Determination of E and G observables in η photo-production on the CLAS Frozen Spin Target (FROST)

for the NSTAR 2013 Workshop

Igor Senderovich[1]

ASU Group: B. T. Morrison, M. Dugger, B. Ritchie, R. Tucker,
and the CLAS Collaboration

Arizona State University
Department of Physics

May 29, 2013

[1]Igor.Senderovich@asu.edu Work supported by the U.S. National Science Foundation

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

JLab Hall B γ beam and Frozen Spin Target

Tagged polarized photon beams are produced at Jefferson Lab's Hall B facility from the CEBAF e^- beam.

peak polarization $\sim 87\%$

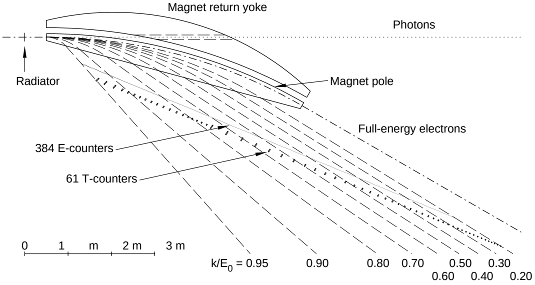


Figure: Hall B photon tagger with scintillation counter configuration shown.

γ beam incident on **Fro**zen **S**pin **T**arget (FROST)

Hydrogen in butanol (C_4H_9OH) is polarized at low temperature

$\sim 85\%$ average polarization; $< 1\,\%/\text{day}$ relaxation rate

Auxiliary targets downstream:

- graphite (pure carbon) for bound nucleon data
- polyethylene (CH2) for background, systematics studies

CLAS Detector (d. 2012)

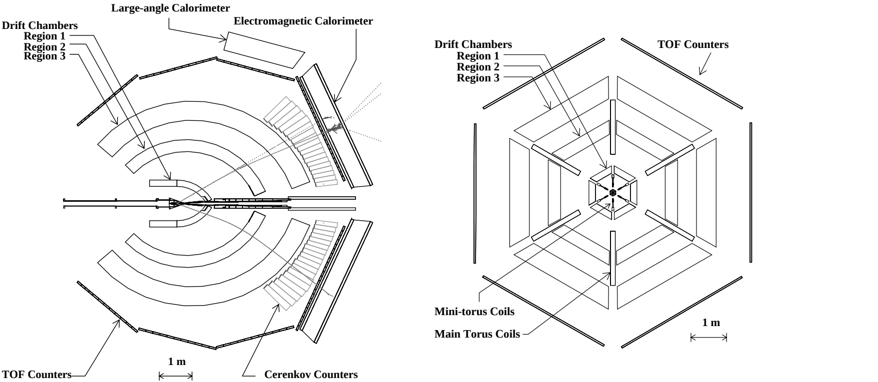


Figure : **C**EBAF **L**arge **A**cceptance **S**pectrometer (CLAS): side and front cut-through

Large acceptance detector designed for variously polarized targets

- good tracking and PID
- efficient identification of neutrals only through missing mass

Assembling Event Rendition

- Particle detection, ID, selection:

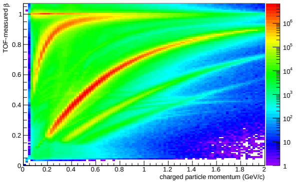
  Neutrals: not used – small angular coverage of the calorimeter

  (especially problematic with many-γ final state η decays)

  missing mass technique for neutral final states used instead

  Charged tracks: ID/selection procedure:

  1. basic tracking, TOF hit-matching, beam γ tagging performed
  2. charged particle ID assigned based on closest β to that measured by TOF
  3. track quality cut: unambiguous beam γ tag, start counter information
  4. TOF β cuts for $\pi^{\pm}$
- Basic event consistency: all charged tracks have timing consistent with a single generating beam γ
- Energy loss corrections performed on tracks



Assembling Event Rendition

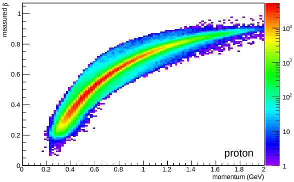
- Particle detection, ID, selection:

  Neutrals: not used – small angular coverage of the calorimeter
  (especially problematic with many-γ final state η decays)
  missing mass technique for neutral final states used instead

  Charged tracks: ID/selection procedure:

  1. basic tracking, TOF hit-matching, beam γ tagging performed
  2. charged particle ID assigned based on closest β to that measured by TOF
  3. track quality cut: unambiguous beam γ tag, start counter information
  4. TOF β cuts for $\pi^{\pm}$

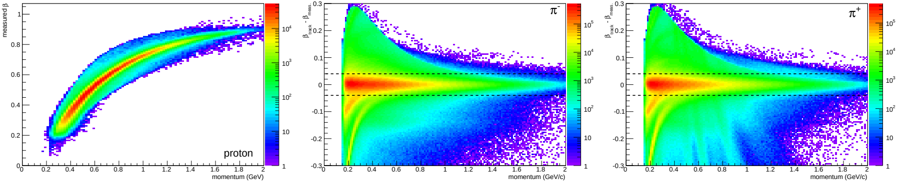
- Basic event consistency: all charged tracks have timing consistent with a single generating beam γ
- Energy loss corrections performed on tracks



Assembling Event Rendition

- Particle detection, ID, selection:
  Neutrals: not used – small angular coverage of the calorimeter
  (especially problematic with many-γ final state η decays)
  missing mass technique for neutral final states used instead

  Charged tracks: ID/selection procedure:
  1. basic tracking, TOF hit-matching, beam γ tagging performed
  2. charged particle ID assigned based on closest β to that measured by TOF
  3. track quality cut: unambiguous beam γ tag, start counter information
  4. TOF β cuts for $\pi^{\pm}$
- Basic event consistency: all charged tracks have timing consistent with a single generating beam γ
- Energy loss corrections performed on tracks

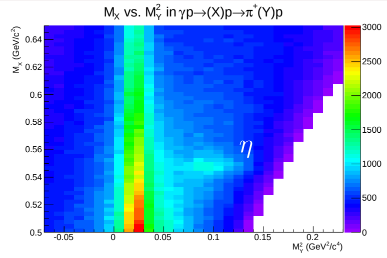


η Reconstruction

η decay modes: 72% neutral, 28% charged modes $\Rightarrow$ Topologies used to isolate η:

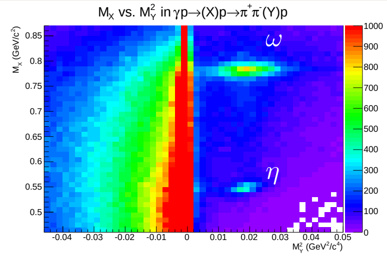
1. $\gamma p \to (X)p$ (inclusive)
2. $\gamma p \to (X)p \Leftarrow$ most of the statistics, more background
3. $\gamma p \to (X)p$ (γs detected) $\Leftarrow$ plenty of the statistics, fairly clean
4. $\gamma p \to (X)p \to \pi^+(Y)p$, $\Leftarrow$ cleaner, low statistics
5. $\gamma p \to (X)p \to \pi^-(Y)p$, $\Leftarrow$ cleaner, low statistics
6. $\gamma p \to (X)p \to \pi^+\pi^-(Y)p \Leftarrow$ cleanest, lowest statistics

Topologies 4,5: $\gamma p \to (X)p \to \pi^\pm(Y)p$



cut: $M_Y^2 > 0.08\,\mathrm{GeV}^2/\mathrm{c}^4$

Topology 6: $\gamma p \to (X)p \to \pi^-(Y)p$



cut: $0.008 < M_Y^2 < 0.028\,\mathrm{GeV}^2/\mathrm{c}^4$

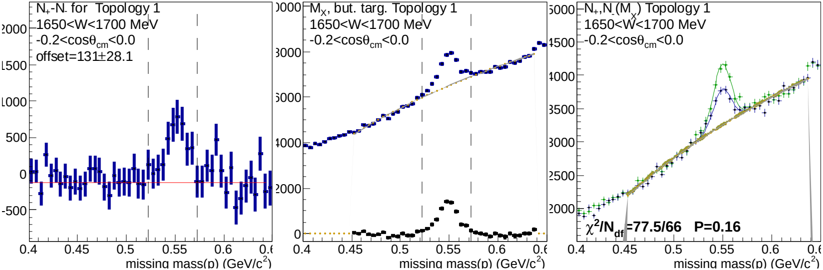
Analysis Per-Kinematic Bin

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

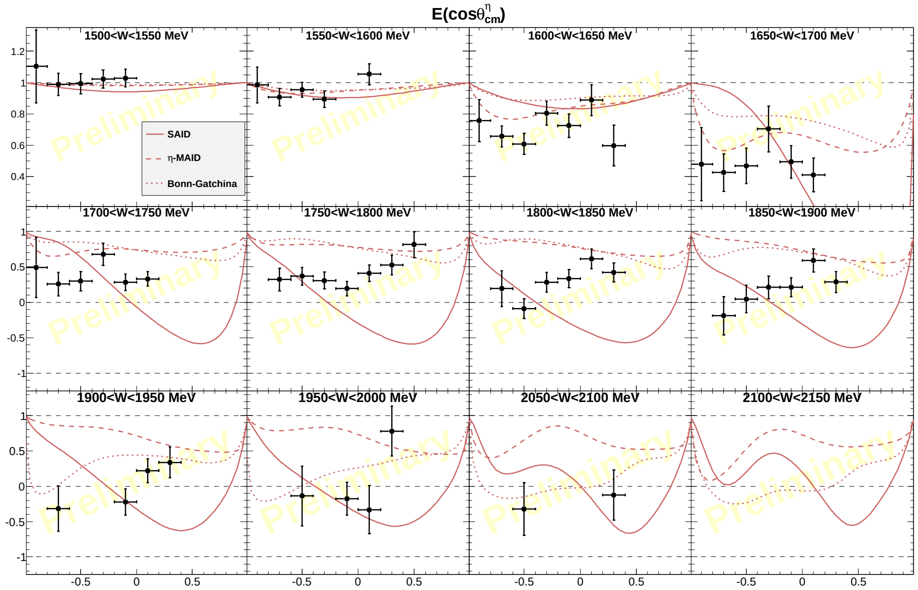
taking care to count only η contribution for yields N

Steps:

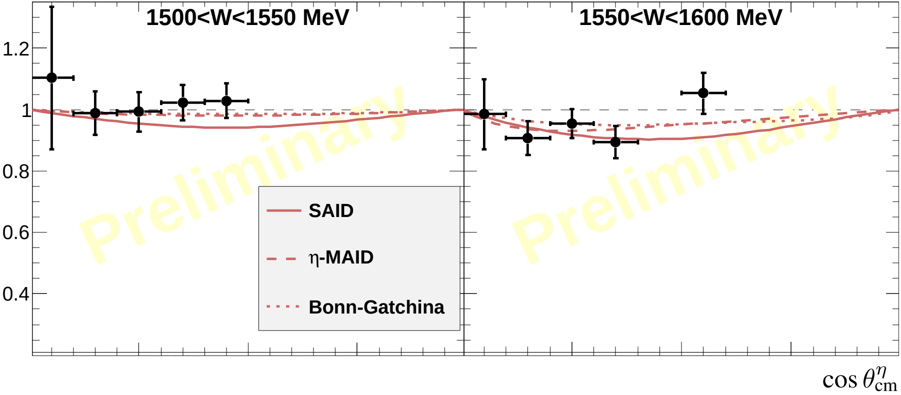
- simultaneously fit meson mass spectra for two beam helicities (right plot)
  helicity $+$ helicity $-$
- use background from fit to correct sum of helicity yields (middle plot)
- form difference of two helicity spectra (left plot)



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



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



E results near η threshold

Results: E vs. W

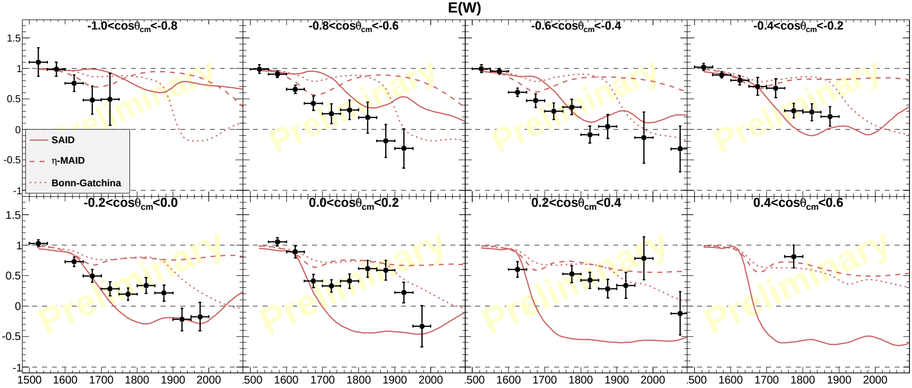


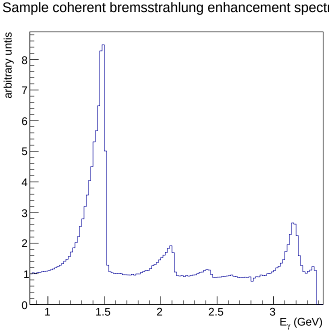
Figure : Helicity asymmetry E as a function of center of mass energy W(MeV)

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



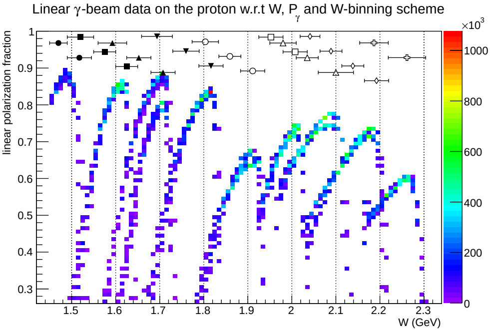


Figure : Distribution of photo-production events with proton detected as a function of center of mass energy W and beam polarization fraction. Brackets of W-binning of the data are shown.

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

G extraction technique (continued)

Analysis steps:

1. $\gamma p \rightarrow (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)

G extraction technique (continued)

Analysis steps:

1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)
3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$

G extraction technique (continued)

Analysis steps:

1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)
3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$
4. Take out the detector azimuthal acceptance. Now we have:
$$\tilde{N}_i(\phi) \equiv \frac{N_i(\phi)}{fN_0 N_{\mathrm{AMO}}(\phi)}$$

G extraction technique (continued)

Analysis steps:

1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)
3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$
4. Take out the detector azimuthal acceptance. Now we have:
   $$\tilde{N}_i(\phi) \equiv \frac{N_i(\phi)}{fN_0N_{\mathrm{AMO}}(\phi)}$$
5. Form combinations of equations 1-4 to cancel all but G term:

G extraction technique (continued)

Analysis steps:

1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)
3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$
4. Take out the detector azimuthal acceptance. Now we have:
$$\tilde{N}_i(\phi) \equiv \frac{N_i(\phi)}{fN_0 N_{\mathrm{AMO}}(\phi)}$$
5. Form combinations of equations 1-4 to cancel all but G term:
$$G\sin 2\phi = a_{\parallel +}\tilde{N}_{\parallel}^{+} + a_{\perp -}\tilde{N}_{\perp}^{-} - a_{\parallel -}\tilde{N}_{\parallel}^{-} - a_{\perp +}\tilde{N}_{\perp}^{+}$$

G extraction technique (continued)

Analysis steps:

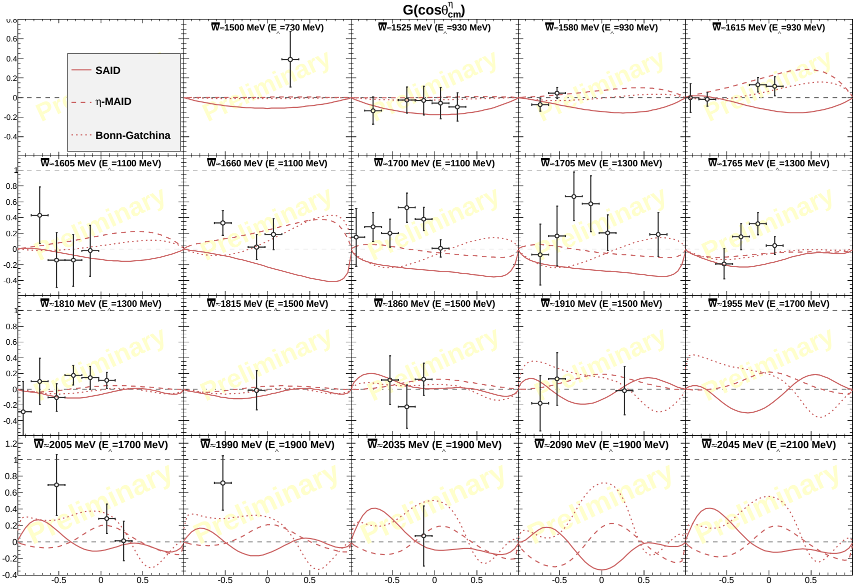
1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)
3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$
4. Take out the detector azimuthal acceptance. Now we have:
   $$\tilde{N}_i(\phi) \equiv \frac{N_i(\phi)}{fN_0 N_{\mathrm{AMO}}(\phi)}$$
5. Form combinations of equations 1-4 to cancel all but G term:
   $$G\sin 2\phi = a_{\parallel+}\tilde{N}_{\parallel}^{+} + a_{\perp-}\tilde{N}_{\perp}^{-} - a_{\parallel-}\tilde{N}_{\parallel}^{-} - a_{\perp+}\tilde{N}_{\perp}^{+}$$
   $$= \frac{(P_{\perp+}+P_{\parallel-})(\tilde{N}_{\parallel}^{+}P_{\perp-}+\tilde{N}_{\perp}^{-}P_{\parallel+})-(P_{\perp-}+P_{\parallel+})(\tilde{N}_{\parallel}^{-}P_{\perp+}+\tilde{N}_{\perp}^{+}P_{\parallel-})}{P_{\perp-}P_{\parallel+}(P_{\perp+}+P_{\parallel-})(|P^{z}_{\perp+}|+|P^{z}_{\perp-}|)+P_{\perp+}P_{\parallel-}(P_{\perp-}+P_{\parallel+})(|P^{z}_{\perp-}|+|P^{z}_{\perp+}|)}$$

G extraction technique (continued)

Analysis steps:

1. $\gamma p \to (X)p$ events selected after track fiducial, PID and γ timing cuts
2. Fit X mass spectrum in η region to get signal fraction (f)
3. Normalize: divide by N_0 from the fit to: $A(\phi) = N_0(1 + a\cos 2\phi + b\sin 2\phi)$
4. Take out the detector azimuthal acceptance. Now we have:
$$\tilde{N}_i(\phi) \equiv \frac{N_i(\phi)}{fN_0 N_{\text{AMO}}(\phi)}$$
5. Form combinations of equations 1-4 to cancel all but G term:
$$G\sin 2\phi = a_{\parallel +}\tilde{N}_{\parallel}^{+} + a_{\perp -}\tilde{N}_{\perp}^{-} - a_{\parallel -}\tilde{N}_{\parallel}^{-} - a_{\perp +}\tilde{N}_{\perp}^{+}$$
$$= \frac{(P_{\perp +}+P_{\parallel -})(\tilde{N}_{\parallel}^{+}P_{\perp -}+\tilde{N}_{\perp}^{-}P_{\parallel +})-(P_{\perp -}+P_{\parallel +})(\tilde{N}_{\parallel}^{-}P_{\perp +}+\tilde{N}_{\perp}^{+}P_{\parallel -})}{P_{\perp -}P_{\parallel +}(P_{\perp +}+P_{\parallel -})(|P^{z}_{\perp +}|+|P^{z}_{\perp -}|)+P_{\perp +}P_{\parallel -}(P_{\perp -}+P_{\parallel +})(|P^{z}_{\perp -}|+|P^{z}_{\perp +}|)}$$
6. Fit the above right-hand side to get G

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



Results: G vs. W

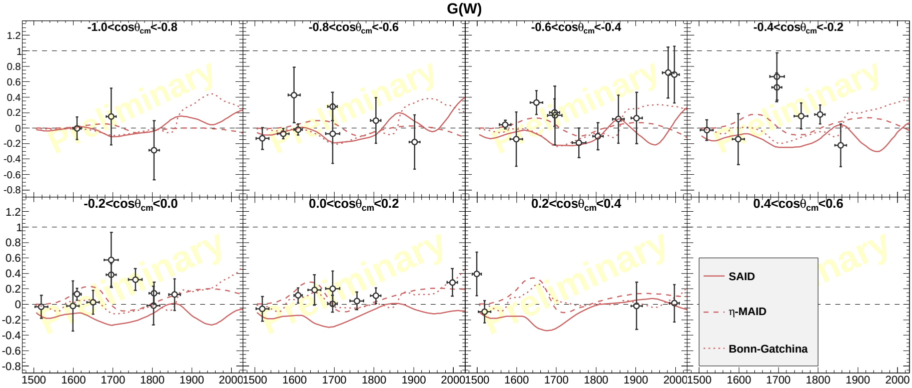


Figure : Beam/target polarization asymmetry G as a function of center of mass energy W(MeV)

Summary and Outlook

- No published data on E and G observables in η-photo-production
- Preliminary but compelling new results ✓
- G results may benefit from more sophisticated extraction methods (work in the pipeline) ⟳
  - more robust at low statistics – more kinematic bins covered
  - smaller statistical error bars
- Finalize systematic uncertainties ⟳
- Cross-check results against other extraction methods ⟳