Measurement of $\pi^0\pi^{+/-}$ Photoproduction off the Deuteron and D-butanol targets

Meson Conference '18, Krakow

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Overview

- Introduction and Motivation for Photoproduction
- Motivation for Photoproduction with $\pi^0\pi^{+/-}$
- Experimental Setup
- Analysis
- Preliminary Results
- Summary and Outlook
- References

Introduction and Motivation for Photoproduction

✓ An efficient tool for the study of decays of nucleon resonances

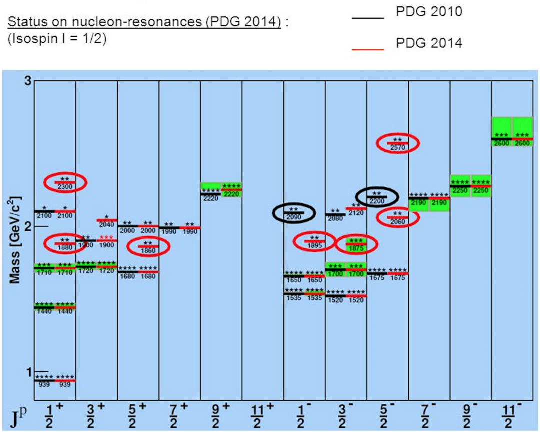
✓ Excitation spectrum of hadrons → the underlying symmetries and the internal degrees of freedom

Photoproduction of pion pairs off nuclei

- insight into low energy **QCD**(large α)
- in medium resonances of nucleons
- Baryons could have less internal degrees of freedom than predicted in quark models
- possibilities of more complex baryonic structures(e.g pentaquarks etc.)

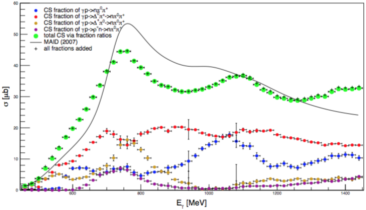
Motivation for Photoproduction with $\pi^0\pi^{+/-}$

For nucleon resonances the effective degrees of freedom are not well understood and many more states have been predicted than observed.[**larger mass region of the spectrum**]



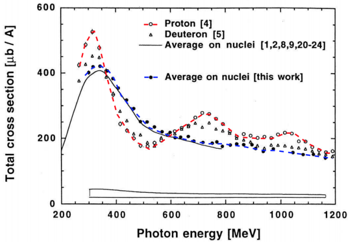
Motivation for Photoproduction with $\pi^0\pi^{+/-}$

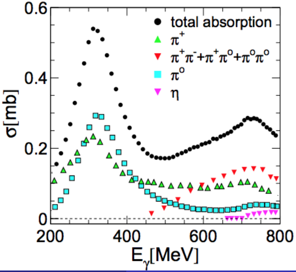
- Higher lying resonances have tendency of cascade-like decays with an intermediate state $\rightarrow$ double pion production interesting.



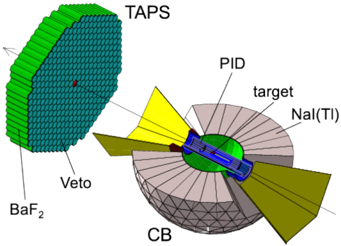
- Special interests in $\pi^0\pi^{+/-}$ include also contributions from ρ meson (forbidden in $\pi^0\pi^0$)

- Influence of ρ on 2nd resonance peak ➡️ study with proton, deuteron, ^{4}He and heavier targets

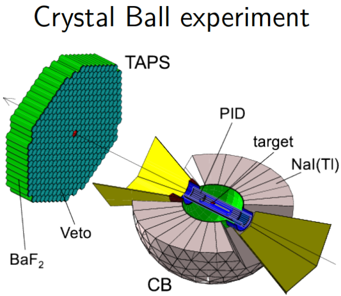


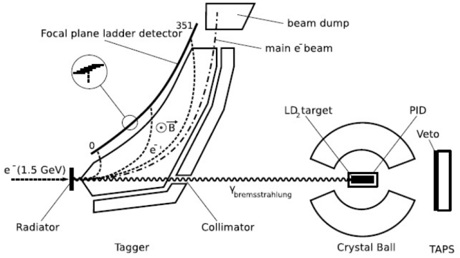


Crystal Ball experiment



Experimental Setup of A2 Mainz





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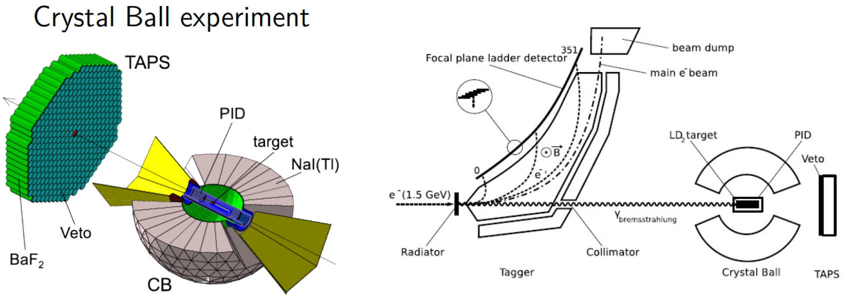

Figure: Schematic overview of the Exp. Setup

Parameters for Data taking with Unpolarized and Polarized targets

Parameters	Unpolarized target	Polarized target
Target type	Liq Deuterium[LD_2]	dButanol
Target length[cm]	3.02	1.88
Multiplicity trigger	M2+	M2+
Photon tagger range[MeV]	400 to 1400	400 to 1400
Radiator	Moeller	Moeller
e^- beam energy[MeV]	1575.5 MeV	1557 MeV

Table: Parameters for deuterium(May 2009) and dButanol(Dec 2015) beamtimes

About the Interested Channels

Investigated reactions of baryon spectrum: NN, πN and γN(limited extent)

Interested Amplitudes:

$\gamma p(n) \longrightarrow \pi^+\pi^0 n(n)$

$\hookrightarrow$ 4 channels:

- Phase space
- via $\Delta^+ \longrightarrow \pi^+ n$
- via $\Delta^0 \longrightarrow \pi^0 n$
- via $\rho^+ \longrightarrow \pi^+\pi^0$

$\gamma n(p) \longrightarrow \pi^-\pi^0 p(p)$

$\hookrightarrow$ 4 channels:

- Phase space
- via $\Delta^0 \longrightarrow \pi^- p$
- via $\Delta^+ \longrightarrow \pi^0 p$
- via $\rho^- \longrightarrow \pi^-\pi^0$

The ρ channel is forbidden for the uncharged $\pi^0\pi^0$ final state (isospin conservation).

$\gamma p(n) \longrightarrow \pi^+\pi^0 n(n)$

$\hookrightarrow$ detected particles:

- 1 charged:
  - π^+
- 3 uncharged:
  - $\pi^0 \longrightarrow \gamma\gamma$ (98.823 %)
  - neutron participant

$\gamma n(p) \longrightarrow \pi^-\pi^0 p(p)$

$\hookrightarrow$ detected particles:

- 2 charged:
  - π^-
  - proton participant
- 2 uncharged:
  - $\pi^0 \longrightarrow \gamma\gamma$ (98.823 %)

Further selection of events necessary through cuts and corrections

Various Cuts for event selection:

- charged particle identification via energy left in PID versus energy in CB ("dE-E cut")

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- coplanarity of the final state (ϕ-angle between the $\pi^{+/-}\pi^0$ system and the participant nucleon)

Analysis
Background Rejection

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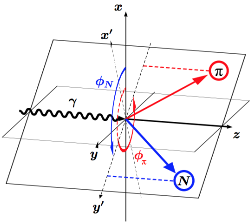

meson candidate(red) and recoil nucleon(blue) lie in the reaction plane, separated by azi. δφ = 180 °

Special Corrections on MC data

- Nucleon Detection Efficiency
  [to compensate for imperfections in the implementation of the experimental setup in GEANT and inefficiencies in the PID and the TAPS vetoes]

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- CB Energy sum correction/CDF
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- Gap correction
  [acceptance hole between the CB and TAPS, where no particles are detected]

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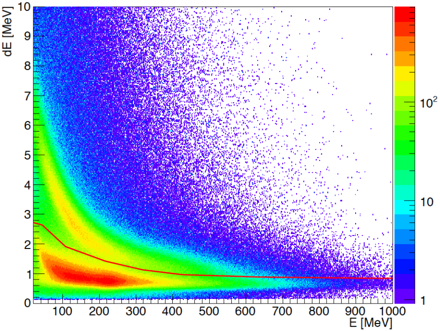
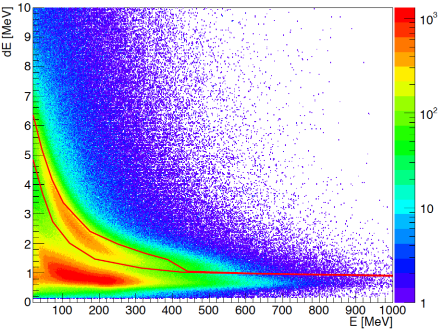
- divide data yield by the efficiency

Proton and Charged Pion identification with PID and CB



(a) For π^+ *channel* : pion

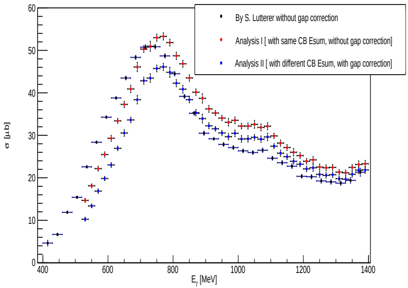


(b) For π^- *channel* : pion and proton

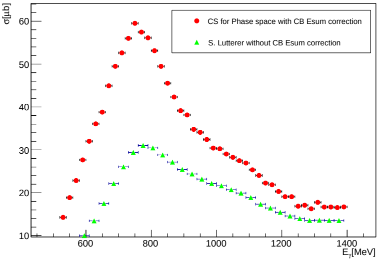
Figure: Identification of charged particle

Preliminary Results

Total Cross section comparison for LD_2 target [May 2009 beamtime]



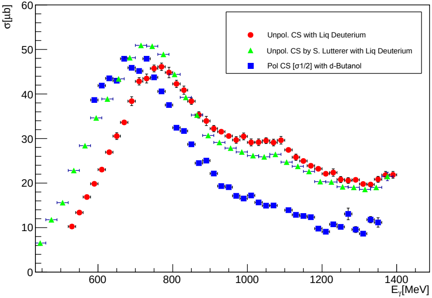
(a) For reaction with final state $\pi^0\pi^+$



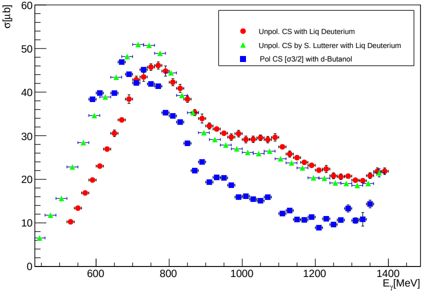
(b) Influence of the CB energy sum correction on total Cross section for $\pi^0\pi^- p$ final state

Preliminary Results

Comparison plot of total cross sections in terms of E_γ with LD_2 and d-Butanol targets



(a) Comparison for reaction with final state $\pi^0\pi^+$



(b) Comparison for reaction with final state $\pi^0\pi^+$

Preliminary Results

Comparison plot of total cross sections in terms of W(COM energy) with LD_2 and d-Butanol targets

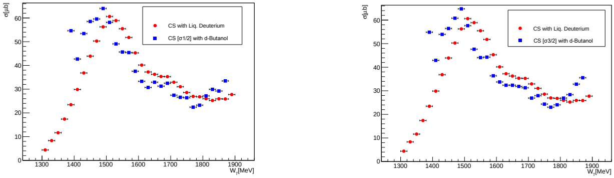


Figure: For $\gamma p \to \pi^0\pi^+ n$ channel

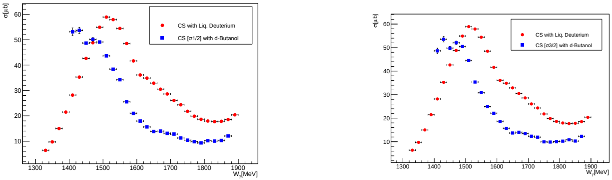


Figure: For $\gamma n \to \pi^0\pi^- p$ channel

Preliminary Results

Cross section Comparison with LD_2 and d-Butanol targets

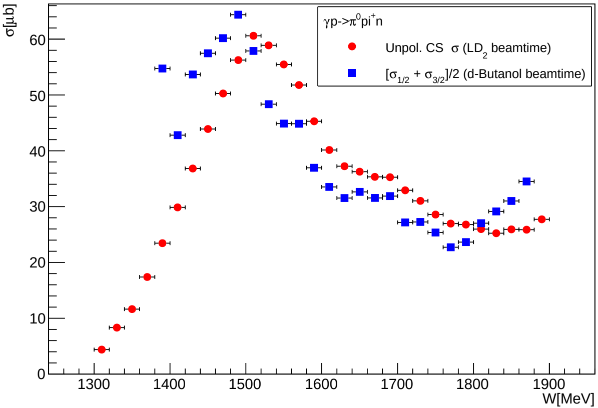


Figure: Comparison for reaction with final state $\pi^0\pi^+$

Preliminary Results: E-observable extraction

Asymmetry between the two helicity states

E-observable determines the conribution from $\sigma_{1/2}$ and $\sigma_{3/2}$ components

$$E_{version1} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sigma_{diff}}{\sigma_{sum}} \text{ or, } E_{version2} = \frac{\sigma_{diff}}{2\sigma_{unpol.}}$$

where, $\sigma_{1/2} : photon - spin \nparallel target - spin$
and $\sigma_{3/2} : photon - spin \parallel target - spin$

•**V1(Carbon subtraction method):** to determine the carbon and oxygen contributions to the dButanol
•**V2(Direct method):** extract tot. CS from dButanol beamtime → to be normalized using 2×unpolarized CS.

- *Circularly polarized photon beam* impinging on a *longitudinally polarized nucleon target*

Preliminary Results: E-observable extraction

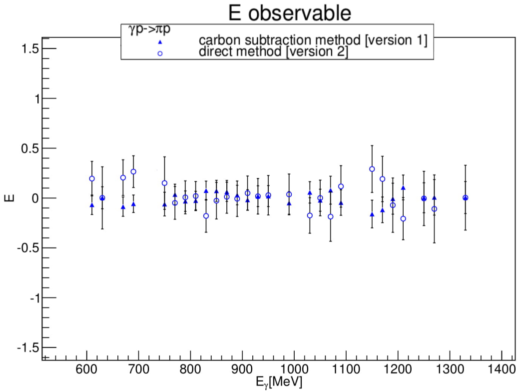


Figure: Preliminary E-observable for reaction with final state $\pi^0\pi^+$

Preliminary result indicates no significant asymmetry!

Summary and Outlook

Summary :

- Preliminary cross sections for both mixed charge double pion production channels extracted
- Compare results from final analysis with previous data
- Extraction of E-observable with hydrogen normalization and carbon subtraction metods
- d-Butanol measurements are still in early stage of analysis

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Outlook :

- Need further investigation on detection efficiency and bkg. subtraction
- Data from further beamtimes to be analyzed

References

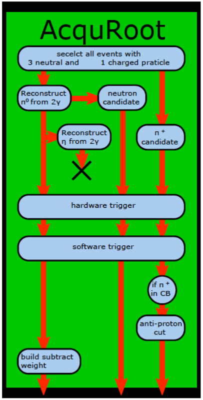
- https://jazz.physik.unibas.ch/site/talks/krusche_dnp08.pdf
- F. Zehr and B. et al. Krusche. Photoproduction of $\pi_0\pi_-$ and $\pi 0\pi_+$ -pairs off the proton from threshold to the second resonance region. The European Physical Journal A, 48(7):98, 2012. ISSN 1434-6001. doi: 10.1140/epja/i2012-12098-1.
- https://jazz.physik.unibas.ch/site/talks/Abt_DPG_17_03_talk.pdf
- https://jazz.physik.unibas.ch/site/talks/lutterer_dpg_talk_pion_photoproduction_30032017.pdf.
- https://edoc.unibas.ch/39089/1/Lilian_Witthauer.pdf
- https://edoc.unibas.ch/55107/1/thesis_kaeser_2017.pdf

THANK YOU

backup

Presort

- select events with: 3 neutral and 1 charged
- reconstruct π^0 from 2γ with χ^2-test where the 3^{rd} particle is assumed to be a neutron
- apply χ^2-test for η, when in favor $\longrightarrow$ discard event
- Pulse shape analysis for γ and neutron
- $\Delta E - E$ analysis for π^+



E-observable calculation

double polarization observable E, which allows to split the results for total cross sections and angular distributions into their helicity 1/2 and helicity 3/2 parts.
'normalization factors' consisting of the detection efficiency ϵ, target density ρ and the branching ratio Γ_i/Γ

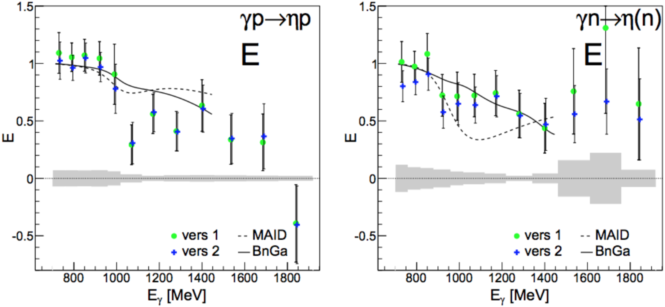


Figure: Example of a standard E-obs plot

Analysis

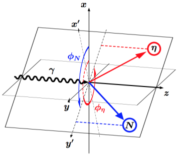
$$m_{n[part.]} = \sqrt{(p^4_{beam} + p^4_{target} - p^4_{\pi^+} - p^4_{\pi^0})^2}$$

where,

- $p^4_{beam} = (0{,}0{,}E\gamma, E_\gamma)$ incoming tagged photon
- $p^4_{target} = (0{,}0{,}0{,}m_{p[part.]})$ participant proton initially assumed at rest (fermi momentum smearing increases inaccuracy of this assumption)
- $p^4_{\pi^+}$ and $p^4_{\pi^0}$ measured final state pions (accurate for $p^4_{\pi^0}$ and with slight correction factor for low energy $p^4_{\pi^+}$)
- $m_{n[part.]}$ = mass of the final state participant neutron
- spectator omitted from this calculation (assumed $p^4_{n[spec.]}$(initial) = $p^4_{n[spec.]}$(final))

Background Rejection

Coplanarity cut−



meson candiate(red) and recoil nucleon(blue) lie in the reaction plane, separated by azi. $\delta\phi = 180^o$

Missing mass cut−

mass M of the nucleon can be calculated from the initial state and the detected final state particles, assuming that the nucleon in the initial state is at rest:

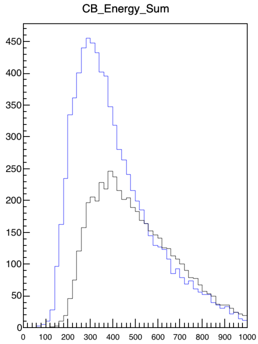
$$M = \sqrt{(E_\gamma + m_N - E_\eta)^2 - (\vec{p}_\gamma - \vec{p}_\eta)^2},$$

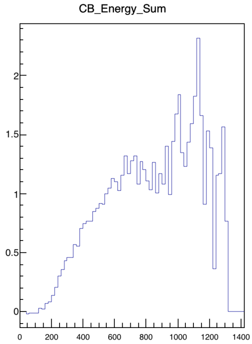
where E_γ and $\vec{p}_\gamma$ are energy and momentum of the incident photon beam, E_η and $\vec{p}_\eta$ are the energy and momentum of the η meson, and m_N is the nucleon mass. With a correct identification of the reaction, the corresponding spectra should have a clear peak at the nucleon mass m_N. Thus, the nucleon mass was directly subtracted to get the missing mass:

$$\Delta M = M - m_N\,.$$

Corrections

software trigger [cdf/CB energy sum]: The CB energy sum trigger is checking the total sum of the analog signals of all NaI(TI) crystals against a threshold, which corresponds to a certain energy. photon energy sum depends on the energy and angular distribution of the -meson and thus a certain model dependence is introduced





Corrections

nucleon detection efficiency correction: The PID detector was shifted upstream during the December 2007 beamtime and to ensure a clean discrimination of protons and neutrons, a strict cut on the nucleon polar angle was applied in the data analysis. The corrections described here were determined for deuterium beamtime by setting the same detector thresholds in the hydrogen analysis and the corresponding deuterium analysis. This is most crucial for the PID and Veto thresholds that have a strong influence on the proton detection efficiency, and the TAPS CFD thresholds, which are important for the detection of neutrons.

Example of mm-fit for C-subtraction method