Transverse Spin Effects @ COMPASS

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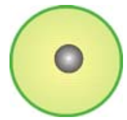
on behalf of the COMPASS Collaboration

three distribution functions

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

$q(x)$: number density or unpolarized distribution

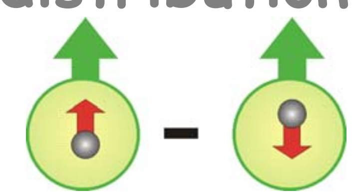


First data from ’70 (SLAC)

$\Delta q(x) = q^{\rightrightarrows} - q^{\leftrightarrows}$: longitudinal polarization or helicity distribution

Starting from the ’80 (E80, EMC)

$\Delta_T q(x) = q^{\uparrow\uparrow} - q^{\downarrow\uparrow}$: transverse polarization or transversity distribution



Still unmeasured

Measurement is difficult and theoretically transverse spin effects have been neglected for long time (re-raised in the ’90)

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 couple of 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):

$$\Delta_T q(x) \le q^+(x) = \frac{1}{2}\left[\Delta_T q(x) + q(x)\right]$$

- Leader sum rule (04):

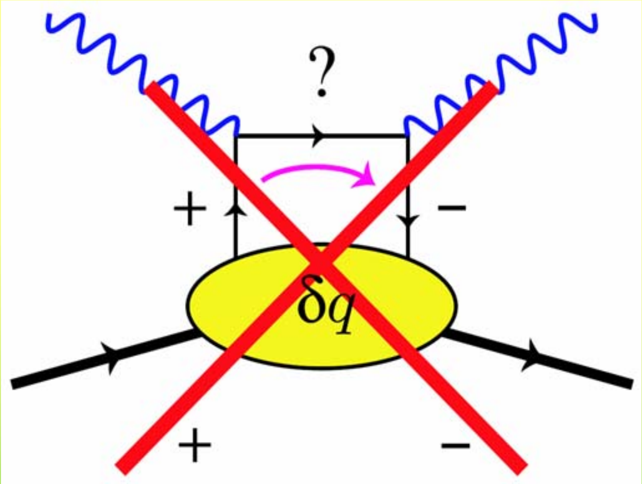
$$\frac{1}{2} = \frac{1}{2}\sum_{q,\bar{q}}\int dx \cdot \Delta_T q(x) + \sum_{q,\bar{q},g}\langle L_T\rangle$$

in analogy with:

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

Measuring $\Delta_T q(x)$

$\Delta_T q(x)$ is chiral odd: decouples from leading twist DIS because helicity of quark must flip. It doesn't play any role in inclusive DIS;

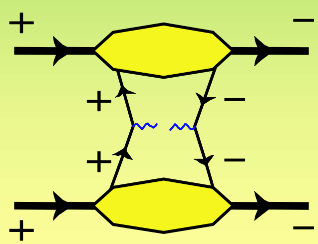


How to access it? $\Rightarrow$

Measuring $\Delta_T q(x)$

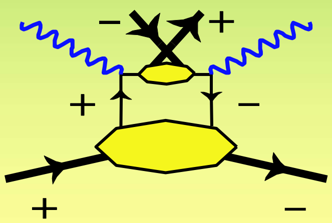
Chiral-odd: requires another chiral-odd partner

$p^{\uparrow}p^{\uparrow} \to l^+ l^- X$



Direct Measurement

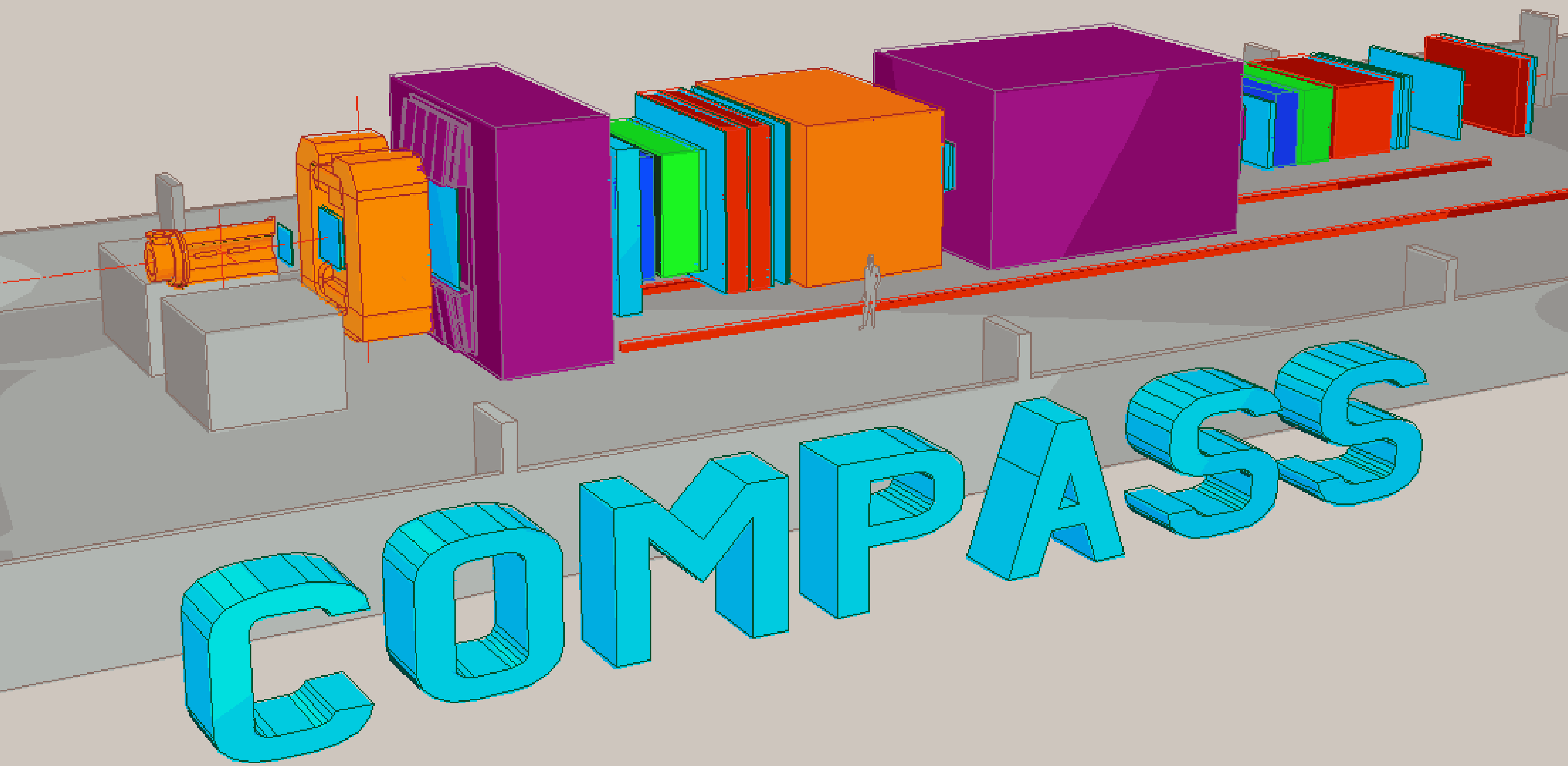
$ep^{\uparrow} \to e' h_{\perp} X$



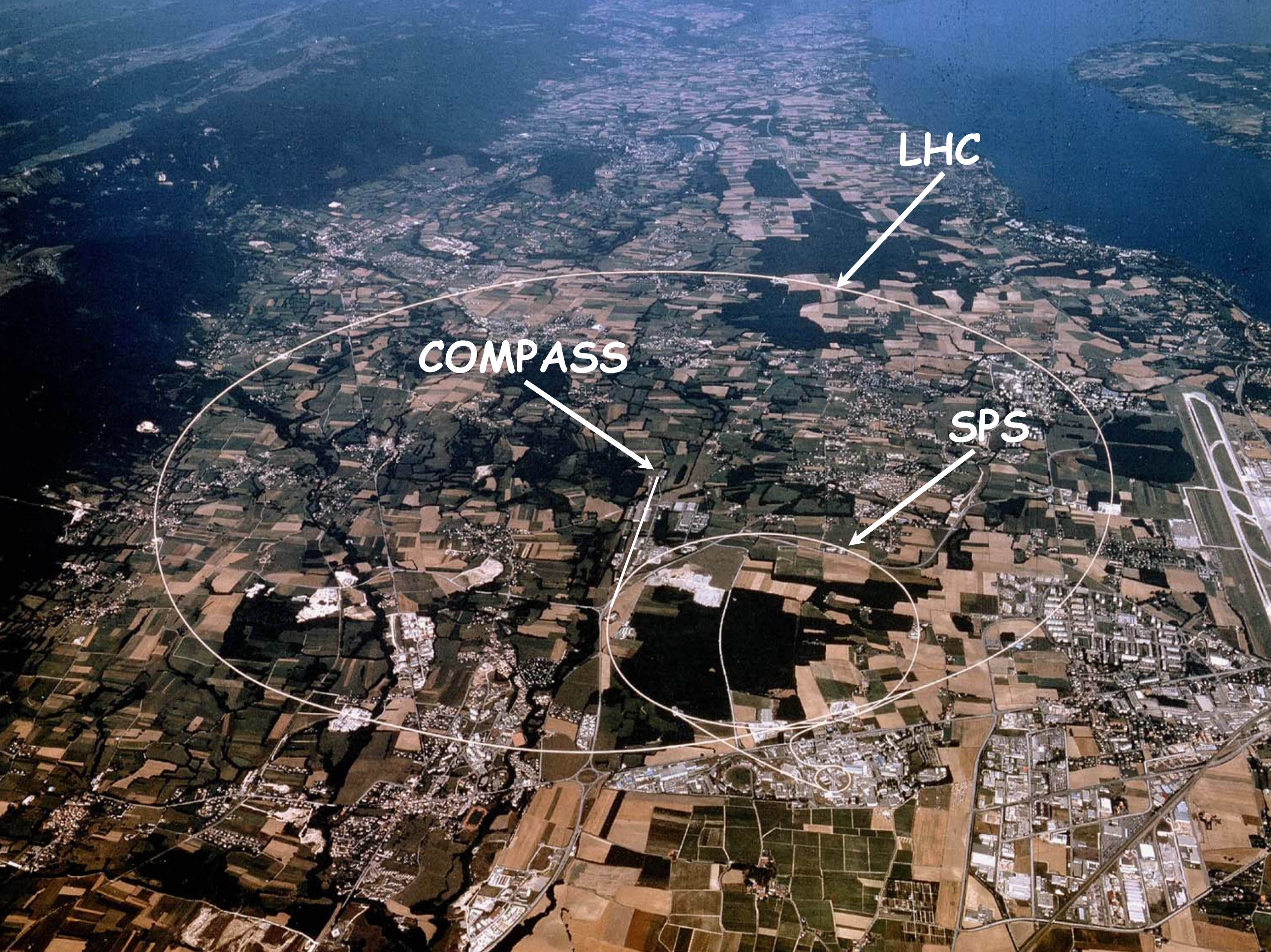
Convolution with fragmentation functions (measurements of ff ongoing at BELLE)

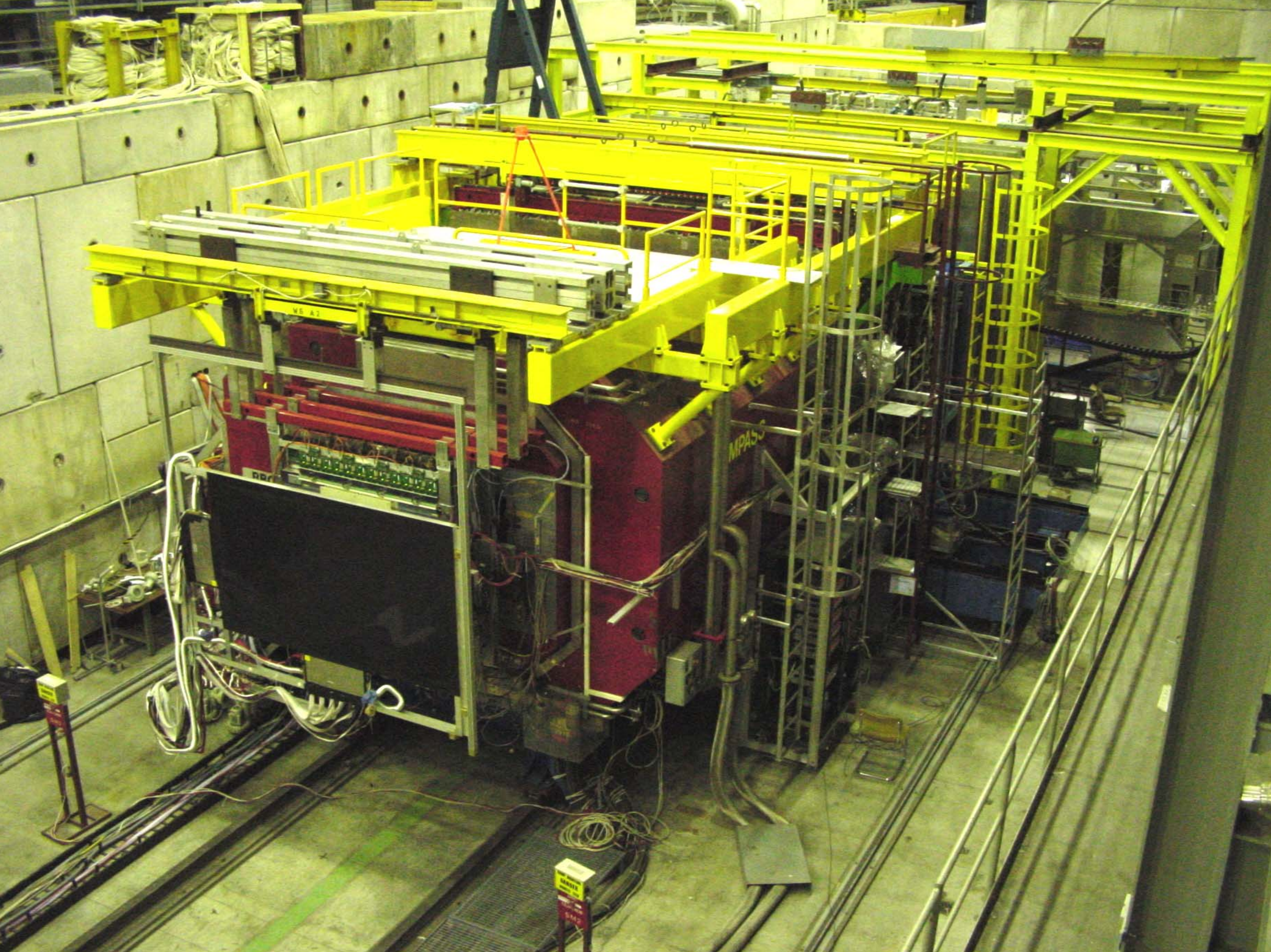
How to access it:

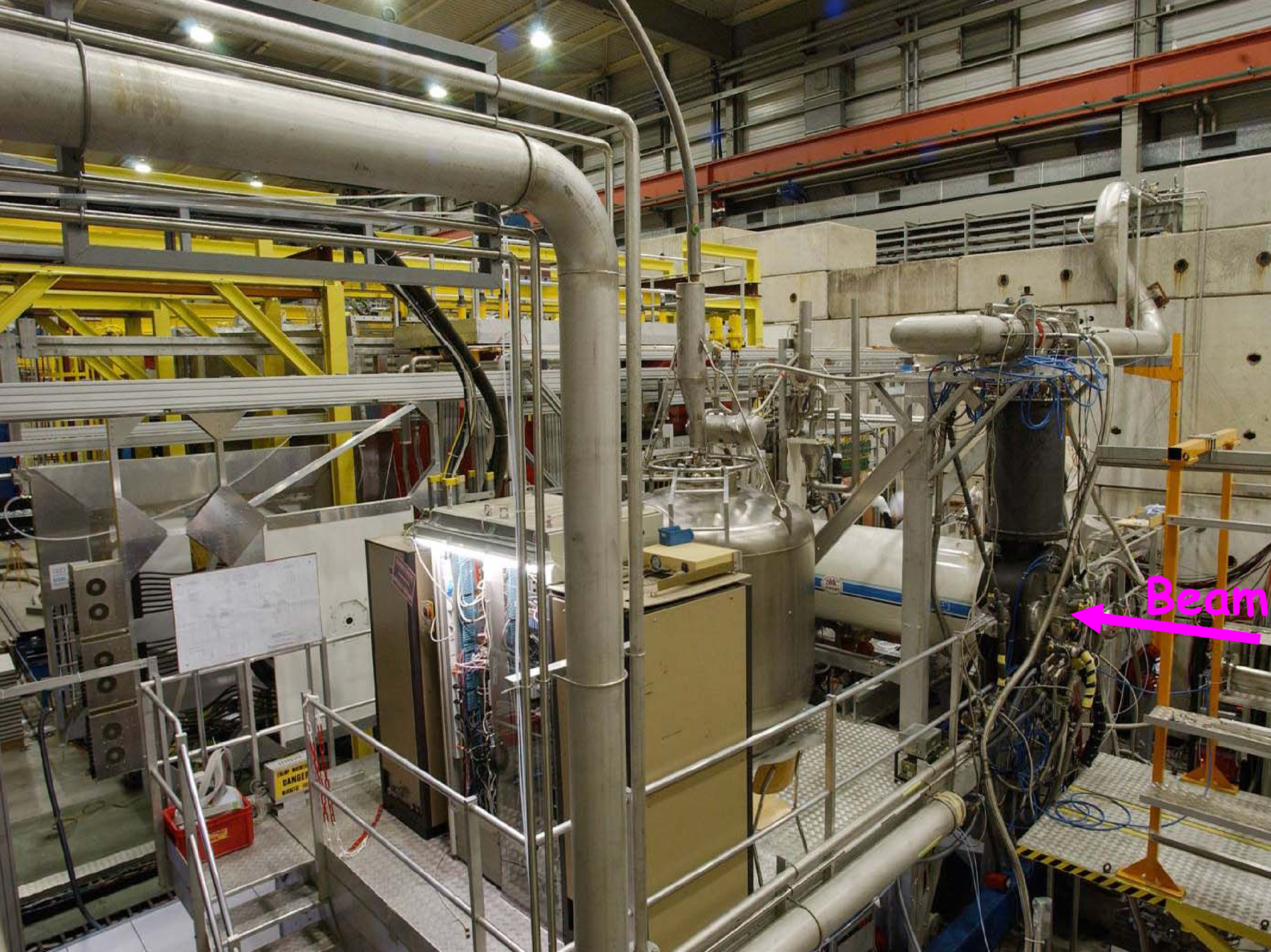
SIDIS (e.g. COMPASS and HERMES)	$\Delta_T q(x) \otimes FF$
Hard scattering NN (e.g. RHIC) - Drell-Yan $\Delta_T q(x_1) \cdot \Delta_T \bar{q}(x_2)$ - Single Spin Asym (e.g. $p^{\uparrow}p \to \pi X$)	Hard scattering $N\bar{N}$ (e.g. GSI) - Drell-Yan $\Delta_T q \cdot \Delta_T q$



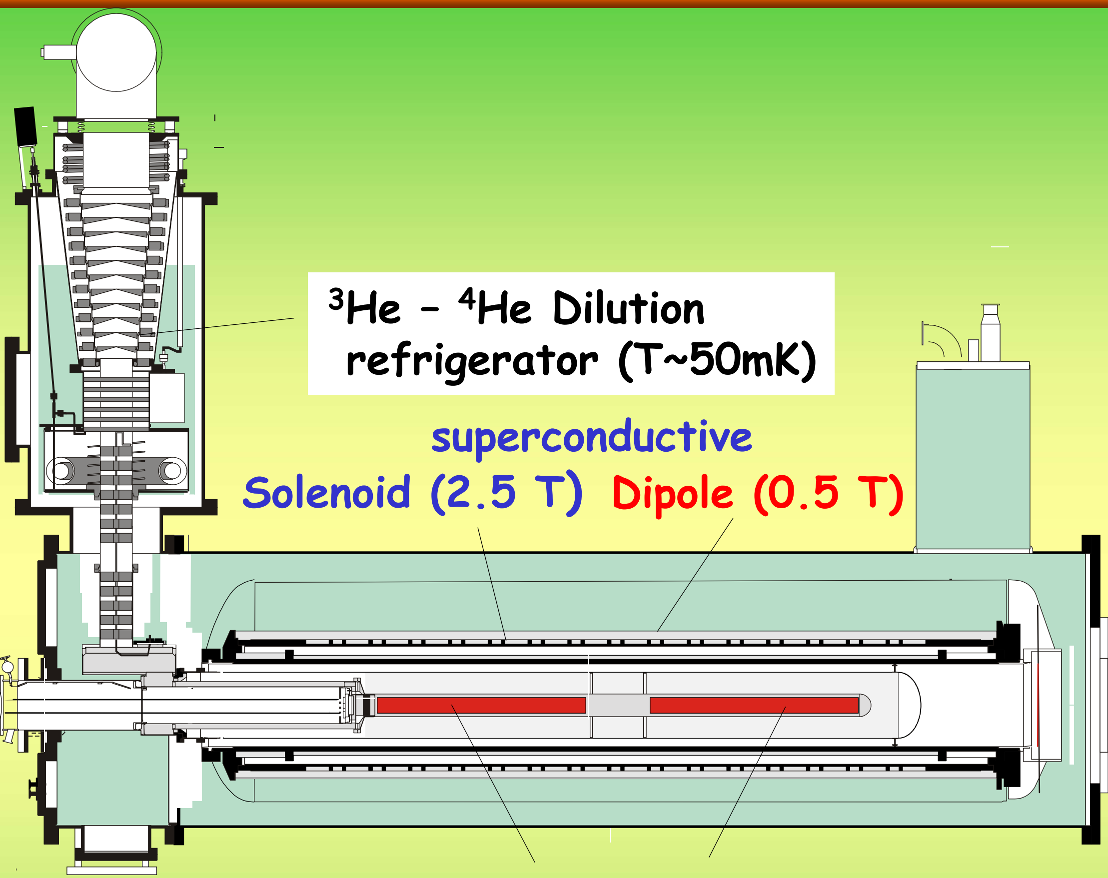
More than 220 physicists from 30 Institutes and 12 Countries


LHC
COMPASS
SPS




Beam
DANGER

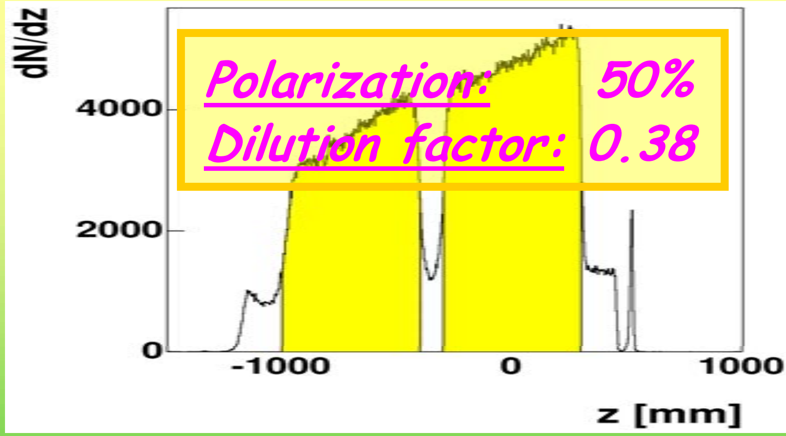
Target



For transversity:

1	↑	↓
2	↓	↑

reversed once a week

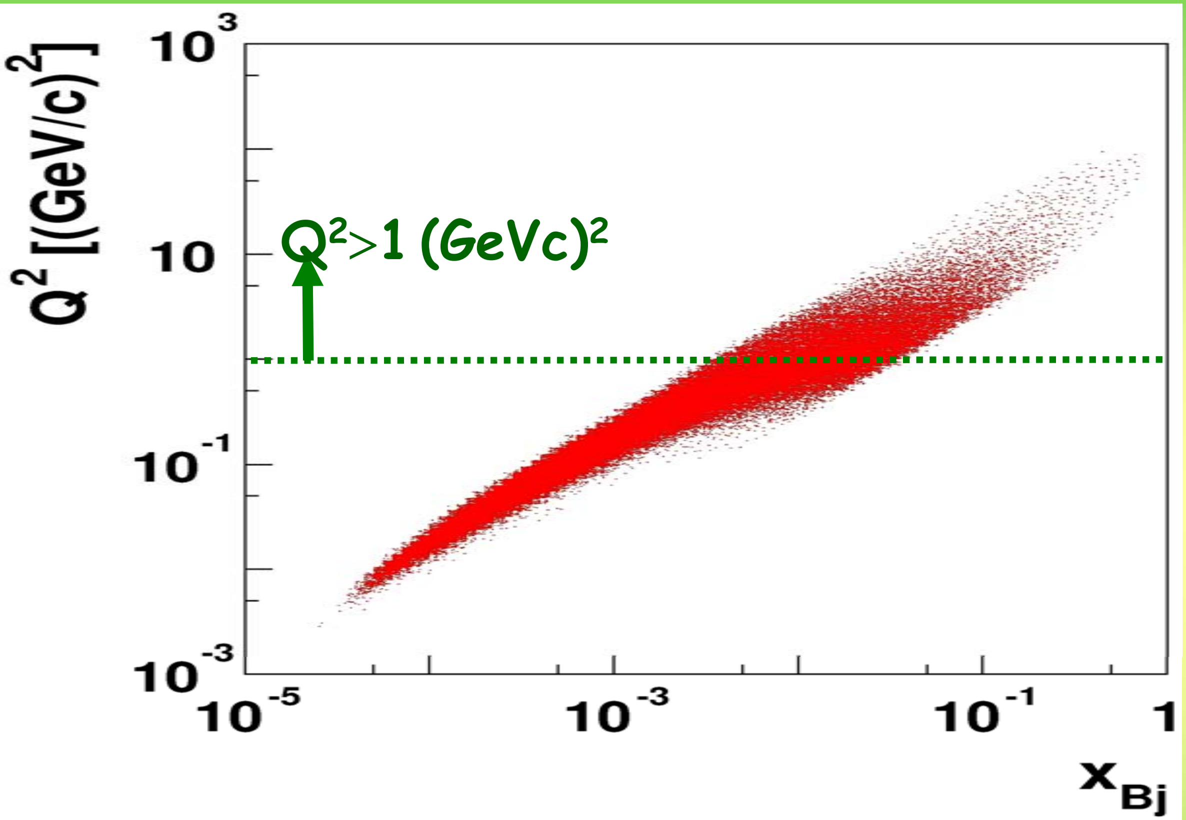


two 60 cm long Target-Containers
with opposite polarization

During data taking for transversity
dipole field always ↑

Relaxing time > 2000 hrs

COMPASS acceptance



DIS variables

$$W^2 = (p+q)^2 = M^2 + 2M\nu + q^2$$

$$Q^2 = -q^2 \cong 2l \cdot l' = 4EE'\sin^2\frac{\theta}{2}$$

$$\nu = \frac{Q^2}{2M} = E - E'$$

$$x_{\mathrm{Bj}} = \frac{Q^2}{2p\cdot q} = \frac{Q^2}{2M\nu}$$

$$y = \frac{p\cdot q}{p\cdot k} = \frac{\nu}{E}$$

$$z = \frac{E_h}{\nu}$$

Excellent for non-perturbative & perturbative physics

- small x_{Bj} & very small Q^2 → $Q^2 > 100$ (GeV/c)^2

COMPASS data sample

- In so far (3 years)
  - only DIS off ^{6}LiD
  - only runs with transverse polarized target being analyzed

	runs	good runs	used events in the analysis
2002	475	453 (100 SPS spills)	$1.6 \cdot 10^6$
2003	479	429 (100 SPS spills)	~4·(2002)
2004	496	470 (200 SPS spills)	~2·(2003)

RICH PID

E-Calorimetry

SIDIS off trans. polarized target

3 possible quark polarimeters are being explored in COMPASS:

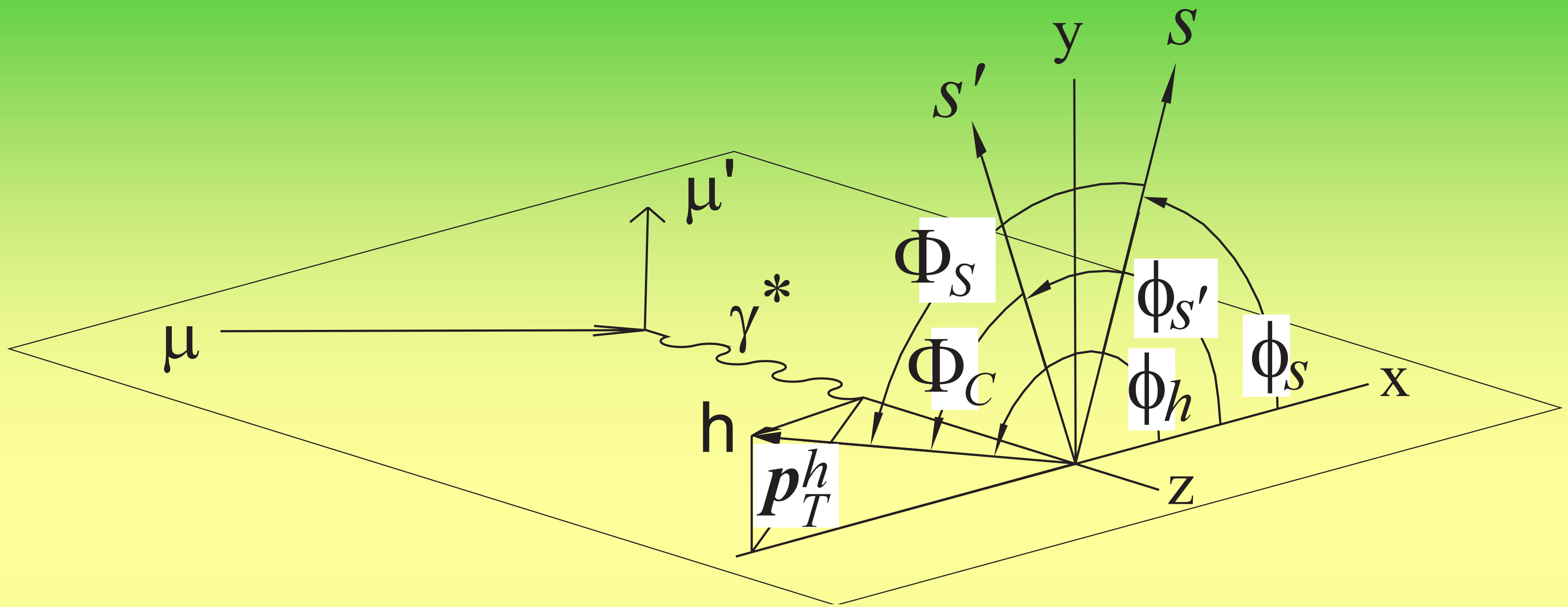
- Collins effects of (leading) $h^{\pm}$
  - Part A: first analisys finalized on 2002 data (accepted for publication on PRL)
- Azimuthal dependence of the plane containing hadrons pairs
  - Part B: first test and preliminary results on 02-03 data
- Measurement of transverse polarization of spin $\frac{1}{2}$ baryons (e.g. Λ hyperon)
  - Analysis ongoing, no results yet

SSA

COLLINS and SIVERS

Collins and Sivers asym's

SIR2005



Breit frame:
ref. system with z axis defined by γ direction and x-z plane defined by the scattering plane

ϕ_S = azimuthal angle of spin vector of **fragmenting** quark (before scattering)

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

ϕ_h = azimuthal angle of hadron

Collins Effect

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

$$N_h^{\pm} = N_h^0 \cdot [1 \pm A_1 \cdot \sin\Phi_{Coll}]$$

$$A_1 = f \cdot P_T \cdot D \cdot A_{Coll}$$

$$A_{Coll} = \frac{\sum_a e_a^2 \cdot \Delta_T q_a(x) \cdot \Delta_T^0 D_a^h\left(z, {p_T^h}^2\right)}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

Calculated as function of x, z and p_t and for “Leading Hadrons” and for “All Hadrons”

Sivers Effect

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

- **The quark intrinsic moment cannot be neglected** → an azimuthal asymmetry not connected with PDF is introduced

But

Azimuthal angular dependence different → sin(ϕ_{siv})

$$A_1 = f \cdot P_T \cdot D \cdot A_{Siv}$$

$$N_h^{\pm} = N_h^0 \cdot \left[1 \pm A_1 \cdot \sin\Phi_{Siv}\right]$$

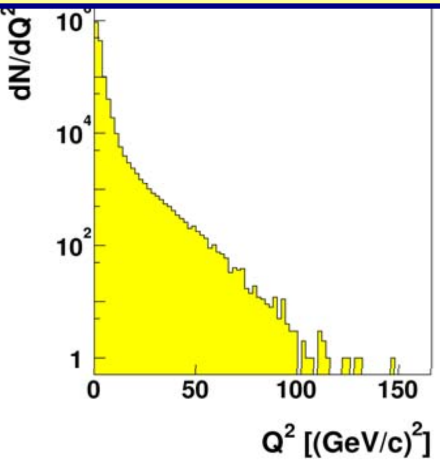
$$A_{Siv}^{\sin\Phi_{Siv}} = \frac{\sum_q e_q^2 \cdot \Delta_0^T q(x) \cdot D_q^h\left(z, {p_T^h}^2\right)}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

Event Selection

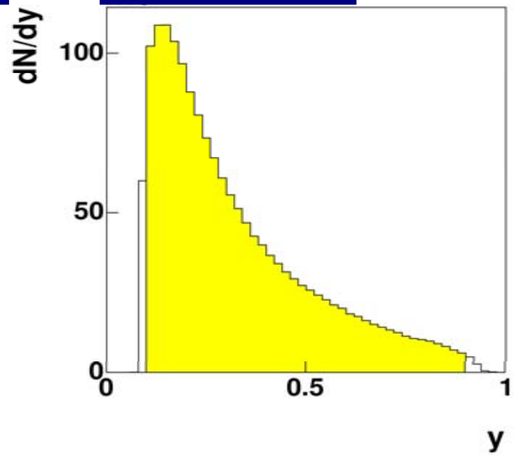
- DIS cuts:
  - $Q^2>1\ (GeV/c)^2$
  - $0.1<y<0.9$
  - $W>5\ GeV/c^2$
- Hadrons
  - Track Length<10 X_0
  - Energy Deposit in ECALs < 5(8) GeV
- Leading Hadron
  - $0.25<z<1$
  - $Pt>0.1\ GeV/c$
  - z-missing cut
- All Hadrons
  - $z>0.2$
  - $P_t>0.1\ GeV/c$

Kinematical distributions

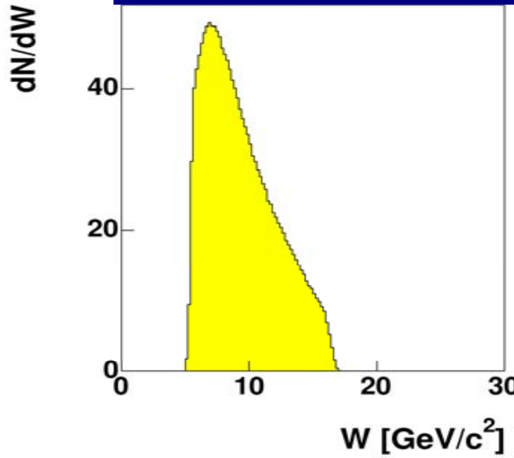
$\langle Q^2 \rangle = 2.4\ (GeV/c)^2$



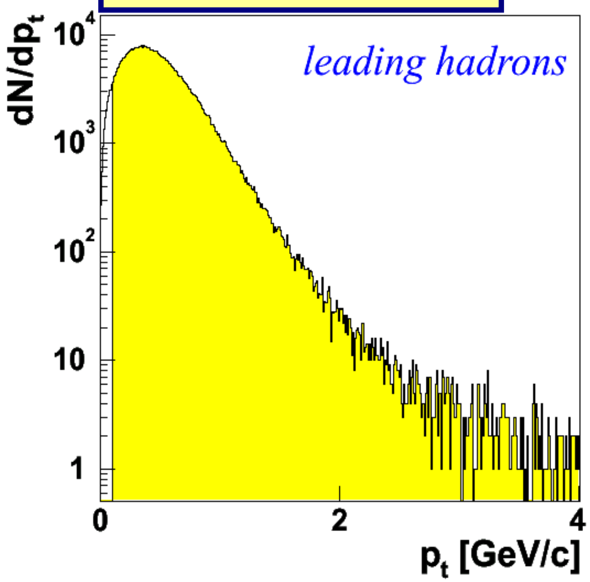
$\langle Y \rangle = 0.33$



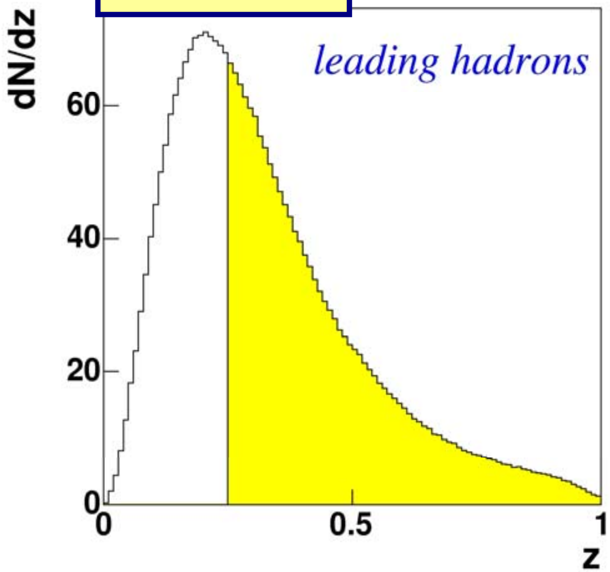
$\langle W \rangle = 9.4\ GeV/c^2$



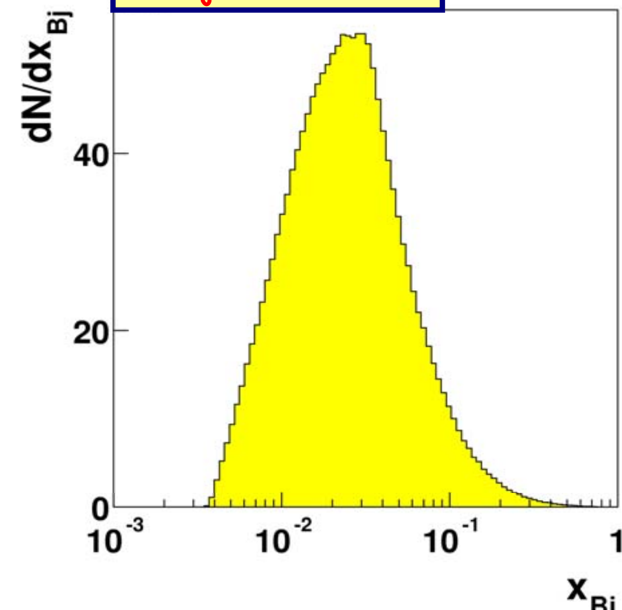
$\langle p_T \rangle = 0.51\ GeV/c$



$\langle z \rangle = 0.45$

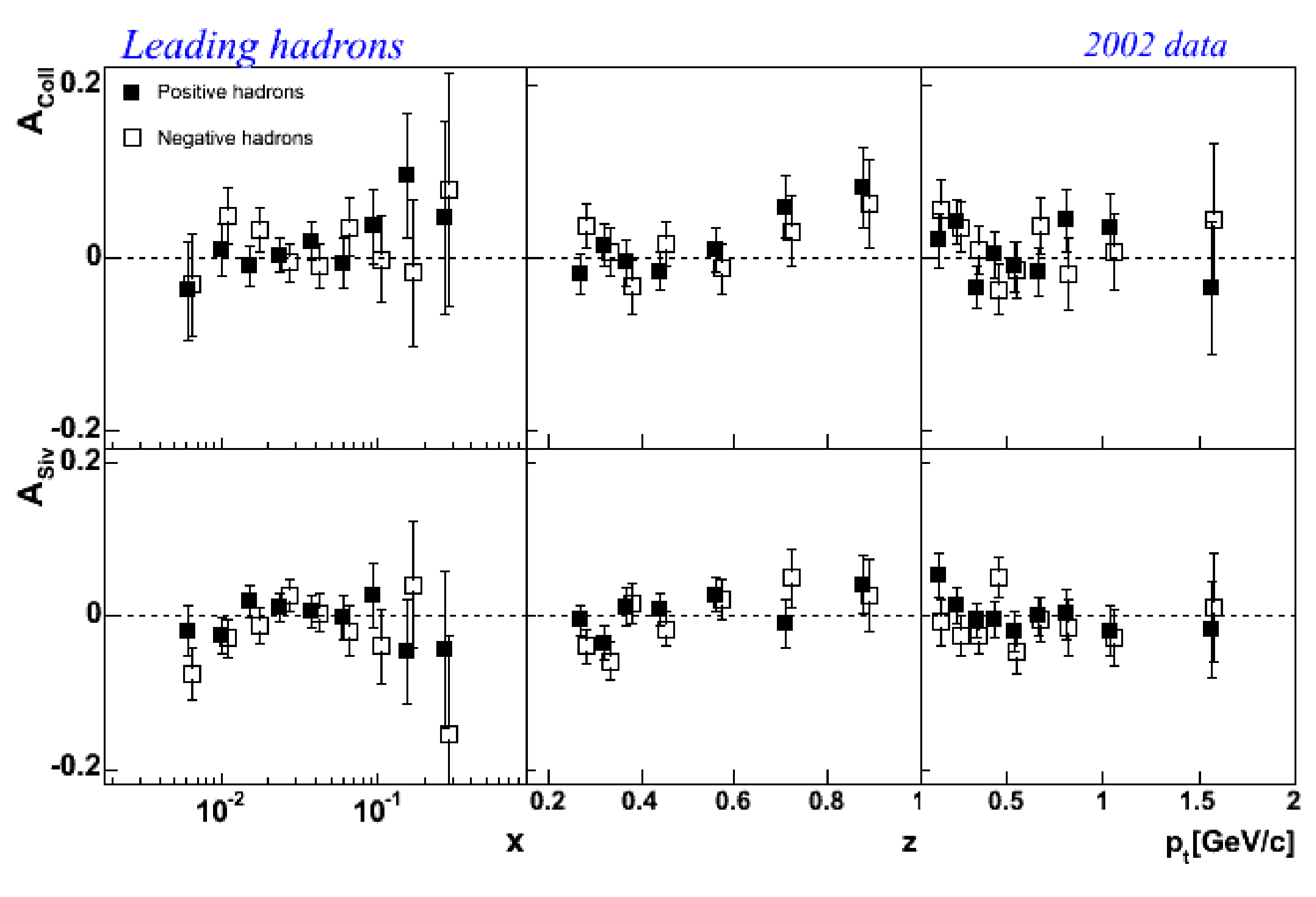


$\langle x_{Bj} \rangle = 0.035$



Collins and Sivers effects

Only statistical errors shown

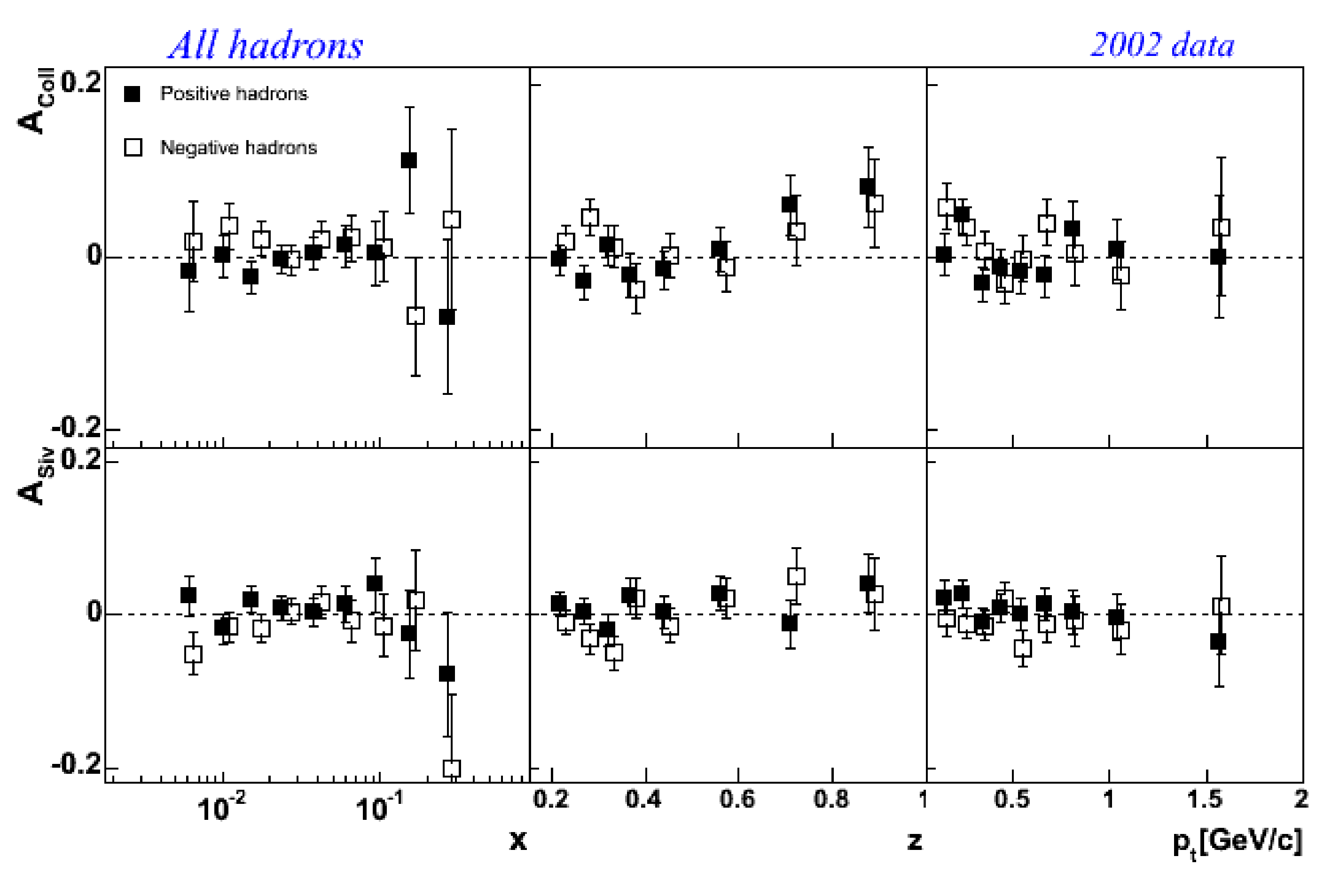


Systematic errors are smaller than the quoted statistical errors.

CERN-PH-EP/2005-003
hep-ex/0503002
PRL

Collins and Sivers effects

Only statistical errors shown



Systematic errors are smaller than the quoted statistical errors.

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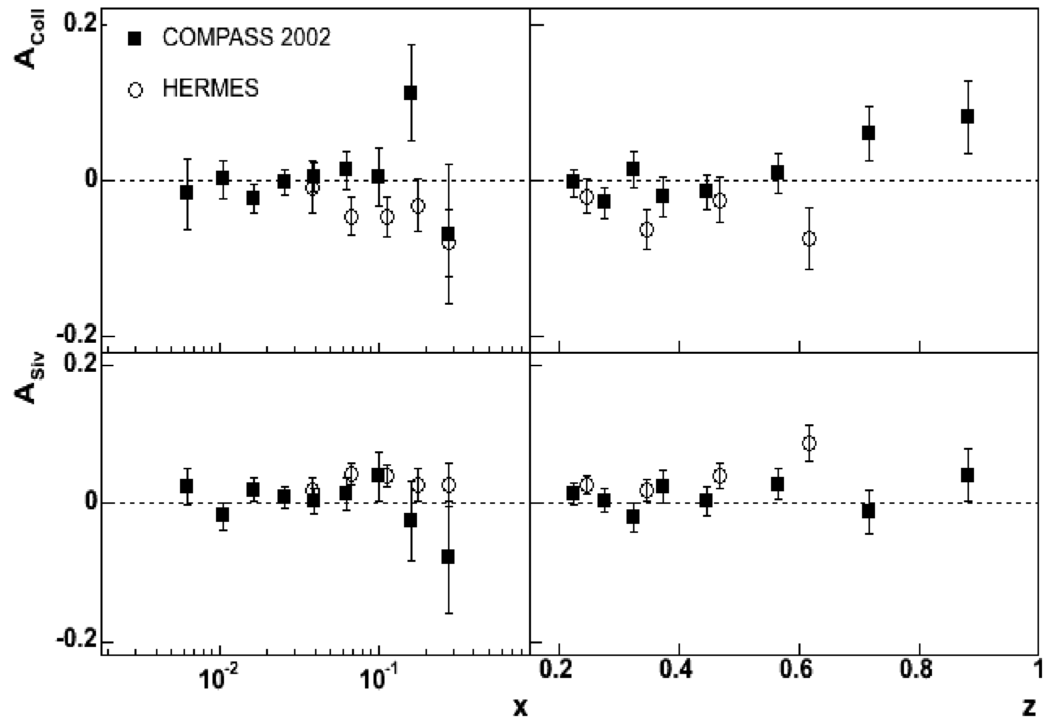
hep-ex/0503002
PRL

COMPASS vs. HERMES Positive hadrons

Corrected for π phase difference in the definition of Φ_C between HERMES and COMPASS

- Deuteron(COMPASS) vs. Proton(HERMES)
- With present errors the 2 data sets are compatible
- COMPASS higher energy $\Rightarrow$ lower x (but with present statistics large errors at high x)
  also higher z
- In Hermes:
  - Negative Collins asymmetries;
  - Positive Sivers asymmetries.
- In COMPASS:
  - No sizeable effect apart…
  - Possible cancellations in iso-scalar target?



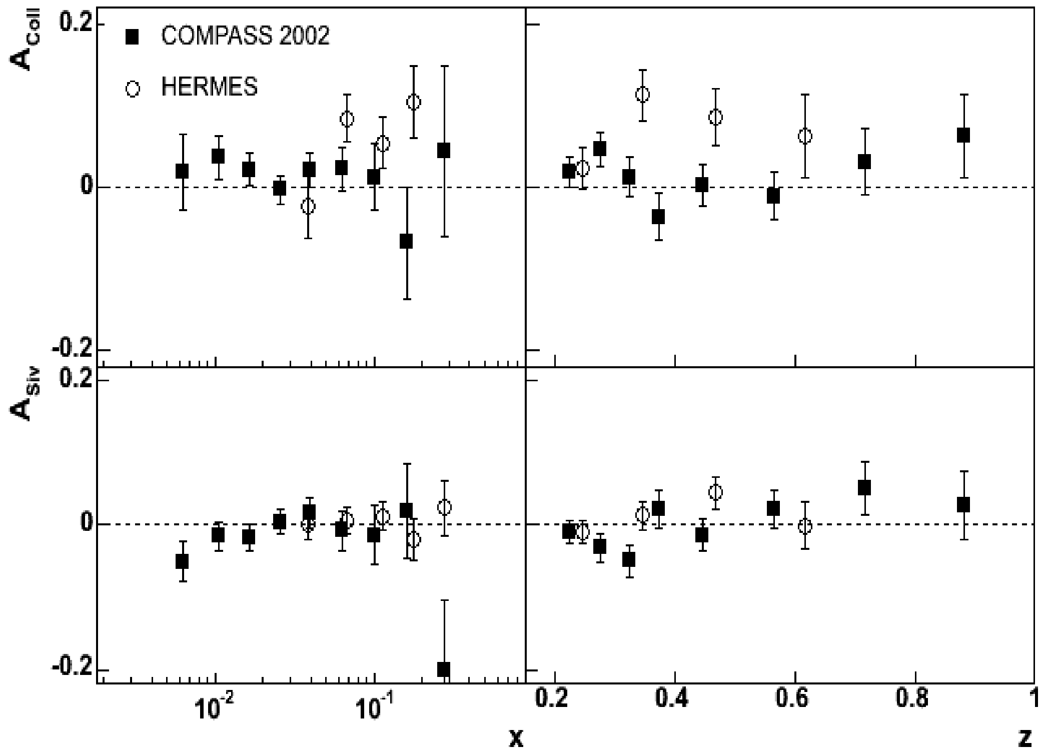
HERMES data points from:
A. Airapetian et al, Phys. Rev. Lett. 94 (2005) 012002[DC53] (hep-ex/0408013)

COMPASS vs. HERMES Negative hadrons

SIR2005

Corrected for π phase difference in the definition of Φ_C between HERMES and COMPASS

- Deuteron(COMPASS) vs. Proton(HERMES)
- With present errors the 2 data sets are compatible
- COMPASS higher energy ⇒ lower x (but with present statistics large errors at high x)
  also higher z
- In Hermes:
  - Large Positive Collins asymmetries;
  - No Sivers effect.
- In COMPASS:
  - No sizeable effect apart…
  - Possible cancellations in iso-scalar target?



HERMES data points from:
A. Airapetian et al, Phys. Rev. Lett. 94 (2005) 012002[DC53]
(hep-ex/0408013)

Expected accuracy for transversity

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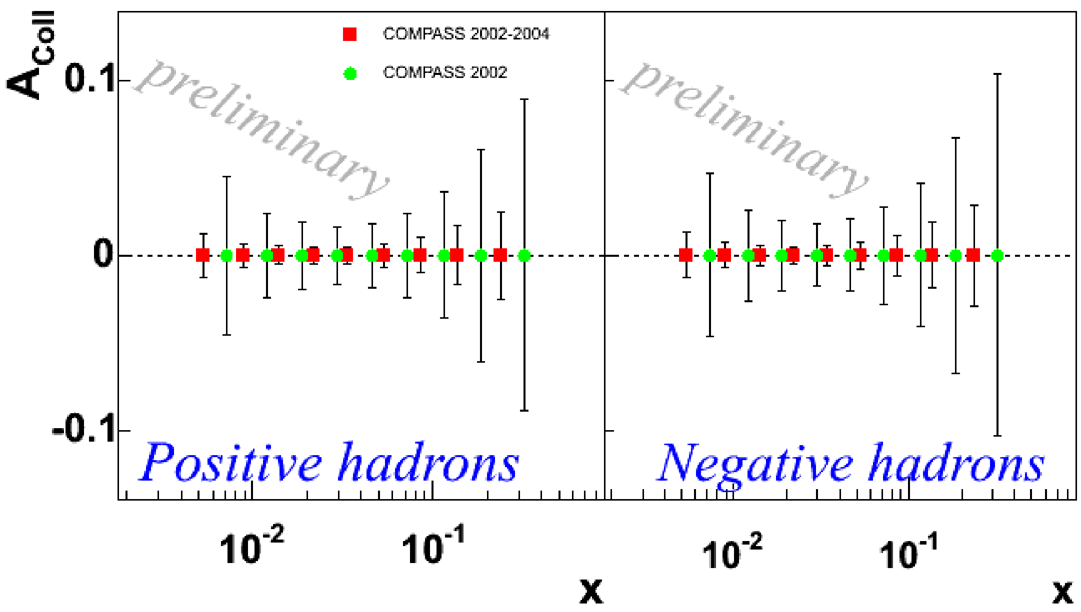


- **Statistical accuracy increased in years 2003/4:**
  - trigger system upgraded;
  - DAQ upgraded;
  - 2004 longer run.
- 2003 data analyzed (systematics evaluation in progress)
- 2004 data production over (analysis in progress)

A_{Coll} statistical errrors:	
Positive hadrons (to the left): 2002 - Green; 2002 – 2004 Red.	Negative hadrons (to the right): 2002 - Green; 2002 – 2004 Red.

2 HADRON ASYMMETRIES

Two Hadron System

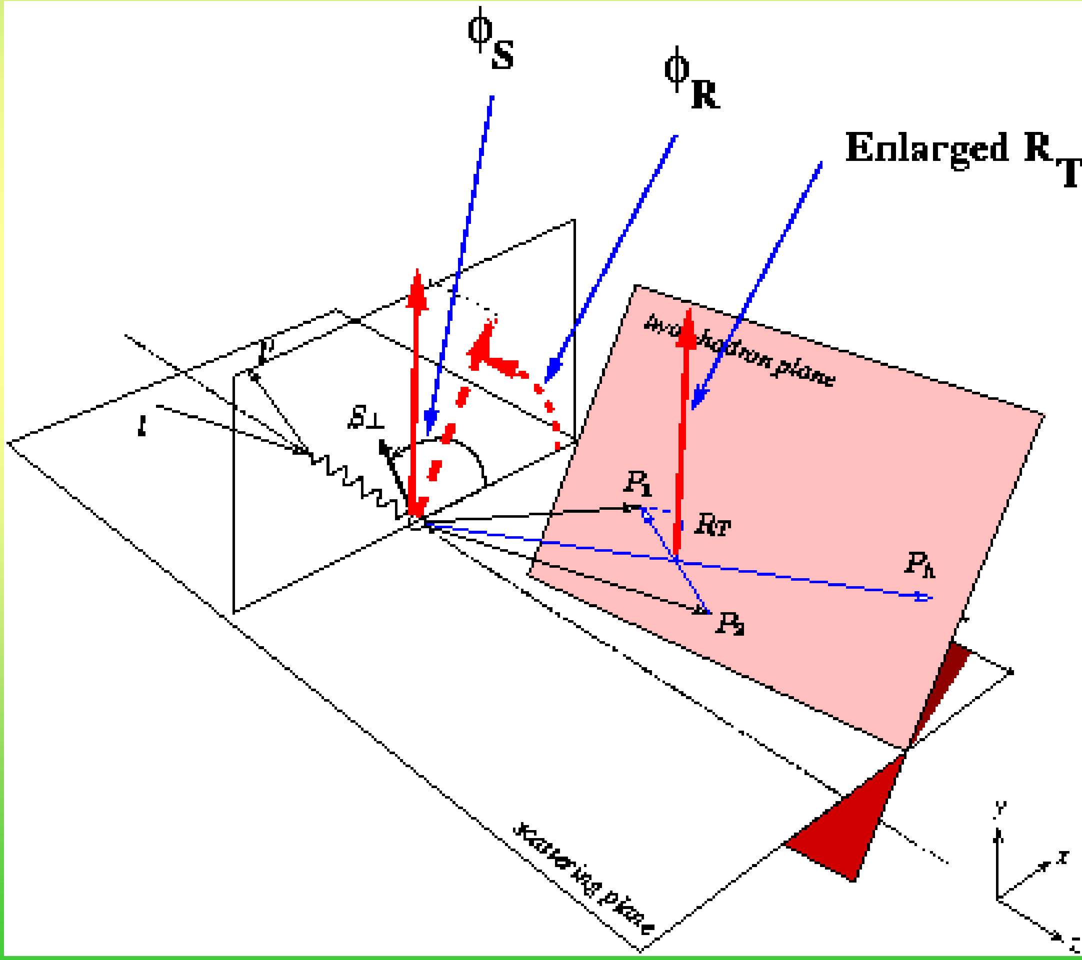
First Measurement following Jaffe et al. (*Phys. Rev. Lett. 80, 1166 (1998)*)
Using two hadrons (e.g. π+π-) the trasversity distribution can be accessed in conjunction with a interference fragmentation function

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

ϕ_R definition:

$$\cos\phi_R = \frac{\vec{q}\times\vec{l}}{|\vec{q}\times\vec{l}|}\cdot\frac{\vec{q}\times\vec{R}_T}{|\vec{q}\times\vec{R}_T|}$$

$$\sin\phi_R = \frac{\vec{q}\times\vec{R}_T}{|\vec{q}\times\vec{R}_T|}\cdot\frac{\vec{q}}{|\vec{q}\times\vec{l}|}$$



Definitions

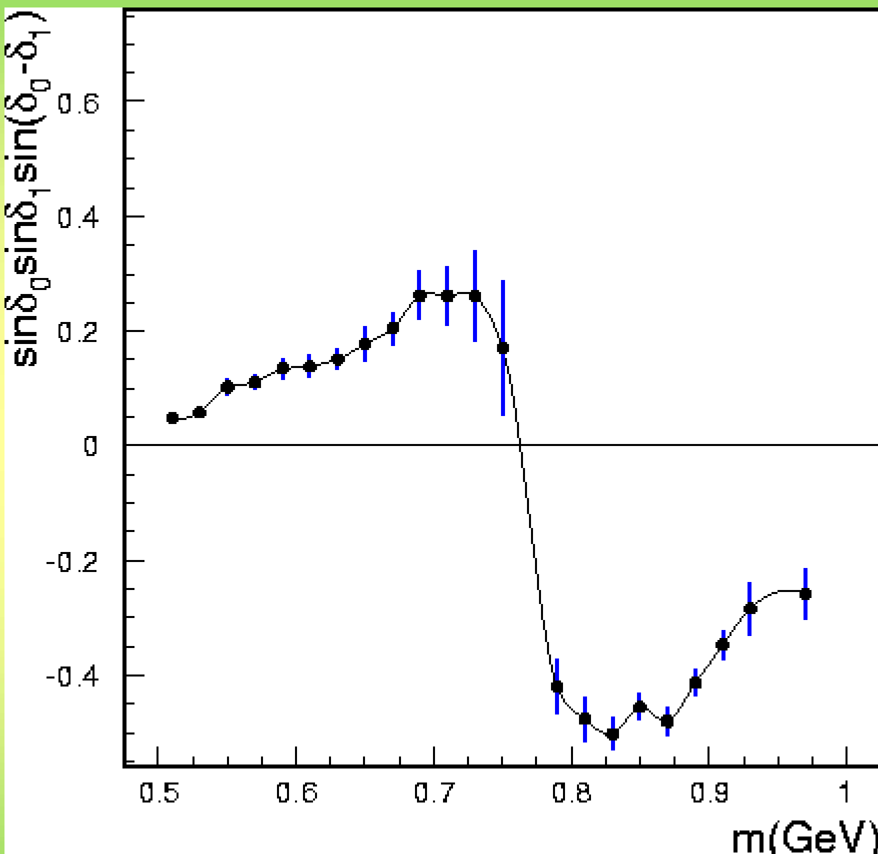
$$\phi_{RS} = \phi_R - \phi_{S'} = \phi_R + \phi_S - \pi$$

$$\mathrm{N}^{\pm}_{h_1,h_2} = \mathrm{N}^{0}_{h_1,h_2} \cdot \left[1 \pm \mathrm{A}_{\mathrm{UT}}^{\sin\phi_{RS}} \cdot \sin\Phi_{\mathrm{RS}}\right]$$

$$\frac{\mathrm{N}^{+}(\phi_{RS}) - r\mathrm{N}^{-}(\phi_{RS}+\pi)}{\mathrm{N}^{+}(\phi_{RS}) - r\mathrm{N}^{-}(\phi_{RS}+\pi)} = \mathrm{A}_{\mathrm{UT}}^{\sin\phi_{RS}} \cdot \sin\phi_{RS} \quad \text{and} \quad \mathrm{A}_{\mathrm{UT}}^{\sin\phi_{RS}} = D_{NN} \cdot f \cdot P_T \cdot A_{\phi_{RS}}$$

$$A_{\phi_{RS}} = \frac{\sum_a e_a^2 \cdot \Delta_T q_a(x) \cdot H_a^{\sphericalangle h}\left(z, M_h^2\right)}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

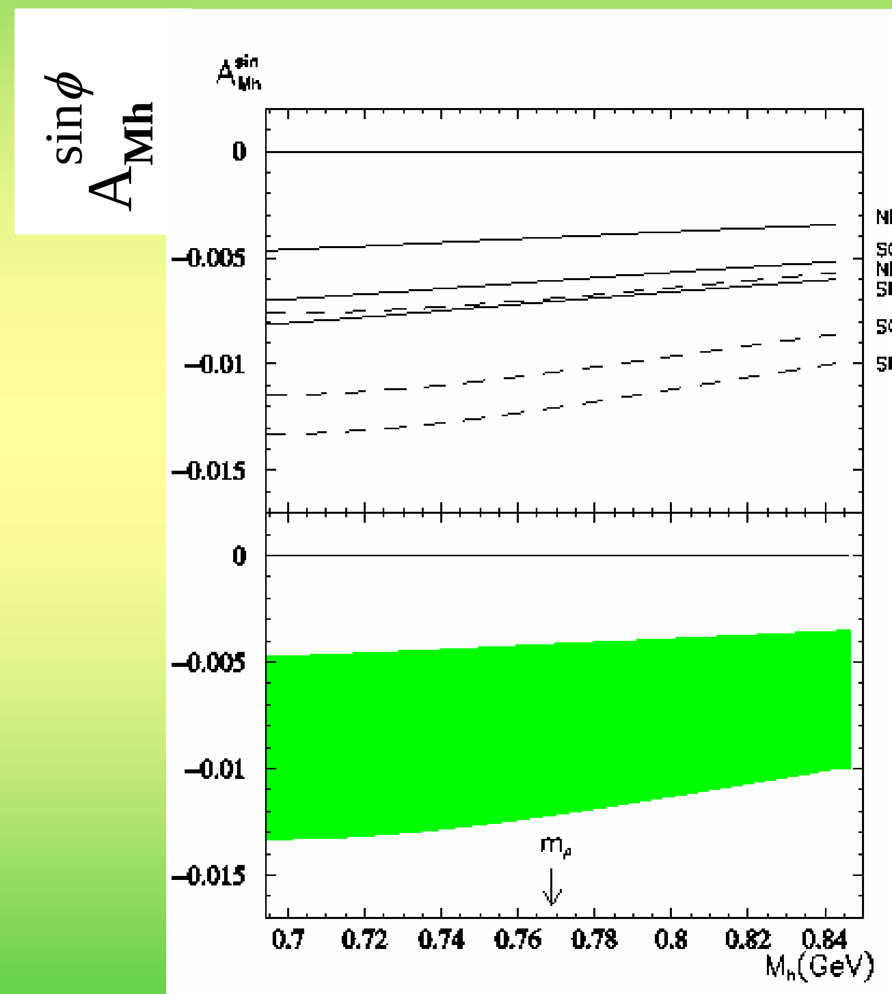
One model !



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

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

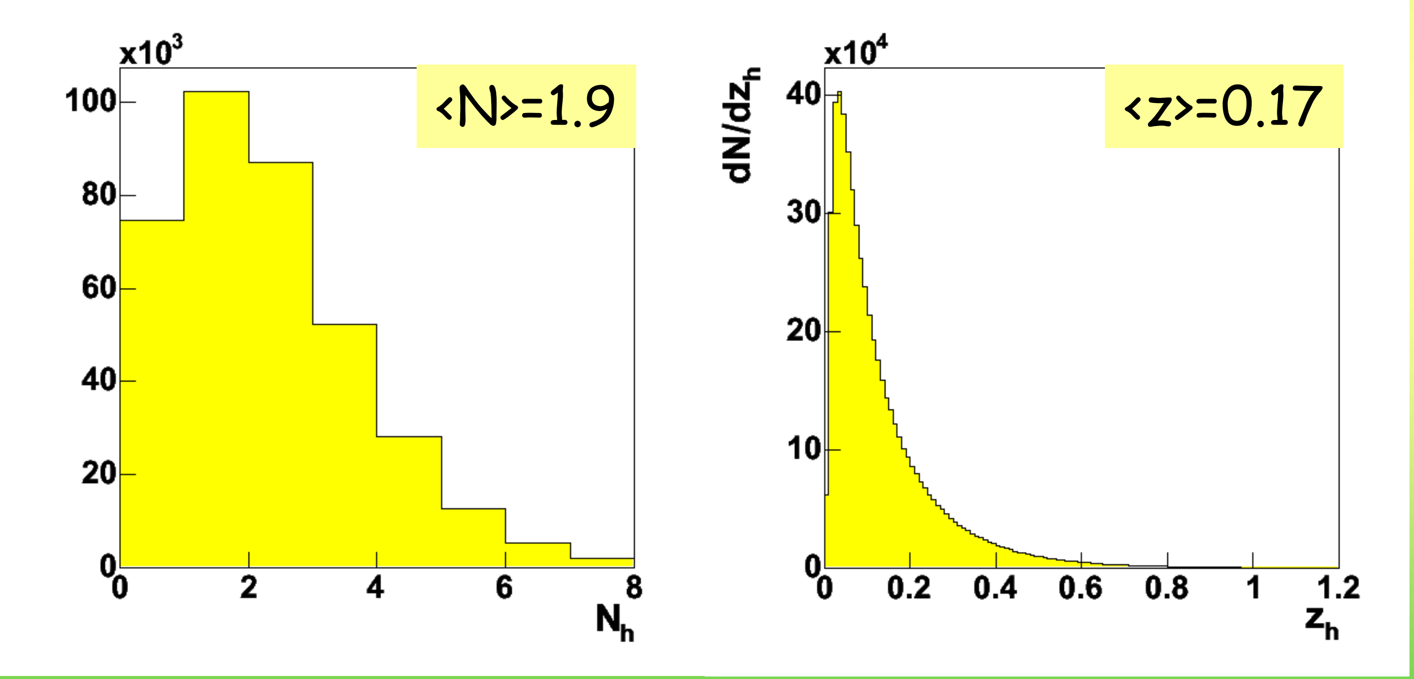
Another model !



Radici, Jakob, Bianconi, PRD 65, 074031

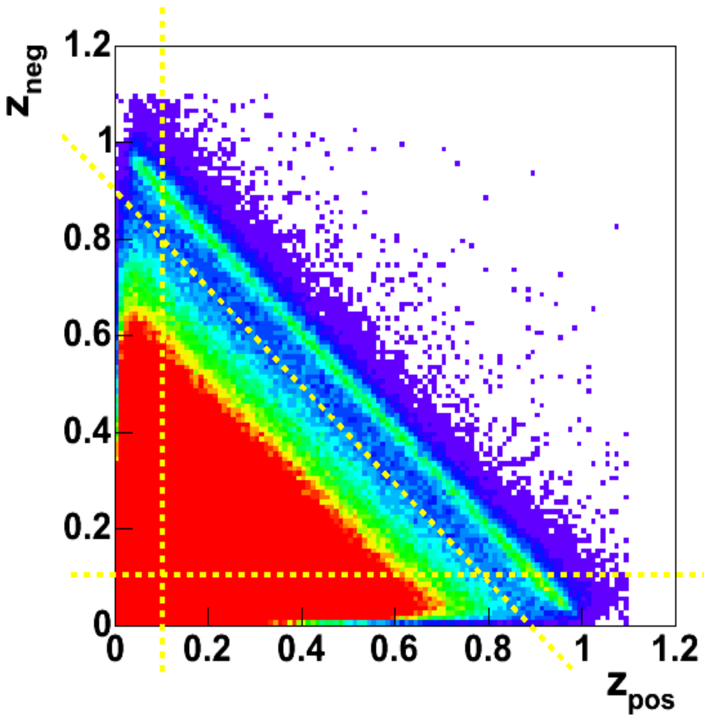
Event Selection - I

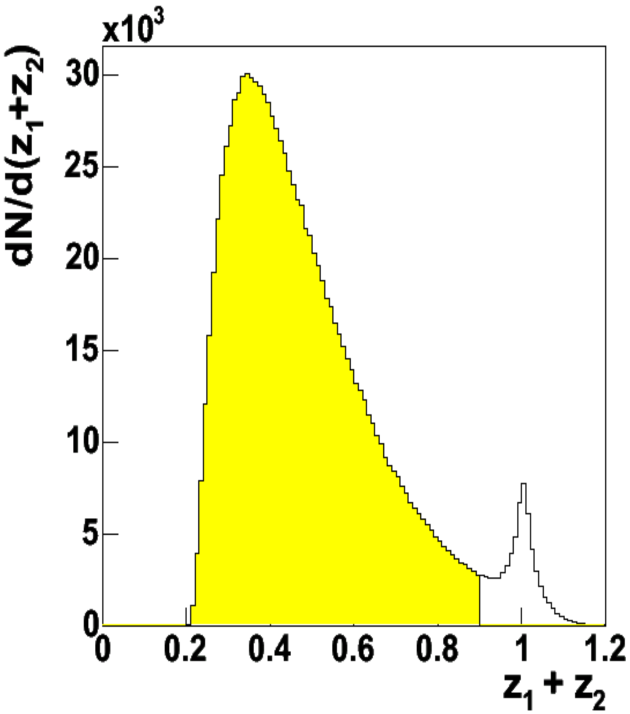
- ►DIS events and hadron identification as in the 1 hadron analysis
- ►No π/K/p separation by using RICH information implemented yet

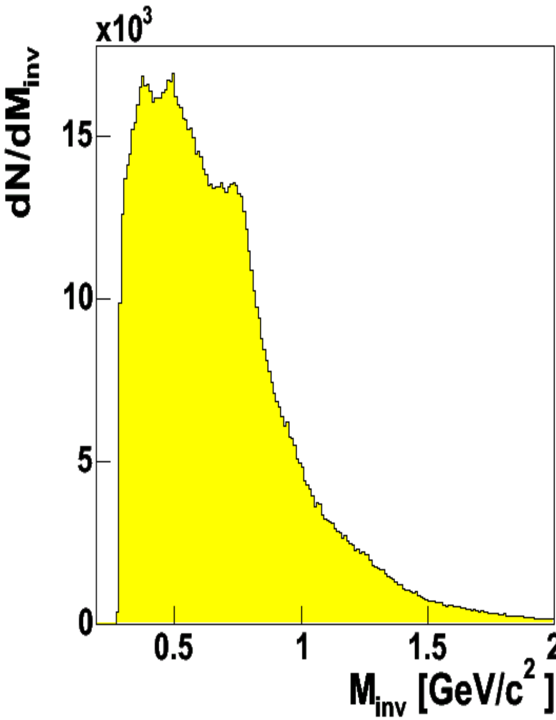


Hadron Pair Selection

- All combinations of positive (h_1) and negative (h_2) hadrons fulfilling:
  - $z_1>0.1$ + $z_2>0.1$
  - $x_{F1}>0.1$ + $x_{F2}>0.1$
  - $z_h = z_1 + z_2 < 0.9$ (to cut exclusive h production)
- $1.02 \Rightarrow 0.22$ combinations/DISevent (2.8×10^6 events in 2002+2003 only)



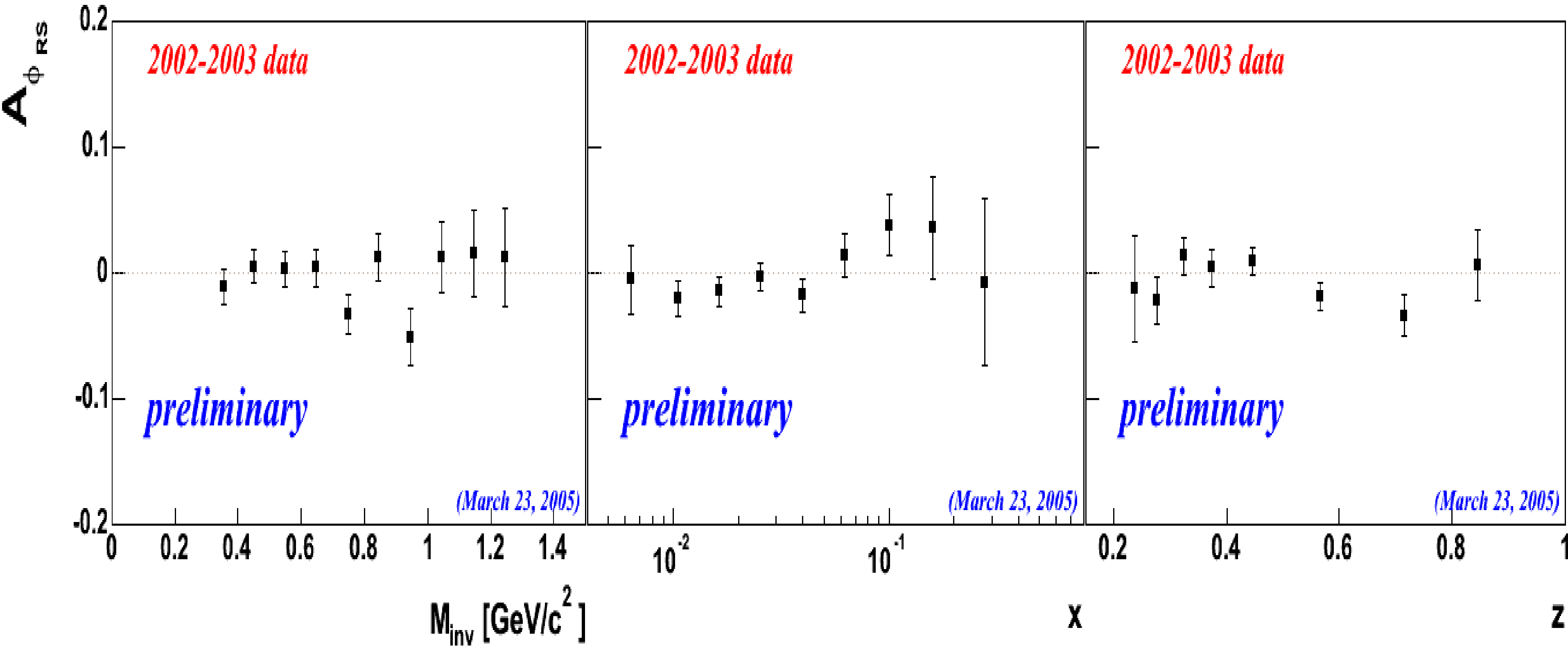




2-Hadron Asymmetries

SIR2005

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



ONE WORD

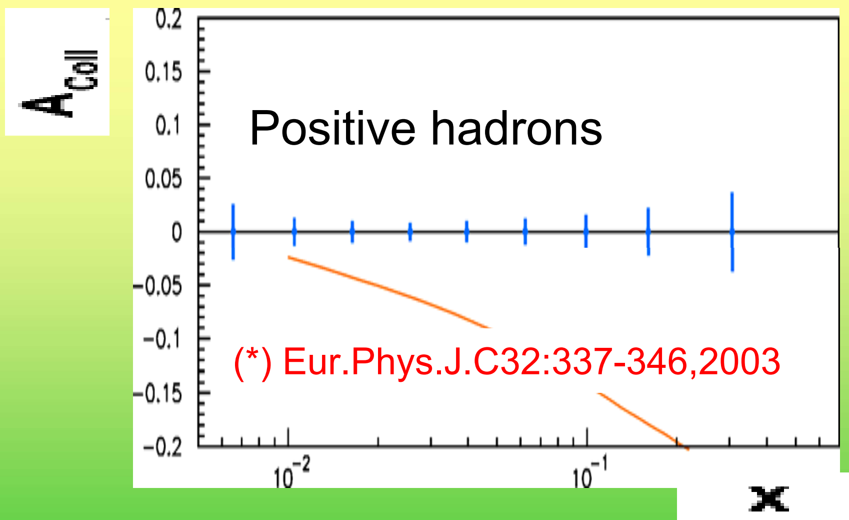
ON

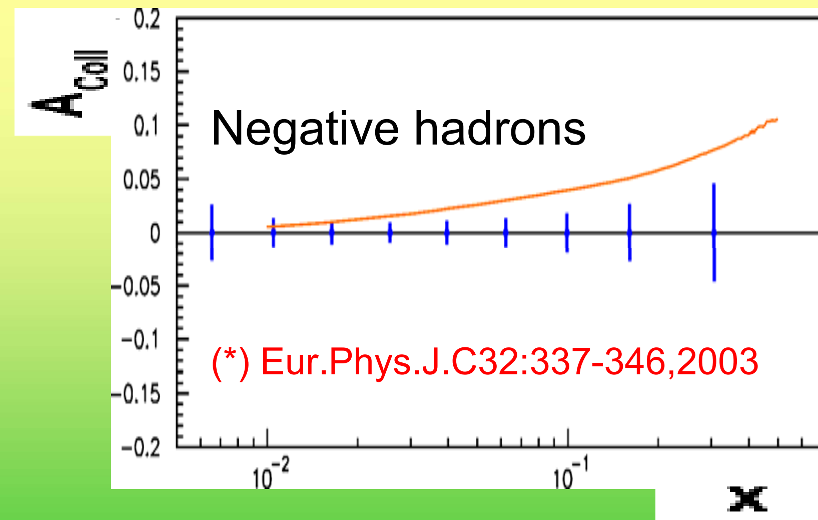
NEAR FUTURE

- Projections for 30 days of data taking with NH_3 target (theoretical predictions by A. Efremov et al.(*) superimposed):

Taking into account:

- Variation of statistical errors: $\sigma(A_{NH_3}) \cong 1.34 \cdot \sigma(A_{^6LiD})$
- taking into account the variation of: $P_T \cdot f$





Outlook

- COMPASS has a multi-purpose spectrometer which will take data at least until 2010;
- Collins and Sivers SSA calculated from 2002 data (first measurements on a deuteron target) accepted for publication (PRL);
- First results of the analysis concerning two opposite charge hadrons asymmetries were shown (2002+2003).
- In both cases the asymmetries are small and compatible with zero
- The total collected statistics allows to increase the presented accuracy on SSA (2002 data only) by a factor of 3 and 2h (2002+2003) by 1.4
- Complementary data (of comparable statistics) will be collected in 2006 on a transversely polarized proton target (NH_3).

THANK YOU