Determination of the polarization observables Σ and G in the reaction $\vec{\gamma}\,\vec{p} \rightarrow p\,\pi^0\,\pi^0$

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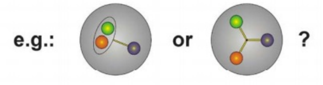
September 30th, 2014

Motivation

Excitation Spectrum of the Baryons

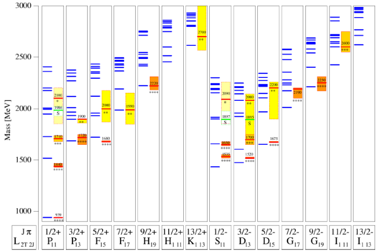
Baryon Spectroscopy (Open Questions)

- Excitation spectrum of the nucleon provides information about interaction/dynamics of constituents
- How many degrees of freedom:



How to analyze the excitation spectrum?

- Most resonances found via $\pi N \rightarrow N^*/\Delta^* \rightarrow X$ **BUT** many resonances still missing compared to the constituent quark model
- Study $\gamma N \rightarrow N^*/\Delta^* \rightarrow N\,\eta', N\,\pi^0, N\,\pi^0\pi^0 \cdots$
- Experiments, e.g., **Crystal Barrel**@ELSA, Crystal Ball@MAMI, CLAS@Jefferson Lab



[U. Loering et al., Eur.Phys.J. A, 10:395-446, 2001]

Motivation

Excitation Spectrum of the Baryons

Why $\vec{\gamma}\,\vec{p} \;\rightarrow\; p\,\pi^0\,\pi^0$?

1. Background suppression

    - Direct $\Delta\pi$ production, t-channel and Born terms are suppressed
    - $\rho(770)$ is not present since decay into $\pi^0\pi^0$ is forbidden

    $\rightarrow$ High sensitivity to baryon resonances!

2. Cascading resonances

    - e.g. $\gamma p \rightarrow N^*/\Delta^* \rightarrow \Delta(1232)\,\pi^0 \rightarrow p\,\pi^0\pi^0$
    - $\gamma p \rightarrow N^*/\Delta^* \rightarrow D_{13}(1520)\,\pi^0 \rightarrow p\,\pi^0\pi^0$
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3. Cross section larger at higher energies compared to $p\,\pi^0$

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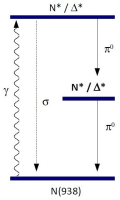

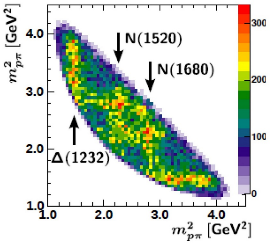

[V. Sokhoyan et al. (CBELSA/TAPS-collaboration)]

Motivation

Excitation Spectrum of the Baryons

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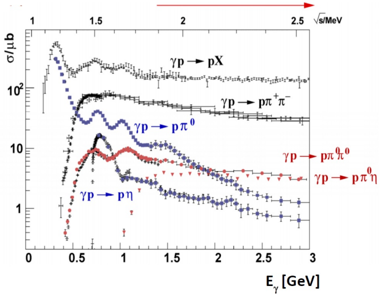


Motivation

Polarization Observables

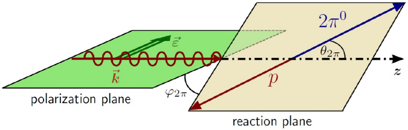
A complete model independent partial wave analysis in pseudoscalar double meson photoproduction requires:

- 14 polarization observables and the unpolarized cross section

[Roberts, W. and T. Oed, Phys.Rev. C **71** (2005) 055201]

Differential cross section for linearly polarized photons and longitudinally polarized target:

$$\frac{d\sigma}{d\Omega}(\theta,\varphi) = \left.\frac{d\sigma}{d\Omega}\right|_0(\theta)\cdot(1-\delta_l\mathbf{\Sigma}\cos 2\varphi+\delta_l\Lambda_z\mathbf{G}\sin 2\varphi)$$



		Target			
			x	y	z
$\mathbf{p}_\gamma$	unpolarized	σ	-	T	-
	linearly polarized	Σ	H	P	G
	circularly polarized	-	F	-	E

measured with Crystal Barrel @ ELSA

measured in this work

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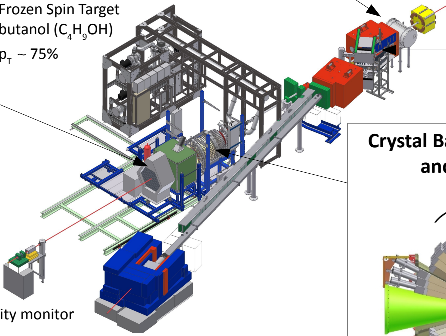
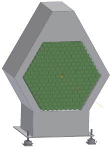
Experimental Setup

CBELSA/TAPS

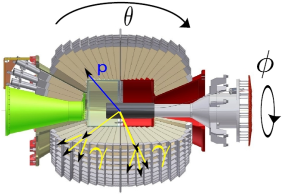


MiniTAPS



216 BaF_2 crystals
covering 1-12° in θ

Crystal Barrel with inner detector and forward detector



1320 CsI(Tl) crystals
covering 12-156° in θ

Selection of Events

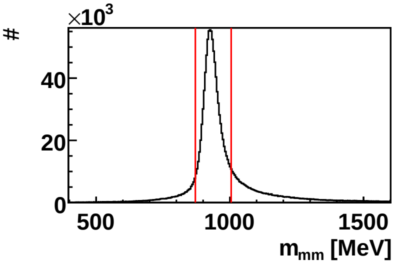
Kinematic Cuts

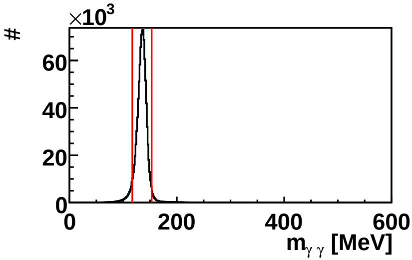
$\gamma\, p \to p\, \pi^0\, \pi^0 \to p\, 4\gamma$

$\to$ **4 neutral particles + 1 charged particle in the final state!**

Mass Cuts

- Cut on the proton mass: $m_{mm} = (938 \pm 67)$ MeV
- Cut on the meson mass: $m_{\gamma\gamma} = (135 \pm 18)$ MeV





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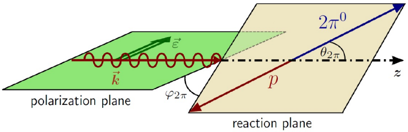
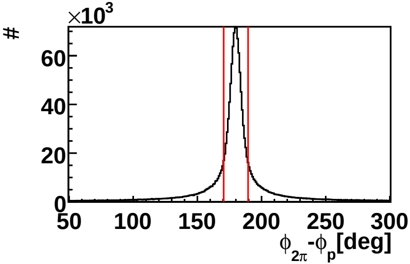
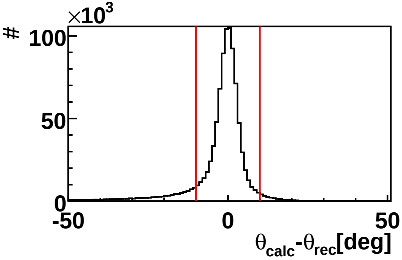
Angular Cuts



- Reaction products decay in one plane: $\phi_{diff} = |\phi_{2\pi} - \phi_p| = (180 \pm 9.5)\ ^\circ$
- Comparison of the calculated & reconstructed proton polar angle: $\theta_{diff} = |\theta_{cal} - \theta_{rec}| = (0 \pm 10)\ ^\circ$





Extraction of the polarization observables

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Angular distribution $N_B(\theta, \phi)$

- Protons in liquid hydrogen not polarizable $\rightarrow$ Use butanol (C_4H_9OH)
- Butanol has unpolarized protons in carbon and oxygen

$$N_B\Big|_{\pm\alpha}^{\pm\Lambda_z}(\theta,\phi) = (\overbrace{N_H + N_C}^{N_B})(\theta)\cdot\left((1-\overbrace{\left(\frac{N_H\Sigma_H + N_C\Sigma_C}{N_H + N_C}\right)}^{\Sigma_B}\delta_l\cos 2(\phi-\alpha) + \overbrace{\left(\frac{N_H}{N_H + N_C}\right)}^{\text{dilution factor D}}\delta_l\Lambda_z G_H \sin 2(\phi-\alpha)\right)$$

$\rightarrow$ Σ_B contains distribution from bound protons

$\rightarrow$ Double polarization observable G requires longitudinally polarized target $\rightarrow$ Find the fraction of reaction on polarized protons $\rightarrow$ Dilution factor

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Extraction of the polarization observables

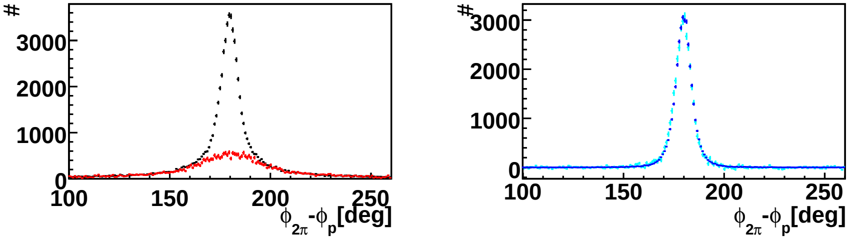
Angular distribution $N_B(\theta, \phi)$

$$N_B\Big|^{\pm\Lambda_z}_{\pm\alpha}(\theta,\phi) = \overbrace{(N_H + N_C)}^{N_B}(\theta)\cdot\left((1 - \overbrace{\left(\frac{N_H\Sigma_H + N_C\Sigma_C}{N_H + N_C}\right)}^{\Sigma_B}\delta_l \cos 2(\phi-\alpha) + \overbrace{\left(\frac{N_H}{N_H + N_C}\right)}^{\text{dilution factor D}} \delta_l \Lambda_z G_H \sin 2(\phi-\alpha)\right)$$

Dilution Factor

E_γ = (1050-1125) MeV and $0.67 < \cos\theta_{2\pi} \leq 0.83$

$$D = \frac{N_H}{N_H + N_C} = \frac{N_H}{N_B} = \frac{N_B - s(E_\gamma)N_C}{N_B} = 1 - s(E_\gamma)\frac{N_C}{N_B} \text{ with } N_B \approx N_H + N_C$$



butanol, scaled carbon, scaled hydrogen, reconstructed hydrogen ($N_B - N_C$)

Extraction of the polarization observables

Angular distribution $N_B(\theta, \phi)$

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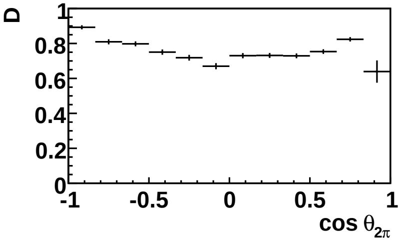

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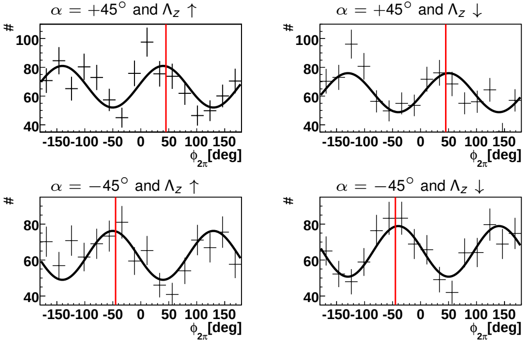
ϕ-asymmetries for different settings

E_γ = (1050-1125) MeV and $0.67 < \cos\theta_{2\pi} \leq 0.83$



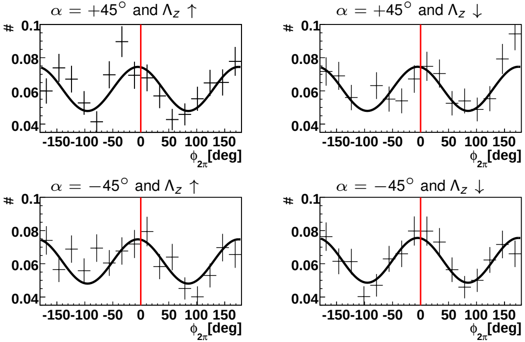
Extraction of the polarization observables

Angular distribution $N_B(\theta, \phi)$

$$N_B(\theta,\phi) = (N_H + N_C)(\theta) \cdot (1 - \Sigma_B \delta_l \cos 2\phi + D\delta_l \Lambda_z G_H \sin 2\phi)$$
$$f(\theta,\phi) = A(\theta) \cdot (1 + B\cos 2\phi + C \sin 2\phi)$$

Shifted ϕ-asymmetries for different settings

E_γ = (1050-1125) MeV and 0.67 $< \cos\theta_{2\pi} \leq$ 0.83



Extraction of the polarization observables

Angular distribution $N_B(\theta, \phi)$

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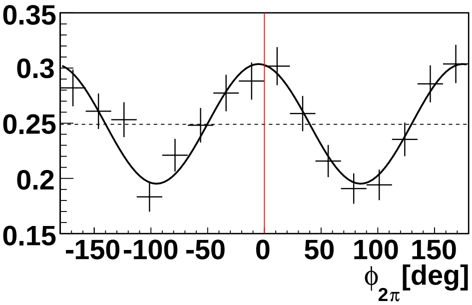
Sum of shifted ϕ-asymmetries for different settings

E_γ = (1050-1125) MeV and $0.67 < \cos\theta_{2\pi} \leq 0.83$



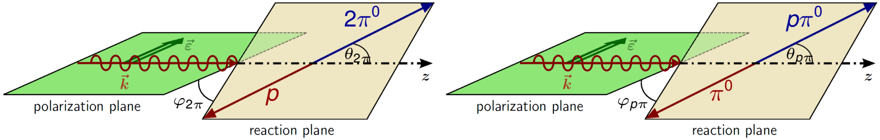
Extraction of the polarization observables

Determination in different systems

Analyze the observables in different systems and kinematic variables

Reason: Covering different parts of the phase space

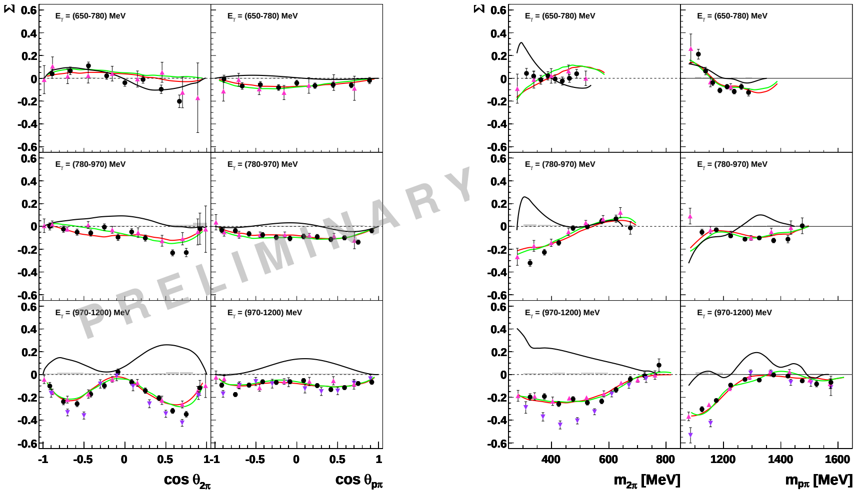
Different systems



Analysis in different kinematic variables: cms polar angle $cos\ \theta_x$ and invariant mass m_x

Results of the polarization observables

Beam asymmetry Σ_B - Comparison with recent results



MAID model — BG2011-01 [1] — BG2011-02 [1] — this work — GRAAL [2] — Sokhoyan [3]

[1] Anisovich et al, Eur.Phys.J. A47 (2011), Eur.Phys.J. A48 (2012) [2] Y. Assafiri et al, Phys. Rev. Lett 90, 222001 (2003) [3] V. Sokhoyan, Dissertation (2012)

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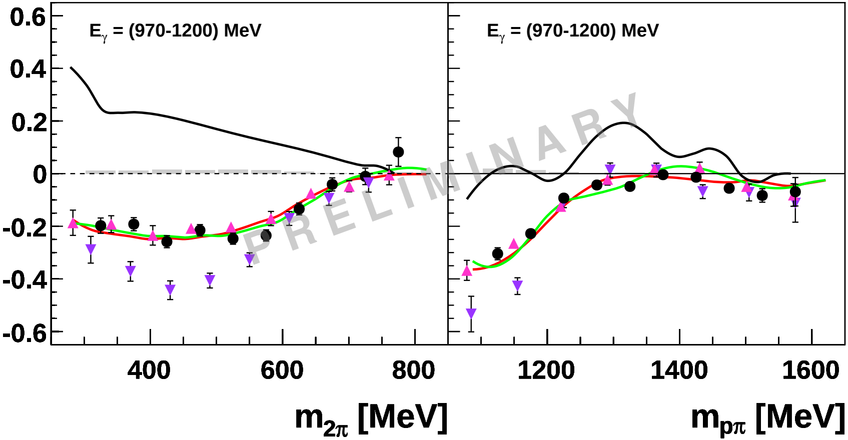

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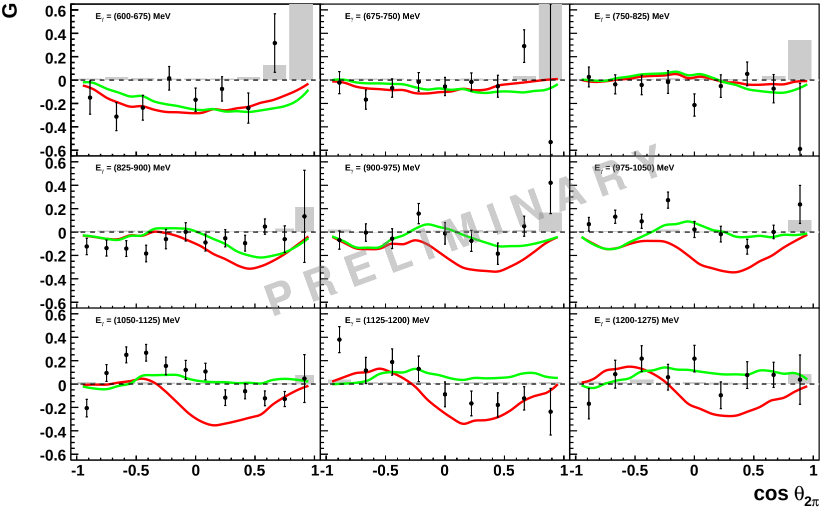
Results of the polarization observables

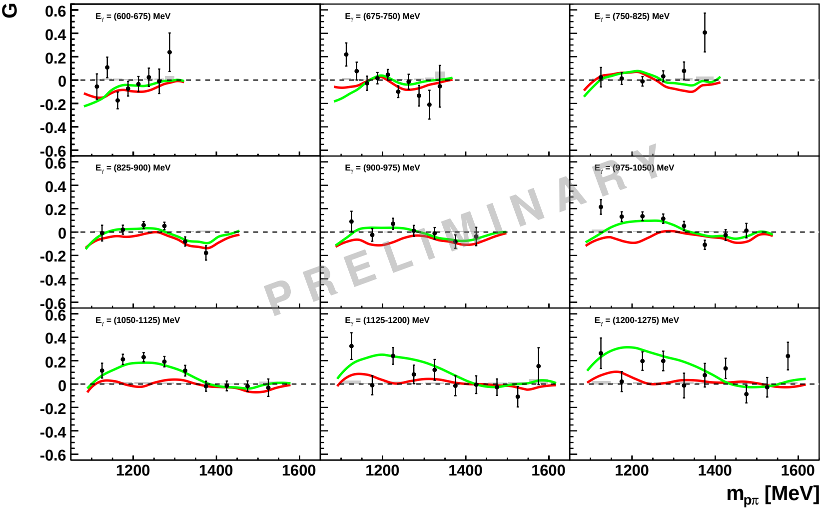
Double polarization observable G - $2\pi^0$-system



■ this work BG2011-01 BG2011-02

Results of the polarization observables

Double polarization observable G - $p\pi^0$-system



■ this work BG2011-01 BG2011-02

Summary

- Successful selection of the reaction $\vec{\gamma}\vec{p} \rightarrow p\,\pi^0\,\pi^0$
- First measurement of the double polarization observable G in the double π^0 channel

Results:

- BnGa predictions describe the results for Σ_B in the energy range (970-1200) MeV better than the MAID predictions $\rightarrow$ In BnGa the $D_{13}(1700)$ resonance dominates whereas in the MAID it is the $F_{15}(1680)$
- Double polarization observable G gives new information for Partial Wave Analyses

Thank you for your attention!

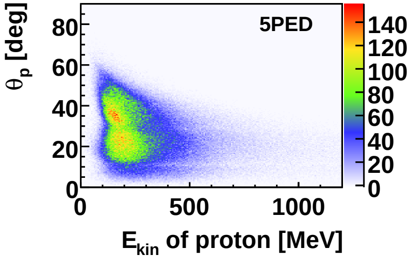
Appendix

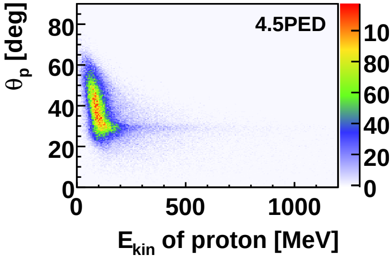
Signature

$\gamma\, p \to p\, \pi^0\, \pi^0 \to p\, 4\gamma$

Different PED event classes are possible:

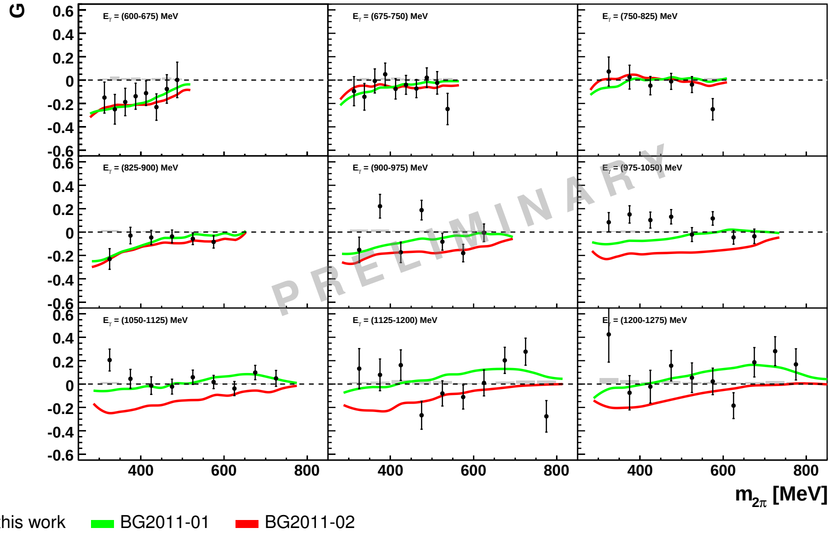
- **5 PED** 4 neutral particles + 1 charged particle in the calorimeters
- **4.5 PED** 4 neutral particles in the calorimeters + 1 charged particle in the inner detector





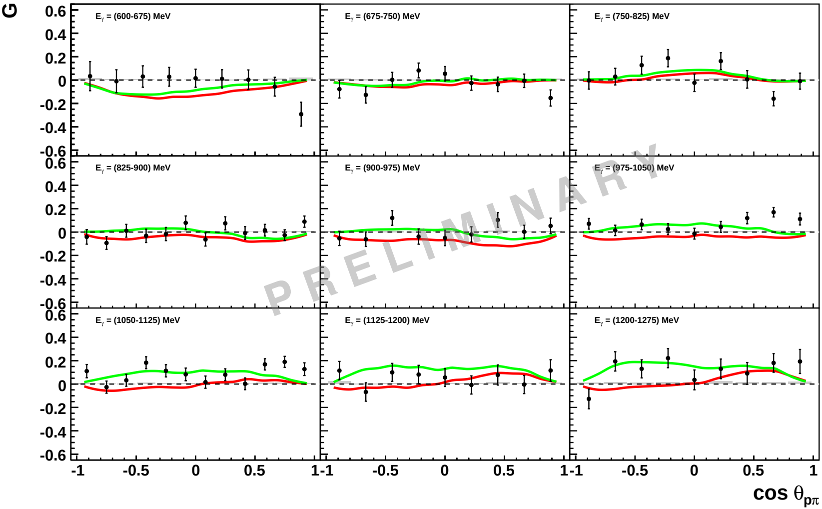
Appendix

Double polarization observable G - $2\pi^0$-system



Appendix

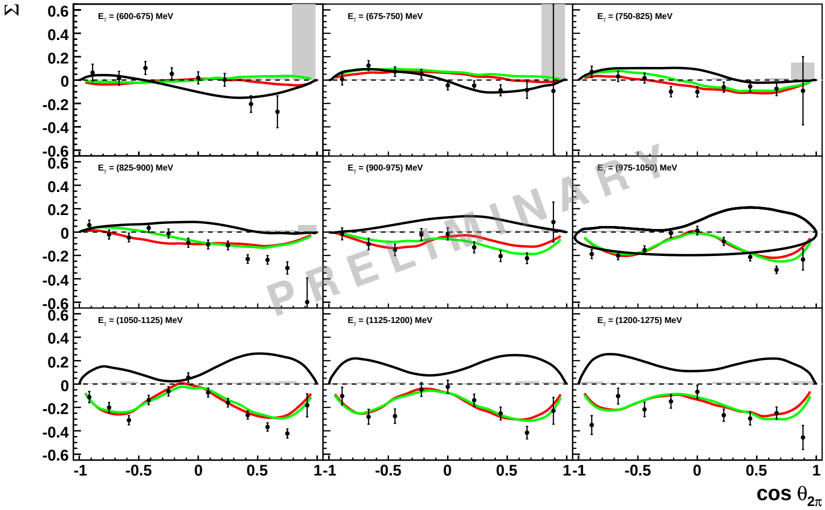
Double polarization observable G - $p\pi^0$-system



■ this work BG2011-01 BG2011-02

Appendix

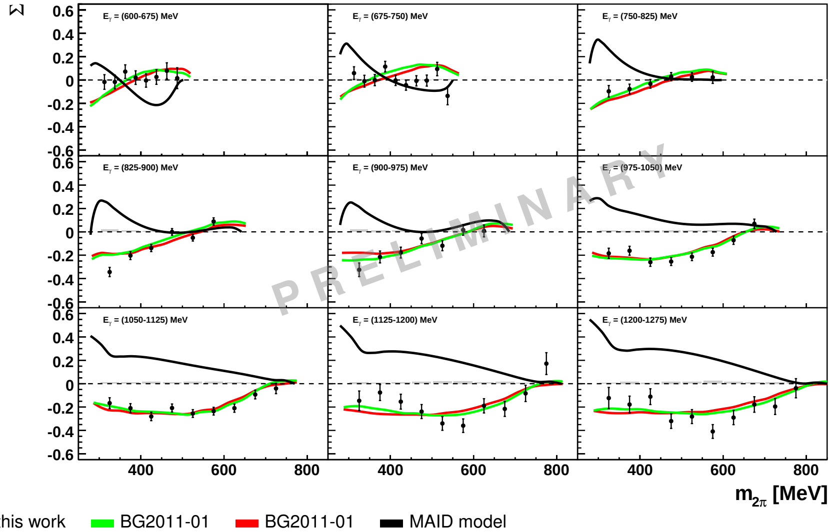
Beam asymmetry Σ_B - $2\pi^0$-system



■ this work — BG2011-01 — BG2011-01 — MAID model

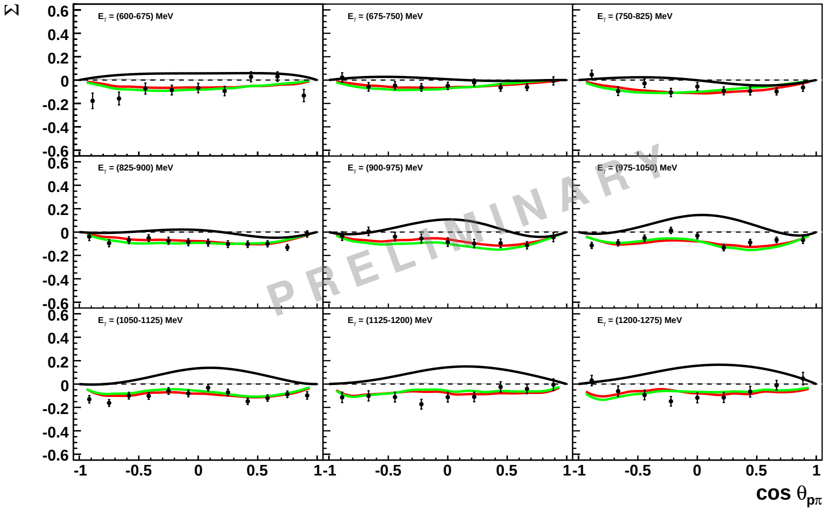
Appendix

Beam asymmetry Σ_B - $2\pi^0$-system



Appendix

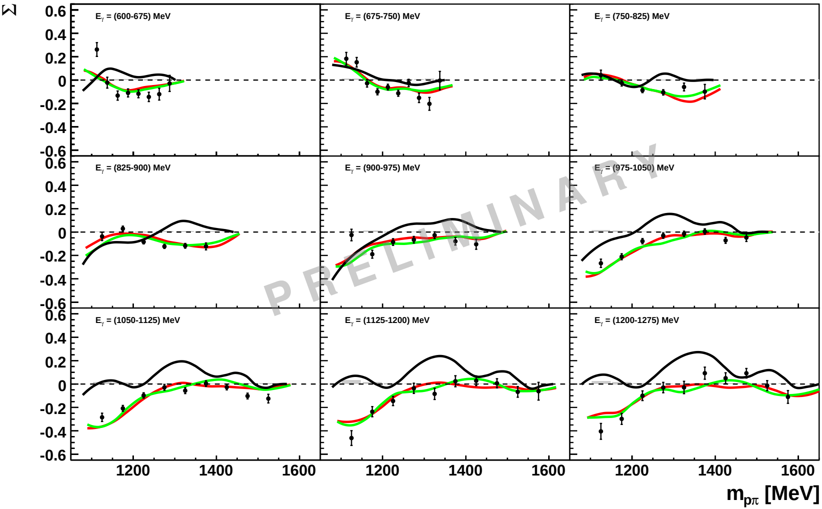
Beam asymmetry Σ_B - $p\pi^0$-system



■ this work — BG2011-01 — BG2011-01 — MAID model

Appendix

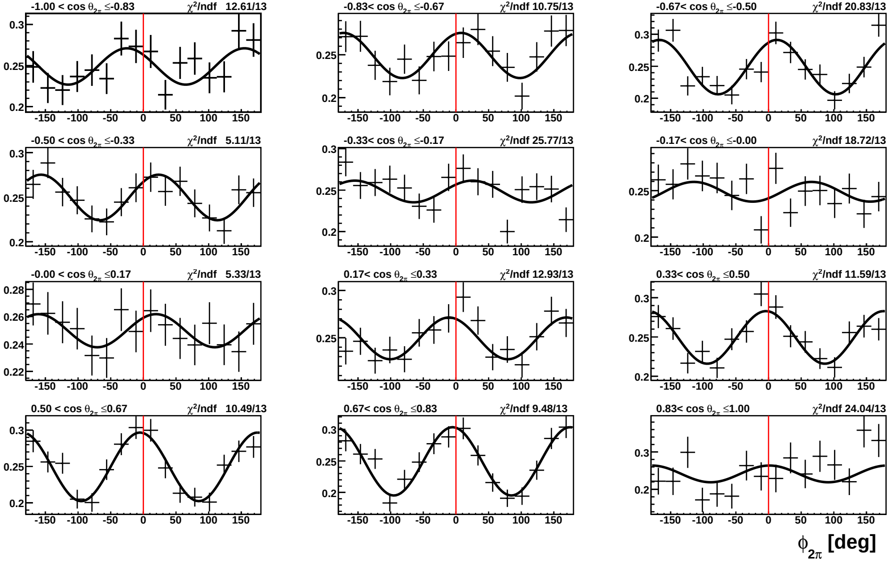
Beam asymmetry Σ_B - $p\pi^0$-system



■ this work — BG2011-01 — BG2011-01 — MAID model

Appendix

Absolute determination – ϕ asymmetries for E_γ = (1050-1125) MeV - $2\pi^0$-system



Appendix

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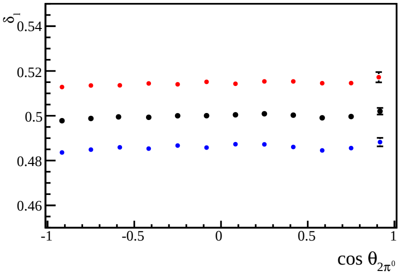
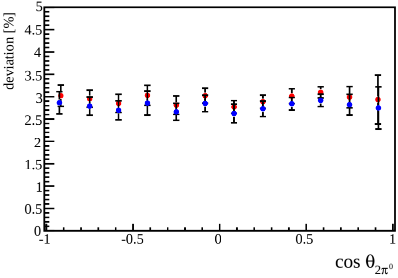
Beam polarization - E_γ = (1050-1125) MeV and $0.67 < \cos\theta_{2\pi} \leq 0.83$

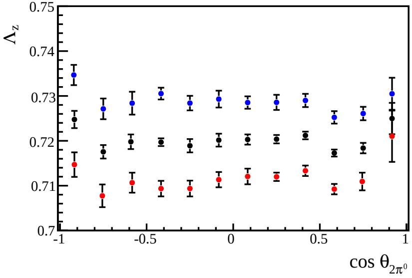


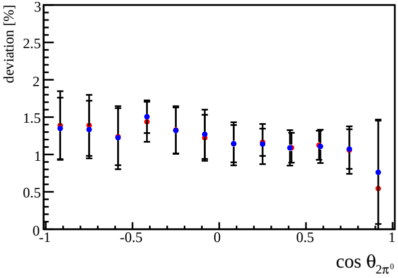


■ beam polarization plane at +45° ■ beam polarization plane at -45° ■ mean polarization

Appendix

Target polarization - E_γ = (1050-1125) MeV and $0.67 < \cos\theta_{2\pi} \leq 0.83$

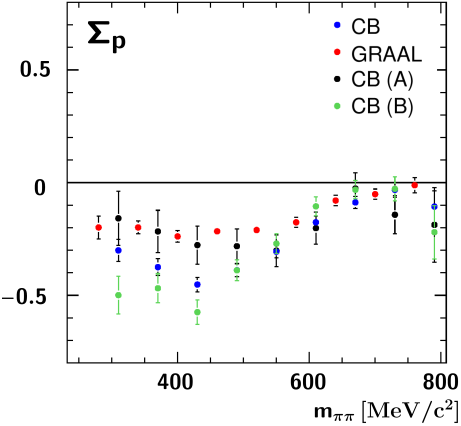




■ positive target polarization ■ negative target polarization ■ mean polarization

Appendix

Influence of different acceptances on the observables



[V. Sokhoyan, Dissertation (2012)]

A 4 photons in the backward direction for $25^\circ < \cos\theta_\gamma < 155^\circ$

B 3 photons in the backward direction for $25^\circ < \theta_\gamma < 155^\circ$ and 1 photon going forward ($\theta_\gamma < 25^\circ$)

Appendix

Acceptance for $m_{2\pi}$