Multi-Dimensional Analysis of the ep → e'p'+X SSA

(For the CLAS12 Collaboration at Jefferson Lab)

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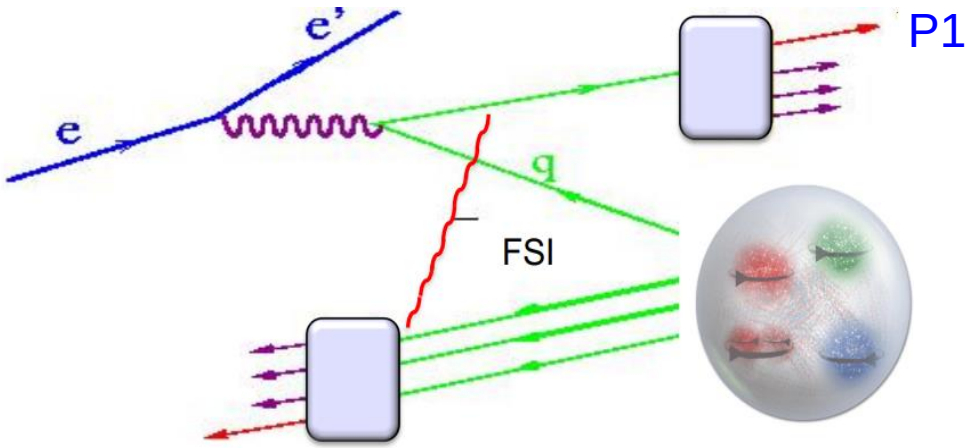
DUQUESNE UNIVERSITY

NSF

Target/Current Fragmentations

X_F – frac. Momentum in the CM frame

Current fragmentation, $x_F>0$

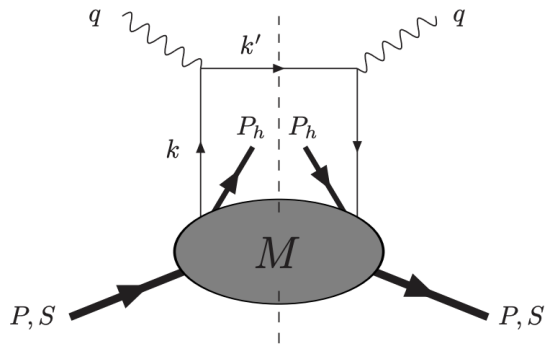


Target fragmentation, $x_F<0$

Karliner, Kharzeev , Ellis & Kotzinian, Strikman,Weiss & Schweitzer, Anselmino, Barone, Kotzinian

- **TMDs and Fragmentation Functions have been extensively studied through azimuthal modulations of a final state hadron (P1) generated in the fragmentation of a struck quark (CFR).**

- **Final state hadrons can also form from the left-over target remnant (TFR) whose partonic structure is defined by "Fracture Functions": the probability to form a certain hadron (P2) given a particular ejected quark.**



Phys. Lett. B. 699 (2011), 108-118, [hep-ph] 1102.4214

N \ q	U	L	T
U	$\tilde{u}_2^{\perp h}$	$\tilde{l}_2^{\perp h}$	$\tilde{t}_2, \tilde{e}_2$
L	$\tilde{u}_{2L}^{\perp h}$	$\tilde{l}_{2L}^{\perp h}$	$\tilde{t}_{2L}, \tilde{e}_{2L}$
T	$\tilde{u}_{2T}^{\perp h}, \tilde{u}_{2T}^{\perp h}$	$\tilde{l}_T, \hat{l}_{2T}^{\perp h}$	$\tilde{t}_{2T}^h, \tilde{e}_{2T}^h, \tilde{t}_{2T}^{\perp h}, \tilde{e}_{2T}^{\perp h}$

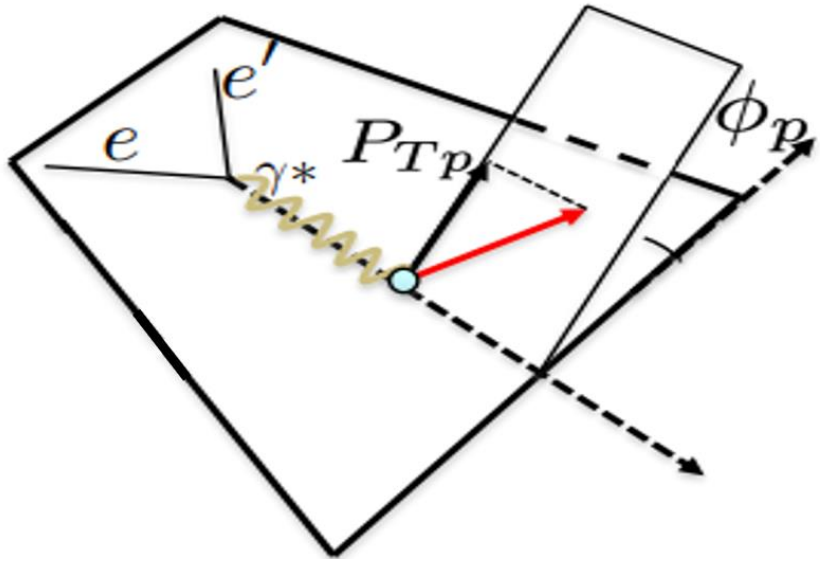
Twist-3 quark collinear FrFs.

Understanding of target fragmentation azimuthal distributions will help with interpretation of the azimuthal distributions in the current fragmentation region.

SSA Extraction for $\vec{e}p \rightarrow e'p'+X$

$$\frac{d\sigma}{dxdyd\zeta dP_T^2 d\phi_h} = \hat{\sigma}_U \Big\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)} F_{UU}^{\cos\phi_h} \cos\phi_h + \varepsilon F_{UU}^{\cos 2\phi_h} \cos 2\phi_h + \lambda_\ell \sqrt{2\varepsilon(1-\varepsilon)} F_{LU}^{\sin\phi_h} \sin\phi_h \Big\}$$

A. Kotzinian, Nucl. Phys., vol. B441, pp. 234–248, 1995.



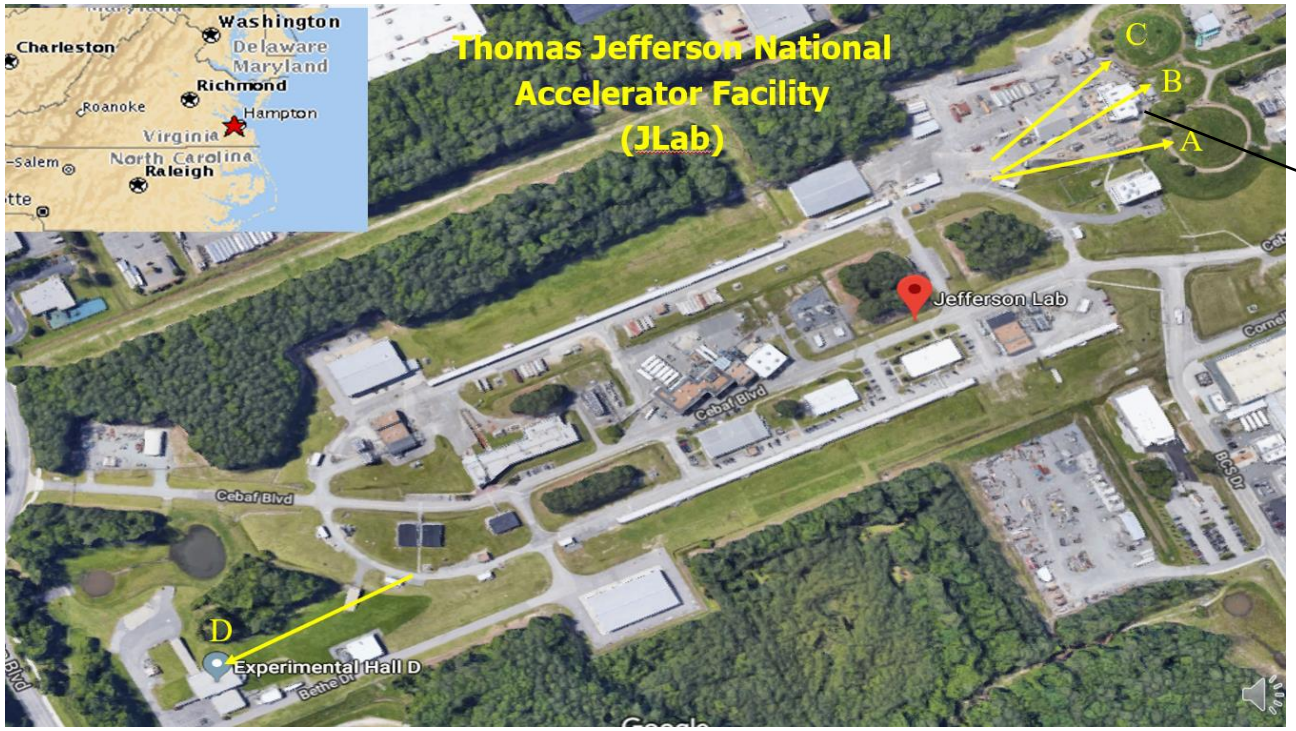
Method: Study Asymmetry modulation :

p0+p1 sin(ϕ) + p2 sin(2 ϕ) for different Variables: P_T, Q^2, x, etc...

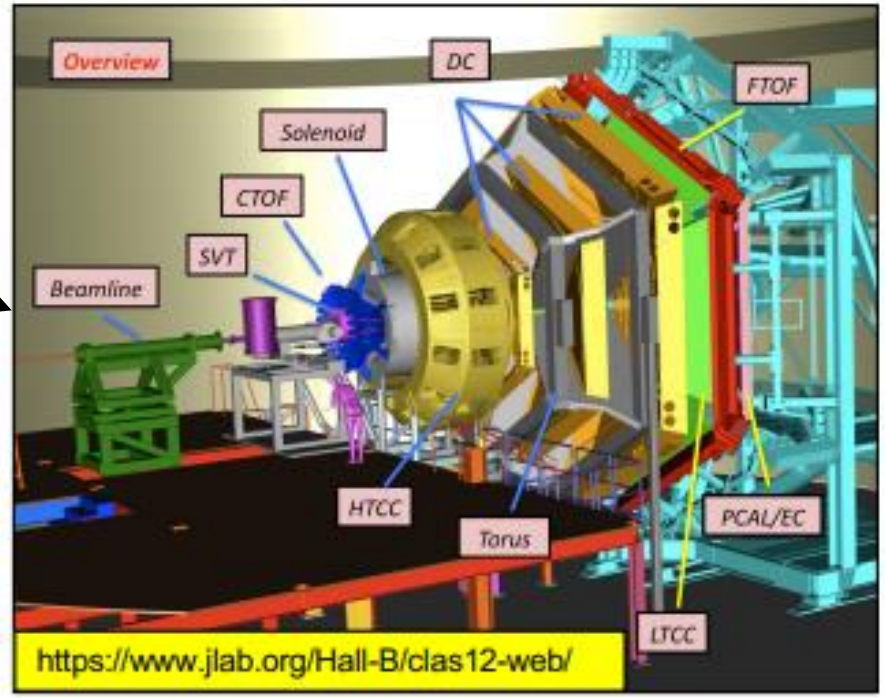
Extract $A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^+ - N^-}{N^+ + N^-}\right)$ → $F_{LU}^{\sin\phi_h} = \frac{A(\phi)_{LU}}{\sqrt{2\varepsilon(1-\varepsilon)}}$

Depol. fac.

The Experiment



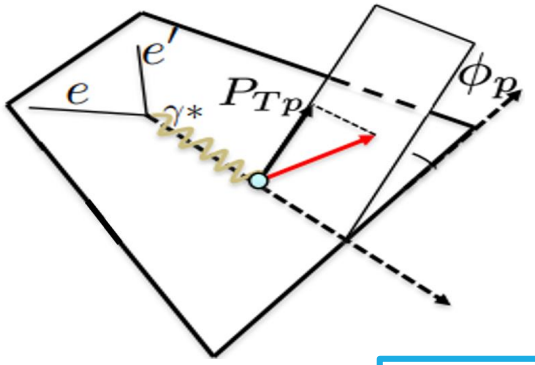
CLAS12 at Jefferson Lab

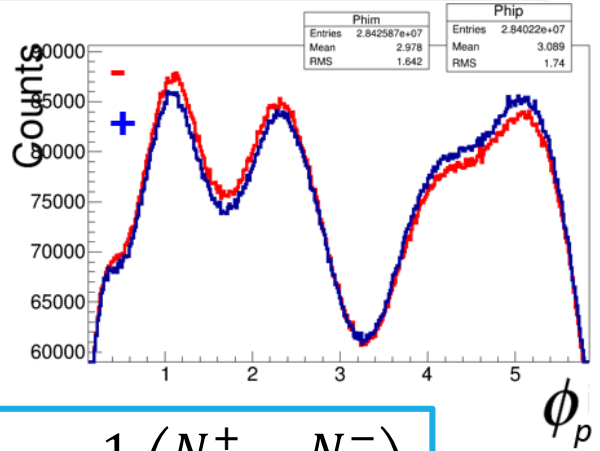


- Data taken in fall 2018 (2019) with 10.6 (10.2) GeV longitudinally polarized electron beam and unpolarized LH_2 target.

- Only fall 2018 data (e-pol 87%) has been analyzed for this channel: **$ep \rightarrow e'p' + X$** , using only forward detector.

- Only **Statistical** uncertainties are presented for these **Preliminary Results.**

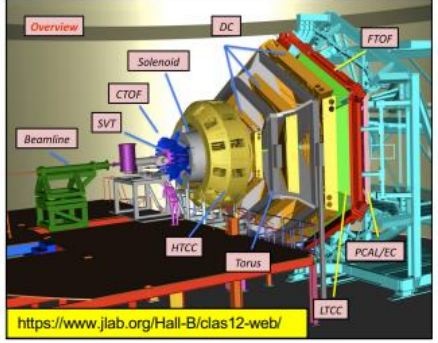




$$A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^+ - N^-}{N^+ + N^-}\right)$$

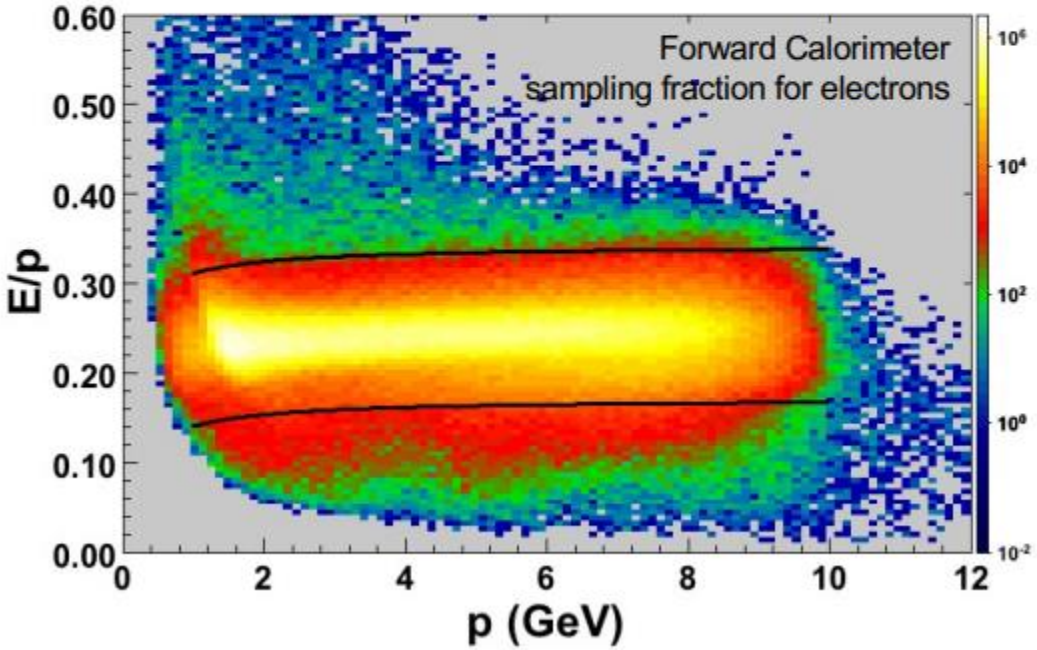
Particle Identification

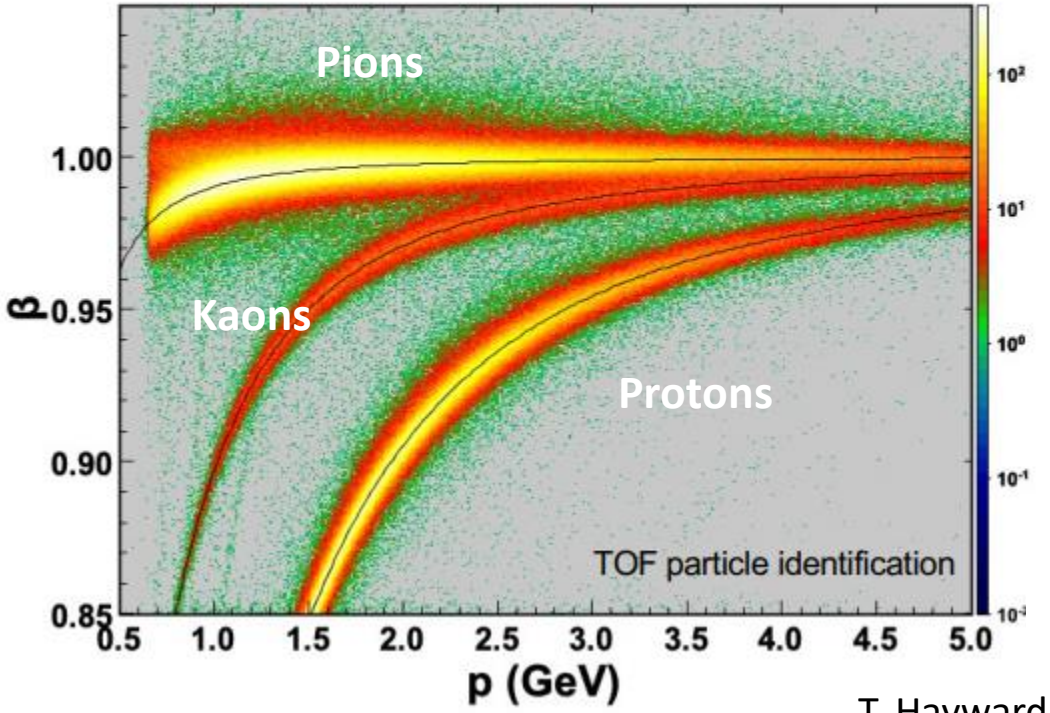
ep → e'p' + X



- Electron
  - Electromagnetic calorimeter.
  - Cherenkov detector.
  - Vertex and fiducial cuts.

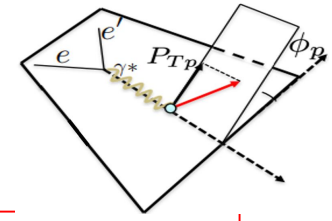
- Hadron
  - β vs p comparison between vertex timing and event start time.
  - Vertex and fiducial cuts.

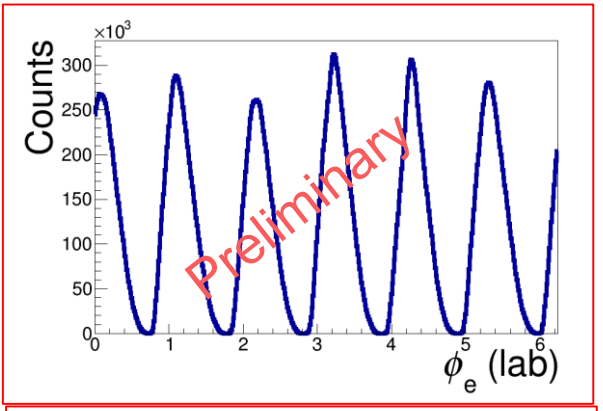


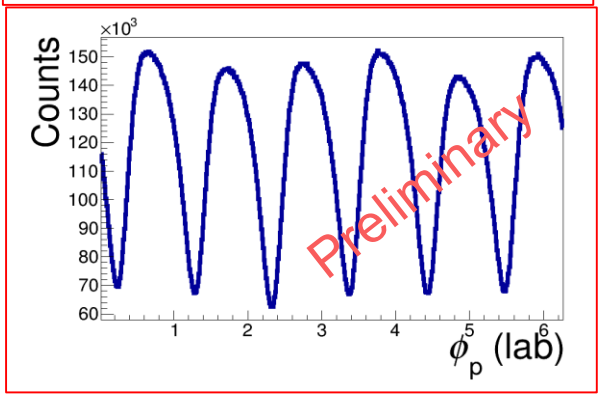


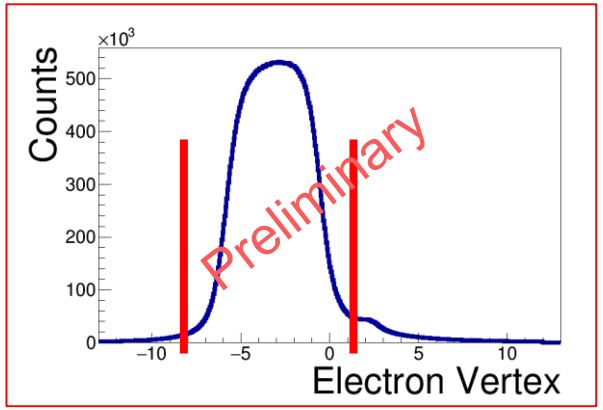
T. Hayward

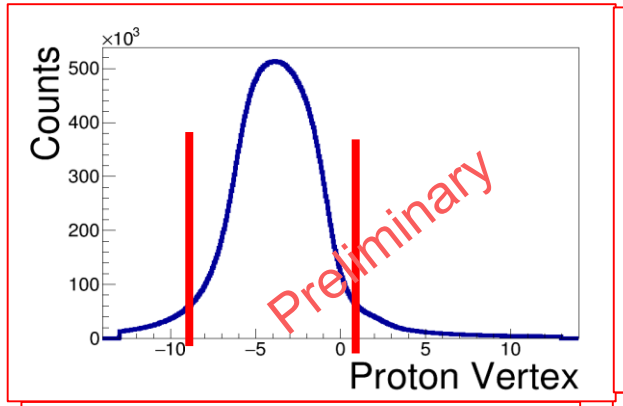
Variables of interest (ep → e'p'+X)

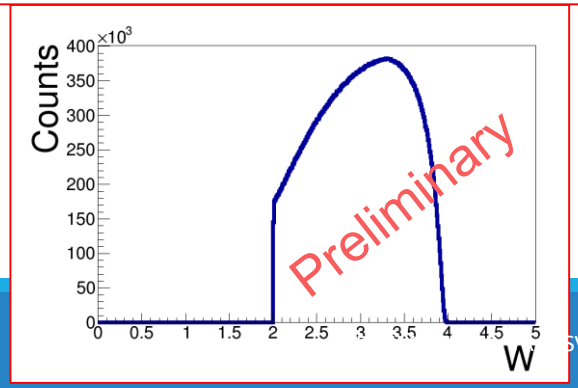


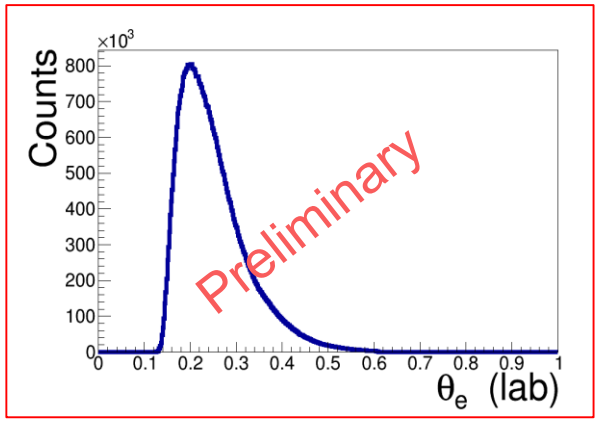


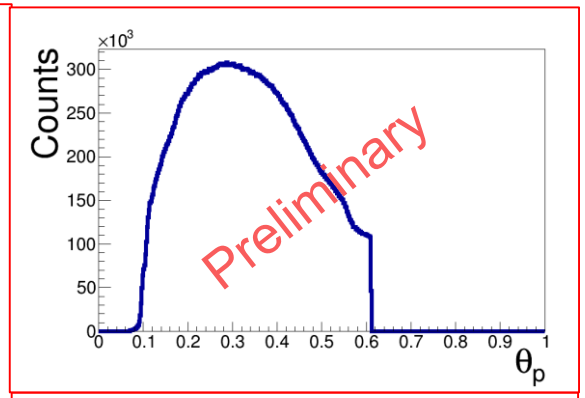


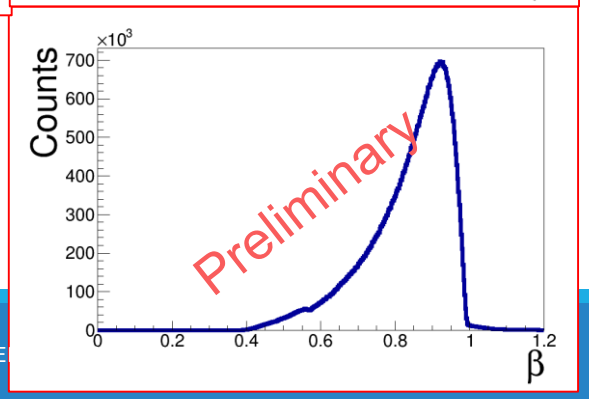


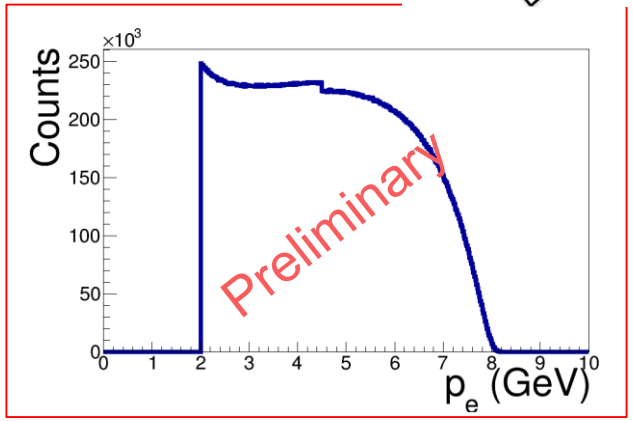


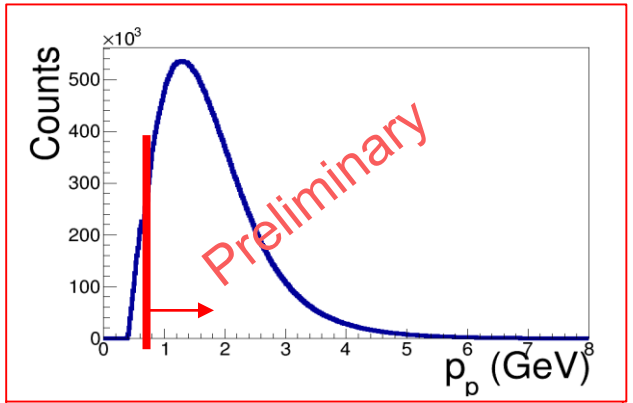


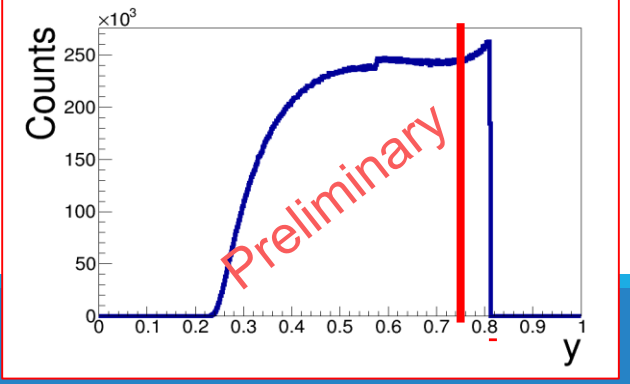


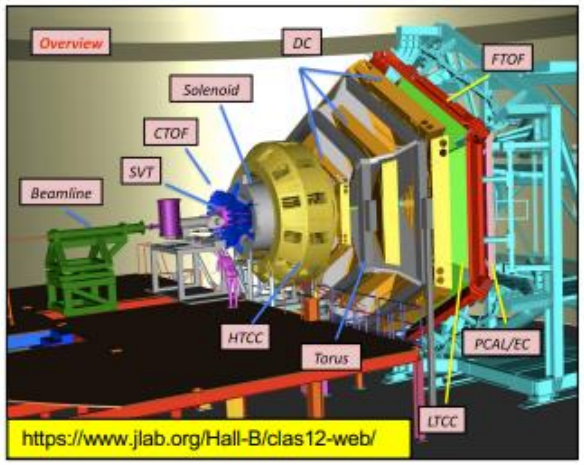




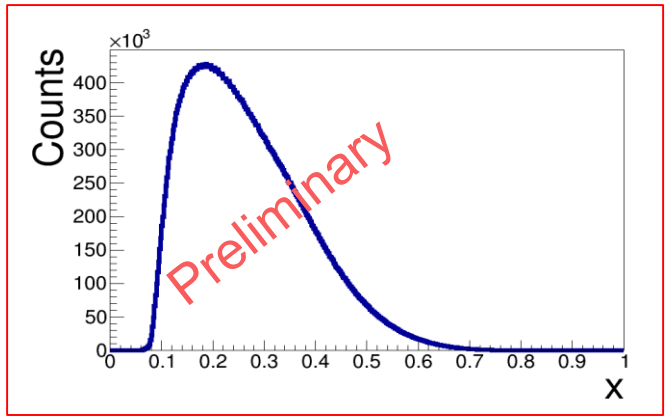


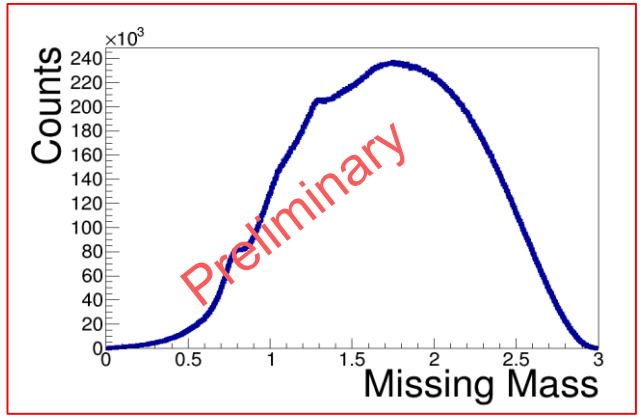


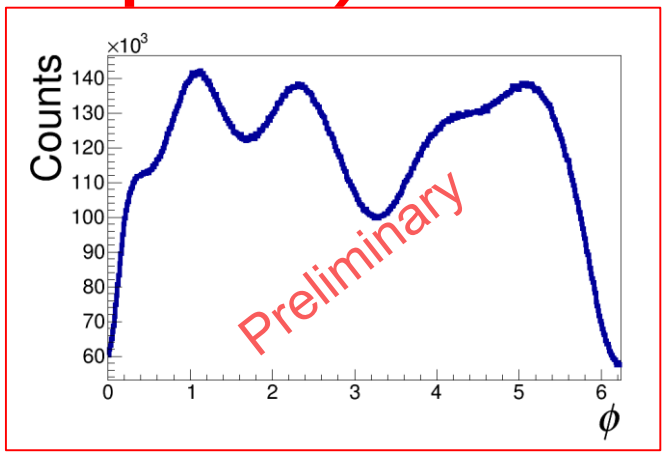


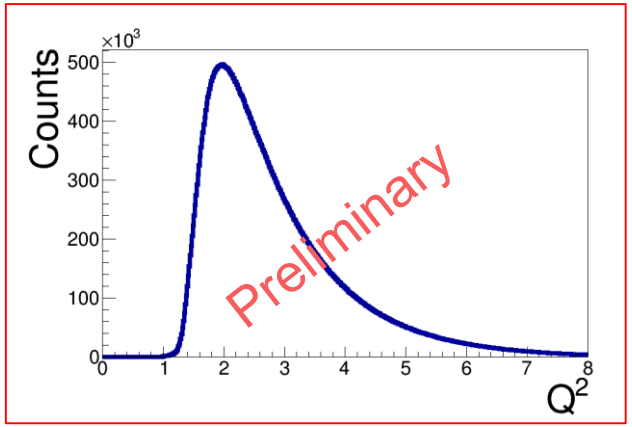


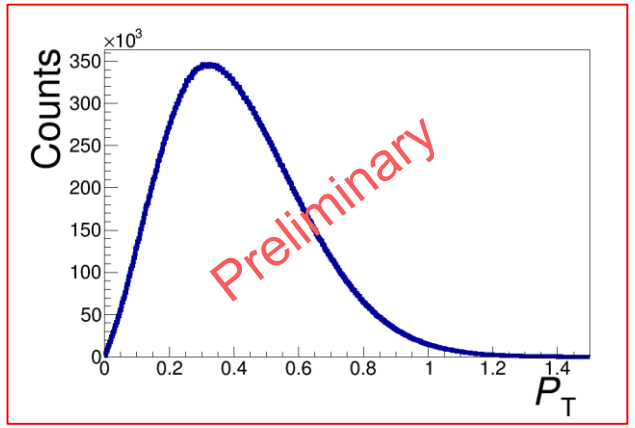
More Variables of interest ($\vec{e}p \rightarrow e'p'+X$)

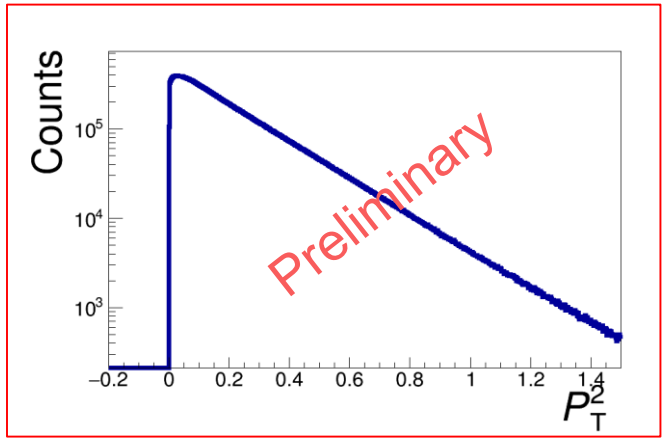


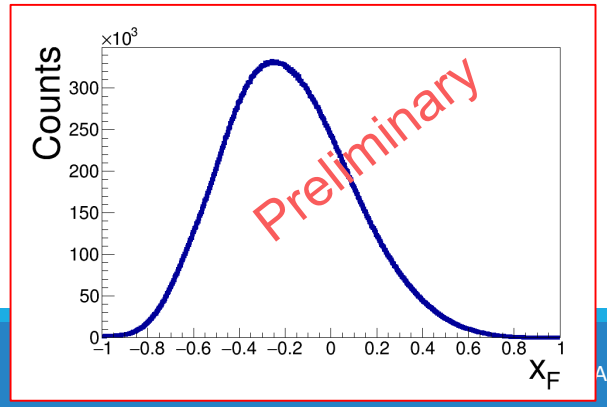


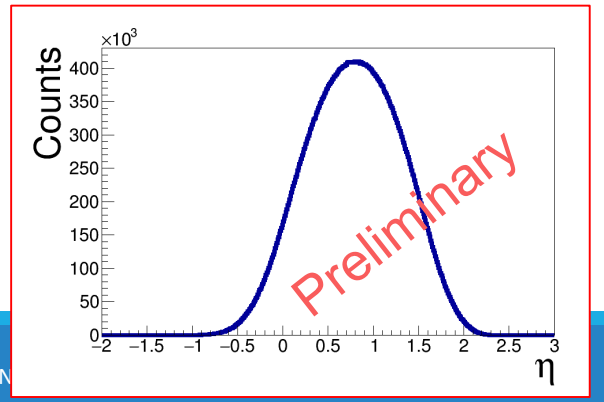


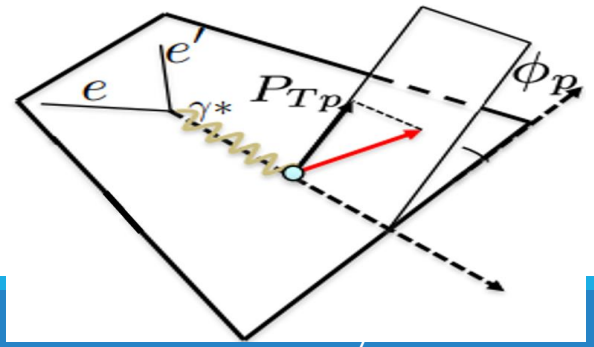


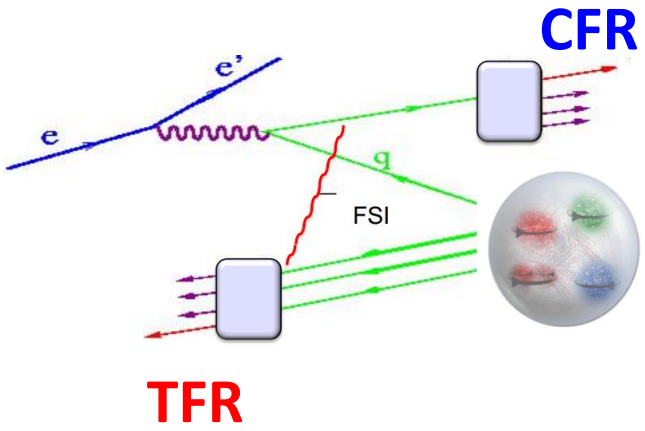










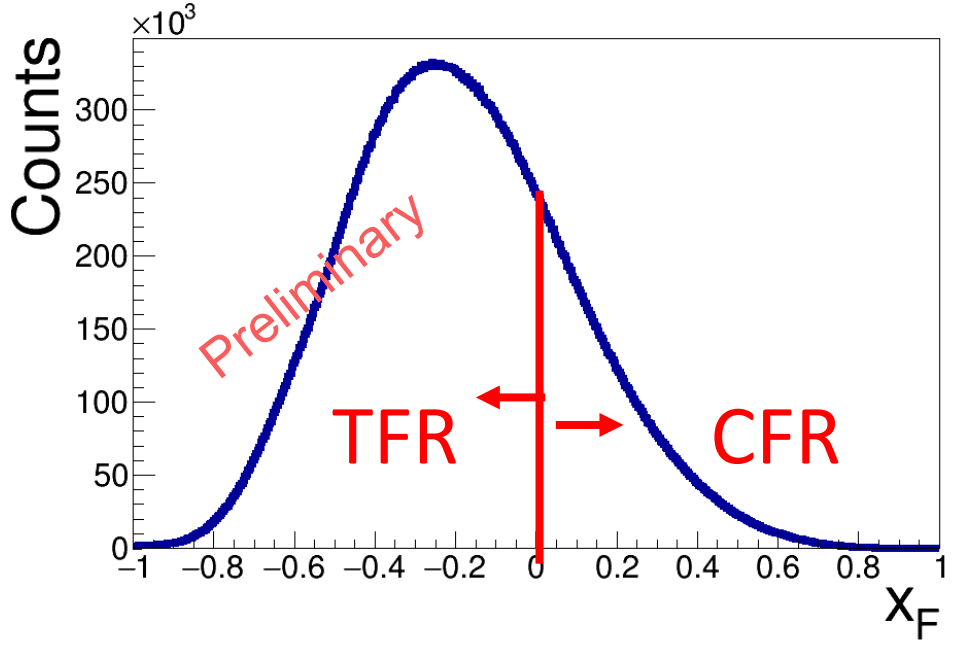


X_F and η

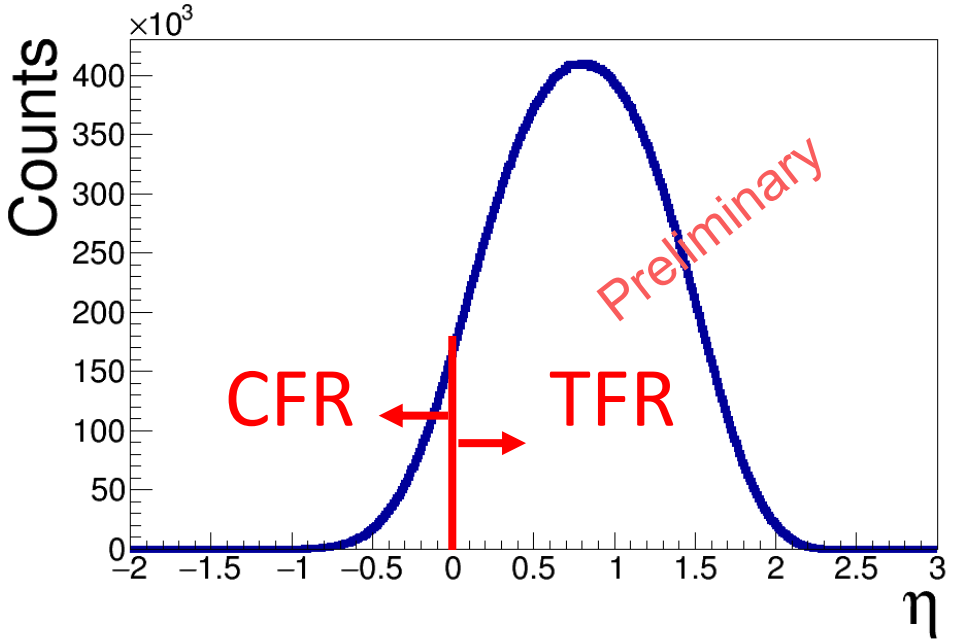
$$x_F = \frac{2P_h \cdot q}{|q|W},$$

$$Y = \frac{1}{2}\log\left[\frac{E_h + p_z}{E_h - p_z}\right],$$

$$\eta = -\ln\sqrt{\frac{x_n^2 M^2 + x_n Q^2}{(1-x_n)Q^2}} - Y,$$



Fraction of longitudinal momentum carried by the hadron in the CM frame

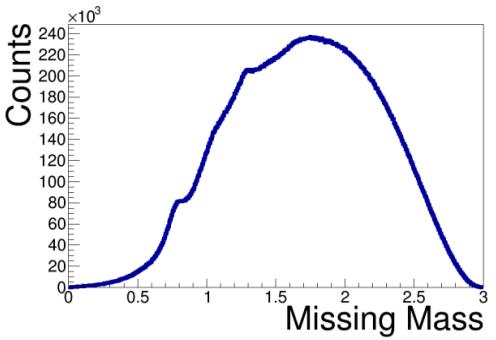


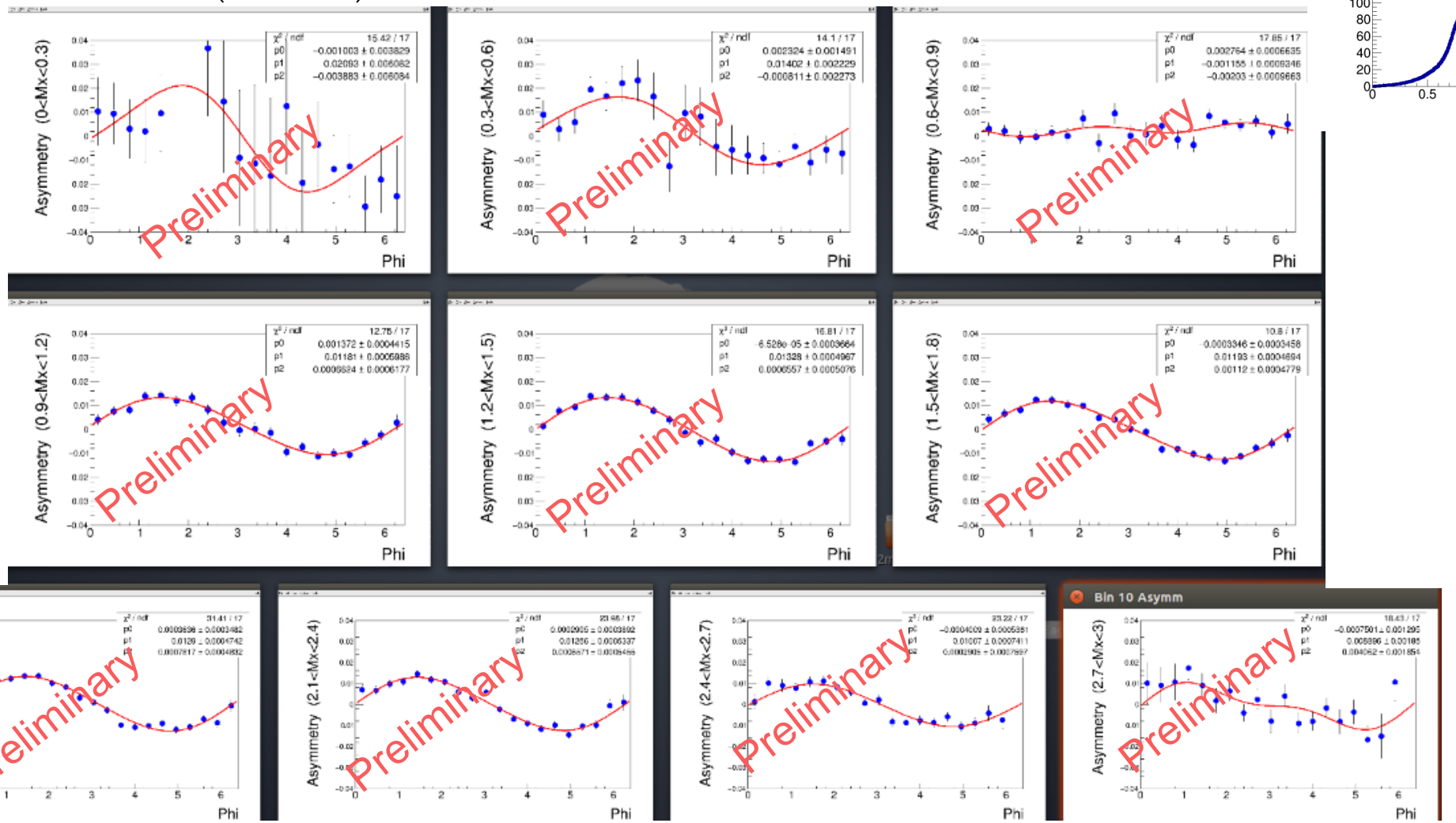
Rapidity in the Breit frame.

Example: Sin(ϕ) modulation vs Missing Mass

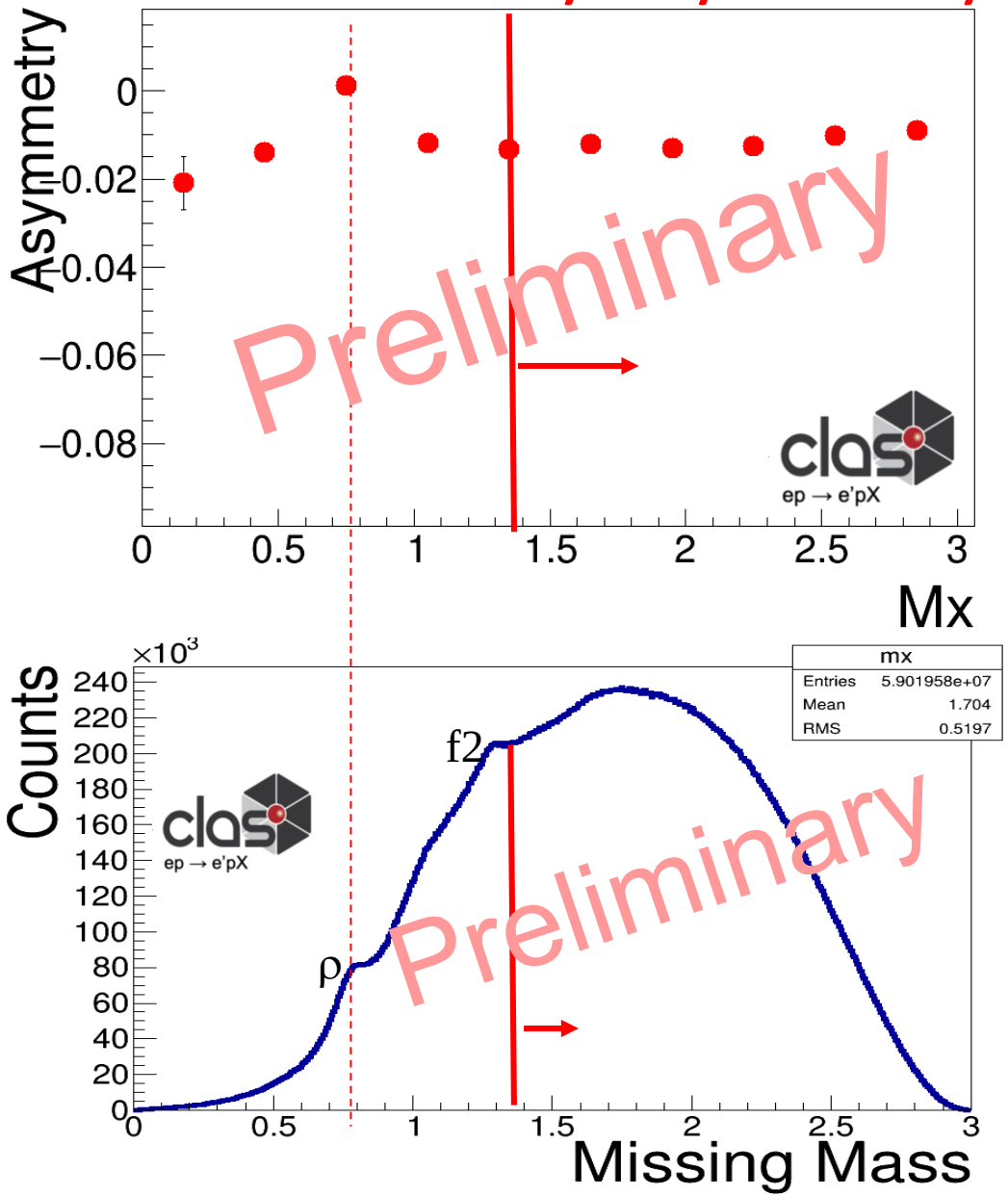
$$A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^+ - N^-}{N^+ + N^-}\right)$$

p0+p1 sin ϕ + p2 sin(2 ϕ)

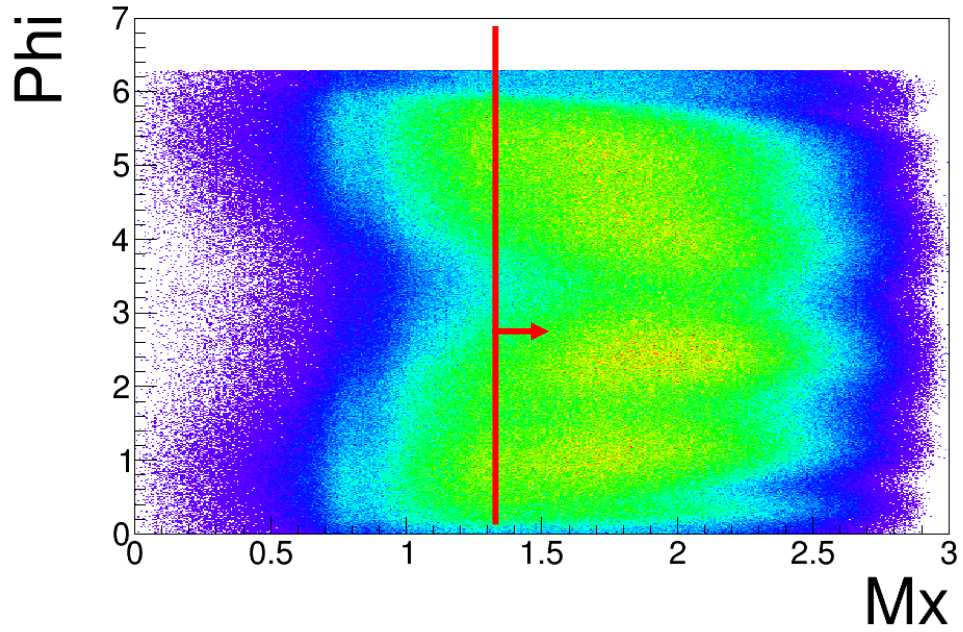




Preliminary Asymmetry vs Mx Results

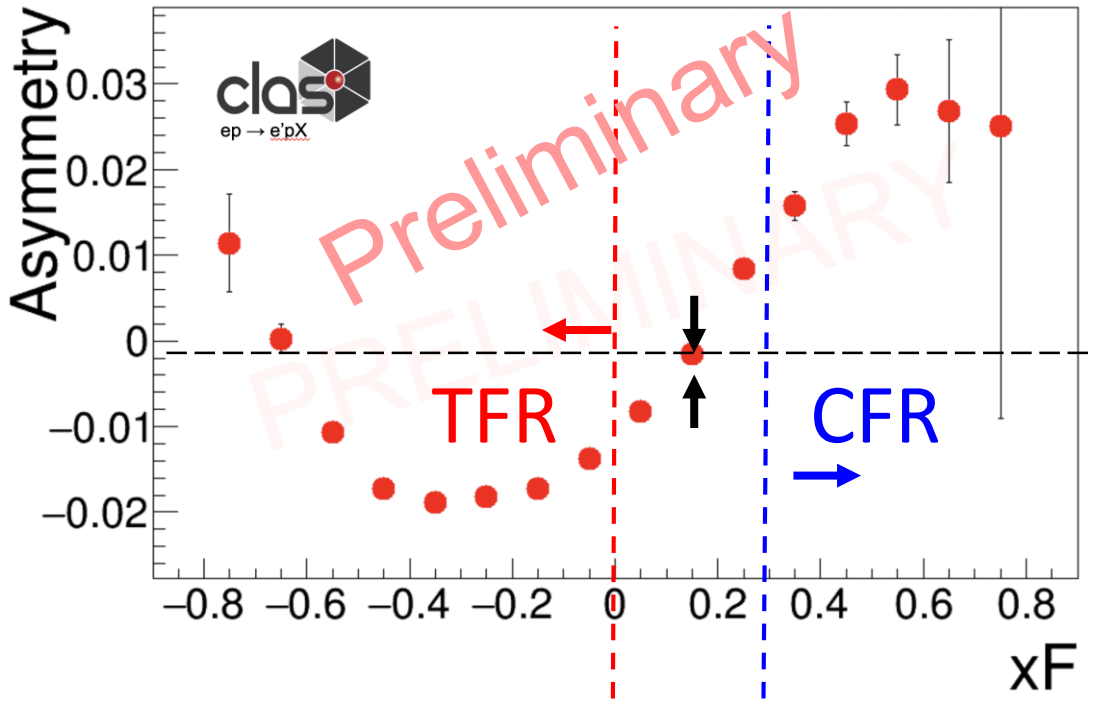


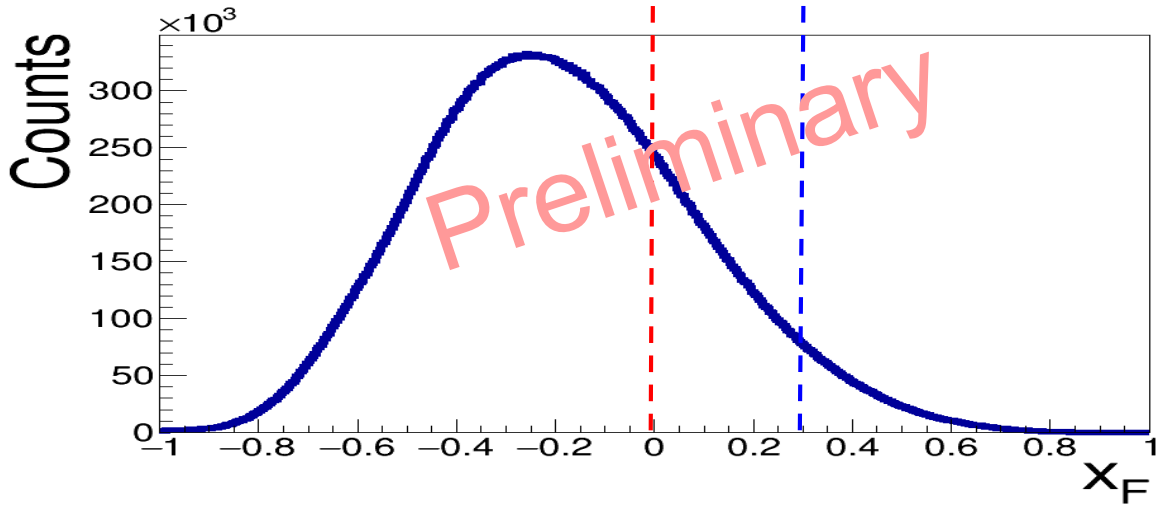
$$A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^+ - N^-}{N^+ + N^-}\right)$$

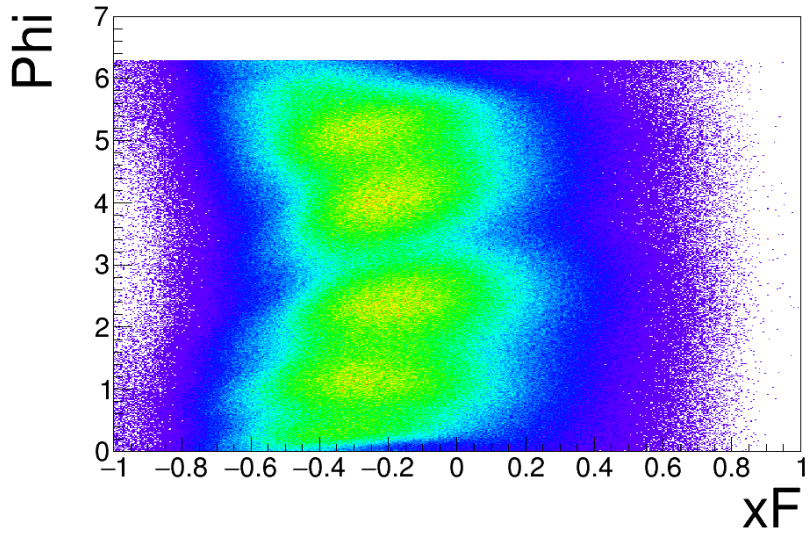


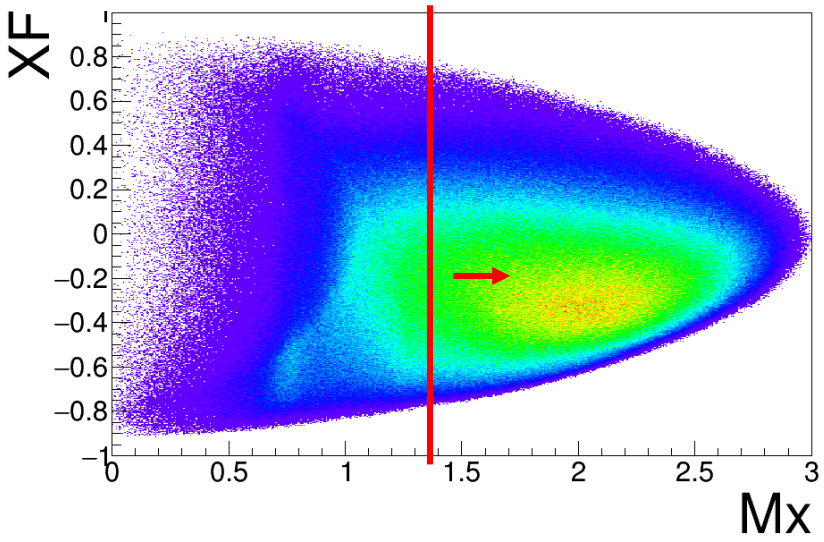
Decision: Take Mx>1.35

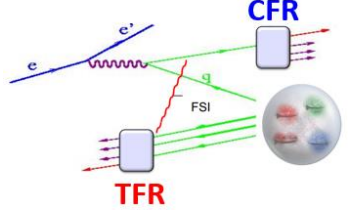
Asymmetry vs X_F Prel. Results, Mx > 1.35 (and appropriate cuts)





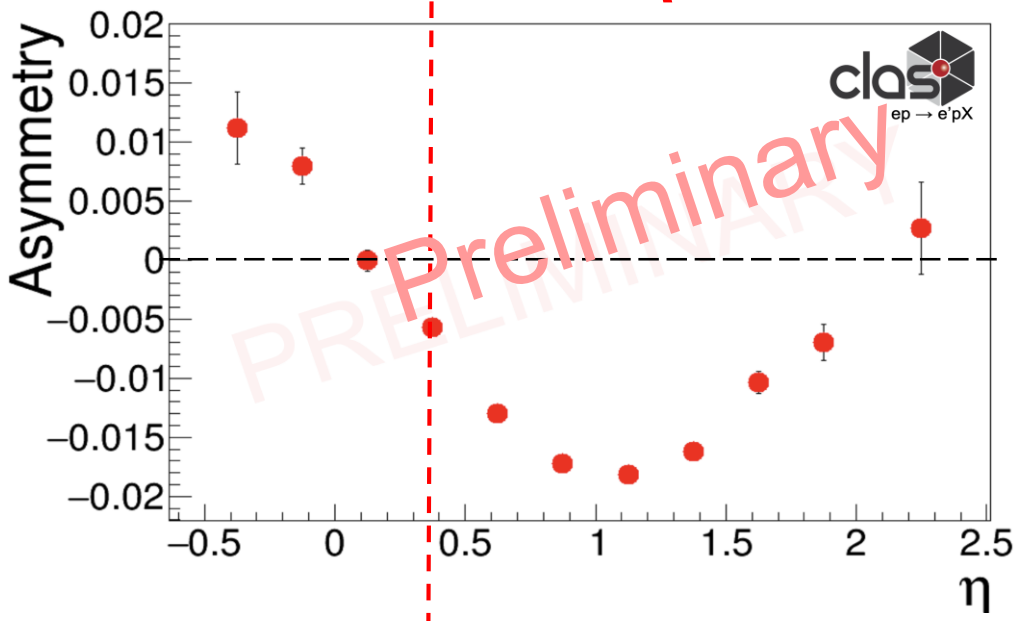


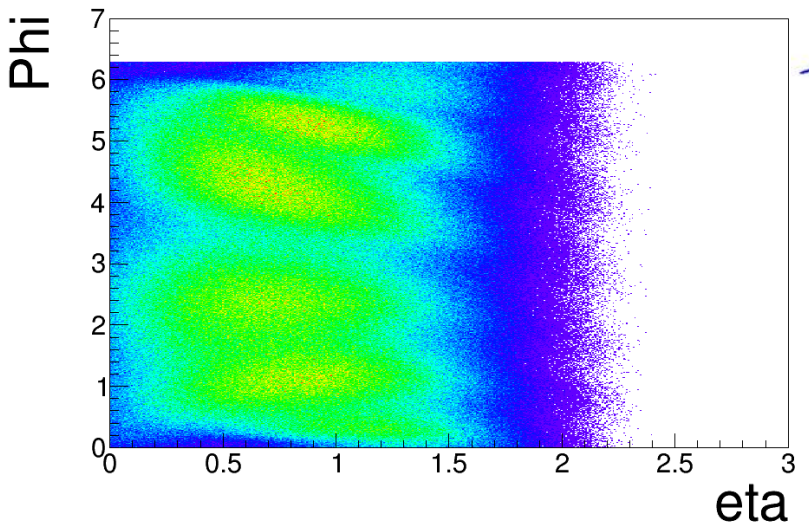


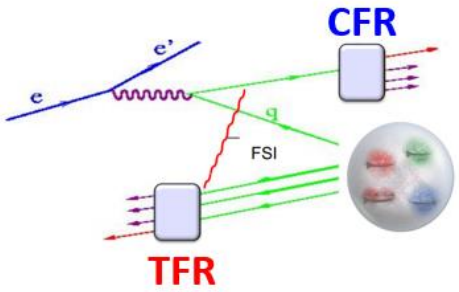


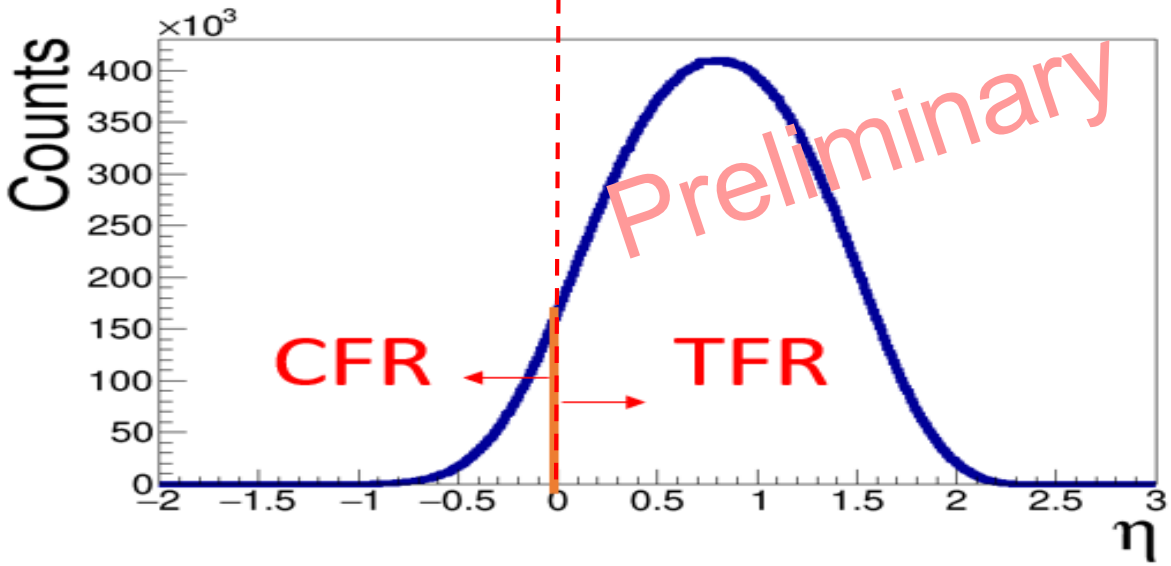
Note***: "*New tool for kinematic regime estimation in semi-inclusive deep-inelastic scattering*: Target, central and current regions": M. Boglione *et al.*, *High Energ. Phys.* **2022,** 84 (2022). https://doi.org/10.1007/JHEP04(2022)084

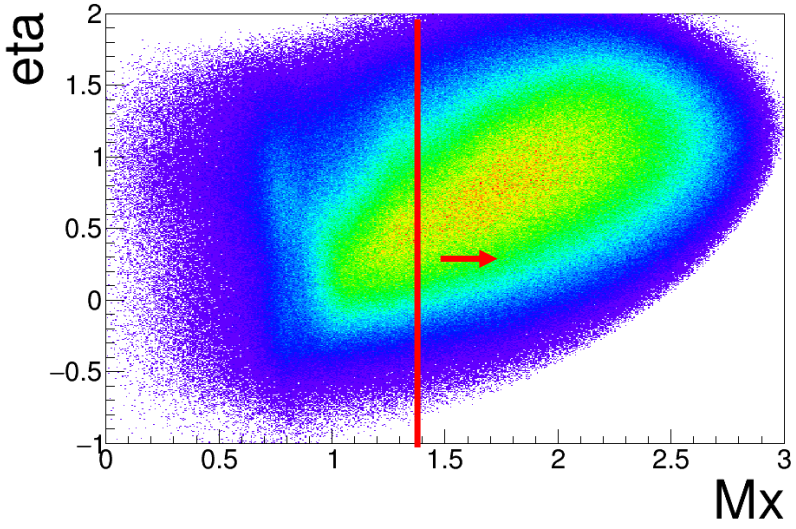
Asymmetry vs η Prel. Results, Mx > 1.35 (and appropriate cuts)



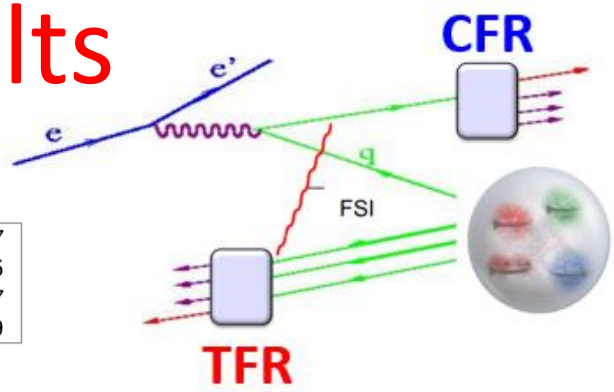


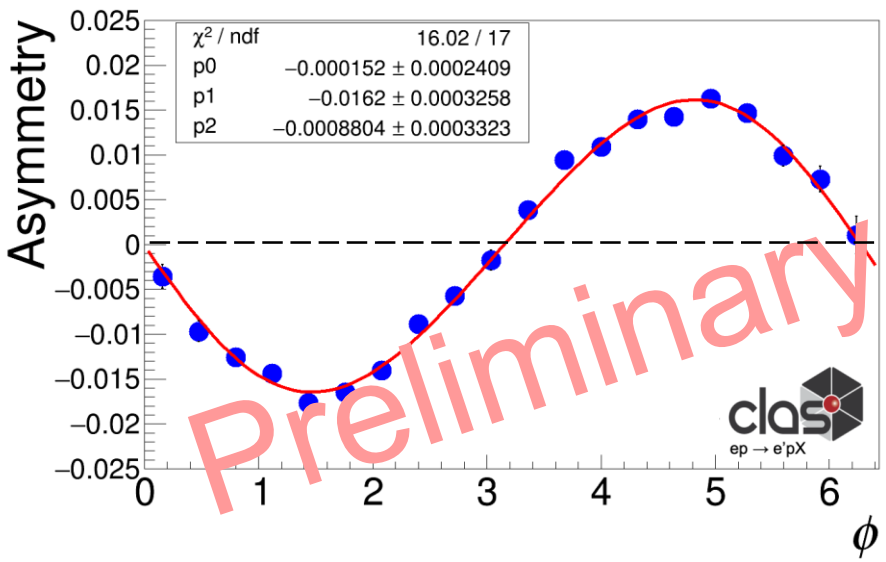




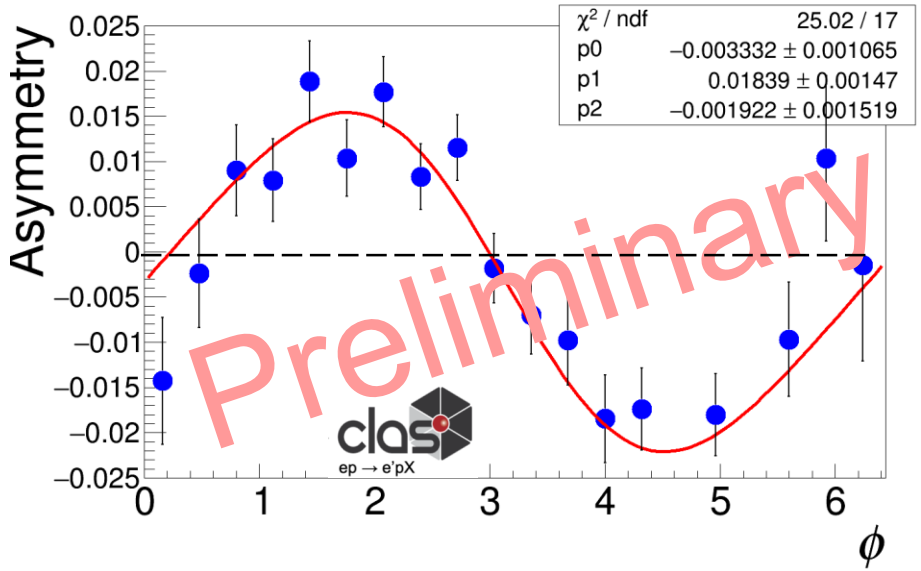


Preliminary Integrated Asymmetry Results





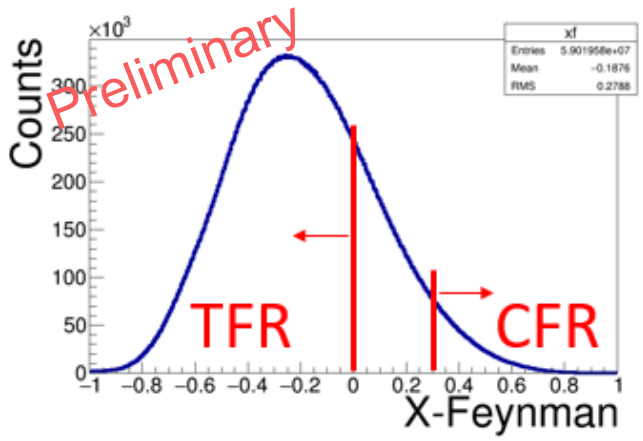
TFR



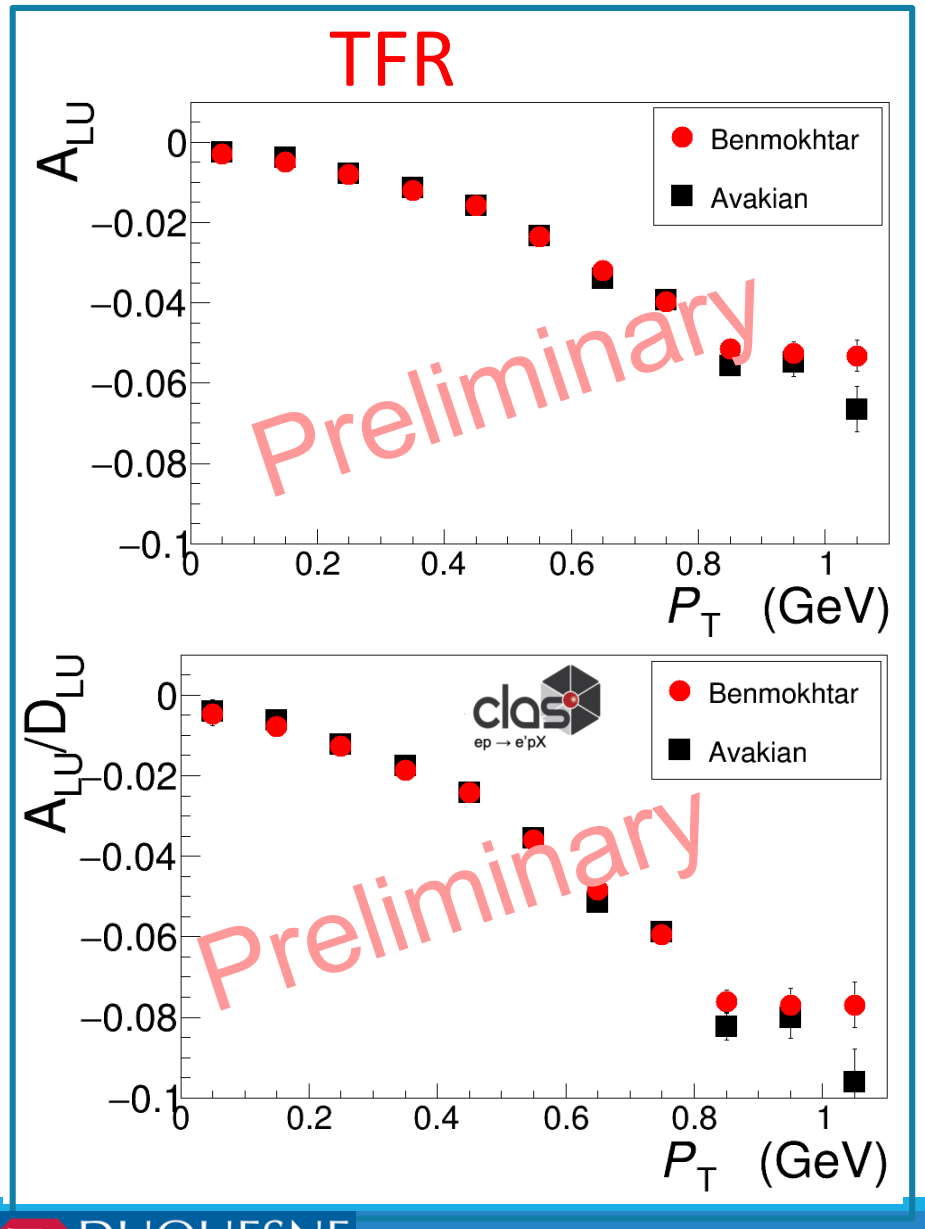
CFR

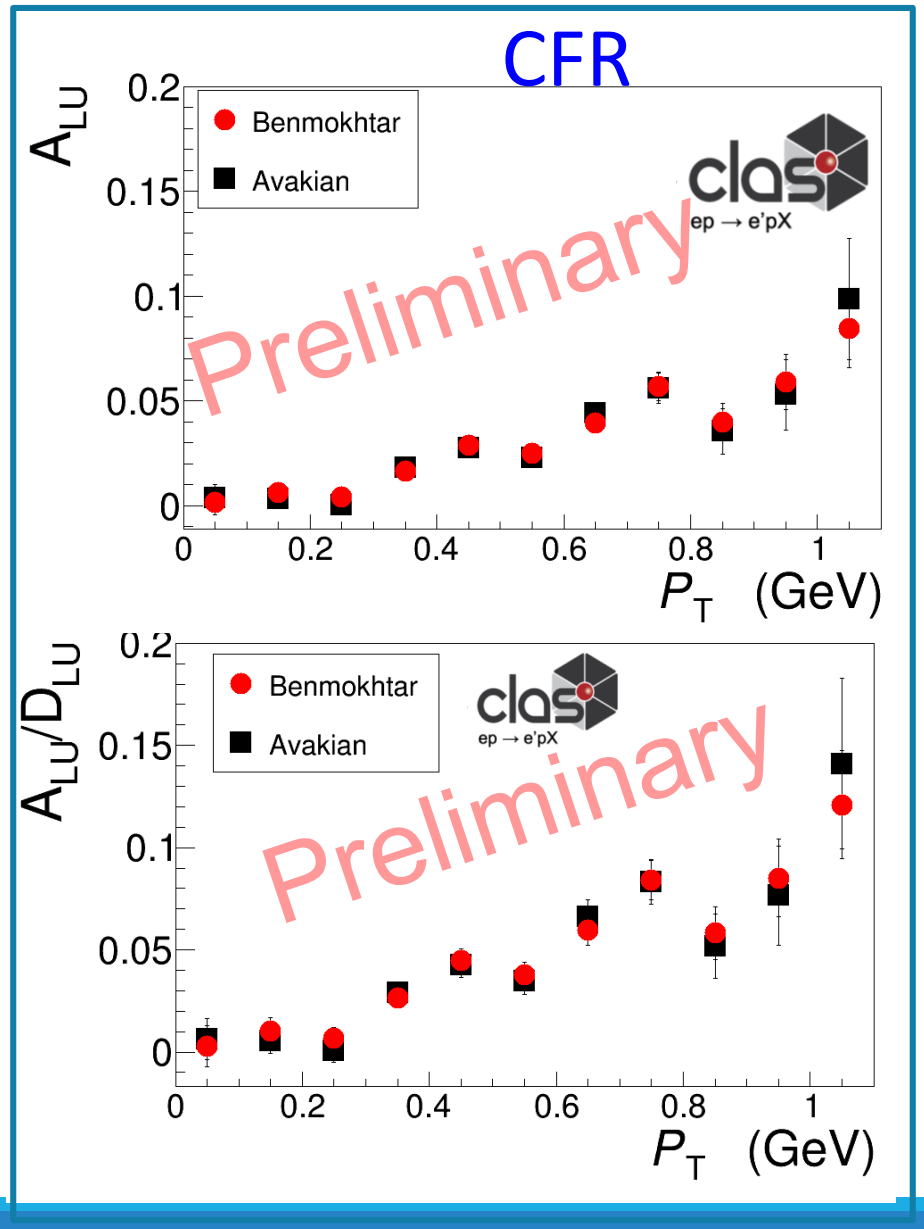
Fit: p0+p1 sin ϕ + p2 sin(2 ϕ)

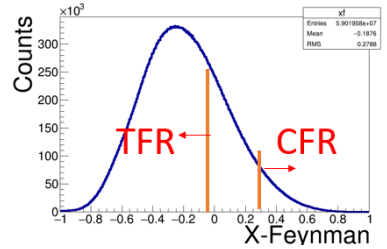
- Clear sinusoidal dependence with excellent statistics.
- Future work will improve the extraction / consider cos terms, etc.

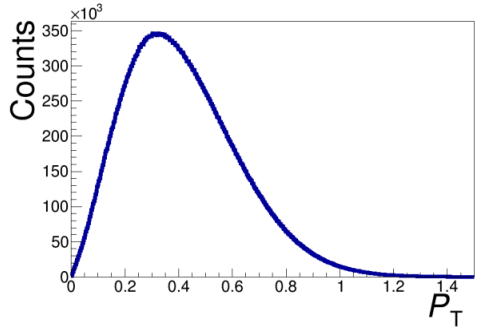


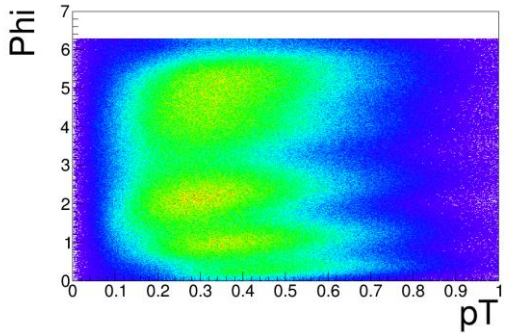
Asymmetry and Diluted Asym. vs P_T , Preliminary Results

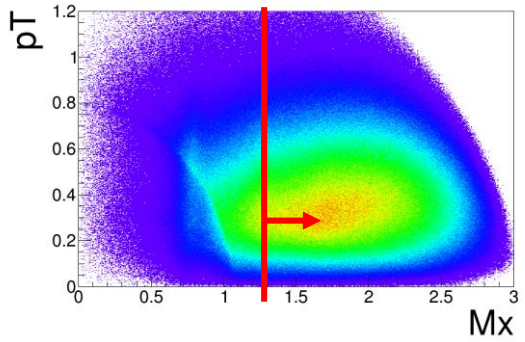






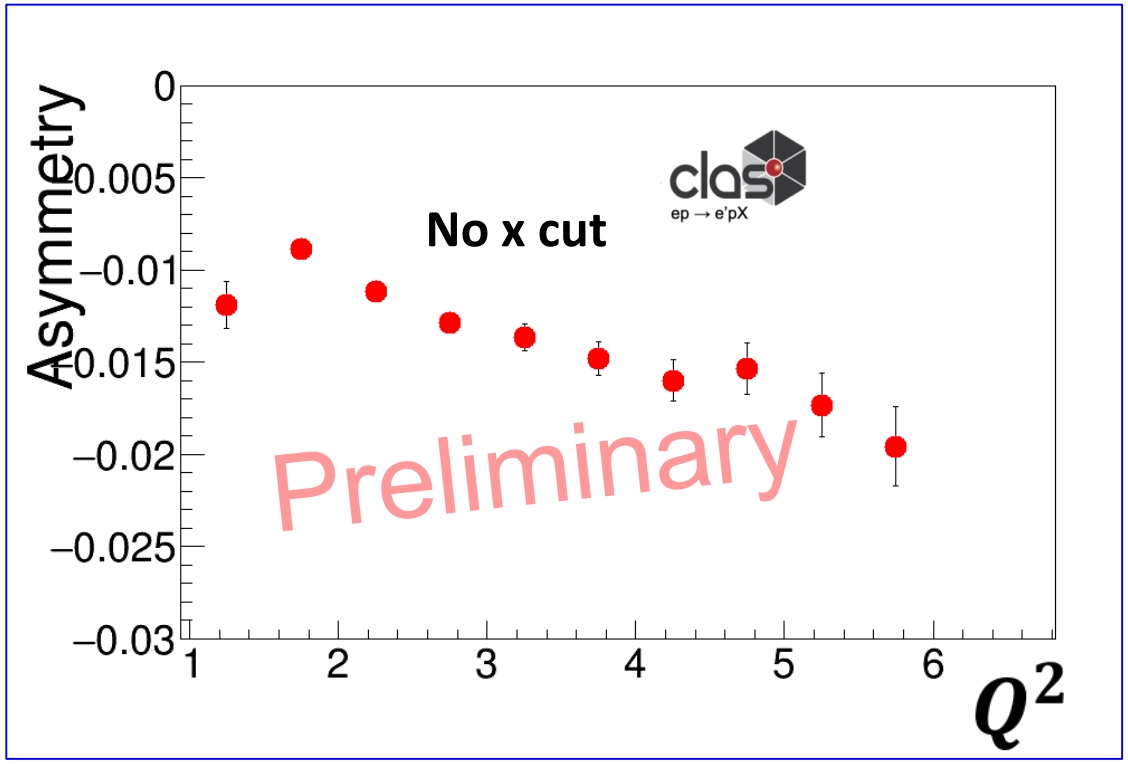


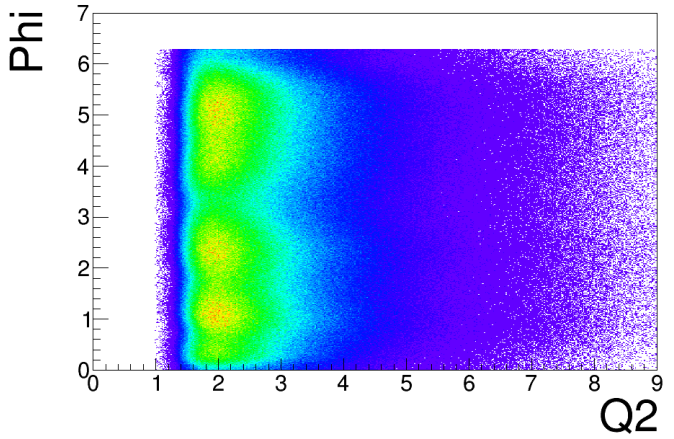


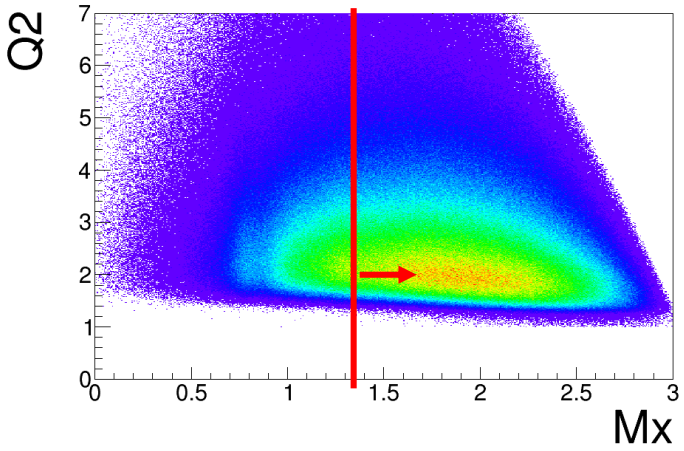


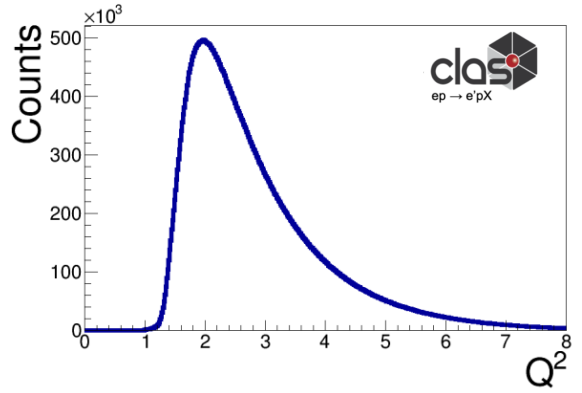
Q^2 Dependence Prel. Results

- SSAs in single hadron production are twist-3
- Proper interpretation of the Q^2 dependence is crucial for our understanding of the underlying dynamics.



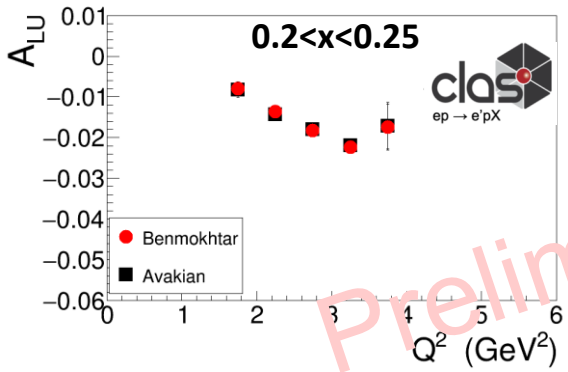


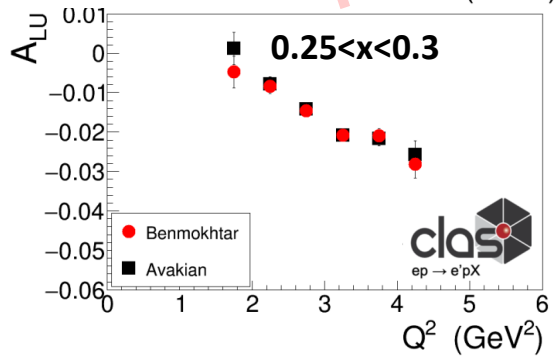


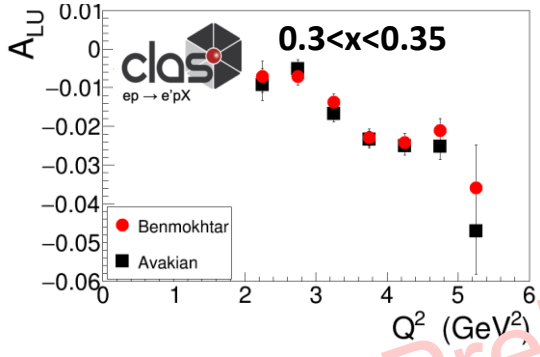


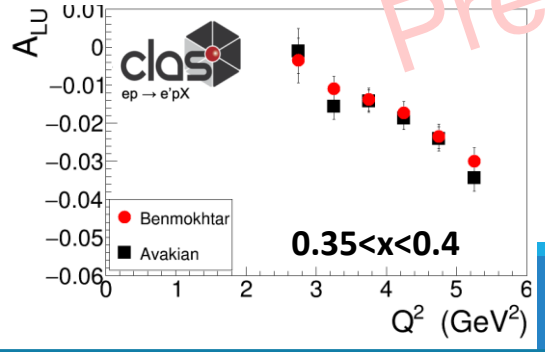
Q^2 Dependence Prel. Res.

Target Fragmentation Single Spin Asymmetries

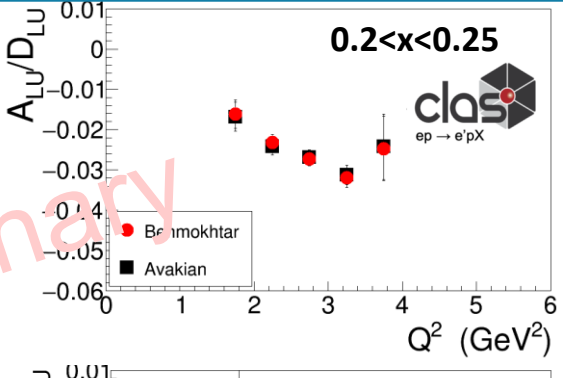


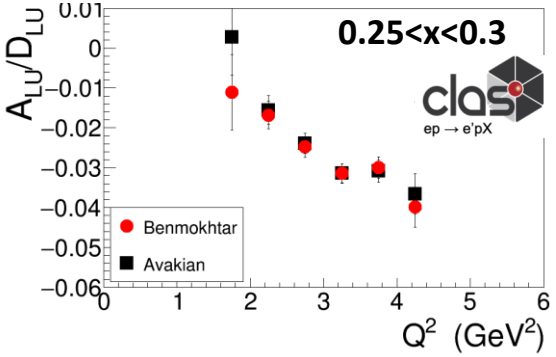


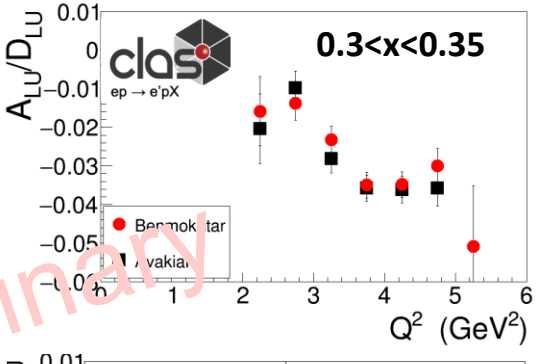


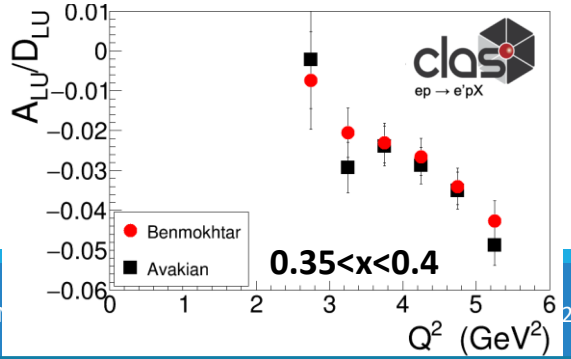


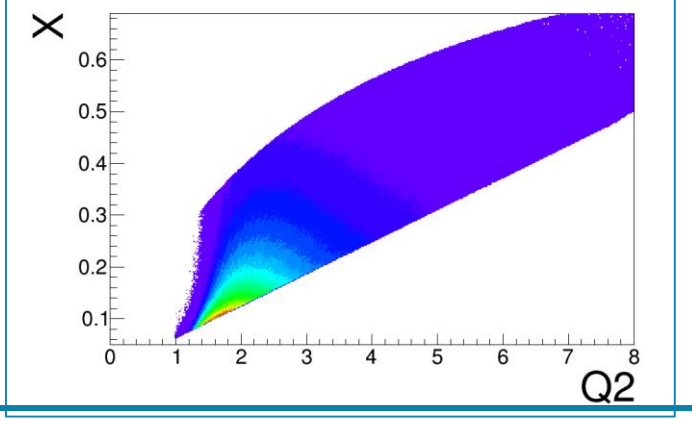
Target Fragmentation Structure Functions



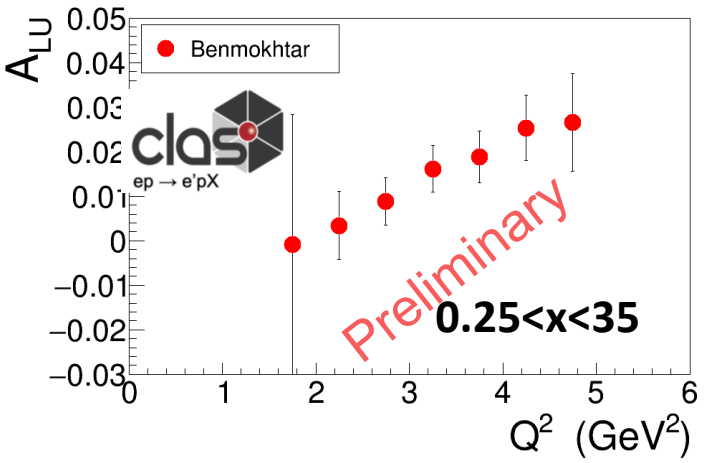


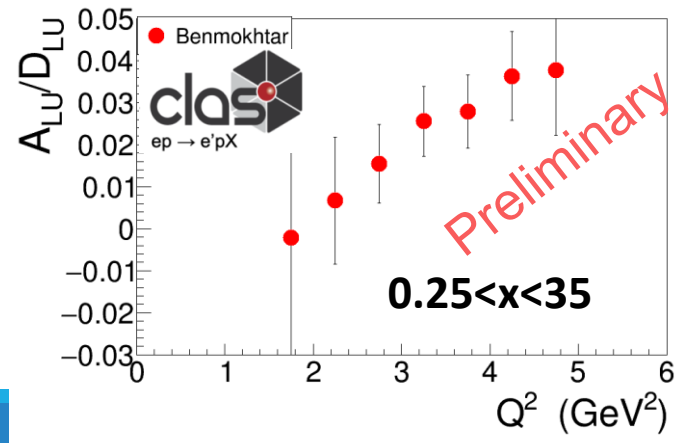




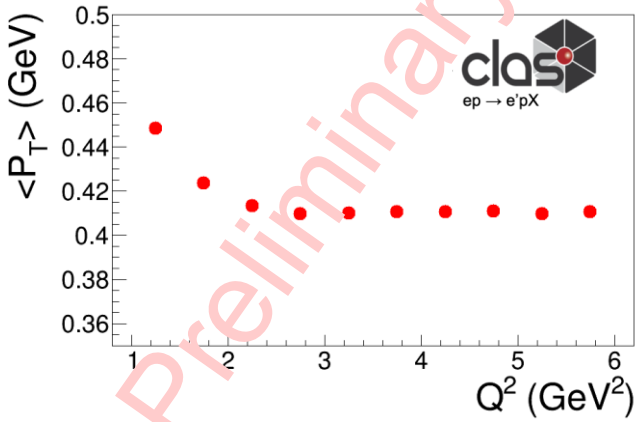


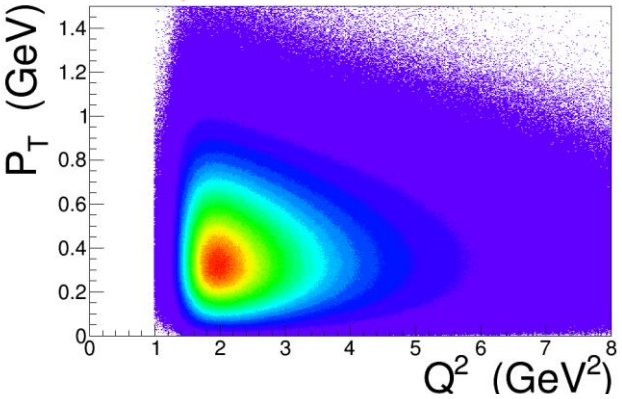
Current Fragmentation

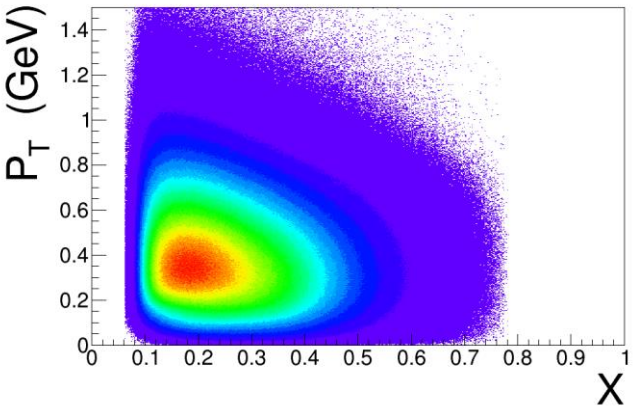


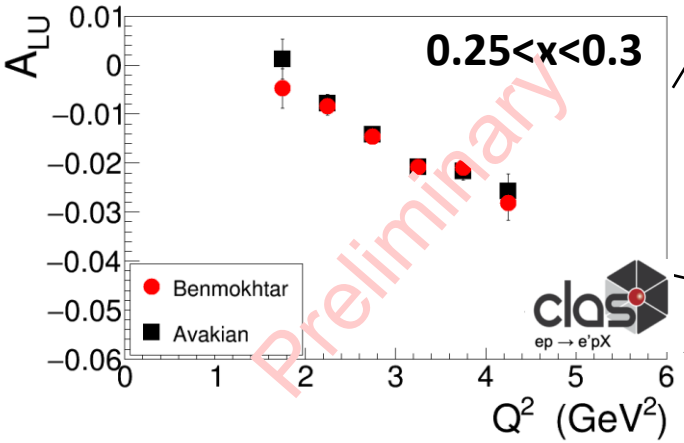


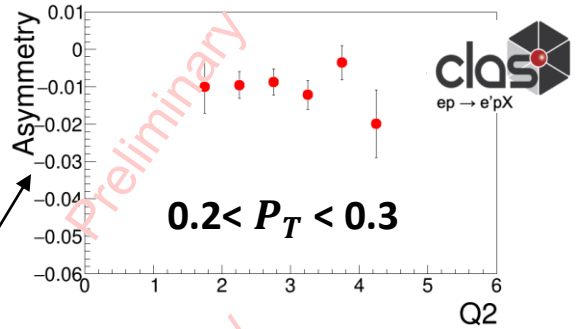
More Q^2 Dependence Studies

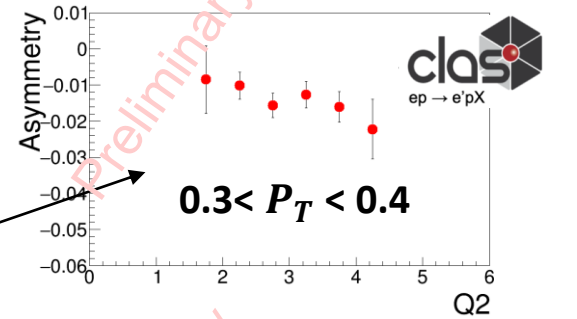


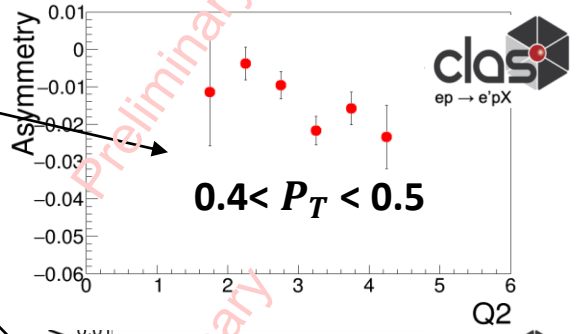


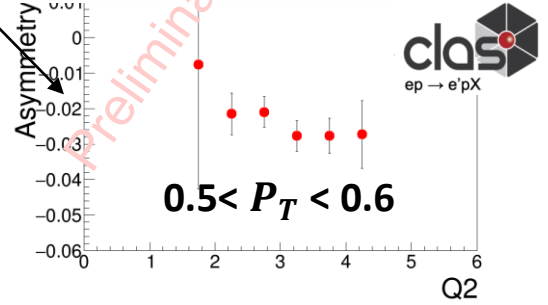


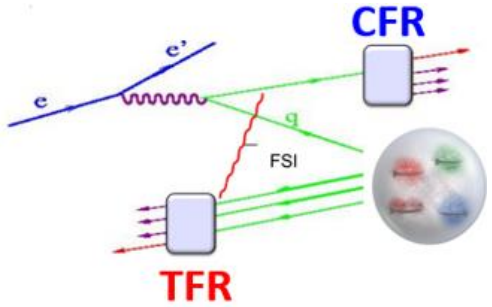








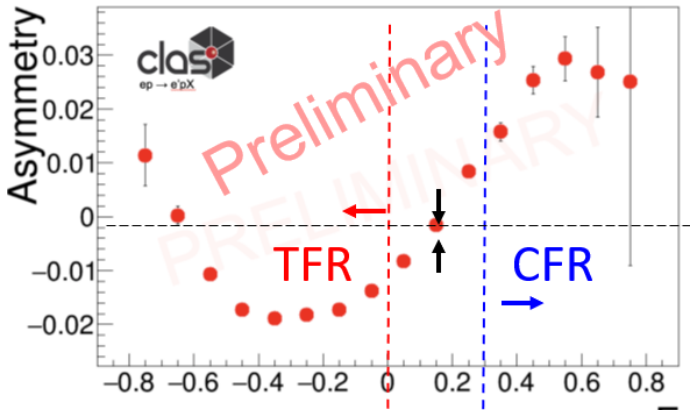


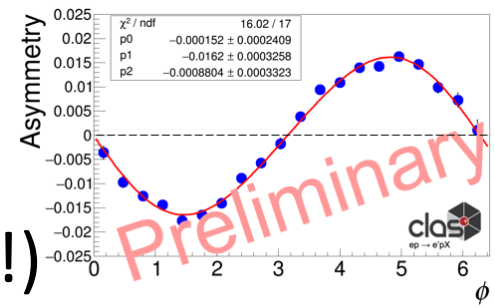


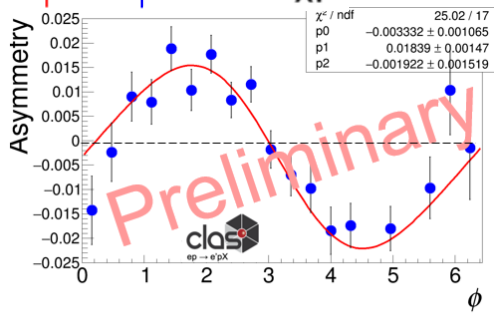
Summary, Conclusion and Outlook

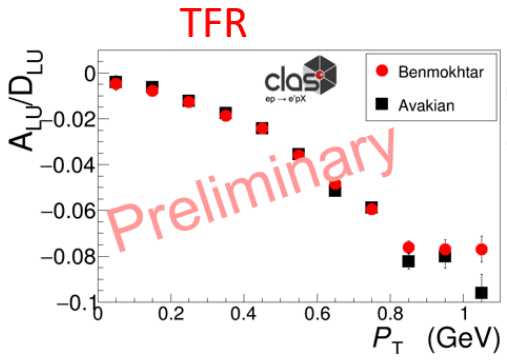
- For the first time at Jlab, we've captured the transition between TFR and CFR in the ep->e'p'X.
- There are significant beam SSAs for baryons in TFR, with opposite sign to what we observe in CFR.

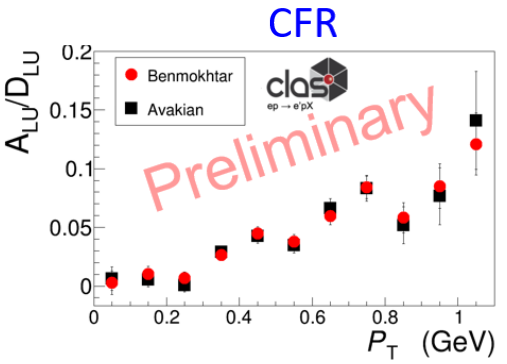
- **Next Steps:**
  - Spring 2019 stat, (more than double the stats!!!)
  - Extensive Multidimensional Analysis.
  - Systematics, radiative corrections, etc …
  - Investigate other channels (pi and K)
  - Thanks to **NSF** for the support!











Thank you!!!