Measurement of the double polarization observable E for the photoproduction of $\pi^0\pi^{+/-}$ pairs off deuteron and dBuntanol targets

Debdeep Ghosal

University of Basel– Krusche Group
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debdeep.ghosal@unibas.ch

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... *in loving memory of Prof. Bernd Krusche*

Overview

- Introduction to Baryon Spectroscopy
- Motivation for Photoproduction with pion pairs $\rightarrow \pi^0\pi^\pm$
- Experimental Setup
- Beam-times and Interested Channels
- Analysis
- Results
- Summary and Outlook
- References

Introduction Baryon Spectroscopy

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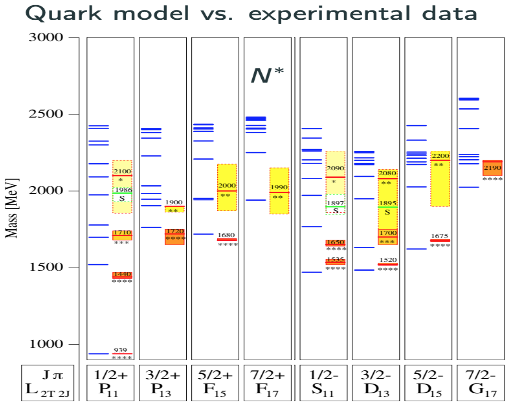
Scope:

- 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 to study baryon spectrum

•An efficient tool for the study of decays of nucleon resonances
photon induced reactions > pion scattering [in the last decades]
Many more states have been predicted than observed.
larger mass region of the spectrum **= missing resonances**



U. Loering, B.C. Metsch, H.R. Petry, EPJA 10 (2001) 395-446

Motivation for Photoproduction with pion pair production

Motivation for Photoproduction with pion pair production

- pair production of pseudoscalar mesons $\rightarrow$ higher lying resonances have tendency of cascade-like decays with an intermediate state $\rightarrow$ double pion production interesting.
- single meson production reactions restrict and strongly bias against contributions from such states
- study of pion pairs $\rightarrow$ resonance decays involving heavier mesons (f_0, ρ etc.)

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- sequential $D_{13} \rightarrow N\rho$

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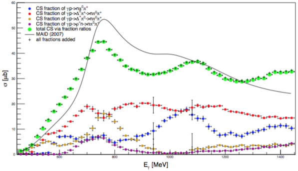
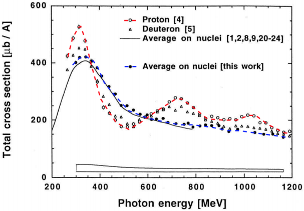
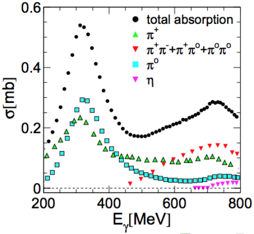


- Special interests in $\pi^0\pi^{+/-}$ include also contributions from ρ meson (forbidden in $\pi^0\pi^0$)

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





Experimental Facility in Mainz

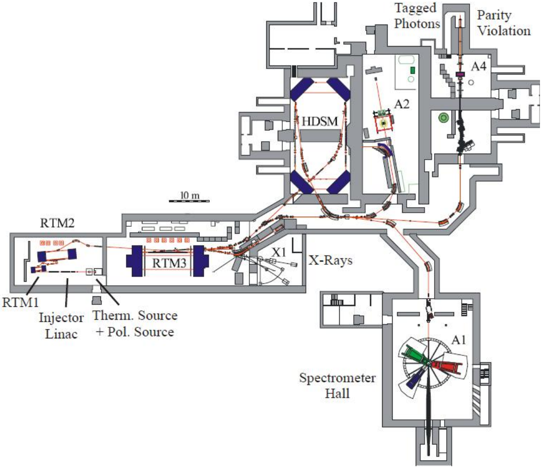
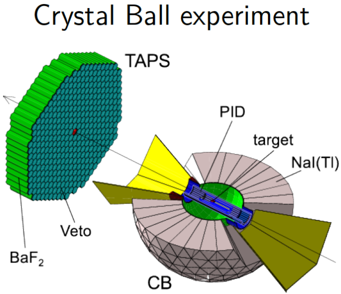


Figure: MAMI floor-plan [5]

Experimental Setup of A2 Mainz



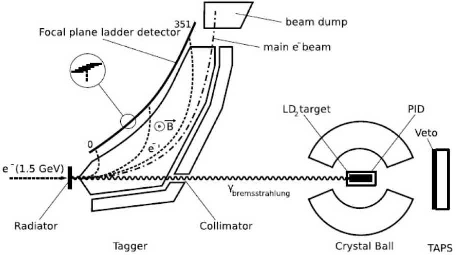


Figure: Schematic overview of the Exp. Setup [5]

Parameters for Data taking with Unpolarized and Polarized targets [5,6]

Parameters	Unpolarized target	Polarized target	Polarized target	Polarized target	Polarized target
Beamtime	May'09	Dec'15	Mar'15	Feb'14	Jul'13
Target type	LD_2	dButanol	dButanol	dButanol	dButanol
Target length[cm]	3.02	1.88	2.0	2.0	2.0
E-sum trigger	>250	>250	>250	>250	>250
Multiplicity trigger	M2+	M2+	M2+	M2+	M2+
Photon tagger range[MeV]	400-1400	400-1400	400-1400	400-1400	400-1400
Radiator	Moeller	Moeller	Moeller	Moeller	Moeller
e^- beam energy[MeV]	1575.5 MeV	1557 MeV	1558 MeV	1558 MeV	1558 MeV

Table: Parameters for deuterium(May 2009) and dButanol(July 2013, February 2014, March 2015 Dec 2015) beamtimes

Interesting 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:

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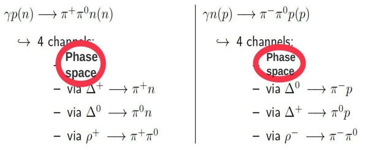

$\gamma p(n) \longrightarrow \pi^+\pi^0 n(n)$

↪ 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:
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Further selection of events necessary through cuts and corrections

Analysis
Particle Identification

- Pulse shape analysis (PSA)
  separation of photons and recoiled nucleons in TAPS
- Time-of-flight (TOF)
  separation of protons, photons and neutrons
- $\Delta E - E$ analysis
  separation of recoiled protons and charged pions
- χ^2 analysis
  distinction of photon pairs from neutrons

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Proton and Charged Pion identification with PID and CB

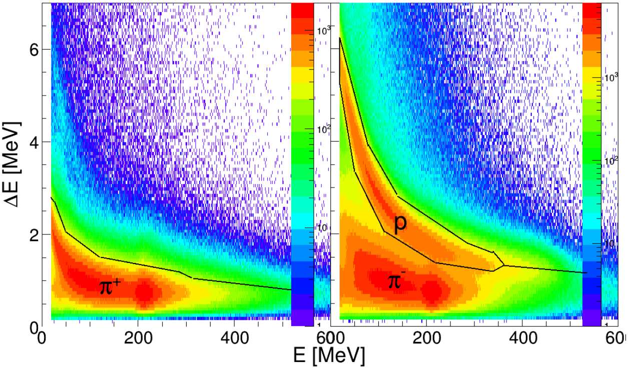

Figure: Identification of charged particle

Major Cuts for event selection:

- invariant mass of the π^0 reconstructed from $\gamma\gamma$
- coplanarity of the final state (ϕ-angle between the $\pi^{+/-}\pi^0$ system and the participant nucleon)
- missing mass of either a charged $\pi^{+/-}$ or the proton

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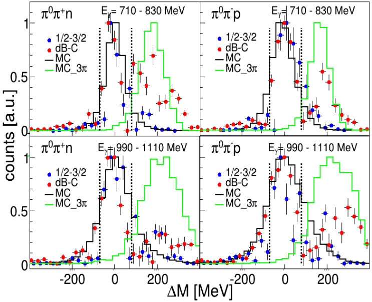
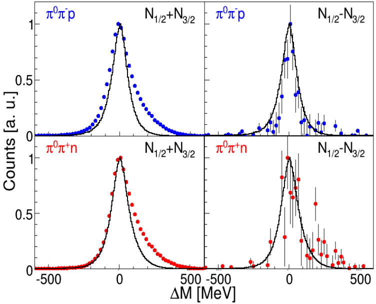


(a) Missing mass comparison spectra of C-subtracted dbutanol data set with the difference of the two helicity states.



(b) ΔM for dButanol for the reaction on proton (blue) and neutron (red); line shape as black line. Influence of the carbon clearly visible in the sum.

Polarization observables

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from the category $\mathcal{BT} \rightarrow E$, F, H as our main interest!

E-observable extraction

Asymmetry between the two helicity states

• $V1$ **(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.

E-observable extraction

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

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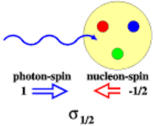

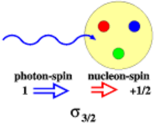

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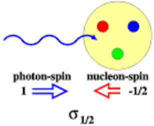

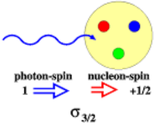

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Results: E-observable with dBprecise target

Averaged over different beamtimes in terms of E_γ and W

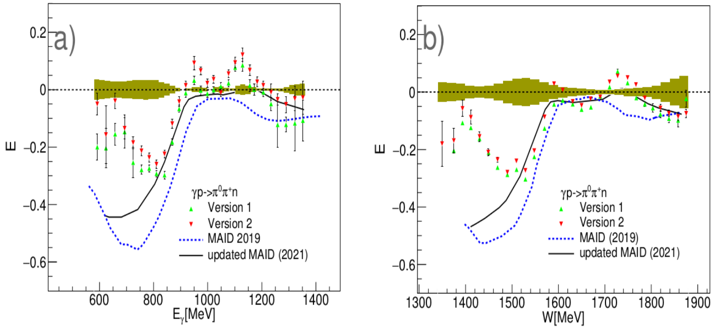

Figure: For reaction with final state $\pi^0\pi^+$

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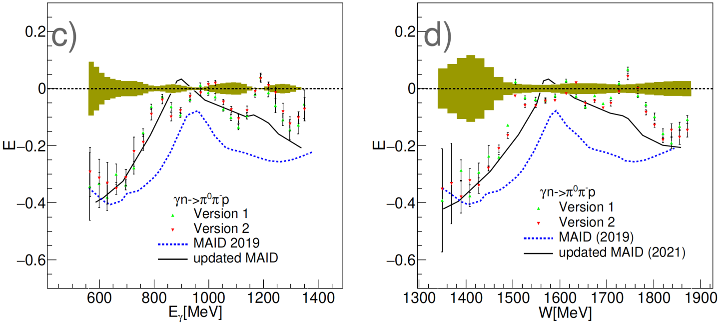

Figure: For reaction with final state $\pi^0\pi^-$

Results: Two Helicity state cross sections

Averaged over different beamtimes for $\pi^0\pi^+$ channel [in terms of E_γ]

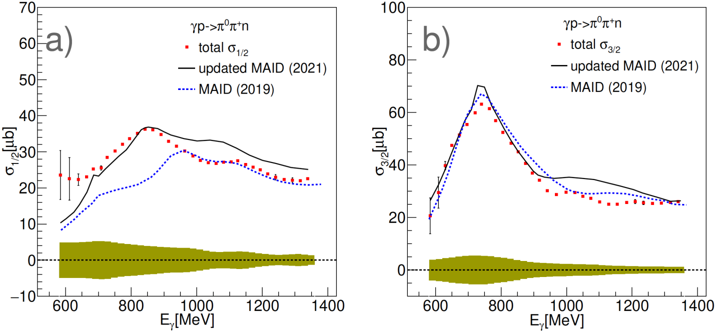

Figure: for $\gamma p \to \pi^0\pi^+ n$

Results: Two Helicity state cross sections

Averaged over different beamtimes for $\pi^0\pi^-$ channel [in terms of E_γ]

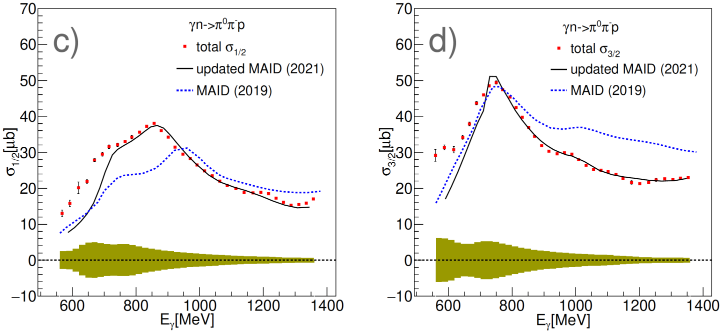

Figure: for $\gamma n \rightarrow \pi^0\pi^- p$

Results: Further comparison and Discussion

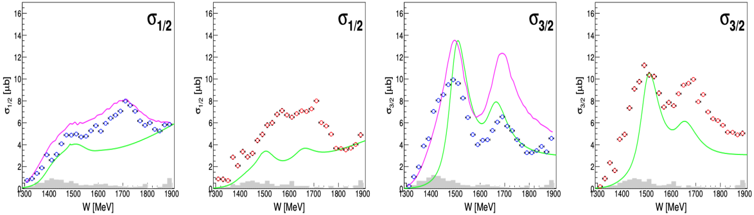

Figure: double π^0 photoproduction [7]

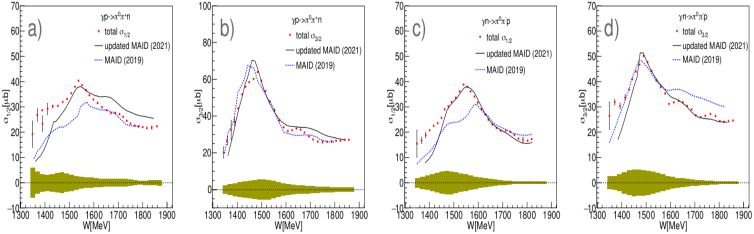

Figure: This work i.e mixed charged pion photoproduction

Summary and Outlook

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- Cross sections for both mixed charged double pion production channels extracted
- E-observable with direct and carbon subtracted methods extracted $\rightarrow$ they are in good comparison
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- Hint about the in-medium modification effects and diffractive production of ρ meson

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Outlook :

- This work contributes to the world database of complete experiment
- A more refined analysis with intermediate channels is followed, although it doesn't affect the current E-asymmetry
- Publish the results of E-asymmetry

References

- https://jazz.physik.unibas.ch/site/talks/krusche_dnp08.pdf
- F. Zehr and B. Krusche et al. The European Physical Journal A, 48(7):98, 2012. ISSN 1434-6001. doi: 10.1140/epja/i2012-12098-1.
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- https://jazz.physik.unibas.ch/site/talks/lutterer_dpg_talk_pion_photoproduction_30032017.pdf.
- https://edoc.unibas.ch/39089/1/Lilian_Witthauer.pdf
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- https://jazz.physik.unibas.ch/site/publications/Manuel_2pi0_E_prl_20.pdf


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
спасибо
dank je
tapadh leat
mochchakkeram
go raibh maith agat
dziękuję
bedankt
obrigado
sukriya
kop khun krap
terima kasih
grazie
arigatô
takk
dakujem
merci
мерси
sagolun
hvala
mauruuru
ευχαριστώ
감사합니다
Баярлалаа
рахмат
хвала

backup

- 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]
- CB Energy sum correction/CDF
  [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

Background Rejection: Invariant mass cut

$$m_{\gamma_{1,2}} = \sqrt{E_{\gamma_{1,2}} \cdot (1 - \cos\phi_{\gamma_{1,2}})} \quad (1)$$

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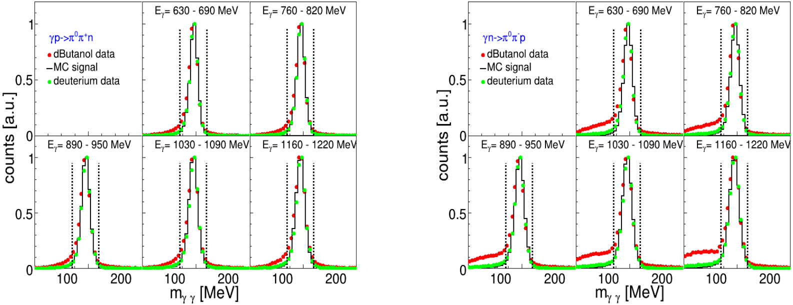

Figure: Invariant mass for bins of the incident photon energy. Cut positions are indicated by the dashed lines.

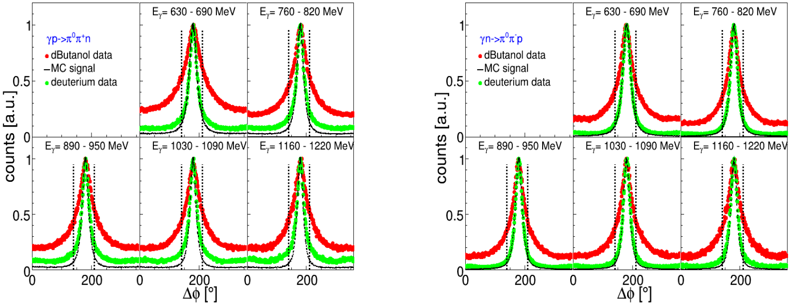

Figure: The angular difference $\Delta\phi$ of the pion-pion system to the recoil nucleon for five different bins of the incident photon energy. Cut positions are indicated by the dashed lines.

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

Version	E
I	$\frac{\sigma_\Delta}{\sigma_\Sigma} \rightarrow E_C$
II	$\frac{\sigma_\Delta}{2\sigma_0} \rightarrow E_{dir.}$

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 σ_0 = unpol. x-sec.

Version	$\sigma_{1/2}$	$\sigma_{3/2}$
I	$\sigma_0(1 + E_{dir.})$	$\sigma_0(1 - E_{dir.})$
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Sys. Uncertainty calc.

In determining of E, the uncertainty coming from the flux and the analysis cuts, cancel out since they appear in the numerator and denominator of the fraction;
the uncertainties coming from the carbon subtraction and different nucleon detection efficiencies of the polarised and unpolarised experiments, were estimated by
$\Delta E = diff.|E^{vers1} - E^{vers2}|$
and For the helicity dependent cross sections:
$\Delta\sigma_{1/2} = Max(\Delta\sigma^1_{1/2}, \Delta\sigma^2_{1/2}, \Delta\sigma^3_{1/2})$
where, $\Delta\sigma^1_{1/2} = diff.|\sigma^{vers1}_{1/2}$ - $\sigma^{vers2}_{1/2}|$, $\Delta\sigma^2_{1/2} = diff.|\sigma^{vers2}_{1/2}$ - $\sigma^{vers3}_{1/2}|$, and so on...
$\Delta\sigma_{3/2} = Max(\Delta\sigma^1_{3/2}, \Delta\sigma^2_{3/2}, \Delta\sigma^3_{3/2})$
where, $\Delta\sigma^1_{3/2} = diff.|\sigma^{vers1}_{3/2}$ - $\sigma^{vers2}_{3/2}|$, and so on...
This systematic uncertainty accounts for uncertainties due to the carbon subtraction, differences in the nucleon detection efficiency, flux, and analysis cuts compared to the unpolarised measurement

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

cdf.png

$d\sigma_{1/2}forproton$

DCS12_Eg_pip.pdf

$d\sigma_{3/2} forproton$

DCS32_Eg_pip.pdf

$d\sigma_{1/2}$*forneutron*

DCS12_Eg_pim.pdf

$d\sigma_{3/2} forneutron$

DCS32_Eg_pim.pdf