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

NSTAR 2019, Bonn

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June 11th, '19

Overview

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

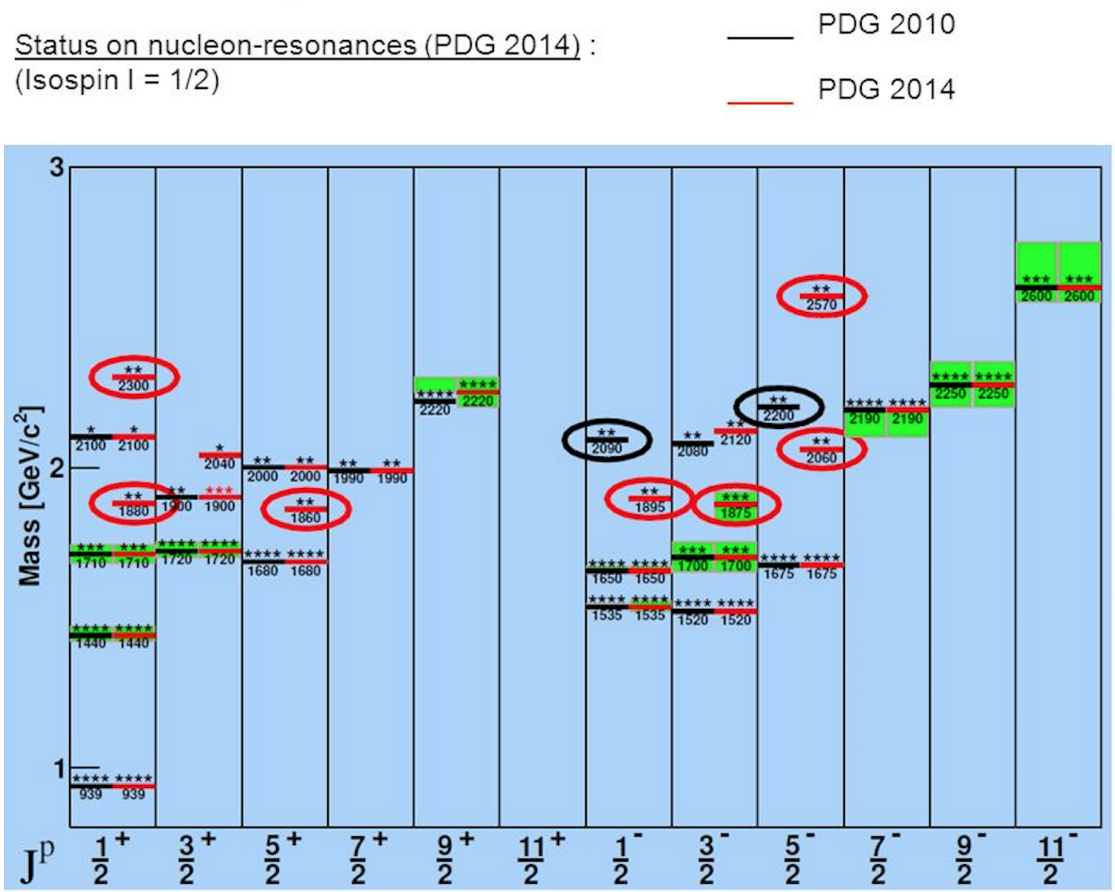
Introduction and Motivation for Photoproduction

✓ An efficient tool for the study of decays of nucleon resonances
✓ Excitation spectrum of hadrons $\rightarrow$ 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.)

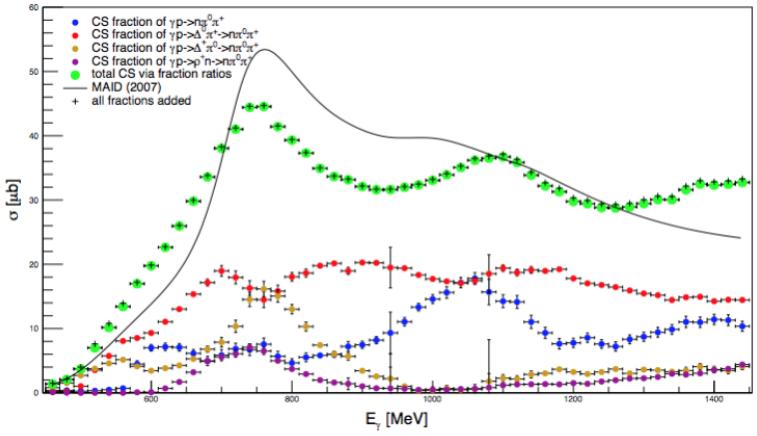
Motivation for Photoproduction with $\pi^0\pi^{+/-}$

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**]



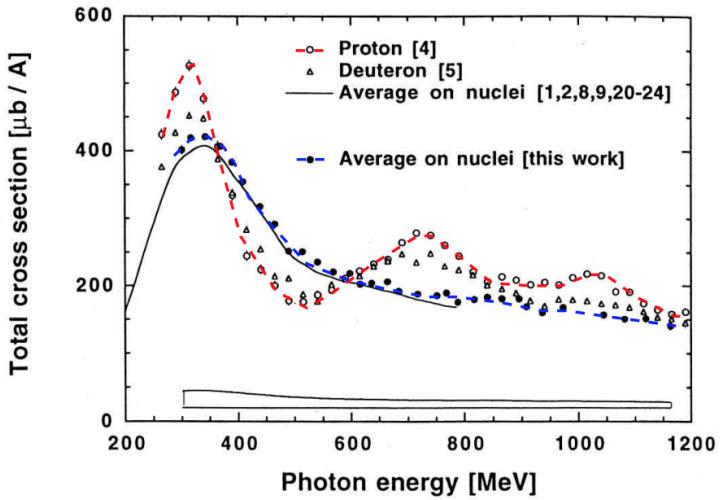
Motivation for Photoproduction with $\pi^0\pi^{+/-}$

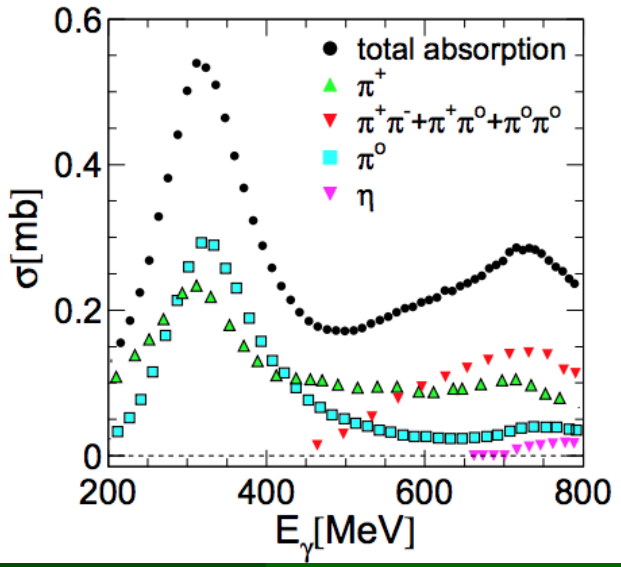
- Higher lying resonances have tendency of cascade-like decays with an intermediate state $\rightarrow$ double pion production interesting.



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

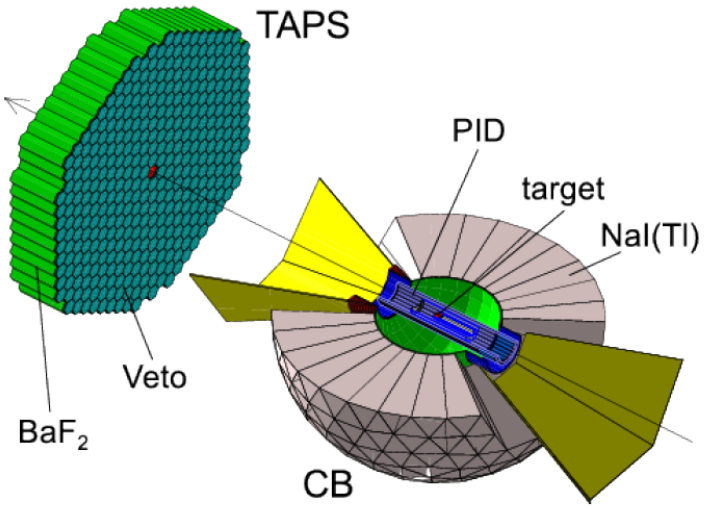
- Influence of ρ on 2nd resonance peak ➡️ study with proton, deuteron, ^{4}He and heavier targets





Experimental Setup of A2 Mainz

Crystal Ball experiment



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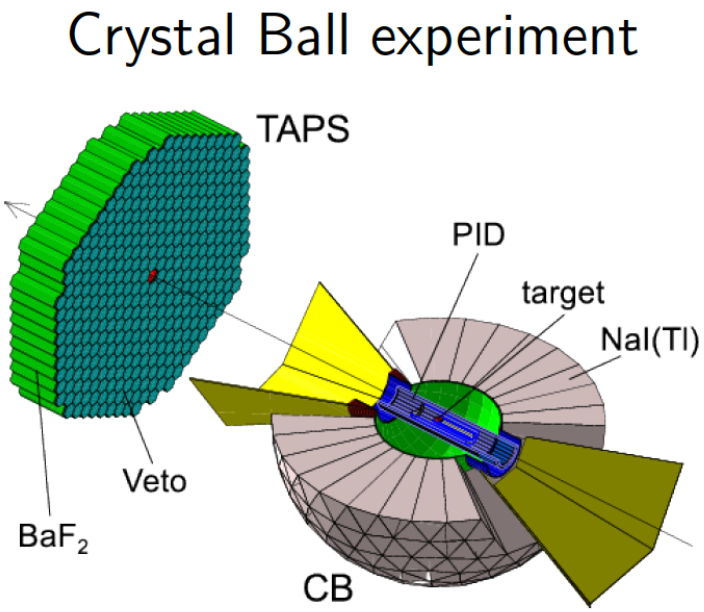

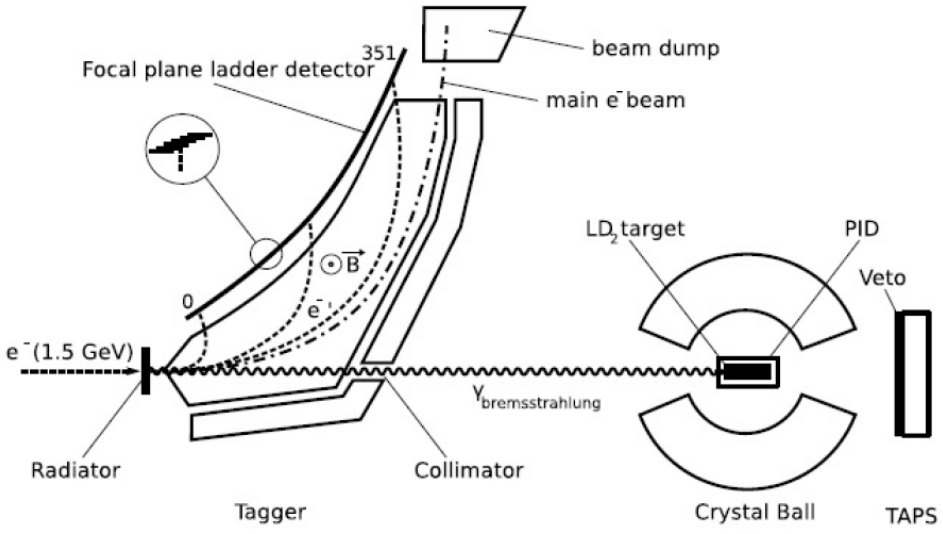

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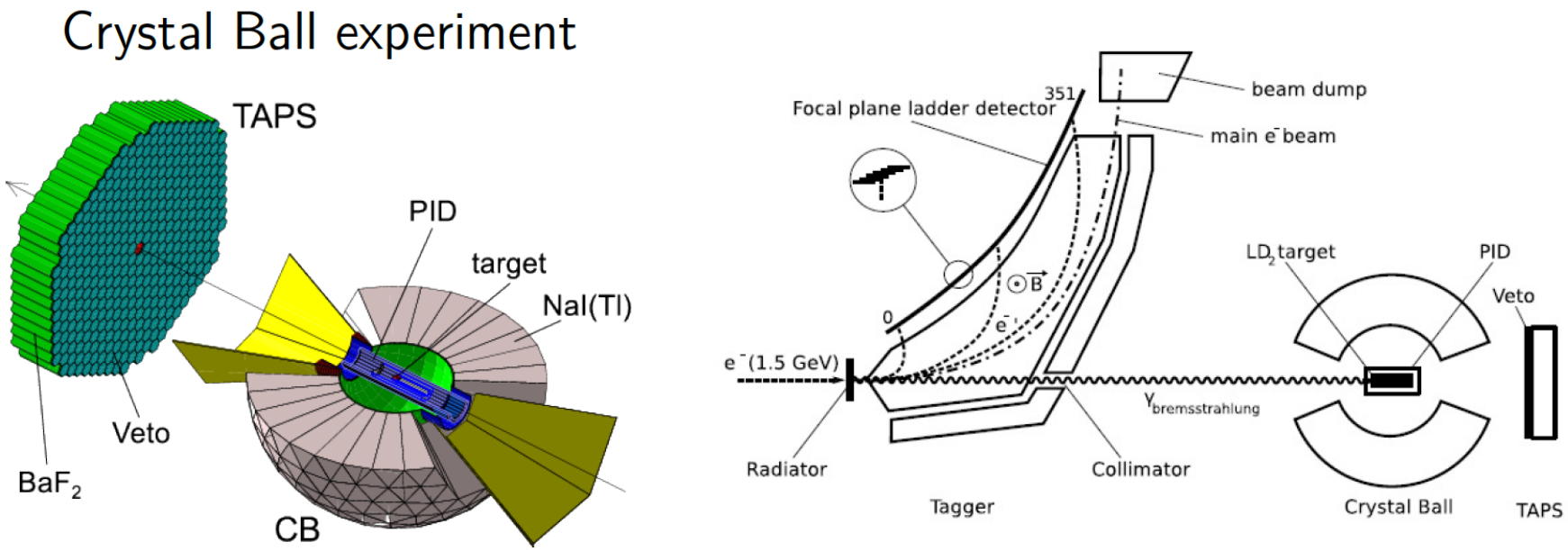

Figure: Schematic overview of the Exp. Setup

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)

About the Interested Channels

Interested Amplitudes:

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

↪ 4 channels:

Phase space

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

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

↪ 4 channels:

Phase space

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

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

↪ detected particles:

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

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

↪ 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

Analysis

Background Rejection

Various Cuts for event selection:

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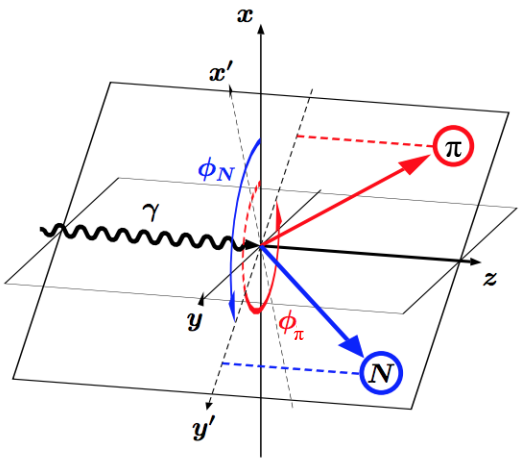

meson candidate(red) and recoil nucleon(blue) lie in the reaction plane, separated by azi. $\delta\varphi = 180°$

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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  [The energy-sum trigger checks the sum of the deposited energies of the particles in CB against a threshold value]
- Gap correction
  [acceptance hole between the CB and TAPS, where no particles are detected]

Analysis

Calculating Cross sections

- apply all cuts and corrections to data

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- retrieve photon flux from tagger channels
- generate MC data for channels with Geant4 simulation
- apply all the cuts and corrections to MC data
- divide data yield by the efficiency

Preliminary Results

Total Cross section comparison for LD_2 target [May'09 beamtime]

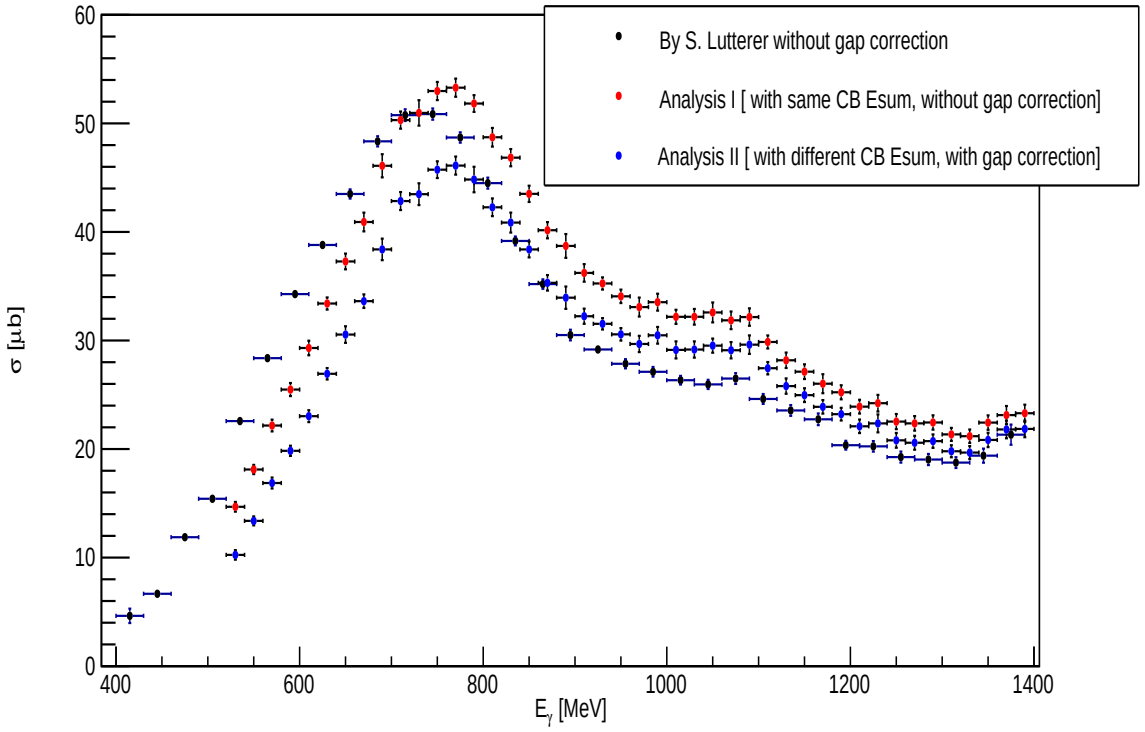
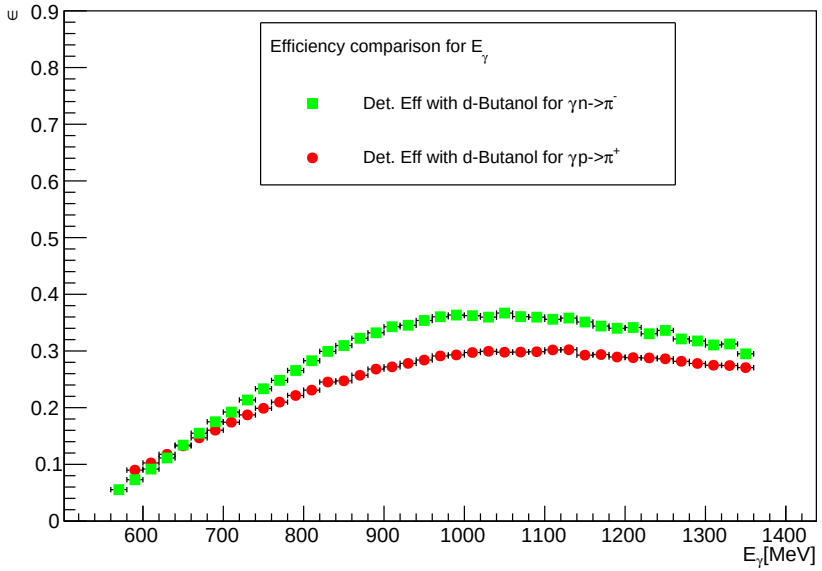
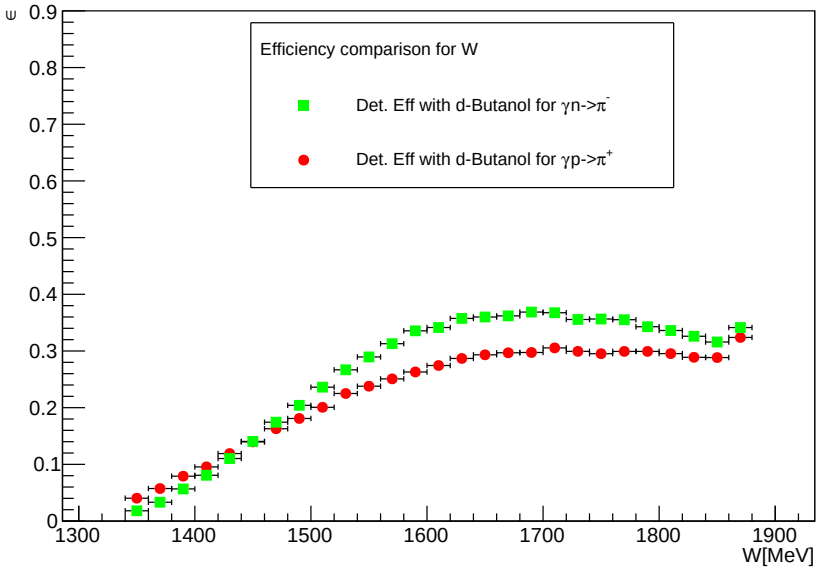


Figure: For reaction with final state $\pi^0\pi^+n$

Comparison of detection efficiency for the respective channels with d-Butanol targets





E-observable extraction

Asymmetry between the two helicity states

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

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

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

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

Calculation of E-observable and the two helicity state cross sections

Version	E
I	$\frac{\sigma_\Delta}{\sigma_\Sigma}$
II	$\frac{\sigma_\Delta}{2\sigma_0}$

Table: Overview of the versions used to extract E

where,
$\sigma_\Sigma = \sigma_{1/2}+\sigma_{3/2}$, $\sigma_\Delta = \sigma_{3/2}$-$\sigma_{1/2}$ and $\sigma_0 =$ unpol. x-sec.

Version	$\sigma_{1/2}$	$\sigma_{3/2}$
I	$\sigma_0(1+E)$	$\sigma_0(1-E)$
II	$\frac{\sigma_\Sigma+\sigma_\Delta}{2}$	$\frac{\sigma_\Sigma-\sigma_\Delta}{2}$

Table: Overview of the versions used to extract the two helicity state cross section

Preliminary Results

Missing mass for difference and sum of the yields

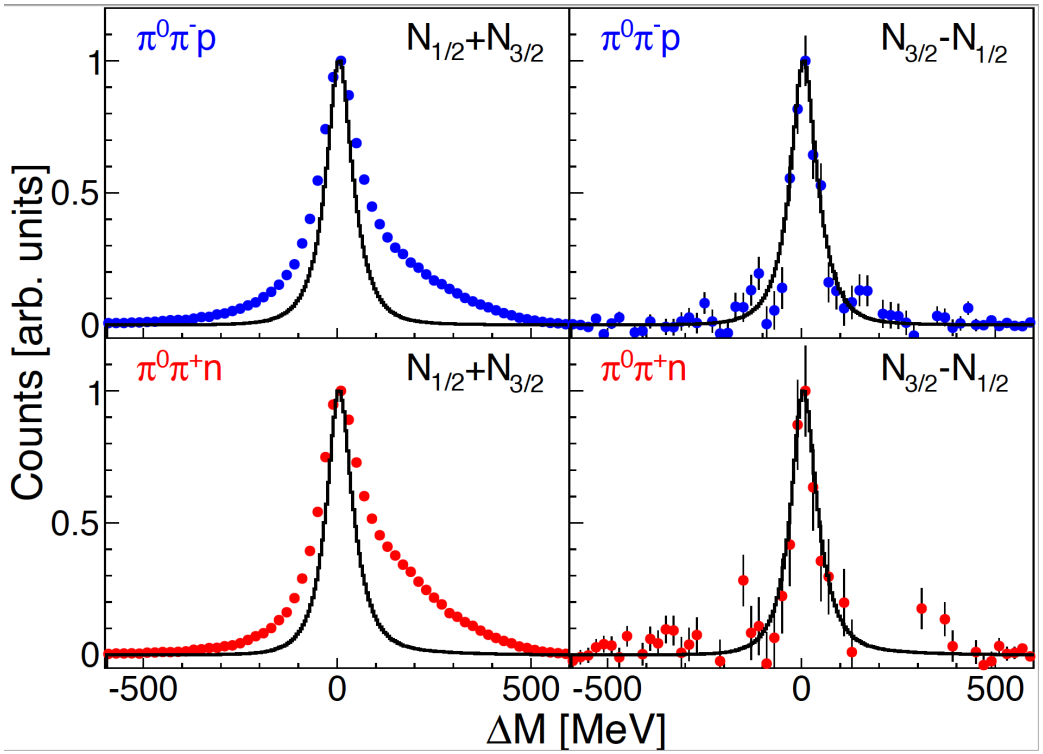


Figure: ΔM for dButanol for the difference $N_{3/2} - N_{1/2}$, and the sum $N_{1/2} + N_{3/2}$ of the two helicity states for the reaction on the proton (blue) and the neutron (red).

Preliminary Results: E-observable extraction with dButanol target

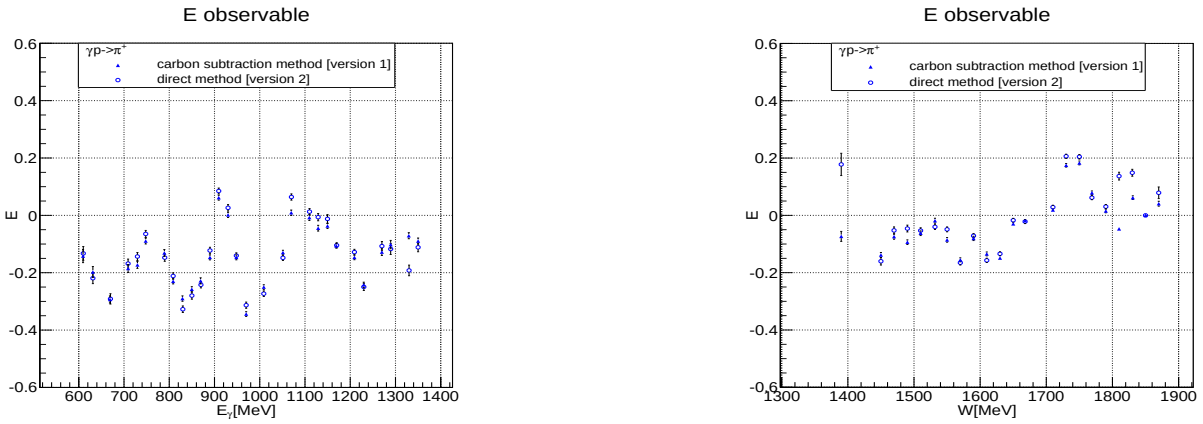


Figure: Preliminary E-observable for reaction with final state $\gamma p \rightarrow \pi^0 \pi^+ n$

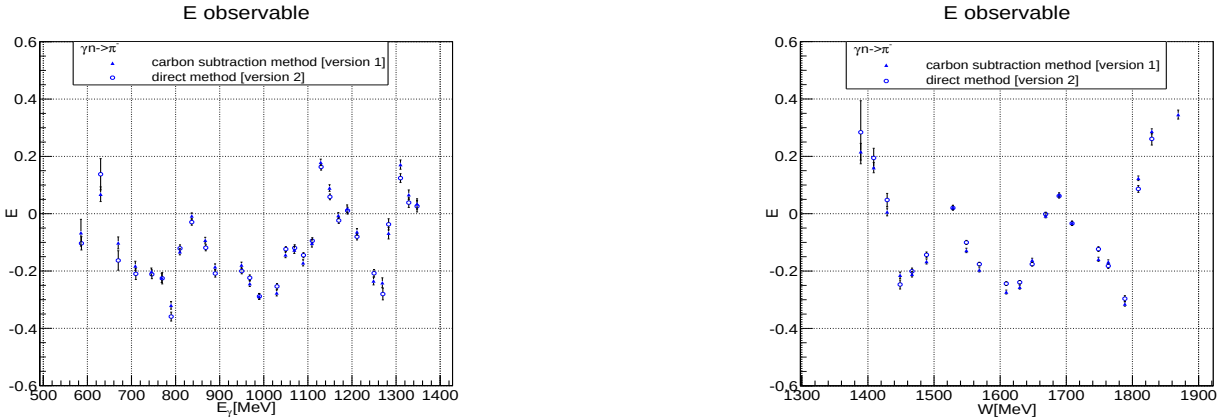


Figure: Preliminary E-observable for reaction with final state $\pi^0 \pi^- p$

Preliminary Results

Comparison plots of total cross sections between liq.deuterium and d-Butanol targets

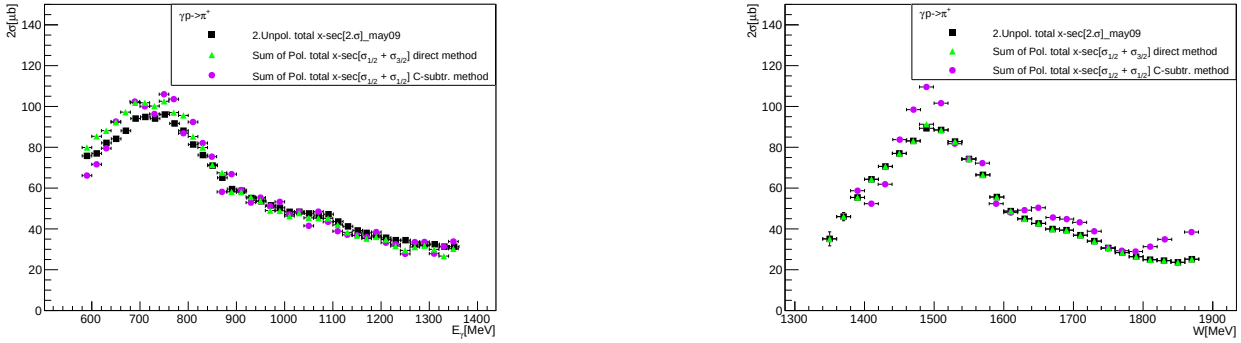


Figure: For $\gamma p \rightarrow \pi^0 \pi^+ n$ channel

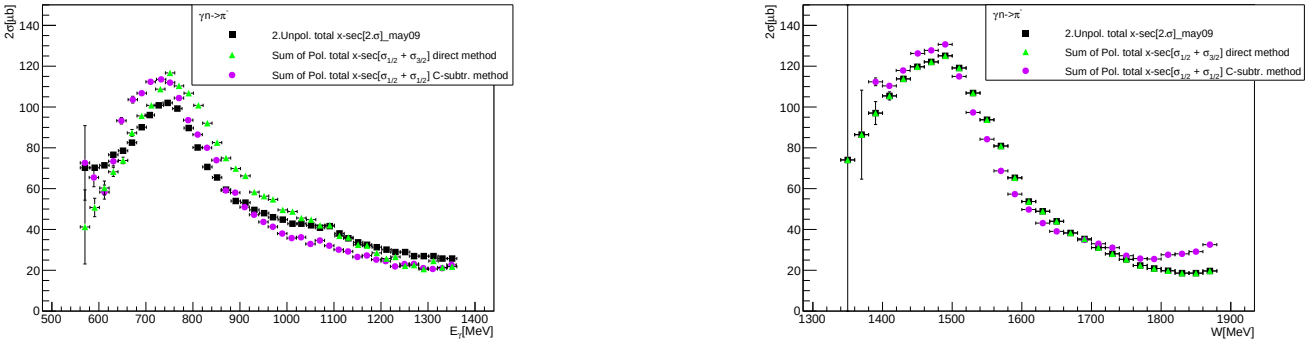
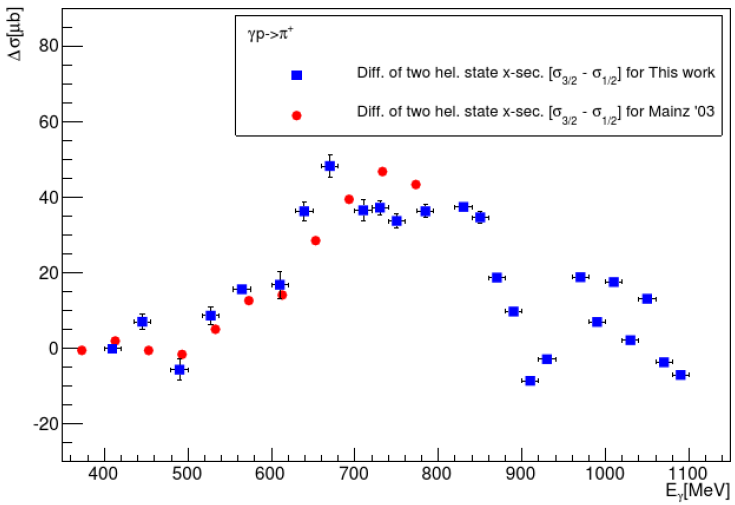


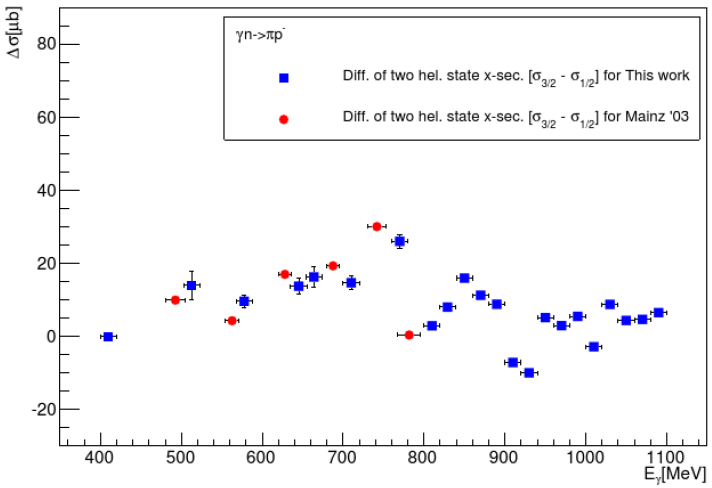
Figure: For $\gamma n \rightarrow \pi^0 \pi^- p$ channel

Preliminary Results

Comparison of Difference of the two helicity state cross sections [σ_Δ] with d-Butanol target



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



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

Two helicity state cross sections extracted with different versions [in terms of W]

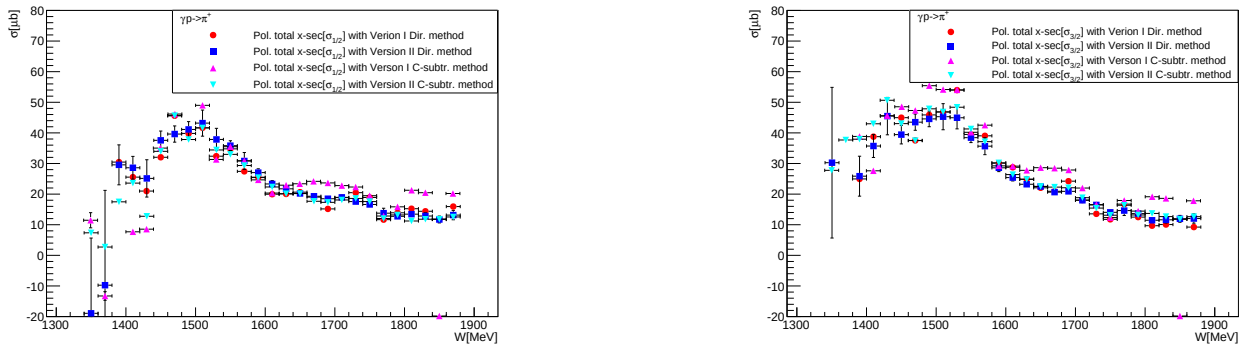


Figure: For $\gamma p \rightarrow \pi^0 \pi^+ n$ channel

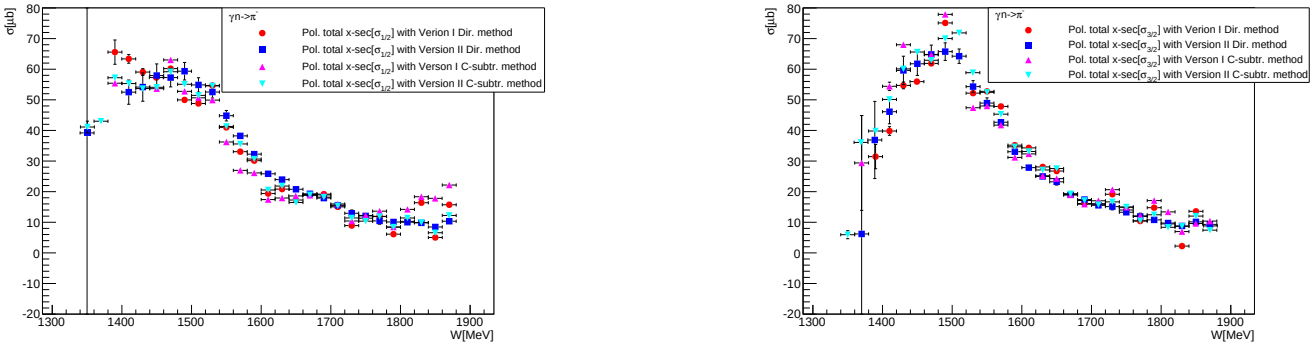


Figure: For $\gamma n \rightarrow \pi^0 \pi^- p$ channel

Summary and Outlook

Summary :

- Preliminary cross sections for both mixed charged double pion production channels extracted
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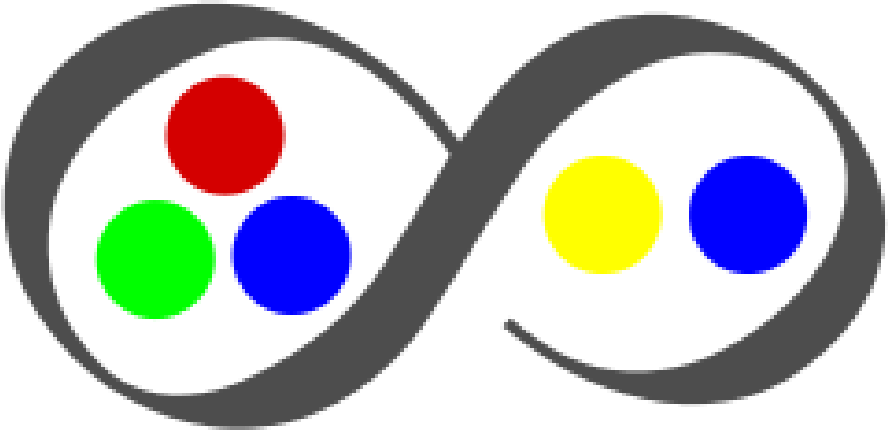
Outlook :

- Further investigation on data from other d-Butanol beamtimes (e.g Mar˙15, May˙16 etc.)
- Comparison with the Bn-Ga predicted model

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

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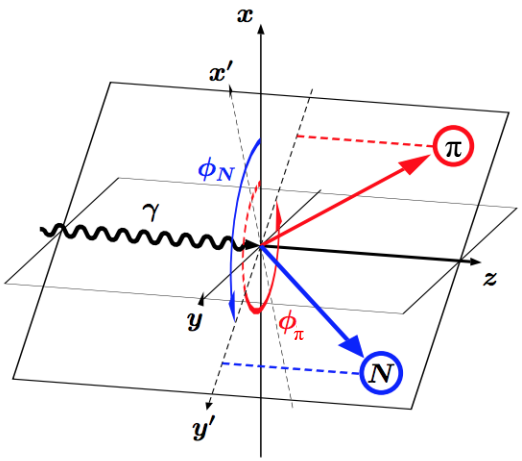
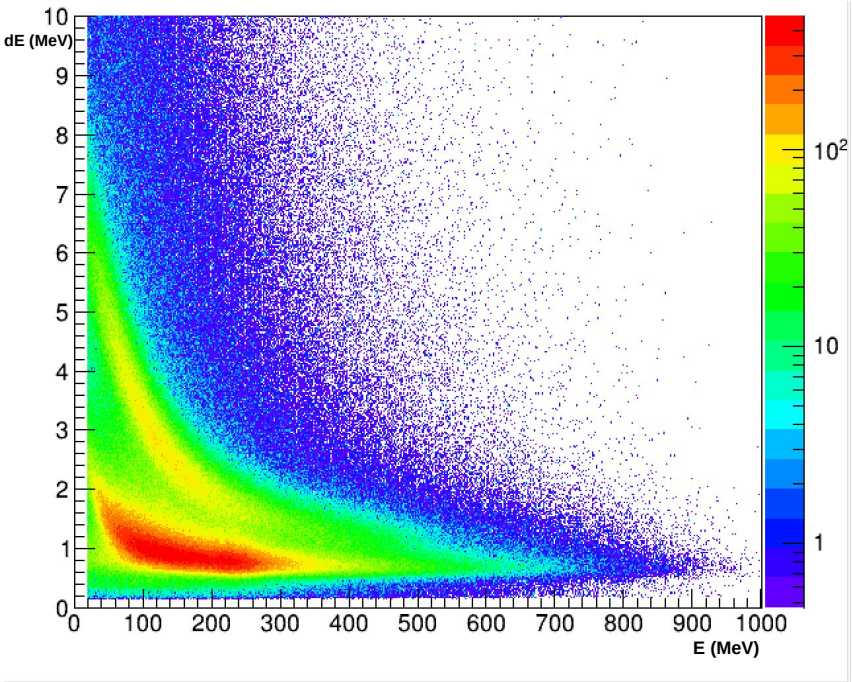


meson candidate(red) and recoil nucleon(blue) lie in the reaction plane, separated by azi. $\delta\varphi = 180°$

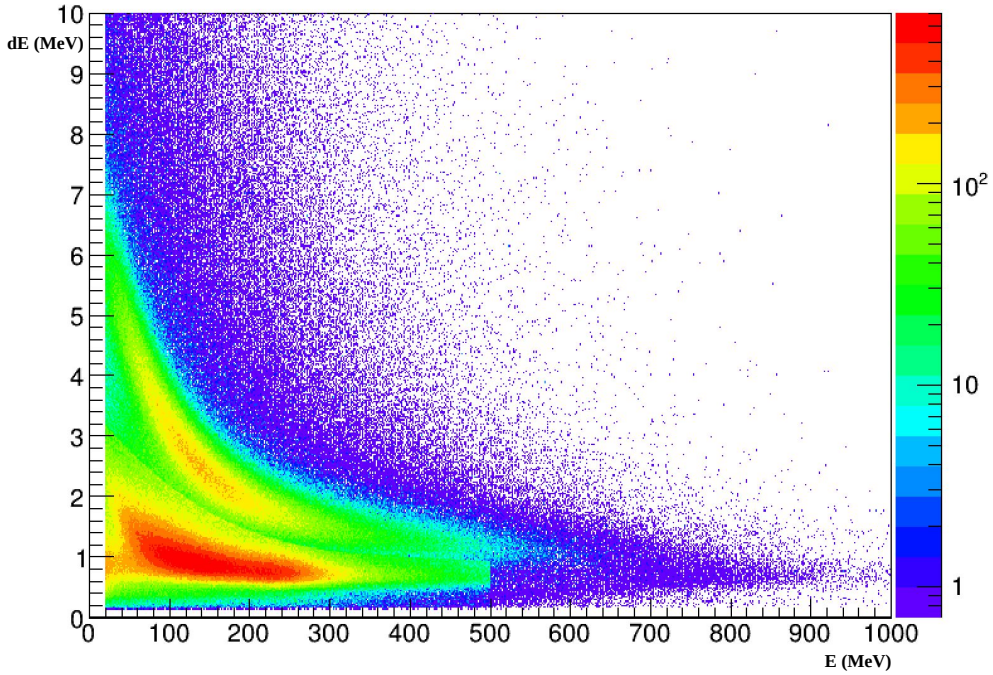
Analysis-Result

dE-E Proton exclusion and selection cut

Proton and Charged Pion identification with PID and CB



(a) For π^+ *channel* : pion

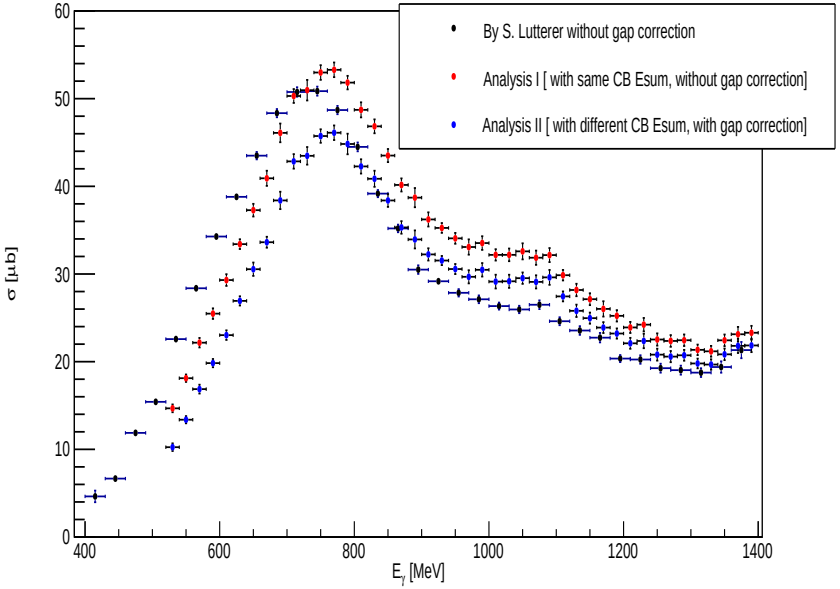


(b) For π^- *channel* : pion and proton

Figure: Identification of charged particle

Preliminary Results

Total Cross section comparison for LD_2 target [May'09 beamtime]



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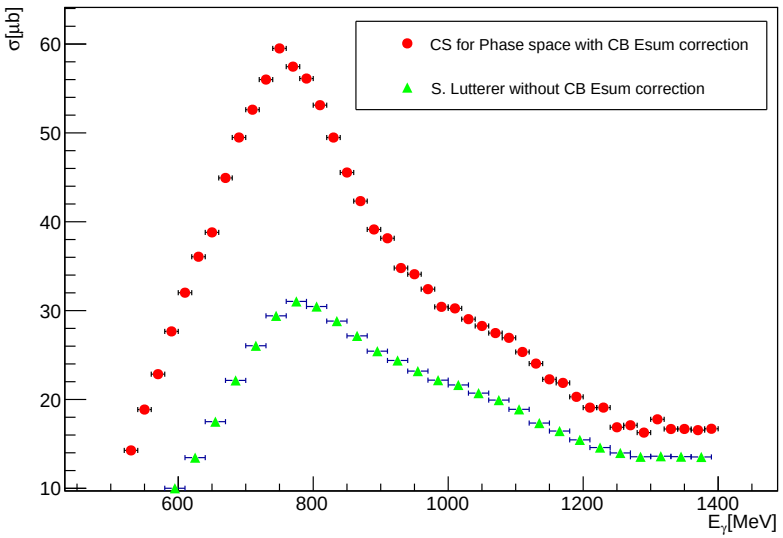

(b) Influence of the CB energy sum & Gap correction on total Cross section for $\pi^0\pi^-p$ final state

Preliminary Results

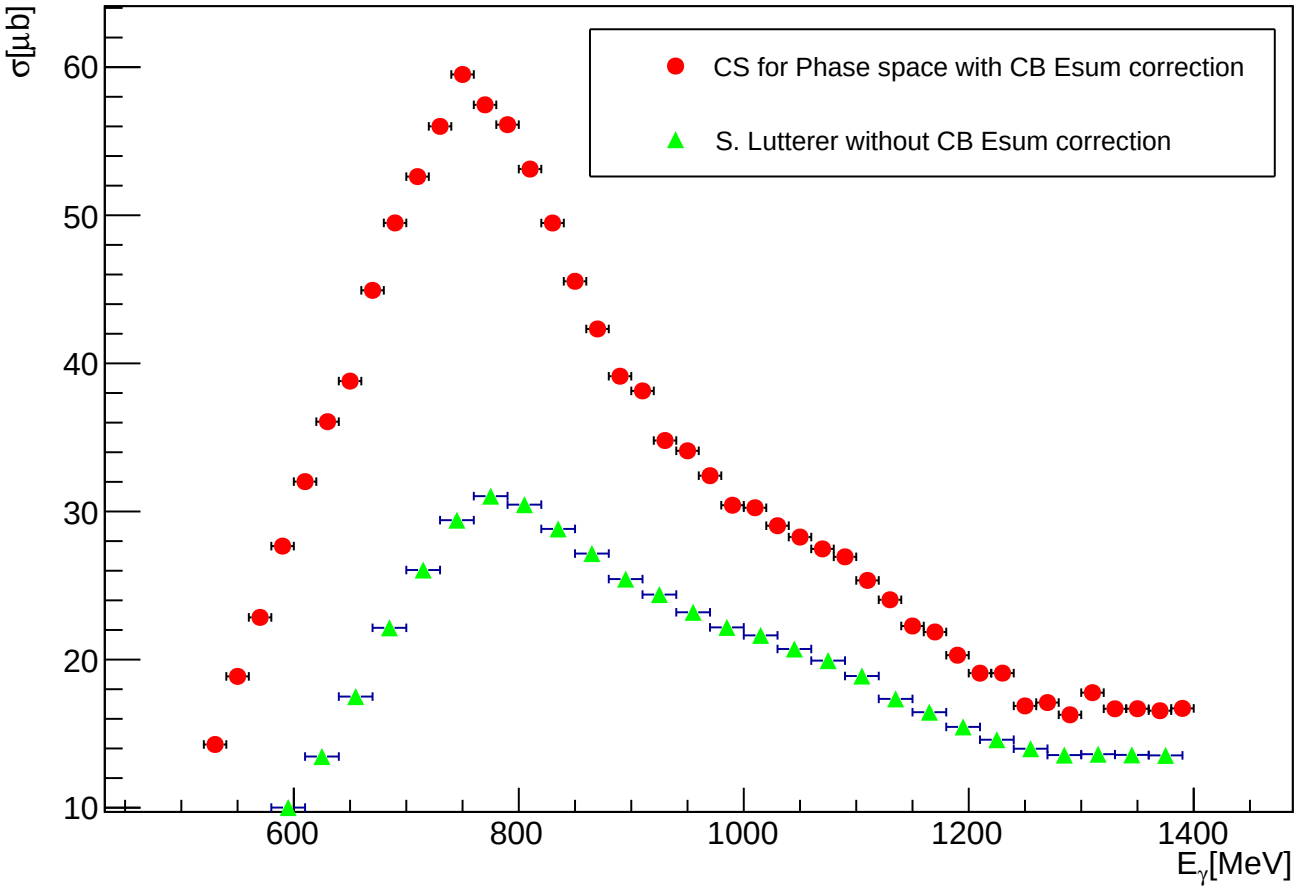

Figure: Influence of the CB energy sum correction on total Cross section for $\pi^0\pi^- p$ final state

Preliminary Results

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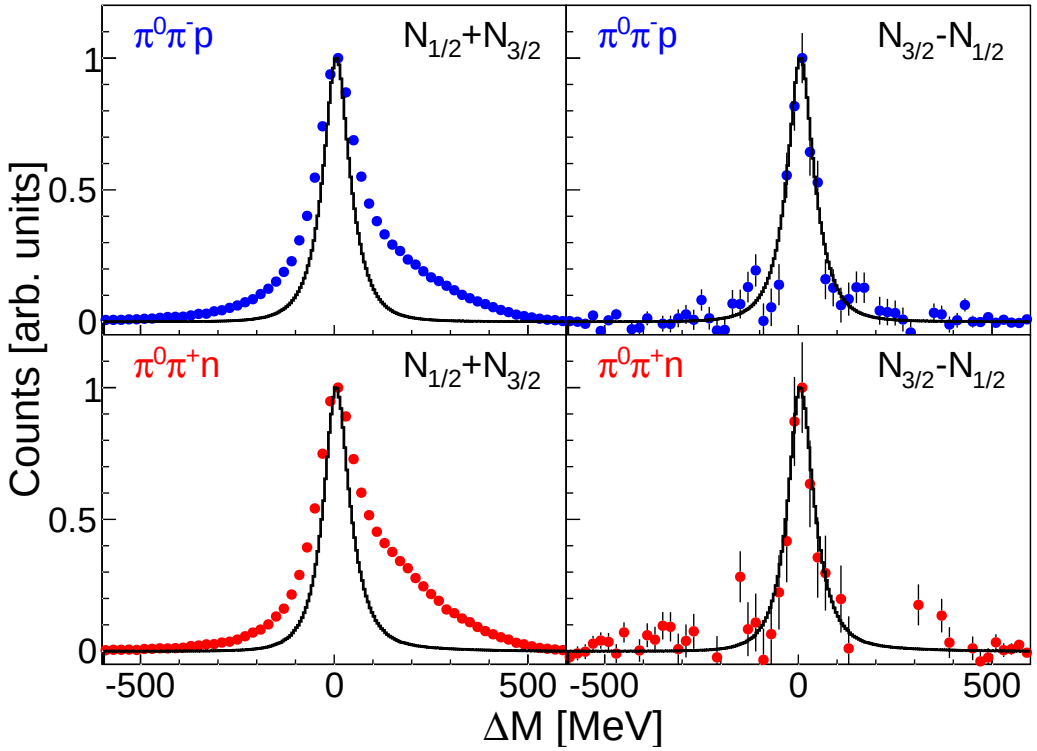


Figure: ΔM for dButanol for the difference $N_{1/2} - N_{3/2}$, and the sum $N_{1/2} + N_{3/2}$ of the two helicity states for the reaction on the proton (blue) and the neutron (red). The line shape of the simulation is shown as black line. The influence of the carbon is clearly visible in the sum, whereas for the difference, the simulation and the experimental data are in agreement.

Analysis

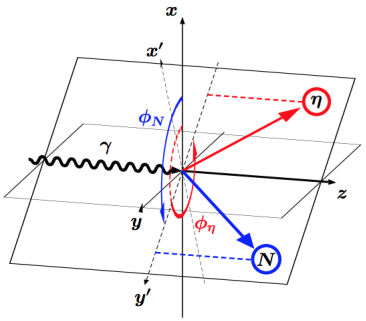
$$m_{n[part.]} = \sqrt{(p^4_{beam} + p^4_{target} - p^4_{\pi^+} - p^4_{\pi^0})^2}$$

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 $p^4_{n[spec.]}(\text{initial}) = p^4_{n[spec.]}(\text{final})$)

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:

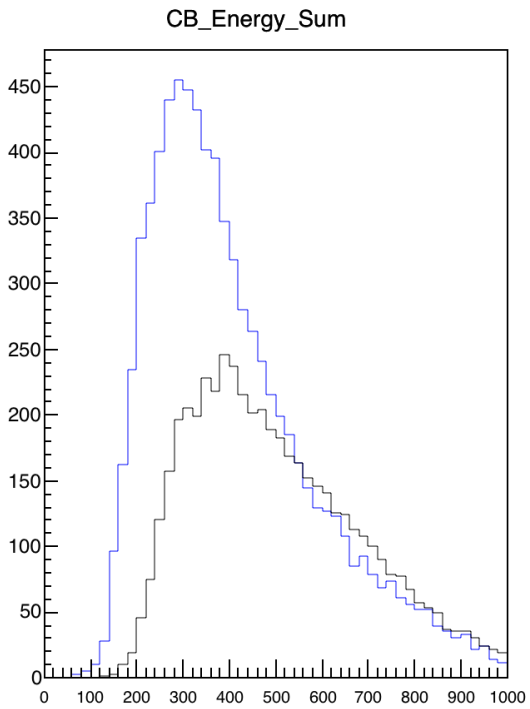
$$M = \sqrt{(E_\gamma + m_N - E_\eta)^2 - (\vec{p}_\gamma - \vec{p}_\eta)^2},$$

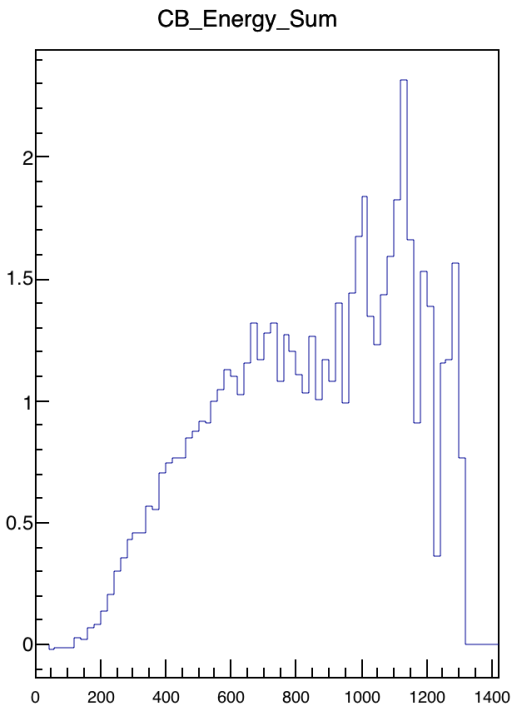
where E_γ and $\vec{p}_\gamma$ are energy and momentum of the incident photon beam, E_η and $\vec{p}_\eta$ are the energy and momentum of the η meson, and m_N is the nucleon mass. With a correct identification of the reaction, the corresponding spectra should have a clear peak at the nucleon mass m_N. 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(Tl) 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