(Update to Conditionally Approved PR12-09-018)

Measurement of SIDIS Pion and Kaon Electroproduction on a Transversely Polarized ^{3}He Target

Proposal C12-09-018

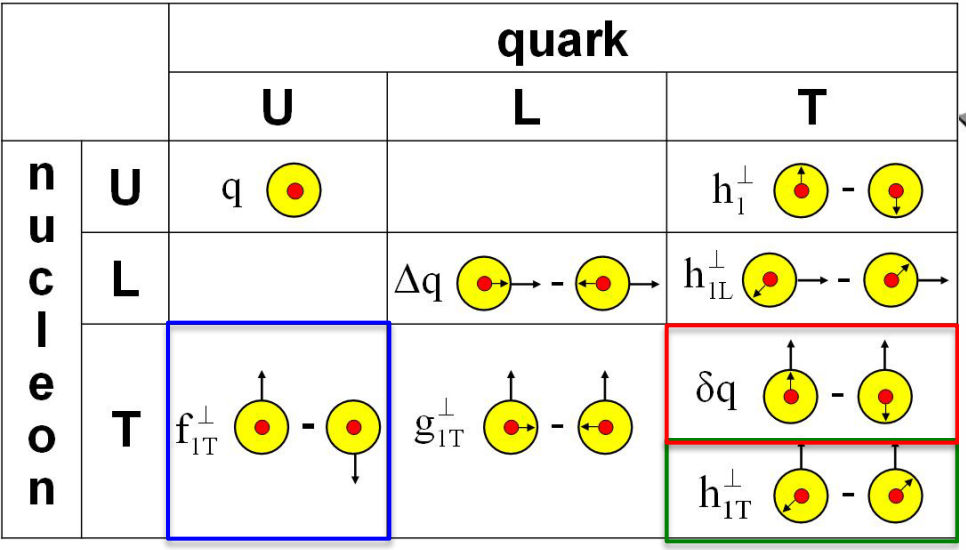
Presented by Andrew Puckett, LANL

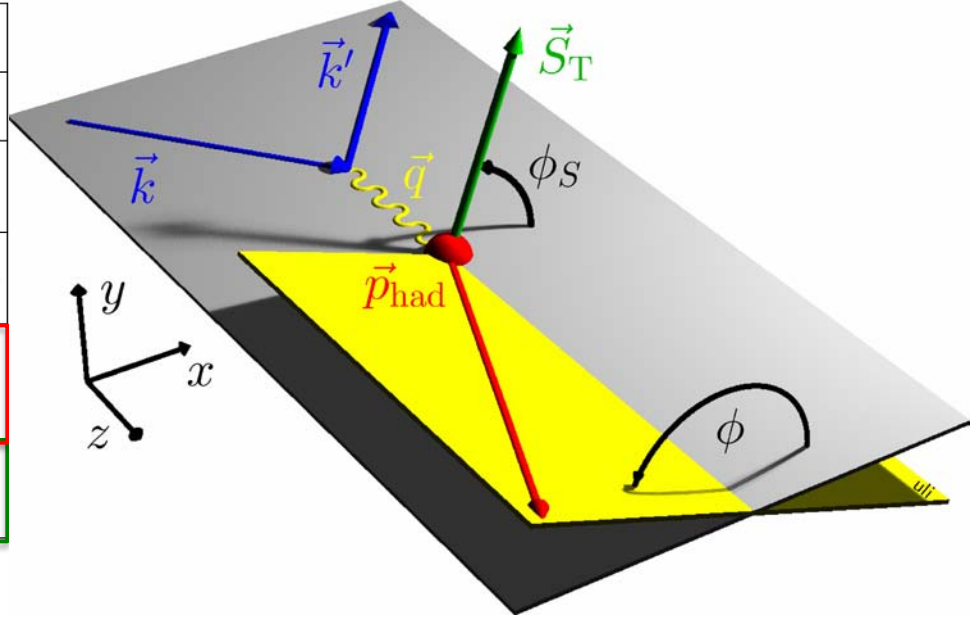
to PAC37, 1/13/2010

on behalf of G. Cates, E. Cisbani, G. Franklin, A. Puckett, B. Wojtsekhowski, and the C12-09-018 Collaboration

Outline

- **Introduction: SIDIS Physics**
  - Polarized TMDs and nucleon structure
  - Experimental and Theoretical Status
- **Proposed Measurements**
  - Experiment Goals
  - Projected uncertainties
- **WHAT IS NEW/SPECIAL:**
  - BB+SBS: very good acceptance for high-momentum, two-arm experiment
  - Next-generation ^{3}He target technology:
    - Cell in vacuum (as at SLAC), much lower background at same luminosity
    - Convection-flow
      - Separation between target and pumping chamber
      - Frequent spin orientation (2 min)
      - Tolerate 40 μA beam
  - HERMES RICH detector: High-quality hadron ID
- **PAC34+TAC concerns**
  - Target upgrades
  - RICH detector background rates: MC and experimental confirmation
  - Trigger/DAQ
- **Summary—Beam time request**





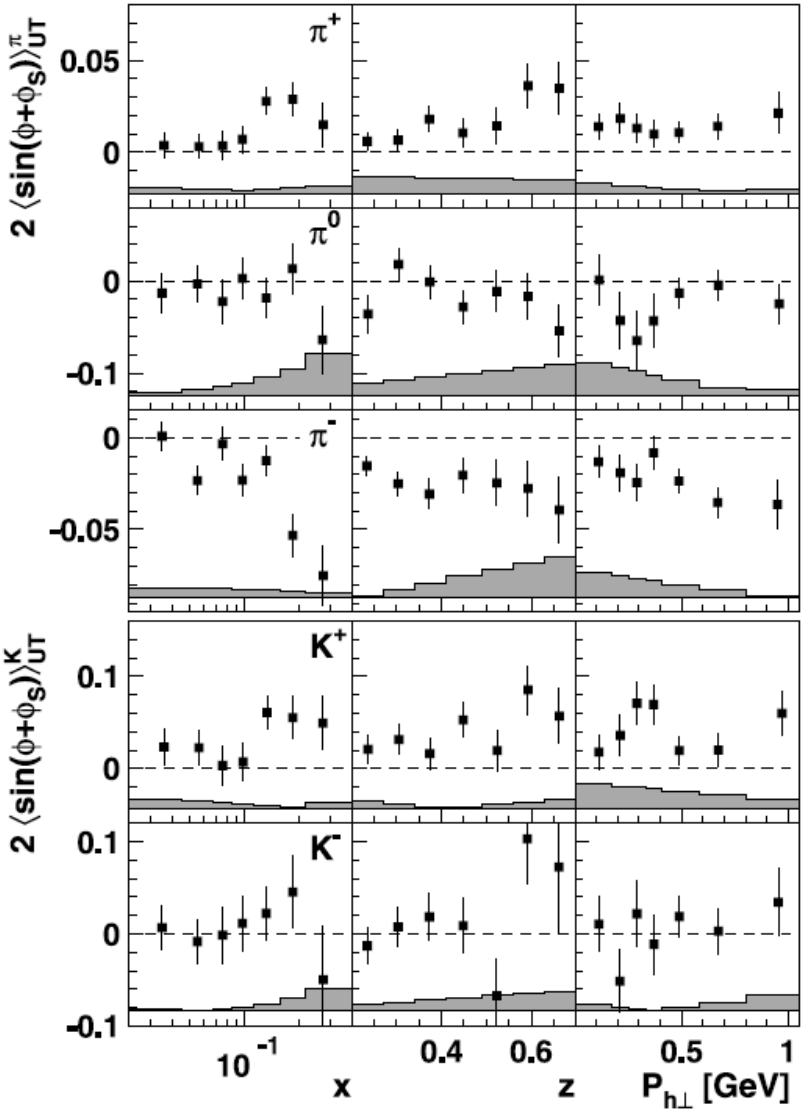
Transverse target spin-dependent cross section for SIDIS

- Collins effect—chiral-odd quark transversity DF; chiral-odd Collins FF
- Sivers effect—access to quark OAM and QCD FSI mechanism
- "Pretzelosity" or Mulders-Tangerman function—access to wavefunction components differing by 2 units of OAM

$$A_{UT} \equiv \frac{1}{|S_T|}\frac{d\sigma(\phi,\phi_S)-d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S)+d\sigma(\phi,\phi_S+\pi)} \equiv \frac{1}{|S_T|}\frac{d\sigma_{UT}}{d\sigma_{UU}}$$

$$d\sigma_{UT} = |S_T|([\delta q \otimes H_1^\perp]\sin(\phi+\phi_S) \quad \text{Collins}$$
$$+ [f_{1T}^\perp \otimes D_1]\sin(\phi-\phi_S) \quad \text{Sivers}$$
$$+ [h_{1T}^\perp \otimes H_1^\perp]\sin(3\phi-\phi_S) + O(1/Q))$$
$$d\sigma_{UU} = [q \otimes D_1] + [h_1^\perp \otimes H_1^\perp]\cos 2\phi + O(1/Q)$$

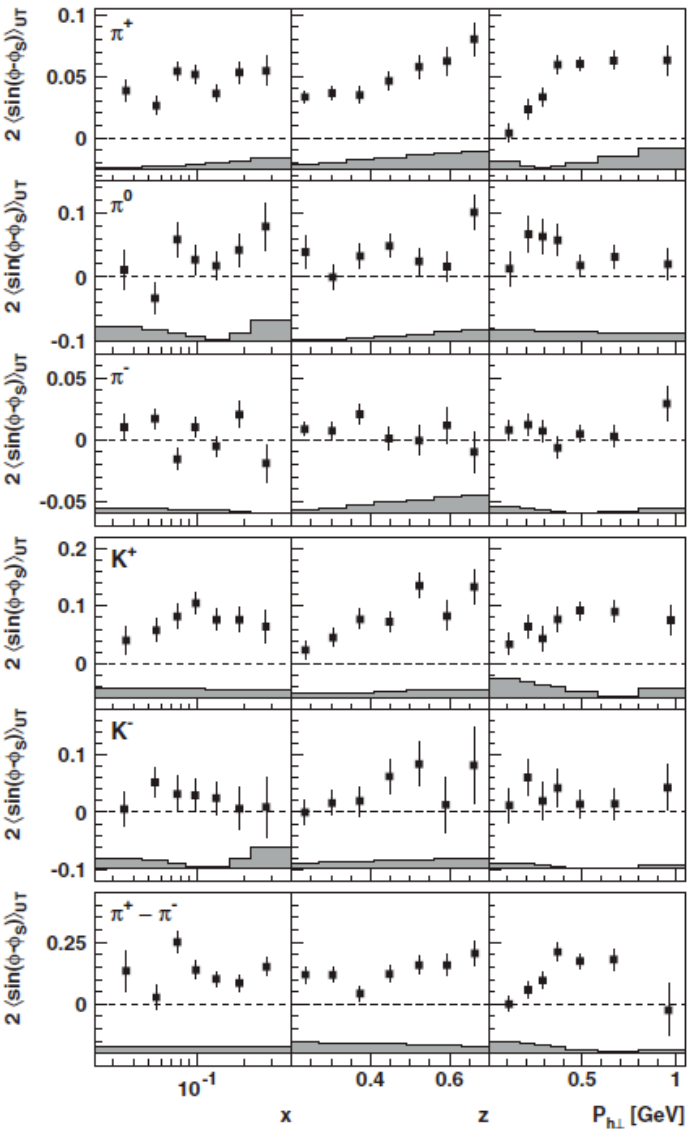
Overview of Published Results



HERMES data for proton Collins effect: PLB 693, 11 (2010)

- $\pi^{\pm,0}$, $K^{\pm}$
- Collins moments for π^+, K^+ positive and significantly non-zero
- Surprisingly, K^+ Collins amplitude larger than π^+
- K^- consistent with zero
- π^- nonzero and negative
- General tendency for Collins amplitudes to increase with x, z
- Compatible with proton transversity being dominated by valence quarks
- HERMES $Q^2 \sim 1\text{-}10\ \text{GeV}^2$

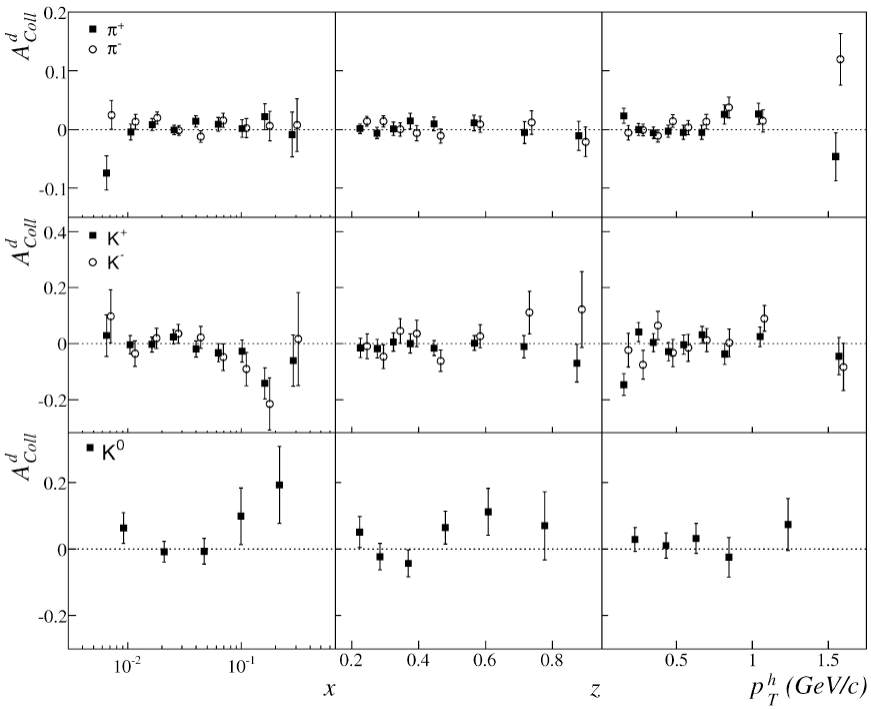
Overview of Published Results



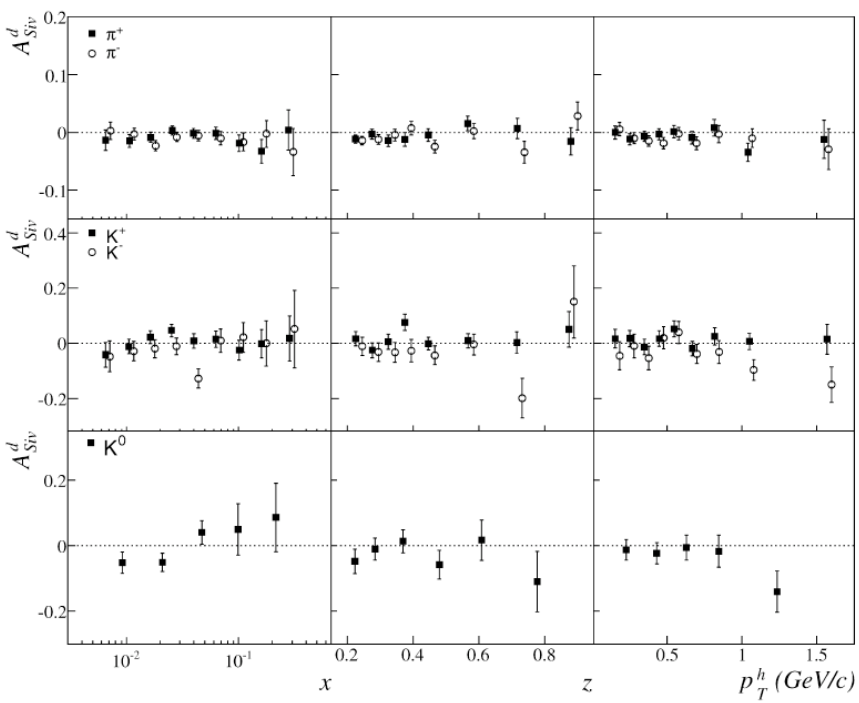
HERMES results on proton Sivers effect: PRL 103, 152002 (2009)

- Large, positive Sivers asymmetries for π^+/K^+
- $K^+ > \pi^+$, disagrees with expectation of u quark dominance
- π^-/K^- more or less consistent with zero
- Vanishing π^- suggests cancellation between u and d quark Sivers functions
- Tendency for amplitude to saturate for $p_T \geq 0.4$ GeV, decrease as $p_T \rightarrow 0$
- Can be linked in a model-dependent way to quark OAM

Overview of Published Results



COMPASS deuteron Collins moments

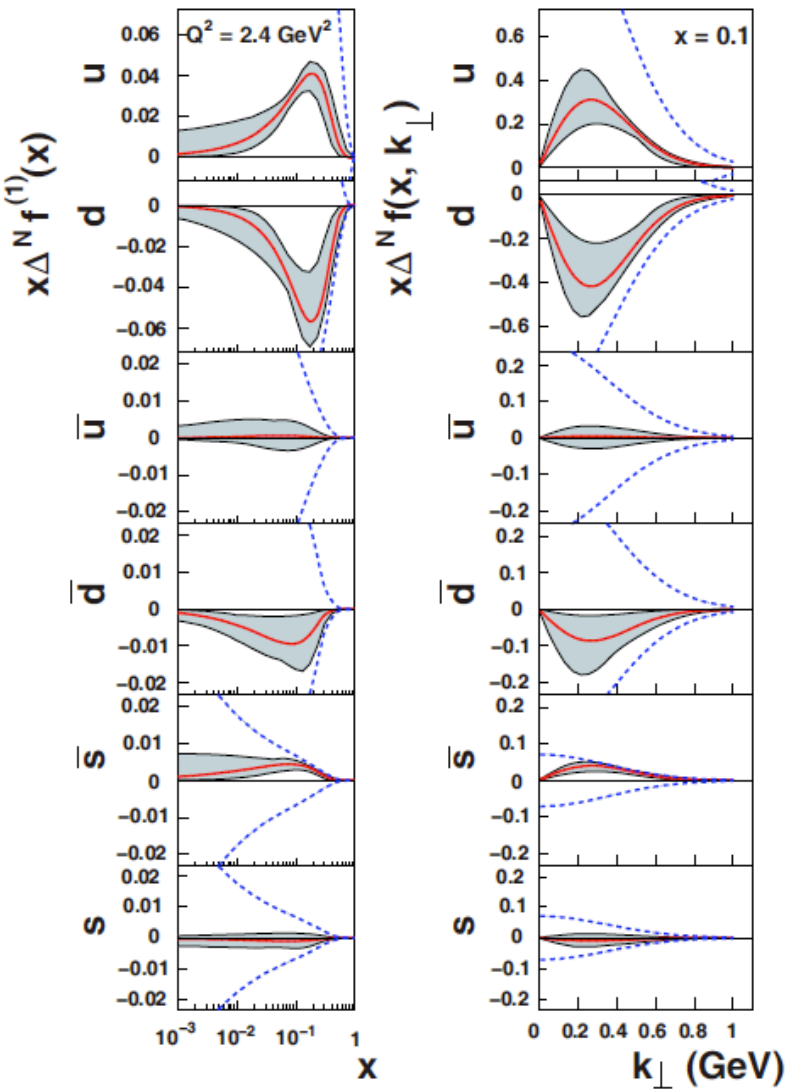


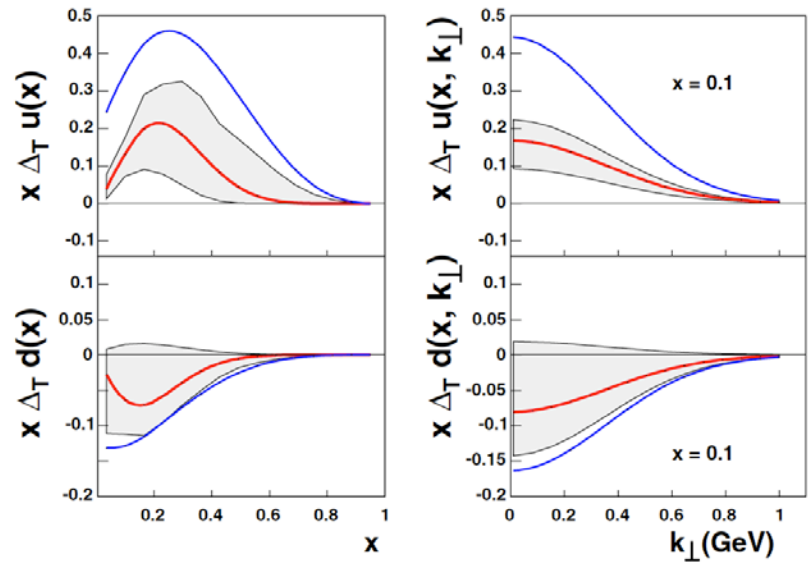
COMPASS deuteron Sivers moments

COMPASS deuteron Collins+Sivers data: PLB 673, 127 (2009)

- $\pi^{\pm}$ Collins+Sivers moments consistent with zero
- Suggest cancellation between proton and neutron (i.e., u and d quarks) for both Collins and Sivers effects;
- Q^2 up to 100 GeV^2, $\langle Q^2 \rangle \sim 20$ GeV^2 at highest x

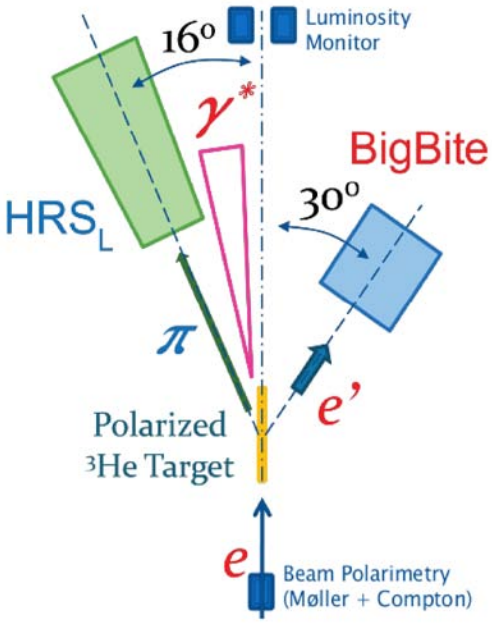
Overview of Published Results



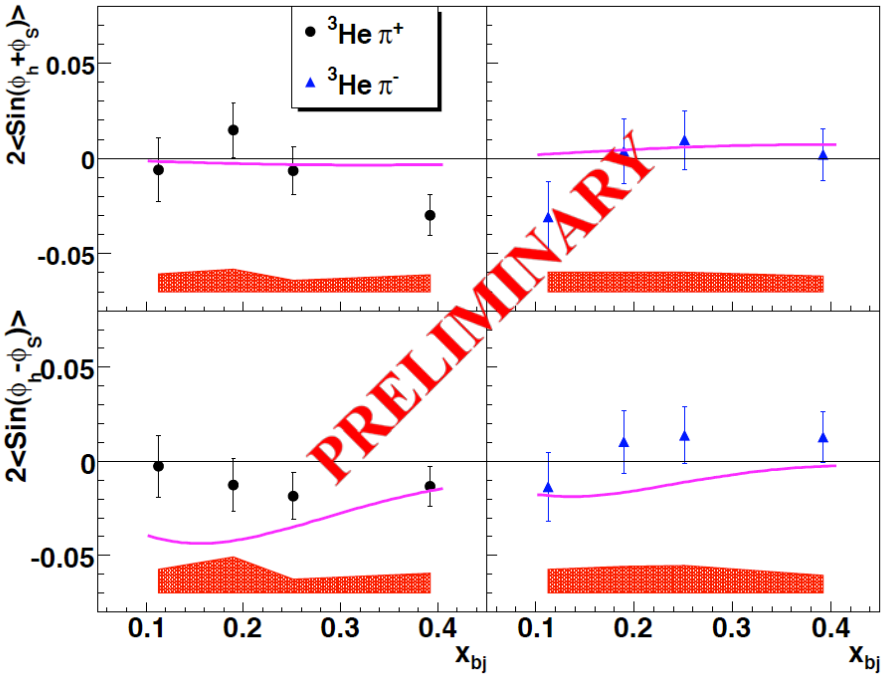


- Above, right: extraction of u and d quark transversity from SIDIS and e^+e^- data in a global phenomenological fit: **PRD 75, 054032 (2007)**
  - u and d quark transversity opposite sign, within Soffer/positivity bounds, **large uncertainties**
- Global Sivers function extraction from HERMES proton and COMPASS deuteron data: **EPJ A, 39, 89 (2009)**
  - u and d quark Sivers also opposite, within Soffer/positivity bounds
  - Valence quarks dominate

JLab E06-010 in Hall A



- Successfully completed 2008-2009
- Publication time scale ~months
- $\langle Q^2 \rangle \sim 2$ GeV^2, $\langle p_T \rangle \sim 0.4$ GeV, $\langle z \rangle \sim 0.5$

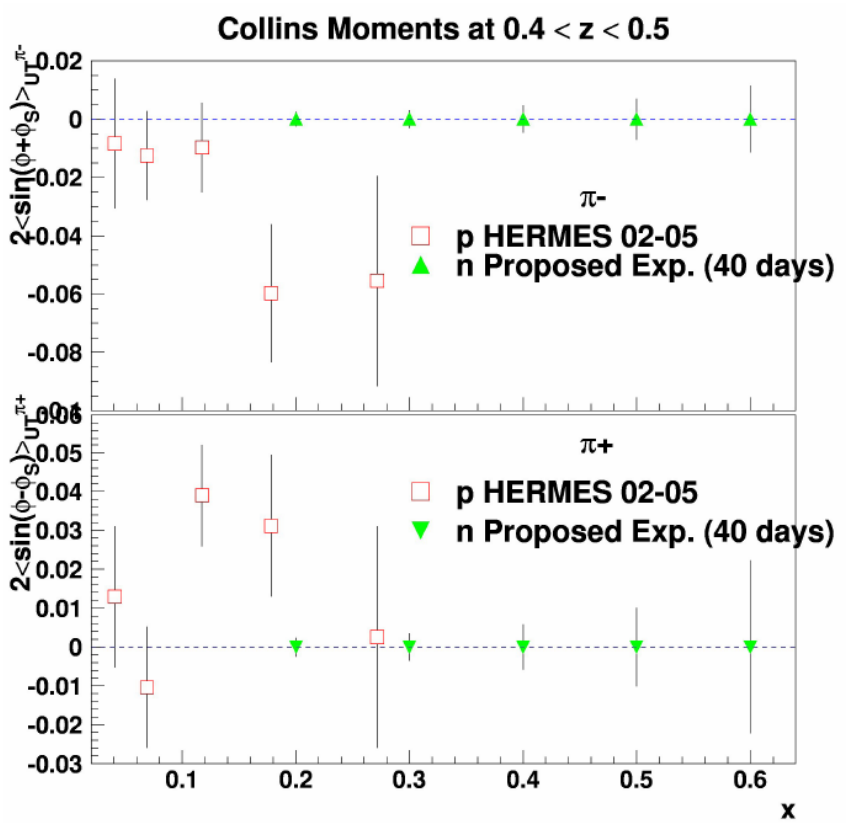


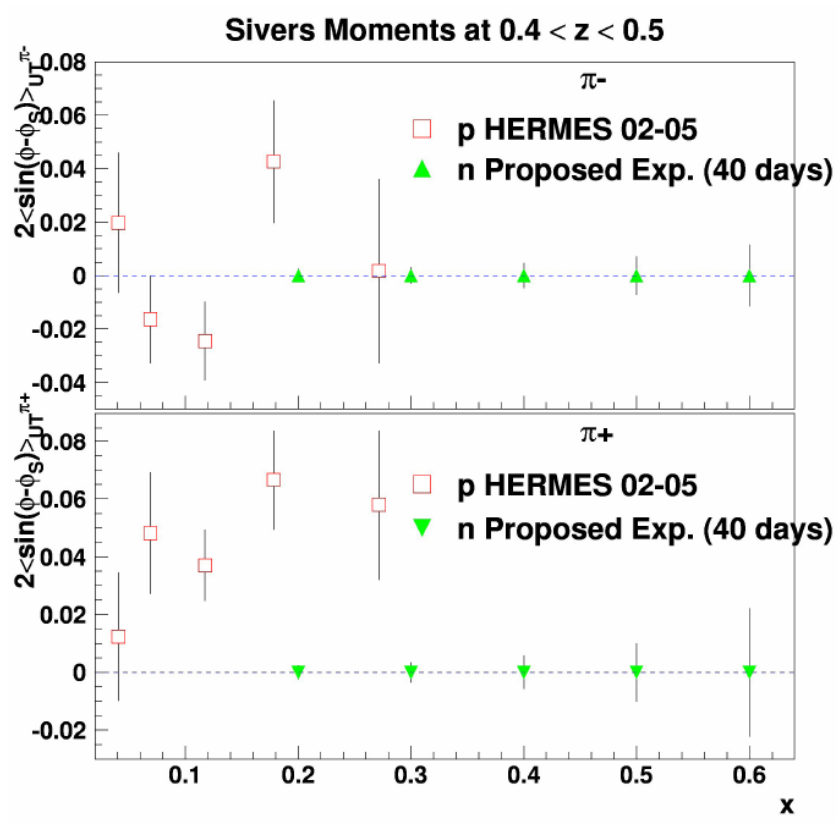
- Fresh results of JLab E06-010/011;
- Pioneering measurement, demonstrates feasibility to extract neutron SSAs with **finite angular coverage**
- Demonstrate experiment technique:
  - Pol. ^{3}He target **fast flip** ~20 min (keep systematics small).
  - Feasibility of **open geometry** e arm in high-luminosity environment

Goals and Methods of the Proposed Experiment

- Go beyond one-dimensional analysis of transversity by acquiring high-statistics for **Collins+Sivers** (+Pretzelosity) effects in **^{3}He(e,e'$\pi^{\pm,0}$)X & ^{3}He(e,e'K$^{\pm}$)X** reactions on a transversely polarized ^{3}He target;
- Expand reach of data to high-x (valence), high-Q^2 region (between HERMES and COMPASS) by measuring DIS electrons and high-momentum hadrons at relatively large angles. Large kinematic coverage, partially overlapping JLab, HERMES, COMPASS experiments.
- Study Q^2-dependence of the asymmetries at fixed x, z by taking data at two beam energies: E=11, 8.8 GeV.
  - Two beam energies provide unique experimental handle to support global fitting
- High statistical precision accomplished through large acceptance and high luminosity
- High systematic accuracy with improvements in target spin-flip rate, greater azimuthal coverage (compared to e.g. E06-010), calibration runs with unpolarized target, SBS polarity reversal.

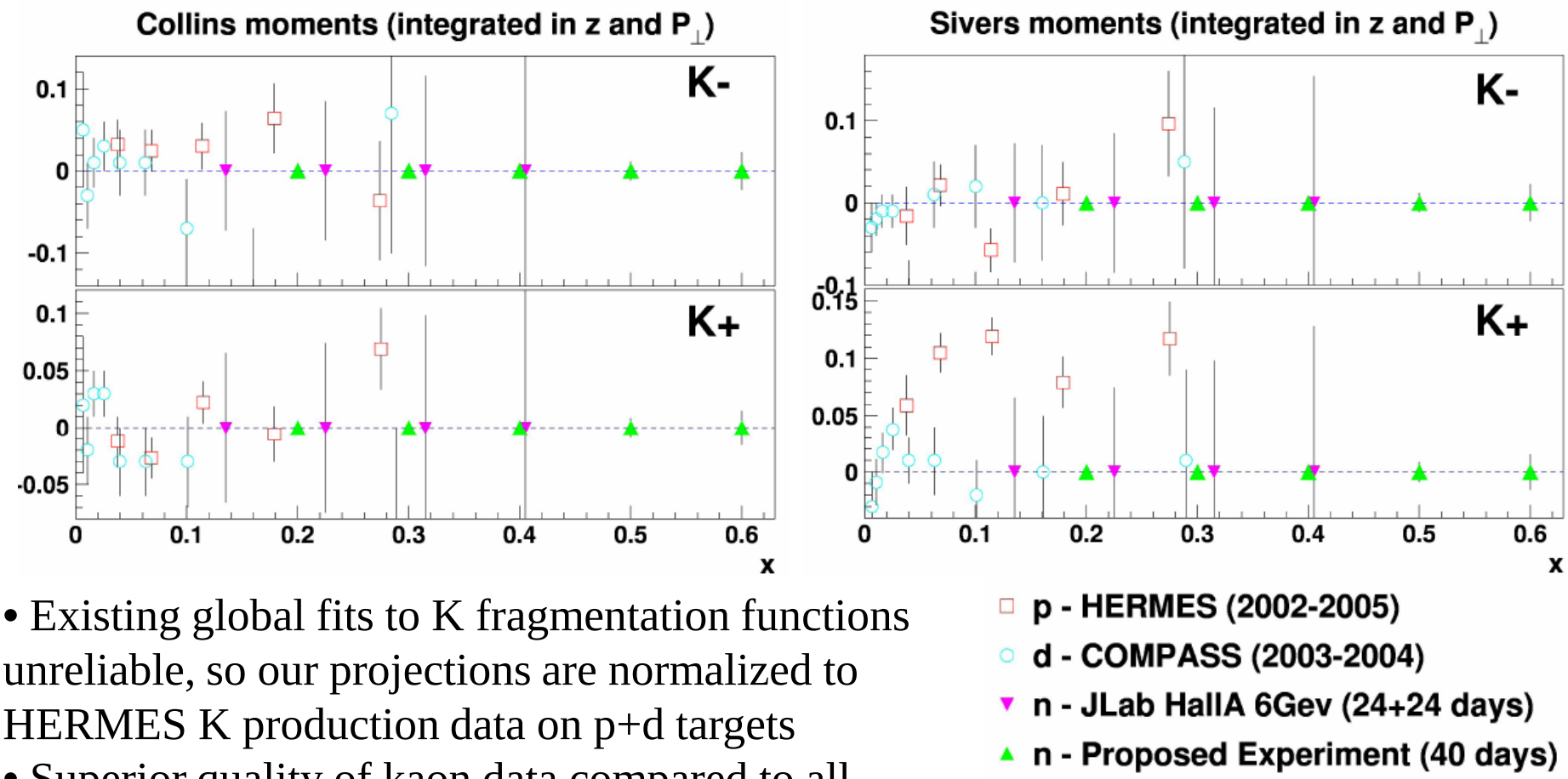
Projected Statistical Precision (neutron $\pi^{\pm}$)



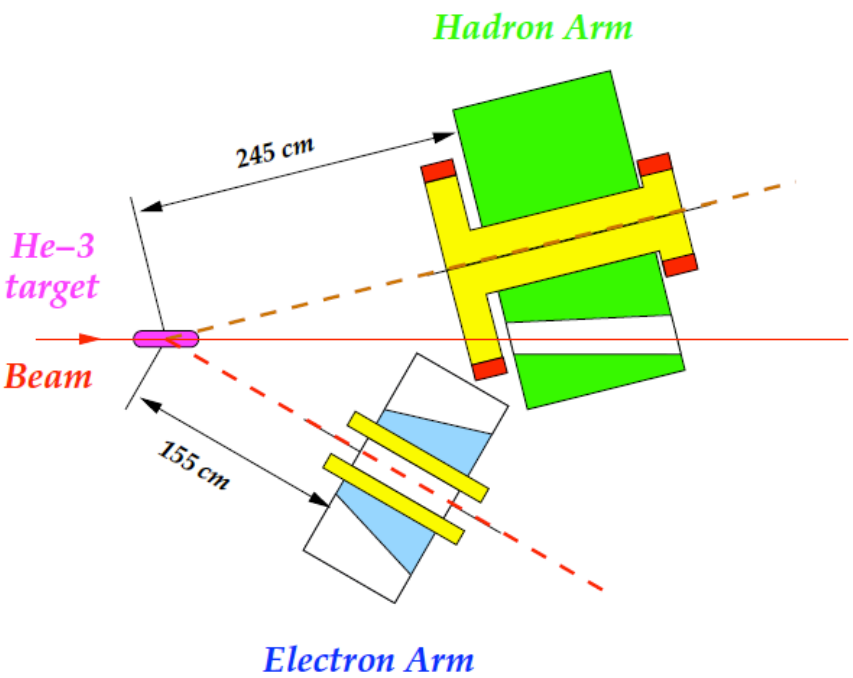


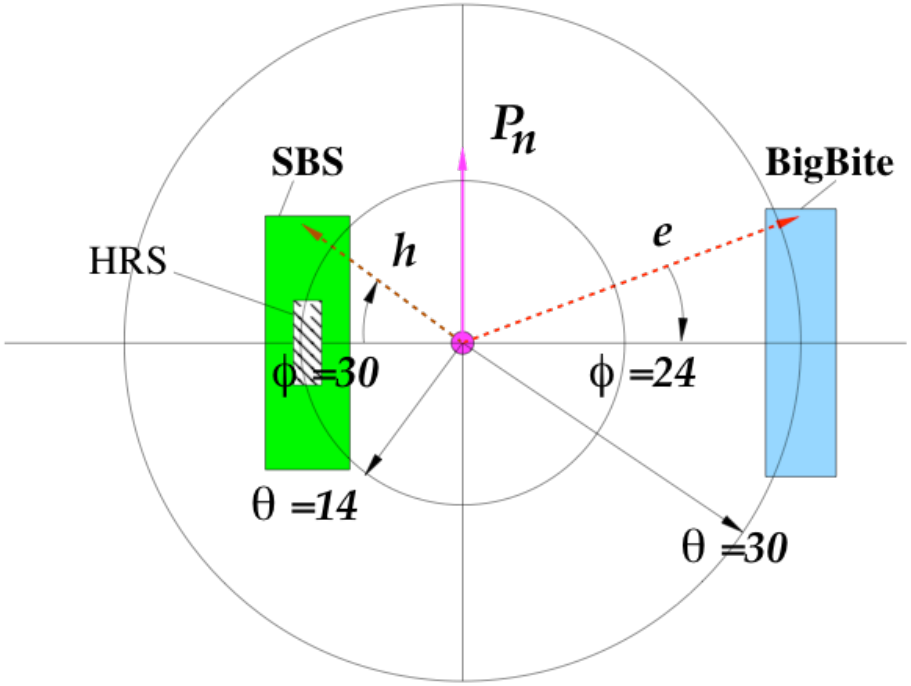
- Cover high-x (valence region) with partial overlap with the HERMES experiment
- Cross sections and rates using CTEQ5M PDFs, DSS2007 FFs
- At least 2D binning in (x,z) and/or (x,p_T) and/or (z,p_T), also Q^2 dependence at fixed x using two beam energies E=11, 8.8 GeV

Projected Statistical Accuracy (neutron $K^{\pm}$)



- Existing global fits to K fragmentation functions unreliable, so our projections are normalized to HERMES K production data on p+d targets
- Superior quality of kaon data compared to all previous experiments
- Excellent PID capability by reusing HERMES RICH detector



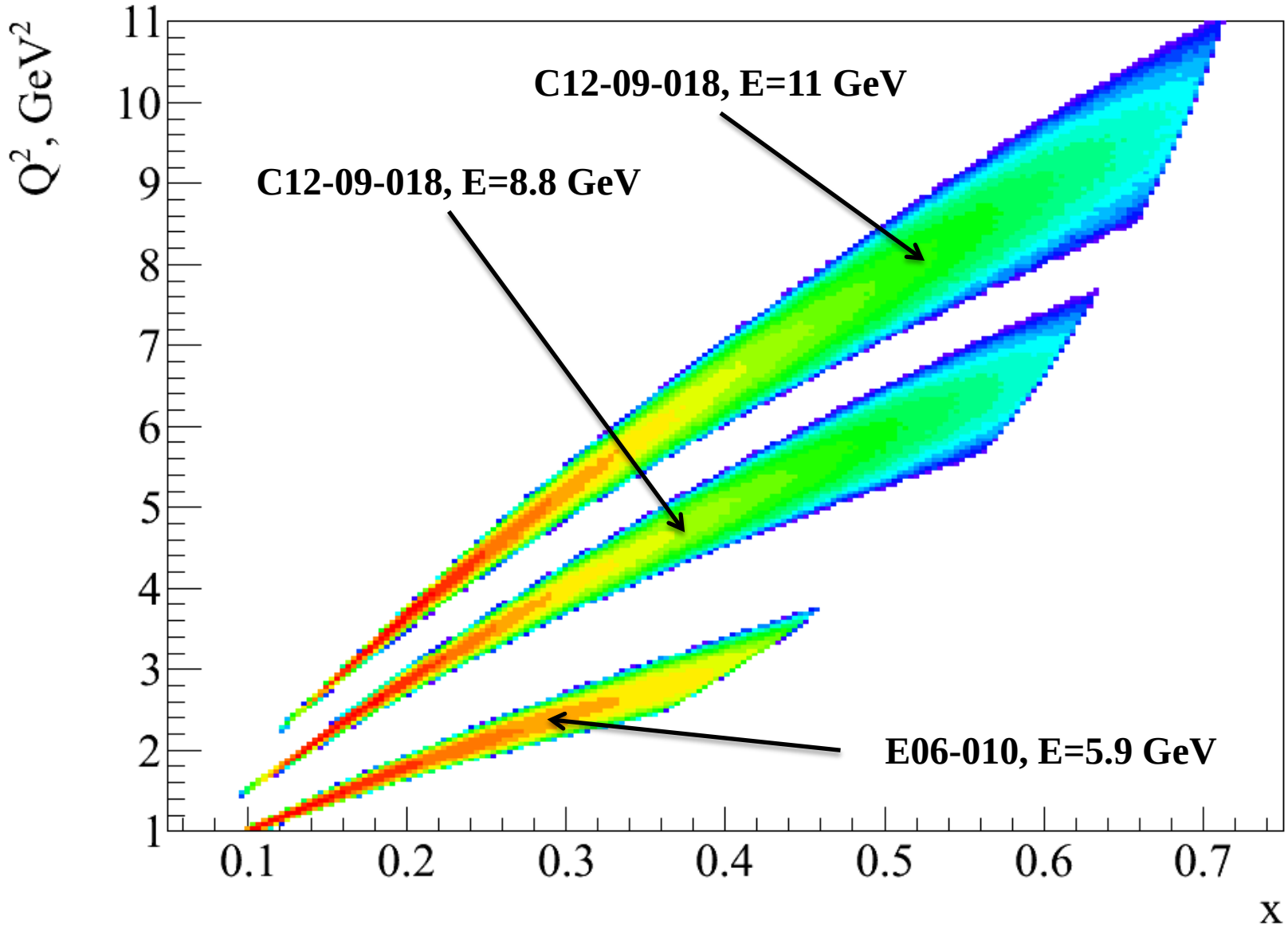


Layout of experiment

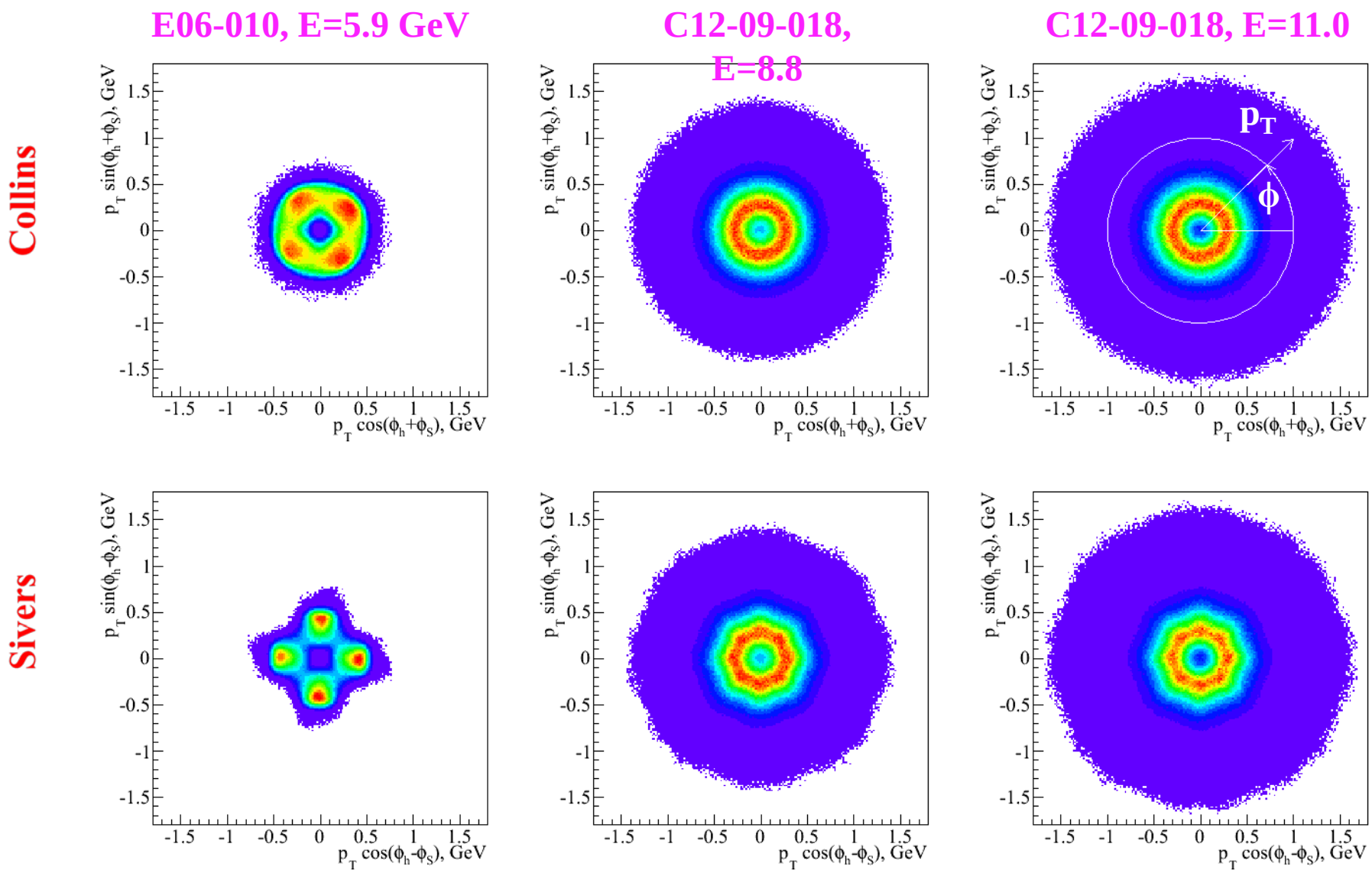
- Electron arm (BigBite) at 30°
- Hadron arm (SBS) at 14°
- Upgraded high-luminosity ^{3}He target, 60 cm long; target spin can be oriented in 8 transverse directions
- 10X larger angular acceptance compared to 6 GeV transversity

- BigBite effective solid angle for 60 cm target = 45 msr; ~5/1 vertical/horizontal aspect ratio
- SBS solid angle = 50 msr; 4/1 vertical/horizontal aspect ratio
- "Super-Big" momentum bite for h arm: 2 GeV < p_h < full beam energy

SBS nSIDIS Q^2-x Coverage

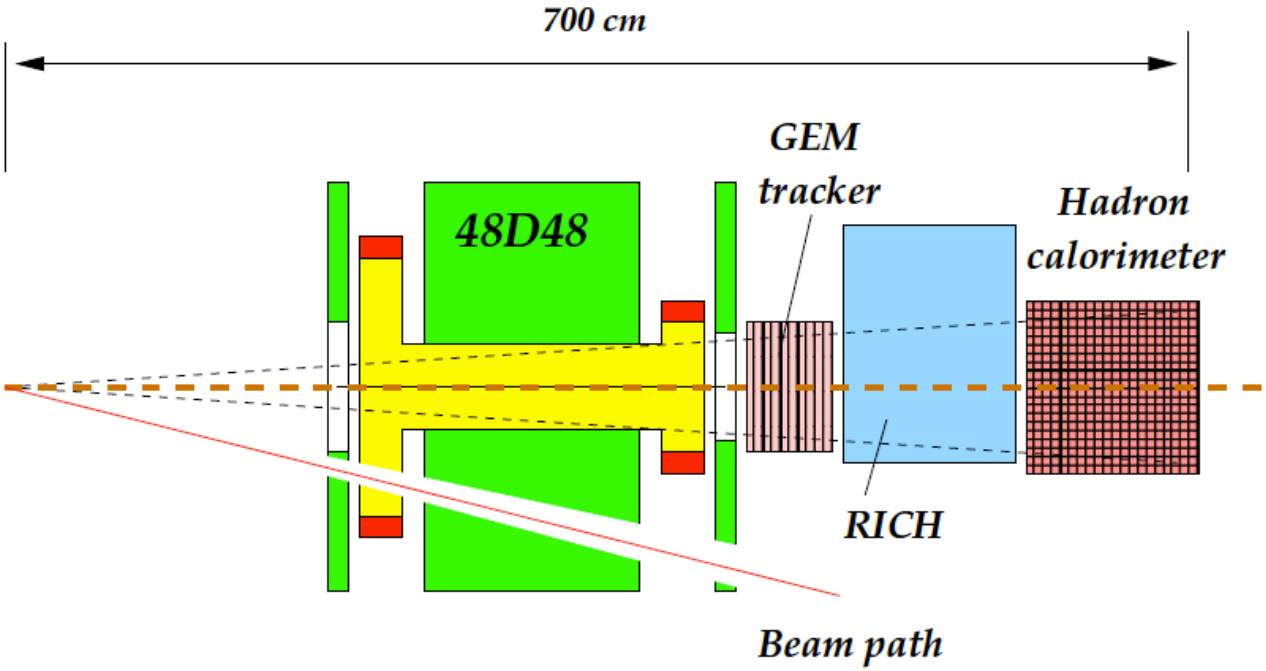


ϕ vs. p_T Coverage: Collins+Sivers Angles



What is special in this experiment?

- Large acceptance for meson arm + orient target spin in 8 transverse directions:
  - **Full Collins and Sivers angle coverage!**
- Excellent PID π/K: HERMES RICH counter; **best hadron PID of any large-acceptance SIDIS experiment at JLab 12 GeV**
- Measure all particles of interest simultaneously: $\pi^{\pm,0}/K^{\pm}$
  - Vertically symmetric acceptance—identical for +/- charged hadrons; also polarity reversal
- Part of essential stage II of SBS physics program
- Additions to SBS apparatus?
  - **One major addition = HERMES RICH**



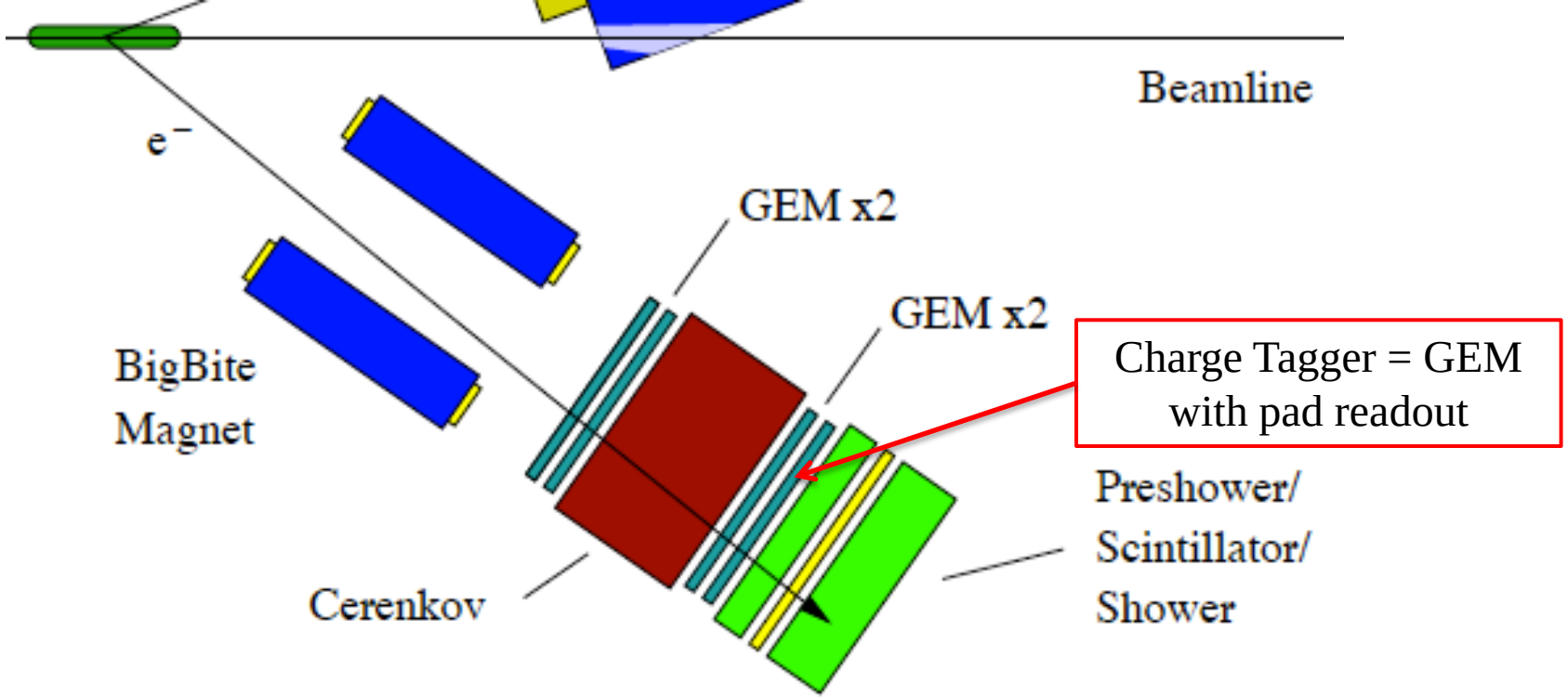
quantity	resolution
δ, %	0.03p+0.29
x'_{tar}, mrad	0.09 + 0.59/p
y_{tar}, mm	0.53 + 4.49/p
y'_{tar}, mrad	0.14+1.34/p

Hadron arm: Super BigBite Spectrometer (SBS)

- http://hallaweb.jlab.org/12GeV/SuperBigBite/
- Warm dipole magnet 48D48, Bdl = 2 Tm; cut in yoke for passage of beam pipe, reach to very forward angles. (Lambertson magnet, familiar concept in accelerator physics).

Detectors for SIDIS

- GEMs: high-rate capability, high-resolution tracking; momentum/angle/vertex/RICH, resolution
- HCAL: Iron-scint hadronic calorimeter; trigger + timing + coordinate measurement**+reduce search area for high-rate tracking**
- HERMES RICH: Hadron PID, full π/K/p separation 2 GeV<p<15 GeV



Electron arm: BigBite Spectrometer

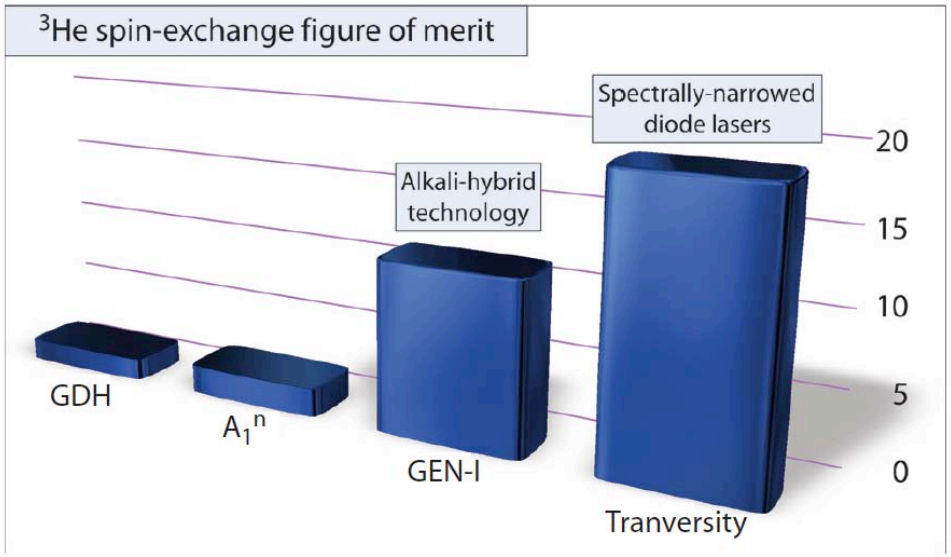
- Already used successfully in a large number of experiments, including E06-010 (transversity)

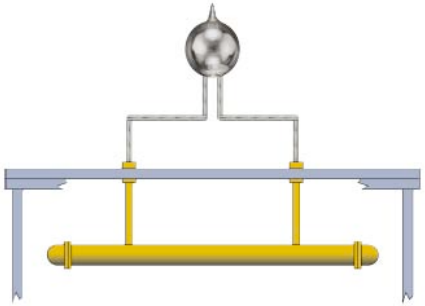
Detectors for SIDIS

- Lead-glass preshower/shower for trigger and offline pion rejection; threshold = 1 GeV
- GEM chambers (INFN) instead of MWDC:
    - Increase rate capability in high-luminosity environment
    - Improve resolution
- Gas Cherenkov: trigger and pion rejection [experience in hand, planned improvements]
- Charge tagger: possible supplement to GC for neutral trigger suppression

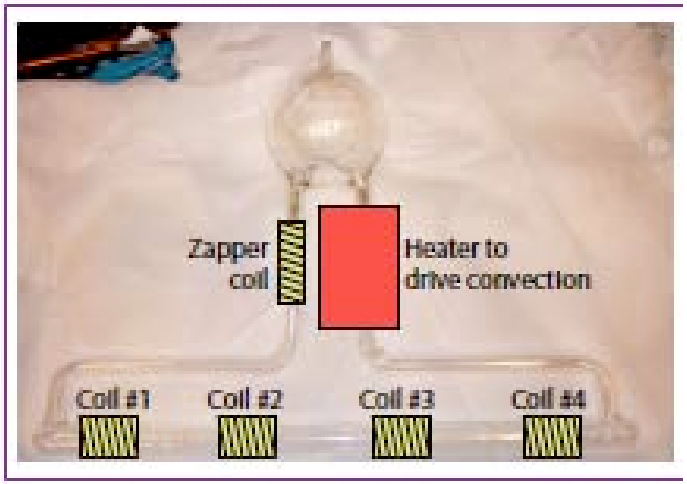
High Luminosity Polarized ^{3}He Target

- History of FOM increases in JLab polarized ^{3}He experiments (top left)
- New design with convection-driven flow
  - Fast replacement of polarized gas
  - Tolerate higher beam currents—support up to 60 μA, 60 cm long cell
  - Decouple location of target chamber and pumping chamber; decouple magnetic field directions
- ***Concept already demonstrated in bench tests***
- Fast spin orientation: ~every 2 minutes
- ***Metal target cell in vacuum: reduce non-^{3}He material on beamline—reduce background rates***



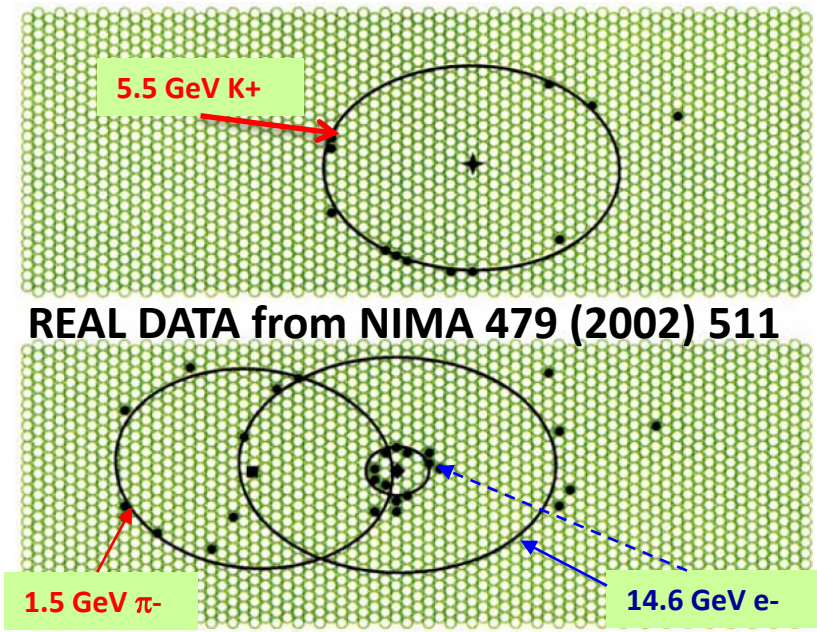


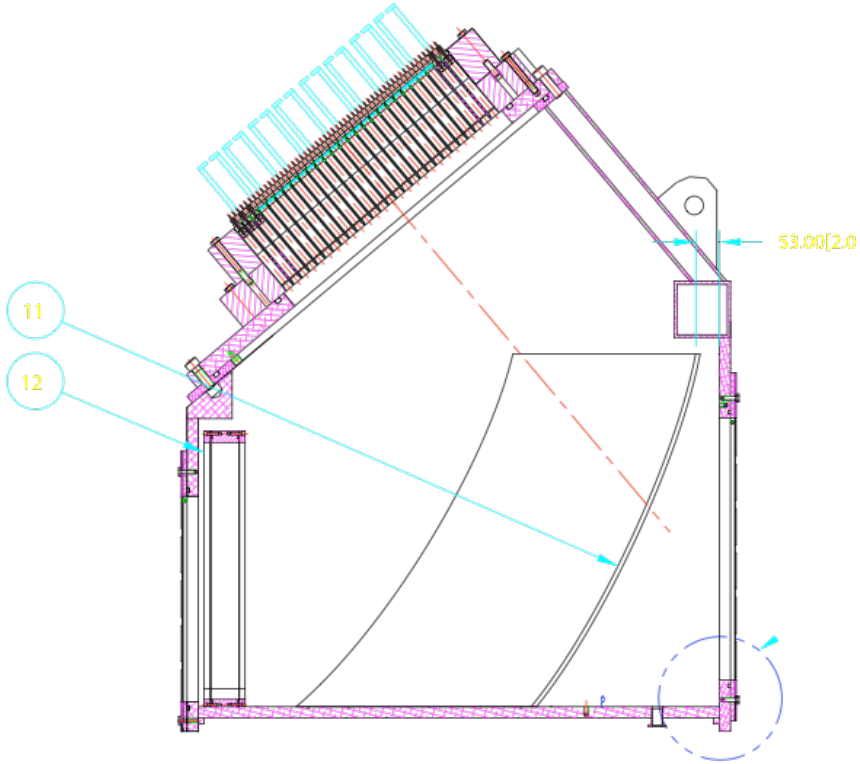
Schematic of target chamber in vacuum



Bench test of convection flow

The HERMES RICH Detector





- Full π/K/p separation (2 GeV < p < 15 GeV) based on dual-radiator (gas+aerogel) design
- High segmentation (1,934 PMTs) = excellent resolution and **high-rate capability**
- ~5 cm aerogel n=1.0304
- C_4F_{10}, n = 1.00137
- Operation in up to 90 G stray field in HERMES

Status

- 1 detector, both aerogels from HERMES in storage @ UVa
- Prototype construction underway @ W&M, with additional 64 PMTs

PAC34 Report

Individual Proposal Report

Proposal: PR12-09-018

Scientific Rating: N/A

Title: Measurement of the Semi-Inclusive π and K electro-production in DIS regime from transversely polarized ^{3}He target with the SBS & BB spectrometers in Hall A

Spokespersons: G. Cates, E. Cisbani, G. Franklin, B. Wojtsekhowski

Motivation:
The motivation is to study the transverse spin structure of the neutron. By measuring the azimuthal dependence of semi-inclusive DIS with respect to the nucleon spin direction, different functions such as the Collins and Sivers asymmetries can be studied, which have sensitivity to initial state and final state quark interactions, respectively. This will lead to a better understanding of the role or orbital motion of quarks in the nucleon.

Concerns in PAC34 Report: **Appendix B**

1) Can a combination of beam tests and fully realistic simulations demonstrate the feasibility of running the experiment at the proposed luminosity?

• Yes: Slides 22-23 and 41-49, Chapter 3 Sections 3.1-3.4

2) Will the very high rates affect the ability to extract relatively small spin asymmetries accurately?

• No: backup slides 35 and 41-49, proposal sections 3.1-3.4 and 5.6

3) Would a better coverage at smaller hadron angles, perhaps combined with running at lower luminosity, give a better overall result (due to better coverage in pt, θpq and φ*).

• Transversity kinematics optimized with h arm centered at non-zero p_T

4) Is it possible to add some (limited) π0 detection to enhance the physics output of the proposal?

• Yes: $\pi^0 \rightarrow 2\gamma$ acceptance ~70% of charged π acceptance, existing HCAL

5) Is a *z cut of 0.2 too low for JLab kinematics?*

• Presented in proposal appendix B

6) What will the effect of diffractive vector meson production be on the extraction of SIDIS structure functions?

• Small, proposal section 5.6.3 and backup slide

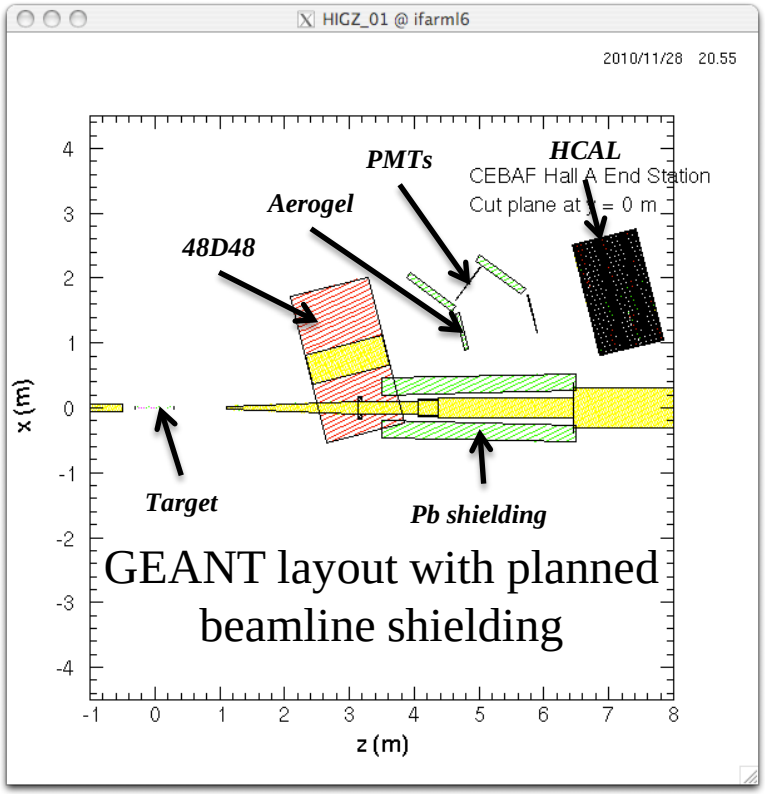
7) What is the impact of radiative tails from exclusive and resonance region scattering on the structure function extraction? (In particular, will the cross sections and spin asymmetries of these regions be sufficiently well known?)

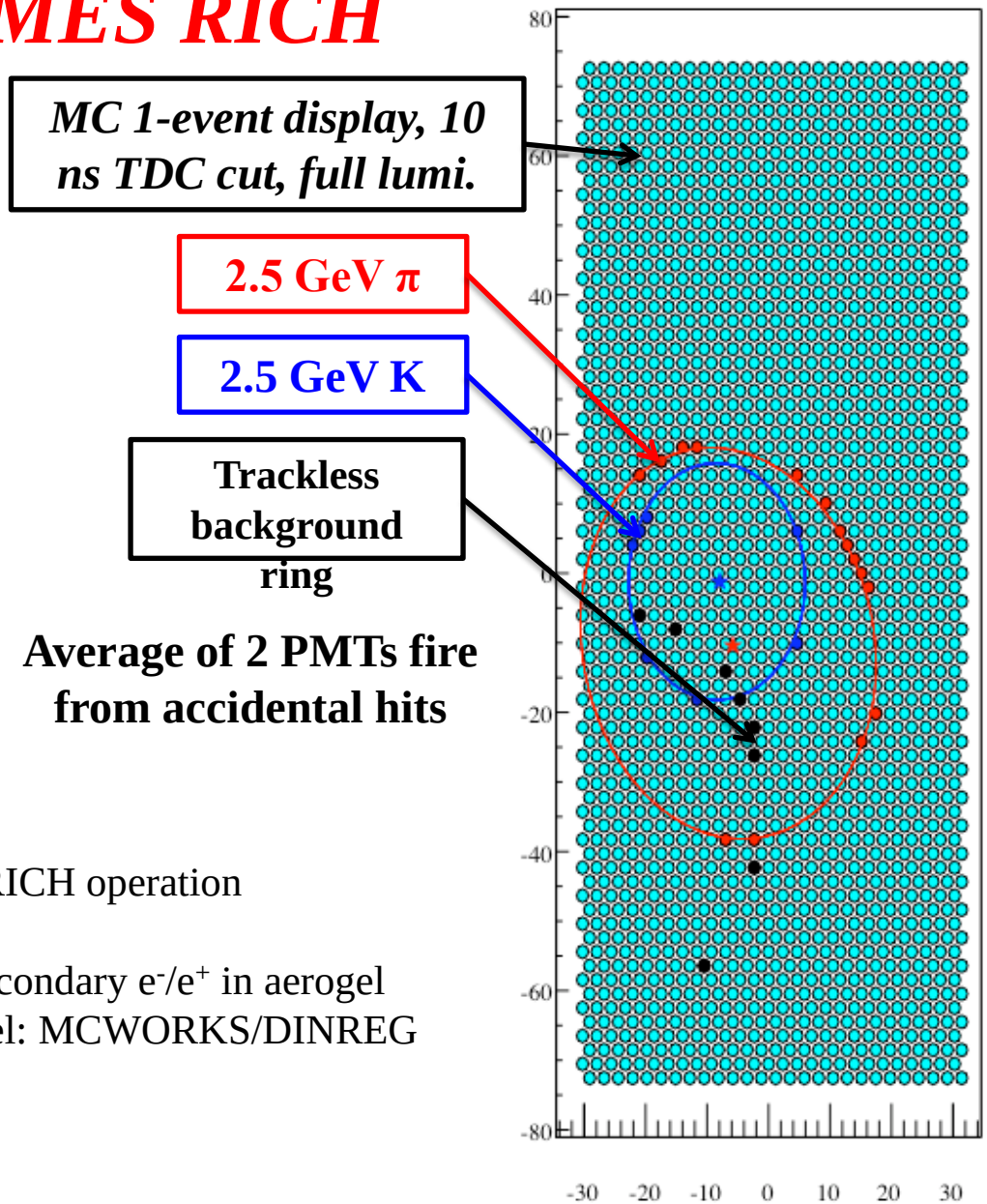
• Very small and exclusive (z=1) is in our acceptance (large momentum acceptance)

8) Can the possibility of polarized proton and deuteron targets to obtain neutron structure functions be considered and integrated into a comprehensive program at JLab?

•See slide 29, ^{3}He is clear advantage for Hall A: BB&SBS

Monte Carlo of HERMES RICH

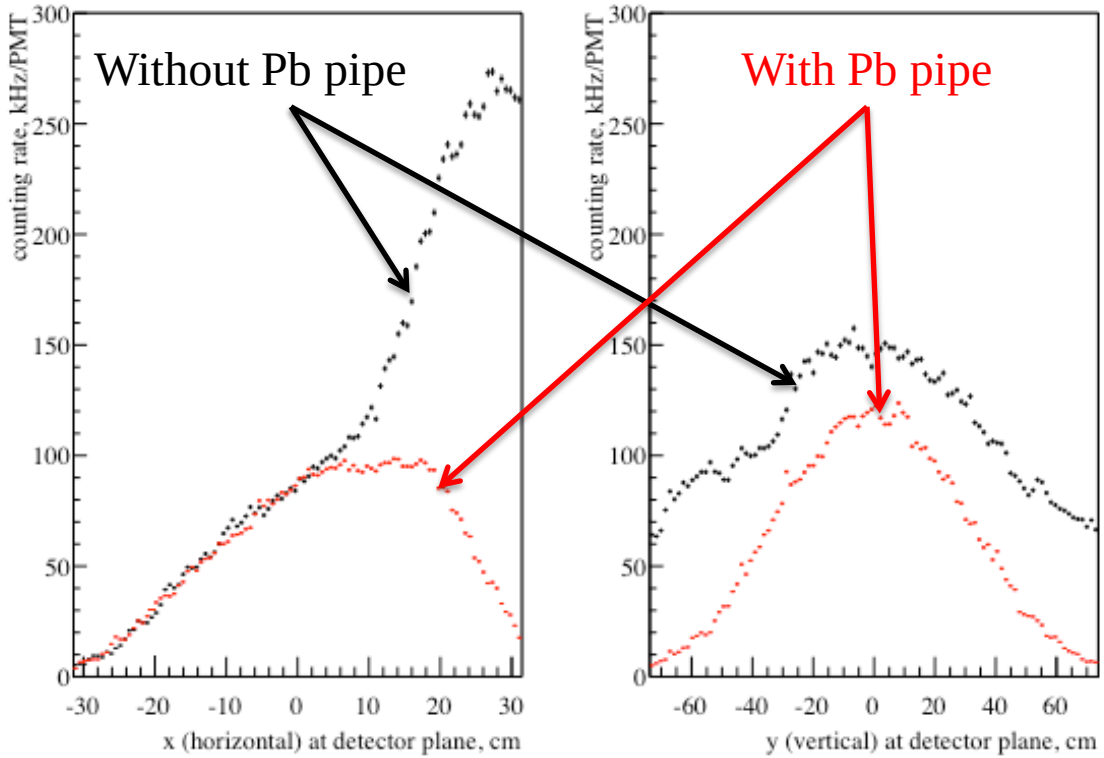




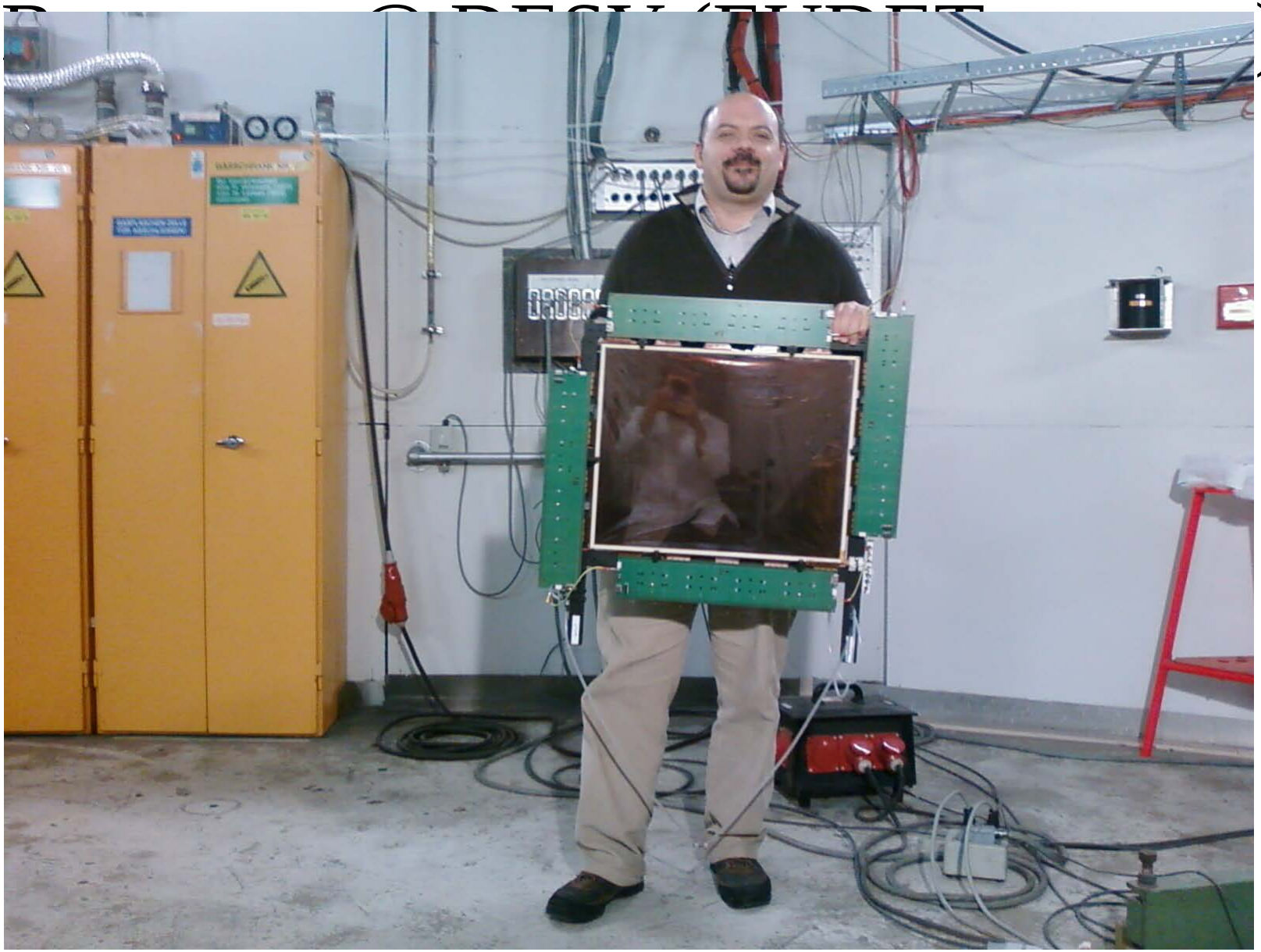
- Soft photon background rate major concern for RICH operation
- Magnet shields charged particles p<1 GeV
- Low energy photons→Compton, pair-prod. of secondary e^-/e^+ in aerogel
- GEANT calculation of background rate in aerogel: MCWORKS/DINREG
- Validated by data in many experiments
- Analytic calculation of Cherenkov yield
- Ray-tracing Monte Carlo.

SBS RICH GEANT simulation:

- **PAC34 main concern: feasibility of operating SBS RICH at proposed lumi→GEANT simulation**
- GEANT validated by comparing to existing data from BigBite—backup:
  - MWDC rates
  - BB GC PMT rate
- **Neutron-induced rate is negligible fraction of total—backup slides**
- **Dominant backgr. = Compton electrons produced in aerogel**
- **Results: ~10^{-3} average PMT occupancy for RICH w/TDC readout and 10 ns (offline) window**
- Pb-pipe beamline shielding reduces rate by 2X on avg. ***mostly from small-angle side***
- Average S:N ≥ 100:1
- **50X safety factor for RICH; i.e., even with 50×GEANT rate, we are at 5% occupancy, which is still a good operating condition.**



Beamline Pb Pipe/Blanket?	No	Yes
Aerogel rate (kHz/PMT)	111	65
Glass+Quartz direct rate	28	17
Total rate	139	82
Occupancy (Δt = 10 ns) (%)	0.139	0.082



Summary of Beam Time Request

Beam Time Request	days
Production at $E_{beam} = 8.8$ GeV	20
Production at $E_{beam} = 11.0$ GeV	40
Calibration, Target Maintenance, Config. Changes	4
Total	**64**

- Justification of beam time:
- Expected size of asymmetries typically few-%; *at most* 15-20% (for neutron; Helium-3 asymmetries smaller—proton dilution, P_{He}, etc.)
- To measure non-zero signals with high significance, we need/will achieve:
  - *Sub-% level stat. on neutron Collins+Sivers moments (for $\pi^{\pm,0}$) in 2D x, z binning for two different Q^2 values*
  - *2-3% asymmetry uncertainty for $K^{\pm}$ asymmetries in 2D binning; sub-% precision in 1D binning;*
- "2nd generation" experiment—next order of magnitude in precision and 2D characterization of neutron SSAs

C12-09-018 in nSIDIS SSA program @ 12 GeV

Parameter		Unit	HERMES	CLAS12	Proposed Exp.
Target			H	HD (×60 days)	^{3}He (×40 days)
Dilution factor	f		1	0.20	0.20
Nucleon Polarization	P	%	80	85	56
Cross Section $\sim s/Q^2$	σ	a.u.	4	1	1
Angular Acceptance	$\Delta\Omega$	sr	0.14	1	0.05
Integrated Luminosity	$\int L$	10^{38} cm^{-2}	1.5	260	4.6×10^5
FOM $= f^2 P^2 \sigma \Delta\Omega \int L$			0.54	7.5	280

- ^{3}He → Best neutron sensitivity
- Two-arm, open geometry @ high luminosity → Superior F.O.M.
- Complementary to SoLiD:
  - SoLiD: more uniform azimuthal coverage at lower x, Q^2, complete 4D binning for $\pi^{\pm}$, very high statistics
  - C12-09-018 = high x, high Q^2 coverage + superior PID capability ($\pi^{\pm,0}/K^{\pm}$), simple setup w/ low incremental cost addition to already SBS apparatus for already approved form factor expts.

Conclusion

- In two-month production run, nSIDIS SSA using the SBS+BB apparatus will improve precision by a factor of 10 comp. HERMES/COMPASS/JLab representative data.
- PAC34 strongly supported our physics goals, which remain largely unchanged.
- Major progress since since PAC34:
  - Theoretical understanding of transverse polarization effects in SIDIS and TMDs, QCD factorization for TMDs; nuclear effects in ^{3}He→n extraction
  - The successful completion of Hall A 6 GeV Transversity: E06-010
  - Construction and testing of GEMs at INFN
  - The development of the SBS project
  - Several steps of HERMES RICH implementation
- These developments have reinforced the case for C12-09-018 and increased our confidence in the expected physics results and their impact.
- C12-09-018 has unique and complementary capabilities in the overall JLab 12 GeV SIDIS program.