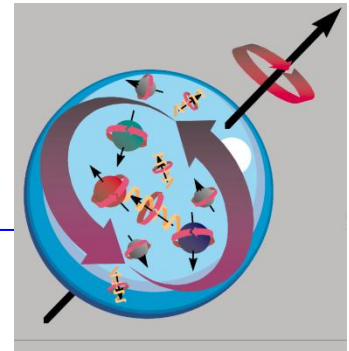# Spin, TMDs and DVCS at COMPASS

F.Kunne – CEA Saclay, France
on behalf of the COMPASS collaboration

- Longitudinal spin

  Gluon and quark helicity distributions
- Transverse spin &

  Transverse Momentum Dependent quark distributions
- Future measurements at COMPASS-II

COMPASS

Fixed target experiment at the CERN SPS:
Use secondary muon or hadron beams.   220 physicists from 26 institutes

Nucleon spin structure

Polarized muon beam:
160 GeV $\vec{\mu}$, P_B=80%
Polarized target:
^{6}LiD P_T=50% 2002-2006
NH_3 P_T=80% 2007
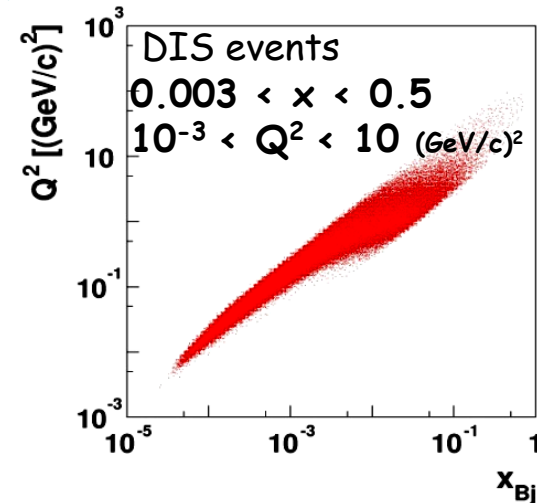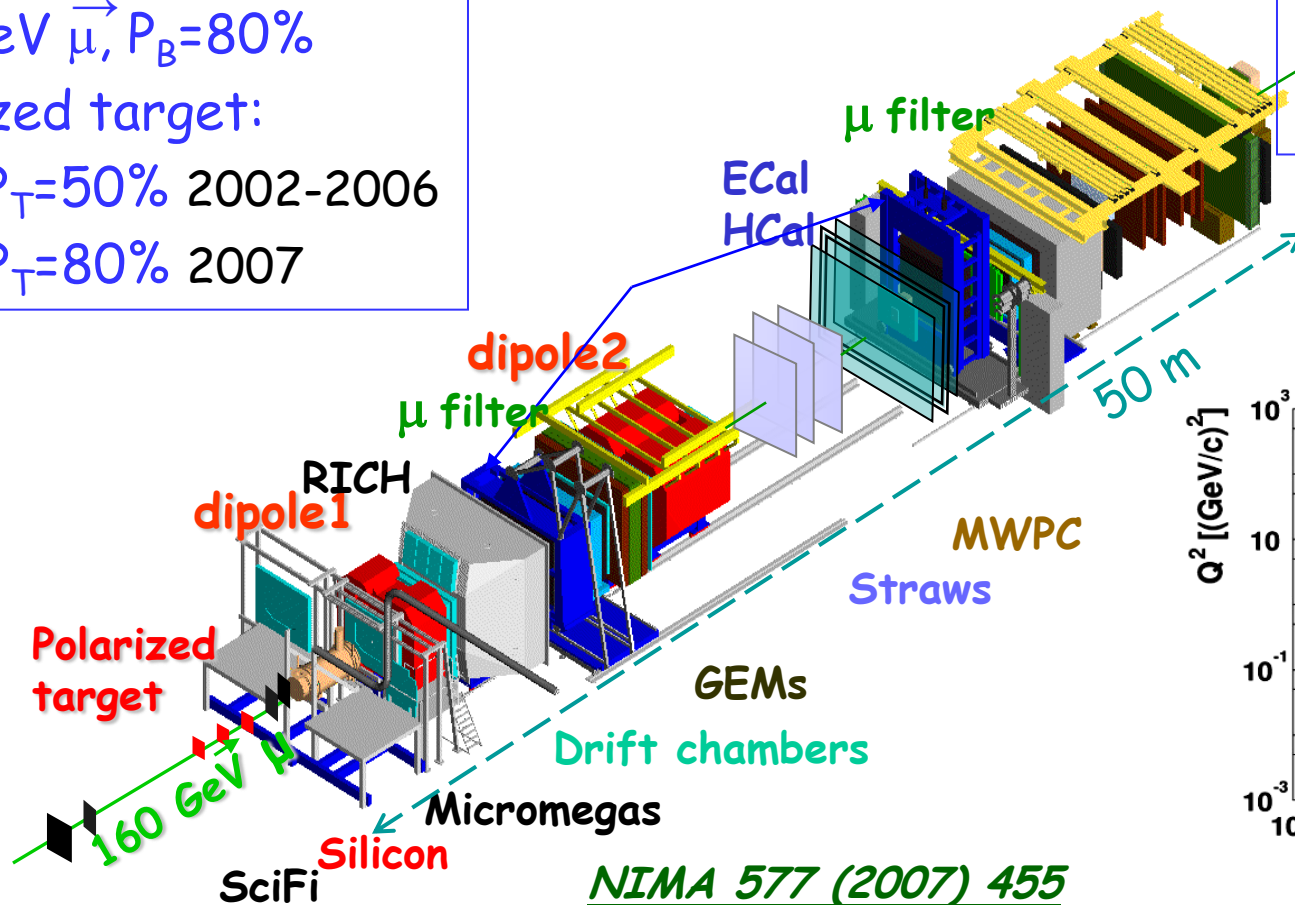
Meson spectroscopy

Hadron beam :
190 GeV π / p
LH_2 2008-2009

µ filter

ECal
HCal

dipole2

µ filter

RICH

dipole1

Polarized
target

160 GeV μ

Silicon

SciFi

Micromegas

Drift chambers

GEMs

Straws

MWPC

50 m

DIS events
0.003 < x < 0.5
10^{-3} < Q^2 < 10 $(GeV/c)^2$

Q^2 [$(GeV/c)^2$]

x_{Bj}

NIMA 577 (2007) 455

How is the nucleon spin distributed among its constituents?

Nucleon Spin

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$$

quark gluon orbital momentum

$$\Delta q = \overrightarrow{q} - \overleftarrow{q}$$

Parton spin parallel or anti parallel to nucleon spin

Theory : QCD, Ellis- Jaffe sum rule assuming $\Delta s = 0$, $\Delta\Sigma \sim 0.6$

Experiment: World data on polarized DIS g_1 + $SU_f(3) \rightarrow$ $a_0 \sim 0.3$

QCD ($\overline{MS}$ scheme) $a_0 = \Delta\Sigma$

$\rightarrow$ "Spin crisis" 1988, EMC measured $a_0 = 0.12 \pm 0.17$

QCD (AB scheme) $a_0 = \Delta\Sigma - n_f (\alpha_s/2\pi) \Delta G$

• For $a_0 \sim 0.3$, need $\Delta G \sim 2.5$ to restore $\Delta\Sigma \sim 0.6$. (Then $L_z \sim -2.3$)

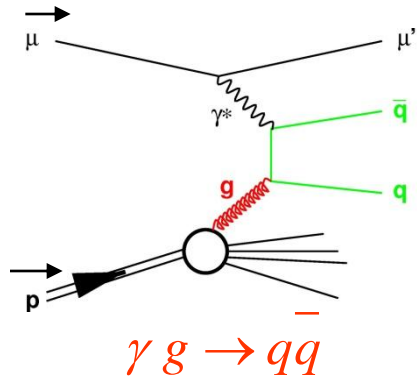• ΔG enters in the spin $\frac{1}{2}$ sum rule

$\rightarrow$ motivated direct measurements of gluon polarization ΔG

ΔG/G Measurement- Photon Gluon fusion PGF

Need:
- a process sensitive to gluon distribution → Photon Gluon Fusion
- measure longitudinal spin asymmetry of cross sections→
  incident polarized lepton beam and polarized nucleon target.

At leading order $A_{||} = R_{PGF} \langle a_{LL} \rangle \langle \Delta G/G \rangle$

$\gamma\, g \to q\bar{q}$

Two signatures for PGF:

• q=c   open charm $c \to D^0 \to K\,\pi$
Clean signature of PGF
pQCD scale $\mu^2 = 4\,(m_c^2 + p_T^2)$
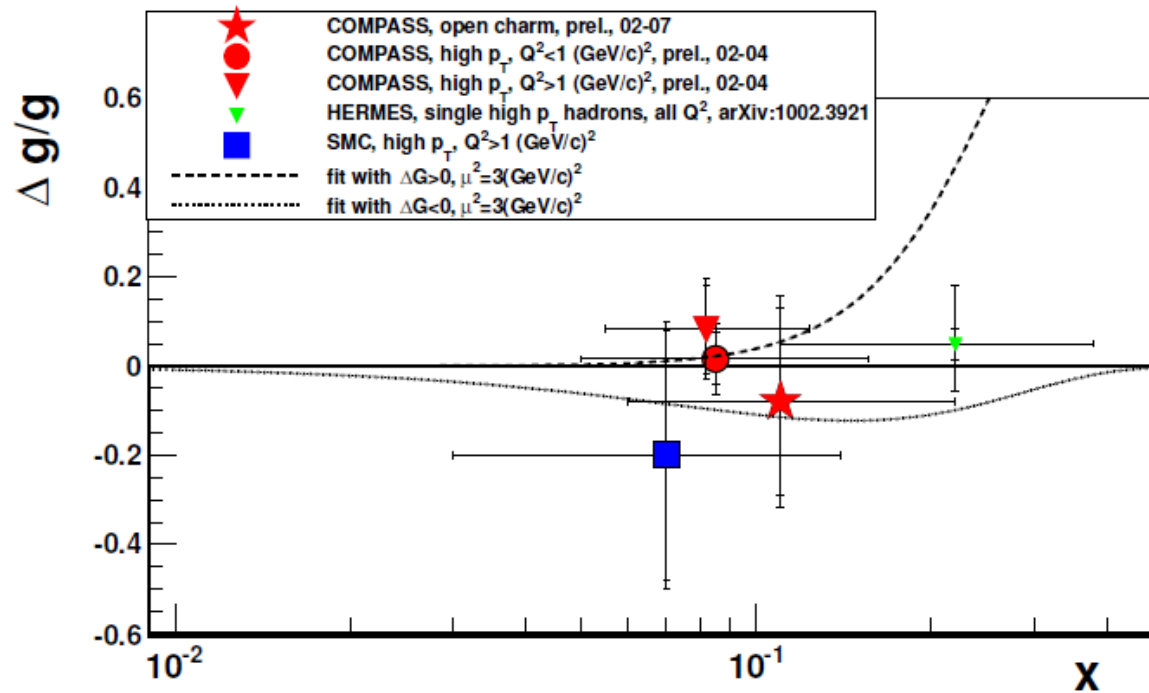Combinatorial background & limited statistics
→ Difficult experiment

• q=u,d,s high p_T hadron pair $q\bar{q} \to h\,h$
High statistics
pQCD scale Q^2 or Σp_T^2
Physical background, better described for high Q^2
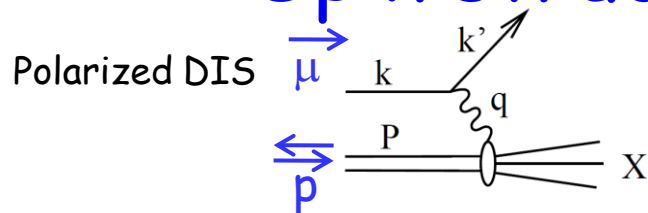
Results for ΔG/G direct measurements

All measurements compatible with 0 for 0.04< x < 0.2

Also in agreement with RHIC results on double spin asymmetry
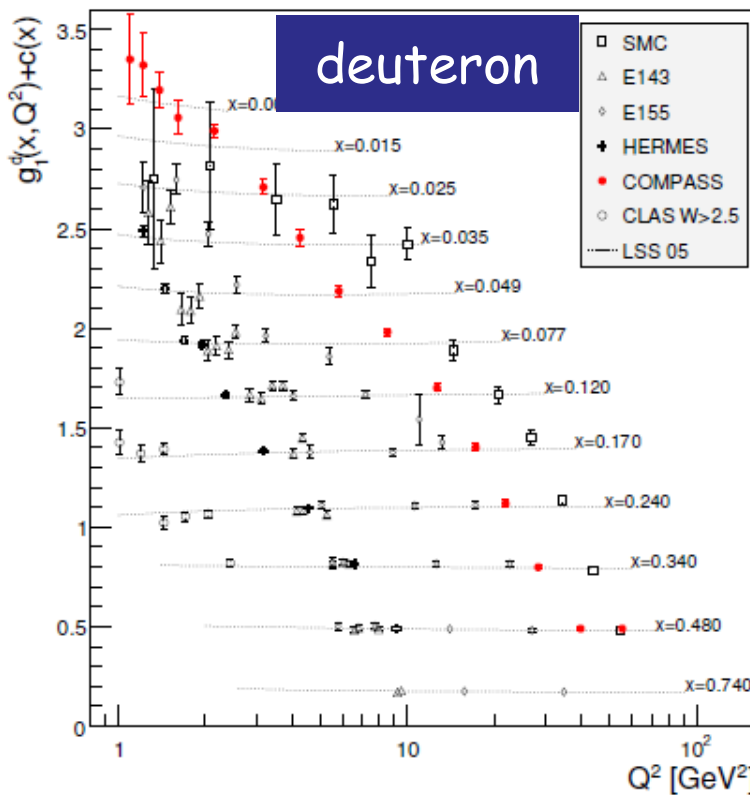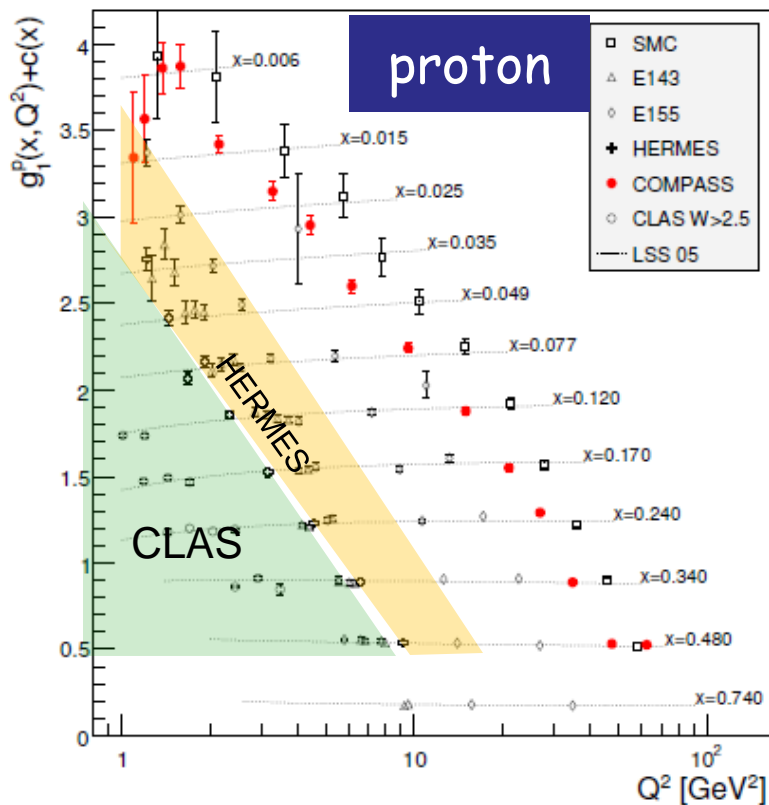in polarized pp reactions, which probe same kinematical range

Direct measurements exclude values for the
integral of ΔG as large as 1 or 2

Spin structure functions - world data

Polarized DIS

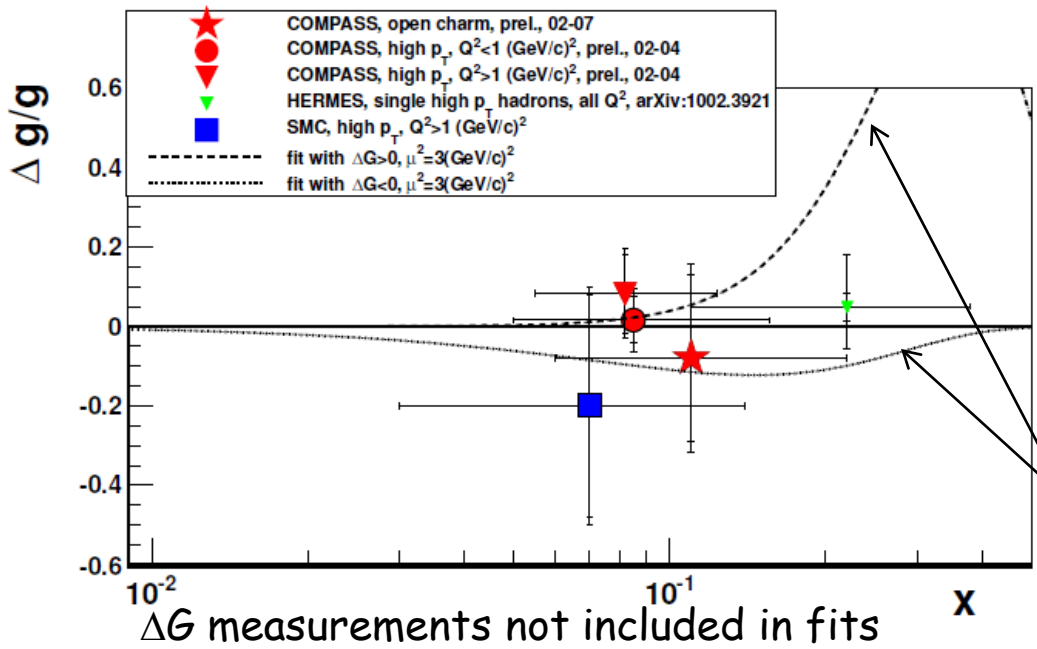$$\sigma_{DIS}^{inclusive} \propto g_1(x) \propto \frac{1}{2}\Sigma e_q^2\left(\Delta q(x) + \Delta\bar{q}(x)\right)$$

Polarized PDFs

From first moment of g_1, at $Q^2 \to \infty$:
- $\Delta\Sigma = 0.30 \pm 0.01$ (stat.) ± 0.02 (evol.) All data
- $\Delta s + \Delta\bar{s} = -0.08 \pm 0.01 \pm 0.02$ Compass data alone

Input to global QCD fits → Extract $\Delta q_f(x)$ and $\Delta G(x)$ through Q^2 evolution
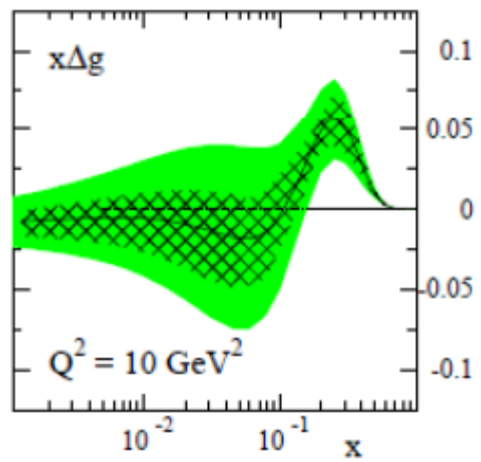
$\Delta G(x)$ from global QCD analysis of polarized DIS data $g_1(x,Q^2)$

Use Q^2 evolution of spin dependent gluon and singlet quark distribution.

Lack of polarized data Fits not so well constrained, however some results

COMPASS NLO fit of g_1 data: 2 solutions with $|\Delta G|=0.2\text{-}0.3$

ΔG measurements not included in fits

DSSV NLO fit of g_1 and $\vec{p}\,\vec{p}$ data
(different scale)

De Florian, Sassot, Stratmann, Vogelsang

Consequence for nucleon spin

- $\Delta G = \int \Delta g(x)dx$ not large, both from direct measurements
(essentially PGF + RHIC) and g_1 QCD fit: $|\Delta G| < 0.35$

$$\Delta\Sigma = a_0 \; + \underbrace{(3\alpha_s/2\pi) \, \Delta G}$$

within   0.06 for ΔG within $\pm$ 0.35 at $Q^2=3$

$\rightarrow \Delta\Sigma \sim 0.30$ small ($\neq$ predictions)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

possible scenarios:

$\frac{1}{2}0.3 + 0.35 + 0.0$

$\frac{1}{2}0.3 + 0.0 \;\; + 0.35$

$\frac{1}{2}0.3 - 0.35 \;\; + 0.7$

Non Singlet structure function and Bjorken sum rule
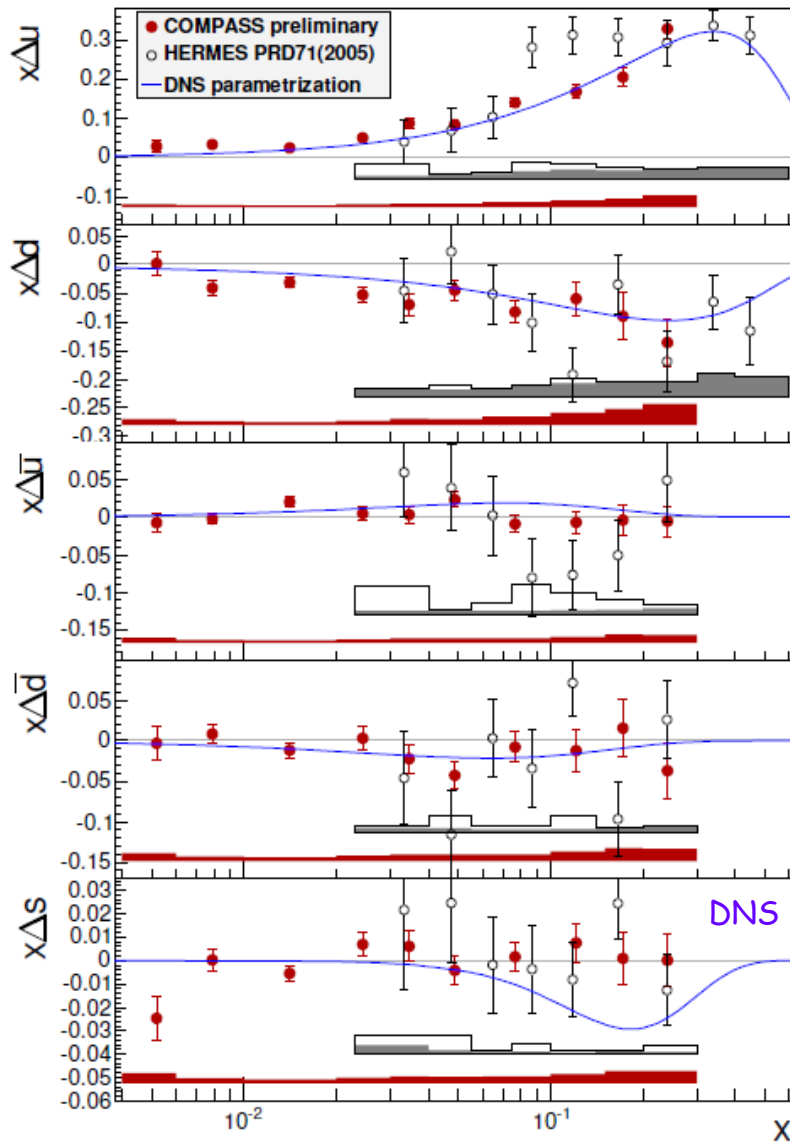
Non-singlet combination : $g_1^p(x) - g_1^n(x)$

The first moment provides a test of the Bjorken sum rule,
a fundamental result of QCD derived from current algebra

$$\int_0^1 g_1^{NS}(x)\,dx = \frac{1}{6}\left|\frac{g_A}{g_V}\right|C^{NS}$$

Fit to COMPASS data: g_A/g_V=
1.28 ±0.07(stat) ± 0.10(syst)

PDG value:
1.268 ±0.003

LO Helicity quark distributions

• Full flavour decomposition down to x~0.004

• Sea quark distributions ~ zero

• Good agreement with previous global fits to g_1 inclusive data, except for Δs.

However, for Δs:

- Large uncertainty on strange quark fragmentation functions.

- New global fits (DSSV) suggest negative contribution at lower x, in agreement with both inclusive result and semi inclusive data.

Q^2=3 (GeV/c)^2
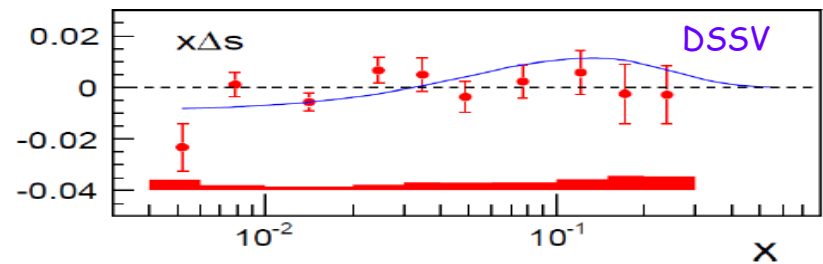
Transversity - Collins and Sivers asymmetries

- Transversely polarized target

- Measure simultaneously several azimuthal asymmetries of outgoing hadron in SIDIS $\mu p \rightarrow \mu p\, h$

Collins: Outgoing hadron direction & quark transverse spin

Sivers: nucleon spin & quark transverse momentum

Collins

q transverse spin distr.

Collins fragmentation function

$$A_{Coll} = \frac{\sum_q e_q^2 \cdot \Delta_T q \cdot \Delta D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$
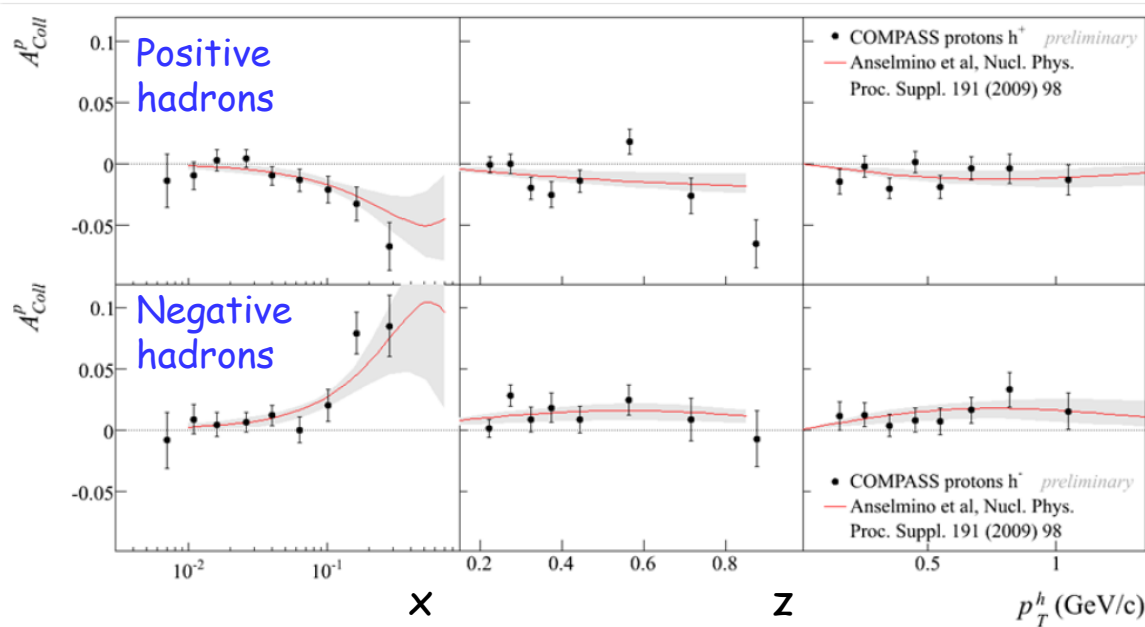
Sivers

$$A_{Siv} = \frac{\sum_q e_q^2 \cdot f_{1Tq}^{\perp} \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

note: $\Delta_T q$ also measured using
- "Two hadron" fragm. fct.
- lambda Transverse. Polarization
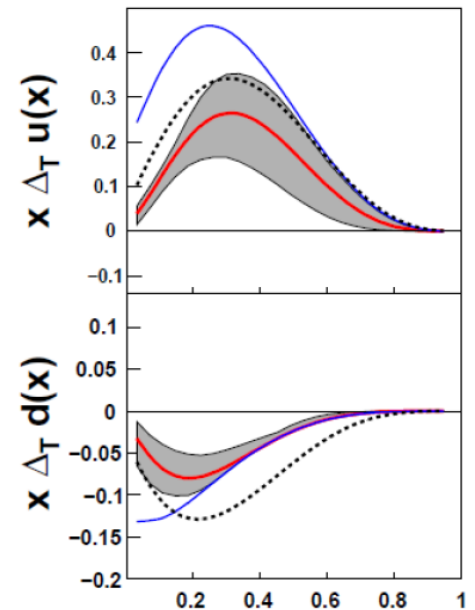
Transversity : Collins Asymmetry on proton

COMPASS data compared to predictions from Anselmino *et al.,*
based on fit of HERMES-p and COMPASS–d data, and BELLE FF.

• Large signals in valence region as seen by HERMES, opposite for + and – hadrons
• Data support assumption of weak Q^2 dependence in this energy range
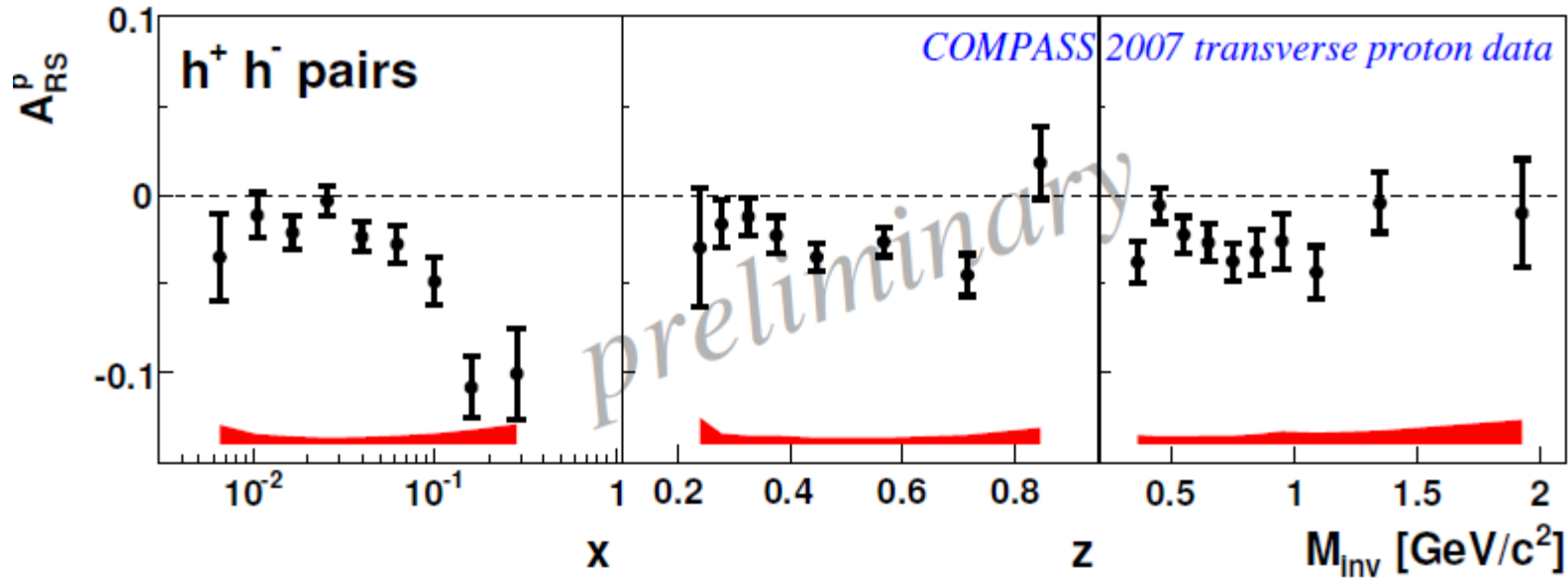
Several combined analyses of HERMES p and COMPASS d data :

• $\Delta_T u > 0$ and $\Delta_T d < 0$

• Do not saturate Soffer bound

• Smaller than helicity

Ex: M. Anselmino et al. arXiv:0812.4366

Transversity via "two hadron"
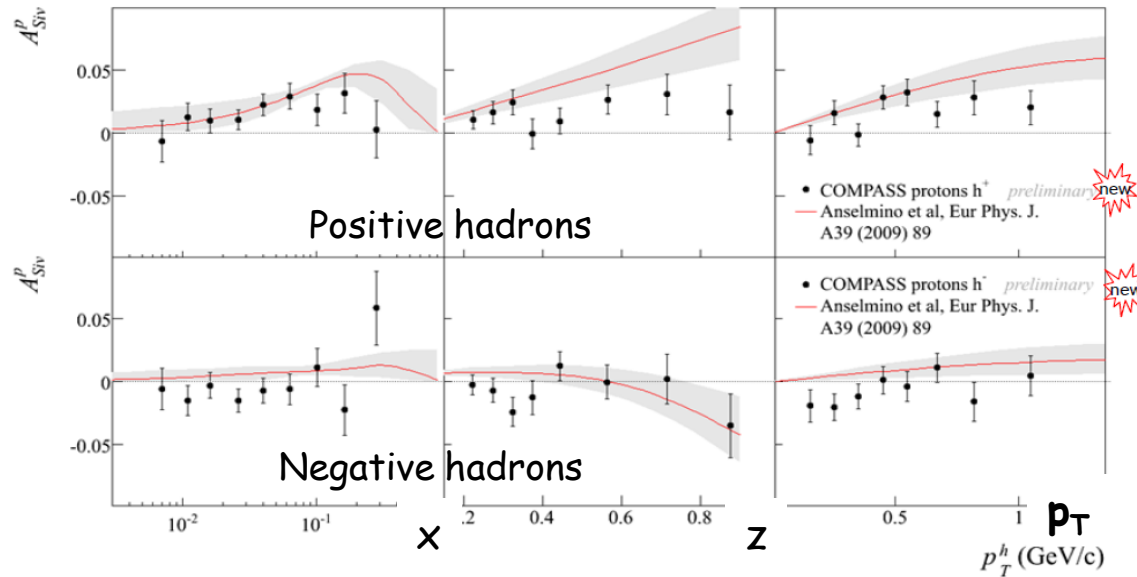
as an alternative for $\Delta_T u$ and $\Delta_T d$

• Confirms non zero effect at large x; larger than Collins asymmetry

• (Smaller) signal was also seen in HERMES in different phase space; difficult to describe both simultaneously *A.Bacchetta et al., Mah et al.*
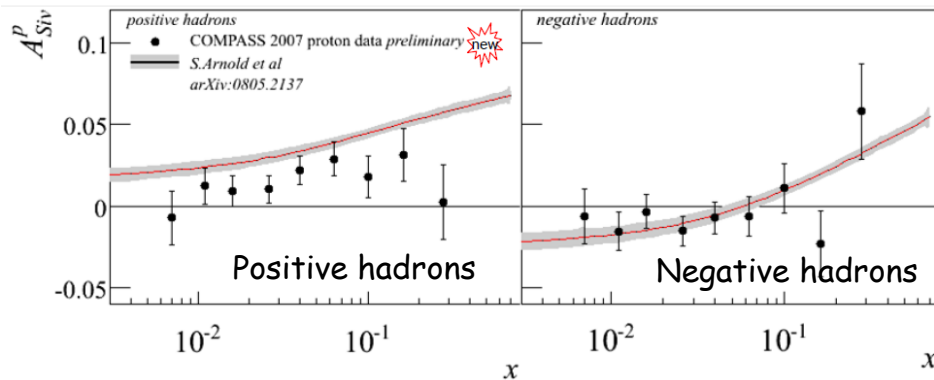
Sivers Asymmetry- proton

Comparison with predictions from Anselmino *et al.*, based on fit of Hermes-p and Compass–d data

Positive hadrons
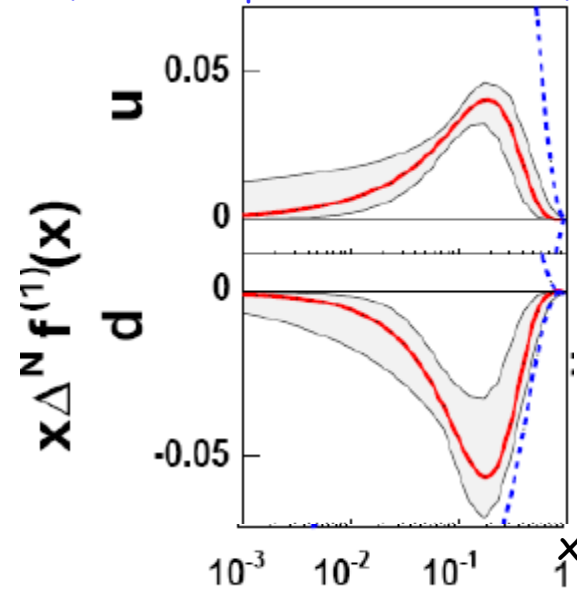
Negative hadrons

- COMPASS protons h⁺ *preliminary* new
- Anselmino et al, Eur Phys. J. A39 (2009) 89

- COMPASS protons h⁻ *preliminary* new
- Anselmino et al, Eur Phys. J. A39 (2009) 89

x   z p_T p_T^h (GeV/c)

Present data not in fit

-COMPASS signal < HERMES signal
-Possible W dependence

Extraction of Sivers fct
(HERMES p and COMPASS d)

Ex: M. Anselmino et al. arXiv:0812.4366

Comparison with calculations of Arnold *et al.*, which are in agreement with Hermes-p data.

positive hadrons
- COMPASS 2007 proton data *preliminary* new
- S.Arnold et al
  arXiv:0805.2137

negative hadrons

Positive hadrons   Negative hadrons

x   x

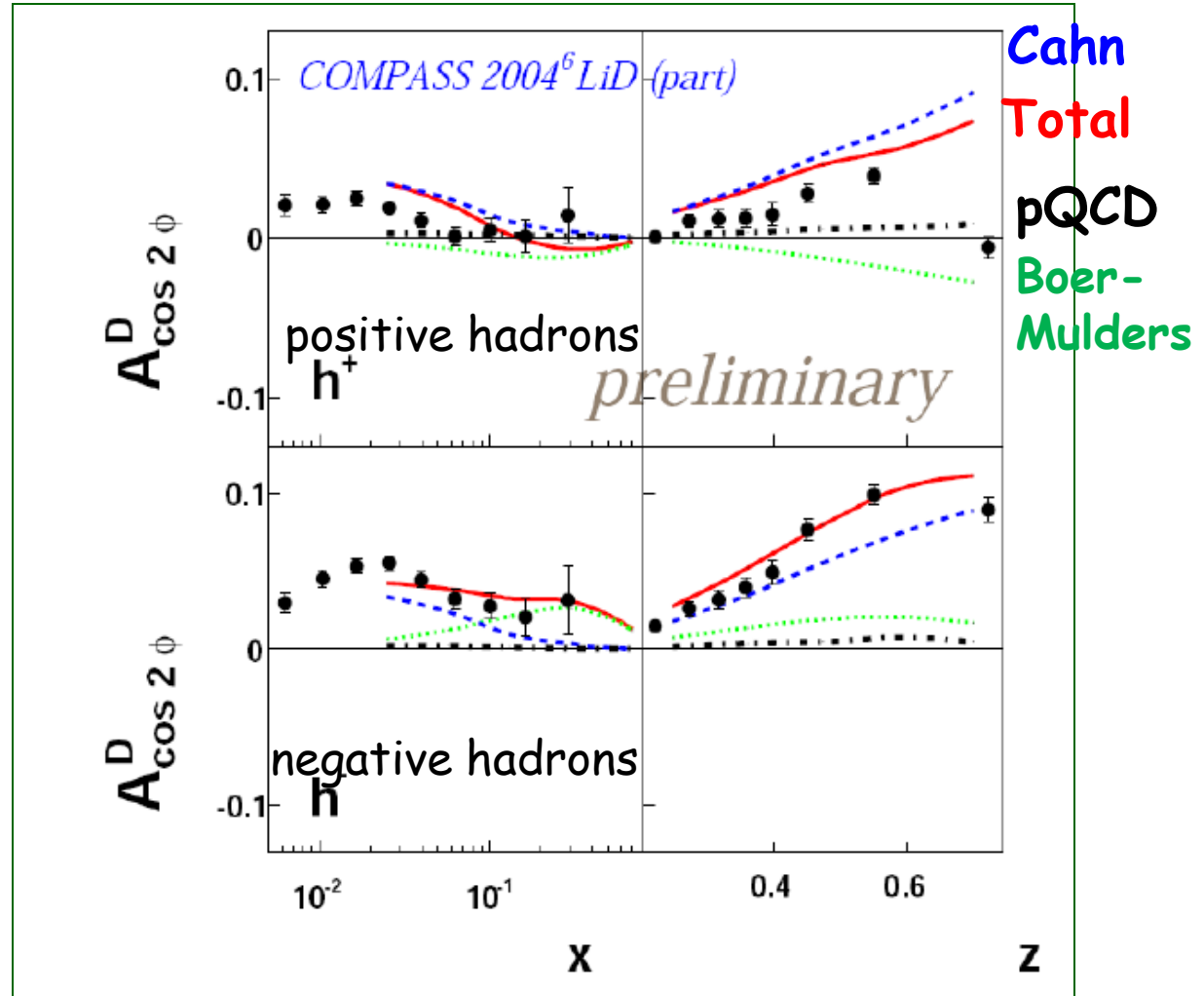# Example of one azimuthal asymmetry

Unpolarized target.

cos(2φ) modulation comparison with theory

total   Boer Mulders
Cahn   pQCD

V.Barone, A.Prokudin, B.Q.Ma
arXiv:0804.3024 [hep-ph]

Sensitivity to Transverse Momentum Distributions
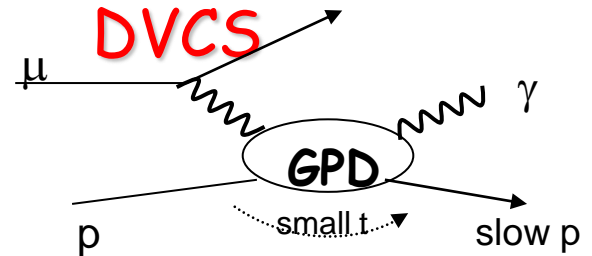
Future QCD studies at COMPASS II

COMPASS-II proposal submitted to CERN SPSC, June 2010

- GPD (Generalized Parton Distributions) $\mu p \rightarrow \mu p \gamma$

by exclusive reactions DVCS (Deep Virtual ComptonScattering)
and DVMP (Meson production),
2 year 'beam charge and spin asymmetry' measurement

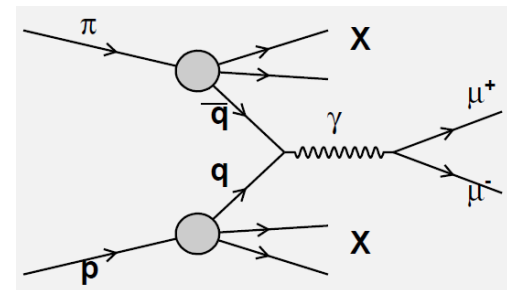- Polarized Drell-Yan $\pi p^{\uparrow} \rightarrow \mu^{+}\mu^{-}X$

Sivers & Boer-Mulders

Transverse Momentum Dependent distributions

2 years transversely polarised proton target

Test of factorization approach

Generalized Parton Distributions

- Unified description of form factors and parton distribution functions
- Transverse imaging = nucleon tomography

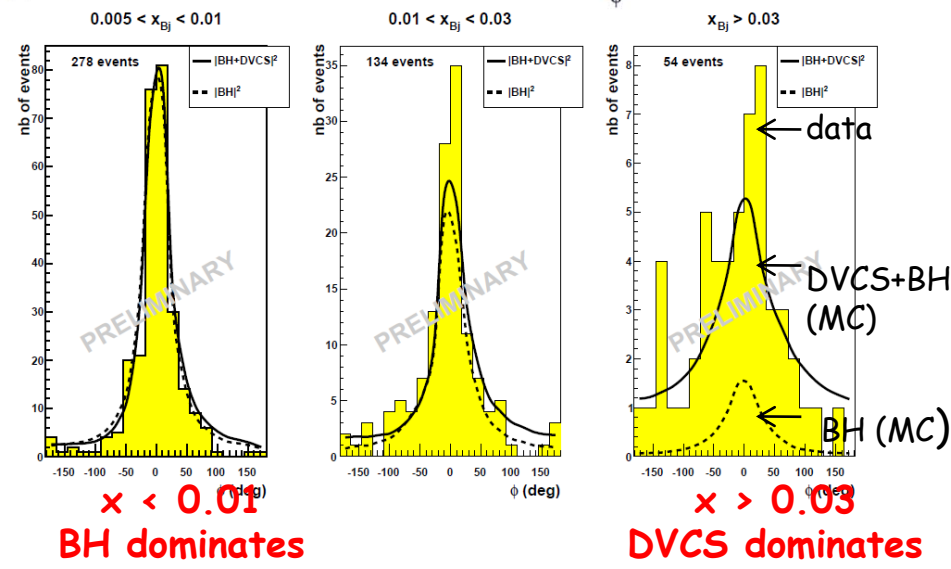and (in far future) sensitivity to the quark angular momentum

Kinematic domain : intermediate between HERA and JLab $\boxed{10^{-2} < x_B < 10^{-1}}$

Ex: Beam charge & spin asymmetry
in DVCS process (interfering with BH):

$\alpha'=0.8$
$\alpha'=0.05$
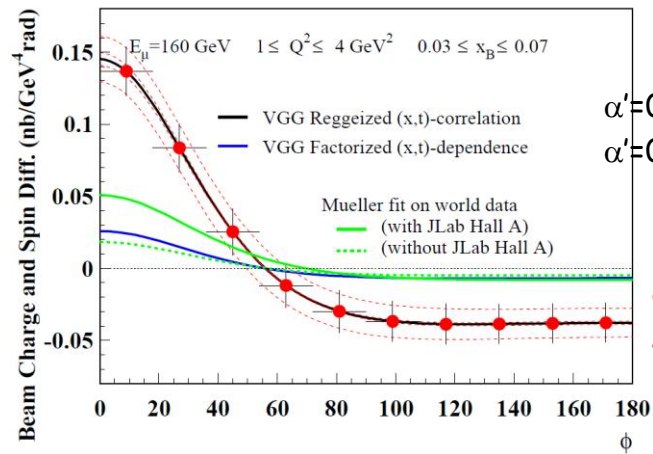
**COMPASS proj.
2years**

First signal of DVCS&BH from 2009
short test run, compared to simulations

x < 0.01
BH dominates

x > 0.03
DVCS dominates

Measurement of unpolarized PDfs

• In parallel to the DVCS/DVMP program,
get (for free) SIDIS data on LH_2 target

• Extract strange quark PDF $s(x)$ as well as quark fragmentation functions
from kaon multiplicities

Short term goal: LO analysis from COMPASS data alone integrated over z
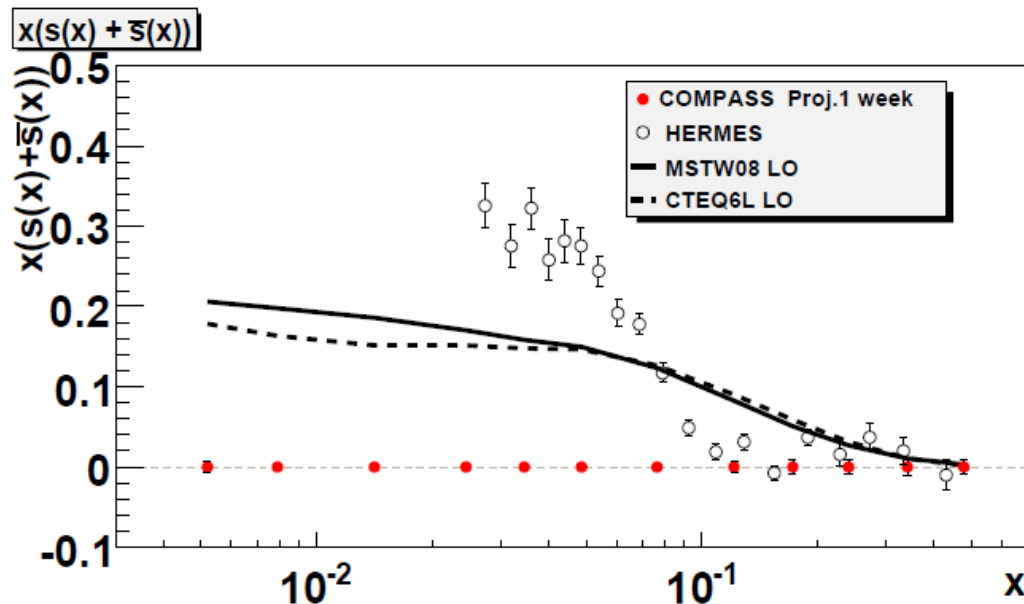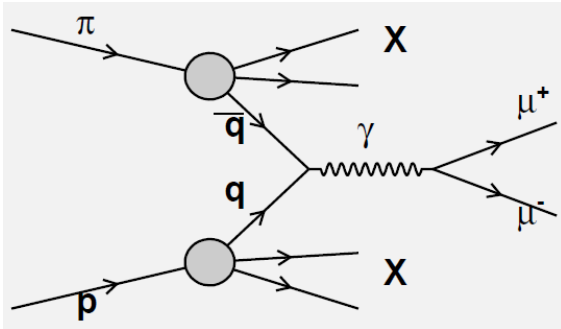

Longer term goal : provide p and K multiplicities as fct of x, z
for global QCD analyses

Polarized Drell-Yan $\pi^- p^\uparrow \rightarrow \mu^+\mu^- X$

transversely polarised NH_3 target

$$\sigma^{DY} \propto f_{\bar{u}|\pi^-} \otimes f'_{u|p}$$

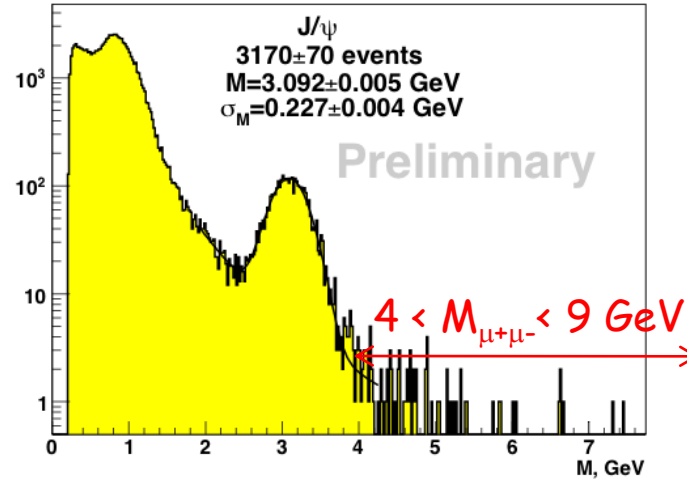→ Transverse Momentum Dependent (TMD) parton distribution functions

Sivers and Boer Mulders fct will be measured :
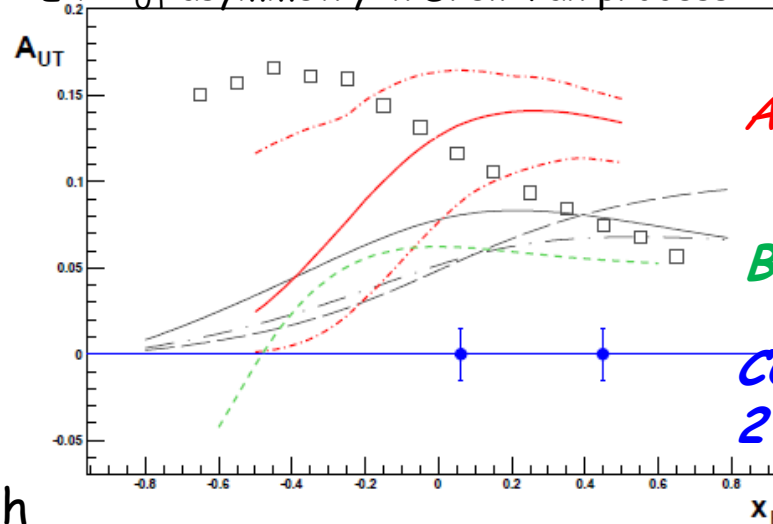- in Drell-Yan process
- in μp SIDIS process
Expect opposite sign
→ Test of factorization approach

COMPASS DY beam test 2009

J/ψ
3170 ± 70 events
$M=3.092\pm0.005$ GeV
$\sigma_M=0.227\pm0.004$ GeV

Preliminary

$4 < M_{\mu^+\mu^-} < 9$ GeV

Ex: A_{UT} asymmetry in Drell-Yan process

Anselmino et al.

Bacchetta et al

COMPASS proj. 2 years

COMPASS (Spin) Summary

- **Gluon polarization**

- High p_T: at LO, $\Delta G/G \sim 0$ at $x \sim 0.1$ two independent & precise results

 - Charm: at LO, $\Delta G/G = -0.08 \pm 0.21 \pm 0.11$

- **Quark helicity :** extraction at LO for all flavours
  $\Delta s \sim 0$ from SIDIS in measured region

- **Transversity:**
  Collins and Sivers deuteron, compatible ~ 0
  Collins proton: Signal in valence region, for pos. and neg. Hadrons
  Extract $\Delta_T u > 0$ and $\Delta_T d < 0$
  Sivers proton: Signal for positive hadrons; possible W dependence

And exciting future program in preparation

2010	Precision measurement on Transverse Spin (Sivers)
2011	Longitudinal Spin
2012 & beyond:	New proposal COMPASS II