



Measurement of Exclusive π^0 and η Photoproduction in the Primakoff Region with a Linearly Polarized Photon Beam at GlueX

Shannen Graham-Howard

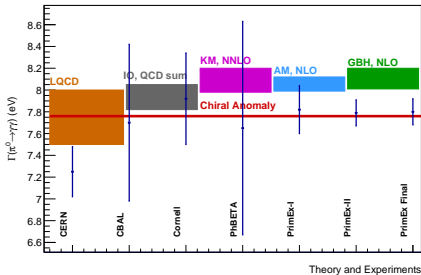
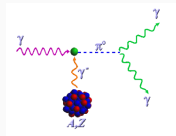
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University of Massachusetts Amherst
Miskimen Group

Physics Motivation

- Decay of the π^0 doesn't require renormalization
 $\Rightarrow \Gamma(\pi^0 \rightarrow \gamma\gamma)$ can be computed analytically
- Provides a good test for low energy QCD
- Primakoff Effect: **Photoproduction off the Coulomb field of a nucleus**

$$\Gamma(\pi^0 \rightarrow \gamma\gamma) = \frac{m_{\pi^0} \alpha^2 N_C^2}{576 \pi^3 F_{\pi^0}^2}$$



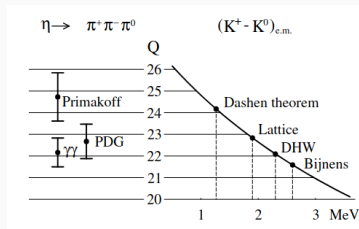
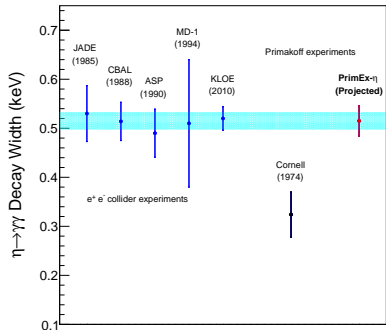
$$\frac{d\sigma_P}{d\Omega} = \Gamma_{\gamma\gamma} Z^2 \frac{8\alpha}{m^3} \frac{\beta^3 E^4}{Q^4} |F(Q)|^2 \sin^2(\theta_\pi)$$

- Primakoff Experiment (PrimeEx I and II) used the Primakoff effect to provide good results for $\Gamma(\pi^0 \rightarrow \gamma\gamma)$ without polarization observables, $\frac{\Delta\Gamma}{\Gamma} \approx 2.1\%$
- Experiment matches $\Gamma(\pi^0 \rightarrow \gamma\gamma)$ at LO, NLO and NNLO tension motivates further study

Physics Motivation

In addition to nonet state physics,

- Light quark mass ratios dependent on $\Gamma(\eta \rightarrow \gamma\gamma)$
- **Cornell Primakoff Measurement agrees with Dashen theorem predictions for light quark mass ratio, disagrees with other predictions**
- $\eta - \eta'$ mixing angle schemes require $\Gamma(\eta \rightarrow \gamma\gamma)$ input



$$\frac{d\sigma_P}{d\Omega} = \Gamma_{\gamma\gamma} Z^2 \frac{8\alpha}{m^3} \frac{\beta^3 E^4}{Q^4} |F(Q)|^2 \sin^2(\theta_\pi)$$

- $\Gamma(\eta \rightarrow \gamma\gamma)$ via Primakoff technique poorly understood and measuring techniques display potential inconsistencies
- PrimEx- η underway (very close to publishing), **High-Z cross-check is important**

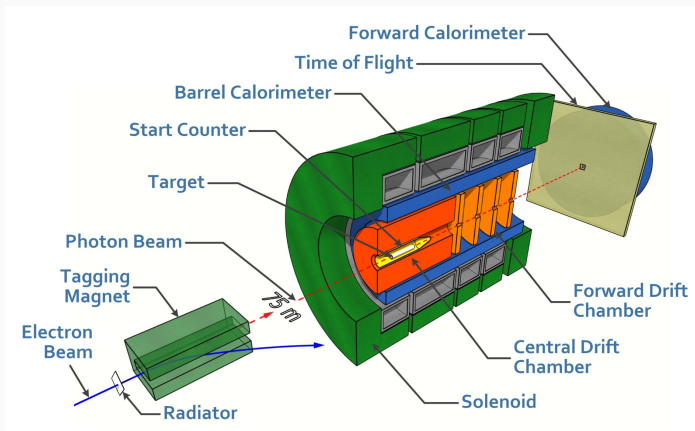
The Charged/Neutral Polarizability (CPP/NPP) provides:

→ A key opportunity for an independent measurement of Primakoff π^0 and η photoproduction **with the same dataset**

π^0 and η production features:

- Photoproduction with polarized tagged photon beam
- ^{208}Pb Target
- Coherent Peak ≈ 5.9 GeV
- High Z Target \Rightarrow **Primakoff Enhancement**
- High polarization fraction (peaks $\approx 70\%$), high event rate, and primakoff peak enhancement \Rightarrow **First measurement of polarization asymmetries in the primakoff region**
- Higher energy photons enhance η cross-section

Experimental Apparatus



GlueX forms a $\approx 4\pi$ detector with good reconstruction of neutral and charged final states

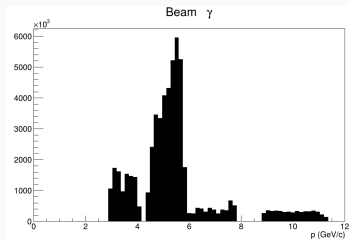
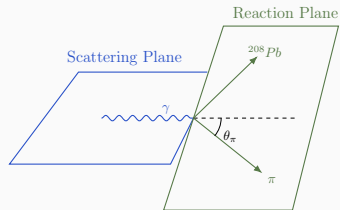


Event Selection

Selecting exclusive π^0 and η photoproduction → Only want events with exactly two photons

From all events with two neutral showers in the calorimeters, I then

- Perform a statistical subtraction of empty target events and accidentals
- For π^0 , require photon beam energies between 4.3 and 6 GeV
- For η , require photon beam energies above 8 GeV
- Subdivide dataset into bins of θ_{π^0} , for each bin perform background subtraction



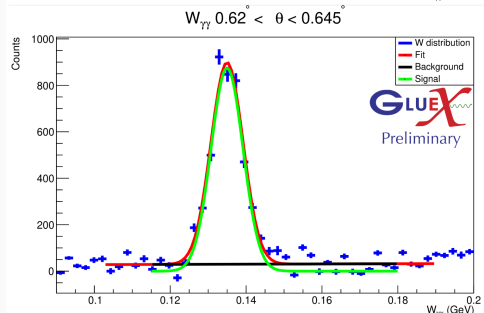
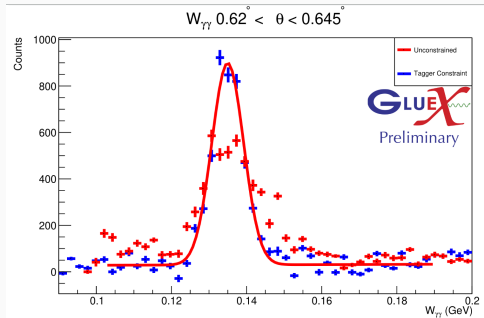
Two Polarization Angles: 135° and 45°

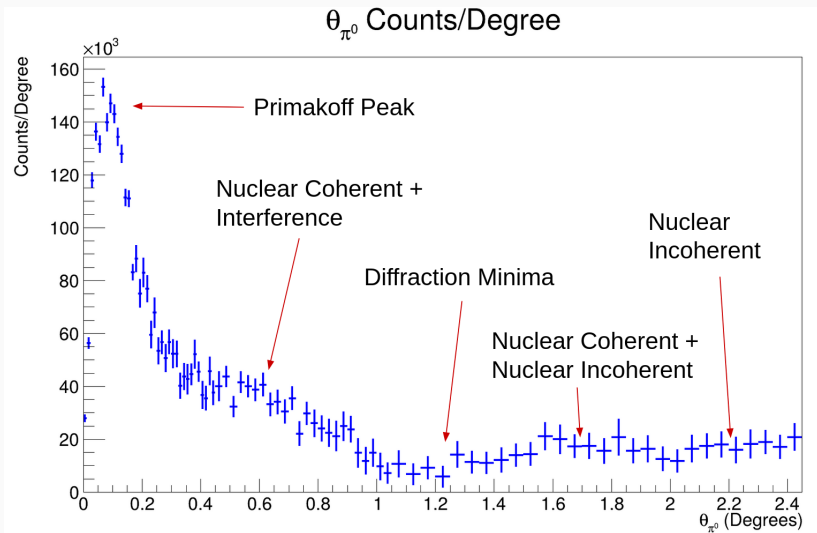
π^0 Signal Extraction

π^0 Yields extracted by peak-and-background fitting for each bin of θ_{π^0}

To improve resolution $W_{\gamma\gamma}$ is constrained such that energy is conserved, i.e. $E_{\pi^0} = E_{Beam}$

Peak and background subtraction performed on the constrained $W_{\gamma\gamma}$ distribution for each bin of θ





Fit to Data

$$Y = N_\gamma N_A (\Gamma(\pi^0 \rightarrow \gamma\gamma) |T_{\text{Prim}}|^2 + C |T_S|^2 + 2\sqrt{\Gamma C} |T_{\text{Prim}}| |T_S| \cos(\phi_{\text{Prim}} - \phi_S + \phi_0))$$

Production amplitudes determined via MC integral of Gyegoryan model over appropriate E_γ , θ_{π^0} and ϕ_{π^0} range.

Γ Statistical

Uncertainties:

$$\frac{\Delta\Gamma}{\Gamma} \approx \pm 0.4\%$$

PrimeEx I/II

Statistical

Uncertainties:

$$\frac{\Delta\Gamma}{\Gamma} \approx \pm 0.7\%$$

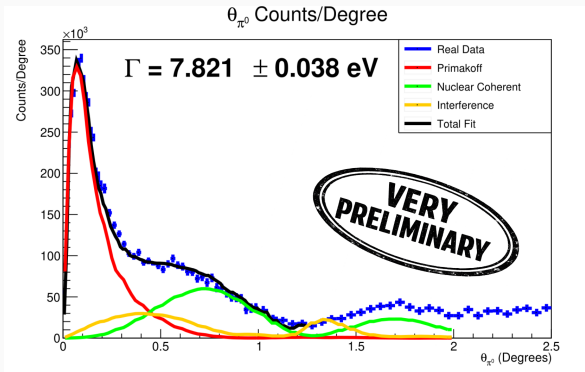
Agrees well with

PrimEx avg of

$$7.806 \pm$$

$$0.052(\text{stat}) \pm 0.105(\text{syst})$$

eV



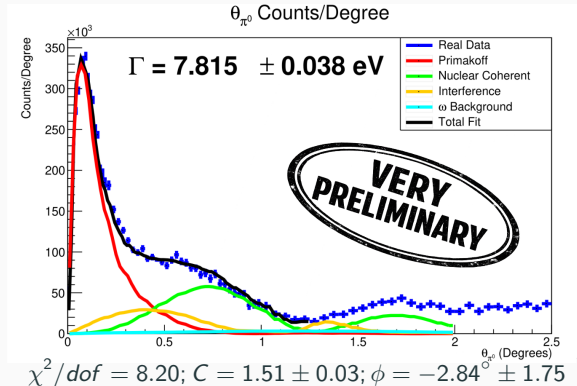
$$\chi^2/dof = 8.36; C = 1.57 \pm 0.03; \phi = -4.53^\circ \pm 1.73$$

Full Fit to Data

$\omega \rightarrow \pi^0 \gamma$ generator made by Ilya, $\sigma_\omega = 0.75 \pm 0.3 \mu\text{b}/\text{nucleon}$,

$R_{\omega \rightarrow \gamma\gamma} = 8.28 \pm 0.28\%$

$$Y = N_\gamma N_A (\Gamma(\pi^0 \rightarrow \gamma\gamma) |T_{\text{Prim}}|^2 + C |T_S|^2 + 2\sqrt{\Gamma C} |T_{\text{Prim}}| |T_S| \cos(\phi_{\text{Prim}} - \phi_S + \phi_0) + \sigma_\omega R_{\omega \rightarrow \gamma\gamma} Y_\omega)$$



Linear Polarization Asymmetries

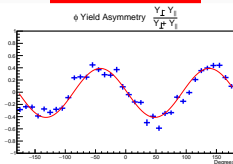
Use Linear Polarization Asymmetries for three bins of θ_{π^0} to search for non-exclusive π^0 contamination

- Exclusive pseudoscalar photoproduction should have an analyzing power of 1
- \Rightarrow Can detect non-exclusive and non-pseudoscalar BG's by measuring the analyzing power
- $< 0.2^\circ$ analyzing power is also diluted by azimuthal resolution

$$Y_{Asymm} = \frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + F_R Y_{\parallel}} \text{ is fit to } \Sigma \cos(2(\phi - \alpha)) + C$$

Primakoff Region

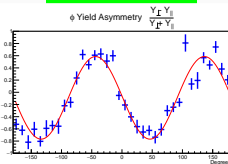
$$0^\circ < \theta < 0.4^\circ$$



$$\Sigma = 0.40 \pm 0.02$$

Nuclear Coherent

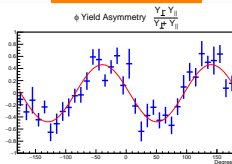
$$0.4^\circ < \theta < 1^\circ$$



$$\Sigma = 0.68 \pm 0.02$$

Nuclear Incoherent

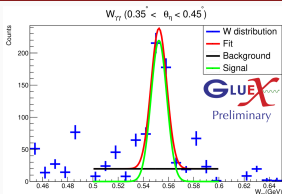
$$1^\circ < \theta < 2.5^\circ$$



$$\Sigma = 0.47 \pm 0.03$$

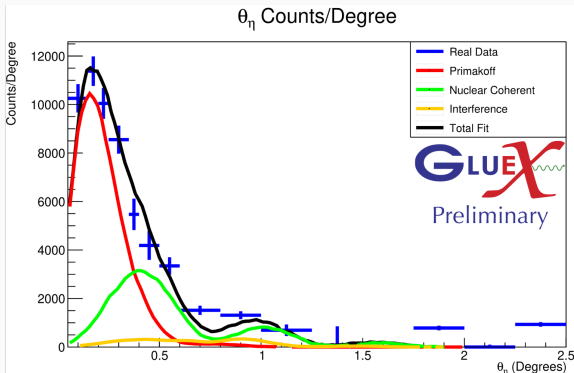
Contamination is Present, Likely $\omega \rightarrow \pi^0 \gamma$

Preliminary η Yields



To extract θ_η Yields:

- Events with $E_{Beam} > 8\text{GeV}$ accepted
- Following θ_{π^0} procedure elasticity $W_{\gamma\gamma}$ is fit to extract θ_η yields
- A three parameter fit to MC is performed



Statistical Uncertainties: $\frac{\Delta\Gamma}{\Gamma} \approx \pm 4\%$

Summary and Outlook

- π^0 Analysis Summary
 - Successful extraction of π^0 Yields
 - θ Yields are fit to MC with $\frac{\Delta\Gamma}{\Gamma} \approx 0.4\%$
 - Linear Polarization Asymmetries are determined and indicate contamination
- η Analysis Next Steps
 - Successful extraction of η Yields
 - η Yields are fit to MC with $\frac{\Delta\Gamma}{\Gamma} \approx 4\%$
- π^0 Analysis Next Steps
 - Simulate linear polarization asymmetries to calculate ϕ resolution
 - Determine physics linear polarization asymmetries
 - Evaluate $\omega \rightarrow \pi^0\gamma$ Monte Carlo
- η Analysis Next Steps
 - Determine flux from 8-12 GeV
 - Extract $\Gamma(\eta \rightarrow \gamma\gamma)$
 - Linear polarization asymmetries of the η in the primakoff region

Questions?

Funding Acknowledgement and
Many Thanks to:



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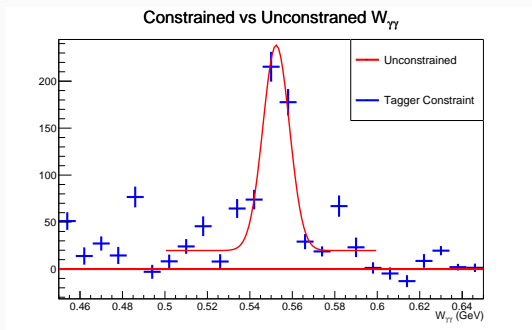
Reserve Slides

θ Yield Selection Criterion

In addition to the π^0 selection criterion:

- Accept events with an elasticity ($\frac{E_{\pi^0}}{E_{\text{Tagger}}}$) is between .875 and 1.125
- Enforce conservation of energy by constraining $E_{\pi^0} = E_{\text{Tagger}}$ and recompute $W_{\gamma\gamma}$

$W_{\gamma\gamma}$ for one θ bin with and without the tagger energy constraint



θ Yield Selection Criterion

To form θ yields, I am subdividing the elasticity constrained $W_{\gamma\gamma}$ dataset into regions of θ and performing peak and background subtraction to extract the θ counts for that bin

- θ binning scheme:
 - Bins of $.0125^\circ$ for $0^\circ < \theta < 0.45^\circ$
 - Bins of $.025^\circ$ for $.45^\circ < \theta < 1^\circ$
 - Bins of $.05^\circ$ for $1^\circ < \theta < 2.5^\circ$
- $\theta < \approx .233^\circ$ fit tagger constrained $W_{\gamma\gamma}$ with single gaussian and flat background
- $.233^\circ < \theta < 1^\circ$ fit with two gaussian and linear background
- $\theta > 1^\circ$ fit with single gaussian and linear background

Running over Full + Empty target 2γ skims, 45° and 135° CPP runs above 101300

All distributions have undergone empty target and accidental subtraction

- Require no charged tracks and exactly two neutral Showers
- BCAL + BCAL, FCAL + FCAL, or FCAL + BCAL trigger
- Require a tagged photon energy between 4.3 and 6 GeV
- Single Shower energy above .2 GeV in BCAL, .4 GeV in FCAL
- Require both photons to satisfy $t_{\text{Shower}} - t_{\text{TOF}} < 1\text{ns}$
- Require no hits in the innermost or outermost blocks of FCAL
- Empirical TOF cut

Elasticity Scaling Procedure

If $E_{\pi^0} = E_{\gamma,1} + E_{\gamma,2}$, presume that the actual measured photon energies are shifted by $\Delta E_{\gamma,1}$ and $\Delta E_{\gamma,2}$ such that

$$E_{\gamma,1} + \Delta E_{\gamma,1} + E_{\gamma,2} + \Delta E_{\gamma,2} = E_{\text{tagger}}$$
$$\frac{\Delta E_{\gamma,1}}{\Delta E_{\gamma,2}} = \frac{\sigma E_{\gamma,1}}{\sigma E_{\gamma,2}}$$

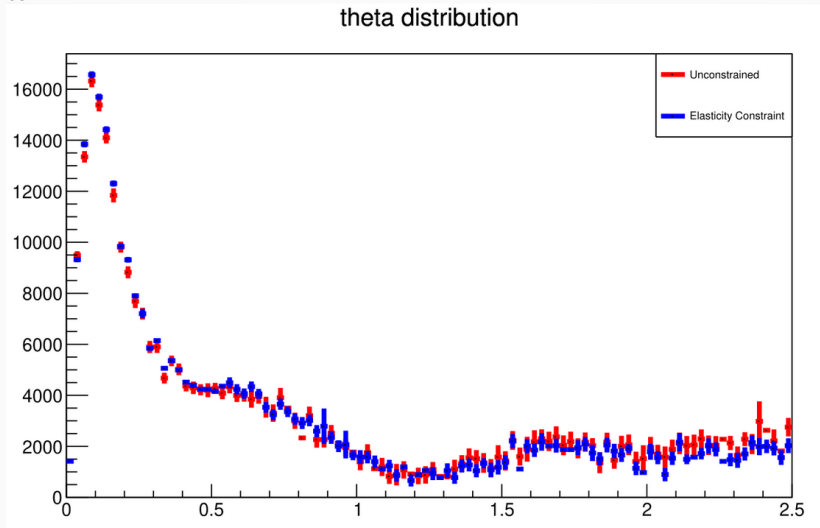
Where $\sigma E_{\gamma,i} = E_{\gamma,i} \sqrt{a^2 + \frac{b^2}{E_i} + d^2}$, a and b are empirical parameters determined by energy calibration data

$$a = .024, b = .054, c = .0074$$

$$\Delta E_{\gamma,i} = \sigma E_{\gamma,i} \frac{E_{\text{tagger}} - E_{\gamma,1} - E_{\gamma,2}}{\sigma E_{\gamma,1} + \sigma E_{\gamma,2}}$$

Elasticity Scaled vs Unscaled θ Yields

Note: Has different binning schema than yields shown earlier in the talk



Coherent π^0 photoproduction is given by

$$\frac{d\sigma}{d\Omega} = |\sqrt{\Gamma} T_P + \sqrt{C} T_S e^{i\phi}|^2$$

T_P is the complex amplitude for primakoff production, T_S is the complex amplitude for nuclear coherent production, Γ is the radiative width, C is a fit parameter, ϕ is the phase.

If ϕ_P is the phase of the primakoff amplitude and ϕ_S is the phase of the strong amplitude

$$\begin{aligned} \frac{d\sigma}{d\Omega} = & \Gamma |T_P|^2 + C |T_S|^2 + 2\sqrt{\Gamma C} [\cos \phi \cos(\phi_P - \phi_S) + \dots \\ & \dots + \sin \phi \sin(\phi_P - \phi_S)] |T_P| |T_S| \end{aligned}$$

Simulation

In calculations by S.Gevorgyan implemented by I.Larin, Form Factors are folded w/ absorption (and for strong form factor shadowing)

Calculating Q , β , and E_{π^0} from kinematics for 1000 bins in θ and 100 bins in E_γ , using the density of tagged photons $\rho(E_\gamma)$, we produced tables of the following:

Amplitudes taken from [2] with Jacobian accounted for

- $|T_P|^2 = \frac{8\alpha Z^2}{m^3} \frac{\beta^3 E^4}{Q^4} |F_{Coul}(Q)|^2 \sin^3 \theta \rho(E_\gamma)$
- $|T_S|^2 = A^2 |F_S(Q)|^2 \sin^3 \theta \rho(E_\gamma) \sin \theta$
- $|T_P| |T_S| \cos(\phi_P - \phi_S) \rho(E_\gamma) \sin \theta$
- $|T_P| |T_S| \sin(\phi_P - \phi_S) \rho(E_\gamma) \sin \theta$

Two-parameter accept/reject is performed to find θ and E_γ

Simulation

For para and perp runs, the azimuthal term is obtained by selecting ϕ with the distribution

$$(1 - P) + 2P \sin^2(\phi + \phi_0)$$

- Para runs: $\phi_0 = 135^\circ$
- Perp runs: $\phi_0 = 45^\circ$
- $P = 1$

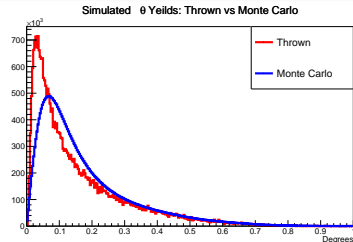
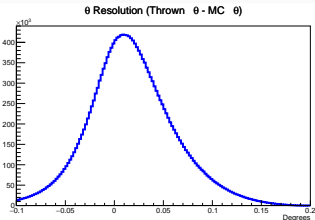
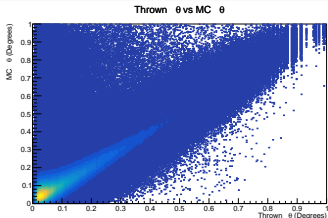
Parity conservation fixes the analyzing power of coherent photoproduction of pseudoscalar mesons to 100%, so simulated analyzing power can be used to check for contamination [3]

E_γ , θ , and ϕ are used to compute four-vectors

Events are written to an hddm file with a target at 1cm and fed through MC Wrapper

Low-angle resolution

Can track the resolution effects at low-angles by comparing thrown Primakoff π^0 angle to the Monte Carlo primakoff π^0 angle



ϕ Selection Criterion

In addition to the π^0 selection criterion, the for the azimuthal yeilds I am requiring that

- Accept events with an elasticity ($\frac{E_{\pi^0}}{E_{\text{Tagger}}}$) is between .875 and 1.125
- Accept events with a tagged photon energy E_γ between 5.55 and 5.75 GeV
- Subdivide the dataset into three regions of θ :
 - Region I: $0^\circ < \theta < 0.4^\circ$
 - Region II: $0.4^\circ < \theta < 1^\circ$
 - Region III: $1^\circ < \theta < 2.5^\circ$
- Subdivide the $W_{\gamma\gamma}$ dataset into 36 bins of ϕ between -180° and 180°

Region I ($0^\circ < \theta < 0.4^\circ$) Primakoff Peak Polarization Asymmetries

$$Y_{\text{Assym}} = \frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + Y_{\parallel}}$$

Y_{\parallel} are the parallel ϕ yields and

Y_{\perp} are the

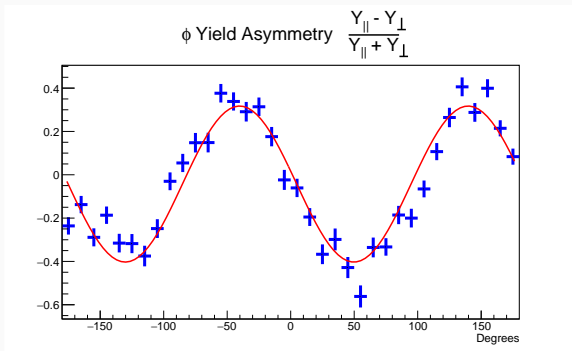
perpendicular ϕ yields

Y_{Assym} is fit to

$$\Sigma \cos(2(\phi - \alpha)) + C$$

- Σ : 0.36 ± 0.01
- α : 40.2 ± 0.8
- C : 0.0152 ± 0.007

χ^2/DOF : 4.5



θ Region II ($0.4^\circ < \theta < 1^\circ$) Nuclear Coherent Polarization Asymmetries

$$Y_{\text{Assym}} = \frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + Y_{\parallel}}$$

Y_{\parallel} are the parallel ϕ yields and

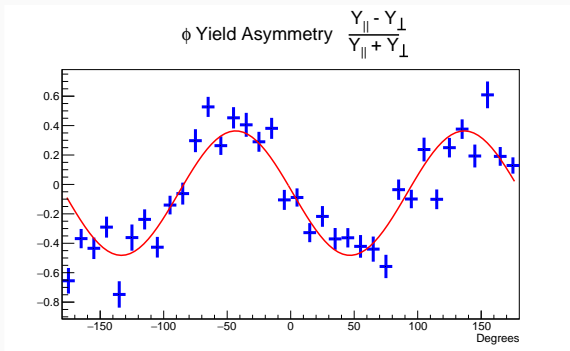
Y_{\perp} are the perpendicular ϕ yields

Y_{Assym} is fit to

$$\Sigma \cos(2(\phi - \alpha)) + C$$

- Σ : 0.42 ± 0.02
- α : 43 ± 1.1
- C : -0.06 ± 0.01

χ^2/DOF : 5.5



θ Region III ($1^\circ < \theta < 2.5^\circ$) Polarization Asymmetries

$$Y_{\text{Assym}} = \frac{Y_{\perp} - F_R Y_{\parallel}}{Y_{\perp} + Y_{\parallel}}$$

Y_{\parallel} are the parallel ϕ yields and

Y_{\perp} are the perpendicular ϕ yields

Y_{Assym} is fit to

$$\Sigma \cos(2(\phi - \alpha)) + C$$

- Σ : 0.57 ± 0.02
- α : 43 ± 1.1
- C : 0.02 ± 0.02

χ^2/DOF : 2.746

