Exclusive Reactions

Spin-Orbit Correlations Studies at JLab

Zein-Eddine Meziani
Temple University

- Boer-Mulders distribution function
  - Semi-Inclusive Deep Inelastic Measurement with unpolarized proton target (a proposal for the 12 GeV upgrade)
- Sivers distribution function
  - SIDIS measurement with a transversely polarized target (in this case a polarized ^3He target to access neutron information)

Azimuthal Asymmetries in SIDIS as a Clean Test of QCD?

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Clean Tests of Quantum Chromodynamics in μp Scattering

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(Received 25 October 1977)

Hard gluon bremsstrahlung in μp scattering produces final-state hadrons with a large component of momentum transverse to the virtual-photon direction. Quantum chromodynamics can be used to predict not only the absolute value of the transverse momentum, but also its angular distribution relative to the muon scattering plane. The angular correlations should be insensitive to nonperturbative effects.

In this Letter we report selected results from a study of semi-inclusive μp scattering. Our analysis is based on QCD (quantum chromodynamics) perturbation theory[1] and the parton-model idea of decay functions.[2] Let k_1 (k_2) be the initial (final) muon four-momentum and P_1 (P_2) be the traget (observed final-state hadron) four-momentum. At high energy, the hadrons will be produced in a jet with momenta nearly parallel to the virtual-photon direction, $q^\mu = k_1{}^\mu - k_2{}^\mu$. Some of our most intersting results involve the transverse momentum $\vec{P}_{2\perp}$, perpendicular to $\vec{q}$.

Integrating over the azimuthal angle of the final muon, we can write the differential cross section in terms of the variables

Cahn's Response

Azimuthal dependence in leptoproduction: A simple parton model calculation[*1]

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Received 5 June 1978. Available online 10 October 2002.

Abstract

Semi-inclusive leptoproduction, $\ell + p \to \ell' + h + X$, is considered in the naive parton model. The scattered parton shows an azimuthal asymmetry about the momentum transfer direction. Simple derivations for the effects in ep, νp and νp scattering are given. Reduction of the asymmetry due to fragmentation of partons into hadrons is estimated. The results cast doubt on the utility of such azimuthal asymmetry as a clean test of quantum chromodynamics.

Structure of the Cross Section

Cahn

Georgi-Politzer

$$d\sigma_{\lambda,S} \propto f_1 \otimes D_1 + \frac{k_T}{Q} f_1 \otimes D_1 \cdot \cos\phi$$ + RC

Kroll -Konig

$$+ \left[\frac{k_T^2}{Q^2} f_1 \otimes D_1 + h_1^\perp \otimes H_1^\perp \right] \cdot \cos 2\phi$$ + RC

Boer-Mulders

$$+|S_T| \cdot f_{1T}^\perp \otimes D_1 \cdot \sin(\phi - \phi_s)$$

Sivers

$$+|S_T| \cdot h_1 \otimes H_1^\perp \cdot \sin(\phi + \phi_s)$$

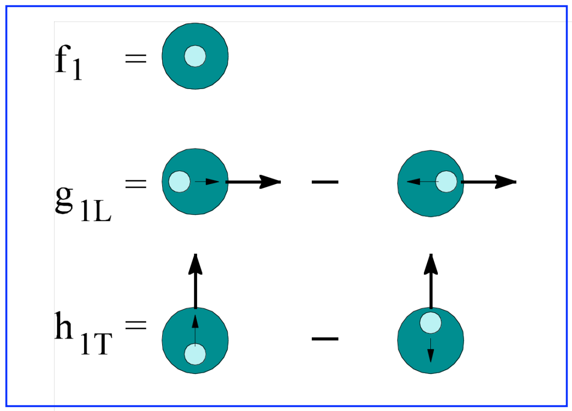
Collins

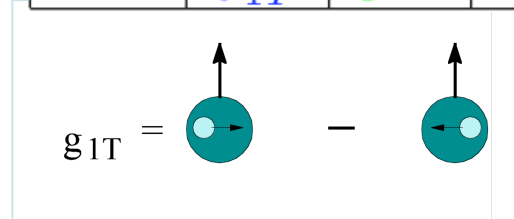
Leading-Twist Quark Distributions

(A total of eight distributions)

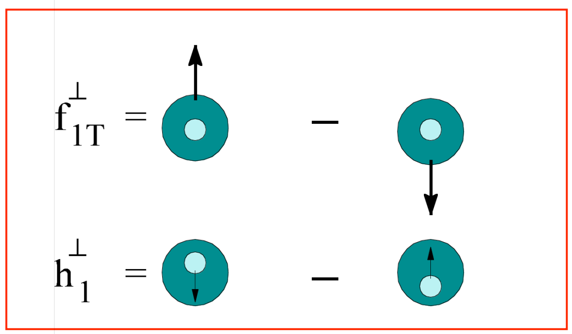
N/q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	$h_1,\ h_{1T}^{\perp}$

No $K_{\perp}$ dependence

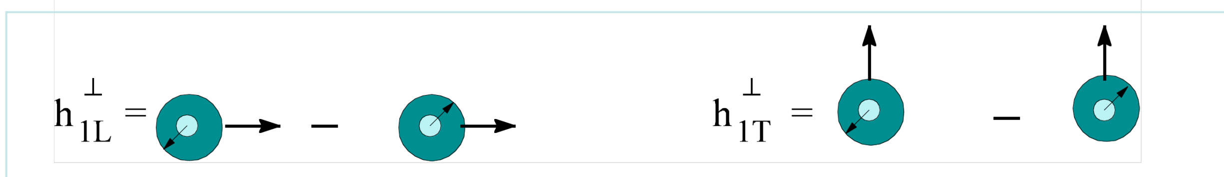




$K_{\perp}$ - dependent, T-odd



$K_{\perp}$ - dependent, T-even



Boer-Mulders distribution function

$$d\sigma_{\lambda,S} \propto f_1 \otimes D_1 + \frac{k_T}{Q} f_1 \otimes D_1 \cdot \cos\phi \text{ + RC}$$

$$+ \left[\frac{k_T^2}{Q^2} f_1 \otimes D_1 + \boxed{h_1^{\perp} \otimes H_1^{\perp}} \right] \cdot \cos 2\phi \text{ + RC}$$

- Can be measured in Drell-Yan and SIDIS
- Allows the test of universality
- Provides some indication on the role of angular momentum

Comprehensive extraction of $h_1^{\perp}$

Need a study of "backgrounds"
with high statistics measurements

- Higher twists (kinematical, dynamical)
  - ➥ Different dependences on z, x, P_t and Q^2
- Radiative corrections

- Understanding the systematic errors in the acceptance

- Comparisons between cos phi and cos 2phi in the same experiment are important

- Checking $\pi^+ + \pi^-$ versus π^0 need to be consistent

- Checking $\pi^+ - \pi^-$

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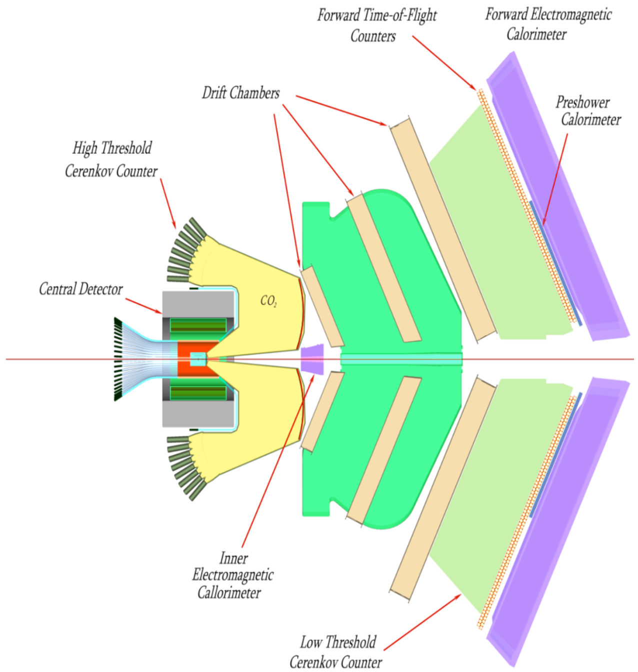
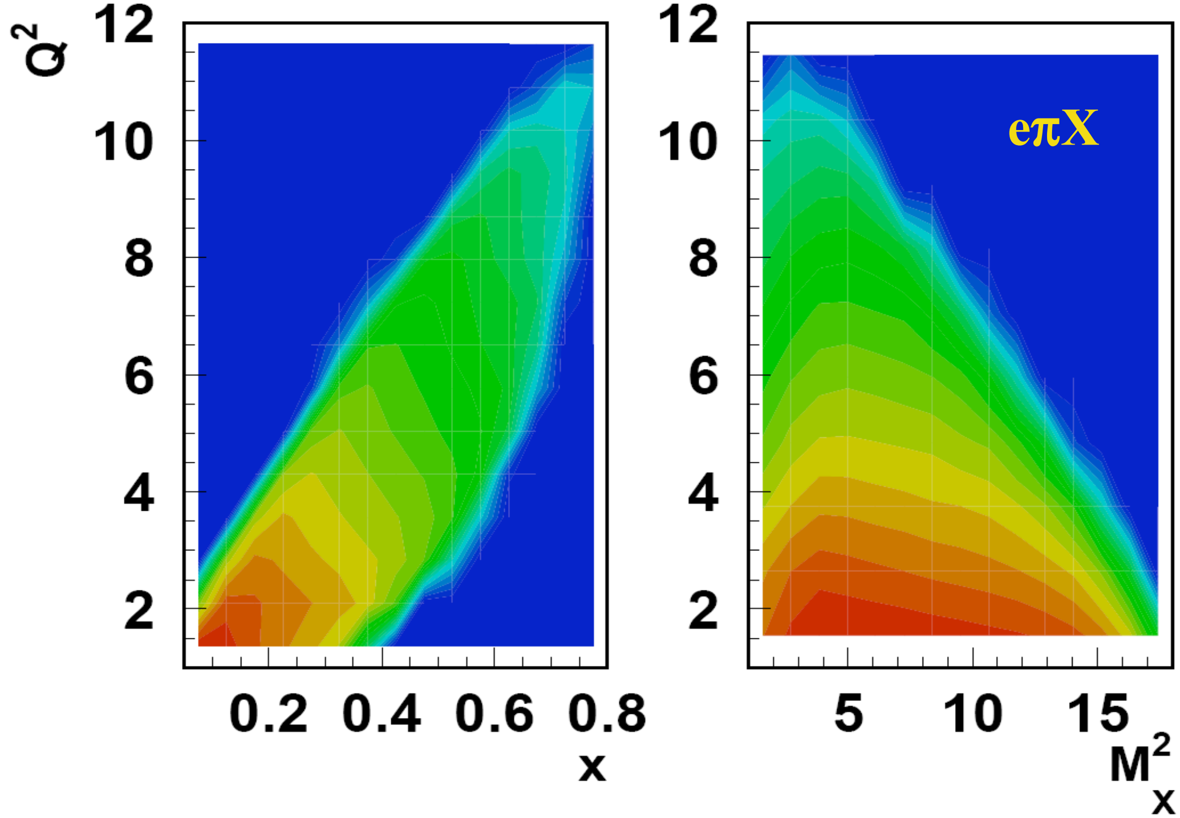
CLAS12: Kinematical coverage





SIDIS kinematics

$Q^2>1$
$W^2>4$
$y<0.85$
$M_X>2$

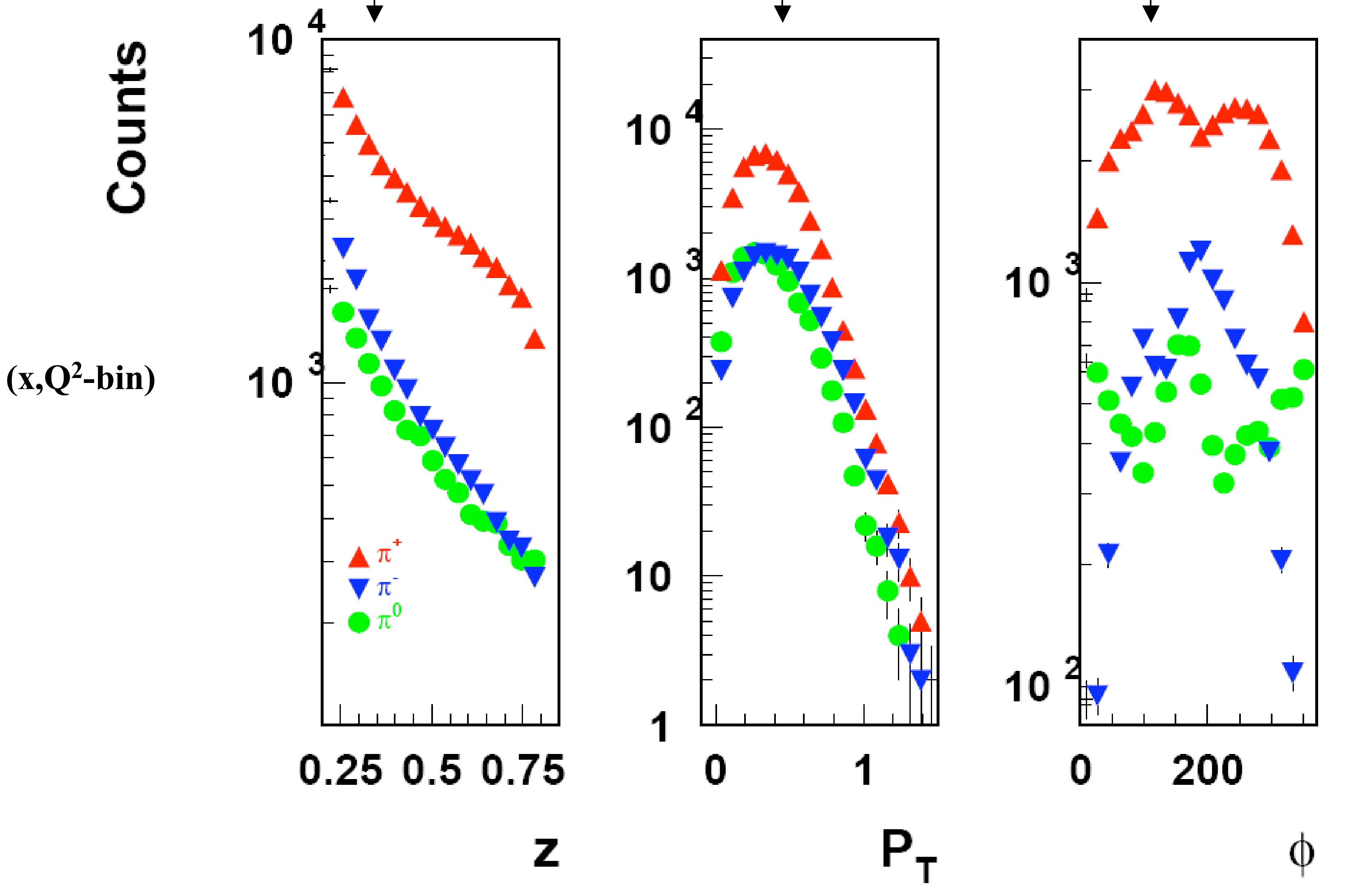
Large Q^2 accessible with CLAS12 are important for $\cos 2\phi$ studies (all background contributions are HT)

CLAS12: kinematic distributions using LUND-MC

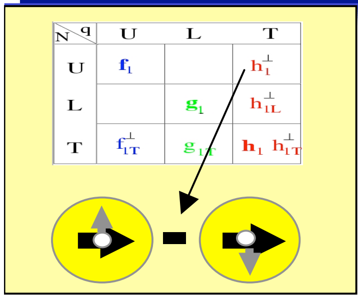
Covers a full z (E_π/ν)-range

Provides access to large transverse momentum of hadrons

Significant moments in the acceptance (different for $\pi^{+/-/0}$)



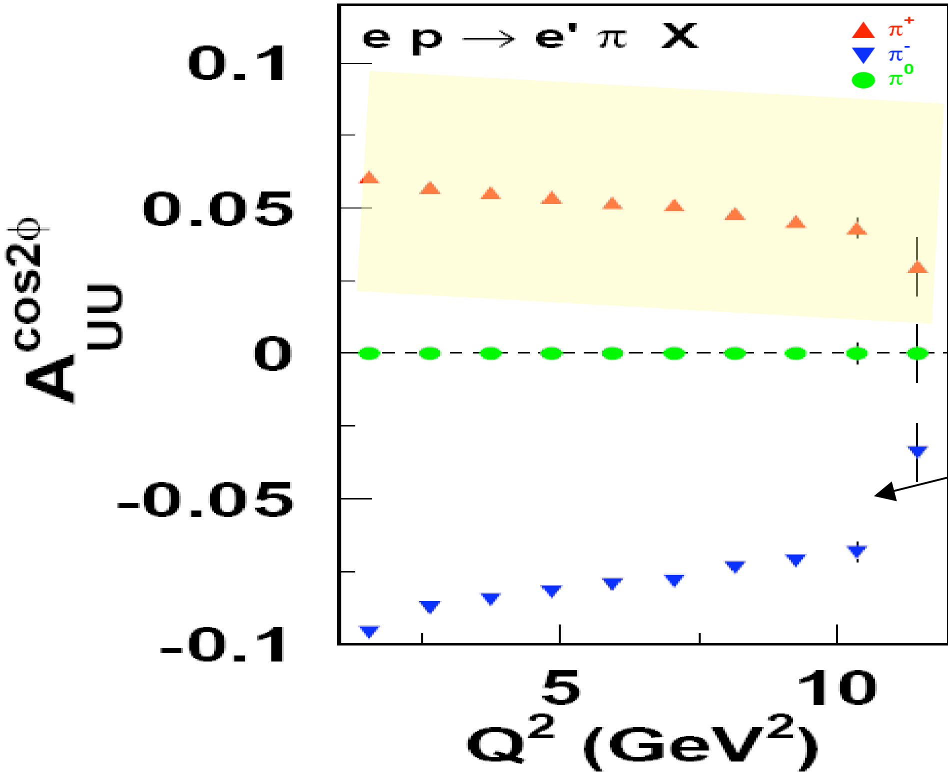
Boer-Mulders Asymmetry: Q^2-dependence



$$A_{UU}^{\cos 2\phi} \propto h_1^\perp H_1^\perp$$

0.5<P_T<0.6 (2000h)

Higher twist contributions ~P_T/Q



approximation:

$$h_1^\perp \approx f_{1T}^\perp$$ ← **quark-scalar diquark model**

$$H_1^{\perp u\to\pi^+} \approx -H_1^{\perp u\to\pi^-}$$

← **Uncertainty in $A_{UU}^{\cos\phi}$ defined by unknown Collins (1σ) and BM-functions**

bigger moment for π^-

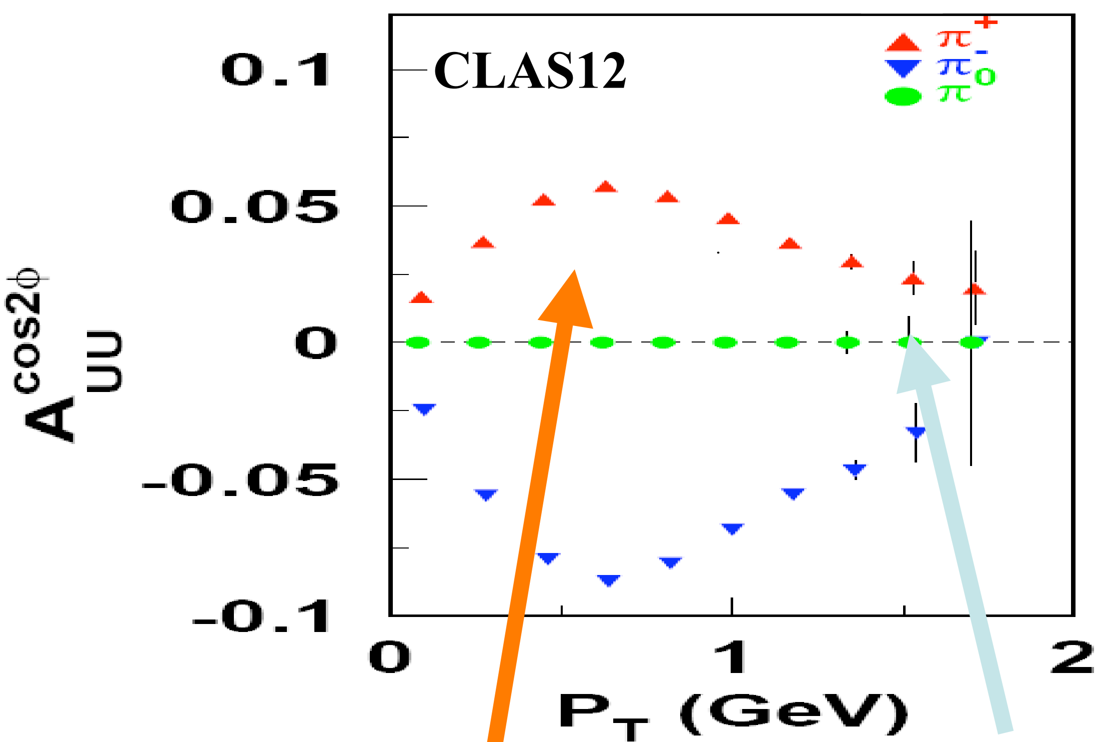
Power counting rules → $h_1^\perp \sim (1-x)^4$

Brodsky, Vogelsang & Yuan 2006

The Q^2 dependence of BM-asymmetry will test its leading twist nature.

Boer-Mulders Asymmetry: P_T-dependence

$$A_{UU}^{\cos 2\phi} \propto h_1^\perp H_1^\perp$$



In the perturbative limit $1/P_T^2$ behavior expected (F.Yuan)

$$H_1^{\perp u \to \pi^+} \approx -H_1^{\perp u \to \pi^-}$$

$4<Q^2<5$ (2000h @ 11 GeV with $10^{35}\text{sec}^{-1}\text{cm}^{-2}$)

$$\Lambda_{QCD} \ll P_T \ll Q$$

Non-perturbative TMD

Perturbative region

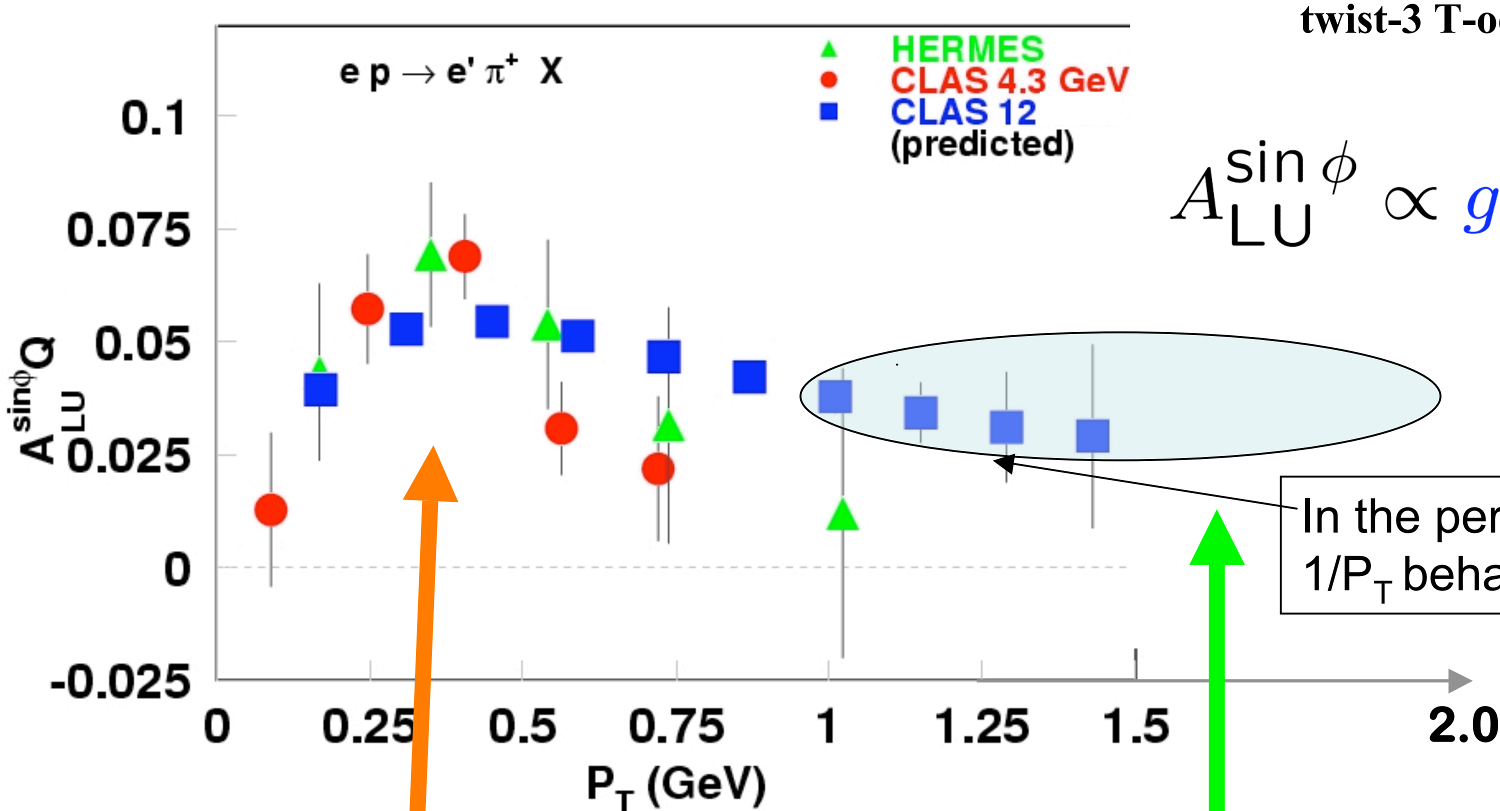
P_T-dependence of azimuthal moments allows studies of transition from non-perturbative to perturbative description (Unified theory by Ji et al).

Beam SSA: CLAS @ 12 GeV

$A_{LU} \sim 1/Q$ (Twist-3)

In jet limit A_{LU} dominated by twist-3 T-odd distribution

$$A_{LU}^{\sin\phi} \propto g^{\perp}(x) D_1(z)$$



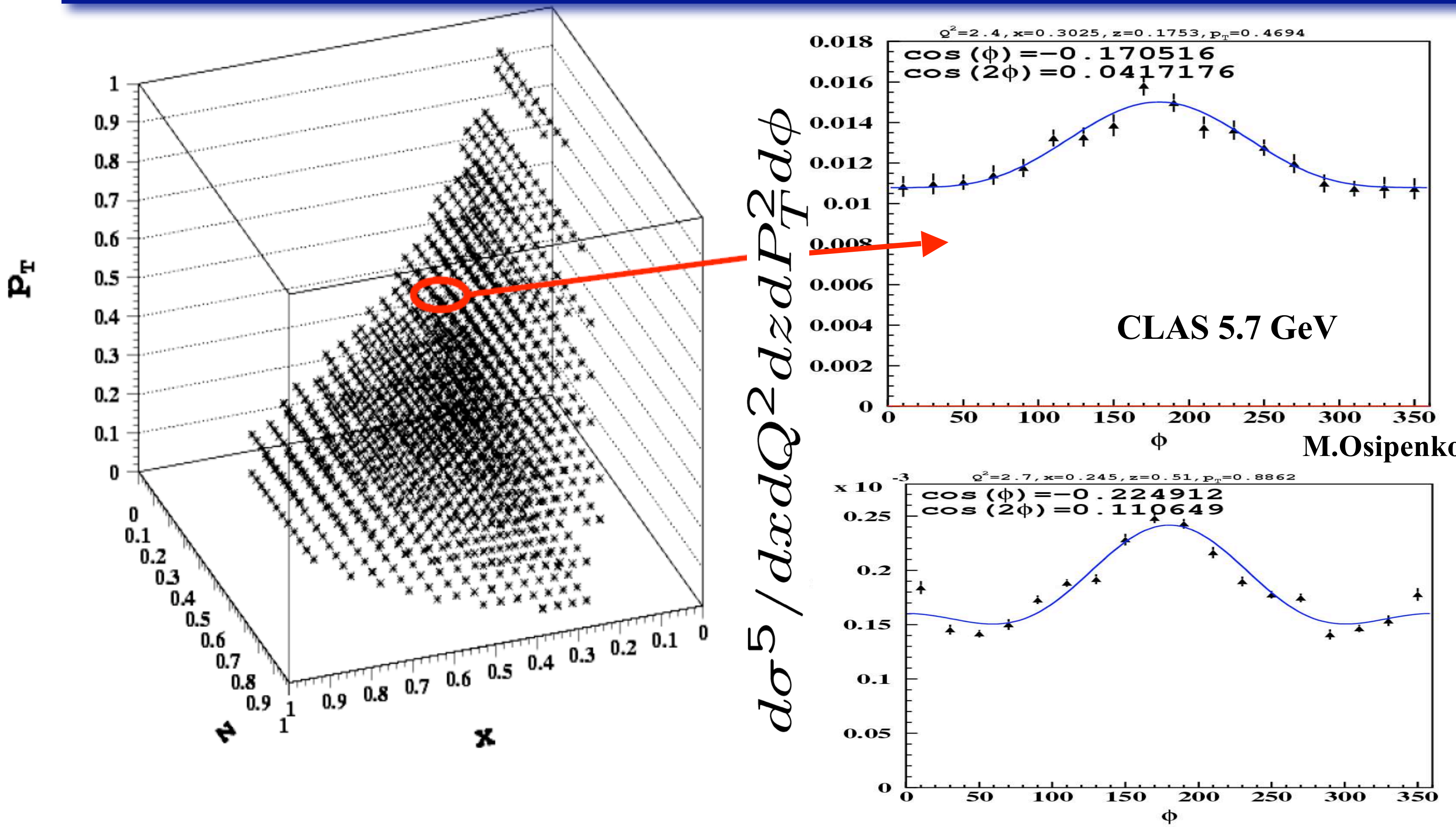
In the perturbative limit $1/P_T$ behavior expected

Non-perturbative TMD

Perturbative region

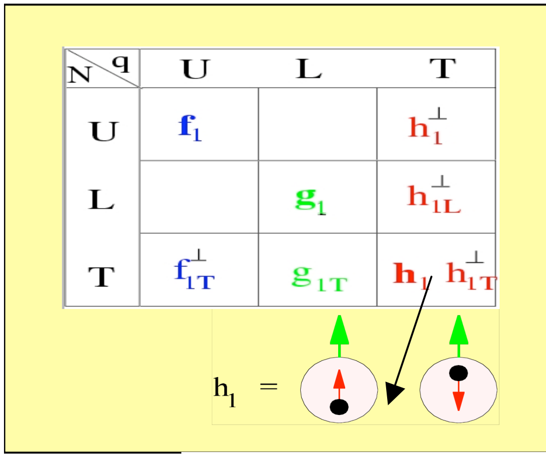
Measurements of kinematic (x,Q^2,z,P_T) dependences of beam SSA will provide a test of its HT nature and will probe HT distribution functions

Unpolarized target azimuthal asymmetries

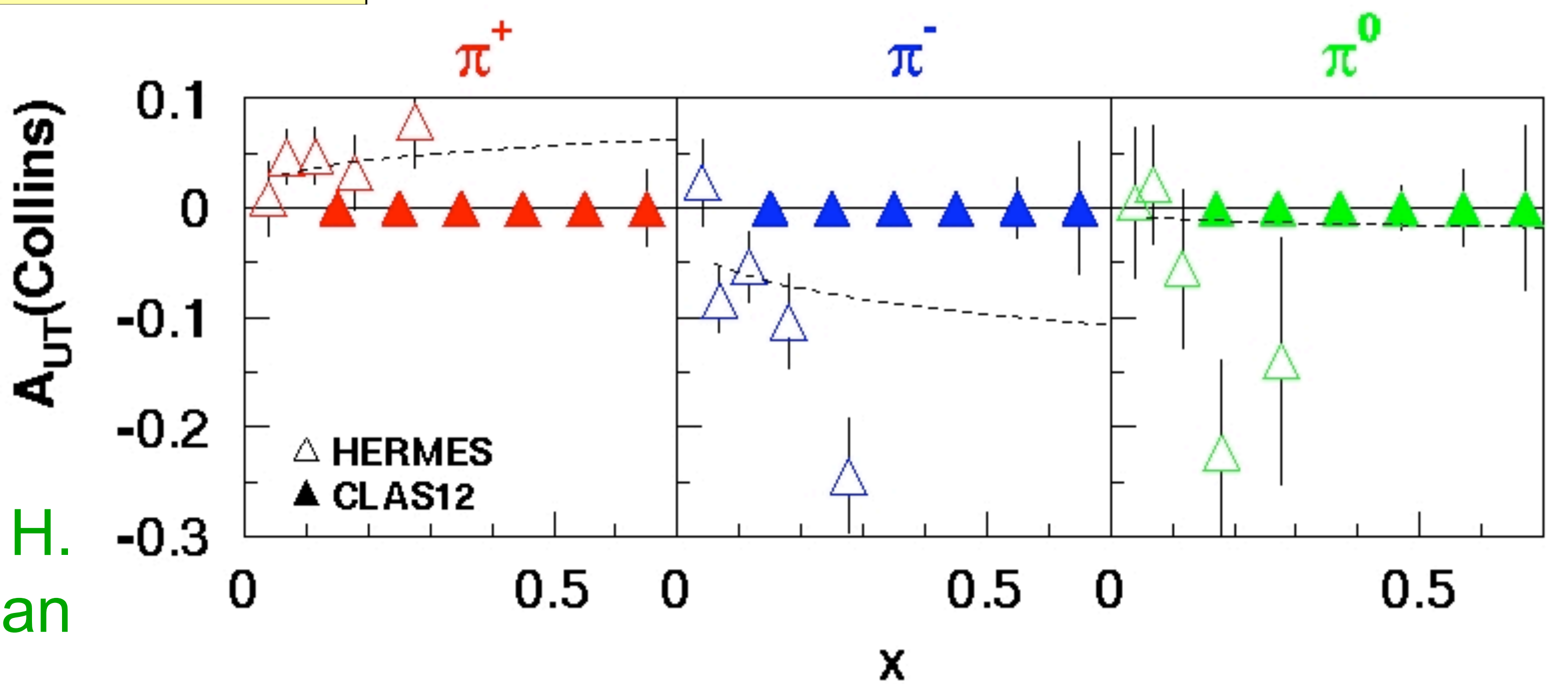


- **Significant cosφ, cos2φ observed at large P_T at 5.7 GeV**
- **CLAS12 covers significantly wider kinematic range (large Q^2 and P_T)**

Collins Effect with 12 GeV Upgrade



$$\sigma_{UT}^{Collins} \sim (1-y)\, h_1 H_1^\perp$$



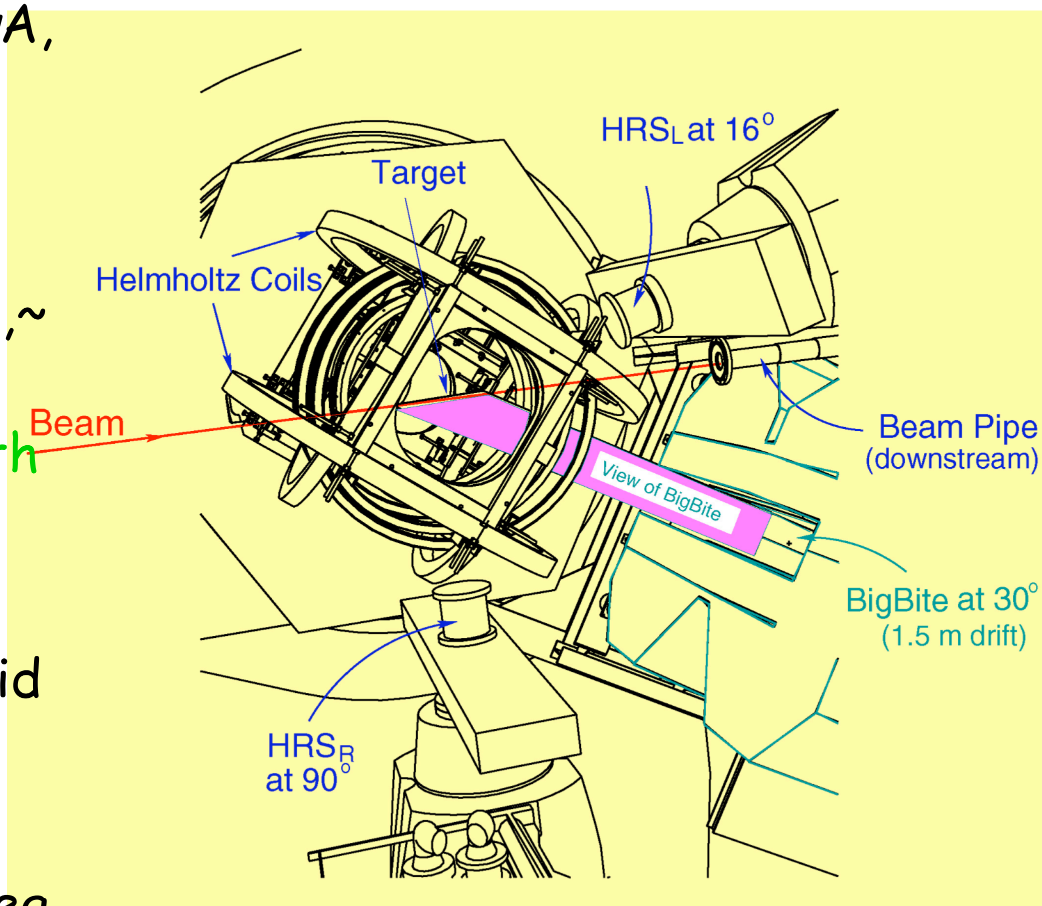
From H. Avakian

Study the Collins fragmentation for all 3 pions with a **transversely polarized target** and measure the transversity distribution function. JLAB12 cover the valence region.

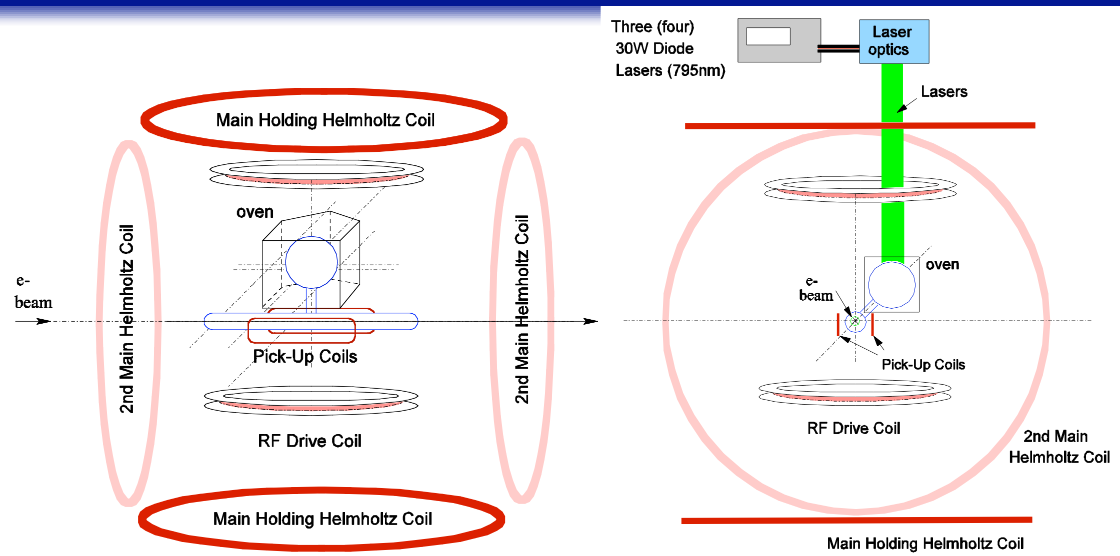
Jlab Hall A E06-010,011 / $^3He^{\neq}$ $(e,e'\pi^-/\pi^+)X$

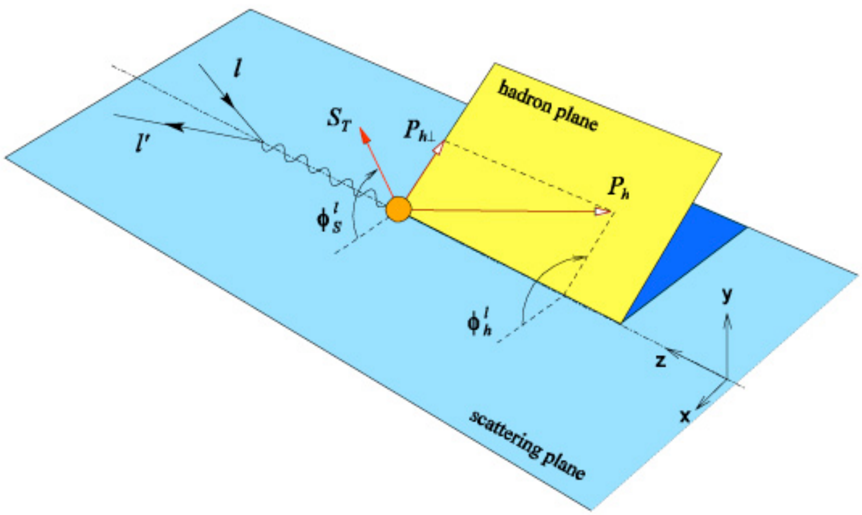
J.-P Chen, H. Gao, E. Cisbani, X. Jiang & J.-C. Peng

- Beam
  - Polarized (P~80%) e-, 15 μA, helicity flip at 60Hz
- Target
  - Optically pumped Rb+spin exchange ^{3}He, 50 mg/cm2,~ 40% polarization
  - Transversely polarized with tunable direction
- Electron detection
  - Bigbite spectrometer, Solid angle 60 msr, θ=30 deg
- Charged pion detection
  - HRS spectrometer, θ=16deg



Transversely polarzied ^{3}He target





Target polarization orientation can be rotated to increase the coverage in $\Phi_S{}^l$

E06-010/06-011 Single Target-Spin Asymmetry in Semi-Inclusive $n^{\uparrow}(e,e'\pi^{+/-})$ Reaction on a Transversely Polarized ^3He Target

Students:

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C. Dutta,
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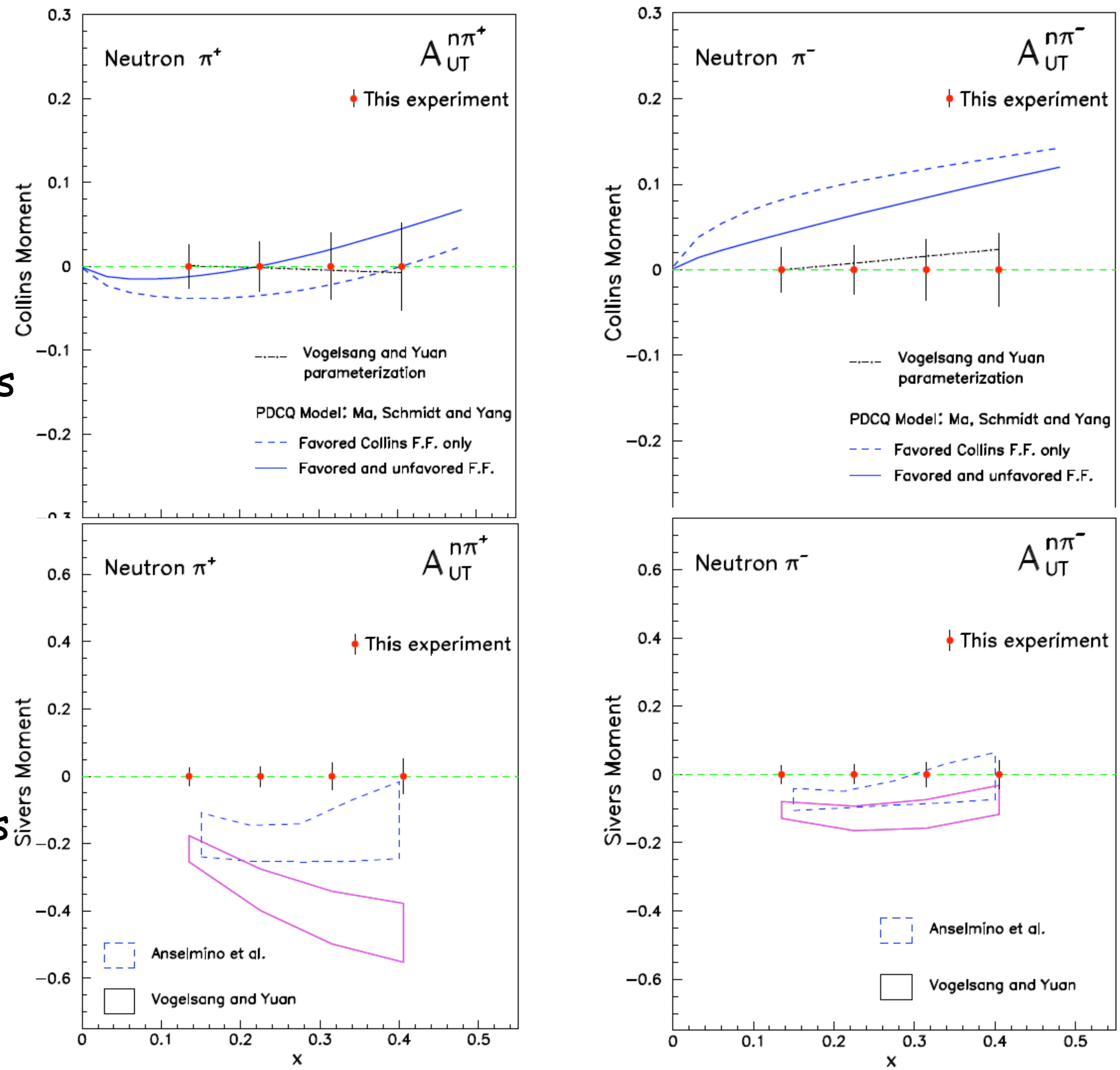
M. Shabestari,
One from UIUC.

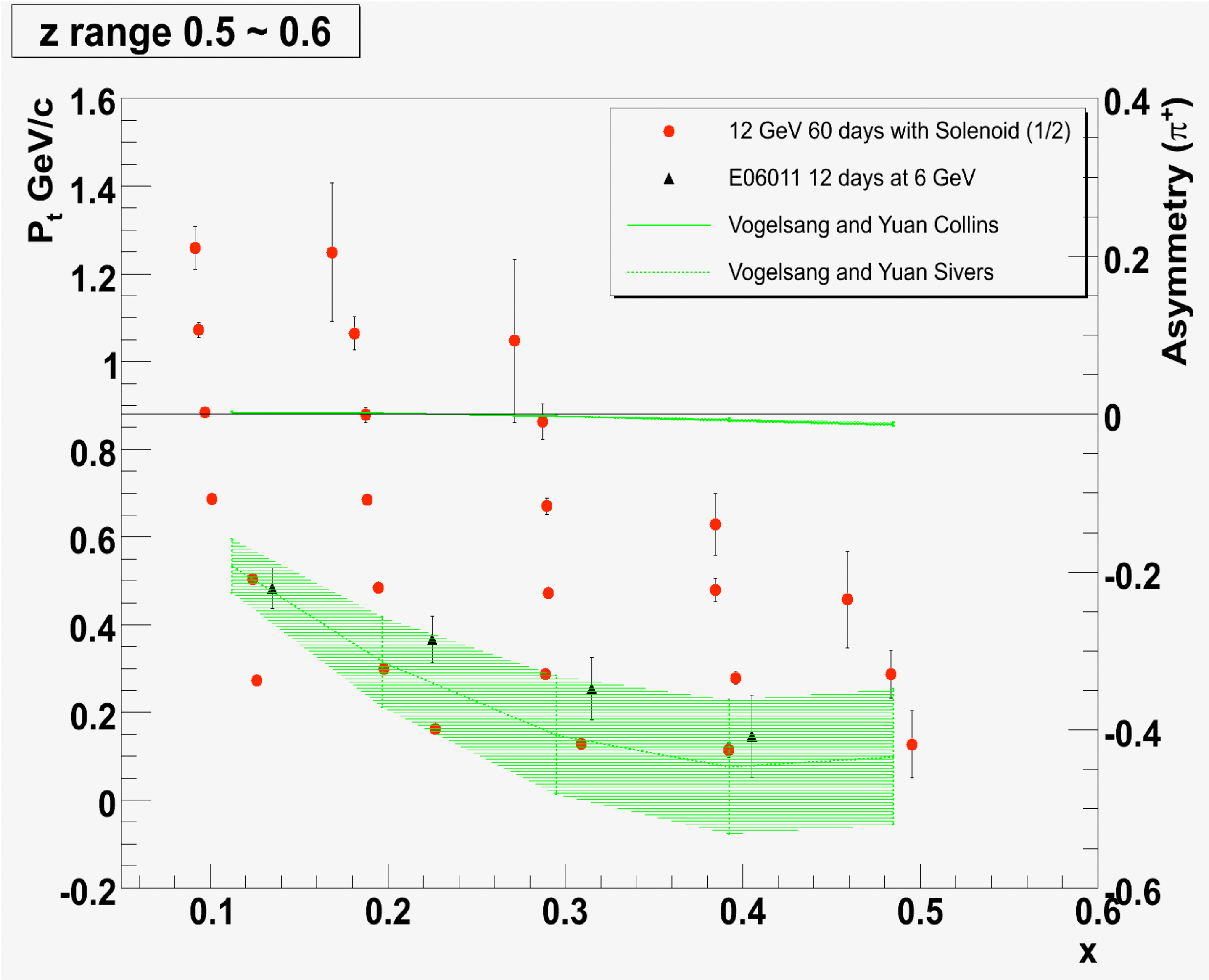
Collins

Sivers



Solenoid Projection vs P_T and x for π+ (60 days)

- For one z bin (0.5-0.6)
- Will obtain 4 z bins (0.3-0.7)
- Also π- at same time
- With upgraded PID for K+ and K-



Conclusion

Near Term: Collins and Sivers effects on a neutron target

Long Term: 12 GeV upgrade allows for a comprehensive study of TMDs in the large x region on proton and neutron targets