workshop on

Mesons and Mesonic States

up to slightly above $1 \text{ GeV}/c^2$

at the Conference Room of the Zentrallabor für Elektronik ZEL

Forschungszentrum Jülich

February 19. - 20. 1990

VII)

J. Speth

Meson - Meson Scattering and the Mass of Scalar Mesons

Meson-Meson Scattering and The Masses of Scalar Mesons

- I. Modeling QCD
chiral invariant Lagrangians
- II. Dynamical model for meson-
meson scattering
- III. $\pi\pi$ scattering
- IV. $K\pi$ scattering
- V. Conclusions

K. Holinde, D. Lohse, J. Duroso, J. Nitschkowski

Theory of the Strong Interaction

Quantum Chromodynamics

$$\mathcal{L} = i\bar{\Psi} \gamma^\mu (\underbrace{d_\mu}_{\text{Quarks}} - ig \underbrace{\frac{d^a}{2} V_\mu^a}_{\text{Gluons}}) \Psi - \frac{1}{4} F_{\mu\nu}^a F^{\mu\nu a}$$

$$F_{\mu\nu}^a = \partial_\mu V_\nu^a - \partial_\nu V_\mu^a + g f^{abc} V_\mu^b V_\nu^c$$

Quark - Gluon Dynamics

$\Rightarrow$ no solutions so far $\Leftarrow$

Modeling QCD

Effective low-energy theories for hadrons

Nambu - Jona Lasinio (1961)

$$\mathcal{L} = i \bar{\Psi} \gamma^\mu \partial_\mu \Psi + \frac{1}{2} g^2 \{ (\bar{\Psi} \Psi)^2 - (\bar{\Psi} \vec{\tau} \gamma_5 \Psi)^2 \}$$

quarks + zero-range interaction

Mesons: correlated quark-antiquark pairs

⇒ quasi-particle RPA

The nonlinear σ -model (1960)

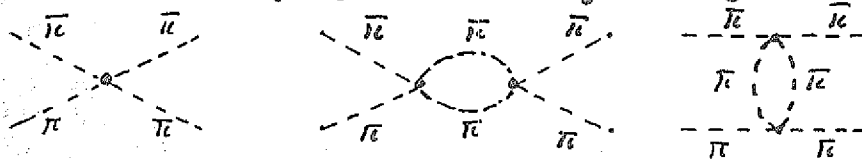
$$\mathcal{L} = \frac{f_\pi^2}{4} \text{Tr}(\partial_\mu U \partial^\mu U) - \frac{1}{2} m_\pi^2 f_\pi^2 (2 - \text{Tr} U)$$

$$U = e^{i \vec{\tau} \vec{\phi} / f_\pi} = \frac{1}{f_\pi} (\sigma + i \vec{\tau} \cdot \vec{\pi})$$

$$\sigma = f_\pi \left(1 - \frac{\vec{\pi}^2}{f_\pi^2} \right)^{1/2}$$

+ fourth-order term ⇒ Skyrme Lagrangian

Meson-scattering: Gasser & Leutwyler, Donoghue



Nonlinear chiral Lagrangian

J. F. Donoghue et al.

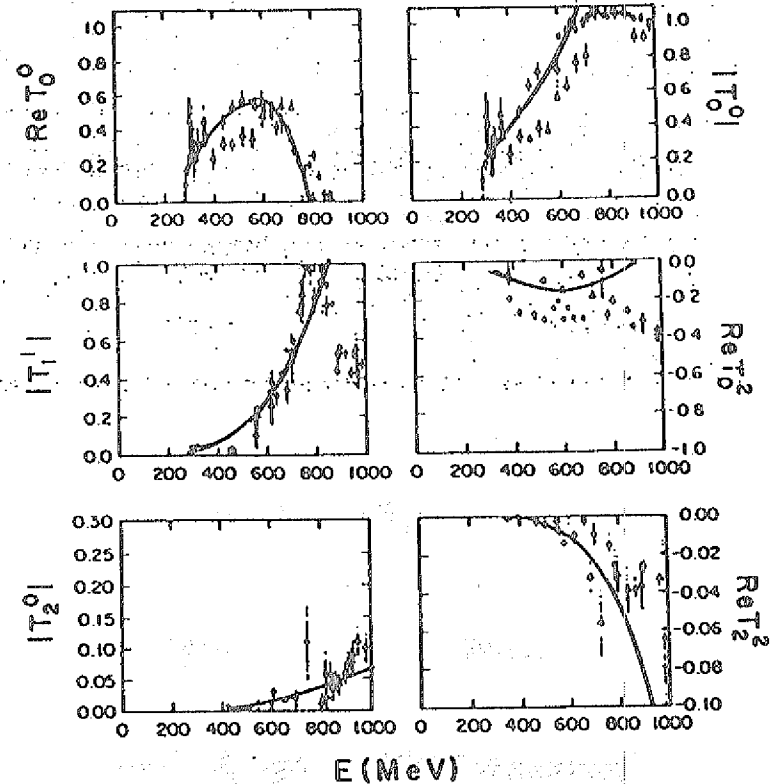
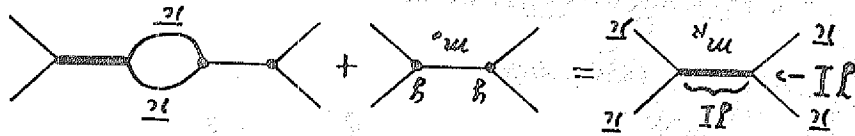


FIG. 6. The best fit to pion scattering at the one-loop level.

4 free parameters
(2 have been previously adjusted to fit the scattering lengths)
→ 2 parameters were used to fit the higher energy behavior

Pot-graph only (see-model)

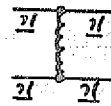


$m_0 \hat{=}$ bare mass $m_R \hat{=}$ physical mass

coupling parameter g as the only interaction parameter

$$\frac{g_{\text{meson}}}{(j=1, I=1)}: m_{\text{Lee}}^0 = 1135 \text{ MeV} \quad \Gamma_{\text{Lee}}^g = \Gamma_{\text{exp}}^g \quad \frac{1}{4\pi} g_{\text{Lee}}^2 = 2.84$$

Pot-graph + π -channel interaction
 π -channel gives additional interaction



$\sim$ pot-graph contribution (g) has to be modified
 $\frac{g_{\text{meson}}}{(j=1, I=1)}: m_0 = 1080 \text{ MeV} \quad \Gamma_{\text{exp}}^g = \Gamma_{\text{exp}}^g \quad \frac{1}{4\pi} g^2 = 2.10$
 π -channel interaction $\sim 30\%$ effect

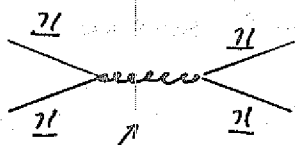
$\Rightarrow$ Effect depends on the OBEF-matrix element
 $V^j(p, p'; z) \propto \int d(\omega_0) V_j(\omega_0) V(p', p; z; \omega_0)$
 $V^j_{j=0} \gg V^j_{j=1} \gg V^j_{j=2}$

Pseudo-scalar Mesons

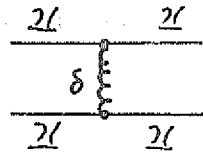
Multiquark States

a) π - π Scattering

"elementary" interaction



Spin 0
Isospin 1



Meson-Exchange

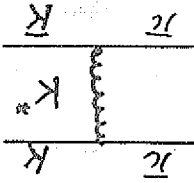
$\rho, (\phi), (\omega)$

$\rightarrow \pi$ -channel $\leftarrow$

Pot-graph

$\rho, K^*, \epsilon, \kappa$

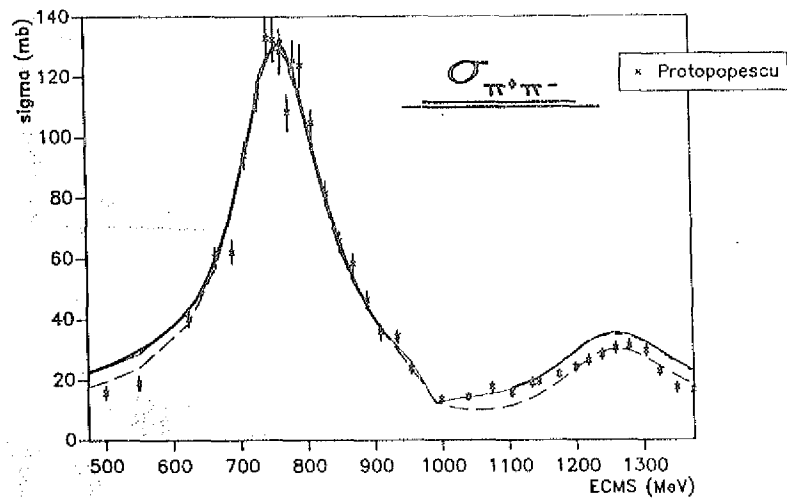
$\rightarrow s$ -channel $\leftarrow$



Strangeness-Exchange

$K\bar{K}$ -threshold
at $\sim 987 \text{ MeV}$

ρ -meson und f_2 -meson seen in $\pi\pi$ -scattering



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Phase-shifts in the ρ - and f_2 -channel

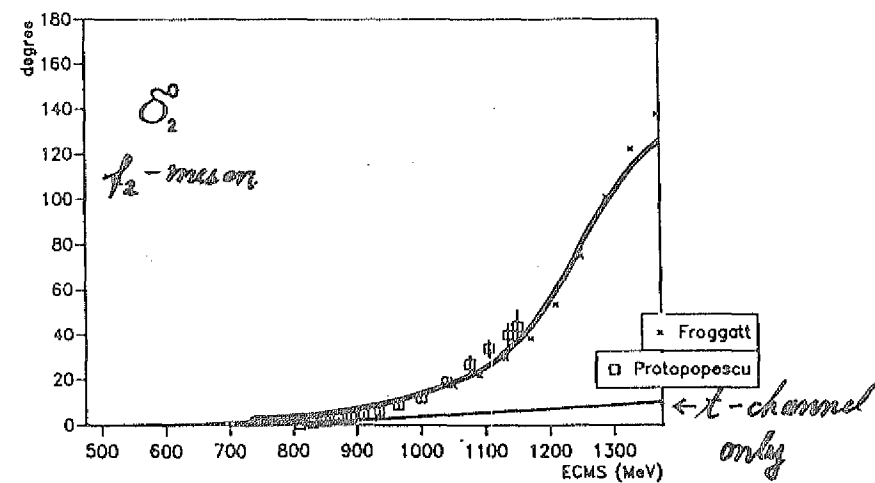
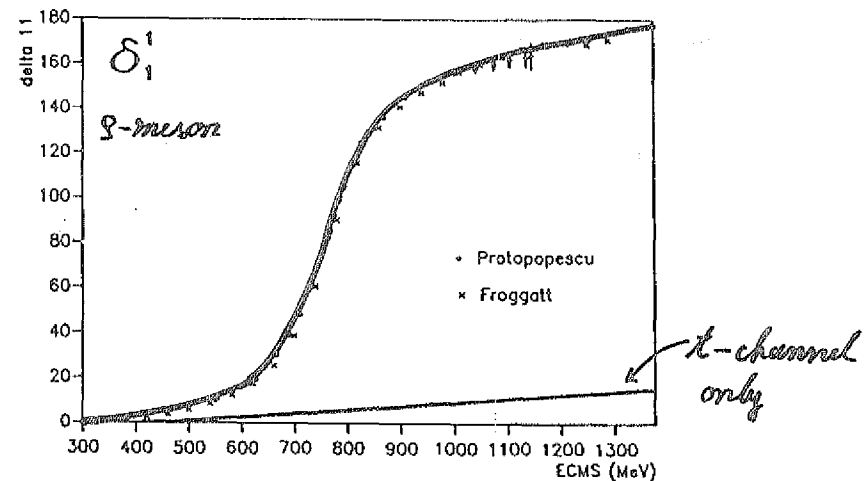
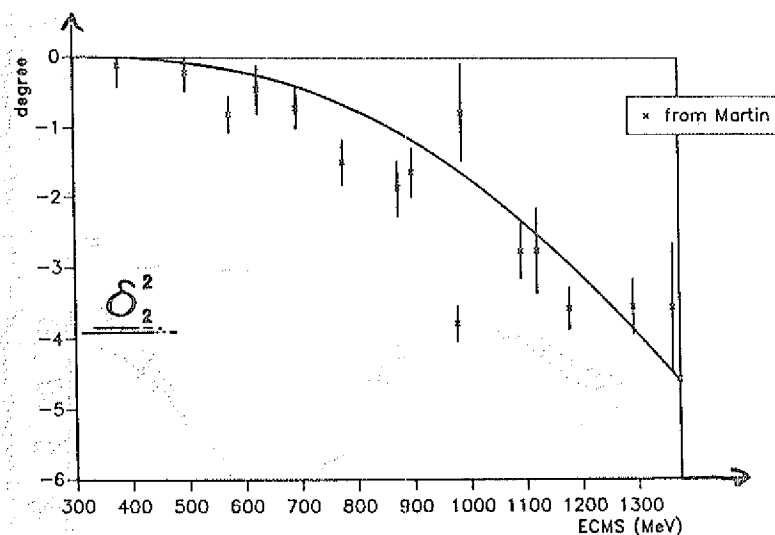


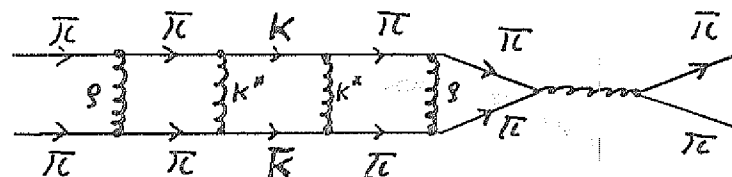
Fig. 8.5.: a) δ_1^1 -Phase b) δ_2^0 -Phase
strichpunktigte Kurve: nur OBE-Graphen;
durchgezogene Kurve: Modell I mit ρ - bzw. f_2 -Polgraphen

$I=2 \quad J=2^+$ - channel.

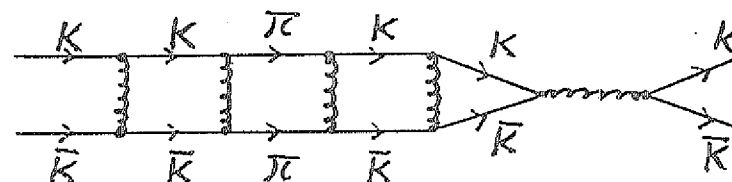


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Coupled - Channel Approach



$\pi\pi$ scattering is coupled to $K\bar{K}$ scattering



Isospin-dependence of the meson-exchange

Graph	Isospin	Factor
$\pi\pi \rightarrow \pi\pi$ (rho)	0	-2
$\pi\pi \rightarrow \pi\pi$ (K*)	1	-1
$\pi\pi \rightarrow \pi\pi$ (K)	2	1
$K\bar{K} \rightarrow K\bar{K}$ (phi)	0	-3
$K\bar{K} \rightarrow K\bar{K}$ (rho, omega, K*)	1	1
$K\bar{K} \rightarrow K\bar{K}$ (K)	2	0
$\pi\pi \rightarrow K\bar{K}$ (K*)	0	$\sqrt{6}$
$\pi\pi \rightarrow K\bar{K}$ (K)	1	2
$\pi\pi \rightarrow K\bar{K}$ (K)	2	0

$SU(3)$ -symmetry

$$(g_1 g_2)_{KK}^\omega = -(g_1 g_2)_{\omega\omega}^\rho$$

$$(g_1 g_2)_{KK}^\phi = 2(g_1 g_2)_{KK}^\omega$$

For $I=0$, ϕ , ρ and ω are attractive and give rise to a bound $K\bar{K}$ -state ($E_B \sim 20$ MeV).

For $I=1$ ω and ρ cancel each other $\rightarrow$ less attractive ($\sim 1/3$)

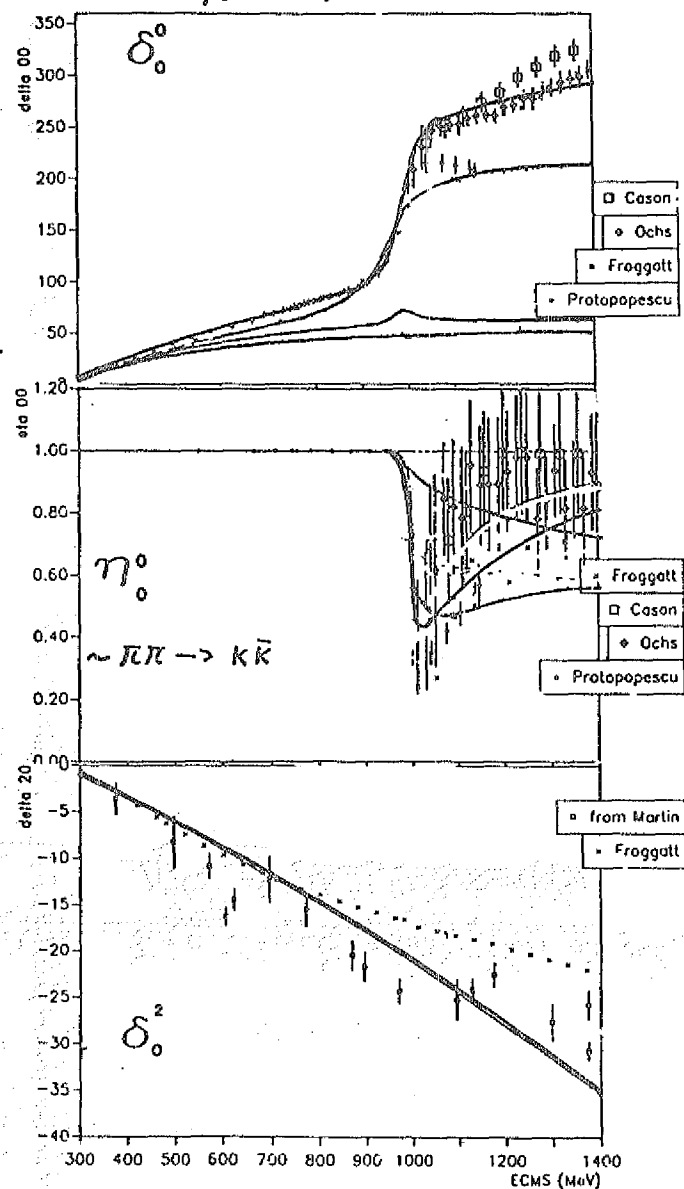
$\pi\pi - \pi\pi$ - Scattering in the scalar channel " $f_0(975)$ "

t -channel

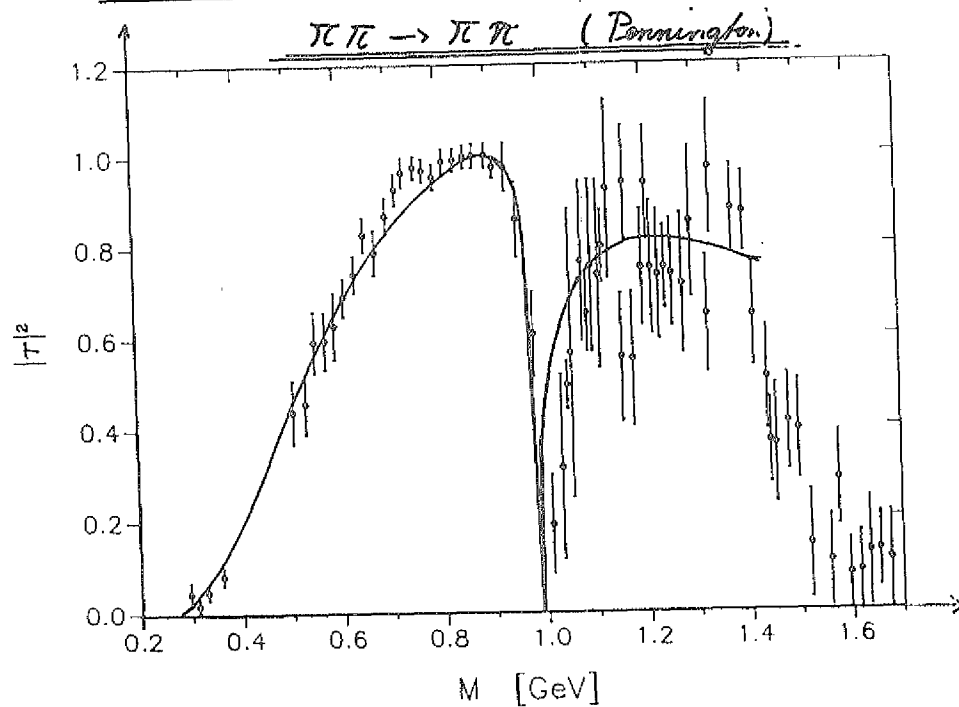
$+ K\bar{K}$ molecule

$+ E''(2400)$

135

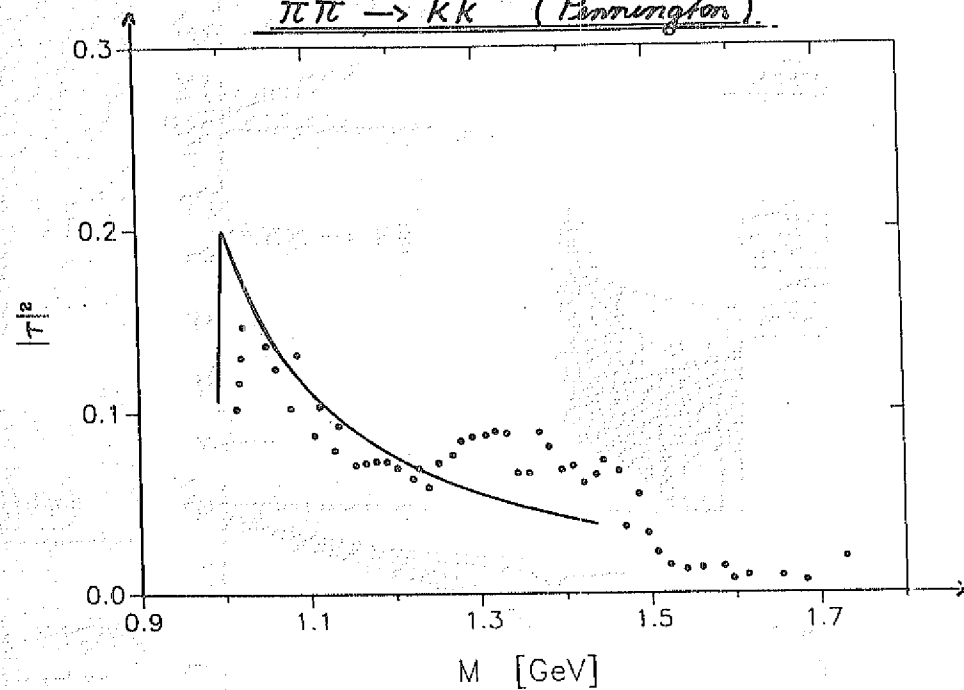


$|\tau|^2$: $I=0$ S-wave cross-section scaled by E^2

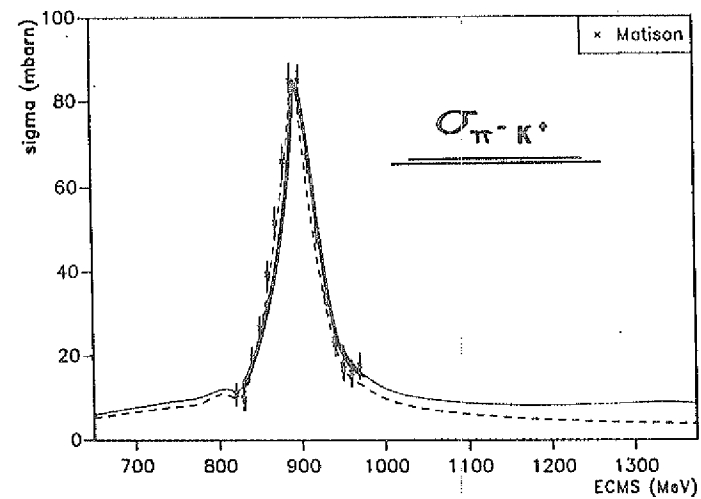


$|\tau|^2$: $I=0$ S-wave cross-section scaled by E^2

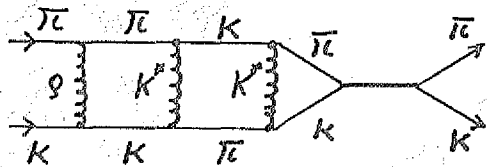
$\pi\pi \rightarrow K\bar{K}$ (Pinnington)



K^* meson seen in πK^+ -scattering



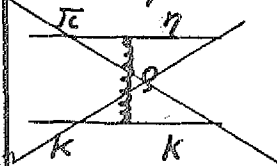
b) πK -scattering



all parameters in the t -channel are fixed by $SU(3)$

K^* -meson $m_0 = 1084 \text{ MeV}$ $m_R = 892 \text{ MeV}$
 $J=1; I=1/2$

The $J=0; I=1/2$ channel (scalar K -mesons) is much simpler than in $\pi\pi$ -scattering

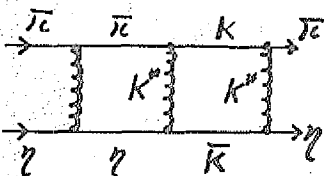


direct coupling to the ηK -channel is not possible in $SU(3)$

$\Rightarrow$ no coupled channel
 $\Rightarrow$ no quasi-bound state

c) $\eta\pi$ -scattering

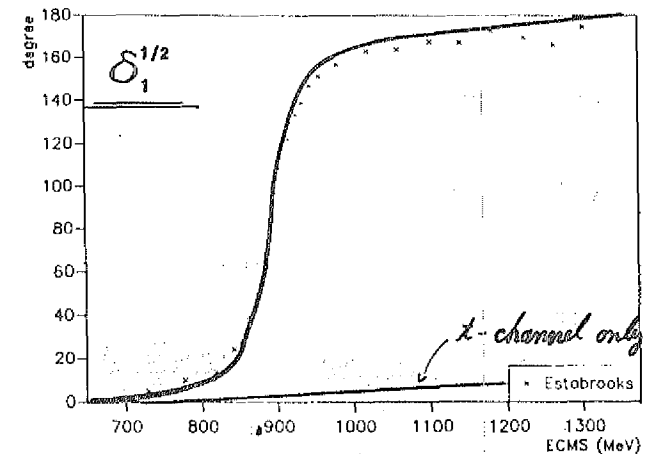
$J=0; I=1$ - channel $a_0(980)$ -meson



t -channel interaction in $\eta\pi$ very weak

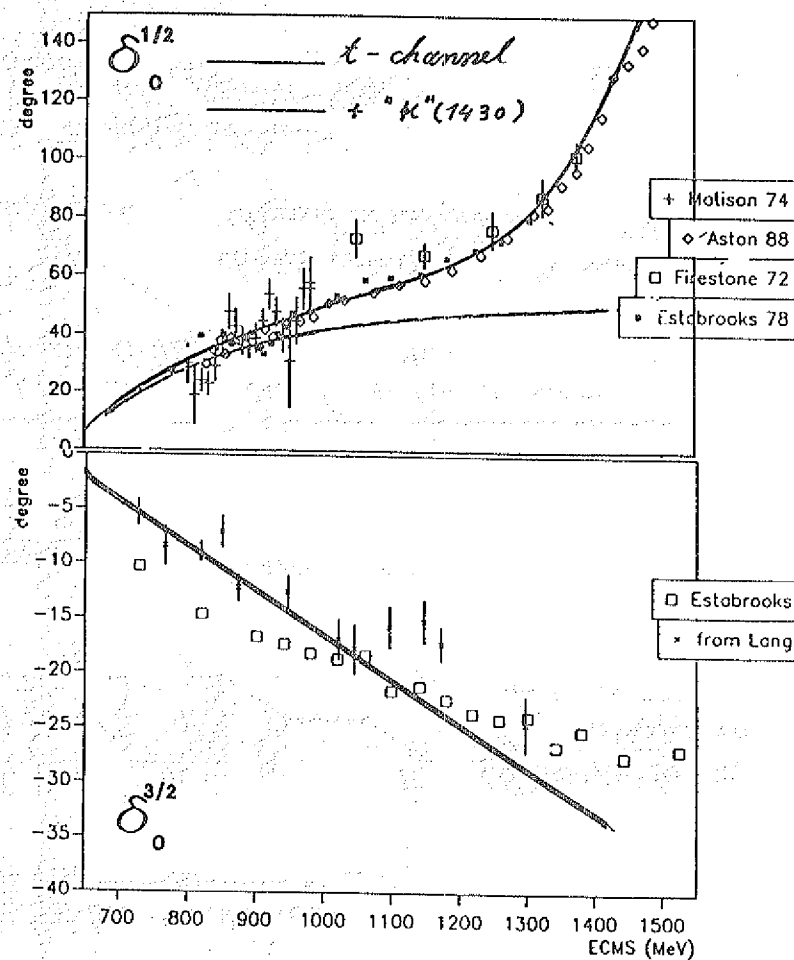
$K\bar{K}$ interaction in the $I=1$ channel $\sim 1/2$ of $I=0$

Phase-shift in the $I=1/2, J=1$ (K^* -meson) channel



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πK -phase-shift in the scalar channel



Scattering lengths in $\pi\pi$ and $K\pi$ scattering

Prozess	a_T^J	$a_T^J(\text{exp})$	Ref.	$a_T^J(\text{I})$	$a_T^J(\text{III})$
$\pi\pi \rightarrow \pi\pi$	a_0^0	0.26 ± 0.05	aus [35]	0.26	0.29
	a_0^0	-0.028 ± 0.012	aus [35]	-0.028	-0.028
	a_1^1	0.038 ± 0.002	aus [35]	0.40	0.40
	a_2^0	$(17 \pm 3) \cdot 10^{-4}$	aus [35]	$9.3 \cdot 10^{-4}$	$9.3 \cdot 10^{-4}$
	a_2^2	$(1.3 \pm 3) \cdot 10^{-4}$	aus [35]	$-2.7 \cdot 10^{-4}$	$-2.7 \cdot 10^{-4}$
$K\pi \rightarrow K\pi$	a_0^0	0.22 ± 0.04	[62]	0.24	0.27
	a_0^0	0.28 ± 0.06	[71]		
	a_0^0	0.24 ± 0.002	[72]		
	a_0^0	0.335 ± 0.014	[73]		
	a_0^0	-0.06	[62]	-0.064	-0.064
	a_0^0	-0.05	[72]		
	a_1^1	-0.144 ± 0.003	[73]		
	a_1^1	0.018 ± 0.002	[72]	0.018	0.018

Tab. 8.6.:
Streu­längen a_T^J in Modell I und III im Vergleich mit dem Experiment.

conclusions:

- 1) Dynamical model for meson-meson scattering nonlinear σ -model plus "hidden" local gauge symmetry provides an appropriate description. Number of free parameters is very restricted due to $SU(3)$ -symmetry.

$\Rightarrow$ quantitative agreement with the $\pi\pi$ - and $K\pi$ -data; consistent description of both (resonant and non-resonant) channels.

- 2) The vector meson ρ and K^* are mixtures of genuine mesons - correlated $\bar{q}q$ -pairs and correlated $\pi\pi$ - and $K\pi$ -pairs - $2\bar{q}2\bar{q}$ pairs.

- 3) The scalar meson $f_0(935)$ and $a_0(980)$

are quasi-bound $K\bar{K}$ -resonances.

$\Rightarrow$ correlated $2\bar{q}2\bar{q}$ states $\Leftarrow$

The genuine scalar mesons - correlated $\bar{q}q$ -pairs have masses ~ 1400 MeV.

SCALAR MESONS IN $\pi\pi$ AND $K\pi$ SCATTERINGD. LOHSE, J.W. DURSO¹, K. HOLINDE and J. SPETH*Institut für Kernphysik, Kernforschungsanlage Jülich, D-5170 Jülich, FRG*

Received 11 September 1989

We analyze the s-wave phase shifts derived from $\pi\pi$ and $K\pi$ scattering data with a meson exchange model that includes both s- and t-channel exchange. Correlated $\pi\pi$, $K\bar{K}$, and $K\pi$ pairs play a crucial role in explaining the phase shifts and the elasticity parameter below 1 GeV. Genuine scalar mesons are necessary to fit the s-wave phases in the $I=0$ $\pi\pi$ channel in the $I=\frac{1}{2}$ $K\pi$ channel for energies beyond 1 GeV.

While quantum chromodynamics (QCD) is generally thought to be the underlying theory of strong interactions, the mathematical intractability of the theory in the low energy (i.e., non-perturbative) domain makes a phenomenological description of low energy processes a practical necessity. Indeed, there are theoretical indications [1] that low energy phenomena can be well described in terms of the quantities observed directly – mesons and nucleons – and their interactions by meson exchange.

Clearly, the meson exchange model of hadronic interactions can only be applicable in a limited energy range, which must be related to the size of the confinement region of the quarks. This size is not necessarily the same as the empirical size of a hadron, since the size of a hadron includes its meson cloud. The range of applicability of meson exchange models may then be somewhat larger than simple estimates based on RMS radii. The interesting question is: how large is this range?: at what point *must* one consider quark effects?

To answer this question it is necessary to investigate different hadronic systems within a consistent framework. Such a program has been started some time ago when the Bonn NN-potential [2] was extended to include the exchange of strange mesons [3,4], enabling the calculation of hyperon–nucleon and K^+N potentials. The further extension of the

model to include the interaction between two mesons is also straightforward. Here we report on some specific results of a more extensive investigation of the interaction between pseudoscalar mesons in a meson-exchange framework [5]. The results which we shall present concern the scalar channel of the $\pi\pi$ and $K\pi$ system, in the systems which have been investigated previously, a repulsive core provided by the exchange of vector mesons, especially by ω -exchange, prevents the two hadrons from coming too close to each other. In those cases one may argue that mesonic exchange masks quark effects. In the case of two pseudoscalar mesons this repulsive ω -exchange is missing, and therefore quark effects might show up more clearly. Indeed, we will see that in order to understand theoretically the weak interaction at threshold in the spin-parity (J^π) = 0^+ and isospin (I) = 0 channel of the $\pi\pi$ system, and in the $J^\pi = 0^+$, $I = \frac{1}{2}$ channel of the $K\pi$ system, one has to introduce a repulsive contribution of very short range into the interaction that cannot be directly connected with experimentally known mesons. This repulsion is necessary in order to cancel at threshold the attraction provided by scalar meson exchange. However, we will also demonstrate that this effect depends on the way in which scalar mesons are coupled to the pseudoscalar mesons. If we use scalar coupling one needs the above mentioned additional repulsion, but if we use derivative coupling this repulsive contribution is no longer necessary.

The main results concern the role of the t-channel

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interaction between two pseudoscalar mesons in a relative s -state and the masses of the scalar mesons. The scalar channels – that is, the δ_0^0 and $\delta_0^{1/2}$ phase shifts – below 1 GeV are essentially determined by correlated $\pi\pi$, $K\bar{K}$ and $K\pi$ pairs. This means that in the underlying quark model correlated two-quark–two-antiquark configurations play an important role. The genuine scalar resonances (mesons) which are described as quark–antiquark pairs influence, at least for the derivative coupling, the scattering process only beyond 1 GeV because their physical masses are around 1400 MeV. For $\pi\pi$ scattering the $K\bar{K}$ channel turns out to be of extreme importance; therefore we treat this channel exactly in a coupled channel framework. For the $K\pi$ case this complication does not exist because the only possible channel within our model, namely the $\eta\pi$ channel, couples very weakly.

In the following we compare theoretical phase shifts with the corresponding experimental data. The theoretical results are obtained from the transition operator $T(z)$ which obeys an integral equation of the Lippmann–Schwinger type:

$$T(z) = V(z) + V(z) \frac{1}{z - H_0 + i\epsilon} T(z), \quad (1)$$

where z is the starting energy. Solution of the resulting equations is done by straightforward numerical matrix inversion.

The quantum numbers and masses of the mesons which are included in the quasipotential $V(z)$ of eq. (1) are given in table 1. All the coupling constants are consistent with $SU(3)$ symmetry relations. For t -channel exchange we have a form factor for each vertex of the form

$$F_1(q^2) = \frac{\Lambda^2 - m^2}{\Lambda^2 + q^2}, \quad (2)$$

where m is the mass of the exchanged meson and q^2 is the square of the three-momentum transfer. For the scalar particles in the s -channel we use the form

$$F_2(q^2) = \frac{\Lambda^4 + m^4}{\Lambda^4 + E_q^4}, \quad (3)$$

where E_q is the total on-shell energy with CM momentum q . In either case Λ is a cutoff parameter to be adjusted to the empirical data.

Pion–pion scattering. The experimental $\pi\pi$ phase shift (δ_0^0) in the scalar–isoscalar channel $I^G(J^{PC}) = 0^+(0^{++})$ shows a 180° jump in a narrow energy range around $E \approx 980$ MeV. This resonance ($f_0(975)$) was originally interpreted as a member of the scalar $q\bar{q}$ nonet. Jaffe [6] has pointed out that this interpretation leads to difficulties and suggested that $f_0(975)$ and $a_0(980)$ might be four-quark states (two-quark–two-antiquark), whereas the genuine $q\bar{q}$ scalar mesons should be several hundred MeV higher in energy. We will show that in our model the spectrum below 1 GeV is essentially given as a correlated two-pion and two-kaon system.

In a first approach we solved the T -matrix equation (1) in the two-pion channel only. The effect of the K -mesons is included as a box diagram in the quasipotential $V(z)$. The effect of this box diagram on the δ_0^0 phase shift is small, as demonstrated in the upper part of fig. 1. The dash-dotted line is the result if one considers the p -exchange (in the t -channel) only. (The effect of scalar exchange is extremely small, and it was dropped from the calculation.) The short dashed line is the result where the $K\bar{K}$ channel is included, without direct interaction. No resonance behavior appears, in contrast to what is seen in the data. In order to explain the experimental phase shift, one possibility is to consider explicitly a scalar meson (pole graph) in the s -channel, the coupling constant and mass of which are appropriately chosen to reproduce the experimental data. We mention that such an approximation, with no t -channel interaction, has been previously used in ref. [12]. Since we include $K\bar{K}$ box diagrams, the $\pi\pi$ flux beyond the $K\bar{K}$ threshold is no longer conserved and therefore the elasticity η_0^0 , which is a measure of the $\pi\pi$ decay into other mesons, deviates from unity. The theoretical result, however, does not reproduce the experimental situation, as shown in the middle part of fig. 1 (dashed line).

Instead of adding an explicit resonance it is much more appealing to include the t -channel interaction between $K\bar{K}$ pairs. For $I=0$ this is rather strong and attractive because all contributions add coherently. Therefore we expect a much larger effect from the $K\bar{K}$ channel if we take this interaction into account by solving eq. (1) simultaneously for the $\pi\pi$ and $K\bar{K}$ amplitudes. The effect due to this direct $K\bar{K}$ interaction on the phase shift is indeed very strong, as dem-

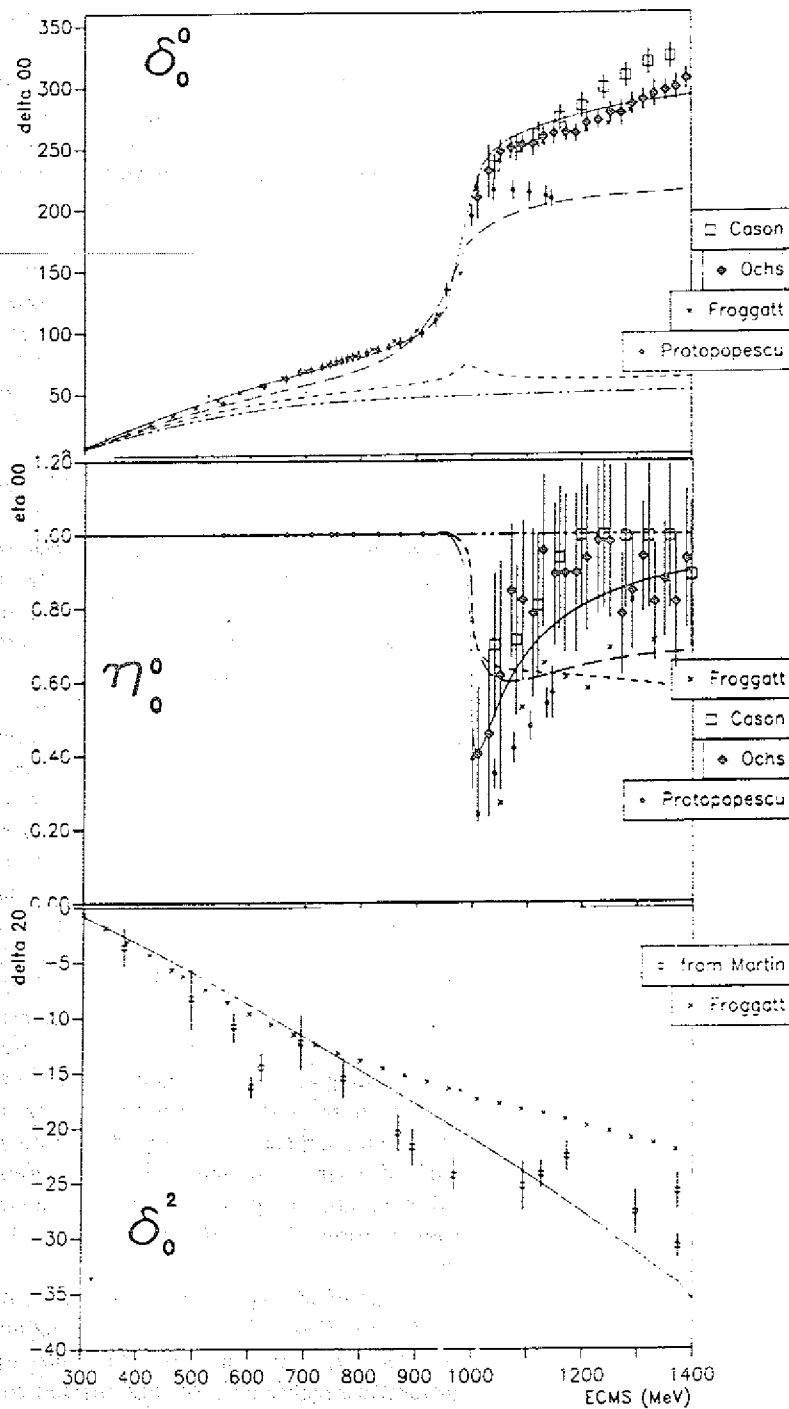


Fig. 1. The results of four different theoretical models for the $I_0, J=0$ $\pi\pi$ phase shift δ_0^0 and elasticity parameter η_0^0 . The long-short dashed curve is the result for p -exchange only. The short dashed curve includes the effect of coupling to the $K\bar{K}$ channel with no $K\bar{K}$ interaction. The long dashed curve includes t -channel exchange contributions in the $K\bar{K}$ channel, the solid curve adds the ϵ as an s -channel process. The experimental phase shifts are taken from refs. [7-10]. In the lower part we compare the $I=2, J=0$ $\pi\pi$ phase shift with the data of refs. [8,11]. The effect here is only due to the t -channel meson exchange.

Table 1

Contributions to the quasi potential $V(z)$. Mesons used in the t - and s -channel interaction for $\pi\pi$ and $K\pi$ scattering. In the first column we show the corresponding graphs and in the second one the isospin (I) and isospin factors (IF) with which the two-body matrix elements have to be multiplied. The coupling constants are given in column 3 and the numbers in column 4 refer to the different form factors defined in eqs. (2), (3). The corresponding cut-off parameters (A) are given in column 5

Graph	I	IF	$g'_1 g'_2 / 4\pi$	$F_\alpha(q^2)$	$A[\text{MeV}]$
	0	-2	2.1	1	1700
	2	1			
	0	$\sqrt{6}$	0.525	1	2750
	2	0			
	0	-3	0.525	1	4000
	2	0			
	0	1	-0.525 -1.05	1	4000
	2	0			
	0	3	0.013	2	3000
	$\frac{1}{2}$	-2	1.05	1	4000 ^{a)} 1700 ^{b)}
	$\frac{3}{2}$	1			
	$\frac{1}{2}$	-1	0.525	1	2750
	$\frac{3}{2}$	2			
	$\frac{1}{2}$	3			
	$\frac{3}{2}$	0	0.0008	2	3000

^{a)} $A_{KK\rho}$ ^{b)} $A_{\pi K\rho}$

onstrated in fig. 1. First of all we see in the upper part of fig. 1 a large jump in the phase shift which comes from a quasi-bound $K\bar{K}$ pair. Because of the attractive interaction in the t -channel, this state occurs about 5 MeV below threshold, which gives rise to a strong resonance-like behavior in the phase shift. From the middle part of fig. 1 we notice that the elasticity η_0^0 has only slightly changed. It is important to mention that so far only t -channel interactions have been taken into account. We do not need to consider a genuine scalar resonance near 1 GeV in order to reproduce the experimental phase shift from the $\pi\pi$ threshold up to 1 GeV. Beyond 1 GeV, however, the theoretical results deviate qualitatively from the more recent experimental phase shift analyses. As we explain the phase jump at 980 MeV as being due to a quasi-bound $K\bar{K}$ pair, it is obvious that the further increase of the phase beyond 1 GeV, in view of the absence of other important open channels in that region, should be connected with the genuine scalar meson which is a member of the scalar $SU(3)$ nonet. Such scalar mesons will give rise to pole terms in the s -channel in $V(z)$. The particle data group [13] lists a scalar meson $f_0(1400)$ (the previous $\epsilon(1300)$) at 1400 MeV with a width of 150–400 MeV that decays mainly into two pions. We now include a scalar meson exchange in the s -channel (which we refer to as ϵ -meson), the bare mass and the coupling constant of which we take as free parameters that are adjusted to fit the experimental phase shift beyond 1 GeV. One can couple the scalar meson in different ways to the pions. One way is the usual scalar coupling. The other possibility is the derivative coupling as defined in eq. (4):

$$L_{pps} = \frac{1}{2} F_s^8 \text{Tr}([\partial^\mu P, \partial_\mu P]_+) S + \frac{1}{2} F_s^1 \text{Tr}([\partial^\mu P, \partial_\mu P]_+) \epsilon_1. \quad (4)$$

One actually expects two scalar mesons: one a member of the octet (S), and the other a singlet ϵ_1 . The quality of the present experimental data does not allow us to distinguish them. The derivative coupling is proportional to the square of the pion momentum and therefore leaves the phase shift below 1 GeV nearly unaltered. For the scalar coupling, however, we also obtain changes in the low energy regime; in fact, the scattering length is then too large by a factor of 5. One can restore the good results without de-

stroying the improvement at higher energies if one introduces a repulsive interaction of very short range. (We parametrize this interaction by a repulsive scalar meson exchange with a bare mass of 4 GeV and adjust the coupling constant so that the experimental scattering length is reproduced, but note that the mass of the repulsive scalar meson is not critical.) The results of the two different approaches are very similar. In fig. 1 (full line) we give the phase shift δ_0^0 and elasticity η_0^0 calculated with the derivative coupling. The agreement with the more recent data is good. The mass of the physical scalar ϵ -meson extracted from an Argand speed analysis is $m_\epsilon = 1400$ MeV. In addition, we compare in fig. 2 the calculated transition phase shift δ_{12} ($I=0, J=0$) for $\pi\pi \rightarrow K\bar{K}$ with the experimental ones, which provides an additional test for our model because all the parameters have already been adjusted to the δ_0^0 phase shift. The agreement is quite satisfactory. Another independent test is the $I=2, J=0$ phase shift, δ_2^0 that is shown in the lower part of fig. 1. Here we need not to solve the coupled system of equations, but only the one-channel T -matrix because the $K\bar{K}$ pairs cannot be coupled to $I=2$. In addition there is no $I=2$ scalar meson known, so we have only the interaction in the t -channel. The theoretical results reproduce the data up to 800 MeV (where the two experimental analyses agree). At least the data of Frogatt et al. seem to indicate that the $\pi\pi$ interaction has to be less repulsive. The missing attraction at higher energy might be connected with the contribution of the correlated two-p channel which we have not yet considered because it is beyond 1.5 GeV.

Kaon-pion scattering. The scalar channel of the $K\pi$ system is now of special interest because, at least in principle, the $K\pi$ interaction is fully determined from the previous investigation and the $SU(3)$ symmetry relations. In the calculations we report, the meson parameters occurring in the t -channel interaction are the same as those used in the $\pi\pi$ system, whereas additional pole contributions in the s -channel have to be adjusted separately. Actually our calculation gives information about the genuine $I(J^P) = \frac{1}{2}(0^+)$ meson with strangeness, usually denoted as κ . There is a one-to-one correspondence between the previous $\pi\pi$ results and the following ones. Because of the isospin $\frac{1}{2}$ of the kaon, the scalar meson κ (the analog of the scalar ϵ -meson discussed before) appears in the $I=\frac{1}{2}$

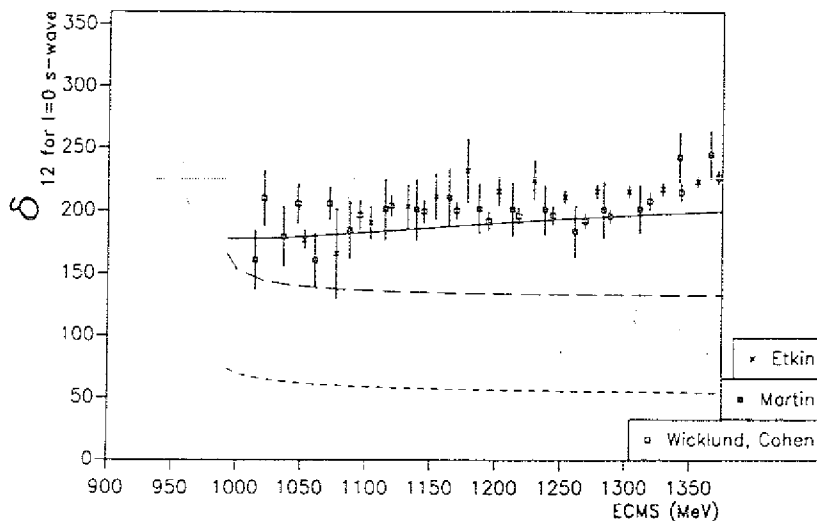


Fig. 2. The transition phase shift for $\pi\pi \rightarrow K\bar{K}$ in the $I=0, J=0$ partial wave calculated within our complete model (full line). The long-dashed curve shows the result when the ϵ -meson is omitted whereas the short-dashed curve is obtained when, in addition, the diagonal $K\bar{K}$ interaction is suppressed. The experimental data are taken from refs. [11,14-16].

$J^P=0^+$ channel of the $K\pi$ system. In the $K\pi$ channel there are now high-statistics data available, and very reliable $\delta_0^{1/2}$ phase shifts. In fig.3 the results of our calculation are compared with the experimental data. The only additional open channel below 1.5 GeV is the $K\eta$ system, which can be neglected because of the weak diagonal $K\eta$ interaction. The theoretical results calculated with the meson exchange interaction in the t -channel only are shown as a dashed line. It is clear from that figure that the t -channel interaction is by far the most important part of the $K\pi$ interaction below 1 GeV. We want to point out again that there are no free parameters in this calculation because we used exactly the same parameters as in $\pi\pi$ scattering.

In $K\pi$ scattering we also have the ambiguity of the coupling of the scalar meson to the two pseudoscalar mesons: one can use either scalar or derivative coupling. The effects are similar to the ones discussed before: if we use scalar coupling we have to introduce an additional short range repulsion whose coupling parameter is adjusted to reproduce the scattering length. Again, the results are insensitive to the mass of the repulsive scalar meson. The $\delta_0^{1/2}$ phase shifts which we get with this model are nearly the same as the ones that we obtain with derivative coupling, and the corresponding results are shown as a full line in

the upper part of fig. 3. The corresponding physical mass of the scalar meson is $m_\kappa=1430$ MeV with a width $\Gamma_\kappa=290$ MeV. The scalar channel of the $K\pi$ system is actually simpler than in the $\pi\pi$ system because here we expect only one single genuine ($q\bar{q}$) scalar meson.

Another good test for the meson-exchange interaction in the t -channel is the $\delta_0^{3/2}$ phase shift. Like the $\delta_0^{1/2}$ phase shift in $\pi\pi$ scattering, it is completely determined by the t -channel interaction. The good agreement between theory and experiment, shown in fig. 3, indicates that our interaction model works well, especially since all of the relevant parameters have been fixed by the fit in the $\pi\pi$ sector.

The indications that in the limit of a large number of colors and at low energies QCD becomes a theory of weakly interacting mesons [1] has led us to attempt to explain low energy meson-meson scattering in the framework of meson exchange. The fact that meson-meson scattering amplitudes remain elastic well above the energy threshold for multiple pion production makes the treatment of meson exchange through a quasipotential in a scattering equation possible. In our model we consider the pseudoscalar mesons as elementary modes which are described in the underlying quark model as correlated quark-anti-

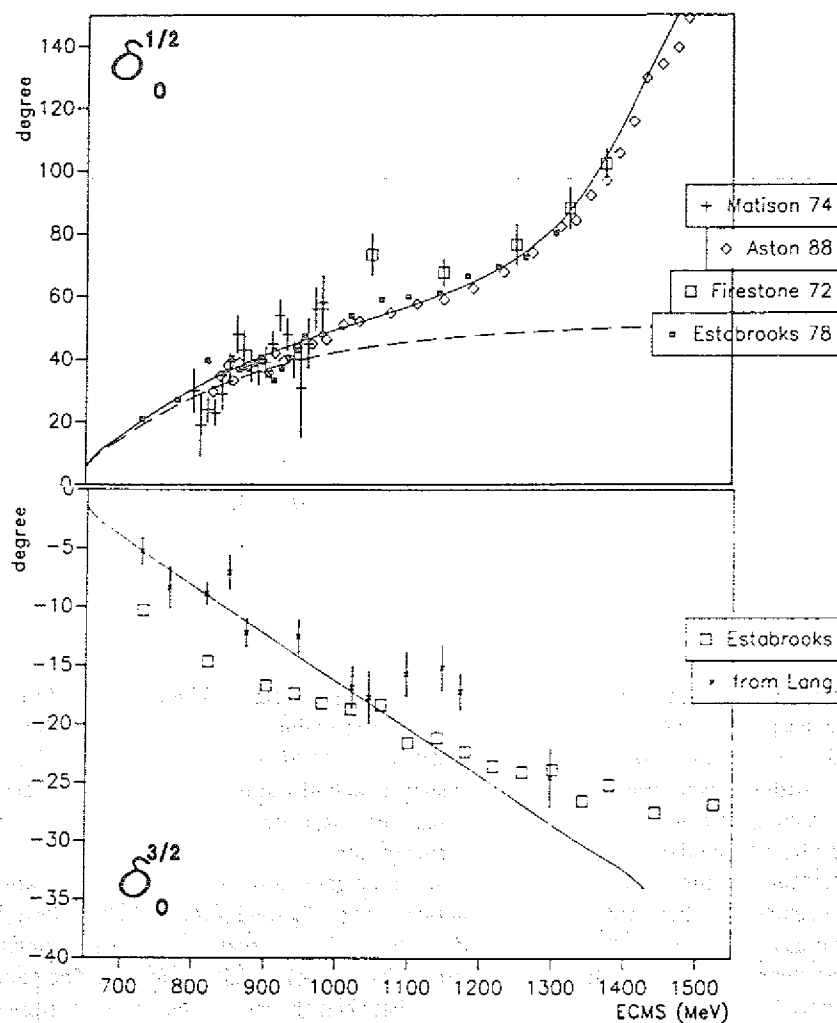


Fig. 3. The $I=\frac{1}{2}, J=0$ $K\pi$ phase shift (upper part) calculated with the t -channel interaction only (dashed curve) and within the complete model which contains the κ -meson contribution. The data are taken from the analyses of refs. [17–20]. In the lower part, the $I=\frac{3}{2}, J=0$ $K\pi$ phase shift is compared with the analyses of refs. [18,21]. The interaction in this channel is due solely to t -channel meson exchange.

quark pairs. The resonances (mesons) in the scalar channel which appear in $\pi\pi$ and $K\pi$ scattering are of a more complicated structure. There exist genuine resonances which can be considered as a correlated quark–antiquark system, but in addition we have correlated pairs of pseudoscalar mesons which strongly couple to the genuine resonances. The phases below 1 GeV are essentially determined by the correlated pseudoscalar meson pairs. Specifically, the jump in the $I=0$ s -wave $\pi\pi$ phase shift turns out to

be due to a quasi-bound $K\bar{K}$ pair in our model. The physical scalar resonances which arise from the coupling to the genuine scalar $q\bar{q}$ mesons are found in our analyses to be around 1400 MeV.

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for discussions and the hospitality he enjoyed at Stony Brook and at LAMPF. Discussions with W. Dunwoodie on the current experimental status of $K\pi$ scattering are also gratefully acknowledged. The work reported here was supported in part by NATO grant RG. 85/0093.

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Workshop on

Mesons and Mesonic States

up to slightly above $1 \text{ GeV}/c^2$

at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich
February 19. - 20. 1990

VIII)

A. Palano

$f_1(975)/S^*$ Production in the Central Region
at the CERN Omega Spectrometer

Jülich 20.2.90

$S^*/f_0(975)$ PRODUCTION
IN THE CENTRAL REGION AT
THE CERN Ω SPECTROMETER

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Amèimo Palamo
Dipartimento di Fisica and Sezione
INFN, Bari, Italy

Summary:

- 1) Physics motivations;
- 2) The WA76 experiment;
- 3) Study of the $S^*/f_0(975)$ in the:
 $\pi^+\pi^-$, $\pi^0\pi^0$, K^+K^- , $K_S^0 K_S^0$

centrally produced final states.

New states, like glueballs (gg or ggg) or hybrids ($q\bar{q}g$) are expected from QCD to exist in the low mass region of the hadrons spectrum.

New resonances (a few of them with a solid experimental evidence) are appearing as "extra" states in the J^{PC} $SU(3)$ multiplets.

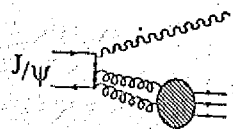
However, glueballs and hybrids may have properties which are similar to normal hadrons.

It now seems clear that no single experiment can establish the existence of gluonic states.

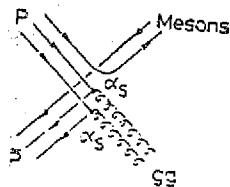
This evidence is likely to come from the study of hadron spectroscopy from different production mechanisms.

The glueballs should appear in:

J/ψ radiative decay



Possibly in $p\bar{p}$ annihilation

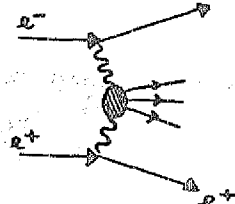


They should not be seen in:

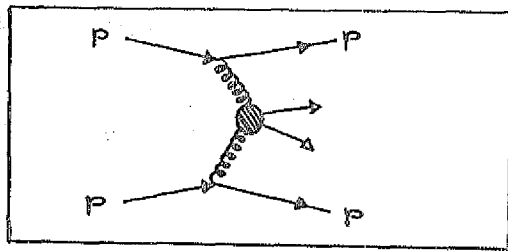
hadron induced reactions



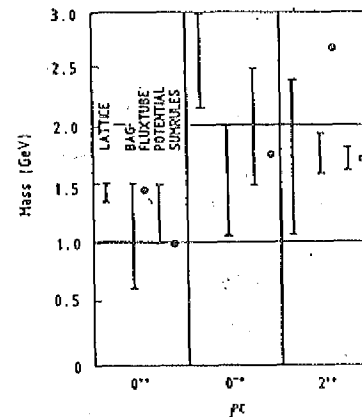
e^+e^- collisions



They are expected to be produced in the central region of $p p$ interactions:



Predictions, from several models, for the lowest lying glueball states.



Candidates for being gluonium states:

$L/\eta(1440) \quad J^{PC} = 0^{-+}$

$m = 1454 \pm 3 \quad \Gamma = 28 \pm 7$

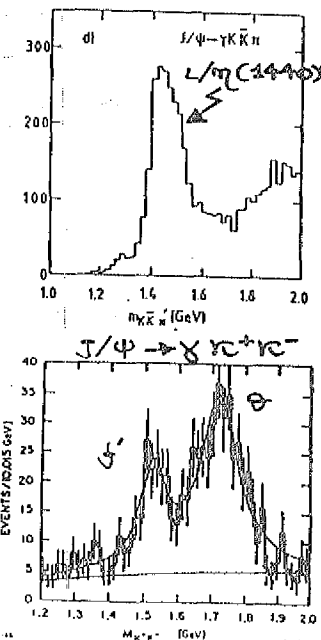
discovered in radiative J/ψ decay to $K\bar{K}\pi$

$\theta/f_2(1720) \quad J^{PC} = 2^{++}$

$m = 1711 \pm 6 \quad \Gamma = 153 \pm 11$

discovered in radiative J/ψ decay to $\eta\eta, K\bar{K}, \pi\pi$

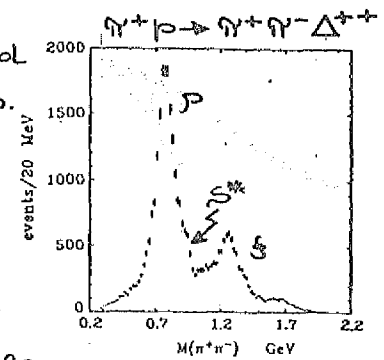
What about the $J^{PC} = 0^{++}$ glueball?



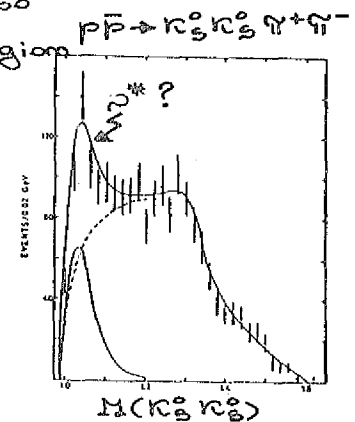
Possibilities for the 0^{++} glueball:

- Something related to the S^* problem;
- The $G(1590)$;
- Structure in the 1.45 GeV region.

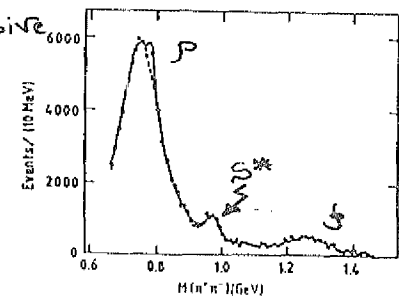
The $S^*/f_0(975)$ is usually observed as a drop around ± 1 GeV in the $\pi\pi$ spectrum.



A scalar contribution is also observed in the threshold region of the $K\bar{K}$ spectrum.



The $S^*/f_0(975)$ is observed as a peak in the inclusive J/ψ decay to $\pi^+\pi^-$

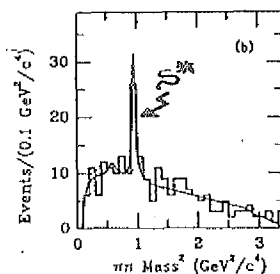
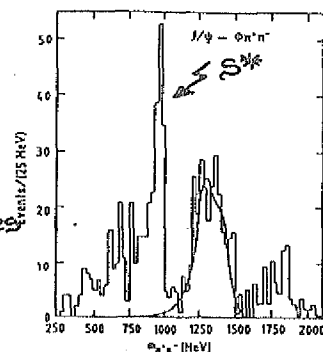


The $S^*/f_0(975)$ is also observed as a peak (with a distorted B-W shape) in a few exclusive processes

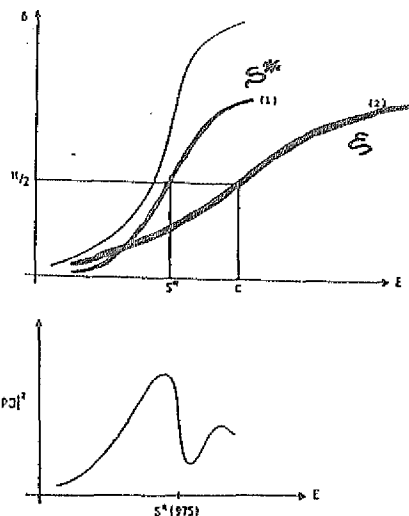
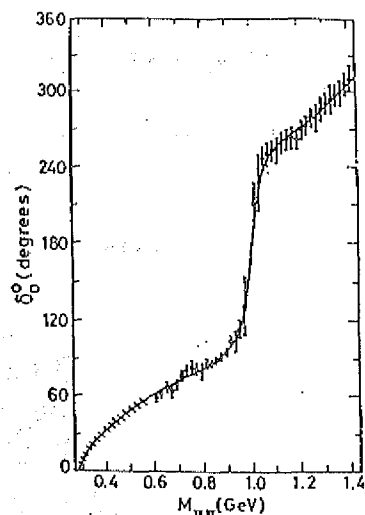
$$J/\psi \rightarrow \phi \pi^+ \pi^-$$

and

$$\rho \rightarrow S^* \pi \rightarrow \pi^+ \pi^-$$



S-wave $\pi^+ \pi^-$ phase shift
from: CERN-Munich



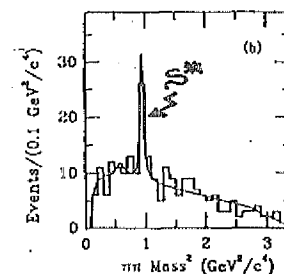
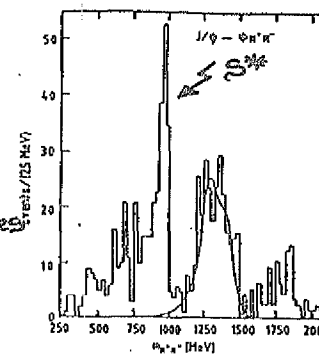
Interpreted as a relatively narrow resonance (S^*) on top of a broad scalar resonance (S).

The $S^*/f_0(975)$ is also observed as a peak (with a distorted B-W shape) in a few exclusive processes

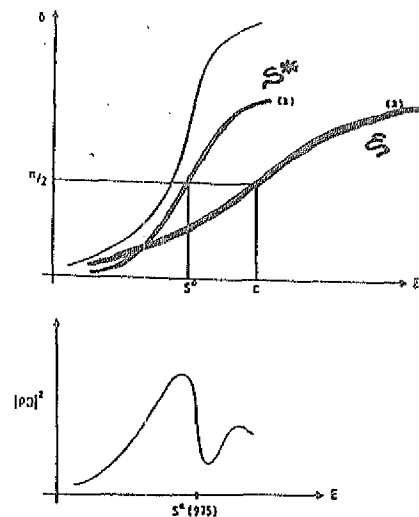
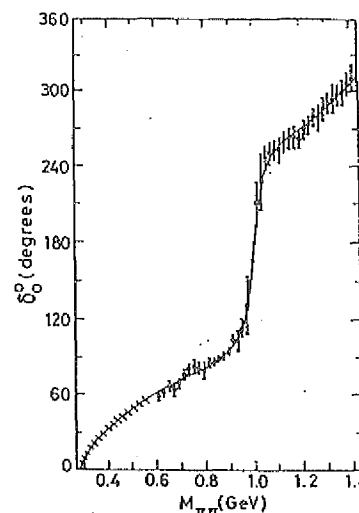
$$J/\psi \rightarrow \phi \pi^+ \pi^-$$

and

$$\rho \rightarrow S^* \pi \rightarrow \pi^+ \pi^-$$

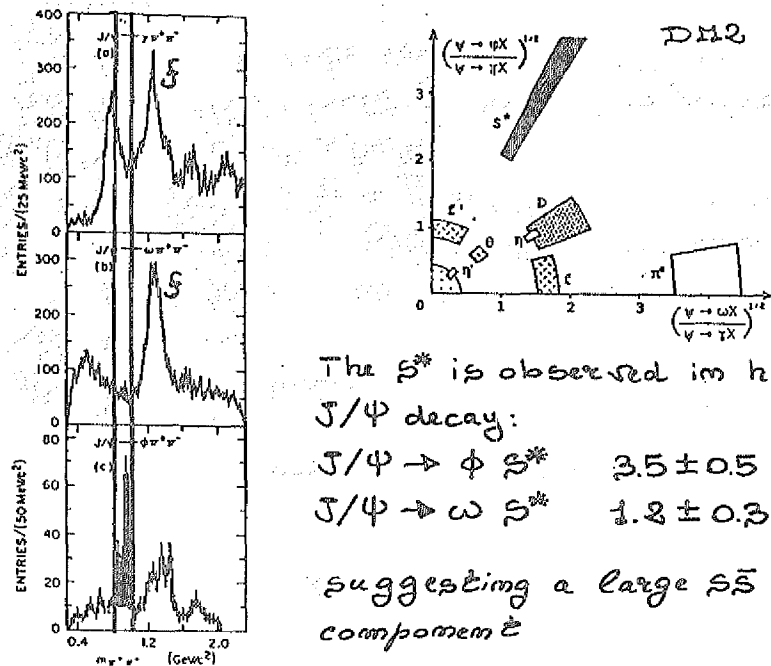


S-wave $\pi^+ \pi^-$ phase shift
from: CERN-Munich

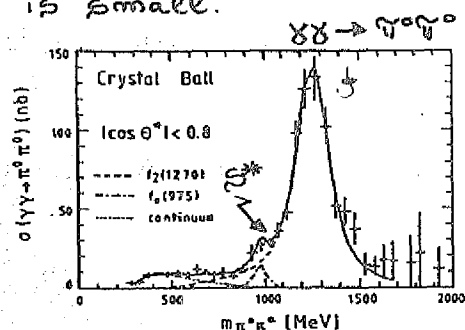


Interpreted as a relatively narrow resonance (S^*) on top of a broad scalar resonance (S).

The $\psi^*/\psi_0(275)$ is most observed in radiative J/ψ decay.



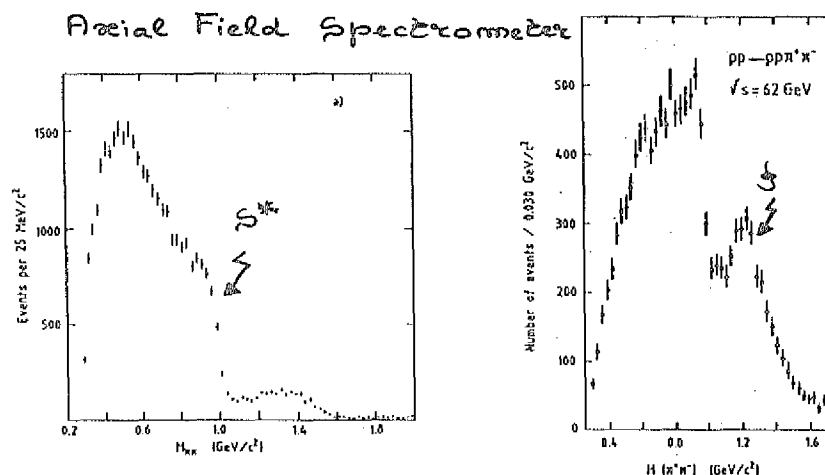
The ψ^* production in $\gamma\gamma$ collisions is small.



Results from the centrally produced $\eta^+ \eta^-$ system at ISR.

Reaction studied: $pp \rightarrow pp \eta^+ \eta^-$
at $\sqrt{s} = 62 \text{ GeV}$

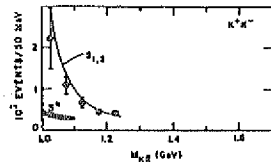
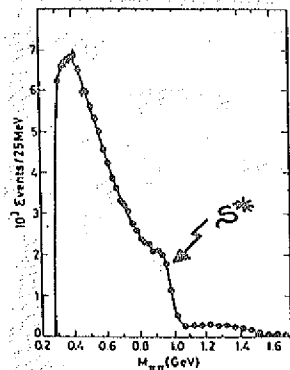
Split Field Magnet



AFS: Strong $\psi^*/\psi_0(275)$ production
at $0.015 < |\cos \theta_{1,2}| < 0.045 \text{ GeV}^2$

SFM: Strong $f_2(1270)$ production
at $|\cos \theta_{1,2}| > 0.08 \text{ GeV}^2$

A.M.P. analysis of the AFS-ISR data.



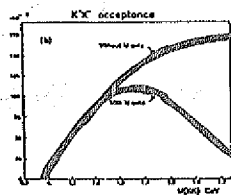
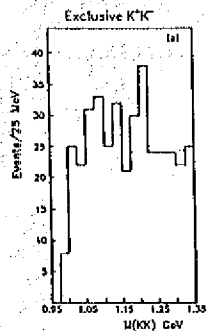
$S^*/f_0(975)$ region fitted with two resonances:

$$S_1(991) \quad g_\pi = 0.22 \quad g_K = 0.28$$

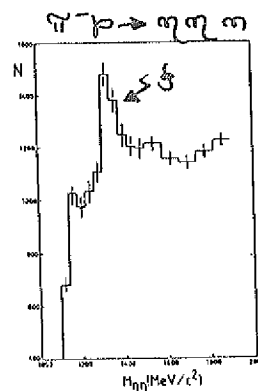
$$S_2(988) \quad g_\pi = 0.02 \quad g_K = 0.35$$

where $S_1(991)$ is a glueball candidate and $S_2(988)$ an $s\bar{s}$ state.

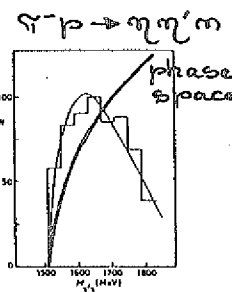
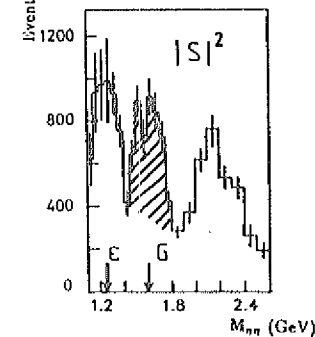
However this result is based on poor data in the K^+K^- channel:



A different scalar gluonium candidate:
 $G(1520)$ (GAMS)



PWA of the $\eta\eta$ system:



- Seen only by only one experiment in a PWA of the $\eta\eta$ system.
- Claim for $\eta\eta'$ and $4\pi^0$ decay.
- Claim for production in the central region

Centrally produced $\eta\eta$ system:

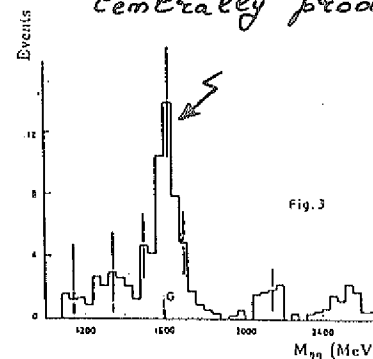


Fig. 3

However:

$f_2'(1525)$ and $\phi/f_2(1720)$ should also decay to $\eta\eta$.

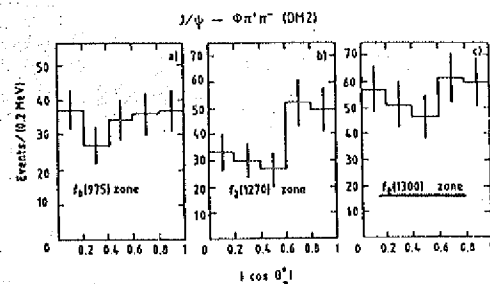
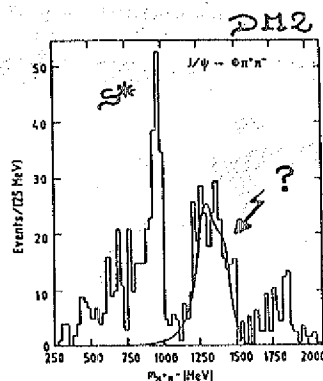
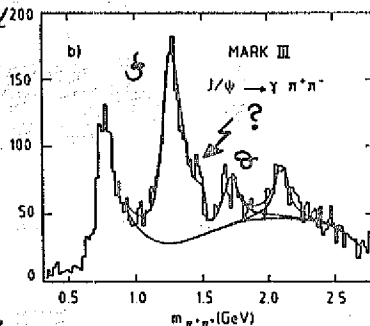
$G(1520)$ or a mixture of $f_2'(1525)$ and $\phi/f_2(1720)$?

L. Köpcke and N. Wermes suggest a new possibility:

A more well understood shoulder is present in the $\pi\pi$ spectrum from radiative J/ψ decay in the 1.45 GeV region.

This shoulder may be also present in the hadronic J/ψ decay to $\phi\pi\pi$.

DM2 finds that this region may have a scalar contribution.



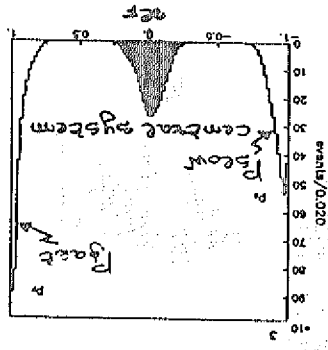
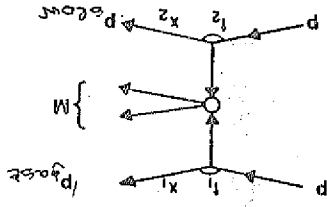
THE WA76 EXPERIMENT

WA76 Collaboration

T.A. Armstrong ^{4,*}, M. Benayoun ⁵, W. Beusch ⁴, I.J. Bloodworth ³, J.N. Carney ³,
R. Childs ³, C. Evangelista ², B.R. French ⁴, B. Ghidini ², M. Girone ²,
A. Jacholkowski ⁴, J. Kahane ⁵, J.B. Kinson ³, A. Kirk ³, K. Knudson ⁴, V. Lenti ²,
Ph. Leruste ⁵, A. Malamant ⁵, J.L. Narjoux ⁵, F. Navach ², A. Palano ², E. Quercigh ⁴,
N. Redaelli ⁴, L. Rossi ⁴, M. Sené ⁵, R. Sené ⁵, M. Stassinaki ¹, M.T. Trainor ⁴,
G. Vassiliadis ¹, O. Villalobos Baillie ³, M.F. Votruba ³

ATHENS¹ - BARI² - BIRMINGHAM³ - CERN⁴ -
COLLEGE DE FRANCE⁵

The aim of this experiment is to study exclusive hadron spectroscopy in the central region.

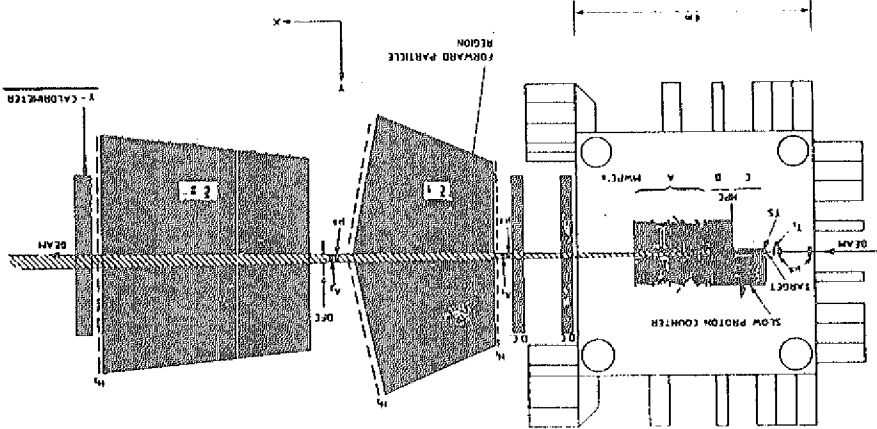


The basic idea is that the production of gluonic states may be enhanced in "Double Pomeron Exchange" (DPE) reactions.

Schedule of WAT6 experiment:

year	beams mon.	GeV/c	events
1982	7+/p	85	10 M
1986	p	300	18 M
1991	p	450	>100 M

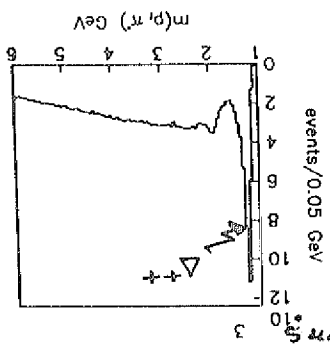
The WAT6 experiment (at 300 GeV/c)

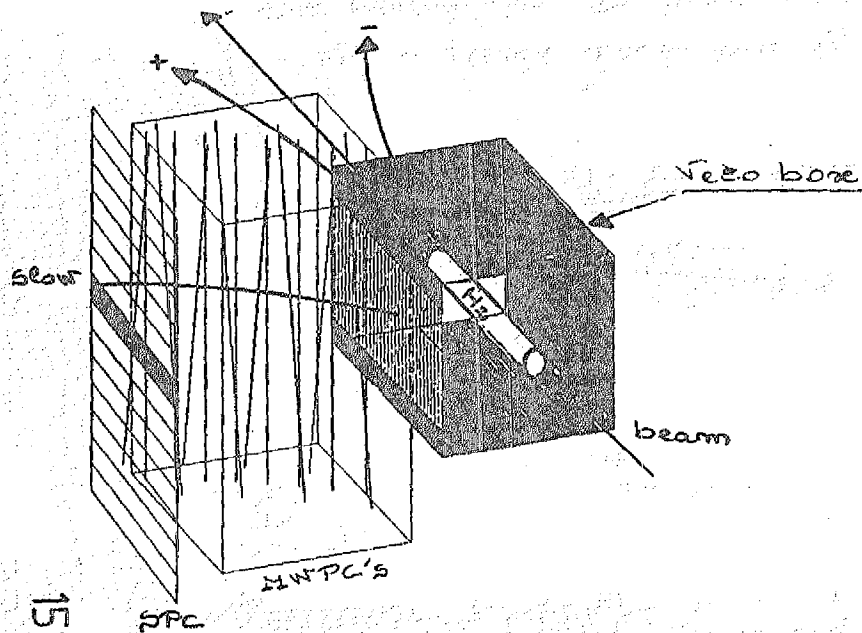


The trigger:

- a) 300 GeV/c incident protons on 60 cm H_2 target;
- b) Fast particle defined by a coincidence between A_1 and A_2 scintillation counters;
- c) No hit on DFC counters;

to reduce forward diffraction;

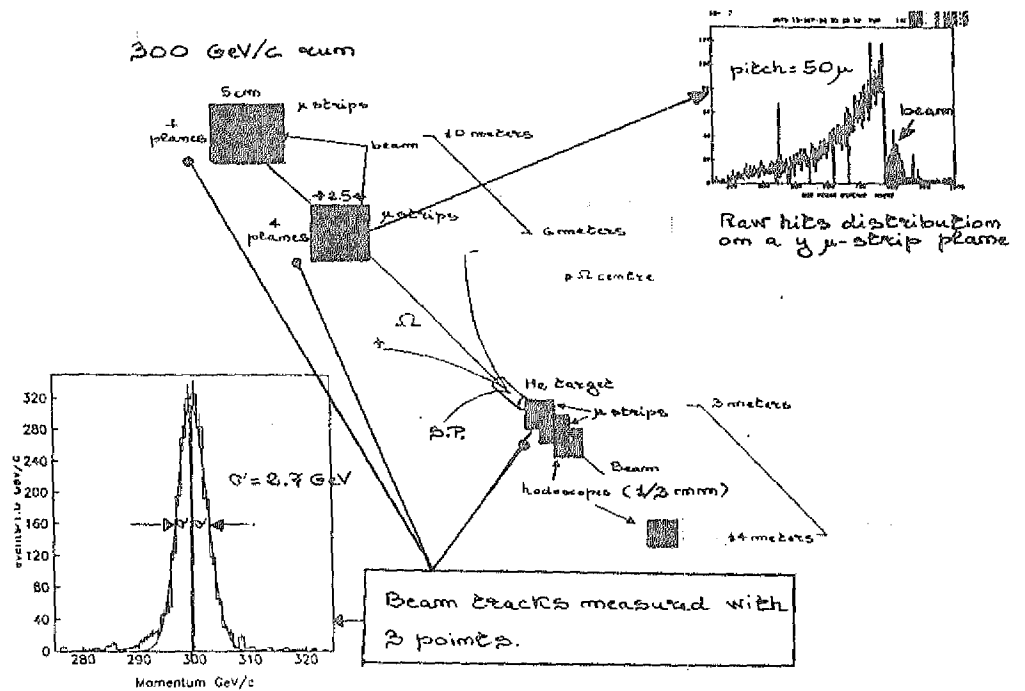
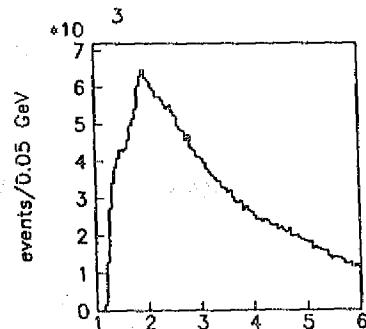
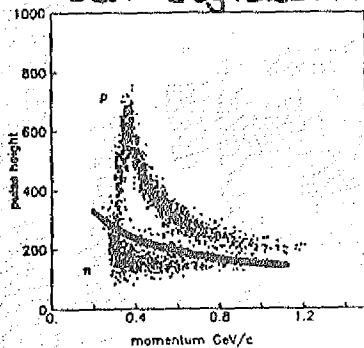




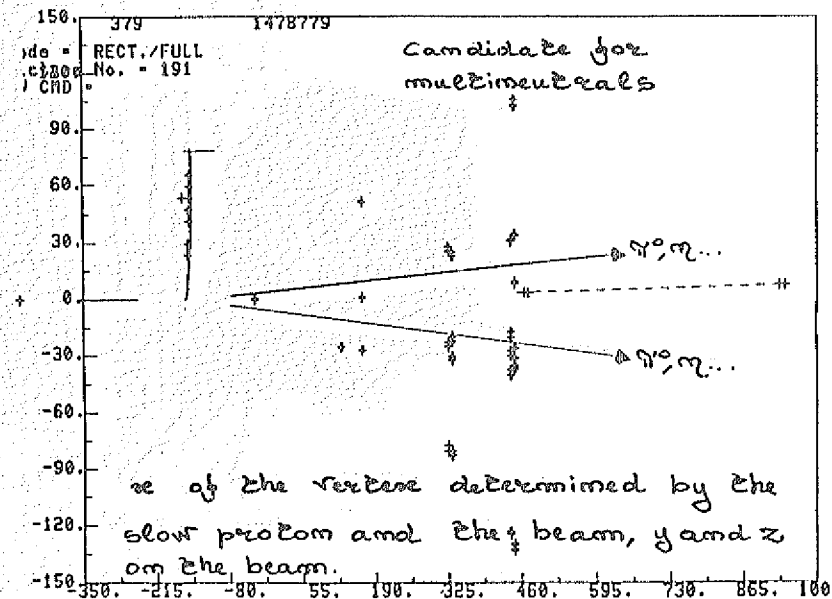
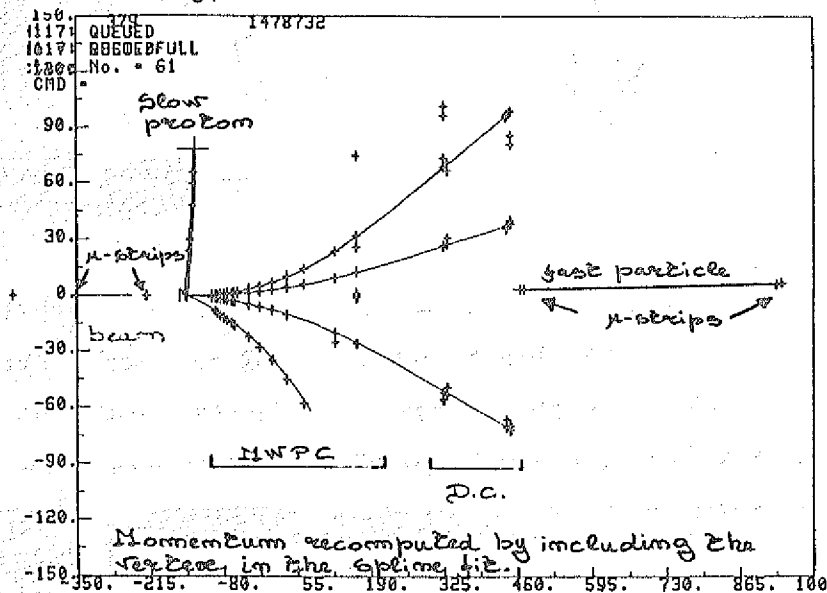
159

- d) Slow particle defined by a coincidence between one side of the target bore, the SPC counter and one plane of the MWPC's;
- e) No hit on the other sides of the target bore to reduce backward diffraction.

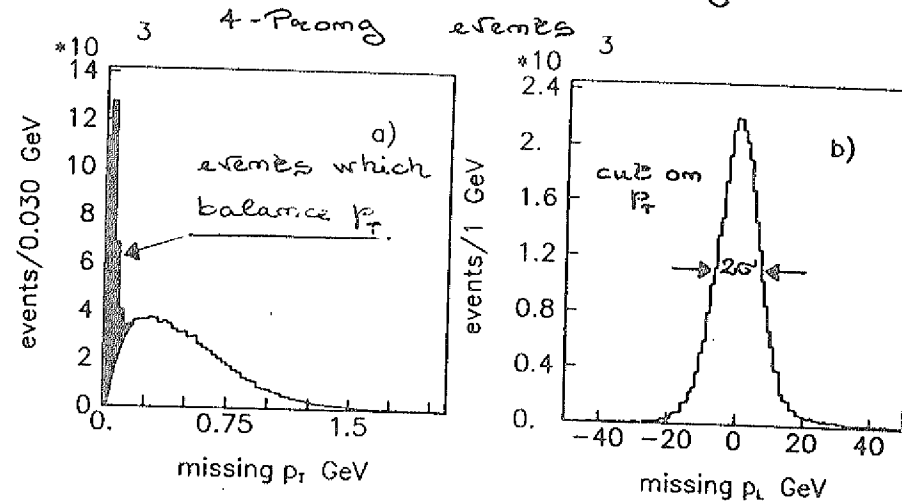
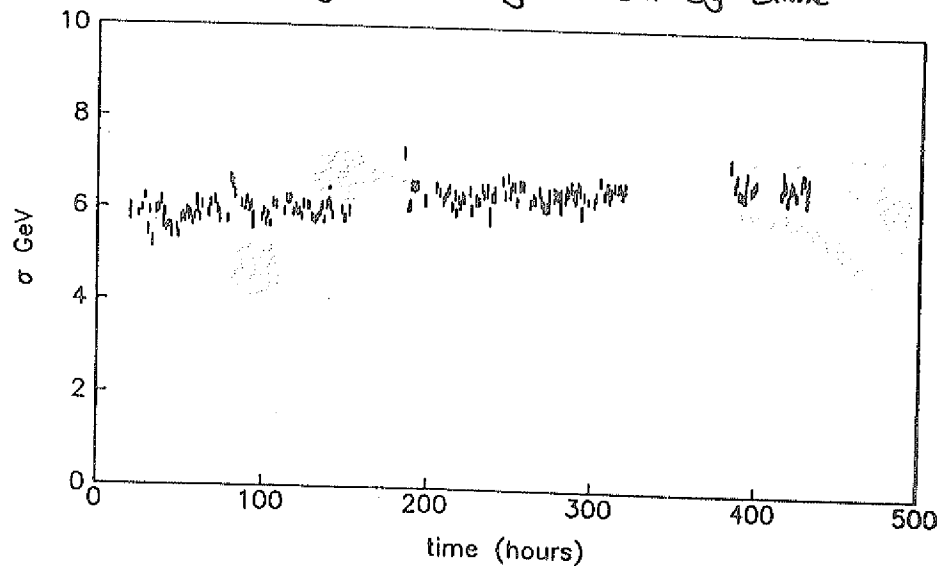
Slow particle identification



Typical events at 200 GeV/c



Selection of momentum balancing events:

Variation of σ as a function of time

σ and the presence of the p_T peak taken as quality tests for the data processing.

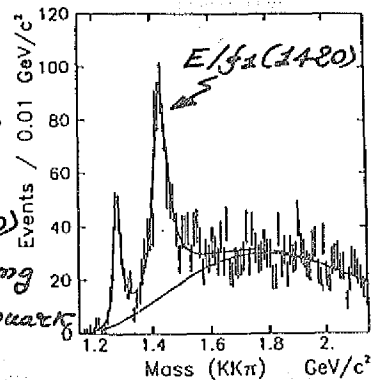
A few important results coming from WA76 experiment.

The reaction:

$$pp \rightarrow p_B (\pi_S^0 \pi^\pm \eta^\mp) p_B$$

Observation of the $J^{PC} = 1^{++}$ $E/f_2(1420)$

a candidate for being an hybrid or a t -quark state.



The reaction:

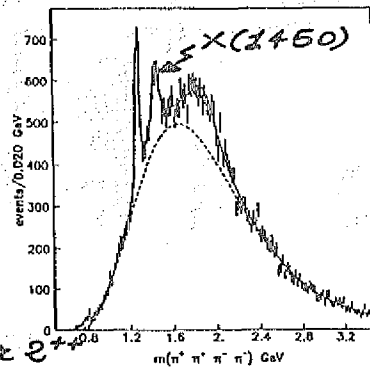
$$pp \rightarrow p_B (2\pi^+ 2\pi^-) p_B$$

Evidence for new resonances. The state:

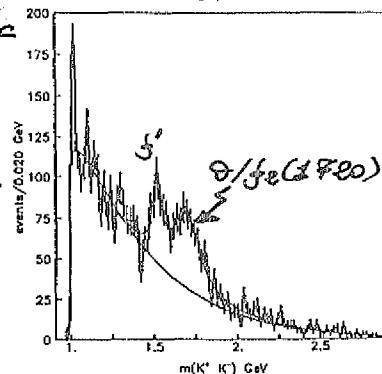
$$X(1450) \rightarrow \rho \pi \pi$$

may have $J^{PC} = 1^{-+}$ or 2^{++}

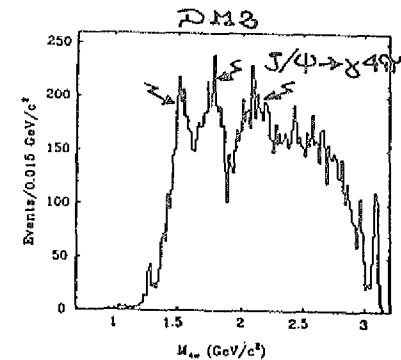
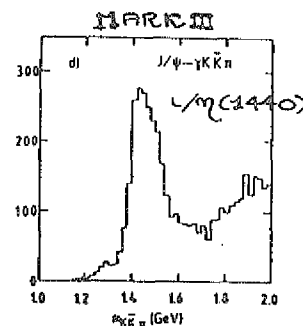
If $J^{PC} = 1^{-+} \Rightarrow$ exotic



Observation of the $\theta/f_2(1720)$ in the $\pi^+ \pi^-$ and $\pi_S^0 \pi_S^0$ final states.



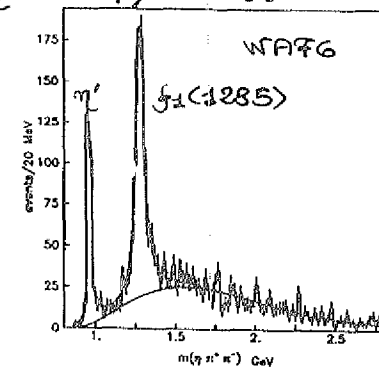
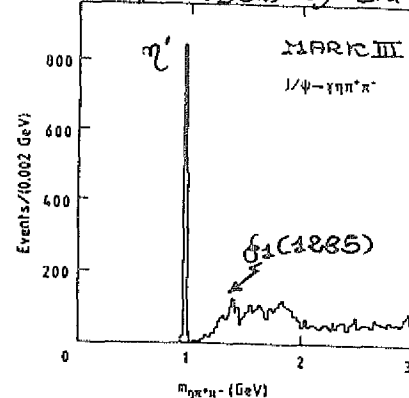
What about pseudoscalars?



Several new pseudoscalar states observed in J/ψ radiative decay.

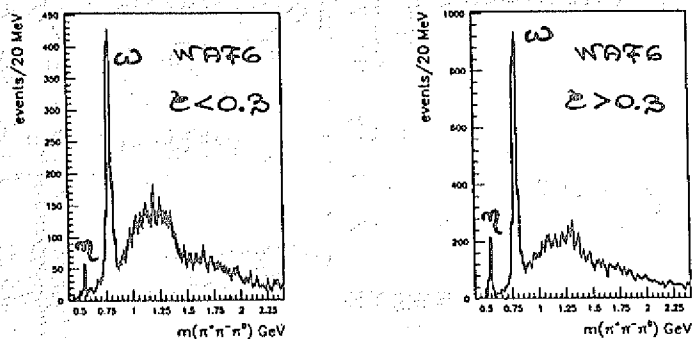
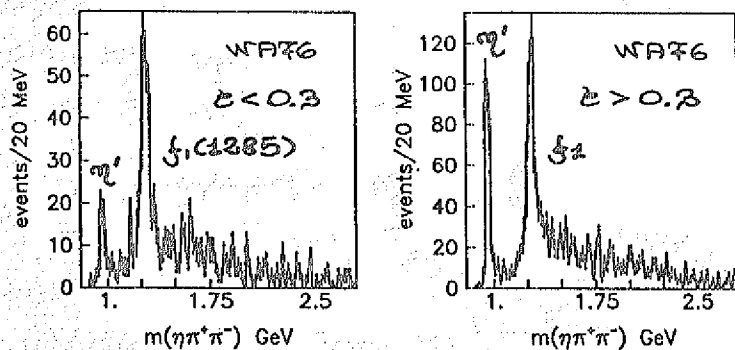
These resonances are not observed in the central region.

Comparison of the $\eta \pi^+ \pi^-$ spectra:

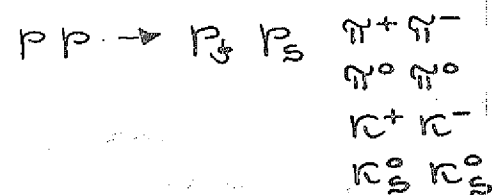


Different filters are active in J/ψ decay and central production. Here 0^{-+} states seem to be suppressed.

The suppression of O^{-+} states is more pronounced at low $\sqrt{s}$



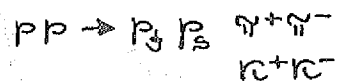
A STUDY OF THE $S^*/f_0(975)$ IN THE CENTRAL REGION OF THE REACTIONS:



AT 85 GeV/c AND 300 GeV/c

These results are still preliminary!

Selection of the reactions:

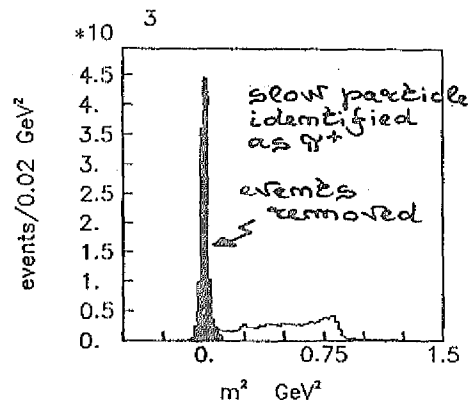
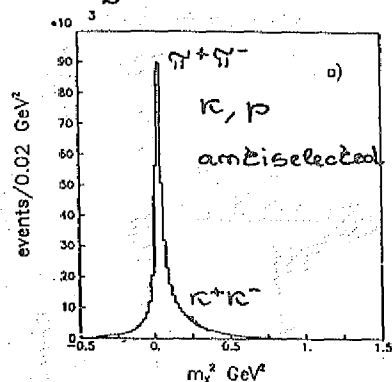


- Require momentum balance
- Recompute the fast track momentum
- Energy balance:

$$E_i = E_{p_3} + E_{p_2} + \sqrt{p_x^2 + m_x^2} + \sqrt{p_x^2 + m_x^2}$$

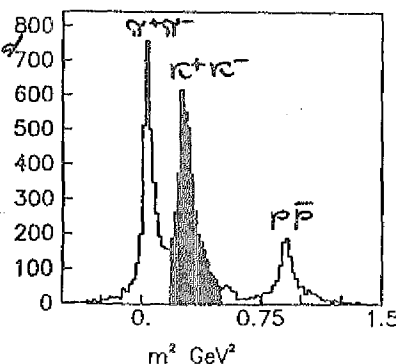
which can be solved directly for m_x^2

- η_S^+ removed

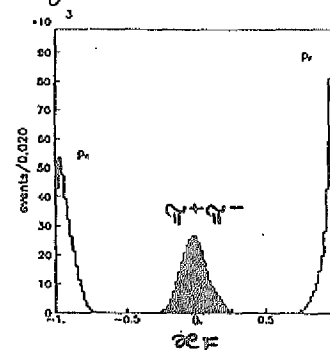


Selection of the $K^+ K^-$ final state

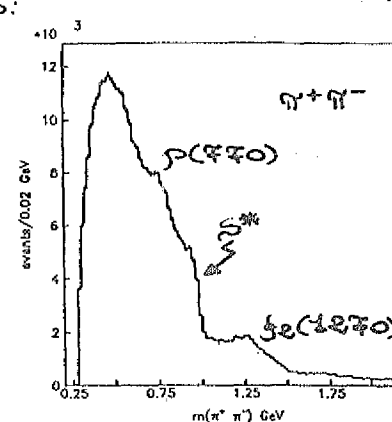
- Require on K identified or ambiguous K/p
- little background in the $K^+ K^-$ channel



Feynman x_F distributions:



• Forward Δ^{++} removed

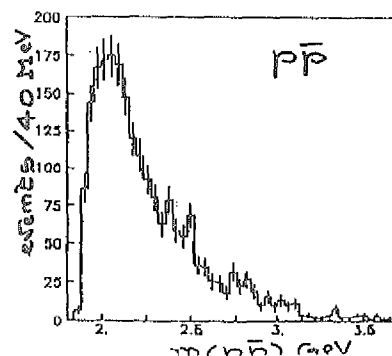
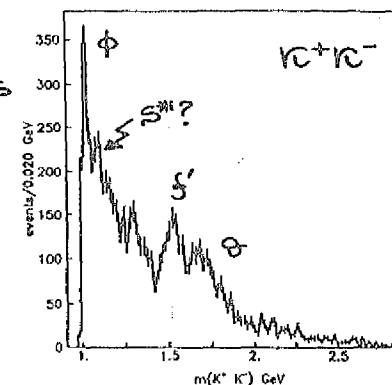


We obtain 302 600

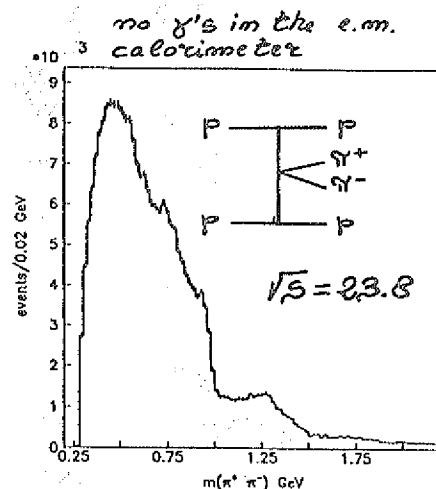
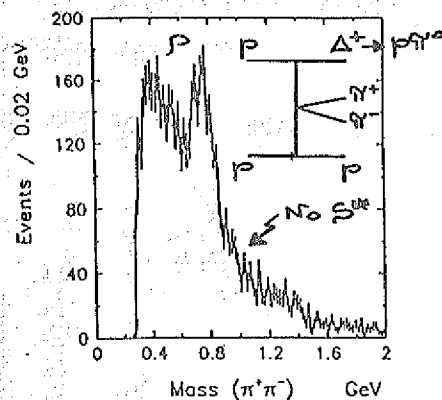
$\eta^+ \eta^-$ events:

$\sim 3 \times \text{ISR statistics}$

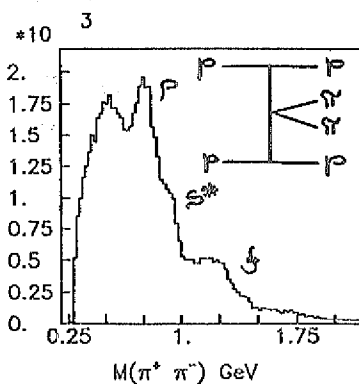
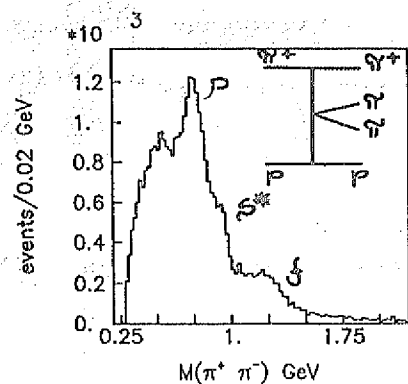
- little $p(770)$
- little $f_2(1270)$
- strong S^*



Comparison with other $\eta^+\eta^-$ spectra in the same experiment.

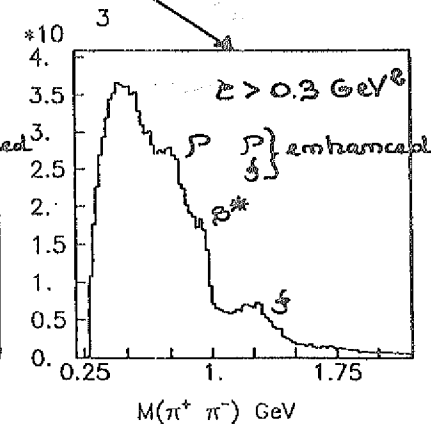
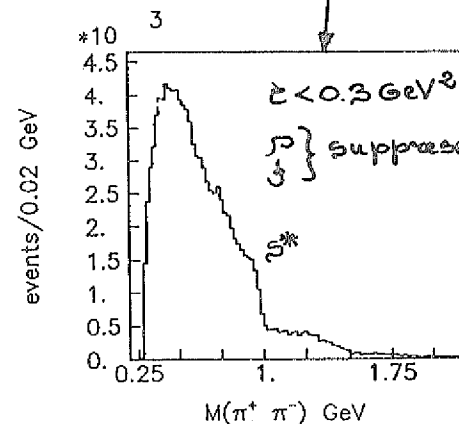
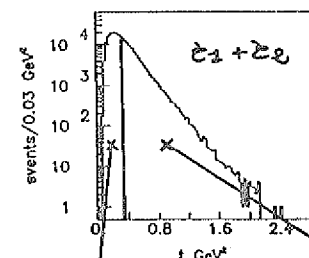
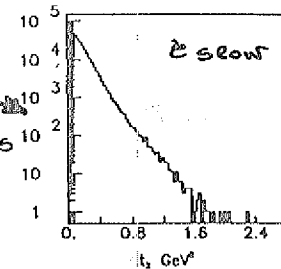
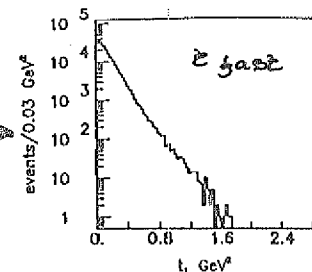
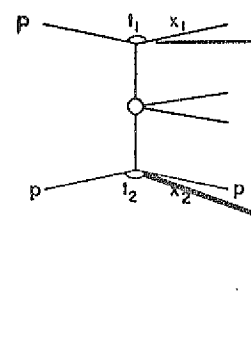


- Comparison with $\eta^+\eta^-$ spectra from the 85 GeV/c run ($\sqrt{s} = 18.7$ GeV)



$\rho(770)$ decreasing with increasing energy.

τ distributions



A fit to the $\eta^+\eta^-$ spectrum.

We have performed a χ^2 fit of the $\eta^+\eta^-$ spectrum by using the following formalism:

$$\frac{dN}{dm} = \omega(m) + \phi(m) [B_S(m) + B_P B_P(m) + B_B B_B(m)]$$

where:

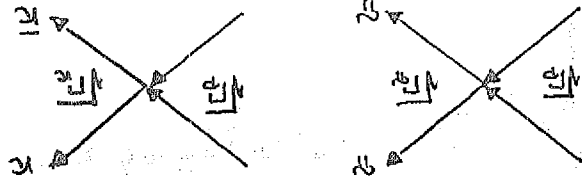
$\omega(m)$ is the ω fraction computed by Monte-Carlo simulation;

$\phi(m)$ background: $(m - m_{th})^2 e^{-\beta m - \gamma m^2}$

$B_P(m), B_B(m)$ relativistic B-W to describe the $P(770)$ and $f_2(1270)$

$B_S(m)$ $S^*/f_0(975)$ contribution.

We assume a coupled channel B-W (Feynman):



In addition, an interference term is required by the data.

$$B_S(m) = 1 + B_S F_P(m) e^{i\delta/2}$$

$$F_P(m) = \frac{m_0 \sqrt{\Gamma_P} \sqrt{\Gamma_P}}{m_0^2 - m^2 - i m_0 (\Gamma_P + \Gamma_P)}$$

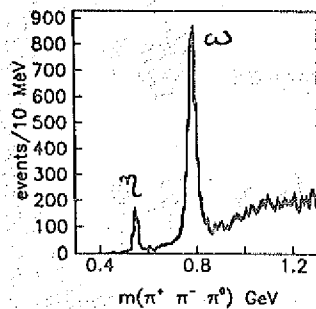
where:

$$\Gamma_P = \Gamma_P (m^2/4 - m_P^2)^{1/2}$$

$$\Gamma_P = \Gamma_P [(m^2/4 - m_P^2)^{1/2} + (m^2/4 - m_{P0}^2)^{1/2}]$$

Γ_P and Γ_P describe the couplings to the $\eta\eta$ and $\eta\eta$ channels

$B_S(m)$ has been convoluted with a Gaussian representing the experimental resolution ($\sigma = 30$ MeV)



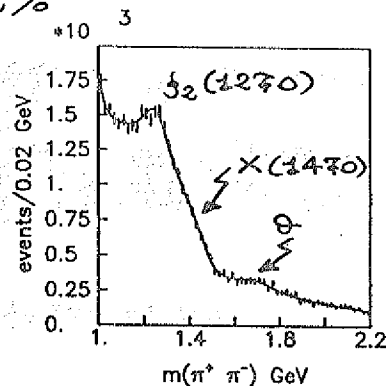
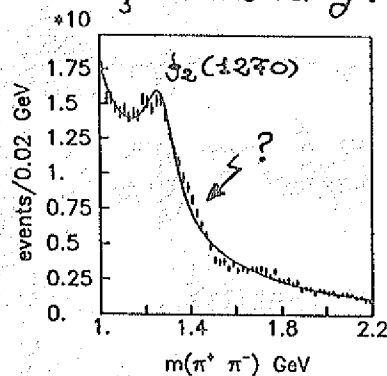
The study of the reaction:
 $pp \rightarrow p_3 (\eta + \eta' + \eta^0) p_3$
 $\quad \quad \quad \rightarrow \eta \eta$
 in the same experiment
 shows a large ω production.

- Need to include a structure in the high mass side of the $f_2(1270)$

We tried two ways of describing this region:

- $f_2'(1525)$ interfering with $f_2(1270)$ and the D -Wave background.

Probability: 0.8%



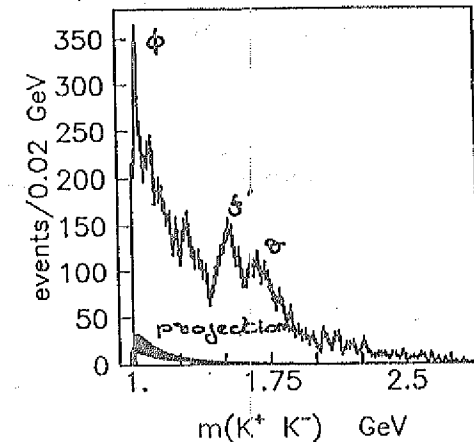
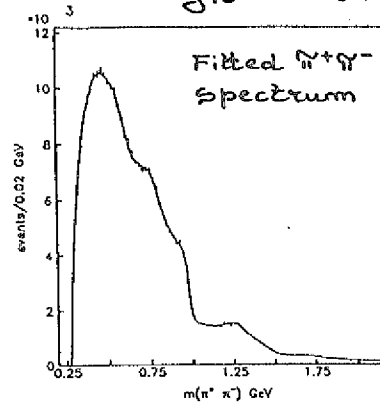
- A new state interfering with the S -Wave background
 Prob.: 51%
 $m = 1472 \pm 12 \text{ MeV}$
 $X(1470)$ parameters: $\Gamma = 125 \pm 33 \text{ MeV}$

Resulting $\rho^*/f_0(975)$ parameters:

$$m_0 = 979 \pm 4 \text{ MeV}$$

$$g_\eta = 0.28 \pm 0.04 \quad \delta = 23^\circ \pm 4$$

$$g_\pi = 0.28 \pm 0.09$$



The projection of the fit on the $\pi^+\pi^-$ spectrum is well accommodated by the data:

$$F_\pi(m) = \frac{m_0 \sqrt{\Gamma_\pi} \sqrt{\Gamma_\eta}}{m_0^2 - m^2 - i m_0 (\Gamma_\pi + \Gamma_\eta)}$$

Warning: $\Gamma_\pi = \Gamma_{\pi^+} + \Gamma_{\pi^0}$

If we merge the $\pi^+\pi^-$ and $\pi^0\pi^0$ thresholds:

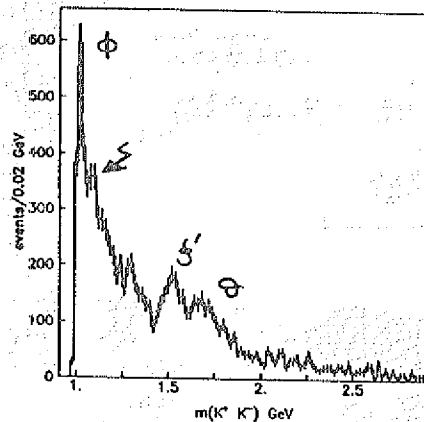
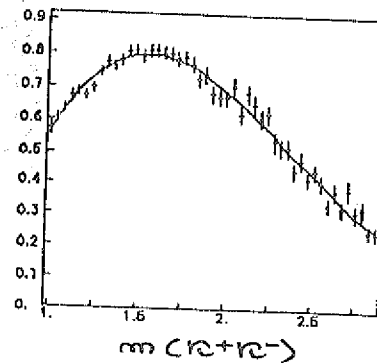
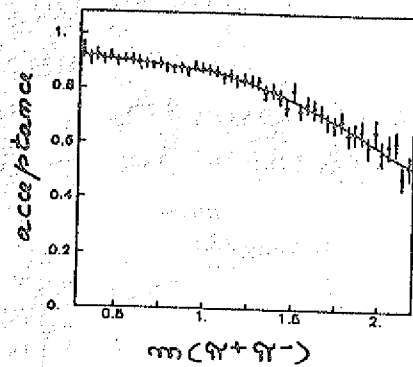
$$g_\eta = 0.28 \pm 0.04 \quad g_\pi = 0.55 \pm 0.17$$

$$g_\pi/g_\eta = 2. \pm 0.9$$

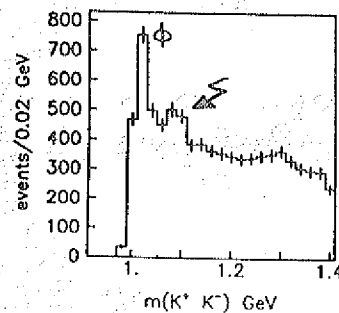
For the $\theta/f_2(1720)$ we measure:

$$\frac{B(\theta \rightarrow \eta\eta)}{B(\theta \rightarrow \pi\pi)} = 0.33 \pm 0.14$$

Study of the geometrical acceptance:

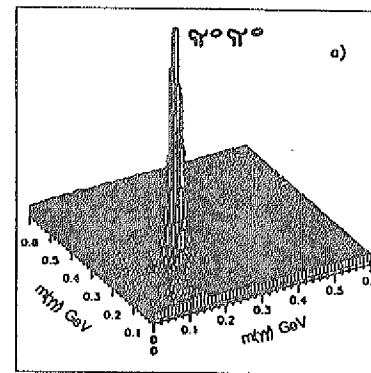
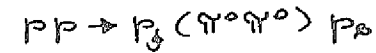


K^+K^- spectrum corrected for the acceptance due to K identification



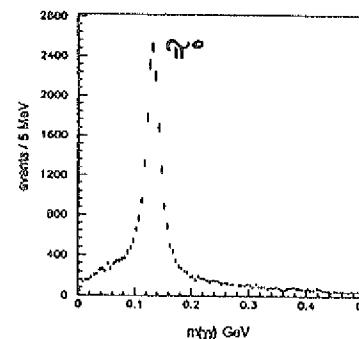
Threshold region of the K^+K^- spectrum from the 85 GeV/c and 300 GeV/c data.

Study of the reaction:



- Require 4 γ in the e.m. calorimeter
- momentum balance
- $E_{\gamma} > 1$ GeV

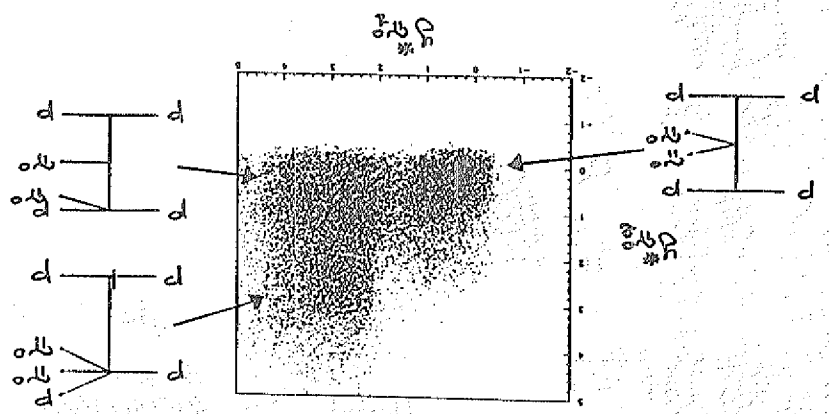
← 3 combinations/event



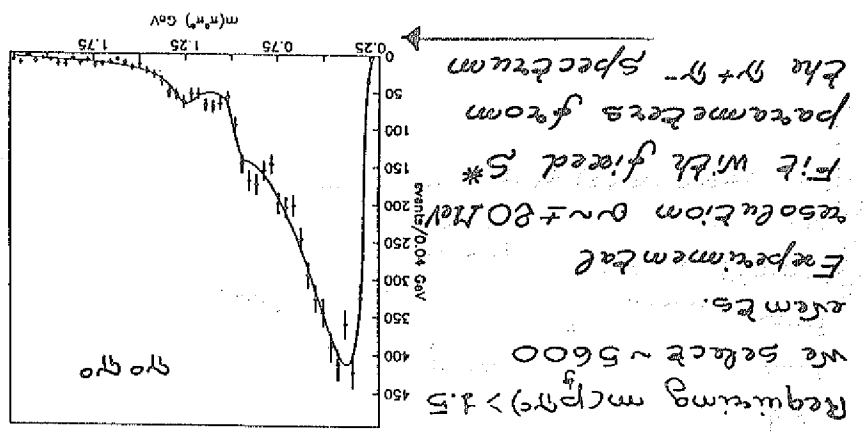
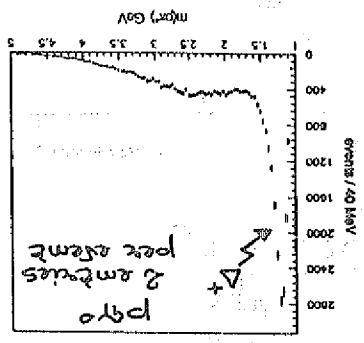
π^0 signal after having required the other combination to be a π^0

Events selected: 17765

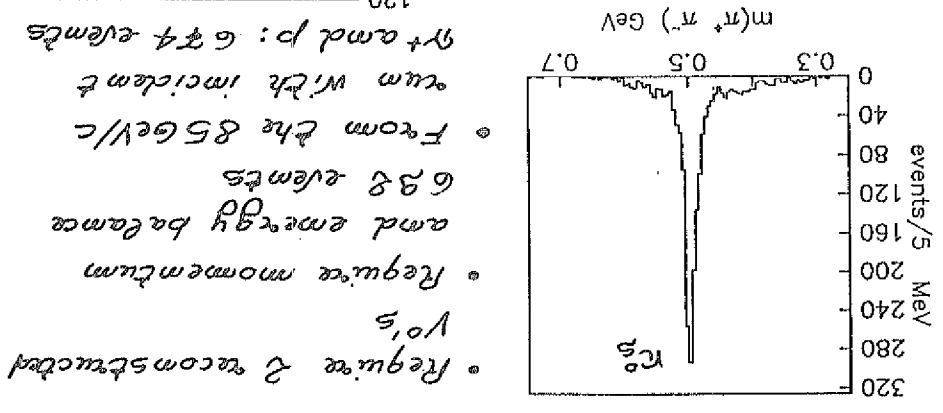
However, only a small fraction of events is in the central region.



In fact, a strong $\Delta^+ \rightarrow p \pi^0$ is observed.

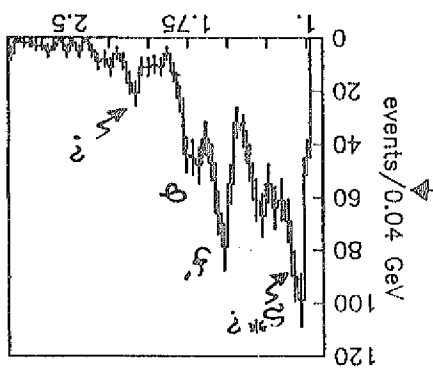


Study of the reaction:
 $p p \rightarrow p_1 \pi_1^0 \pi_2^0 p_2$

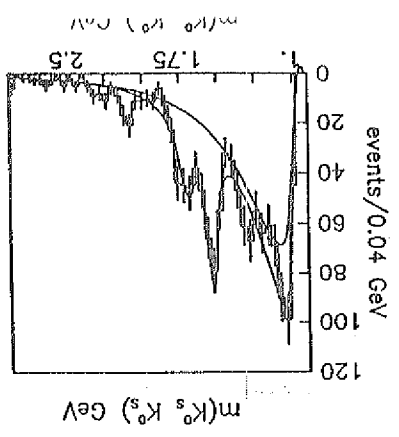


- Requite 2 reconstructed V^0 's
- Requite momentum and energy balance
- From the 85 GeV/c π^+ and p : 674 events

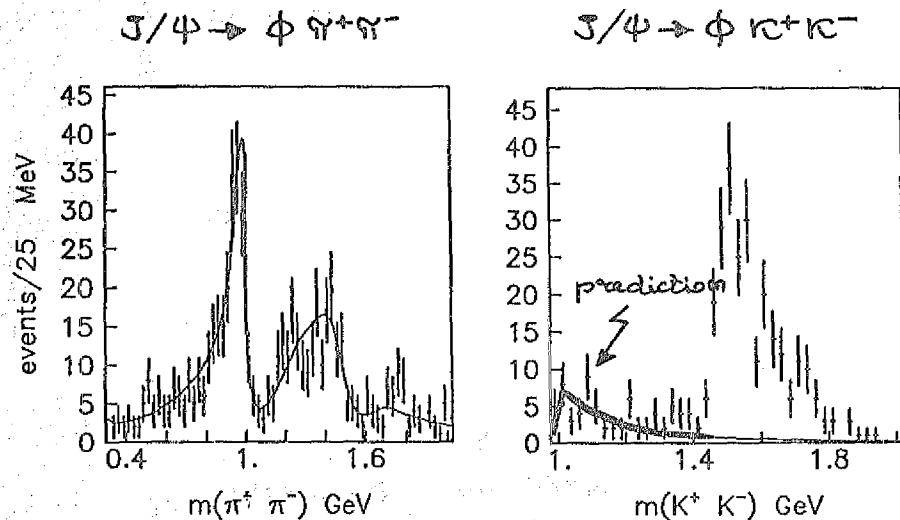
Combining all the data from the two



Fit of the $\pi_1^0 \pi_2^0$ spectrum with an S^* having the parameters measured in the $p\pi^+\pi^-$ channel. Intensity free.



Test with Mark III data:



Fit performed by using the solution found from the NA76 $\pi^+ \pi^-$ fit. Only intensities and phases free.

Conclusions:

We have studied the $\pi\pi$ and $K\bar{K}$ systems in the central region at $\sqrt{s} = 12.7$ and $\sqrt{s} = 23.8$ GeV from incident π^+ and p .

We find:

- The production of $I=1 \rho(770)$ decreases with increasing energy;
- The production of $\rho(770)$ and $f_2(1270)$ occur mostly at high ϵ ;

To describe the $S^*/f_0(975)$ we need

- a $\pi\pi, K\bar{K}$ coupled channel Breit-Wigner;
- an interference with the s-wave background.

The resulting $S^*/f_0(975)$ parameters are:

$$m_0 = 979 \pm 4 \text{ MeV}$$

$$g_\pi/g_K = 2.0 \pm 0.9 \quad (K \equiv K^\pm \text{ and } K_S^0)$$

The expected behaviour at the $K\bar{K}$ threshold is in agreement with the above formalism.

• There is little room for an extra $J^P = 0^{++}$ state in the π GeV region.

We find evidence for structure in the π GeV region of the $\eta + \eta^-$ spectrum. If interpreted as a resonance, it has

$$m = 1442 \pm 22 \text{ MeV}$$

$$\Gamma = 195 \pm 33 \text{ MeV}$$

Recent WA76 Results on Central Production

WA76 Collaboration

International Conference on Hadron Spectroscopy, Hadron 89,
September 1989, Ajaccio, France

presented by Antimo Palano

T.A. Armstrong ^{1,*}), M. Benayoun ⁵⁾, W. Beusch ¹⁾, I.J. Bloodworth ²⁾, J.N. Carney ²⁾,
R. Childs ²⁾, B.R. French ¹⁾, B. Ghidini ³⁾, M. Girone ³⁾, A. Jacholkowski ¹⁾, J. Kahane ⁵⁾,
J.B. Kinson ²⁾, A. Kirk ²⁾, V. Lenti ³⁾, Ph. Leruste ⁵⁾, A. Malamant ⁵⁾, J.L. Narjoux ⁵⁾,
F. Navach ³⁾, A. Palano ³⁾, E. Quercigh ¹⁾, N. Redaelli ^{1,**}), L. Rossi ^{1,***}), M. Sene' ⁵⁾,
R. Sene' ⁵⁾, M. Stassinaki ⁴⁾, M.T. Trainor ¹⁾, G. Vassiliadis ⁴⁾, O. Villalobos Baillie ²⁾ and
M.F. Votruba ²⁾

Abstract

The present status is presented on the search for gluonium and hybrid states centrally produced in the reaction $pp \rightarrow p_f(X^0)p_s$ at 300 GeV/c using the CERN Ω spectrometer.

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1. Introduction

In the last few years, one of the basic motivations of in high energy physics has been the testing of the predictions of QCD, the quantum field theory of strong interactions. The validity of the theory largely depends on the existence of gluons for which experimental evidence has been found in jet studies and in deep inelastic scattering. However, one of the most striking expectations of QCD is the existence of new kinds of matter, built up by valence gluons (glueballs) or by mixtures of quarks and gluons (hybrids).

Experiment WA76 is designed to study exclusive final states in the reaction

$$p p \rightarrow p_f (X^0) p_s$$

where the subscripts f and s indicate the fastest and slowest particles in the laboratory respectively and X^0 represents the central system that is presumed to be produced by a double exchange process. At high centre of mass energies these double exchange processes are believed to be dominated by Double Pomeron Exchange. The Pomeron is thought to have a large gluonic content, so Pomeron - Pomeron scattering could be a source of non $q\bar{q}$ states.

Experiment WA76 has been performed using the CERN Omega spectrometer at two incident beam momenta, 85 and 300 GeV/c, ($\sqrt{s} = 12.7$ and 23.8 GeV). Results from the 85 GeV/c run can be found in ref. [1], while this paper deals mostly with the analysis of the 300 GeV/c data. Details of the layout of the apparatus, trigger conditions and data processing have been given in a previous publication [2]. This paper gives the present situation regarding our analysis of the $X^0 \rightarrow \pi\pi$, $K\bar{K}$, $K_S^0 K_L^0$, $\eta\pi^+\pi^-$, $\rho^0\gamma$ and $\pi^+\pi^-\pi^+\pi^-$ final states.

2. Observation of the gluonium candidate $\theta/f_2(1720)$

The K^+K^- channel has been isolated from the other central two-body final states by requiring momentum and energy balance and the request of one of the two Kaons being identified as a K or ambiguous K/p by the Cerenkovs system. In addition, to ensure good geometrical acceptance, only events having the K^+K^- system with Feynman $x_F < 0$, have been selected. The K^+K^- mass spectrum is shown in fig. 1a.

The spectrum shows evidence for several resonant structures: the $\phi(1020)$ is observed on top of a threshold enhancement and the $f_2(1525)$ is clearly seen. In addition a $\theta/f_2(1720)$ signal is observed. A fit to this spectrum gives $m = 1713 \pm 10$, $\Gamma = 181 \pm 30$ MeV for the parameters of the $\theta/f_2(1720)$.

The $K_S^0 K_S^0$ channel has been isolated from the sample of events having two reconstructed V^0 's by requiring total energy and momentum balance. In order to remove the background from random $\pi^+\pi^-$ combinations, a decay length of at least 3 cm was required for each of the two V^0 's. The $\pi^+\pi^-$ mass spectrum of the two V^0 's (inset fig. 1b) reveals a clear K^0 signal over little background. The $K_S^0 K_S^0$ combined spectrum from the 85 GeV/c and 300 GeV/c experiments is shown in fig. 1b and shows evidence for $f_2(1525)$ and $\theta/f_2(1720)$. A fit to this spectrum yields the following $\theta/f_2(1720)$ parameters: $m = 1706 \pm 10$, $\Gamma = 104 \pm 30$ MeV.

We have fitted the $\theta/f_2(1720)$ angular distributions in the Gottfried - Jackson frame defined in ref. [3] by using the density matrix elements formalism as given in ref. [4] assuming the K^+K^- system to be a mixture of S, P and D interfering waves. The results of the fits are superimposed on the $\cos\theta$ and ϕ distributions in fig. 2. The fit has a probability of 55% and gives $80 \pm 4\%$ as the D wave contribution indicating that the $\theta/f_2(1720)$ meson is compatible with having $J^{PC} = 2^{++}$. The observation of $\theta/f_2(1720)$, in a kinematic region which has been suggested [5] to be a possible source for the production of glueballs, reinforces the likelihood that the $\theta/f_2(1720)$ is a gluonic state.

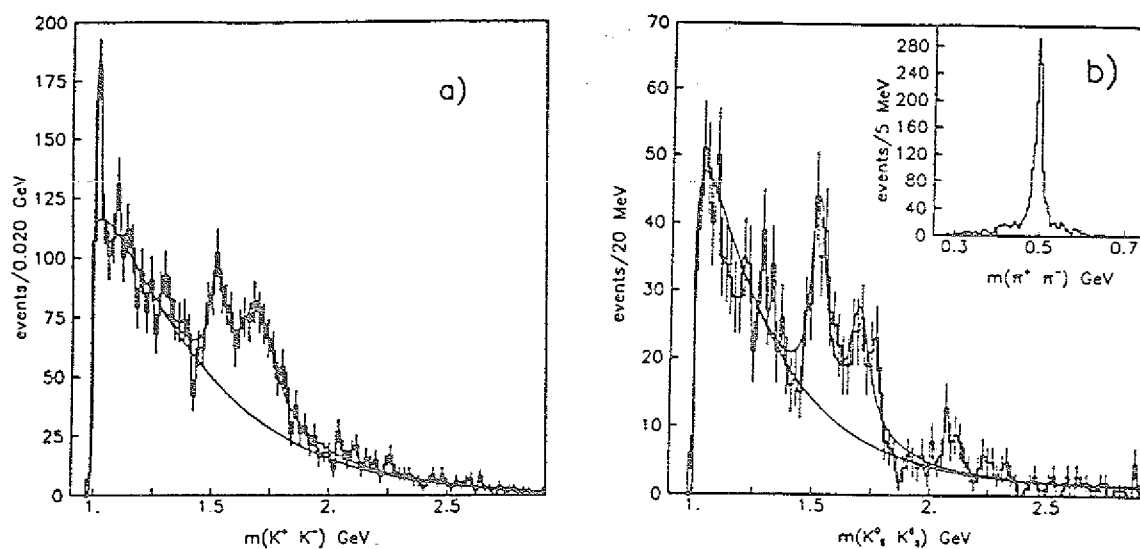


Figure 1: a) K^+K^- effective mass distribution with fit. b) $K_S^0 K_S^0$ combined mass spectrum from the 85 GeV/c and 300 GeV/c runs. The inset shows the K_S^0 signal.

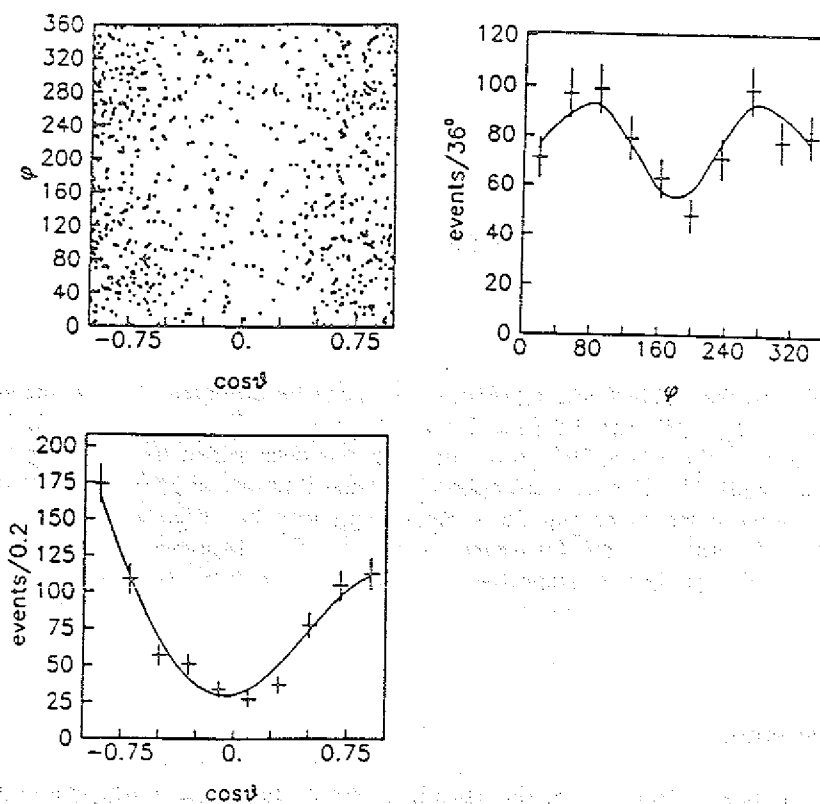


Figure 2: $(\cos\theta, \phi)$ scatter plot with $\cos\theta$ and ϕ projections in the Gottfried – Jackson frame for the $\theta/f_2(1720)$ region. The curves are the results of the fit with 80% D wave.

3. The $K_S^0 K^\pm \pi^\mp$ channel

The $K_S^0 K^\pm \pi^\mp$ final state has been selected from the sample of events with one V^0 by requiring momentum and energy balance. In addition compatibility was required with the information coming from the Cerenkov system. Fig. 3a shows the $K_S^0 K^\pm \pi^\mp$ effective mass spectrum.

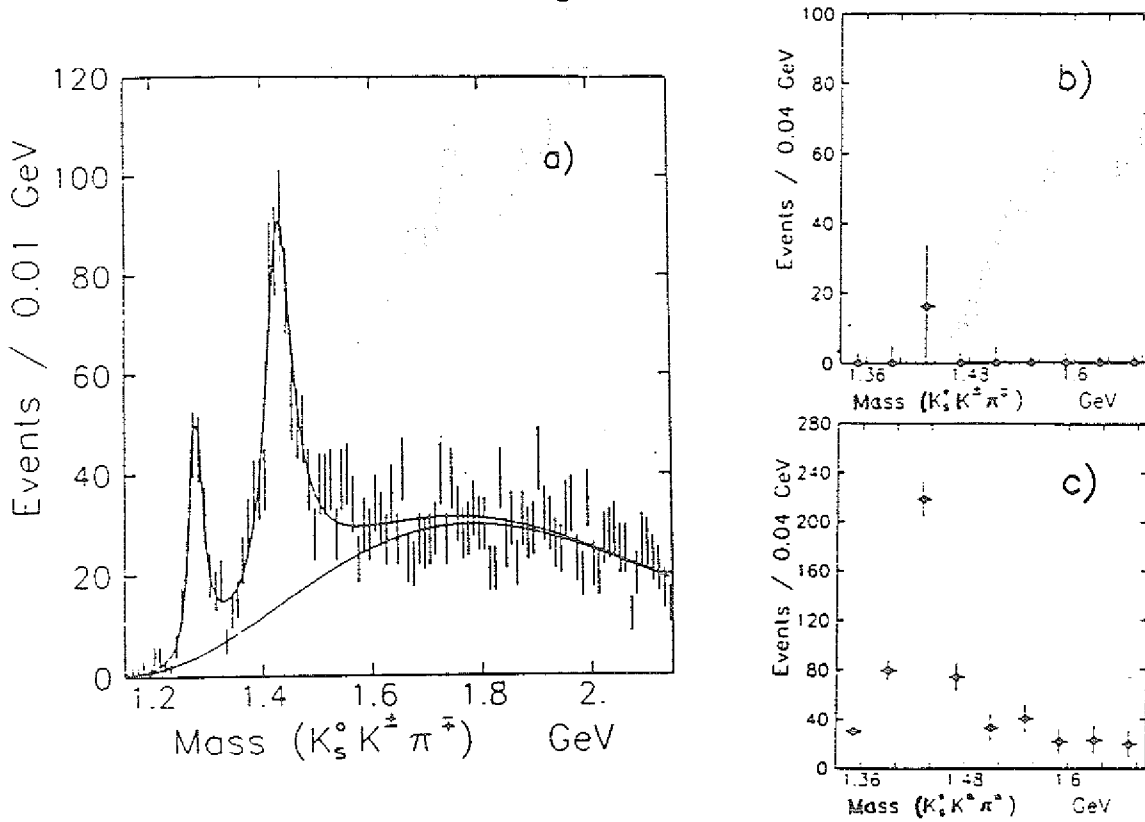


Figure 3: a) $K_S^0 K^\pm \pi^\mp$ effective mass distribution; Results from the Dalitz plot analysis, b) 0^-+ ($\delta\pi + K^* \bar{K}$), c) 1^{++} $K^* \bar{K}$ contributions.

Clear signals corresponding to the $f_1(1285)$ and $f_1(1420)$ mesons can be observed. A fit to the spectrum yields masses and widths of $f_1(1285)$: $m = 1278 \pm 2$, $\Gamma = 25 \pm 4$ MeV; $f_1(1420)$: $m = 1429 \pm 3$, $\Gamma = 58 \pm 8$ MeV. A Dalitz plot analysis of the $K_S^0 K^\pm \pi^\mp$ mass spectrum has been performed by using the Zemach tensors and an isobar model [6]. The $f_1(1420)$ region has been fitted in 40 MeV slices from 1.33 to 1.69 GeV. Interference between waves having the same spin-parity has been allowed. Interference was also allowed between 1^{++} and 1^{+-} ($K^* \bar{K}$) waves. The $J^{PC} = 0^{-+}$ ($a_0 \pi + K^* \bar{K}$) and 1^{++} ($K^* \bar{K}$) contributions are shown in fig. 3b and 3c respectively, all the other contributions other than phase space being consistent with zero. The fit shows that the 1^{++} ($K^* \bar{K}$) is the dominant wave.

4. The $\eta \pi^+ \pi^-$ final state

The $\eta \pi^+ \pi^-$ final state has been selected from the sample of events having 2 central tracks and 2 γ 's reconstructed in the electromagnetic calorimeter for the $\eta \rightarrow \gamma\gamma$ decay mode, and 4 central tracks and 2 γ 's for the $\eta \rightarrow \pi^+ \pi^- \pi^0$ decay mode. Momentum and energy balance was required. Fig. 4a shows the η signal in the $\gamma\gamma$ spectrum, fig. 4b shows the η and ω signals in the $\pi^+ \pi^- \pi^0$ mass spectrum. Fig. 4c shows the combined $\eta \pi^+ \pi^-$ effective mass distribution where clear $\eta'(980)$ and $f_1(1285)$ signals can be observed.

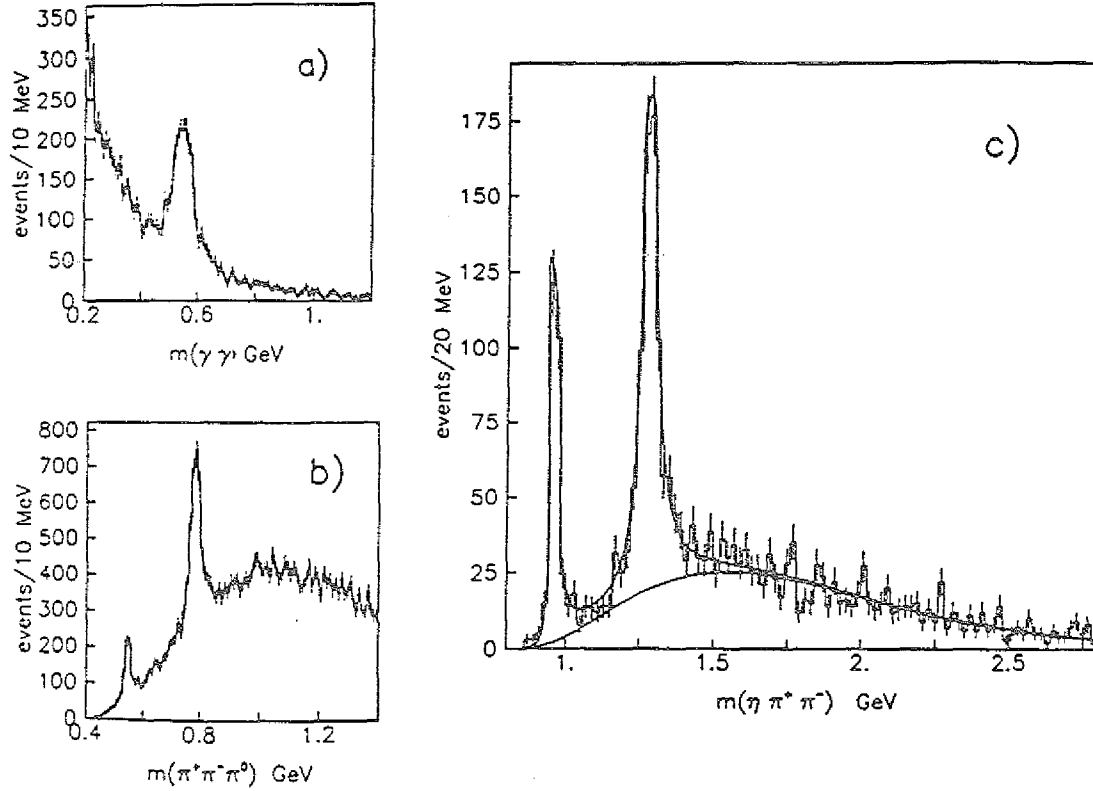


Figure 4: a) η signal in the $\gamma\gamma$ effective mass; b) η and ω signals in the $\pi^+\pi^-\pi^0$ mass distribution; c) combined $\eta\pi^+\pi^-$ effective mass distribution.

No evidence is found for an $\eta\pi^+\pi^-$ decay mode of the $f_1(1420)$. A fit of this spectrum gives $m = 1279 \pm 2$, $\Gamma = 55 \pm 5$ MeV as $f_1(1285)$ parameters where the experimental resolution has not been folded out.

5. The $\rho^0\gamma$ final state

The $\rho^0\gamma$ final state has been isolated from the sample of events having two central particles and one single gamma reconstructed in the electromagnetic calorimeter. Balance of momentum and energy was required. The γ was required to have an energy above 2. GeV. The γ centre of mass rapidity was also required to be < 1.3 in order to remove γ 's coming from fast π^0 decays where one γ is not detected. In addition, in order to antiselect the $\pi^+\pi^-\pi^0$ which dominates the background under the $\rho^0\gamma$ final state, cuts have been performed on the $\pi^\pm\gamma$ mass in order to antiselect the $\rho^\pm$ reflections which dominate the $\pi^+\pi^-\pi^0$ channel. The resulting $\rho^0\gamma$ spectrum is shown in fig. 5a and clear signals due to the $\eta'(950)$ and $f_1(1285)$ mesons can be seen.

No evidence is found for a $\rho^0\gamma$ decay mode of the $f_1(1420)$. A fit of this spectrum gives $m = 1278 \pm 6$, $\sigma = 38 \pm 6$ MeV as parameters of the $f_1(1285)$. An angular analysis has been performed by measuring the angle between the π^+ and the γ in the ρ^0 rest frame. For a pseudoscalar resonance decaying to $\rho^0\gamma$ the angular distribution should be proportional to $\sin^2\theta_\pi$ while for an axial vector resonance the distribution should be proportional to $\cos^2\theta_\pi$ [7]. The angular distribution for the $f_1(1285)$ region is shown in fig. 5b and shows a good agreement with the $J^{PC} = 1^{++}$ hypothesis.

In conclusion, it appears that the only decay observed for the $f_1(1420)$ meson is the $K^*\bar{K}$ mode, which suggests a large $s\bar{s}$ component. It should then be observed in K induced reactions. Instead, a

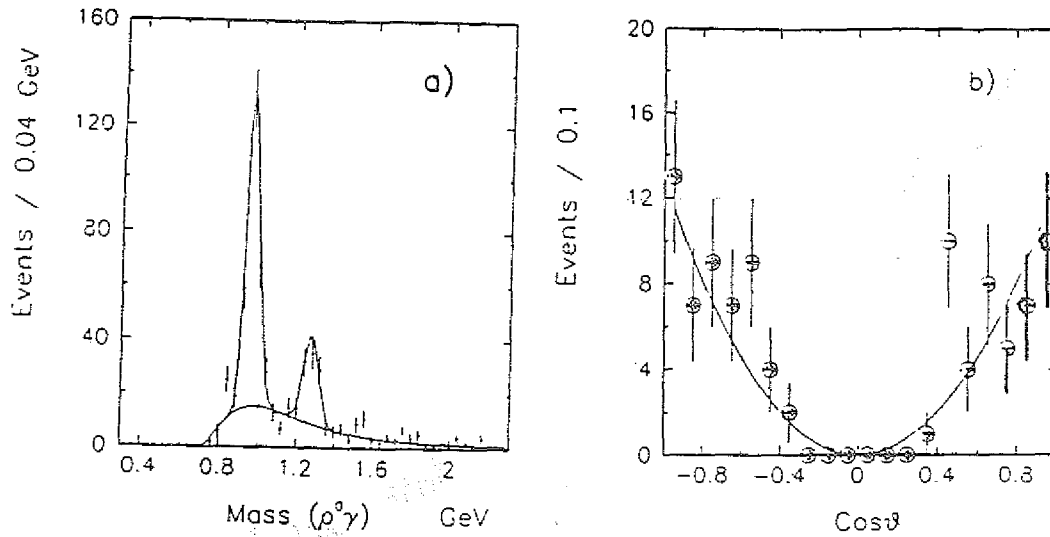


Figure 5: a) $\rho^0\gamma$ effective mass; b) $f_1(1285)$ angular distribution. The curve is a fit for $J^{PC} = 1^{++}$.

different state, the $f_1(1525)$ is observed in this process, which fits into the $J^{PC} = 1^{++}$ nonet better than the $f_1(1420)$. This suggests an exotic nature of the $f_1(1420)$ meson which is a candidate for being a hybrid [8] or a $K^*\bar{K}$ molecule [9].

6. Evidence for new states in the $\pi^+\pi^-\pi^+\pi^-$ channel

The $\pi^+\pi^-\pi^+\pi^-$ final state has been selected by requiring momentum and energy balance and compatibility with the Cerenkov information. Fig. 6a shows the $\pi^+\pi^-\pi^+\pi^-$ effective mass distribution for the sample of events having no γ 's detected in the electromagnetic calorimeter.

A clear $f_1(1285)$ signal can be seen, together with two new structures in the 1.45 and 1.9 GeV regions. A fit to the spectrum gives the following parameters for the three structures; $f_1(1285)$: $m = 1281 \pm 1$, $\Gamma = 31 \pm 5$ MeV; $X(1450)$: $m = 1449 \pm 4$, $\Gamma = 78 \pm 18$ MeV; $X(1900)$: $m = 1901 \pm 13$, $\Gamma = 312 \pm 61$ MeV. A channel likelihood fit of the whole channel shows that the $f_1(1285)$ and $X(1450)$ are consistent with decaying entirely through $\rho^0\pi^+\pi^-$, while the $X(1900)$ decays 50% through $a_2(1320)\pi$ and 50% through $f_2(1270)\pi^+\pi^-$. The presence of more than one resonance contribution to the 1.9 structure cannot be excluded. We notice that the $X(1450)$ has a mass which is different from the one measured for the $f_1(1420)$. In addition a study of the t behaviour of the two states shows that they are inconsistent with being the same resonance. A study of the $X(1450)$ angular distribution in both the $\rho(\pi\pi)$ and $(\rho\pi)\pi$ decay modes (fig. 6b) shows that the spin parity of this state is compatible with being 1^- or 2^- . This leaves open the interesting possibility for the $X(1450)$ being an exotic $J^{PC} = 1^{-+}$ state.

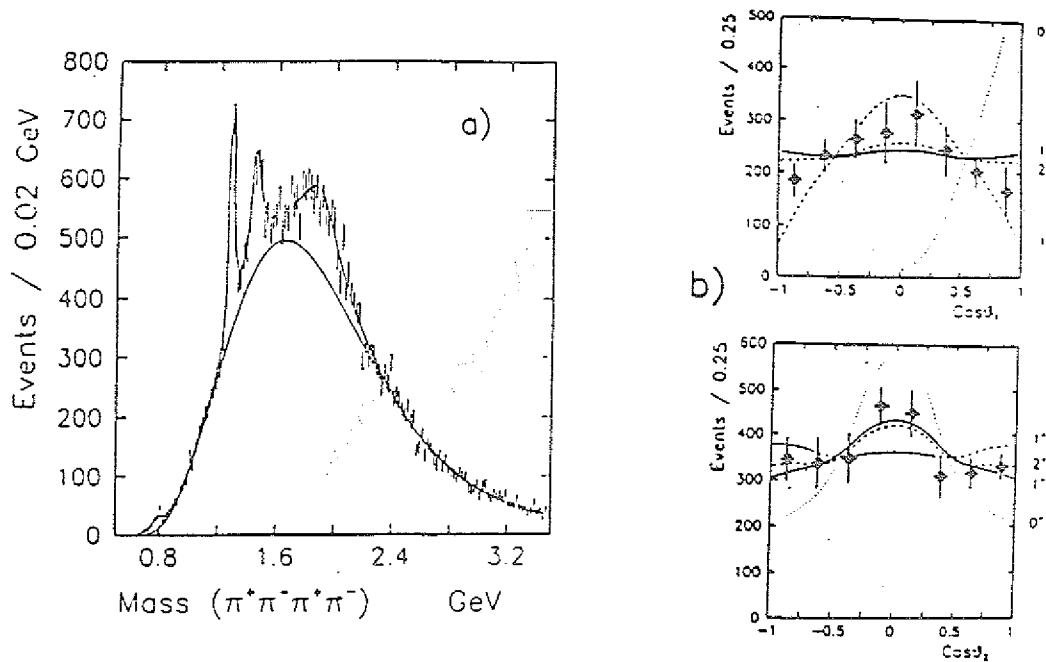


Figure 6: a) $\pi^+\pi^-\pi^+\pi^-$ effective mass distribution; b) X(1450) angular distributions. The curves correspond to J^P assignments for the $(\rho^0\pi)\pi$ decay mode.

7. The $\pi^+\pi^-$ final state

The $\pi^+\pi^-$ final state has been selected by requiring momentum balance and energy conservation. In addition Cerenkov compatibility was required for both pions. The centrally produced $\pi^+\pi^-$ mass spectrum is shown in fig. 7a and contains 310 000 events. We observe little ρ^0 and $f_2(1270)$ production and a large contribution of $S^*/f_0(975)$ in the $K\bar{K}$ threshold region. A fit to this spectrum has been performed by using a Flatté coupled channel Breit Wigner interfering with the S-wave background. The resulting $S^*/f_0(975)$ parameters are $m_0 = 979 \pm 2$ MeV, $g_\pi = 0.25 \pm 0.02$ and $g_K = 0.20 \pm 0.04$. The number of events predicted to appear in the K^+K^- channel is easily accommodated by the data (fig. 7b).

A fit with ρ^0 , $S^*/f_0(975)$ and $f_2(1270)$ only gives a good description of the data in the first part of the $\pi^+\pi^-$ spectrum but fails to describe it in the 1.45 GeV region as can be seen from fig. 8a.

It was found that by introducing an interference between the $f_2(1270)$, $f_2(1525)$ and the background the data could be described reasonably. However, the fit probability is 0.2% and we measure a branching ratio $\Gamma(f_2' \rightarrow \pi\pi)/\Gamma(f_2' \rightarrow K\bar{K}) = 0.21 \pm 0.08$. If, on the other hand, we leave as free parameters the mass and width of the Breit-Wigner term describing the 1.45 region, the fit probability increases to 49% (fig. 8b) and results in a mass of 1473 ± 11 MeV and a width of 189 ± 20 MeV for this structure.

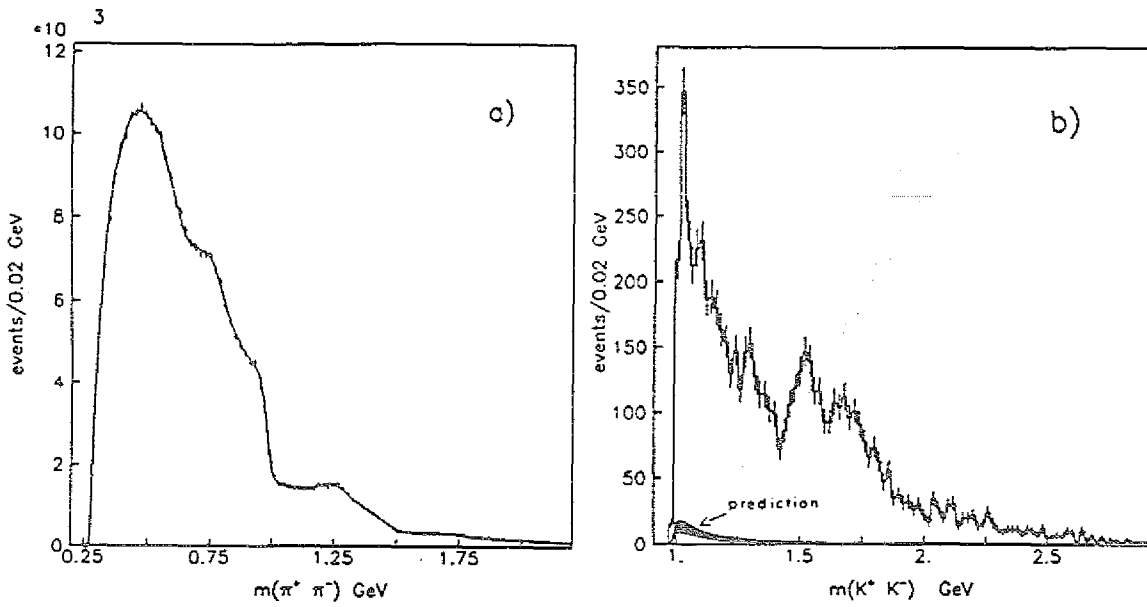


Figure 7: a) $\pi^+\pi^-$ effective mass distribution; b) K^+K^- effective mass distribution. The band drawn in the threshold region represents the estimated contribution from the $S^*/f_0(975)$ measured in the $\pi^+\pi^-$ spectrum with one standard deviation.

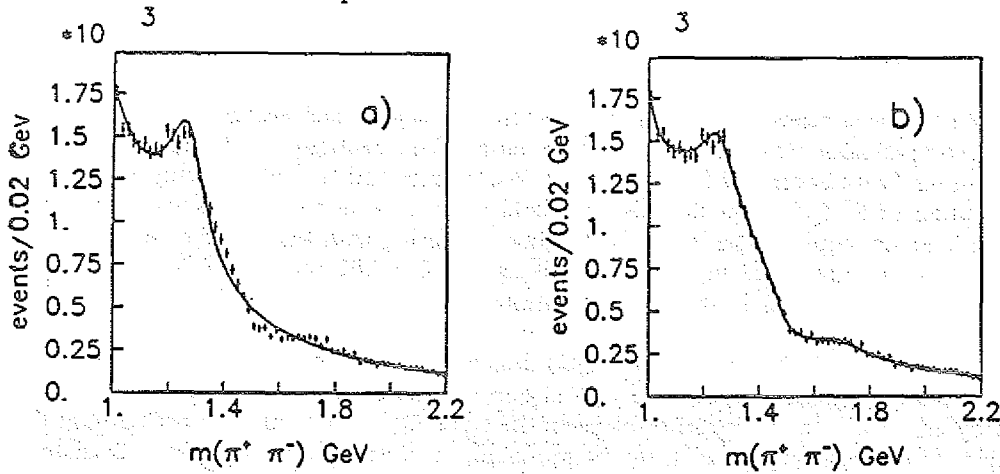


Figure 8: a) Expanded view of the fit to the $\pi^+\pi^-$ spectrum. The fit has been performed without including a Breit - Wigner in the 1.45 GeV region; b) As in a) but with a new Breit - Wigner term to describe the 1.45 GeV region and a $\theta/f_2(1720)$ contribution included in the fit.

8. Conclusions

We have studied the production of mesons in the central region in $p\bar{p}$ collisions at 300 GeV/c. We find evidence for the states $\theta/f_2(1720)$, $f_1(1420)$, $S^*/f_0(975)$ and a new state $X(1450)$. Each of these mesons has some peculiar characteristic and are candidates for being non $q\bar{q}$ mesons.

9. References

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T.A. Armstrong et al., Phys. Lett. 166B (1986) 133;
T.A. Armstrong et al., Phys. Lett. 166B (1986) 245;
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T.A. Armstrong et al., Z. Phys. C43 (1989) 55.
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C. Dionisi et al., Nucl. Phys. B169 (1980) 1.
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Workshop on
Mesons and Mesonic States
up to slightly above $1 \text{ GeV}/c^2$

at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich
February 19. - 20. 1990

IX)

P. Weidenauer

η , η' , ω , and ϕ Production in the
 $\bar{p}$ - Annihilation

PP Annihilation at Rest in H₂ Gas into
 $\pi^+\pi^-\eta, \pi^+\pi^-\eta', \pi^+\pi^-\omega, \pi^+\pi^-\phi, \eta\phi, \omega\phi, \rho\omega, \rho\phi$

Patrick Weidenauer, K. Beauchet, H. Kolinowsky, E. Klempt
 B. Hay, J. Reifendörfer
 Inst. f. Physik, Uni Mainz
 and ASTERIX-Kollaboration

ASTERIX-Experiment PS 171 at LEAR (1983-1986)

Aims of the Experiment:

Protonium X-ray spectroscopy

Search for "Baryonia" and other exotic resonances

Spectroscopy of light mesonic resonances up to 2. mp

Results among others

PP K₁ line

Annihilation into 2 charged mesons $\pi^+\pi^-, K^+K^-$

PWA: $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ (E(4120)), $E(4120) \rightarrow K^+\pi^-K^-$

PWA: $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$, Evidence for new state $A_1(1565) \rightarrow \pi^+\pi^-\pi^0$
 $J^{PC} = 2^{++}$

Report today:

Spectroscopy of intermediate states in 4 prong final state

data: LEAR $p = 105 \text{ MeV}$ $\Delta E = 10^{-3}$ note $3.4 \cdot 10^4 \text{ p/s}$
 Oct. 1985 June 1986

Interest for COSY:

- 1) Analysis methods used in connection with η, η', ω and ϕ production (here, in $\bar{p}p$ annihilation)
- 2) Ratios of η and η' production and of ω and ϕ production (is there a $\bar{s}s$ component of the proton)?

exp. data so far:

$$\frac{\bar{p}n \rightarrow \pi^-\phi}{\bar{p}n \rightarrow \pi^-\omega} \approx \frac{1}{4}$$

$$\frac{\bar{p}p \rightarrow \pi^0\phi}{\bar{p}p \rightarrow \pi^0\omega} = \frac{1}{15}$$

$$\frac{\bar{p}p \rightarrow \pi^+\pi^-\phi}{\bar{p}p \rightarrow \pi^+\pi^-\omega} = \frac{1}{143}$$

$$\frac{\bar{p}p \rightarrow \rho\phi}{\bar{p}p \rightarrow \rho\omega} \approx \frac{1}{110}$$

these body reaction

ASTERIX Result

Production cross sections of 2) should give information on η and η' wave function; present

$$\eta = \frac{1}{\sqrt{3}} (\bar{u}u + \bar{d}d - \bar{s}s)$$

$$\eta' = \frac{1}{\sqrt{6}} (\bar{u}u + \bar{d}d + 2\bar{s}s)$$

$\bar{s}s$ component of proton tested via comparison of ω and ϕ production

Detector

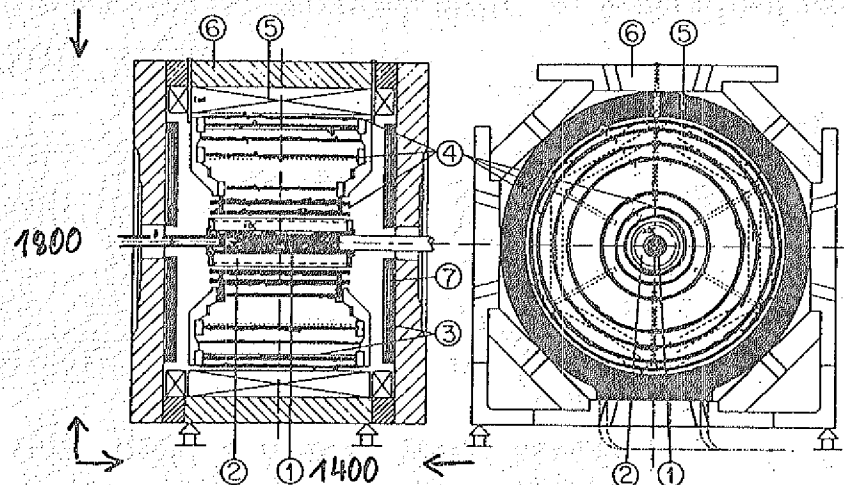


Fig. 1. Side and front views of the ASTERIX spectrometer. 1 - H_2 gas target, 2 - X-ray drift chamber, 3 - lead converter, 4 - cylindrical MWPC, 5 - coil, 6 - yoke, 7 - planar MWPC.

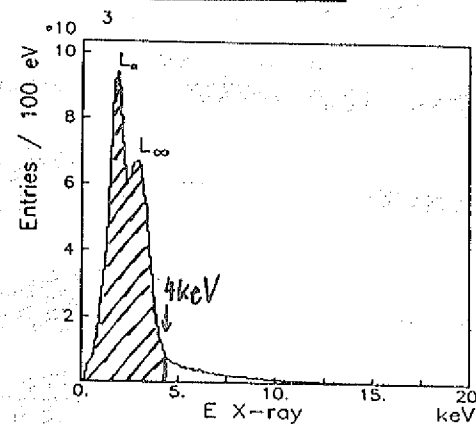
- 1) gas target
- 2) X-ray drift chamber $\frac{\sigma}{E} = 12 \pm 2\%$ $E_x = 6 \text{ keV}$
- 3) Lead converter 0.9 rad length
- 4) 7 cylindrical MWPCs 5 have Anode/Kathode readout
- 5) Magnet 0.82 Tesla
- 7) Position sensitive γ detectors

Momentum resolution:

$$\frac{\sigma(p)}{p} = \sqrt{(0.042p)^2 + 0.023^2} \quad [\text{GeV}/c]$$

51% $\cdot 4\pi$ solid angle

Data selection



Data set

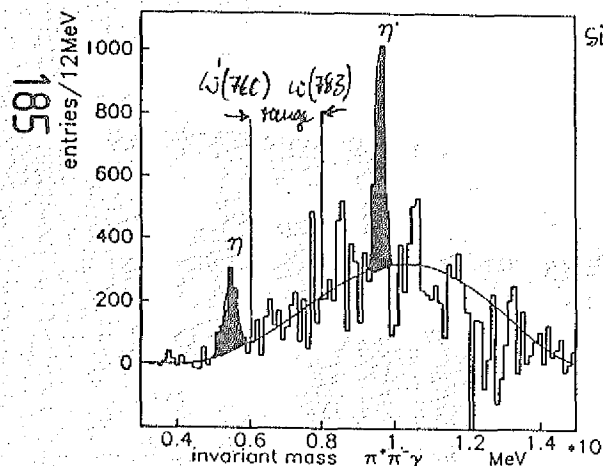
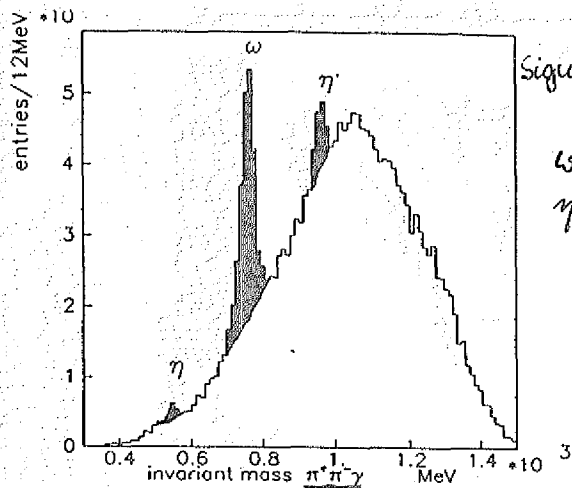
- ① $1.885 \cdot 10^6$ Ev taken 4 longtrucks, good χ^2 $61 \pm 6\%$ P-wave ann.
- ② $0.441 \cdot 10^6$ Ev " " " + L X-ray ($< 4 \text{ keV}$) $86 \pm 4\%$ P-wave

total contribution of 4 prong exts in $\bar{p}p$ Annihilation is $0.49 \pm 4\%$

all data submitted to kinematical fitting routine

- A) $\bar{p}p \rightarrow \pi^+ \pi^- \pi^+ \pi^-$
- B) $\bar{p}p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0$
- C) $\bar{p}p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$
- D) $\bar{p}p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^-$

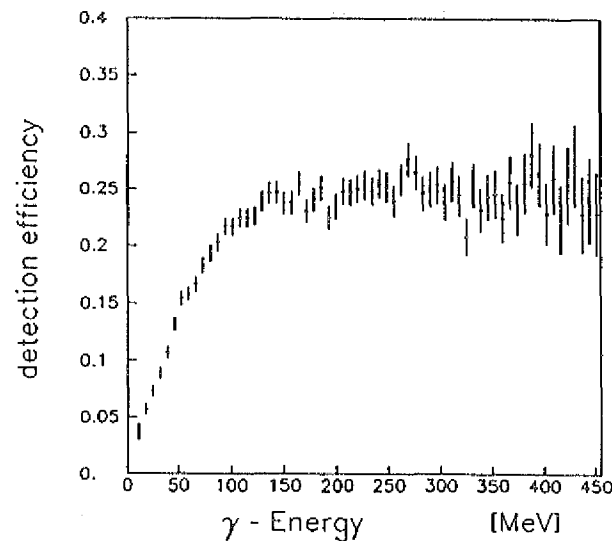
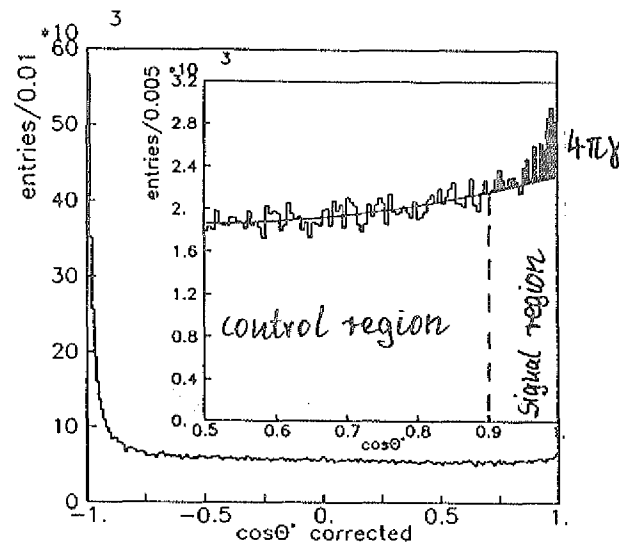
directional information on γ impact not used as constraint in kinematical fit!



Fit in 600 - 850 keV mass range
assuming 2 Gaussians for $\omega(783) \rightarrow \pi^+\pi^-\gamma$ (no signal seen)
and fake " $\omega(760) \rightarrow \pi^+\pi^-\gamma$ "
finds upper limit

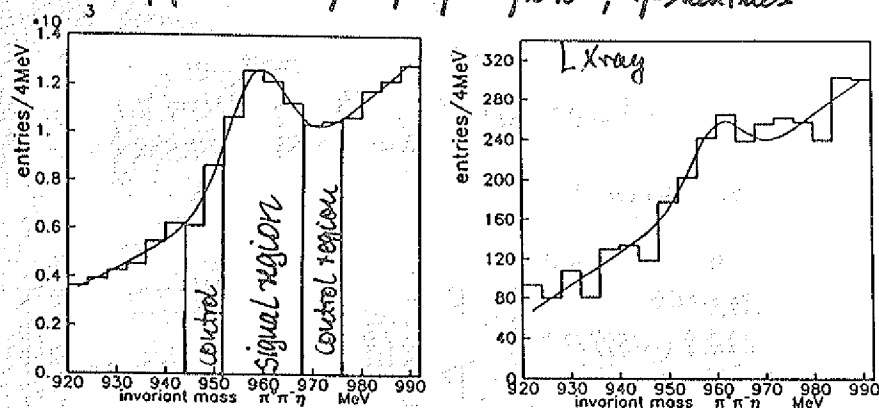
$$B.R. \frac{\omega \rightarrow \pi^+\pi^-\gamma}{\omega \rightarrow \text{all}} < 3 \cdot 10^{-3} \quad (90\% CL)$$

PDG ($4 \cdot 10^{-2}$)



$$d_\gamma = 25 \pm 2\%$$

$\bar{p}p \rightarrow \pi^+\pi^-\eta'$, $\eta' \rightarrow \gamma\pi^+\pi^-$, $\gamma \rightarrow \text{neutrals}$

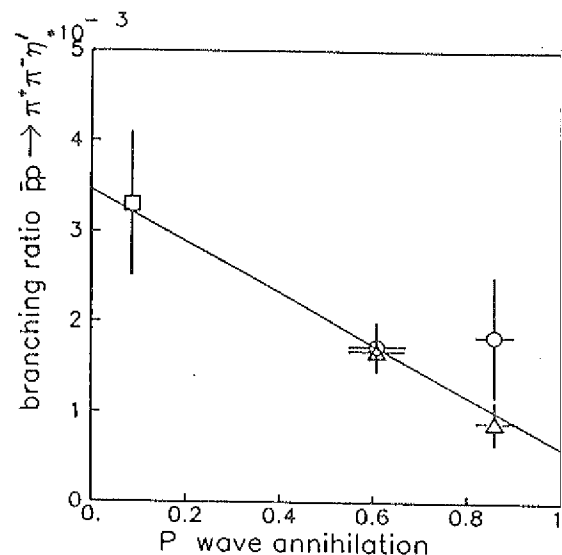


η' production decreases in P-wave annihilation

$$N_{\eta'} = 1550 \pm 100 \text{ ev}$$

$$N_{\eta'} = 205 \pm 50 \text{ ev}$$

side bin subtraction:

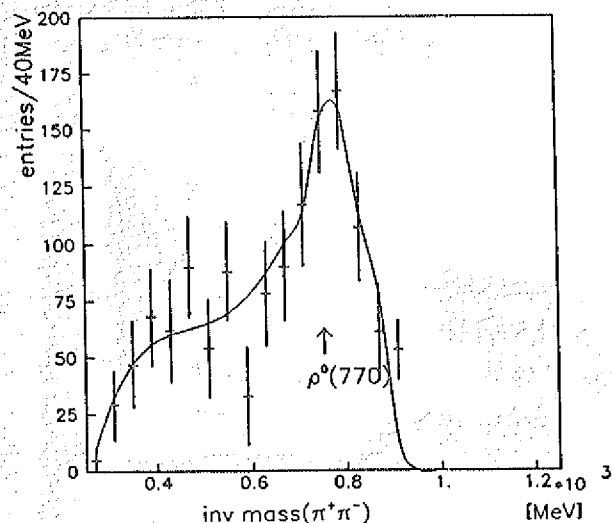


$$\begin{aligned} \text{B.R. } (\bar{p}p \rightarrow \pi^+\pi^-\eta') &= (346 \pm 0.67) \cdot 10^{-3} \\ &= (0.61 \pm 0.33) \cdot 10^{-3} \end{aligned}$$

S Wave

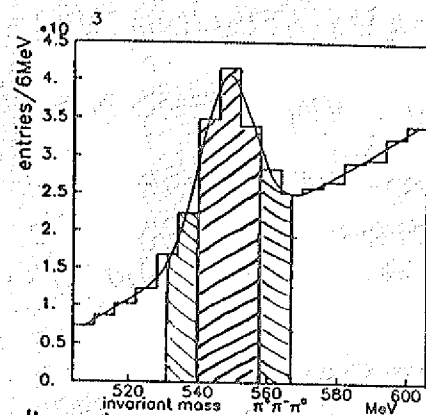
P Wave

$$\text{B.R. } ({}^3S_1 \bar{p}p \rightarrow {}^0S^0 \eta') = (1.81 \pm 0.44) \cdot 10^{-3}$$



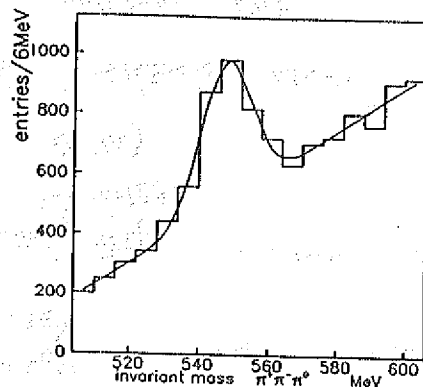
recoiling against η'

$$p\bar{p} \rightarrow \pi^+ \pi^- \gamma, \quad \gamma \rightarrow \pi^+ \pi^- \pi^0$$



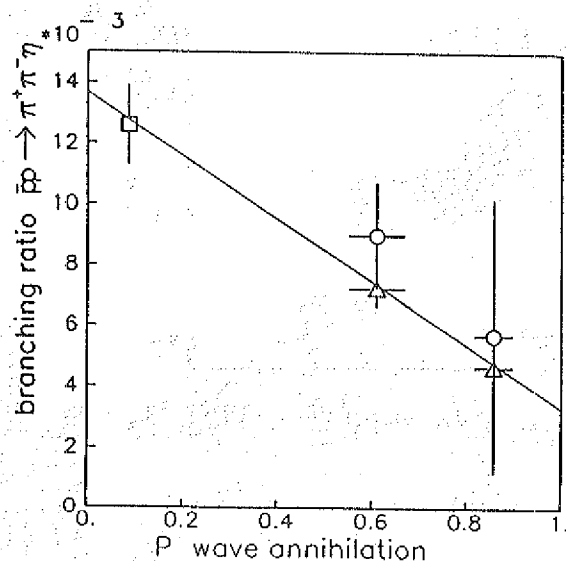
4 entries/event

Fit: $m_\gamma = 548.1 \pm 0.2 \text{ keV}$
 $\sigma = 4.6 \pm 0.2 \text{ keV}$
 $N_\gamma = 7000 \pm 160 \text{ ev}$



$N_\gamma = 1125 \pm 70 \text{ ev}$

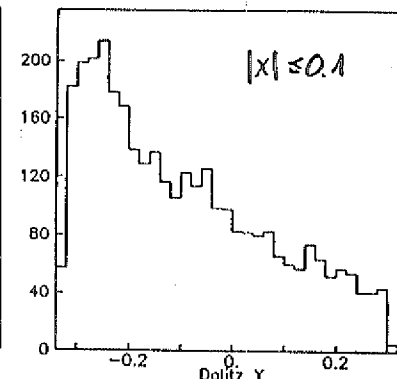
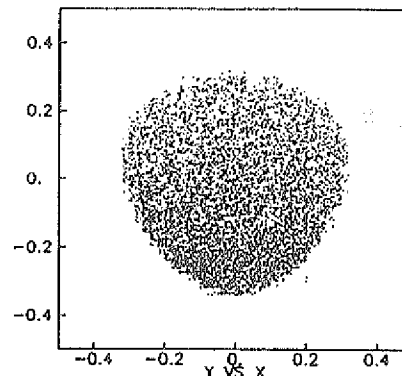
Result:



B.R. ($p\bar{p} \rightarrow \pi^+ \pi^- \gamma$) =
 $(13.7 \pm 1.46) \cdot 10^{-3}$ S-wave
 $(3.35 \pm 0.84) \cdot 10^{-3}$ P-wave

Dalitz Plot $\gamma \rightarrow \pi^+ \pi^- \pi^0$

cut: $540 \leq m_{\pi^+ \pi^-} \leq 558 \text{ MeV}$; 7703 entries

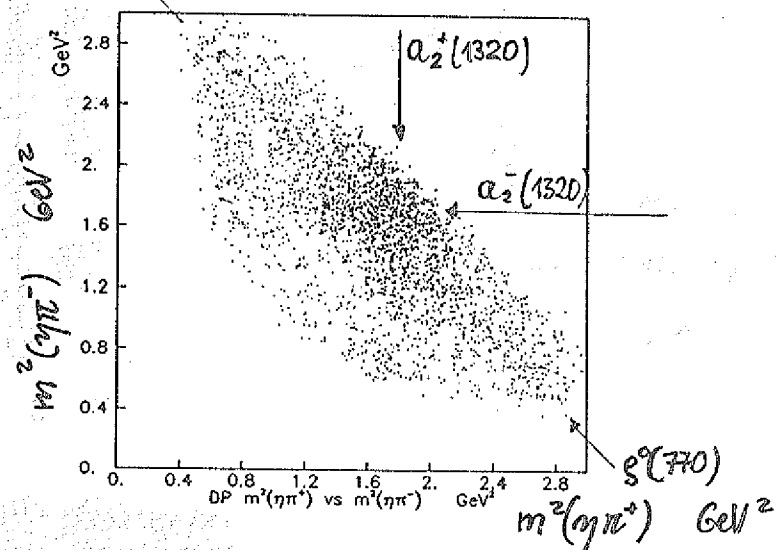


Koordinates: $x = \frac{T_2 - T_1}{T_3 - Q}$; $y = \frac{T_3}{Q} - \frac{1}{3}$

- Energy dependence of γ decay matrix element seen:

$|K(x,y)|^2 \sim 1 - (1.07 \pm 0.013) \cdot 3y$ (Layter et al. Phys.Rev. D9 (1973) 2566)

- in a partial wave analysis of the $\pi^+ \pi^- \gamma$ production D.P. in a 2π solid angle detector exist correlations between γ production and γ decay which has to be taken into account!

Dalitz Plot $\bar{p}p \rightarrow \eta \pi^+ \pi^-$ 

Selection:

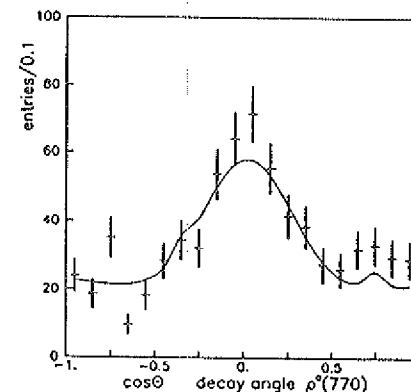
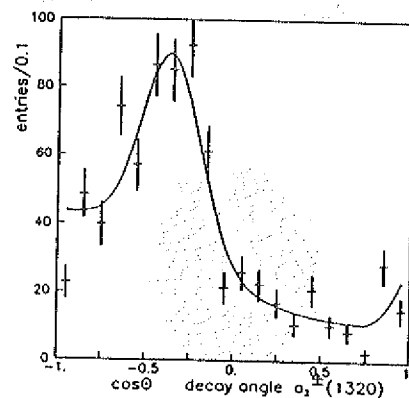
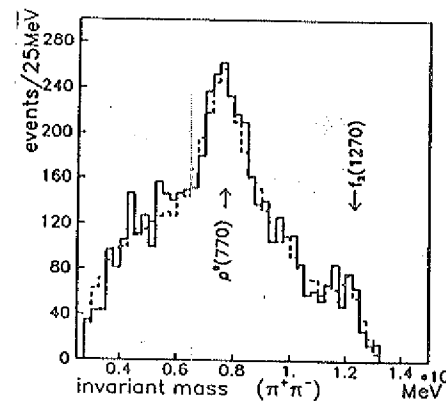
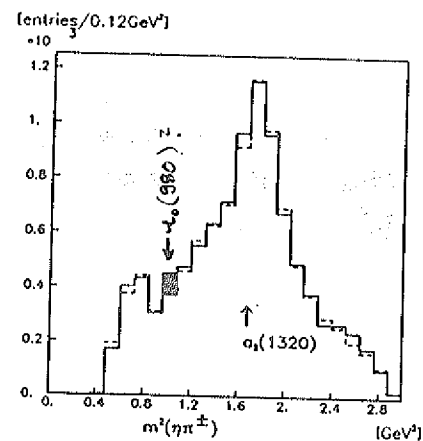
signal $540 \leq M_{\pi^+ \pi^-} \leq 558 \text{ MeV}$ - 5435 γ 's 2268 backgr.sidebands $522 \leq M_{\pi^+ \pi^-} \leq 534 \text{ MeV}$
 $564 \leq M_{\pi^+ \pi^-} \leq 576 \text{ MeV}$ } 505 γ 's 2043 backgr.

all events having 1 or more entries in the 10(783) region

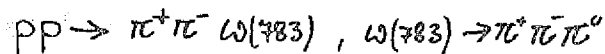
 $744 \leq M_{\pi^+ \pi^-} \leq 820 \text{ MeV}$ excluded(reflection into η region possible)

Analysis method: PWA using interfering amplitudes

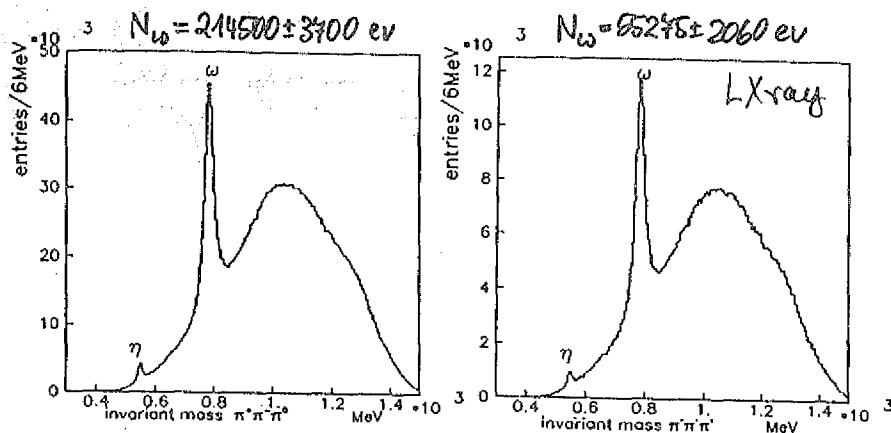
$$A_{jre}(\vec{P}, \vec{Q}) = A_{jre} \sum_{T, E} b_{T, E} Z_{jre, T, E}(\vec{P}, \vec{Q}) F_{T, E}(\vec{Q})$$

 η decay matrix elementb_{T, E}
C.G.Z_{jre, T, E}
describing
angular distributionsrelativ. BW
describing
decay dynamics

$$B.R.(\bar{p}p \rightarrow a_0^{\pm}(980) \pi^{\mp}, a_0^{\pm} \rightarrow \gamma \pi^{\mp}) < 2 \cdot 10^{-4}$$



4 entries/event



$m_\omega = 782.4 \pm 0.2 \text{ MeV}$ (shows exact calibration of B-field)
 $\sigma_\omega = 14.2 \pm 0.2 \text{ MeV}$
 $\Gamma = 8.5 \text{ MeV}$ fixed (PDG value)

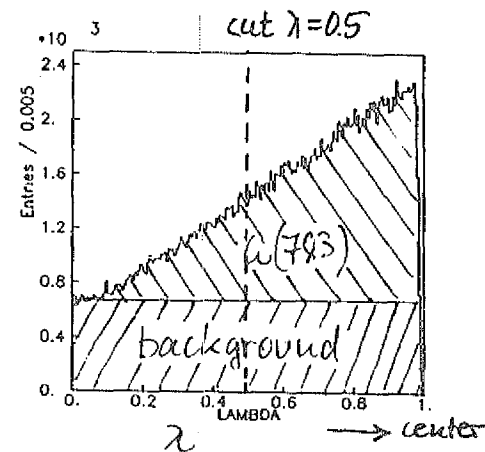
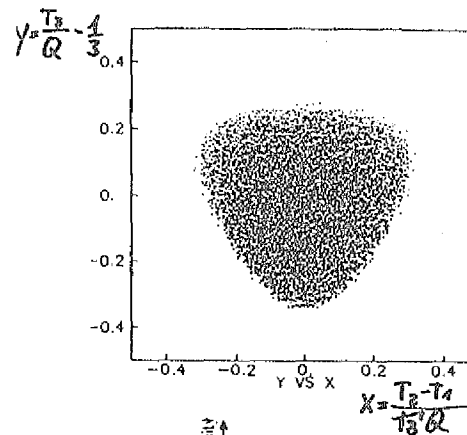
$\text{B.R.}(pp \rightarrow \pi^+ \pi^- \omega) = (6.82 \pm 0.58)\%$ $\text{B.R.}(\bar{p}p \rightarrow \pi^+ \pi^- \omega) = (7.03 \pm 1.06)\%$

bubble chamber: $\text{B.R.}(\bar{p}p \rightarrow \pi^+ \pi^- \omega) = (6.6 \pm 0.6)\%$

question: how to get a clean $\omega \pi^+ \pi^-$ sample without $4\pi\pi^0$ nor $\pi^+ \pi^- \omega$ combinatorial background for an analysis of the $\bar{p}p \rightarrow \pi^+ \pi^- \omega$ production D.P.

answer: cut on kinematics of the ω decay DP!
 (suggested by Goldhaber Phys. Rev. Lett. 15 (1965) 119)
 never used in b.c. days due to limited statistics!

cut: $758 \leq M_{\pi^+ \pi^-} \leq 806 \text{ MeV}$



decay matrix element of $\omega(783)$ given by:

$$|M(x,y)|^2 \propto |\vec{q}_\pi \times \vec{q}_{\pi^-}|^2$$

- nonuniform
- ω Events in center
- cut variable

$$\lambda = |\vec{q}_\pi \times \vec{q}_{\pi^-}|^2$$

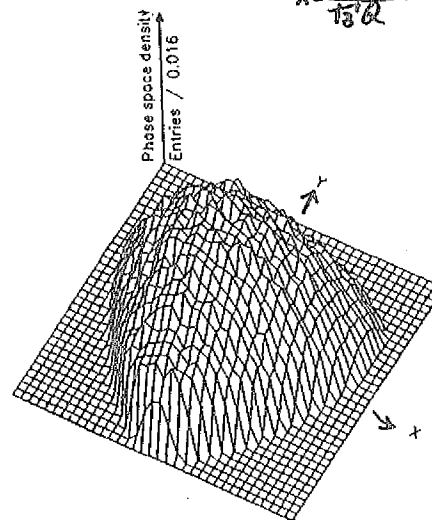
- shows: uniform background
 ω linear slope

- subtract 2 data sets

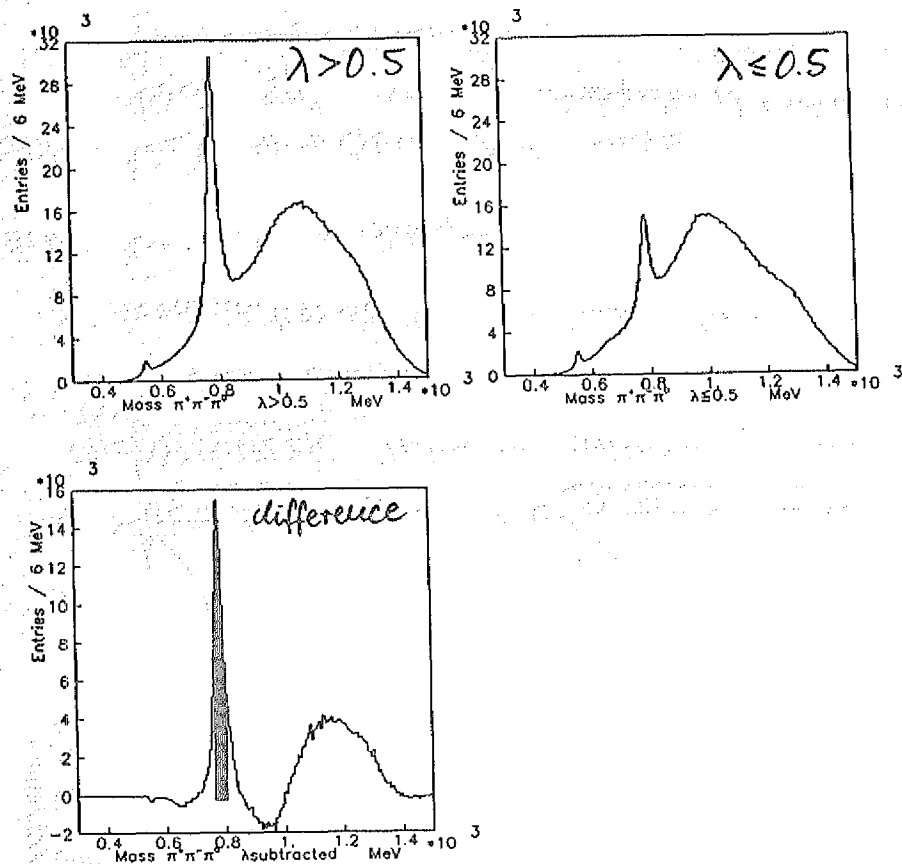
a) $\lambda \geq 0.5$

b) $\lambda < 0.5$

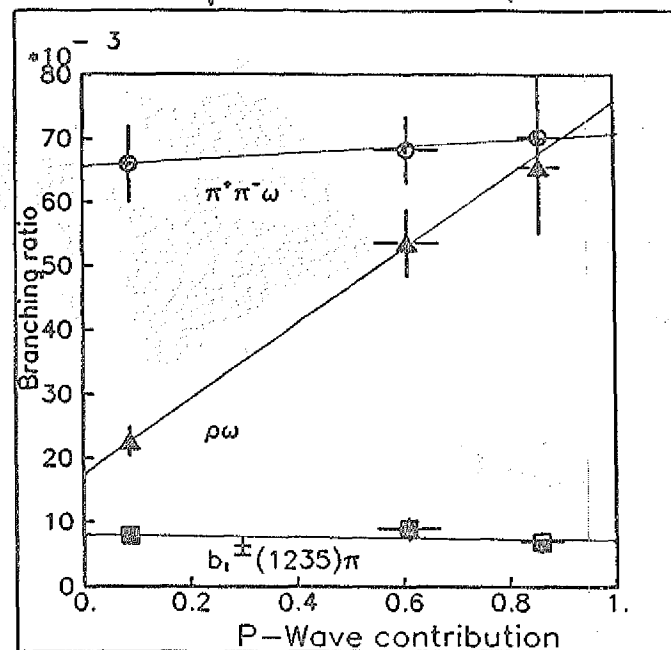
} = clear $\omega(783)$ signal



ω Decay Dalitz Plot



Results of the analysis of the $\pi^+\pi^-\omega$ final state:



$$\begin{aligned} \text{B.R.}(\bar{p}p \rightarrow b_1^*(1235)\pi^\mp) &= (8.1 \pm 1.2) \cdot 10^{-3} \\ &= (7.4 \pm 1.8) \cdot 10^{-3} \end{aligned}$$

S wave

P wave

$$\begin{aligned} \text{B.R.}(\bar{p}p \rightarrow g^0\omega) &= (1.77 \pm 0.27) \cdot 10^{-2} \\ &= (7.54 \pm 0.76) \cdot 10^{-2} \end{aligned}$$

S wave

P wave

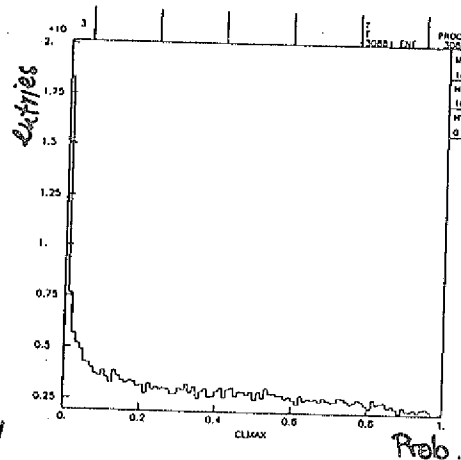
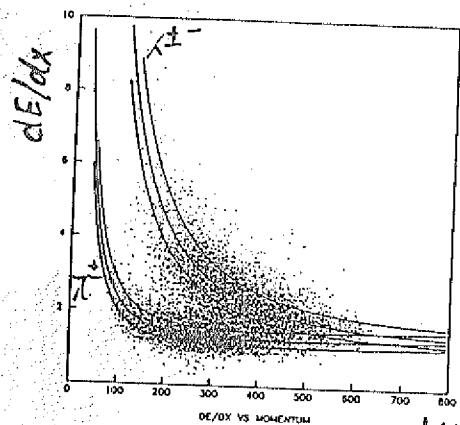
$$\begin{aligned} \text{B.R.}(\bar{p}p \rightarrow \pi^+\pi^-\omega) &= (6.55 \pm 0.68) \cdot 10^{-2} \\ &= (7.05 \pm 0.93) \cdot 10^{-2} \end{aligned}$$

measurement of dE/dx :

define

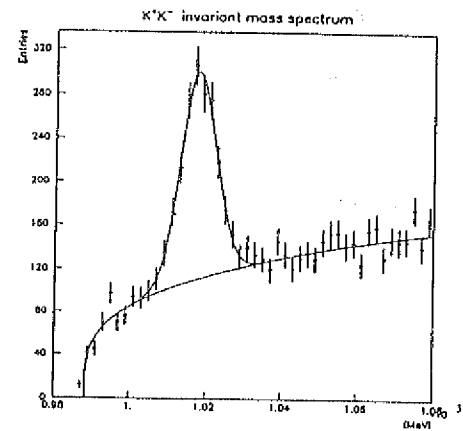
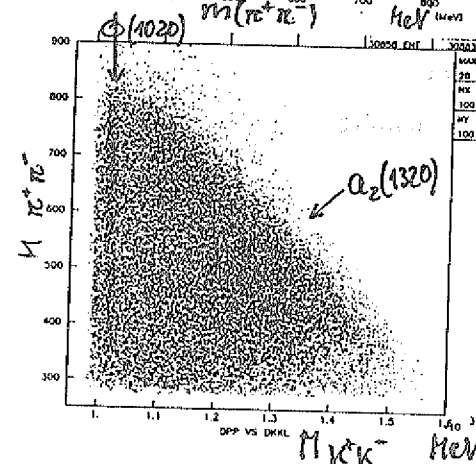
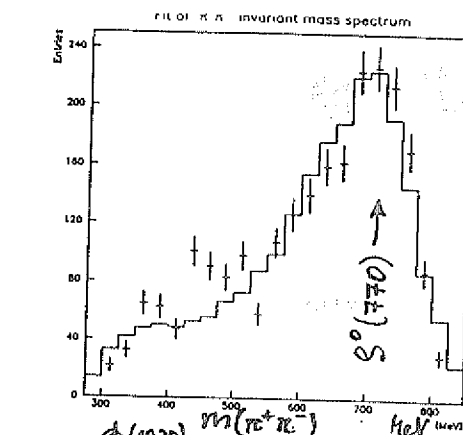
$$\chi = \frac{dE/dx \text{ (measured)}}{dE/dx \text{ (Bethe Bloch)} \cdot \lambda(\beta)} - 1 \cdot \frac{1}{\delta}$$

↑ detector correction



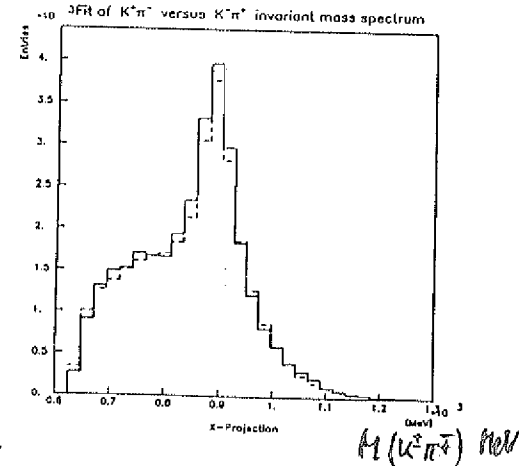
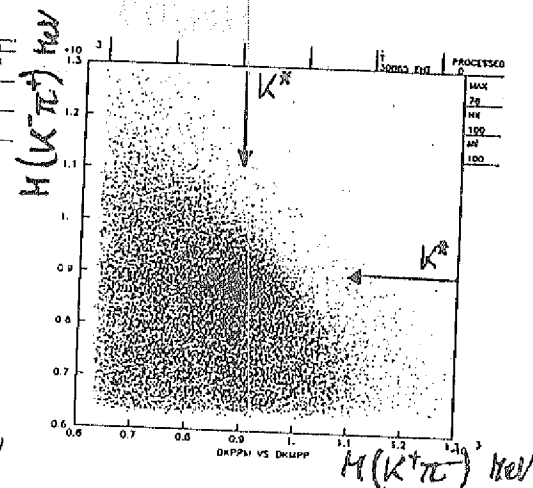
cut $\chi^2(2\pi^+2K^-) > \chi^2(4\pi)$

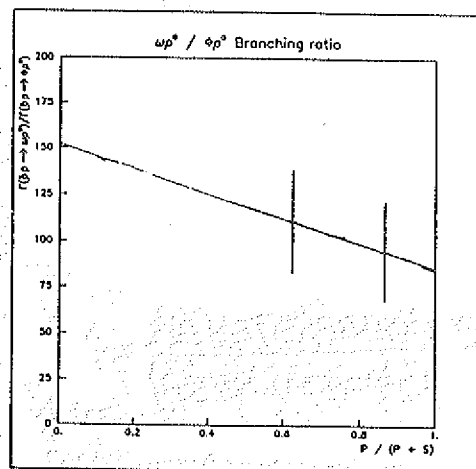
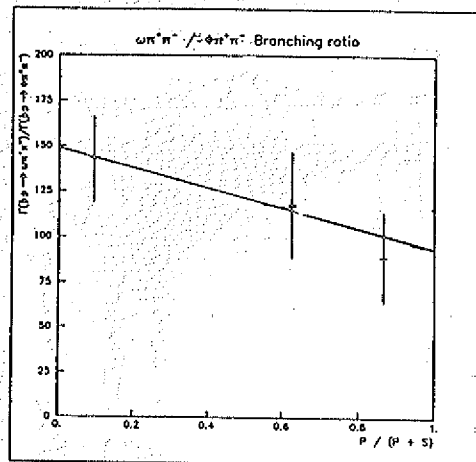
$\Rightarrow 30883$ ev remain



$m_\phi = 1017.8 \pm 4.8$ MeV $m_{K^+K^-}$ MeV

$K^+K^-\pi^+\pi^-$ final state



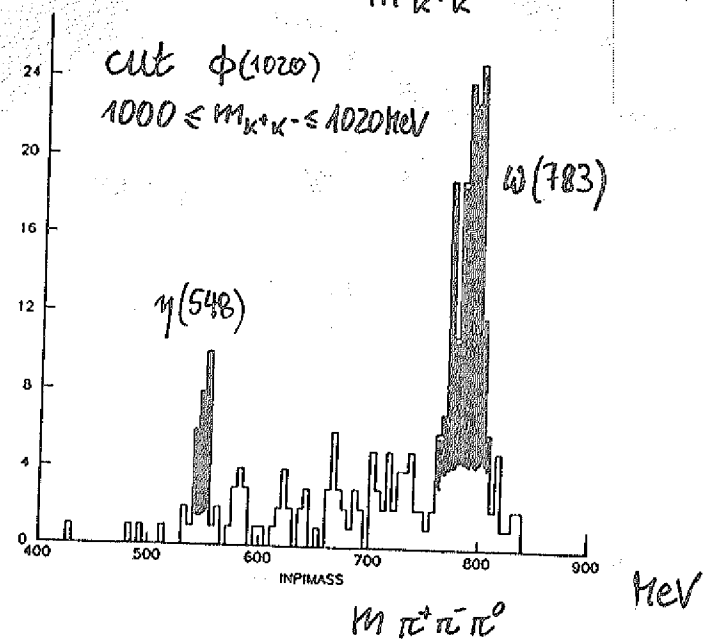
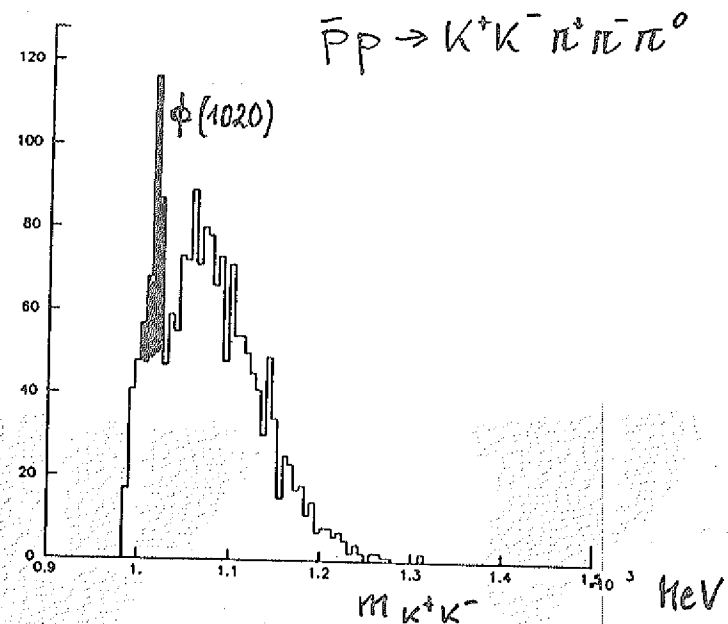


$$\text{B.R.}(\bar{p}p \rightarrow \kappa^0 \bar{\kappa}^0) = 5.0(8) \cdot 10^{-4}$$

$$\text{B.R.}(\bar{p}p \rightarrow \kappa^0 \kappa) = 10.0(4.6) \cdot 10^{-4}$$

$$\text{B.C.} : 30(7) \cdot 10^{-4} \text{ LH}_2$$

$$\text{B.C.} : 17(12) \cdot 10^{-4} \text{ LH}_2$$



Workshop on
Mesons and Mesonic States
up to slightly above $1 \text{ GeV}/c^2$

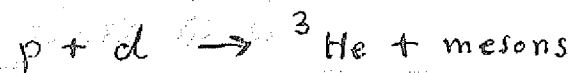
at the Conference Room of the Zentrallabor für Elektronik ZEL
Forschungszentrum Jülich
February 19. - 20. 1990

X)

R. Jahn

Meson-Production Experiments Utilizing Hadronic Fusion Reactions

Meson Production Experiments utilizing Hadronic Fusion Reactions



existing data inclusive
experiments presently under
preparation:
at SATURNE
at COSY exclusive

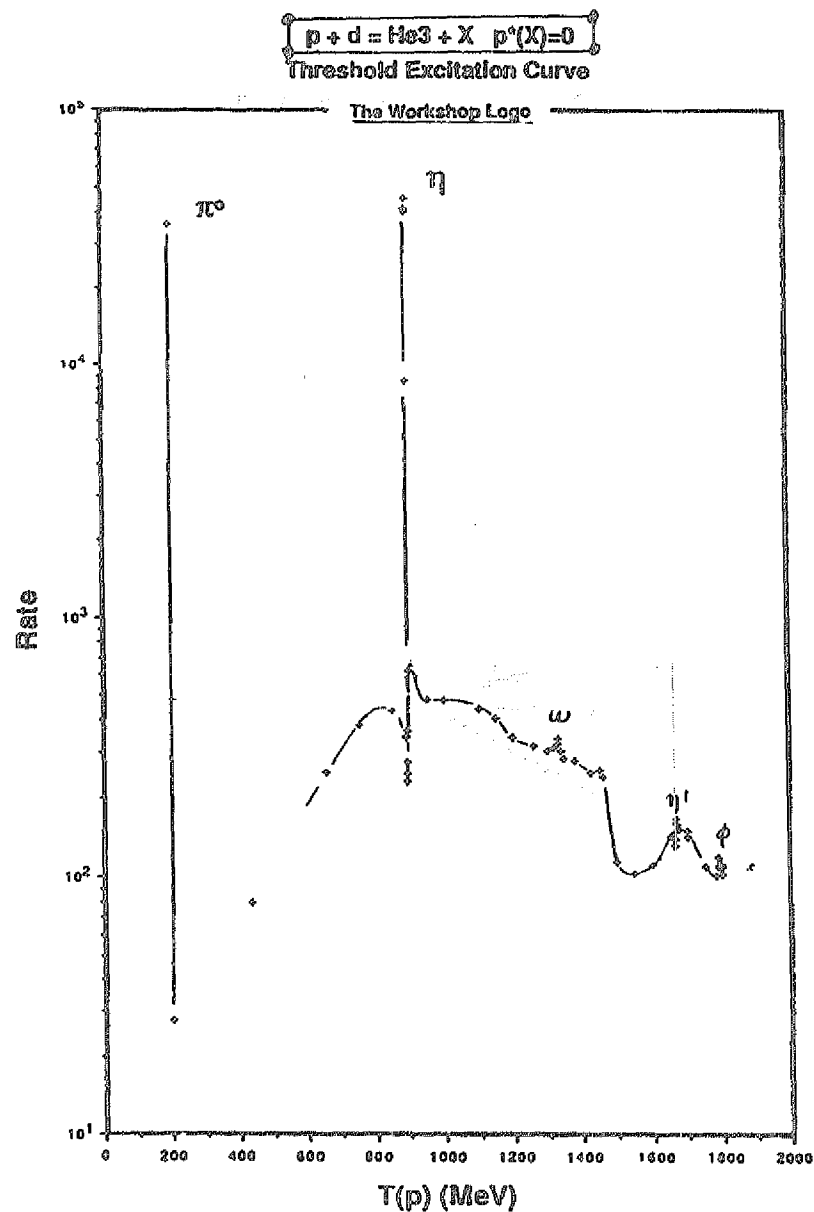
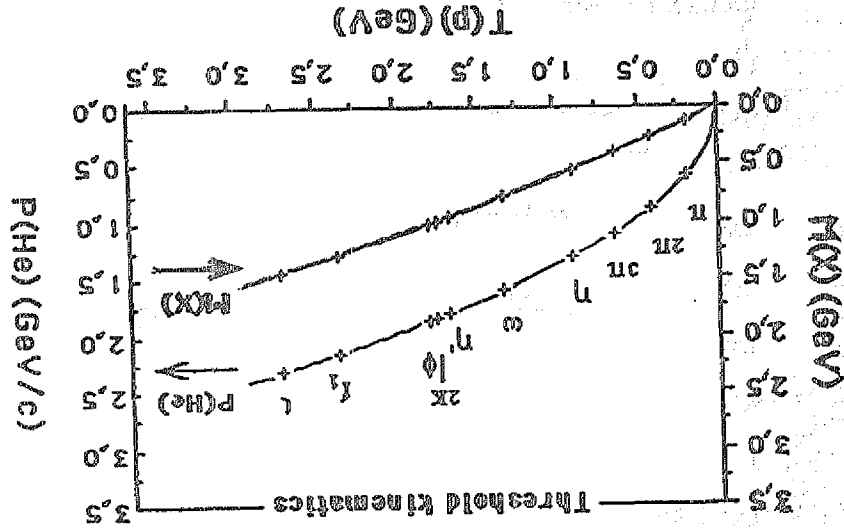


Fig.1. The threshold excitation curve. We have derived the two data points at the π^0 threshold from the 1986 Saclay raw data. The other points are from the 1987 data. The event rate corresponds to an integration over a c.m. momentum space as sketched in Fig.3.

$$p + d = He3 + X \quad p^*(X)=0$$



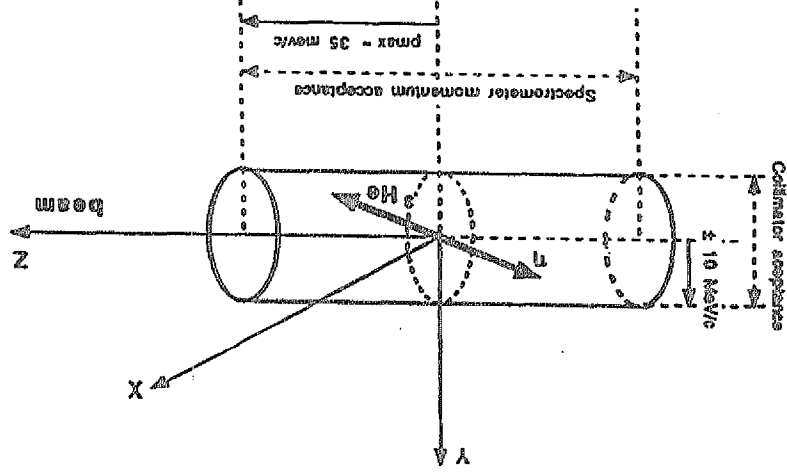
S P E S IV
The threshold microscope

$$\Delta m^* \approx 1 \text{ MeV}/c^2$$

$$5 \cdot 10^{11} \text{ p/burst} ; 2 \text{ cm } - O_2\text{-target}$$

$$L \approx 10^{34} \text{ s}^{-1} \text{ cm}^{-2}$$

longitudinal and transverse c.m. momenta vs. acceptance



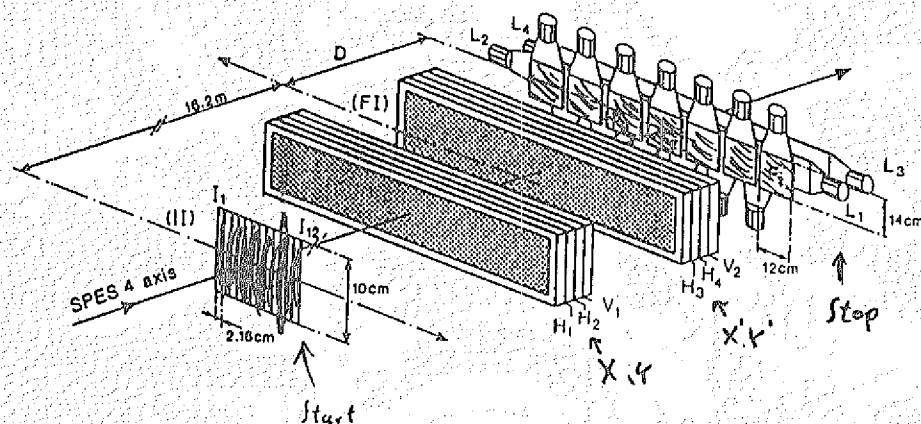
S P E S IV acceptance:

100% at threshold

rapidly falling off

⇒ Threshold microscope

STANDARD DETECTION SPES IV



MESON PRODUCTION NEAR THRESHOLD FROM THE $\phi(1020)$ TO THE $f_1(1285)$

J.P. Didelez, R. Frascaria, M. Morlet, R. Siebert, E. Warde

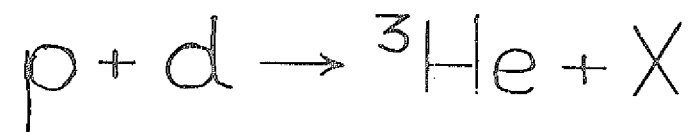
IPN Orsay

J. Arvieux, F. Plouin

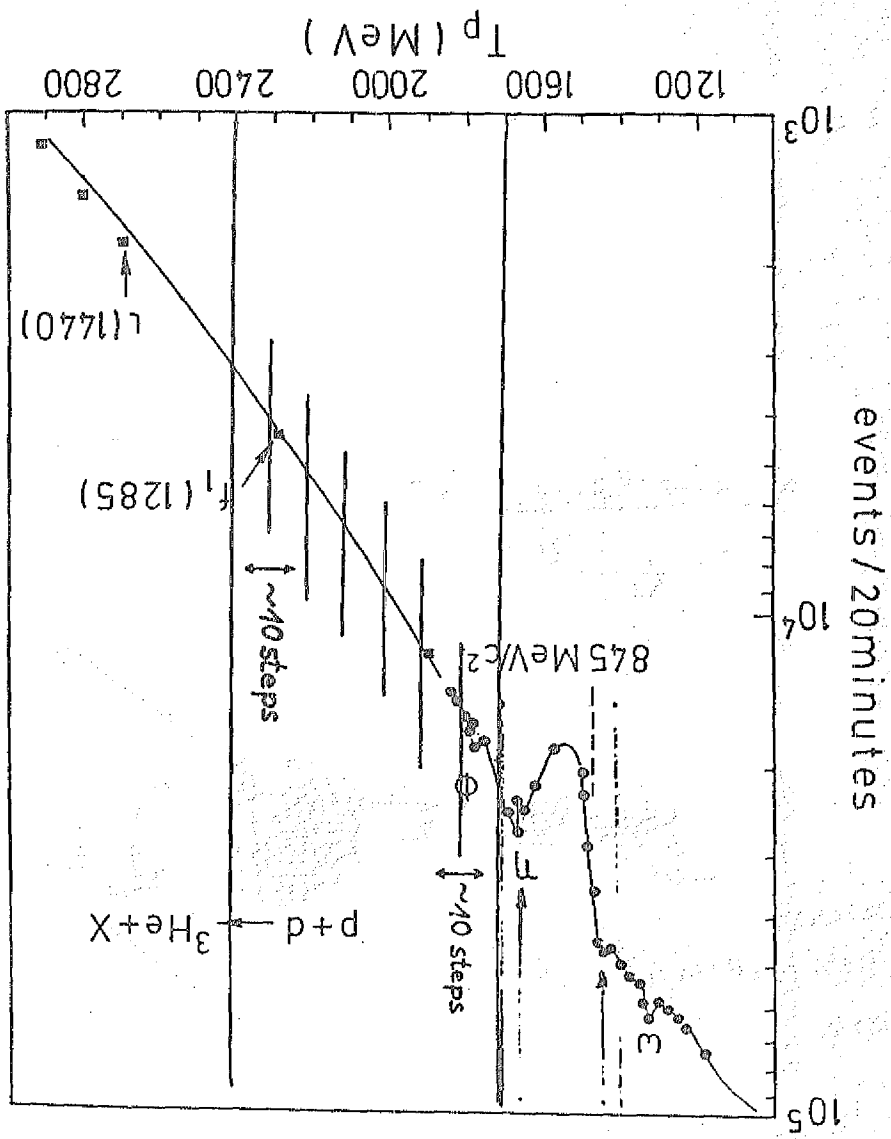
LN SATURNE

J. Bisplinghoff, J. Ernst, F. Hinterberger, R. Jahn, U. Lahr
C. Lippert, A. Marx, R. Wurzinger

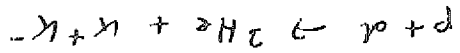
ISKP Bonn



Spokesmen: Rainer Jahn + Rainer Siebert



Towards Exclusivity



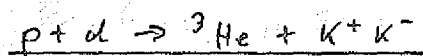
coincidence measurement

=> reduce background

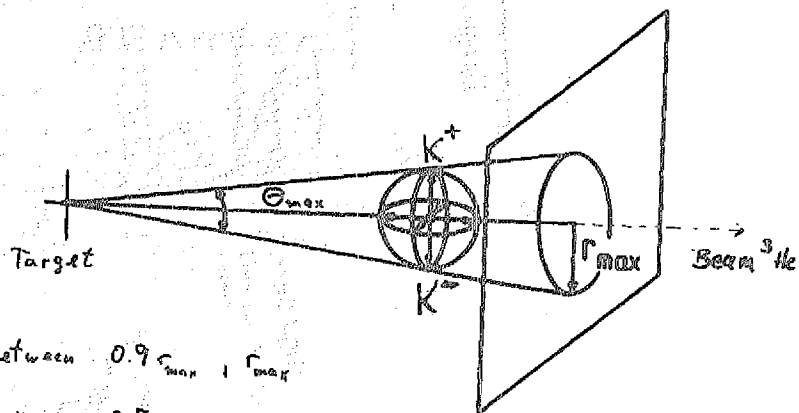
due to multi-pion

emission

KINEMATIK



$$p_{\text{cm } {}^3\text{He}} = 0$$



Efficiency

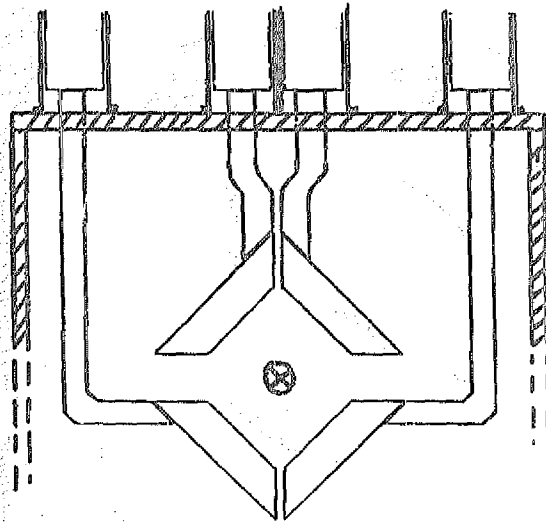
50% between $0.9 r_{\text{max}}$ and r_{max} 90% " $0.5 r_{\text{max}}$ and r_{max} 

$$\theta_{{}^3\text{He}} = 0^\circ$$

$$p_{0\text{cm } {}^3\text{He}} = 0$$

T (beam) (MeV)	T (c.m.) (MeV)	Missing Mass (MeV/c ²)	Theta (K) max (Degrees)	
1731	0.5	988	2.7	
1745	7.4	995	10.5	
1760	14.8	1002	14.5	
1775	22.2	1010	17.5	
1790	29.5	1017	20	
1805	36.9	1024	22	<- phi
1820	44.2	1031	24	
1835	51.5	1039	25.5	

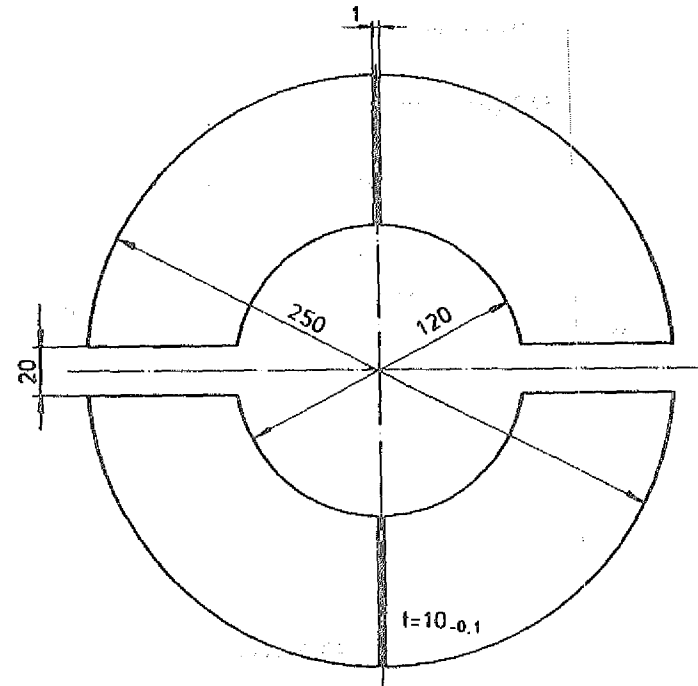
SCHEMATIC VIEW OF THE COINCIDENCE SET-UP



Scintillators

$$12^\circ \leq \theta_{lab} \leq 26^\circ$$

1cm thick



counting rates (from GEANT calculations):

- total hadronic cross section 100 mb
- $\Rightarrow$ 5 mb/counter (acceptance 10-26 deg.)
- D_2 -target 2cm

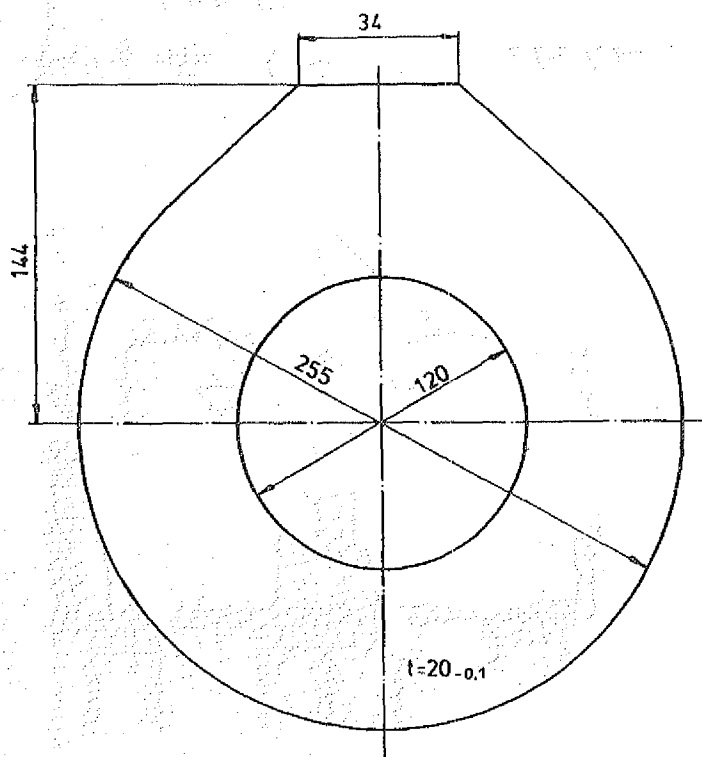
$$10^9 \text{ p/burst} \Rightarrow 1 \text{ MHz counts/burst}$$

Cross Plot			
Q ₁	Q ₂	Q ₃	Q ₄
100	100	100	100
100	100	100	100
100	100	100	100
100	100	100	100
100	100	100	100
100	100	100	100
100	100	100	100
100	100	100	100
100	100	100	100

zul. Abw. DIN 7168 m		Maßstab 1:2
Datum	12.2.90	Szintillatoren
Gepr.	11	
Norm	115	
ISKP		AB-769.3
Zust.		Blatt 2

Čerenkov Detector

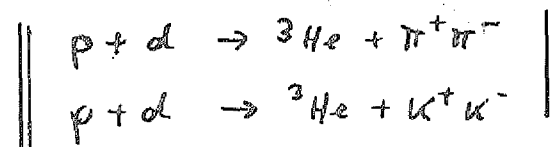
2cm Plastic



202

COSY exp. #6

A precision study of near
threshold two meson production
via the reactions



J. Bisplinghoff, J. Ernst, O. Erberheim, F. Hinterberger
R. Jahn, G. Marx, T. Mayer-Kuehn, T. v. Oepen, P. Schenk
R. Wurtzinger ISKP Bonn

B. Metsch, H. Petry ITKP Bonn

P. v. Neumann-Losel TH Darmstadt

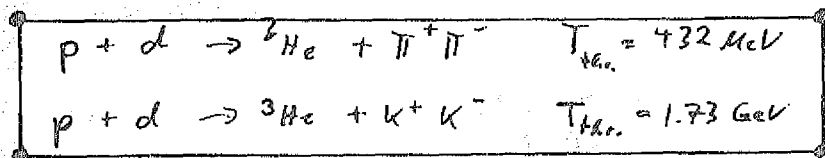
W. Oelert, P. von Rosen, B. Seligmann
KFA Jülich

L. Garczyk, J. Smyrski, A. Strzałkowski
Univ. Krakow

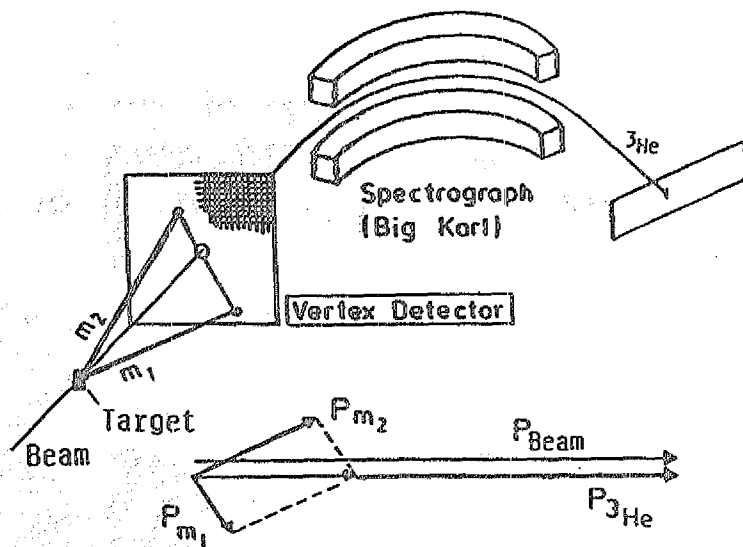
J.P. Didelez, R. Francina, R. Siebert, E. Wards
IPK Orsay

U. Wienands TRIUMF

Bedeutung Abkürzungen für Eigenschaften (Werte in eV)									
Eigenschaften	Massen					Lebensdauer			
	0.5	1	2	5	10	0.5	1	2	5
Elektron	0.5	1	2	5	10	0.5	1	2	5
Proton	0.5	1	2	5	10	0.5	1	2	5
Neutron	0.5	1	2	5	10	0.5	1	2	5
Photon	0.5	1	2	5	10	0.5	1	2	5
Neutrino	0.5	1	2	5	10	0.5	1	2	5



Vertex Method

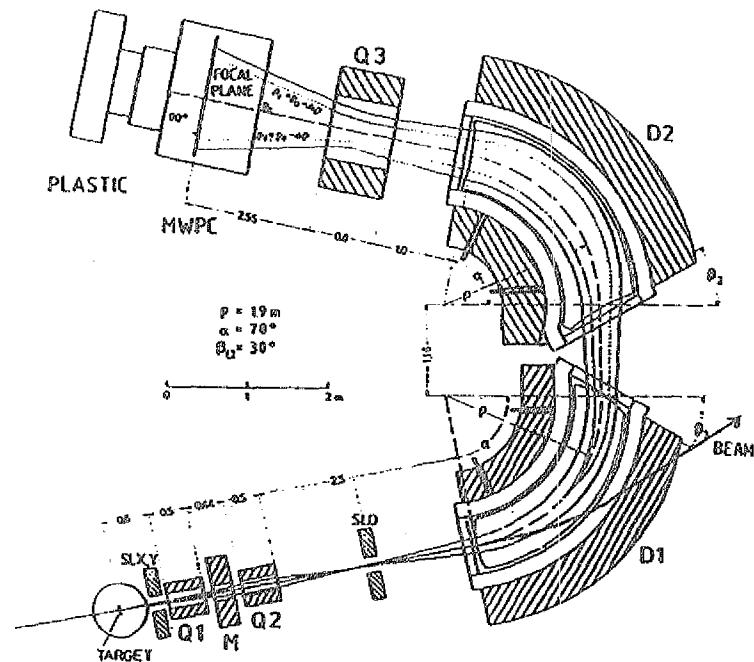
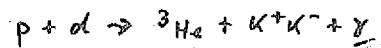


measured quantities: $\vec{P}_{3\text{He}}$, $T_{3\text{He}}$

$\vec{P}_{m_1} (\rightarrow T_{m_1})$

$\vec{P}_{m_2} (\rightarrow T_{m_2})$

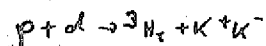
Total energy conservation $\Rightarrow m_1 + m_2$
 $\Rightarrow$ kinematically complete (+1)



'BIG KARL'

Time of Flight

(BIG KARL)

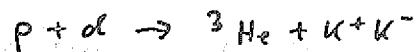


Distance target - focal plane detector : 15 m

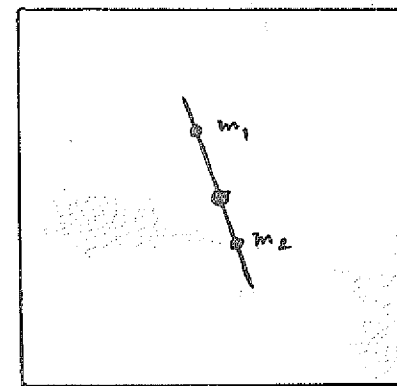
$$P_{3\text{He}} : 2.6 \text{ GeV}/c \hat{=} B_S = 3.336 \text{ Tm}$$

momentum acceptance: $\Delta p/p = 8\%$

	π	K	p	d	t	${}^3\text{He}$	
To F:	51	56	<u>68</u>	<u>102</u>	151	<u>86</u>	[ns]

 $\Rightarrow$ unique + fast ${}^3\text{He}$ identification $\rightarrow$ 'clean' coincidence with vertex wall $\rightarrow$ very few chance coincidences'Physics' background:

discrimination by 'wrong' kinematics



Vertexwand

"echte" Ereignisse koplanar

$$(\theta_{3\text{He}} = 0^\circ)$$

$$\theta_{3\text{He}} \neq 0^\circ$$

Koplanar bezgl. Richtung
des Gesamtmesonenimpulses

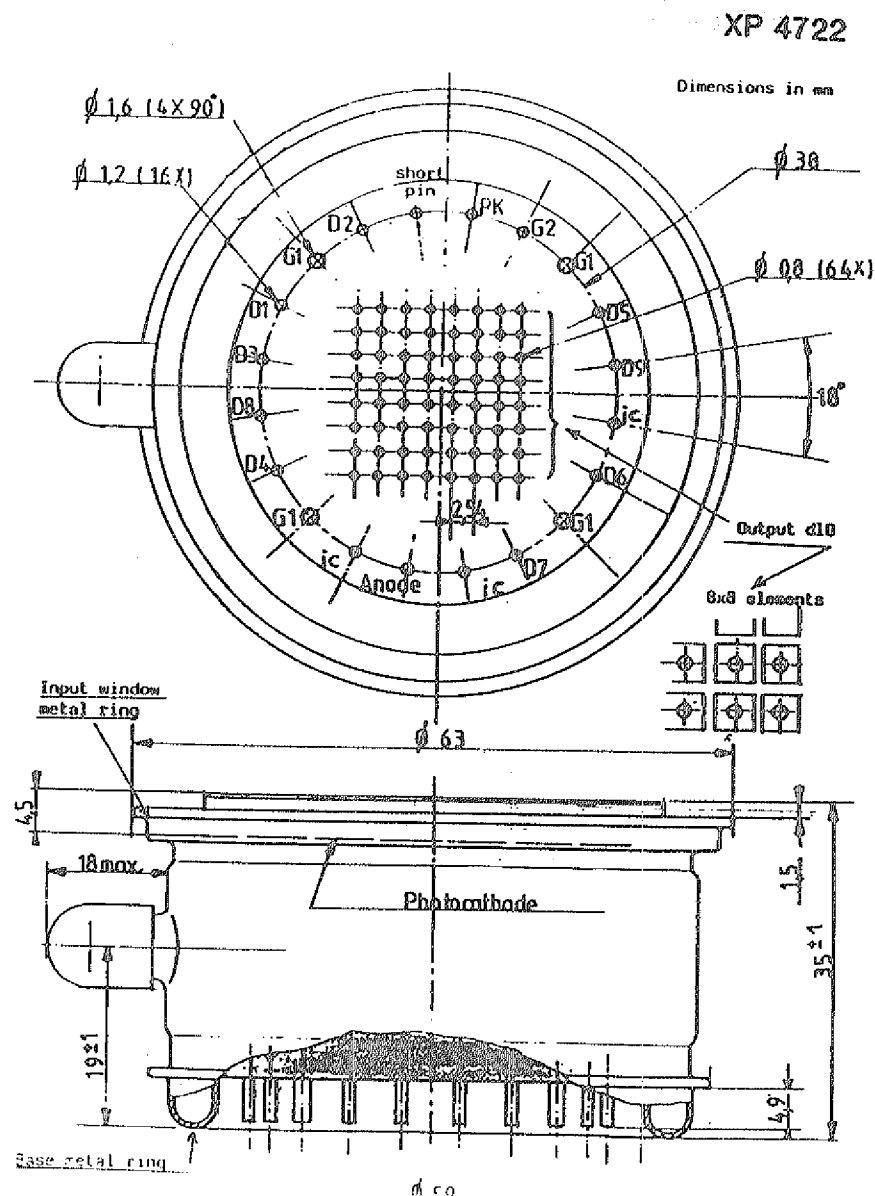
Scintillating Fibres

Test in focal plane
of Sper IV

Bonn → COSY experiments
3 tubes , 2 students

Orsay → strangerer project
1 tube

Collaboration: Bonn, LNS, Orsay



Count rates

3 mm liquid D_2 - target

$$\hat{=} 50 \text{ mg/cm}^2 \hat{=} 1.5 \cdot 10^{22} \text{ d/cm}^2$$

average beam current: 10^9 p/s (5 s on, 5 s off)

$$\Rightarrow \boxed{L = 1.5 \cdot 10^{31} \text{ cm}^2/\text{s}}$$

$$\boxed{10 \text{ nb} \hat{=} 1.3 \cdot 10^4 \text{ events per day}}$$

background: $\sigma_{tot} \sim 100 \text{ mb}$

$$\hat{=} 3 \cdot 10^6 / \text{s} \quad (\text{beam on})$$

$$\hat{=} 250\,000 / \text{s} \quad \text{in each front hodoscope segment}$$

coincidence rate in hodoscope $\sim 100\,000 / \text{s}$

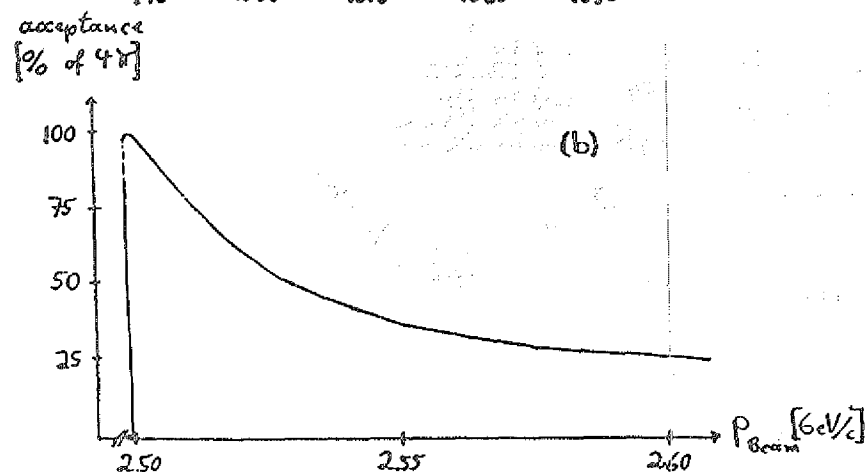
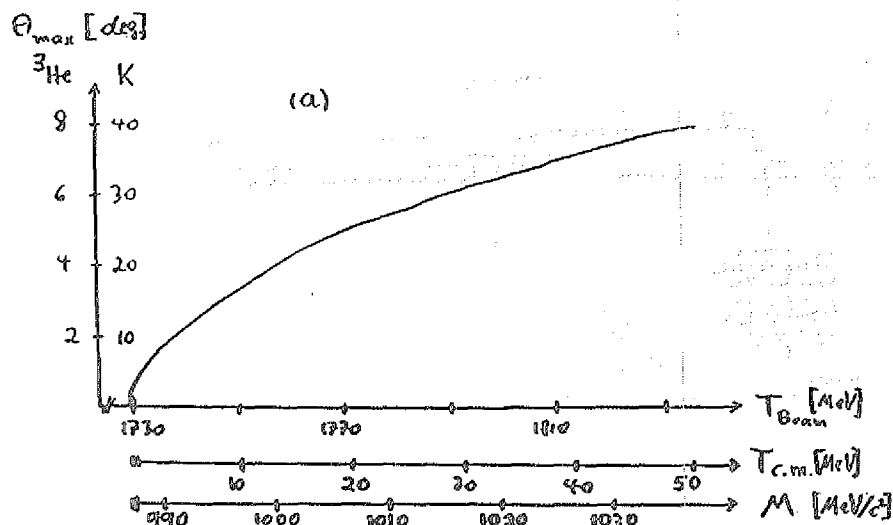
average time between two coincidences in

hodoscope: 10 000 ns!

^3He count rate in focal plane: $< 100 / \text{s}$

ON LINE Trigger:

^3He in focal plane + coincidence in hodoscope



Maximum laboratory opening angles (a) and detection efficiency (b) for the energy range under study

Physics

in the 1 GeV missing mass region

(see e.g. N. Isgur talk at meson workshop)
Paris 1988

Search for a $K\bar{K}$ bound state

Φ - nucleon interaction

Search for lowest $s\bar{s}$ (0^+) state via radiative
 $\Phi(1020)$ decay

Search for lightest glueball ???!

K.L. Au, D. Morgan, M. Pennington Phys. Rev. D35 (1987)

$f_0(975)$ (former) $\begin{cases} \rightarrow S_1(991) & \text{glueball ???} \\ \rightarrow S_2(988) & s\bar{s} \text{ ground state?} \end{cases}$

measure : $\Phi \rightarrow S_2 \gamma$!

$S_1 \rightarrow K\bar{K}$
 $\pi\pi$

1000

1000

1000

1000

1000

1000

1000

1000

1000

1000

1000

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