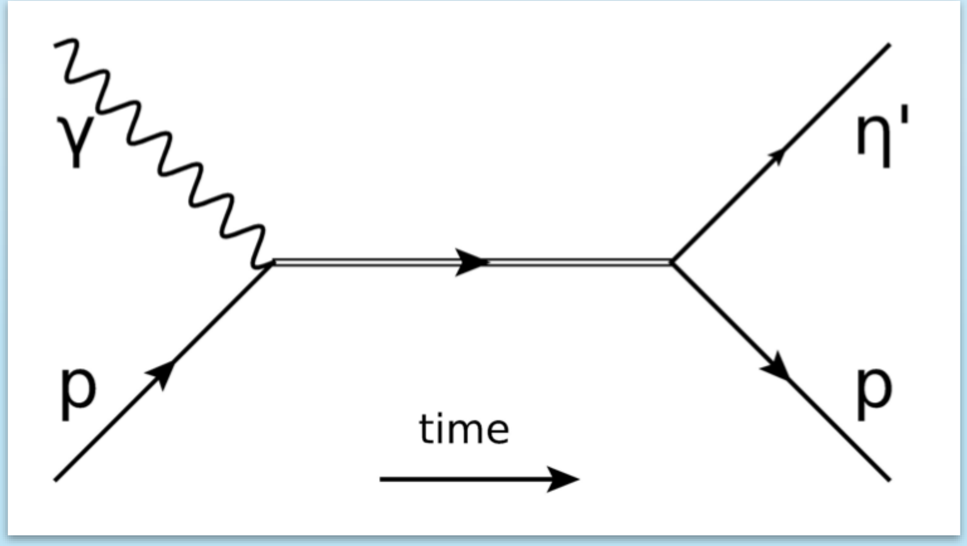
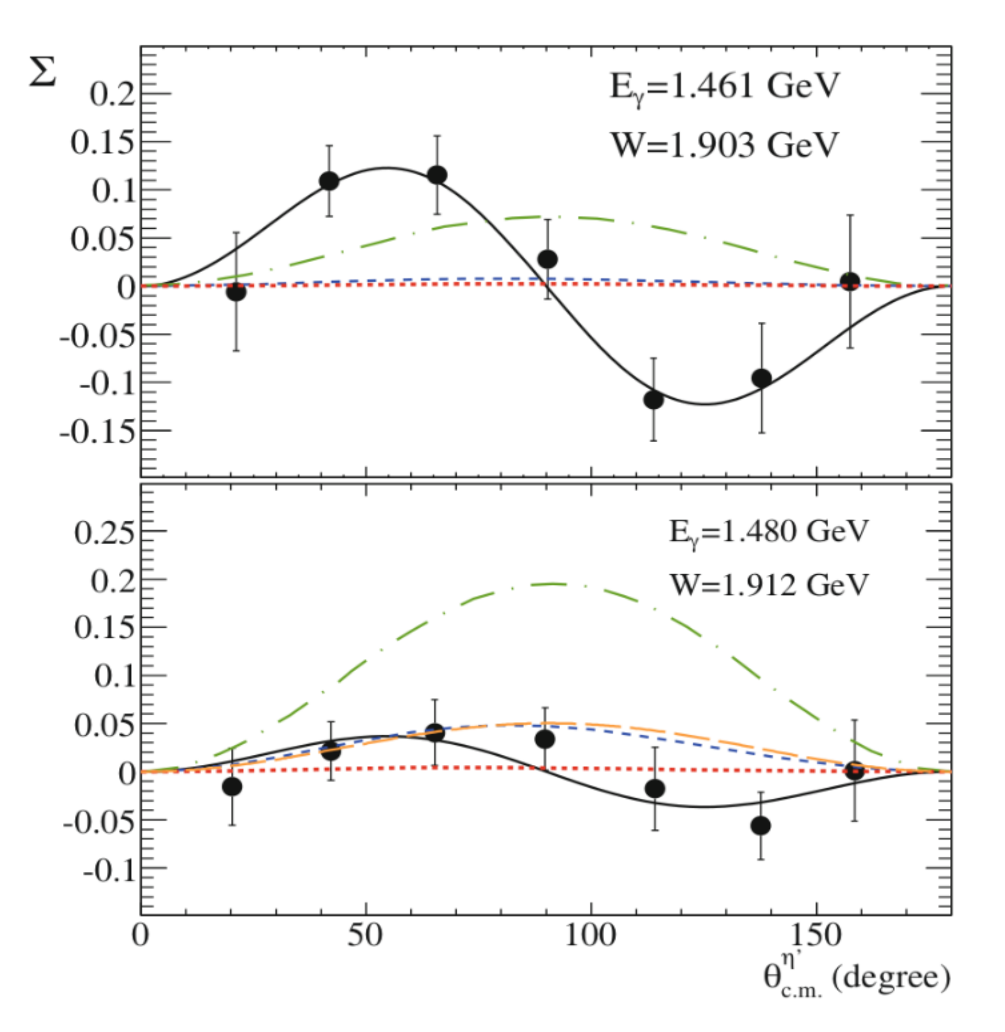
η' beam asymmetry at threshold using the BGOOD experiment



Leoni Lutter, University of Bonn

Motivation – Results from the GRAAL experiment

- Unexpected structure in Σ vs $\theta_{\eta'}^{CMS}$
- Close to threshold, vanishes within 20 MeV
- Possible explanation → unobserved narrow resonance

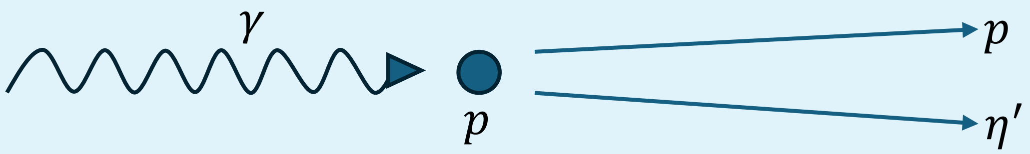


P. Levi Sandri et al.,Eur. Phys. J. A (2015) 51: 77

Experimental requirements

- Unique forward angle acceptance needed
- Additional charged particle identification
- Polarized photon beam

$$\gamma\, p \to \eta'\, p$$



BGOOD experiment

Analysis Steps:

1. Identifying the **reaction channel**:

$$\gamma\, p \rightarrow \eta'\, p \rightarrow X\, p$$

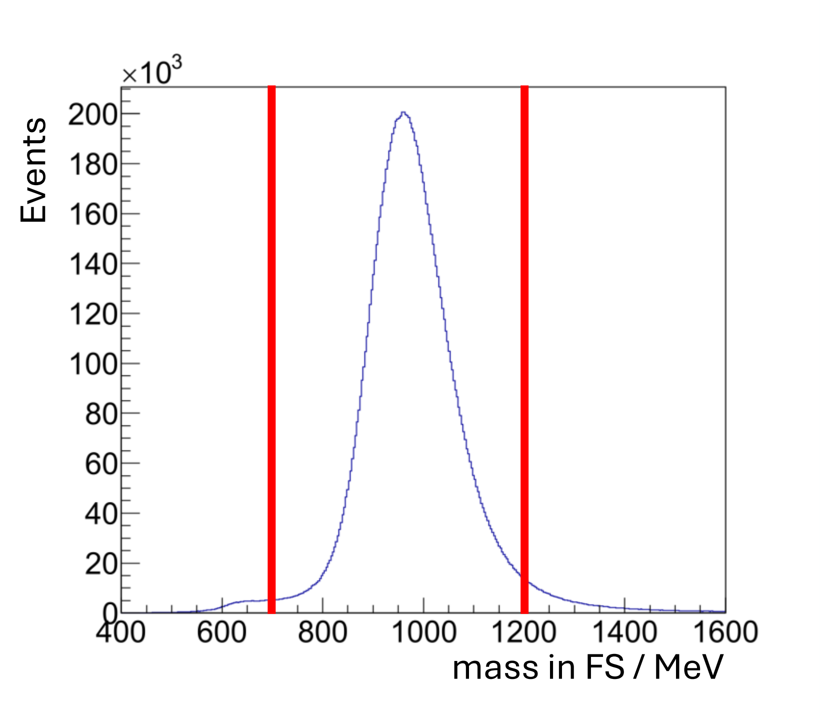
2. **Background** fit & reduction

3. Determination and comparison of $\frac{d\sigma}{d\Omega}$

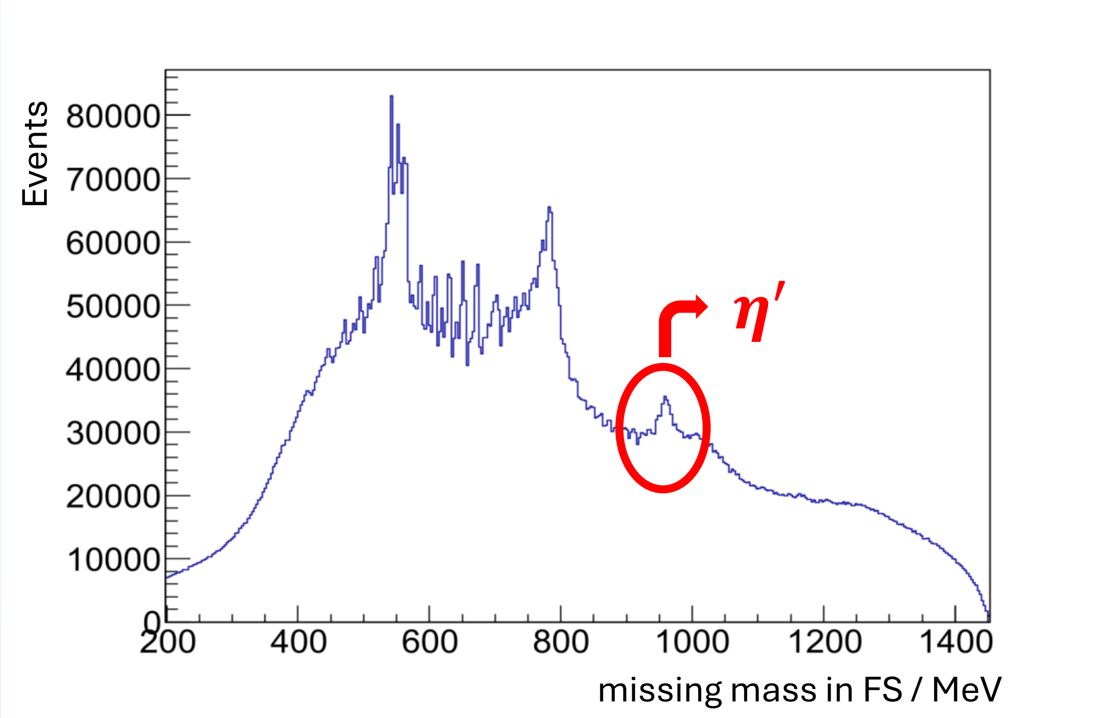
4. Determination of the **beam asymmetry** Σ

Proton selection

$\gamma\, p \rightarrow \eta'\, p$



Select p



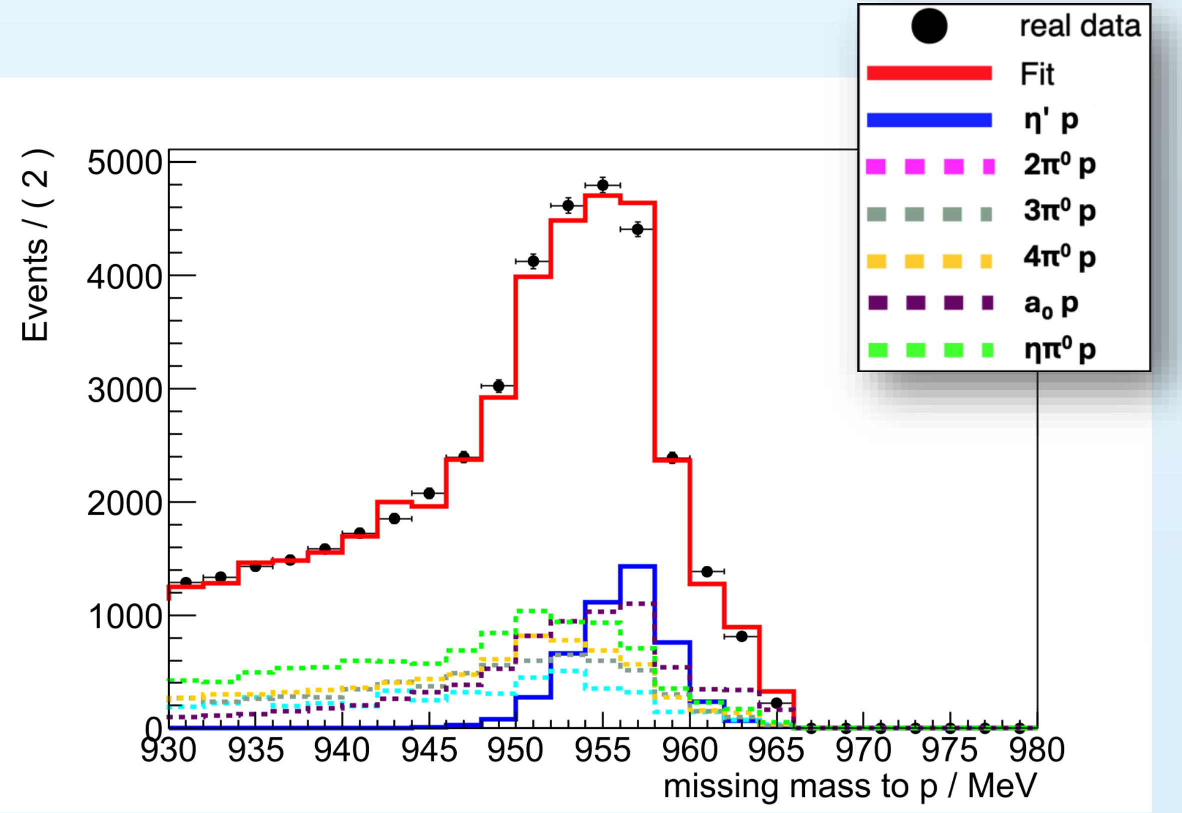
Determine m_{miss} for η‘

Background fit & reduction

Possible background channels

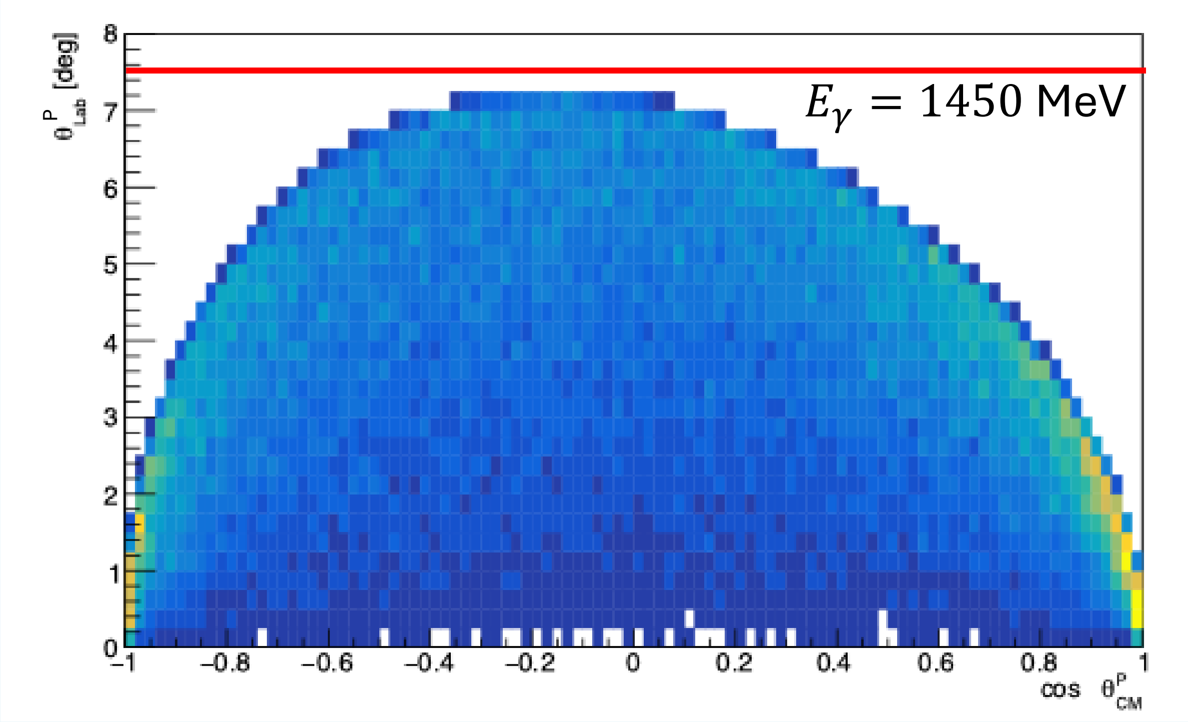
Include MC simulations of different background channels:

$$\gamma p \rightarrow 2\pi^0 p$$
$$\gamma p \rightarrow 3\pi^0 p$$
$$\gamma p \rightarrow 4\pi^0 p$$
$$\gamma p \rightarrow a_0 p$$
$$\gamma p \rightarrow \eta\pi^0 p$$

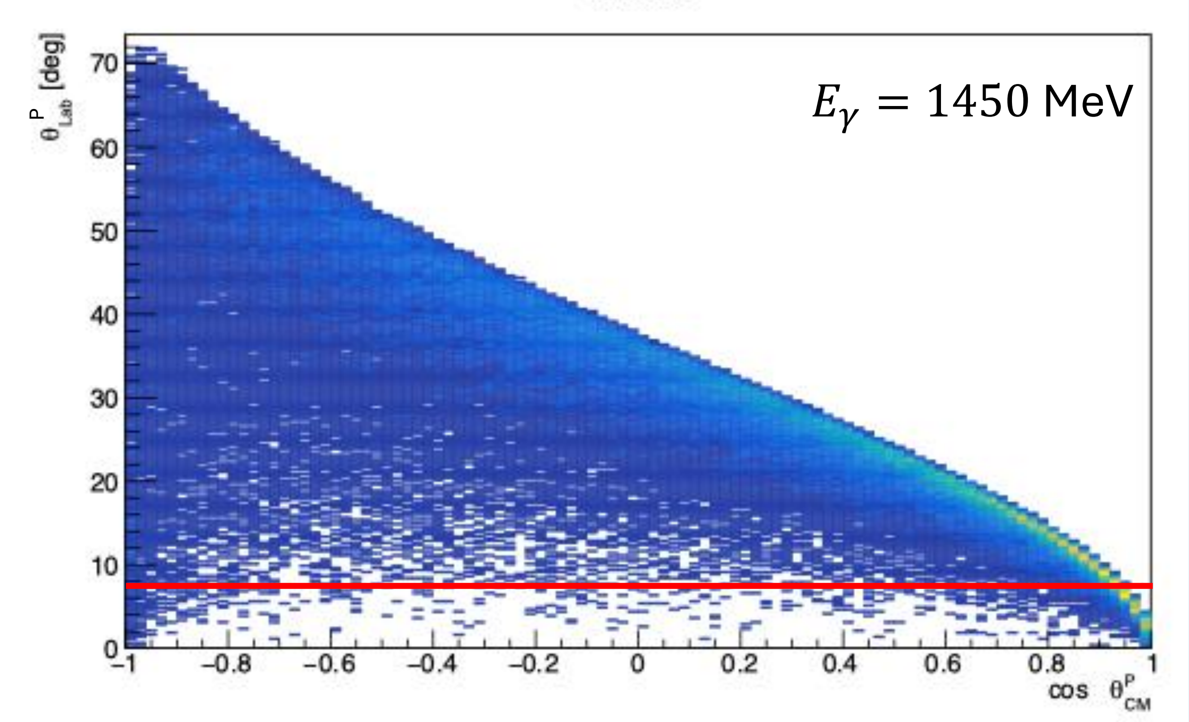


$E_\gamma = 1450$ MeV

θ^P_{lab} selection



$\gamma\, p \rightarrow \eta'\, p$

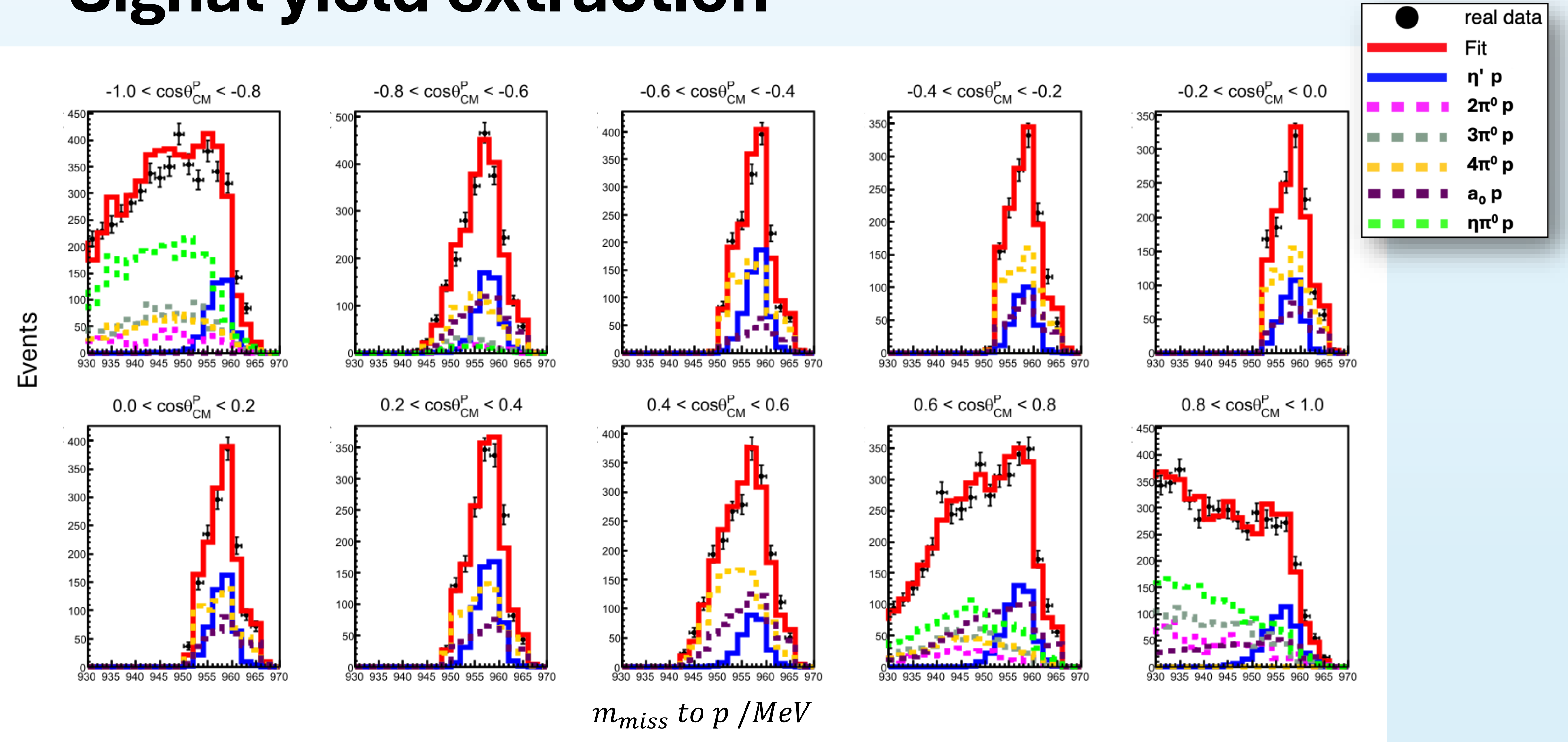


Background example:

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

→ setting selection on θ^P_{lab} < 7.5°

Signal yield extraction

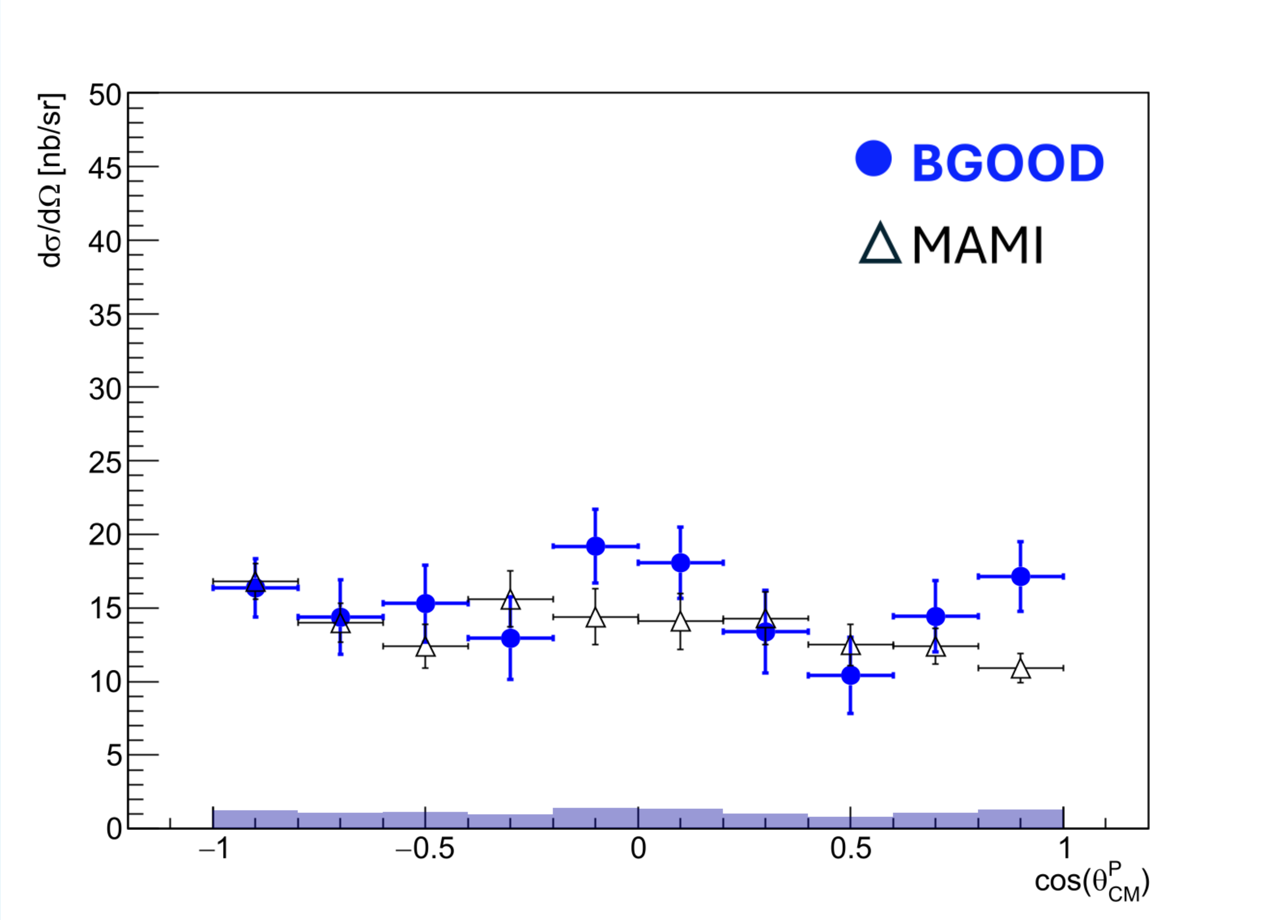


Determination of $\frac{d\sigma}{d\Omega}$

$\frac{d\sigma}{d\Omega}$ of the $\eta' \, p$ photoproduction

- In agreement with MAMI data

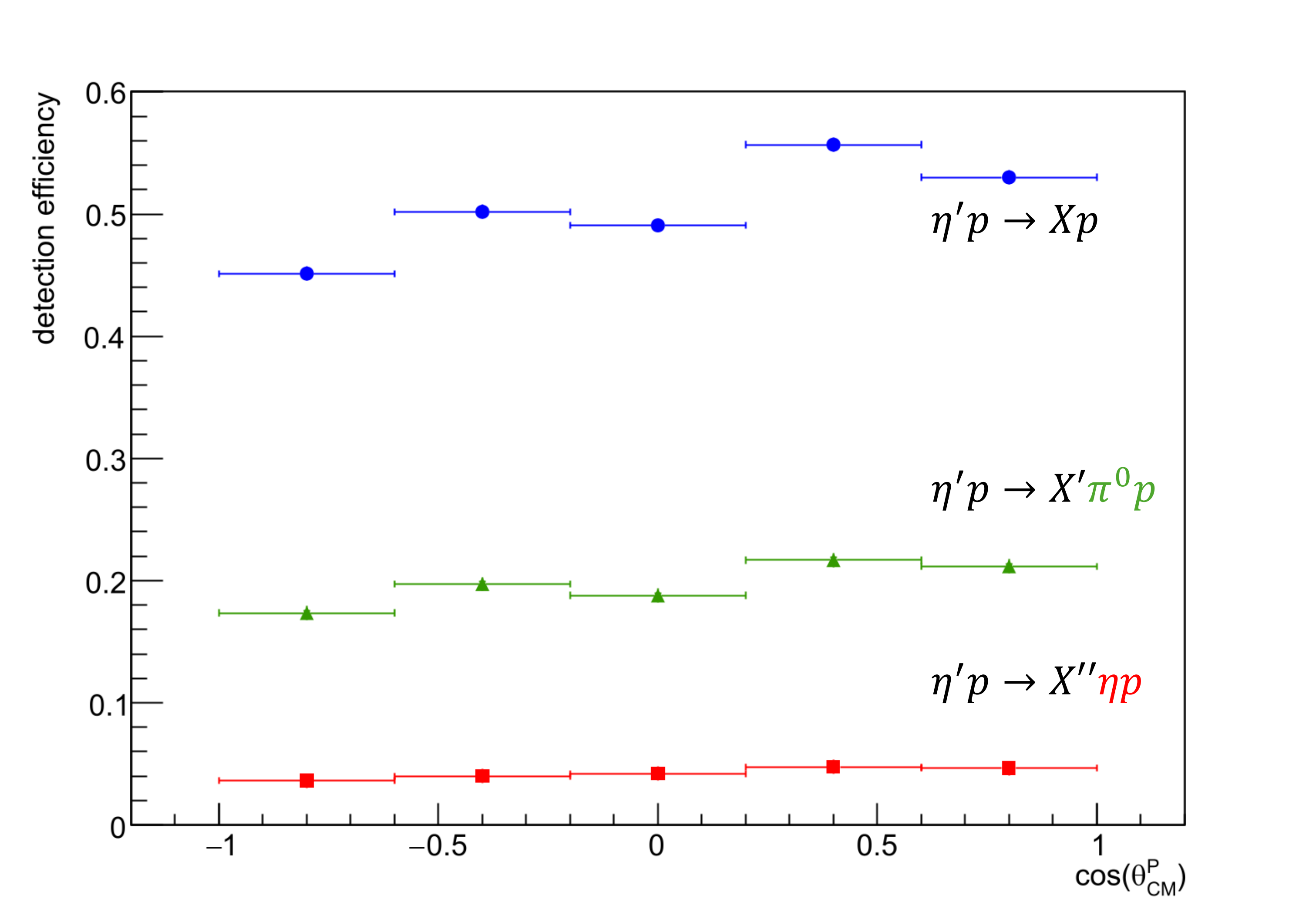
- Next: check with different particle selection



$E_\gamma = 1450$ MeV

MAMI data : arXiv:1807.04525

Semi-exclusive reconstruction

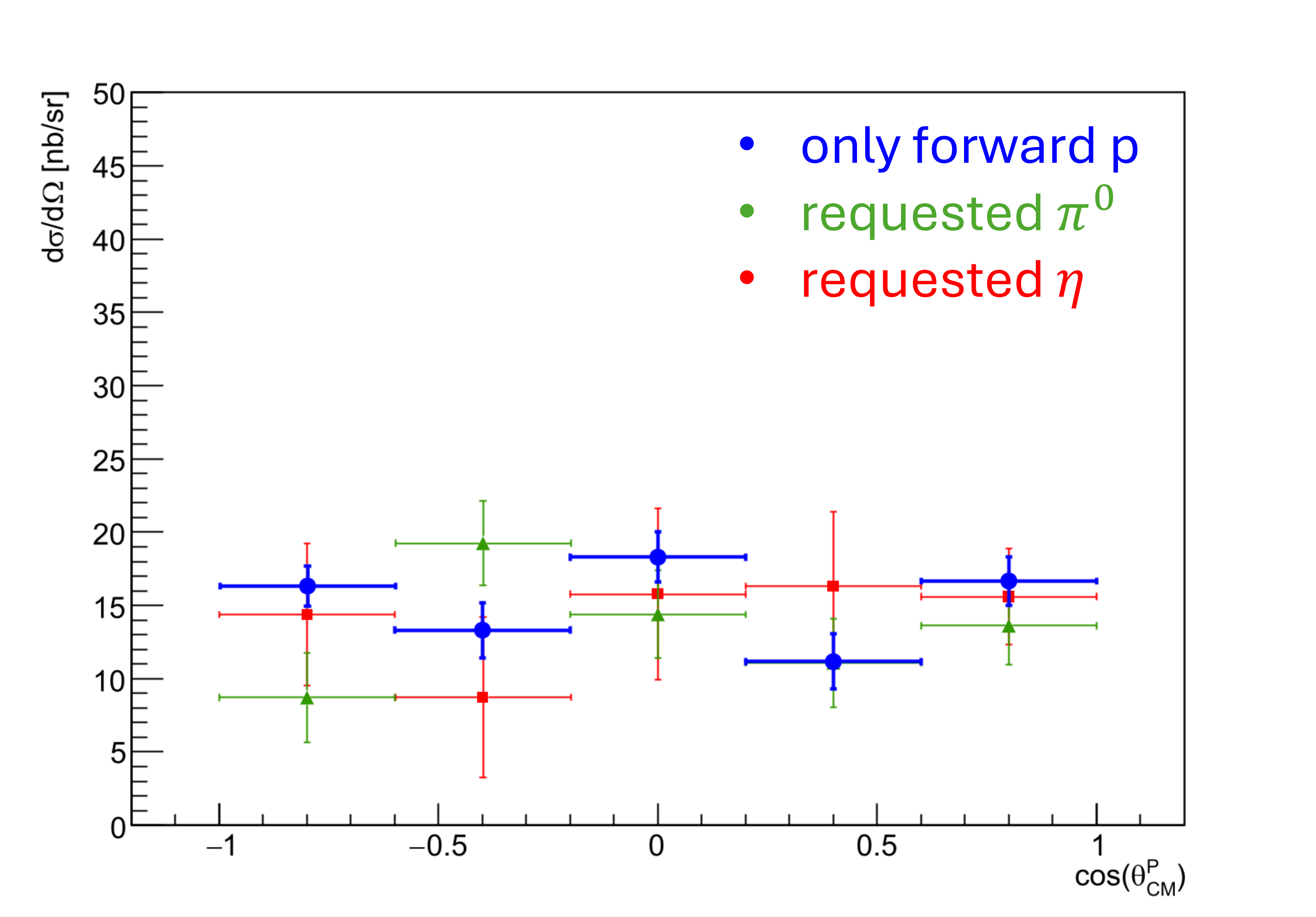


Decay modes

Γ_1	$\pi^+ \pi^- \eta$	$\sim 42.6\%$
Γ_3	$\pi^0 \pi^0 \eta$	$\sim 22.8\%$

- Requested $\pi^0 \to \gamma\gamma$
- Requested $\eta \to \gamma\gamma$

Results including π^0 / η



$$\gamma p \rightarrow \eta' p \rightarrow X p$$

$$\gamma p \rightarrow \eta' p \rightarrow X' \pi^0 p$$

$$\gamma p \rightarrow \eta' p \rightarrow X'' \eta p$$

Determination of the beam asymmetry Σ

Beam Asymmetry Σ

$$\frac{\frac{N^-}{F^-}}{\frac{N^-}{F^-}+\frac{N^+}{F^+}} = \frac{1}{2}[1 + \overbrace{P(E_\gamma)\Sigma}^{\text{amplitude}}\sin(2\phi)]$$

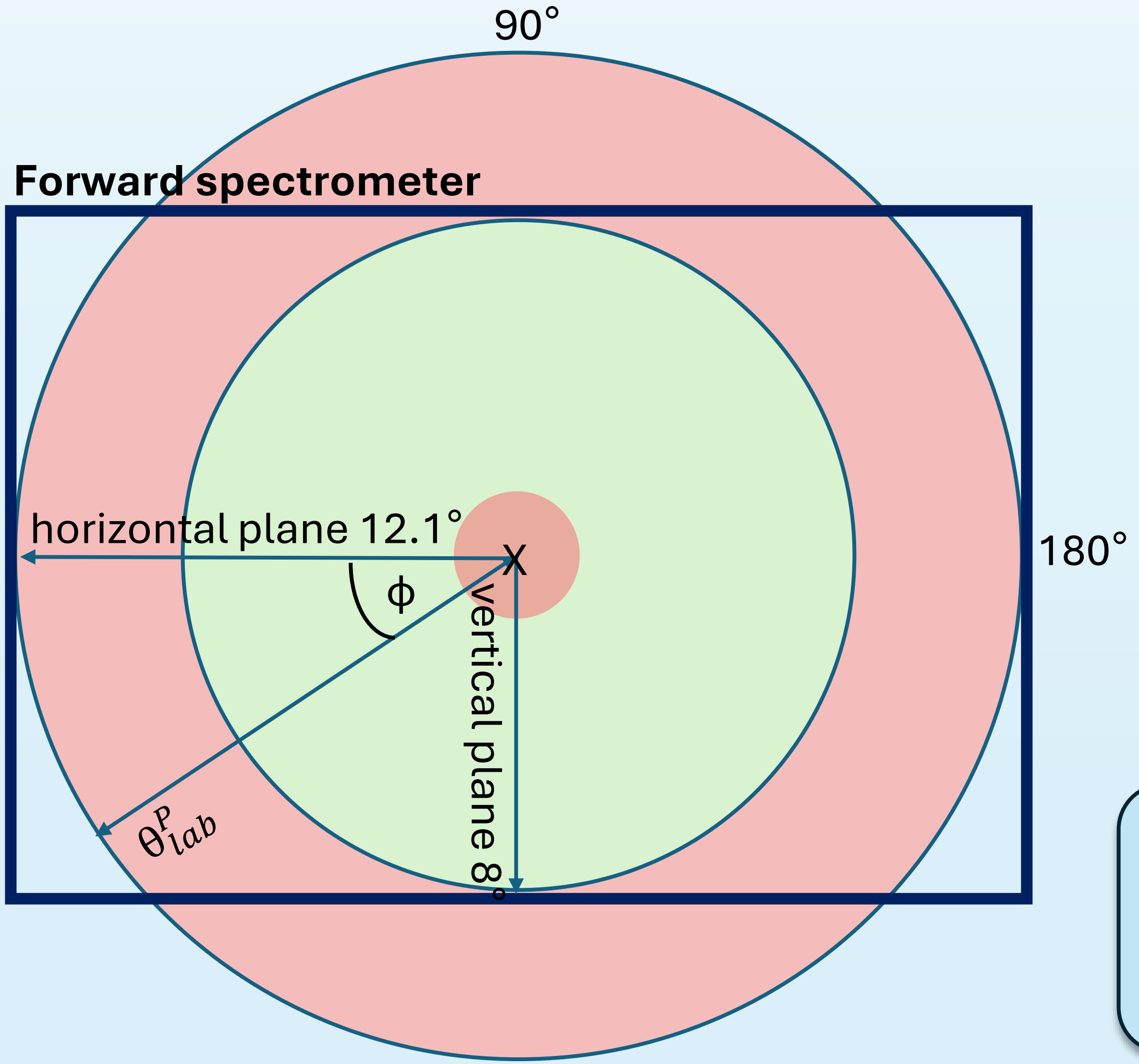
$N^{-/+}$	minus/plus polarized counts
$F^{-/+}$	minus/plus flux
$P(E_\gamma)$	degree of polarization
ϕ	azimuthal angle

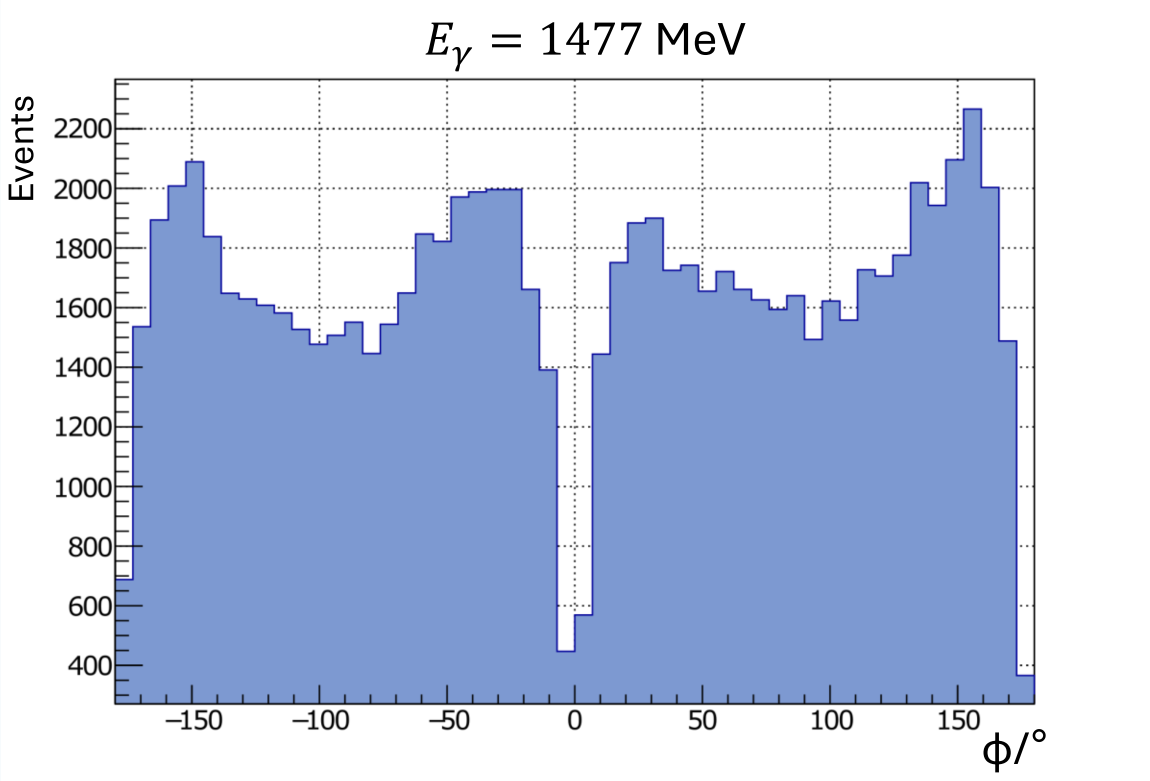
- Separate data into + and – polarization
- Less signal counts for signal yield extraction
- Including bg counts & assuming Σ_{bg}=0

$$\rightarrow \Sigma_{sum} = \Sigma_{signal+background}$$

- Σ_{sum} in amplitude of $\sin(2\phi)$ distribution

ϕ acceptance

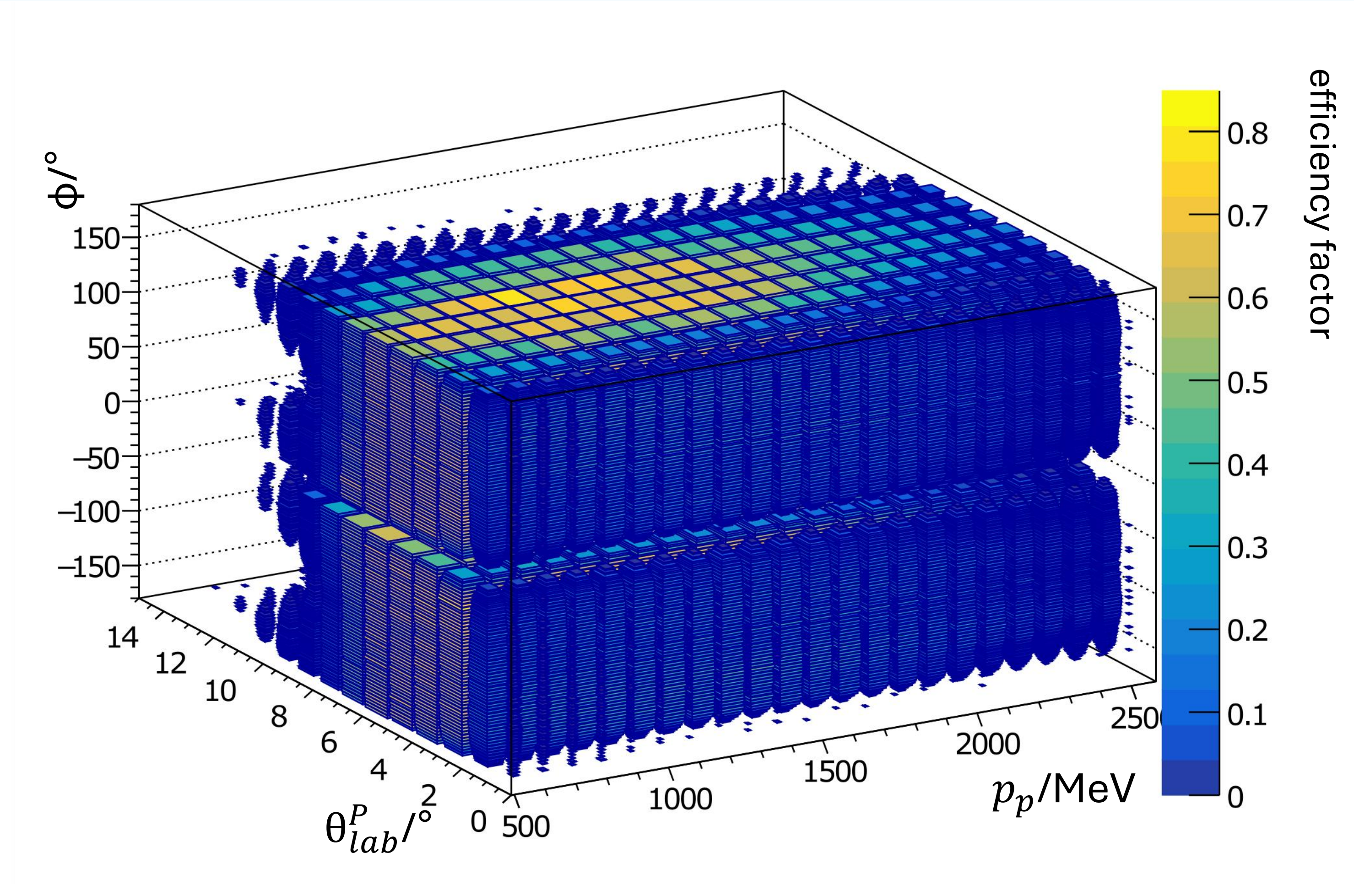




3 issues:

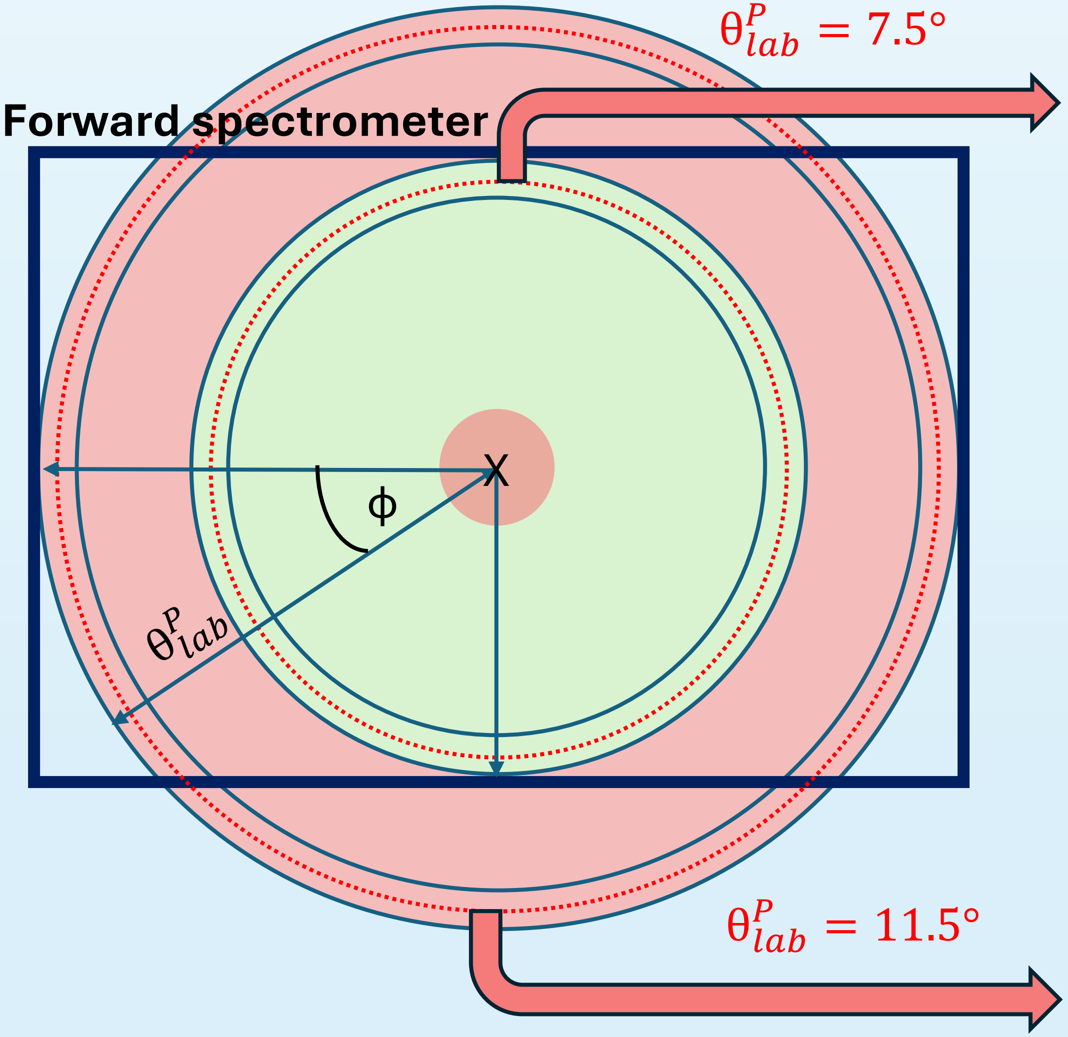
1) rectangular shaped forward spectrometer
2) horizontal gap in ToF walls
3) general inefficient regions

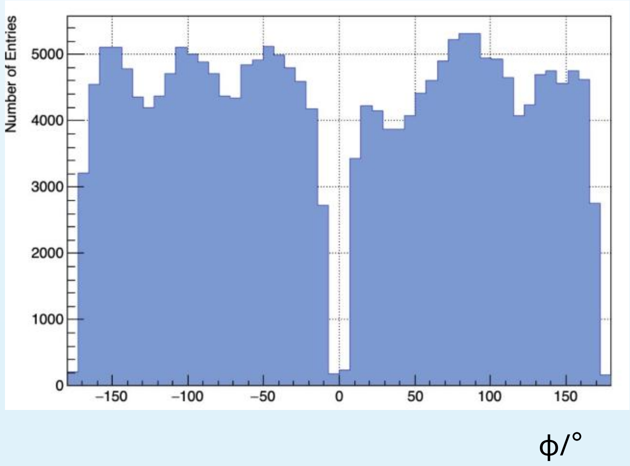
Efficiency factor $\varepsilon(\phi,\theta_{lab}^{P},p_p)$

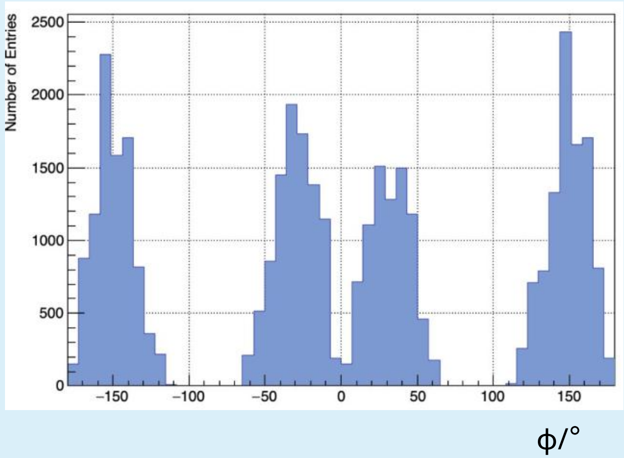


- Simulation of single proton
- 3D-efficiency plot
- Scale eventwise with weight: $w = \frac{1}{\varepsilon(\phi,\theta_{lab}^{P},p_p)}$

Efficiency factor application

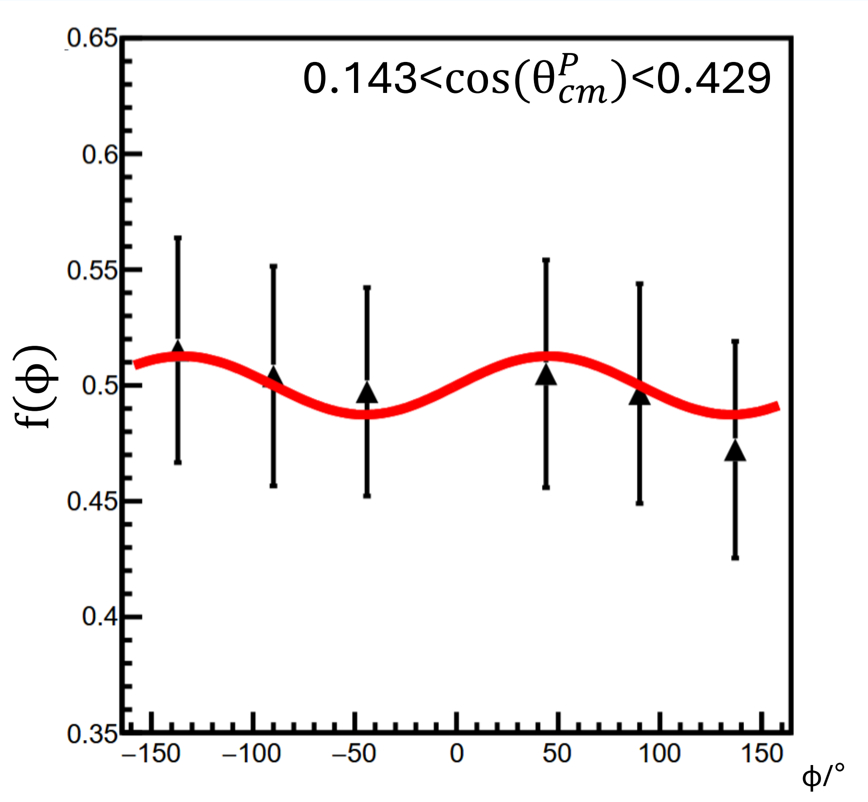


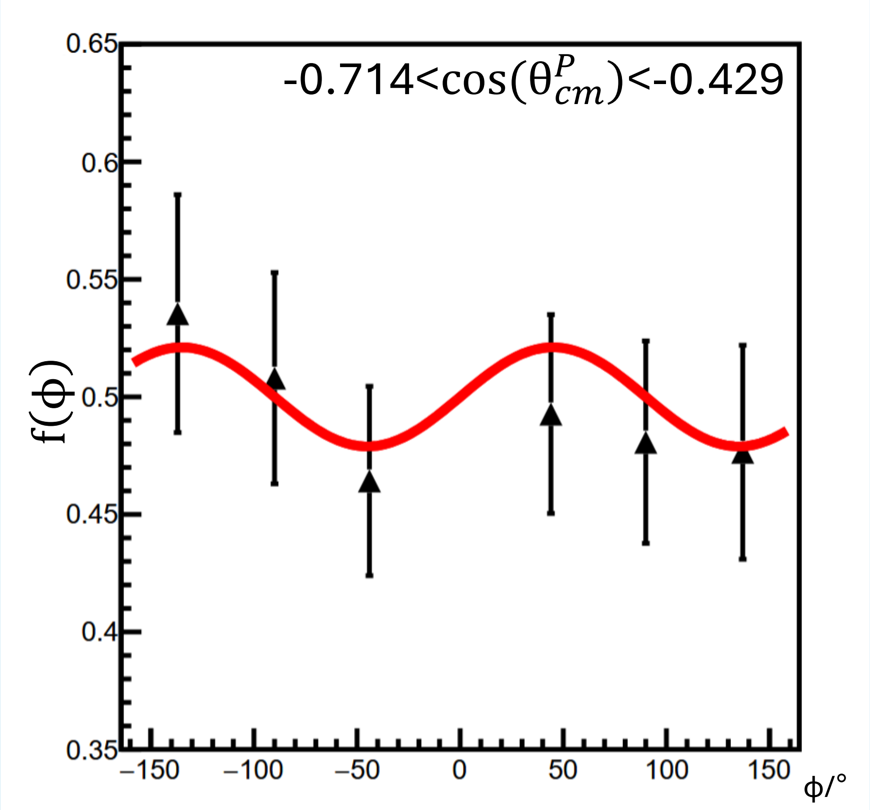




Modelling ϕ distribution

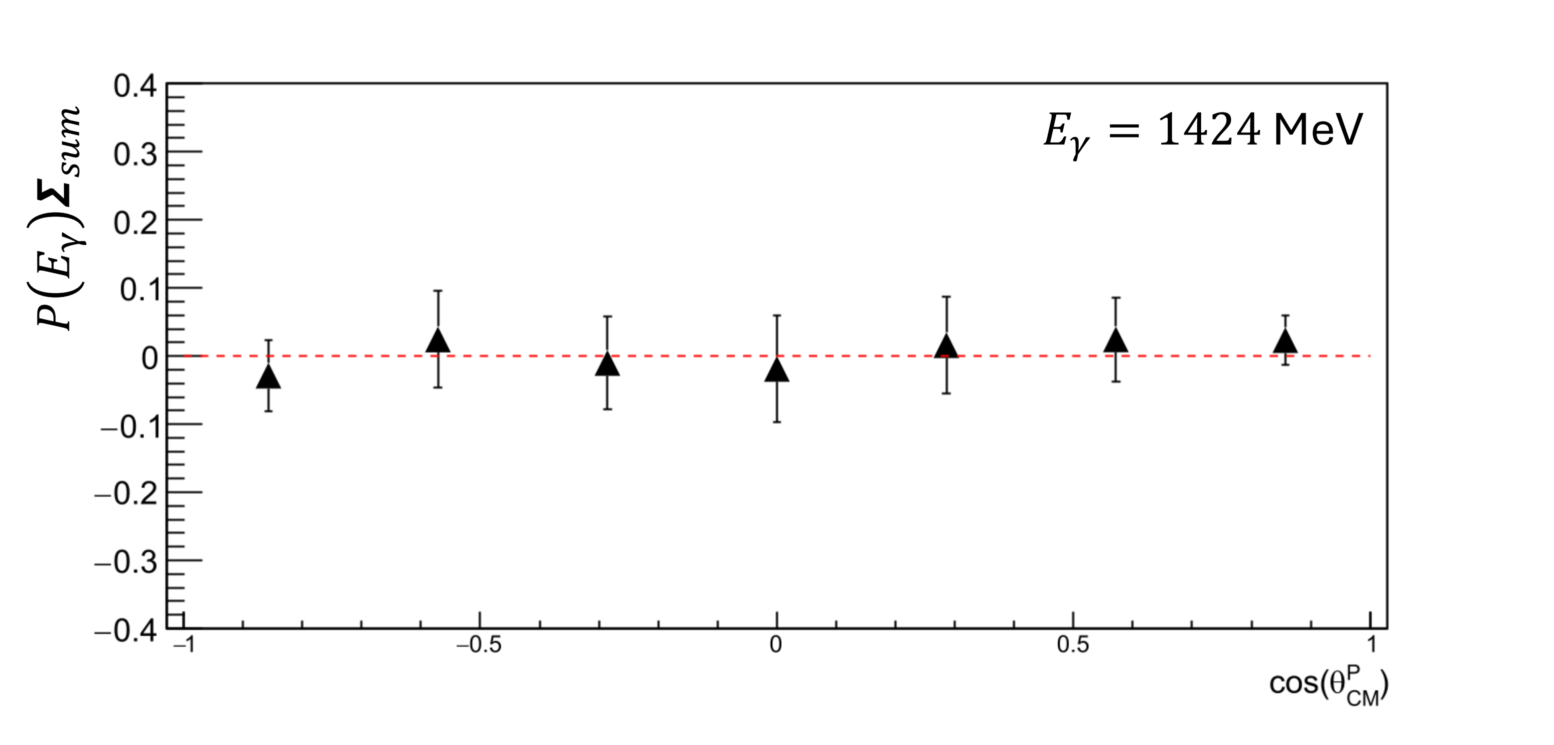
$E_\gamma = 1450$ MeV





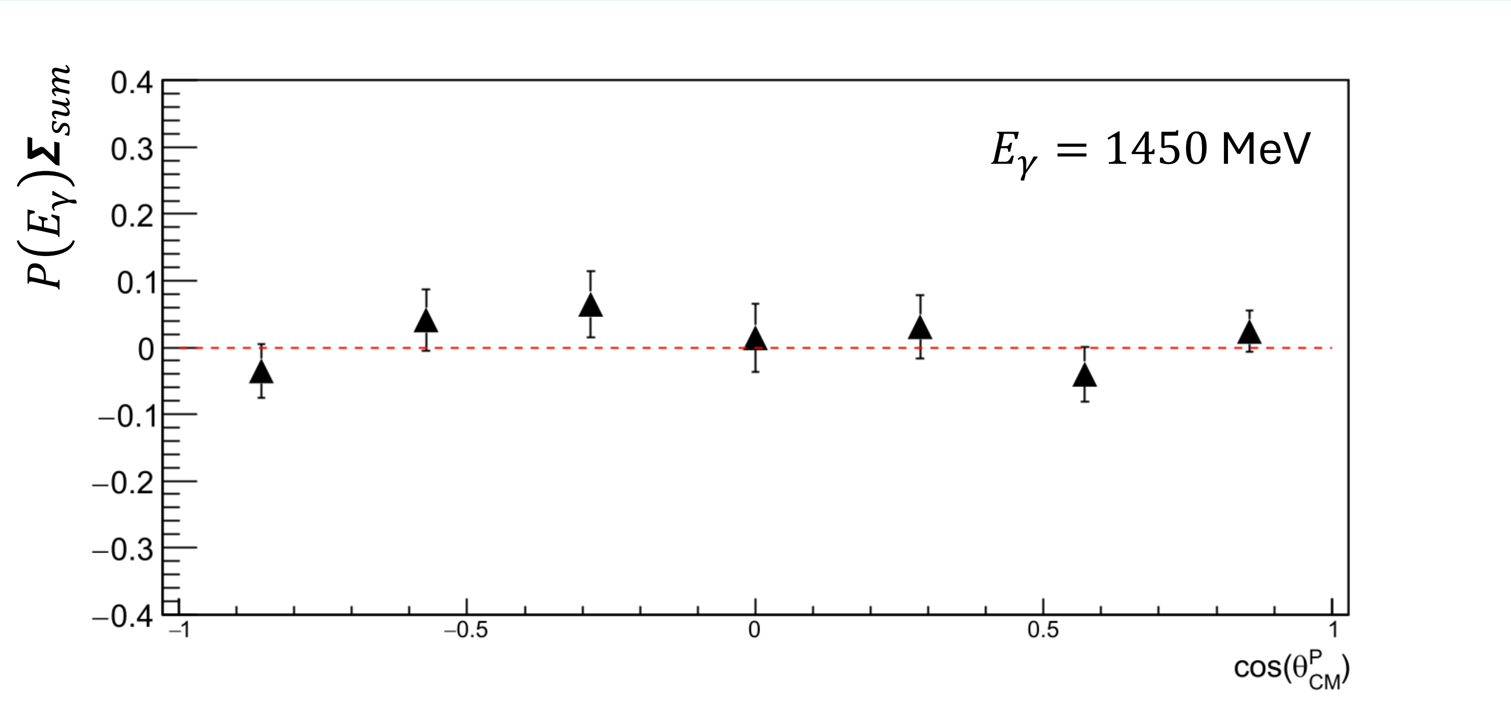
$$f(\phi) = \frac{\frac{N^-}{F^-}}{\frac{N^-}{F^-} + \frac{N^+}{F^+}} = \frac{1}{2}\left[1 + \underbrace{P(E_\gamma)\boldsymbol{\Sigma}_{sum}}_{a} \sin(2\phi)\right]$$

Extraction of the measured amplitude



- Below threshold only background
- Consistent with Σ_{bg}=0

Extraction of the measured amplitude

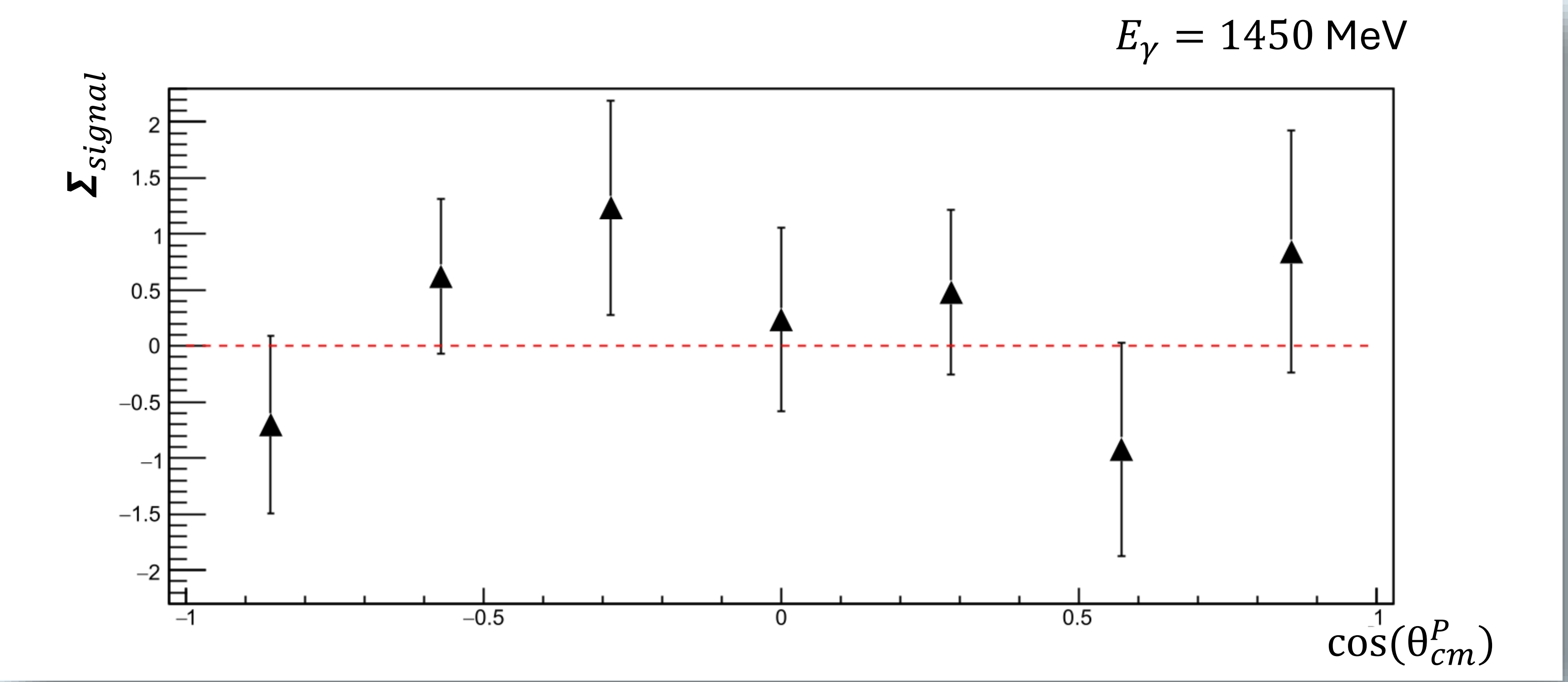


- Threshold bin diluted by Σ_{bg}
- Need dilution factor D for correction

$$\Sigma_{signal} = \Sigma_{sum} \cdot \underbrace{\left(1 + \frac{N_B}{N_S}\right)}_{\text{dilution factor } D}$$

→ beam asymmetry becomes $\boldsymbol{\Sigma}_{signal} = \frac{a \cdot D}{P(E_\gamma)}$

Extraction of the beam asymmetry



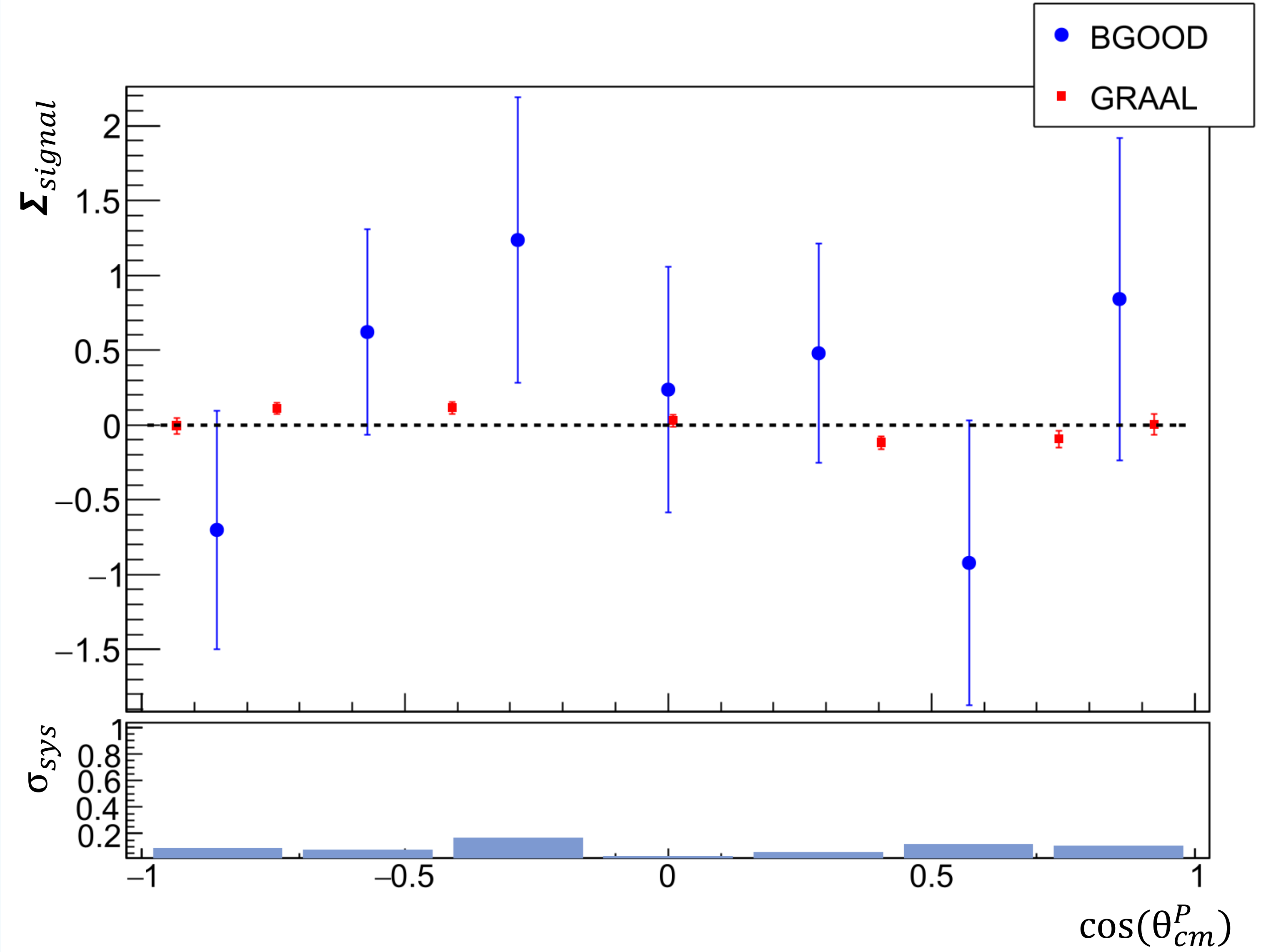
Reminder

$$f(\phi) = \frac{1}{2}\left[1 + \underbrace{P(E_\gamma)\boldsymbol{\Sigma}_{sum}}_{a} \sin(2\phi)\right]$$

$$\boldsymbol{\Sigma}_{signal} = \frac{a \cdot D}{P(E_\gamma)}$$

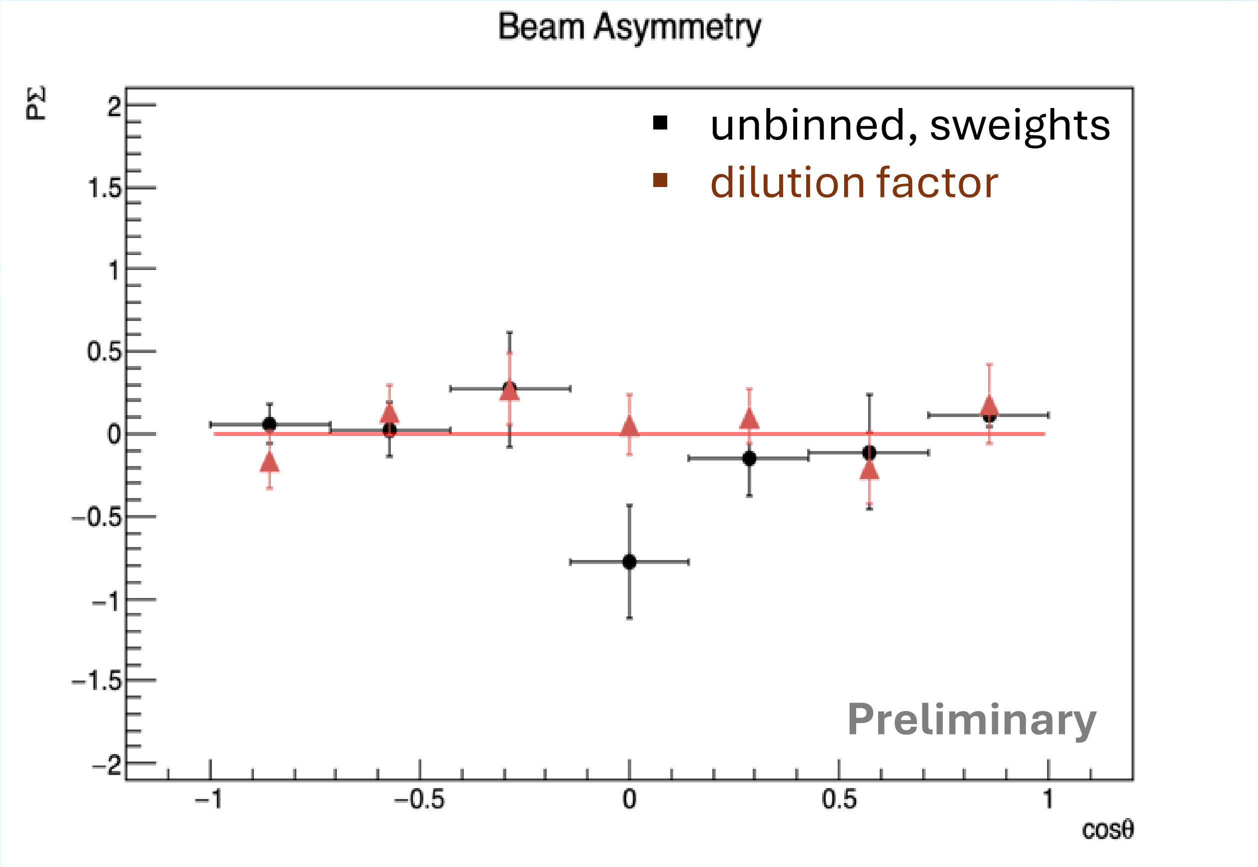
Comparison to GRAAL

- Consistent with GRAAL
- Limited by statistical precision



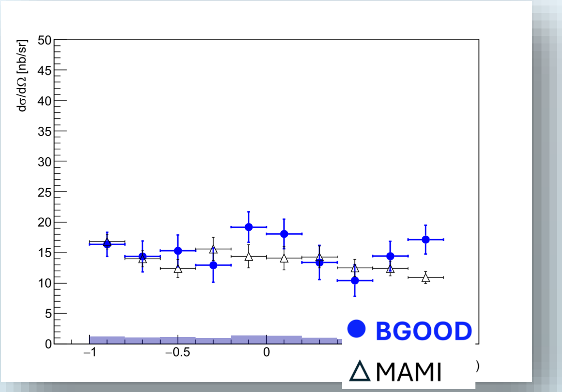
Ongoing Analysis: sPlot technique

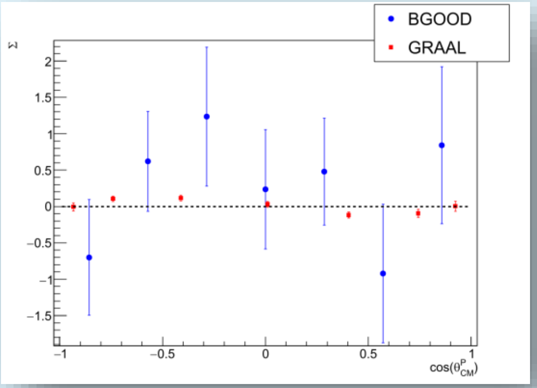
- Using event-by-event weights: **sweights**
- Sweights to describe bg & signal
- No dilution factor needed
- Unbinned likelihood fit



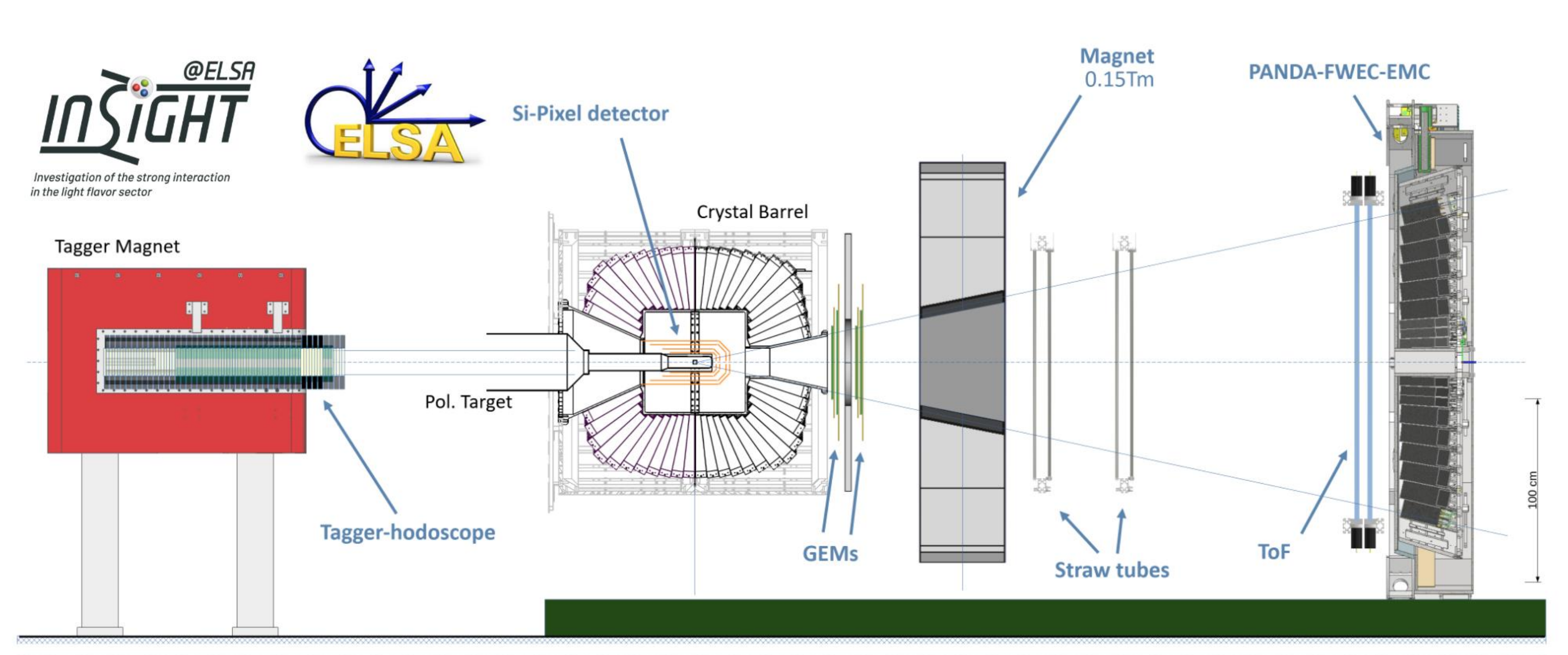
Summary

- Studied $\gamma\, p \rightarrow \eta'\, p$ process
- $\frac{d\sigma}{d\Omega}$ of η' p photoproduction agrees with earlier results of MAMI
- Uniform phi acceptance achieved by efficiency factor $\varepsilon(\phi,\theta^{P}_{lab},p_p)$
- $\boldsymbol{\Sigma}$ of η' p photoproduction determined at threshold
- Consistent with GRAAL data, but limited stat. Precission
- SPlot technique to avoid dilution factor





Outlook



T.C. Jude et al., PoS QNP2025

- Combine beam times to improve statistical precision
- New Insight experiment at ELSA
  upgrade for BGOOD & CB-photoproduction exp
  polarized beam & polarized target
  able to perform Σ measurements

Thank you for your attention!

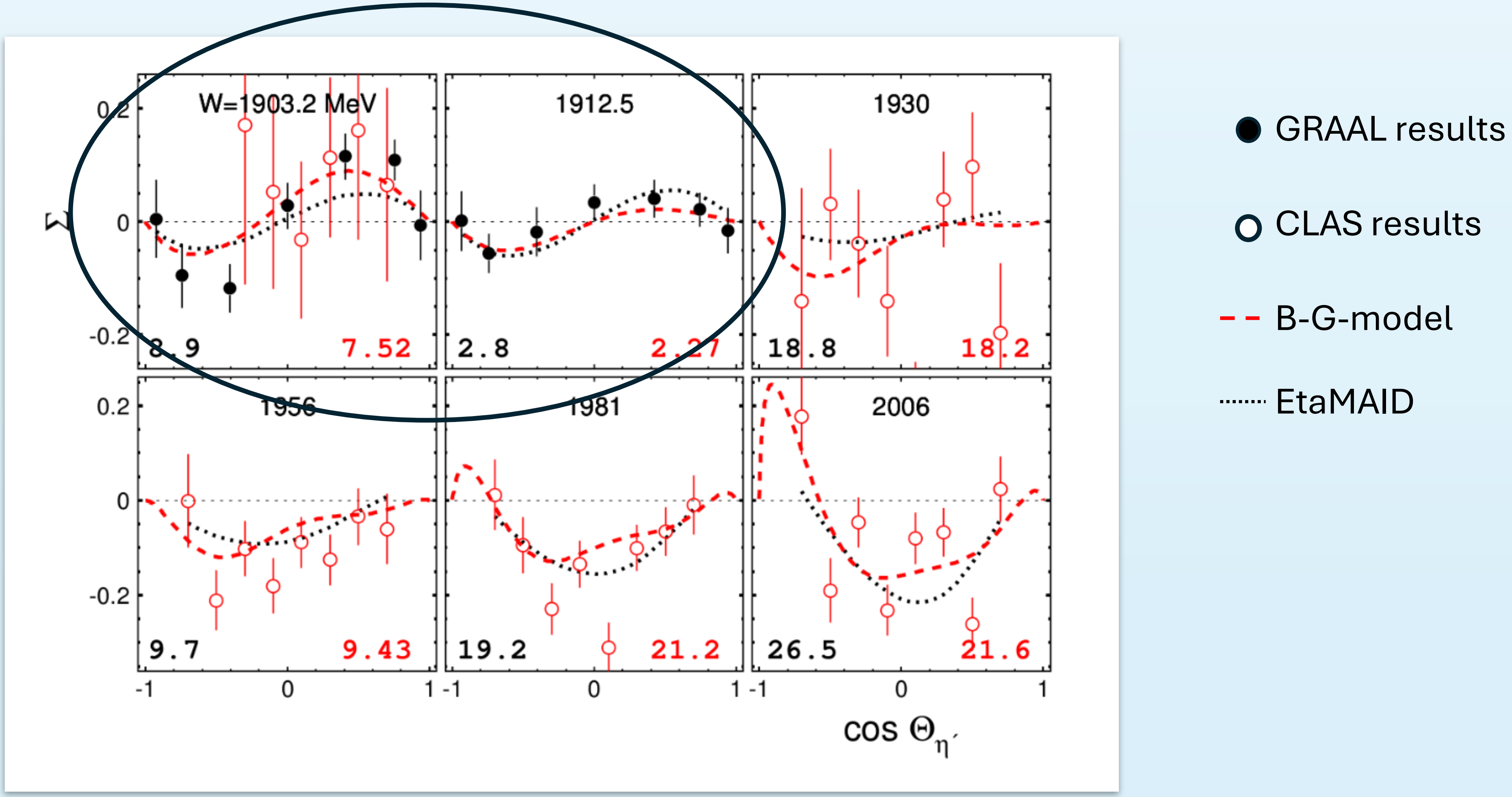
Beam Asymmetry: nodal structure

Reaction amplitudes of partial waves can be expanded in Legendre Polynomials $\mathbf{P_l(\cos(\theta))}$

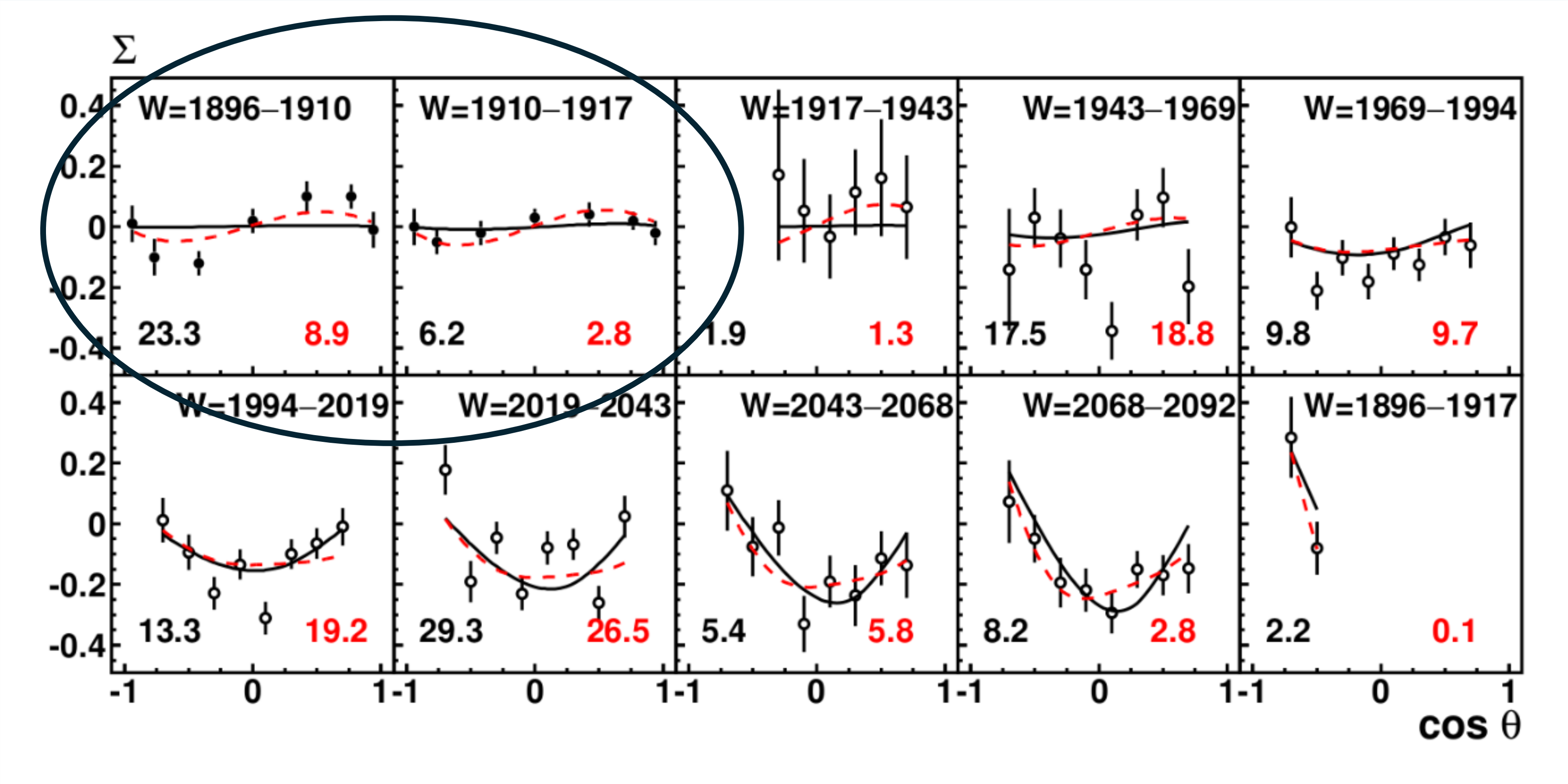
- S wave (l=0) independend of θ
- P wave (l=1) proportional to $\cos(\theta)$
- D wave (l=2) proportional to $\cos(\theta)^2$
- F wave (l=3) proportional to $\cos(\theta)^3$

→ Nodal structure can arise from interefernce terms such as P-D or S-F

EtaMAID: $S_{11}(1900)$



Bonn-Gatchina Model: $D_{13}(1900)$

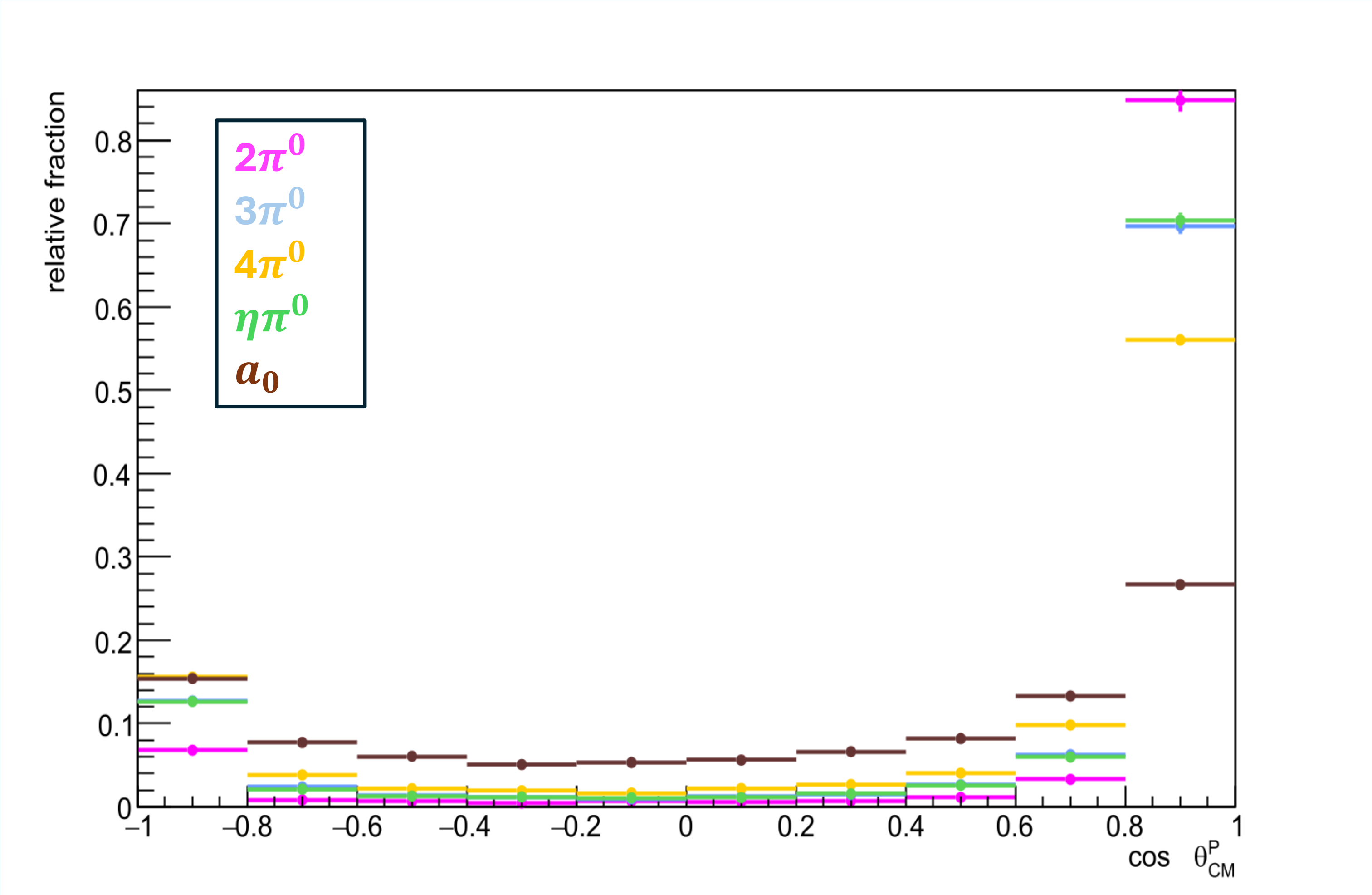


GRAAL results

CLAS results

B-G-model

Angular dependence



- barely bg in the bins between $-0.6 < \cos\theta^P_{CM} < 0.6$
- only a_0 and 4 π^0 considered for these bins

η′ decay channels:

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\pi^+\pi^-\eta$	$(42.6 \pm 0.7)\%$
Γ_2	$\rho^0\gamma$	$(28.9 \pm 0.5)\%$
Γ_3	$\pi^0\pi^0\eta$	$(22.8 \pm 0.8)\%$
Γ_4	$\omega\gamma$	$(2.62 \pm 0.13)\%$
Γ_6	$\gamma\gamma$	$(2.22 \pm 0.08)\%$

Table 4.1: The dominant decay modes of η' including the fraction (Γ_i/Γ).

Determination of $\frac{d\sigma}{d\Omega}$

$$\frac{d\sigma}{d\Omega}(E_\gamma, cos\theta^P_{CM}) = \frac{N(E_\gamma, cos\theta^P_{CM})}{F(E_\gamma)\cdot A\cdot\Omega\cdot\varepsilon(E_\gamma, cos\theta^P_{CM})}$$

- $N(E_\gamma, cos\theta^P_{CM})$ number of events
- $F(E_\gamma)$ photon flux
- A target area density
- Ω solid angle
- $\varepsilon(E_\gamma, cos\theta^P_{CM})$ detection efficiency

systematic uncertainties →

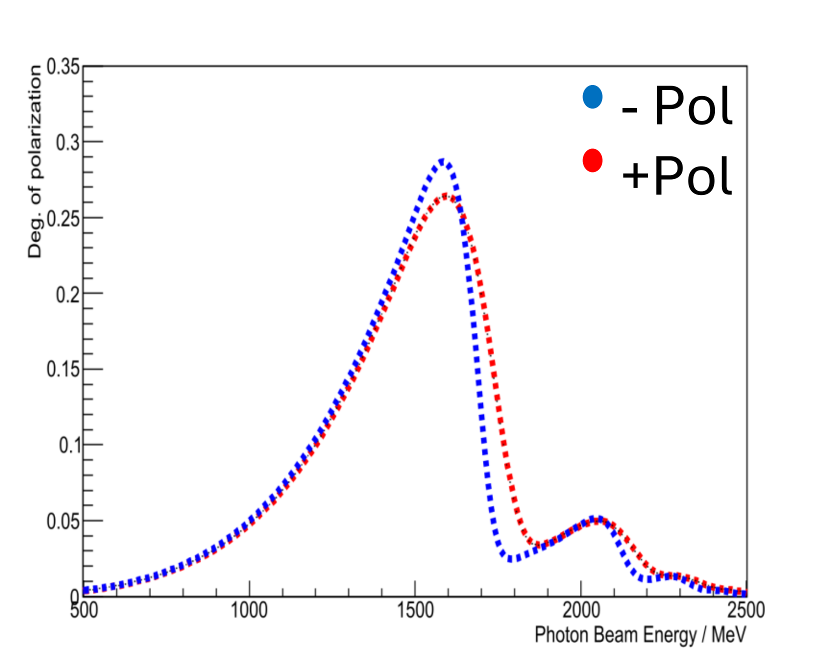
Reaction	Source	% error
$\eta' p \longrightarrow X p$	detector performance	7.1
	proton identification	2.0
	Summed in quadrature	7.38

Polarization correction:

$$\frac{\frac{N^{P}_{Pol+}}{F^{P}_{Pol+}}}{N^{P}_{UNP,norm}} = \frac{1}{2}\left(1 + P^{P}_{Pol+}\Sigma \cdot \cos(2\varphi)\right)$$

where:

$$N^{P}_{UNP,norm} = \frac{2}{P^{P}_{Pol+} + P^{P}_{Pol-}}\left(P^{P}_{Pol-}\frac{N^{P}_{Pol+}}{F^{P}_{Pol+}} + P^{P}_{Pol+}\frac{N^{P}_{Pol-}}{F^{P}_{Pol-}}\right)$$



Dilution factor:

$$\Sigma_{sum} = \Sigma_{signal+background}$$

$$\frac{N^-}{N^- + N^+} = \frac{N_S^- + N_B^-}{N_S^+ + N_B^+ + N_S^- + N_B^-}$$

$$\frac{N^-}{N^- + N^+} = \frac{1}{2}[1 + P(E_\gamma)\Sigma\sin(2\phi)]$$

assuming:

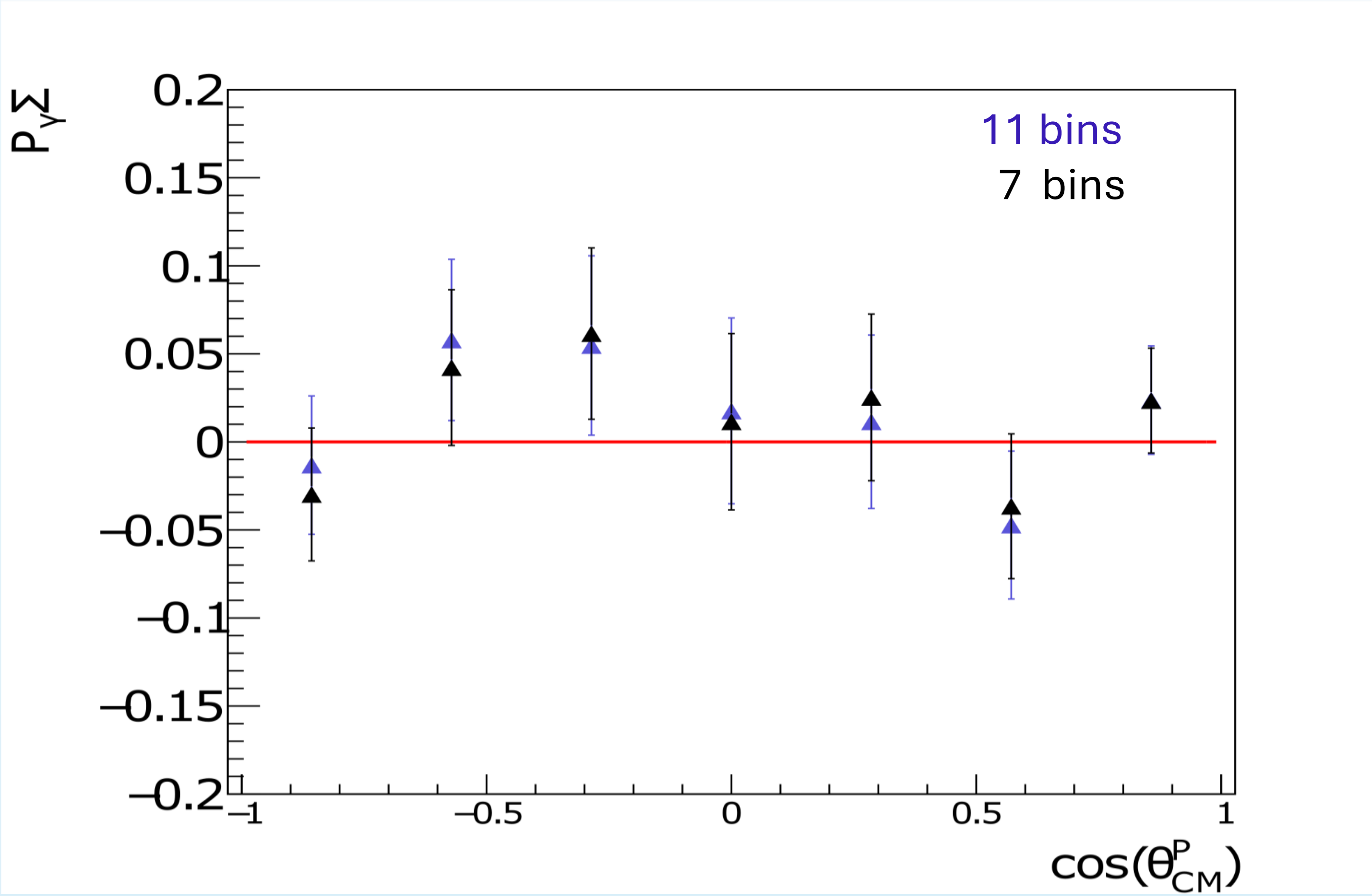
$$\Sigma_{bg} = 0 \rightarrow N_B^- = N_B^+ = \frac{1}{2}N_B$$

$$\Sigma_{signal} = \Sigma_{sum} \cdot \underbrace{\left(1 + \frac{N_B}{N_S}\right)}_{\text{dilution factor } D}$$

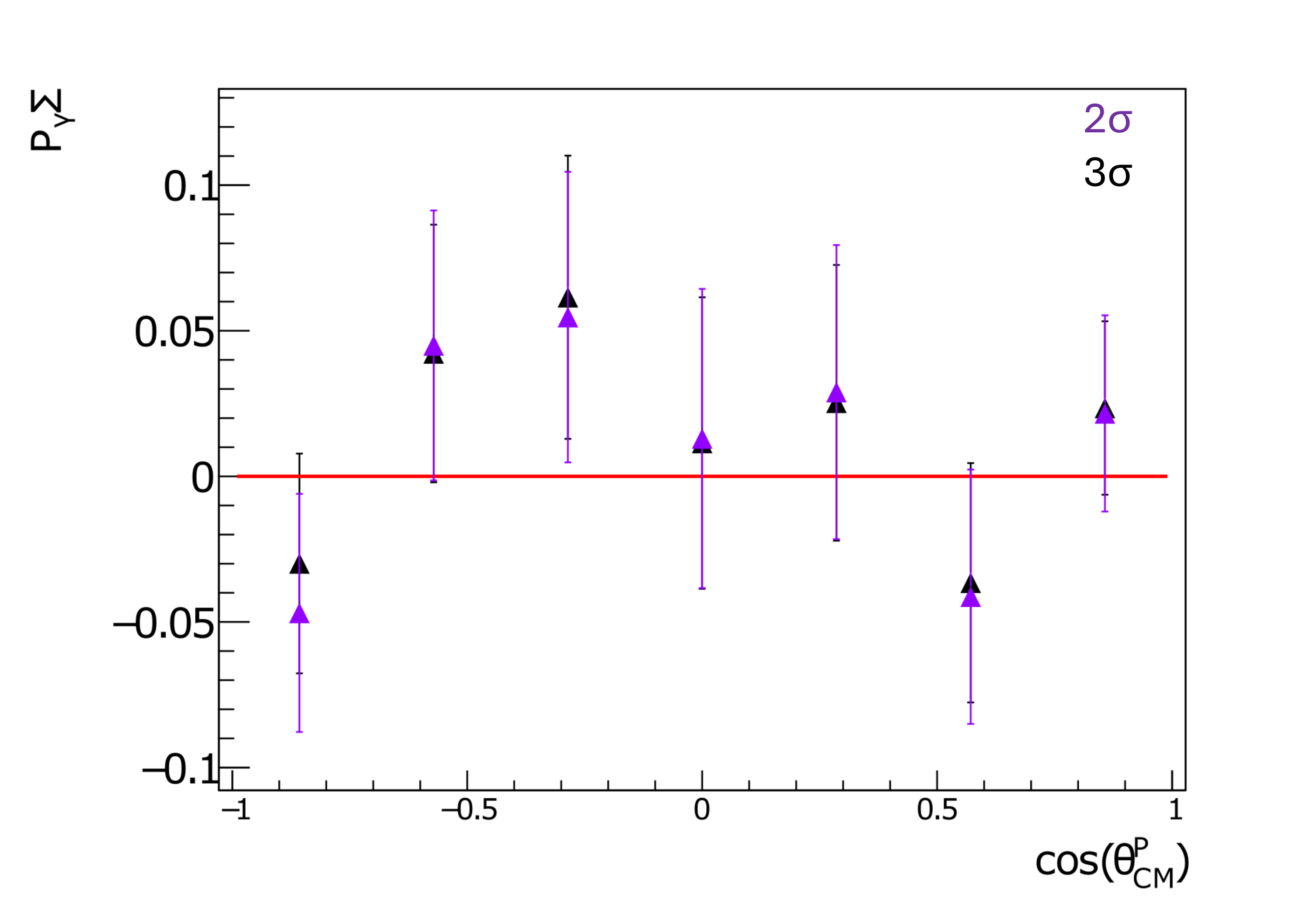
Σ – systematic uncertainties:

Source	% error
P_γ	3.0
$\epsilon(\theta^{\mathrm{p}}_{\mathrm{lab}}, \phi, p_{\mathrm{P}})$	1.0
p selection	1.0
plus polarized data	5.2
Integration range on m_{miss}	10.1
# ϕ bins	5.5
Summed in quadrature	13

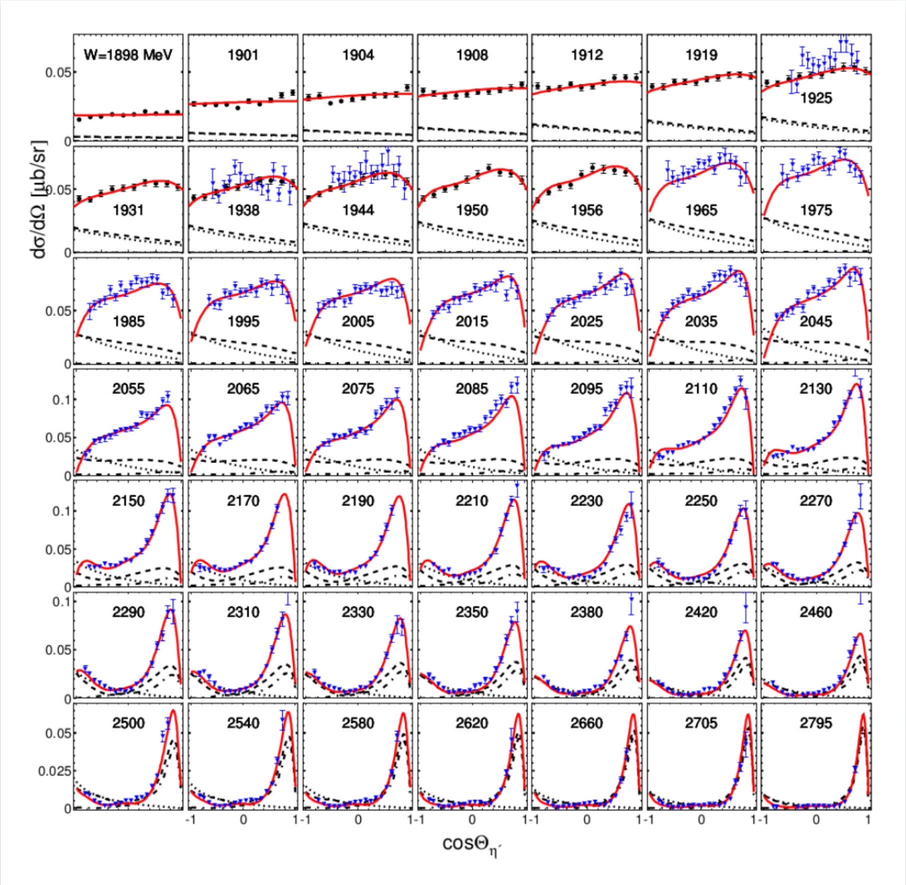
Σ – systematic uncertainties: Φ binning



$\boldsymbol{\Sigma}$ – systematic uncertainties: Integrated m_{miss} range of η′

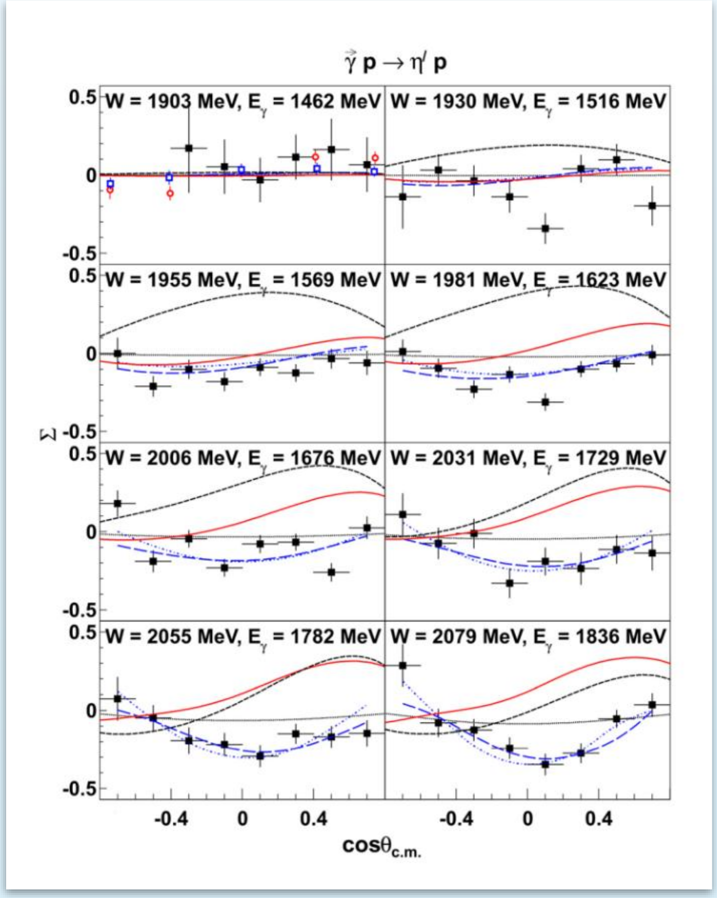


Current Results of the $\eta' p$ photoproduction



Diff Cross section

A2MAMI (black circles) and CLAS (blue triangles)



Beam asymmetry Σ

CLAS Close to zero, no interference