E06-010: Transversity in Jefferson Lab Hall A

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Duke University

for Hall A Collaboration Meeting

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Transversity Experiment in Hall A

- E06-010: Single Target-Spin Asymmetry in Semi-Inclusive $n^{\uparrow}(e, e'\pi^{+/-})$ Reaction on a Transversely Polarized ^{3}He Target.
- Spokespersons:

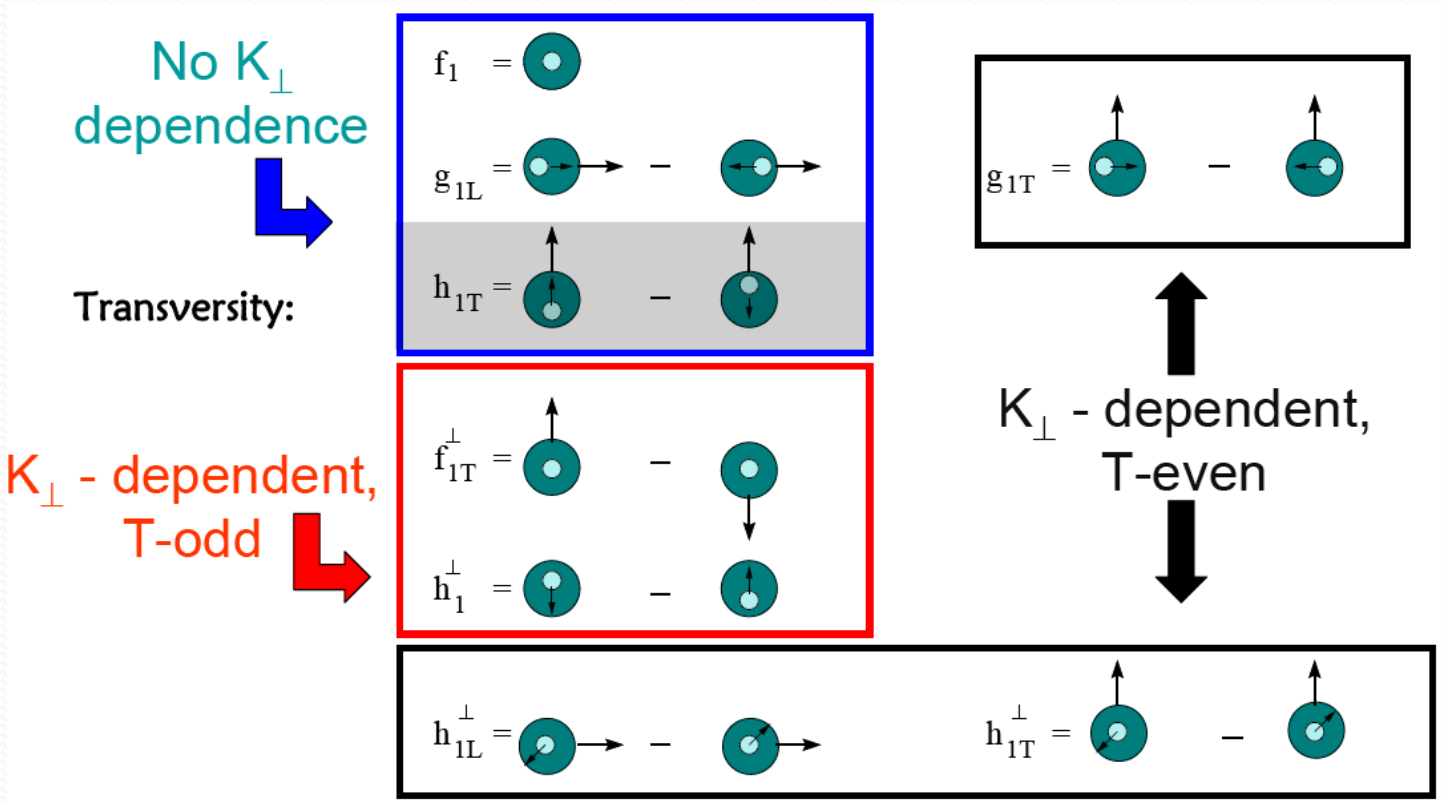
  Xiaodong Jiang (Rutgers/LANL, Contact Person), Jian-ping Chen (JLab), Evaristo Cisbani (INFN-Rome), Haiyan Gao (Duke), Jen-Chieh Peng (UIUC) .
- Thesis Students:

  C. Dutta (Kentucky), A. Kalyan (Kentucky), X. Qian (Duke), Y. Wang (UIUC), Y. Zhang (Lanzhou U), J. Huang (MIT).
- Approved with **A** rating, total beam time of 29 days, currently running.

Experiment Observables and Kinematics

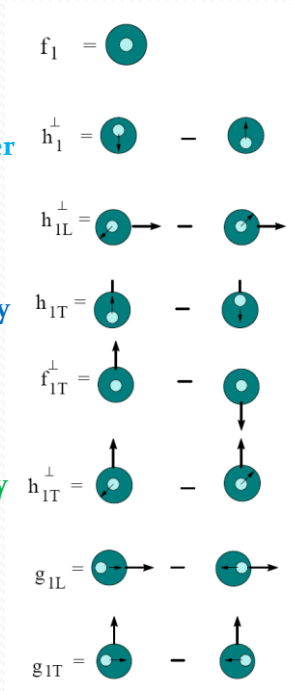
Leading Twist Quark Distributions

Eight Parton Distribution Functions



Access Parton Distributions through Semi-Inclusive DIS

$$\frac{d\sigma}{dxdyd\phi_S dzd\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\cdot$$



$$\{F_{UU,T} + \ldots$$
$$+ \varepsilon\cos(2\phi_h)\cdot F_{UU}^{\cos(2\phi_h)} + \ldots$$

Unpolarized

$$+ S_L[\varepsilon\sin(2\phi_h)\cdot F_{UL}^{\sin(2\phi_h)} + \ldots]$$
$$+ S_T[\varepsilon\sin(\phi_h+\phi_S)\cdot F_{UT}^{\sin(\phi_h+\phi_S)}$$
$$+ \sin(\phi_h-\phi_S)\cdot(F_{UL}^{\sin(\phi_h-\phi_S)} + \ldots)$$
$$+ \varepsilon\sin(3\phi_h-\phi_S)\cdot F_{UT}^{\sin(3\phi_h-\phi_S)} + \ldots]$$

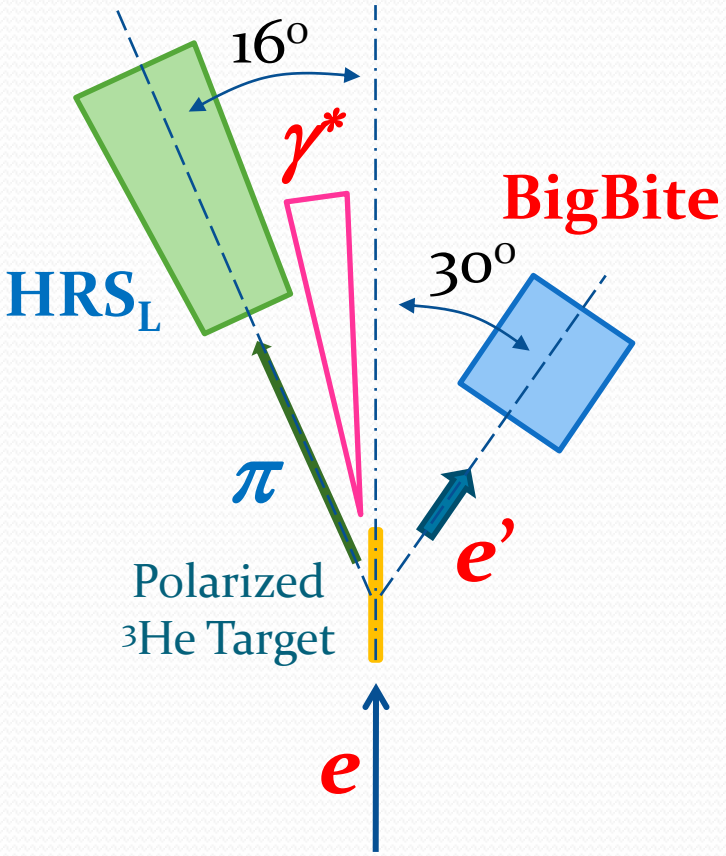
Polarized Target

$$+ S_L\lambda_e[\sqrt{1-\varepsilon^2}\cdot F_{LL} + \ldots]$$
$$+ S_T\lambda_e[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\cdot F_{LT}^{\cos(\phi_h-\phi_S)} + \ldots]\}$$

Polarized Beam and Target

S_L, S_T: Target Polarization; λ_e: Beam Polarization

Experiment Setup



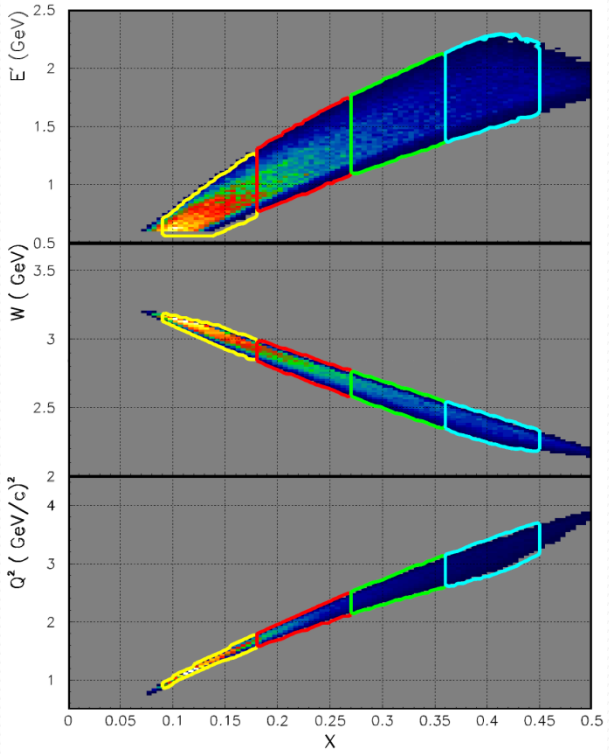
- Polarized ^{3}He Target, 10 atm pressure. With 10 uA beam:

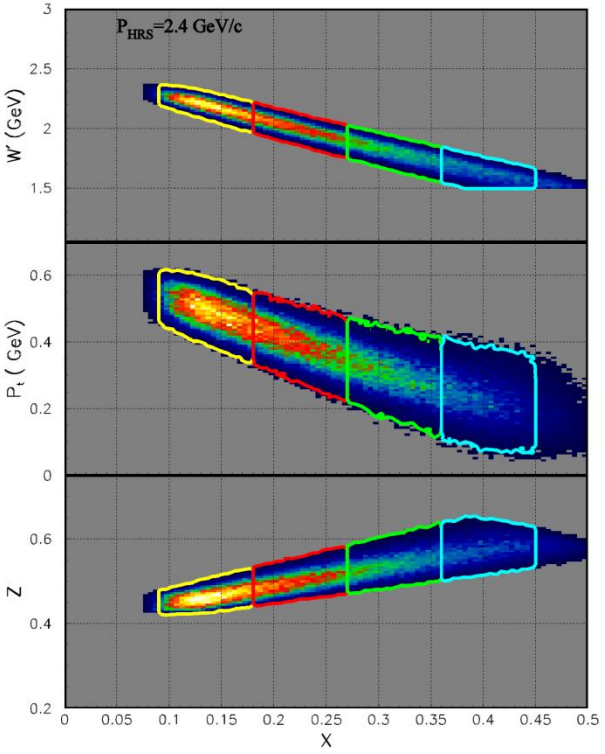
  $L(n) = 10^{36}$ cm^{-2} s^{-1}
- Electron Beam: 5.9 GeV
- HRSL at 16 degrees as **hadron** arm.

  $P = 2.4$ GeV/c
- BigBite at 30 degrees as **electron** arm.

  $\Delta\Omega = 64$ msr

Kinematics Coverage

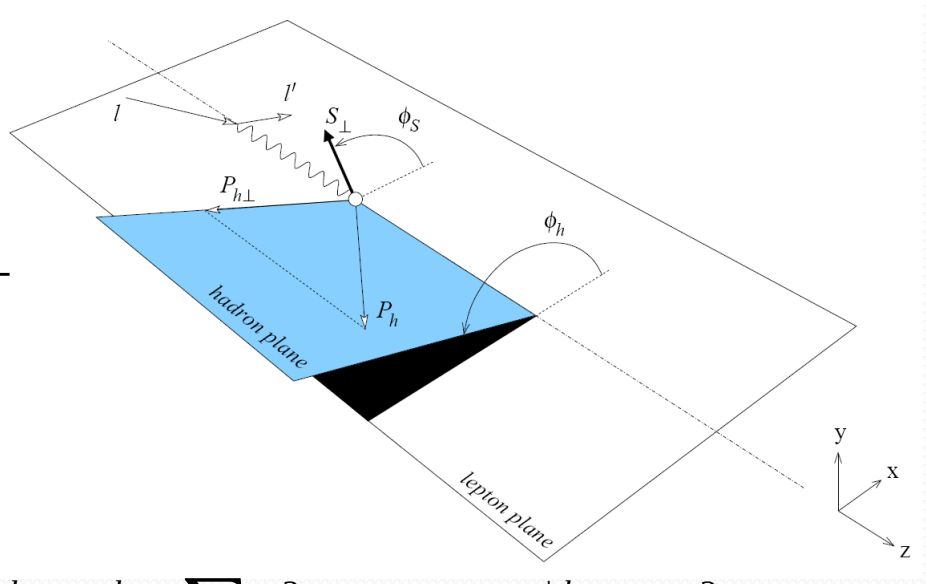




- x : 0.13 ~ 0.405, Valance Quark Region
- $\mathbf{Q^2}$: 1.3 ~ 3.1 $(GeV/c)^2$.

Separation of Collins and Sivers effects through angular dependence

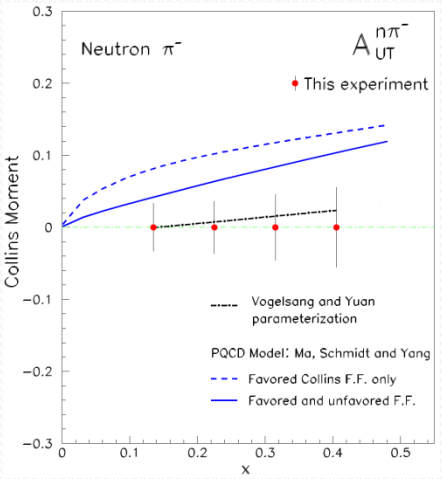
$$A_{UT}(\phi_h^l, \phi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

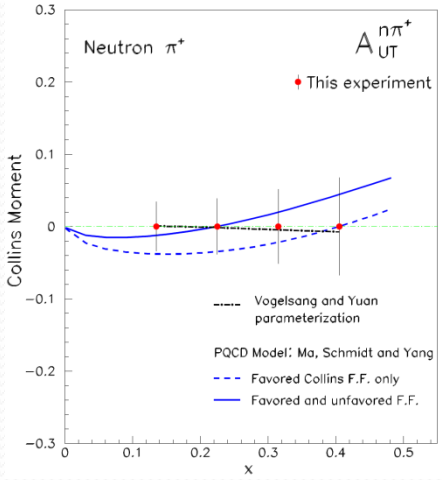


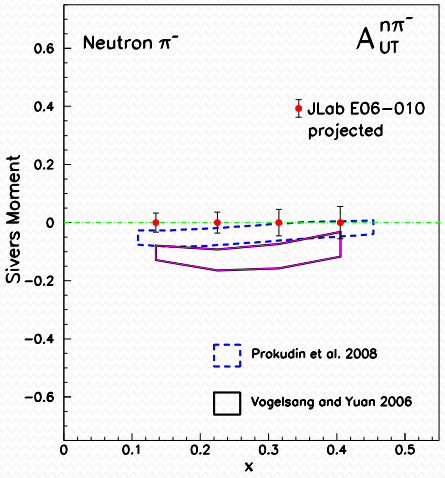
$$\sigma_{UT} \propto S_T(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^l + \phi_S^l)\cdot\sum e_q^2 h_1^q(x)\otimes H_{1q}^{\perp h}(z, P_{h\perp}^2)$$

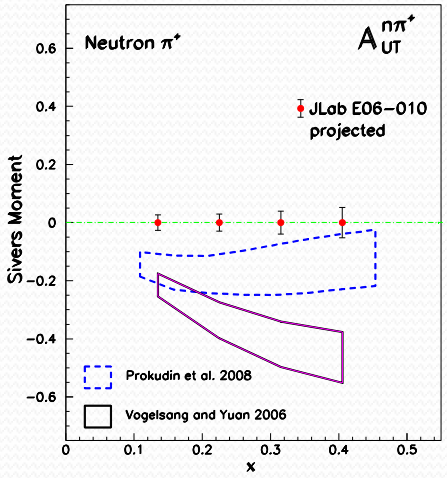
$$+ S_T(1-y+\frac{y^2}{2})\frac{P_{h\perp}}{zM_N}\sin(\phi_h^l - \phi_S^l)\cdot\sum e_q^2 f_{1T}^{\perp q}(x)\otimes D_{1q}^h(z_h, P_{h\perp}^2)$$

Goal





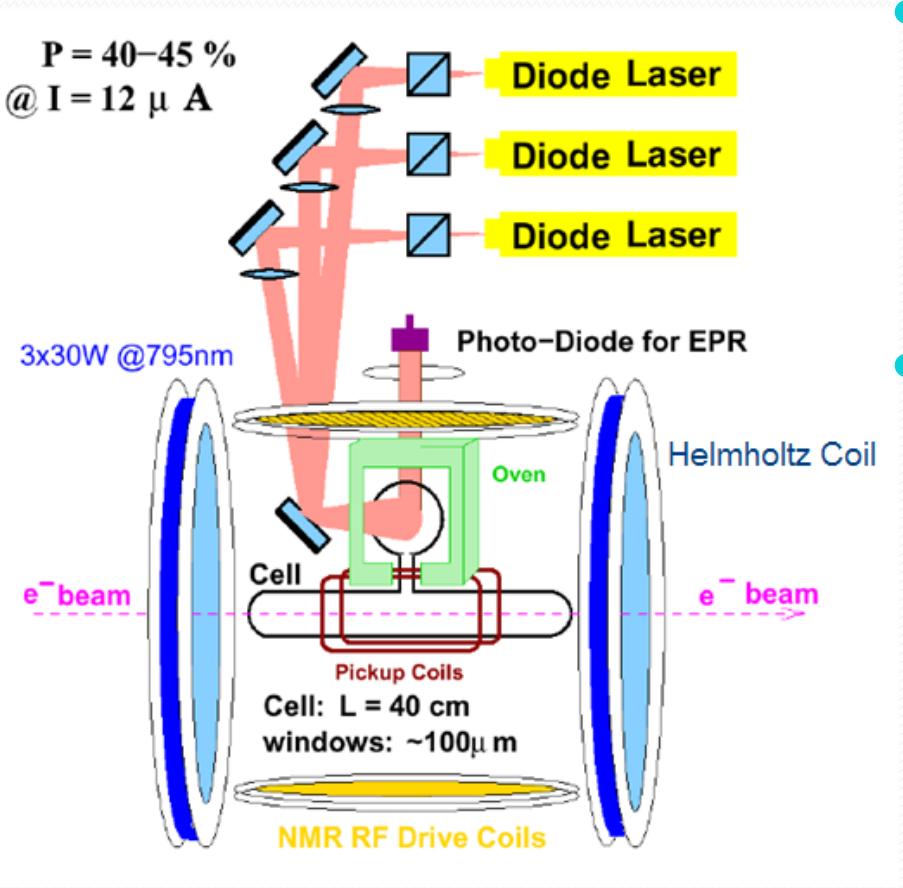




- Determine Sivers and Collins asymmetries to 5% level.
- Extract asymmetries on Kaon as well.
- Extract Prezelosity.
- Double spin asymmetry: g1T.

^{3}He Polarized Target Performance

Hall A Polarized ^{3}He Target



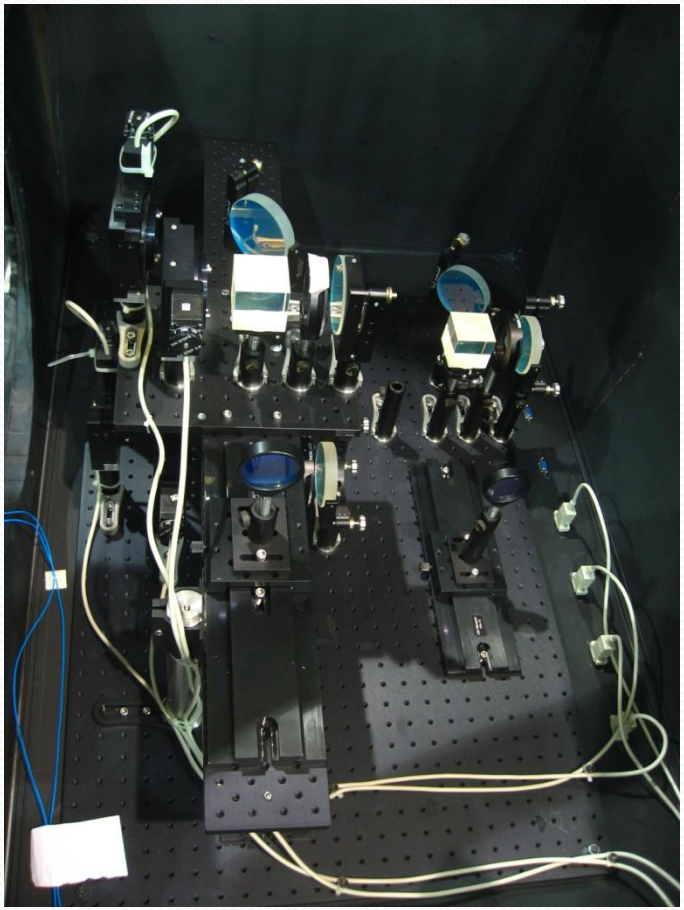
- Optical Pumping System
  - High Luminosity:

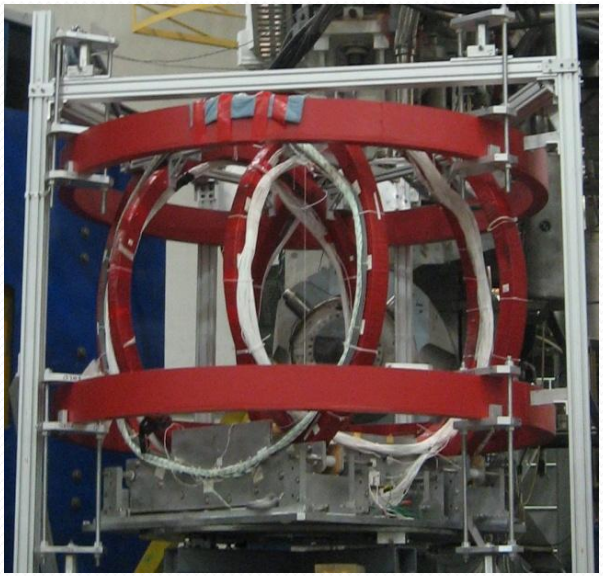
    $L = 10^{36}\ cm^{-1}s^{-1}$ (world record)
- K-Rb Hybrid Cell
  - High polarization:

    $P \sim 45\%$ with 12 uA beam and 100 W diode laser array
  - Short Pumping Up Time: 2-6 hours

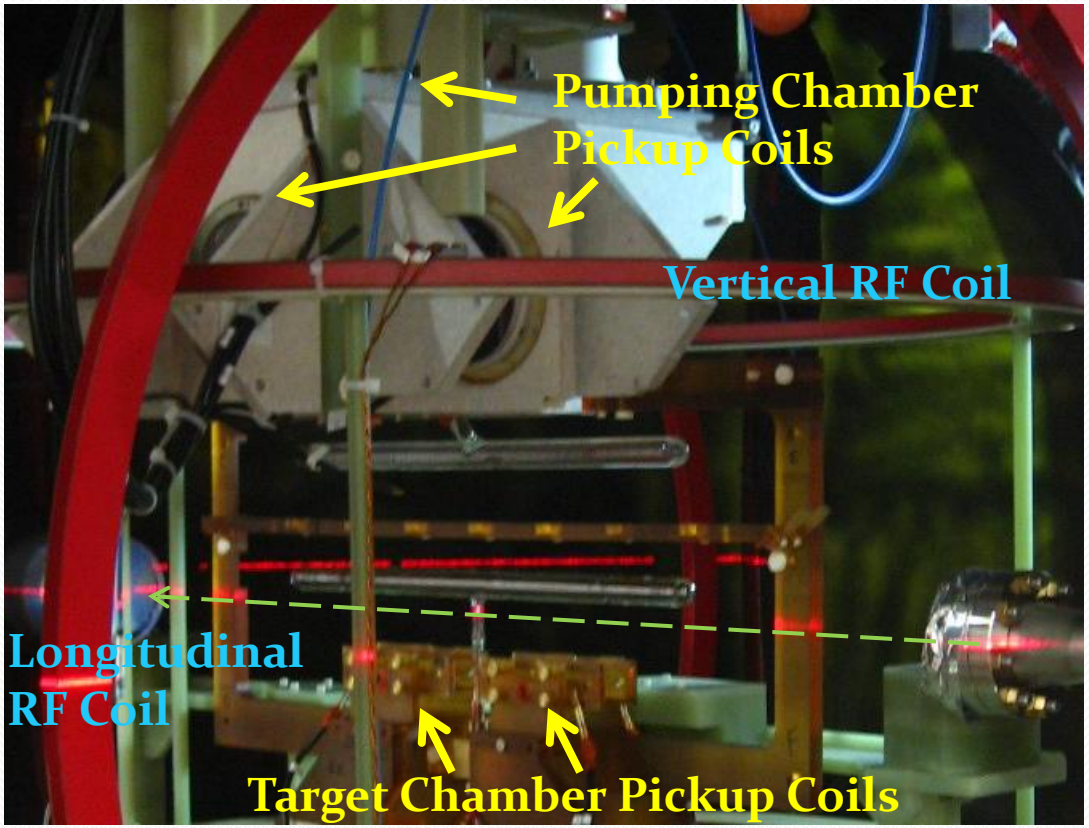
3 Dimensional Pumping

- 3 pairs of Helmholtz Coils.
- 3 sets of optics for 3 pumping direction:
  - Transverse, Vertical and Longitudinal





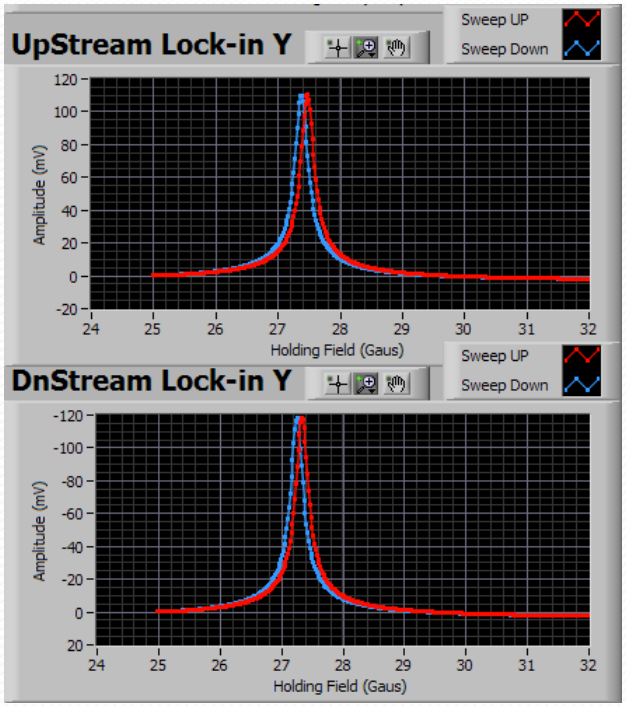
NMR Polarimetry

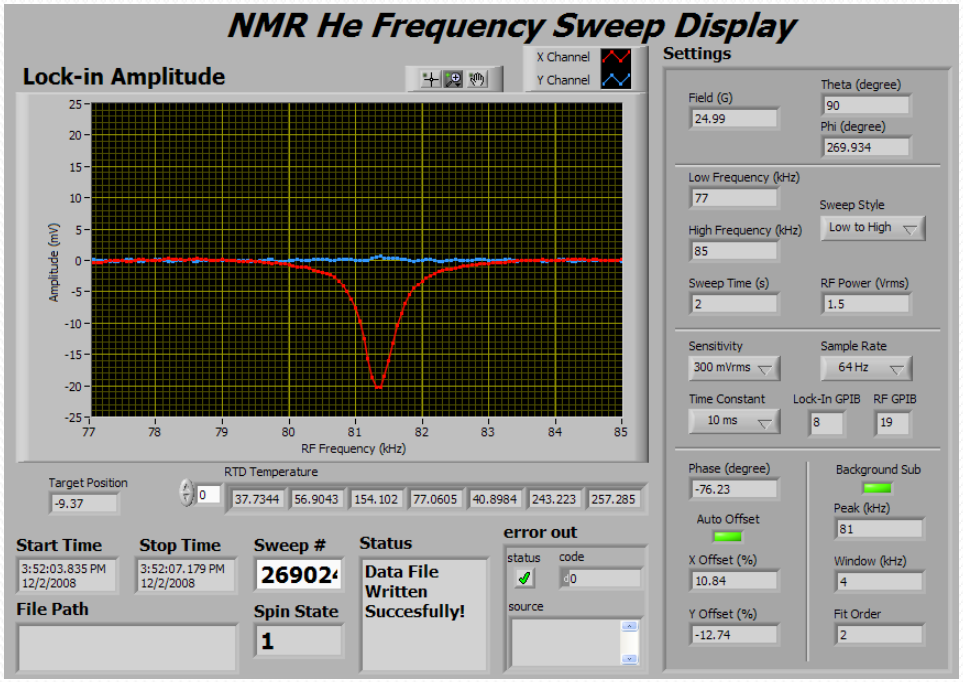


- 2 pairs of RF Coils
- 3 pairs of Pickup Coils around Pumping Chamber to give online Polarization Measurement
- 2 pairs of Target Chamber Pickup coils for Water Calibration
- Can measure ^{3}He polarization in all 3 pumping directions!

NMR Field/Frequency Sweep

- Typical NMR Measurements from two types of sweeps:

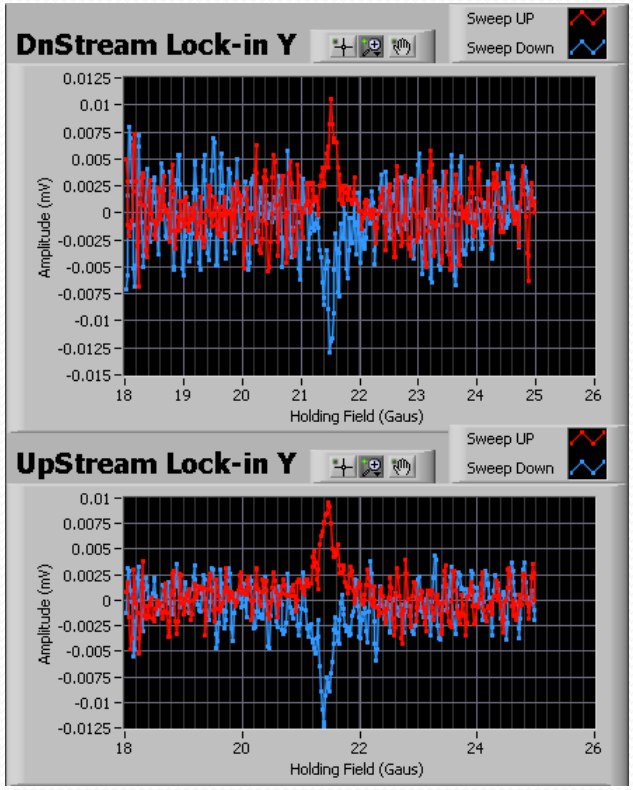


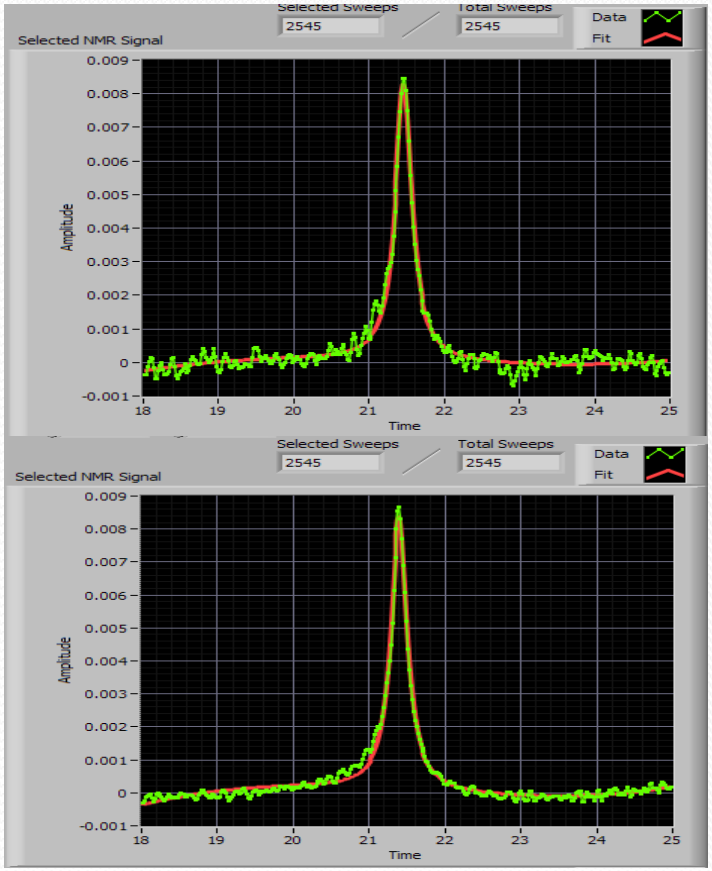


- Both measurements have precision better than 1%

Water Calibration in Hall

10 Sweeps

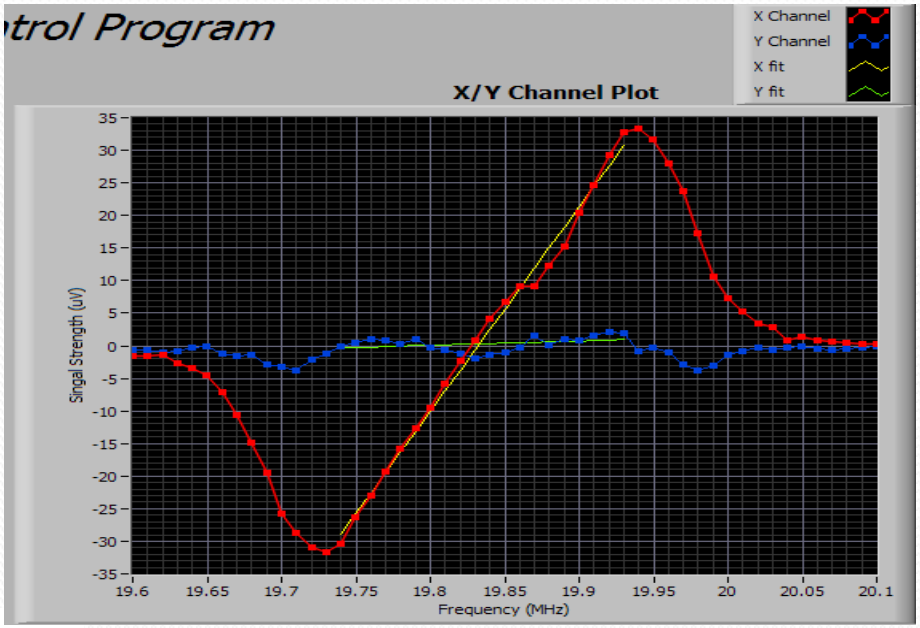




Uncertainty well below 1% after 2500 sweeps (~ 20 h)

EPR Polarimetry

- EPR Coil is located inside oven.
- EPR D2 light is collected through a 800 um fiber.
- One D2 light filter is placed before the photo-diode.
- Diode output is about 20~100 mV.



EPR FM
Line Shape directly gives appropriate gain for PI box

EPR Calibration

- Statistic precision better than 0.5%.
- One Calibration can be done within 5 minutes including FM sweep.

Automatic Spin Flip

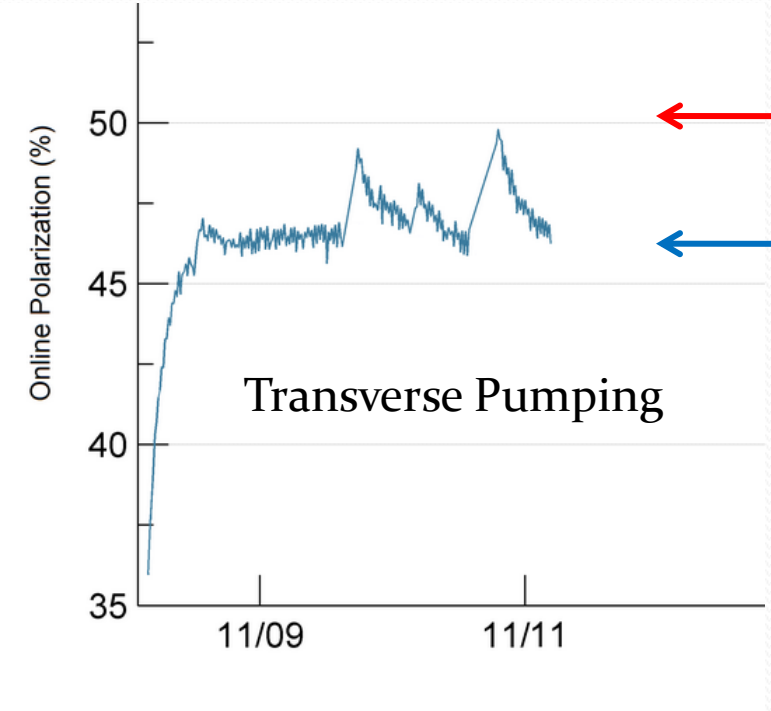
- Holding Field remains constant.
- Use RF frequency sweep to do AFP spin flip every 20 minutes. NMR data is taken at the same time (free polarization measurement).
- Q-wave plates are rotated remotely to change the polarization of circular polarized pumping laser at the mean time.
- Sign of the lock-in X channel signal from pumping chamber pickup coils is used to tell/verify the ^{3}He spin direction.

Stability of Automatic Spin Flip

- Controlled by LabView programs on a Windows XP Machine.
- No Spin flip failure so far.
- No NMR measurement failure so far.
- The only crash happened during the waiting time due to the memory leakage of LabView.
- Longest auto flip sequence has more than 400 flips.

Performance with FAP Laser

- Used 4/5 FAP lasers, 100W total power, during early stage of the experiment.
- Oven Temperature: 230 °C

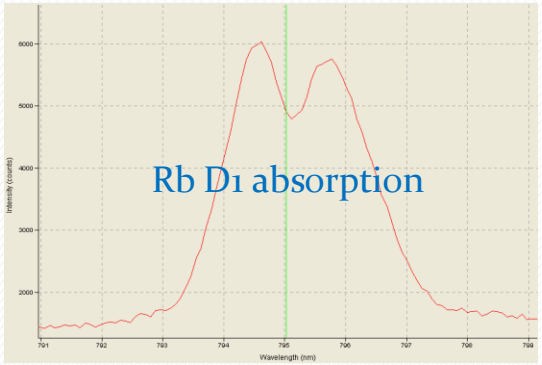


Max Polarization ~ 50%

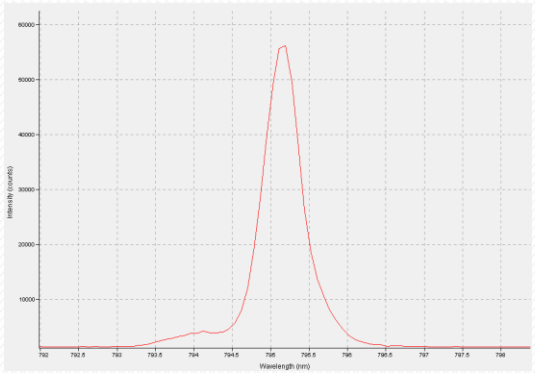
Stabilized with auto spin flip and 8 μA Beam ~ 46%

COMET Lasers

- Narrow Band COMET Lasers were proved to be more efficient for optical pumping in UVa and Duke.
- Higher Polarization is expected.
- Three COMET lasers in JLab now: W&M, Rutgers U and JLab.



FAP: FWHM ~ 2.5 nm

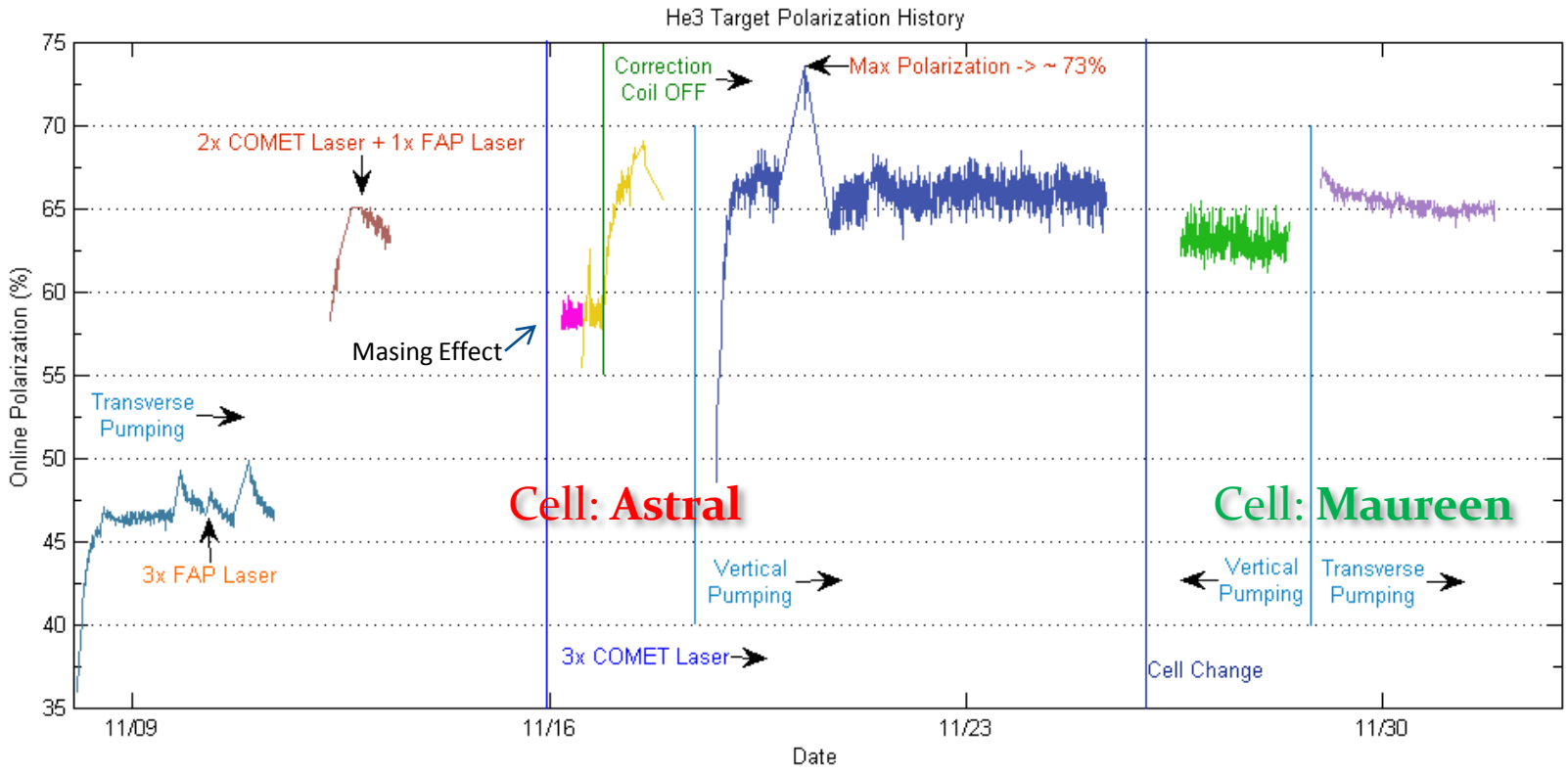


COMET: FWHM~ 0.3 nm

Narrower than D1 absorption!

Power of COMET Lasers

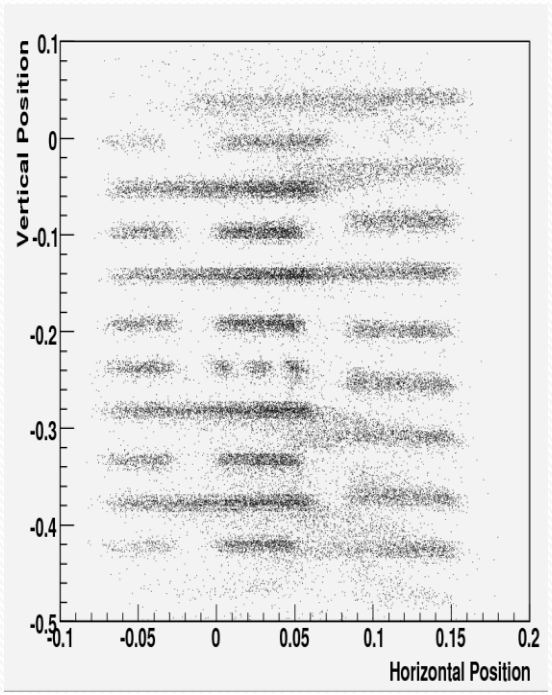
- Max Polarization with 3 COMET (75W) ~ 73%.
- Stabilized at 62~66% w/ 12uA beam and auto spin flip.

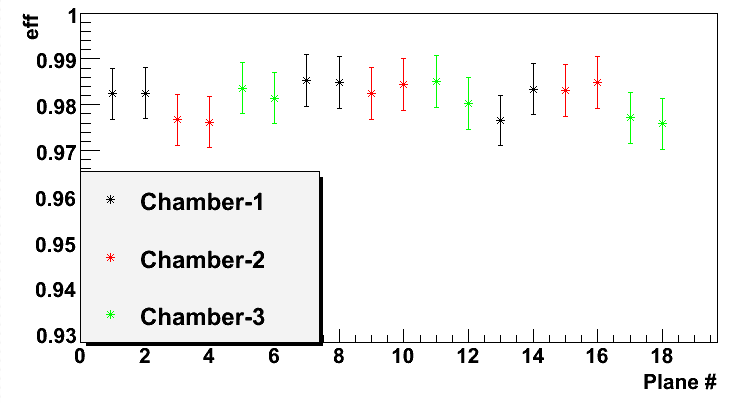


BigBite Electron Package

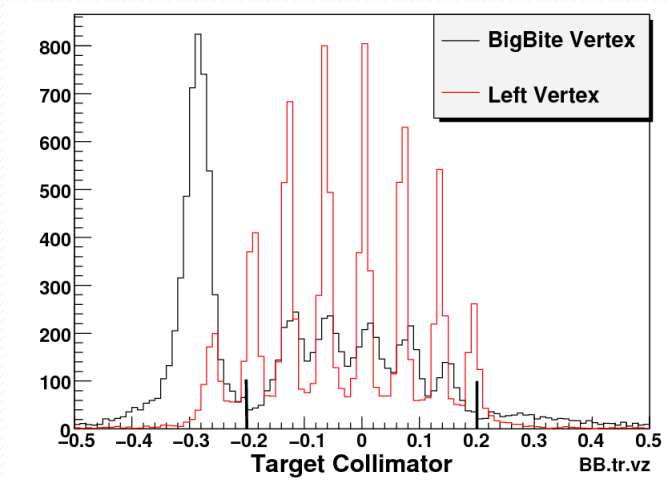
Multi-Wire Drift Chamber

- High efficiency ~ 98 %
- Clear Sieve Pattern:



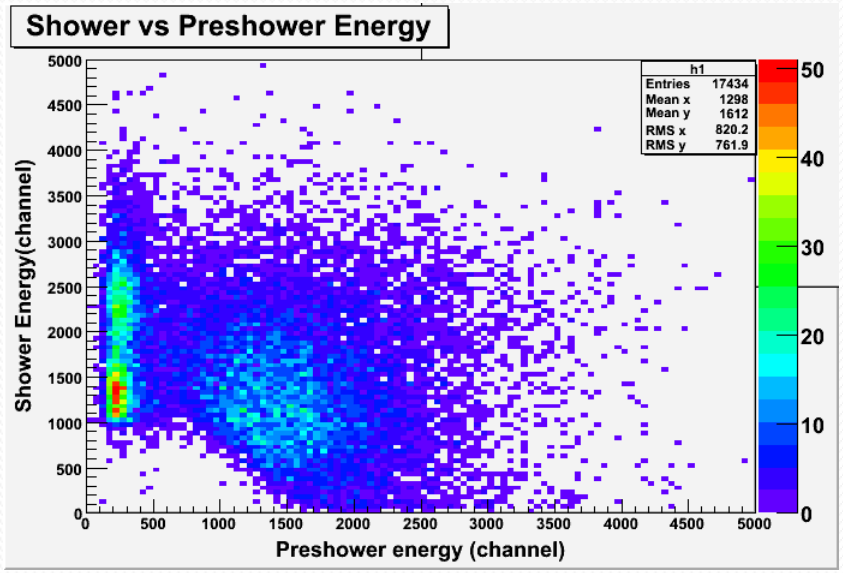


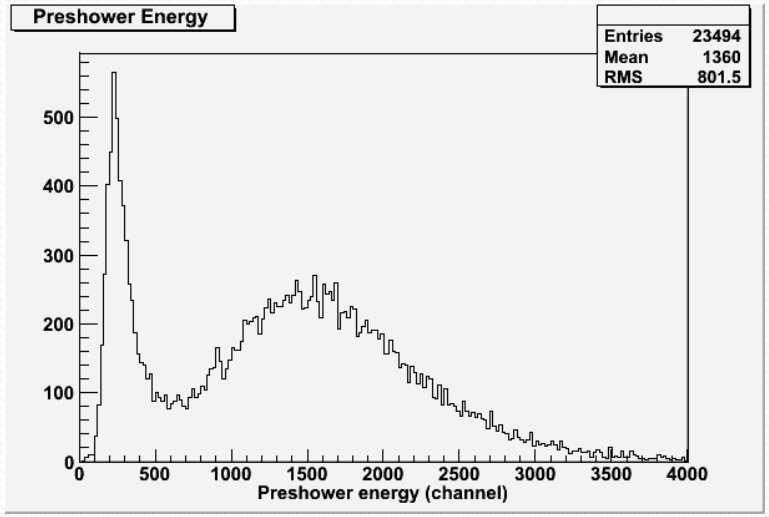
- Vertex Reconstruction:



Pre-Shower/Shower

- Good Electron/Pion Separation.

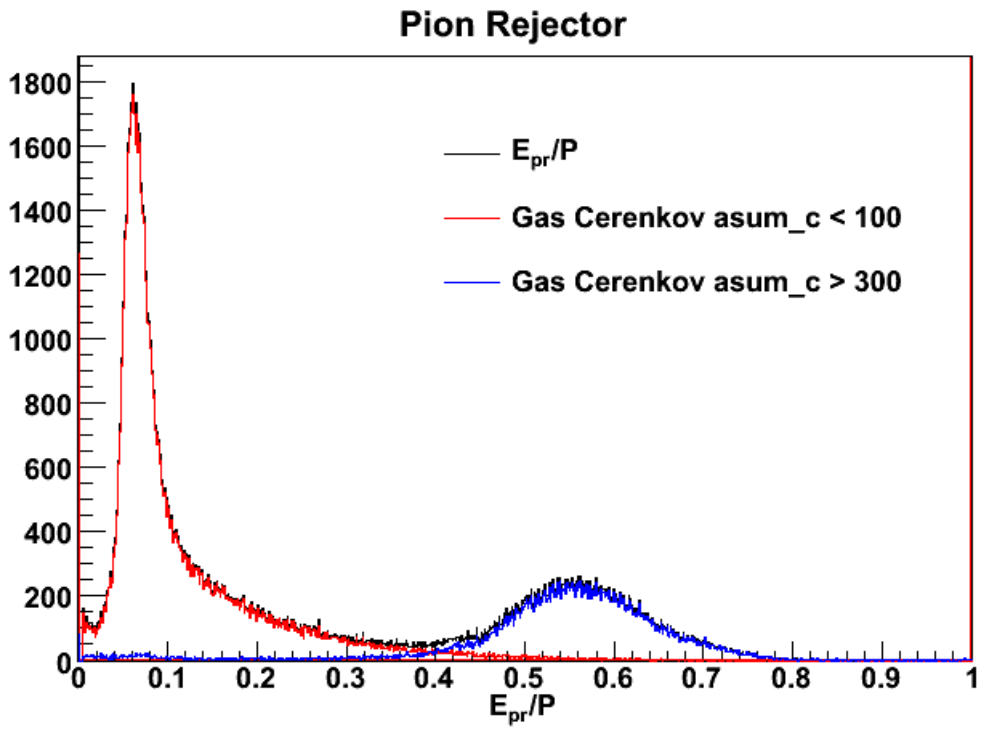


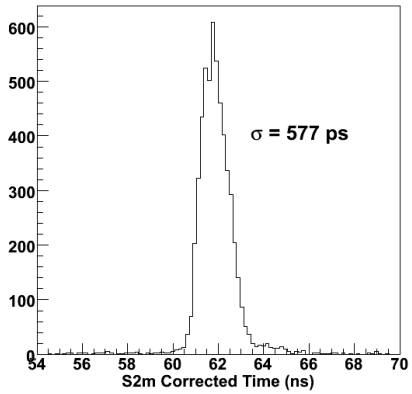


Left HRS: Hadron Arm

Pion Rejector, Gas Cherenkov and s2m Scintillator

- Clean separation of pion/electron after combined cut of pion rejector and Gas Chrenkov detectors.
- Good Time Resolution of s2m: ~ 600 ps

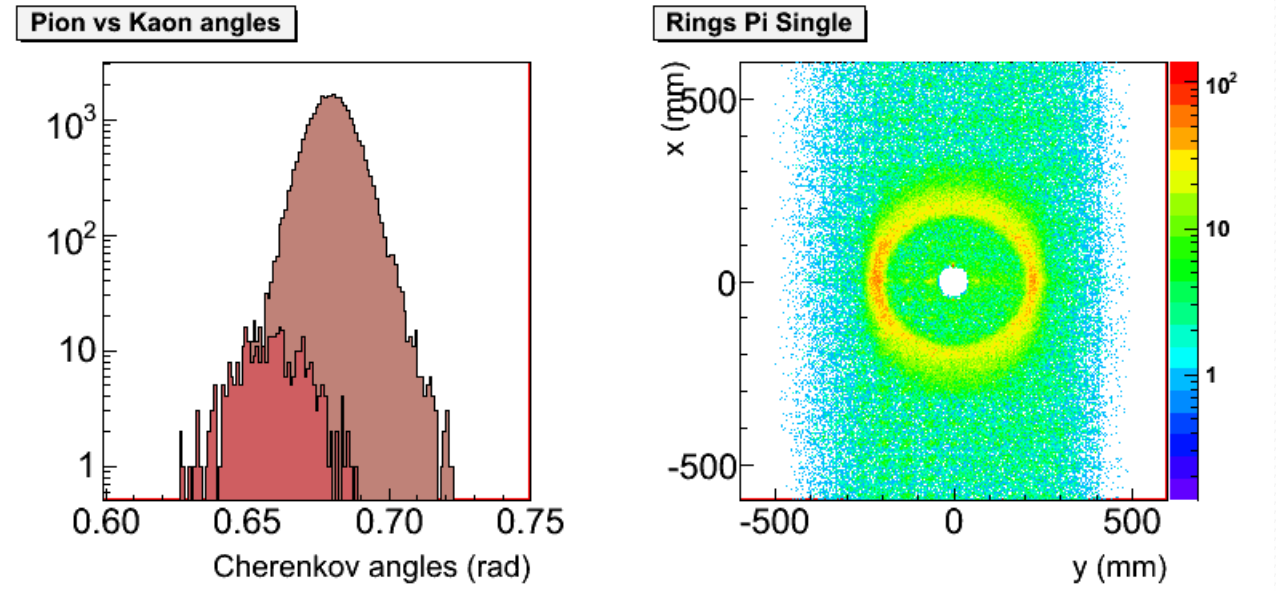




Can be better !

RICH Detector

- Clearly identified Cherenkov rings from both pions and kaons (photon number ~ 10).



- More off-line work needs to be done for a better K/π separation. Expecting factor of 2 improvement in angle resolution.

Experiment Status

Commissioning Stage: Oct.22-Nov.6

- 1 pass beam: 1.2 GeV
  - Optics Data BigBite.
  - Electron elastic scattering from polarized ^{3}He target.
  - Delta production from Polarized ^{3}He target.
  - Reference cell test
- 2 pass beam: 2.4 GeV
  - Optics Data for both HRS and BigBite.
  - Delta production from Polarized ^{3}He target.
  - Reference cell test with 1.2 and 2.4 GeV beam.

Production Stage: Nov.7 - now

- 5 pass beam: 5.9 GeV.
- For each setting, expecting 7C throughout the experiment.
- Nov 7 – Nov 17:
  - π^- Production with Transverse Pumping 1.2C
- Nov 18 – Nov 28:
  - π^- Production with Vertical Pumping 4.7C
  - Changed cell on Nov 25
- Nov 28 – Dec 5:
  - π^- Production with Transverse Pumping goal: 4.5C

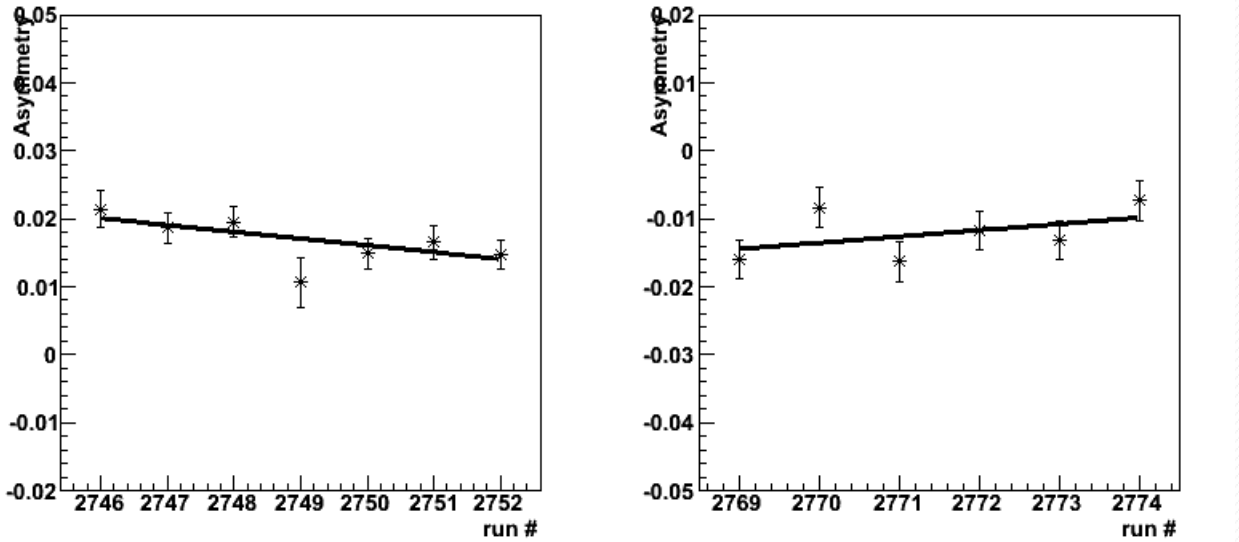
Future Plan

- Change HRS polarity to positive.
- Take π^+ production with Vertical/Transverse pumping still Christmas shut down, Dec 21.
- Water calibration during Christmas break.
- Holding Field Measurement .
- Install a new ^{3}He cell.
- Survey the target ladder after new cell installation.
- Continue production till the end.

Acknowledgement

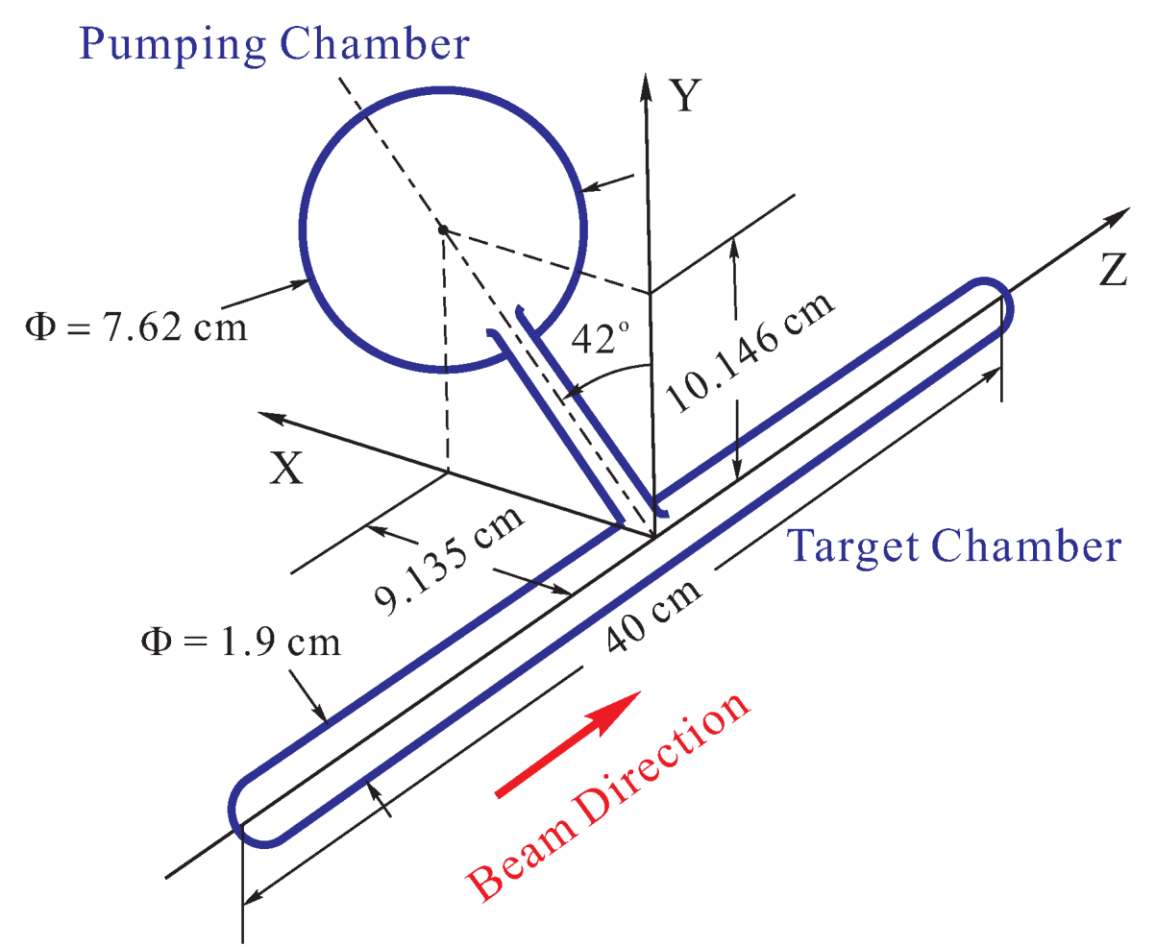
- Many thanks to the hard working students and post docs:
  - Xin, Kalyan, Chiranjib, Joe, Youcai, Jin, Yi', Yawei and Diana
  - Brad, Alexander, Bryan and Vince
- Many thanks to Hall A technicians for their support:
  - Ed, Jack, Scot, Heidi, Gary and Todd
- Many thanks to Hall A engineers:
  - Al, Susan, Joyce and Macon
- Thanks to all the collaborators for their contributions to the experiment preparation and shifts!

Asymmetry in ^{3}He elastic Scattering

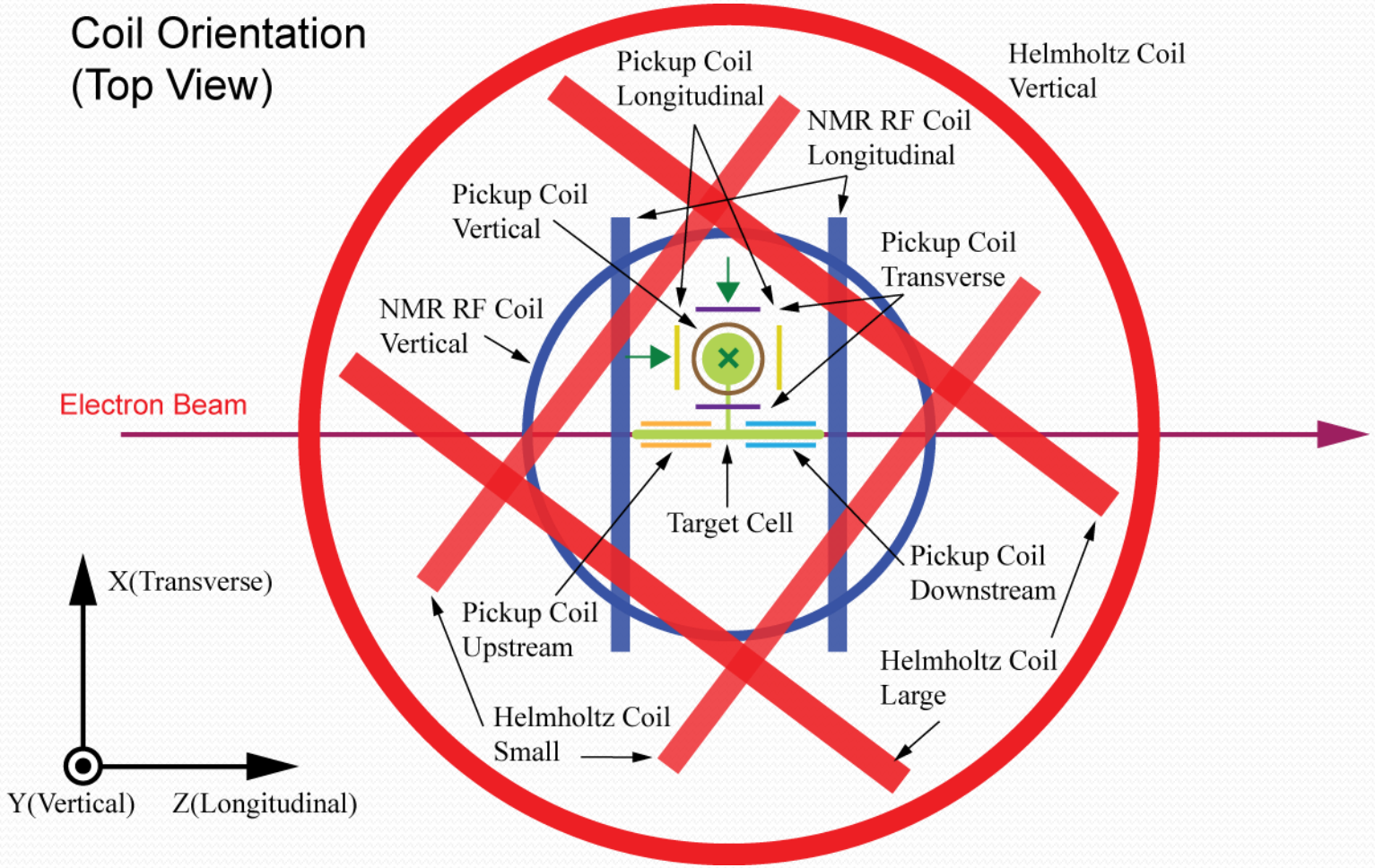


- Longitudinal Polarized 3He Target.
- Changed ½-λ plate in the middle.
- Data is still under analysis.

Target Cell


Pumping Chamber
Y
Z
Φ = 7.62 cm
42°
10.146 cm
X
9.135 cm
Target Chamber
Φ = 1.9 cm
40 cm
Beam Direction

Coil Setup


Coil Orientation
(Top View)
Pickup Coil
Longitudinal
Helmholtz Coil
Vertical
NMR RF Coil
Longitudinal
Pickup Coil
Vertical
Pickup Coil
Transverse
NMR RF Coil
Vertical
Electron Beam
Target Cell
Pickup Coil
Downstream
Pickup Coil
Upstream
Helmholtz Coil
Large
Helmholtz Coil
Small
X(Transverse)
Y(Vertical)
Z(Longitudinal)

A_{LT} in E06-010 Transversity

- Error is estimated to be

$$\delta A_{LT} \approx \frac{1}{P_{Beam}} \delta A_{LT}$$

- So, Expected Error is about 3% to 5% for x=0.14 to 0.40

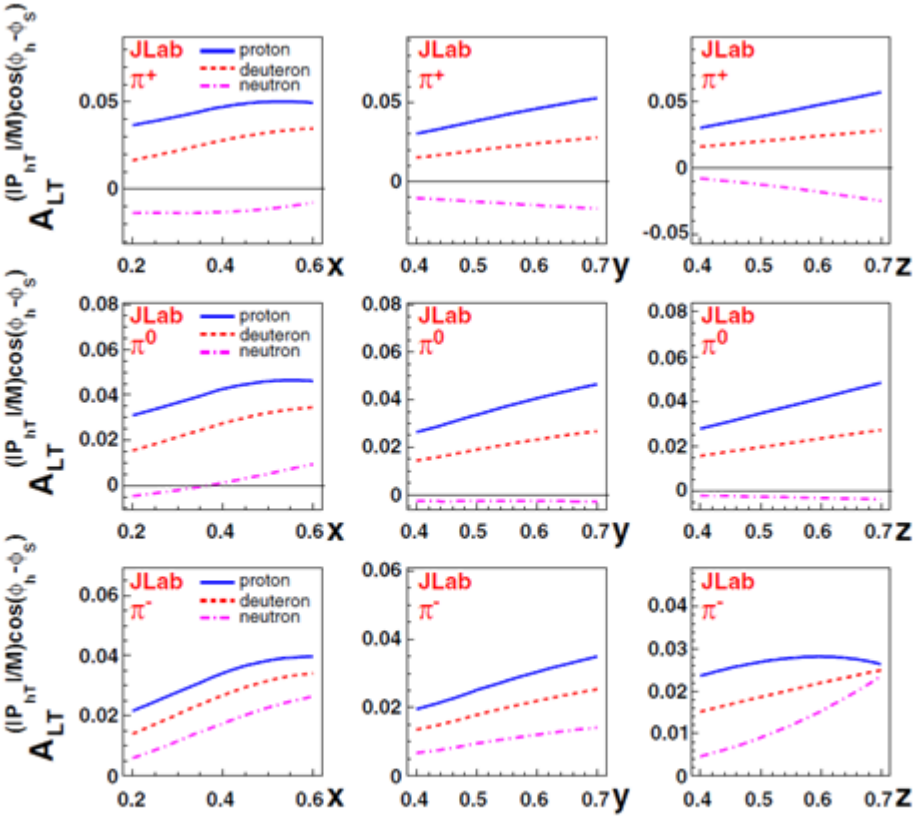


FIG. 4 (color online). Predicted dependence of $A_{LT}^{(|\mathbf{P}_{hT}|/M)\cos(\phi_h-\phi_S)}$ on x, y, and z for π^+, π^0, and π^- production at JLab for SIDIS on transversely polarized proton (solid line), deuteron (dashed line), and neutron (dot-dashed line) targets.

E06-010 Collaboration

- **Institutions**

California State Univ., Duke Univ., Florida International. Univ., Univ. Illinois, JLab, Univ. Kentucky, LANL, Univ. Maryland, Univ. Massachusetts, MIT, Old Dominion Univ., Rutgers Univ., Temple Univ., Penn State Univ., Univ. Virginia, College of William & Mary, Univ. Sciences & Tech, China Inst. Of Atomic Energy, Beijing Univ., Seoul National Univ., Univ. Glasgow, INFN Roma and Univ. Bari, Univ. of Ljubljana, St. Mary's Univ., Tel Aviv Univ.

- **Collaboration members**

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