SIDIS/A1n/TDIS Overview

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SBS Collaboration Meeting

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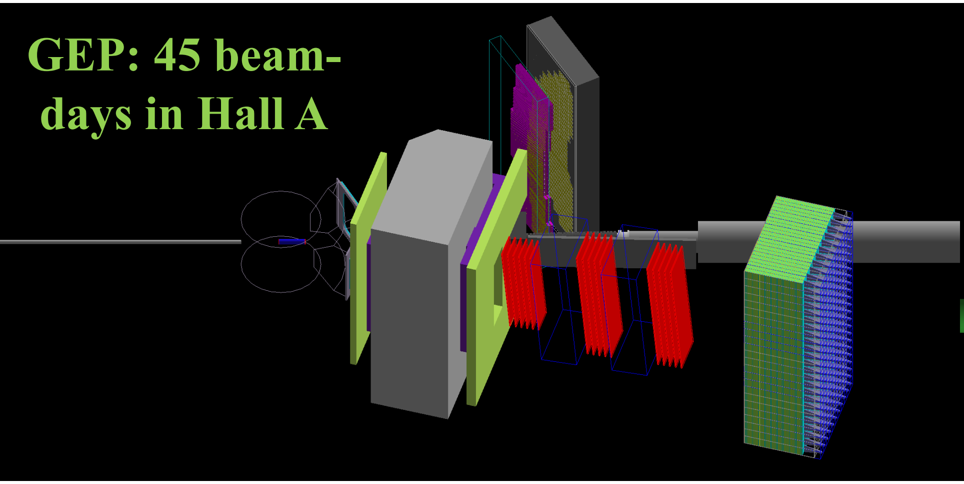
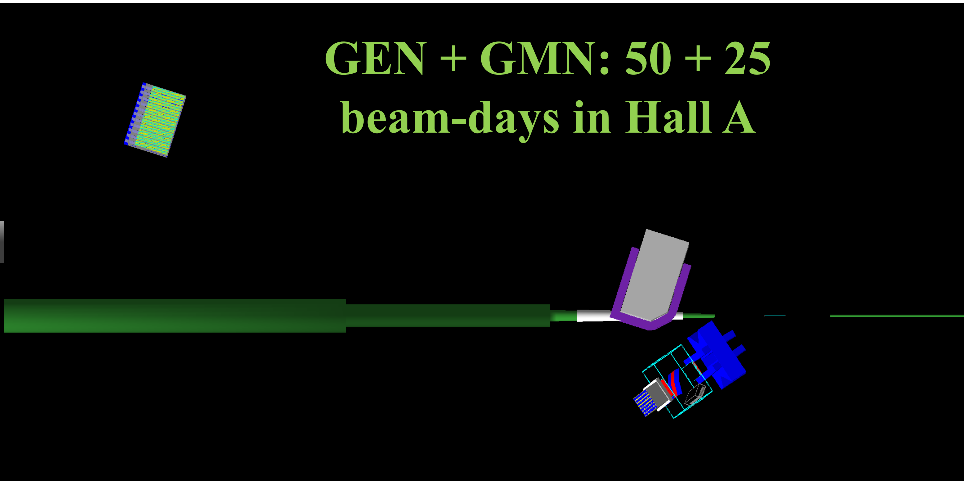
UCONN Jefferson Lab

Outline

- Introduction
- E12-09-018: Semi-Inclusive Deep Inelastic Scattering (SIDIS) on a transversely polarized ^{3}He target
- E12-06-122: Measurement of Neutron Spin Asymmetry A_1^n in the valence quark region using 8.8 GeV and 6.6 GeV Beam Energies and BigBite Spectrometer in Hall A
- E12-15-006: Measurement of Tagged Deep-Inelastic Scattering

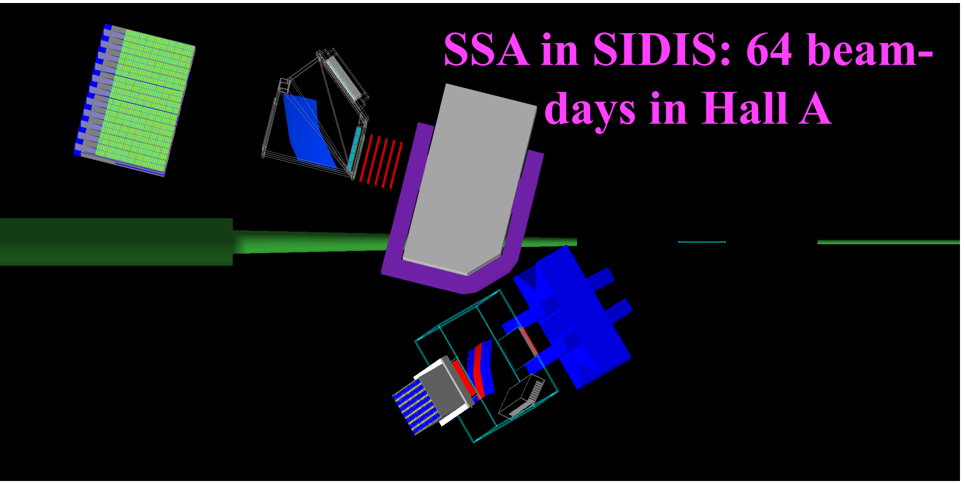
The Super BigBite Spectrometer (SBS) in Hall A





E12-07-109: Proton form factor ratio G_{Ep}/G_{Mp} using polarization transfer

E12-09-016 and E12-09-019: Neutron magnetic form factor G_{Mn} and neutron form factor ratio G_{En}/G_{Mn}

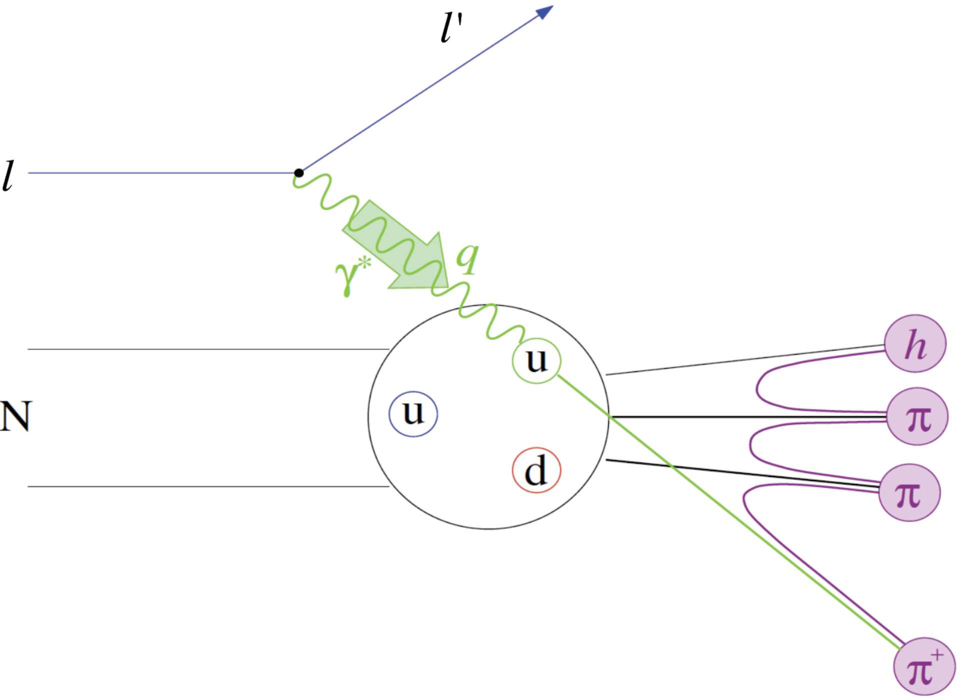


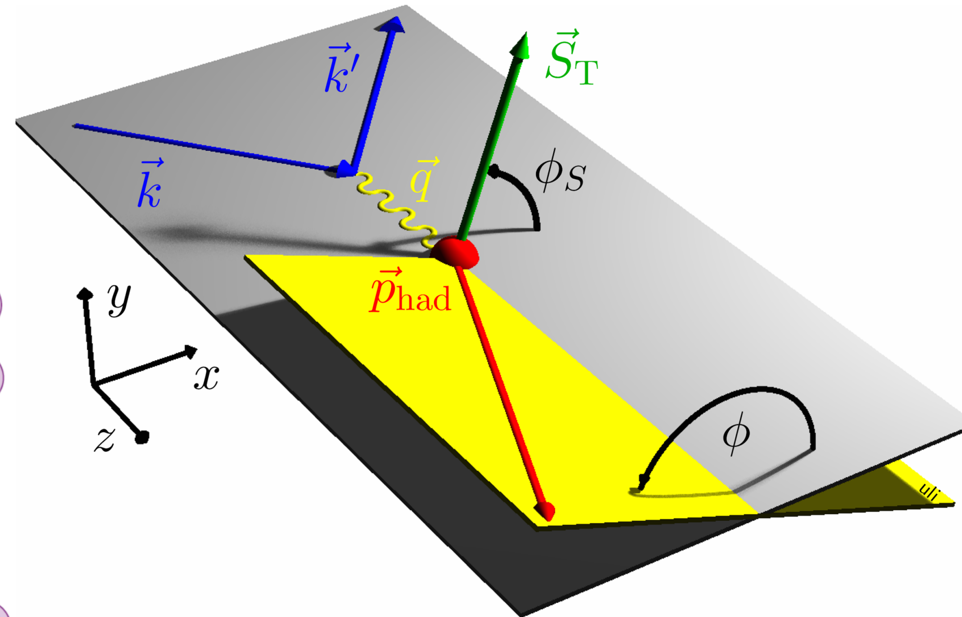
E12-09-018: Transverse target SSA in SIDIS

- SBS is a novel magnetic spectrometer based on time-tested “detectors behind a dipole magnet” approach
- Detects forward-going, high-energy particles with medium solid angle acceptance and large momentum bite at highest achievable luminosities of CEBAF
- **Physics program: nucleon EMFFs and SIDIS, 180 beam-days approved in Hall A**
- **Conditionally approved: Pion structure function via tagged DIS, 27 days Hall A**

E12-09-018: SIDIS on transversely polarized ^{3}He target

Semi-Inclusive Deep Inelastic Scattering





• Detecting leading (high-energy) hadrons in DIS, N(e,e'h)X process provides sensitivity to additional aspects of the nucleon's partonic structure not accessible in inclusive DIS:

- quark flavor
- quark transverse motion
- quark transverse spin

• ***Goal of SIDIS studies is (spin-correlated) 3D imaging of nucleon's quark structure in momentum space.***

• Transverse Momentum Dependent (TMD) PDF formalism: ***Bacchetta et al. JHEP 02 (2007) 093, Boer and Mulders, PRD 57, 5780 (1998), etc, etc...***

Transverse target spin effects in SIDIS

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

Transverse target spin-dependent cross section for SIDIS

- Collins effect—chiral-odd quark transversity DF; chiral-odd Collins FF
- Sivers effect—access to quark OAM and QCD FSI mechanism
- "Transversal helicity" g_{1T}—real part of S wave-P wave interference (Sivers = imaginary part) (requires polarized beam)
- "Pretzelosity" or Mulders-Tangerman function—interference of wavefunction components differing by 2 units of OAM

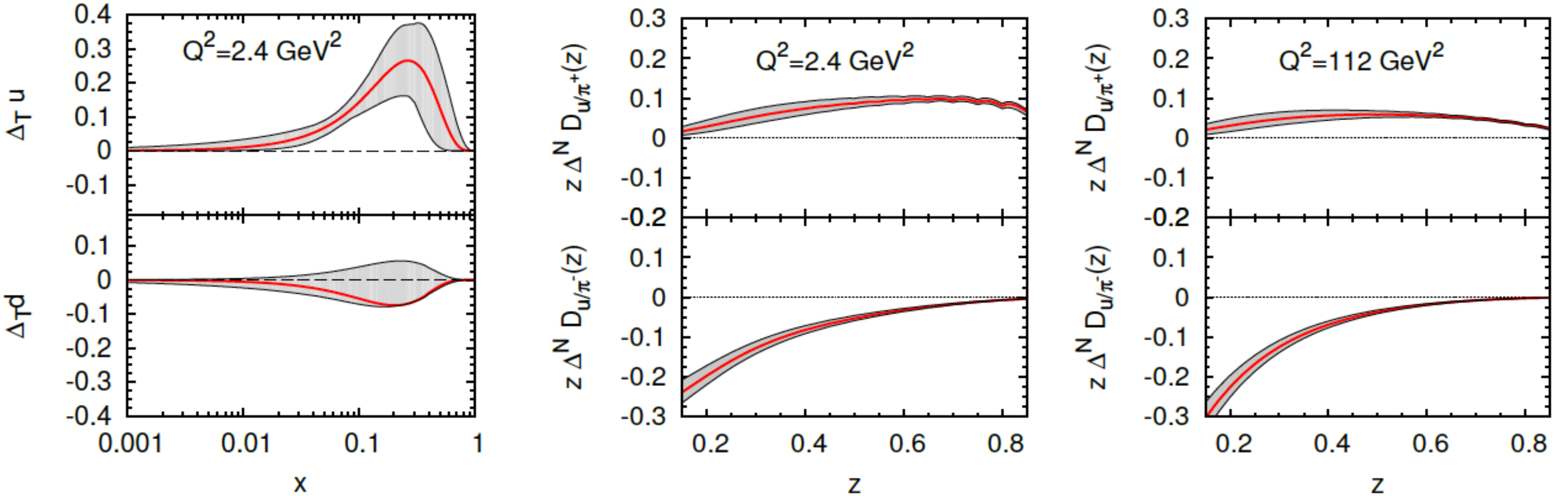
$$A_{UT}(\phi,\phi_S) = \frac{1}{P_T}\frac{d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S) + d\sigma(\phi,\phi_S+\pi)}$$
$$= A_{UT}^{Collins}\sin(\phi+\phi_S) + A_{UT}^{Sivers}\sin(\phi-\phi_S) + A_{UT}^{Pretz}\sin(3\phi-\phi_S)$$

$$A_{UT}^{Collins} \propto \delta q \otimes H_1^\perp$$
$$A_{UT}^{Sivers} \propto f_{1T}^\perp \otimes D_1$$
$$A_{UT}^{Pretz} \propto h_{1T}^\perp \otimes H_1^\perp$$

$D_1 =$ unpolarized fragmentation function
$H_1^\perp =$ Collins fragmentation function

$$A_{LT}(\phi,\phi_S) = \frac{1}{P_e P_T}\frac{Y_+(\phi,\phi_S) - Y_-(\phi,\phi_S)}{Y_+(\phi,\phi_S) + Y_-(\phi,\phi_S)}$$
$$\sim A_{LT}^{\cos(\phi-\phi_S)}\cos(\phi-\phi_S)$$
$$\sim g_{1T}\otimes D_1$$

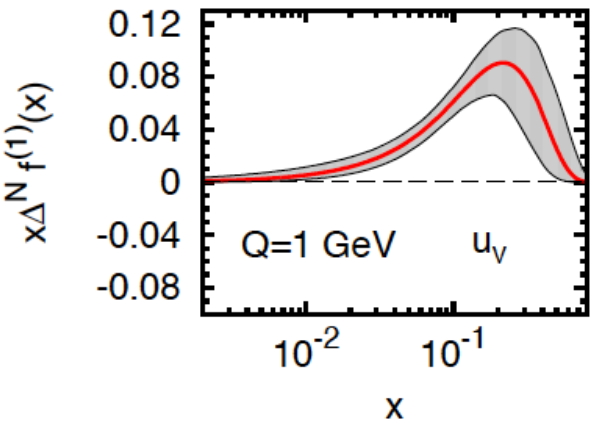
Transversity and Collins Functions: Existing Knowledge

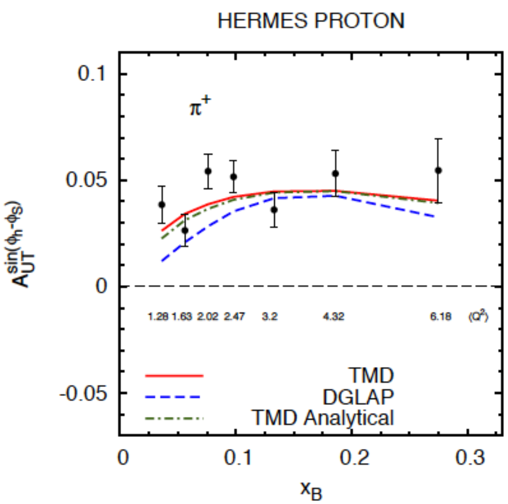


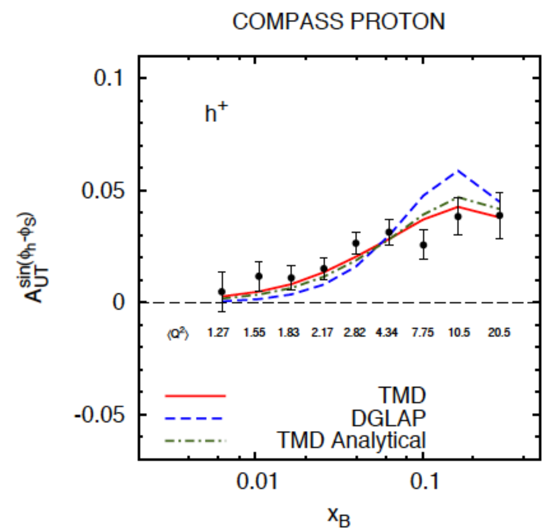
Anselmino *et al.*, arXiv:1510.05389v1 (2015): latest extractions of valence u and d quark transversities and favored/unfavored Collins FFs

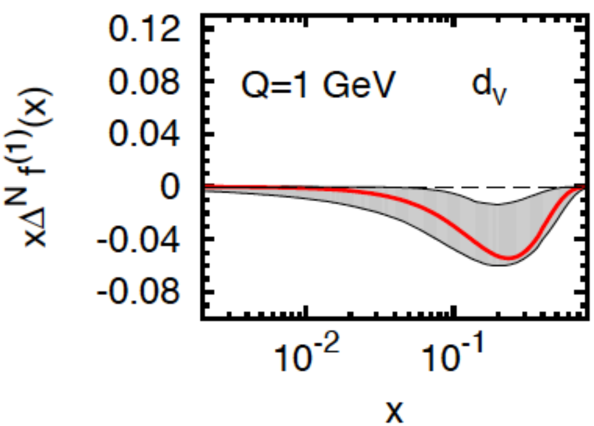
- SIDIS data from HERMES on proton target, COMPASS on proton and deuteron targets
- Data on azimuthal asymmetries in e^+/e^- annihilation to pion pairs from BELLE and BaBar collaborations—very recent, high statistical precision
- First look at combined z and p_T dependencies of Collins FFs.
- Note—d quark transversity is poorly constrained—proton data dominated by u quarks, limited sensitivity to d from COMPASS deuteron and JLab Hall A ^{3}He data.

Sivers effect—Existing knowledge





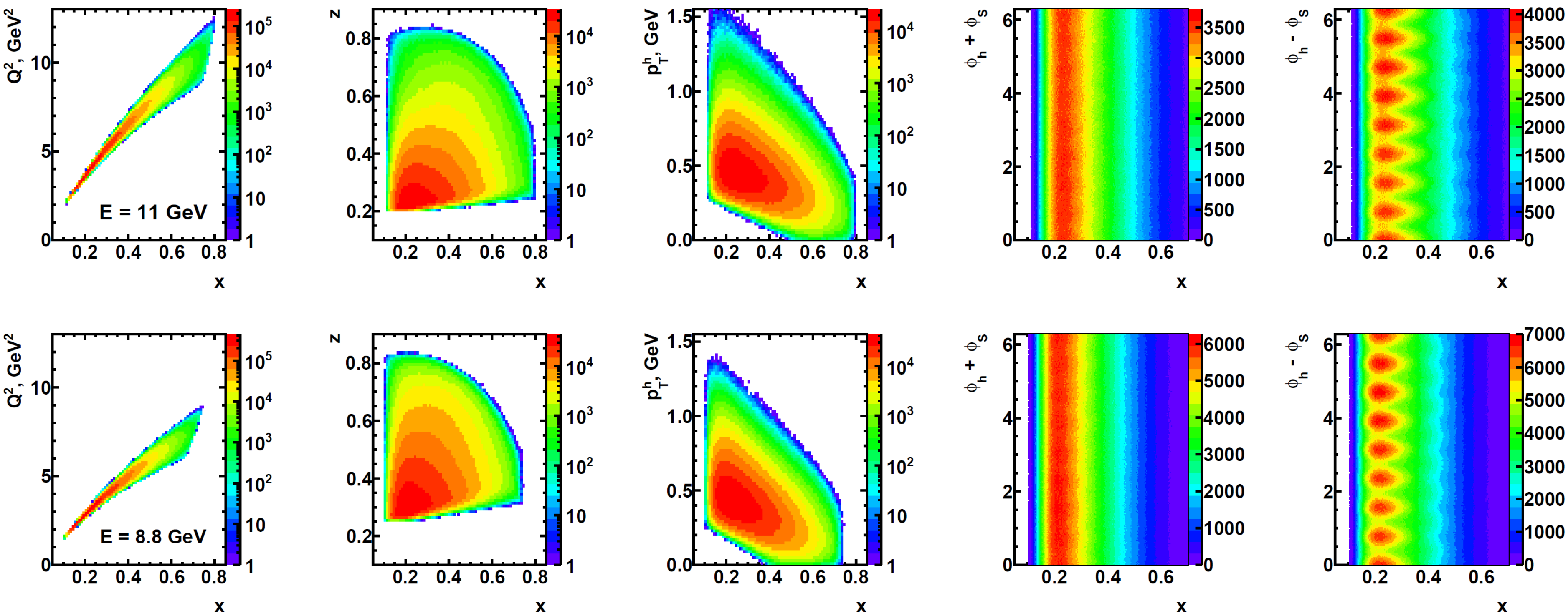




Anselmino *et al.*, Phys.Rev. D86 (2012) 014028, arXiv:1204.1239v1

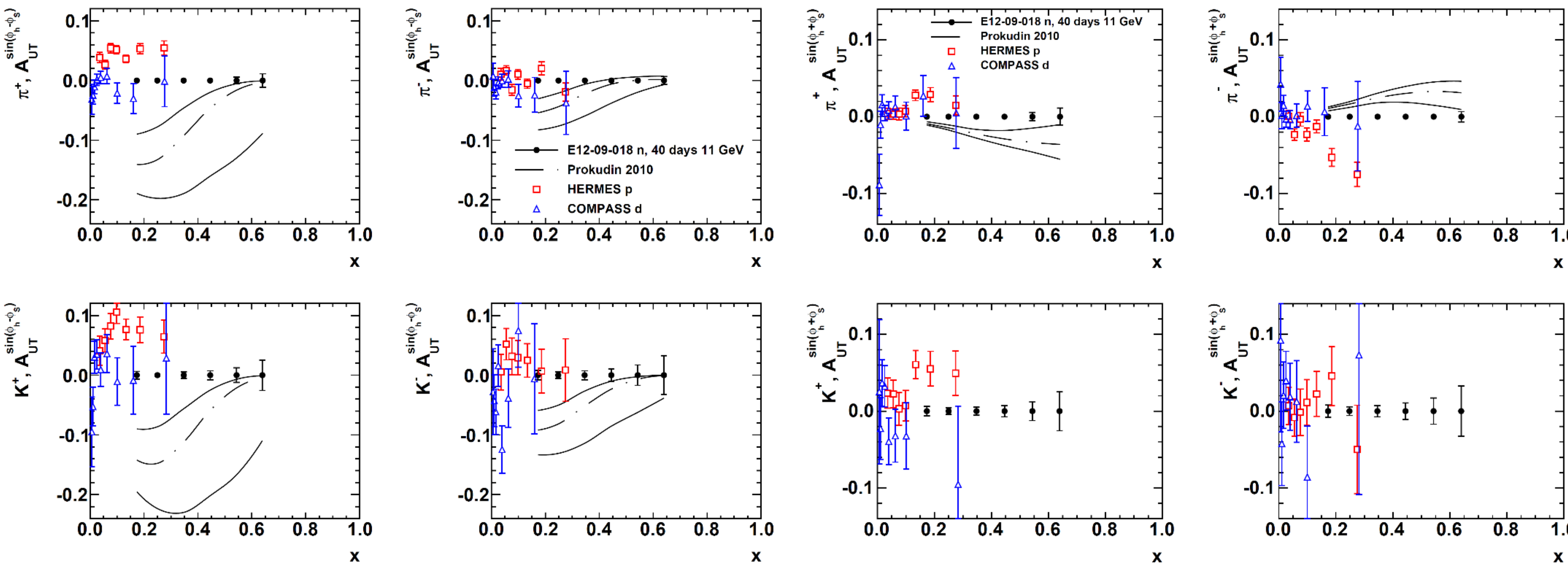
- Fits to most recent HERMES and COMPASS SIDIS Sivers data with TMD/DGLAP evolution
- As in the case of Collins/Transversity, d-quark Sivers is poorly constrained by existing data
  - Proton data dominated by u-quarks
  - Limited precision/sensitivity to d quark from COMPASS deuteron/JLab Hall A ^3He data

SIDIS Kinematic Coverage in E12-09-018



- Wide, independent coverage of x, z, p_T, $\phi_h \pm \phi_S$.
- Q^2, x strongly correlated due to dimensions of BigBite magnet gap.
- Data at E = 11, 8.8 GeV provide data for significantly different Q^2 at same x
- Systematics control → independent spectrometers, detectors in field-free regions, straight-line tracking, simple, well-defined (but adequately large) acceptance, etc.

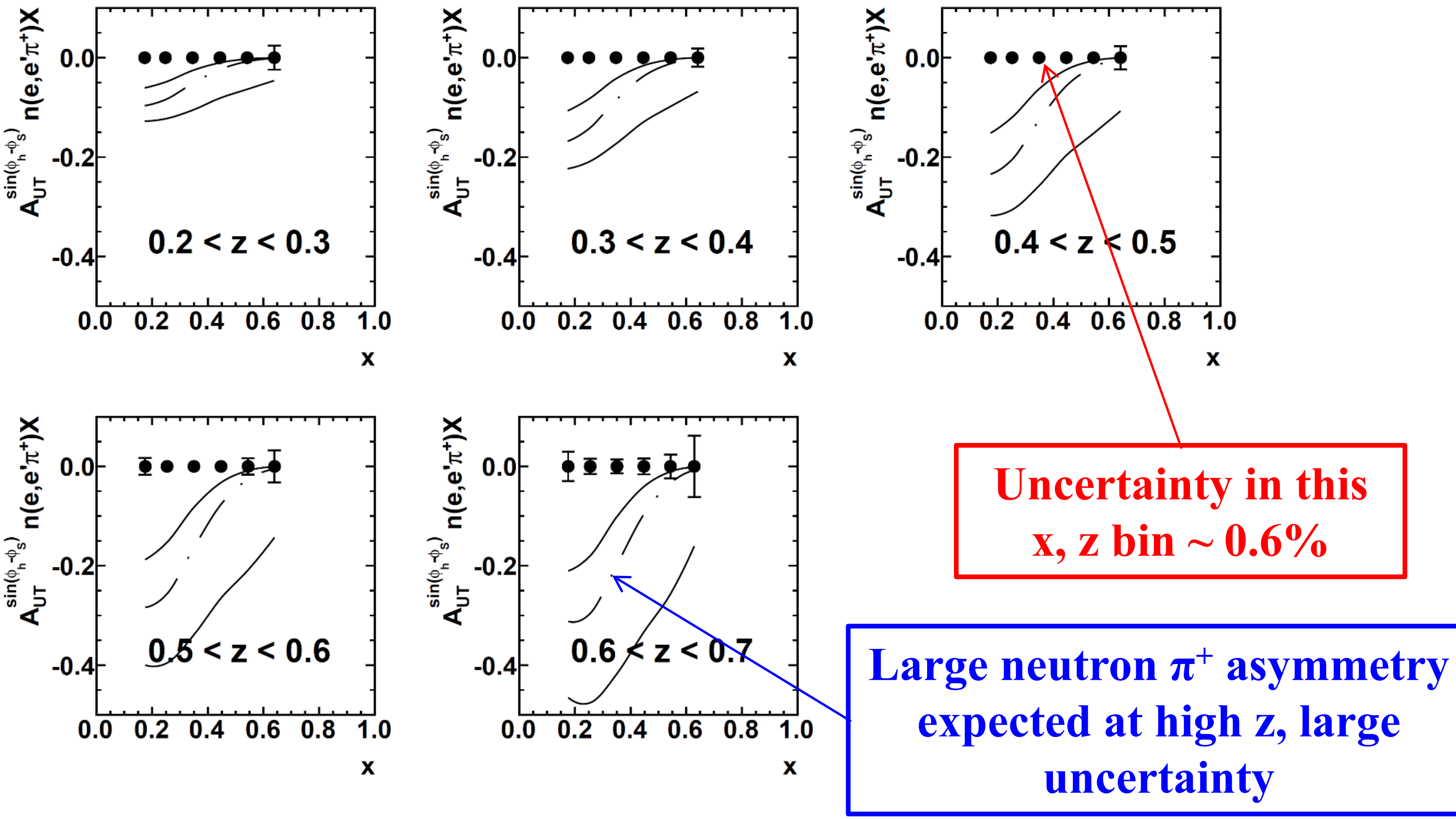
SBS+BB Projected Results: Collins and Sivers



Projected A_{UT}^{Sivers} precision vs. x   **Projected $A_{UT}^{Collins}$ precision vs. x**

- E12-09-018 will achieve statistical FOM for the neutron ~100X better than HERMES proton data and ~1000X better than E06-010 neutron data.
- Kaon and neutral pion data will aid flavor decomposition, and understanding of reaction-mechanism effects.

SBS+BB Projected Precision in 2D (x,z) binning



- 2D Extraction: Sivers A_{UT} in n(e,e'π^+)X, 6 x bins 0.1<x<0.7, 5 z bins 0.2<z<0.7
- Curves are theory predictions (Anselmino et al.) with central value and error band

Summary of E12-09-018 Physics Impact

- Pioneering HERMES+COMPASS experiments conclusively demonstrated the existence of the Collins and Sivers effects in SIDIS.
- SSAs in SIDIS are large, especially in the valence region
- Experiment E12-09-018 will be the first SIDIS experiment in the JLab 12 GeV era on a transversely polarized neutron (^{3}He) target.
  - First precise measurements of Collins/Sivers effects in multi-dimensional phase space.
  - Extend knowledge further into the valence region (where asymmetries are large) to x ~ 0.7 at Q^2 values between those of HERMES and COMPASS
  - Polarized neutrons→ unrivaled d quark sensitivity
  - Large impact to global TMD extraction

E12-09-018 Apparatus and Requirements

- **Target:** High-luminosity polarized ^{3}He; similar to GEN target, but requires (almost) complete freedom in target polarization orientation. Required orientations include (at a minimum) horizontal and vertical polarization transverse to the beamline (and preferably $\pm 45^\circ$ as well), plus longitudinal polarization for calibrations.
- **Hadron arm:** SBS at 14 deg. central angle equipped with:
  - HCAL for hadron trigger
  - Large-area GEM-based tracker
  - RICH for charged hadron PID
- **Electron arm:** BigBite at 30 deg. central angle equipped with:
  - Pre-shower and shower for electron trigger
  - Timing hodoscope
  - GEM-based tracker
  - GRINCH
- **DAQ and trigger:**
  - HCAL threshold low enough to be efficient for SIDIS charged hadrons p > 2-3 GeV
  - BigBite threshold low enough to be efficient for electrons p > 1 GeV

(Some) Unique Challenges for SBS-SIDIS

- Small raw asymmetries ⬄ tight control of systematics => As fast as possible change of spin orientation—with adiabatic rotation of target holding field expect T ~ 120 s?
- Inclusive kinematics—low trigger thresholds ⬄ high accidental coincidence rates. Proposal estimate was ~20 kHz online coincidence trigger rate.
  - Addition of GRINCH to the trigger for BigBite would be extremely helpful here, since ~90% of BigBite calorimeter-based triggers are photon-induced!
- GEM-based tracking with no real constraints on track search area (other than HCAL hadronic shower signal and SBS acceptance) due to inclusive kinematics (but 40X lower luminosity than GEP helps)

E12-06-122: A1n in the valence region using BigBite in Hall A

Polarized DIS and Spin Structure Functions

• Helicity asymmetries in the scattering of longitudinally polarized electrons on longitudinally and transversely (in the scattering plane) polarized nucleons provide access to spin structure functions g_1, g_2.

• The longitudinal virtual photon asymmetry A_1 is defined as the asymmetry between parallel and antiparallel virtual photoabsorption cross sections and is related to the spin structure function $g_1(x,Q^2)$:

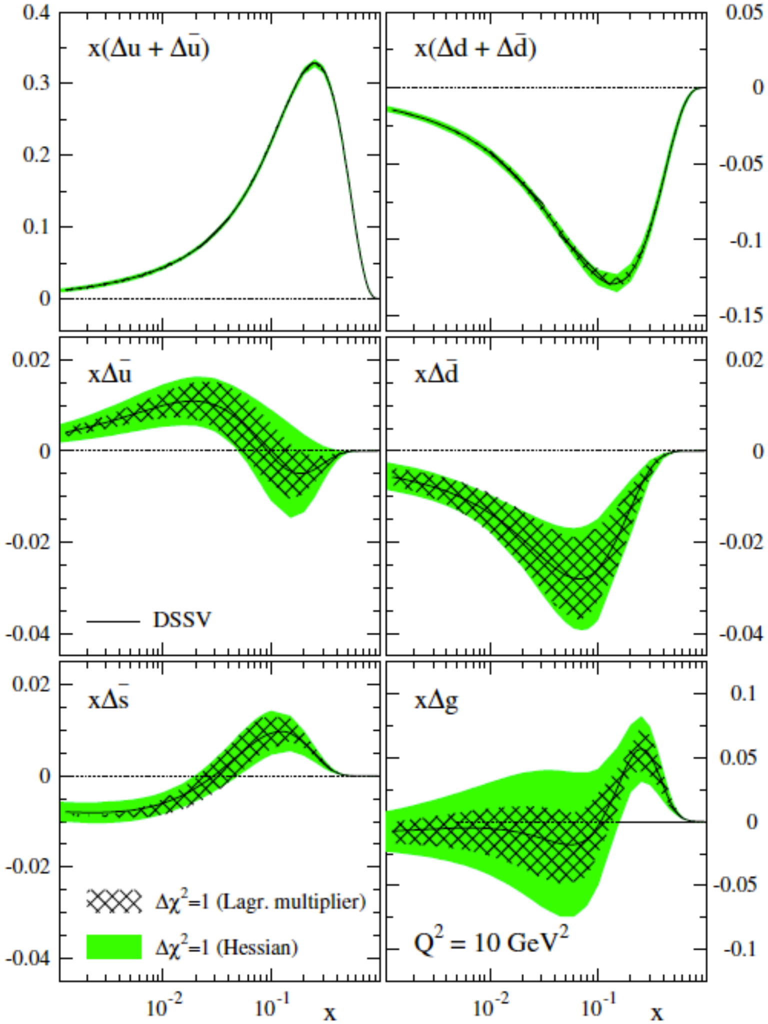
$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

$$A_1 \approx \frac{g_1}{F_1}, Q^2 \to \infty$$

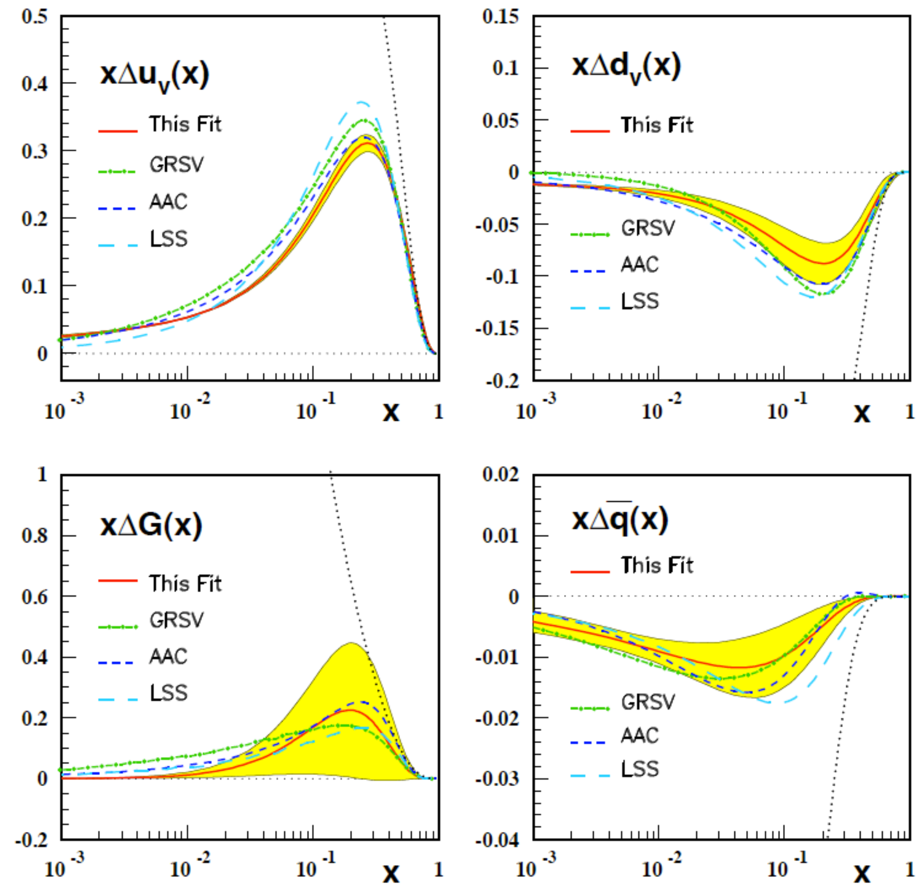
• In the naïve parton model, g_1 is an incoherent sum over parton helicity distributions Δq_i, equal to the difference in number density of quarks polarized parallel and antiparallel to the nucleon spin:

$$\frac{g_1}{F_1} \approx \frac{\sum_i e_i^2(\Delta q_i + \Delta \bar{q}_i)}{\sum_j e_j^2(q_j + \bar{q}_j)}$$

Experimental Status of *Δq*



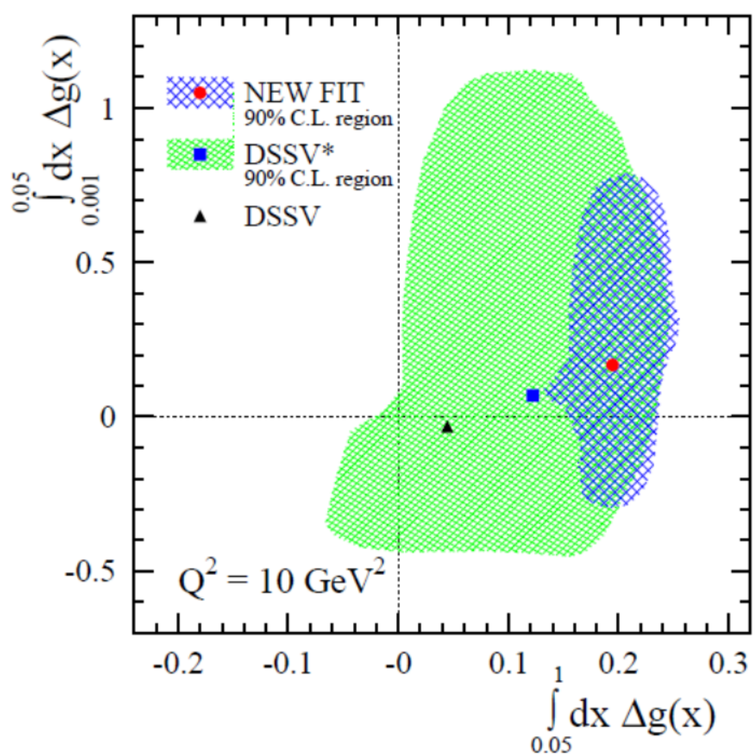
DSSV: PRD 80, 034030 (2009)

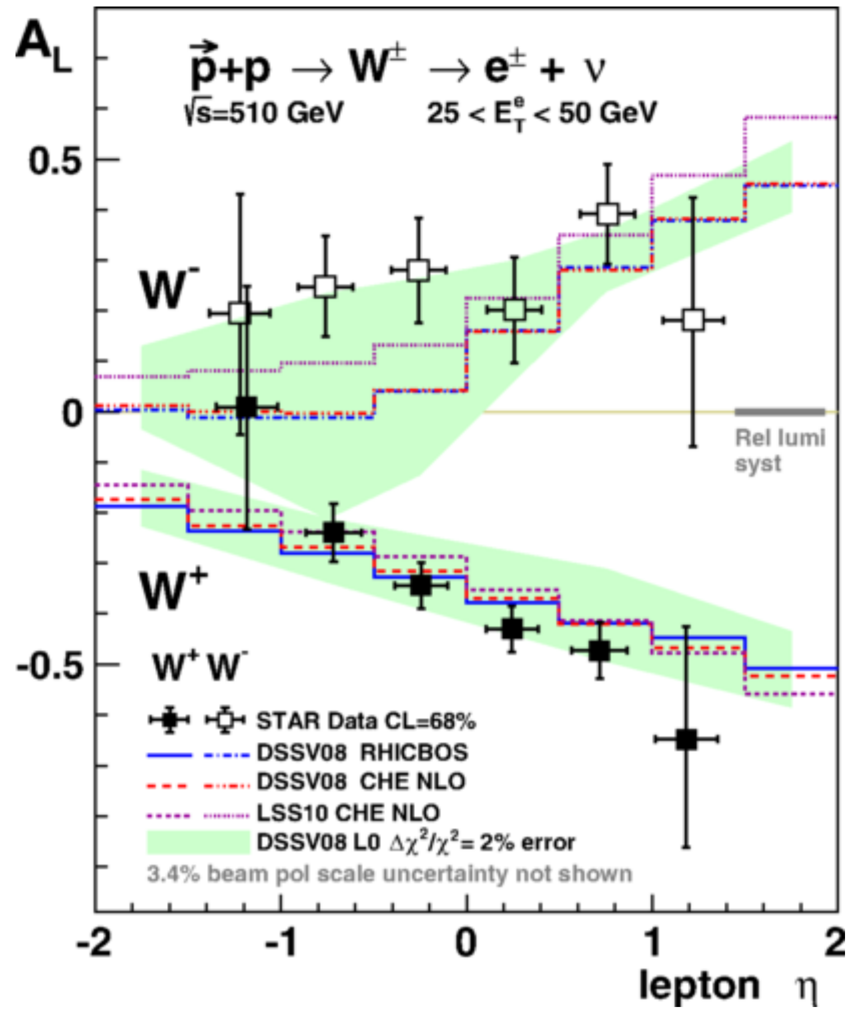


Blumlein and Bottcher, hep-ph/1005.3113

- Recent Global Analyses:
  - DSSV, includes SIDIS and pp data, asymmetric sea
  - BB, DIS data only

Progess in gluon and sea polarization from RHIC-spin

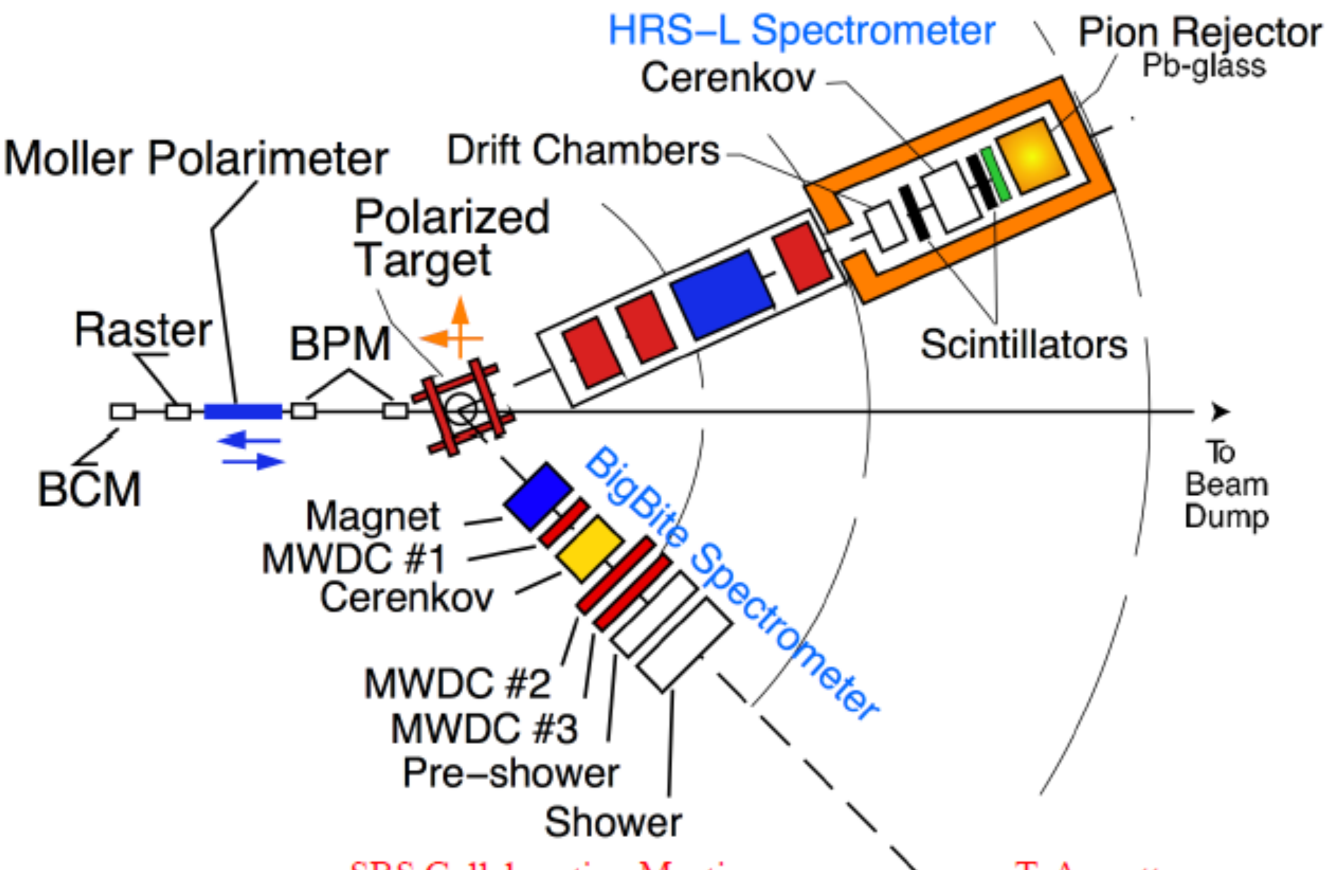




DSSV→ RHIC spin program constraints to gluon polarization (arXiv:1404.4293v1)

Jefferson Lab Hall A for A1n at 6.6 and 8.8 GeV

- LHRS at -30deg to measure unpolarized cross section
- BigBite at +30 deg to measure asymmetries
- Note: BigBite shown as proposed with all MWDCs



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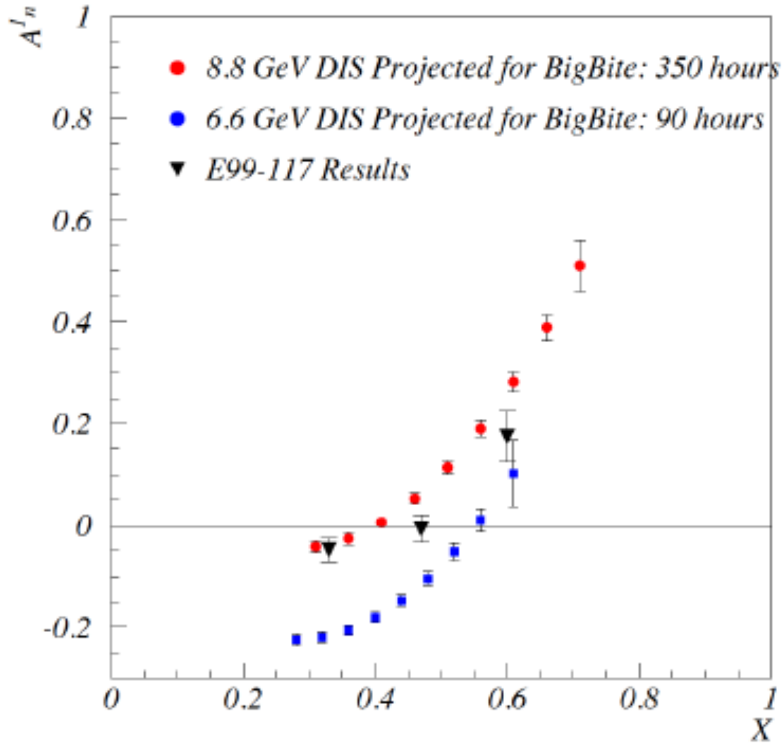
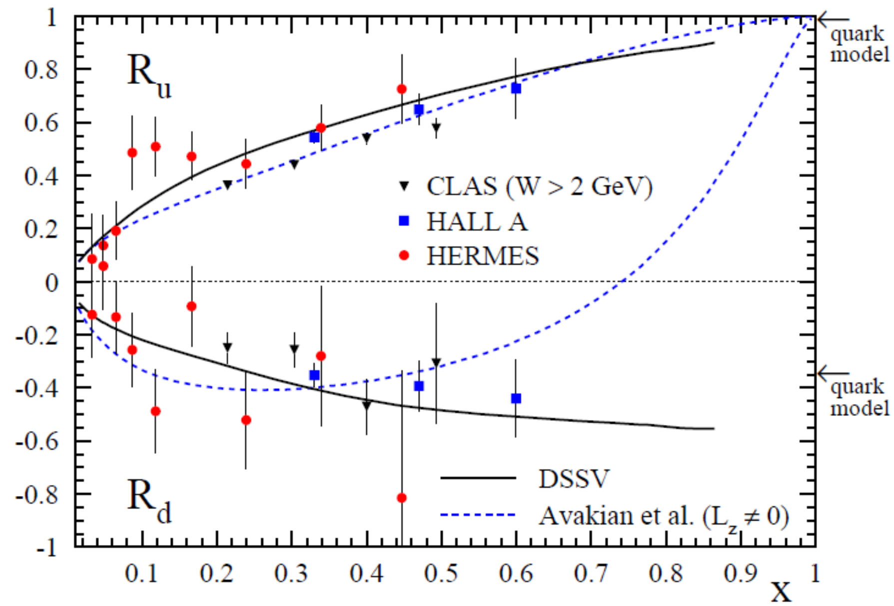
Expected Results



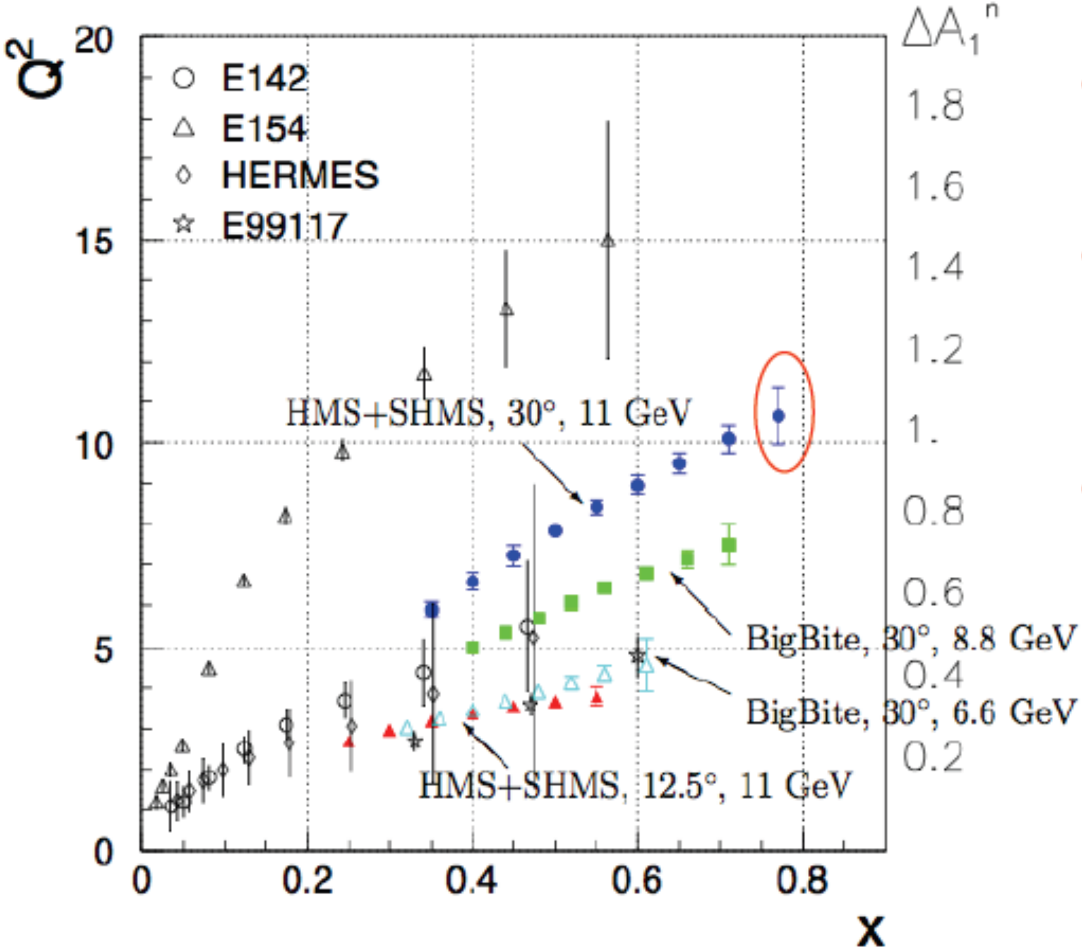


The systematic uncertainty on A_1^n is dominated by the following terms:

1. Effective proton polarization in the ^{3}He: $P_p = -0.028 \pm 0.003$.
2. Unpolarized structure functions F_1: constructed from PDF parameterizations. We used the weighted average of MRST and CTEQ for the uncertainty on F_1^p and F_1^n [1].
3. Proton spin asymmetry A_1^p: from a fit to world g_1^p/F_1^p data, with uncertainties [36].
4. Beam and target polarizations $P_b = 0.8(1 \pm 0.5\%)$ and $P_t = 0.50(1 \pm 3\%)$.

The systematic uncertainties for the proposed measurement are smaller than or comparable to the statistical uncertainties.

Hall C HMS+SHMS Experiment



- Only one data point at larger *x* for Hall C
- Hall A will be ready sooner and should run first
- Possibly reach higher *x* with 11 GeV?

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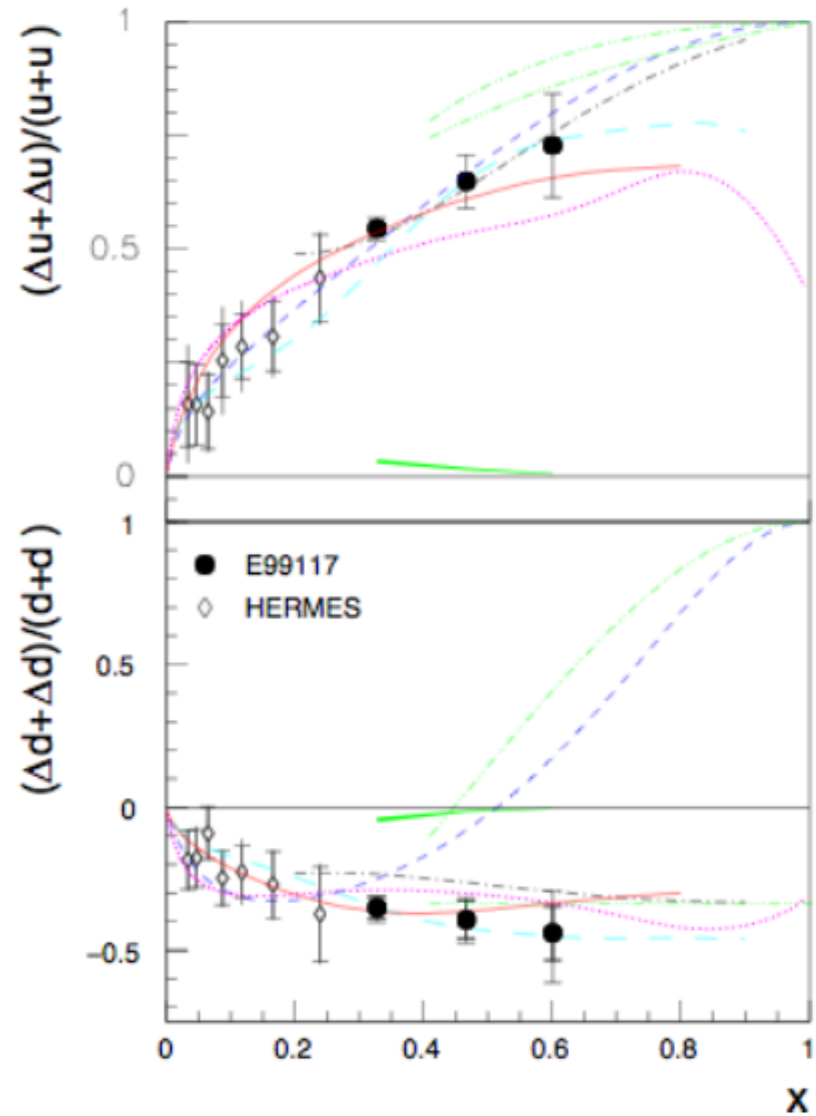
Extracting Δ u/u and Δ d/d from neutron results

- Assume s-quark contrib. small for x>0.3.
- Ignoring Q^2-dep., use JLab g_1^n/F_1^n and world data for g_1^p/F_1^p.
- u-quark results agree with models.
- d-quark results agree with most models, but not with pQCD assuming HHC (blue dashed line).



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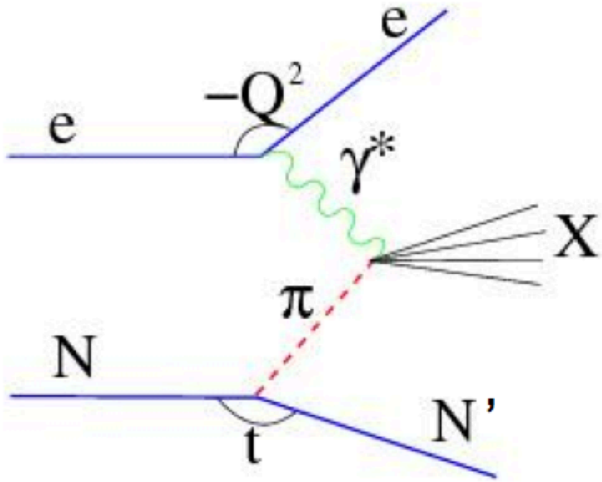
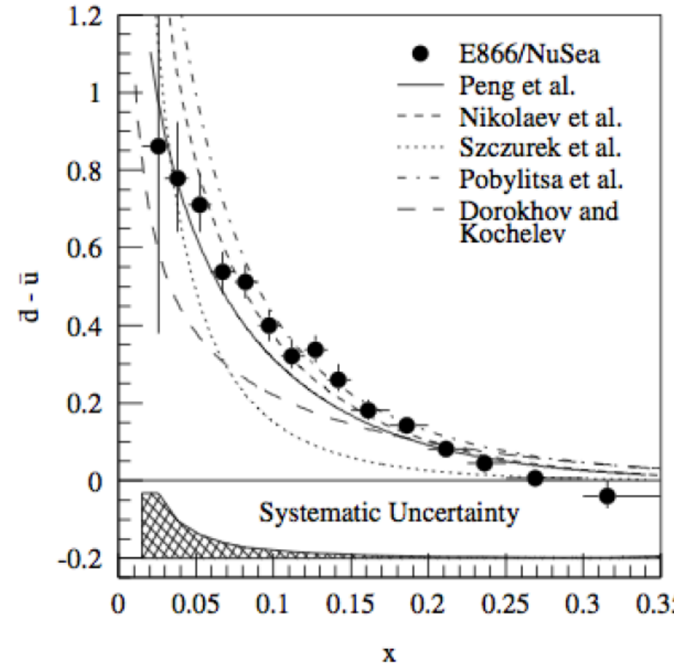
A1n Requirements and Status

- High-luminosity polarized ^{3}He target
- BigBite detector upgrades:
  - GRINCH
  - Partially replace MWDCs with GEMs
  - BigBite Timing hodoscope
- BigBite configurations are largely identical between A1n and neutron SIDIS proposal
- Status—A1n still approved but not scheduled.
- Is Hall A A1n as approved by PAC 30 (2006) still a high priority?
- Plans to re-optimize using BB+SBS, resubmit to PAC?
- Jeopardy process for proposals approved for more than 4 years but not scheduled will start in 2019 (according to draft policy presented by B. McKeown at recent Users' Group Meeting).

E12-15-006: Tagged Deep Inelastic Scattering

Physics Motivation: DIS from the pion cloud of the nucleon



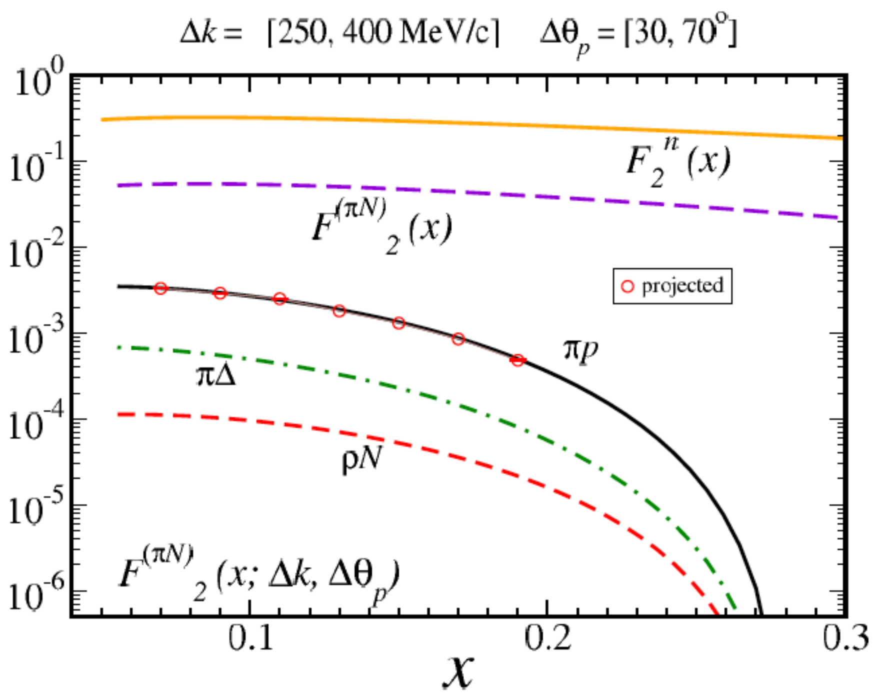


- DIS from the pion cloud of the nucleon can be ”tagged” by detecting low-energy recoil nucleons in coincidence with DIS electrons, in suitably chosen kinematics:
  - $8 < W^2 < 18$ GeV^2
  - $1 < Q^2 < 3$ GeV^2
  - $0.05 < x < 0.2$
- Nucleon exists ~20% of the time in a virtual pion-nucleon (5-quark) configuration
- Measurement at low-*t* can provide for a model-dependent extraction of pion structure function
- d(e,e'pp) and p(e,e'p) to measure charged and neutral pion

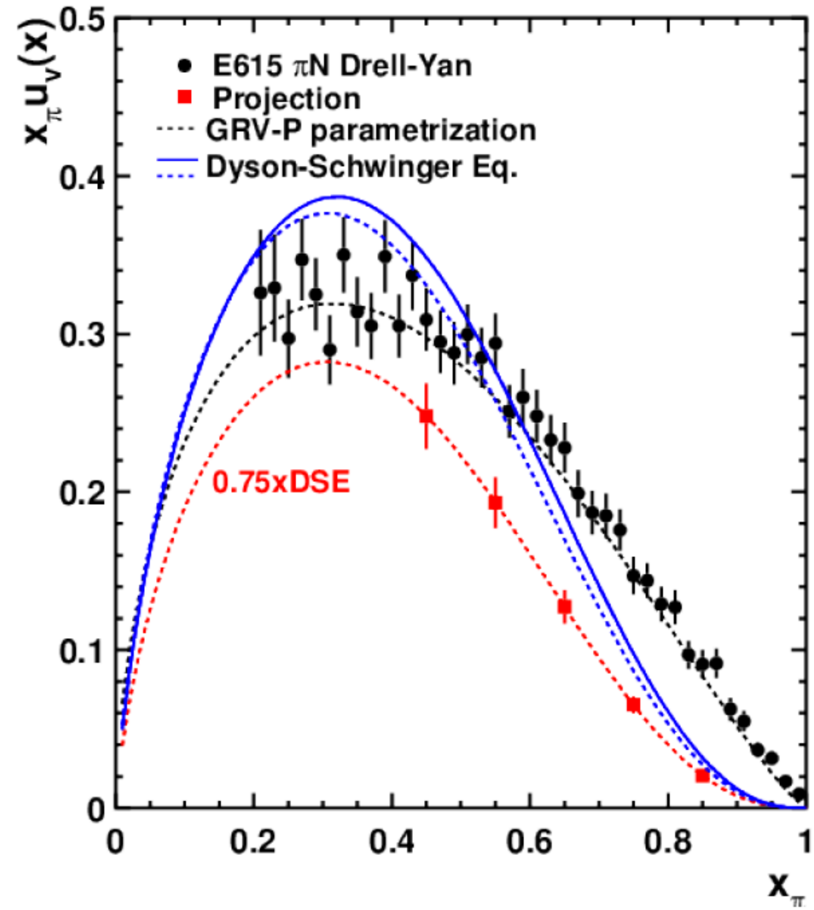
- Flavor asymmetry of the nucleon sea as observed in Fermilab E866 (Drell-Yan) has been interpreted as evidence for significant pion-cloud contributions to the nucleon structure

$$|p> \rightarrow \sqrt{1-a-b}|p_0> + \sqrt{a}\left(-\sqrt{\frac{1}{3}}|p_0\pi^0> + \sqrt{\frac{2}{3}}|n_0\pi^+>\right)$$
$$+\sqrt{b}\left(\sqrt{\frac{1}{2}}|\Delta_0^{+}\pi^-> - \sqrt{\frac{1}{3}}|\Delta_0^{+}\pi^0> + \sqrt{\frac{1}{6}}|\Delta_0^{0}\pi^+>\right)$$

Some projected results from TDIS



- Projected results of **π**p semi-inclusive structure function with experimental kinematic cuts, compared to inclusive structure function, and expected contributions from other channels



Projected pion structure function results

TDIS apparatus

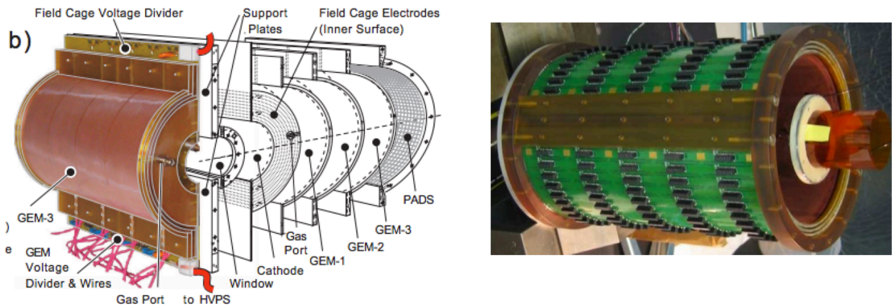


Figure 15: (left) Photograph of the BoNuS RTPC, showing the left module with the readout padboard removed and a complementary exploded view exposing the components of the right module. (right) Photograph of the eg6 RTPC during assembly.

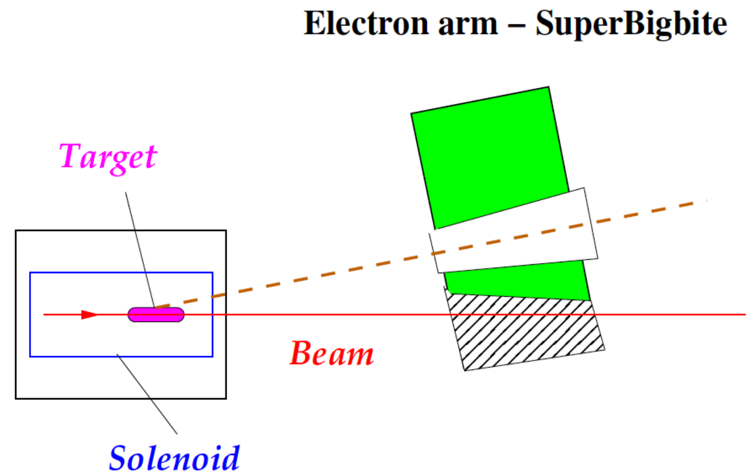
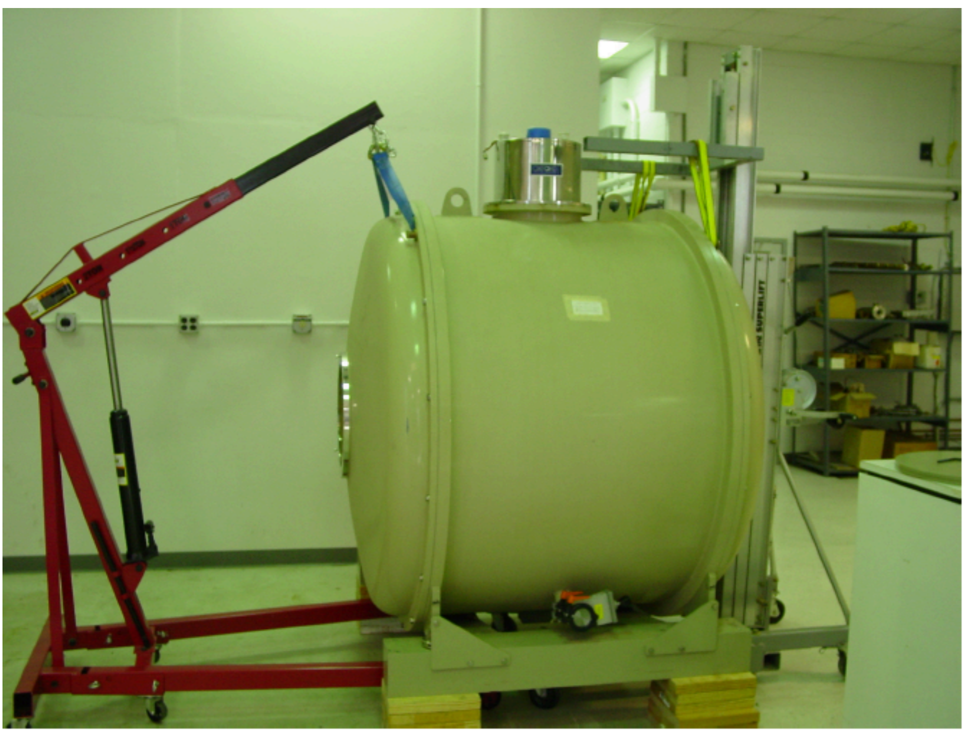


Figure 12: Schematic layout of the proposed experiment.



- Low-density Hydrogen and Deuterium gas targets in 5 T Solenoid field
- rTPC to track low-energy recoil protons
- SBS to detect DIS electrons, with
  - GEM-based tracker
  - Refurbished CLAS Large-angle Calorimeter (LAC)
  - SBS RICH repurposed as electron Gas Cherenkov for pion rejection

TDIS Update

Refurbishing the Large Angle Calorimeter (LAC)

Hall A Shed

ESB

Refurbishing to commence once the LAC is moved to the ESB in the next couple of weeks.

TDIS Status

- ”C1” approved, 27 days, A- rating by PAC43
- Miss. State. committed to refurbish CLAS Large angle Calorimeter for SBS as electron spectrometer
- Glasgow U. Working on simulations of rTPC for TDIS—See Rachel Montgomery talk
- JLab Cap. Equipment project approved for DAQ/trigger development
- Test-stand and small prototype detector planned to be set up this fall
- Several recent workshops on TDIS have focused the physics motivation for such a measurement
- HERMES/SBS RICH will be repurposed as gas Cherenkov for SBS as electron spectrometer (see talks from UConn grad students Nilesh Deokar and Freddy Obrecht for RICH progress)

Backup Slides