TRANSVERSITY PHYSICS IN DEEP INELASTIC SCATTERING

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on behalf of the COMPASS Collaboration

Trento, June 5, 2006

CONTENT

- **PHYSICS ISSUES**
- **HERMES vs COMPASS**
- **RESULTS on the**
  Proton (HERMES) and Deuteron (COMPASS)
  - **Collins and Sivers asymmetries**
    - ***positive and negative hadrons,*** $\pi^{\pm}$, $K^{\pm}$ — *NEW*
  - **Two hadron asymmetries** — *NEW*
  - **Λ polarimetry**
- **PERSPECTIVES**

TRANSVERSE SPIN PHYSICS

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

$q(x)$

momentum distribution

$\Delta q(x)$

helicity distribution

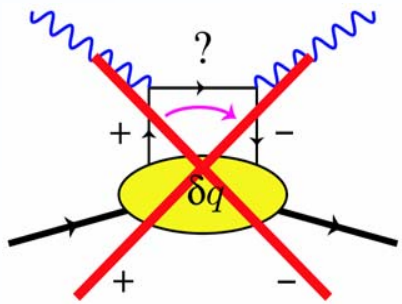
$\Delta_T q(x)$

transversity distribution

all of equal importance!

$\Delta_T q\,(x)$ **decouples from leading twist DIS because helicity of quark must flip**

NO MIXTURE WITH GLUON



TRANSVERSITY

In the last ten years:

- great development in the theory of transversity
- remarkable role of $\Delta_T q(x)$, notably complementary to $\Delta q(x)$

In the last few years:

- role of the k_t structure functions clarified (Cahn and Sivers effects, …)

Key features of transversity:

- probes relativistic nature of quarks
- no gluon analog for spin-1/2 nucleon
- different Q^2 evolution and sum rule than $\Delta q(x)$
- sensitive to valence quark polarization

- **Tensor charge ('91 – '92):**

$$g_T = \int dx \left[\Delta_T q(x) - \Delta_T \bar{q}(x) \right]$$

in analogy with:

$$g_A = \int dx \left[\Delta q(x) + \Delta \bar{q}(x) \right]$$

- **Soffer inequality (95):**

$$\Delta_T q(x) \leq \frac{1}{2} \left(\Delta q(x) + q(x) \right)$$

- **Leader sum rule (04):**

$$\frac{1}{2} = \frac{1}{2} \sum_{q,\bar{q}} \int dx \cdot \Delta_T q(x) + \sum_{q,\bar{q},g} \langle L_z \rangle$$

in analogy with:

$$S_z = \frac{1}{2} \Delta\Sigma + \Delta G + \langle L_z \rangle$$

Collins and Sivers asymmetries

$$N_h^{\pm}(\Phi_C) = N_h^0 \cdot \left\{ 1 \pm A_C^h \cdot \sin\Phi_C \right\}$$

$$A_{Coll} = \frac{1}{f \cdot P_T \cdot D_{nn}} \cdot A_C^h = \frac{\sum_a e_a^2 \cdot \Delta_T q_a \cdot \Delta D_a^h}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

$$N_h^{\pm}(\Phi_S) = N_h^0 \cdot \left\{ 1 \pm A_S^h \cdot \sin\Phi_S \right\}$$

$$A_{Siv} = \frac{1}{f \cdot P_T} \cdot A_S^h = \frac{\sum_a e_a^2 \cdot \Delta_0^T q_a \cdot D_a^h}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

calculated as function of x, z and p_t

for *Leading Hadrons* and *All Hadrons*

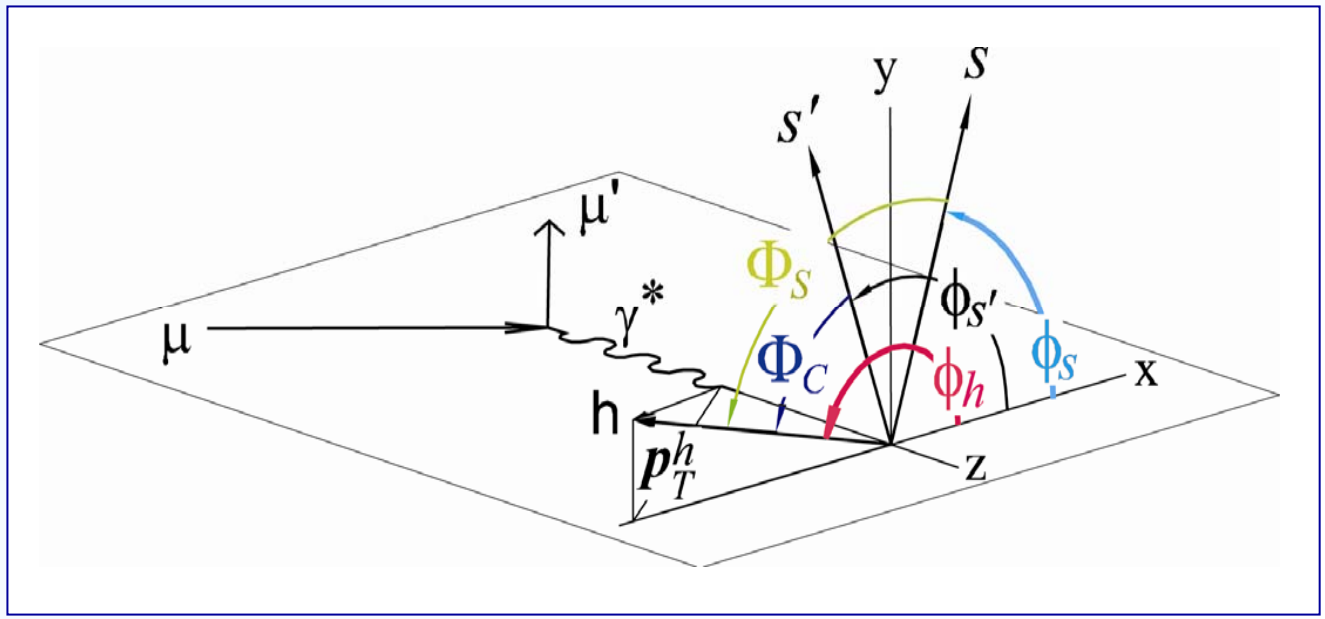
Collins and Sivers angles

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

ϕ_h azimuthal angle of hadron momentum

$$\Phi_C = \phi_h - \phi_{S'}$$

$$\Phi_S = \phi_h - \phi_S$$



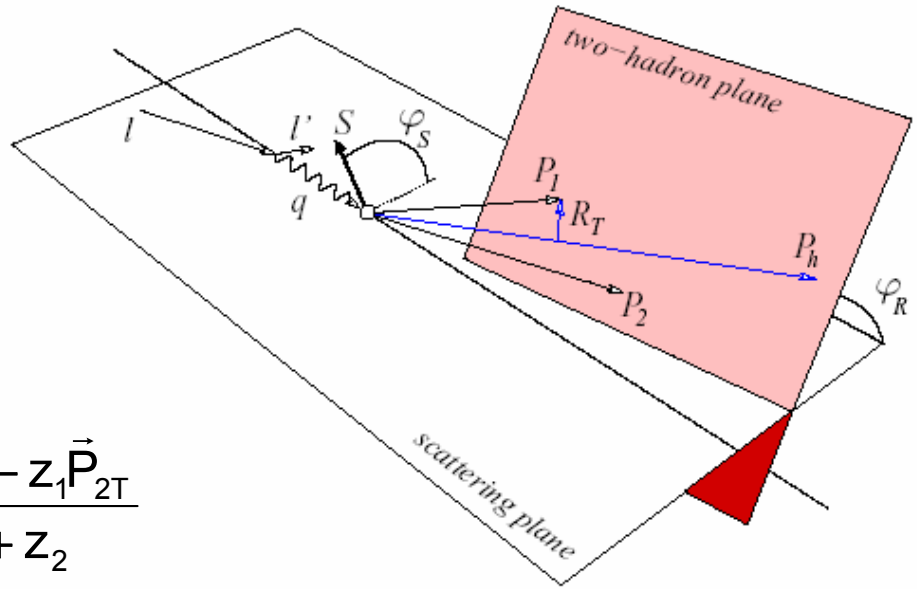
WATCH OUT: some authors define Φ_C as $\phi_{S'} - \phi_h$

Two Hadron Asymmetries

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

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

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

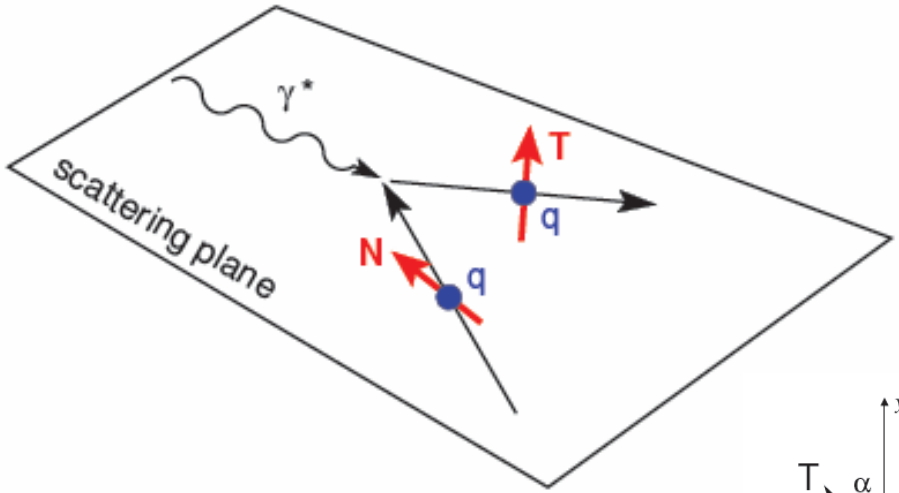


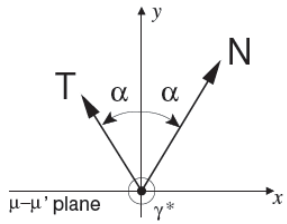
$$\vec{P}_h = \vec{P}_1 + \vec{P}_2 \qquad \vec{R}_T = \frac{z_2\vec{P}_{1T} - z_1\vec{P}_{2T}}{z_1 + z_2}$$

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

Λ polarimetry

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





N: component of target spin perpendicular to p_{γ^*}

T: symmetric of N wrt. the normal to the scattering plane

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

f = target dilution factor, P_N = target polarization,

$D(y)$ = virtual photon depolarization factor

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

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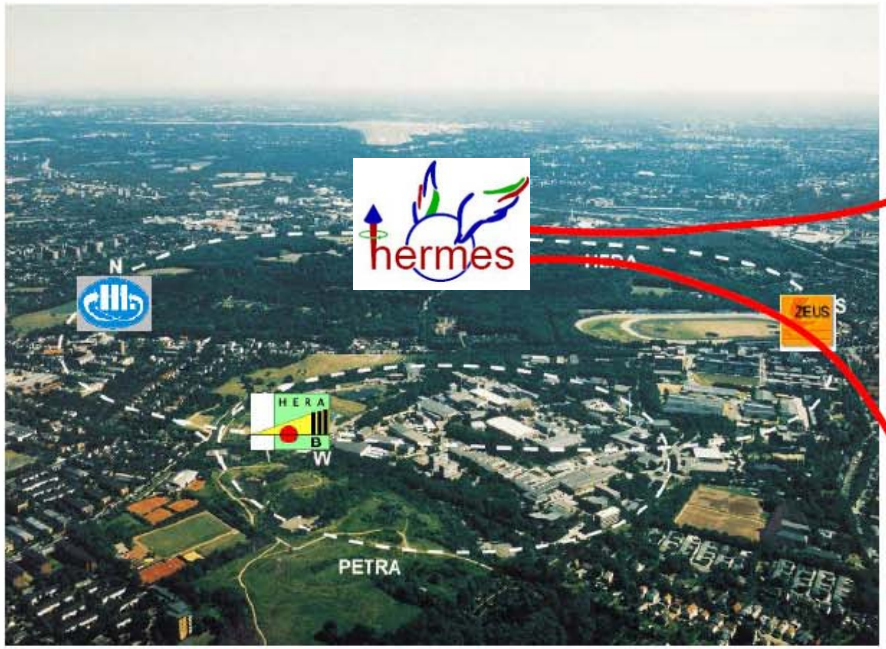
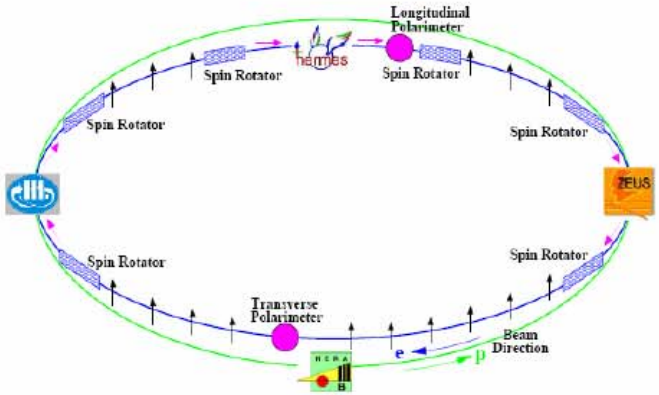
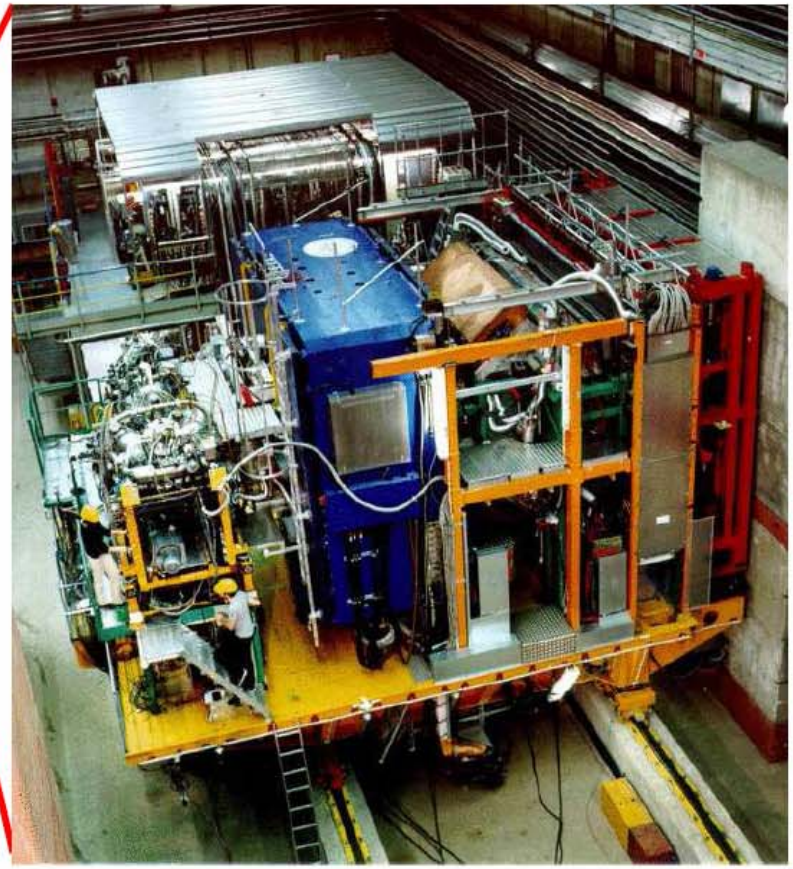
The HERA storage ring (DESY)





- 27.5 GeV e^+/e^- beam
- Self-polarizing through Sokolov-Ternov-Effect
- Average beam polarization of about 55%

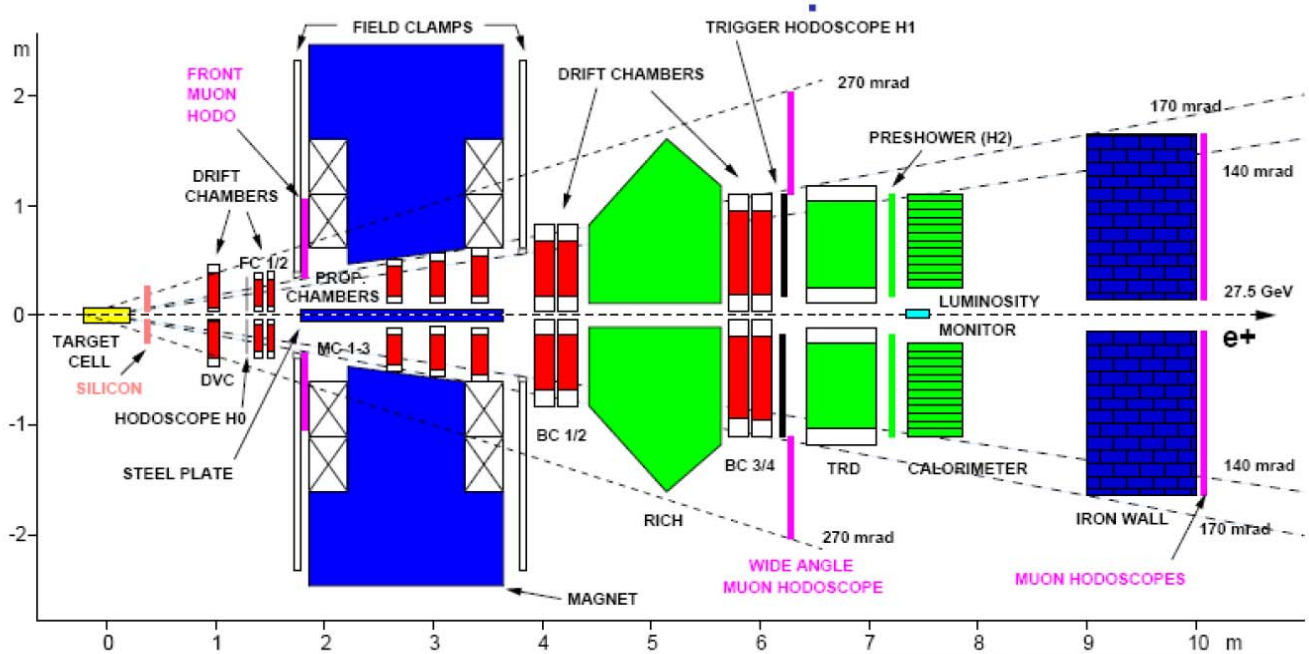
The HERMES Spectrometer

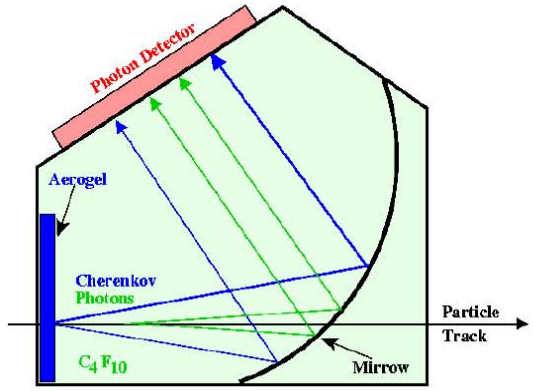


- Fixed target experiment
- forward spectrometer symmetric above and below the beampipe
- Polarized internal gas target
- Relatively large acceptance

Angular acceptance: $40\ mrad < |\theta_y| < 140\ mrad \quad |\theta_x| < 170\ mrad$

Resolution: $\delta p \le 2.6\% \ ; \quad \delta\vartheta \le 1\ mrad$





Dual radiator RICH

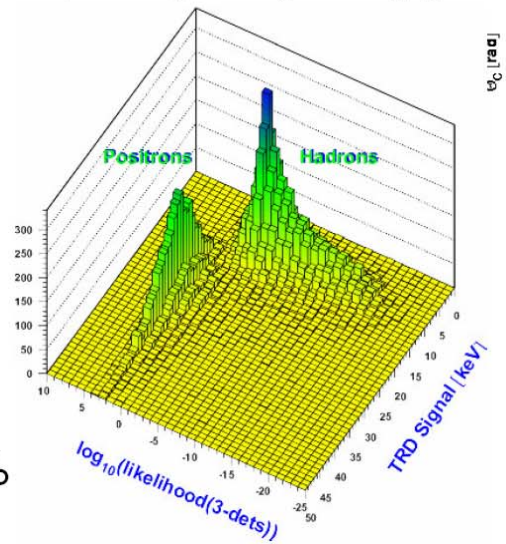
Particle Identification:

TRD, Calorimeter, preshower, RICH:

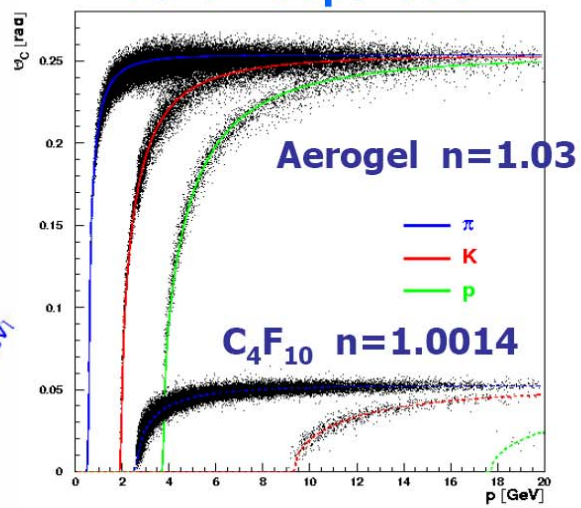
lepton-hadron > 98%

RICH:

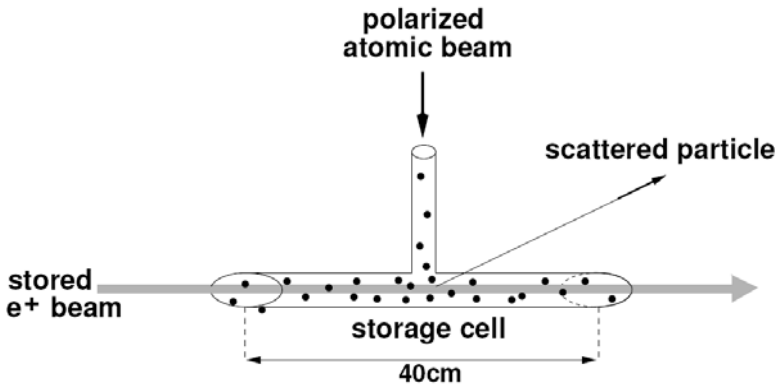
Hadron: π ~ 98%, K ~ 88% , P ~ 85%



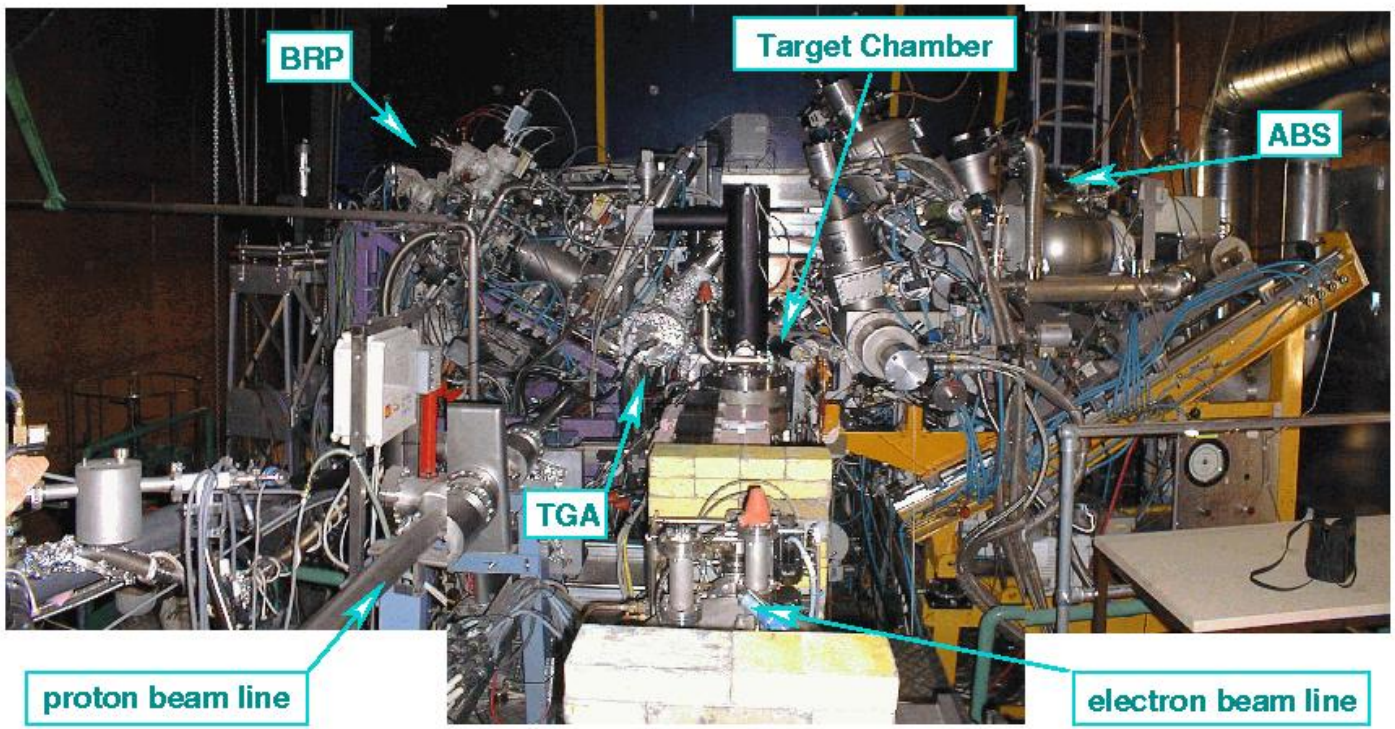
hadron separation

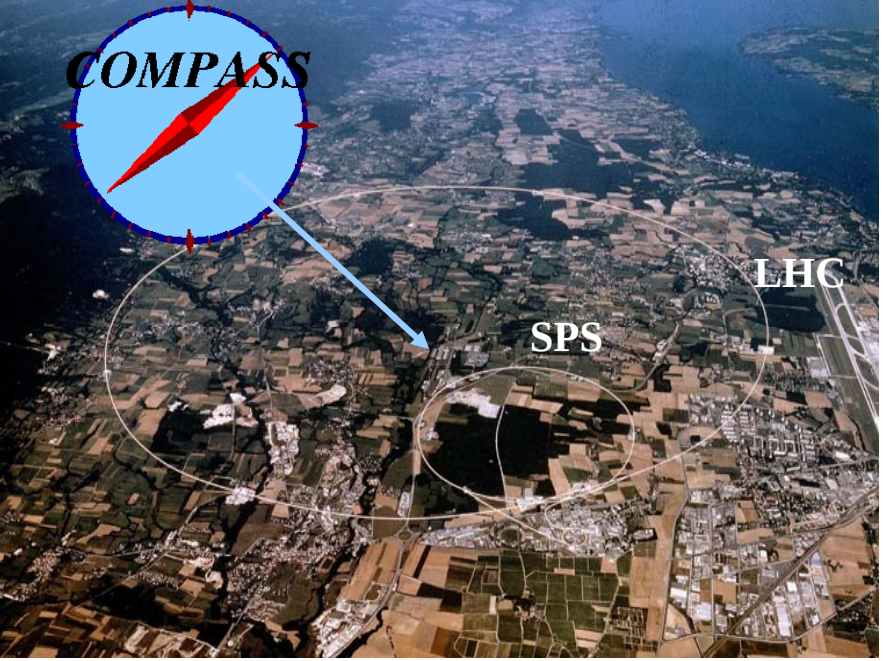


The polarized target

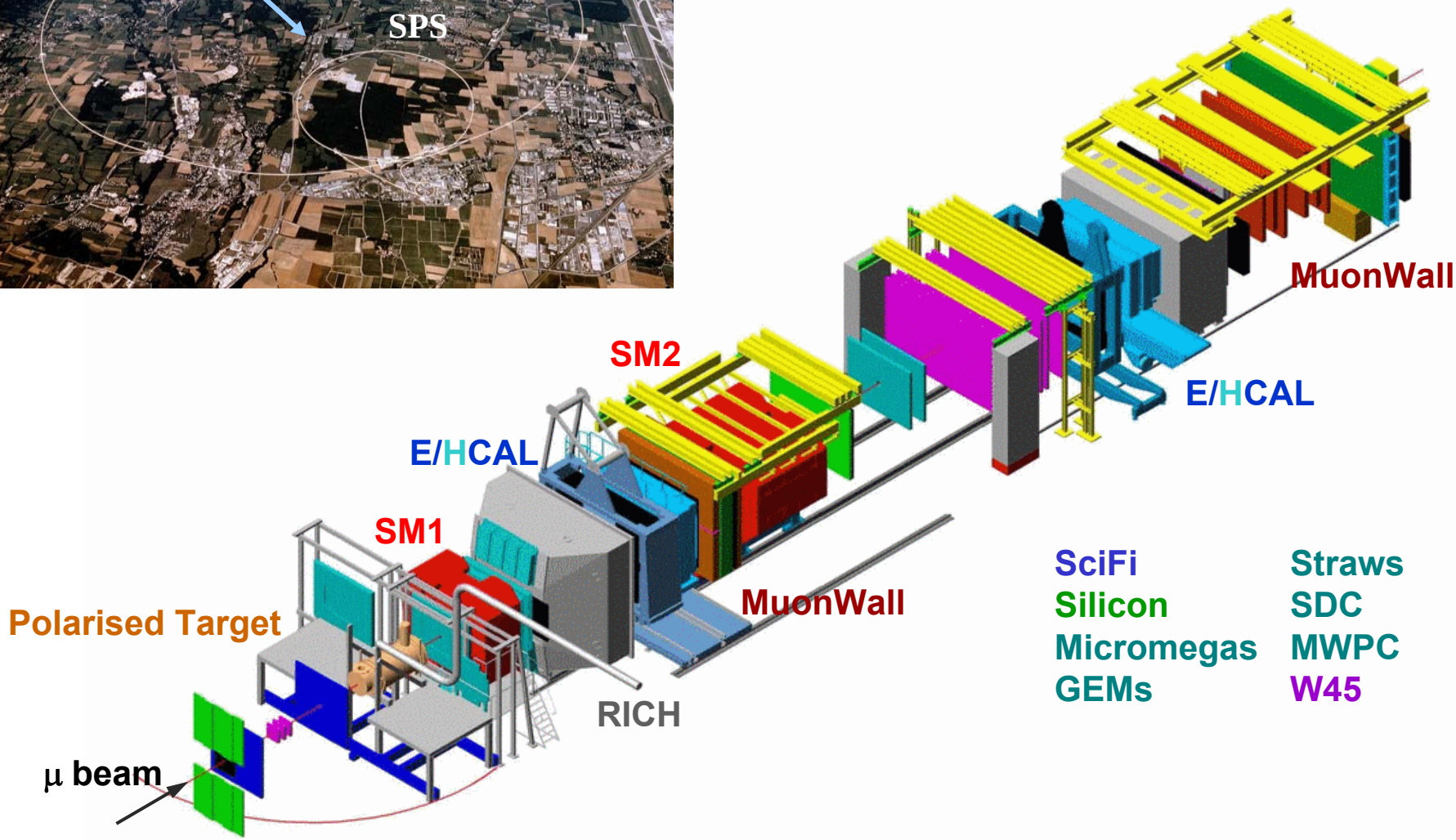


- High degree of polarization ($P^T > 0.8$)
- No dilution ($f \approx 1$)
- Fast spin reversal (< 1 s)

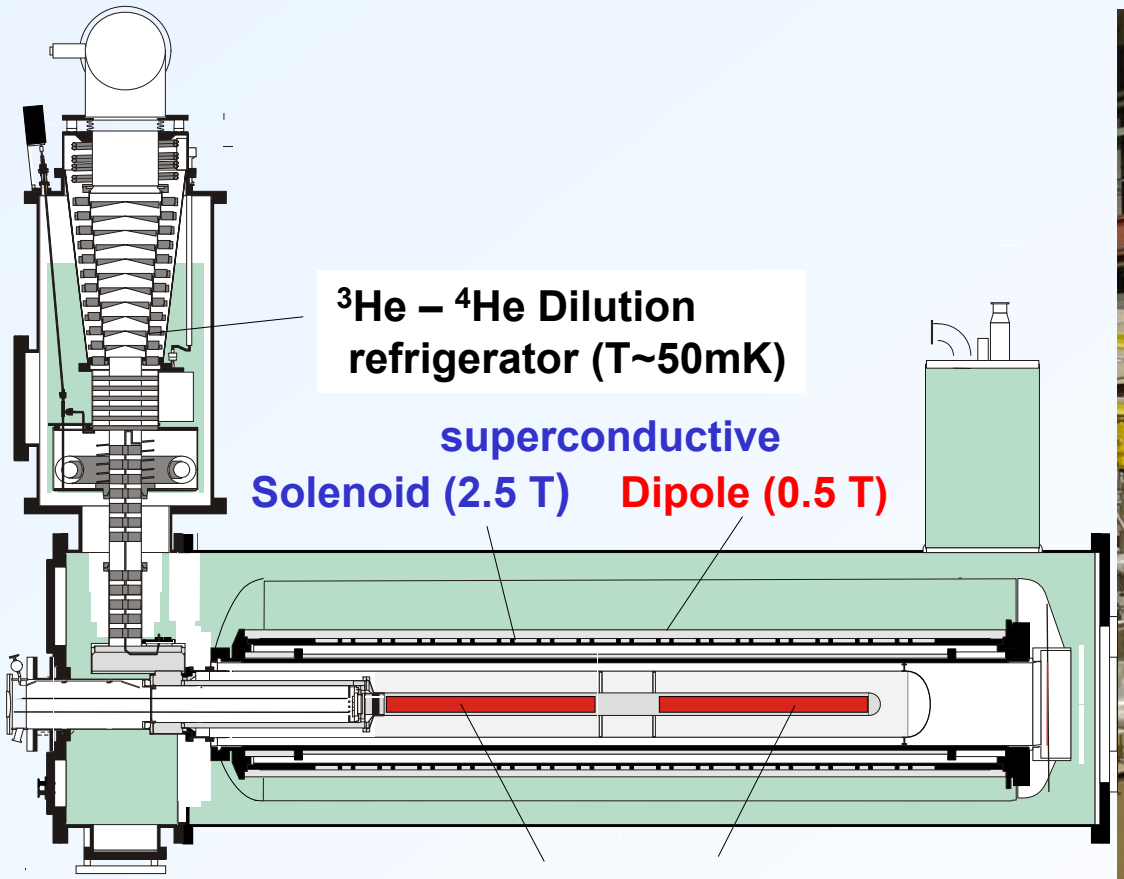


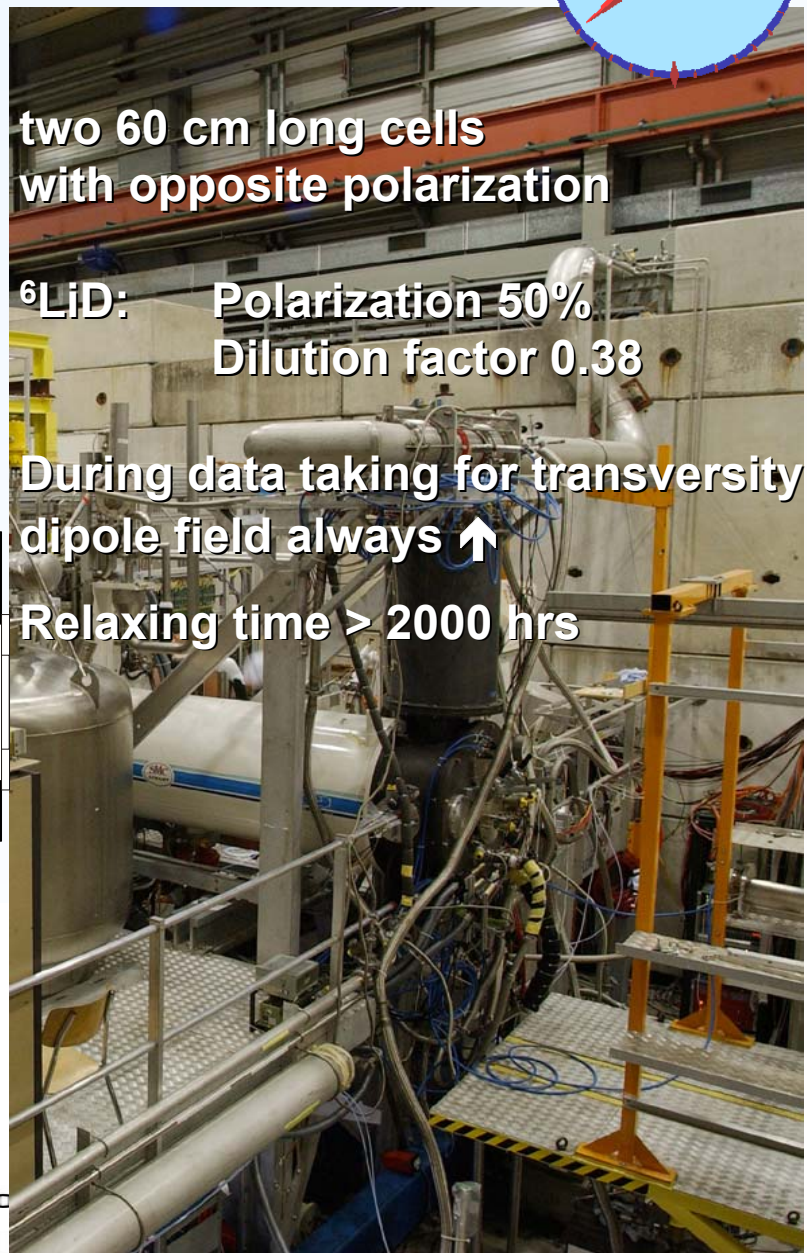


longitudinally polarised muon beam
beam intensity: $2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)
beam momentum: 160 GeV/*c*
luminosity: $\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}

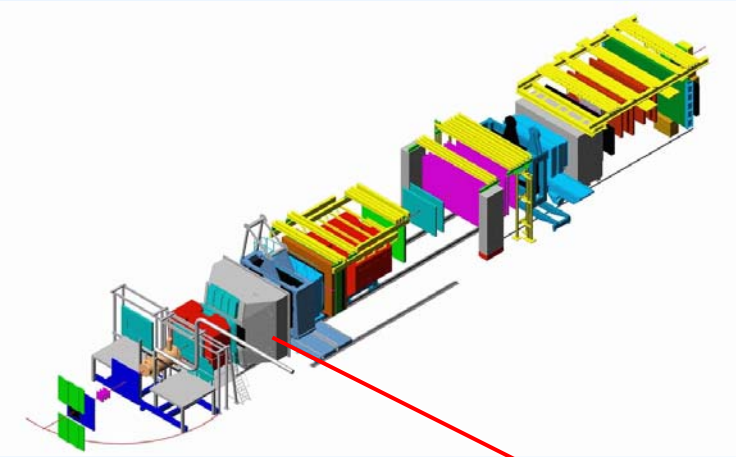


THE TARGET SYSTEM





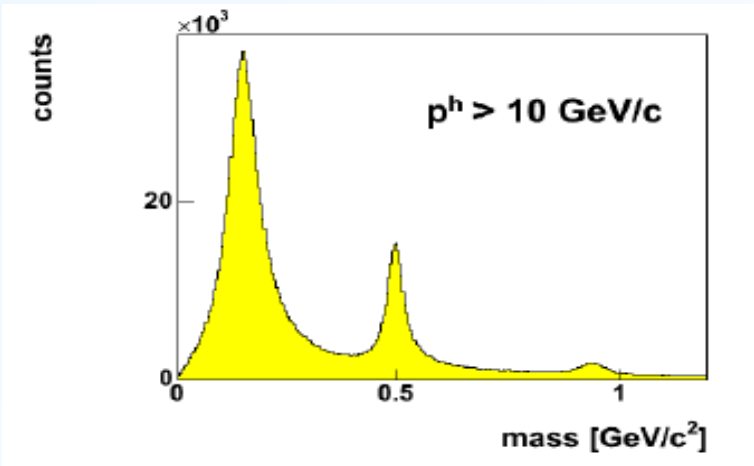
COMPASS RICH

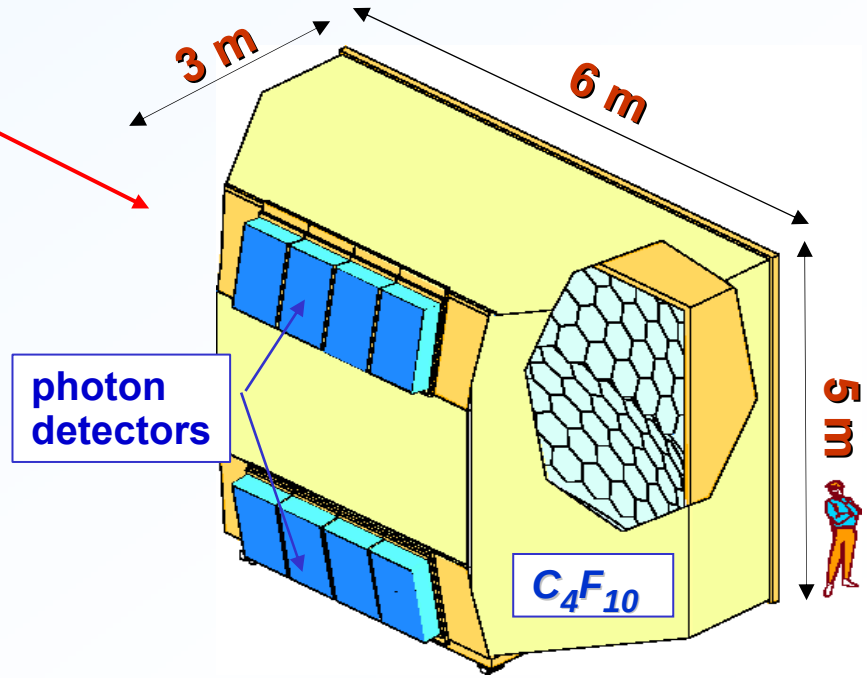


Fully operated for transverse data since 2003

Threshold momenta:

- P_π = 2 GeV/c
- p_K = 9 GeV/c
- p_P =17 GeV/c



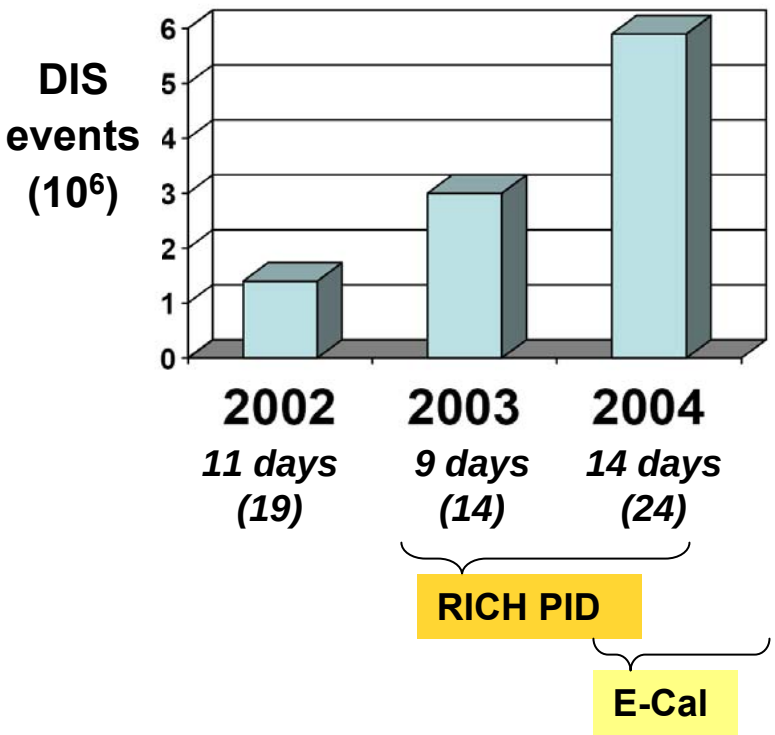


DATA SAMPLES

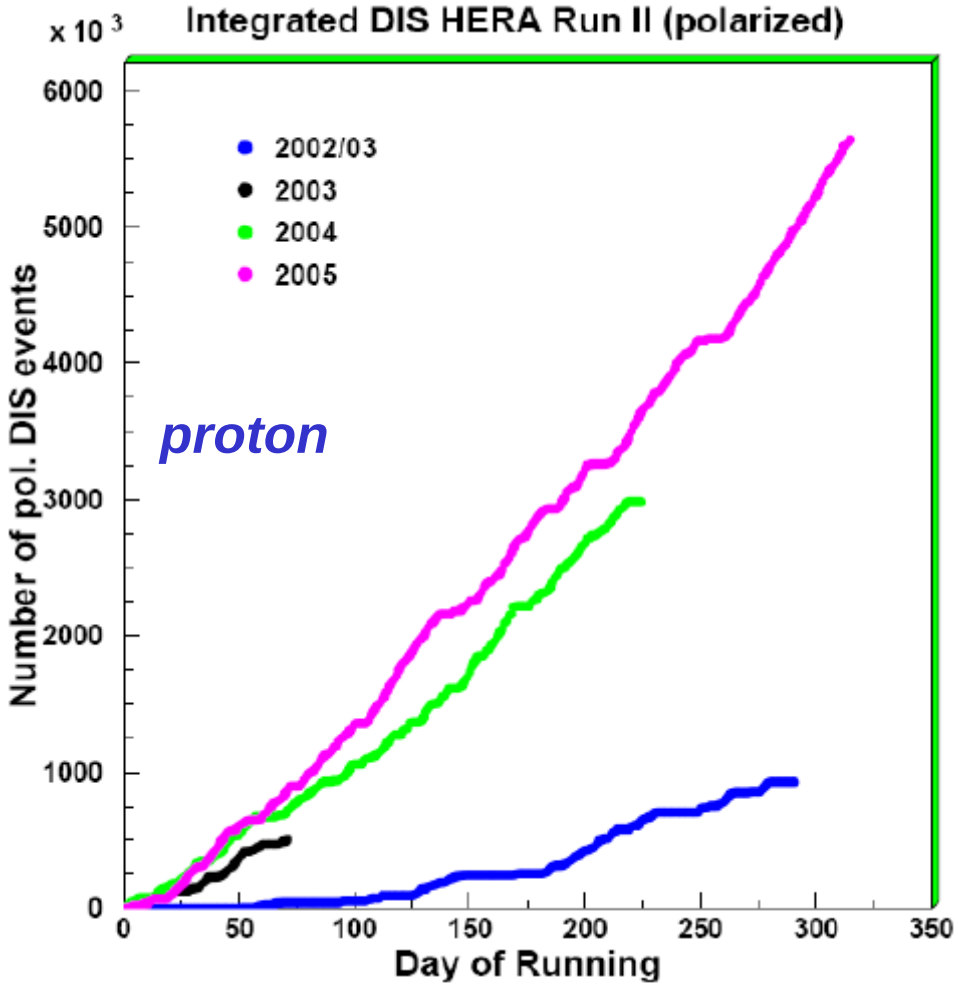
COMPASS

^6LiD

20% of the time with transverse target polarization



hermes



EVENT SELECTION

COMPASS

$Q^2 > 1$ GeV^2

$W^2 > 25$ GeV^2

$0.1 < y < 0.9$

$0.004 < x < 0.4$

$p^h_t > 0.1$ GeV/c

$z > 0.2$ (all h)

$z > 0.25$ (leading h)

hermes

$Q^2 > 1\,\mathrm{GeV}^2$

$W^2 > 10\,\mathrm{GeV}^2$

$y < 0.85$

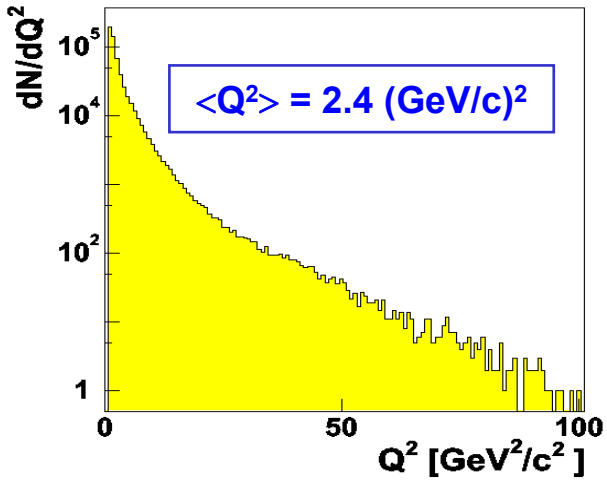
$0.023 < x < 0.4$

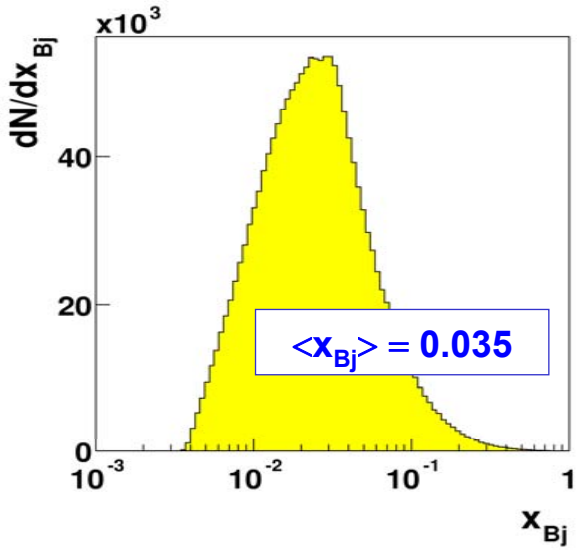
$\theta_{\gamma^* h} > 0.02$ rad

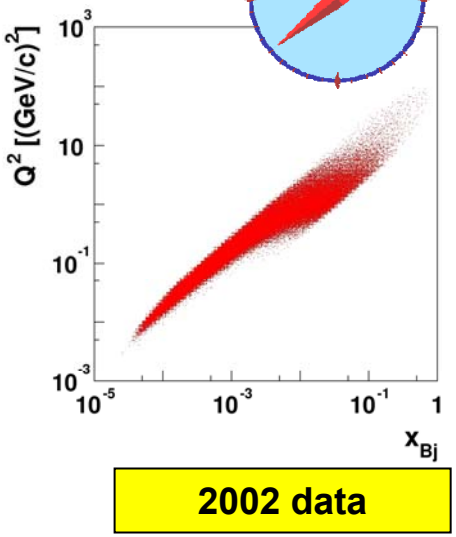
$2\,\mathrm{GeV} < P_h < 15\,\mathrm{GeV}$

$0.2 < z < 0.7$ $(0.7 < z < 1.2)$

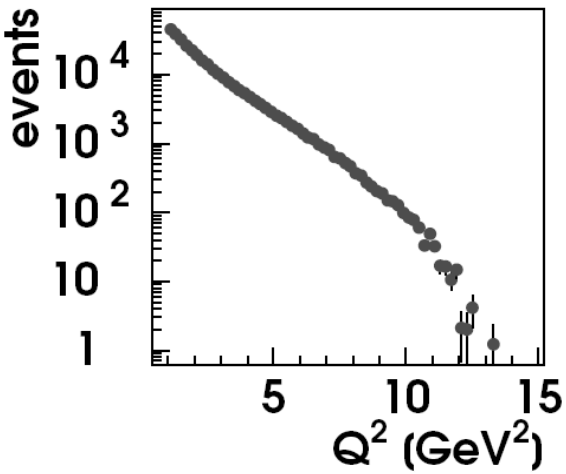
KINEMATICS - 1

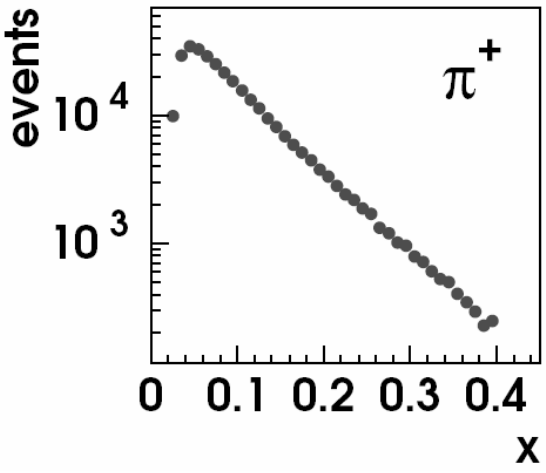




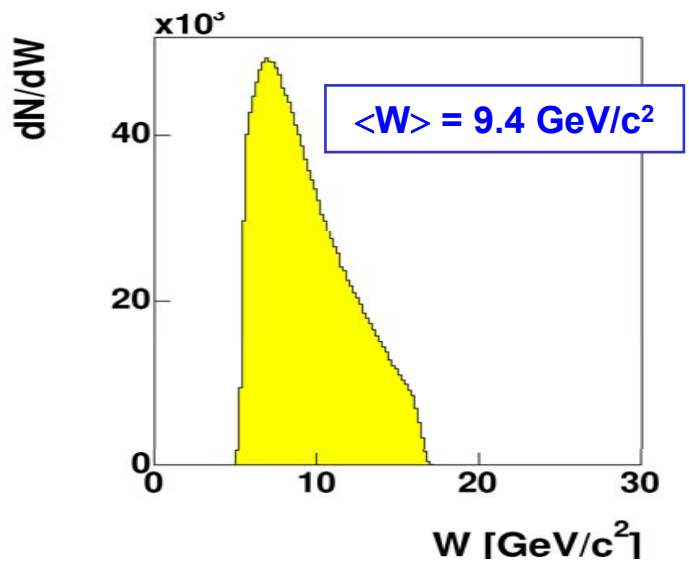


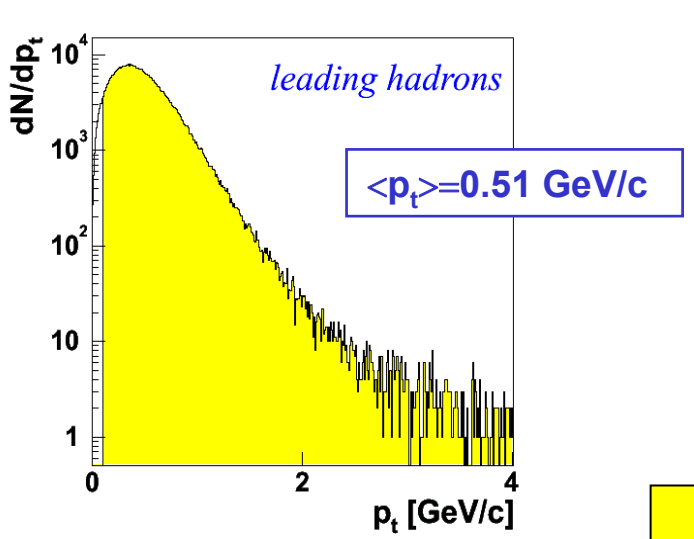
2002 data





KINEMATICS - 2





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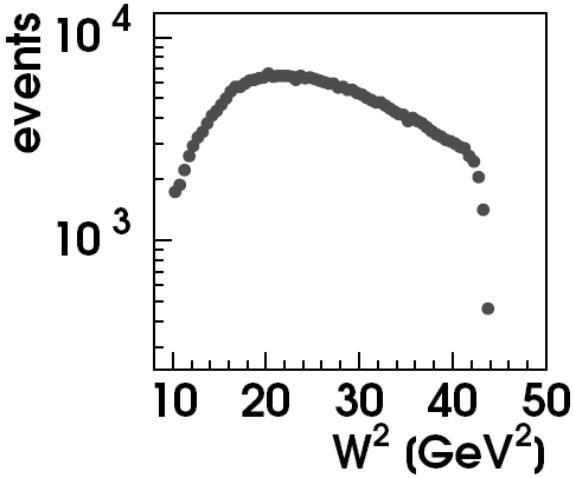

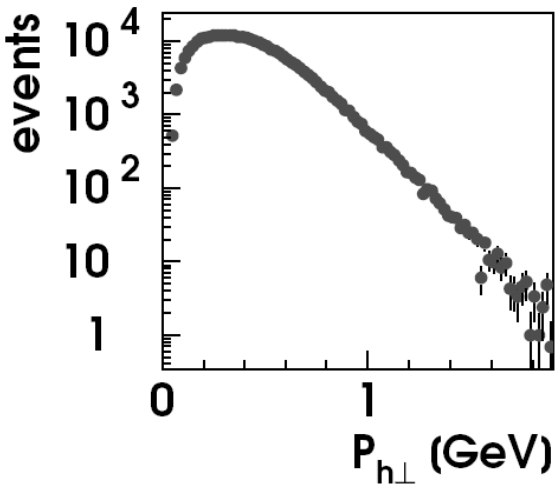

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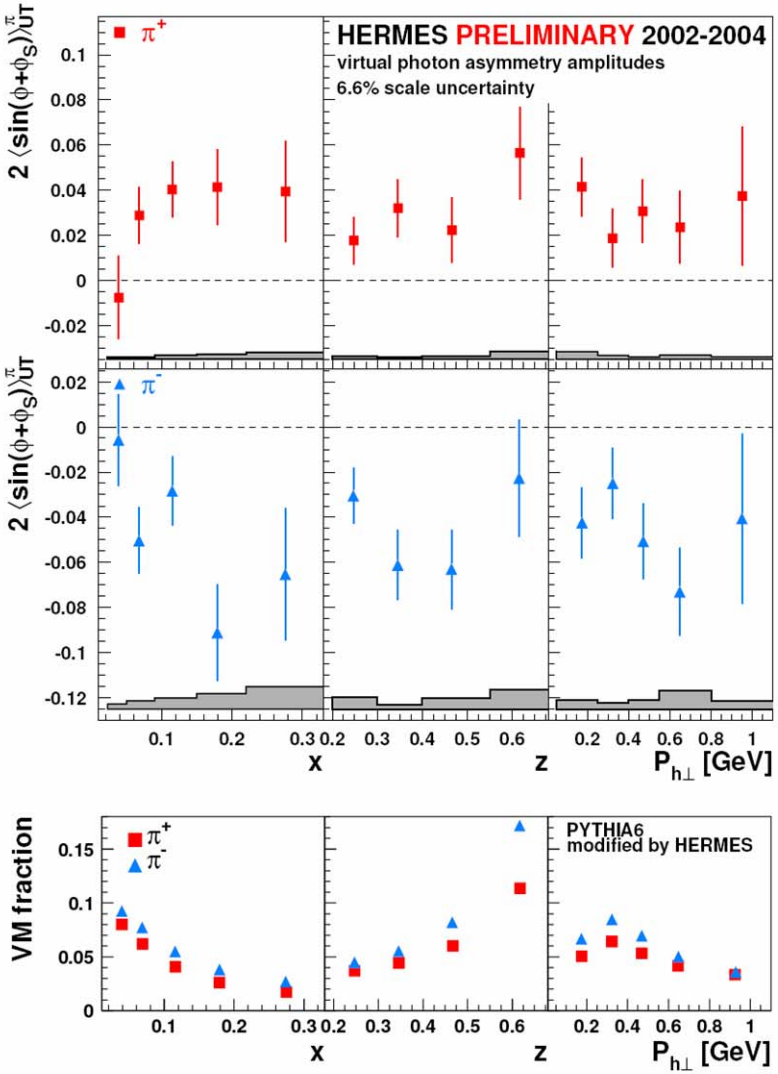
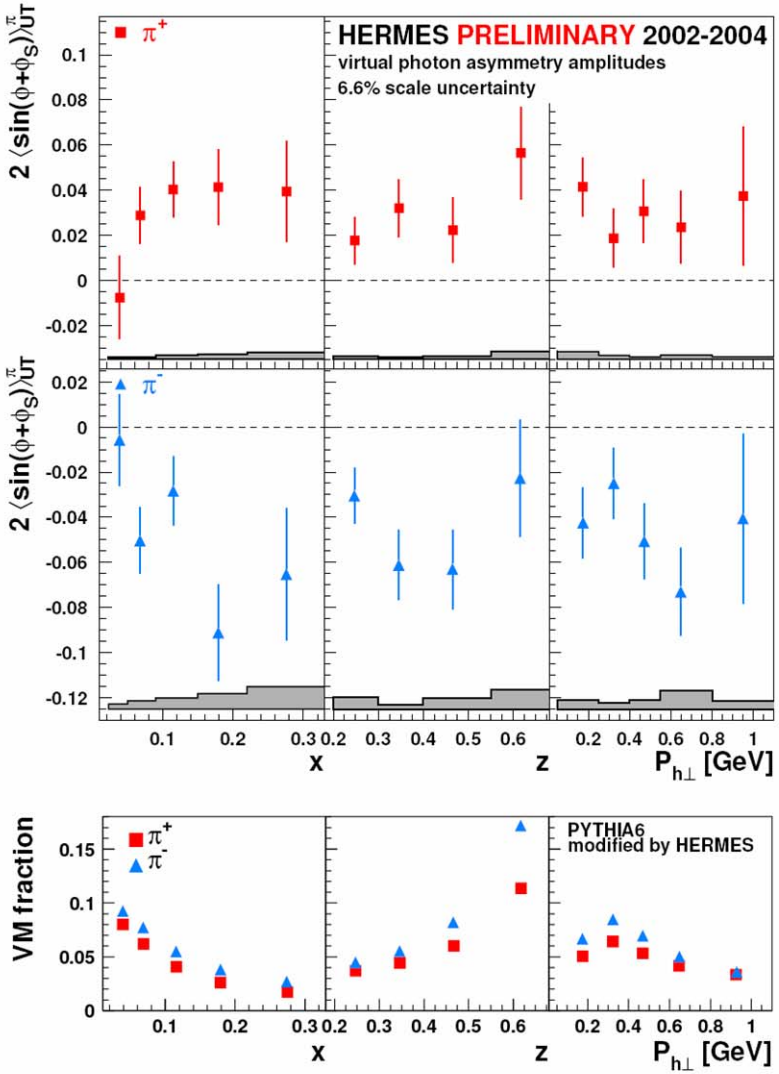
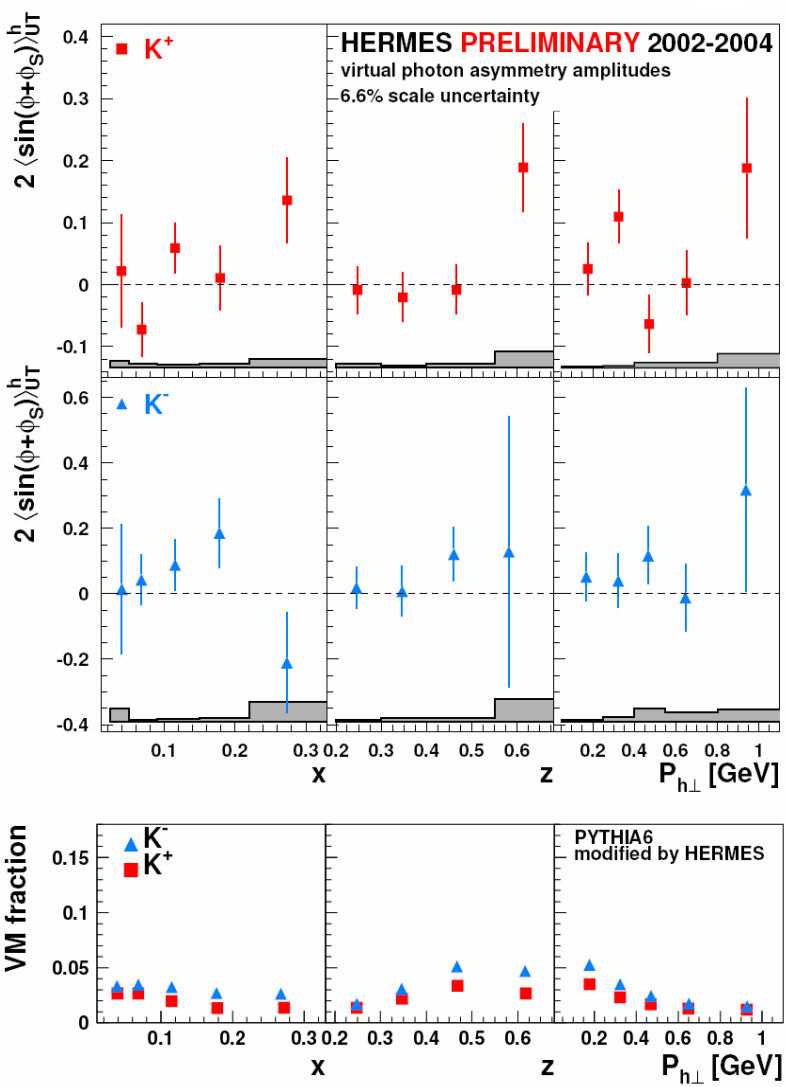
Collins Asymmetries 2002-2004



- $\propto \delta q(x) H_1^{\perp q}(z)$
- First evidence for non-zero Collins function
- Collins moment is positive for π^+
- Collins moment negative for π^-
- the large negative π^- amplitude suggests disfavored Collins function with opposite sign
- systematic errors (shaded bands) include acceptance and smearing effects and contributions from unpolarised $\langle\cos(2\varphi)\rangle$ and $\langle\cos(\varphi)\rangle$ moments

Collins Asymmetries 2002-2004



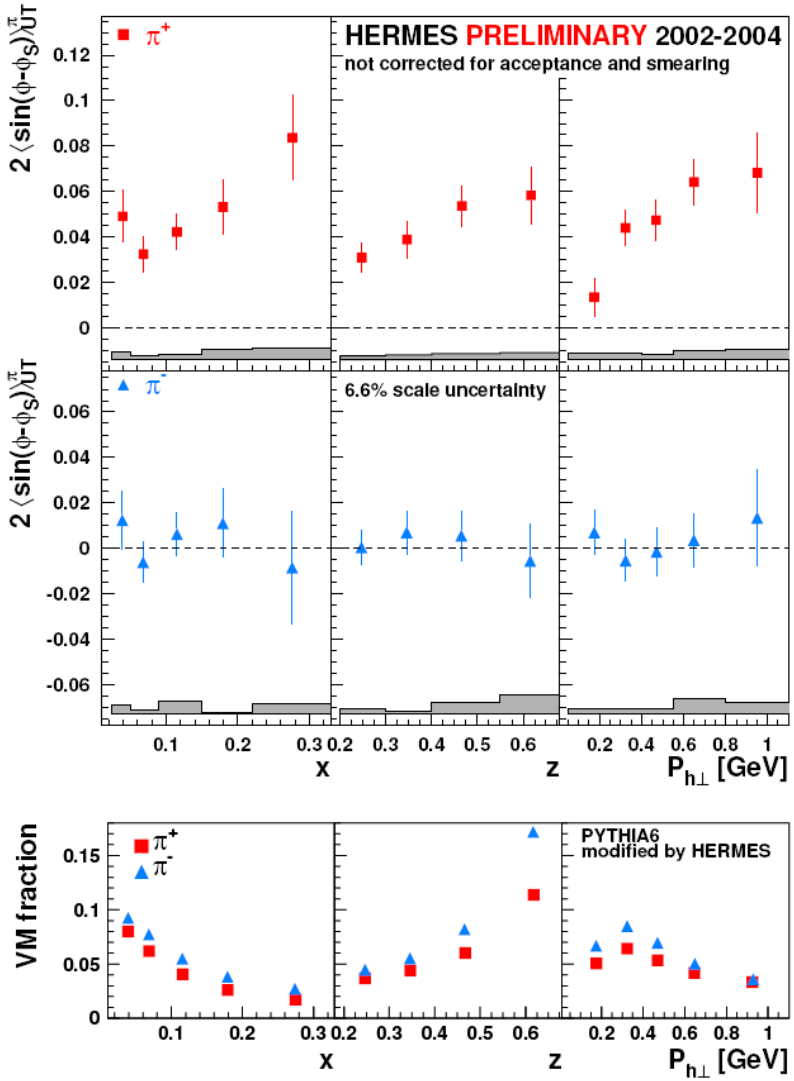


F. Bradamante

L. Pappalardo, DIS2006

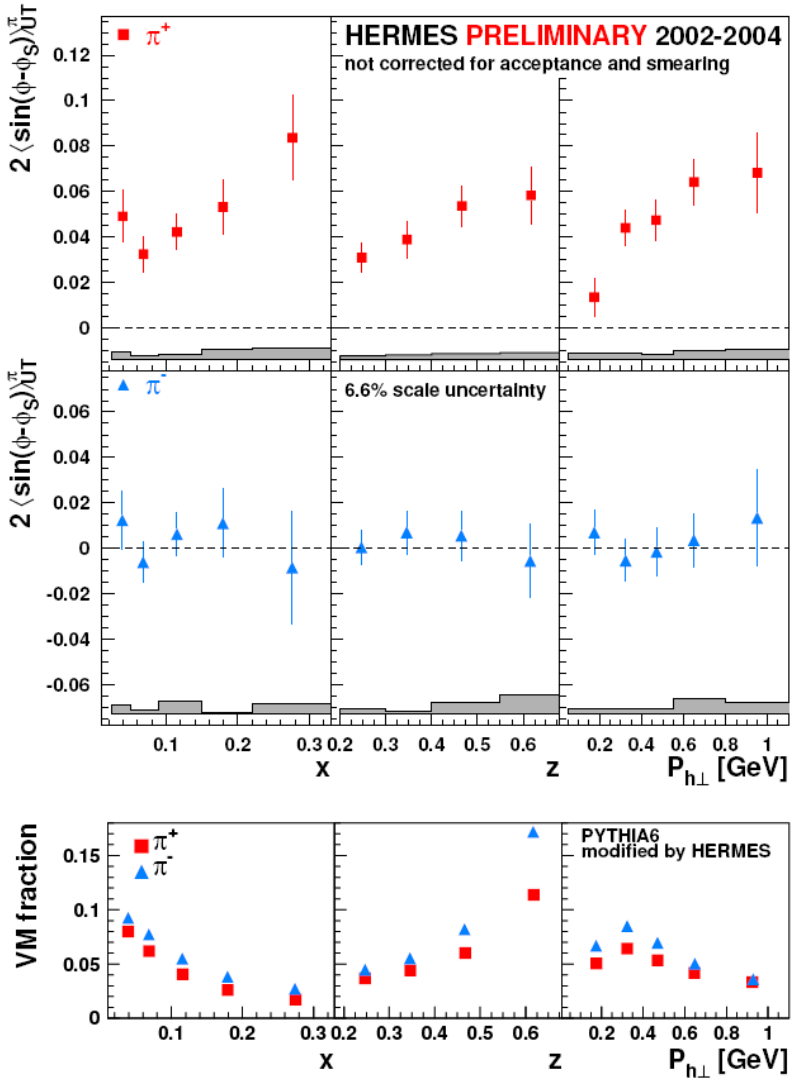
GPD2006

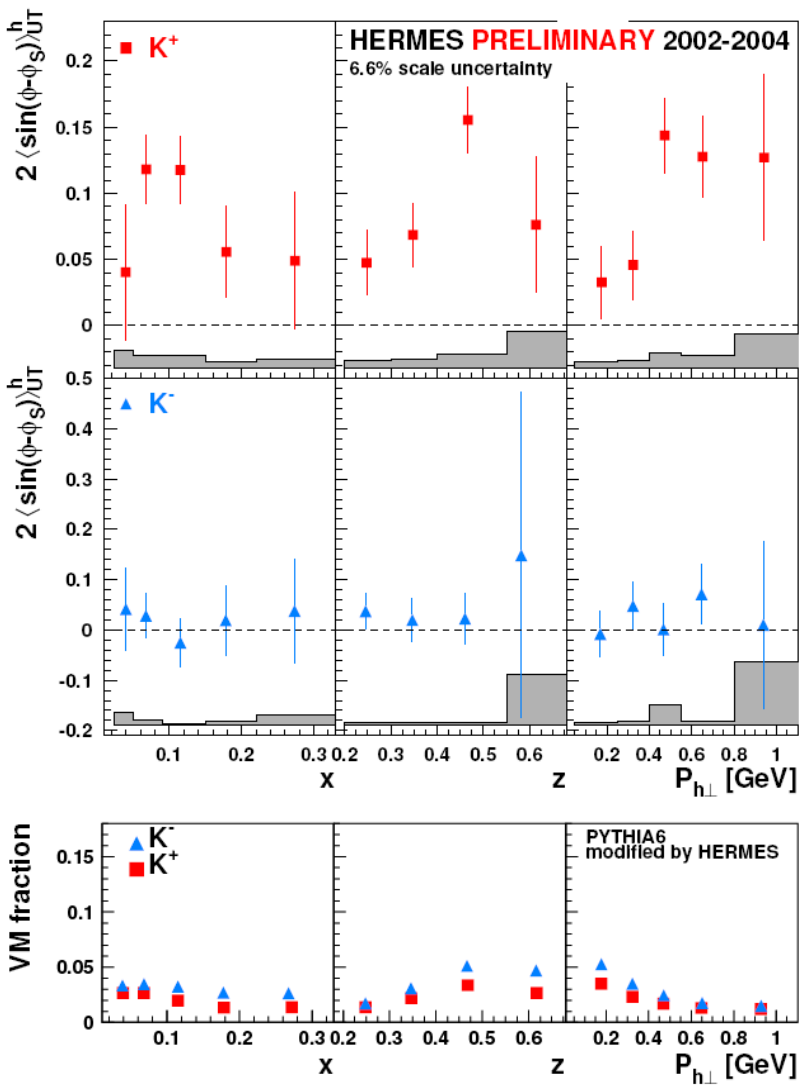
Sivers Asymmetries 2002-2004



- $\propto f_{1T}^{\perp q}(x) D_1^q(z)$
- Sivers moment is positive for π^+
- First evidence for non-zero Sivers function $\Rightarrow$ non-vanishing orbital angular momentum L_z^q
- Sivers moment consistent with zero for π^-
- systematic errors (shaded bands) include acceptance and smearing effects and contributions from unpolarised $\langle\cos(2\varphi)\rangle$ and $\langle\cos(\varphi)\rangle$ moments

Sivers Asymmetries 2002-2004

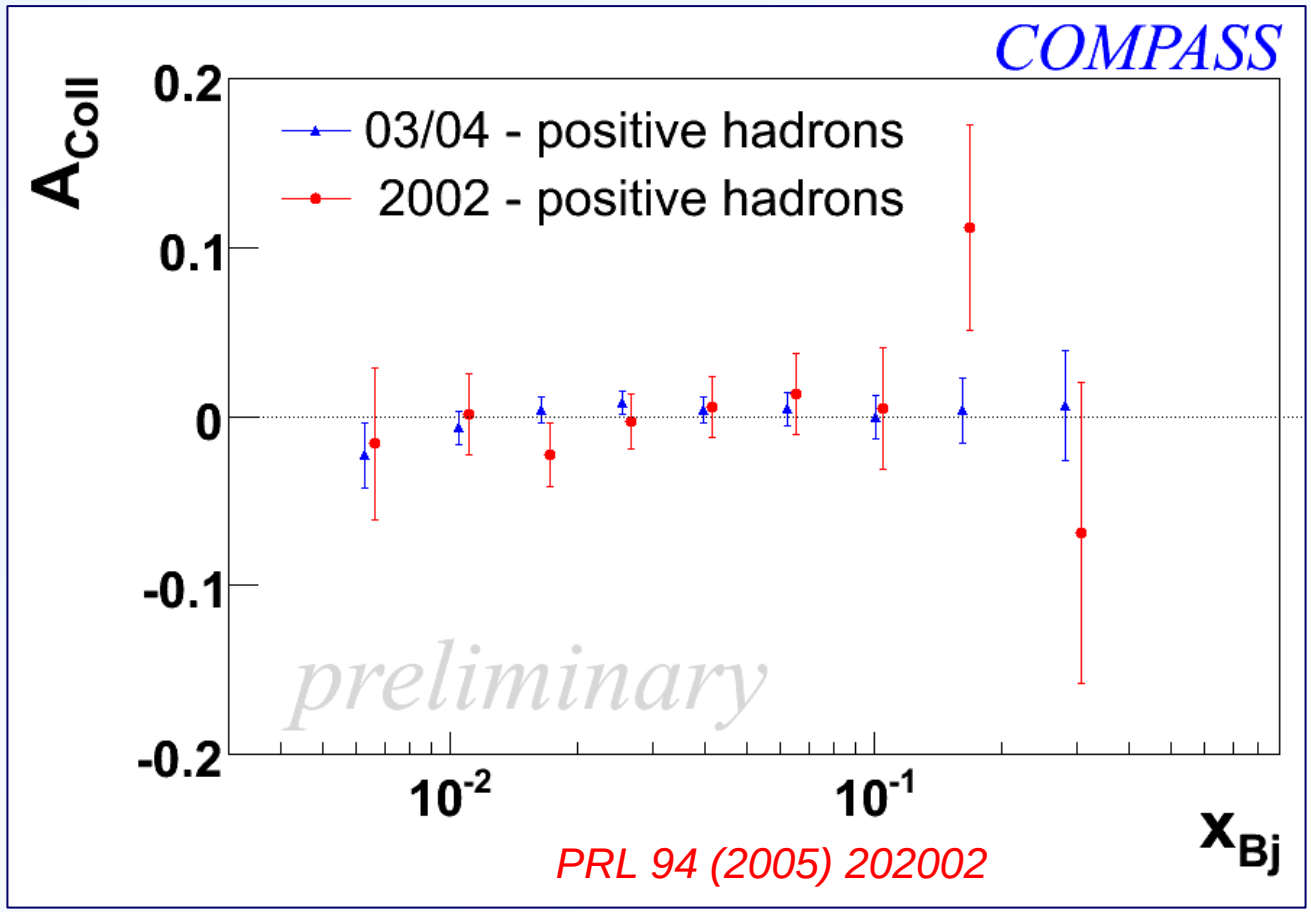




Collins Asymmetries 2002, 2003-2004

results from 2003-2004 data released (DIS2006)

comparison with the published 2002 data



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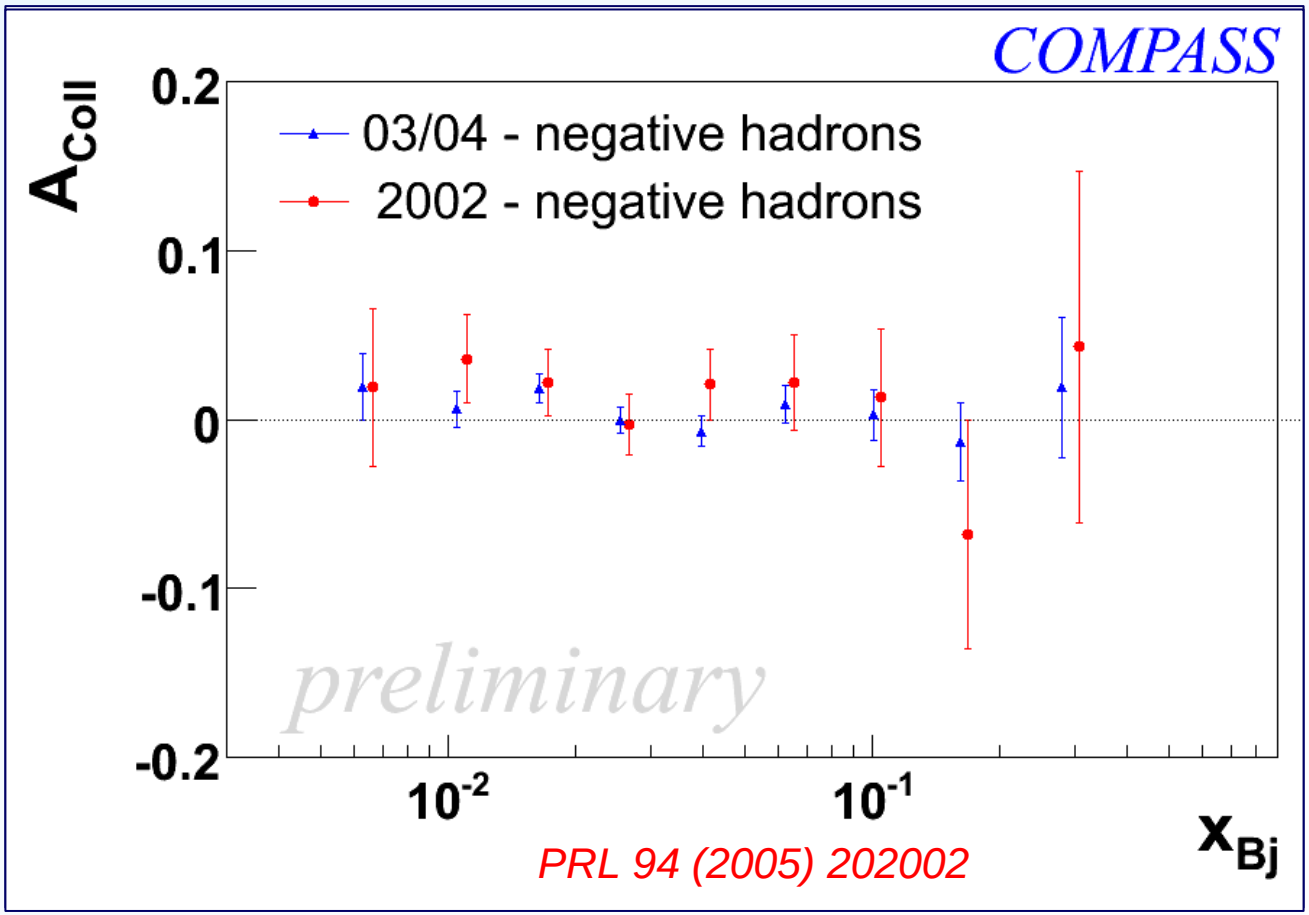
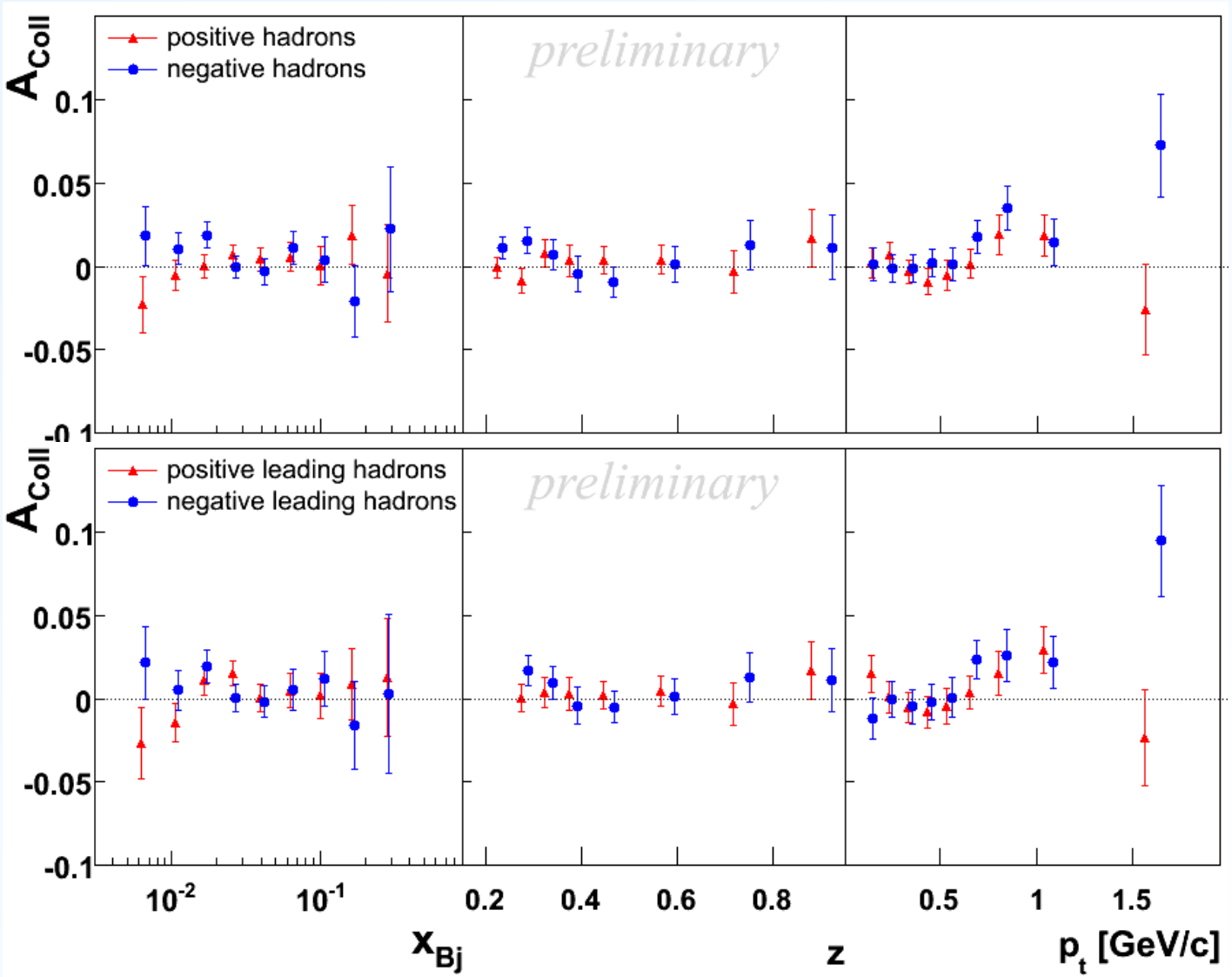
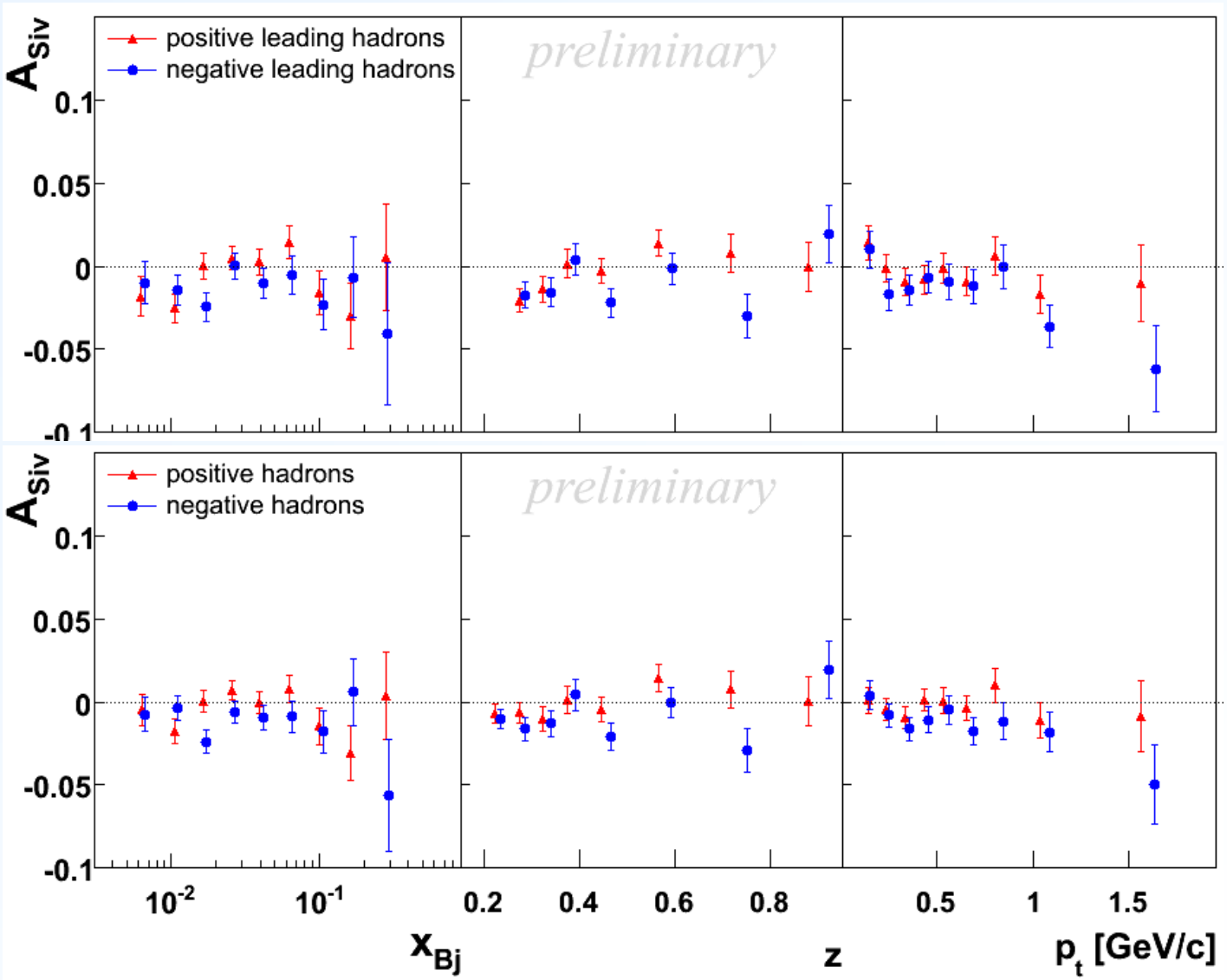


Collins Asymmetries 2002-2004



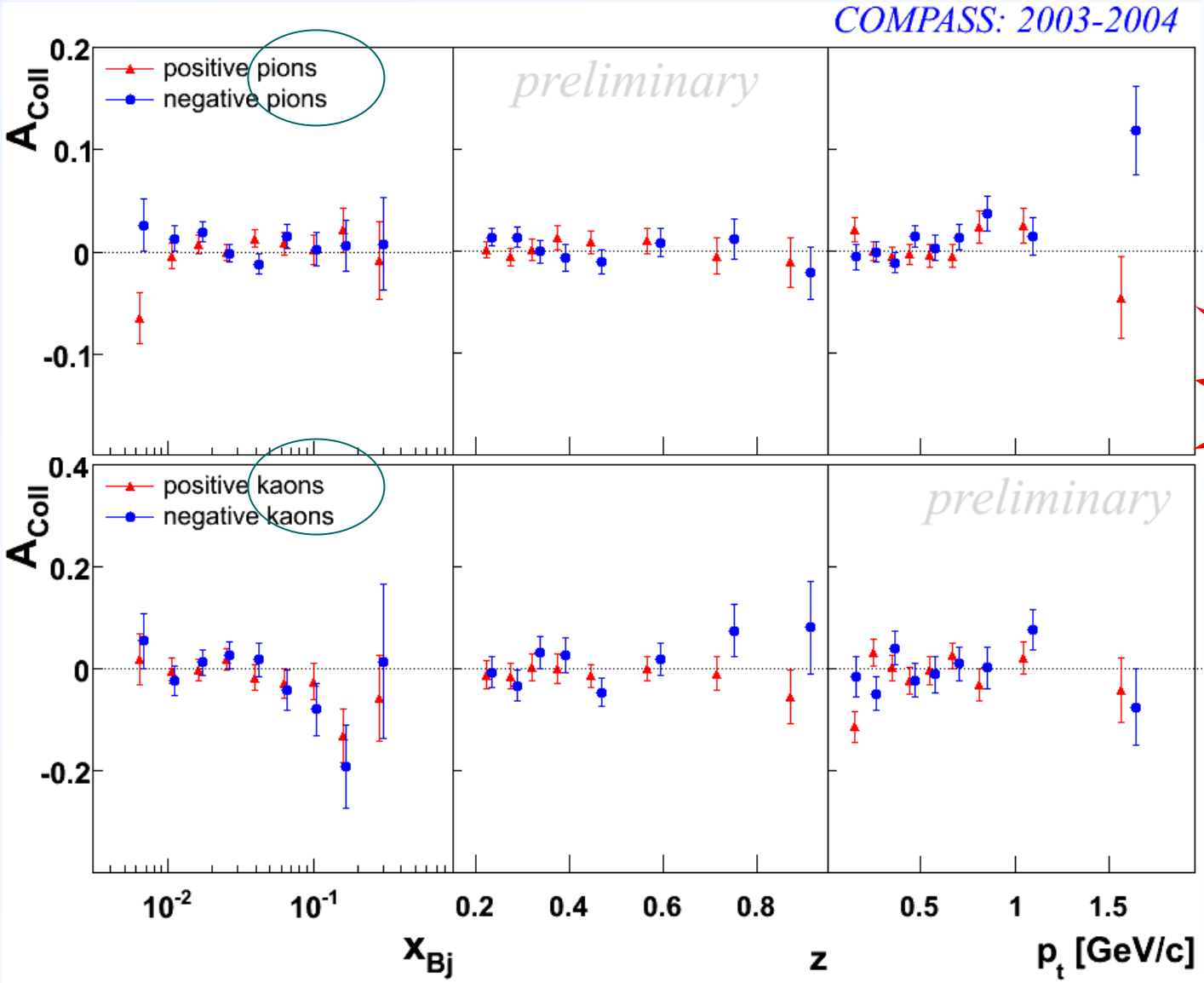
DIS2006

Sivers Asymmetries 2002-2004



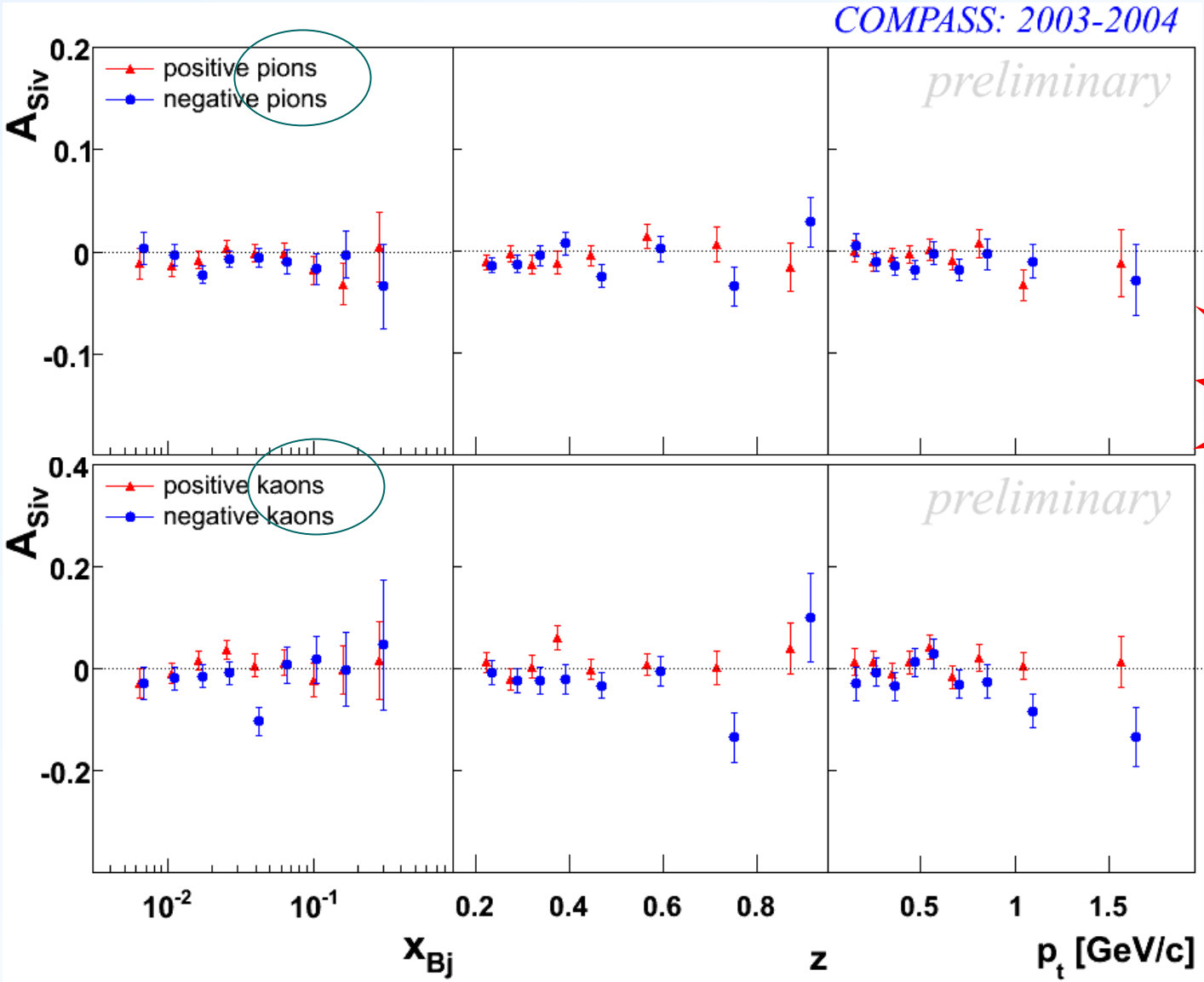
DIS2006

Collins Asymmetries 2003-2004



NEW!

Sivers Asymmetries 2003-2004



NEW!

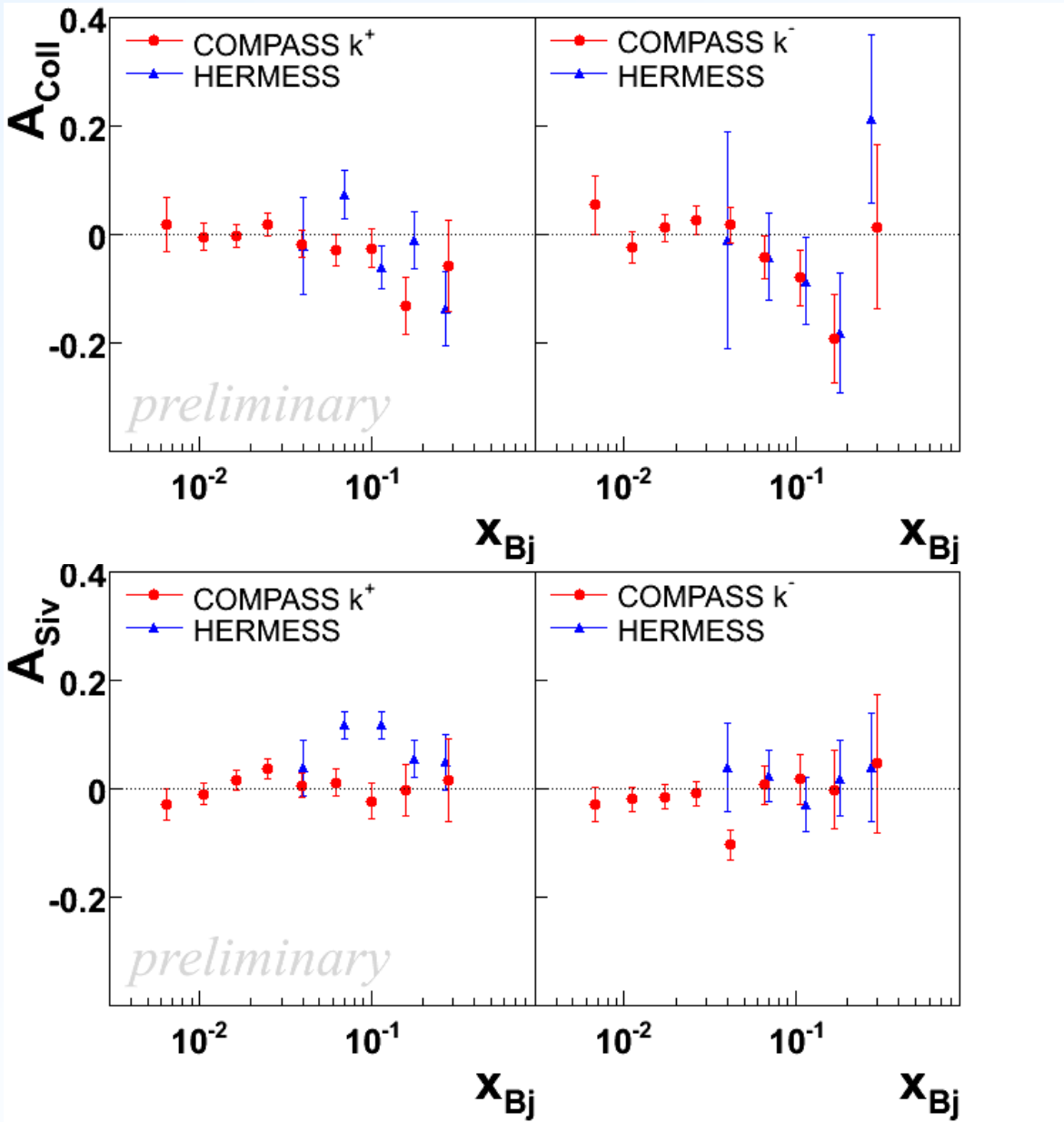
Kaon Asymmetries

HERMES
2002-2004
DIS2006

proton

COMPASS
preliminary
2003-2004
NEW!

deuteron



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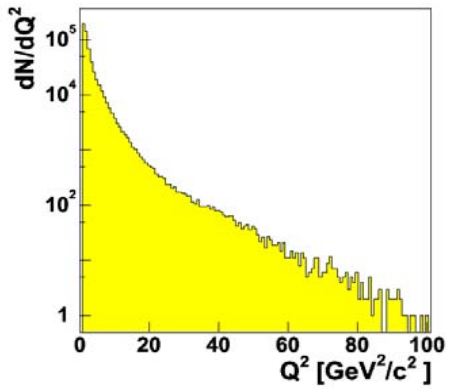
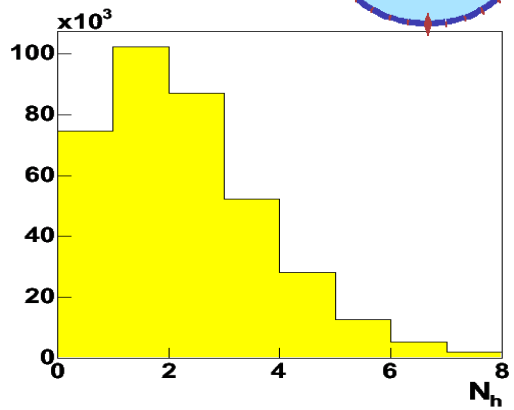
- PERSPECTIVES

Two Hadron Asymmetries

Selection of events

- $Q^2 > 1\ (GeV/c)^2$
- $0.9 > y > 0.1$
- at least one +/- hadron pair





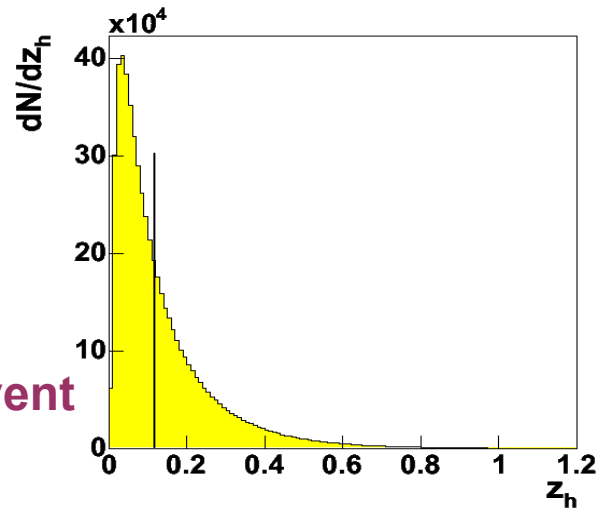
Selection of hadrons

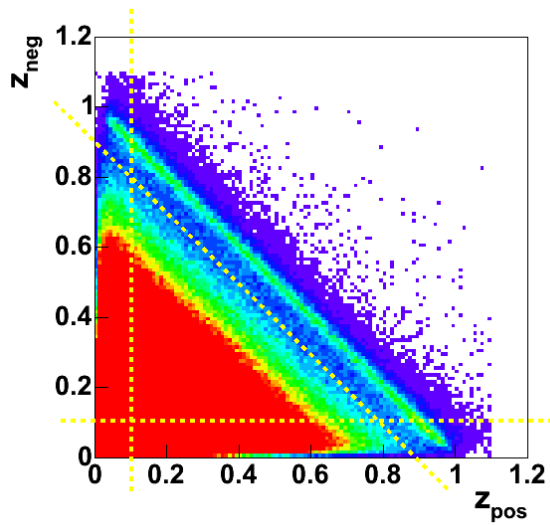
- $z_{1,2} > 0.1$ and $x_{f1,2} > 0.1$
- $z_1 + z_2 < 0.9$

h_1 = +ve hadron

h_2 = - ve hadron

all combinations / event



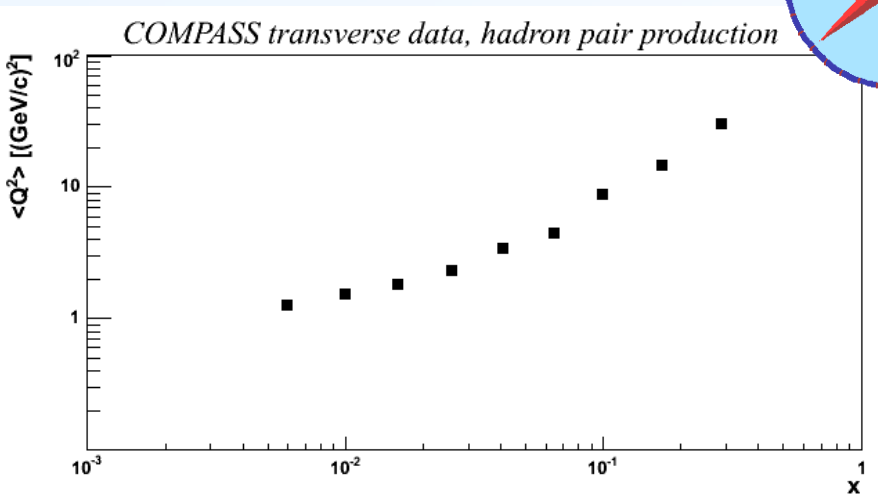


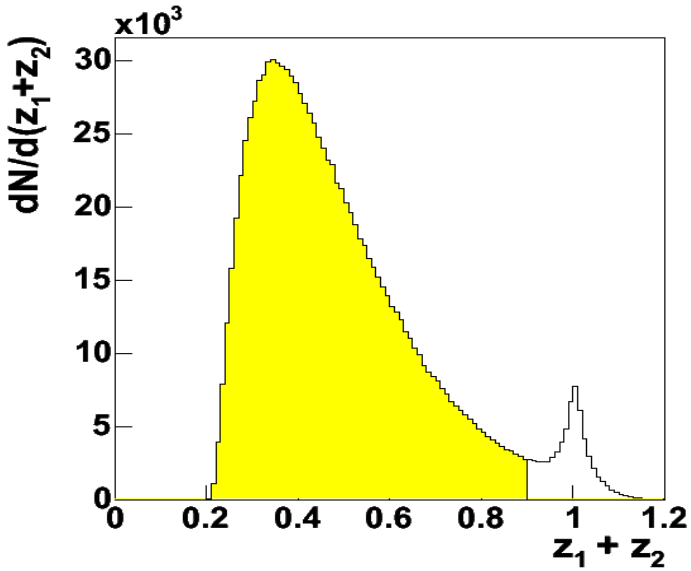
Two Hadron Asymmetries

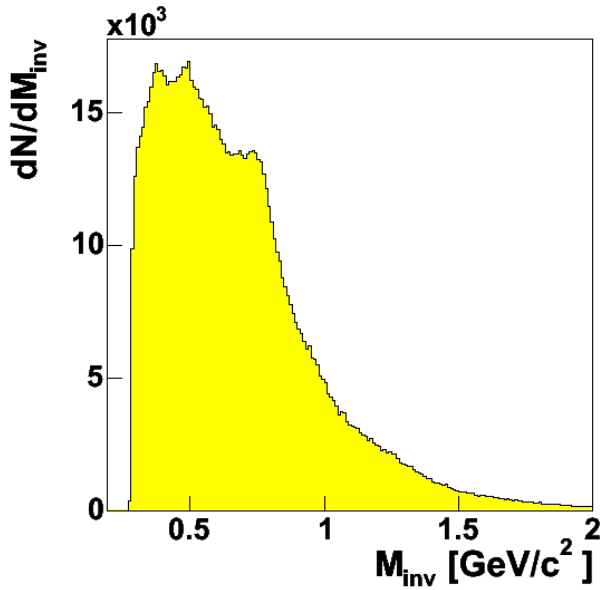
final sample 2002-2004

all hadron pairs

after cuts ~ 6.1 M ev

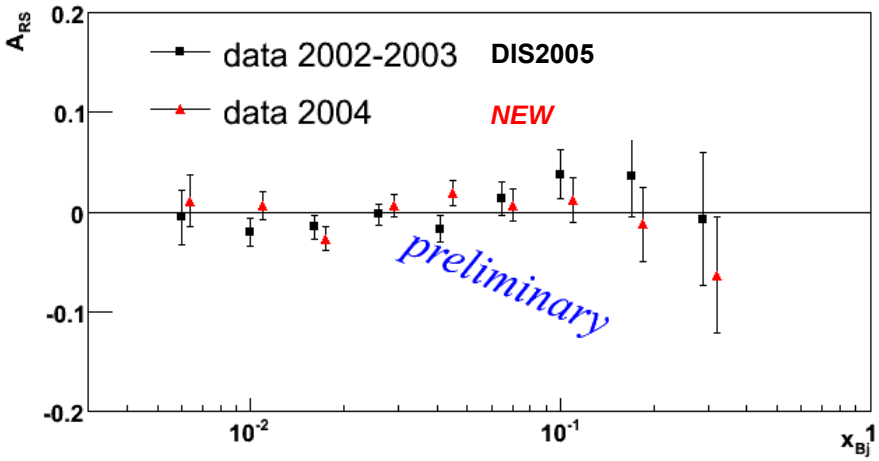


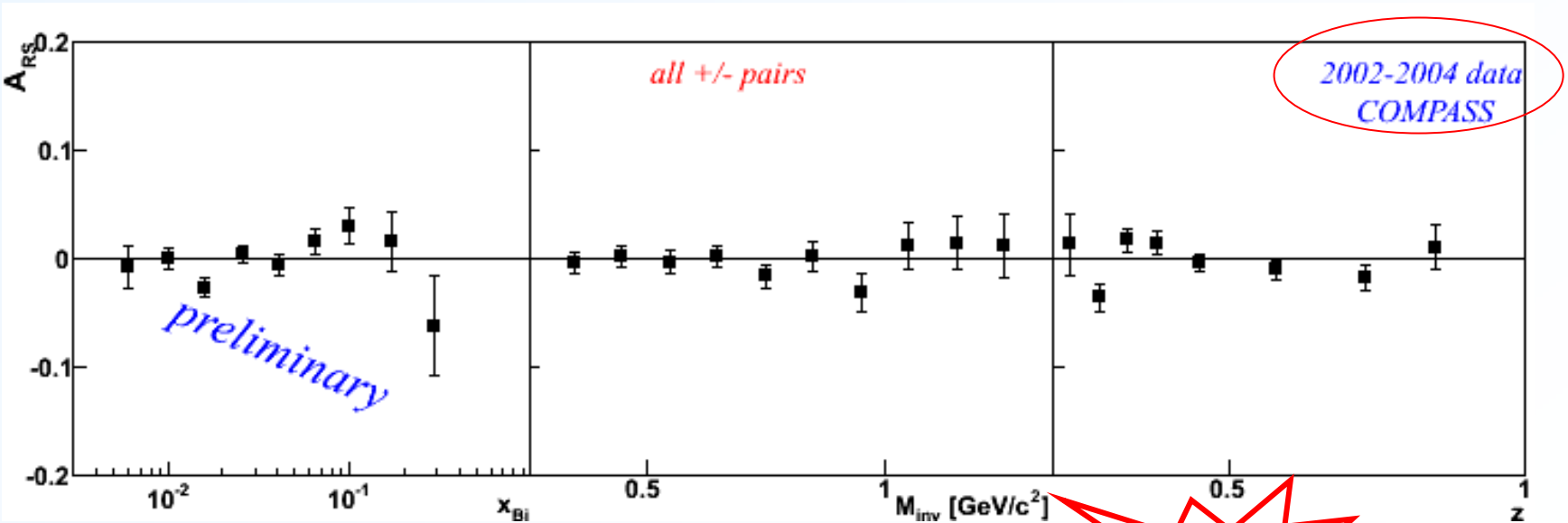




Two Hadron Asymmetries

all hadron pairs

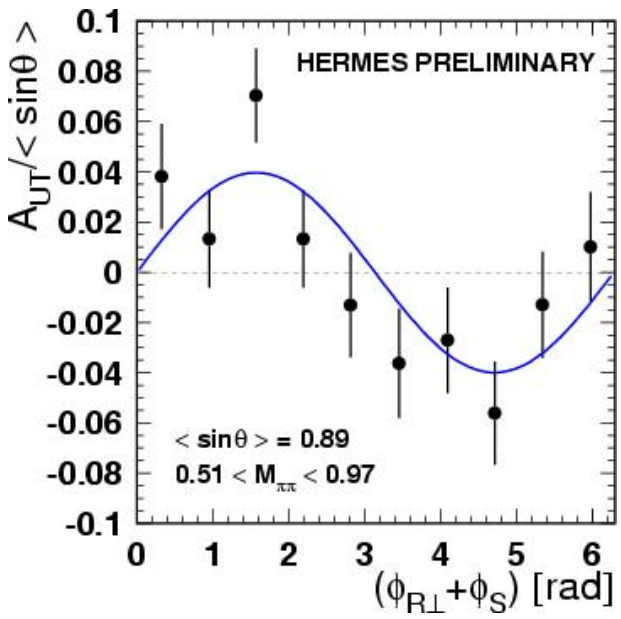


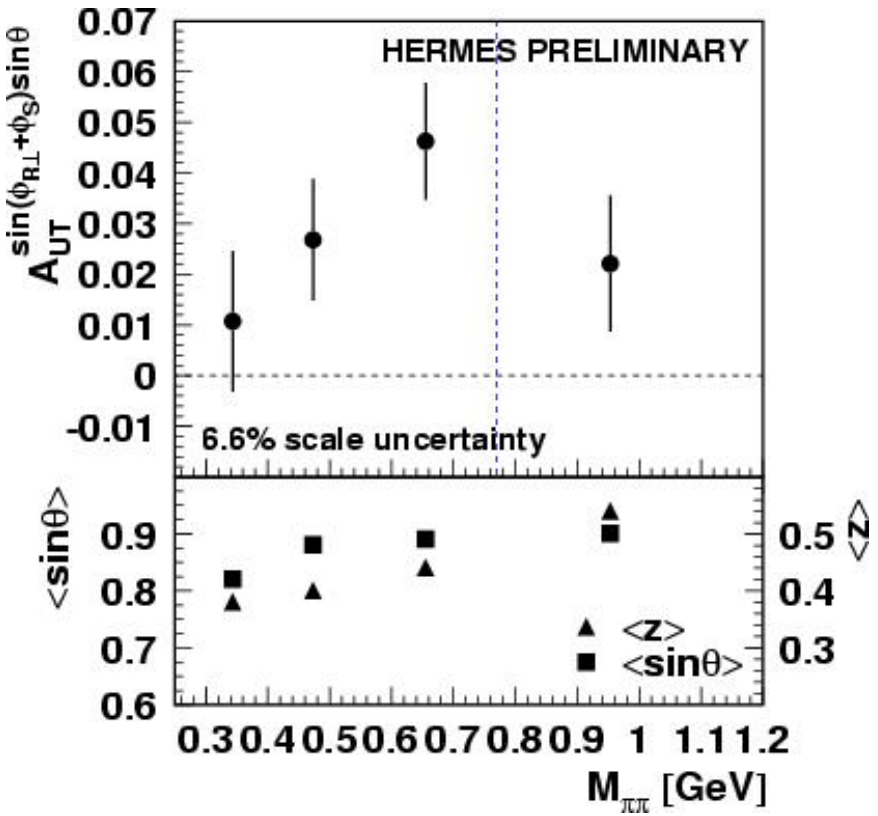


CIPANP06

Two Hadron Asymmetries

all hadron pairs
2002-2004





Two Hadron Asymmetries 2

different hadron pairs selections have been tried
(still based on the string fragmentation model)

1 entry/event

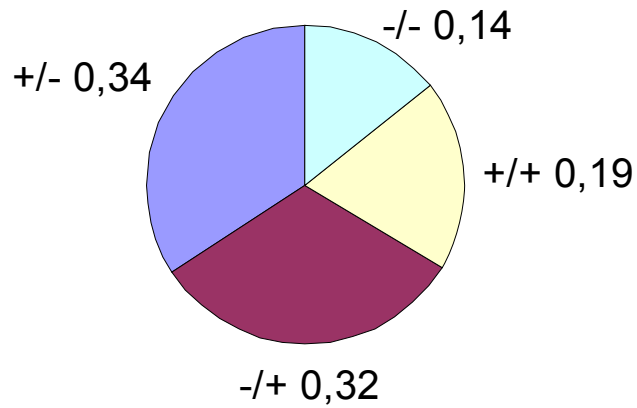
1. **h1 = +ve hadron largest p_T**
   h2 = -ve hadron with second largest p_T
   and
   h1 = -ve hadron largest p_T
   h2 = +ve hadron with second largest p_T

SPIN 2005

2. **h1 = +ve hadron largest z**
   h2 = -ve hadron with second largest z
   and
   h1 = -ve hadron largest z
   h2 = +ve hadron with second largest z
   plus equal charge combinations

CIPANP06

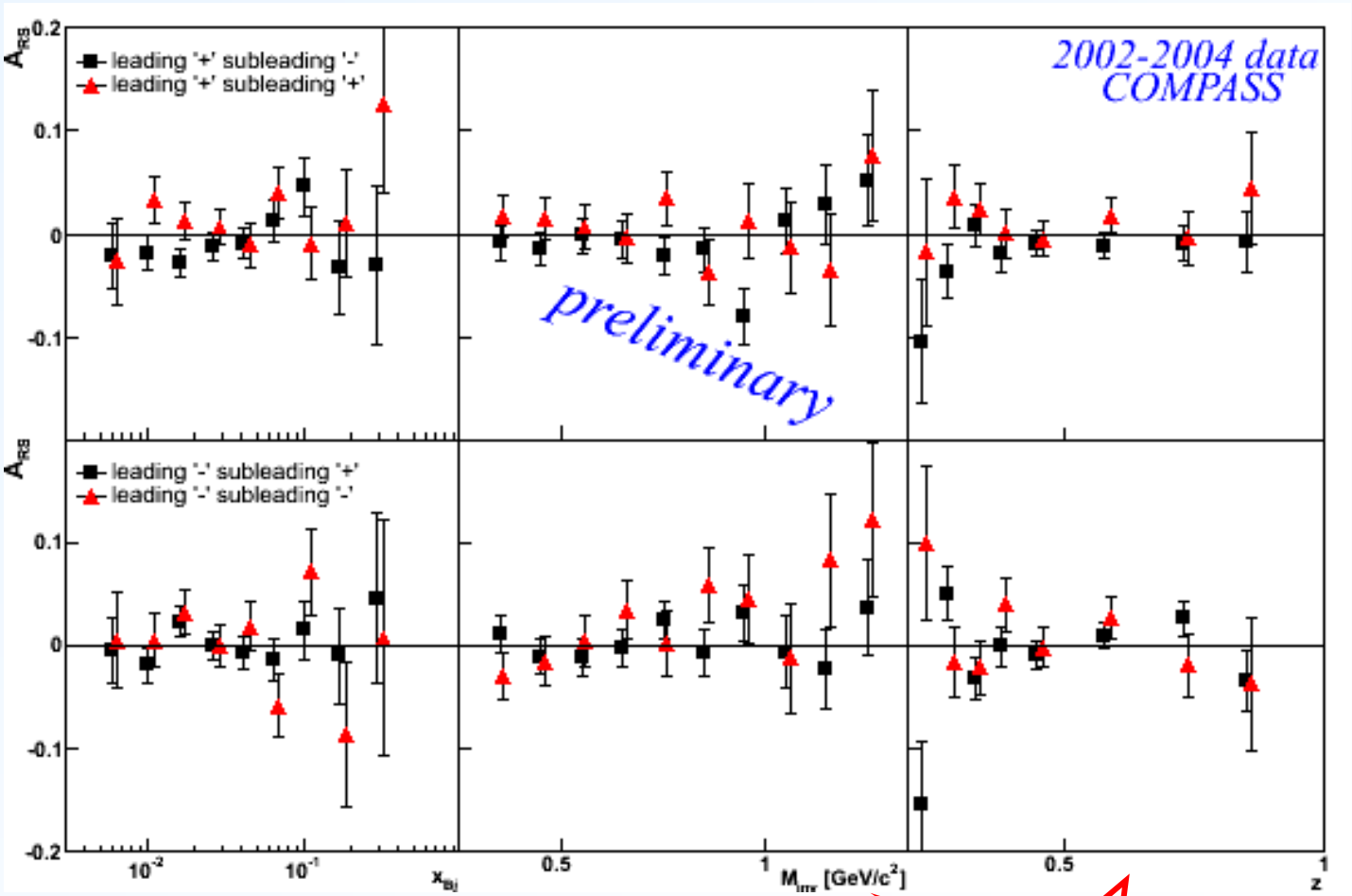
Fractions



6.4 M events

Two Hadron Asymmetries 2

leading hadron pairs



CIPANP06

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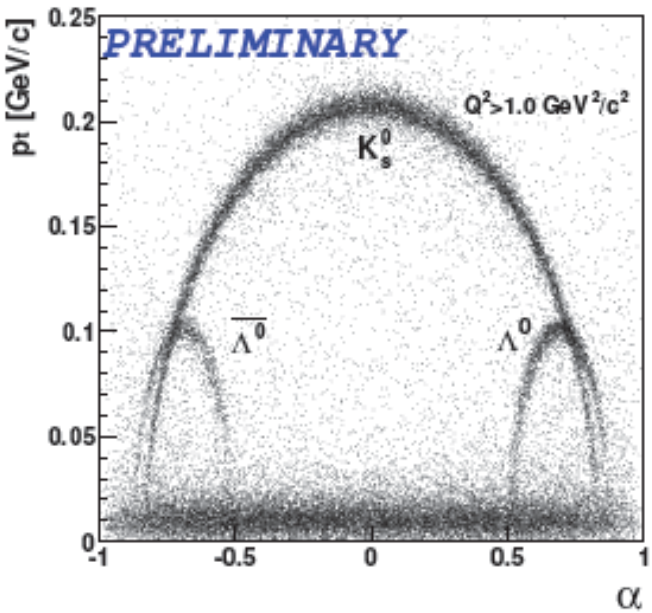
  Λ polarimetry
- PERSPECTIVES

Λ polarimetry – events selection

2002-2003 data

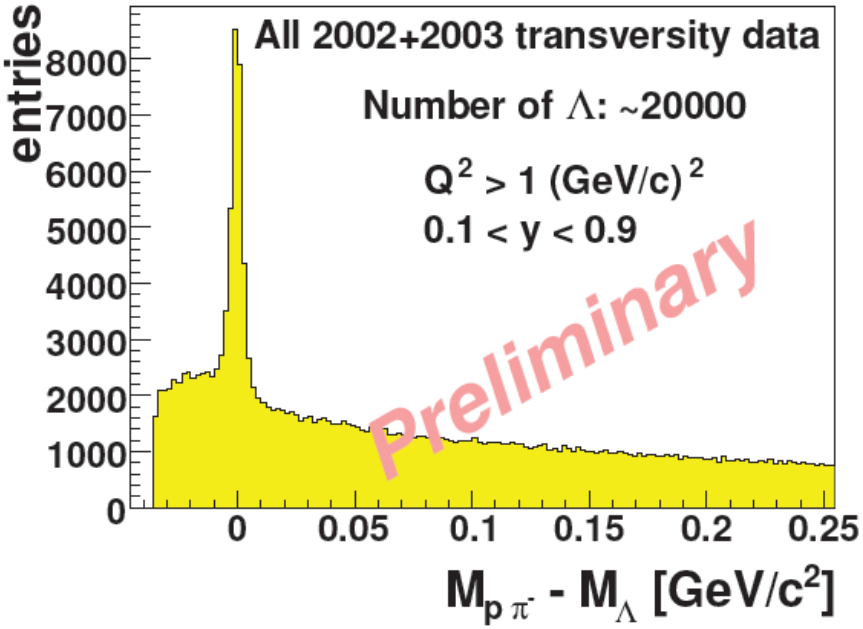
- Primary vertex in target cell material, beam crossing both cells
- μ' traverses at least 30 radiation lengths
- Tracks of p and π^- candidates traverse at least the SM1 magnet
- momentum of both decay particles > 1 GeV/c

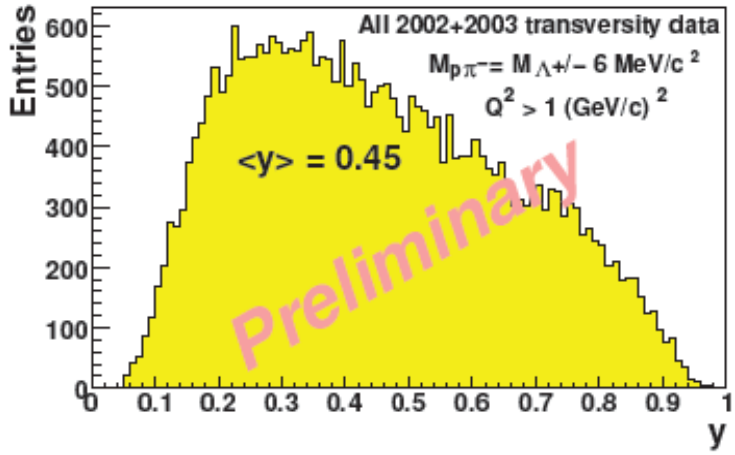


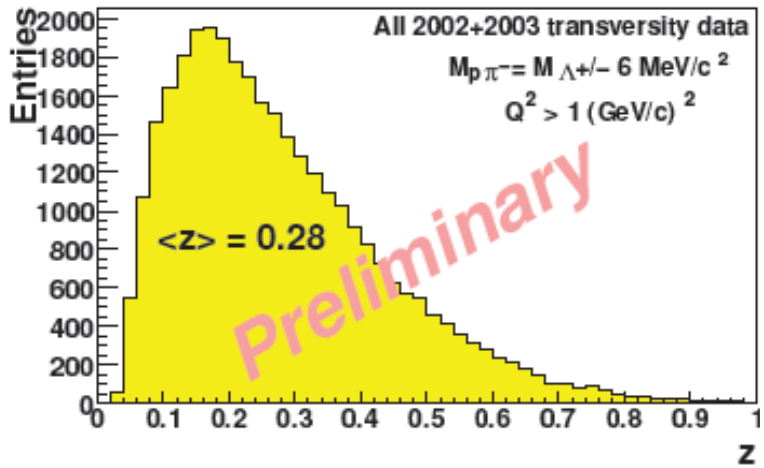
- The candidate Λ decay is downstream of the target and outside of it
- collinearity < 10 mrad
- Armenteros $p_T > 23$ MeV/c
- $0.1 < y < 0.9$

Λ polarimetry

2002-2003 data



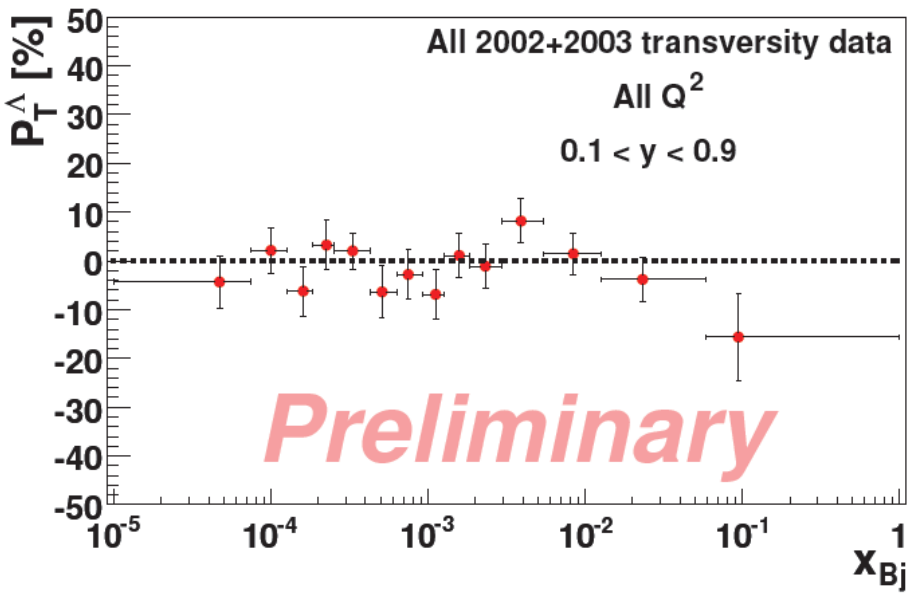


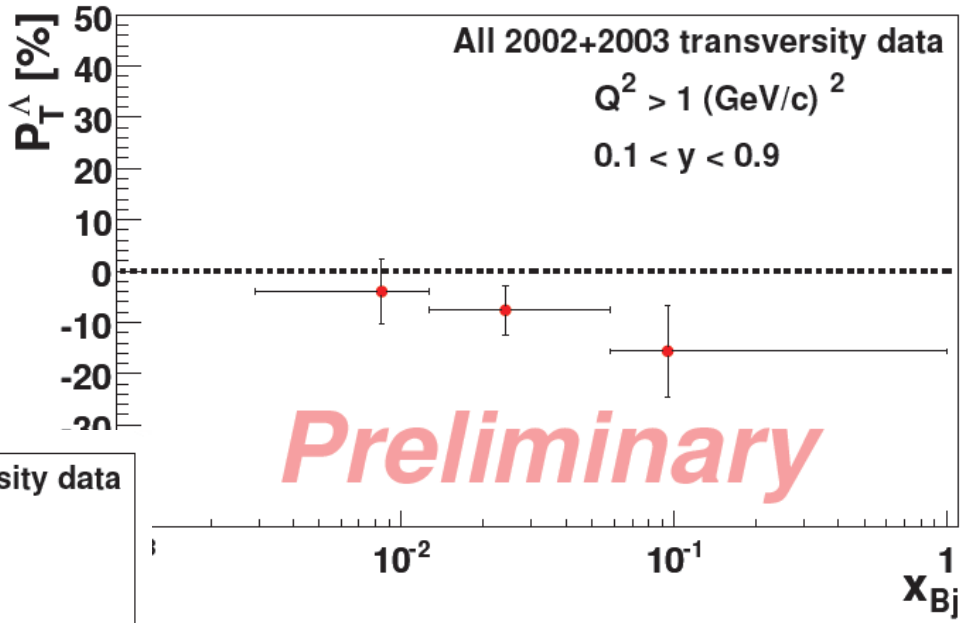


The majority of Lambda events are produced at $x_F > 0$ (current fragmentation region)

Λ polarimetry

2002-2003 data





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- **PERSPECTIVES**

Perspectives

Fairly precise DIS proton and deuteron data now available

The measured proton asymmetries are rather small (a few %) and have an unusual interpretation

The comparison of proton and deuteron data shows interesting features

HERMES: statistical errors will be reduced by ~ 1.5 with 2005 data

COMPASS: - two hadron and Λ results will be improved
- plans to measure with protons in 2006

Exclusive ρ production studies to get hold of the E GPD ongoing (preliminary results from HERMES already available)

Perspectives

A global analysis, including BELLE data, is necessary to

- **have first information on $\Delta_T q$**
- **to evaluate the size of the effort necessary to complete the programme**

COMPASS is considering a new proposal based on

TRANSVERSITY

and

GPDs

and spectroscopy for the next decade

- Input to CERN Council Strategy Group (Jan. 15, 2006)
- SPSC-EOI-005 (Jan. 18, 2005)