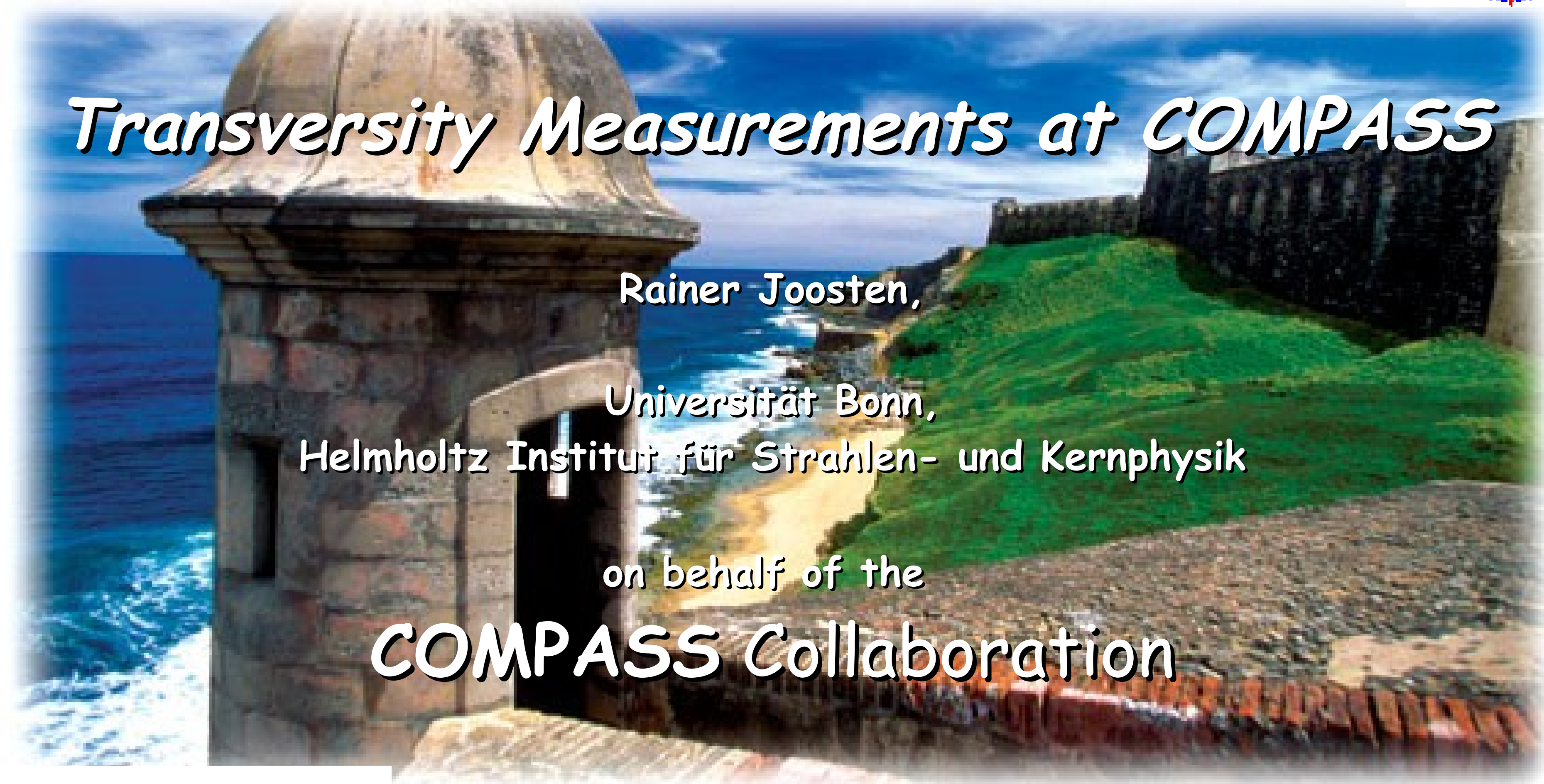
CIPANP 2006

Westin Rio Mar Beach, Puerto Rico



Transversity Measurements at COMPASS

Rainer Joosten,

Universität Bonn,
Helmholtz Institut für Strahlen- und Kernphysik

on behalf of the

COMPASS Collaboration

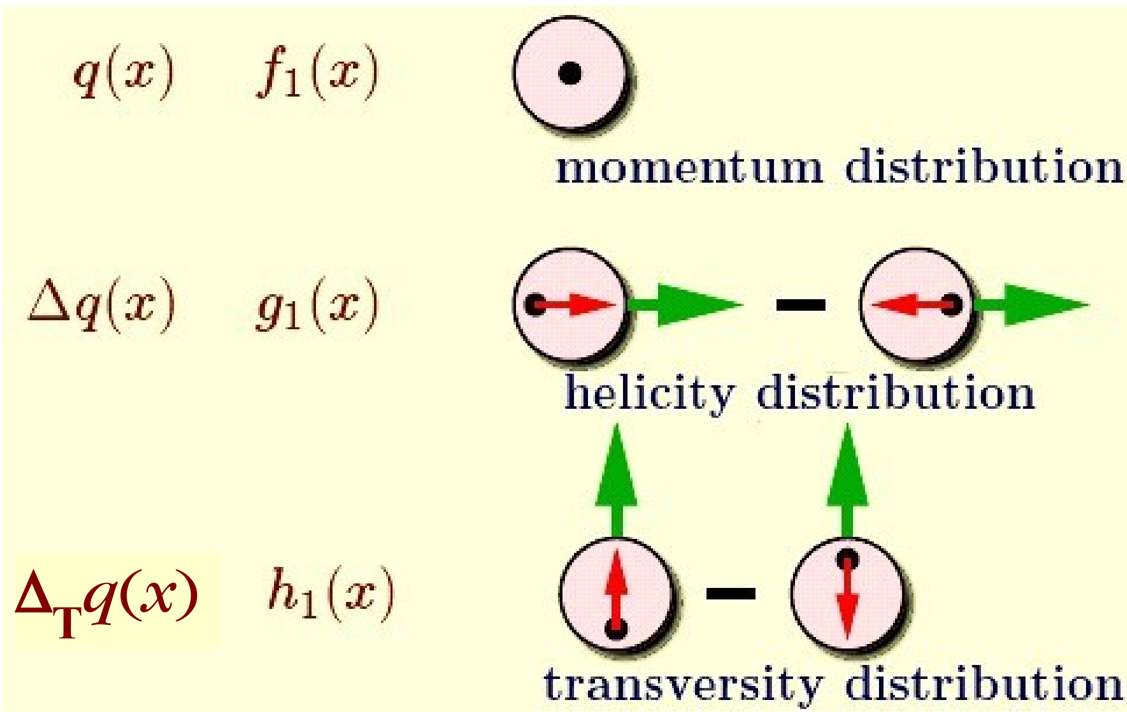
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

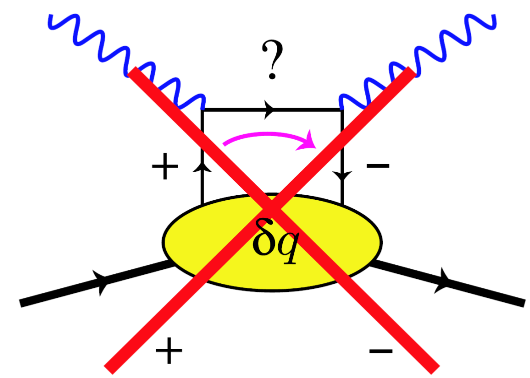
universitätbonn
RHEINISCHE FRIEDRICH-WILHELMS-UNIVERSITÄT

Puerto Rico, 3.6.2005

Transverse Spin Physics

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





$\Delta_T q(x)$ decouples from inclusive DIS because helicity of quark must flip

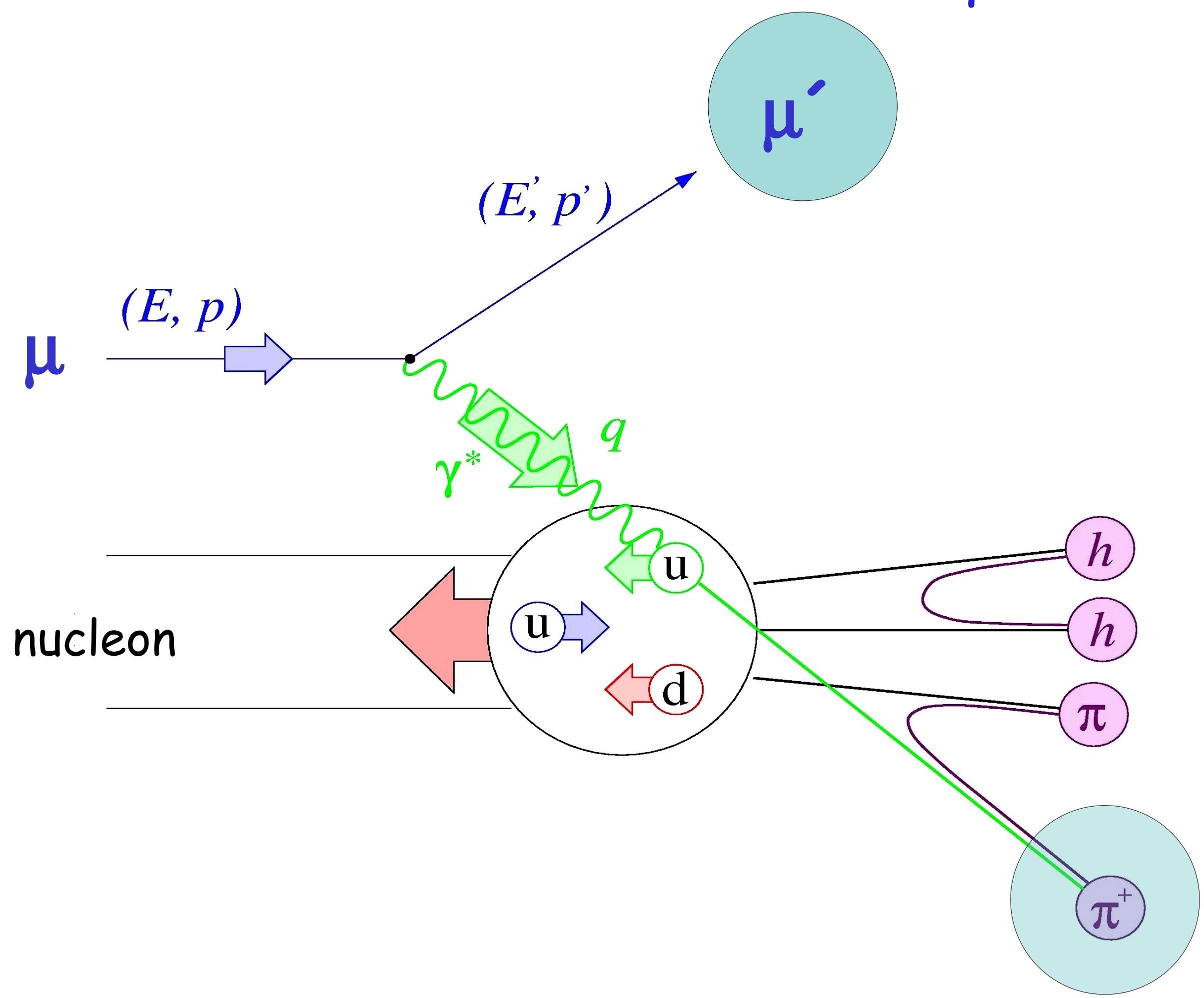
$\Rightarrow$ SIDIS

Transverse Spin Physics in SIDIS

Two processes:

Scattering of the lepton on a quark $\rightarrow$ distribution function

Production of hadrons from struck quark $\rightarrow$ fragmentation function



Kinematic variables:

$Q^2 = -q^2 \cong 4\,E\,E'\,\sin\theta/2$

Q ~ resolution

$\nu = (E_l - E_{l'})$

photon energy

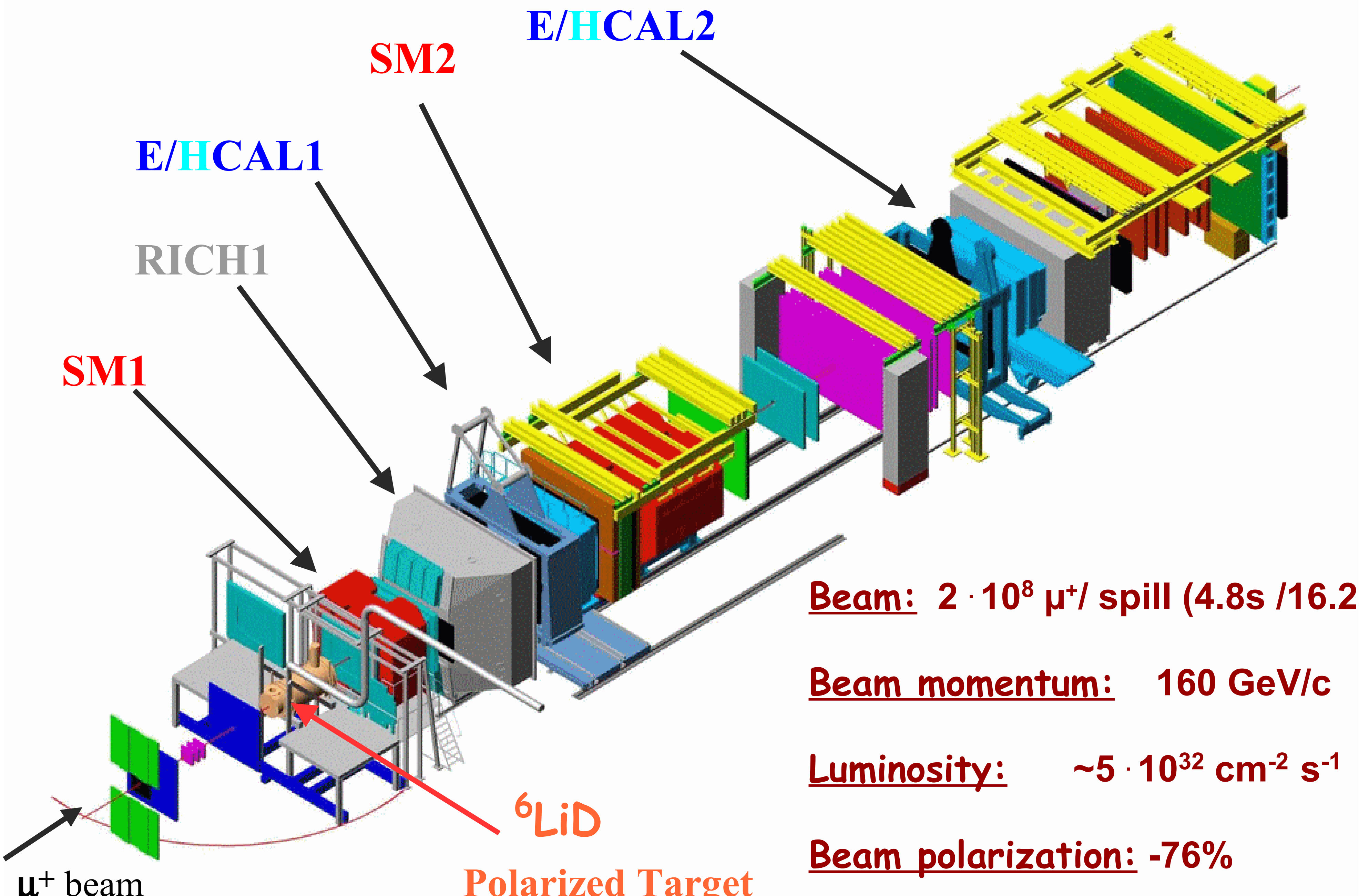
$x_{Bj} = Q^2/2M\nu$

momentum fraction of struck quark

$y = \nu/E_l$ inelasticity

$z = E_h/\nu$ exclusivity

The COMPASS Spectrometer at CERN



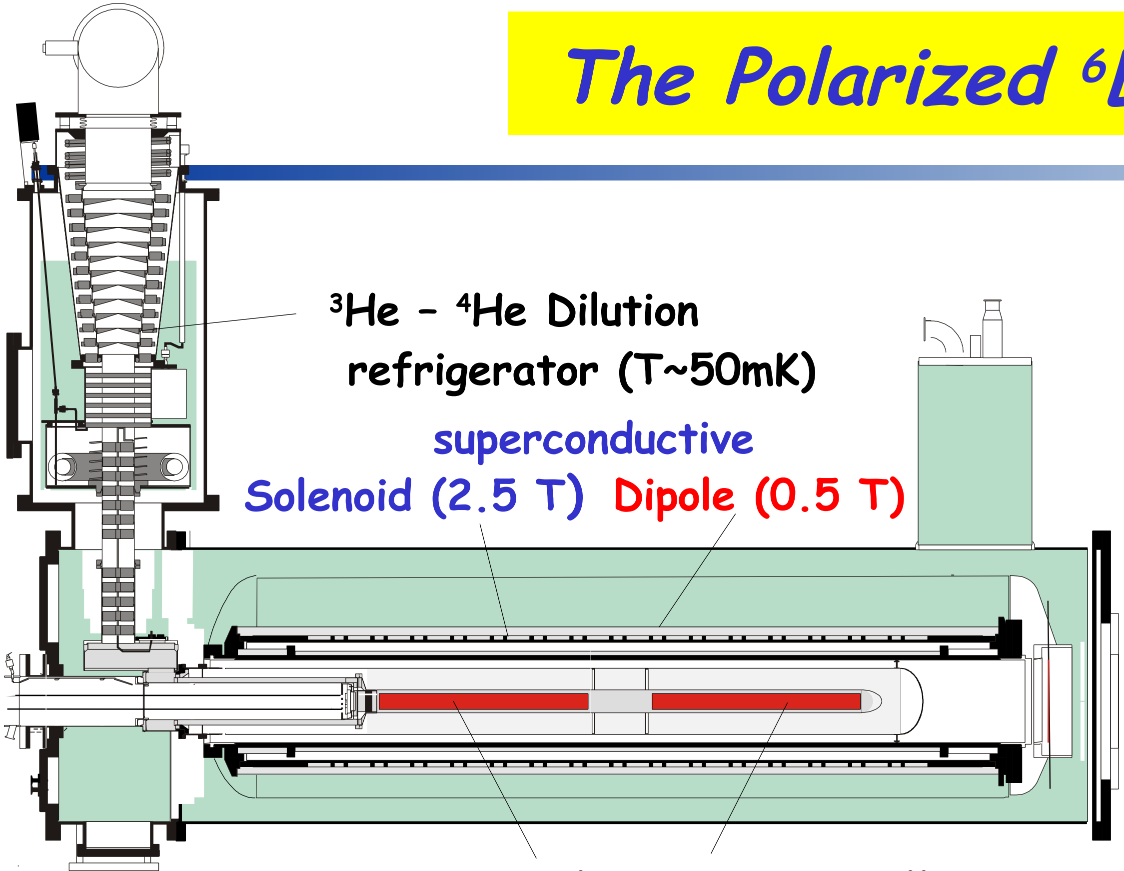
Beam: $2 \cdot 10^8$ μ^+/ spill (4.8s /16.2s)

Beam momentum: 160 GeV/c

Luminosity: $\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}

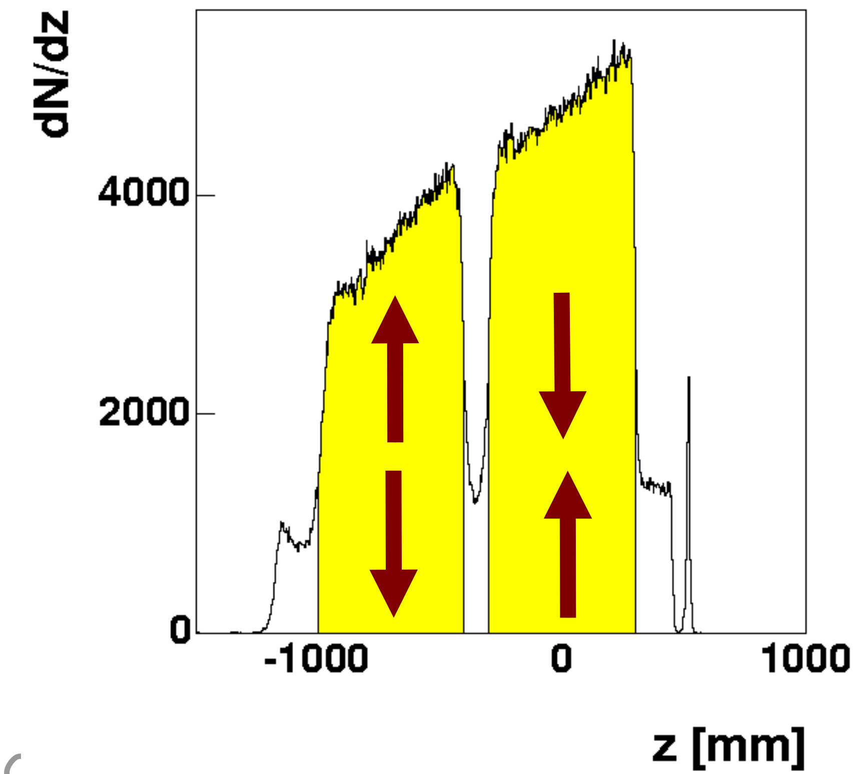
Beam polarization: -76%

The Polarized ^{6}LiD-Target



Polarization: 50%

Dilution factor: 0.38



Transverse target polarization:

(dipole field)

changed by microwave reversal

(once a week)

Transverse Spin Physics

3 possible quark polarimeters suggested using SIDIS:

- Azimuthal distribution of single hadrons

  paper on 2002 data published Phys. Rev. Lett. 94, 202002 (2005)

- Azimuthal dependence of the plane containing hadron pairs

- Measurement of transverse polarization of baryons

  (e.g. Λ hyperon)

Transversity Data Sample

Target: ^{6}LiD (deuterium)

2002: 12+7 days of data taking

- $1.8 \cdot 10^{9}$ raw events

2003: 14 days of data taking

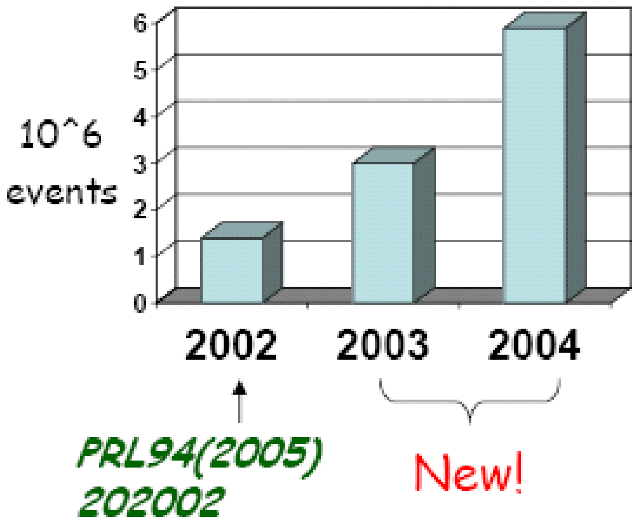
trigger upgrade to gain on large x_{Bj} & large Q^2 events !

- 2002 data doubled

2004: 14 days of data taking

DAQ improved and online filter added

- ~ 2003 data doubled



Single hadron production

Two possible azimuthal asymmetries:

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

$\rightarrow$ **Collins effect --- (access to transversity)**

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

$\rightarrow$ **Sivers effect**

Collins:

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

Sivers:

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

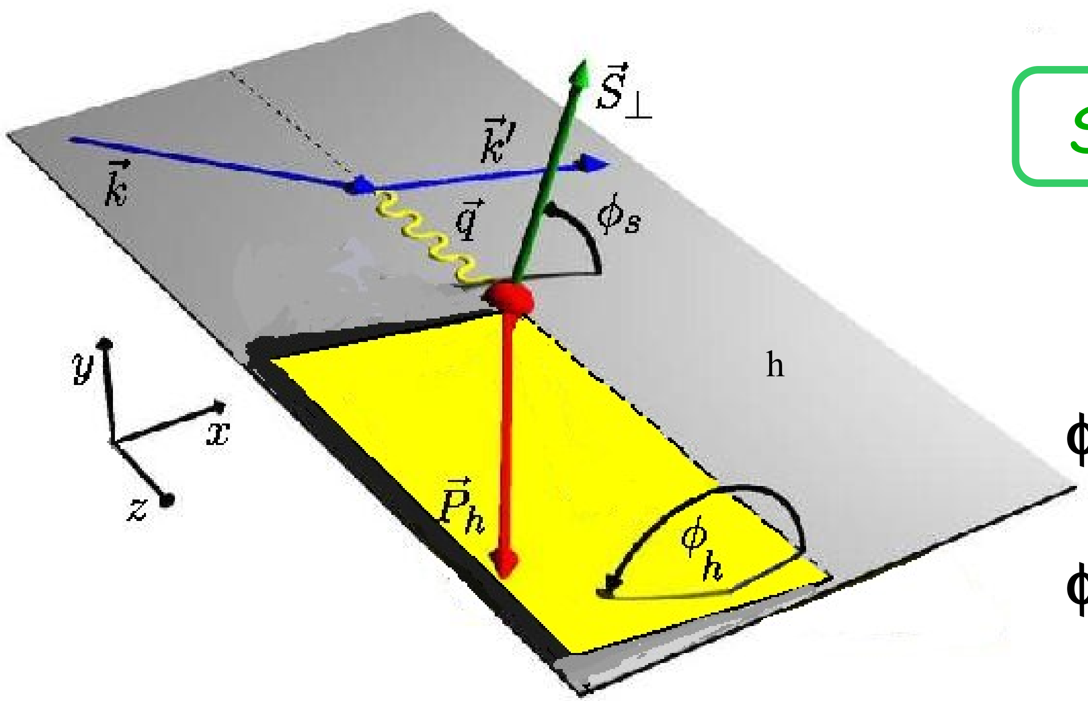
f dilution factor; P target polarization; $D_{NN} = (1-y)/(1-y+y^2/2)$ Depolarization factor

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

Transversity Acceptance

DIS cuts:

$Q^2 > 1\ (GeV/C)^2$
$0.1 < y < 0.9$

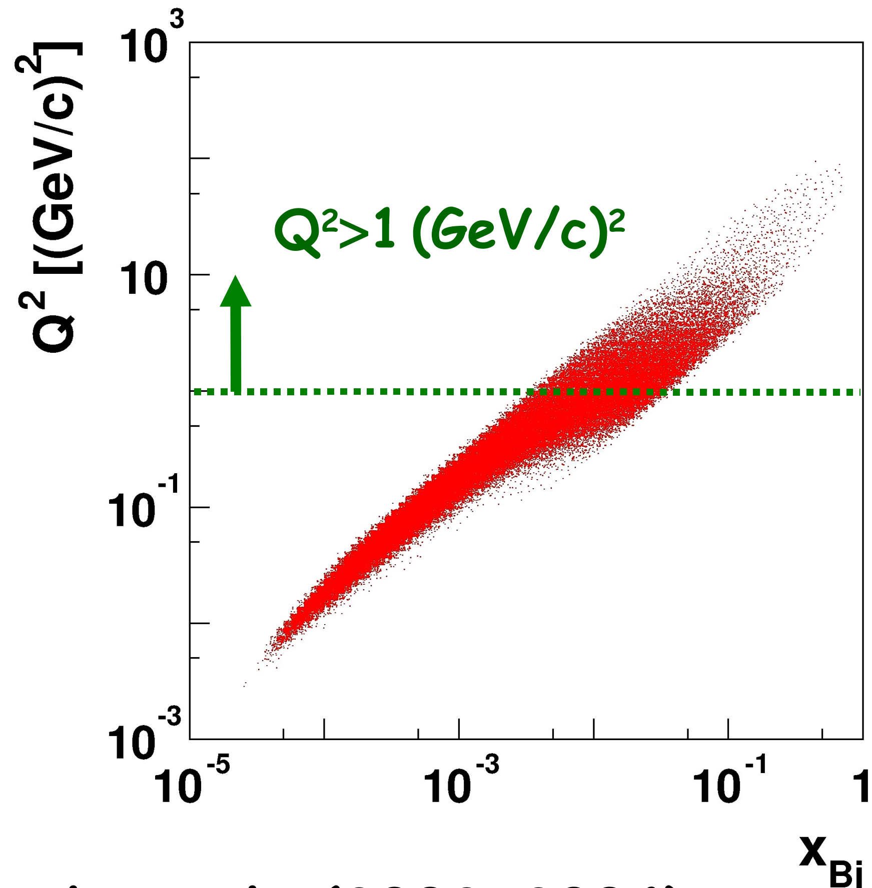
hadron cuts:

$p_t > 0.1\ GeV/c$

$z > 0.20$
(all hadrons)

$z > 0.25$
(leading hadrons)

→ *FILTER!*

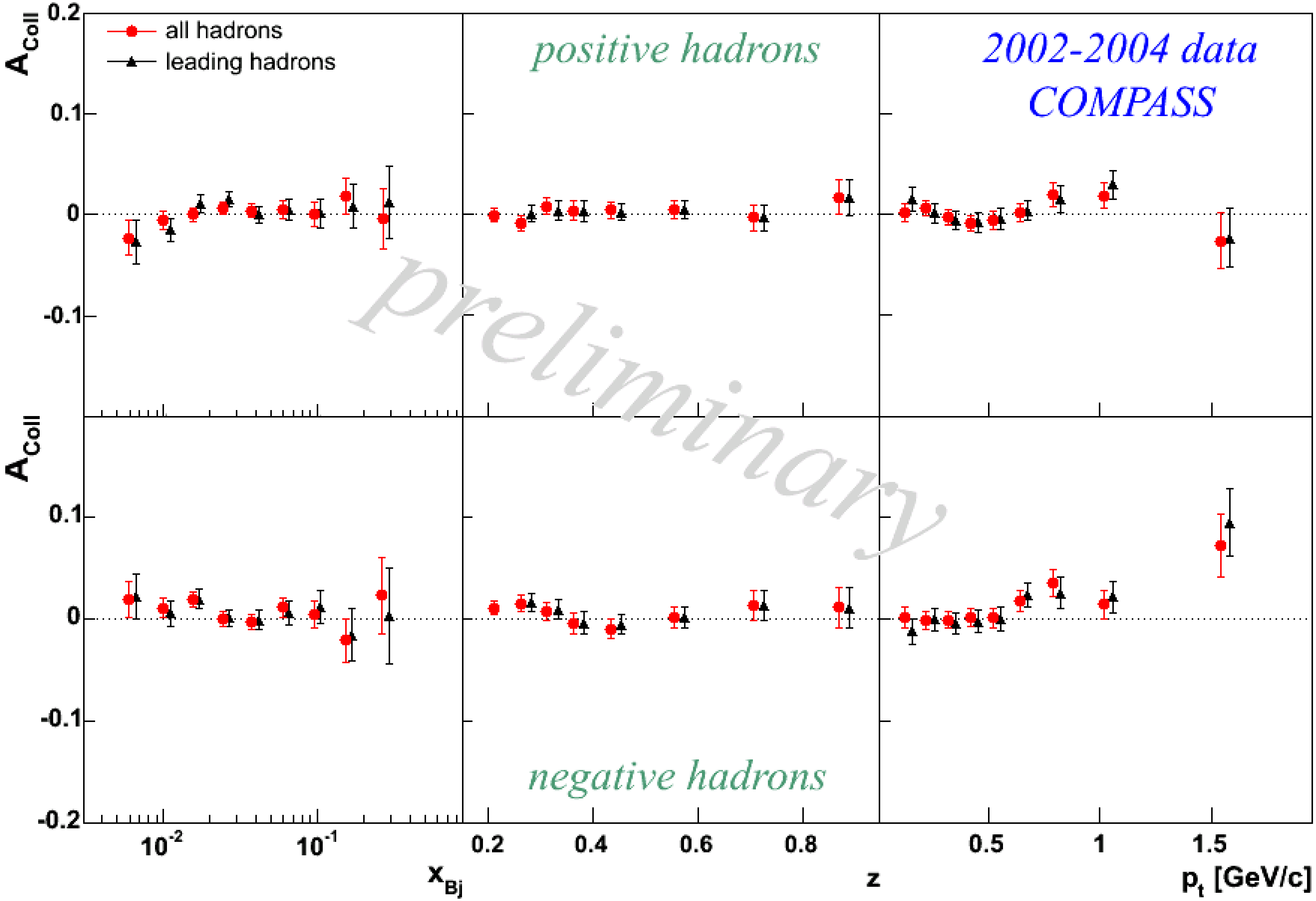


Final sample (2002-2004):

$5.8 * 10^6$ positive leading hadrons
$4.6 * 10^6$ negative leading hadrons

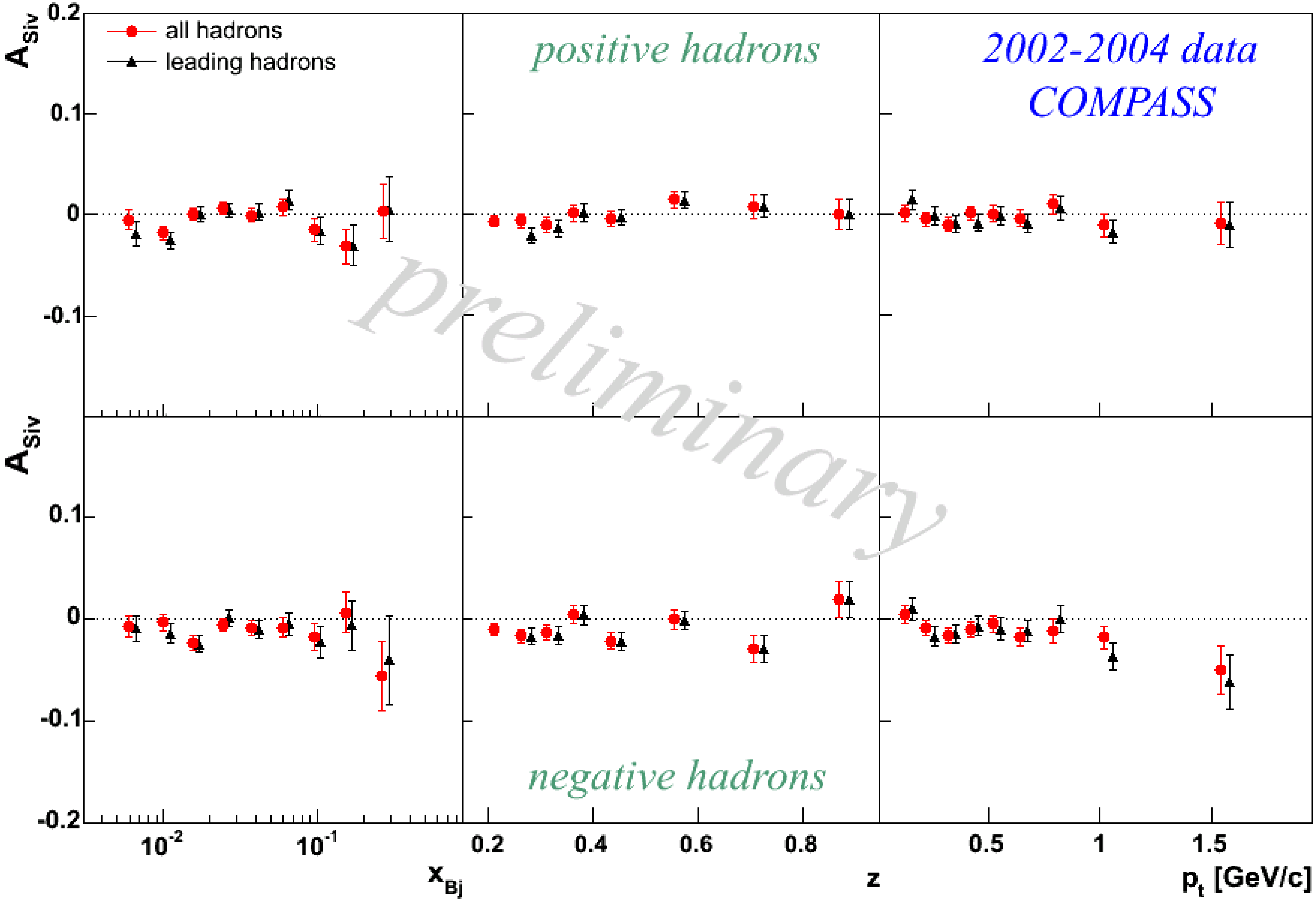
$8.5 * 10^6$ positive hadrons
$7.0 * 10^6$ negative hadrons

Collins Asymmetries



deuteron target

Sivers Asymmetries



deuteron target

Interpretations

- Possible explanations for small asymmetries:
  - Cancellation between proton and neutron;
  - Small Collins mechanism.

- Peliminary measurement by BELLE (hep-ex/0507063):

  $\Delta_T D_q \neq 0$ and large!

  $\Rightarrow$ evidence for cancellation in isoscalar target;

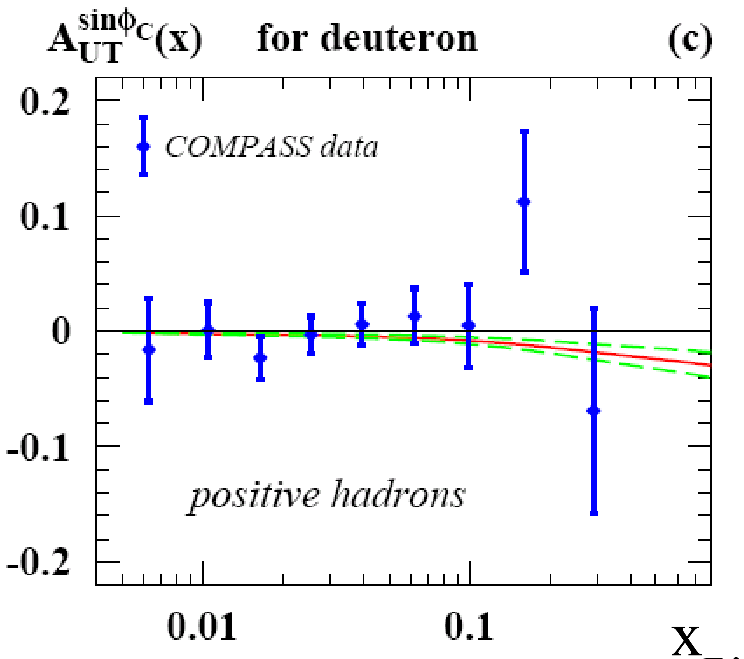
- Phenomenological fits of the data from HERMES and predictions for COMPASS by

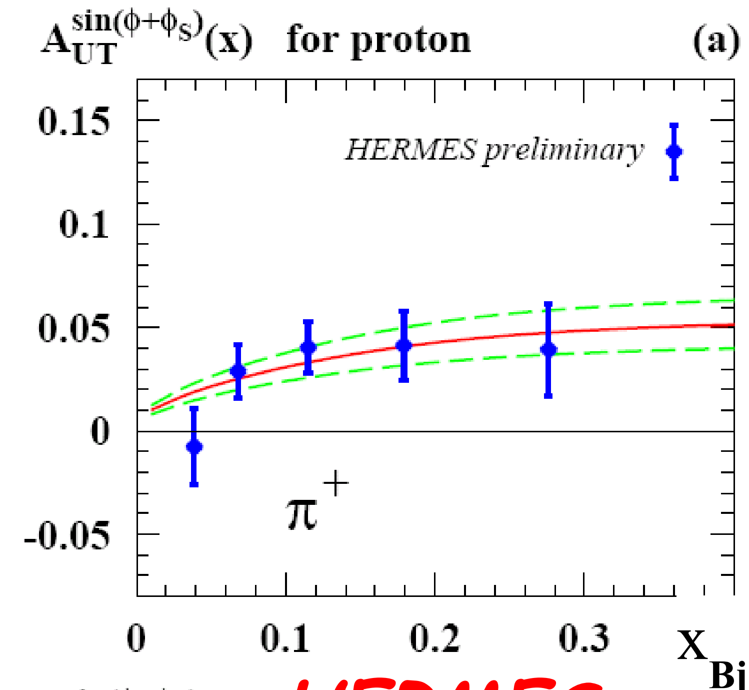
  Anselmino et al. (hep-ph/0507181),

  Vogelsang and Yuan (hep-ph/0507266),

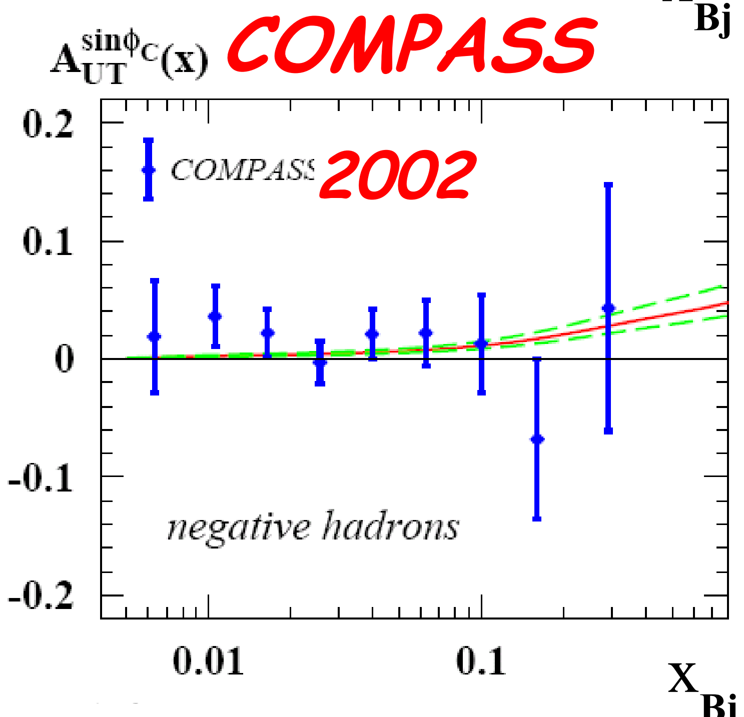
  Efremov, Goeke and Schweitzer (hep-ph/0603054)

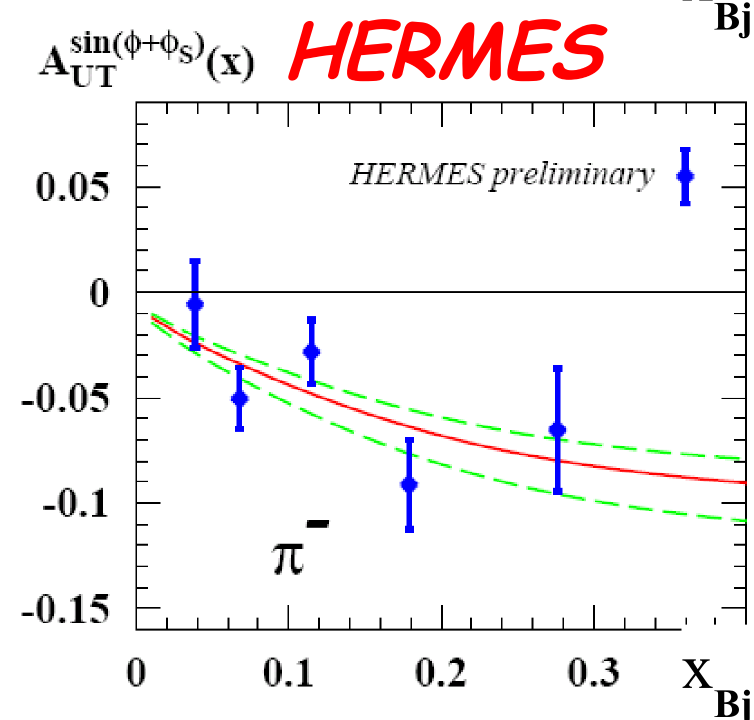
Fits and calculations (Collins effect)





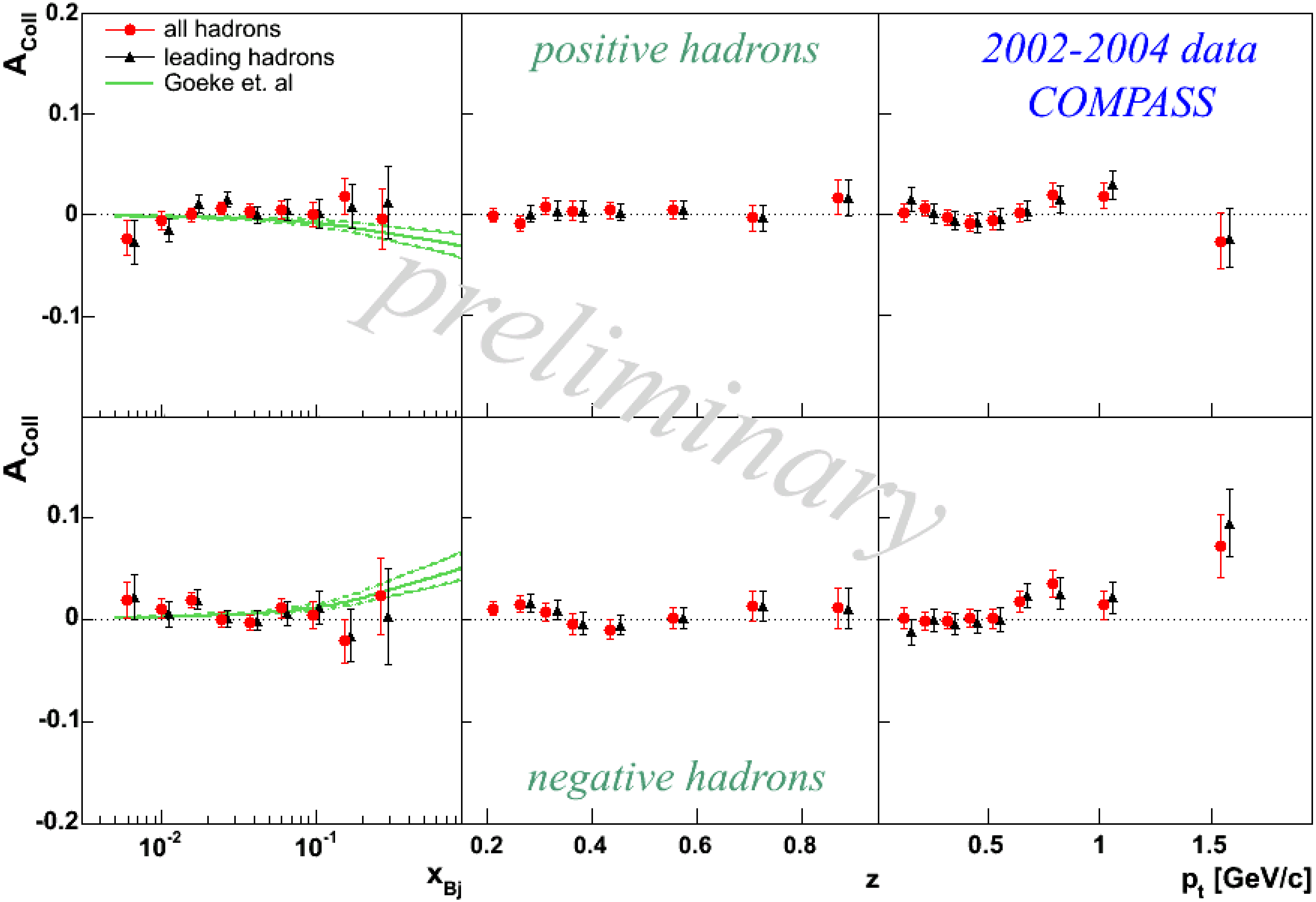
Collins





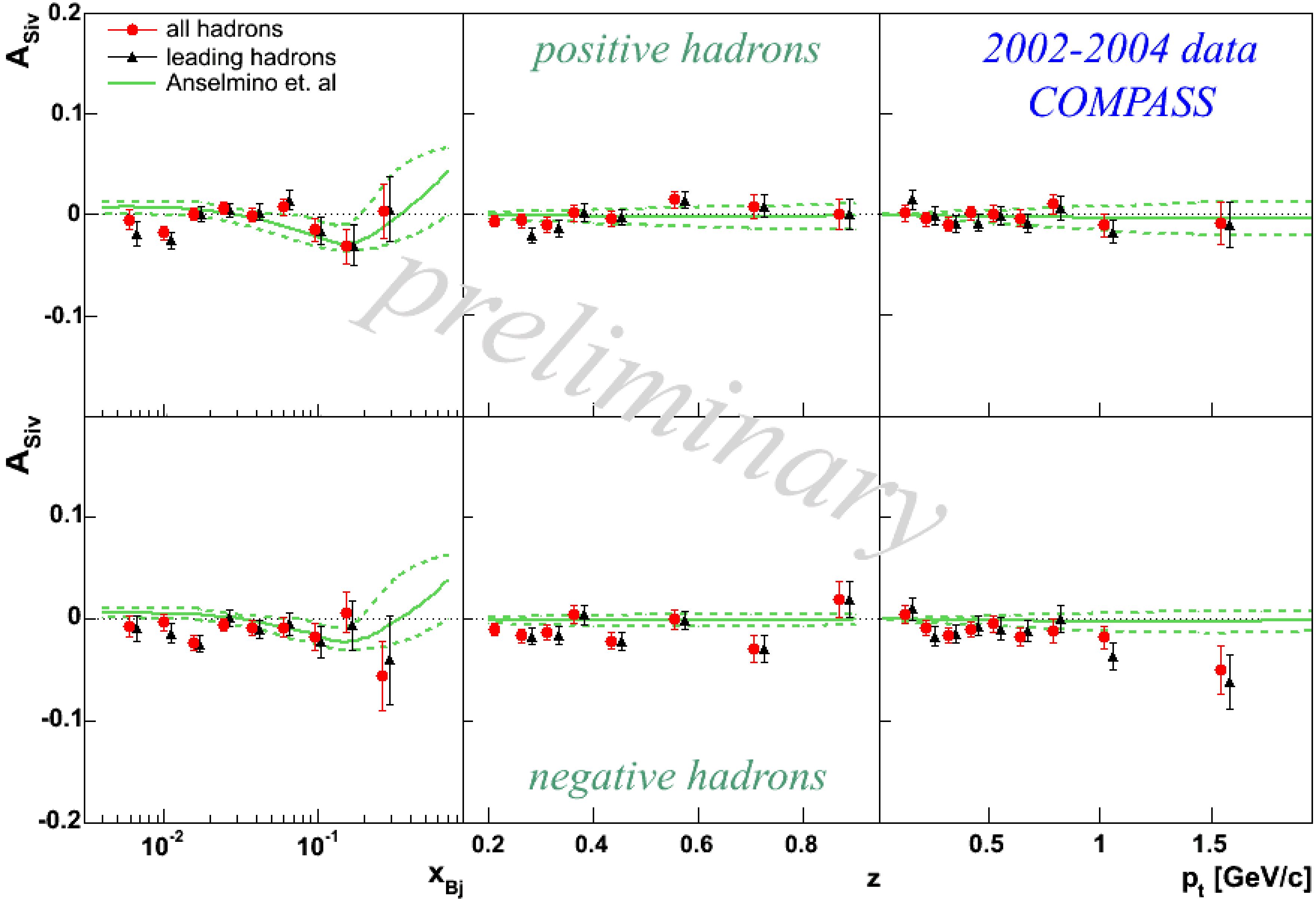
A. V. Efremov, K. Goeke and P. Schweitzer
Collins on Proton and Deuterium
(hep-ph/0603054)

Collins Asymmetries



A. V. Efremov, K. Goeke and P. Schweitzer, Collins on Proton and Deuterium (hep-ph/0603054)

Sivers Asymmetries



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

Conclusion (1)

- A first measurementof Collins and Sivers asymmetries has been performed with a polarized deuteron (^{6}LiD) target.
- The measured asymmetries are very small and compatible with zero within the current statistical errors.
- Investigations of systematic effects prove them to be small compared to the statistical error
- Both COMPASS (deuteron) and HERMES (proton) data can be described by the same model, implying for deuteron a cancellation between protons and neutrons.

Transverse Spin Physics

3 possible quark polarimeters suggested using SIDIS:

- Azimuthal distribution of single (leading) hadrons
- Azimuthal dependence of the plane containing hadron pairs

  First results on the effect proposed by e.g.

  Collins et al., Nucl. Phys. B 420 (1994) 565.

  Jaffe et al., Rev. Lett. 80 (1998) 1166.

- Measurement of transverse polarization of baryons

  (e.g. Λ hyperon)

Interference fragmentation function

In SIDIS $(l N \to l' h_1 h_2 X)$ 2-hadron production

$\Delta_T q_i(x)$ couples to $H_i^{\measuredangle h}(z,\zeta,M_h{}^2,k_T{}^2,k_T P_T)$ $\zeta = z_1/(z_1+z_2)$

Integrated over $P_{h\perp}$:

$$\sigma_{UT} \propto \Sigma_i e_i{}^2 |S_T| \sin\theta \sin\phi_{RS} \, \Delta_T q_i(x) \, H_i^{\measuredangle h}(z,M_h{}^2) \propto A_{UT}^{\sin\phi_{RS}} \cdot \sin\phi_{RS}$$

(A. Bacchetta and M. Radici, hep-ph/0407345)

$$\frac{A_{UT}^{\sin\phi_{RS}}}{D_{NN} \cdot f \cdot P} = A_{RS} = \frac{\Sigma_i e_i{}^2 \Delta_T q_i(x) H_i^{\measuredangle h}(z,M_h{}^2)}{\Sigma_i e_i{}^2 q_i(x) D_i^{h}(\vec{z},M_h{}^2)}$$

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

The Coordinate System

Frame where:

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

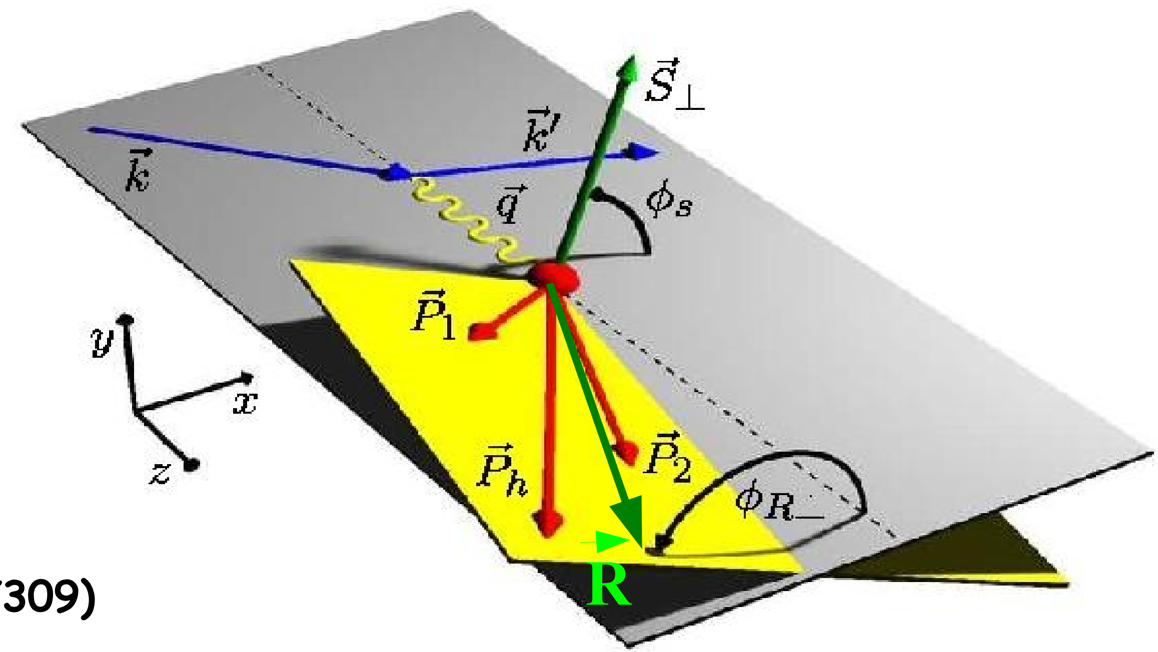
$\phi_{S'}$ = azimuthal angle of spin vector of **fragmenting** quark

with $\phi_{S'} = \pi - \phi_S$ *(spin flip)*

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

ϕ_R = is defined by:

$$R = (z_2 \mathbf{p}_1 - z_1 \mathbf{p}_2)/(z_1 + z_2)$$

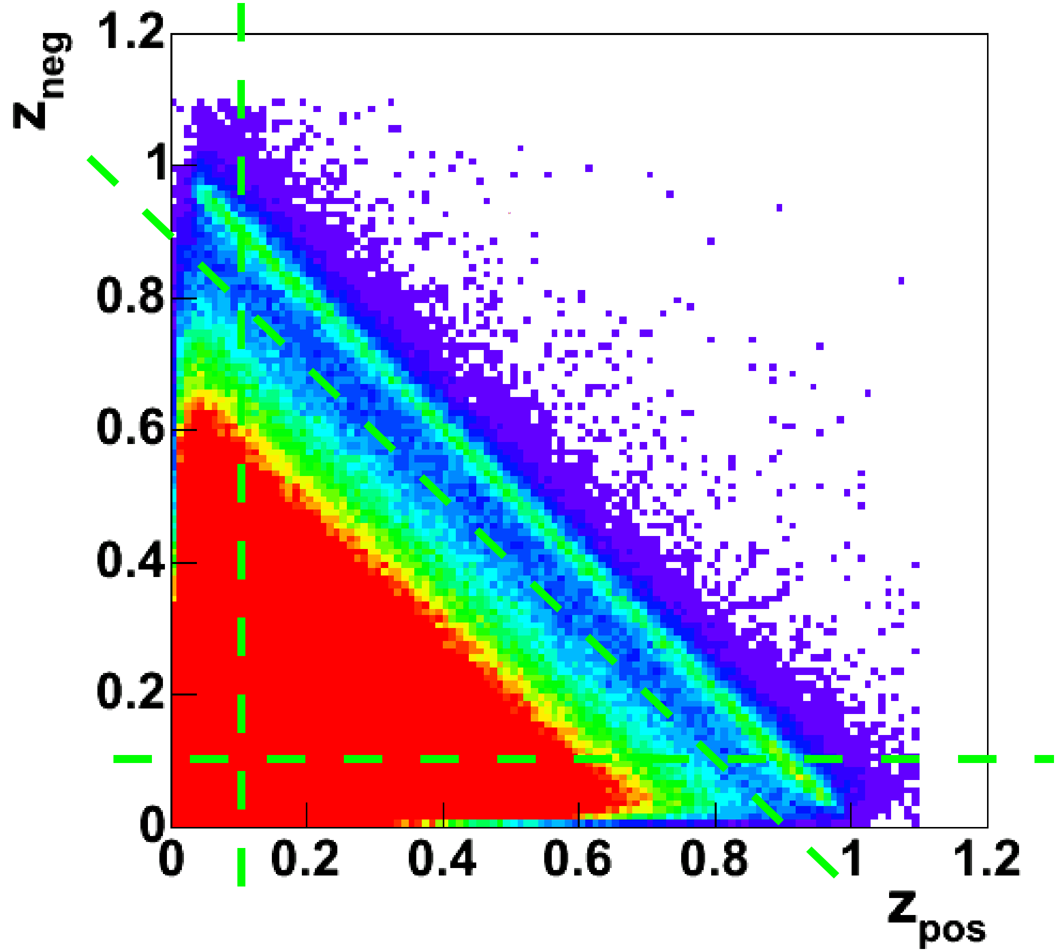


(X. Artru, hep-ph/0207309)

Selection of Hadron Pairs

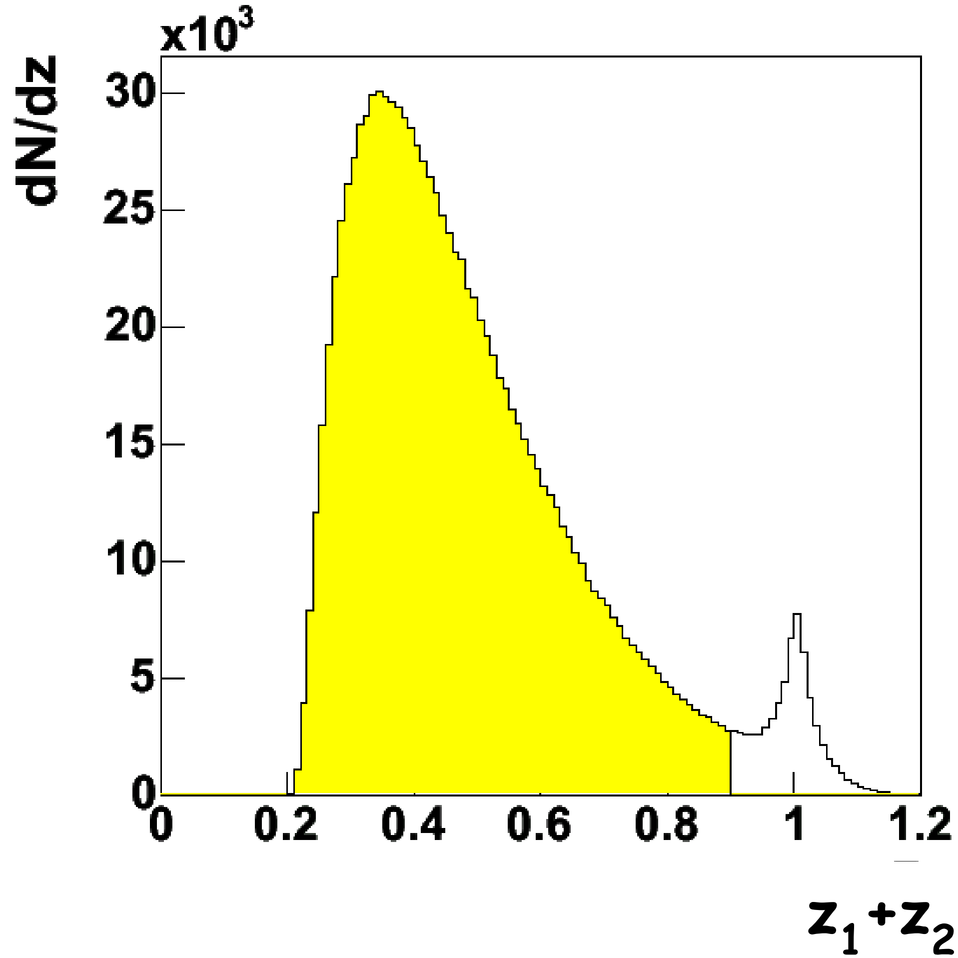
Select all combinations of positive (h_1) and negative (h_2) hadrons with:

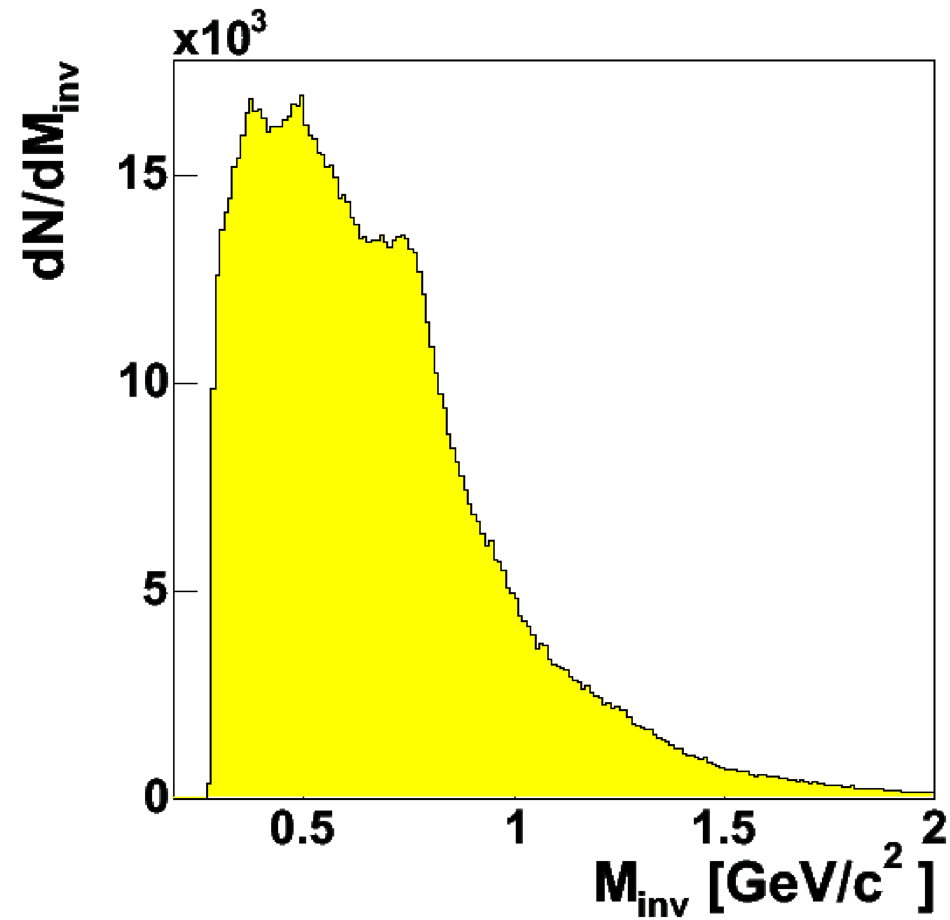
- $z_1 > 0.1$ & $z_2 > 0.1$ and $x_{f1} > 0.1$ & $x_{f2} > 0.1$
- $z = z_1 + z_2 < 0.9$



Presently no π / K / p separation by RICH

Final Sample





2002-2004:

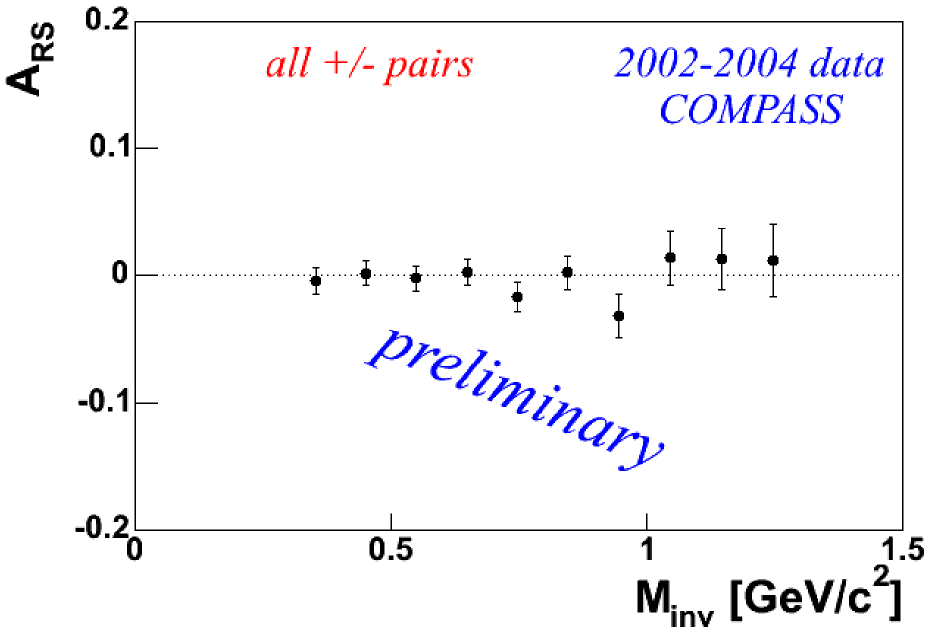
$6.1\ 10^6$ combinations

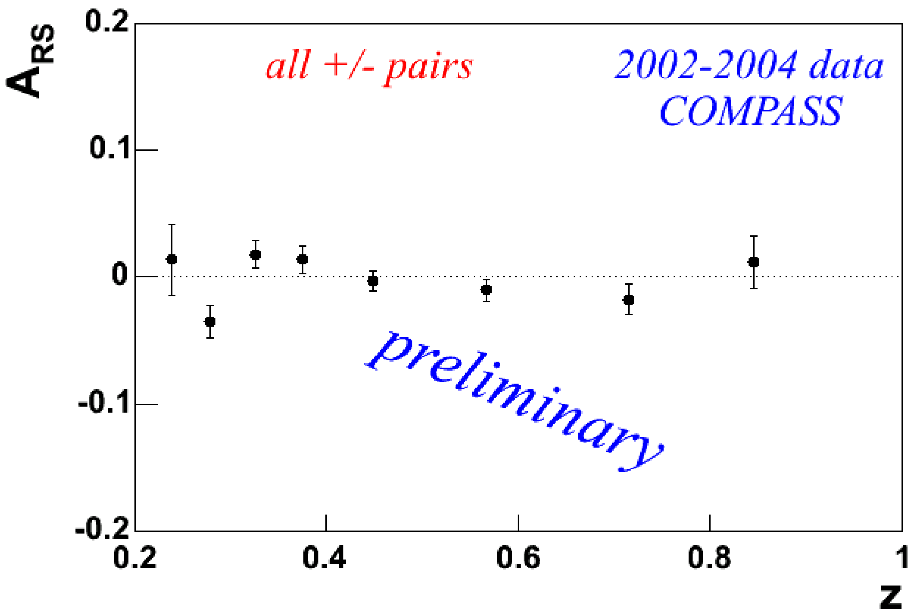
Presently no π / K / p separation by RICH

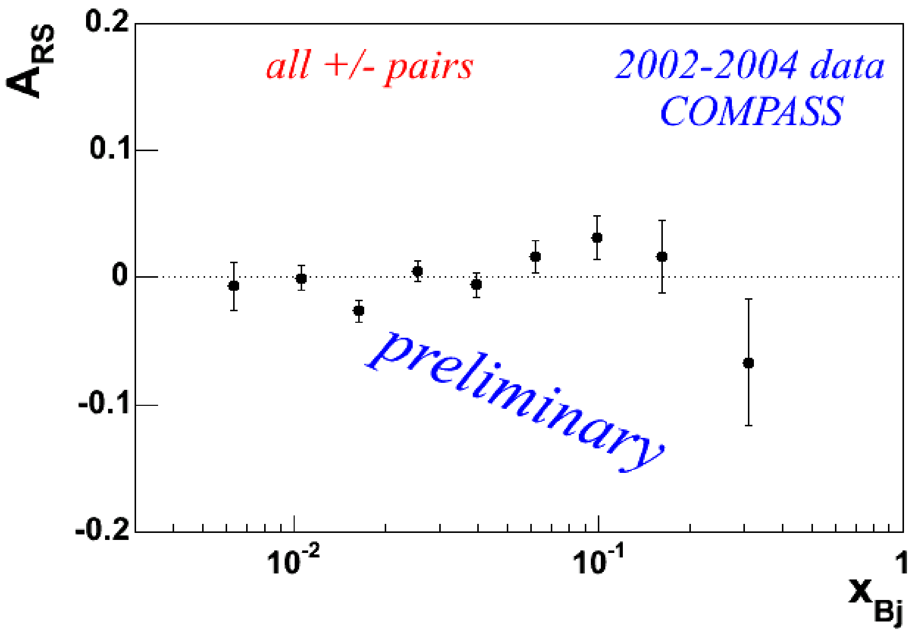
2-Hadron Asymmetry all +/- pairs

2002-2004 data

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







Conclusion (2)

- First results of the analysis of our transverse target data concerning two hadron asymmetries were shown.
- The observed asymmetries are small.
- Systematics checks performed on the data show, that systematic effects are smaller than the statistical error.

Transverse Spin Physics

3 possible quark polarimeters suggested using SIDIS:

- Azimuthal distribution of single (leading) hadrons
- Azimuthal dependence of the plane containing hadron pairs
- Measurement of transverse polarization of baryons

  (e.g. Λ hyperon)

$\Delta_T q(x)$ from Λ polarization

In the reaction

$$\mu N^{\uparrow} \rightarrow \mu' \Lambda^{\uparrow} X$$

the Λ polarization is related to $\Delta_T q(x)$ by:

$$P_T^{\Lambda} = f P_T D(y) \frac{\sum_a e_a^2 \, \Delta_T q_a(x) \cdot \Delta_T D_{\Lambda/q}(z)}{\sum_a e_a^2 \cdot q_a \cdot D_{\Lambda/q}(z)}$$

Introducing the chiral-odd fragmentation function $\Delta_T D_{\Lambda/q}(z)$.

$\Delta_T q(x)$ from Λ polarization

In the self- analyzing decay:

$$\Lambda \rightarrow p\,\pi^- \quad \text{B.R.} \cong 64\,\%$$

The Λ polarisation along a certain direction $\vec{S}$ is measured from the angular distribution of the decay protons:

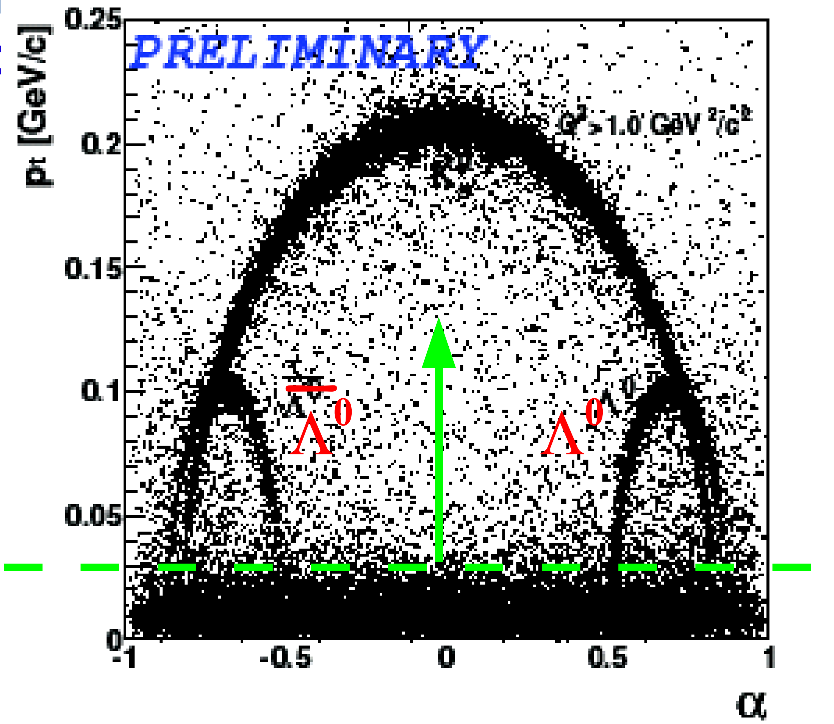
$$W(\vartheta^*) \propto (1 + \alpha\, P_s^{\Lambda} \cos(\vartheta^*))\; Acc(\vartheta^*)$$

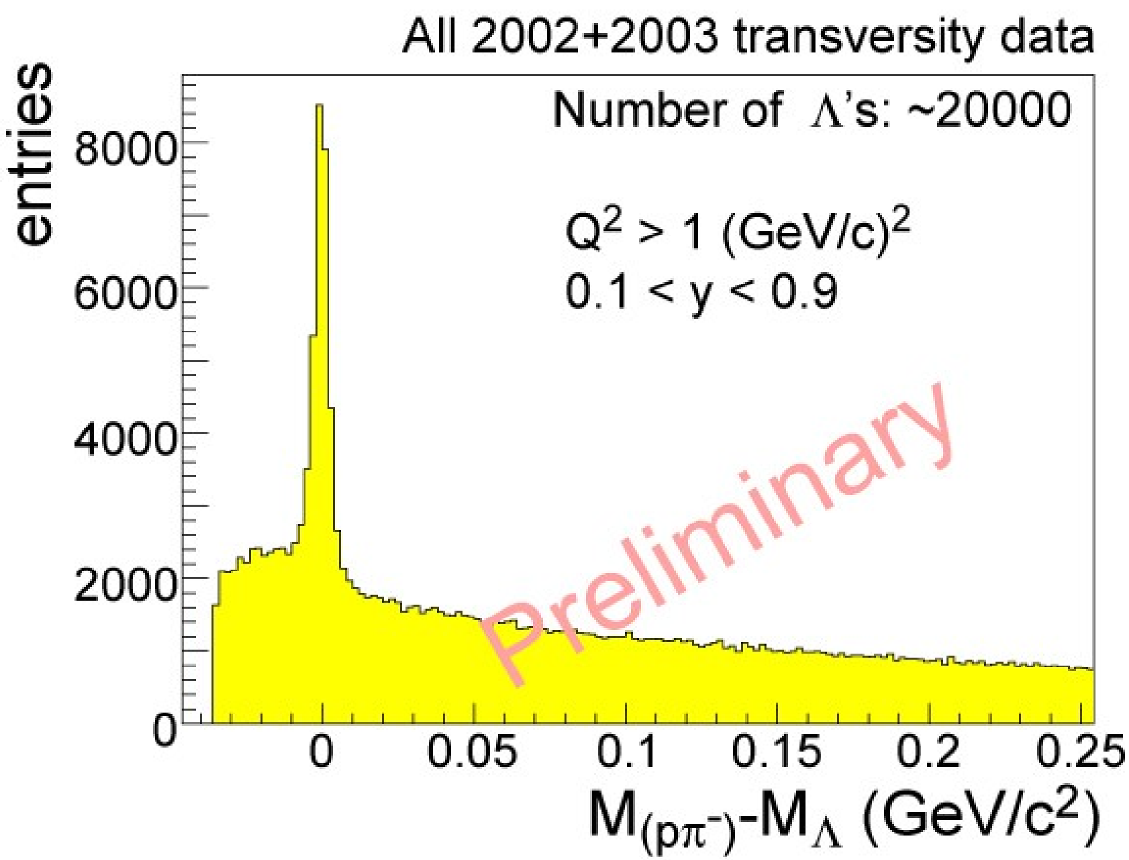
ϑ^* proton emission angle w.r.t. To S in the Λ rest frame

$Acc(\vartheta^*)$ the experimental acceptance

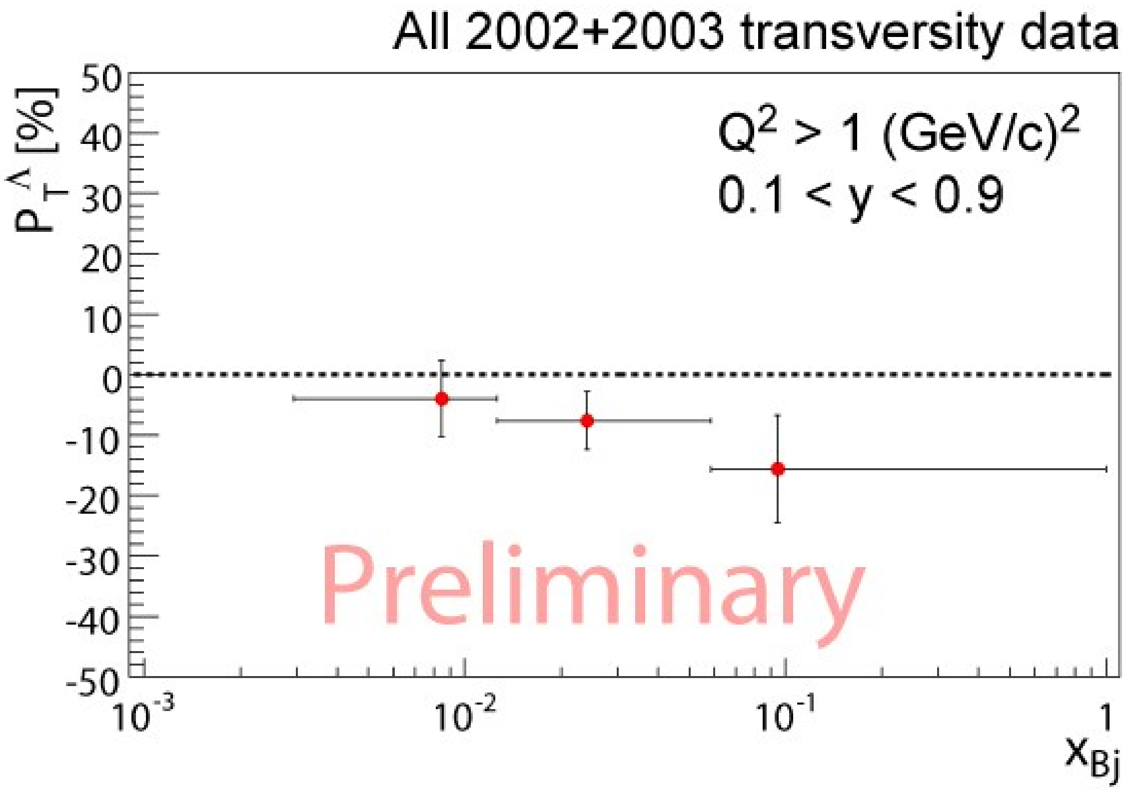
Event selection

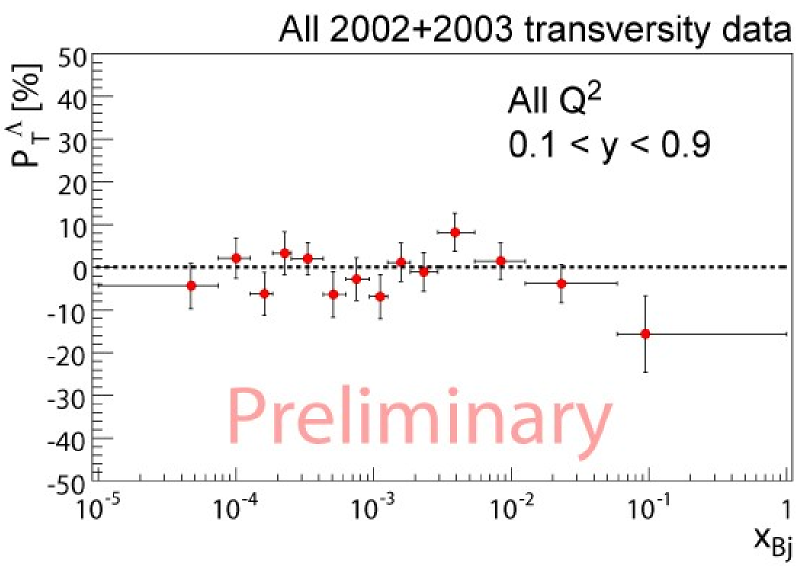
- Momentum of both decay particles > 1 GeV/c
- Collinearity < 10 mrad
- Decay vertex outside of the target
- Armenteros p_T > 23 MeV/c





$\Delta_T q(x)$ from Λ polarization





Conclusion (3)

- P_T^{Λ} has been measured in the COMPASS 2002+2003 transversity data sample.
- The x_{Bj} dependence does not show a significant deviation from zero
- The statistics in the most interesting region ($x_{Bj} > 0.1$) is still poor.
- The study of systematic effects show that they are not larger than the statistical errors
- Including the 2004 data will improve the statistics by a factor of two.

Outlook

- RICH identification of the hadrons in the one and two hadron analysis will be included

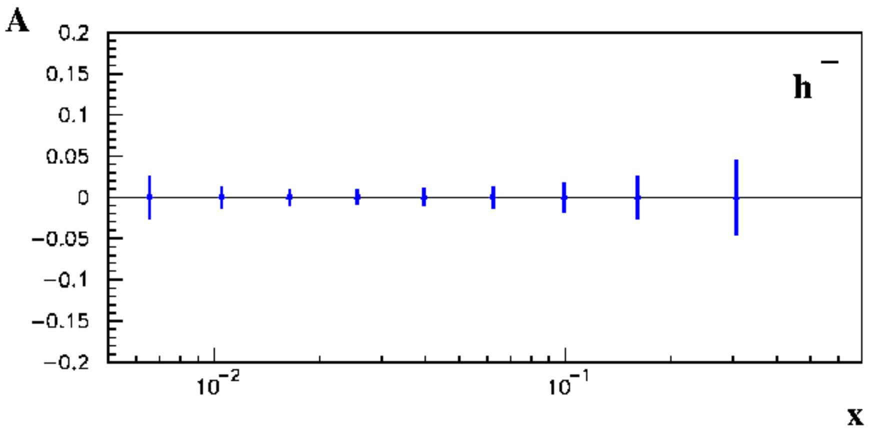
- <u>COMPASS in 2006:</u>

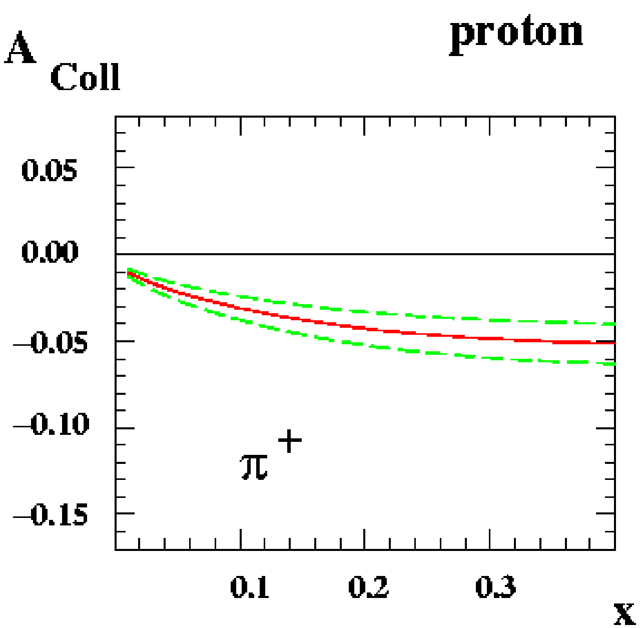
  → complementary measurements with proton target planned.

Data (of comparable statistics) will be collected on a transversely polarized proton target (NH_3) in 2006 and will allow for a flavor separation.

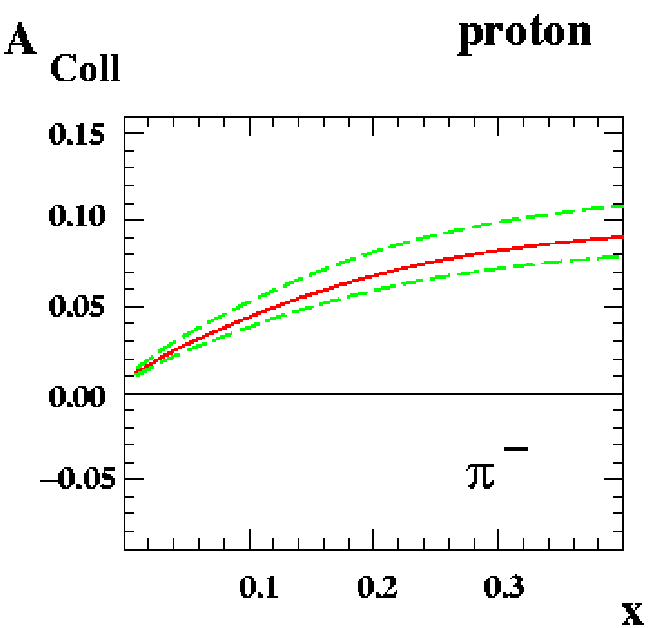
Expected signal for proton running

Expected signal for
~30 days running on NH_3





Collins effect



A. V. Efremov, K. Goeke and P. Schweitzer (hep-ph/0603054)

Expected signal for proton running

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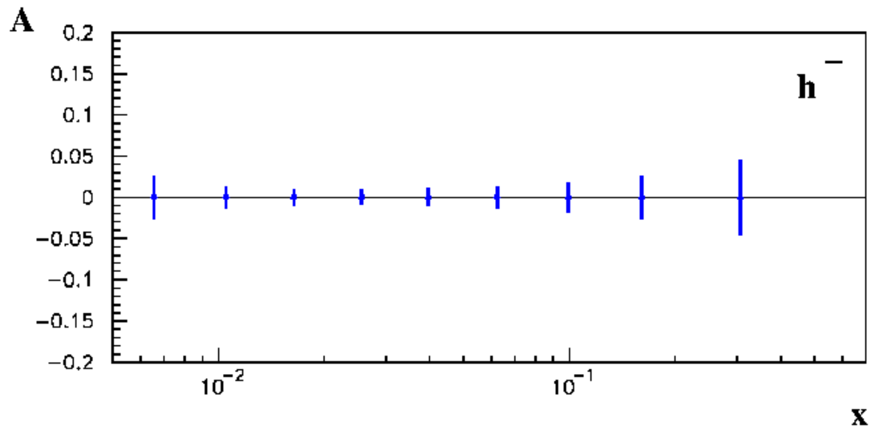
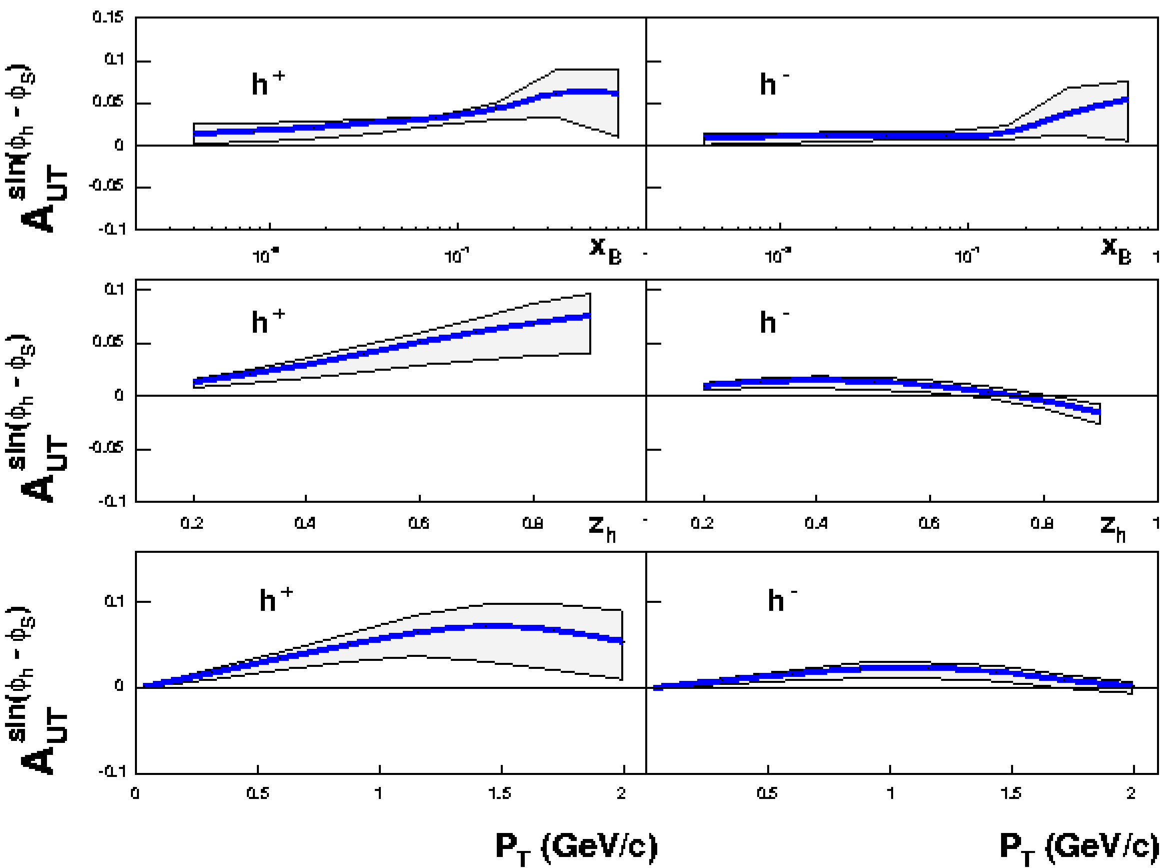




Sivers effect

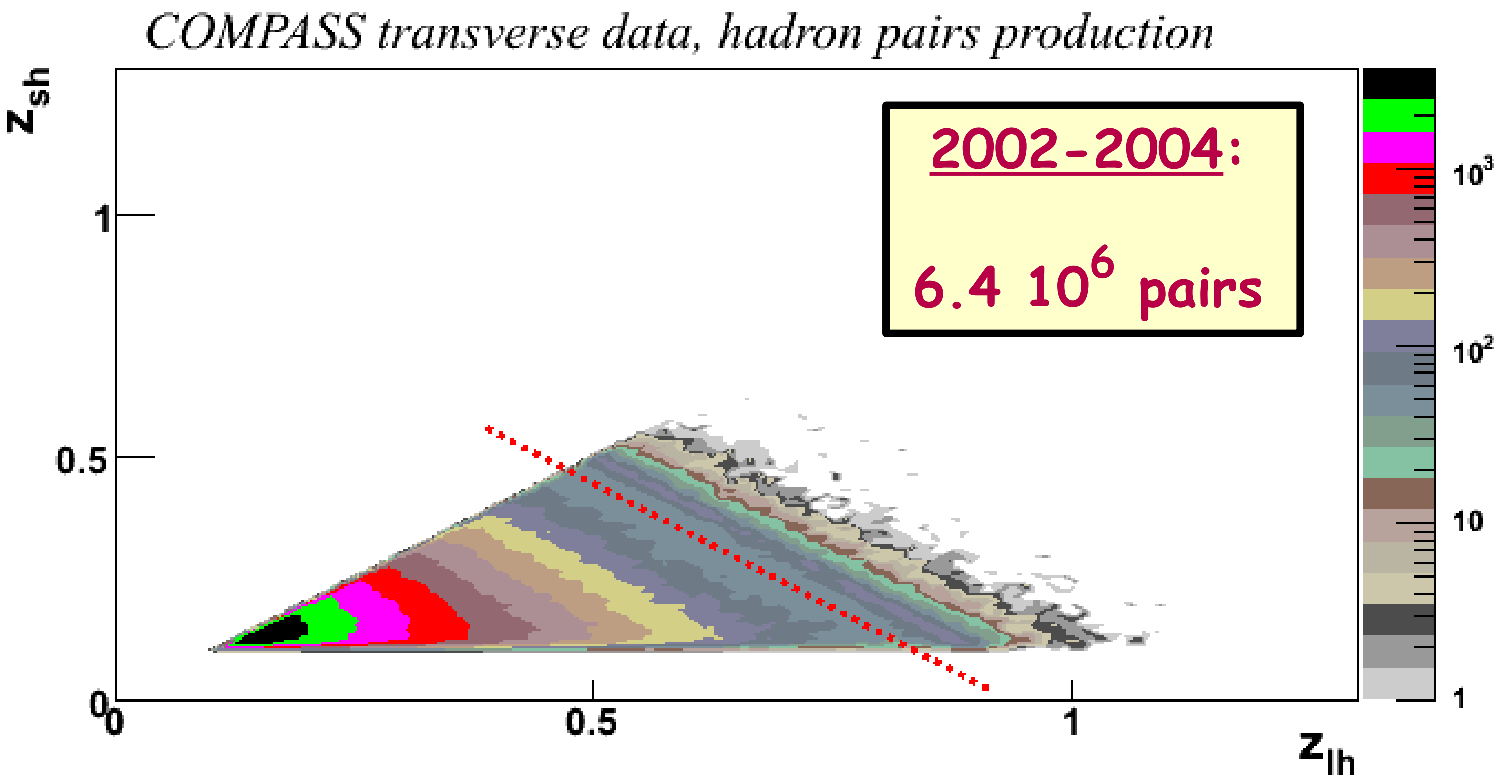
Anselmino et al.
(hep-ph/0507181)

Thank you

2-Hadron Asymmetries (z ordered pairs)

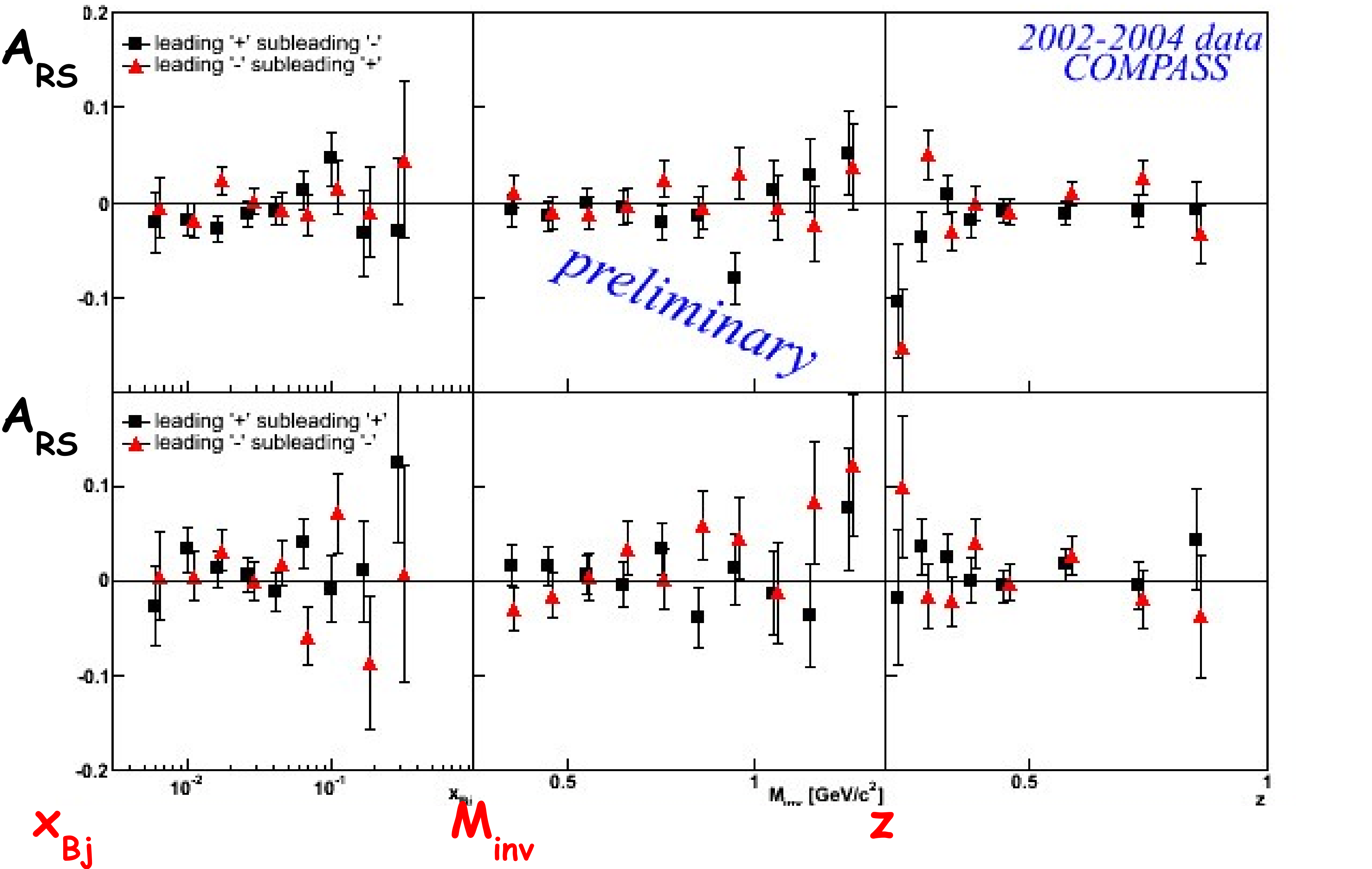
Select the combinations of leading (h_1) and next to leading (h_2) hadrons with:

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



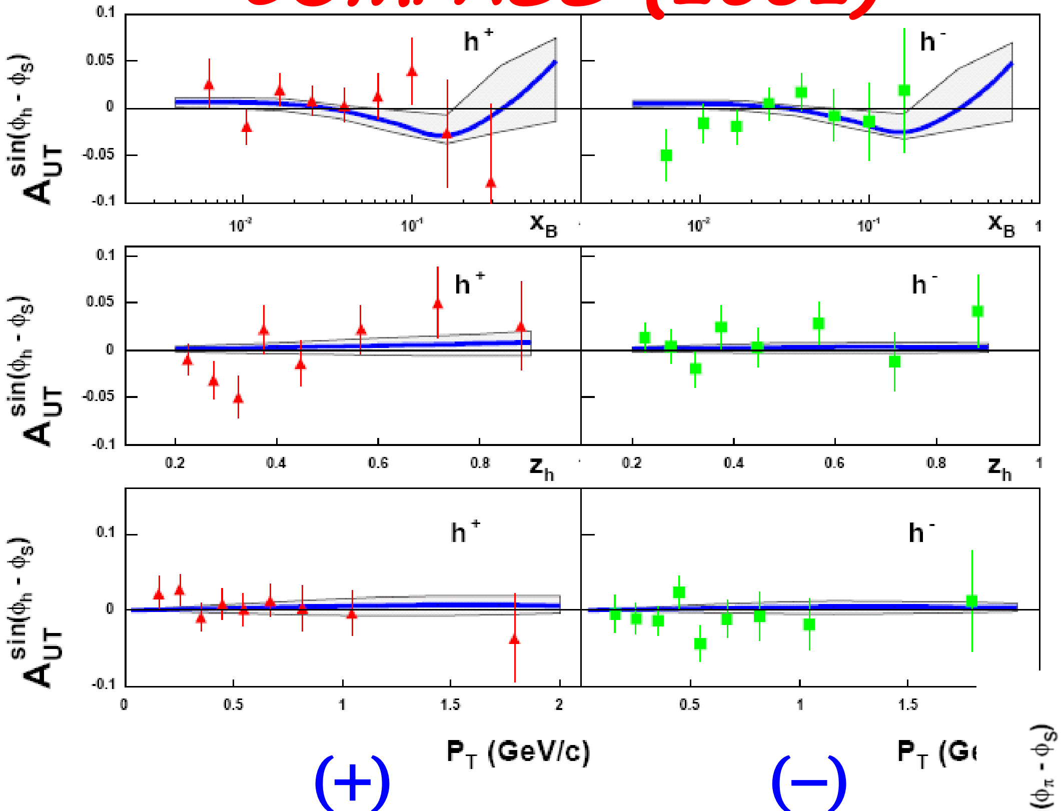
+/+	19.2 %	+/-	34.2 %
-/-	14.3 %	-/+	32.2 %

2-Hadron Asymmetries (z ordered pairs)



Fits and calculations (Sivers effect)

COMPASS (2002)



x_{Bj}

z

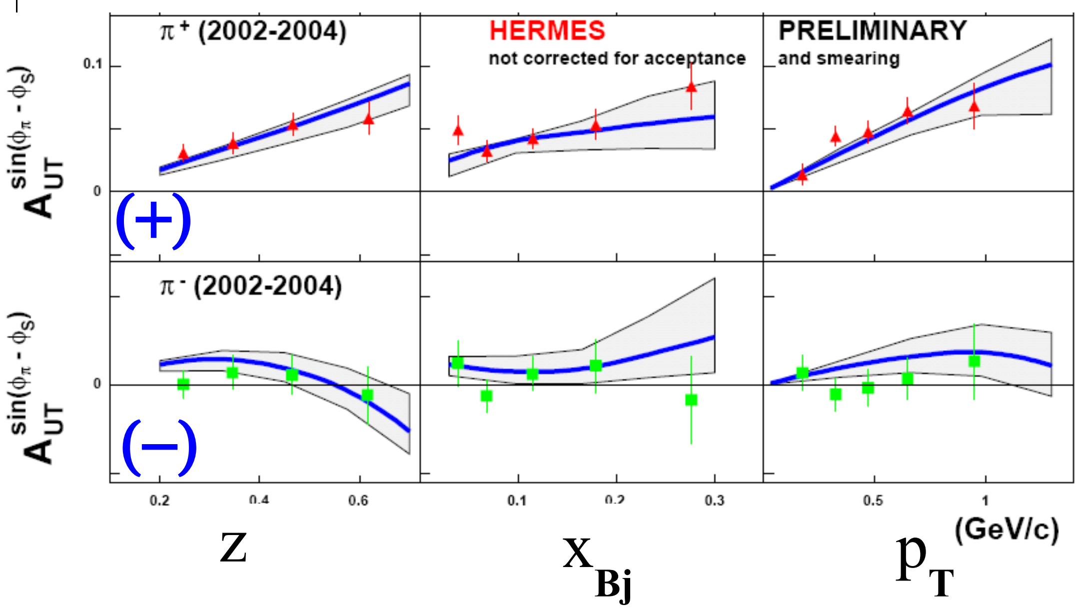
p_T

Sivers

M. Anselmino et al.

Sivers on Deuterium (hep-ph/0507181)

HERMES



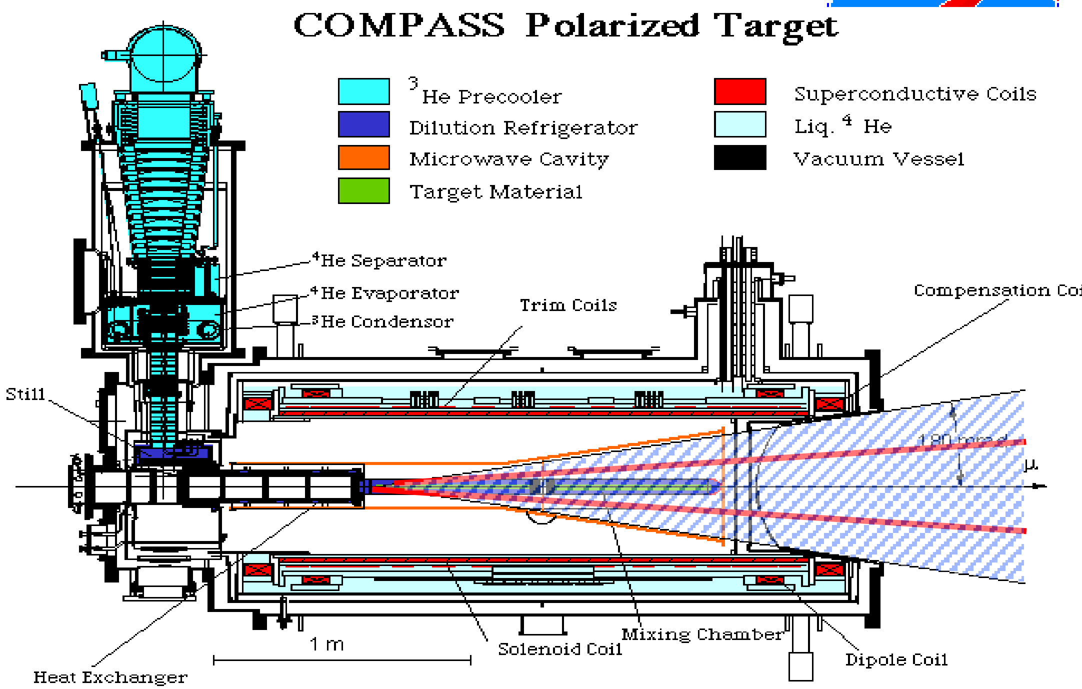
Phenomelogical model with full k_T parametrization of the HERMES and COMPASS (2002) data,

parameters are constrained by HERMES proton measurements;

COMPASS upgrades for 2006

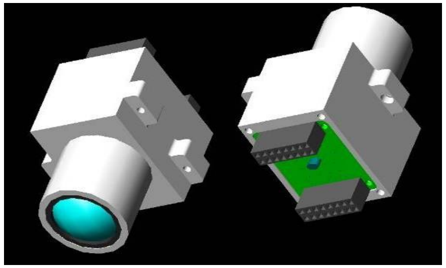
New solenoid magnet

- 70 mrad → 180 mrad



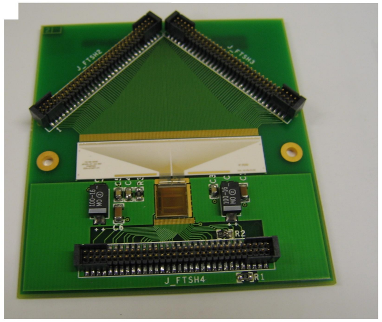
RICH upgrade

- Central region: MAPMT system
  - More photons
  - Improved S/N
- Outer region: New faster electronics
  - Improved S/N



Other important upgrades:

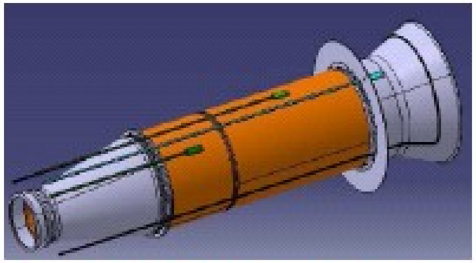
- Large Drift Chamber
- RICHWall
- Full ECAL coverage
- trigger



New target magnet

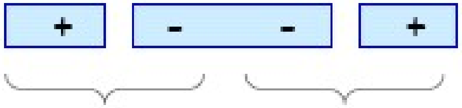
70 mrad $\rightarrow$ 180 mrad

Gain in statistics ~ 30%

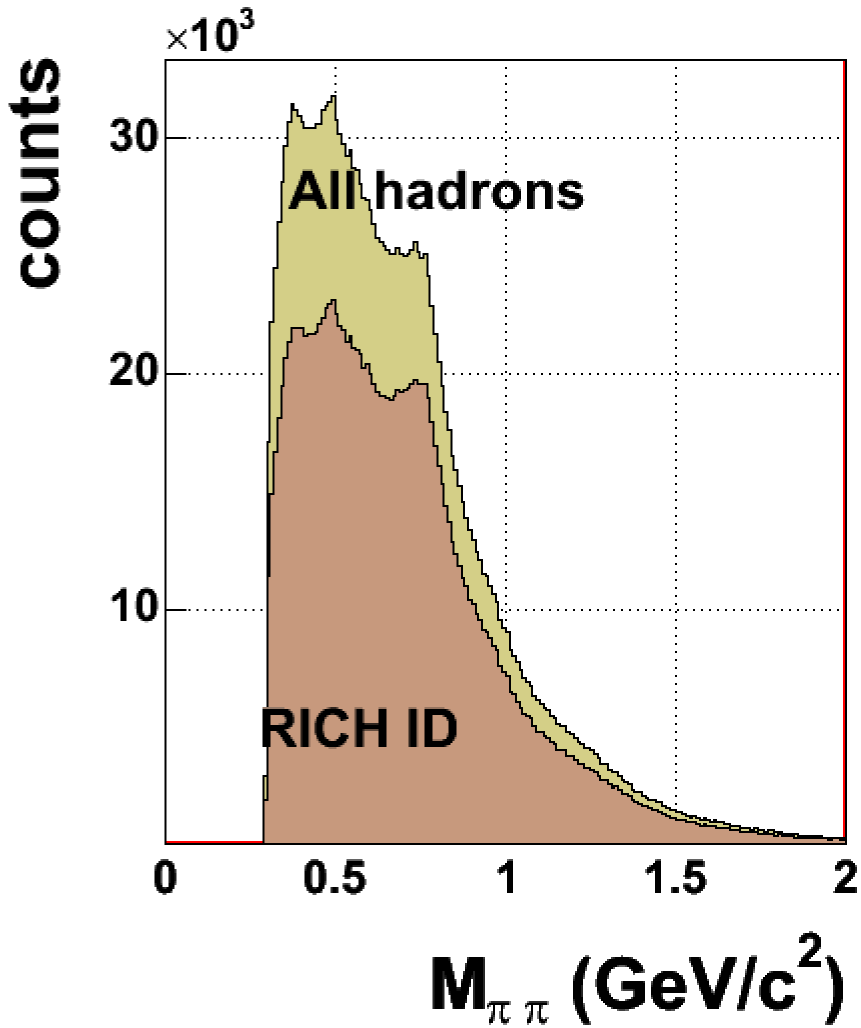


New 3 cell- cavity

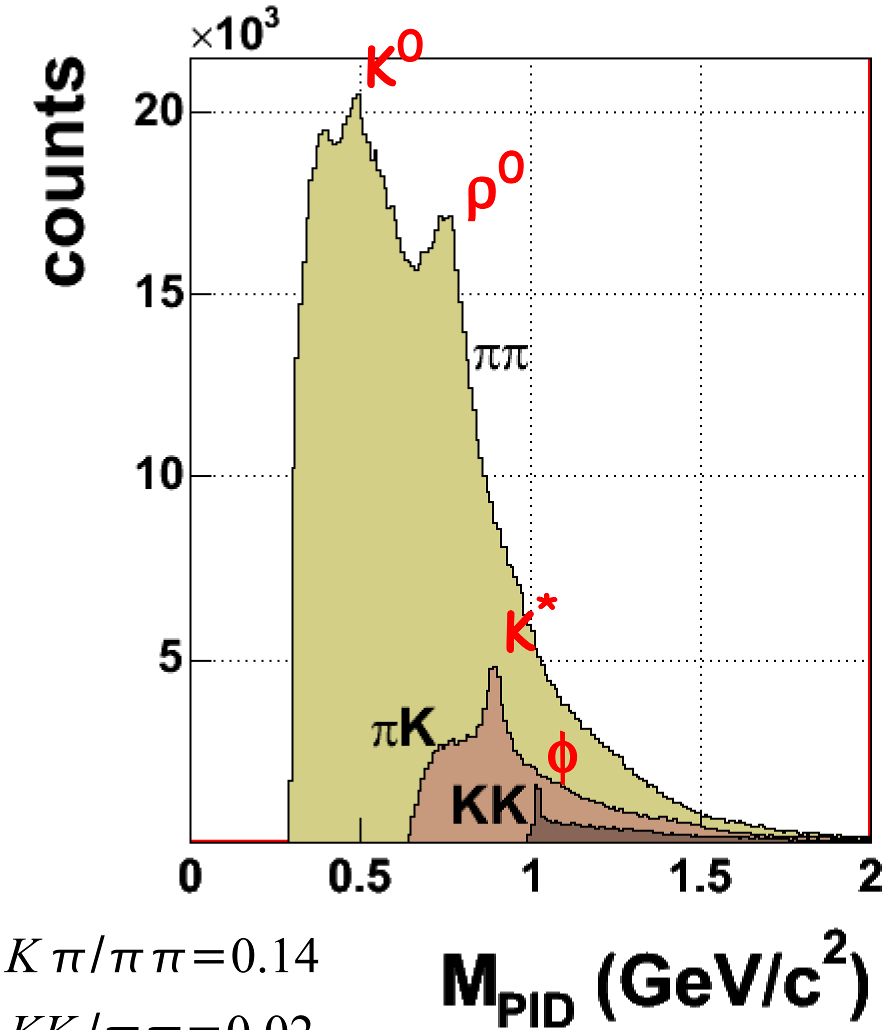
Reduce systematic effects



Using RICH PID



$$\frac{RICH\ ID}{All\ hadrons} = 0.74$$

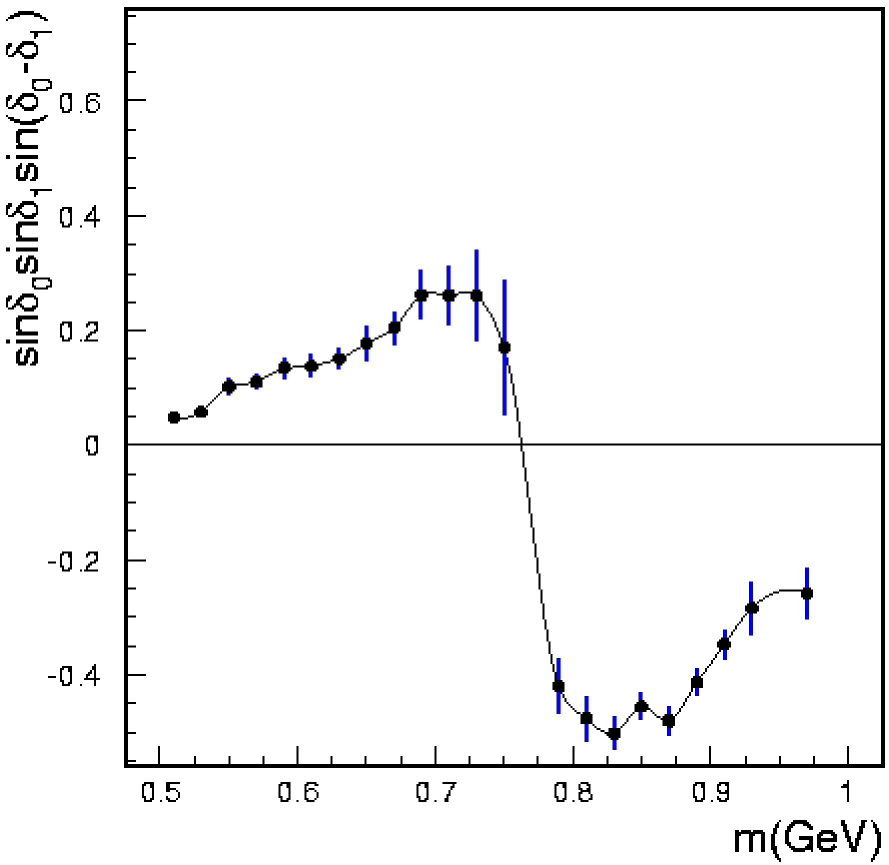


$K\pi / \pi\pi = 0.14$

$KK / \pi\pi = 0.02$

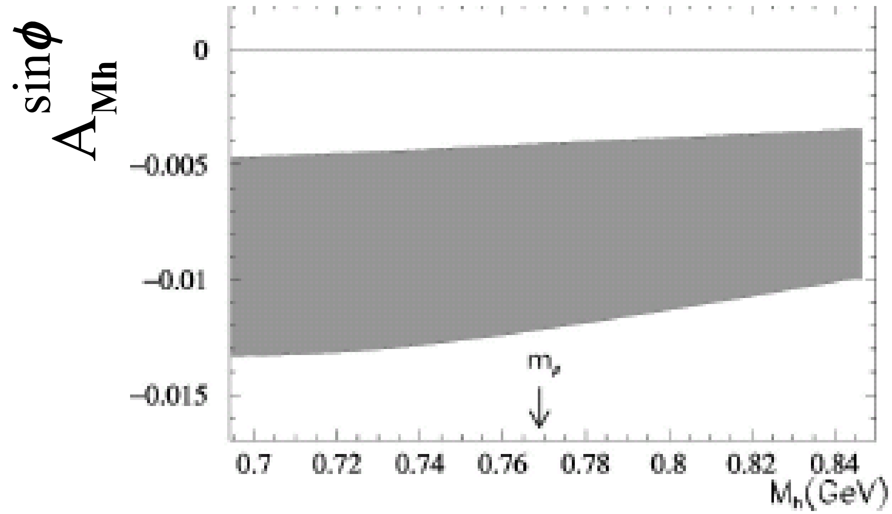
Interference Fragmentation Function $H_q^{\measuredangle h}(z, M_h^2)$

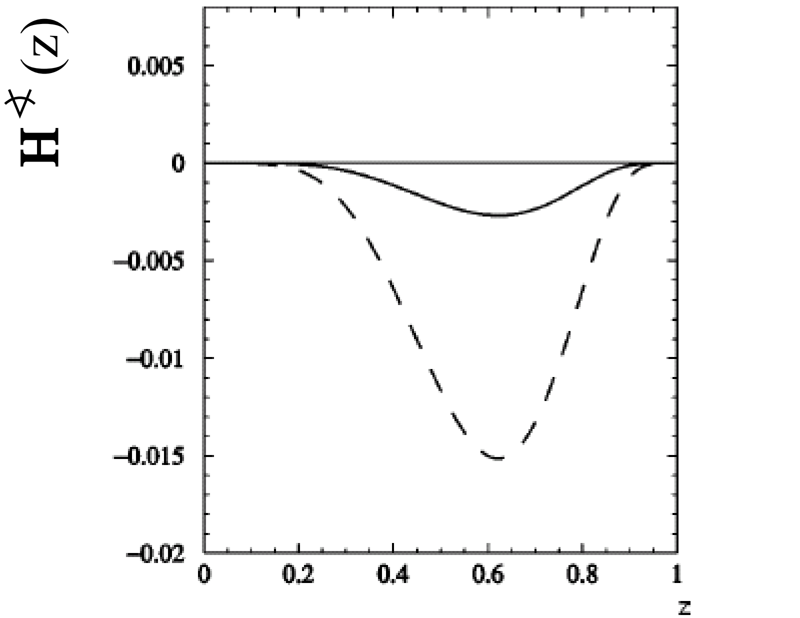
One model !



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

Another model !

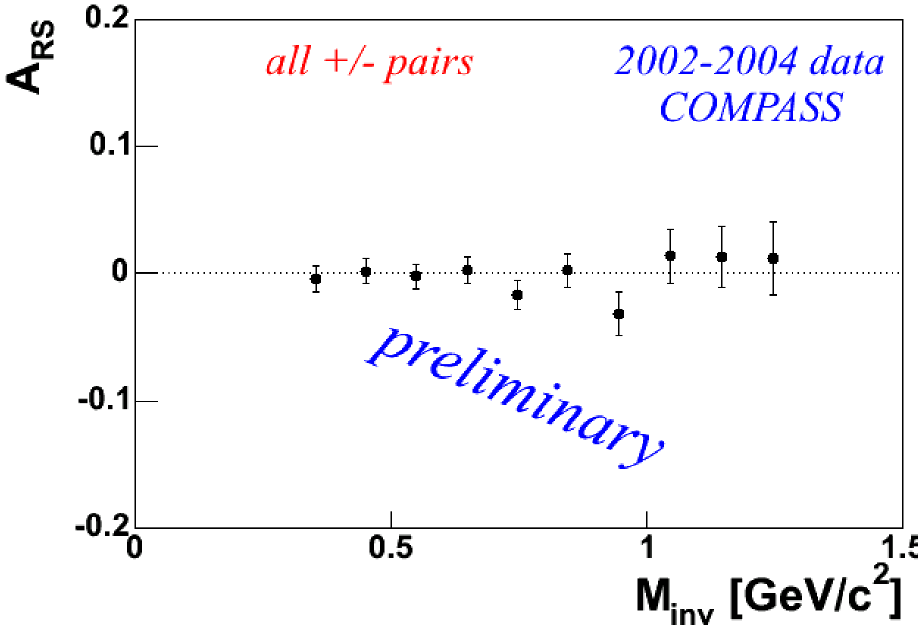




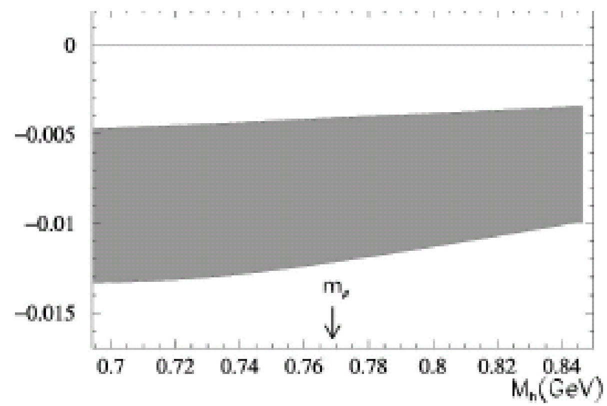
Radici, Jakob, Bianconi, PRD 65, 074031

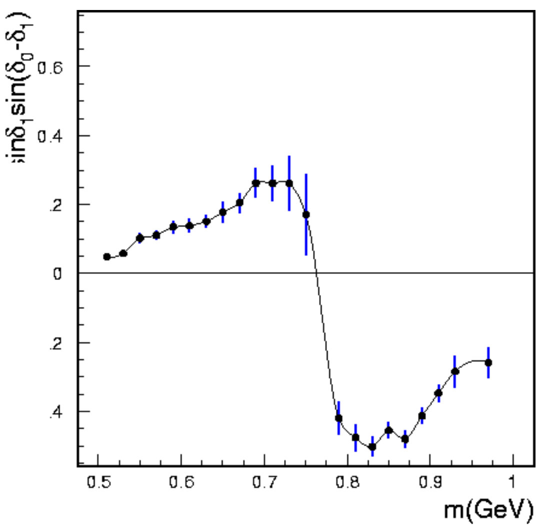
$$H^{\measuredangle}(z, M^2_{\pi^+\pi^-}) \sim \sin\delta_0 \, \sin\delta_1 \, \sin(\delta_0-\delta_1) \hat{H}^{\measuredangle}(z, M^2_{\pi^+\pi^-})$$

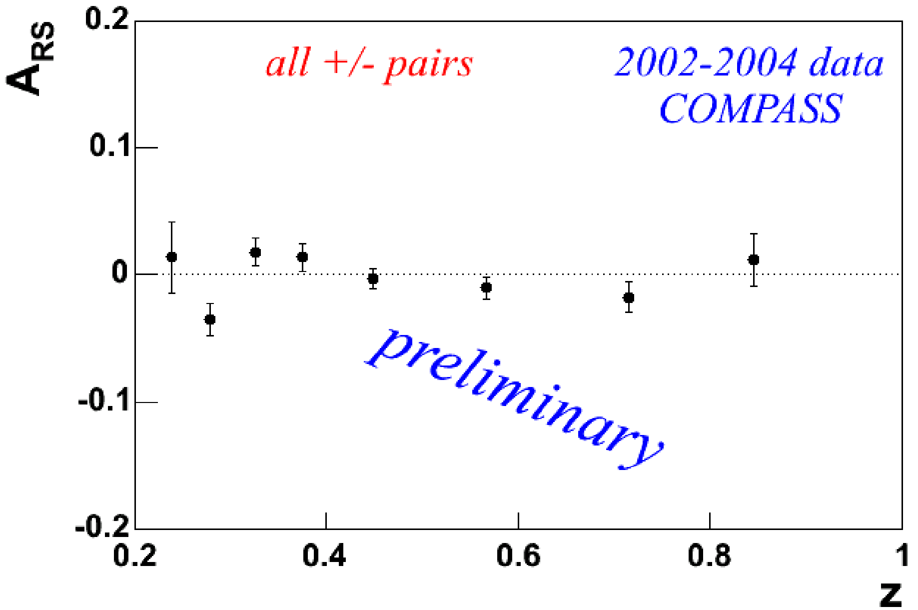
2-Hadron Asymmetry all +/- pairs



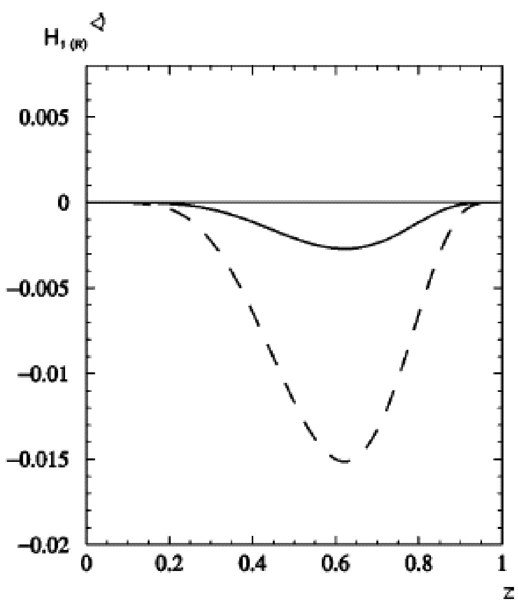
M_{inv}



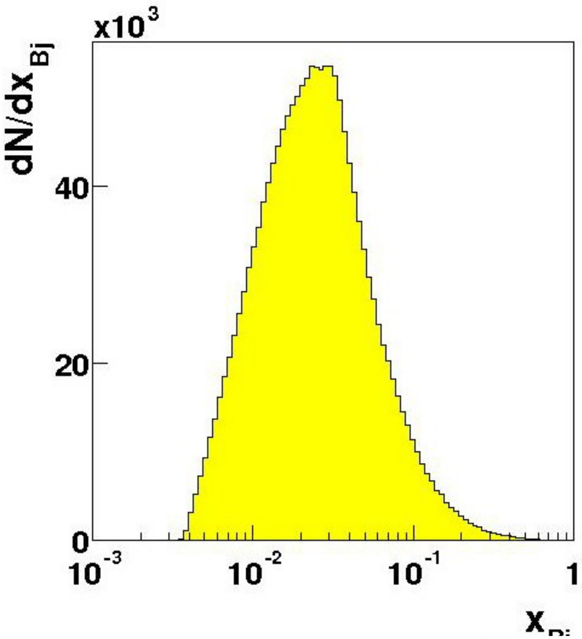




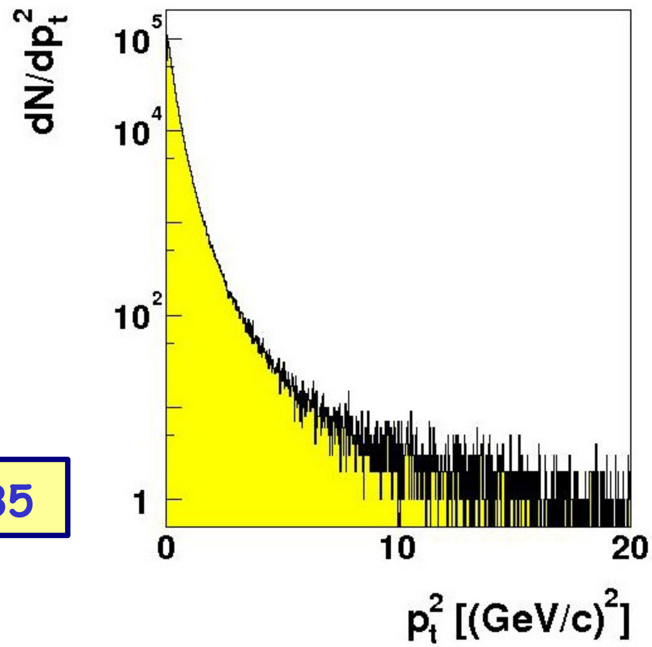
z



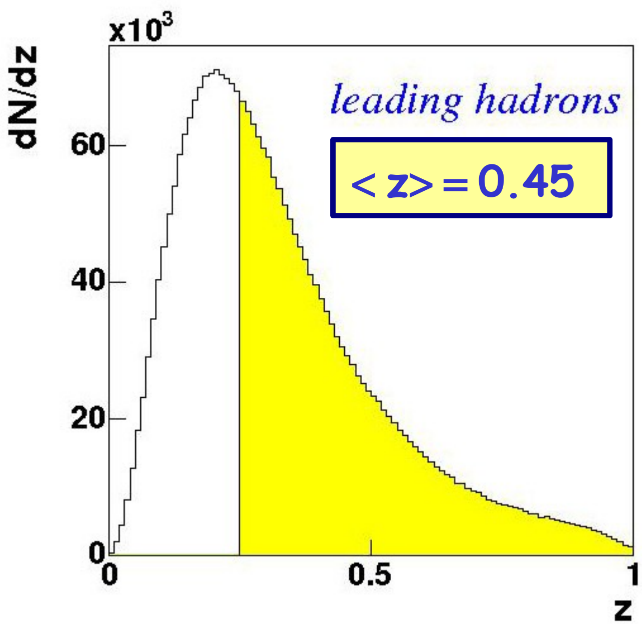
Final sample



$< x_{Bj} > = 0.035$



$< p_T^2 > = 0.3\ (GeV/c)^2$



Presently no

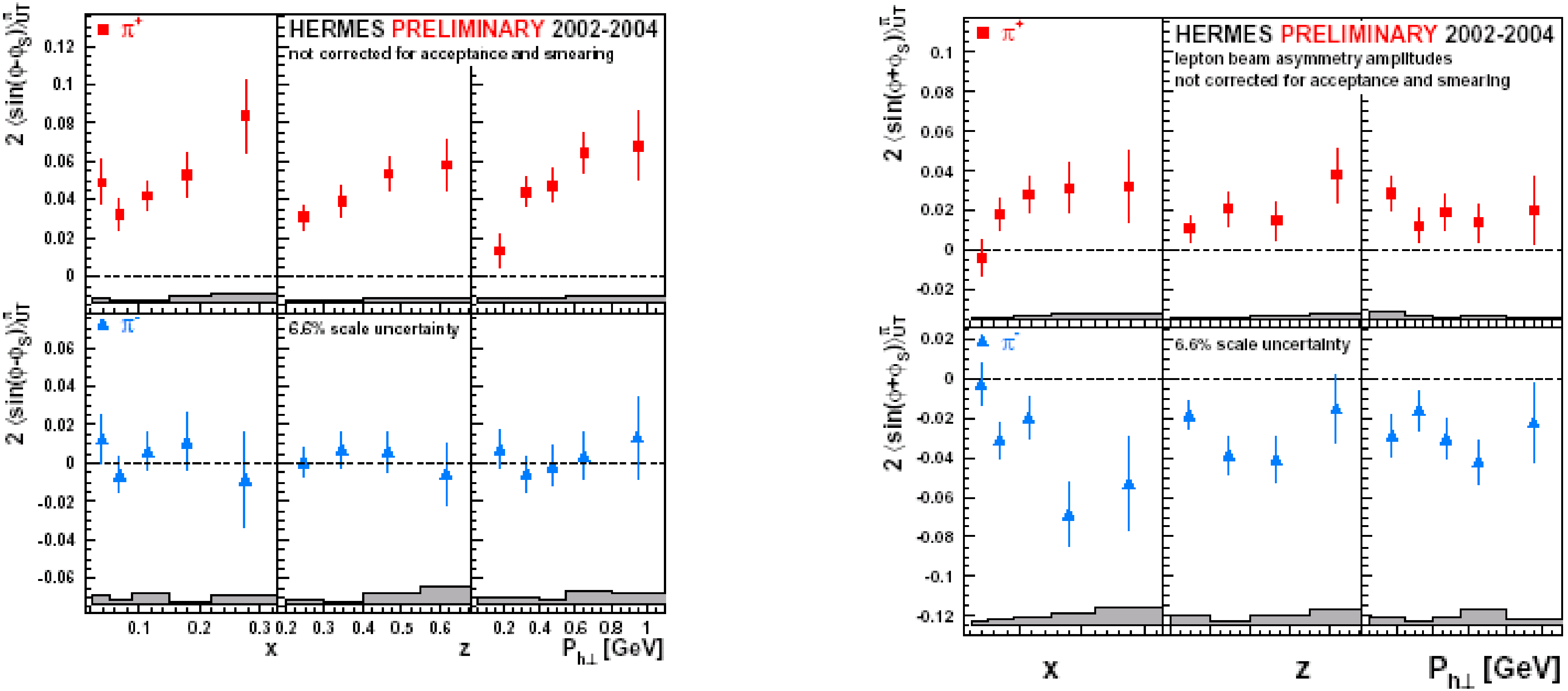
π / K / p separation

by RICH

Collins and Sivers effects

HERMES data (2002-2004, proton target):

Sivers   Collins



G. Schnell, Transverse Spin workshop 05, Como Sep, 7 2005

Interference fragmentation function $H_q^{\measuredangle h}(z, M_h^2)$

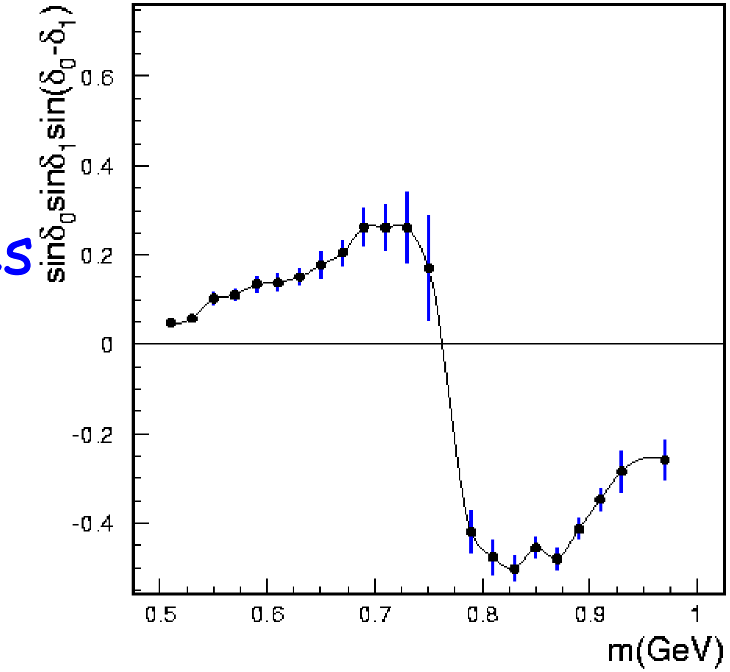
One model !

Example $\pi^+\pi^-$ fragmentation:

- $\pi^+\pi^-$ can be produced via the σ (I=0,L=0) and ρ (I=1,L=1) resonances
- Final state is a superposition of two resonant states with different relative phases

$$|\pi^+\pi^-, X\rangle = e^{i\delta_0}\,|\sigma, X\rangle + e^{i\delta_1}\,|\rho, X\rangle$$

leading to:



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

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

δ_0, δ_1 depend on $M^2_{\pi^+\pi^-}$ and can be obtained from $\pi\pi$ phase shifts

Asymmetry calculation

We measure:

$$N(\Phi) = N_0 \{1 + A_{UT}^{\sin\phi} \cdot \sin\Phi\} \cdot F_{acc}(\Phi)$$

$\mathbf{F_{acc}}$ unknown !

Reverse spins to cancel out $\mathbf{F_{acc}}$ and fit: $A_{UT}^{\sin\phi} \cdot \sin\Phi$

$$A_{Coll} = \frac{A_{UT}^{\sin\phi_C}}{D_{NN} \cdot f \cdot P} \qquad A_{Siv} = \frac{A_{UT}^{\sin\phi_S}}{f \cdot P}$$

Predicted Asymmetry

Expected count rate difference:

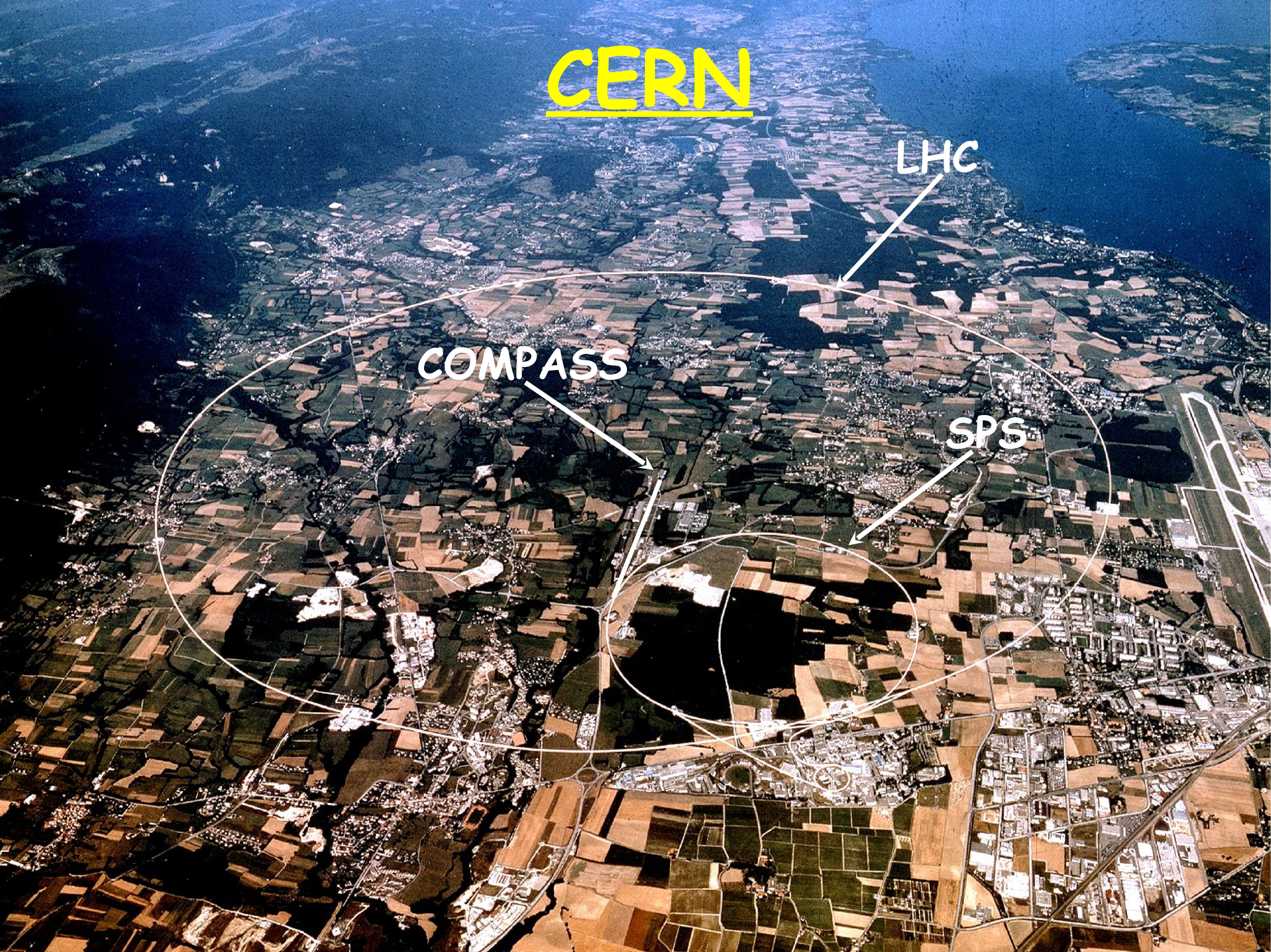
$$\frac{N^{\uparrow}(\phi_{RS}) - R\cdot N^{\downarrow}(\phi_{RS}+\pi)}{N^{\uparrow}(\phi_{RS}) + R\cdot N^{\downarrow}(\phi_{RS}+\pi)} = A_{UT}^{\sin\phi_{RS}} \cdot \sin\phi_{RS}$$

$$A_N(\phi_{RS}) = \frac{N_u^{\uparrow}(\phi_{RS})\, N_d^{\uparrow}(\phi_{RS})}{N_u^{\downarrow}(\phi_{RS})\, N_d^{\downarrow}(\phi_{RS})} \simeq C\left(1 + 4A_{UT}^{\sin\phi_{RS}} \sin\phi_{RS}\right)$$

From this we get:

$$\frac{A_{UT}^{\sin\phi_{RS}}}{D_{NN}\cdot f \cdot P} = A_{RS} = \frac{\sum_i e_i^2 \Delta_T q_i(x) H_i^{\sphericalangle h}(z, M_h^2)}{\sum_i e_i^2 q_i(x) D_i^h(\vec{z}, M_h^2)}$$

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