Transversity results from COMPASS

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on behalf of the
COMPASS Collaboration

DIS2006

XIV International Workshop
on Deep Inelastic Scattering

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Single Hadrons Hadron Pairs Λ Polarization

Physics Goals of COMPASS

Contribute to the understanding of the non-perturbative physics of the nucleon

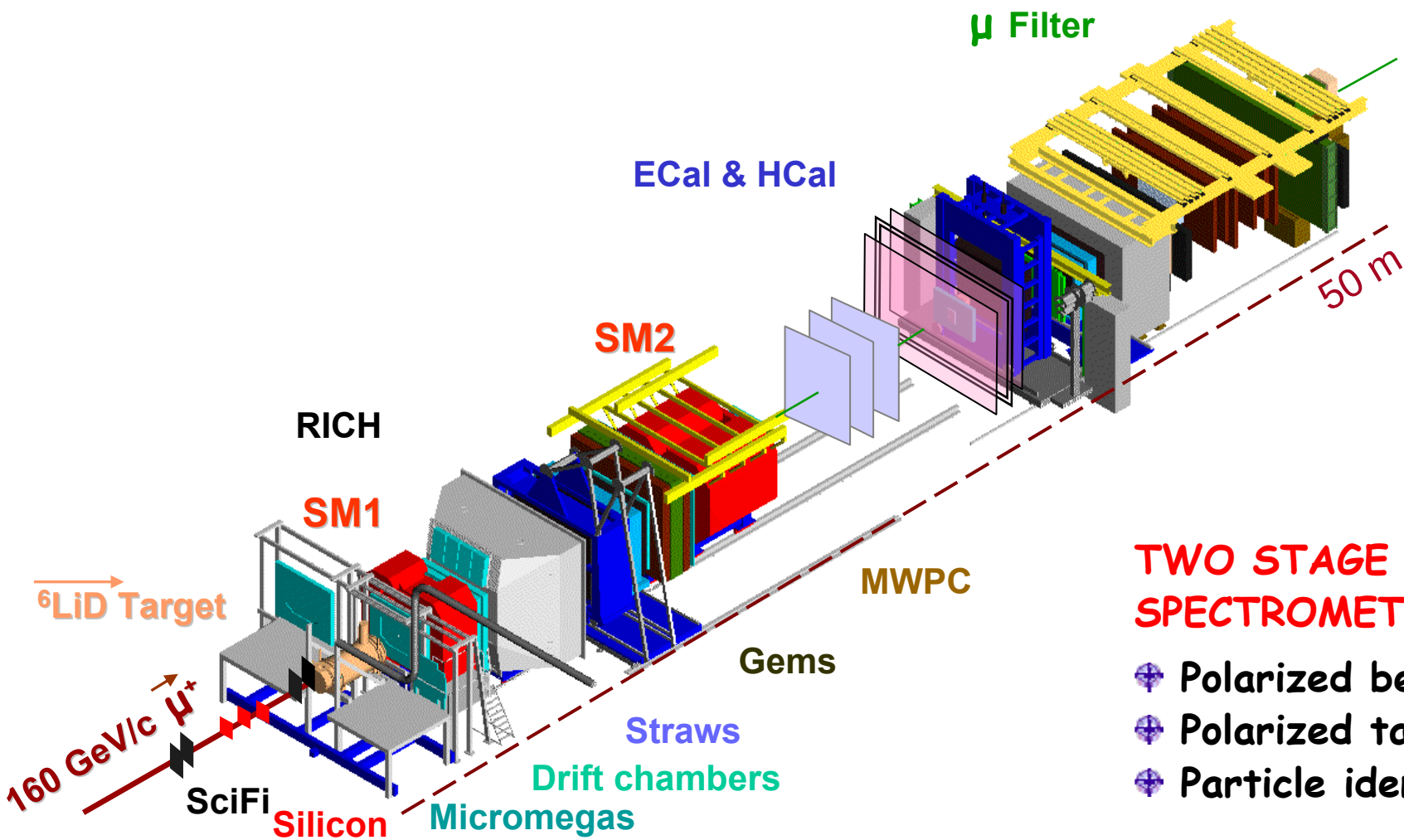
nucleon spin structure

- Gluon Polarization $\Delta G/G$
- **transverse spin structure function $h_1(x)$**
- **Sivers distribution function**
- Flavor dependent polarized quark helicity densities $\Delta q(x)$
- spin dependent fragmentation functions ΔD_q^{Λ}
- Diffractive VM-Production

nucleon spectroscopy

- Primakoff-Reactions
  - polarizability of π and K
- glueballs and hybrids
- charmed mesons and baryons
  - semi-leptonic decays
  - double-charmed baryons

The COMPASS Spectrometer @ CERN

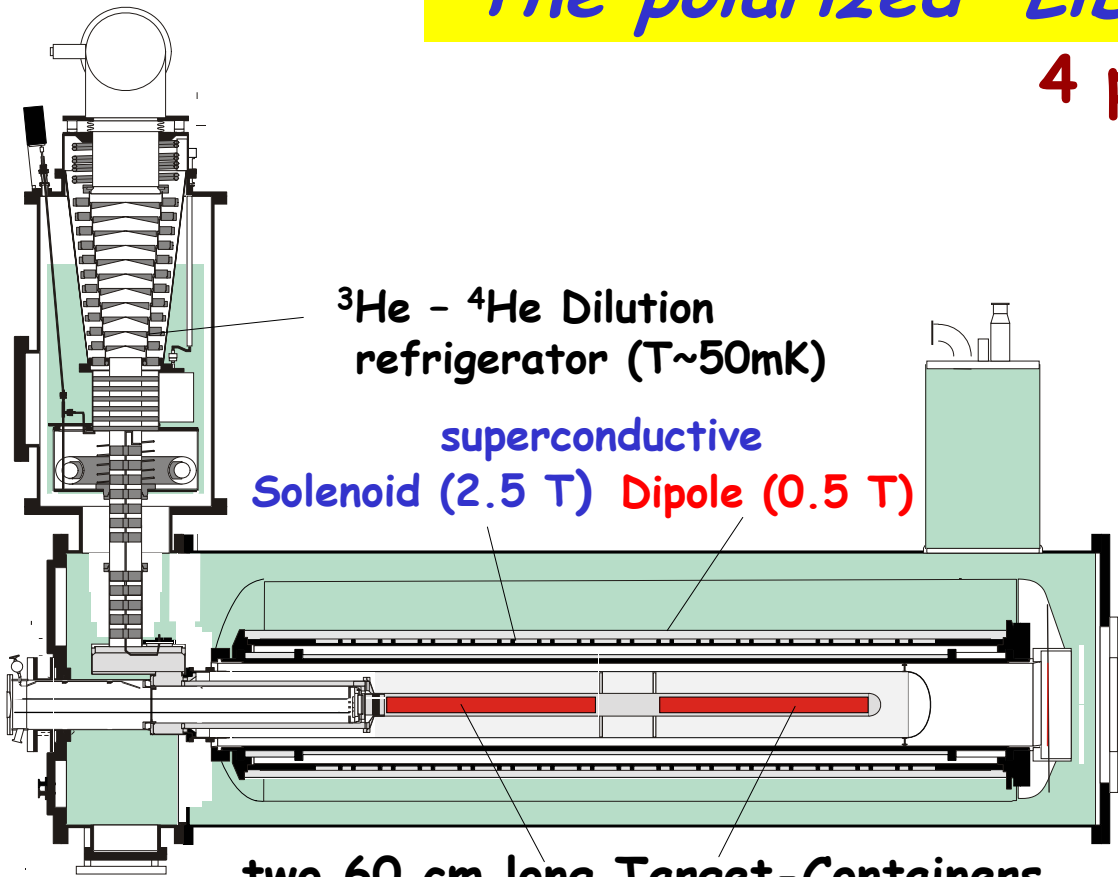


TWO STAGE SPECTROMETER:

- Polarized beam
- Polarized target
- Particle identification

Beam:	$2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)	luminosity:	$\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}
		momentum:	160 GeV/c
		polarization:	-76%

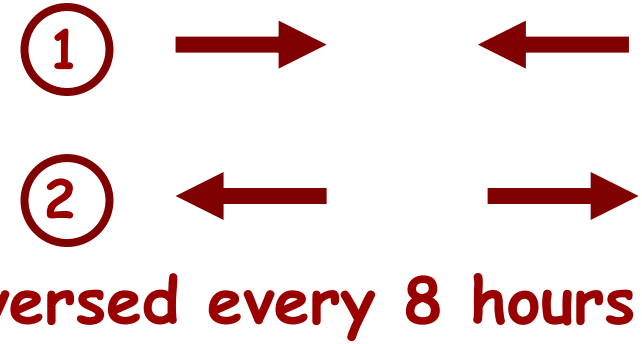
The polarized ^{6}LiD-Target



During data taking for transversity dipole field always ↥

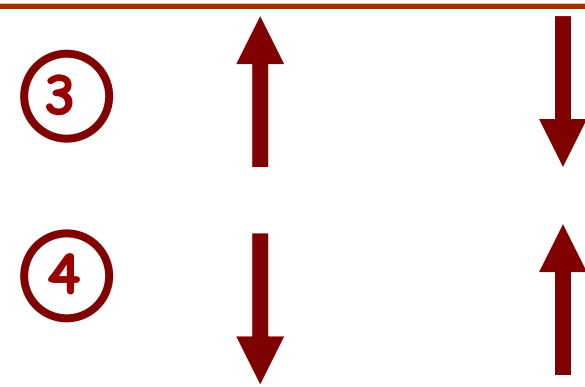
Relaxation time > 2000 hrs

4 possible spin combinations:



reversed every 8 hours

For transversity:



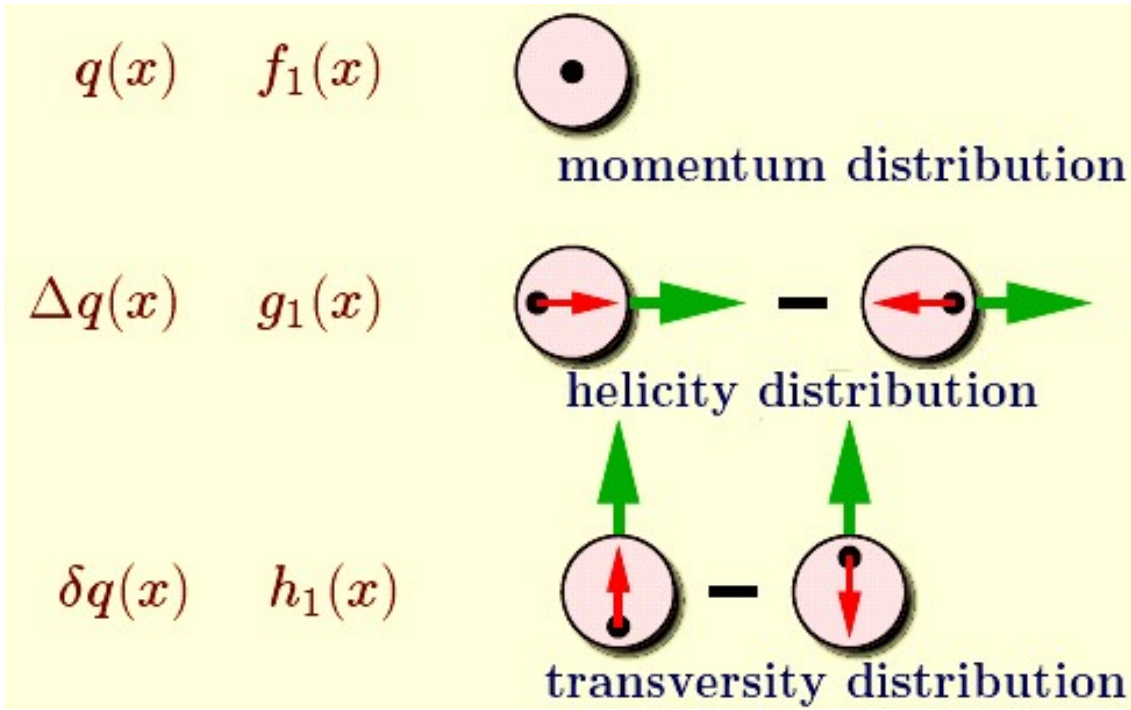
reversed once a week

Polarization: 50%

Dilution factor: 0.38

Transverse Quark Polarizations (1)

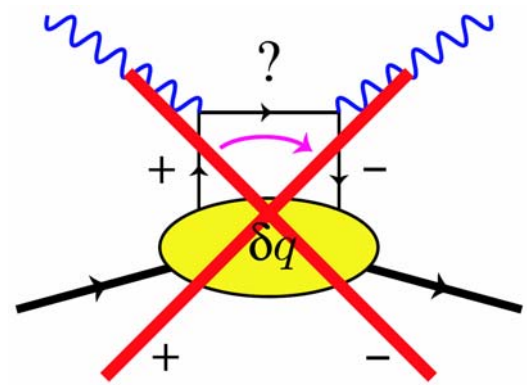
3 distribution functions are necessary to describe the spin structure of the nucleon at LO:



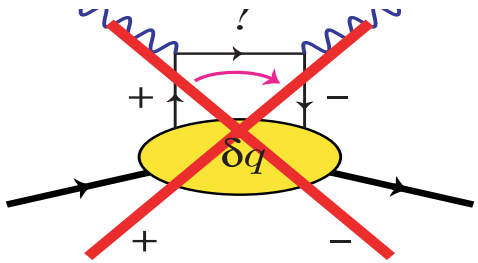
All of equal importance!

$h_1(x)$ decouples from leading twist DIS because helicity of quark must flip

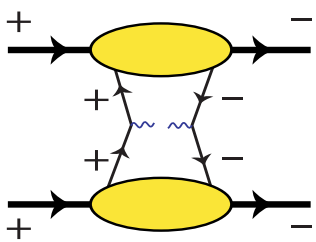
No mixture with Gluons in evolution - Valence like behavior



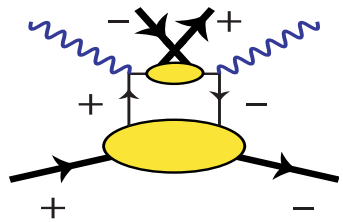
Transverse Quark Polarizations (2)



impossible



direct measurement $\Sigma\Delta_T q(x) \cdot \Delta_T q(x)$



convolution with spin dependent fragment. func.

$\Delta_T q\,(x) \otimes FF$

For DIS three possible quark polarimeters suggested:

- Azimuthal distribution of leading π ← Results!
- Azimuthal dependence of the plane containing leading & next to leading hadrons ← Results!
- Measure transverse polarization of Λ ← Results!

Data Sample

- Data taking with transversely polarized ^{6}LiD Target during 5 periods distributed over 3 years

Year	Days data taking	DIS Events
2002	19	$1.6*10^6$
2003	14	$3.2*10^6$
2004	14	$6.3*10^6$

- Trigger upgrade
  - x_{Bj}, Q^2 acceptance enlarged
- PID
  - ECAL, RICH

DIS Single-Hadron Event Analyses

- Leading Hadrons only
- All Hadrons

Single hadron production

Two possible azimuthal asymmetries:

(a) fragmentation of transversely polarized quarks with finite transverse momentum to unpolarized hadrons

→ **Collins effect (access to transversity)**

(b) modulation of transverse momentum of unpolarized quarks in the transverse polarized nucleon

→ **Sivers effect**

Collins:

$$A_{Coll} = \frac{A_{UT}^{\sin\Phi_{Coll}}}{D_{NN} \cdot f \cdot P} = \frac{\sum_a e_a^2 \cdot \Delta_T q_a \cdot \Delta D_a^h}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

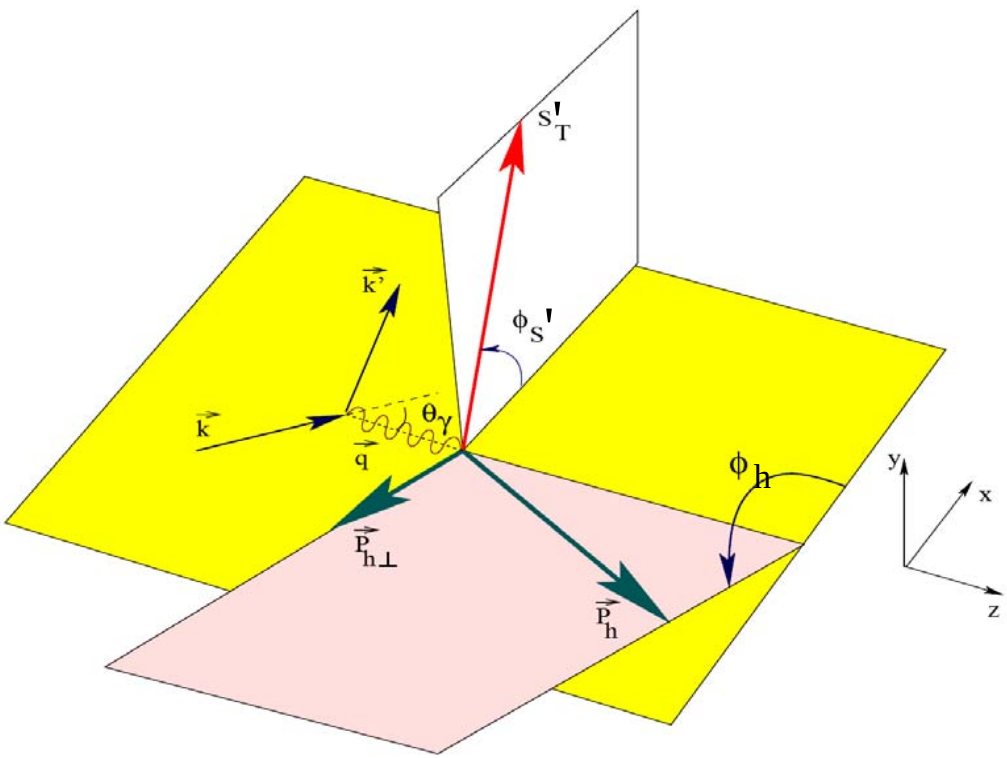
Sivers:

$$A_{Siv} = \frac{A_{UT}^{\sin\Phi_{Siv}}}{f \cdot P} = \frac{\sum_a e_a^2 \cdot f_{1T\,a}^{\perp} \cdot D_a^h}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

f dilution factor; P target polarization; $D_{NN} = (1-y)/(1-y+y^2/2)$ Depolarization factor

The Coordinate System

Collins and Sivers terms in SIDIS cross-section depend on separate angles ⇒ **distinguishable**



Collins: $A_{Coll} \sim \sin \phi_{Coll}$

$\phi_{Coll} = \phi_h - \phi_{S'} = \phi_h + \phi_S - \pi$

Sivers: $A_{Siv} \sim \sin \phi_{Siv}$

$\phi_{Siv} = \phi_h - \phi_S$

ϕ_S = azimuthal angle of spin vector of **initial-state** quark/nucleon

$\phi_{S'}$ = azimuthal angle of spin vector of **fragmenting** quark with $\phi_{S'} = \pi - \phi_S$ *(spin flip)*

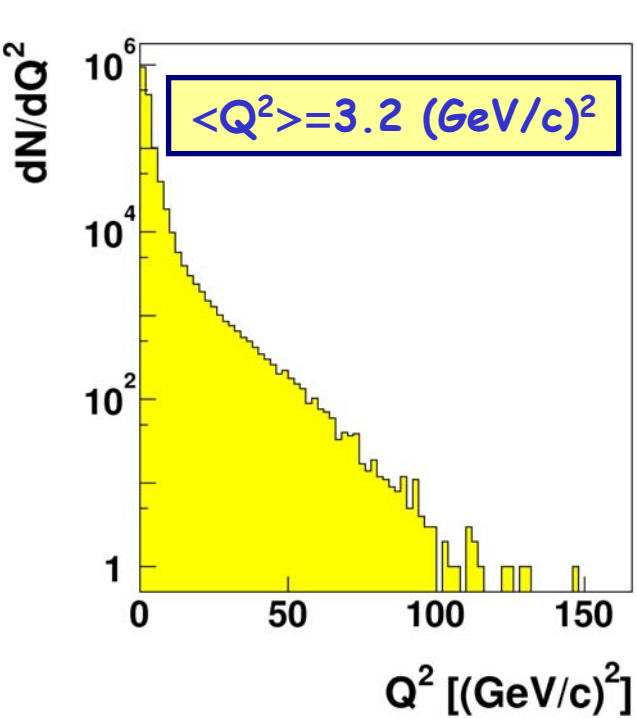
ϕ_h = azimuthal angle of hadron momentum

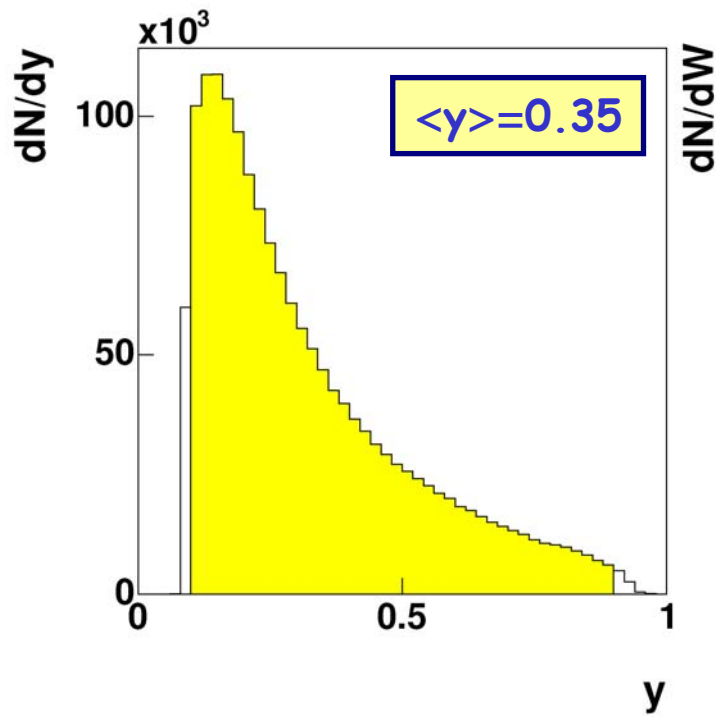
Event selection (1)

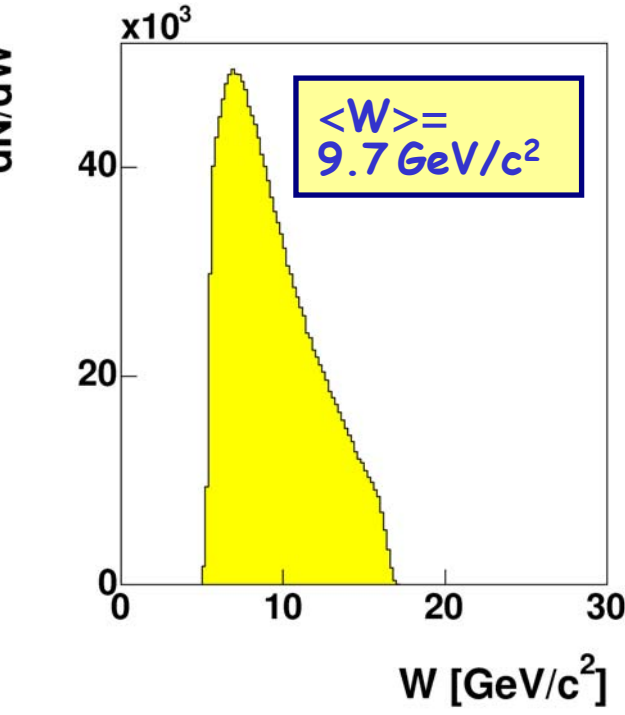
- Primary vertex with identified μ, μ' & hadron

Cuts on μ' based on kinematics:

- $Q^2 > 1\ (GeV/c)^2$
- $0.1 < y < 0.9$
- $W > 5\ GeV/c^2$







Event selection (2)

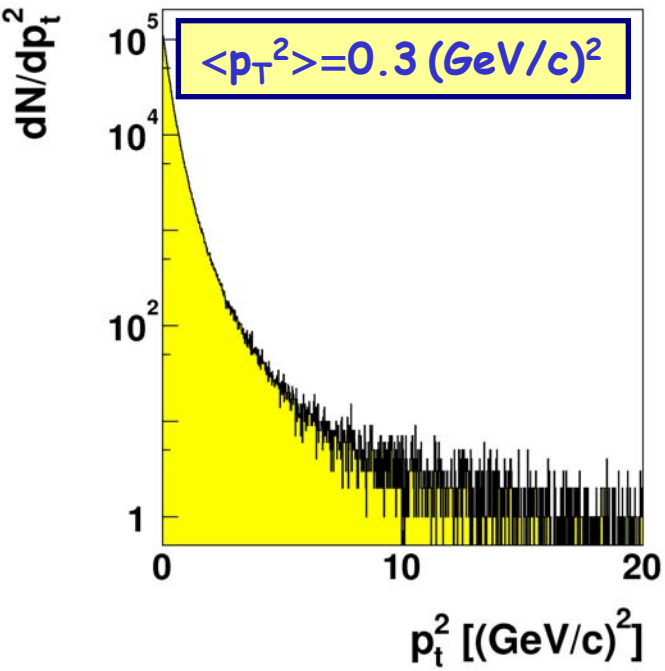
Leading hadron selection:

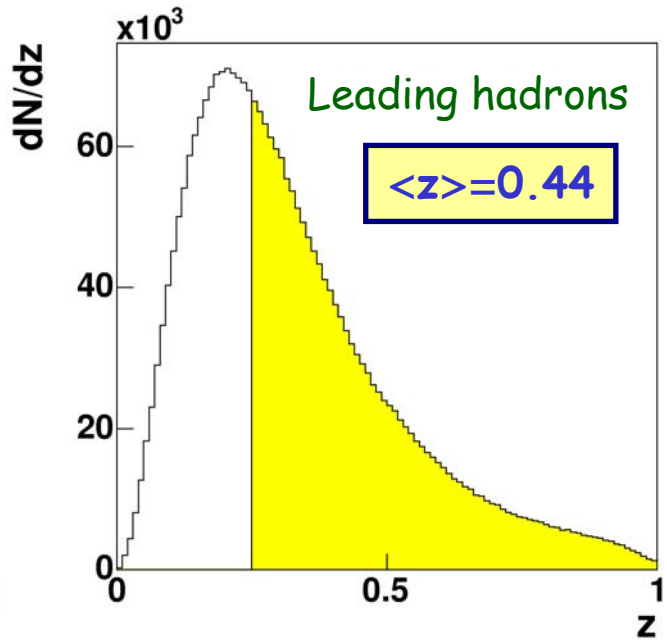
- energy deposit in hadron calorimeters > 5 GeV (HCAL 1)
  > 8 GeV (HCAL 2)
- Penetration < 10 X_0

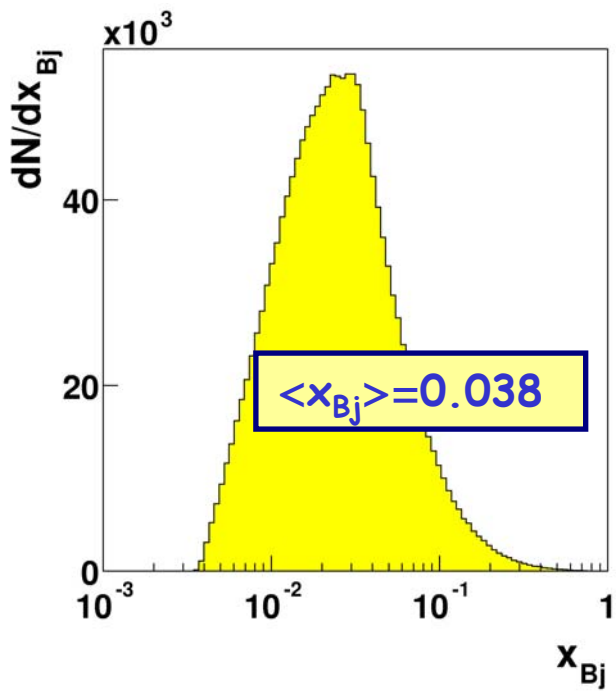
Cuts on leading hadrons based on kinematics:

- $p_T > 0.1$ GeV/c
- $z > 0.25$
- $z_{lh} > 1 - \Sigma z_i$

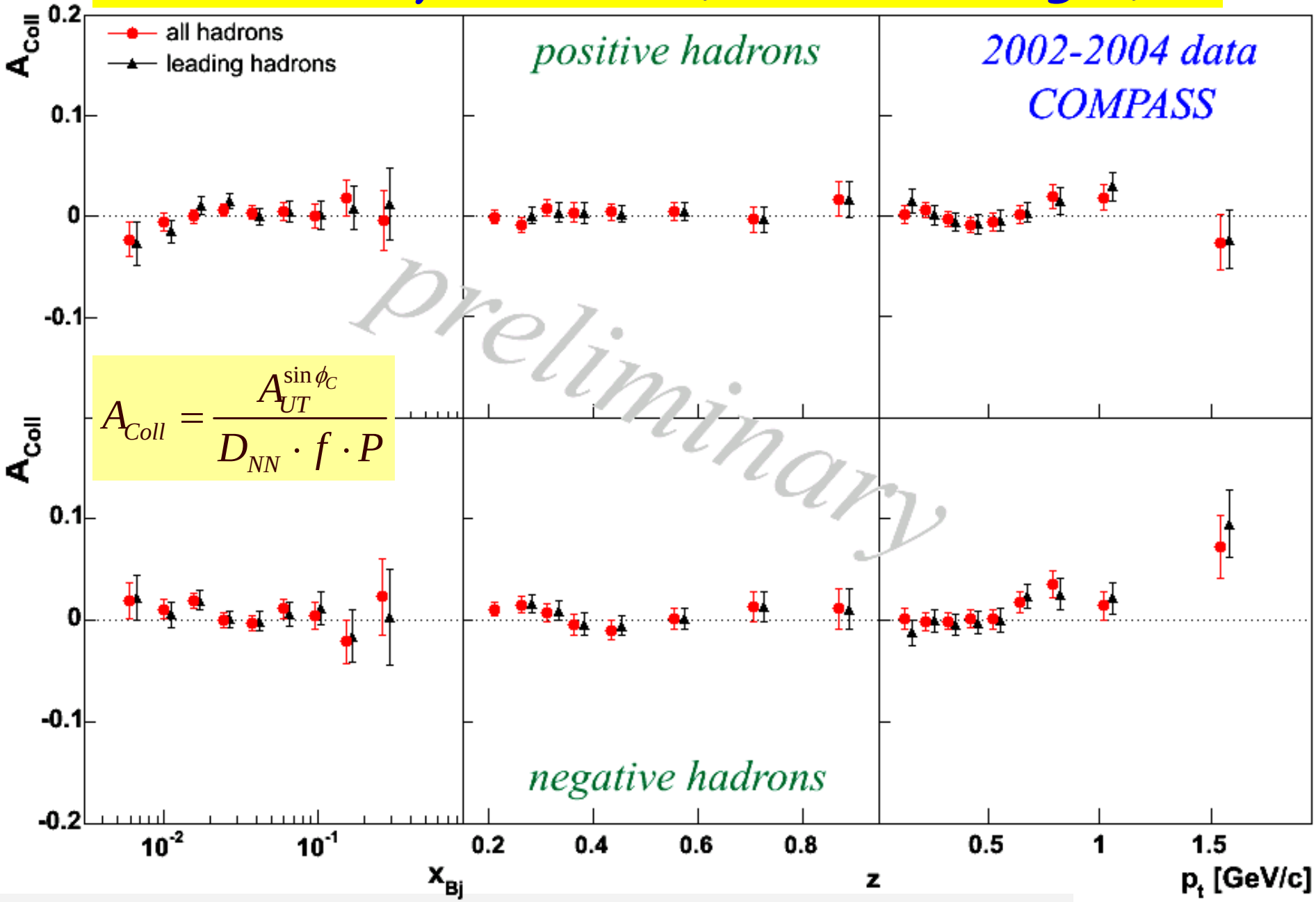
Final sample





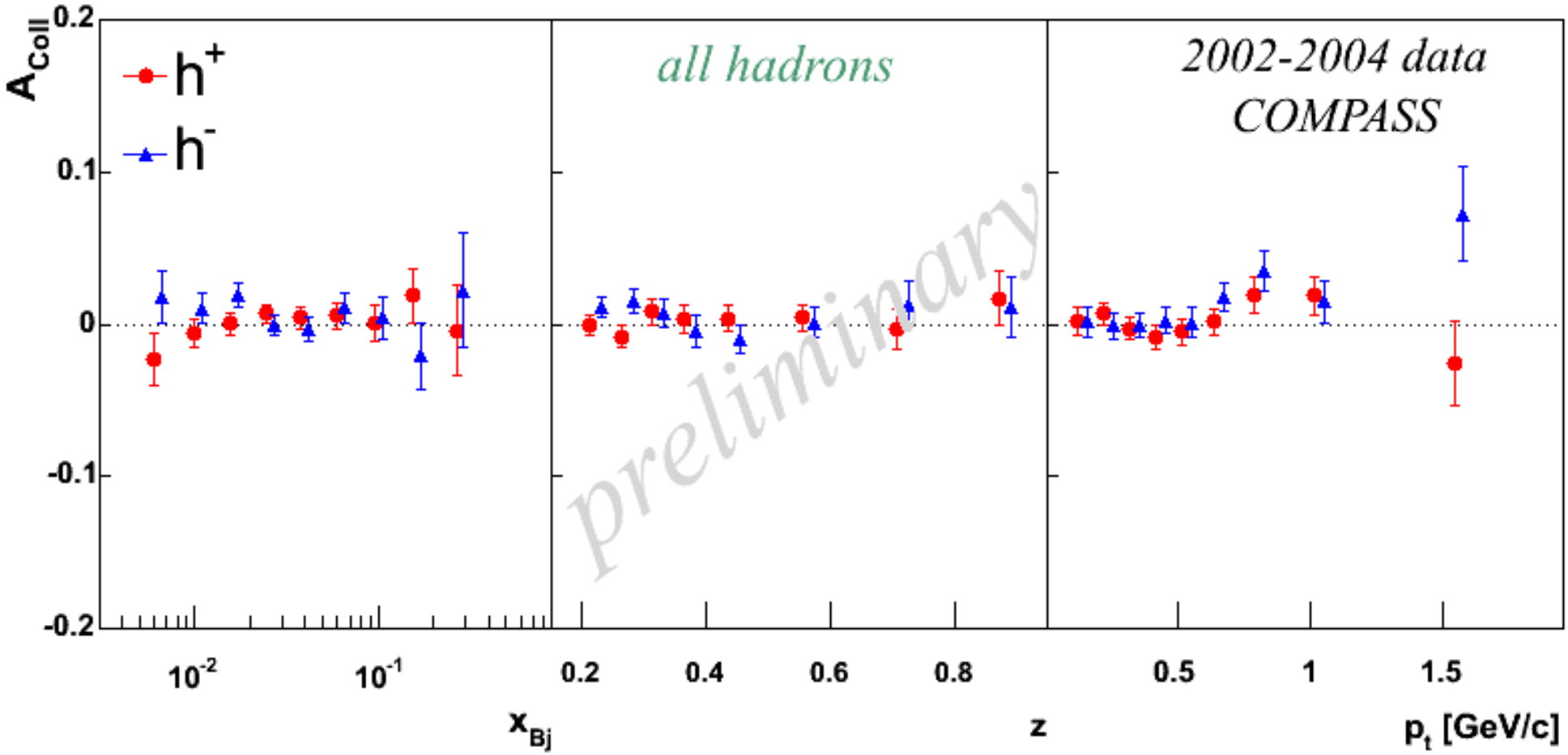


Collins-Asymmetries (Deuteron Target)



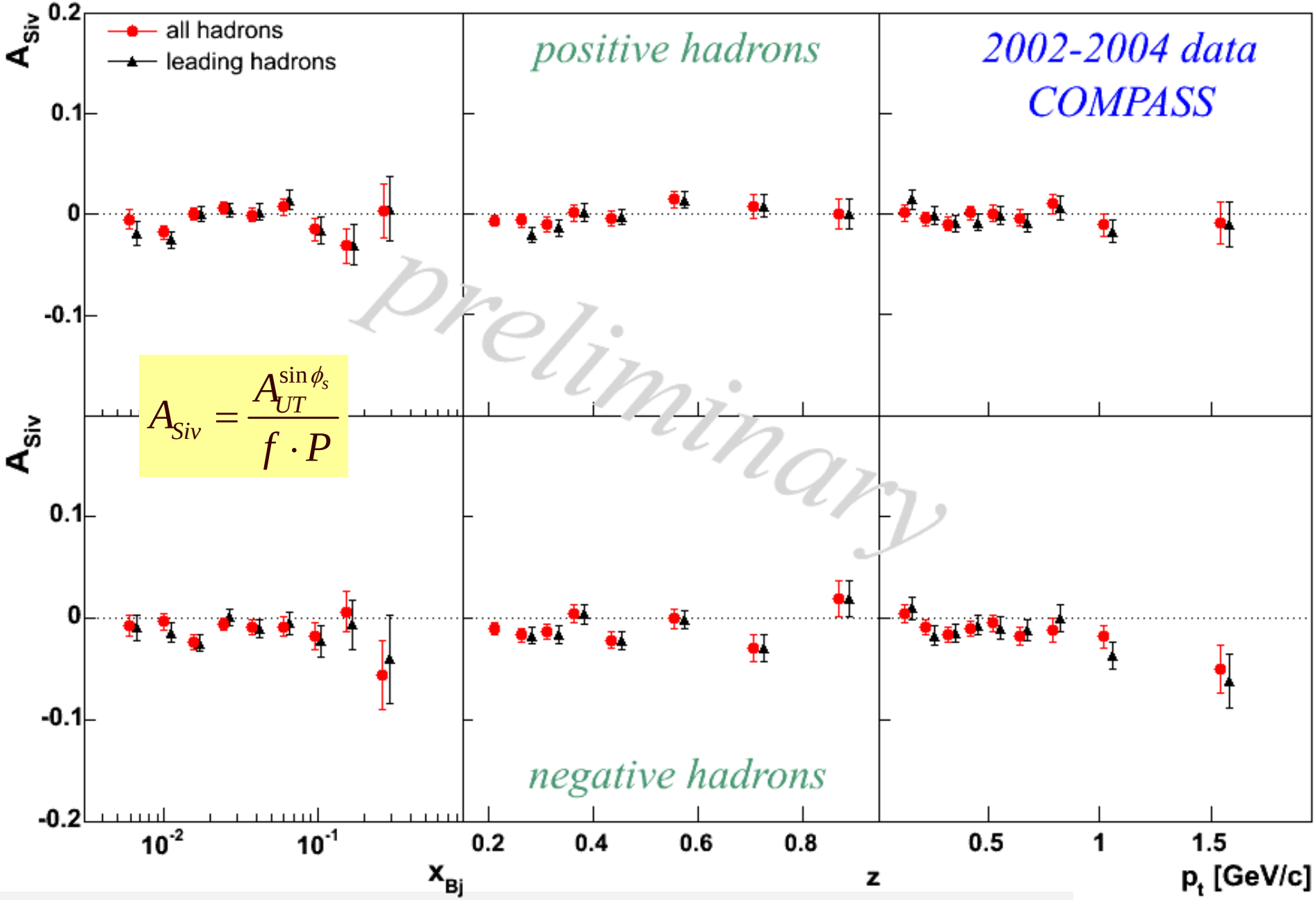
Systematic errors are considerable smaller than the quoted statistical errors

Collins-Asymmetries (Deuteron Target)



Systematic errors are considerable smaller than the quoted statistical errors

Sivers-Asymmetries (Deuteron Target)



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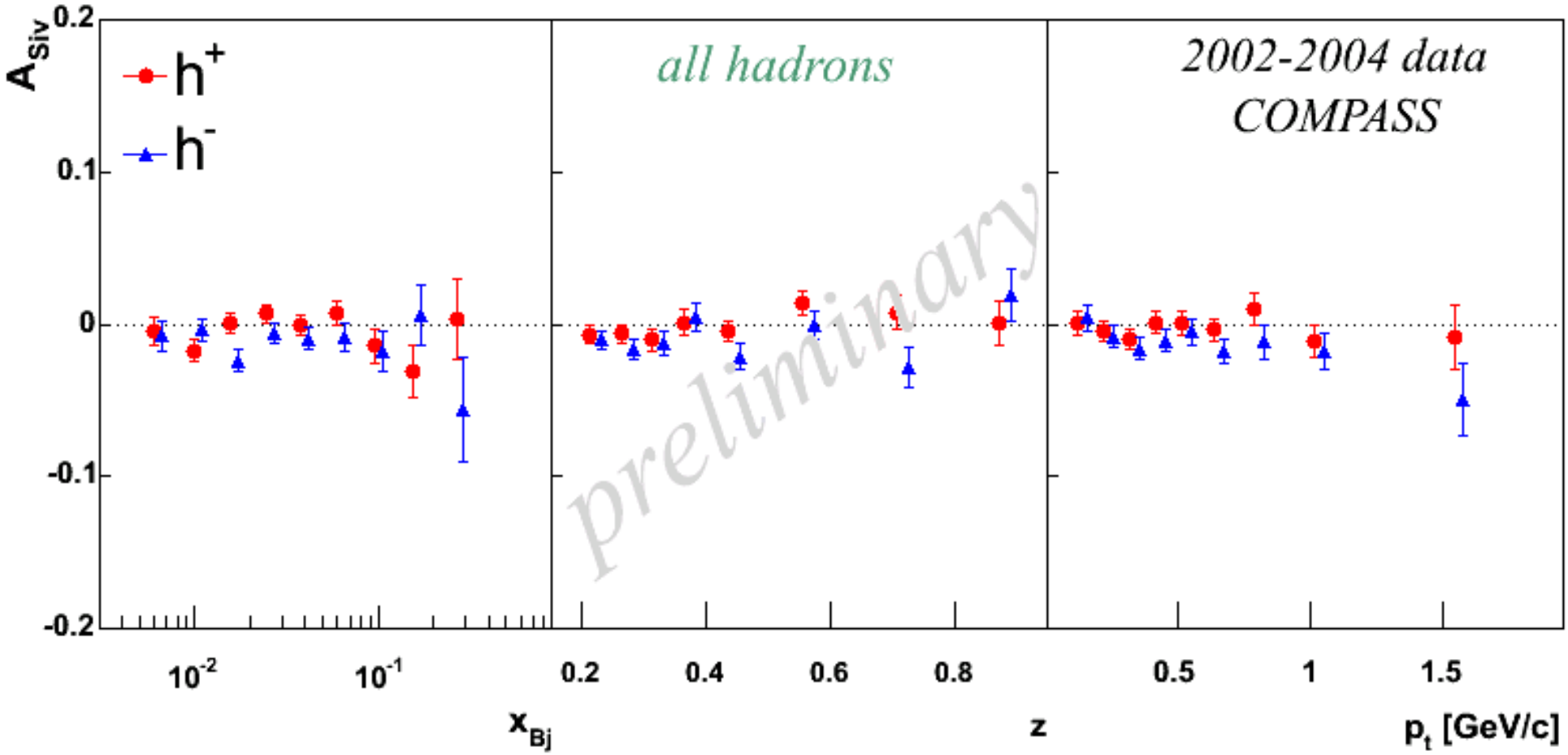
Sivers-Asymmetries (Deuteron Target)

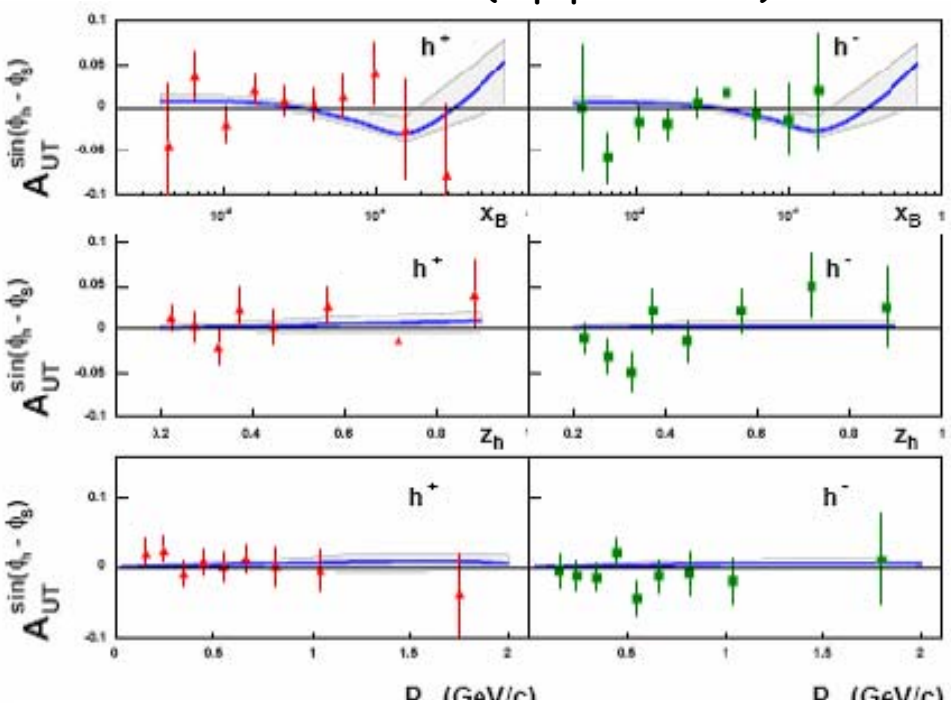


Systematic errors are considerable smaller than the quoted statistical errors

Comparison to Theory

Sivers from Deuterium

M. Anselmino et al. (hep-ph/0507181)



x_{Bj}

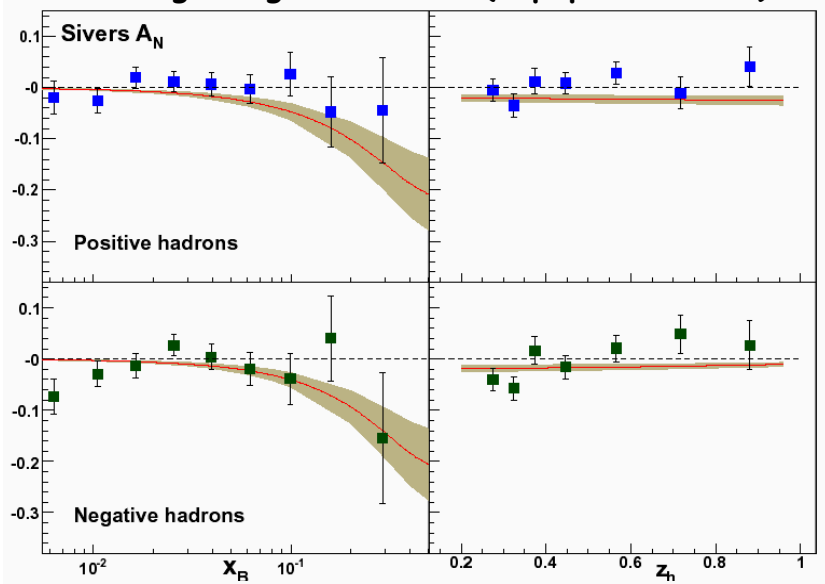
z

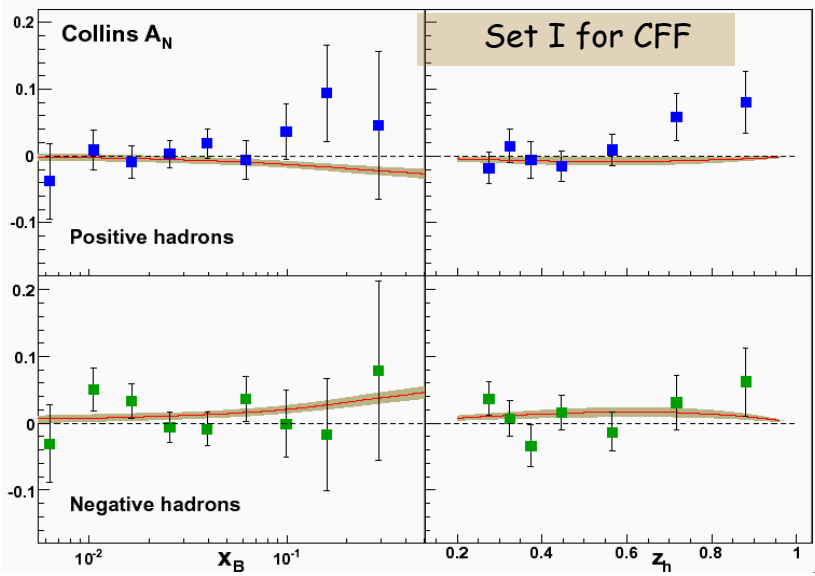
p_T

- Phenomelogical model (hep-ph/0507181)
  - parameters are constrained by HERMES proton measurements
- COMPASS results for Sivers effect are in agreement with the model

Collins from Deuterium

W. Vogelsang and F. Yuan(hep-ph/0507266)





DIS Events with Hadron-Pairs

The Coordinate System

Breit frame, where

- z is the virtual photon direction
- the x-z plane is the lepton scattering plane

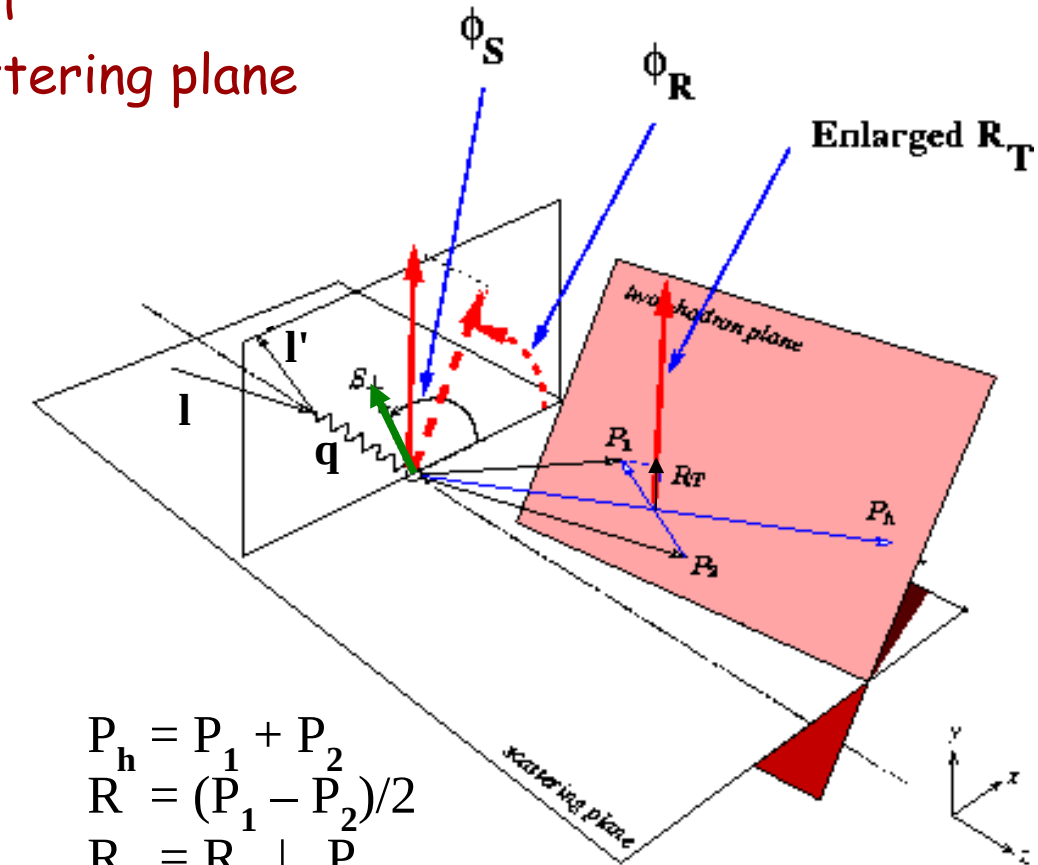
$\phi_{S'}$ = azimuthal angle of spin vector of **fragmenting** quark with $\phi_{S'} = \pi - \phi_S$ *(spin flip)*

ϕ_R = is defined by:

$$\cos\phi_R = \frac{(\mathbf{q} \times \mathbf{l})}{|\mathbf{q} \times \mathbf{l}|} \cdot \frac{(\mathbf{q} \times \mathbf{R_T})}{|\mathbf{q} \times \mathbf{R_T}|}$$

$$\sin\phi_R = \frac{(\mathbf{l} \times \mathbf{R_T}) \cdot \mathbf{q}}{|\mathbf{q} \times \mathbf{l}|\,|\mathbf{q} \times \mathbf{R_T}|}$$

$\phi_{RS} = \phi_R - \phi_{S'} = \phi_R + \phi_S - \pi$

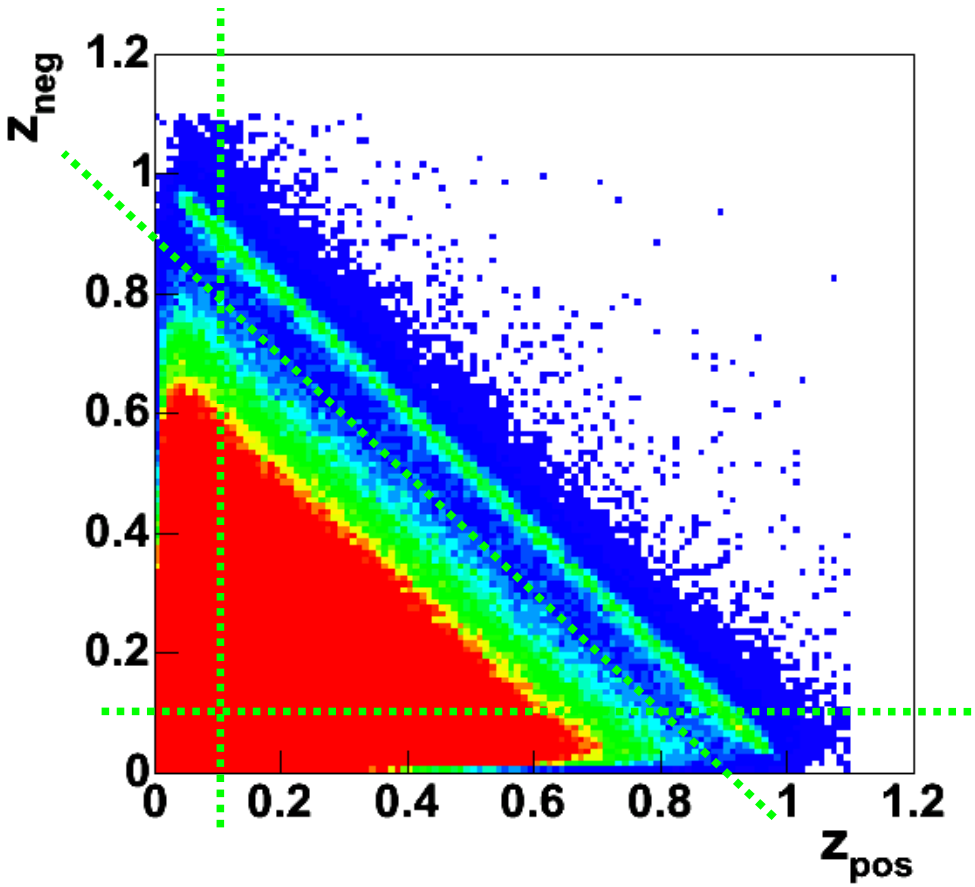


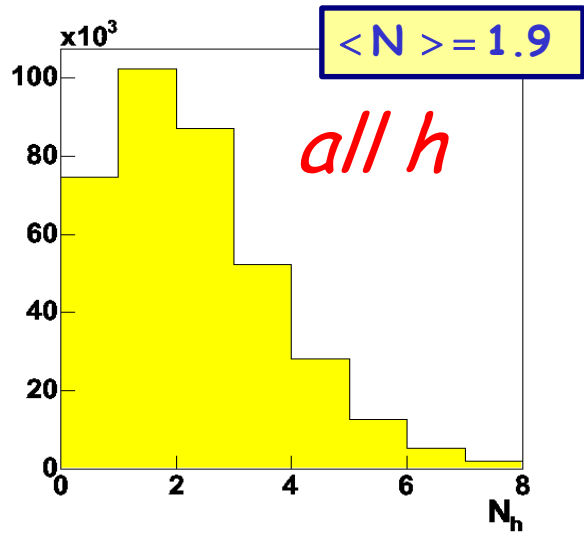
$P_h = P_1 + P_2$
$R = (P_1 - P_2)/2$
$R_T = R \perp P_h$

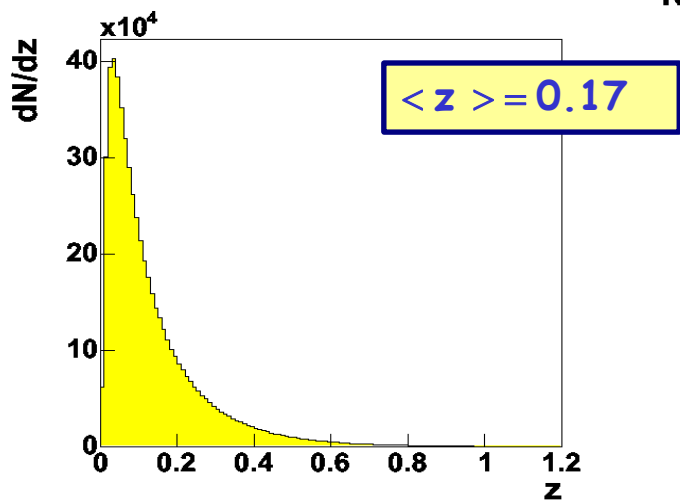
Selection of Hadron Pairs

Select all combinations of h^+ and h^- hadrons with:

- $z_1 > 0.1$ & $z_2 > 0.1$ and $x_{f1} > 0.1$ & $x_{f2} > 0.1$
- $z = z_1 + z_2 < 0.9$



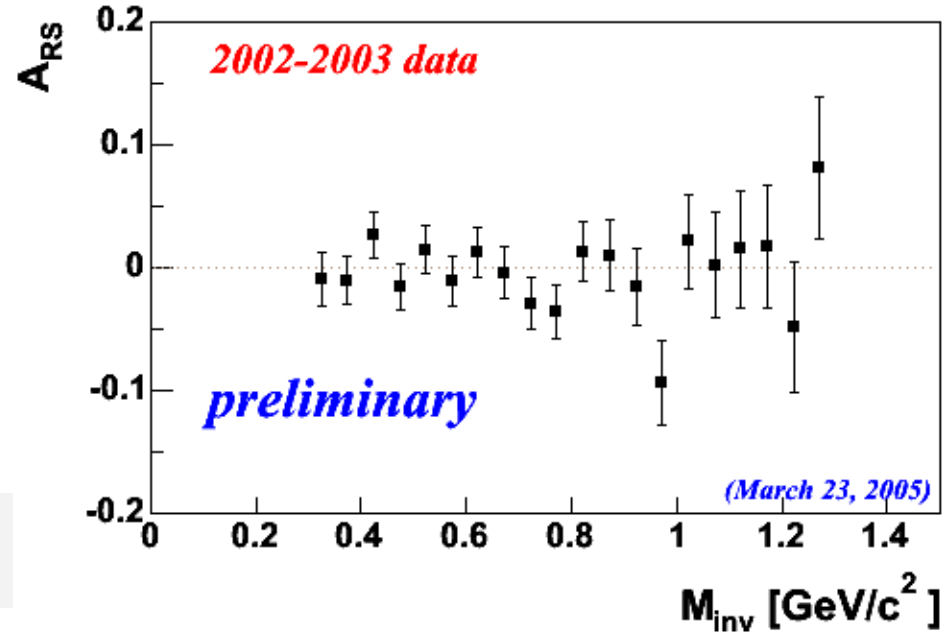


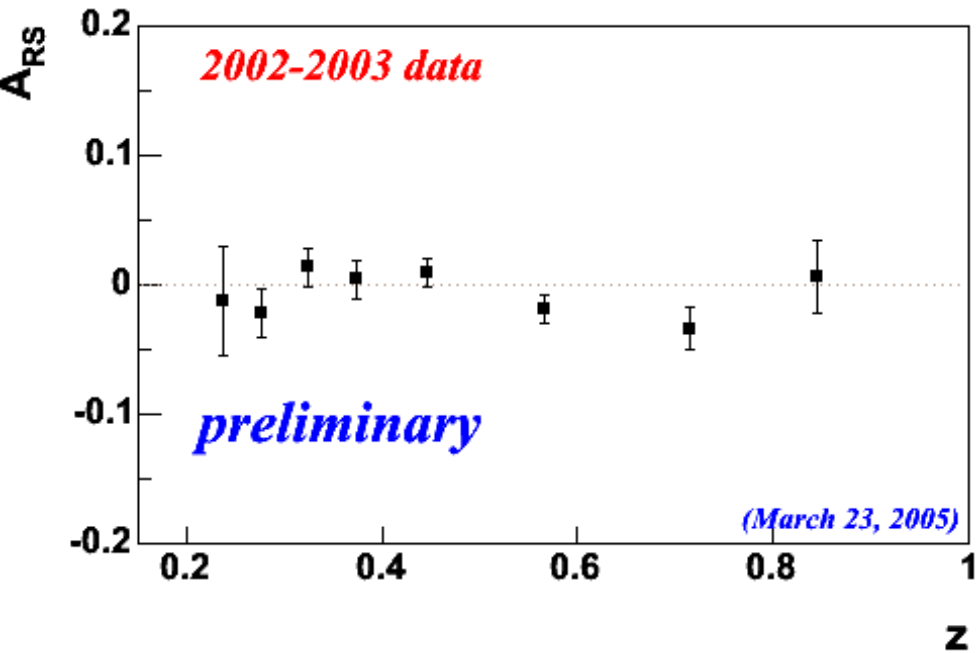


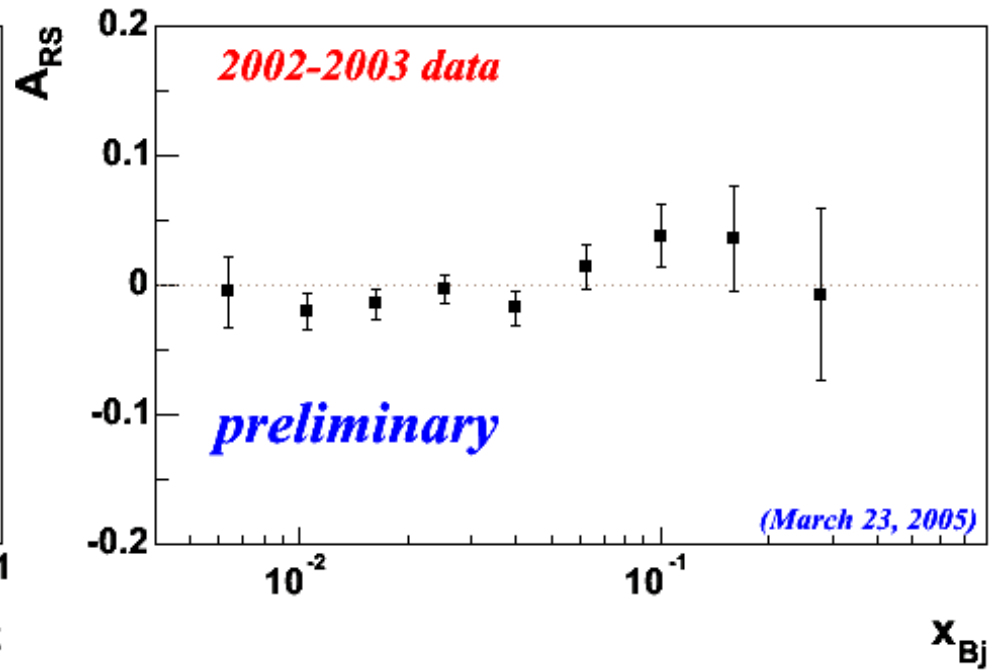
Two-Hadron Asymmetries

$$A_{RS} = \frac{A_{UT}^{\sin\phi_{RS}}}{D_{NN} \cdot f \cdot P}$$

Systematic errors are smaller than the quoted statistical errors

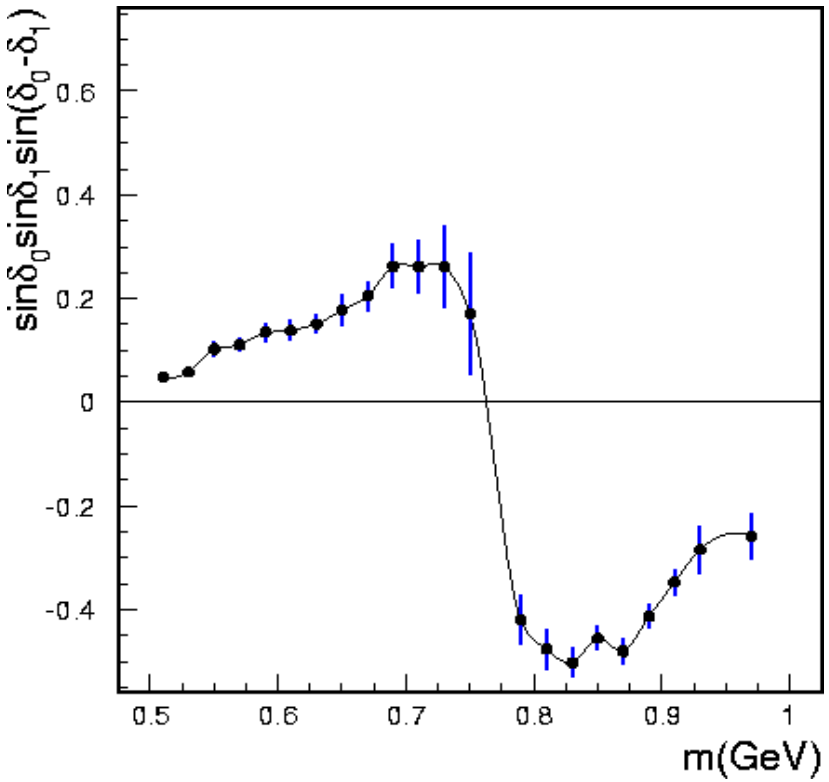






Interference Fragmentation Function $H_q^{\sphericalangle h}(z,M_h^2)$

One model . . .

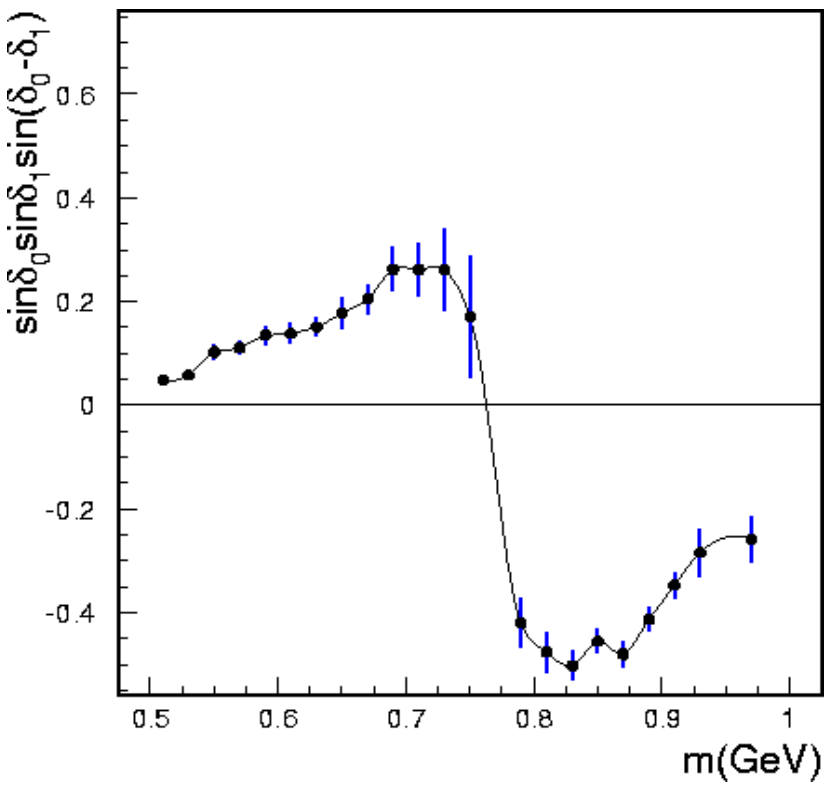


R. L. Jaffe, X. Jin and J. Tang,
Phys. Rev. Lett. 80, 1166 (1998)

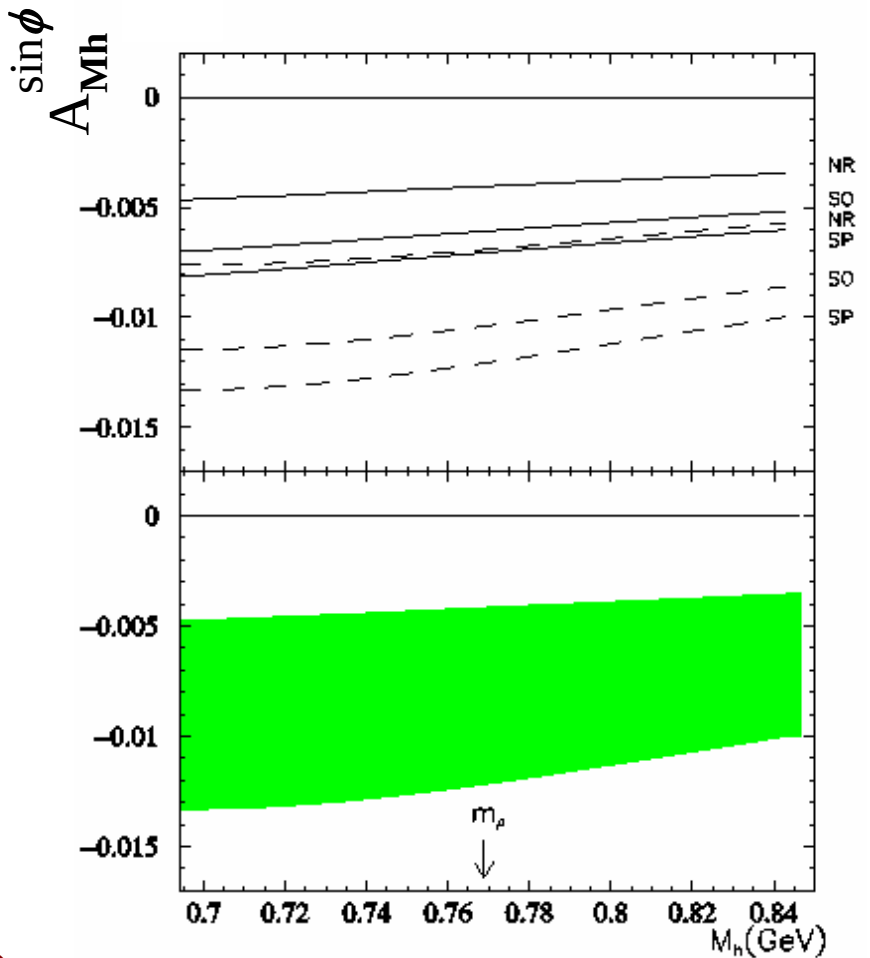
$H^{\sphericalangle}(z,M^2_{\pi^+\pi^-}) \sim \sin\delta_0 \sin\delta_1 \sin(\delta_0-\delta_1) H^{\sphericalangle}(z,M^2_{\pi^+\pi^-})$

Interference Fragmentation Function $H_q^{\sphericalangle h}(z,M_h^2)$

One model . . . Another model !



R. L. Jaffe, X. Jin and J. Tang, Phys. Rev. Lett. 80, 1166 (1998)



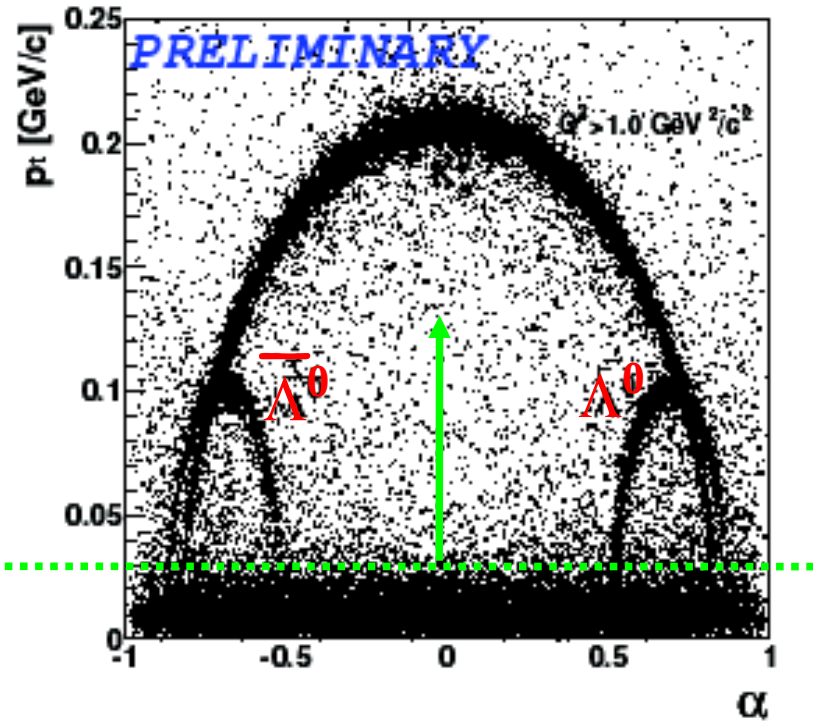
Radici, Jakob, Bianconi, PRD 65, 074031

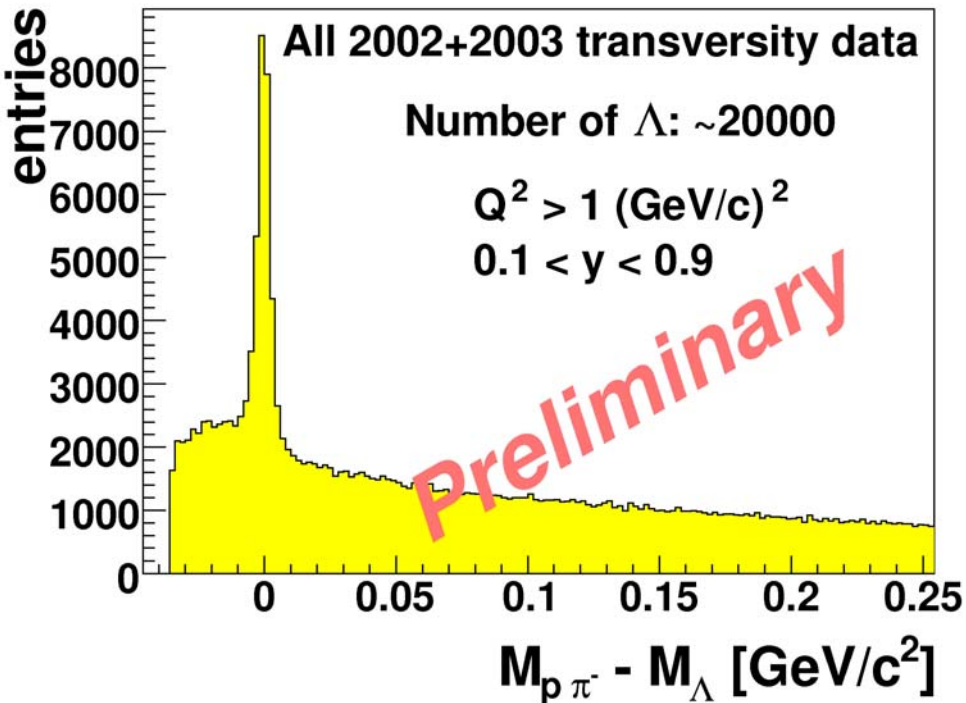
$$H^{\sphericalangle}(z,M^2_{\pi^+\pi^-}) \sim \sin\delta_0 \sin\delta_1 \sin(\delta_0-\delta_1) H^{\sphericalangle}(z,M^2_{\pi^+\pi^-})$$

DIS Events with Λ

Event selection

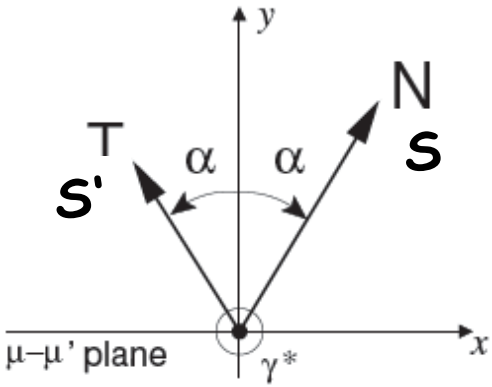
- Momentum of both decay particles > 1 GeV/c
- Collinearity < 10 mrad
- Decay vertex outside of the target
- Armenteros p_T > 23 MeV/c





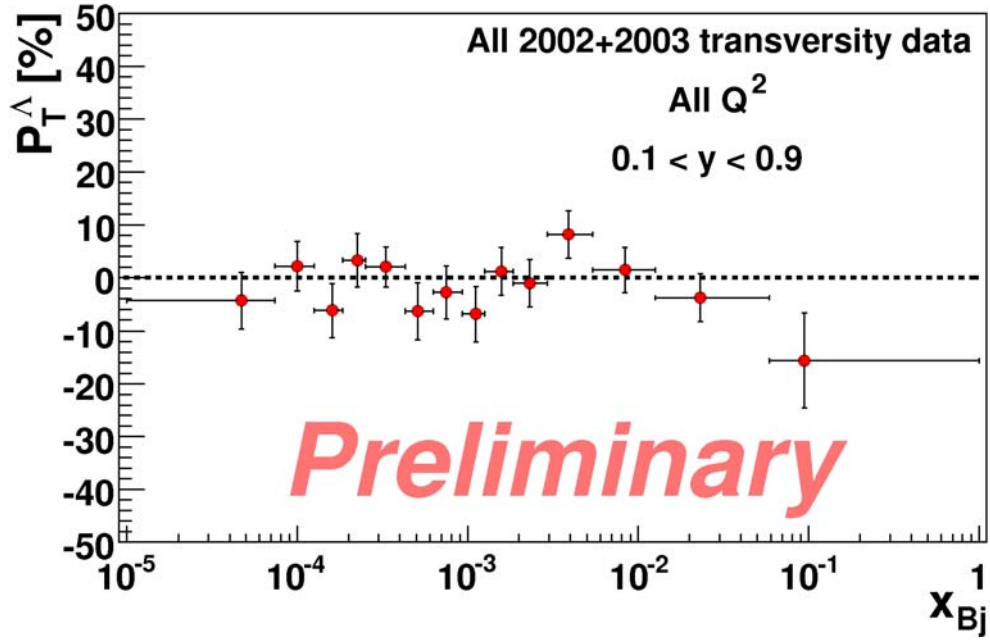
Mostly current fragmentation !

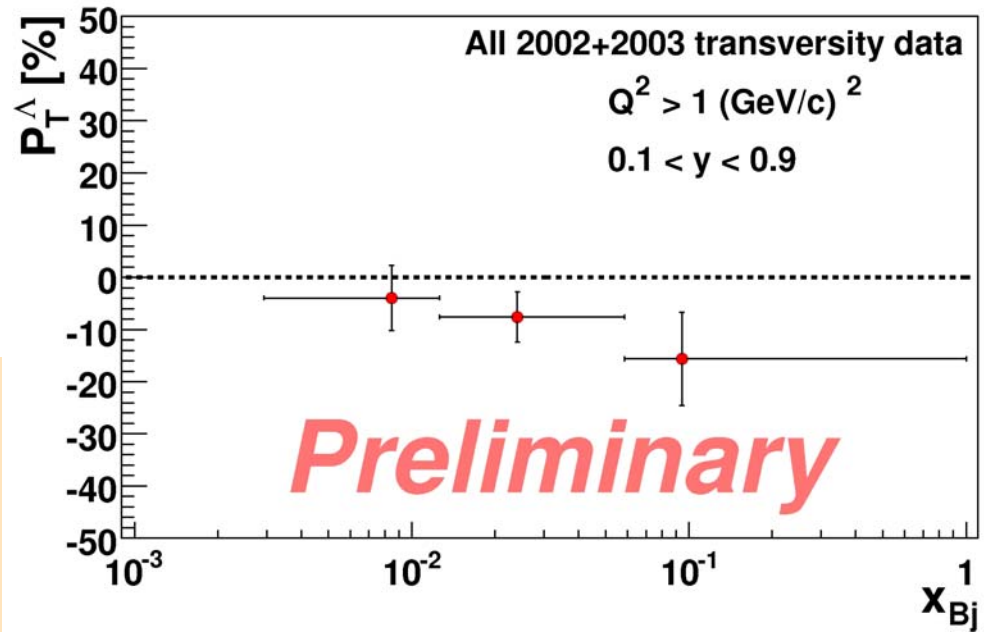
Λ from scattering off Deuteron



$$P_{T,exp}^{\Lambda} = \frac{d\sigma^{\mu N^{\uparrow}\to\mu'\Lambda^{\uparrow}X} - d\sigma^{\mu N^{\downarrow}\to\mu'\Lambda^{\uparrow}X}}{d\sigma^{\mu N^{\uparrow}\to\mu'\Lambda^{\uparrow}X} + d\sigma^{\mu N^{\downarrow}\to\mu'\Lambda^{\uparrow}X}} = fP_N D(y)\frac{\sum_q e_q^2 \Delta_T q(x)\Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2 q(x) D_{\Lambda/q}(z)}$$

$$\Delta_T D_{\Lambda/q}(z) = D_{\Lambda^{\uparrow}/q^{\uparrow}}(z) - D_{\Lambda^{\downarrow}/q^{\uparrow}}(z)$$





- Negative trend, but no significant deviation from zero
- Systematic effects not larger than statistical errors

Summary & Outlook

- COMPASS has produced transverse spin asymmetries the deuteron
  - Collins asymmetries for - single hadron
    - two-hadron asymmetries - all pairs
      - leading pairs
    - Λ polarization
  - Sivers asymmetries for single hadron

- All analyzed data, so far, indicate small Asymmetries
  - cancellation of proton & neutron?

- Next steps:
  - extracting asymmetries including PID information
  - Hadron-pair and Λ analysis on 2004 data ongoing → double event sample
  - Measurements with transversely polarized proton target planned
  - 2006 enlarged x_{Bj} acceptance with new target magnet