Measurements of the Neutron Single Spin Asymmetries Using a Polarized 3He Target

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On behalf of the Jefferson Lab Hall A and polarized ^{3}He collaborations

Beijing Hadron Workshop, July 27-30, 2010

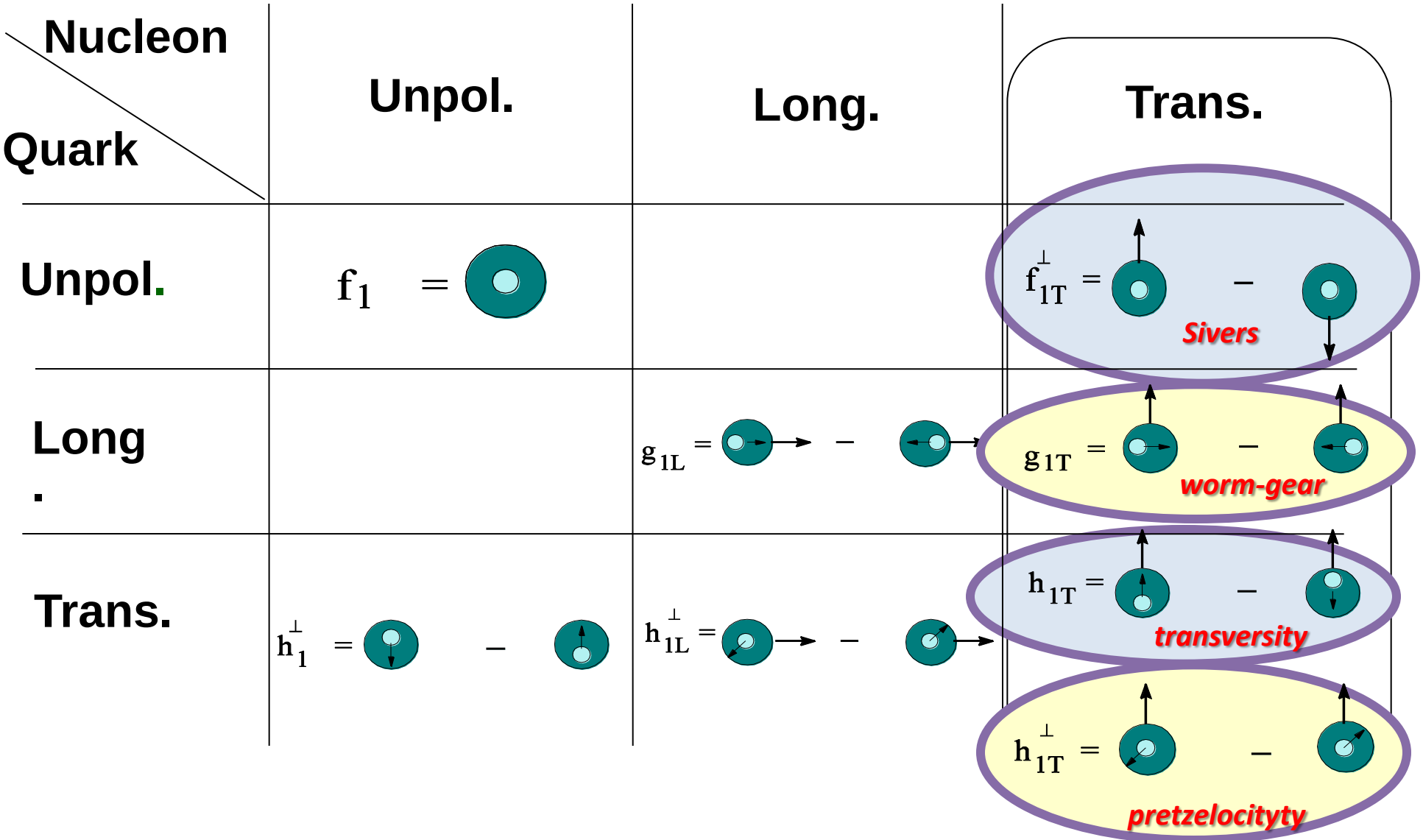
- Introduction
- 6 GeV transversity experiment: preliminary results
- Single Vertical Target Spin Asymmetries in inclusive scattering

Introduction

Transversity and TMDs

- Three twist-2 quark distributions:
  - Momentum distributions: $q(x,Q^2) = q^{\uparrow}(x) + q^{\downarrow}(x)$
  - Longitudinal spin distributions: $\Delta q(x,Q^2) = q^{\uparrow}(x) - q^{\downarrow}(x)$
  - Transversity distributions: $\delta q(x,Q^2) = q^{\perp}(x) - q_T(x)$
- It takes two chiral-odd objects to measure transversity
  - Semi-inclusive DIS
    - Chiral-odd distributions function (transversity)
    - Chiral-odd fragmentation function (Collins function)
- TMDs: (without integrating over P_T)
  - Distribution functions depends on x, $k_\perp$ and Q^2 : $\delta q,\ f_{1T}^{\perp}(x,k_\perp,Q^2),\ \ldots$
  - Fragmentation functions depends on z, $p_\perp$ and Q^2 : $D,\ H_1(x,p_\perp,Q^2)$
  - Measured asymmetries depends on x, z, $P_\perp$ and Q^2 : *Collins, Sivers, …*
    ($k_\perp$, $p_\perp$ and $P_\perp$ are related)

"Leading-Twist" *TMD* Quark Distributions

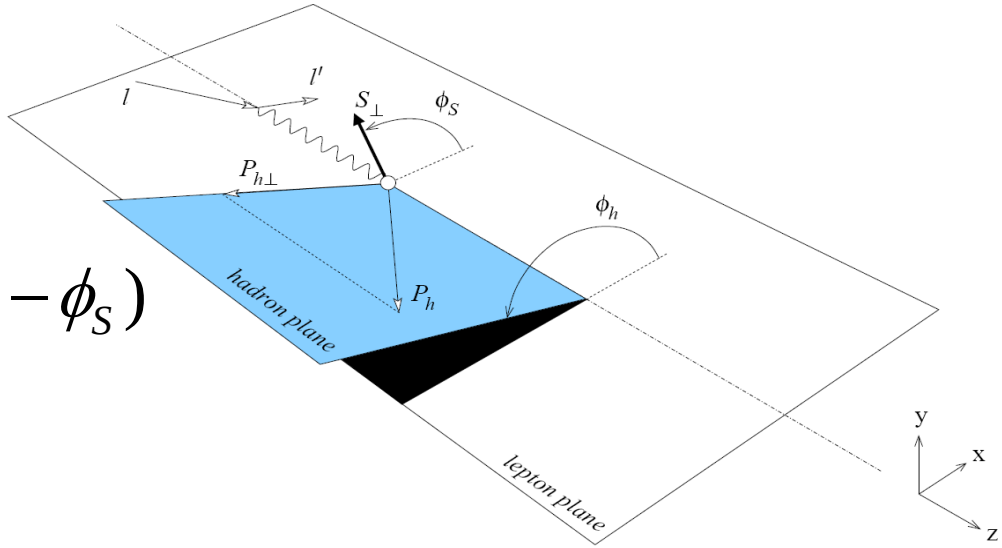


Separation of Collins, Sivers and pretzelocity effects through angular dependence in SIDIS

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

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

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



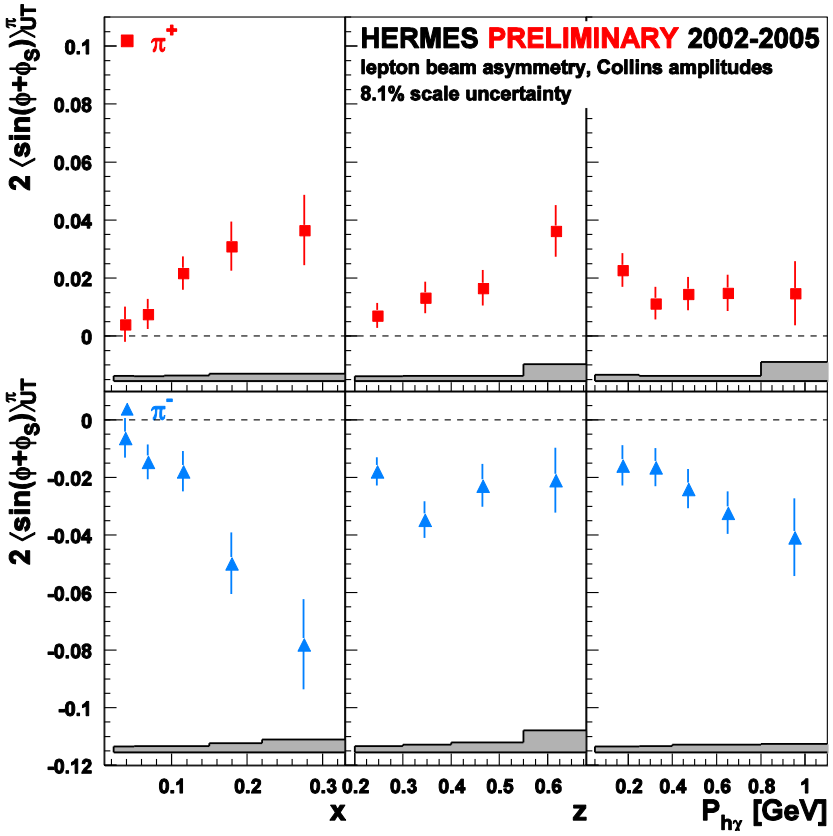
$$A_{UT}^{Collins} \propto \left\langle \sin(\phi_h + \phi_S) \right\rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

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

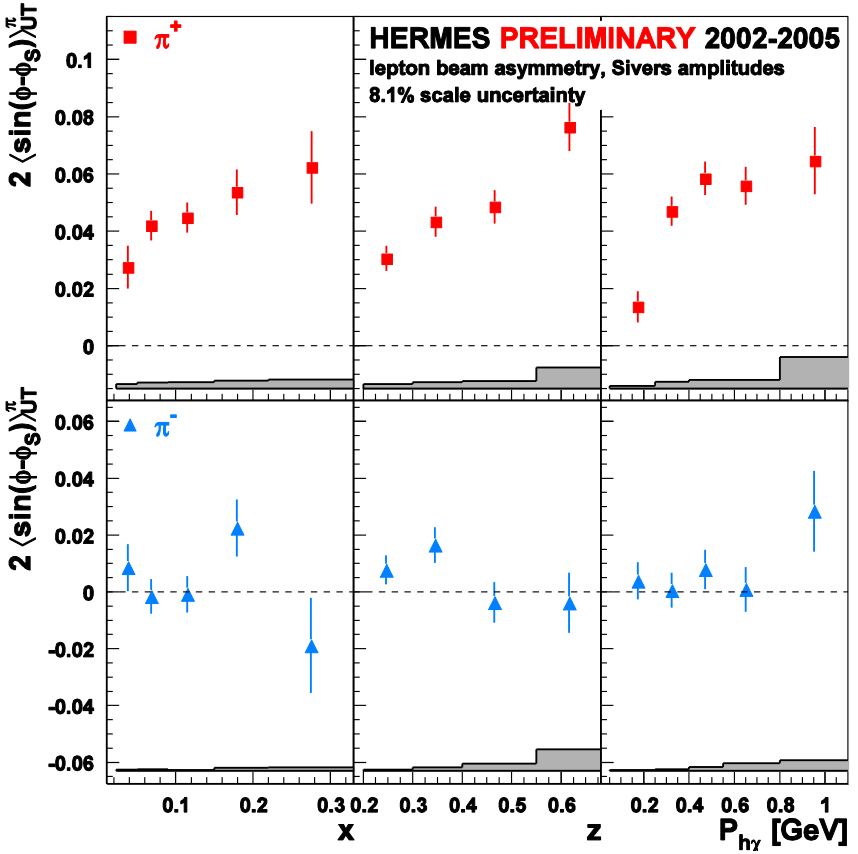
$$A_{UT}^{Pretzelosity} \propto \left\langle \sin(3\phi_h - \phi_S) \right\rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

$A_{UT}^{\sin(\phi)}$ from transv. pol. H target

`Collins' moments



`Sivers' moments



- Non-zero Collins asymmetry
- Assume $\delta q(x)$ from model, then

  H_1_unfav ~ -H_1_fav
- H_1 from Belle (arXiv:0805:2975)

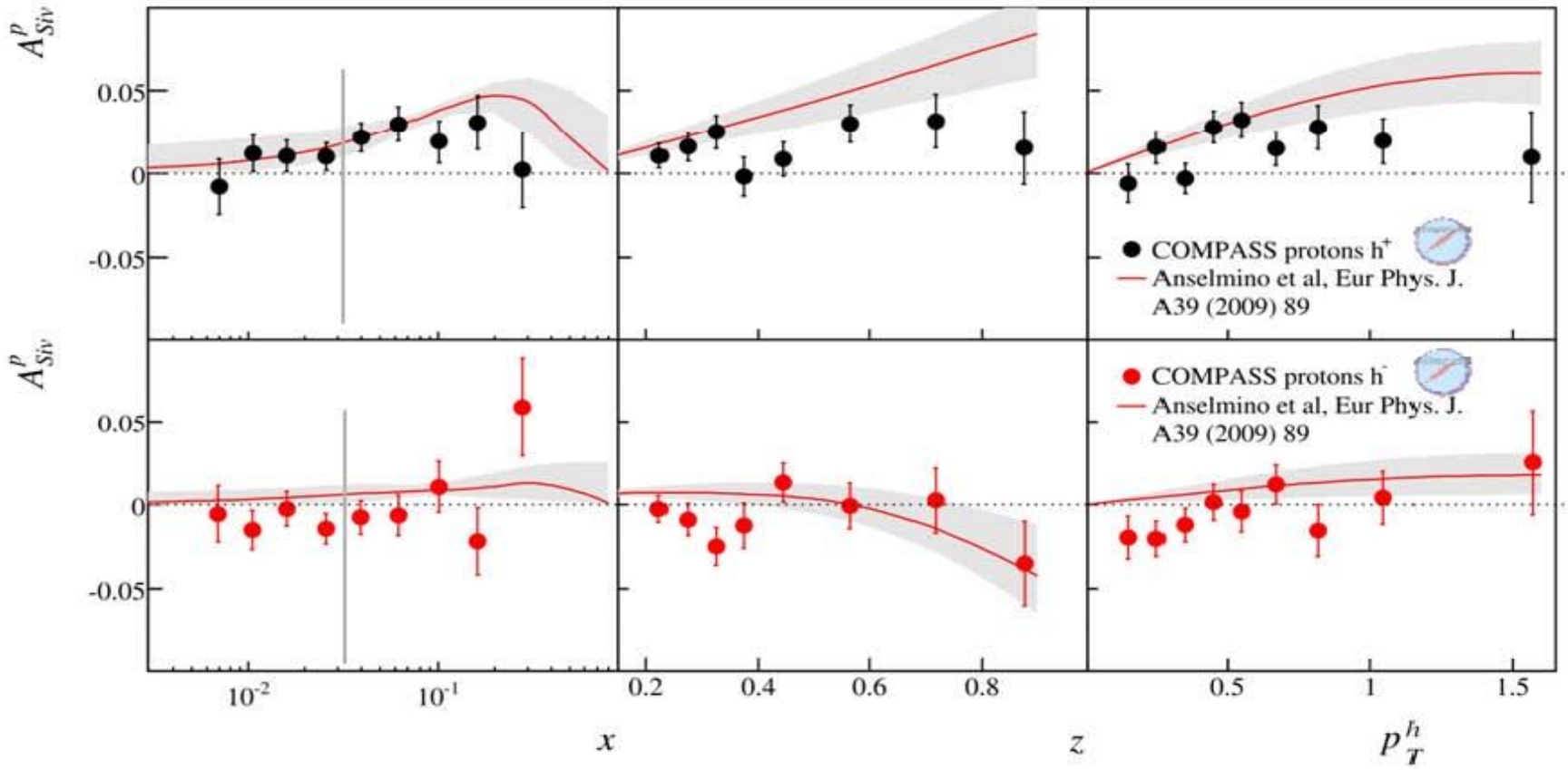
- Sivers function nonzero (π^+)→ orbital angular momentum of quarks
- Regular flagmentation functions

Sivers asymmetry - proton

comparison with theory

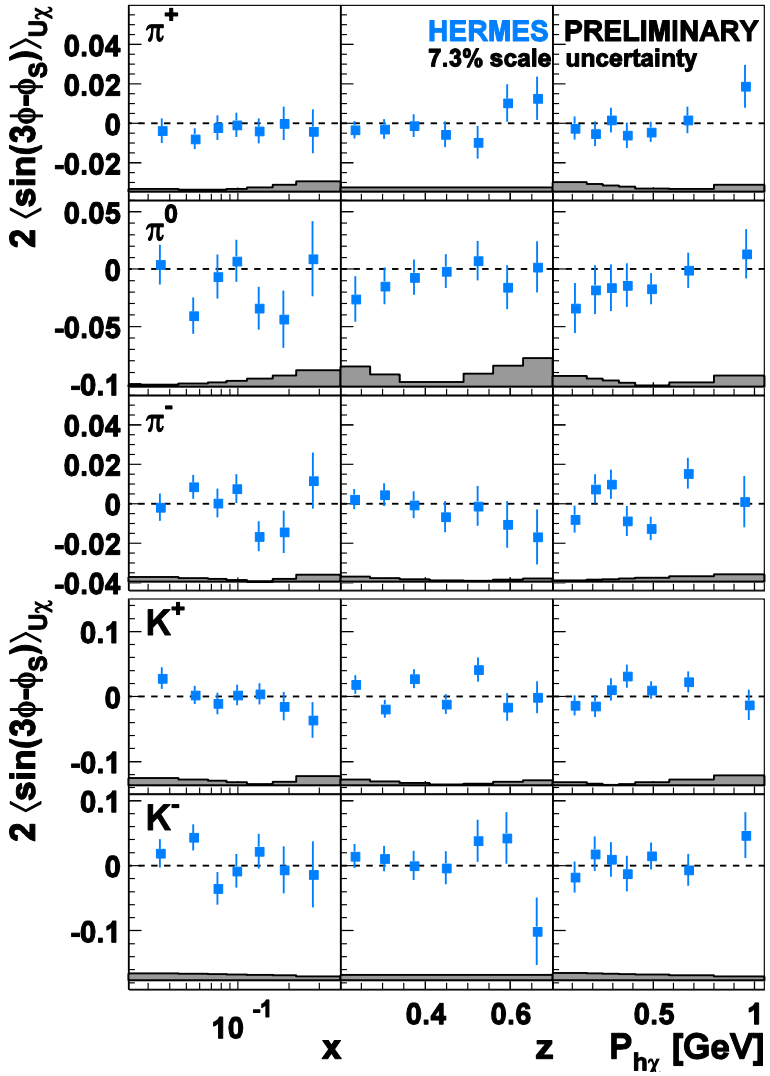
... **most recent predictions from *M. Anselmino et al.***

based on the fit of HERMES proton and COMPASS deuteron data

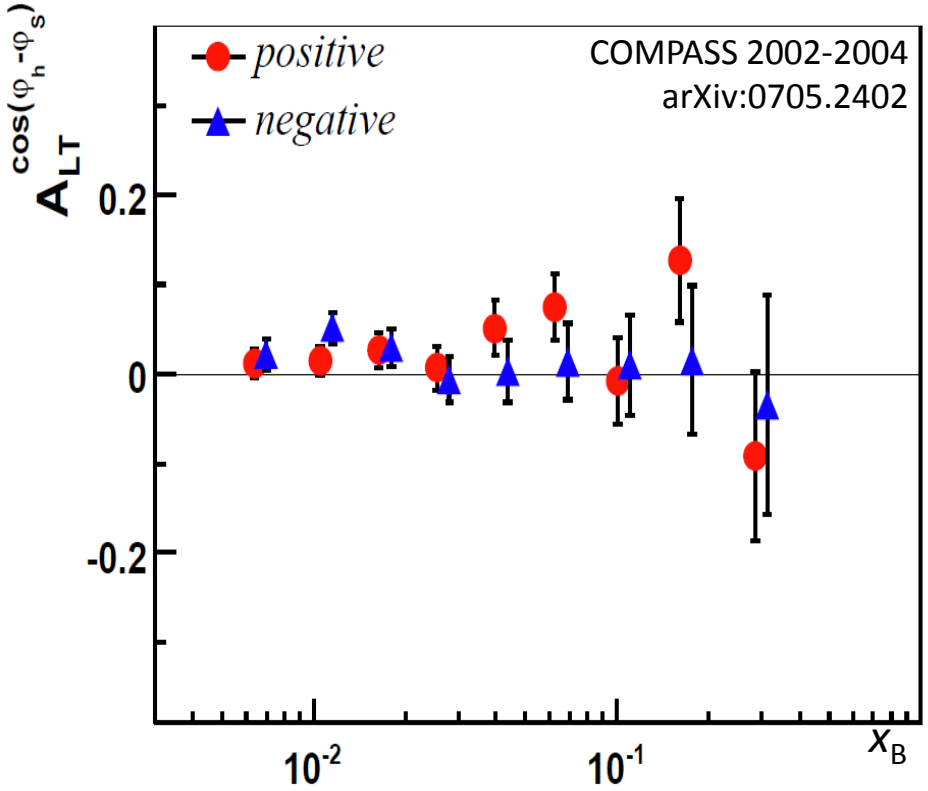


Other TMDs

Pretzelocity



g_1^T



Summary of Current Status

- Large single spin asymmetry in *pp*->πX
- Collins Asymmetries

  - sizable for the *proton* (HERMES and COMPASS)

    large at high *x*, π^- and π^+ has opposite sign

    unfavored Collins fragmentation as large as favored (opposite sign)?

  - consistent with 0 for the *deuteron* (COMPASS)

- Sivers Asymmetries

  - non-zero for π^+ from *proton* (HERMES), new COMPASS data consistent?
  - consistent with zero for π^- from proton and for all channels from *deuteron*
  - large for K^+ ?

- Collins Fragmentation from Belle (e+e-)
- Global Fits/models by Anselmino *et al., Yuan et al.* and …
- Very active theoretical and experimental study

  RHIC-spin, JLab (6 GeV and 12 GeV), Belle, FAIR, J-PARC, … EIC

6 GeV Transversity Experiment: E06-010

Preliminary Results

E06-010 Overview

- **First measurement of the SSA and DSA in SIDIS**

$$^3He^{\uparrow}(\vec{e},e'\pi^{\pm})X$$

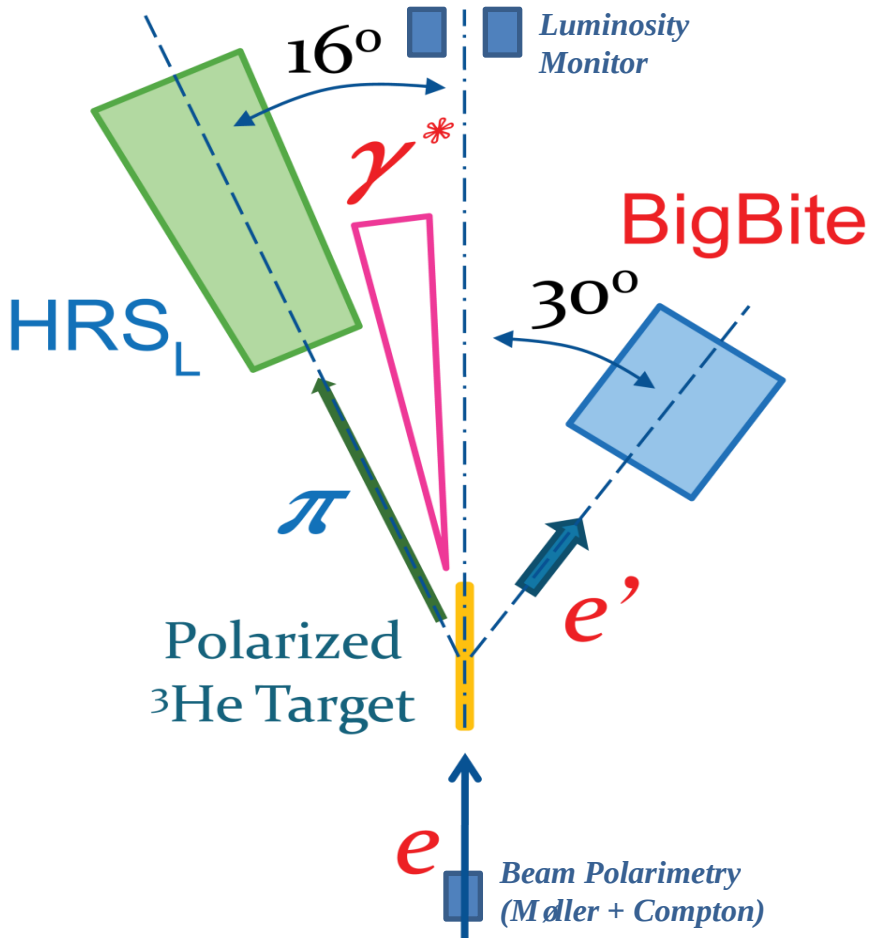
- **Major installation/upgrade**
  - **^{3}He Target, BigBite Electron Package, LHRS RICH**
- **Successful data taking from Oct 08 to Feb 09**
- **Spokespersons**

  Xiaodong Jiang (Los Alamos), Jian-ping Chen (JLab), Evaristo Cisbani (INFN-Rome), Haiyan Gao (Duke), Jen-Chieh Peng (UIUC)
- **7 PhD Thesis Students, 1 Master Student**
  - ***K. Allada*** **(Kentucky),** ***C. Dutta*** **(Kentucky),** ***X. Qian*** **(Duke)**

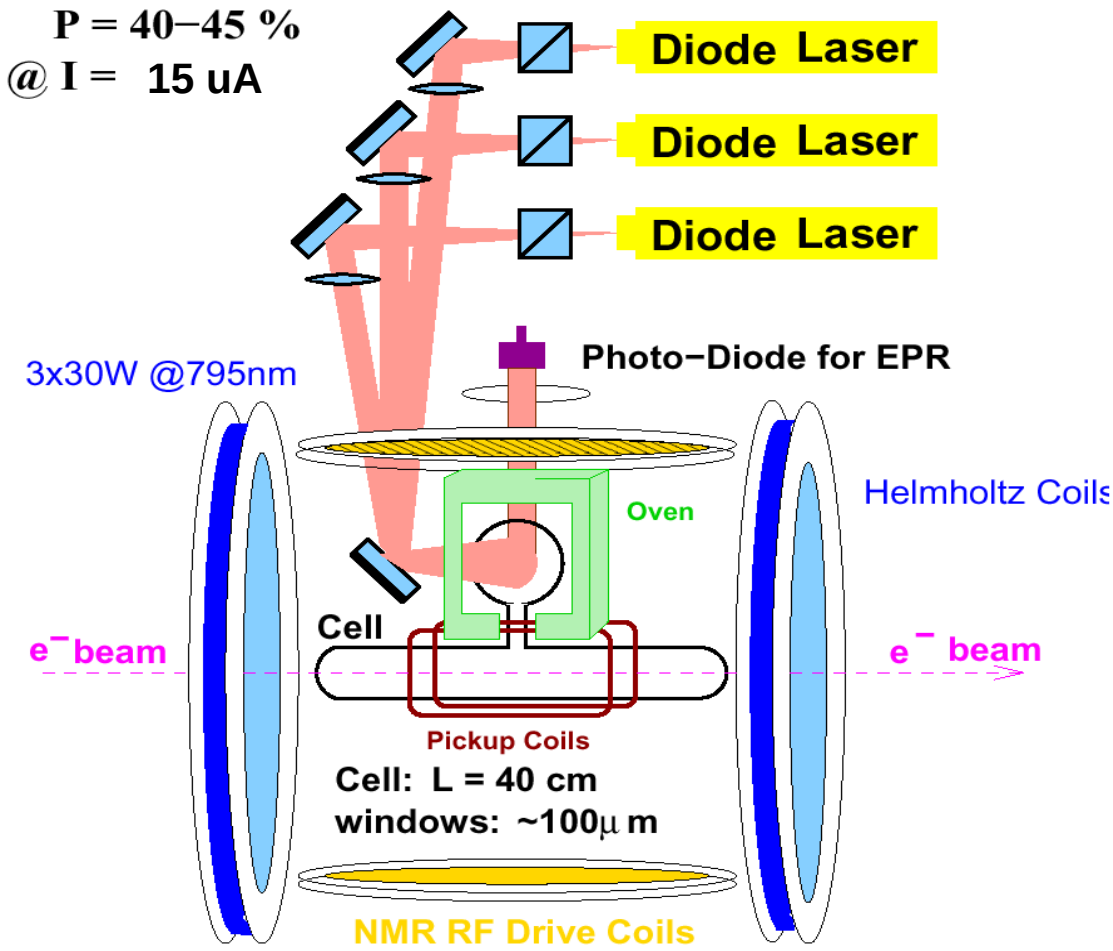
    Graduated in May, 2010.
  - ***J. Huang*** **(MIT),** ***J. Katich*** **(W&M),** ***Y. Wang*** **(UIUC),** ***Y. Zhang*** **(Lanzhou)**
  - **L. Ye (CIAE, master)**
  - **Chinese institutions: Beijing U, CIAE, Lanzhou U, USTC.**

E06-010 Experiment Setup

- Polarized ^{3}He Target
- Polarized Electron Beam
  - ~80% Polarization
  - Fast Flipping at 30Hz
  - PPM Level Charge Asymmetry controlled by online feed back
- BigBite at 30º as Electron Arm
  - P_e = 0.7 ~ 2.2 GeV/c
- HRS_L at 16º as Hadron Arm
  - P_h = 2.35 GeV/c



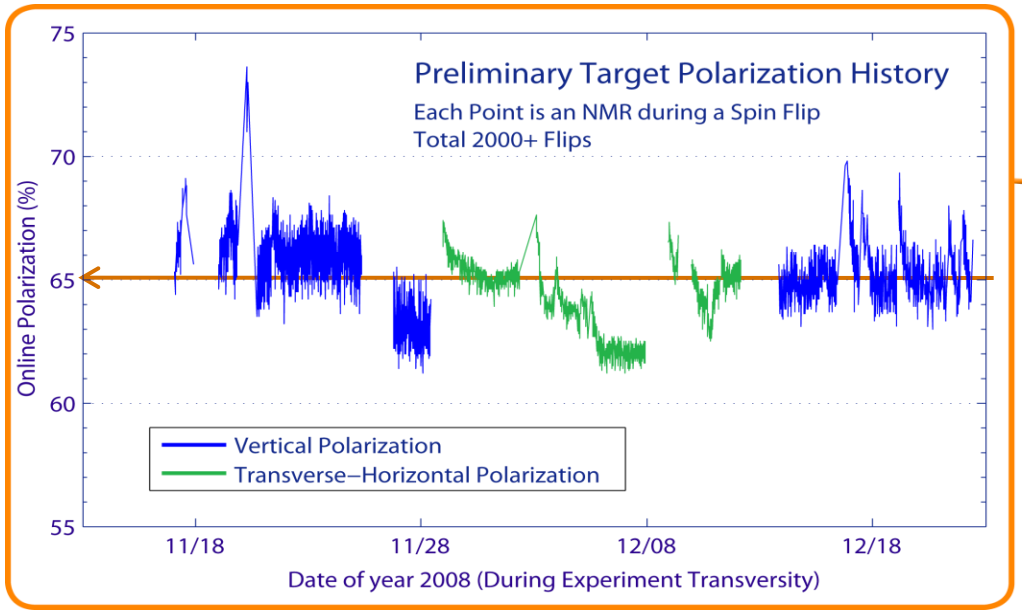
JLab polarized ^{3}He target

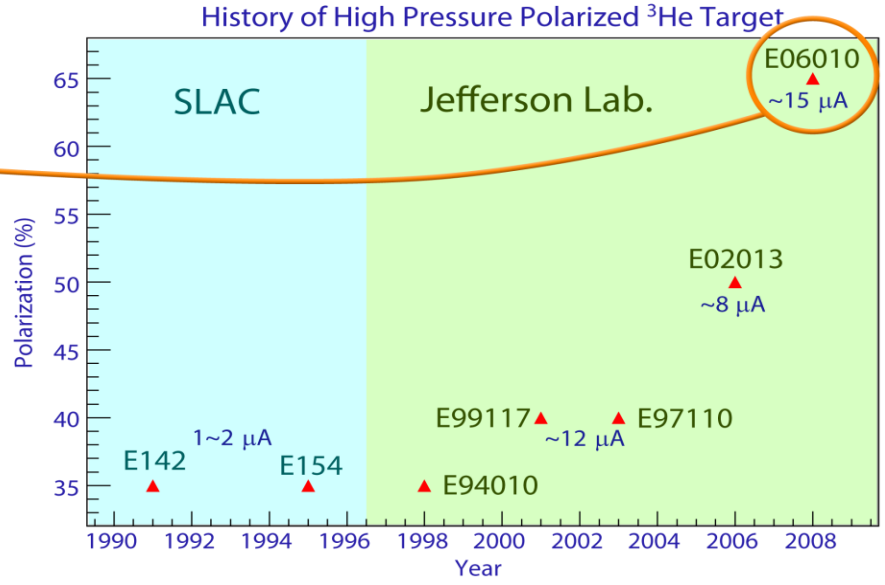


- ✓longitudinal, transverse and vertical
- ✓Luminosity=10^{36} (1/s) (highest in the world)
- ✓High in-beam polarization ~ 65%
- ✓Effective polarized neutron target
- ✓13 completed experiments
  7 approved with 12 GeV (A/C)

Performance of ^{3}He Target

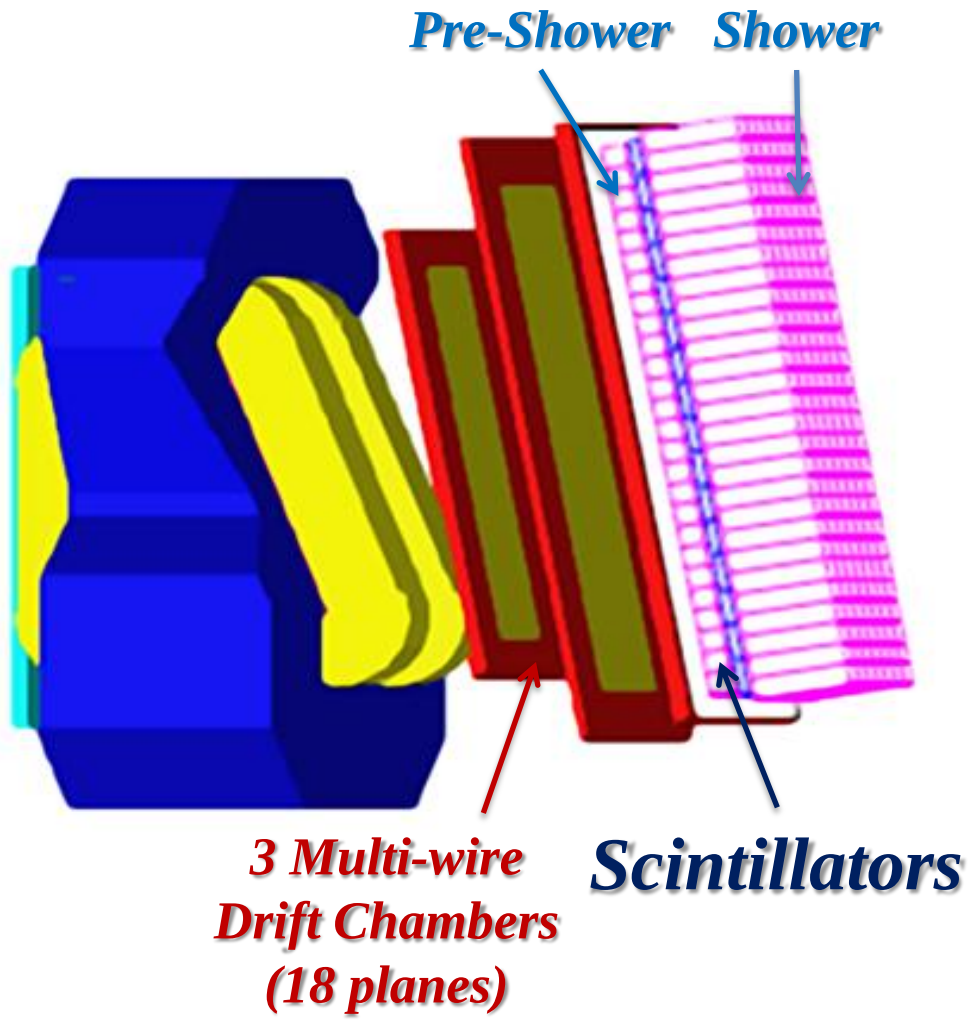
- High luminosity: L(n) = 10^{36} cm^{-2} s^{-1}
- Record high 65% polarization (preliminary) in beam with automatic spin flip / 20min





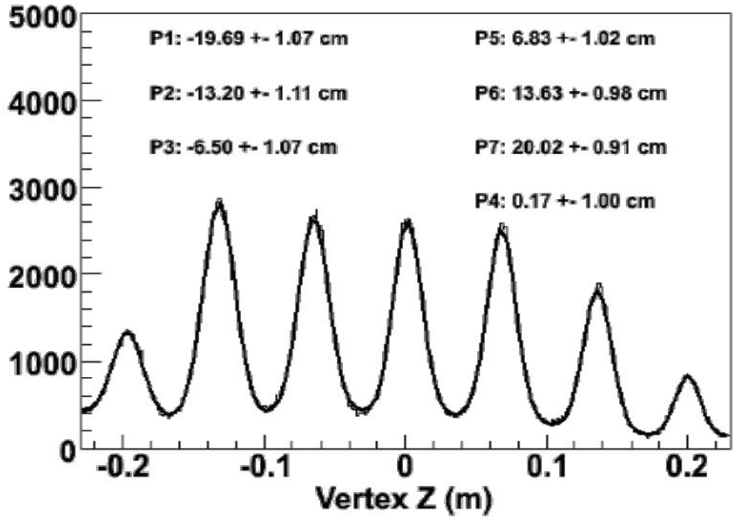
BigBite Spectrometer

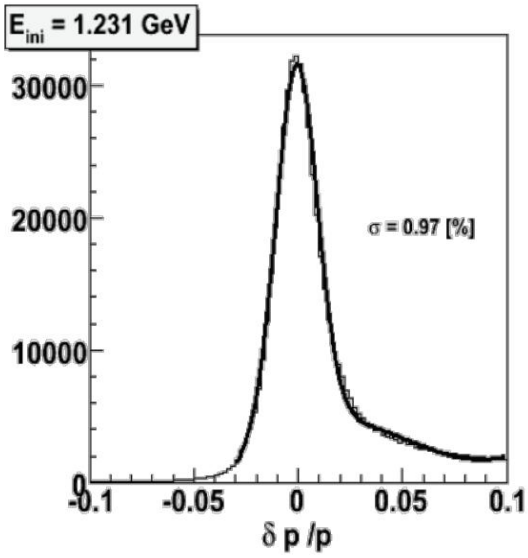
- Single Dipole Magnet
- Detects electrons
- A “big bite” of acceptance
  - $\Delta\Omega = 64$ msr
  - P : 0.7 ~ 2.2 GeV/c
- 3 Wire Chambers: 18 planes for precise tracking
- Bipolar momentum reconstruction
- Pre-Shower and Shower for electron PID
- Scintillator for coincidence with Left HRS

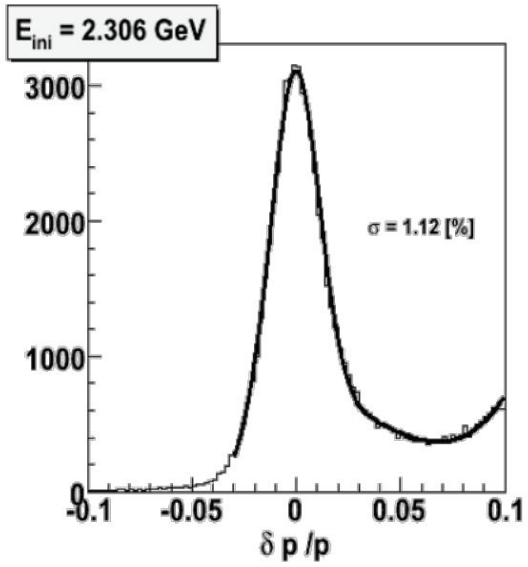


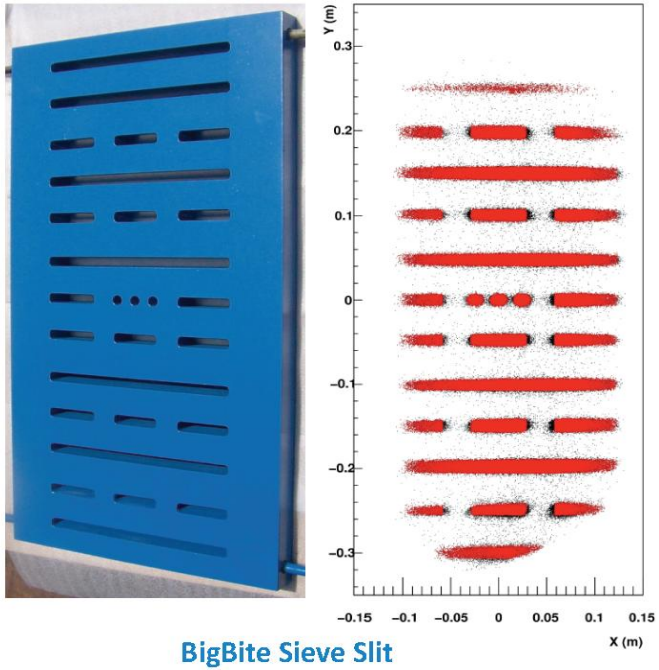
BigBite Optics Calibration

- Optics for both negative and positive charged particles have been done
- Wire Chamber Spatial Resolution: 180 μm
- Vertex Resolution: 1 cm
- Angular Resolution: ~ 10 mrad
- Momentum Resolution: 1%





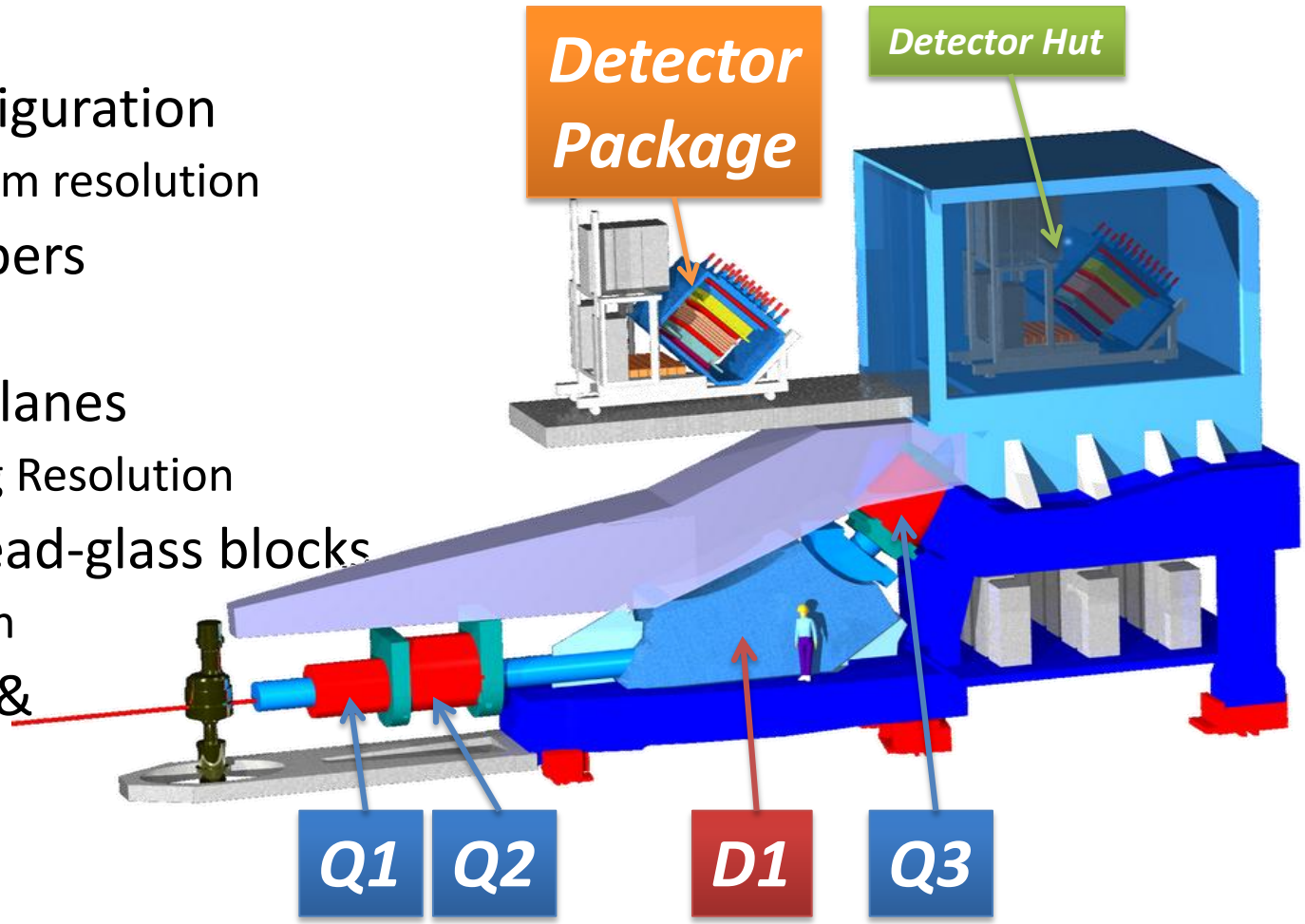




BigBite Sieve Slit

High Resolution Spectrometer

- Left HRS to detect hadrons of p_h = 2.35 GeV/c
- QQDQ magnet configuration
  - Very high momentum resolution
- Vertical Drift Chambers
  - Tracking
- Scintillator trigger planes
  - 340ps Coinc. Timing Resolution
- Gas Cherenkov & Lead-glass blocks
  - e/hadron separation
- Aerogel Cherenkov & RICH detector
  - π/K separation

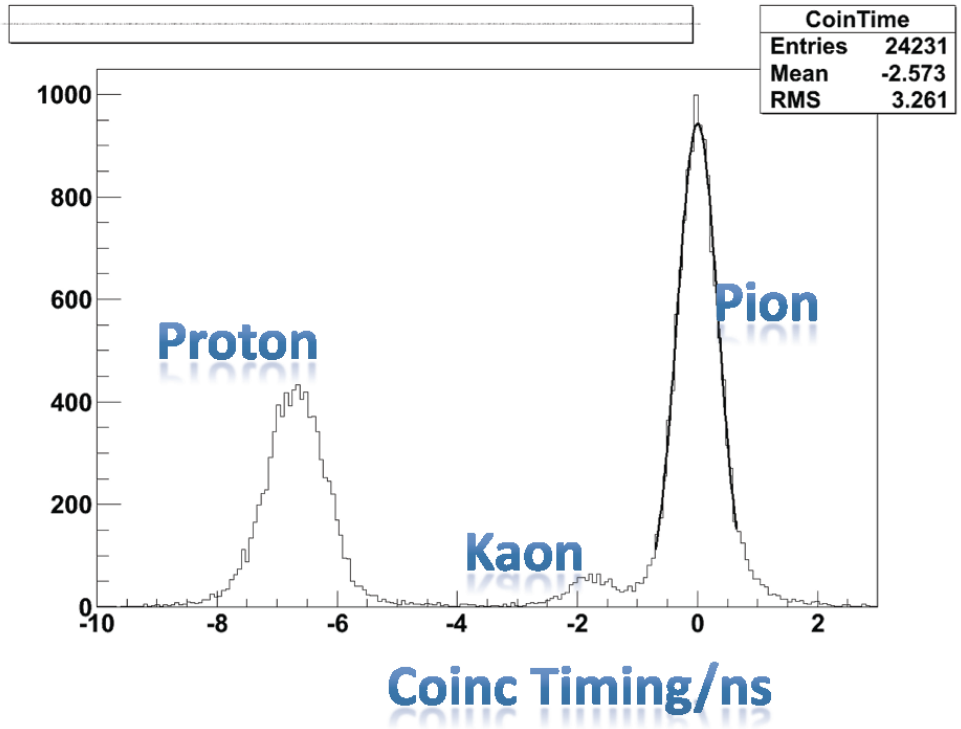


In addition to the HRS_L standard PID detectors …

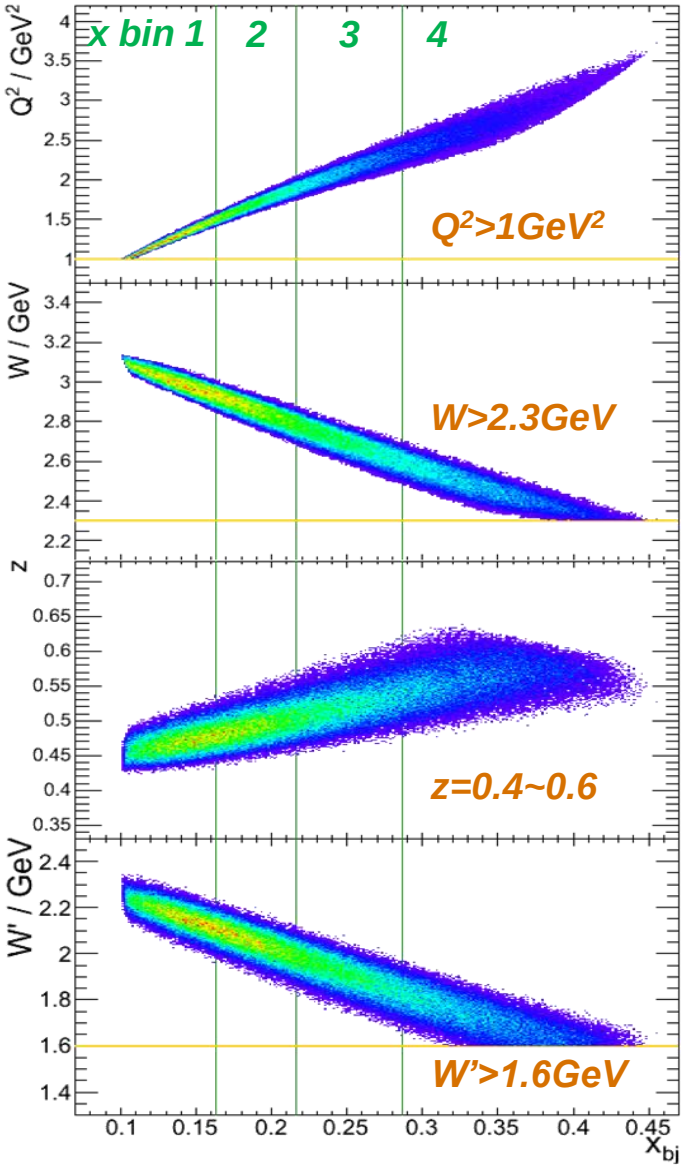
Coincidence time-of-flight as redundant particle identification

$$^3\mathrm{He}^{\uparrow}(e,e'h)$$

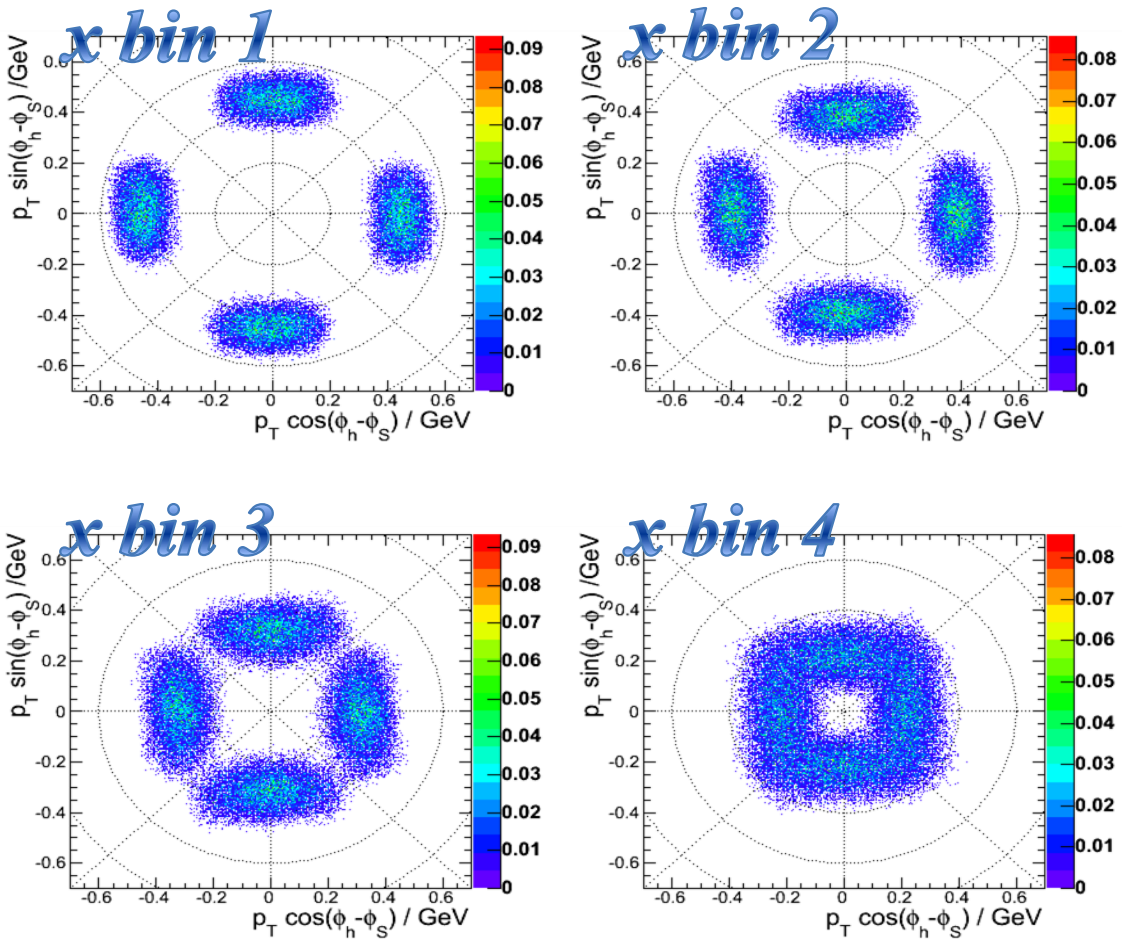
$$h = \pi^{+/-}, K^{+/-}$$



Data Coverage



Kinematics Coverage



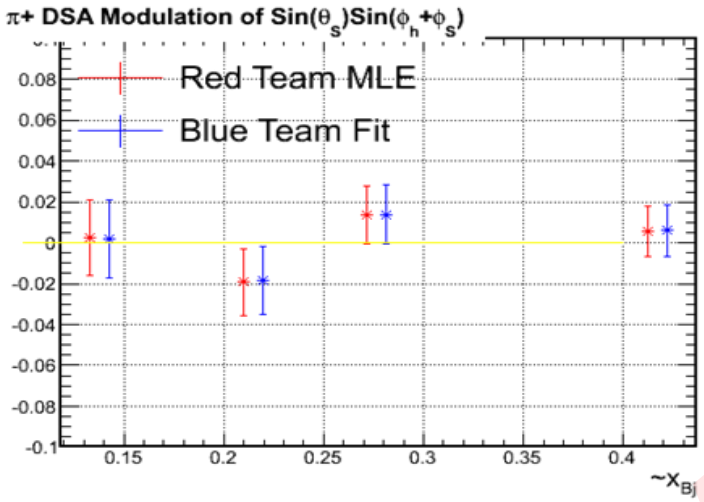
p_T & ϕ_h- ϕ_S Coverage

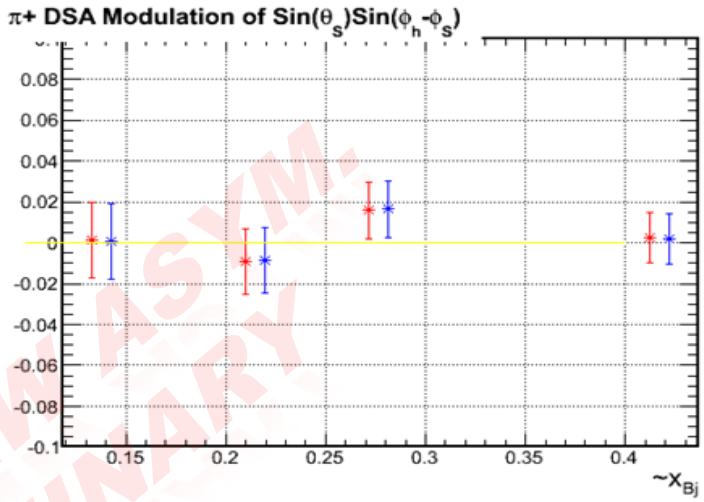
Analysis Progress

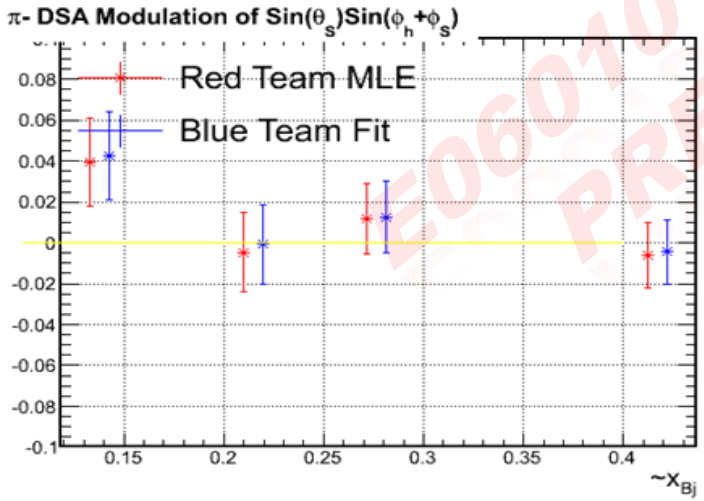
- 7 PhD Students
  - 3 graduated in May, 2010
- Extensive data quality checks and systematic study
  -- Run selection/beam trip cut/yield check/witness channel
- Two analysis teams cross check results
  - Red Team: Maximum Likelihood Method
  - Blue Team: Local Pair-Angular Bin-Fit Method
  - Results are consistent
- Radiative corrections not done yet
- Systematics need further check

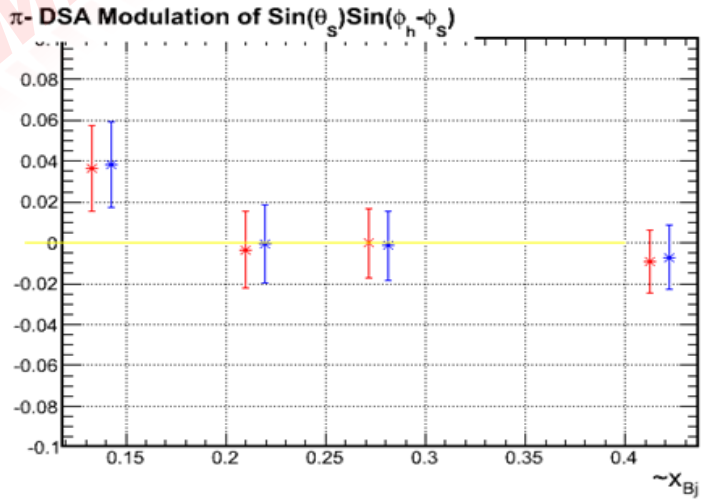
Result Comparison

- Both asymmetry and modulation cross checked
- Results are consistent

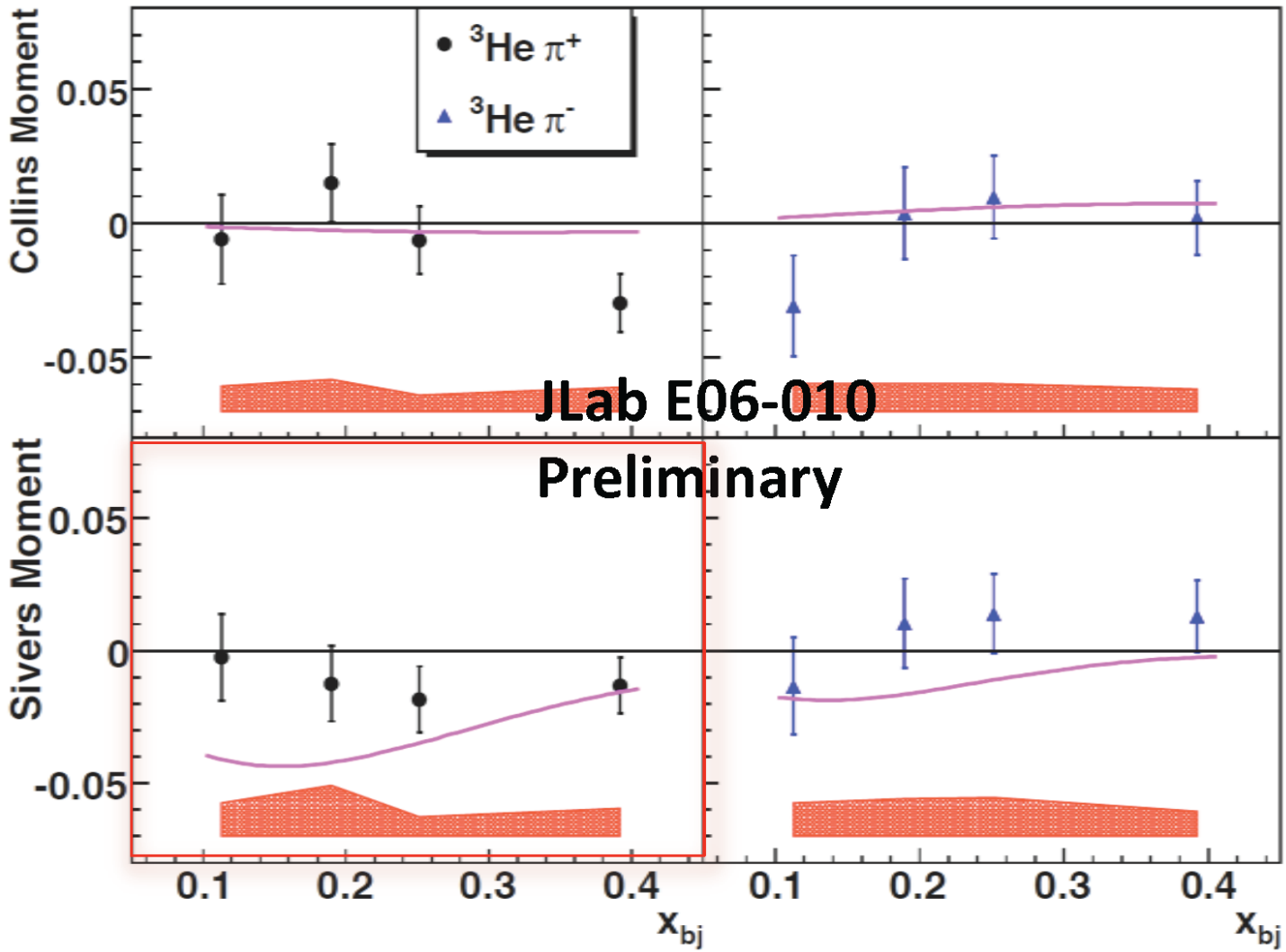




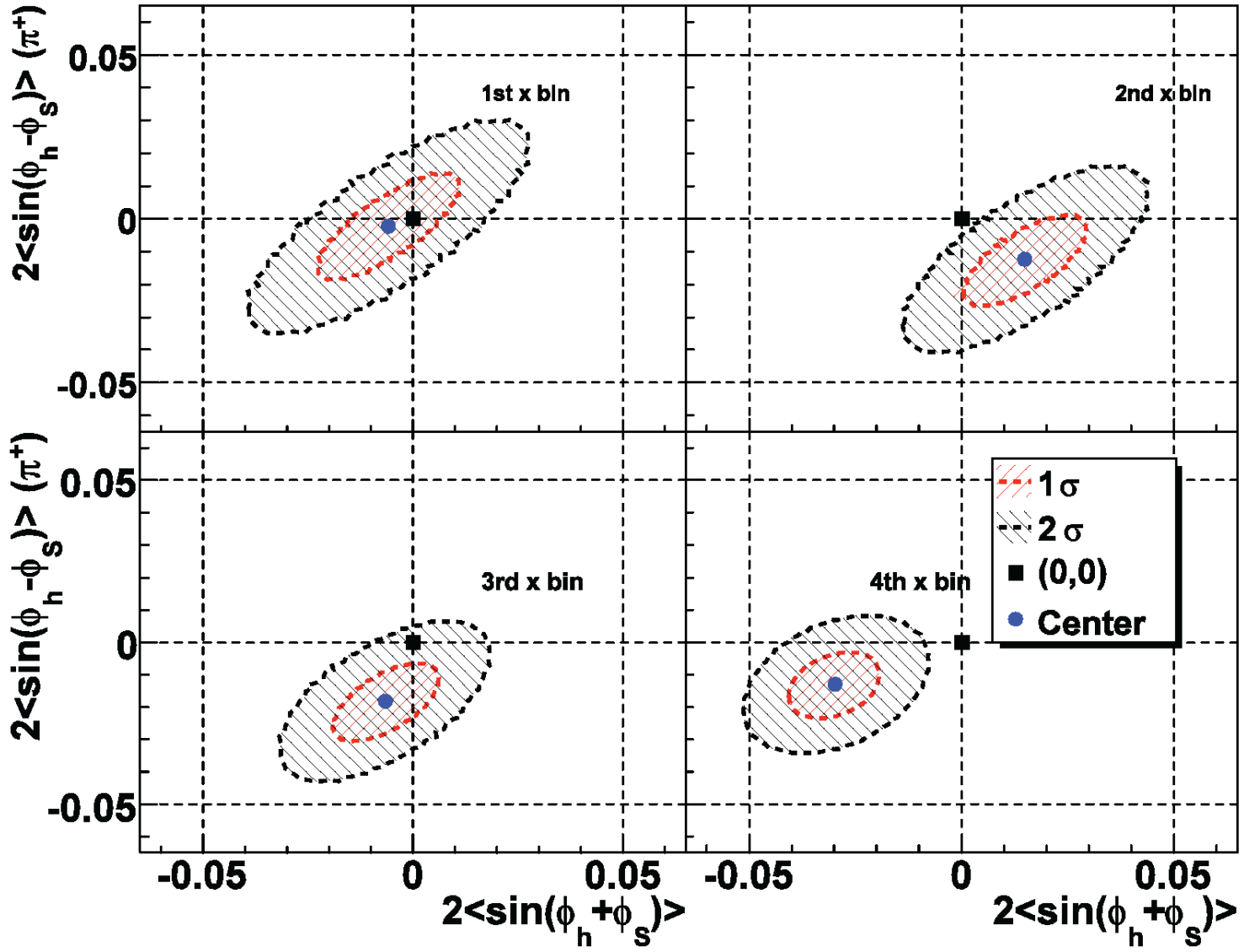




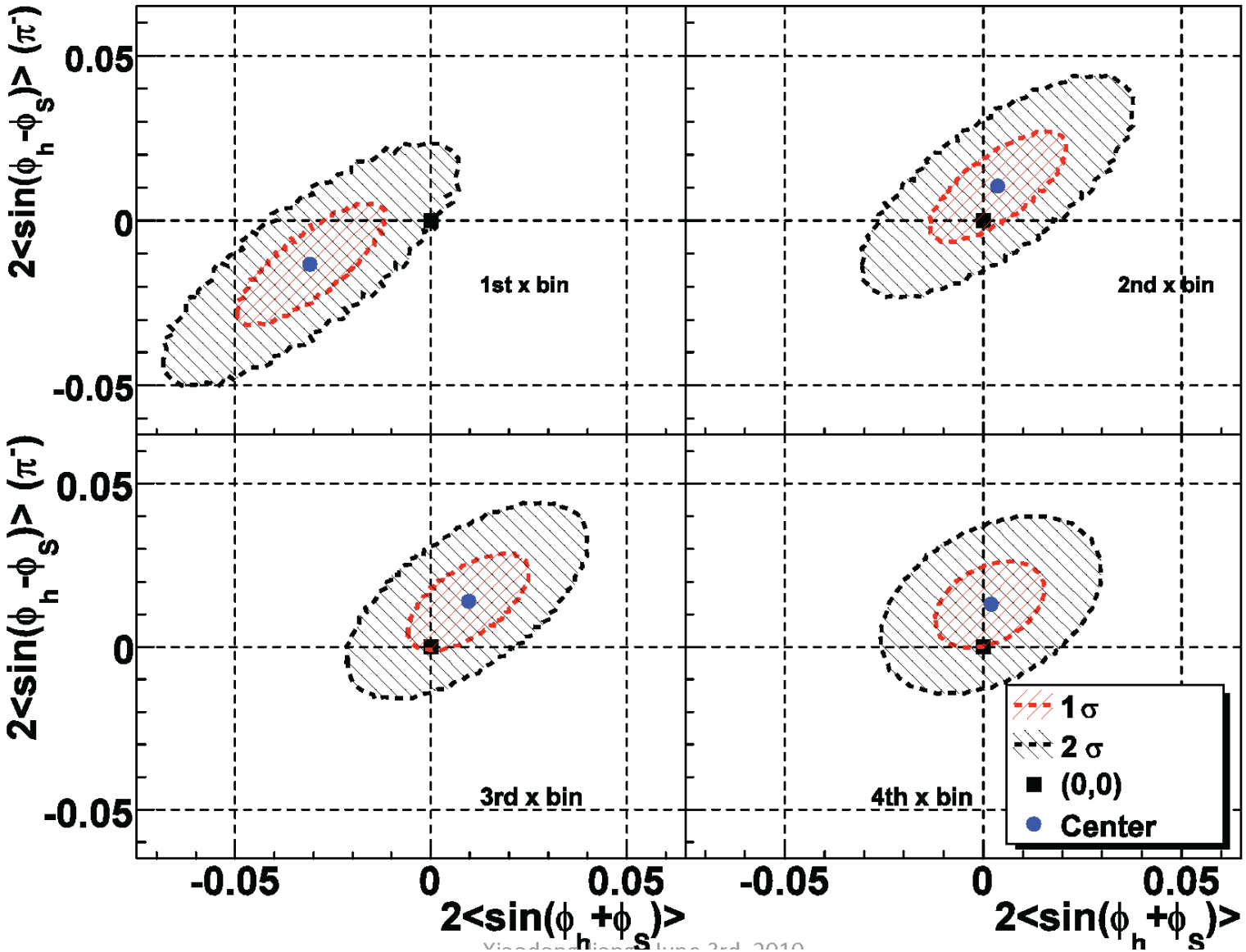
^{3}He Target Single-Spin Asymmetry in SIDIS: JLab E06-010



Statistical uncertainties are correlated between Collins and Sivers asymmetries on ^{3}He (π^+)

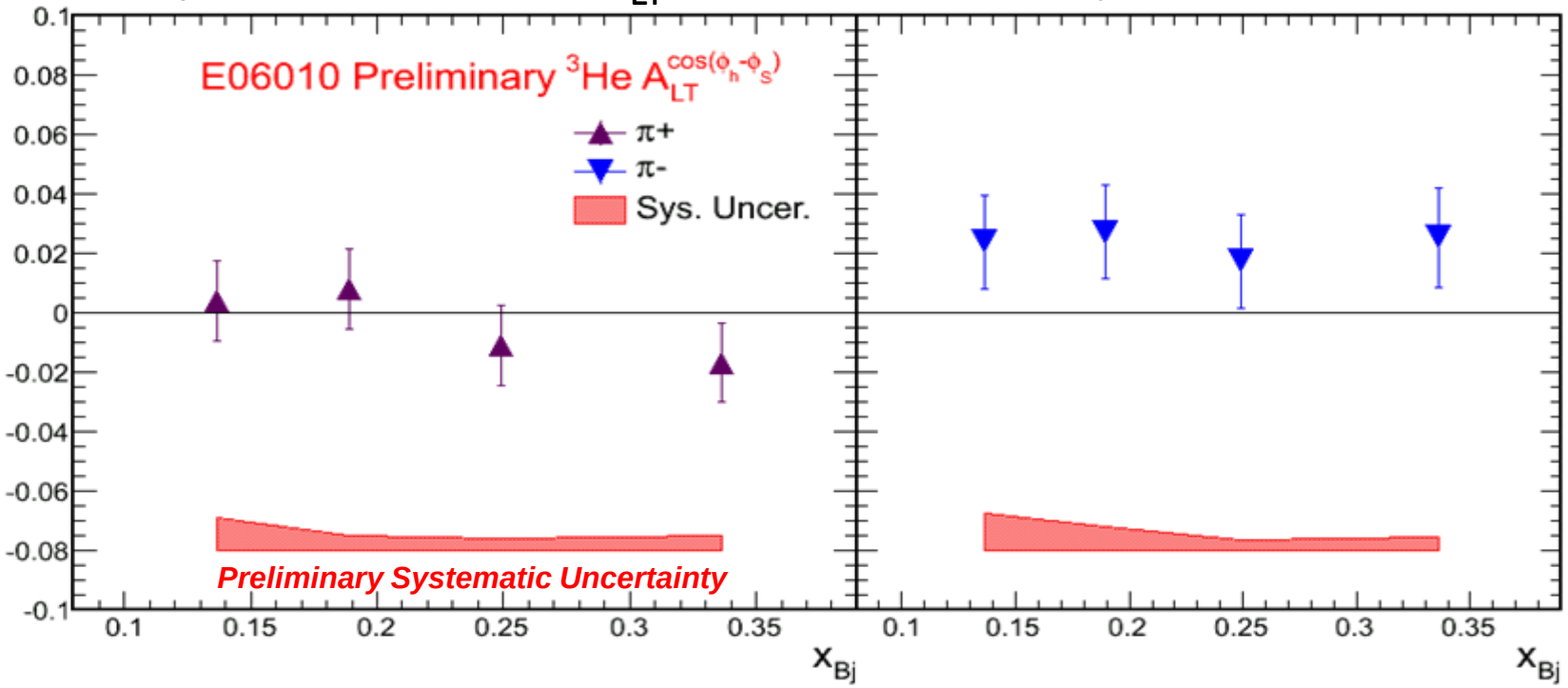


^3He (π^-)


2<sin(φh -φs)> (π-)
0.05
0
-0.05
1st x bin
2nd x bin
3rd x bin
4th x bin
1 σ
2 σ
(0,0)
Center
-0.05
0
0.05
2<sin(φh +φs)>

Preliminary A_{LT} Result

- Preliminary ^{3}He A_{LT}
  - Systematic uncertainty is still under work
  - Projected neutron A_{LT} stat. uncertainty : 6~10%



Summary on 6 GeV Transversity Experiment

- First measurement of angular modulated SSA and DSA in neutron (^{3}He) SIDIS
- Data cover valence range
- Preliminary Results
- In progress:
  - Simulation (coincidence)
  - Systematics (further check)
  - Neutron asymmetry extraction
  - Kaon asymmetries
- Submitting first paper in few months

  -- First measurements of Collins ,Sivers, A_{LT} asymmetries on the neutron

  -- Important inputs for global analysis

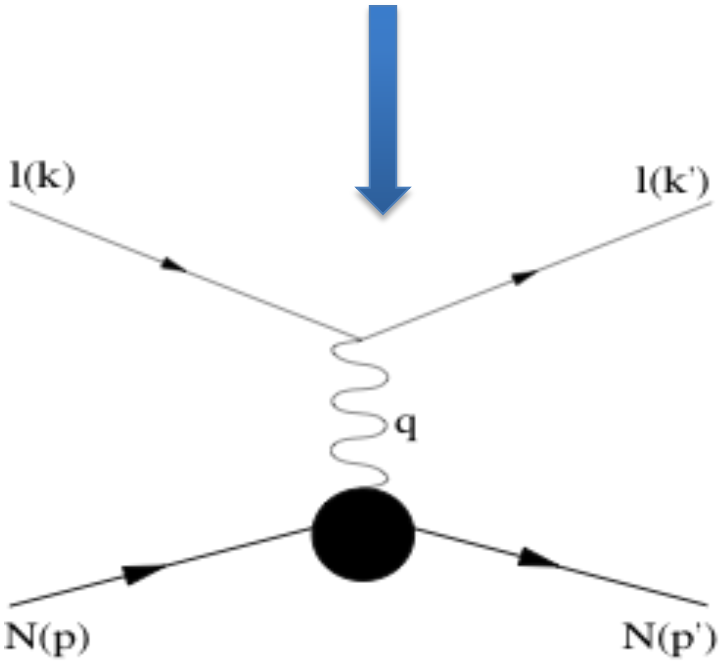
  -- Constraints on d-quark distributions
- Future12 GeV measurements with SOLID and EIC (H. Gao's talk)

SSA in Inclusive Electron Scattering

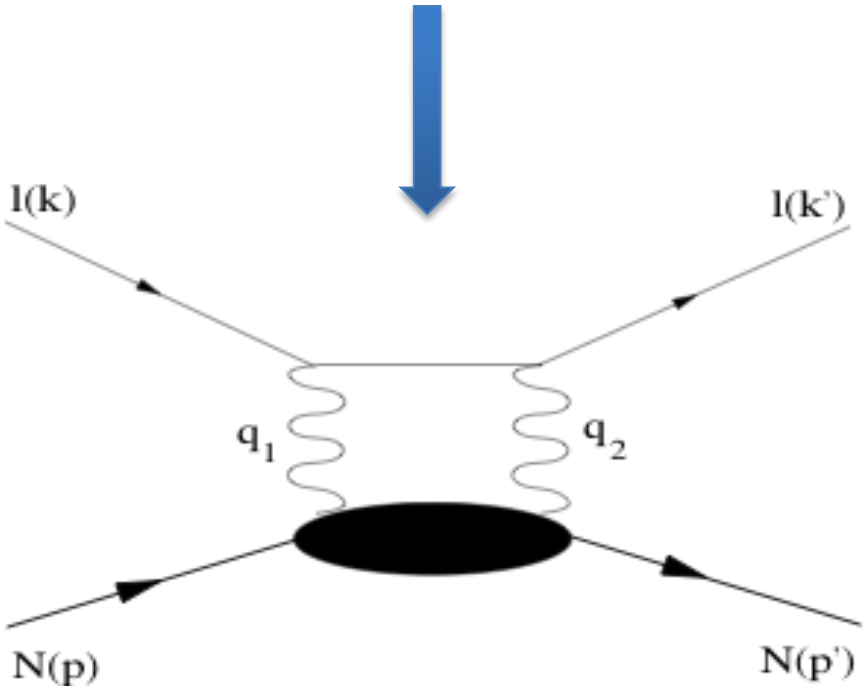
2-photon exchange to explore nucleon structure

Born scattering and beyond

- Dominates unpolarized and most polarized N(e,e’) scattering.



- How is it useful?
- Loop integral contains *entire nucleon response*.
- How do we observe this?



SSA physics: 2-photon

$$A_y \propto \frac{Im(T_{1\gamma} T_{2\gamma}^*)}{|T|^2}$$

Absorptive part=Imaginary contribution

A. DeRujula *et al., Nuc. Phys. B35* (1971) 365

For *inclusive* scattering N(e,e′), $A_y^{Born} = 0$

N. Christ-T.D.-Lee, Phys. Rev. 143 (1966) 1310

Time reversal invariance, parity conservation, and the hermiticity of the electromagnetic cur- rent operator

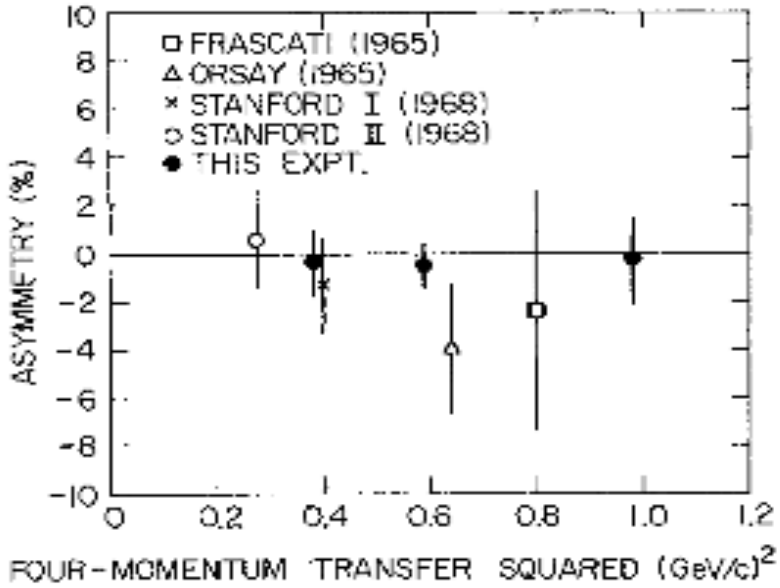
When we allow 2-photon exchange, the leading contribution is from 1γ + 2γ interference

- Calculable at large Q^2 using moments of GPD′ s.
- Measurement of A_y at large Q^2 provides new constraint on GPD′ s

Existing A_y Data

- SLAC Proton Data for A_y (solid) and P_n (open); expected $A_y^p < 1\%$

  T. Powell *et al.*, PRL **24** (1970) 753.

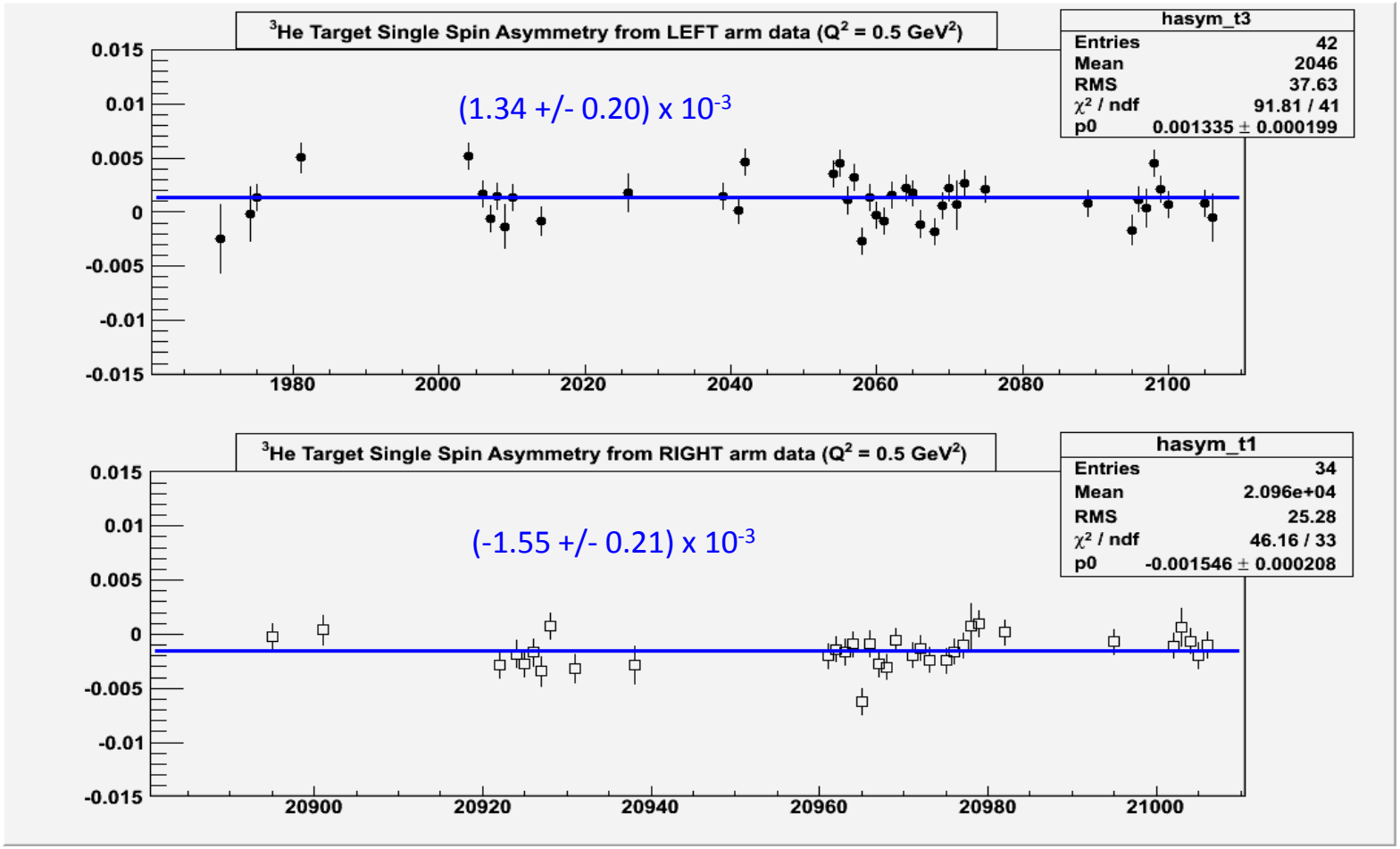


- NIKHEF QE $^3\mathrm{He}^{\uparrow}(e,e')$ at $Q^2 = 0.1$ GeV^2 gave $A_y = -1.0 \pm 5.4\%$.

  M. C. Harvey, Ph.D. thesis, Hampton University, 2001

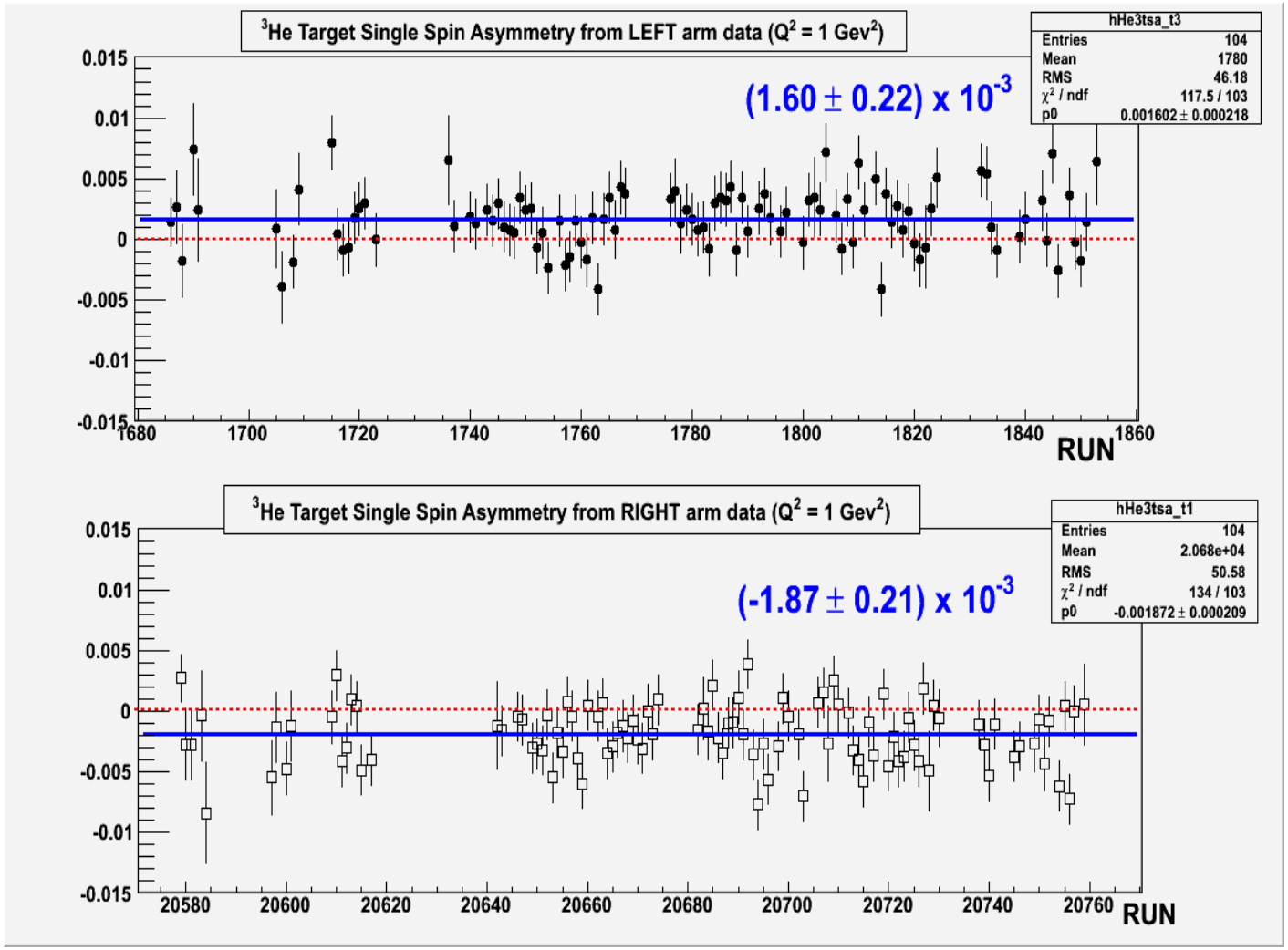
- Precision measurements of A_y do not exist! A non-zero A_y never measured!

E05-015: SSA Inclusive Quasi-elatics 3He(e,e’)
Preliminary ^{3}He results at Q^2=0.5 GeV^2



- A_y^{3He} ~ - 0.14% at Q^2=0.5 GeV^2

Preliminary ^{3}He results at Q^2=1.0 GeV^2



- A_y^{3He} ~ - 0.17% at Q^2=1 GeV^2

Summary for Inclusive SSA

- **First measurements of the inclusive target SSA using vertically polarized ^{3}He in QE, DIS scattering.**

- **QE $A_y^{^3He} \sim -0.14, 0.17\%$ for $Q^2=0.5, 1.0$ GeV^2**

- **DIS preliminary results for A_y at $Q^2=1.0\text{-}3.0$ GeV^2 also available.**
  - **-- Statistical precision comparable to HERMES proton results.**

- **Theoretical calculations needed.**

- **Measurements at high Q^2 possible with Jefferson Lab 12 GeV upgrade.**