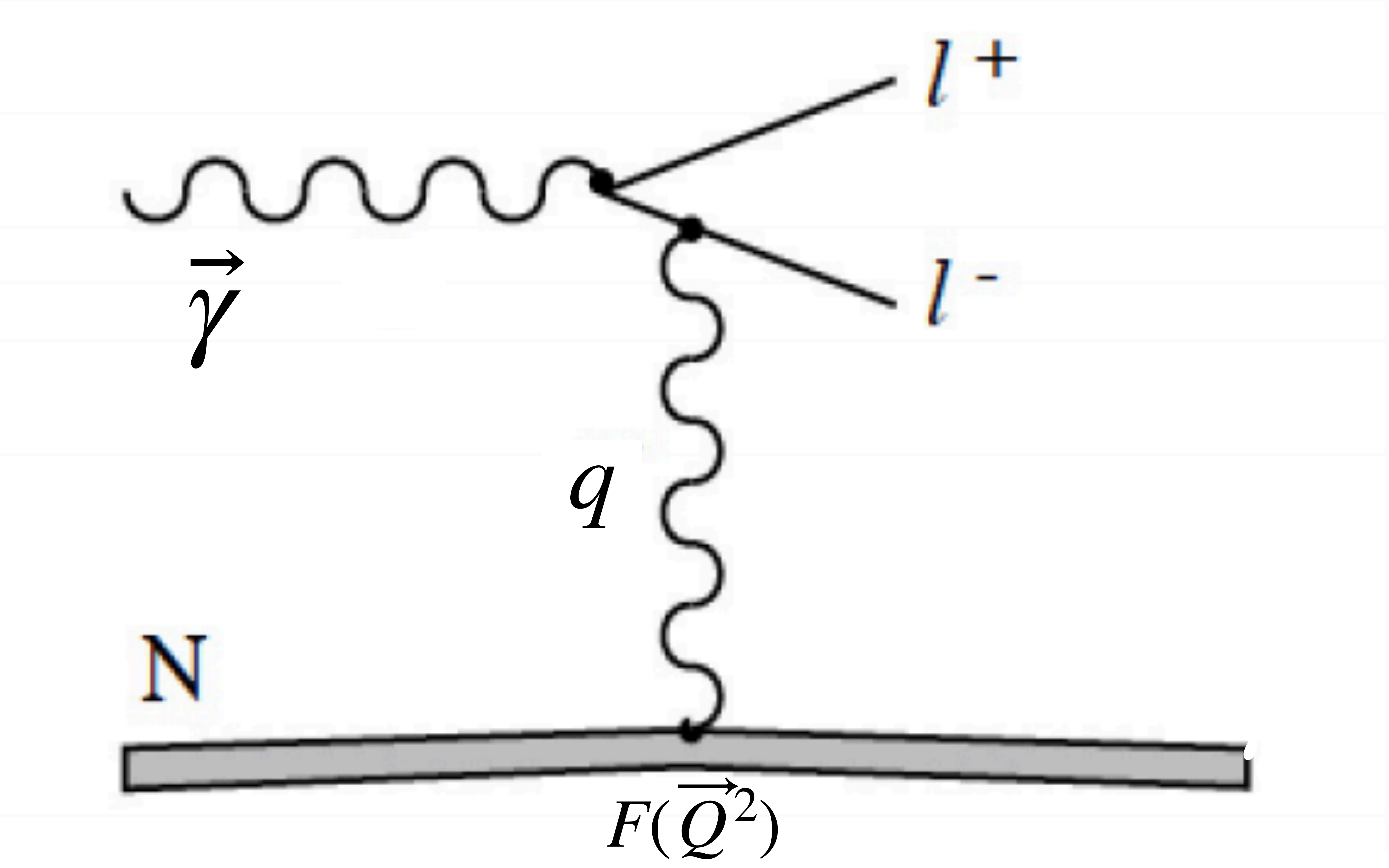
University of Massachusetts Amherst
MENP

Using Bethe Heitler Pairs as a Polarimeter in GlueX



Andrew Schick

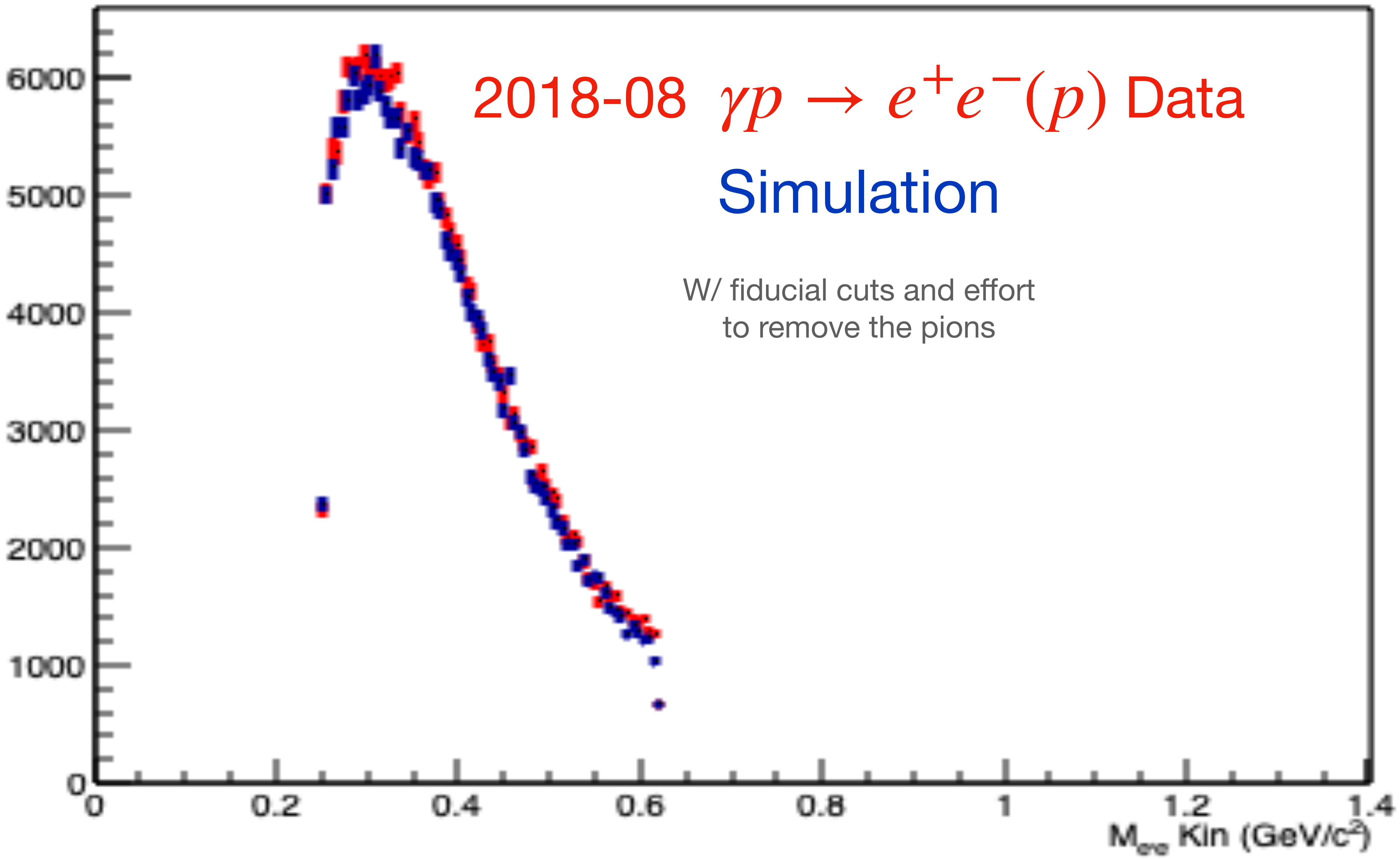
GlueX Spring Collaboration Meeting, Friday, May 28 2021

Jefferson Lab

Motivation

- Have a method of verifying the result from TPOL in the CPP experiment
- **Advantages**
  - For sufficiently long runs you get this method “for free”
  - High analyzing power ~60%
- **Challenges**
  - Addressing/removing pion background

e^+e^- Invariant Mass



Neural Net to sort pions and electrons

Fiducial cuts to get agreement between data and simulation

Still actively studying

Use Bethe-Heitler pairs to measure linear photon polarization.

$$\mathrm{d}\sigma = \left(\frac{1+\mathcal{P}}{2}\right)\mathrm{d}\sigma_{\|} + \left(\frac{1-\mathcal{P}}{2}\right)\mathrm{d}\sigma_{\perp}$$
$$= \left(\frac{\mathrm{d}\sigma_{\|}+\mathrm{d}\sigma_{\perp}}{2}\right) + \mathcal{P}\left(\frac{\mathrm{d}\sigma_{\|}-\mathrm{d}\sigma_{\perp}}{2}\right)$$

$\mathrm{d}\sigma_0$ — Unpolarized

$\mathrm{d}\sigma_1$ — Polarized

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$d\sigma_0$ Unpolarized

$d\sigma_1$ Polarized

Bakmaev et al, Physics Letters B 660 (2008) 494-500

Modern Vectorized Approach

$$\vec{J}_T = \frac{\vec{p_1}}{p_1^2 + m^2} + \frac{\vec{p_2}}{p_2^2 + m^2} = \frac{\vec{p_1}}{c_1} + \frac{\vec{p_2}}{c_2}$$

$\vec{p_1}$, $\vec{p_2}$ are the lepton's transverse momenta

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$$d\sigma_1 \sim P_\gamma |\vec{J}_T|^2 \cos(2\phi_{J_T})$$

Bakmaev's formulation is really only valid at very large t

Vectorizing the Classic Bethe-Heitler Formulation

$$d\sigma = \frac{Z^2}{137}\frac{e^4}{4\pi^2}\frac{p_+p_-dE_+d\Omega_+d\Omega_-}{k^3q^4}\left\{\frac{(\boldsymbol{\varepsilon}\cdot\mathbf{p}_+)^2(q^2-4E_-^2)}{(E_+-p_+\cos\theta_+)^2} + \frac{(\boldsymbol{\varepsilon}\cdot\mathbf{p}_-)^2(q^2-4E_+^2)}{(E_--p_-\cos\theta_-)^2} - \frac{2(\boldsymbol{\varepsilon}\cdot\mathbf{p}_+)(\boldsymbol{\varepsilon}\cdot\mathbf{p}_-)(q^2+4E_+E_-)}{(E_+-p_+\cos\theta_+)(E_--p_-\cos\theta_-)} + \frac{k^2[p_+^2\sin^2\theta_+ + p_-^2\sin^2\theta_- + 2p_+p_-\sin\theta_+\sin\theta_-\cos(\varphi_+-\varphi_-)]}{(E_+-p_+\cos\theta_+)(E_--p_-\cos\theta_-)}\right\}.$$

$\boldsymbol{\varepsilon}$ is a unit vector in the direction of polarization of the incident photon.

T.H. Berlin and L. Madansky, Phys. Rev. **78**, 623 (1950)

Vectorizing the Classic Bethe-Heitler Formulation

$$\vec{J}_T = \frac{2E_2}{E_1 - p_1 \cos\theta_1}\vec{p_1}_T + \frac{2E_2}{E_2 - p_2 \cos\theta_2}\vec{p_2}_T$$

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

Then:

$$d\sigma = \frac{Z^2}{137}\frac{e^4}{4\pi^2}\frac{p_+p_-dE_+d\Omega_+d\Omega_-}{k^3q^4}\left\{\frac{(\boldsymbol{\varepsilon}\cdot\mathbf{p}_+)^2(q^2-4E_-^2)}{(E_+-p_+\cos\theta_+)^2} + \frac{(\boldsymbol{\varepsilon}\cdot\mathbf{p}_-)^2(q^2-4E_+^2)}{(E_--p_-\cos\theta_-)^2} - \frac{2(\boldsymbol{\varepsilon}\cdot\mathbf{p}_+)(\boldsymbol{\varepsilon}\cdot\mathbf{p}_-)(q^2+4E_+E_-)}{(E_+-p_+\cos\theta_+)(E_--p_-\cos\theta_-)} + \frac{k^2[p_+^2\sin^2\theta_++p_-^2\sin^2\theta_-+2p_+p_-\sin\theta_+\sin\theta_-\cos(\varphi_+-\varphi_-)]}{(E_+-p_+\cos\theta_+)(E_--p_-\cos\theta_-)}\right\}.$$

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$\boldsymbol{\varepsilon}$ is a unit vector in the direction of polarization of the incident photon.

Then:

$$\mathrm{d}\sigma = \mathrm{d}\sigma_0 + P_\gamma \mathrm{d}\sigma_1$$

$$\mathrm{d}\sigma_0 = \frac{\mathrm{d}\sigma_\parallel + \mathrm{d}\sigma_\perp}{2} = k\left[-\left|\vec{J}_T\right|^2 + \left|\vec{K}_T\right|^2 + 2E_0^2\frac{\left|\vec{p}_{1T}+\vec{p}_{2T}\right|^2}{\left(E_1 - p_1\cos\theta_1\right)\left(E_2 - p_2\cos\theta_2\right)}\right]$$

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

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$\boldsymbol{\varepsilon}$ is a unit vector in the direction of polarization of the incident photon.

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$$\mathrm{d}\sigma = \mathrm{d}\sigma_0 + P_\gamma \mathrm{d}\sigma_1$$

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

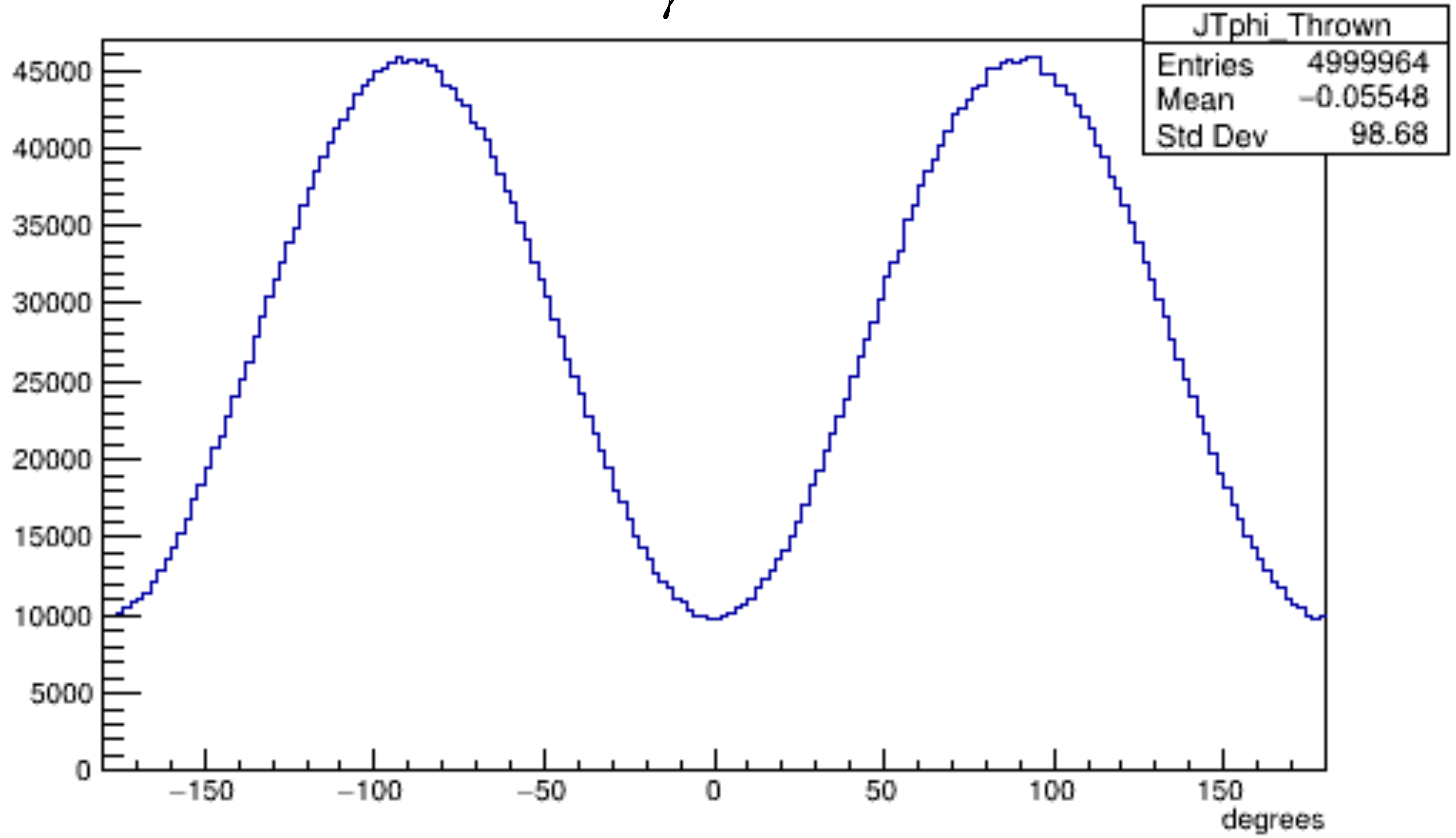
$$\left|\vec{J}_T\right|^2 \gg \left|\vec{K}_T\right|^2$$

Plotting ϕ of $\overrightarrow{J}_T$ from Monte Carlo

$$d\sigma = d\sigma_0 + P_\gamma d\sigma_1$$

$$d\sigma_1 = \sim \left|\overrightarrow{J}_T\right|^2 \cos 2\phi_{J_T}$$

$$P_\gamma = 1$$



MC with BH Cross-Section

1. Generate e+e- 4 vectors using this cross section

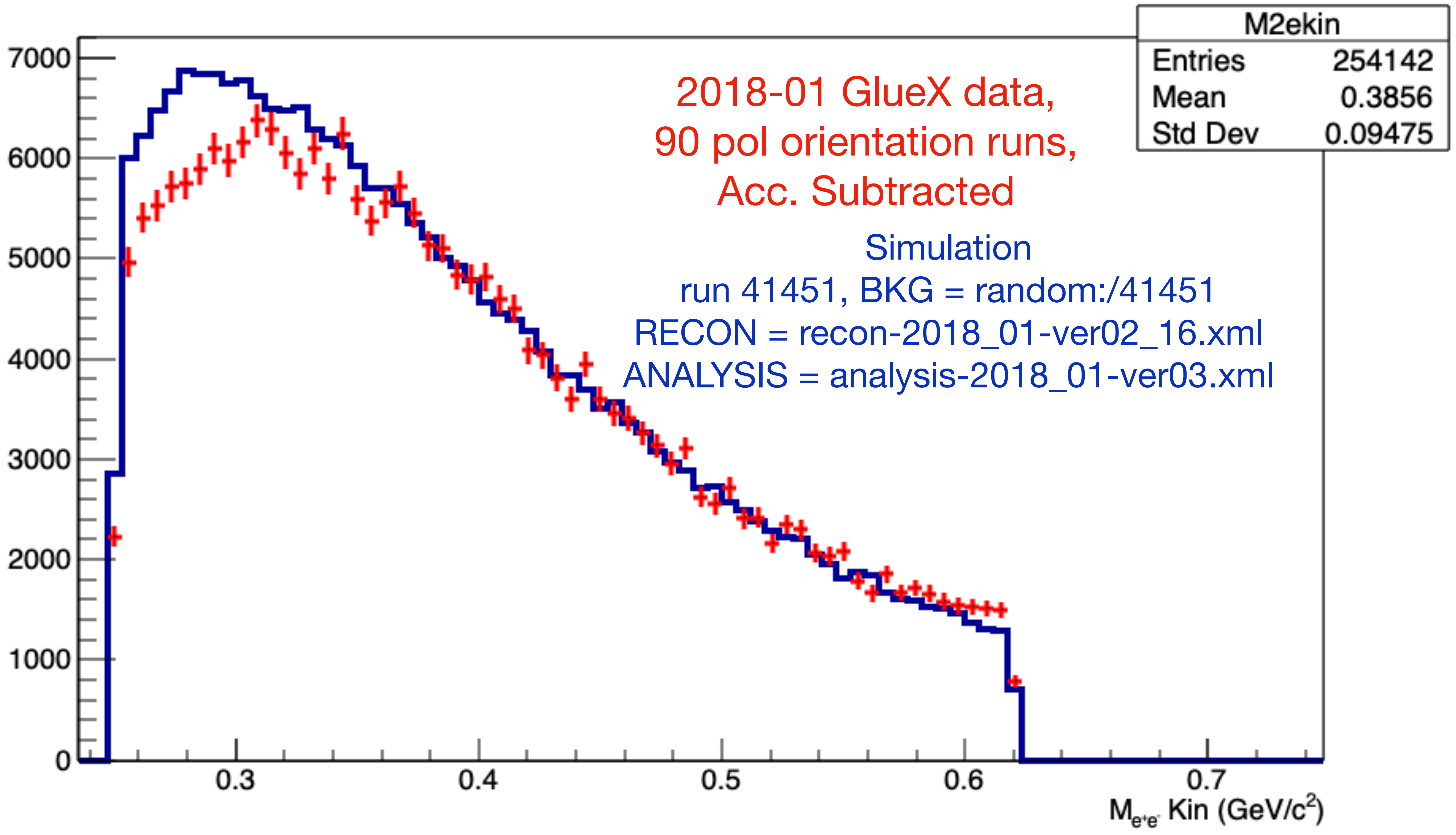
2. Plot ϕ_{J_T} from the 4 vectors

3. Measuring ϕ_{J_T} allows you to infer the beam polarization

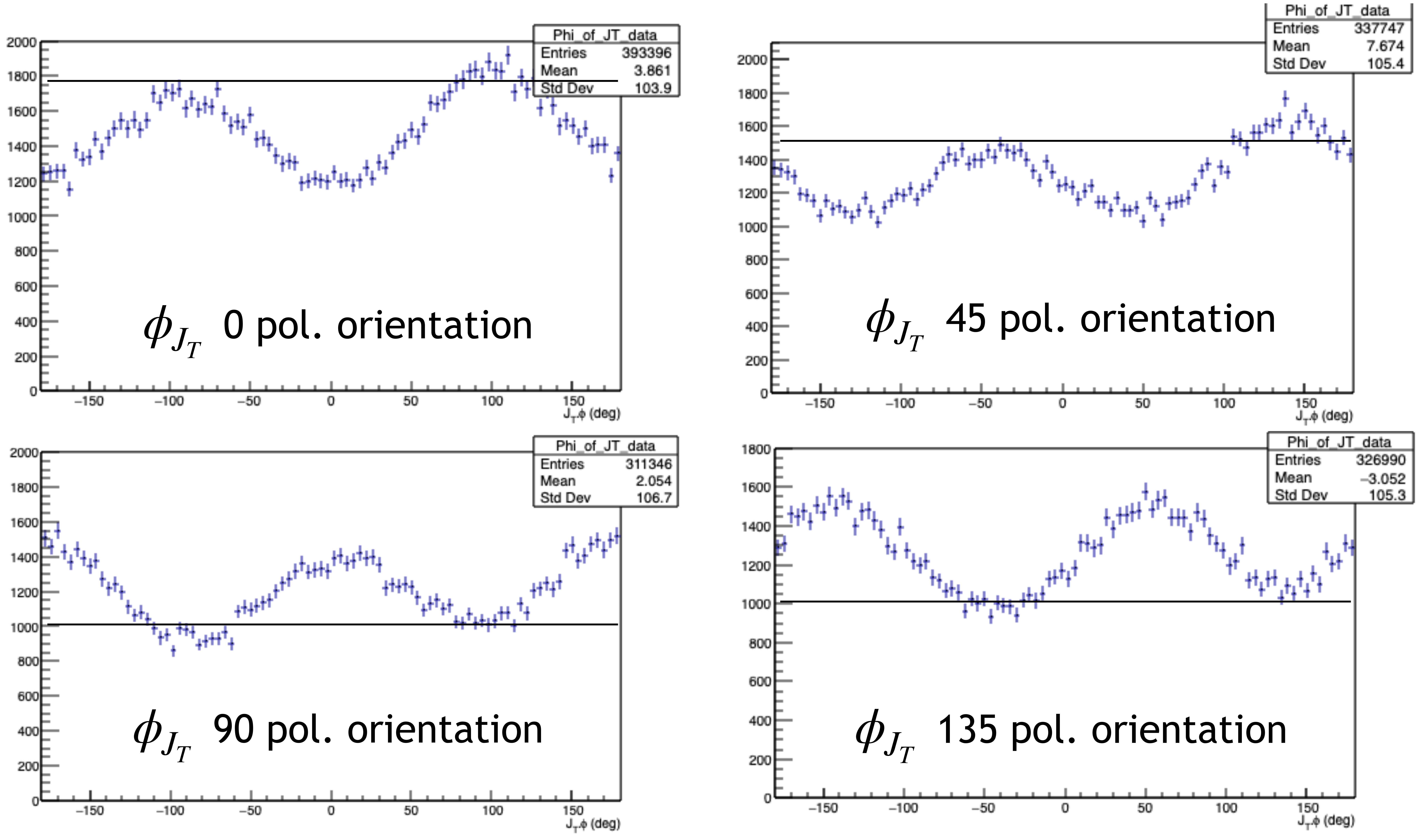
2018-01 GlueX data
$\gamma p \rightarrow e^+e^-(p)$ Reaction Filter

Neural Net Cuts:
Neural Net Classification Cuts (NN1, NN2 > 0.8)
Fiducial Cuts:
$8.2\,\text{GeV} < E_\gamma < 8.8\,\text{GeV}$
$0.25\,\text{GeV} < W_{ee} < 0.621\,\text{GeV}$
Both tracks have hits in the TOF
$\theta_1, \theta_2 > 1.5\,\text{deg}$
FCAL Elasticity > 0.9
Vertex cut (Window free): 52 < z < 78 cm

e^+e^- Invariant Mass



$\gamma p \rightarrow e^+e^-(p)$ 2018-01 GlueX data, w/ fiducial+N.N. cuts



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

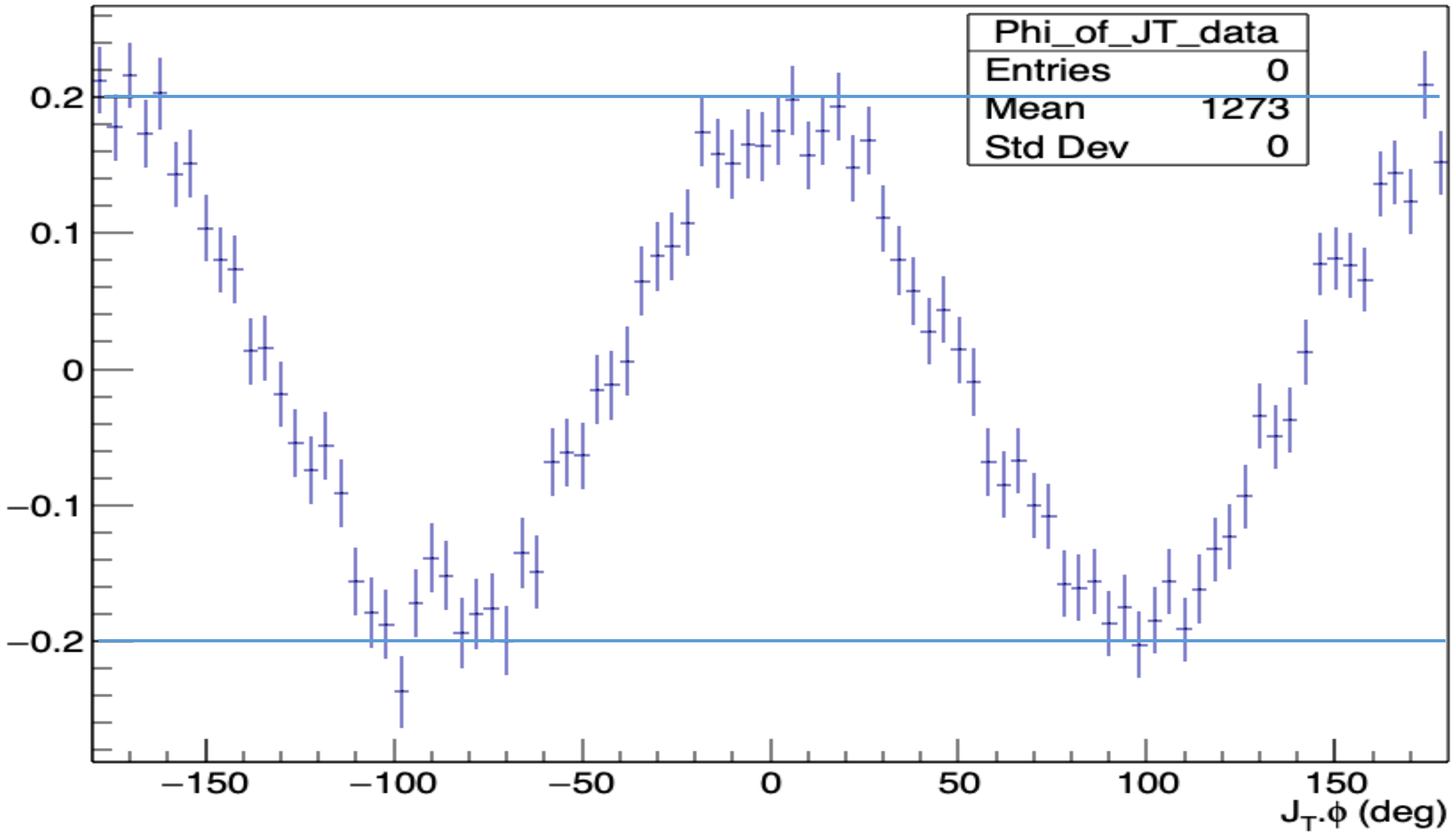
$$N_\perp = 311346 \qquad \frac{N_\perp}{N_\parallel} = 0.9564$$

$$N_\parallel = 325538$$

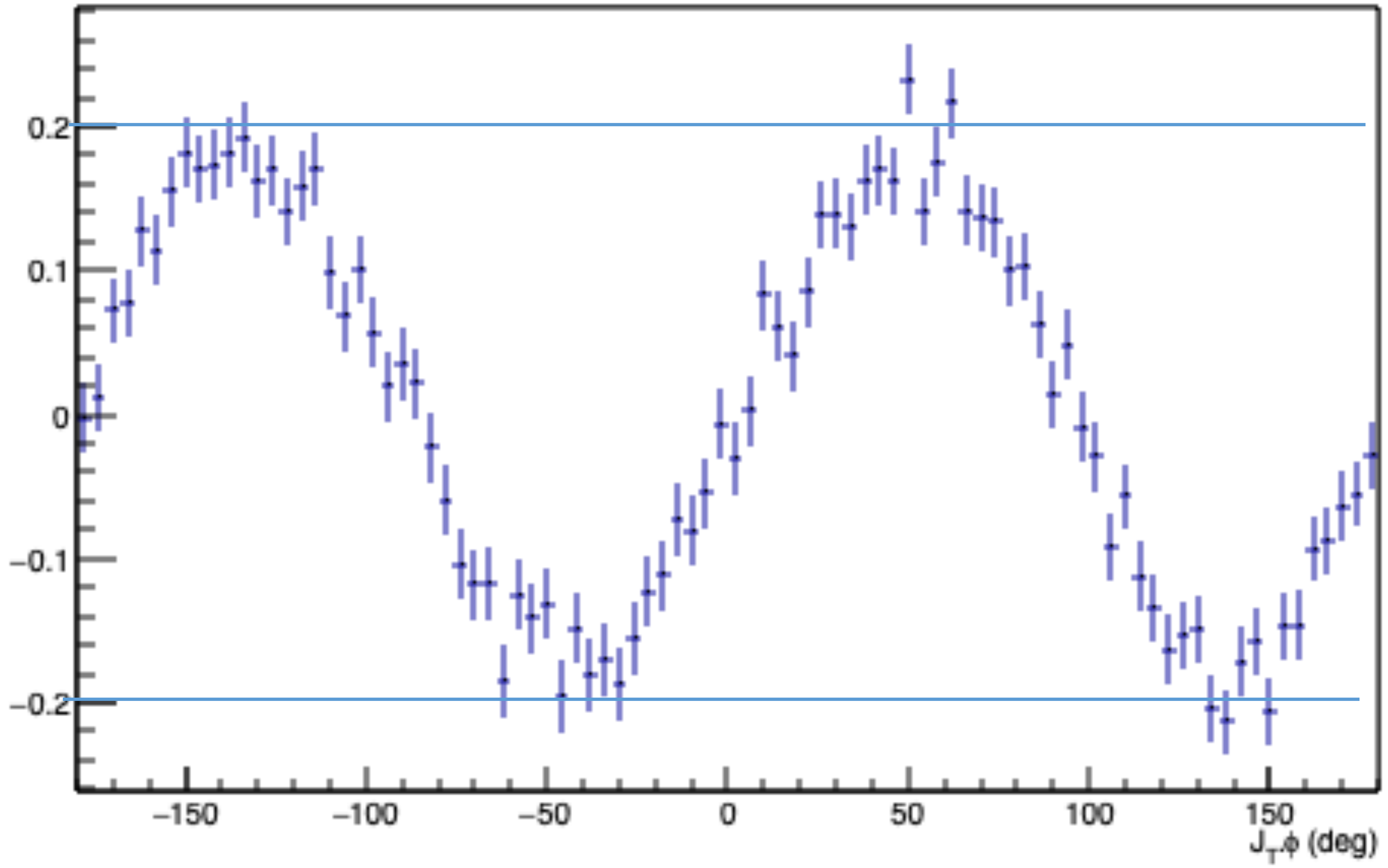
2018-01 GlueX data, $\gamma p \rightarrow e^+ e^- (p)$

Yield Asymmetry

0/90 runs



45/135 runs

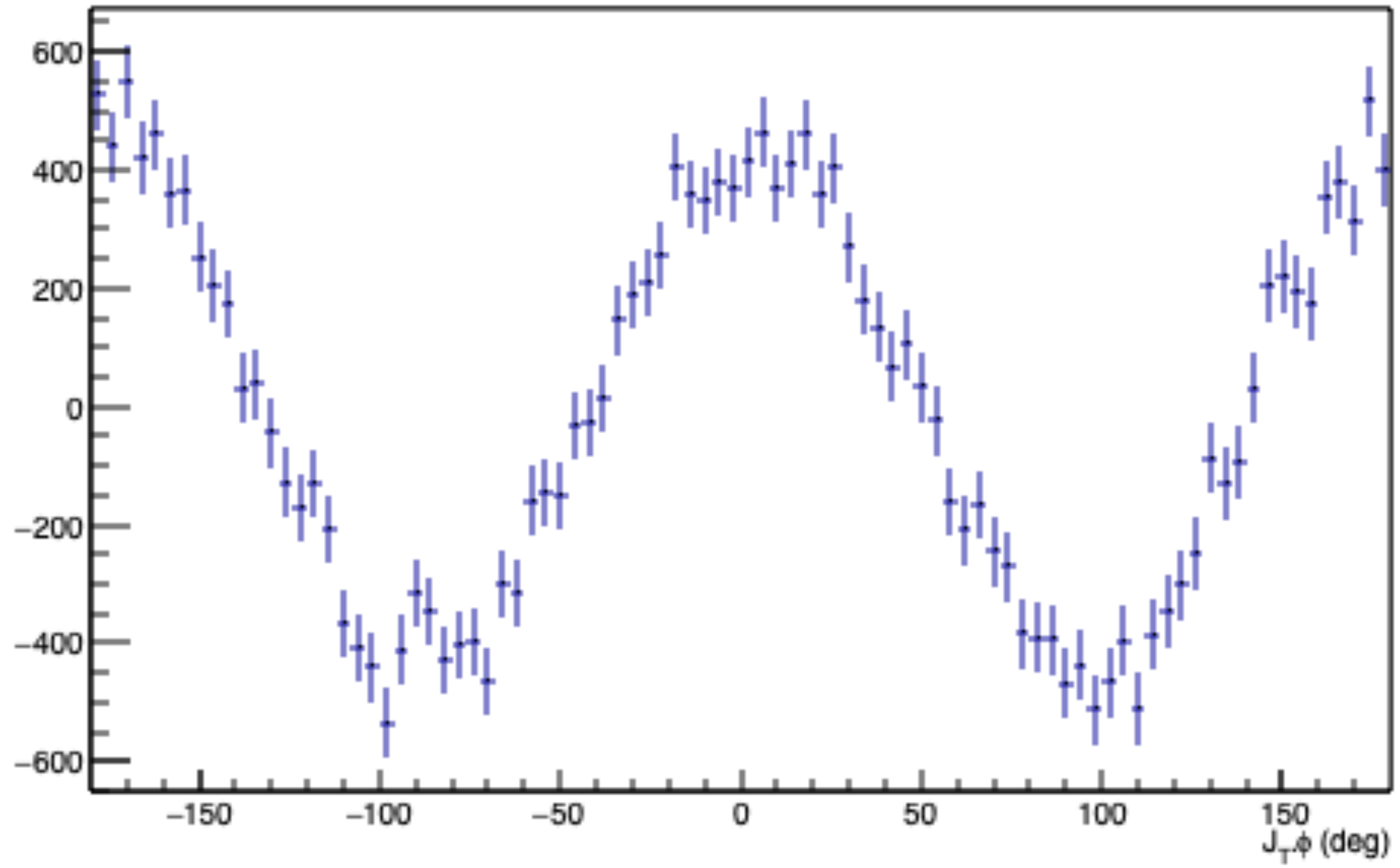


2018-01 GlueX data, $\gamma p \to e^+e^-(p)$

0/90 pol. Orientation

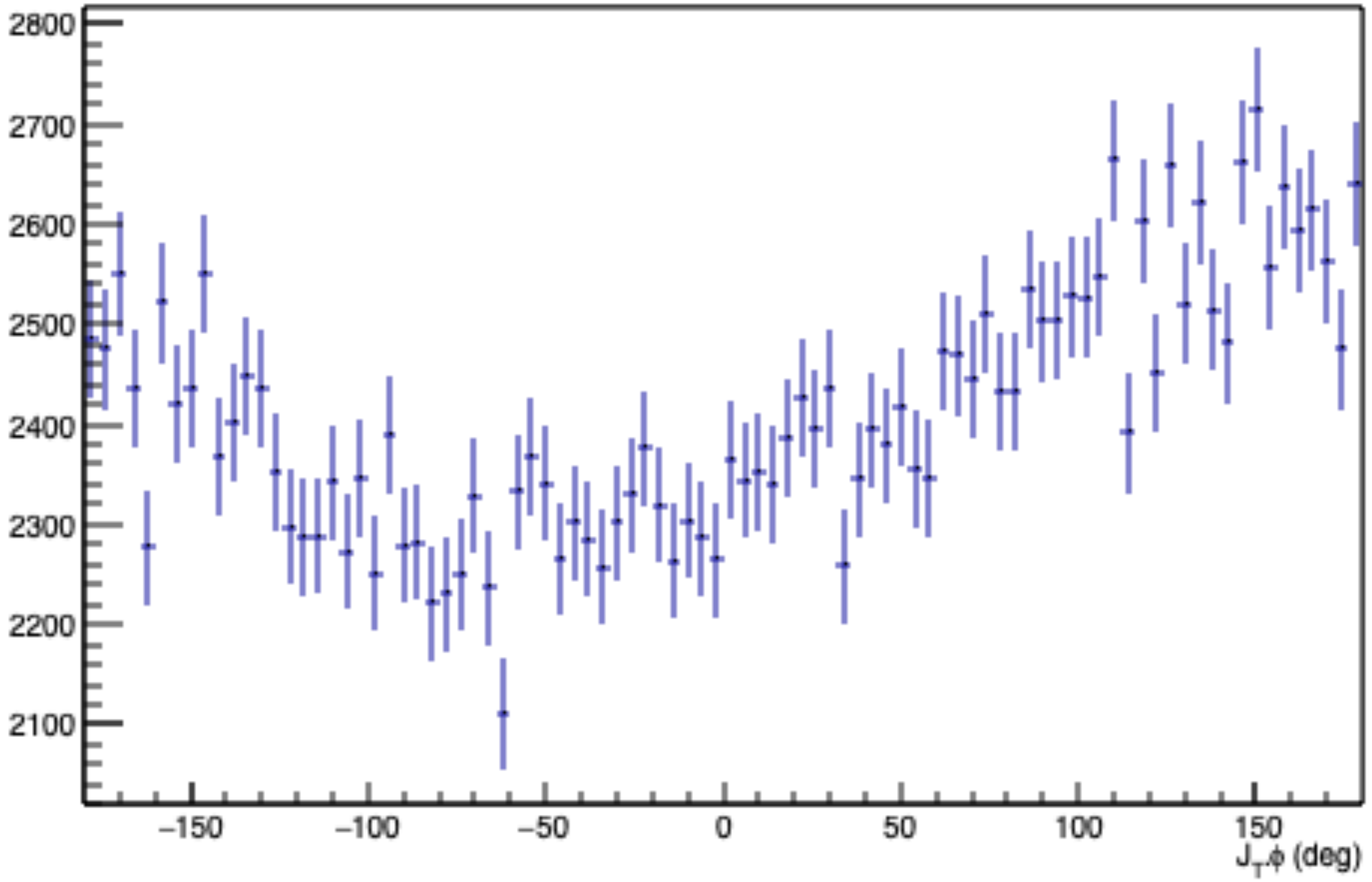
Just Numerator

$$Y_\perp(\phi) - \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)$$



Just Denominator

$$Y_\perp(\phi) + \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)$$



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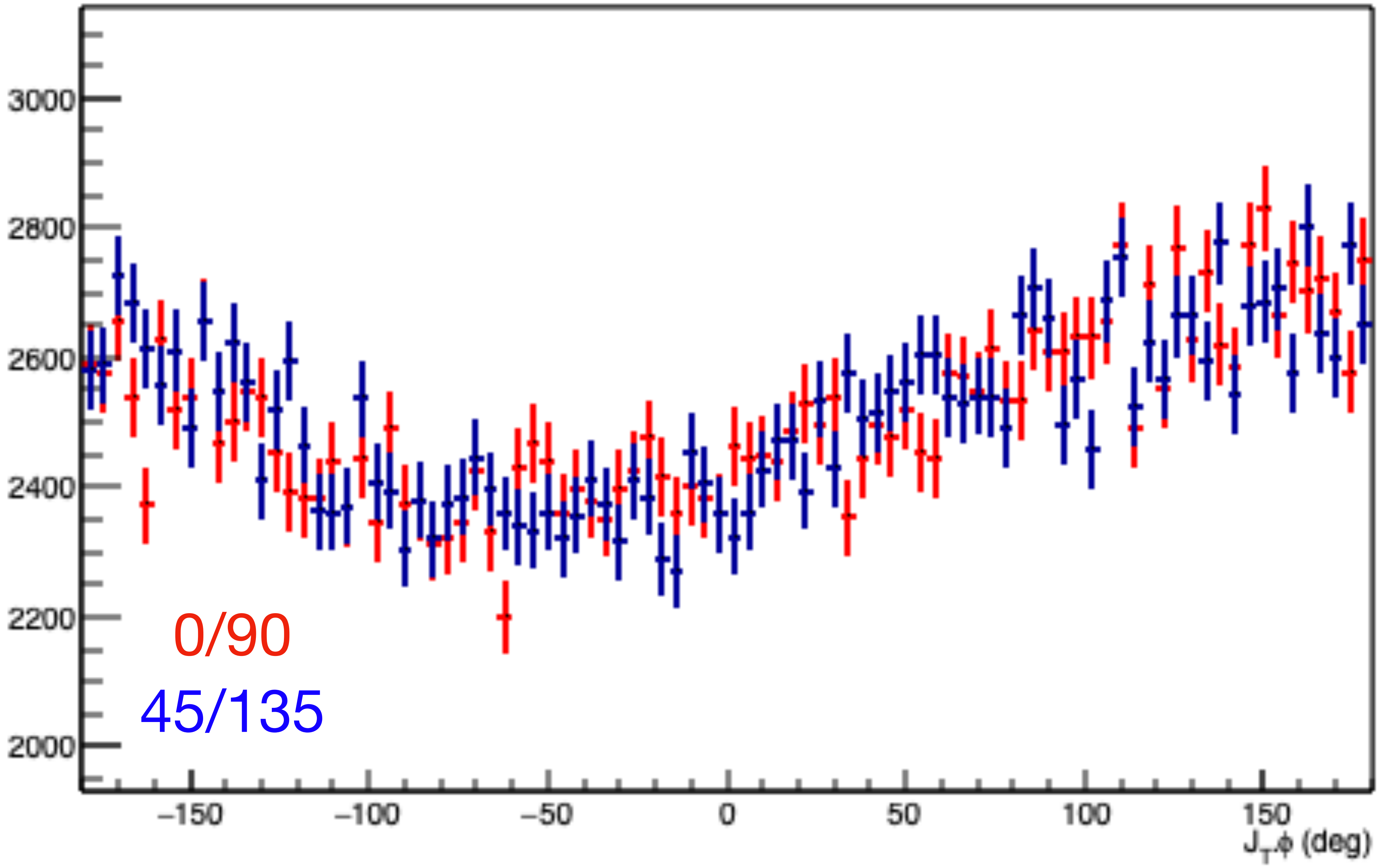
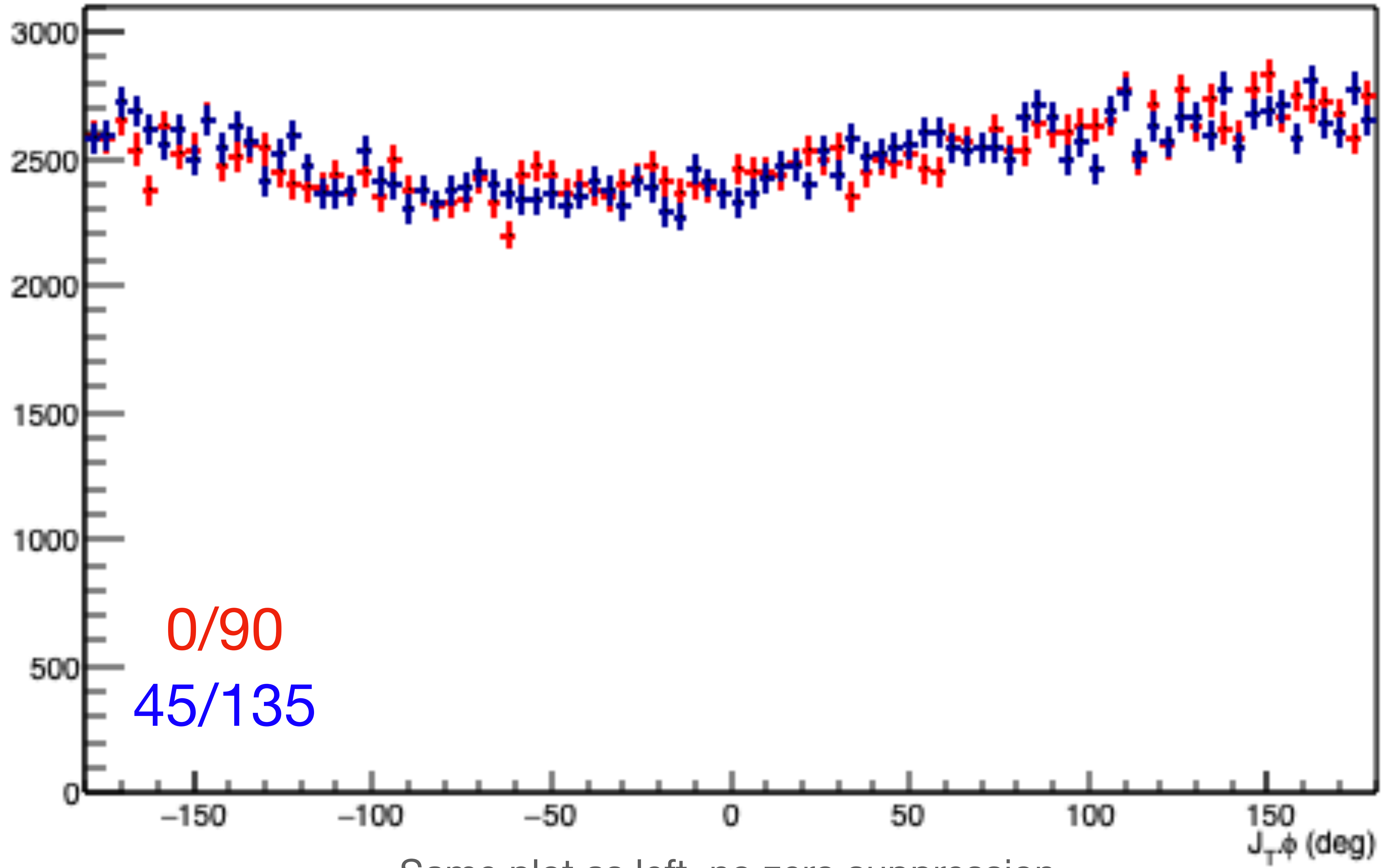




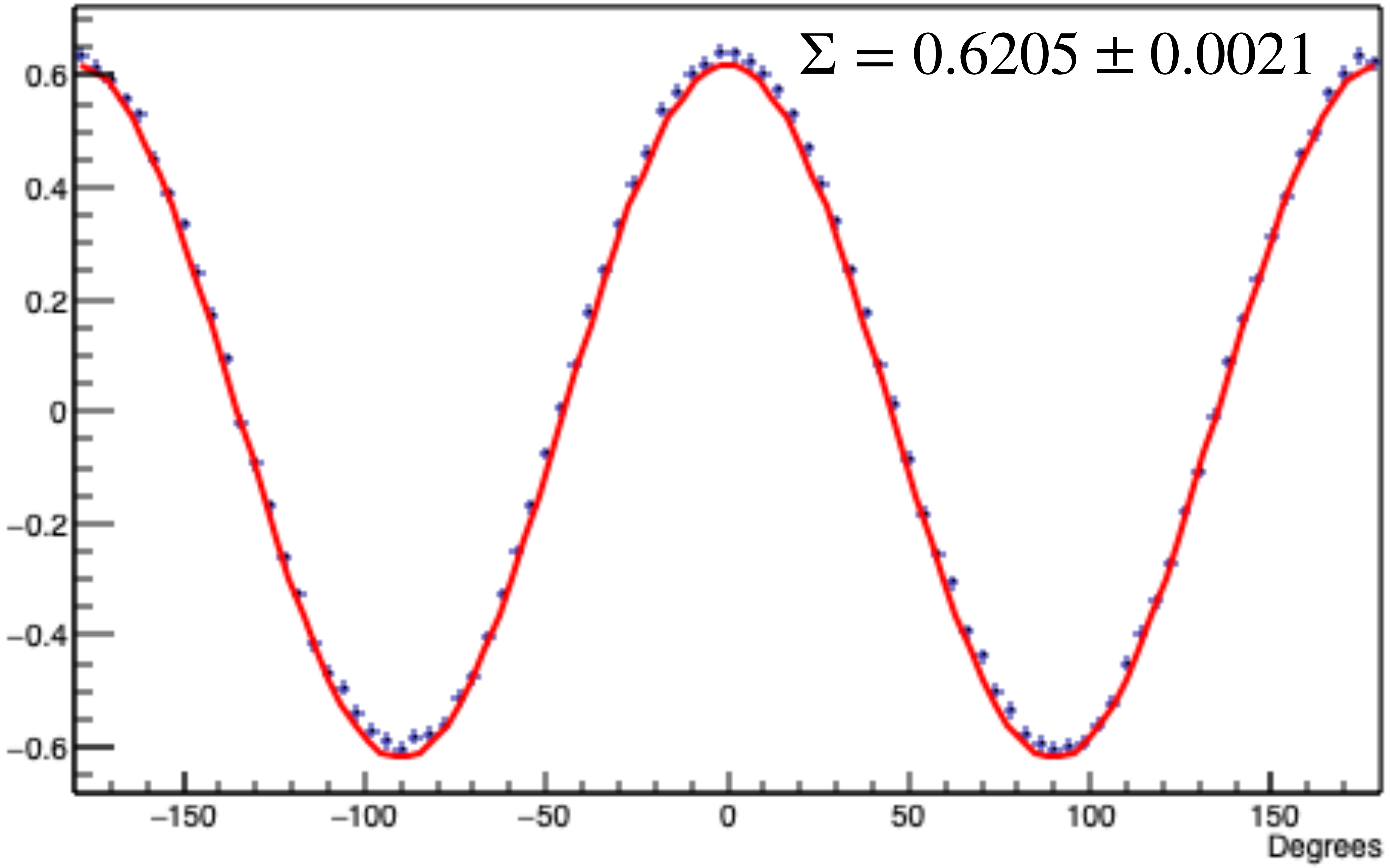
Same plot as left, no zero suppression

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

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

Assume $P_{\perp} - P_{\|} = 0$

Simulated Yield Asymmetry



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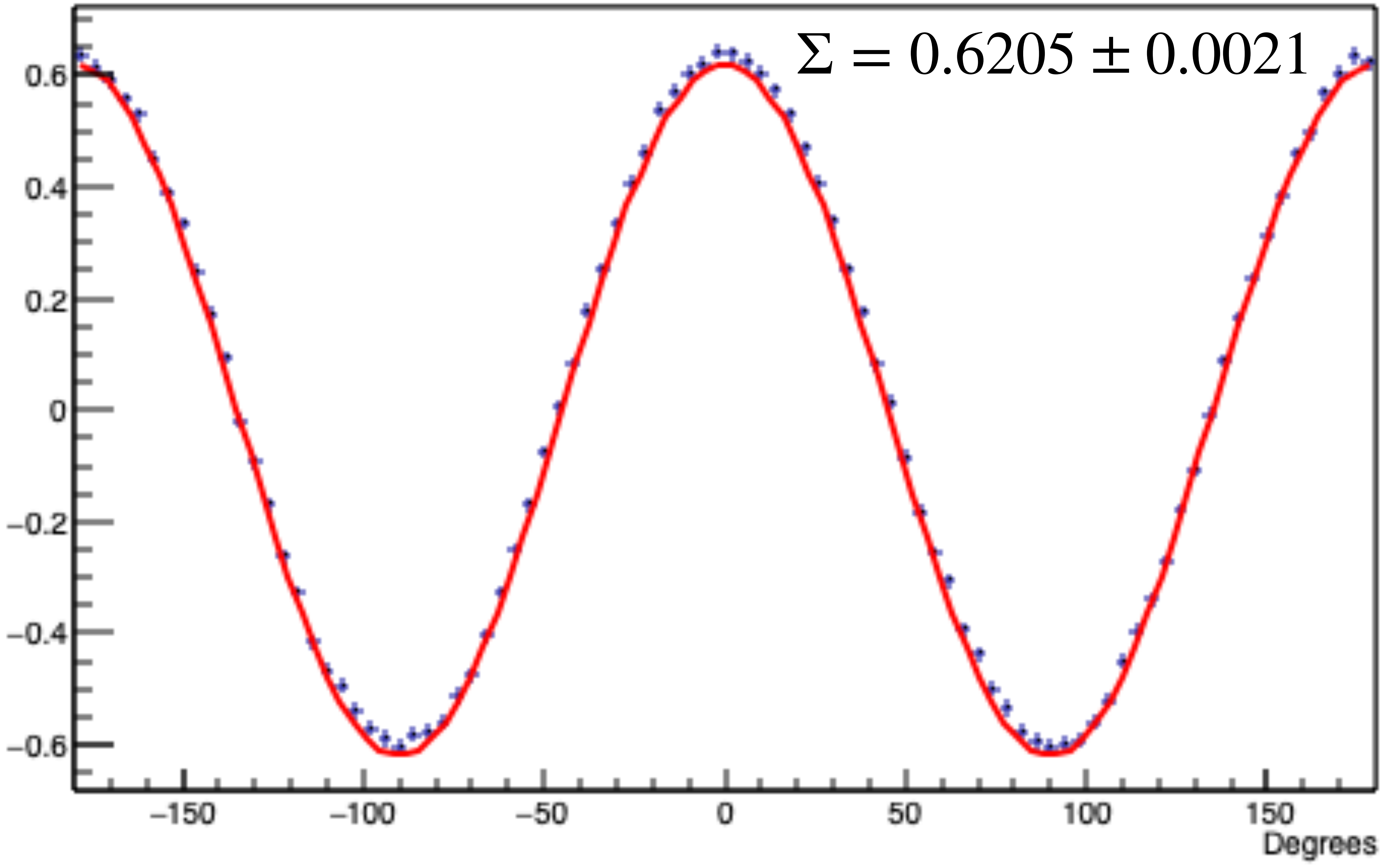
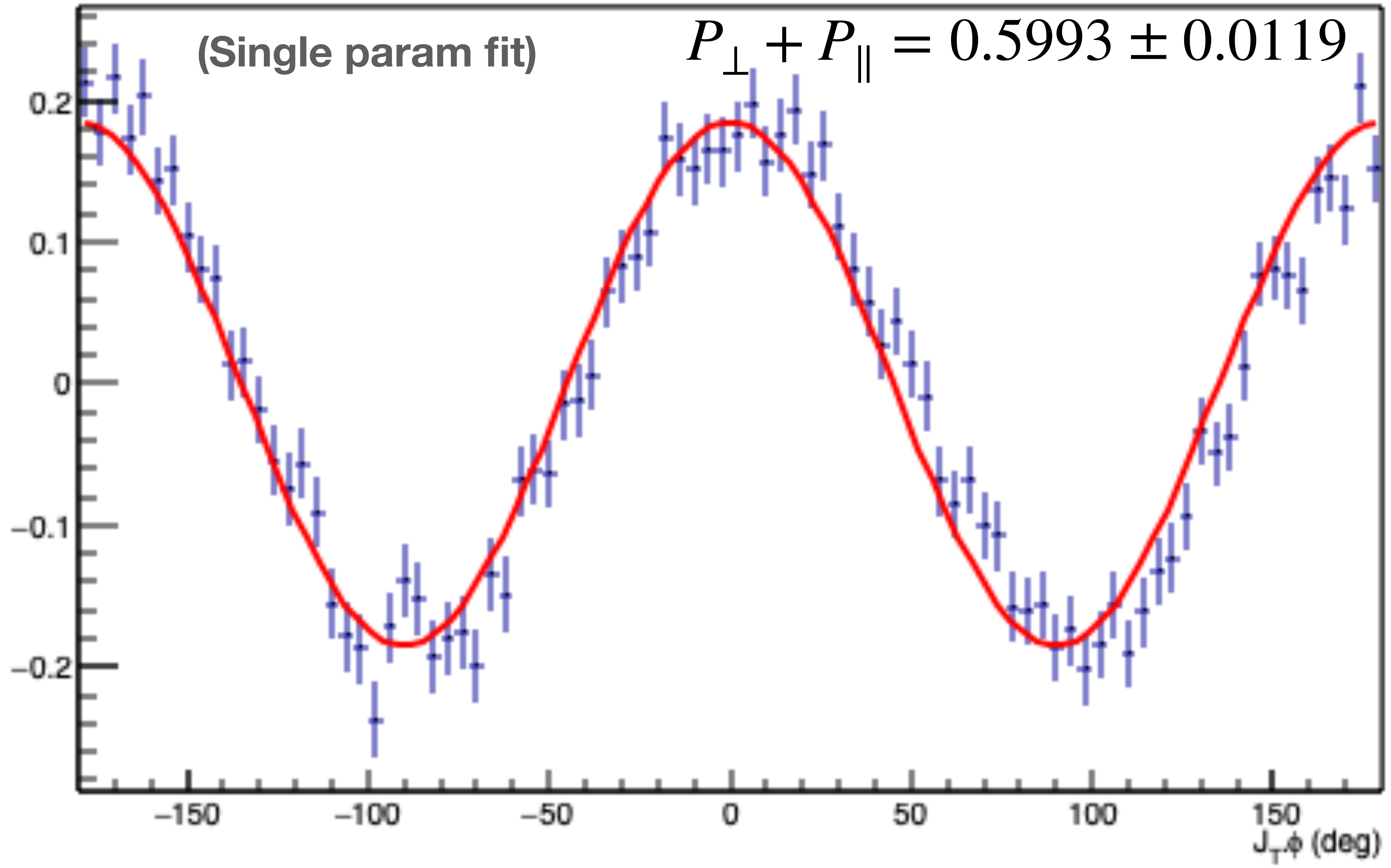


2018-01 Pol = 0 and 90 runs

Data Yield Asymmetry



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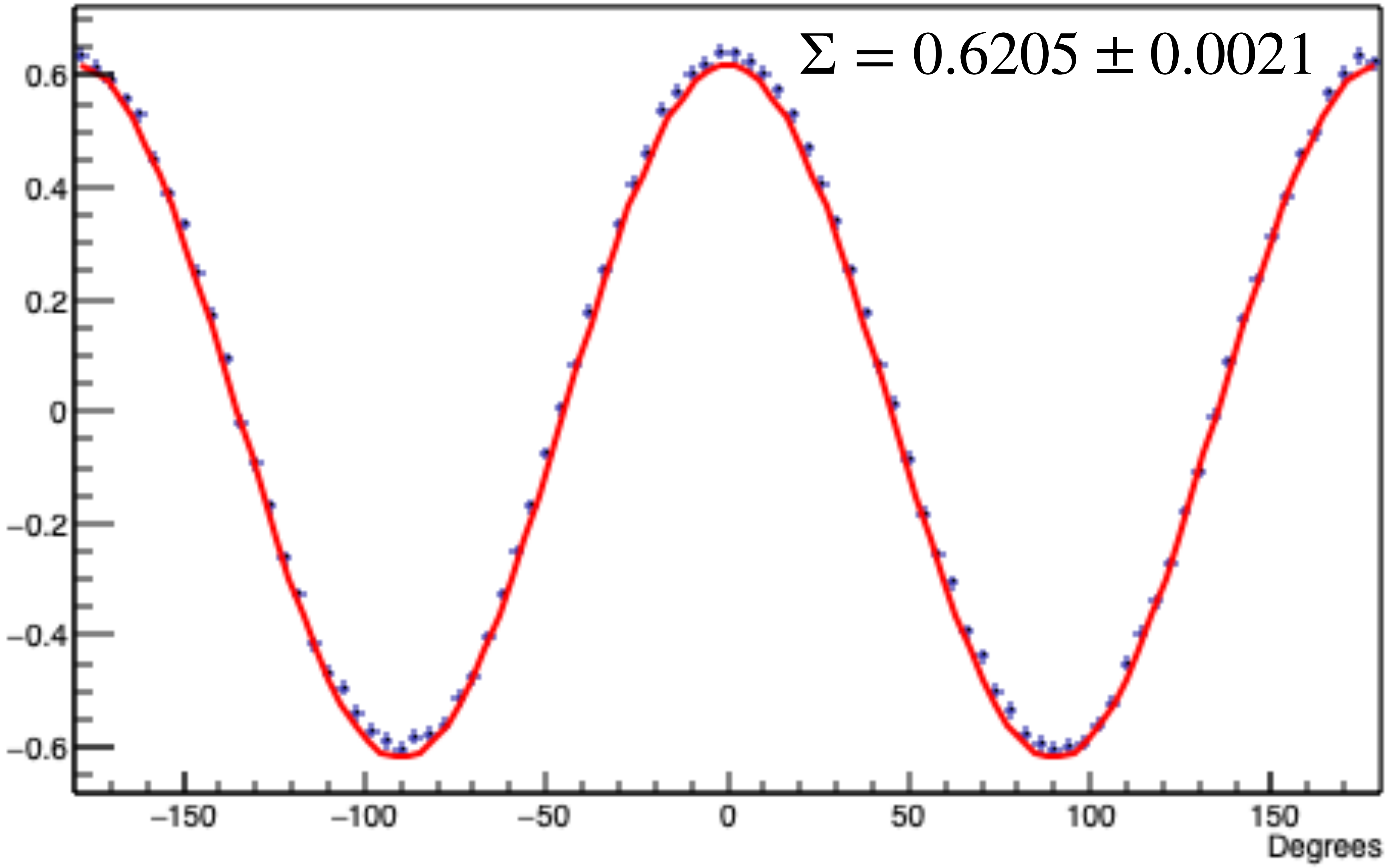
$$\frac{Y_\perp(\phi) - \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)}{Y_\perp + \frac{N_\perp}{N_\parallel} Y_\parallel(\phi)} = \frac{\Sigma (P_\perp + P_\parallel)\cos 2(\phi + \alpha)}{2}$$

2018-01 Pol = 0 and 90 runs

Simulated Yield Asymmetry



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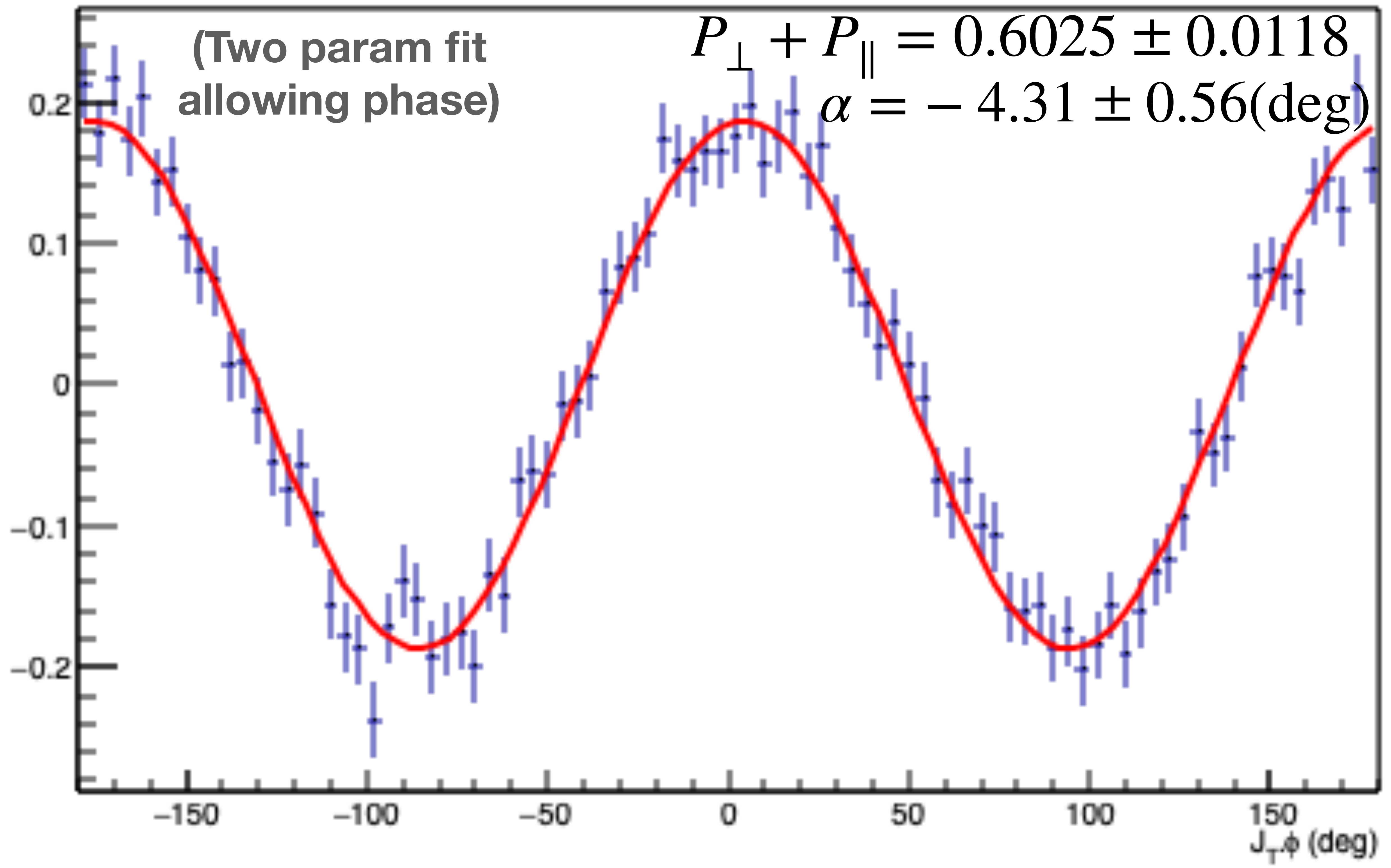
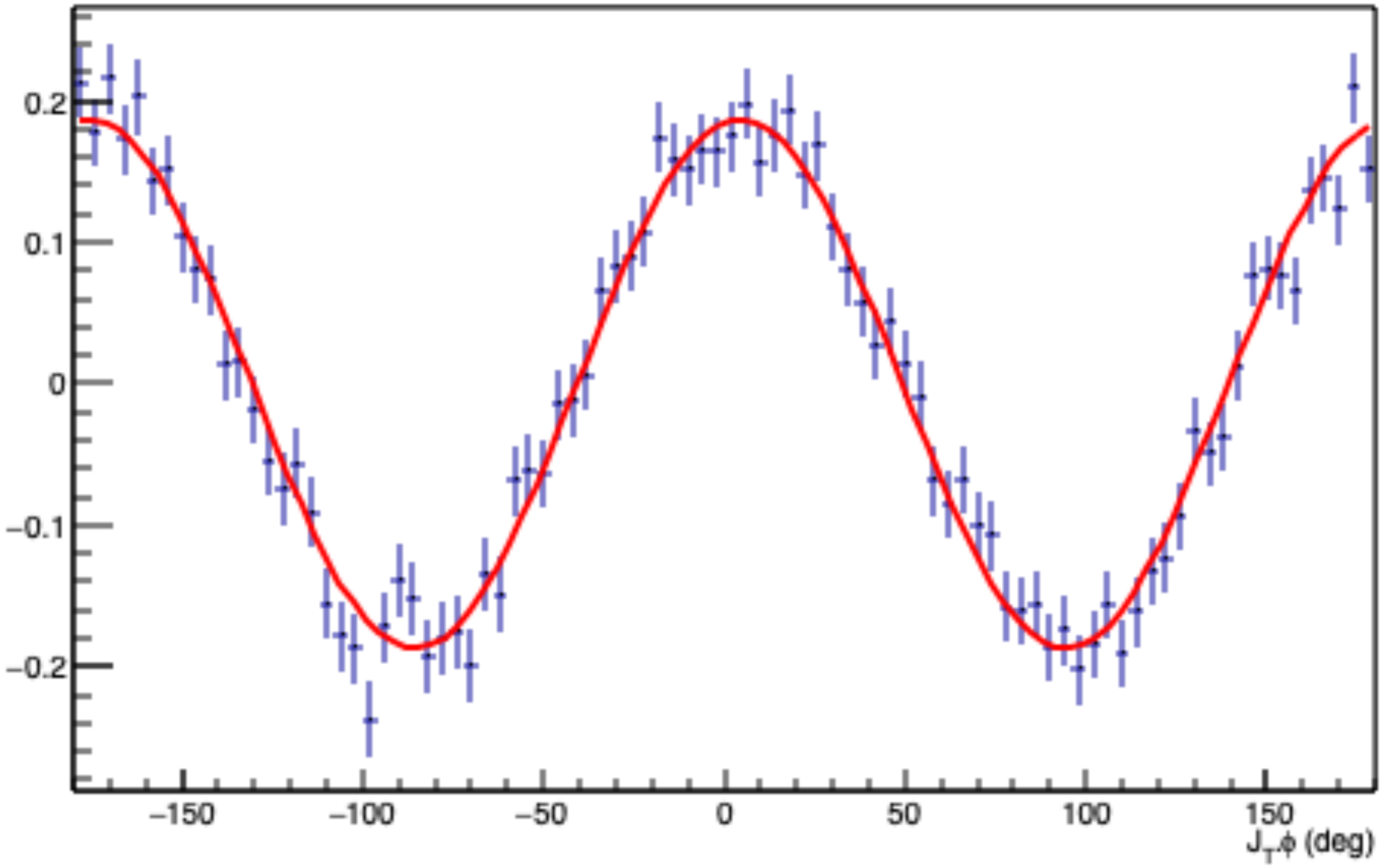


2018-01 GlueX data, $\gamma p \rightarrow e^{+}e^{-}(p)$, ϕ_{J_T} Yield Asymmetry

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

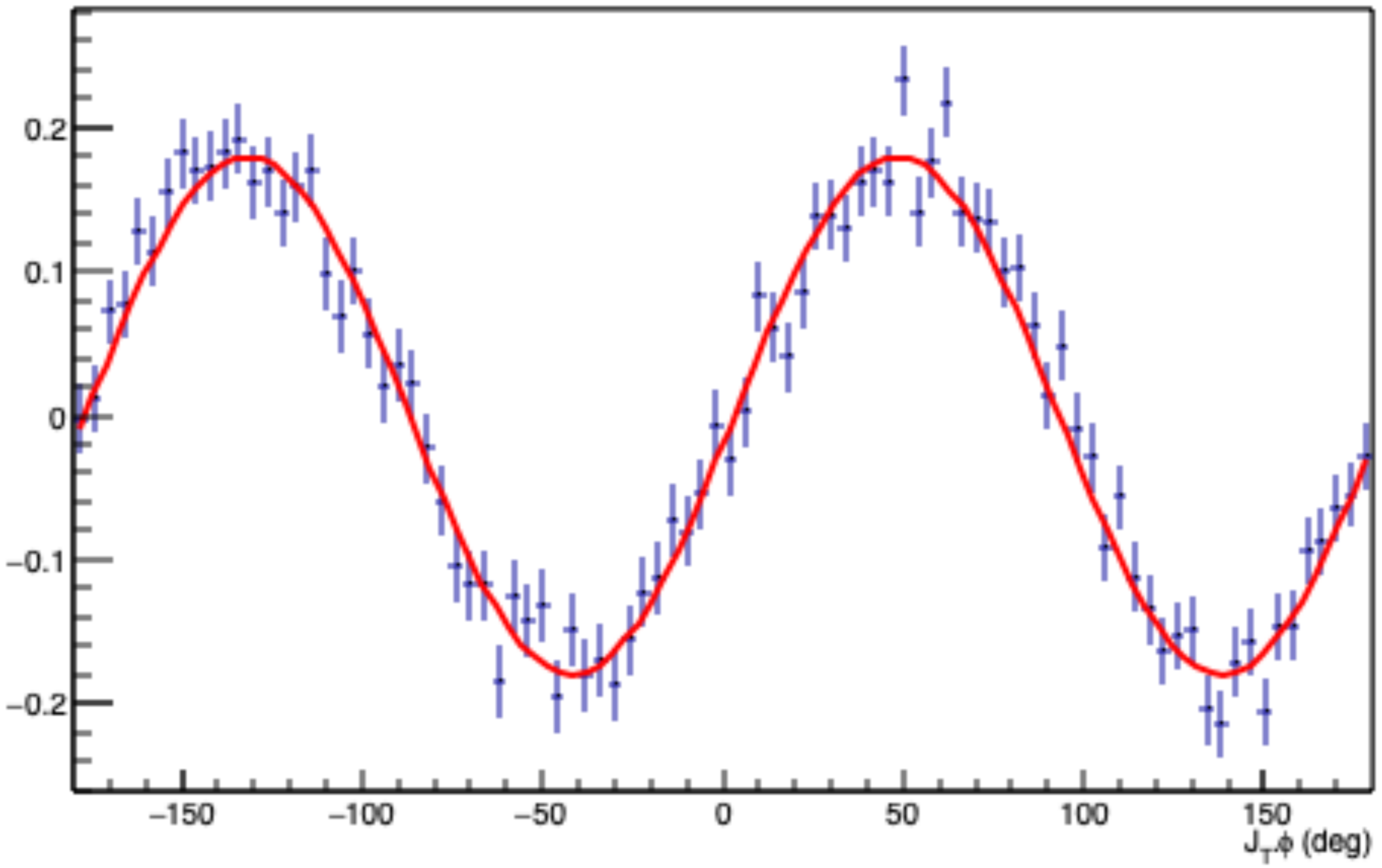
0/90



$P_{\perp} + P_{\parallel} = 0.6025 \pm 0.0118$

$\alpha = -4.31 \pm 0.56$(deg)

45/135



$P_{\perp} + P_{\parallel} = 0.5789 \pm 0.0116$

$\alpha = 41.77 \pm 0.57$(deg)

Preliminary Results

TPOL expected average polarization, 0 and 90 runs $$\frac{\mathscr{P}_{\perp} + \mathscr{P}_{\parallel}}{2} = 0.341 \pm 0.004$$

BH average polarization; 0 and 90 runs: $$\frac{\mathscr{P}_{\perp} + \mathscr{P}_{\parallel}}{2} = 0.301 \pm 0.006$$

TPOL expected average polarization, 45 and 135 runs $$\frac{\mathscr{P}_{\perp} + \mathscr{P}_{\parallel}}{2} = 0.344 \pm 0.004$$

BH average polarization; 0 and 90 runs: $$\frac{\mathscr{P}_{\perp} + \mathscr{P}_{\parallel}}{2} = 0.290 \pm 0.006$$

Next Steps

Redo study now that improvements in the neural net have been implemented

Rigorously Investigate systematics/stability of result w.r.t. fiducial cuts

Estimated pion contamination is approximately 0.6%. Next, subtract pion yields from the ϕ_{J_T} distributions

Measure analyzing power using Richard's Bethe-Heitler generator to compare with our generator