Proposal C12-11-108:
Target Single Spin Asymmetry in SIDIS *(e, e′π±)* Reaction on a Transversely Polarized Proton Target and SoLID

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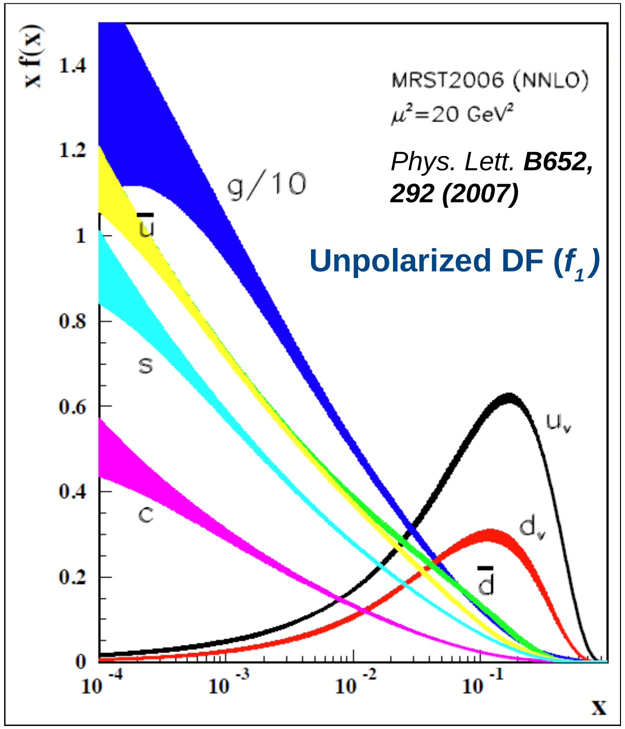
for C12-11-108 and Hall A Collaboration

PAC39 Meeting, June 18th 2012

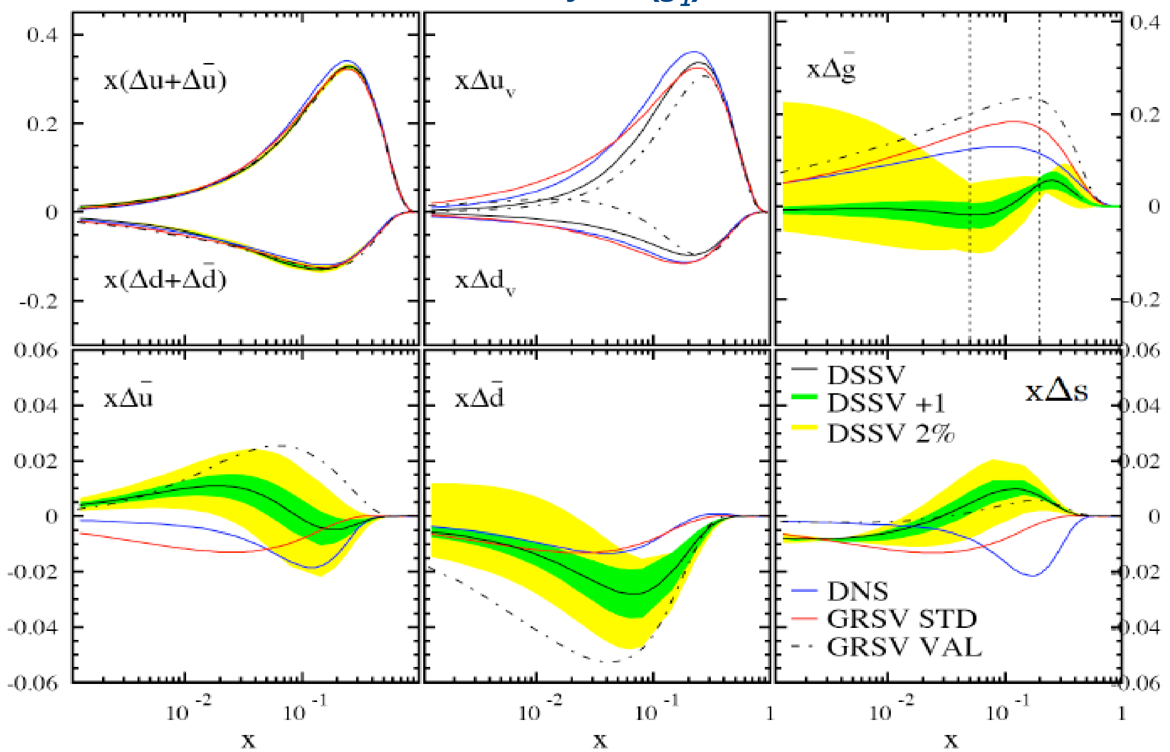
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Motivation

- Leading twist Parton Distribution Function
  - Unpolarized PDF : $f_1(x)$ (very well known)
  - Longitudinally polarized: $g_1(x)$ (well known)
  - Transversity: $h_1(x)$ (least known)
- Experimental efforts to measure h_1 have recently begun
- First global extraction of transversity DF (Anselmino *et al., 2007*)
  - Related to nucleon tensor charge (first moment of $h_1(x)$)
- Nucleon spin puzzle:
  - Orbital angular momentum of quarks and gluons is important
- Transverse Momentum Dependent PDFs
  - Mapping of 3-d structure in momentum space
  - Access OAM through spin-orbit correlations
  - Study QCD dynamics
  - Semi-Incluisve DIS is an ideal tool to measure TMDs



Helicity DF (g_1)



Leading Twist Transverse Momentum Dependent PDFs

: Nucleon Spin :Quark Spin

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

f_1, g_{1L} and h_1 survive integration over quark transverse momentum k_T

Leading Twist Transverse Momentum Dependent PDFs

: Nucleon Spin :Quark Spin

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

Accessible using transversely polarized target

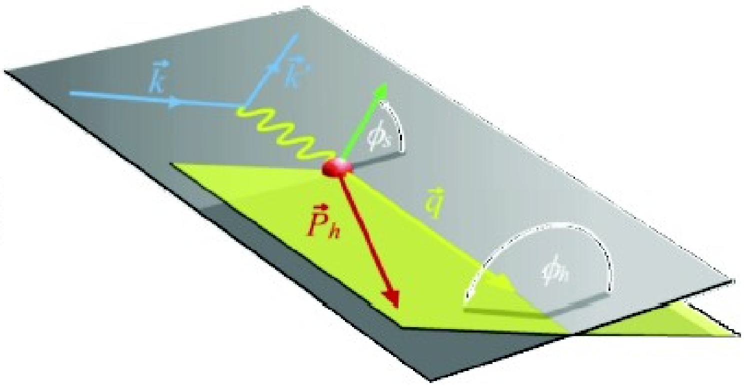
f_1, g_{1L} and h_1 survive integration over quark transverse momentum k_T

Separation of Azimuthal Moments

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

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

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



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

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

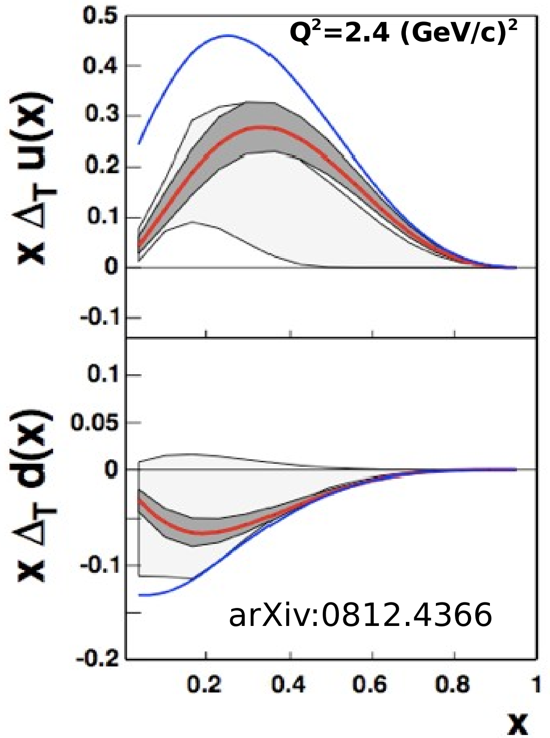
$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

Collins frag. Func. from e^+e^- collisions

SIDIS SSAs depend on 4-D variables (x, Q^2, z and P_T)

Large angular coverage and precision measurement of asymmetries in 4-D phase space is essential.

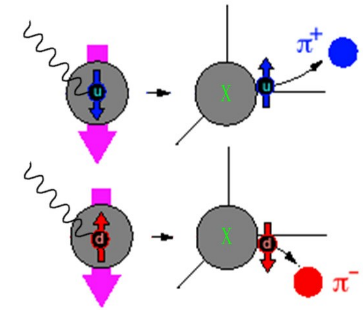
Transversity



$$\sigma_{UT}^{SIDIS} \propto \sin(\phi_h + \phi_S)\ h_1 \otimes H_1^{\perp}$$

Transversely polarized quark generates left-right asymmetry during fragmentation

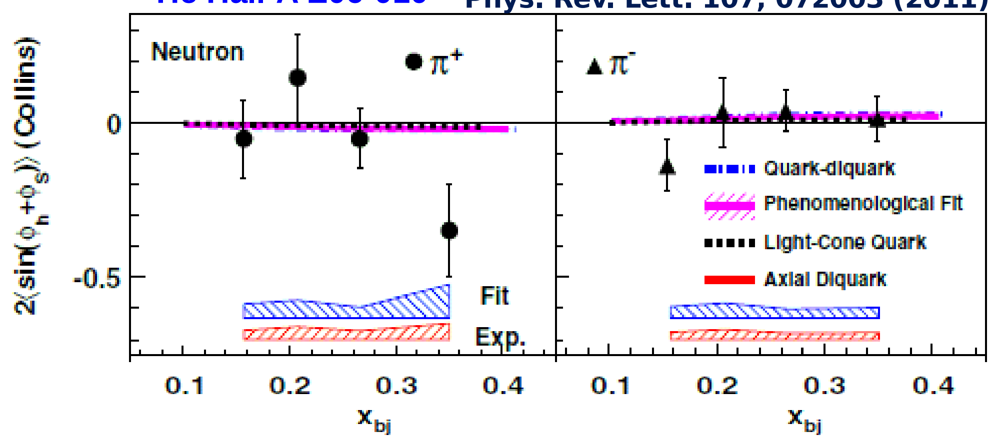
Collins Effect



Solid blue line: Soffer bound
|h1T| <= (f1+g1L)/2

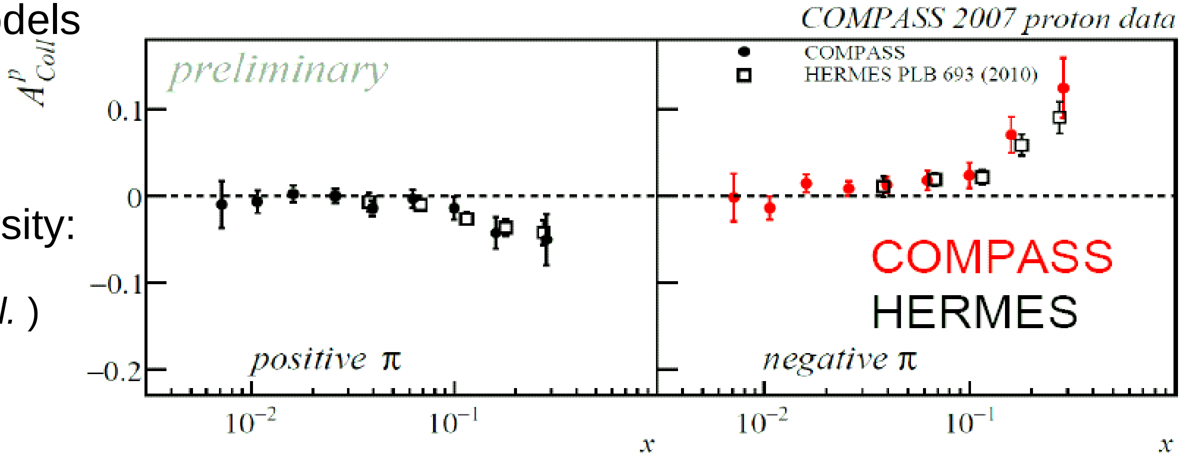
³He Hall-A E06-010

Phys. Rev. Lett. 107, 072003 (2011)



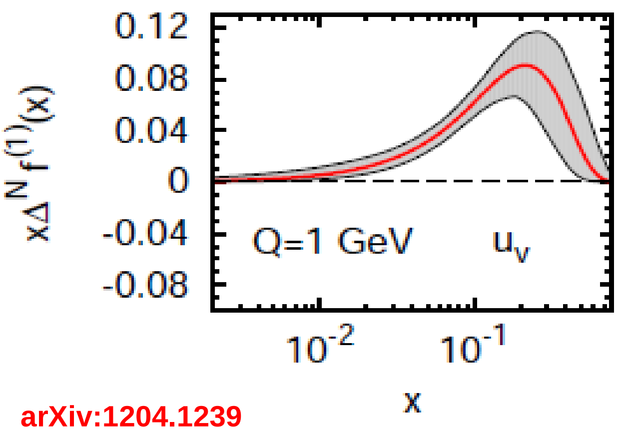
- Least known leading twist PDF
  - Valence like behavior
- Lower moment gives tensor charge - fundamental property, benchmark test for Lattice QCD + models
- First data from:
  - HERMES(p), COMPASS(p,d) and Hall-A(n)
- Initial model-dependent extraction of transversity:
  - Global fit to HERMES(p) and COMPASS (d) and BELLE e+e- data by Torino group (Anselmino *et al.*)
- Need precision data in high x region

COMPASS 2007 proton data

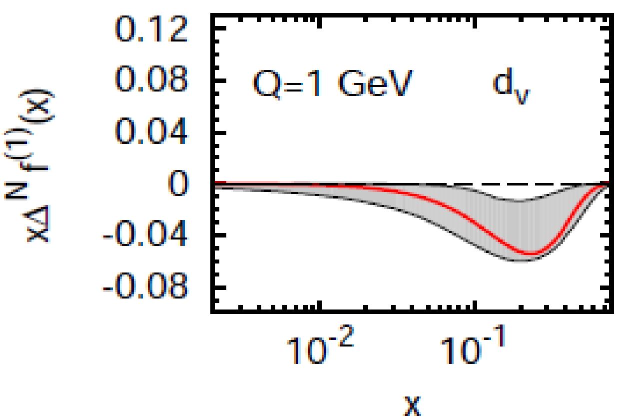


C. Schill, DIS2011 Workshop

Sivers Function

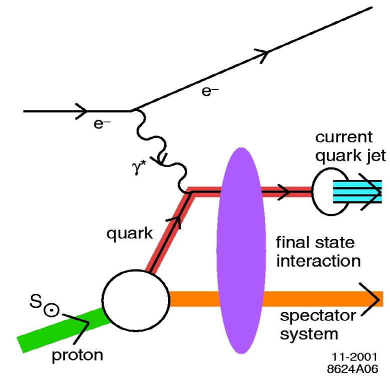


arXiv:1204.1239

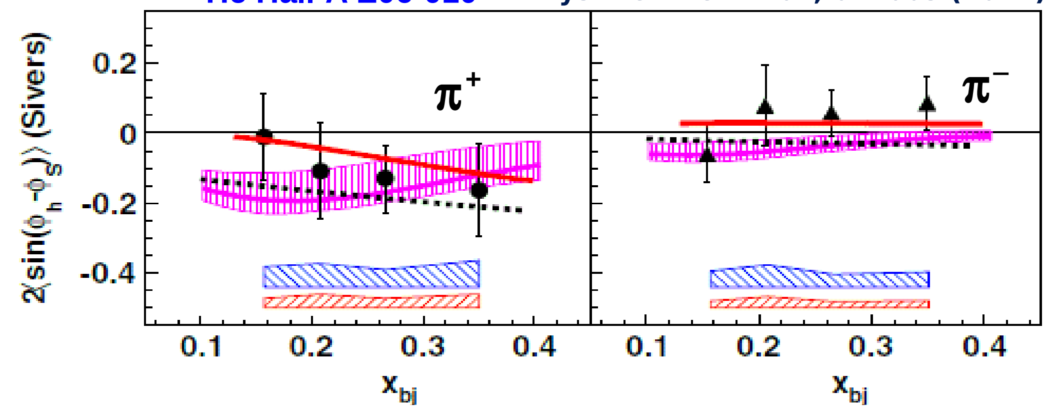


$$\sigma_{UT}^{SIDIS} \propto \sin(\phi_h - \phi_S)\; f_{1T}^{\perp} \otimes D_1$$

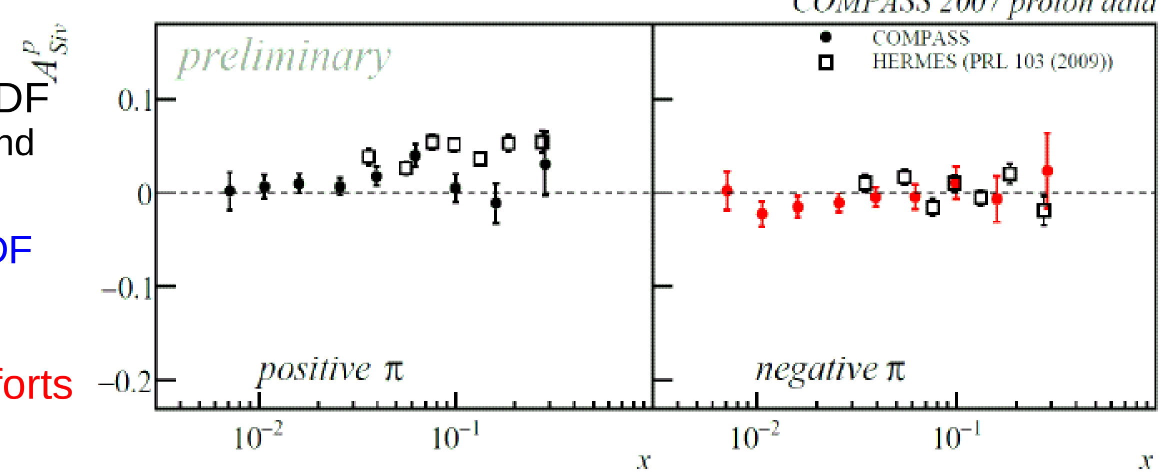
Correlation between transverse spin of nucleon and transverse momentum of the quark



^{3}He Hall-A E06-010 **Phys. Rev. Lett. 107, 072003 (2011)**



COMPASS 2007 proton data



- Requires non-zero quark OAM
- Sign change from SIDIS to DY - important test of TMDs factorization in QCD
- Initial model-dependent extraction of Sivers DF
  - Using HERMES and COMPASS proton data and TMD evolution (Anselmino *et al.*)
- Constrain quark OAM using GPD *E* and Sivers DF
  Bacchetta *et. al,* Phys. Rev. Lett. 107, 212001 (2011)
- Very active theory and phenomenological efforts to understand parton dynamics using TMDs

C. Schill, DIS2011 Workshop

World Data on Transverse SSA

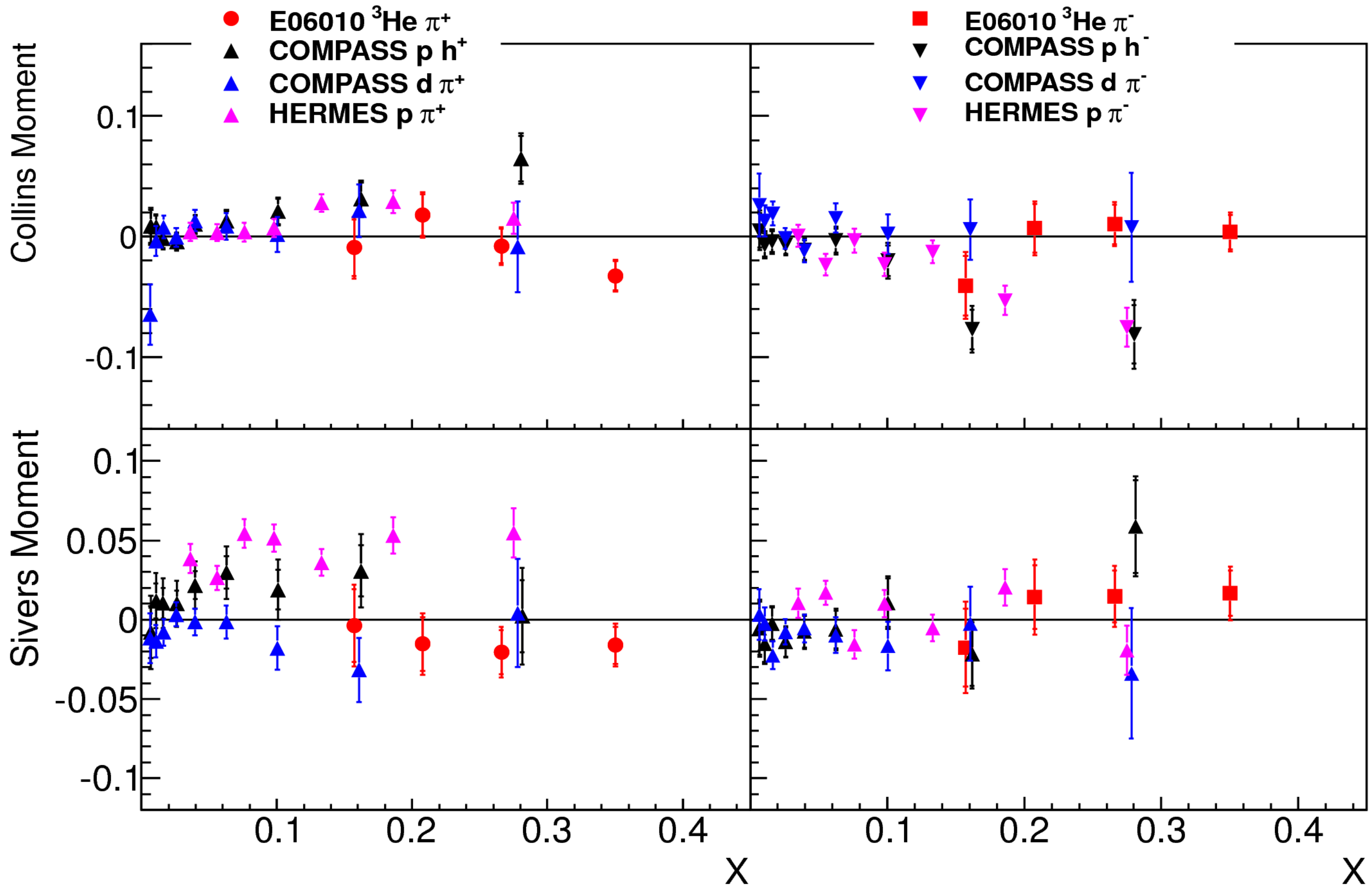
(proton, deuteron, ^{3}He)

Target SSA on transversely polarized targets

JLab(E06-010)
Q^2 = 1.4 - 2.7 GeV^2

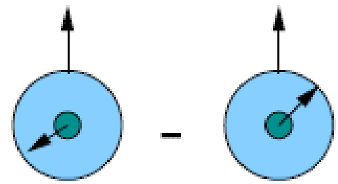
HERMES:
Q^2 = 1.3 - 6.2 GeV^2

COMPASS:
Q^2 = 1.3 – 20.2 GeV^2



Moments integrated
over other dimensions (Q^2, z, P_T)

Pretzelosity

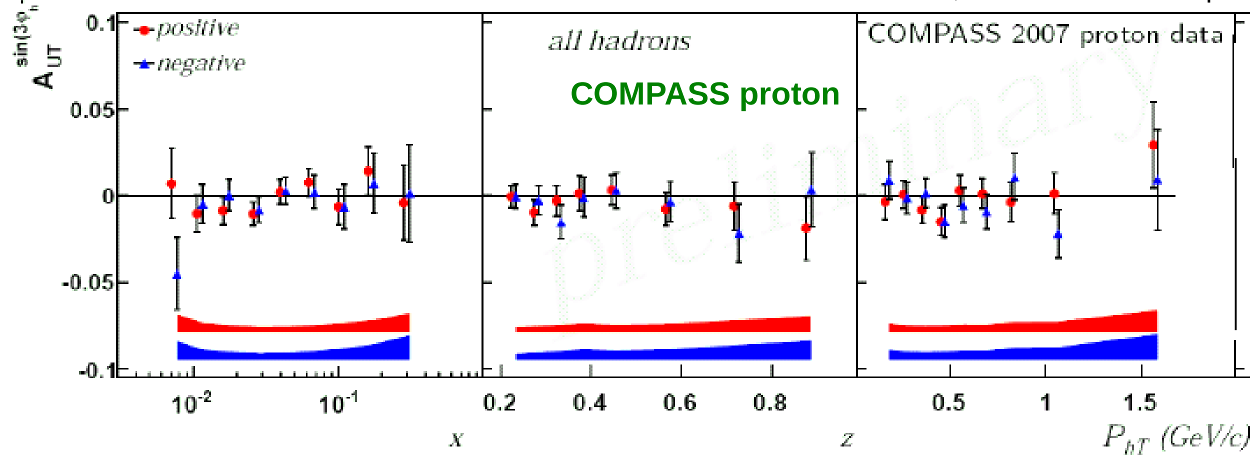
$h_{1T}^{\perp}$ 

Correlation between transverse momentum and transverse polarization of the nucleon

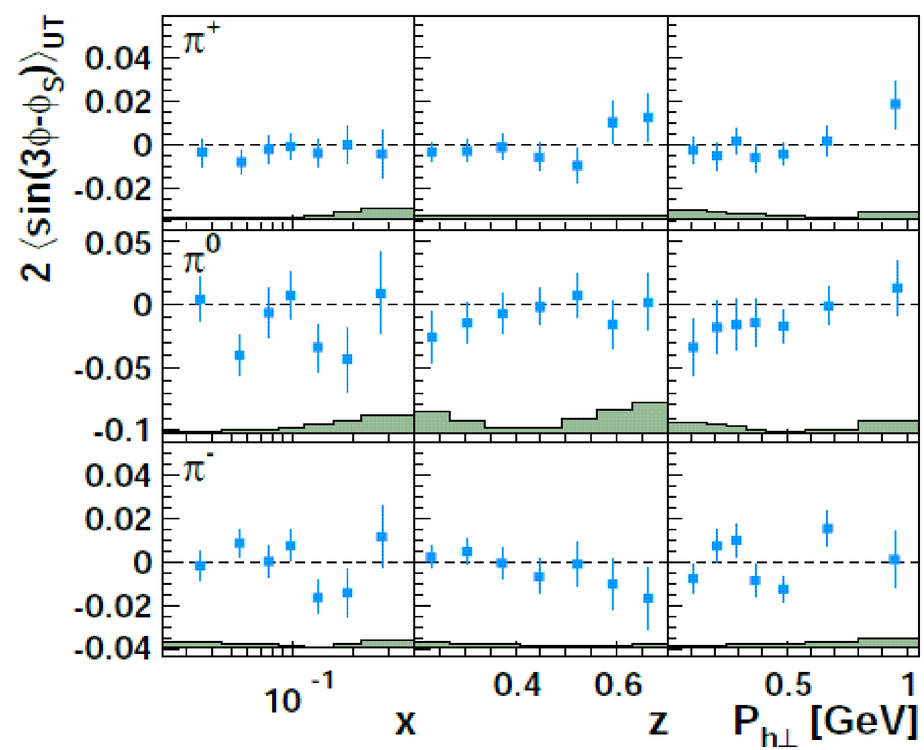
$$\sigma_{UT}^{SIDIS} \propto \sin(3\phi_h - \phi_S)\ h_{1T}^{\perp} \otimes H_1^{\perp}$$

- Direct probe of relativistic effects
- Access to quark OAM (model dependent)
- Limited precision - no clear signal seen yet!

C. Schill, DIS2011 Workshop



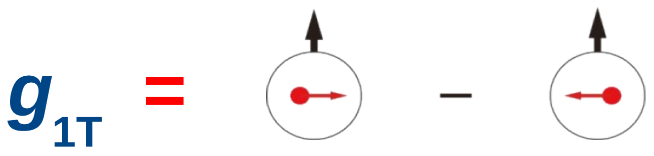
HERMES proton



M. Diefenthaler's
Dissertation (HERMES)

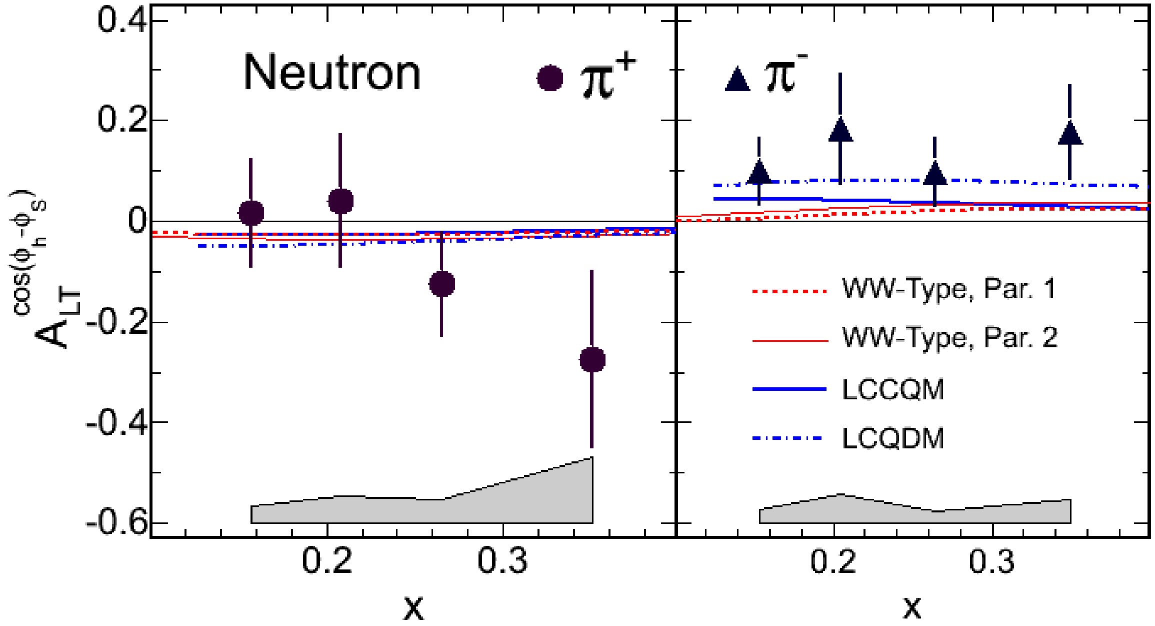
Trans-Helicity

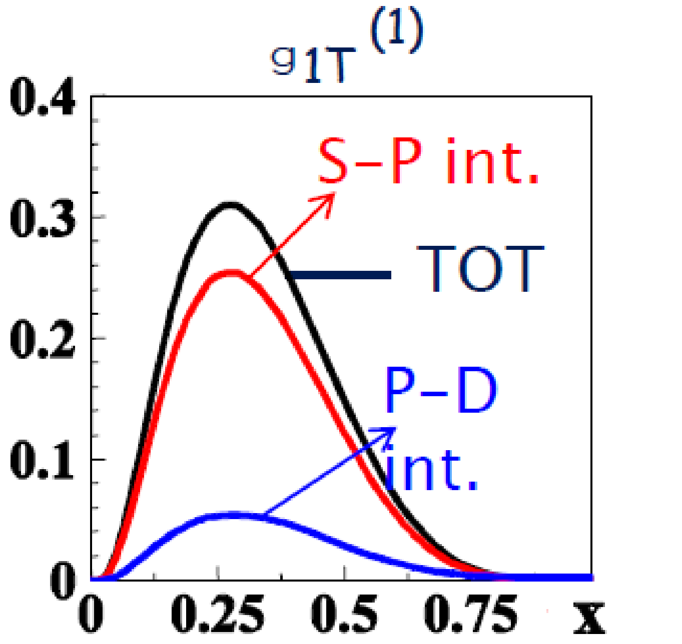
$$\sigma_{LT}^{SIDIS} \propto \cos(\phi_h - \phi_S)\ g_{1T} \otimes D_1$$



- Leading twist TMD
- T-even, chiral-even
- No GPD correspondence
- Accessible using polarized beam+ polarized target
- g_{1T} dominated by ~ Re[(L=0) x (L=1)] -> spin-orbit correlation
- First non-zero A_{LT} signal from Hall-A E06-010 experiment using polarized ^{3}He

Phys. Rev. Lett. 108, 052001 (2012)





Light-Cone CQM by B. Pasquini
B.P., Cazzaniga, Boffi, PRD78, 2008

Proposed Experimental Goals

- Provide ultimate precision 4d(x, z, P_T, Q^2) mapping of target SSA in the valence quark region
- Flavor decomposition of Transversity, Sivers and Pretzelosity (when combined with neutron data)
- Extract tensor charge of both u and d-quark to better than 10% accuracy combined with ^{3}He SoLID data
- Extract leading-twist TMD g_{1T} using Double Spin Asymmetry

$$P = u_p(\frac{4}{9}) \oplus u_p(\frac{4}{9}) \oplus d_p(\frac{1}{9}) = u_p(\frac{8}{9}) \oplus d_p(\frac{1}{9})$$

Dominated by u-quark

$$N = u_n(\frac{4}{9}) \oplus d_n(\frac{1}{9}) \oplus d_n(\frac{1}{9}) \overset{C.S.}{=} d_p(\frac{4}{9}) \oplus u_p(\frac{2}{9})$$

Sensitive to d-quark

PAC 38 Report

- Strong endorsement from PAC38

Motivation: This experiment will measure the semi-inclusive cross-sections for π^+ and π^- production from a transversely polarized proton target, using the large acceptance detector "SoLID" in Hall A. By mapping out the dependence of the target single spin asymmetry on the angle ϕ_h of the hadronic plane and the angle ϕ_S of the target spin (relative to the leptonic plane), one can (in principle) extract three of the leading twist transverse momentum-dependent structure functions (TMDs) of the proton. Measuring double spin asymmetries (with beam helicity) simultaneously, a forth TMD becomes available. Together with equivalent measurements on ^3He (n), this type of experiment is crucial for a complete picture of the 3-D quark structure of the nucleon.

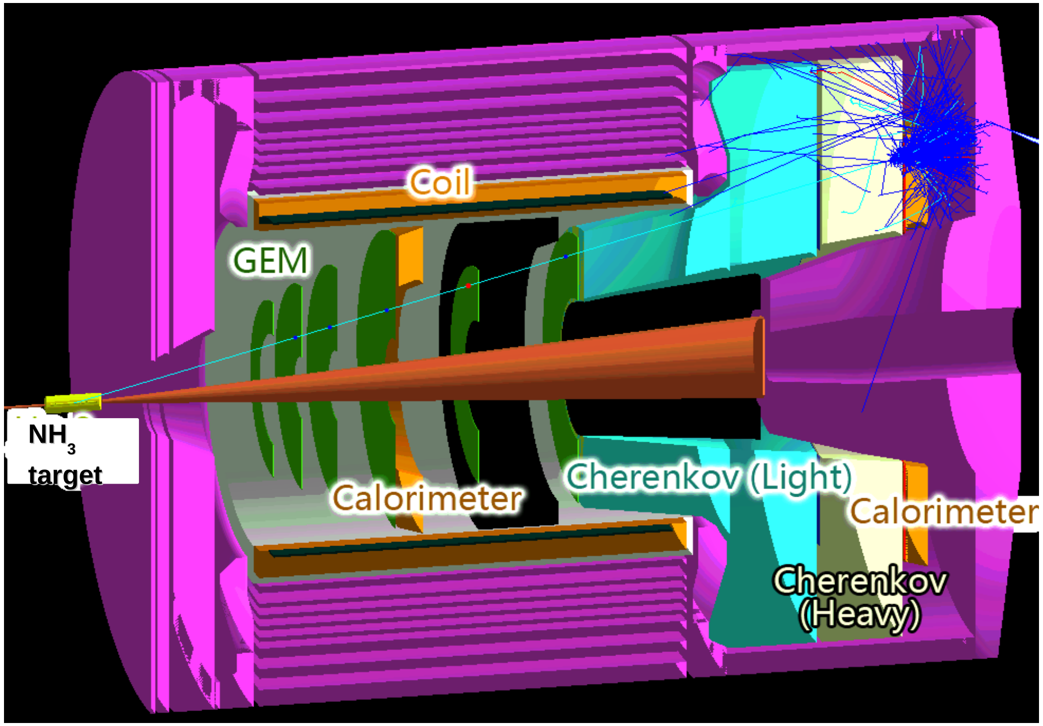
Questions/concerns raised by PAC38

- Complete design of the target magnet with proposed opening angle
- Interactions between magnets, affect of resultant forces on each other and field uniformity
- Detailed simulation of the backgrounds and effect on detector performance/tracking

Experiment Overview

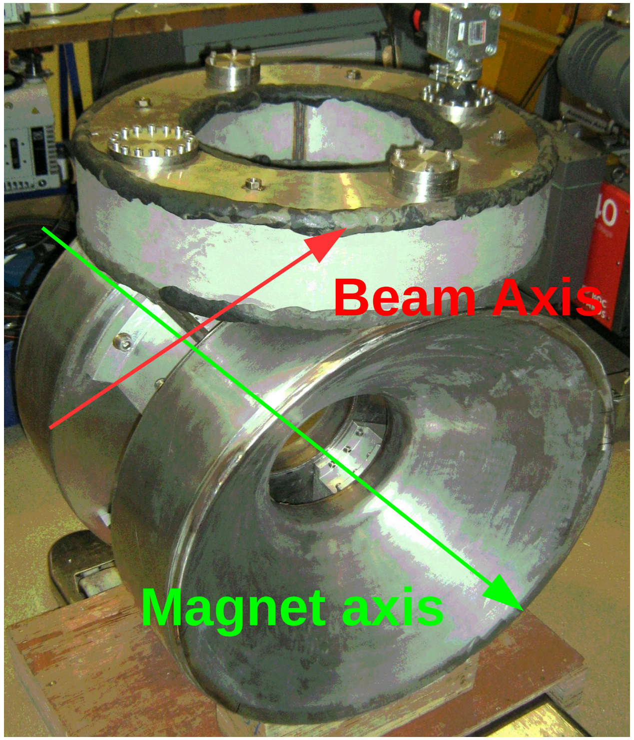
$$e + p^{\uparrow} \longrightarrow e' + \pi^{+/-} + X$$

- Measure SSA in SIDIS using transversely polarized proton target
- Use similar detector setup as that of two approved ^{3}He-SoLID SIDIS expts.
- Use JLab/UVa polarized NH_3 target with upgraded design of the magnet
- Target spin-flip every 2 to 4 hours with average in-beam polarization of 70%
- Two Beam energies: 11 GeV and 8.8 GeV
- Polarized luminosity with 100nA current: 10^{35} cm^{-2}s^{-1}
- Beamline chicane to transport beam through 5T target field

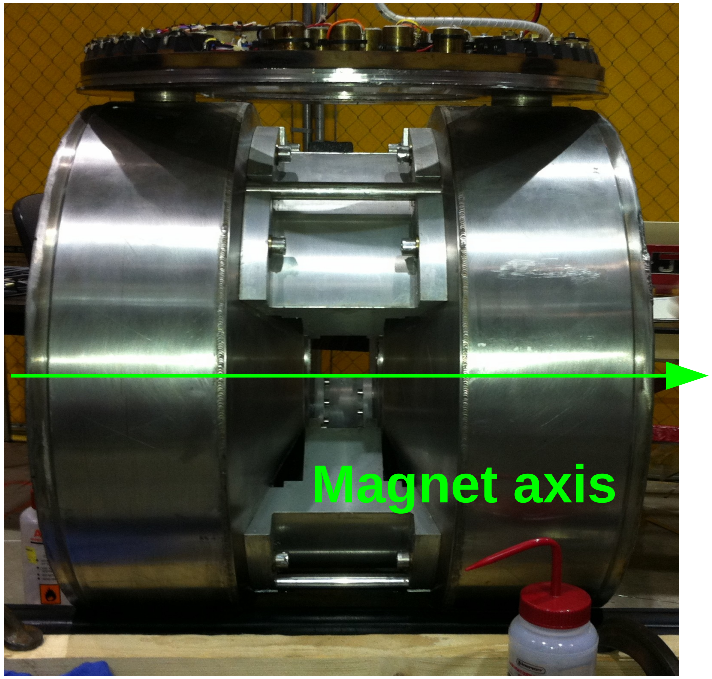


Polarized Proton Target

- Well known system - used in many experiments at Jlab/SLAC
  - 3 cm long NH_3 target
  - Dynamic Nuclear Polarization(DNP) using microwave pumping
  - 5 Tesla superconducting magnet
  - 1K refrigerator
  - NMR system for polarization measurement
  - Spin-reversal using microwaves
  - Magnet cone:
    - Opening of +/- 45° in longitudinal direction
    - Opening of +/- 17° in transverse direction



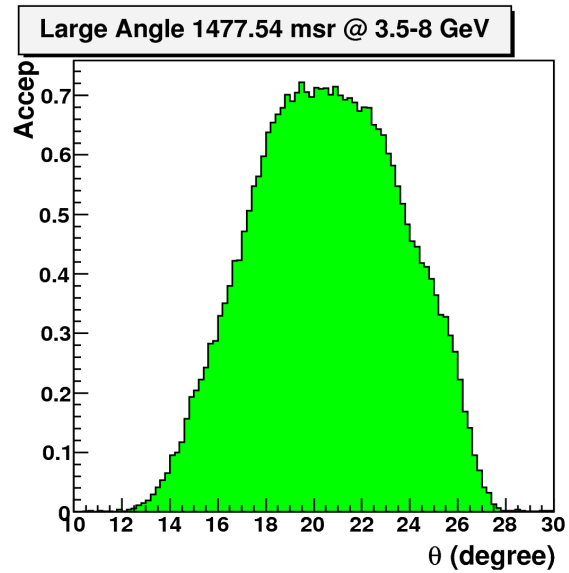
- Most recently used in Hall-A for g2p/gep experiments
  - Very successful with 90% polarization

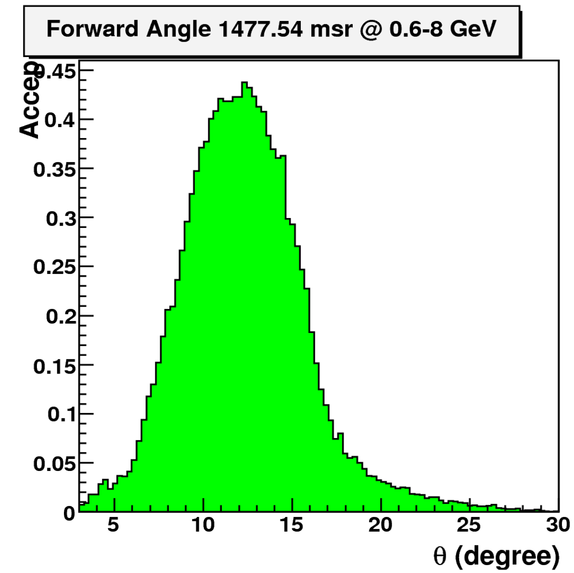


- Proposed upgrade of the magnet:
  - Larger opening in transverse direction (+/- 25°)
- Preliminary design report from Oxford Instruments ready
- Possible improvements:
  - Fast spin-reversal using RF induced adiabatic fast passage (AFP)
  - Improved packing fraction using target disks

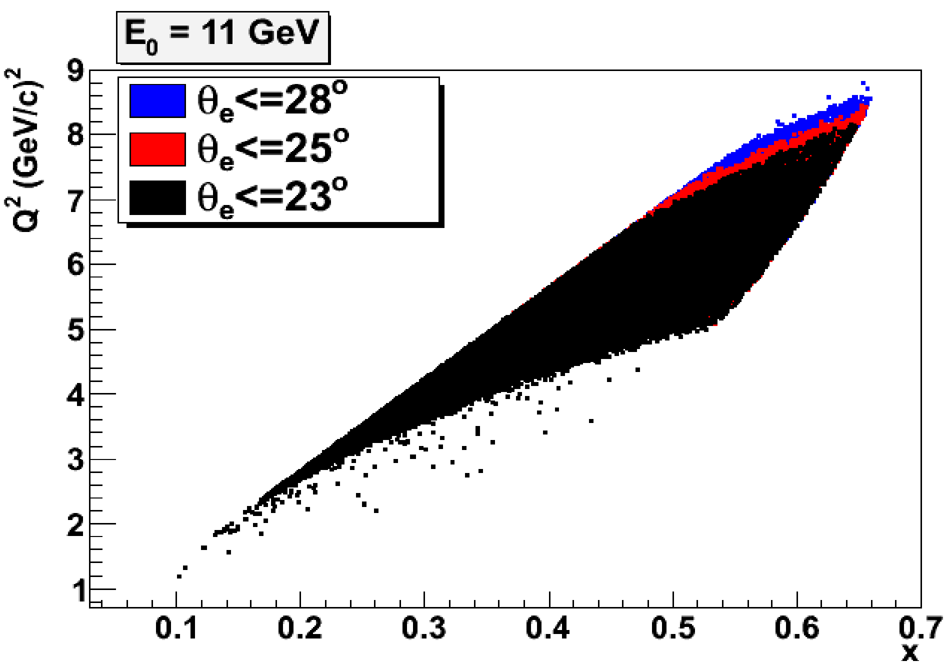
Acceptance

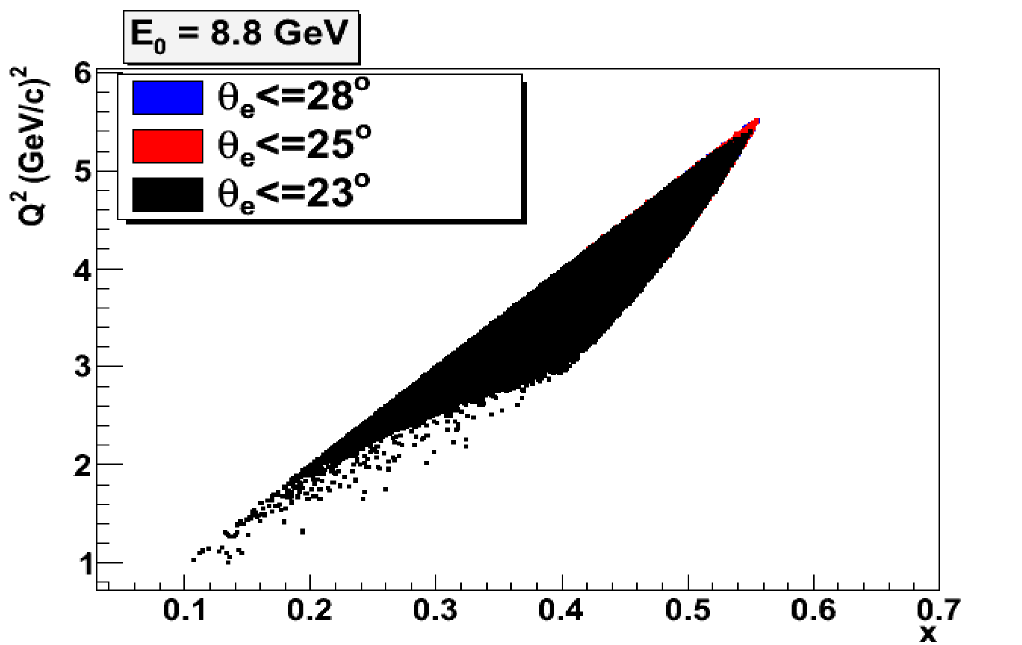
- Opening angle of 25^o can cover almost all of the proposed phase space
- Loss in statistics is negligible (less than 5% for 11 GeV)
- New magnet with 25^o opening angle is possible





Phase space with different opening angle in transverse direction





New Target Magnet Design Study

- Preliminary report from Oxford Instruments is now available!

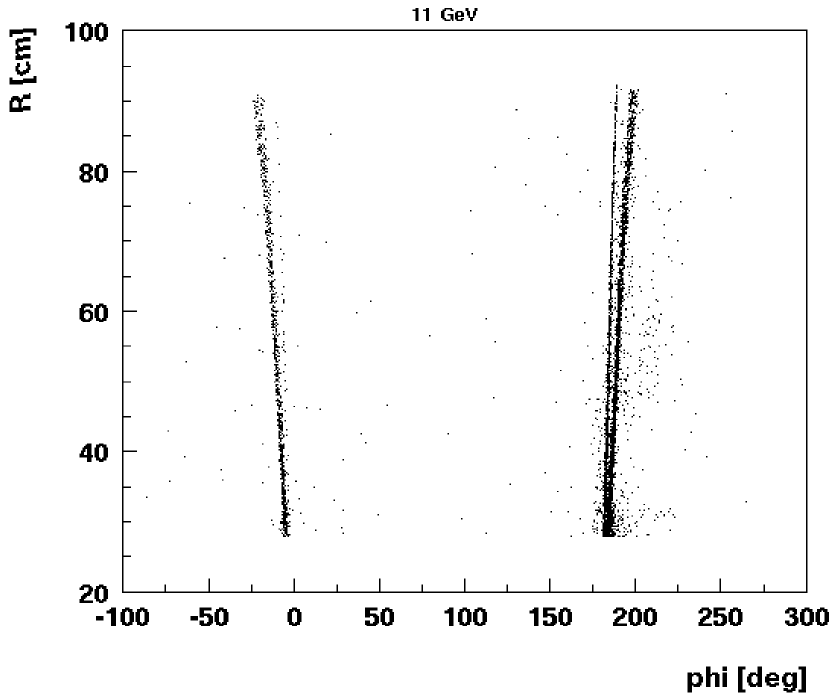
• Central Field	5 tesla
• Field Direction	horizontal
• Split Access	±25 degrees minimum
• Homogeneity	1 part in 10^4 over a 15mm diameter spherical volume
• Operating temperature	4.2 K.
• Field stability	better than 10^{-4} per hour in the persistent mode
• Bore Access	as allowed by split requirement
• Operating current	< 120 amps

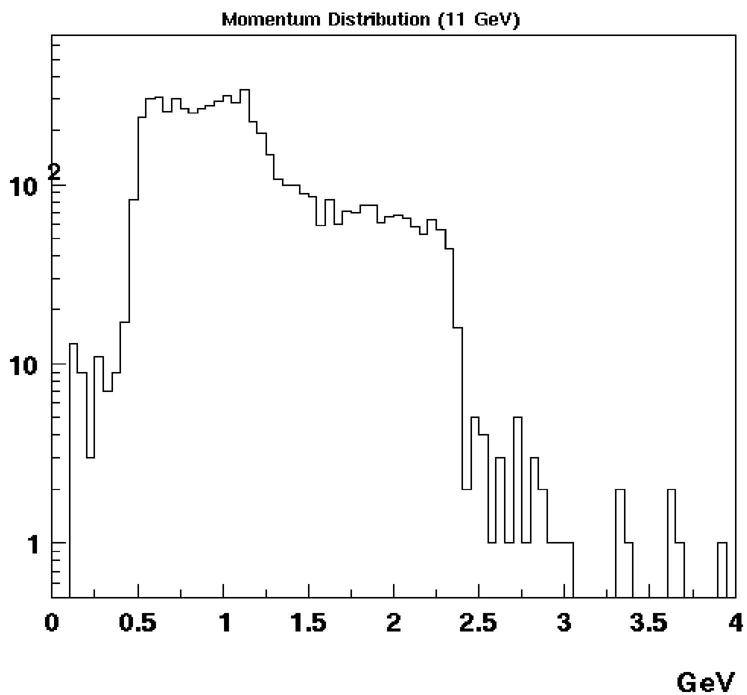
Conclusion :

Preliminary analysis indicates that 5 tesla with +/-25 degrees split access is possible

Background Studies

- Background simulations done using GEANT3 model
- In general background is lower than ^{3}He-SoLID SIDIS proposal
- Low momentum particles (< 400 MeV/c) are suppressed in the acceptance due to transverse target field
- *"Sheet of flame"* background : high rates in localized area of the acceptance
  - caused by the 5 T target field
  - dominated by changed particles (e^-/e^+)

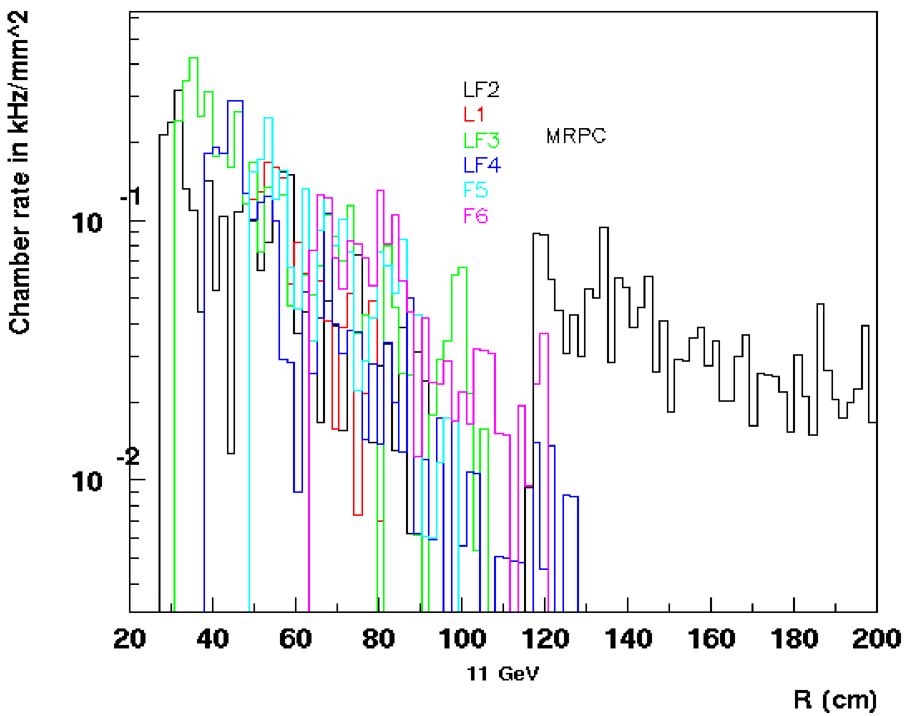


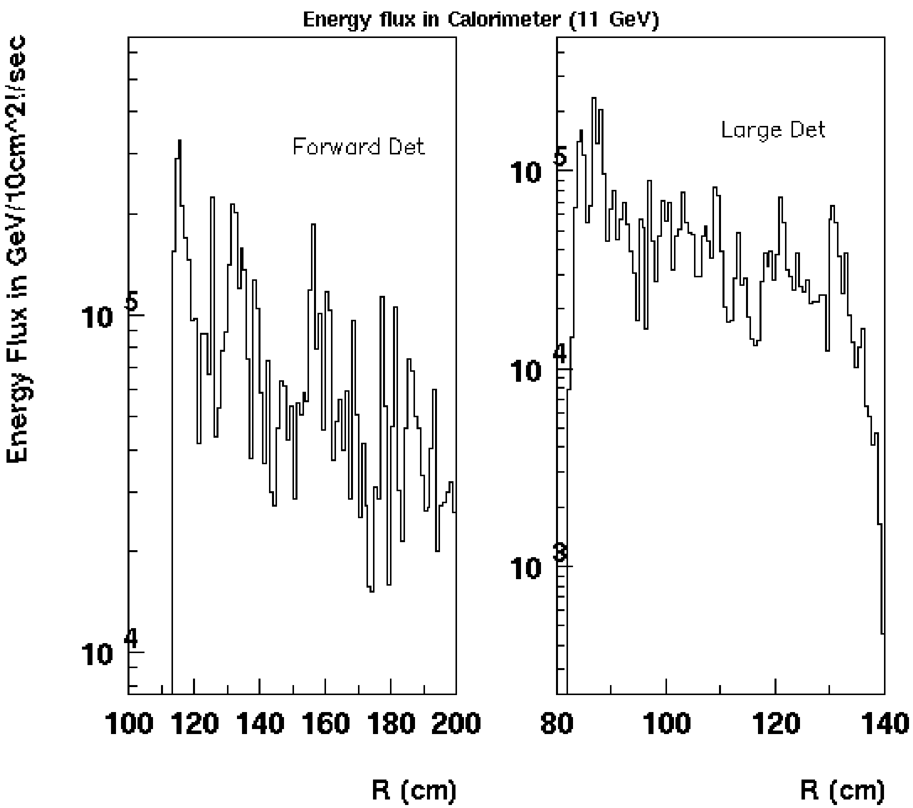


- Ways to deal with this background:
  - Turn off affected sectors of the detectors (preferred)
  - Add local shielding at the target (under study)

Background Rates

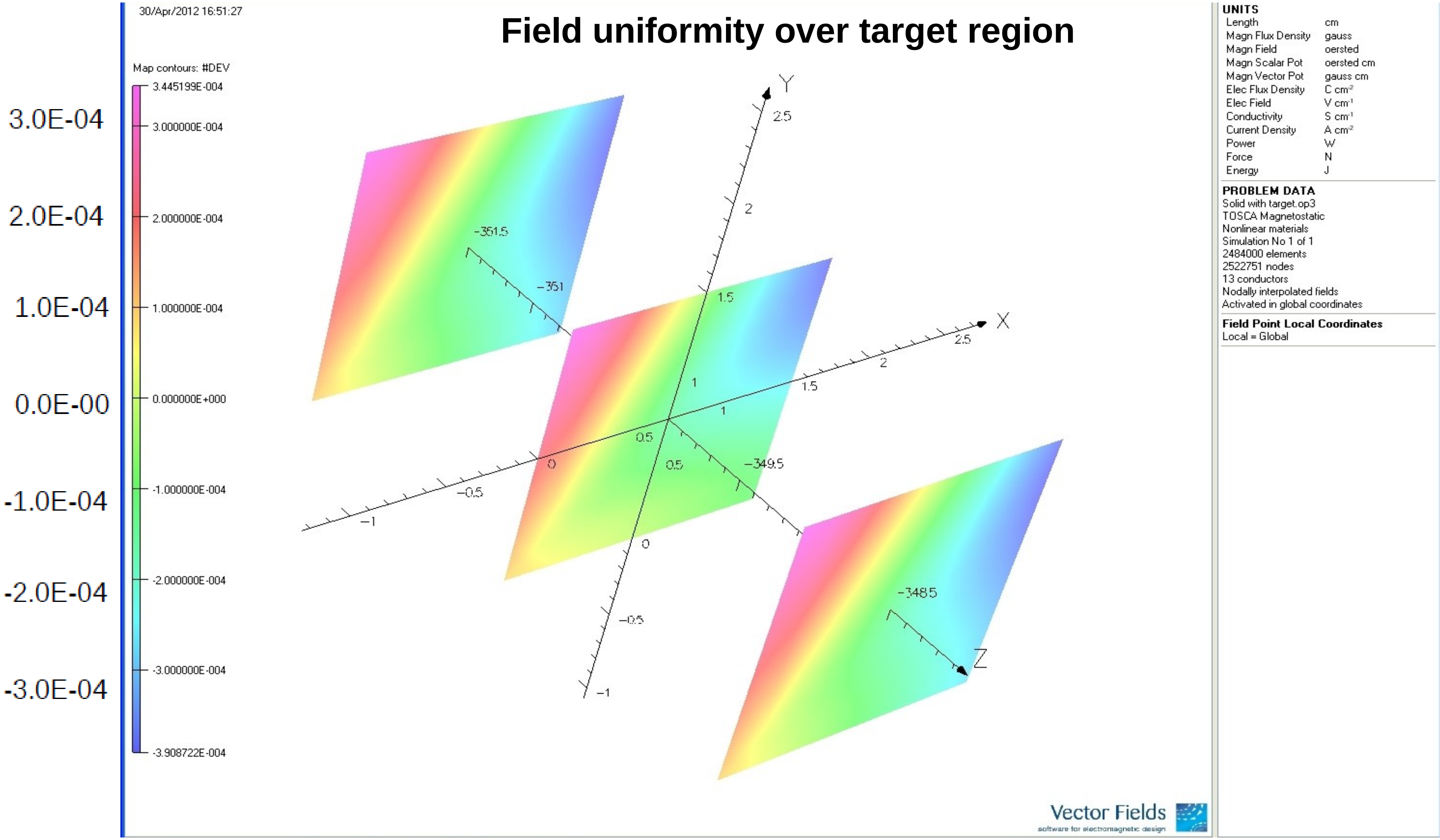
- Rates on GEM chamber < 1 kHz/mm^2 (GEMs can handle much higher rates)
- Fairly localized background in the GEM chambers
- Hit multiplicities are lower than ^{3}He-SoLID proposal (due to lower luminosity with NH_3 target)
- Tracking is not an issue a – well demonstrated in the ^{3}He-SoLID SIDIS proposal
- Front-end APV25 chips for GEMs designed to withstand high radiation dose (up to 10 MRad)
- Radiation limit for the calorimeter: 500 kRad
  - Expected radiation dose in 94 days run : < 100 kRad





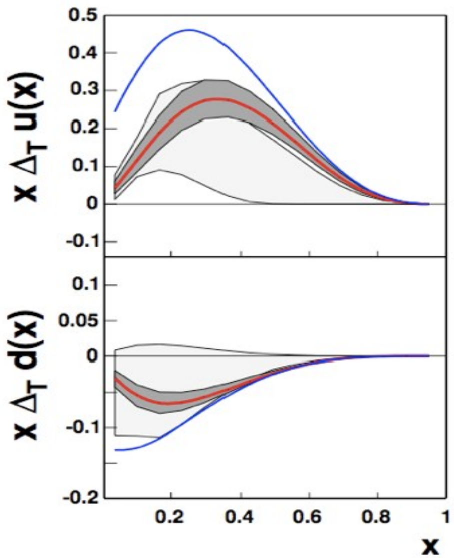
Magnet Interaction and Field Uniformity

- TOSCA calculation was done to study magnet interactions
- Forces between magnets manageable
  - About ~7.7 ton on iron plate in front of SoLID
  - Much smaller on the target coil (~0.25 ton)
- Recent experience with g2p/gep experiment is encouraging
  - Use 5 Tesla polarized target + pair of septum magnets close to target
  - No major problem due to magnet forces



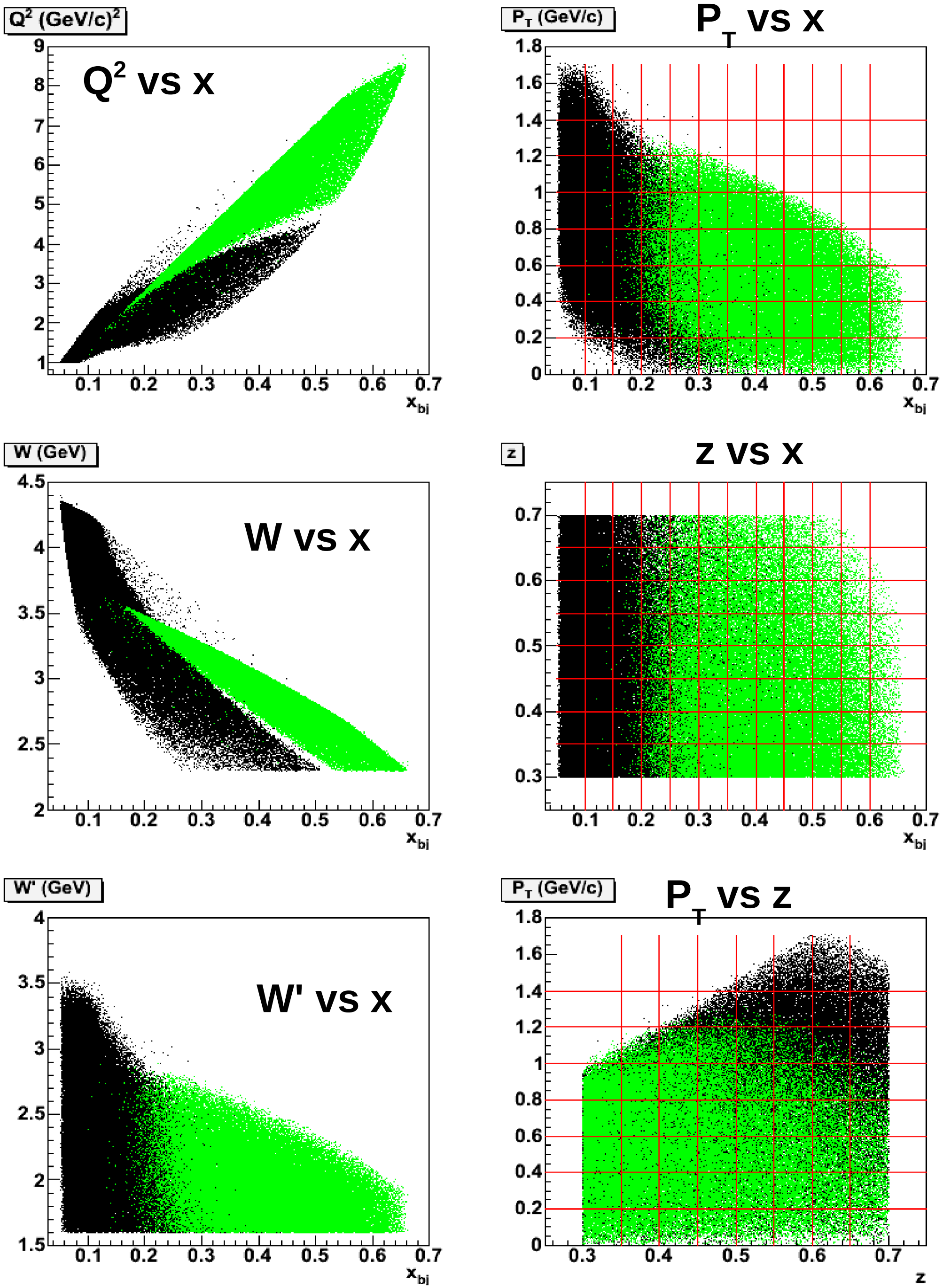
Kinematics Coverage

Transversity



Coverage with 11 GeV beam
(**forward** and large angle)

- x_B = 0.05 – 0.68
- Q^2 = 1.0 – 8.0 (GeV/c)^2
- P_T = 0 – 1.4 GeV/c
- z = 0.3 – 0.7
- W > 2.3 GeV



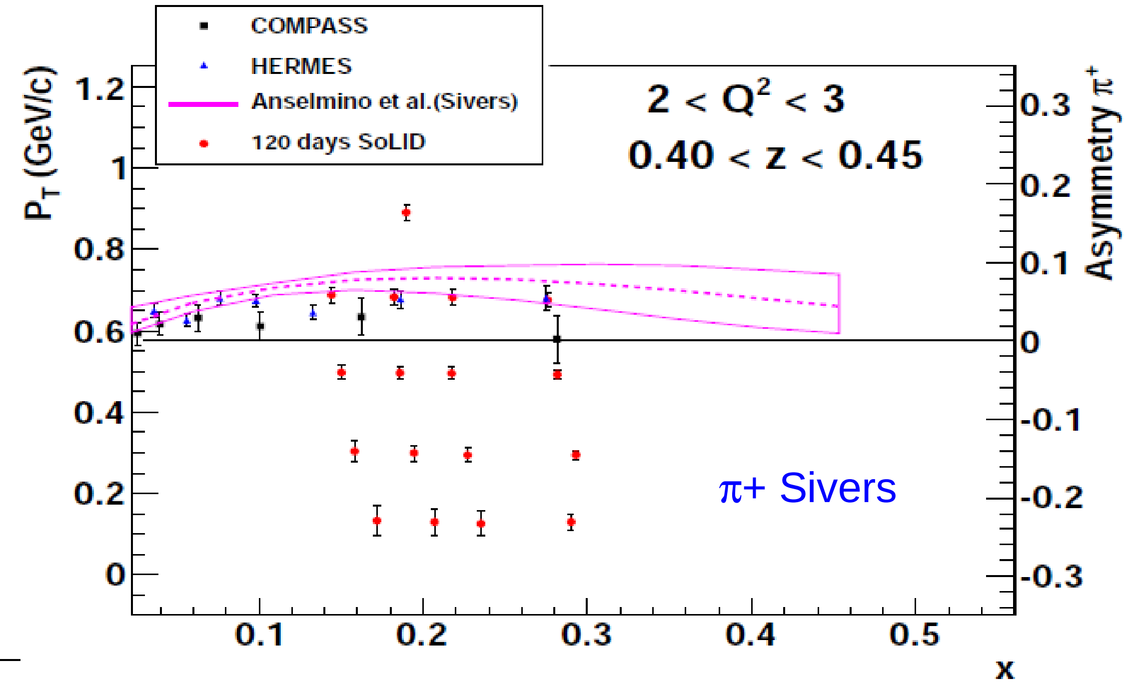
Estimated Systematic Uncertainties

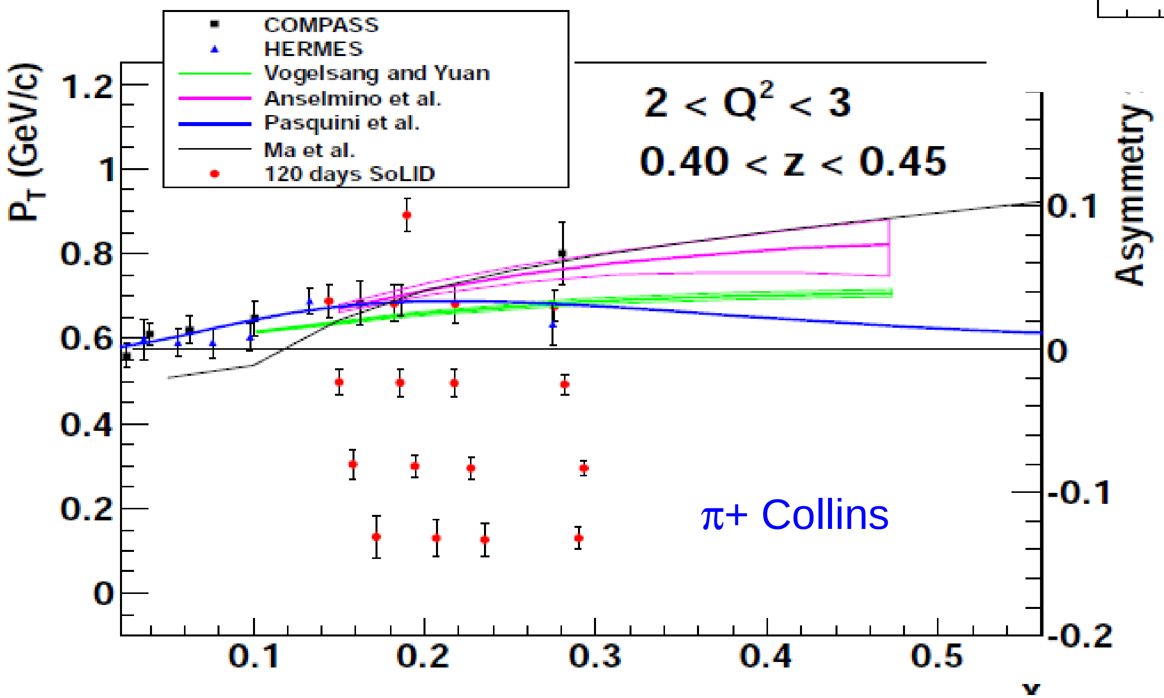
Sources	Type	Collins(π+)	Collins(π-)	Sivers(π+)	Sivers(π-)
Raw asymmetry	absolute	6.5E-4	6.5E-4	6.5E-4	6.5E-4
Dilution factor	relative	5%	5%	5%	5%
Diffractive vector meson	relative	3%	2%	3%	2%
Radiative correction	relative	2%	2%	2%	2%
Target polarization	relative	3%	3%	3%	3%

- Other systematics:
  - Detector efficiency/acceptance/luminosity : < 2 % in each spin-pair
  - Target polarization direction, random background: negligible
  - For contributions from A_{UL} , we will take dedicated data

A_{UT} Projections

- Projections for one out of 48 panels in Q^2 and z
- Partial loss of azimuthal coverage due to "*sheet of flame*" background taken into account
- Dilution and packing fraction included





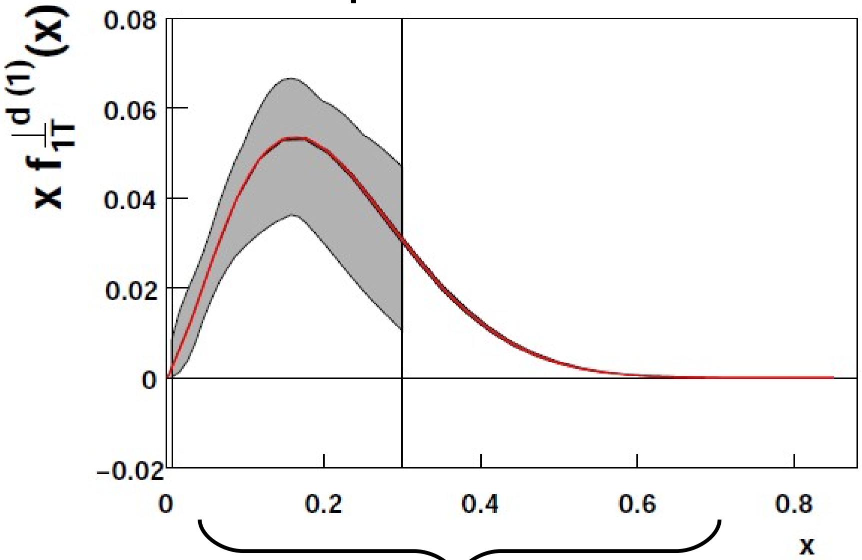
Multi-dimensional binning in x, Q^2, p_T, z

(674 bins in total)

Impact of Proposed Measurement

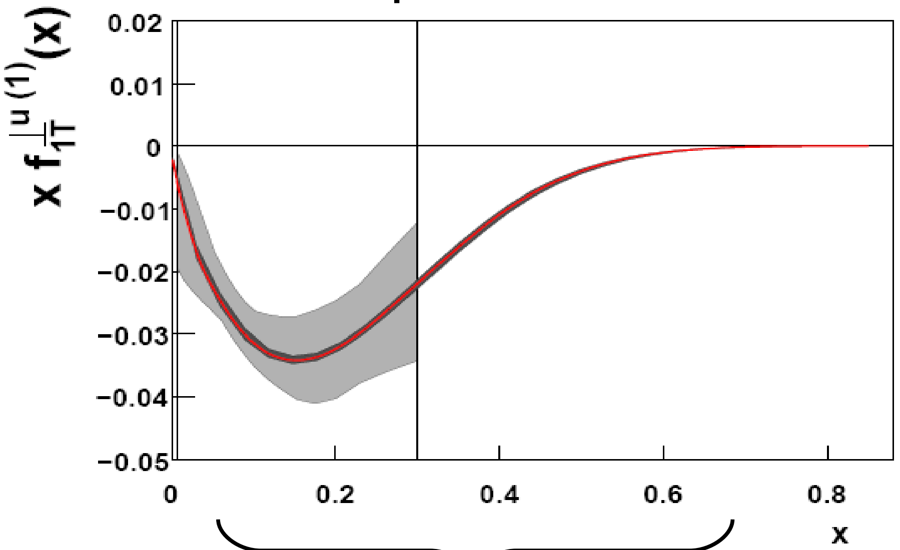
Impact of this measurement combined with ^{3}He-SoLID measurement on u and d-quark Sivers distribution function

d-quark Sivers



Region covered

u-quark Sivers



Region covered

A. Prokudin

- Only Sivers function is shown
- Similar precision on transversity distribution
- Current experimental uncertainties in large light grey band
- Projected uncertainties in dark grey band

Beam Time Request

	Time (Hour)	Time (Day)
Trans. Pol. NH_3 at 11 GeV	**1320**	55
Trans. Pol. NH_3 at 8.8 GeV	**660**	27.5
Longi. Pol. NH_3 at 11 GeV	60	2.5
Longi. Pol. NH_3 at 8.8 GeV	36	1.5
Dilution measurements	36	1.5
optics and detector calibration	144	6
Target Overhead regular annealing	624	26
Total Time Request	**2256+624**	**94+26 days**

We request a total of 120 days of beam time

Summary

- We propose to perform a precision 4-d mapping of target SSA using SoLID and polarized NH_3(p) target
  - Flavor separation of TMDs when combined with ^{3}He(n) data
  - Constrain u and d-quark tensor charge
  - Complete 3D imaging of the nucleon in momentum space
- SoLID is an ideal device to carry out such precision measurements:
  - High luminosity, large acceptance and full azimuthal coverage
  - Will provide most precise SSA/DSA data in the kinematic region $0.05<x<0.68$, $0.3<z<0.7$, P_T up to 1.4 GeV/c and Q^2 up to 8.0 $(GeV/c)^2$
  - Crucial input to global analysis of TMDs
- Updated proposal addresses all the issues/concerns raised by PAC38
- Global efforts to study TMDs:
  - **SIDIS:** JLab, HERMES, COMPASS, Future EIC
  - **Drell-Yan:** RHIC spin, Fermilab DY program, GSI/FAIR etc..

Spare Slides

SoLID vs CLAS12 (Figure of Merit)

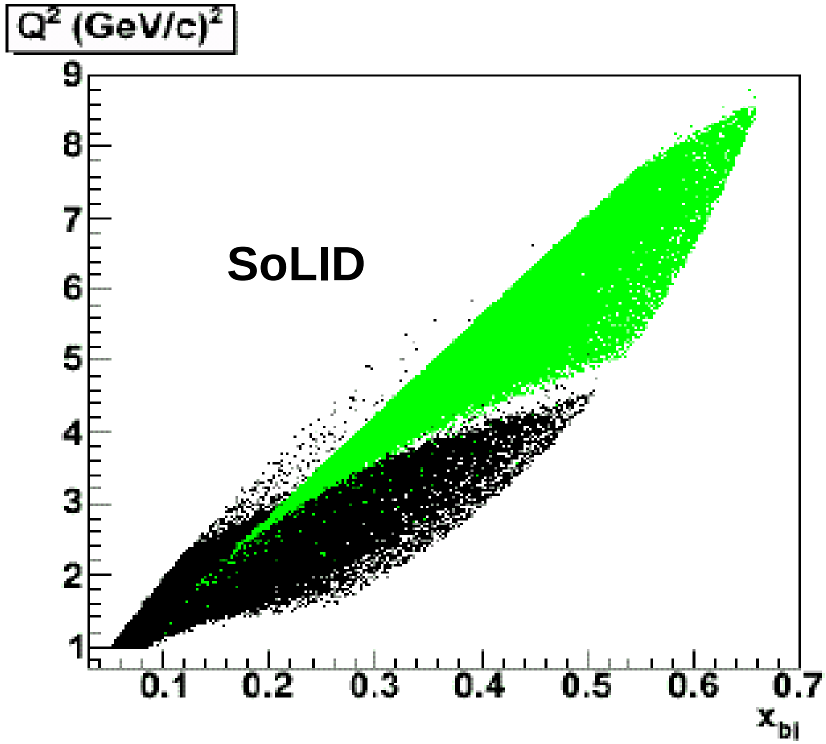
- Luminosities : 1×10^{35} (SoLID) vs 5×10^{33} (CLAS)
- $FOM = N * P^2 * f^2$

  (N = Ave. number of events, P = polarization, f=dilution)

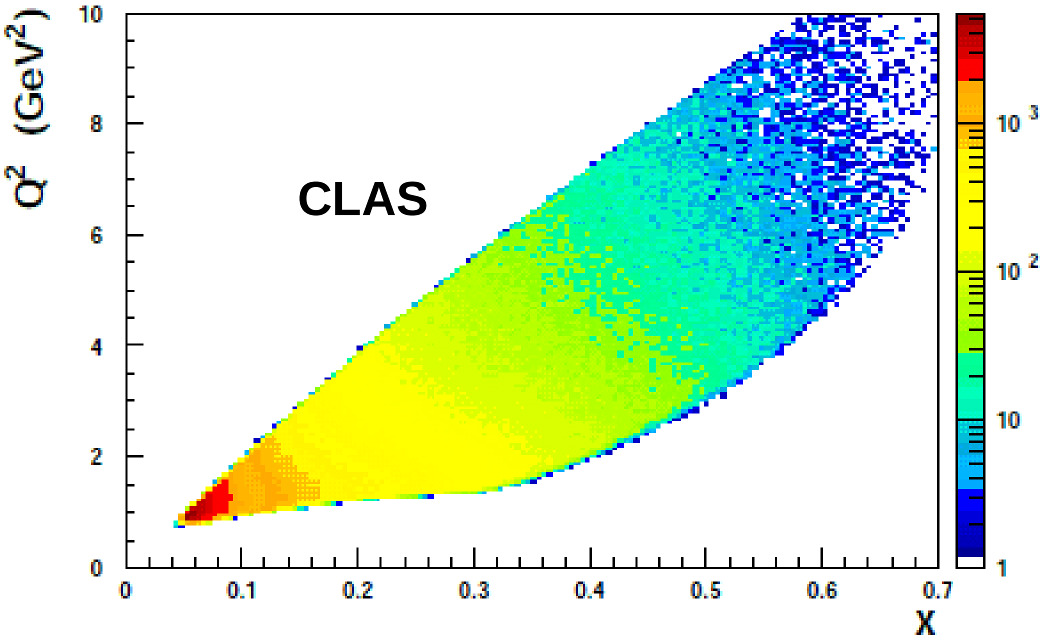
  - $N_{SoLID}(N_{CLAS})$ = 1.56e9 (0.40e8)
  - $P_{SoLID}(P_{CLAS})$ = 70% (60%)
  - $f_{SoLID}(f_{CLAS})$ = 0.13 (0.33)
- **FOM_{SOLID} : FOM_{CLAS} = 8 : 1**

Based on proposal
C12-11-111

SoLID and CLAS12 Phase Space



W > 2.3 GeV



W > 2.0 GeV

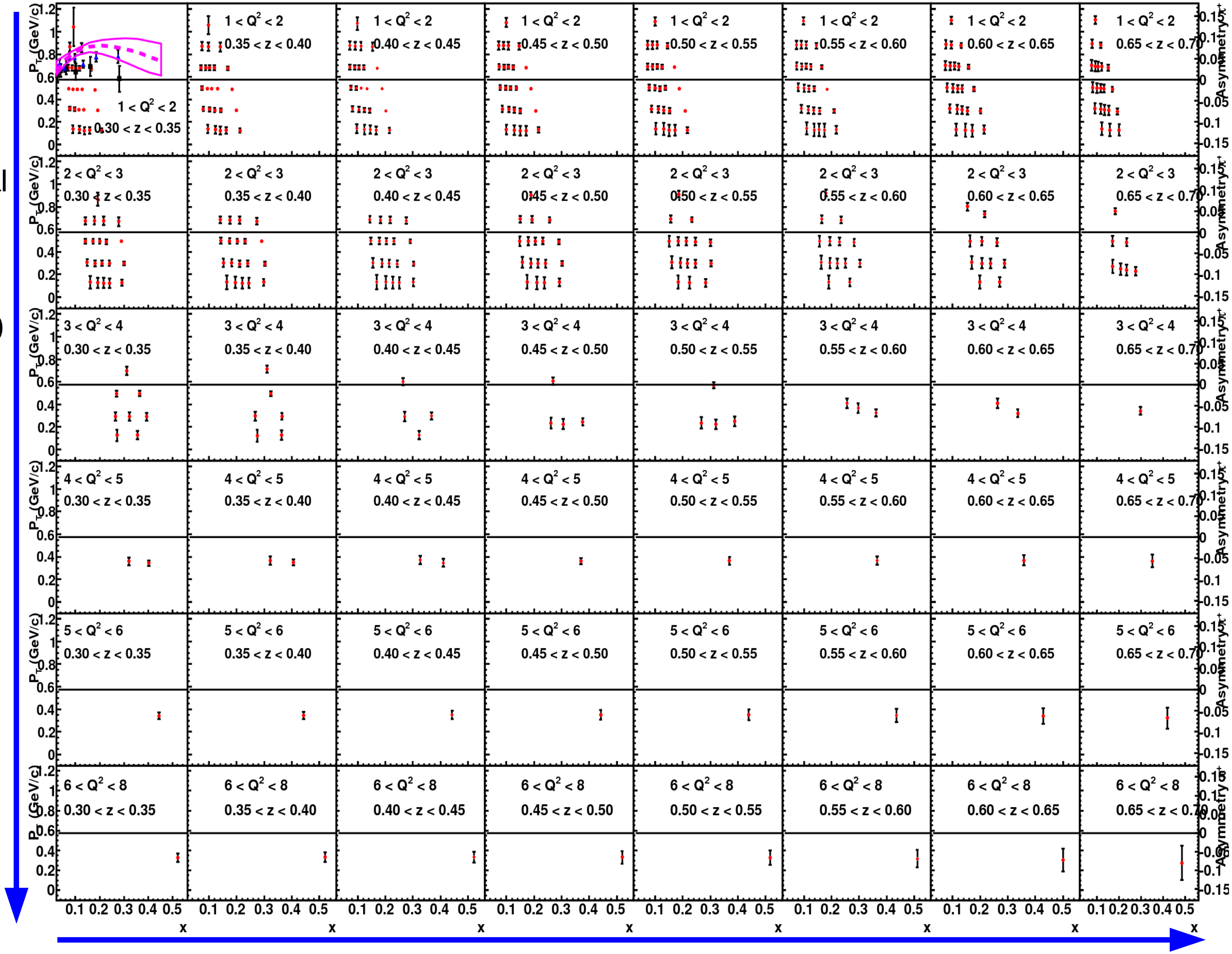
A_{UT} Projections (π^+ Sivers)

$Q^2 = 1.0\ (GeV/c)^2$

Multi-dimensional binning in x, Q^2, p_T, z

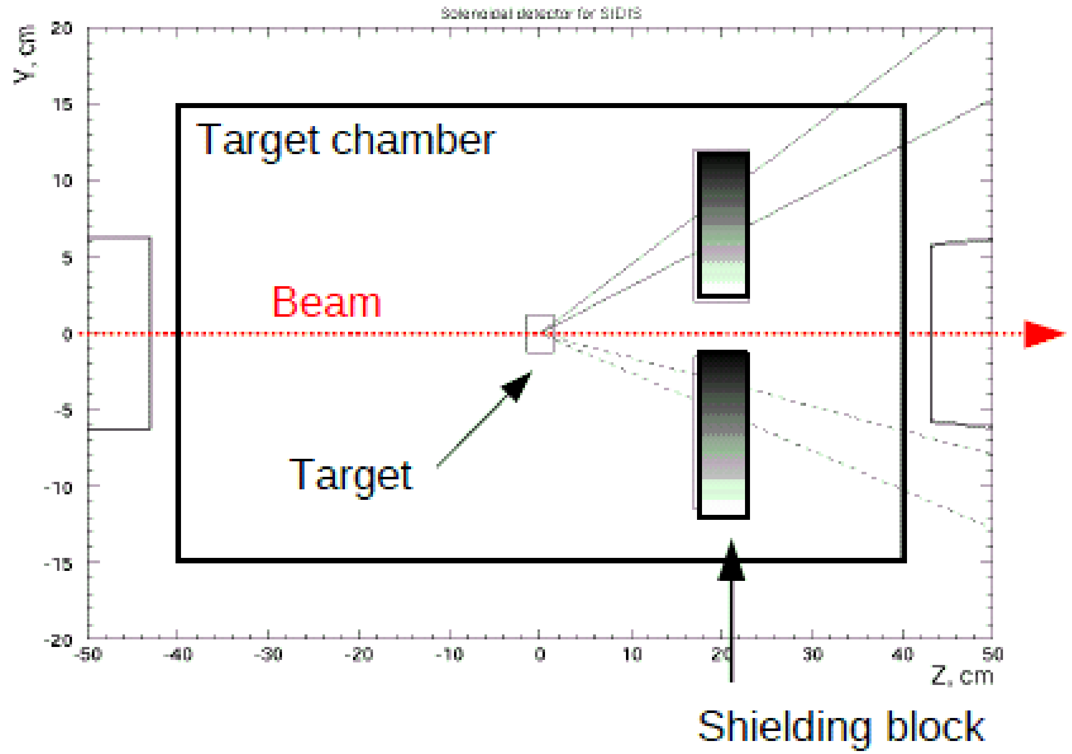
(674 bins in total)

$Q^2 = 8\ (GeV/c)^2$

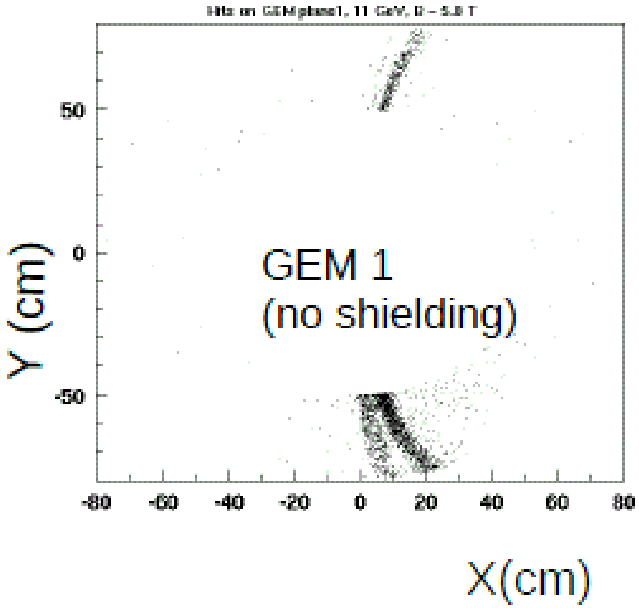


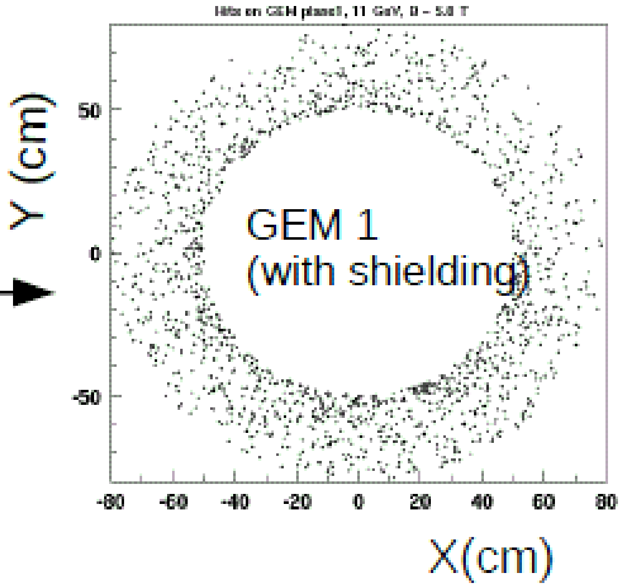
Background Studies: Local shielding

- Background rates studied with local shielding
- Lead shielding block of dimensions:
  - +/- 1.8cm in X (left-right)
  - +/- 5 cm in Y (up-down)
  - +/- 3 cm in Z (beam dir.)
- The hit distribution becomes more uniform
- Sheet of flame blocked by shielding



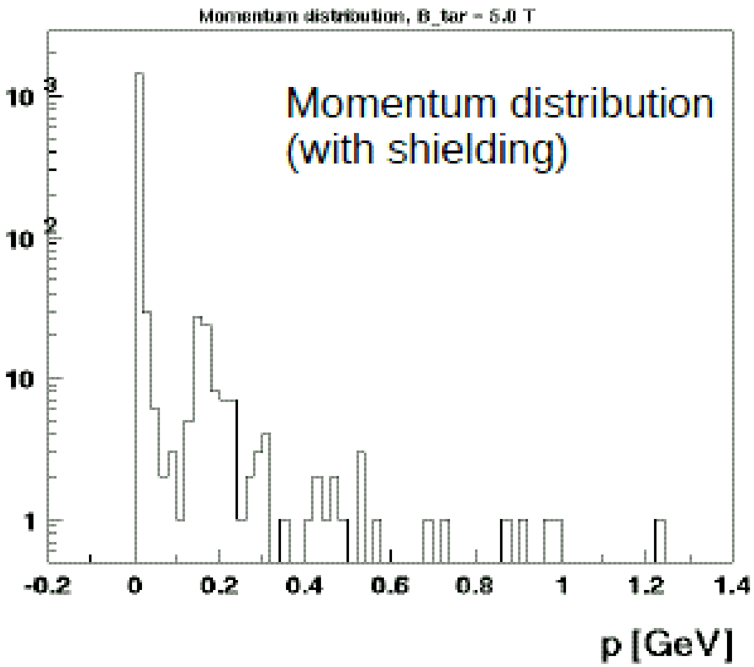
Hits on GEM

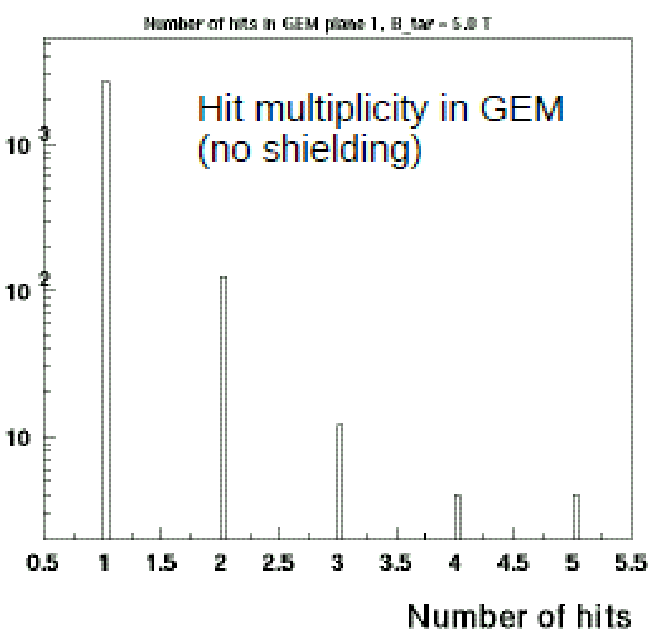


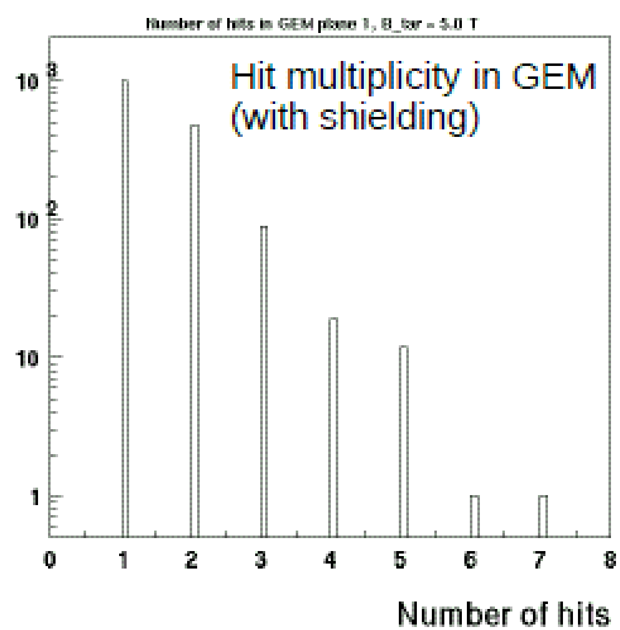


Background Studies: Local shielding

- Momentum distribution
- Enhancement of photon-like events
- Large reduction of positrons on the detectors
- Hit multiplicities on GEM are lower with shielding
  - Due to suppressed e+ events

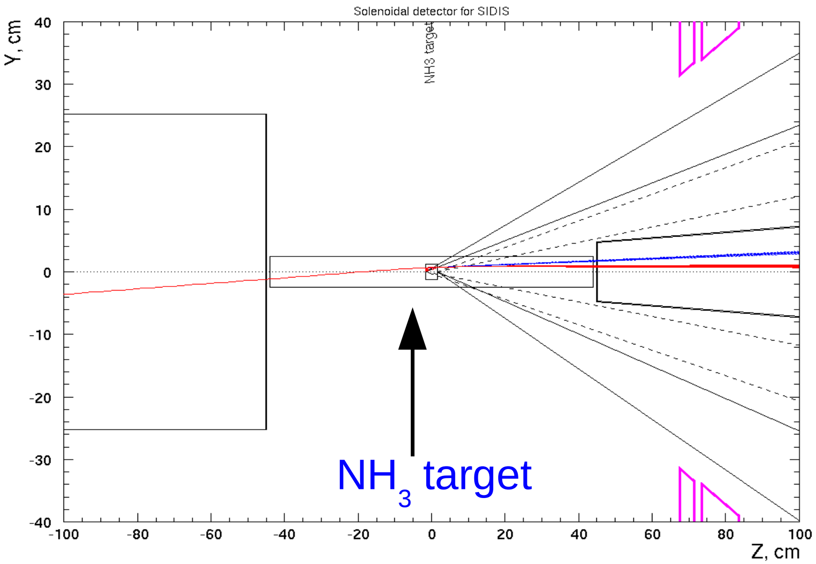


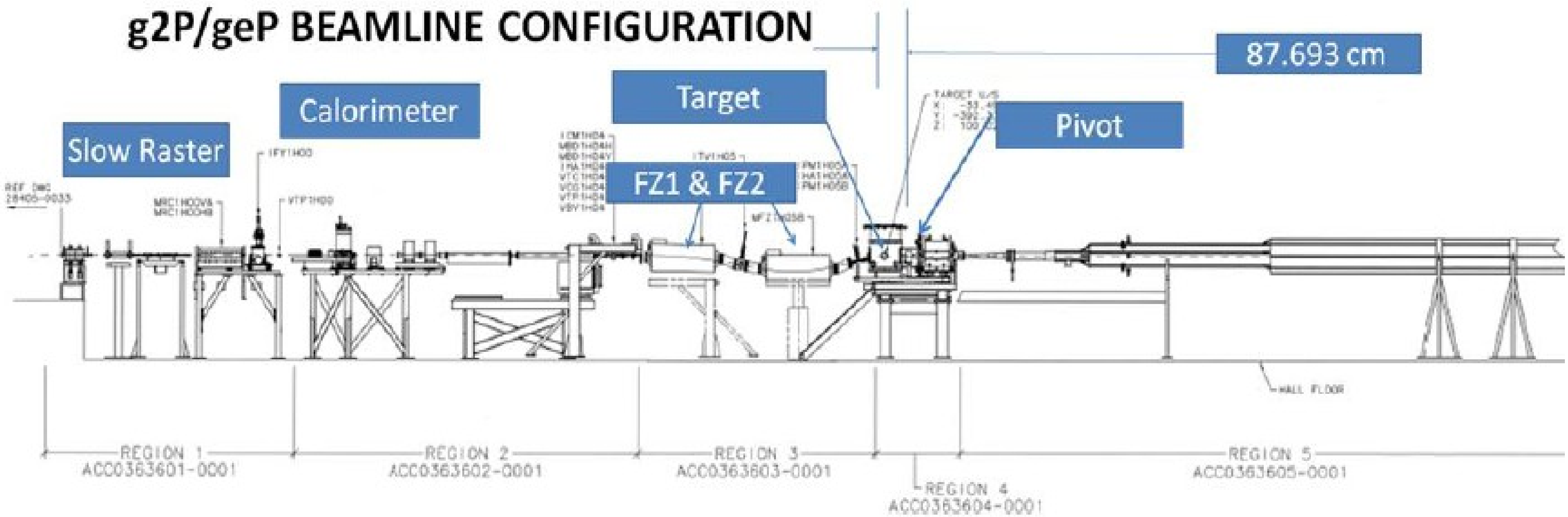




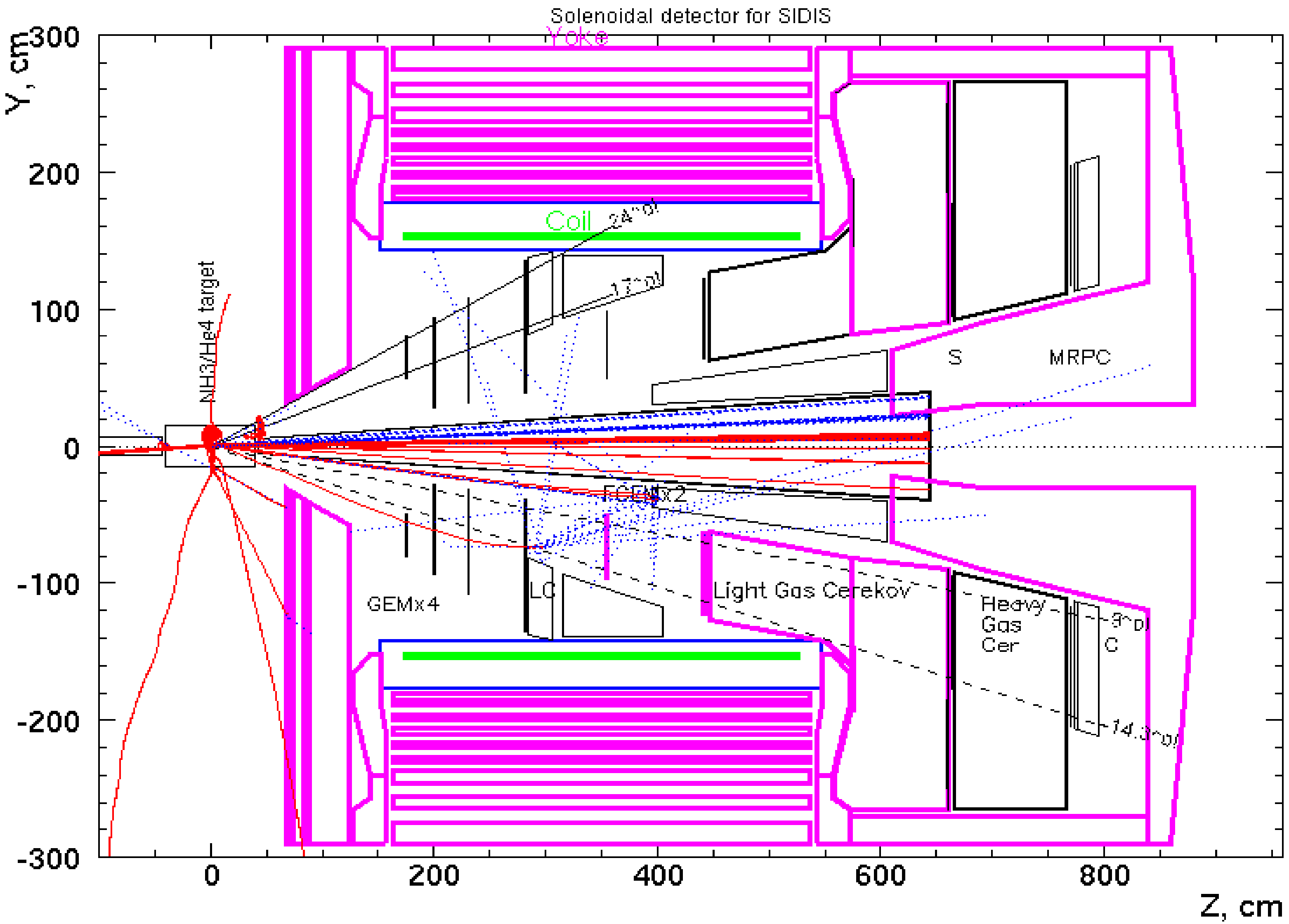
Beamline Instrumentation

- Beam line chicane:
  - Two chicane magnets will be added
- Beam line diagnostics
  - Use upgraded beam diagnostics from recently concluded g2p/gep experiments
  - Low current BCM, BPM, raster and Harps





Event Display



Tensor Charge

- Unmeasured region <3-4%
  - Will constrain by our data
- Higher twist <5%
  - Can be improved with comparison of EIC and our data
- Q2 evolution of transversity: <3%
  - EIC data can definitely help.
- PT dependence: <2-3%
  - Our data will put strong constrains
- Collins fragmentation 10% now (5% with future data and our data in terms of shape)
- NLO formalism + evolution on Collins fragmentation function (<3%)?
- Final determination better than 10%, current best educated guess ~7-15% level (can only determined by data)
  - Also will improved with additional data from EIC, e+e-, and DY data.
  - Currently 30-50% level, also violation of Soffer's bound?