Perspectives on SSA with a transversely polarized ^{3}He target in JLab Hall-A

Jen-Chieh Peng
University of Illinois
Transversity Workshop, October 6-7, 2003, Athens, Greece

- JLab Hall-A proposal E03-004
  - Goals of the proposed measurements
  - Experimental approach and expected sensitivities
- Feasibility of Sivers function measurements in SSA Drell-Yan
- Feasibility of $h_1^{\perp}$ measurement in unpolarized Drell-Yan

Transversity

- Three twist-2 quark distributions:
  - Density distributions: $q(x,Q^2) = q^{\uparrow}(x) + q^{\downarrow}(x)$
  - Helicity distributions: $\Delta q(x,Q^2) = q^{\uparrow}(x) - q^{\downarrow}(x)$
  - Transversity distributions: $\delta q(x,Q^2) = q^{\perp}(x) + q_{\top}(x)$
- Some characteristics of transversity:
  - $\delta q(x) = \Delta q(x)$ for non-relativistic quarks
  - δq and gluons do not mix $\rightarrow$ Q^2-evolution for δq and Δq are different
  - Chiral-odd $\rightarrow$ not accessible in inclusive DIS
- It takes two chiral-odd objects to measure transversity
  - Drell-Yan (Doubly transversely polarized p-p collision)
  - Semi-inclusive DIS

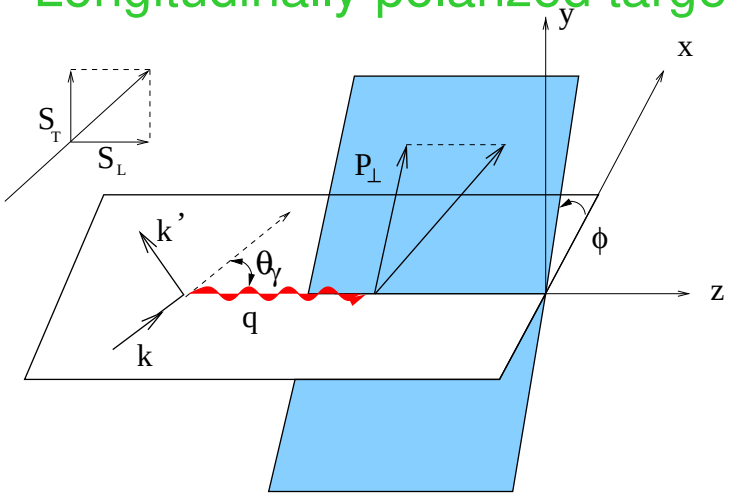
    Chiral-odd distributions function (transversity)

    Chiral-odd fragmentation function (Collins function)

Observation of Single-Spin Azimuthal Asymmetry

$ep \rightarrow e'\pi X$

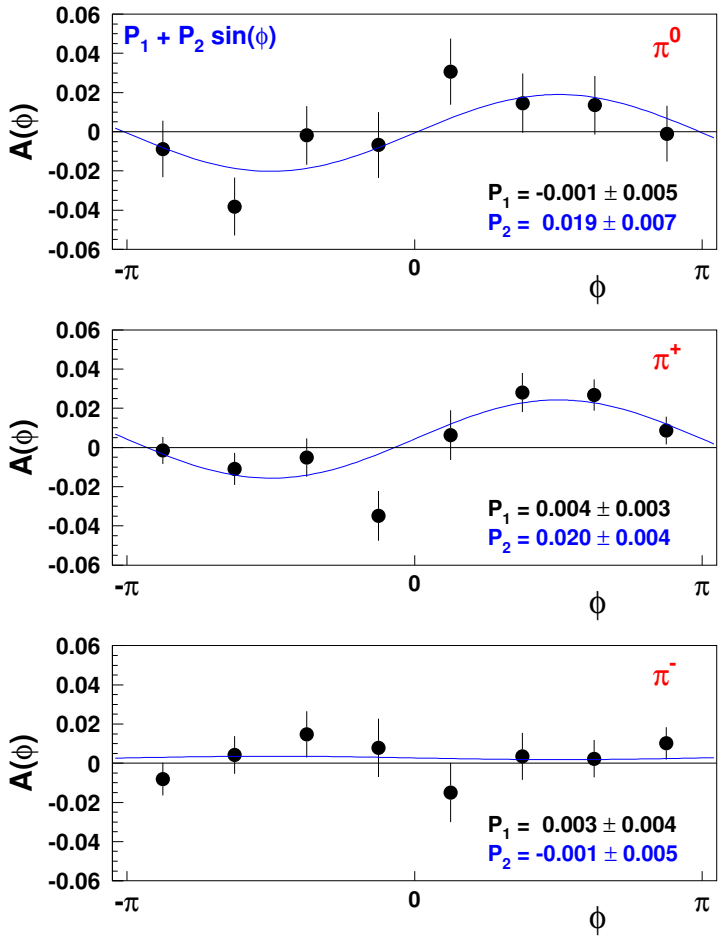
Longitudinally polarized target



$\langle S_T \rangle \sim 0.15$

- **Suggests transversity, δq(x), is sizeable**
- **Suggests Collins T-odd fragmentation function is sizeable**
- **Other effects (Sivers effect, higher twist) could also contribute**
- **Requires a transversely polarized target**

HERMES

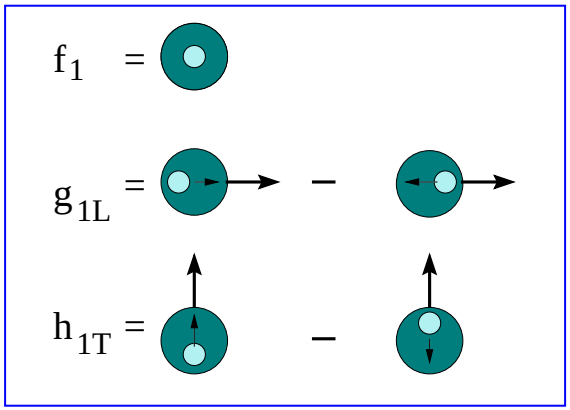


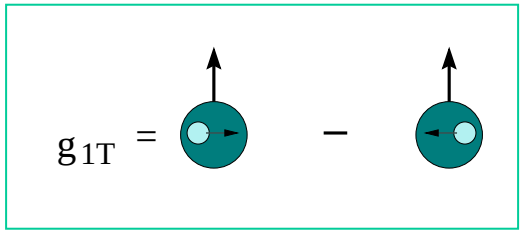
hep-ex/0104005

Leading-Twist Quark Distributions

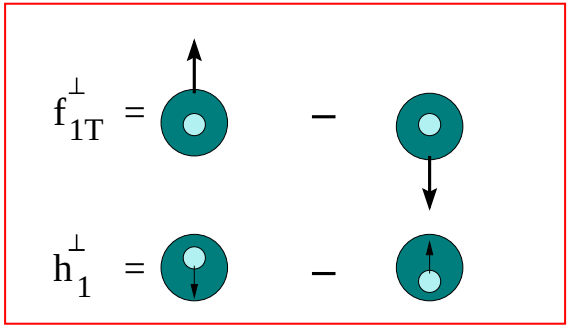
(A total of eight distributions)

No $K_\perp$ dependence

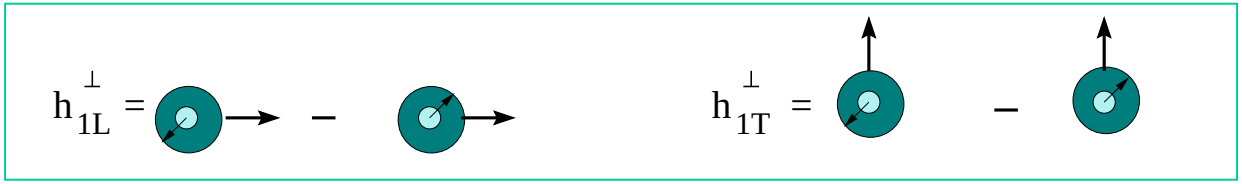




$K_\perp$ - dependent, T-odd

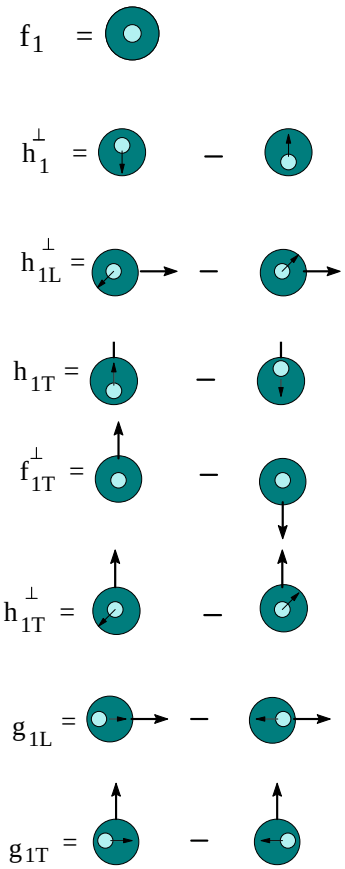


$K_\perp$ - dependent, T-even



All Eight Quark Distributions Are Probed in Semi-Inclusive DIS

$$d^6\sigma = \frac{4\pi\alpha^2 sx}{Q^4}\times$$



Transversity

Sivers

$$\{[1+(1-y)^2]\sum_{q,\bar{q}} e_q^2 f_1^q(x) D_1^q(z,P_{h\perp}^2)$$
$$+(1-y)\frac{P_{h\perp}^2}{4z^2 M_N M_h}\cos(2\phi_h^l)\sum_{q,\bar{q}} e_q^2 h_1^{\perp(1)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$

Unpolarized

$$-|S_L|(1-y)\frac{P_{h\perp}^2}{4z^2 M_N M_h}\sin(2\phi_h^l)\sum_{q,\bar{q}} e_q^2 h_{1L}^{\perp(1)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^l+\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_1^q(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{P_{h\perp}}{zM_N}\sin(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z,P_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{P_{h\perp}^3}{6z^3 M_N^2 M_h}\sin(3\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_{1T}^{\perp(2)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$

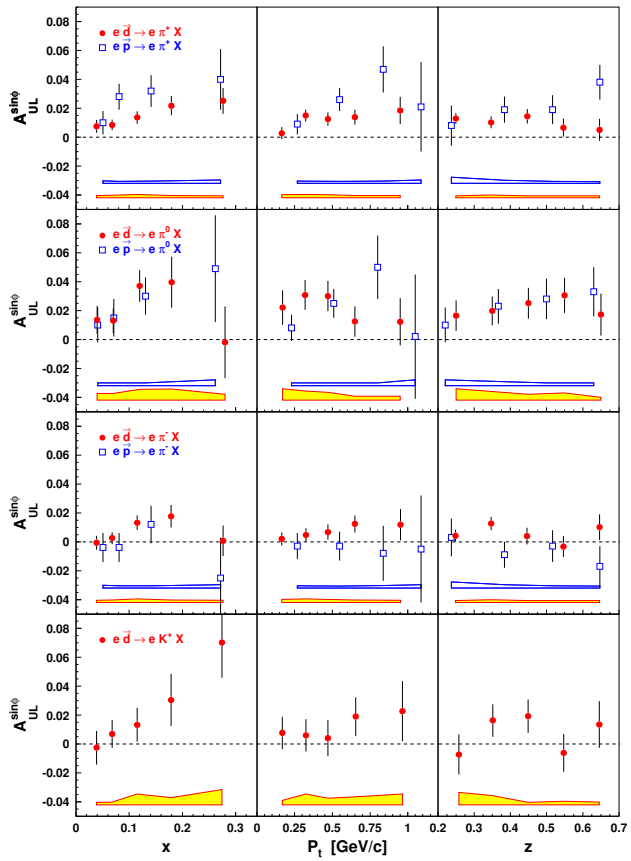
Polarized target

$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_{q,\bar{q}} e_q^2 g_1^q(x) D_1^q(z,P_{h\perp}^2)$$
$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{P_{h\perp}}{zM_N}\cos(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 g_{1T}^{(1)q}(x) D_1^q(z,P_{h\perp}^2)\}$$

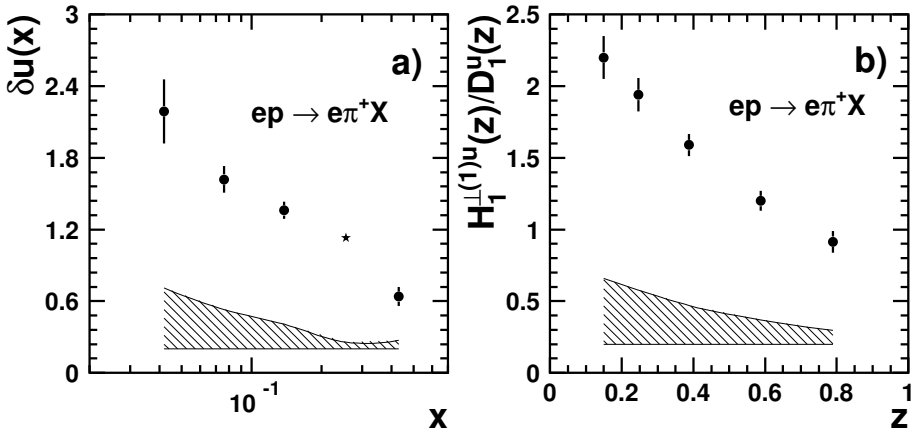
Polarzied beam and target

S_L and S_T: Target Polarizations; λe: Beam Polarization

Azimuthal Asymmetry with longitudinnaly polarized targets



- HERMES data on longitudinally polarized deuterium and proton targets
- π^+, π^-, π^0 and K^+ are detected
- Data well described by models of transversity
- SSA data with transversely polarized targets are collected at HERMES and COMPASS



HERMES, PL B562 (2003) 182

Projected HERMES sensitivities

SSA measurements using transversely polarized ^{3}He target is complementary to HERMES and COMPASS

JLab Hall-A E03-004 Experiment

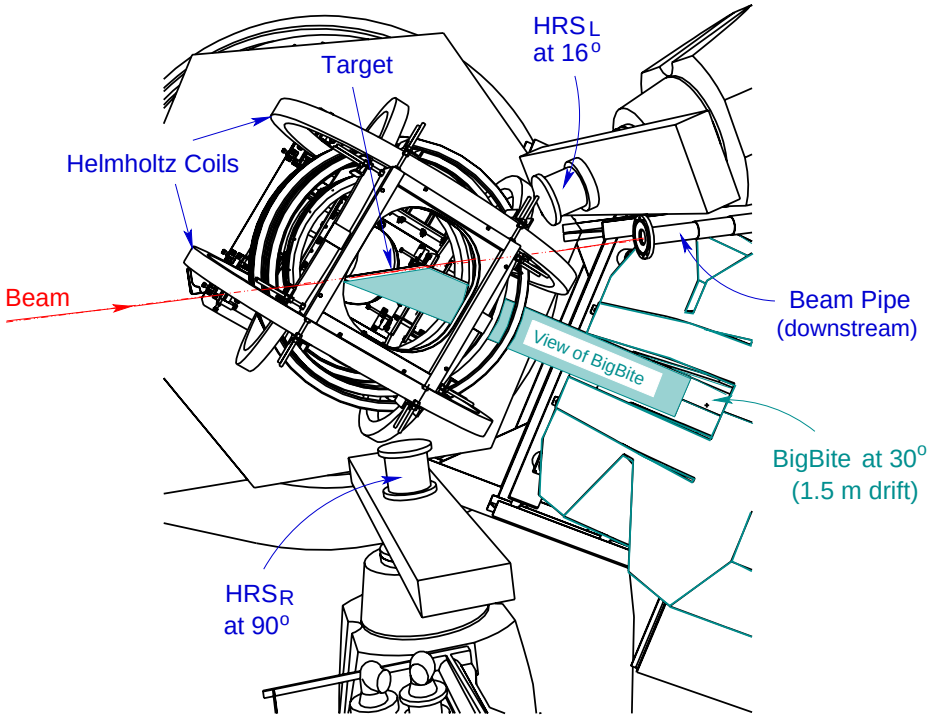
Measurement of Single Target-Spin Asymmetry in Semi-Inclusive Pion Electroproduction on a Transversely Polarized ^{3}He Target

Argonne, CalState-LA, Duke, E. Kentucky, FIU, UIUC, JLab, Kentucky, Maryland, UMass, MIT, ODU, Rutgers, Temple, UVa, W&M, USTC-China, CIAE-China, Glasgow-UK, INFN-Italy, U. Ljubljana-Slovenia, St. Mary's-Canada, Tel Aviv-Israel, St. Petersburg-Russia

Spokespersons: J.-P. Chen (JLab), X. Jiang (Rutgers), J. C. Peng (UIUC)

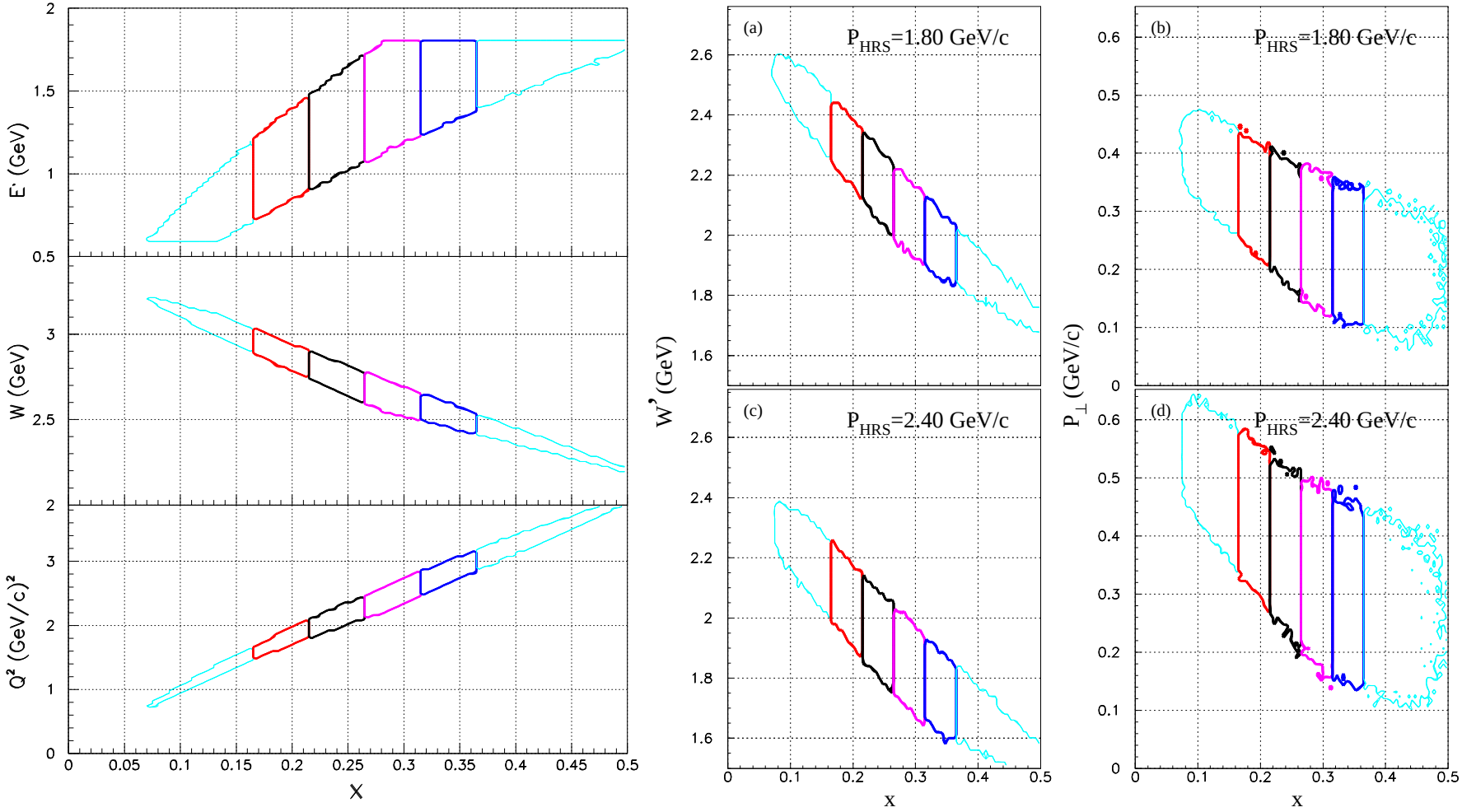
- High luminosity
  - 15 μA electron beam on 10-atm 40-cm ^{3}He target
- Measure neutron transversity
  - Sensitive to δd, complementary to HERMES
- Disentangle Collins/Sivers effects
- Probe other $K_\perp$-dependent distribution functions

Experimental Setup for $^3He^{\uparrow}(e,e'\pi^-)x$



- **Beam**
  - **6 GeV polarized e^-, 15 μA, helicity flip at 60 Hz**
- **Target**
  - **Optically pumped Rb spin-exchange ^{3}He target, 50 mg/cm^2, ~42% polarization, transversely polarized with tunable direction**
- **Electron detection**
  - **BigBite spectrometer, Solid angle = 60 msr, $\theta_{Lab} = 30^0$**
- **Charged pion detection**
  - **HRS spectrometer, $\theta_{Lab} = -16^0$**

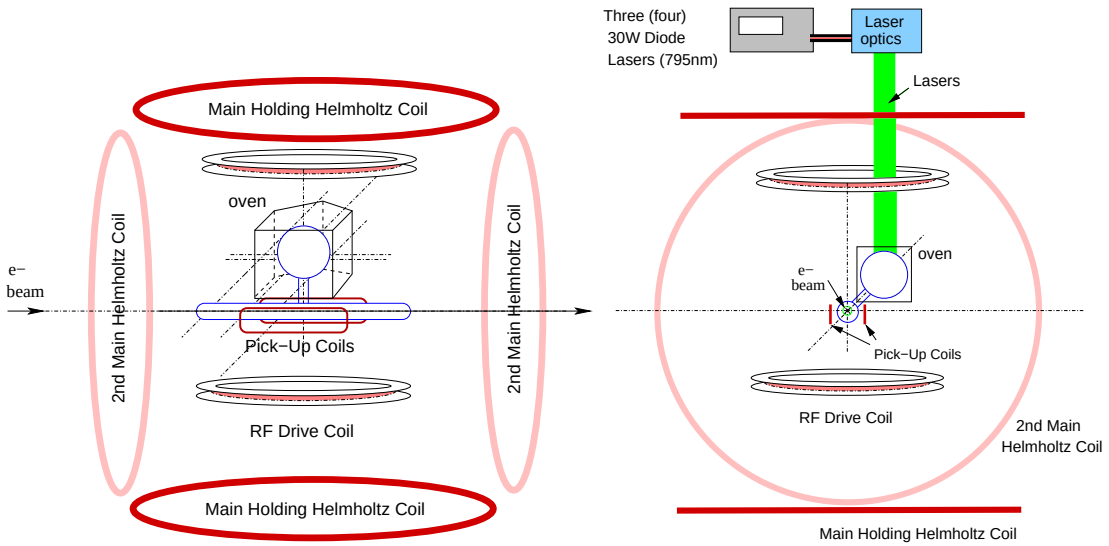
Kinematic acceptance

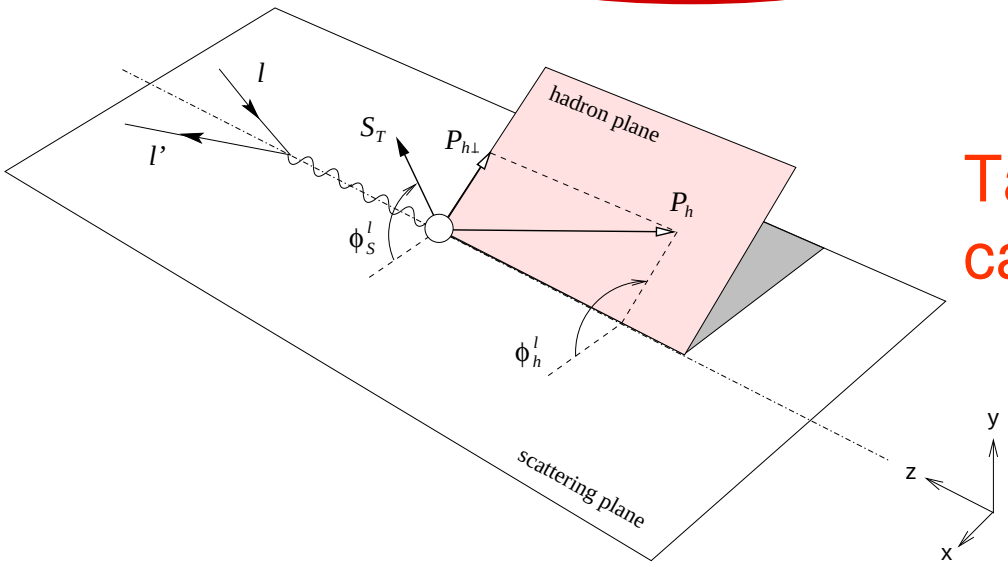


Hall-A : *x*: 0.19 – 0.34, Q^2: 1.8 – 2.7 GeV², *W*: 2.5 – 2.9 GeV, *z*: 0.37 – 0.56

HERMES: $\langle Q^2 \rangle$ = 2.5 GeV²

Transversely polarzied ^{3}He target



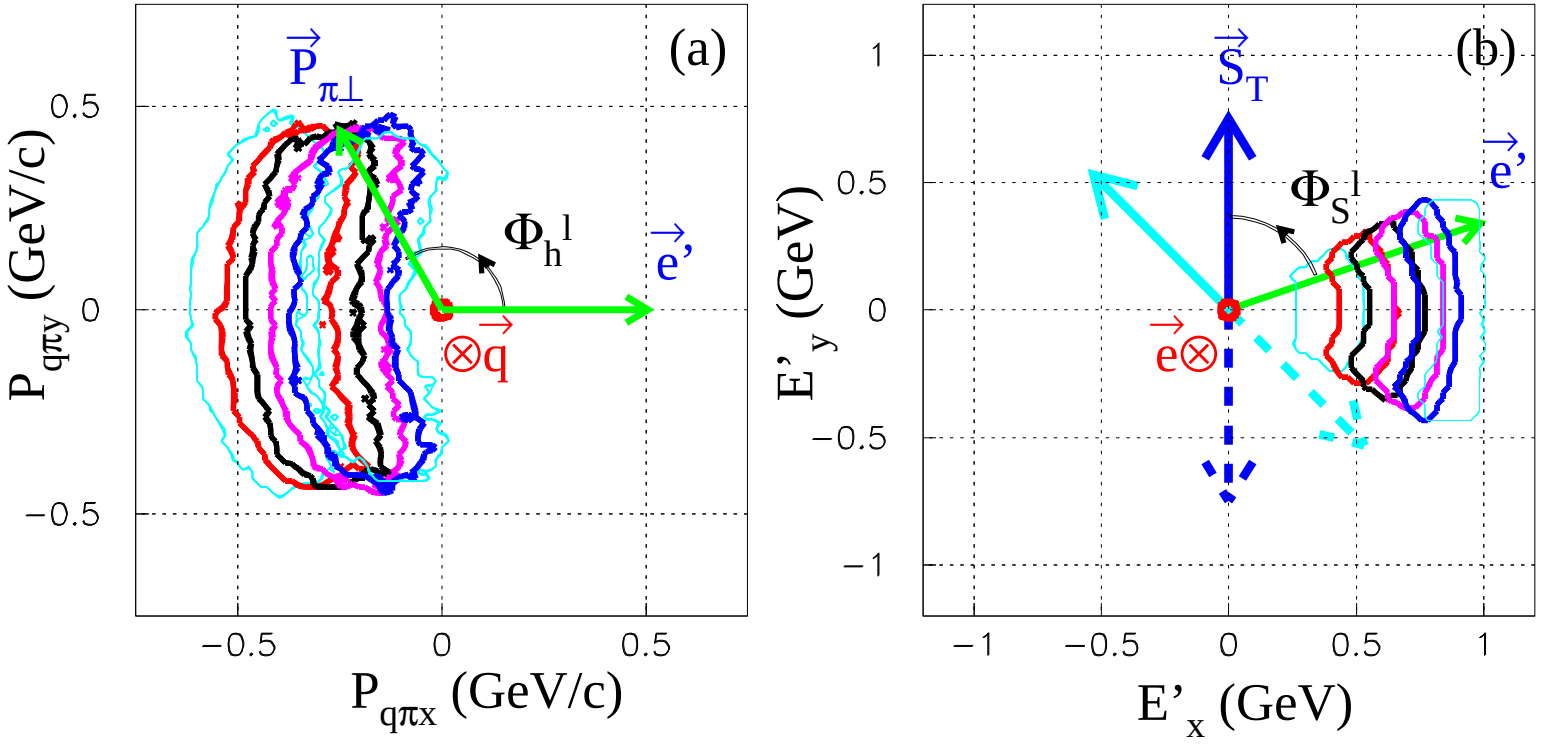


Target polarization orientation can be rotated to increase the coverage in Φ_S^l

Disentangling Collins and Sivers Effects

Collins angle: $\Phi_C = \Phi_h^l + \Phi_s^l$

Sivers angle: $\Phi_S = \Phi_h^l - \Phi_s^l$

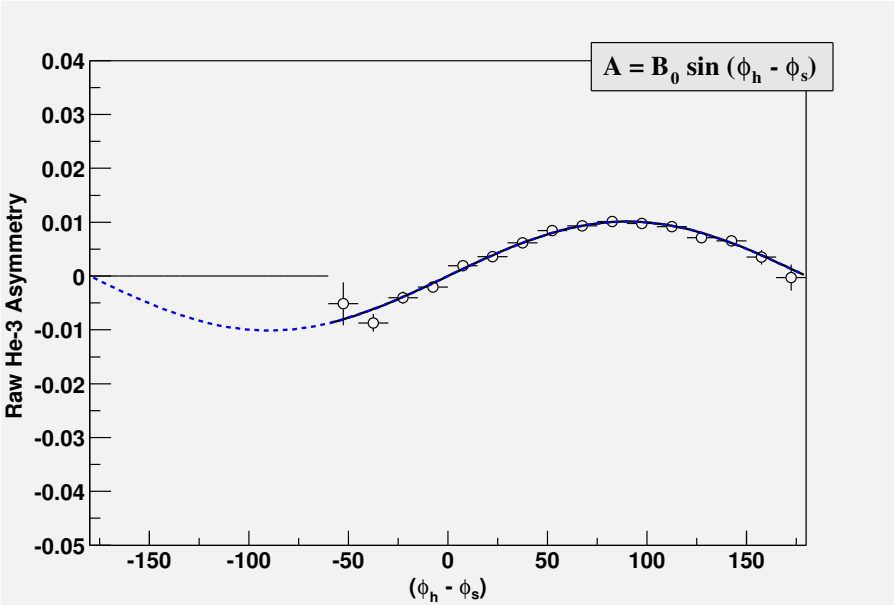


Coverage in Φ_s^l is increased by rotating target polarization

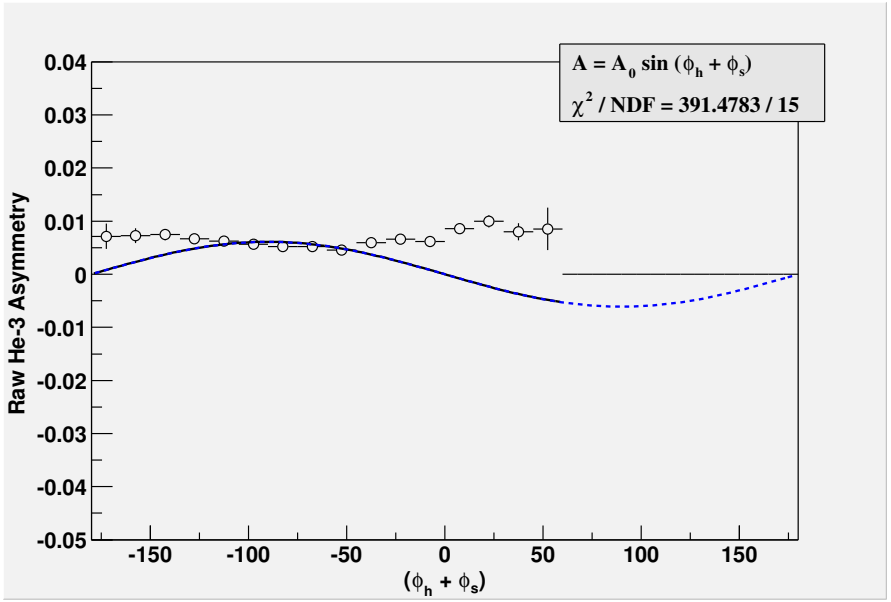
Disentangling Collins and Sivers Effects

Monte Carlo assuming 1.0% asymmetry due to Sivers effect

Asymmetry versus Sivers Angle



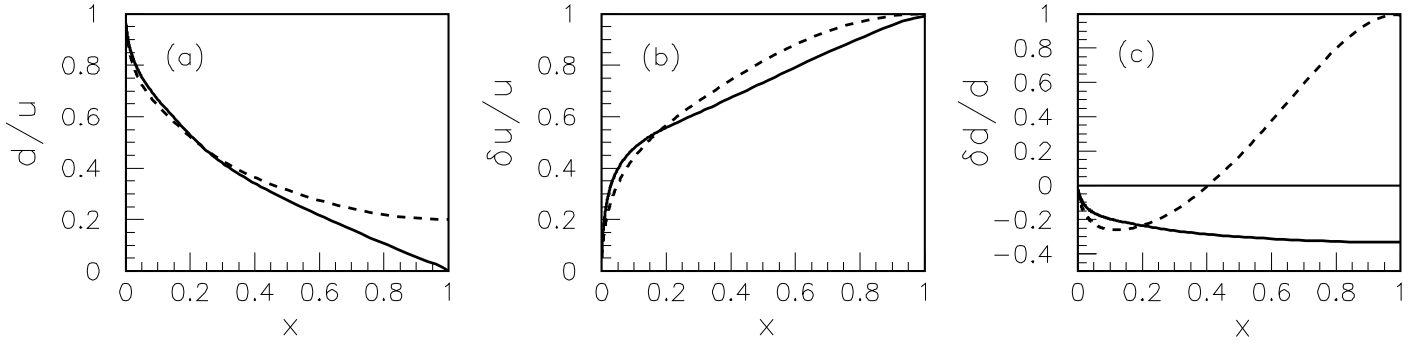
Asymmetry versus Collins angle

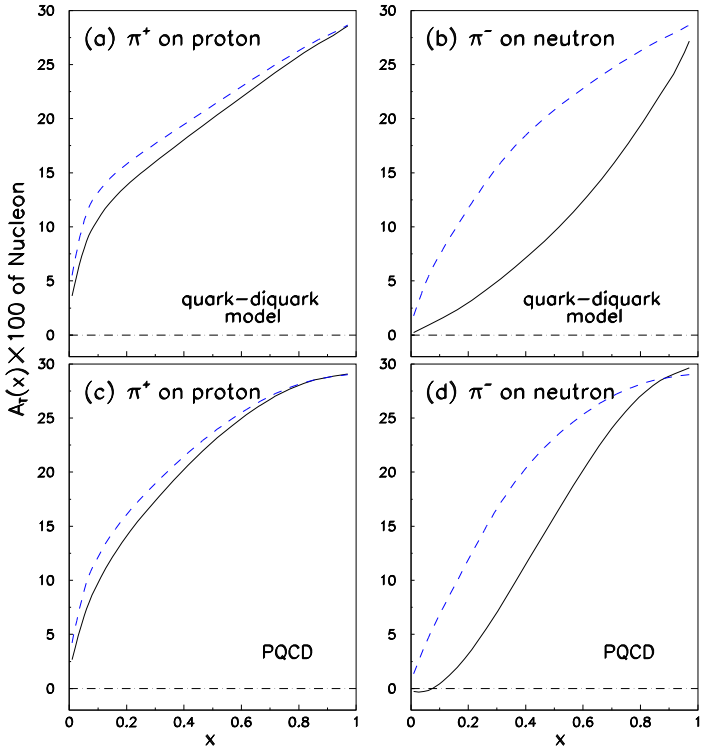


Model Predictions for δq and A_{UT}

Quark – diquark model (solid) and pQCD-based model (dashed)

B. –Q. Ma, I. Schmidt and J. –J. Yang, PRD 65, 034010 (2002)

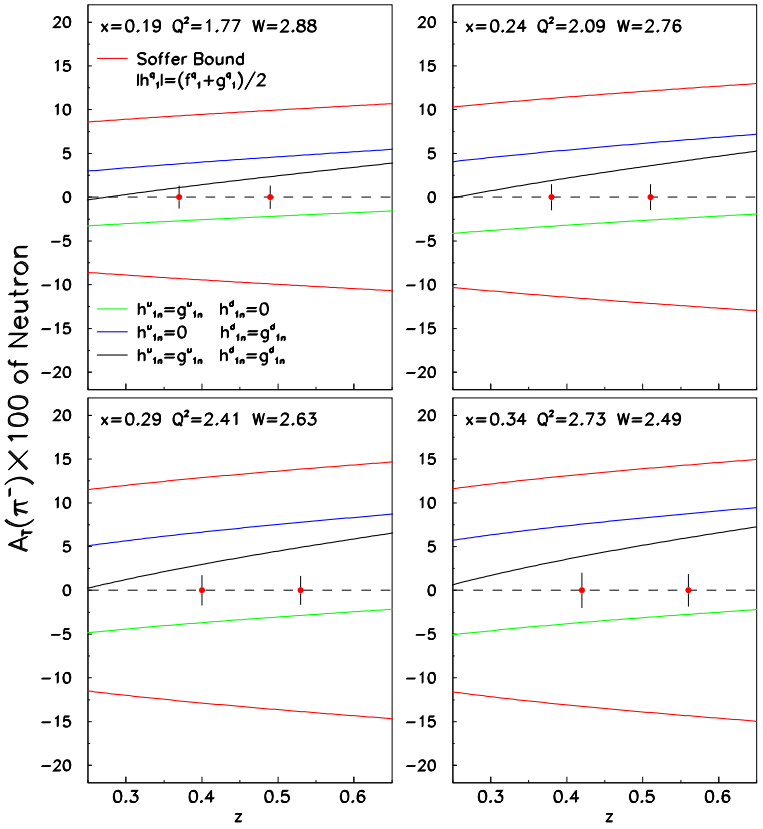




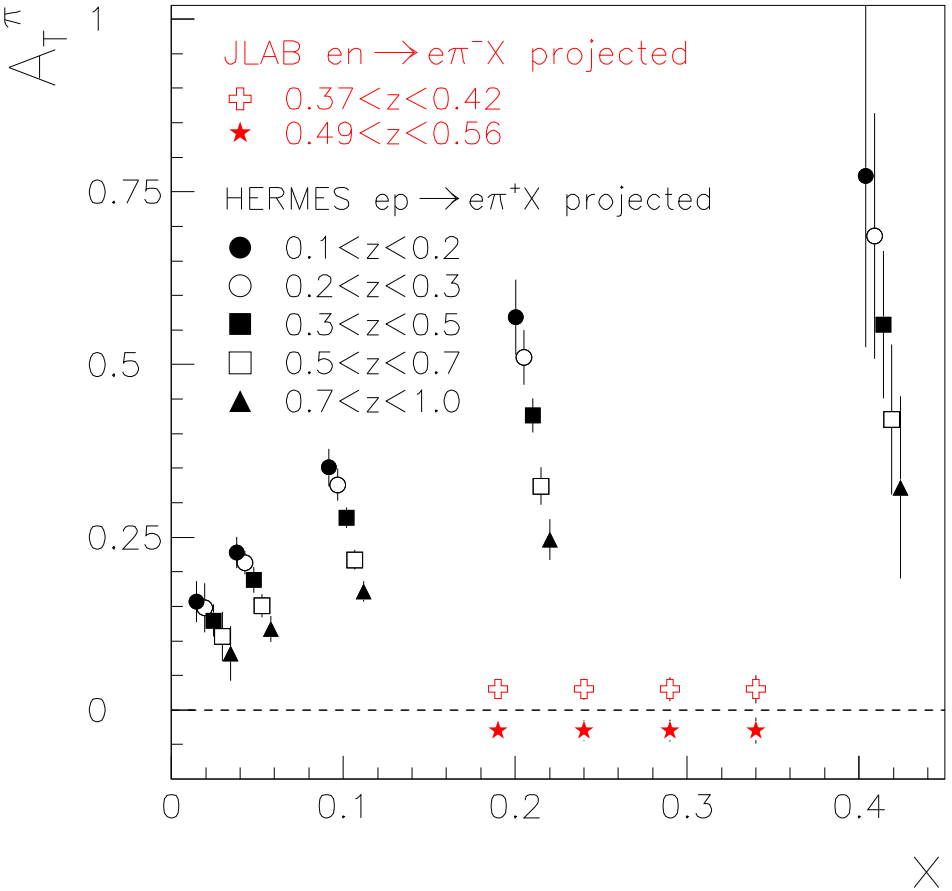
- A_{UT} for favored quark fragmentation (dashed) and favored + unfavored (solid) at $Q^2 = 2.5$ GeV^2 and integrated over z
- A_{UT} is large, increasing with x
- $A_{UT}^{\pi+}$(p): dominated by δu
- $A_{UT}^{\pi-}$(n): both δu and δd contribute

Expected Statistical Sensitivities

JLab E03-004

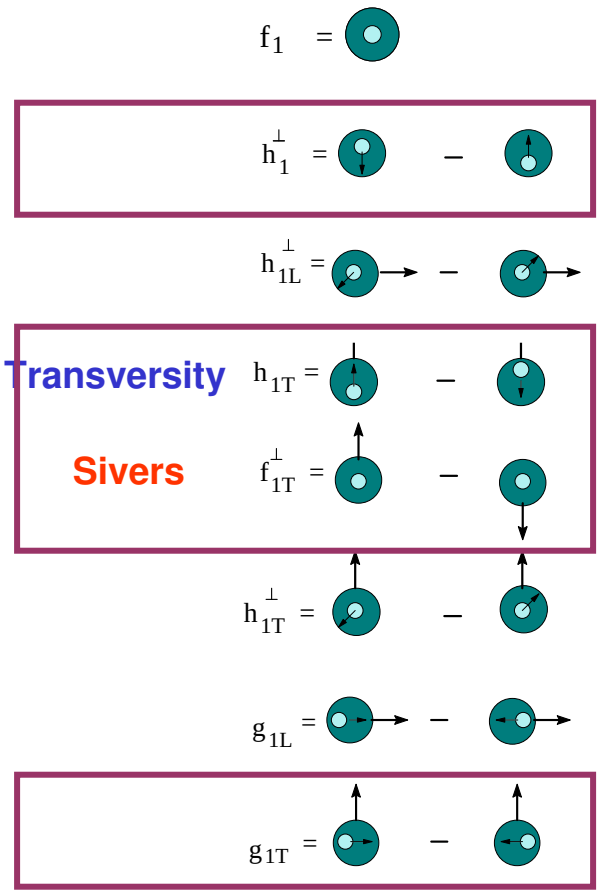


Comparison with HERMES projection



Probing other quark distributions in Semi-Inclusive DIS?

$$d^6\sigma = \frac{4\pi\alpha^2 sx}{Q^4}\times$$



$$\{[1+(1-y)^2]\sum_{q,\bar{q}} e_q^2 f_1^q(x) D_1^q(z,P_{h\perp}^2)$$
$$+(1-y)\frac{P_{h\perp}^2}{4z^2 M_N M_h}\cos(2\phi_h^l)\sum_{q,\bar{q}} e_q^2 h_1^{\perp(1)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$

Unpolarized

$$-|S_L|(1-y)\frac{P_{h\perp}^2}{4z^2 M_N M_h}\sin(2\phi_h^l)\sum_{q,\bar{q}} e_q^2 h_{1L}^{\perp(1)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^l+\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_1^q(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{P_{h\perp}}{zM_N}\sin(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z,P_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{P_{h\perp}^3}{6z^3 M_N^2 M_h}\sin(3\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_{1T}^{\perp(2)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$

Polarized target

$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_{q,\bar{q}} e_q^2 g_1^q(x) D_1^q(z,P_{h\perp}^2)$$
$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{P_{h\perp}}{zM_N}\cos(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 g_{1T}^{(1)q}(x) D_1^q(z,P_{h\perp}^2)\}$$

Polarzied beam and target

Future Extension at 12 GeV ?

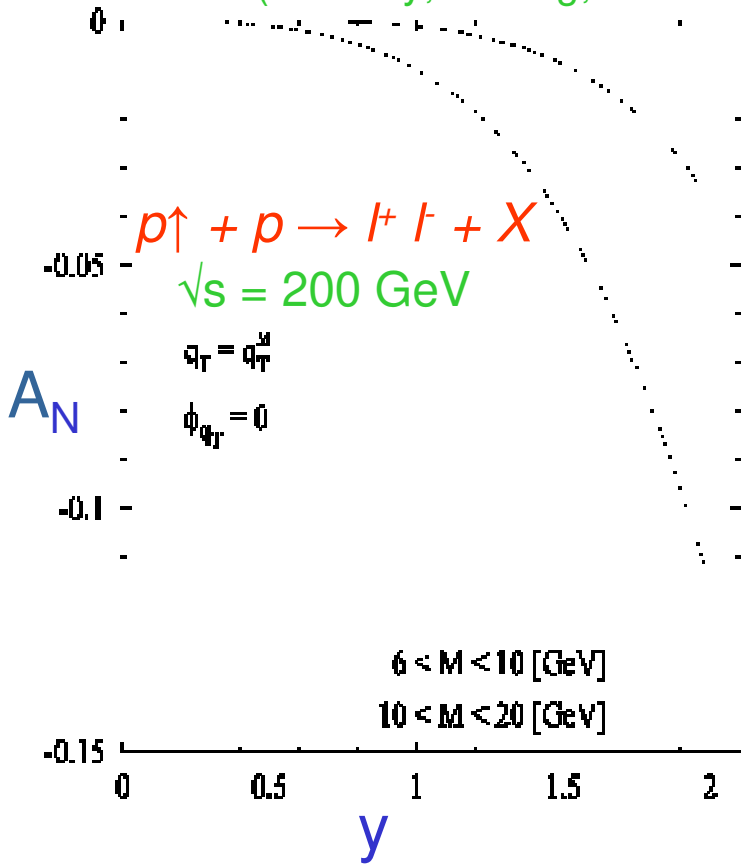
SSA with Transversely Polarized Drell-Yan

Analysing power (A_N) is sensitive to Sivers function

$$A_N^{DY} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp}(x_q) f_{\bar{q}}(x_{\bar{q}})}{\sum_q e_q^2 f_q(x_q) f_{\bar{q}}(x_{\bar{q}})}$$

Sivers function in Drell-Yan is expected to have a sign opposite to that in DIS!

(Brodsky, Hwang, Schmidt, hep-ph/0206259; Collins, hep-ph/0204004)



- Prediction by Anselmino, D'Alesio, Murgia (hep-ph/0210371) for a negative A_N.
- $|A_N|$ increases with rapidity, y, and with dilepton mass, M.

Is this measurement feasible at RHIC?

Simulation of Drell-Yan events in PHENIX

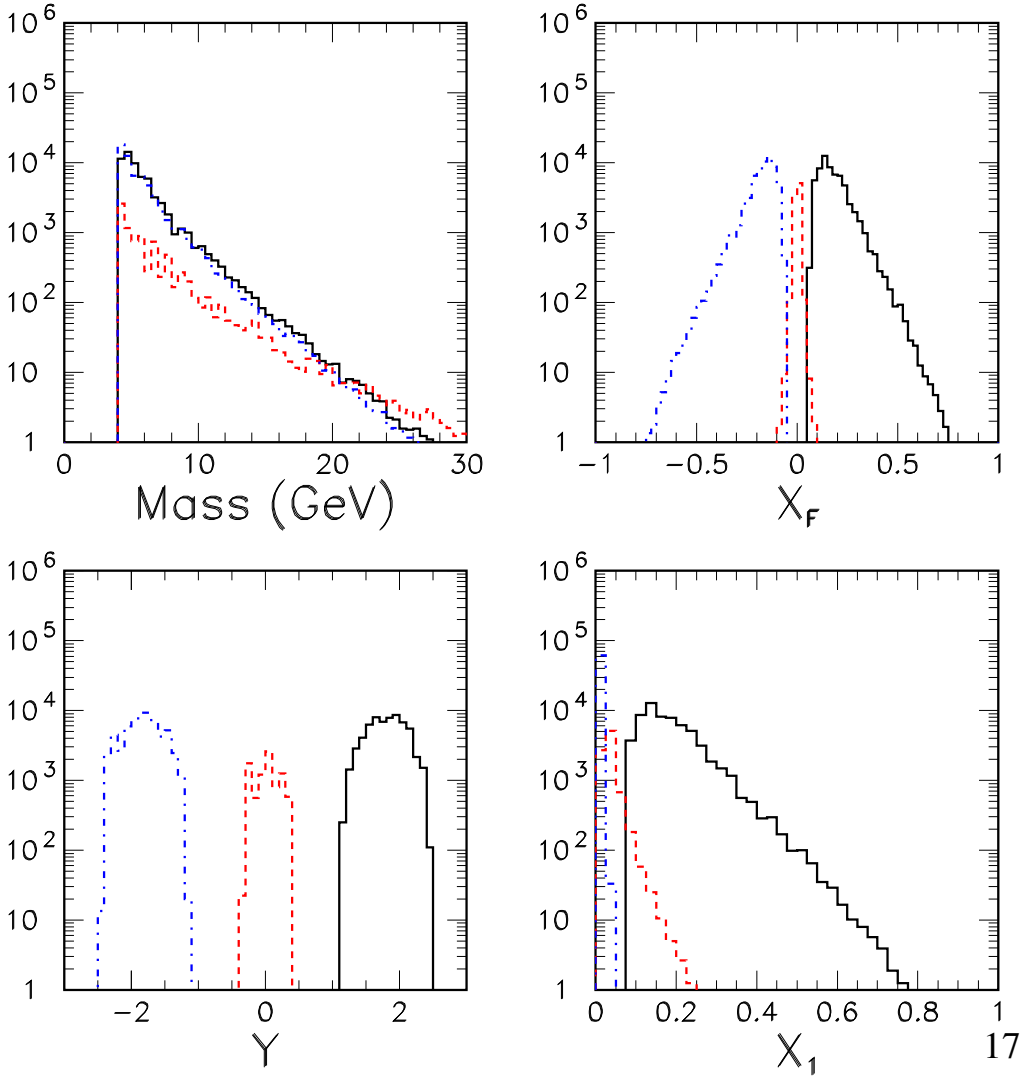
Assuming 400 pb^{-1} at $\sqrt{s}$ = 200 GeV

----- : South muon arm

----- : North muon arm

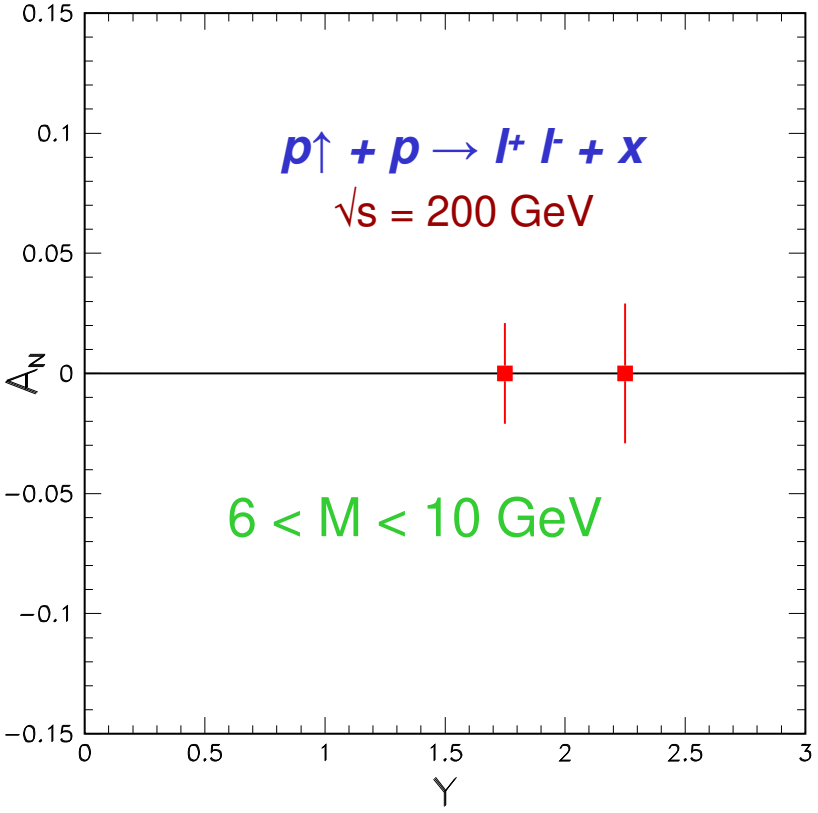
----- : e+ e- central arm

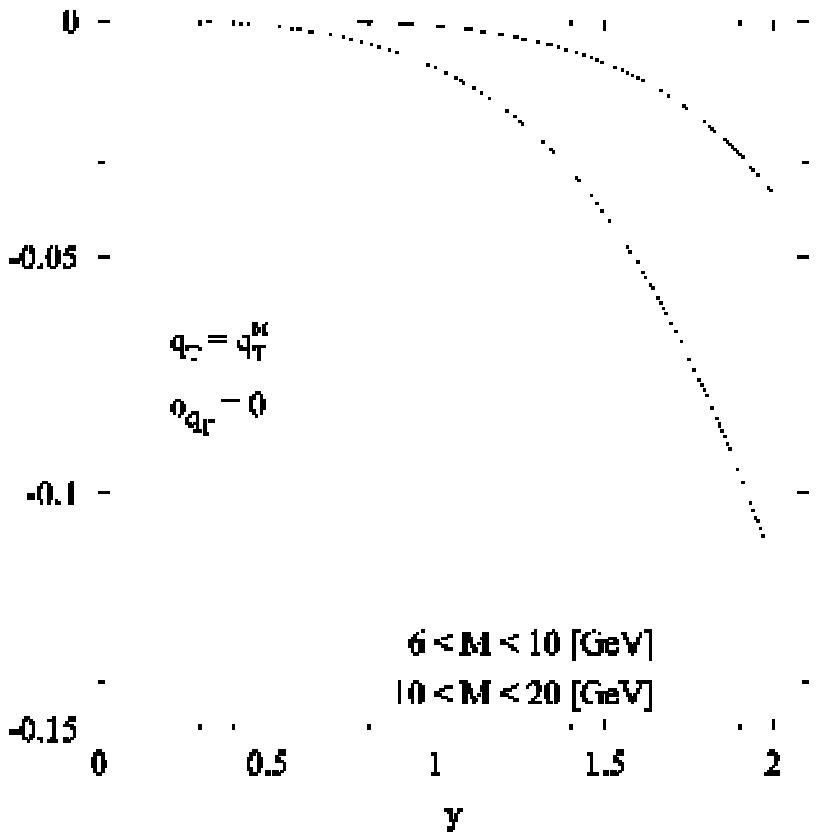
Mass > 6 GeV →



Expected statistical sensitivity for Drell-Yan A_N

Assuming 400 pb^{-1} 50% polarization





- Might be feasible to determine the sign of the Sivers function at RHIC
- Should consider fixed-target polarized Drell-Yan too

Cos2Φ Dependence in Unpolarized Drell-Yan

Large cos2Φ dependences have been observed in π – induced Drell-Yan

This azimuthal dependence could arise from a product of K_T-dependent distribution function $h_1^{\perp}$

(Boer, hep-ph/9902255; Boer, Brodsky, Hwang, hep-ph/0211110)

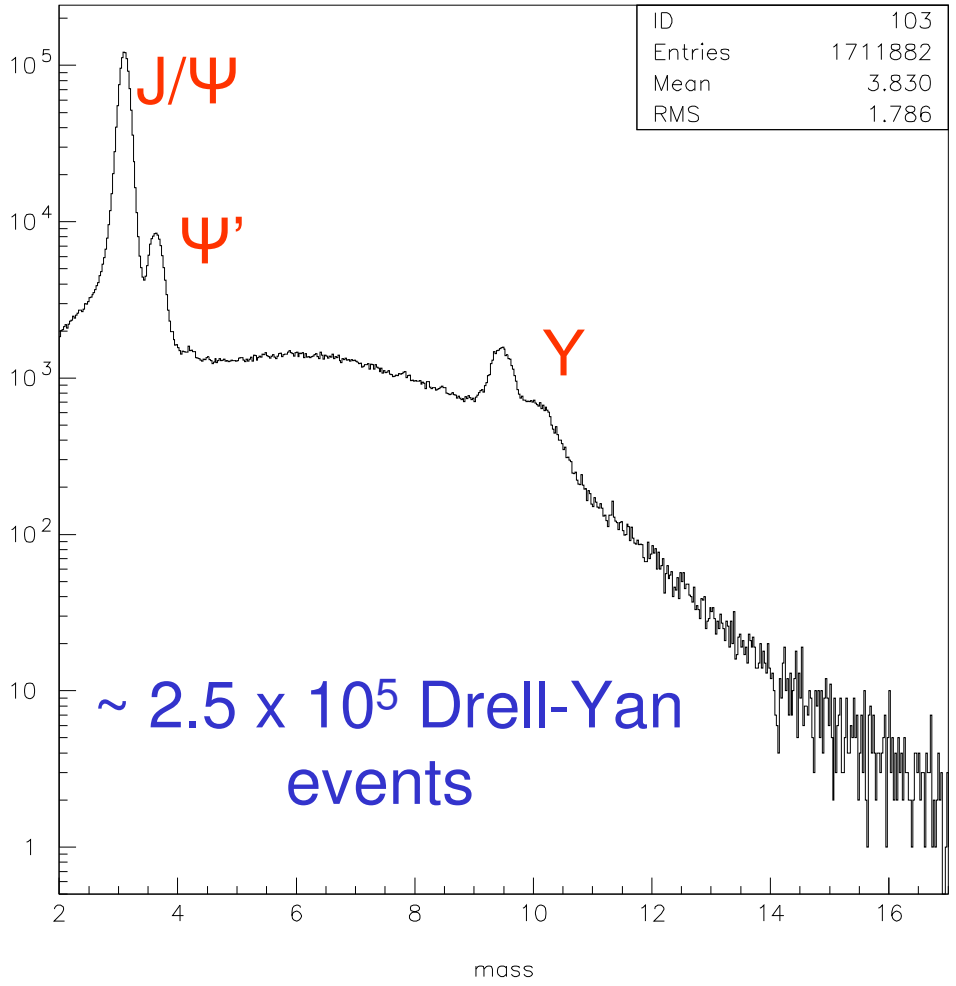
In quark-diquark model, $h_1^{\perp}$ is identical to Sivers function

No Cos2Φ depenence for unpolarized p-p Drell-Yan has been reported yet (The effect from $h_1^{\perp}$ is expected to be smaller)

- RHIC would provide unpolarized p-p Drell-Yan data too
- Fixed-target unpolarized p-p Drell-Yan data also exist

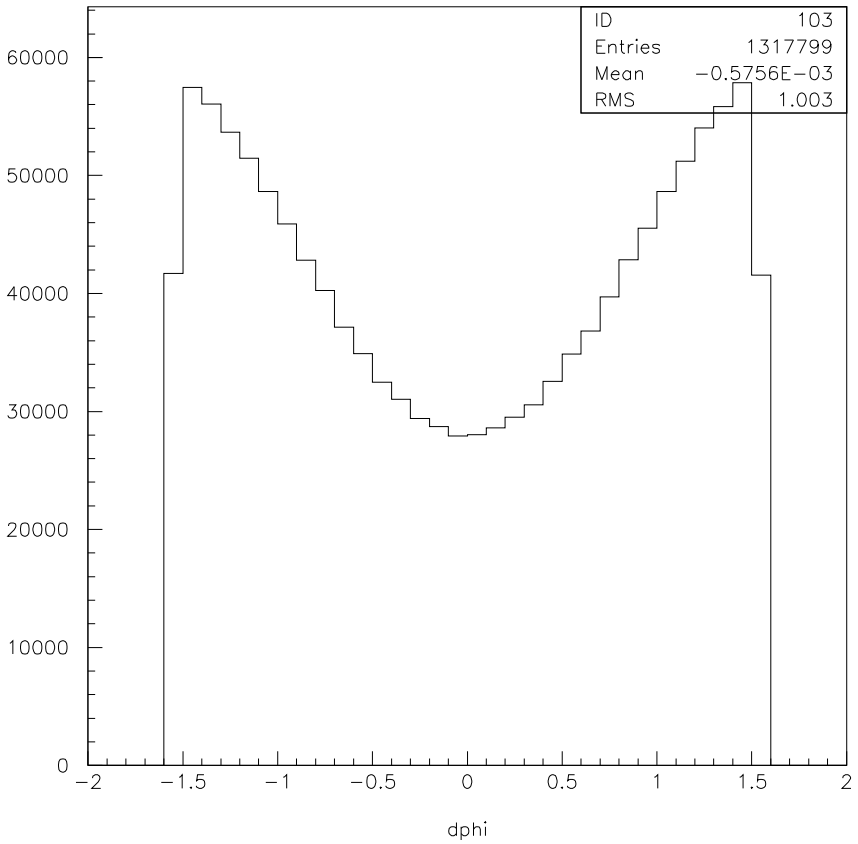
Unpolarized p-p and p-d dimuon production

Fermilab E866, $\sqrt{s}$ = 38.8 GeV

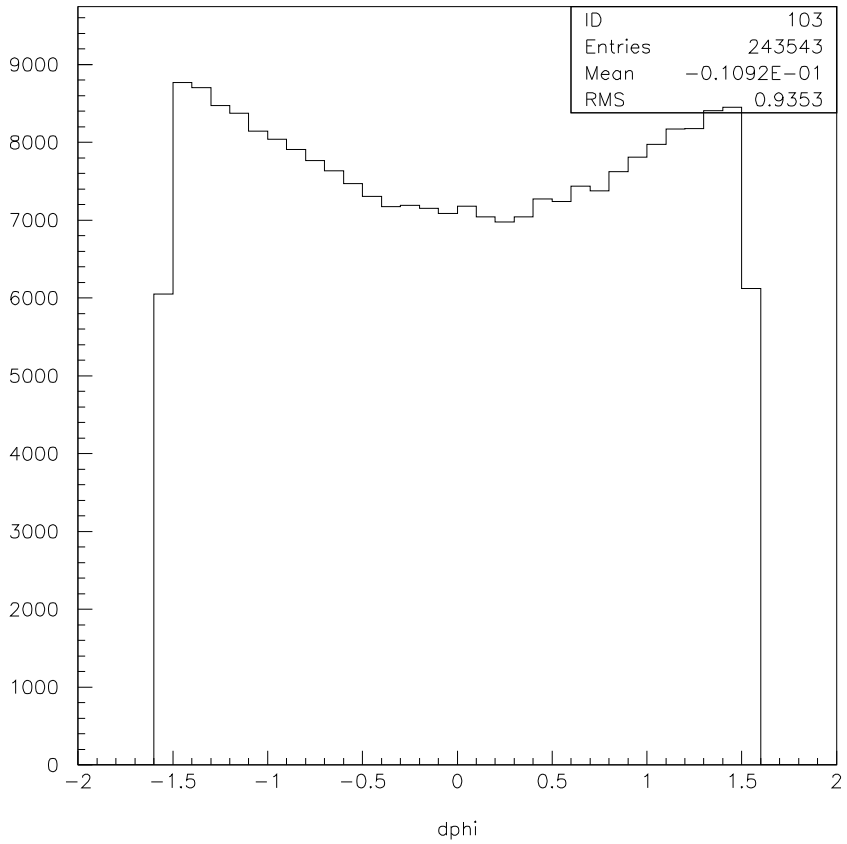


Φ – coverage of the E866 dimuon data

J/Ψ events



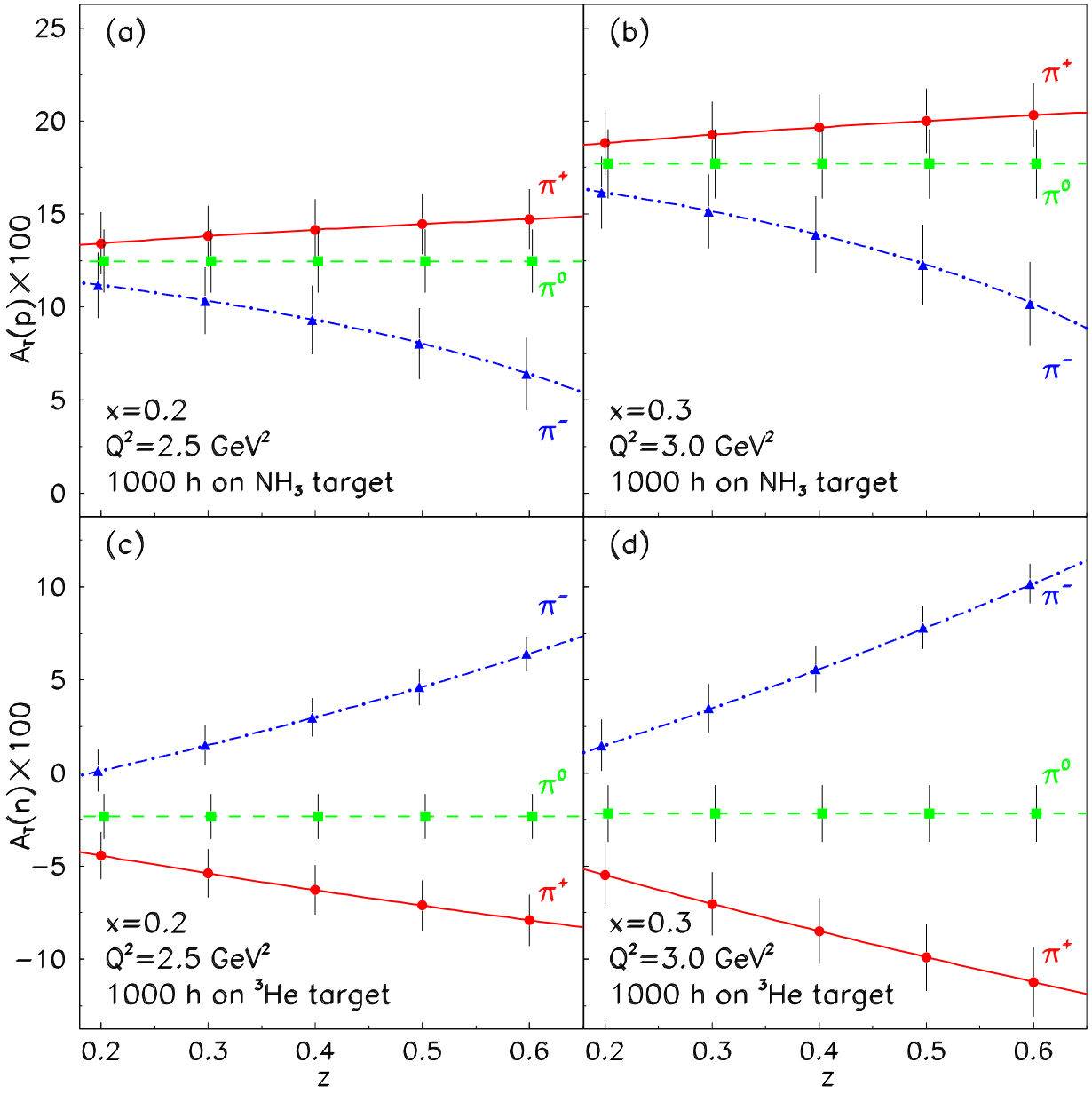
Drell-Yan events

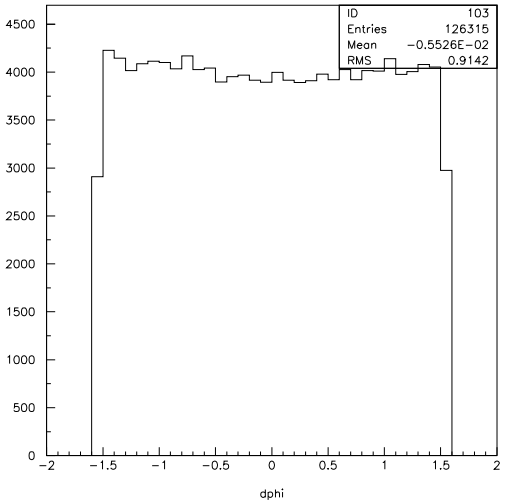


Not corrected for acceptance yet

Summary

- JLab experiment E03-004 will measure SSA using transversely polarized ^{3}He target.
- Information complementary to the HERMES SSA data on transversely polarized proton could be obtained.
- SSA Drell-Yan with transversely polarized proton appears feasible at RHIC.
- Azimuthal asymmetry with unpolarized Drell-Yan could also be pursued at RHIC. Existing fixed-target p-p Drell-Yan data might provide useful information on the origin of the azimuthal asymmetry observed in pion-induced Drell-Yan data.


(a)
(b)
(c)
(d)
$A_T(p) \times 100$
$A_T(n) \times 100$
z
x=0.2
Q^2=2.5 GeV^2
1000 h on NH_3 target
x=0.3
Q^2=3.0 GeV^2
1000 h on NH_3 target
x=0.2
Q^2=2.5 GeV^2
1000 h on ^{3}He target
x=0.3
Q^2=3.0 GeV^2
1000 h on ^{3}He target
π^+
π^0
π^-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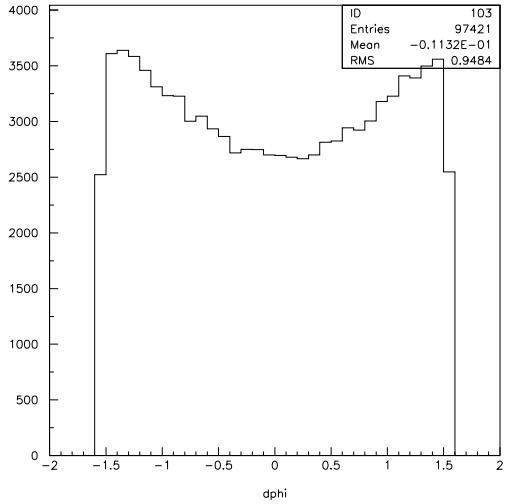
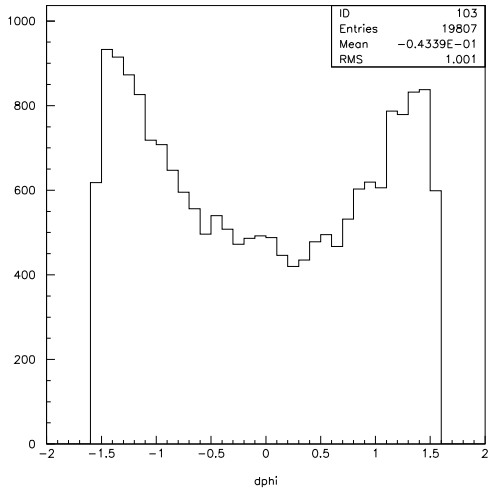
Mean −0.5526E−02
RMS 0.9142
dphi


ID 103
Entries 97421
Mean −0.1132E−01
RMS 0.9484
dphi


ID 103
Entries 19807
Mean −0.4339E−01
RMS 1.001
dphi