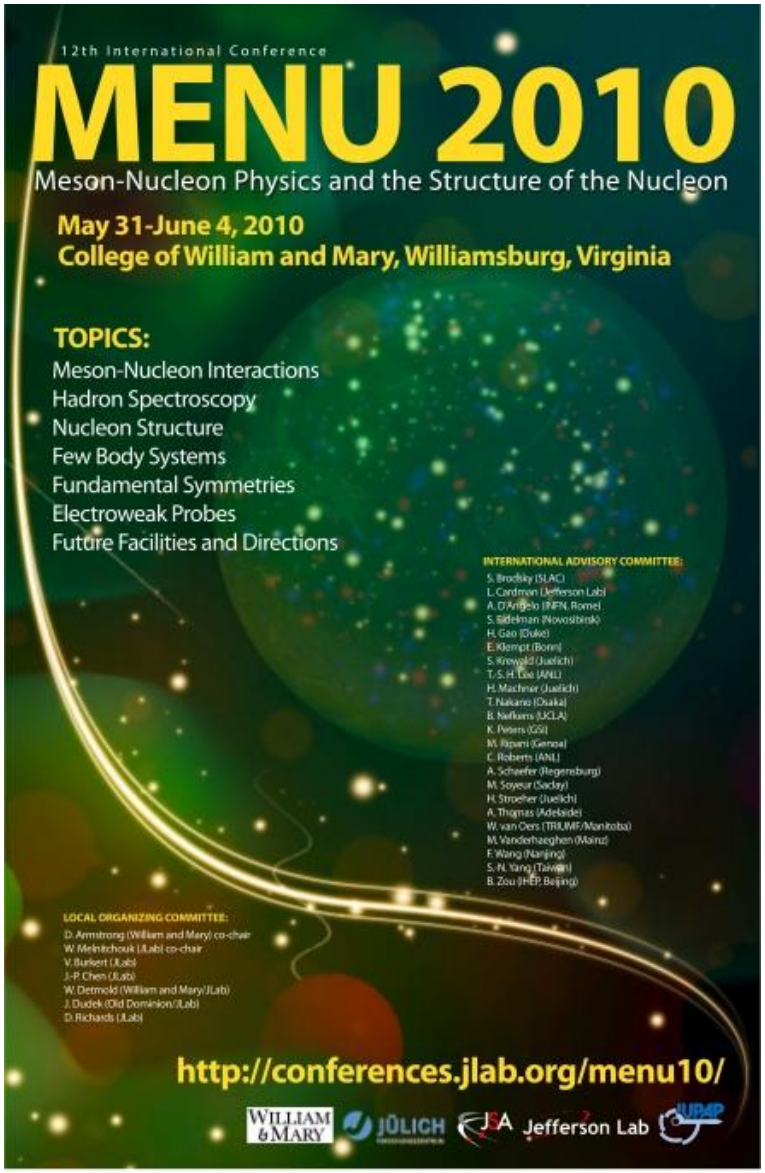


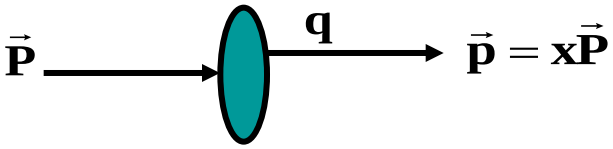
Recent results on SIDIS from pion production at CLAS

Patrizia Rossi
Laboratori Nazionali di Frascati-INFN
on behalf of the CLAS Collaboration

- Introduction to TMD & SIDIS
- pion TMDs with CLAS @ 6 GeV
  - unpolarized and longitudinally polarized targets
  - future data with transversely polarized target
- Conclusion

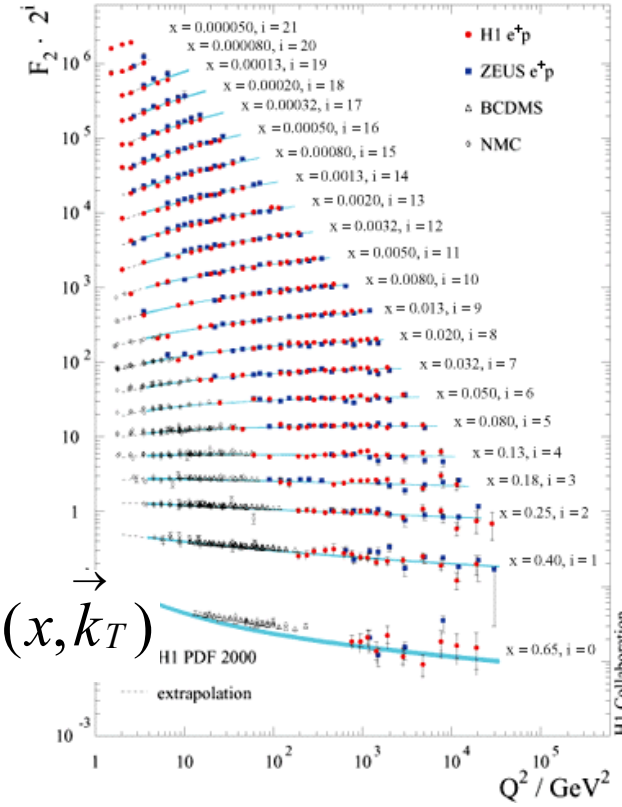
The nucleon parton model

In the collinear approximation:

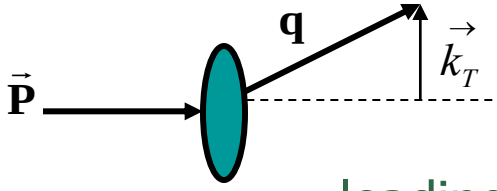


DIS PDF

$$f_1(x), g_1(x), h_1(x)$$



Parton transverse momentum



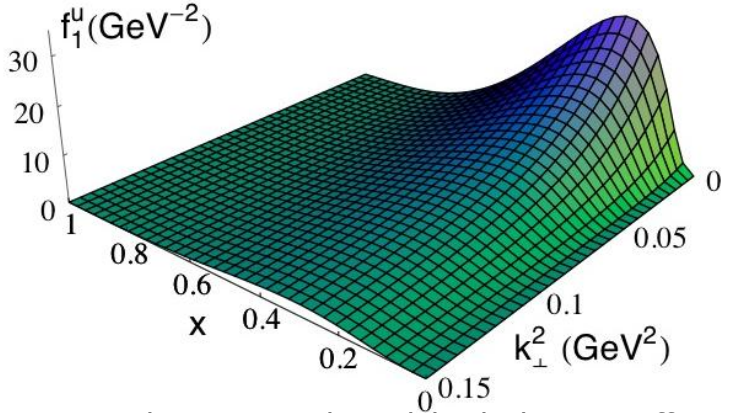
$$\vec{p} = x\vec{P} + \vec{k}_T$$

more complex PDF
$\Rightarrow$TMDs

$$f_1(x,\vec{k}_T),\ g_1(x,\vec{k}_T),\ h_1(x,\vec{k}_T)$$

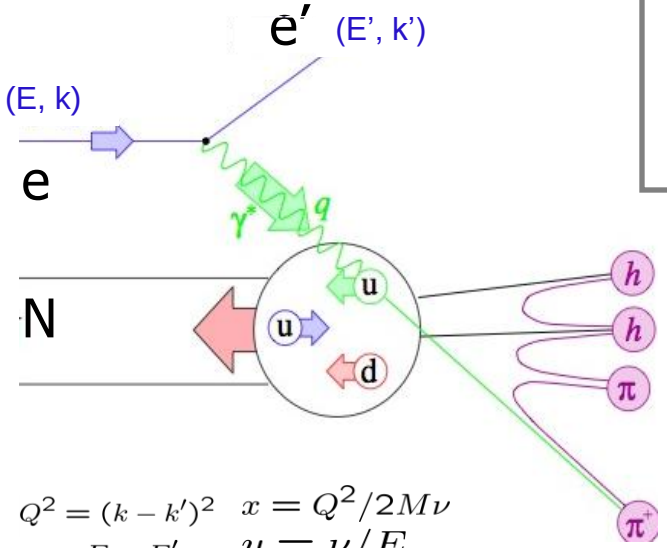
leading twist TMDs

		quark		
		U	L	T
nucleon	U	f1		$h_1^\perp$
	L		g1	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	h1, $h_{1T}^\perp$



Light-cone quark model calculation, Boffi et al.

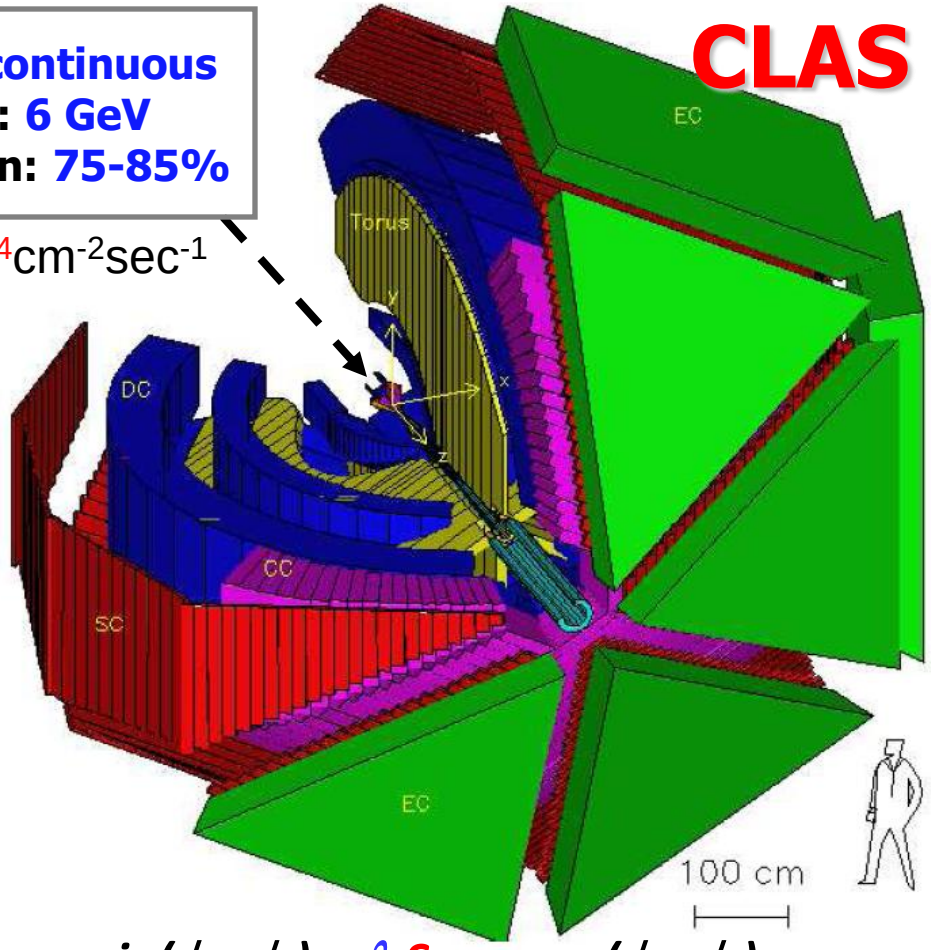
SIDIS @ CLAS

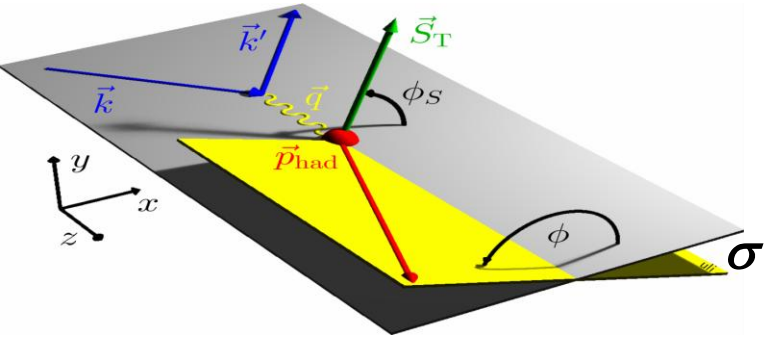


$Q^2 = (k - k')^2 \quad x = Q^2/2M\nu$
$\nu = E - E' \quad y = \nu/E$
$z = E_h/\nu$

Beam: e⁻ continuous
Energy: 6 GeV
Polarization: 75-85%

Lumi ~10^{34}cm^{-2}sec^{-1}

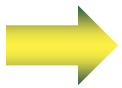




$\sigma = \sigma_{UU} + S_T \sigma_{UT} \sin(\phi - \phi_S) + \lambda S_T \sigma_{LT} \cos(\phi - \phi_S) + ...$

$$A_{UL}^{\sin 2\phi} = \frac{\sigma_{UL}}{\sigma_{UU}}$$

azimuthal asymmetries due to correlations of spin and transverse momentum of quarks



moments of ϕ

SIDIS Cross-Section

$$d\sigma^h \propto \sum f^{H\to q}(x,k_T) \otimes d\sigma_q(y) \otimes D^{q\to h}(z,p_\perp)$$

$d\sigma^h \propto d\sigma_q(y) \otimes FF$

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}$$

$$+ S_\parallel\Big[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h) F_{UL}^{\sin 2\phi_h}\Big]$$

$$+ S_\parallel\lambda_e\Big[\sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\Big]$$

$$+ |\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) + \varepsilon\sin(\phi_h+\phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\sin(3\phi_h-\phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+ \sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S F_{UT}^{\sin\phi_S} + \sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+ |\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S) F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S F_{LT}^{\cos\phi_S}$$

$$+ \sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

$F_{LU}(x,P_T,z,Q^2)$

$F_{UL}(x,P_T,z,Q^2)$

$F_{LL}(P_T)$

Unpol. target ✓

Long. Pol. target ✓

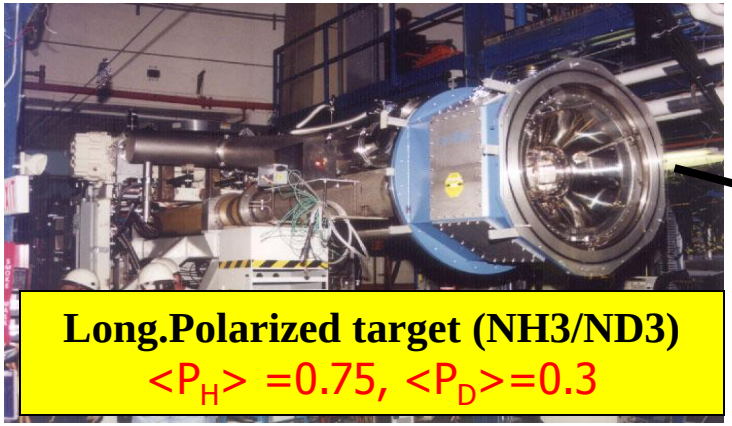
Trans. Pol. Target

Experiment in preparation

18 structure functions !!

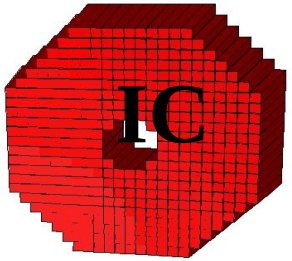
Bacchetta et al., JHEP 0702:093,2007

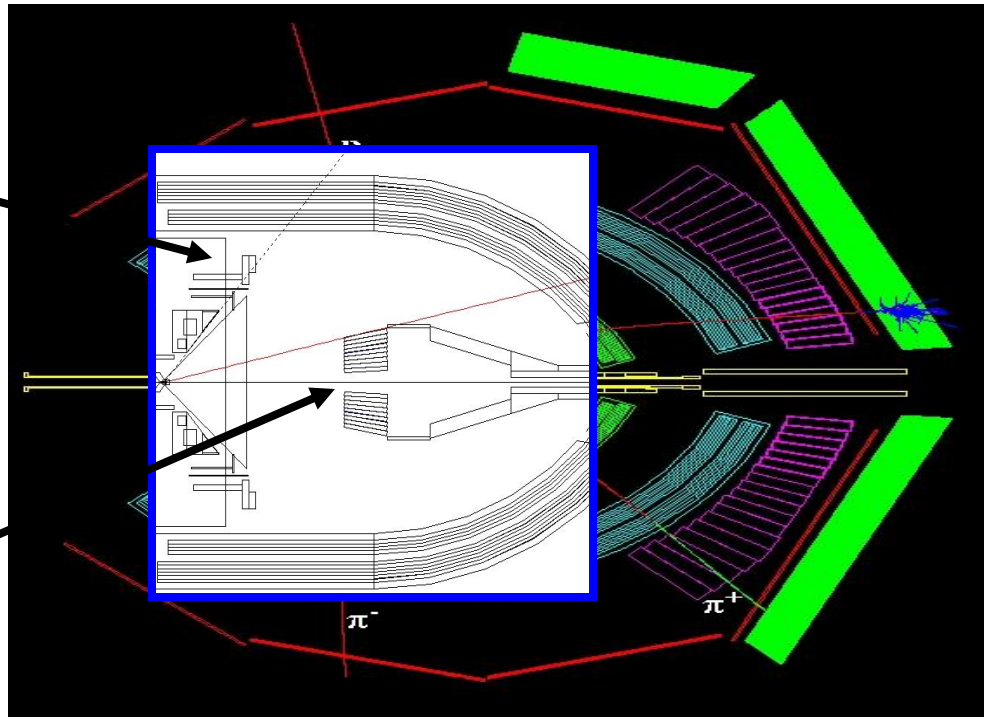
ep →e′πX : Unp. & Long. Pol. Target



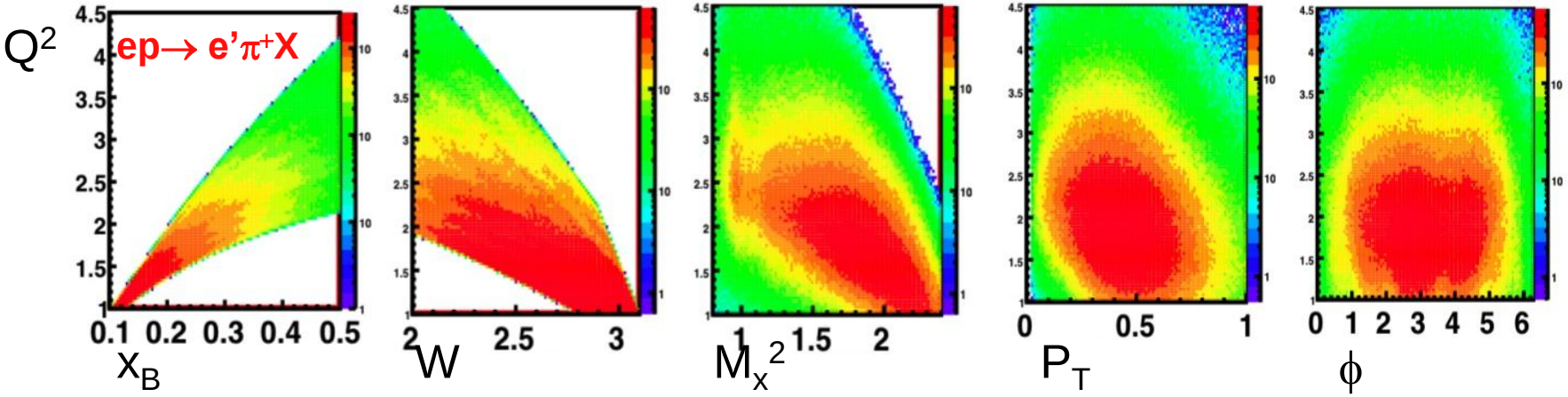
Long.Polarized target (NH3/ND3)
$<P_H> = 0.75, <P_D> = 0.3$

Inner Calorimeter (424 $PbWO_4$ crystals) to detect high energy photons at forward lab angles.



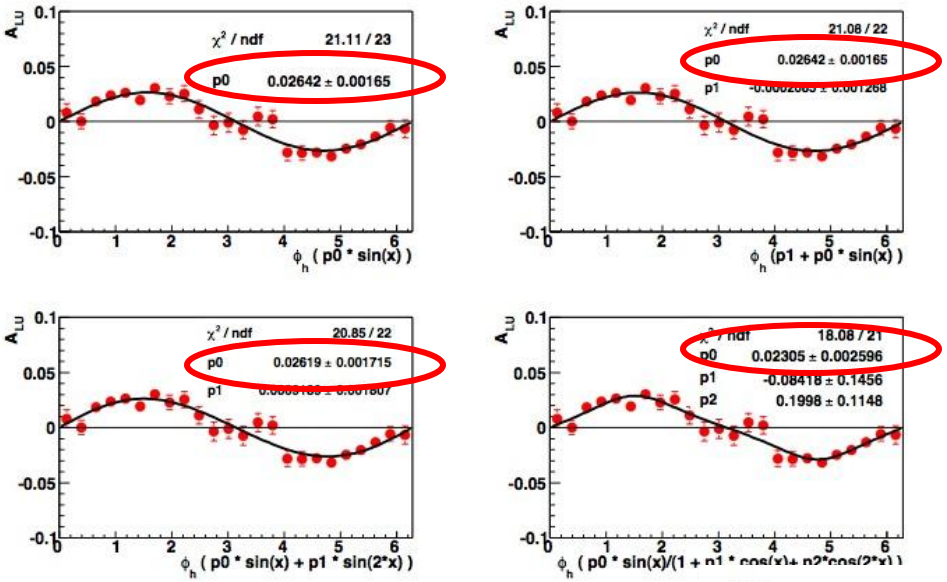


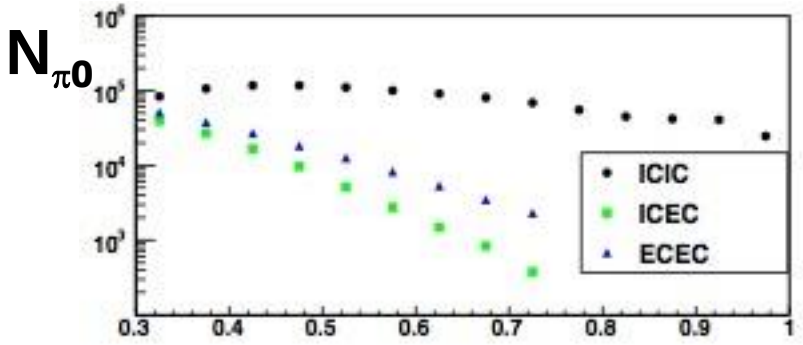
- **DIS kinematics:**
  $Q^2>1$ GeV^2, $W^2>4$ GeV^2, $y<0.85$



BSA: e p →e'π^0 X

- π^0 events (γ detected both in IC and EC)
- Choice of the fitting function





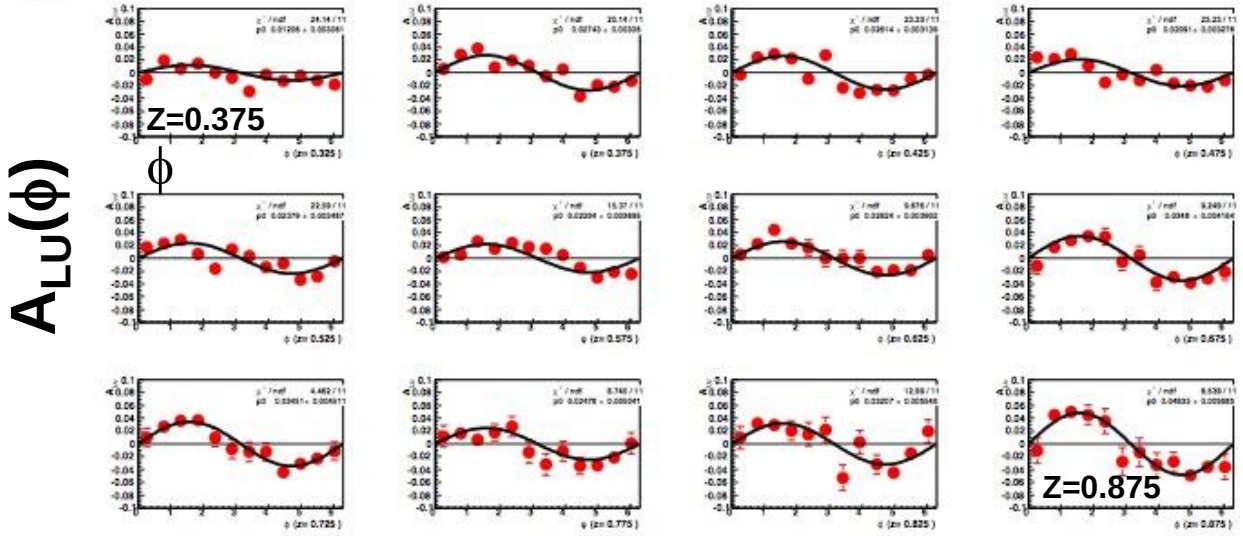
$$d\sigma_{LU} \propto \sin\phi_h F_{LU}^{\sin\phi_h}$$

$$A_{LU}^{\sin(\phi)} = \frac{\sigma_{LU}}{\sigma_{UU}}$$

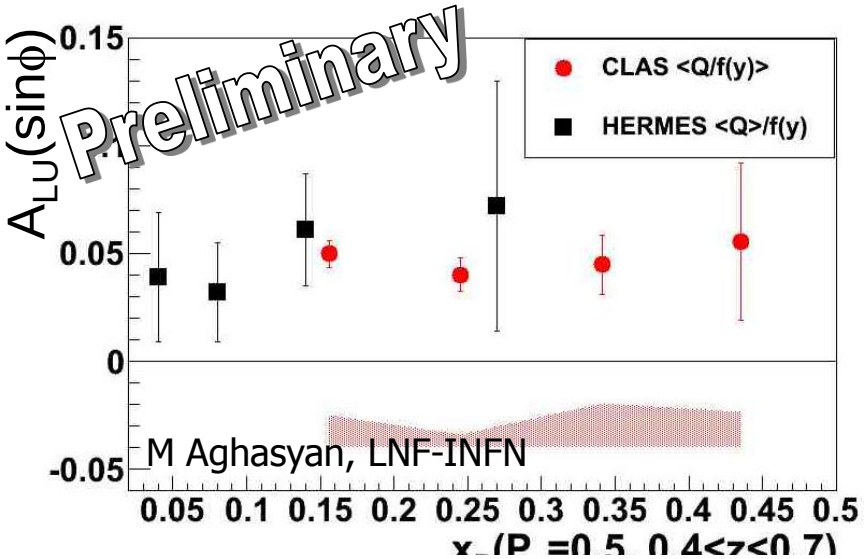
$$A_{LU}(\phi) = \frac{1}{P}\frac{N^+ - N^-}{N^+ + N^-} \sim \sin\phi$$

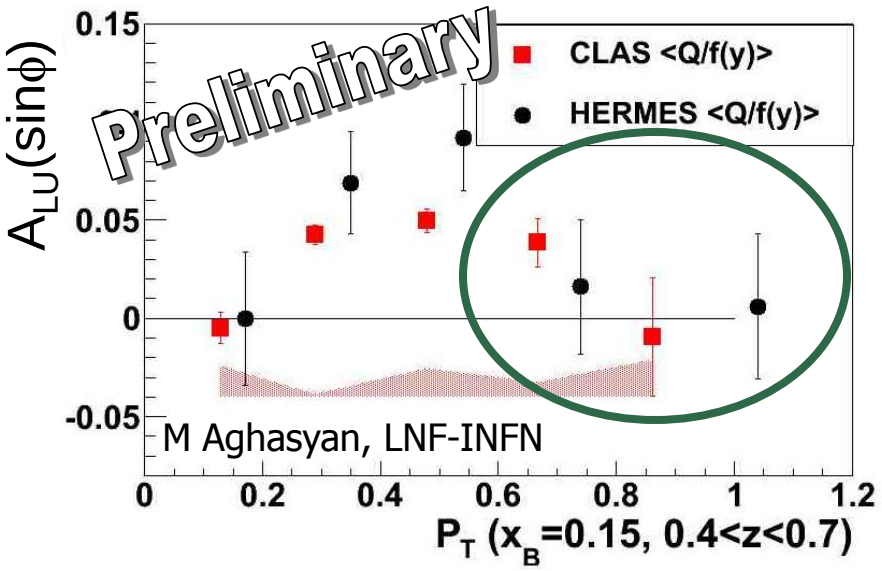
- Extraction of moments

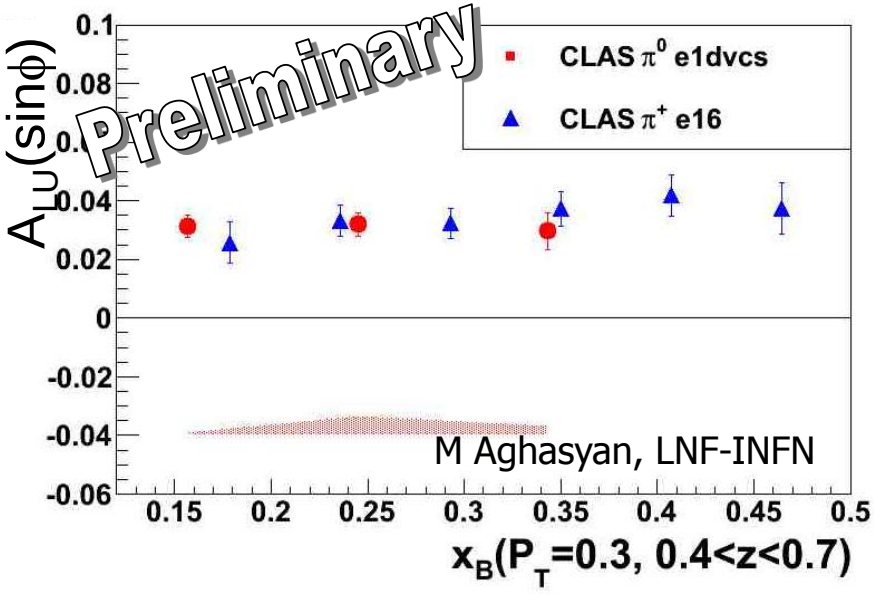
ϕ	0-2π
x_B	0.1-0.6
P_T	0.0-1.2
z	0.4-0.7



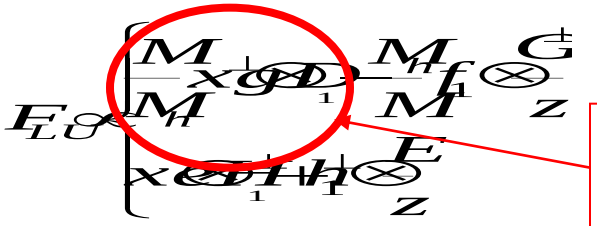
π^0 BSA Asymmetry results







- Drop with P_T below 1 GeV/c
- A_{LU} in agreement with HERMES data
- Comparable BSA for π^0 and π^+
  Small Collins type contributions for π^+?



Main contribution?

Long. Pol. Target: Kotzinian-Mulders asymmetry

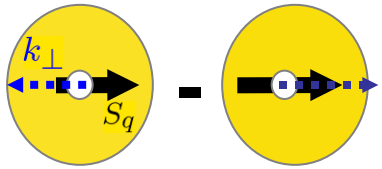
Leading twist

$$\frac{d\sigma}{dxdydzd^2\vec{P}_h} = \frac{4\pi\alpha^2 s}{Q^4}[\lambda_e\lambda x(1-y/2)F_{LL} + x(1-y)\sin(2\phi)F_{UL}]$$

$$\longrightarrow g_1 D_1$$

$$\longrightarrow h_{1L}^{\perp} H_1^{\perp}$$

Kotzinian & Mulders $S_L \frac{\vec{k}_T}{M} h_{1L}^{\perp}(x, k_T^2)$ $\longrightarrow$

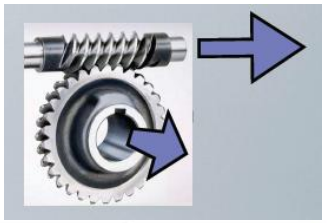


Correlation between the **transverse momentum** and **transverse spin** of quarks in longitudinally polarized proton

Collins effect measurement with **longitudinally pol. target** provide access to the chiral-odd Mulders distribution functions

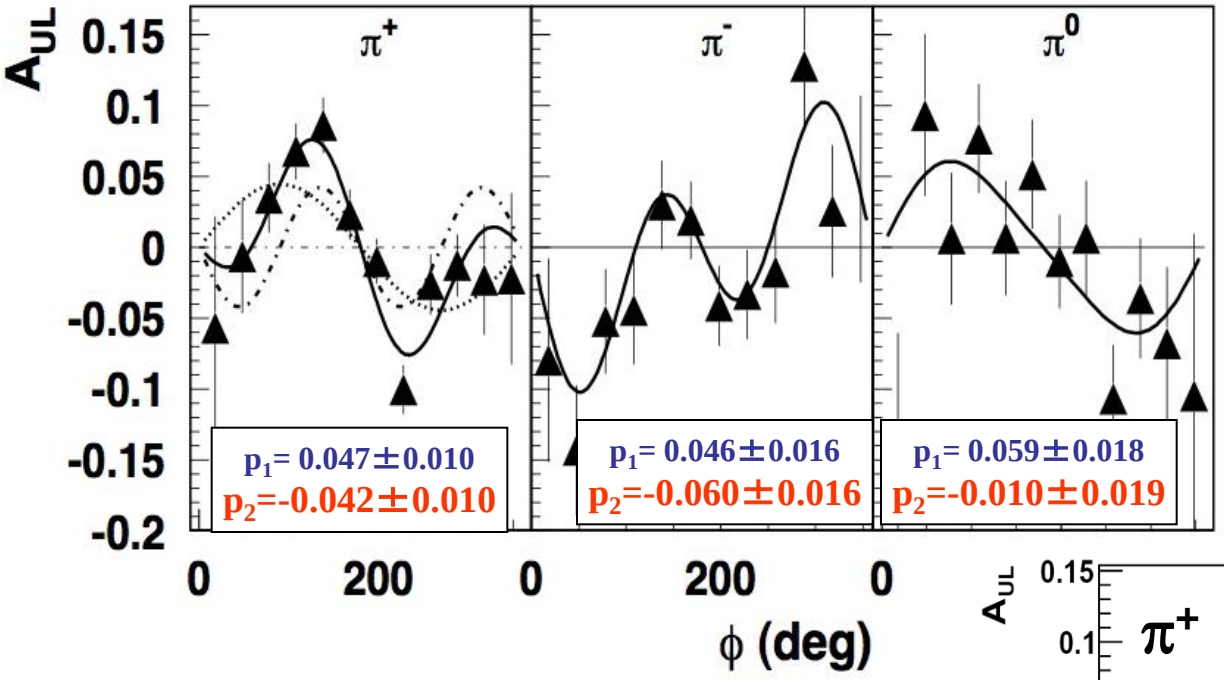
Long. Pol. Target: Kotzinian-Mulders asymmetry

$e\,p \rightarrow e'\pi^{+/-/0}\,X$



Transversely polarized quarks in a longitudinally polarized nucleon

$$A_{UL}^{\sin 2\phi} \sim h_{1L}^{\perp} H_1^{\perp} \sin 2\phi$$

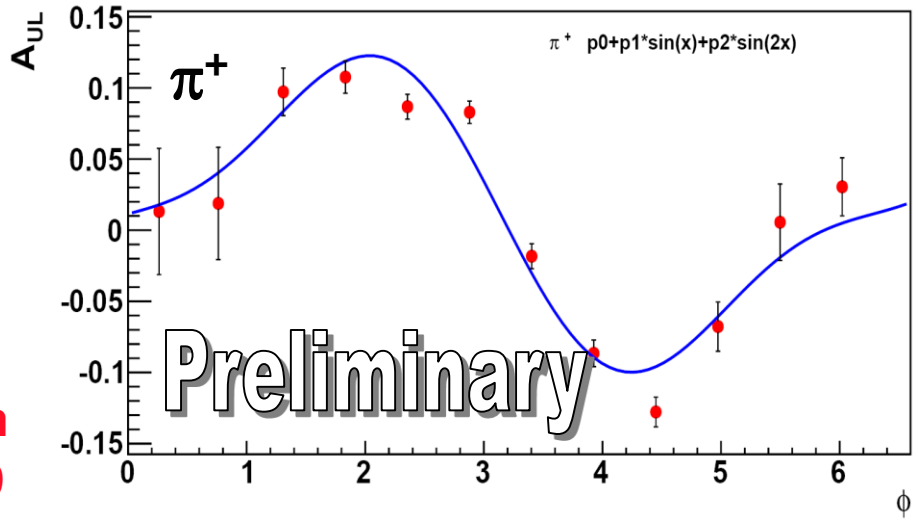


~5 days data taking (2001)

- A_{UL} ∫ over the full kinematics
- Fitting function: $p_1 \sin\phi + p_2 \sin 2\phi$

H. Avakian et al. arXiv:1003.4549

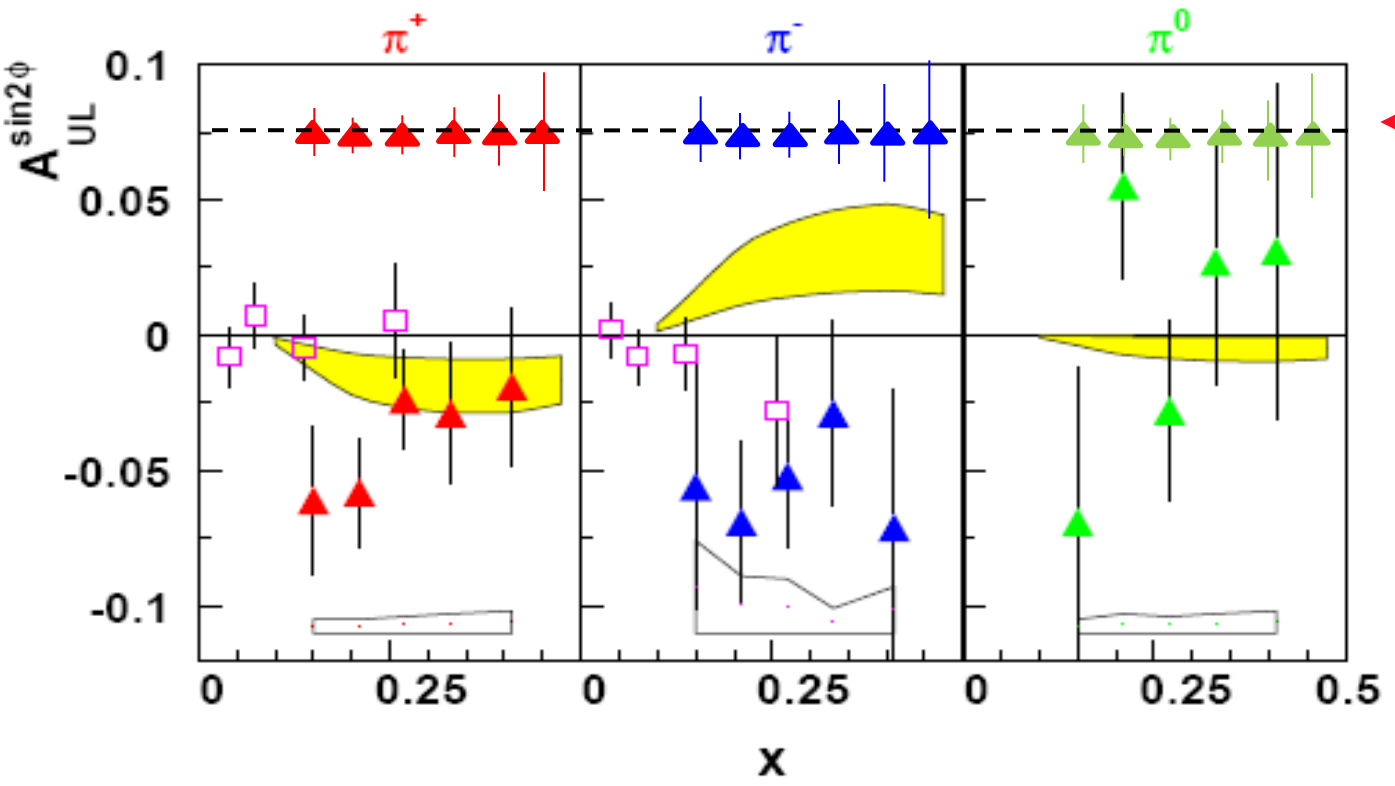
- No indication of Collins effect for π^0
- Non-zero negative asymmetry for $\pi^{+/-}$



~10% of E05-113 data

End data taking sep. 2009

Long. Pol. Target: Kotzinian-Mulders asymmetry



curves, χQSM from Efremov et al

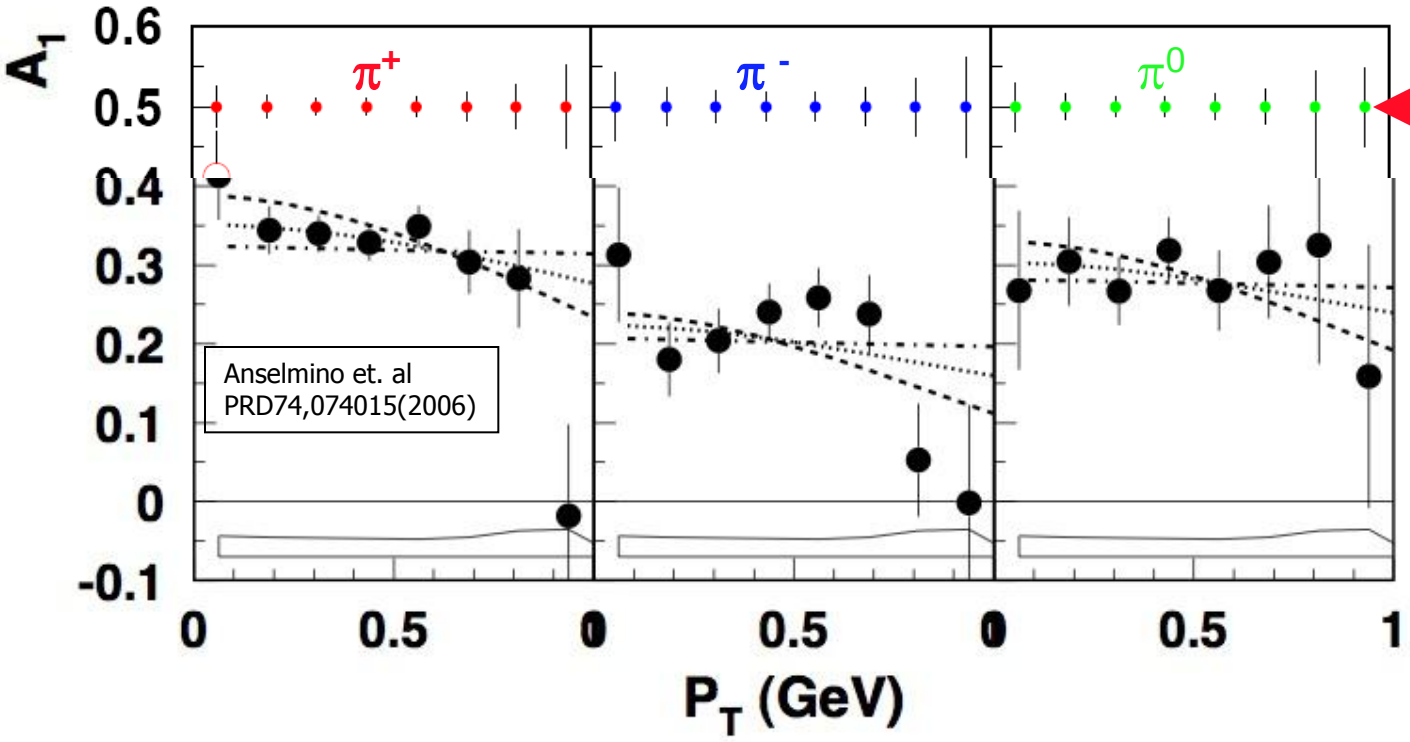
et al. arXiv:1003.4549

Projected results for Exp. E05-113

- Total good events accumulated on proton with CLAS in 3 months ~ 10 times statistics accumulated by HERMES in 2 years

- Analysis Topics : $\pi^{+/-/0}$ $A_{UL}(\sin 2\phi)$, A_{LL}, $A_{LU}(\sin\phi)$
  $\rho^{+/-}$ $A_{UL}(\sin 2\phi)$

Long. Pol. Target: A_1-P_T dependence



Projected results for Exp. E05-113

H. Avakian et al. arXiv:1003.4549

Different width of TMDs of quarks with different flavor and polarizations

$$R = \frac{k_\perp width\ dist(g_1)}{k_\perp width\ dist(f_1)}$$

– – – R=0.40

..... R=0.68

– · – · R=1.0

f_1=0.25 GeV^2

- Data shows slight preference for R< 1
- New experiment with 10 times more data will study the P_T-dependence for different quark helicities and flavors **for bins in x**

Transversely polarized HD-ice target

- **Target used by LEGS at BNL with photon beam**

Pros

- Small field ($\int Bdl \sim 0.005\text{-}0.05 Tm$)
- Small dilution factor
- Less radiation length
- Less nuclear background
- Wider acceptance
- much better FOM, especially for deuteron

Need to demonstrate that the target can remain polarized for long periods with an electron beam with currents of order of 1-2 nA

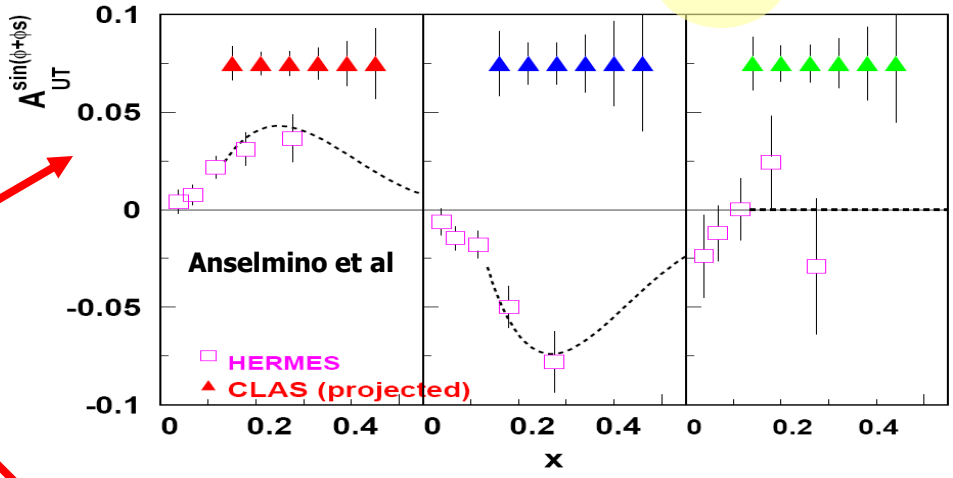
- **The target is now at Jlab and all equipment moved to the new HDice lab**

- Currently installing dilution refrigerators
- Parallel development of new in-beam cryostat
- **Installation ~ January 2011**
- **Test with electrons ~ April 2011**

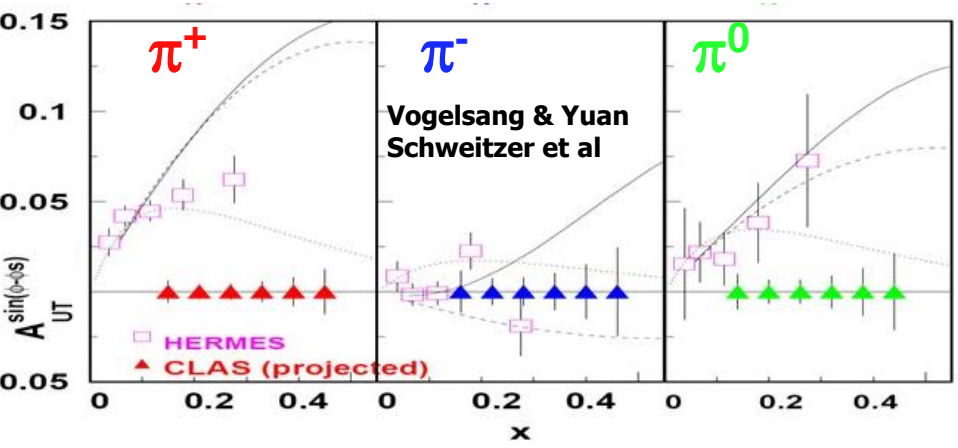
TMDs with transversely polarized target

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

$$A_{UT}^{\sin(\phi+\phi_S)} \sim h_1 H_1^\perp$$

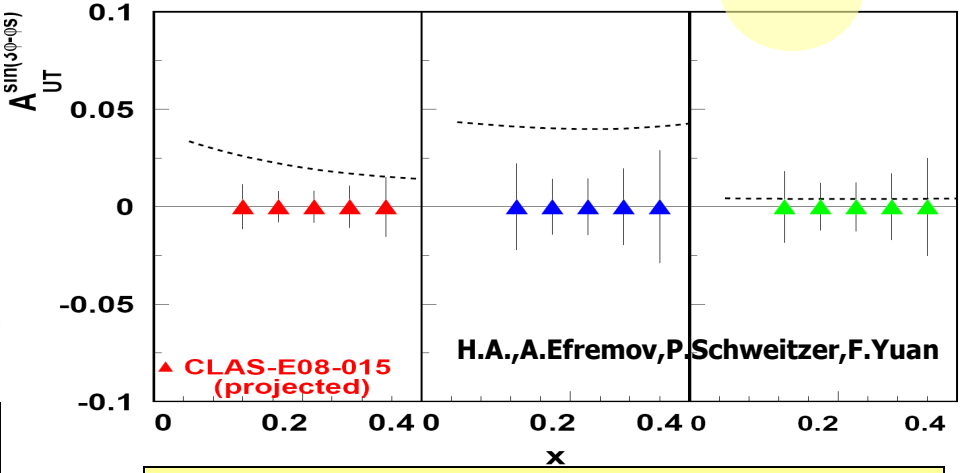


$$A_{UT}^{\sin(\phi-\phi_S)} \sim f_{1T}^\perp D_1$$



CLAS will provide a superior measurements of Sivers asymmetry at large x, where the effect is large and models unconstrained by previous measurements.

$$A_{UT}^{\sin(3\phi-\phi_S)} \sim h_{1T}^\perp H_1^\perp$$



CLAS will allow measurements of transverse spin distributions and constrain Collins fragmentation function

Conclusions and Outlook

- Transverse Momentum Dependent (TMD) distributions of partons contain novel information on the nucleon structure

- TMDs can be accessed in SIDIS with polarized leptons and nucleons by observing the azimuthal distributions of produced hadrons.
  - •Latest experimental data indicate that spin-orbit correlations are significant and lead to observable SSAs

- CLAS in Hall B at Jlab is playing a major role in these studies

- Interesting results obtained from the π^0 BSA measurement

- The new CLAS experiment with longitudinally polarized NH3 and ND3 targets provides superior sample of events allowing multidimensional binning to study:
  - SSAs for π and ρ in SIDIS
  - Higher Twists and quark-gluon correlations
  - Double spin asymmetries and flavor decomposition of helicity dist.

- New data are expecting soon with a transversely polarized target