Photoproduction of $\eta/\pi^0$ on the deuteron at 1 GeV

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GeV $\gamma$ experiments at Laboratory of Nuclear Science (LNS) founded in 1966

layout of beam lines

120t magnet
DC 160cm$\phi$

GeV $\gamma$ line #1
New NKS charged particles

GeV $\gamma$ line #2
SCISSORS II neutral mesons

$\gamma$ counters

NKS spectrometer

1967

1967

FOREST 4$\pi$ EM Calorimeter
very high intensity photon beam

internal radiator

carbon fiber 11µmφ
Experimental setup

**SCISSORS II** : 206 pure CsI Crystals
(1.57 str = 12.5% of 4 \( \pi \))
16.2 \( X_0 \) for Forward 148 crystals
13.5 \( X_0 \) for Backward 58 crystals

Pseudosphere 55 cm

\[ \gamma + N \rightarrow \eta + X \]

Identification of \( \eta \) meson
\[ \Gamma_{\eta-\gamma} = (39.43 \pm 0.26)\% \]
\[ \rightarrow \gamma\gamma \text{ Decay Channel} \]

\[ \gamma + N \rightarrow \pi^0 + X \]

\( \gamma\gamma \) Invariant Mass Analysis
\[ M_{\gamma\gamma}^2 = 2E_{\gamma_1}E_{\gamma_2}(1 - \cos \Phi_{\gamma\gamma}) \]

Energy  : \( E = \Sigma E_i \)
Position  : \( R = \Sigma R_i E_i / \Sigma E_i \)

**Hydrogen/Deuterium**
**Solid Target**
\( t = 8 \text{ cm} \) \( (N_T \sim 4 \times 10^{23}/\text{cm}^2) \)
Good agreement!

\( \gamma p \rightarrow \pi^0 p \)

\[ \sigma'(-0.9 < \cos \theta^* < 0.6) \]
Discussion and Questions

- Can the familiar physics account for the structure observed in $\gamma n \rightarrow \eta n$?
- Do we have any reasons to expect narrow non-strange baryonic states having non-exotic nature?
- Could we consider any other reactions to look for such a narrow non-strange baryon?
- Do we need exotica?
- .......
- .......

Experimentally:
Look into the neutron channel!
(neutron data: not well-established)
Dying for a convenient tool

(like SAID and MAID)

- to analyze data for meson production on the DEUTERON
- to analyze data at least for the QF process
- to extract neutron information

despite many theoretical works reproducing deuteron data to a certain degree.
Disagreement between theoretical and experimental results is still open question for $\gamma d \rightarrow \pi^0 np$ in the 2nd resonance region.
Angular distributions

\[ \frac{d\sigma}{d\Omega}(\gamma d \rightarrow \pi^0 np) \]

in the \( \pi^0 N \) CM system under QF condition:

\[ \gamma N' \rightarrow \pi^0 N \]

- new data
- Mainz

\[ \sigma'_p + \sigma'_n \]

SAID

MAID
Angular distributions

\[
d\sigma / d\Omega(\gamma N' \rightarrow \pi^0 p)
\]

with detection of a charged particle

\[\gamma p' \rightarrow \pi^0 p\]

\[\pi \rightarrow \Omega\]

\[\bullet\] our data

\[\downarrow\] SAID

\[\bullet\] MAID

Need to check the acceptance!
Consistency check for the acceptance with a proton target with (without) detection of an additional charged particle.

Good agreement between data
\[ \sigma'(-0.7 < \cos \theta^* < 0.6) \]

- Solid lines: SAID
- Broken: MAID
- Black: \( \sigma'_p + \sigma'_n \)
- Red: \( \sigma'_p \)
- Blue: \( \sigma'_n \)

Wanted a tool!
Effects of FSI in the QF process

$$\gamma d \rightarrow \pi^0 np$$

\[ \frac{d\sigma}{d\Omega}(\gamma d \rightarrow \pi^0 np) \propto \left| T_{\pi p} + T_{\pi p} T_{pn} + T_{\pi n} T_{np} \right|^2 + \left| T_{\pi n} + T_{\pi n} T_{np} + T_{\pi p} T_{pn} \right|^2 \]

$$\gamma N' \rightarrow \pi^0 p$$
$$\gamma N' \rightarrow \pi^0 n$$

N-N FSI plays an important role.
Reduction factor $\alpha$

\[
\frac{\frac{d\sigma}{d\Omega}(\gamma N' \rightarrow \pi^0 p)_{\text{exp}}}{\frac{d\sigma}{d\Omega}(\gamma p' \rightarrow \pi^0 p)_{\text{MAID}}} = \alpha
\]

$E_\gamma > 640\,\text{MeV}$

$-0.7 < \cos \theta^* < 0.6$

$\alpha = 0.8$
Angular distribution

\[ \frac{d\sigma}{d\Omega}(\gamma N' \to \pi^0 p) \]

with detection of a charged particle

↑ our data

--- SAID

\[ \gamma p' \to \pi^0 p \]

----- MAID
Angular distribution

\( \frac{d\sigma}{d\Omega}(\gamma N' \rightarrow \pi^0 p) \)

\( \uparrow \) our data

---

**MAID**\( ^*0.8 \)

\( \gamma p' \rightarrow \pi^0 p \)

---

**MAID**\( ^*0.8 \)

\( \gamma n' \rightarrow \pi^0 n \)
\( \sigma'(−0.7 < \cos θ^* < 0.6) \)

\[ γd \to π^0 np \]

\[ γN' \to π^0 p \]

\[ γN' \to π^0 n \]

\( \sigma'_d = \sigma'_p + \sigma'_n \)
Effects of the change of helicity amplitudes on each resonance

\[ A^n \times 1.2 \]
\[ \times 1.4 \]
\[ \times 1.6 \]
\[ \times -1.6 \]
\[ \sigma'( -0.7 < \cos \theta^* < 0.6 ) \]

Helicity amplitudes

Fitted

\begin{align*}
\gamma p' \to \pi^0 p \\
\gamma n' \to \pi^0 n
\end{align*}

MAID*0.8

\[ A_{1/2}^n, A_{3/2}^n \]

\begin{align*}
D_{13}(1520) \\
S_{11}(1535) \\
S_{11}(1650) \\
D_{15}(1675) \\
F_{15}(1680) \\
P_{13}(1720)
\end{align*}
## Helicity amplitudes in the neutron channel

<table>
<thead>
<tr>
<th></th>
<th>$A_{1/2}^n$</th>
<th>$A_{3/2}^n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDG</td>
<td>MD07</td>
<td>Fit</td>
</tr>
<tr>
<td>$D_{13}(1520)$</td>
<td>$-59\pm9$</td>
<td>$-76.53$</td>
</tr>
<tr>
<td>$S_{11}(1535)$</td>
<td>$-46\pm27$</td>
<td>$-50.67$</td>
</tr>
<tr>
<td>$S_{11}(1650)$</td>
<td>$-15\pm21$</td>
<td>$+9.25$</td>
</tr>
<tr>
<td>$D_{15}(1675)$</td>
<td>$-43\pm12$</td>
<td>$-61.74$</td>
</tr>
<tr>
<td>$F_{15}(1680)$</td>
<td>$+29\pm10$</td>
<td>$+27.89$</td>
</tr>
<tr>
<td>$P_{13}(1720)$</td>
<td>$+1\pm15$</td>
<td>$-5.4$</td>
</tr>
</tbody>
</table>

[$\times10^{-3} GeV^{1/2}$]

Fit was made within the error range of PDG values.
Speculation: $N^*(1680)$ might couple to $\pi^0n$ channel?
Summary of the present experiment

- \( \frac{d\sigma}{d\Omega}(\gamma d \rightarrow \pi^0 np) \) has been measured.
  \((-0.9 < \cos \theta^* < 0.9) \) New data for \( E_\gamma > 800 \, MeV \).

- MAID and SAID overestimate the data by about 30% at the 2\textsuperscript{nd} resonance region. The discrepancy gradually gets smaller and looks disappear at \( E_\gamma > 1 \, GeV \).

- Good agreement at 1 GeV is kind of illusion due to poor information on the neutron channel. Cuz MAID and SAID predictions exceed data of semi-exclusive \( \gamma N' \rightarrow \pi^0 p \) even at \( E_\gamma > 1 \, GeV \).

- A rough estimation of the data indicates a possibility that \( N^*(1680) \) might couple to the \( \pi^0 n \) channel.
Solid/Liquid Hydrogen Target

Detector holder: acrylic pipe 120mmf (outer diameter) 3mm t
CFRP vacuum pipe: 113mmf (outer diameter) 1.5mm t
Radiation shield pipe: 90mmf 0.1mm t
Target pipe: 65mmf (outer diameter) 5mm t
Solid/Liquid Hydrogen Target

- feeding pipe (4N pure Al) cooled by a GM cooling system
  - length: 1000 mm
- target cell
  - cooled down to 4.7 K
  - target thickness: 40 mm
  - inner diameter: 61 mm
  - outer diameter: 65 mm
  - window (Aramid): 12.5 µm x 2
- operation
  - pre-cooling: 3 hours
  - target making: 2 hours
  - target vaporizing: 1 hour
2γ invariant mass distributions

Data taking started in autumn, 2008.

Fast DAQ system

- Efficiency of 76%
- Trigger rate: 2kHz
- ~40k events/day
- 2.6kB/event

π^0

~2M events/day