



Institut für Kernphysik

3rd ANKE Workshop on "Scalar Meson Production at ANKE/COSY"

Proceedings

Edited by

Markus Büscher, Vera Kleber and Iza Zychor

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft



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3rd ANKE Workshop on "Scalar Meson Production at ANKE/COSY"

Proceedings

Organized by
The Andrzej Soltan Institute for Nuclear Studies (IPJ)
and Forschungszentrum Jülich GmbH (FZJ)
at the
Madralin Conference Center
of the Polish Academy of Sciences
May 22/23, 2002

Edited by
Markus Büscher, Vera Kleber and Iza Zychor

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Preface

The workshop on "Scalar Meson Production at ANKE/COSY" was held at the *Maḡdralin Conference Center of the Polish Academy of Sciences* close to Warsaw, Poland, on May 22/23, 2002. The meeting was jointly organized by the *Andrzej Soltan Institute for Nuclear Studies (IPJ)* and the *Institute for Nuclear Physics of the Forschungszentrum Jülich GmbH (FZJ)*. It was the third in a series of topical workshops of the ANKE collaboration, the first took place at ITEP, Moscow (2000)¹ and the second at PNPI, Gatchina (2001)².

During the workshop the latest experimental results on the production of $a_0^+(980)$ resonances in proton-proton interactions, obtained with the ANKE spectrometer at the synchrotron COSY-Jülich, were intensively discussed. 15 scientists from Poland, Russia and Germany joined the workshop and 11 talks were presented. These presentations focussed on yet unpublished data from ANKE, on possible theoretical interpretations of these data, and on future measurements at ANKE. In addition, two talks were given on related experimental results from other facilities (WASA@CELSIUS, TAPS@AGOR&GSI).

The workshop benefitted greatly from financial support by the German Ministry for Education and Research (BMBF)³, the Polish State Committee for Scientific Research (KBN) and the board of management of the FZJ which is gratefully acknowledged. Last but not least we would like to thank the local organizers for the organization of the meeting. We enjoyed very much the inspiring atmosphere at the *Maḡdralin Conference Center* which led to extremely lively and fruitful discussions.

Jülich, June 2002

Markus Büscher, Vera Kleber and Iza Zychor

¹ Berichte des Forschungszentrums Jülich, Jül-3801, ISSN 0944-2952, Editors M.Büscher and V.Kleber (July 2000)

² Berichte des Forschungszentrums Jülich, Jül-3922, ISSN 0944-2952, Editors M.Büscher, V.Kleber, P.Kulesa and M.Nekipelov (Nov. 2001)

³ WTZ-POL-99/007, WTZ-POL-01/015

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**3rd ANKE workshop on
"Scalar Meson Production at ANKE/COSY"
May 22/23, 2002
IPJ Swierk**

Wednesday, May 22

		<i>Chairperson: H. Ströher</i>
09:00	Z. Sujkowski (IPJ)	Welcome/Introduction
09:30	M. Büscher (FZJ)	Investigation of Light Scalar Mesons at ANKE
10:45	V. Kleber (FZJ)	Status of Data Analysis: $pp \rightarrow dK^+\bar{K}^0$ Channel
11:30	P. Fedorets (ITEP, FZJ)	Status of Data Analysis: $pp \rightarrow d\pi^+\eta$ Channel
13:45	J. Stepaniak (IPJ)	Light Meson Production and Decay Studies with WASA
14:30	T. Matulewicz (IPJ)	Particle Production in Proton and Nucleus Induced Reactions around 200A MeV
15:45	A. Sibirtsev (FZJ)	Identification of Resonant a_0^+ Structures in the $dK^+\bar{K}^0$ Dalitz Plot
16:30	V. Koptev (PNPI)	Heavy Hyperons at ANKE

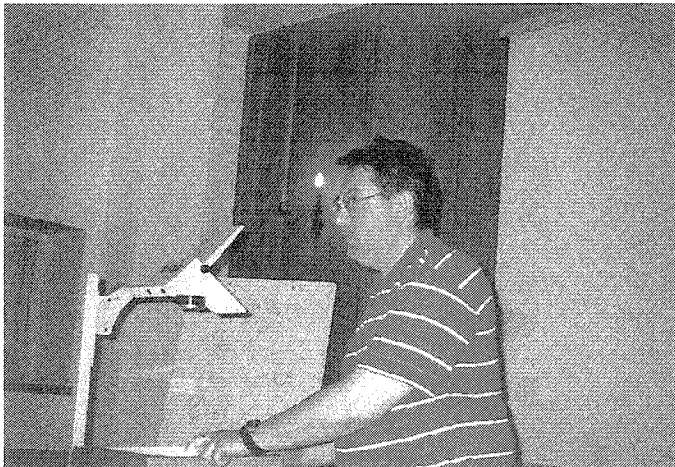
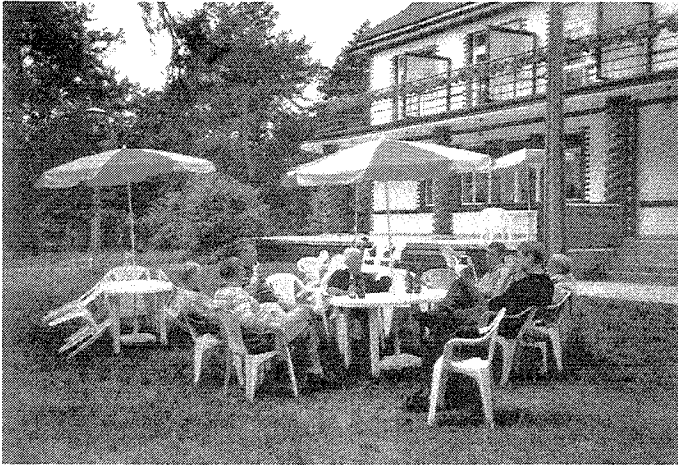
Thursday, May 23

		<i>M. Büscher</i>
09:00	V. Grishina (ITEP)	$a_0(980)$ Resonance Production and Nonresonant Background in the Reaction $pp \rightarrow dK^+\bar{K}^0$ near Threshold
09:45	C. Hanhart (FZJ)	Theoretical Approaches to Meson Production in NN Collisions
11:00		Discussion
11:45	H. Ströher (FZJ)	Workshop Summary

List of participants

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11	J. Stepaniak	IPJ Warsaw	joste@fuw.edu.pl
12	H. Ströher	FZ Jülich	h.stroeher@fz-juelich.de
13	Z. Sujkowski	IPJ Swierk	sujkowsk@ipj.gov.pl
14	P. Zupranski	IPJ Warsaw	zupran@fuw.edu.pl
15	I. Zychor	IPJ Swierk	zychor@iriss.ipj.gov.pl

Photos taken during the workshop



Investigation of Light Scalar Mesons at ANKE

M. Büscher

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Germany

The investigation of the light scalar resonances $a_0/f_0(980)$ has attracted wide interest during the last decades, both on the theoretical and experimental side. However, it is not clear yet whether they are members of a $J^P = 0^+ q\bar{q}$ nonet or whether they have a different structure. Some authors claim (see e.g. [1]) that these states are of dynamical origin, e.g. generated via strong final-state interaction (FSI) effects. The existing data on the production of the light scalars in $\bar{p}p$, π^-p and $p(450\text{GeV})p$ reactions do not allow to draw unambiguous conclusions about their nature. The experimental program on the production (in pp collisions) and decay of the $a_0/f_0(980)$ [2,3] with the ANKE spectrometer at COSY-Jülich aims at additional information which might be sensitive to the structure of these resonances.

In a first set of experiments the reactions $pp \rightarrow dK^+\bar{K}^0$ and $pp \rightarrow d\pi^+\eta$ were studied up to the maximum COSY beam energy of $T_p = 2.83$ GeV by detecting two coincident charged ejectiles, dK^+ or $d\pi^+$, with high momentum resolution. This beam energy is ideally suited to study the production of the pure isospin ($I=1$) state a_0^+ close to the $K\bar{K}$ threshold. It has been pointed out [1] that reactions of the type $pp \rightarrow dP_1P_2$ (the P_i denote pseudoscalar mesons) are sensitive to *both* the meson-meson and meson-baryon final-state interaction, in particular close to threshold where FSI effects are supposed to be large. Furthermore, the deuteron in the exit channel is a spin-/isospin filter which might simplify the interpretation of the data.

The first measurement was carried out in the beginning of 2001 at $T_p = 2.65$ GeV. Both reaction channels could be identified, the data are almost background free for the dK^+ case, whereas the η signal sits on a huge background in the $d\pi^+$ missing-mass distribution [4,5]. It is expected that the total production cross sections (for $K\bar{K}$ and $\pi\eta$), differential distributions like Dalitz plots (see also [6]) and angular distributions can be extracted from the data. However, it will be difficult to model-independently determine the fraction of resonantly produced $K\bar{K}$ pairs since only a limited mass range of $\Delta m_{KK} \approx 45$ MeV/ c^2 is accessible in this experiment.

The (very preliminary) shape of the $K^+\bar{K}^0$ mass distribution measured during a second beam time at $T_p = 2.83$ GeV in spring 2002 agrees well with model predictions [7]. Since these data cover a significantly wider mass interval, $\Delta m_{KK} \approx 100$ MeV/ c^2 , it should be possible to separate the a_0^+ signal from the non-resonant background [4].

A proposal [3] to measure the production of the neutral a_0^0/f_0 resonances in $pn \rightarrow da_0^0/f_0$ reactions has already been approved by the COSY-PAC and three weeks of beam time have been granted. It is planned to perform the measurements in 2003 using the detection system for K^- mesons which has been taken into operation in spring 2002. Additional information about the structure of the neutral scalar states might be obtained here from the measurement of isospin breaking $a_0(I=1)$ - $f_0(I=0)$ mixing [3,8].

- [1] E.Oset et al., Eur.Phys.J **12** (2001) 435–446; nucl-th/0109050.
- [2] M.Büscher et al., COSY proposal #55, available via www.fz-juelich.de/ikp/anke.
- [3] M.Büscher et al., COSY proposal #97, available via www.fz-juelich.de/ikp/anke.
- [4] V.Kleber, contribution to this workshop.
- [5] P.Fedorets, contribution to this workshop.
- [6] A.Sibirtsev, contribution to this workshop.
- [7] V.Grishina, contribution to this workshop.
- [8] C.Hanhart, contribution to this workshop.



3rd ANKE Workshop on
 a_0 Physics
May, 22/23, 2002
Swierk, Poland

- Thanks to the local organizers !!
- Proceedings
→ I.Zychor
Copies of transparencies
Written contributions (~1 page, LaTeX)
List of participants → MB, V.Kleber
P.Fedorets
- Agenda
- Goals (M.B.'s viewpoint)
Interpretation of the data on $pp \rightarrow da_0^+$
Ideas for further experiments like a_0^0/f_0 ?
.....and..... (input from YOU)?

This talk:

- Short overview over a_0 experiments with ANKE

Scalar mesons above and below 1 GeV

Frank E. Close¹

*Department of Theoretical Physics, University of Oxford,
Keble Rd., Oxford, OX1 3NP, United Kingdom*

Nils A. Törnqvist²

*Dept of Physical Sciences
University of Helsinki, Finland*

Abstract

We show that two nonets and a glueball provide a consistent description of data on scalar mesons below 1.7 GeV. Above 1 GeV the states form a conventional $q\bar{q}$ nonet mixed with the glueball of lattice QCD. Below 1 GeV the states also form a nonet, as implied by the attractive forces of QCD, but of more complicated nature. Near the center they are $(qq)_3(\bar{q}\bar{q})_3$ in S-wave, with some $q\bar{q}$ in P-wave, but further out they rearrange as $(q\bar{q})_1(q\bar{q})_1$ and finally as meson-meson states. A simple effective chiral model for such a system with two scalar nonets can be made involving two coupled linear sigma models. One of these could be looked upon as the Higgs sector of nonperturbative QCD.

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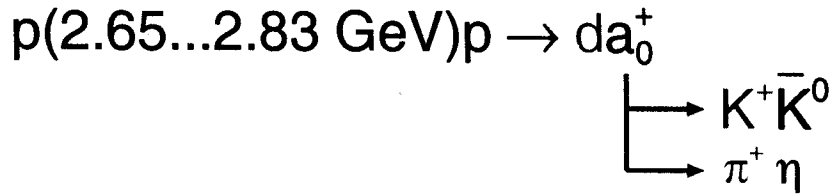
²e-mail: nils.tornqvist@helsinki.fi

Overview of the available data on a_0 production.

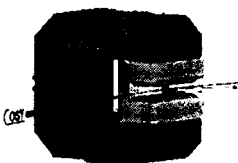
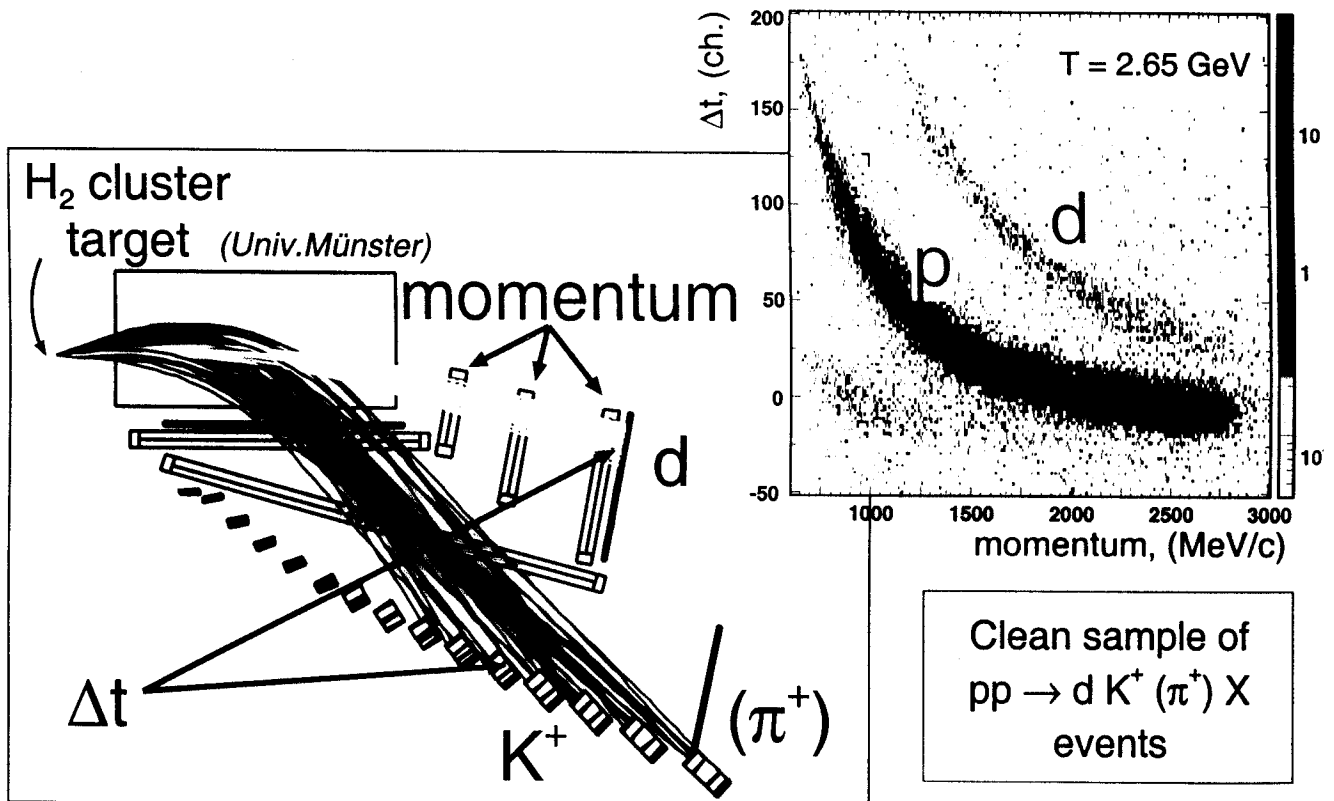
	Initial state	Detected a_0 decay	m_{a_0} (MeV)	Γ_{a_0} (MeV)	$\Gamma(K\bar{K}/\pi\eta)$	Ref.
WA 102	$p(450 \text{ GeV})p$	$\pi\eta$	988 ± 8	61 ± 19	$0.166^{+0.01}_{-0.02} *$	[8]
	$C\bar{B}$ $\left\{ \begin{array}{l} \bar{p}p \\ \bar{p}p \\ \bar{p}p \end{array} \right.$	$\pi\eta$	$984.45^{+1.23}_{-0.34}$	$54.21^{+0.34}_{-0.12}$		[4]
		$K\bar{K}$	982 ± 3	92 ± 8	$0.23 \pm 0.05^{**}$	[5]
		$K\bar{K}$	975 ± 15	65 ± 10		[6]
SL	$\pi^- p$	$\pi\eta$	993.1 ± 2.1	71 ± 7		[7]

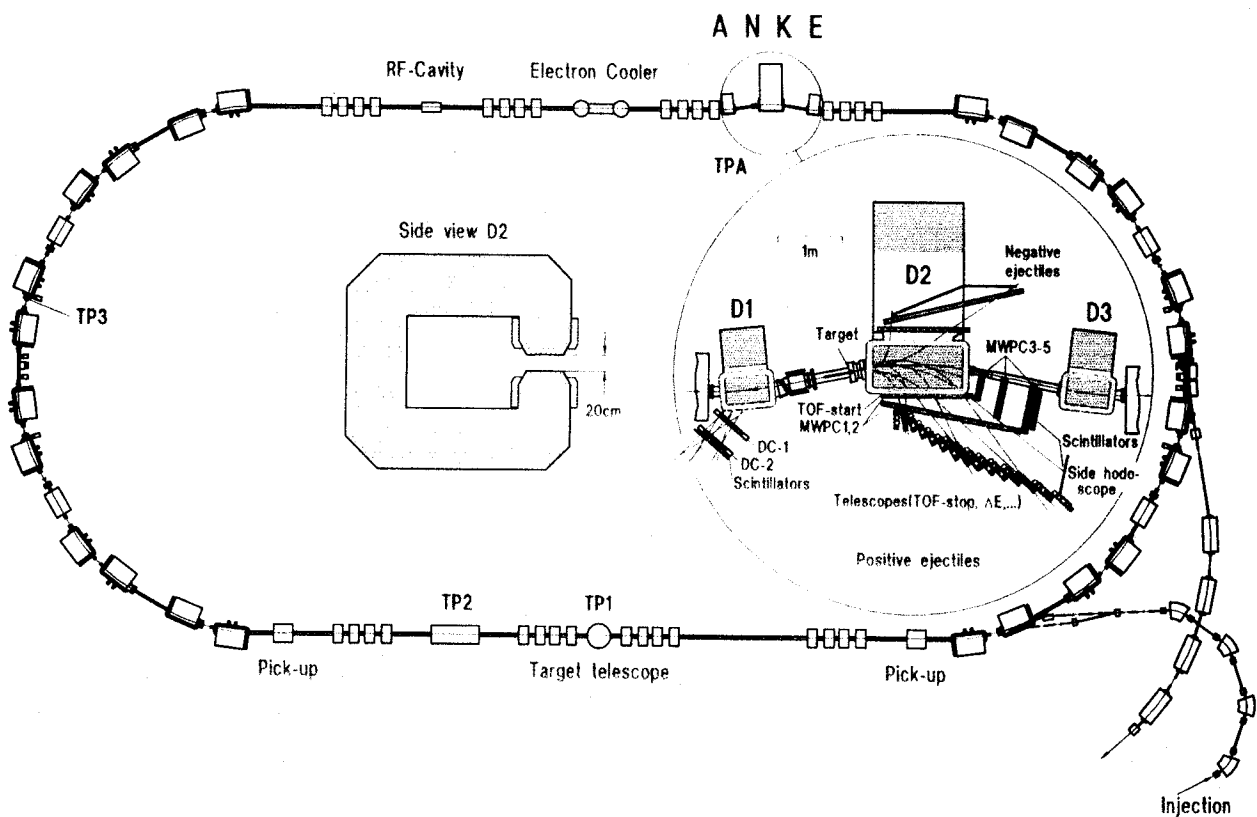
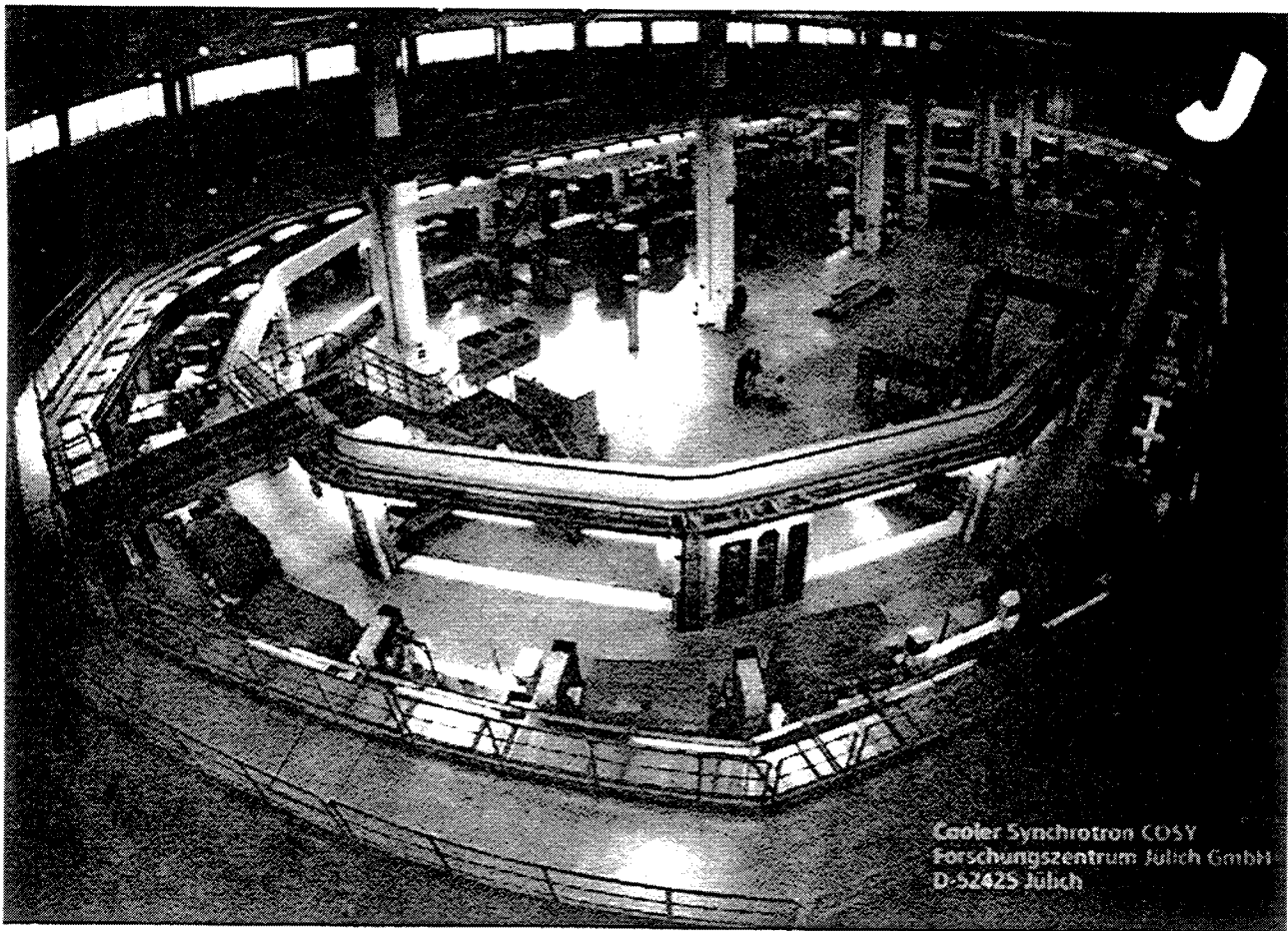
*using the known branching ratio $f_1(1285) \rightarrow K\bar{K}\pi$ **ratio of branching ratios using the results from [4] for $\Gamma(\pi\eta)$

Measurement of the a_0^+ (980) at ANKE



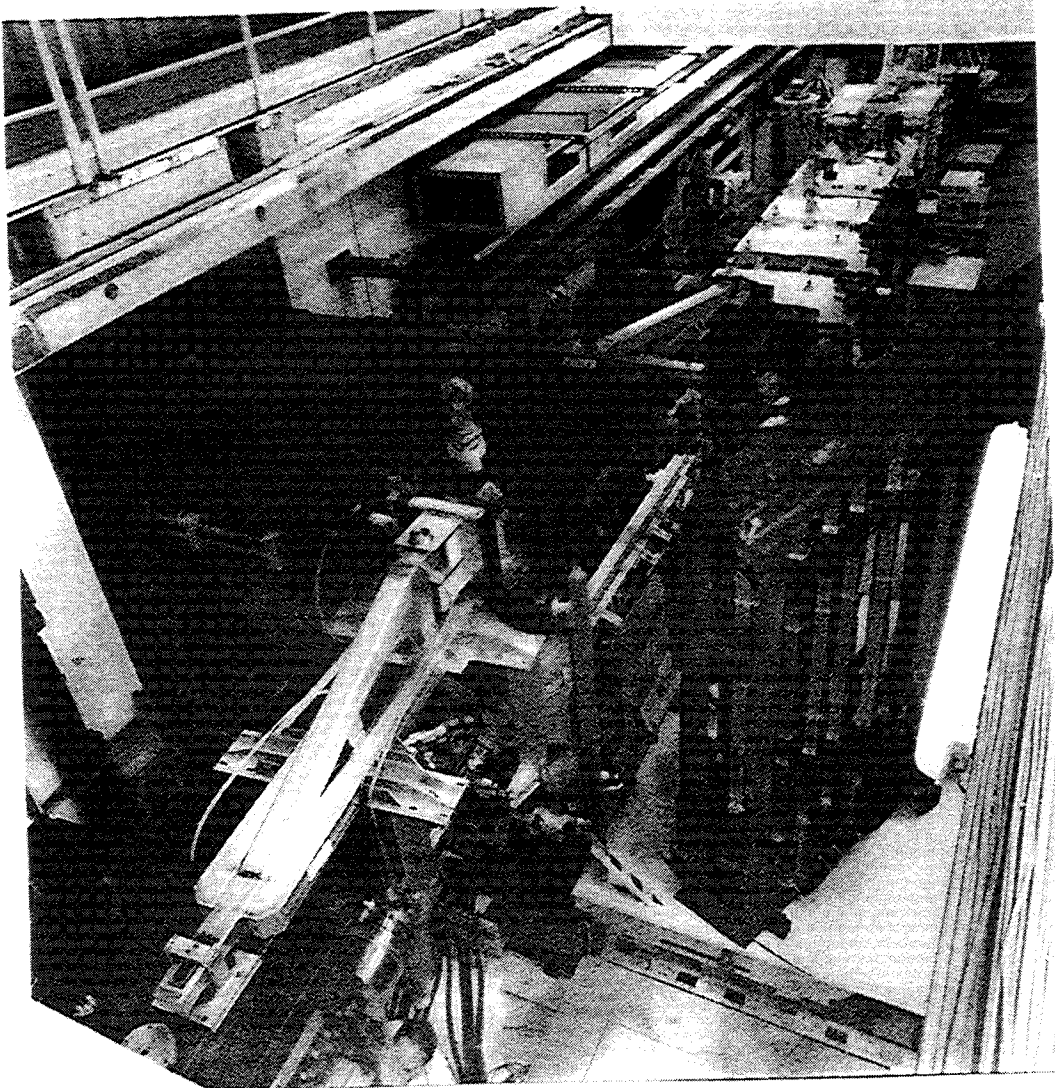
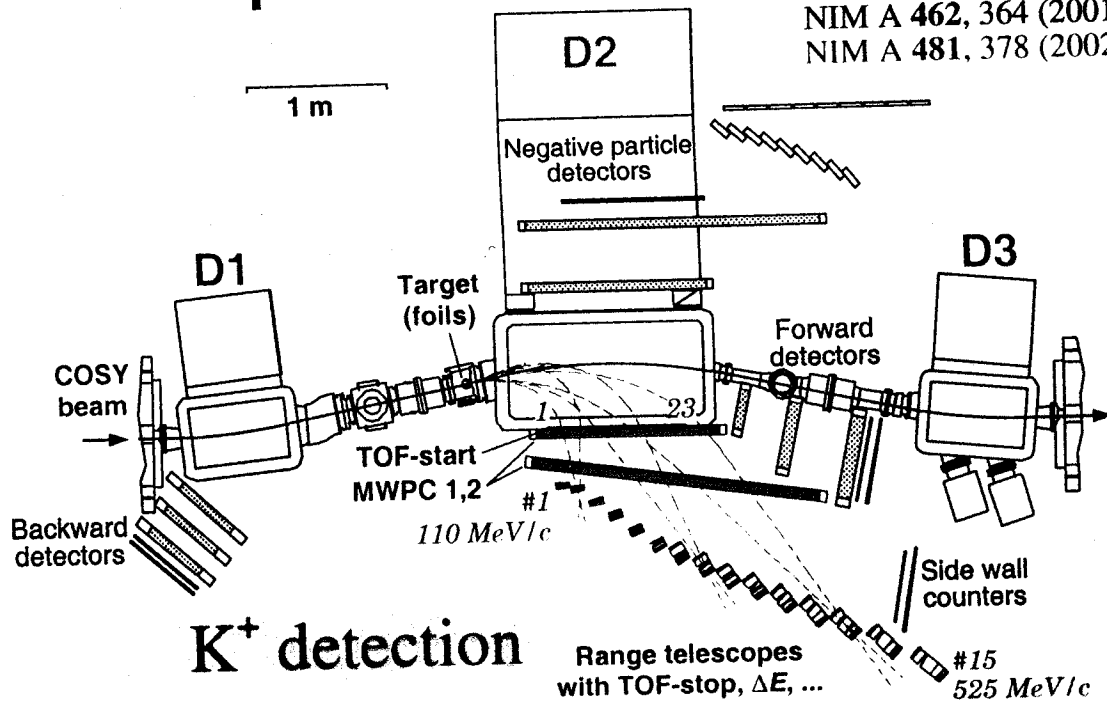
- Deuteron in final state $\rightarrow$ (iso-)spin filter
- Detection of both decay channels in a single experiment
 - Good missing mass resolution $\Delta m \sim 10 \text{ MeV}/c^2$
- Determination of absolute production cross sections





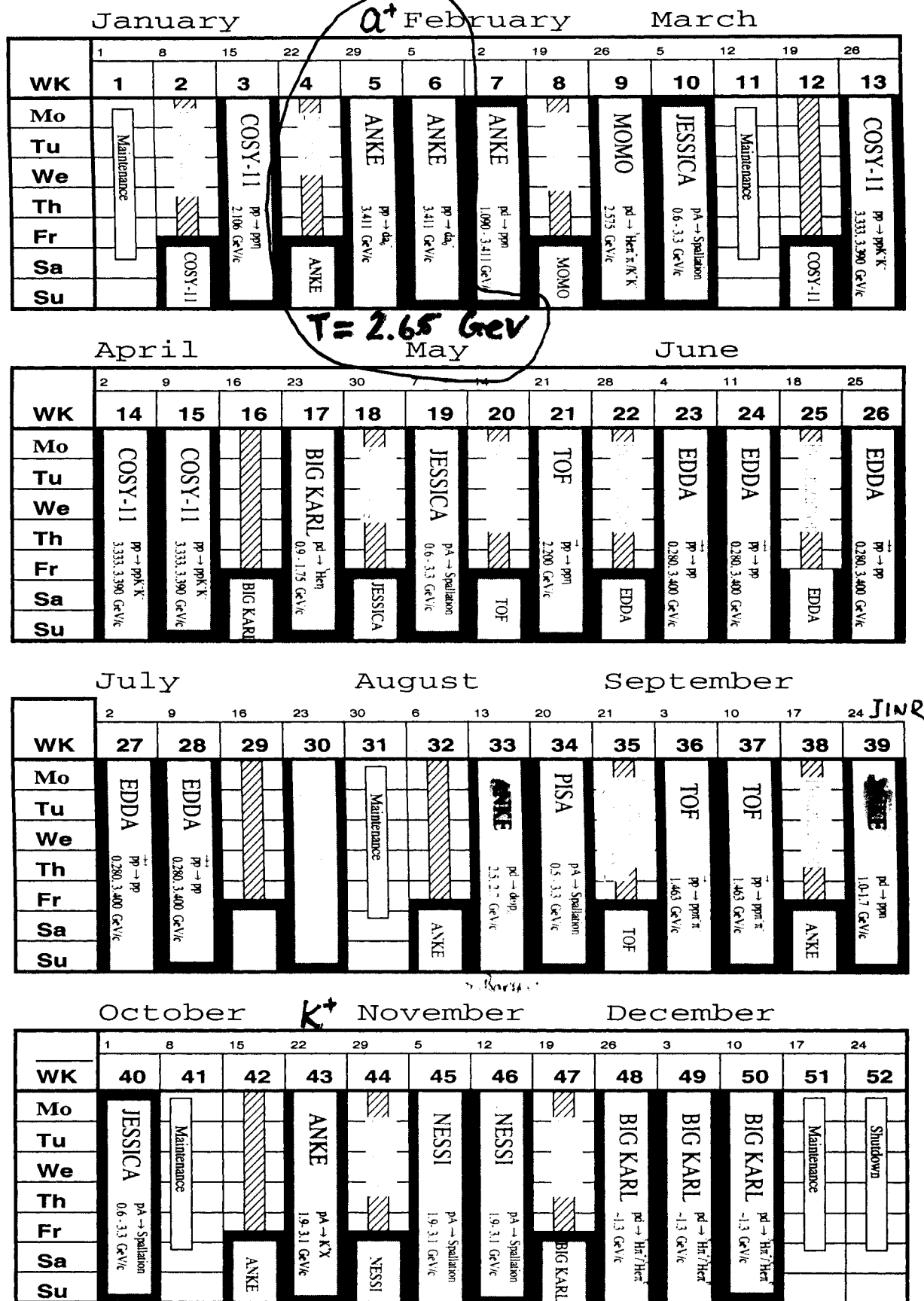
Spectrometer ANKE

NIM A 462, 364 (2001)
NIM A 481, 378 (2002)



M.Büscher, Φ 2002

COSY working scheme 2001



■ User Operation

▨ Machine Development

□ Maintenance

May 3, 2001

M. Büscher

m.buescher@fz-juelich.de

COSY beam-time schedule 2002

January					February					March				
	31	7	14	21	28	4	11	18	25	1	8	15	22	29
WK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mo														
Tu	Maintenance													
We														
Th														
Fr														
Sa														
Su														

April					May					June				
WK	1	8	15	22	29	6	13	20	27	3	10	17	24	
Mo	14	15	16	17	18	19	20	21	22	23	24	25	26	
Tu	CONV 11	ANKE 104	NESSI 64.6	NESSI 64.6	extraction & cooling	ESSICA 104	Maintenance	d beam	CONV 11	polarized d		CONV 11 100	CONV 11 62.3	
We		extraction											100	
Th													219.2 J 64.6	
Fr														
Sa														
Su														

July							August							September						
	1	8	15	22	29	5	12	19	26	2	9	16	23							
WK	27	28	29	30	31	32	33	34	35	36	37	38	39							
Mo	extraction	Tue 10C	Tue 10C		Wed 10C	Wed 10C		Thu 10C	Thu 10C		Conc 10C	Conc 10C								
Tu																				
We																				
Th																				
Fr																				
Sa				ANN									JESSICA							
Su																				

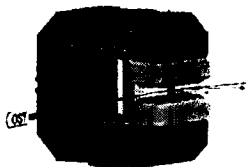
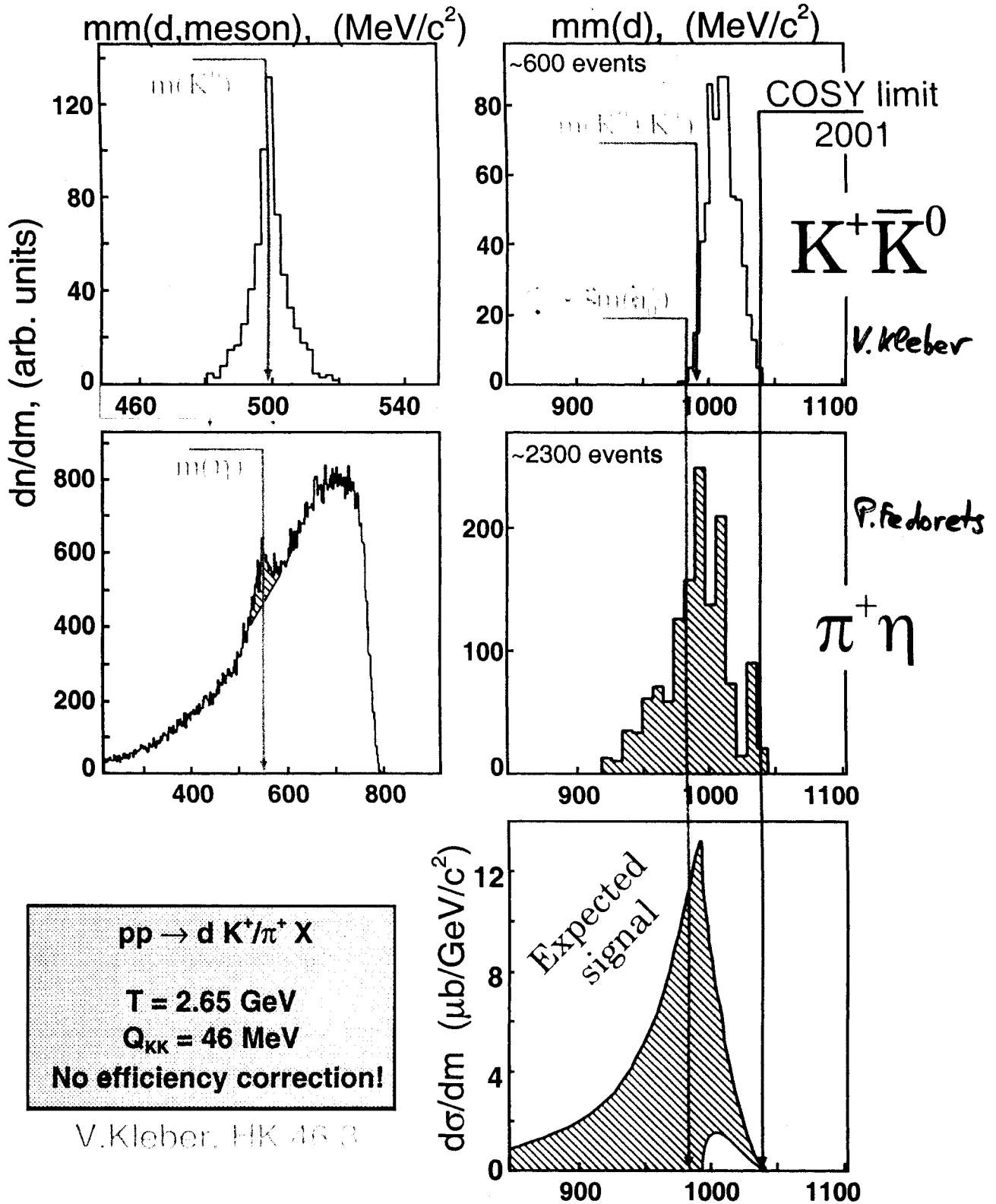
October					November					December				
	30	7	14	21	28	4	11	18	25	2	9	16	23	
WK	40	41	42	43	44	45	46	47	48	49	50	51	52	
Mo	JESSICA 105 PHILIP 106 21 (AVA)	Maintenance	PINA 105 21 (AVA)		TOM 105 21 (AVA)	TOM 105 21 (AVA)	TOM 105 21 (AVA)	TOM 105 21 (AVA)		TOM 105 21 (AVA)	TOM 105 21 (AVA)	Maintenance	Shutdown	
Tu														
We														
Th														
Fr														
Sa														
Su														

 User Operation
  Machine Development
  Maintenance
  Ring access

May 13, 2002

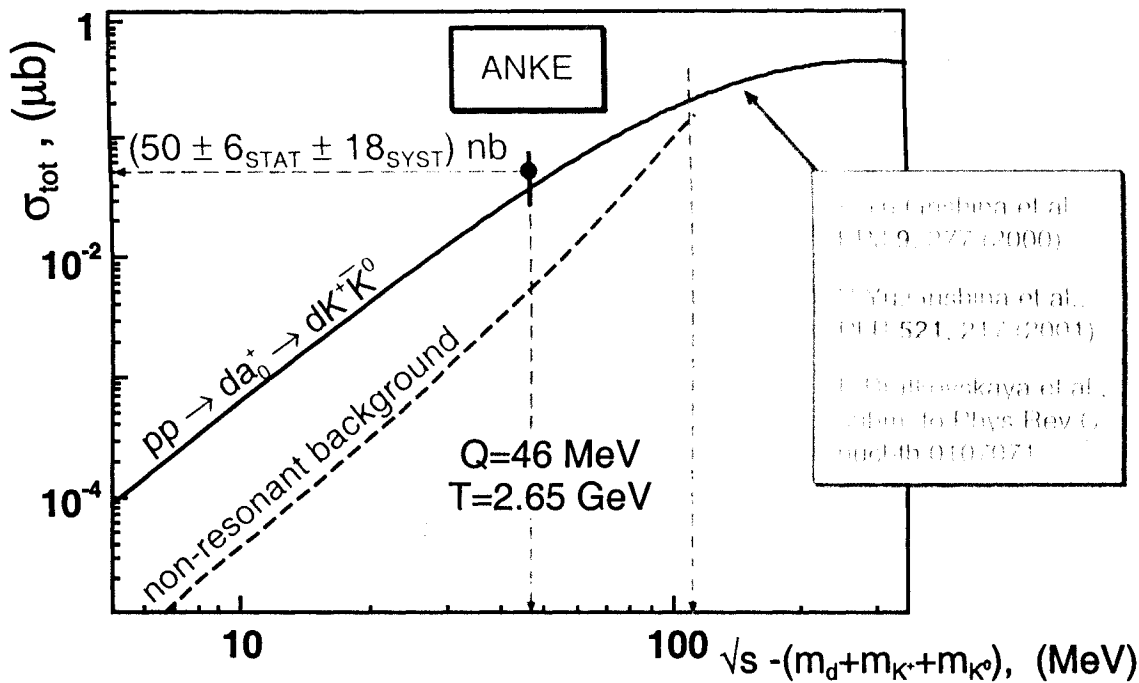
M. Büscher (m.buescher@fz-juelich.de)

$a_0^+(980)$ mesons at ANKE



a_0^+ (980) production cross section

V. Kleber, HK, 16/3, D. Fedorova, HK, 12/22



$$\sigma(pp \rightarrow da_0^+ \rightarrow dK^+ \bar{K}^0) = (50 \pm 6 \pm 18) \text{ nb}$$

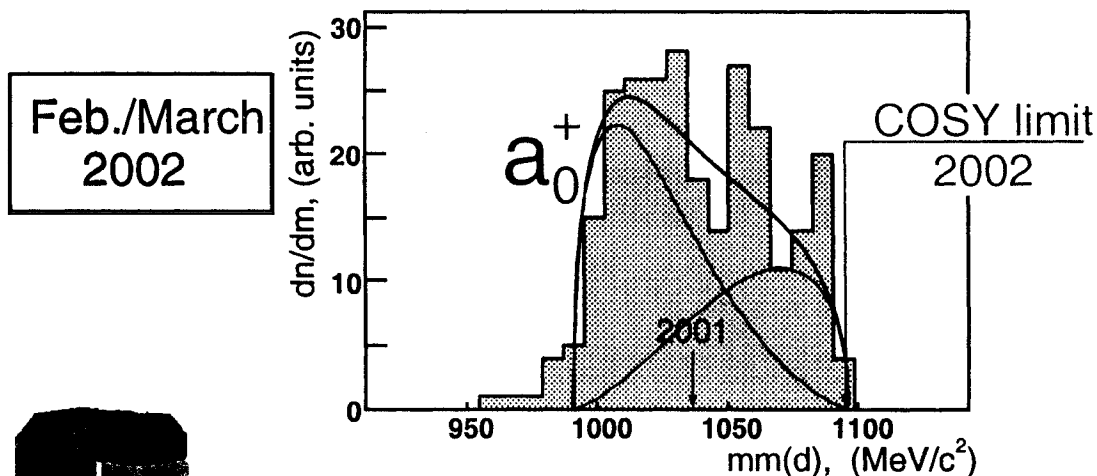
~15% non-resonant background

$$\sigma(pp \rightarrow da_0^+)/\sigma(pp \rightarrow d\rho^+) \sim 1/6$$

Comparable cross sections

M.A. Anisovich et al., PRL 25, 469 (1970)

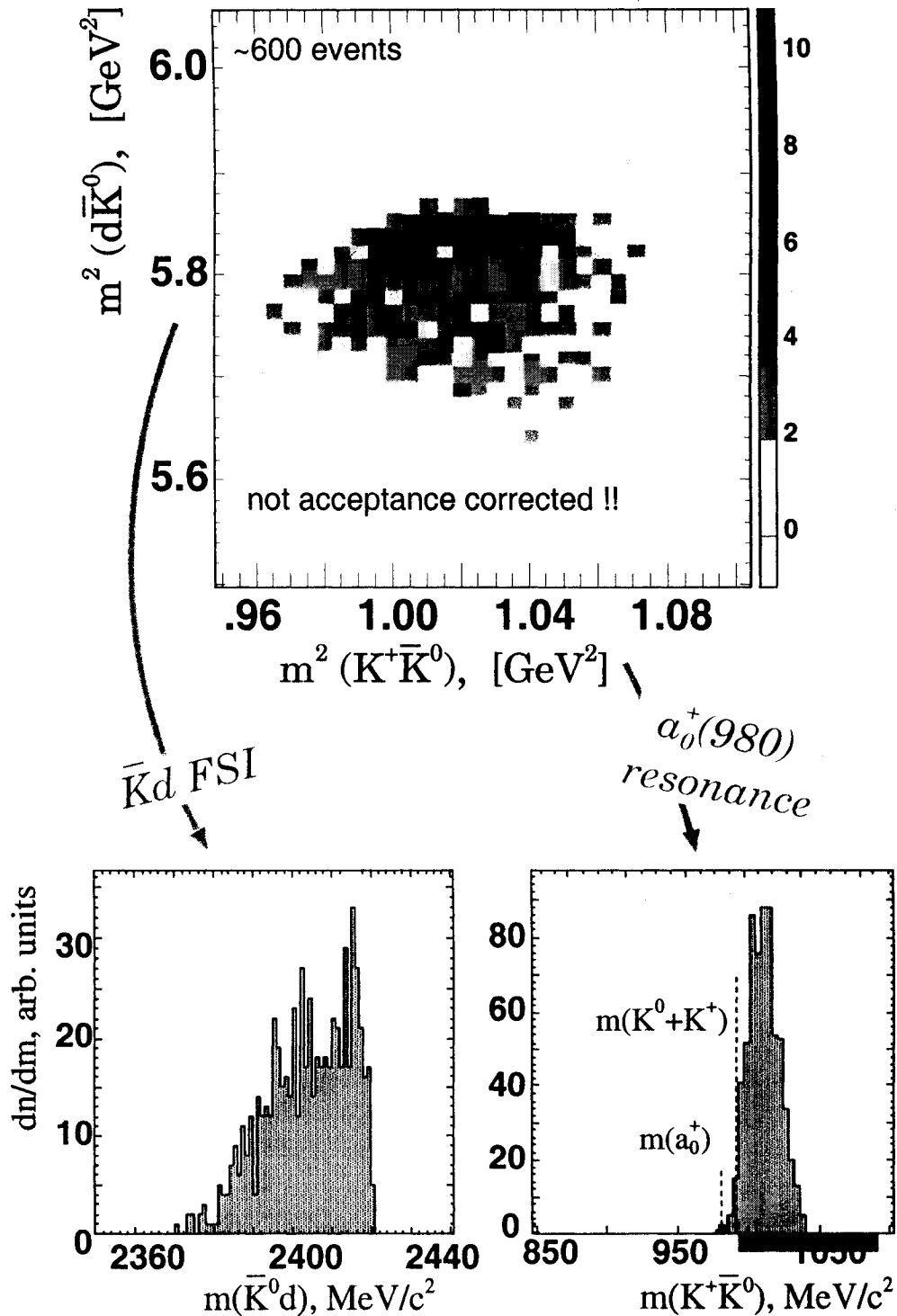
New data after energy increase of COSY ($\rightarrow 2.83 \text{ GeV}$)
(No acceptance/efficiency corrections yet, $\sim 1/6$ of total statistics)



M.Büscher, Φ 2002

Dalitz plot for the reaction $p(2.65 \text{ GeV})p \rightarrow dK^+\bar{K}^0$

V. Kleber, HK 46.3



Status report for COSY experiment #55
“Study of $a_0^+(980)$ -mesons at ANKE”
and
Proposal
“Investigation of neutral scalar mesons a_0/f_0 with
ANKE”

M. Büscher (Spokesperson), M. Hartmann, V. Kleber, R. Koch,
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and the ANKE collaboration

March 16, 2001

Abstract

During two weeks of beam time in Jan./Febr. 2001, the production of a_0^+ -mesons in the reaction $p(2.645\text{GeV})p \rightarrow da_0^+$ has been studied at the ANKE spectrometer. About 1000 correlated dK^+ ($d\pi^+$) events have been identified which can be interpreted in terms of $a(980)$ -meson production followed by a decay $a_0^+ \rightarrow K^+\bar{K}^0$ ($\rightarrow \pi^+\eta$). These count rates allow systematic investigations of the scalar mesons and we propose **3 weeks** of measurements of the neutral scalar mesons produced in a deuteron target $pn \rightarrow da_0^0/f_0$. The mesons will be identified by measuring their decay into $\pi^+\pi^-$ - and K^+K^- -mesons in coincidence with the fast deuteron. This requires the use of the detection system for negatively charged ejectiles which will be available at ANKE in the beginning of 2002.

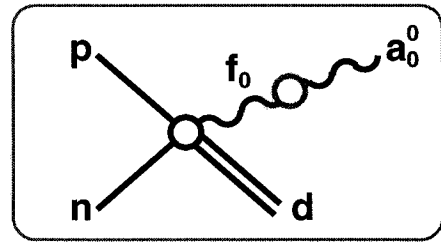
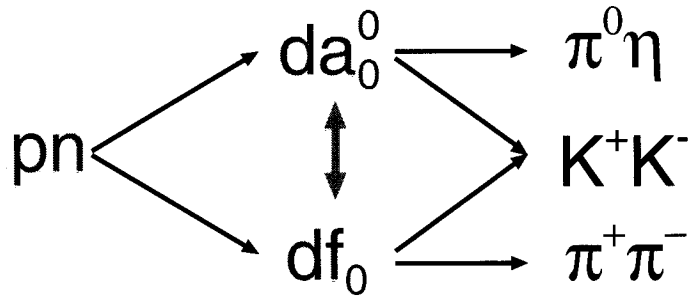
2. ANKE

Proposal 97 (M. Büscher):

The proposal to study the a_0 properties at ANKE (proposal #55) had received strong support from the PAC, resulting in 2 weeks of beam-time allocation in 2001. The collaboration has carried out the measurements and observed evidence compatible with a_0 production in $pp \rightarrow da_0^+$ reaction at 2.645 GeV. Based on these data, they propose to study neutral scalar meson (a_0^0/f_0) production in pn collisions using a deuteron cluster-jet target and a new detection system for negatively charged particles, available in the beginning of 2002.

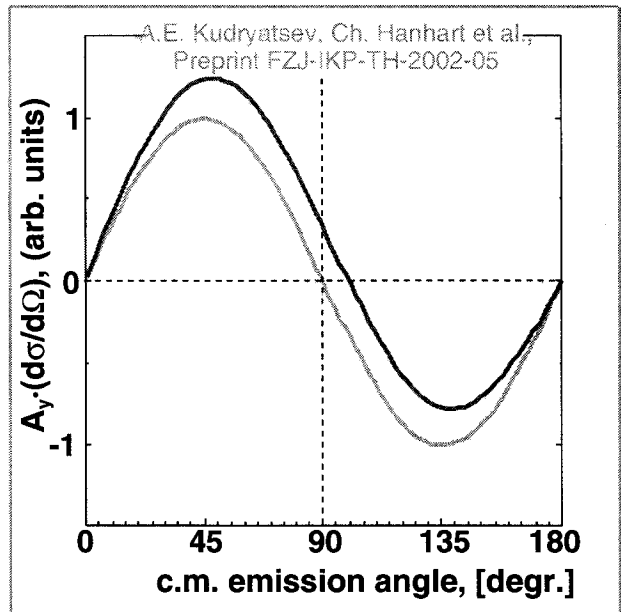
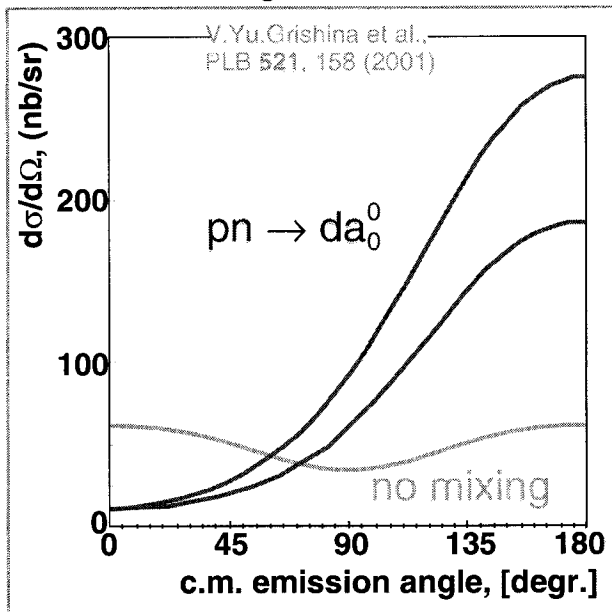
The PAC expressed its **unanimous appreciation for the proposal**. The physics case of the nature and the dynamical interaction of the $a_0(980)$ and $f_0(980)$ is one of the open problems which need clarification. The proposal represents a focussed effort that might lead to new knowledge. In addition, possible effects of isospin violation can also be investigated, which could represent an interesting cross check of the results of the experiment 59.5. In conclusion, the PAC feels it is important to verify that the observed events actually do represent an a_0 . PAC thus encourages the collaboration to carry out detailed Dalitz analyses. With this caveat, the PAC accepted the proposal and agreed with the estimate, based on the counting rate for the a_0^+ production, of the **3 weeks** necessary to collect few thousands of neutral scalar mesons. The collaboration is encouraged to present a request for beam time at the November PAC meeting.

$a_0/f_0(980)$ mesons @ ANKE



$a_0^0 \leftrightarrow f_0$ mixing

- violates isospin symmetry
- 'new' observable $\rightarrow$ structure of a_0/f_0
- distorts angular distributions
- Asymmetric analyzing power

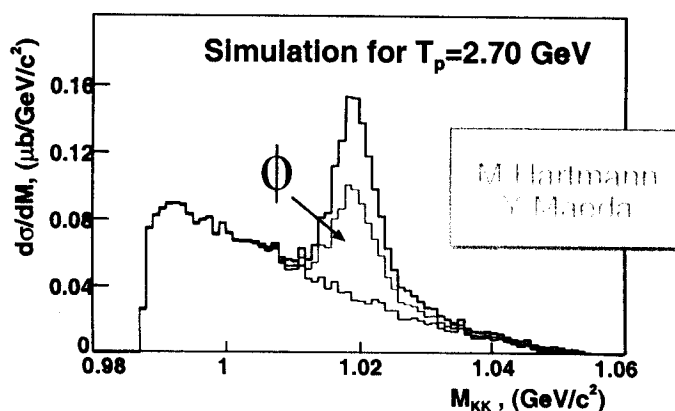
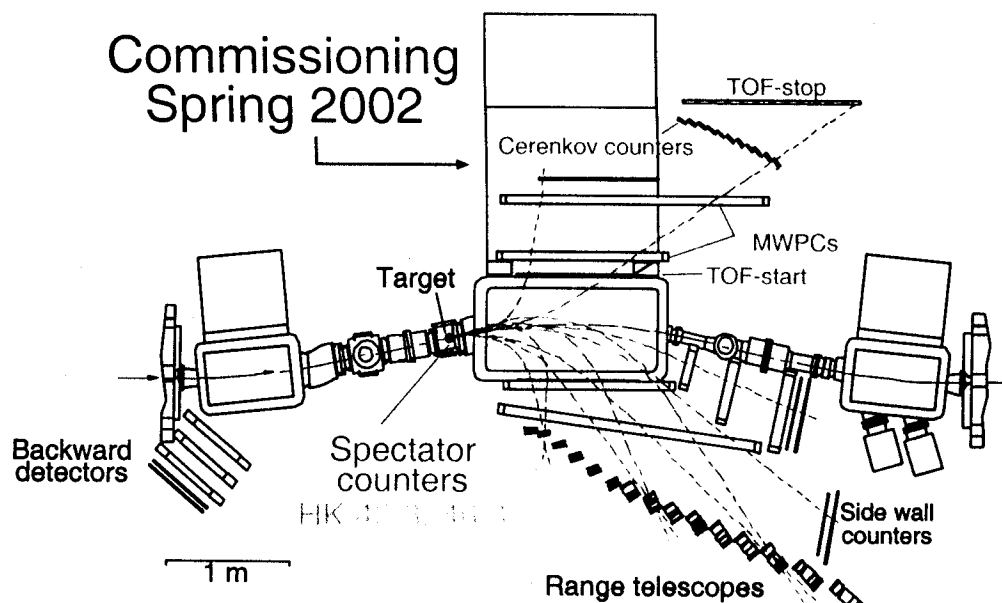


Experimental challenges

- Polarized proton beam
- Neutron target $\rightarrow$ spectator proton detection
- Detection of negatively charged decay products



K detection @ ANKE



First measurements, Feb./March 2002: $p(2.83 \text{ GeV})p \rightarrow pp \phi$

Plans: $pn \rightarrow d a_0/f_0, \phi$ and $pA \rightarrow K^+ K^- X$

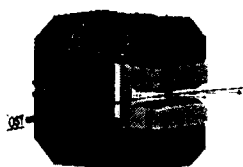
Long-term perspectives

spectator and vertex detectors

polarized beam&target: double polarization exp's HK 5.9, 14.31

frozen-pellet target: high luminosity HK 14.30

photon detector: neutral mesons, ... $dd \rightarrow {}^4\text{He } a_0^0$

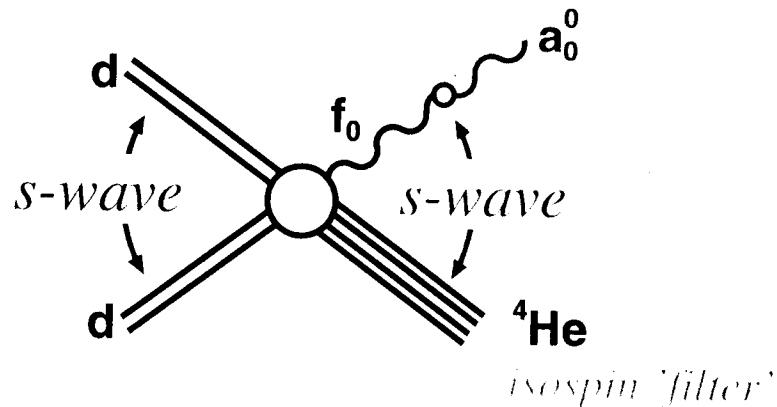


M. Büscher, Φ 2002

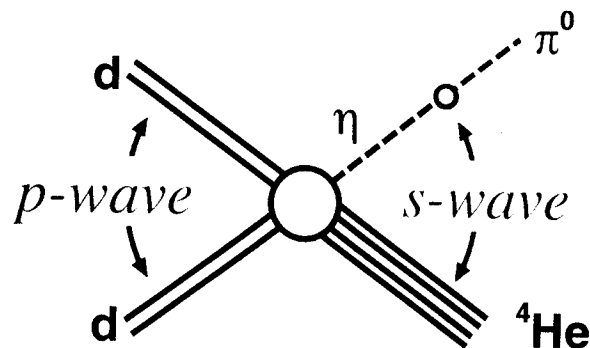
The reaction $dd \rightarrow {}^4\text{He } a_0^0$

$dd \rightarrow {}^4\text{He } a_0^0$ is forbidden, if isospin is conserved

isospin-breaking mechanism



- Observation of $dd \rightarrow {}^4\text{He } \pi^0 \eta$
= indication of isospin violation !
- Needs photon detection
- $p_{\text{beam}} \sim 3.7 \text{ GeV}/c$!
- Possible advantage compared to $dd \rightarrow {}^4\text{He } \pi^0$



VL Buscher, 5/01

Status of Data Analysis:
 $pp \rightarrow dK^+\bar{K}^0$
at ANKE

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Two experiments on the production of the $a_0^+(980)$ resonance in pp collisions have recently been performed with ANKE at COSY Jülich. The first was carried out in the beginning of 2001 at an energy of $T=2.65$ GeV, the second in the beginning of 2002 at $T=2.83$ GeV. The goal of these experiments is to investigate the $a_0^+(980)$ resonance, a candidate for the light scalar meson nonet, in the reaction $pp \rightarrow da_0^+$.

The $a_0(980)$ is known to decay into $K\bar{K}$, $\pi\eta$ and 2γ . At ANKE the deuteron and the decay K^+ or π^+ can be detected. The mesons are identified by TOF and energy loss, the coincident deuterons by their TOF relative to the mesons. Subsequently the $a_0^+(980)$ is investigated with a missing mass analysis.

The focus of this talk on $a_0^+(980)$ data analysis are the investigations of the $K\bar{K}$ decay channel at $T = 2.65$ GeV. A clean sample of about 600 $dK^+\bar{K}^0$ events is obtained due to the unambiguous identification of K^+ mesons and deuterons at ANKE as well as to energy and strangeness conservation.

In the missing mass distribution $m(pp, d)$ a narrow peak structure is observed, mainly given by the $K\bar{K}$ production threshold ($m_{\min}=992$ MeV) and the COSY beam energy of $T=2.65$ GeV ($m_{\max}=1038$ MeV). Due to this limited mass interval it is difficult to judge whether the $K\bar{K}$ pairs have been produced via an a_0^+ or not. The missing mass $m(pp, K^+)$ allows to investigate the FSI of the d and the $\bar{K}^0$. The experimental distribution is compared with predictions by Oset et al. for a certain set of parameters [1]. It looks quite different but the data is not acceptance corrected yet. It becomes clear from the following transparencies that the acceptance is rather flat for the $m(pp, d)$ distribution but varies strongly in case of $m(pp, K^+)$.

In order to perform a model-independent acceptance correction it is necessary to determine the acceptance in dependence of all kinematic variables which describe the reaction. The two squared invariant masses of the Dalitzplot and two angles (azimuthal deuteron angle, angle of the $K^+\bar{K}^0$ plane to the deuteron - beam axis plane) have been chosen. The acceptance has been obtained as a four dimensional matrix in dependence of these variables. Any distribution will then be corrected model independent with this matrix (i.e. independent of the initial distribution at the target) as it has preliminarily been done on transparency 10 as an example. The performing of acceptance correction has just been started. The experimental resolution has to be included and the procedure to be checked though.

The ~ 600 experimentally observed $dK^+\bar{K}^0$ events correspond to a total cross section of $(50 \pm 6 \pm 16)$ nb. According to the prediction of the model developed by L.Kondratyuk et al. [2,3] these events dominantly stem from a_0^+ production.

A preliminary analysis of the new data at $T=2.83$ GeV has been performed. Again clean $dK^+\bar{K}^0$ events can be identified and the mass interval $m(pp, d)$ became substantially wider which will make it easier to determine the ratio of nonresonantly and resonantly produced $K^+\bar{K}^0$ pairs. A rough estimation of the cross section at this energy yields $\sigma(2.83\text{GeV}) \sim 3 \cdot \sigma(2.65\text{GeV})$.

In order to complete the analysis of the 2001 data the acceptance correction has to be performed. For the new data the first and most important task is an improvement of the momentum reconstruction in the forward detection system.

- [1] E.Oset et al., EPJA 12, 435 (2001)
- [2] V.Yu.Grishina et al., EPJA 9, 277 (2000)
- [3] V.Yu.Grishina et al., Phys. Lett. B 521, 217 (2001)

3rd ANKE Workshop

on a_0 Physics

May 22/23, 2002

V.Kleber

Status of Data Analysis:

$$p + p \rightarrow d + K^+ + \overline{K}^0$$

at ANKE

$$p + p \rightarrow d + a_0^+$$

$$\begin{array}{l} \longrightarrow \pi^+ \eta \\ \longrightarrow K^+ \overline{K}^0 \end{array}$$

Motivation

nature:

$q\bar{q}$ state ?

multiquark state?

$K\bar{K}$ bound state ?

?

properties*:

$$IG(JPC) = 1^-(0^{++})$$

$$m(a_0) = 984.7 \pm 1.3 \text{ MeV}$$

$$\Gamma(a_0) = 50 - 100 \text{ MeV}$$

decay modes: $\eta\pi$ dominant

$K\bar{K}$ seen

$\gamma\gamma$ seen

$$\Gamma(K\bar{K}/\pi\eta) = 0.177 \pm 0.024$$

why at ANKE?

both decay channels $a_0 \rightarrow K\bar{K} / \pi\eta$

high mass resolution

production cross section

$\bar{K}d$ final state interaction

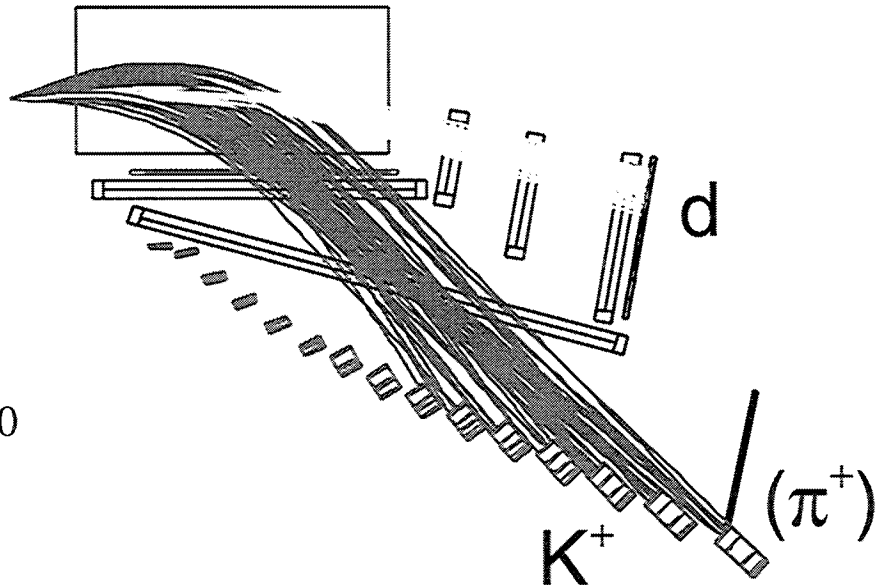
direct production of a_0^+

* D.E.Groom et. al. (PDG), European Physical Journal C15, 1 (2000) and 2001 partial update for edition 2002

Identification of K^+/π^+

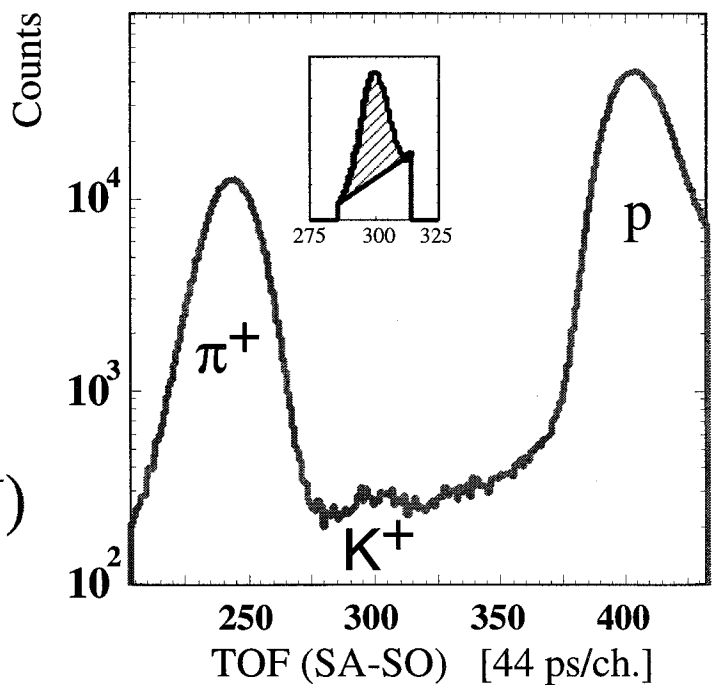
$$p(T=2.65 \text{ GeV}) + p \rightarrow \Lambda + a_0^+$$

$$\begin{array}{l} \rightarrow \pi^+ \eta \\ \rightarrow K^+ \bar{K}^0 \end{array}$$

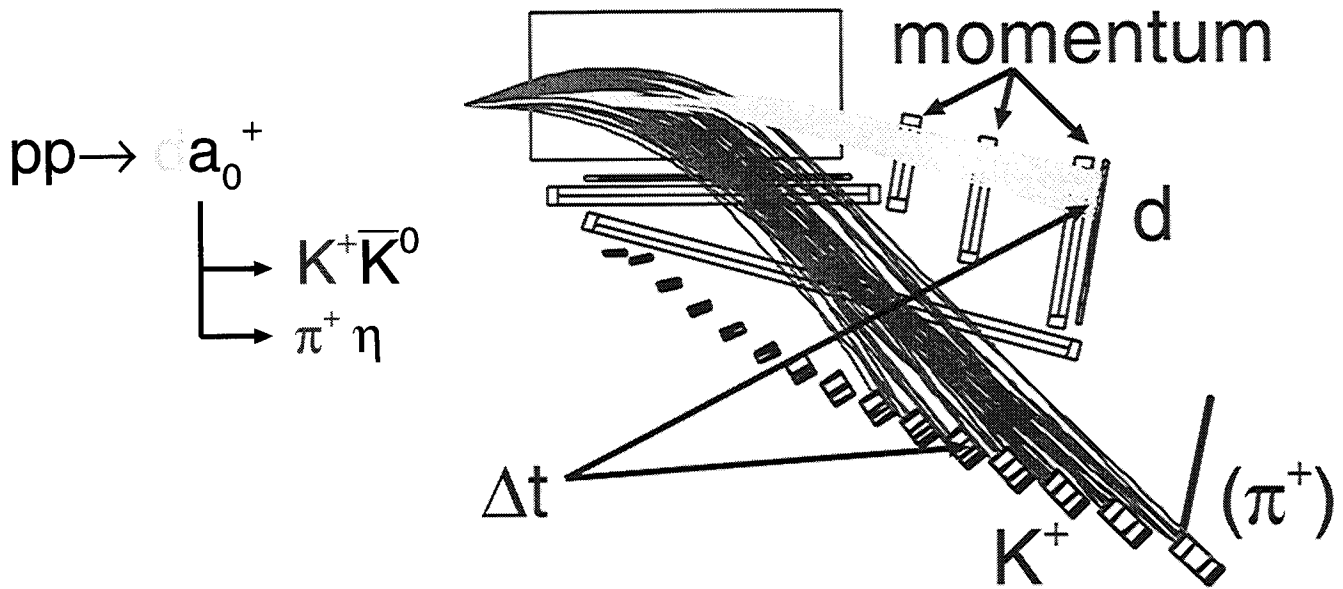


K^+/π^+ selected by:

- * MWPC information
- * TOF
- * energy loss of K^+ (π^+)

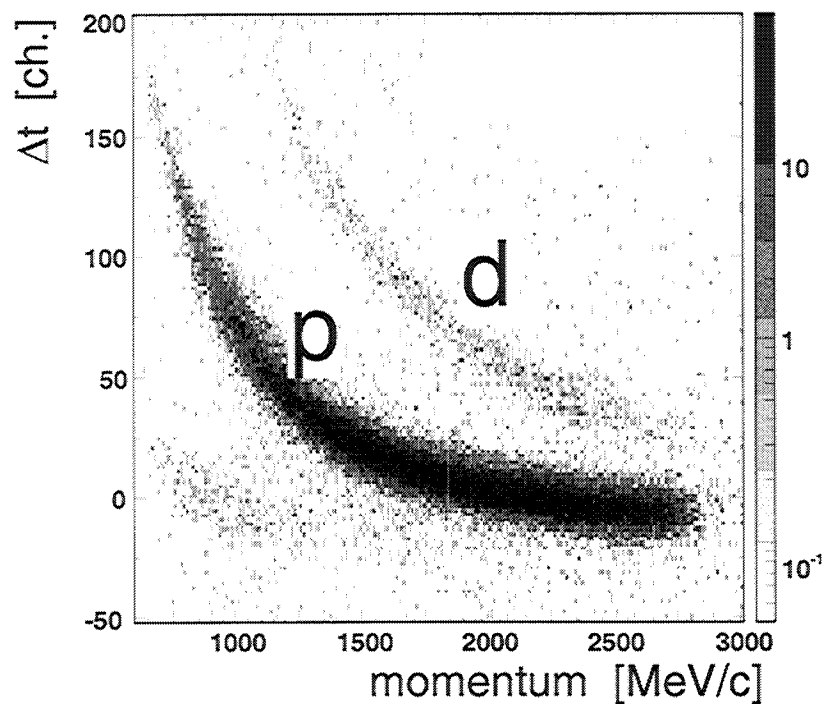


Deuteron Identification



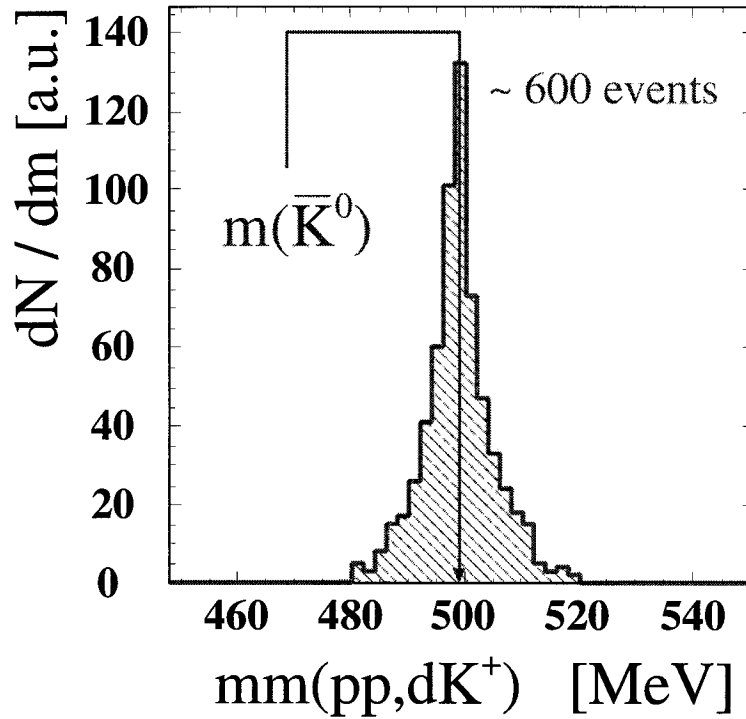
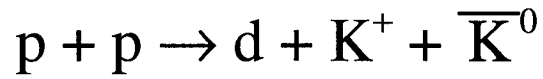
TOF versus momentum distribution

(for a π^+ in the sidewall and a particle in the FD detection system)



→ unambiguous identification of
 $pp \rightarrow dK^+/\pi^+ X$ events

Missing Mass

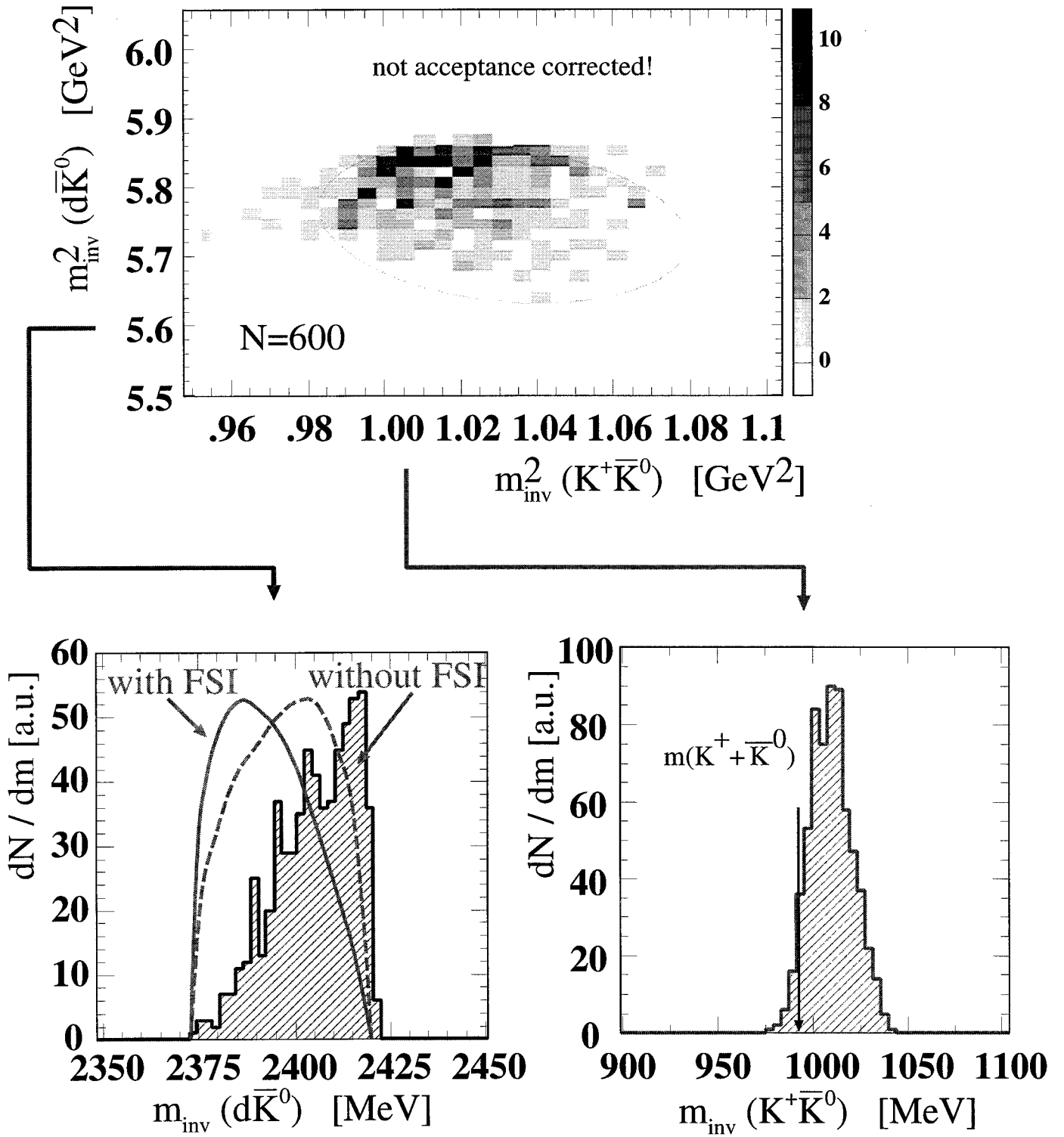


$$\rightarrow \sigma(pp \rightarrow dK^+\bar{K}^0) \sim (50 \pm 6_{\text{stat}} \pm 18_{\text{sys}}) \text{ nb}$$

$$L = (2.70 \pm 0.2 \pm 0.5) \text{ s}^{-1} \text{ cm}^{-2}$$

$$\epsilon_{\text{MWPC}} = (36 \pm 3 \pm 9) \%$$

Dalitz Plot



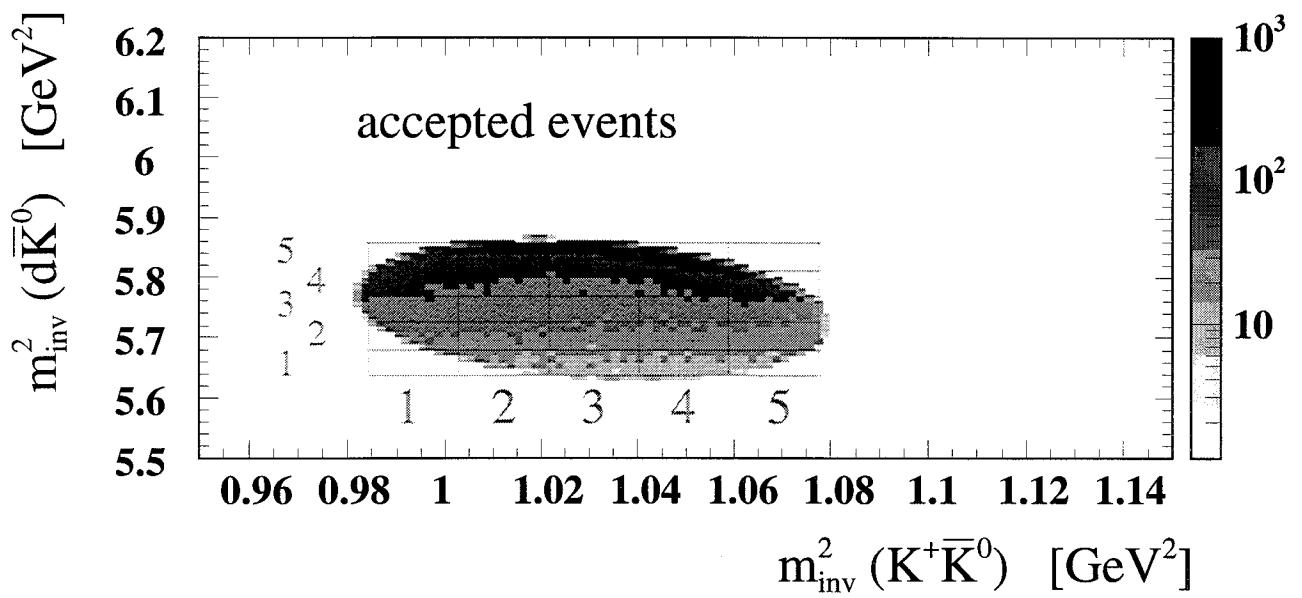
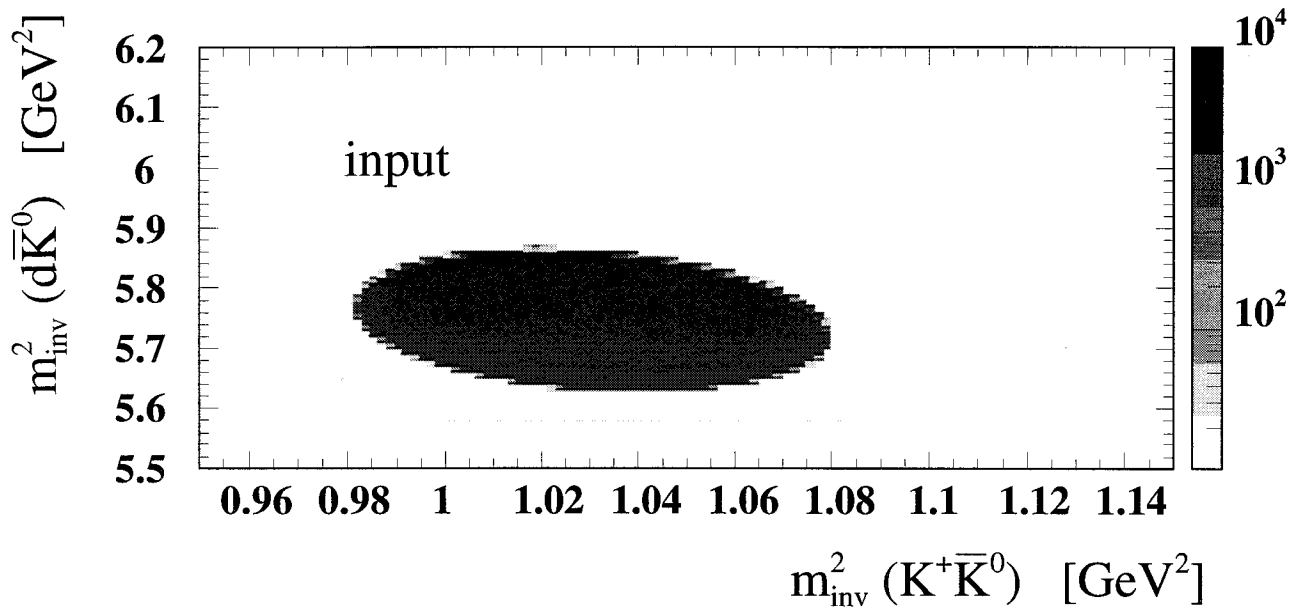
Oset et al., Eur. Phys. J. A 12, 435 (2001)

model independent acceptance correction

irrelevant to physics case
→ integration over $\varphi_{\text{cm}}(d)$

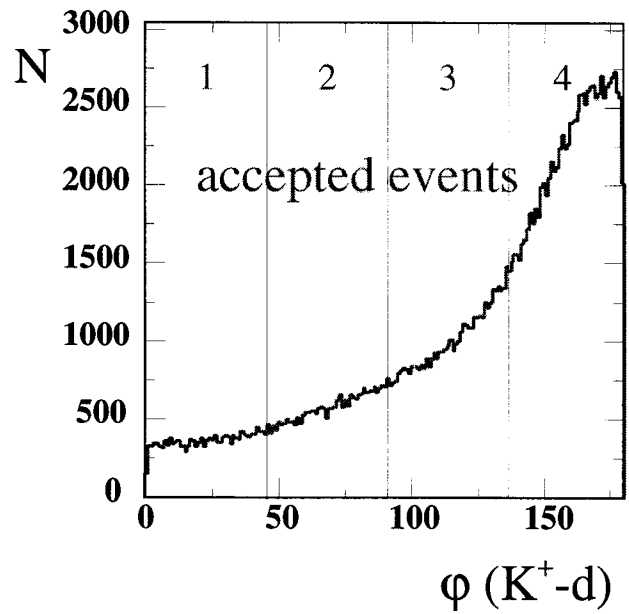
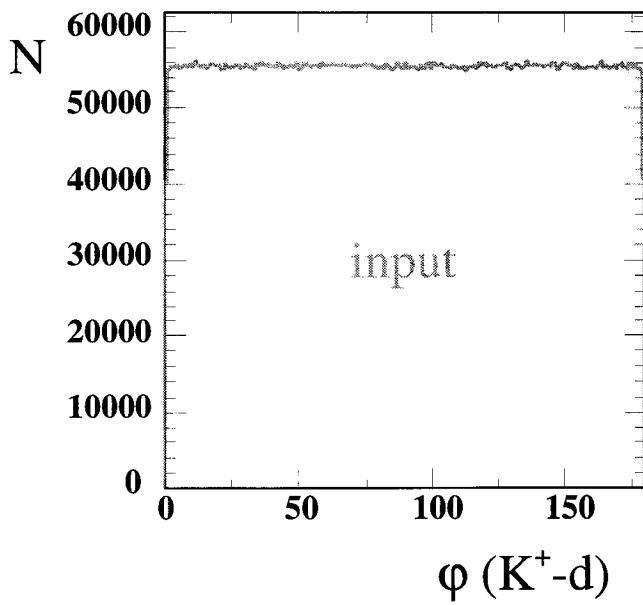
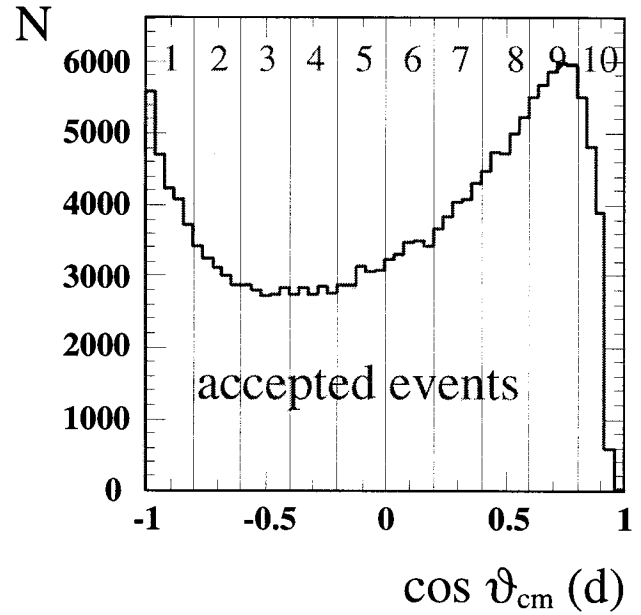
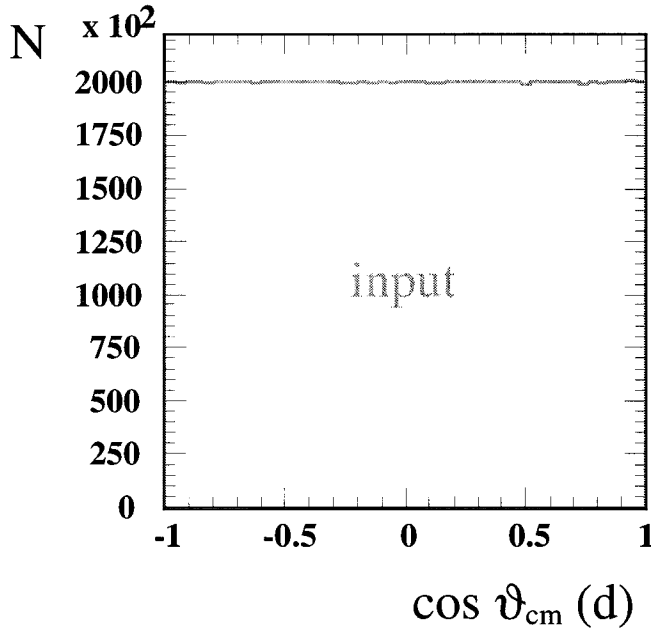
Acceptance Correction: Dalitzplot

s-wave phasespace distribution



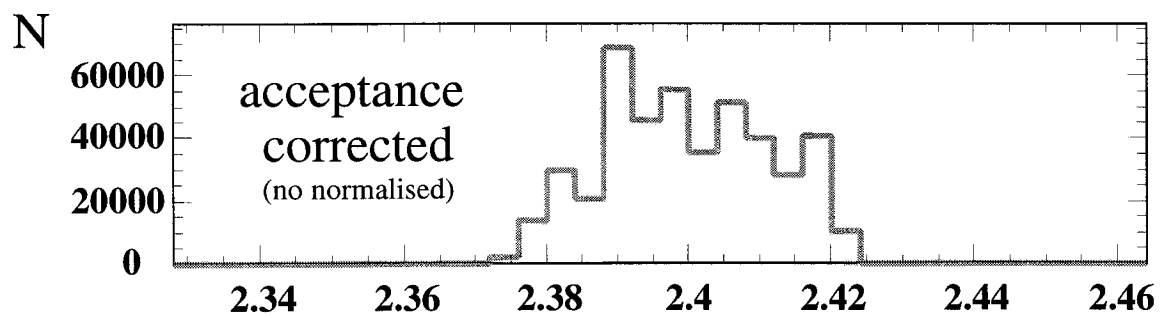
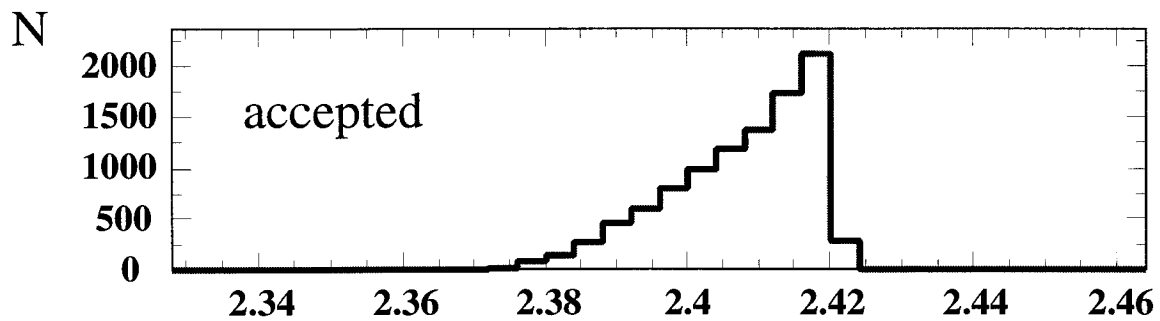
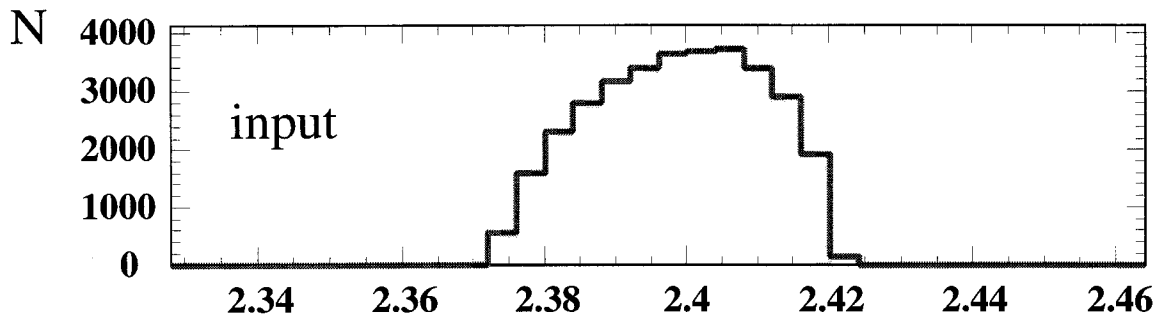
Acceptance Correction

s-wave phasespace distribution



Acceptance Correction: Example

p-wave phasespace distribution



$m_{\text{inv}} (d\bar{K}^0) \text{ [GeV]}$

Summary of a_0^+ Analysis at $T=2.65$ GeV

$pp \rightarrow dK^+\bar{K}^0$:

clear identification of $dK^+\bar{K}^0$ events

but ratio of resonant to nonresonant $K^+\bar{K}^0$ events?

$N \sim 600$ events

$$\sigma(pp \rightarrow dK^+\bar{K}^0) \sim (50 \pm 6_{\text{stat}} \pm 18_{\text{sys}}) \text{ nb}$$

prediction from model*:

mainly resonant production

$$\sigma(pp \rightarrow da_0^+ \rightarrow dK^+\bar{K}^0)$$

$$\sim \sigma(pp \rightarrow dK^+\bar{K}^0)$$

still to be done: acceptance correction

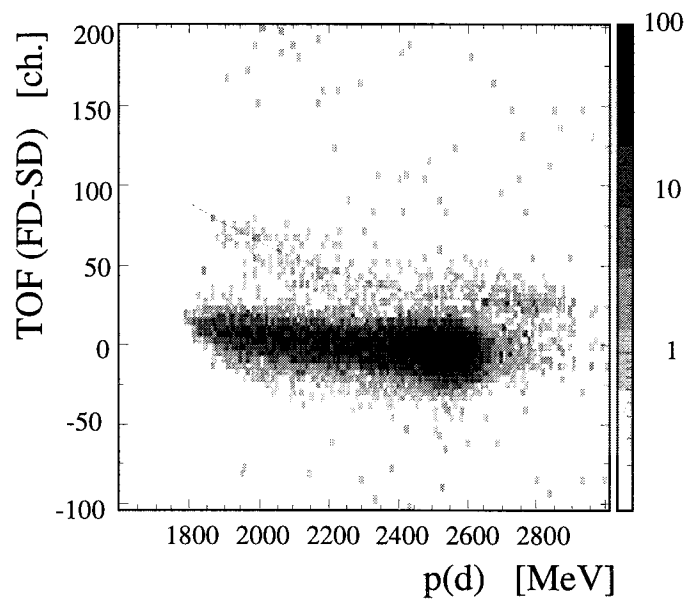
* developed by L.Kondratyuk et al.

New Data at $T = 2.83$ GeV

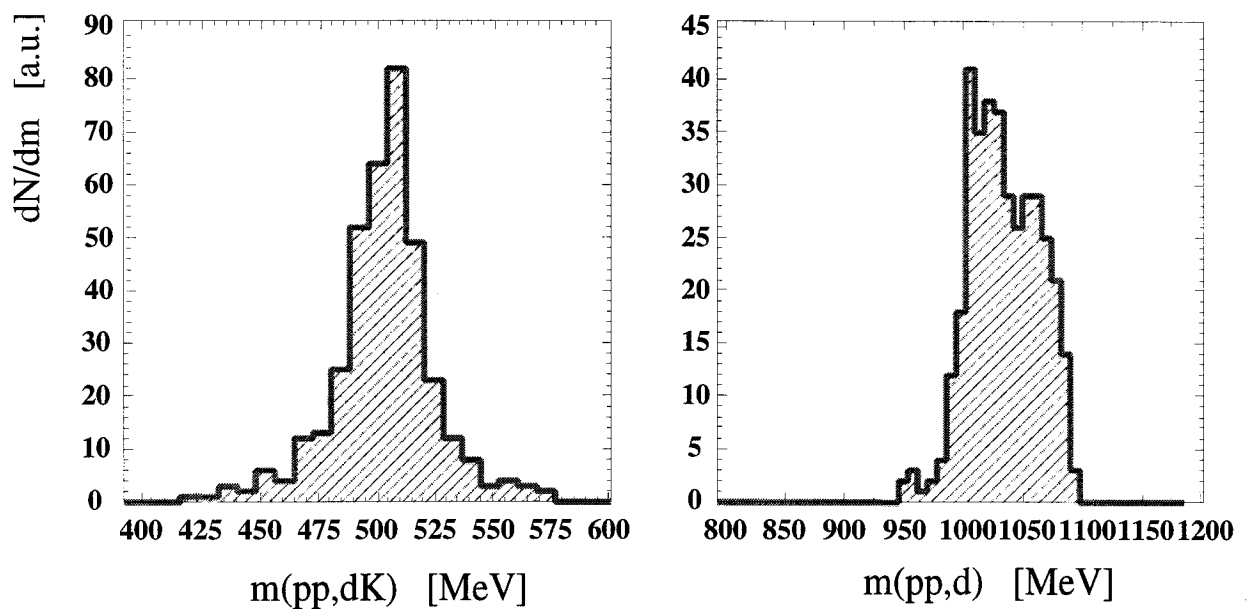
I Kaon identification

delayed veto $\rightarrow$ clean kaon events

II Deuteron identification



III Identification of reaction channel



Comparison of Beam Times

Jan./Feb. 2001

$T = 2.65 \text{ GeV}$

2 weeks

$L \sim 3 * 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

$N_{\text{veto}} \sim 210$

$N_{\Delta E} \sim 600$

$\sigma = 50 \text{ nb}$

Feb./Mar. 2002

$T = 2.83 \text{ GeV}$

3 weeks

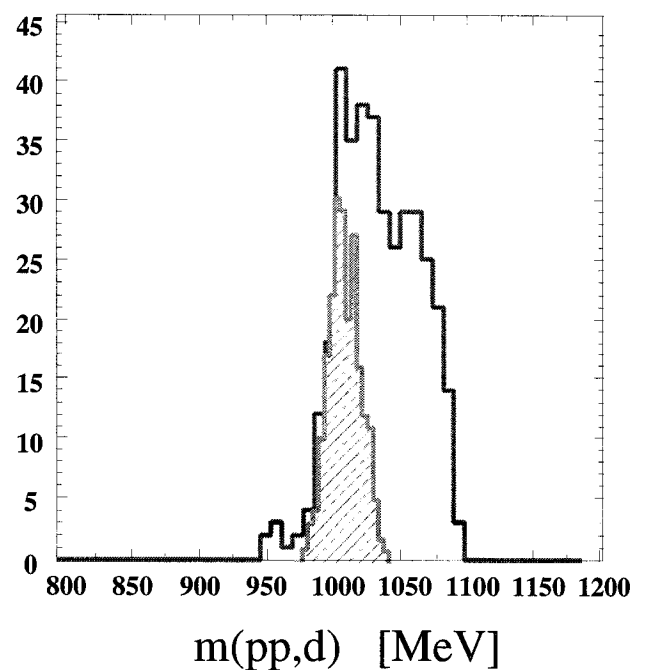
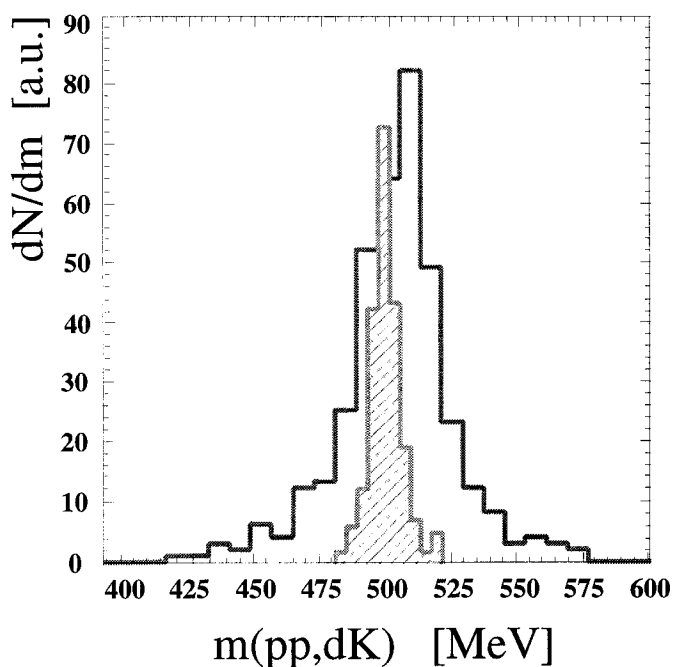
$L \sim 1-2 * 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

$N_{\text{veto}} \sim 370$

$\rightarrow N_{\Delta E} \sim 1000$

K^+ in sidewall

estimation: $\sigma \sim 3 * \sigma_{2.65}$



Outlook

old data: acceptance correction

new data: analysis is going on ...

improve relative TOF resolution

improve momentum resolution/
momentum reconstruction

→ V.Koptev

Status of a_0^+ Investigations at ANKE in the Reaction $pp \rightarrow da_0^+ \rightarrow d\pi^+\eta$

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Forschungszentrum Jülich
52425 Jülich
Germany

The goal of the investigations at ANKE is a simultaneous measurement of two decay channels of the a_0^+ resonance: $a_0^+ \rightarrow \eta\pi^+$ and $a_0^+ \rightarrow K^+\bar{K}^0$. It is expected that differential and total cross sections for both channels as well as their branching ratio can be extracted from the data.

The measurements were performed at two different energies; $T = 2.65$ GeV in January/February 2001 and $T=2.83$ GeV in February/March 2002. The status of the data analysis for the $K^+\bar{K}^0$ channel was shown by V.Kleber. In this report the current results for the $\pi^+\eta$ channel are discussed.

According to the compilation by the PDG, the $\pi^+\eta$ channel is the dominant a_0 decay. At ANKE this channel was detected using the forward detection system (3 MWPCs, scintillator hodoscope) for deuterons and the positive side detection system (TOF-start counters, 2 MWPCs, side-wall counters) for pions.

The separation of pions from protons was achieved by TOF between the TOF-start and side-wall counters. The information from the MWPCs was used for the rejection of scattered background. The deuterons were discriminated against fast protons via a 2d plot, Δt (between π^+ and a forward particle) versus then momentum of the forward particle.

About 120.000 deuteron-pion pairs were selected at $T = 2.65$ GeV. Most of them are background events from multi-pion production. There is a shoulder around 980 MeV ($m(a_0^+)$) in the missing mass distribution $mm(pp, d)$. The distribution of $mm(pp, d\pi^+)$ contains a background distribution with a distinct peak at the mass of the η meson. After background subtraction, assuming a uniform behavior under and outside the peak, ~ 2300 events remain in the missing mass distribution $mm(pp, d)$. These events are peaked at 980 MeV with a width of 40 MeV. This is a strong indication, that the peak in $mm(pp, d\pi^+)$ at 540 MeV is connected with the $pp \rightarrow da_0^+ \rightarrow d\eta\pi^+$ reaction. The missing mass spectra are without efficiency and acceptance corrections though.

During the data analysis it was found, that the η peak from $mm(pp, d\pi^+)$ is not seen in each side-wall counter. The peak is absent in the counters 1,2 (lower momentum) and starts to be visible from counter 3 and increases with the counter number (counter 6 is switched off from the trigger). However, the shoulder at $m(a_0^+)$ is present in the $mm(pp, d)$ distributions for each side-wall counter. As a first attempt to understand this behavior, GEANT simulations of the reaction $pp \rightarrow da_0^+ \rightarrow d\eta\pi^+$ including the procedure of momentum reconstruction were performed. The simulations show that from counter 1 to counter 5:

- the number of $d\pi^+$ events going into the ANKE acceptance increases;
- the width of the peak in the $mm(pp, d\pi^+)$ distribution decreases from 50 MeV to 25 MeV.

This might explain the observed suppression of the η peak in the lower counters.

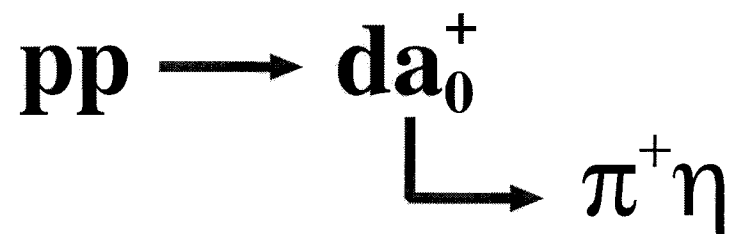
For $T=2.83$ GeV about 370.000 deuteron-pion pairs were selected. The range of the missing masses is larger due to the larger available phase space. In the $mm(pp, d\pi^+)$ distribution there is no distinct η peak visible. The parameters of the momentum reconstruction in the forward direction are not finally established though.

As a conclusion, we can say, that the $\pi^+\eta$ decay channel can be detected at ANKE, but the background reactions demand a more detailed analysis. For the analysis of the angular distributions we need acceptance corrections, which are in progress now.

**3rd ANKE Workshop
on a_0 Physics
May 22/23, 2002**

P. Fedorets

**Results from ANKE
on the reaction**



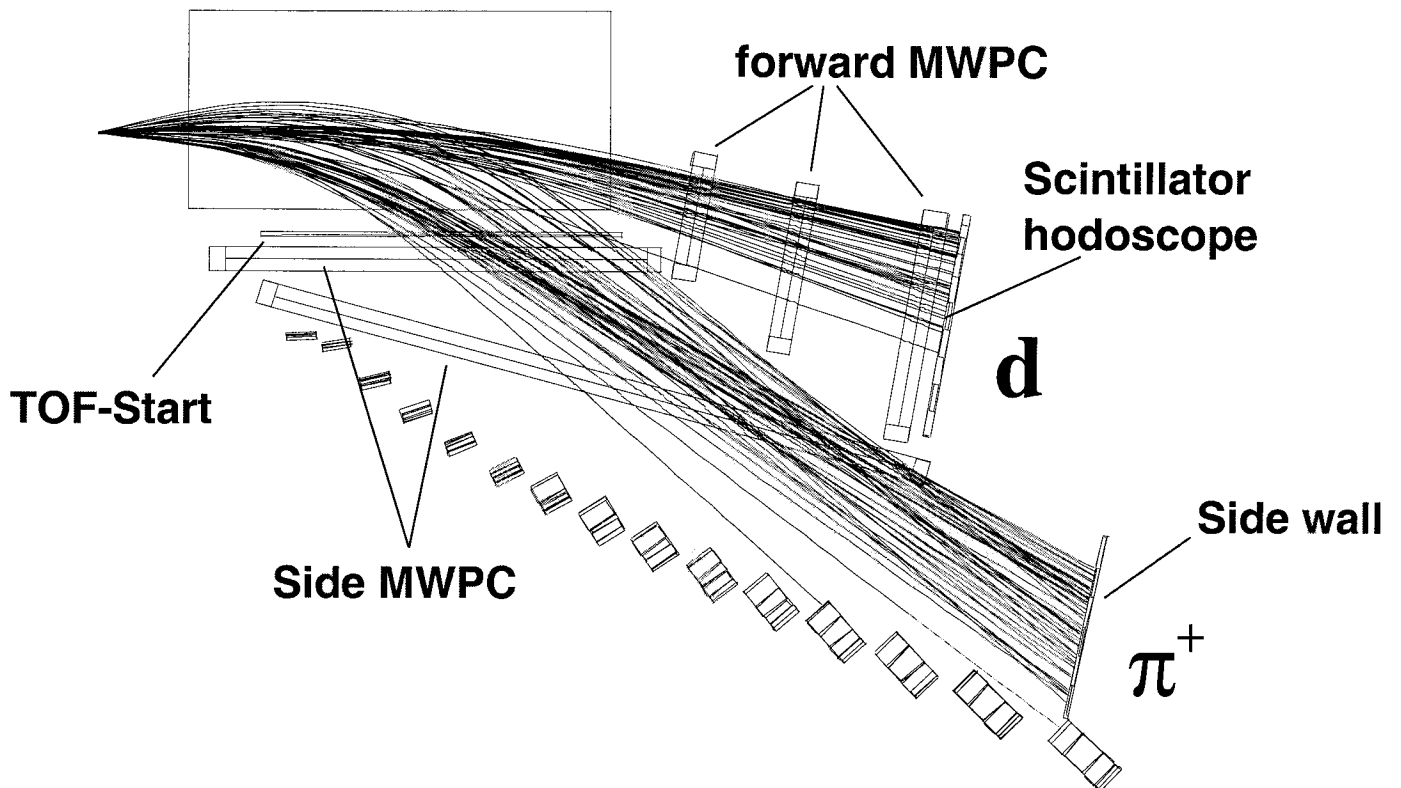
Plan of the report

- events identification
- result for $T=2.65$ GeV
- dependence of missing mass ($pp, d\pi^+$) from the side counter number
- result for $T=2.83$ GeV
- summary

T=2.65 GeV February 2001

T=2.83 GeV February/March 2002

$$\mathbf{p+p \rightarrow d+ a_0^+ \rightarrow d+\pi^++\eta}$$

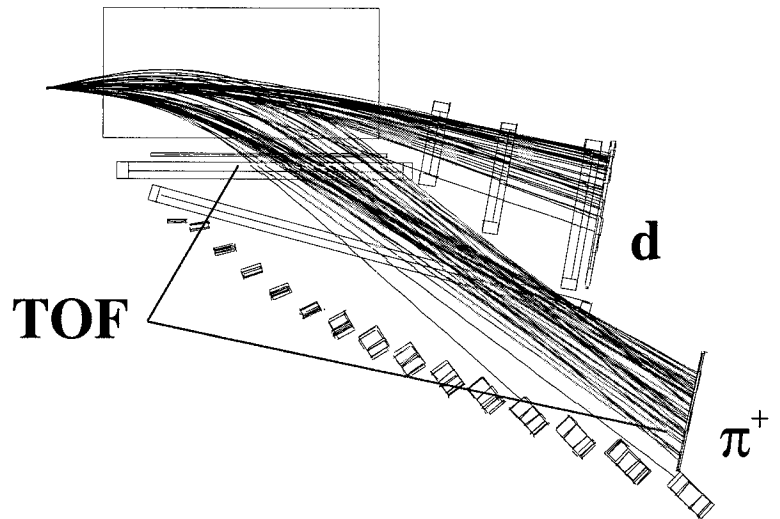


- strategy:**
1. π^+ by TOF (start-side wall)
 2. d by TOF (forward-side)+ momentum
 3. a_0^+ by missing mass + others

Identification of π^+

$p(T=2.65 \text{ GeV}) + p$
 $\rightarrow d + a_0^+$

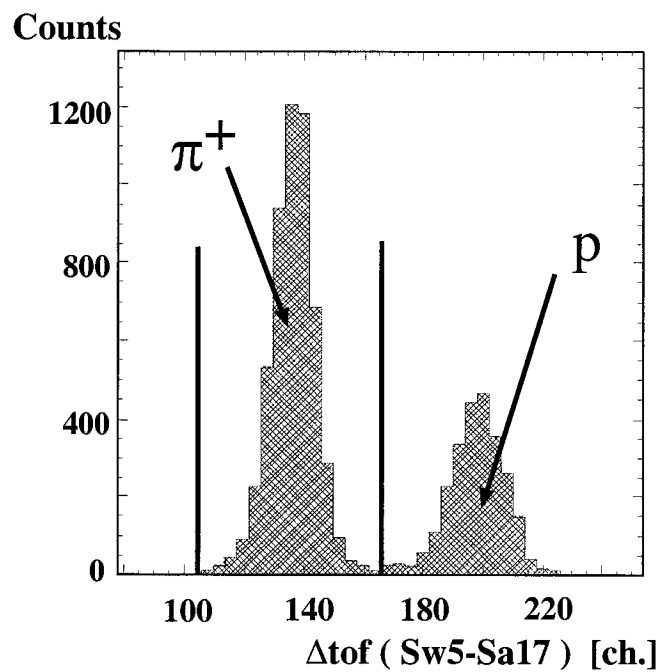
$\searrow \pi^+ \eta$



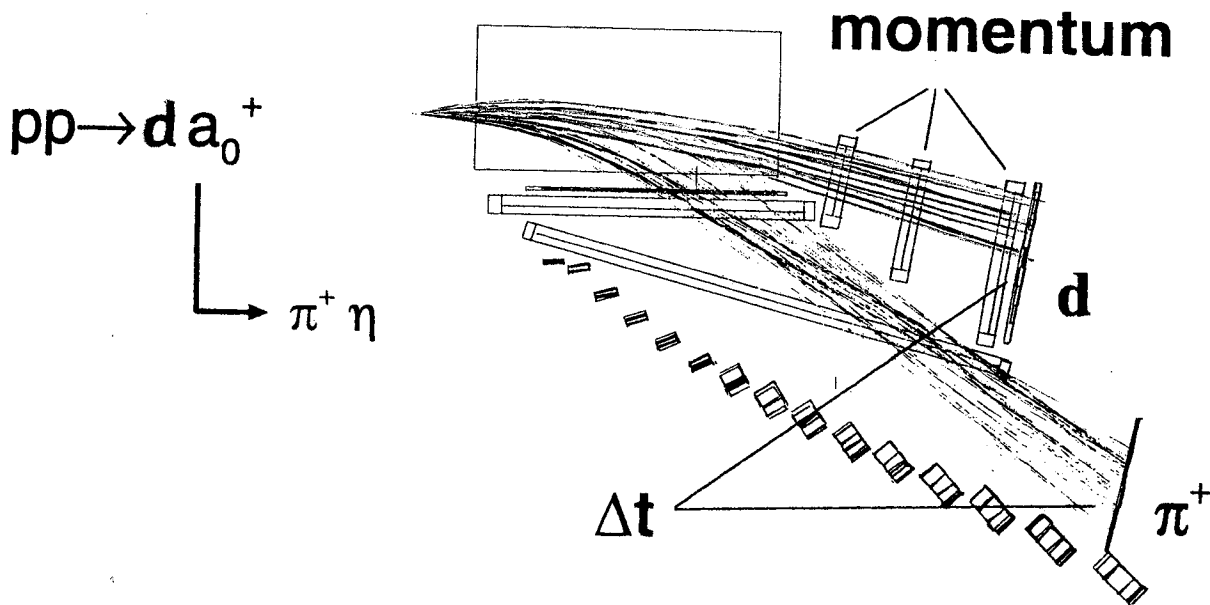
π^+ selected by:

* MWPC information

* TOF

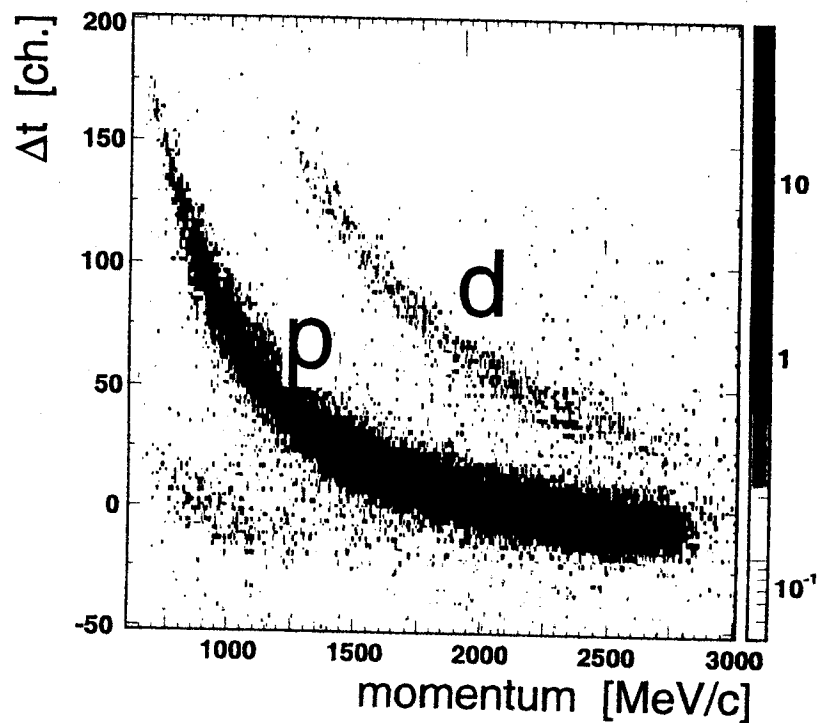


Deuteron Identification



TOF versus momentum distribution

(for a π^+ in the sidewall and a particle in the FD detection system)



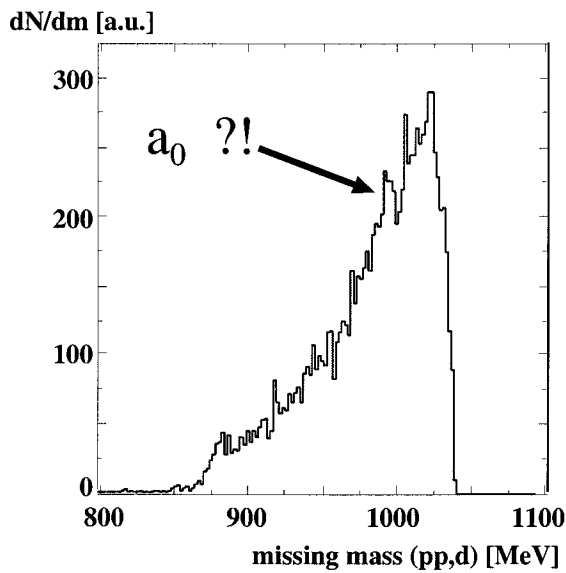
→ unambiguous identification of
 $pp \rightarrow d\pi^+ X$ events

T=2.65 GeV February 2001

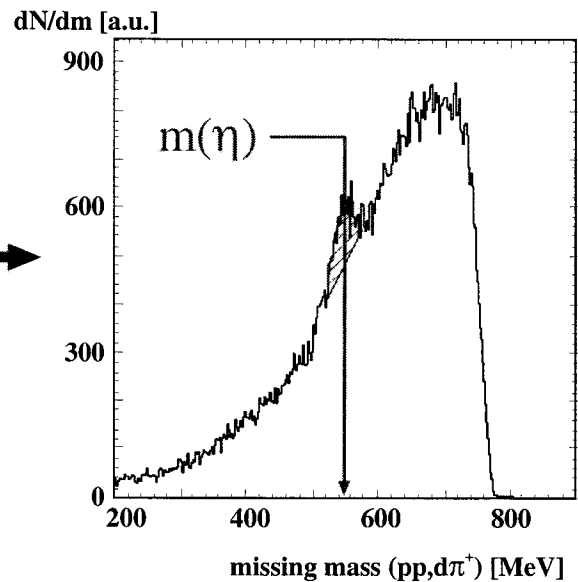
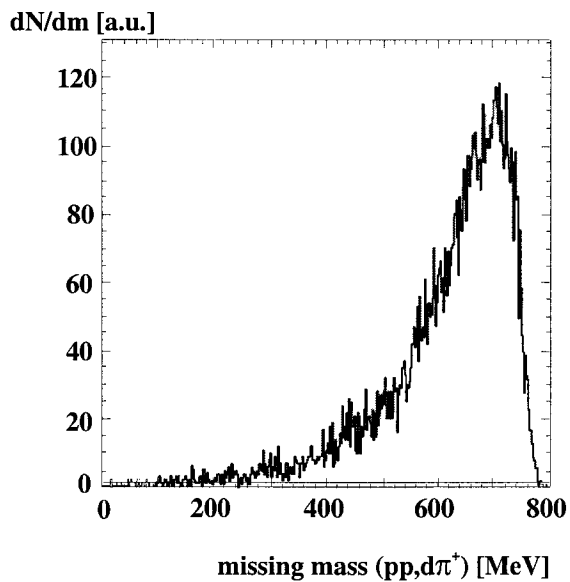
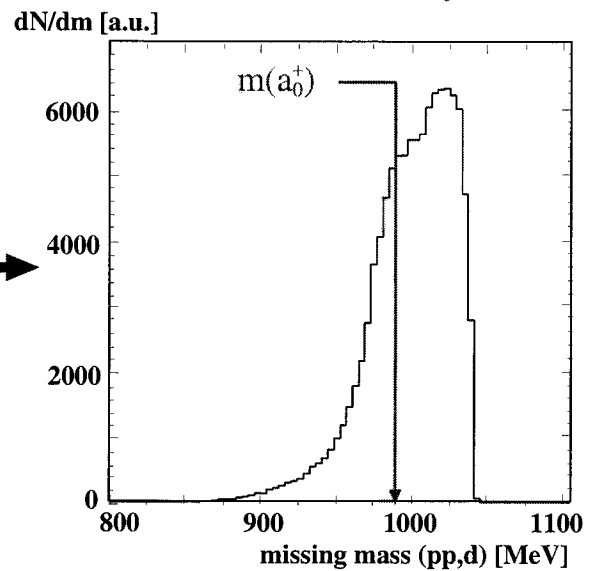
Vera Kleber

$$\mathbf{p + p \rightarrow d + a_0^+ \rightarrow d + \pi^+ + \eta}$$

online results

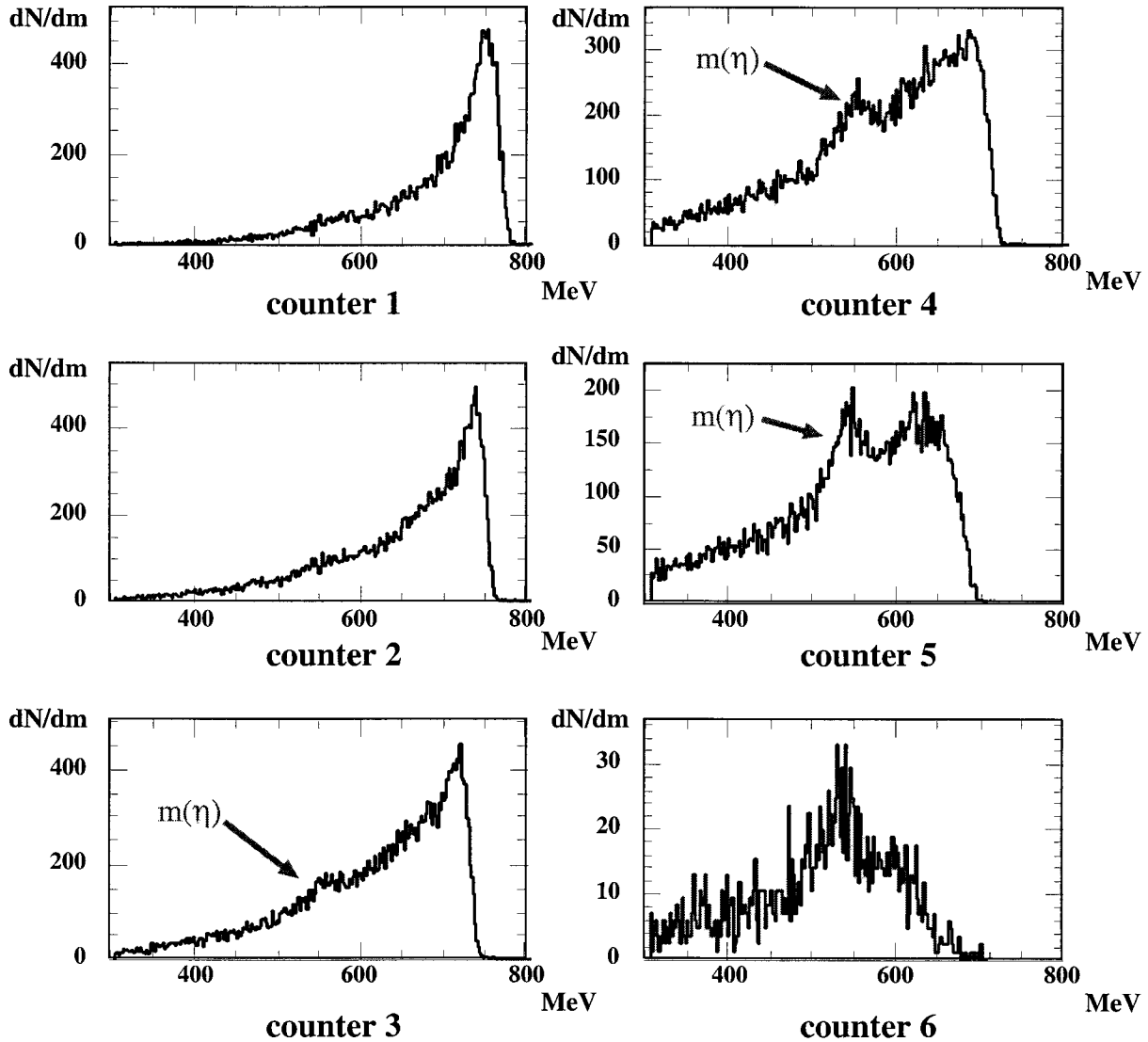


More detailed analysis



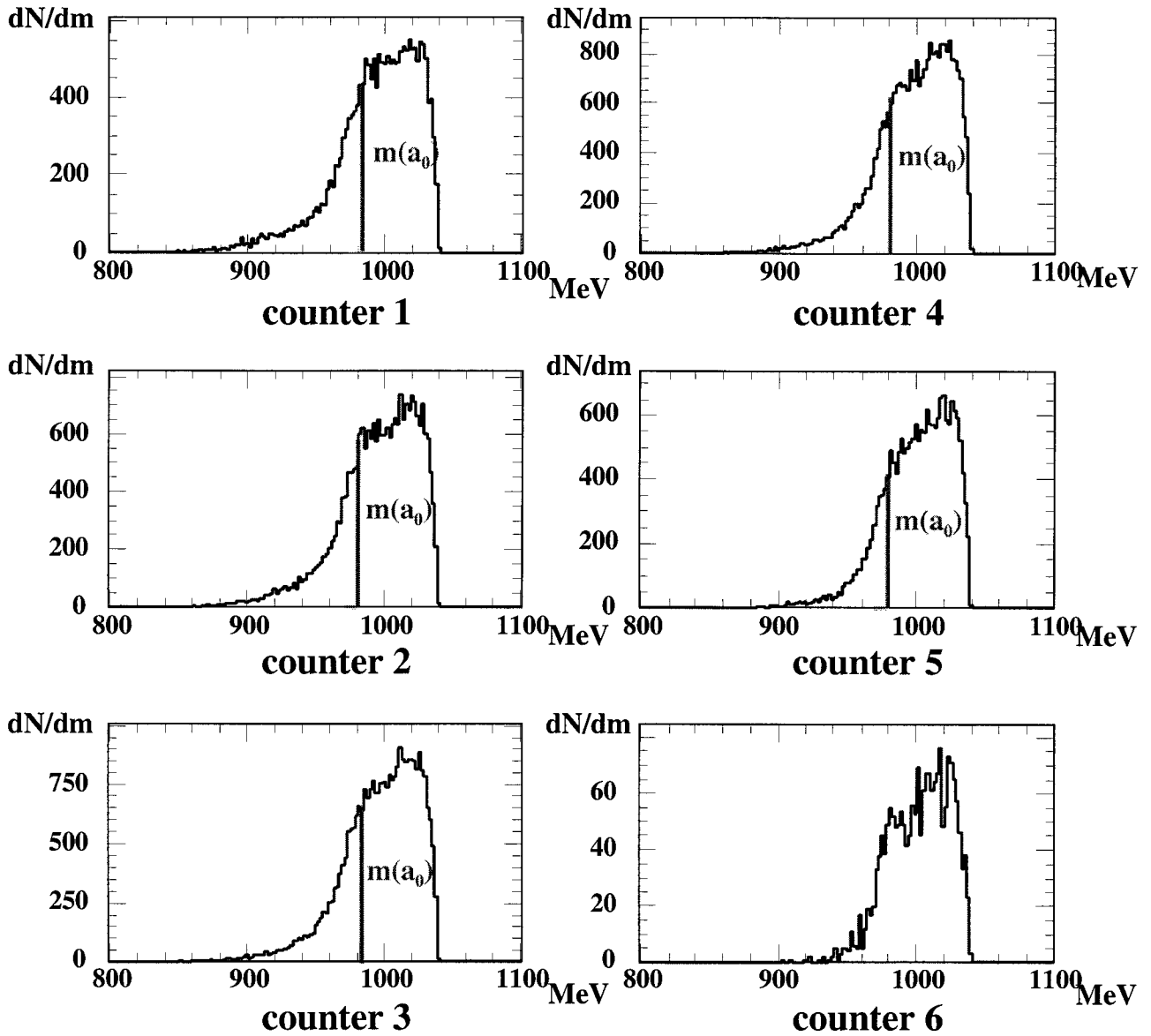
T=2.65 GeV February 2001

**missing mass ($pp, d\pi^+$)
for the individual side-wall counter**

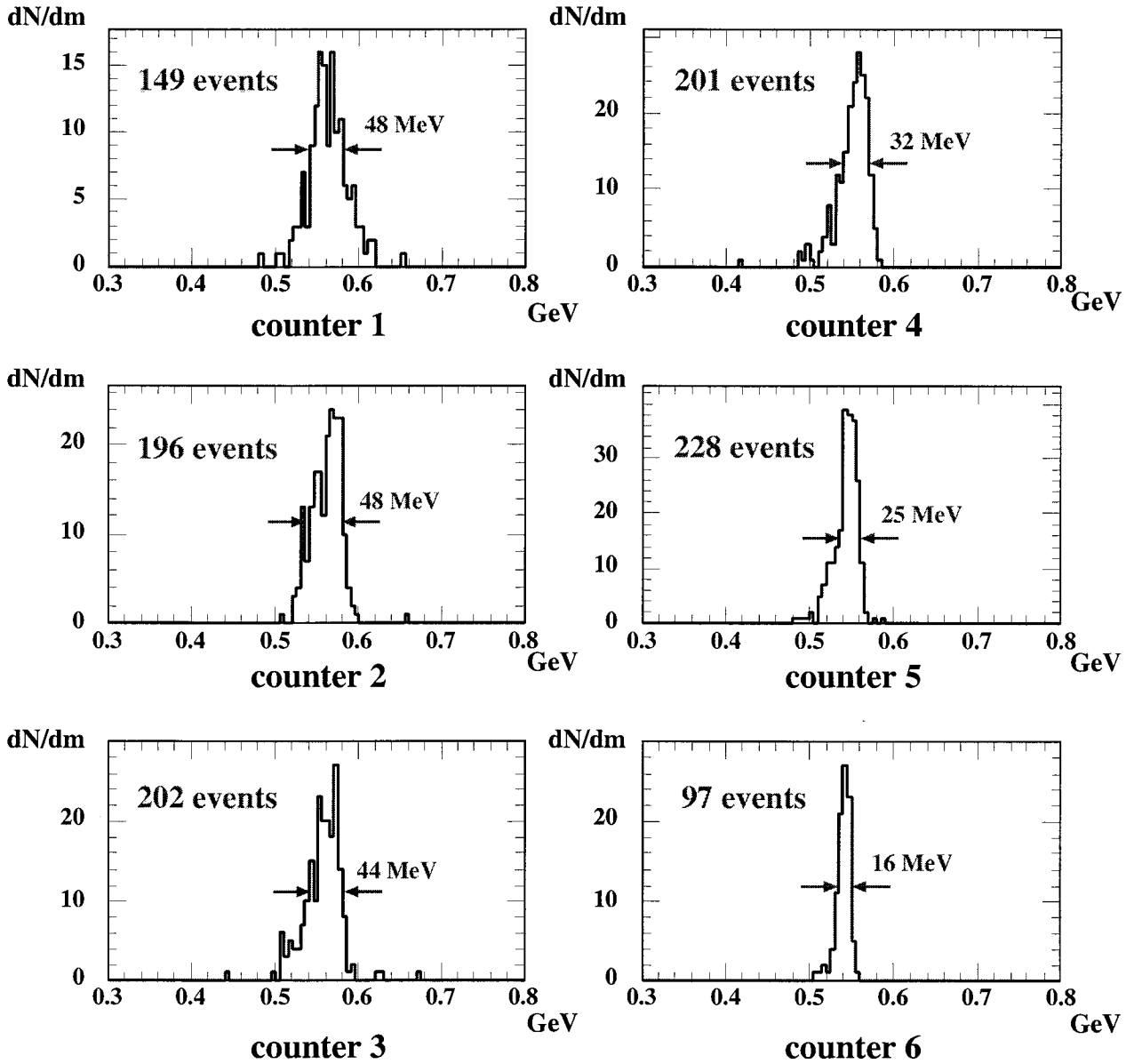


T=2.65 GeV February 2001

**missing mass (pp,d)
for the individual side-wall counter**

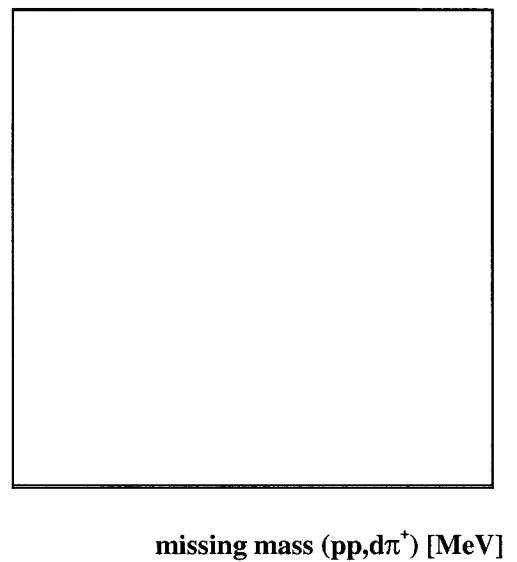
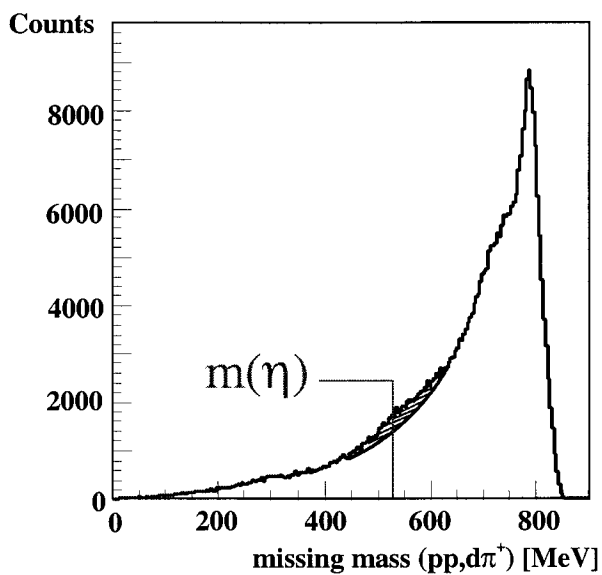
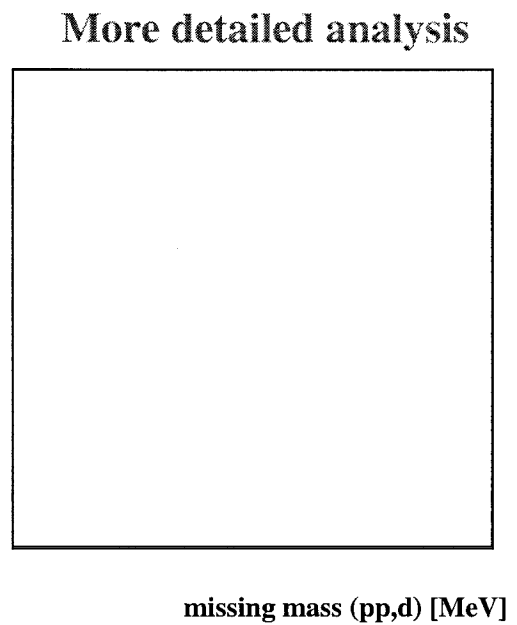
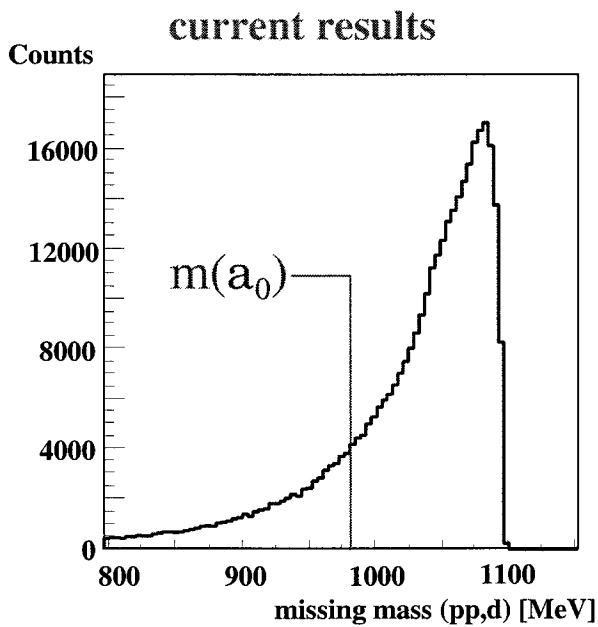


Geant simulations for missing mass ($pp, d\pi^+$) at $T=2.65$ GeV for the individual side-wall counter



T=2.83 GeV February/March 2002

$$\mathbf{p + p \rightarrow d + a_0^+ \rightarrow d + \pi^+ + \eta}$$



Summary

for the channel $a_0^+ \rightarrow \pi^+ \eta$

- $pp \rightarrow da_0^+$ reaction measurements were performed at two energies $T=2.65$ GeV and $T=2.83$ GeV
- clear signal of $\pi^+ \eta$ system production around a_0 mass is observed at $T=2.65$ GeV
- ~ 2300 $\pi^+ \eta$ events are interpreted as $a_0^+ \rightarrow \pi^+ \eta$ decay channel at $T=2.65$ GeV
- the statistics analysis of measurements at $T=2.83$ GeV is started
- the data reconstruction with acceptance correction is in a progress now

Light Meson Production and Decay Studies with WASA

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for the CELSIUS/WASA Collaboration

The Andrzej Soltan Institute for Nuclear Studies
05400 Swierk
Poland

The WASA (Wide Angle Shower Apparatus) is a large acceptance detector system installed at the CELSIUS accelerator and storage ring located at The Svedberg Laboratory in Uppsala, Sweden. CELSIUS provides a high-quality proton beam up to 1360 MeV incident kinetic energy. The WASA set-up has been built around an internal pellet target. The target system provides a stream of hydrogen pellets of about 40 μm in diameter and a production rate of the pellets of about 8 kHz.

The detector has the capability of measuring photons, electrons and hadrons. It has been designed to study rare decays of light mesons, the η meson in particular, as well as to measure total and differential cross sections for meson production in pp, pd and dd interactions. More information on the WASA detector can be found in Ref. [1]. The detector now is after the commissioning phase and the precise calibration of the central calorimeter is in progress.

Physics program

Since the η meson is an eigenstate of both C and CP a violation of these symmetries can be searched in the decays of this meson. There is no precise experimental limit for the CP violation in the flavor conserving sector. The experimental limits on some decay channels are not very stringent. Moreover even the most frequent decay channels of the η meson are not well understood. The decay rates $\eta \rightarrow \pi^+\pi^-\pi^0$ are sensitive to the mass difference $m_u - m_d$ and the Dalitz decays can give new information about the meson transition form factor.

The near threshold meson production can be sensitive to short range interactions because large momentum transfers are involved. The small number of partial waves that are involved make the theoretical analysis simpler.

Some results

An extensive study of the π^- and η production near threshold has been done with the forward part of the WASA detector, 2x56 CsI crystals from the central calorimeter and a cluster gas-jet target. The deuteron target was used to study the η production in the proton-neutron interactions.

On the basis of the obtained results the following conclusions can be drawn:

1. The energy dependence of the cross section for $pp \rightarrow pp\pi^0$ near threshold is well described by phase space modified by pp final state interaction, but the absolute value of the cross section is much higher than expected from pion rescattering alone. This confirms an earlier finding of the Indiana group [3]. Heavy meson exchange and off-shell modification of the πN is needed. It was shown that already at an energy of 310 MeV the higher partial waves became important and the Sd state strongly influences the pion angular distribution via its interference with the Ss state [4]
2. An enhancement was observed close to threshold in the ratio between the measured cross section and the phase-space predictions both in $pp \rightarrow pp\eta$ and $pn \rightarrow d\eta$ reactions [5]. This is most probably due to the strong attractive η -nucleon interaction.
3. The production of the η in pn interactions is about 6.5 times more abundant than in proton-proton collisions [6].

4. The cross section for $pp \rightarrow pp\pi^+\pi^-$ was found to be much smaller than previously reported by an old experiment on a deuteron target.
5. The relation between the cross section for the pion pair production with different charges are not well described by a model assuming the Roper dominance.

Running experiments and perspectives

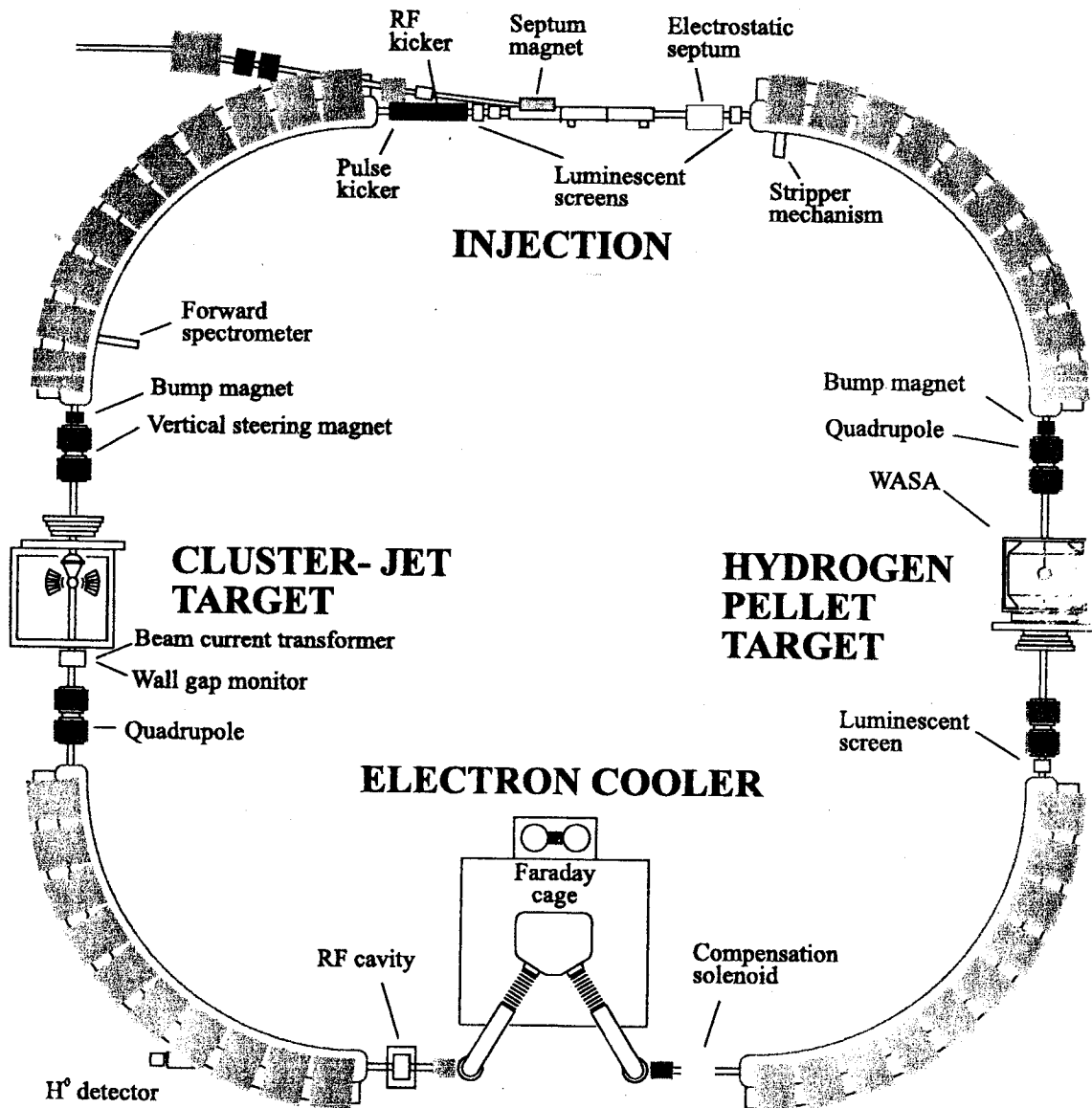
At present multiple production of neutral and charged mesons in proton-proton interactions are being studied. It will permit to understand the response of the detector to different types of particles and the background for the study of η decays. The data are being collected for a high statistic study of the $\eta \rightarrow \pi^0\pi^0\pi^0$, $\eta \rightarrow \pi^0\pi^-\pi^+$ and $\eta \rightarrow \pi^-\pi^+\gamma$ decay channels. The $\eta \rightarrow \pi^+\pi^-e^+e^-$ decay will be measured in the nearest future. The energy upgrade of CELSIUS will open up new physics possibilities, such as η' and ϕ meson production and decay studies. The production of the $\eta\pi$ system near threshold can be studied as well. Since the invariant mass of the $\eta\pi$ system is small relative s-wave production should dominate. Therefore we will have access to the production of the a_0 tail.

The CELSIUS/WASA Collaboration has an extended program of studies of rare decays of the η meson. This will allow to search for violation of fundamental symmetries in the flavor conserving sector and to provide crucial tests of Chiral Perturbation Theory. The differential cross sections of single and multiple production of light mesons will be measured at energies above 1 GeV.

- [1] A.Kupsc at the Meson 2000, Cracow, Poland, Acta.Phys.Pol.B 31(2000)2249
- [2] R.Bilger et al., Nucl.Phys.A663 (2000) 1073
- [3] H.Calen et al., Phys.Lett. B336 (1996) 39
- [4] J.Zlomanczuk et al., Nucl.Phys. A663 (2000) 452
- [5] H.Calen et al., Phys.Rev.Lett. 80 (1998) 2069
- [6] H.Calen et al., Phys.Rev. C 80 (1998) 2667

The CELSIUS/WASA facility

- CELSIUS storage ring for internal target experiments located in Uppsala, Sweden
maximum proton beam energy 1360 MeV (cooled 550 MeV)
relative momentum spread $\Delta p/p$ 2×10^{-3} (2×10^{-4})

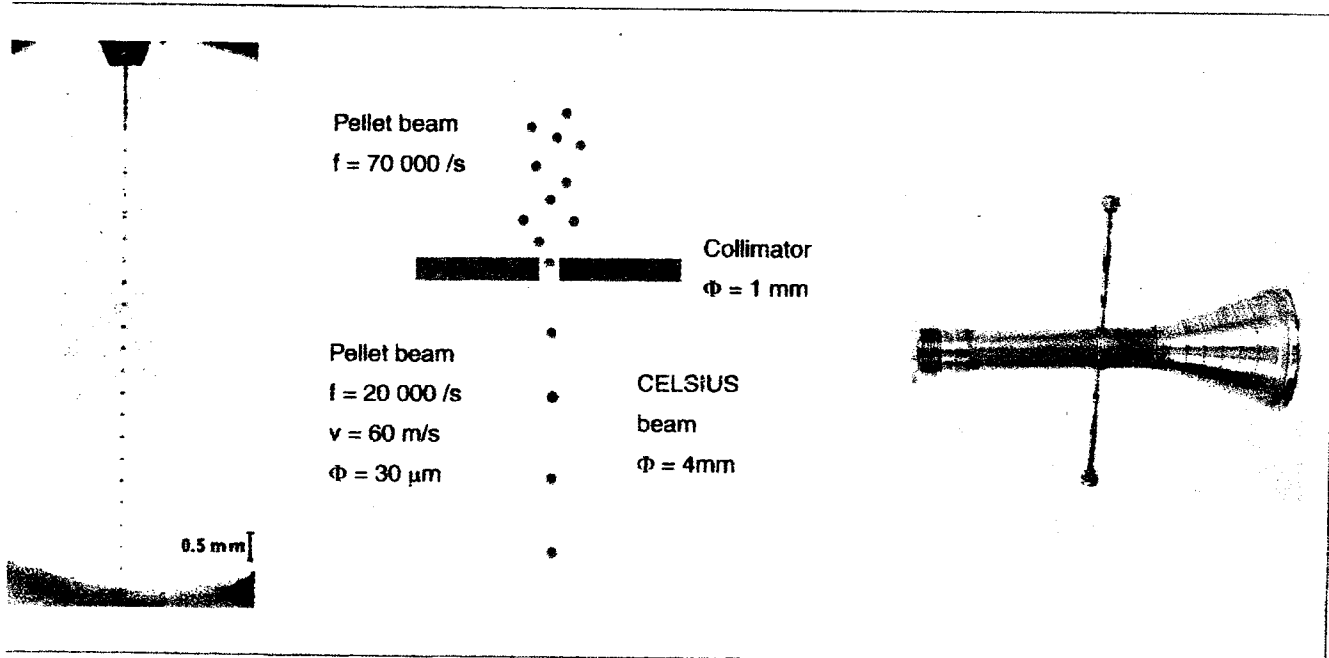


- Pellet target

A stream of small (about $30\mu\text{m}$) frozen hydrogen pellets

Effective thickness $10^{15} \text{ atoms/cm}^2$

Estimated position accuracy for individual pellet $< 0.5\text{mm}$

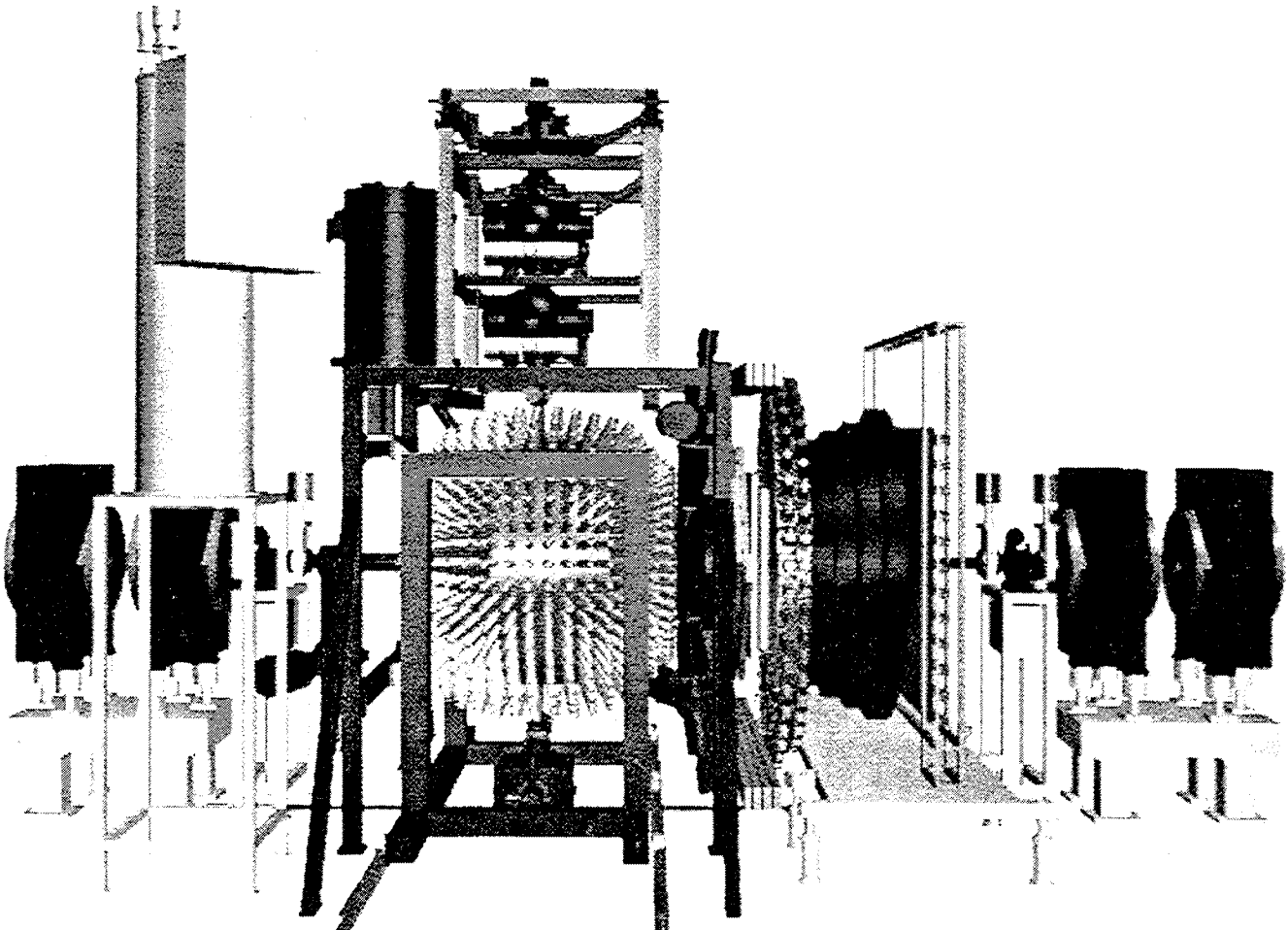


- WASA - Wide Angle Shower Apparatus

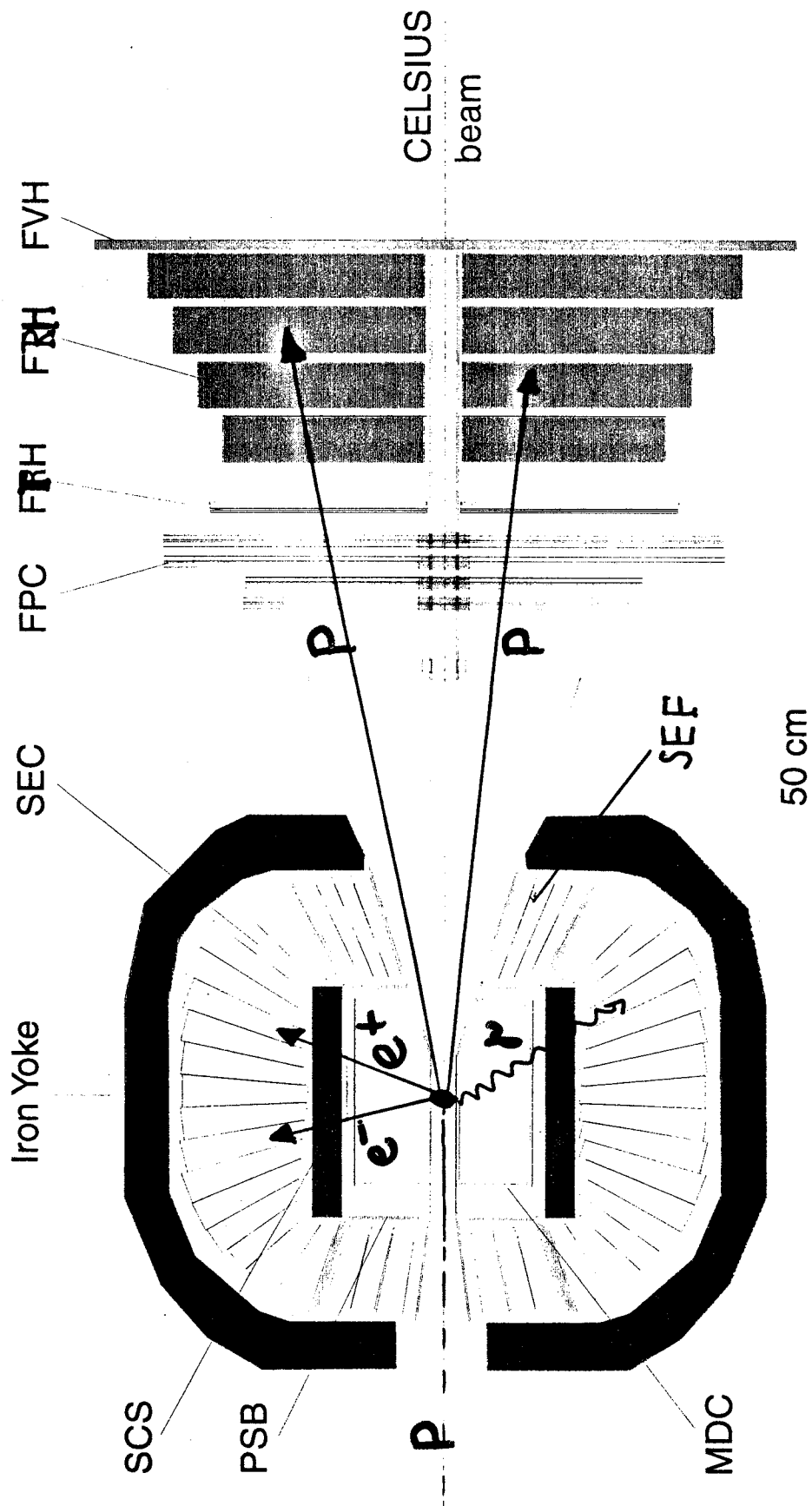
The Wasa detector system has been built by Collaboration of laboratories and universities in Dubna, Julich, Łódź, Moscow, Novosibirsk, Osaka, Tsukuba, Tubingen, Uppsala and Warsaw

Polish group from the Soltan Institute from Nuclear Studies
Swierk, Łódź, Warsaw

A.Kupść, P.Marciniewski, A.Nawrot, J.Stepaniak, J.Zabierowski
+students, technicians



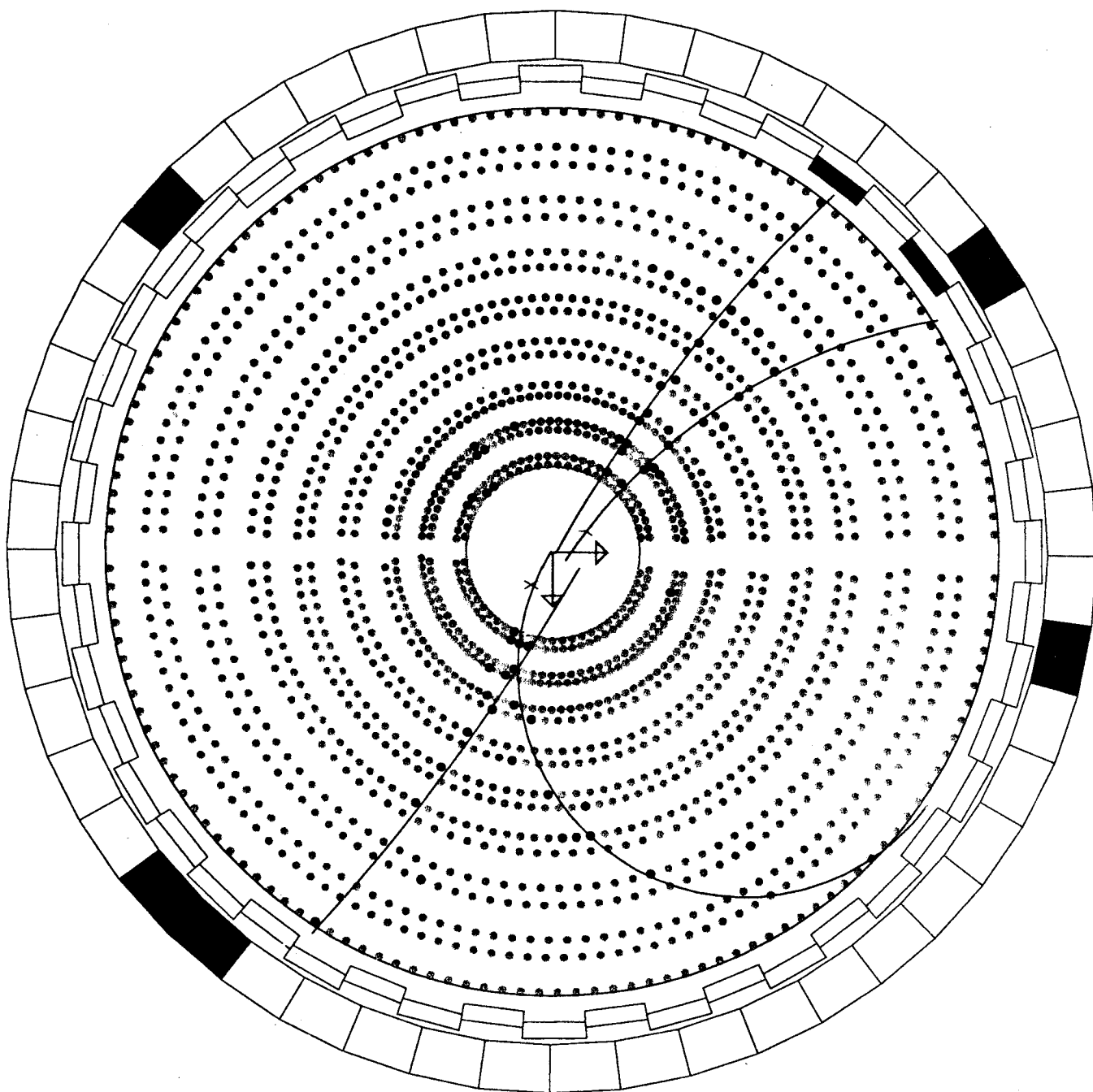
Wasa 4π detector setup



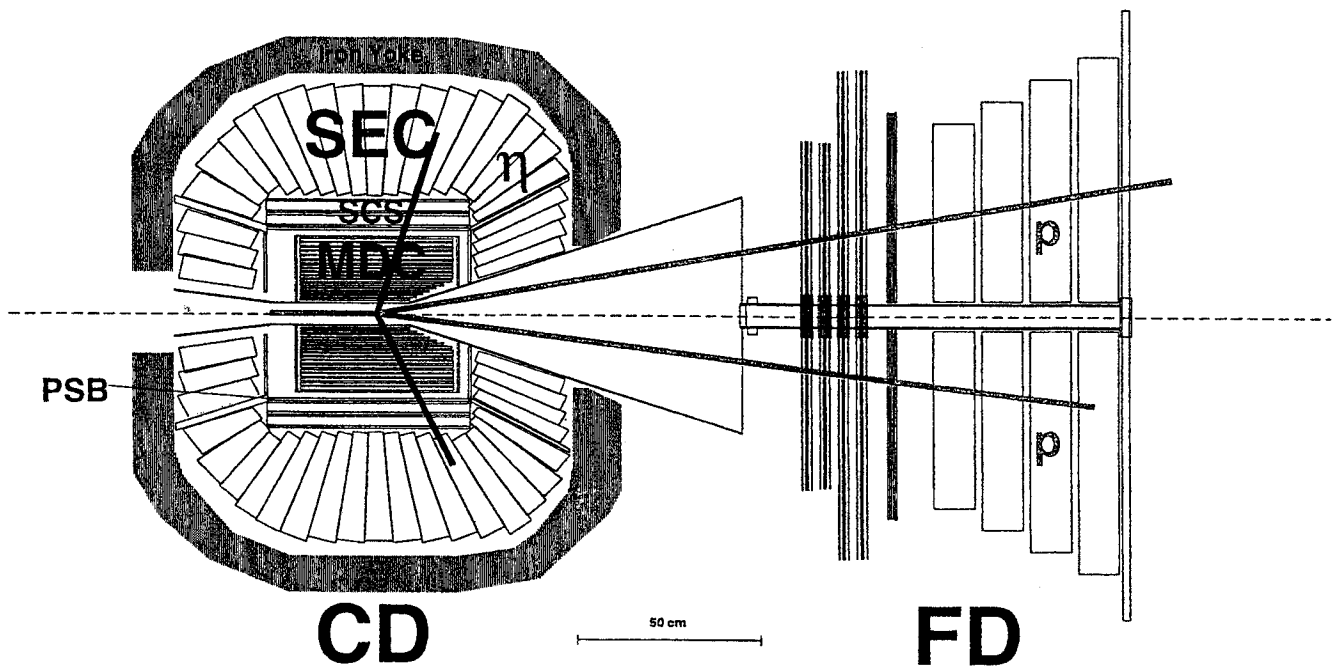
Central Detector

Event No. 974

Nb. of tracks found 4

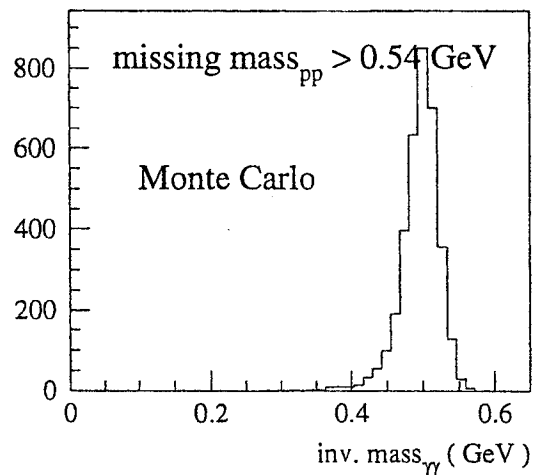
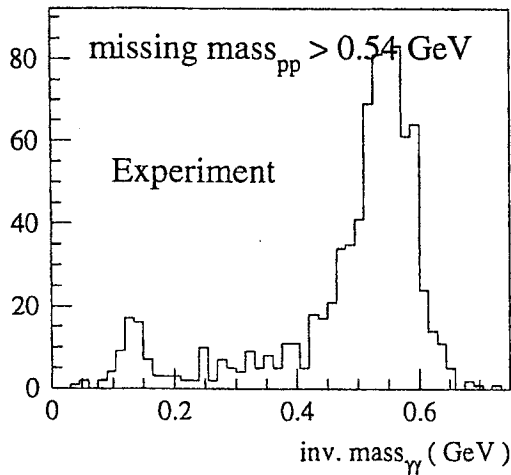
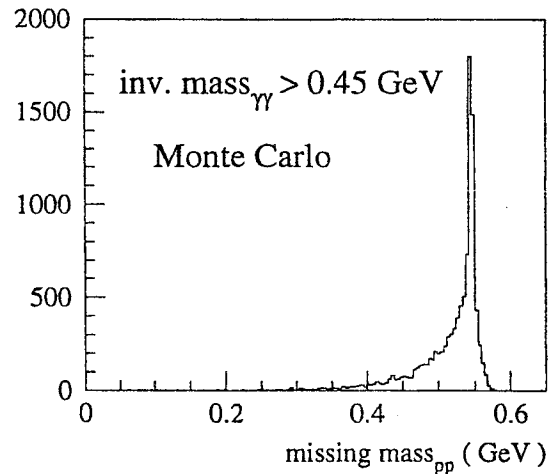
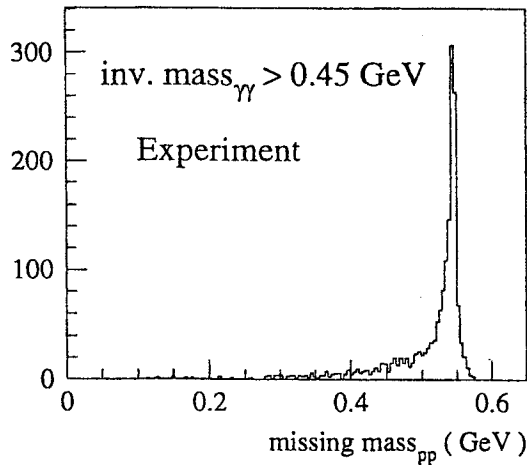
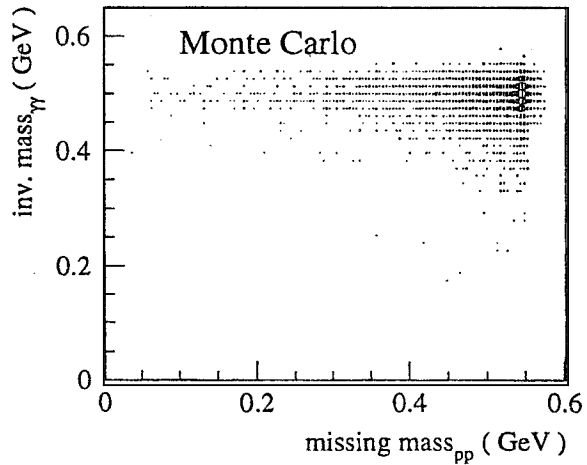
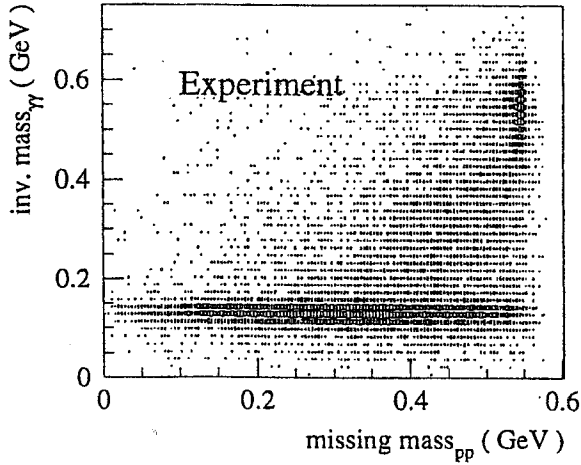


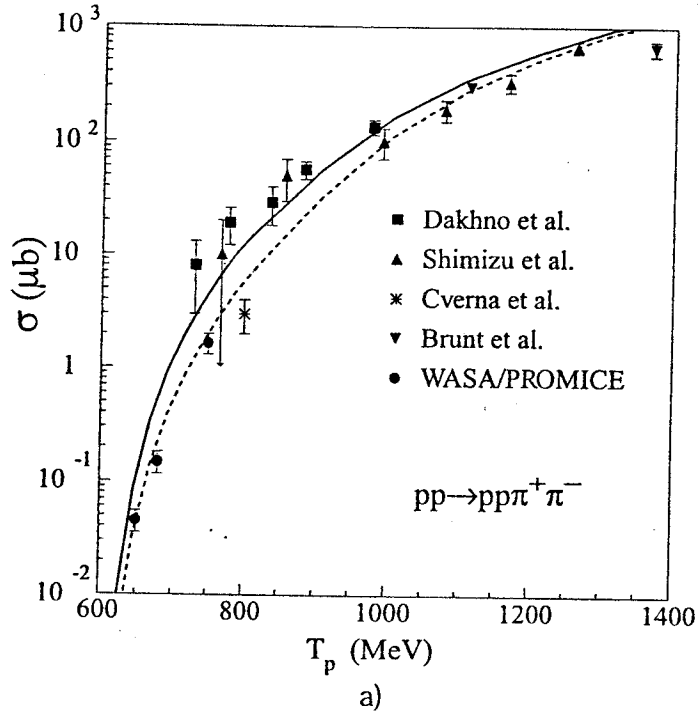
$pp \rightarrow pp \eta (\rightarrow \gamma\gamma)$
-Identification with WASA



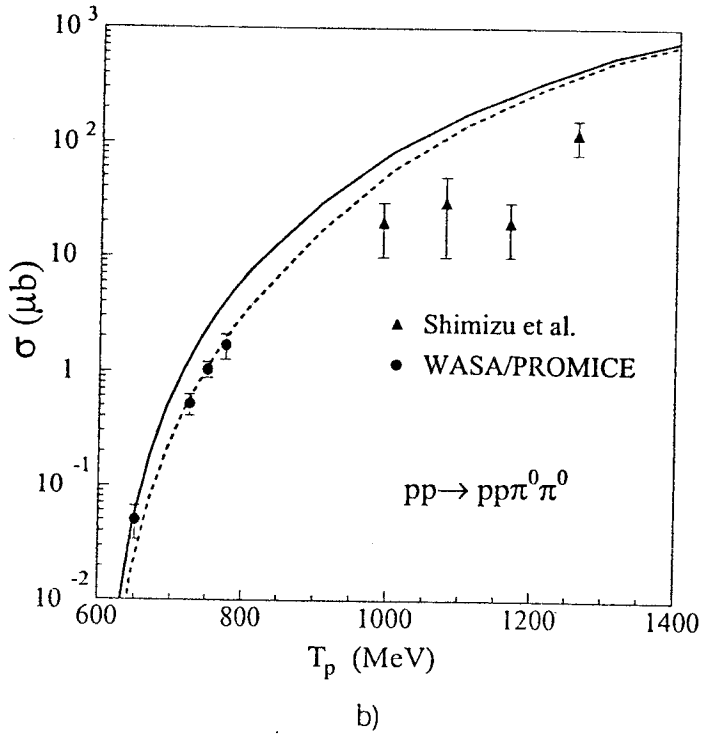
- proton beam at 1360 MeV
- 2 charged tracks in the Forward Detector
- 2 identified protons in the Forward Detector
- Cut on proton proton missing mass

$pp \rightarrow pp \eta(\rightarrow \gamma\gamma)$ -Identification with WASA





$pp \rightarrow pN^*(1440)$
 $\rightarrow pp(\pi\pi)_S^{I=0}$



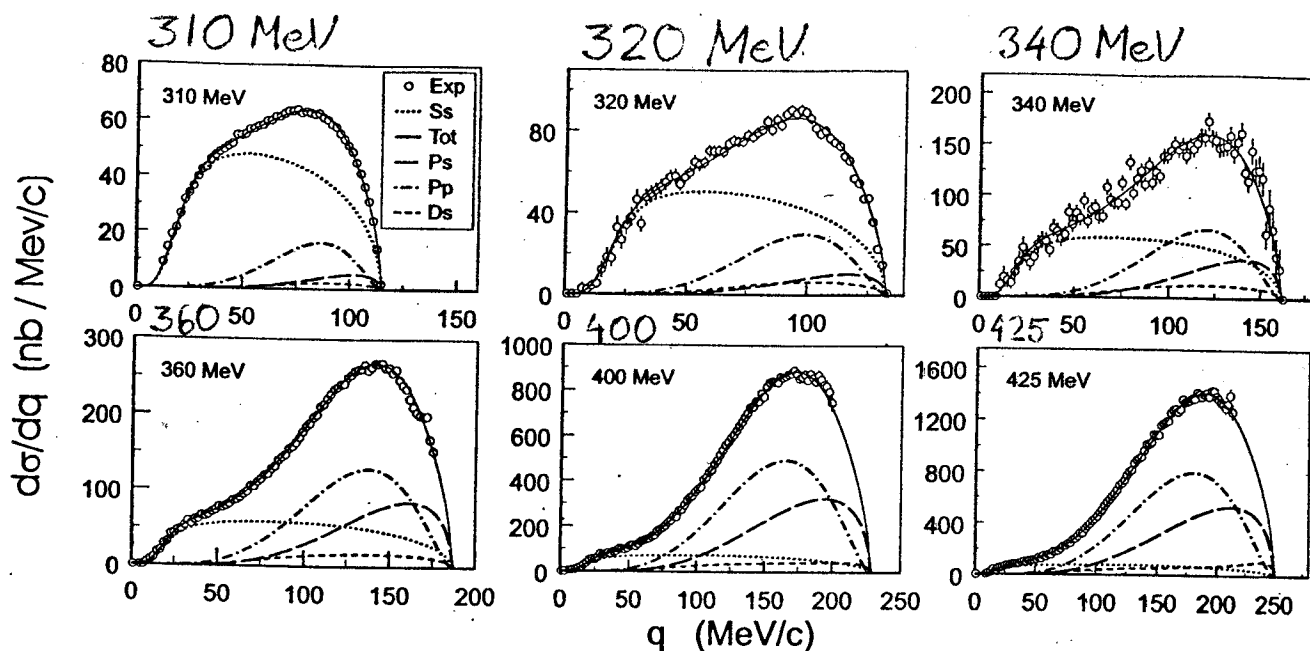
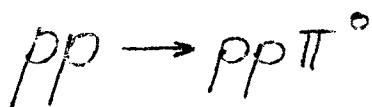


Figure 1 Acceptance-corrected proton-proton relative momentum distributions, q , at six beam energies for the $pp \rightarrow pp\pi^0$ reaction. The insert in the upper left figure gives the legend for the decomposition of the amplitudes.



q is proton-proton relative momentum

Higher partial waves contribute quite close to the threshold.

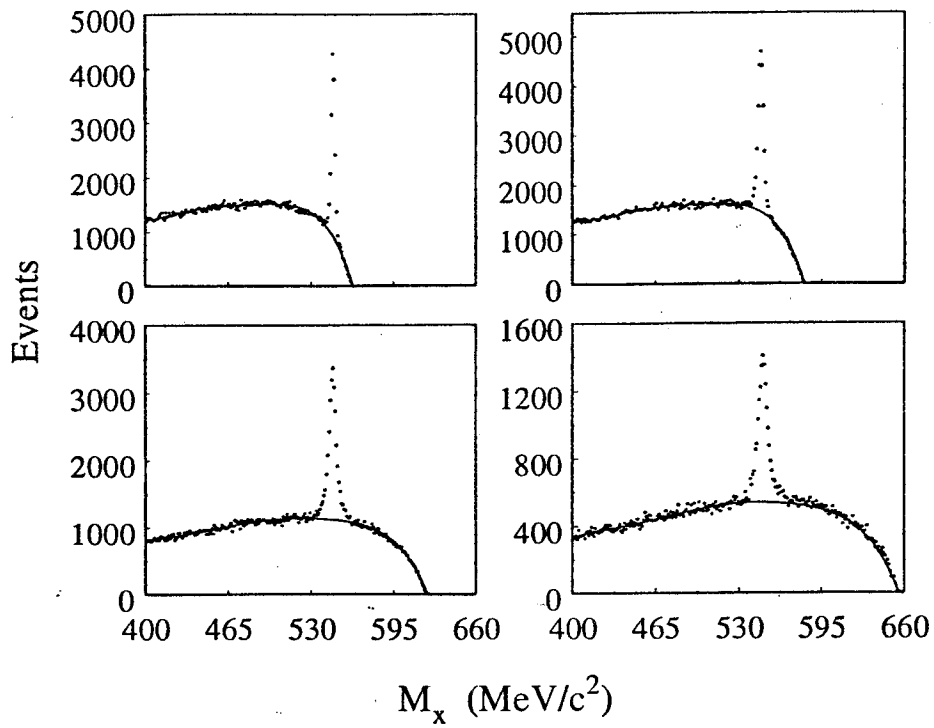
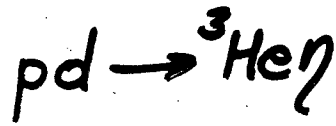


Fig. 3.

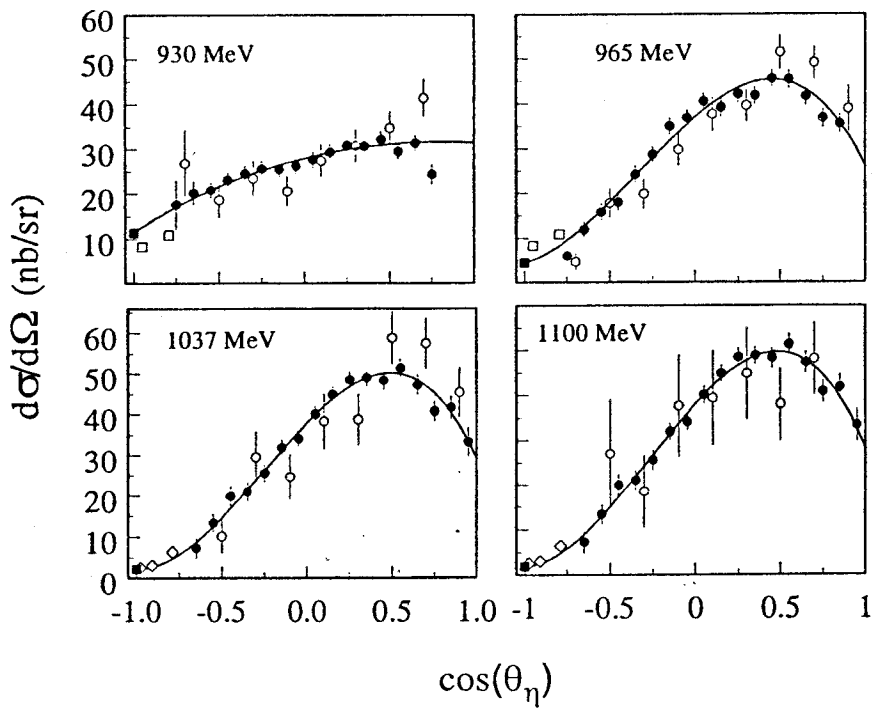
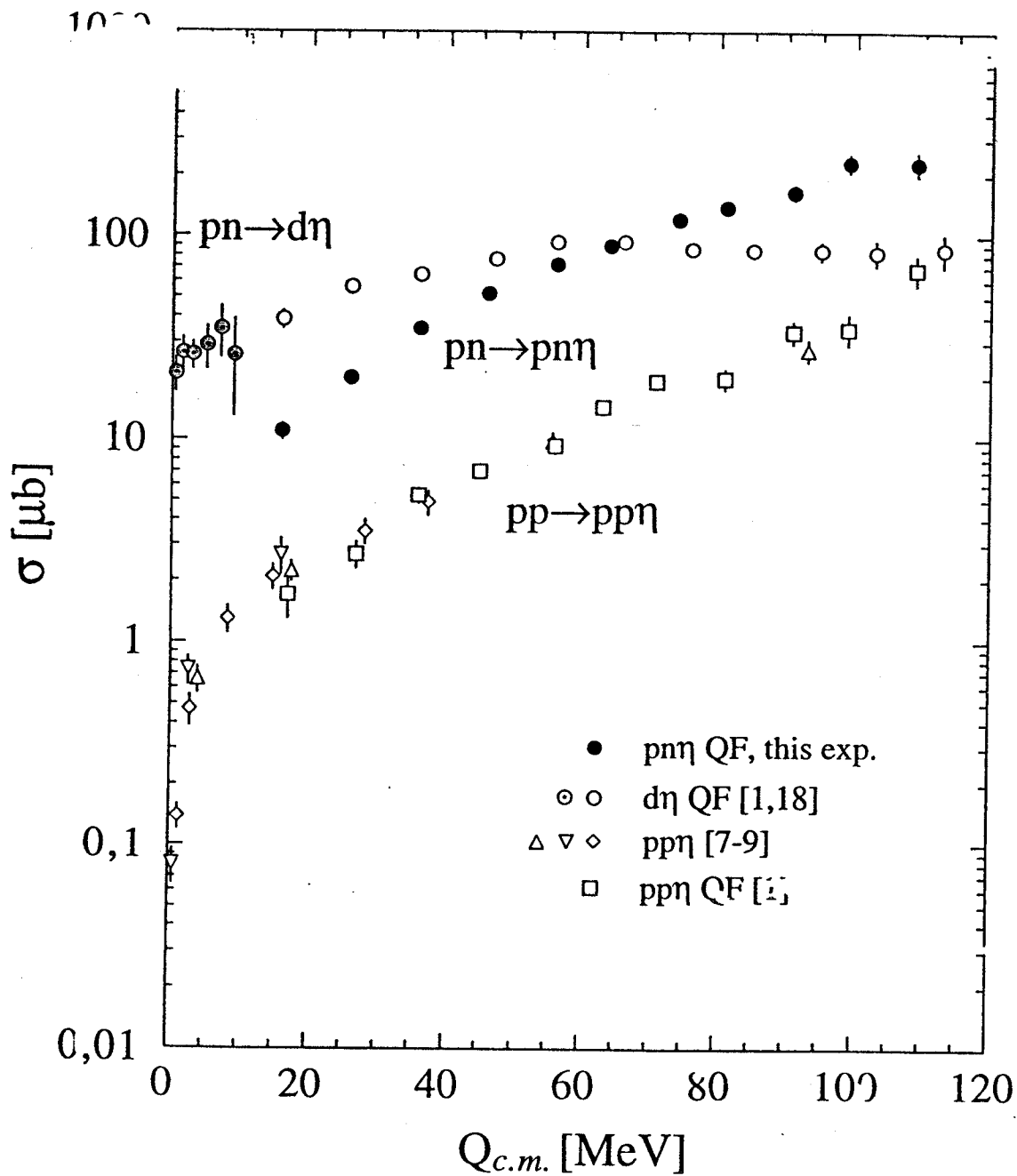


Fig. 4.

Measurements of the quasi-free
 $pn \rightarrow pn\eta$ reaction
 Phys. Rev. C 2667 (1998) 58



$$pd \rightarrow pn\eta + p_s$$

$$\frac{\sigma(pn \rightarrow pn\eta)}{\sigma(pp \rightarrow pp\eta)} \approx 6.5$$

[Properties of the $\eta(547)$]

life time $5 \times 10^{-19} \text{ s}$, $\Gamma = 1.2 \text{ keV}$

$$C = +1 \quad P = -1$$

$$\eta \approx 1/\sqrt{3} (u\bar{u} + d\bar{d} - s\bar{s})$$

octet-singlet mixing angle $\sim 20^\circ$

Main decay channels:

$$\gamma\gamma \quad 39\%$$

$$\pi^+\pi^-\pi^0 \quad 23\%$$

$$\pi^0\pi^0\pi^0 \quad 32\%$$

$$\pi^+\pi^-\gamma \quad 4.8\%$$

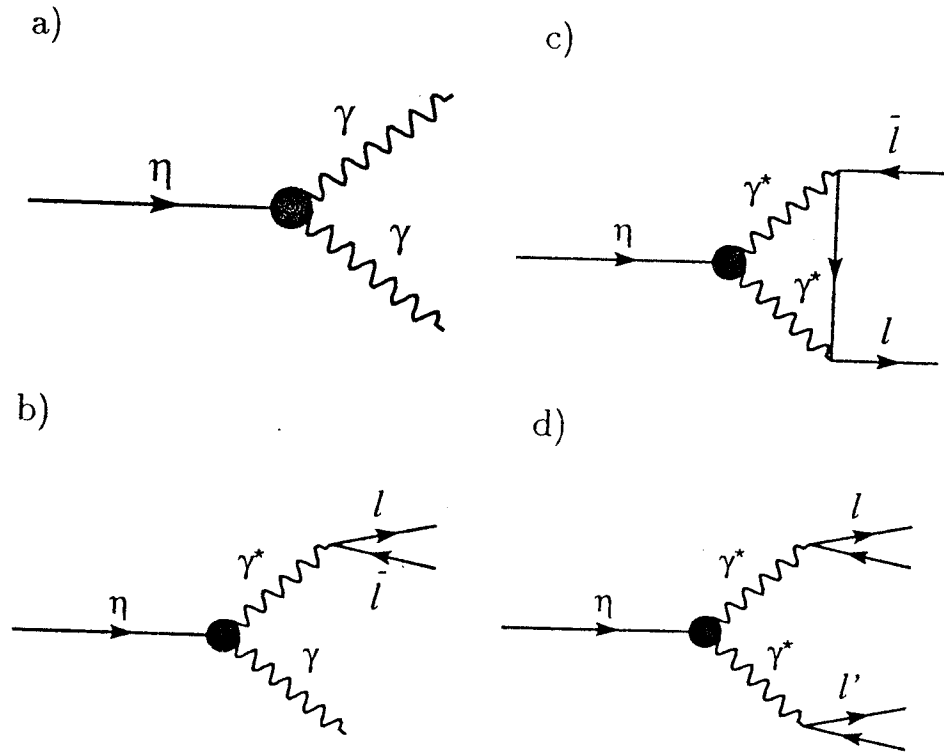
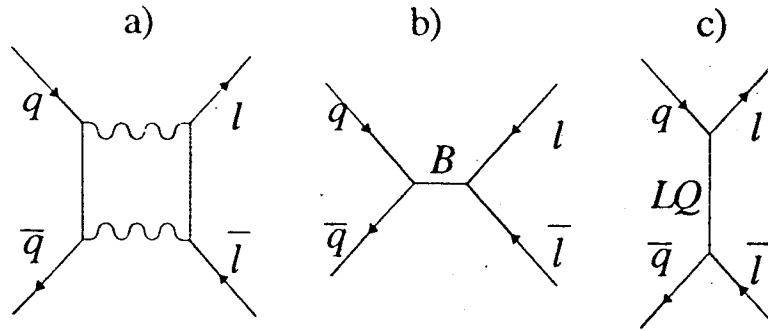
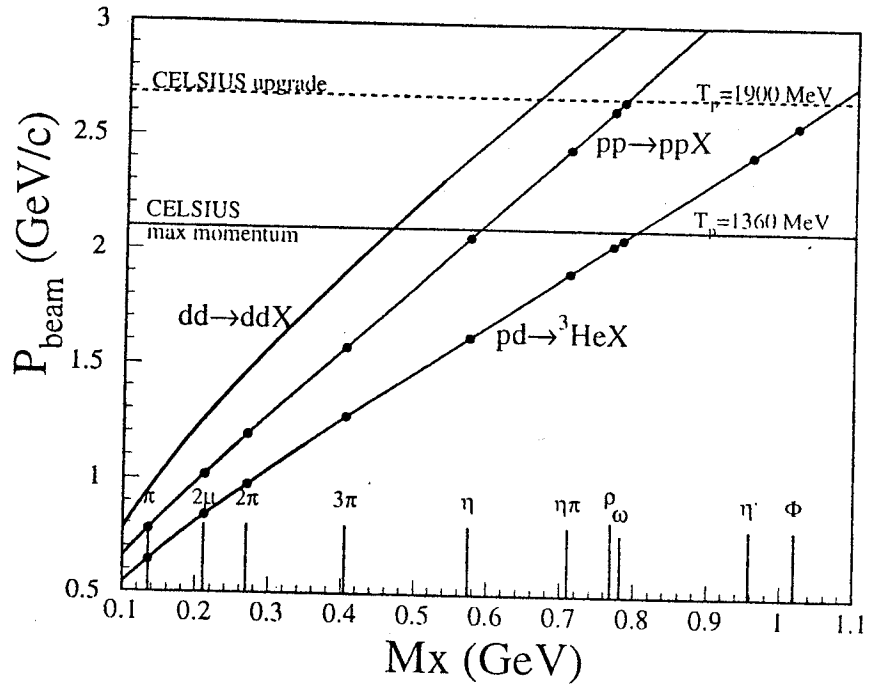


Fig. 3. Four different electromagnetic η decays having an eta-photon-photon vertex function. Here ℓ or ℓ' denote a lepton (μ or e) and $\bar{\ell}$ or $\bar{\ell}'$ the antilepton.

Structure of the $\eta \rightarrow \gamma\gamma$ vertex from
 leptonic decays as a function of
 l^+l^- invariant mass $\equiv -Q^2$



Possible mechanisms for the decay of a pseudoscalar meson (π^0, η) into a lepton-antilepton pair: (a) QED, (b) heavy propagator, (c) hypothetical lepto-quark.



Particles that can be studied at CELSIUS/WASA.

Particle Production in Proton and Nucleus induced Reactions around 200A MeV

Tomasz Matulewicz
for the TAPS Collaboration

Institute of Experimental Physics
Warsaw University
00681 Warsaw
Poland

Heavy-ion collisions are the only, currently available, experimental tool to explore the phase diagram of nuclear matter. A hot and compressed reaction zone is created through multiple nucleon-nucleon collisions, in which the initial longitudinal momentum of the projectile is dissipated. Nucleon-nucleon collisions allow not only for a conversion of longitudinal momentum into transverse momentum, but also for the creation of secondary particles. At energies per nucleon below the free pion production threshold (280 MeV) the created particles are pions, hard photons ($E_\gamma > 30$ MeV) and, extremely rarely, heavier mesons like η or K^+ . These particles witness the early phase of the reaction, the phase of maximum energy and matter density. Favorite particles are energetic photons, as they escape the creation zone without the disturbing influence of final state strong interactions. On the contrast, the observed pion yield is significantly reduced, due to strong reabsorption effects, compared to the primordial pion flux.

Extracting the information relevant to the thermodynamical state of the dense reaction zone, the principal goal of these investigations, is far from being straightforward. The complicated many-body problem of heavy-ion collision has to be studied with the use of sophisticated transport models extrapolating the free nucleon-nucleon interactions towards increased nuclear density. As an alternative, an empirical approach can be envisaged, which is based on the comparison of various observables between heavy-ion collisions and proton-nucleus collisions. Since in the case of proton-nucleus collisions a compressional phase is very unlikely, the in-medium effects can be studied without the complex dynamics and thermodynamics of heavy-ion collision.

Photon and neutral meson production was studied with the TAPS spectrometer. Experiments were performed with a 180A MeV Ar beam at SIS (GSI Darmstadt) and a 190 MeV proton beam at AGOR (KVI Groningen). Experimental data on pion reabsorption processes were obtained at AGOR and GANIL (Caen).

In the 180A MeV Ar+Ca reaction a variety of observables have been obtained. The production of the neutral mesons π^0 and η was studied, pointing to the important role of secondary processes when the production becomes deep-subthreshold (beyond the simple cooperative addition of the Fermi momenta to the beam momentum). The correlations between neutral pions and protons revealed the presence of Δ -resonances. Assuming isospin symmetry, the analysis demonstrated that more than half of the observed pions originate from Δ -resonance decay. Finally, the careful evaluation of neutral pion contribution to the total photon spectrum allowed the extraction of the direct hard photon spectrum, expanding our knowledge on the photon production studied previously at and below ~ 100 A MeV. The observed cross section of hard photons is much larger than the extrapolation of the existing systematics.

190 MeV proton-induced reactions allowed a simultaneous study of hard photon and neutral meson production. The energy spectra were measured up to their kinematical limits. From the target mass dependence of the cross sections the transition between surface production and volume production was clearly demonstrated.

The important problem of pion reabsorption in nuclear matter was studied in Ar-induced reactions at 60A MeV and 95A MeV on various targets. A simple geometrical model with momentum-dependent absorption length was developed and applied to the existing data. The principal conclusion is that the angular distribution of primordial pions is independent of the beam energy and collision system: the observed anisotropic angular distributions can be explained as a result of pion reabsorption in nuclear matter.

- [1] G.Martinez *et al.*, Phys. Rev. Letters **83** (1999) 1538
- [2] G.Martinez *et al.*, Physics Letters **B461** (1999) 28
- [3] T. Matulewicz *et al.*, Europ. Phys. J. **A9** (2000) 69
- [4] L. Aphecetche *et al.*, Physics Letters **B519** (2001) 8
- [5] K. Piasecki *et al.*, Acta Phys. Pol. **B33** (2002) 973
- [6] K. Tymińska *et al.*, Acta Phys. Pol. **B33** (2002) 981

PARTICLE PRODUCTION IN PROTON AND NUCLEUS INDUCED REACTIONS AROUND 200 *A* MeV

Tomasz Matulewicz

Institute of Experimental Physics

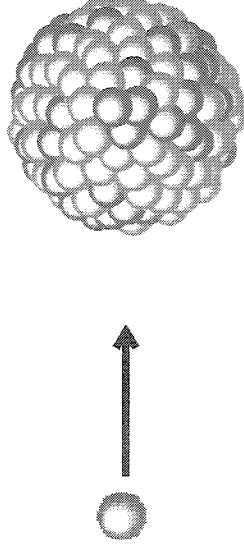
Warsaw University

for the TAPS Collaboration

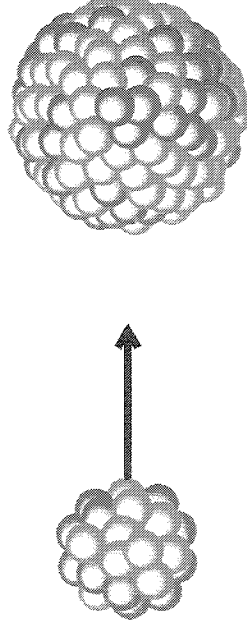
(GANIL-Giessen-Groningen-GSI-Rez-Valencia)

Particle production at $\sim 200A$ MeV

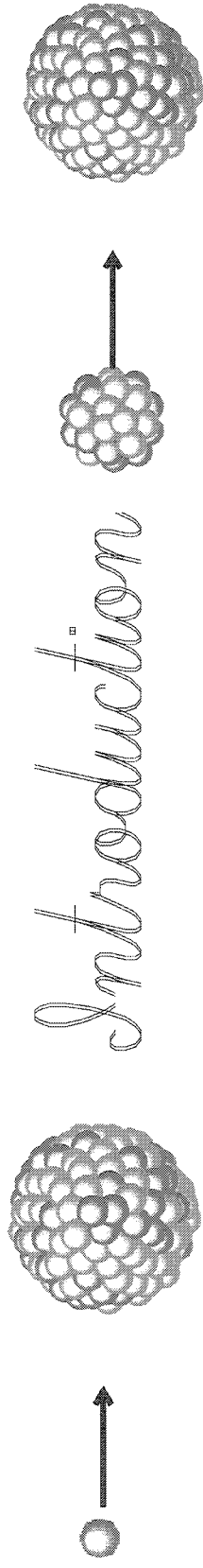
- Introduction



- 190 MeV p+A: *simple case*



- 180A MeV Ar+Ca: *complex case*
- Outlook



- Beam energy per nucleon below the NN threshold for light meson production (280 MeV for π^0): *probing the initial stage of the collision*
- **p+A vs A+A: cold vs hot nuclear matter**
- **p+A vs A+A: saturation vs increased density effects**

Thermodynamical state of the initial stage of the AA collision

- Modelling the multiparticle dynamics through transport equations numerically approximated (BUU, #QMD, etc).
Ingredients of the models : EOS, ???
- Empirical approach: comparison of various observables between AA and pA collisions.

Photon - the ultimate probe

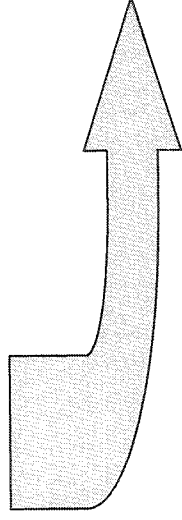
- Leaves the interaction zone without any distortion due to the final state strong interactions

- Low energy scale

- Background from $\pi\pi$ decay products

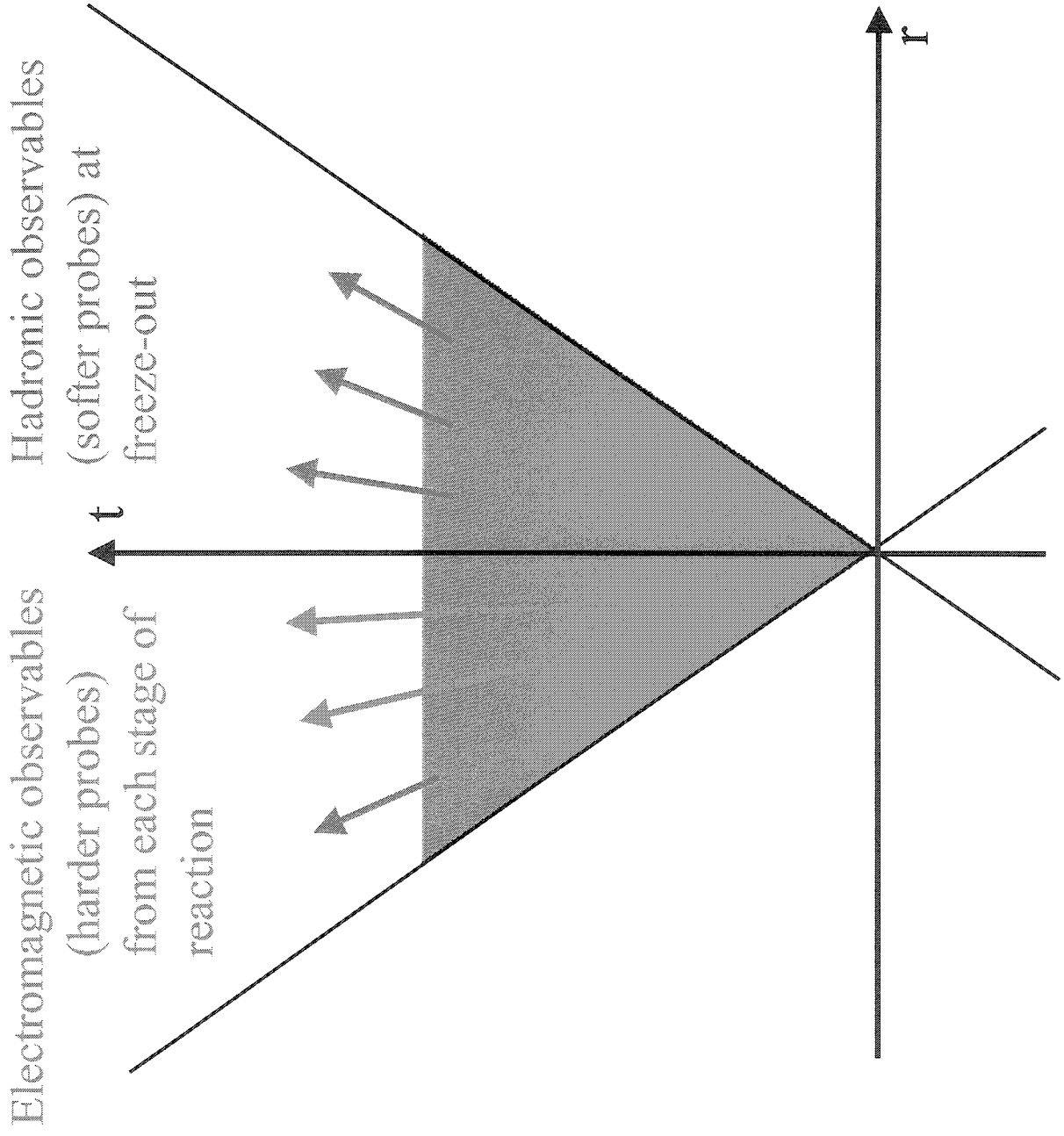
- baryons (Δ , Λ) and excited states

- ($\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$, ...)



**Data on meson production
and baryon excitations
are necessary!**

E-m vs strong probes



Experimental techniques

- Photon detection in BaF₂ detectors of TAPS spectrometer in experiment-specific configurations
- Identification of photons via: time-of-flight with FWHM~600 ps, pulse-shape analysis, thin veto counter rejecting charged particles
- Identification of neutral mesons via invariant mass analysis $m_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - \cos\mathcal{G}_{\gamma_1\gamma_2})}$
- Reconstruction of neutral meson kinematics (a novel method was proposed in 2000:

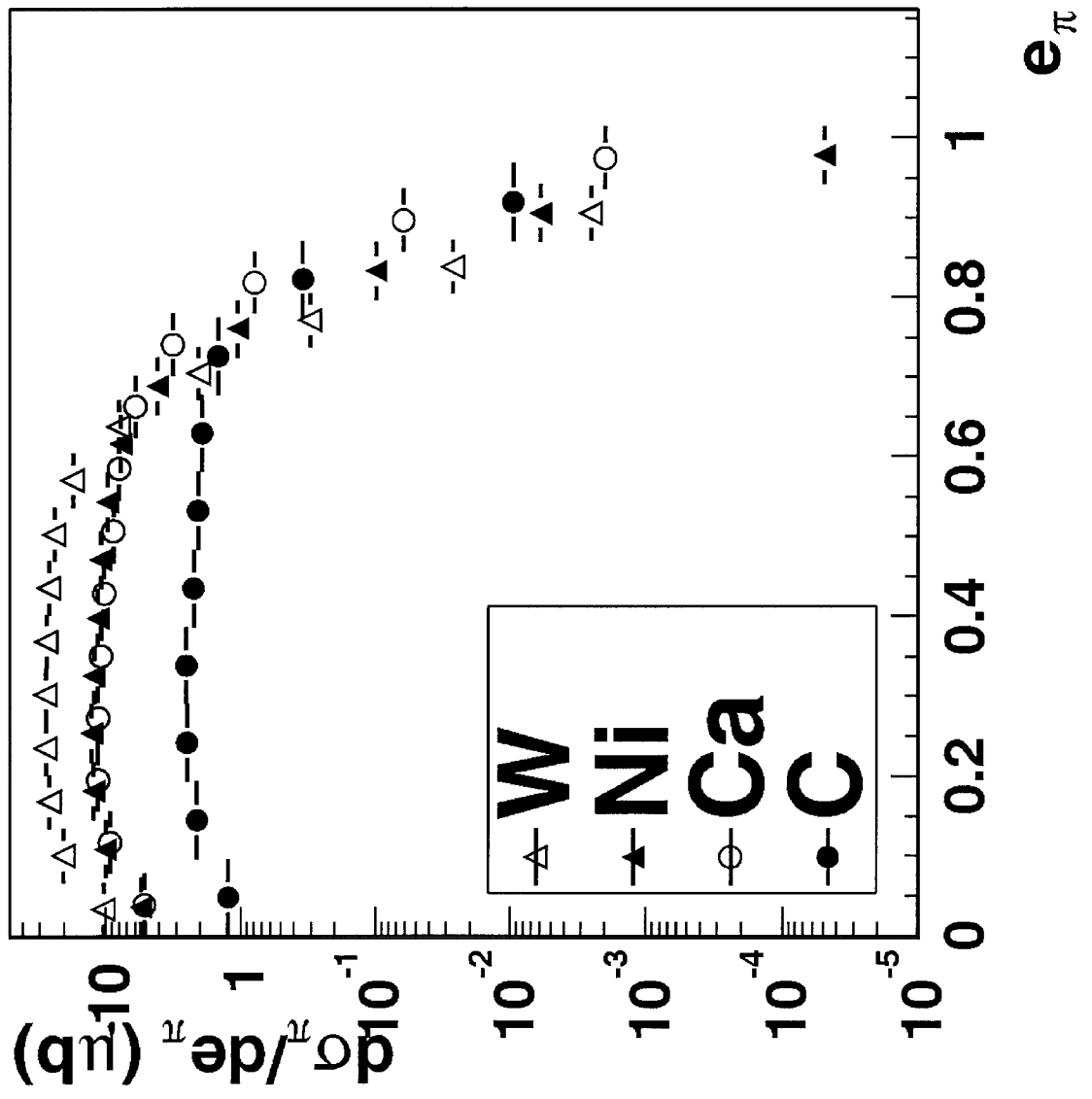
K. Korzecka & TM, Nucl. Instr. Meth. **A453**, 606)

Proton-nucleus collision

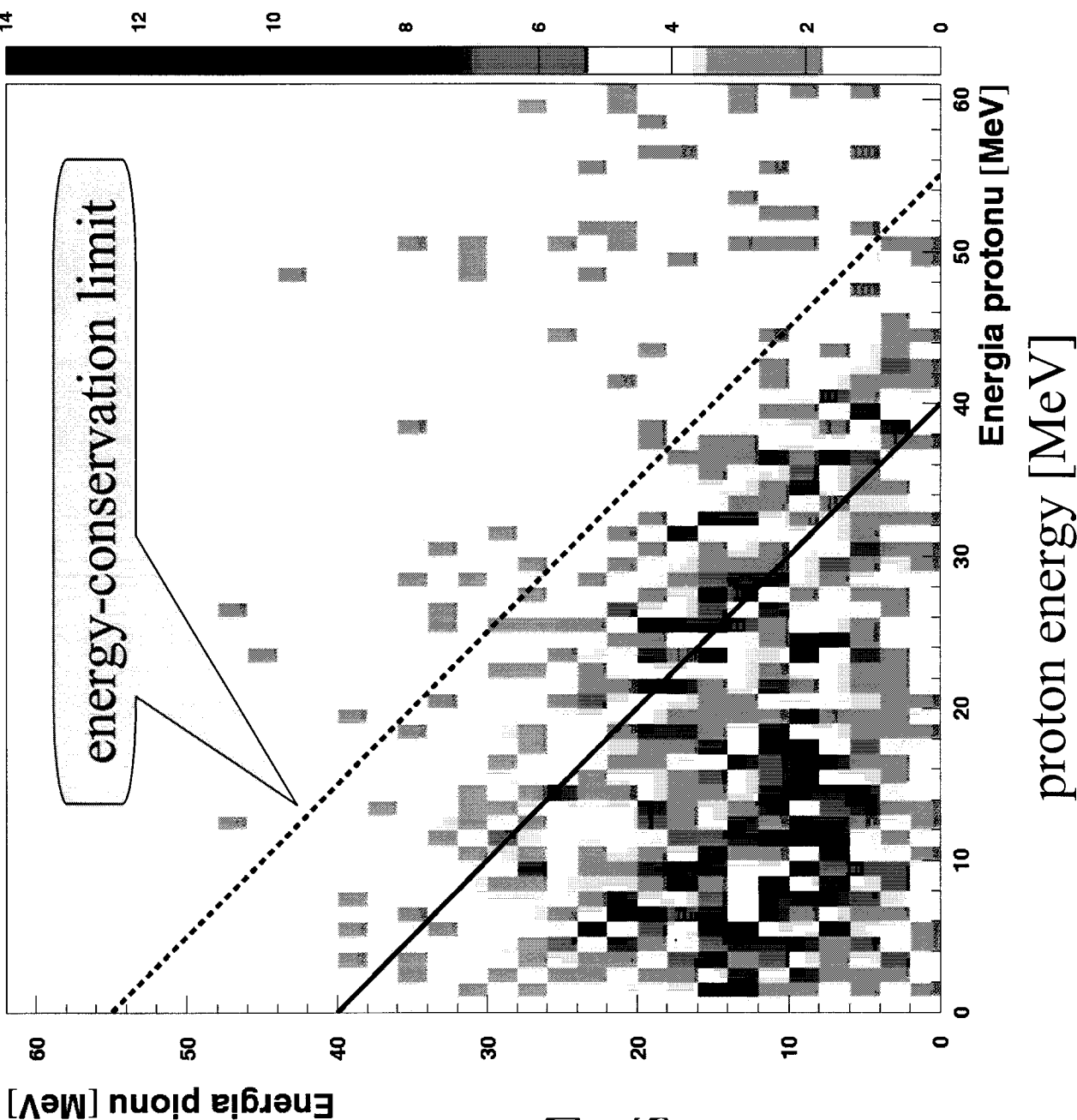
$p (190 \text{ MeV}) + C, Ca, Ni, W$

- Experiment: AGOR at KVI Groningen
- neutral pion production
- photon production
- multi-step processes in photon production

π^0 energy spectra



$$e_\pi = \frac{E_\pi}{E_{MAX_\pi}}$$

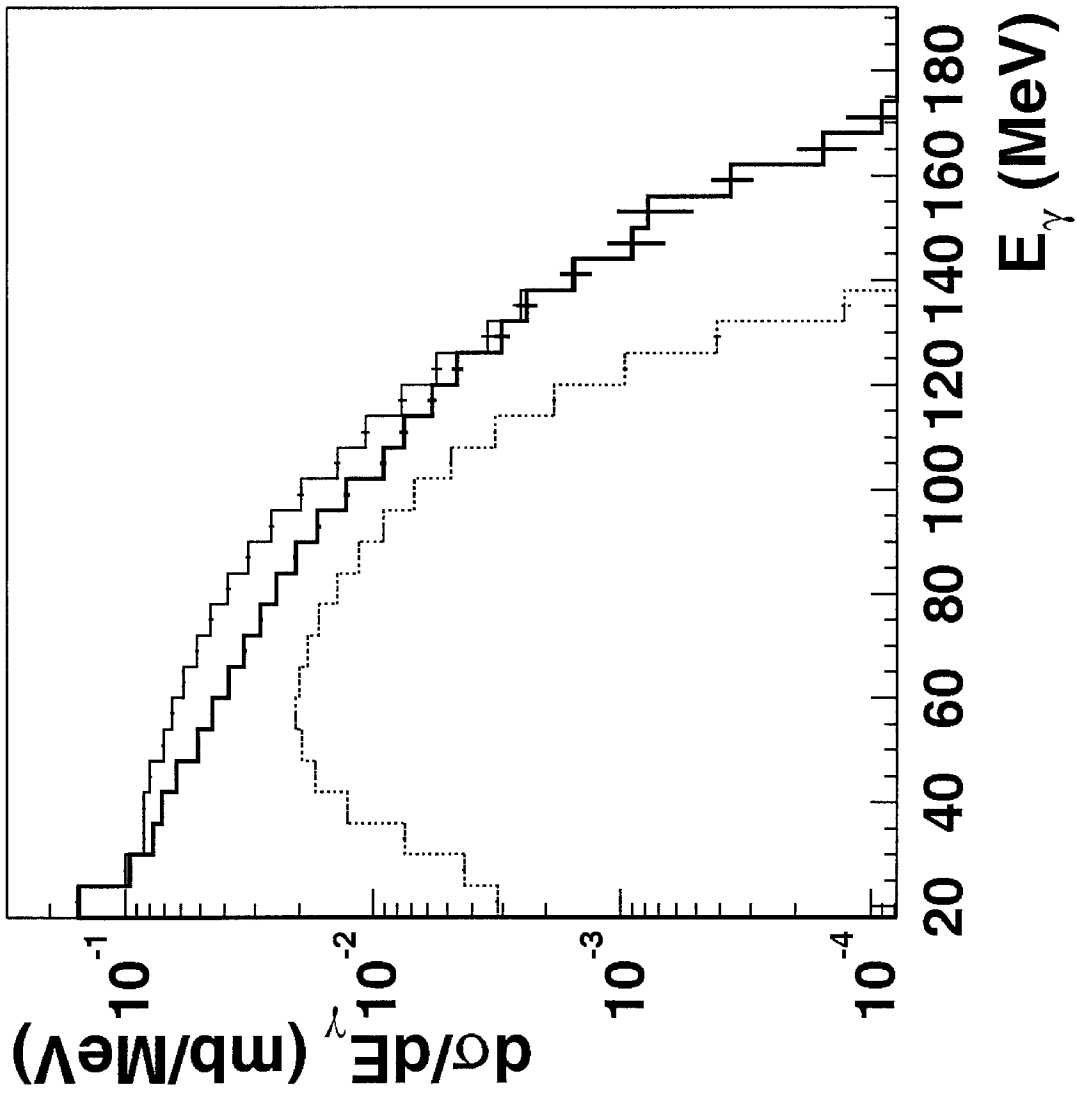


Pion-proton correlations

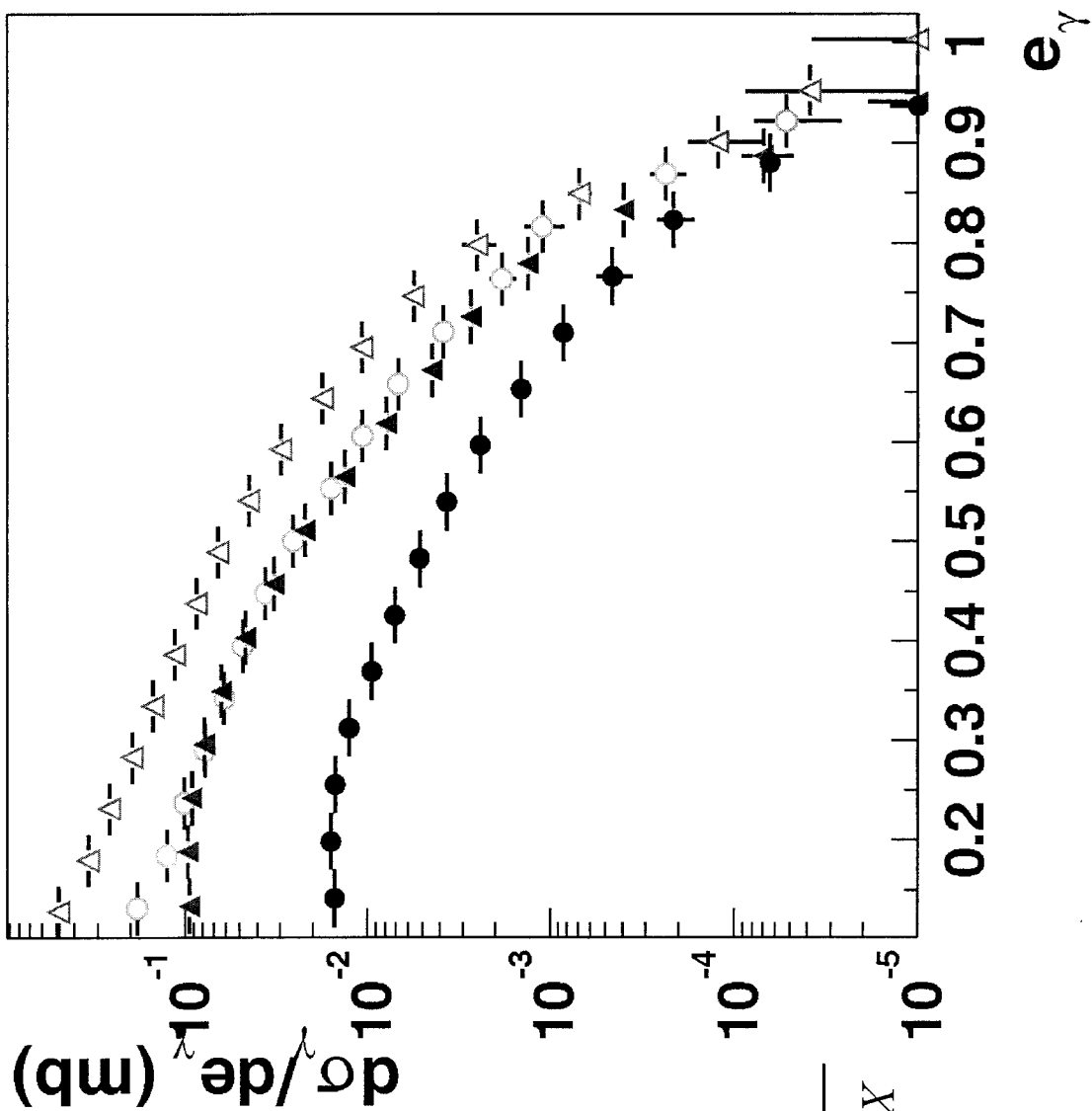
K. Tymińska
MSc thesis

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

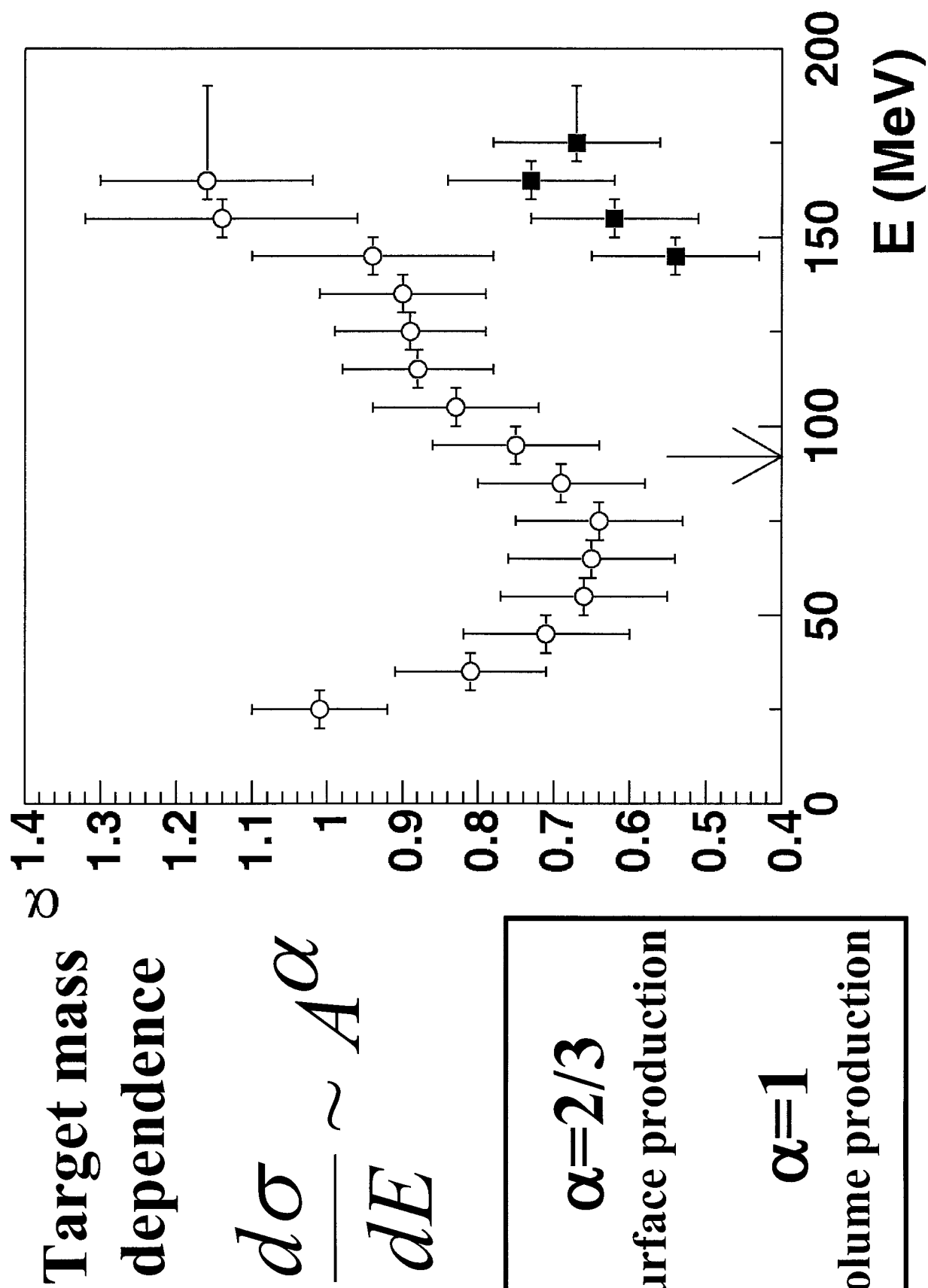
Spectrum of photons following $\pi^0 \rightarrow \gamma\gamma$ is simulated, but π^0 are measured in a wide acceptance range in the same experiment.



Photons corrected for $\pi^0 \rightarrow \gamma\gamma$



$$e_\gamma = \frac{E_\gamma}{E_\gamma^{MAX}}$$



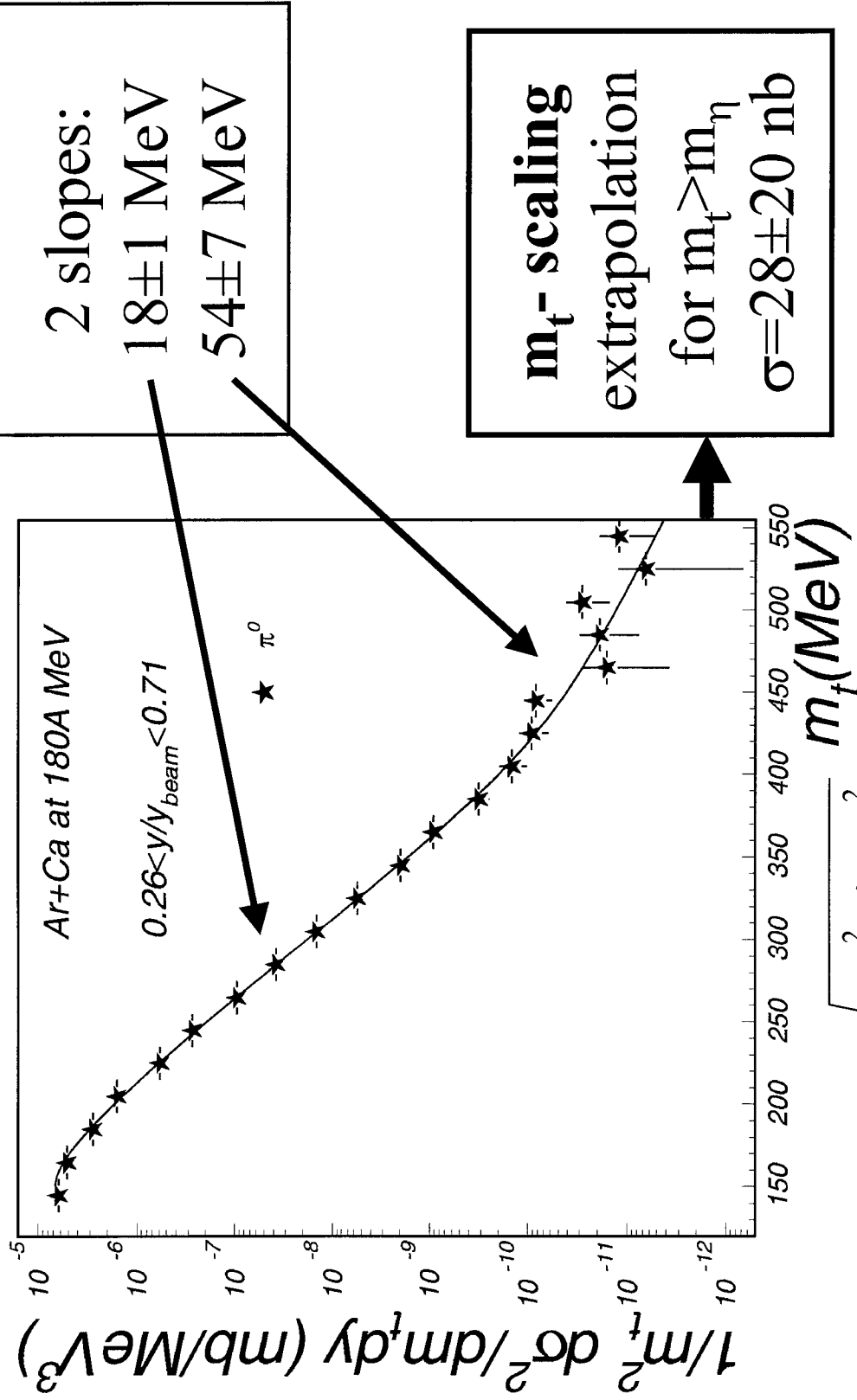
Heavy-ion collision

$\text{Ar } (180A \text{ MeV}) + \text{Ca}$

- Experiment: SIS at GSI Darmstadt
- meson production
- evidence of Δ -resonance
- photon spectrum: how to correct for the neutral pion contribution?

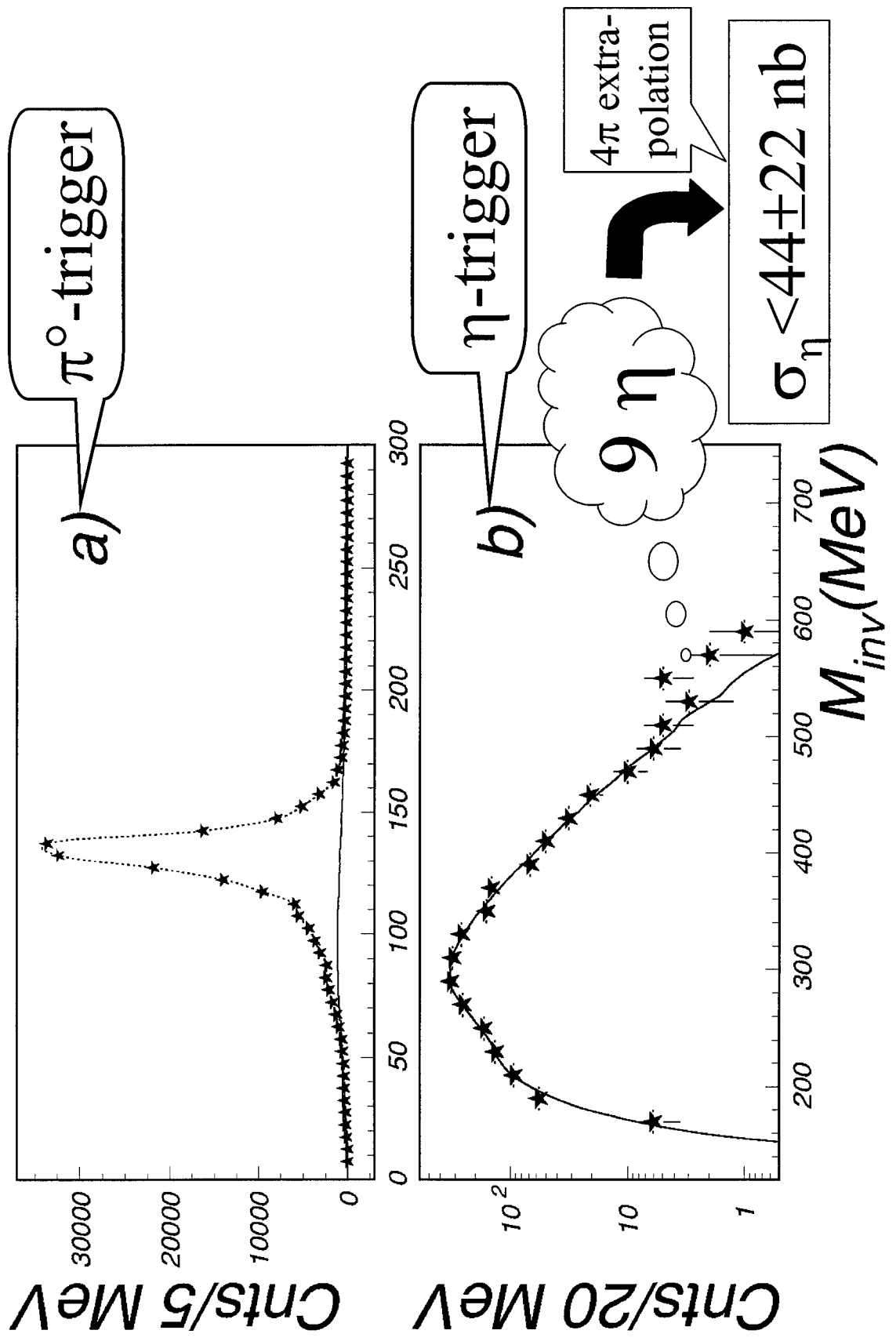
π^0 m_t spectrum

acceptance-corrected



$$m_t = \sqrt{m^2 + p_t^2}$$

$\gamma\gamma$ invariant mass spectrum



Threshold-energy scaling

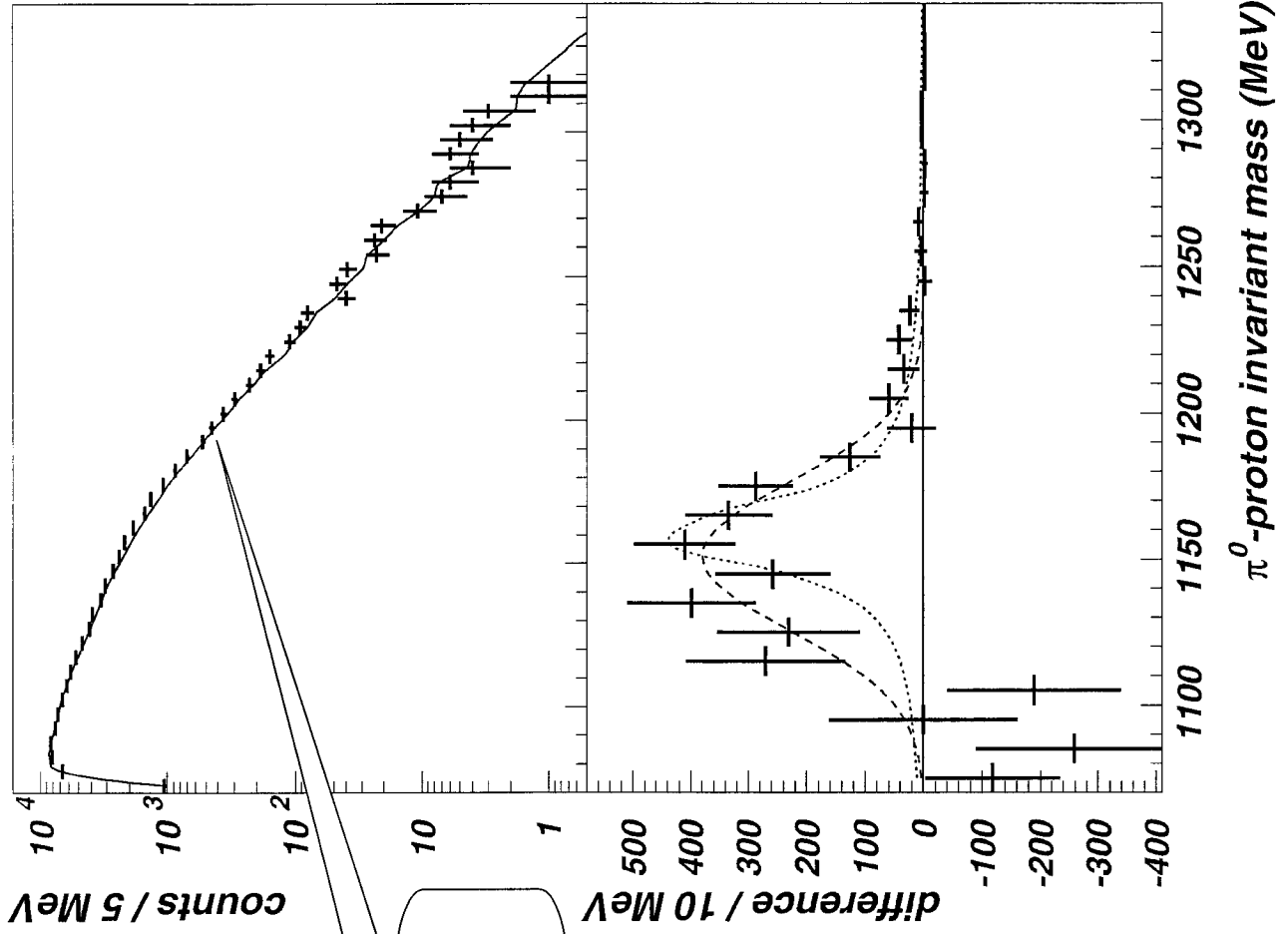
$$p_x = f \left(\frac{E_{BEAM}^{CC}}{E_{THRESHOLD}^{NN \rightarrow NN\pi}} \right)$$

determined by pion cross
section measurements:

1804 MeV for η
corresponds to
40.44 MeV for π^0

Observed η yield is
factor 10-20 below
this prediction.

π^0 -proton correlations



**1940 $\pm$ 740 events
above combinatorial
background**

(error is not only statistical,
it includes error from
background normalization)

On the origin of pions

$$\frac{N_{\Delta}}{N_{\pi}} = \frac{Y_{\Delta^+}}{Y_{\pi^0}} \times \frac{f_{\pi^0}}{p_{\Delta \rightarrow N\pi}} \times \frac{\varepsilon_{\pi^0}}{\varepsilon_{\Delta^+ \rightarrow p\pi^0}}$$

$$f_{\Delta^+ \rightarrow N\pi} f_{\Delta^+ \rightarrow p\pi^0}$$

$$\varepsilon_{\Delta^+ \rightarrow p\pi^0}$$

exp. yields

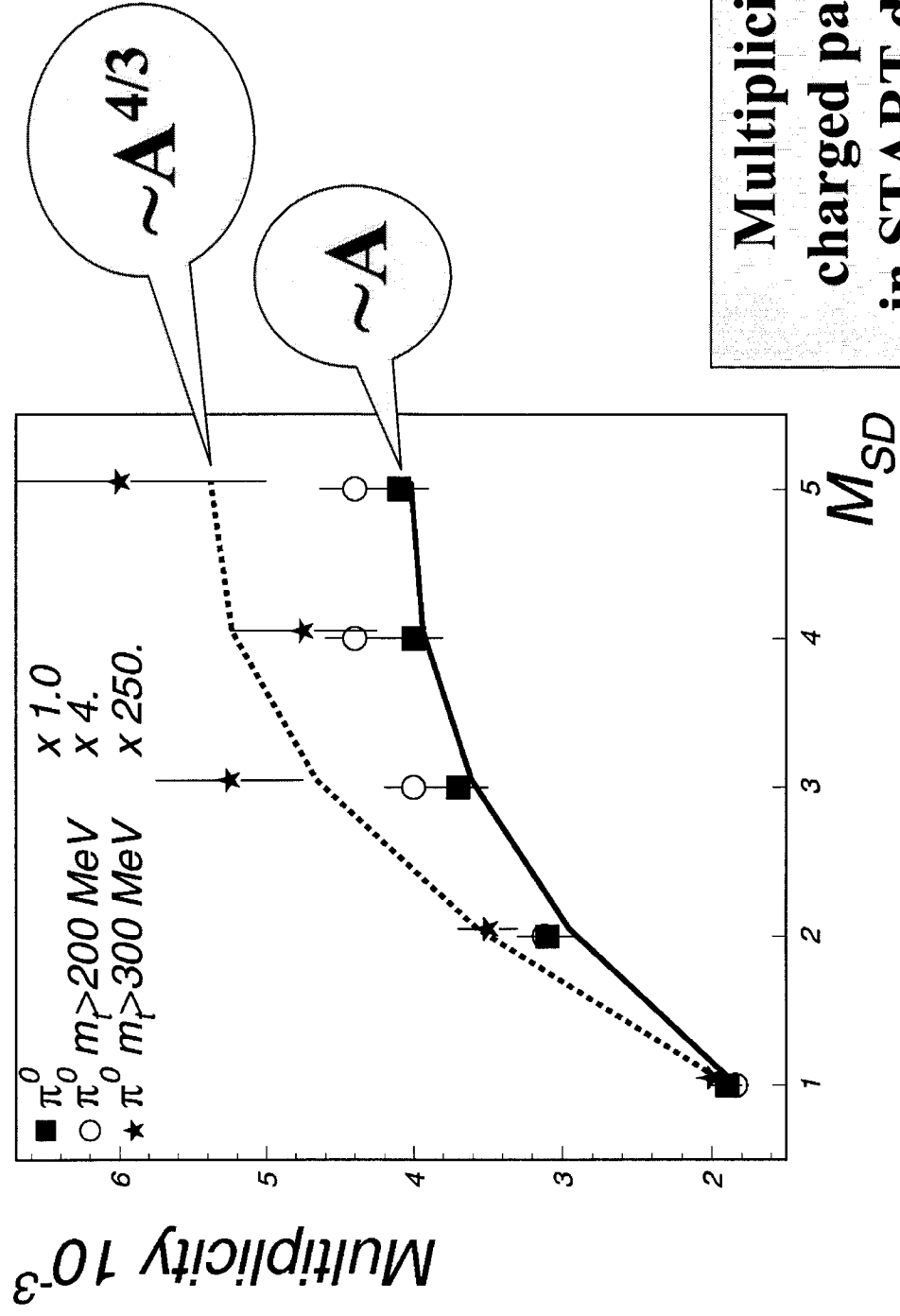
C-G coefficients
accounting for izospin

efficiency

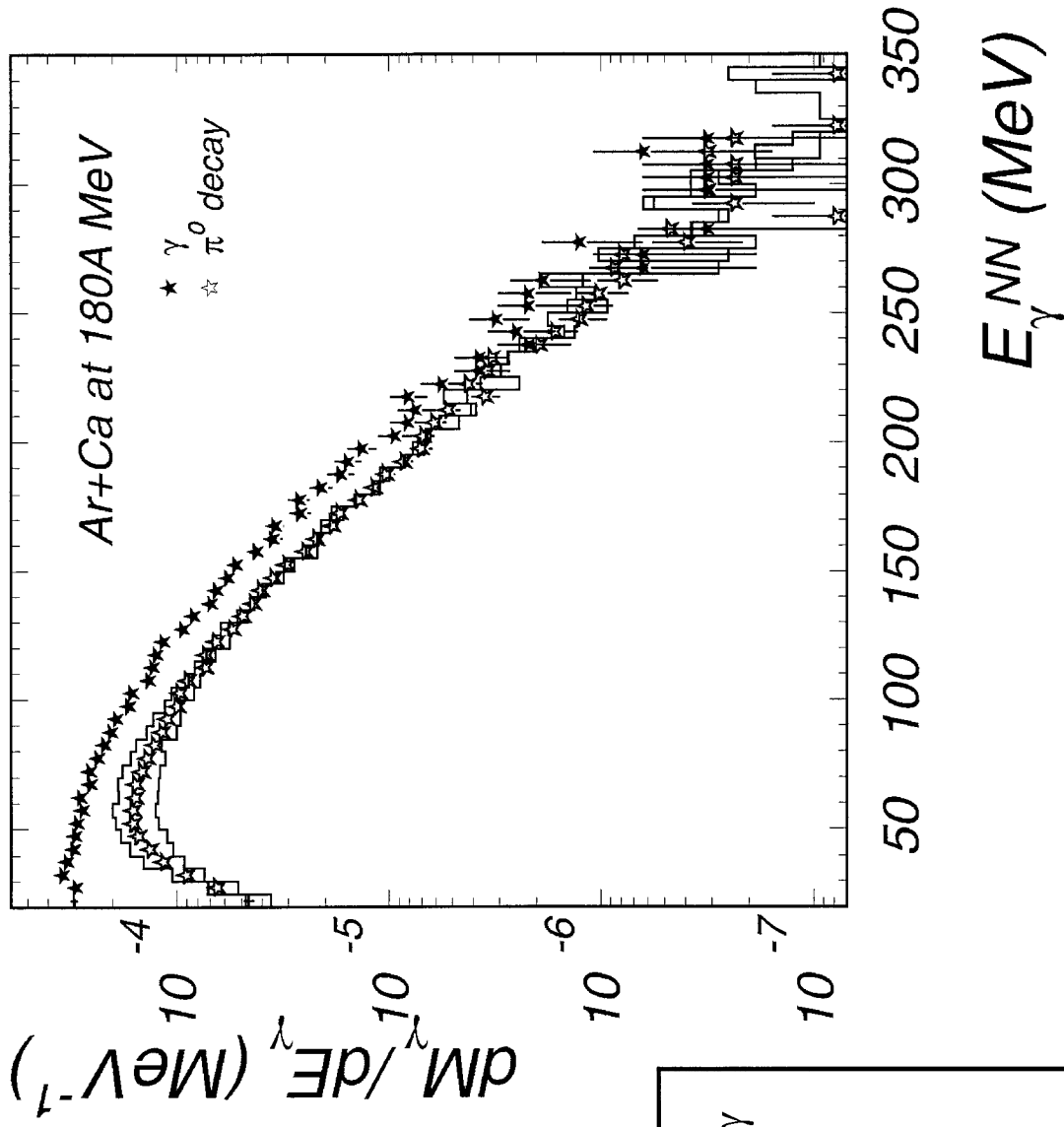
$$\frac{N_{\Delta}}{N_{\pi}} = 0.79 \pm 0.30_{\text{STAT}} \pm 0.2_{\text{SYST}}$$

Δ to pion
ratio

High m_t pions: from multi-step processes

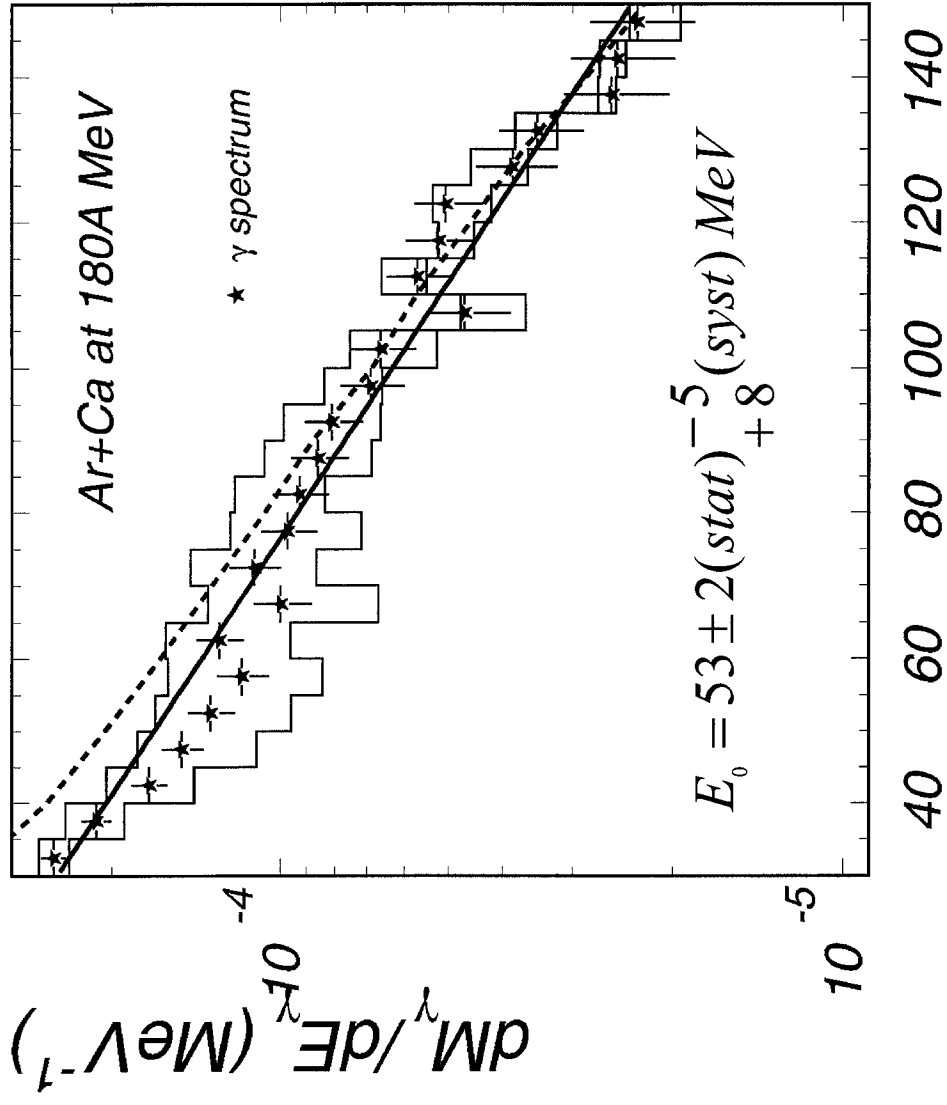


Raw photon spectrum and contribution from $\pi^0 \rightarrow \gamma\gamma$

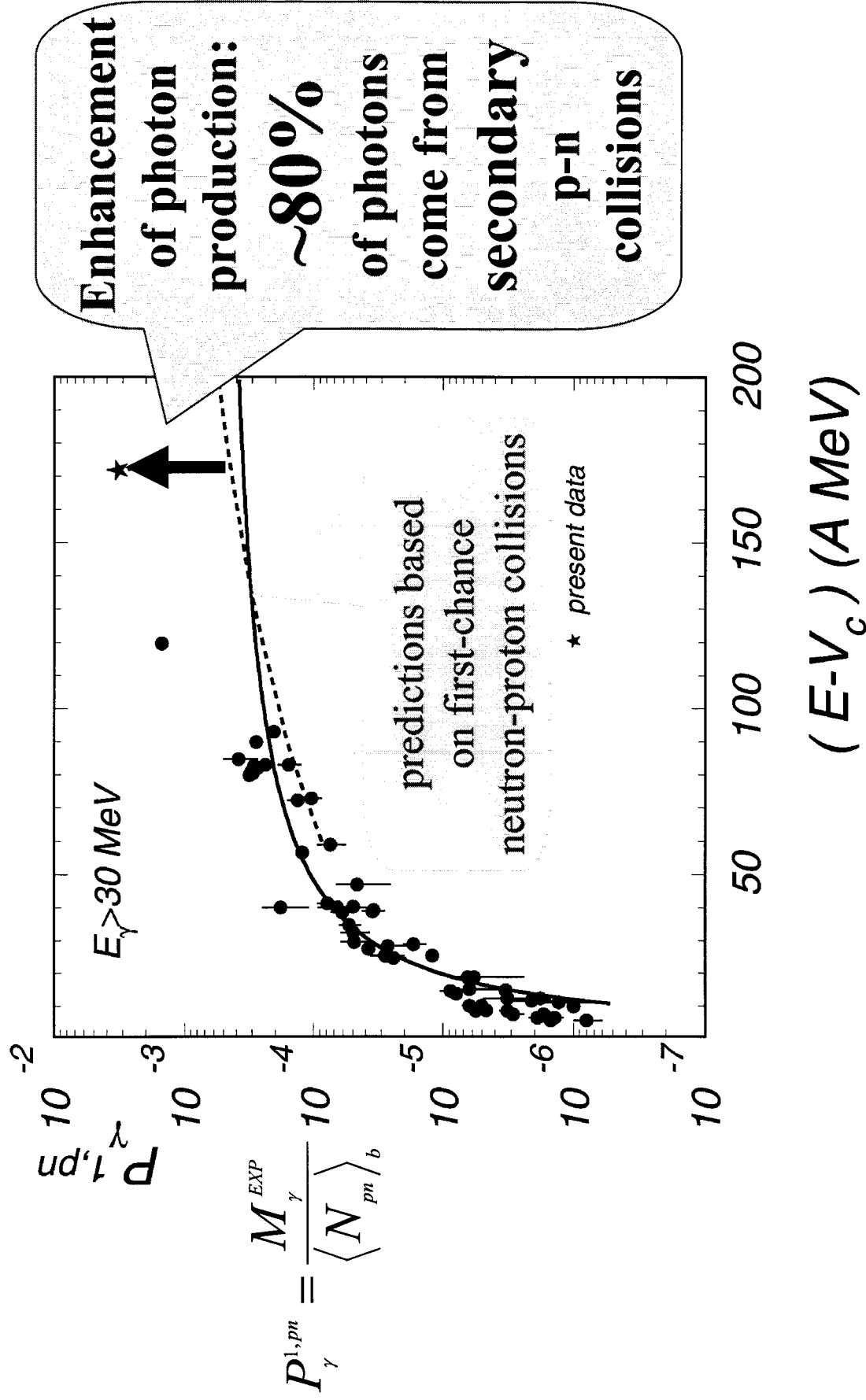


Contribution from $\pi^0 \rightarrow \gamma\gamma$ is simulated, but neutral pions in this experiment were measured in a relatively narrow acceptance window: **large systematic error**

photon spectrum

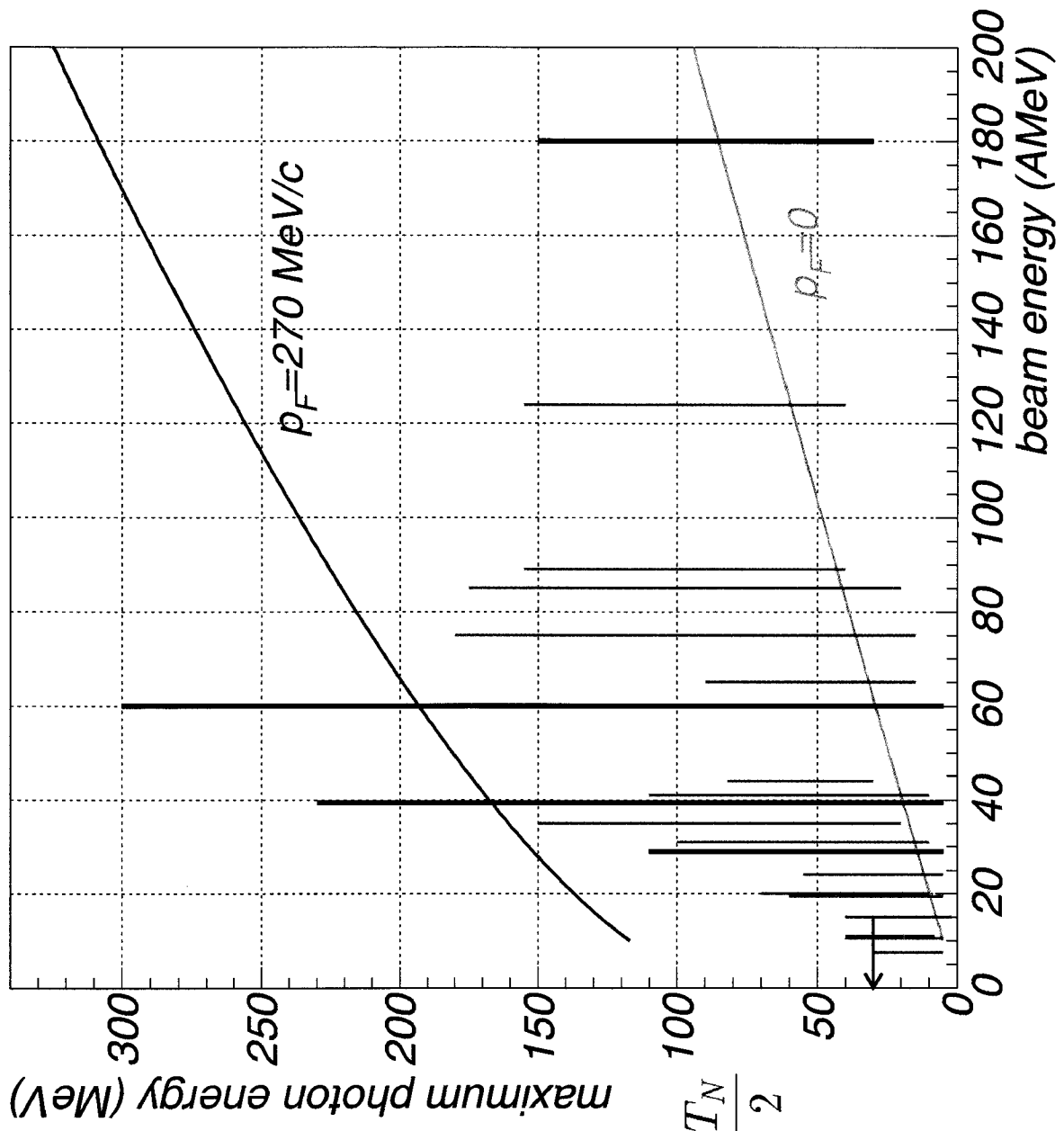


In-medium photon production probability

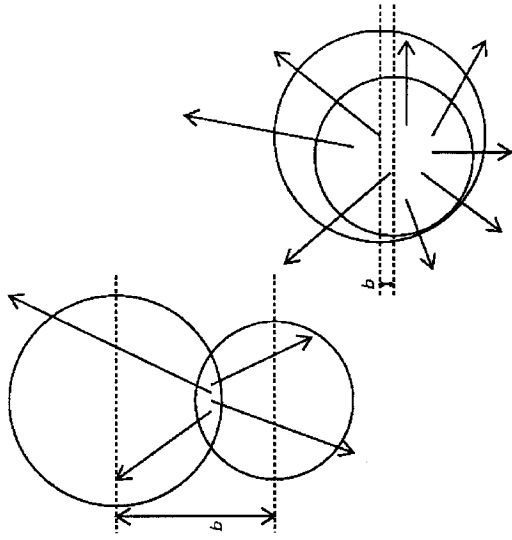


**Photon
energy:
where it
comes
from ?**

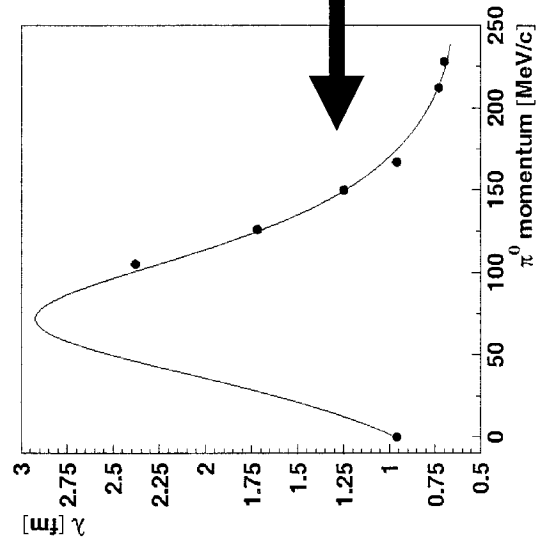
$$E_{\gamma}^{max} = \frac{s - 4m_N^2}{\sqrt{s}} \approx \frac{T_N}{2}$$



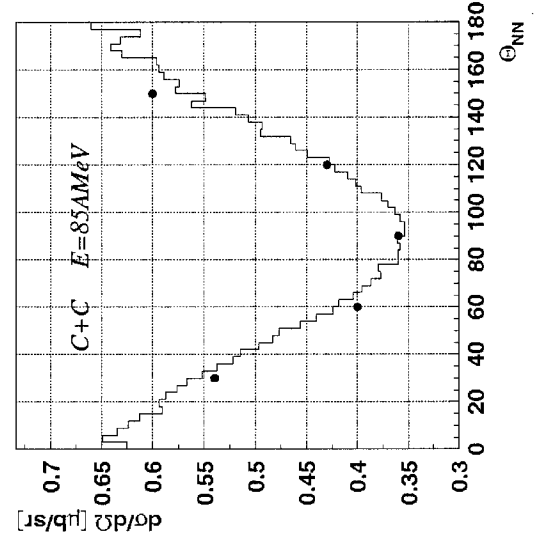
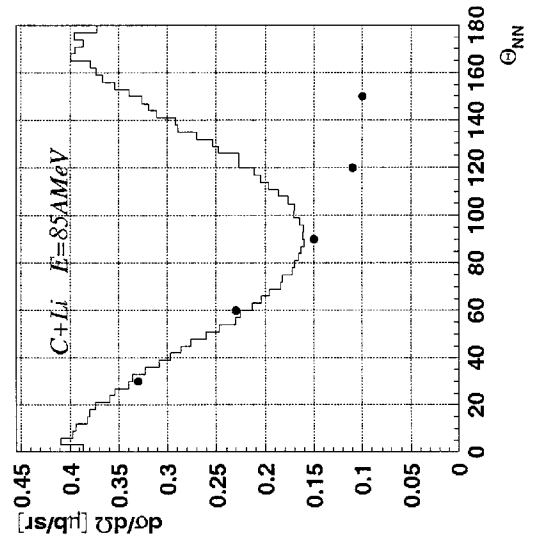
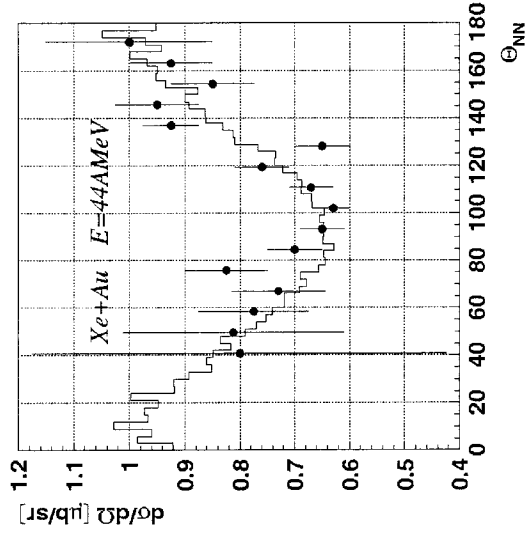
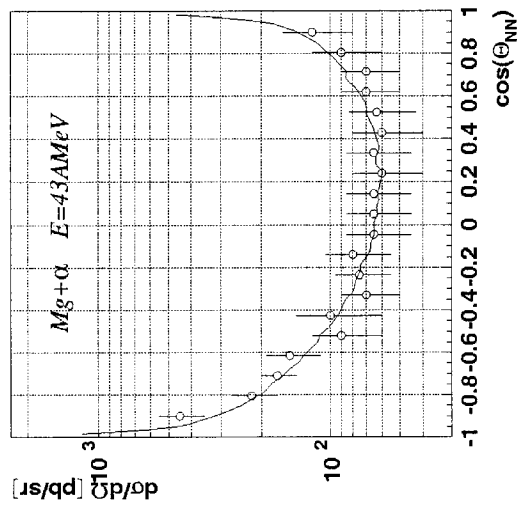
Pion reabsorption in nuclear matter



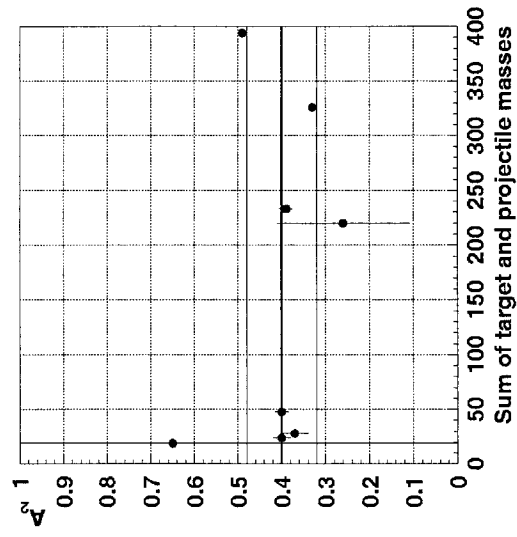
- Pion production proportional to the overlap volume
- Random emission according to $1+A_2P_2(\cos\theta)$ angular distribution and thermal energy distribution in NN center of mass system
- Absorption of pions depending on the distance travelled in nuclear matter (frozen shape)
- Momentum-dependent absorption length



angular distribution of primordial pions: constant



A_2 fitted to reproduce
experimental angular
distribution



$$A_2 = 0.40 \pm 0.08$$

Outlook

- Subthreshold particles do not originate only from first-chance NN collisions, but also from multiple-step processes:
 - high-energy tail: fluctuations
 - low-energy tail: quasi-thermal stage
- Transverse mass scaling valid also at subthreshold energies
- Experimental evidence for the dominant role of Δ -resonance for pion production
- Direct photons measurable at energies close to the pion threshold
- Reliable model accounting for pion reabsorption: better predictions for photons of hadronic origin

TAPS papers on this subject

- G.Martínez *et al.*, Phys. Rev. Letters **83** (1999) 1538
 η and π^0 production in Ar+Ca
- G.Martínez *et al.*, Physics Letters B **461** (1999) 28
high-energy γ production in Ar+Ca
- T. Matulewicz *et al.*, Europ. Phys. J. A **9** (2000) 69
evidence for $\Delta^+ \rightarrow p\pi^0$ decay in Ar+Ca
- L. Aphenecetche *et al.*, Physics Letters **B519** (2001) 8
 π^0 and γ production in p+X
- K. Piasecki *et al.*, Acta Phys. Pol. **B33** (2002) 973
- K. Tyimińska *et al.*, Acta Phys. Pol. **B33** (2002) 981
 π^0 reabsorption and π^0 primordial angular distribution

Identification of Resonant a_0^+ Structures in the $dK^+\bar{K}^0$ Dalitz Plot

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Identification of Resonant a_0^+ Structures in the $dK^+\bar{K}^0$ Dalitz Plot

- Reaction Kinematics and Dalitz plot for proton-proton collisions.
- What is the difference between a_0^+ resonance and $K^+\bar{K}^0$ non-resonant system in s -wave?
- Is it possible to isolate different production mechanisms?
- Partial wave decomposition of $dK^+\bar{K}^0$ system.
- Final state interaction between deuteron and $\bar{K}^0$.
- First model results.
- The strategy!
- Conclusions and perspectives will be given through my presentation.

- Reaction Kinematics.

some simple relations useful for the construction of experimental measurements and theoretical models

- Reaction threshold in NN collisions:

$$\text{Invariant collision energy} = \sqrt{s}$$

$$s = 2m_N(2m_N + T_{beam})$$

$$s = (\text{total mass of final particles})^2 = (\sum m_f)^2$$

- Accelerators:

IUCF, CELSIUS, SATURNE, COSY

state	T_{beam} (GeV)	IUCF	CELSIUS	SATURNE	COSY
$NN\pi$	0.28	○	○	○	○
$NN\eta$	1.25		○	○	○
$N\Lambda K$	1.58			○	○
$N\Sigma K$	1.788			○	○
$NN\omega$	1.89			○	○
$NN\eta'$	2.40			○	○
$NN\phi$	2.59			○	○

- High beam energy resolution

Reaction cross section σ as function of n-body final phase space Φ_n and production matrix element $M(\Phi_n)$

$$\sigma = \frac{1}{flux} \int |M(\Phi_n)|^2 d\Phi_n$$

$$\Phi_n = \frac{(2\pi^3)^{(n-1)/2} (\prod m_f)^{0.5}}{2\Gamma[1.5(n-1)] (\sum m_f)^{1.5}} (\sqrt{s} - \sum m_f)^{1.5n-2.5}$$

$$\sqrt{s} - \sum m_f = \epsilon \leftarrow \text{excess energy}$$

$$\sigma(NN \rightarrow NNM, NN \rightarrow NYM) \propto \epsilon^2$$

Very strong phase space dependence. Small (even negligible) error in reconstruction of ϵ might cause enormous variation in σ
 $\epsilon \in [1 \rightarrow 100 \text{ MeV}] \Rightarrow \sigma \in [1 \rightarrow 10^4]$

- It is useful to implement reduced cross section $= \sigma/\epsilon^2$
- For $n = 3$: $NN \rightarrow NYM$

$$d\Phi_3 = ds_{KY} ds_{NY},$$

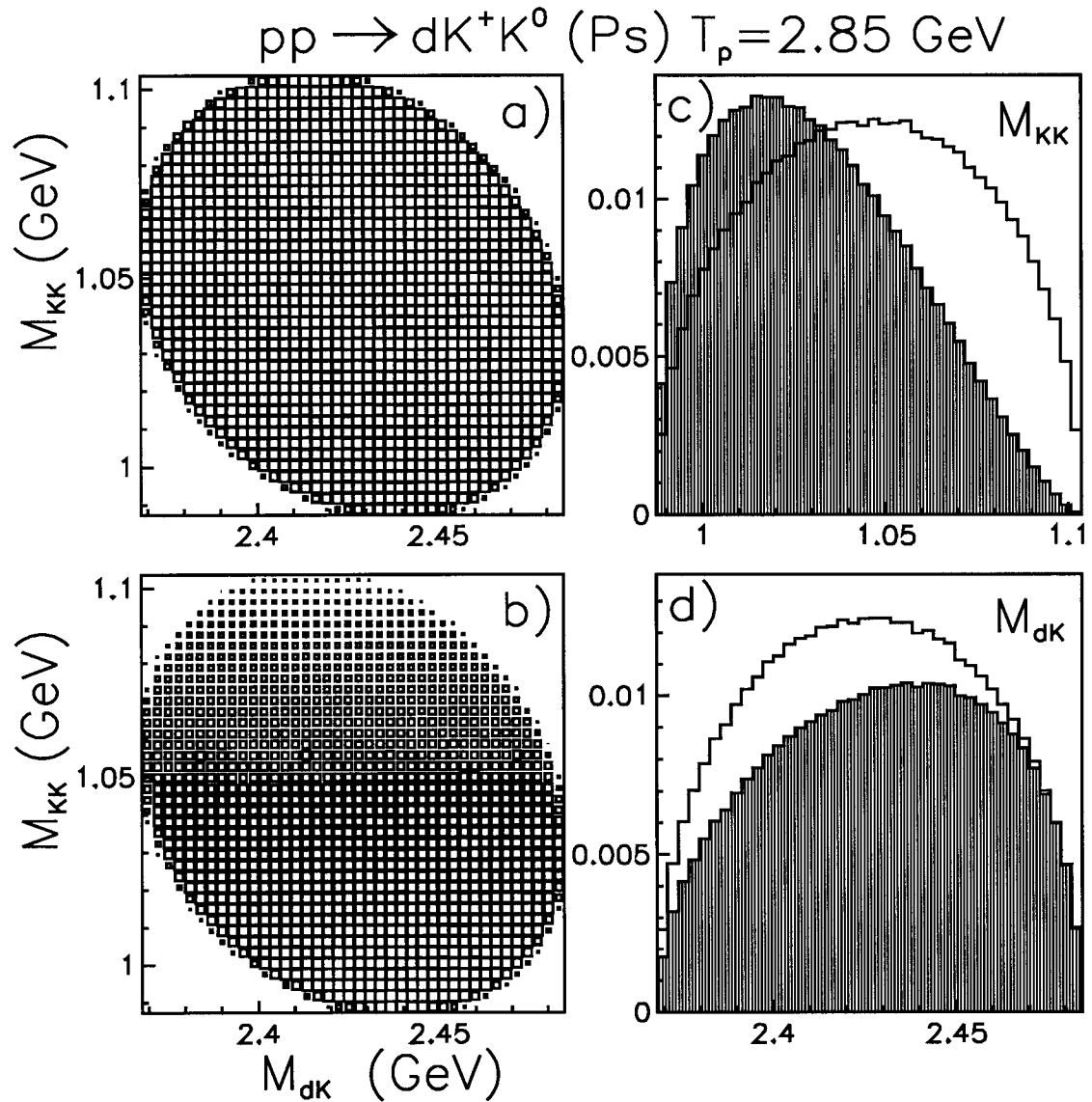
where s_{KY} and s_{NY} are squared invariant energies of the produced KY and NY subsystems.

- Dalitz plot

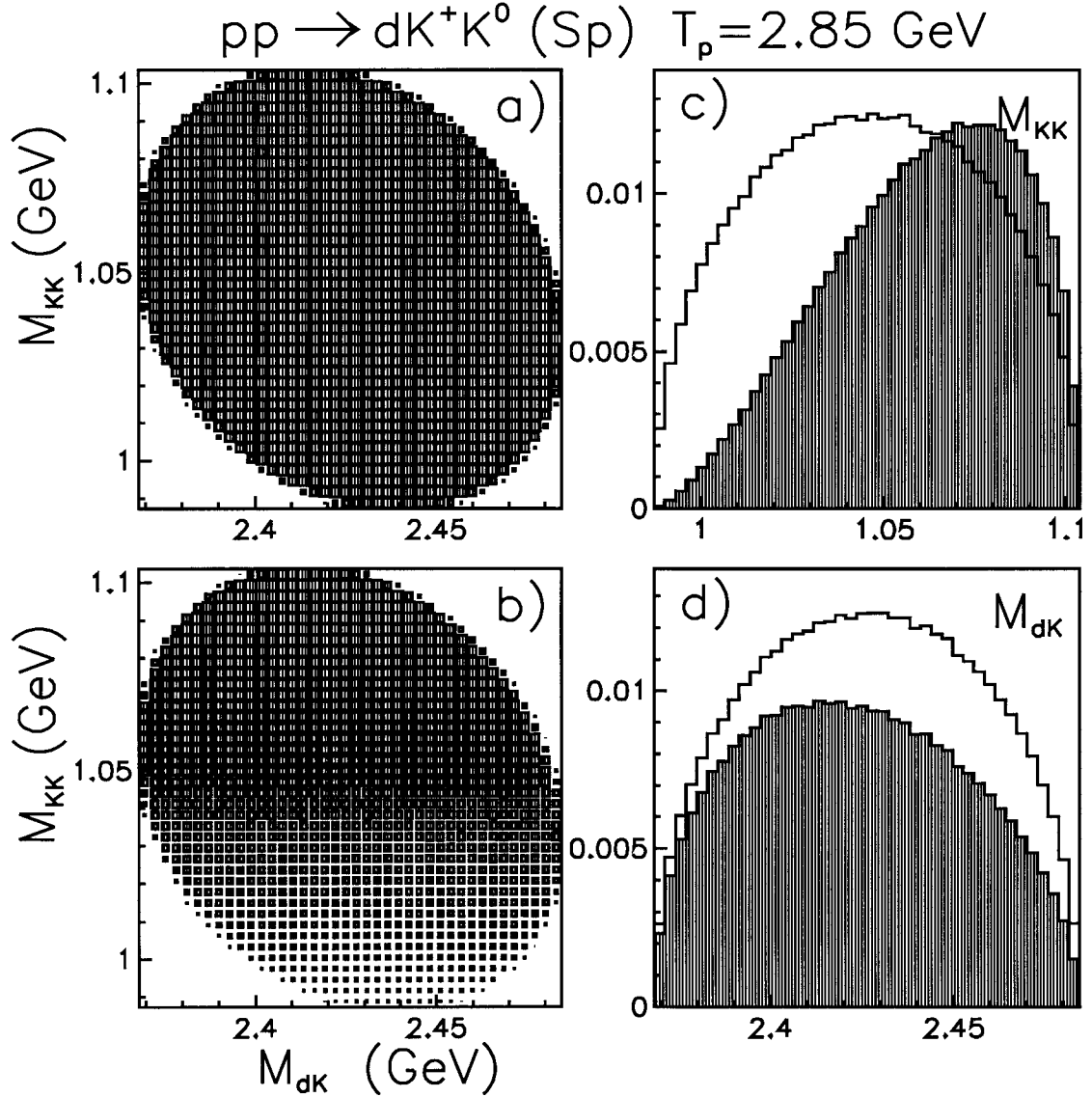
$$\frac{d\sigma}{ds_{K^+\bar{K}^0} ds_{\bar{K}^0 d}} = \frac{1}{64\pi^5 (s^2 - 4sm_p^2)} |M|^2,$$

and matrix element M depends on invariant collision energy $\sqrt{s}$, invariant masses of the final KY and NY subsystems and other independent invariants, which were over integrated within the Dalitz plot representation.

- However, to study structure of $K^+\bar{K}^0$ subsystem and FSI induced structure of $\bar{K}^0 d$ subsystem we should perform partial decomposition of the three body final state, i.e. to move beyond the Dalitz plot analysis.
- Let me denote by large S , P etc. orbital angular momentum of the $K^+\bar{K}^0$ subsystem with respect to the deuteron, while small s , p , etc. is the orbital angular momentum of the $K^+\bar{K}^0$ subsystem itself.
- Because of the quantum numbers conservation, the lowest allowed final state are Ps or Sp or their mixture. The Ss final state is forbidden.
- Nevertheless, in the following figures the unphysical Ss calculations will be also shown in order to illustrate the difference with respect to the Ps , Sp final states as well as their mixture.



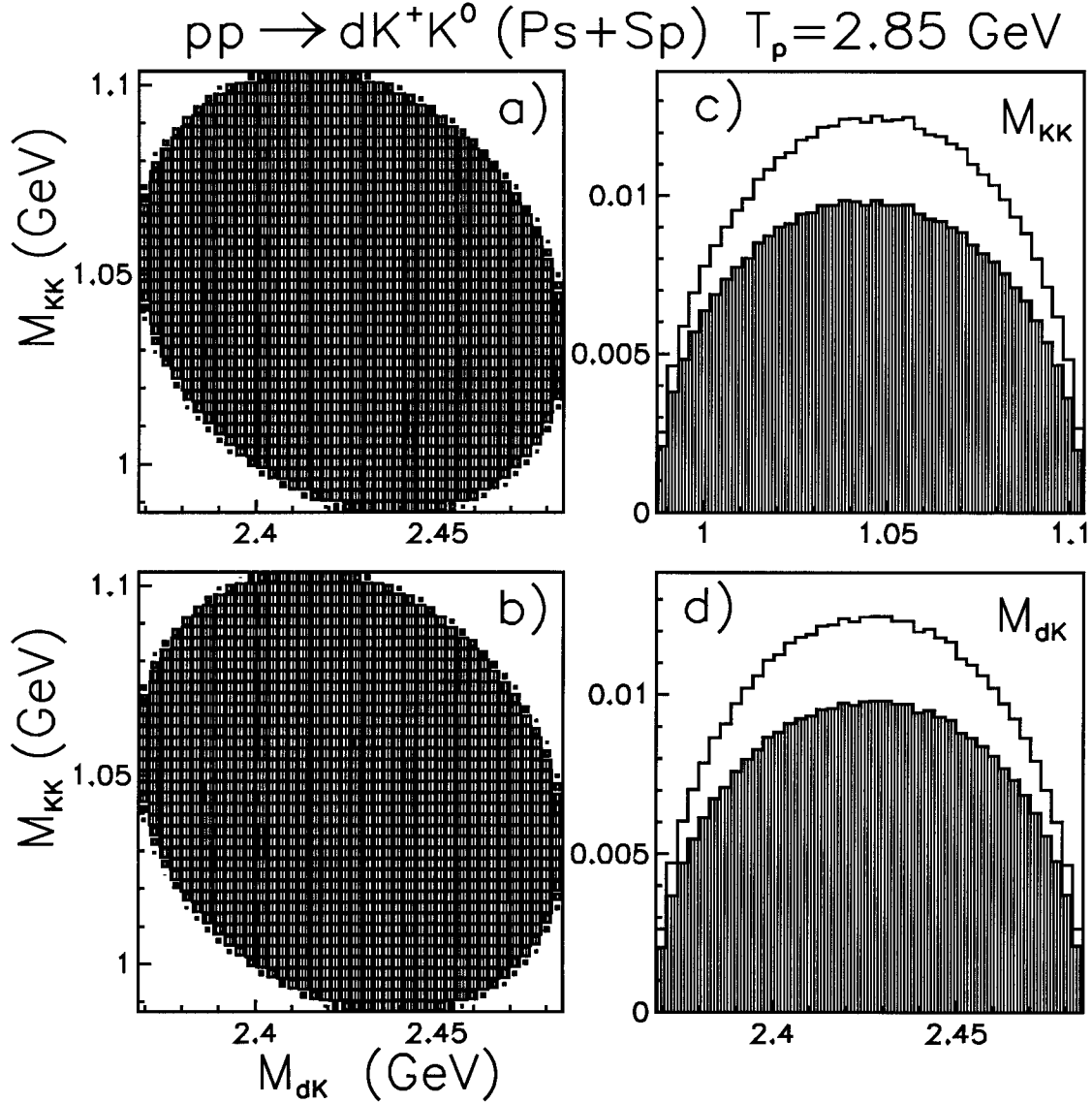
- Calculations for $pp \rightarrow K^+\bar{K}^0 d$ reaction at proton beam energy of 2.85 GeV. Dalitz plots are shown for Ss (a) and Ps final states. The Dalitz plot projections for $K^+\bar{K}^0$ (c) and $d\bar{K}^0$ (d) subsystems are shown by the hatched histograms for Ps and by open histograms for Ss states.



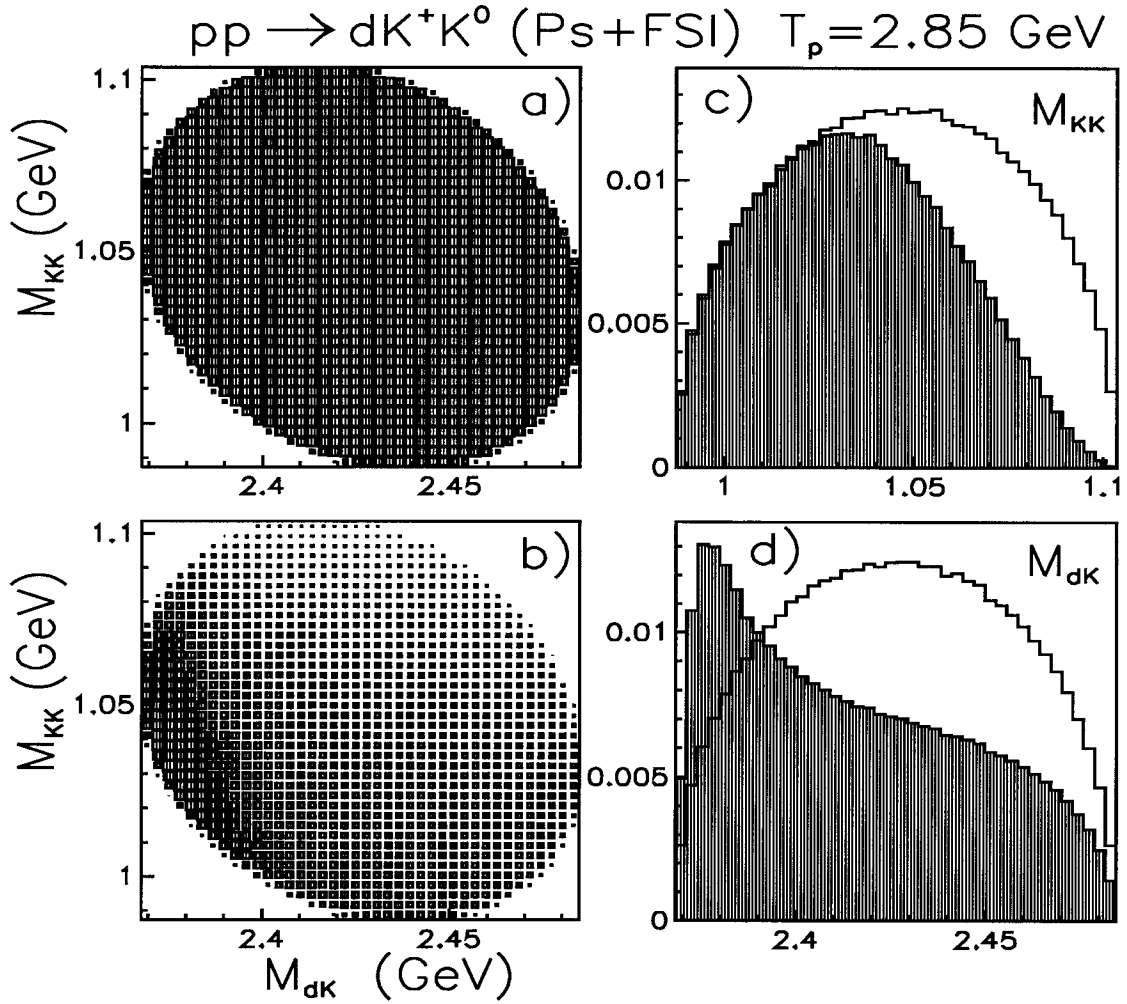
- Calculations for $pp \rightarrow K^+ \bar{K}^0 d$ reaction at 2.85 GeV. Dalitz plots are shown for Ss (a) and Sp final states. The Dalitz plot projections for $K^+ \bar{K}^0$ (c) and $d \bar{K}^0$ (d) subsystems are shown by the hatched histograms for Sp and by open histograms for Ss states.

- Moreover, calculated projections are the same as results shown in:
- E.Oset, Jose A. Oller and Ulf-G. Meissner, Eur. Phys. J. A12 (2001) 435,
- V.P. Chernyshev, P.V. Fedorets, A.E. Kudryavtsev and V.E. Tarasov, nucl-th/0110069.
- It is absolutely clear that P_s and S_p final states have different signatures and what is more important - both of them strongly differ from S_s results.
- Moreover, $K^+\overline{K}^0$ squared invariant mass distribution seems to be more sensitive to the partial wave content.

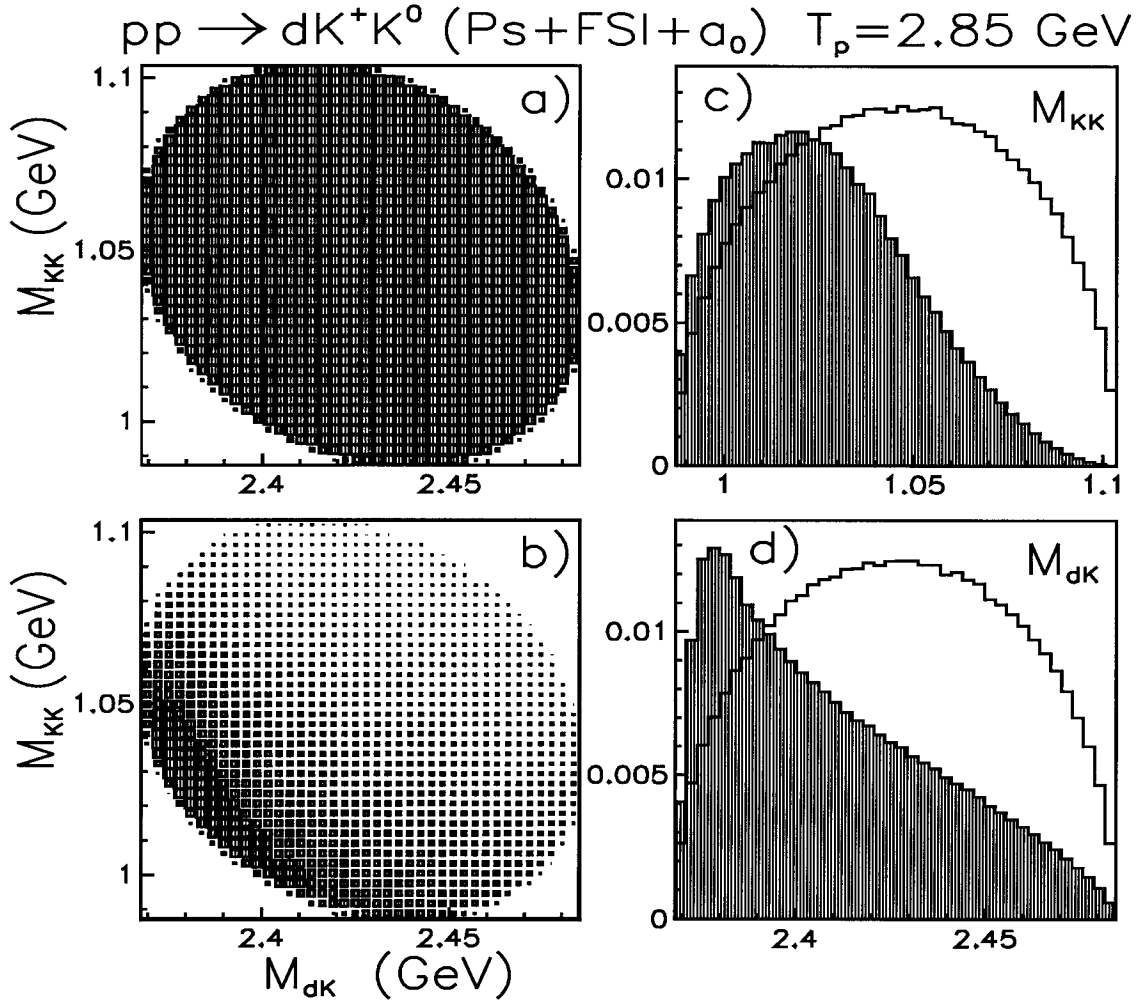
Now, I would like to understand whether the mixture of P_s and S_p final states can emulate the results from unphysical S_s calculations. Whether possible observation of uniformly occupied Dalitz plot might contradict the quantum number conservation law.



- Calculations for $pp \rightarrow K^+ \bar{K}^0 d$ reaction at 2.85 GeV. Dalitz plots are shown for S_s (a) and mixed Ps and Sp final states. The Dalitz plot projections for $K^+ \bar{K}^0$ (c) and $d \bar{K}^0$ (d) subsystems are shown by the hatched histograms for mixture of Sp and Ps states and by open histograms for S_s states.



- Calculations for $pp \rightarrow K^+ \bar{K}^0 d$ reaction at 2.85 GeV. Dalitz plots are shown for Ss (a) and Ps final states. The Ps calculations as well include the final state interaction between the deuteron and $\bar{K}^0$ -meson. The Dalitz plot projections for $K^+ \bar{K}^0$ (c) and $d \bar{K}^0$ (d) subsystems are shown by the hatched histograms for Ps state with $\bar{K}^0 d$ FSI and by open histograms for Ss states without FSI.



- Calculations for $pp \rightarrow K^+ \bar{K}^0 d$ reaction at 2.85 GeV. Dalitz plots are shown for Ss (a) and Ps final states. The Ps calculations include the $\bar{K}^0 d$ final state interaction and resonant structure of the $K^+ \bar{K}^0$ subsystem. The Dalitz plot projections for $K^+ \bar{K}^0$ (c) and $d \bar{K}^0$ (d) subsystems are shown by the hatched histograms for Ps state with $\bar{K}^0 d$ FSI and a_0^+ and by open histograms for Ss states without FSI.

Conclusions

- The S_p and P_s final states of $pp \rightarrow K^+ \bar{K}^0 d$ reaction can be distinguished experimentally, if they are not mixed. The P_s state alone might be identified and $K^+ \bar{K}^0$ subsystem in s -wave can be studied. The a_0^+ -meson denotes as well a $K^+ \bar{K}^0$ system in s -wave.
- It is important to measure the $K^+ \bar{K}^0$ angular distribution to ensure independently s -wave.
- Within ANKE kinematics the range of measured $K^+ \bar{K}^0$ invariant mass is too small to conclude whether the $K^+ \bar{K}^0$ system in s -wave has some resonant structure or not.
- It seems to be absolutely impossible to distinguish between resonant and non-resonant contribution to $pp \rightarrow K^+ \bar{K}^0 d$ reaction when $K^+ \bar{K}^0$ subsystem is in s -wave. But it is valuable to conclude about p -wave contribution to produced $K^+ \bar{K}^0$ state.
- The final state interaction between the deuteron and $\bar{K}^0$ -meson should be well identified, if such an interaction actually exists. If not - it might make a troubles in our understanding of the $pp \rightarrow K^+ \bar{K}^0 d$ reaction mechanism.

Hyperon Production
in $pp \rightarrow pK^+Y$ Reactions
at $T = 2.65, 2.7$ and 2.83 GeV

V. Koptev, M. Nikipelov

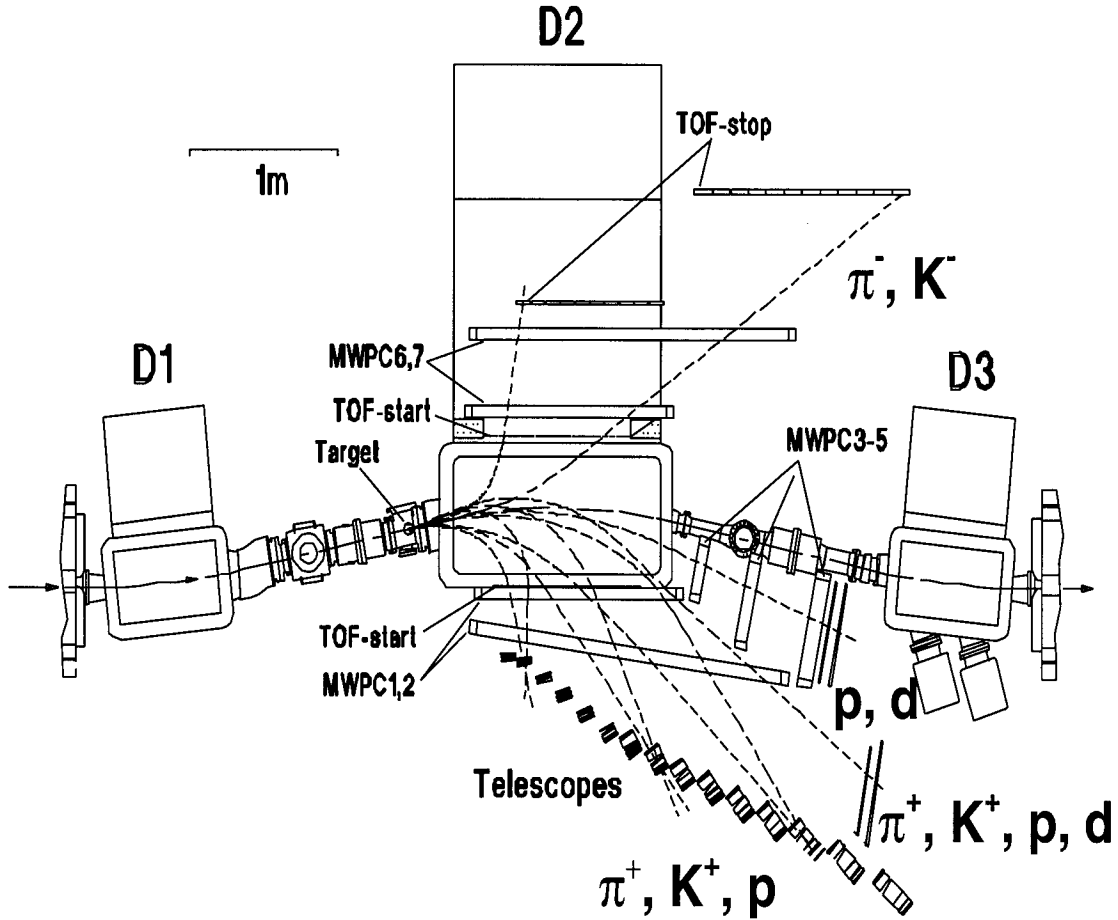
High Energy Physics Department
Petersburg Nuclear Physics Institute
188350 Gatchina
Russia

OVERVIEW

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Hyperon production in $pp \rightarrow pK^+Y$ reactions at 2.65, 2.7 and 2.83 GeV.

V.Koptev, M.Nekipelov, PNPI



- 2.65 GeV is above the production threshold of $\Phi(1020)$, K^+K^- , $\Lambda(1405)$, $\Sigma(1385)$
- 2.70 GeV is close to the production threshold of $\Sigma(1480)$ with quantum numbers $I=1$, $J^P=?^?$, $\Gamma = 30 - 80$ MeV and branching ratios $\bar{K}N/\Lambda\pi = 0.7 \pm 0.5$, $\Lambda\pi/\Sigma\pi = 0.8 \pm 0.5$
- 2.83 GeV is 19 MeV above the threshold of $\Lambda(1520)$ production whereas the $\Lambda(1520)$ has a width of about 16 MeV

INTRODUCTION

Presented in this report are the results of the first fast analysis of the data on hyperon production in pp interactions obtained as a by-product during six weeks of beamtime at COSY proton beams. The cluster target has been used providing luminosities of $(1 - 4) \cdot 10^{31} \text{cm}^{-2} \text{s}^{-1}$ with beam intensities of about $(2 - 4) \cdot 10^{10}$ stored protons. The main goal of these studies is not to give the final answer on cross sections or branching ratios but to understand how effective ANKE can be used in this field of physics. Most attention has been paid to $\Sigma(1480)$ which is marked in the 'Review on Particle Properties' by the Particle Data Group with one star only and presented not as a particle but a bump with unknown quantum numbers and uncertain decay branching ratios.

For this analysis there were no special studies of the K^+ detection efficiency in the telescopes. This has been done and described several times before. There were also no special studies of the forward MWPC efficiencies for track reconstruction. A fast analysis showed that in February-April 2002 it was higher than in February 2001 (about 50%).

To minimize background to the level of less than (10-15)% rather strong TOF cuts were applied to select protons in the forward detector and protons or pions in the side detector in coincidence with K^+ mesons. In this case pion or proton detection efficiencies were estimated to be about 80%. The side MWPCs track reconstruction efficiency was estimated as (85-90)%. No analysis of the information from the negatively charged particles detector has been done.

During these beamtimes we used the side wall detector for the K^+ detection for the first time. To make the studies on hyperon production more complete several additional figures are presented. These data were analysed in 2001 and presented by Polina Kravchenko at the Gatchina workshop in June 2001 (see proceedings).

DETECTOR POSITIONS AND TRIGGER CONDITIONS

$T = 2.65 \text{ GeV}$, $pp \rightarrow da_0^+$ beamtime

- trigger 1: K^+ mesons (TOF) in the 'proper' start-stop combinations (telescopes) in coincidence with any particle in the forward hodoscope
- trigger 2: 999 times prescaled signals from FD counters were used for luminosity studies from pp -elastic and $pp \rightarrow d\pi^+$
- only one layer of the side wall (SW1) was working, SW2 was off. SW1 did not fit to the kaon detection and its position was good for FSI studies but not the best for $p_{FD} - p_{SD} - K^+$ correlation studies
- negatively charged particle detector (ND) was not yet ready

$T = 2.83 \text{ GeV}$, $pp \rightarrow da_0^+$ beamtime

set-up: the side wall set-up was strongly modified

- SW1 was shifted side-close to telescope 15. The momentum gap in the region of 600 MeV/c disappeared and SW1 could identify p and π^+ with momenta up to 1000 MeV/c (restricted by SD-MWPC2)
- SW2 was on and moved downstream from SW1 to a distance of ~ 2 m. At this position SW2 allowed us (by TOF) to select kaons (the number of identified kaons in SW2 corresponds to 35% of the kaon count rate in telescopes 8-15 used for a_0^+ studies). SW2 in this position was able to analyse kaons in the momentum range of 600-900 MeV/c but the range of 600-700 MeV/c was shaded by the telescopes. In the future it will be good to shift SW2 by 10-20 cm away from the telescopes and to move it closer by 40-50 cm to SW1. It will make SW2 more efficient in the range of 600-1000 MeV/c
- ND was on (two MWPCs, 20 start counters and 16 stop counters). Starting from run 4507 it is possible to detect and analyse particles with momenta above 350 MeV/c. Low momenta stop counters are in progress

trigger conditions

- trigger 1 before run 4507: coincidence of kaons in TEL or SW2 with any particle in FD and no signal from ND
- trigger 1 after run 4507: coincidence of kaons in TEL and SW2 with any particle in FD. ND was not in the trigger but partially read out or had its own trigger
- trigger 2: unchanged
- trigger 5: coincidence of kaons in TEL or SW2 with any particle in FD and any particle in ND
- trigger 4: coincidence of kaons in TEL or SW2 with any particle in ND requiring no signals from FD

2.70 GeV, $pp \rightarrow pp\phi$ beamtime

The set-up was the same as for 2.83 GeV,
only two triggers were deployed

- 5 ND Cherenkov counter were tested
- trigger 2: unchanged
- trigger 4: kaons in TEL or SW2 in coincidence with particles in ND

EVENT SELECTION

Since we understand the operation of plastic scintillation counters slightly better than the operation of MWPCs, the first stages of kaon separation from background were done with the information from the scintillation counters only.

1. First step: Cuts on TOF. Shown in the upper-left subfigure on the next three pages is the TOF distribution between the start and the stop / sidewall counters. The cuts were 2-3 times stronger than in the hardware fast trigger for both telescopes (kaon TOF peak around 300 ± 20) and SW2 (kaon TOF peak around 375 ± 25).
2. Second step for da_0^+ : For hits in the telescopes a cut on energy loss in the De-counters (bottom-left) is done, for hits in SW2 a coincident hit in SW1 is demanded.
3. Next step: Selection of coincidences with particle signals which were not included in the hardware trigger (e.g. π^+ or protons in telescopes or in SW1).
4. Sometimes veto signals were used to suppress background (more than 50 ch. in the TOF distribution between the stop and veto counters (top-right) and energy loss cuts (bottom-right)).

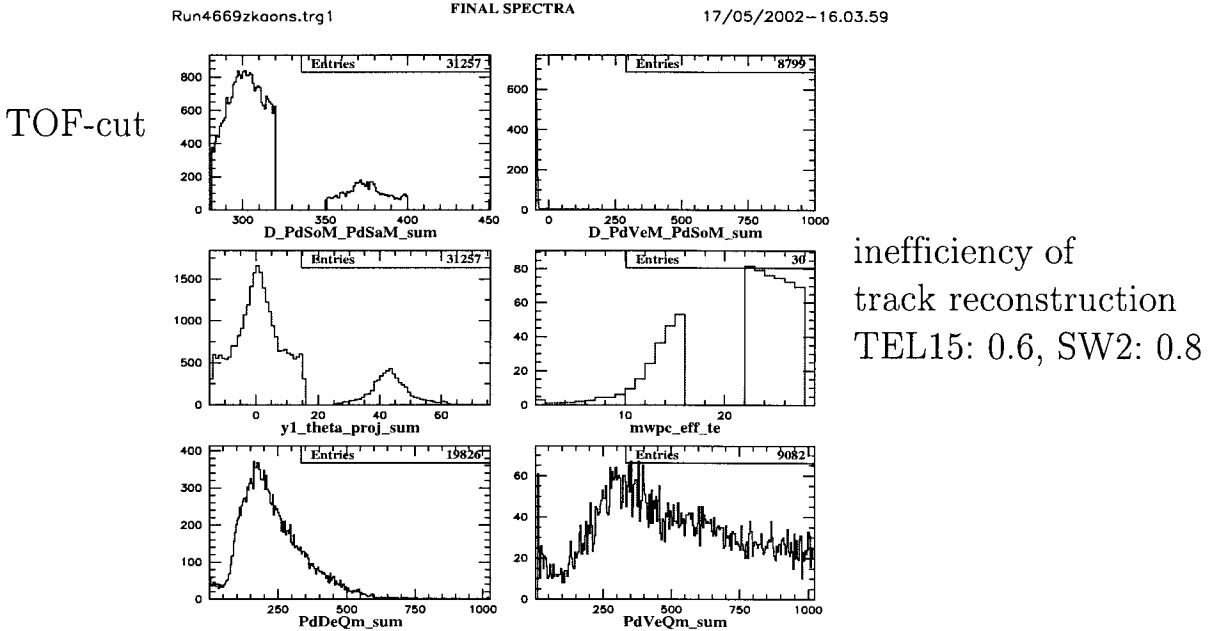
SD-MWPC EFFICIENCY

The MWPCs were only used at a stage close to the final analysis of the data and it helped to better understand the track reconstruction efficiency of the SD-MWPCs. This is demonstrated with the next figures where the inefficiency of the SD-MWPCs is determined at different stages of the analysis (described in the previous chapter).

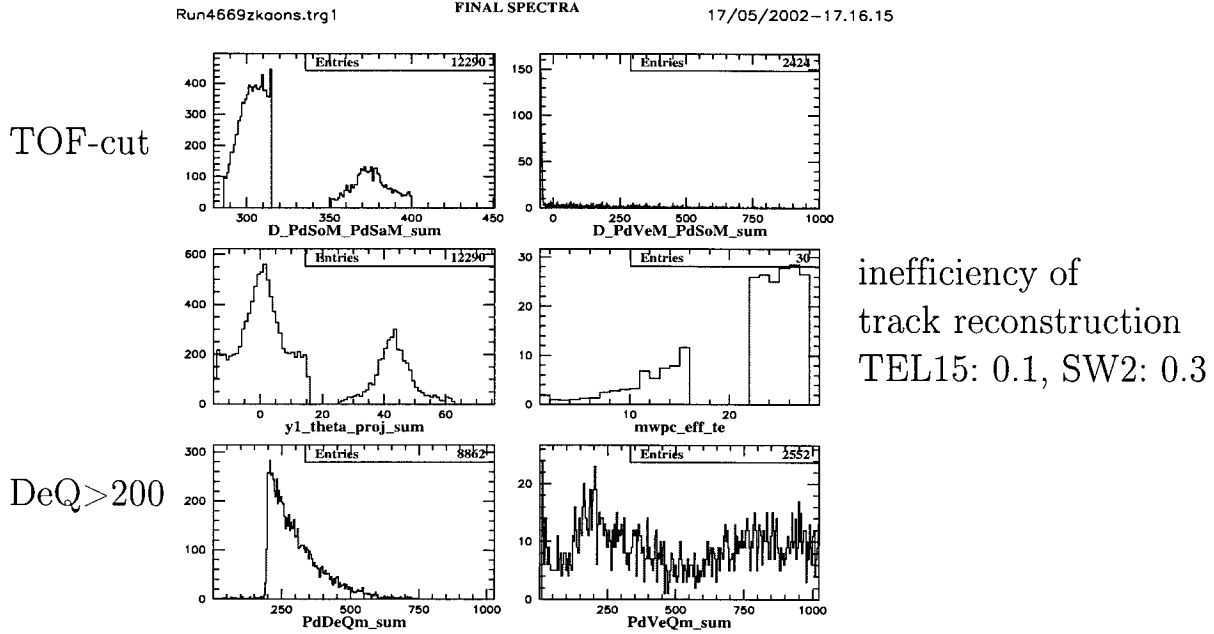
Each figure consists of 6 subfigures. The upper left figure shows the TOF distribution for particles passing the start and stop counters (left peak) and particles passing the start and the side wall counters (right peak). Only valid start-stop combinations are taken into account. The upper right figure contains the TOF distribution between the stop and the veto counters in the telescopes. Pions cause a prompt peak, kaons a delayed signal. The middle left figure reflects the deviation from a straight track line starting at the target (left: telescope hits, right: side wall hits). The right-middle distribution shows the inefficiency for each stop and SW2 counter. In the lower left figure the energy loss of particles in the ΔE counters is presented, in the lower right figure the energy loss in the veto counters is shown.

SD-MWPCs are used after the first analysis step

Run4669.kaons.TOFtel-20.TOFsw2-25.FD-p.trg1

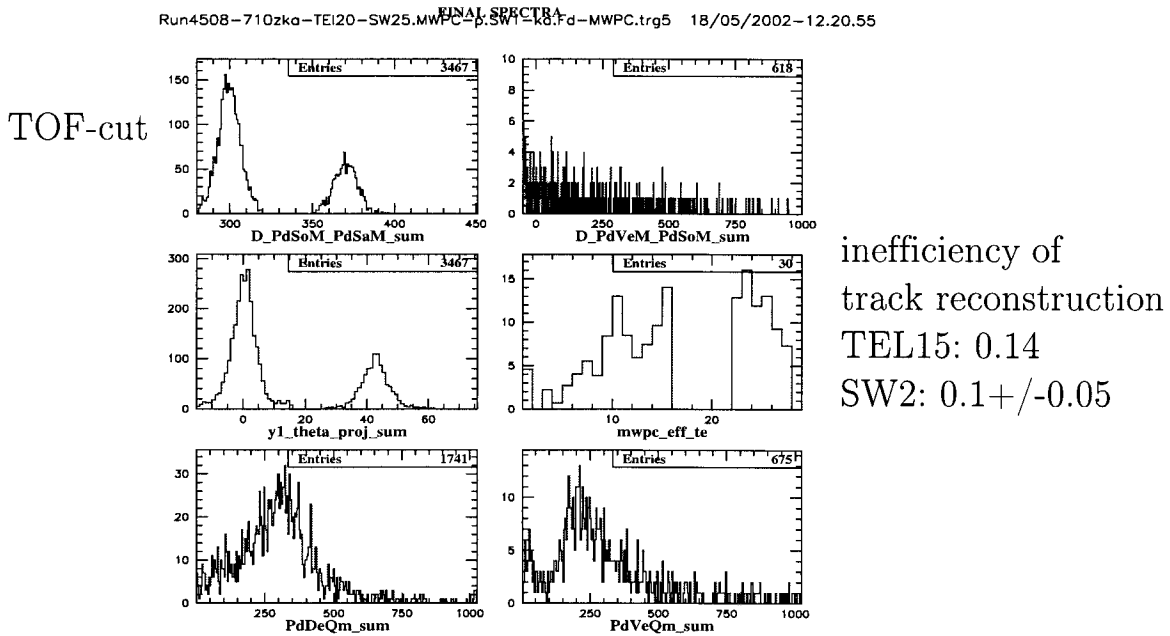


SD-MWPCs are used after the second analysis step
Run4669.kaons.TOFtel-15.DeQ-200.TOFsw1-sw2-25.FD-p.trg1



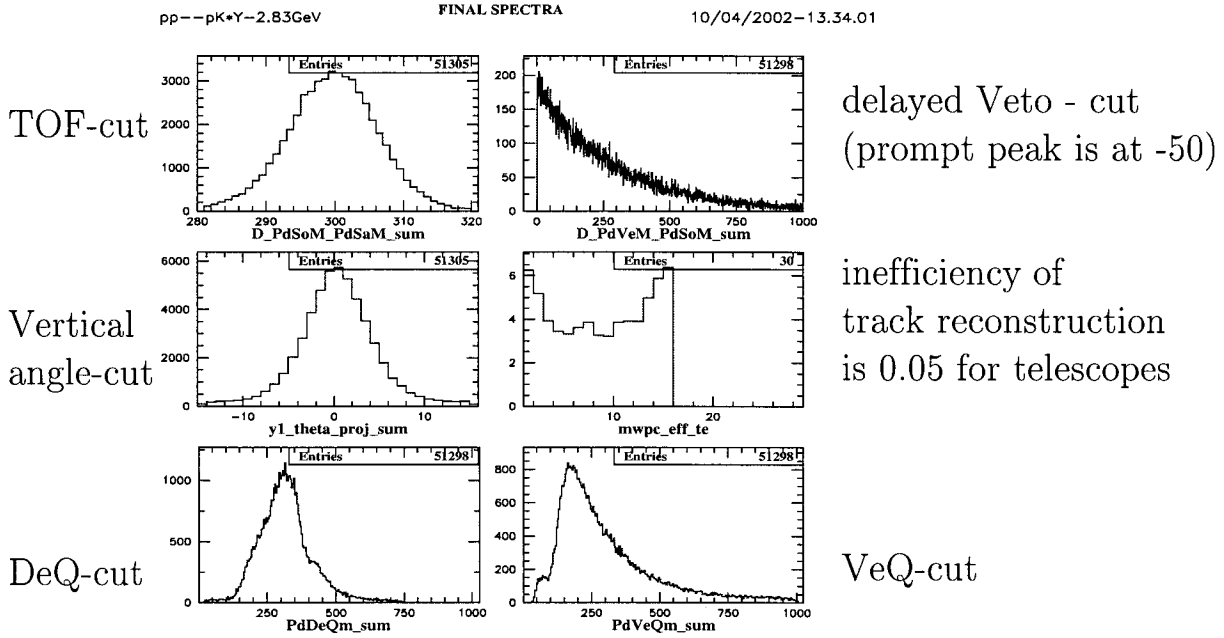
SD-MWPCs are used after the third step, when kaons were selected in coincidence with a FD-proton, a second proton in the telescopes or SW1 and a particle in ND

Run4508-710.kaons.TOFtel-20.TOFsw2-25.MWPC-p.SW1-ka.Fd-MWPC.trg5



Kaon spectra at 2.83 GeV from telescopes with delayed Veto

Run4468-710.Sa-ka.Veto50.DeQ150.trg1



Conclusion:

The efficiency of track reconstruction by the SD-MWPCs
is not worse than 0.9!

The bad efficiency determined after the first analysis steps is caused by background only.

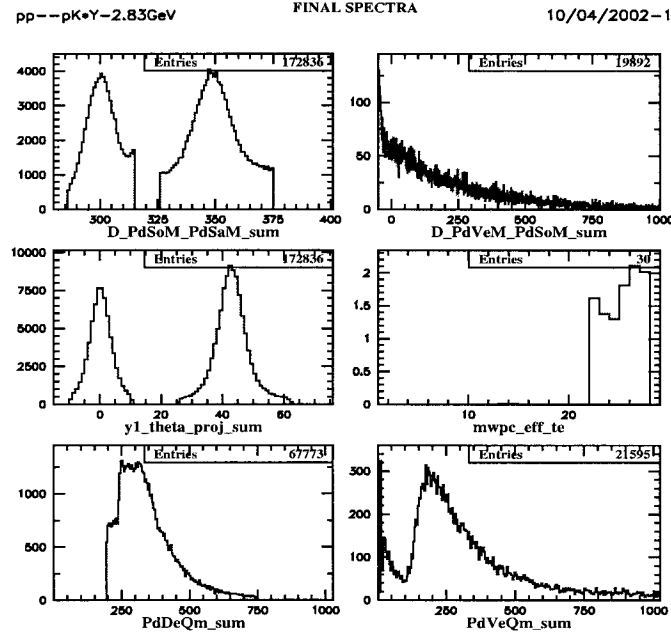
Proposal: The best way to check this efficiency is to apply the delayed veto criteria. For the next figures this has been done.

Comment: The 4-fold coincidence (K^+ in SD, p in SD and FD and any particle in ND) is very useful. Kaon are seen in the telescopes with very small background although only the TOF-criterion was used. Therefore this event sample has been used to determine the efficiency of the cut in the veto counters. In the future the same procedure can be performed to determine the efficiency of the cuts in the ΔE -counters.

KAONS IN SW2

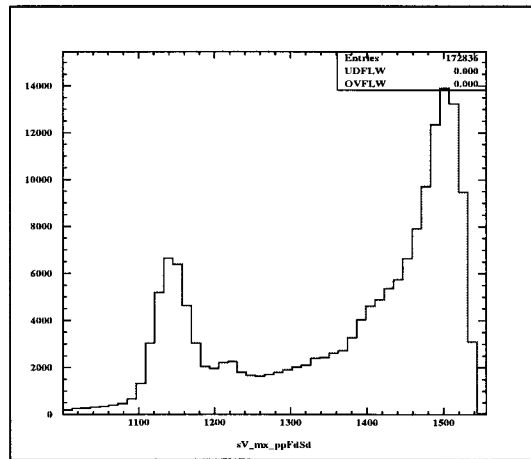
Kaons at 2.83 GeV from tel8-15 and SW2 used also for $dK^+\bar{K}^0$ studies

Run4468-710.Sa-ka.TOFtel-15.TOFsw2-25.DeQ200.SW1-ka.Fd-p.trg1
(efficiency distribution not valid)



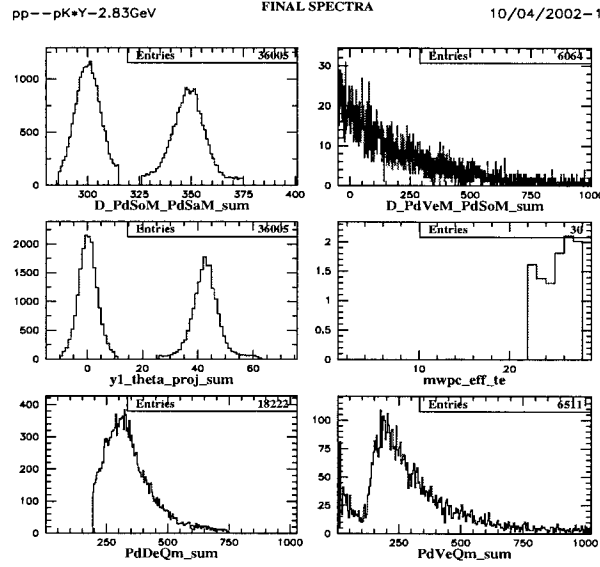
Question: Do we really see kaons in SW2?

The answer comes from the $pp \rightarrow K^+pM_x$ missing mass distribution.

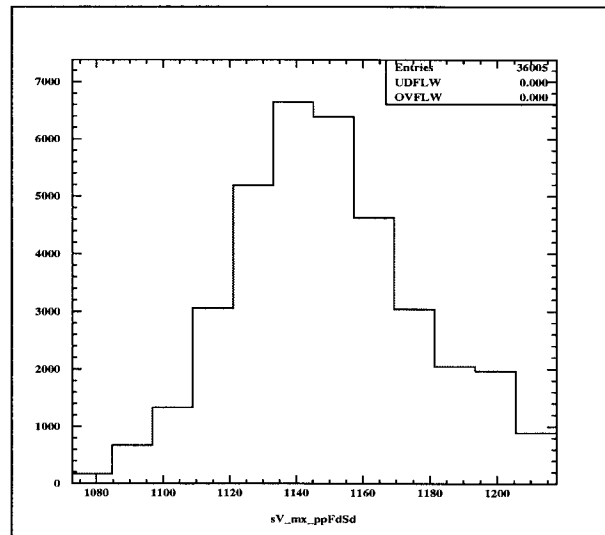


Let's use only the $M_\Lambda = 1116$ MeV region of the missing mass distribution in order to select clean events.

Kaons at 2.83 GeV for tel8-15 and SW2 from $pp \rightarrow K^+ p \Lambda$
Run4468-710.Sa-ka.TOFtel-15.TOFsw2.DeQ200.SW1-ka.Fd-p.trg1
 (efficiency distribution not valid)



Cut in $pp \rightarrow K^+ p(M_x \approx \Lambda)$ missing mass distribution:



Conclusion: When the reaction is well identified ($\Lambda(1116)$) kaons are seen in SW2 practically without background (see upper left subfigure). This proves that the particle in SW2 really are kaons. The peak of M_Λ has it's maximum at ~ 1140 MeV though???

Following Isa Zychor's studies let's slightly vary the Fd-MWPCs geometry.

MOMENTUM RECONSTRUCTION

The figures on the previous pages showed that the efficiency of kaon track reconstruction of the Sd-MWPCs is about 95% but the peak of the $\Lambda(1116)$ is located at ~ 1140 MeV. The next missing mass distributions show the sensitivity of M_x to the position of the X1 plane of FD-MWPC1 the deuteron momentum.

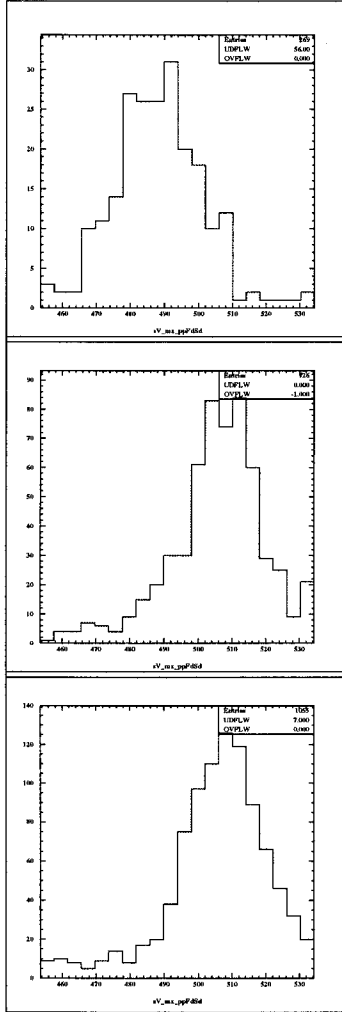
$$pp \rightarrow dK^+(M_x \rightarrow \bar{K}^0) \text{ at } T_p = 2830 \text{ MeV}$$

Runs4467-710.TEL8-15.TOF15,Vert10.De200.FD-d.trg1

X1=-55.03cm

P_d interval

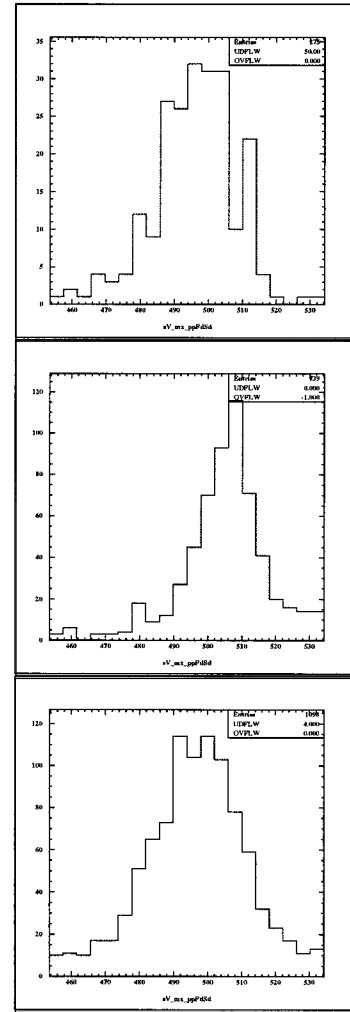
X1=-55.08cm



1600-2100
MeV/c

2100-2550
MeV/c

2550-2950
MeV/c



Questions: Do calibration reactions provide 0.05 cm accuracy? Are we such precise in geometry of the beam, target and device?

Conclusion: X1=-55.08cm looks better. Let's take it!

HYPERON STUDIES

$$pp \rightarrow K^+ p M_x \text{ at } T_p = 2.65 \text{ GeV}$$

1. Experiment

events at $M_x > 1.3 \text{ GeV}$ are from
 $\Lambda(1405)$ and $\Sigma(1385)$ production
 or background from

$pp \rightarrow K^+ N \Lambda(1116) \pi$ with

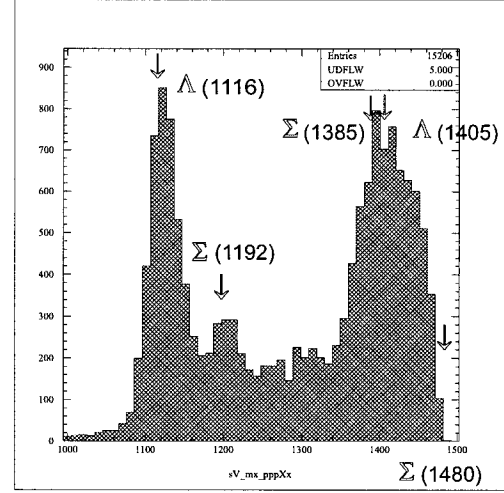
$$\langle M_{\Lambda\pi} \rangle = 1367 \text{ MeV}$$

$pp \rightarrow K^+ N \Sigma(1193) \pi$ with

$$\langle M_{\Sigma\pi} \rangle = 1415 \text{ MeV}$$

$pp \rightarrow K^+ N Y \pi \pi$ with

$$\langle M_{Y\pi\pi} \rangle = 1440 \text{ MeV}$$



2. Simulations of

$pp \rightarrow K^+ N \Lambda(1116)$ and $pp \rightarrow K^+ N \Sigma(1193)$:

peaks are caused by vertex protons

events at $M_x > 1.23 \text{ GeV}$ are due to protons
 from $Y \rightarrow p\pi$

Conclusions: no events at $M_x > 1.35 \text{ GeV}$

$$\text{and } \frac{\sigma_{Kp\Lambda}^{tot}}{\sigma_{Kp\Sigma}^{tot}} = 6.6 \pm 0.6$$

About $pp \rightarrow K^+ N Y \pi$ background:

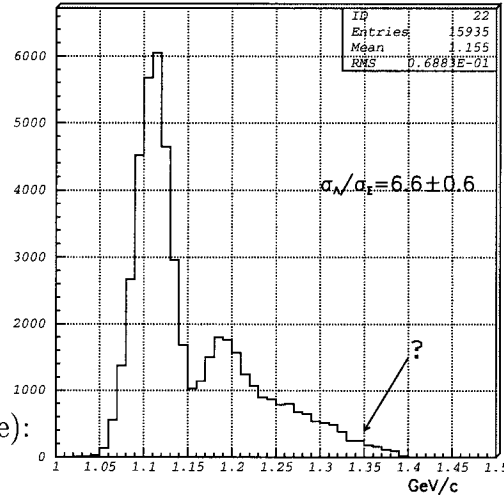
if $\sigma_{K+NY\pi} = \sigma_{K+NY} * \alpha$

then in the region $T=1 \text{ GeV}$ (from literature):

$$\alpha = \frac{1}{3} \quad \text{for } K^- p \rightarrow \pi \Lambda \text{ and}$$

$$\alpha = 1 \quad \text{for } \pi p \rightarrow K \Lambda$$

no data on $pp \rightarrow K^+ N Y \pi$

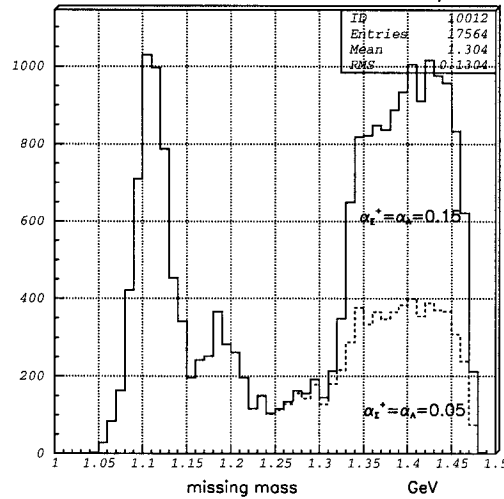


3. Simulations of

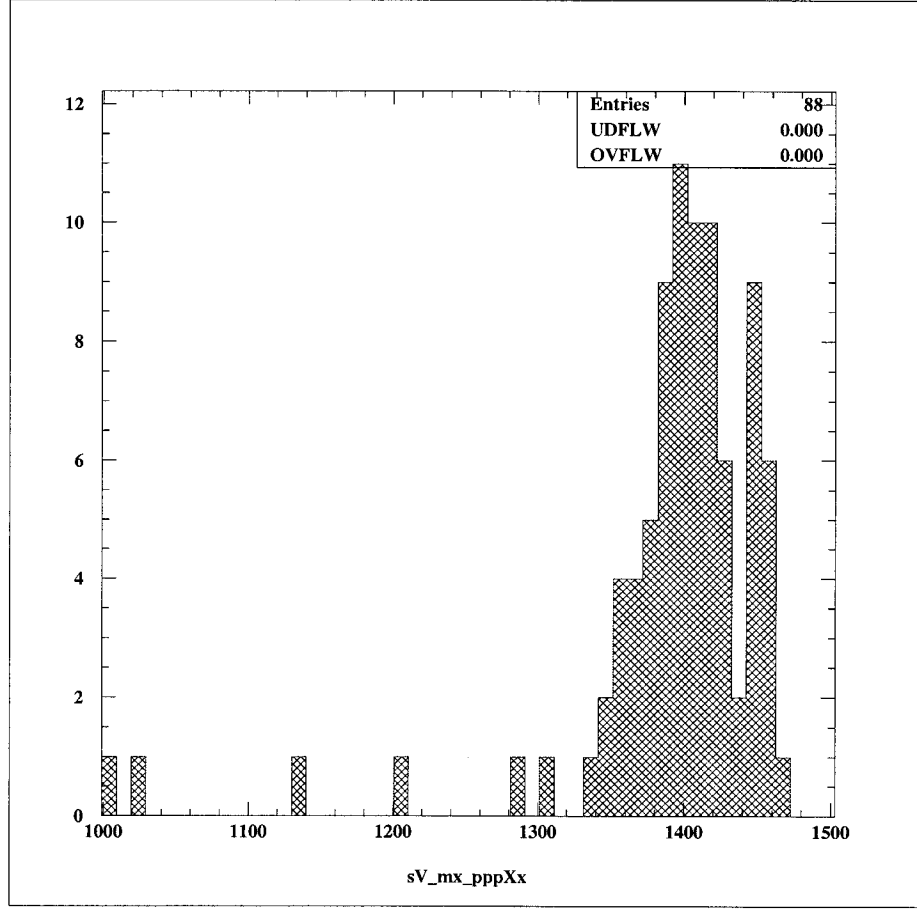
$pp \rightarrow K^+ N Y \pi$

Conclusions: $\alpha \approx 0.12$ and

$$N(\Sigma(1385)) + N(\Lambda(1405)) < 300$$



$K^+p(M_x = \pi^+ + x)$ correlations
Experimental data



K^+ in telescope, p in forward detector

π^+ in telescopes (MWPC1 and 2 were used for pion selection)

no processes : $pp \rightarrow K^+ p \Lambda, \quad pp \rightarrow K^+ p \Sigma^0$

should be seen :

$$pp \rightarrow K^+ p \Lambda^* \rightarrow K p_1 \pi^+ \pi^- n$$

$$pp \rightarrow K^+ p \Lambda^* \rightarrow K p_1 \pi^+ \Sigma^-$$

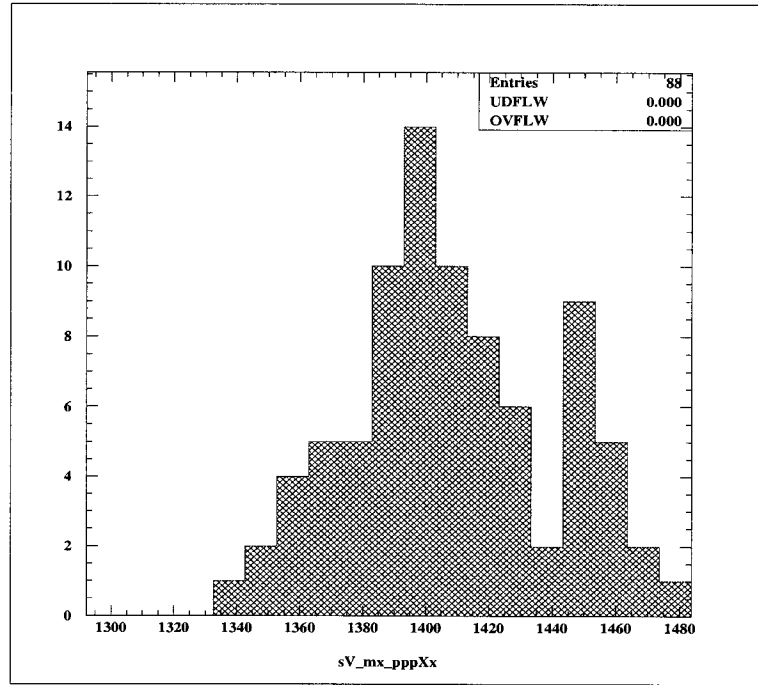
$$pp \rightarrow K^+ p \Sigma^{0*} \rightarrow K p_1 \pi^+ \pi^- n$$

$$pp \rightarrow K^+ p \Sigma^{0*} \rightarrow K p_1 \pi^+ \Sigma^-$$

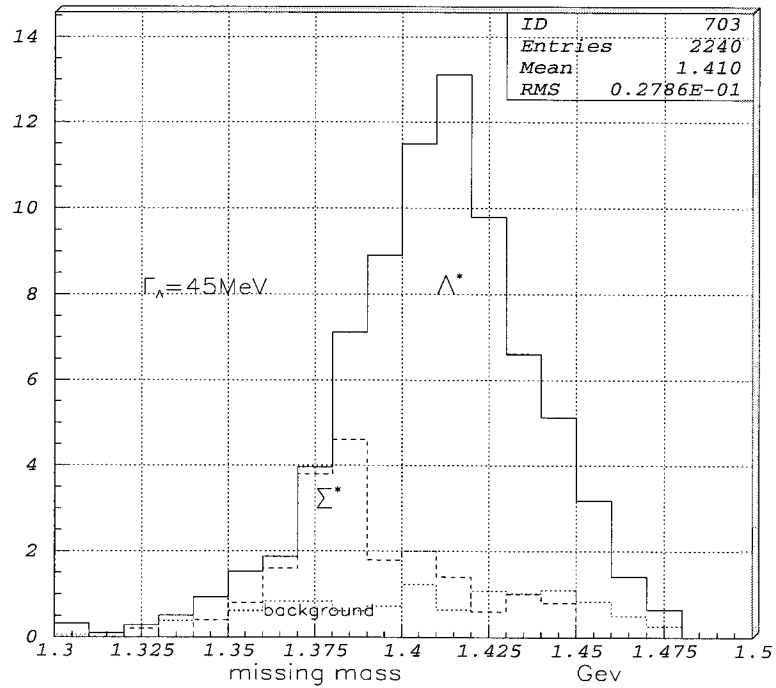
$$pp \rightarrow K^+ n \Sigma^{+*} \rightarrow K p_2 \pi^+ \pi^- n$$

practically no background at $M_x < 1.300$ GeV

$K^+p(M_x = \pi^+ + x)$ correlation
Experiment



Simulations: $\alpha_{\Sigma^+} \approx \alpha_{\Lambda} \approx 0.12$



Conclusion: $\frac{\sigma_{\Lambda}}{\sigma_{\Lambda^*}} = 55 \pm < 30\%$, $\frac{\sigma_{\Lambda}}{\sigma_{\Sigma^*}} = 35 \pm ?$

$pp \rightarrow KNY\pi\pi$ is not yet considered (it should give a peak around 1440 MeV)

Conclusion:

1. $\frac{\sigma_{Kp\Lambda}^{tot}}{\sigma_{Kp\Sigma}^{tot}} = 6.6 \pm 1.0$

This result is more or less reliable, since is checked in the frame of two models.

2. $\frac{\sigma_{Kp\Lambda}^{tot}}{\sigma_{Kp\Lambda(1405)}^{tot}} = 55 \pm 18$ and $\frac{\sigma_{Kp\Lambda}^{tot}}{\sigma_{Kp\Sigma(1385)}^{tot}} = 35 \pm ?$

Only stat-model was used to get this result. Since $T_p = 2.65$ GeV is close to the thresholds of $\Sigma(1385)$ and $\Lambda(1405)$ production the Y^*N final state interaction must be important.

- Peak (??) at 1450 MeV can be connected with $pp \rightarrow K^+ N \pi \pi Y$ or $pp \rightarrow K^+ p \Sigma(1480)$. The last reaction is of utmost interest, because properties of $\Sigma(1480)$ are practically not known.

Analysis of these assumptions is in progress.

- In order to understand the nature of this peak one needs:
 - Highest possible beam energy;
 - more statistics.

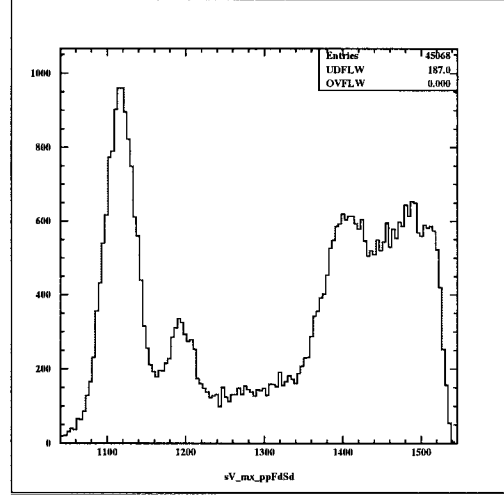
3. It has been shown that the cross sections for $pp \rightarrow K^+ N \pi Y$ are rather high and it

- practically closes the door for heavy hyperon studies in two-fold coincidences

$$pp \rightarrow K^+ p M_X \text{ at } T_p = 2830 \text{ MeV}$$

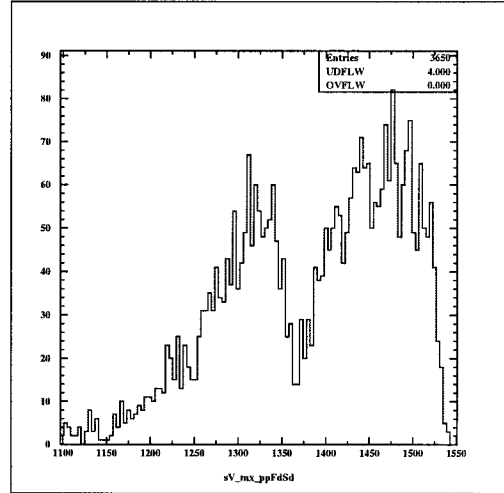
Trigger 1 (after Run1507):

kaons (selected by the delayed veto criterion) in coincidence with FD protons and in anticoincidence with Nd particle. 2000-2500 ev. in the region of 1400 MeV can be treated as $\Sigma(1385)$ and $\Lambda(1405)$. A 350-400 ev. enhancement at ~ 1480 MeV. Is it $\Sigma(1480)$??



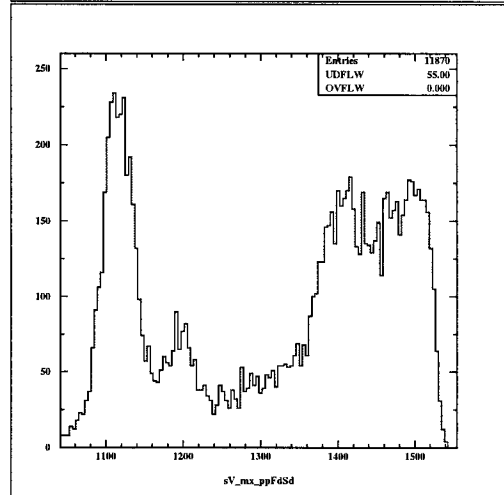
Trigger 5:

kaons (selected by the delayed veto criterion) in coincidence with FD protons and in coincidence with Nd particles. No Y peaks. The first peak is caused by protons from Y decays. The second one is a mixture of different processes. This trigger seems to be the best for Z^+ studies but with the Nd analysis and in coincidence with π^+ in TEL. Kaons must be analysed without veto criteria.



Trigger 1 (before Run1507):

kaons (selected by the delayed Veto criterion) in coincidence with FD protons and with not clear information from Nd. This is equivalent to the sum of the two previous figs. It contains 25% of the total statistics and was used only for studies of K^+ , π^+ , p_{FD} coincidences.



Conclusion: after a small X1 change the Y peaks are in proper positions. 2-fold coincidences contain not enough information for heavy hyperons studies.

$\Sigma(1480)$ production in pp at 2.83 MeV (3650 MeV/c)

$$pp \rightarrow pK^+\Sigma^0(1480), \Sigma^0(1480) \rightarrow \Sigma^-(1197)\pi^+ \text{ or } \rightarrow \Sigma^+(1189)\pi^-$$

Event selection: K^+ were detected by the telescopes only in the momentum range of 150-600 MeV/c (angular acceptance of 12°). Delayed veto signals were used in the software trigger. A π^+ or p in coincidence with kaons was detected by the complete side detector (SD or Side) in the same angular interval and 150-1000 MeV/c momentum range. Protons in coincidence with pions and kaons were detected by the forward detector (FD or Forward) in the angular interval of 8° and the 1000-3300 MeV/c momentum range (criteria of event selections are practically the same as for 2.65 GeV).

The following name convention has been used for the shown missing mass spectra for triple coincidences (x^+ : π^+ or proton in SD):

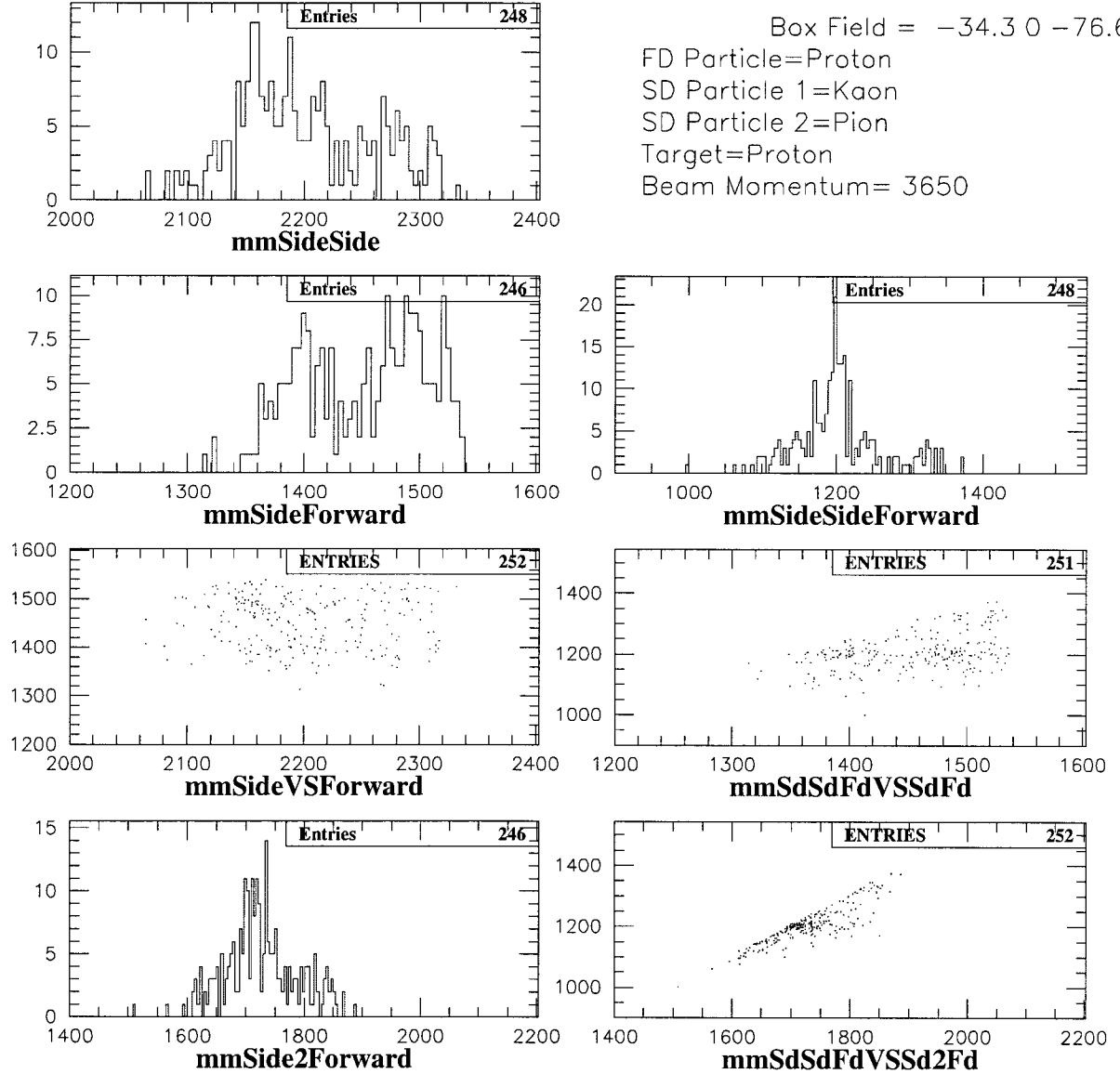
1. $pp \rightarrow K^+x^+M_x$ mmSideSide
2. $pp \rightarrow K^+pM_x$ mmSideForward
3. two dimensional distribution of 1. and 2. .. mmSideVSForward
4. $pp \rightarrow x^+pM_x$ mmSide2Forward
5. $pp \rightarrow K^+x^+pM_x$ mmSideSideForward
6. two dimensional distribution of 2. and 5. ... mmSdSdVSSdFd
7. two dimensional ditribution of 4. and 5. mmSdSdVSSd2Fd

On the next four pages triple coincidences of a K^+ , a proton and a π^+ are shown. In the subsequent 7 pages coincidences of a K^+ , a proton and second proton with different trigger conditions are presented and finally the data at $T_p=2.7$ GeV for K^+ pp coincidences are shown.

$$pp \rightarrow K^+ \pi_{Sd}^+ p_{Fd} M_x, T_p = 2830 \text{ MeV}, \text{trig1}$$

Missing Mass (MeV). Two Side and One Forward Particle

Run4467-710zkaons.veto50.De.MWPC.Fd-MWPC.pi-MWPC.trg1 14/05/2002-14.59.23



In the $pp \rightarrow K^+ p M_x$ mm-spectrum (2) three peaks are seen. Two of them about 50 MeV wide are at 1400 ± 5 MeV and 1480 ± 7 MeV can correspond to $\Lambda(1405)$ and $\Sigma^0(1480)$, decaying into $\pi^+ \Sigma^- (1197)$ (see peak at ≈ 1200 MeV in $pp \rightarrow K^+ \pi^+ p M_x$) or into $\pi^- \Sigma^+ \rightarrow \pi^- \pi^+ n$. $\Sigma^0(1385) \rightarrow \pi \Sigma$ is suppressed since the branching ratio of this decay mode is 12% only.

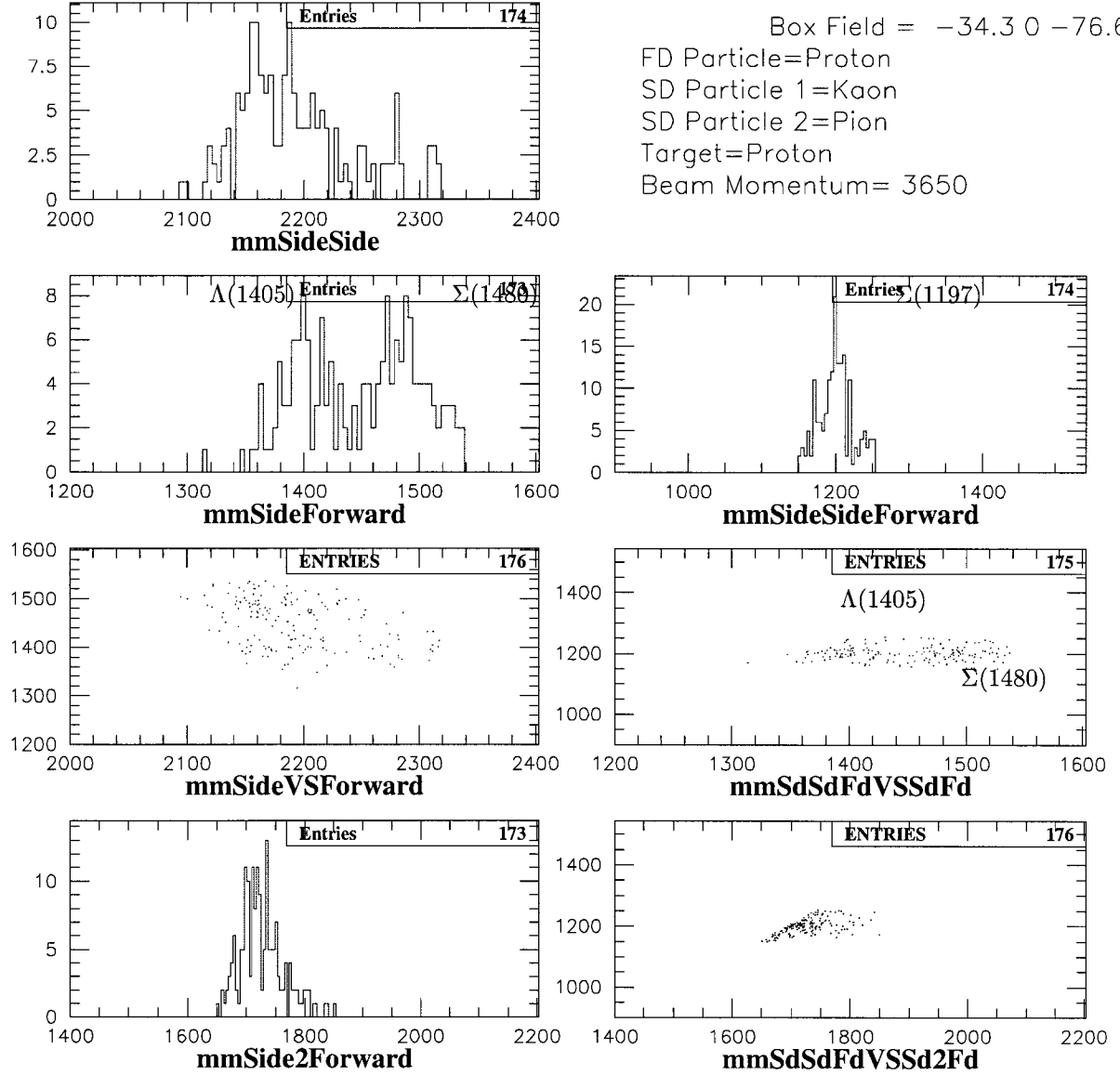
Does the sharp enhancement at 1525 correspond to $\Lambda(1520)$???

$pp \rightarrow K^+ \pi_{Sd}^+ p_{Fd} M_x$, $T_p = 2830$ MeV, *trig1*
 additional cut: $pp \rightarrow K^+ p \pi^+ (1150 < M_x < 1250)$

Missing Mass (MeV). Two Side and One Forward Particle

14/05/2002–15.08.25

Run4467–710zkaons.veto50.De.MWPC.Fd–MWPC.pi–MWPC.trg1



After a mild cut on $pp \rightarrow K^+ \pi^+ p M_x$ with $M_x = 1200 \pm 50$ MeV there are no serious changes for $\Lambda(1405)$ and $\Sigma^0(1480)$. $N_{\Lambda(1405)} \approx N_{\Sigma(1480)}$. The sharp enhancement at 1525 MeV disappears.

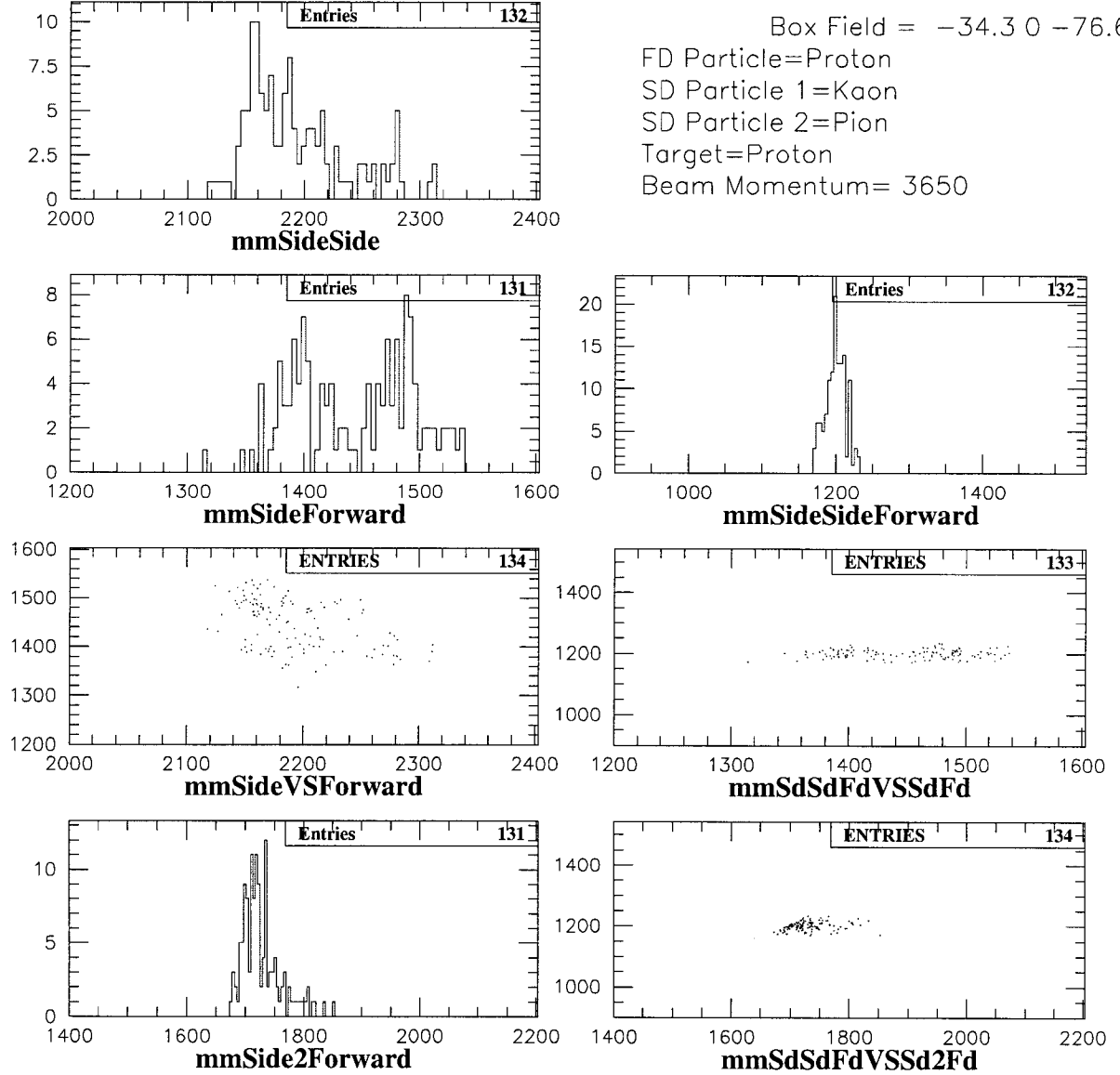
For checking it is good to analyse data with trigger 5. To see $pp \rightarrow K^+ p Y^*$ reactions with $Y^* \rightarrow \pi^- \Sigma^+$ decays we must analyse data from Nd (if we have enough statistics).

$pp \rightarrow K^+ \pi^+_{Sd} p_{Fd} M_x$, $T_p = 2830$ MeV, *trig1*
stronger cut: $pp \rightarrow K^+ p \pi^+ (1170 > M_x > 1230)$

Missing Mass (MeV). Two Side and One Forward Particle

Run4467-710zkaons.veto50.De.MWPC.Fd-MWPC.pi-MWPC.trg1

14/05/2002-15.16.15



A puzzle: after the strong cut on $pp \rightarrow K^+ \pi^+ p M_x$ with $M_x = 1200 \pm 30$ MeV practically nothing changes for $\Lambda(1405)$ but the $\Sigma^0(1480)$ mass becomes narrower (~ 40 MeV). Why???

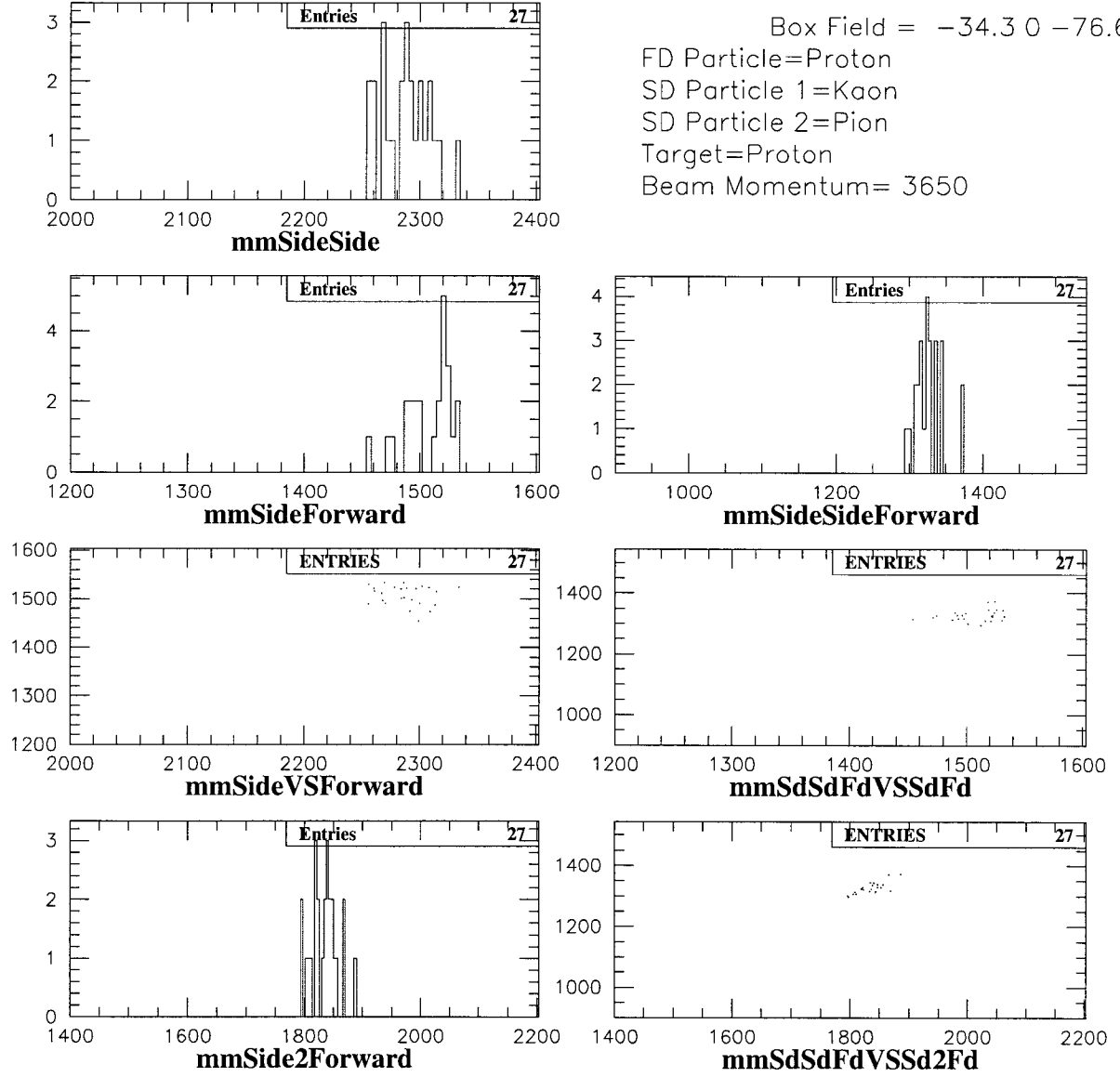
May be there is still influence by $pp \rightarrow K^+ p(n\pi)$ reactions or we also analyse $pp \rightarrow K^+ n(Y^*)^+ \rightarrow K^+ n \pi^+ Y \rightarrow K^+ n \pi^+ \pi^- p \rightarrow K^+ \pi^+ p M^x$ with the Fd-proton stemming not from the reaction vertex but from a Y^* decay. In both cases stronger M_x cuts decrease the influence of these channels. Simulations must be performed in order to help to understand this situation.

$pp \rightarrow K^+ \pi_{Sd}^+ p_{Fd} M_x$, $T_p = 2830$ MeV, *trig1*
 additional cut: $pp \rightarrow K^+ p \pi^+ (M_x > 1290)$

Missing Mass (MeV). Two Side and One Forward Particle

14/05/2002-15.23.07

Run4467-710zkaons.veto50.De.MWPC.Fd-MWPC.pi-MWPC.trg1



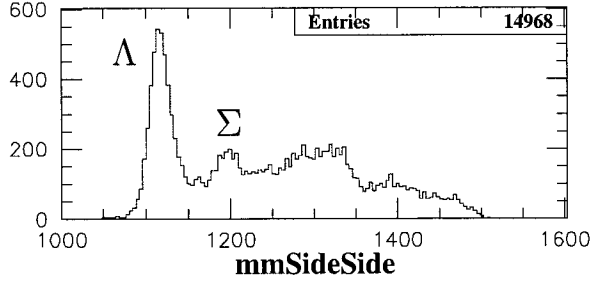
The peak at 1525 MeV is connected to a three particle missing mass $M_x \approx 1320$ MeV. Whether this can possibly be $\Lambda(1520)$ only simulations will show. To increase statistics we must select K^+ without delayed veto information. It also is necessary to study the $pp \rightarrow K^+ \pi_{Nd}^- p_{Fd} M_x$ channel from the data with trigger 5.

$$pp \rightarrow K^+ p_{Sd} p_{Fd} M_x, T_p = 2830 \text{ MeV, } trig1$$

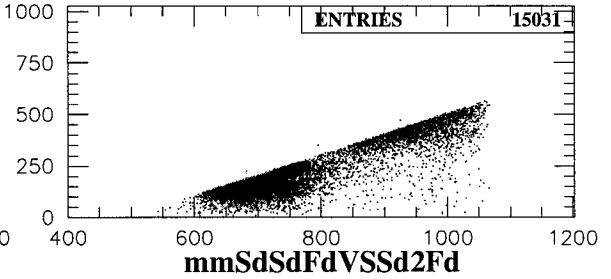
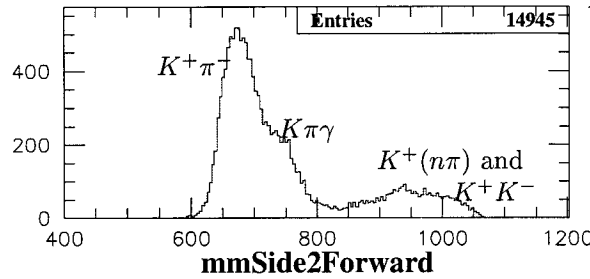
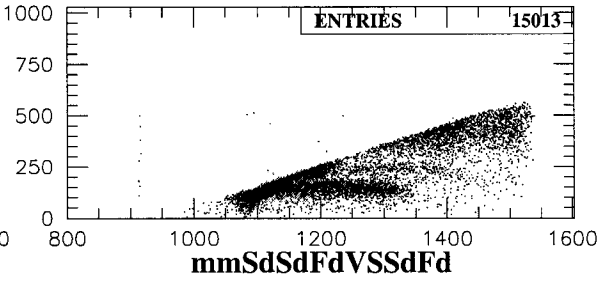
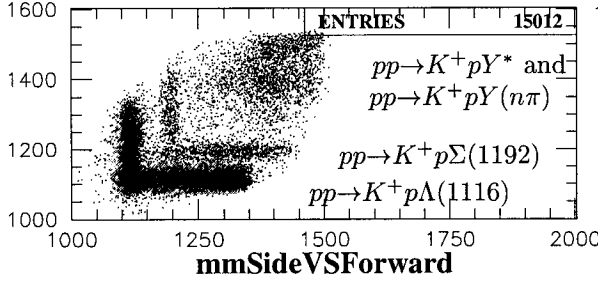
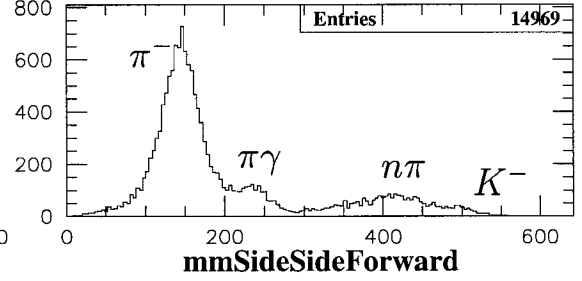
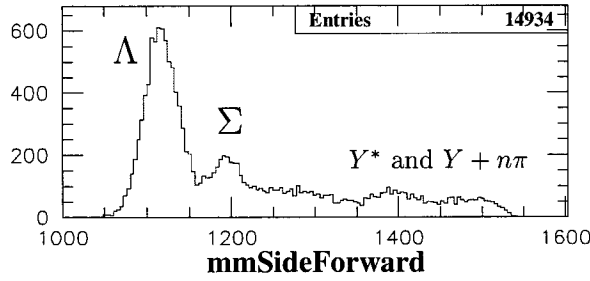
Missing Mass (MeV). Two Side and One Forward Particle

19/05/2002-23.51.22

Run4508-710zka-TEI25-SW25.MWPC-p.SW1-ka.Fd-MWPC



Box Field = -34.3 0 -76.61
 FD Particle=Proton
 SD Particle 1=Kaon
 SD Particle 2=Proton
 Target=Proton
 Beam Momentum= 3650



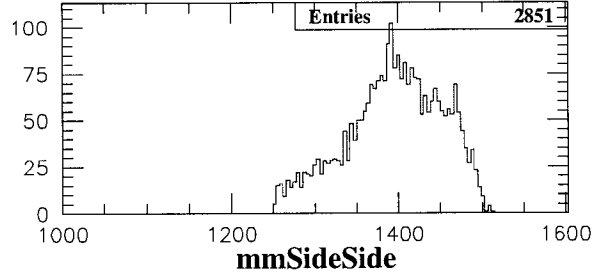
TOF criteria were such that K^+ are in telescopes and in (SW2-SW1), protons p_{Sd} are in tel. and SW1 and p_{Fd} protons in Fd. No signals from Nd. After the X1-shift peaks corresponding to Λ , Σ , π^- , K^- and Φ are at the proper masses within 0.5% (accidental??). But for the events $pp \rightarrow K^+ p_{Sd} M_x$ the width of Λ peak is 26-28 MeV (as expected) whereas for $pp \rightarrow K^+ p_{Fd} M_x$ it is 48 MeV and as a result the π^- peak is 60 MeV wide.

$pp \rightarrow K^+ p_{Sd} p_{Fd} M_x$, $T_p = 2830$ MeV, *trig1*
 additional cut: $pp \rightarrow K^+ p (M_x > 1250) \rightarrow$ search for Y^* production.

Missing Mass (MeV). Two Side and One Forward Particle

20/05/2002-00.09.32

Run4508-710zka-TEI25-SW25.MWPC-p.SW1-ka.Fd-MWPC.trg1.mmY1250



Box Field = -34.3 0 -76.61

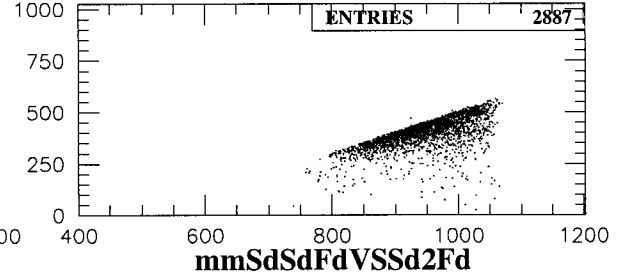
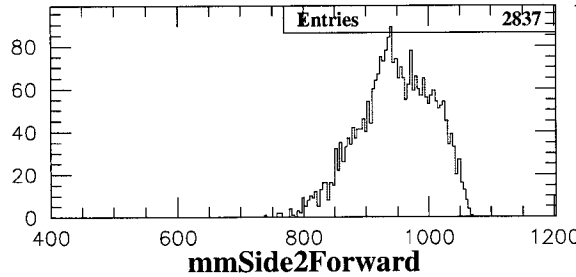
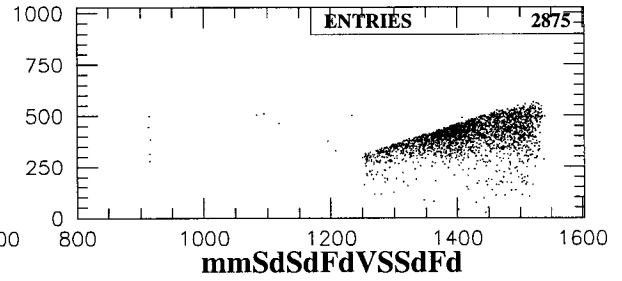
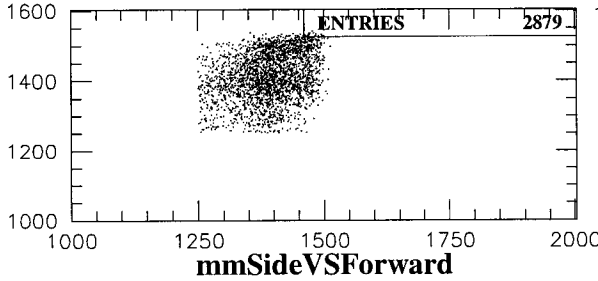
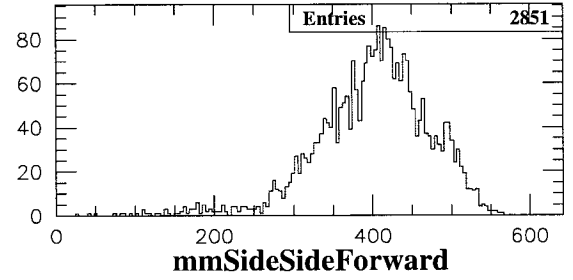
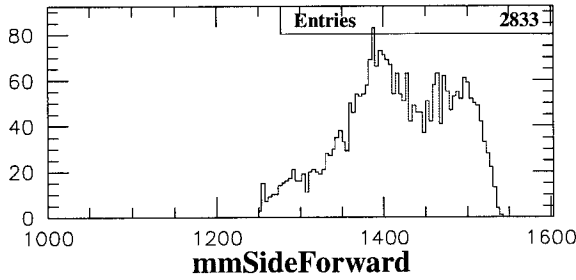
FD Particle=Proton

SD Particle 1=Kaon

SD Particle 2=Proton

Target=Proton

Beam Momentum= 3650



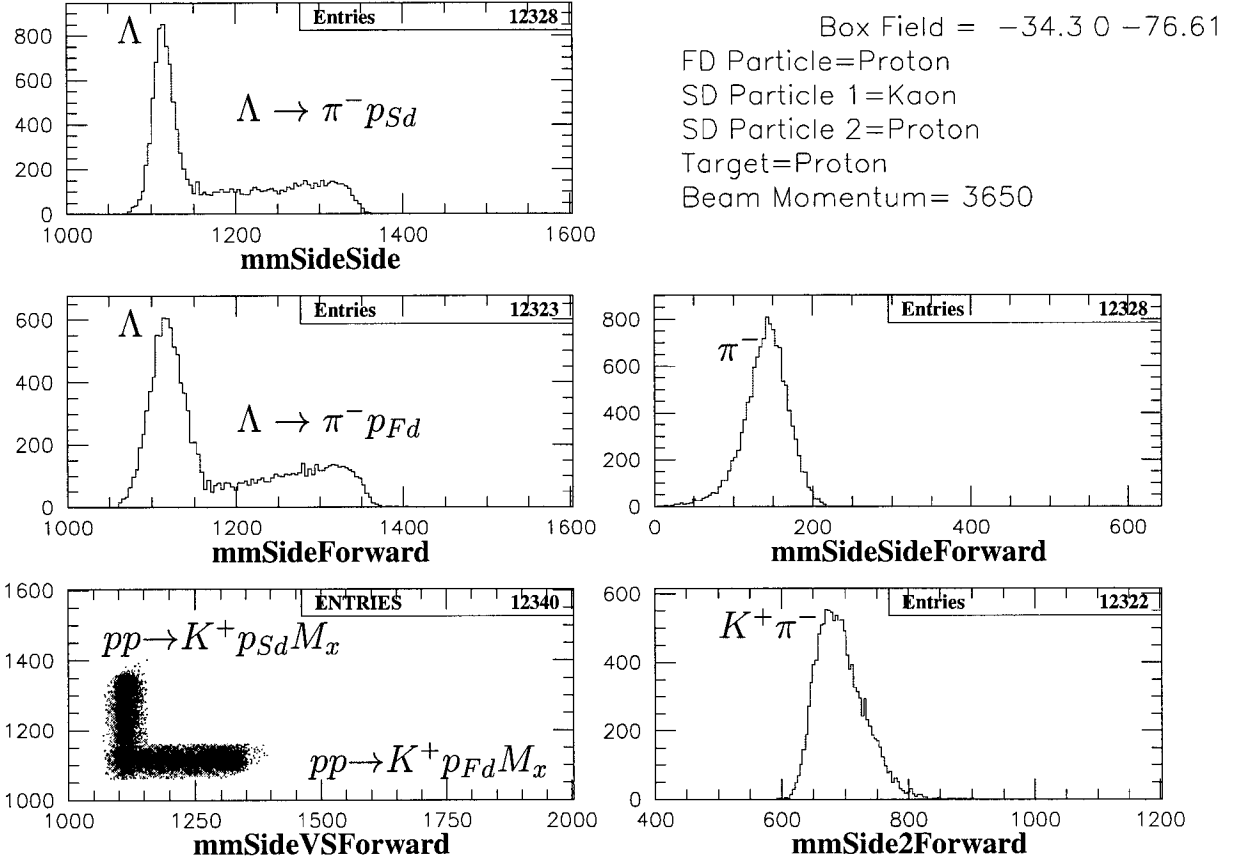
A (65-70) MeV wide peak of about 600 events is seen at $M_x \approx 1400$ MeV in both $pp \rightarrow K^+ p_{Sd} M_x$ and $pp \rightarrow K^+ p_{Fd} M_x$ mm-spectra. This peak could be the sum of two 45 MeV wide hyperons ($\Sigma^0(1385) \rightarrow \Lambda \pi^0 \rightarrow p \pi^- \pi^0$, $\Sigma^0(1385) \rightarrow \Sigma^+ \pi^- \rightarrow p \pi^0 \pi^-$) and ($\Lambda(1405) \rightarrow \Sigma^0 \pi^0 \rightarrow \Lambda \gamma \pi^0 \rightarrow p \pi^- \gamma \pi^0$, $\Lambda(1405) \rightarrow \Sigma^+ \pi^- \rightarrow p \pi^0 \pi^-$). Since here only trig 1 events are analysed, the π^- must be either soft ($P_{\pi^-} < 350$ MeV/c) or escape out of the close-to-target region of Λ, Σ decays at angles larger than the ANKE acceptance. No evidence of $\Sigma(1480)$, only an enhancement of 30-40 events. Is it a problem of acceptance? This will be clear after simulations are done.

$pp \rightarrow K^+ p \Lambda(1116)$, $T_p = 2830$ MeV, *trig1* and *trig5*

Missing Mass (MeV). Two Side and One Forward Particle

25/06/2002-13.41.52

Run4508-710.Lambda-cut.trg1-and-trg5

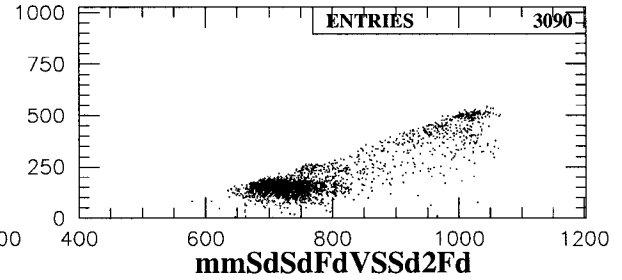
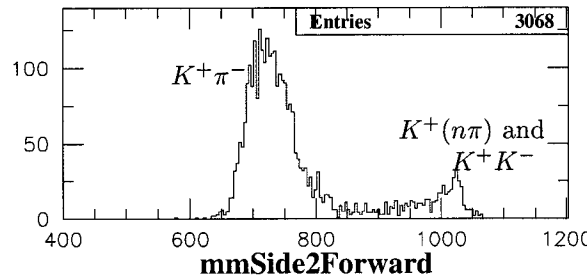
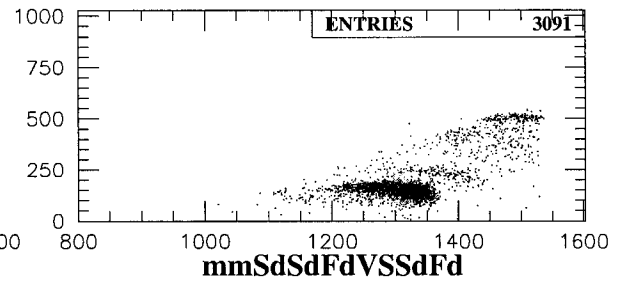
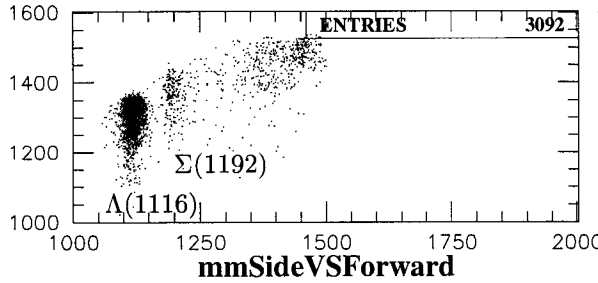
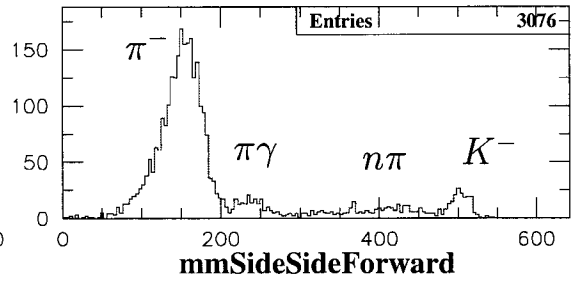
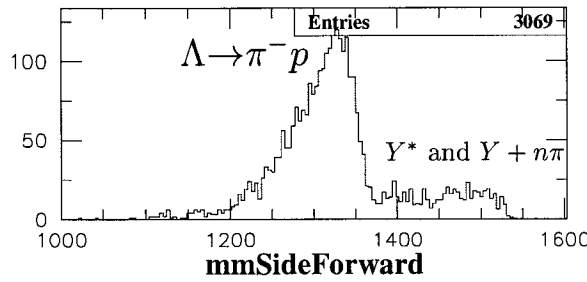
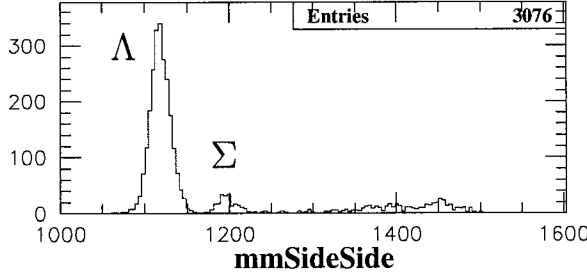


After rejecting events from $\Sigma(1192)$ and heavy hyperon production (cuts on the two-dimensional $mmSideVSForward$ spectrum) about 12500 exclusive and practically background free events for the reaction $pp \rightarrow K^+ p \Lambda(1116)$ survived from Runs 4508-4710 with trigger 5 and trigger 1. Additional 3000 events can be obtained from Runs 4468-4507.

Attractive is to use these events for Λ polarization studies. In the case of unpolarized beam and target the longitudinal Λ polarization must be equal to zero. The angular distribution of protons (or π^-) from Λ decays in the Λ cm-system with respect to the Λ direction is a good test for possible false asymmetries. The transverse Λ polarization will depend on the reaction mechanism and can be obtained from similar angular distributions but with respect to the normal to the scattering plane ($K^+ \Lambda$ plane in the case of the pion exchange mechanism). These studies are in progress and as the first step simulations are necessary.

$$pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x = Nd + x), T_p = 2830 \text{ MeV}, trig5$$

Missing Mass (MeV). Two Side and One Forward Particle 12/05/2002-18.02.23
Run4508-710zka-TEI20-SW25.MWPC-p.SW1-ka.SW2-MWPC.Fd-MWPC.trg5-Nd-is-on



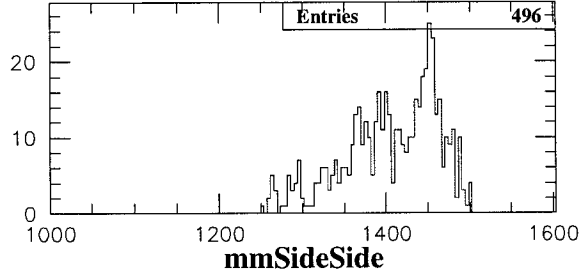
The event selection is the same as for the events presented on the previous pages, but events presented here are obtained with the hardware trigger 5 or four-fold coincidences of K^+ meson and two protons with a negatively charged particle with momenta $>350 \text{ MeV}/c$ (detected by Nd). Analysis of data from Nd is not done yet. About 2500 events are from $pp \rightarrow K^+ p \Lambda$ reaction and they must be used for Nd calibration.

$pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x = Nd + x), T_p = 2830 \text{ MeV}, trig5$
 additional cut: $pp \rightarrow K^+ p_{Sd} (M_x > 1250)$

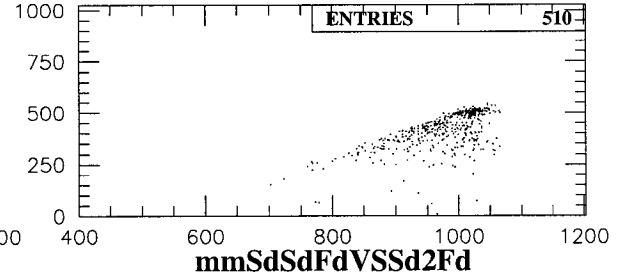
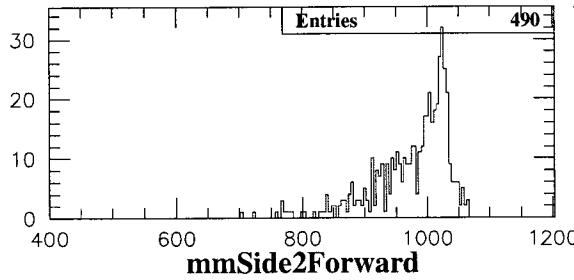
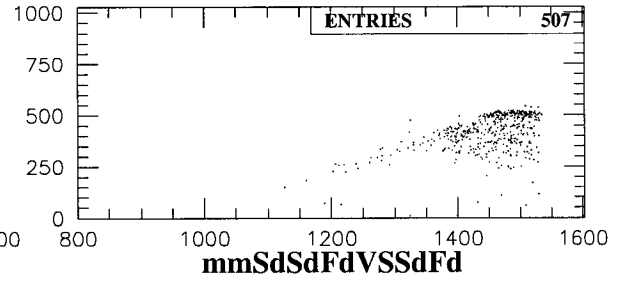
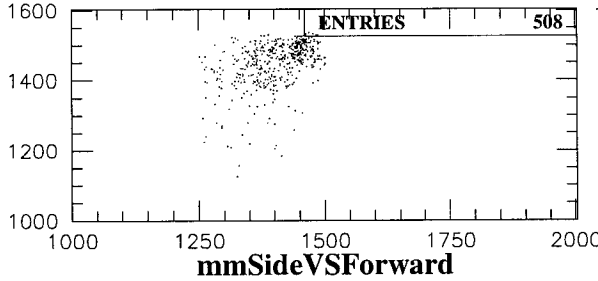
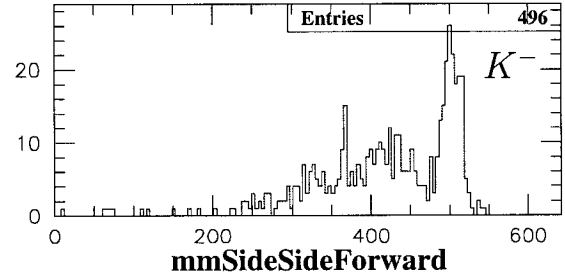
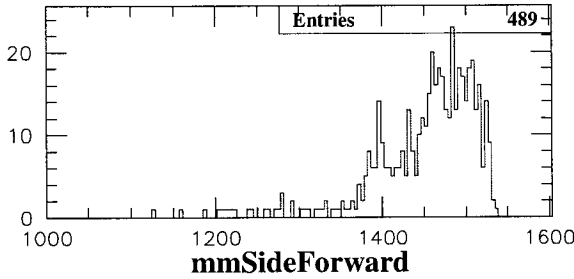
Missing Mass (MeV). Two Side and One Forward Particle

12/05/2002-18.49.48

Run4508-710zka-TEI20-SW25.MWPC-p.SW1-ka.SW2-MWPC.Fd-MWPC.mmSideSide-cut



Box Field = -34.3 0 -76.61
 FD Particle=Proton
 SD Particle 1=Kaon
 SD Particle 2=Proton
 Target=Proton
 Beam Momentum= 3650



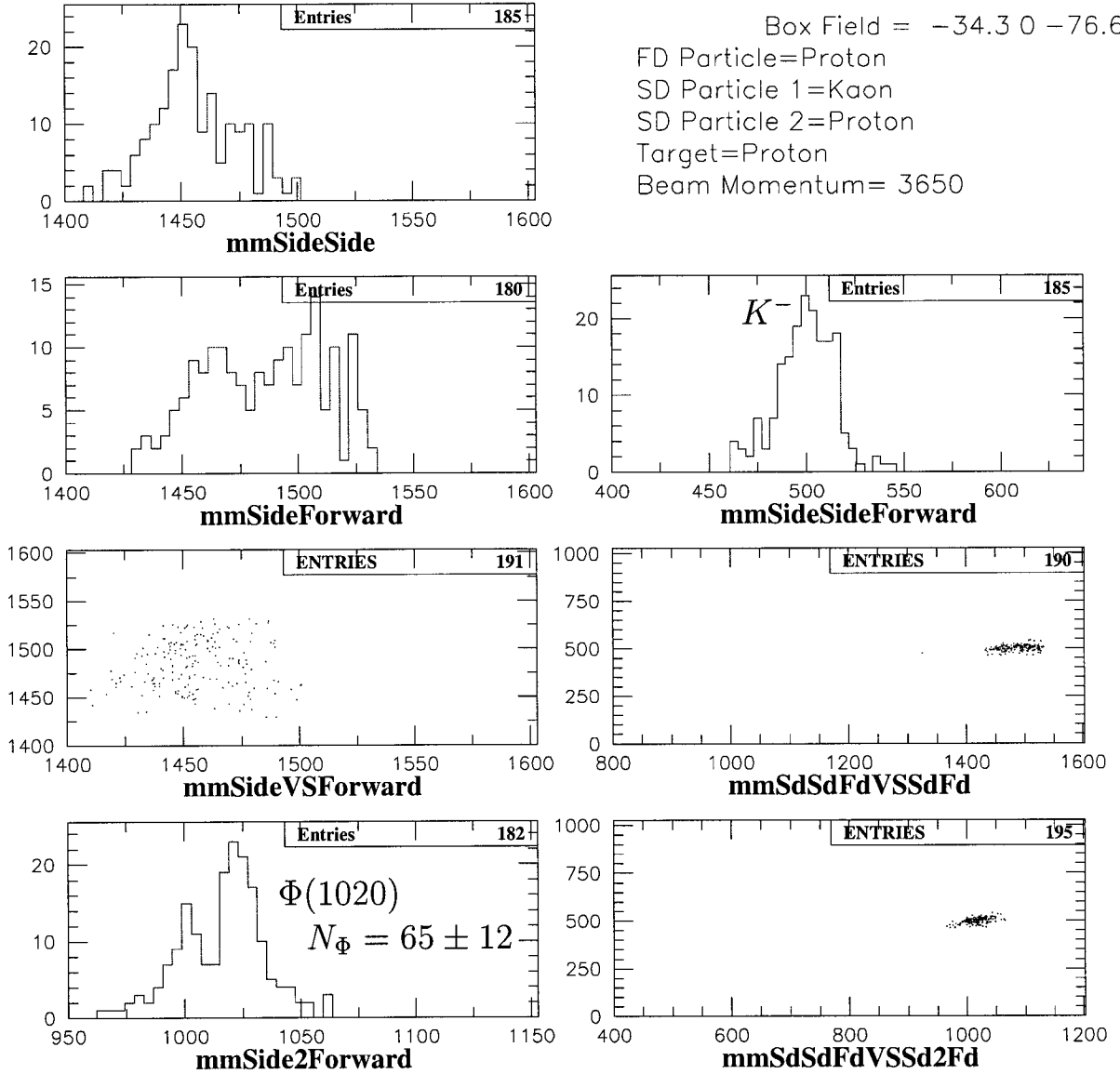
The 4-fold coincidences (*trig5*) make Y^* studies practically impossible. Only some hints on $\Sigma(1480)$ and $\Sigma(1385)$ or $\Lambda(1405)$ are seen. But this strong criterion permits to observe a rather clean peak of K^- even without any analysis of the Nd information. The selection of K^- mesons permits to look for $\Lambda(1520) \rightarrow K^- p$ and $\Sigma(1480) \rightarrow K^- p$ decay modes.

$pp \rightarrow K^+ p_{Sd} p_{Fd}(M_x = Nd + x), T_p = 2830 \text{ MeV}, trig5$
 additional cut: $pp \rightarrow K^+ pp(M_x > 460) \rightarrow \text{search for } \Sigma(1480) \rightarrow pK^- \text{ decay}$

Missing Mass (MeV). Two Side and One Forward Particle

24/05/2002-17.27.43

Run4508-710zka-TEI20-SW25.MWPC-p.SW1-ka.Fd-MWPC.mmS-S-Fd460.trg5



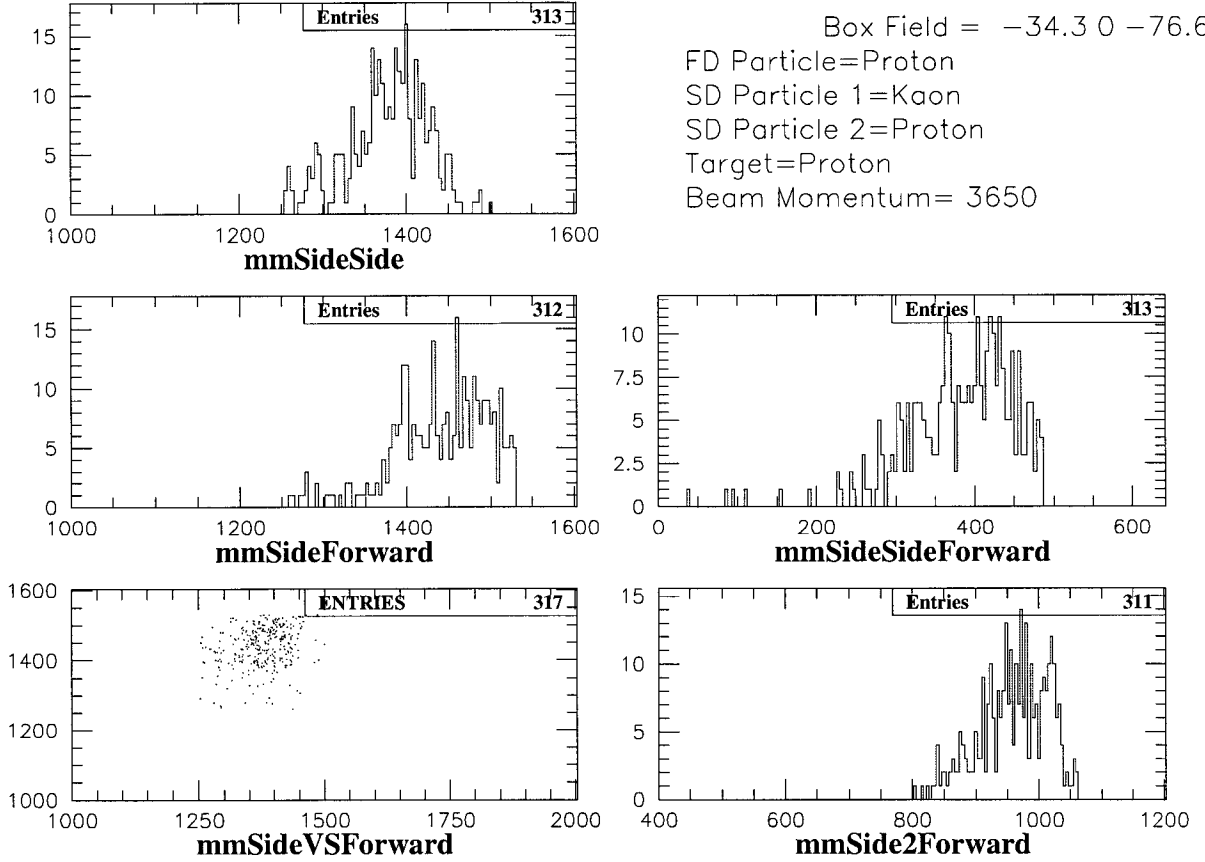
No events at $M_x \approx 1400 \text{ MeV}$ after the K^- selection is done. It seems that the cross sections for $\Sigma(1480) \rightarrow pK^-$ and $\Lambda(1520) \rightarrow pK^-$ production are much less than those for $\Phi(1020)$ and nonresonant K^+K^-p production. The last two reactions are responsible for more than 70% of the events here and strongly shade possible effects from $\Sigma(1480)$ and $\Lambda(1520)$. It is not clear whether K^+K^-p 3-fold coincidences with K^- given by an analysis of the Nd information will improve the situation. It is still good to try with a hope to increase statistics and to see at least a narrow peak of $\Lambda(1520)$.

$pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x = Nd + x)$, $T_p = 2830$ MeV, *trig5*
 additional cut: $pp \rightarrow K^+ p (M_x > 1250)$ and $pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x > 480)$

Missing Mass (MeV). Two Side and One Forward Particle

25/06/2002-15.26.22

Run4508-710.Y.and.K-.cutoff.trg5



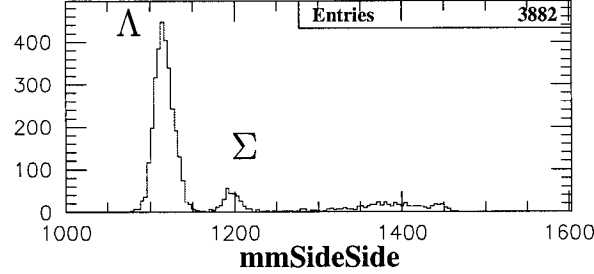
Trig5 data without events containing $\Lambda(1116)$, $\Sigma(1192)$ and K^- is the 4-fold coincidence of K^+ , p , p and π^- . There seems to be a hint on resonances at 1400 MeV and 1480 MeV in the (mm SideForward) missing mass spectrum. This spectrum must be similar to that discussed on pages at the beginning of this section if 3-fold coincidences (K^+ , p , π^-) are analysed with the use of information about π^- from Nd. This analysis must be done because information about $\Sigma \rightarrow \pi^- \Sigma^+ (1190)$ and $\Lambda(1520 \rightarrow \pi^- \Sigma^+ (1190))$ decays can be obtained from $pp \rightarrow K^+ p (M_x = \pi^- + x)$ and $pp \rightarrow K^+ \pi^- p M_x$ missing mass spectra. It would be good to separately analyse $pp \rightarrow K^+ p_{Fd} (M_x = \pi^- + x)$ and $pp \rightarrow K^+ p_{Sd} (M_x = \pi^- + x)$ with protons in Fd or in Sd. At 2830 MeV it is impossible because the coincidence with Fd-protons was included into the hardware trigger. It can be done at 2700 MeV though.

$$pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x = Nd + x), T_p = 2700 \text{ MeV}$$

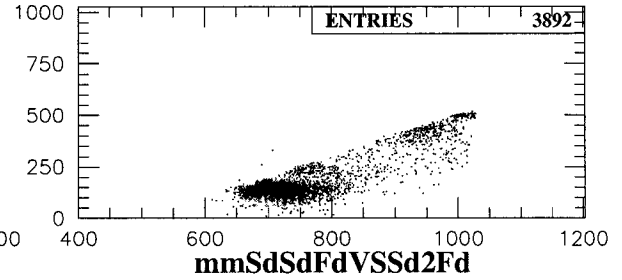
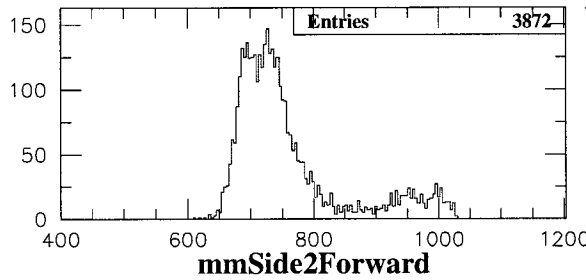
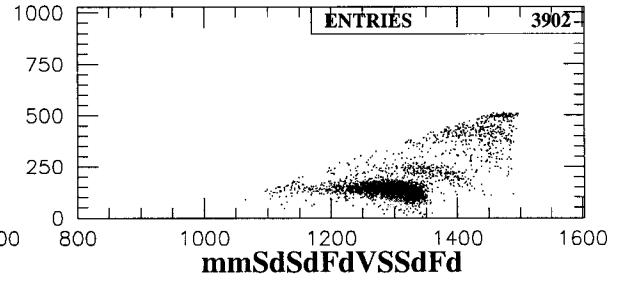
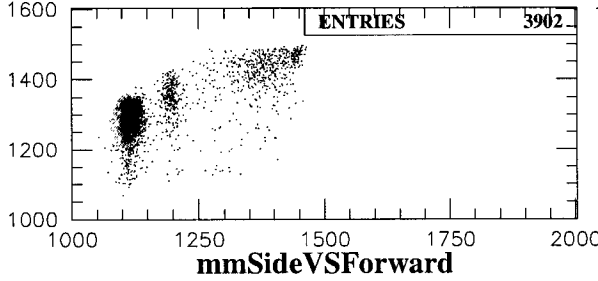
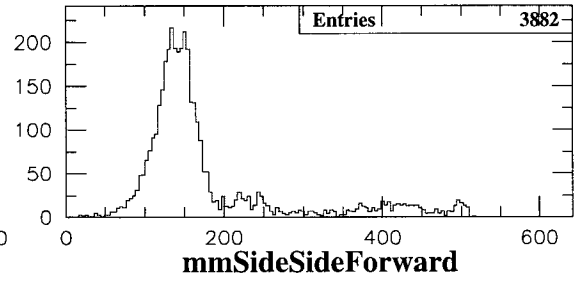
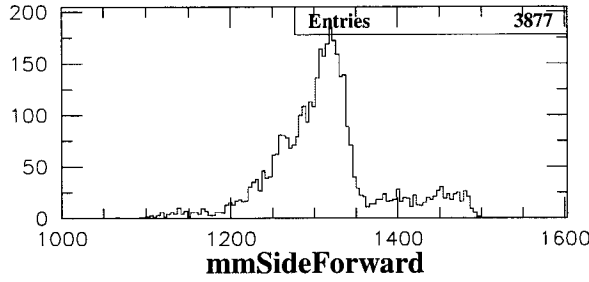
Missing Mass (MeV). Two Side and One Forward Particle

26/05/2002-03.04.47

Run4762-807zkaons.phi.Fd-MWPC.Sd-pMWPC.SW1-ka.trg4



Box Field = -33.9 0 -76.61
 FD Particle=Proton
 SD Particle 1=Kaon
 SD Particle 2=Proton
 Target=Proton
 Beam Momentum= 3515



About 90% of the data at 2700 MeV are analysed.

$$n_{\Lambda} = \frac{N_{2700}^{\Lambda}}{N_{2830}^{\Lambda}} \approx 1.35 \text{ and } n_{\Sigma} = \frac{N_{2700}^{\Sigma}}{N_{2830}^{\Sigma}} \approx 1.35$$

Corrected for efficiencies, acceptances and the cross section ratios which are known from literature, these ratios must be equal to the ratio of integrated luminosities $l = L_{2700}^{int} / L_{2830}^{int}$, obtained from *trig2* data. This could be a good test for the simulations.

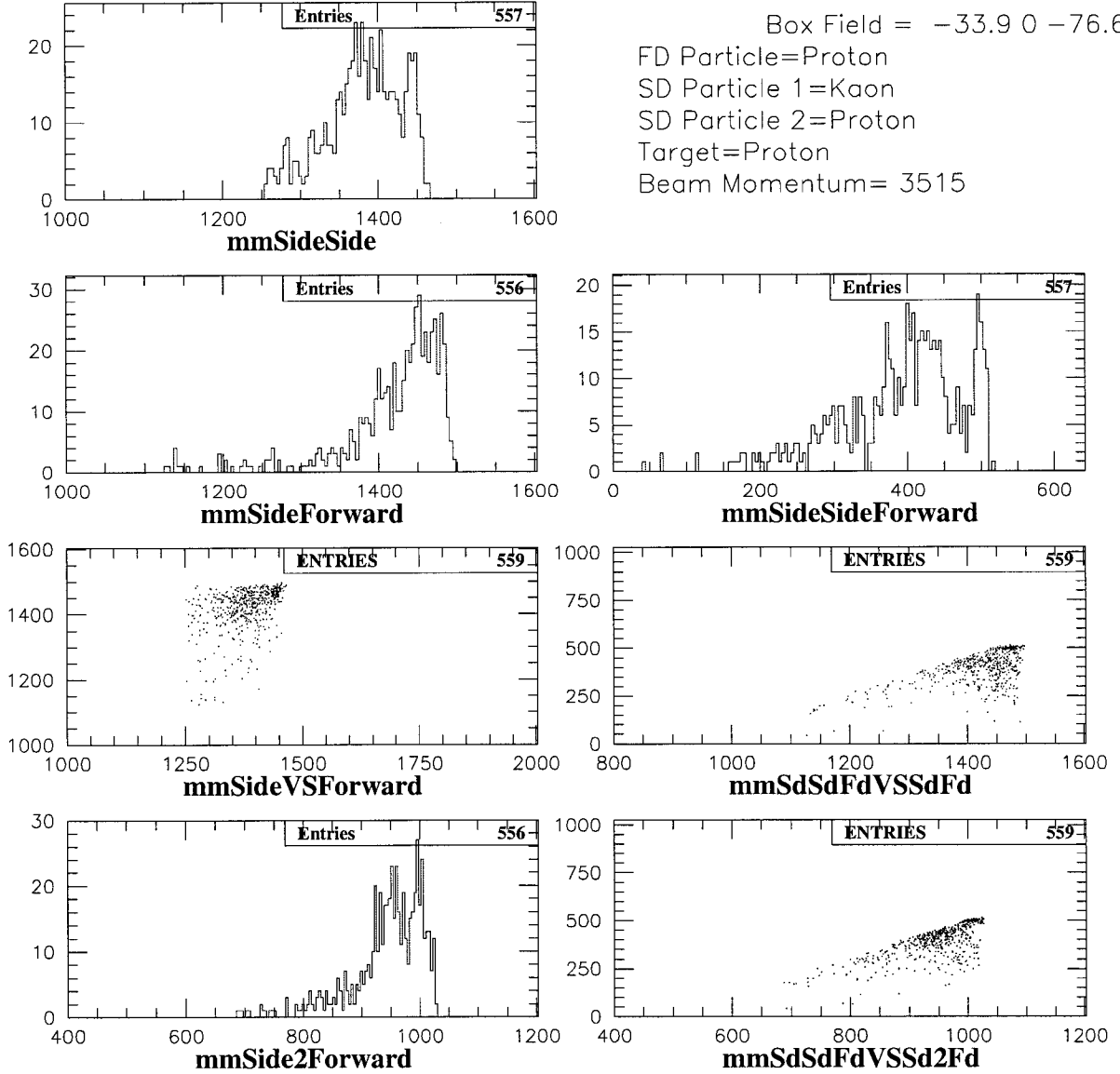
$$pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x = Nd + x), T_p = 2700 \text{ MeV}$$

after cuts $pp \rightarrow K^+ p_{Sd} (M_x > 1250)$

Missing Mass (MeV). Two Side and One Forward Particle

26/05/2002-03.15.10

Run4762-807zkaons.phi.Fd-MWPC.Sd-pMWPC.SW1-ka.mmS-S1250.trg4



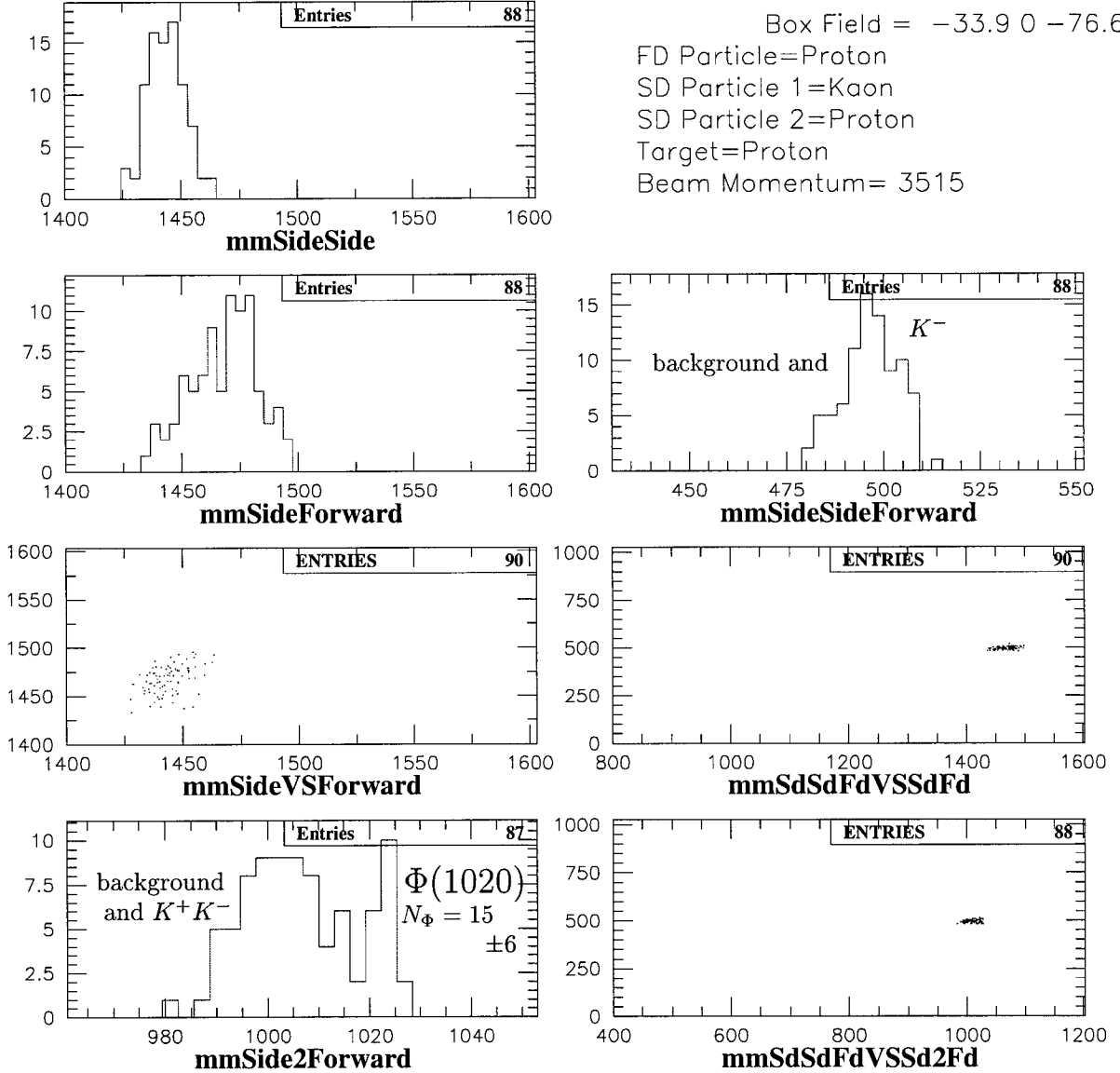
See discussions on the previous pages with the exception that $T_p = 2700 \text{ MeV}$ is close to the threshold of $\Sigma(1480)$ production and below the threshold of $\Lambda(1520)$ production.

$pp \rightarrow K^+ p_{Sd} p_{Fd} (M_x = Nd + x), T_p = 2700 \text{ MeV}$
 additional cut: $pp \rightarrow K^+ pp (M_x > 480)$

Missing Mass (MeV). Two Side and One Forward Particle

26/05/2002-03.54.31

Run4762-807zkaons.phi.Fd-MWPC.Sd-pMWPC.SW1-ka.mmS-S-Fd480-3.trg4



Selected K^- events at $T_p = 2700 \text{ MeV}$ can be used only for Φ and nonresonant $K^+ K^-$ production studies. The ratio

$$n_\Phi = \frac{N_{2700}^\Phi}{N_{2830}^\Phi} = 0.23 \pm 0.11,$$

corrected for efficiencies, acceptances and the ratio of integrated luminosities and multiplied by the cross section of Φ production at 2.83 GeV (known from literature), can give an estimation of the Φ production cross section at 2.70 GeV with the statistical accuracy of about 50%.

SUMMARY

A first fast analysis of the experimental data at 2.65, 2.70 and 2.83 GeV has been done. The goal was not to give the final answer about hyperon production from the data measured in 2001/2 but to understand what can be seen from this data. The results of this analysis are at least not very pessimistic. Before starting a more detailed analysis several problems must be solved:

- Simulation: They started at 2.65 GeV and are in progress at other energies.
- It is necessary to understand the problems with resolutions and peak positions in the missing mass spectra which were discussed above.
- Develop the program of a combined analysis of information about positively and negatively charged particles.

Only after this is done, it seems reasonable to start a new step of hyperon studies and may be starting from the beginning. At 2.65 GeV this will be done in the nearest future since there were no Nd-detector.

$a_0(980)$ Resonance Production and
nonresonant Background in the Reaction
 $pp \rightarrow dK^+ \bar{K}^0$ near Threshold

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60th October Anniversary Prospect 7A
117312 Moscow
Russia

Recently we have analyzed different mechanisms of $a_0(980)$ meson production in πN and NN collisions. The calculated cross section of the reaction $pp \rightarrow da_0^+(980)$ is in a good agreement with existing experimental data on the $pp \rightarrow da_0^+(980)$ forward differential cross section at $p_{lab} \geq 3.8$ GeV/c from Berkeley. New preliminary data measured at COSY are also coincide with our predictions for the $pp \rightarrow da_0^+ \rightarrow dK^+\bar{K}^0$ cross section. An important problem is to understand the role of nonresonant contribution to $pp \rightarrow dK^+\bar{K}^0$. We considered π - and K - exchange mechanisms of the nonresonant $K\bar{K}$ production in NN collisions. The calculated K -exchange contribution is negligibly small. To constrain the π -exchange mechanism we use the data on the reaction $\pi N \rightarrow NK\bar{K}$. The results of calculations for the $\pi N \rightarrow NK\bar{K}$ cross sections in different channels lead us to the conclusion that the resonant part is expected to be more pronounced at $Q \leq 250$ MeV while the nonresonant background is essential at $Q \geq 250$ MeV. We used this results to analyse the role of the nonresonant background in the $pp \rightarrow dK^+\bar{K}^0$ reaction. It was found that the resonant part is dominant up to $Q \simeq 100$ MeV. The background mainly contributes to the P -wave in the $K^+\bar{K}^0$ -system, while its contribution to the S -wave is rather small.

[1] M.A. Abolins et al., Phys. Rev. Lett. **25**, 469 (1970)

3rd ANKE Workshop

on a_0 Physics

May 22/23, 2002

V.Grishina

$a_0(980)$ Resonance Production
and nonresonant Background
in the Reaction

$$p + p \rightarrow d + K^+ + \overline{K}^0$$

near Threshold

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3. Elementary reaction

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 $\quad \quad \quad \searrow K \bar{K}$

(comparison with data)

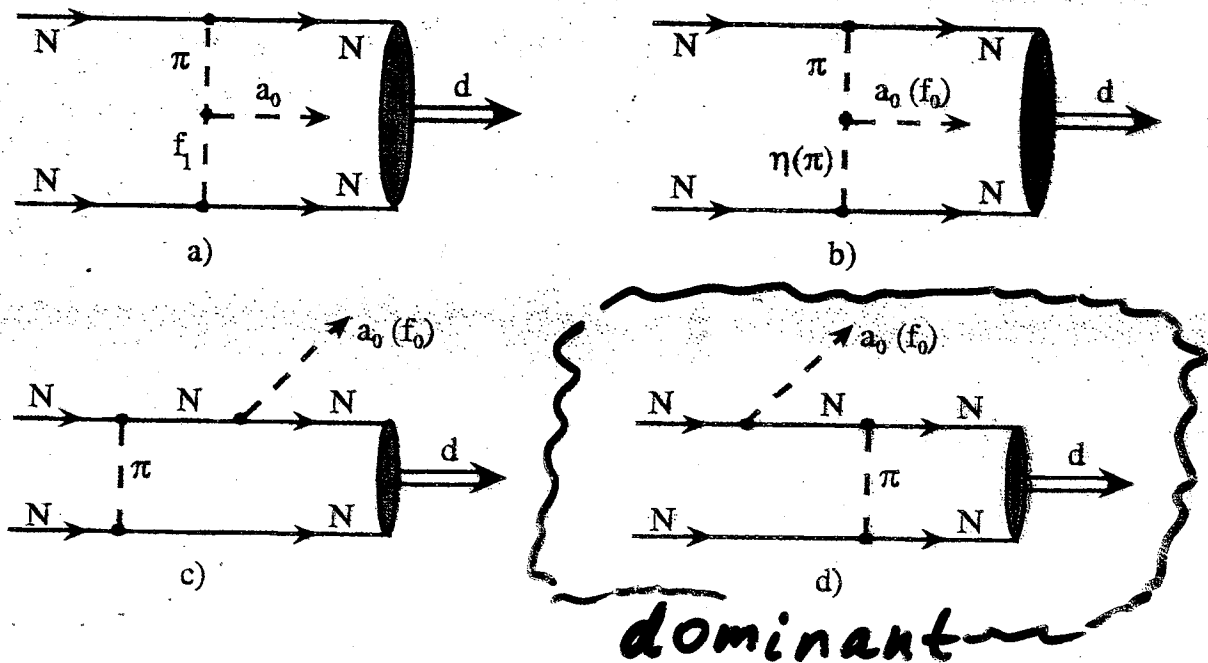
4. Production of $pp a_0^0$ $\quad \quad \quad \searrow K^+ K^-, K^0 \bar{K}^0$

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One pion exchange model
for the $NN \rightarrow NN a_0$
amplitude



By L. Kondratyuk, V. Grishina,
L. Bratkovskaya, M. Büscher,
W. Cassing

Eur. Phys. J. A 9, 277-285 (2000);
Phys. Lett. B 521, 217 (2001);
nucl-th / 0107071

An effective Lagrangian Approach (parameters)

For the meson exchanges we used form factors at the different vertices j ($j = f_1 NN, \eta NN$), which are taken of the monopole form

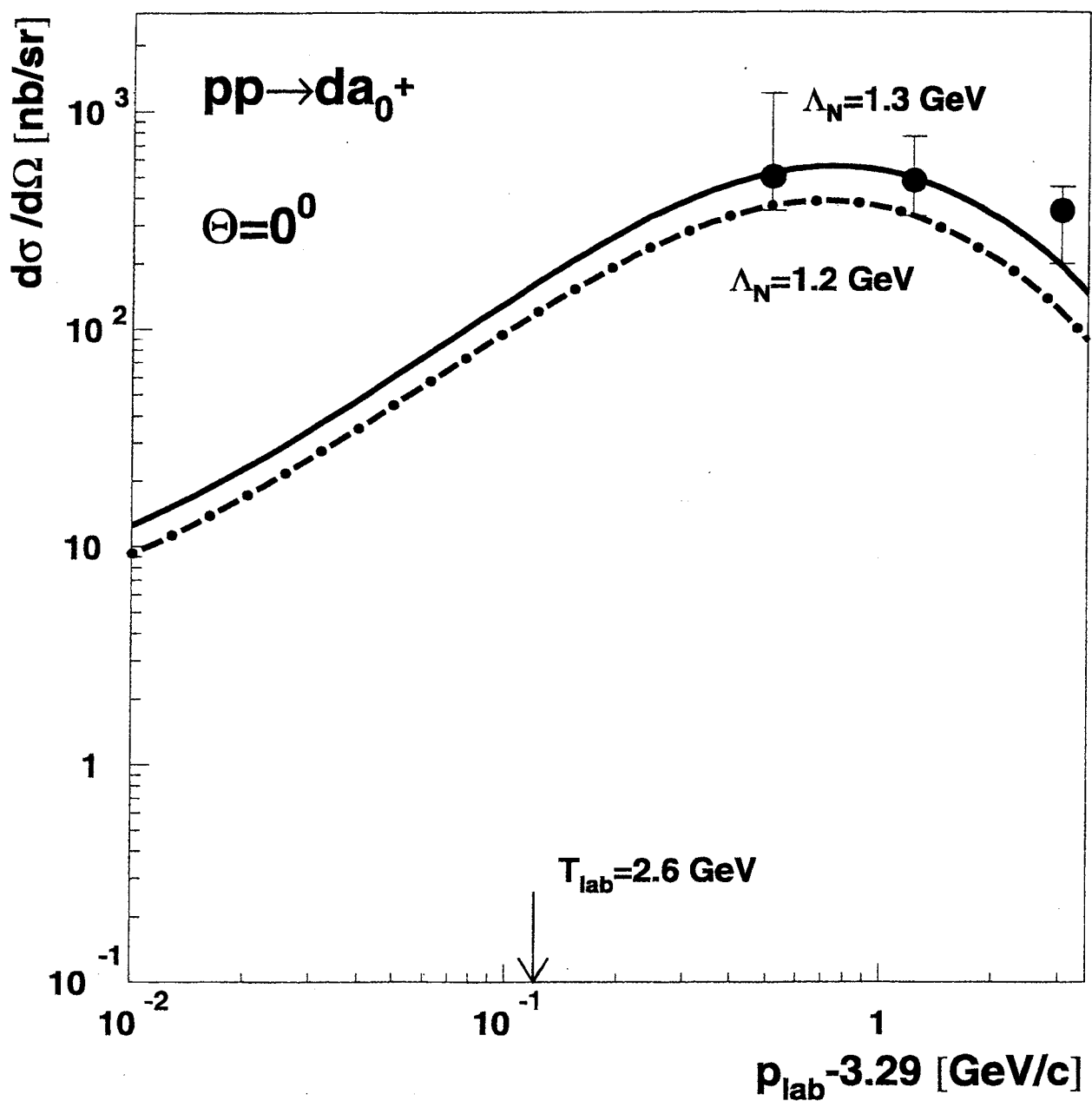
$$F_j(t) = \frac{\Lambda_j^2 - m_j^2}{\Lambda_j^2 - t},$$

where Λ_j is a cut-off parameter. In the case of η exchange we use $g_{\eta NN}^2/4\pi = 3$, $\Lambda_{\eta NN}=1.5$ GeV from Ref. R. Machleidt, K. Holinde, Ch. Elster, Phys. Rep. **149**, 1 (1987) and $g_{\eta\pi a_0} = \sqrt{8\pi\Gamma_{a_0 \rightarrow \pi\eta}/q_{\pi\eta}}=2.5$ which results from the width $\Gamma_{a_0 \rightarrow \eta\pi} = 80$ MeV. The contribution of the f_1 exchange is calculated for two parameter sets; set A: $g_{f_1 NN} = 11.2$, $\Lambda_{f_1 NN} = 1.5$ GeV from (V. Mull, K. Holinde, Phys. Rev. C **51**, 2360 (1995)), set B: $g_{f_1 NN} = 14.6$, $\Lambda_{f_1 NN} = 2.0$ GeV from (M. Kirchbach, D.O. Riska, Nucl. Phys. A **594**, 419 (1995)) and $g_{f_1 a_0 \pi}=2.5$ for both cases. The latter value for $g_{f_1 a_0 \pi}$ corresponds to $\Gamma(f_1 \rightarrow a_0 \pi) = 24$ MeV and $\text{Br}(f_1 \rightarrow a_0 \pi) = 34\%$.

An effective Lagrangian Approach (parameters) The πNN coupling constant is taken as $f_{\pi NN}^2/4\pi = 0.08$ (See R. Machleidt, K. Holinde, Ch. Elster, Phys. Rep. **149**, 1 (1987)) and the form factor for each virtual nucleon is taken in the so-called monopole (i=1) or dipole (i=2) form form

$$F_N(u) = \left(\frac{\Lambda_N^4}{\Lambda_N^4 + (u - m_N^2)^2} \right)^i.$$

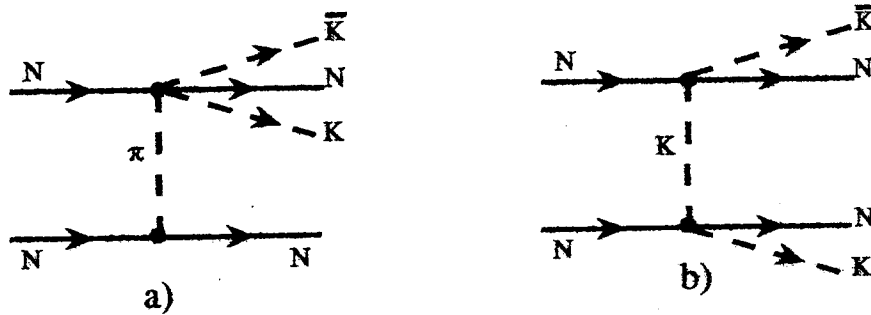
Following we adopt here a cut-off parameter $\Lambda_N = 1.24$ GeV for i=1 (when we considered the effective One Pion Exchange Model for the $NN \rightarrow NN a_0$ reaction) and $\Lambda_N = 1.35$ GeV for i=2 (this parameter is found from the constraints on the near-threshold a_0 production in the reaction $\pi^+ p \rightarrow K^+ \bar{K}^0 p$). The coupling $g_{a_0 NN}^2/4\pi \simeq 1$ have been employed in line with the Bonn potential (See R. Machleidt, K. Holinde, Ch. Elster, Phys. Rep. **149**, 1 (1987)).



exp. data are from M.A. Abolins et al.
 PRL 25, 469 (1970)

Calculations by V. Grishina, L. Kondratyuk
 et al., 2000

π - and K -exchange mechanisms
for the nonresonant $K\bar{K}$ production
in the $NN \rightarrow NN K\bar{K}$ reaction



/we take $\Lambda_K = 1.2 \text{ GeV}$ /

The mechanisms have been
discussed previously in Ref.

A.A. Sibirtsev, W. Cassing, and
C.M. Ko, Z.Phys. A 358, 101 (1997)

The $a_0(980)$ invariant mass distribution in $K\bar{K}$ and $\pi\eta$ modes can be parametrized by the well-known **Flatté formula** which follows from analyticity and unitarity for the two-channel T -matrix.

For example, in the case of the reaction $NN \rightarrow a_0 NN \rightarrow K\bar{K} NN$ the mass distribution of the final $K\bar{K}$ system can be written as a product of the total cross section for a_0 production (with the “running” mass M) in the $NN \rightarrow NN a_0$ reaction and the Flatté mass distribution function

$$\frac{d\sigma_{K\bar{K}}}{dM^2}(s, M) = \sigma_{a_0}(s, M) C_F \frac{M_R \Gamma_{a_0 K\bar{K}}(M)}{(M^2 - M_R^2)^2 + M_R^2 \Gamma_{\text{tot}}^2(M)} \quad (1)$$

with the total width $\Gamma_{\text{tot}}(M) = \Gamma_{a_0 K\bar{K}}(M) + \Gamma_{a_0 \pi\eta}(M)$. The partial widths

$$\begin{aligned} \Gamma_{a_0 K\bar{K}}(M) &= g_{a_0 K\bar{K}}^2 \frac{q_{K\bar{K}}}{8\pi M^2}, \\ \Gamma_{a_0 \pi\eta}(M) &= g_{a_0 \pi\eta}^2 \frac{q_{\pi\eta}}{8\pi M^2} \end{aligned} \quad (2)$$

are proportional to the decay momenta in the c.m. system (in case of scalar mesons),

$$\begin{aligned} q_{K\bar{K}} &= \frac{[(M^2 - (m_K + m_{\bar{K}})^2)(M^2 - (m_K - m_{\bar{K}})^2)]^{1/2}}{2M}, \\ q_{\pi\eta} &= \frac{[(M^2 - (m_\pi + m_\eta)^2)(M^2 - (m_\pi - m_\eta)^2)]^{1/2}}{2M} \end{aligned}$$

for a meson of mass M decaying to $K\bar{K}$ and $\pi\eta$, correspondingly.

The branching ratios $\text{Br}(a_0 \rightarrow K \bar{K})$ and $\text{Br}(a_0 \rightarrow \pi \eta)$ are given by the integrals of the Flatté distribution over the invariant mass squared $dM^2 = 2M dM$:

$$\text{Br}(a_0 \rightarrow K \bar{K}) = \int_{m_K+m_{\bar{K}}}^{\infty} \frac{dM}{2M} \frac{C_F M_R \Gamma_{a_0 K \bar{K}}(M)}{(M^2 - M_R^2)^2 + M_R^2 \Gamma_{\text{tot}}^2(M)}, \quad (3)$$

$$\begin{aligned} \text{Br}(a_0 \rightarrow \pi \eta) &= \int_{m_K+m_{\bar{K}}}^{\infty} \frac{dM}{2M} \frac{C_F M_R \Gamma_{a_0 \pi \eta}(M)}{(M^2 - M_R^2)^2 + M_R^2 \Gamma_{\text{tot}}^2(M)} + \\ &+ \int_{m_{\pi}+m_{\eta}}^{m_K+m_{\bar{K}}} \frac{dM}{2M} \frac{C_F M_R \Gamma_{a_0 \pi \eta}(M)}{(M^2 - M_R^2 - M_R \Gamma_{a_0 K \bar{K}}(M))^2 + M_R^2 \Gamma_{a_0 \pi \eta}^2(M)}. \end{aligned} \quad (4)$$

The parameters $C_F, g_{K\bar{K}}, g_{\pi\eta}$ have to be fixed under the constraint of the unitarity condition

$$\text{Br}(a_0 \rightarrow K \bar{K}) + \text{Br}(a_0 \rightarrow \pi \eta) = 1. \quad (5)$$

Choosing the parameter $\Gamma_0 = \Gamma_{a_0 \pi \eta}(M_R)$ in the interval 50 – 100 MeV (as given by the PDG one can fix the coupling $g_{\pi\eta}$ according to (2). In A. Abele *et al.*, Phys. Rev. D **57**, 3860 (1998) a ratio of branching ratios has been reported,

$$r(a_0(980)) = \frac{\text{Br}(a_0 \rightarrow K \bar{K})}{\text{Br}(a_0 \rightarrow \pi \eta)} = 0.23 \pm 0.05, \quad (6)$$

for $m_{a_0} = 0.999$ GeV, which gives $\text{Br}(a_0 \rightarrow K \bar{K}) = 0.187$. In another recent study D. Barberis *et al.* (WA102 Collaboration), Phys. Lett. B **440**, 225 (1998) the WA102 collaboration reported the branching ratio

$$\Gamma(a_0 \rightarrow K \bar{K})/\Gamma(a_0 \rightarrow \pi \eta) = 0.166 \pm 0.01 \pm 0.02, \quad (7)$$

which was determined from the measured branching ratio for the $f_1(1285)$ -meson.

In our present analysis we use the results from A. Abele *et al.*, Phys. Rev. D **57**, 3860 (1998) , however, keeping in mind that this branching ratio $\text{Br}(a_0 \rightarrow K\bar{K})$ more likely gives an “upper limit” for the $a_0 \rightarrow K\bar{K}$ decay.

Thus, the two other parameters in the Flatté distribution C_F and $g_{a_0 K\bar{K}}$ can be found by solving the system of integral equations, for example, Eq. (3) for $\text{Br}(a_0 \rightarrow K\bar{K}) = 0.187$ and the unitarity condition (5). For our calculations we choose either $\Gamma_{a_0\pi\eta}(M_R) = 70$ MeV or 50 MeV, which gives two sets of independent parameters $C_F, g_{a_0 K\bar{K}}, g_{a_0\pi\eta}$ for a fixed branching ratio $\text{Br}(a_0 \rightarrow K\bar{K}) = 0.187$:

$$\text{set 1 } (\Gamma_{a_0\pi\eta} = 70 \text{ MeV}) : \quad (8)$$

$$g_{a_0 K\bar{K}} = 2.297, \quad g_{a_0\pi\eta} = 2.189, \quad C_F = 0.365$$

$$\text{set 2 } (\Gamma_{a_0\pi\eta} = 50 \text{ MeV}) : \quad (9)$$

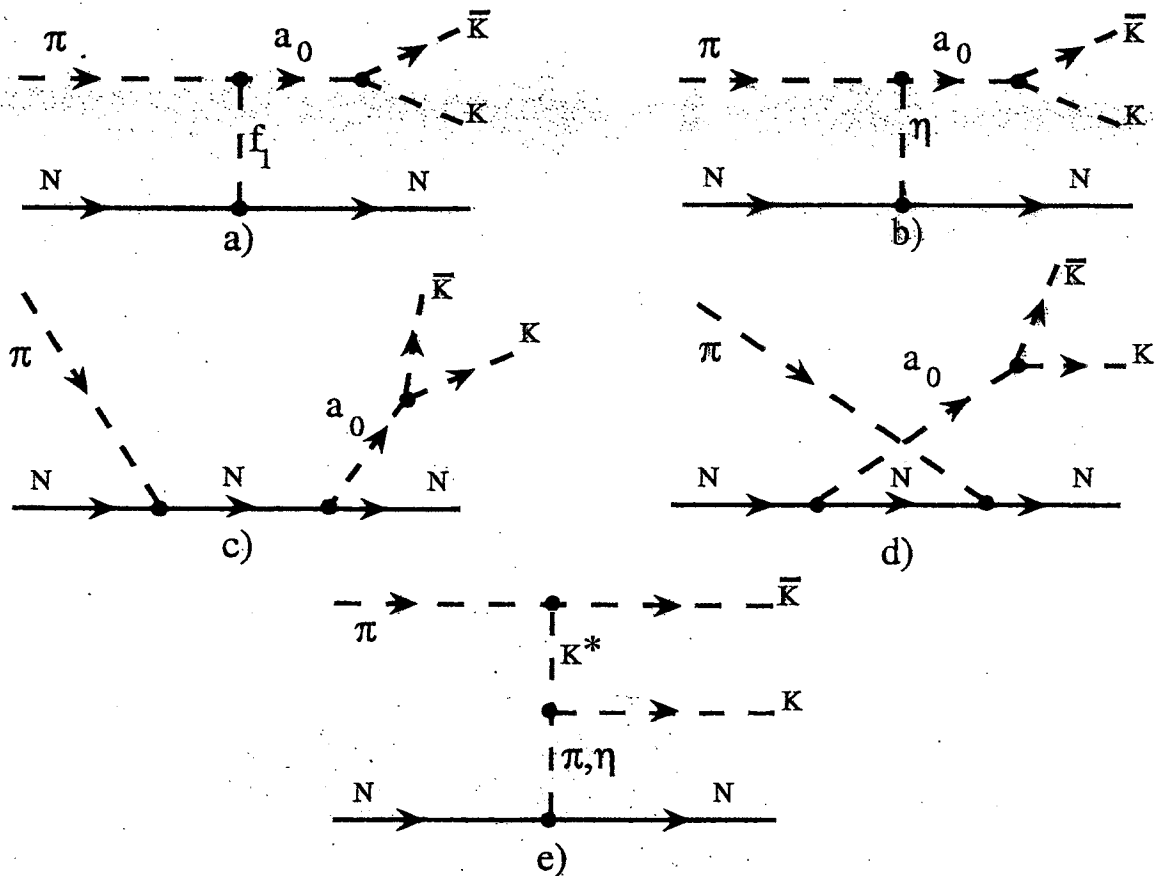
$$g_{a_0 K\bar{K}} = 1.943, \quad g_{a_0\pi\eta} = 1.937, \quad C_F = 0.354.$$

Note, that for the K^+K^- or $K^0\bar{K}^0$ final state one has to take into account an isospin factor for the coupling constant, i.e. $g_{a_0 K^+K^-} = g_{a_0 K^0\bar{K}^0} = g_{a_0 K\bar{K}}/\sqrt{2}$, whereas $g_{a_0 K^+\bar{K}^0} = g_{a_0 K^-\bar{K}^0} = g_{a_0 K\bar{K}}$.

The reactions $\pi N \rightarrow a_0 N$

& $\pi N \rightarrow K \bar{K} N$

an effective Lagrangian Approach



The background contribution in $\pi N \rightarrow NK\bar{K}$ was calculated using parameters of the K^* exchange from the Jülich model (See G. Janssen, B. Pierce, K. Holinde and J. Speth, Phys. Rev. D **52**, 2690 (1995)) .

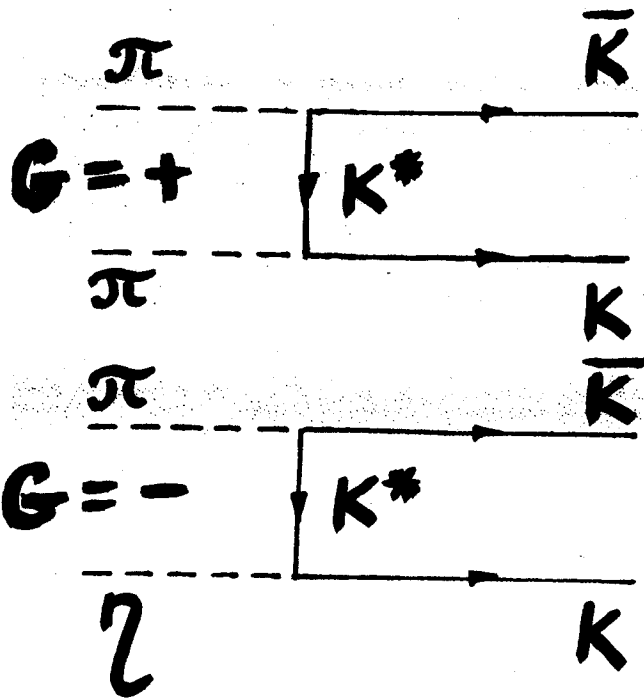
TABLE I. Vertex parameters for t channel exchanges. Relations between coupling constants are obtained using SU(3) and ideal mixing between the octet and singlet.

Vertex	g	Λ [MeV]
$\pi\pi\rho$	6.04	1355
πKK^*	$g_{\pi KK^*} = g_{\pi \bar{K} K^*} = -\frac{1}{2}g_{\pi\pi\rho}$	1900
$KK\rho$	$g_{KK\rho} = g_{\bar{K} K\rho} = \frac{1}{2}g_{\pi\pi\rho}$	1850
$KK\omega$	$g_{KK\omega} = -g_{\bar{K} K\omega} = \frac{1}{2}g_{\pi\pi\rho}$	2800
$KK\phi$	$g_{KK\phi} = -g_{\bar{K} K\phi} = \frac{1}{\sqrt{2}}g_{\pi\pi\rho}$	2800
ηKK^*	$g_{\eta KK^*} = -g_{\eta \bar{K} K^*} = -\frac{\sqrt{3}}{2}g_{\pi\pi\rho}$	3290

It is important that for the reactions $\pi^+p \rightarrow pK^+\bar{K}^0$ and $\pi^-p \rightarrow pK^0K^-$, where the $K\bar{K}$ pair has isospin 1, the main contributions come from P -wave $K\bar{K}$ pair production from the $\pi\pi$ state and from S -wave $K\bar{K}$ pair production from the $\eta\pi$ state. These selection rules follow from G -parity conservation (note that the G -parity of the $K\bar{K}$ system with orbital momentum L and isospin I is given by $(-1)^{L+I}$). At the same time for the reactions $\pi^-p \rightarrow nK^+K^-$ and $\pi^-p \rightarrow nK^0\bar{K}^0$ the essential contribution to the background stems from S -wave $K\bar{K}$ pair production from the isoscalar $\pi\pi$ state.

Background

G-parity constraints



$$L = 0 \text{ for } I_{K\bar{K}} = 0$$

$$L = 1 \text{ for } I_{K\bar{K}} = 1$$

$$L = 0 \text{ for } I_{K\bar{K}} = 1$$

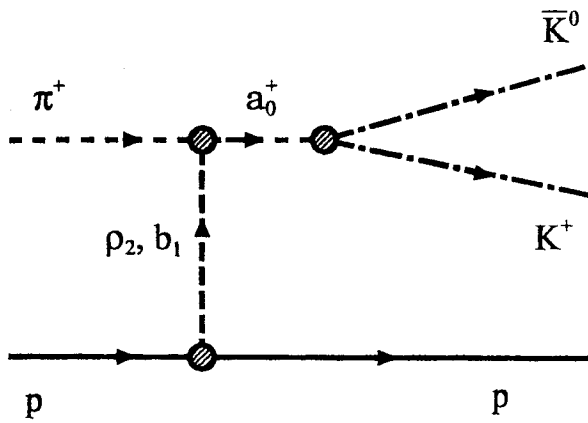
$$L = 1 \text{ for } I_{K\bar{K}} = 0$$

$$G(K\bar{K}) = (-1)^{L+I}$$

for $K^+ \bar{K}^0$ $I = 1$

and $\pi\pi \rightarrow K\bar{K}$ amplitude

has dominant contribution from P-wave
but for $K^0 \bar{K}^0$ system S-wave



The Regge-pole Model
for the $\pi N \rightarrow N a_0$ amplitude

The Regge-pole Model

There is a single experimental point for the forward differential cross section of the reaction $\pi^- p \rightarrow a_0^0 n$ at 2.4 GeV/c (D. L. Cheshire *et al.*, Phys. Rev. Lett. **28**, 520 (1972).),

$$\left. \frac{d\sigma}{dt}(\pi^- p \rightarrow a_0^0 n) \right|_{t \approx 0} = 0.49 \text{ mb/GeV}^2.$$

Since in the forward region ($t \approx 0$) the s - and u - channel diagrams only give a smaller cross section, the charge exchange reaction $\pi^- p \rightarrow a_0^0 n$ is most probably dominated at small t by the isovector $b_1(1^{+-})$ - and $\rho_2(2^{--})$ - meson exchanges (see e.g. N.N. Achasov, S.A. Devyanin, and G.N. Shestakov, Phys. Lett. **B88**, 367 (1979)). Though the couplings of these mesons to πa_0 and NN are not known, we can estimate $\frac{d\sigma}{dt}(\pi^- p \rightarrow a_0^0 n)$ in the forward region using the Regge-pole model as developed by Achasov and Shestakov (N.N. Achasov, G.N. Shestakov, Phys. Rev. D **56**, 212 (1997)). Note, that the Regge-pole model is expected to provide a reasonable estimate for the cross section at medium energies of about a few GeV and higher (see e.g. A.B. Kaidalov, Sov. J. Nucl. Phys. **53**, 872 (1991); L.A. Kondratyuk *et al.*, Phys. Rev. C **48**, 2491 (1993).and references therein).

The s - channel helicity amplitudes for the reaction $\pi^- p \rightarrow a_0^0 n$ can be written as

$$M_{\lambda'_2 \lambda_2}(\pi^- p \rightarrow a_0^0 n) = \bar{u}_{\lambda'_2}(p'_2) \left[-A(s, t) + \right. \\ \left. + (p_1 + p'_1)_\alpha \gamma_\alpha \frac{B(s, t)}{2} \right] \gamma_5 u_{\lambda_2}(p_2),$$

where the invariant amplitudes $A(s, t)$ and $B(s, t)$ do not contain kinematical singularities and (at fixed t and large s) are related to the helicity amplitudes as

$$M_{++} \approx -sB, \quad M_{+-} \approx \sqrt{t_{\min} - t} A.$$

The differential cross section then can be expressed through the helicity amplitudes in the standard way as

$$\frac{d\sigma}{dt}(\pi^- p \rightarrow a_0^0 n) = \frac{1}{64\pi s} \frac{1}{(p_1^{\text{cm}})^2} (|M_{++}|^2 + |M_{+-}|^2).$$

Usually it is assumed that the reaction $\pi^- p \rightarrow a_0^0 n$ at high energies is dominated by the b_1 Regge-pole exchange. However, as shown by Achasov and Shestakov (N.N. Achasov, G.N. Shestakov, Phys. Rev. D **56**, 212 (1997)) this assumption is not compatible with the angular dependence of $d\sigma/dt(\pi^- p \rightarrow a_0^0 n)$ observed at Serpukhov at 40 GeV/c (D. Alde *et al.*, Phys. Atom. Nucl. **59** (1996) 982; S. Sadovsky, in Proceedings of the 6th International Conference on Hadron Spectroscopy, Hadron'95, edited by M.C. Birse *et al.*, (World Scientific Publ. Co., 1996) p. 445.) and Brookhaven at 18 GeV/c (A.R. Dzierba, in Proceedings of the Second Workshop on Physics and Detectors for DAΦNE'95, Frascati, 1995, edited by R. Baldini *et al.*, Frascati Physics Series **4**, 99 (1996)). The reason is that the b_1 Regge trajectory contributes only to the amplitude $A(s, t)$ giving a dip in differential cross section at forward angles, while the data show a clear forward peak in $d\sigma/dt(\pi^- p \rightarrow a_0^0 n)$ at both energies.

To interpret this phenomenon Achasov and Shestakov introduced a ρ_2 **Regge-pole exchange conspiring with its daughter trajectory**. Since the ρ_2 Regge trajectory contributes to both invariant amplitudes, $A(s, t)$ and $B(s, t)$, its contribution does not vanish at $\Theta = 0$ thus giving a forward peak due to the term $|M_{++}|^2$ in $d\sigma/dt$. At the same time the contribution of the ρ_2 daughter trajectory to the amplitude $A(s, t)$ is necessary to cancel the kinematical pole at $t = 0$ introduced by the ρ_2 main trajectory (conspiracy effect). In this model the s channel helicity amplitudes can be expressed through the b_1 and the conspiring ρ_2 Regge trajectories exchange as

$$M_{++} \approx M_{++}^{\rho_2}(s, t) = \gamma_{\rho_2}(t) \exp\left[-i\frac{\pi}{2}\alpha_{\rho_2}(t)\right] \left(\frac{s}{s_0}\right)^{\alpha_{\rho_2}(t)},$$

$$M_{+-} \approx M_{+-}^{b_1}(s, t) = \sqrt{(t_{\min} - t)/s_0} \gamma_{b_1}(t) \times \\ \times i \exp\left[-i\frac{\pi}{2}\alpha_{b_1}(t)\right] \left(\frac{s}{s_0}\right)^{\alpha_{b_1}(t)},$$

where $\gamma_{\rho_2}(t) = \gamma_{\rho_2}(0) \exp(b_{\rho_2}t)$, $\gamma_{b_1}(t) = \gamma_{b_1}(0) \exp(b_{b_1}t)$, $t_{\min} \approx -m_N^2(m_{a_0}^2 - m_\pi^2)/s^2$, $s_0 \approx 1 \text{ GeV}^2$ while the meson Regge trajectories have the linear form $\alpha_j(t) = \alpha_j(0) + \alpha'_j(0)t$.

Achasov and Shestakov describe the Brookhaven data on the t distribution at 18 GeV/ c for $-t_{\min} \leq -t \leq 0.6$ GeV² by the expression

$$\frac{dN}{dt} = C_1 \left[e^{\Lambda_1 t} + (t_{\min} - t) \frac{C_2}{C_1} e^{\Lambda_2 t} \right],$$

where the first and second terms describe the ρ_2 and b_1 exchanges, respectively. They found two fits: a) $\Lambda_1 = 4.7$ GeV⁻², $C_2/C_1 = 0$, $C_1 \approx 0$; b) $\Lambda_1 = 7.6$ GeV⁻², $C_2/C_1 \approx 2.6$ GeV⁻², $\Lambda_2 = 5.8$ GeV⁻². This implies that at 18 GeV/ c the b_1 contribution yields only 1/3 of the integrated cross section. Moreover, using the available data on the reaction $\pi^- p \rightarrow a_2^0(1320)n$ at 18 GeV/ c and comparing with the data on the $\pi^- p \rightarrow a_0^0 n$ reaction they estimated the total and forward differential cross sections $\sigma(\pi^- p \rightarrow a_0^0 n \rightarrow \pi^0 \eta n) \approx 200$ nb and $[d\sigma/dt(\pi^- p \rightarrow a_0^0 n \rightarrow \pi^0 \eta n)]_{t=0} \approx 940$ nb/GeV². Taking $\text{Br}(a_0^0 \rightarrow \pi^0 \eta) \approx 0.8$ we find $\sigma(\pi^- p \rightarrow a_0^0 n) \approx 0.25$ μb and $[d\sigma/dt(\pi^- p \rightarrow a_0^0 n)]_{t=0} \approx 1.2$ $\mu\text{b}/\text{GeV}^2$. In this way all the parameters of the Regge model can be fixed and we will employ it for the energy dependence of the $\pi^- p \rightarrow a_0^0 n$ cross section to obtain an estimate at lower energies, too.

The mass of the $\rho_2(2^{--})$ is expected to be about 1.7 GeV and the slope of the meson Regge trajectory in the case of light (u, d) quarks is 0.9 GeV^{-2} . Therefore, the intercept of the ρ_2 Regge trajectory is $\alpha_{\rho_2}(0) = 2 - 0.9m_{\rho_2}^2 \approx -0.6$. Similarly – in the case of the b_1 trajectory – we have $\alpha_{b_1}(0) \approx -0.37$. At forward angles we can neglect the contribution of the b_1 exchange (see discussion above) and write the energy dependence of the differential cross section in the form

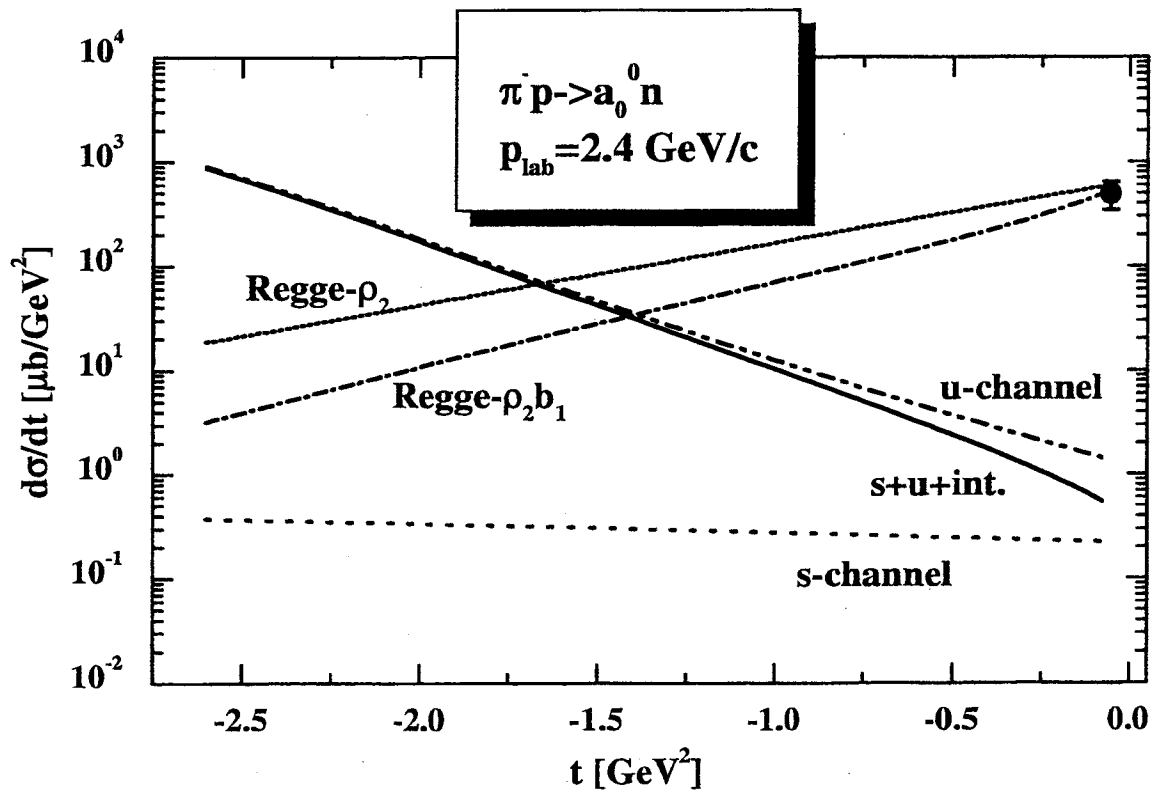
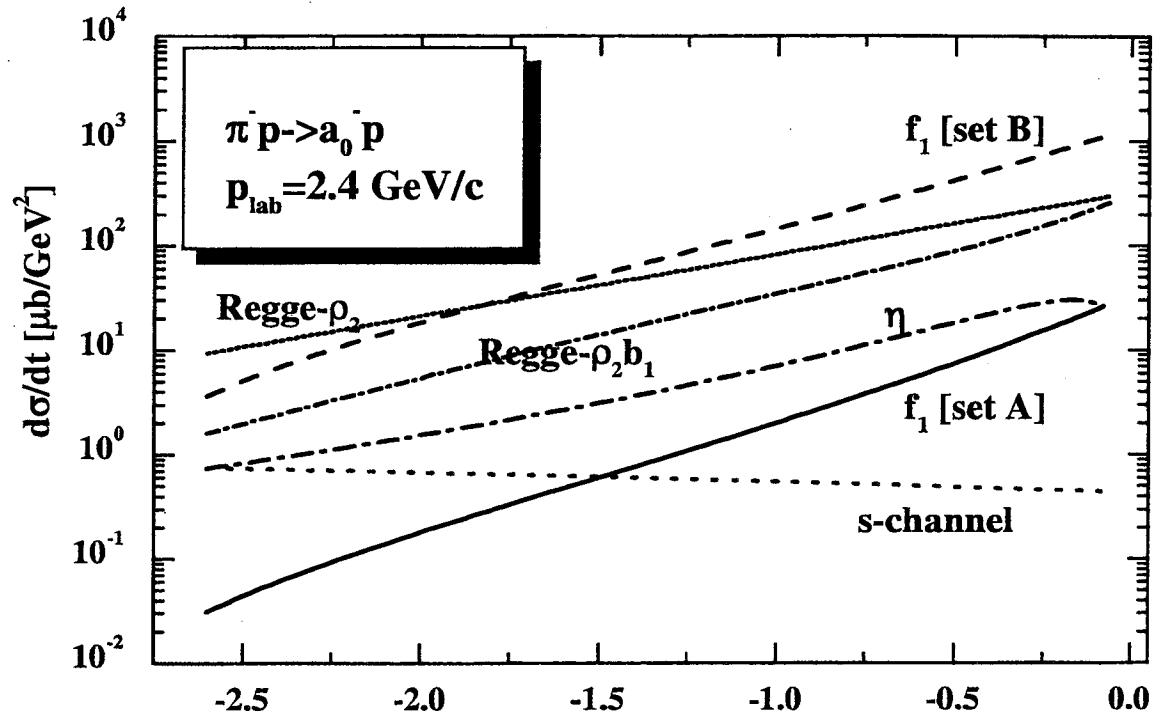
$$\begin{aligned} \frac{d\sigma_{\text{Regge}}}{dt}(\pi^- p \rightarrow a_0^0 n) \Big|_{t=0} &\approx \frac{d\sigma_{\rho_2}}{dt} \Big|_{t=0} \sim \\ &\sim \frac{1}{(p_1^{c.m.})^2} \left(\frac{s}{s_0} \right)^{-2.2}. \end{aligned}$$

This provides the following estimate for the forward differential cross section at $2.4 \text{ GeV}/c$,

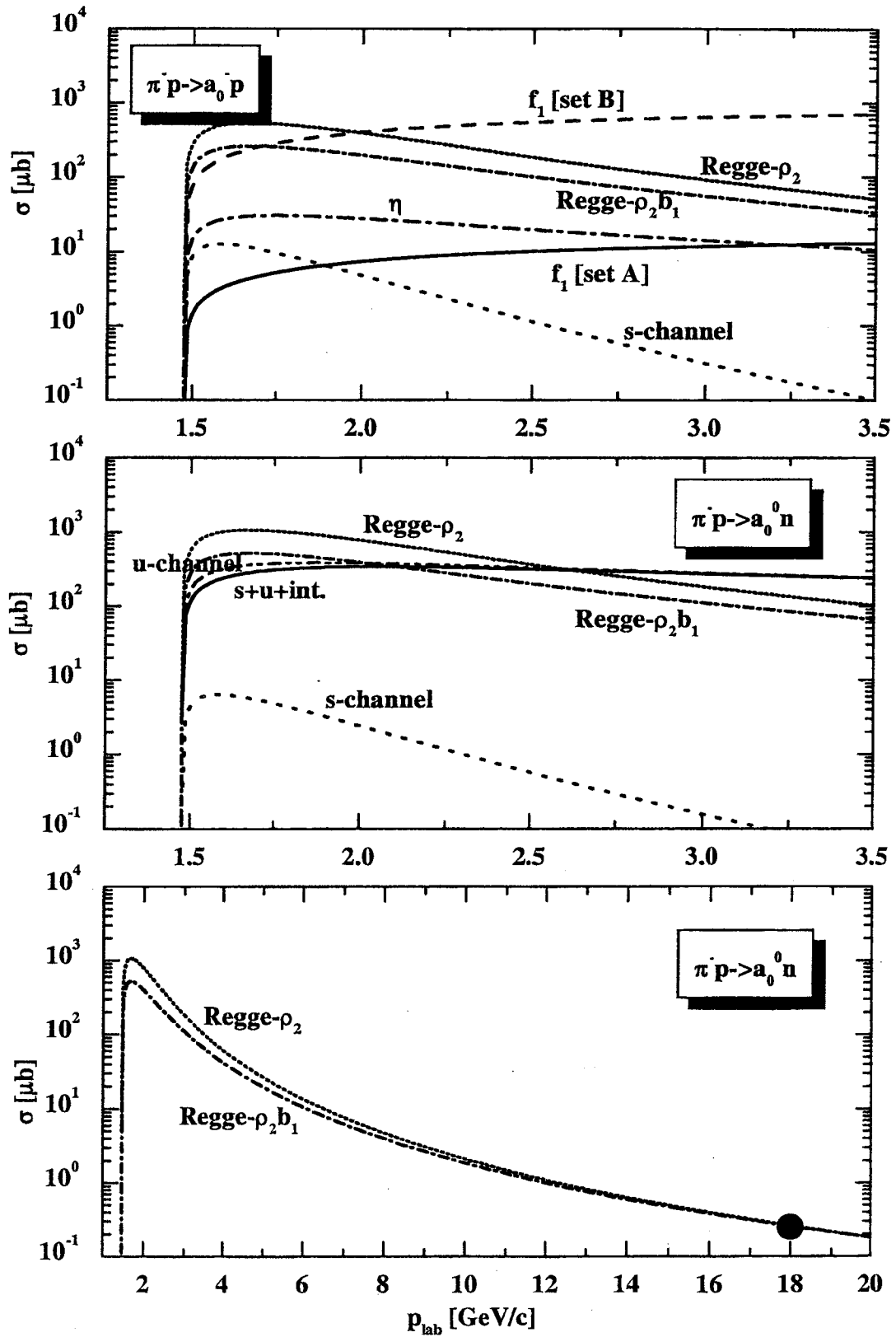
$$\frac{d\sigma_{\text{Regge}}}{dt}(\pi^- p \rightarrow a_0^0 n) \Big|_{t=0} \approx 0.6 \text{ mb/GeV}^2,$$

which is in agreement with the experimental data point (D. L. Cheshire *et al.*, Phys. Rev. Lett. **28**, 520 (1972)). Since the b_1 and ρ_2 Regge trajectories have isospin 1, their contribution to the cross section for the reaction $\pi^- p \rightarrow a_0^- p$ is twice smaller,

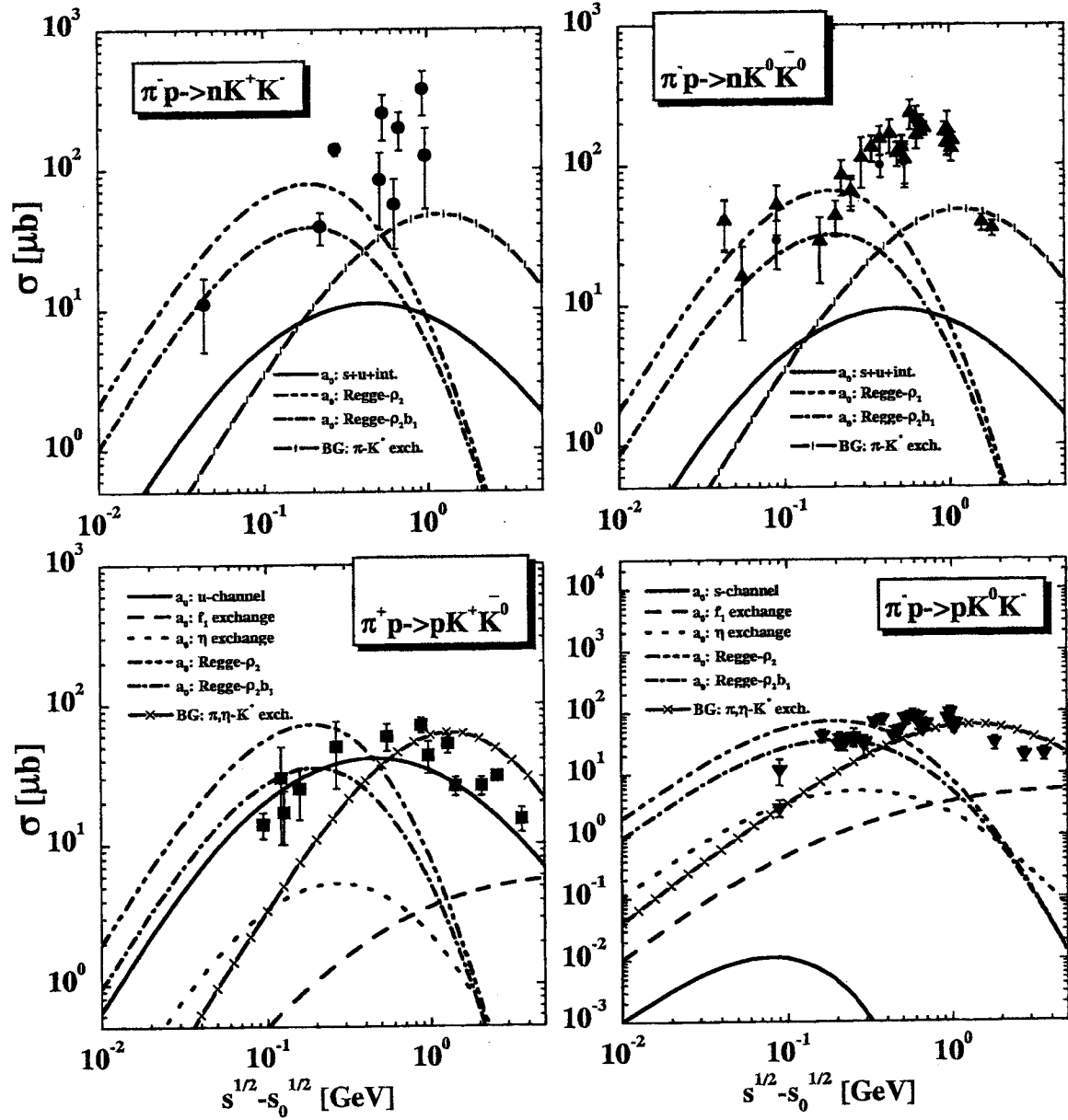
$$\frac{d\sigma_{\text{Regge}}}{dt}(\pi^- p \rightarrow a_0^- p) = \frac{1}{2} \frac{d\sigma_{\text{Regge}}}{dt}(\pi^- p \rightarrow a_0^0 n).$$



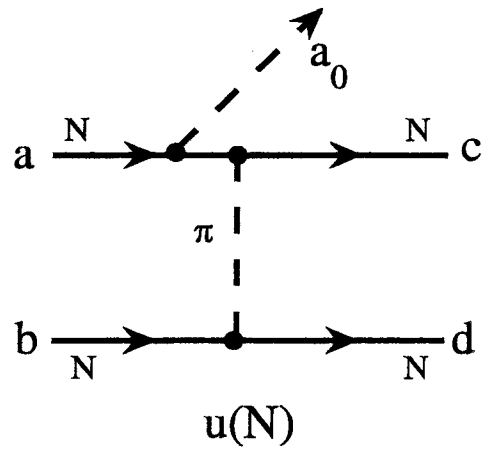
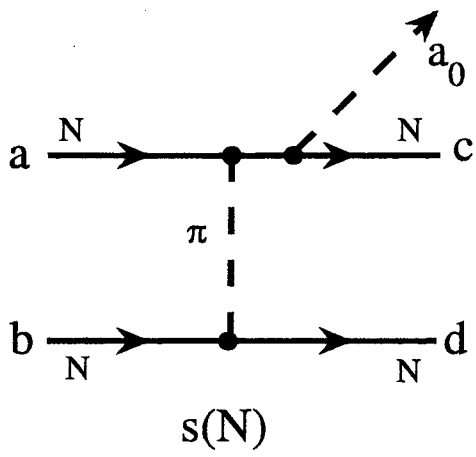
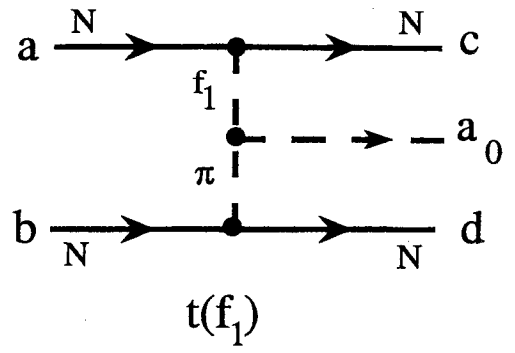
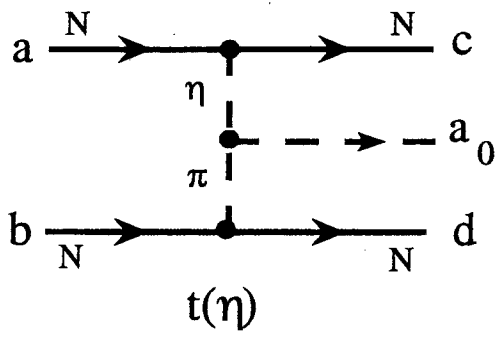
By E. Bratkovskaya et al., 2000

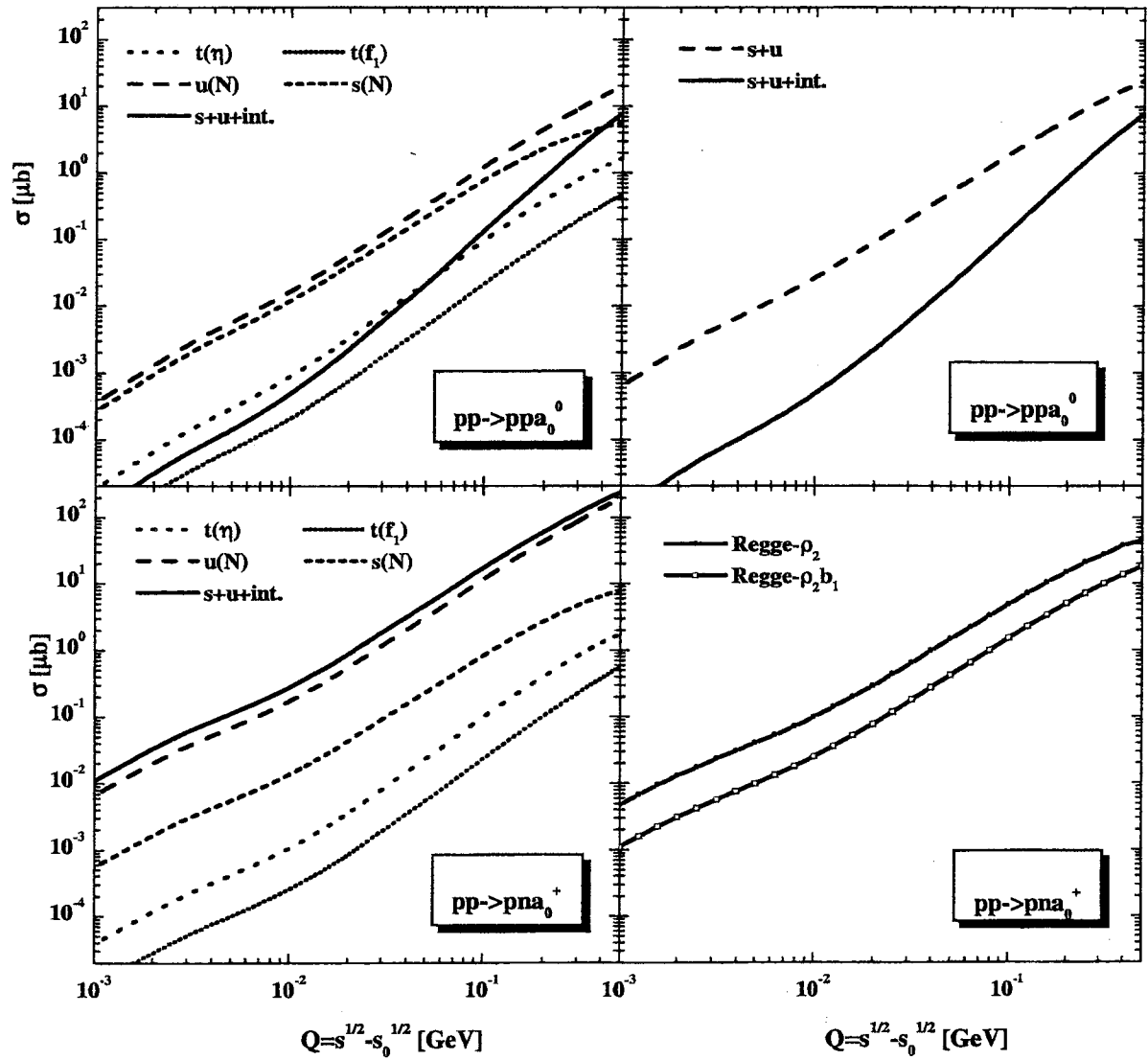


By E. Bratkovskaya et al., 2000

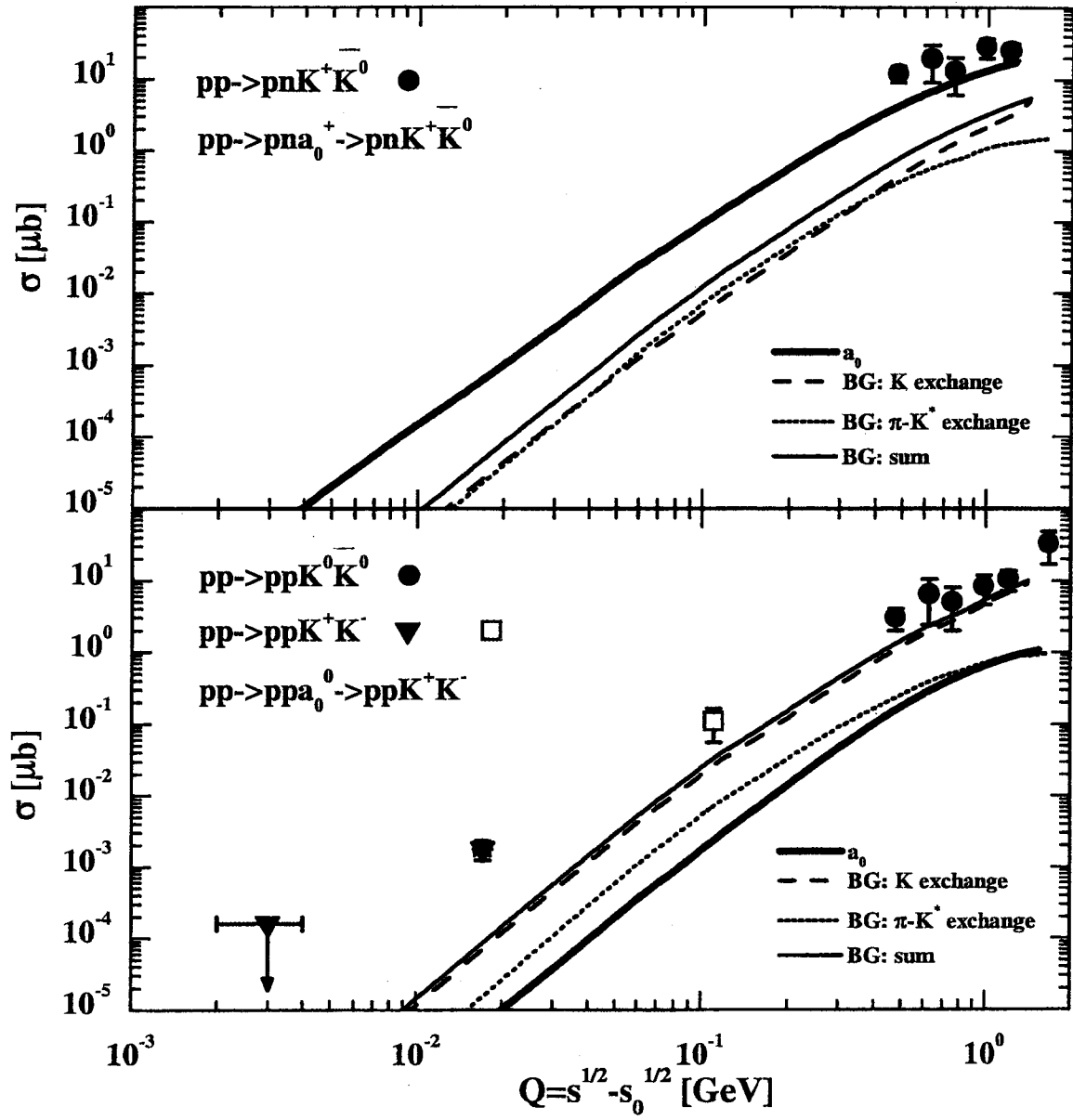


By E. Bratkovskaya, V. Grishina et al.,
2002



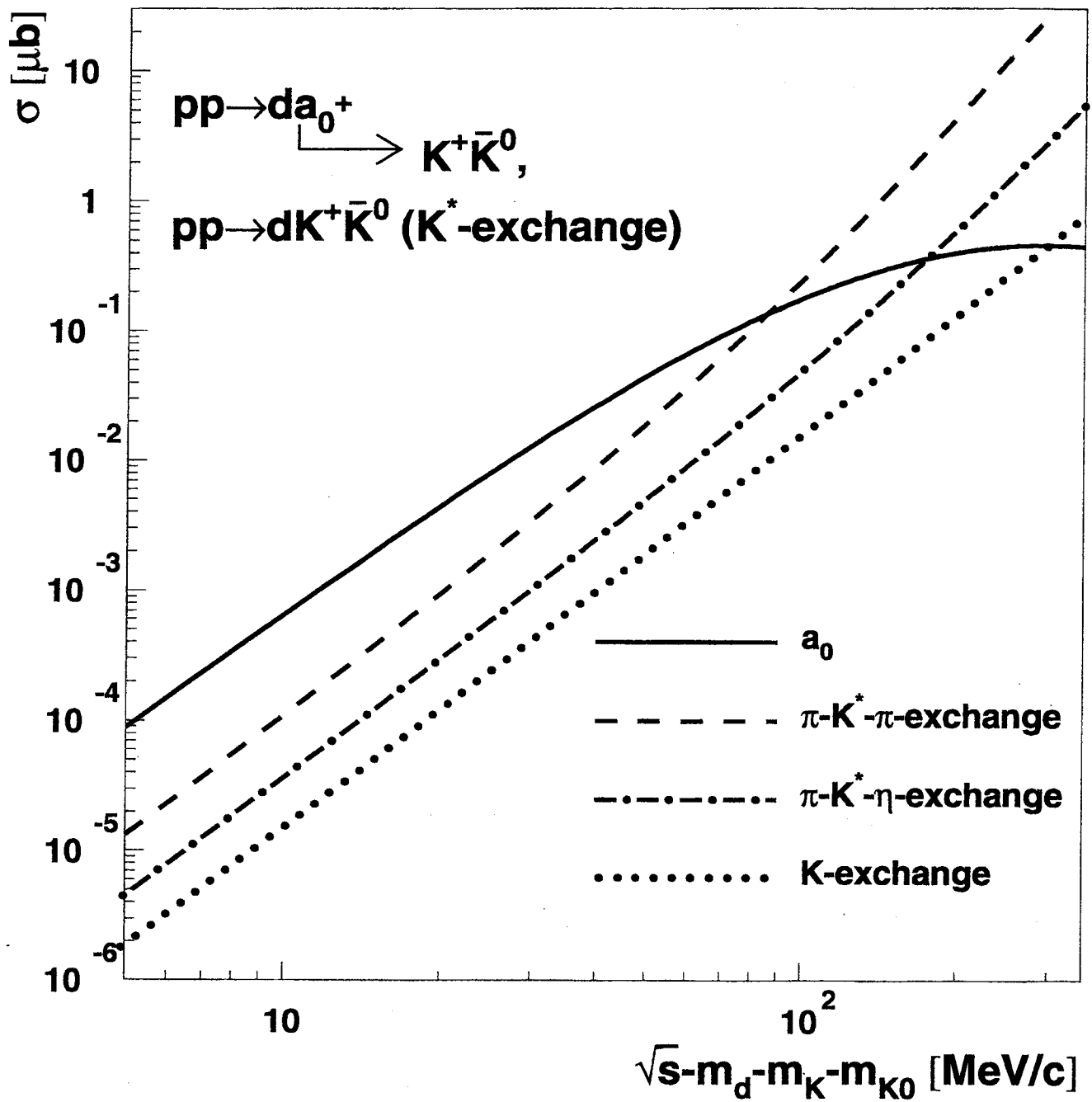


By E. Bratkovskaya, V. Grishina et al.
2001

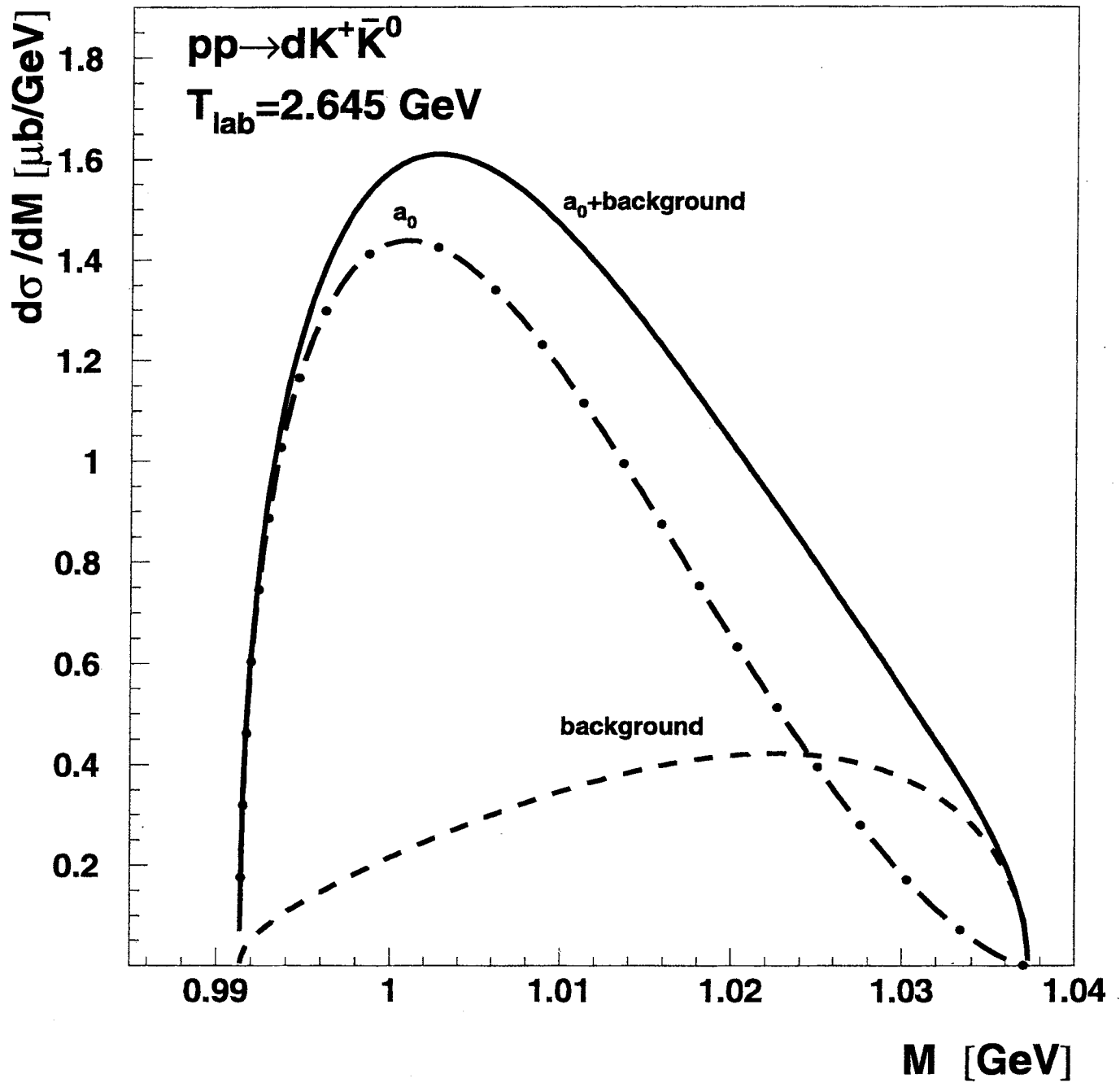


By E. Bratkovskaya, V. Grishina et al.

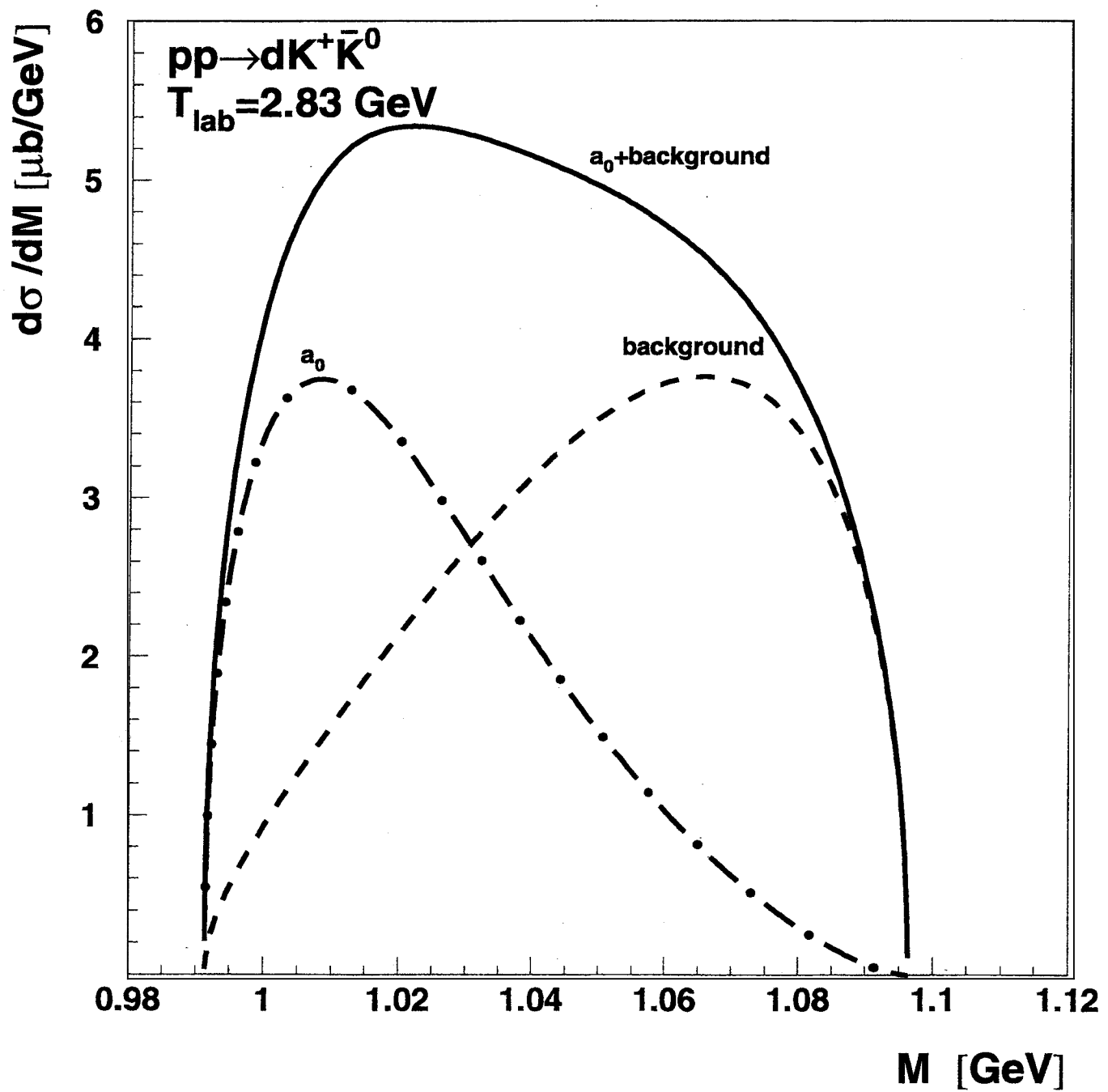
2002



By V. Grishina, L. Kondratyuk et al.
 2002



By V. Grishina, L. Kondratyuk et al.
 2002



By V. Grishina, L. Kondratyuk et al.
 2002

Conclusions

1. For the $pp \rightarrow dK^+\bar{K}^0$ reaction the background might give some contribution at

$$Q \gtrsim 100 \text{ MeV}$$

and is mainly related to the $K\bar{K}$ P-wave state

2. at $Q \lesssim 60 \text{ MeV}$

the background is small

Remarks on Meson Production in NN Collisions

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With the advent of new accelerator technology measurements with very high accuracy became possible for meson production close to threshold. This improvement opens the possibility for the investigation of a lot of interesting physics phenomena. Unfortunately, the theoretical understanding of the production operator as well as the initial state interaction is far from complete. On the other hand, for small excess energies it is still possible to extract interesting information from meson production reactions. This talk tries to present an overview over current theoretical understanding/problems.

To produce a heavy meson in a nucleon–nucleon collision demands a large kinetic energy of the incoming nucleons. For small excess energies this calls for a correspondingly large momentum transfer — the mesons are produced at rather short distances. On the other hand the nucleons can undergo elastic and inelastic scattering as they approach each other. This interaction is of a lot longer range. Thus, for a quantitative understanding of the over all scale of meson production in nucleon–nucleon collisions a inclusion of the initial state interaction is essential. Unfortunately, so far only the calculations for pion production reactions fulfill this requirement — mostly due to a lack of reliable models for nucleon–nucleon scattering at the relevant energies.

The production operator itself is equally badly understood¹. As an example I presented the current level of understanding for pion production close to threshold. For this reaction a complete set even of double polarization observables for both neutral as well as charged pion production is available. At present, the only phenomenological model available is able to predict the data on π^+ production very well, whereas it fails badly for the production of π^0 . Effective field theory was used to give an understanding for this difference. This discrepancy makes it difficult to argue what might be the most significant class of mechanisms for the production of heavier mesons.

However, the situation is not as bad as it might seem. In contrast to initial state interaction and production operator, that are expected to vary on a scale of the initial momentum, the final state interaction amongst the outgoing mesons and baryons should be controlled by the typical final momentum. Thus, it is sensible to assume the energy dependence induced by initial state interaction and production operator to be negligible compared to that stemming from the final state interactions — at least as long as the excess energy stays low. This idea allows a construction of the complete transition amplitude in terms of the possible spin structures. The number of terms appearing stays low, as long as the number of relevant partial waves stays low.

As an example possibilities to extract information on $f_0 - a_0$ mixing were discussed. After a short introduction, highlighting the difficulties to infer the nature of the resonances from experiment directly, recent results for the expected signal from the mixing on the analyzing power and the differential cross section were presented. Obviously, in this kind of an approach the transition amplitude cannot be determined theoretically, but has to be extracted from experiment. This observation makes the use of polarization essential, if the strength of the mixing is to be extracted.

¹The initial state interaction is separated from the production operator through the so called last cut lemma: every interaction that happens before the last two nucleon cut is called initial state interaction. Thus, any intermediate state after this cut contains at least one meson in addition to the two baryons.

REMARKS ON MESON PROD. IN NN COLL.

C. HANHART

FZ-JÜLICH

IN COLLABORATIONS WITH

J. HAIDENBAUER

A.E. KUDRYAUTSEV

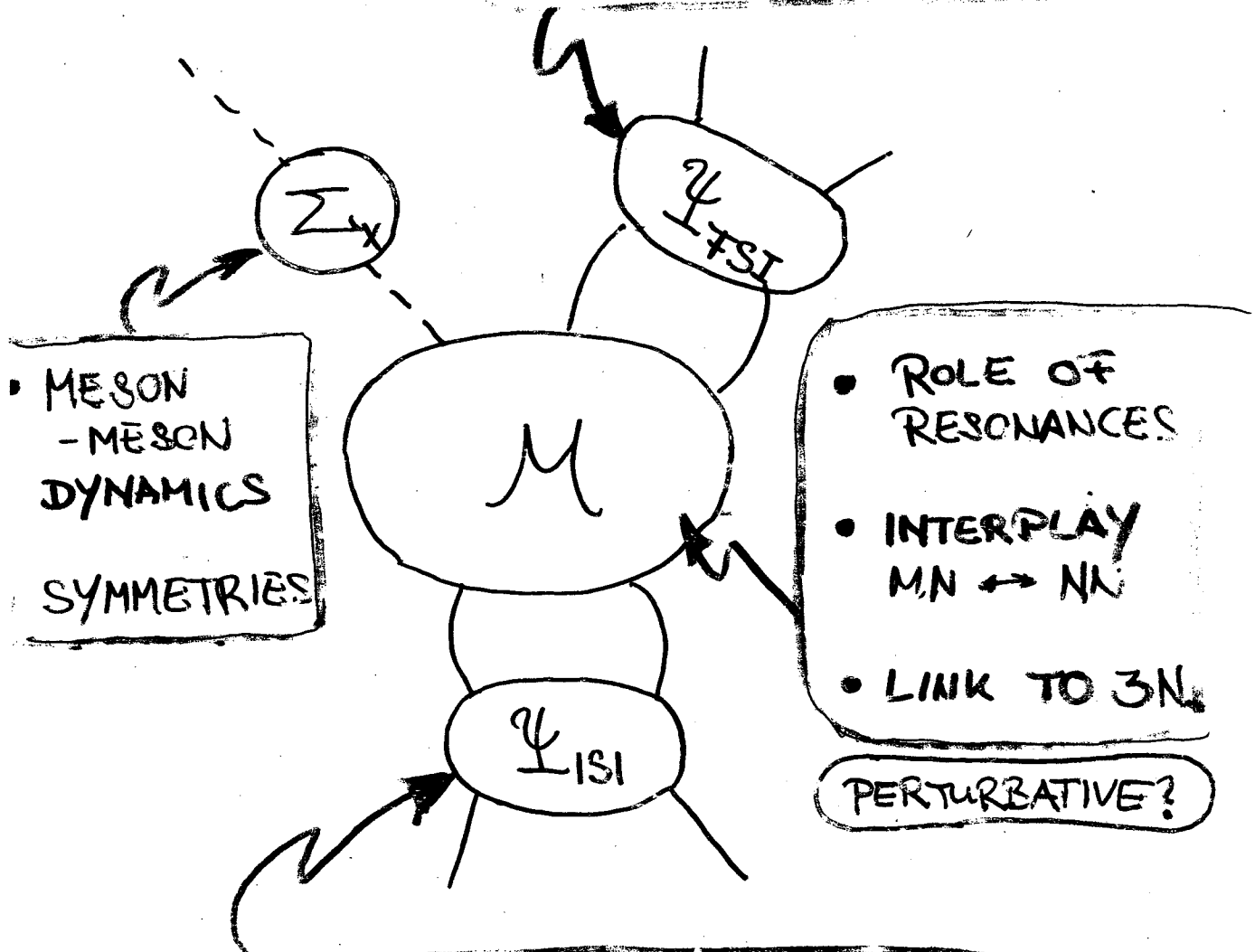
V.E. TARASOV

J. SPETH

CONCENTRATE ON $NN \rightarrow NN\pi$

NON-PER-
TURBATIVE

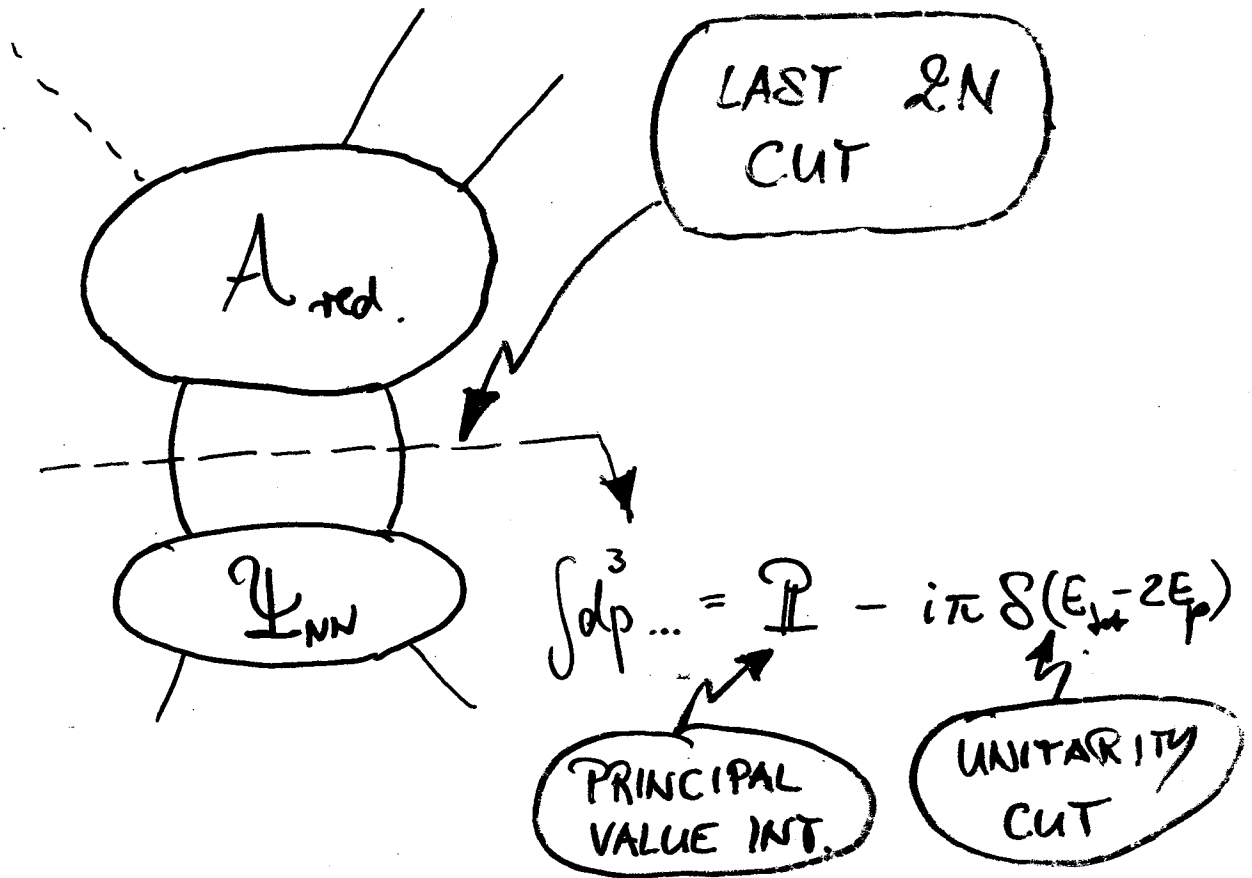
- STUDY OF 2 BARYON SYS. OTHERWISE HARD TO GET (e.g. YN)



- "TRUE" INITIAL CURRENT REDUCED DUE TO ELASTIC & INELASTIC SCATTERING
- UNITARITY COMBINES $NN \rightarrow NN$ & $NN \rightarrow NN\pi$

THE ISI (INITIAL STATE INT.)

(C.H. & K. NAKAYAMA, PLB 454 (1999) 176)



PRINCIPAL VALUE PART:

- MODEL DEPENDENT
- $\rightarrow 0$ for $s \rightarrow \infty$

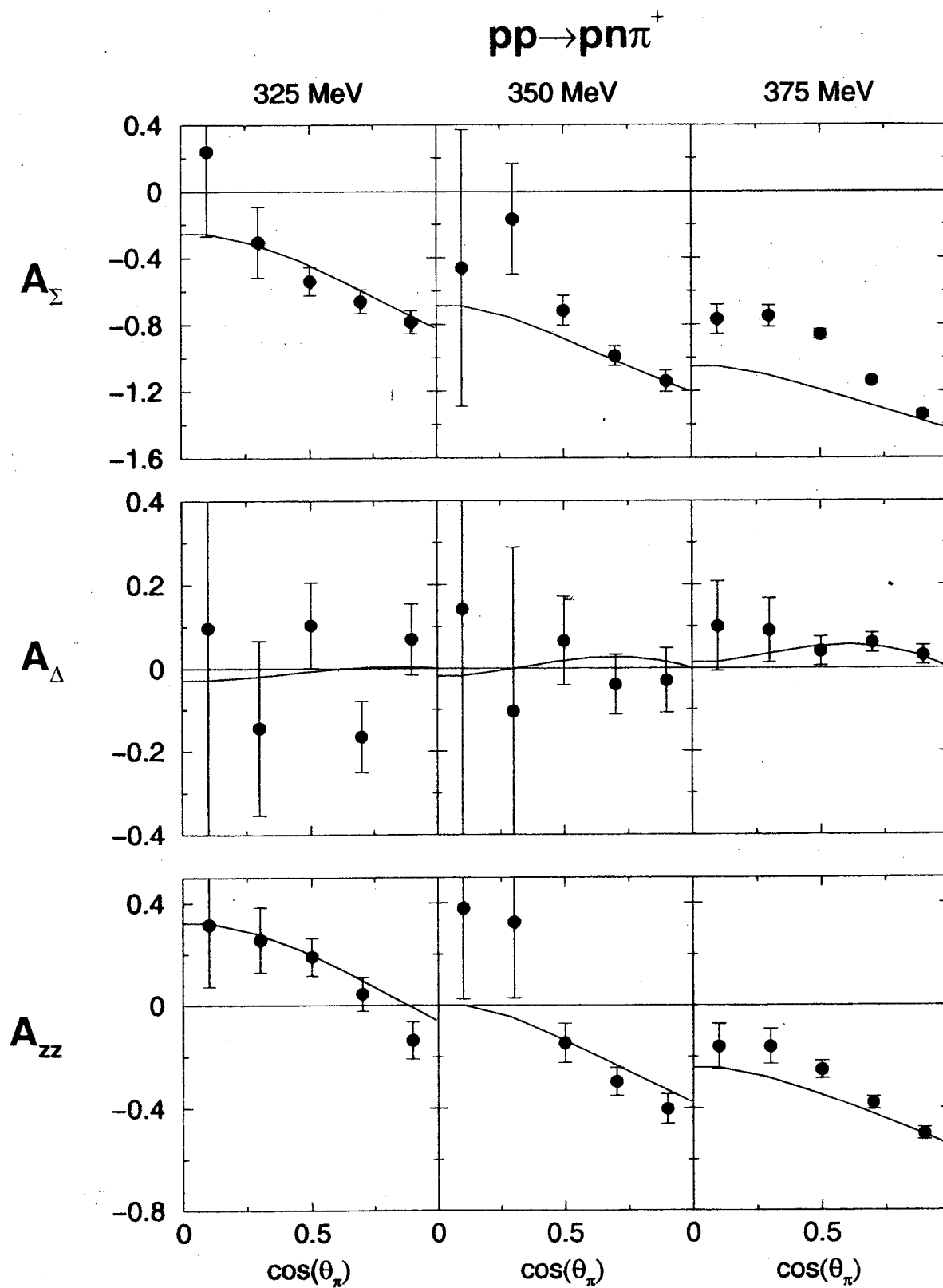
UNITARITY CUT

- FIXED BY NN SCATTERING

- $$\lambda_{PW} = \frac{1}{2} e^{i\delta_{PW}} [\gamma_{PW} e^{i\delta_{PW}} + e^{-i\delta_{PW}}]$$

IMPORTANT FOR POL. OBS. !

DATA: W.W. DAHNICK, PRC (2001)
 CALC: C.H. et al., PRC 61 (2000) 064008

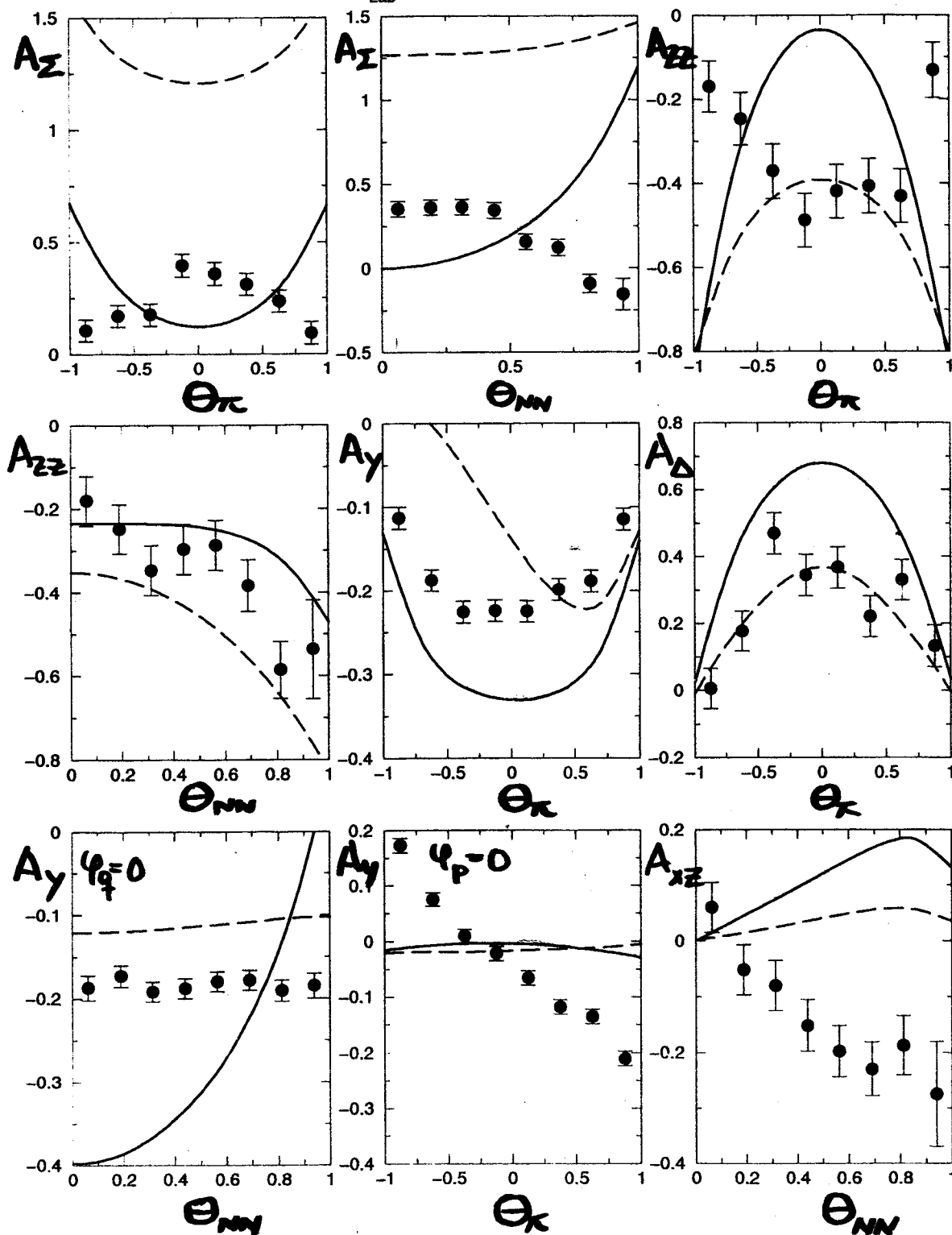


SOME REPRESENTATIVE RESULTS:

— FULL MODEL — NO Δ $\pm$ H.G. MEYER ET AL.
 PRC 63 064002 (2001)

$pp \rightarrow pp\pi^0$

$T_{\text{Lab}} = 375 \text{ MeV } (\eta=0.83)$



RESULTS SIMILAR TO OSAKA MODEL

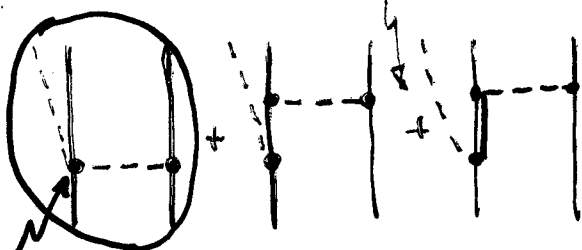
NOW

DESTRUCTIVE

RESULTS (SO FAR WITHOUT DISTORTIONS)

LO

WT TERM

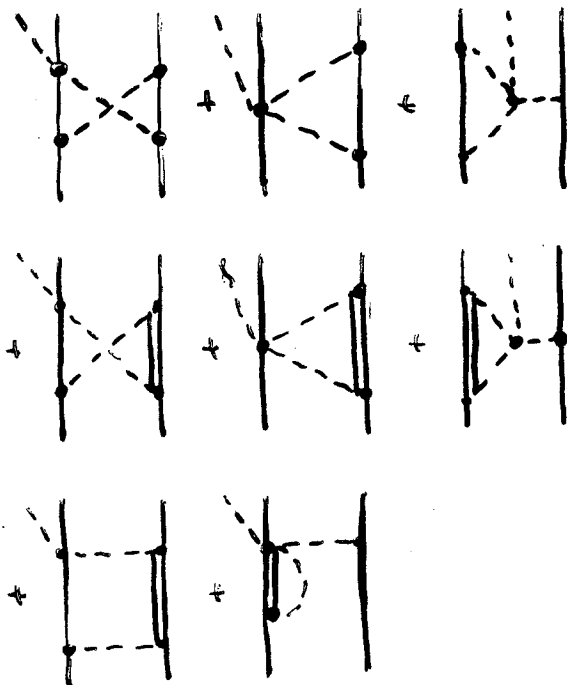


CONTRIBUTES TO π^+ ONLY

$$\approx WT = -\frac{g_A}{2M f_\pi^3} P$$

$$\approx \frac{1}{f_\pi^3} \chi$$

NLO

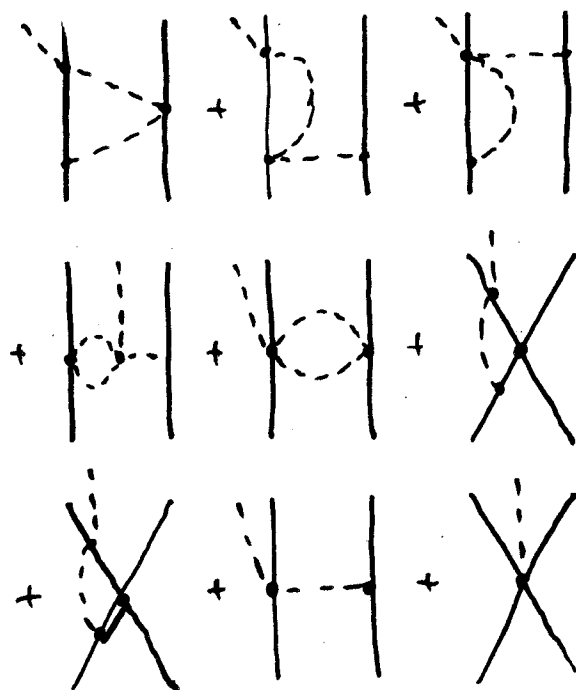


LARGE CANCELLATIONS

LOOPS SCALE AS

$$\frac{1}{f_\pi^3} \frac{P^2}{128 F_\pi^2} \sim \frac{1}{f_\pi^3} \chi^2$$

N²LO



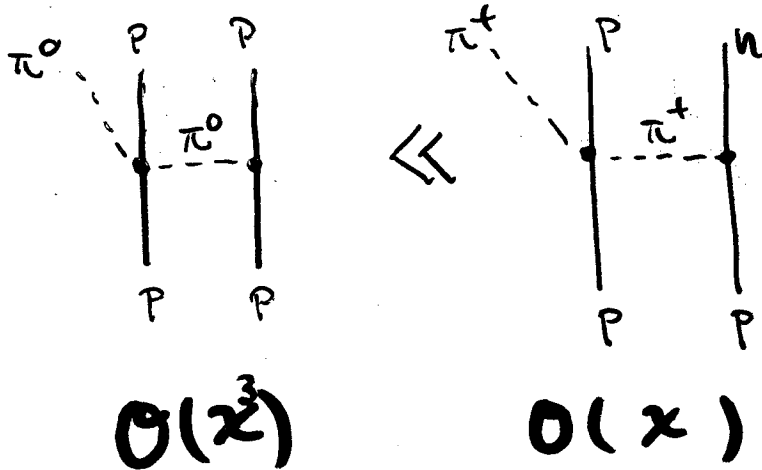
NOT YET DONE....

THUS:

- π^+ WORKS WELL
- WE UNDERSTAND WHY π^0 DOES NOT WORK

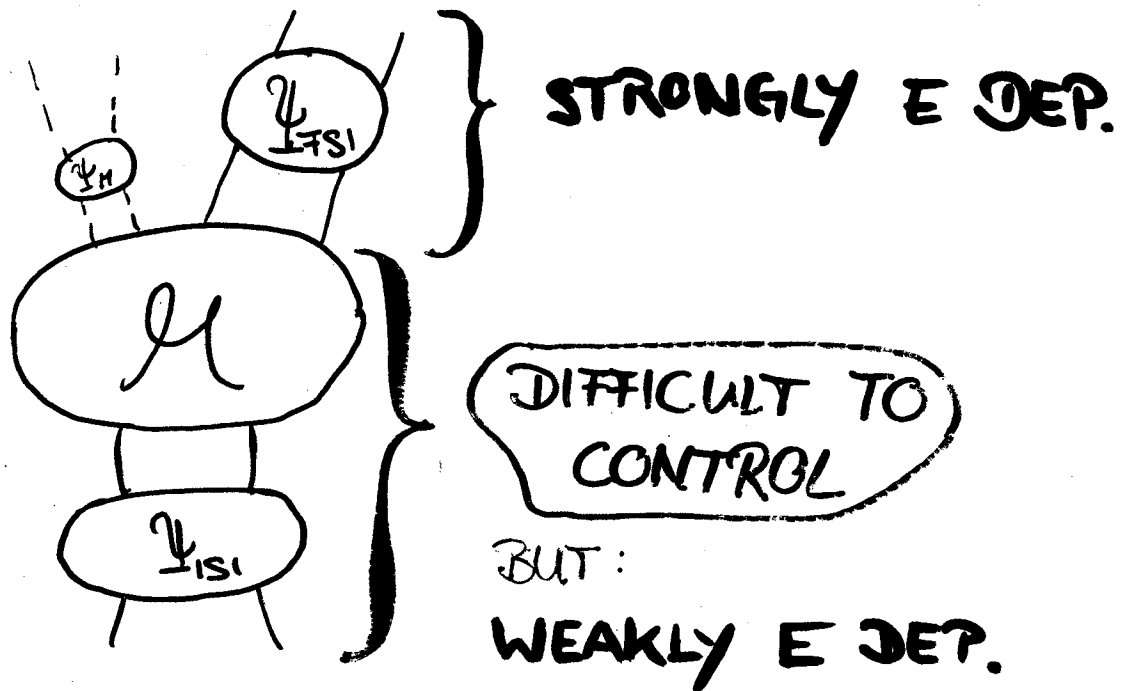
HEAVIER MESONS ?

NOTE: π^0 EXCEPTION DUE TO
CHIRAL SUPPRESSION OF
 THE RESCATTERING TERM!



$\Rightarrow \pi^+$ MIGHT BE THE "NORMAL" ONE

THUS: (K. WATSON, PR 88 (1952.) 1163)



EVEN WITH LIMITED KNOWLEDGE
ABOUT H & ψ_{ISI} WE CAN EXTRACT
INFORMATION ABOUT

**INTERACTIONS OF OUTGOING
PARTICLES !**

FSI

WE CONCENTRATE ON

$$NN \rightarrow d(\pi\eta, K\bar{K}, \pi\pi)$$

TO STUDY SCALAR RESONANCES

$$f_0 / a_0$$

NOTE: THERE IS **NO** UNIQUE
SIGNAL KNOWN THAT PROVES
THE NATURE OF THE RES.

CONTRARY TO MANY CLAIMS!

SO FAR ALL EXPERIMENTS COULD
BE DESCRIBED BY BOTH

• **DYNAMICAL** $\leftarrow$ MOLECULE/CUSP

AND • GENUINE (WITH LARGE $K\bar{K}$ COMPONENT
RESONANCES.

REASON:

ASSUME: THERE IS A GENUINE $q\bar{q}$
POLE $\Rightarrow$

$$T(s) = g^+(s) \frac{1}{s - m_0^2 - \Sigma(s)} g(s) + T^{NP}(s)$$

$$=: \tilde{g}^+(s) \frac{1}{s - m_R^2 + i m_R \Gamma(s)} \tilde{g}(s) + \tilde{T}^{NP}(s)$$

$$\text{where } \Sigma(m_R^2) = m_R^2 - m_0^2 - i m_R \Gamma(m_R^2)$$

ASSUME: THERE IS **NO** GENUINE POLE,
BUT A DYNAMICAL SINGULARITY $\Rightarrow$

$$T(s) = V(s) + [VG T](s)$$

$$\Rightarrow T(s) = [1 - VG]^{-1} V(s)$$

LAURENT EXPANSION $\nearrow$

$$=: \tilde{g}^+(s) \frac{1}{s - m_R^2 + i m_R \Gamma(s)} \tilde{g}(s) + \tilde{T}^{NP}(s)$$

$\nwarrow$ QUASI PARTICLE

BUT:

PHYSICS OF THE RESONANCE IS
ENCODED IN THE **EFFECTIVE
PARAMETERS!**

FOR THE DEUTERON THIS WAS
SHOWN BY WEINBERG

IN THE PRESENCE OF INELASTIC
CHANNELS NO QUANTITATIVE
ARGUMENT EXISTS

IDEA:

$$|\text{PHYSICAL STATE}\rangle = \sqrt{Z} |\text{BARE}\rangle + \sqrt{1-Z} |X_1, X_2\rangle$$

$\leadsto Z \rightarrow 0 \Rightarrow$ SINGUL. DYNAMICAL
(BUT Z NOT WELL DEFINED IN THE
PRESENCE OF INELASTICITIES)

a_0 / f_0 MIXING

WE WORK IN THE QUASI-PARTICLE
PICTURE

IMPORTANT OBSERVATIONS:

- $m_{a_0} \approx m_{f_0}$
- $\Gamma_{a_0} \approx \Gamma_{f_0}$

$\Rightarrow$ AS LONG AS WE ARE CLOSE TO
THE RESONANCE POSITION

MIXING IN EXIT CHANNEL
SHOULD DOMINATE

c.f. $\pi-\eta$ MIXING: $m_\eta \gg m_\pi$

$S-W$ MIXING: $\Gamma_\omega \ll \Gamma_\rho$

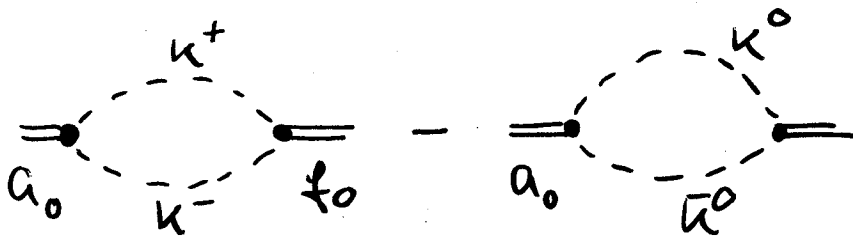
CAN BE
CHECKED!

$\Rightarrow$ WE HAVE TO DEAL WITH OVER-
LAPPING RESONANCES

MIXING MECHANISMS:

(N.N. ACHASOV et al. PLB 88 (1979) 367)

a) K MASS DIFFERENCE:

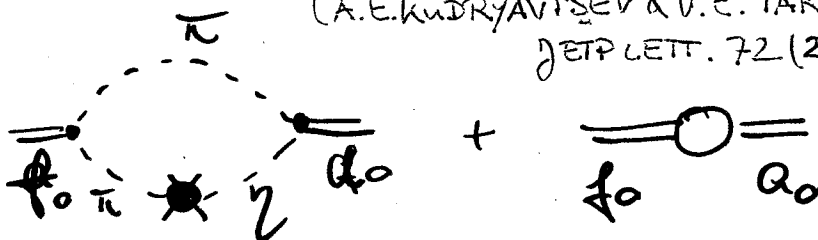


EFFECT LOCALIZED AROUND

$$2 \frac{1}{2} (m_{K^+} + m_{K^0}) \pm (m_{K^+} - m_{K^0})$$

b) $\pi\eta$ MIXING & DIRECT TRANSITION

(A.E. KUDRYAVTSEV & V.E. TARASOV
JETP LETT. 72 (2000) 401)



(ROUGHLY) ENERGY INDEPENDENT

$\Rightarrow$ IT IS IMPORTANT TO INVESTIGATE ALL QUANTITIES

AS $\frac{d}{dm_{\pi\eta}}$ WITH FINE BINNING!

IDEA: (V.YU. GRISHINA et al., PLB 521(2001)217)

WRITE DOWN MOST GENERAL
AMPLITUDE TO PRODUCE ℓ_0/a_0

IN LOWEST PW ALLOWED $\Rightarrow$
AMPLITUDES ARE ASSUMED CONST.
CORRECTIONS SHOULD BE

SUPPRESSED BY $\left(\frac{|k|}{|p|}\right)^2$

k: RELATIVE MOMENTUM - ℓ_0/a_0 to α

p: INITIAL MOMENTUM

$\sim$ TYPICAL MOMENTUM TRANSFER

HIGHER PARTIAL WAVES CAN
BE CONTROLLED BY DIFFERENTIAL
OBSERVABLES...

WE LOOK AT $pn \rightarrow d(\pi\gamma)$

WE RESTRICT OURSELVES TO

- $(\pi\gamma)$ S-WAVE $\rightarrow$ CHANNEL WITH RESONANCES
- $d(\pi\gamma)$ max. in p-WAVE

FINAL STATE

$(^3S_1, ^3D_1)P$

INITIAL STATE

3P_0
 3P_1
 3P_2
 3F_2

$T_{NN}^i = 1$

4 COMPLEX
PRIMARY PROD.
AMPLITUDES

SHOULD
BE
IRRELEVANT

1P_1

$T_{NN}^i = 0$

$(^3S_1, ^3D_1)S$

3S_1
 3D_1

$T_{NN}^i = 0$

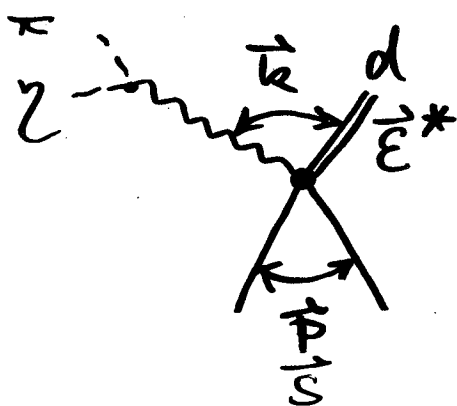
2 COMPLEX
PRIMARY PROD.
AMPLITUDES

GENERAL STRUCTURE: (A.E. KUDRYAVTSEV et al. nucl-th/0203034)

FORM SCALARS FROM $\vec{p}, \vec{s}, \vec{k}, \vec{E}^*$

$$M_1 = a(\vec{p} \cdot \vec{s})(\vec{k} \cdot \vec{E}^*) + b(\vec{p} \cdot \vec{k})(\vec{s} \cdot \vec{E}^*) + c(\vec{k} \cdot \vec{s})(\vec{p} \cdot \vec{E}^*) + d(\vec{p} \cdot \vec{s})(\vec{p} \cdot \vec{E}^*)(\vec{k} \cdot \vec{p})$$

↑
PROP. OF ISVECTOR

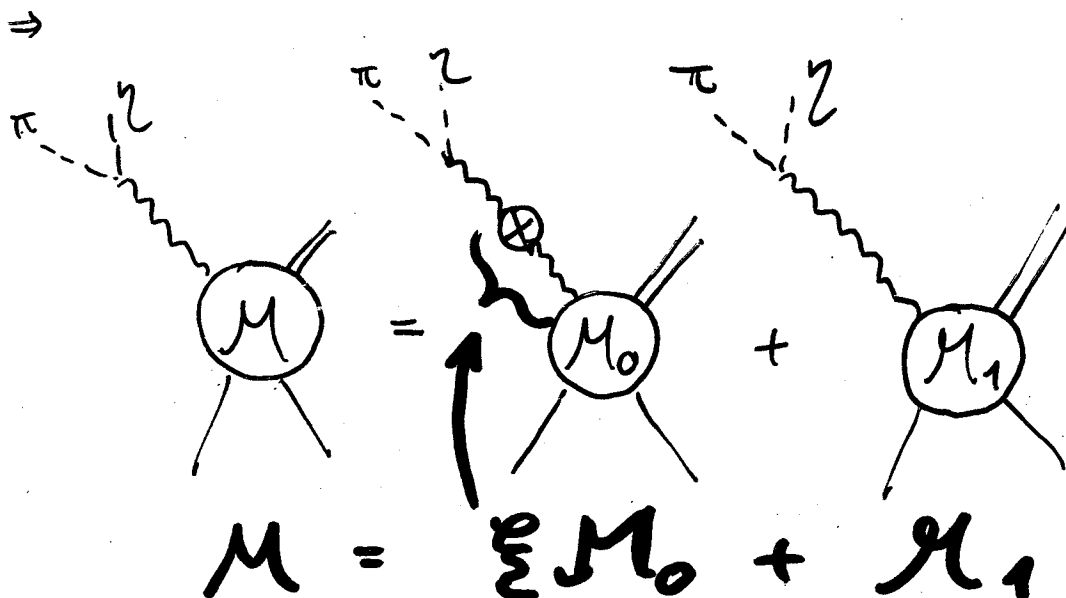


$$\vec{s} = \phi_1^T \sigma_2 \vec{\sigma} \phi_2$$

= SPIN OF INITIAL NUCLEONS

FORM SCALARS FROM $\vec{p}, \vec{s}, \vec{E}^*$

$$M_0 = f(\vec{s} \cdot \vec{E}^*) + g(\vec{p} \cdot \vec{s})(\vec{p} \cdot \vec{E}^*)$$



NOW WE ALLOW FOR A POL. OF THE NUCLEON $\Rightarrow$

$$\phi_i \phi_i^\dagger = (1 + \vec{r}_i \cdot \vec{E}) \vec{k}_i$$

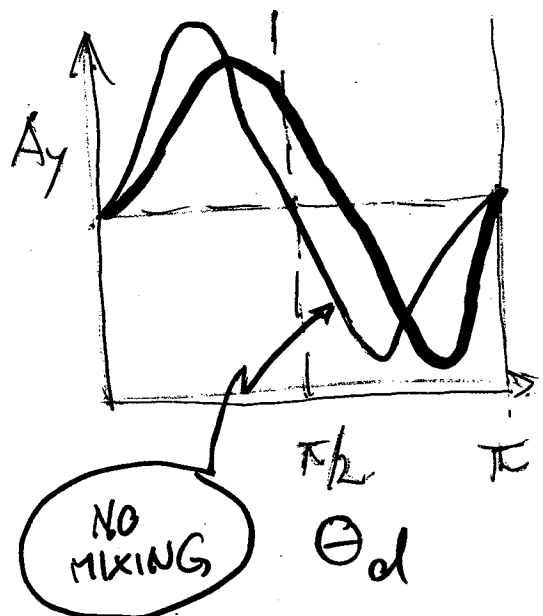
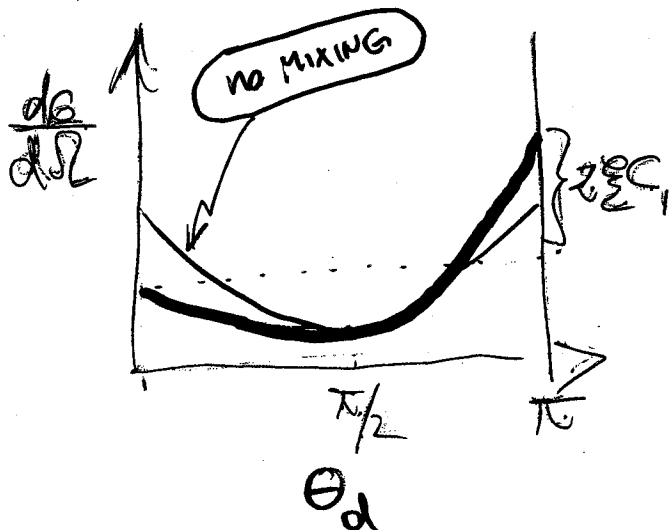
THUS WE GET:

Choose this along
X axis

$$|M|^2 = C_0 + \sum C_1 \cos \Theta + C_2 \cos^2 \Theta + \sum \sin \Theta \sin \Theta' \left(\sum D_0 + D_1 \cos \Theta \right)$$

ANGULAR ASSYM.
IN UNPOLARIZED
DIFFERENTIAL
CROSS SECTION

SHIFT OF ZERO
IN ANALYSING
POWER



- THE COEFFICIENTS DEPEND ON DIFFERENT AMPLITUDES.
- BOTH SIGNAL SHOULD STRONGLY DEPEND ON THE MASS SLICE SELECTED

COMBINING THESE POINTS $\Rightarrow$

MEASURING BOTH A_γ & $d\sigma/d\Omega$

ALLOWS TO CHECK, IF MIXING

OCCURS IN PROPAGATOR ONLY!

WHAT HAPPENS AT HIGHER ENERGIES ?

→ MORE PW. WILL CONTRIBUTE

• $\frac{d\sigma}{d\Omega}$: d HAS $T=0$

⇒ FOR $pn \rightarrow d(\pi\eta)$

$T_i = 1$ FOR CHARGE
SYMMETRIC SITUATION

⇒ FORWARD - BACKWARD
ASSYM. $\Leftrightarrow$ CSB

HOWEVER: FOR $pn \rightarrow d K \bar{K}$

$T_i = 0$ or 1 FOR CHARGE
SYM. SITUATION

⇒ THERE WILL BE
FORWARD - BACKWARD
ASSYM. IN ANY CASE

- A_y : FIRST RESTRICT TO
MESONS IN S-WAVE

FOR $p_n \rightarrow \pi n$

$\Rightarrow$ TERMS THAT CONTAIN HIGHER
P.W. COULD DO HARM, BUT

$$A_y(\pi/2) \neq 0 \iff \text{CSB}$$

AGAIN: NOT TRUE FOR $K\bar{K}$
CHANNEL

NOTE: $(\pi\eta)$ P-WAVE PRESENTLY
UNDER INVESTIGATION

(MEIPNER, OLLER, OSET (2000): THIS
P.W. IS NEGLECTIBLE)

SUMMARY

- CONSTRUCTION OF PRODUCTION AMPLITUDE EXTREMELY DIFFICULT
- FOR SMALL EXCESS ENERGIES FINAL STATE INTERACTIONS CAN STILL BE STUDIED
- THE REACTION $pn \rightarrow d(\pi\gamma)$ ALLOWS EXTRACTION OF m -DEP. OF f_0 - a_0 MIXING AMPLITUDE
- POLARIZATION NECESSARY FOR DEFINITIVE CONCLUSIONS

Summary Talk
of the 3rd ANKE Workshop on
Scalar Meson Production
at ANKE/COSY

H. Ströher

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Forschungszentrum Jülich
52425 Jülich
Germany

Two experimental runs, aiming to identify and investigate the production of a_0^+ mesons in proton-proton collisions at ANKE, have been performed in 2001 (at $T_p = 2.65$ GeV) and 2002 (at $T_p = 2.83$ GeV). The idea was to exploit the reaction $pp \rightarrow dX$ with identification of the fast forward moving deuteron and to search for a_0^+ production in the two main decay channels (with a K^+ or a π^+ as a tag) simultaneously.

- It is an important achievement that in both decay channels a signal has been seen which is consistent with a_0^+ production. However, much work lies ahead in order to prove this assertion in more detail.
- After analysis of part of the low-energy run, it became clear that for a detailed investigation of the a_0^+ meson, COSY would have to deliver a higher beam energy to extend the range of the missing mass spectrum. This request to the accelerator crew was actually fulfilled for the second measurement, a significant achievement for COSY, which we all appreciate.
- The program at ANKE to investigate scalar mesons and in particular the $a_0/f_0(980)$ was from the very beginning accompanied by theory groups, which help and strengthen this effort significantly; it is clear to everyone that only such a close cooperation between theory and experiment will lead to progress in the scalar meson sector. Therefore, I would also like to emphasize and acknowledge in particular the efforts of the people from theory.
- Finally, I would like to mention that our understanding always was that those two experiments are only the beginning and part of a larger program to study not only the positively charged a_0 , but also the two other charge states and the isospin $I = 0$ state (including mixing) for all possible channels on both nucleons. This program will help to keep us busy for the next years to come, and I am looking forward to the experimental and theoretical results.
- Last, but not the least I want to thank those speakers of the workshop, who were educating us in related fields by giving talks on their current fields of research, as well as to the great local organization.

