Hyperon Physics at COSY
Forschungszentrum Jülich

March 14th 2008, Michael Hartmann
Scope of the talk

I. Ground state Hyperon production (TOF)
   - $\Lambda(1116)$ (N* resonances)

II. Excited states Hyperon production (ANKE)
    - $\Lambda(1405)/\Sigma^0(1385)$
      - kaon anti-kaon pair production
    - $Y^0(1480)$

   all in proton-proton collisions
Starting point: \( pp \rightarrow NK^+Y \)

COSY: COoler SYnchrotron
“high quality beam”

TOF: “large acceptance, Dalitz plot analysis”

ANKE: “certain reaction channels, charged kaon selectivity”

WASA: “detect both neutral and charged particles”

WASA is now in operation!

brief look at COSY, TOF and ANKE
COSY facility, experimental setups

- Circumference ~ 184m
- Polarized protons and deuterons

- max. momentum ~ 3.7 GeV/c
- Electron and stochastic cooling
TOF – large acceptance spectrometer at external target position of COSY

\[ pp \rightarrow K^+ \Lambda p \rightarrow \pi^- p \]

Intermediate fiber hodoscope

"starttorte"

doublesided ring-\(\mu\)-strip

beam veto

LH$_2$ target

2x12 wedges

Si-\(\mu\)-strip 100 rings 128 segments

scintillator 2x96 fibers 2x192 fibers

K$^+$

P

\( \pi^- \)

Barrel Hodoscope

Ring Hodoscope

Kalorimeter

„Erlangen“ Startdetector system

LH$_2$ Target

Central Hodoscope „Quirl“

3.4 m
ANKE – forward angle magnetic spectrometer at internal target position of COSY
Investigation of N* resonances via N* → KY
Expt.: pp → pK^+Λ  (TOF)

Little is known on N* decaying into strange channels

<table>
<thead>
<tr>
<th>N*</th>
<th>Status</th>
<th>L_{2I·2J}</th>
<th>BR(N*→KΛ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N(1650)</td>
<td>****</td>
<td>S_{11}</td>
<td>3 - 11%</td>
</tr>
<tr>
<td>N(1710)</td>
<td>***</td>
<td>P_{11}</td>
<td>5 - 25 %</td>
</tr>
<tr>
<td>N(1720)</td>
<td>****</td>
<td>P_{13}</td>
<td>1 - 15 %</td>
</tr>
<tr>
<td>N(1900)</td>
<td>**</td>
<td>P_{13}</td>
<td>2.4 ± 0.3 %</td>
</tr>
</tbody>
</table>

No information on N* → KΛ for L >1
No information on N* → KS at all

first step → pK^+Λ data for momenta: 2.85-3.3 GeV/c
pp → pK^+\Lambda, total cross section

Excitation function is not sufficient!
Expt.: \( pp \rightarrow pK^+\Lambda \), Dalitz plot analysis

A. Sirbirtsev et al., EPJ A27 (2006) 269, personal communication

\[
\frac{d^2\sigma}{dm_{KA}^2 dm_{p\Lambda}^2} = (\text{flux}) \cdot \left| \sum_R \left( C_R \cdot A_R + C_N \cdot A_N \right) \cdot (1 + C_{FSI} \cdot A_{FSI}) \right|^2
\]
Expt.: $pp \rightarrow pK^+\Lambda$, Dalitz plot analysis

Strong contribution of $N^*$-Resonances in the reaction $pp \rightarrow pK^+\Lambda$

In good agreement with calculation of R. Shyam (PRC 60 (1999) 055213)

No discrimination between $N^*(1710)$ and $N^*(1720)$
Separation using polarized beam
Other approach: Full partial wave analysis, \( pp/\overrightarrow{pp} \rightarrow pK^+\Lambda \)

Very different behavior of the two solutions! Discrimination possible!


1. Solution (red)
   Initial. \( pp \) interaction
   \( ^3P_2, \ ^3P_0, \ ^1S_0 \)

2. Solution (blue)
   Initial. \( pp \) interaction
   \( ^3P_2, \ ^3P_1, \ ^1S_0 \)

Dependence of beam asymmetry
Expt.: $pp \rightarrow pK^+\Lambda$, high statistics Dalitz plot analysis

Very new data at $p_{\text{mom}} = 3.06$ GeV/c

300,000 $pK^+\Lambda$

First data at $p_{\text{mom}} = 3.06$ GeV/c

15,000 $pK^0\Sigma^+$

$N^* \rightarrow K\Sigma$

$m(p\Sigma^0)$ cusp effect?
Expt.: $\Lambda(1405)$ (\& $\Sigma^0(1385)$)  

(Nature of $\Lambda(1405)$)

$\Lambda(1405) \, S_{01}$

\[ l(J^P) = 0(\frac{1}{2}^-) \]

Mass $m = 1406 \pm 4$ MeV  
Full width $\Gamma = 50 \pm 2$ MeV  

Below $K\Lambda$ threshold

<table>
<thead>
<tr>
<th>$\Lambda(1405)$ DECAY MODES</th>
<th>Fraction ($\Gamma_f/\Gamma$)</th>
<th>$p$ (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma \pi$</td>
<td>100 %</td>
<td>157</td>
</tr>
</tbody>
</table>

PDG: status ****, but ...  
Theory: $q^3$, or $(qqqqq\bar{q})$, $\bar{K}N$-molecule, 2 states, ... ?
Starting point: $pp \rightarrow \Lambda N \Sigma Y$

Experimental problem: overlap $\Sigma(1385)$ and $\Lambda(1405)$
Expt: \( pp \rightarrow pK^+Y^0(1405), \) four-particle coincidences \( pK^+p\pi^- \)

\[
Y^0 \rightarrow (p\pi^-)X^0
\]

\[
\pi^0\Sigma^0 \quad \text{(cleanest channel)}
\]

\[
\gamma\Lambda
\]

\[
p\pi^-
\]

\[
pp \rightarrow pK^+\Sigma^0(1385) \rightarrow pK^+(\Lambda\pi^0) \rightarrow pK^+(p\pi^-)\pi^0
\]

\[
pp \rightarrow pK^+\Lambda(1405) \rightarrow pK^+(\Sigma^0\pi^0) \rightarrow pK^+(\Lambda\gamma)\pi^0 \rightarrow pK^+(p\pi^-)\gamma\pi^0
\]
Solution: \( pp \rightarrow pK^+(p\pi^-)X^0 \)

Clean separation of \( \Sigma(1385) \) and \( \Lambda(1405) \) achieved
Results: pp $\rightarrow$ pK$^+$(pπ$^-$)X$^0$

- Influence of the K$^*$N-threshold?
- Comparison with results from
  $\pi^-p \rightarrow K^0(\Sigma N)^0$ (solid line)
    "Thomas" NPB 56 (1973) 15
  and
  $K^-p \rightarrow \pi^+\pi^-\Sigma^+\pi^-$ (dotted line)
    "Hemmingway" NPB 253 (1984) 742

$\Lambda(1405)$: clean separation by ANKE

Theory: L.S. Geng & E. Oset

Expt.: $pp \rightarrow ppK^+K^-(\phi)$

$pp \rightarrow pK^+(\Sigma^0\pi^0)$

$\Lambda(1405)$

$pp \rightarrow K^+p(K^-p)$

$pp, K^-p & K^-pp, KK FSI$

$pn \rightarrow d\phi$

$pp \rightarrow pp\phi$

$pp \rightarrow ppK^-K^-$

$pn \rightarrow dK^-K^-$

(preliminary)

Expt.: \( pp \rightarrow pK^+Y^0(1405, \text{width 50MeV}) \rightarrow K^-p \)

The simplest description of the \( I = 0 \) coupled-channel system is provided by a separable-potential model, e.g. used in Shevshenko et al. [PRC 76 (2007) 055204].

Suggests that \( \Lambda(1405) \) is the main doorway state also for \( ppK^+K^- \). (If so, kaon pair production is not dominated by \( a_0/f_0 \).

Should analyse \( \pi^0\Sigma^0 \) and \( K^-p \) production at the same time!
Expt.: $pp \rightarrow ppK^+K^-$

Assumption: $K^-p$ FSI effect

$$f(q) = (1-iaq)^{-1}, \; q: \text{relative momentum}$$

$$a: \text{scattering length}$$

,,3-body-FSI" $\leftrightarrow f(q_1) \times f(q_2)$,

$$|a| \approx (1-2) \, \text{fm}$$

---

EPJ A4 (1999) 259
Expt.: \( pp \rightarrow ppK^+K^- \), total cross section

Phase space
\[
+ f_{pp} \times f(q_1) \times f(q_2)
\]

\( K^+K^- \leftrightarrow K^0\bar{K}^0 \)
coupled channel effect?

PRC 77 (2008) 015204
Expt.: pp → ppK^+K^-(φ)

K^+K^- ↔ K^0\bar{K}^0
coupled channel effect?

PRC 77 (2008) 015204

ε = 51MeV

dσ/dM [µb/GeV c^2]

K^+K^- invariant mass [GeV/c^2]
Expt.: \( pp \rightarrow pK^+Y^0*(1480), Y^0* \rightarrow \pi^-X^+ \) or \( \pi^+X^- \) (ANKE)

The \( \Sigma(1480) \) hyperon is far from being an established resonance.

In PDG, it is described as a “bump”, with unknown quantum numbers, one-star rating.

Two final states: \( Y^0* \rightarrow \pi^+X^- \) and \( \pi^-X^+ \), with unidentified residue \( X \)

\[
X^- = \Sigma^- \quad \text{or} \quad X^+ = \Sigma^+ 
\]

Three-particle coincidences \( pK^+\pi^+ / \pi^- \)
Result: Evidence for $Y^{0*}(1480)$

Add in MC a $Y^{0*}$

$M = 1480 \text{ MeV/c}^2$, $\Gamma = 60 \text{ MeV/c}^2$

experiment —

simulation

without $Y^{0}(1480)$

PRL 96 (2006) 012002
Summary/Outlook

- TOF – the detector for hyperon studies at COSY
  - Detailed investigation of N* resonances
  - Determination of $p\Lambda$ scattering length ($a_{\text{triplet}}$)
  - Preliminary results with polarized beam
    ($\Lambda$ polarization, spin transfer coefficient: $\overline{p}p \rightarrow p\overline{\Lambda}K^+$)
  - Measurements with LD$_2$-Target, e.g. $pn \rightarrow pK^0\Lambda$ (HK 34.9)

- ANKE – hyperon production close to threshold
  - Results on $Y(1405/1480) \leftrightarrow$ significantly more ANKE can't do
  - Preliminary results on $pp \rightarrow nK^+\Sigma^+$ (Y. Valdau, HK 35.7)
  - Determination of $n\Lambda$ scattering length ($a_{\text{triplet},n\Lambda}$): $\overline{p}n \rightarrow n\Lambda K^+$
WASA at COSY

WASA is a internal $4\pi$ detector in COSY
EM calorimeter, SC solenoid, forward det´s, pellet target
WASA is now in operation!

Symmetries and symmetry-breaking
(HK / many talks)

W. Weglorz (HK 35.6)

$pp \rightarrow pK^+\Lambda(1405) \rightarrow pK^+(p\pi^-)\gamma\pi^0 \quad 3\gamma$

$pp \rightarrow pK^+\Sigma(1385) \rightarrow pK^+(p\pi^-) \pi^0 \quad 2\gamma$

– thank you for your attention –
Hadron Physics
Summer School 2008
(formerly COSY Summer School)
Physikzentrum Bad Honnef, Germany
August 11 – 15, 2008

Lectures and working groups

- QCD and its Phenomenological Implications
- Symmetries and Symmetry-Breaking
- Hadron Spectroscopy
- New Detector and Target Concepts
- Synchrotrons and Storage Rings
- Polarized and Cooled Beams

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