Spin Azimuthal Asymmetries on a Longitudinally Polarized Proton

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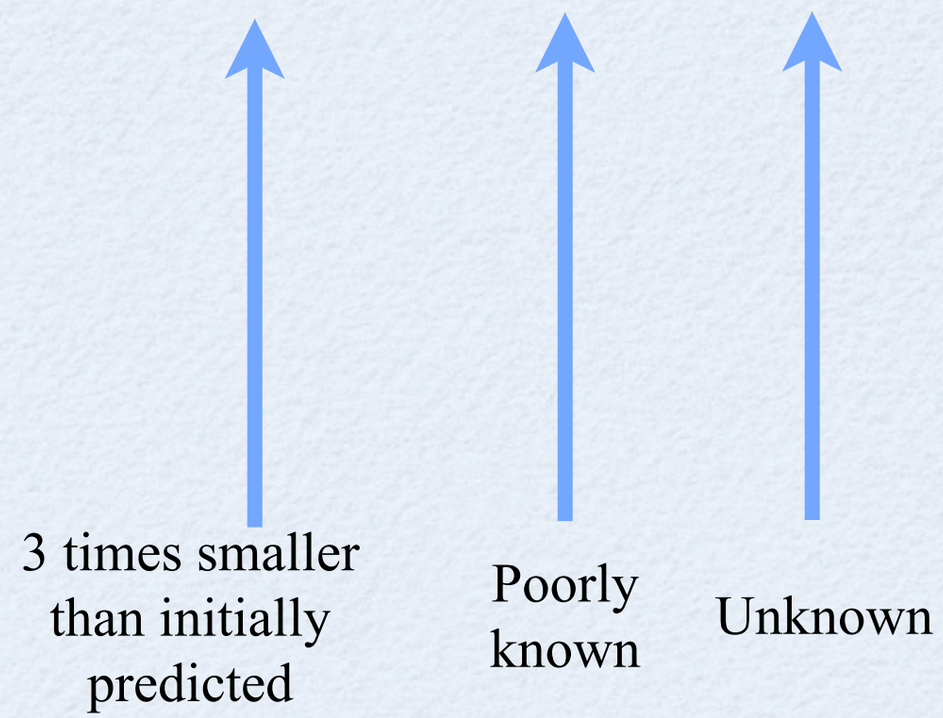
International WorkShop on DIS XIX

Agenda

- Formalism review for TMDs and SIDIS
- Summary of the eg1-dvcs measurement in CLAS
- Review of data analysis
- Results for A_1 and A_{UL}

Transverse Momentum Distributions

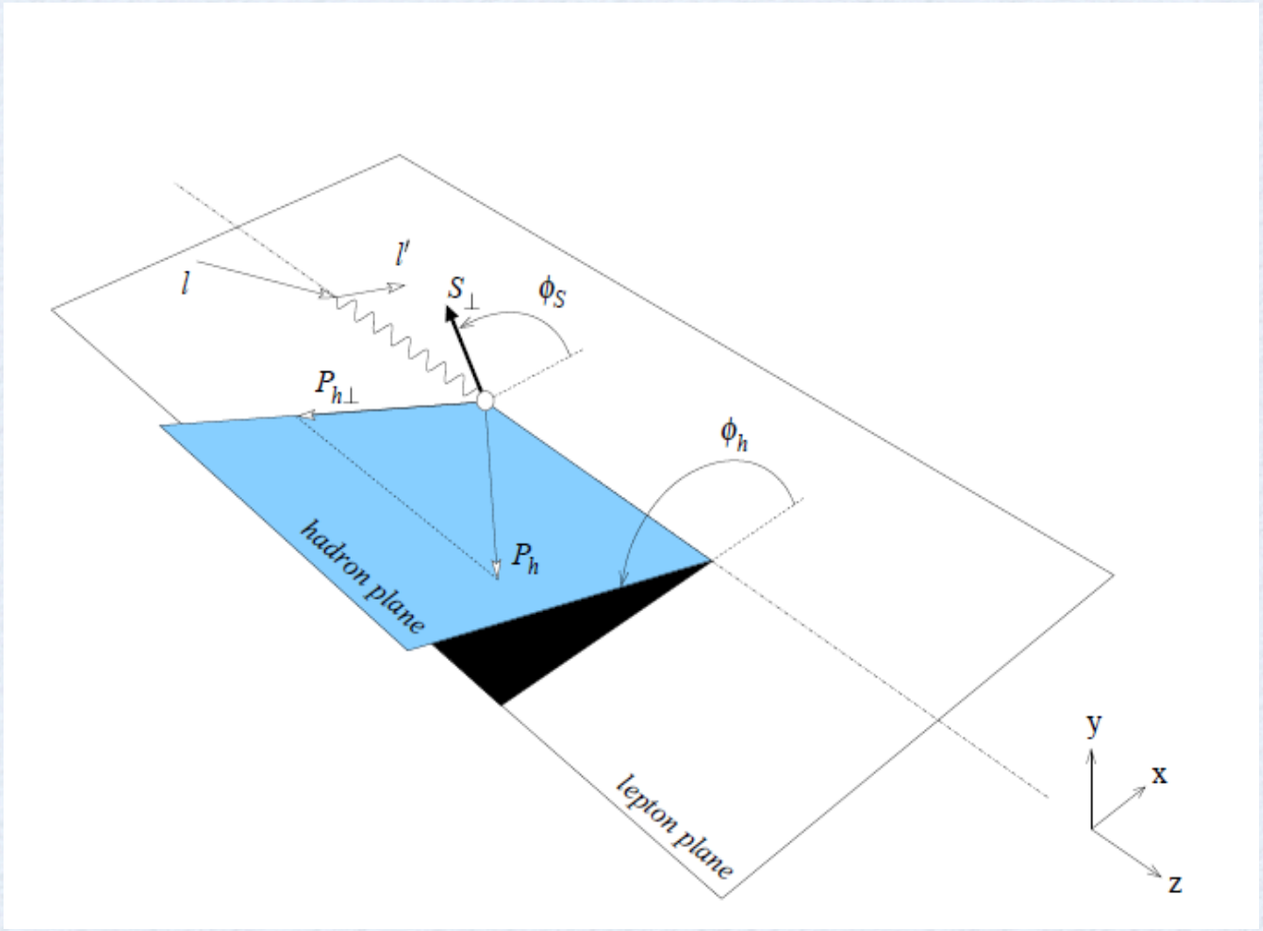
$$\frac{1}{2} = \frac{1}{2}(\Delta q + \Delta \bar{q}) + \Delta G + L_z$$

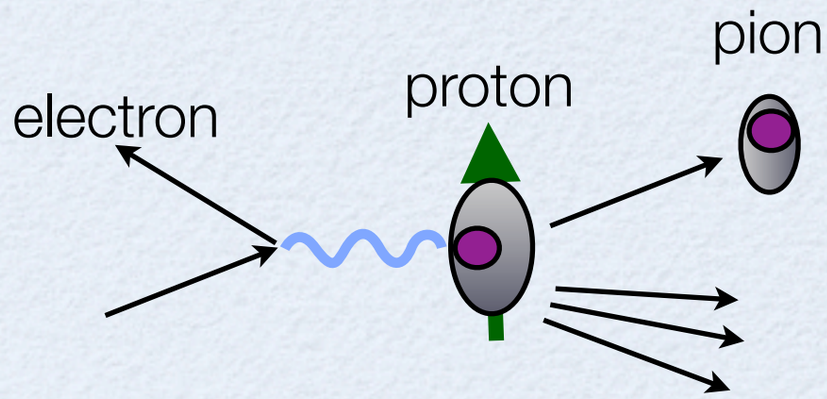


- Unintegrated parton distributions a.k.a. Transverse Momentum Distributions correlate with **orbital angular momentum** and can be defined as probabilities in momentum space

- Single and double spin asymmetries provide access to moments of TMDs

Semi-inclusive Deep Inelastic Scattering

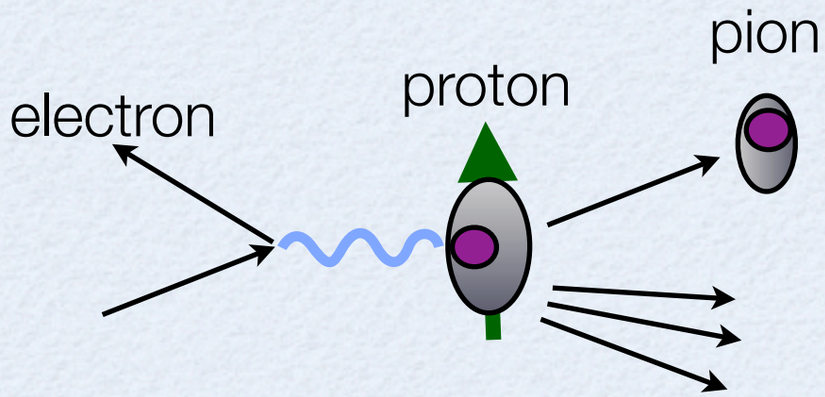




Q^2 =momentum transfer
x_B = momentum fraction
z = fractional energy of the struck pion
p_T = transverse momentum of the struck pion
Φ_h = Angle between hadron and lepton plane

Accessing TMDs from asymmetries

$$\frac{d\sigma}{dxdydz_h d^2\vec{P}_{h\perp}} = \frac{4\pi\alpha_{\rm em}^2 s}{Q^4}(1-y+y^2/2)xF_{UU}^{(1)} - (1-y)x\cos(2\phi_h)F_{UU}^{(2)}$$
$$+\lambda S_L y(1-y/2)xF_{LL} + S_L(1-y)x\sin(2\phi_h)F_{UL}$$
$$+|S_T|(1-y+y^2/2)x\sin(\phi_h-\phi_S)F_{UT}^{(1)}$$
$$+|S_T|(1-y)x\sin(\phi_h+\phi_S)F_{UT}^{(2)}$$
$$+\lambda|S_T|y(1-y/2)x\cos(\phi_h-\phi_S)F_{LT}$$
$$+\tfrac{1}{2}|S_T|(1-y)x\sin(3\phi_h-\phi_S)F_{UT}^{(3)}]$$



Accessing TMDs from asymmetries

U: Unpolarized
L: Longitudinally polarized

$$\frac{d\sigma}{dxdydz_h d^2\vec{P}_{h\perp}} = \frac{4\pi\alpha_{\rm em}^2 s}{Q^4}(1-y+y^2/2)xF_{UU}^{(1)} - (1-y)x\cos(2\phi_h)F_{UU}^{(2)}$$
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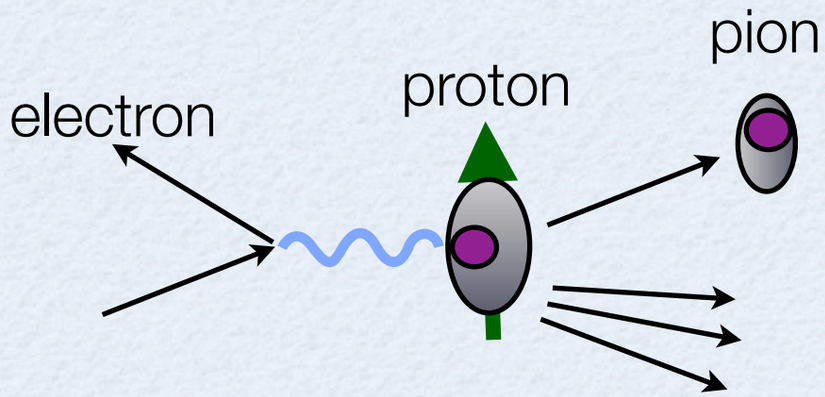


o : Unpolarized
→ : Longitudinally polarized(+)
← : Longitudinally polarized(-)

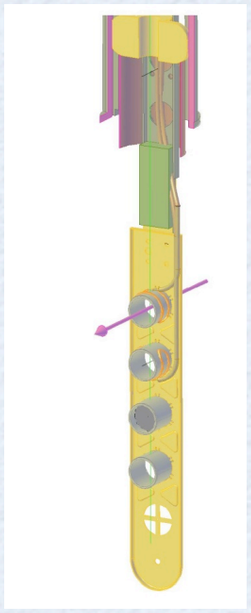
$$A_{UL}^{l} = \frac{d\sigma^{0\rightarrow} - d\sigma^{0\leftarrow}}{d\sigma^{0\rightarrow} + d\sigma^{0\leftarrow}}$$

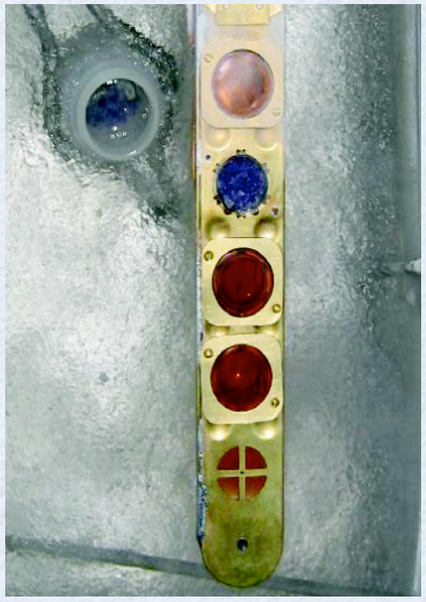
$$A_{LL}^{l} = \frac{d\sigma^{\rightarrow\rightarrow} - d\sigma^{\leftarrow\rightarrow} - d\sigma^{\rightarrow\leftarrow} + d\sigma^{\leftarrow\leftarrow}}{d\sigma^{\rightarrow\rightarrow} + d\sigma^{\leftarrow\rightarrow} + d\sigma^{\rightarrow\leftarrow} + d\sigma^{\leftarrow\leftarrow}}$$

$$A_1 \approx \frac{A_{\parallel}}{D} \approx (1+\gamma^2)\left[\frac{g_1}{F_1}\right]$$

The eg1-dvcs experiment

- Ran from February to September 2009
- Used the polarized **electron** beam at Jefferson with energy ~ 6 Gev and beam polarization ~ 85%
- Used a solid, frozen ammonia target to get to the **polarized proton** with proton polarization ~ 80%
- Used the CEBAF large acceptance spectrometer (CLAS) to detect the **outgoing electron and hadron**.
- Used the Inner Calorimeter to detect **photons at small angles**





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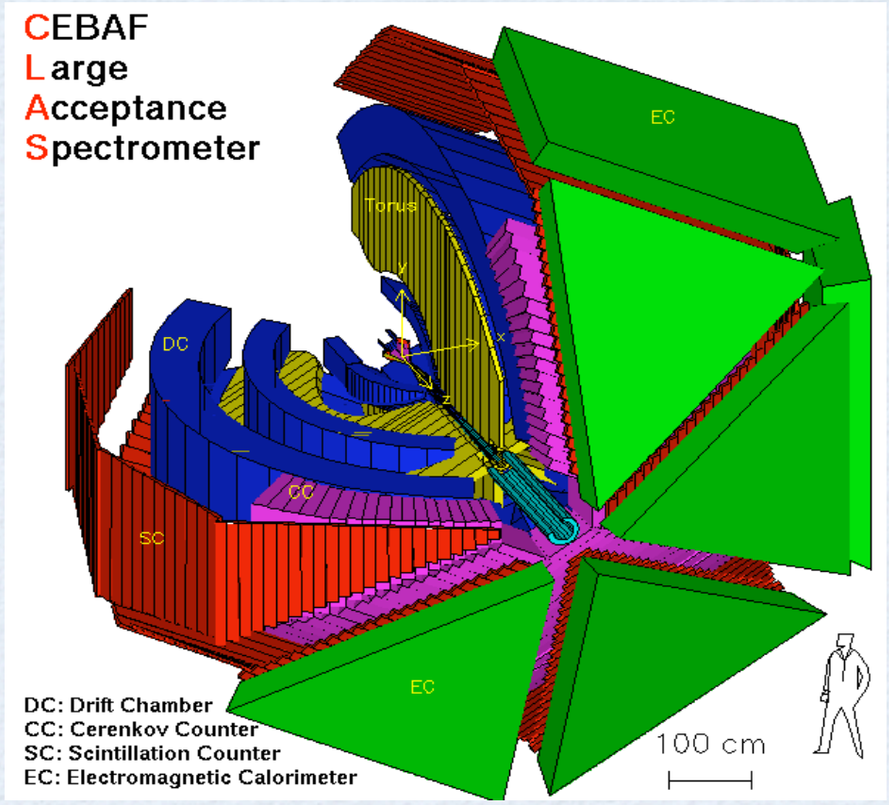
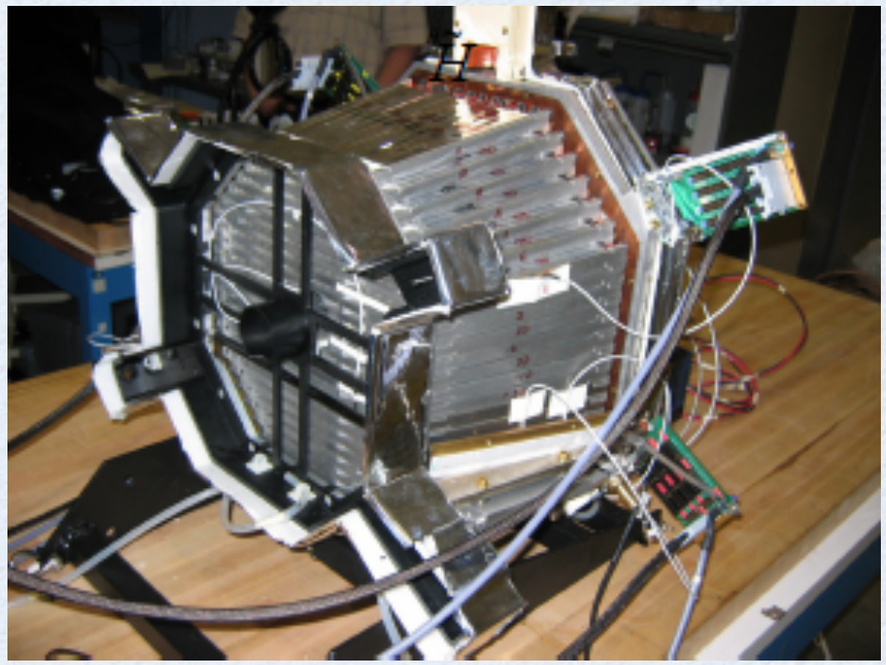


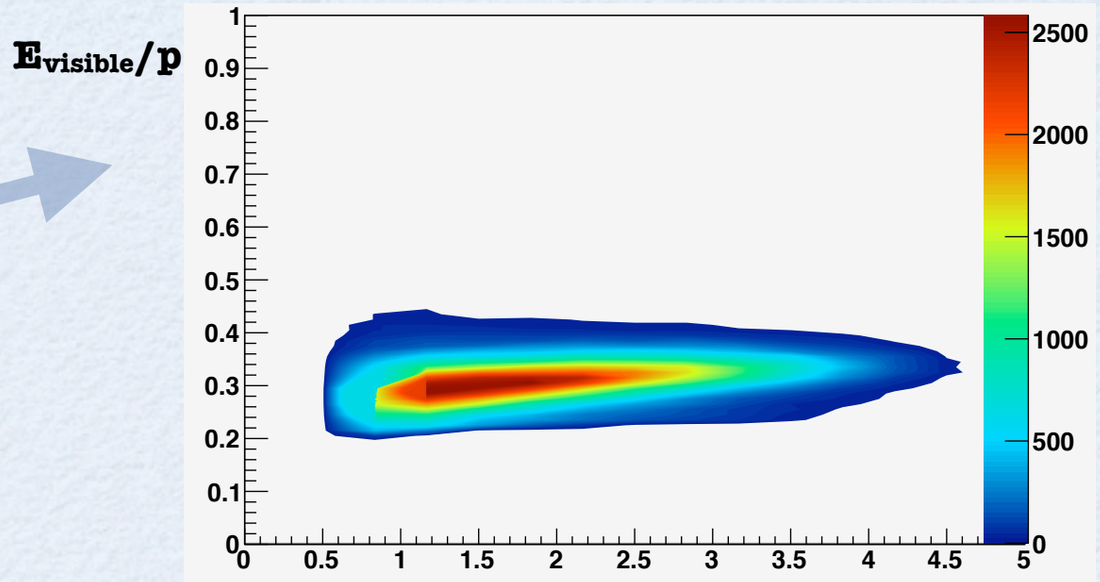


Event Selection

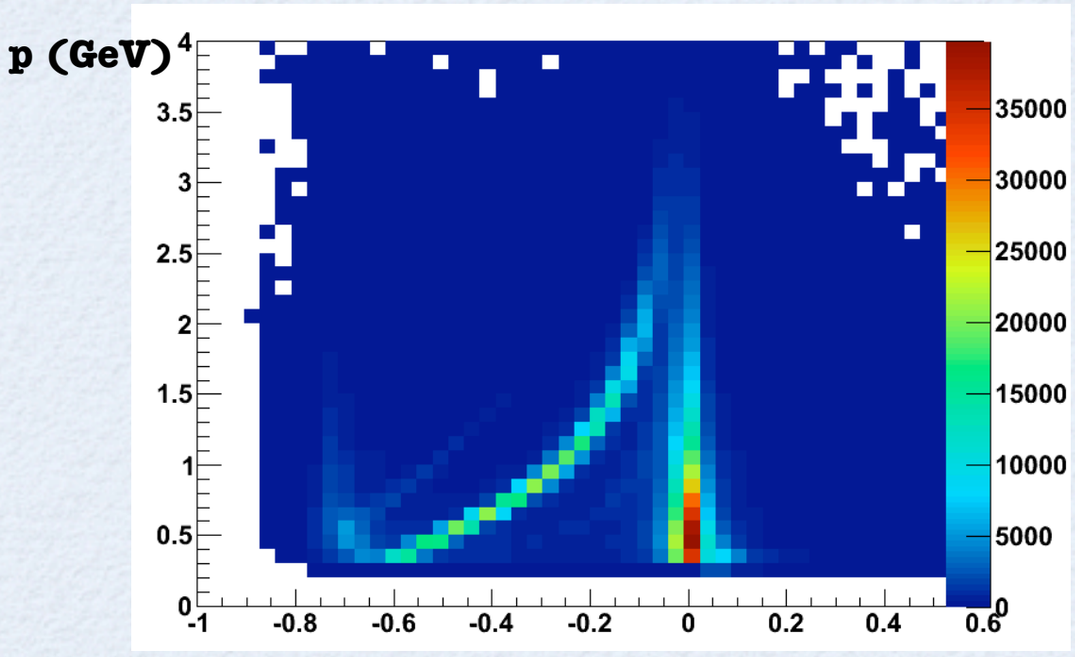
$$e + p \rightarrow e + \pi + X$$

Charged

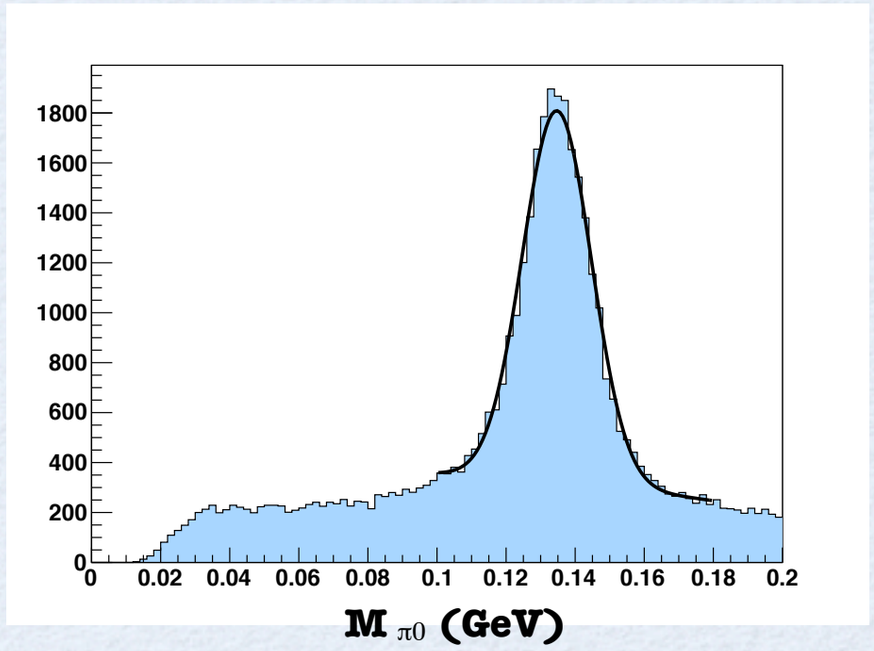
Neutral



Total Energy deposited in the EC/p vs. momentum of electron (p)



Δβ between calculated and measured pion vs. momentum (GeV)



Reconstructed invariant mass (GeV) for $\pi^0 \rightarrow \Upsilon + \Upsilon$

Kinematics

π^+ π^- π^0

x_B vs Q^2 positive pion

x_B vs Q^2 negative pion

x_B vs Q^2 neutral pion

z vs Q^2 positive pion

z vs Q^2 negative pion

z vs Q^2 neutral pion

p_T vs Q^2 positive pion

p_T vs Q^2 negative pion

p_T vs Q^2 neutral pion

x_B 0.6 - 0.0 -

z 1.0 - 0.1 -

p_T (GeV) 1.2 - 0.0 -

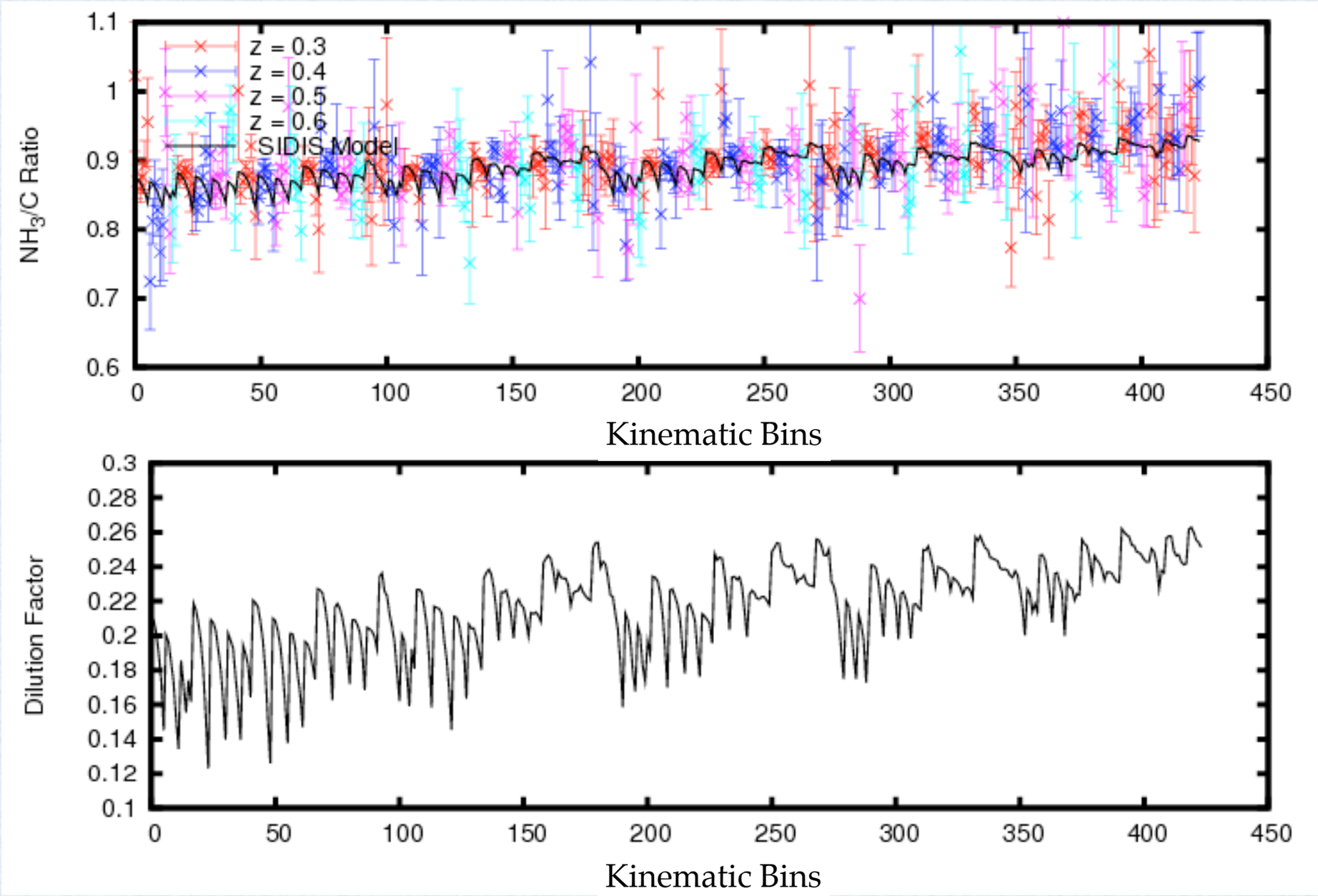
0.0 - 6.0 -

Q^2 (GeV^2)

Dilution factor

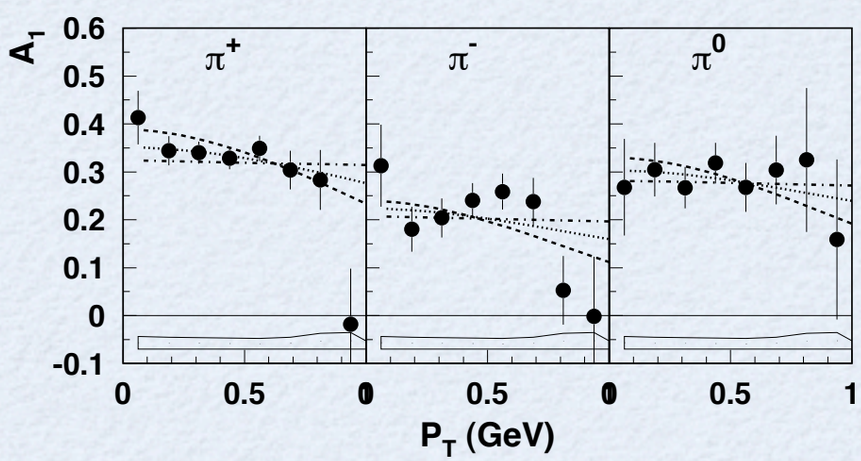
$$f = \frac{n_{Proton}}{n_N + n_{Proton} + n_{Al} + n_{Kapton} + n_{He}}$$

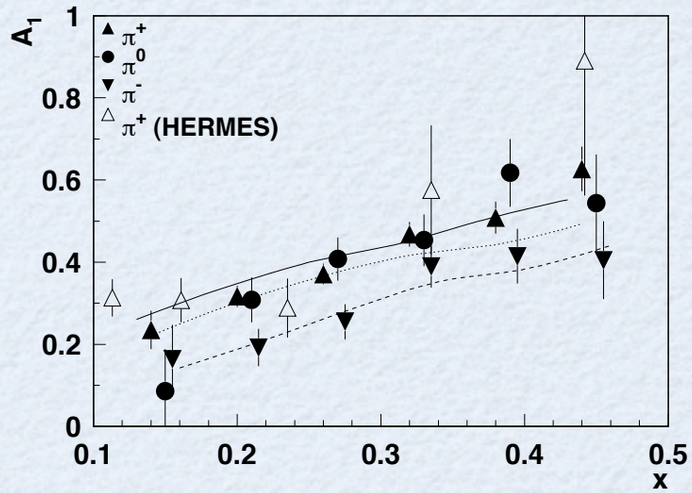
- Use dilution to account for materials in target other than the polarized proton
- Dilution itself depends on kinematics, hence accurate determination is key
- Build an empirical SIDIS model to simulate the kinematic dilution

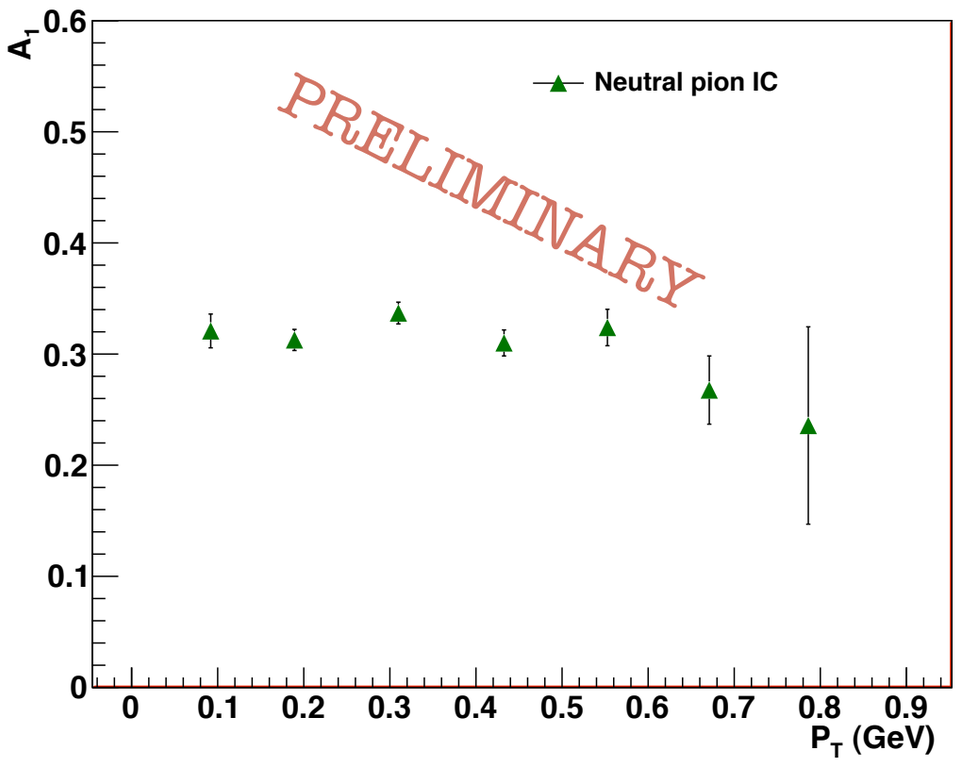


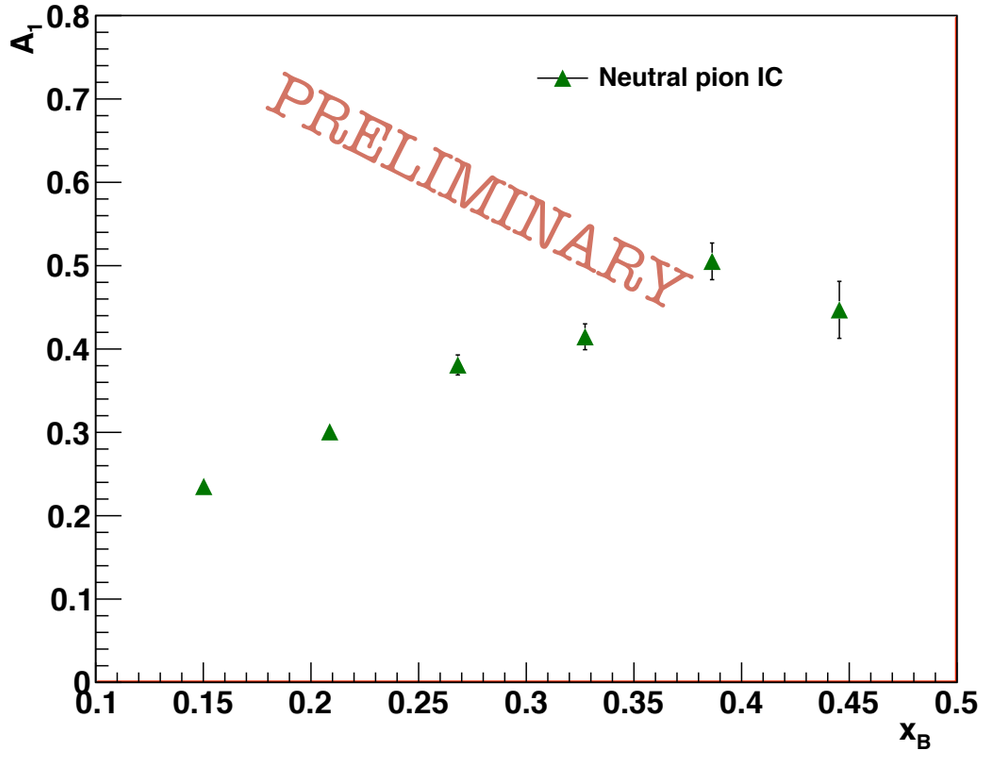
Helicity Asymmetry A_1

H. Avakian et. al. Published in Phys Rev Lett 105 262002, **2010**

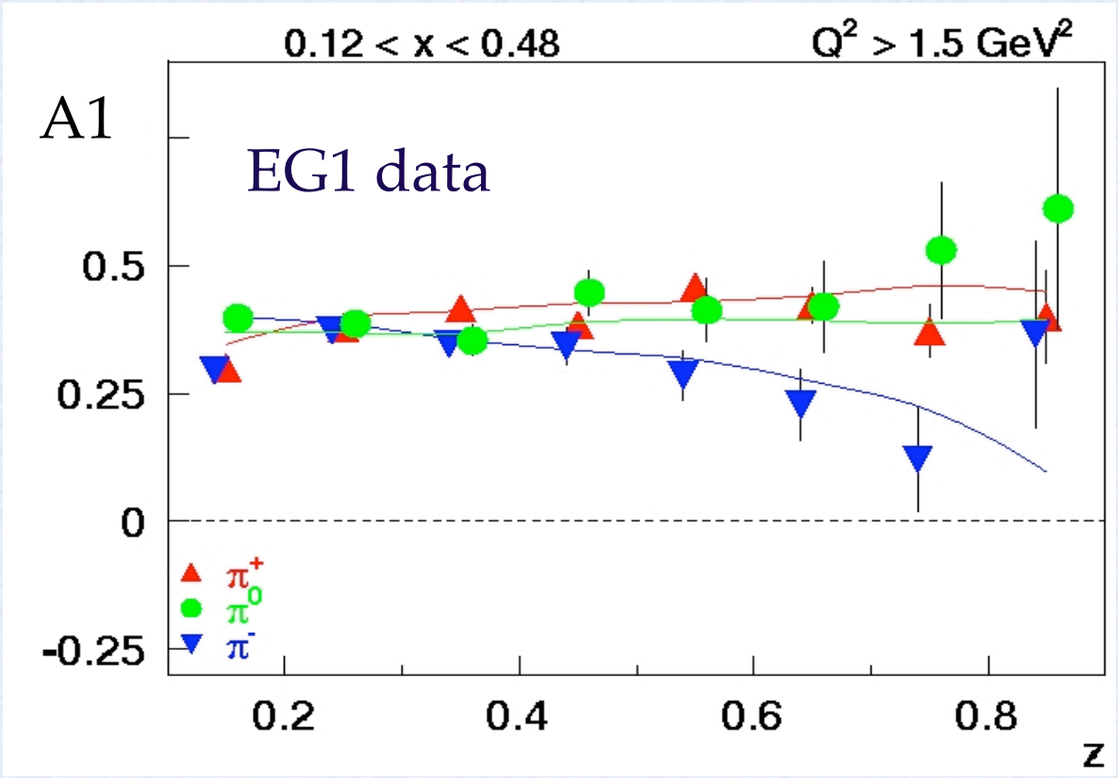




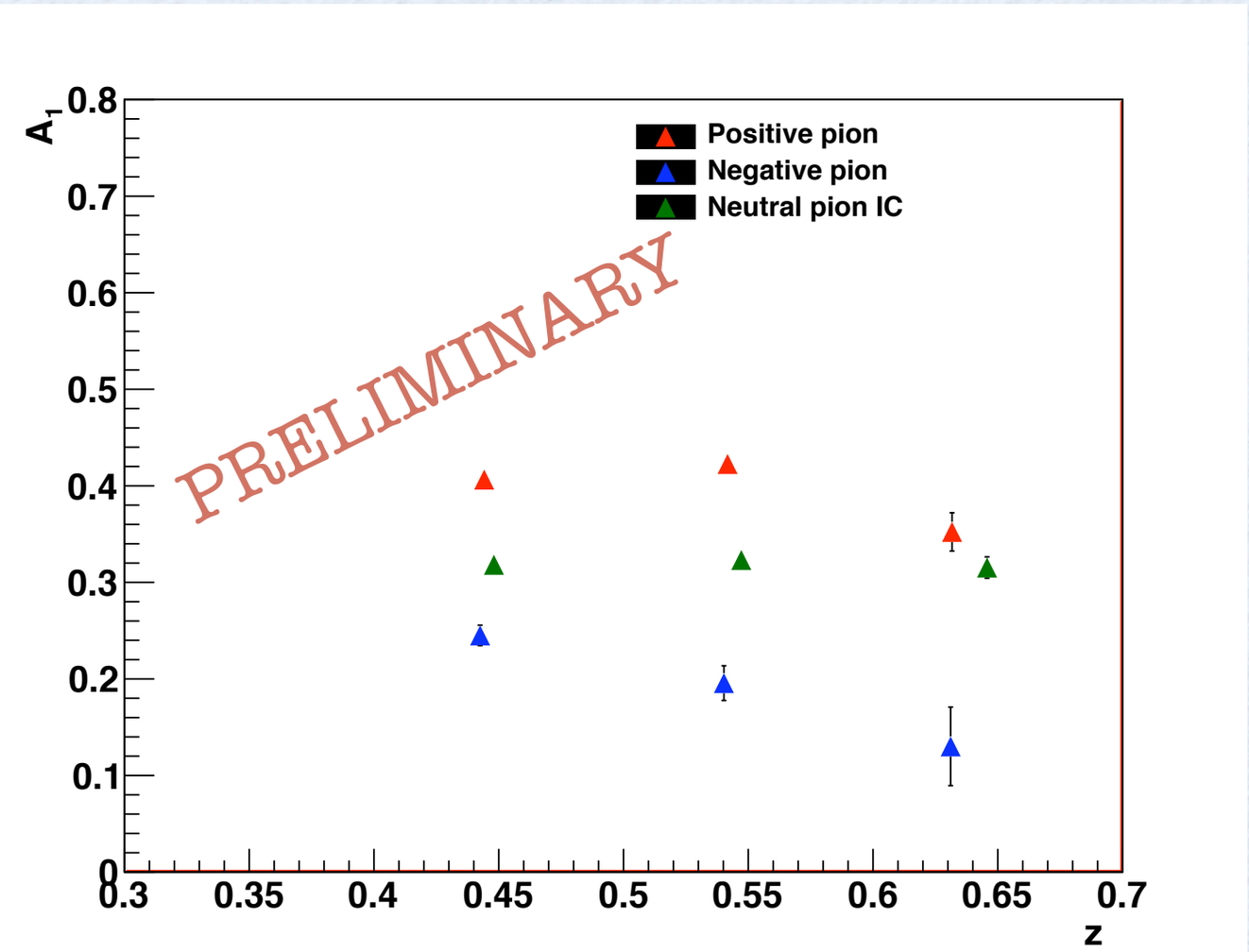




More on A_1

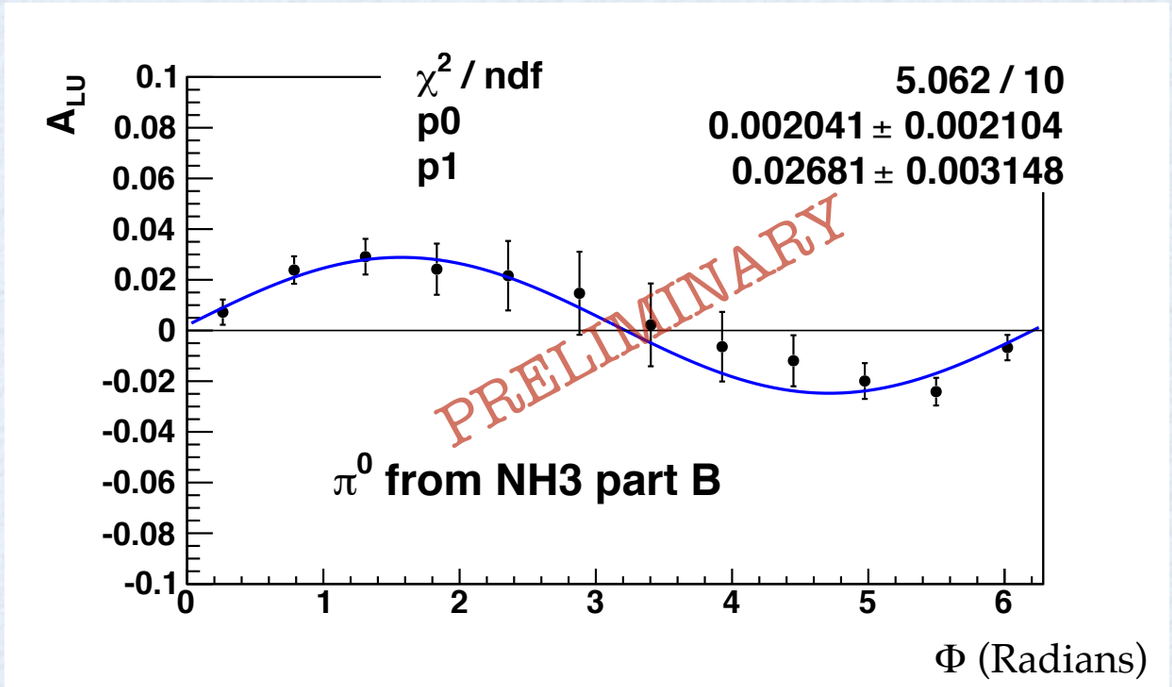


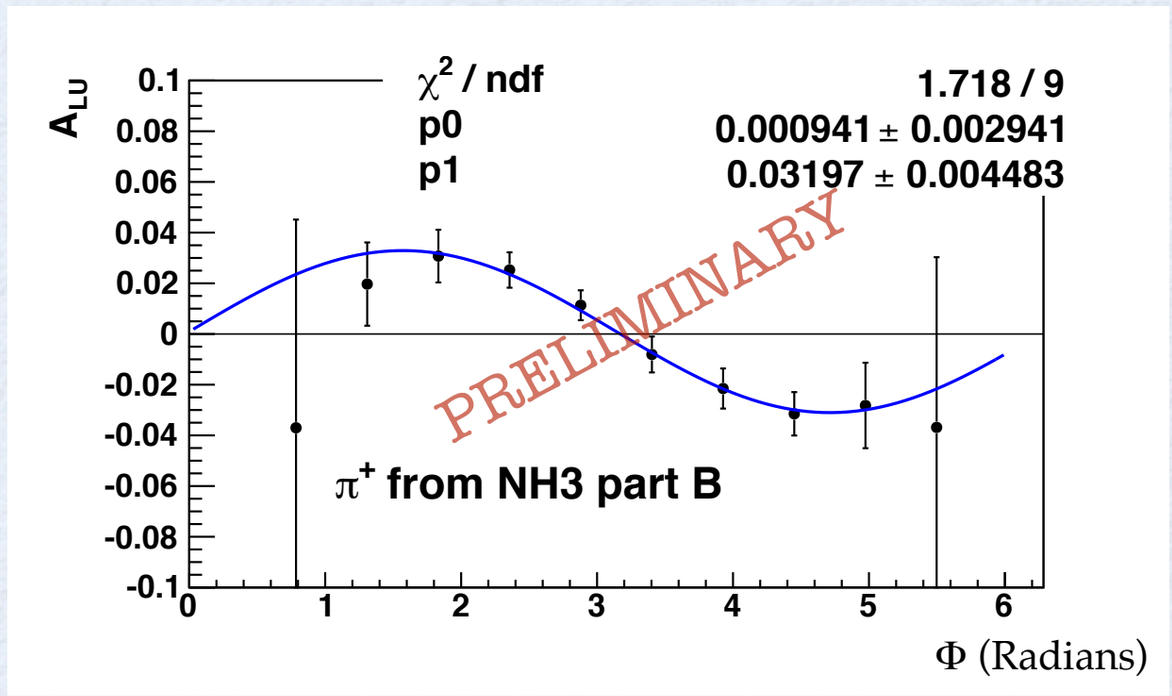
Seen above is A_1 as a function of z from previous CLAS data. On the right is 2/3 of eg1-dvcs data



Beam spin asymmetry A_{LU}

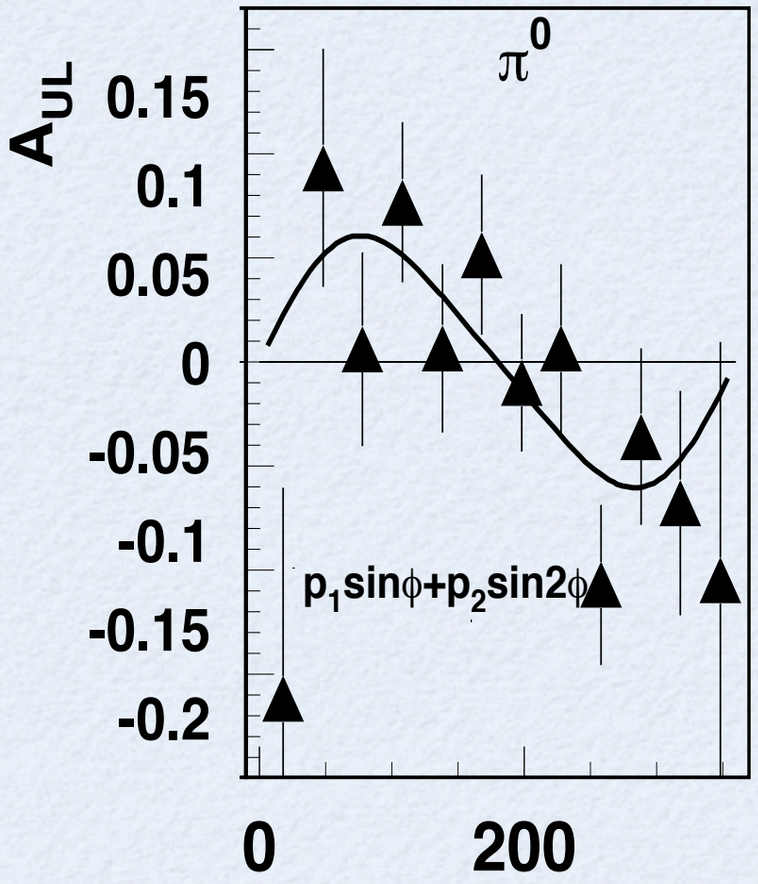
- Fit function: p0 + p1 sin Φ
- $Q^2 > 1\ GeV^2$
- $W > 2\ GeV$
- $0.1 > p_T\ (GeV) > 0.6$
- $M_x > 1.5\ GeV$
- $0.1 < x_B < 0.4$
- $0.4 < z < 0.7$





Single spin asymmetry A_{UL}

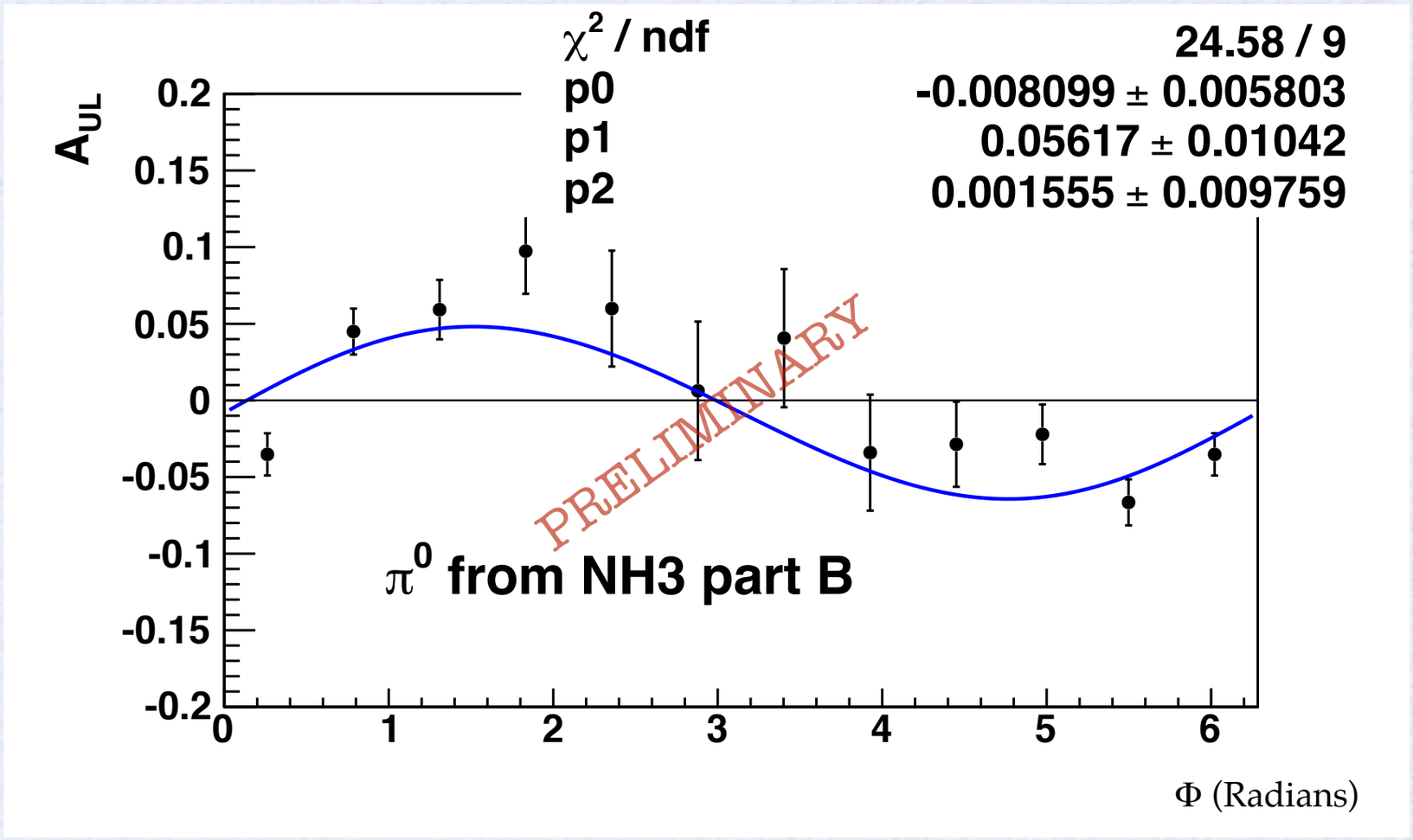
H. Avakian et. al. Published in Phys Rev Lett 105 262002, **2010**



2/3 of eg1-dvcs data

Observe a significant sin Φ dependance

Do not observe a significant sin 2Φ dependance.



Fit using p0 + p1 sin Φ + p2 sin 2 Φ and extract moments

Summary

- eg1-dvcs measures spin azimuthal asymmetries with significantly improved statistical precision for a longitudinally polarized proton
- Beam spin asymmetries are consistent with unpolarized target measurements
- First statistically significant measurement of A_{UL} for π^0 showing asymmetries dominated by sin Φ_h

Future Plans

- Continue to separate data in multiple dimensions until statistics becomes an issue
- Radiative Corrections
- Systematic Errors
- Test factorization
- The data can be used in a wide range of model calculations to study TMDs e.g. LO Relativistic QP Model, Bag Models, Quark-Diquark Models, etc.