Transverse spin effects in SIDIS at 11 GeV with transversely polarized target using the CLAS12 detector

(A CLAS12 experiment proposal for PAC39)

Contalbrigo Marco
INFN Ferrara

JLab PAC 39 – Open session
June 18, 2012 Newport News

A CLAS12 Proposal For PAC38

H. Avakian[1], S. Boyarinov, V.D. Burkert, A. Deur, L. Elouadrhiri, T. Kageya,
V. Kubarovsky, M. Lowry, B. Musch, A. Prokudin, A. Sandorfi, Yu. Sharabian, S. Stepanyan, X.Wei
Jefferson Lab, Newport News, VA 23606, USA

F. Klein[1]
Department of Physics, The Catholic University of America, Washington, DC 20064, USA

M. Aghasyan[1], E. De Sanctis, D. Hasch, L. Hovsepyan, V. Lucherini
M. Mirazita, and S. Anefalos Pereira, S. Pisano, P. Rossi
LNF INFN, Frascati, I-00044, Rome Italy

K. Joo[1], N. Markov, M. Ungaro
University of Connecticut, Storrs, CT 06269, USA

L. Barion, G. Ciullo, M. Contalbrigo[1,2], P.F. Dalpiaz, P. Lenisa, L.L. Pappalardo, M. Statera
University of Ferrara and INFN Ferrara, Via Saragat, I-44100, Ferrara, Italy

G. De cataldo, R. De Leo, L. La Gamba, E. Nappi
University of Bari and INFN Bari, Via Orabona, I-70125, Bari, Italy

M. Battaglieri, A. Celentano, R. De Vita, M. Osipenko, G. Ricco, M. Ripani, M. Taiuti
INFN Genova, Via Dodecaneso, 33 I-16146 Genova, Italy

Y. Prok
Christopher Newport University

K. Griffioen
College of William & Mary, 23187, USA

V. Bellini, A. Giusa, F. Mammoliti, R. Potenza, G. Russo, L. Sperduto, C. Sutera
University of Catania and INFN Catania, Via S. Sofia, I-95123 Catania, Italy

R. Perrino
INFN Lecce, Via Arnesano, I-73100 Lecce, Italy

K. Hafidi, J. Arrington, L. El Fassi, D. F.Geesaman, R. J. Holt,
D. H. Potterveld, P. E. Reimer, P. Solvignon
Argonne National Lab, Argonne, IL 60439, USA

J. Ball, A. Fradi, M. Garçon, M. Guidal, S. Niccolai, F. Sabatié
IPNO (Orsay), SPhN (Saclay) France

M. Amarian, G. Dodge, G. Gavalian Old Dominion University, Norfolk, VA 2

A. D'Angelo, C. Schaerf, I. Zonta
Dipartimento di Fisica, Universita' di Roma Tor Vergata,
INFN Sezione di Roma Tor Vergata, Via della Ricerca Scientifica, I-00133, Ro

A. Biselli
Fairfield University, Fairfield CT 06824, USA

F. Meddi, G.M. Urciuoli
INFN Roma I, P.le aldo Moro, I-00185, Roma, Italy

E. Cisbani, A. Del Dotto, F. Garibaldi, S. Frullani
INFN Roma I and Istituto Superiore di Sanita', Viale Regina Elena, I-00161, Roma, Italy

M. Capogni
INFN Roma I and ENEA Casaccia, Via Anguillarese, I-00123, Roma, Italy

A. Puckett Los Alamos National Laboratory, Los Alamos, NM 87545, USA

M. Anselmino, A. Kotzinian, B. Parsamyan,
Università di Torino and INFN, Sezione di Torino, Via P. Giuria 1, I-10125 Torino

A. Bacchetta, A. Courtoy, M. Radici, B Pasquini
Universita' di Pavia and INFN Sezione di Pavia, via Bassi 6, 27100 Pavia, Italy

M. Anselmino, A. Kotzinian, B. Parsamyan
Università di Torino and INFN, Sezione di Torino, Via P. Giuria 1, I-10125 Torino

L. Gamberg
Penn State Berks, Reading, PA 19610, USA

---

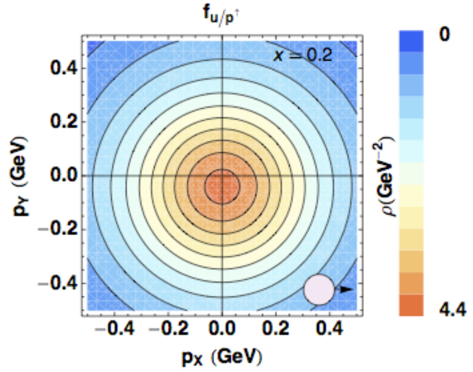
[1] Co-spokesperson
[2] Contact person

PHYSICS MOTIVATIONS

Quantum phase-space distributions of quarks

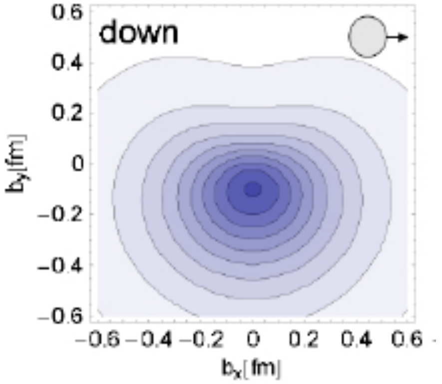
$W_p^q(x,k_T,r)$ “Mother” Wigner distributions

Probability to find a quark q in a nucleon P with a certain polarization in a position r & momentum k



d^3r

d^2k_T (FT)



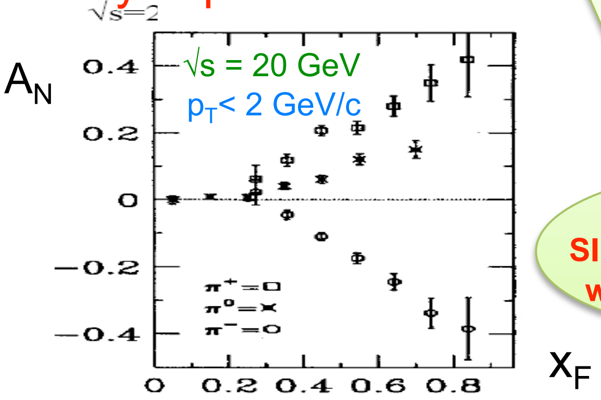
TMD PDFs: $f_p^u(x,k_T)$,…

Semi-inclusive measurements
Momentum transfer to quark
Direct info about momentum distribution

GPDs: $H_p^u(x,\xi,t)$, …

Exclusive Measurements
Momentum transfer to target
Direct info about spatial distribution

May explain SSA



d^2k_T

ξ=0,t=0

PDFs $f_p^u(x)$,…

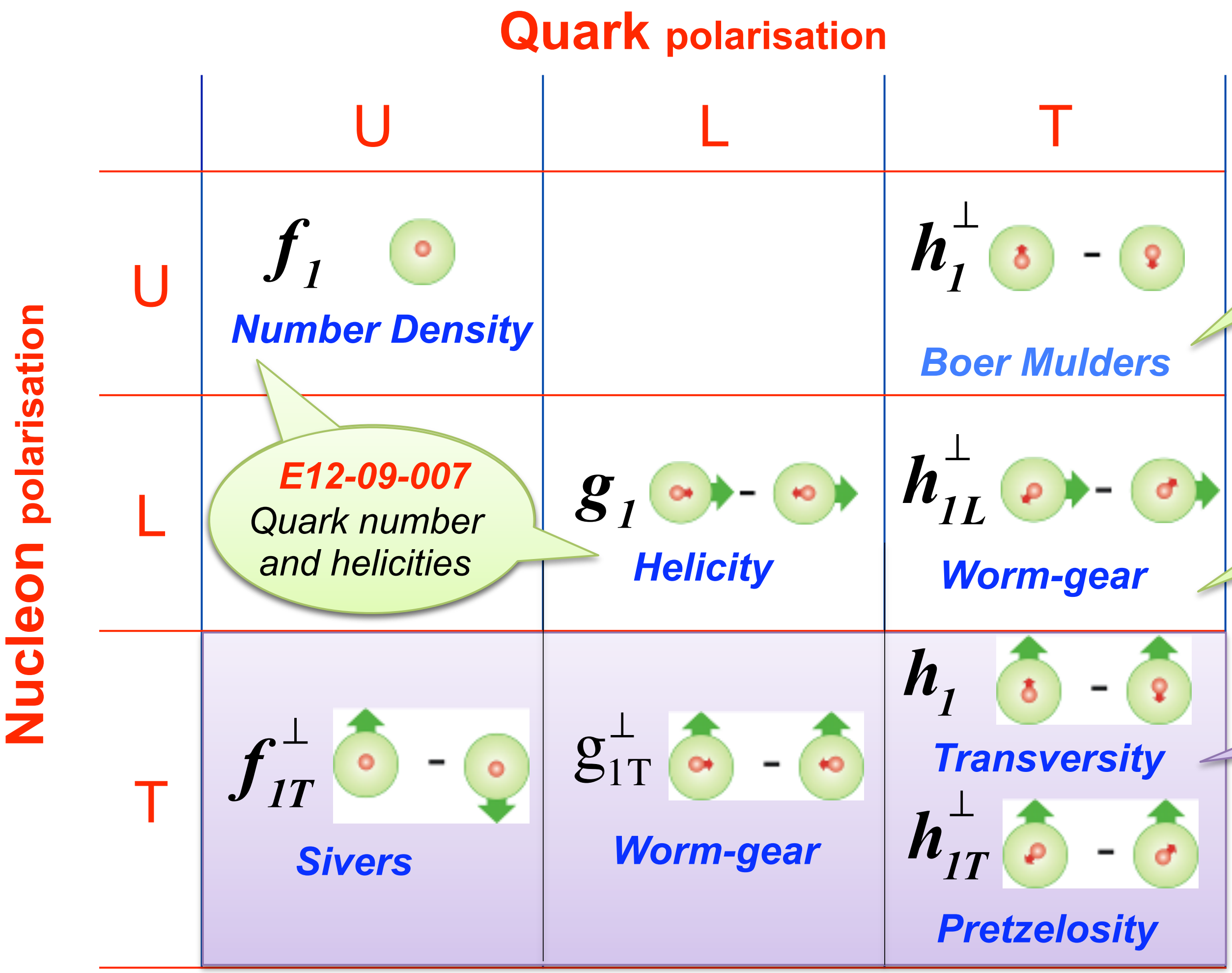
PR 12-105
SIDIS Physics: di-hadron with Transverse Target

PR 12-105
Exclusive Physics: DVCS with Transverse Target

May solve
proton spin puzzle

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \lim_{t\to 0}\int_{-1}^{1} dx\ x\left[H(x,\zeta,t)+E(x,\zeta,t)\right]$$

Leading Twist TMDs



Quark polarisation

Nucleon polarisation

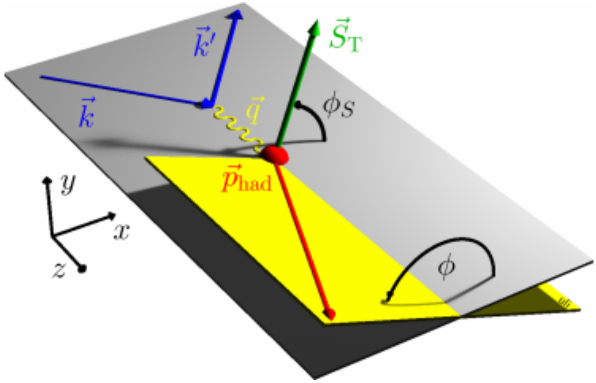
	U	L	T
U	f_1 *Number Density*		$h_1^{\perp}$ *Boer Mulders*
L		g_1 *Helicity*	$h_{1L}^{\perp}$ *Worm-gear*
T	$f_{1T}^{\perp}$ *Sivers*	$g_{1T}^{\perp}$ *Worm-gear*	h_1 *Transversity* $h_{1T}^{\perp}$ *Pretzelosity*

E12-09-007
Quark number and helicities

E12-06-112
E12-09-008
Boer-Mulders for pions and kaons

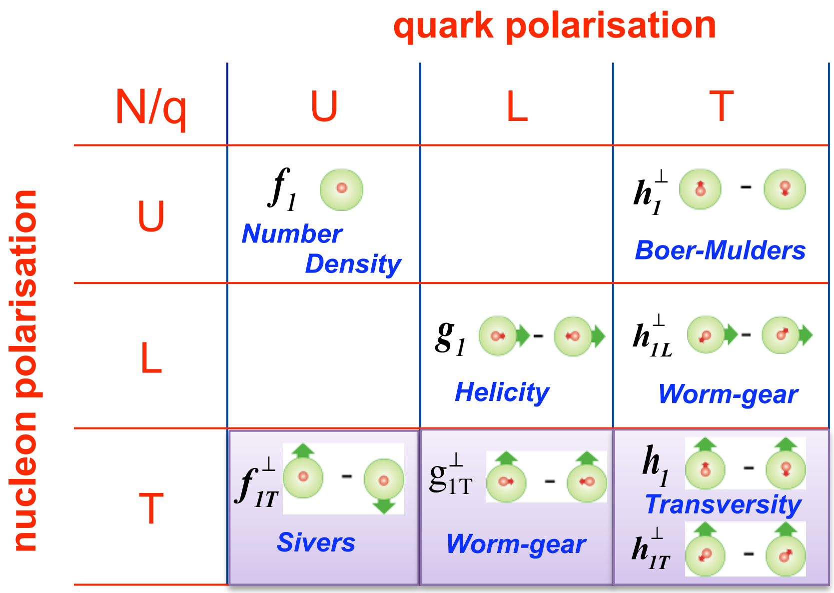
E12-07-107
E12-09-009
Spin-effects for pions and kaons

C12-11-111
This proposal



CLAS12 has access to all of them through specific azimuthal modulations (ϕ, ϕ_S) of the cross-section thanks to the polarized beam and target

Leading Twist TMDs



quark polarisation

nucleon polarisation

N/q	U	L	T
U	f_1 **Number Density**		$h_1^\perp$ - **Boer-Mulders**
L		g_1 - **Helicity**	$h_{1L}^\perp$ - **Worm-gear**
T	$f_{1T}^\perp$ - **Sivers**	$g_{1T}^\perp$ - **Worm-gear**	h_1 - **Transversity** $h_{1T}^\perp$ -

Transversity:

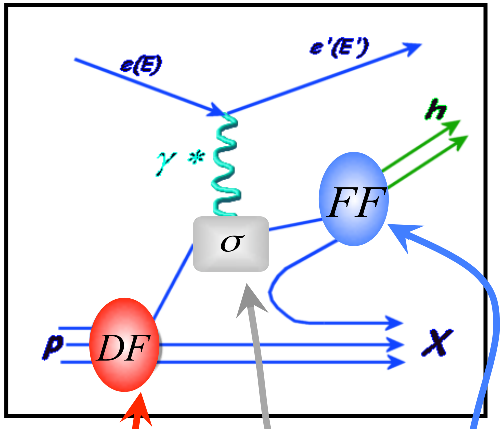
Survives transverse momentum integration (missing leading-twist collinear piece)

Differs from helicity due to relativistic effects and no mix with gluons in the spin-1/2 nucleon

Wants multidimensional approach to investigate factorization and transverse momentum dependence

Other elements:

Interference between wave functions with different angular momenta: contains information about parton orbital angular motion and spin-orbit effects



$$\sigma^{ep\to ehX} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$

$h_1 \otimes H_1^\perp$

$$\frac{d^6\sigma}{dx\,dy\,dz\,d\phi_S d\phi\,dP_{h\perp}^2} \underset{\text{Twist}}{\overset{\text{Leading}}{\propto}} S_T\left\{\sin(\phi-\phi_S)F_{UT,T}^{\sin(\phi-\phi_S)}\right\}$$

$f_{1T}^\perp \otimes D_1$

$h_{1T}^\perp \otimes H_1^\perp$

$$+S_T\left\{\varepsilon\sin(\phi+\phi_S)F_{UU}^{\sin(\phi+\phi_S)} + \varepsilon\sin(3\phi-\phi_S)F_{UU}^{\sin(3\phi-\phi_S)}\right\}$$

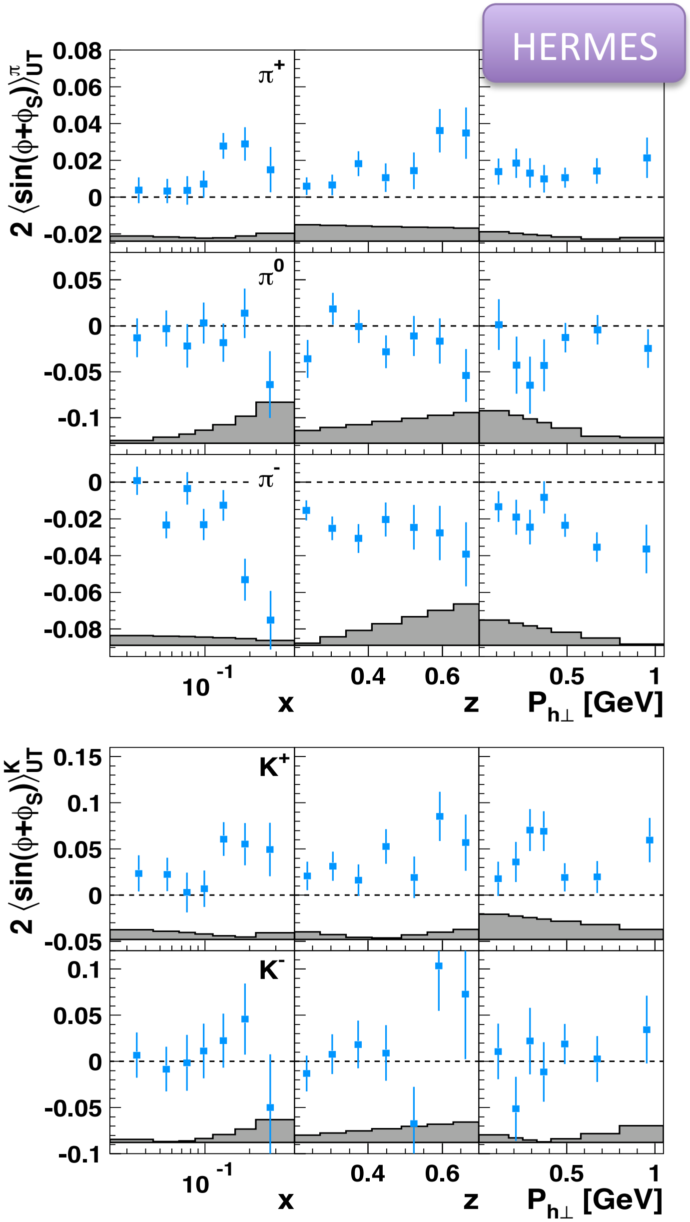
$$+S_T\lambda_e\left\{\sqrt{1-\varepsilon^2}\cos(\phi\ -\phi_S)F_{LT}^{\cos(\phi\ -\phi_S)}\right\}+\dots$$

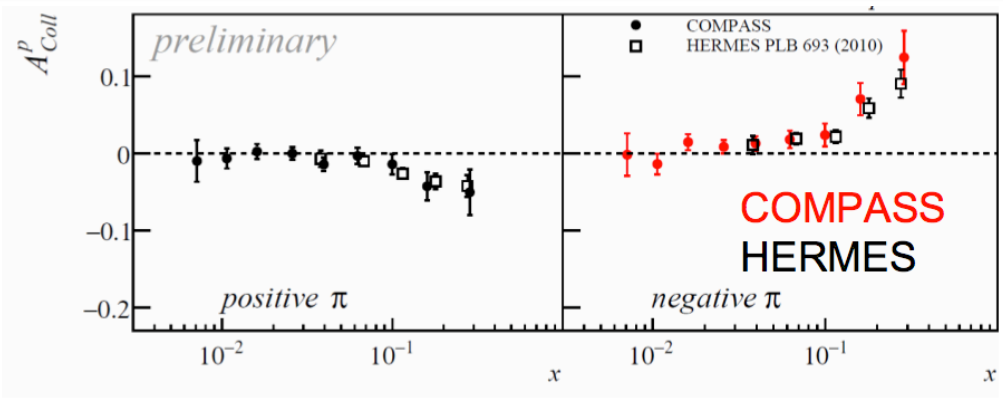
$g_{1T}^\perp \otimes D_1$

The Collins amplitude

$h_1 \otimes H_1^\perp$

HERMES





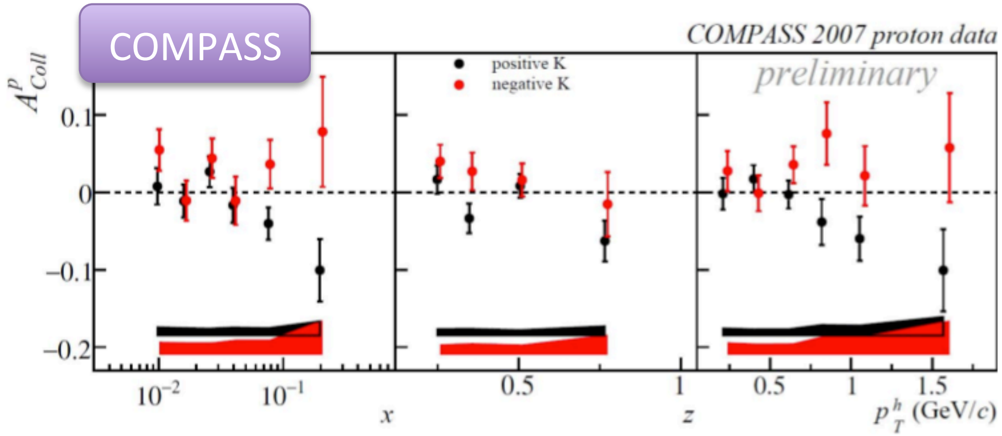
Access to transversity and Collins functions

Consistent non-zero signals for pions

Opposite sign for pions reveal Collins features

Puzzle in (low-statistics) kaon signals:
K^+ amplitudes larger then π^+
K^- amplitudes are not in agreement

COMPASS



Transversity Signals

hermes $lp \rightarrow l' h X$

BELLE $e^+ e^- \rightarrow h_1 h_2 X$

$$A_{UT}^{\sin(\phi+\phi_S)} \propto h_1(x) \otimes H_1^{\perp q}(z)$$

COMPASS $ld \rightarrow l' h X$

hermes COMPASS $lp \rightarrow l' \pi^+ \pi^- X$

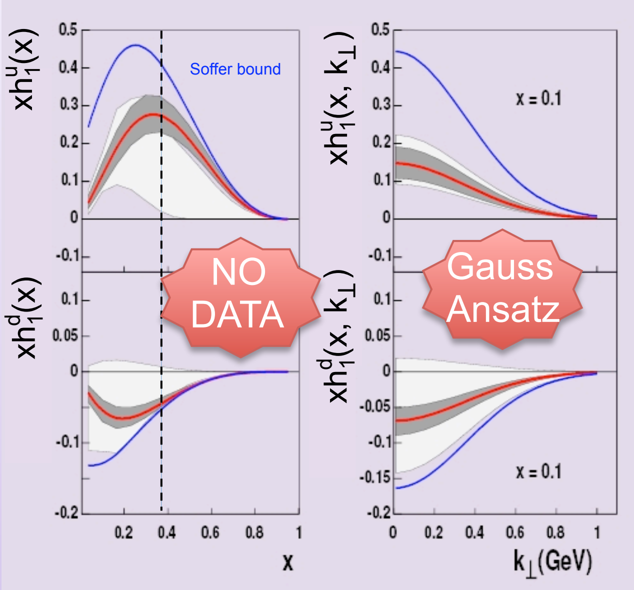
BELLE

$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)} \propto \sin\vartheta\, h_1(x) \otimes H_1^{\triangleleft q}(z)$$

First extractions Role of Q^2 evolution

? High-x and tensor charge

1st extraction of Transversity!

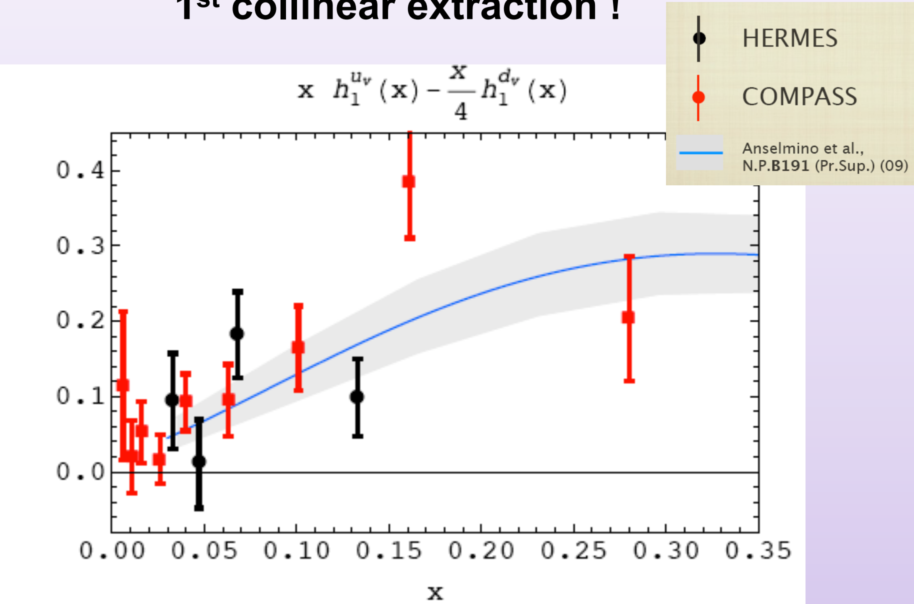


NO DATA

Gauss Ansatz

Anselmino et al. Phys. Rev. D 75 (2007)

1st collinear extraction !

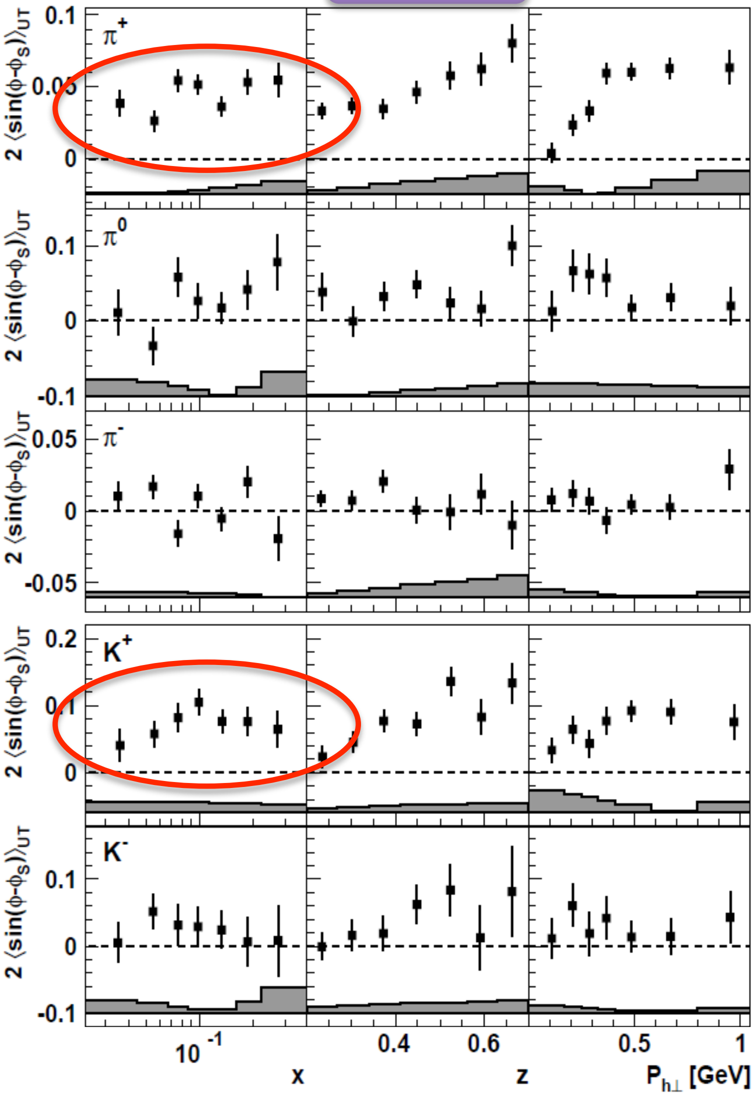


Bacchetta et al., PRL 107 (2011)

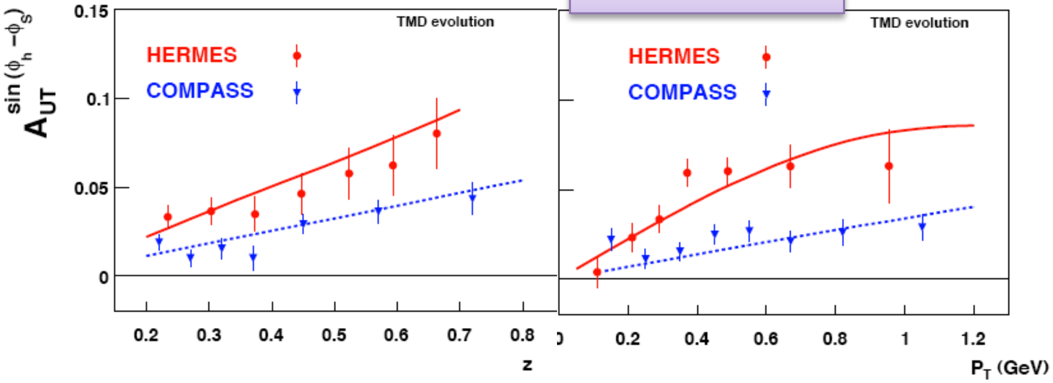
The Sivers effect

$f_{1T}^{\perp} \otimes D_1$

HERMES



arXiv:1112.4423



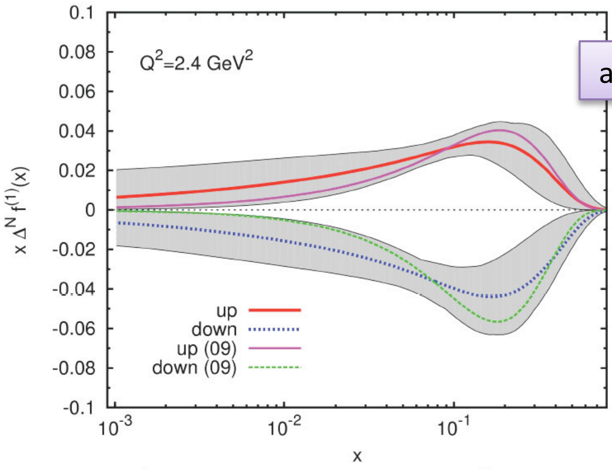
Related to quark orbital angular momentum

Non zero signals for π^+ and K^+

Significant Q^2 evolution ?

K^+ signals larger than π^+

?



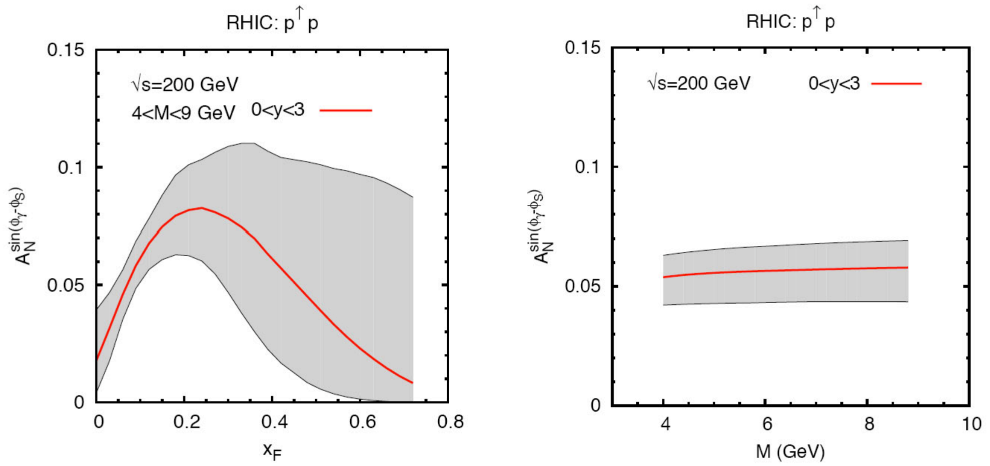
arXiv: 1107.4446

The Sivers effect

$f_{1T}^{\perp} \otimes D_1$

Sivers effect from SIDIS to Drell-Yan

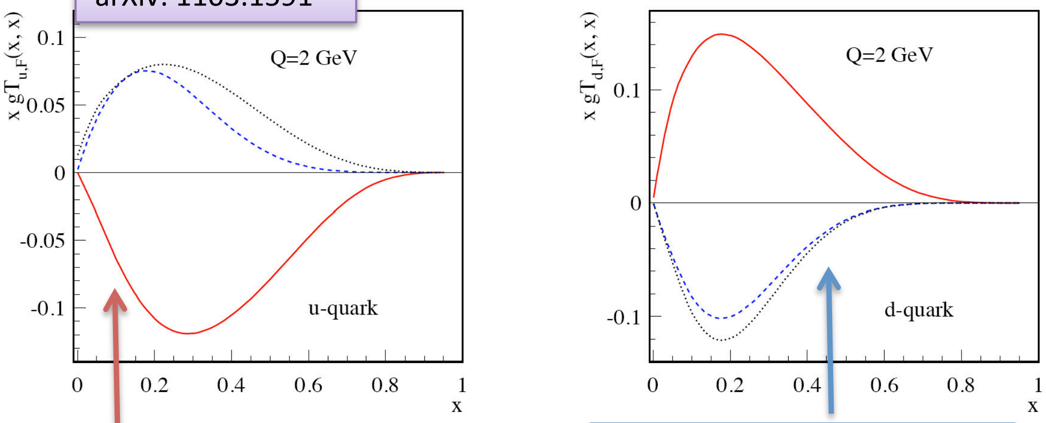
arXiv: 0901.3078



Coverage at large x and relation with Drell-Yan

Sign change is a crucial test of TMDs factorization

arXiv: 1103.1591



T3 correlator from pp

Sivers moment from SIDIS

$$gT_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp|^2}{M} f_{1T}^{\perp q}(x,k_\perp^2)|_{\text{SIDIS}}$$

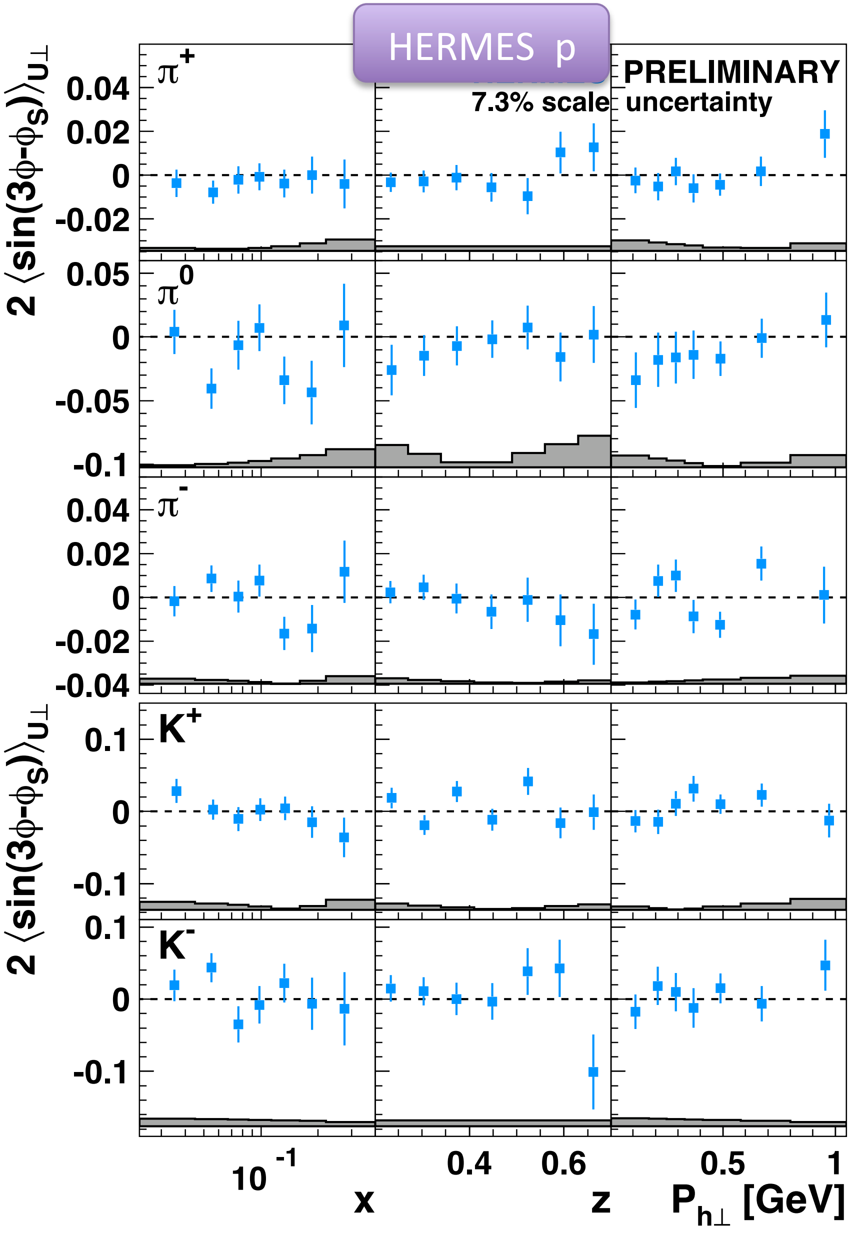
Coverage at large p_T and relation with twist-3 collinear approach

Sign mismatch between SIDIS and pp SSA ?

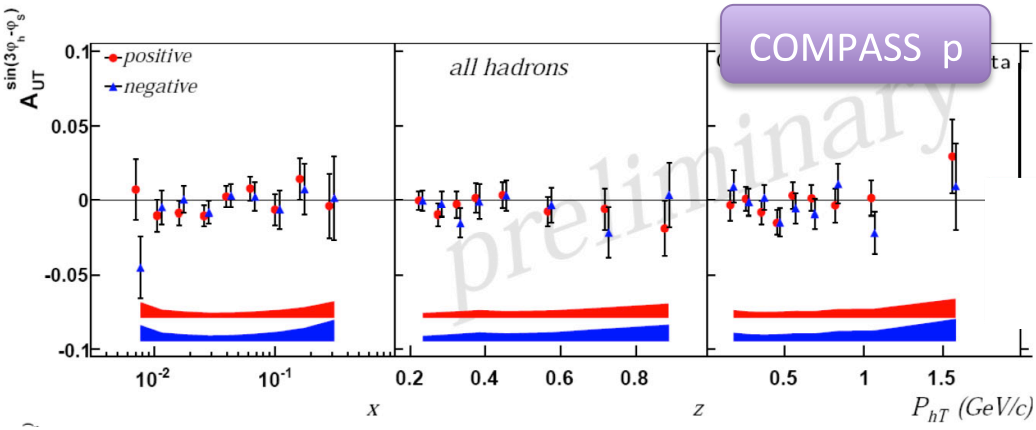
The Pretzelosity

$h_{1T}^{\perp} \otimes H_1^{\perp}$

HERMES p



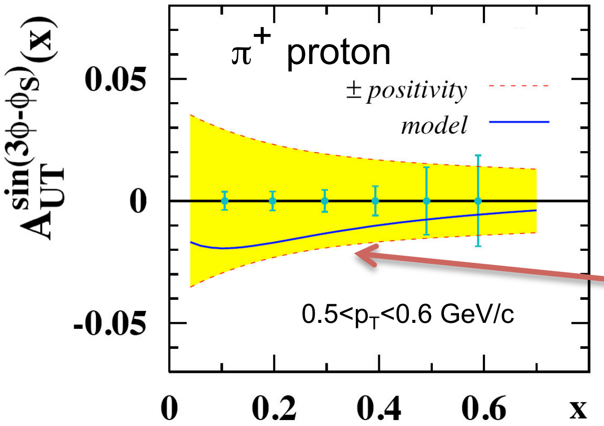
COMPASS p



Sensitive to the D-wave component and the non spherical shape of the nucleon

Statistical power of existing data is not enough to observe significant signals

"pretzelosity" still basically unknown!

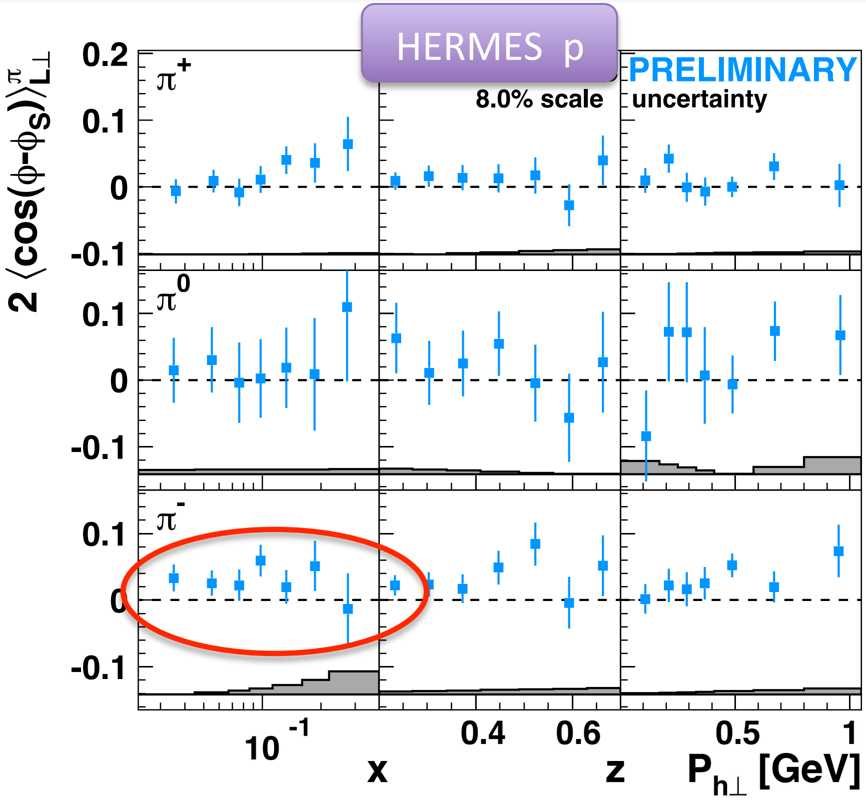


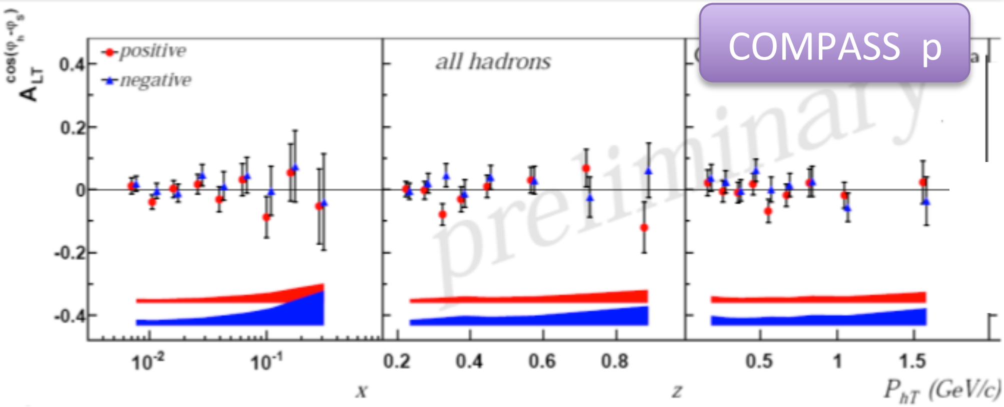
arXiv: 0812.3246

Few % signal expected at Jlab from relativistic covariant model

The Worm-gear function

$g_{1T}^{\perp} \otimes D_1$



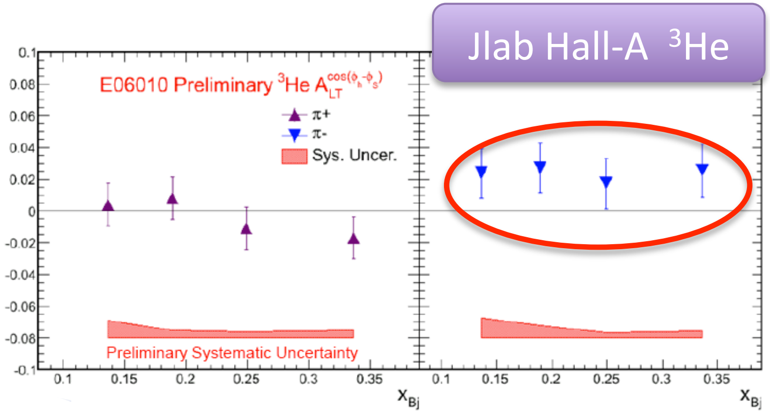


Related to quark orbital motion

Statistics not enough to investigate relations supported by many theoretical models:

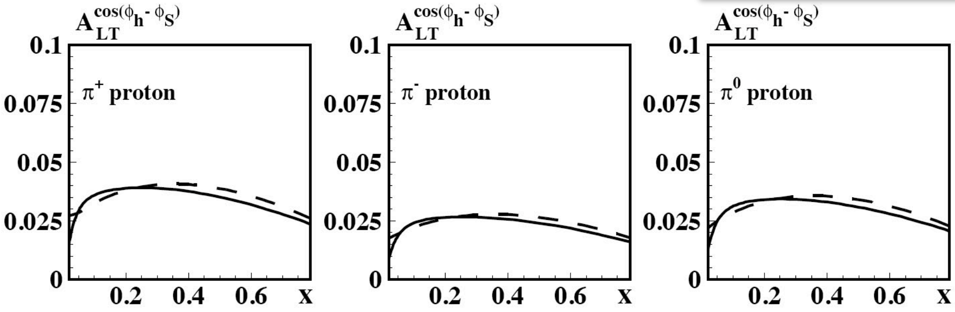
$g_{1T}^{q} = -h_{1L}^{\perp q}$ (supported by Lattice QCD and first data) ?

$g_{1T}^{q(1)}(x) \overset{WW-type}{\approx} x \int_x^1 \frac{dy}{y} g_1^q(y)$ (Wandura-Wilczek type approximation) ?



From constituent quark model:

arXiv: 0903.1271



Honour and Duty

TMDs are a new class of phenomena
providing novel insights into the rich nuclear structure

DIS experiments get access to all PDFs and FFs, but in a convoluted way,
first generation non-zero results provide promises but also open questions

Full coverage of valence region not achieved

Limited knowledge on transverse momentum dependences

Flavor decomposition often missing

Evolution properties to be defined

Role of the higher twist to be quantified

Universality ↔ Fundamental test of QCD

Still incomplete phenomenology is asking for new inputs

Crucial: completeness
flavor tagging and four-fold differential
extraction in all variables (x,z,Q^2,P_T)
to have all dependencies resolved

EXPERIMENTAL SETUP

The CLAS12 Spectrometer

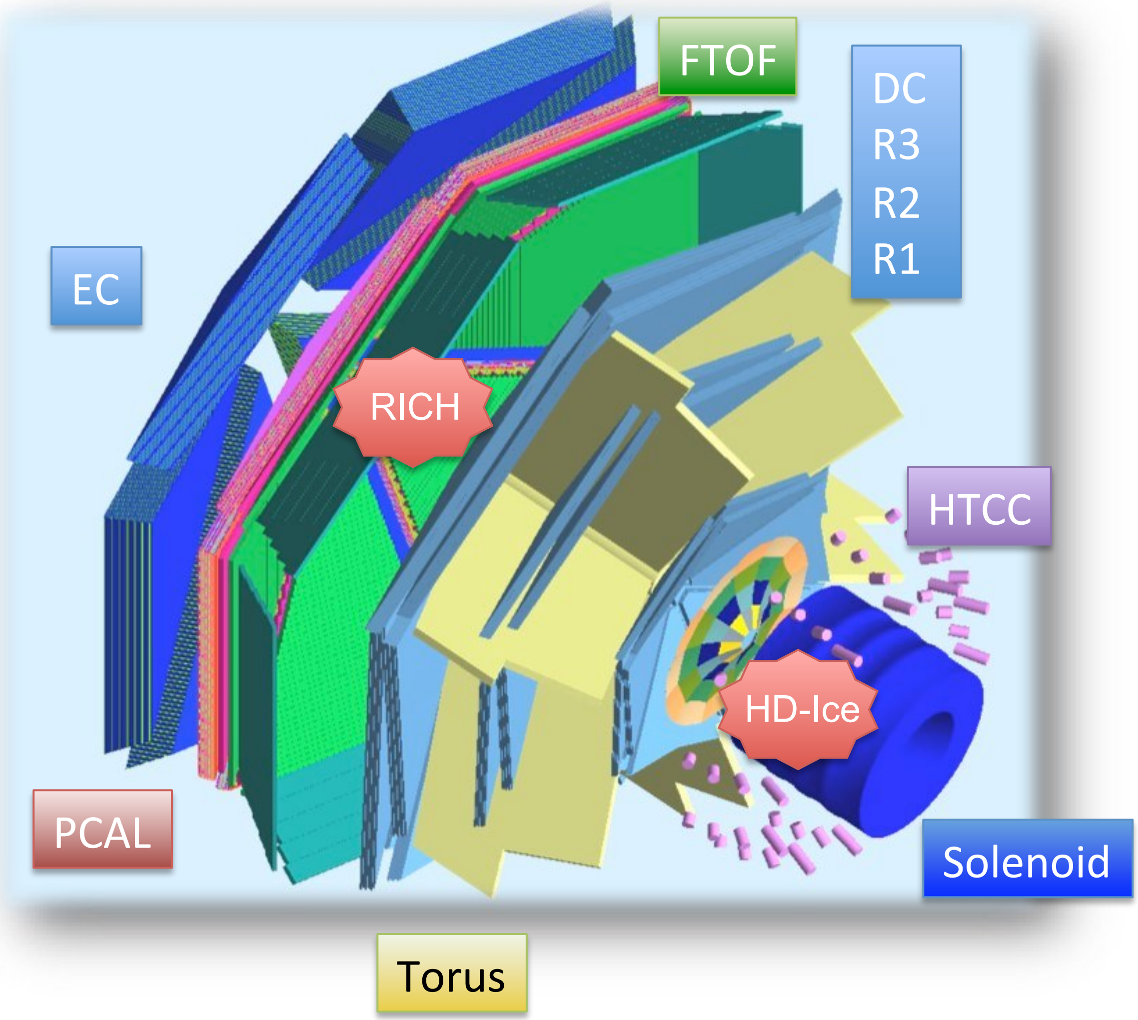
Luminosity up to 10^{35} cm^{-2} s^{-1}

H and D polarized targets

Broad kinematic range coverage
(current to target fragmentation)

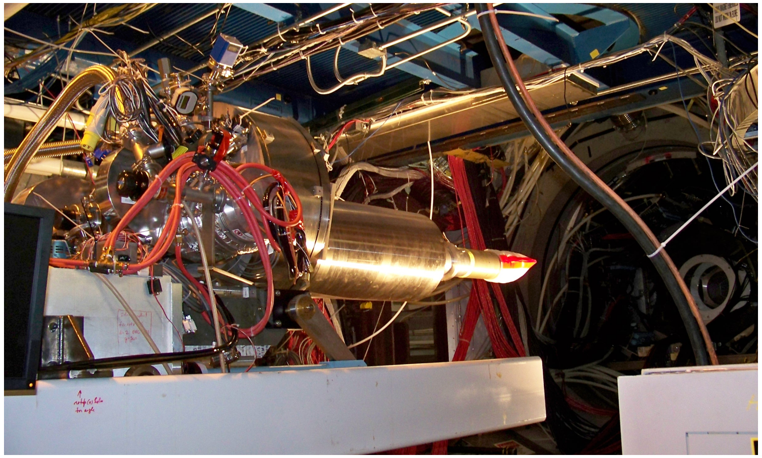
HD-Ice: Transverse Target
new concept
(common to LOI 11-105)

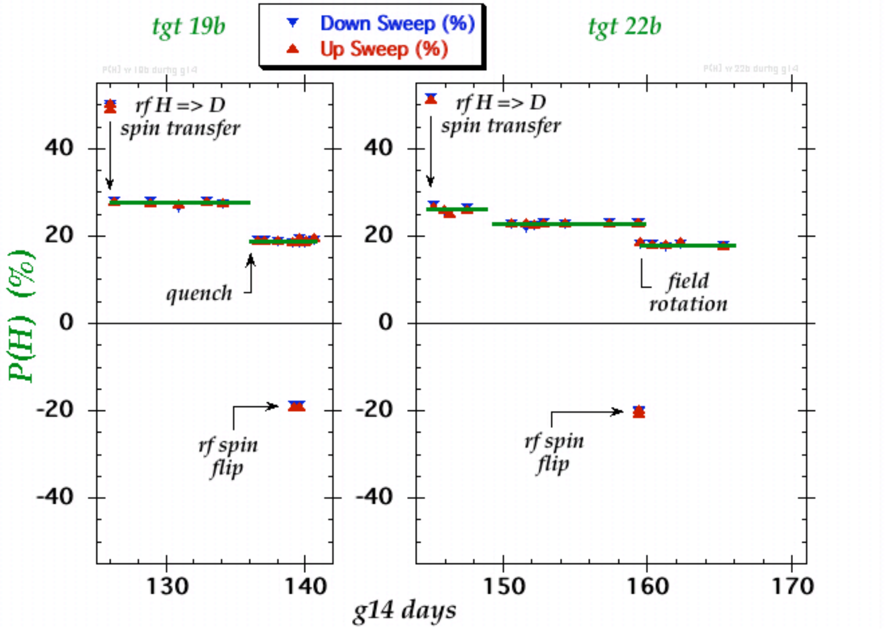
RICH: Hadron ID
for flavor separation
(common to SIDIS approved exp.)



Transversely Polarized HD-Ice Target

HD-ice ran from Nov/11 to May/12 at Jlab with 15mm Ø ×50 mm long HD cells





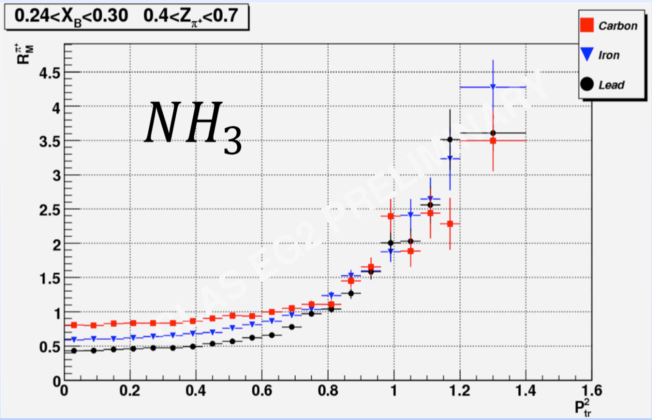
HD-Ice target vs standard nuclear targets

Advantages:

- Minimize nuclear background
  small dilution, no attenuation at large p_T
- Weak holding field (BdL ~ 0.1 Tm)
  wide acceptance, negligible beam deflection

Disadvantages:

- Very long polarizing times (months)
- Sensitivity to local heating by charged beams



Question 1: HD-Ice vs Electron Beam

- *HD targets used for eHD tests in Feb/12 and Mar/12*

➔ *H polarization does not appear to suffer radiation damage with 1 nA; D does*

➔ *heat removal needs improvement – faster raster, larger diameter cell, additional cooling wires, …*

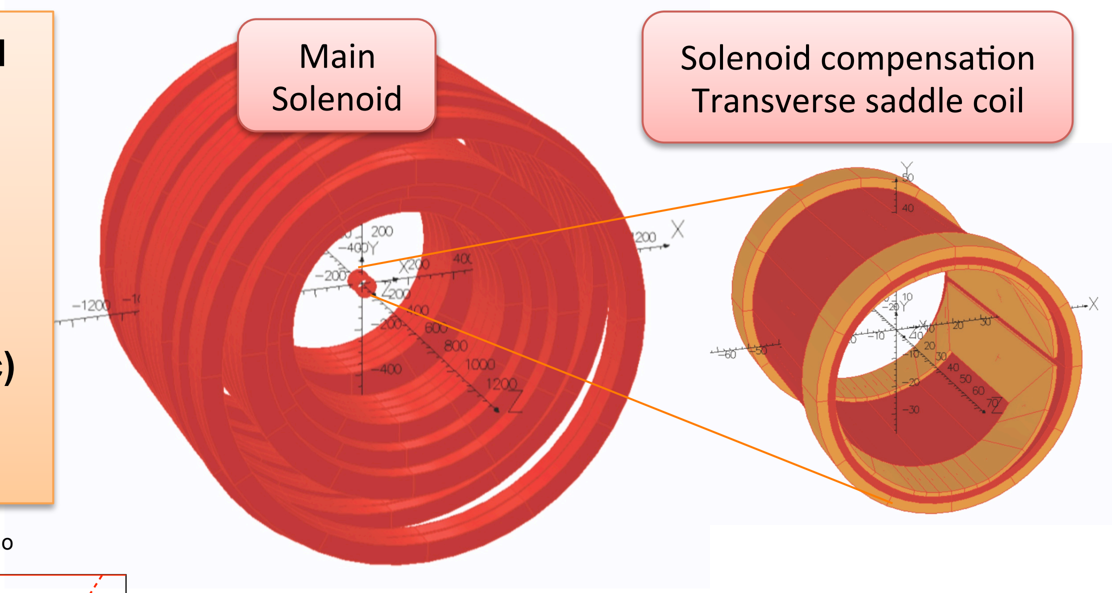
PLOT ?????

Target wider but not-longer than the existing one (5 cm)

- **Luminosity 5 10^{33} cm^2s^{-1} (minor impact on projections)**
- **Magnet configuration simplifies (smaller zero-field volume)**

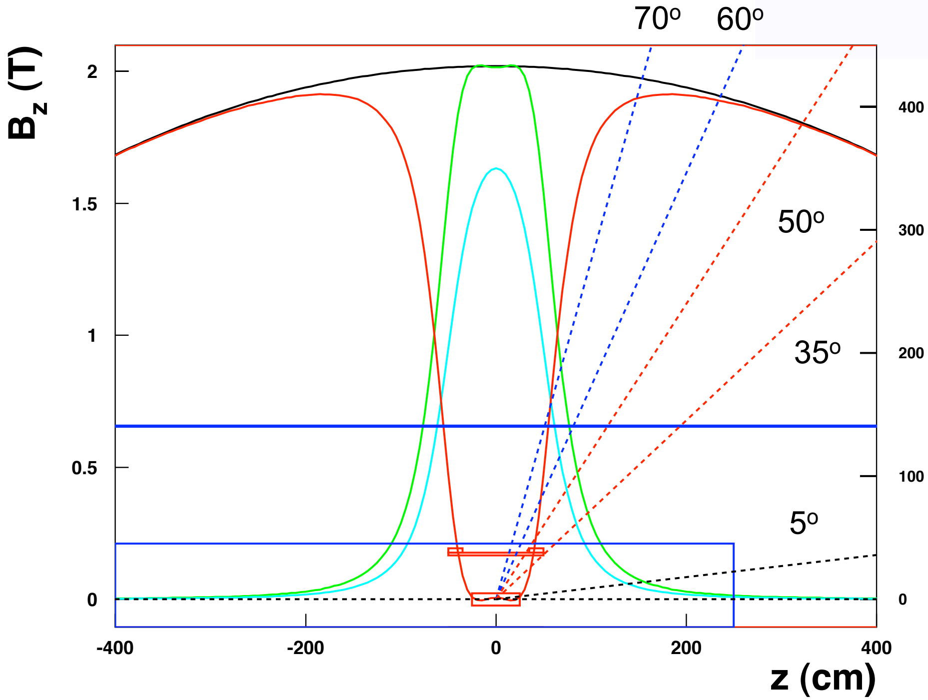
Question 2: Magnet Configuration

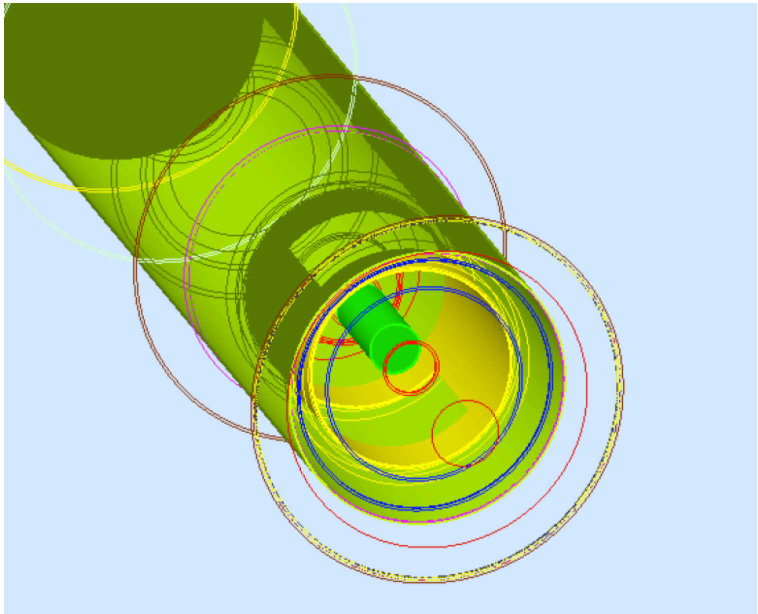
- **2T compensating, 0.5T transverse field**
- **Enhanced version of the existing NMR magnet system inside HD-ice cryostat**
- **Free forward acceptance (up to 35°)**
- **Recoiling proton detection (>0.4 GeV/c)**
- **No impact on CLAS12 central detector**



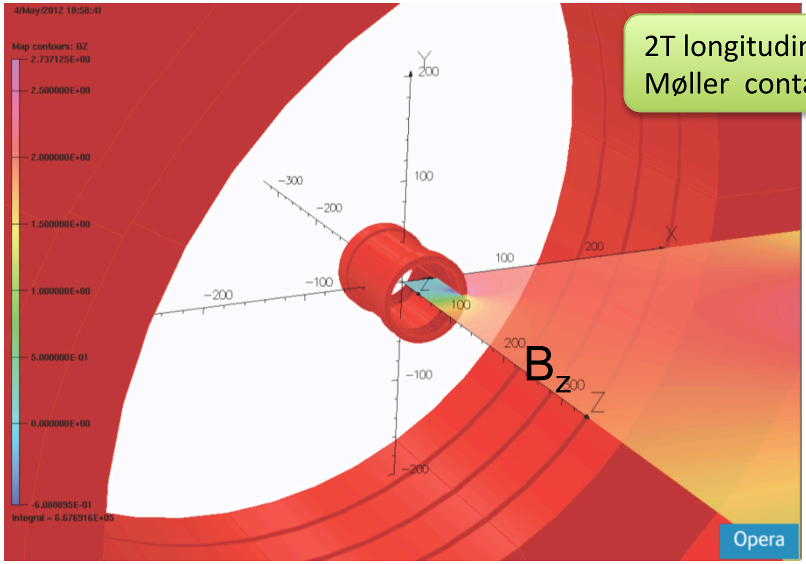
Main Solenoid

Solenoid compensation Transverse saddle coil

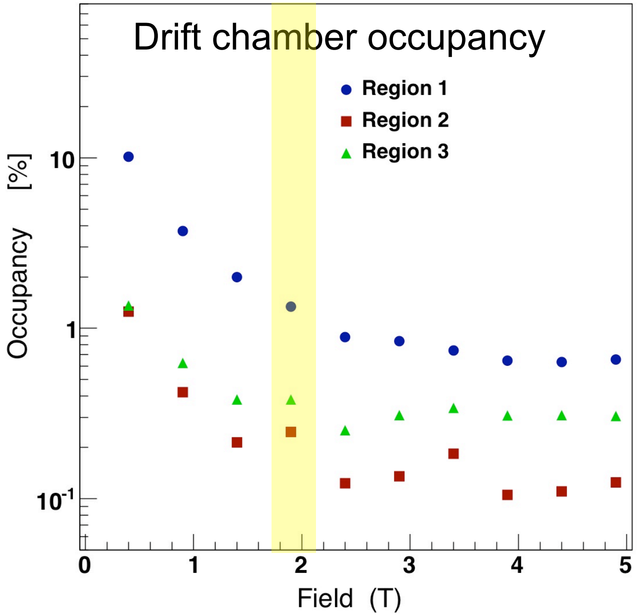




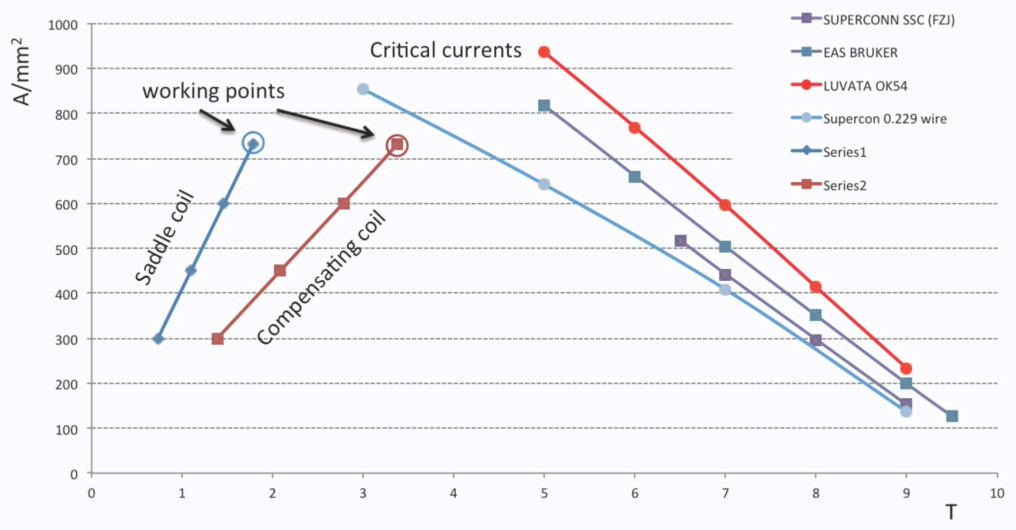
Question 2: Magnet Configuration



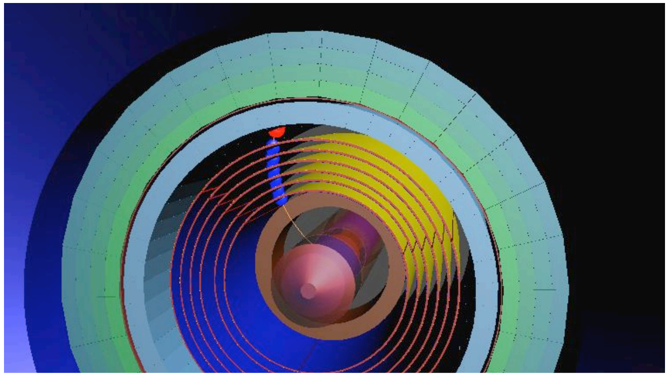
2T longitudinal field for Møller containment



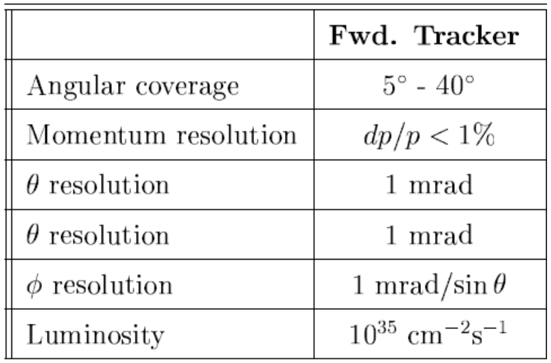
- **Good homogeneity (< 5mT long. field)**
- **Moeller background under control**
- **Working point below critical current of existing SC wires**
- **Dimensioned for standard quench protection**
- **Static forces one order of magnitude smaller than G10 epoxy tensile strength**



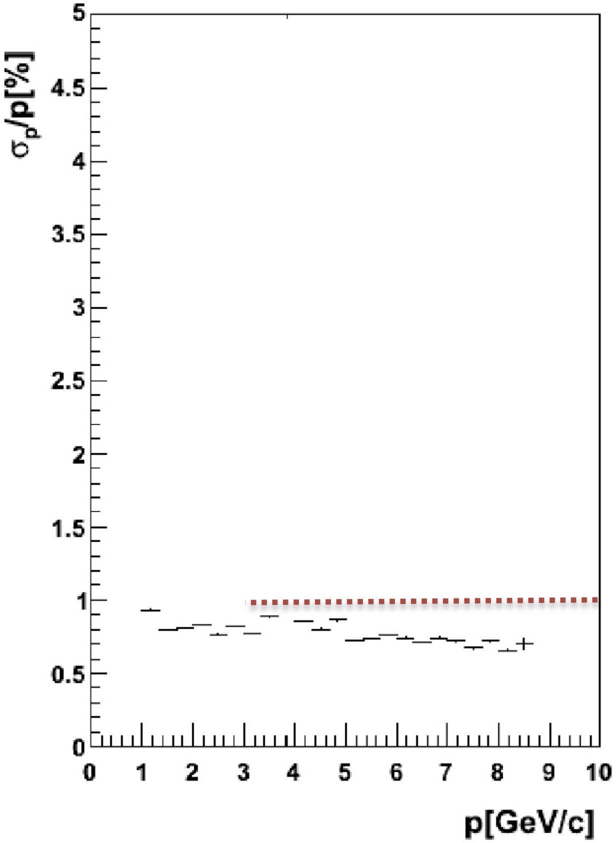
Question 3: Tracking

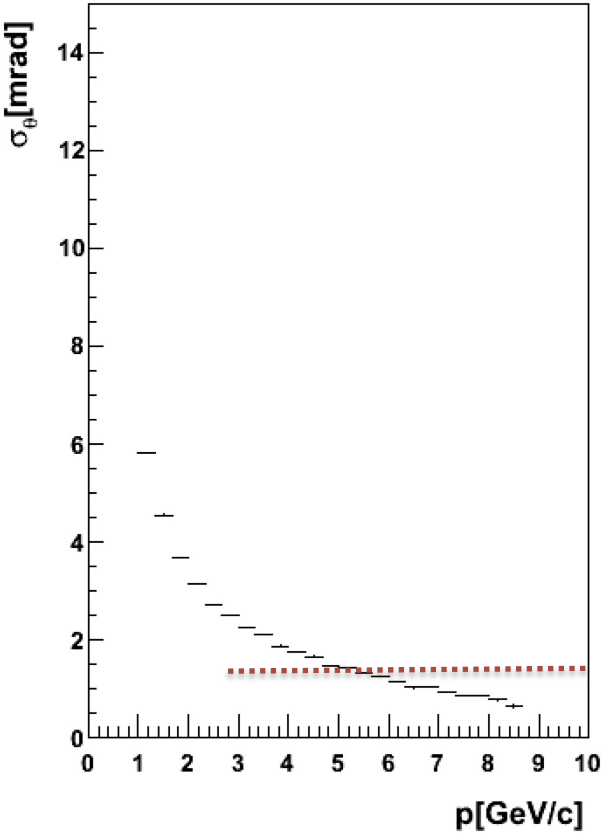


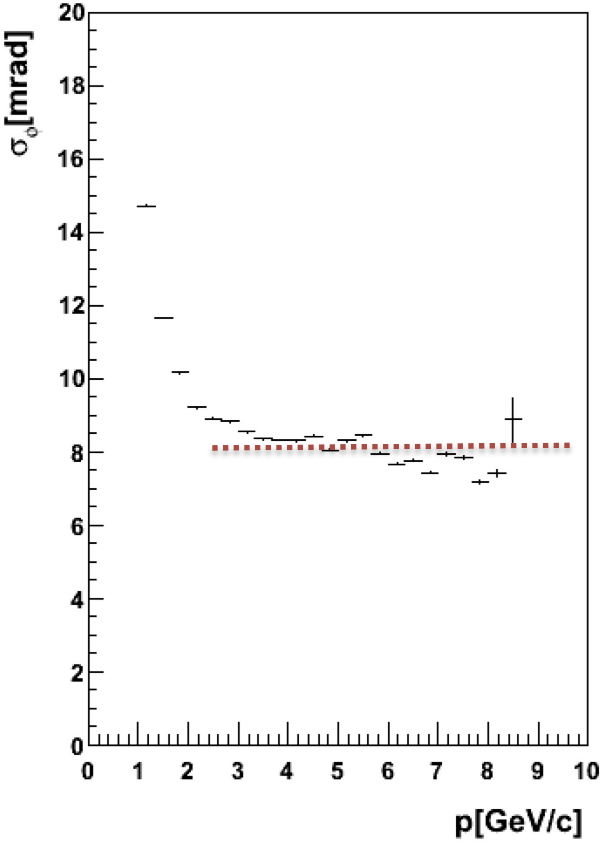
Resolutions fulfill TDR general specifications



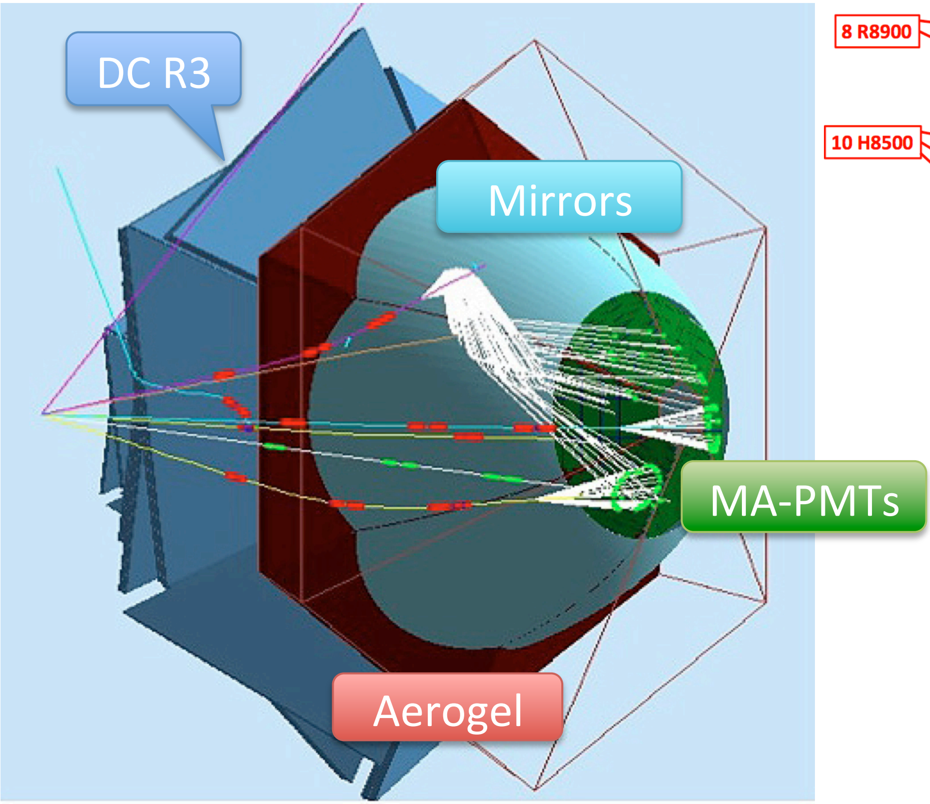
	Fwd. Tracker
Angular coverage	5° - 40°
Momentum resolution	$dp/p < 1\%$
θ resolution	1 mrad
θ resolution	1 mrad
ϕ resolution	1 mrad/$\sin\theta$
Luminosity	10^{35} cm^{-2}s^{-1}

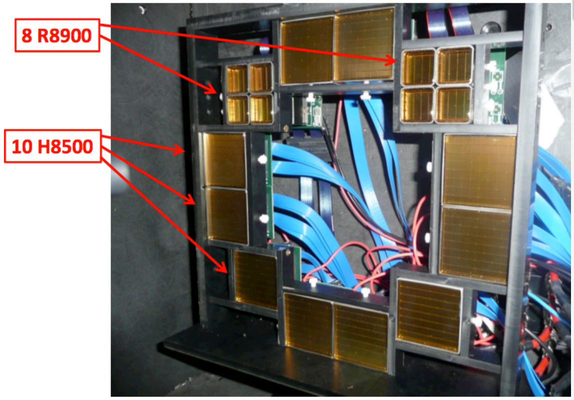


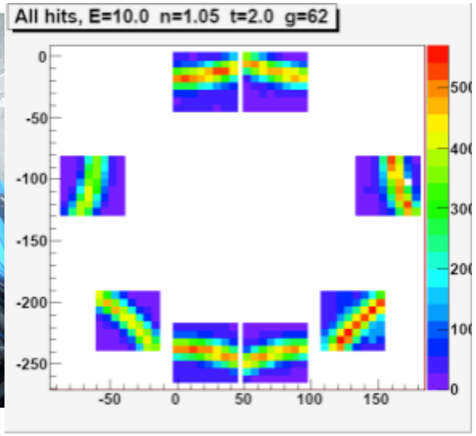




The RICH Detector







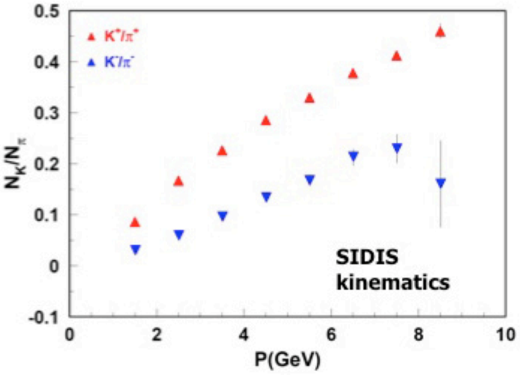
Simulation of n=1.05 aerogel + H8500:

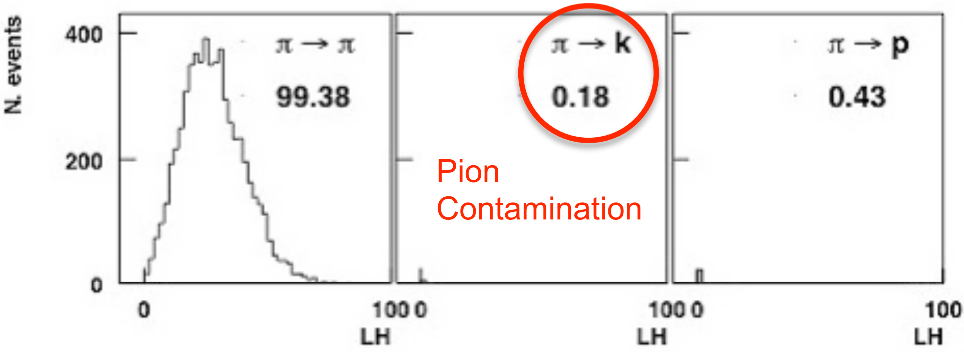
≥ 10 p.e. for direct rings
(confirmed by preliminary test-beam results)

≥ 5 p.e. for reflected rings

≥ 500 pion rejection factor @ 99% kaon eff.

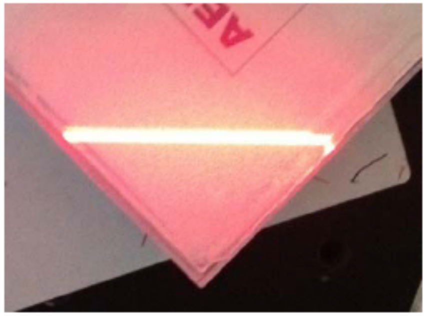
RICH goal:
π/K/p separation
of **4-5 σ @ 8 GeV/c**
for a pion rejection
factor **1:1000**

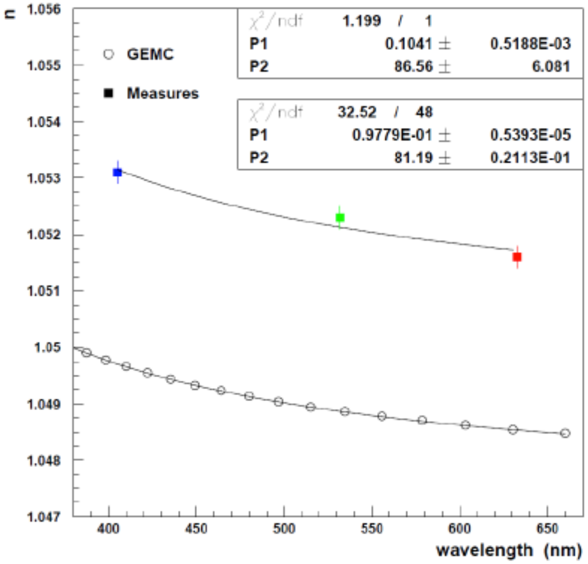




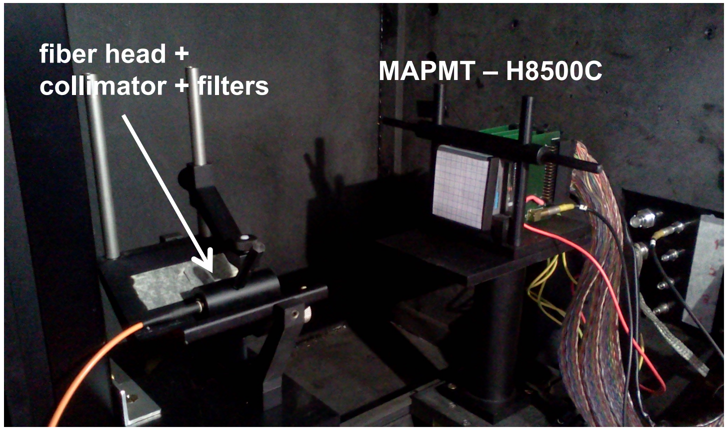
The RICH Detector

Aerogel characterization:
- dispersion law
- transmittance

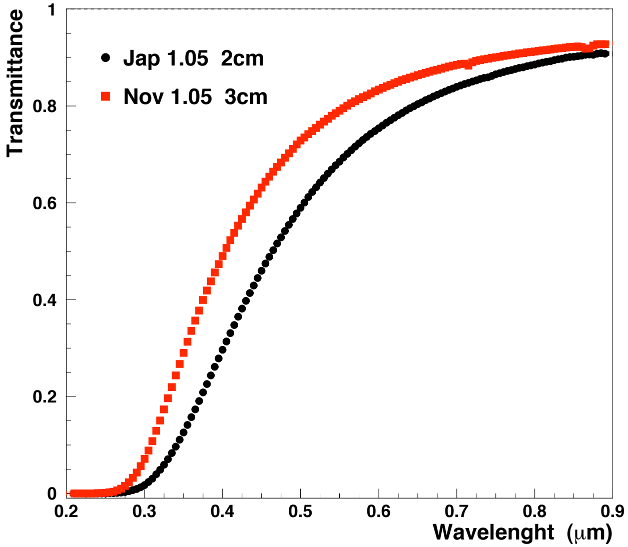




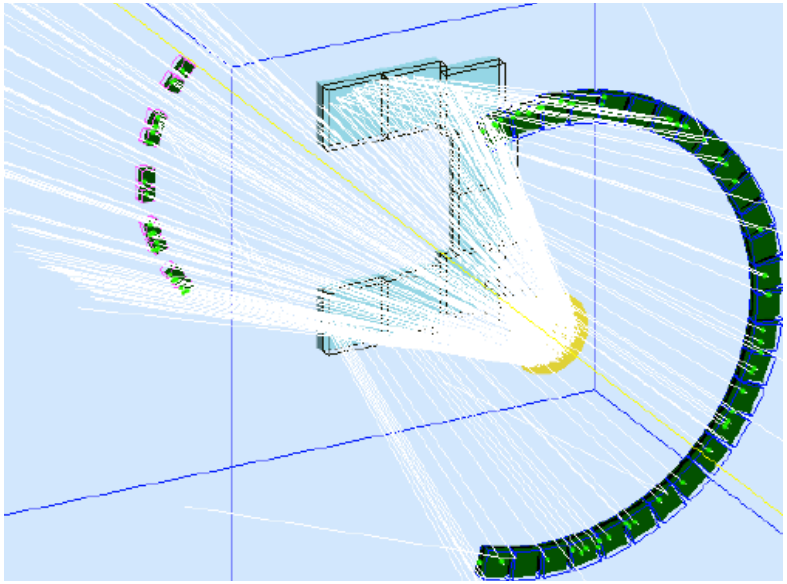
About 30 H8500 & 10 R8900 under test



Ongoing R&D with Budker Institute to improve transmittance



Realistic prototype under construction for beam test in July 2012



CLAS12 Kinematic Coverage

$0.05 < x < 0.6$

for $Q^2 > 1$ GeV^2 and $W^2 > 4$ GeV^2

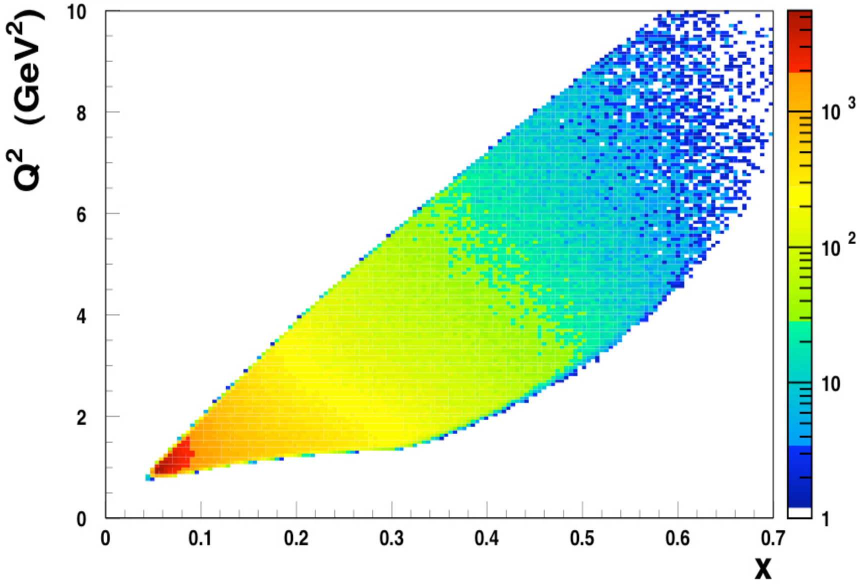
Cover valence region at several GeV Q^2
Constrain sub-leading twist terms

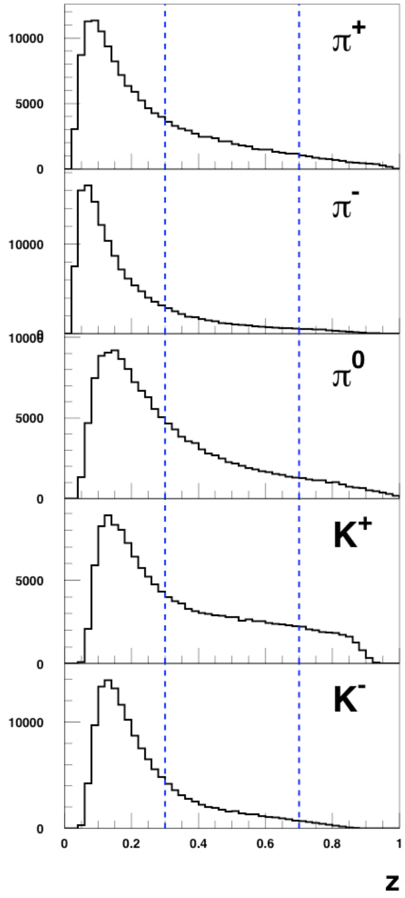
$0.3 < z < 0.7$

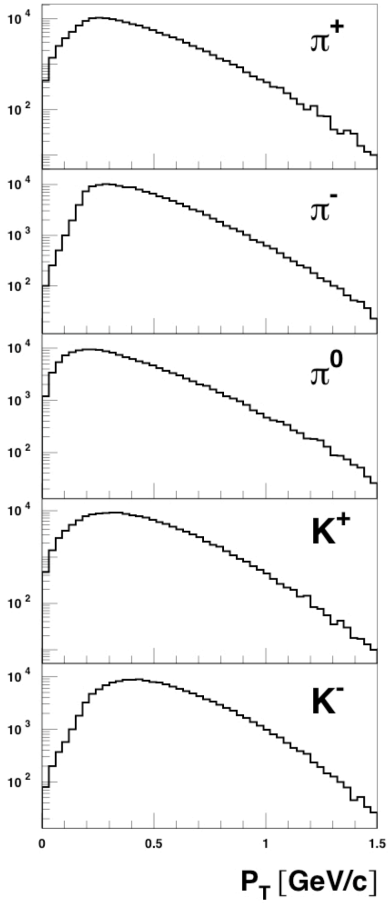
Current fragmentation
No exclusivity corner

$P_T > 1$ GeV/c

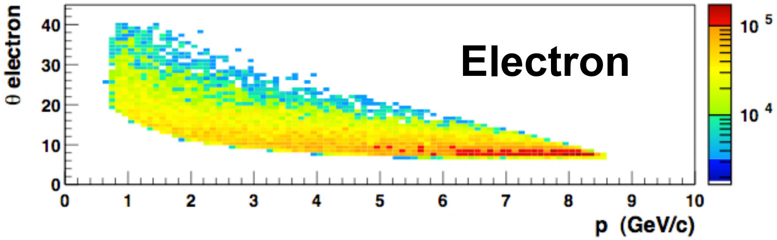
Limit given by
cross-section

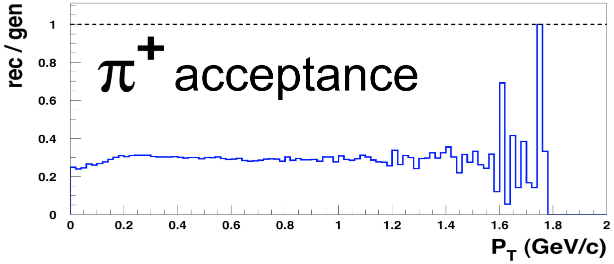






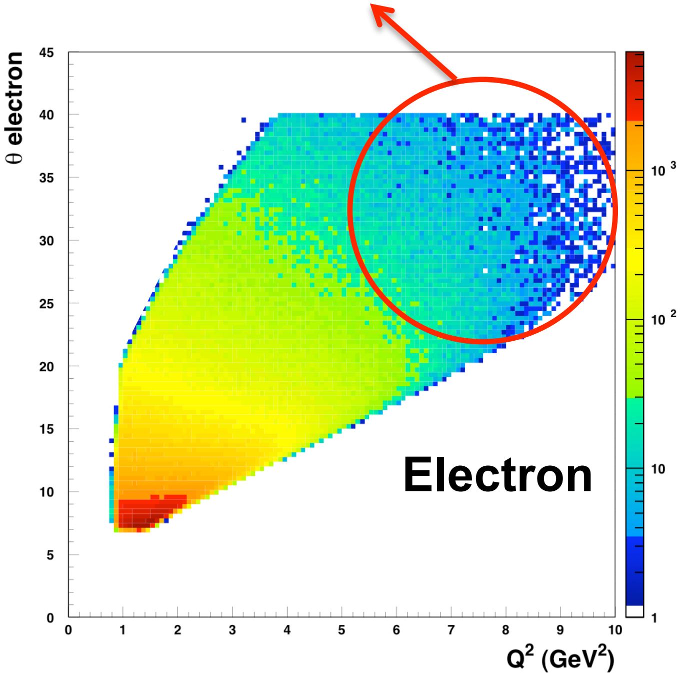
CLAS12 Kinematic Coverage

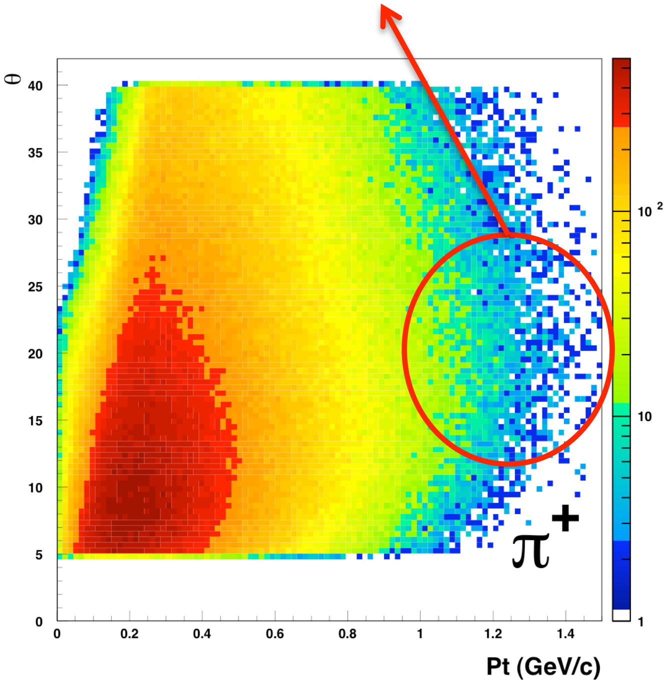




Large electron scattering angles (> 20°) mandatory to reach high Q^2 values

Intermediate anguar range (15-25°) mandatory to reach high P_T values

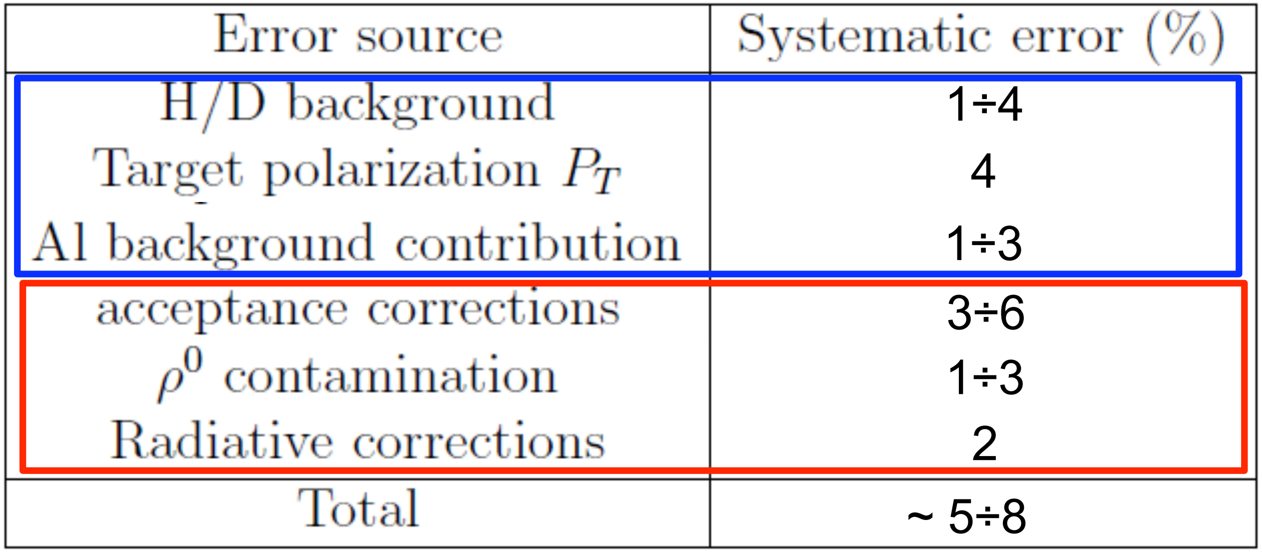




The CLAS12 forward detector is perfectly suitable for high-Q^2 and high-p_T measurements since designed to cover up to 40 degrees angles

PROJECTIONS

Systematic uncertainty



Error source	Systematic error (%)
H/D background	1÷4
Target polarization P_T	4
Al background contribution	1÷3
acceptance corrections	3÷6
ρ^0 contamination	1÷3
Radiative corrections	2
Total	~ 5÷8

Estimates based on:

- Current knowledge on HD-Ice target

Dominated by uncertainties in transfer losses between cryostats

Optimization after tests in fall

- Experience from CLAS/HERMES measurements

Reduces with statistics and bin number

Benefits from the large acceptance

Single- and Double-Spin asymmetries

- **Experiment:** CLAS12 with
  HD-Ice transversely polarized target
  75 % polarization and 1/3 dilution for Hydrogen @ 10^{34} cm^{-2} s^{-1}
  RICH detector for flavor tagging
  pions, kaons and protons ID in the 3-8 GeV/c momentum range

$$\left.\begin{aligned} \sigma_{UT}^{\sin\phi} \;\propto\;& S_T(1-y)\sin(\phi+\phi_S)\sum_{q,\bar q} e_q^2 x h_1(x) H_1^{\perp q}(z) \\ &+ S_T(1-y+y^2/2)\sin(\phi-\phi_S)\sum_{q,\bar q} e_q^2 x f_{1T}^{\perp q}(x) D_1^q(z) \\ &+ S_T(1-y)\sin(3\phi-\phi_S)\sum_{q,\bar q} e_q^2 x h_{1T}^{\perp q}(x) H_1^{\perp q}(z) \end{aligned}\right\} \quad A_{UT} = \frac{1}{fP_t}\frac{(N^+ - N^-)}{(N^+ + N^-)}$$

$$\downarrow$$

equivalent to the cross-section asymmetry for opposite spin states

$$\underbrace{\sigma_{LT}^{\cos\phi} \;\propto\; \lambda_e S_T y(1-y/2)\cos(\phi-\phi_S)\sum_{q,\bar q} e_q^2 x g_{1T}^q(x) D_1^q(z)}$$

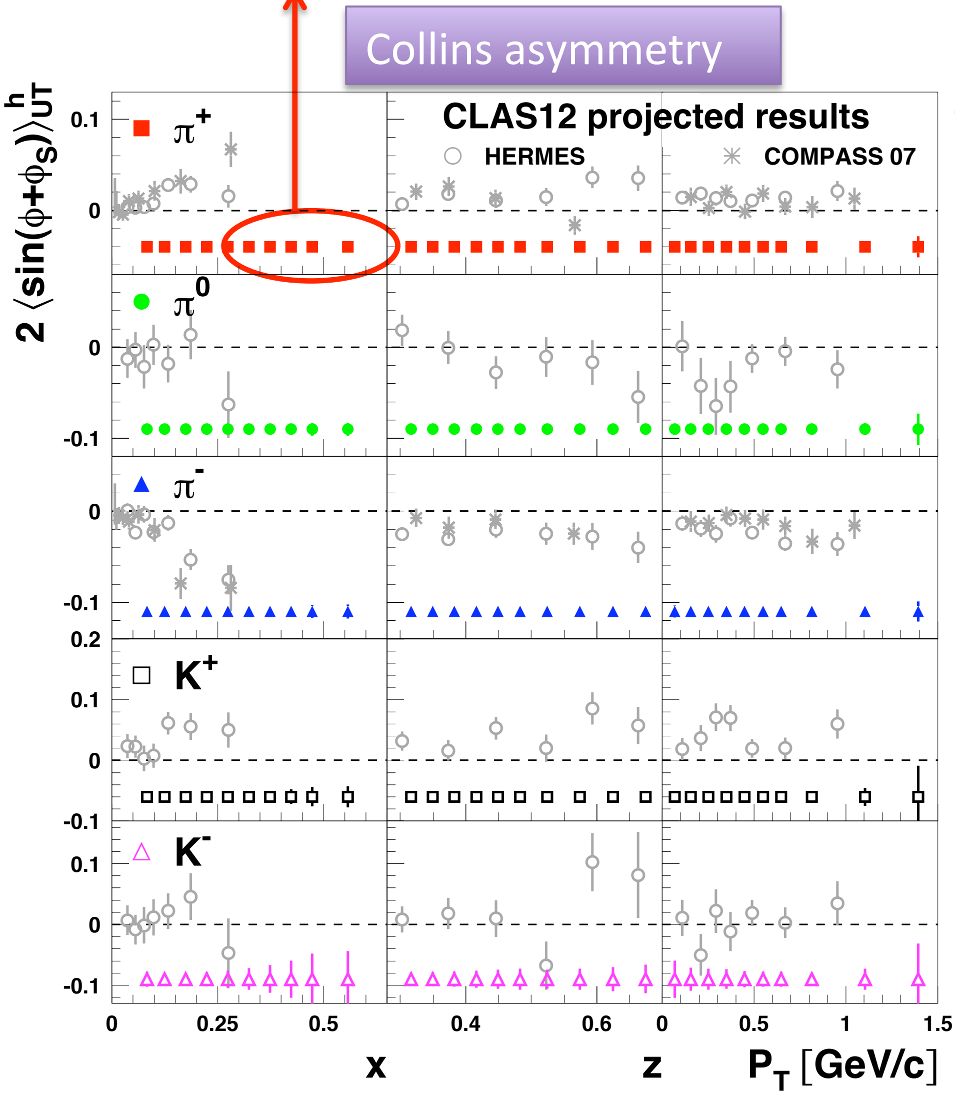
$$A_{LT} = \frac{1}{fP_BP_t}\frac{(N^{+\uparrow} + N^{-\downarrow}) - (N^{+\downarrow} + N^{-\uparrow})}{(N^{+\uparrow} + N^{-\downarrow}) + (N^{+\downarrow} + N^{-\uparrow})}$$

- **Analysis**: the relevant Fourier amplitudes (Collins, Sivers, etc) are extracted simultaneously, thanks to their specific azimuthal dependence, by fitting (ML unbinned in ϕ,ϕ_S) the yield (cross-section) asymmetries for opposite spin states

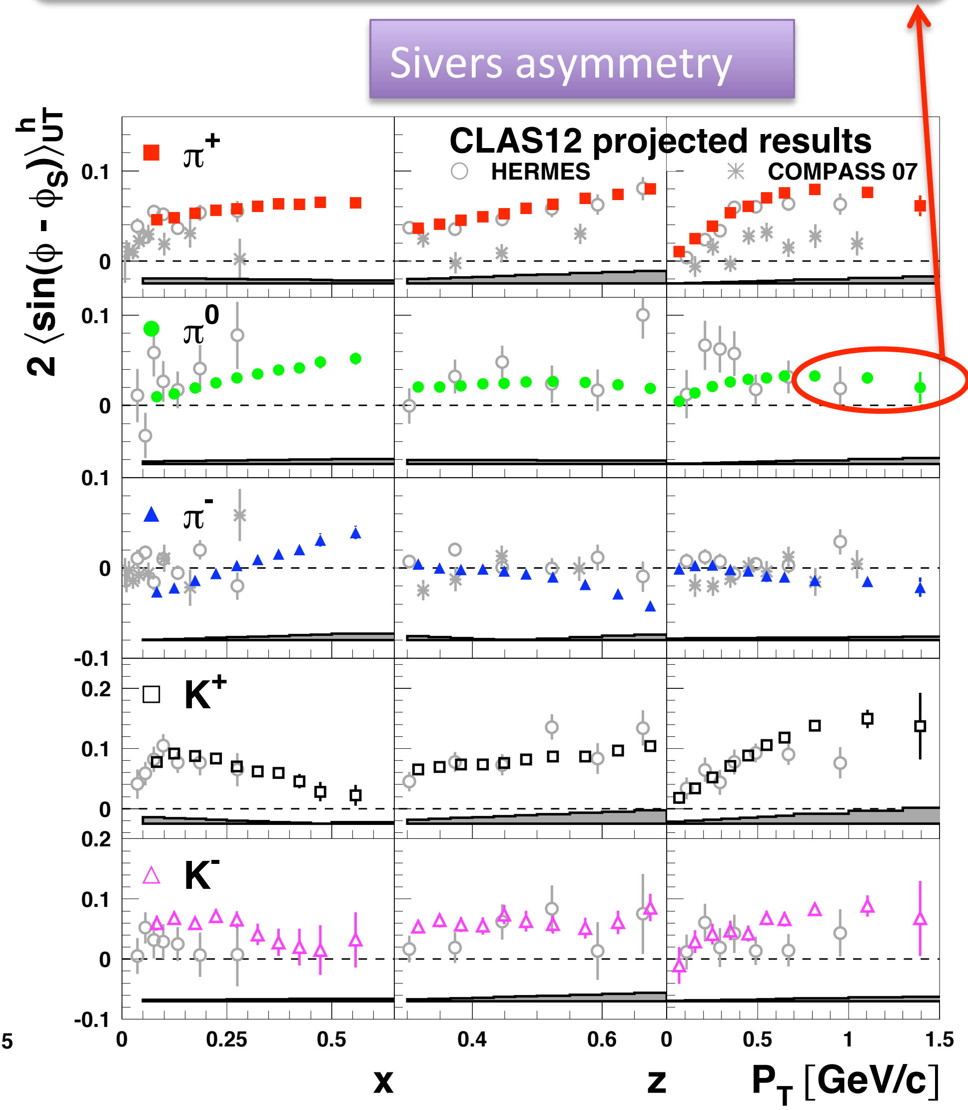
CLAS12 Projections

Large x important to constrain the tensor charge

Large p_T important to test perturbative to non-perturb. transient and for Bessel function analysis

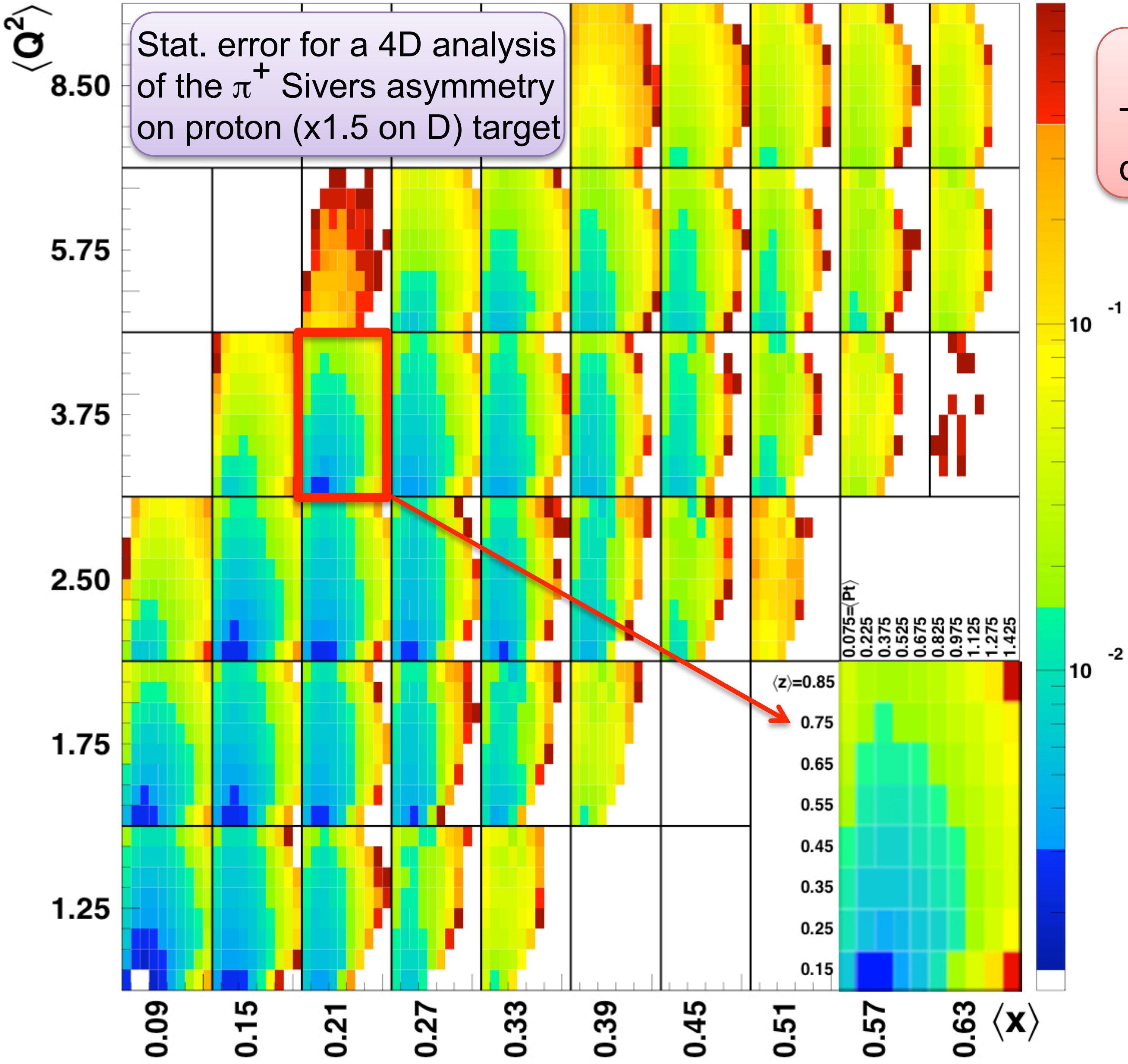


Collins asymmetry



Sivers asymmetry

Statistical precision

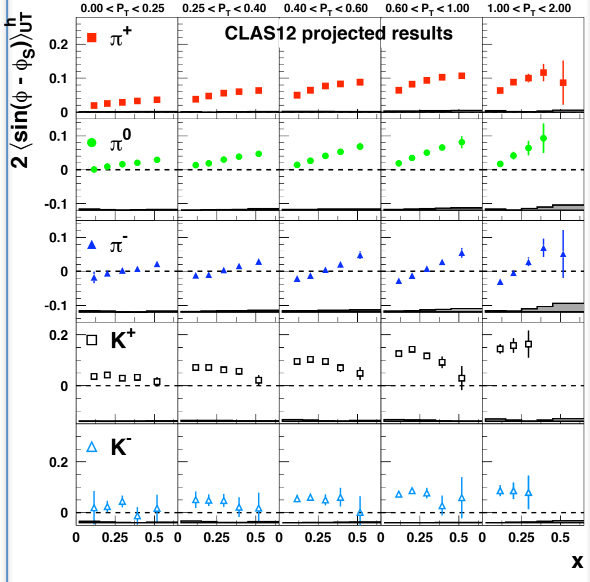


Stat. error for a 4D analysis of the π^+ Sivers asymmetry on proton (x1.5 on D) target

4D analysis is possible

The wanted high-Q^2 high-p_T defines the beam-time request

2D projection (x-p_T) of the π^+ Sivers asymmetry



The main goals

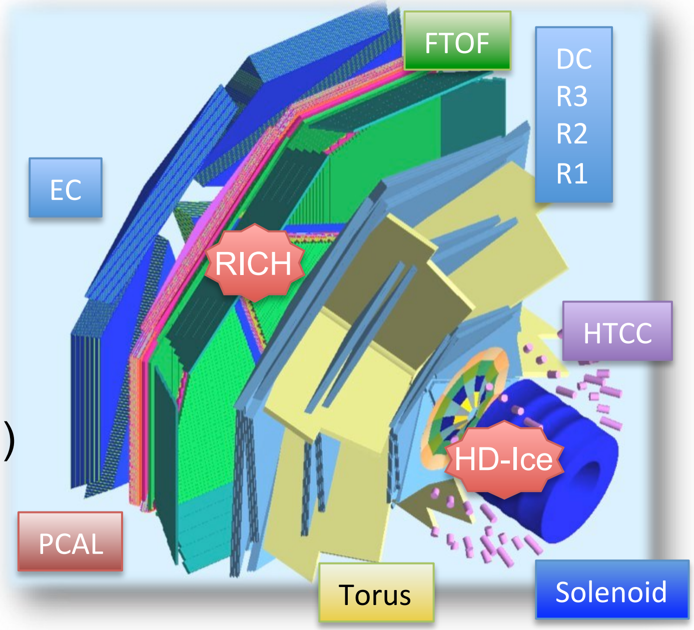
Transverse spin effects in SIDIS at 11 GeV with transversely polarized target using the CLAS12 detector

- Main interest on transverse-target single and double spin asymmetries;
- **Access to leading-twist poorly known or unmeasured TMD PDFs** which provide 3-dimensional picture of the nucleon in momentum space (nucleon tomography);
    - SSA Transversity, Sivers, Pretzelosity functions;
    - DSA Worm-gear function;
- Multi dimensional analysis in x, Q^2, z, p_T thanks to large-acceptance and high-luminosity;
    - **disentangle parton distribution from fragmentation functions** (x vs z);
    - **isolate sub-leading-twist effects** from 1/Q dependence;
    - **investigate transverse degrees of freedom** and perturbative to non-perturbative QCD transient from p_T dependence;
- Together with already approved experiments with unpolarized and longitudinally polarized targets, **complete the mapping of the TMD table at CLAS12**.

Beam time request

The proposed experiment requires:

- 11 GeV (highly polarized) electron beam
- CLAS12 detector equipped with:
  - HD-Ice transversely polarized target
  - Suitable magnetic system (compensation + saddle coil)
  - RICH (pion/kaon separation within 3-8 GeV/c)

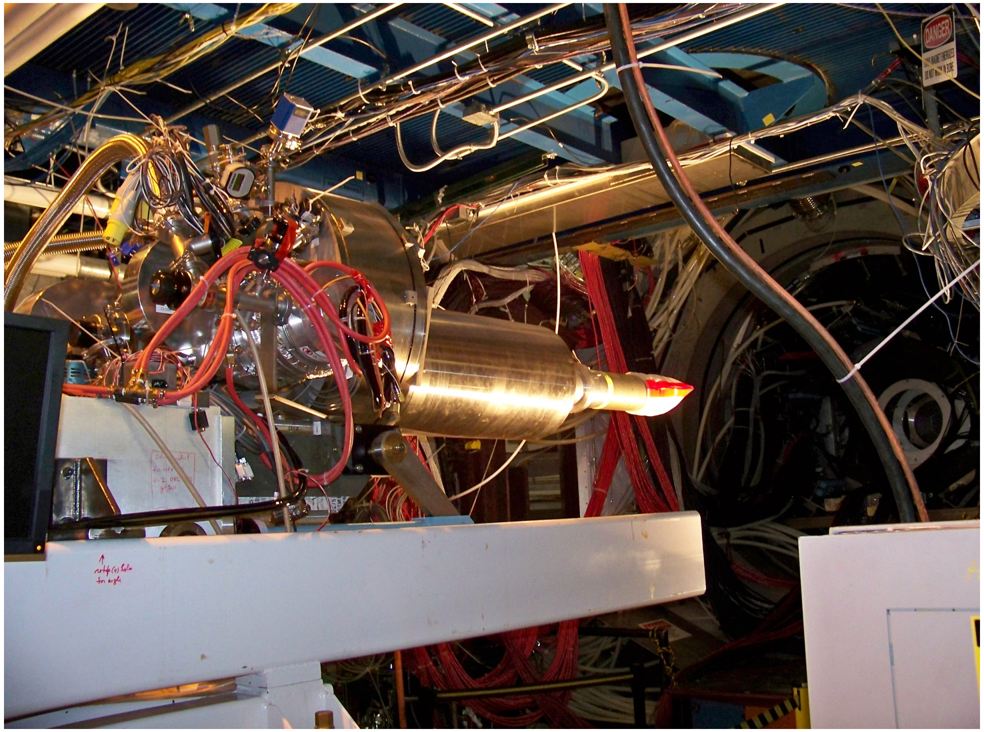


In order to reach the desired statistical precision at high-x (valence region) and high p_T for both pion and kaons, and to allow a fully differentyal analysis in x,Q^2,z,p_T

we ask the PAC to award 110 days of beam time

(including 10 days for calibrations, empty target runs, supportive tests, etc.)

HDice operations during g14 / E06-101



- *HD targets condensed, polarized and aged to the Frozen-Spin state in HDice Lab (TestLab annex)*
- *transferred as solid, polarized HD between cryostats; moved to Hall B*
- *In-Beam Cryostat (IBC) operates in Hall at 50 mK, 0.9 tesla*
- *g14 ran from Nov/11 to May/12 with 15mm Ø ×50mm long HD cells*
- *γ-beam lifetimes ~ years with 10^8 γ/s*
- *HD targets used for eHD tests in Feb/12 and Mar/12*

➔ *H polarization does not appear to suffer radiation damage with 1 nA; D does*

➔ *heat removal needs improvement – faster raster, larger diameter cell, additional cooling wires, …*

$\vec{H}$D polarization during g14/E06-101