First multidimensional $ep \rightarrow e'p'X$ Single Spin Asymmetries in the Target Fragmentation at Jefferson Lab

(For the CLAS12 Collaboration at Jefferson Lab)

Fatiha Benmokhtar

(Duquesne University)

Light Cone 2022 Online: Physics of Hadrons on the Light Front

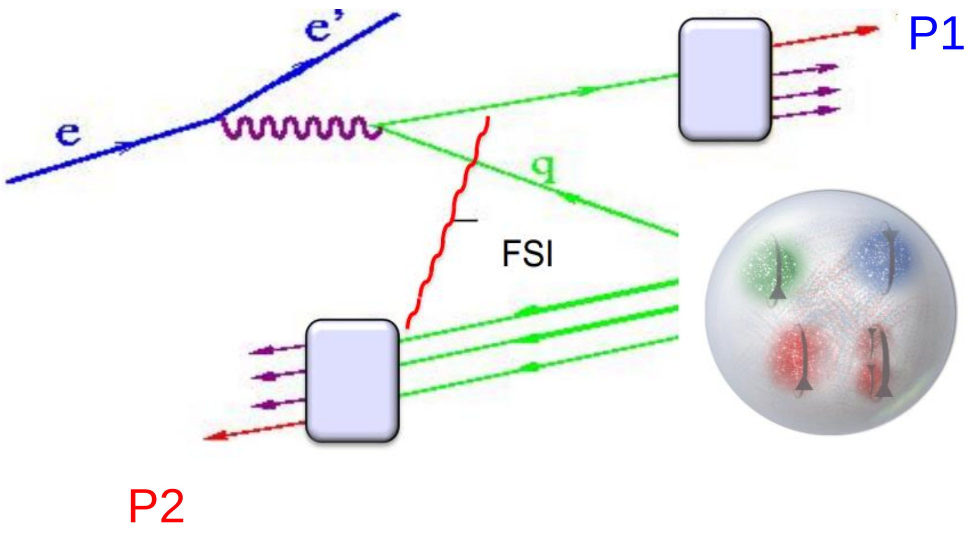
H. Avakian (Jefferson Lab),
T. Hayward (UConn)
A. Gadsby & H. Valenty (Duquesne)
(Students supported by: JSA support, NSF, SULI)

DUQUESNE UNIVERSITY

Target/Current Fragmentations

x_F – frac. Momentum in the CM frame

Current fragmentation, $x_F>0$

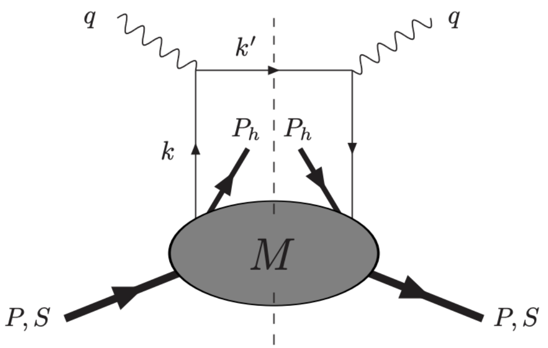


Target fragmentation, $x_F<0$

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	$\tilde{u}_{2T}^{\perp\prime h}, \tilde{u}_{2T}^{\perp h}$	$\tilde{l}_T, \hat{l}_{2T}^{\perp h}$	$\tilde{t}_{2T}^{h}, \tilde{e}_{2T}^{h}, \tilde{t}_{2T}^{\perp h}, \tilde{e}_{2T}^{\perp h}$

Twist-3 quark collinear FrFs.

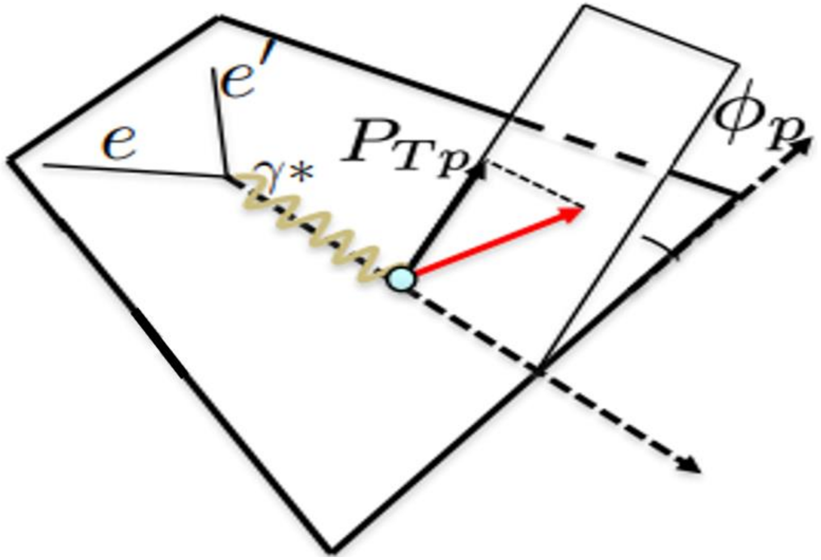
Understanding of target fragmentation azimuthal distributions will help with interpretation of the azimuthal distributions in the current fragmentation region.

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

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

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

Fracture Function



Method: Study Asymmetry modulation :

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

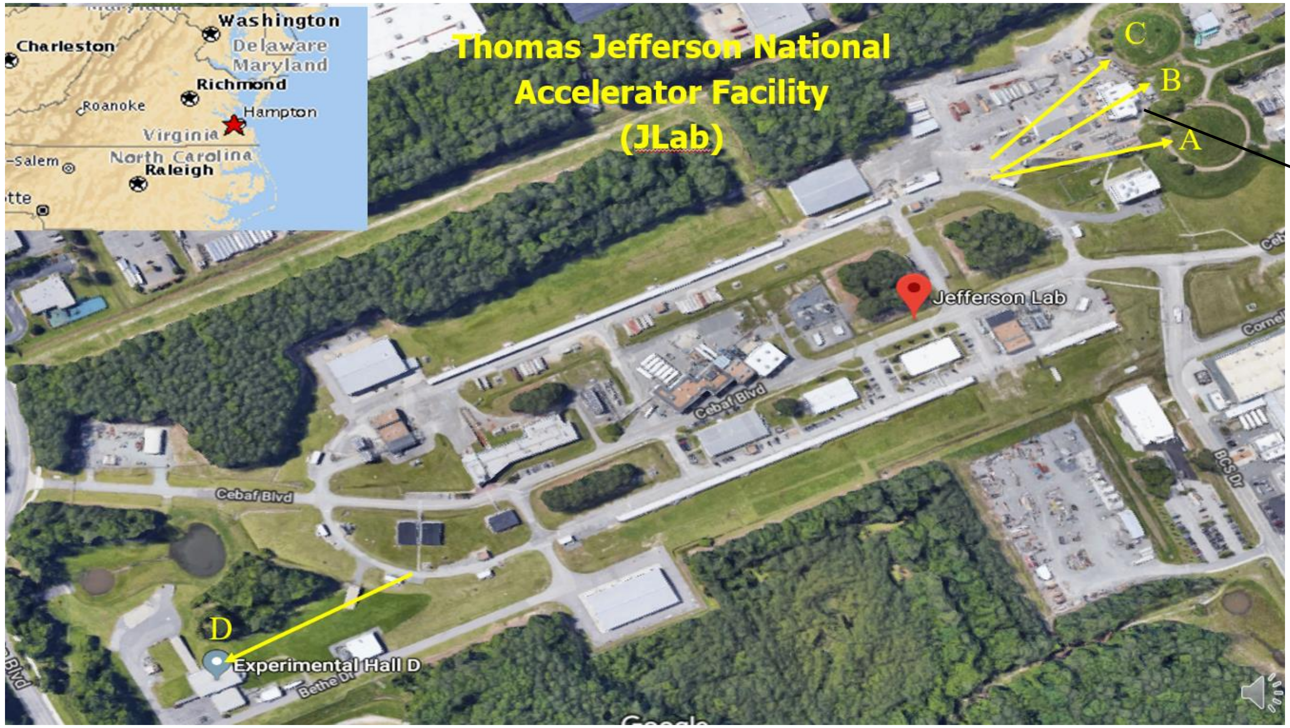
Extract

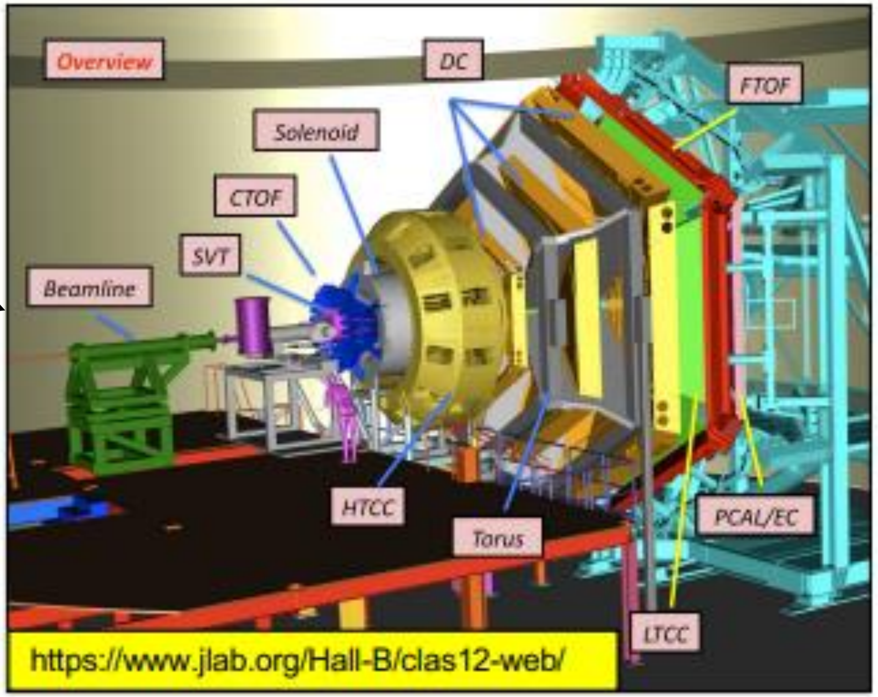
$$A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^+ - N^-}{N^+ + N^-}\right) \rightarrow F_{LU}^{\sin\phi_h} = \frac{A(\phi)_{LU}}{\sqrt{2\varepsilon(1-\varepsilon)}}$$

Depol. fac.

The Experiment

CLAS12 at Jefferson Lab

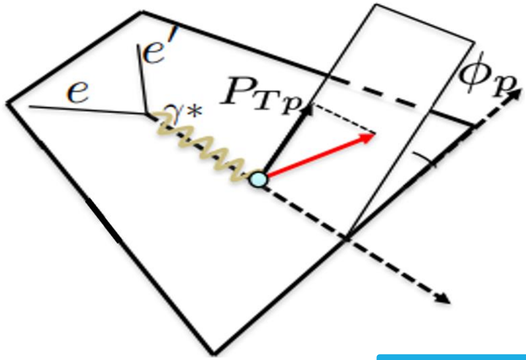


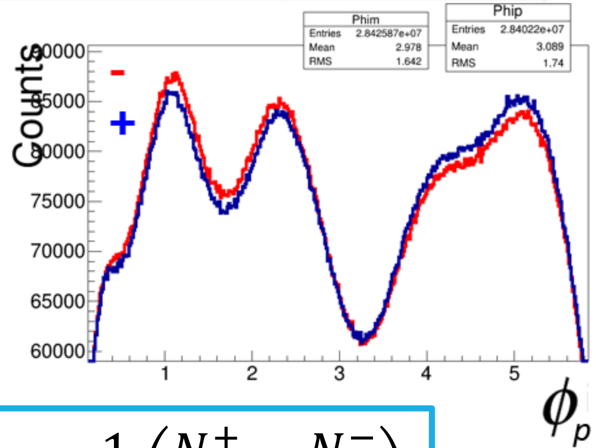


- Data taken in fall 2018 (2019) with 10.6 (10.2) GeV longitudinally polarized electron beam and **unpolarized LH2 target**.

- The full data set has been analyzed, but only the 2018 (e-pol 87%) be presented in this talk. **ep → e'p' + X** , using only forward detectc

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

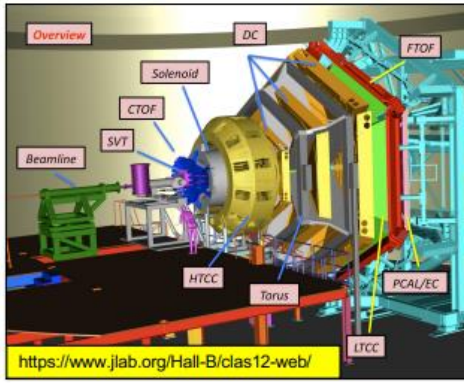




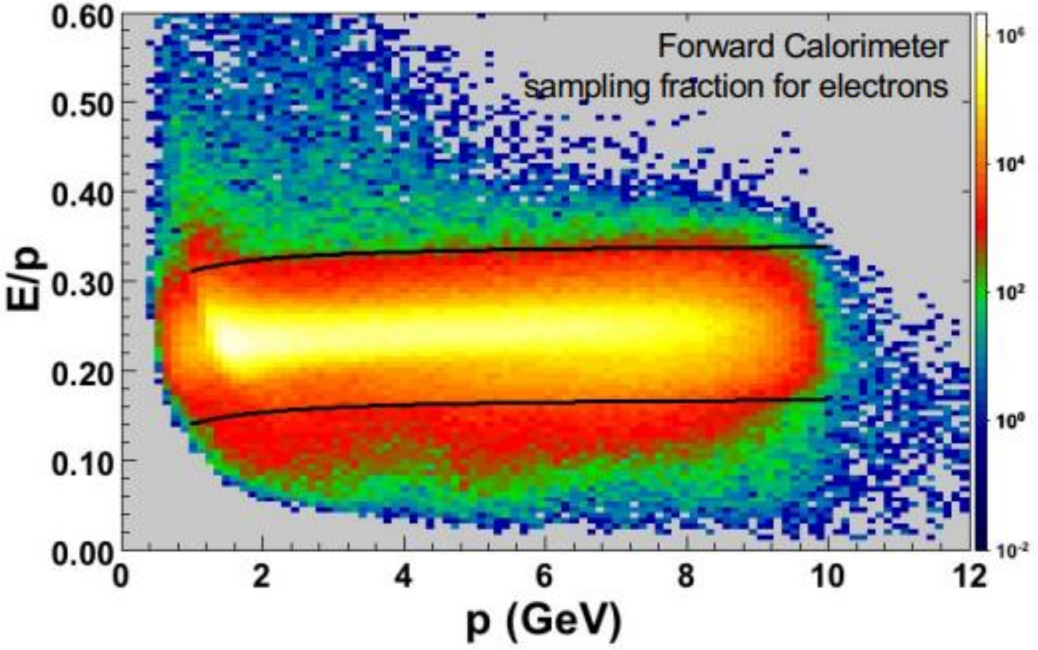
$$A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^{+} - N^{-}}{N^{+} + N^{-}}\right)$$

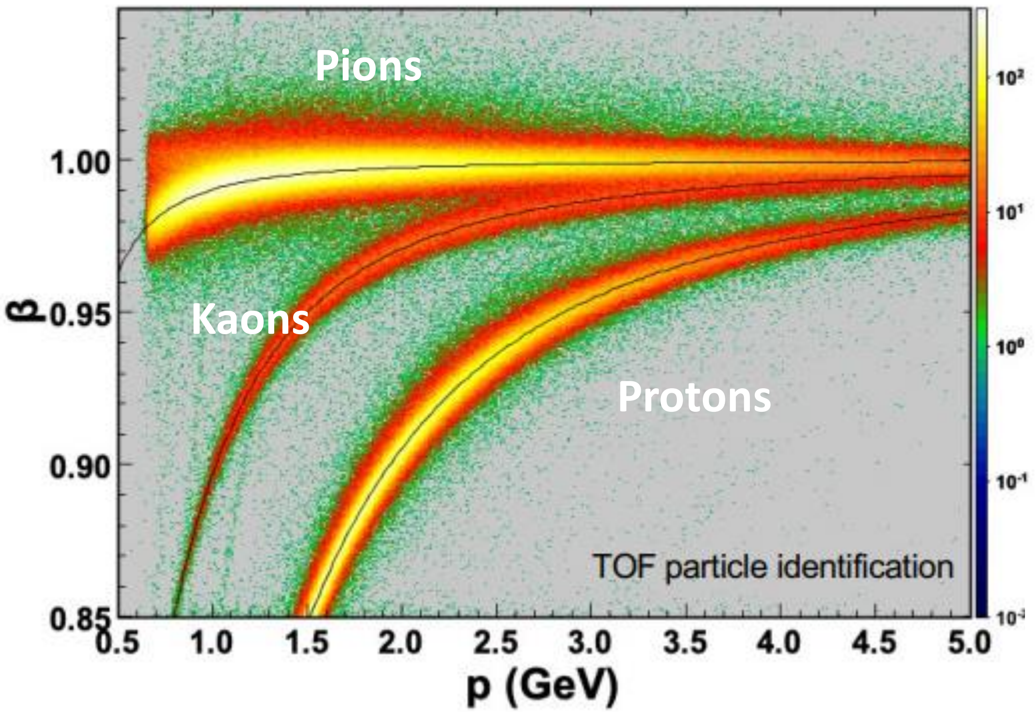
Particle Identification

ep → e’p’ + X

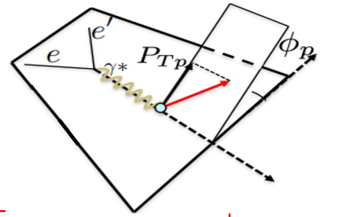


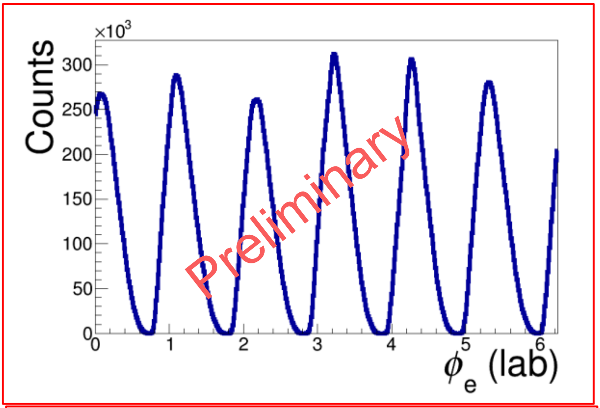
- Electron
  - Electromagnetic calorimeter.
  - Cherenkov detector.
  - Vertex and fiducial cuts.
- Hadron
  - β vs p comparison between vertex timing and event start time.
  - Vertex and fiducial cuts.

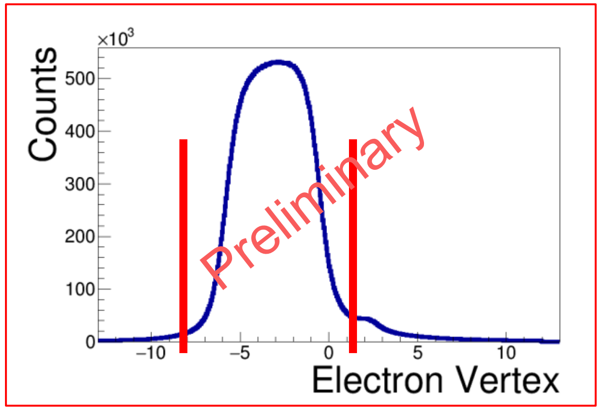


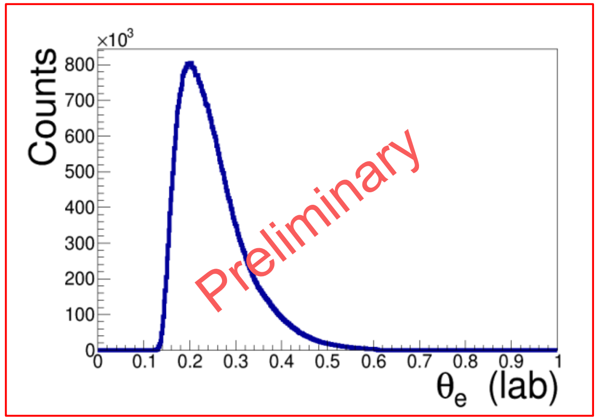


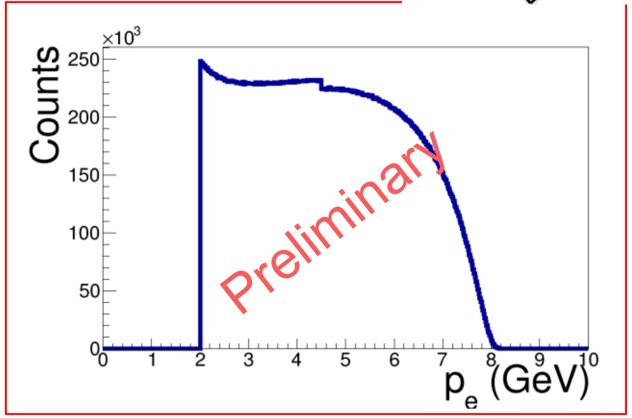
Variables of interest (ep → e’p’+X)

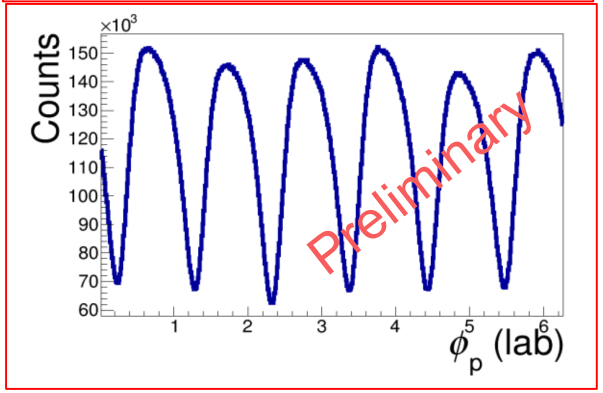


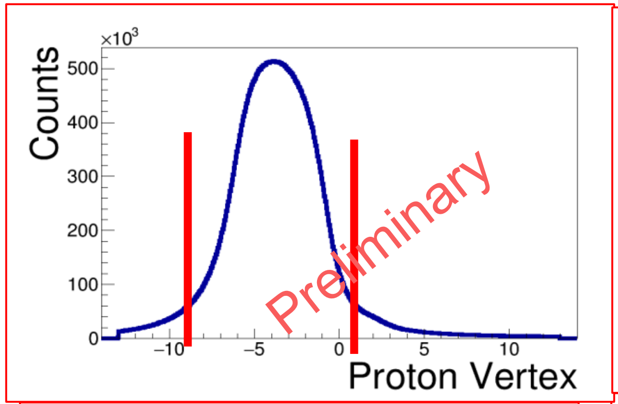


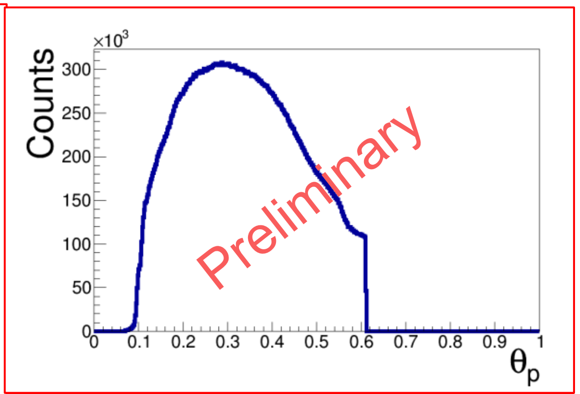


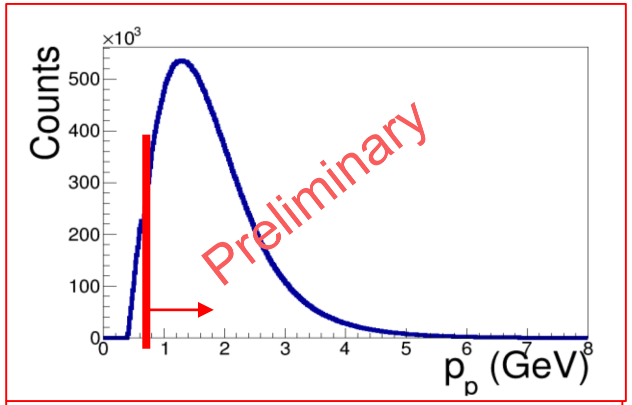


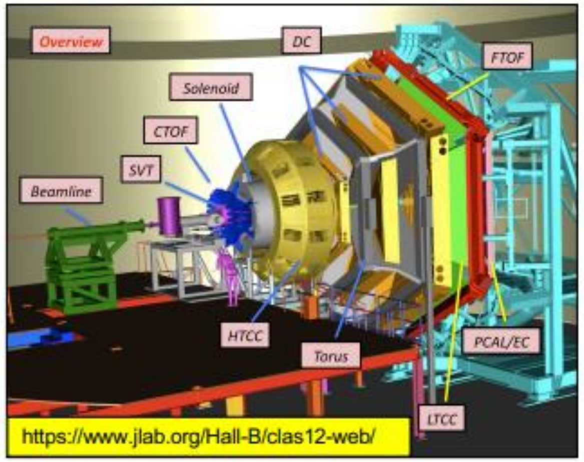


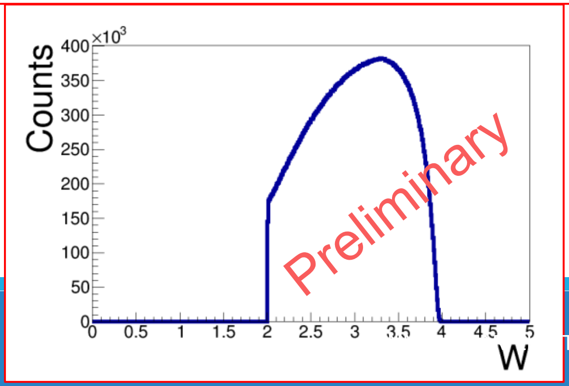


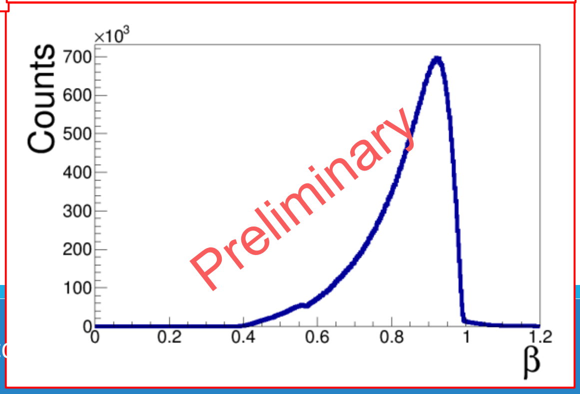


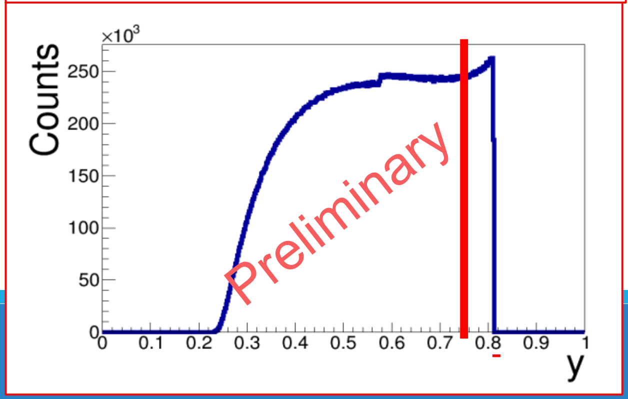




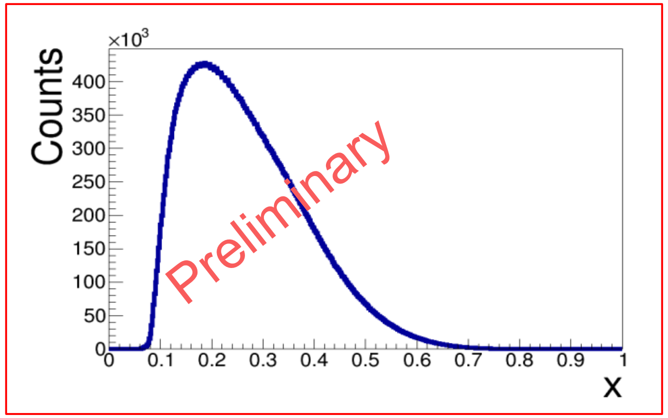


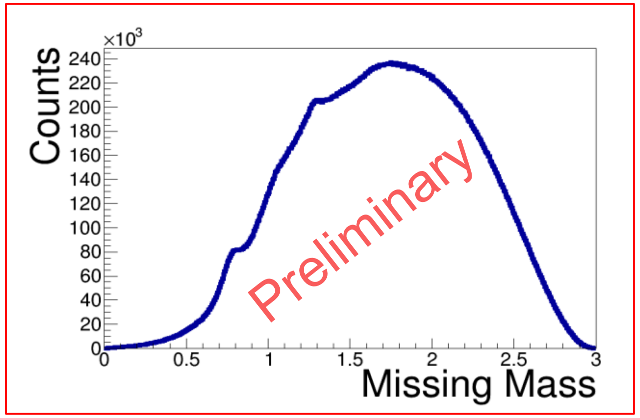


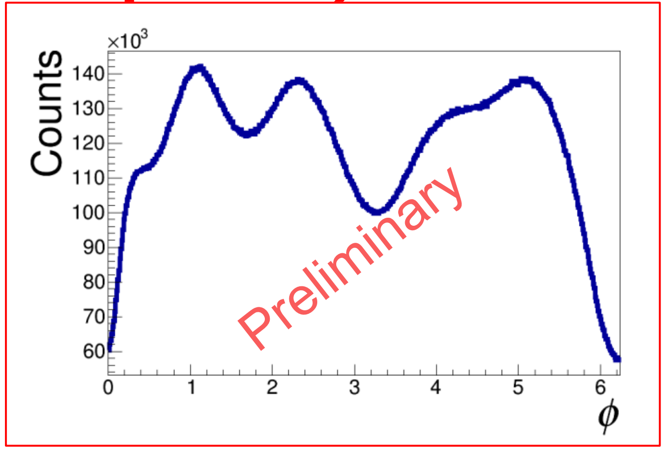


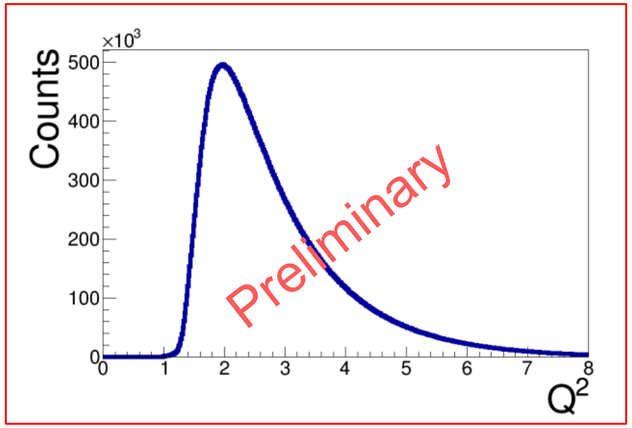


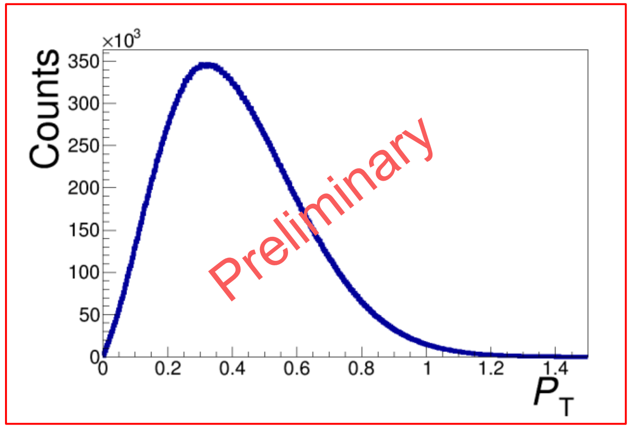
More Variables of interest $(\vec{e}p \rightarrow e'p'+X)$

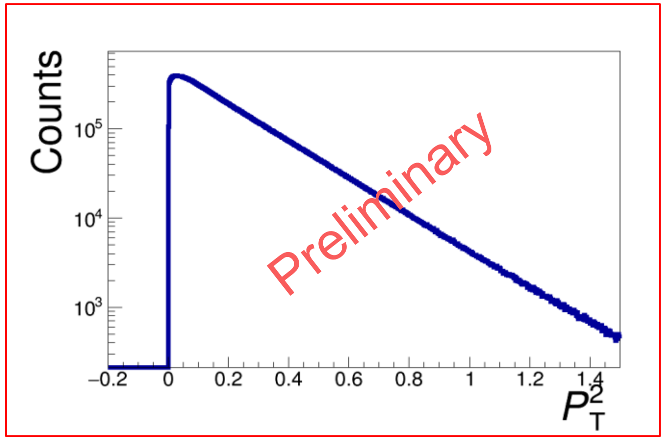


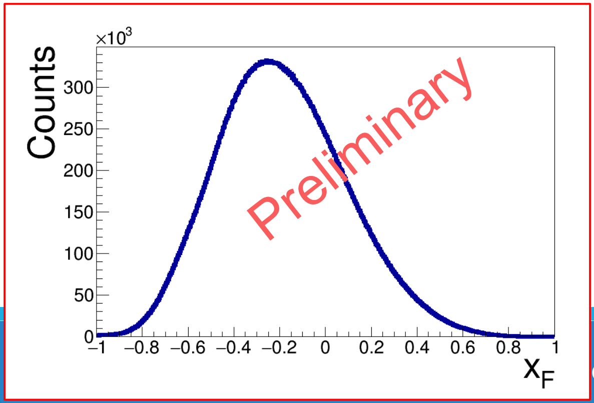


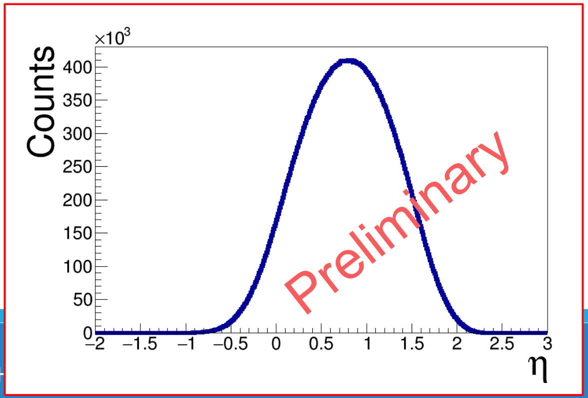


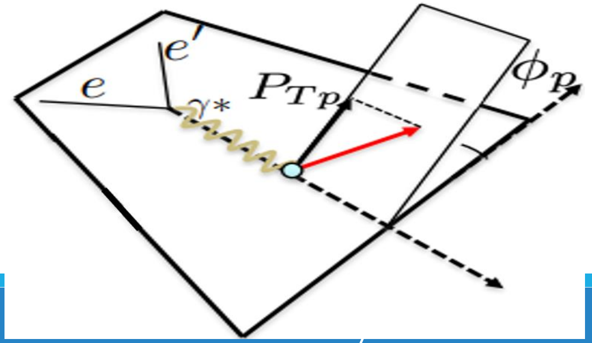


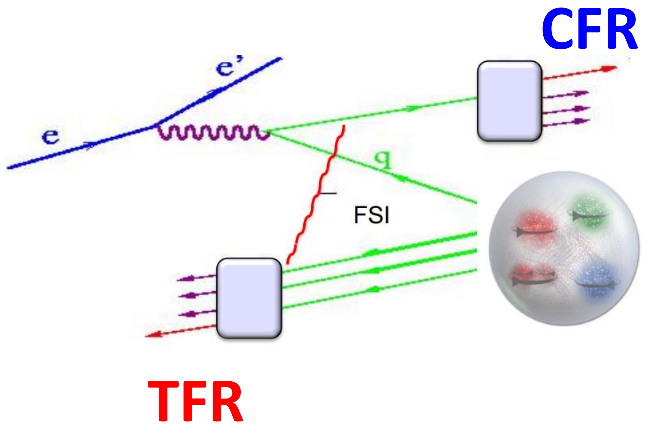










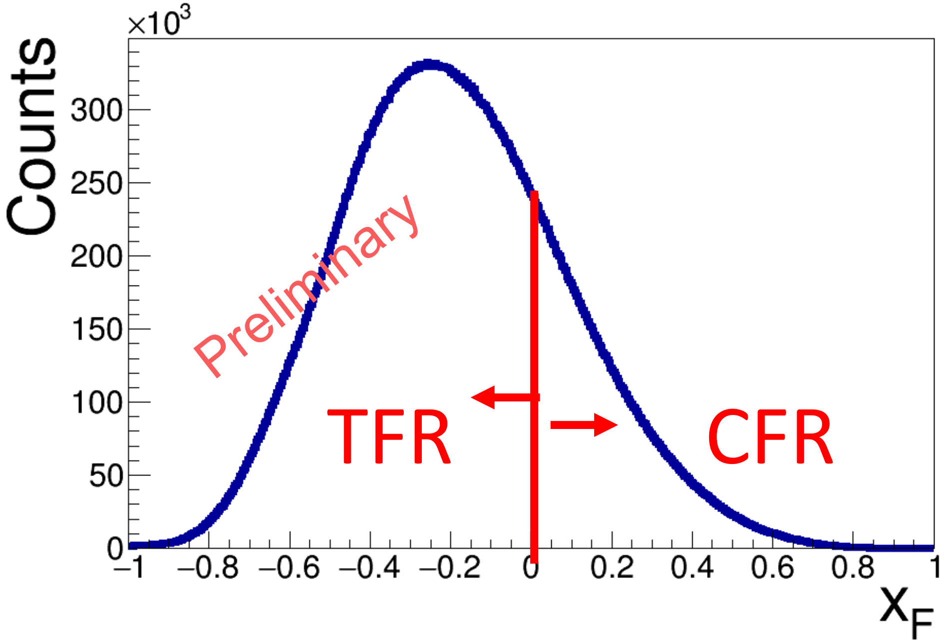


X_F and η

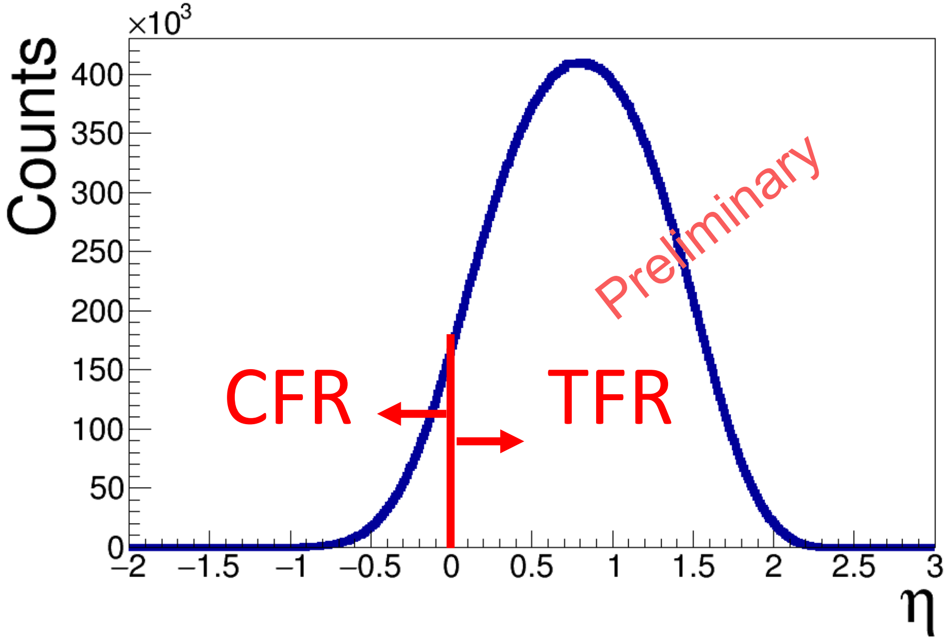
$$x_F = \frac{2P_h \cdot q}{|q|W},$$

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

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



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

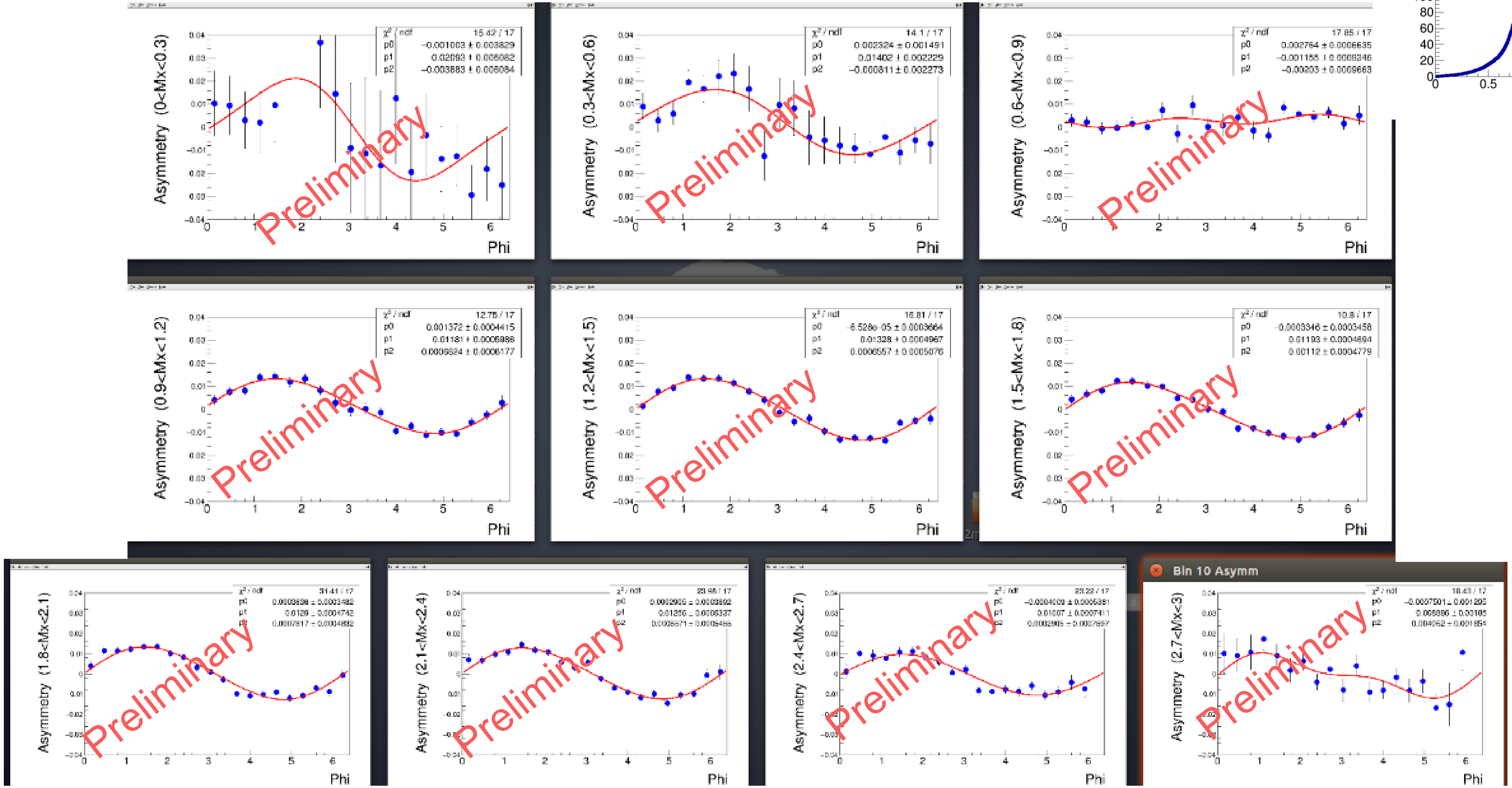


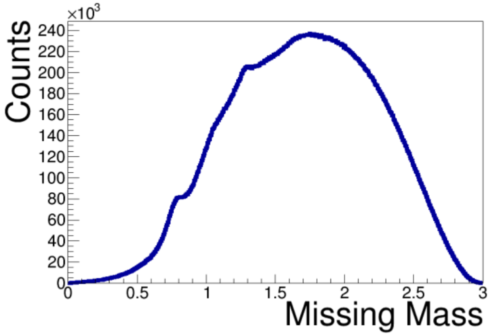
Rapidity in the Breit frame.

Example: Sin(ϕ) modulation vs Missing Mass

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

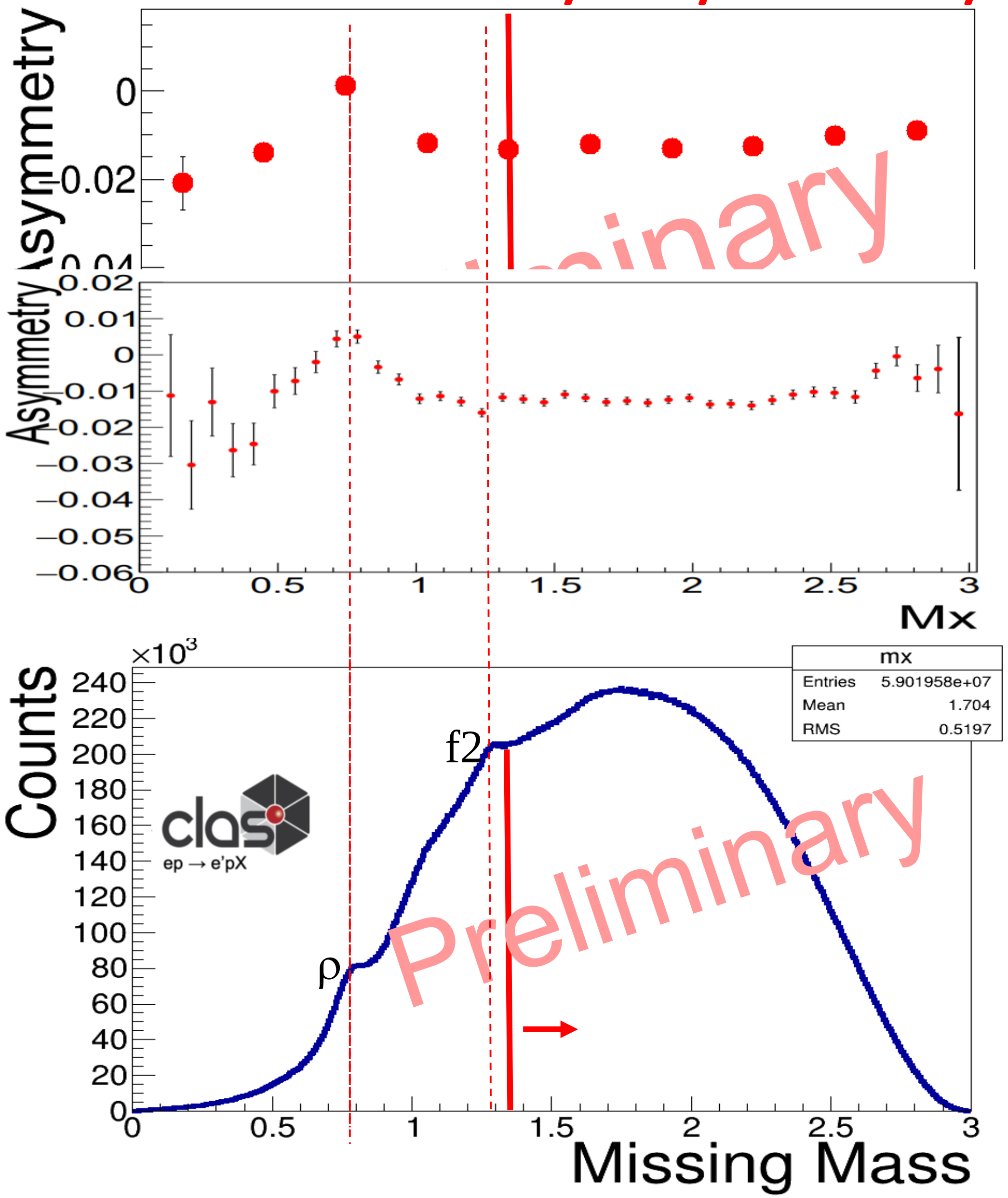
p0+p1 sin ϕ + p2 sin(2 ϕ)

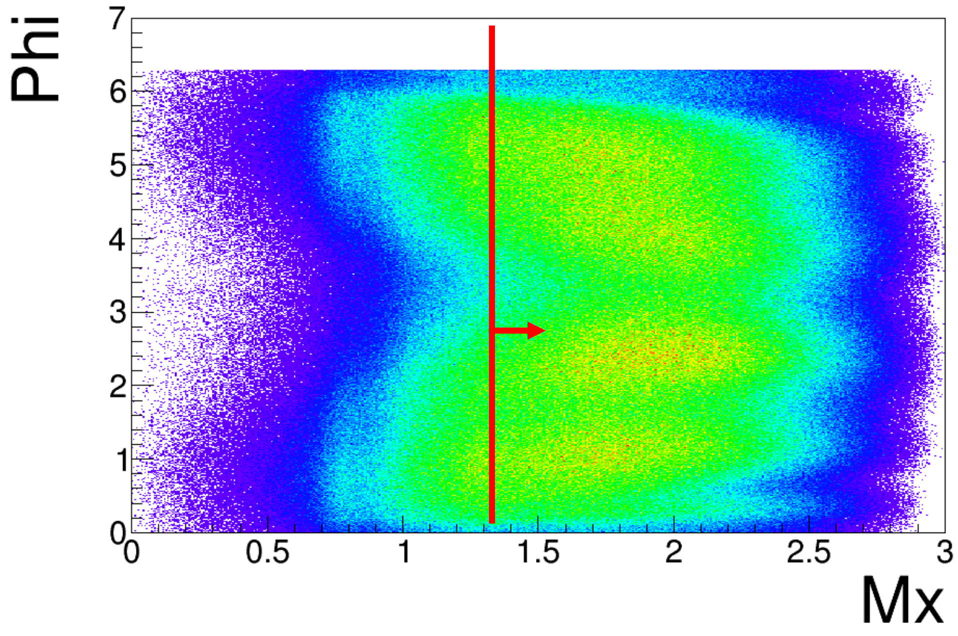




Preliminary Asymmetry vs Mx Results

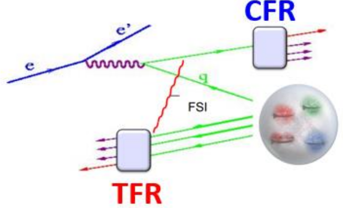
$$A(\phi)_{LU} = \frac{1}{p}\left(\frac{N^{+} - N^{-}}{N^{+} + N^{-}}\right)$$

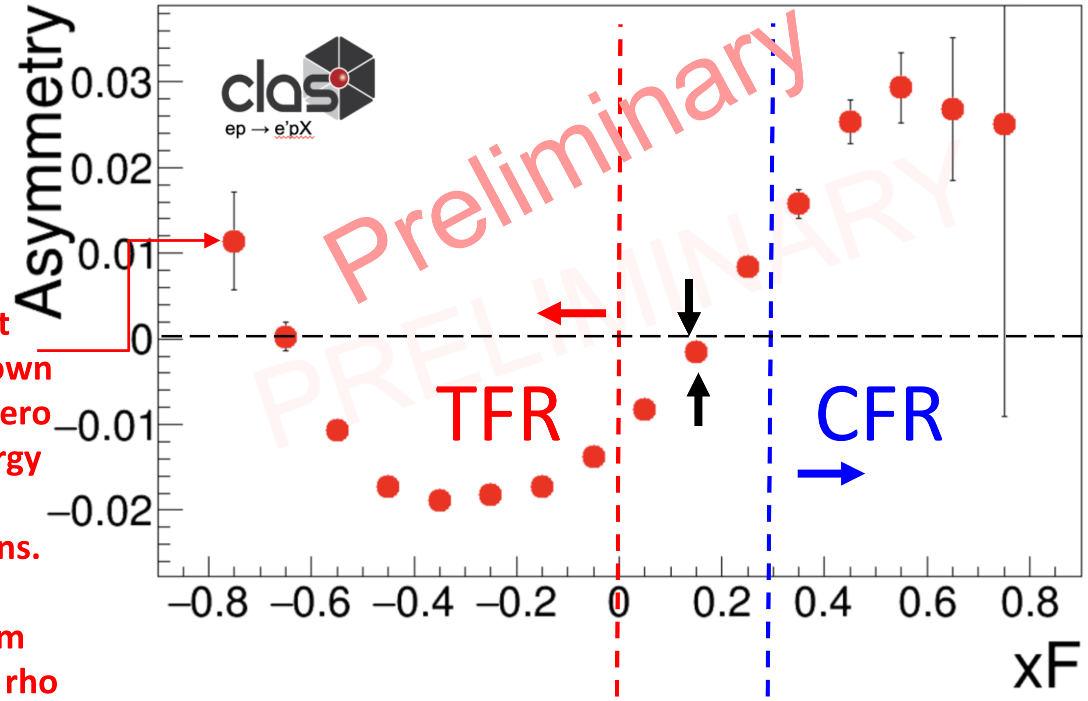




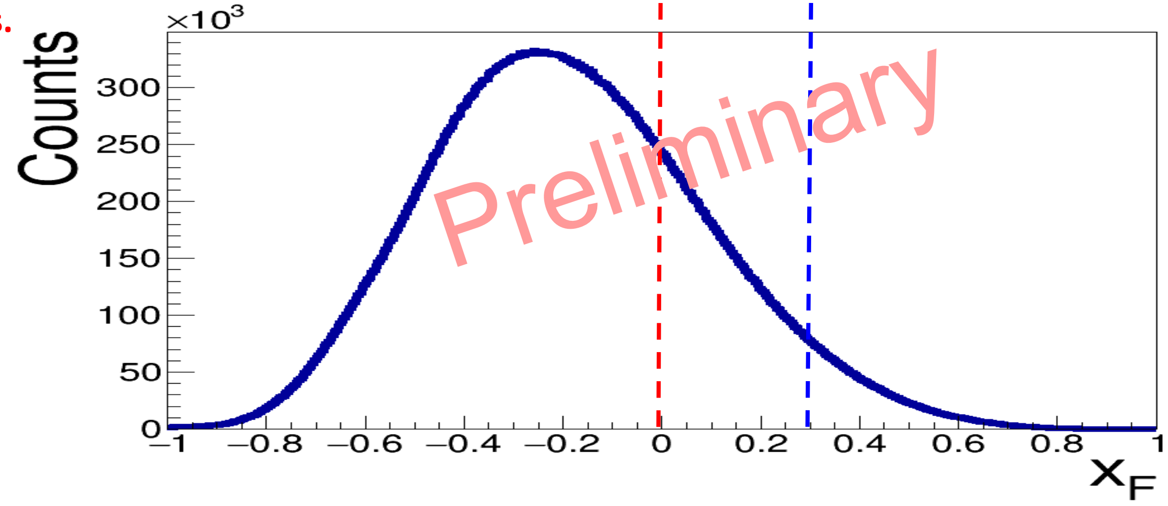
Decision: Take Mx>1.35

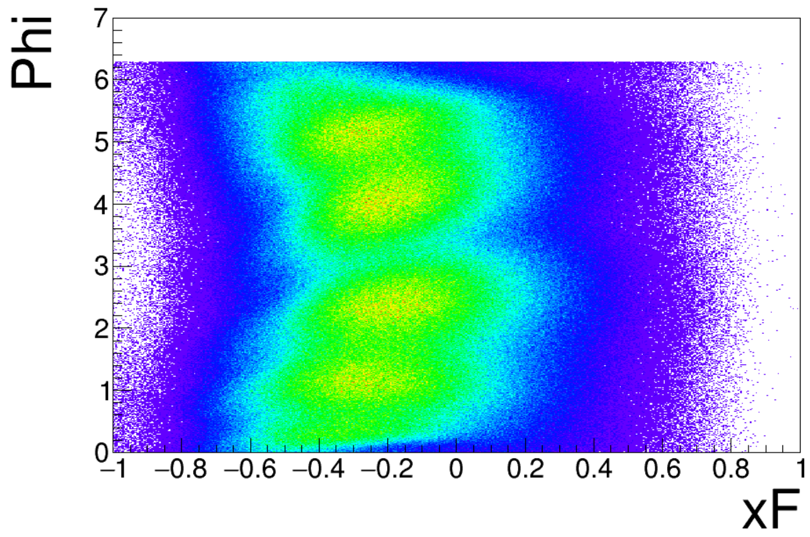
Asymmetry vs x_F Prel. Results, $M_x > 1.35$ (and appropriate cuts)

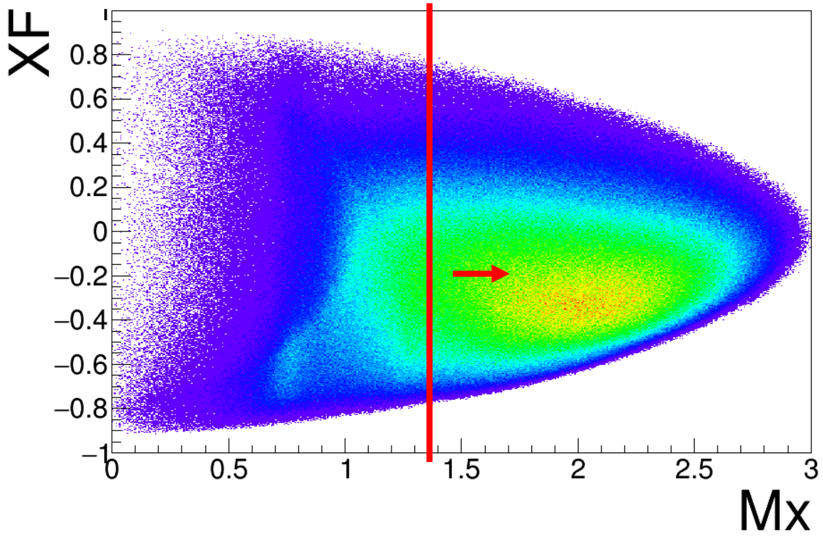




This point comes down close to zero with energy loss corrections. Also ight come from exclusive rho events.

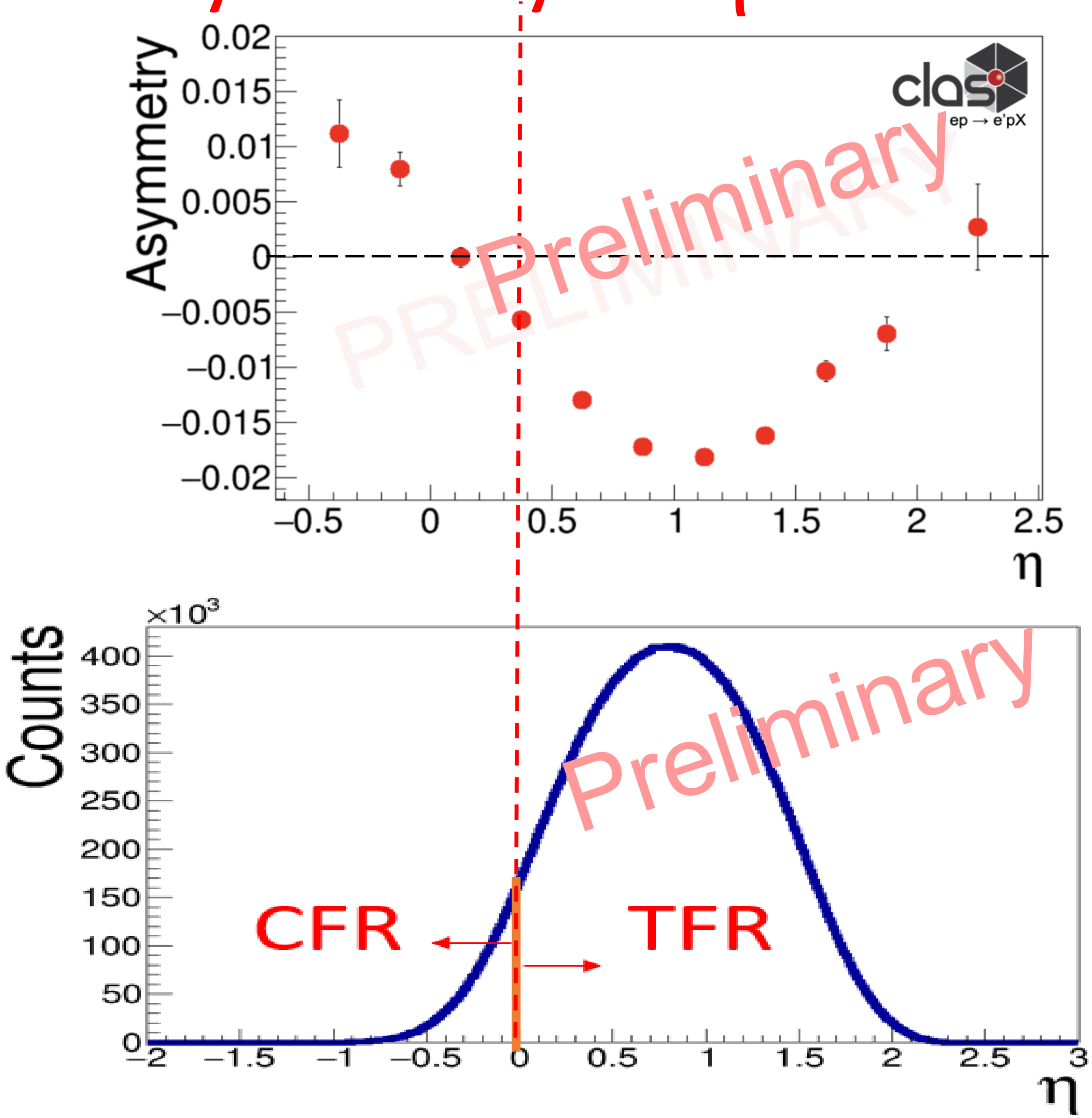


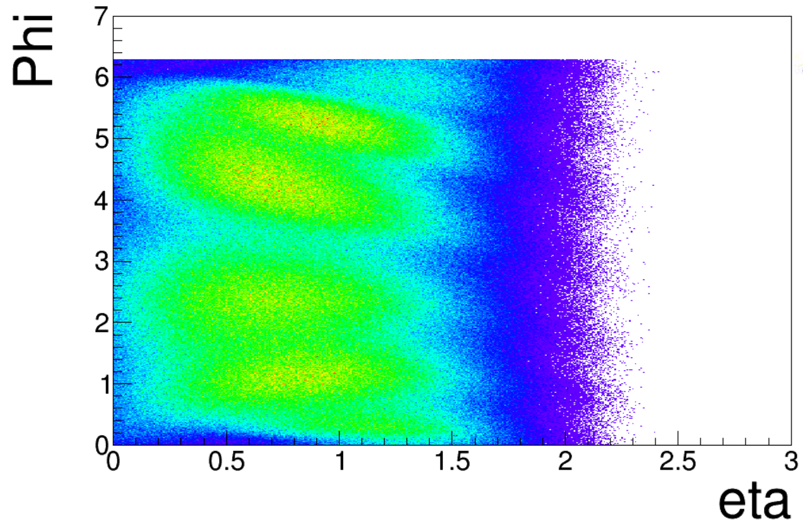


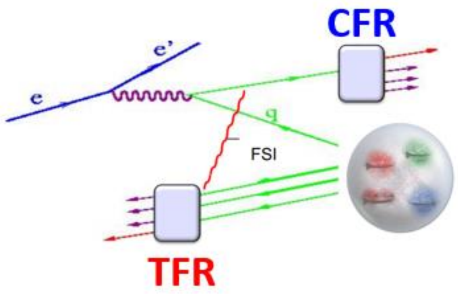


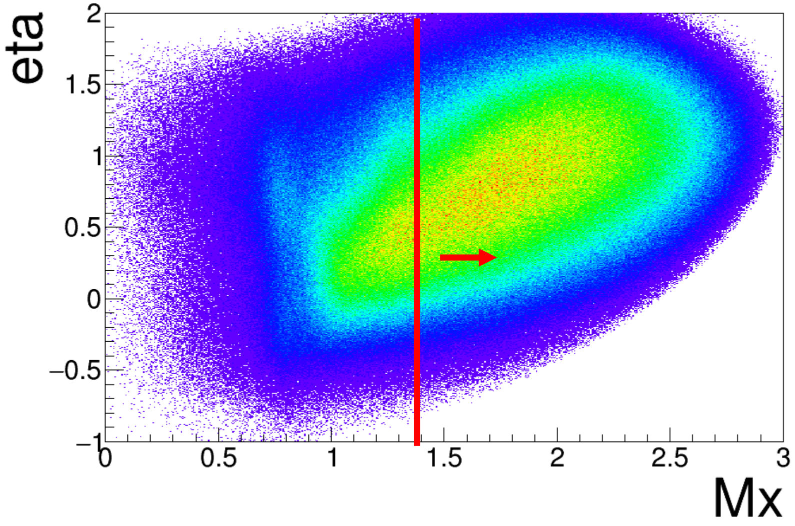
Note***: "*New tool for kinematic regime estimation in semi-inclusive deep-inelastic scattering*: Target, central and current regions": M. Boglione *et al.*, *High Energ. Phys.* **2022,** 84 (2022). https://doi.org/10.1007/JHEP04(2022)084

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

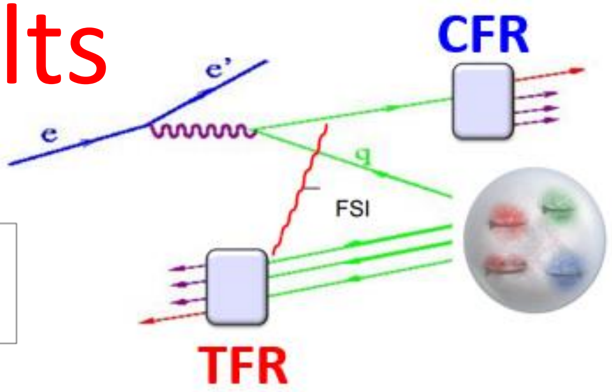


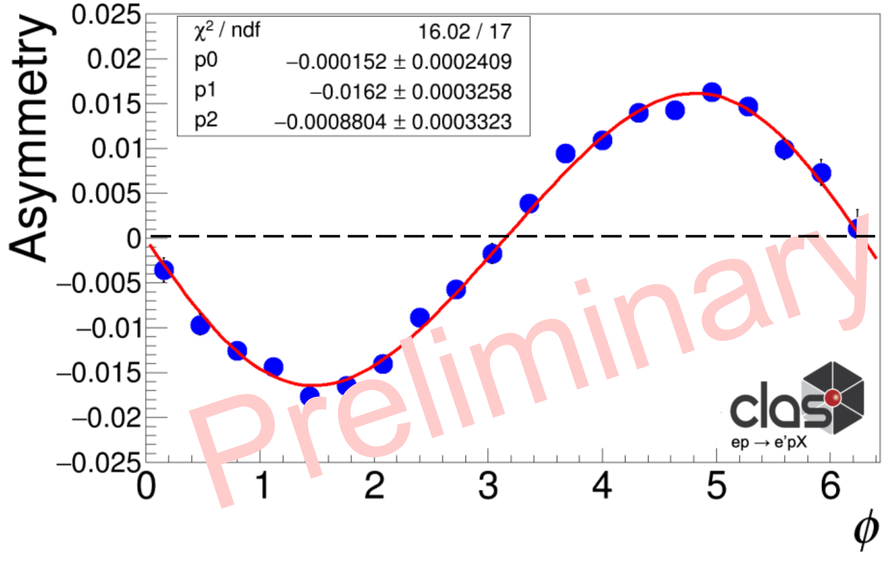




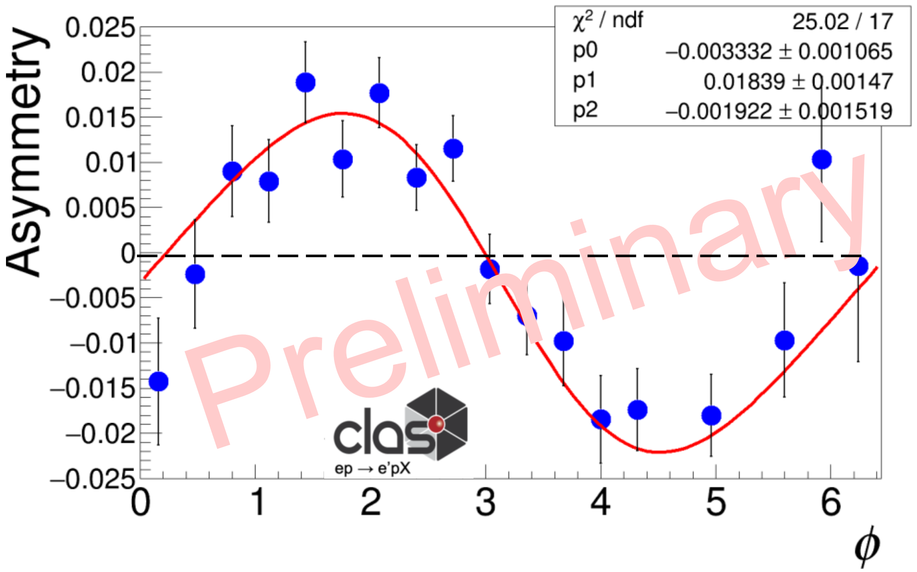


Preliminary Integrated Asymmetry Results

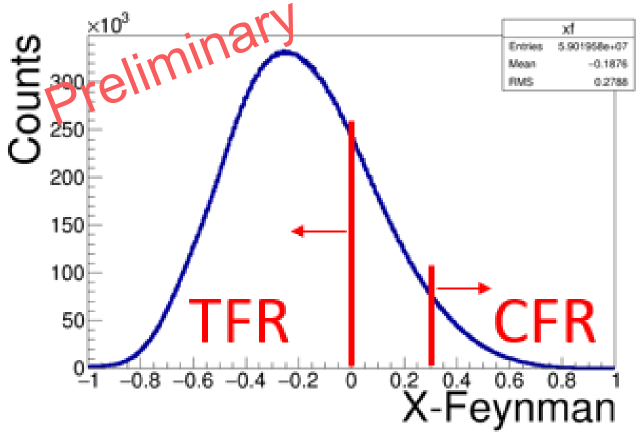




TFR



CFR

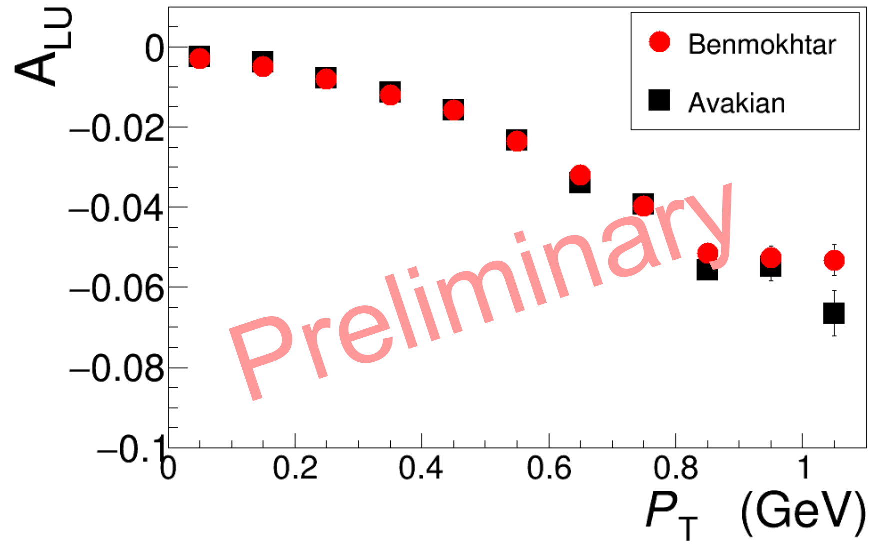


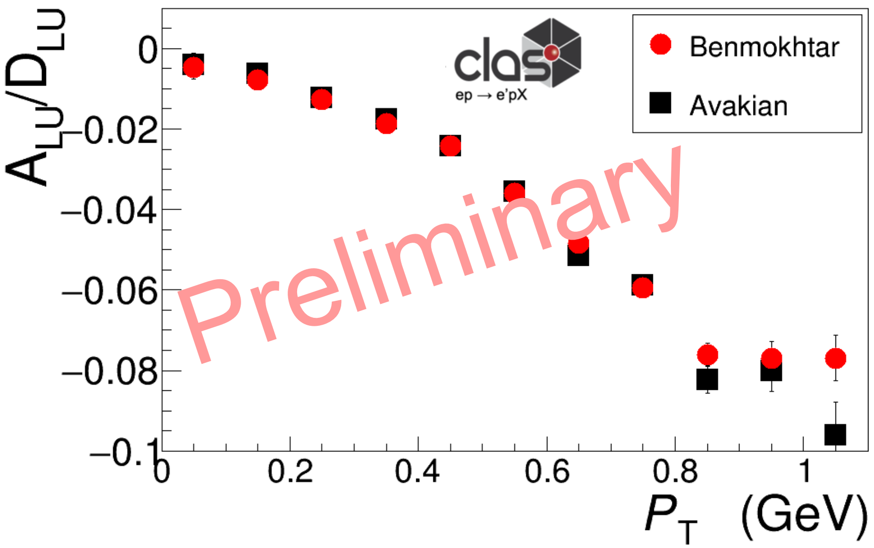
Fit: p0+p1 sin ϕ + p2 sin(2 ϕ)

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

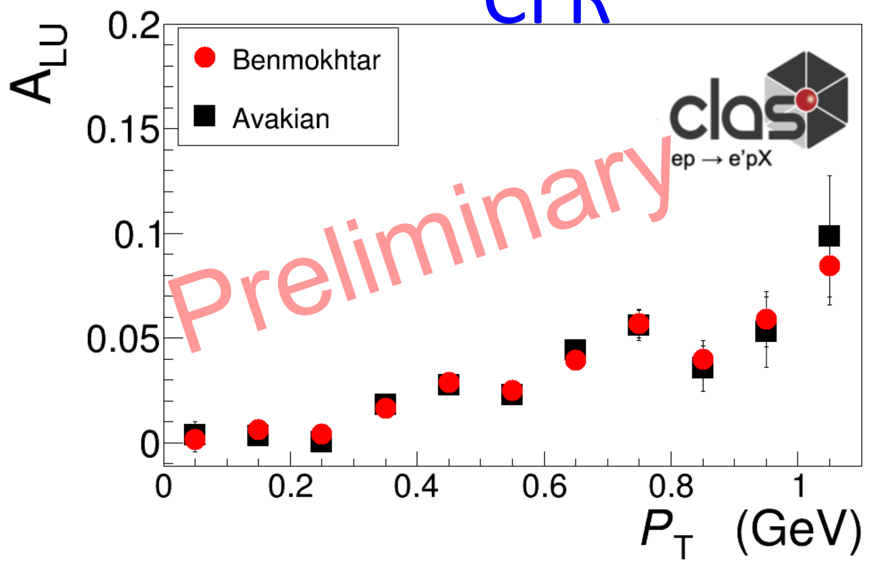
Asymmetry and Diluted Asym. vs P_T , Preliminary Results

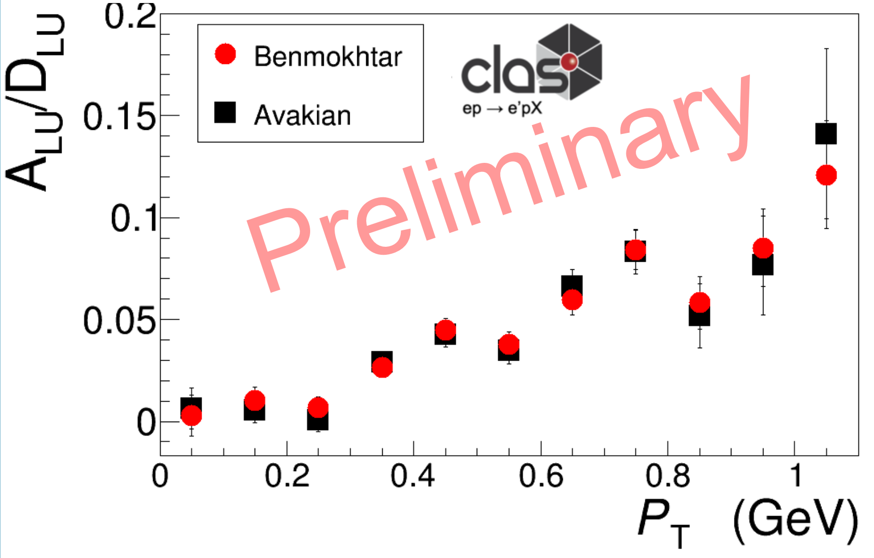
TFR

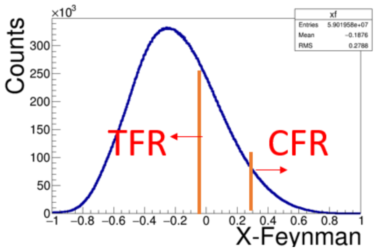


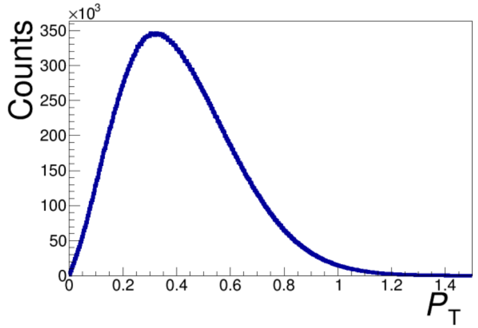


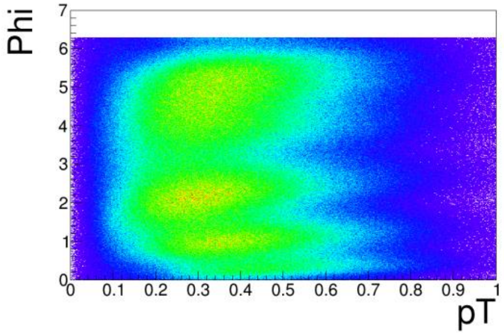
CFR

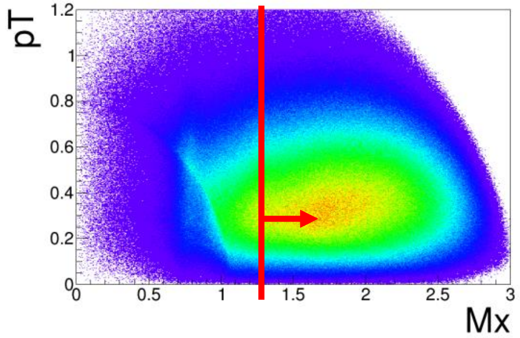




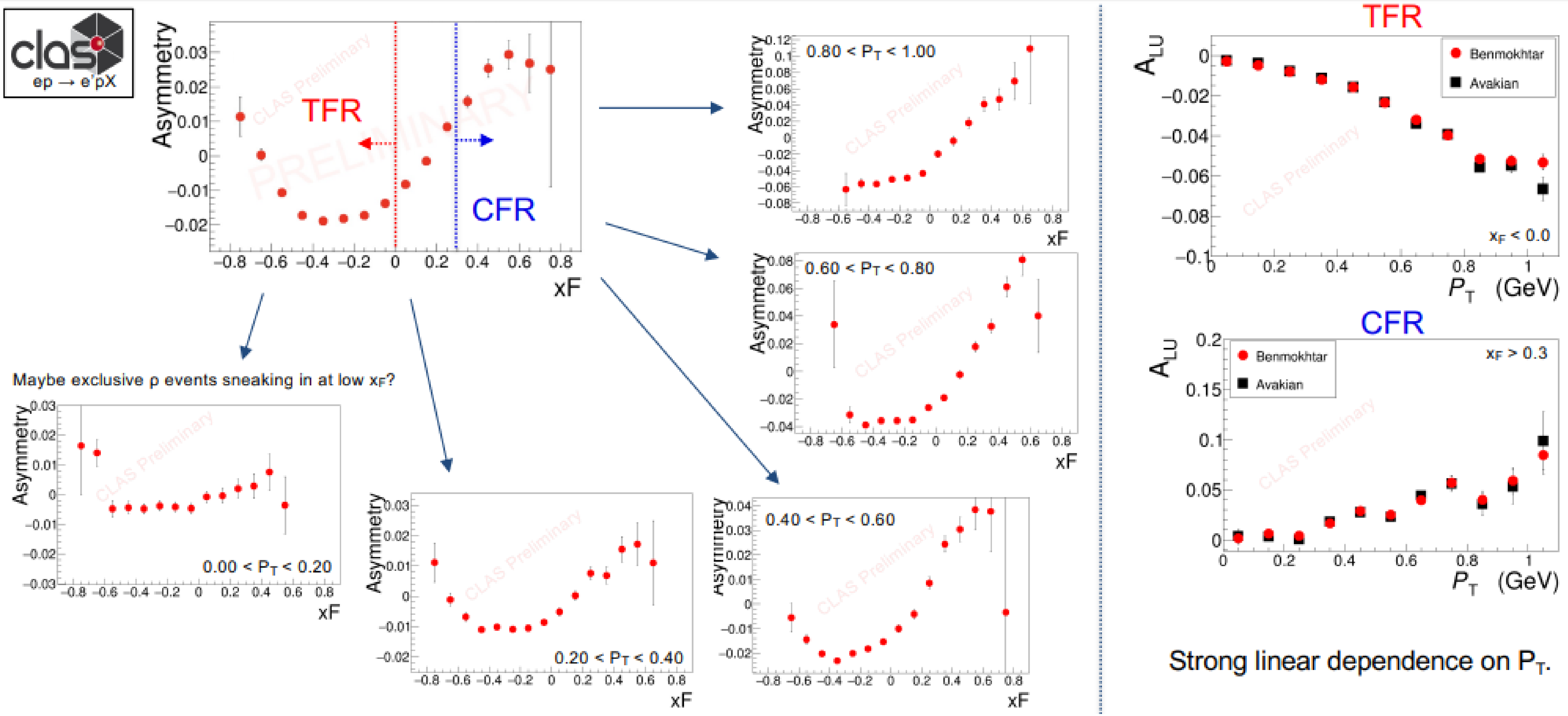








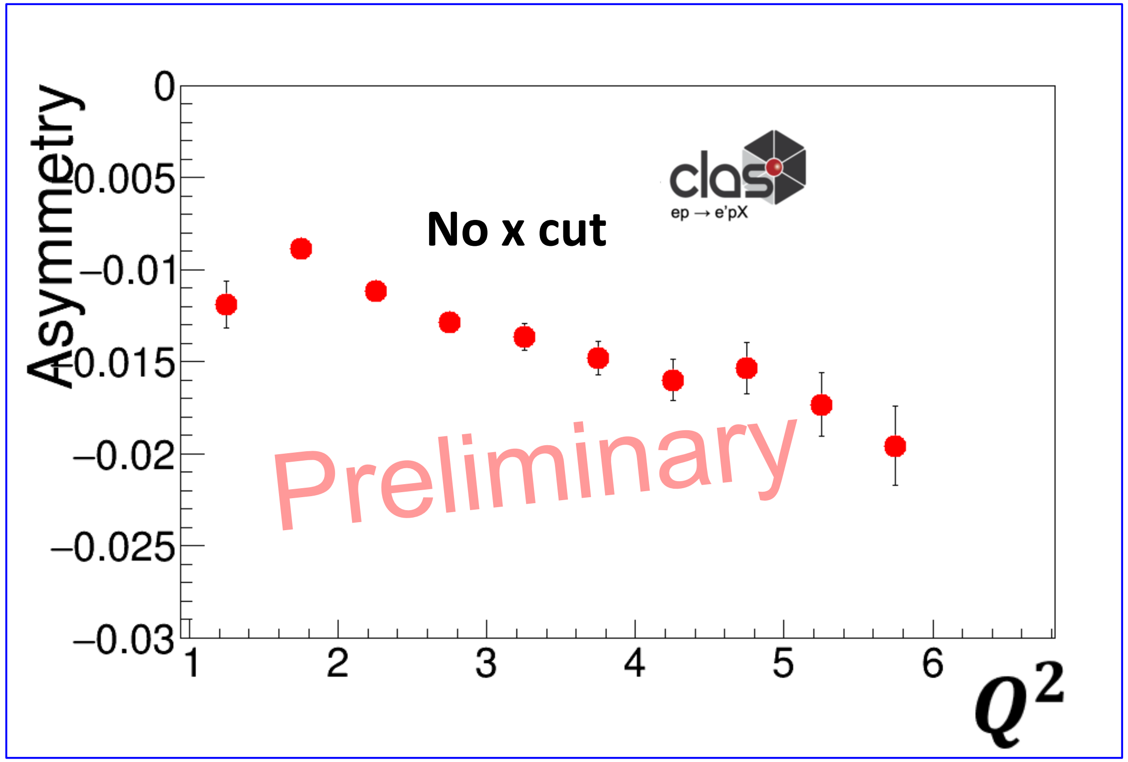
Transverse Momentum Effects

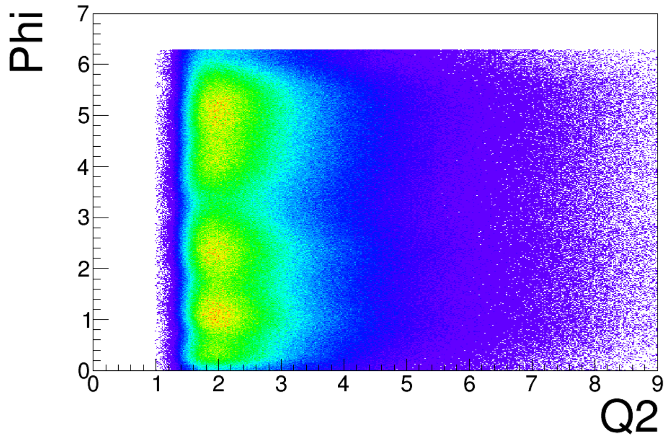


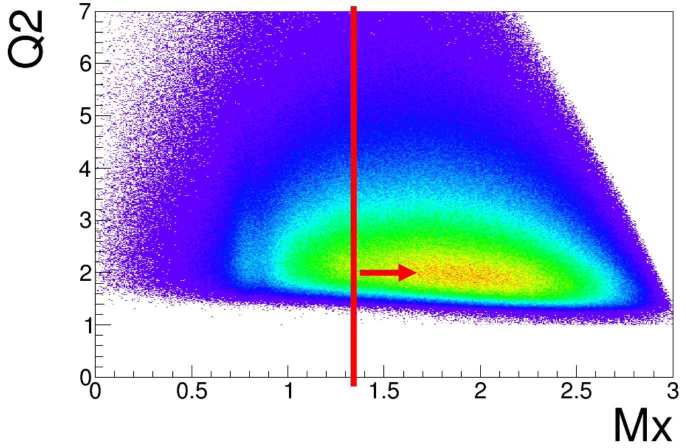
Strong linear dependence on P_T.

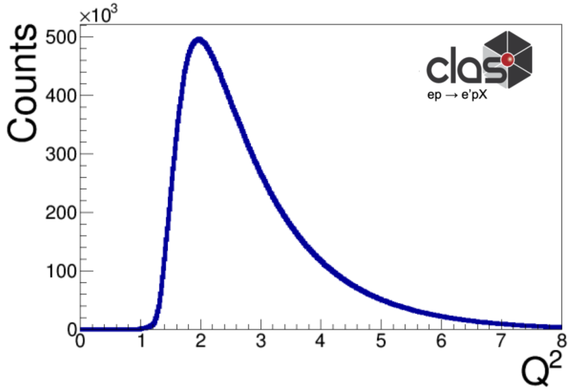
Q^2 Dependence Prel. Results

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



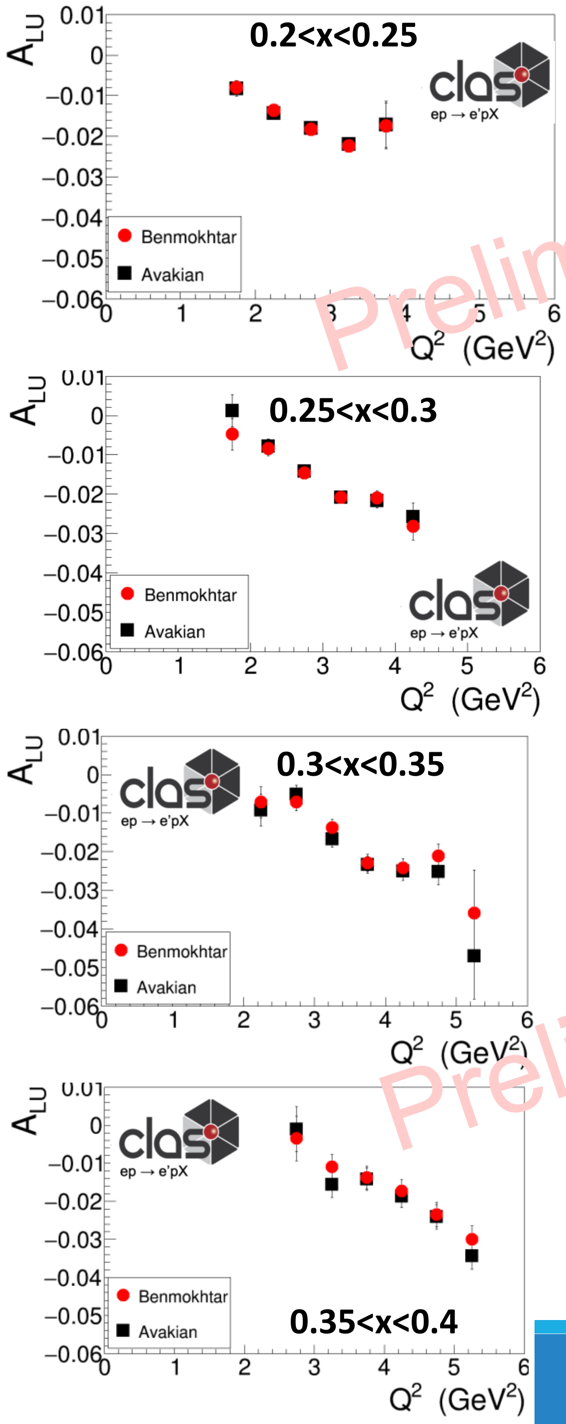




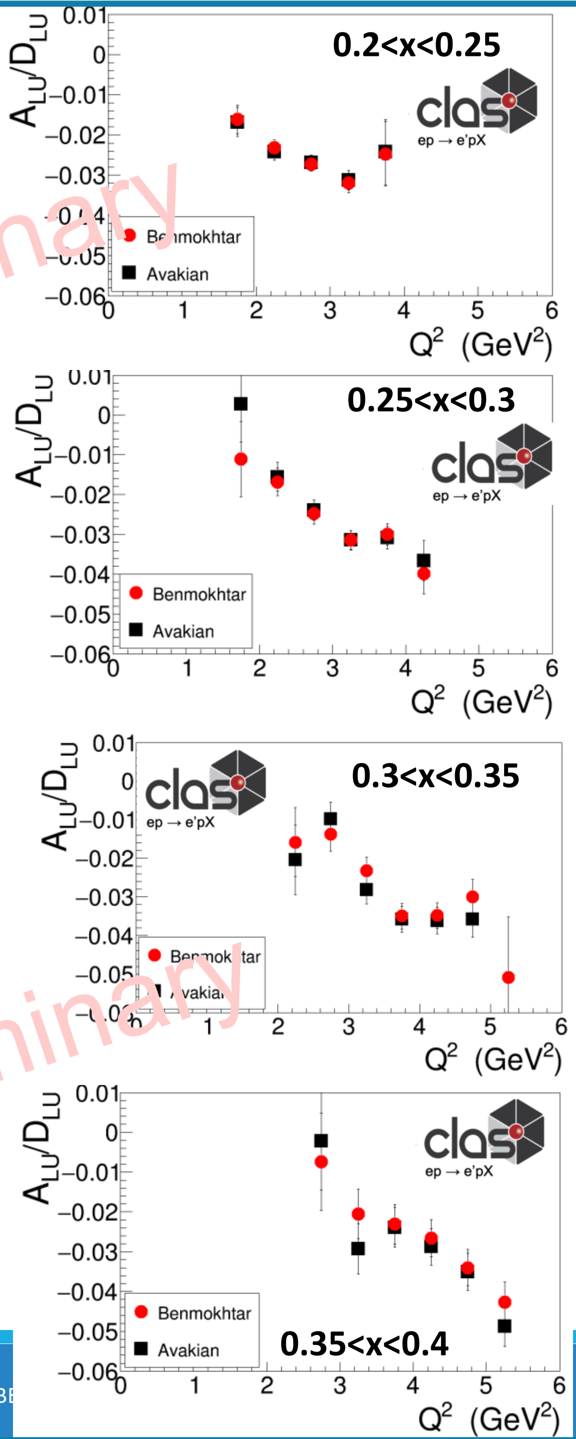


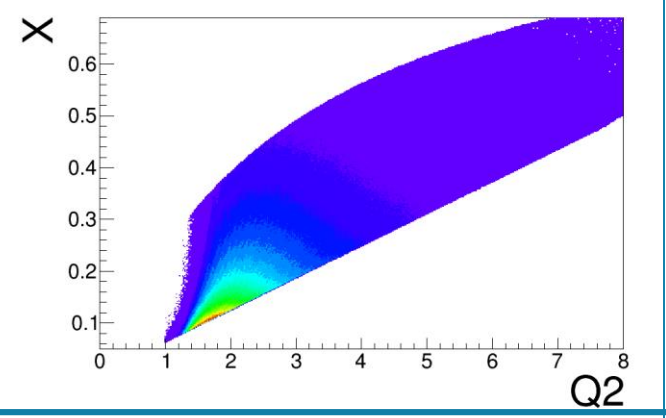
Q^2 Dependence Prel. Res.

Target Fragmentation Single Spin Asymmetries

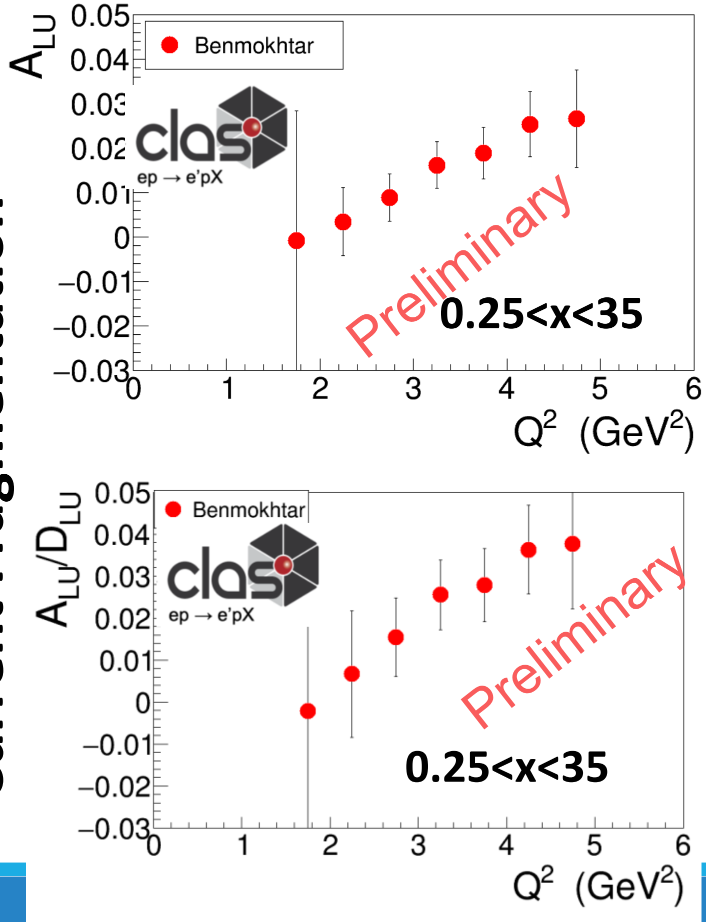


Target Fragmentation Fracture Functions

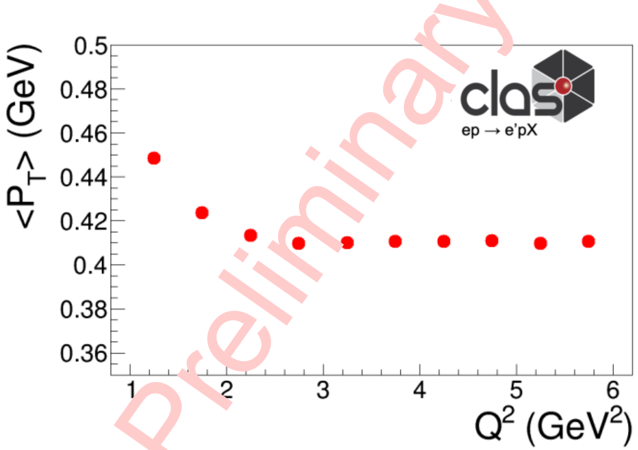


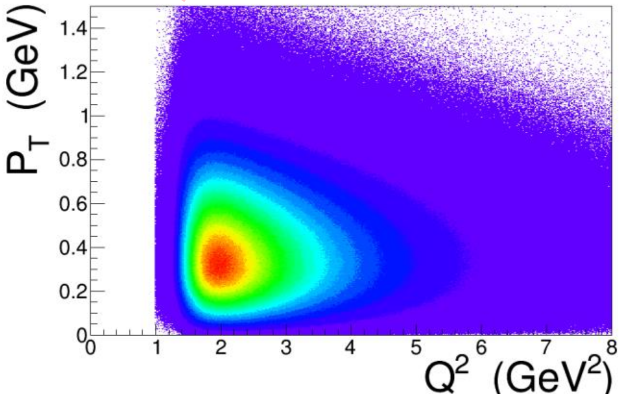


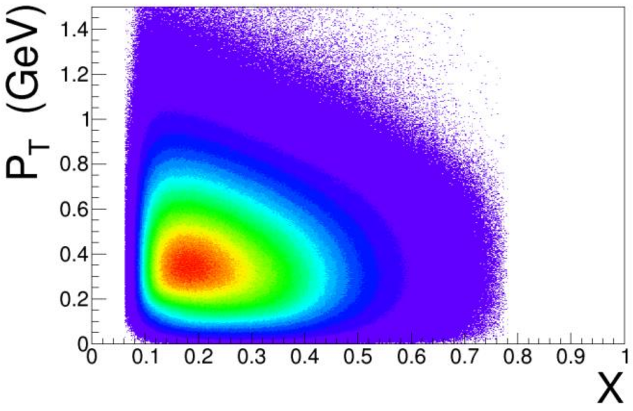
Current Fragmentation

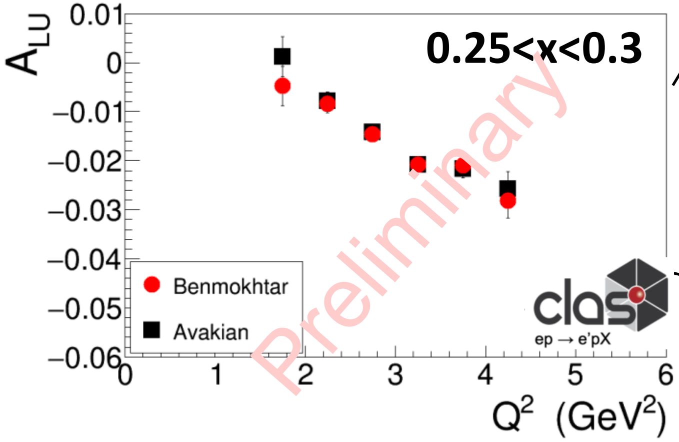


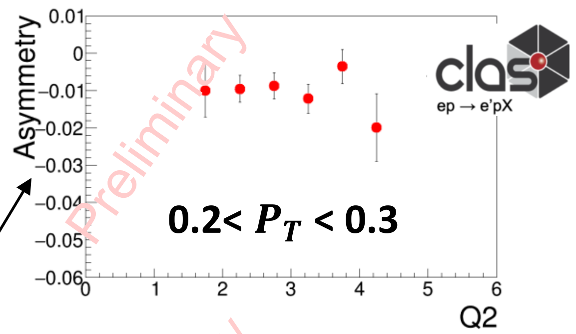
More Q^2 Dependence Studies

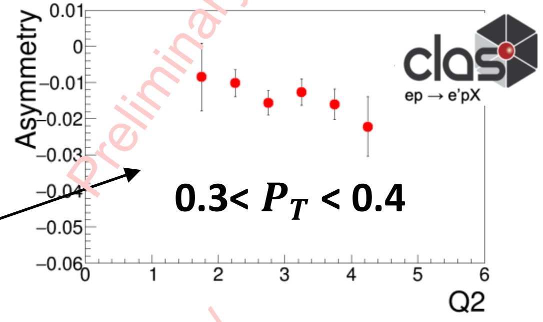


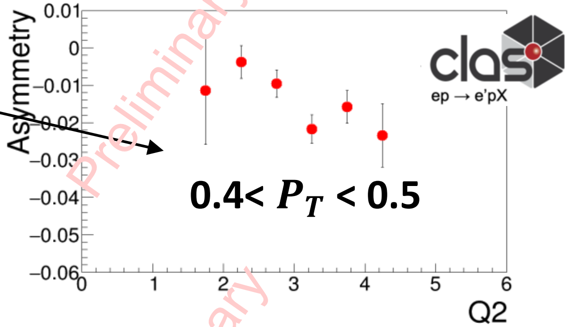


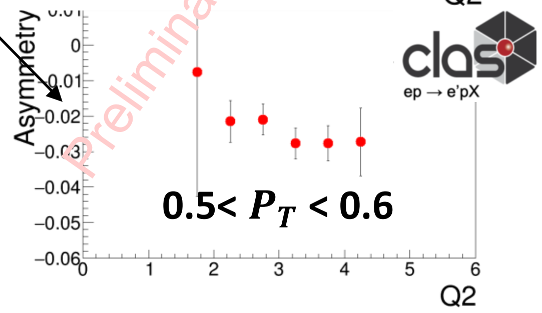




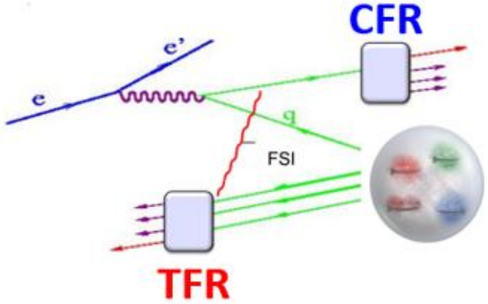




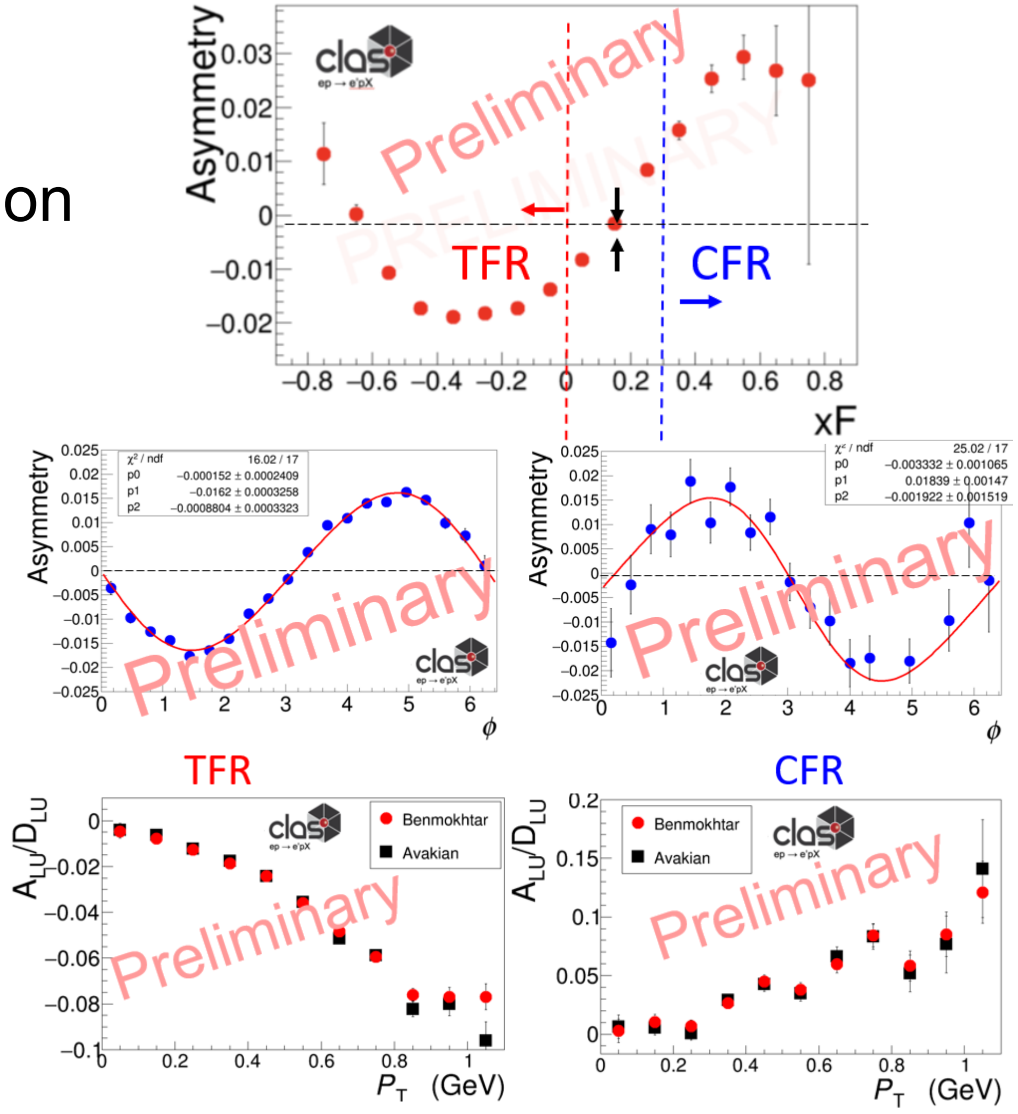




Note: ***With the full data set we are able to involve more dimensions.***



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:**

  - Systematics, radiative corrections, etc …
  - Release full data set in a couple of months
  - Investigate other channels
  - Thanks to **NSF** for the support!

Thank you!!!