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

*3rd Jagiellonian Symposium '19, Krakow*

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# Overview

# 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

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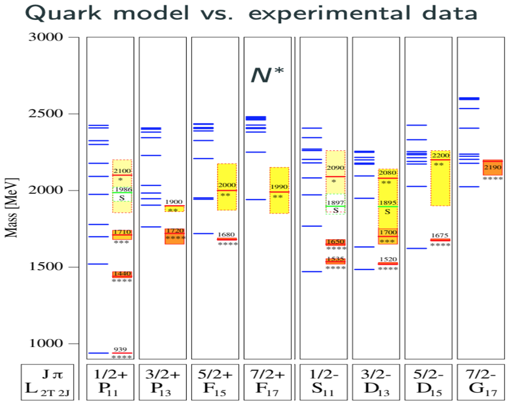
Photoproduction of pion pairs off nuclei

- insight into low energy **QCD**(large $\alpha$)
- 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.)

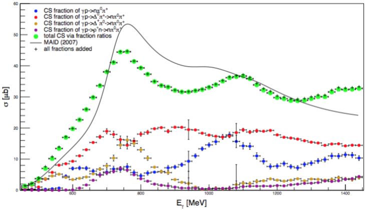
# Motivation for Photoproduction to study baryon spectrum

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* = **missing resonances**




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

- 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

# Motivation for Photoproduction with $\pi^0\pi^{+/-}$ [1,3]

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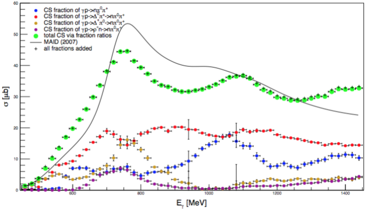


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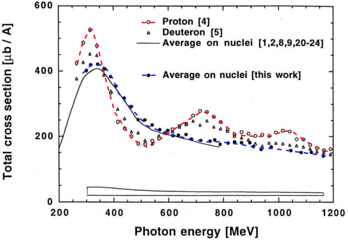
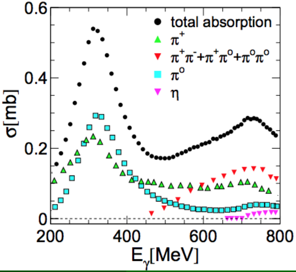
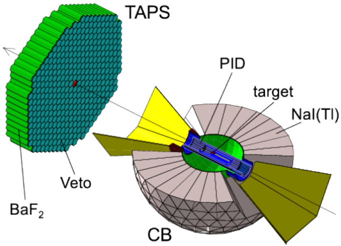


# Experimental Setup of A2 Mainz

Crystal Ball experiment



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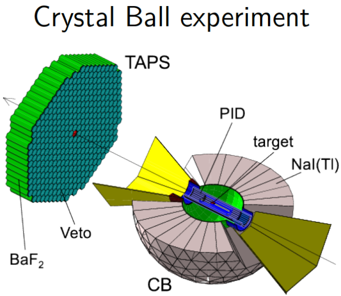


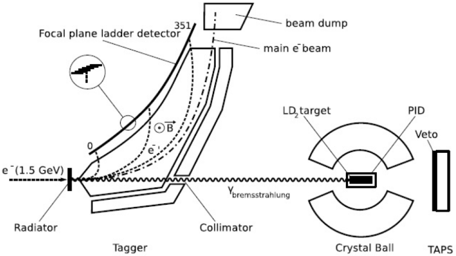


Figure: Schematic overview of the Exp. Setup [5]

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

| 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, $\pi$N and $\gamma$N(limited extent)

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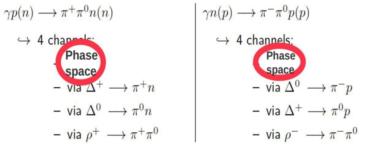


$\gamma p(n) \longrightarrow \pi^+\pi^0 n(n)$

↪ detected particles:

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

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

↪ detected particles:

- 2 charged:
  - $\pi^-$
  - proton participant
- 2 uncharged:
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Further selection of events necessary through cuts and corrections

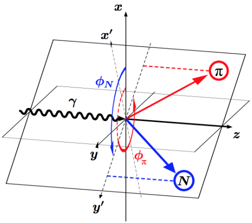
Various Cuts for event selection:

# Analysis

## Background Rejection [Corrections on true data]

Various Cuts for event selection:

- charged particle identification via energy left in PID versus energy in CB ("dE-E cut")
- invariant mass of the $\pi^0$ reconstructed from $\gamma\gamma$ in case of three neutral particles, get neutron candidate via $\chi^2$ test
- missing mass of either a charged $\pi^{+/-}$ or the proton
- coplanarity of the final state ($\phi$-angle between the $\pi^{+/-}\pi^0$ system and the participant nucleon)




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

- 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]*

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# Analysis

## Calculating Cross sections

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- divide data yield by the efficiency

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| Beam-Target | Beam-Recoil | Target-Recoil |
|---|---|---|
| G, H, E, F | $O_x$, $O_z$, $C_x$, $C_z$ | $T_x$, $T_z$, $L_x$, $L_z$ |

Table: The double polarisation observables can be divided into three groups of four observables [5]

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|---|---|---|
| E | | |

Table: The double polarisation observables can be divided into three groups of four observables [5]

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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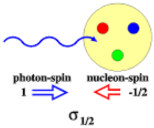


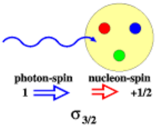

# E-observable extraction

## Asymmetry between the two helicity states

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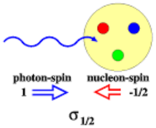


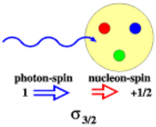


- *Circularly polarized photon beam* impinging on a *longitudinally polarized nucleon target*

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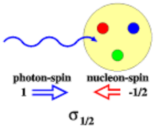


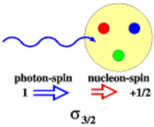


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•$V1$**(Carbon subtraction method):** to determine the carbon and oxygen contributions to the dButanol
•$V2$**(Direct method):** extract tot. CS from dButanol beamtime $\rightarrow$ to be normalized using 2$\times$unpolarized CS.

# 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

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| 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

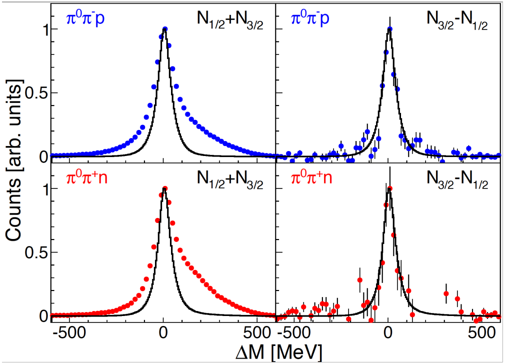
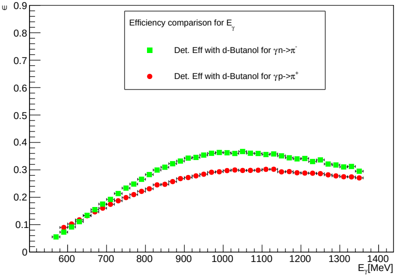
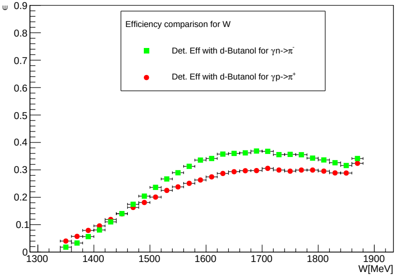



Figure: ΔM for dButanol for the difference $N_{3/2} - N_{1/2}$, and the sum $N_{1/2} + N_{3/2}$ of the two helicity states for the reaction on the proton (blue) and the neutron (red).

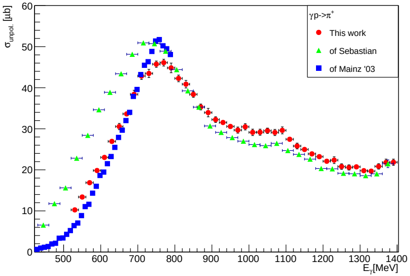
# Comparison of detection efficiency for the respective channels with d-Butanol targets



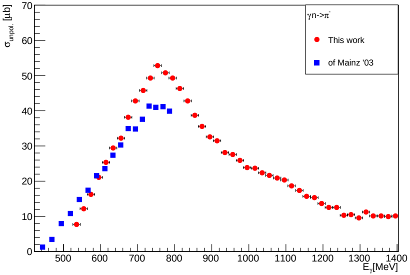



# Preliminary Results

## Total Cross section comparison with $LD_2$ target




(a) For reaction with final state $\pi^0\pi^+$ [4]




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

# Preliminary Results: E-observable extraction with dButanol target

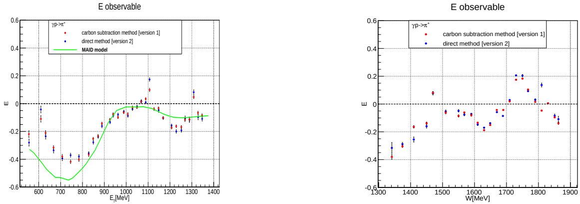
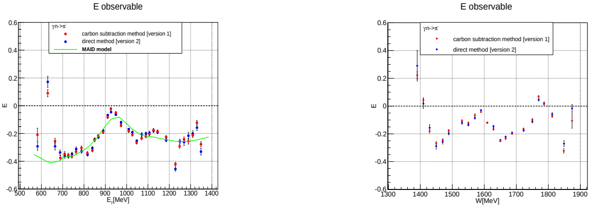



Figure: Preliminary E-observable for reaction with final state $\gamma p \rightarrow \pi^0\pi^+ n$

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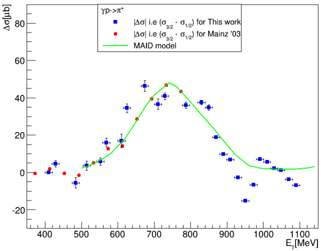
# Preliminary Results

Comparison of Difference of the two helicity state cross sections $[\sigma_\Delta]$ with d-Butanol target

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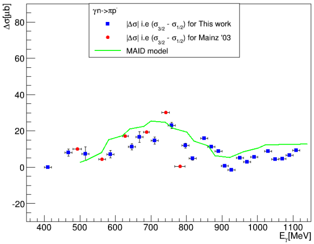


(b) For reaction with final state $\pi^0\pi$

# Two helicity state cross sections extracted with different versions [in terms of photon energy]

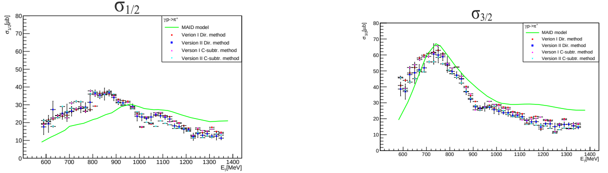


Figure: For $\gamma p \rightarrow \pi^0 \pi^+ n$ channel

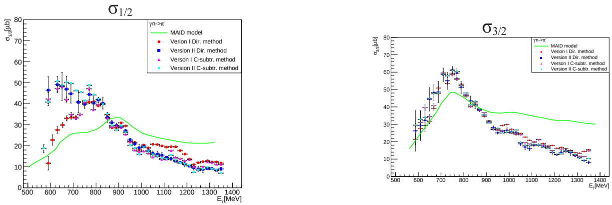


Figure: For $\gamma n \rightarrow \pi^0 \pi^- p$ channel

# Summary and Outlook

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- 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.) from MAMI or from CB-ELSA experiment
- 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 $\pi0\pi_+$ -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
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
merci
obrigado
bedankt
dziękuje
спасибо
Баярлалаа
рахмат
dank je
tapadh leat
mochchakkeram
go raibh maith agat
sukriya
kop khun krap
terima kasih
arigatô
dakujem
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grazie
hvala
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мерси
감사합니다
ありがとう
ευχαριστώ
хвала
asante
manana
obrigada
enkosi
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dankie
dhanyavad
blagodaram
misaotra
matondo
paldies
grazzi
mahalo
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vinaka
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# backup

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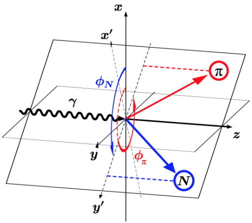
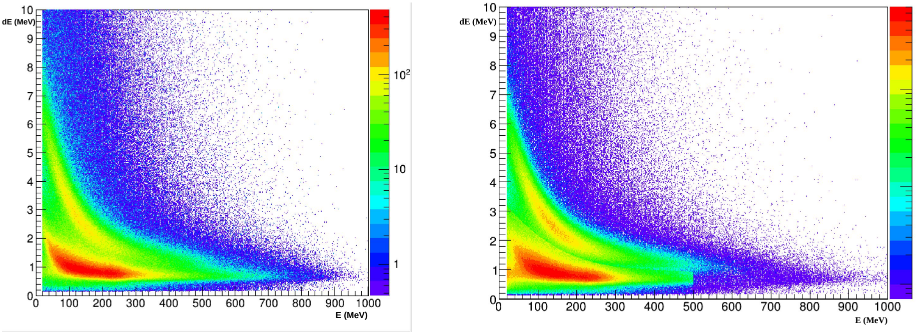



meson candidate(red) and recoil nucleon(blue) lie in the reaction plane, separated by azi. δφ = 180 °

## Proton and Charged Pion identification with PID and CB



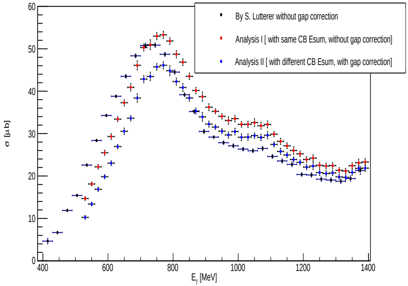

(a) For $\pi^+$ *channel* : pion

(b) For $\pi^-$ *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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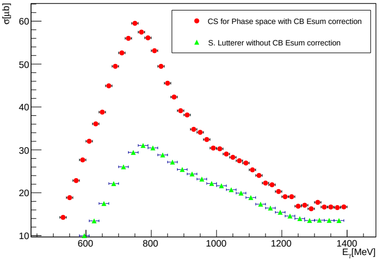


(b) Influence of the CB energy sum & Gap correction on total Cross section for $\pi^0\pi^- p$ final state

# Preliminary Results

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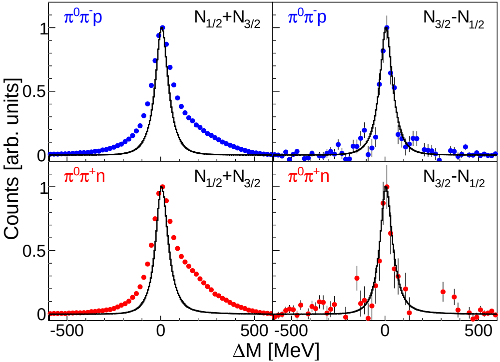



Figure: ΔM for dButanol for the difference $N_{1/2} - N_{3/2}$, and the sum $N_{1/2} + N_{3/2}$ of the two helicity states for the reaction on the proton (blue) and the neutron (red). The line shape of the simulation is shown as black line. The influence of the carbon is clearly visible in the sum, whereas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

# Preliminary Results

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

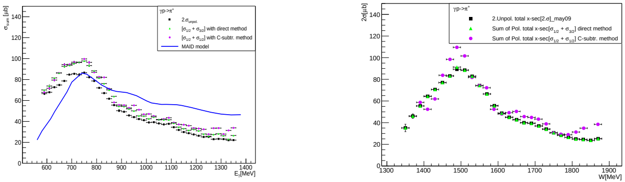



Figure: For $\gamma p \rightarrow \pi^0\pi^+ n$ channel

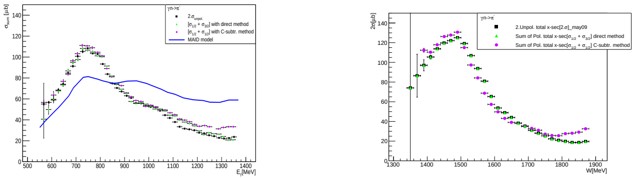



Figure: For $\gamma n \rightarrow \pi^0\pi^- p$ channel

# Analysis

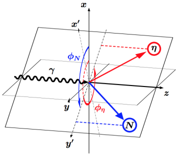
$$m_{n[part.]} = \sqrt{(p^4_{beam} + p^4_{target} - p^4_{\pi^+} - p^4_{\pi^0})^2}$$

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:

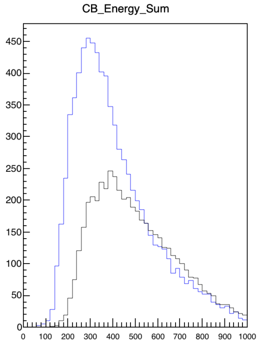
$$M = \sqrt{(E_\gamma + m_N - E_\eta)^2 - (\vec{p}_\gamma - \vec{p}_\eta)^2},$$

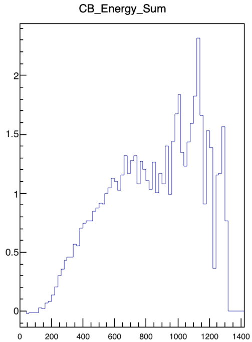
where $E_\gamma$ and $\vec{p}_\gamma$ are energy and momentum of the incident photon beam, $E_\eta$ and $\vec{p}_\eta$ are the energy and momentum of the $\eta$ meson, and $m_N$ is the nucleon mass. With a correct identification of the reaction, the corresponding spectra should have a clear peak at the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