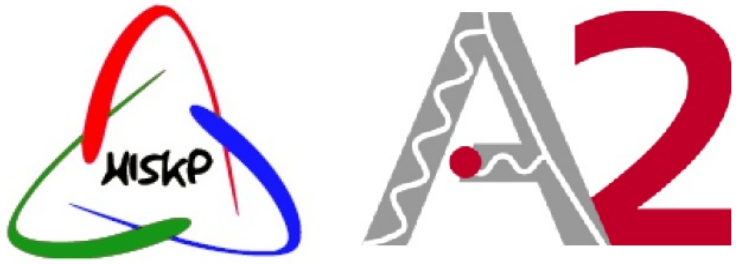
Measurement of the double polarization observable G/E in the reactions $\gamma p \to p\pi^0/n\pi^+$



Karsten Spieker on behalf of the A2 collaboration @ MAMI

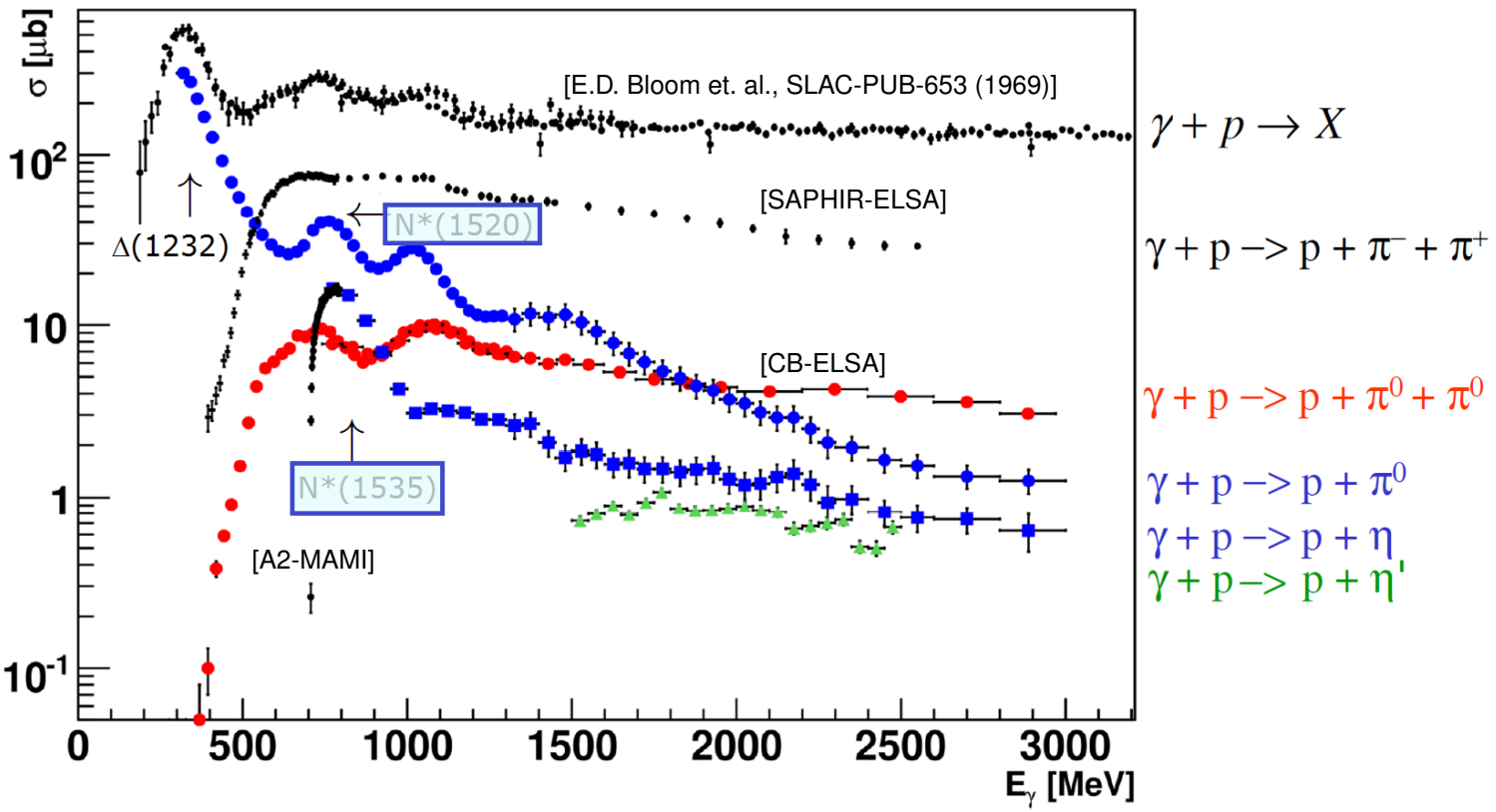
Helmholtz-Institut für Strahlen- und Kernphysik
University of Bonn, Germany

September 26th, 2017

Motivation

Excitation spectrum of the nucleons

Photoabsorption cross section on the proton for several final states

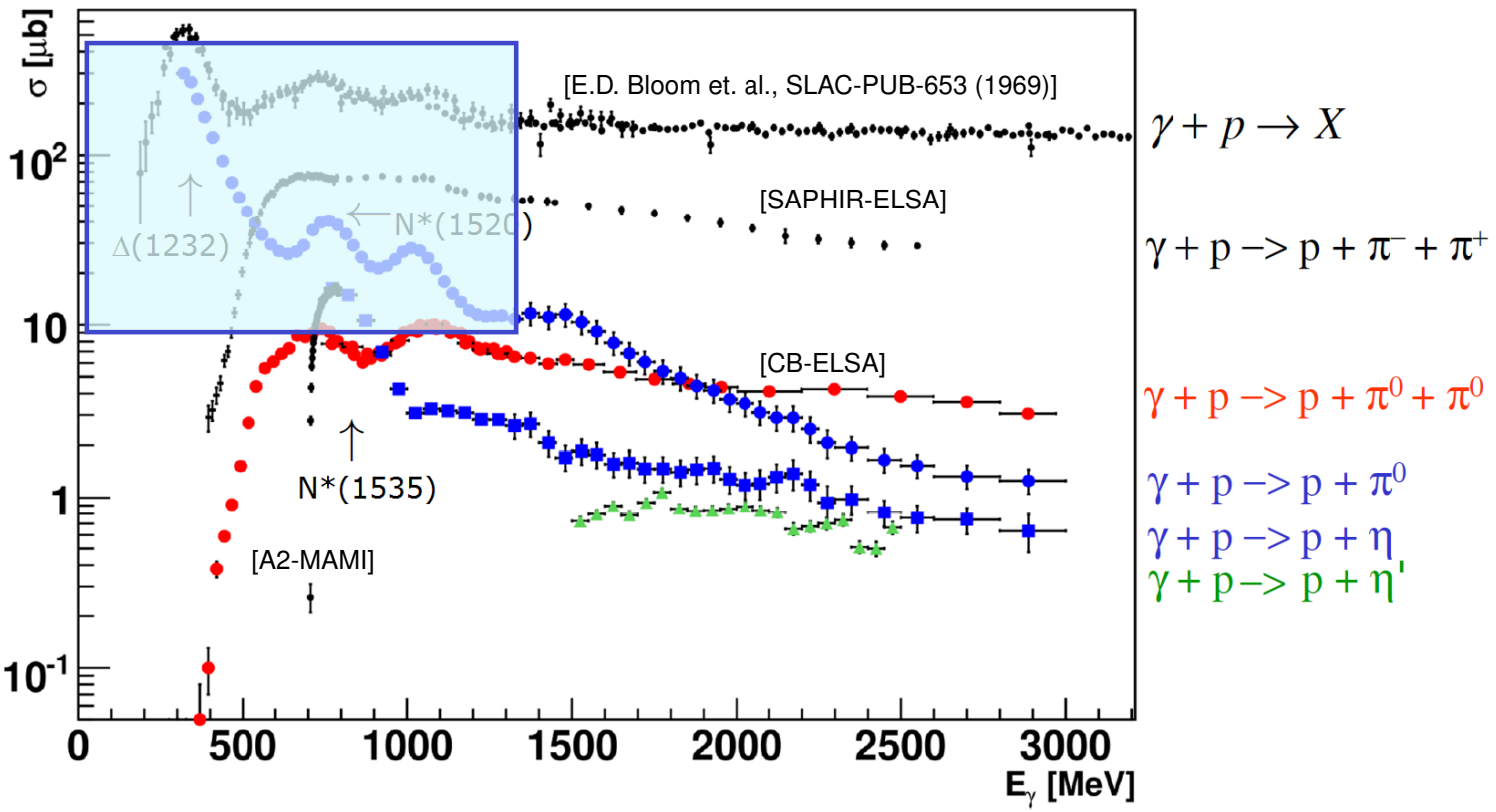


- Resonances contribute with different strength to distinct channels

Motivation

Excitation spectrum of the nucleons

Photoabsorption cross section on the proton for several final states



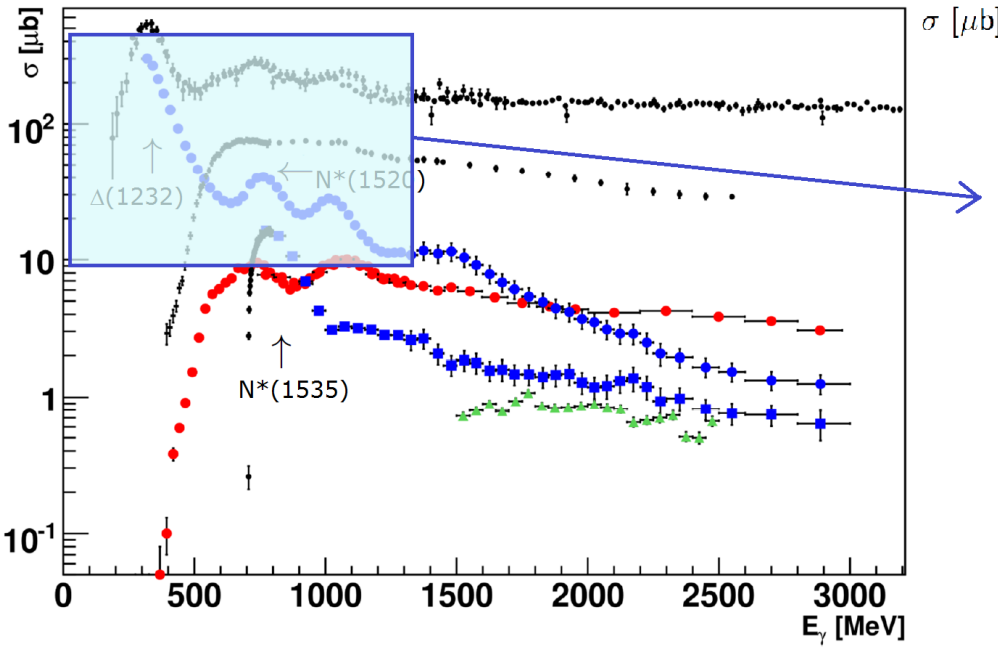
- How can we disentangle the resonances, e.g. for the $p\pi^0$ channel?

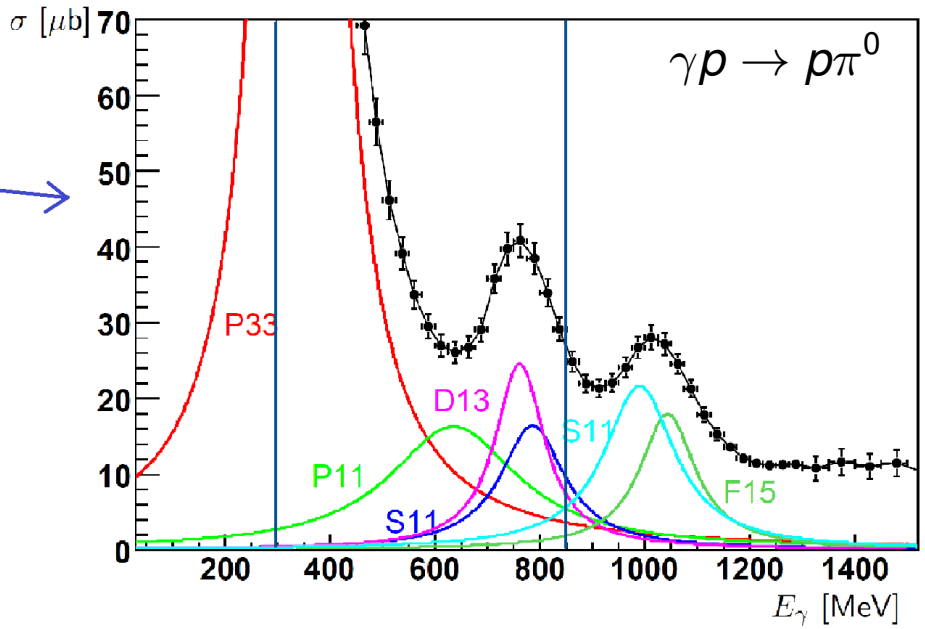
Motivation

Partial Wave Analysis and Polarization observables

How can we disentangle the resonances?

- Partial wave analysis needed to disentangle the resonances
- Total cross section only sensitive to the square of partial waves → not sensitive to weakly contributing partial waves
- **Polarization observables** are sensitive to interference terms!





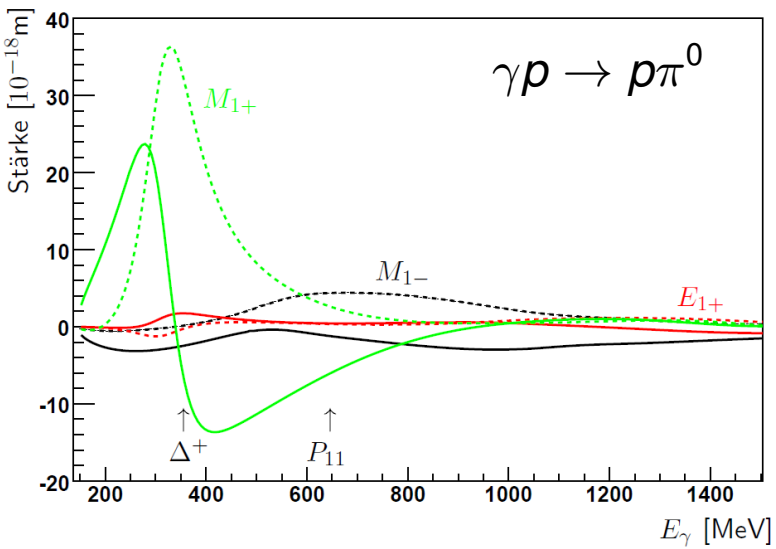
Motivation

Multipole expression of G for $l \leq 1$ in single pion photoproduction off the proton

Double polarization observable G: linearly polarized photons in combination with longitudinally polarized target

$$\frac{d\sigma}{d\Omega} \cdot G(\cos\theta) = Im\{M_{1-}^{*}(E_{1+} - M_{1+}) - 2E_{1+}^{*}M_{1+}\} \cdot 3\sin^2\theta$$

$$\approx Im M_{1-} Re M_{1+} \cdot 3\sin^2\theta$$



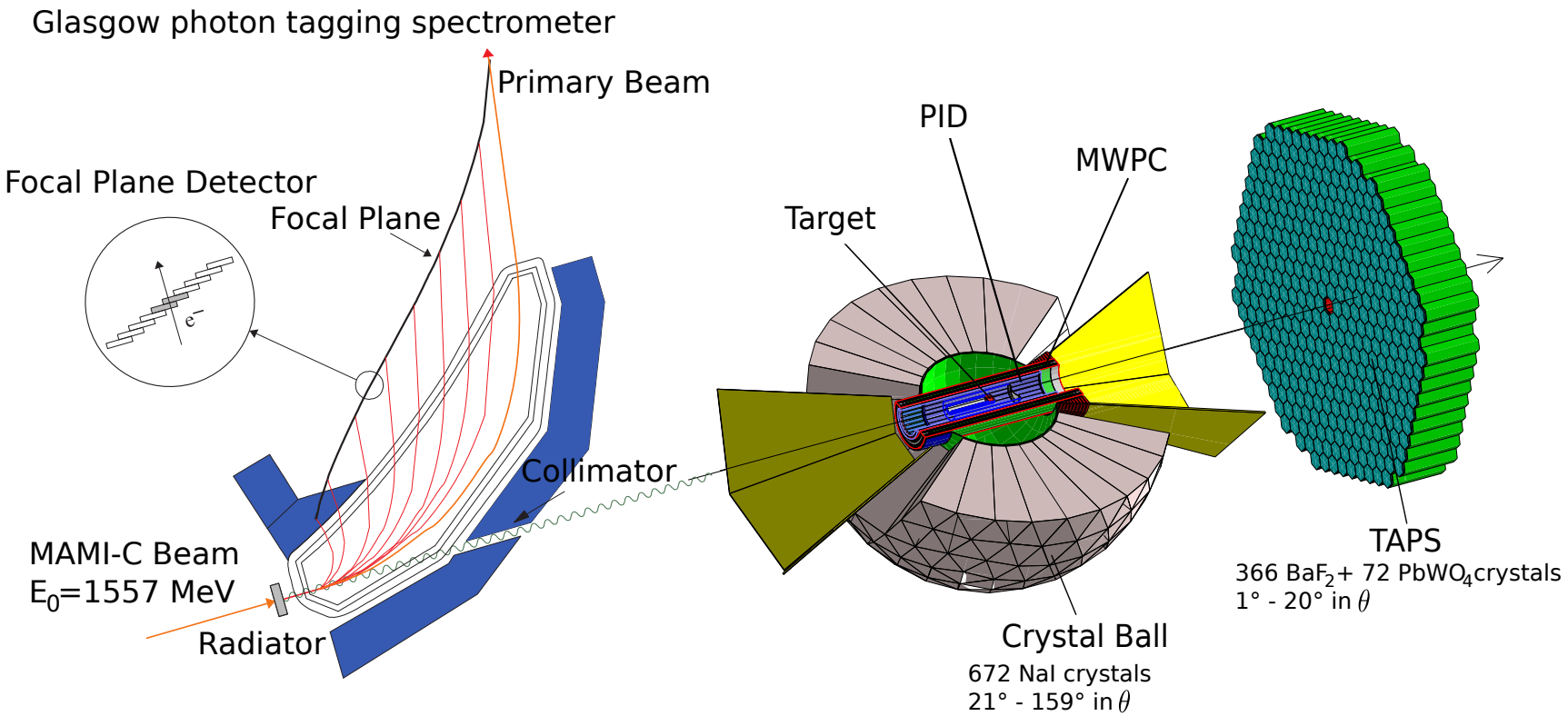
— real part - - imaginary part

- sensitive to the M_{1-} partial wave
- **sensitive to Roper Resonance $P_{11}(1440)$!**
- **$p\pi^0$ together with $n\pi^+$ allows isospin separation!**

Experimental setup

A2@MAMI

long. polarized electrons incident on diamond crystal in combination with long. polarized butanol target



→ **Measurement of G & E at the same time!**

→ **Perfectly suited to identify charged and neutral final states!**

Selection of Events

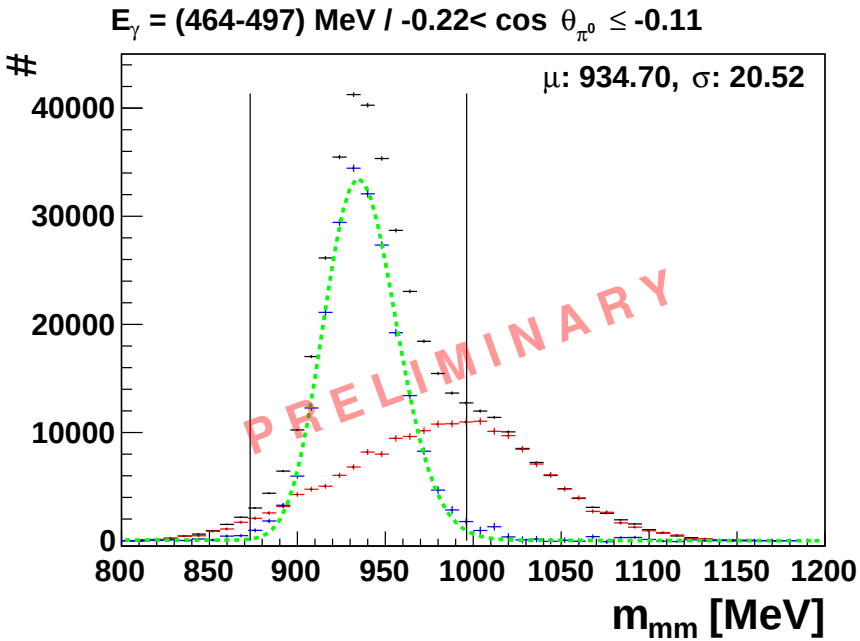
Kinematic Cuts - $p\pi^0$

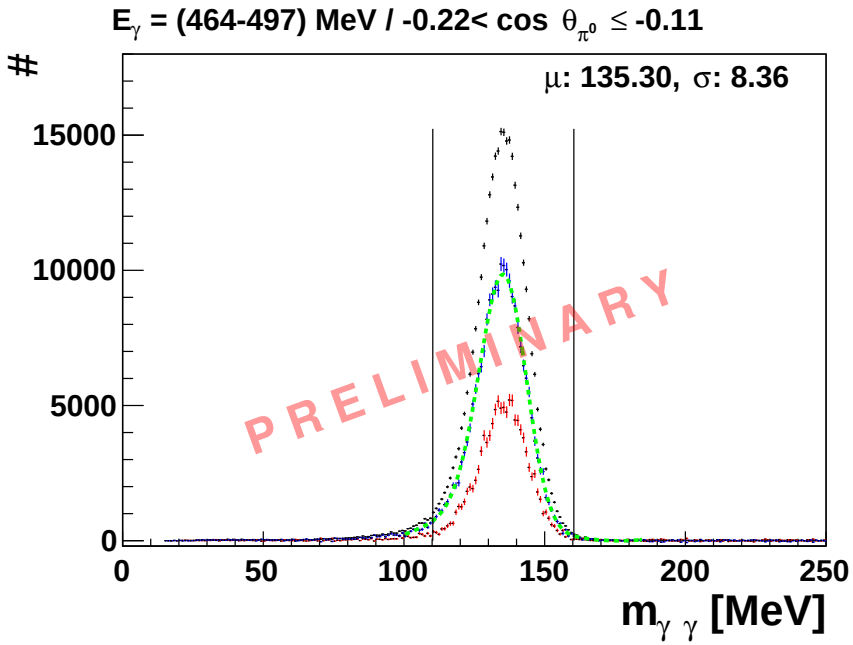
$\gamma\, p \rightarrow p\, \pi^0 \rightarrow p\, 2\gamma$

$\rightarrow$ 2 neutral particles + 1 charged particle in the final state!

Mass Cuts

- Cut on the proton mass: $m_{mm} = (938 \pm 3\sigma)$ MeV
- Cut on the meson mass: $m_{\gamma\gamma} = (135 \pm 3\sigma)$ MeV



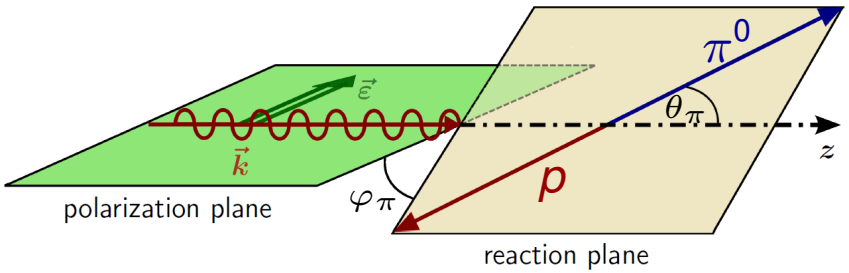


butanol — scaled carbon — reconstructed hydrogen — fit function

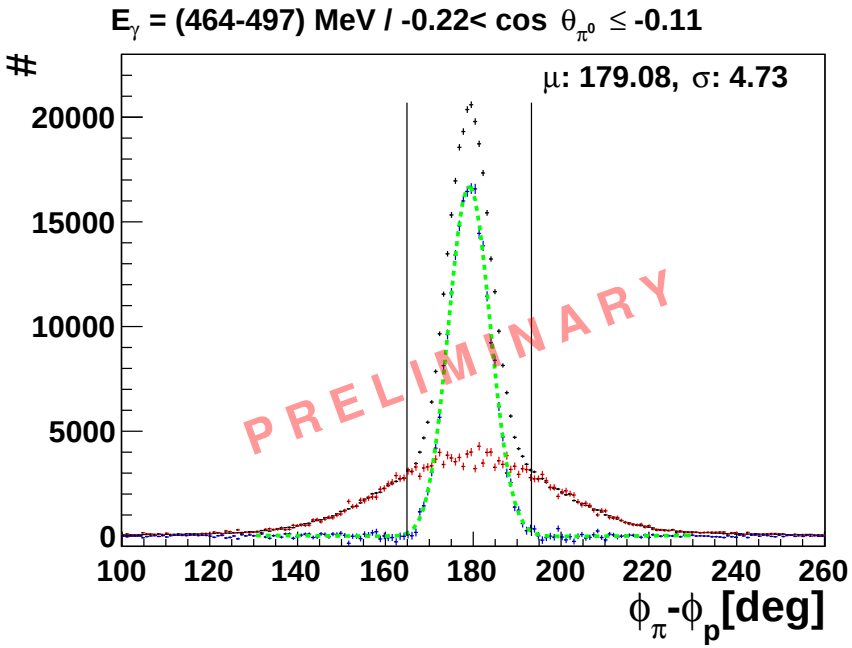
Selection of Events

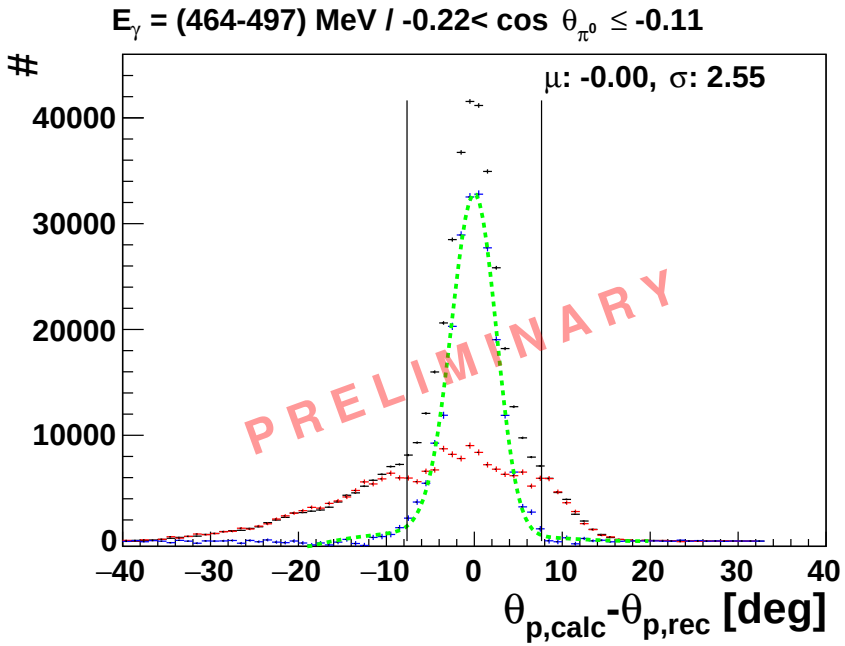
Kinematic Cuts - $p\pi^0$

Angular Cuts



- Reaction products decay in one plane:
  $\phi_{diff} = |\phi_\pi - \phi_p| = (180 \pm 3\sigma)\ ^\circ$
- Comparison of the calculated & reconstructed proton polar angle:
  $\theta_{diff} = |\theta_{cal} - \theta_{rec}| = (0 \pm 3\sigma)\ ^\circ$



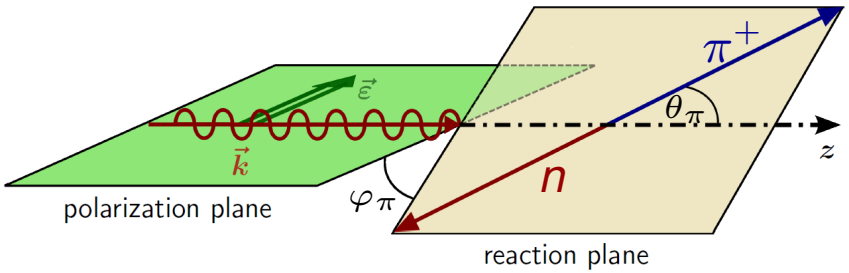


— butanol — scaled carbon — reconstructed hydrogen — fit function

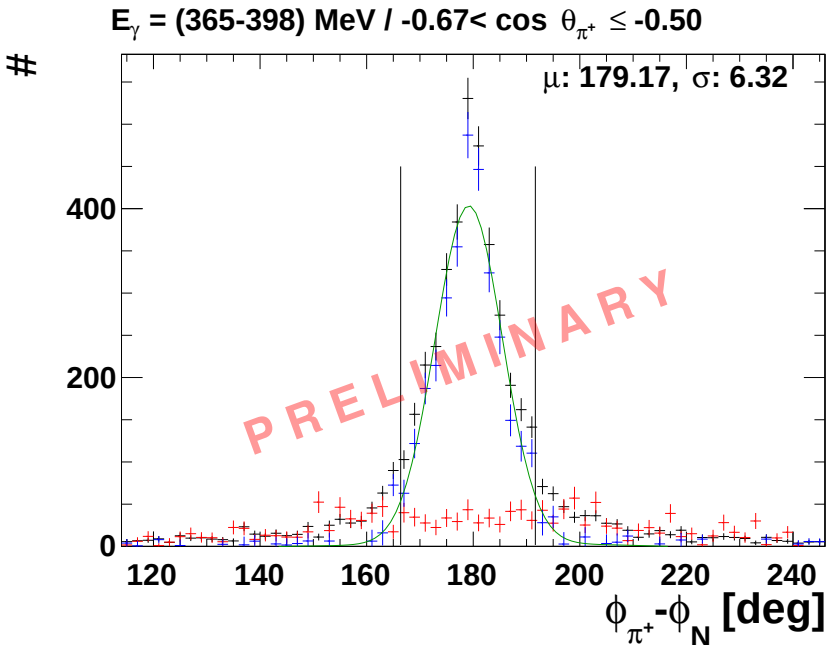
Selection of Events

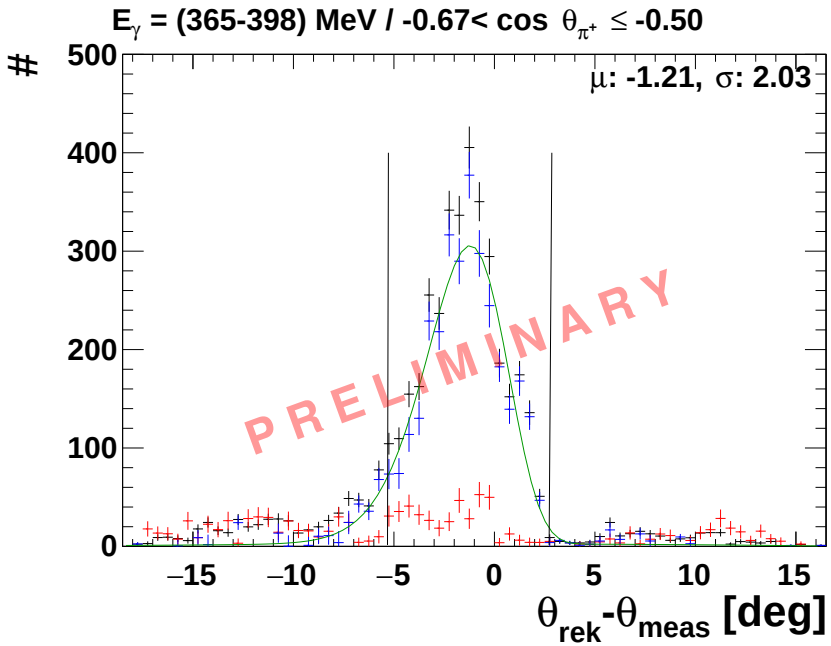
Kinematic Cuts - $n\pi^+$

Angular Cuts



- Reaction products decay in one plane:
  $\phi_{diff} = |\phi_\pi - \phi_n| = (180 \pm 3\sigma)\ ^\circ$
- Comparison of the calculated & reconstructed neutron polar angle:
  $\theta_{diff} = |\theta_{cal} - \theta_{rec}| = (0 \pm 3\sigma)\ ^\circ$





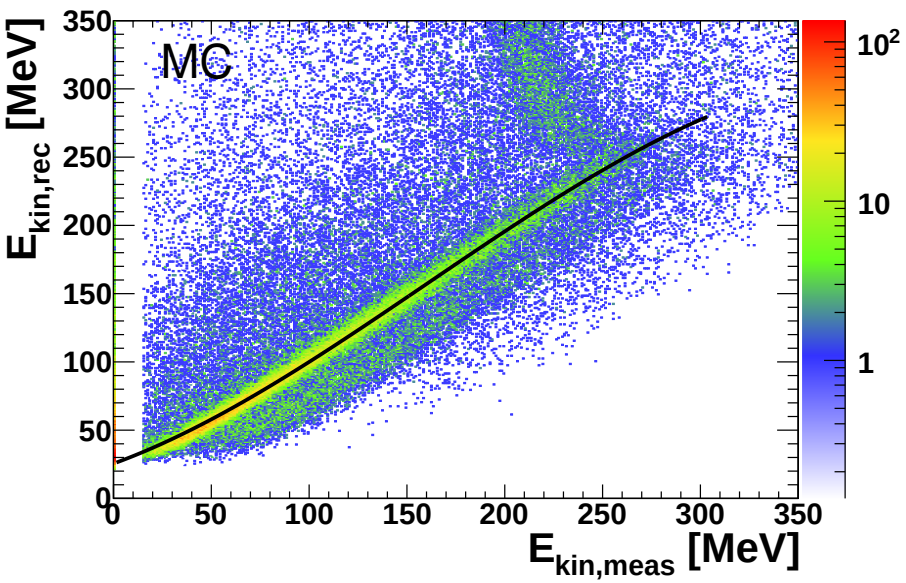
butanol — scaled carbon — reconstructed hydrogen — fit function

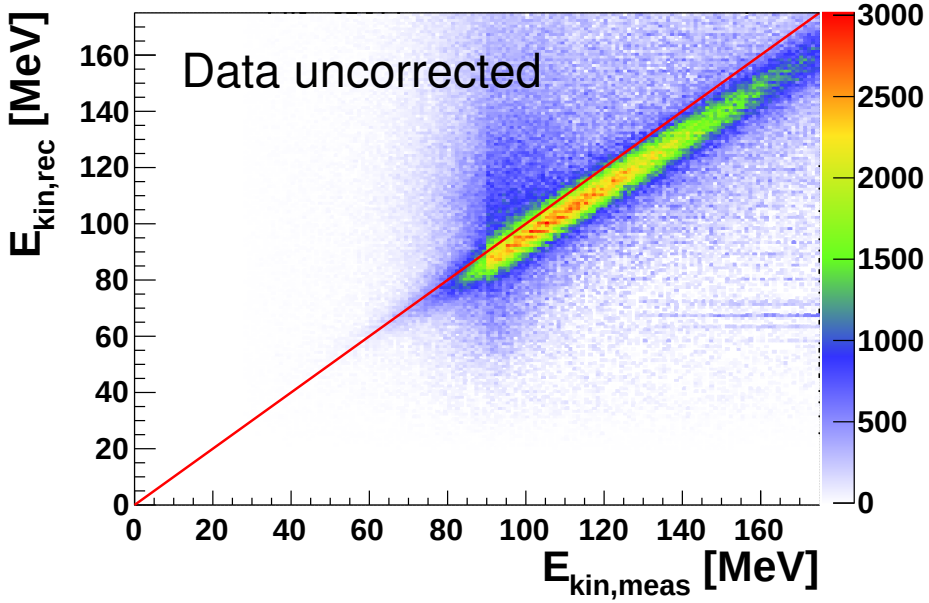
Selection of Events

Kinematic Cuts - $n\pi^+$

Missing Mass Cut - π^+ energy calibration

- For a missing mass cut, the energy of the pion must be calibrated
- MC simulations are used to correct the measured pion energy with respect to the calculated one
- Missing mass cut used for cluster energies below "punch-through"



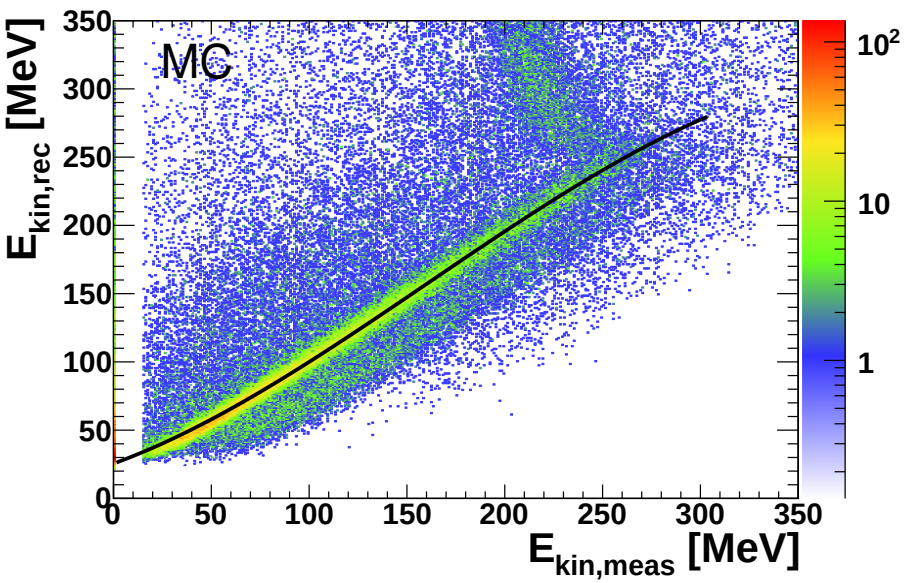


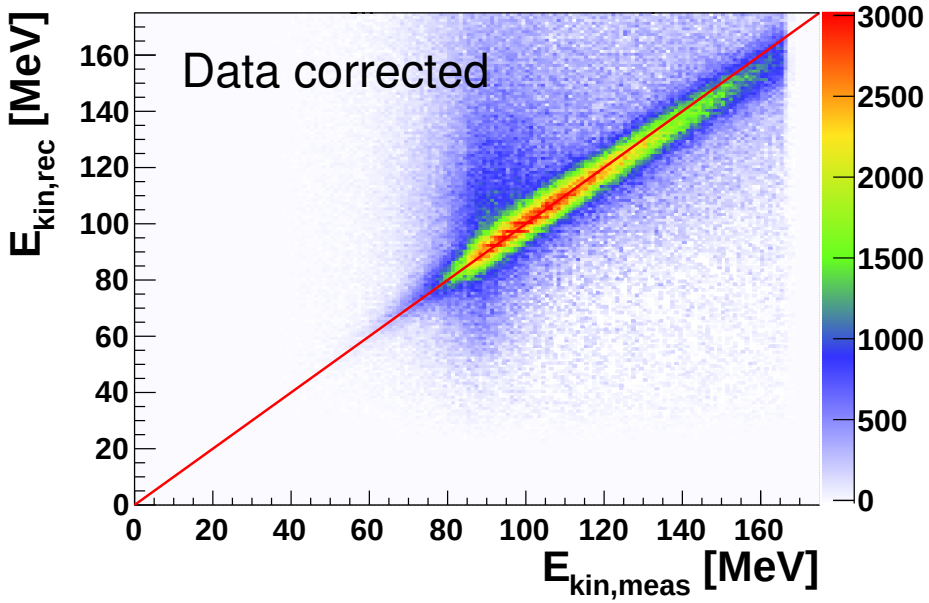
Selection of Events

Kinematic Cuts - $n\pi^+$

Missing Mass Cut - π^+ energy calibration

- For a missing mass cut, the energy of the pion must be calibrated
- MC simulations are used to correct the measured pion energy with respect to the calculated one
- Missing mass cut used for cluster energies below "punch-through"



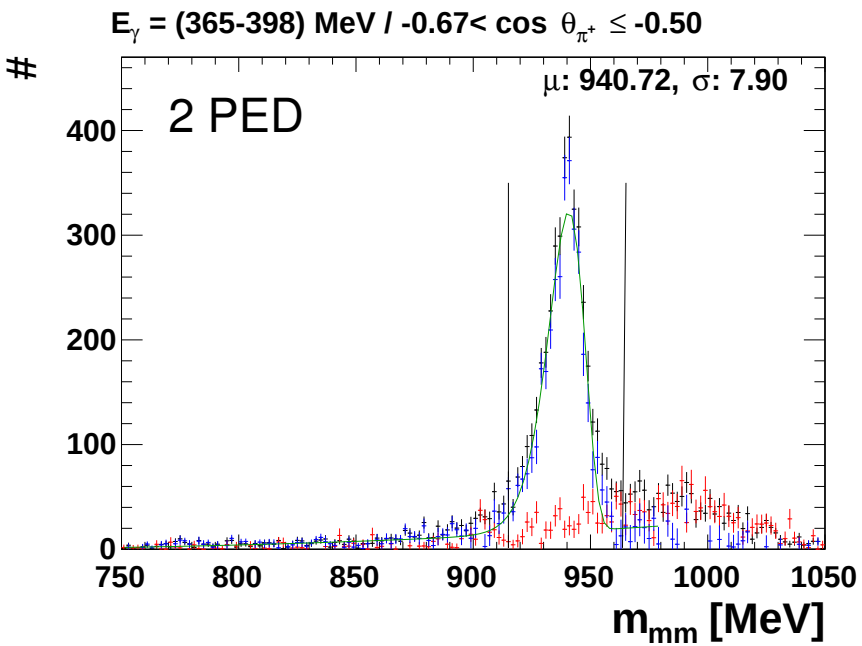


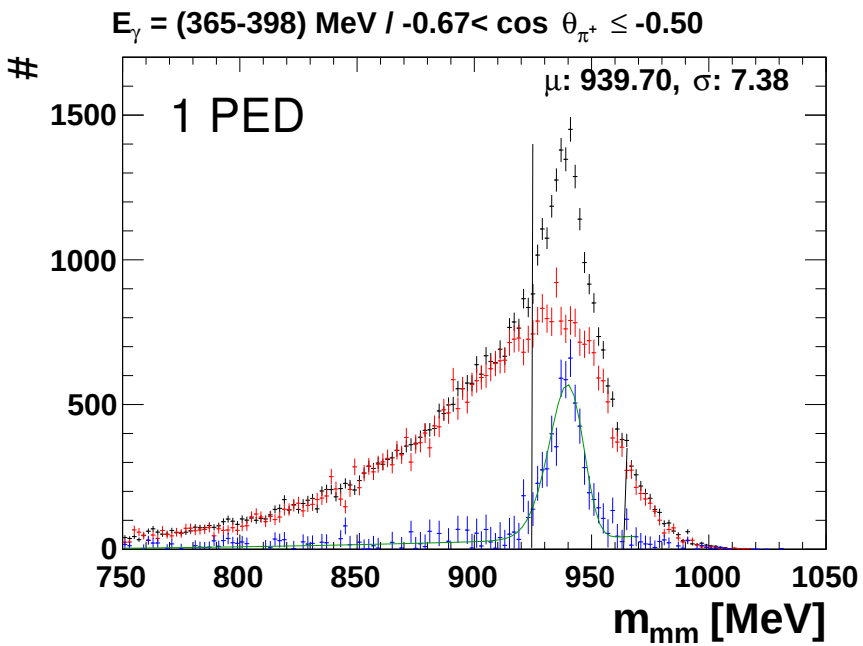
Selection of Events

Kinematic Cuts - $n\pi^+$

Missing Mass Cut

- For a missing mass cut, the energy of the pion must be calibrated
- MC simulations are used to correct the measured pion energy with respect to the calculated one
- Missing mass cut used for cluster energies below "punch-through"

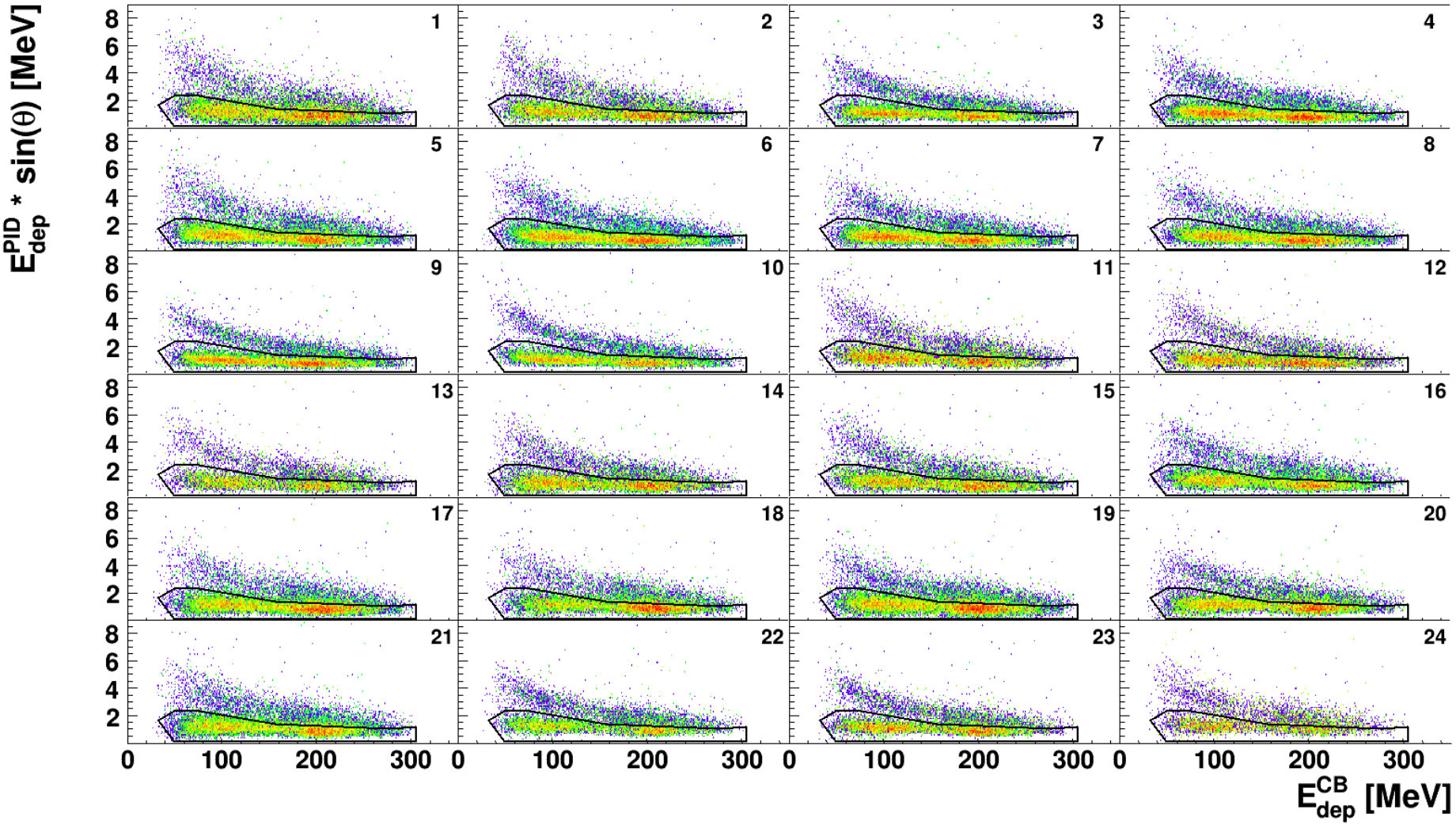




butanol — scaled carbon — reconstructed hydrogen — fit function

Selection of Events

Kinematic Cuts - $n\pi^+$ - dE over E cut



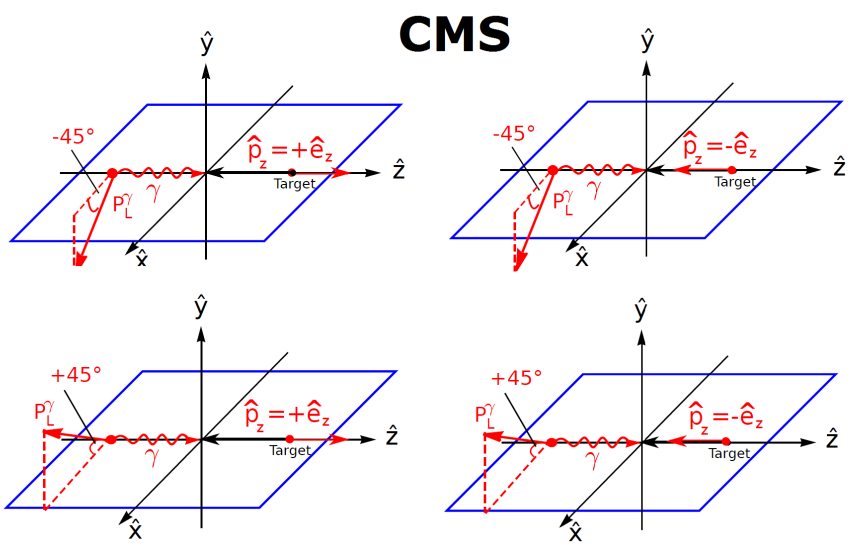
Extraction of the polarization observables

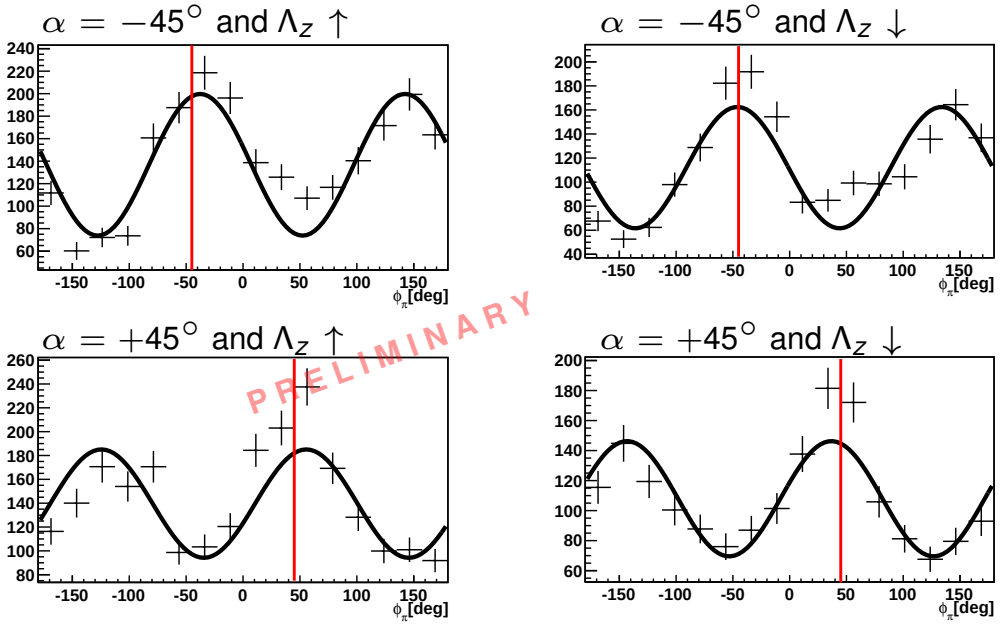
Angular distribution $N_B(\theta, \phi)$

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

ϕ-asymmetries for different settings

E_γ = (464-497) MeV and $-0.22 < \cos\theta_\pi \leq -0.11$





Extraction of the polarization observables

Absolute normalized determination

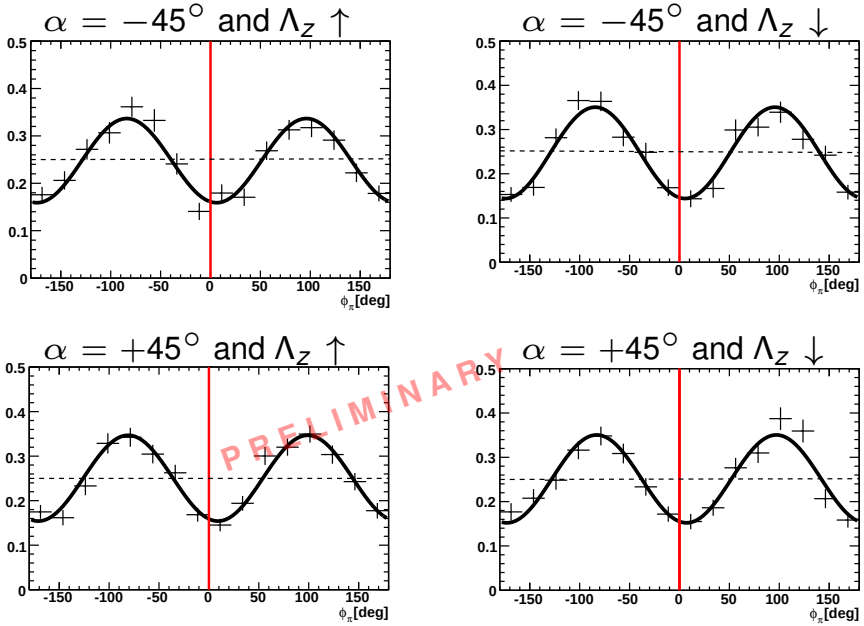
- Sum of different ϕ-asymmetries results in unpolarized cross section

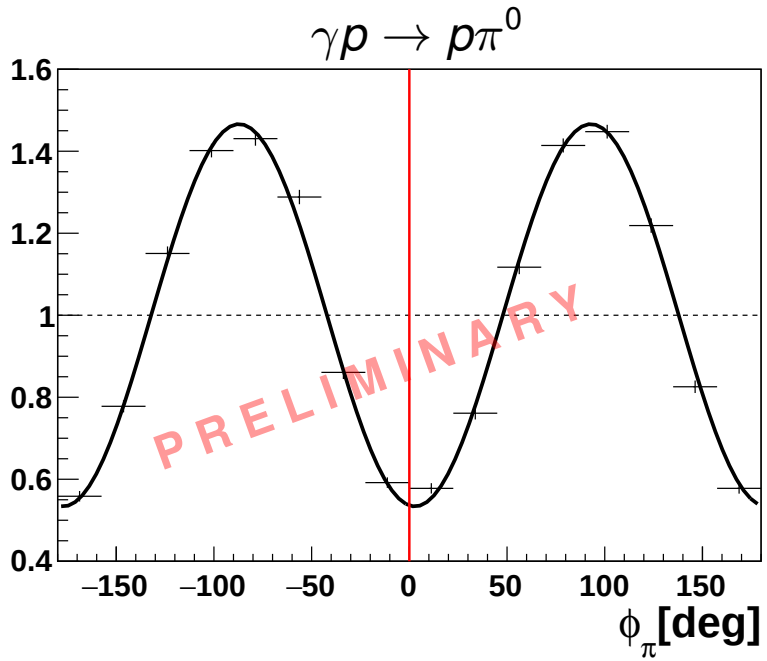
→ **Normalize the different settings before they are shifted!**

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

Shifted and normalized ϕ-asymmetries and their sum

E_γ = (464-497) MeV and $-0.22 < \cos\theta_\pi \leq -0.11$





Extraction of the polarization observables

Absolute normalized determination

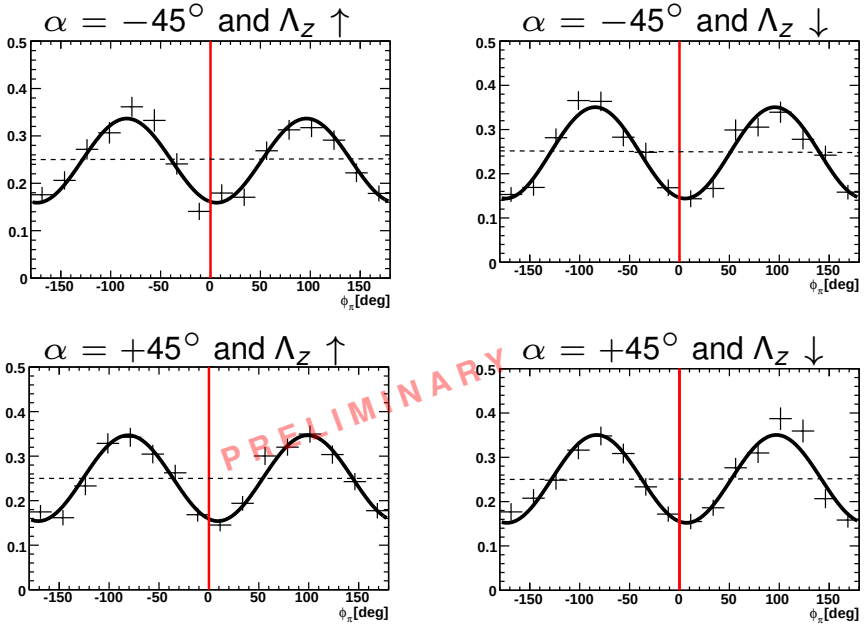
- Sum of different ϕ-asymmetries results in unpolarized cross section

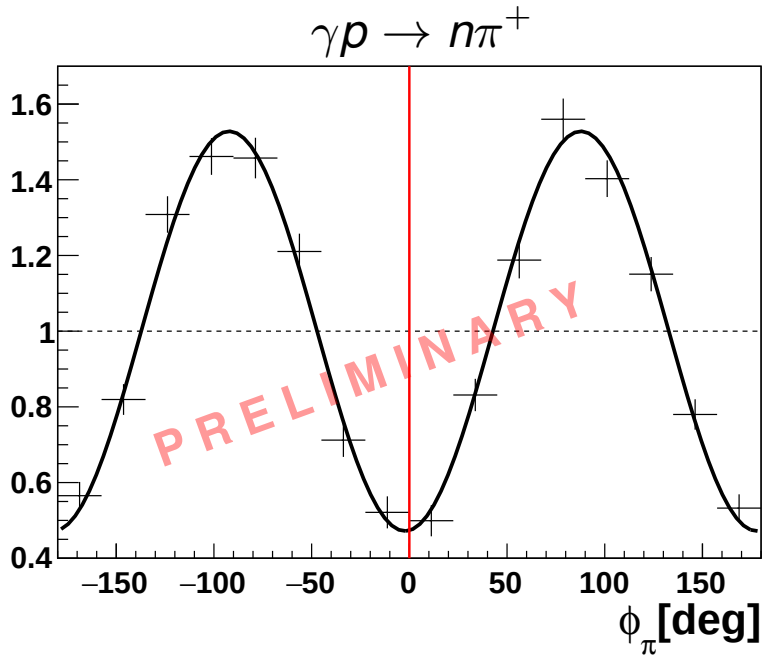
→ **Normalize the different settings before they are shifted!**

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

Shifted and normalized ϕ-asymmetries and their sum

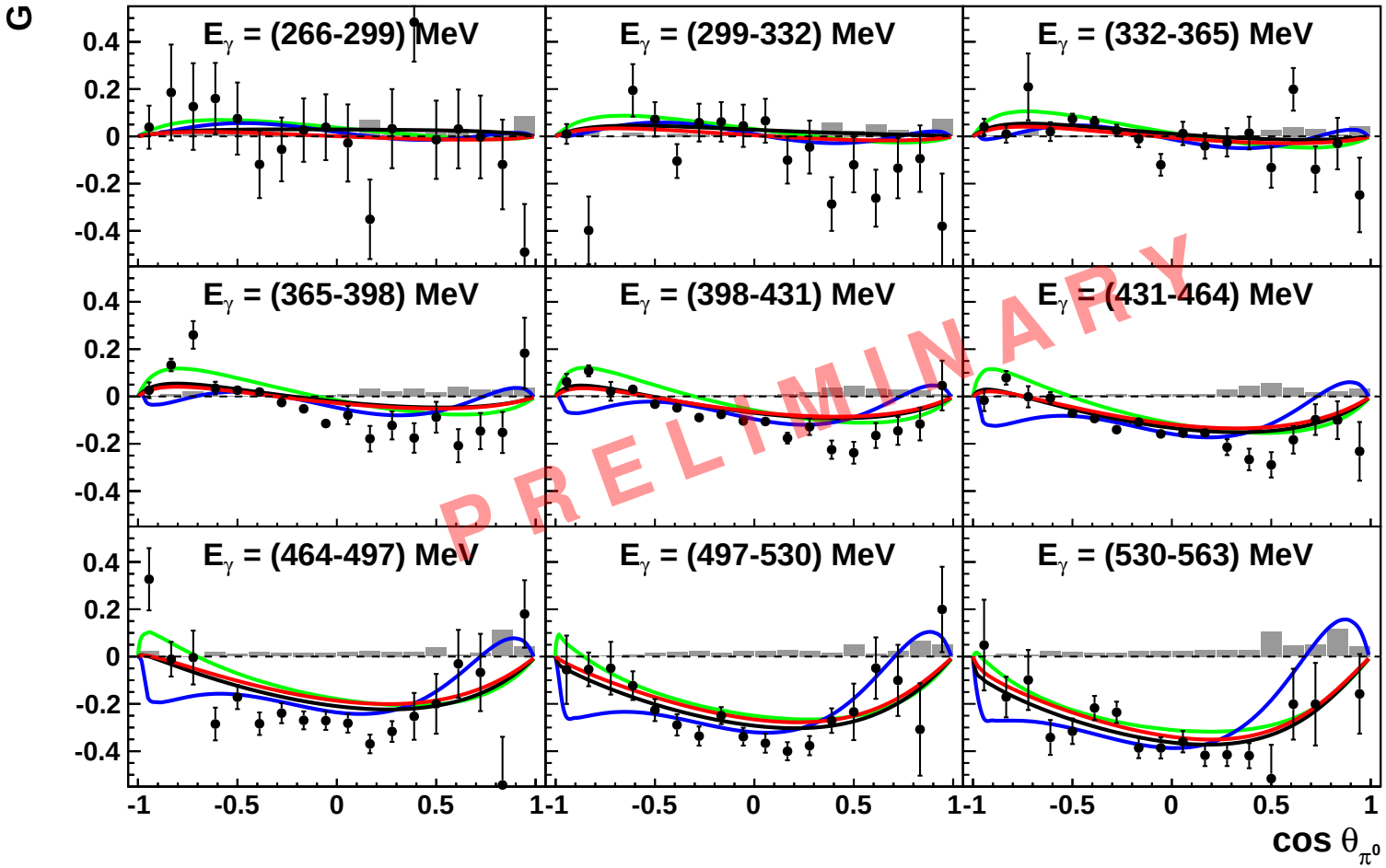
E_γ = (464-497) MeV and $-0.22 < \cos\theta_\pi \leq -0.11$





Results of the polarization observables

Double polarization observable G - p π^0

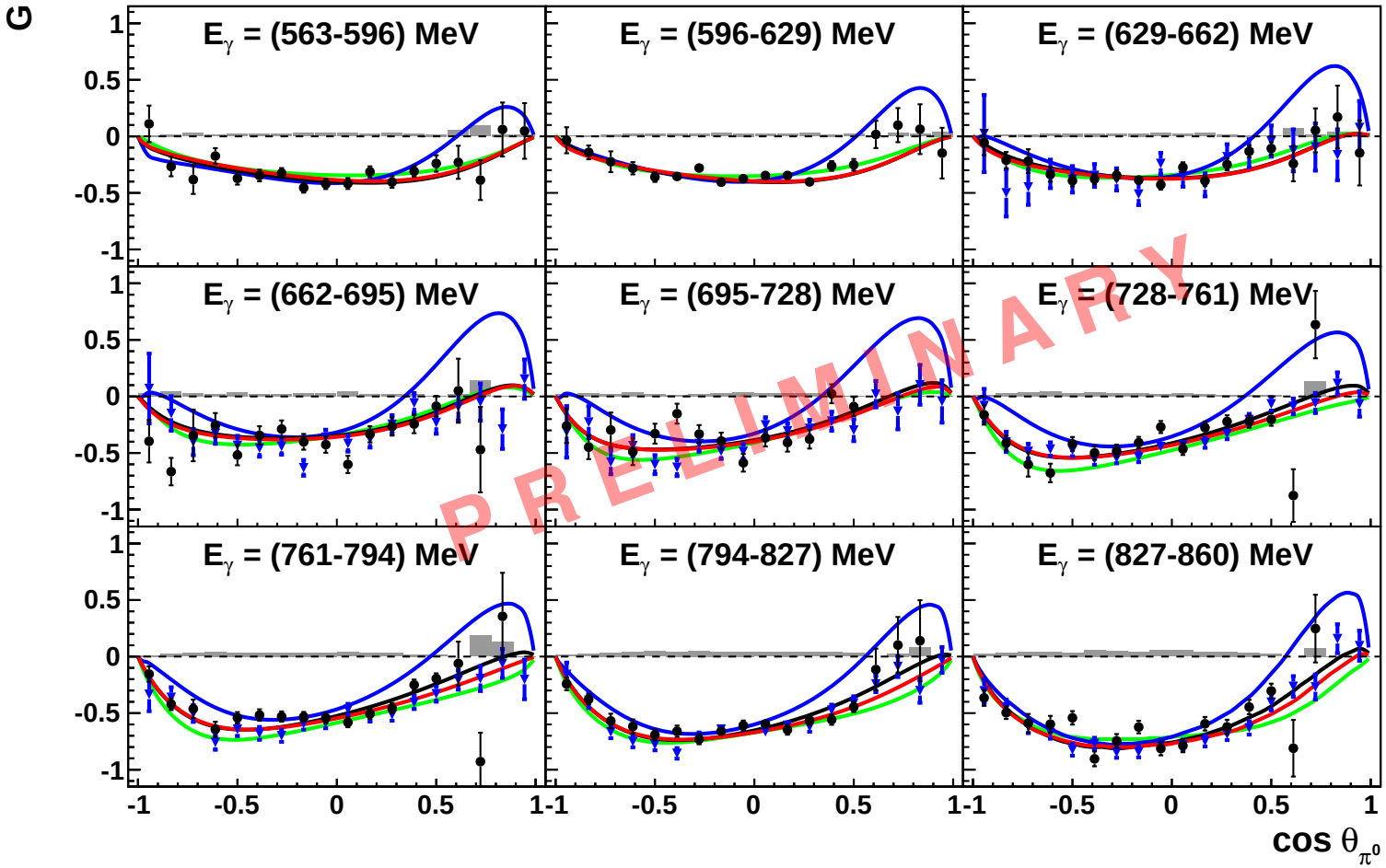


● this work ● CBELSA/TAPS [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] A. Thiel et al., Phys. Rev. Lett. 109 (2012) 102001 [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Results of the polarization observables

Double polarization observable G - p π^0

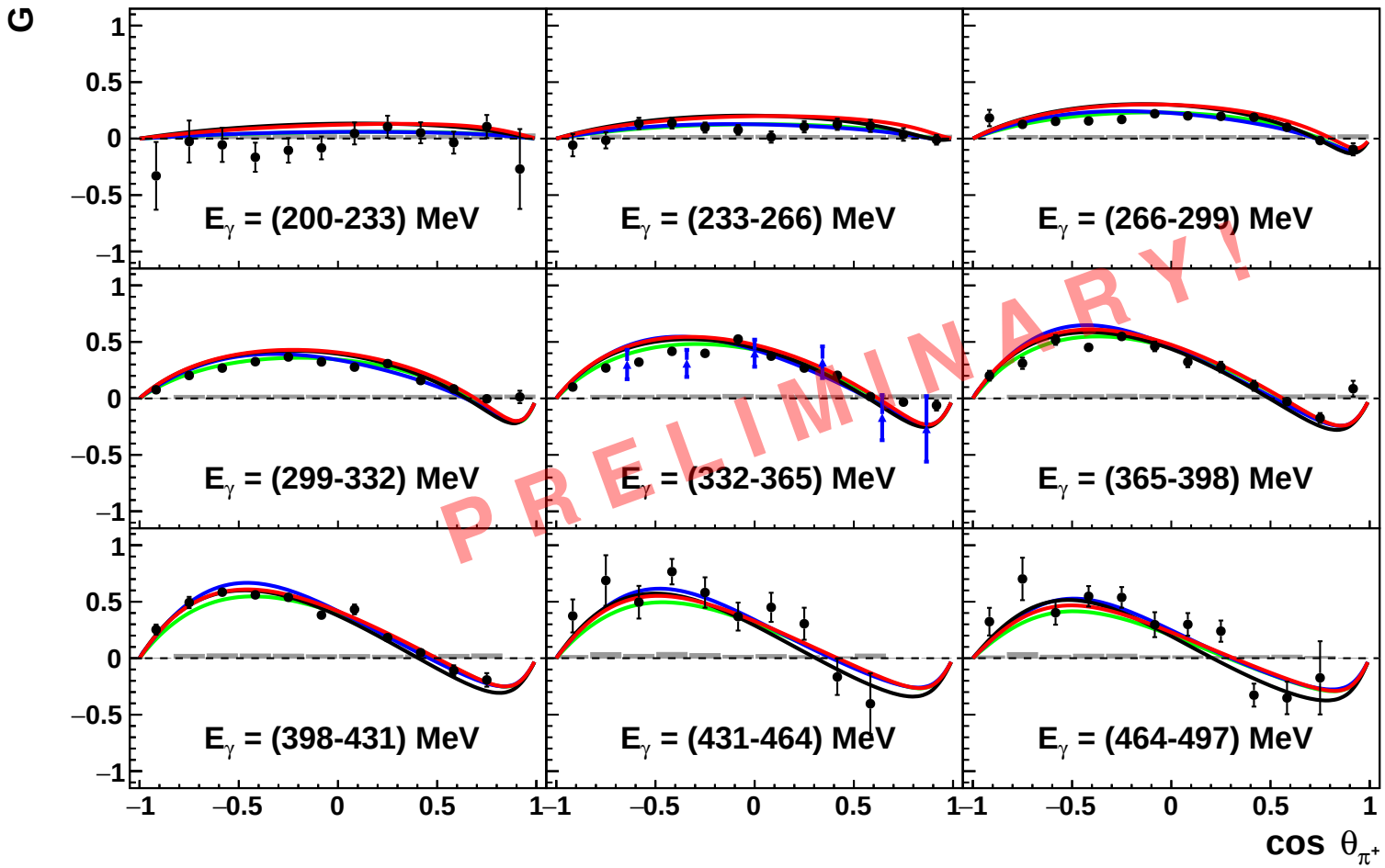


● this work ● CBELSA/TAPS [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] A. Thiel et al., Phys. Rev. Lett. 109 (2012) 102001 [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Results of the polarization observables

Double polarization observable G - n π^+

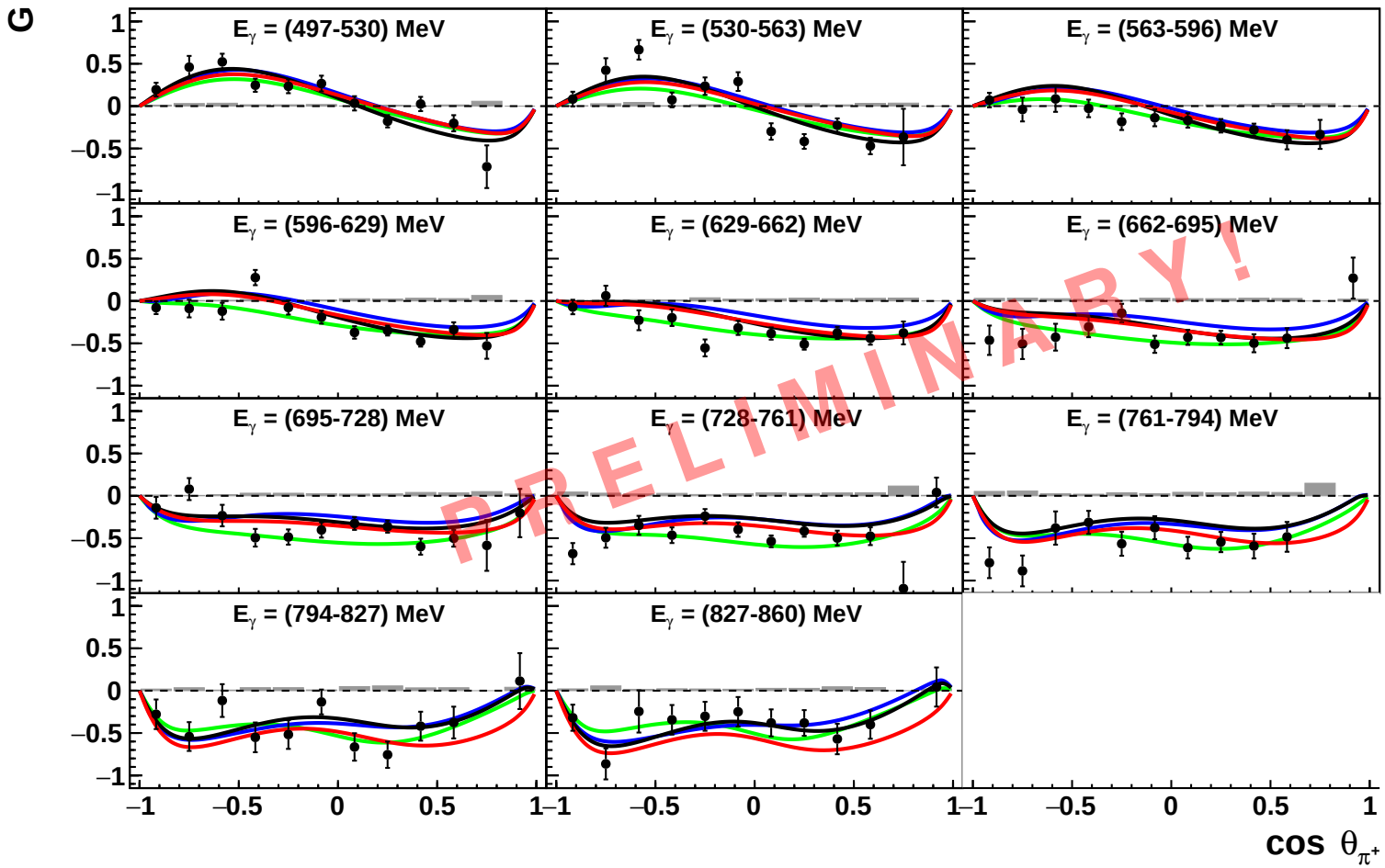


● this work ▲ Mainz [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] J. Ahrens et al., Eur. Phys. J. A26 (2005) [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Results of the polarization observables

Double polarization observable G - n π^+



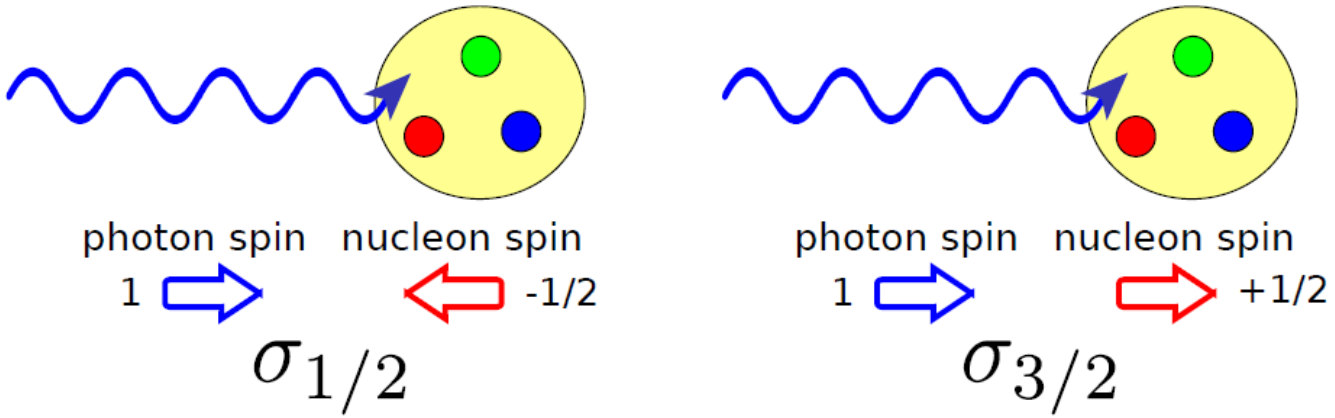
● this work ▲ Mainz [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] J. Ahrens et al., Eur. Phys. J. A26 (2005) [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Results of the polarization observables

Double polarization observable E

Helicity dependent cross section

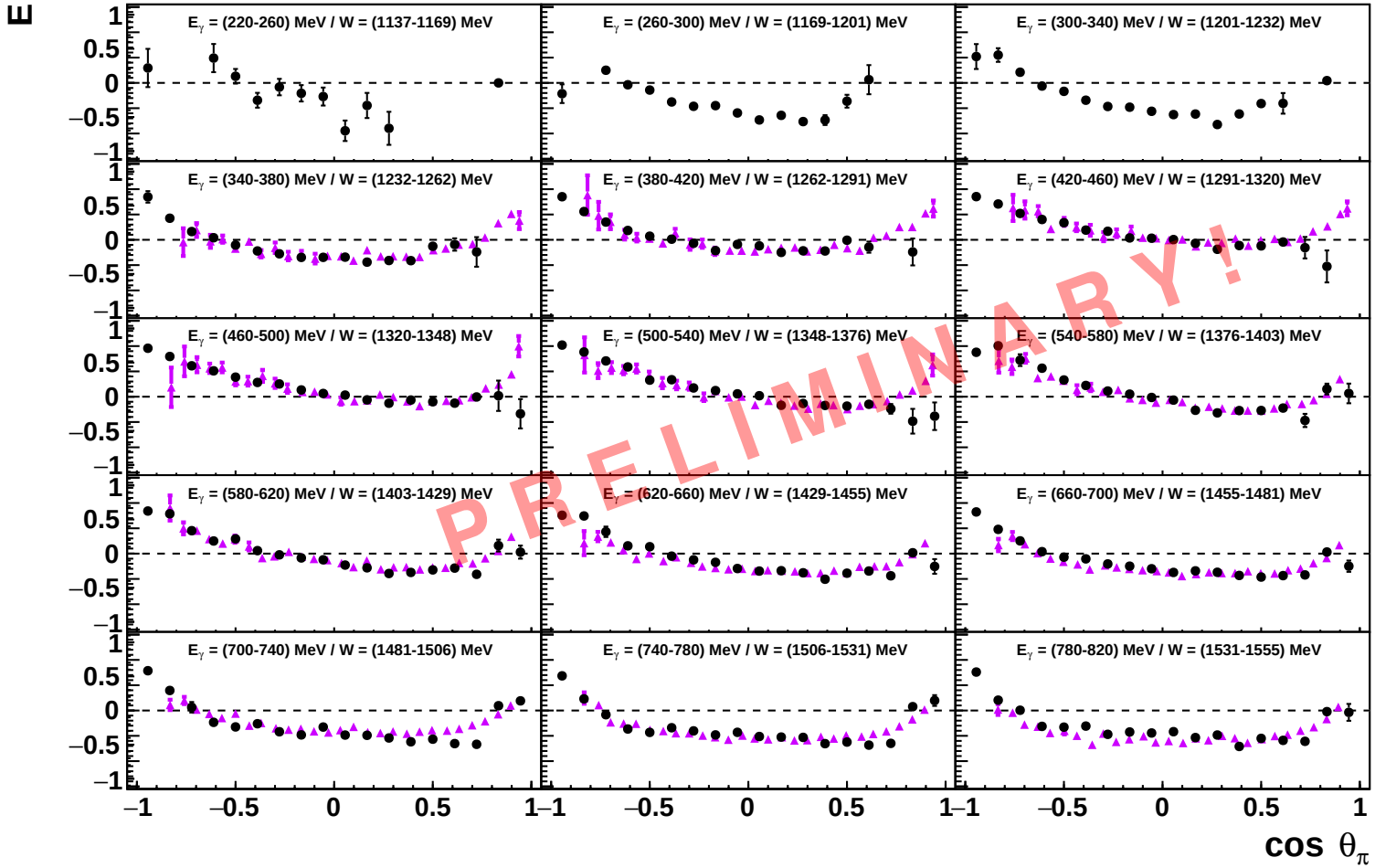


$$N\Big|_{3/2}^{1/2}(\theta) = N_0 \cdot (1 \pm D\delta_c\Lambda_z E)$$

$$\rightarrow E = \frac{1}{D}\frac{1}{\delta_c}\frac{1}{\Lambda_z}\frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}}$$

Results of the polarization observables

Double polarization observable E - n π^+

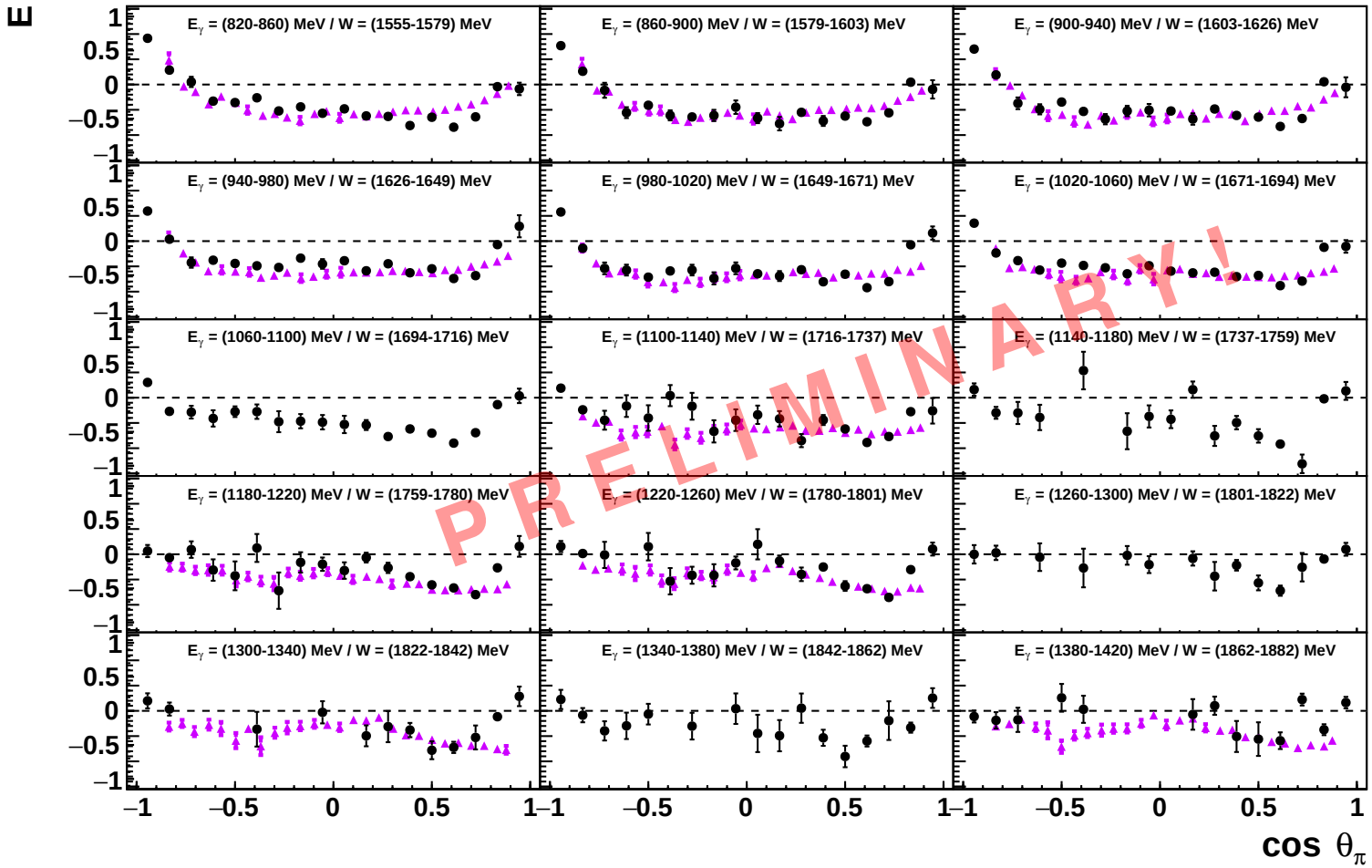


● this work ▲ CLAS [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] S. Strauch et al.,arXiv:1503.05163 [nucl-ex] [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Results of the polarization observables

Double polarization observable E - n π^+



● this work ▲ CLAS [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] S. Strauch et al.,arXiv:1503.05163 [nucl-ex] [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Summary

$p\pi^0$

- Good agreement with recent results for the double polarization observable G
- Covered additionally the low energy region (good agreement with PWAs)

$n\pi^+$

- Good agreement with recent results for the double polarization observable G
- Covered additionally the low energy region with **high** statistics (good agreement with PWAs)
- Results for the double polarization observable E are in very good agreement with recent results
- Additional data points in backward direction and in future in forward direction

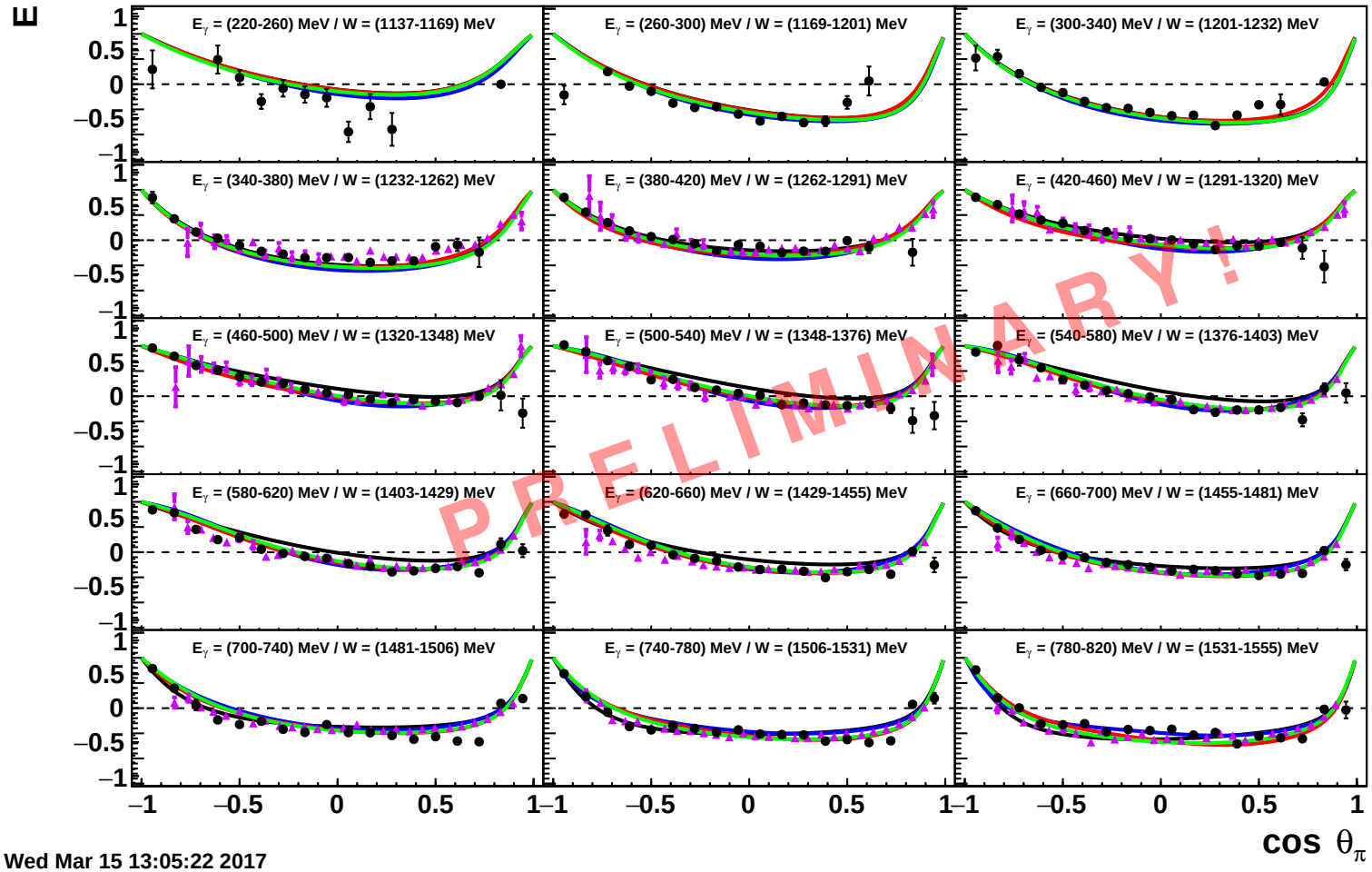
G & E measurements at the same time seem to be possible!

Summary

Thank you for your attention!

Appendix

Double polarization observable E

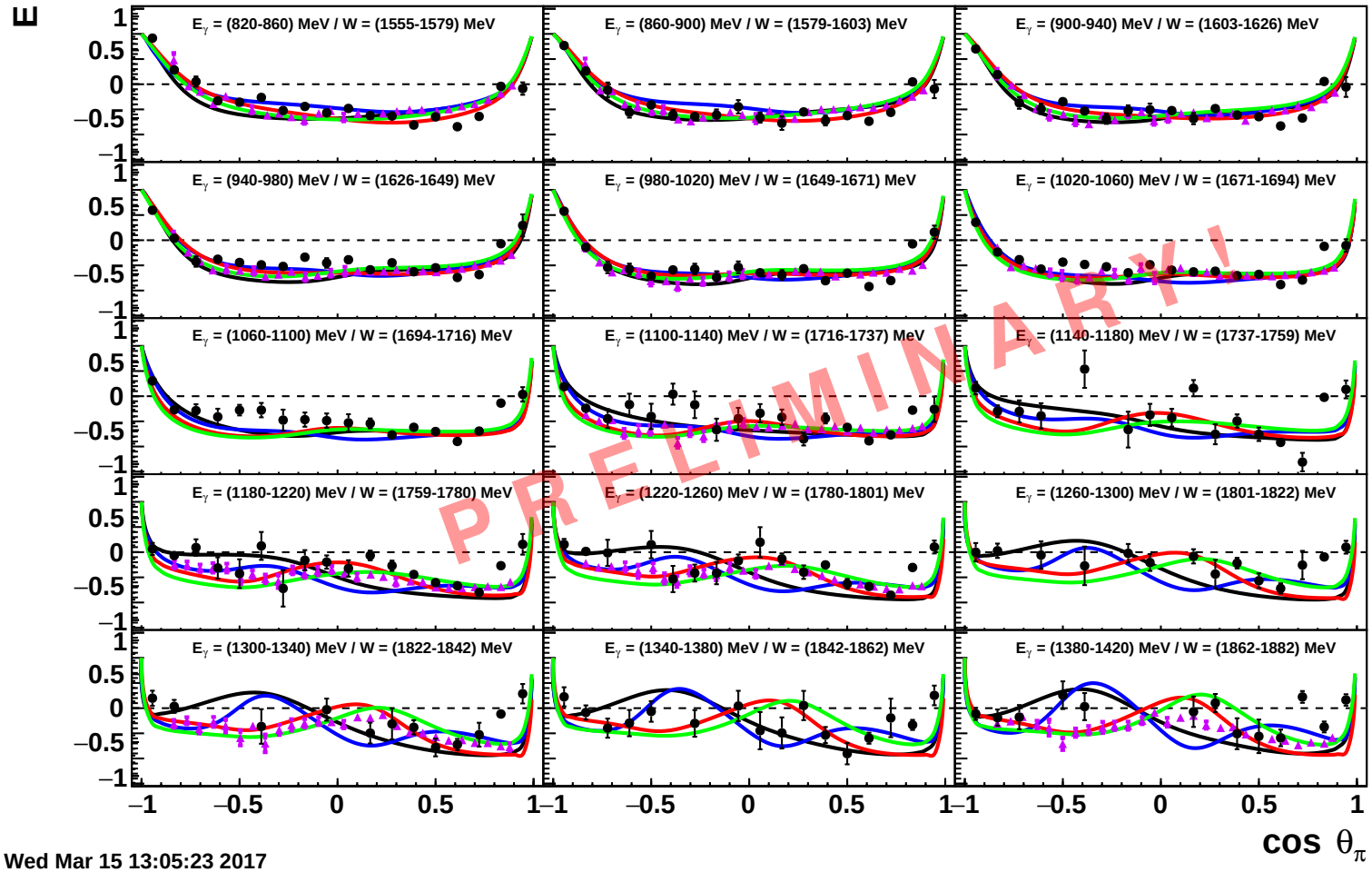


● this work ▲ CLAS [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] S. Strauch et al.,arXiv:1503.05163 [nucl-ex] [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Appendix

Double polarization observable E

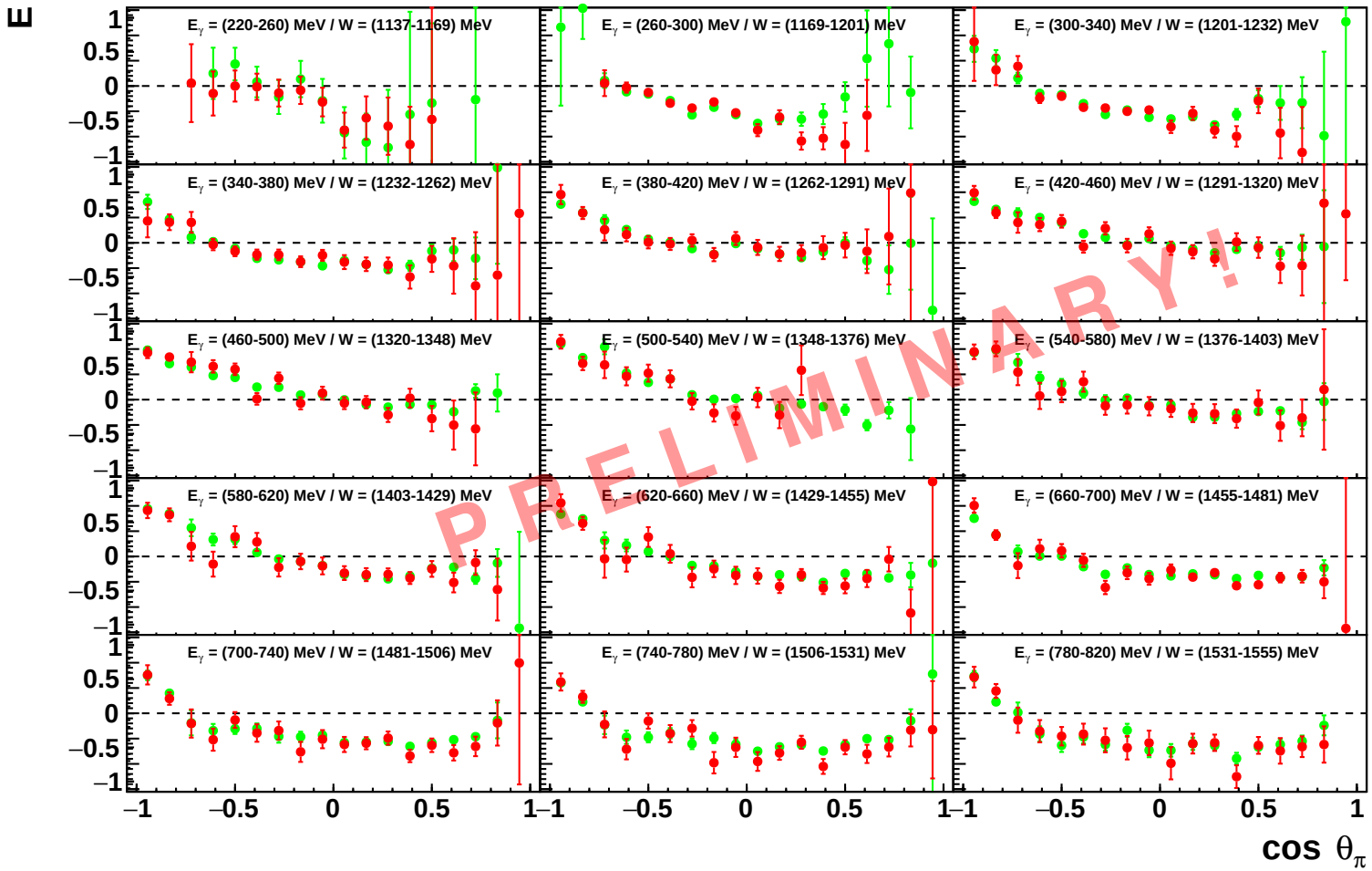


● this work ▲ CLAS [1] — BG2014-01 [2] — BG2014-02 [2] — MAID-07 [3] — SAID-CM12 [4]

[1] S. Strauch et al.,arXiv:1503.05163 [nucl-ex] [2] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[3] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [4] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Appendix

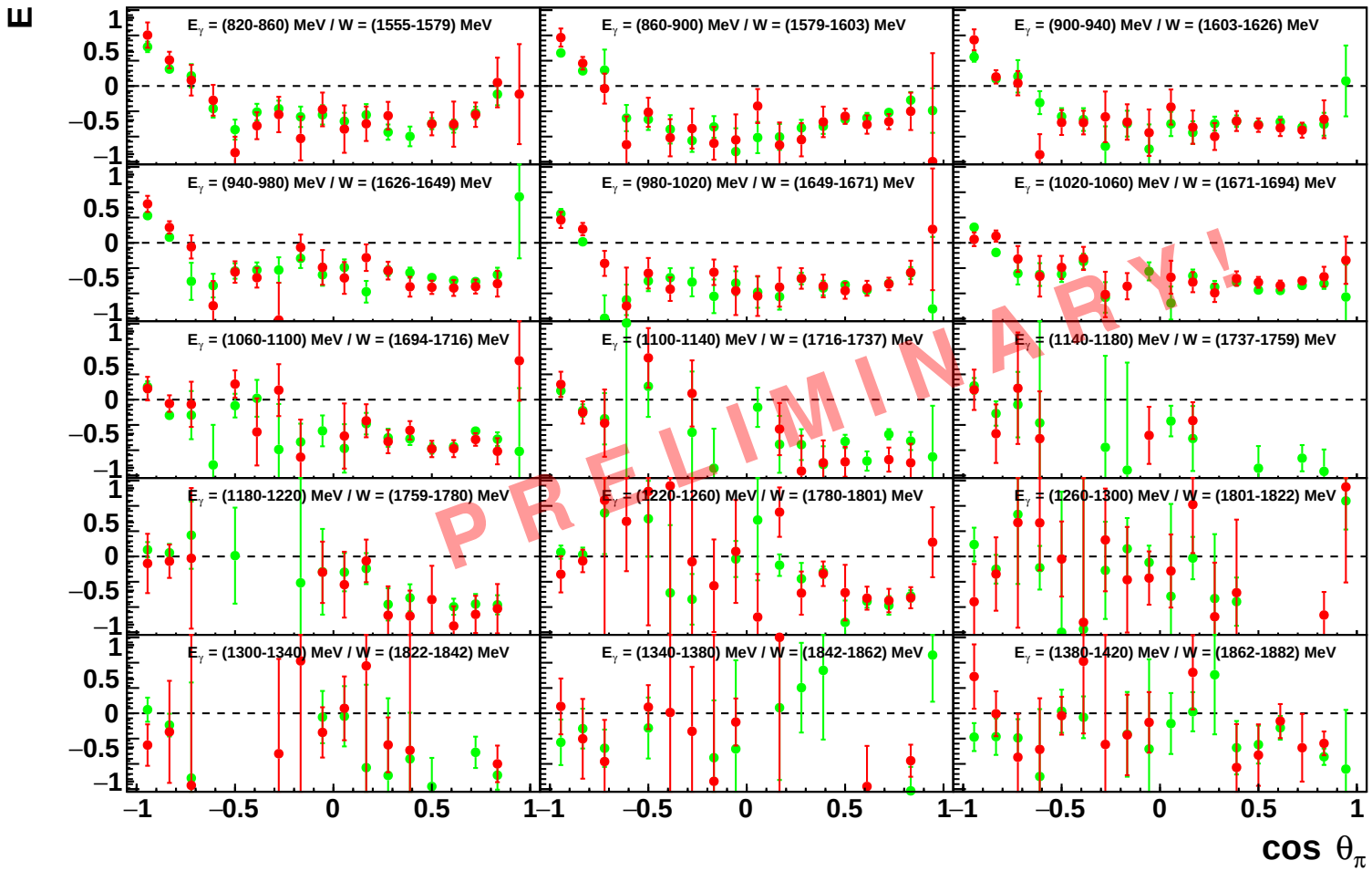
Double polarization observable E - September 2015 beam time



● diamond ● moeller

Appendix

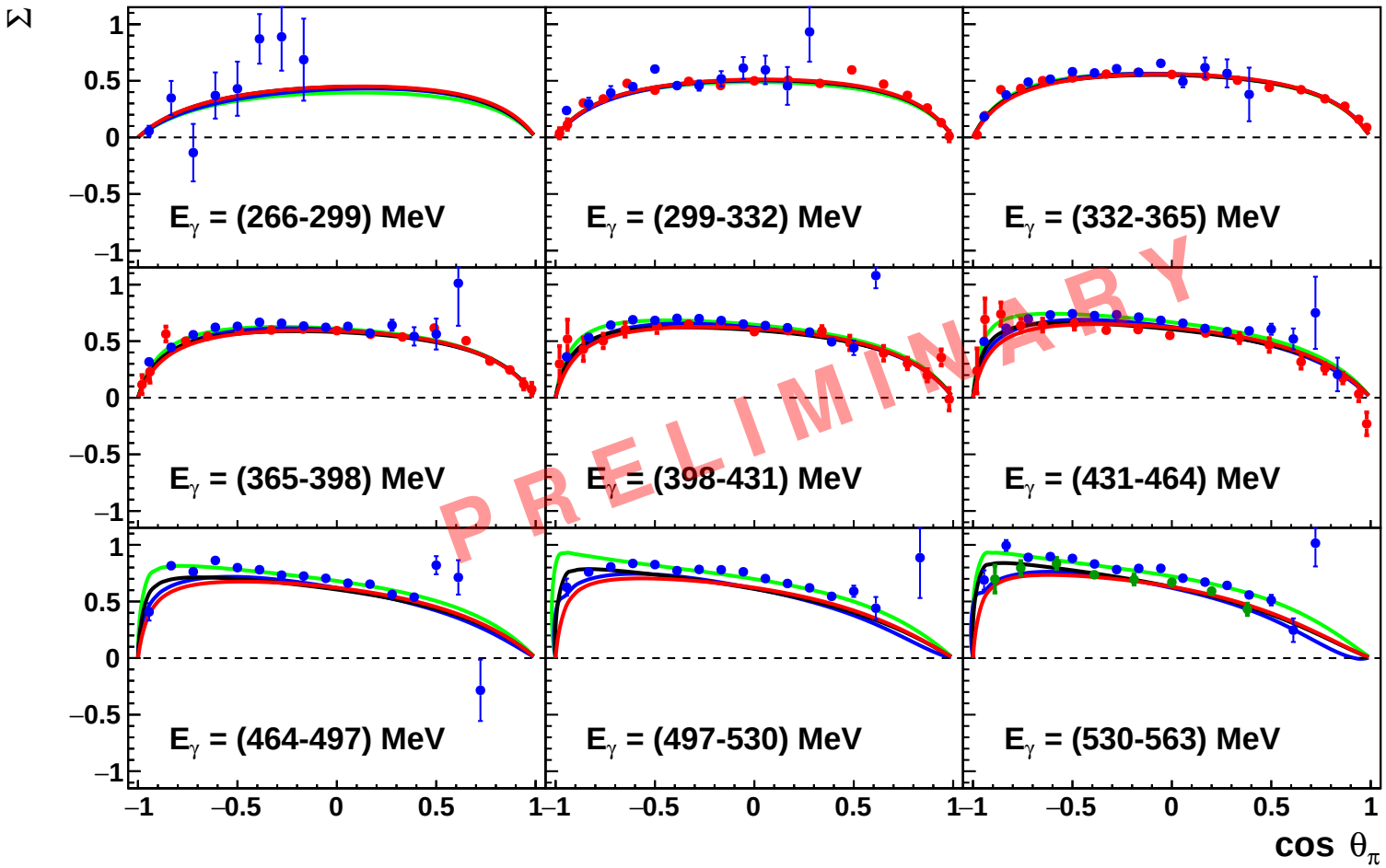
Double polarization observable E - September 2015 beam time



● diamond ● moeller

Appendix

Beam asymmetry Σ_B

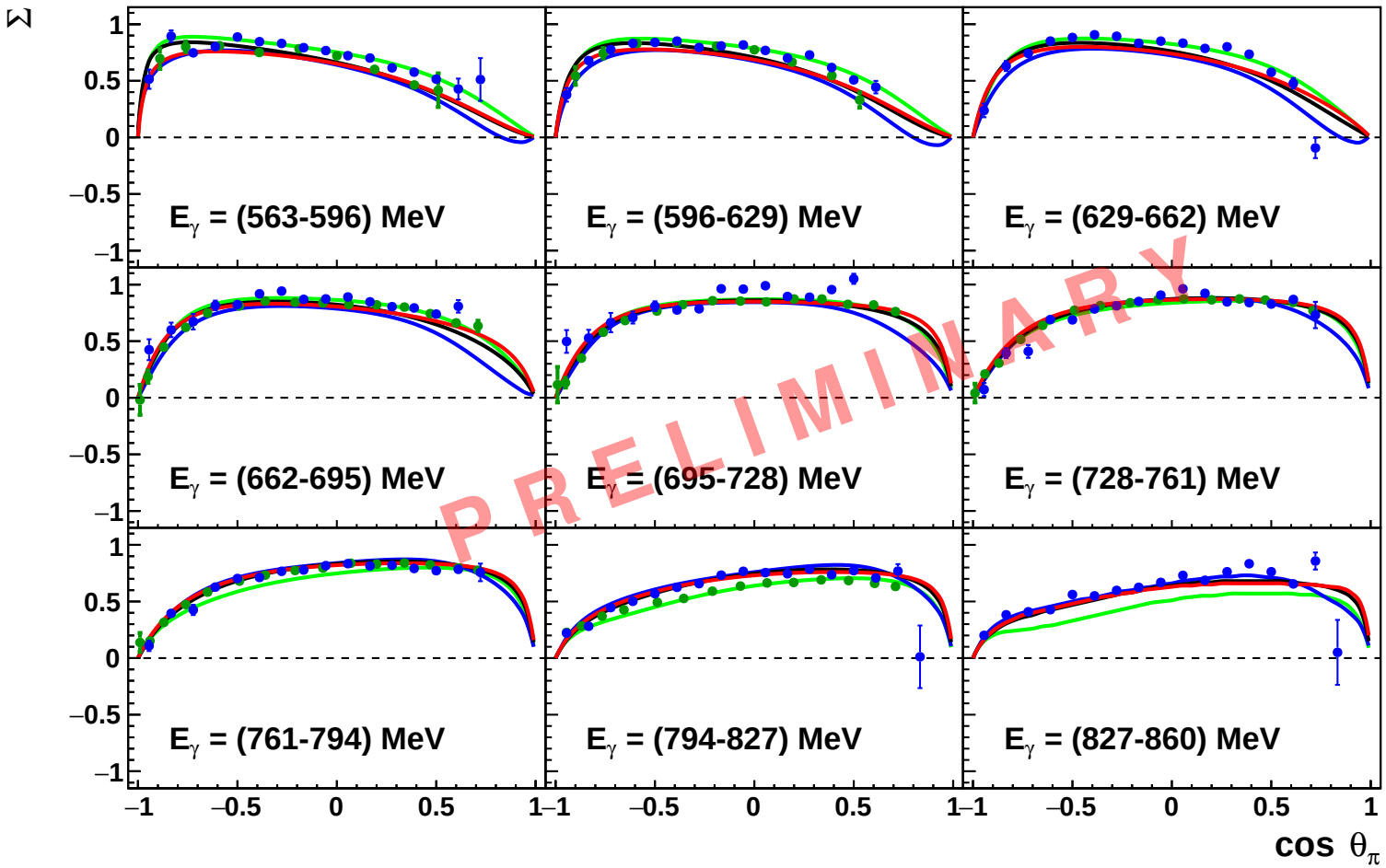


● this work ● MAMI [1] ● GRAAL [2] — BG2014-01 [3] — BG2014-02 [3] — MAID-07 [4] — SAID-CM12 [5]

[1] R. Beck et al, Eur. Phys. J. **A28** (2006) 173-183 [2] O.Bartalini et al., Eur. Phys.J. **A26** (2005) 399 [3] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[4] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [5] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Appendix

Beam asymmetry Σ_B

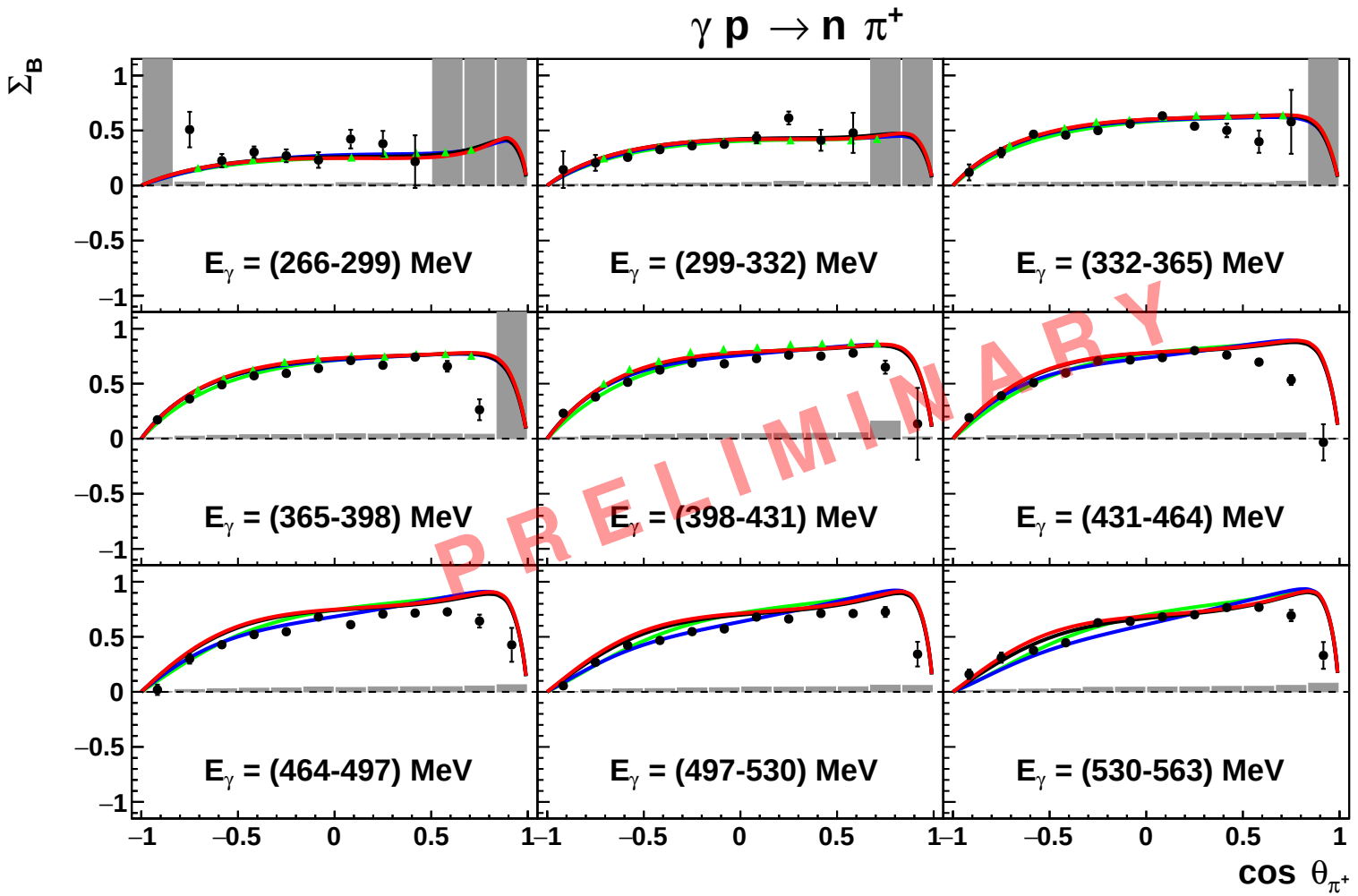


● this work ● MAMI [1] ● GRAAL [2] — BG2014-01 [3] — BG2014-02 [3] — MAID-07 [4] — SAID-CM12 [5]

[1] R. Beck et al, Eur. Phys. J. **A28** (2006) 173-183 [2] O.Bartalini et al., Eur. Phys.J. **A26** (2005) 399 [3] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[4] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [5] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Appendix

Beam asymmetry Σ_B

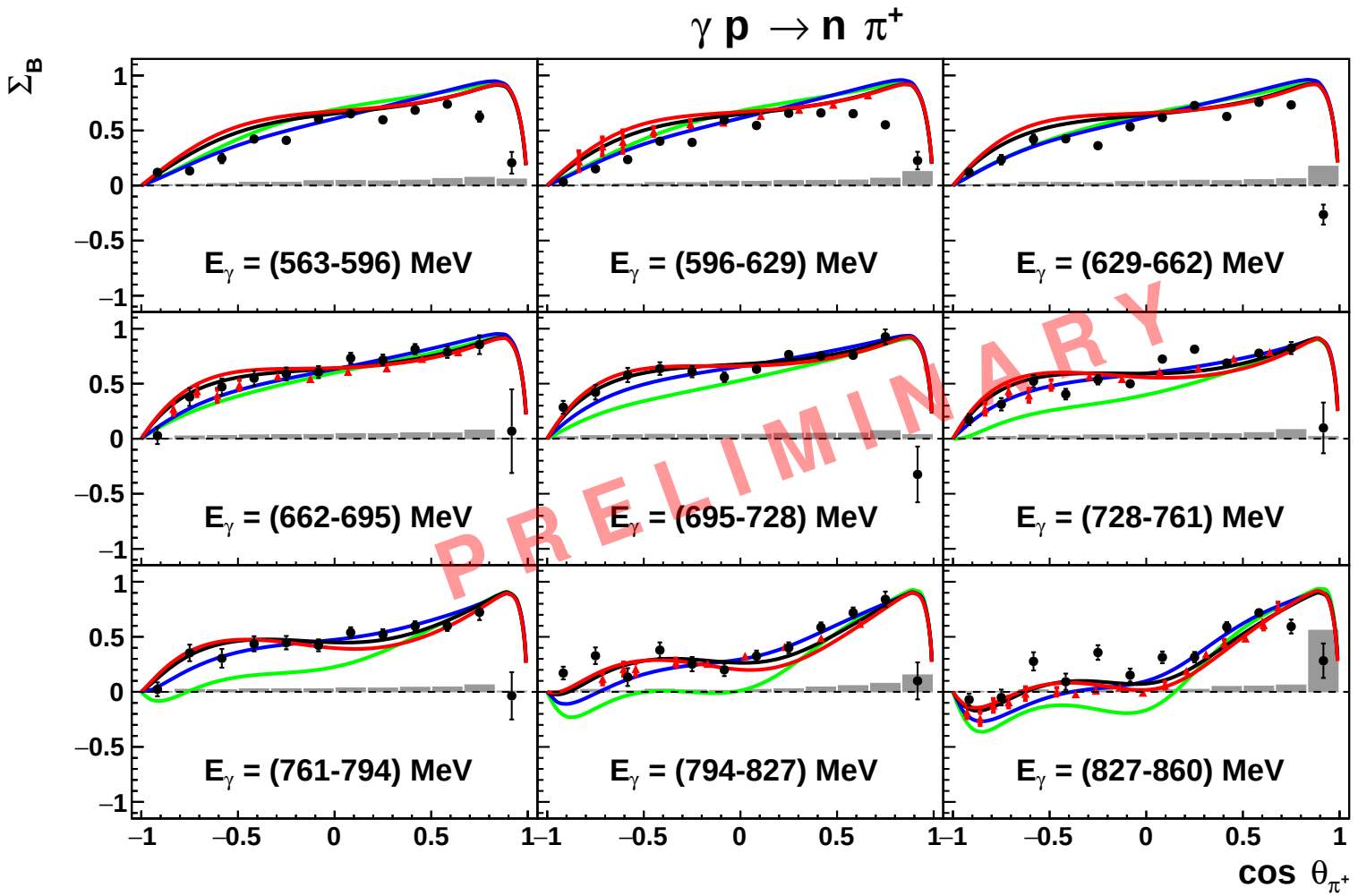


● this work ● MAMI [1] ● GRAAL [2] — BG2014-01 [3] — BG2014-02 [3] — MAID-07 [4] — SAID-CM12 [5]

[1] R.Beck et al., Phys.Rev. **C61**, 035204 (2000) [2] R. Bartalini et al., arXiv:nucl-ex/0207010 [3] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[4] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [5] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Appendix

Beam asymmetry Σ_B



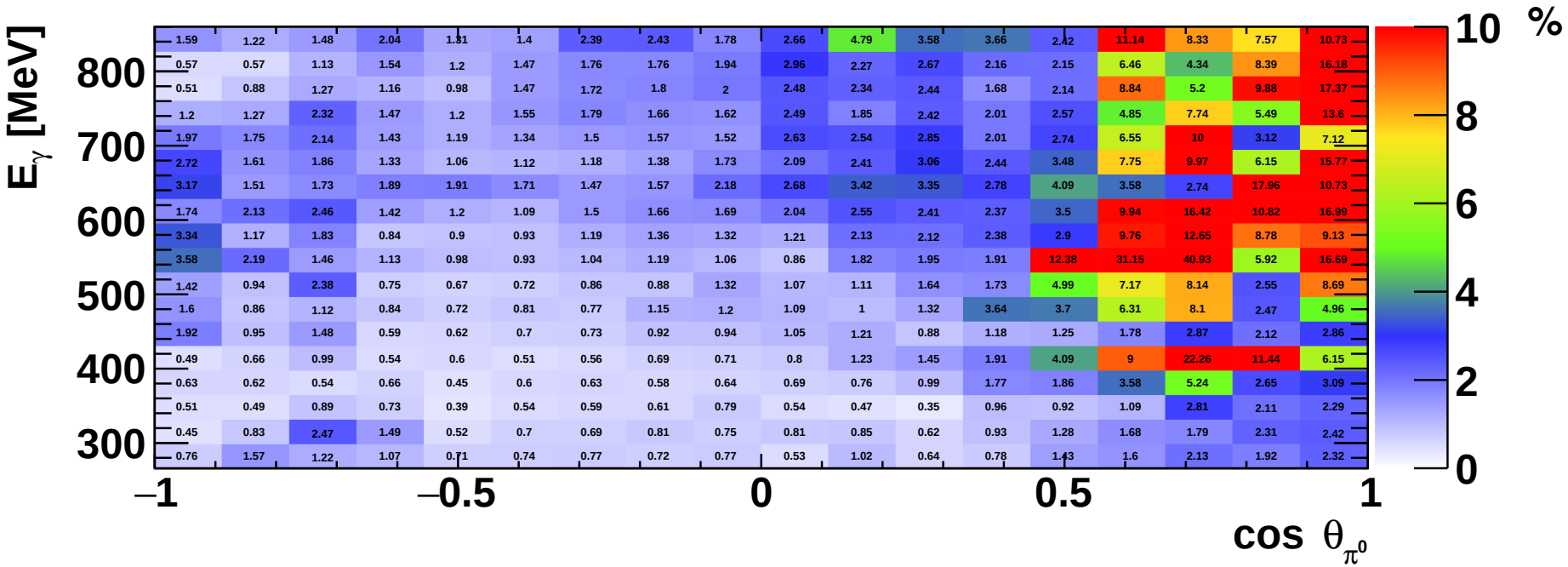
● this work ● MAMI [1] ● GRAAL [2] — BG2014-01 [3] — BG2014-02 [3] — MAID-07 [4] — SAID-CM12 [5]

[1] R.Beck et al., Phys.Rev. **C61**, 035204 (2000) [2] R. Bartalini et al., arXiv:nucl-ex/0207010 [3] E. Gutz et al, Eur. Phys. J. **A50** (2014) 74
[4] D. Drechsel, S. S. Kamalov, and L. Tiator, Eur. Phys. J. **A34**, (2007) 69-97 [5] R. Workman et al, Phys. Rev. **C86**, (2012) 015202

Appendix

Background - $p\pi^0$

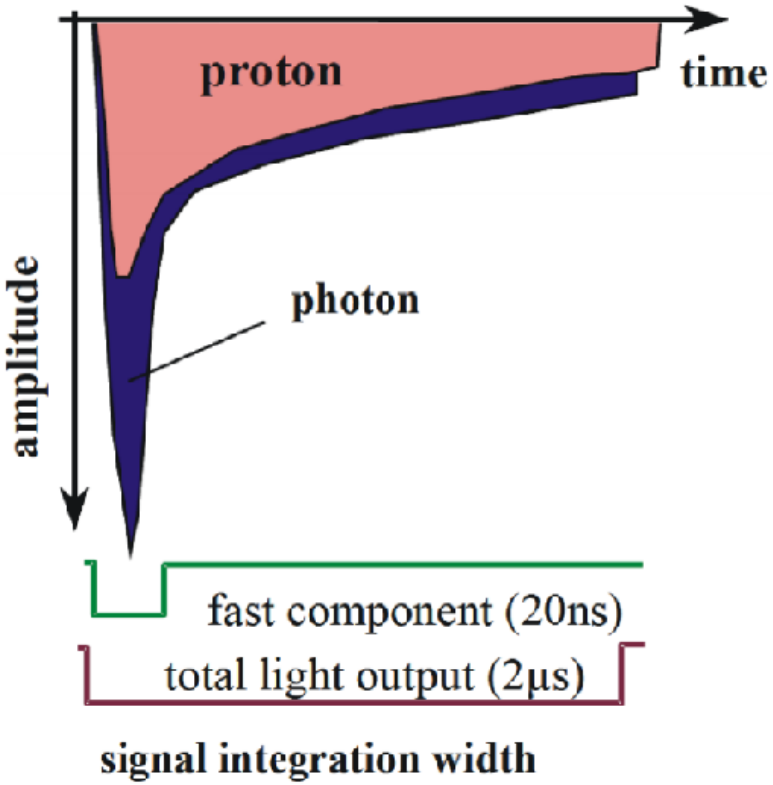
- Carbon subtracted invariant mass distribution
- Background described by shebyshev polynomial of the fifth order
- 3PED events mostly background far below 5%
- 2PED events still not under control

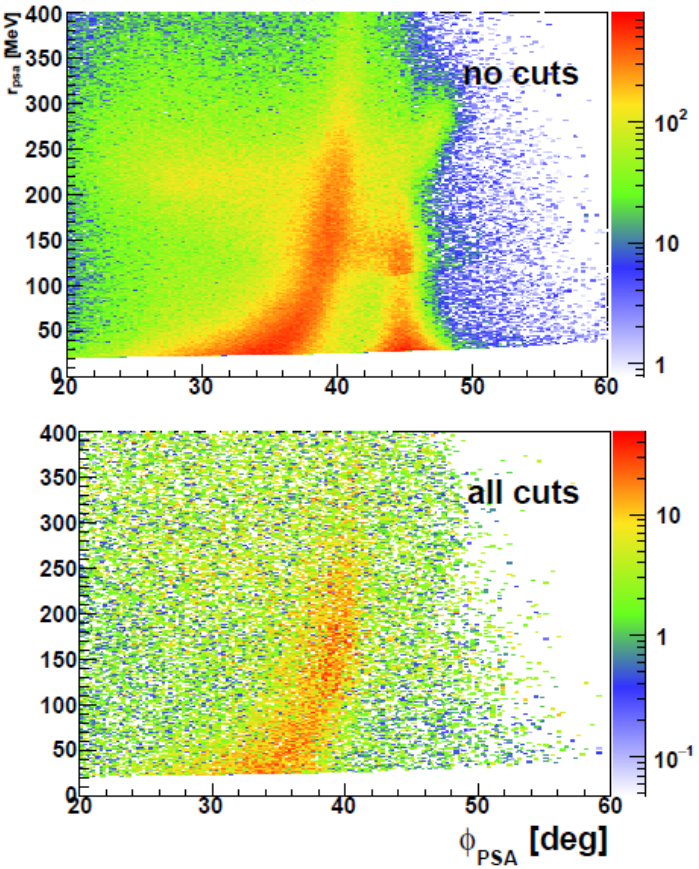


Appendix

Cross Check - PSA for neutron candidate

$$\phi_{PSA} = atan\left(E_{short}/E_{long}\right) \text{ and } r_{psa} = \sqrt{{E_{short}}^2 + {E_{long}}^2}$$

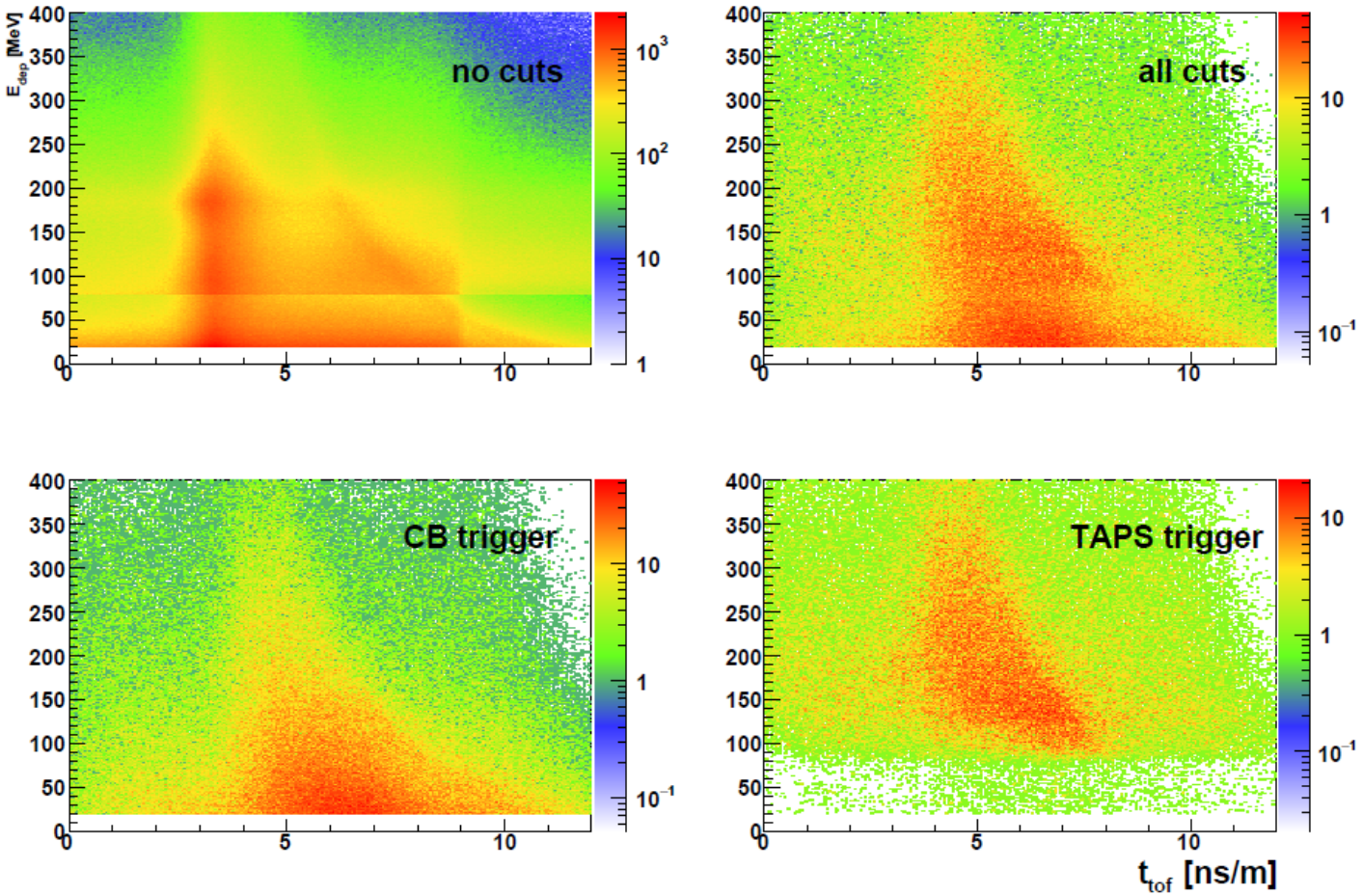




Appendix

Cross Check - TOF analysis for neutron candidate

$$t_{tof} = \frac{1}{c} + \frac{t_\gamma - t_N}{d}$$



Appendix

Comparison of dominant multipole contributions from the different PWA