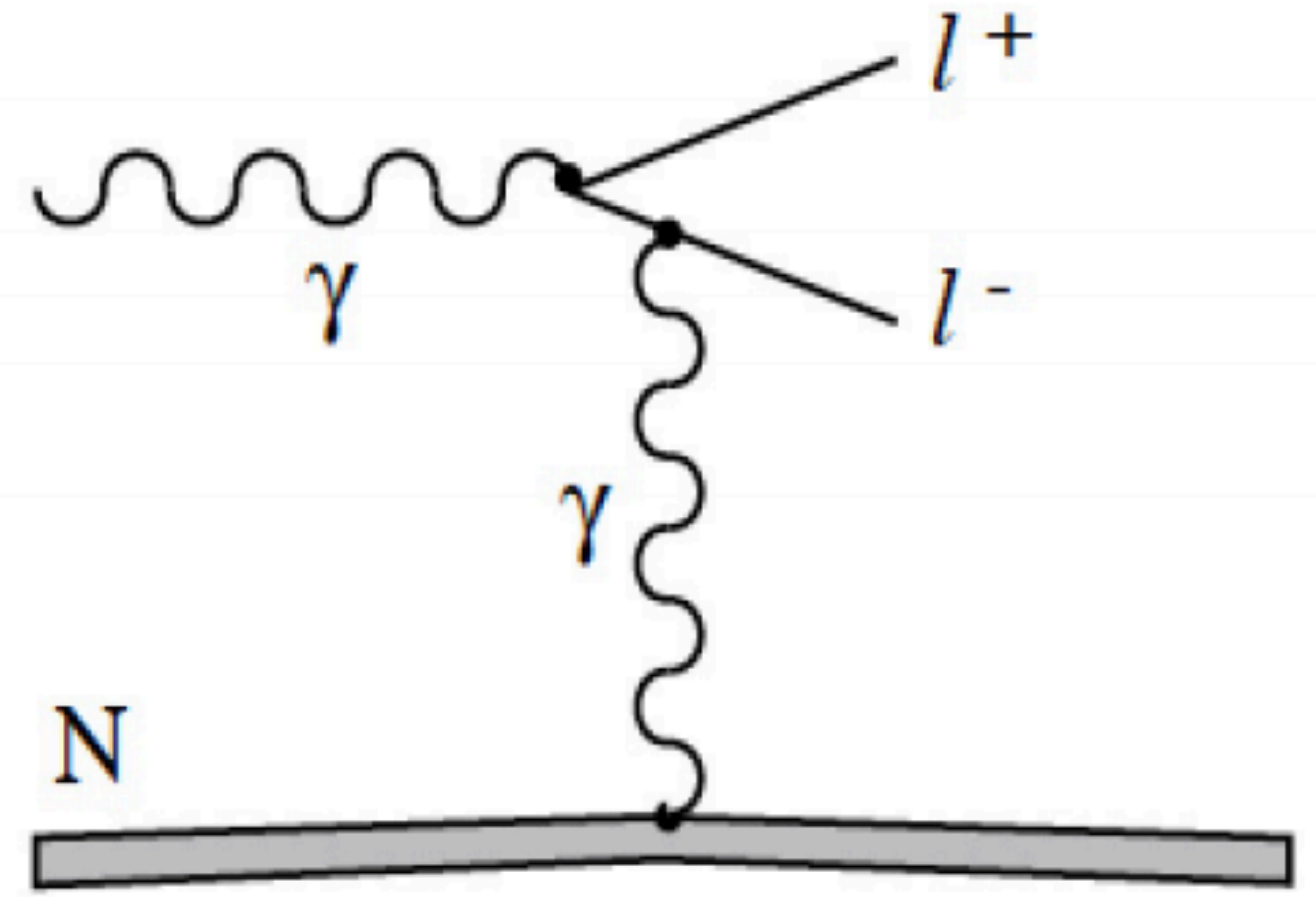
University of Massachusetts Amherst

MENP

Measuring Photon Beam Polarization Through Detection of e^+e^-

Jefferson Lab

GlueX

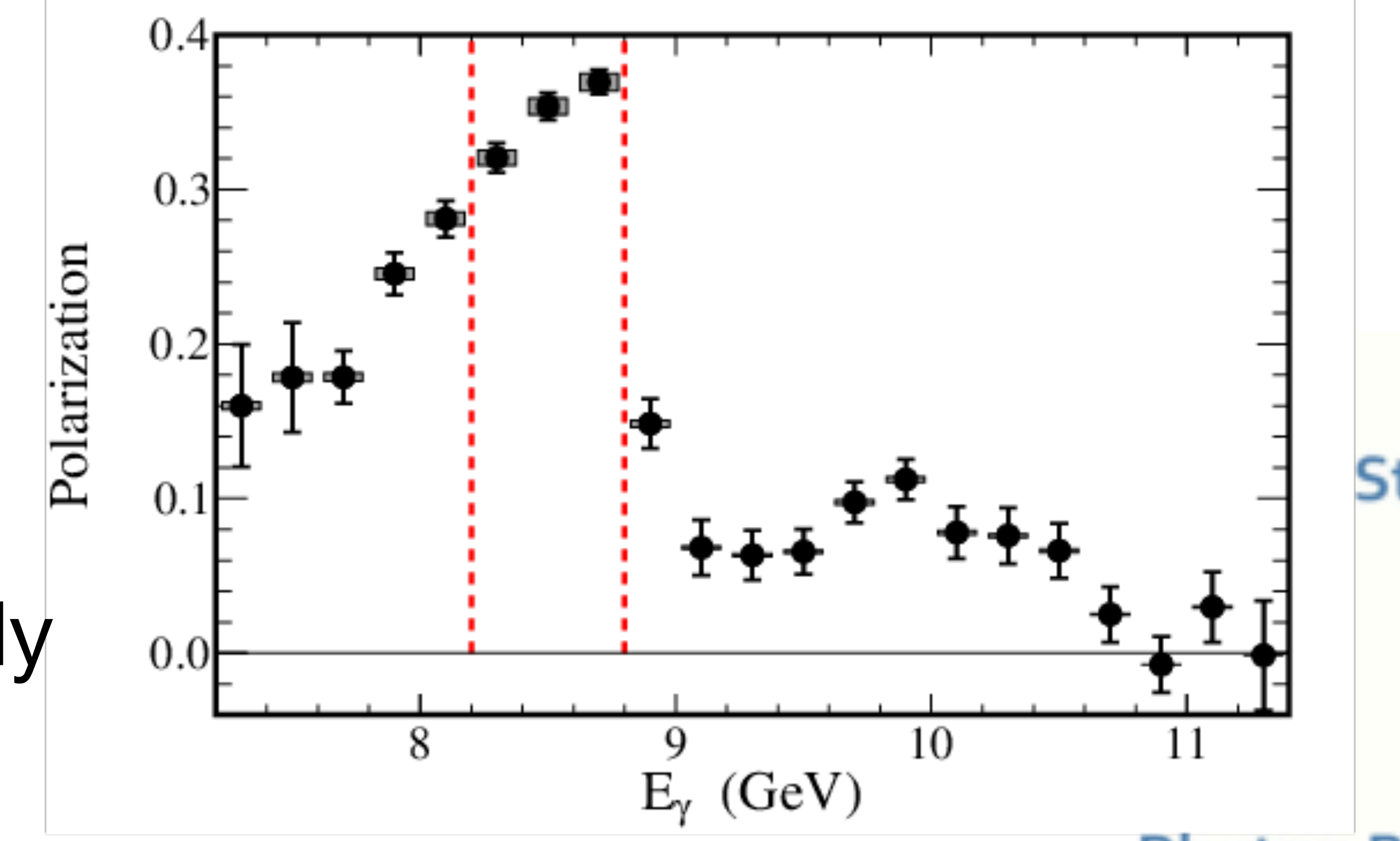


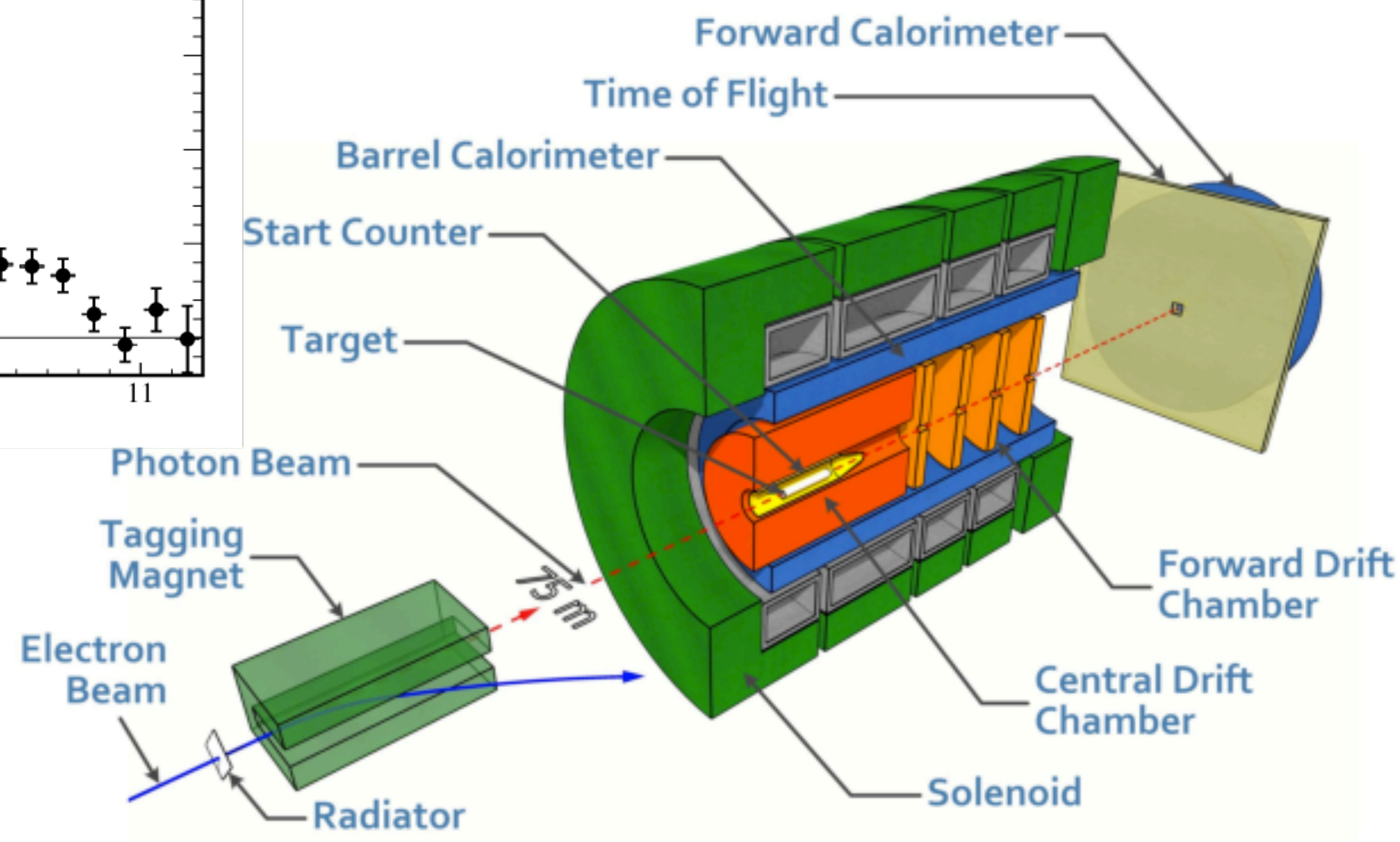
Albert Fabrizi

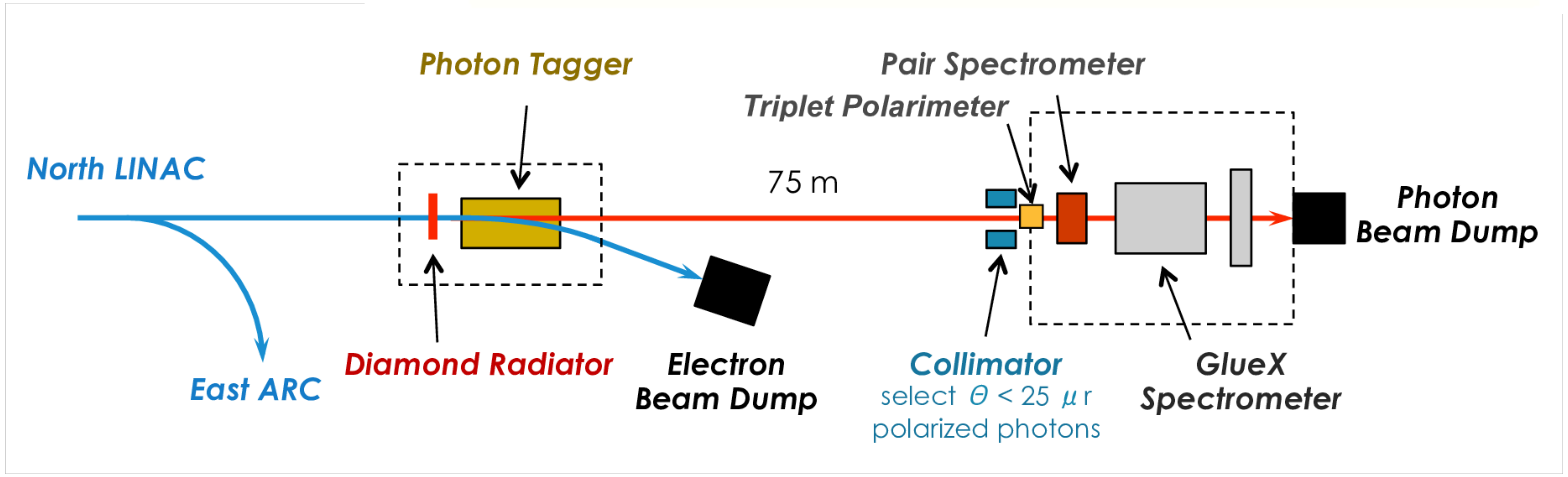
SPIN Conference 2023

GlueX Detector in Hall D at JLAB

- GlueX Experiment's purpose is to study QCD by identifying exotic mesons.
- An electron beam penetrates the diamond radiator creating coherent Bremsstrahlung photon beam with a peak between 8.2 and 9 GeV and peak polarization of 40%
- The photon beam continues to the Hall through the collimator.
- The TPOL measures the degree of polarization of the linearly polarized beam.
- The photon beam strikes the LH2 target, then we look for e^+e^- pairs utilizing the forward drift chambers and calorimeter.







Motivation

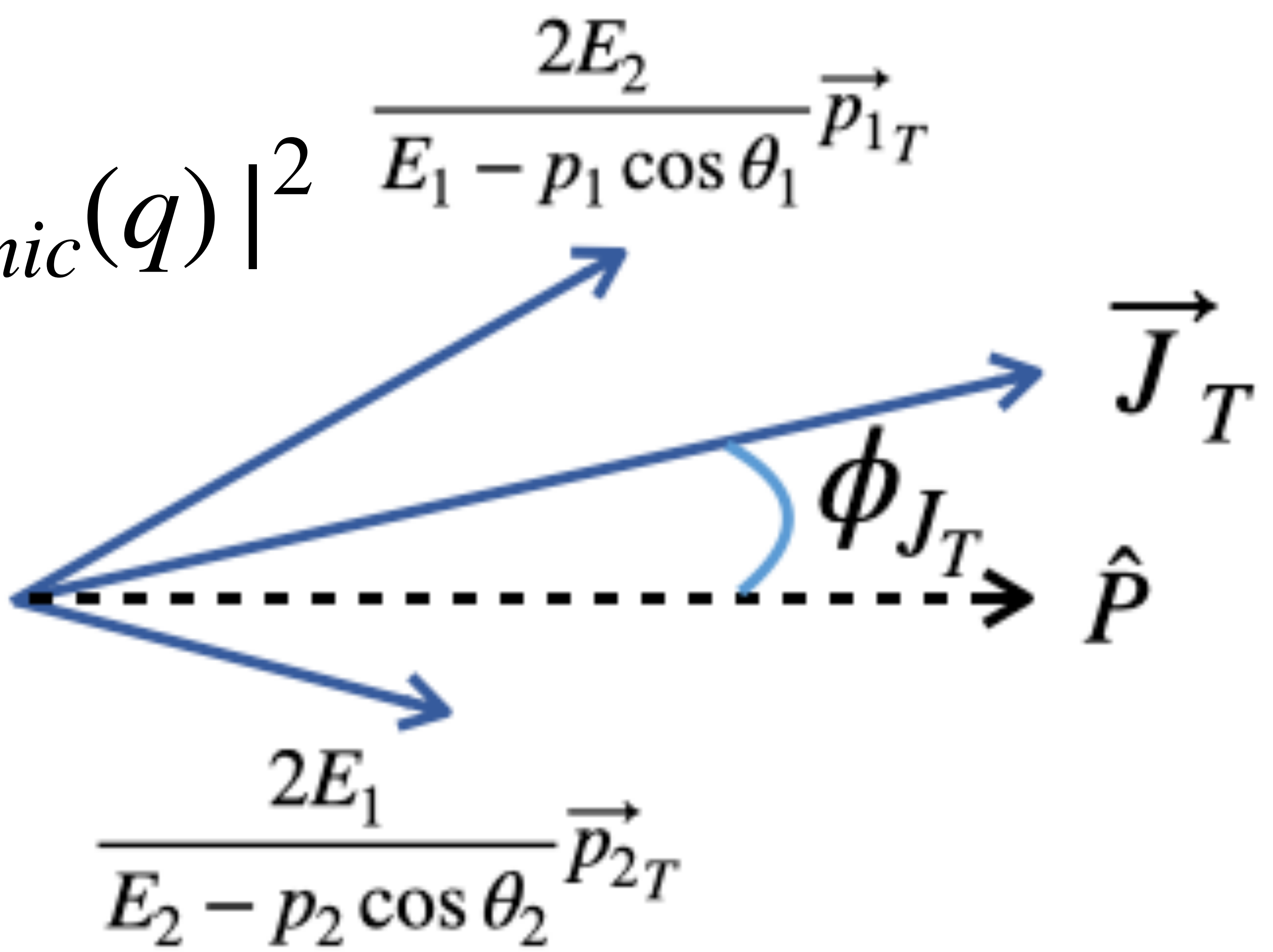
- **Charged Pion Polarizability (CPP) experiment at GlueX**
  - Experiment uses a polarized photon beam
  - CPP utilizes a lead (Pb^{208}) target
  - Desirable to know and monitor the photon polarization (currently done with a triplet polarimeter). Knowing polarization precisely is required for background separation.
  - Measuring polarizability from primakoff pions
  - Need a precision cross-check on triplet polarimeter that can be done synchronously with data taking
  - Not only for CPP but analysis of GlueX-I (data taken from 2017- 2018) data requires a check on the polarization.

Polarimetry with Bethe-Heitler Pairs

- **Conventional Technique:**
    - Triplet Polarimeter (TPOL): pair production on atomic electrons
- **New Technique:**
    - Pair production with detection of *both* e^+ and e^- in the forward drift chambers and calorimeters

$$\frac{d\sigma}{dx_1 d\Omega_1 d\Omega_2} = Z^2\alpha^3 \frac{P_1 P_2}{4\pi^2 E_0^2 q^4}(\sigma_0 + \mathscr{P}\sigma_1) \,|\, F_{charge}(q) - F_{atomic}(q) \,|^2$$

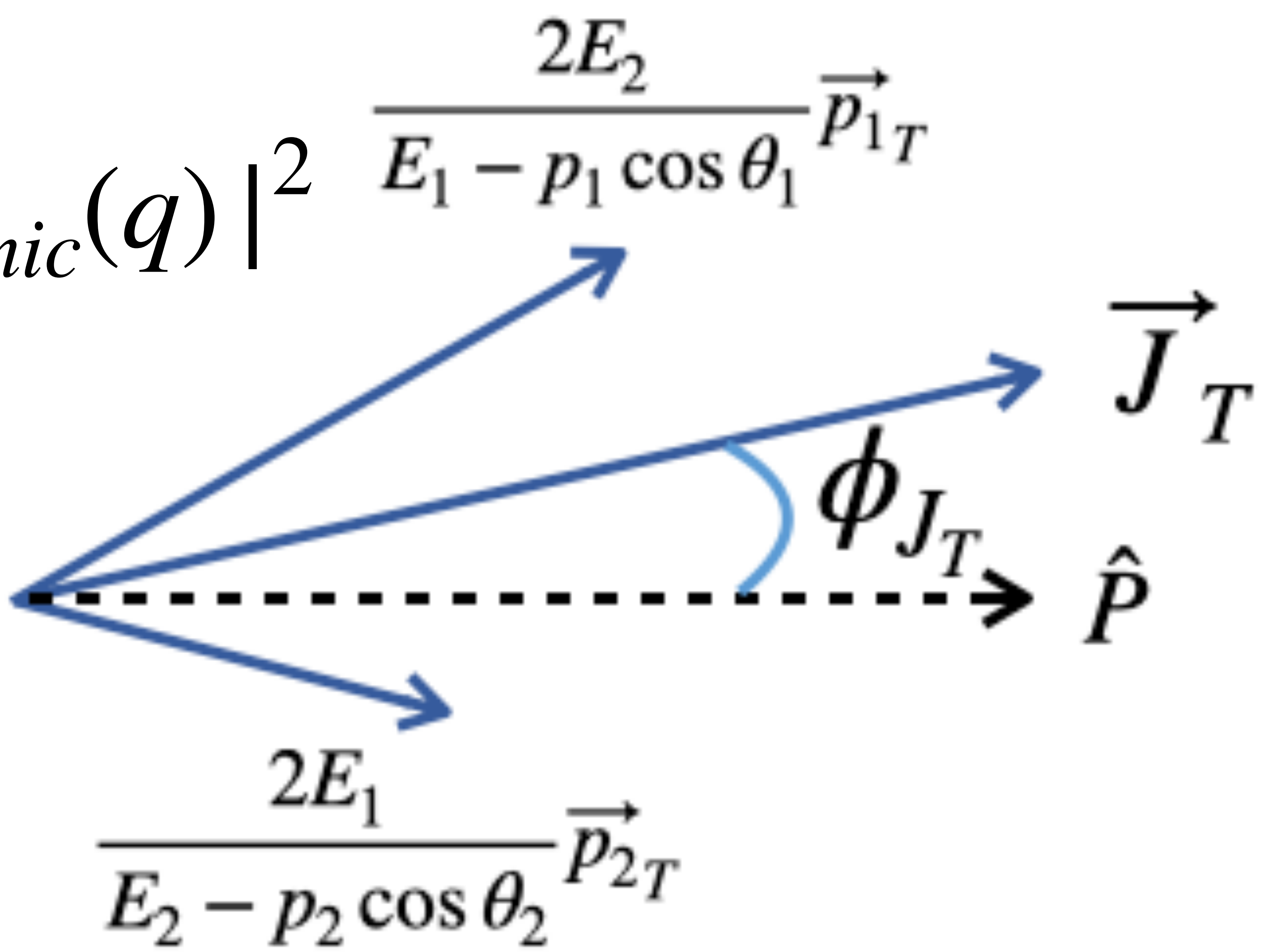
$$\frac{d\sigma}{dx_1 d\Omega_1 d\Omega_2} = Z^2\alpha^3 \frac{P_1 P_2}{4\pi^2 E_0^2 q^4}(\sigma_0 + \mathscr{P}\sigma_1)\,|F_{charge}(q) - F_{atomic}(q)|^2$$



$$\mathrm{d}\sigma_1 = \frac{\mathrm{d}\sigma_{\parallel} - \mathrm{d}\sigma_{\perp}}{2} = k\left[-\left|\vec{J}_T\right|^2 \cos 2\phi_{J_T} + \left|\vec{K}_T\right|^2 \cos 2\phi_{K_T}\right]$$

$$\vec{J}_T = \frac{2E_2}{E_1 - p_1\cos\theta_1}\overrightarrow{p_1}_T + \frac{2E_1}{E_2 - p_2\cos\theta_2}\overrightarrow{p_2}_T \qquad \vec{K}_T = \frac{\sqrt{q^2}}{E_1 - p_1\cos\theta_1}\overrightarrow{p_1}_T - \frac{\sqrt{q^2}}{E_2 - p_2\cos\theta_2}\overrightarrow{p_2}_T$$

$$\frac{d\sigma}{dx_1 d\Omega_1 d\Omega_2} = Z^2\alpha^3 \frac{P_1 P_2}{4\pi^2 E_0^2 q^4}(\sigma_0 + \mathscr{P}\sigma_1)\,|F_{charge}(q) - F_{atomic}(q)|^2$$



$$E_{1(2)} \gg q$$

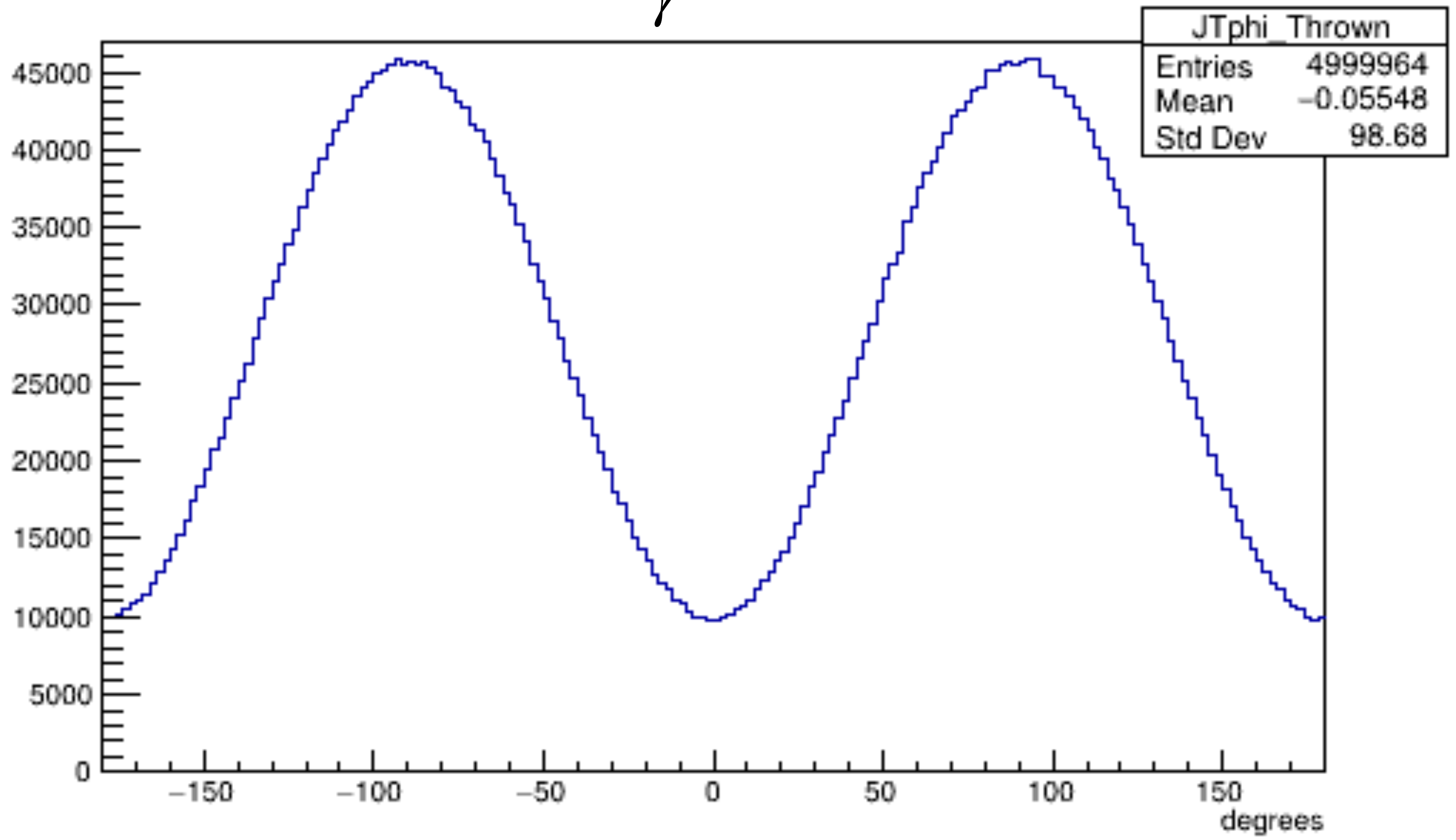
$$\mathrm{d}\sigma_1 = \frac{\mathrm{d}\sigma_\parallel - \mathrm{d}\sigma_\perp}{2} = k\left[-\left|\vec{J}_T\right|^2 \cos 2\phi_{J_T} + \left|\overrightarrow{K}_T\right|^2 \cos 2\phi_{K_T}\right]$$

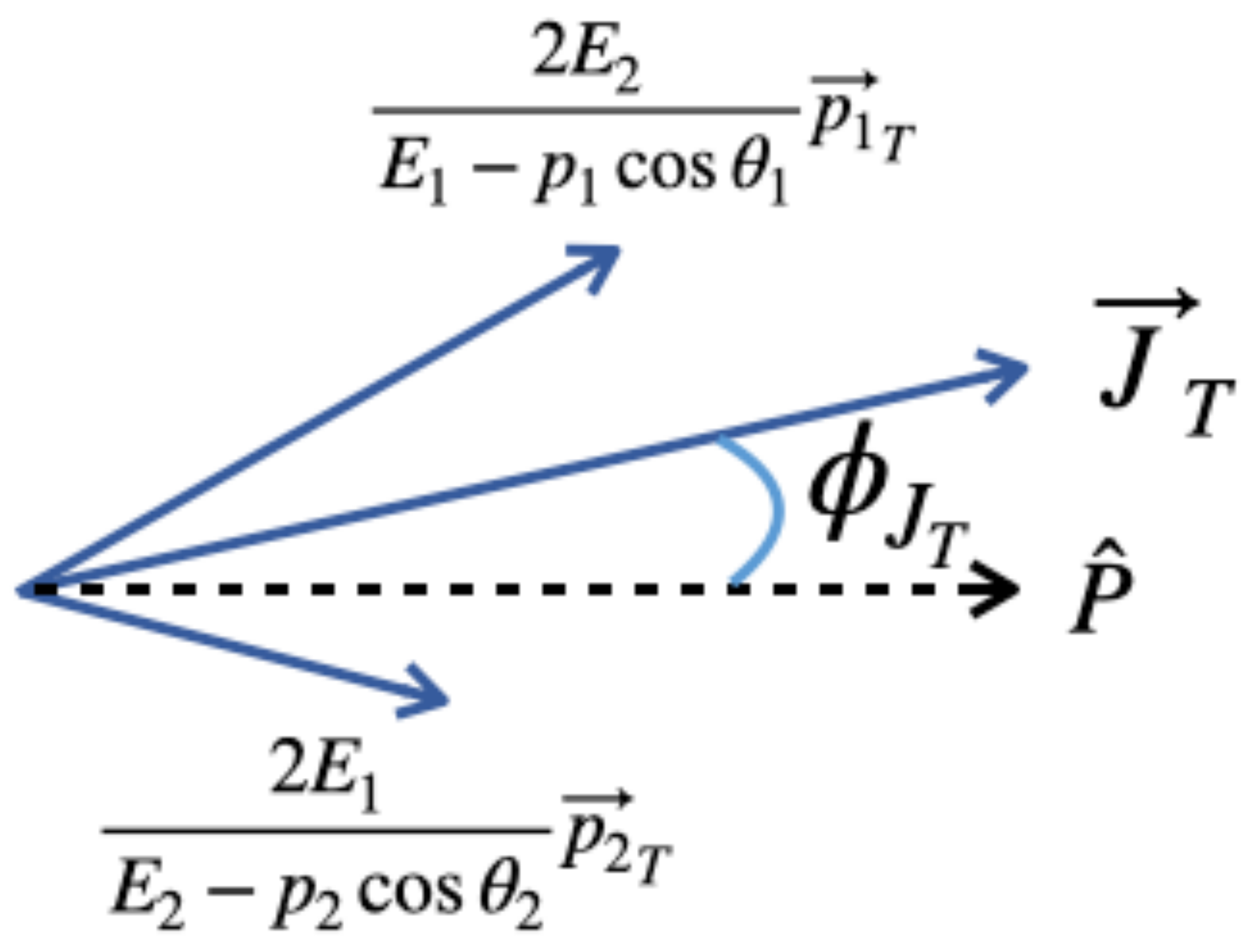
$$\left|\vec{J}_T\right|^2 \gg \left|\overrightarrow{K}_T\right|^2$$

$$\vec{J}_T = \frac{2E_2}{E_1 - p_1\cos\theta_1}\overrightarrow{p_1}_T + \frac{2E_1}{E_2 - p_2\cos\theta_2}\overrightarrow{p_2}_T \qquad \overrightarrow{K}_T = \frac{\sqrt{q^2}}{E_1 - p_1\cos\theta_1}\overrightarrow{p_1}_T - \frac{\sqrt{q^2}}{E_2 - p_2\cos\theta_2}\overrightarrow{p_2}_T$$

$$\mathrm{d}\sigma = \mathrm{d}\sigma_0 + P_\gamma \mathrm{d}\sigma_1 \qquad \mathrm{d}\sigma_1 = \sim \left|\vec{J}_T\right|^2 \cos 2\phi_{J_T}$$

$$P_\gamma = 1$$





MC with BH Cross-Section

1. Generate e+e- 4 vectors using the classic BH cross-section
2. Plot ϕ_{J_T} from the 4 vectors
3. Measuring ϕ_{J_T} allows you to infer the beam polarization

Analysis of GlueX-I Data

Neural Nets

Trained a neural net to separate electrons and pions.

Pion background subtraction (5.4% contamination)

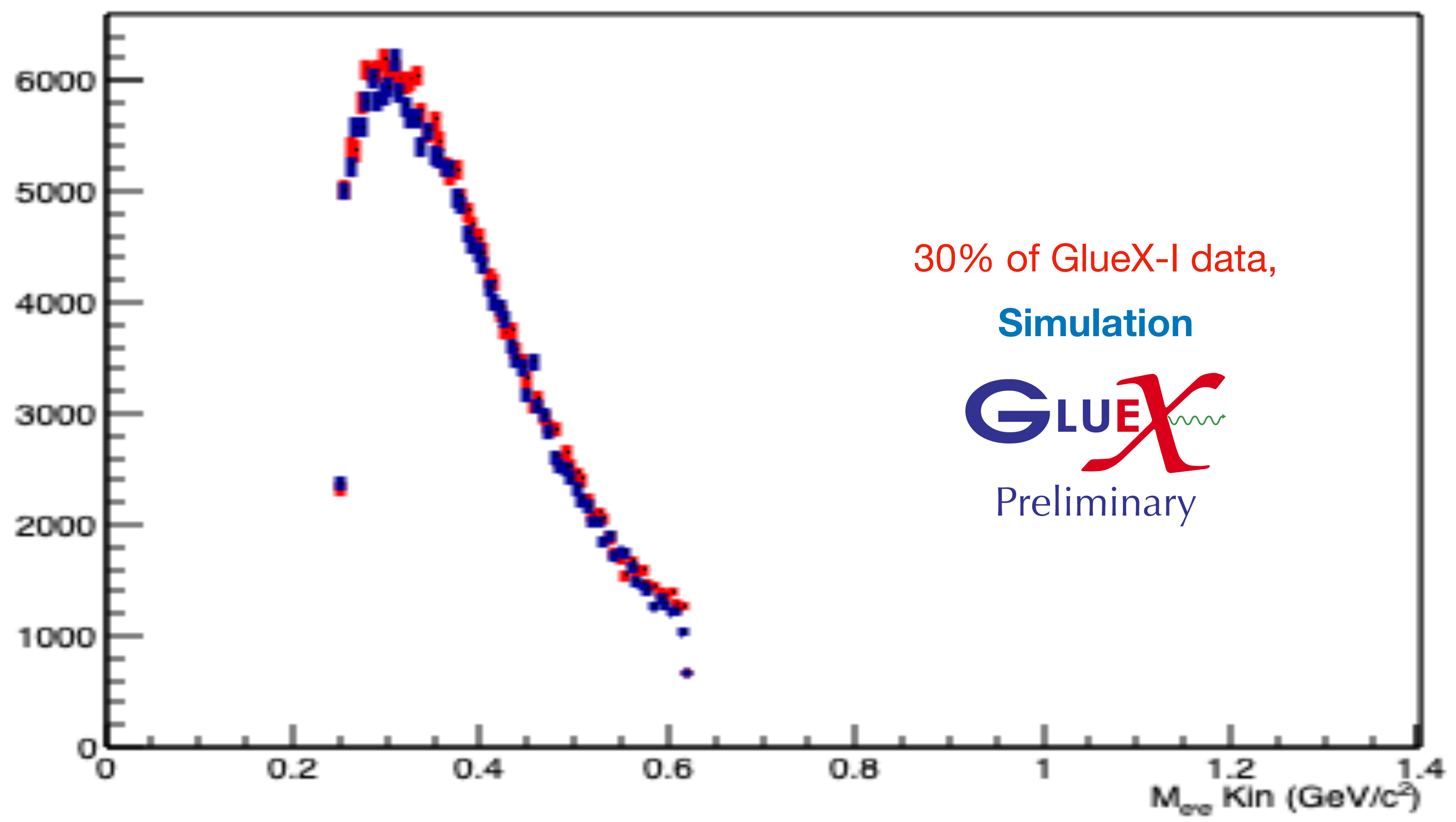
Fiducial Cuts:

$8.2\,\mathrm{GeV} < E_\gamma < 8.8\,\mathrm{GeV}$(Coherent Peak)

$0.25\,\mathrm{GeV} < W_{ee} < 0.621\,\mathrm{GeV}$

$\theta_1, \theta_2 > 1.5\,\mathrm{deg}$

e^+e^- Invariant Mass



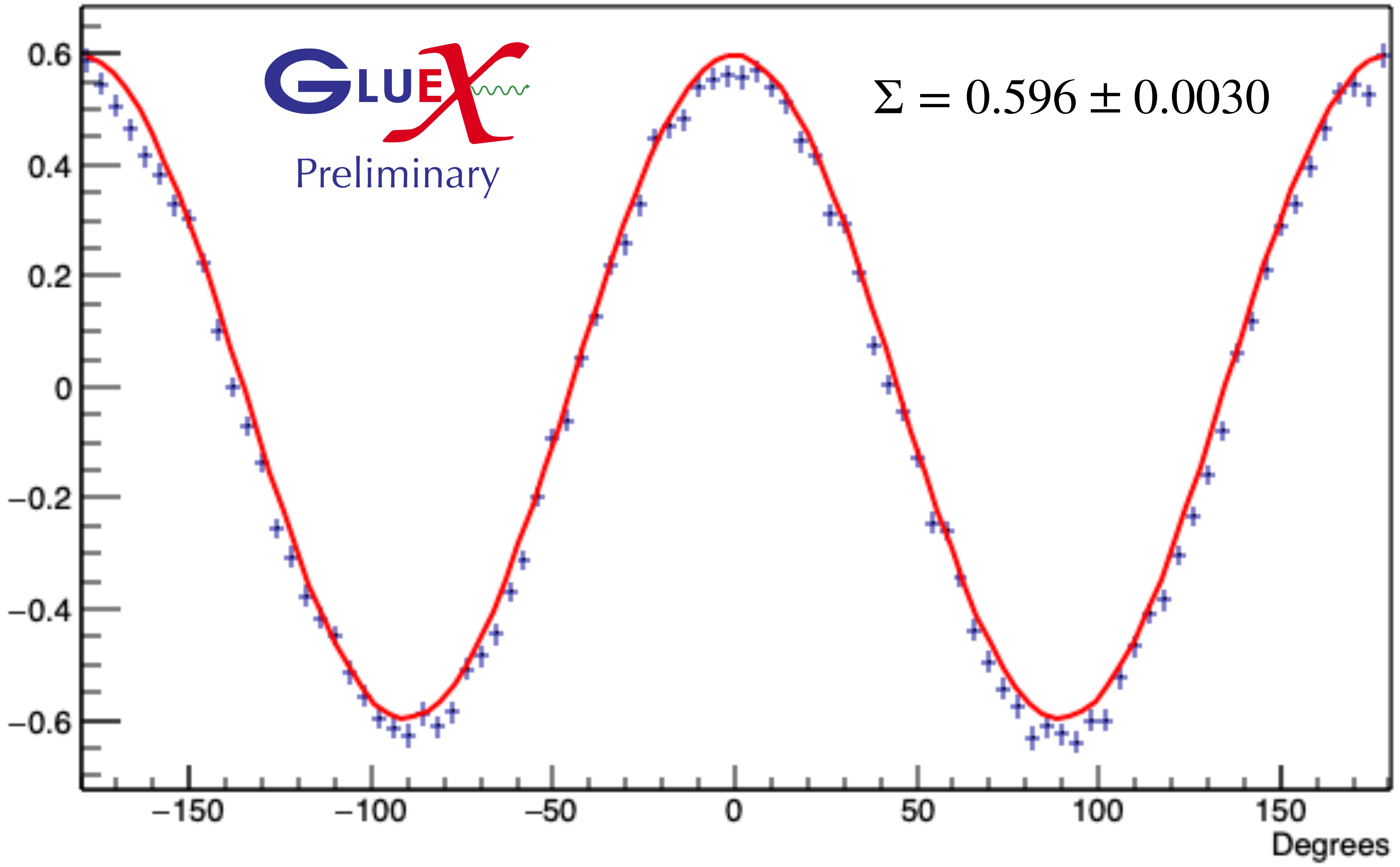
Calculating the Analyzing Power, Σ

$$\frac{Y_\perp(\phi) - Y_\parallel(\phi)}{Y_\perp + Y_\parallel(\phi)} = \Sigma \cos 2\phi$$

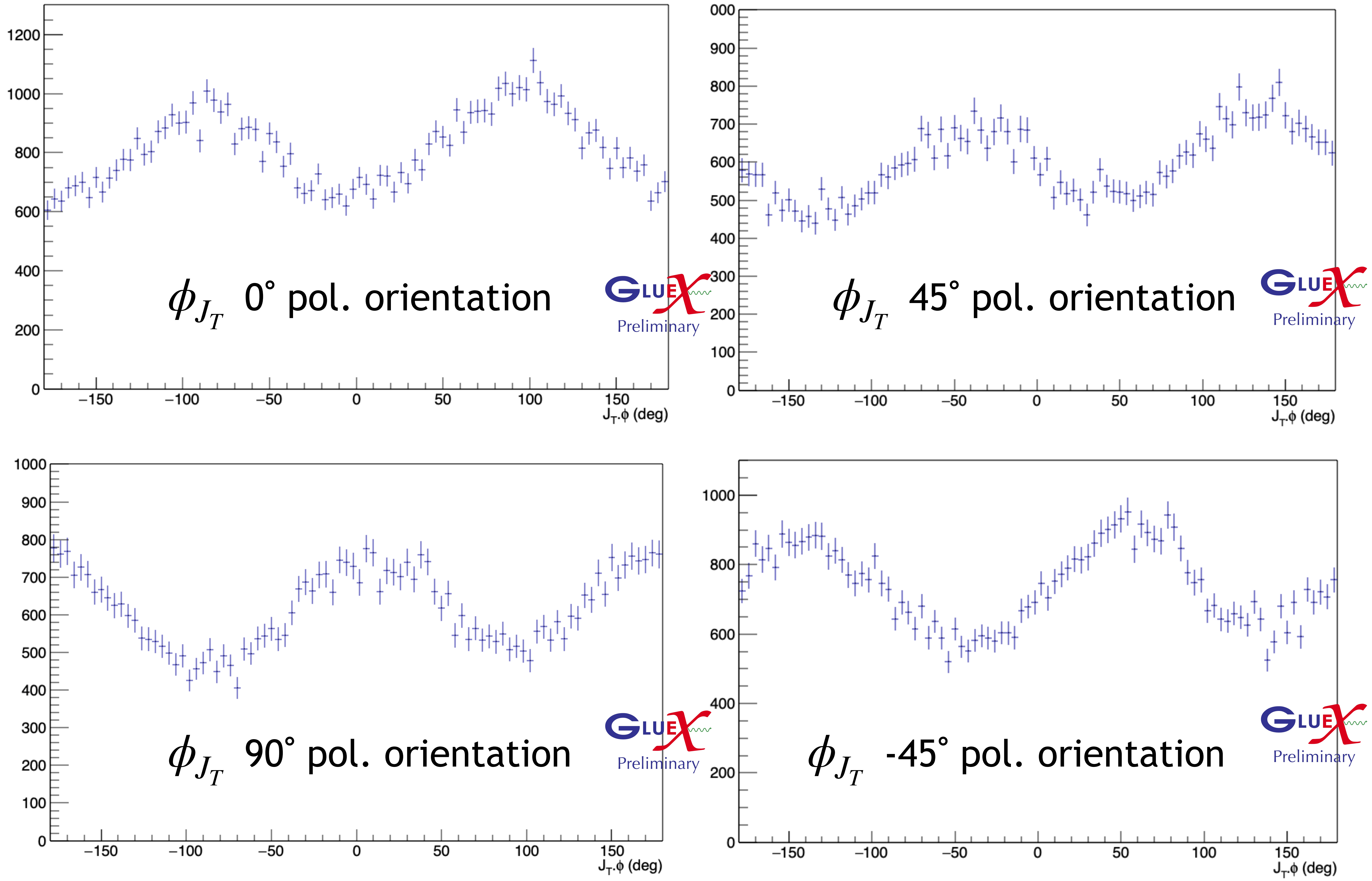
Predicted Analyzing Power = 59.6%

Simulated Yield Asymmetry

Assuming 100% polarization



$\gamma p \rightarrow e^+e^-(p)$, 50% of GlueX-I data



$$\frac{Y_\perp(\phi) - \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)}{Y_\perp + \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)} = \Sigma \mathscr{P} \cos 2(\phi + \alpha)$$

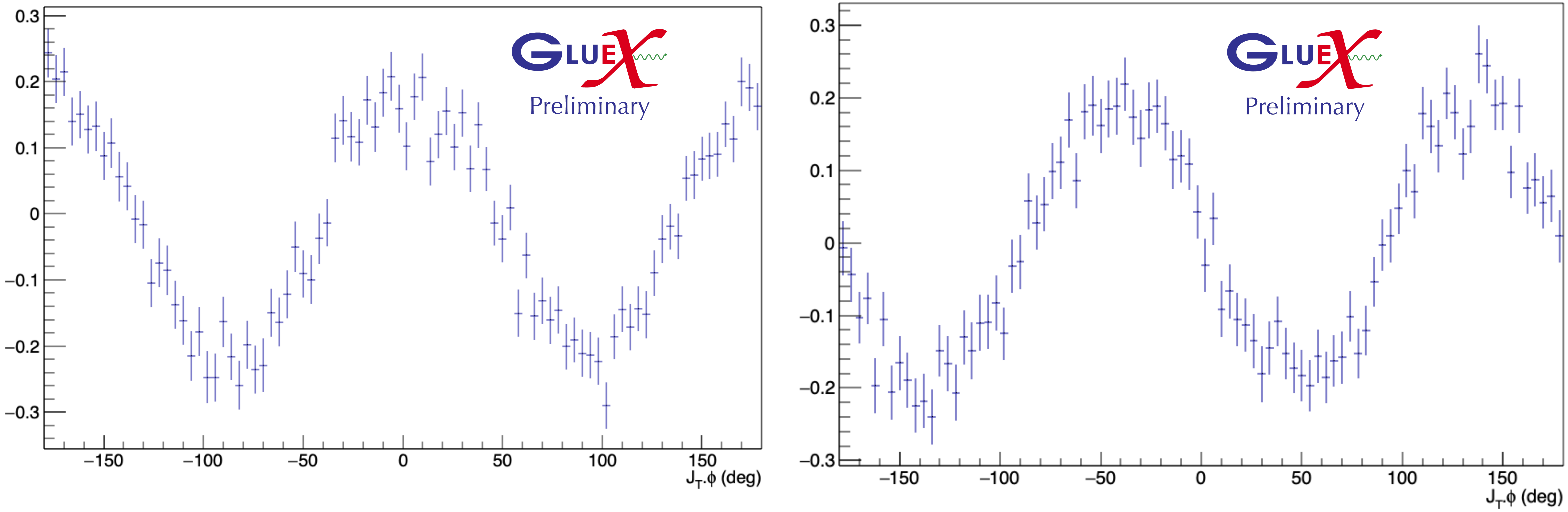
Assume $P_\perp \approx P_\parallel$
And allow for angular offset

GlueX data, $\gamma p \to e^+ e^- (p)$

Yield Asymmetry

0˚/90˚ runs

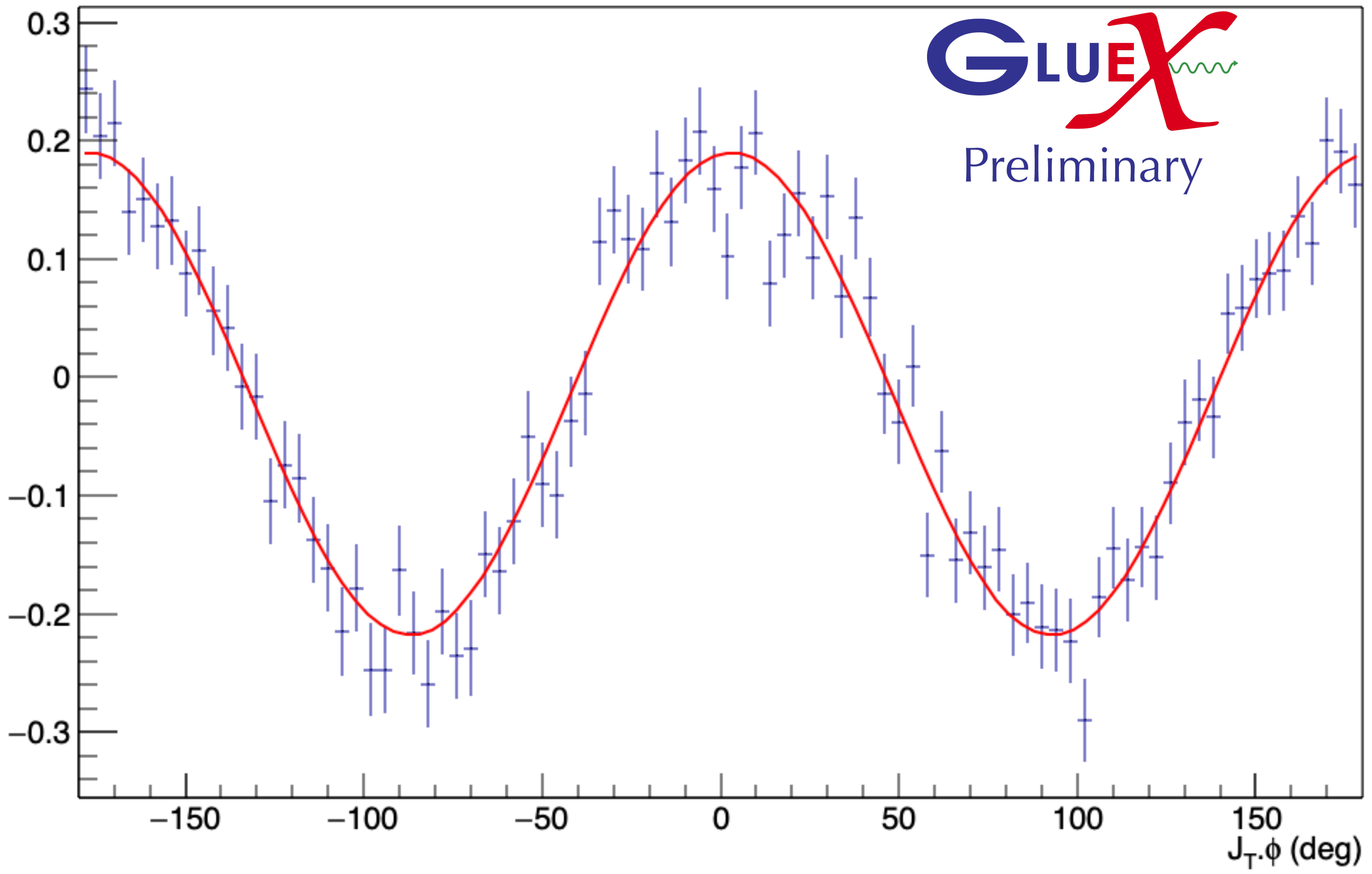
-45˚/45˚ runs



50% of GlueX-I data, Average Polarization

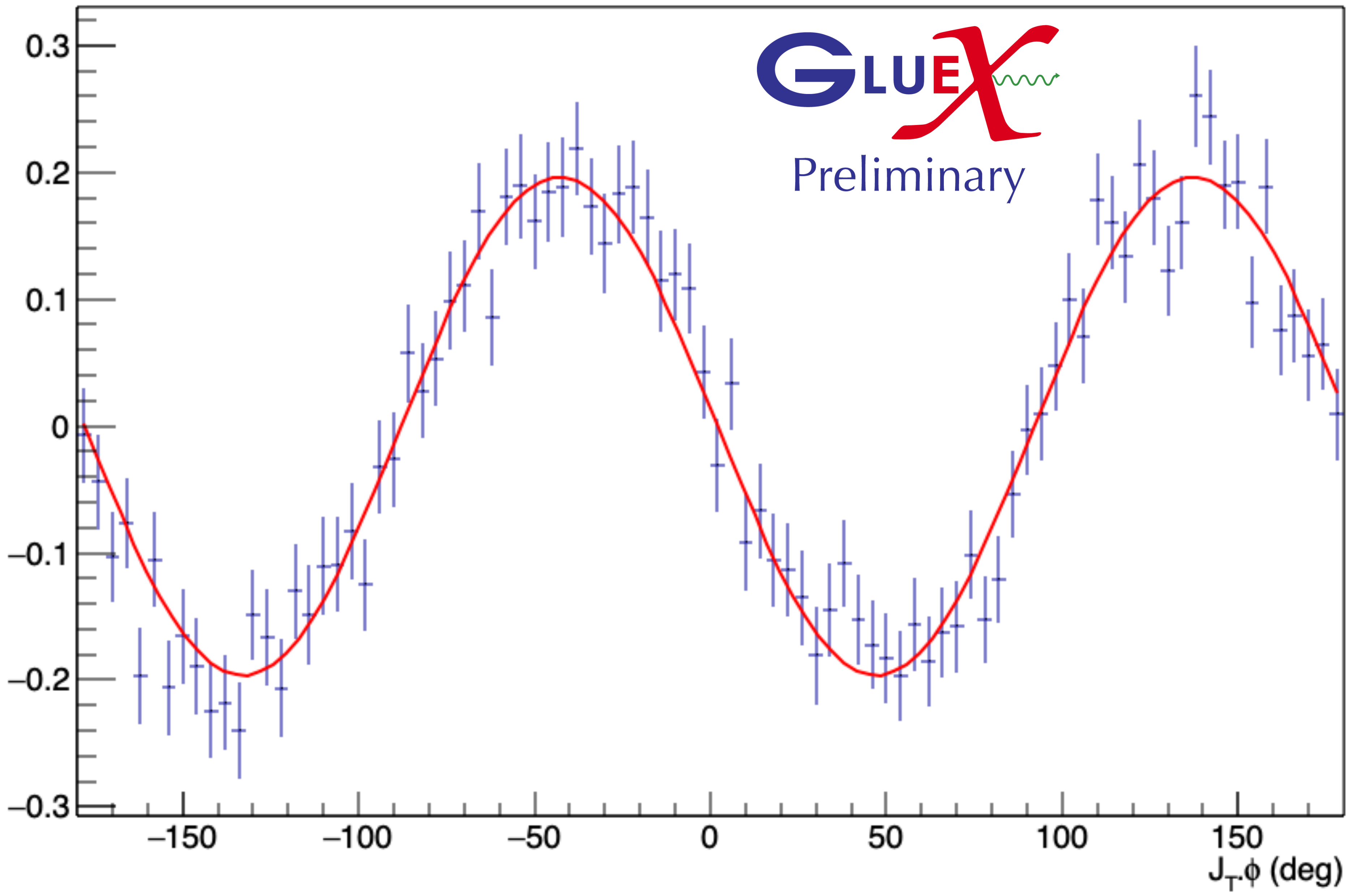
0˚ and 90˚

BH average polarization: $\dfrac{\mathscr{P}_{\perp} + \mathscr{P}_{\parallel}}{2} = 0.342 \pm 0.009$ (stat)



-45˚ and 45˚

BH average polarization: $\dfrac{\mathscr{P}_{\perp} + \mathscr{P}_{\parallel}}{2} = 0.336 \pm 0.009$ (stat)



Results

	Run Period	Pol. Orientations	$\frac{\mathscr{P}_\perp + \mathscr{P}_\parallel}{2}$ Triplet Polarimeter Avg. Pol.	$\frac{\mathscr{P}_\perp + \mathscr{P}_\parallel}{2}$ BH Pairs Avg. Pol.
50% of GlueX-I data	2018 Spring GlueX-I	0° and 90°	0.341 ± 0.004	0.342 ± 0.009 (stat)
	2018 Spring GlueX-I	-45° and 45°	0.344 ± 0.004	0.336 ± 0.009 (stat)
30% of GlueX-I data	2018 Fall GlueX-I	0° and 90°	0.345 ± 0.005	0.337 ± 0.011 (stat)
	2018 Fall GlueX-I	-45° and 45°	0.342 ± 0.005	0.332 ± 0.013 (stat)

- Preliminary systematic errors dominated by pion subtraction, are small compared to statistical errors

Conclusions

- The measured average polarization agrees within statistical uncertainties
- Two complementary methods—different systematics
- Technique is general: can obtain linear beam polarization from e^+e^- events in any photo-production experiments where detection of e^+e^- pairs is achieved with good particle ID

Acknowledgements

- Andrew Schick - Graduate Student UMass Amherst Physics Department, Topic of Ph.D. Contact: aschick@umass.edu

- GlueX acknowledges the support of several funding agencies and computing facilities: http://gluex.org/thanks/

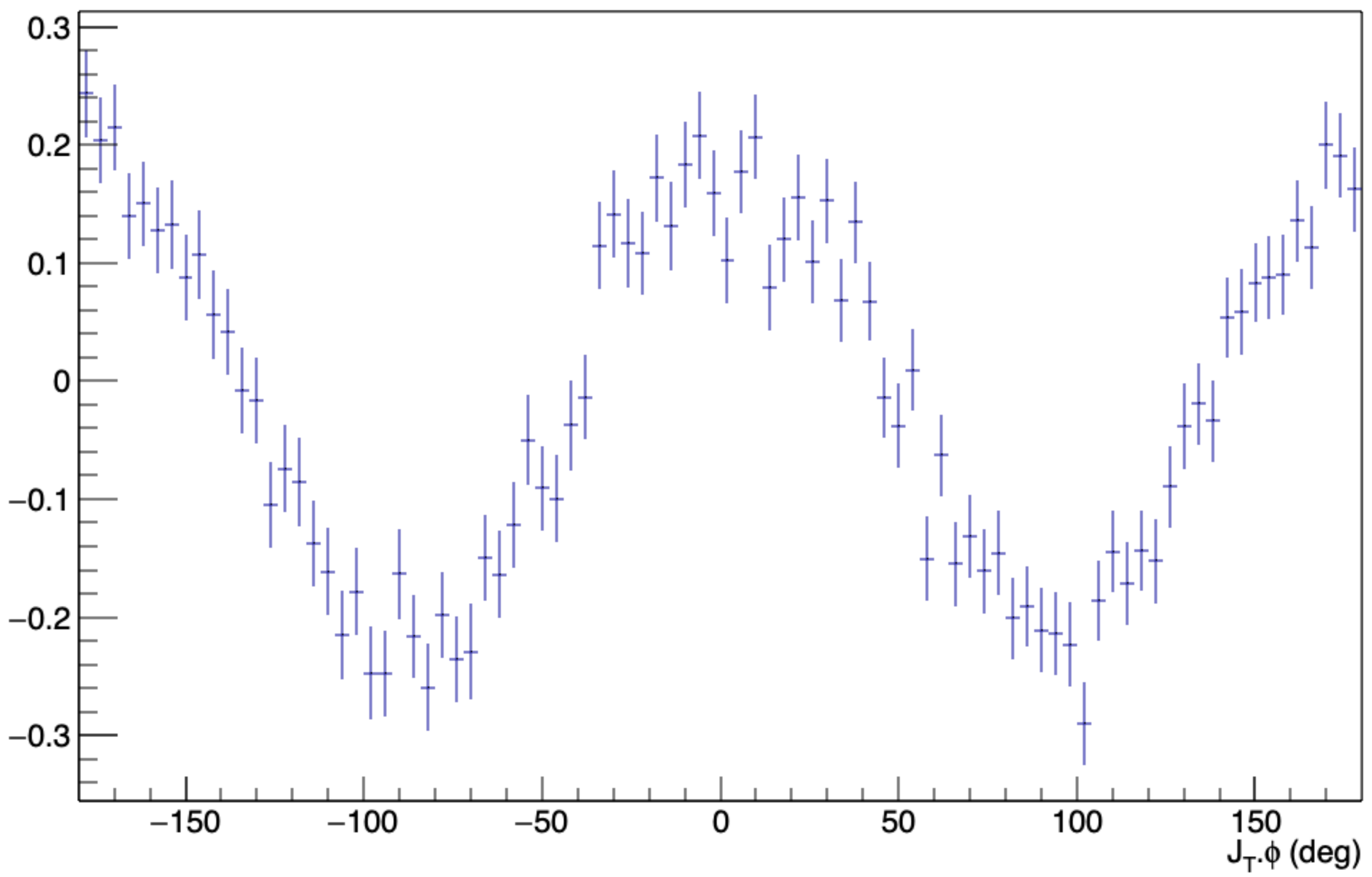
Back ups

$$\frac{Y_\perp(\phi) - \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)}{Y_\perp + \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)} = \frac{\Sigma \cos 2\phi (P_\perp + P_\parallel)}{2 + \Sigma \cos 2\phi (P_\perp - P_\parallel)}$$

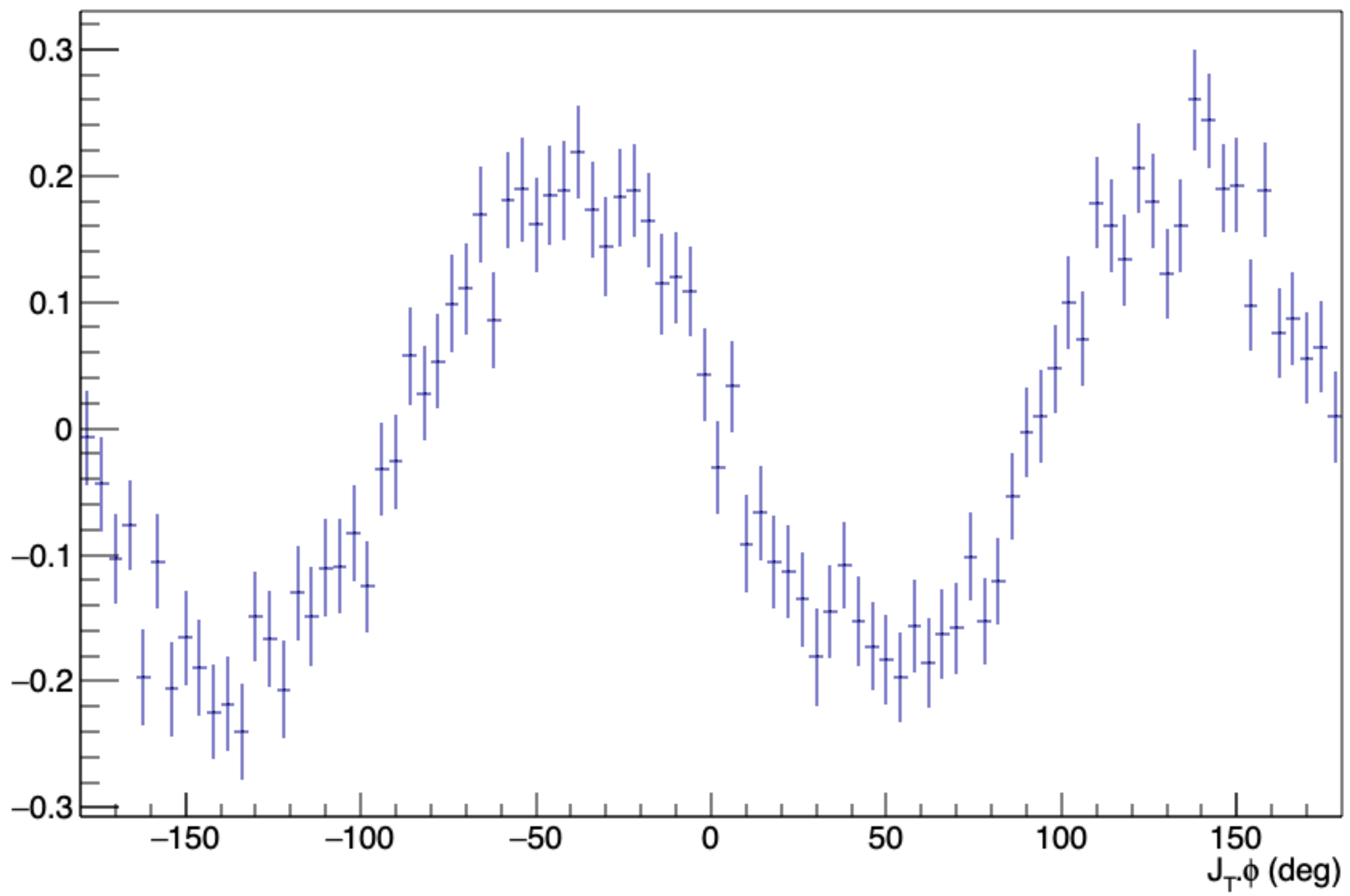
GlueX data, $\gamma p \rightarrow e^+ e^- (p)$

Yield Asymmetry

0°/90° runs



-45°/45° runs



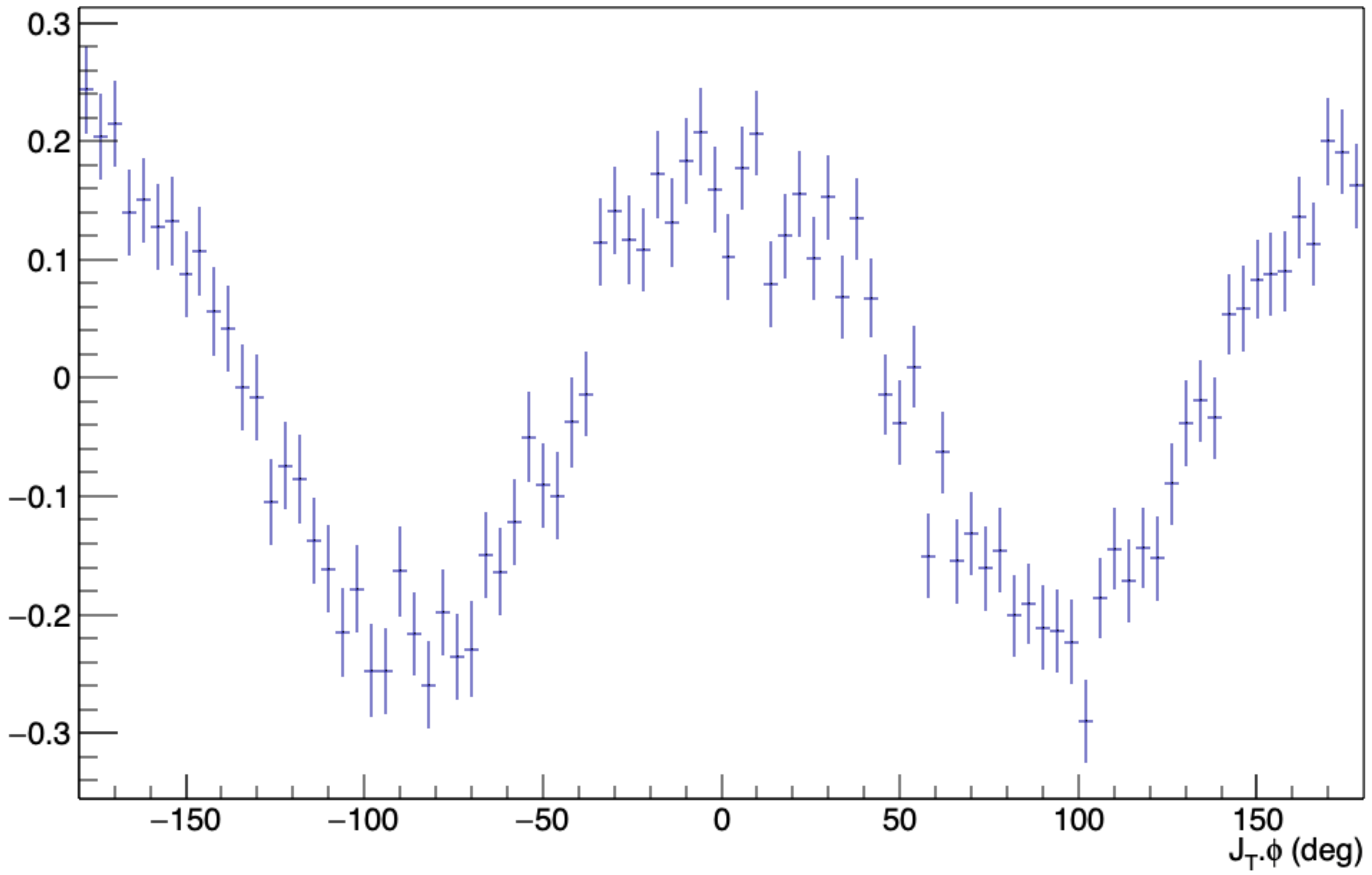
$$\frac{Y_\perp(\phi) - \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)}{Y_\perp + \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)} = \frac{\Sigma \cos 2\phi (P_\perp + P_\parallel)}{2 + \cancel{\Sigma \cos 2\phi (P_\perp - P_\parallel)}}$$

Assume $P_\perp \approx P_\parallel$
And allow for angular offset

GlueX data, $\gamma p \rightarrow e^+ e^- (p)$

Yield Asymmetry

0°/90° runs



-45°/45° runs