Exclusive Charged Rho Beam Spin Asymmetry Extraction

Tyler Hellstern

Advisor: Anselm Vossen

Duke

clas

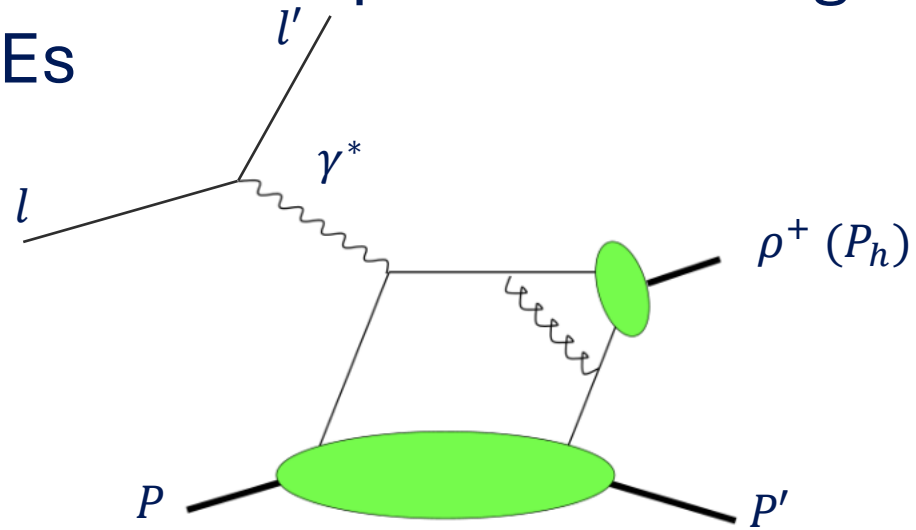
CEBAF Large Acceptance Spectrometer

Exclusive Rho Production

$$e(l) + p(P) \rightarrow e(l') + \rho^+(P_h) + n(P')$$

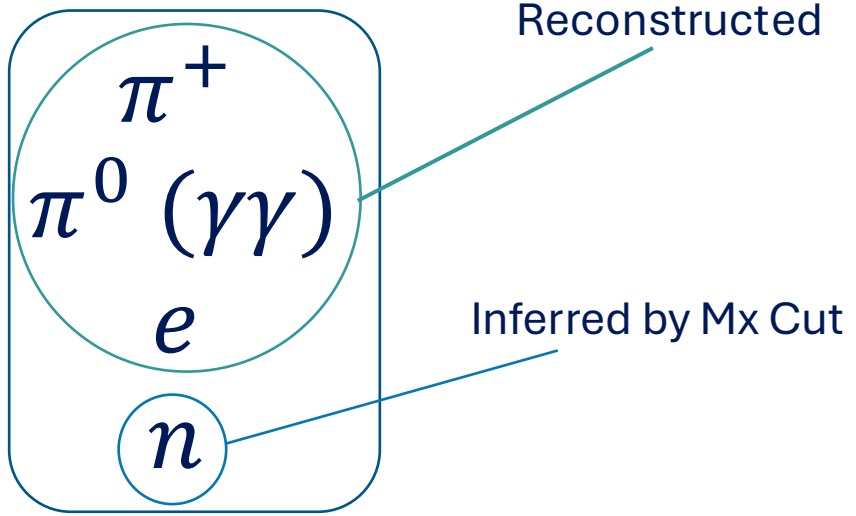
Motivation:

- SIDIS Single Hadron Background
- Access to GPDs – main contribution is quark scattering
- SDMEs



Exclusivity Disclaimer: no neutron reconstructed

Final Products:



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Definitions:

$$z = \frac{P \cdot P_h}{P \cdot q}$$

$$-t = -(P - P')^2$$

$$M_h^2 = (P_1 + P_2)^2$$

$$M_x^2 = (q + P - P_h)^2$$

$P_h \rightarrow \rho^+$ Momentum

$P_1 \rightarrow \pi^+$ Momentum

$P_2 \rightarrow \pi^0$ Momentum

$P \rightarrow$ Target Proton

$P' \rightarrow$ Outgoing Neutron

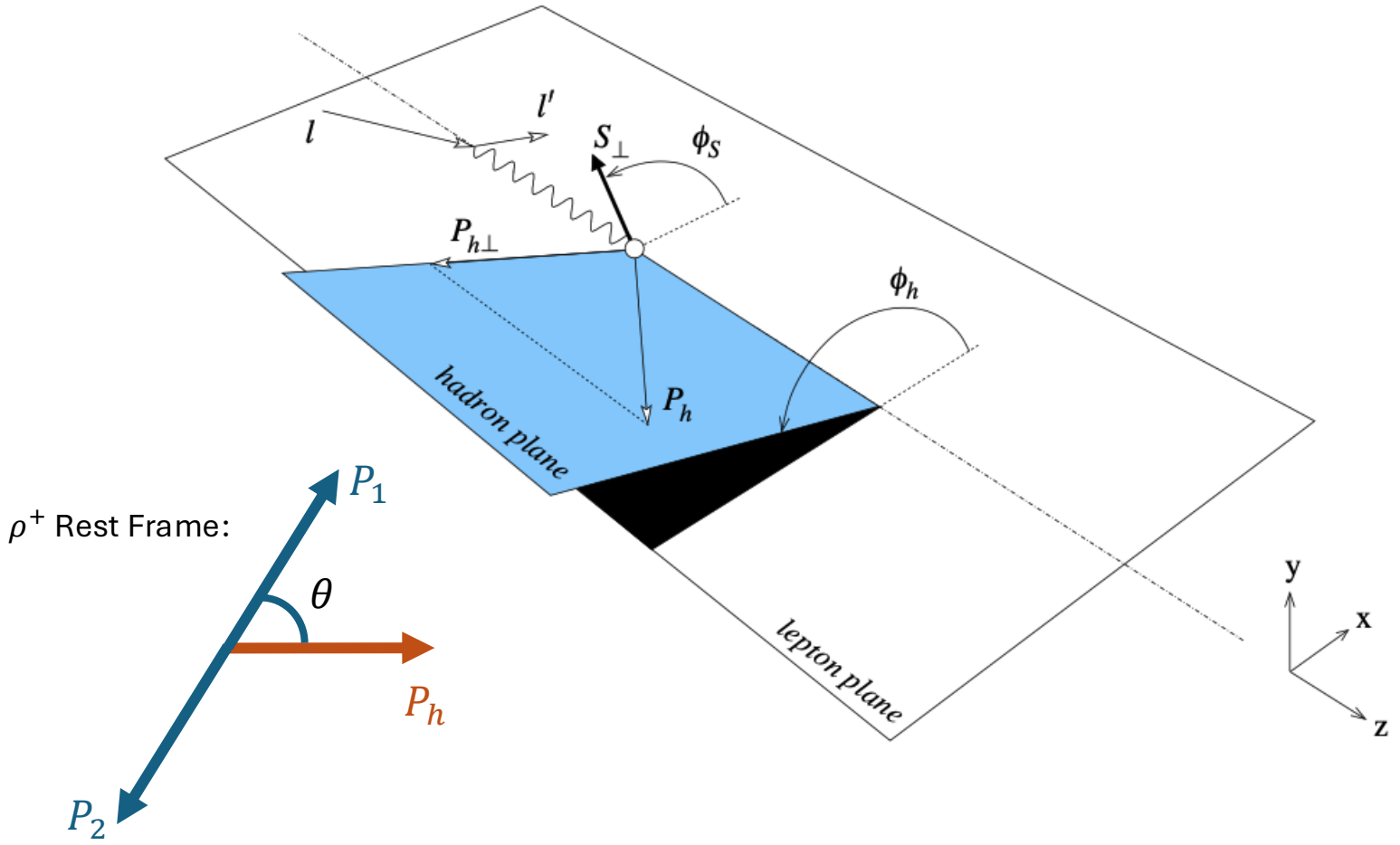

Image credit: Alessandro Bacchetta et al. "Semi-inclusive deep inelastic scattering at small transverse momentum". In: Journal of High Energy Physics 2007.02 (Feb. 2007). doi: 10.1088/1126-6708/2007/02/093.

Beam Spin Asymmetry – SIDIS Cross Section

$$\frac{d^4\sigma}{dQ^2 dx\, dt\, d\phi} = \frac{1}{2\pi}\Gamma_y \left[F_{UU} + \sqrt{2\epsilon(1+\epsilon)}F_{UU}^{\cos\phi}\cos\phi\right.$$

$$+\epsilon F_{UU}^{\cos(2\phi)}\cos(2\phi)$$

$$\left. + \lambda_e\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi}\sin\phi\right]$$

$$A = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{\alpha\sin\phi}{1+\beta\cos\phi+\gamma\cos 2\phi}$$

$$\alpha \sim \frac{F_{LU}^{\sin\phi}}{F_{UU}}$$

$$\beta \sim \frac{F_{UU}^{\cos\phi}}{F_{UU}} = 0$$

$$\gamma \sim \frac{F_{UU}^{\cos 2\phi}}{F_{UU}} = 0$$

- Extracting $A_{LU}^{\sin\phi} = \frac{F_{LU}^{\sin\phi}}{F_{UU}}$
- Setting Unpolarized Modulations to zero

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Different Methods of Fitting

Maximum Likelihood Method ("MLM")

- Calculates A_{LU} by seeking to maximize the Likelihood function - $\mathcal{L}$

$$\mathcal{L}(A_{LU}) = \prod_i \mathrm{P}_i(A_{LU}^{\sin\phi}, \overrightarrow{x_i})$$

$$\overrightarrow{x_i} = \{P_b, \lambda_e, \epsilon, \phi\}$$

$$P \sim 1 + P_b \lambda_e \sqrt{2\epsilon(1-\epsilon)} A_{LU}^{\sin\phi} \sin\phi$$

- Signal Extraction using **sideband subtraction**

$$A_{sig+bkg} = uA^{sig} + (1-u)A^{bkg}$$

u →Exclusive Event Purity

Binned Fit in Phi ("Chi2")

- Bin in Phi to calculate A and fit for α

$$\frac{N^+ - N^-}{N^+ + N^-} = \alpha \sin\phi$$

- Signal Extraction by fitting to signal peak for each phi bin

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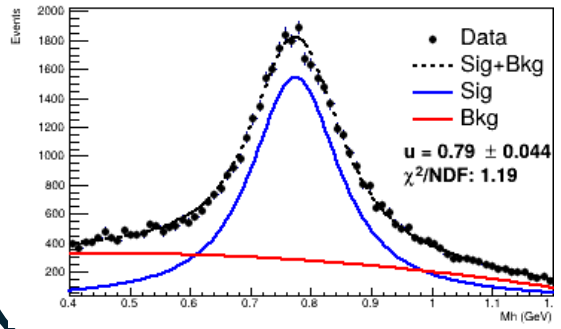
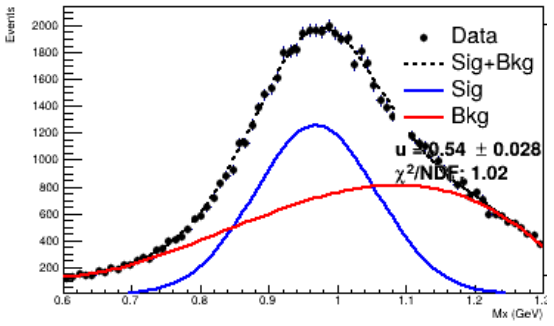
Two methods of Signal Extraction:

$$e(l) + p(P) \rightarrow e(l') + \rho^+(P_h) + n(P')$$

Fitting the Rho Peak:



Fitting the Neutron Peak:



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Data and Results

LIST OF CUTS

RGA inbending – Fall 2018, Spring 2019

DIS Cuts:

- $y < 0.8$
- $Q^2 > 1\ GeV^2$
- $W > 2\ GeV$
- $5^\circ < \theta < 35^\circ$
- Hadrons detected in FD

Electron Cuts:

- $-6.36cm < v_z < 1.52cm$
- Sampling Fraction with diagonal cut
- DC Pass2 "edge" Fiducial Cuts
- $E_{PCAL} > 0.06\ GeV, E > 0$
- $p > 2\ GeV$
- Detected in FD
- Calo: $9 < lu, lw, lv < 400$
- Maximum energy particle with PID 11

Photon Cuts:

- Greg's GBT Model: $p > 0.78$
- $E_{tot} > 0.2\ GeV$
- $\alpha(e,\gamma) > 8^\circ$
- Calo: $9 < lu, lw, lv < 400$
- Detected in FD
- $0.9 < \beta < 1.1$

Pion Cuts:

- DC Pass2 "edge" Fiducial Cut
- 3 sigma χ^2 PID cut
- Detected in FD
- $|v_{z,elec} - v_{z,pion}| < 20cm$

Exclusive Dihadron Cuts:

- $x_F > 0$ for π^+ and diphoton
- $0.104 < M_{\gamma\gamma} < 0.164$
- $0.85 < M_x < 1.05$ when fitting M_h
- $0.65 < M_h < 0.9$ when fitting M_x
- No additional charged particle in event

Total number of events after all cuts: 1,190,775

GBT Photon Classifier: 10.48550/arXiv.2402.13105

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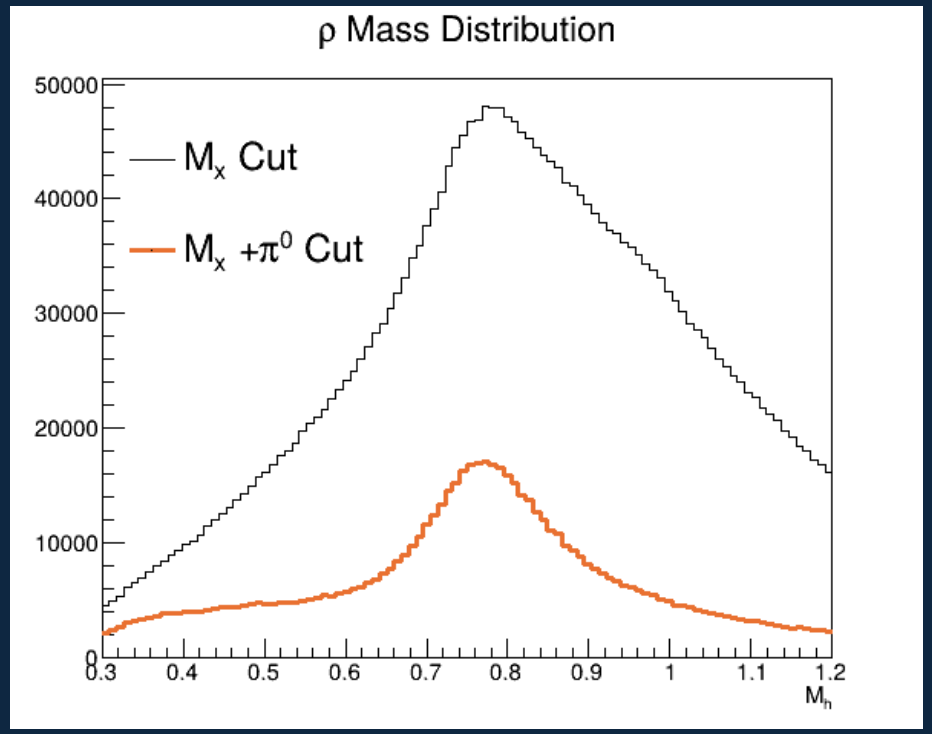

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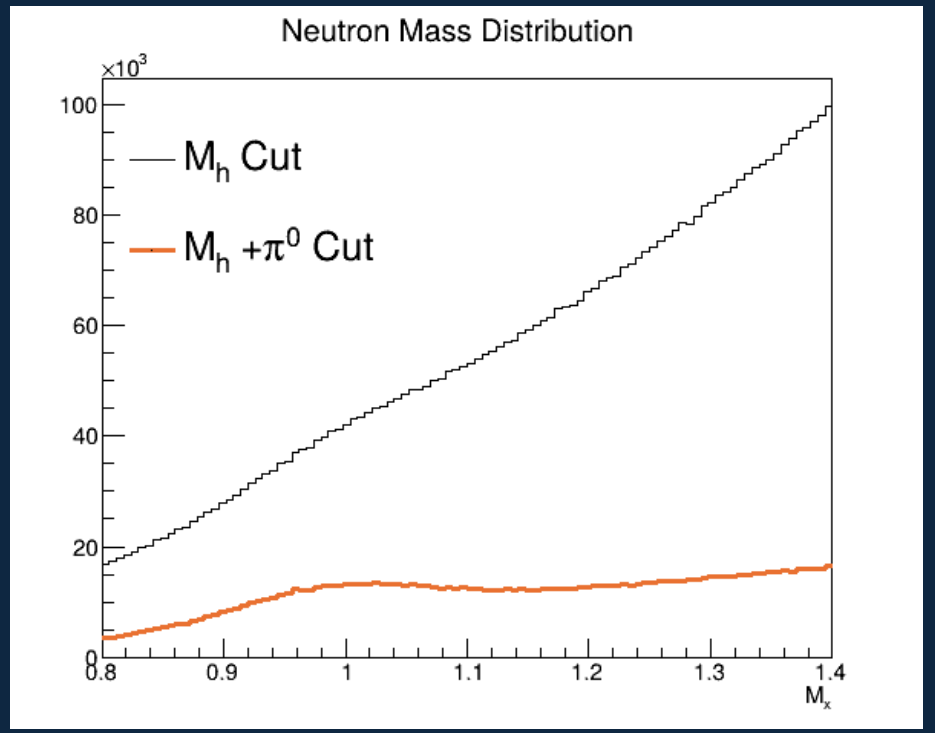

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Unbinned Maximum Likelihood

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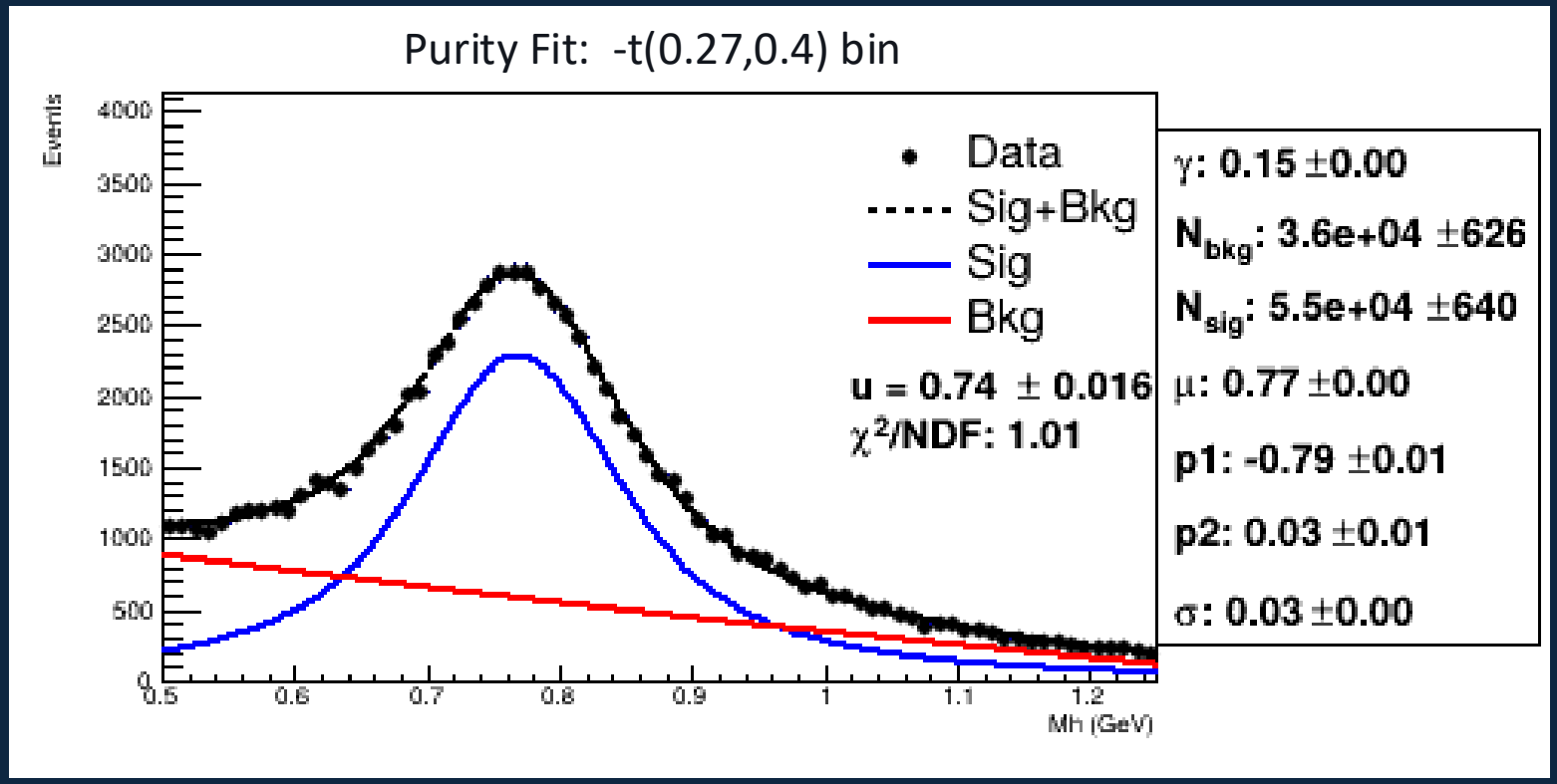
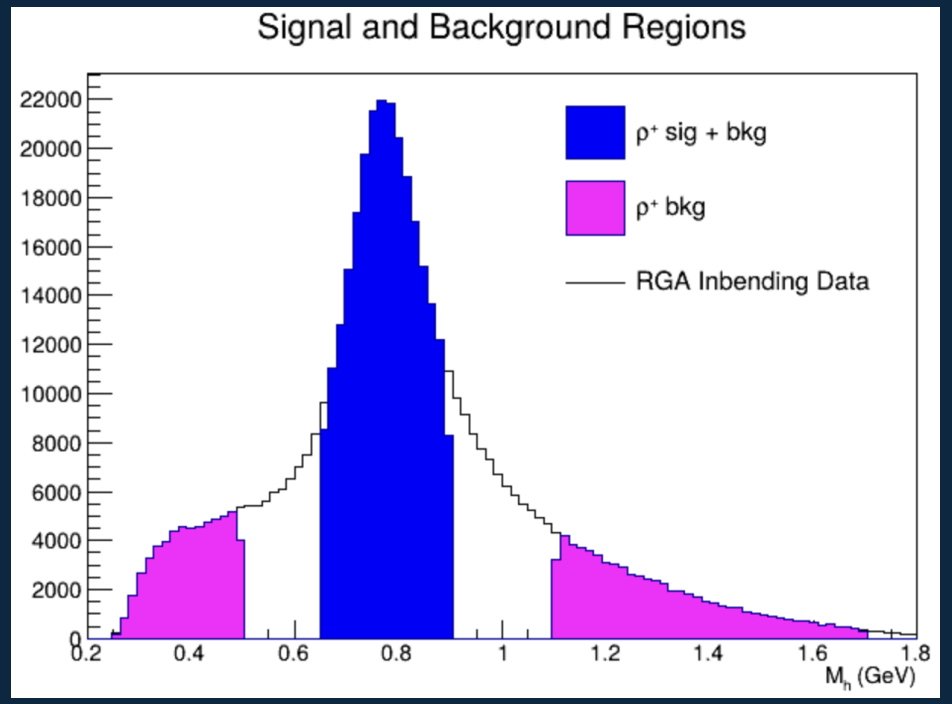
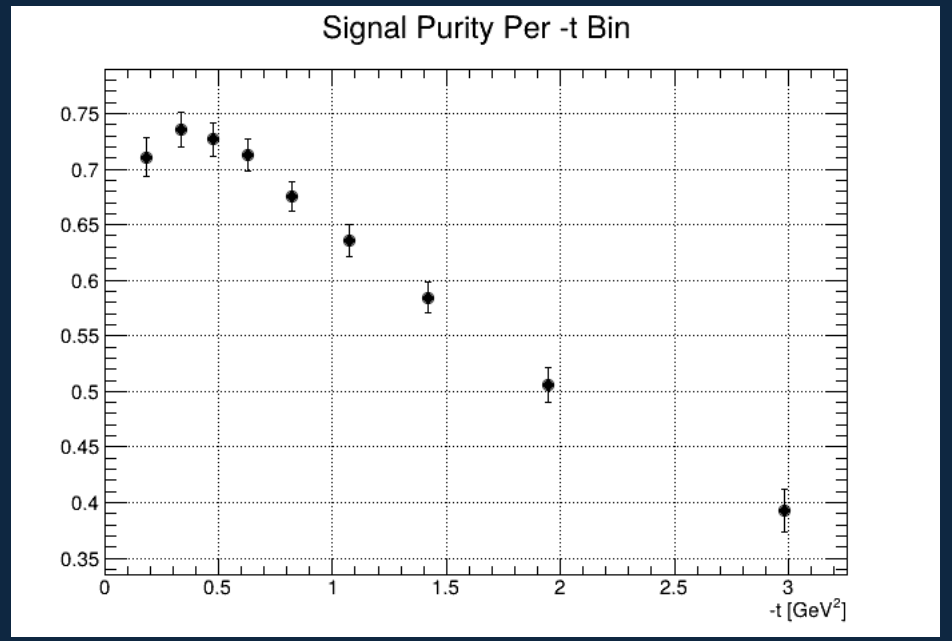
Signal Fit – Voigtian
Background Fit – 2nd order Chebychev Polynomial

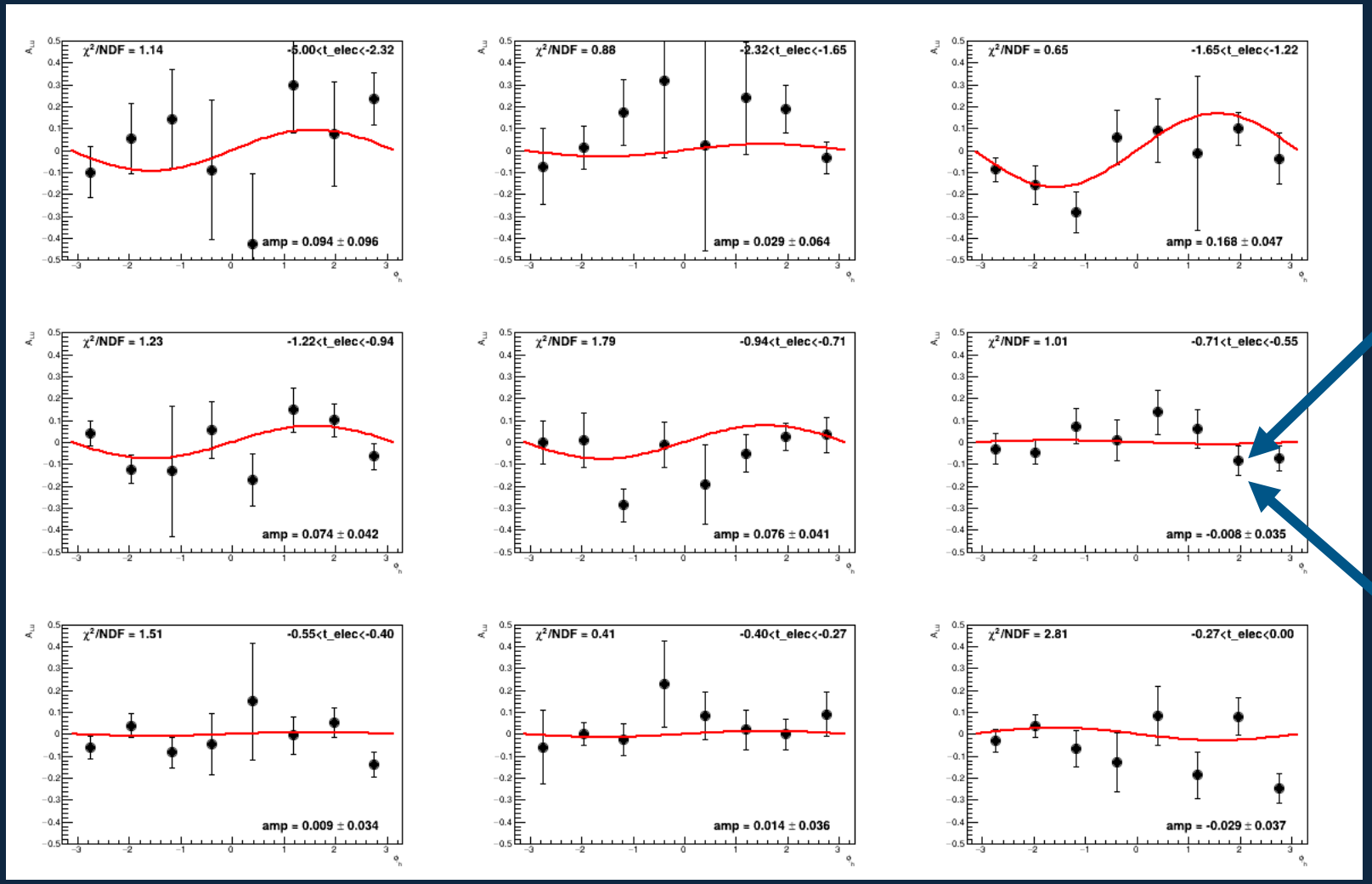






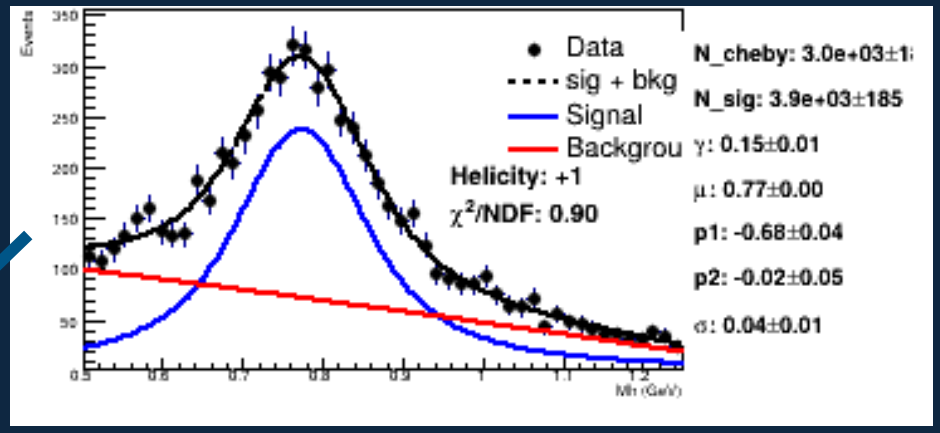
Phi Binned Fit (Chi2)

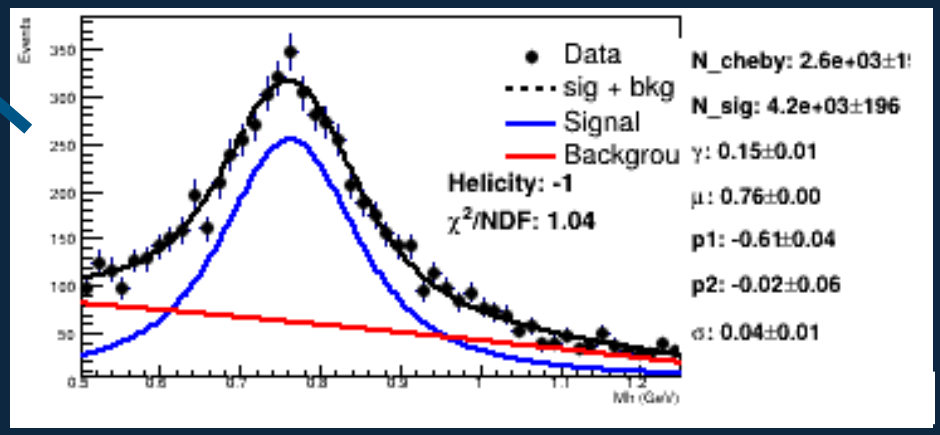
$$\frac{1}{P_b\sqrt{2\epsilon(1-\epsilon)}}\frac{N^+ - N^-}{N^+ + N^-} = \alpha \sin\phi$$



Signal Fits:

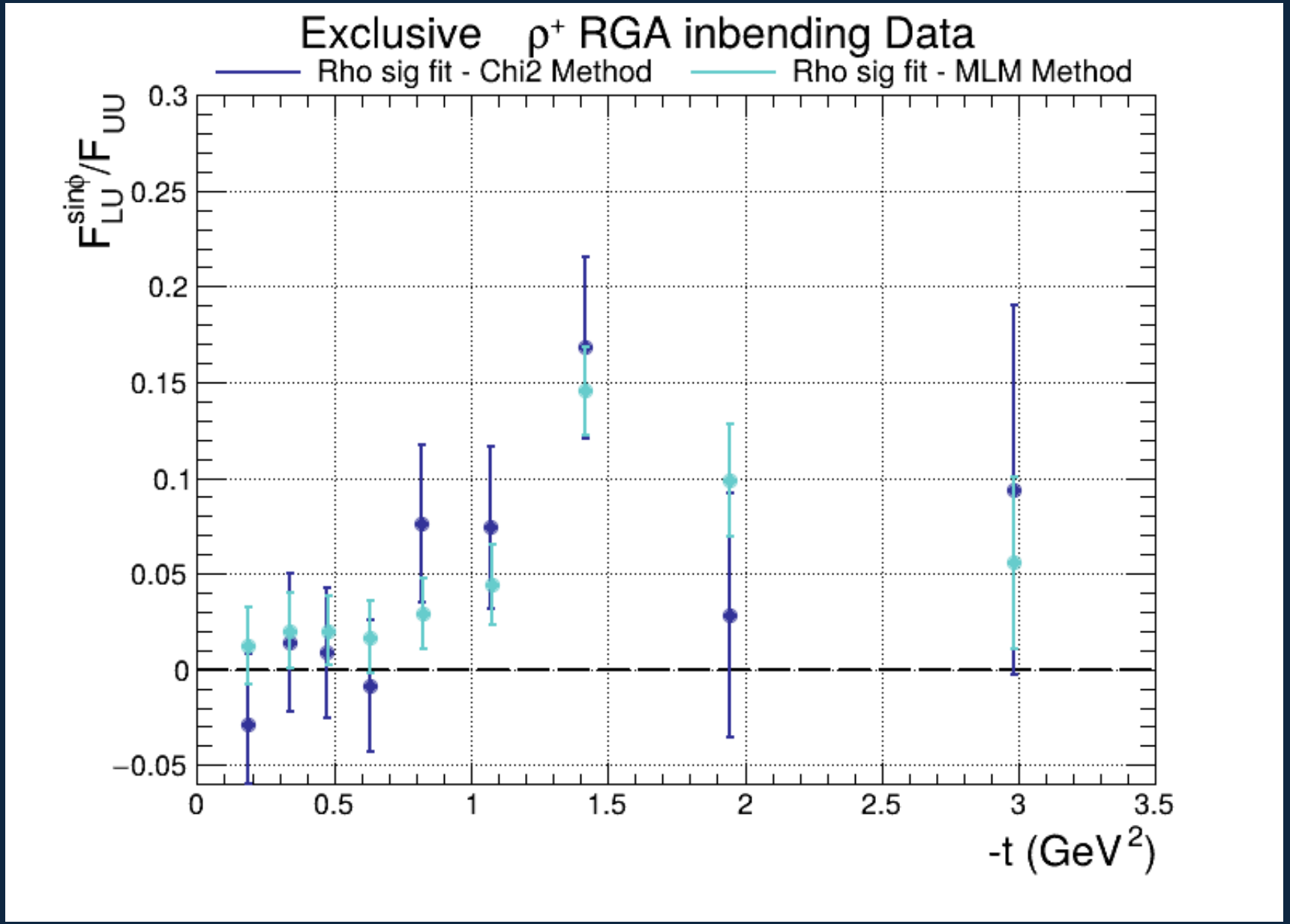
Voigtian Signal, 2nd order Chebychev background





Results

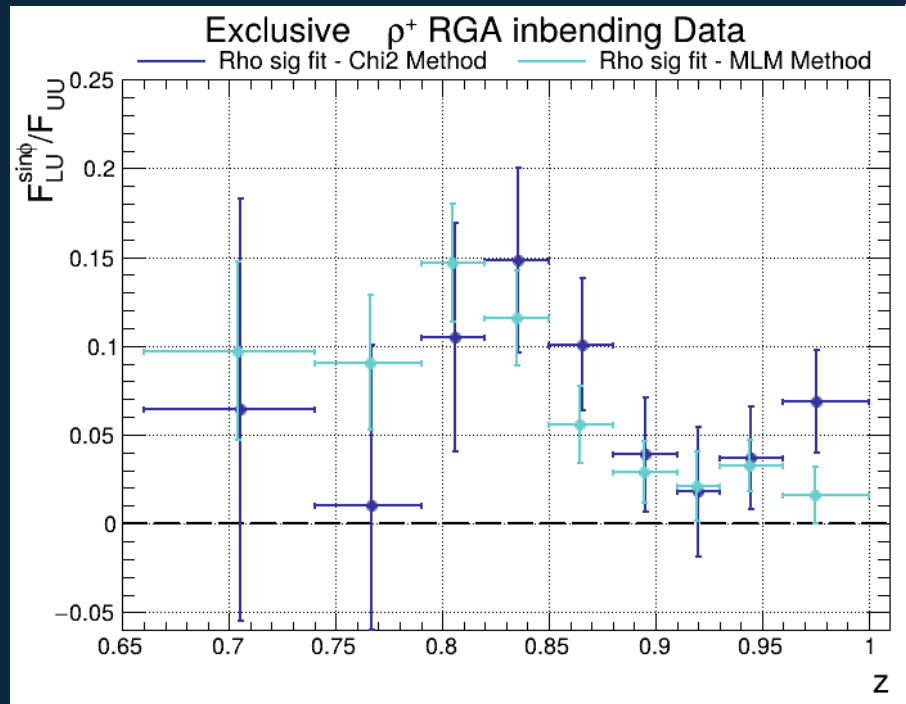
- Good agreement between two separate methods of Fitting.
- MLM has smaller statistical uncertainty

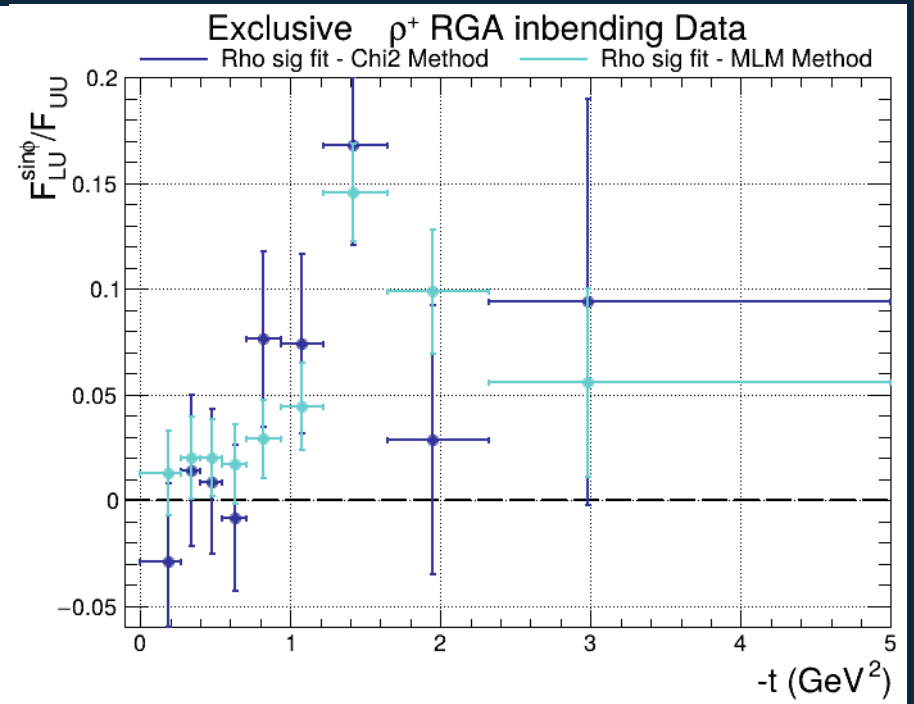


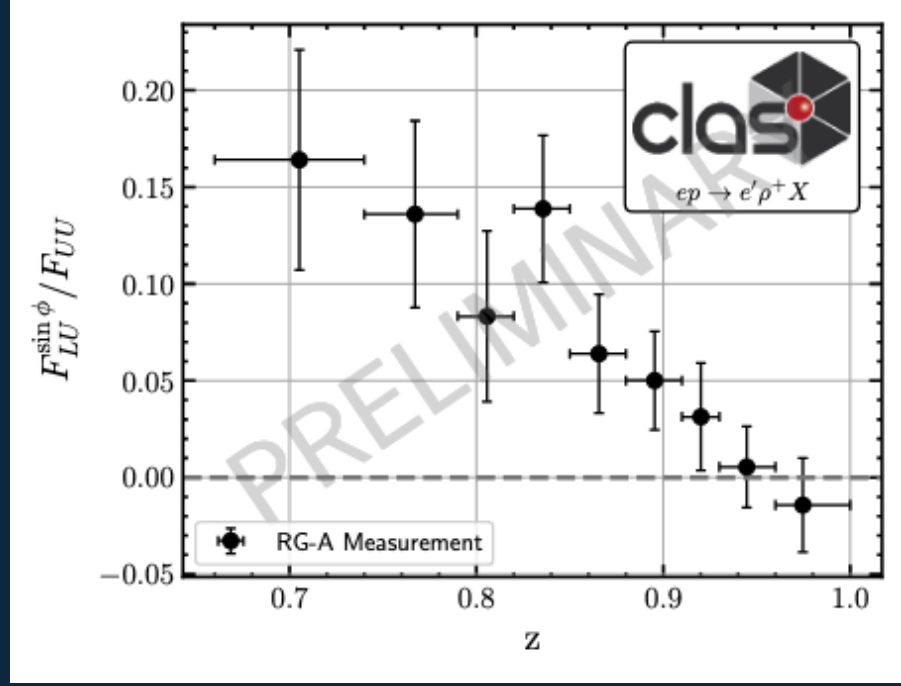
Comparisons

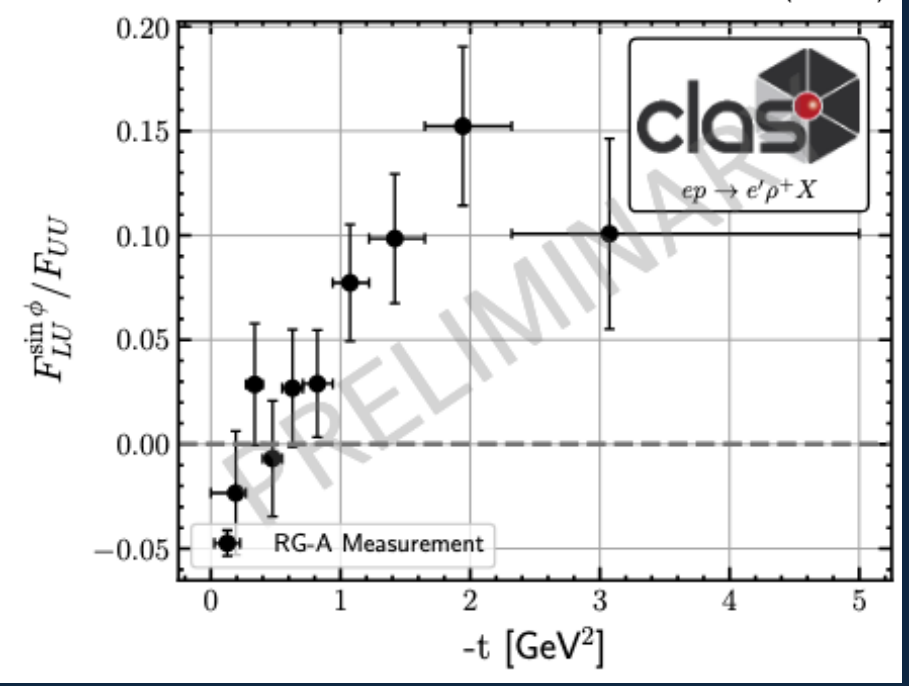
Consistency Check with Gregory Matousek's Release Note Results

(note – Greg's results are with pass1 RGA data)



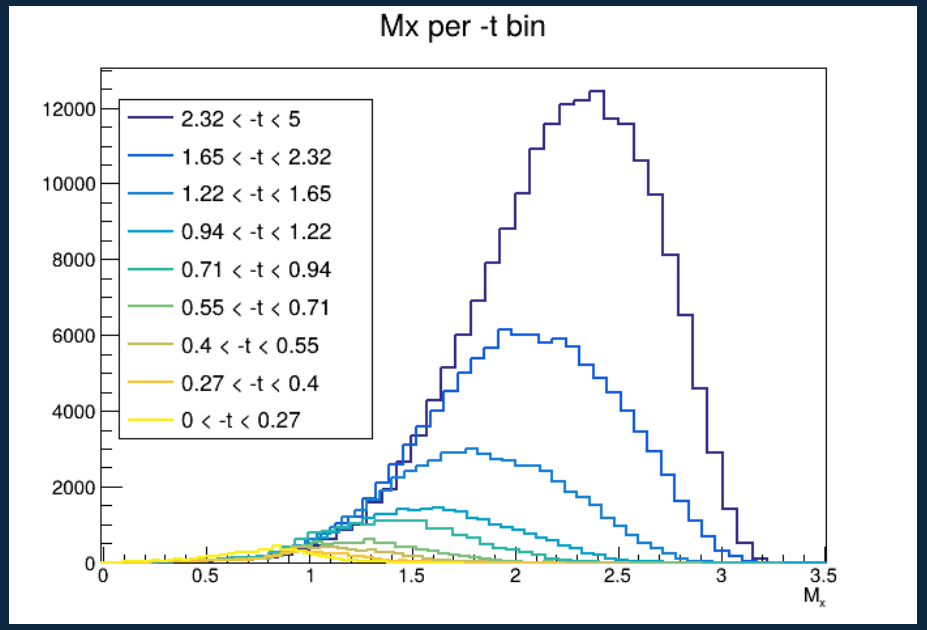


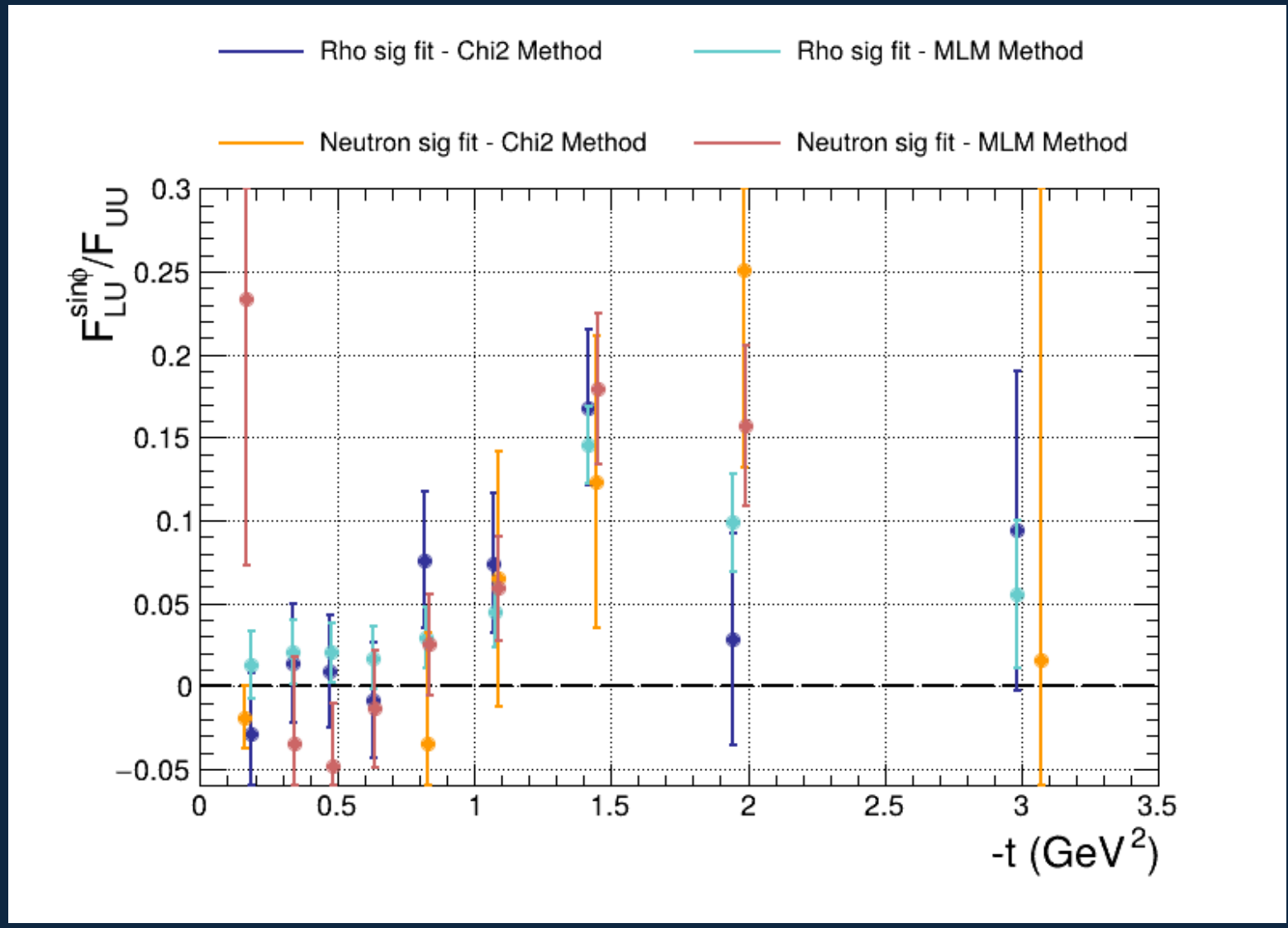




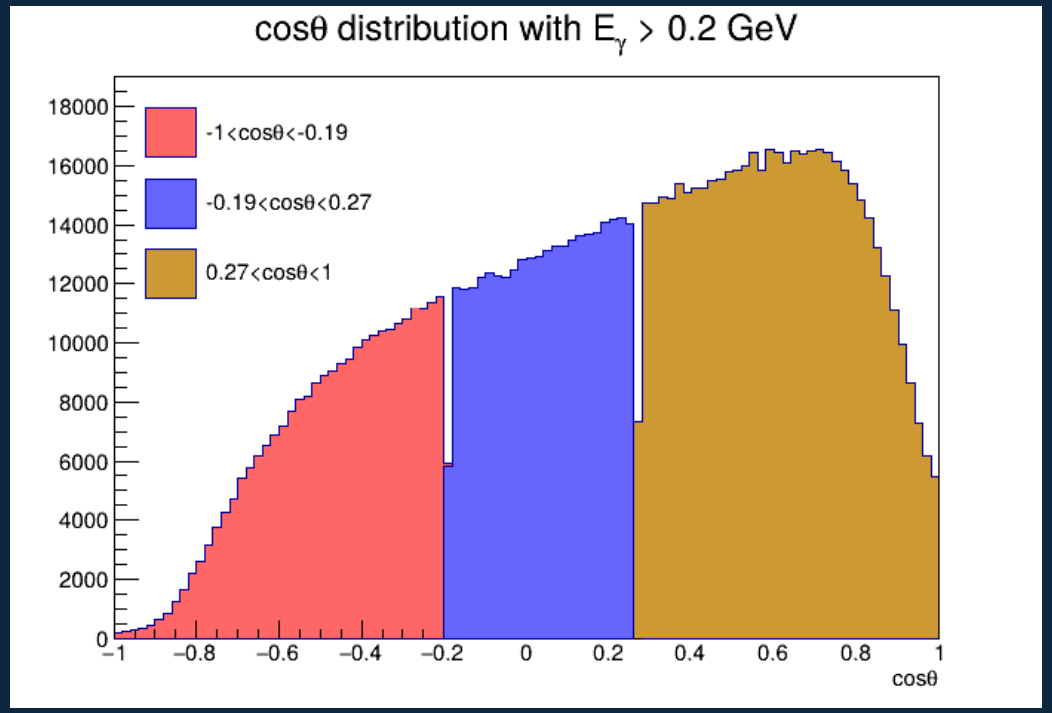
Signal Fitting the Neutron Peak

Mx signal fitting is unreliable at extremes due to high background at high –t and low statistics at low –t.



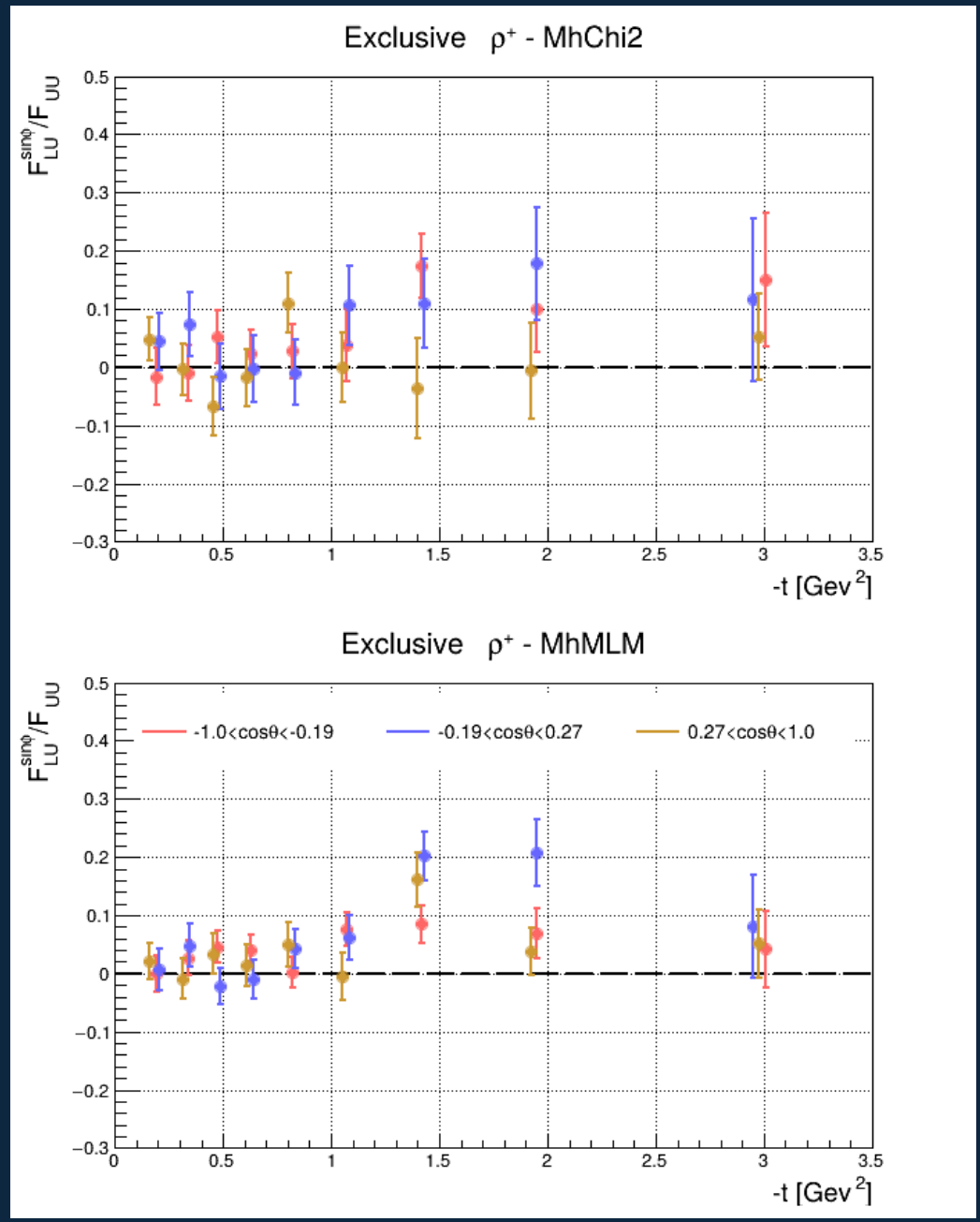


cos θ Dependencies



$$W_{XY}(\phi,\varphi,\vartheta) = \frac{3}{4\pi}\left[\cos^2\vartheta\, W_{XY}^{LL}(\phi) + \sqrt{2}\cos\vartheta\,\sin\vartheta\, W_{XY}^{LT}(\phi,\varphi) + \sin^2\vartheta\, W_{XY}^{TT}(\phi,\varphi)\right]$$

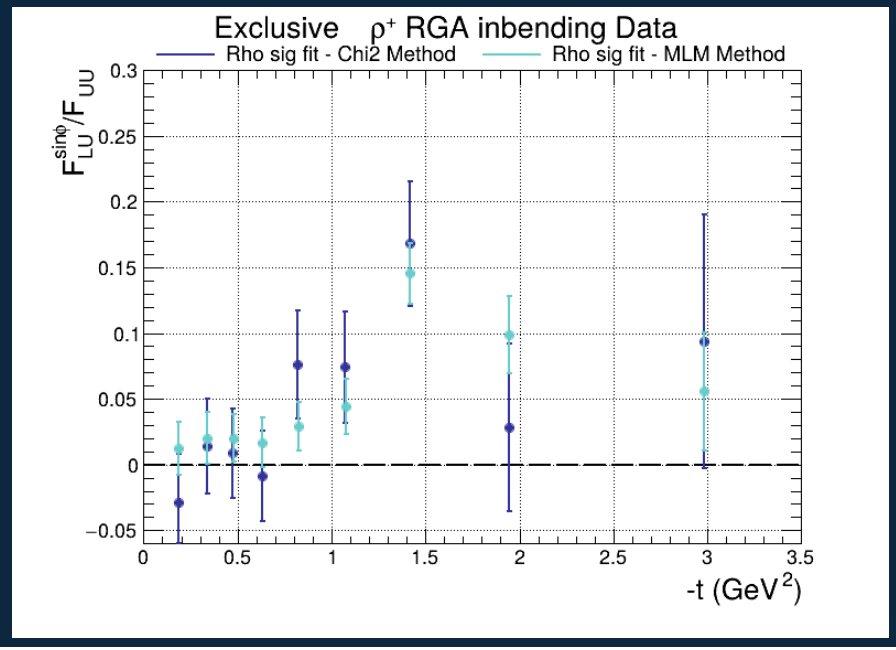
M. Diehl 10.1088/1126-6708/2007/09/064

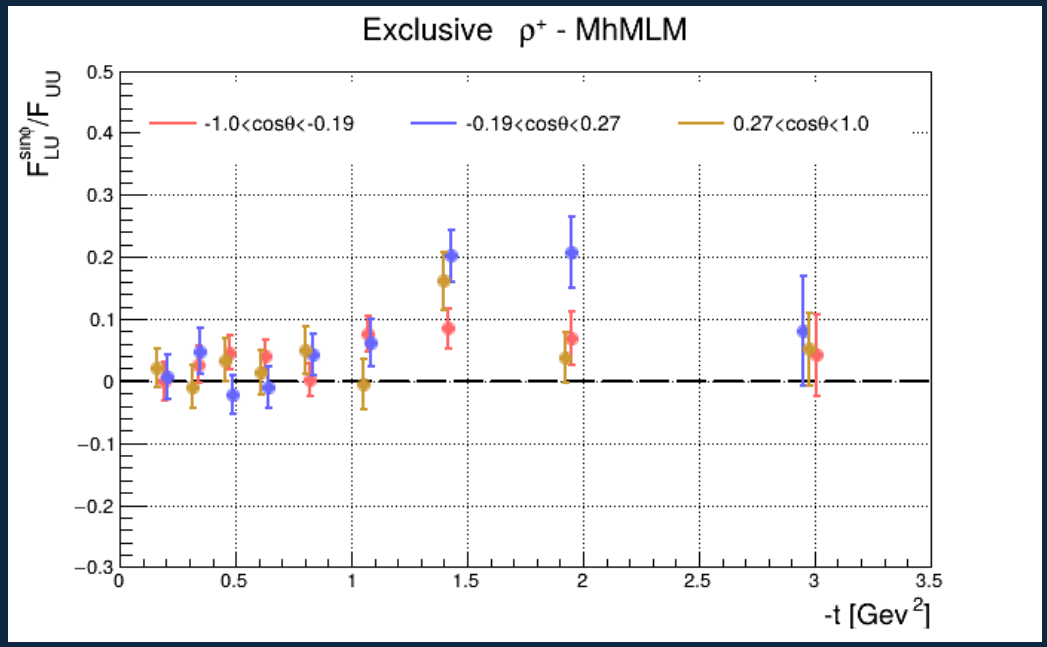


Conclusions and Future Work

Future Work:

- Systematic Studies
- Interpretation and connection to GPDs and SDMEs
- Make these results available for SIDIS single hadron background subtraction
- Apply this analysis toward RGC to get Target and Double Spin Asymmetries



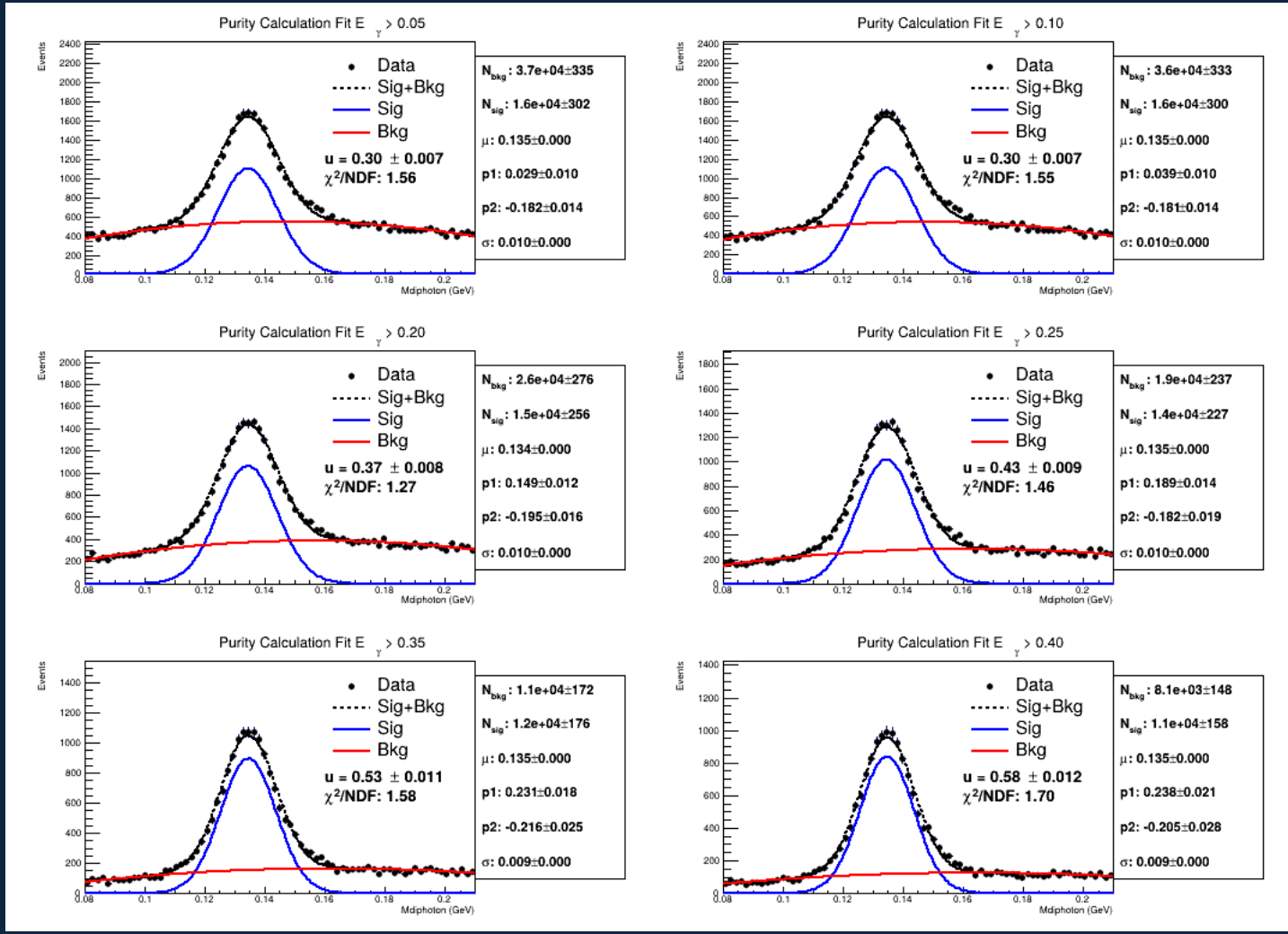


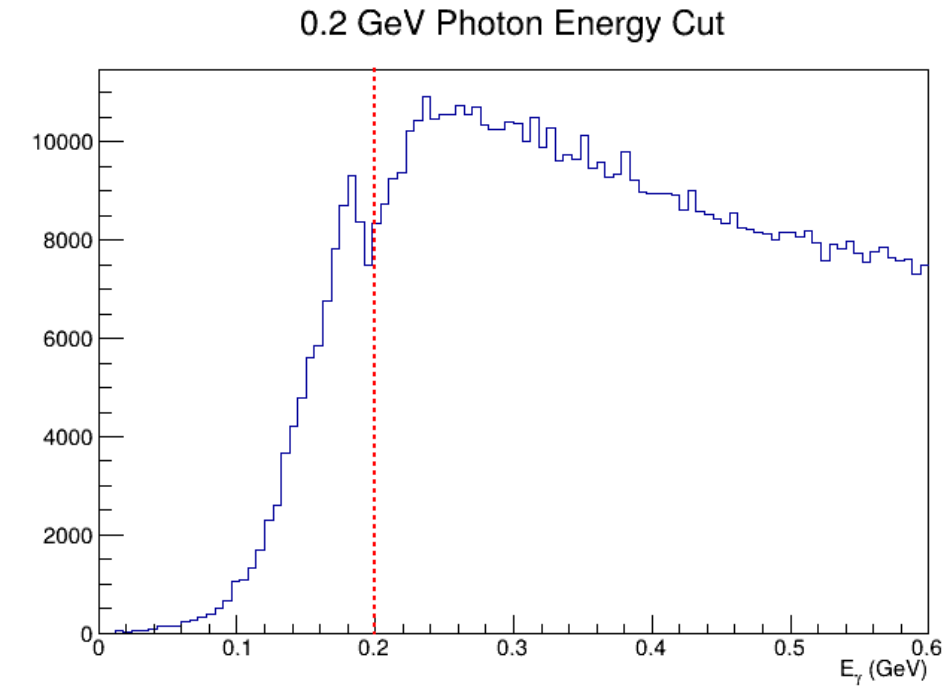
Thank you!

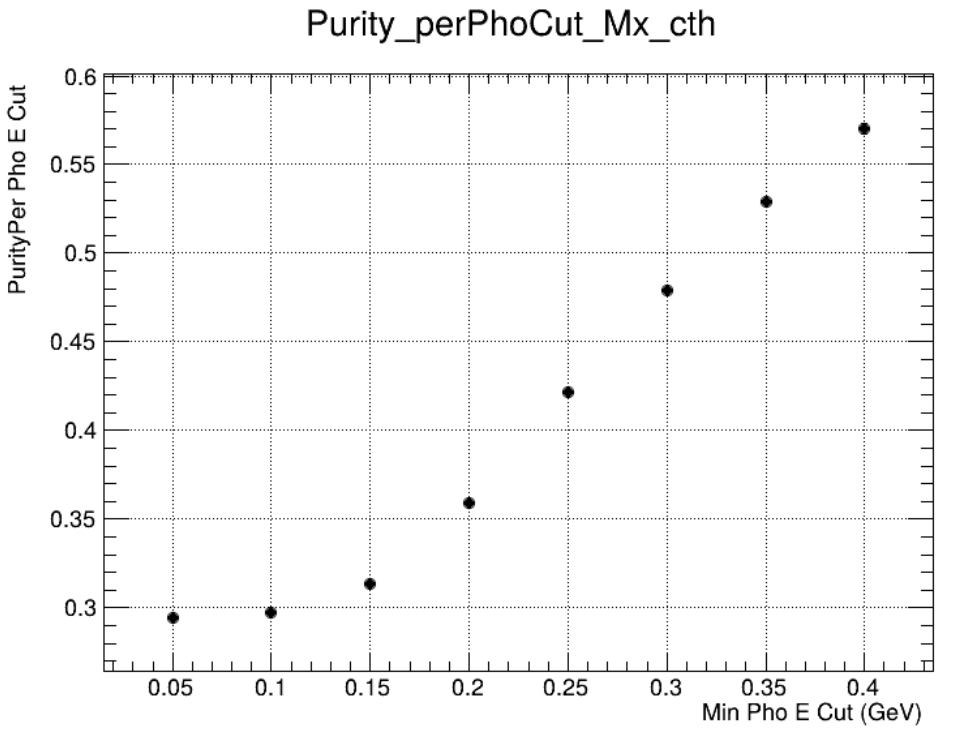
Questions?

Photon Background

$\pi^0 \rightarrow \gamma\gamma$

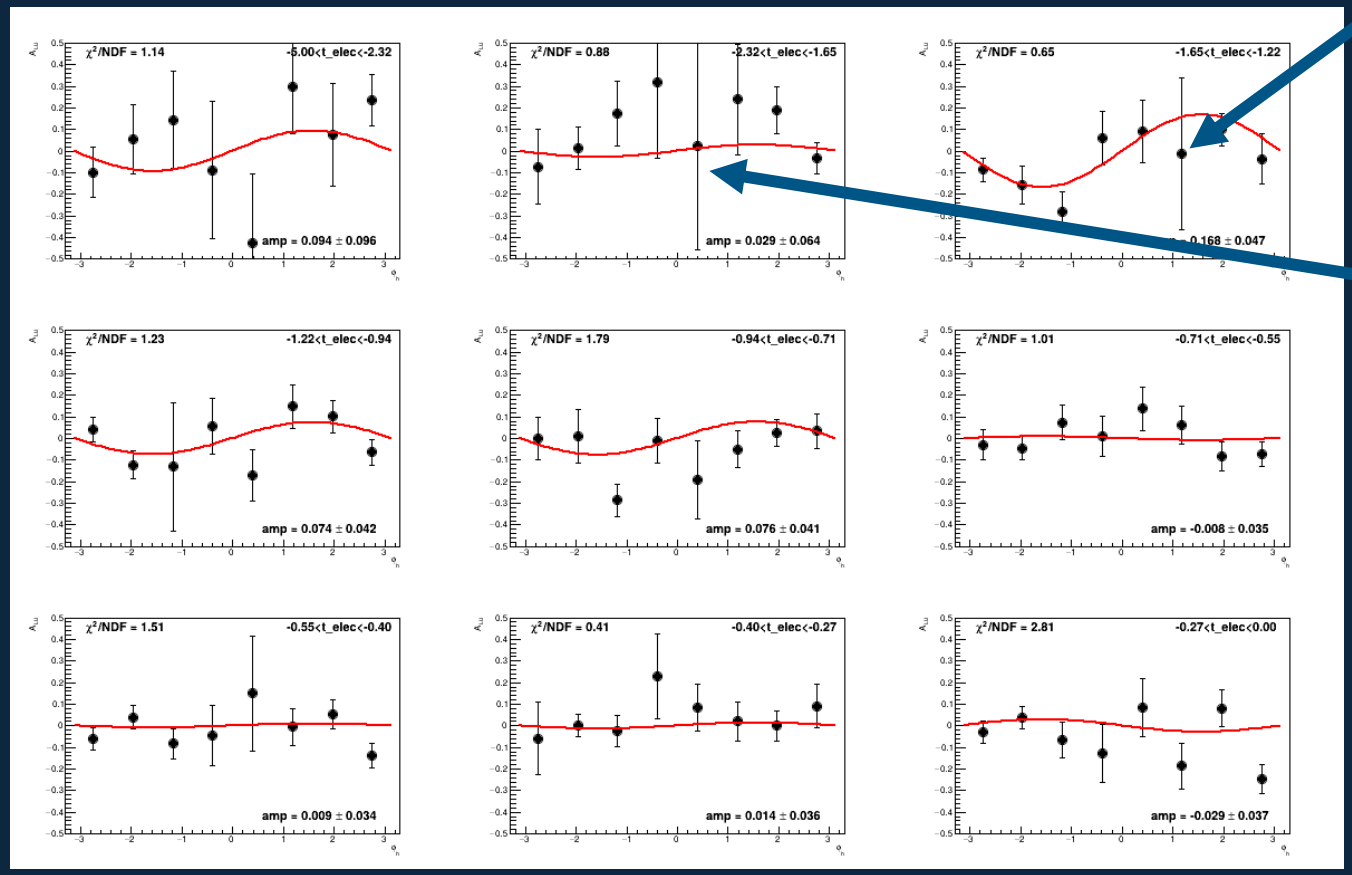


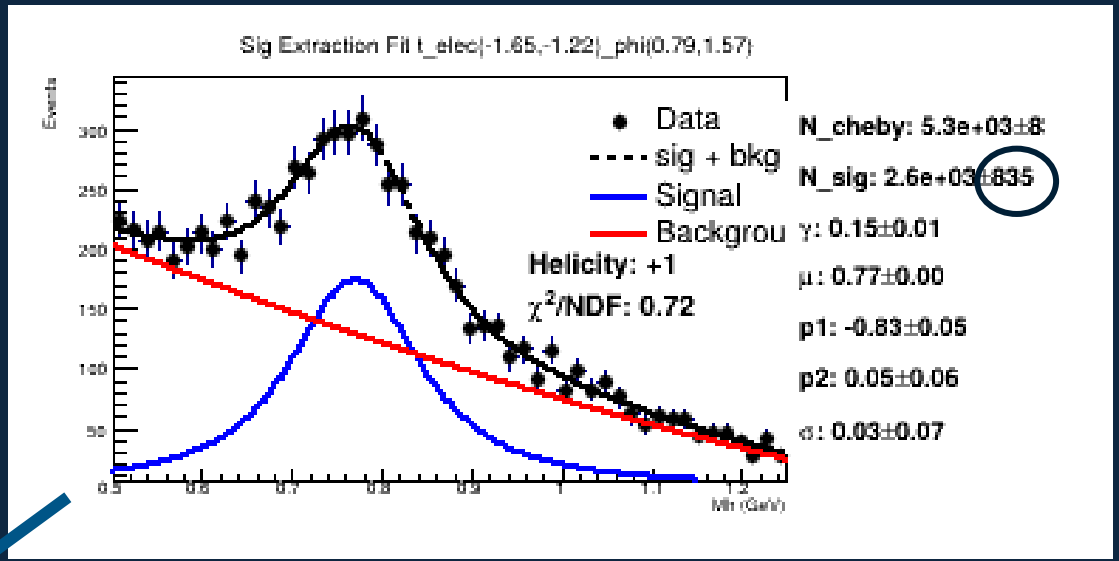


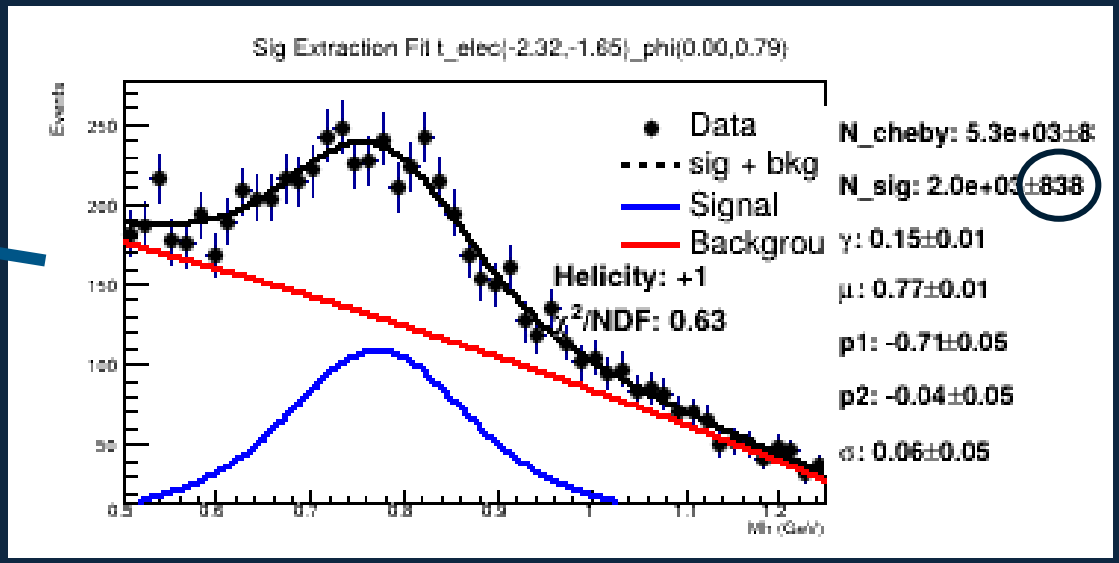


Chi2 Uncertainties

Uncertainties in the Chi2 method are dominated by fit uncertainties, which

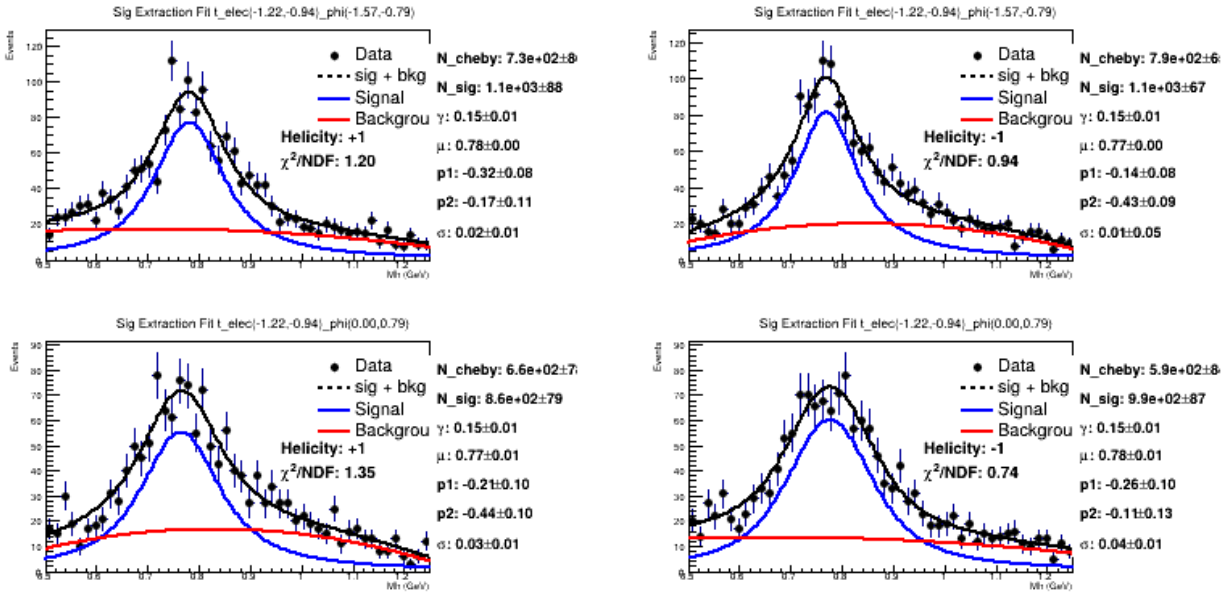






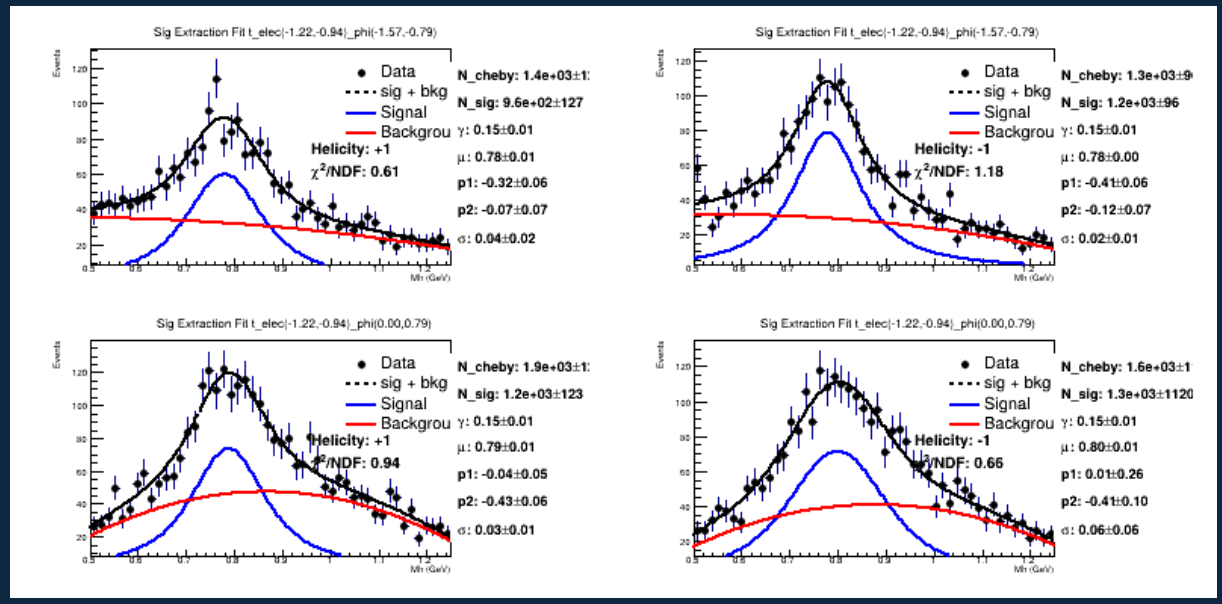
Mh Chi2 Fitting Details

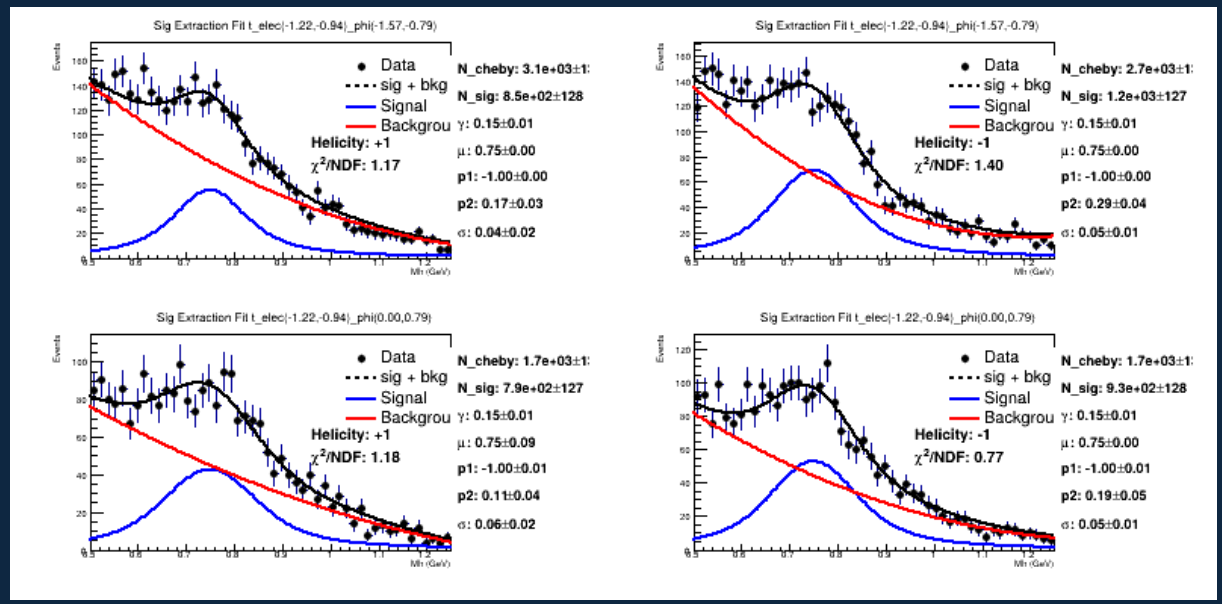
$-1 < cos\theta < -0.19$



High cos θ bins hold low energy photons, which adds background to the left tail of the Rho peak

$-0.19 < cos\theta < -0.27$

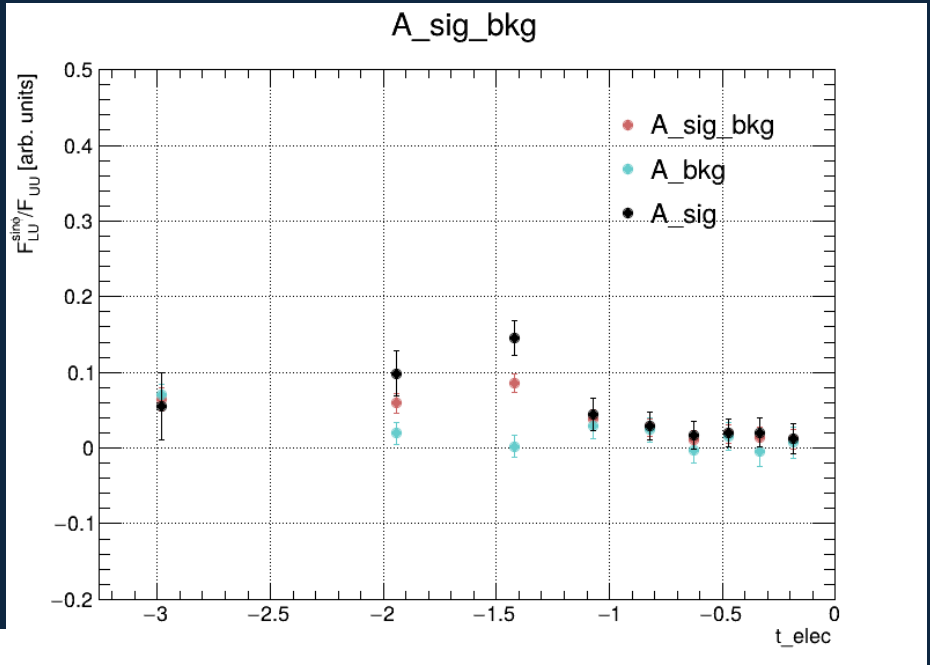


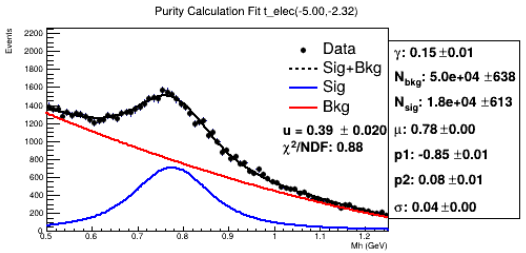


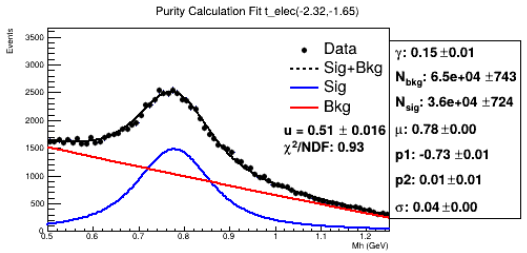
$-0.27 < cos\theta < 1$

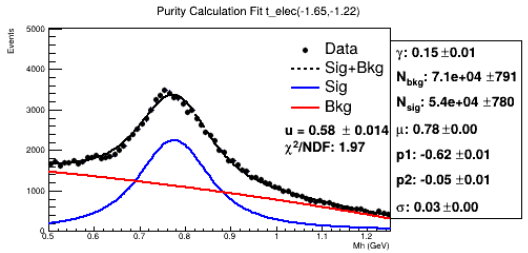
Mh MLM Fitting Details

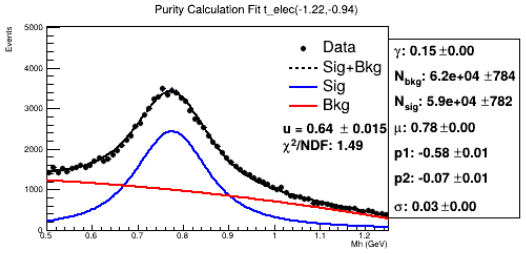
Purity Fitting Performs for each t bin

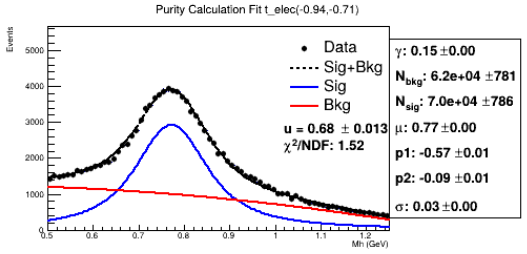


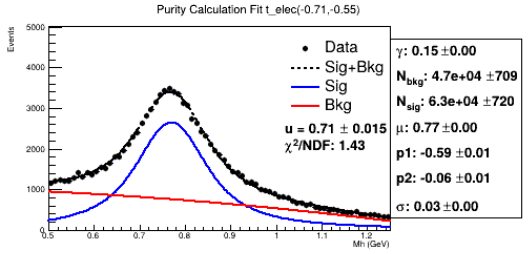


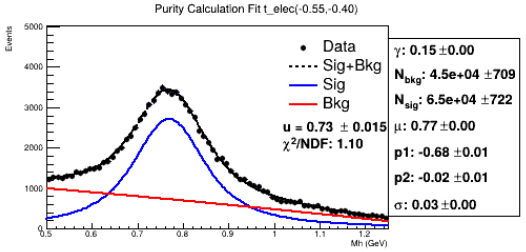


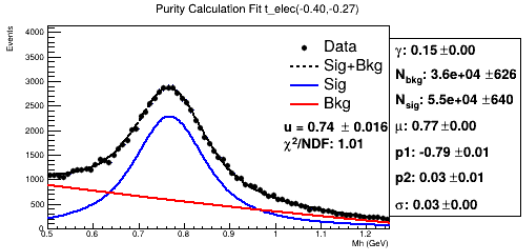


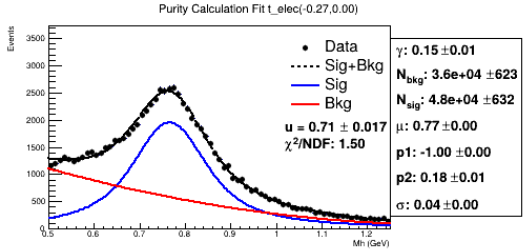




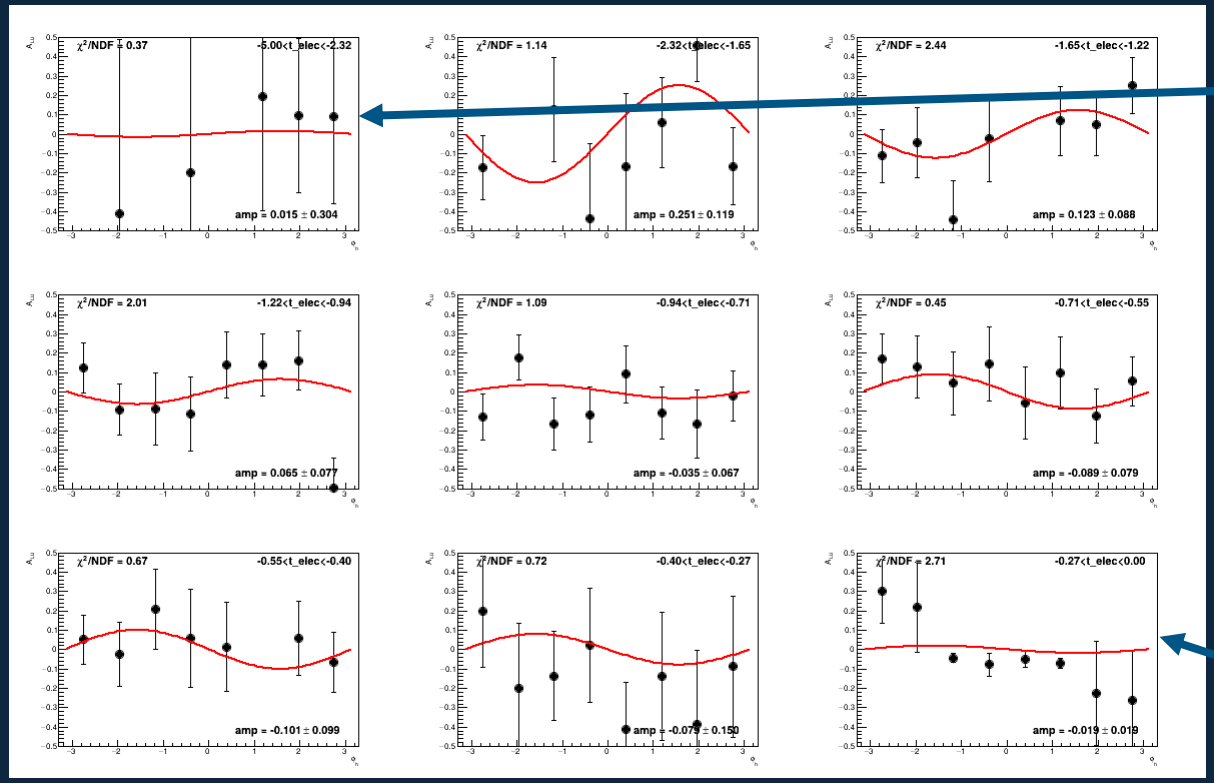


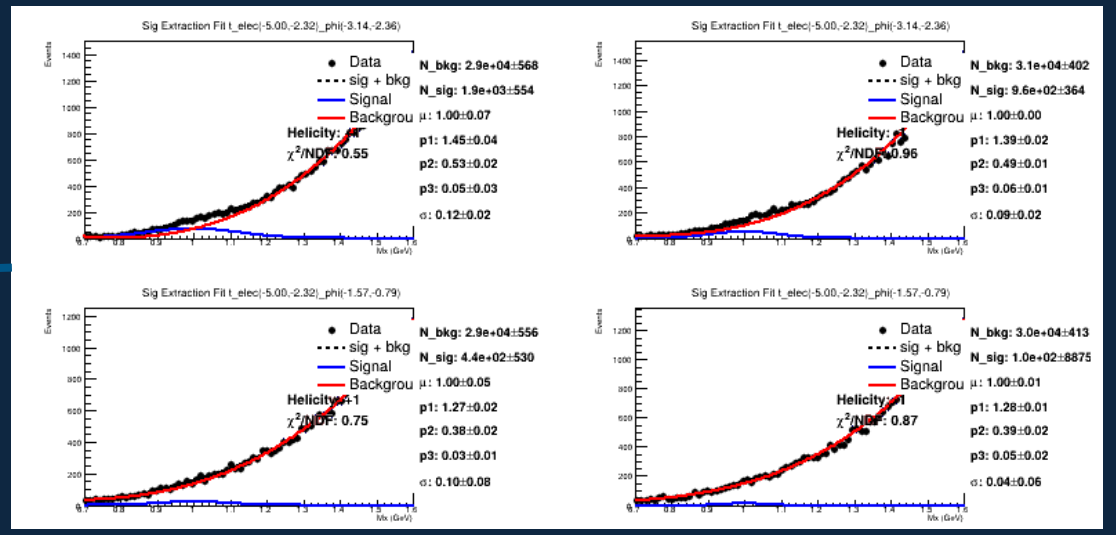


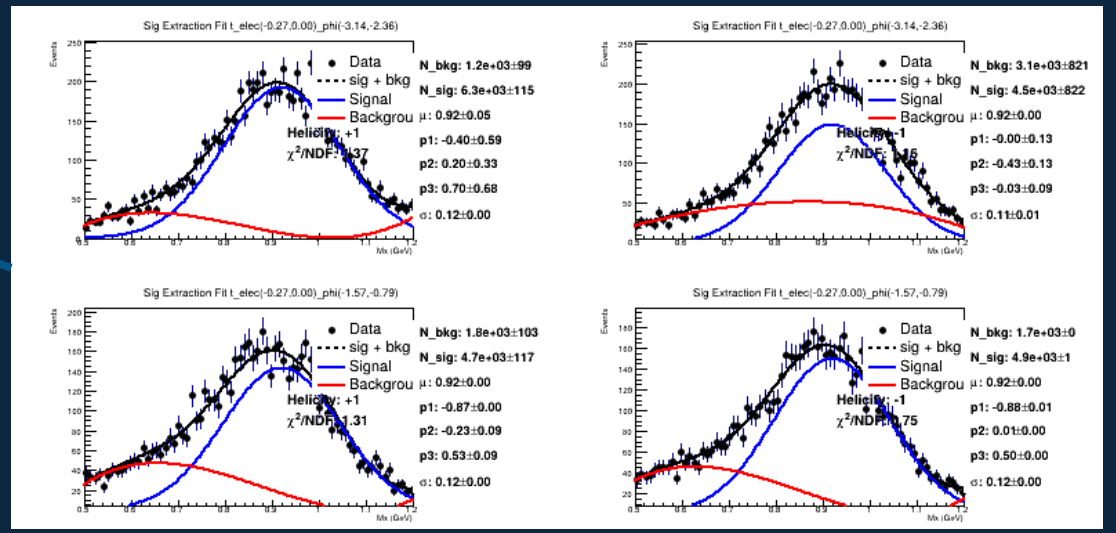




Neutron Signal Fitting – Chi2







Neutron Signal Fitting – MLM