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
Preface

The workshop on "Scalar Meson Production at ANKE/COSY" was held at the Madralin 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 These presentations focused on yet unpublished data from ANKE, on possible theoretical interpretations of these data, and on future measurements at ANKE.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 Madralin 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, Jü-3801, ISSN 0944-2952, Editors M.Büchner and V.Kleber (July 2000)
² Berichte des Forschungszentrums Jülich, Jü-3922, ISSN 0944-2952, Editors M.Büchner, V.Kleber, P.Kulessa and M.Nekipelov (Nov. 2001)
³ WTZ-POL-99/007, WTZ-POL-01/015
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Wednesday, May 22

Chairperson: H. Ströher

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 → dK⁺K⁰ Channel
11:30 P. Fedorets (ITEP, FZJ) Status of Data Analysis: pp → dπ⁺η 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 a₀⁺ Structures in the dK⁺K⁰ Dalitz Plot
16:30 V. Koptev (PNPI) Heavy Hyperons at ANKE

Thursday, May 23

M. Büscher

09:00 V. Grishina (ITEP) a₀(980) Resonance Production and Nonresonant Background in the Reaction pp → dK⁺K⁰ 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
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Photos taken during the workshop
Investigation of Light Scalar Mesons at ANKE

M. Büscher

Institut für Kernphysik
Forschungszentrum Jülich
52425 Jülich
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 $pp, \pi^- p$ and $p(450 GeV)p$ 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 $pp \to dK^+K^0$ and $pp \to d\pi^+\eta$ 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 $pp \to dP_1P_2$ (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 $\eta$ 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 $K^+K^0$ 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 $pn \to da_0^0/f_0$ 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].

[4] V. Kleber, contribution to this workshop.
[7] V. Grishina, contribution to this workshop.
[8] C. Hanhart, contribution to this workshop.
3\textsuperscript{rd} ANKE Workshop on $a_0$ Physics
May, 22/23, 2002
Swierk, Poland

• Thanks to the local organizers !!

• Proceedings
  Copies of transparencies
  Written contributions (~1 page, LaTeX)
  List of participants

• Agenda

• Goals (M.B.'s viewpoint)
  Interpretation of the data on $pp \rightarrow d a_0^+ $
  Ideas for further experiments like $a_0^0 / f_0$ ?
  .....and..... (input from YOU)?

This talk:

• Short overview over $a_i$ experiments with ANKE
Scalar mesons above and below 1 GeV

Frank E. Close¹

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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.

¹e-mail: F.Close@physics.ox.ac.uk
²e-mail: nils.tornqvist@helsinki.fi
Overview of the available data on $a_0$ production.

<table>
<thead>
<tr>
<th>Initial state</th>
<th>Detected $a_0$ decay</th>
<th>$m_{a_0}$ (MeV)</th>
<th>$\Gamma_{a_0}$ (MeV)</th>
<th>$\Gamma(K\bar{K}/\pi\eta)$</th>
<th>Ref.</th>
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<tbody>
<tr>
<td>$p(450 \text{ GeV})p$</td>
<td>$\pi\eta$</td>
<td>$988 \pm 8$</td>
<td>$61 \pm 19$</td>
<td>$0.166^{+0.01}_{-0.02}$ *</td>
<td>[8]</td>
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<tr>
<td>$\bar{p}p$</td>
<td>$\pi\eta$</td>
<td>$984.45^{+1.23}_{-0.34}$</td>
<td>$54.21^{+0.34}_{-0.12}$</td>
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<td>[4]</td>
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<td>$\bar{p}p$</td>
<td>$K\bar{K}$</td>
<td>$982 \pm 3$</td>
<td>$92 \pm 8$</td>
<td>$0.23 \pm 0.05**$</td>
<td>[5]</td>
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<td>$\bar{p}p$</td>
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<td>$975 \pm 15$</td>
<td>$65 \pm 10$</td>
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<td>[6]</td>
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<td>$\pi^-p$</td>
<td>$\pi\eta$</td>
<td>$993.1 \pm 2.1$</td>
<td>$71 \pm 7$</td>
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<td>[7]</td>
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*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

$p(2.65...2.83 \, \text{GeV})p \rightarrow da_0^+$

- Deuteron in final state → (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

H$_2$ cluster target (Univ. Münster)

$\Delta t$, (ch.)

$p$, $d$

$p \rightarrow d K^+ (\pi^+) X$ events

M. Büscher, Φ 2002
Spectrometer ANKE

D1

1m

TOF-start
MWPC 1,2

#1

110 MeV/c

D2

Target (foils)

D3

Forward detectors

Range telescopes with TOF-stop, ΔE, ...

D1

COSY beam

Backward detectors

1 m

Range telescopes with TOF-stop, ΔE, ...

K⁺ detection

Side wall counters

#15

525 MeV/c

NIM A 462, 364 (2001)
NIM A 481, 378 (2002)
**COSY working scheme 2001**

**January**

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**May**

**June**

**July**

**August**

**September**

**October**

**November**

**December**

- **User Operation**
- **Machine Development**
- **Maintenance**

May 3, 2001

M. Büscher
m.buescher@fz-juelich.de
### COSY beam-time schedule 2002

#### January

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#### February

#### March

#### April

#### May

#### June

#### July

#### August

#### September

#### October

#### November

#### December

- **User Operation**
- **Machine Development**
- **Maintenance**
- **Ring access**

*May 13, 2002*

M. Büscher (m.buescher@fz-juelich.de)
$a^+_0 (980)$ mesons at ANKE

$\text{mm(d,meson), (MeV/c}^2\text{)}$

$\text{mm(d), (MeV/c}^2\text{)}$

$\text{COSY limit 2001}$

$\text{K}^+\text{K}^0$

$\text{V. Kleber}$

$\text{P. Fedorets}$

$\text{\pi^+ \eta}$

$\text{pp \to d K^+/\pi^+ X}$

$T = 2.65 \text{ GeV}$

$Q_{KK} = 46 \text{ MeV}$

No efficiency correction!

V. Kleber, HK 46 3

M. Büscher, Φ 2002
\( a_0^+ (980) \) production cross section

\[ \sigma_{\text{tot}} (\mu b) \]

- (50 \pm 6_{\text{STAT}} \pm 18_{\text{SYST}}) \text{ nb}
- Q=46 \text{ MeV}
- T=2.65 \text{ GeV}

\[ \sigma(pp \rightarrow da_0^+ \rightarrow dK^+K^0) = (50 \pm 6 \pm 18) \text{ nb} \]
- \approx 15\% non-resonant background

\[ \sigma(pp \rightarrow da_0^+)/\sigma(pp \rightarrow dp^+) \approx 1/6 \]
- Comparable cross sections

New data after energy increase of COSY (->2.83 GeV)
(No acceptance/efficiency corrections yet, \sim 1/6 of total statistics)

Feb./March 2002

M. Büscher, PhD 2002
Dalitz plot for the reaction
\[ p(2.65 \text{ GeV})p \rightarrow dK^+\bar{K}^0 \]

\[ m^2 (d\bar{K}^0), \text{ [GeV}^2] \]

\[ m^2 (K^+\bar{K}^0), \text{ [GeV}^2] \]

\[ \bar{K}d \text{ FSI} \]

\[ a_0^+(980) \text{ resonance} \]

\[ \text{dn/dm, arb. units} \]

\[ m(K^0d), \text{ MeV/c}^2 \]

\[ m(K^0+K^+) \]

\[ m(a_0^+) \]

\[ m(K^0\bar{K}^0), \text{ MeV/c}^2 \]

M. Büscher, Φ 2002
Status report for COSY experiment #55
“Study of $a_0(980)$ mesons at ANKE”
and
“Proposal for investigation of neutral scalar mesons $a_0/16$ with ANKE”

M. Büscher (Spokesperson), M. Hartmann, V. Kleber, R. Koch, R. Schleichert, H. Ströher
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E. L. Bratkovskaya, W. Cassing
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and the ANKE collaboration

March 16, 2001

Abstract

During two weeks of beam time in Jan./Feb. 2001, the production of $a_0^+$-mesons in the reaction $p(2.615 \text{ GeV/c})p \to d a_0^+$ has been studied at the ANKE spectrometer. About 1000 correlated $d a_0^{+} (d a_0^{*})$ events have been identified which can be interpreted in terms of $a_0(980)$-meson production followed by a decay $a_0^+ \to K^+K^0 (\to \pi^+\eta)$. 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 $pn \to d a_0^*/f_0$. 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 (\( a_0^0/\pi_0^0 \)) 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 \( 5 \) 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

![Diagram of meson transitions and decay]

- $a_0^0 \leftrightarrow f_0$ mixing
  - violates isospin symmetry
  - 'new' observable $\rightarrow$ structure of $a_0/f_0$
- distorts angular distributions
- Asymmetric analyzing power

![Graphs showing angular distributions]  
(V.Yu.Grishina et al., PLB 521, 168 (2001)  
A.E. Kudryavtsev, Ch. Hanhart et al., Preprint FZJ-KIP-TH-2002-06)

Experimental challenges

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

M.Bücher, Φ 2002
**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
- frozen-pellet target: high luminosity
- photon detector: neutral mesons, ... $dd \rightarrow ^4\text{He}\, a_0^0$

M. Büscher, Φ 2002
The reaction \( \text{dd} \rightarrow ^4\text{He} \ a_0^0 \)

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

isospin-breaking mechanism

\[ \text{isospin 'filter'} \]

- **Observation of** \( \text{dd} \rightarrow ^4\text{He} \ \pi^0 \eta \)
  
  = indication of isospin violation!

- **Needs photon detection**

- **\( p_{\text{beam}} \sim 3.7 \text{ GeV/c} \)**!

- **Possible advantage compared to** \( \text{dd} \rightarrow ^4\text{He} \ \pi^0 \)

- **\( p_{\text{beam}} \sim 3.7 \text{ GeV/c} \)**!
Status of Data Analysis:

\[ pp \rightarrow dK^+\bar{K}^0 \]

at ANKE

V. Kleber

Institut für Kernphysik
Forschungszentrum Jülich
52425 Jülich
Germany
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 $pp \rightarrow d a_0^+$.

The $a_0(980)$ is known to decay into $K\bar{K}$, $\pi\eta$ and $2\gamma$. At ANKE the deuteron and the decay $K^+$ or $\pi^+$ 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 ($m_{\text{min}}=992$ MeV) and the COSY beam energy of $T=2.65$ GeV ($m_{\text{max}}=1038$ 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 $K^0$. 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 independence 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 $\sim 600$ 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.

Status of Data Analysis:

\[ p + p \rightarrow d + K^+ + \bar{K}^0 \]

at ANKE

\[ p + p \rightarrow d + a_0^+ \]

\[ \pi^+ \eta \]

\[ K^+ \bar{K}^0 \]
Motivation

nature: $\bar{q}q$ state?  
multiquark state?  
$K\bar{K}$ bound state?

properties*: $I^G (J^{PC}) = 1^- (0^{++})$

$m(a_0) = 984.7 +/- 1.3$ MeV

$\Gamma(a_0) = 50 - 100$ MeV

decay modes: $\eta\pi$ dominant

$K\bar{K}$ seen

$\gamma\gamma$ seen

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

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 $a_0^+$

Identification of $K^+/\pi^+$

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

$\pi^+ \eta$

$K^+ \bar{K}^0$

$K^+/\pi^+$ selected by:

* MWPC information
* TOF
* energy loss of $K^+ (\pi^+)$

Counts

$\begin{array}{c}
\begin{array}{cccc}
275 & 300 & 325 & 250 \\
10^2 & 10^3 & 10^4 & 10^2 \\
\end{array}
\end{array}$

TOF (SA-SO) [44 ps/ch.]
Deuteron Identification

TOF versus momentum distribution
(for a \( \pi^+ \) in the sidewall and a particle in the FD detection system)

\[ pp \rightarrow a_0^+ \]
\[ \rightarrow K^+K^0 \]
\[ \rightarrow \pi^+\eta \]

\[ \Delta t \]
\[ d \]

\[ K^+ \]
\[ \sqrt{(\pi^+)} \]

\[ \Delta t [\text{ch.}] \]
\[ \text{momentum} \ [\text{MeV/c}] \]

\[ \text{unambiguous identification of} \]
\[ pp \rightarrow dK^+/\pi^+ \ X \text{events} \]
Missing Mass

\[ p + p \rightarrow d + K^+ + \bar{K}^0 \]

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

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

\[ \varepsilon_{\text{MWPC}} = (36 \pm 3 \pm 9) \% \]
Acceptance Correction

3 body reaction $\rightarrow 5$ independent variables

model independent acceptance correction

$\rightarrow m^2(K\bar{K})$

$m^2(\bar{K}d)$ \{ Dalitzplot \}

$\vartheta_{cm}(d)$ \{ fix deuteron direction \}

$\varphi_{cm}(d)$

$\varphi \rightarrow$ fix K+ relative to the deuteron

irrelevant to physics case $\rightarrow$ integration over $\varphi_{cm}(d)$
Acceptance Correction: Dalitzplot

s-wave phasespace distribution

\( m^2_{\text{inv}} (K^+\bar{K}^0) \) [GeV^2]

input

\( m^2_{\text{inv}} (K^+\bar{K}^0) \) [GeV^2]

accepted events

\( m^2_{\text{inv}} (K^+\bar{K}^0) \) [GeV^2]
Acceptance Correction

s-wave phasespace distribution

\[ N \times 10^2 \]

\[ \cos \theta_{cm} (d) \]

\[ N \]

\[ \cos \theta_{cm} (d) \]

\[ \phi (K^+ - d) \]

\[ \phi (K^+ - d) \]

\[ \text{accepted events} \]

\[ \text{accepted events} \]

\[ \text{input} \]

\[ \text{input} \]
Acceptance Correction: Example

p-wave phasespace distribution

Acceptance corrected
(no normalised)

\( m_{\text{inv}} (d\bar{K}^0) \) [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?

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

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 → clean kaon events

II Deuteron identification

III Identification of reaction channel
Comparison of Beam Times

<table>
<thead>
<tr>
<th>Jan./Feb. 2001</th>
<th>Feb./Mar. 2002</th>
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<tr>
<td>T = 2.65 GeV</td>
<td>T = 2.83 GeV</td>
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<tr>
<td>2 weeks</td>
<td>3 weeks</td>
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<tr>
<td>$L \sim 3 \times 10^{31}$ cm$^{-2}$ s$^{-1}$</td>
<td>$L \sim 1-2 \times 10^{31}$ cm$^{-2}$ s$^{-1}$</td>
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<td>$N_{\text{veto}} \sim 210$</td>
<td>$N_{\text{veto}} \sim 370$</td>
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<td>$N_{\Delta E} \sim 600$</td>
<td>$\rightarrow N_{\Delta E} \sim 1000$</td>
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<td>$\sigma = 50$ nb</td>
<td>$K^+$ in sidewall</td>
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<td>estimation: $\sigma \sim 3 \times \sigma_{2.65}$</td>
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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 $pp \rightarrow da_0^+ \rightarrow d\pi^+\eta$

P. Fedorets

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The goal of the investigations at ANKE is a simultaneous measurement of two decay channels of the $a_0^+$ resonance: $a_0^+ \to \eta \pi^+$ and $a_0^+ \to K^+\bar{K}^0$. 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, $\Delta t$ (between $\pi^+$ 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 $\eta$ meson. After background subtraction, assuming a uniform behavior under and outside the peak, $\sim 2300$ 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 $pp \to d a_0^+ \to d\eta\pi^+$ reaction. The missing mass spectra are without efficiency and acceptance corrections though.

During the data analysis it was found, that the $\eta$ 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 $pp \to da_0^+ \to d\eta\pi^+$ 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 $\eta$ 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 $\eta$ 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.
Results from ANKE on the reaction

\[ pp \rightarrow da_0^+ \rightarrow \pi^+ \eta \]
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
strategy:

1. $\pi^+$ by TOF (start-side wall)
2. $d$ by TOF (forward-side) + momentum
3. $a_0^+$ by missing mass + others
Identification of $\pi^+$

\[ p(T=2.65 \text{ GeV}) + p \rightarrow d + a_0^+ \rightarrow \pi^+ \eta \]

$\pi^+$ selected by:

* MWPC information
* TOF

Counts

\[ \Delta \text{tof (Sw5-Sa17) [ch.]} \]

45
Deuteron Identification

TOF versus momentum distribution
(for a $\pi^+$ in the sidewall and a particle in the FD detection system)

$pp \rightarrow d a_0^+$

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

\[ p + p \rightarrow d + a_0^+ \rightarrow d + \pi^+ + \eta \]
missing mass \((pp,d\pi^+)\)
for the individual side-wall counter

\[\frac{dN}{dm}\]

Febr. 2001
missing mass (pp,d)
for the individual side-wall counter
Geant simulations for missing mass (pp,dπ⁺) at T=2.65 GeV for the individual side-wall counter

dN/dm for counter 1: 149 events, 48 MeV

dN/dm for counter 2: 196 events, 48 MeV

dN/dm for counter 3: 202 events, 44 MeV

dN/dm for counter 4: 201 events, 32 MeV

dN/dm for counter 5: 228 events, 25 MeV

dN/dm for counter 6: 97 events, 16 MeV
\[ p + p \rightarrow d + a_0^+ \rightarrow d + \pi^+ + \eta \]
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
- $\sim 2300 \pi^+\eta$ 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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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 $\pi^-$ 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 $\pi N$ is needed. It was shown that already at an energy of 310 MeV the higher partial waves became important and the $S_d$ state strongly influences the pion angular distribution via its interference with the $S_s$ 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 $\eta$-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 \( \eta \) 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 \( \eta' \) and \( \phi \) 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 \( \eta \) 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.

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 $\Delta p/p 2 \times 10^{-3} (2 \times 10^{-4})$
• Pellet target

A stream of small (about 30μm) frozen hydrogen pellets
Effective thickness $10^{15}$ atoms/cm$^2$
Estimated position accuracy for individual pellet < 0.5mm
• 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 $4\pi$ detector setup

Central Detector  Forward Detector

Iron Yoke

SCS  PSB  SEC  FPC  FRH  FRH  FVH

MDC  SEP

50 cm

CELSIUS beam
$pp \rightarrow pp \eta(\rightarrow \gamma \gamma)$

- 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
Shimizu et al. "WASA/PROMICE"}

\( pp \rightarrow pp\pi^+\pi^- \)

\( pp \rightarrow p\Lambda^*(1440) \rightarrow pp(\pi^+\pi^-)_{\Sigma} \)

\( pp \rightarrow pp\pi^0\pi^0 \)
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.

$pp \rightarrow pp\pi^0$

$q$ is proton-proton relative momentum

Higher partial waves contribute quite close to the threshold.

65
Fig. 3.

Fig. 4.
Measurements of the quasi-free \( pn \rightarrow pnn \) reaction

\[ \sigma \text{ [mb]} \]

\[ \text{Q.c.m. [MeV]} \]

\[ \text{pd} \rightarrow pnn + ps \]

\[ \frac{\sigma(pn \rightarrow pnn)}{\sigma(pp \rightarrow ppn)} \approx 6.5 \]
Properties of the $\eta(547)$:

- Lifetime: $5 \times 10^{-19}$ s, $T = 1.2$ keV
- $C = +1$, $P = -1$

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

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

Main decay channels:

- $\eta \eta$: 38%
- $\pi^+\pi^-\pi^0$: 23%
- $\pi^0\pi^0\pi^0$: 32%
- $\pi^+\pi^-\gamma$: 4.8%
Fig. 3. Four different electromagnetic $\eta$ decays having an eta-photon-photon vertex function. Here $\ell$ or $\ell'$ denote a lepton ($\mu$ 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 $\ell^+\ell^-$ invariant mass $\equiv -Q^2$. 

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Possible mechanisms for the decay of a pseudoscalar meson \((\pi^0, \eta)\) 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

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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 $\eta$ 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 180 A 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 180 A MeV Ar+Ca reaction a variety of observables have been obtained. The production of the neutral mesons $\pi^0$ and $\eta$ 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 $\Delta$-resonances. Assuming isospin symmetry, the analysis demonstrated that more than half of the observed pions originate from $\Delta$-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 $\sim$ 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 60 A MeV and 95 A 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.
PARTICLE PRODUCTION IN PROTON AND NUCLEUS INDUCED REACTIONS AROUND 200\(A\) MeV

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for the TAPS Collaboration
(GANIL-Giessen-Groningen-GSI-Rez-Valencia)
Particle production at \( \sim 200\,\text{A MeV} \)

- Introduction
- 190 MeV \( \text{p+A} \): *simple case*
- 180\(\text{A}\) MeV \( \text{Ar+Ca} \): *complex case*
- Outlook
Introduction

- Beam energy per nucleon below the NN threshold for light meson production (280 MeV for $\pi^0$): *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, ???

Photon - the ultimate probe

- Leaves the interaction zone without any distortion due to the final state strong interactions
  - Low energy [E < m]
  - Background from soft photons (e.g., γγ) and central mesons (π^0, ρ, ω, η, ...)

Data on meson production and baryon excitations are necessary!
E-m vs strong probes

Electromagnetic observables (harder probes) from each stage of reaction

Hadronic observables (softer probes) at freeze-out
Experimental techniques

- Photon detection in BaF$_2$ 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
  \[ m_\gamma = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - \cos \theta_{\gamma_1\gamma_2})} \]
- Reconstruction of neutral meson kinematics (a novel method was proposed in 2000: K. Korzecka & TM, Nucl. Instr. Meth. A453, 606)
Proton-nucleus collision
\[ p (190 \text{ MeV}) + C, \text{ Ca, Ni, W} \]

- Experiment: AGOR at KVI Groningen
- neutral pion production
- photon production
- multi-step processes in photon production
neutral pion energy [MeV]

Pion-proton correlations

K. Tymińska
MSc thesis

energy-conservation limit

proton energy [MeV]
π⁰ → γγ contribution

Spectrum of photons following π⁰ → γγ is simulated, but π⁰ are measured in a wide acceptance range in the same experiment.
Photons corrected for $\pi^0 \rightarrow \gamma\gamma$

$$e_\gamma = \frac{E}{E_{\gamma}^{MAX}}$$
Target mass dependence

\[ \frac{d\sigma}{dE} \sim A^\alpha \]

\( \alpha = 2/3 \)  
surface production

\( \alpha = 1 \)  
volume production
Heavy-ion collision
Ar (180A MeV) + Ca

- Experiment: SIS at GSI Darmstadt
- meson production
- evidence of Δ-resonance
- photon spectrum: how to correct for the neutral pion contribution?
$\pi^0$ $m_t$ spectrum
acceptance-corrected

Ar+Ca at 180A MeV

$0.26 < y/y_{beam} < 0.71$

2 slopes:
18±1 MeV
54±7 MeV

$m_t$- scaling extrapolation for $m_t > m_\eta$
$\sigma = 28\pm 20$ nb

$m_t = \sqrt{m^2 + p_t^2}$
\gamma\gamma\text{ invariant mass spectrum}

\begin{align*}
\text{Counts/5 MeV} & \\
\text{Counts/20 MeV} & \\
\end{align*}

\begin{align*}
M_{\text{inv}}(\text{MeV}) & \\
\end{align*}

\text{a)} \pi^0\text{-trigger} \\
\text{b)} \eta\text{-trigger} \\
\sigma_\eta < 44 \pm 22 \text{ nb}
Threshold-energy scaling

\[ p_x = f \left( \frac{E_{CC}^{BEAM}}{E_{\text{NN\rightarrowNNX}}^{\text{THRESHOLD}}} \right) \]

Determined by pion cross section measurements:
180\text{A MeV} for \( \eta \)
corresponds to
40.4\text{A MeV} for \( \pi^0 \)

Observed \( \eta \) yield is factor 10-20 below this prediction.
\( \pi^0 \)-proton correlations

background from event-mixing

1940±740 events above combinatorial background
(error is not only statistical, it includes error from background normalization)
On the origin of pions

\[
\frac{N_\Delta}{N_\pi} = \frac{Y_{\Delta^+}}{Y_{\pi^0}} \times \frac{f_{\pi^0}}{p_{\Delta \rightarrow N\pi} f_{\Delta^+ \rightarrow p\pi^0} f_{\Delta^+ \rightarrow p\pi^0}} \times \frac{\mathcal{E}_{\pi^0}}{\mathcal{E}_{\Delta^+ \rightarrow p\pi^0}}
\]

exp. yields \hspace{1cm} C-G coefficients accounting for isospin \hspace{1cm} efficiency

\[\frac{N_\Delta}{N_\pi} = 0.79 \pm 0.30_{\text{STAT}} \pm 0.2_{\text{SYST}}\]
High $m_t$ pions: from multi-step processes

- $\pi_0^0$ $x\ 1.0$
- $\pi_0^0$ $m_t > 200$ MeV $x\ 4.$
- $\pi_0^0$ $m_t > 300$ MeV $x\ 250.$

$\sim A^{4/3}$

$\sim A$

Multiplicity of charged particles in START detector
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**

Ar+Ca at 180A MeV

$E_\gamma^{NN}$ (MeV)
photon spectrum

![Graph showing the photon spectrum with error limits and systematic uncertainty]

- $dM_\gamma/dE_\gamma$ (MeV$^{-1}$)
- $E_0 = 53 \pm 2$ (stat) $^{+5}_{-8}$ (syst) MeV

 histograms: systematic error limits
In-medium photon production probability

\[ P_{\gamma}^{1,pn} = \frac{M_{\gamma}^{\text{EXP}}}{\langle N_{pn} \rangle_b} \]

\( E_\gamma > 30 \text{ MeV} \)

Enhancement of photon production: \(~80\%\) of photons come from secondary p-n collisions

Predictions based on first-chance neutron-proton collisions

* present data
Photon energy: where it comes from?

\[ E_{\gamma}^{\text{max}} = \frac{s - 4m_N^2}{\sqrt{s}} \leq \frac{T_N}{2} \]

\[ \rho_F = 270 \text{ MeV/c} \]

\[ \rho_{\nu} = 0 \]

maximum photon energy (MeV) vs. beam energy (AMeV)
Pion reabsorption in nuclear matter

- Pion production proportional to the overlap volume
- Random emission according to $1 + A_2 P_2(\cos\theta)$ 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 $\Delta$-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

  \( \eta \) and \( \pi^0 \) production in Ar+Ca
  high-energy \( \gamma \) production in Ar+Ca
  evidence for \( \Delta^+ \rightarrow p\pi^0 \) decay in Ar+Ca
  \( \pi^0 \) and \( \gamma \) production in p+X
  \( \pi^0 \) reabsorption and \( \pi^0 \) 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 $d K^+ K^0$ Dalitz Plot

- Reaction Kinematics and Dalitz plot for proton-proton collisions.
- What is the difference between $a_0^+$ resonance and $K^+ K^0$ non-resonant system in $s$-wave?
- Is it possible to isolate different production mechanisms?
- Partial wave decomposition of $d K^+ K^0$ system.
- Final state interaction between deuteron and $K^0$.
- 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:

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

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<th>state</th>
<th>$T_{beam}$ (GeV)</th>
<th>IUCF</th>
<th>CELSIUS</th>
<th>SATURNE</th>
<th>COSY</th>
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<td>$NN\phi$</td>
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• High beam energy resolution

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

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

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

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

$$\sigma(\text{NN} \to \text{NNM}, \text{NN} \to \text{NYM}) \propto \epsilon^2$$

Very strong phase space dependence. Small (even negligible) error in reconstruction of $\epsilon$ might cause enormous variation in $\sigma$

$\epsilon \in [1 \to 100 \text{ MeV}] \Rightarrow \sigma \in [1 \to 10^4]$

• It is useful to implement reduced cross section $= \sigma/\epsilon^2$

• For $n = 3$: $\text{NN} \to \text{NYM}$

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

where $s_{KY}$ and $s_{NY}$ are squared invariant energies of the produced $KY$ and $NY$ subsystems.
Dalitz plot
\[
\frac{d\sigma}{ds_{K^+K^0} ds_{K^0 d}} = \frac{1}{64\pi^5(s^2 - 4s m_p^2)} |M|^2,
\]
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 \( K^+K^0 \) subsystem and FSI induced structure of \( K^0 d \) 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 \( K^+K^0 \) subsystem with respect to the deuteron, while small \( s, p \), etc. is the orbital angular momentum of the \( K^+K^0 \) 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 $pp \rightarrow K^+ K^0 d$ 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 $K^+ K^0$ (c) and $dK^0$ (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:

- 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, $K^+K^0$ squared invariant mass distribution seems to be more sensitive the 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 $pp \rightarrow K^+K^0 (Ps+Sp) \ T_p=2.85$ GeV

- Calculations for $pp \rightarrow K^+K^0 d$ reaction at 2.85 GeV. Dalitz plots are shown for $Ss$ (a) and mixed $Ps$ and $Sp$ final states. The Dalitz plot projections for $K^+K^0$ (c) and $dK^0$ (d) subsystems are shown by the hatched histograms for mixture of $Sp$ and $Ps$ states and by open histograms for $Ss$ states.
Calculations for $pp \rightarrow K^+K^0 d$ 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 $Sp$ and $Ps$ final states of $pp\rightarrow K^+\bar{K}^0 d$ reaction can be distinguished experimentally, if they are not mixed. The $Ps$ 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

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## 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 $KN/\Lambda\pi = 0.7\pm0.5, \Lambda\pi/\Sigma\pi = 0.8\pm0.5$

- 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

\[ T = 2.65 \text{ GeV}, \; pp \rightarrow da_0^+ \text{ beamtime} \]

- 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

\[ T = 2.83 \text{ GeV}, \; pp \rightarrow da_0^+ \text{ beamtime} \]

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 \( \pi^+ \) with momenta up to 1000 MeV/c (restricted by SD-MWPC2)
- SW2 was on and moved downstream from SW1 to a distance of \( \sim 2 \) 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 $d\alpha_0^+$: 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. $\pi^+$ 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 left 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

TOF-cut

inefficiency of track reconstruction
TEL15: 0.6, SW2: 0.8
SD-MWPCs are used after the second analysis step

Run $4669$. 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

Run $4508-710$. 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**

**TOF-cut**
- **delayed Veto - cut**
  - (prompt peak is at -50)

**Vertical angle-cut**
- inefficiency of track reconstruction is 0.05 for telescopes

**DeQ-cut**
- VeQ-cut

**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 $\Delta E$-counters.
KAONS IN SW2

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


(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 $M_A = 1116$ MeV region of the missing mass distribution in order to select clean events.
Kaons at 2.83 GeV for tel8-15 and SW2 from \( pp \rightarrow K^+ p A \) 
\[ \text{Run4468-710.Sa-ka.TOFTel-15.TOFSw2.DeQ200.SW1-ka.Fd-p.trg1} \] 
(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 \( M_\Lambda \) has it’s maximum at \( \sim 1140 \) 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 $\sim 1140$ 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.

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

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

X1=-55.03cm

<table>
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<tr>
<th>Pd interval</th>
<th>X1=-55.08cm</th>
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<tbody>
<tr>
<td>1600-2100 MeV/c</td>
<td></td>
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<tr>
<td>2100-2550 MeV/c</td>
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<tr>
<td>2550-2950 MeV/c</td>
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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!
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 $< M_{\Lambda\pi} > = 1367\text{ MeV}$
- $pp \rightarrow K^+ N\Sigma(1193)\pi$ with $< M_{\Sigma\pi} > = 1415\text{ MeV}$
- $pp \rightarrow K^+ N\Sigma(1480)\pi$ with $< M_{\Sigma\pi\pi} > = 1440\text{ MeV}$

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 $M_x > 1.35\text{ GeV}$ and $\frac{\sigma_{K\Lambda}}{\sigma_{Kp\Sigma}} = 6.6 \pm 0.6$

About $pp \rightarrow K^+ N\Sigma(1480)$ background:
- If $\sigma_{K+N\Sigma} = \sigma_{K+N\Sigma} \cdot \alpha$
- Then in the region $T = 1\text{ GeV}$ (from literature):
  - $\alpha = \frac{1}{3}$ for $K^+ p \rightarrow p\Lambda$
  - $\alpha = 1$ for $\pi p \rightarrow K\Lambda$
- No data on $pp \rightarrow K^+ N\Sigma(1480)$

3. Simulations of $pp \rightarrow K^+ N\Sigma(1385)$

- 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

$\pi^+$ 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 $M_x < 1.300 \text{ GeV}$
$K^+ p(M_x = \pi^+ + x)$ correlation

Experiment

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

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

$pp \rightarrow KNY\pi\pi$ 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 $\sim 1480$ 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 $\pi^+$ 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 $K^+, \pi^+, p_{FD}$ 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.
**Σ(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 \( \pi^+ \) 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 (\( x^\pm: \pi^+ \) 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. .. mmSideVSSForward
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 \( \pi^+ \) 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 \( T_p = 2.7 \text{ GeV} \) for \( K^+pp \) coincidences are shown.
In the $pp \to K^+p M_x$ 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 $\approx 1200$ MeV in $pp \to K^+\pi^+p M_x$) or into $\pi^-\Sigma^+ \to \pi^-\pi^+n$. $\Sigma^0(1385) \to \pi\Sigma$ is suppressed since the branching ratio of this decay mode is 12% only.

Does the sharp enhancement at 1525 correspond to $\Lambda(1520)$???
\[ pp \rightarrow K^+\pi^+pFdM_x, \quad T_p = 2830 \text{ MeV}, \quad trig1 \]
additional cut: \[ pp \rightarrow K^+p\pi^+(1150 < M_x < 1250) \]

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

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

[Graphs and plots]

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

After a mild cut on \[ pp \rightarrow K^+\pi^+pM_x \] with \[ M_x =1200\pm50 \text{ MeV} \] 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 \[ pp \rightarrow K^+pY^* \] reactions with \( Y^* \rightarrow \pi^-\Sigma^+ \) decays we must analyse data from Nd (if we have enough statistics).
\[ pp \rightarrow K^+\pi^+_SD p_{FD} M_x, \quad T_p = 2830 \text{ MeV}, \quad \text{trig1} \]

stronger cut: \[ pp \rightarrow K^+p\pi^+ (1170 > M_x > 1230) \]

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

Run 4467–710kons, ver50. De.MWPC, Fd–MWPC, pi–MWPC, trg1

Box Field = \(-34.30, -76.61\)

FD Particle = Proton
SD Particle 1 = Koon
SD Particle 2 = Pion
Target = Proton
Beam Momentum = 3650

A puzzle: after the strong cut on \[ pp \rightarrow K^+\pi^+p M_x \] with \( M_x = 1200 \pm 30 \text{ MeV} \) practically nothing changes for \( \Lambda(1405) \) but the \( \Sigma^0(1480) \) mass becomes narrower (\( \sim 40 \text{ MeV} \)). 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.
$pp \rightarrow K^+ \pi_S p_{FD} M_x, \; T_p = 2830 \text{ MeV}, \; trig1$

additional cut: $pp \rightarrow K^+ \pi^+ (M_x > 1290)$

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 $pp \rightarrow K^+ \pi^{-}_{N_d} p_{FD} M_x$ channel from the data with trigger 5.
\[ pp \rightarrow K^+ p_S d p_{F_d} M_x, \quad T_p = 2830 \text{ MeV}, \quad \text{trig1} \]

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

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

<table>
<thead>
<tr>
<th>Entries</th>
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<td>Entries</td>
<td>15012</td>
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| 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 $p_S d$ are in tel. and SW1 and $p_{F_d}$ protons in Fd. No signals from Nd. After the X1-shift peaks corresponding to $\Lambda$, $\Sigma$, $\pi^-$, $K^-$ and $\Phi$ are at the proper masses within 0.5% (accidental??). But for the events $pp \rightarrow K^+ p_S d M_x$ the width of $\Lambda$ peak is 26-28 MeV (as expected) whereas for $pp \rightarrow K^+ p_{F_d} M_x$ it is 48 MeV and as a result the $\pi^-$ peak is 60 MeV wide.
\[ pp \rightarrow K^+ p_{SD} p_{FD} M_x, \quad T_p = 2830 \text{ MeV}, \quad trig1 \]
additional cut: \[ pp \rightarrow K^+ p (M_x > 1250) \rightarrow \text{search for } Y^* \text{ production.} \]

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

A (65-70) MeV wide peak of about 600 events is seen at \( M_x \approx 1400 \text{ MeV} \) 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 \((\Sigma^0(1385) \rightarrow \Lambda \pi^0 \rightarrow p \pi^- \pi^0, \quad \Sigma^0(1385) \rightarrow \Sigma^+ \pi^- \rightarrow p \pi^0 \pi^-)\) and \((\Lambda(1405) \rightarrow \Sigma^0 \pi^0 \rightarrow \Lambda \gamma \pi^0 \rightarrow p \pi^- \gamma \pi^0, \quad \Lambda(1405) \rightarrow \Sigma^+ \pi^- \rightarrow p \pi^0 \pi^-)\). Since here only trig 1 events are analysed, the \( \pi^- \) must be either soft \((P_{\pi^-} < 350 \text{ MeV/c})\) or escape out of the close-to-target region of \( \Lambda, \Sigma \) 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.
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 $\Lambda$ polarization studies. In the case of unpolarized beam and target the longitudinal $\Lambda$ polarization must be equal to zero. The angular distribution of protons (or $\pi^-$) from $\Lambda$ decays in the $\Lambda$ cm-system with respect to the $\Lambda$ direction is a good test for possible false asymmetries. The transverse $\Lambda$ 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.
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 $>350$ 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.
\[ pp \rightarrow K^+ p_{SD} p_{FD} (M_x = Nd + x), \quad T_p = 2830 \text{ MeV}, \quad trig5 \]

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
Run 4508–710zka–TE120–SW25 MWPC–p_SW1–ka SW2–MWPC_fd–MWPC_mmSideSide cut

**Box Field** = \(-34.3 \, 0 \, -76.61\)

FD Particle = Proton
SD Particle 1 = Koon
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.
\[ pp \rightarrow K^+ p_{SD} p_{FD}(M_x = Nd + x), \quad T_p = 2830 \text{ MeV}, \quad \text{trig5} \]

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

Run4508-710zka-TE120-SW25.MWPC-p.SW1-ka.Fd-MWPC.mmS-S-Fd460.trg5

\[ \text{Box Field} = -34.30 - 76.61 \]

FD Particle=Proton
SD Particle 1=Kaon
SD Particle 2=Proton
Target=Proton
Beam Momentum= 3650

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 \( K^+K^- \) 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 \( \Lambda(1520) \).
$pp \rightarrow K^+ p_{SD} p_{FD} (M_x = Nd + x), \quad T_p = 2830 \text{ MeV, \textit{trig5}}$

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**

Run4508-710.Y.and.K-.cutoff.trig5

25/06/2002-15.26.22

**Box Field** = $-34.3 \,\text{to}\, -76.61$

- **FD Particle** = Proton
- **SD Particle 1** = Koon
- **SD Particle 2** = Proton
- **Target** = Proton
- **Beam Momentum** = 3650

$Trig5$ data without events containing $\Lambda(1116), \Sigma(1192)$ and $K^-$ is the 4-fold coincidence of $K^+, p, p$ and $\pi^-$. 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 ($K^+, p, \pi^-$) are analysed with the use of information about $\pi^-$ 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.
\[ pp \rightarrow K^+ p_{SD} p_{FD}(M_x = Nd + x), \quad T_p = 2700 \text{ MeV} \]

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

Run 4762–807zkaons, phi.Fd–MWPC.Sd–pMWPC.SW1–ka.trg4

<table>
<thead>
<tr>
<th>mmSide</th>
<th>Entries</th>
<th>5882</th>
</tr>
</thead>
</table>

| mmSide | Entries | 3877 |

| mmSide | Entries | 3882 |

| mmSide | Entries | 3902 |

| mmSide | Entries | 3572 |

| mmSide | Entries | 2892 |

Box Field = \(-33.90 - 76.61\)

FD Particle = Proton
SD Particle 1 = Koon
SD Particle 2 = Proton
Target = Proton
Beam Momentum = 3515

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

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

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 \( I = L_{2700}^{\text{int}} / L_{2830}^{\text{int}} \), obtained from trig2 data. This could be a good test for the simulations.
$pp \rightarrow K^+p_{sd}p_{Fd}(M_x = N\delta + x)$, $T_p = 2700$ MeV
after cuts $pp \rightarrow K^+p_{sd}(M_x > 1250)$

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

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

26/05/2002-03.15.10

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

See discussions on the previous pages with the exception that $T_p = 2700$ MeV is close to the threshold of $\Sigma(1480)$ production and below the threshold of $\Lambda(1520)$ production.
$pp \rightarrow K^+ p_{SD} p_{FD} (M_x = N d + x), \quad T_p = 2700 \text{ MeV}$

additional cut: $pp \rightarrow K^+ pp (M_x > 480)$

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

$26/05/2002-03.54.31$


Box Field = $-33.9 \ 0 \ -76.61$

FD Particle=Proton
SD Particle 1=Kaon
SD Particle 2=Proton
Target=Proton
Beam Momentum= 3515

Selected $K^-$ events at $T_p = 2700 \text{ MeV}$ can be used only for $\Phi$ and nonresonant $K^+ K^-$ production studies. The ratio $n_\Phi = \frac{N_{\Phi}^{2700}}{N_{\Phi}^{2.83}} = 0.23 \pm 0.11$, corrected for efficiencies, acceptances and the ratio of integrated luminosities and multiplied by the cross section of $\Phi$ production at 2.83 GeV (known from literature), can give an estimation of the $\Phi$ 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 2.65GeV 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

V.Yu. Grishina

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60th October Anniversary Prospect 7A
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Russia
Recently we have analyzed different mechanisms of $a_0(980)$ meson production in $\pi N$ 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 coincident with our predictions for the $pp \rightarrow dK^+K^0$ cross section. An important problem is to understand the role of nonresonant contribution to $pp \rightarrow dK^+K^0$. We considered $\pi$- 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 $\pi$-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 $pp \rightarrow dK^+K^0$ 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 $K^+K^0$-system, while its contribution to the $S$-wave is rather small.

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

p + p → d + K^+ + \bar{K}^0

near Threshold
Contents

1. $NN \rightarrow NNK\bar{K}$ reaction:
   Effective one-pion exchange model
   for $NN \rightarrow NNa_0 \rightarrow K\bar{K}$

& nonresonant background
   ($\pi^-$ & $K^-$-exchange contributions)

2. Parameters of the Flatté distribution for $d\sigma/dm_{K\bar{K}}$

3. Elementary reaction
   $\pi N \rightarrow Na_0 \rightarrow K\bar{K}$ and background
   (comparison with data)

4. Production of $ppa_0^0 \rightarrow K^+K^-, K^0\bar{K}^0$
   and $pna_0^+ \rightarrow K^+\bar{K}^0$ in $pp$-collision
   and background part

5. $pp \rightarrow da_0 \rightarrow K^+K^0$ & $pp \rightarrow dK^+\bar{K}^0$
   resonant part & nonresonant part
One pion exchange model for the $NN\rightarrow NNA_0$

amplitude

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

nucl-th/0107071
An effective Lagrangian Approach (parameters)

For the meson exchanges we used form factors at the different vertices \( j \) \((j = f_1NN, \eta NN)\), which are taken of the monopole form

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

where \( \Lambda_j \) is a cut-off parameter. In the case of \( \eta \) 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 \( g_{\eta a_0} = \sqrt{8\pi \Gamma_{a_0 \rightarrow \eta \pi}/q_{\pi \eta}} = 2.5 \) 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 \( A \): \( g_{f_1NN} = 11.2 \), \( \Lambda_{f_1NN} = 1.5 \) GeV from (V. Mull, K. Holinde, Phys. Rev. C 51, 2360 (1995)), set \( B \): \( g_{f_1NN} = 14.6 \), \( \Lambda_{f_1NN} = 2.0 \) GeV from (M. Kirchbach, D.O. Riska, Nucl. Phys. A 594, 419 (1995)) and \( g_{f_1a_0\pi}=2.5 \) for both cases. The latter value for \( g_{f_1a_0\pi} \) 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 \( \pi NN \) 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 \( \pi^+ p \rightarrow K^+ K^0 p \)). 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)).
$pp \rightarrow da_0^+$

$\Theta = 0^0$

$\Lambda_N = 1.3 \text{ GeV}$

$\Lambda_N = 1.2 \text{ GeV}$

$T_{lab} = 2.6 \text{ GeV}$

$P_{lab} = 3.29 \text{ [GeV/c]}$

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 K̅K production in the NN → NN K̅K reaction.

\[\text{we take } \Lambda_K = 1.2 \text{ GeV}\]

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 \(NN \rightarrow a_0NN \rightarrow K\bar{K}NN\) 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 \(NN \rightarrow NNa_0\) reaction and the Flatté mass distribution function

\[
\frac{d\sigma_{KK}}{dM^2}(s, M) = \sigma_{a_0}(s, M) C_F \frac{M_R \Gamma_{a_0KK}(M)}{(M^2 - M_R^2)^2 + M_R^2 \Gamma^2_{\text{tot}}(M)}
\]

with the total width \(\Gamma_{\text{tot}}(M) = \Gamma_{a_0KK}(M) + \Gamma_{a_0\pi\eta}(M)\). The partial widths

\[
\Gamma_{a_0KK}(M) = g_{a_0KK}^2 \frac{q_{KK}}{8\pi M^2}, \\
\Gamma_{a_0\pi\eta}(M) = g_{a_0\pi\eta}^2 \frac{q_{\pi\eta}}{8\pi M^2}
\]

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

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

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 \( dM^2 = 2MdM \):

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

\[
\text{Br}(a_0 \rightarrow \pi\eta) = \int_{m_K+m_K}^{\infty} \frac{dM}{m_K+m_K} \frac{C_F M_R \Gamma_{a_0 \pi\eta}(M)}{(M^2 - M_R^2)^2 + M_R^2 \Gamma_{\text{tot}}^2(M)} + \int_{m_{\pi}+m_\eta}^{m_K+m_K} \frac{dM}{m_{\pi}+m_\eta} \frac{C_F M_R \Gamma_{a_0 \pi\eta}(M)}{(M^2 - M_R^2 - M_R \Gamma_{a_0 K\bar{K}}(M))^2 + M_R^2 \Gamma_{a_0 \pi\eta}(M)}. \tag{4}
\]

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

\[
\text{Br}(a_0 \rightarrow K\bar{K}) + \text{Br}(a_0 \rightarrow \pi\eta) = 1. \tag{5}
\]

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,

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

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

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

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 $g_{a_0K\bar{K}}$ 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 $C_F, g_{a_0K\bar{K}}, g_{a_0\pi\eta}$ for a fixed branching ratio $\text{Br}(a_0 \rightarrow K\bar{K}) = 0.187$:

\begin{align*}
\text{set 1 (}\Gamma_{a_0\pi\eta} = 70 \text{ MeV):} & \\
g_{a_0K\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):} & \\
g_{a_0K\bar{K}} &= 1.943, \quad g_{a_0\pi\eta} = 1.937, \quad C_F = 0.354.
\end{align*}

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. $g_{a_0K^+K^-} = g_{a_0K^0\bar{K}^0} = g_{a_0K\bar{K}}/\sqrt{2}$, whereas $g_{a_0K^+\bar{K}^0} = g_{a_0K^-\bar{K}^0} = g_{a_0K\bar{K}}$. 

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The reactions $\pi N \rightarrow a_0 N$ and $\pi N \rightarrow K\bar{K} N$

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.**

<table>
<thead>
<tr>
<th>Vertex</th>
<th>$g$</th>
<th>$\Lambda$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi\pi\rho$</td>
<td>6.04</td>
<td>1355</td>
</tr>
<tr>
<td>$\pi KK^*$</td>
<td>$g_{\pi KK^<em>} = g_{\pi KK^</em>} = -\frac{1}{2} g_{\pi\pi\rho}$</td>
<td>1900</td>
</tr>
<tr>
<td>$KK\rho$</td>
<td>$g_{KK\rho} = g_{KK\rho} = \frac{1}{2} g_{\pi\pi\rho}$</td>
<td>1850</td>
</tr>
<tr>
<td>$KK\omega$</td>
<td>$g_{KK\omega} = -g_{KK\omega} = \frac{1}{2} g_{\pi\pi\rho}$</td>
<td>2800</td>
</tr>
<tr>
<td>$KK\phi$</td>
<td>$g_{KK\phi} = -g_{KK\phi} = \frac{1}{\sqrt{2}} g_{\pi\pi\rho}$</td>
<td>2800</td>
</tr>
<tr>
<td>$\eta KK^*$</td>
<td>$g_{\eta KK^<em>} = -g_{\eta KK^</em>} = -\frac{\sqrt{3}}{2} g_{\pi\pi\rho}$</td>
<td>3290</td>
</tr>
</tbody>
</table>

It is important that for the reactions $\pi^+p \rightarrow pK^+\bar{K}^0$ and $\pi^-p \rightarrow pK^0\bar{K}^-$, where the $KK$ pair has isospin 1, the main contributions come from $P$-wave $KK$ pair production from the $\pi\pi$ state and from $S$-wave $KK$ pair production from the $\eta\pi$ state. These selection rules follow from $G$-parity conservation (note that the $G$-parity of the $KK$ 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 $KK$ pair production from the isoscalar $\pi\pi$ state.
Background

$G$-parity constraints

\[ G(\bar{K}K) = (-1)^L \]

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)),

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

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 $\pi a_0$ 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

$$M_{\lambda_2\lambda_2}(\pi^- p \rightarrow a_0^0 n) = \bar{u}_{\lambda_2}(p_2) \left[-A(s, t) + \alpha B(s, t) \right] \gamma_5 u_{\lambda_2}(p_2),$$
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

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

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

$$\frac{d\sigma}{dt}(\pi^-p \rightarrow a^0_0n) = \frac{1}{64\pi s} \frac{1}{(p_{1\text{cm}})^2} (|M_{++}|^2 + |M_{+-}|^2).$$

Usually it is assumed that the reaction $\pi^-p \rightarrow a^0_0n$ 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 $d\sigma/dt(\pi^-p \rightarrow a^0_0n)$ 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 $d\sigma/dt(\pi^-p \rightarrow a^0_0n)$ at both energies.
To interpret this phenomenon Achasov and Shestakov introduced a $\rho_2$ Regge-pole exchange conspiring with its daughter trajectory. Since the $\rho_2$ 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 $\rho_2$ daughter trajectory to the amplitude $A(s,t)$ is necessary to cancel the kinematical pole at $t = 0$ introduced by the $\rho_2$ main trajectory (conspiracy effect). In this model the $s$ channel helicity amplitudes can be expressed through the $b_1$ and the conspiring $\rho_2$ Regge trajectories exchange as

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

\[ M_{+-} \approx M_{+-}^{b_1}(s,t) = \sqrt{(t_{\text{min}} - t)/s_0} \gamma_{b_1}(t) \times \]

\[ \times i \exp[-i\frac{\pi}{2} \alpha_{b_1}(t)] \left( \frac{s}{s_0} \right)^{\alpha_{b_1}(t)}, \]

where $\gamma_{\rho_2}(t) = \gamma_{\rho_2}(0) \exp(b_{\rho_2} t)$, $\gamma_{b_1}(t) = \gamma_{b_1}(0) \exp(b_{b_1} t)$, $t_{\text{min}} \approx -m_N^2(m_{a_0} - m_{\pi}^2)/s_0$, $s_0 \approx 1$ 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 $-t_{\text{min}} \leq -t \leq 0.6$ GeV$^2$ by the expression

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

where the first and second terms describe the $\rho_2$ 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 $\pi^- p \rightarrow a_0^0(1320)n$ 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/GeV$^2$. Taking $\text{Br}(a_0^0 \rightarrow \pi^0 \eta) \approx 0.8$ we find $\sigma(\pi^- p \rightarrow a_0^0 n) \approx 0.25$ $\mu$b and $[d\sigma/dt(\pi^- p \rightarrow a_0^0 n)]_{t=0} \approx 1.2$ $\mu$b/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 $\rho_2$ 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

$$\frac{d\sigma}{dt} \left( \pi^- p \to a_0^0 n \right) \bigg|_{t=0} \approx \frac{d\sigma_{\rho_2}}{dt} \bigg|_{t=0} \sim \frac{1}{(p_{c.m.}^2)^2} \left( \frac{s}{s_0} \right)^{-2.2}.$$ 

This provides the following estimate for the forward differential cross section at 2.4 GeV/c,

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

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 $\rho_2$ Regge trajectories have isospin 1, their contribution to the cross section for the reaction $\pi^- p \to a_0^- p$ is twice smaller,

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

2004
By E. Bratkovskaya, V. Grishina et al.

2002
$\sigma [\mu b]$ vs. $\sqrt{s} - m_d - m_K - m_{K^0}$ [MeV/c]

$pp \rightarrow da_0^+ \rightarrow K^+K^0,$

$pp \rightarrow dK^+\bar{K}^0 (K^-\text{-exchange})$

By V. Grishina, L. Kondratyuk et al.

2002
$p p \rightarrow d K^+ \bar{K}^0$

$T_{lab} = 2.645 \text{ GeV}$

By V. Grishina, L. Kondratyuk et al.

2002
$pp \rightarrow dK^+\bar{K}^0$
$T_{lab} = 2.83 \text{ GeV}$

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 $Q \geq 100 \text{ MeV}$

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

2. at $Q \leq 60 \text{ MeV}$ 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 understood. 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 $\pi^+$ production very well, whereas it fails badly for the production of $\pi^0$. 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.

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1 The 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 COLLABORATION WITH

M. HAIDENBAUER
A.E. KUROYAHTSEV
V.E. TARASOV
J. SPETH
CONCENTRATE ON NN→NNx

NON-PERTURBATIVE

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

MESON -MESON DYNAMICS
SYMMETRIES

ROLE OF RESONANCES
INTERPLAY MN → NN
LINK TO 3N
PERTURBATIVE?

"TRUE" INITIAL CURRENT REDUCED DUE TO ELASTIC & INELASTIC SCATTERING
UNITARITY COMBINES NN→NN & NN→NNx
**THE ISI (INITIAL STATE INT.)**

(C. H. K. Nakayama, PLB 454 (1999) 176)

**Principal Value Part:**
- MODEL DEPENDENT
- $\to 0$ for $s \to \infty$

**Unitarity Cut**
- FIXED BY NN SCATTERING
- \[ \Lambda_N = \frac{1}{2} e^{i\delta_{NN}} \left( e^{i\delta_{NN}} + e^{-i\delta_{NN}} \right) \]
DATA: W.W. DAENHICK, PRC (2001)

\[ pp \rightarrow pnp^+ \]

\[ \begin{array}{c}
325 \text{ MeV} \\
350 \text{ MeV} \\
375 \text{ MeV}
\end{array} \]

\( A_\Sigma \)

\( A_\Delta \)

\( A_{zz} \)

\[ \cos(\theta_p) \]

0.4

0.2

0

-0.2

-0.4

-0.8

0.4

0.2

0

-0.2

-0.4

-0.8

0

0.5

0

0.5

0

0.5

0.5

0

0.5

0

0.5

0
SOME REPRESENTATIVE RESULTS:

- FULL MODEL -- NO Δ

I. G. MEYER ET AL.
PRC 63 064002 (2001)

\[ \text{pp} \rightarrow \text{pp}π^0 \]

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

RESULTS SIMILAR TO OSAKA MODEL
RESULTS (SO FAR WITHOUT DISTORTIONS)

\[ \approx \text{WT} = - \frac{\gamma N_c}{N_f} \frac{\alpha_s}{\pi} \] 
\[ \approx \frac{1}{\alpha_s^3} \frac{1}{N_f} \]

LARGE CANCELLATIONS

LOOPS SCALE AS

\[ \frac{1}{\alpha_s^3} \frac{\gamma^2}{128 \pi^2} \approx \frac{1}{\alpha_s^3} \gamma^2 \]

NOT YET DONE....
Thus:

- $\pi^+$ works well
- We understand why $\pi^0$ does not work...

Heavier mesons?

Note: $\pi^0$ exception due to chiral suppression of the rescattering term.

$O(x^3)$ $O(x)$

$\Rightarrow \pi^+$ might be the "normal" one.
THUS: (K. WATSON, PR 88 (1952) 1163)

\begin{align*}
&\begin{aligned}
&\Psi_1 &\Psi_{FC}
&\end{aligned}
&\} \quad \text{STRONGLY E DEP.}
&\begin{aligned}
&\Psi_{IS1} &\Psi_{FC}
&\end{aligned}
&\} \quad \text{DIFFICULT TO CONTROL}
&\begin{aligned}
&\Psi_{IS1} &\Psi_{FC}
&\end{aligned}
&\} \quad \text{BUT: WEAKLY E DEP.}
\end{align*}

\text{Even with limited knowledge about } \Psi_1 \text{ & } \Psi_{IS1}, \text{ we can extract information about interactions of outgoing particles!}
WE CONCENTRATE ON

NN $\to d(\pi^\pm, K^\pm, \pi^\mp)$

TO STUDY SCALAR RESONANCES $
\alpha_0 / \alpha_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
- GENUINE (WITH LARGE KT COMPONENT,
RESONANCES.
REASON:

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

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

$$= g^+(s) \frac{1}{S-m_R^2 + i m_R \Pi(s)} g(s) + T^{\text{NP}}(s)$$

where $\Sigma(m_R^2) = m_R^2 - m_0^2 - i m_R \Pi(m_R^2)$

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

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

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

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:

\[ |\text{physical state}\rangle = \sqrt{\varepsilon} |\text{bare}\rangle + \sqrt{1-\varepsilon} |x_1, x_2\rangle \]

\( \varepsilon \to 0 \Rightarrow \text{singular dynamical} \)

(but \( \varepsilon \) not well defined in the presence of inelasticities)
$a_0 \rightarrow$ MIXING

WE WORK IN THE QUASI-PARTICLE PICTURE

IMPORTANT OBSERVATIONS:

$\bullet$ $m_{a_0} \approx m_{f_0}$

$\bullet$ $\Gamma_{a_0} \approx \Gamma_{f_0}$

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

MIXING IN EXIT CHANNEL SHOULD DOMINATE

C.f. $\pi^0$ MIXING: $m_{\pi^0} \gg m_\pi$

$\psi$-W MIXING: $\Gamma_\omega \ll \Gamma_\psi$

$\Rightarrow$ WE HAVE TO DEAL WITH OVERLAPPING RESONANCES

CAN BE CHECKED?
**MIXING MECHANISMS:**
(N.N. ACHASOV et al. PLB 88 (1979) 367)

a) **K MASS DIFFERENCE:**

\[
\begin{align*}
\kappa^+ & \rightarrow \kappa^{-} + \kappa^0 \\
\kappa^{-} & \rightarrow \kappa^{+} + \kappa^0
\end{align*}
\]

Effect localized around

\[
2 \frac{1}{2}(m_{\kappa^+} + m_{\kappa^0}) \pm (m_{\kappa^+} - m_{\kappa^0})
\]

b) **πν MIXING & DIRECT TRANSITION**

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

\[
\frac{\pi^+}{\nu} \rightarrow \frac{\pi^0}{\nu} + \frac{\pi^0}{\nu}
\]

(Roughly) energy independent

\[
\Rightarrow \text{IT IS IMPORTANT TO INVESTIGATE ALL QUANTITIES AS } \frac{d}{d\text{m}_{\pi^0}} \text{ WITH FINE BINNING}
\]
IDEA: (V. Yu. Grishina et al., PLB 527 (2002) 217)

WRITE DOWN MOST GENERAL AMPLITUDE TO PRODUCE \( \sigma_0 / \sigma_0 \).

IN LOWEST PW ALLOWED \( \Rightarrow \)
AMPLITUDES ARE ASSUMED CONST.
CORRECTIONS SHOULD BE SUPPRESSED BY \( \left( \frac{|k|}{|p|} \right)^2 \).

**k**: RELATIVE MOMENTUM - \( \frac{\sigma_0}{\sigma_0} \) TO 0.

**p**: INITIAL MOMENTUM

\( \sim \) TYPICAL MOMENTUM TRANSFER.

HIGHER PARTIAL WAVES CAN BE CONTROLLED BY DIFFERENTIAL OBSERVABLES...
WE LOOK AT $\pi n \to d(\pi\gamma)$

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

$\left\{ \begin{array}{c} 3p_0^i \\ 3p_1^i \\ 3p_2^i \\ 3f_2^i \\ \end{array} \right\}$

$T_{NN} = 1$

$1P_1$

$T_{NN}^i = 0$

4 COMPLEX PRIMARY PROD. AMPLITUDES

SHOULD BE IRRELEVANT

2 COMPLEX PRIMARY PROD. AMPLITUDES

$3s_1$

$3d_1$

$T_{NN}^i = 0$
**General Structure:**

Form scalars from $\bar{\phi}, \bar{e}, \bar{\phi}, \bar{e}^*$

\[
M_1 = a (\bar{\phi} \cdot \bar{e})(\bar{\phi} \cdot \bar{e}^*) + b (\bar{\phi} \cdot \bar{\phi})(\bar{\phi} \cdot \bar{e}^*) + c (\bar{\phi} \cdot \bar{e})(\bar{\phi} \cdot \bar{e}^*)(\bar{\phi} \cdot \bar{\phi})
\]

\[\Downarrow\]

**Prop. Of Isovector**

\[
\bar{s} = \phi_1^T \bar{e} \bar{\phi} \phi_2
\]

= Spin of initial nucleons

Form scalars from $\bar{\phi}, \bar{e}, \bar{e}^*$

\[
M_2 = f (\bar{\phi} \cdot \bar{e}^*) + g (\bar{\phi} \cdot \bar{\phi})(\bar{\phi} \cdot \bar{e}^*)
\]

\[\Downarrow\]

\[
M = \bar{e} M_0 + M_1
\]
Now we allow for a pol. of the nucleon ⇒

\[ \Phi^+ = (1 + \hat{r} \cdot \hat{S}) \hat{r}. \]

Thus we get:

\[ |H|^2 = C_0 + \mathcal{C}_1 \cos \Theta + C_2 \cos^2 \Theta \]

+ \mathcal{C}_3 \sin \Theta \sin \Theta \left( \mathcal{C}_4 \sin \phi + \mathcal{D}_5 \cos \phi \right)

Angular asymm. in unpolarized differential cross section

SHIFT OF ZERO IN ANALYSING POWER

\[ \frac{d\sigma}{d\Omega} \]

\[ A_y \]

NO MIXING

NO MIXING
• The coefficients depend on different amplitudes.

• Both signal should strongly depend on the mass slice selected.

Combining these points => measuring both $A_y$ and $d\phi/dN$ allows to check if mixing occurs in propagator only!
WHAT HAPPENS AT HIGHER ENERGIES?

→ MORE PH. WILL CONTRIBUTE

\[ \frac{d\sigma}{dN} : \text{ph. has } T = 0 \]

\[ \Rightarrow \text{FOR ph. } \rightarrow d(T\psi) \]

\[ T_i = 1 \text{ FOR CHARGE SYMMETRIC SITUATION} \]

\[ \Rightarrow \text{FORWARD - BACKWARD ASSYM. } \leftrightarrow \text{ CSB} \]

HOWEVER: FOR ph. \( \rightarrow d_K \bar{K} \)

\[ T_i = 0 \text{ or } 1 \text{ FOR CHARGE SYM. SITUATION} \]

\[ \Rightarrow \text{THERE WILL BE FORWARD - BACKWARD ASSYM. IN ANY CASE} \]
• $A_y$: FIRST RESTRICT TO MESONS IN S-WAVE FOR $pn \rightarrow \Omega n$

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

$A_y$ (π/2) ≠ 0 $\iff$ CSB

AGAIN: NOT TRUE FOR $K\Omega$ CHANNEL

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

(HEIDEN, OLLER, OSER (2000): THIS PS. IS NEGLECTIBLE)
SUMMARY

- CONSTRUCTION OF PRODUCTION AMPLITUDE EXTREMELY DIFFICULT

- FOR SMALL EXCESS ENERGIES FINAL STATE INTERACTIONS CAN STILL BE STUDIED

- THE REACTION $pn \rightarrow d(\pi^2)$ ALLOWS EXTRACTION OF $M$-DEP. OF $p-q_\circ$ MIXING AMPLITUDE

- POLARIZATION NECESSARY FOR DEFINITIVE CONCLUSIONS
Summary Talk
of the 3rd ANKE Workshop on
Scalar Meson Production
at ANKE/COSY

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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 $\pi^+$ 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.