Double-polarization E and G observables in η photo-production on the CLAS Frozen Spin Target

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Introduction

Realized long ago: just looking at cross sections is not enough to disentangle the overlapping states of baryon spectra

Additional complication: superposition of states detected *e.g.* N^* and Δ

Solutions:

- study energy & angular dependence of **polarization observables**: polarization of one or several of: beam, target, recoil
- **resonance filtering:** $\eta(I=0)$ production ensures $N^*(I=\frac{1}{2})$ resonances

Presented: η photo-production to the proton ($\gamma p \to \eta p$) to extract:

obs.	**beam pol.**	**target pol.**	**expression**
E	circular (C)	longitudinal (z)	$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 \left(1 - P_z^T P_C^\gamma E\right)$
G	linear (L)	longitudinal (z)	$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 \left(1 - P_L^\gamma \Sigma \cos 2\phi + P_L^\gamma P_z^T G \sin 2\phi\right)$

Phenomenological fits to constrain with data:

η-MAID:	Mainz η-photo-production isobar model fit
SAID:	fit with couplings from πN, ηN data
Bonn-Gatchina:	coupled-channel partial wave analysis

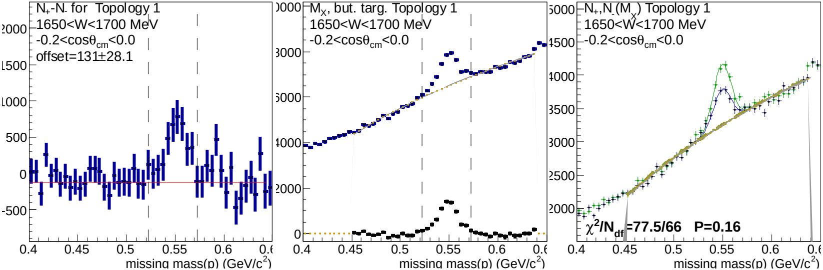
Analysis Per-Kinematic Bin

The goal is to form: $$E = -\frac{1}{P_z^T P_C^\gamma}\left(\frac{N_+ - N_-}{N_+ + N_-}\right)$$

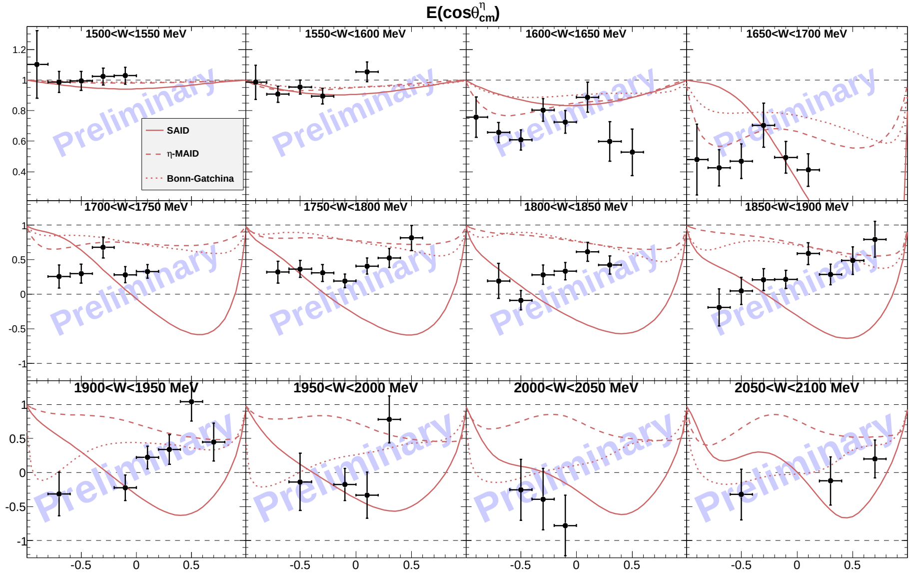
counting η via missing mass reconstruction and subtracting background

Steps:

- simultaneously fit meson mass spectra for two beam helicities (right plot)
  helicity $+$ helicity $-$
- use background from fit to correct sum of helicity yields (middle plot)
- form difference of two helicity spectra (left plot)



Results: E vs. $cos\theta^{\eta}_{cm}$



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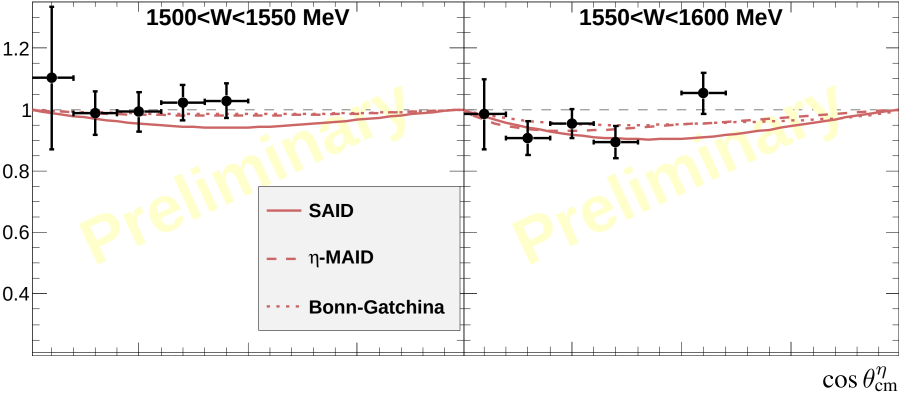


E results near η threshold

Results: E vs. W

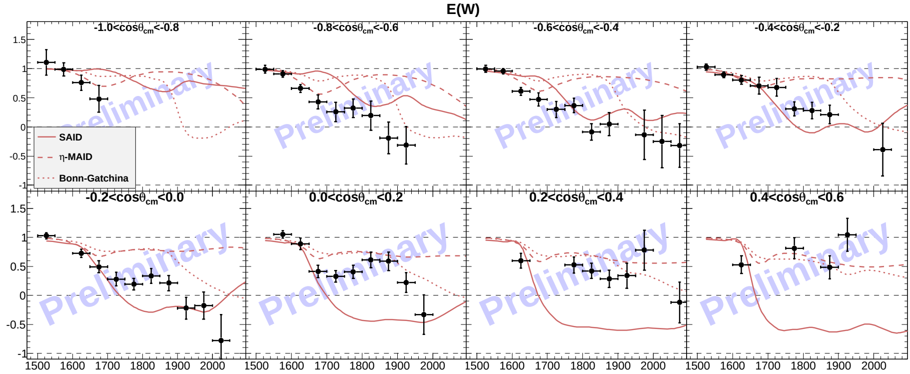


Figure : Helicity asymmetry E as a function of center of mass energy W(MeV)

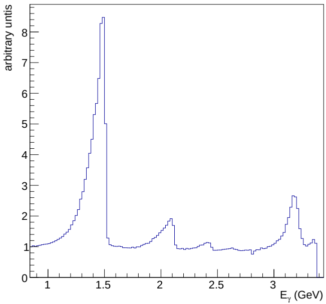
Linearly Polarized Beam Data

- coherent bremsstrahlung (CB) data taken at various positions of the coherent edge
- polarization fraction determined using CB Spectrum Analysis (CBSA)
- binning in W done for each coherent edge data set separately, allowing W overlaps

  Advantage: ensures consistency of P^{γ} estimation and other systematics

  In practice: statistics and asymmetry resolving power in coherent edge tail are poor

Sample coherent bremsstrahlung enhancement spectrum



Linear γ-beam data on the proton w.r.t W, P_{γ} and W-binning scheme

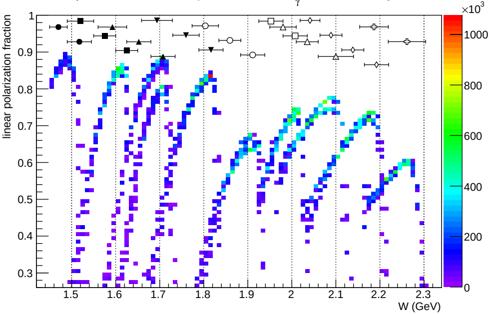


Figure : Distribution of photo-production events with proton detected as a function of center of mass energy W and beam polarization fraction. Brackets of W-binning of the data are shown.

Review of G observable and its extraction technique

Review of the G observable term:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0}\left(1 - P_L^\gamma \Sigma \cos 2\phi + P_L^\gamma P_z^T G \sin 2\phi\right)$$

where

- *linear* beam photon polarization (P_L^γ): $\parallel$ ($\hat{x}$) or $\perp$ ($\hat{y}$)
- azimuthal meson angle ϕ is relative to polarization vector
- P_z^T is target's *longitudinal* polarization ('T' dropped henceforth)

Writing this out explicitly for all beam/target configurations:

$$N_{\parallel}^{+}(\phi) = N_{0\parallel}^{+}(\phi)\left(1 - P_{\parallel+}^{\gamma}\Sigma\cos 2\phi + P_{\parallel+}^{\gamma}\left|P_{\parallel+}^{z}\right| G\sin 2\phi\right) \quad (1)$$

$$N_{\parallel}^{-}(\phi) = N_{0\parallel}^{-}(\phi)\left(1 - P_{\parallel-}^{\gamma}\Sigma\cos 2\phi - P_{\parallel-}^{\gamma}\left|P_{\parallel-}^{z}\right| G\sin 2\phi\right) \quad (2)$$

$$N_{\perp}^{+}(\phi) = N_{0\perp}^{+}(\phi)\left(1 + P_{\perp+}^{\gamma}\Sigma\cos 2\phi - P_{\perp+}^{\gamma}\left|P_{\perp+}^{z}\right| G\sin 2\phi\right) \quad (3)$$

$$N_{\perp}^{-}(\phi) = N_{0\perp}(\phi)\left(1 + P_{\perp-}^{\gamma}\Sigma\cos 2\phi + P_{\perp-}^{\gamma}\left|P_{\perp-}^{z}\right| G\sin 2\phi\right) \quad (4)$$

$N^0(\phi)$ contains acceptance in ϕ and relative integrated flux

G extraction technique (continued)

Analysis steps:

1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts

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3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$

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4. Take out the detector azimuthal acceptance. Now we have:

$$\tilde{N}_i(\phi) \equiv \frac{N_i(\phi)}{fN_0 N_{\mathrm{AMO}}(\phi)}$$

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   $$G\sin 2\phi = a_{\parallel+}\tilde{N}_{\parallel}^{+} + a_{\perp-}\tilde{N}_{\perp}^{-} - a_{\parallel-}\tilde{N}_{\parallel}^{-} - a_{\perp+}\tilde{N}_{\perp}^{+}$$

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$$= \frac{(P_{\perp+}+P_{\parallel-})(\tilde{N}_{\parallel}^{+}P_{\perp-}+\tilde{N}_{\perp}^{-}P_{\parallel+})-(P_{\perp-}+P_{\parallel+})(\tilde{N}_{\parallel}^{-}P_{\perp+}+\tilde{N}_{\perp}^{+}P_{\parallel-})}{P_{\perp-}P_{\parallel+}(P_{\perp+}+P_{\parallel-})(|P^{z}_{\perp+}|+|P^{z}_{\perp-}|)+P_{\perp+}P_{\parallel-}(P_{\perp-}+P_{\parallel+})(|P^{z}_{\perp-}|+|P^{z}_{\perp+}|)}$$

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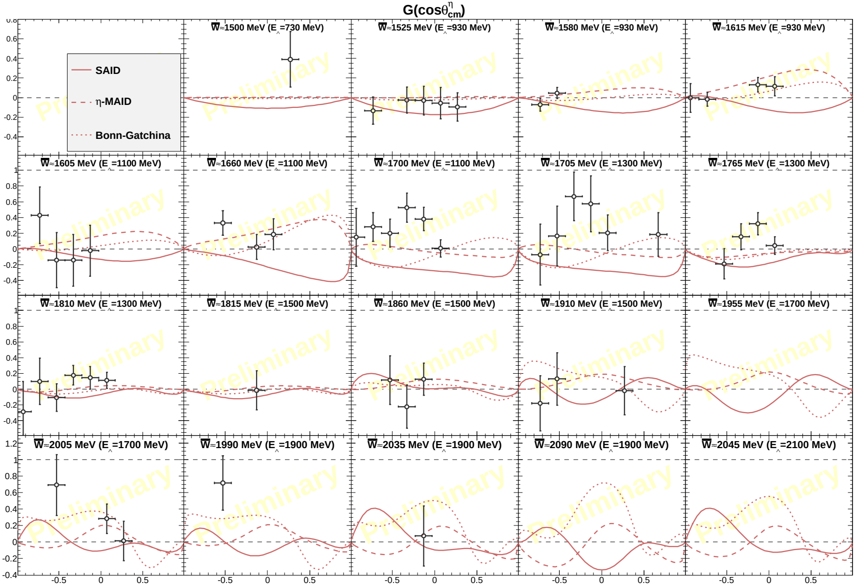
6. Fit the above right-hand side to get G

Results: G vs. $cos\theta^{\eta}_{cm}$



Results: G vs. W

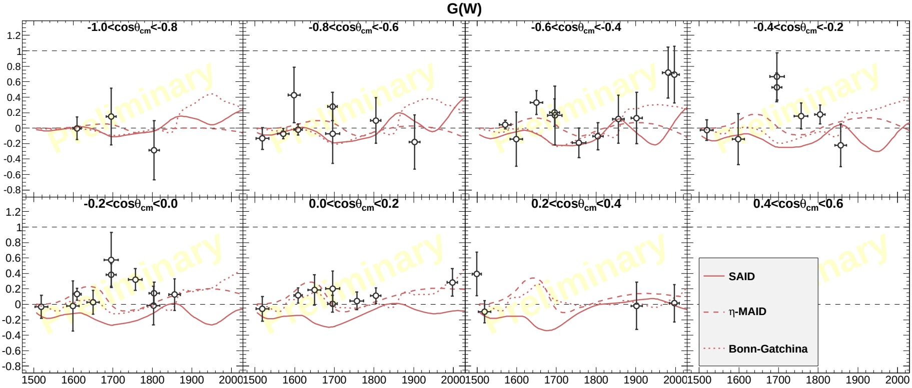


Figure : Beam/target polarization asymmetry G as a function of center of mass energy W(MeV)

Summary and Outlook

- No published data on E and G observables in η-photo-production
- E results ready for analysis review ✓
- G results may benefit from more sophisticated extraction methods
  - more robust at low statistics – more kinematic bins covered
  - smaller statistical error bars
  - work on systematic uncertainties
  - Cross-check results against other extraction methods