Coherent $\pi^0\pi^0$ and $\pi^0\pi^0\pi^0$ photoproduction on deuteron at MAMI

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on behalf of the A2 Collaboration
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Outline

1 Motivation
   Strong hadronic interaction
   Known data
   Motivation

2 Experimental settings
   Data information

3 Event selection
   Preselection and reconstruction
   Pion identification
   Deuteron identification
   Checking the selection process

4 Preliminary results
   Coherent Cross Sections

5 Outlook and Conclusion
Fundamental forces

- Fundamental theories: Standard model and general relativity

- 4 fundamental interactions
  - gravity
  - electronic
  - weak
  - strong
Strong Hadronic Interaction

» Quarks in Nuclei bound by strong interaction

» Hadrons are formed either with $q\bar{q}$-pairs (meson) or with $qqq$-triplets (baryon)
  ▶ What about more complicated bound states?
  ▶ Exotic particles?
Access to exotic particles

- Exotic particles are still not completely verified
- $d^*(2380)$ is a much discussed candidate
- Reported observation by CELSIUS/WASA and WASA@COSY
- Coherent photoproduction of $\pi^0$-pairs is a possible production channel

- M. Bashkanov et al. (CELSIUS/WASA Collaboration) Phys. Rev. Lett. 102, 052301
Known quasifree $\pi^0\pi^0$ channel

$\gamma + d \rightarrow p(n) + \pi^0\pi^0$ is rather well explored

**Figure:** taken from M. Dieterle et all (Eur. Phys. J. A (2015) 51: 142)
Quasifree $\pi^0\pi^0\pi^0$ channel

- $\gamma + d \rightarrow p^{(n)} + \pi^0\pi^0\pi^0$ is mostly unknown
- Highly dominated by the $\eta \rightarrow \pi^0\pi^0\pi^0$ reaction
- No data has been published on isolated $\pi^0\pi^0\pi^0$ photoproduction off deuterium
Motivation

- $\pi^0\pi^0$ channel:
  - Possible access to $d^*(2380)$ di-baryon resonance

- $\pi^0\pi^0\pi^0$ channel:
  - First time analysis of this channel

- Help test and improve models for the strong hadronic interaction
MAMI electron accelerator
Cascade of racetrack Microtrons
Final stage: Harmonic Double Sided Microtron
Electron beam energy up to 1508 MeV
A2 - CB/TAPS

- Liquid deuterium target @A2 real photon experiment
- Glasgow Photon Tagger to identify photon energy
- Crystal Ball + TAPS - nearly $2\pi$ detector system
- Roughly 470 hours of data taking
Presort and Reconstruction of $\pi^0$

- **Final state**: $d + \pi^0\pi^0(\pi^0) \rightarrow d + \gamma\gamma + \gamma\gamma(+\gamma\gamma)$
- **First step**: Require 1 charged and 4 (6) uncharged particles
- **Reconstruction of the $\pi^0$s via $\chi^2$-method from the 4(6) neutral particles

* $\pi^0$-decay probability into $\gamma\gamma = 98,823 \pm 0,034\%$
**π^0 identification**

- Kinematic cuts on coplanarity and invariant mass of π^0
- Identify η background
Deuteron identification

- Identification of deuterons is much more complicated
  - Highly dominated by quasi-free protons
  - Deuterons tend to get stuck in VETO/PID
- Kinematic cuts on $\Theta$, missing mass, $dE_E$,ToF
Deuteron time of flight

![Graph showing Deuteron and Proton in TAPS]
Check with Missing Mass

$$\text{MissingMassDeuteron, } E_\gamma = 828 \text{ MeV} - 845 \text{ MeV}$$
Check with Missing Mass
Check with Missing Mass

\[ \text{Missing Mass}_{\text{Deuteron}}, E_\gamma = 507 \text{ MeV} - 524 \text{ MeV} \]
Total coherent cross section - Preliminary

Coherent cross section of $3\pi^0$

$\gamma + d \rightarrow d + 3\pi^0$

σ_{tot} [μ barn]

E_W [MeV]

Motivation
Experimental settings
Event selection
Preliminary results
Outlook and Conclusion
Total coherent cross section - Preliminary

\[ \sigma_{tot}(\pi^0 \pi^0 d) \]
π^0-pairs:

► Achieved a somewhat precise measurement of the π^0π^0-coherent channel on deuteron
► Found signs of an enhancement at the predicted d*(2380) resonance
► Need of further statistical/analytically investigations
► Take a look at other deuteron beamtimes from A2

π^0-triplets:

► First measurement of isolated π^0π^0π^0 photoproduction off deuterons
► Results look quite promising
► Still early level of analysis
Event selection - Invariant mass cut

The figure shows a two-dimensional distribution of the invariant mass of \( \pi^0 \) versus the energy \( E_\gamma \) in MeV. The x-axis represents the energy \( E_\gamma \) ranging from 400 to 1400 MeV, and the y-axis represents the invariant mass of \( \pi^0 \) ranging from 80 to 200 MeV. The color scale indicates the distribution of events with a logarithmic color map ranging from 1 to \( 10^2 \). The cuts are indicated by red lines on the plot.
Event selection - Invariant mass cut

Inv Mass [MeV]

Counts [a.u.]

= 400 MeV - 483 MeV

= 483 MeV - 566 MeV

= 566 MeV - 649 MeV

= 649 MeV - 733 MeV

= 733 MeV - 816 MeV

= 816 MeV - 899 MeV

= 899 MeV - 982 MeV

= 982 MeV - 1066 MeV

= 1066 MeV - 1149 MeV

= 1149 MeV - 1232 MeV

= 1232 MeV - 1315 MeV

= 1315 MeV - 1399 MeV
Check with Missing Mass

\[ p_{\text{missing}} = p_{\text{beam}} + p_{\text{target}} - p_{\pi^0} \]

\[ m_{\text{missing}}^{\text{old}} = \sqrt{E^2 - (\vec{p}_{\text{missing}})^2} \]

\[ m_{\text{missing}}^{\text{new}} = \frac{(p_{\text{beam}} - p_{\pi^0})^2}{2(E_{\pi^0} - E_{\text{beam}})} \]
Check with Missing Mass

![Graph showing the relationship between missing mass and new missing mass. The x-axis represents the old missing mass [MeV], ranging from -100 to 400 MeV. The y-axis represents the new missing mass [MeV], ranging from -100 to 400 MeV. The color scale on the right indicates the number of events, with colors ranging from purple (low) to red (high).]
Event selection - Coplanarity cut

CopCut

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

\( \phi \text{ between } d \text{ and } \pi^- \text{ Meson} \)

\( 0 \)

\( 50 \)

\( 100 \)

\( 150 \)

\( 200 \)

\( 250 \)

\( 300 \)

\( 350 \)

\( 400 \)

\( 600 \)

\( 800 \)

\( 1000 \)

\( 1200 \)

\( 1400 \)

\( 10^2 \)

\( 10 \)

\( 1 \)
Event selection - Coplanarity cut
Event selection - Coplanarity cut

Coplanarity stopped deuteron

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<tbody>
<tr>
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<tr>
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<tr>
<td>Mean y</td>
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<tr>
<td>RMS x</td>
</tr>
<tr>
<td>RMS y</td>
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\( \gamma E \)
Event selection - Theta information cut

The plot shows a 2D distribution of events in the $E_\gamma$-d theta plane, with color-coded intensity levels indicating the number of events. The cuts are applied to select events based on the theta information.

- The x-axis represents the energy $E_\gamma$ in MeV.
- The y-axis represents the angle between d and $\pi$-Meson ($\theta$).
- The intensity levels are color-coded from blue (low intensity) to red (high intensity), with a logarithmic scale.

The cuts are applied to separate event selections, with a focus on the BtBCut as indicated in the graph.
Event selection - Theta cut

- For each energy range (400 MeV - 483 MeV, 483 MeV - 566 MeV, 566 MeV - 649 MeV, etc.), there are multiple plots showing the distribution of counts for BackToBack_Calc. Each plot represents a specific energy range and shows the counts in a.u. for different values of BackToBack_Calc. The energy ranges are as follows:
  - 400 MeV - 483 MeV
  - 483 MeV - 566 MeV
  - 566 MeV - 649 MeV
  - 649 MeV - 733 MeV
  - 733 MeV - 816 MeV
  - 816 MeV - 899 MeV
  - 899 MeV - 982 MeV
  - 982 MeV - 1066 MeV
  - 1066 MeV - 1149 MeV
  - 1149 MeV - 1232 MeV
  - 1232 MeV - 1315 MeV
  - 1315 MeV - 1399 MeV

- The plots are likely used to analyze the efficiency and angular distribution of events across different energy ranges, which is crucial for understanding the behavior of particles in high-energy physics experiments.
Event selection - Theta cut

\[ \theta \text{ difference stopped } d \]

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<td>RMS y</td>
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ToF With Cuts - MC

ToF_TAPS_MC_WithCut

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ToF with Cuts - Data

TOF_TAPS_3

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<td>RMS x</td>
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<td>RMS y</td>
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![Graph showing ToF with Cuts - Data](image)
Event selection - Missing Mass cut

MMDeut_cut

γ-Energy in MeV

Missing Mass in MeV (gauged on Deuteron)
Event selection - Missing Mass cut
Conclusion and Outlook

- A reasonable match with the coherent $\pi^0\pi^0$ model.
- Statistical and/or analytically problems in regions below 2450 W or above 2800 W.
- For the $\pi^0\pi^0\pi^0$ channel, still more data available (Dec + Feb).
CS Beamtime separated

![Graphs showing total cross section vs. energy for different periods: May 2009, February 2009, December 2007, and all combined.]
CS Beamtime separated - W

Total CS May_09

Total CS Feb_09

Total CS Dec_07
Total Efficiency

Global Detector Efficiency May_09

Global Detector Efficiency Feb_09

Global Detector Efficiency Dec_07
ToF With Cuts - Data

**TOF_TAPS_3**

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<thead>
<tr>
<th>Entry</th>
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![Graph showing the distribution of data points with energy (E) and time of flight (ToF) axes. The graph includes a color legend indicating different energy bins.]
ToF With Cuts - Data

TOF_TAPS_WithCut

Entries: 4620729
Mean x: 9.138
Mean y: 170.4
RMS x: 2.493
RMS y: 120.1
## Beamtime overview

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<td>10 nA</td>
<td>5 nA</td>
<td>4.5 nA</td>
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<td>413 - 1401 MeV</td>
<td>423 - 1447 MeV</td>
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<tr>
<td>collimator</td>
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<td>10 μm Cu</td>
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<td>$LD_2$</td>
<td>$LD_2$</td>
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<td>&gt; 300 MeV</td>
<td>&gt; 300 MeV</td>
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