Transversity at CLAS

…..or exploring the 3D structure of the nucleon

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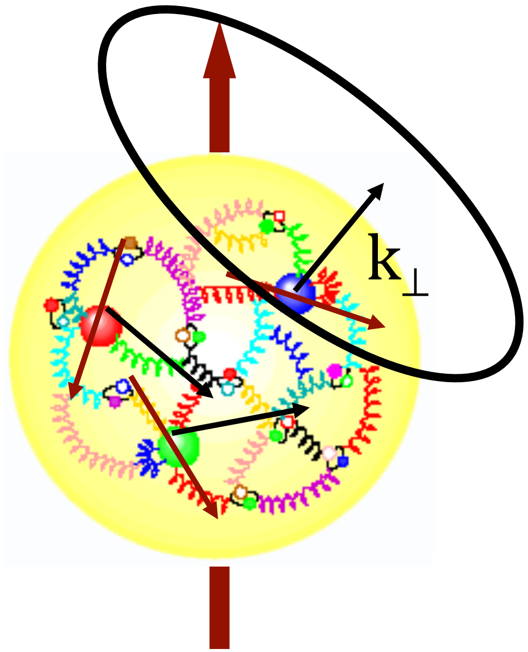
- Introduction
- TMD Experimental program @ 6 GeV
- Future experiments @ 12 GeV
- Conclusion

Introduction

Nucleon structure is more complex than the one believed for many years: naïve picture of nucleon spin as probed in DIS is incomplete!



First attempt to explain the nucleon spin in the naive CQM framework

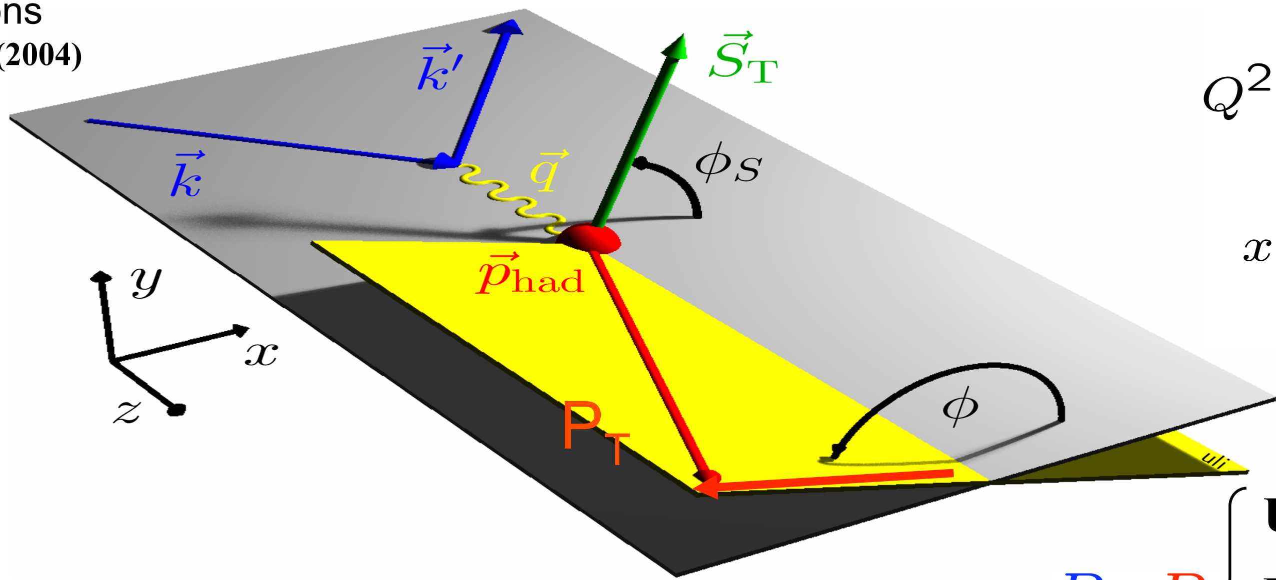
$$\Delta\Sigma = \Delta u_V + \Delta d_V + \Delta q_S$$

$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma}_{\approx 0.3} + \underbrace{\Delta G}_{\text{small}} + \underbrace{L_q}_{\text{could be large}}$$

Transverse structure of the nucleon accessible through measurements of correlations between transverse momentum of quarks ($k_\perp$) and the spin of the quark/nucleon

SIDIS

Trento Conventions
Phys.Rev. D70, 117504 (2004)



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

P_b, P_t { **U** unpolarized, **L** long.polarized, **T** trans.polarized

Target polarization **Beam polarization**

$$\sigma = \sigma_{UU} + P_t \sigma_{UT} \sin(\phi - \phi_S) + P_b P_t \sigma_{LT} \cos(\phi - \phi_S) \ldots$$

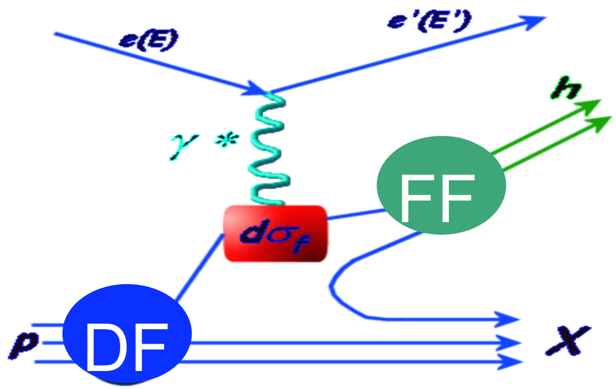
Observables:
spin azimuthal asymmetries

$$A_{UT}^{\sin(\phi - \phi_S)} = \frac{\sigma_{UT}}{\sigma_{UU}}$$

⇒ moments of ϕ/ϕ_S

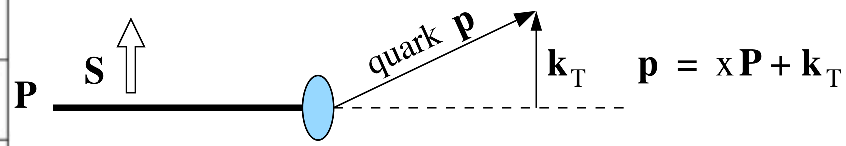
TMDs

$$d\sigma^h \propto \sum q_f(x) \otimes \mathbf{d}\sigma_f(y) \otimes D_f^{q\to h}(z)$$



Nucleon description at leading Twist

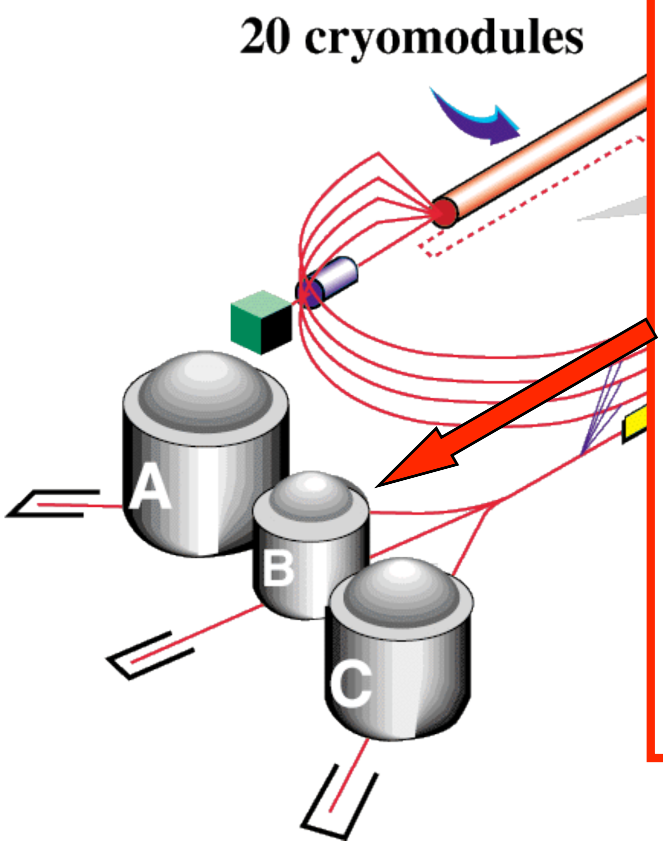
TMD		quark		
		U	**L**	**T**
nucleon	**U**	q		$h_1^{\perp}$
	L		Δq	$h_{1L}^{\perp}$
	T	$f_{1T}^{\perp}$	$g_{1T}^{\perp}$	δq $h_{1T}^{\perp}$



Parton Distribution Functions generalized to contain information not only on longitudinal, but also on the transverse momentum distribution of partons

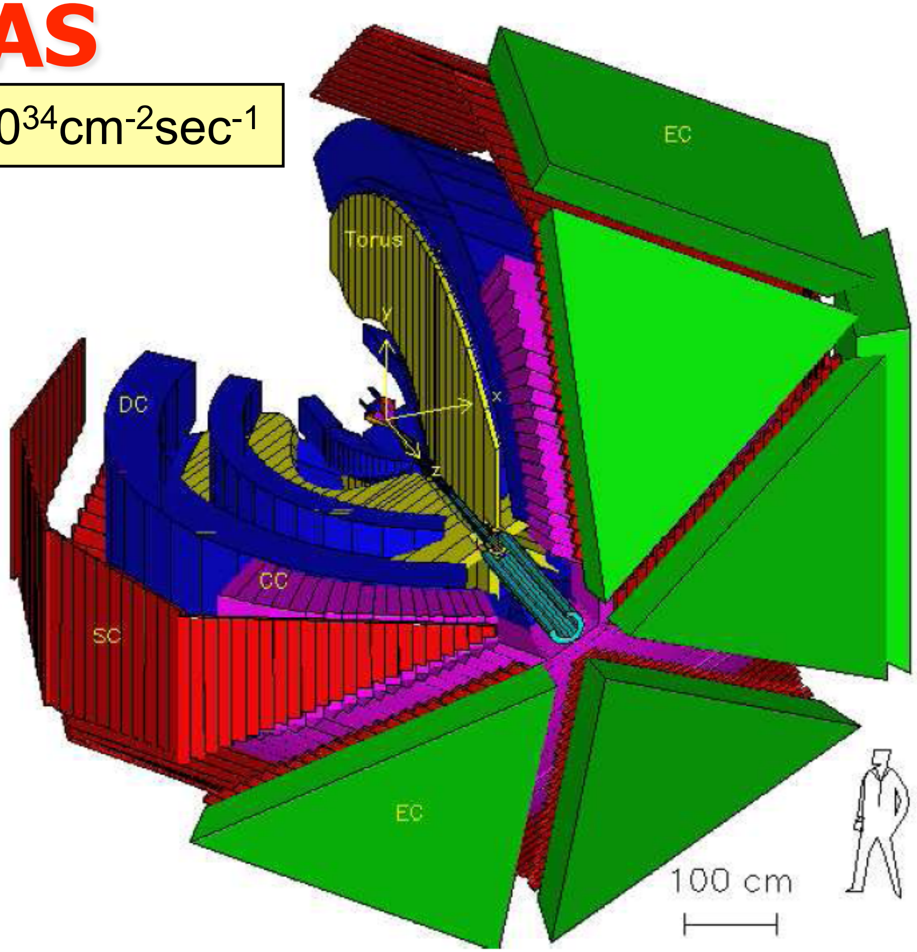
Jefferson Lab and CLAS

Beam: **continuous**
Energy: **0.8 - 5.7 GeV**
$\Delta E/E$ = **10^{-4} (4σ)**
Current: **0.1nA - 200 μA**
Polarization: **75-85%**



CLAS

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

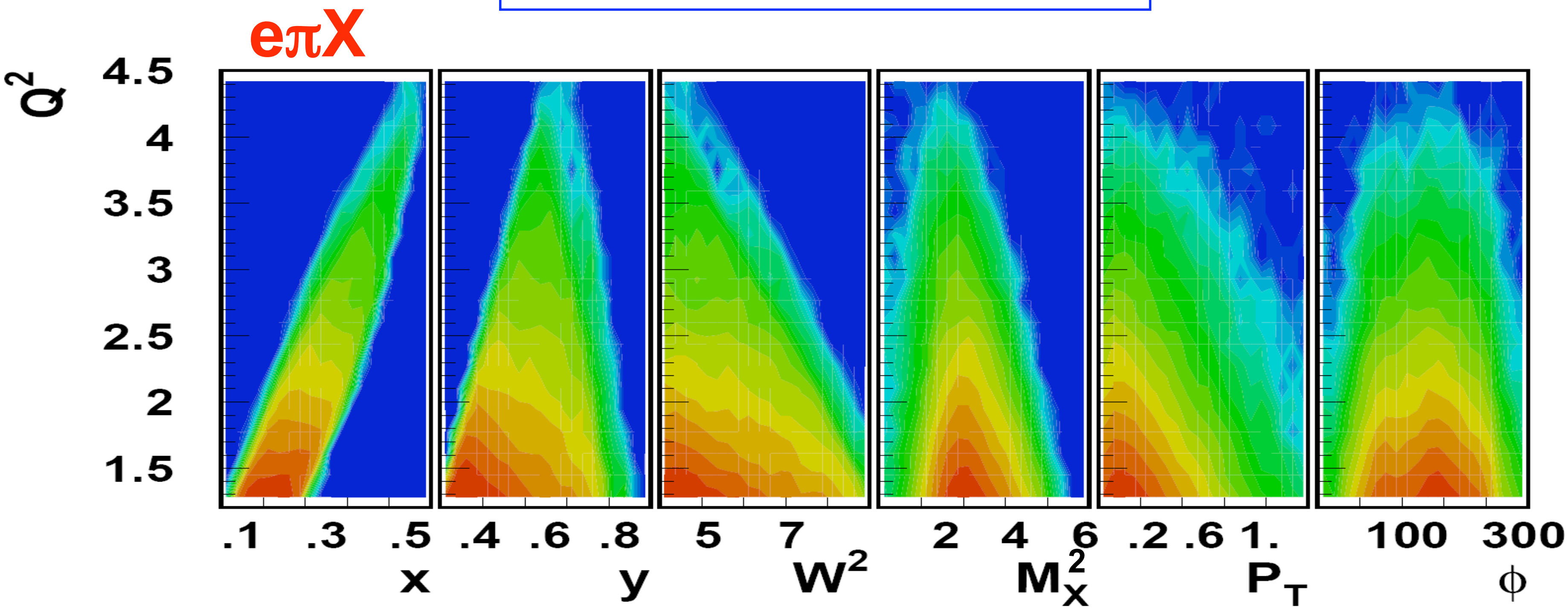


Pol. $N\vec{H}_3$, $N\vec{D}_3$ targets $\langle P_H \rangle$ =0.8, $\langle P_D \rangle$=0.3
Longitudinal polarization

SIDIS with CLAS at 6 GeV

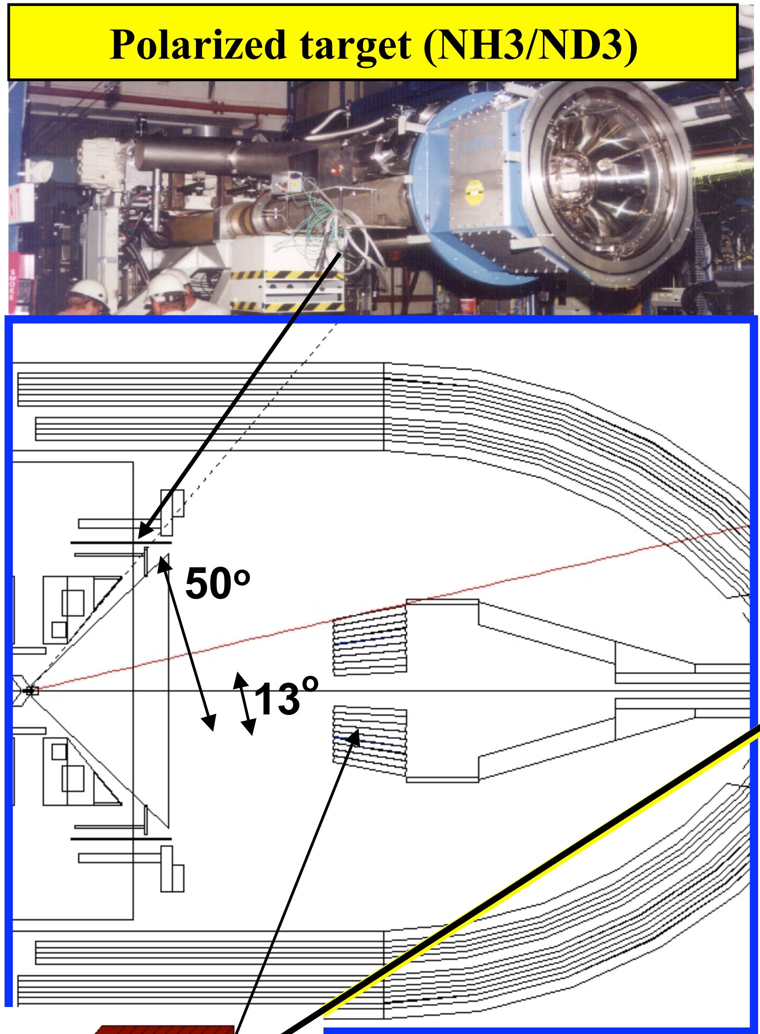
Scattering of 5.7 GeV electrons off polarized proton and deuteron targets

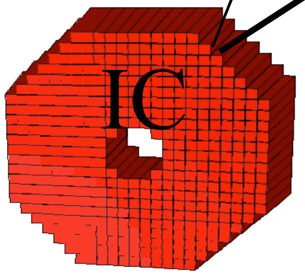
- DIS kinematics, $Q^2>1$ GeV^2, $W^2>4$ GeV^2, $y<0.85$
- $0.4>z>0.7$, $M_X^2>2$ GeV^2



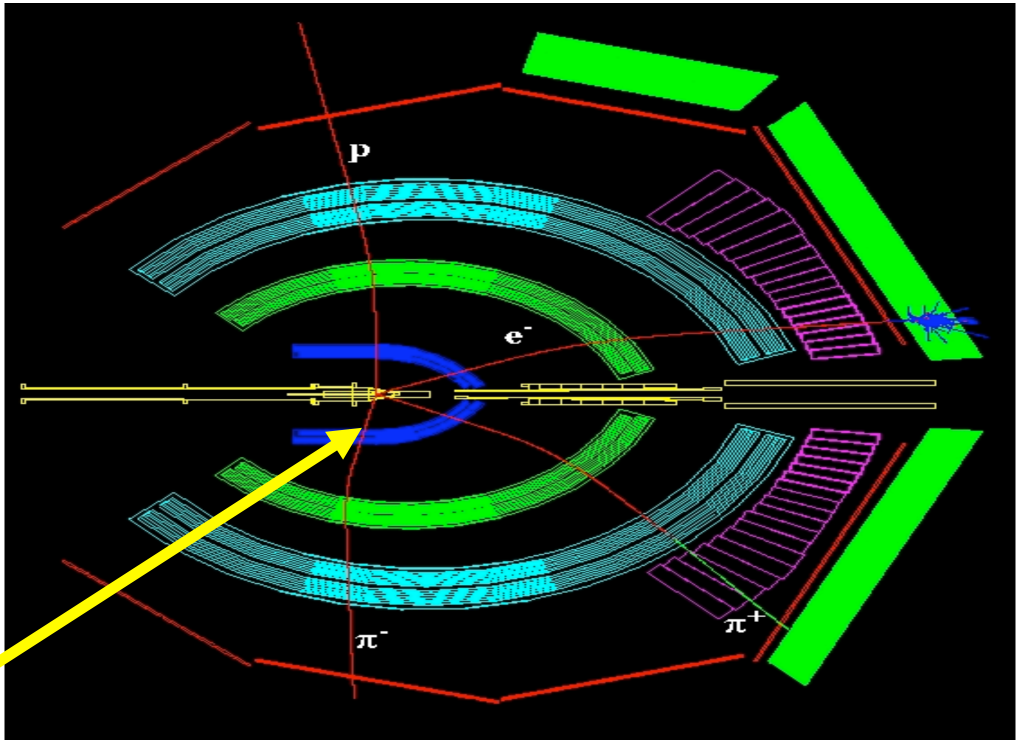
Large P_T range and full coverage in azimuthal angle ϕ crucial for studies

Experimental setup





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



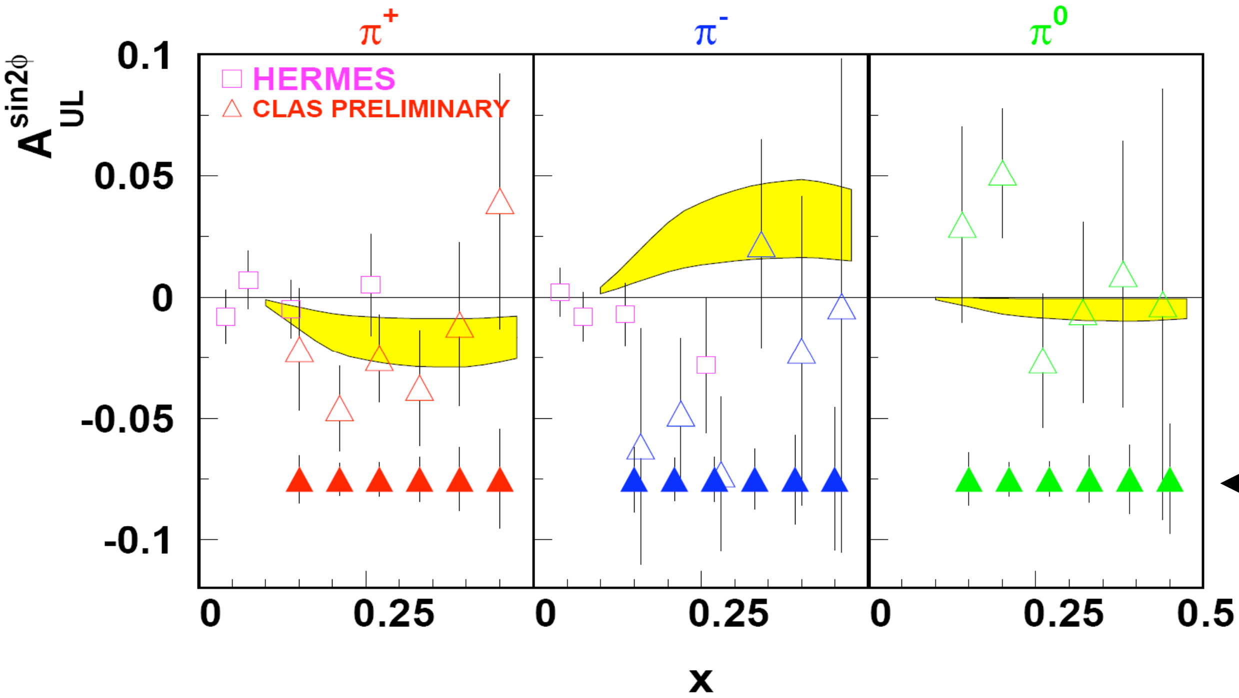
1) Polarized NH3/ND3 (no IC, ~5 days)	A_{LL}, $h_{1L}^{\perp} H_1^{\perp}$
2) Polarized NH3 with IC 60 days	Currently running (E05-113)
3) Unpolarized H with IC 30+30 days	π^0 BSA
4) Polarized HD-Ice (no IC, 25 days)	Run in 2011 (E08-015)

Kotzinian-Mulders asymmetry

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 $h_{1T}^{\perp}$

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

Transversely polarized quarks in the longitudinally polarized nucleon



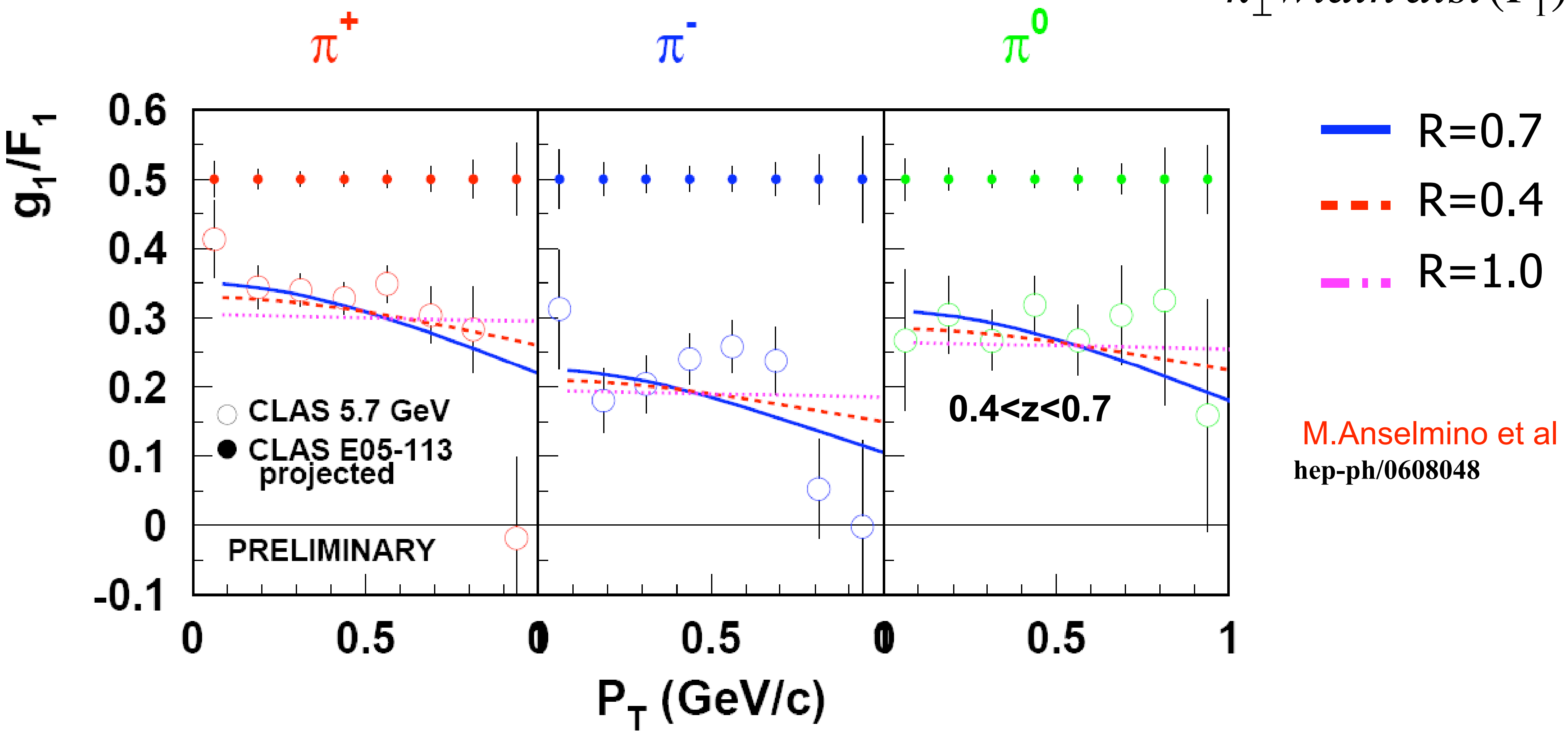
curves, χQSM from Efremov et al

60 days of CLAS
$L=1.5.10^{34} cm^{-2} s^{-1}$

Measurement of sin2ϕ asymmetry will give access to the Kotzinian-Mulders function and will allow to study Collins fragmentation with longitudinally polarized target

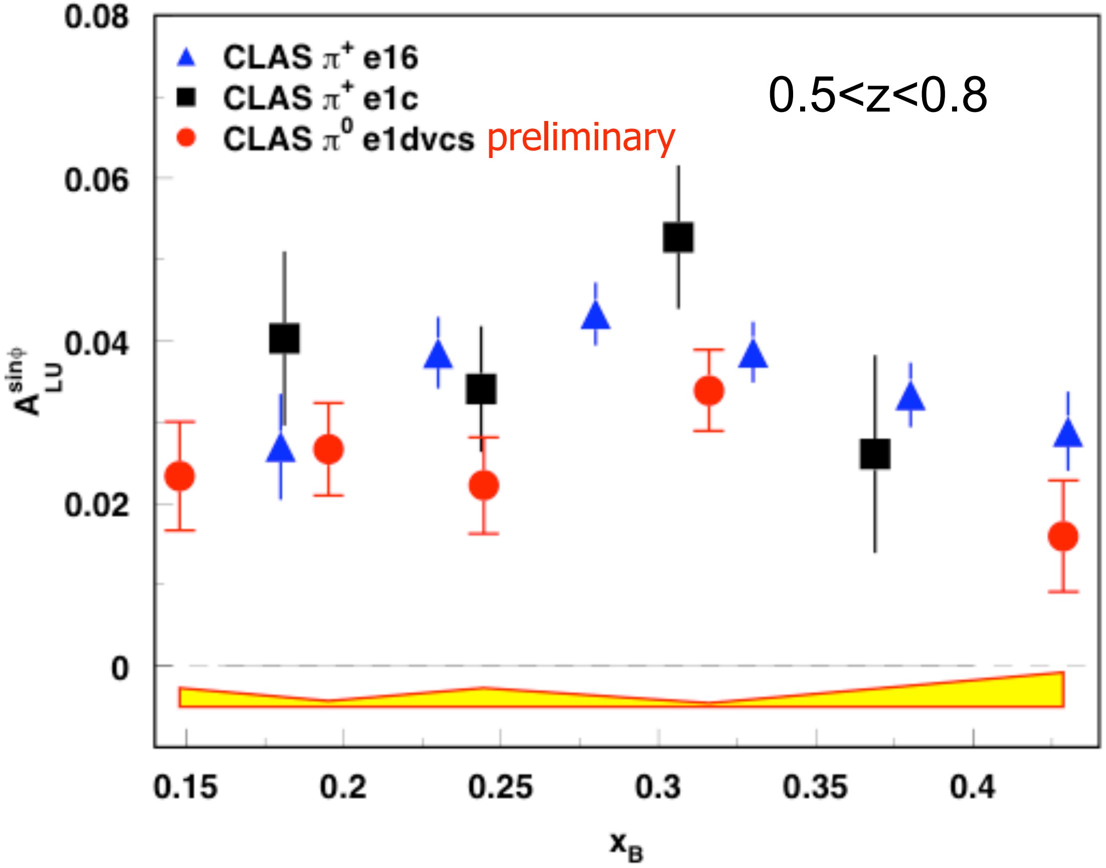
A_{LL} P_T-dependence in SIDIS - E05-113

$$R = \frac{k_\perp \, width\, dist(g_1)}{k_\perp \, width\, dist(F_1)}$$



- 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

π^0 Beam Spin Asymmetry



Beam SSA for π^0 and π^+ are comparable indicating small Collins type contributions

CLAS transversely polarized HD-Ice target

HD-Ice target vs std nuclear targets

Heat extraction is accomplished with thin aluminum wires running through the target (can operate at ***T~500-750mK***)

Material	gm/cm^2	mass fraction
HD	0.735	77%
Al	0.155	16%
CTFE (C_2ClF_3)	0.065	7 %

Pros

1. Small field ($\int Bdl$~*0.005-0.05Tm*)
2. Small dilution (fraction of events from polarized material)
3. Less radiation length
4. Less nuclear background (no nuclear attenuation)
5. Wider acceptance

much better FOM, especially for deutero**n**

HD-Ice target at ~2nA ~ NH3 at 5 nA

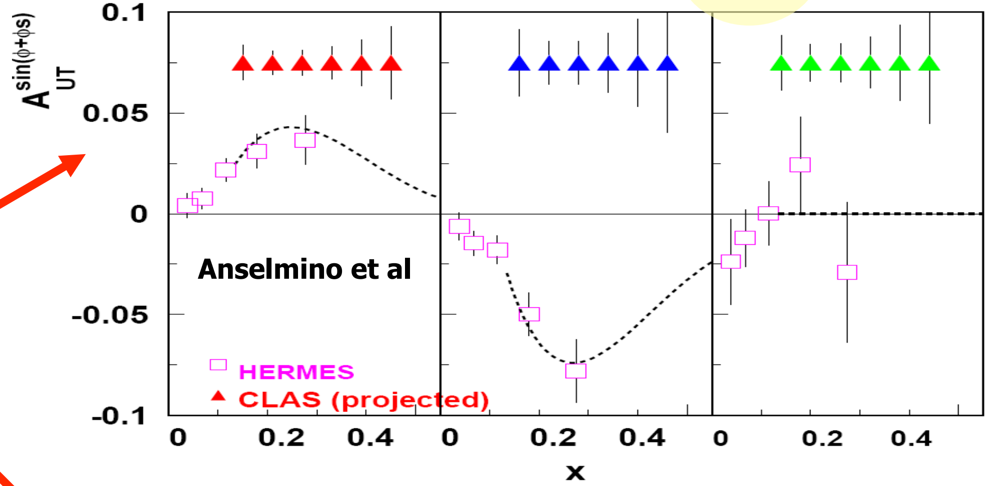
Cons

1. HD target is highly complex and there is a need for redundancy due to the very long polarizing times (months).
2. Need to demonstrate that the target can remain polarized for long periods with an electron beam with currents of order of 1-2 nA

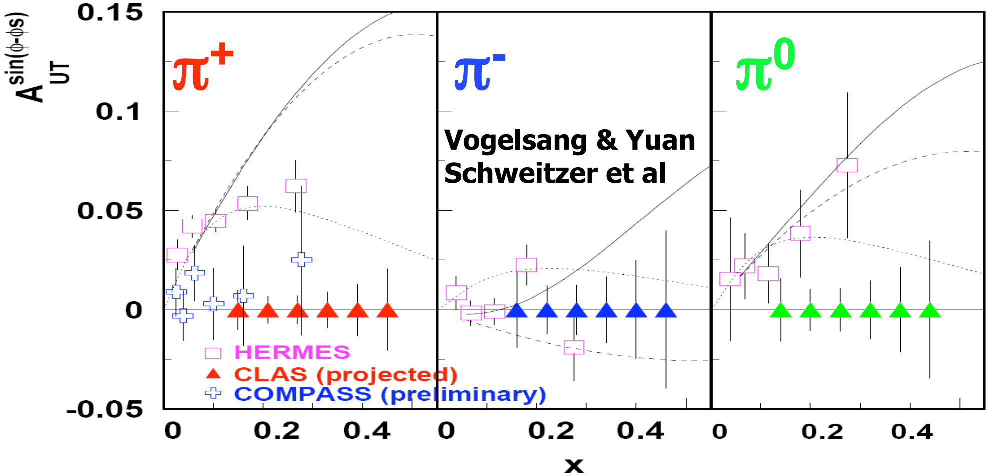
Sivers and Collins with transversely pol target: E08-015

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

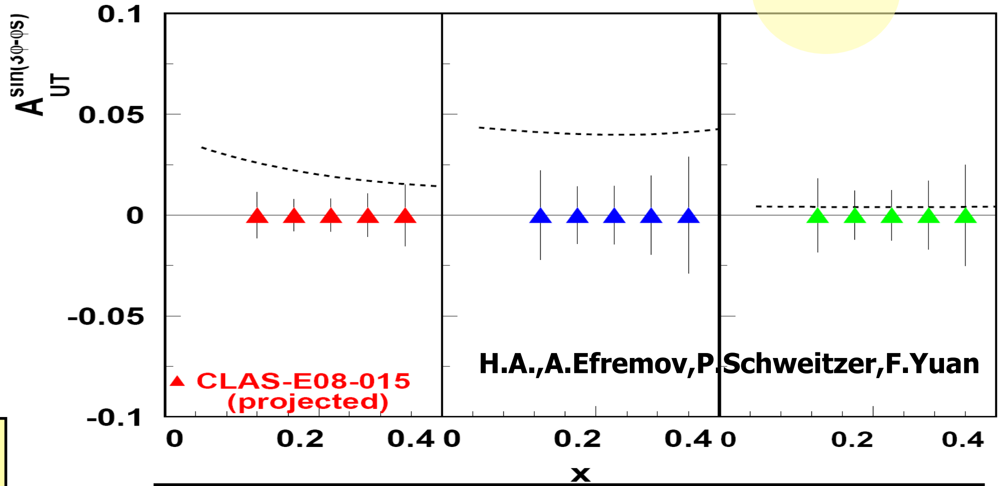
$$A_{UT}^{\sin(\phi+\phi_S)} \sim h_1 H_1^\perp$$



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



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



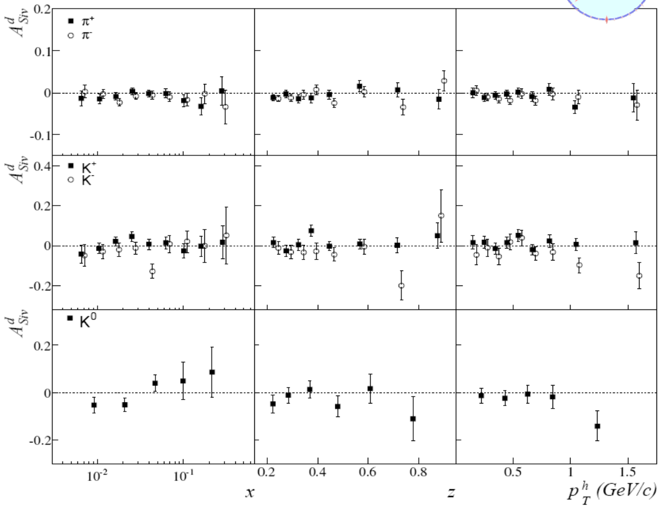
CLAS will provide a superior measurements of Sivers asymmetry at large x, where the effect is large and models unconstrained by previous measurements.

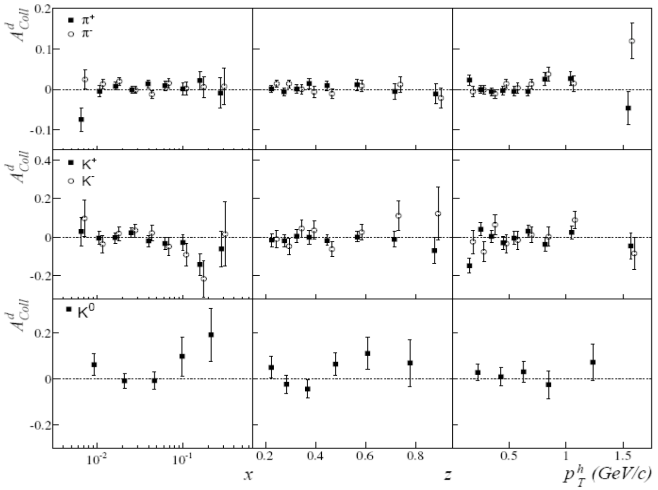
CLAS will allow measurements of transverse spin distributions and constrain Collins fragmentation function

Some observations on Sivers and Collins asym.

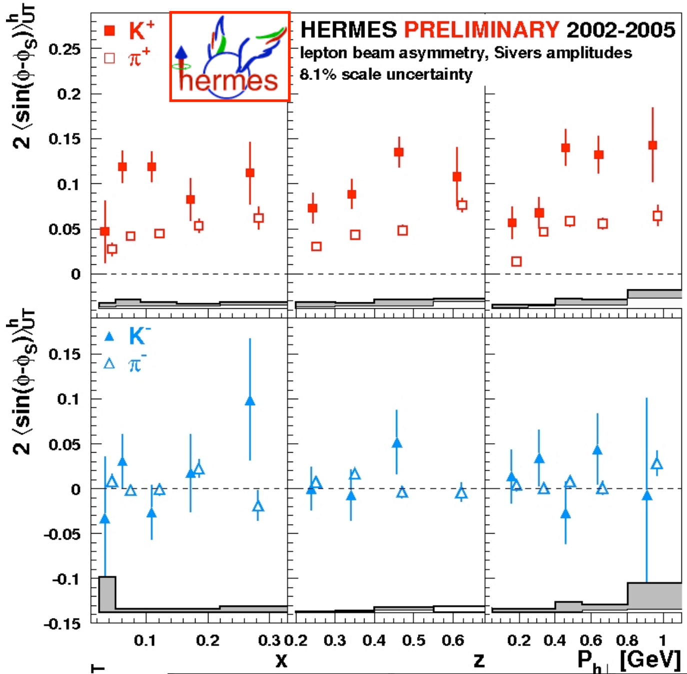
Deuteron

PLB 673 (2009) 127





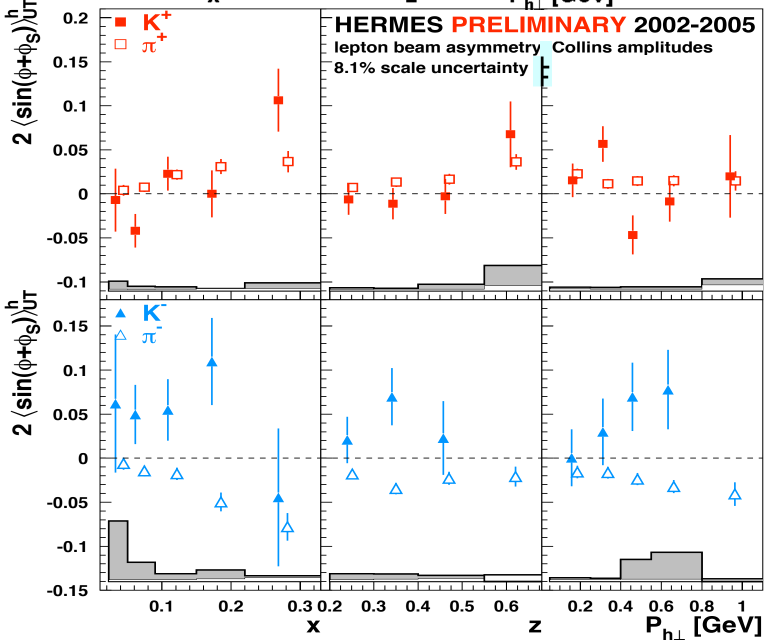
Sivers and Collins Asymmetries compatible with zero for both positive and negative π and K



- Significantly positive K $^+$moments
- K^- moments consistent with zero
- K^+ amplitude > π^+ amplitude

  Unexpected from u-quark dominance

$\pi^+ \equiv (u, \bar{d})$ $\quad K^+ \equiv (u, \bar{s})$



- K^+ and π^+ asymmetries consistent within error bars
- K^- and π^- asymmetries may have opposite sign

.....The Outcome

Crucial to provide additional data

- for pion and kaon
- in a broad kinematical range and large x
- with high statistics
- for both H and D target

→ CLAS12 program

E12-06-112: **Probing the Proton's Quark** Dinamics in Semi-Inclusive Pion Production at 12 GeV

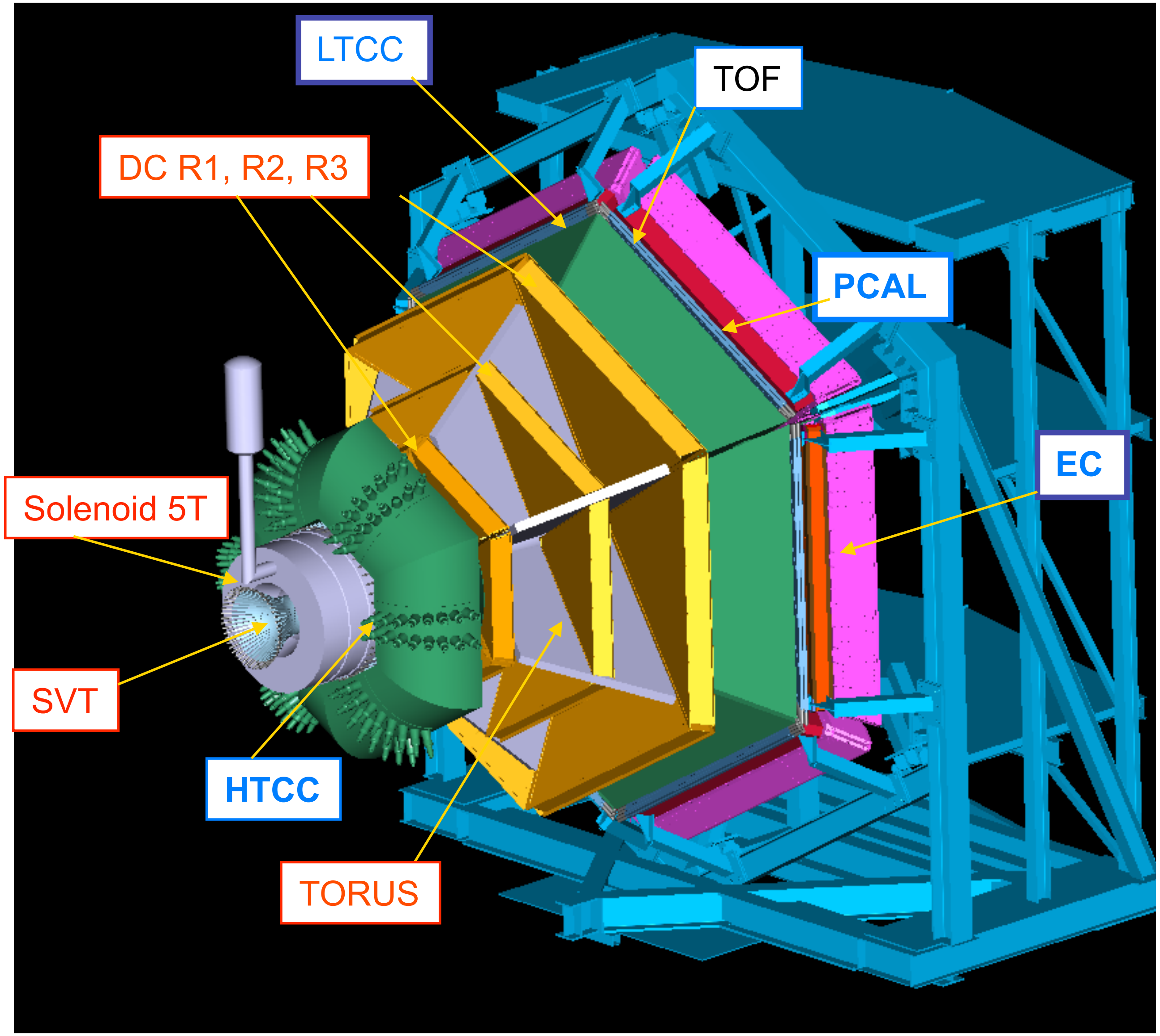
E12-07-107: **Studies** Studies of Spin-Orbit Correlations with Longitudinally Polarized Target (**Pion**)

E12-09-008: **Studies of the Boer-Mulders asymmetry in Kaon electroproduction with hydrogen and deuterium targets**

E12-09-009: **Studies of spin-orbit correlations in Kaon electroproduction in DIS with longitudinally polarized hydrogen and deuterium targets**

LOI12-09-004: **Transverse Spin Effects in Kaon SIDIS w/ transversely polarized target**

CLAS12



Wide detector and physics acceptance

High beam polarization 85%

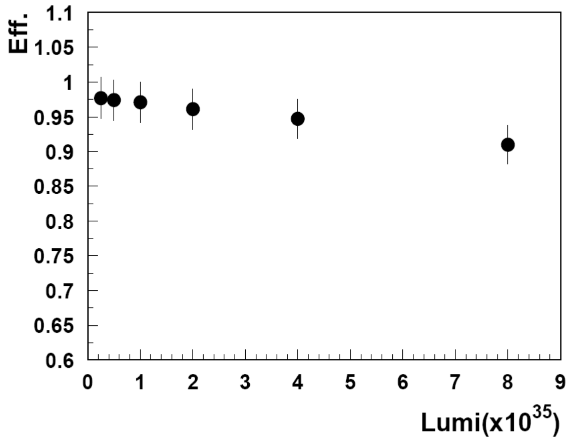
High target polarization 85%

NH_3,ND_3 targets

Track resolutions:

δp (GeV/c)		**0.003p + 0.001p²**
δθ (mr)	<	**1**
δϕ (mr)	<	**3**

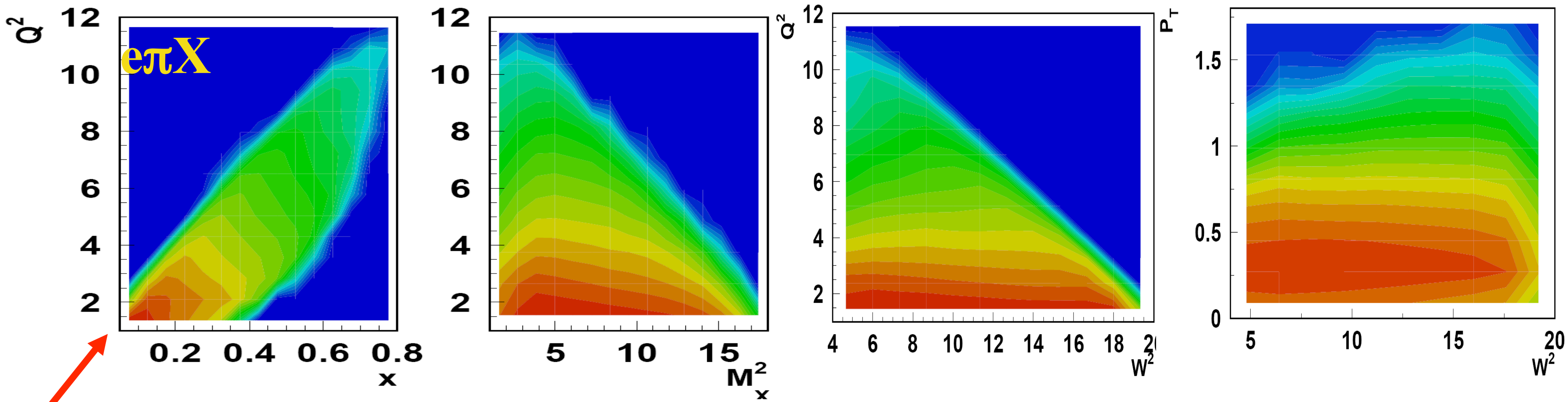
Lumi > 10^{35}cm^{-1}s^{-1}



CLAS12: Kinematical coverage

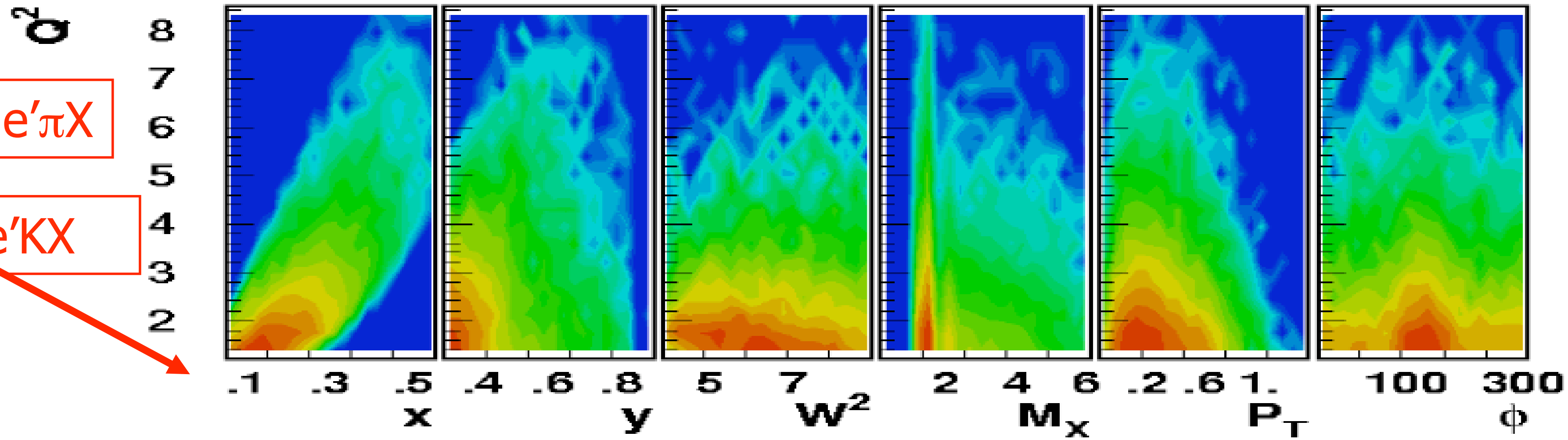
SIDIS kinematics

$Q^2 > 1 GeV^2$; $W^2 > 4 GeV^2 (10)$; $y < 0.85$; $M_X > 2 GeV$



ep → e′πX

ep → e′KX

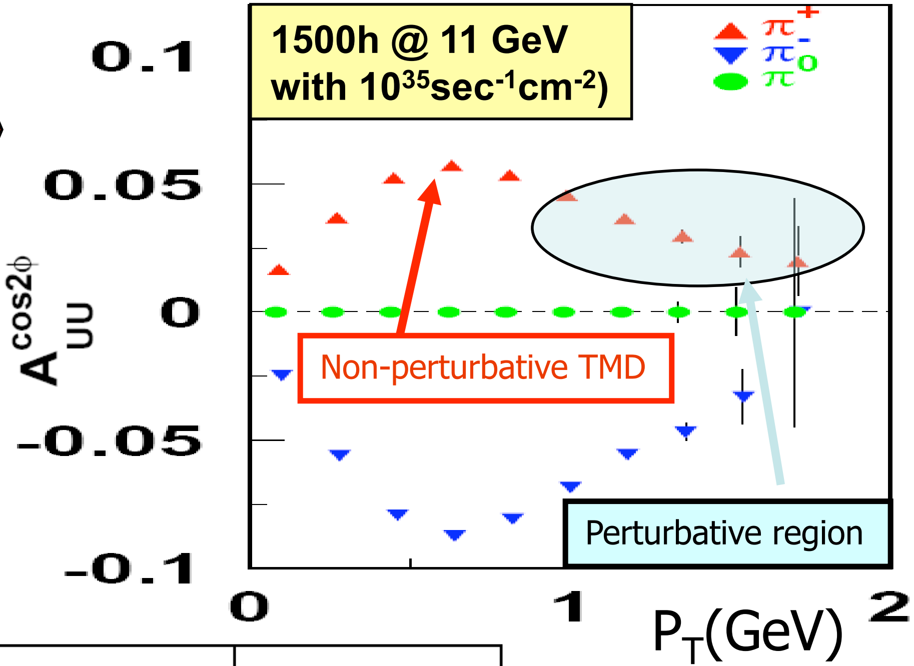


Large Q^2, M_X, and P_T accessible with CLAS12 are important for separation of Higher Twist contributions

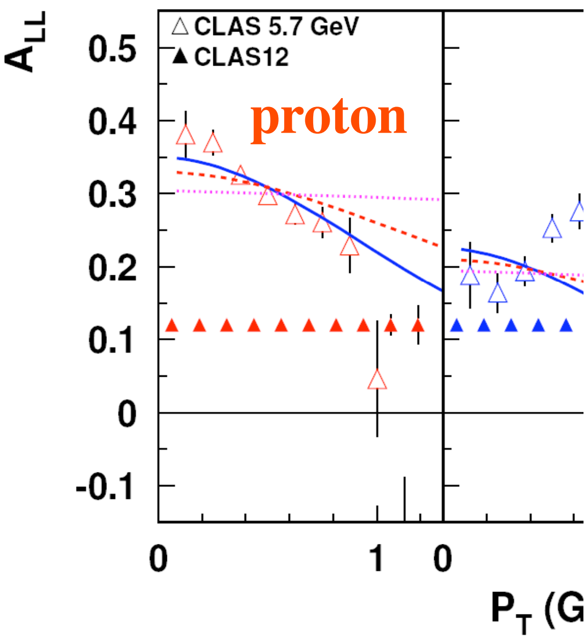
π SIDIS at 12 GeV

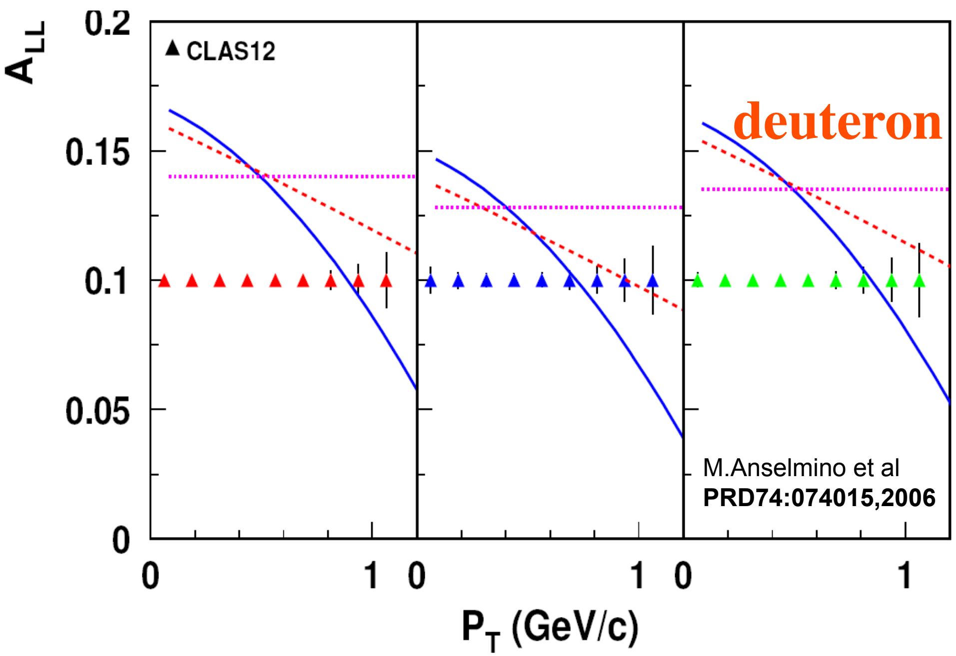
N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	$h_1 \; h_{1T}^\perp$

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



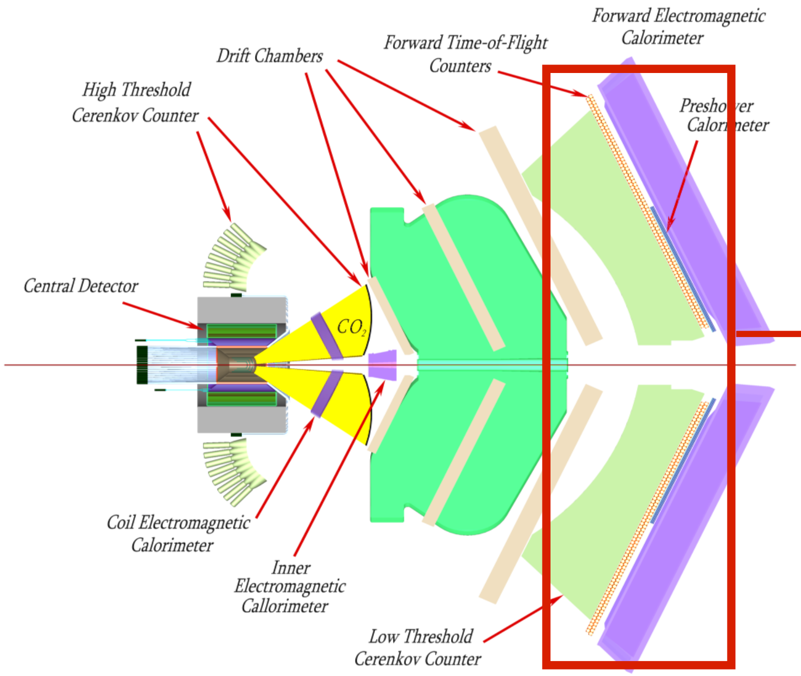
$$A_{LL} \propto \frac{g_1}{f_1} \; ; \; A_{UL}^{\sin 2\phi} \sim h_{1L}^\perp H_1^\perp$$



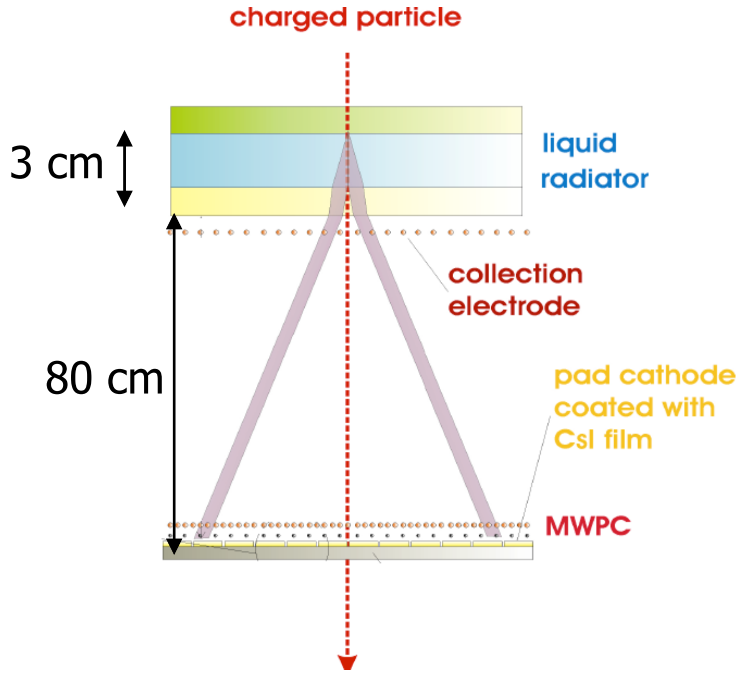


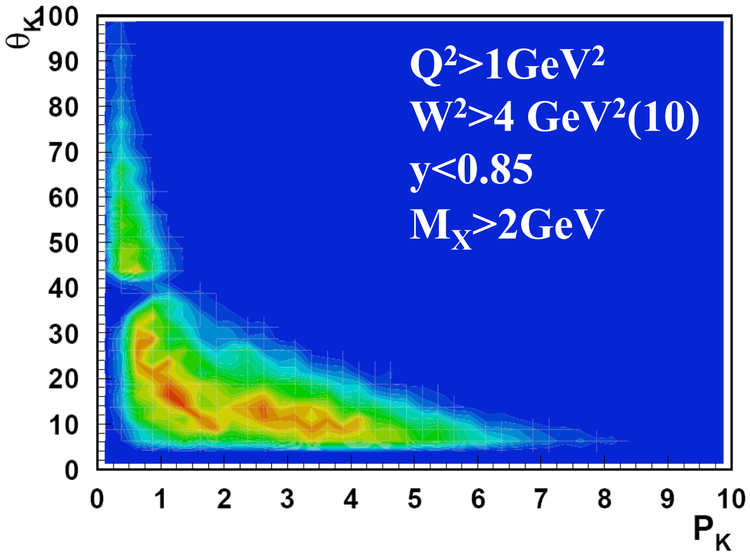
2000h @ 11 GeV
with 10^{35}sec^{-1}cm^{-2})

Kaon SIDIS at 12 GeV



Replace 2 sectors of LTCC with a proximity RICH detector





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<tr><th>GeV/c</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th></tr>
<tr><td rowspan="3">π/K</td><td colspan="2">TOF</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">LTCC</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="5">HTCC</td></tr>
<tr><td rowspan="3">π/p</td><td colspan="5">TOF</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="8">LTCC</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="5">HTCC</td></tr>
<tr><td rowspan="2">K/p</td><td colspan="4">TOF</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">LTCC</td></tr>
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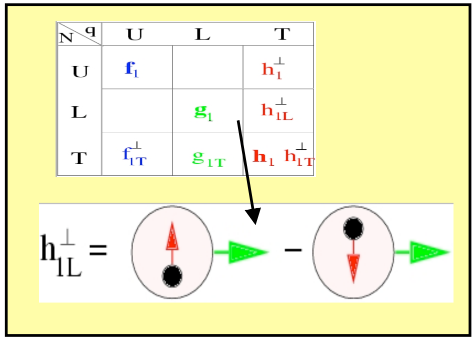
Longitudinally polarized target: Collins fragmentation

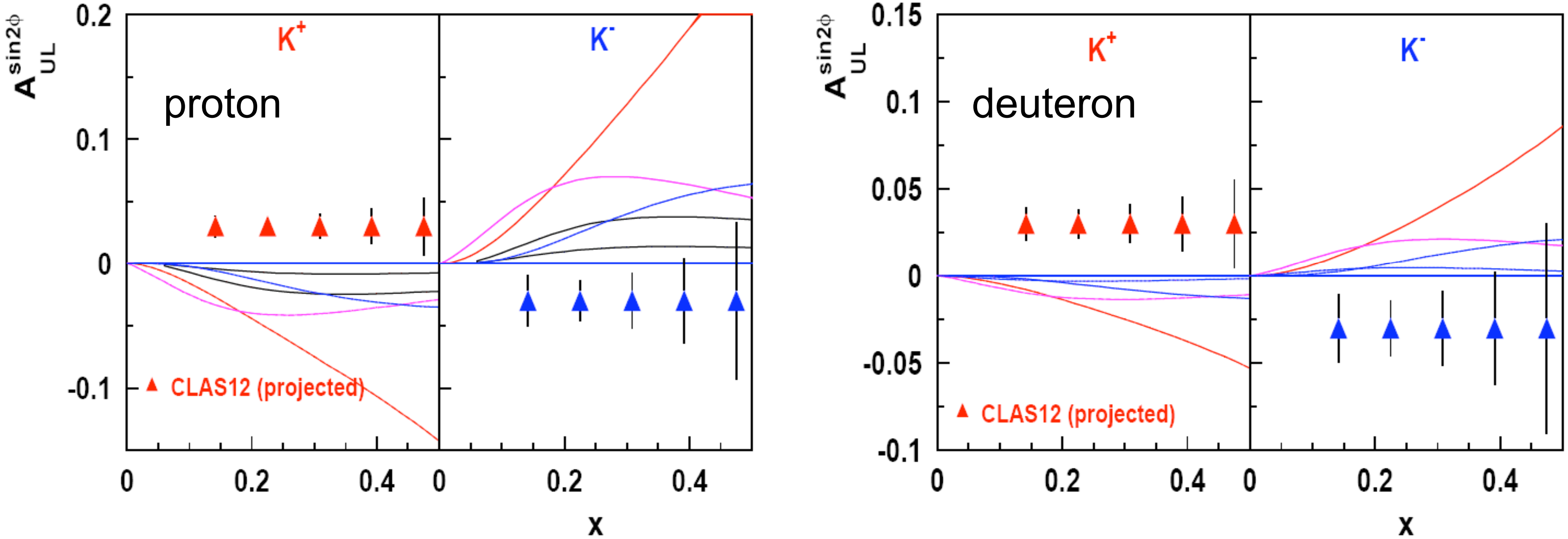


Kotzinian-Mulders Asymmetry

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

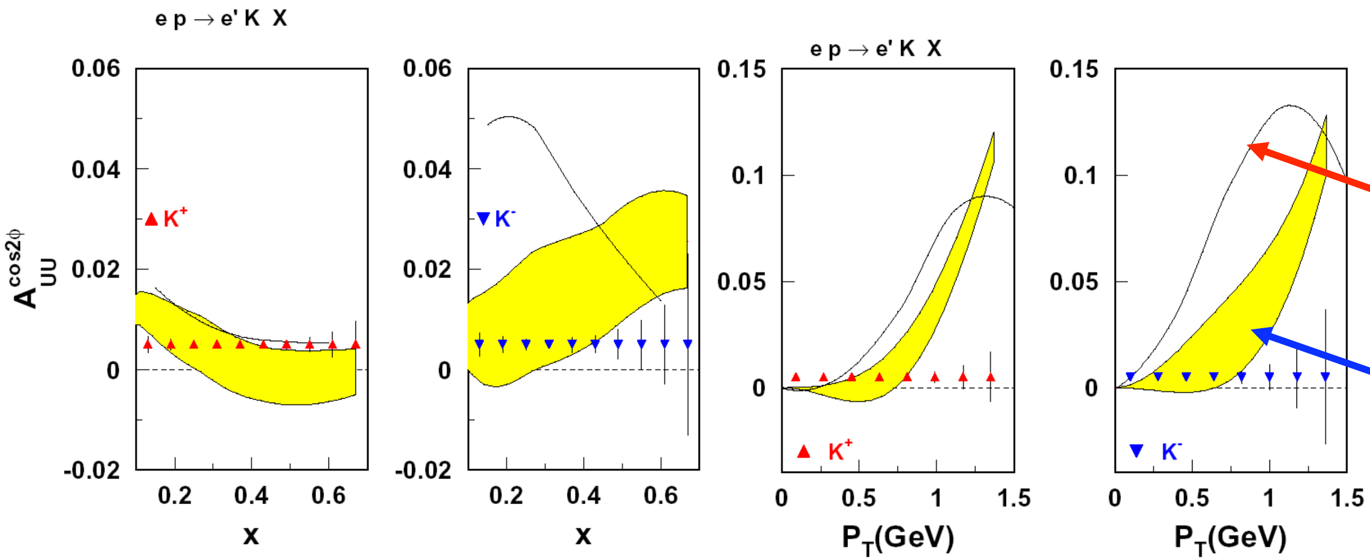
$$K^+ \sim u\bar{s} \quad K^- \sim s\bar{u}$$

30 days NH_3
50 days ND_3
(including about 20% overhead)



- Study the Collins function of kaons
- Provides independent information on the Kotzinian-Mulders TMD

Boer-Mulders kaon asymmetry

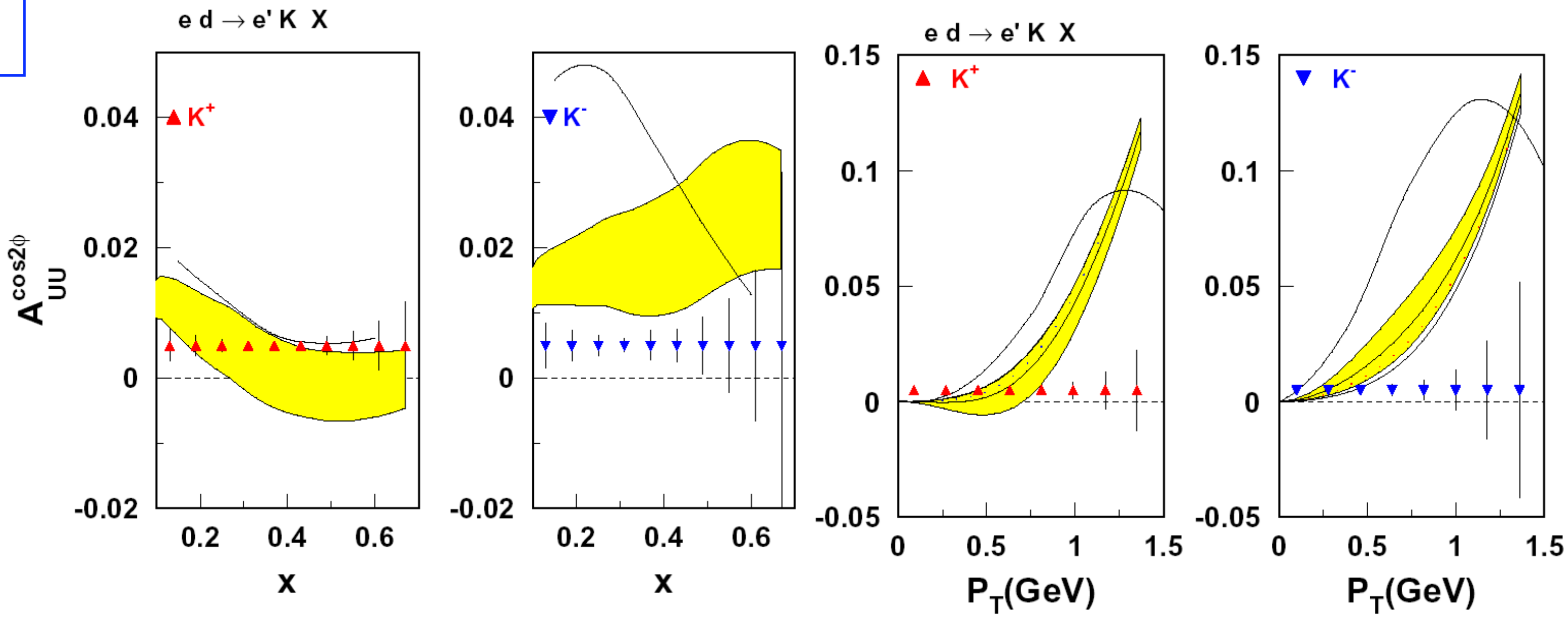


Line: **Phys Rev D78 045022**
Boer-Mulders from Sivers
Collins from e+e- data

Band: **Phys Rev D78 034035**
Boer-Mulders from DY data
Collins from chiral limit

56 days at
L=1x10^{35} cm^{-2}s^{-1}

Excellent precision vs model uncertainties



Conclusions

- Studies of the spin-structure of the nucleon is one of the main driving forces behind the upgrade of Jefferson Lab

- Correlation of spin and transverse momentum of partons is crucial in understanding of the nucleon structure in terms of quark and gluon degrees of freedom of QCD

- The data from CLAS with unpolarized, longitudinally and transversely polarized targets will provide a COMPLETE set of measurements required for the separation of all 8 leading-twist TMDs in the valence region, providing important information on spin-orbit correlations

- JLab12 with

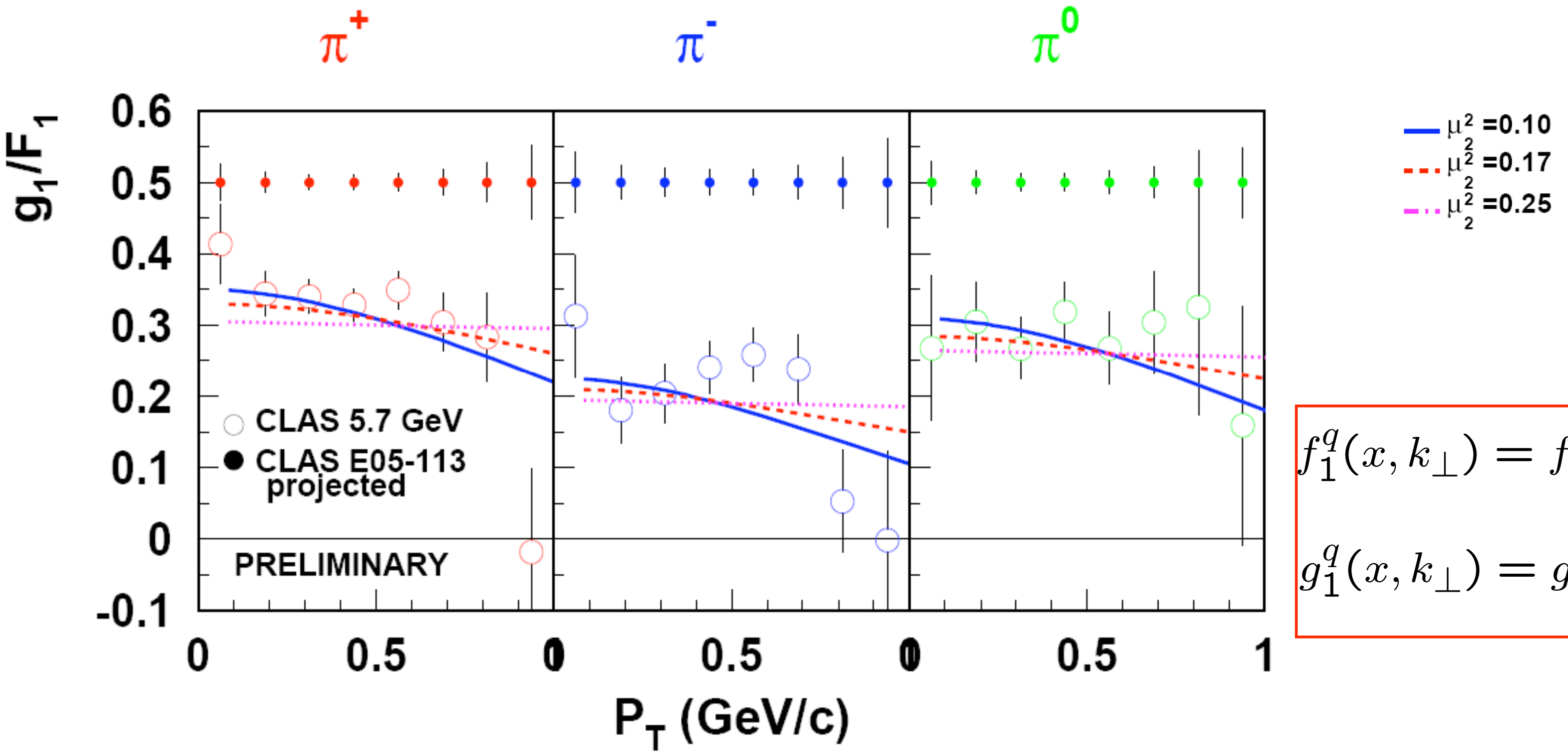
  ☆ wide kinematic coverage
  ☆ high luminosity
  ☆ high polarization

  is essential for high precision measurements of 3D PDFs in the valence region

A_{LL} P_T-dependence in SIDIS - E05-113

$$A_{LL}(\pi) \propto \frac{\sum_q e_q^2 g_1^q(x) D_1^{q\to\pi}(z)}{\sum_q e_q^2 f_1^q(x) D_1^{q\to\pi}(z)}\, e^{-z^2 P_T^2 \frac{(\mu_0^2-\mu_2^2)}{(\mu_D^2+z^2\mu_0^2)(\mu_D^2+z^2\mu_2^2)}}$$

M.Anselmino et al
hep-ph/0608048



μ_0^2=0.25GeV^2
μ_D^2=0.2GeV^2

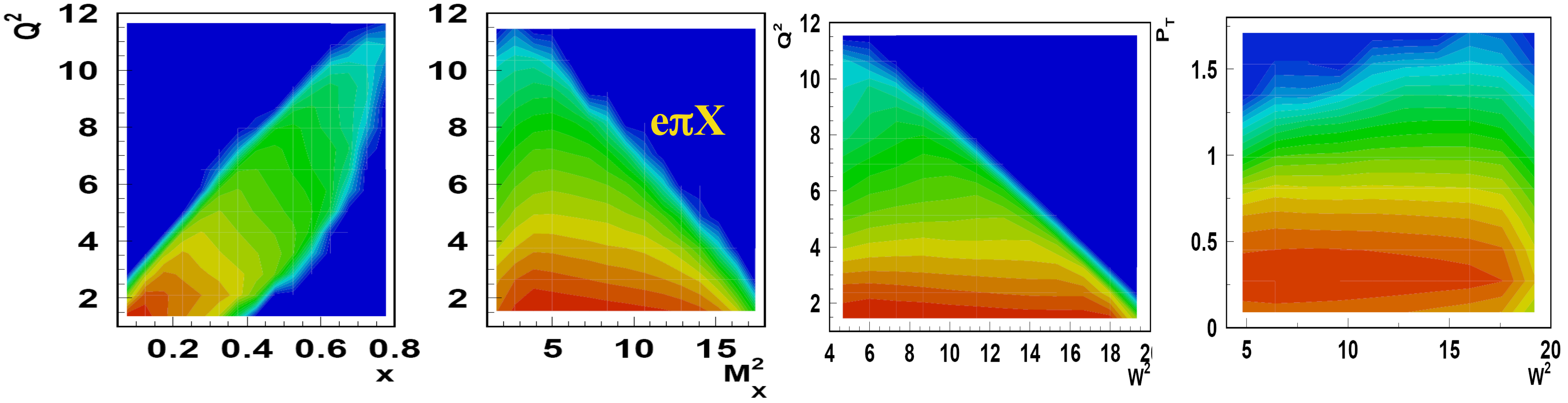
0.4<z<0.7

$$f_1^q(x,k_\perp) = f_1^q(x)\frac{1}{\pi\mu_0^2}exp(-\frac{k_\perp^2}{\mu_0^2})$$

$$g_1^q(x,k_\perp) = g_1^q(x)\frac{1}{\pi\mu_2^2}exp(-\frac{k_\perp^2}{\mu_2^2})$$

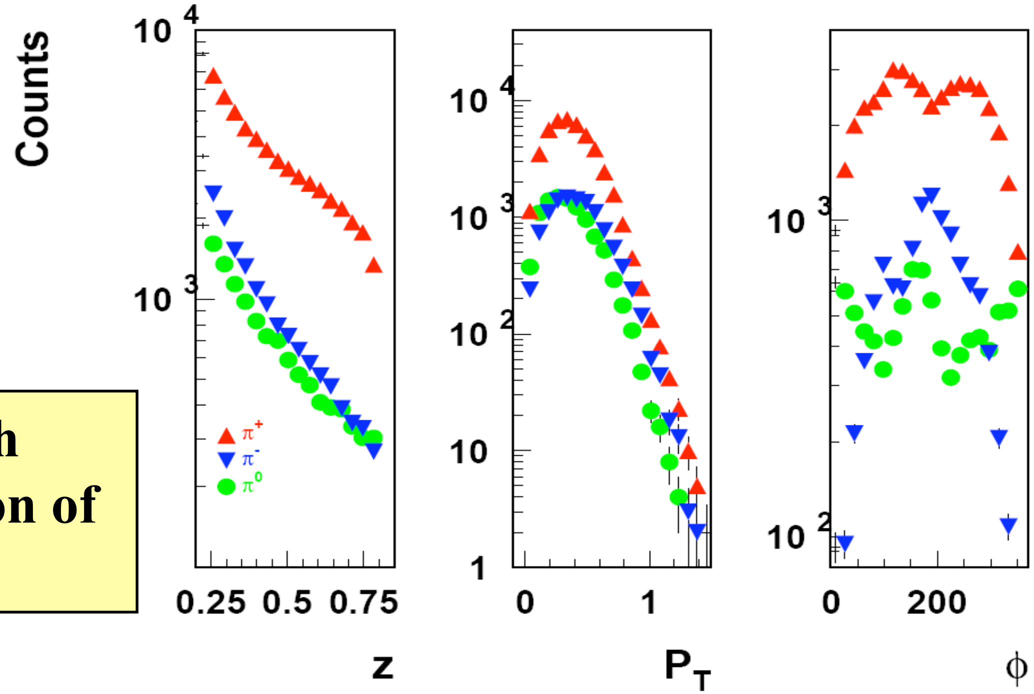
- **Data shows slight preference for $\mu_0 < \mu_2$**
- **New experiment with 10 times more data will study the P_T-dependence for different quark helicities and flavors for bins in x**

CLAS12: Kinematical coverage



SIDIS kinematics

Q^2>1GeV²
W^2>4 GeV²(10)
y<0.85
M_X>2GeV



Large Q^2, M_X, and P_T accessible with CLAS12 are important for separation of Higher Twist contributions