Measurement of polarized (quark) structure functions at COMPASS

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on behalf of the COMPASS collaboration

1. The COMPASS experiment at CERN
2. Longitudinal quark helicity distributions

   A_1^d ,DS, Dq flavour decomposition
3. Transversity

   Collins & Sivers, 2 hadron correlation
4. Summary and outlook

第5回環太平洋
シンポジウム
高エネルギー
スピン物理」
東京、7月、2005

COMPASS Collaboration

More than 220 physicists from 30 Institutes

Д у б н а (LPP and LNP), М о с к в а (INR, LPI, State University), П р о т в и н о

CERN

Bielefeld, Bochum, Bonn (ISKP & PI), Erlangen, Freiburg, Heidelberg, Mainz, München (LMU & TU)

Warsawa (SINS), Warsawa (TU)

Nagoya/Chubu/Yamagata

Miyazaki/KEK

Helsinki

Praha

Lisboa

Saclay

Burdwan, Calcutta

Tel Aviv

Torino (University,INFN), Trieste (University,INFN)

1. The COMPASS experiment at CERN

The aim of COMPASS (muon program)

- ★gluon polarization
  → Prof. F. Kunne on this Tuesday.
- ★longitudinal quark polarizations
  (g_1^d, ? q flavour decompositon)

} Longitudinal PT

Data are taken simultaneously

- ★Transversity

} Transverse PT

Data taking History

- **2002 year** **muon run (L,T target)**
- **2003 year** **muon run (L,T target)**
- **2004 year** **muon run (L,T target) + Hadron run**

(muon beam share:

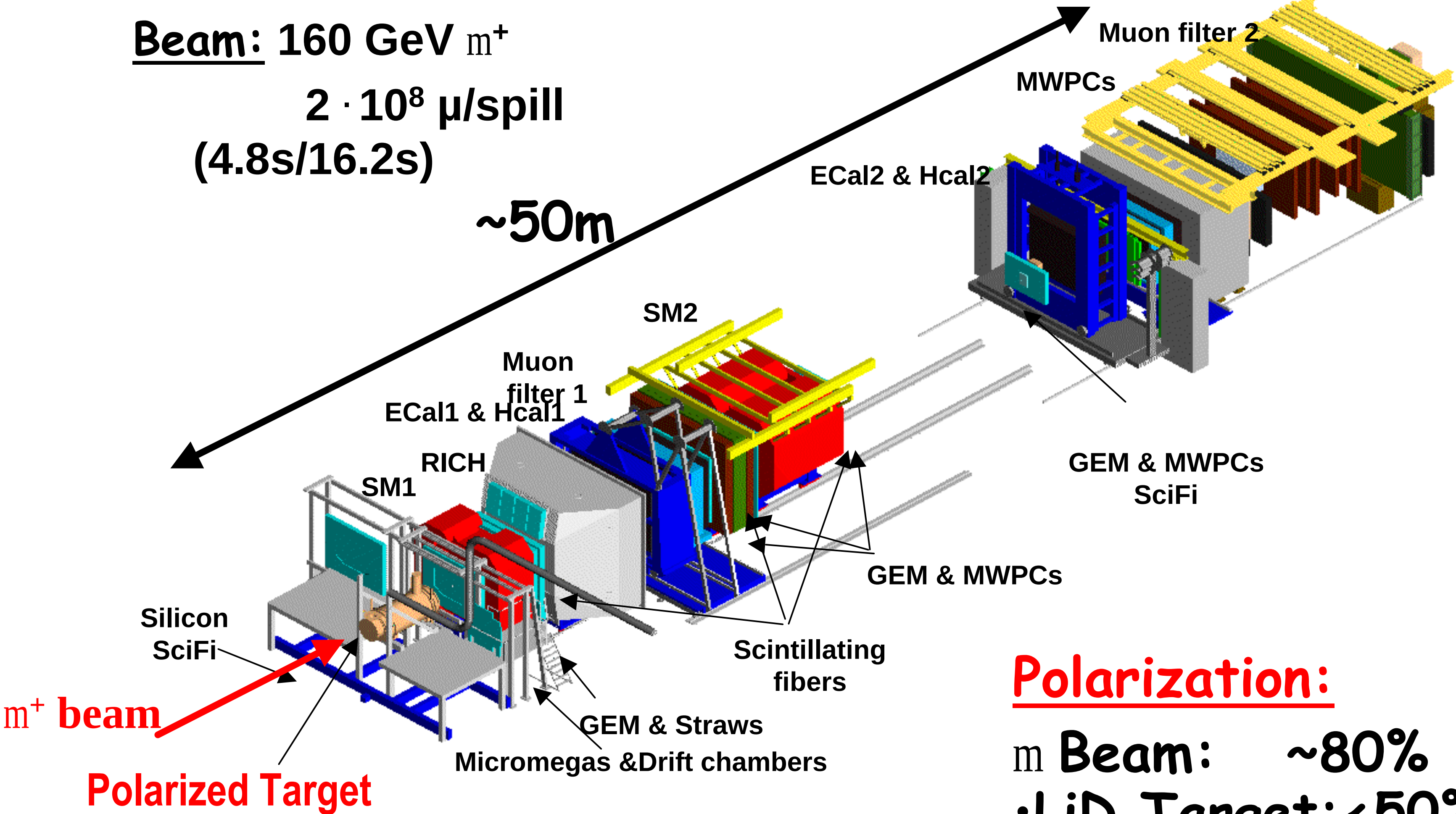
longitudinal PT ~80%, transeverse PT ~20%)

--COMPASS spectrometer--

Beam: 160 GeV μ^+

$2 \cdot 10^8$ μ/spill

(4.8s/16.2s)



Polarization:

μ **Beam: ~80%**

·LiD Target:<50%>

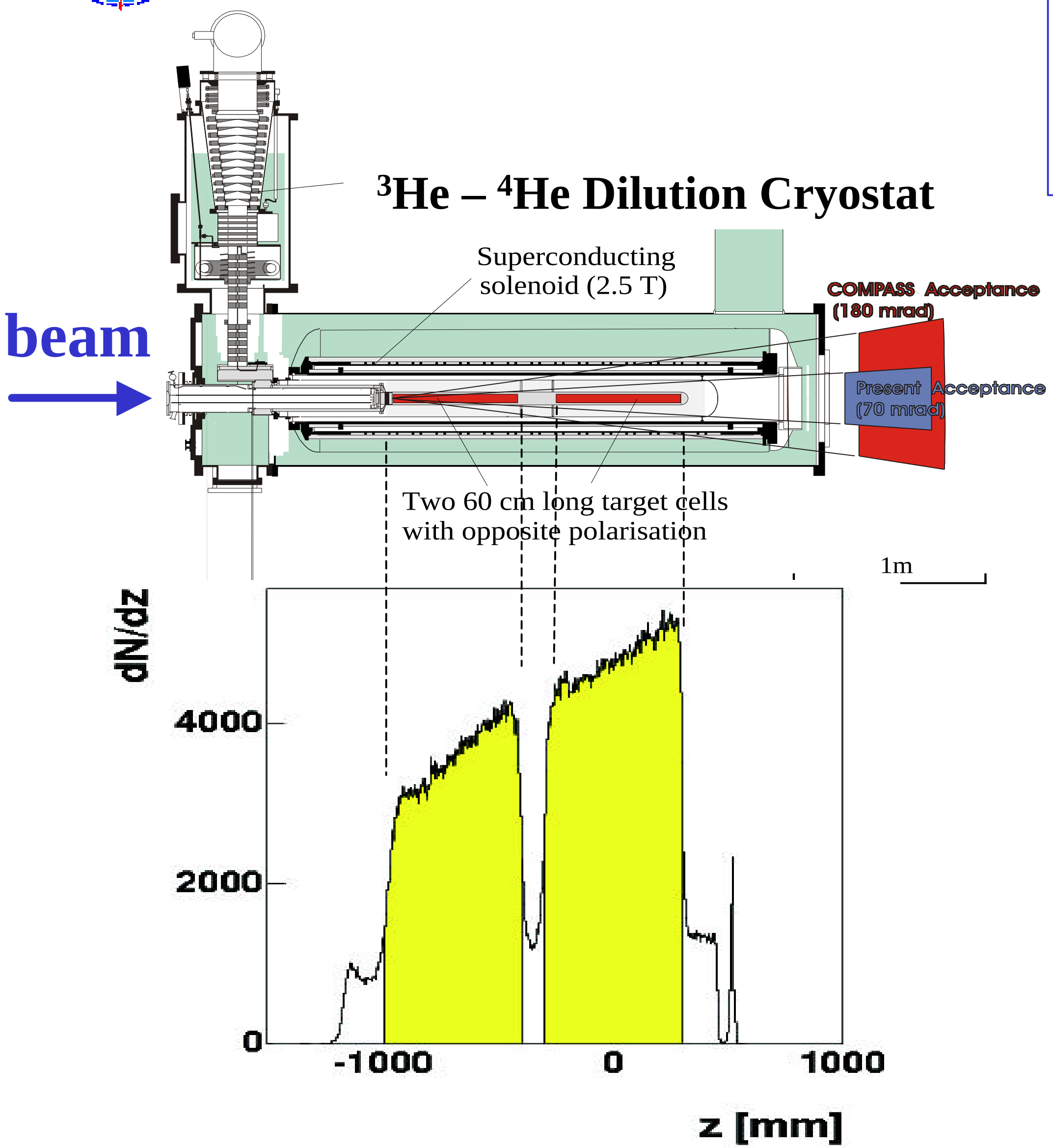
Common **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

Compass ^{6}LiD Polarized target

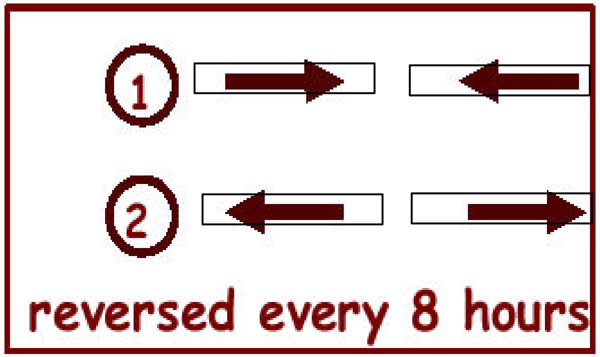
Dynamic Nuclear Polarization

Dilution factor: ~40%

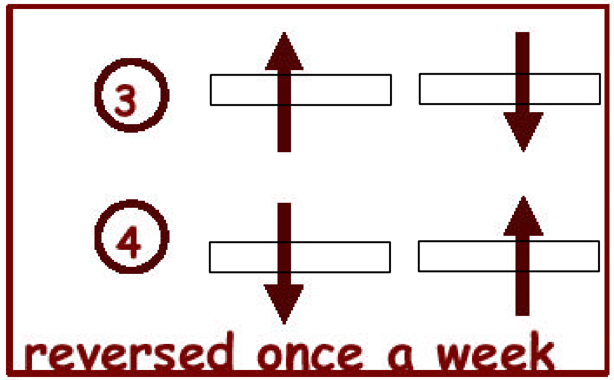
Maximum Polarization: +57%



Longitudinal orientation



Transverse orientation



2. Longitudinal target experiment

- A_1^d , (g_1^d)
- A QCD fit to world data
- Semi-inclusive asymmetries

The inclusive asymmetry A_1^d --2002 & 2003 data--

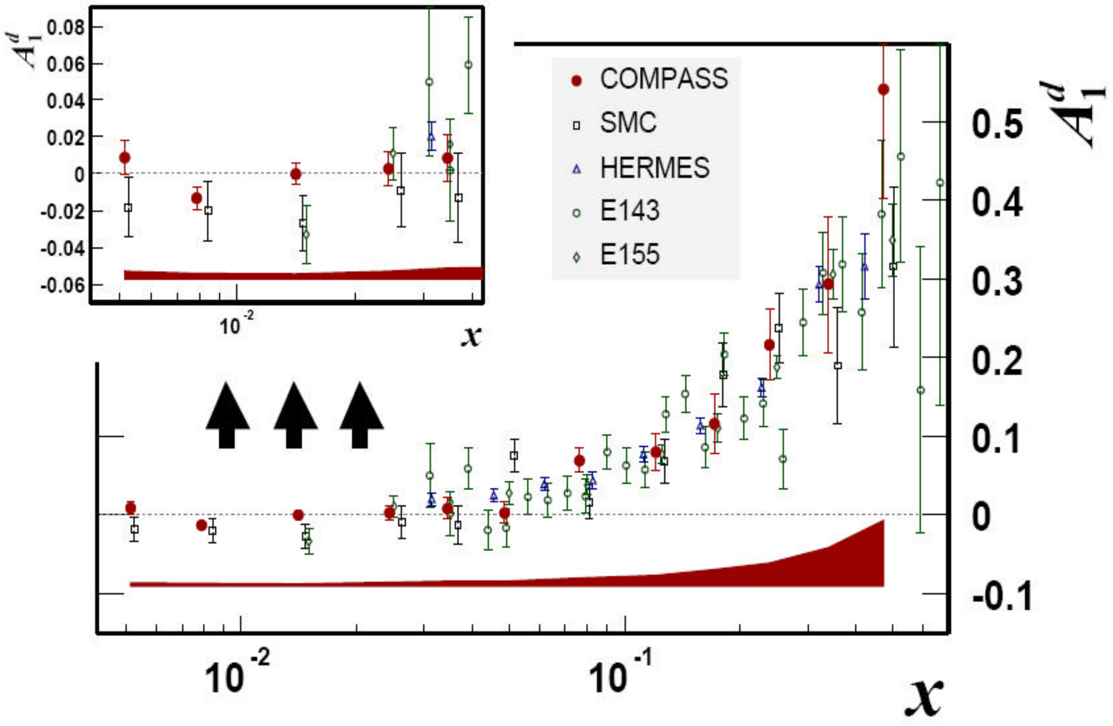
- g-nucleon asymmetry:

$$\frac{A_{\mu N}}{D} \approx A_1 = \frac{\Sigma e_q^2 (\Delta q + \Delta \bar{q})}{\Sigma e_q^2 (q + \bar{q})}$$

- **COMPASS is:**
  - **higher luminosity (~ 5 times stronger)**
  - **larger dilution factor (~2 times larger)(LiD)**
  - **-- more variety of trigger than SMC.**
  - **-- almost the same kinematic region covered as SMC**

- $g_1 = A_1 F_1$ **derived.**

- **Unique result** **in the low *x* region** **important to test QCD sum rules**

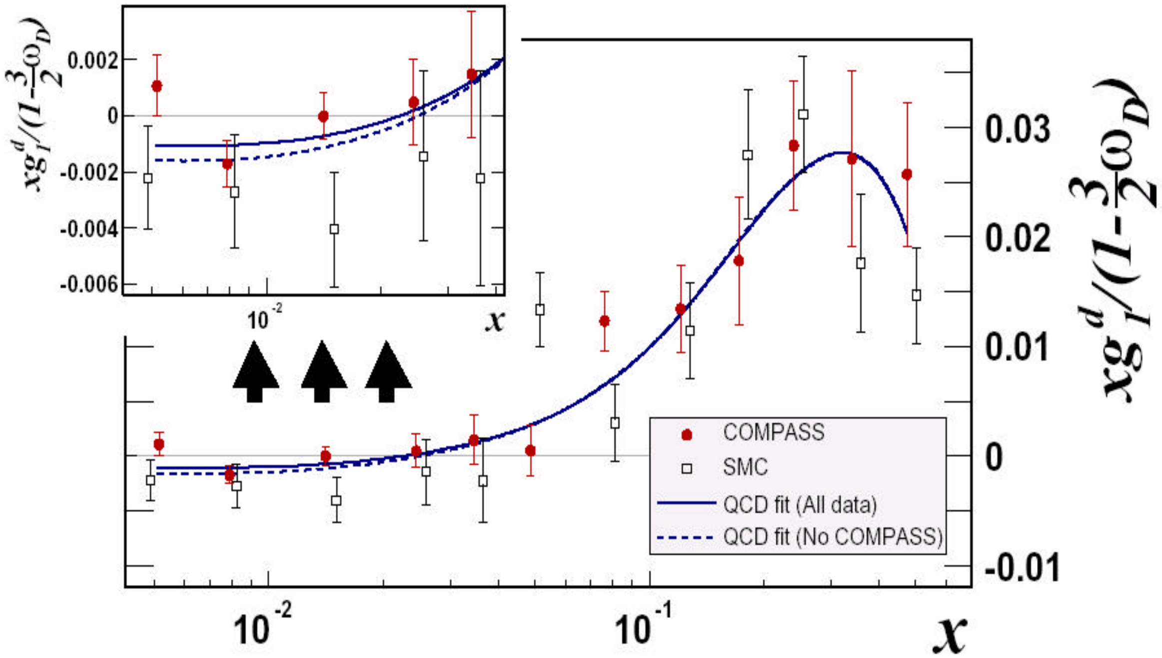


Published in PLB 612 (2005) 154

QCD evolution and fit

A QCD fit to world data

low x accuracy has been much improved



ω_d : the deuterium D-wave state probability

Program by D. Fasching, hep-ph/9610261
(program “2” in SMC notation)

Results of QCD fit to world data

The COMPASS data change the $\int_0^1 \Delta\Sigma(x)\mathrm{d}x$ Integral:

$$\mathrm{DS} = \int_0^1 \Delta\Sigma(x)\mathrm{d}x = 0.237^{+0.024}_{-0.029} \quad \text{all data}$$

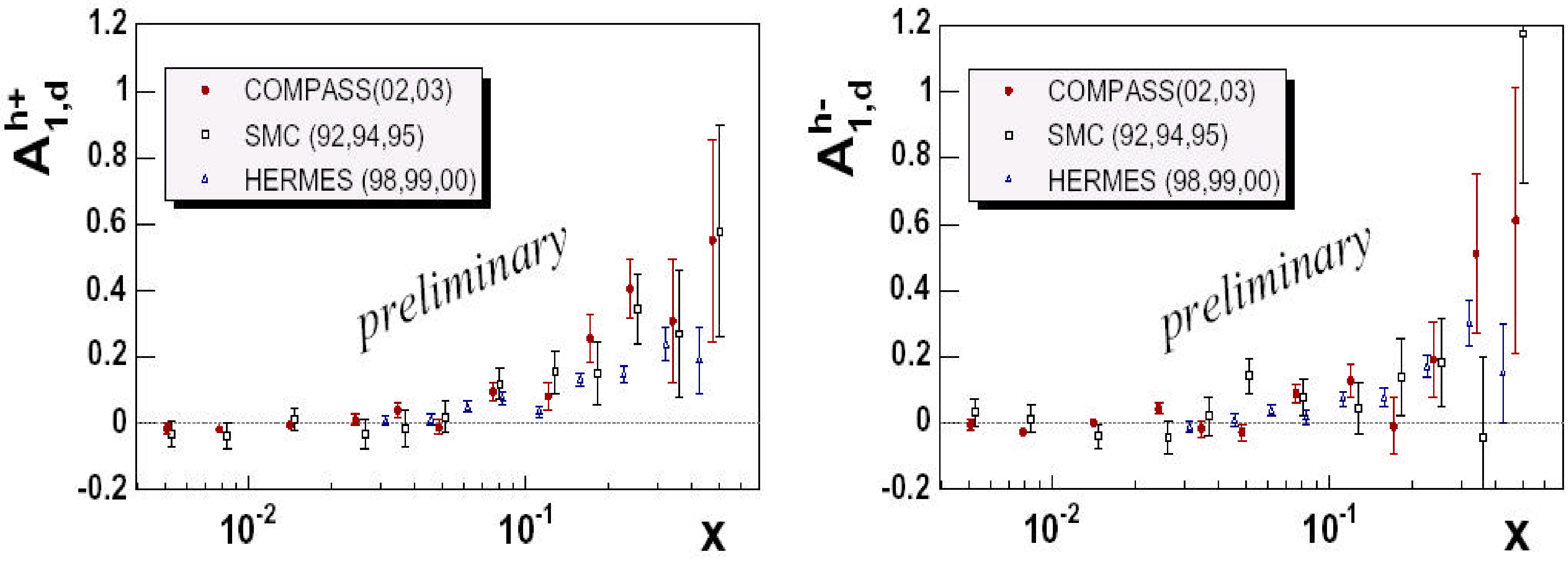
$$= 0.202^{+0.042}_{-0.077} \quad \text{w/o COMPASS}$$

Taken at $Q^2 = 4\mathrm{GeV}^2/c^2$.

Precision improved by a factor of 2

Semi-inclusive asymmetries $A^{h+}_{1,d}$, $A^{h-}_{1,d}$ extracted from 2002+2003 COMPASS data

- low x precision improved



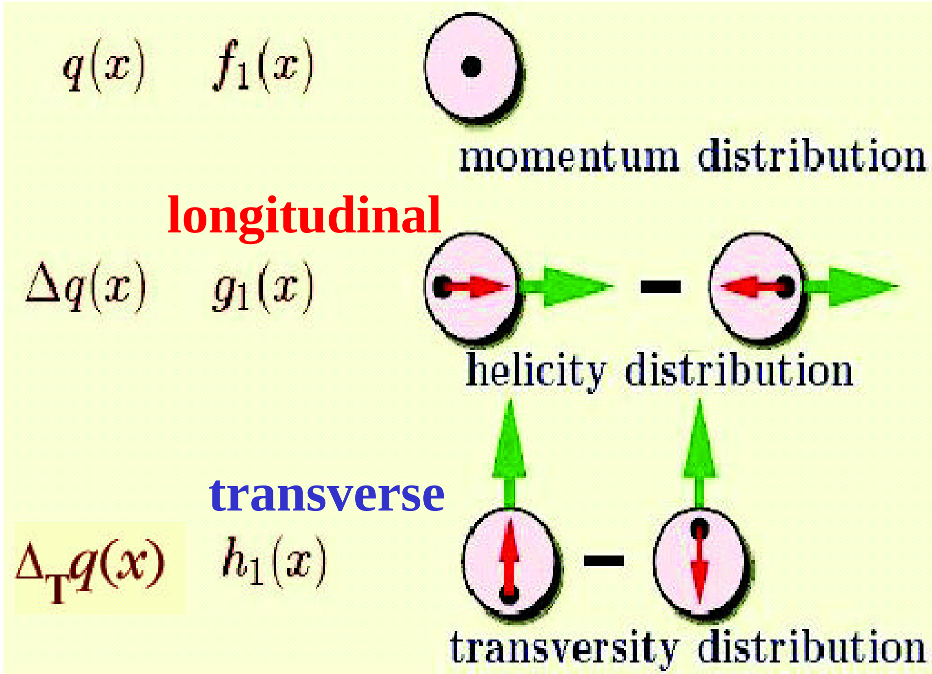
3. Transverse target experiment

- Transversity –introduction
- Transversity –Collins & Sivers asymmetry
- Transversity – two hadron correlation

What is Transversity？

- Nucleon structure functions are described with 3 functions at twist 2 and they are complete at twist level 2.

- $\Delta q(x)$ is different from $\Delta_T q(x)$ generally because rotation does not commute with Lorentz boost in relativity.
 ($\Delta q(x) = \Delta_T q(x)$ in non-relativity)



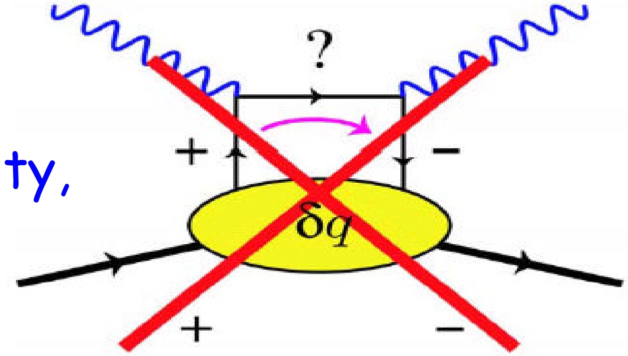
- $\Delta q(x)$ is a chiral even fuction, $\Delta_T q(x)$ is a chiral odd function.

- $\Delta_T q(x)$ does not couple with gluon structure function , then it evolves with Q^2 unlike $\Delta q(x)$.

$\Delta_T q(x) \leq \frac{1}{2}[q(x) + \Delta q(x)]$	$g_T = \int dx[\Delta_T q(x) - \Delta_T \bar{q}(x)]$	$\frac{1}{2} = \frac{1}{2}\sum_{q,\bar{q}} \int \Delta_T q(x)dx + \sum_{q,\bar{q},g} < L_{S_T} >$
(Soffer inquality)	(Tensor charge)	(Transverse Spin SR)

How do we measure **transversity?**

•Quark helicity is conserved in totally Inclusive Deep Inelastic Scattering (IDIS) , so Inclusive DIS does not access to transversity, because transversity needs quark helicty flip in helicity base.



•In case of Semi-Inclusive Deep Inelastic(SIDIS) it is possible to access transversity, because SIDIS allows both flip and non-flip cases.

Then we measure SIDIS events to study transversity.

•If we choose phenomena with chiral odd fragmentation functions, we can access chiral odd quark distribution functions.

•We measure SIDIS including transversity in
(1) Collins asymmetry and Sivers asymmetry
(2) SSA in two hadron correlation.

(1) Collins and Sivers asymmetries

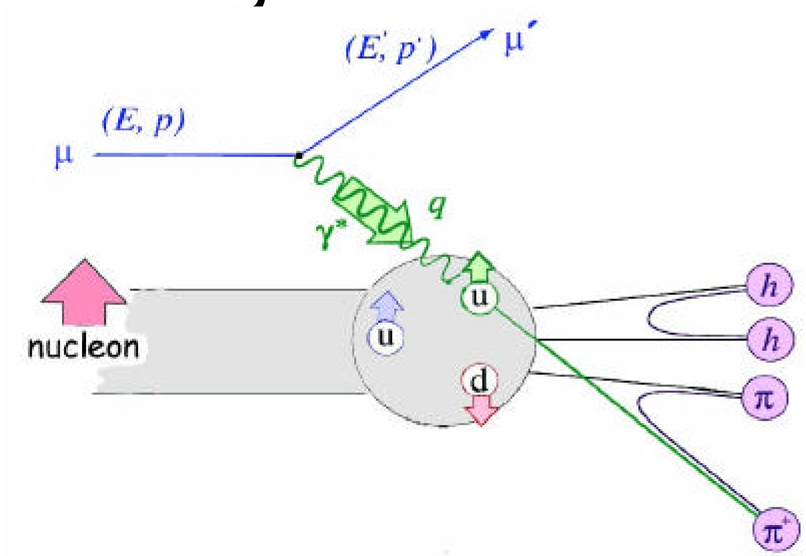
Collins angle & Sivers angle.

f_S = azim. angle of inital quark spin

$f_{S'}$ = azim. angle of struck quark spin

$f_S = \pi - f_{S'}$ (due to helicity conservation)

f_h =azim. Angle of leading hadron



- **Collins angle**

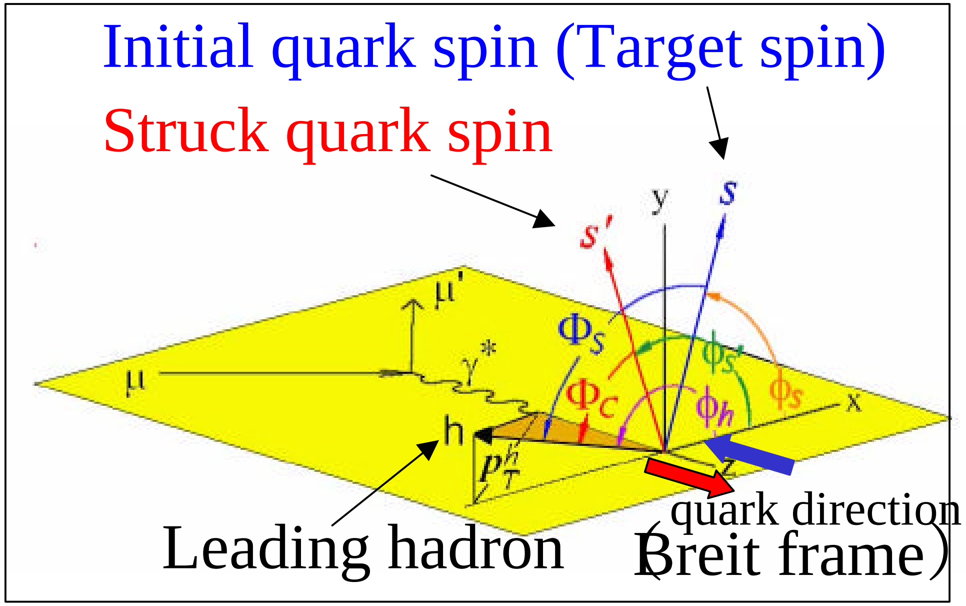
  (Azimuthal angle of a leading hadron around a struck quark spin)

  $F_C = f_h - f_{S'}$ $(= f_h + f_S - \pi)$

- **Sivers angle**

  (Azimuthal angle of a leading hadron around an initial quark spin (=nucleon spin))

  $F_S = f_h - f_S$



Collins asymmerty and Sivers asymmetry

spin independent part **spin dependent part**

FF: $D^h_{Tq}(z, \vec{p}^h_T) = D^h_q(z, |\vec{p}^h_T|^2) + \Delta^0_T D^h_q(z, |\vec{p}^h_T|^2) \cdot \sin\Phi_C$

If the spin information of the struck quark propagates to the fragment function, we observe Collins asymmetry.

Collins asymmetry

$$A_{Coll} = \frac{e_{Coll}}{f \cdot |P_T| \cdot D_{NN}} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot \Delta^0_T D^h_q}{\sum_q e_q^2 \cdot q(x) \cdot D^h_q}$$

measure

transverse spin transfer coefficient

Transversity

Spin-dependent FF

If quarks move asymmetrically around nucleon spin orientation, we observe Sivers asymmetry.

$$q_T(x, \vec{k}_T) = q_T(x, |\vec{k}_T|^2) + \Delta^T_0 q(x, |\vec{k}_T|^2) \cdot \sin\Phi_S$$

Sivers asymmetry

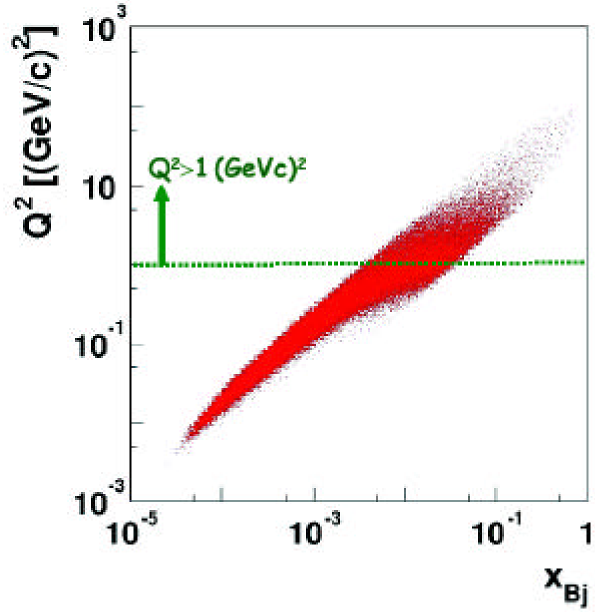
$$A_{Siv} = \frac{e_{Siv}}{f \cdot |P_T|} = \frac{\sum_q e_q^2 \cdot \Delta^T_0 q(x) \cdot D^h_q}{\sum_q e_q^2 \cdot q(x) \cdot D^h_q}$$

measure

the effect of quark orbital motion in nucleon

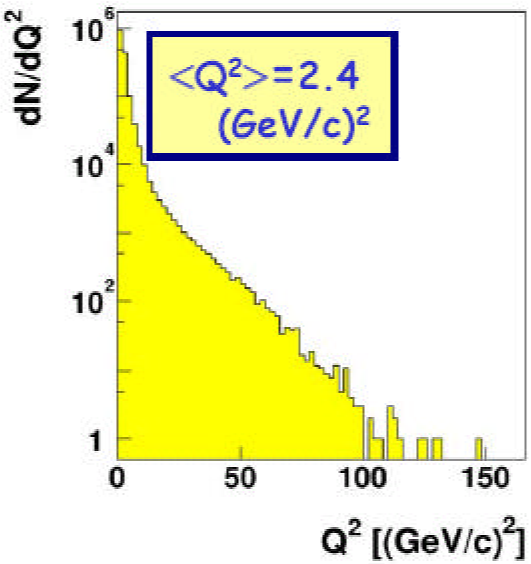
Event selection

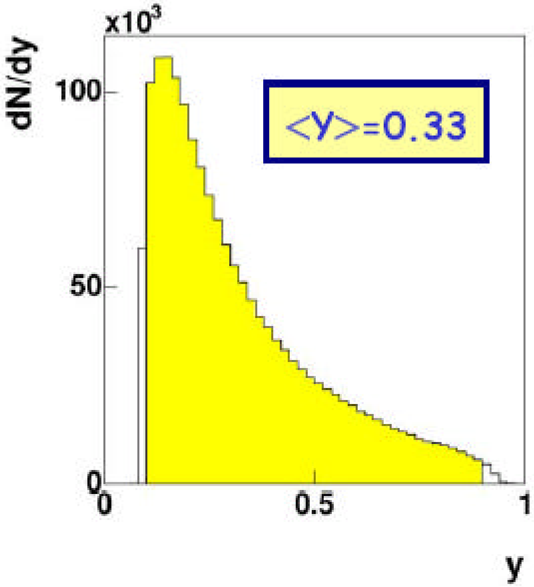
for muons

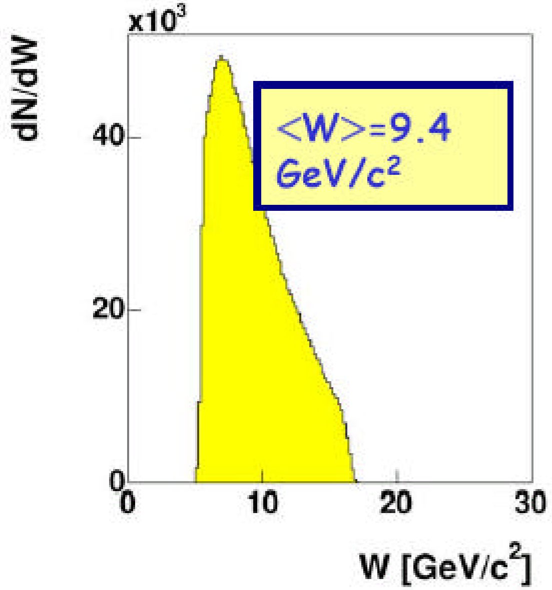


- Primary vertex with identified μ, μ' & hadron

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



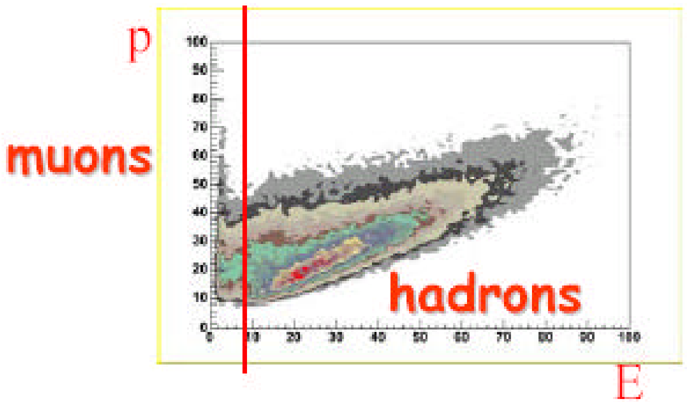




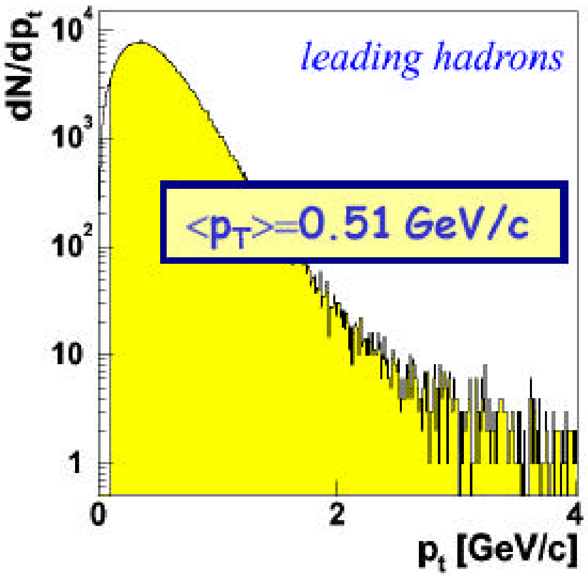
Event selction cont.
for hadrons

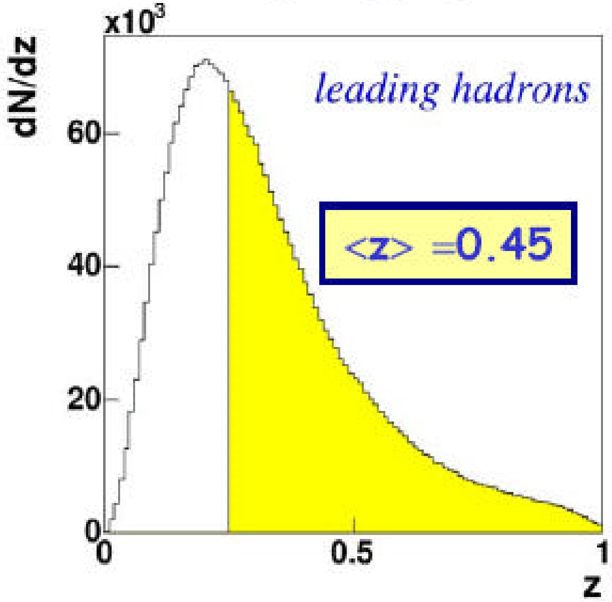
Hadron selection:

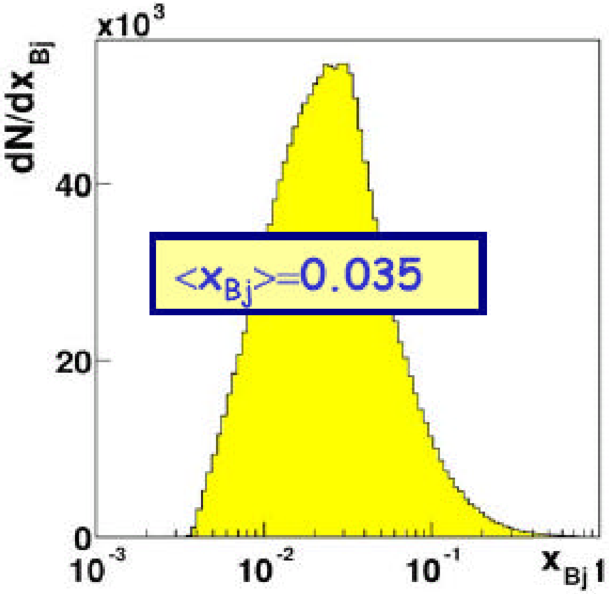
- energy deposit in hadron calorimeters
- Penetration < 10 X_0
- Presently no π / K / p separation by RICH



- $p_T > 0.1$ GeV/c
- $z > 0.25$







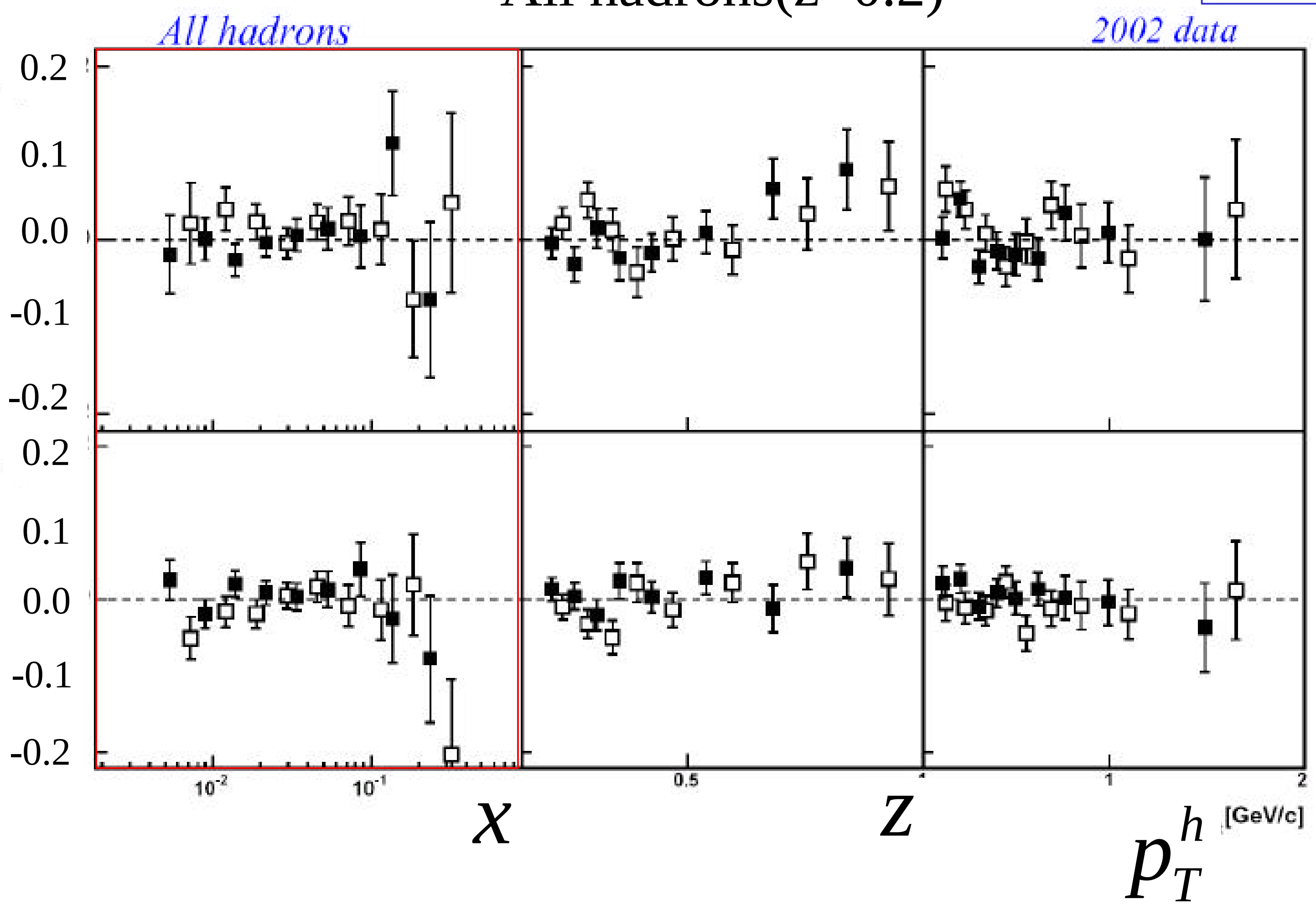
Collins and Sivers asymmetries for all hadrons (2002 final results)

PRL 94(2005) 202002

All hadrons(z>0.2)

Collins asymmetry

Sivers asymmetry



Black:Positive hadrons

White: Negative hadrons

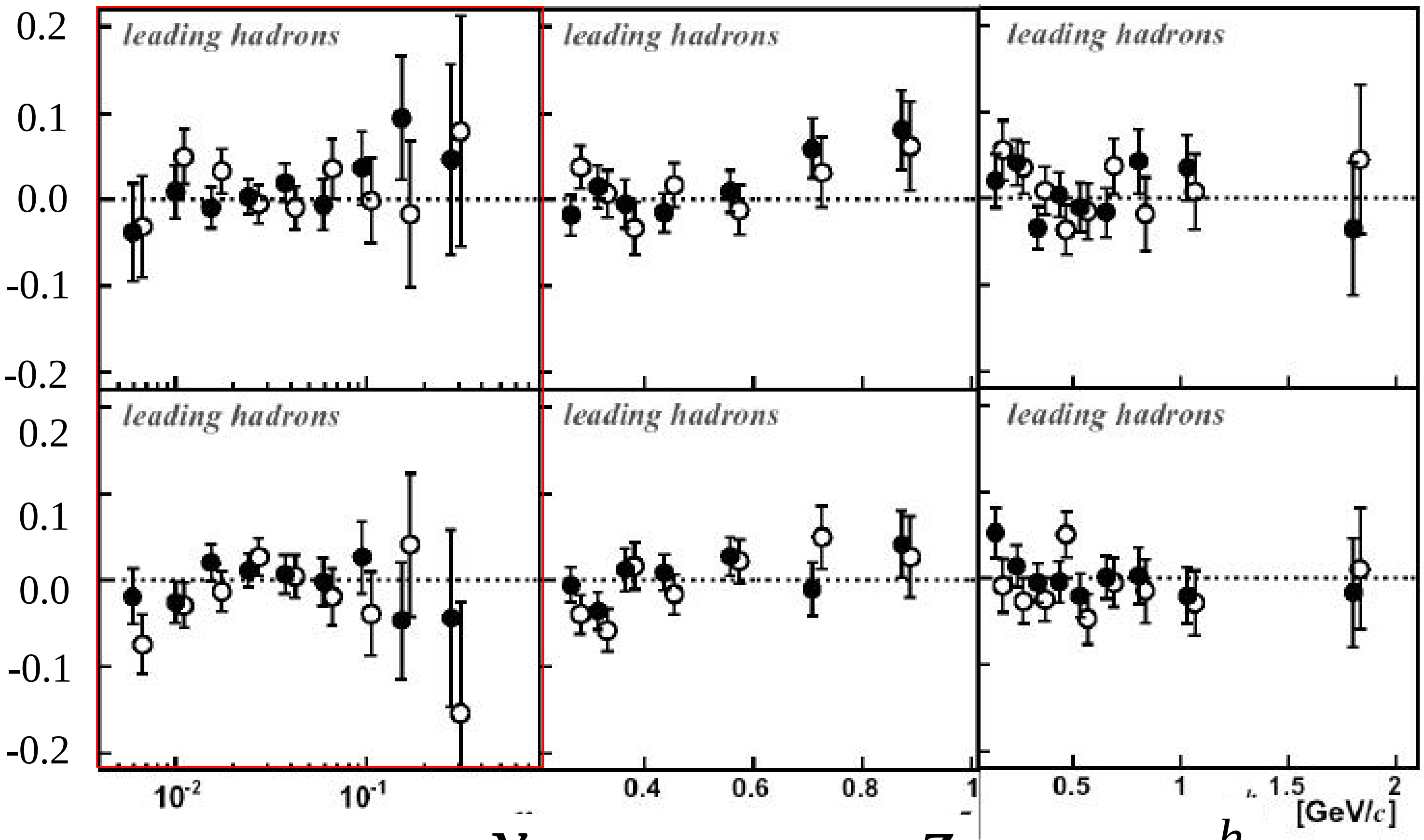
Collins and Sivers asymmetries for leading hadron (2002 final results)

PRL 94(2005) 202002

Leading hadrons (z>0.25)

Collins asymmetry

Sivers asymmetry



x z p_T^h

Black:Positive hadrons

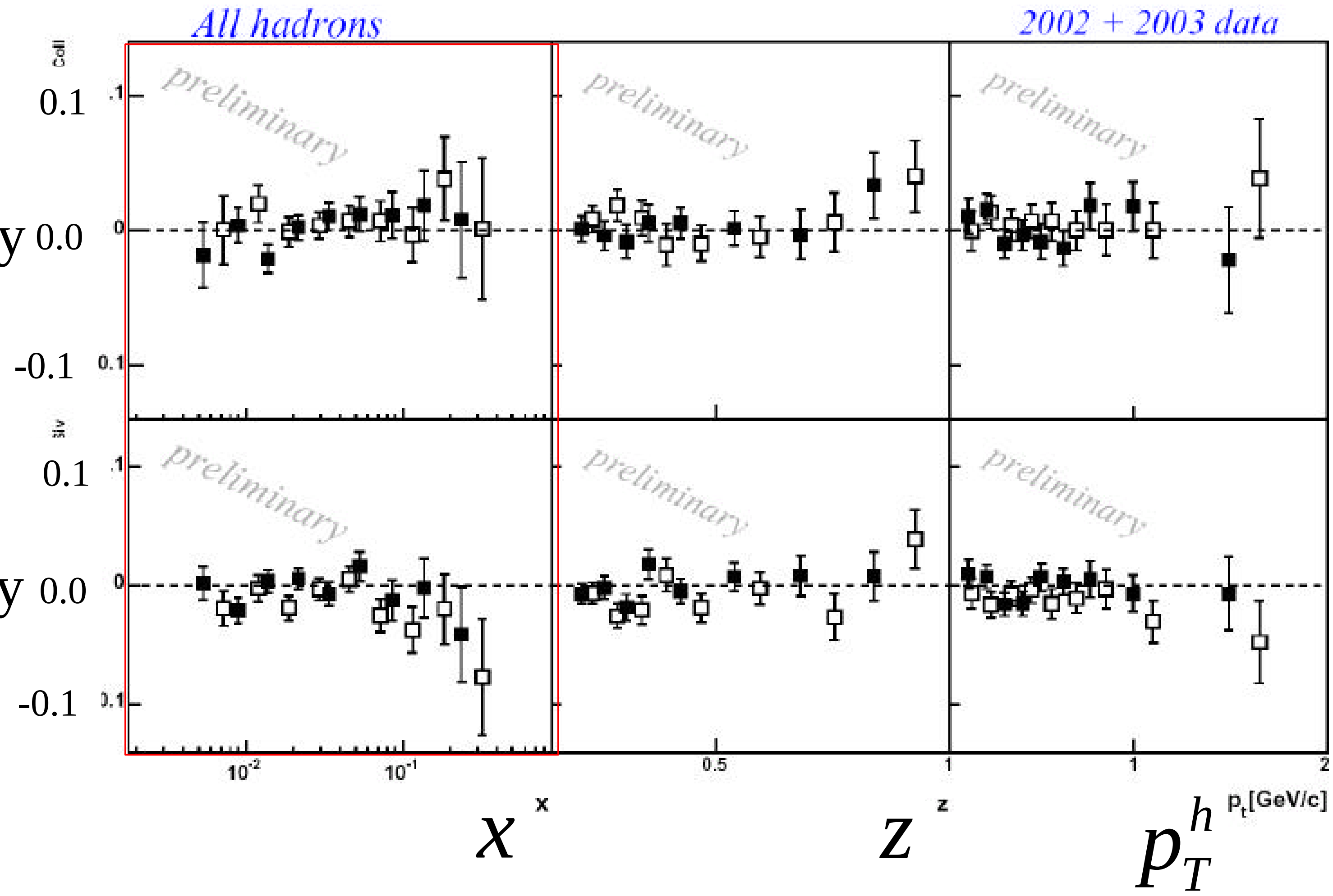
White: Negative hadrons

Collins and Sivers asymmetries for all hadrons (2002+2003 data)

preliminary

Collins asymmetry

Sivers asymmetry



Black:Positive hadrons

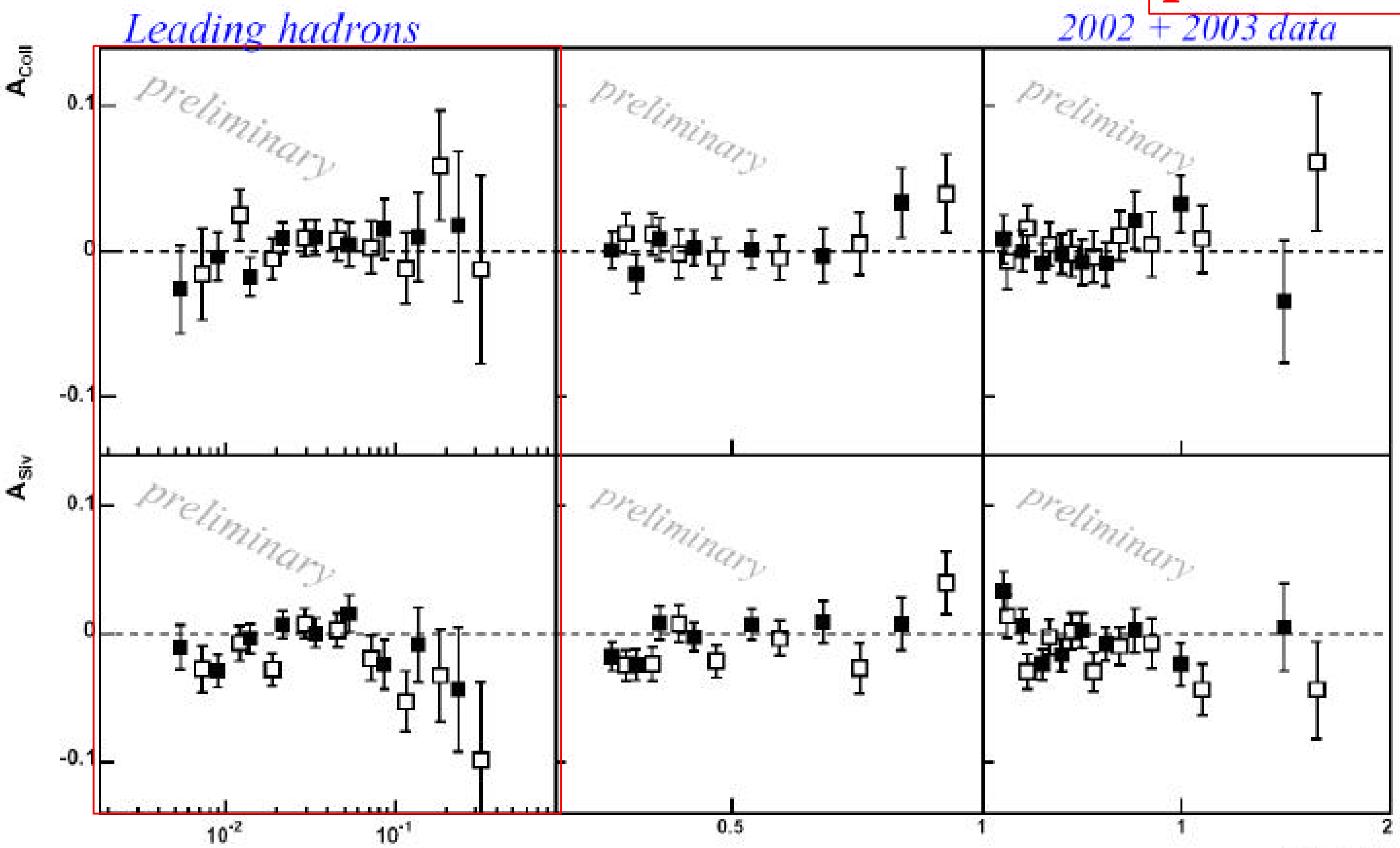
White: Negative hadrons

Collins and Sivers asymmetries for leading hadrons (2002+2003 data)

preliminary

Collins asymmetry

Sivers asymmetry



x z p_T^h

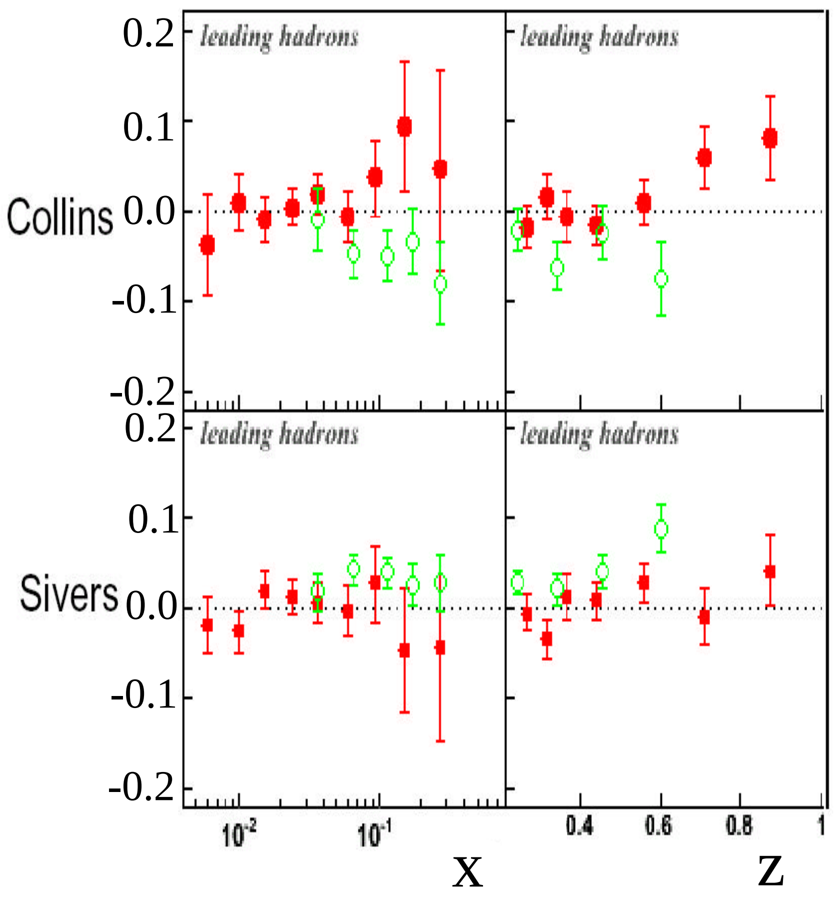
Black:Positive hadrons

White: Negative hadrons

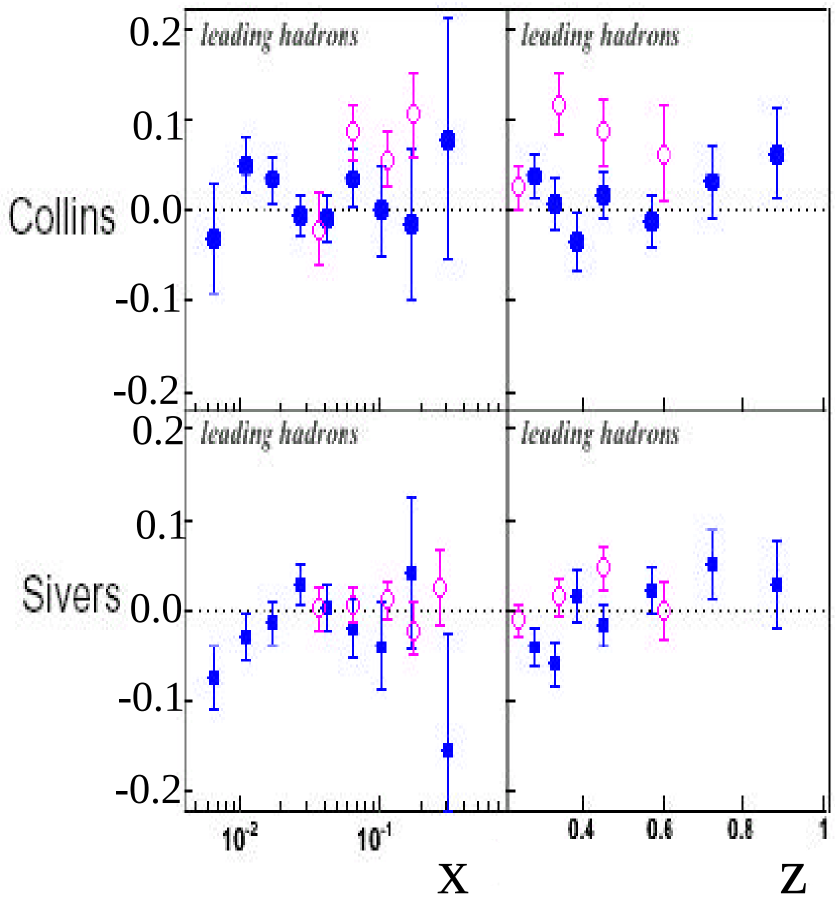
Comparison of COMPASS 2002 results with HERMES ones.

(COMPASS;deuteron, HERMES;proton)

POSITIVE HADRONS: COMPASS vs HERMES



NEGATIVE HADRONS: COMPASS vs HERMES



Note:The sign of the original definition of HERMES is opposite.

(2) SSA in two hadron correlation

Which angle we measure? → Trento conventions

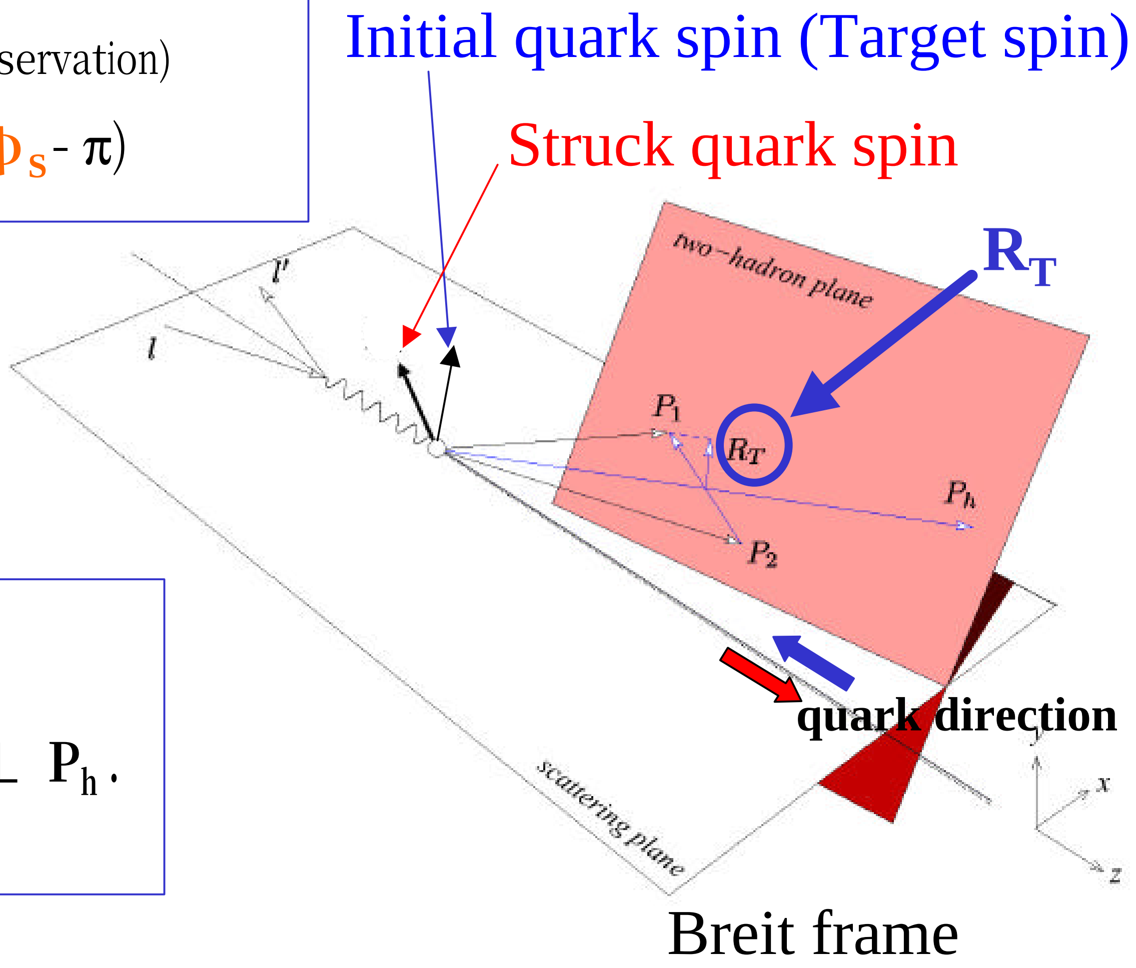
see hep-ph/0407345

ϕ_S = azim. angle of inital quark spin

$\phi_{S'}$ = azim. angle of struck quark spin

$\phi_S = \pi - \phi_{S'}$ (due to helicity conservation)

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



$R=(P_1-P_2)/2$, $P_h=P_1+P_2$

R_T is the component of $R \perp P_h$.

ϕ_R = azimuthal angle of R_T

COMPASS

Two hadron correlation
--the interference frgmentaion function--

spin independent part — spin dependent part

FF: $D_q^h(z, M_h^2) + H_1^{\triangleleft}(z, M_h^2) \cdot \sin\varphi_{RS}$

If the spin information of the struck quark propagates to the interference fragmentation function, we observe the following asymmetry.

$$A_{RS} = \frac{\varepsilon_{RS}}{f \cdot |P_T| \cdot D_{NN}} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot H_1^{\triangleleft h}(z, M_h^2)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h(z, M_h^2)}$$

measure

transverse spin transfer coefficient

Transversity

interference FF

Event Selection-two hadron correlation-

For m

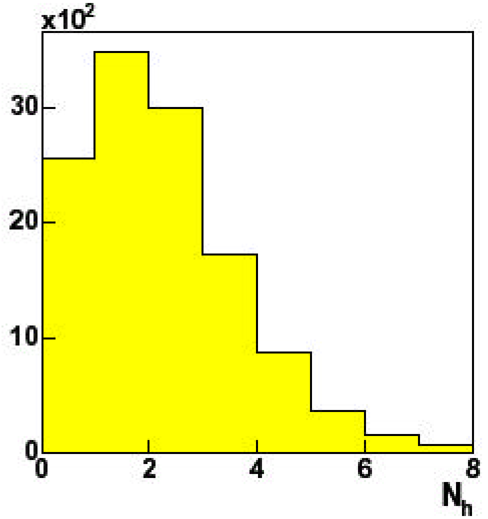
same as others.

For hadron in order to select the current fragmentation region

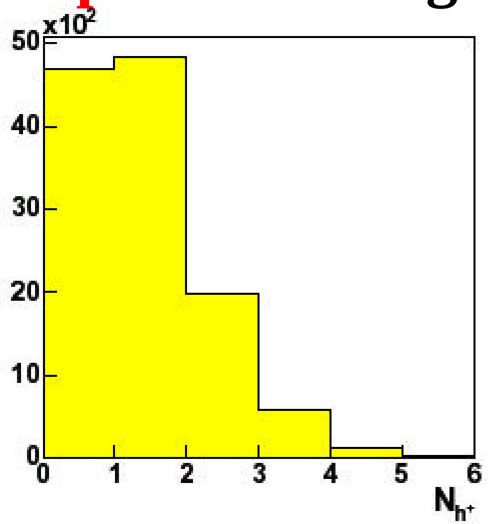
$z_h > 0.1$ (then $z_{h1} + z_{h2} > 0.2$)

$x_{fh} > 0.1$

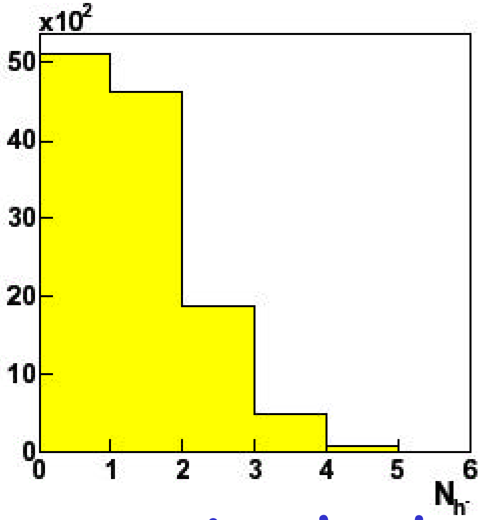
Hadron multiplicity for all charges



Hadron multiplicity for positive charges

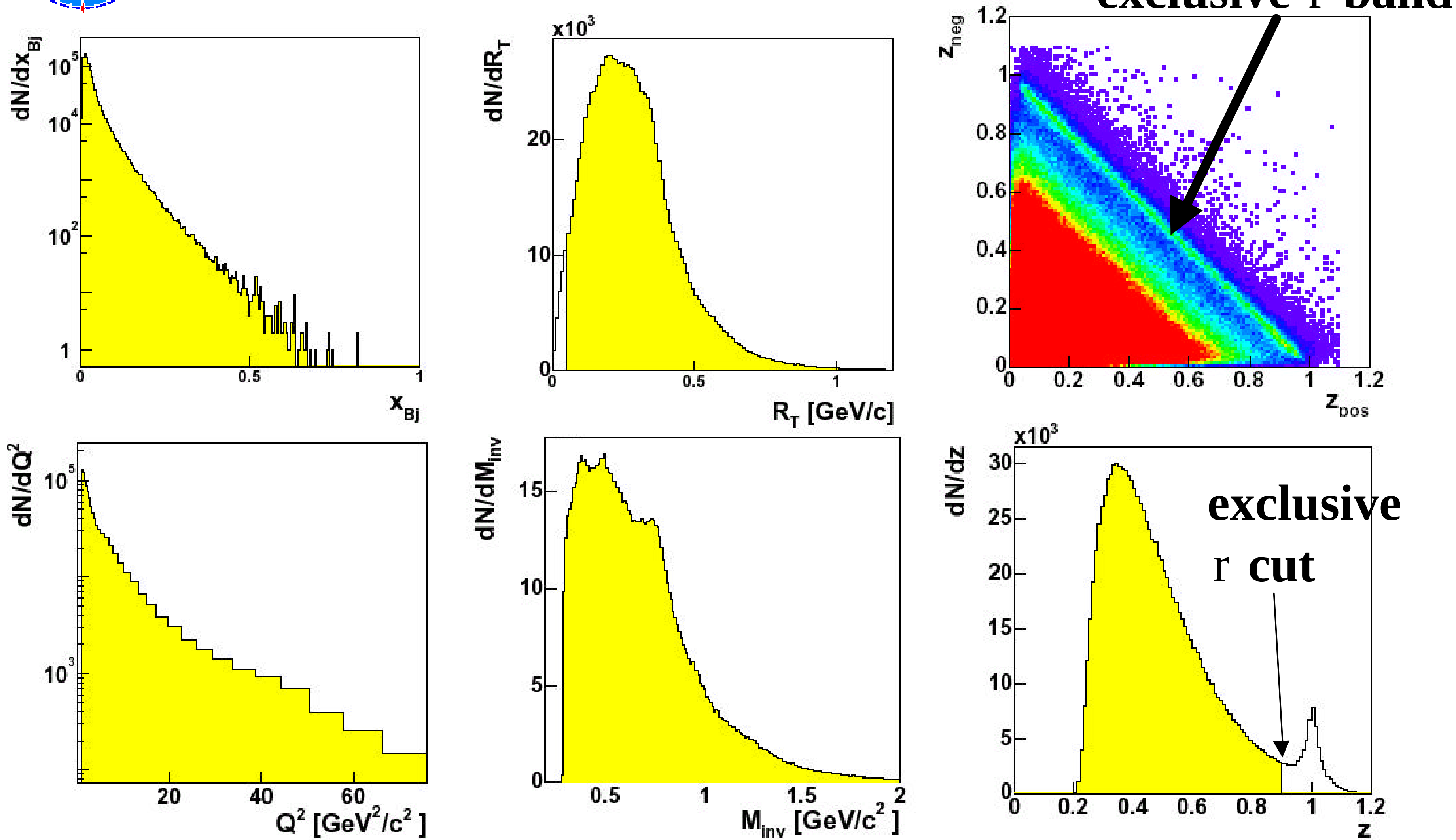


Hadron multiplicity for negative charges



We choose one positve hadron and one negative hadron.

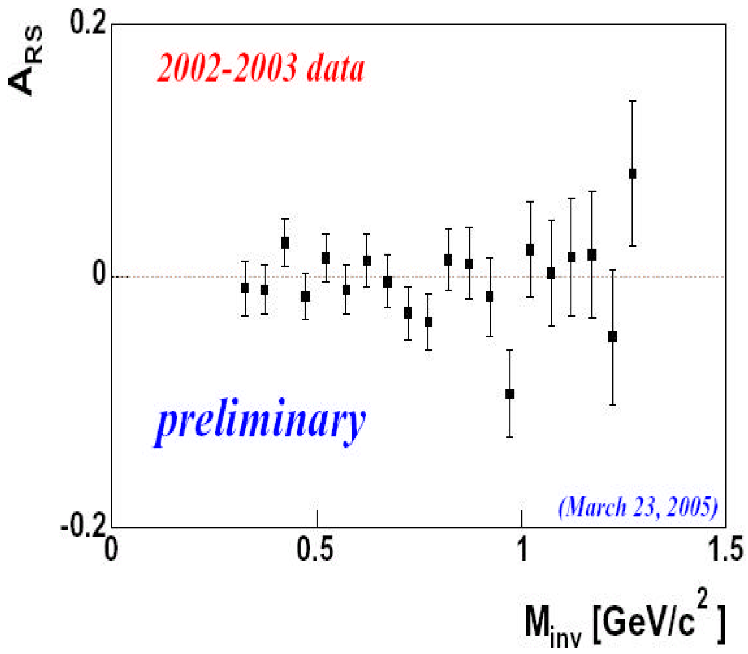
Distributions and cut **for hadrons**

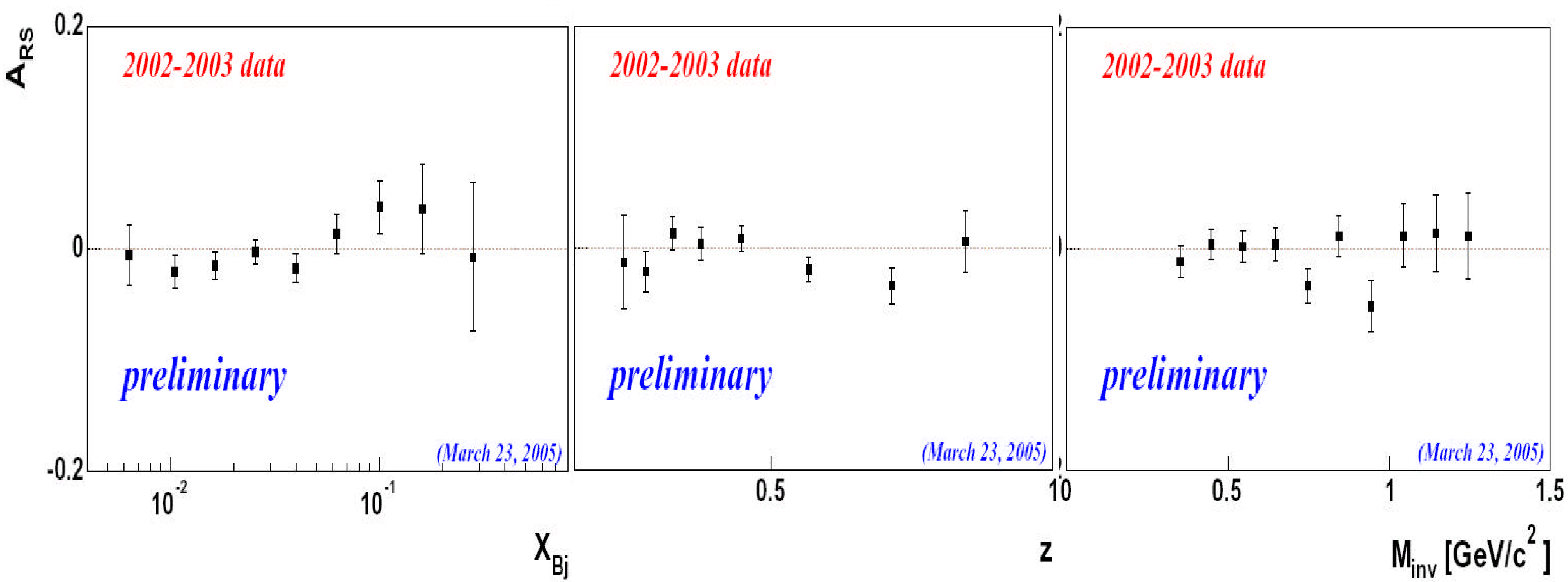


2-hadron asymmetries (2002+2003 data)

preliminary

very small or compatible to zero





4 Summary and ...

(longitudinal part)

- New data (2002+2003) for A_1^d and g_1^d were shown (published).

    significant improvement at low x

- A QCD fit including new deuteron data was shown. $\Delta\Sigma$ obtained
- New data (2002+2003) for semi-inclusive asymmetries $A^{h+}_{1,d}$, $A^{h-}_{1,d}$ were shown (preliminary).

(transverse part)

- Collins and Sivers SSA calculated

    2002 data (published) , 2003 data (preliminary)

- SSA in two hadron correlation were shown

    2002 +2003 data (preliminary)

- In both cases asymmetries are small and compatible with zero.

… Outlook

(analysis)

• 2004 data (both longitudinal and transvers) under analysis

(experiment)

• muon program will be going on in 2006 and more data will be accumulated

--deutron target(LiD) for longitudinal part

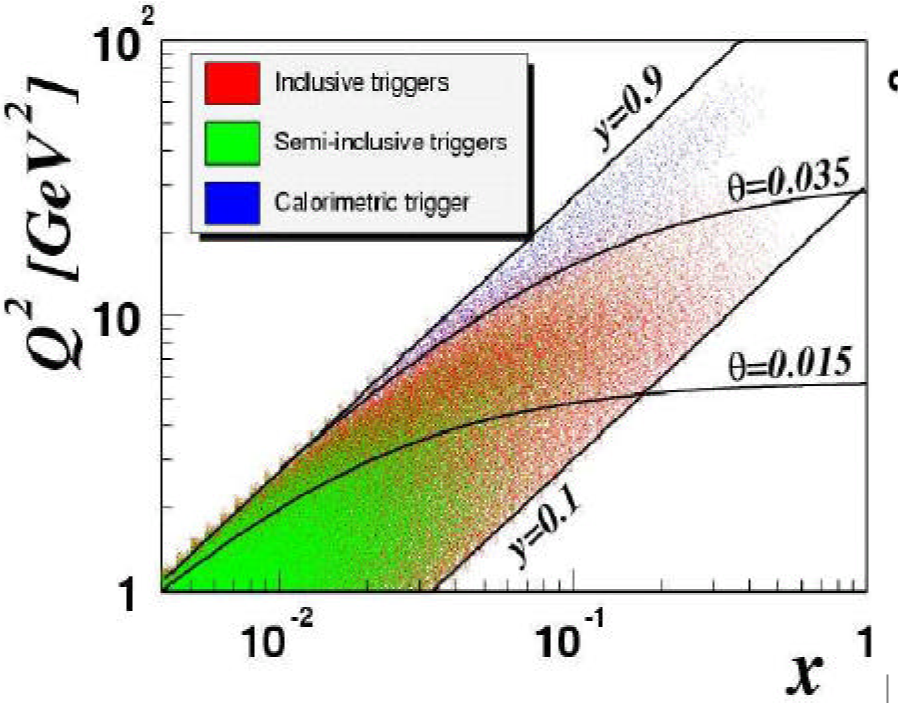
--proton target(NH_3) for transverse part

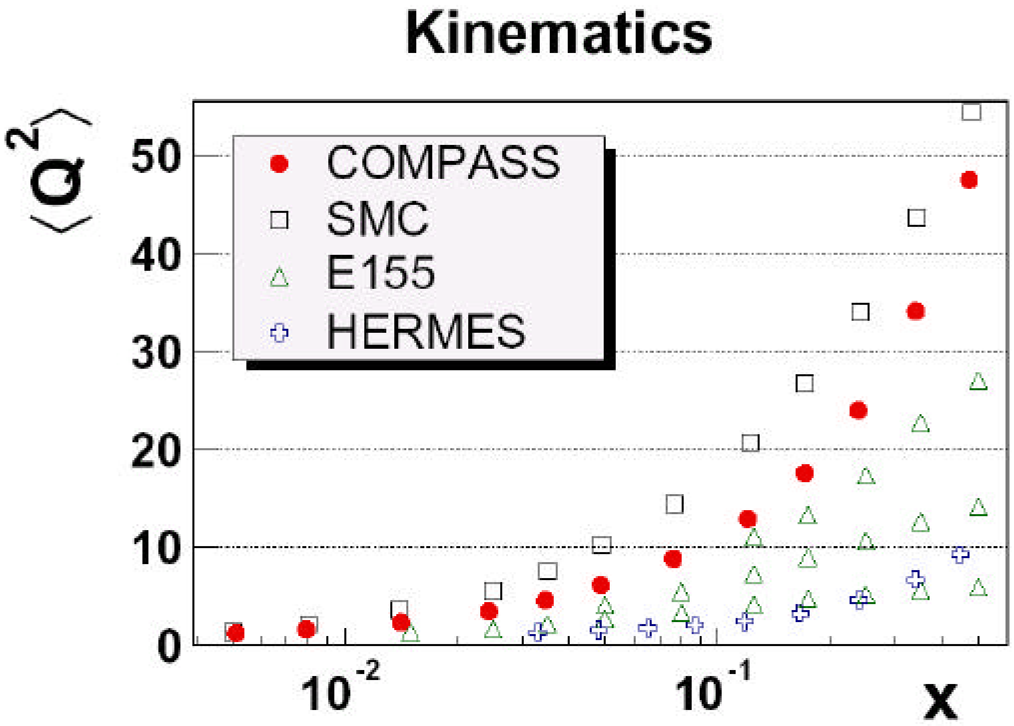
--> complementary and comparable accuracy to deuteron data expected

Merci

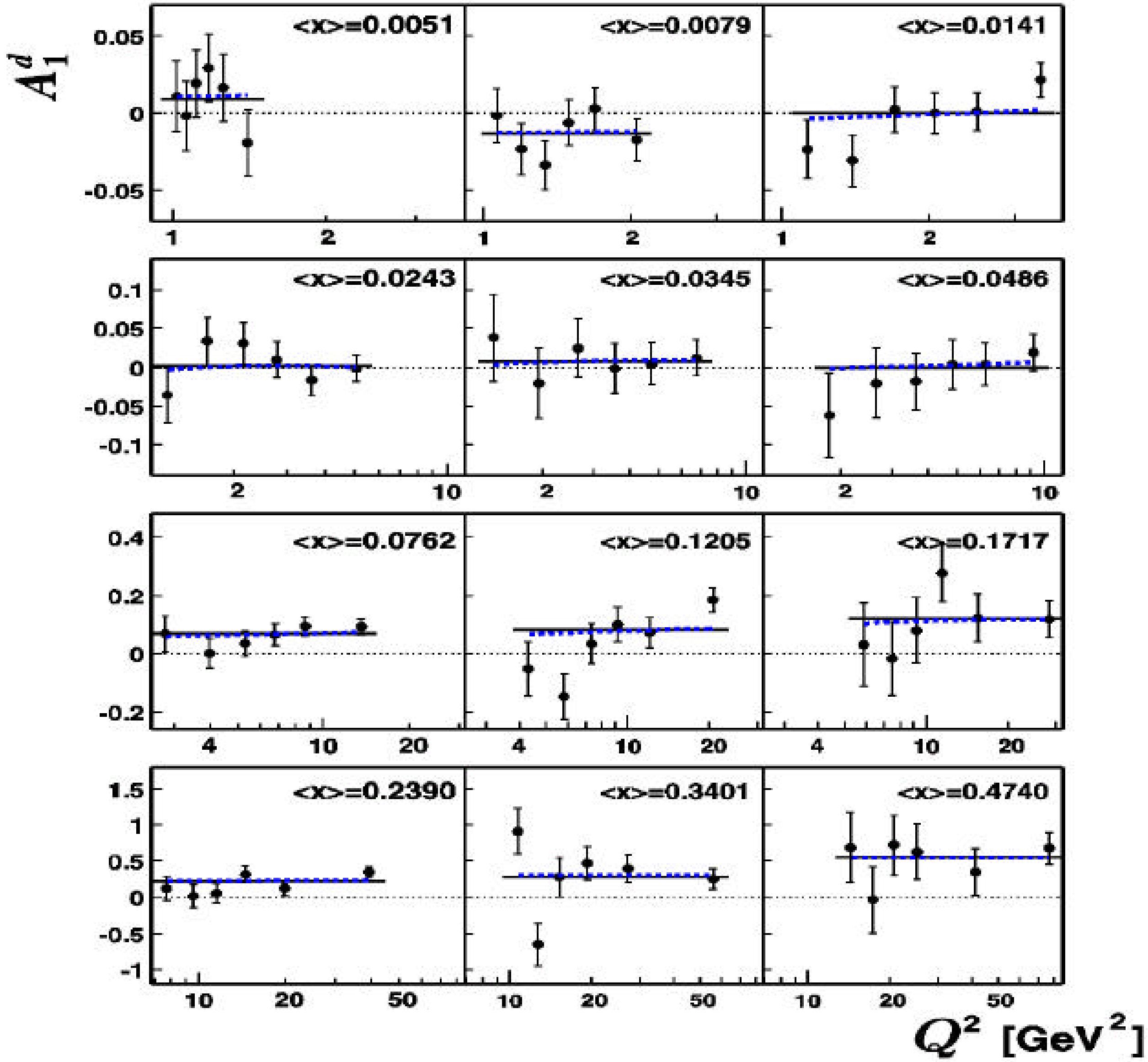
Addendum after my talk

x vs Q^2 distribution





Dependence of A_1^d on Q^2



QCD fit to world data

Table 3: Quark spin content ($\Delta\Sigma$ in $\overline{MS}$ scheme) and ΔG. The quoted errors are only statistical.

		Compass fit Comp. data incl.	Compass fit Comp.data excl.	AAC03	LSS05
$\Delta\Sigma$	$Q^2 = 1$ GeV^2	$0.239^{+0.024}_{-0.025}$	$0.216^{+0.036}_{-0.048}$	0.213 ± 0.039	0.189 ± 0.054
	$Q^2 = 4$ GeV^2	$0.237^{+0.024}_{-0.029}$	$0.202^{+0.042}_{-0.077}$		
ΔG	$Q^2 = 1$ GeV^2	0.44 ± 0.19	0.44 ± 0.21	0.50 ± 0.35	0.20 ± 0.26
	$Q^2 = 4$ GeV^2	$0.47^{+0.21}_{-0.20}$	0.53 ± 0.23		