



Multi-Dimensional Studies of the Proton Fragmentations in the $ep \rightarrow epX$ Reaction with CLAS12

Daniel Terrero

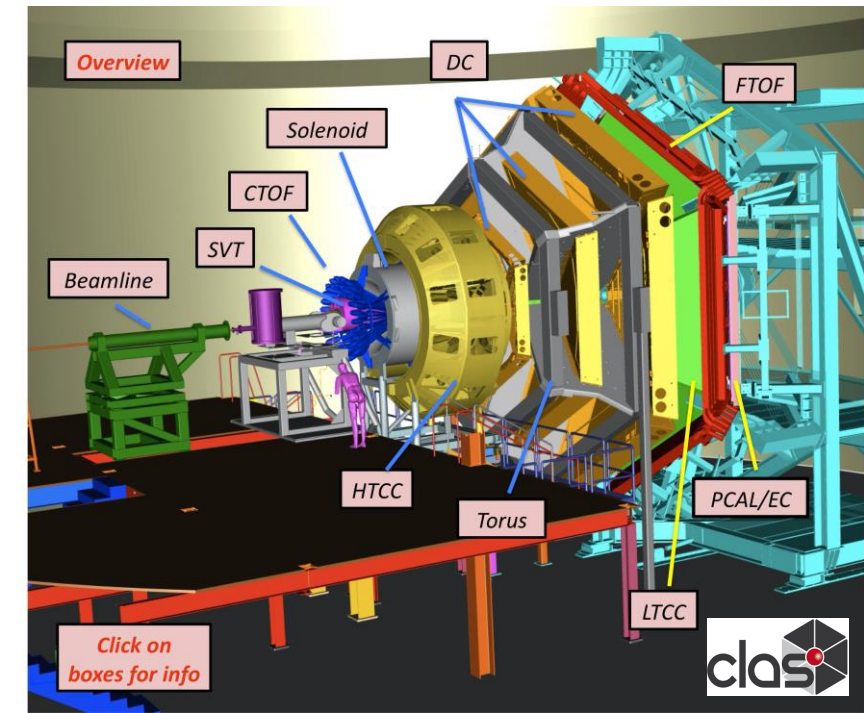
With: F. Benmokhtar, H. Avakian, T. Hayward, H. Valenty,
N. Nicholson, A. Gadsby, and A. Boyer.

Focus

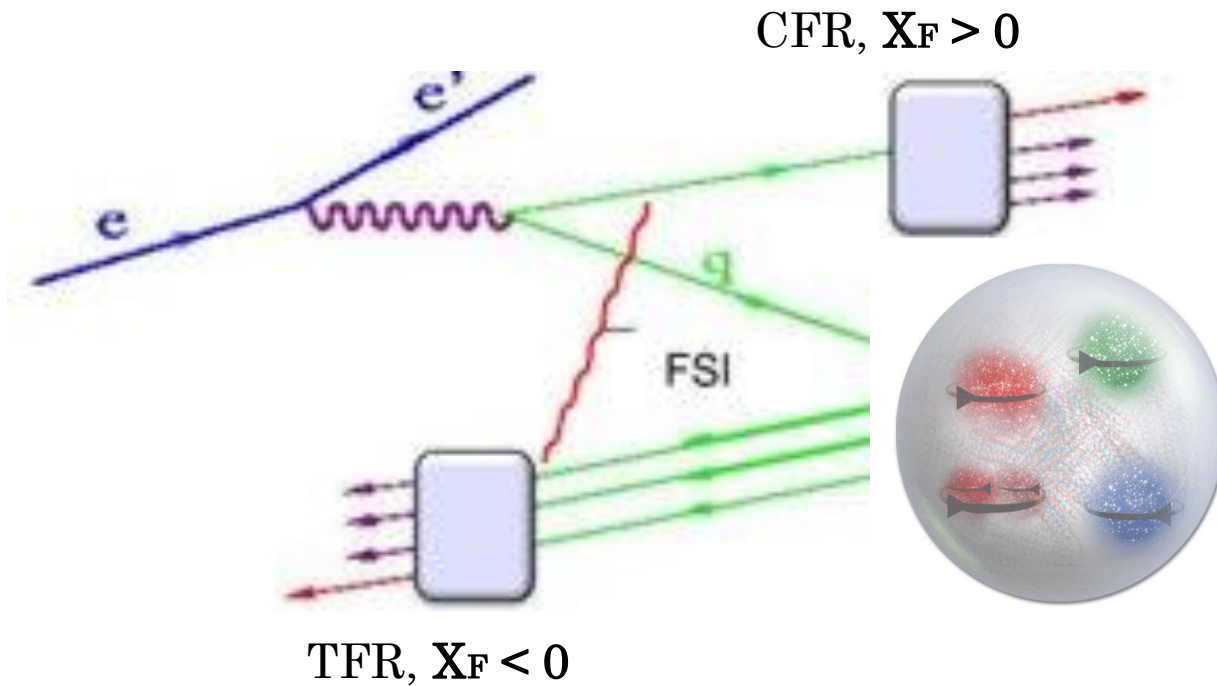
- Semi-Inclusive Deep Inelastic Scattering (SIDIS)
- **Collision of Interest:** $ep \rightarrow e'p' + X$ (the proton!)
- **Goal:** Test understanding of SIDIS production of hadrons

Experimental Setup

- Data of Fall 2018 and Spring 2019
- Hall B at Jefferson Lab using CLAS12 detector
- **Beam:** 10.6 GeV longitudinally polarized electron beam
- **Target:** Unpolarized liquid hydrogen



Fragmentation Regions

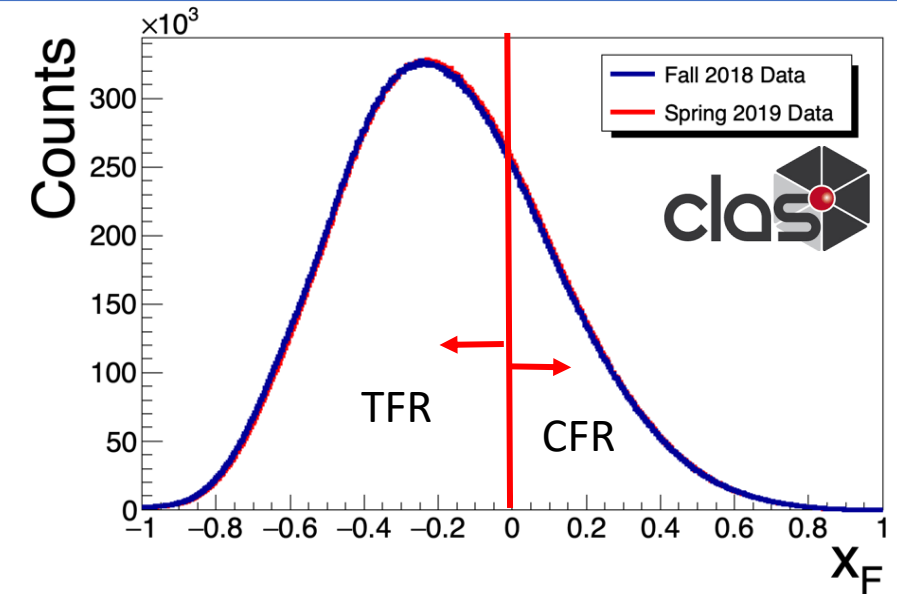


CFR: hadron produced from the collision by the virtual photon and this is described by **Fragmentation Functions**. Well studied.

TFR: hadron produced by the remnant of target nucleon after a quark is ejected by virtual photon collision and this is described by **Fracture Functions**.

Initial theory assumed

- Target Fragmentation Region, $X_F < 0$
- Current Fragmentation Region $X_F > 0$



Feynman-X: Fraction of momentum in CM frame

SSA with the Fracture Function Formalism

SIDIS Cross Section

$$\frac{d\sigma}{dx dy d\zeta dP_T^2 d\phi_h} = \hat{\sigma}_U \left\{ F_{UU} + \sqrt{2\varepsilon(1+\varepsilon)} F_{UU}^{\cos\phi_h} \cos\phi_h \right.$$

$$\left. + \varepsilon F_{UU}^{\cos 2\phi_h} \cos 2\phi_h + \lambda_\ell \sqrt{2\varepsilon(1-\varepsilon)} F_{LU}^{\sin\phi_h} \sin\phi_h \right\}$$

$$F_{LU}^{\sin\phi_h} = \frac{2|\vec{P}_{h\perp}|}{Q} x_B^2 l^h$$

F.F. Theory

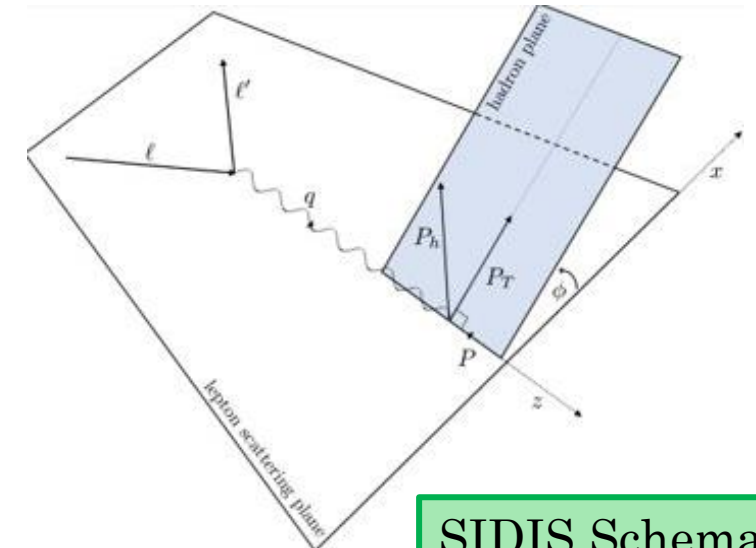
$$A(\phi)_{LU} = \frac{1}{p} \left(\frac{N^+ - N^-}{N^+ + N^-} \right)$$

Raw Asymmetry

Fracture Function Ratio

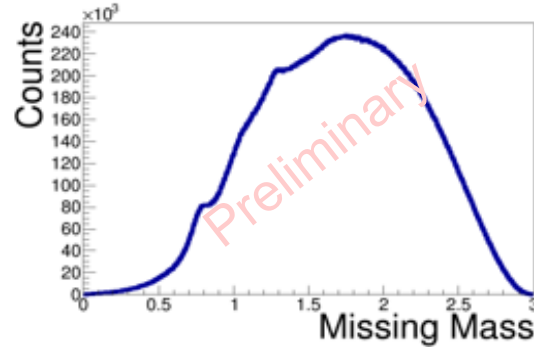
$$\frac{F_{LU}}{F_{UU}} = \frac{A(\phi)_{LU}}{\sqrt{2\varepsilon(1-\varepsilon)}}$$

Depolarization Factor

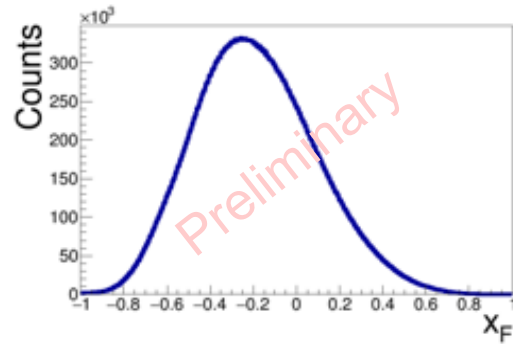


SIDIS Schematic

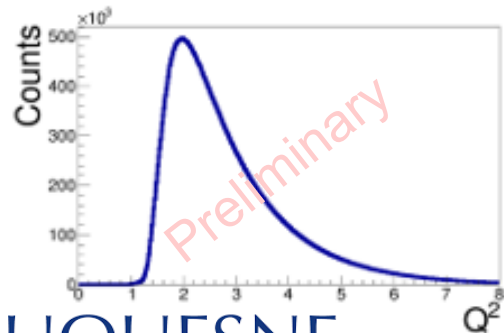
Variables of Interest



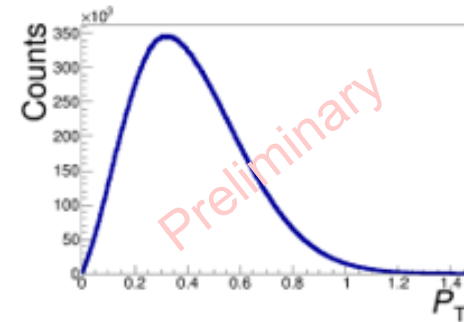
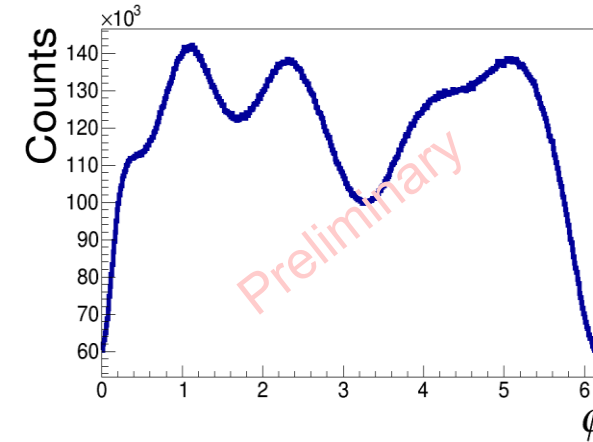
Accounts for
particles not
detected post-
collision



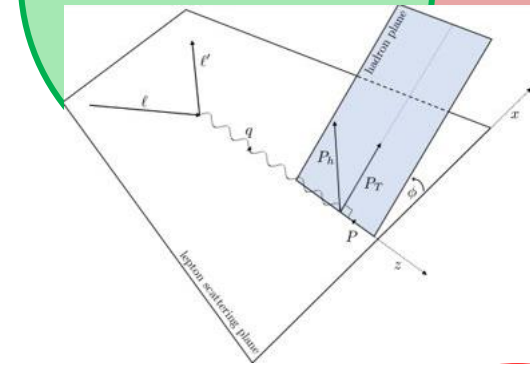
$$x_F = \frac{2P_h \cdot q}{|q|W}$$



$$Q^2 = -q^2$$



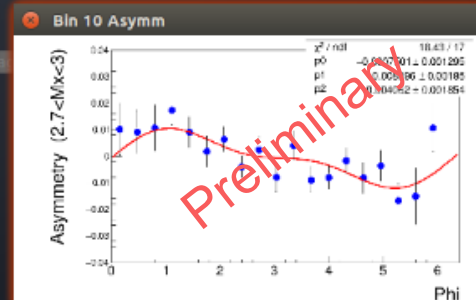
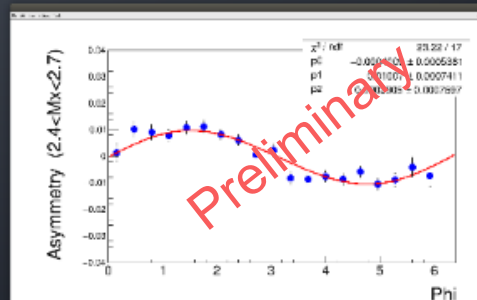
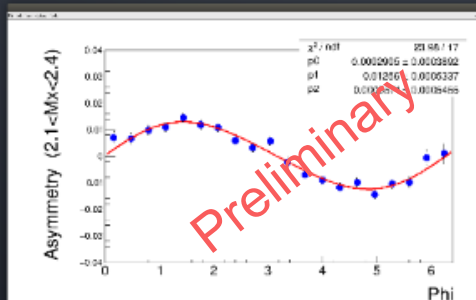
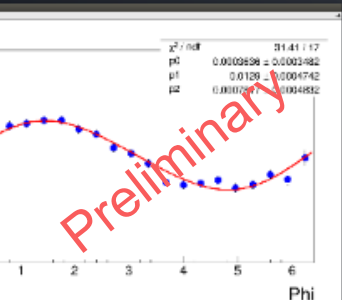
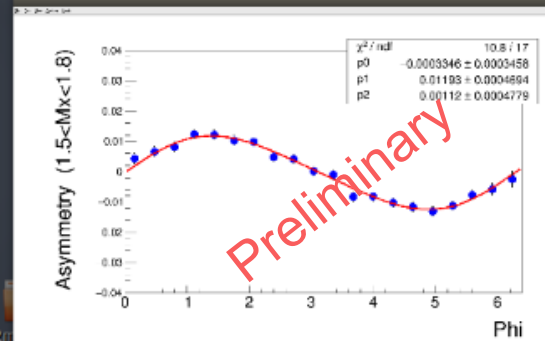
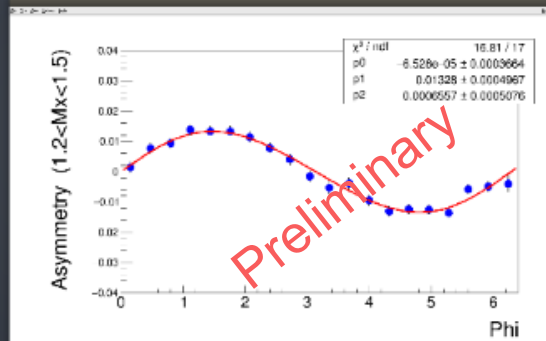
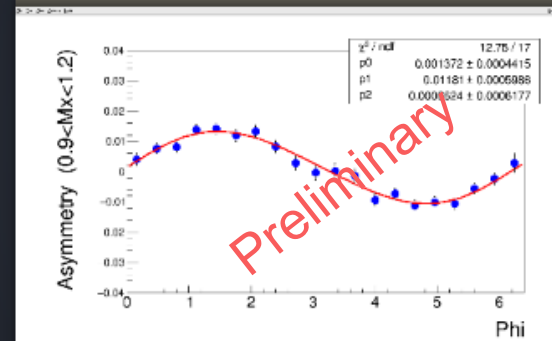
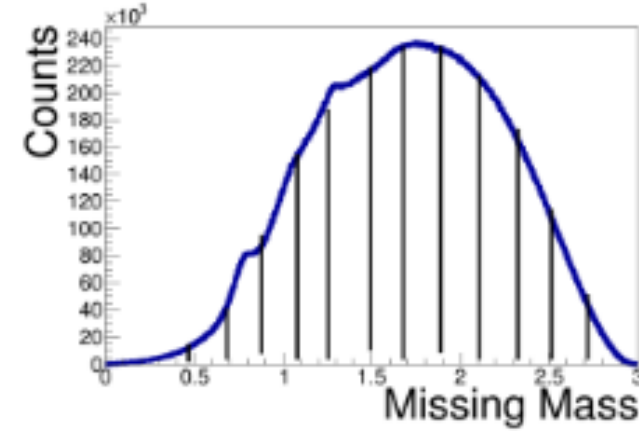
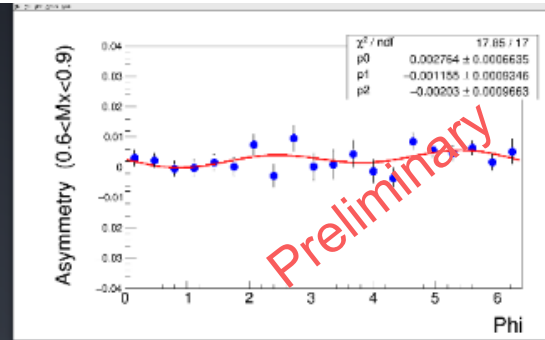
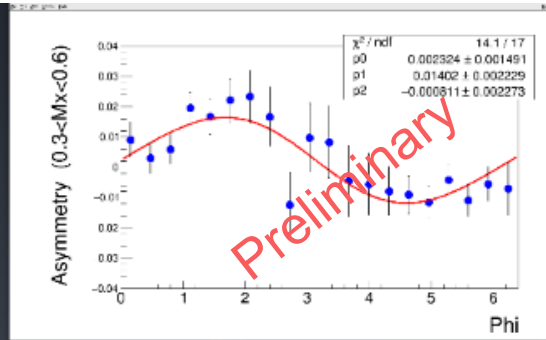
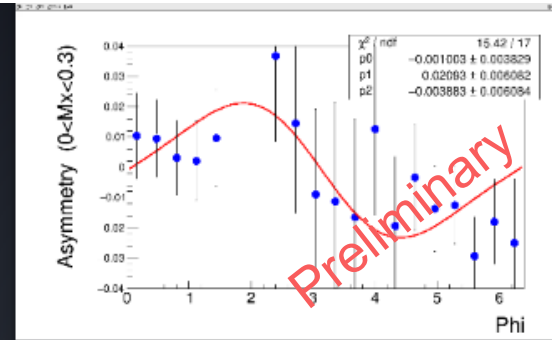
Transverse
momentum ascribed
to proton post-
collision



SSA Extraction

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

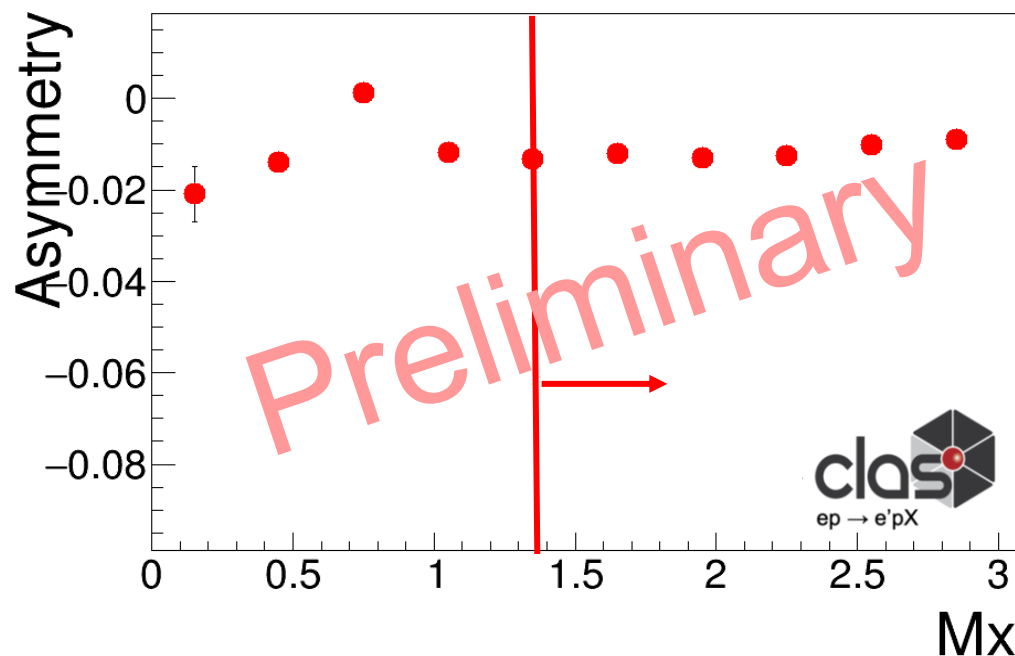
$$p_0 + p_1 \sin \phi + p_2 \sin(2 \phi)$$



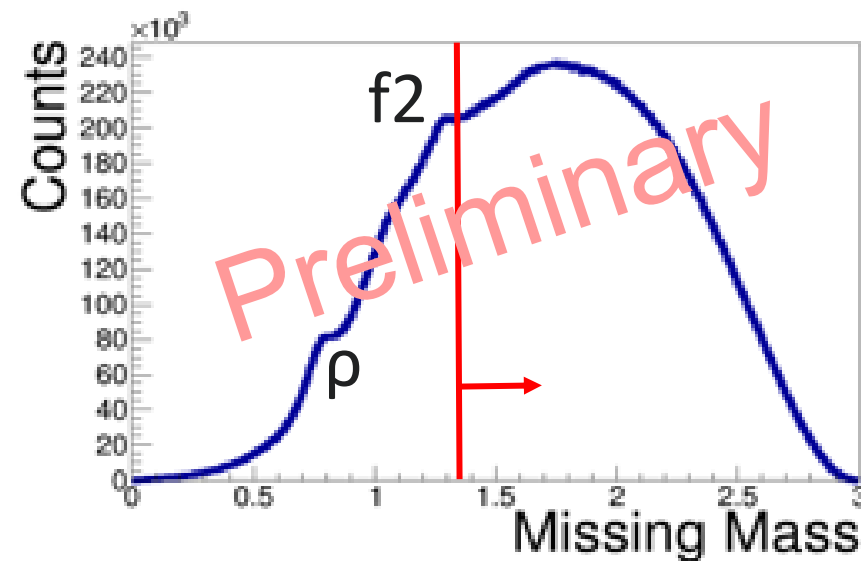
Sin ϕ Modulation
vs. Missing Mass

Data Cleanup

Missing mass histogram and asymmetry plots revealed 2 peaks



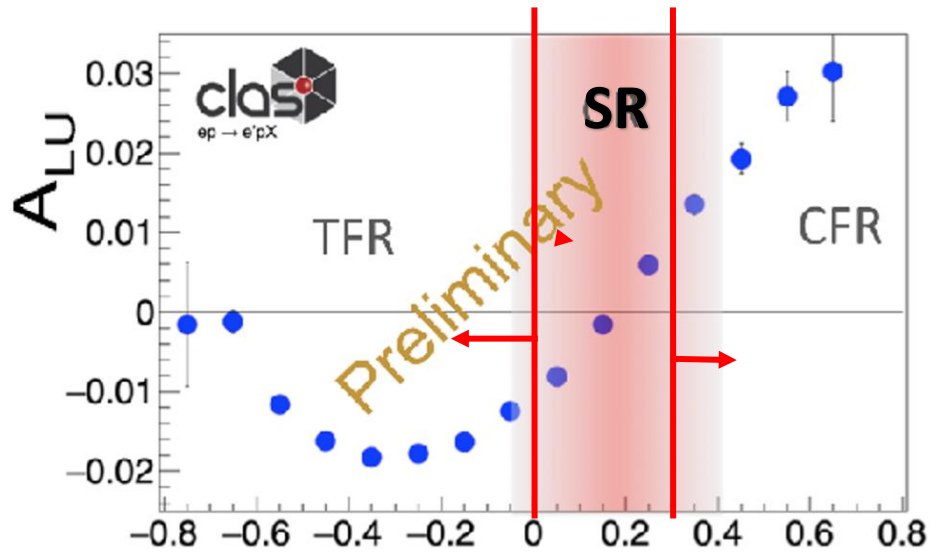
Defined a universal cut for rest of analysis, $M_x > 1.35$



Cuts in addition to M_x :

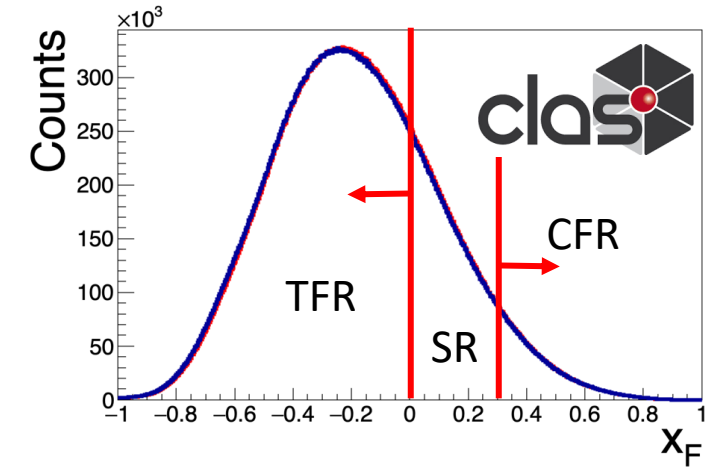
- Fiducial
 - Hard cuts applied in analyzer
- Target
 - Remove target walls from experiment

Fragmentation Regions



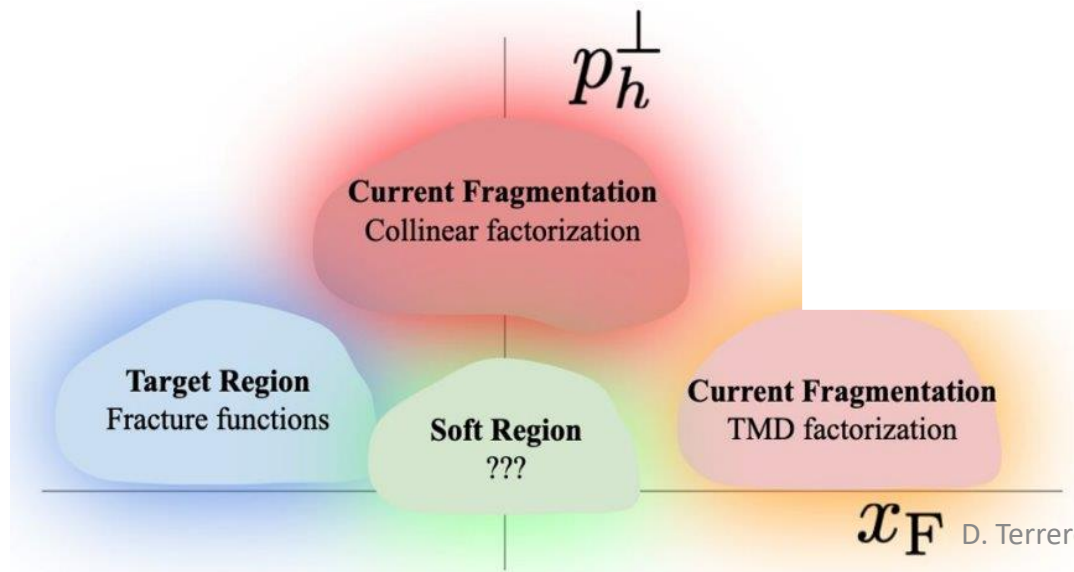
Analysis suggests

- Target Fragmentation Region, $x_F < 0$
- Current Fragmentation Region $x_F > 0.3$



Fragmentation regions determined to be separated by soft region

Asymmetry extracted for x-Feynman



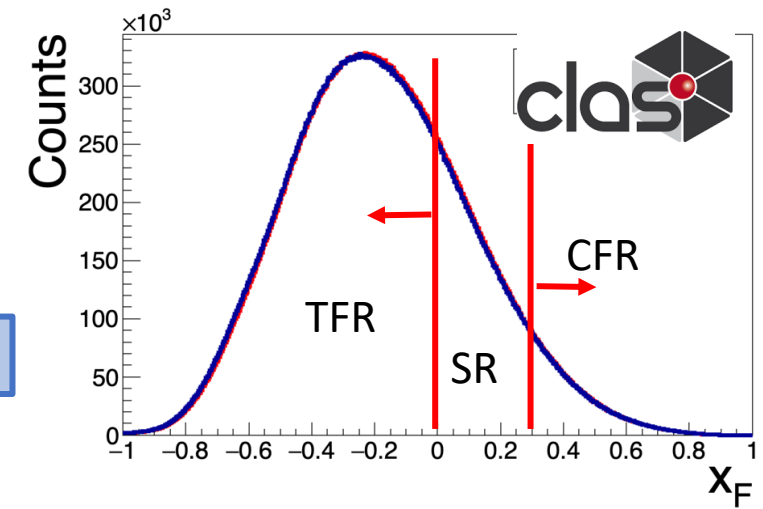
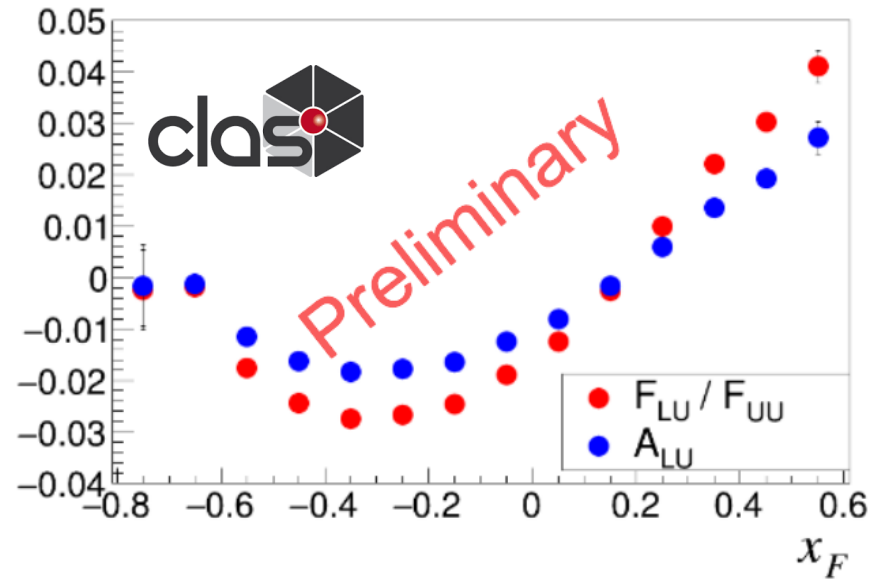
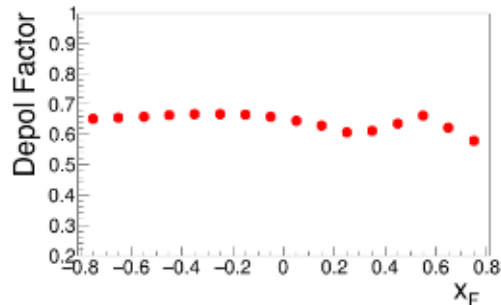
Feynman-X

Asymmetry and Fracture Function comparison for x_F

Fracture Function Ratio

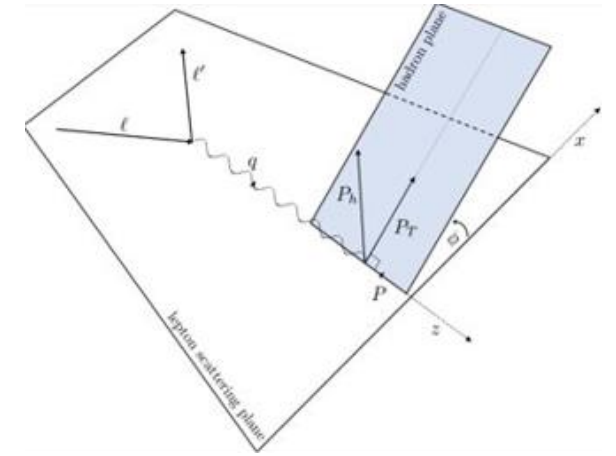
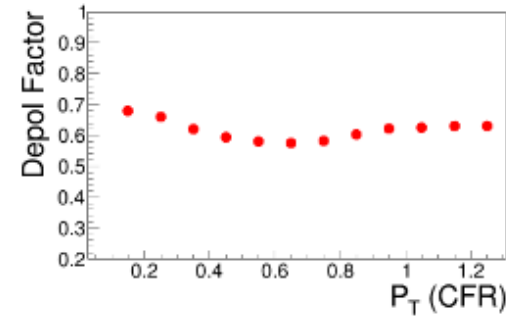
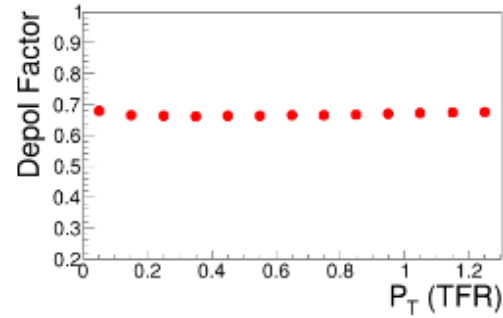
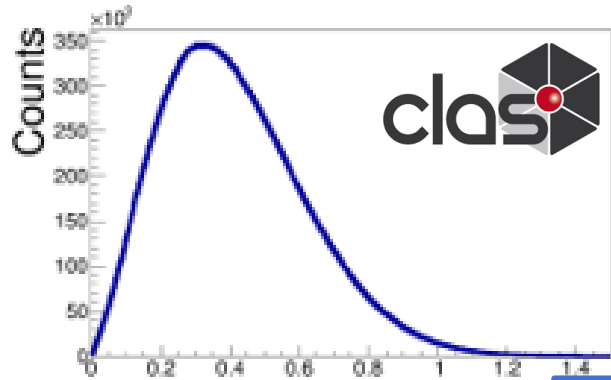
$$\frac{F_{LU}}{F_{UU}} = \frac{A(\phi)_{LU}}{\sqrt{2\epsilon(1-\epsilon)}}$$

Depolarization Factor



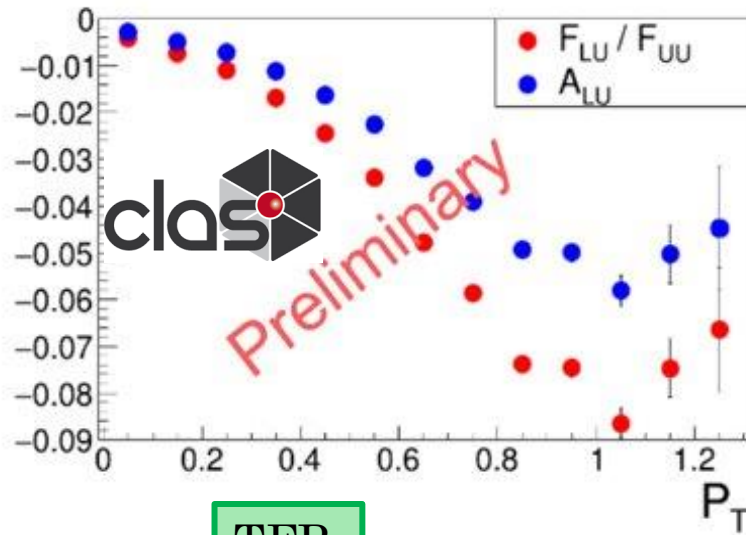
Depolarization factor calculated for each asymmetry value and applied to raw ALU

Transverse Momentum

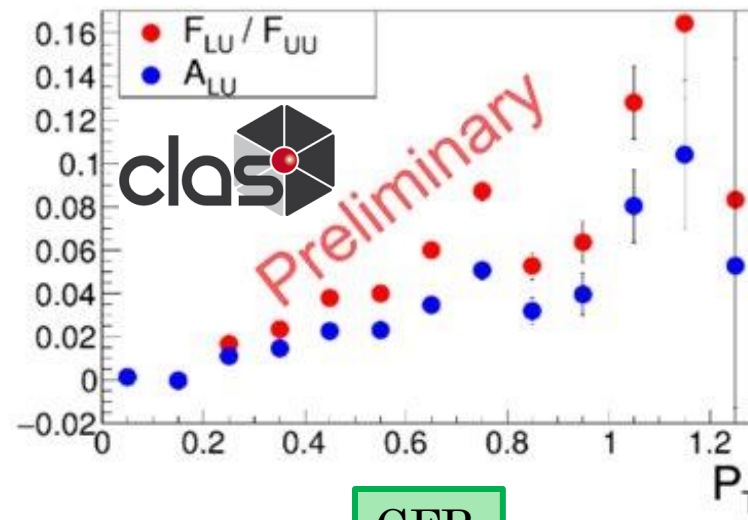


Asymmetry and Fracture Function comparison for p_T

Fracture Function Ratio



TFR



CFR

$$\frac{F_{LU}}{F_{UU}} = \frac{A(\phi)_{LU}}{\sqrt{2\epsilon(1-\epsilon)}}$$

Depolarization Factor

Proton Energy Loss Corrections

Momentum corrections analysis have been described in great detail in the exclusive π^0 electro-production analysis note of A. Kim.

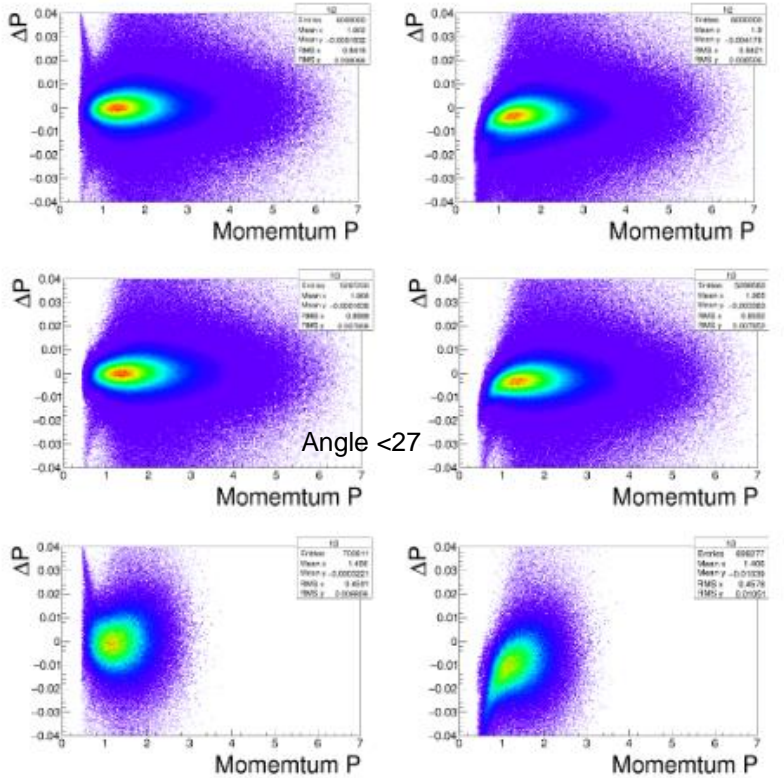
Same methods applied to our analysis.

$$\Delta P = P_{gen} - P_{rec}$$

$$\Delta P = e^{p^0+p^1P} + p^2$$

No Eloss Cor.

Eloss Cor.



Angle <27

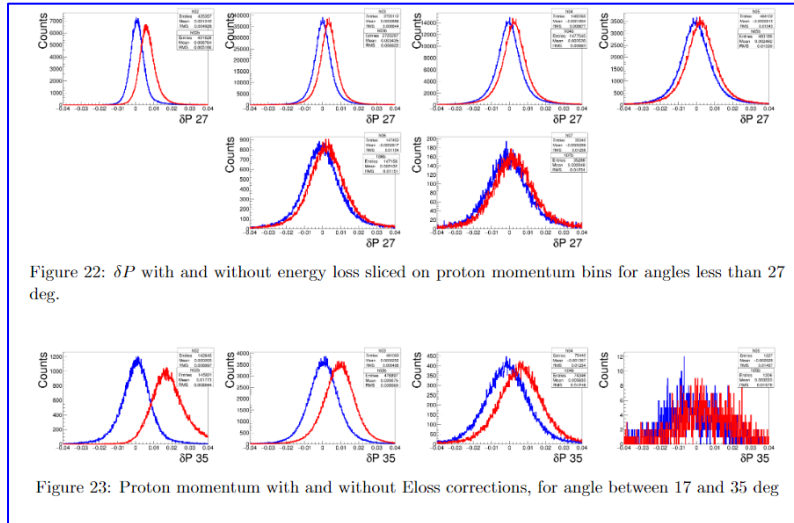
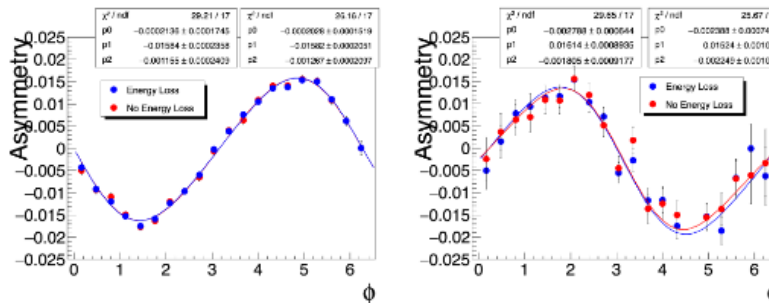
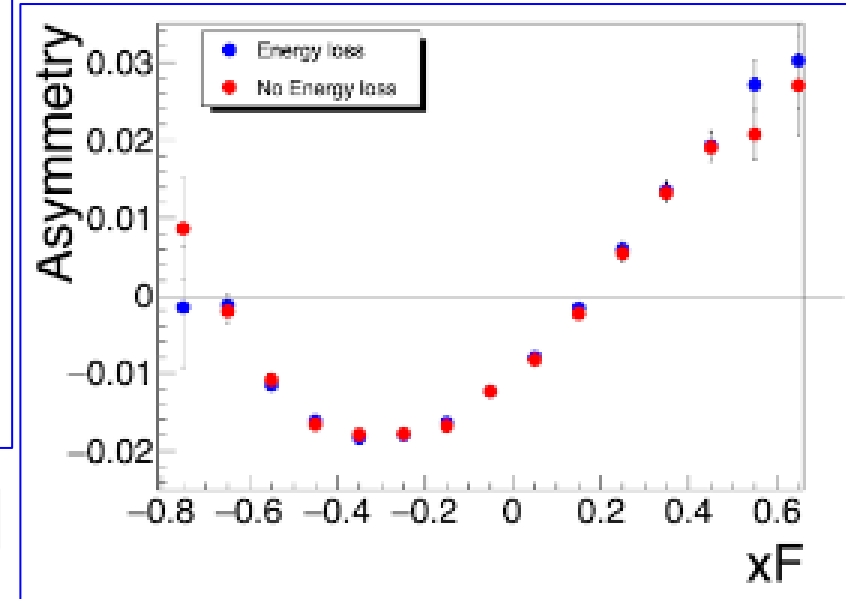


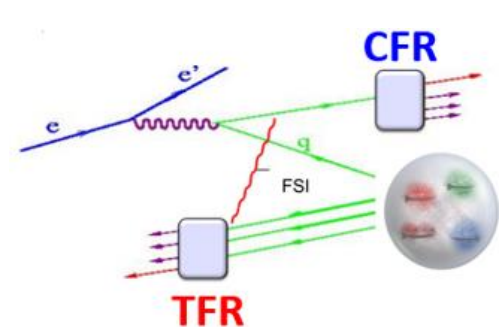
Figure 22: δP with and without energy loss sliced on proton momentum bins for angles less than 27 deg.

Figure 23: Proton momentum with and without Eloss corrections, for angle between 17 and 35 deg



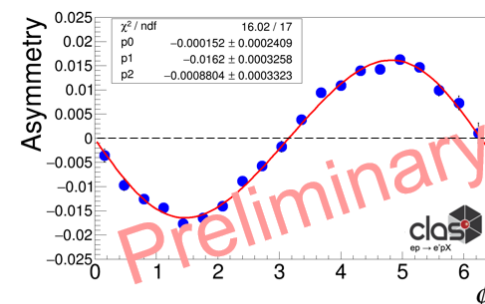
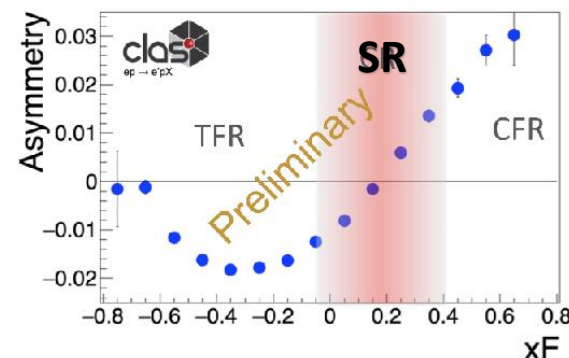
Energy loss corrections were applied to the data from now on.



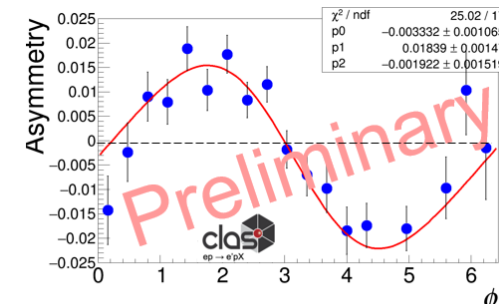


Summary, Conclusion and Outlook

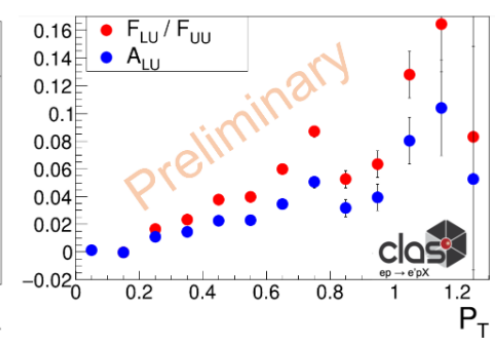
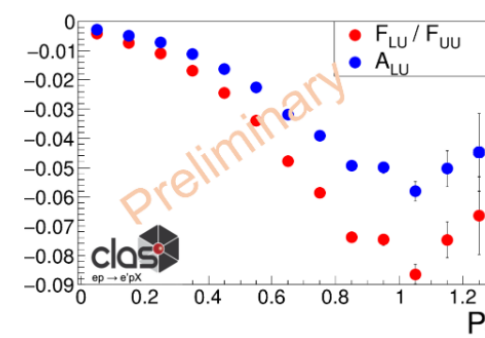
- For the first time at Jlab, we've captured the transition between **TFR** and **CFR** in the $ep \rightarrow e'pX$.
- There are significant beam SSAs for baryons in TFR, with opposite sign to what we observe in CFR.
- Many more multidimensional analysis versus all the other variables are available.
- Status: Full data set has been analyzed, systematics analysis underway and final results will be available for full review soon.



TFR



CFR



Acknowledgements

- Dr. Fatiha Benmokhtar
- Dr. Harut Avakian
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- Alyssa Gadsby and all the Duquesne interns
- Project made possible by funding from the NSF



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Supplemental Slides

Variables of Interest

