Transverse Spin Structure with muon beam and Drell-Yan Measurements at COMPASS

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University of Trieste and INFN Trieste

on behalf of the **COMPASS Collaboration**

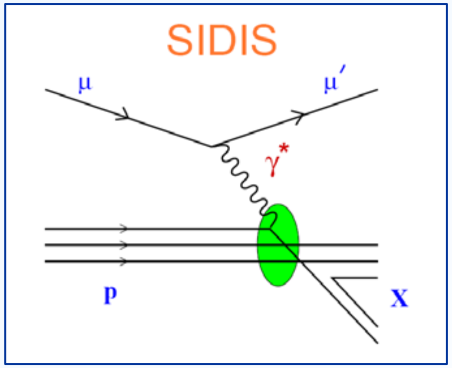
new opportunities IN PHYSICS

CERN, 11 May 2009

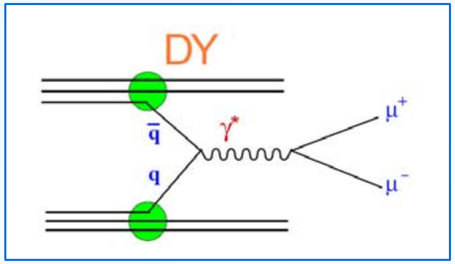
Transverse Spin Structure

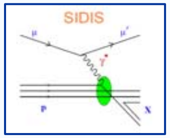
international effort

SIDIS: HERMES at DESY
COMPASS at CERN
spin experiments at JLab



hard pp scattering: spin experiments at RHIC / BNL





and several future projects:

COMPASS at CERN
experiments at JParc / KEK
Panda and PAX at FAIR / GSI
Nica at JINR
SPASCHARM at IHEP

eRHIC, ELIC
ENC at FAIR

several topical Workshops

Nucleon Structure

three distribution functions

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

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

f_1

probability of finding a quark with a fraction x of the longitudinal momentum of the parent nucleon

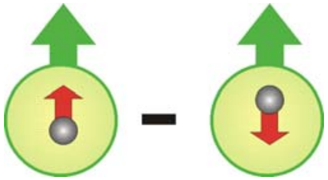
$\Delta q(x) = q^{\rightrightarrows} - q^{\leftrightarrows}$: longitudinal polarization or helicity distribution

g_1

in a longitudinally polarised nucleon, probability of finding a quark with a momentum fraction x and spin parallel to that of the parent nucleon

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

h_1



in a transversely polarised nucleon, probability of finding a quark with a momentum fraction x and spin parallel to that of the parent nucleon

ALL OF EQUAL IMPORTANCE !

Transversity

- **proposed in ’77** (Ralston & Soper)

- **different properties than helicity, more difficult to measure**

- **convincing evidence that it is non zero only recently in SIDIS from the HERMES and the COMPASS experiments**

$$A_{Coll} \approx \frac{\sum_q e_q^2 \, \Delta_T q \otimes \Delta_T^0 D_q^h}{\sum_q e_q^2 \, q \otimes D_q^h} \Rightarrow$$

“Collins FF”
left-right asymmetry in the hadronization of a transversely polarized quark

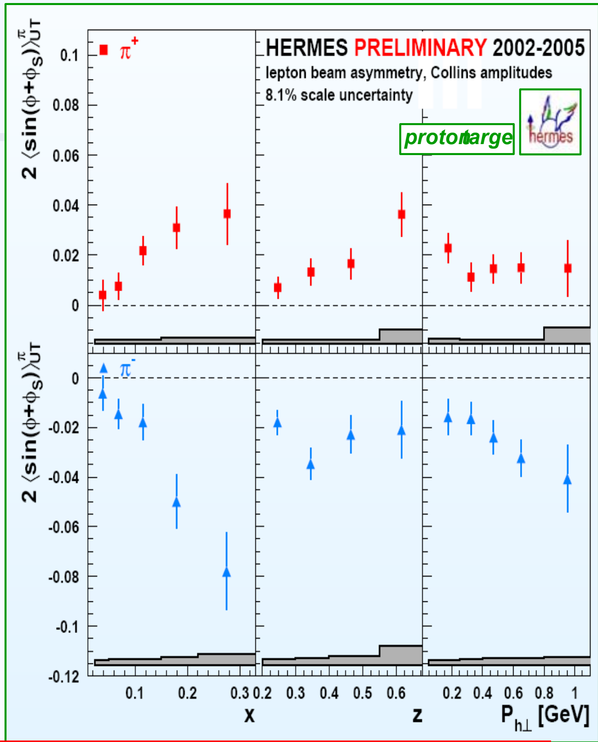
$$A_{Coll} \approx \frac{\sum_q e_q^2 \, h_1^q \otimes H_1^{\perp q}}{\sum_q e_q^2 \, f_1 \otimes D_1^q}$$

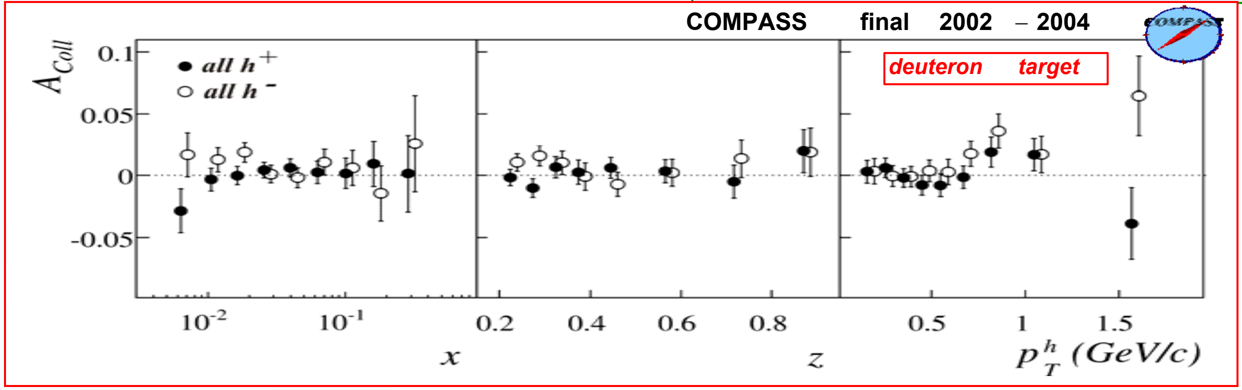
Transversity

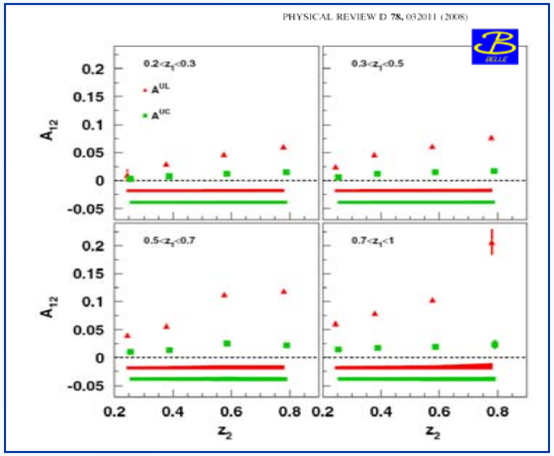
SIDIS results

- **clear non-zero effects first seen by HERMES on p**
- **~ zero asymmetries measured by COMPASS on d and understood as u – d cancellation**

independent measurement of Collins effect using BELLE $e^+e^- \rightarrow \pi^+\pi^- X$ data







Transversity

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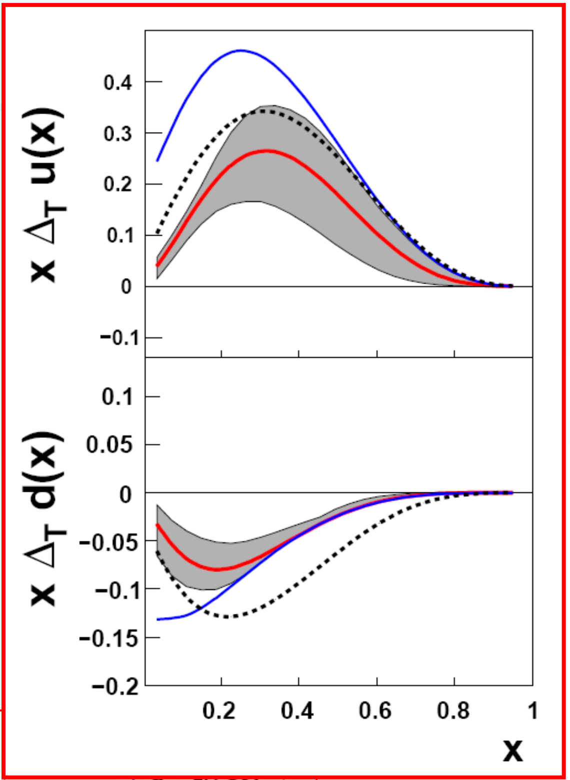
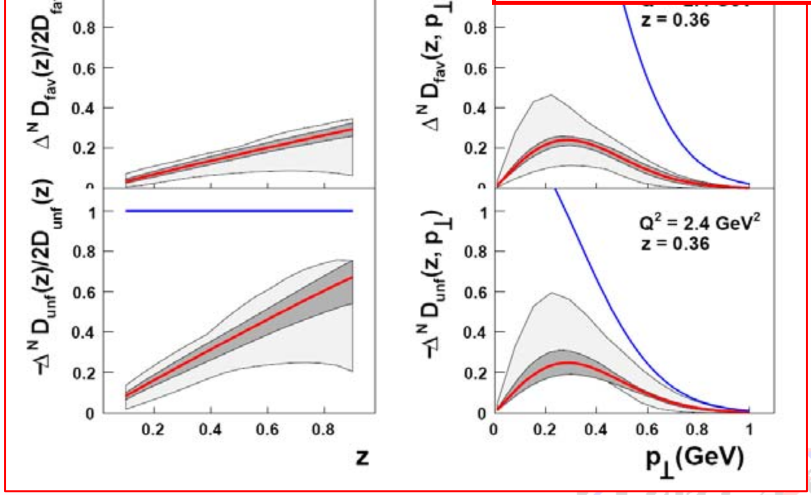


first extraction of the

Collins FF and of

transversity using

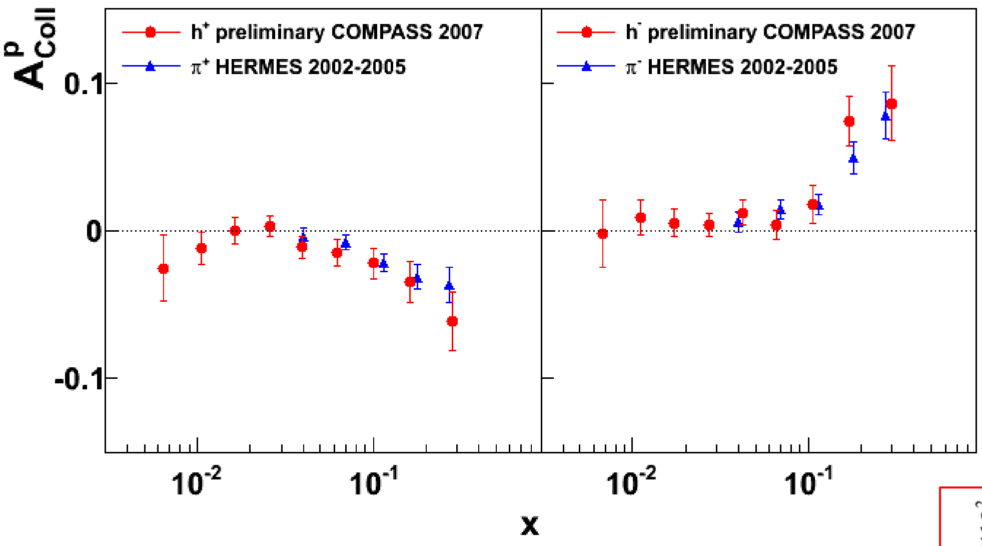
HERMES	$e^- p$	
COMPASS	$\mu^+ d$	
BELLE	$e^+ e^-$	**data**

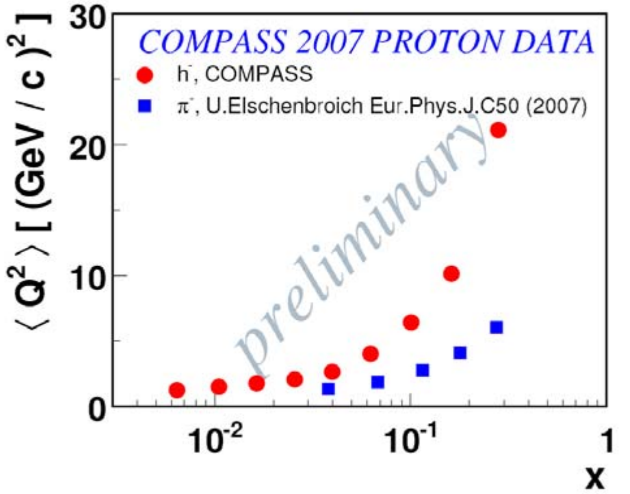


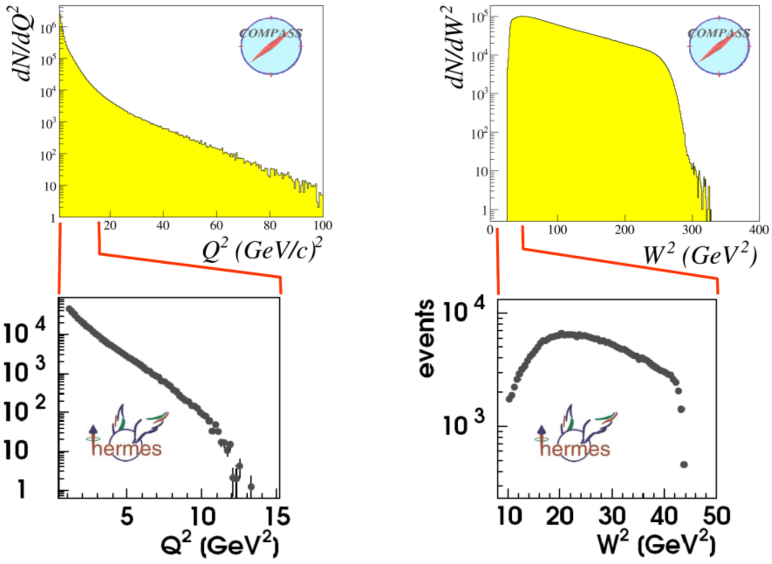
M. Anselmino et al., arXiv:0812.4366v1 [hep-ph] 23 Dec 2008

Transversity

new results from COMPASS proton target run in 2007
(much interest in the international community)







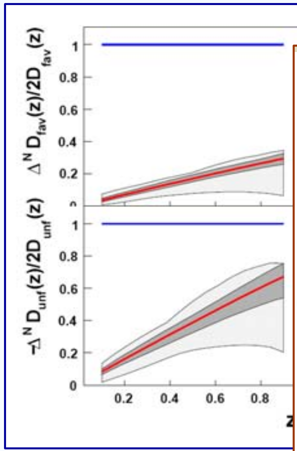
- **good agreement in the x overlap region**
- **quite different Q^2 and W ranges**

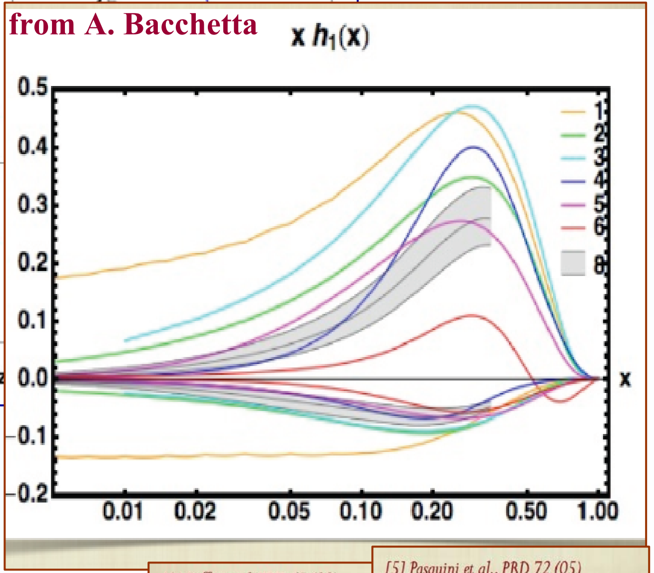
- **strong support to the present theoretical interpretation**

Transversity

conclusion:

transversity is different from zero and
can be measured in SIDIS thanks to the “Collins effect”





from A. Bacchetta

[1] Soffer et al. PRD 65 (02)
[2] Korotkov et al. EPJC 18 (01)
[3] Schweitzer et al., PRD 64 (01)
[4] Wakamatsu, PLB 509 (01)

[5] Pasquini et al., PRD 72 (05)
[6] Bacchetta, Conti, Radici, PRD 78 (08)
[7] Anselmino et al., PRD 75 (07)
[8] Anselmino et al., arXiv:0807.0173

the work has just started

more data are needed to map the Q^2, z and $p_\perp$ dependence

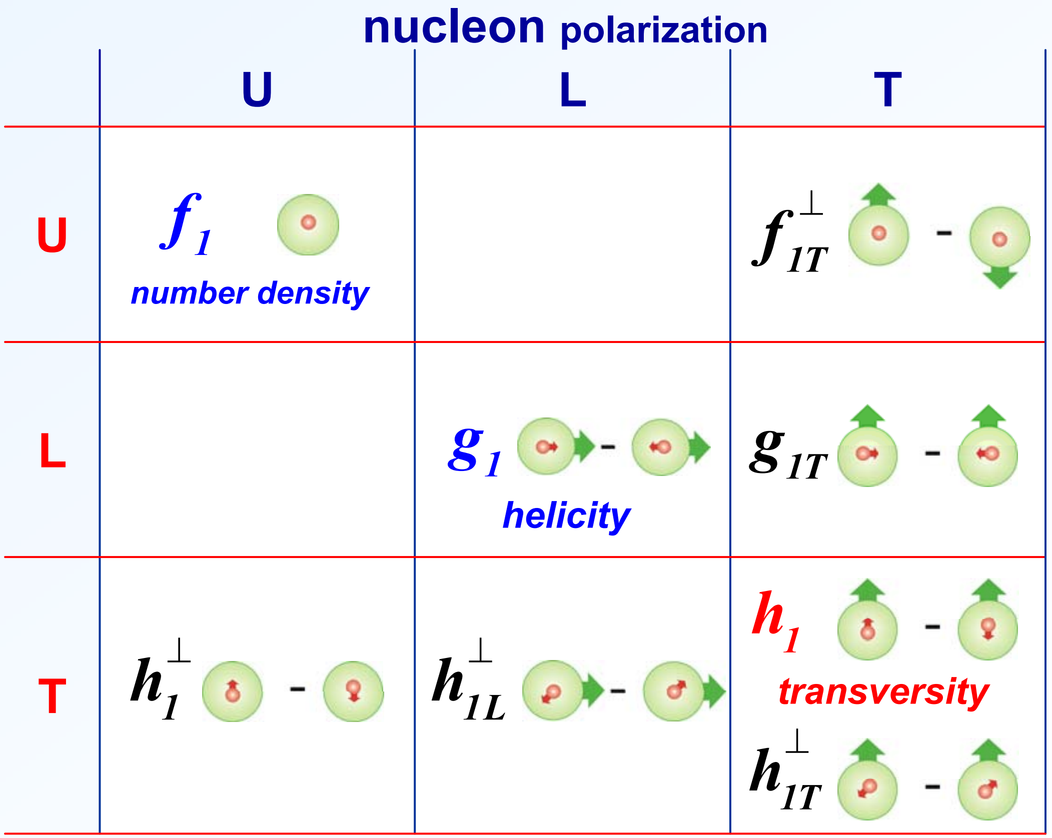
REQUEST TO CERN SPSC

(CERN-SPSC-2009-003 SPSC-I-238, 21 January 2009)

run one full year with transversely polarised proton target
with the present muon beam and COMPASS spectrometer
(~9 10^{13} μ on tape, ~6 10^{18} p on T6)

Nucleon Structure

taking into account the quark intrinsic transverse momentum k_T,
at leading order 8 PDFs are needed for a full description



		nucleon polarization		
		U	L	T
quark polarization	U	f_1 *number density*		$f_{1T}^{\perp}$ -
	L		g_1 - *helicity*	g_{1T} -
	T	$h_1^{\perp}$ -	$h_{1L}^{\perp}$ -	h_1 - *transversity* $h_{1T}^{\perp}$ -

interesting properties

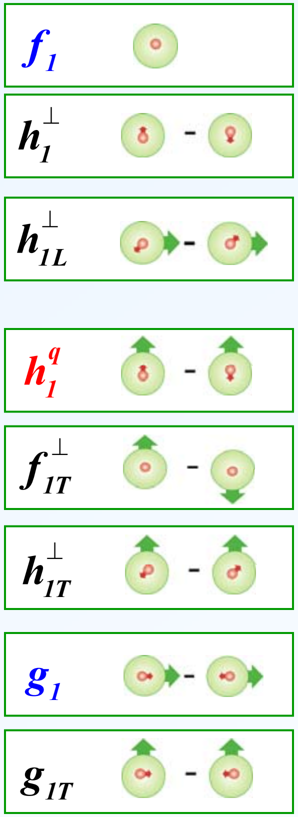
at twist-3 more TMD PDF’s

not all have a simple interpretation in the framework of the QPM

SIDIS cross-section

leading order

Collins asymmetry



$$d^6\sigma \approx \frac{4\pi\alpha^2 sx}{Q^4}\cdot$$

$$\{[1+(1-y)^2]\sum_q e_q^2 f_1^q(x) D_1^q(z,p_{h\perp}^2)$$

$$+(1-y)\frac{p_{h\perp}^2}{4z^2 M_N M_h}\cos(2\phi_h)\sum_q e_q^2 h_1^{\perp(1)q}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

unpol

$$-|S_L|(1-y)\frac{p_{h\perp}^2}{4z^2 M_N M_h}\sin(2\phi_h)\sum_q e_q^2 h_{1L}^{\perp(1)q}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

L pol. target

$$+|S_T|(1-y)\frac{p_{h\perp}}{zM_h}\sin(\phi_h+\phi_S)\sum_q e_q^2 h_1^q(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{p_{h\perp}}{zM_N}\sin(\phi_h-\phi_S)\sum_q e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z,p_{h\perp}^2)$$

T pol. target

$$+|S_T|(1-y)\frac{p_{h\perp}^3}{6z^3 M_N^2 M_h}\sin(3\phi_h-\phi_S)\sum_q e_q^2 h_{1T}^{\perp(2)q}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_q e_q^2 g_1^q(x) D_1^q(z,p_{h\perp}^2)$$

$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{p_{h\perp}}{zM_N}\cos(\phi_h-\phi_S)\sum_q e_q^2 g_{1T}^{(1)q}(x) D_1^q(z,p_{h\perp}^2)\}$$

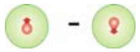
pol. beam & target

S_L and S_T: target polarizations; λ_e: beam polarization

SIDIS cross-section

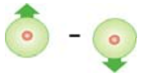
presently, the most “famous” transverse momentum dependent PDFs are:

- **the Boer-Mulders function**

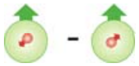
$h_1^\perp$ 

correlates the quark transverse spin and the quark k_t (unpol. N)

- **the Sivers function**

$f_{1T}^\perp$ 

correlates the nucleon spin and the quark k_t (tr. pol. N)

- **and** $h_{1T}^\perp$ 

which correlates the quark transverse spin and the quark k_t (tr. pol. N)

$$d^6\sigma \approx \frac{4\pi\alpha^2 sx}{Q^4}\cdot$$

$$\{[1+(1-y)^2]\sum_q e_q^2 f_1^q(x) D_1^q(z,p_{h\perp}^2)$$

$$+(1-y)\frac{p_{h\perp}^2}{4z^2 M_N M_h}\cos(2\phi_h)\sum_q \boxed{e_q^2 h_1^{\perp(1)q}}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

unpol

$$-|S_L|(1-y)\frac{p_{h\perp}^2}{4z^2 M_N M_h}\sin(2\phi_h)\sum_q e_q^2 h_{1L}^{\perp(1)q}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

L pol. target

$$+|S_T|(1-y)\frac{p_{h\perp}}{zM_h}\sin(\phi_h+\phi_S)\sum_q e_q^2 h_1^q(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{p_{h\perp}}{zM_N}\sin(\phi_h-\phi_S)\sum_q e_q^2 \boxed{f_{1T}^{\perp(1)q}}(x) D_1^q(z,p_{h\perp}^2)$$

$$+|S_T|(1-y)\frac{p_{h\perp}^3}{6z^3 M_N^2 M_h}\sin(3\phi_h-\phi_S)\sum_q \boxed{e_q^2 h_{1T}^{\perp(2)q}}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

T pol. target

$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_q e_q^2 g_1^q(x) D_1^q(z,p_{h\perp}^2)$$

$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{p_{h\perp}}{zM_N}\cos(\phi_h-\phi_S)\sum_q e_q^2 g_{1T}^{(1)q}(x) D_1^q(z,p_{h\perp}^2)\}$$

pol. beam & target

all important for assessing the orbital angular momentum of the quarks

SIDIS cross-section

all the structure functions can be extracted

simultaneously

from the azimuthal modulations

f.i. the Collins and Sivers asymmetries depend on *different angles* and both asymmetries have been extracted from the same data by COMPASS and HERMES

Collins asymmetry

$$d^6\sigma \approx \frac{4\pi\alpha^2 sx}{Q^4}\cdot$$

$$\{[1+(1-y)^2]\sum_q e_q^2 f_1^q(x) D_1^q(z,p_{h\perp}^2)$$

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L pol. target

$$+|S_T|(1-y)\frac{p_{h\perp}}{zM_h}\sin(\phi_h+\phi_S)\sum_q e_q^2 h_1^q(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{p_{h\perp}}{zM_N}\sin(\phi_h-\phi_S)\sum_q e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z,p_{h\perp}^2)$$

$$+|S_T|(1-y)\frac{p_{h\perp}^3}{6z^3 M_N^2 M_h}\sin(3\phi_h-\phi_S)\sum_q e_q^2 h_{1T}^{\perp(2)q}(x) H_1^{\perp q}(z,p_{h\perp}^2)$$

T pol. target

$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_q e_q^2 g_1^q(x) D_1^q(z,p_{h\perp}^2)$$

$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{p_{h\perp}}{zM_N}\cos(\phi_h-\phi_S)\sum_q e_q^2 g_{1T}^{(1)q}(x) D_1^q(z,p_{h\perp}^2))\}$$

pol. beam & target

Sivers asymmetry

Sivers function

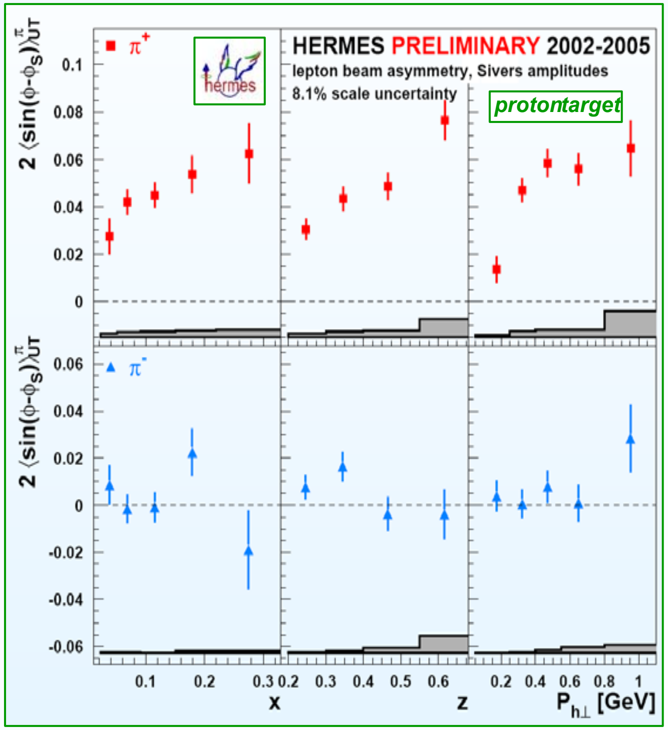
- proposed in 1990
- initially thought to be zero (Collins, 1993)
- resurrected in 2002 (Brodsky, Hwang, Schmitt) – *FSI, gauge link …*
- related to the “Sivers asymmetry” in SIDIS on transversely polarized targets

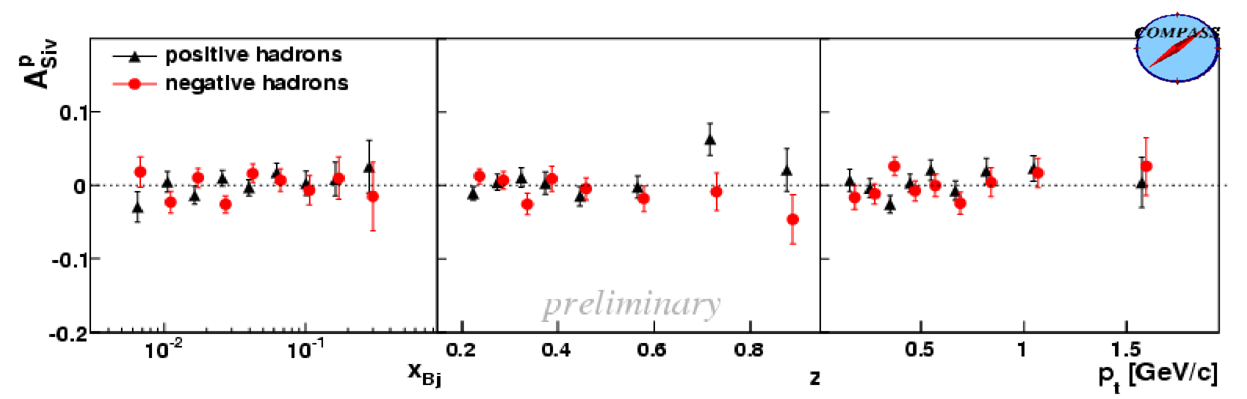
$$A_{Siv} \approx \frac{\sum_q e_q^2 \, f_{1T}^{\perp q} \otimes D_1^q}{\sum_q e_q^2 \, f_1 \otimes D_1^q}$$

Sivers function

SIDIS results

- strong signal seen by HERMES in π^+ production on transversely polarized protons
- no signal seen by COMPASS on transversely polarized deuterons, interpreted as u- and d-quark cancellation (as for the Collins asymmetry)
- no signal seen by COMPASS on transversely polarized protons
  - marginal compatibility with HERMES data
  - difficult theoretcal interpretation





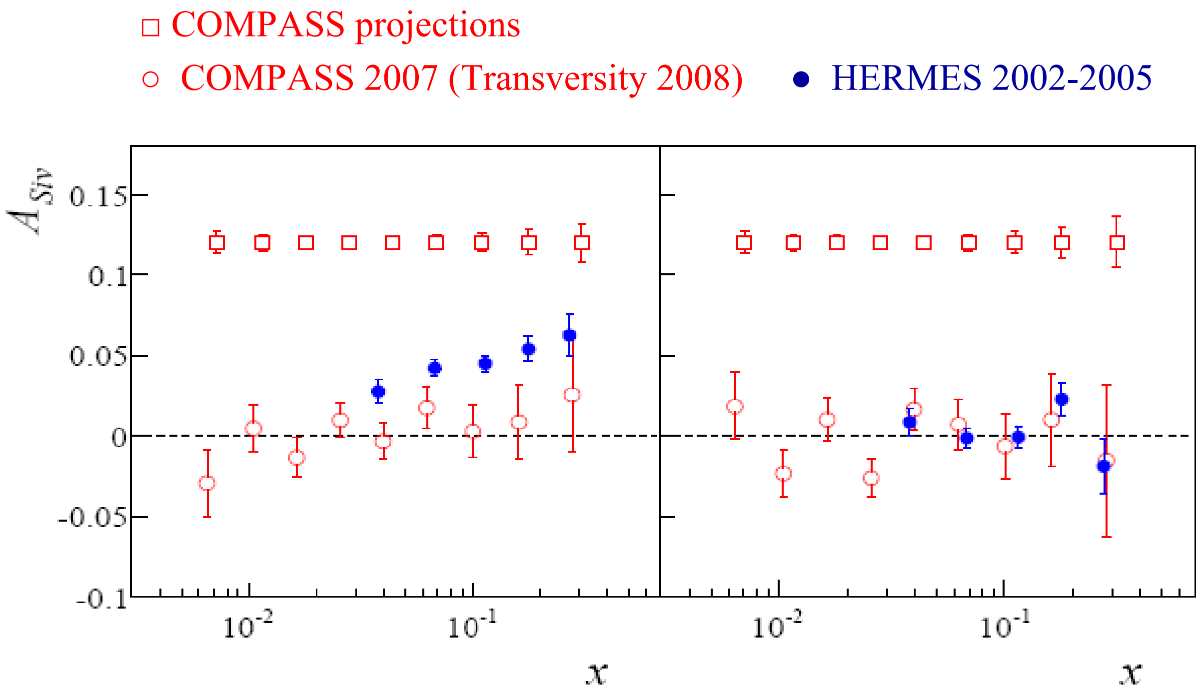
COMPASS 2007 *(S. Levorato, Transversi ty2008)*

Sivers function

situation not clear:

COMPASS accuracy has to be improved!
hopefully already in 2010

projections for 1 year of data taking with NH_3 transversely polarized target



SIDIS - Conclusion

SIDIS at high energy has provided unique information on the transverse spin and intrinsic momentum structure of the nucleon

easy flavour separation, broad x range, SIMPLE INTERPRETATION

- the high energy muon beam and the COMPASS spectrometer are unique facilities and CERN is the only place where SIDIS measurements can be made at high energy and high Q^2

A GUARANTEE FOR THE HARD SCALE

- in the very short term, one year of running will clarify the Sivers issue and will allow to improve the knowledge of transversity
- on a longer time scale, this program will greatly benefit from higher intensity / energy muon beam as foreseen in the SPS upgrade program

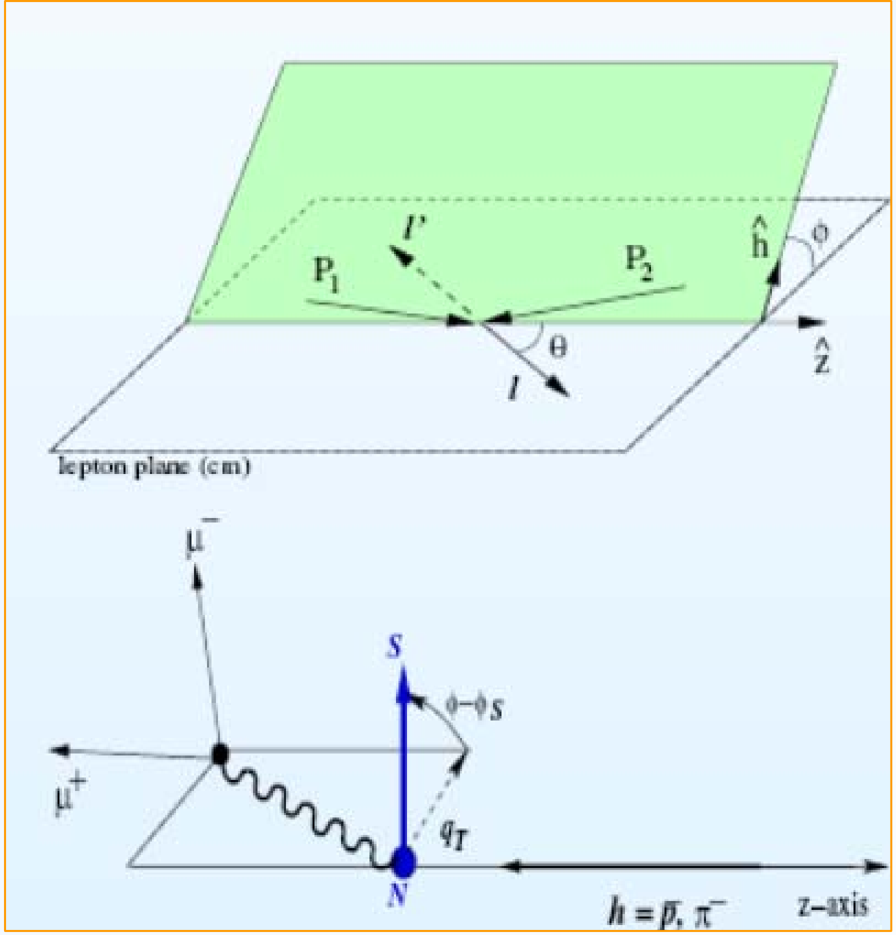
today: JLab (6 GeV → 12 GeV)

future projects:

eRHIC or ELIC
ENC at FAIR

Drell-Yan measurements at COMPASS

The Drell-Yan process



Collins-Soper frame

θ, ϕ lepton plane wrt hadron plane

ϕ_{S2} target transverse spin vector S_{2T} wrt lepton plane

phase space defined by x_1 and x_2

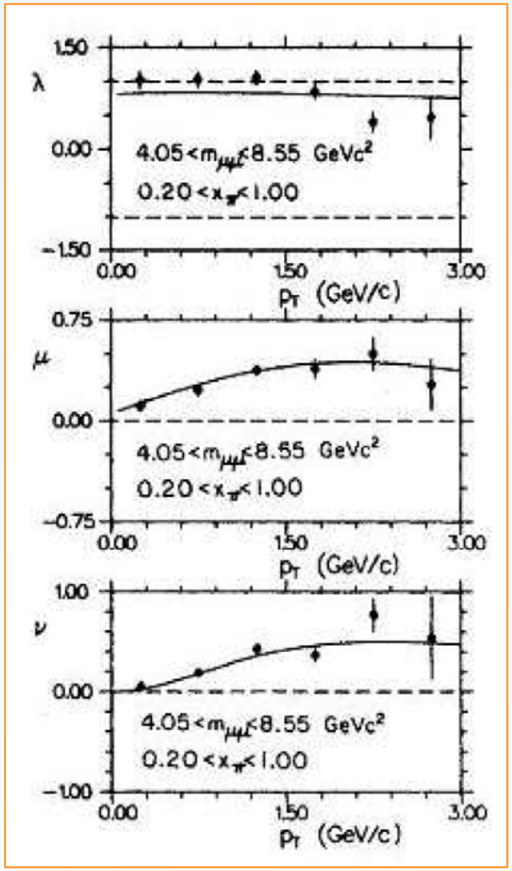
$$x_F = x_1 - x_2 = \frac{2p_L}{\sqrt{s}}$$

$$\tau = \frac{M^2}{s} = x_1 \cdot x_2$$

The Drell-Yan process

angular distribution (unpolarized)

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}(1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi)$$



E615, Conway et al (1989)

Lam-Tung sum rule: $1-\lambda-2\nu=0$

at LO and in the collinear approximation one gets

$$\begin{aligned}\lambda &= 1\\ \nu = \mu &= 0\end{aligned}$$

large violations of the sum rule seen in experiments at CERN (NA10) and FNAL (E615)

$\cos 2\phi$ **modulation, up to 30%**

such a modulation could arise from the product of 2 Boer-Mulders functions: (beam PDF $\otimes$ target PDF)

The Drell-Yan process in $\pi^- p$

very much like in SIDIS several azimuthal modulations are possible in the cross-section:

- **DY on unpolarized target**

$$d\sigma^{DY} \propto \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_1^{\perp}(x_2, k_{T2}^2) \cos 2\phi$$

↑ Boer-Mulders ↑

- **DY on transversely polarized target**

$$d\sigma^{DY} \propto \bar{f}_1(x_1, k_{T1}^2) \otimes f_{1T}^{\perp}(x_2, k_{T2}^2) \sin(\phi - \phi_{S2}) +$$

↑ Sivers

$$+ \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_1(x_2, k_{T2}^2) \sin(\phi + \phi_{S2}) +$$

↑ Boer-Mulders ↑ Transversity

$$+ \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_{1T}^{\perp}(x_2, k_{T2}^2) \sin(3\phi - \phi_{S2})$$

↑ Boer-Mulders ↑ Pretzelosity

the amplitudes are convolutions of TMD PDFs

The Drell-Yan process in $\pi^- p$

in the valence region, u quark-dominance

$$\boxed{\sigma^{DY} \propto f_{\bar{u}|\pi^-} \otimes f_{u|p}}$$ where $$\boxed{f = h_1^\perp, f_1, f_{1T}^\perp, h_1, h_{1T}^\perp}$$

→ extraction of the u-quark Sivers function

→ model dependent extraction of transversity and Boer-Mulders functions

COMPASS can do it

Testing non-perturbative QCD

confronting Drell-Yan and SIDIS results provides a crucial test of non-perturbative QCD

→ check the predictions: $$\boxed{f_{1T}^\perp(DY) = -f_{1T}^\perp(SIDIS)}$$

$$\boxed{h_1^\perp(DY) = -h_1^\perp(SIDIS)}$$

due to the T-odd character of the Sivers and Boer-Mulders functions

J/ψ production in $\pi^- p$

J/ψ and γ being vector particles, the analogy between J/ψ and DY production mechanisms might be of interest:

$$\boxed{\pi p \rightarrow J/\psi X \rightarrow \mu^+\mu^- X}$$

J/ψ production via $q\bar{q}$ annihilation dominates at low-energies, justifying such analogy J/ψ - DY duality

from the study of J/ψ production in the dileptons decay channel:

- check duality hypothesis – polarized J/ψ production cross-section
- access PDFs from J/ψ events – larger statistics available

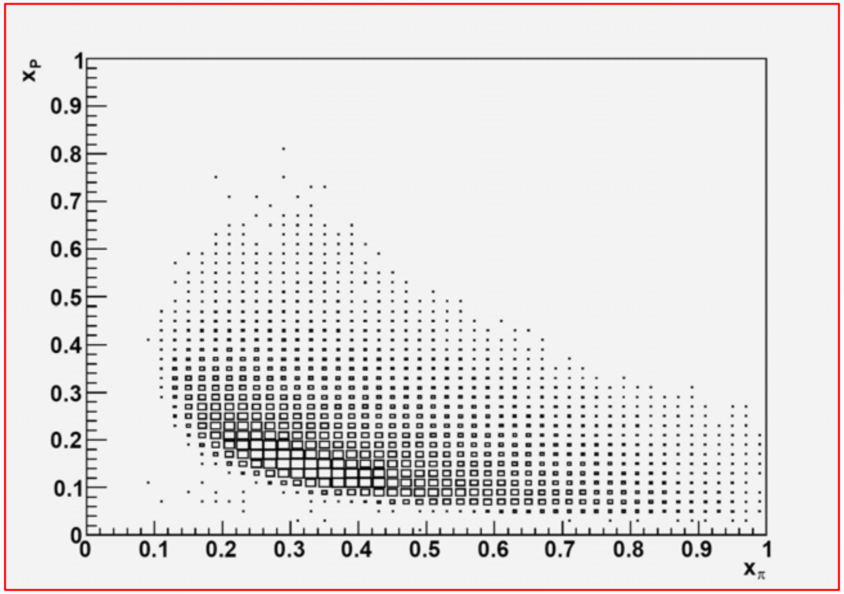
secondary hadron beam: possible to vary the beam energy (from 50 to 200 GeV), in order to study different J/ψ production mechanisms

Why Drell-Yan at COMPASS ?

COMPASS is a multi-purpose spectrometer:

- availability of both muon and pion beams
- unique polarized target, well suitable for transversity studies
- spectrometer with wide angular acceptance
- a muon detection system

COMPASS phase-space is in the
beam fragmentation region,
where valence quarks contribution
is dominating ($x_\pi > 0.1$)



not an easy experiment
in the COMPASS environment

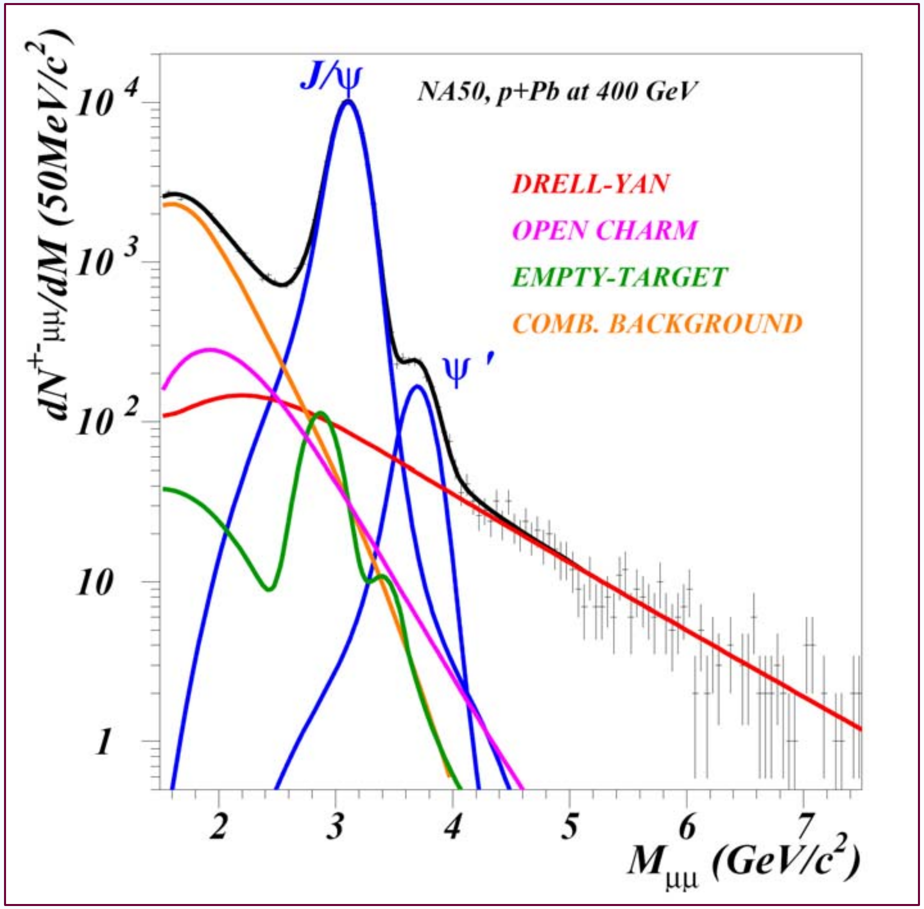
- test beam in 2007 *with NH_3 PT and low intensity beam*
- test beam in 2008 *with CH T and 10^7* π^- / sec
- many MC simulations
- LoI *CERN-SPSC-2009-003 SPSC-I-238, 21 January 2009*

Drell-Yan at COMPASS

signal and background

the dimuon mass spectrum
is known from
past DY experiments

spectrum from NA50



$M < 2.5$ GeV/c^2:

Large physics background

from decays $D \to \mu^{\pm} X$

Combinatorial background

π and K decaying to $\mu\nu$

- Absorber option

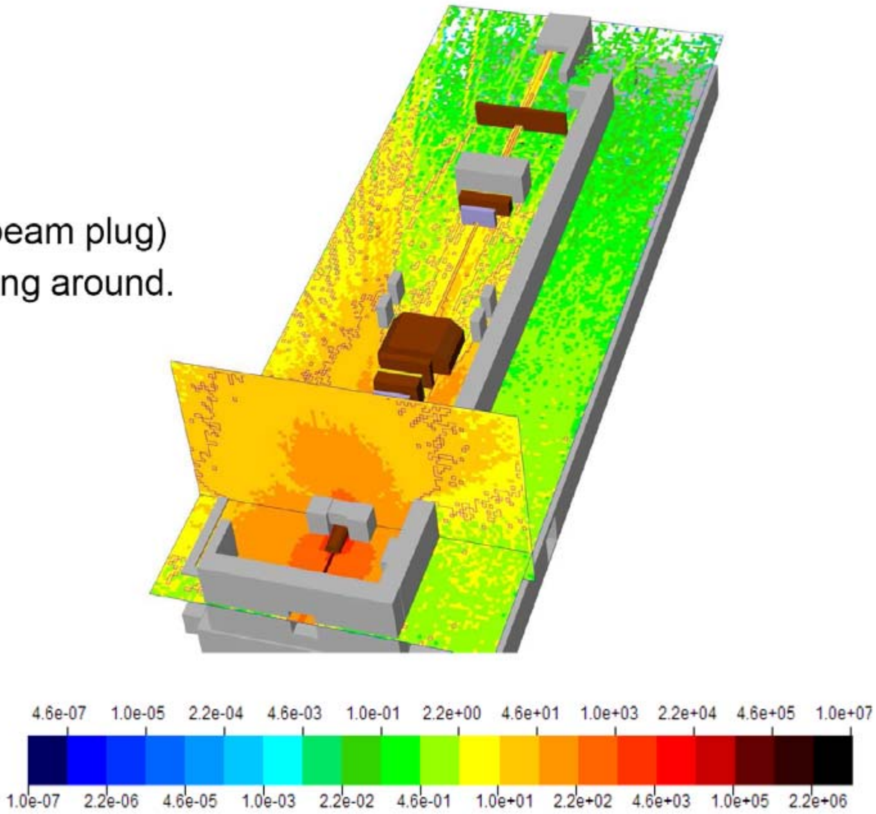
J/ψ and ψ' region: the charmonium polarization is itself a subject of research

$M > 4.$ GeV/c^2: safe region to study Drell-Yan

Drell-Yan beam tests

Simulations from Heinz Vincke (Rad-Prot/CERN)

Beam I=$8 \times 10^7\ \pi^-$/s
Absorber (Al$_2$O$_3$ with W beam plug)
of 1.5 m. Concrete shielding around.



COMPASS is a radiation supervised area

- **the dose limits in the control room must stay < 3 μSv/h**
- **all the region around target and absorber must be shielded**

Drell-Yan at COMPASS

expected precision in two years of data taking

with
- a transversely polarized NH_3 target (120 cm long)
- a π^- beam of 190 GeV/c with intensity $6 \cdot 10^7$ particles/second,

a luminosity of $1.7 \cdot 10^{33}$ $cm^{-2}s^{-1}$ can be obtained

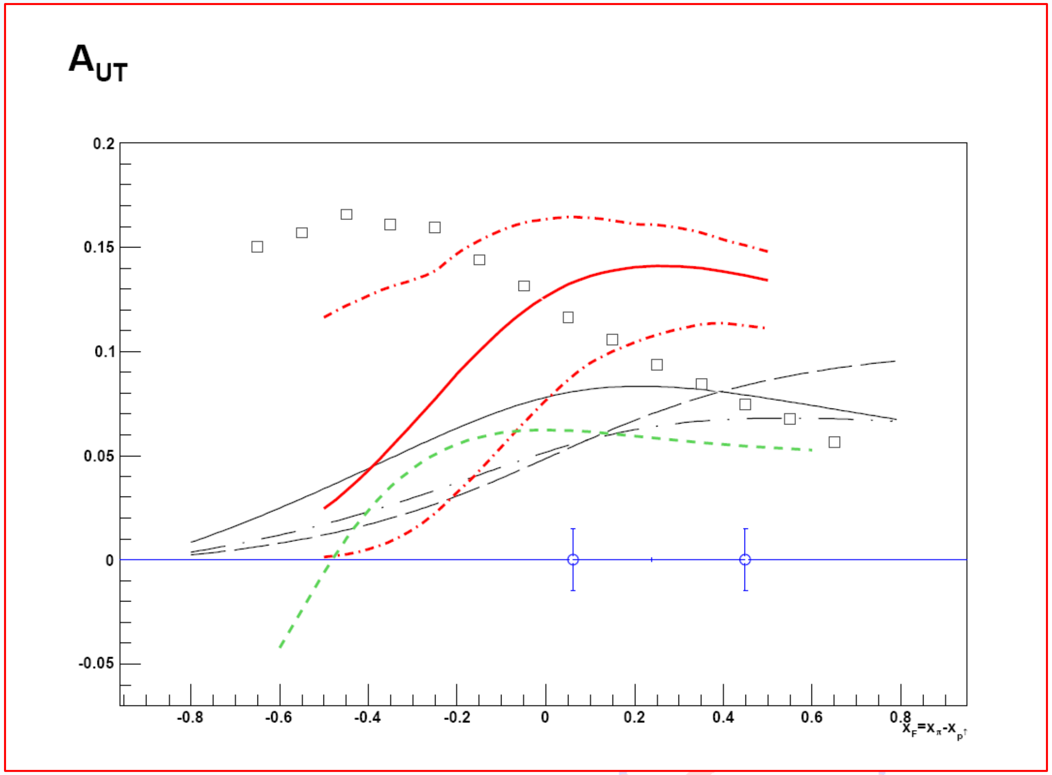
the statistical error in the asymmetries measured is expected to be

$$\delta A^{sin(\phi_{S2}-\phi)} \approx 1-2\,\%$$

predictions for the "Sivers asymmetry" (based on HERMES p Sivers asymmetry in SIDIS) in the COMPASS phase-space

mass region 4 < M < 9 GeV/c²

- solid and dashed: Efremov et al, PLB612(2005)233;
- dot-dashed: Collins et al, PRD73(2006)014021;
- solid, dot-dashed: Anselmino et al, PRD79(2009)054010;
- boxes: Bianconi et al, PRD73(2006)114002;
- short-dashed: Bacchetta et al, PRD78(2008)074010.



Further Drell-Yan measurements

what if COMPASS could dispose of a RF separated $\bar{p}/K^-$ beam?

from L. Gatignon: 3 · 10^8 ppp (limiting factor: radiation)

$\bar{p}:K^- = 1:1$

$(\bar{p}, p\uparrow)$ $\bar{p}$: $(\bar{u}\bar{u}\bar{d})$ p: (uud)

in this case $f_{\bar{u}|\bar{p}} = f_{u|p}$ thus $\boxed{\sigma^{DY} \propto f_{u|p} f_{u|p}}$

- **model independent extraction of the Sivers function**

$(K^-, p\uparrow)$ K^-: $(\bar{u}s)$ $\boxed{\sigma^{DY} \propto f_{\bar{u}|K^-} f_{u|p}}$

- **model dependent extraction of valence Sivers, transversity and Boer-Mulders functions**
- **access to unpolarized kaon distribution functions (poorly known)**

Drell-Yan: conclusion

- DY is a well understood process
- DY provides unique information of the hadron structure and dynamics, and of TMD PDFs, complementary to SIDIS
- COMPASS experimental conditions probe the valence quark region where the TMD effects are expected to be larger
- the $\pi^- p$ part of the program can start soon
- COMPASS can provide the first ever DY data on a polarized target and test the fundamental prediction on the sign of the Sivers function

Proposal in preparation

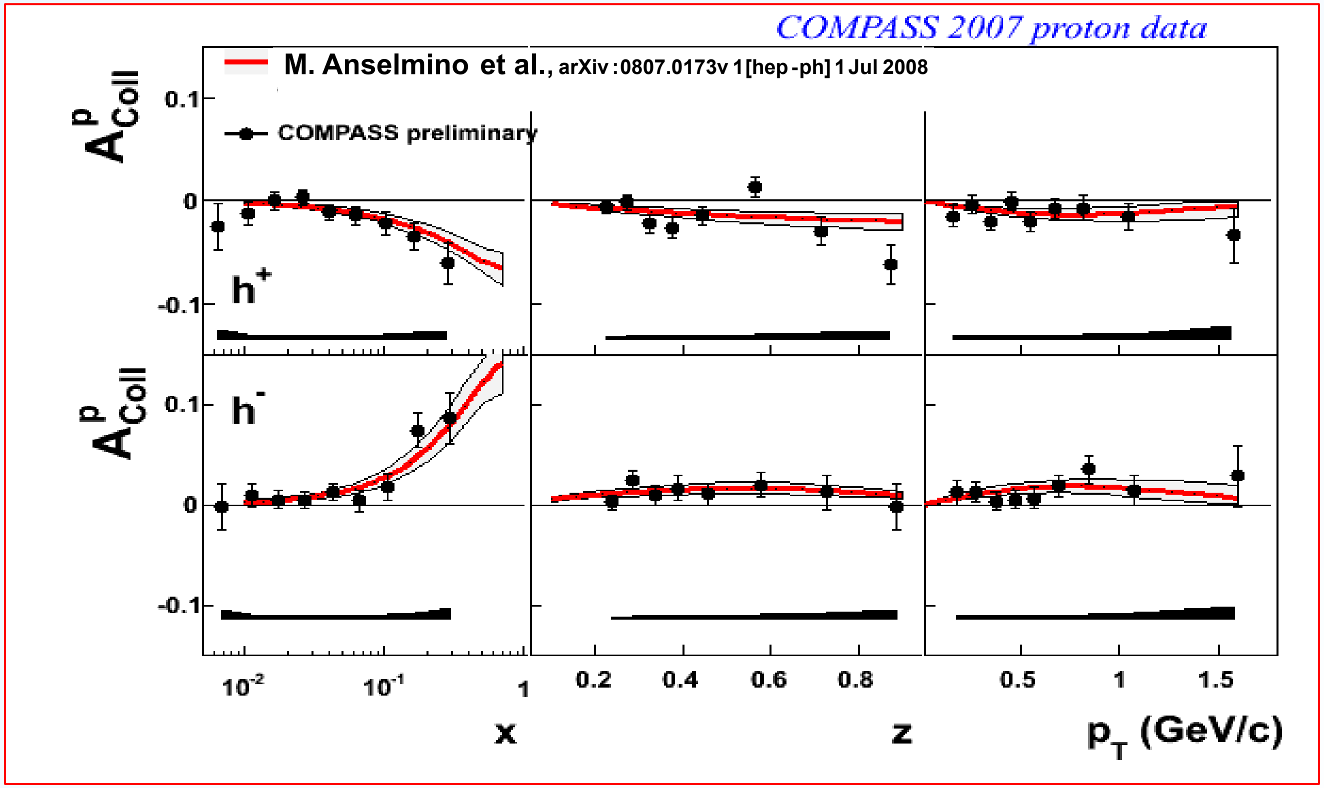
1st phase: $\pi^- p$ collisions
using polarized NH_3 target
using long liquid H_2 target

2nd phase: $\bar{p}\,p$ collisions and $K^- p$ collisions
if RF separated beam available

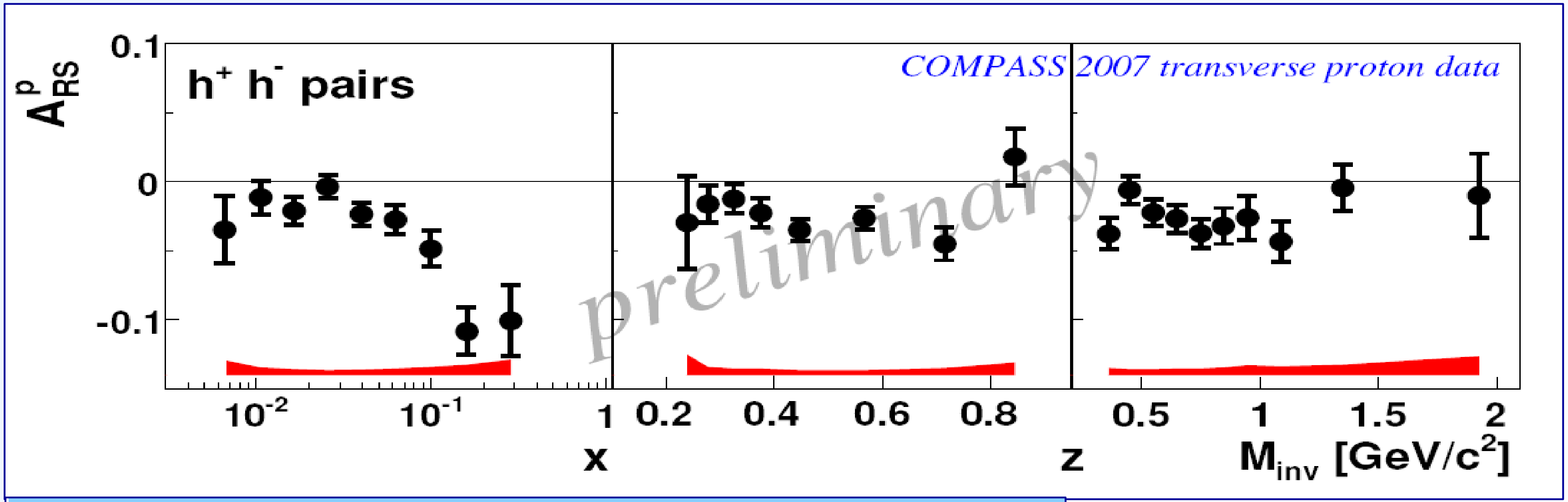
Thank you !

Transversity

new results from COMPASS proton target run in 2007



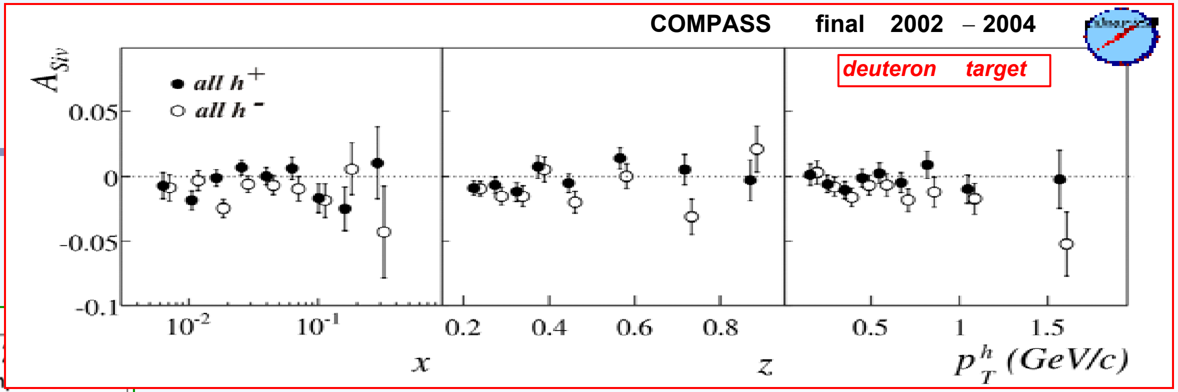
Two- hadron asymmetry on p

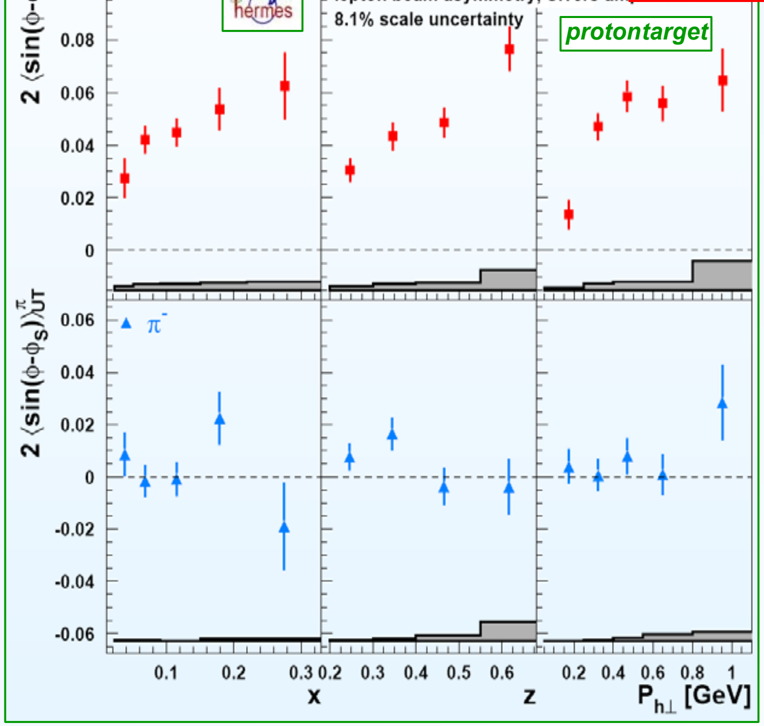


Heiner Wollny (University of Freiburg) DIS 2009

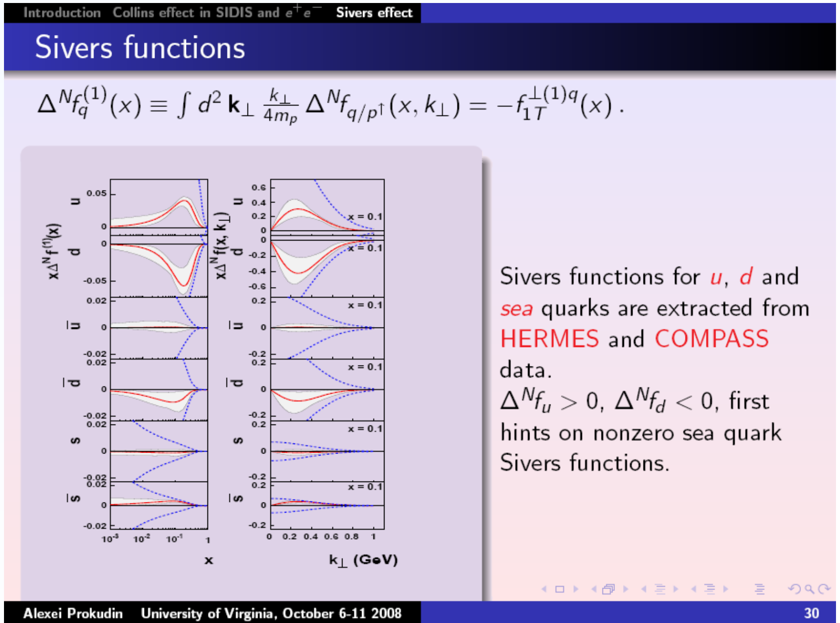
Sivers function

SIDIS results





- strong signal seen by HERMES in π^+ production on transversely polarized protons
- no signal seen by COMPASS on transversely polarized deuterons, interpreted as u- and d-quark cancellation (as for the Collins asymmetry)



Introduction Collins effect in SIDIS and e^+e^- Sivers effect

Sivers functions

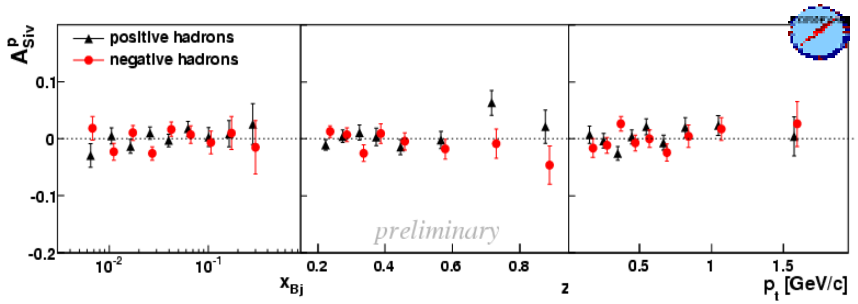
$$\Delta^N f_q^{(1)}(x) \equiv \int d^2\mathbf{k}_\perp \frac{k_\perp}{4m_p}\Delta^N f_{q/p^\uparrow}(x,k_\perp) = -f_{1T}^{\perp(1)q}(x)\,.$$

Sivers functions for *u*, *d* and *sea* quarks are extracted from HERMES and COMPASS data. $\Delta^N f_u > 0$, $\Delta^N f_d < 0$, first hints on nonzero sea quark Sivers functions.

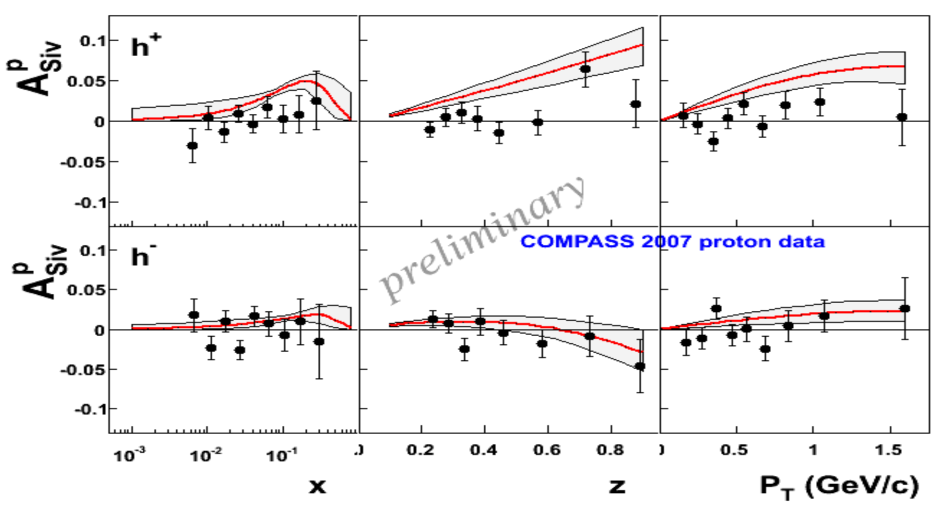
Alexei Prokudin University of Virginia, October 6-11 2008 30

Sivers function

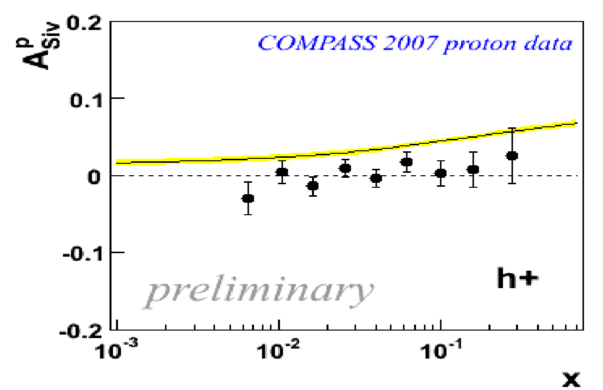
results from COMPASS proton target run in 2007

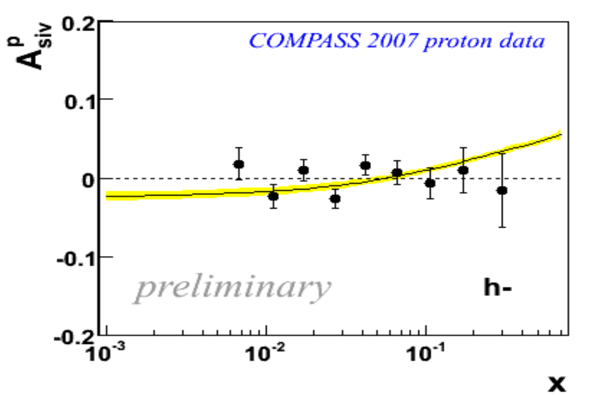


COMPASS 2007 *(S. Levorato, Transversity2008)*



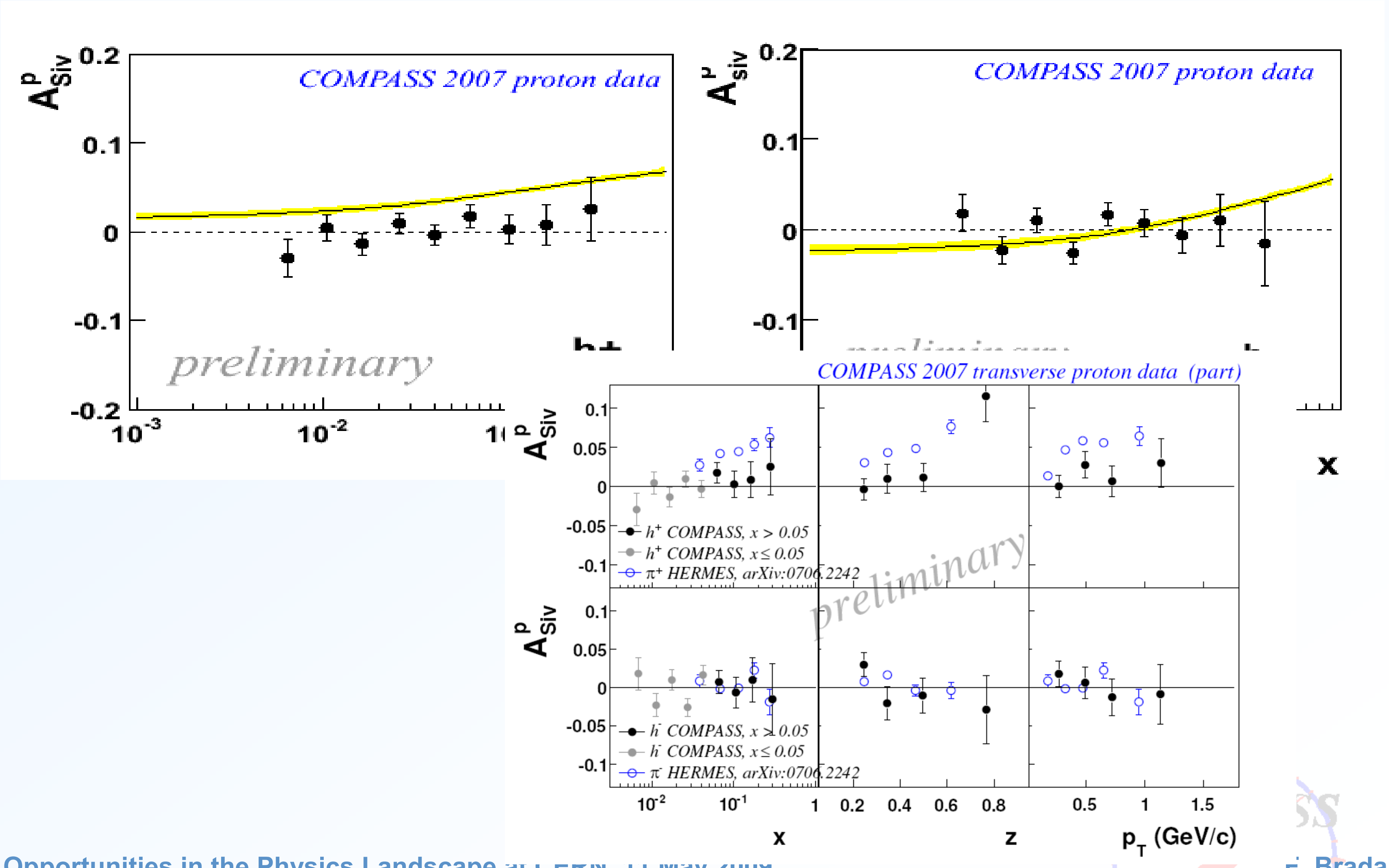
comparison with recent predictions from Anselmino et al., Goeke et al.





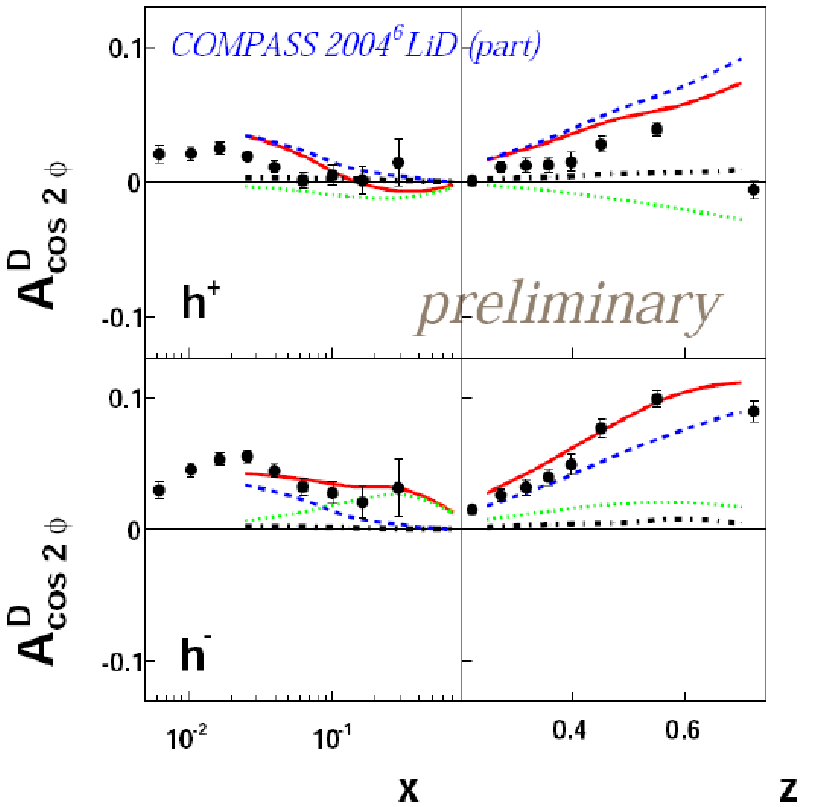
Sivers function

comparison with predictions from
S.Arnold, A.V.Efremov, K.Goeke, M.Schlegel and P.Schweitzer arXiv:0805.2137



Boer-Mulders function

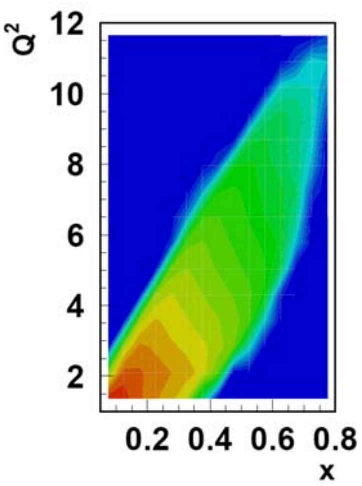
in principle can be extracted by the *cos* $2\phi_h$ modulation of the unpolarized SIDIS cross-section



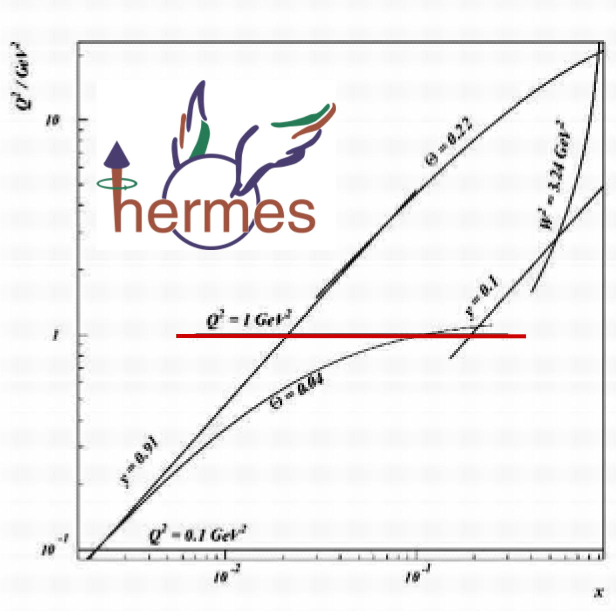
V.Barone, A.Prokudin, B.Q.Ma
arXiv:0804.3024 [hep-ph]

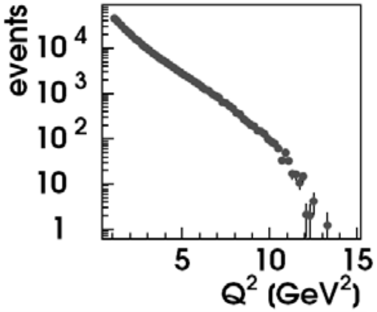
difficult experiment

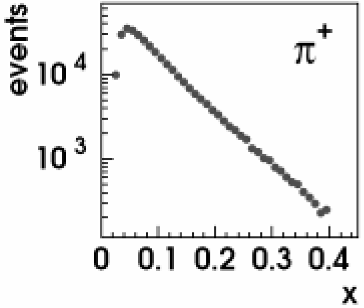
run with LH target,
in parallel with DVCS?



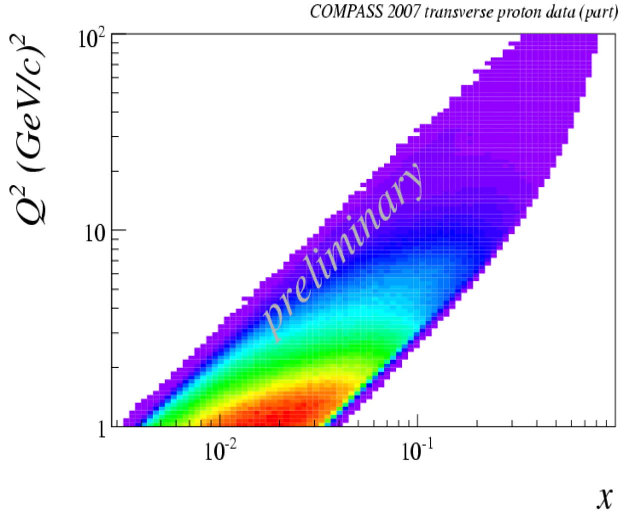
CLAS12

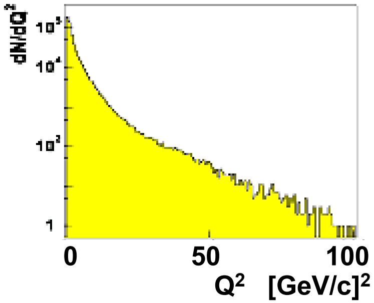


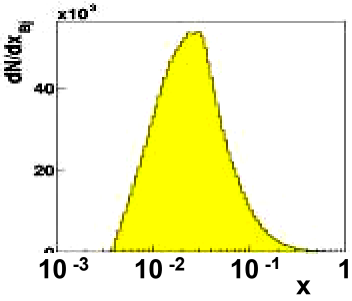




0.02 < x < 0.6







0.004 < x < 0.4

SIDIS on transversely polarized targets

WHY MEASURE @ CERN ?

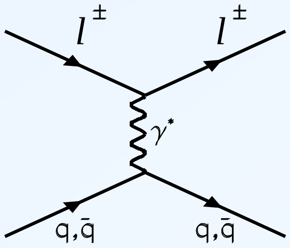
- the existing COMPASS spectrometer with its long Polarized Target can be used as such

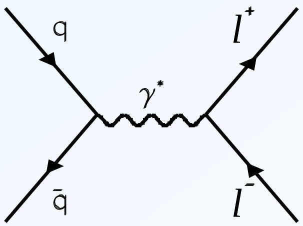
- the high energy beam ensures the hardness of the process
  - large W
    current jet and target fragmentation
    well separated
  - small x
    parameterization
    spin sum rule, tensor charge
  - large Q^2 coverage

complementary kinematic range to JLab12

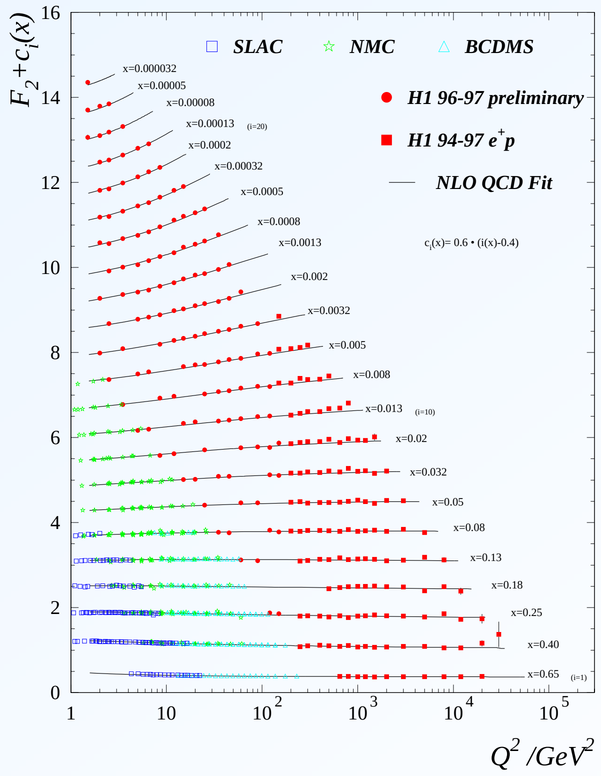
Complementarity between DIS and Drell-Yan

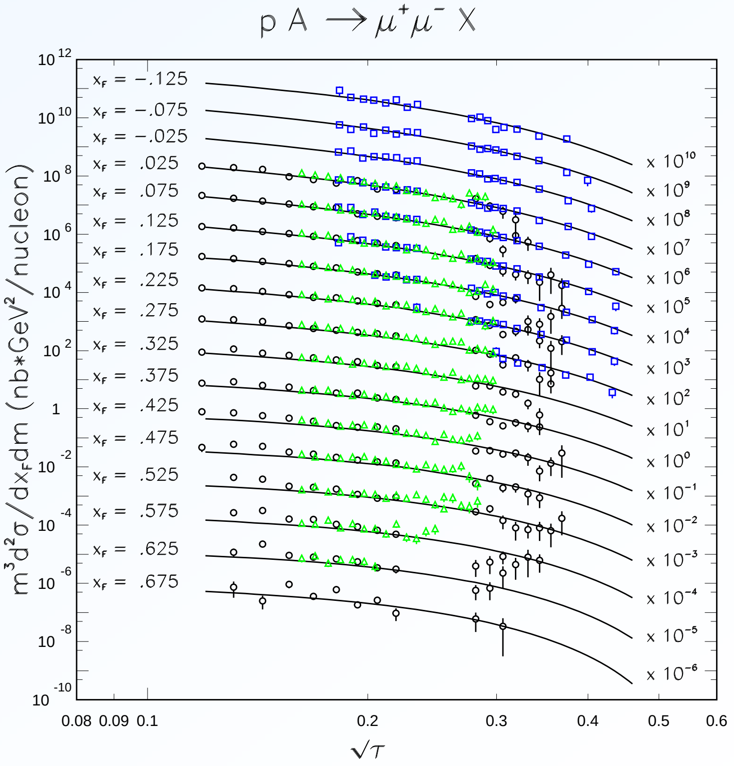
DIS





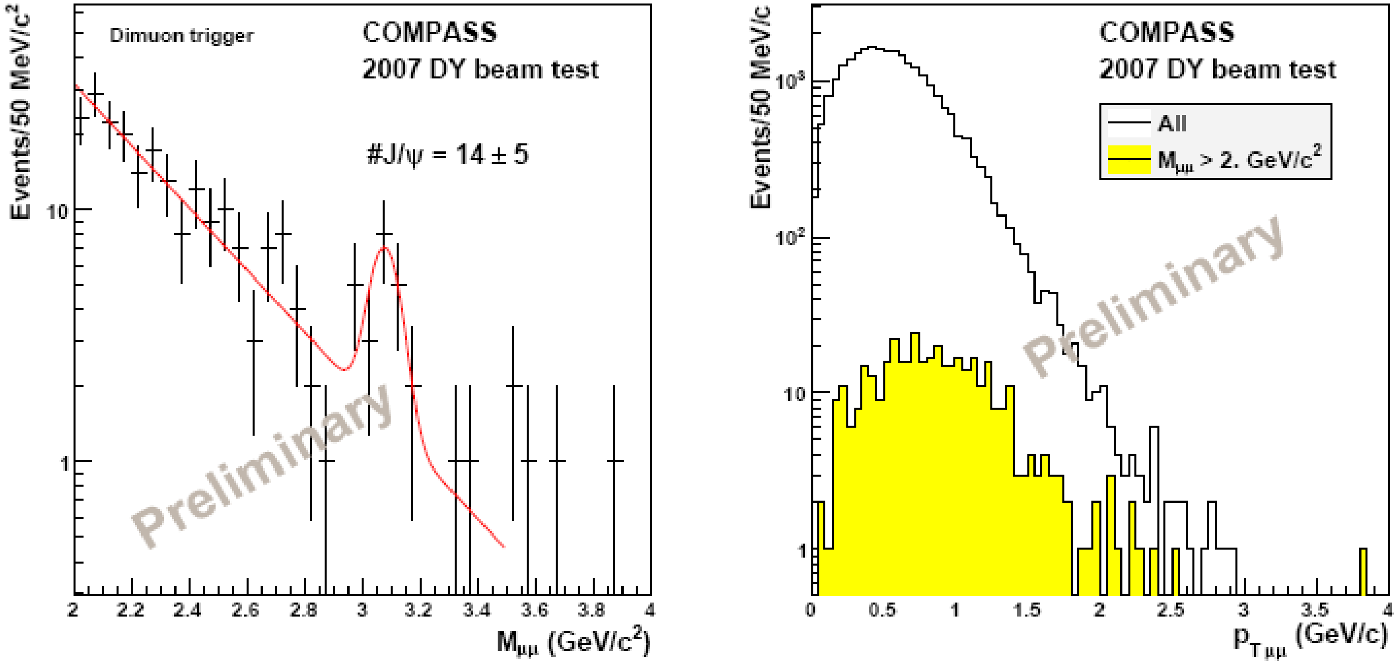
Drell-Yan





both DIS and Drell-Yan cross sections are well described by NLO calculations

Drell-Yan beam tests



results from 2007 beam test

In 2008, a test without hadron absorber and increasing the π^- beam intensity was done ↪ too large detectors occupancy.

By adding an absorber after the target one can reduce the detectors occupancy, and the combinatorial background.

Drell-Yan future experiments

There is a strong interest in the scientific community on the subject of spin dependent PDFs. Several experiments are being planned:

Facility	type	s (GeV^2)	timeline
RHIC (STAR)	collider, $p^{\uparrow}p$	200^2	> 2013
J-PARC	fixed target, $p^{\rightarrow\uparrow}$ D	60 – 100	> 2014
FAIR (PAX)	collider, $\bar{p}^{\uparrow}$ $p^{\uparrow}$	200	> 2016
NICA	collider, $p^{\uparrow}$ $p^{\uparrow}$, $D^{\uparrow}$ $D^{\uparrow}$	676	> 2014
COMPASS	fixed target, $\pi^{\pm}$ $H^{\rightarrow\uparrow}$, $\pi^{\pm}$ $D^{\rightarrow\uparrow}$	300 – 400	> 2010