Hyperon production in photonuclear reactions on proton:

$K^0 \Sigma^+$ channel

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outline

• motivation
• the setup at ELSA (Bonn)
• results on $K^0 \Sigma^+$ production
• comparison to theory
• conclusion
\[ \Sigma \text{ hyperon production} \]

SAPHIR and ABBHMM data

**SAPHIR:**
- Experiment at ELSA (1997)
- Using electromagnetic spectrometer
- Large error bars
- Up to 1.5 GeV

**ABBHMM:**
- Bubble chamber
- Large error bars

Coupled channels calculations require better data in \( K^0 \Sigma^+ \) channel
Σ hyperon production

New SAPHIR and CLAS data

SAPHIR:
- New analysis
- Improved error bars
- Higher energies
- 50% lower due to better background subtraction

CLAS:
- Similar in quality
- Differential cross sections need to be extracted due to limited acceptance
Experimental setup

CB and TAPS photon spectrometers

Unique setup: two photon spectrometers cover almost $4\pi$ solid angle
Channel of interest
neutral decay

We are investigating:
\[ \gamma + p \rightarrow K^0 \Sigma^+ \rightarrow 3\pi^0 + p \rightarrow 6\gamma + p \]

This requires:
- Photon spectrometer
- High granularity
- High acceptance

<table>
<thead>
<tr>
<th>photons</th>
<th>80% of 4 ( \pi )</th>
<th>90% of 4 ( \pi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 photon</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>2 photons</td>
<td>64%</td>
<td>81%</td>
</tr>
<tr>
<td>3 photons</td>
<td>51%</td>
<td>72%</td>
</tr>
<tr>
<td>4 photons</td>
<td>41%</td>
<td>65%</td>
</tr>
<tr>
<td>5 photons</td>
<td>32%</td>
<td>59%</td>
</tr>
<tr>
<td>6 photons</td>
<td>26%</td>
<td>53%</td>
</tr>
</tbody>
</table>
Kinematical fitting

Improving the resolution

In a kinematical fit the measured values are varied, to minimize certain constraints:

- Conservation of energy (1)
- Conservation of momentum (3)
- Pion invariant mass (3)

Unknovns:
- Proton energy (punch through)

6 times overdetermined

Confidence level cut at 10%
Background not altered
The $\pi^0 \pi^0 \pi^0$ channel

Selecting the data

Channel of interest:
$\gamma + p \rightarrow K^0 \Sigma^+ \rightarrow 3\pi^0 + p \rightarrow 6\gamma + p$

Background:
$\gamma + p \rightarrow \eta + p \rightarrow 3\pi^0 + p \rightarrow 6\gamma + p$
$\gamma + p \rightarrow 3\pi^0 + p \rightarrow 6\gamma + p$
combinatorics ...

The $\eta$ channel is used for normalisation
Identifying $K^0_S$ and $\Sigma^+$

The invariant mass spectra

- Cut on the $p\pi^0$ invariant mass around the $\Sigma^+$ mass (1189 MeV)
- Kaon invariant mass resolution 10 MeV ($\sigma$)
Background subtraction

- Background subtraction using polynomial
- Integration of the subtracted signal
Acceptance

angular distributions in bins of photon energy

- Using phasespace MC
- Acceptance is shown for $K^0$ channel and the normalisation channel ($\eta$)
- The acceptance for $K^0$ is flat
  - due to decay of the $K^0$ and $\Sigma^+$
- Covers full angular range
  - no extrapolation
Acceptance
angular distributions in bins of photon energy

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Normalisation using $\eta$ channel

- Comparison to CB data (2002) 
- good agreement
- acceptance well understood

Differential $\eta$ cross sections
Normalisation using $\eta$ channel

- good agreement over entire energy range
- acceptance well understood
The photon flux

- Obtained flux follows: $1/E$ form with polynomial modification
- Agrees with online flux estimate, obtained using scalers
Differential cross section

- The differential cross sections agree with the SAPHIR result except at forward angles.
- The CBELSA / TAPS result is flatter for the lower energies.
Excitation function
comparison to SAPHIR and CLAS

- The excitation function is slightly above the CLAS result
- The excitation function lies below the SAPHIR result at around 1.8 GeV
- Due to disagreement in the forward angles
Recoil polarisation

- $\Sigma^+$ is self analyzing
- Polarisation defined by the number of protons emitted above and below the reaction plane
- Recoil polarisation agrees with the new SAPHIR results
  - finer binning
Comparison to K-matrix calculations

- Comparison between the data and K-matrix calculation by Usov and Scholten (dashed)
  - using all known resonances
  - using coupled channels approach
- Including additional $P_{13}(1830)$ describes the data better (solid)
- More details in talk of O. Scholten
Excitation function

- The excitation function shows the difference between the different model inputs more clearly.
Recoil polarisation

- Polarisation observables are also calculated within the K-matrix framework.
- Sensitivity of recoil polarisation data does not allow to discriminate between the different model inputs.
Summary & outlook

Summary:

• Photoproduction cross sections and recoil polarisations of $K^0\Sigma^+$ channel have been obtained using neutral decay mode.
• Results agree with new Saphir analysis and Jlab results.
• The $K$-matrix calculations of Usov and Scholten reproduce the measured data significantly better when an additional $P_{13}$ is included at 1830 MeV.

Outlook:

• Analysis of the data taken with a polarized beam.
• Analysis of the data taken with a deuteron target.
  • to obtain information on the hyperon-nucleon interaction.
Pull distributions of the fit

- Pull distributions compared to Gaussian:
  - \( \sigma = 1 \)
  - \( \text{mean} = 0 \)
- Systematic errors under control
Confidence level distribution

- Important: confidence level distribution for $\eta$ and $K^0$ are the same
- Calibration relative to $\eta$
Effect of thresholds on differential cross sections

![Graph showing effect of thresholds on differential cross sections.]

\( E_\gamma: 1450 \text{ MeV} - 1550 \text{ MeV} \)
Acceptance holes for $\eta$
Recoil polarisation determination

- Reaction plane defined by kaon and sigma
- Recoil polarisation determined by counting the number of times the proton is emitted above (N1) or below the plan (N2)
- \( P = \frac{N_1 - N_2}{\alpha(N_1 + N_2)} \)
- \( \alpha = 0.980 \) (PDG)
Selection
- hits = 7
- coincidence tagger - taps
- 3\(\pi^0\)s (wide mass cut)

Kinematic Fit
- constraints: E, Px, Py, Pz
- constraints: 3\(\pi^0\) masses
- unknown: proton energy

Determine \(\eta\) counts

Determine \(\eta\) acceptance

Compare to published data

Determine flux

Calculate \(K^0 \Sigma^+\) cross section
- using \(K^0 \Sigma^+\) acceptance
- using flux from \(\eta\) channel