SOLID Physics Overview

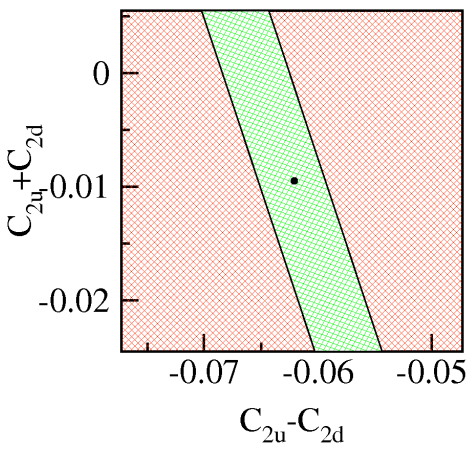
Physics Topics

- SIDIS
  - 8 TMD's; function of x Q^2, PT, z
- PVDIS
  - Standard Model test
  - CSV at the quark level
  - Quark-quark correlations

Motivation for PVDIS

Standard Model

$$b(x) = \frac{\sum_i C_{2i} Q_i f_i^-(x)}{\sum_i Q_i^2 f_i^+(x)}$$



$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[\mathbf{a}(x) + Y(y)\,\mathbf{b}(x)\right]$$

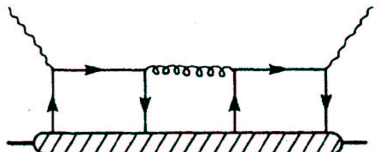
CSV at Quark Level

$$\delta u(x) = u^p(x) - d^n(x)$$

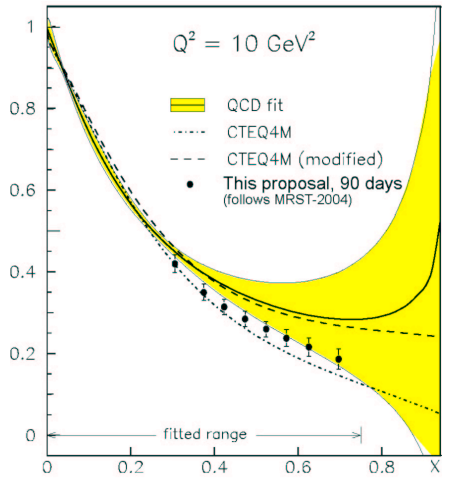
$$\delta d(x) = d^p(x) - u^n(x)$$

$$R_{CSV} = \frac{\delta A_{PV}(x)}{A_{PV}(x)} = 0.28\,\frac{\delta u(x) - \delta d(x)}{u(x) + d(x)}$$

Di-quarks in the nucleon (Q^2 Dependence)

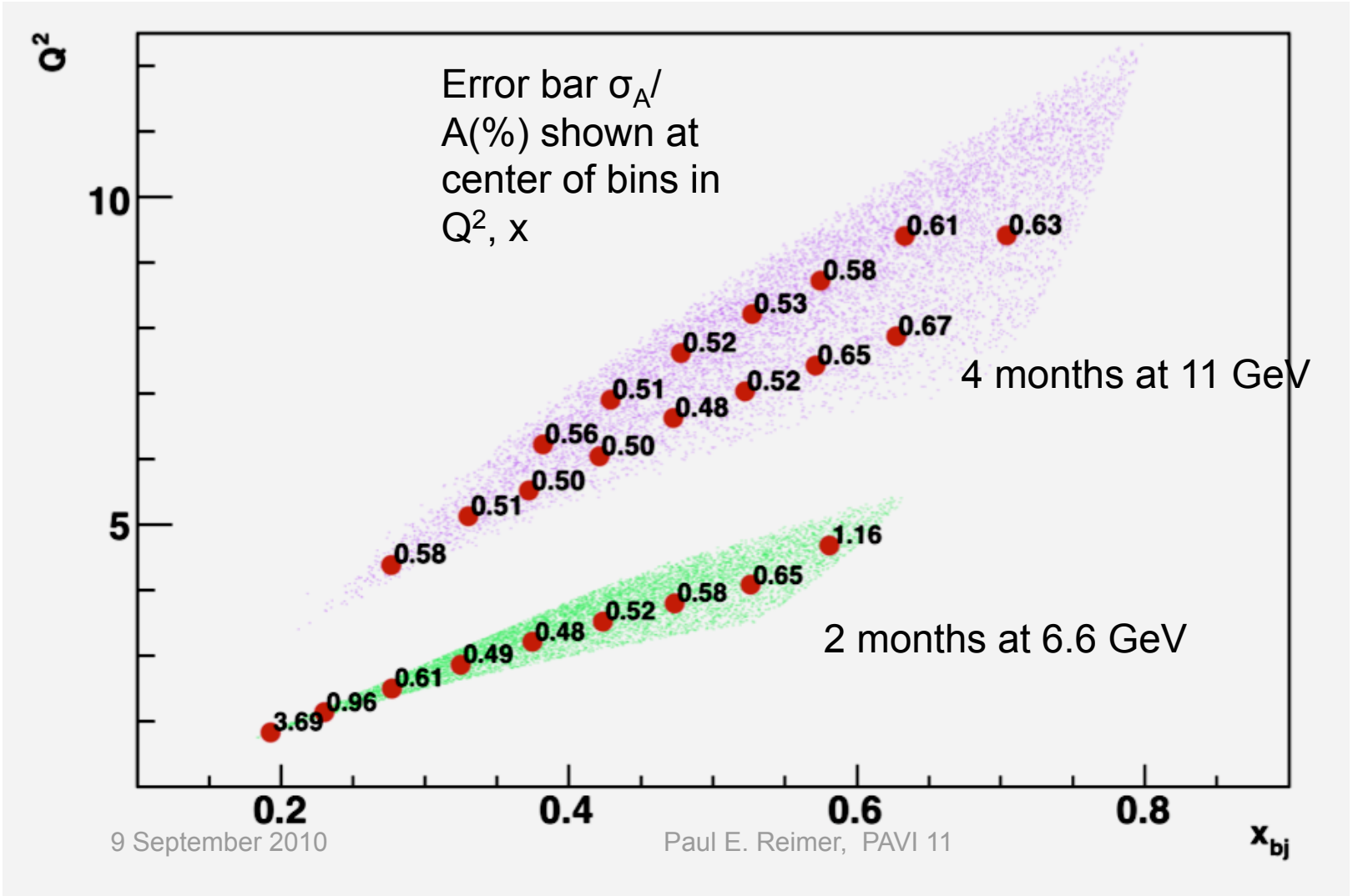


d/u for Hydrogen



Statistical Errors (%) vs. Kinematics

A/Q^2 should be perfectly flat! (Modulo small y-dep)

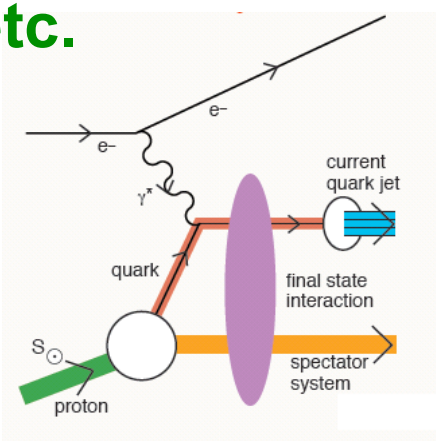


Measurement of TSSA in SIDIS with SoLID on ^{3}He

TMDs are a fundamental property of the nucleon. They provide a 3-D description of nucleon structure in momentum space, and a direct access to QCD dynamics.

- **<10% d quark tensor charge (Collins moments)**
  - Fundamental property of nucleon **benchmark test of Lattice QCD**
- 4-D (x,Q^2,z,P_T) mapping of **Sivers moments, etc.**
  - Spin-orbital correlation: promising to access **Orbital Angular Momentum (OAM)**
  - Provide precision data to test TMD **factorization and scale evolution**

Sivers Effect



Leading-Twist TMD PDFs

Nucleon Polarization	Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = – Boer-Mulders
L		g_1 = – Helicity	$h_{1L}^\perp$ = – Worm Gear
T	$f_{1T}^\perp$ = – Sivers	g_{1T} = – Worm Gear	h_1 = – Transversity $h_{1T}^\perp$ = – Pretzelosity

Nucleon Spin

Quark Spin

: Survive trans. Momentum integration

Measuring TMD's

$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

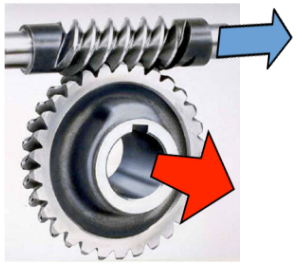
$A_{UL}(\sin(2\phi_h)) \rightarrow h_{1L}^{\perp}$ 

$A_{LT}(\cos(\phi_h - \phi_S)) \rightarrow g_{1T}$ 

$A_{LL} \rightarrow g_{1L}$ 

WORM-GEAR
distributions,
interference of OAMs:
$\mathrm{Re}[(L=0)_q \times (L=1)_q]$

p_T dependent helicity distribution



All 8 TMD's will be measured

Data Required

Variables:

x: Strong Dependence

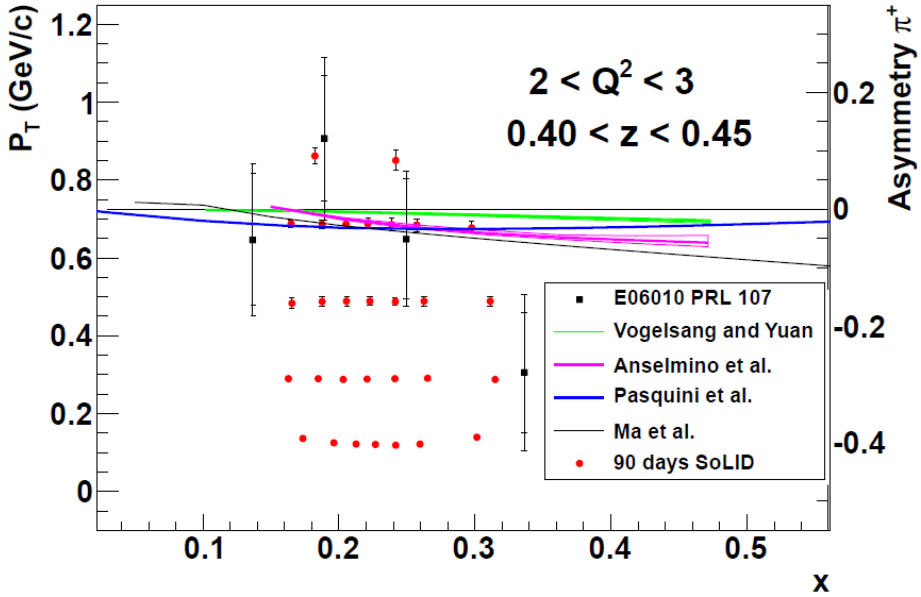
P_T: Strong Dependence

Q^2: HT and QCD Evolution

z: Test Fragmentation Theory

Need precise data

In 4 variables!

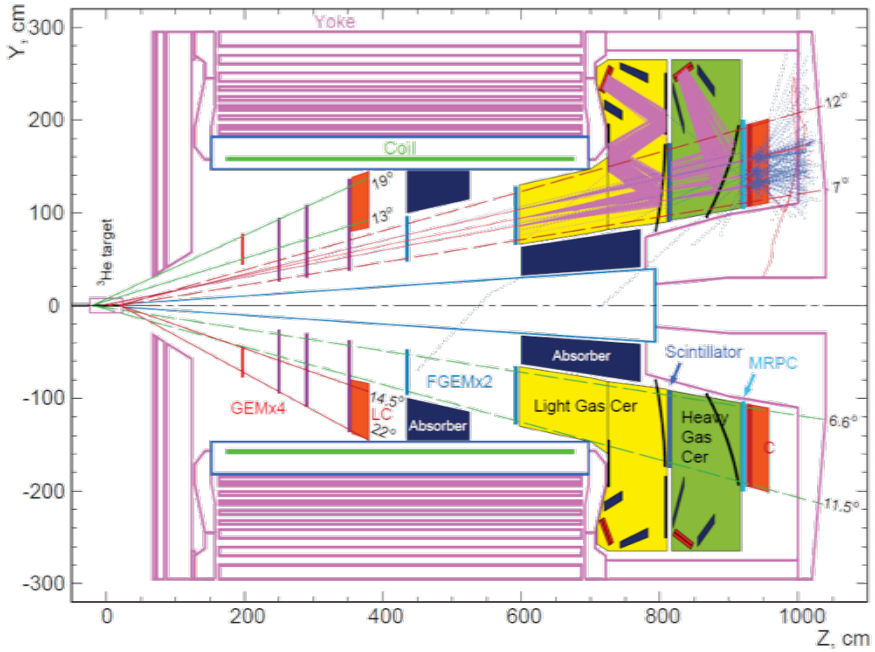


Example projections of Neutron Collins moments, 1/48 bins in z vs. Q^2.


1 < Q² < 2
0.30 < z < 0.35
1 < Q² < 2
0.35 < z < 0.40
1 < Q² < 2
0.40 < z < 0.45
1 < Q² < 2
0.45 < z < 0.50
1 < Q² < 2
0.50 < z < 0.55
1 < Q² < 2
0.55 < z < 0.60
1 < Q² < 2
0.60 < z < 0.65
1 < Q² < 2
0.65 < z < 0.70
2 < Q² < 3
0.30 < z < 0.35
2 < Q² < 3
0.35 < z < 0.40
2 < Q² < 3
0.40 < z < 0.45
2 < Q² < 3
0.45 < z < 0.50
2 < Q² < 3
0.50 < z < 0.55
2 < Q² < 3
0.55 < z < 0.60
2 < Q² < 3
0.60 < z < 0.65
2 < Q² < 3
0.65 < z < 0.70
3 < Q² < 4
0.30 < z < 0.35
3 < Q² < 4
0.35 < z < 0.40
3 < Q² < 4
0.40 < z < 0.45
3 < Q² < 4
0.45 < z < 0.50
3 < Q² < 4
0.50 < z < 0.55
3 < Q² < 4
0.55 < z < 0.60
3 < Q² < 4
0.60 < z < 0.65
3 < Q² < 4
0.65 < z < 0.70
4 < Q² < 5
0.30 < z < 0.35
4 < Q² < 5
0.35 < z < 0.40
4 < Q² < 5
0.40 < z < 0.45
4 < Q² < 5
0.45 < z < 0.50
4 < Q² < 5
0.50 < z < 0.55
4 < Q² < 5
0.55 < z < 0.60
4 < Q² < 5
0.60 < z < 0.65
4 < Q² < 5
0.65 < z < 0.70
5 < Q² < 6
0.30 < z < 0.35
5 < Q² < 6
0.35 < z < 0.40
5 < Q² < 6
0.40 < z < 0.45
5 < Q² < 6
0.45 < z < 0.50
5 < Q² < 6
0.50 < z < 0.55
5 < Q² < 6
0.55 < z < 0.60
5 < Q² < 6
0.60 < z < 0.65
5 < Q² < 6
0.65 < z < 0.70
6 < Q² < 8
0.30 < z < 0.35
6 < Q² < 8
0.35 < z < 0.40
6 < Q² < 8
0.40 < z < 0.45
6 < Q² < 8
0.45 < z < 0.50
6 < Q² < 8
0.50 < z < 0.55
6 < Q² < 8
0.55 < z < 0.60
6 < Q² < 8
0.60 < z < 0.65
6 < Q² < 8
0.65 < z < 0.70
P_T (GeV/c)
Asymmetry π⁻
x

SIDIS Setup

- **10^{36} N/cm^2/s** polarized luminosity
- Achieved Target Performance:
  - Transverse/Vertical Polarized
  - ~60% polarization + Fast Spin Flip
- Large acceptance → **4-D mapping**
- **Full azimuthal-angular** coverage
  -> smaller systematic uncertainties

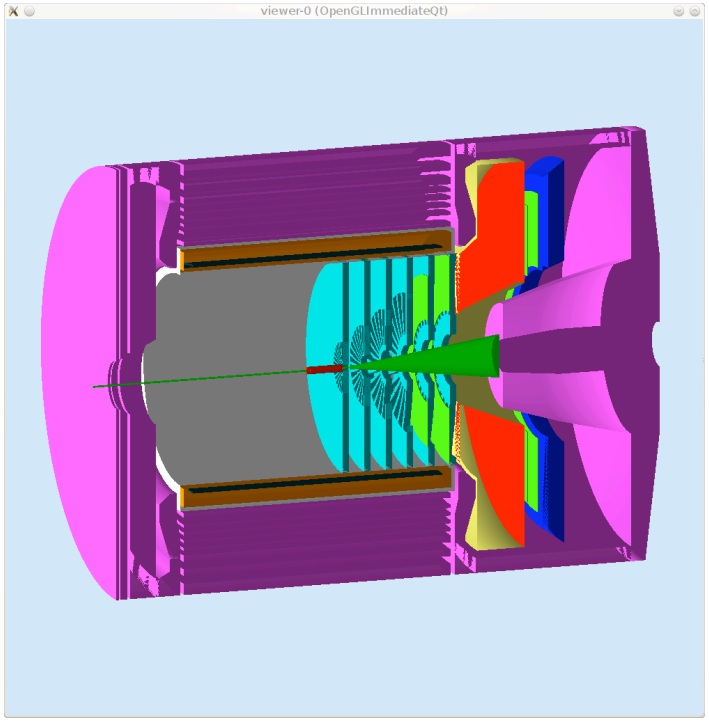


SIDIS Setup

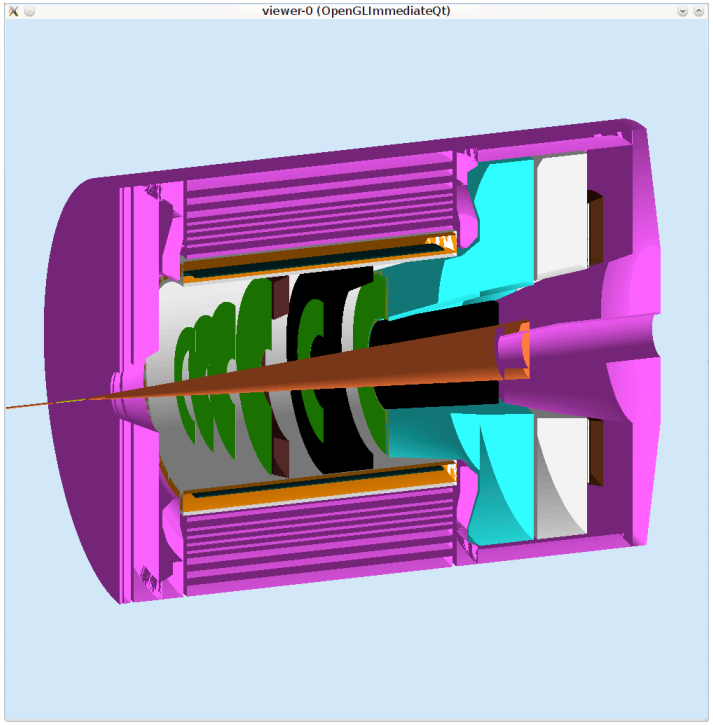
- ✓ **International collaboration** (8 countries, 50+ institutes)
  - ✓ Rapid Growth in US-China Collaboration
- ✓ **Joint effort** with PVDIS-SoLID (shared detector/DAQ). Transverse and longitudinal-^{3}He.
- ✓ M**agnet:** CLEO [ANL, Syracuse, Jlab, UVA]
- ✓ **Pipeline DAQ** (Hall D standard) {Umass, Jlab}
- ✓ **GEM Tracker** (Chinese Hadron Collaboration with Jlab/UVA/INFN, large GEM plane @ CERN + Improved Electronics)
- ✓ **MRPC TOF** (Chinese Hadron Collaboration, successful in RHIC-STAR)
- ✓ Detailed conceptual design of **Gas Cerenkov** (1-mirror + Cs-GEM readout or PMT + Wiston Cone) [Temple, Duke, Stonybrook]
- ✓ 1st choice of Shashlyk with detailed detector simulation for **E&M Cal [**UVA, Los Alamos, ANL**]**

PVDIS vs SIDIS

PVDIS



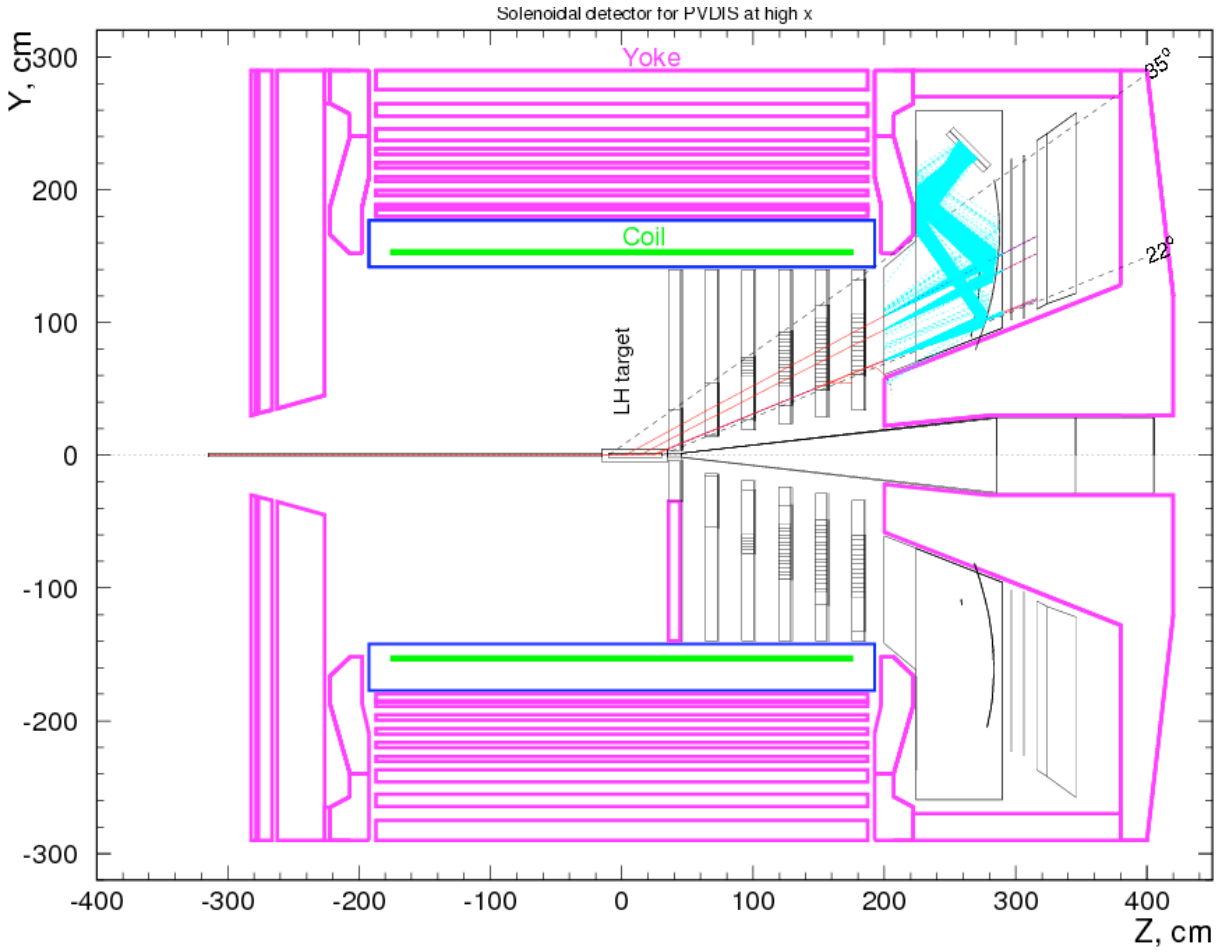
SIDIS



Can you find six differences between these panels?

Target Location, Baffles (PVDIS), Cerenkov's,
GEM Layout, Extra E-Cal, Beam Pipe

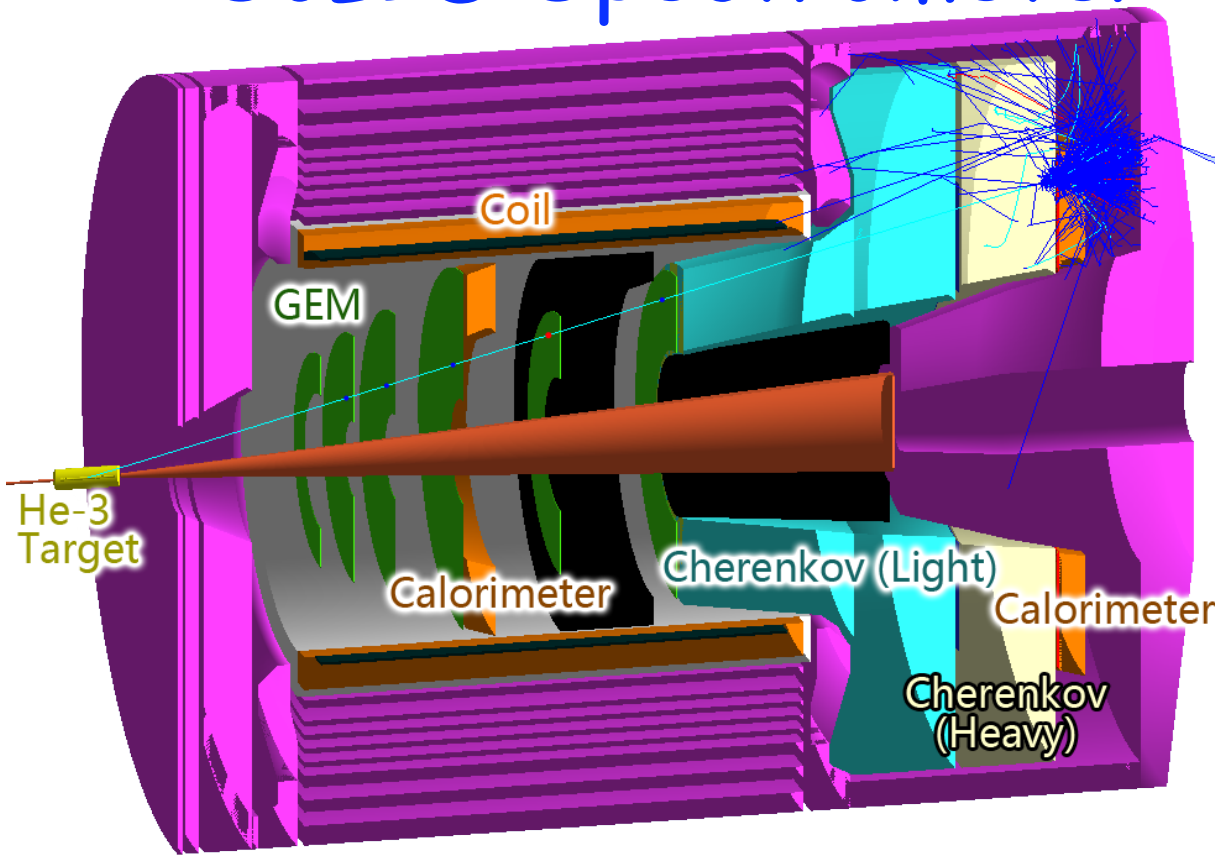
PVDIS Setup


Solenoidal detector for PVDIS at high x
Yoke
Coil
LH target
35°
22°
Y, cm
Z, cm
300
200
100
0
-100
-200
-300
-400
-300
-200
-100
0
100
200
300
400

Conclusions

- The SOLID collaboration has a broad collection of physics topics
- A single (sort of) apparatus can meet all the needs of the program.

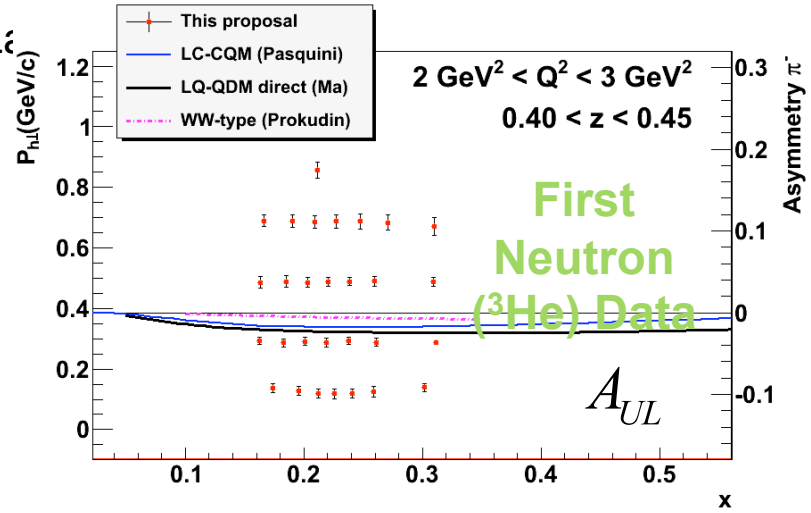
SIDIS and Transverse Spin with the SoLID Spectrometer

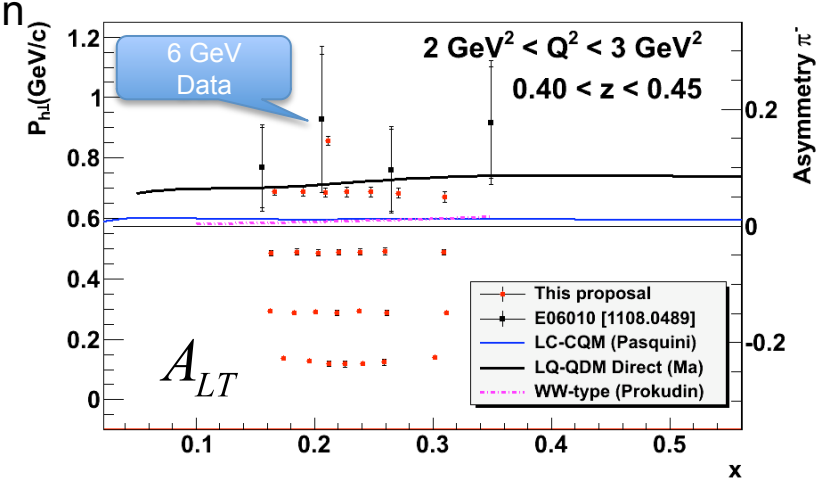


Projections and Comparison with Calculations

ultimate precision 4-D mapping of azimuthal asymmetries

- ***35 PAC days on longitudinally pol. ^{3}He target (8.8 & 11 GeV)***
- Share commissioning and g_{1T} data with E12-10-006 (SoLID-Neutron Transversity)
- ***High statistics and excellent systematic uncertainty***
- **>1000 4-D bins** for A_{LL}, A_{UL} or A_{LT} with $\pi^{\pm}$ together, **1 of 48 Z-Q^2 panels** of π^- shown here
- Neutron asymmetries: δA_{stat} **≈ 0.5%** (absolute)
- La oin

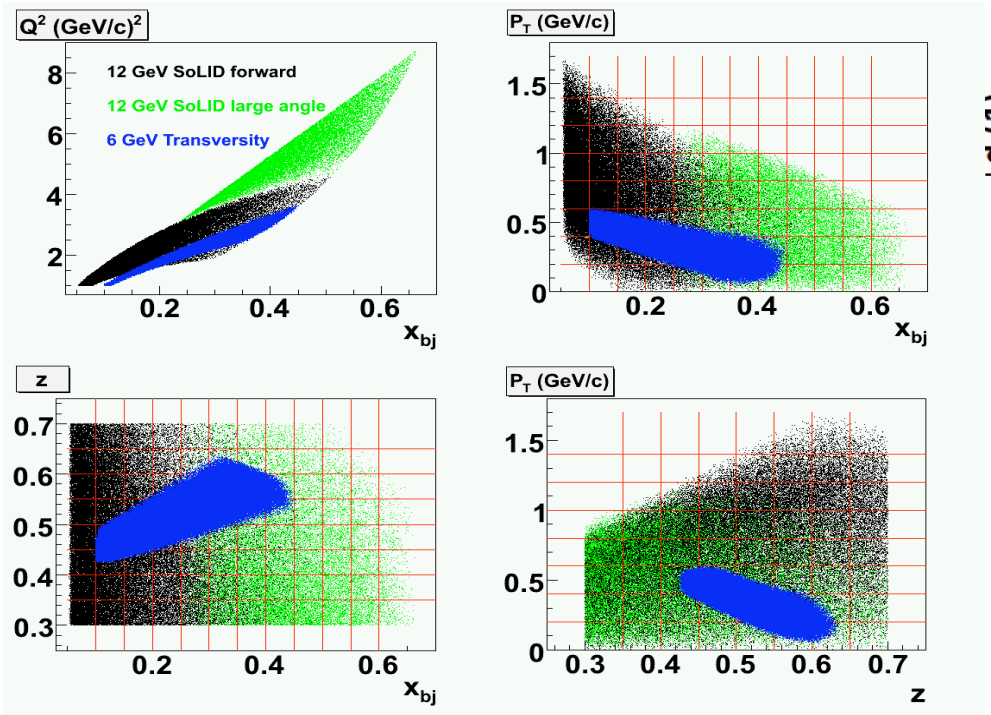


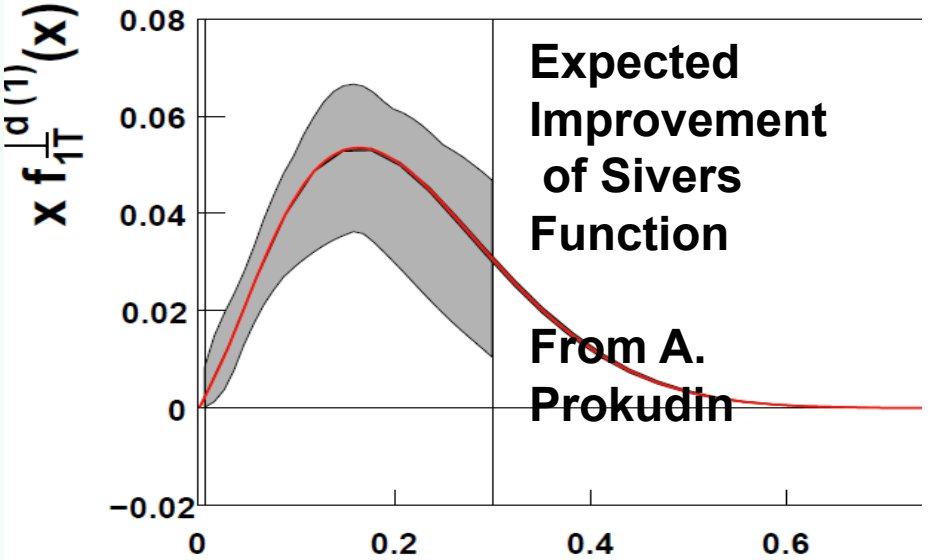


- ***Test TMD relations at matching kinematics***

$g_{1T} \approx ? - h_{1L}^{\perp}$

- suggested by a large class of models based on geometrical symmetry, also supported by lattice calculations
- Test of WW relations, provides a constraint on Transversity

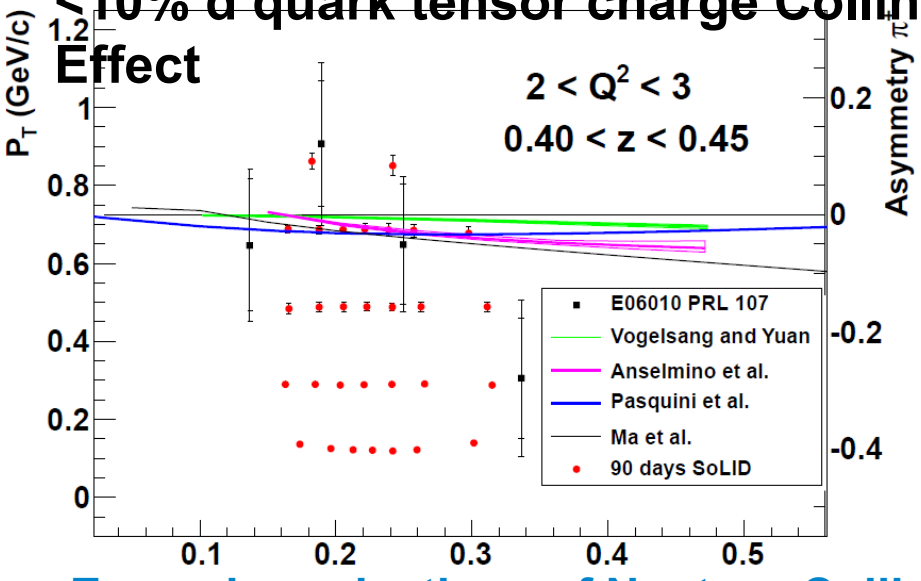




$$A_{UT}^{Collins} \propto \left\langle \sin(\phi_h + \phi_s) \right\rangle \propto h_{1T} \otimes H_1^{\perp}$$

$$A_{UT}^{Sivers} \propto \left\langle \sin(\phi_h - \phi_s) \right\rangle \propto f_{1T}^{\perp} \otimes D_1$$

<10% d quark tensor charge Collins Effect



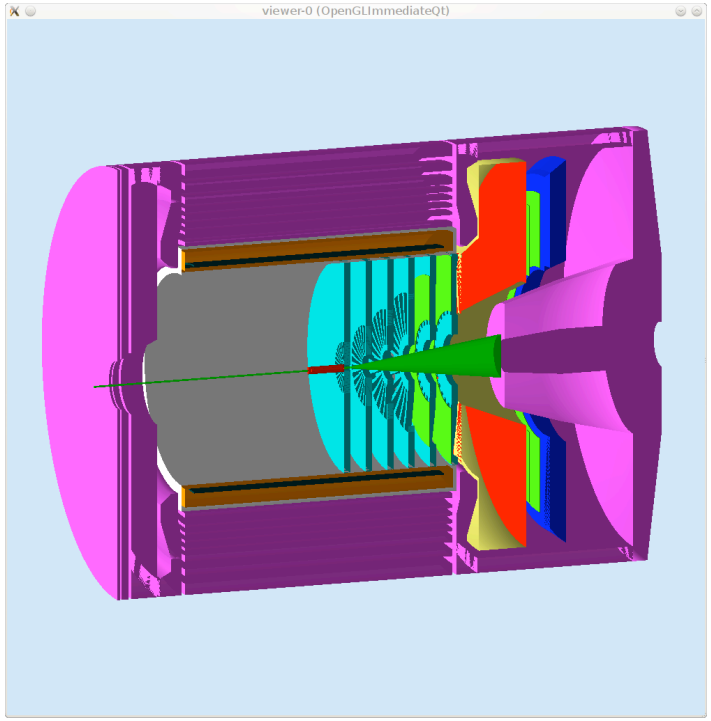
Example projections of Neutron Collins moments, 1/48 bins in z vs. Q^2.

Sys.: 0.1% (abs.) + ~6% (rel.) + Nuclear Effect/ FSI

50 days @ 11 GeV + 22 days @ 8.8 GeV + 10 days on H/D (Dilution, FSI, Mechanism) + 8 days calibration

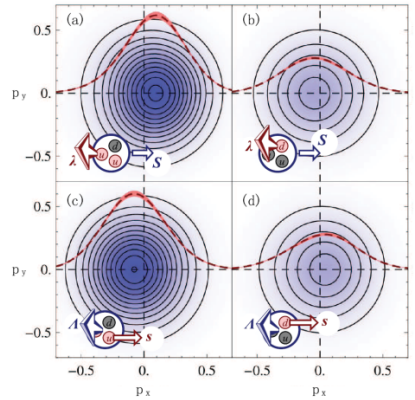
= 90 days!

These data will provide ultimate precision mapping of Neutron SSA in the valence region

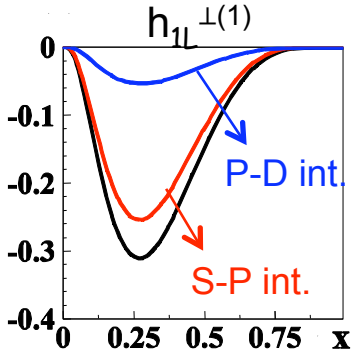

viewer-0 (OpenGLImmediateQt)

g_{1T}

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



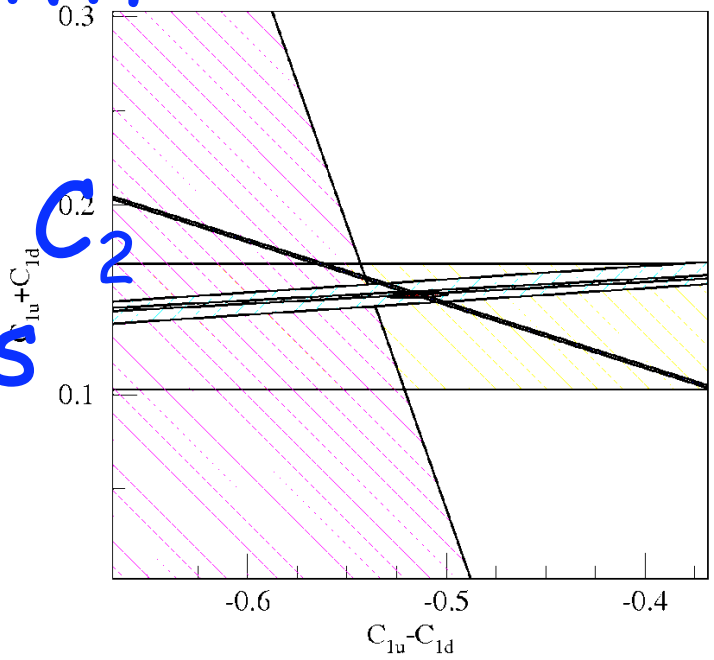
Lattice QCD, arXiv:0908.1283

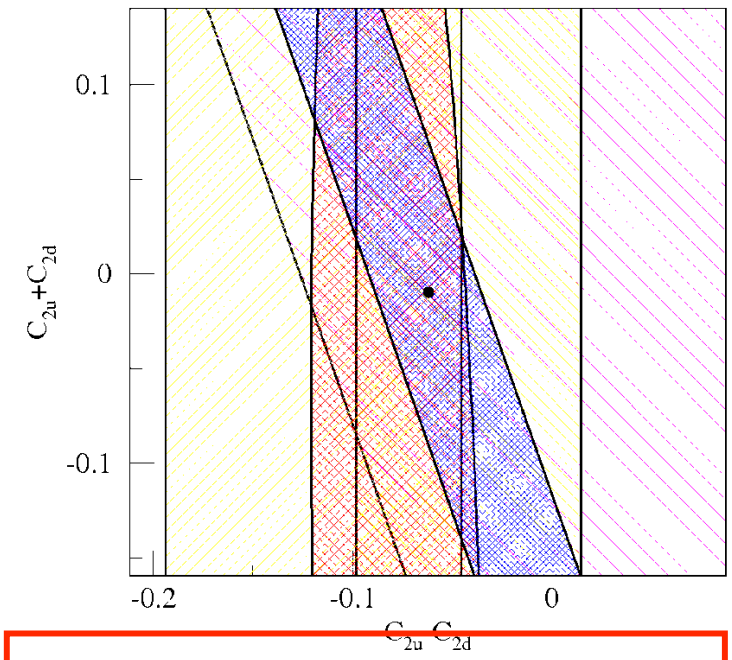


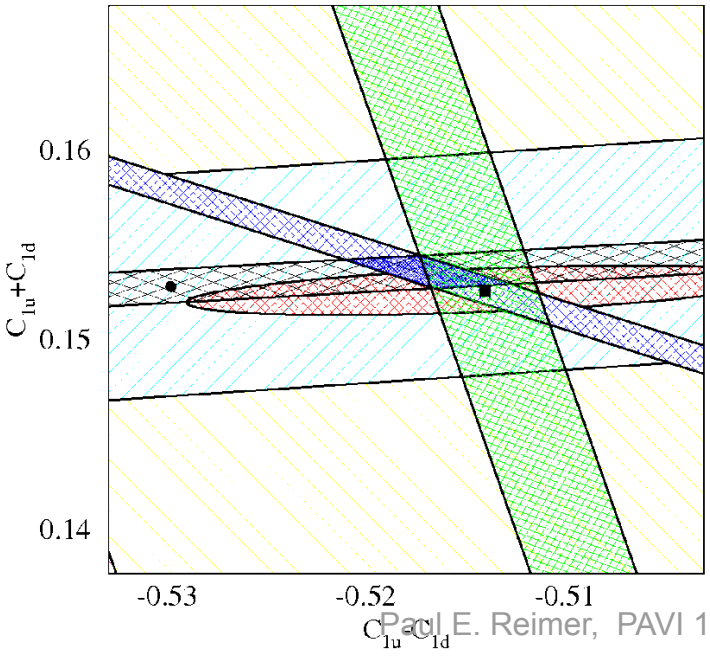
Light-Cone CQM,
arXiv:0806.2298

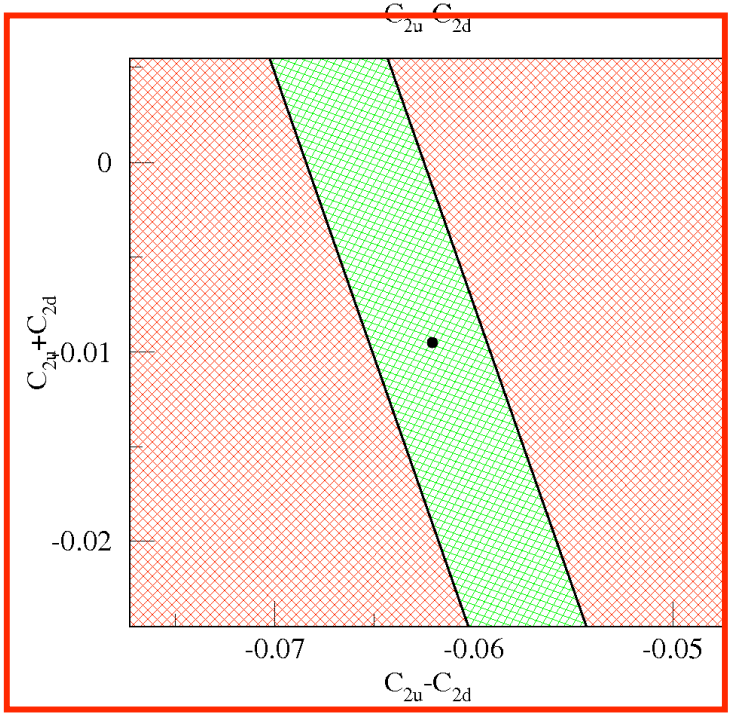
Sensitivity: C_1 and C_2 Plots

World's data





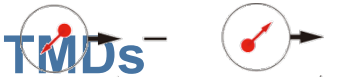




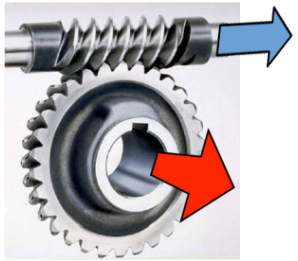
E12-11-007: SIDIS using Longitudinally Pol. ^{3}He and SoLID

a study of spin-orbital correlation

- **Semi-Inclusive DIS $\pi^{\pm}$ production**
  - **Longitudinally Pol. ^{3}He target** effective pol. neutron target, achieved world-best performance
  - **SoLID** large symmetric acceptance detector, high statistics and better angular modulation separation
  - **Extraction of novel TMDs**

- $A_{UL}(\sin(2\phi_h)) \rightarrow h_{1L}^{\perp}$ 
- $A_{LT}(\cos(\phi_h - \phi_S)) \rightarrow g_{1T}$ 

WORM-GEAR distributions, interference of OAMs: Re[(L=0)$_q$×(L=1)$_q$]



- $A_{LL} \rightarrow g_{1L}$  p_T dependent helicity distribution

- **Many predictions available**
- First Lattice QCD calculation
- Light-cone quark model and others
- **No GPD Correspondence**
- Genuine sign of intrinsic transverse motion
- **Links to Collinear PDFs**

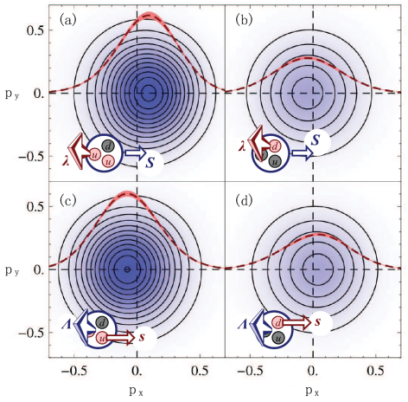
$$h_{1L}^{\perp q(1)}(x) \overset{WW-type}{\approx} -x^2\int_x^1 \frac{dy}{y^2}\cdot h_1^q(y)$$

hep-ph/0603194

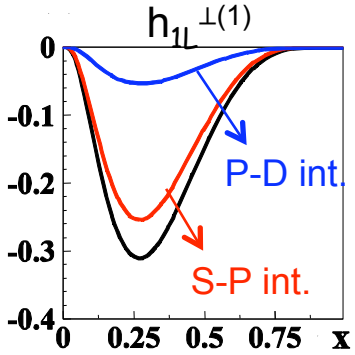
$$g_{1T}^{q(1)}(x) \overset{WW-type}{\approx} x\int_x^1 \frac{dy}{y}\cdot g_1^q(y)$$

g_{1T}

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



Lattice QCD, arXiv:0908.1283



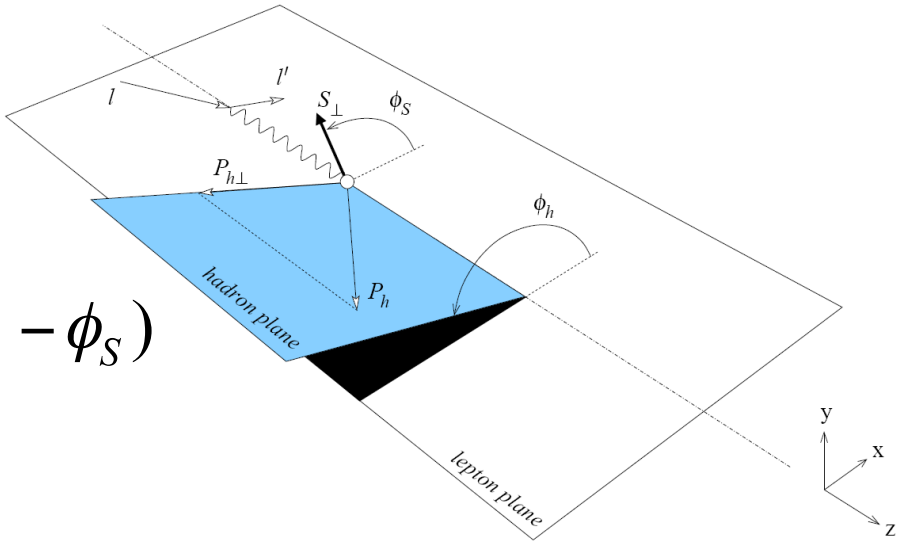
Light-Cone CQM, arXiv:0806.2298

Separation of Collins, Sivers and pretzelocity effects through angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins} \sin(\phi_h + \phi_S) + A_{UT}^{Sivers} \sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity} \sin(3\phi_h - \phi_S)$$



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$$A_{UT}^{Pretzelosity} \propto \left\langle \sin(3\phi_h - \phi_S) \right\rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

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  -
  -
  -
- **Many predictions available**
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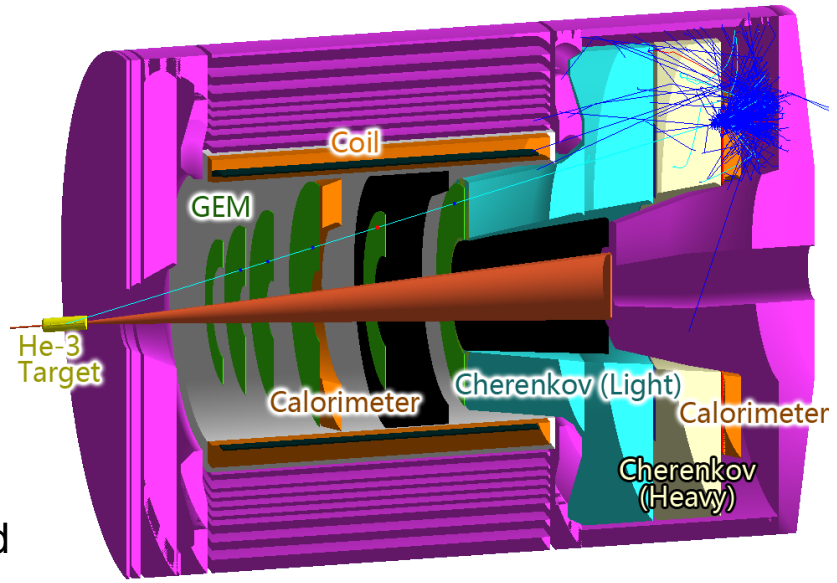
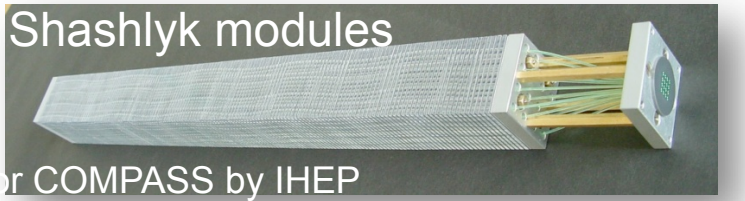
- **No GPD Correspondence**
- Genuine sign of intrinsic transverse motion
- **Links to Collinear PDFs**

Experimental Update

steady progress since approval by PAC37

- **Joint efforts of three approved experiments + one new proposal, international collaboration: eight countries and 50+ institutions**
  - Same detector/DAQ setup with E12-10-006 (SoLID-Neutron Transversity), share beam time for calibration and A_{LT} data
  - Share detector/DAQ setup with E12-10-007 (SoLID-PVDIS)
  - SoLID-Proton Transversity being proposed
- **Status of SoLID Components**
  - **Magnet**: completed study of all magnet options, pursuing CLEO now
  - **DAQ**: pipelined, similar to Hall D
  - **Simulation Frame Work**: customized GEANT4 environment, fully set up
  - **Calorimeter**: options studied, Shashlyk selected as 1st choice, contacted IHEP (Russia) production group
  - **Tracking/Cerenkov/MRPC**: presented in the SoLID-neutron Transversity update
- **Complementary data on proton target**
  - A_{UL}: CLAS12 E12-07-107
  - A_{LT}: Proton Transversity SoLID/CLAS12





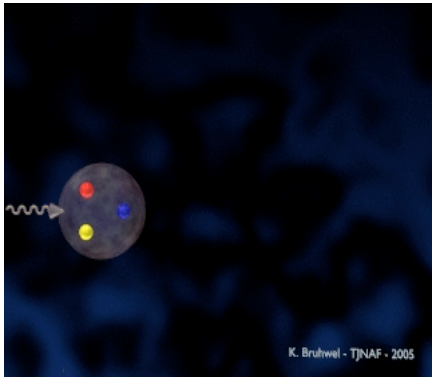
Measurement of TSSA in SIDIS with SoLID on ^{3}He

TMDs provide a 3-D description of nucleon structure in momentum space

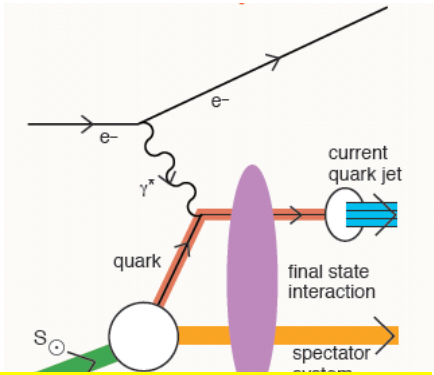
and a direct access to QCD dynamics.

- **<10% d quark tensor charge (Collins moments)**
  - Fundamental property of nucleon **benchmark test of Lattice QCD**
- 4-D (x,Q^2,z,P_T) mapping of **Sivers moments**
  - Spin-orbital correlation: promising to access **Orbital Angular Momentum (OAM)**
  - Provide precision data to test TMD **factorization and scale evolution**
  - Search for **sign change** in Sivers function (possible resolution to sign mismatch SIDIS vs. pp)
- Aim for first non-zero Pretzelosity Moments
  - Direct Probe of **relativistic effect and OAM** within models
- Large Acceptance Device handling High Luminosity
  - **Need a dedicated device: SoLID!**
- Measuring cross section ratios on p, d, ^{3}He

Collins Effect



Sivers Effect

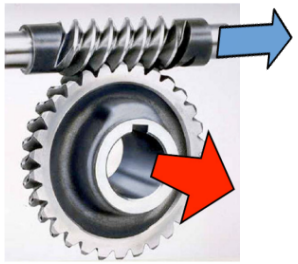


Ultimate Precision Measurements of 4-D Neutron Collins, Sivers, and Pretzelosity Moments

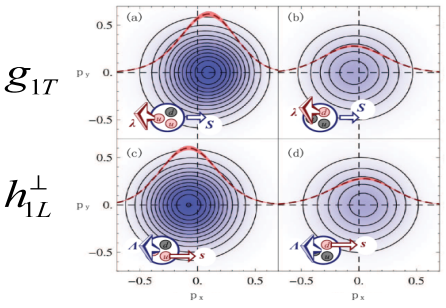
SIDIS Physics

- **Semi-Inclusive DIS $\pi^{\pm}$ production**
  - **Longitudinally Pol. ^{3}He target** effective pol. neutron target, achieved world-best performance
  - **SoLID** large symmetric acceptance detector, high statistics and better angular modulation separation
  - **Extraction of novel TMDs**
    - $A_{UL}(\sin(2\phi_h)) \rightarrow h_{1L}^{\perp}$ 
    - $A_{LT}(\cos(\phi_h - \phi_S)) \rightarrow g_{1T}$ 

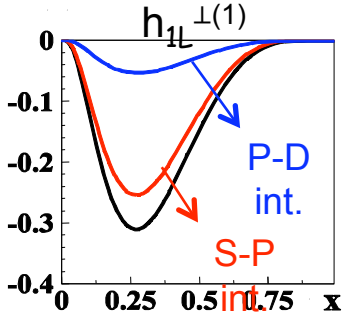
      WORM-GEAR distributions, interference of OAMs: $\mathrm{Re}[(L=0)_q \times (L=1)_q]$
    - $A_{LL} \rightarrow g_{1L}$  p_T dependent helicity distribution



- **Many predictions available**
- First Lattice QCD calculation
- Light-cone quark model and others
- **No GPD Correspondence**
- Genuine sign of intrinsic transverse motion
- **Links to Collinear PDFs**



Lattice QCD, arXiv:0908.1283



Light-Cone CQM, arXiv:0806.2298