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

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Trieste University and INFN

on behalf of the COMPASS Collaboration

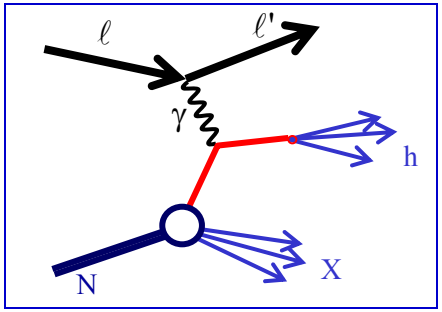
SPIN-Praha-2009

ADVANCED STUDIES INSTITUTE
SYMMETRIES AND SPIN

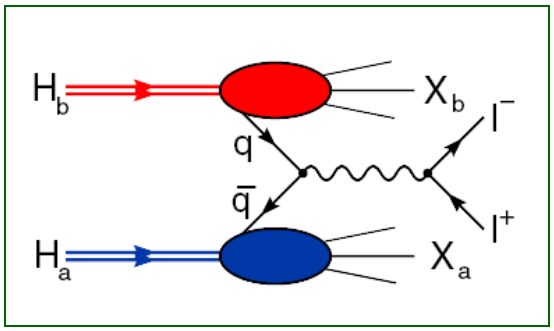
Transverse Spin Structure of the Nucleon

international theoretical and experimental effort

SIDIS: HERMES at DESY
COMPASS at CERN
spin experiments at JLab
and future projects
eRHIC, ELIC, ENC at FAIR



hard pp scattering: spin experiments at RHIC / BNL



and several future projects for Drell-Yan:
COMPASS
experiments at JParc / KEK
Panda and PAX at FAIR / GSI
Nica at JINR
SPASCHARM at IHEP

OUTLINE

- the COMPASS experiment
- the spin structure of the nucleon
- transverse spin effects in SIDIS
  - transversity and Collins asymmetry
  - Sivers function and asymmetry
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- transverse spin effects in Drell-Yan
  - spin asymmetries
  - COMPASS plans

Common Muon and Proton Apparatus for Structure and Spectroscopy

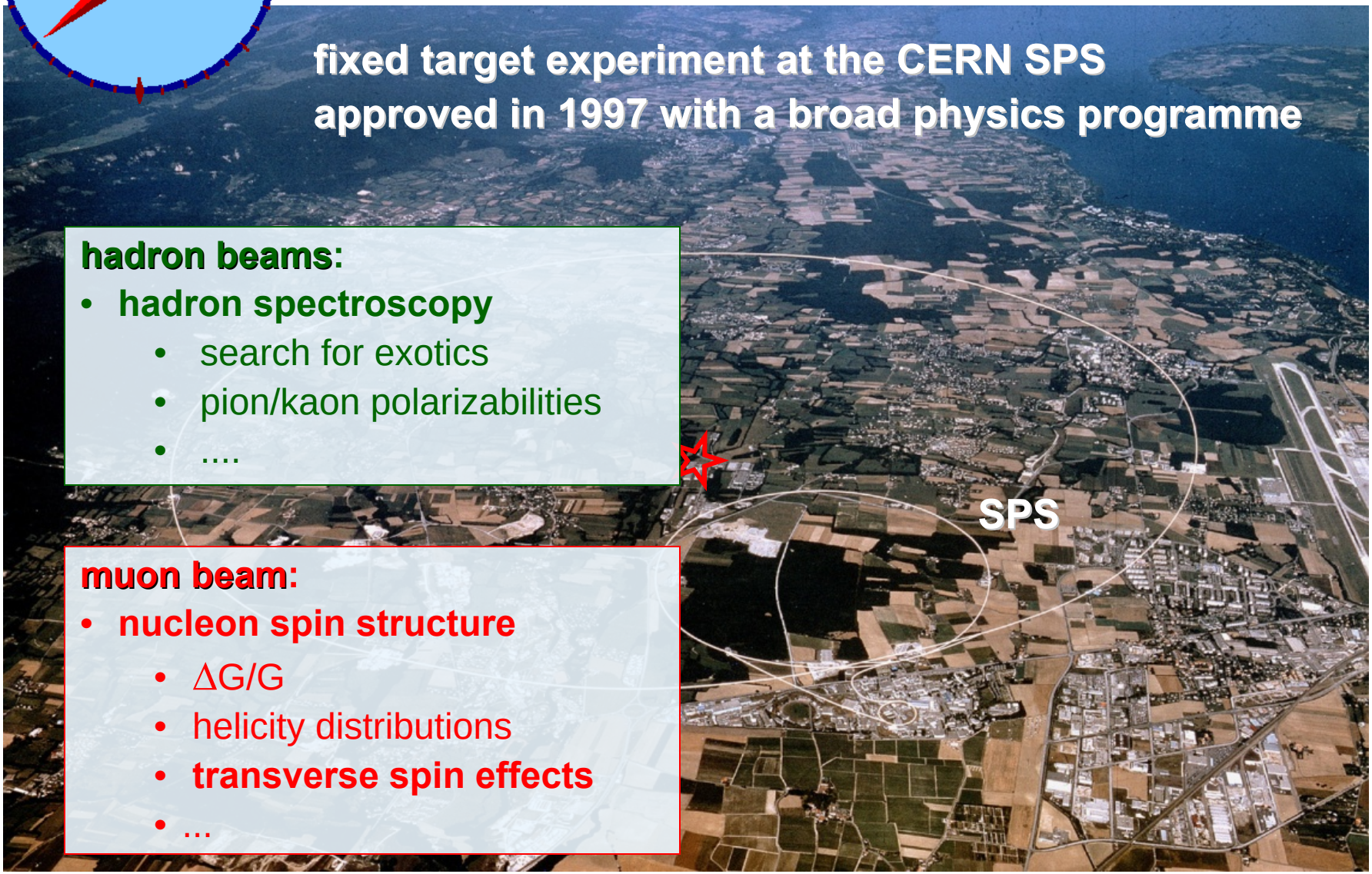
fixed target experiment at the CERN SPS
approved in 1997 with a broad physics programme

hadron beams:

- **hadron spectroscopy**
  - search for exotics
  - pion/kaon polarizabilities
  - ....

muon beam:

- **nucleon spin structure**
  - $\Delta G/G$
  - helicity distributions
  - **transverse spin effects**
  - ...



Common Muon and Proton Apparatus for Structure and Spectroscopy

fixed target experiment at the CERN SPS
approved in 1997 with a broad physics programme

L: *E. Zemlianishkina*
B. Pawlukiewicz *today*

data taking since 2002:

muon beam	**deuteron** (^{6}LiD) **polarised target**	**2002** **2003** **2004**	**L/T target polarisation** **4:1**
		2006	**L target polarisation**
	proton (NH_3) **polarised target**	**2007**	**L /T target polarisation** **1:1**
hadron beam	**LH target**	**2008** **2009**	

T: *G. Pesaro*, *tomorrow*

S. Grabmueller
J. Bernhard
P. Jasinski
T. Schlueter *today*

muon beam: 160 GeV/c longitudinal polarisation -80%
intensity $2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)

COMPASS spectrometer – muon beam

- high energy beam
- large angular acceptance
- broad kinematical range

two stages spectrometer

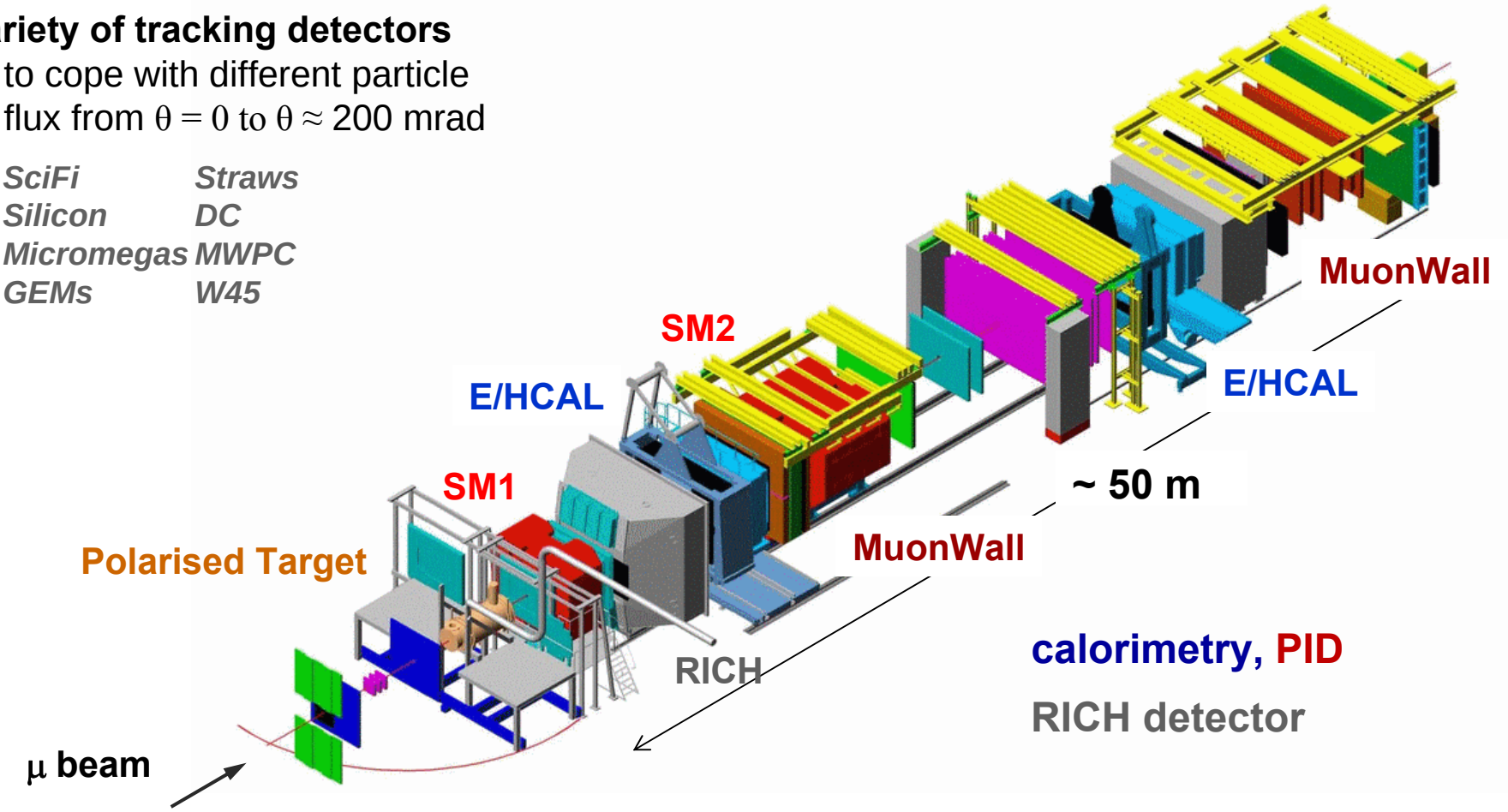
Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad

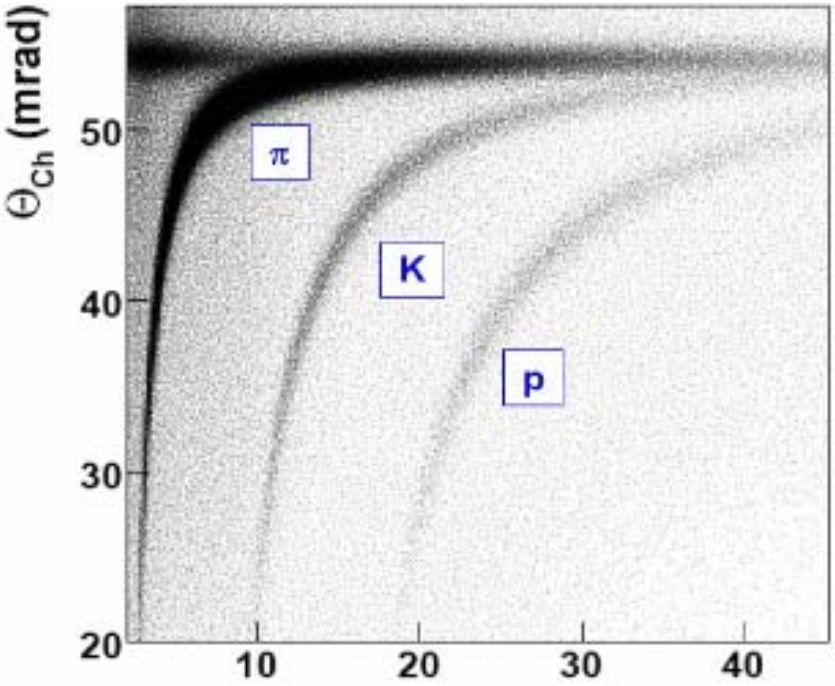
SciFi	*Straws*
Silicon	*DC*
Micromegas	*MWPC*
GEMs	*W45*



calorimetry, PID

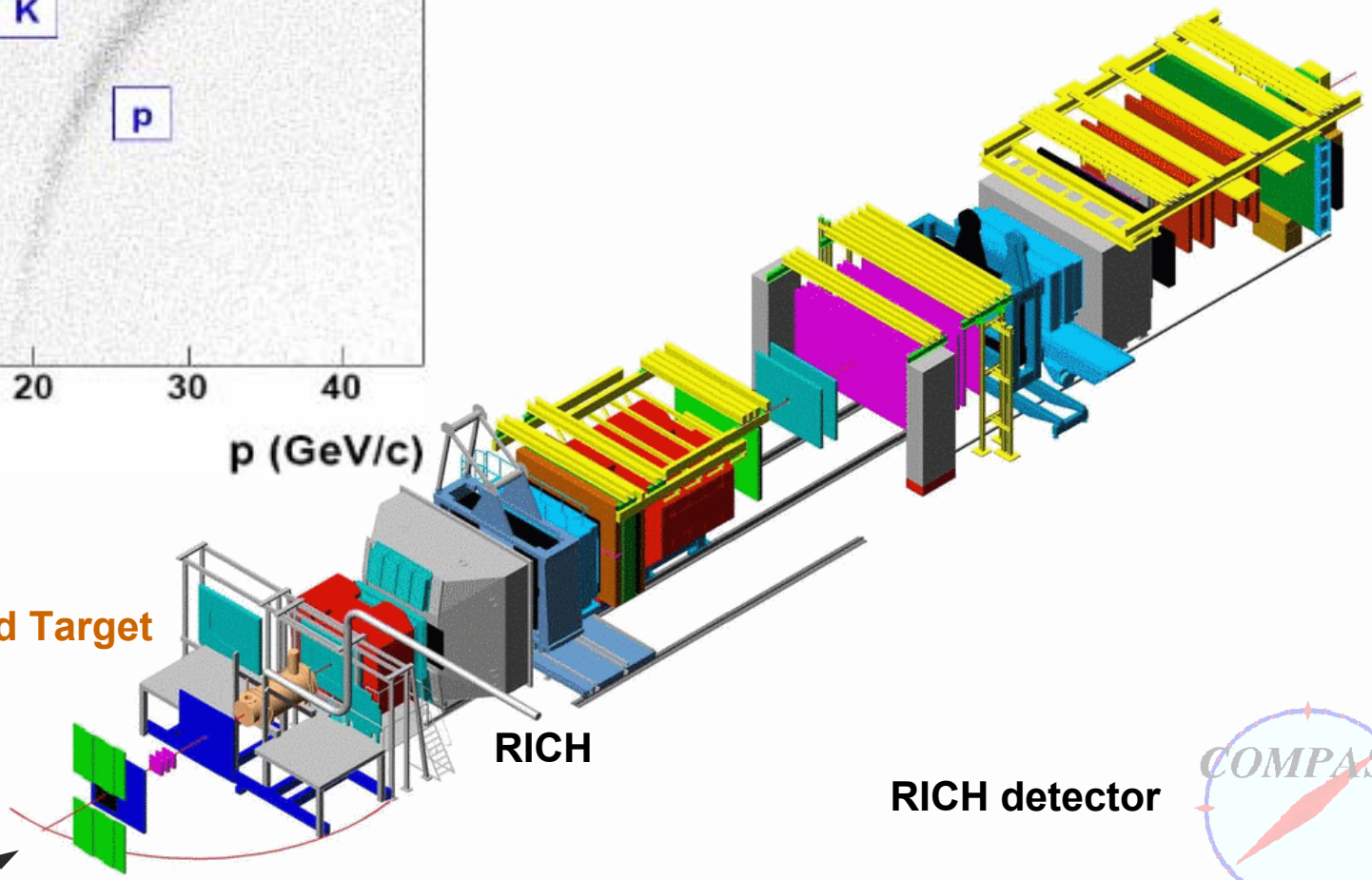
RICH detector

COMPASS spectrometer – muon beam



radiator C_4F_{10}

threshold: π ~2 GeV/c
K ~ 10 GeV/c



RICH detector

COMPASS

The Target System

solid state target operated in frozen spin mode

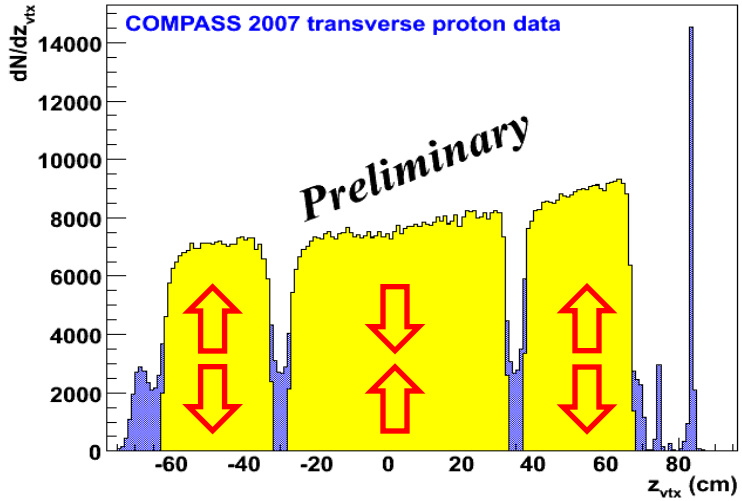
during data taking with transverse polarization, polarization reversal after ~ 4-5 days

2002-2004: ^{6}LiD (polarised deuteron)
dilution factor f = 0.38
polarization P_T = 50%

two 60 cm long cells with opposite polarization

2006:
- PTM replaced with the large acceptance COMPASS magnet (180 mrad)
- 2 target cells ➔ 3 target cells

2007: NH_3 (polarised protons)
dilution factor f = 0.14
polarization P_T = 90%



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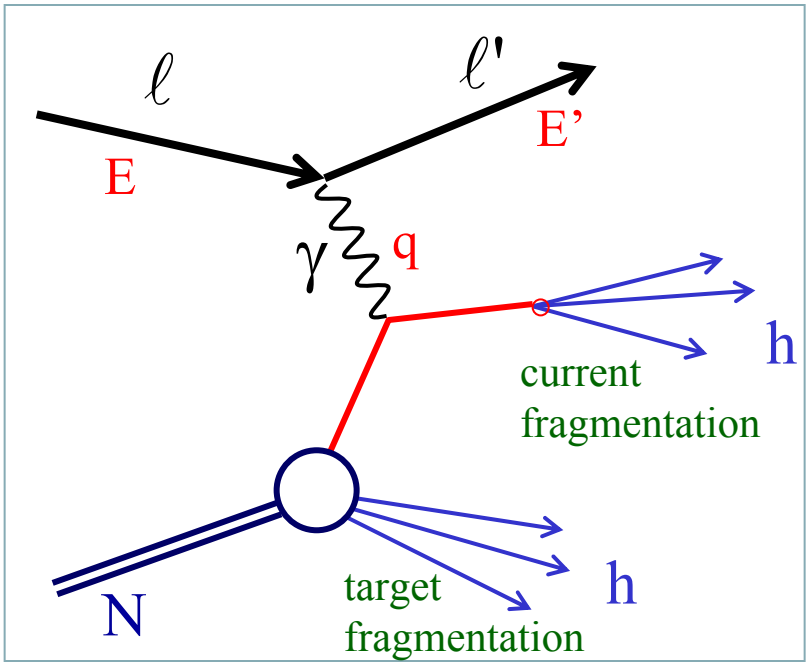
Structure of the Nucleon

key process: Deep Inelastic Scattering



the lepton interacts with a nucleon's parton exchanging a virtual photon

q virtual photon four-momentum

$$Q^2 = -q^2 > 0$$

$$x = Q^2/2M\nu$$

$$\nu = E - E'$$

$$y = \nu/E$$

$$\gamma = \sqrt{Q^2}/\nu$$

$Q^2 >> M^2$

$W^2=(P+q)^2 >> M^2$

Inclusive DIS: only the incident and scattered leptons are measured

Semi-Inclusive DIS: the incident and scattered leptons, and at least one final state hadron are measured

$$z = E_h/\nu$$

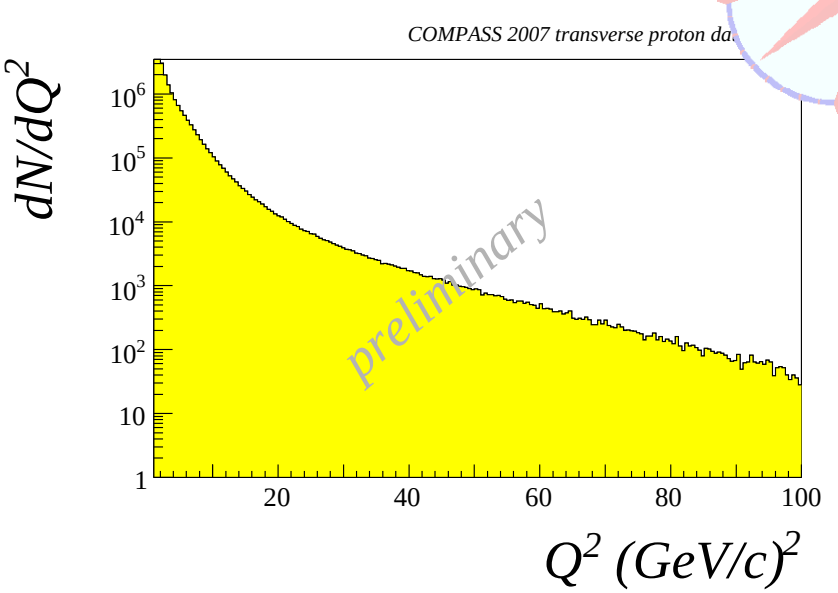
$$\sigma^{\ell N\to\ell hX} \propto \sum_q \sigma^{\ell q\to\ell q} \otimes q(x) \otimes D_q^h(z)$$

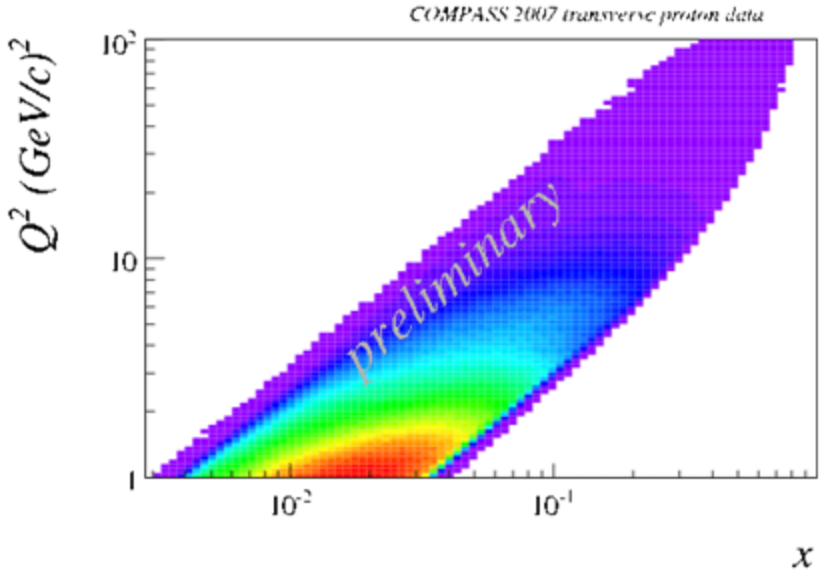
COMPASS kinematics

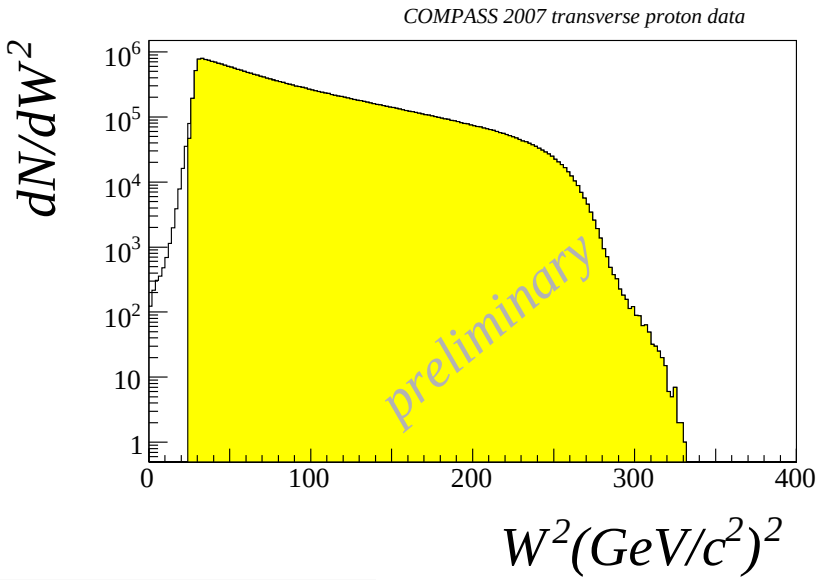
160 GeV/c muon beam

DIS event selection:

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







wide kinematical range

COMPASS kinematics

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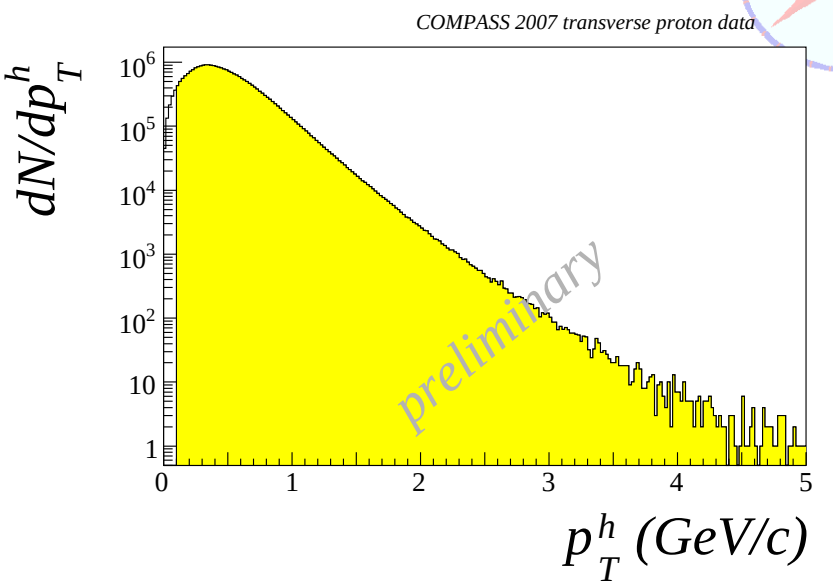
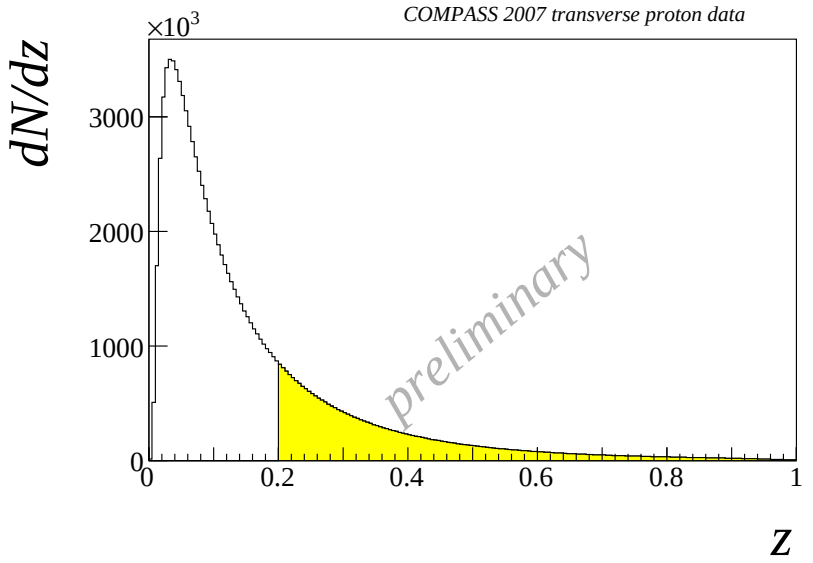
Hadron selection

- $p_T>0.1$ GeV/c
- $z>0.2$





Structure of the Nucleon

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

q(x) : number density or unpolarised distribution

f_1 

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

very well known

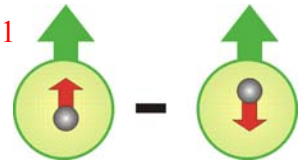
$\Delta q(x) = q^{\rightrightarrows} - q^{\rightleftarrows}$: longitudinal polarization or helicity distribution

g_1 

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

well known

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

h_1 

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

new

poorly known

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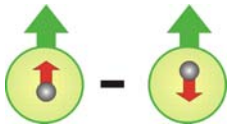
Transversity distribution



- **proposed in ’79** (Ralston & Soper), **reappraised in ’90**
- **properties**
  - $\Delta_T q(x) \neq \Delta q(x)$
  - **probes the relativistic nature of quark dynamics**
  - **no contribution from the gluons → simple Q^2 evolution**
  - **positivity (Soffer) bound** $2|\Delta_T q| \leq q + \Delta q$
  - **first moment: tensor charge** $\Delta_T q \equiv \int dx\, \Delta_T q(x)$
  - **sum rule for transverse spin in Parton Model framework** $\frac{1}{2} = \frac{1}{2}\sum \Delta_T q + L_q + L_g$
  - **it is related to GPD’s**

    Bakker, Leader, Trueman, PRD 70 (04)
  - **is chiral-odd**
- **more difficult to measure**

How to measure $\Delta_T q(x)$

$\Delta_T q(x)$ is chiral-odd

→ cannot be measured in inclusive DIS

it can be measured in SIDIS on transversely polarized targets:

the observable is the convolution of $\Delta_T q(x)$ with another chiral-odd quantity

several channels are being investigated

→ *G. Pesaro talk*

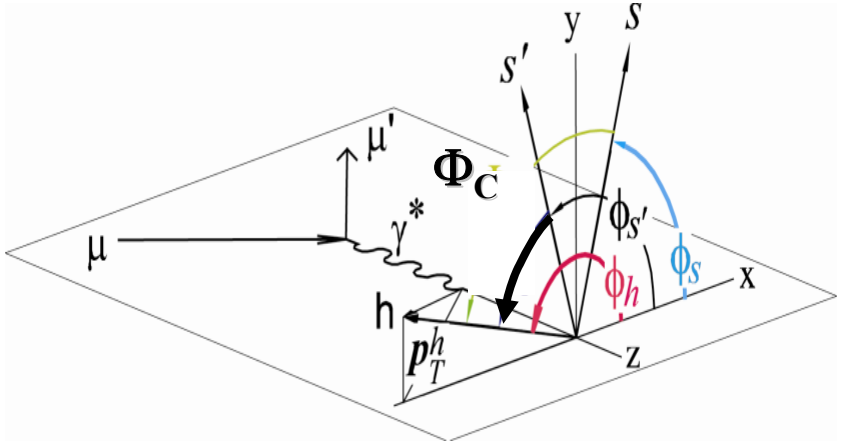
in $\ell N^{\uparrow} \to \ell' h X$

the chiral-odd partner is the "Collins" fragmentation function,

which describes a possible left-right asymmetry of the hadrons in the hadronization process of a transversely polarized quark

Collins asymmetry

$\ell N^{\uparrow} \rightarrow \ell' h X$ the observable is the so-called "Collins asymmetry", an azimuthal modulation in the cross-section of the type $\sin\Phi_C$



$$\Phi_C = \phi_h + \phi_S - \pi$$

ϕ_h azimuthal angle of the hadron,

ϕ_S azimuhtal angle of the spin of the nucleon

transversity

"Collins FF"

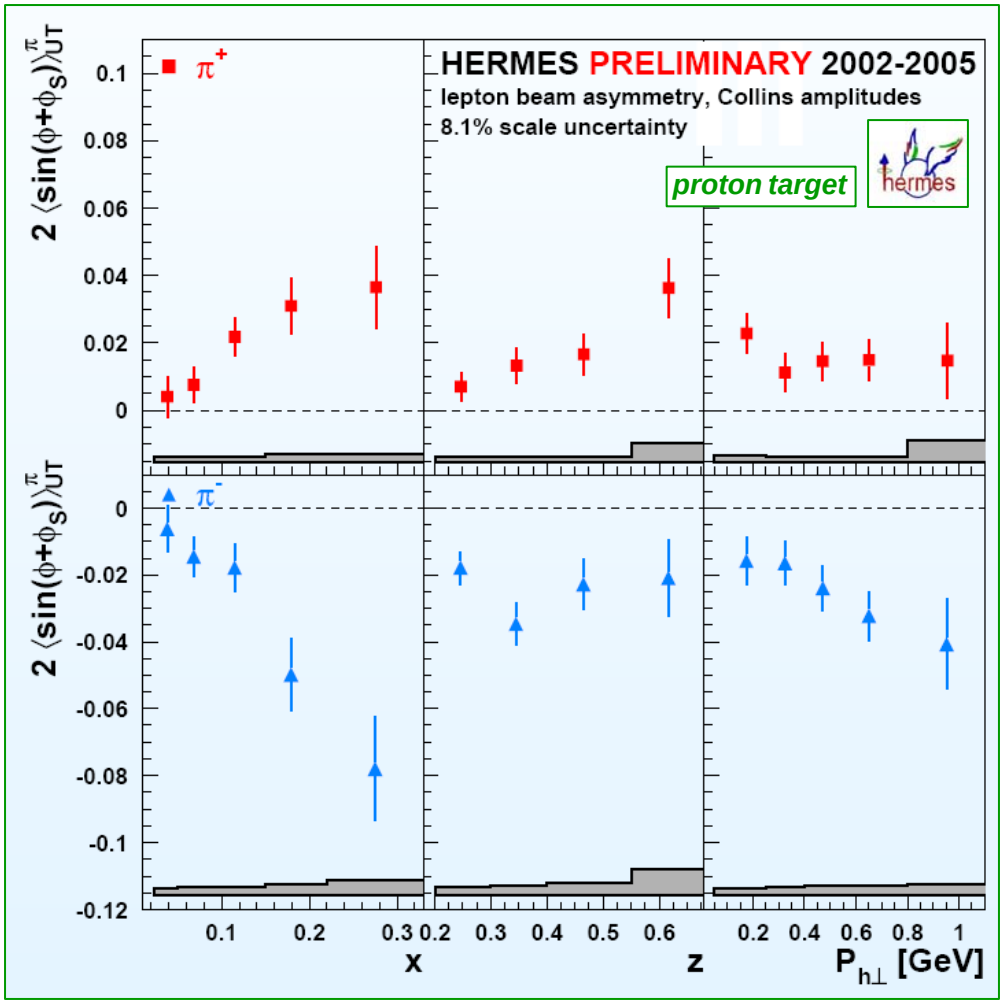
$$A_{Coll} \approx \frac{\sum_q e_q^2 \Delta_T q \otimes \Delta_T^0 D_q^h}{\sum_q e_q^2 \, q \otimes D_q^h}$$

- recently measured by HERMES (proton target) and COMPASS (deuteron and proton targets)
- convincing evidence that it is non zero from the proton data

Collins asymmetry

SIDIS results

- clear non-zero effects first seen by HERMES on p



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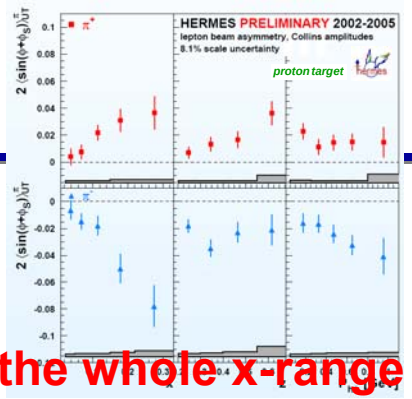

SIDIS results

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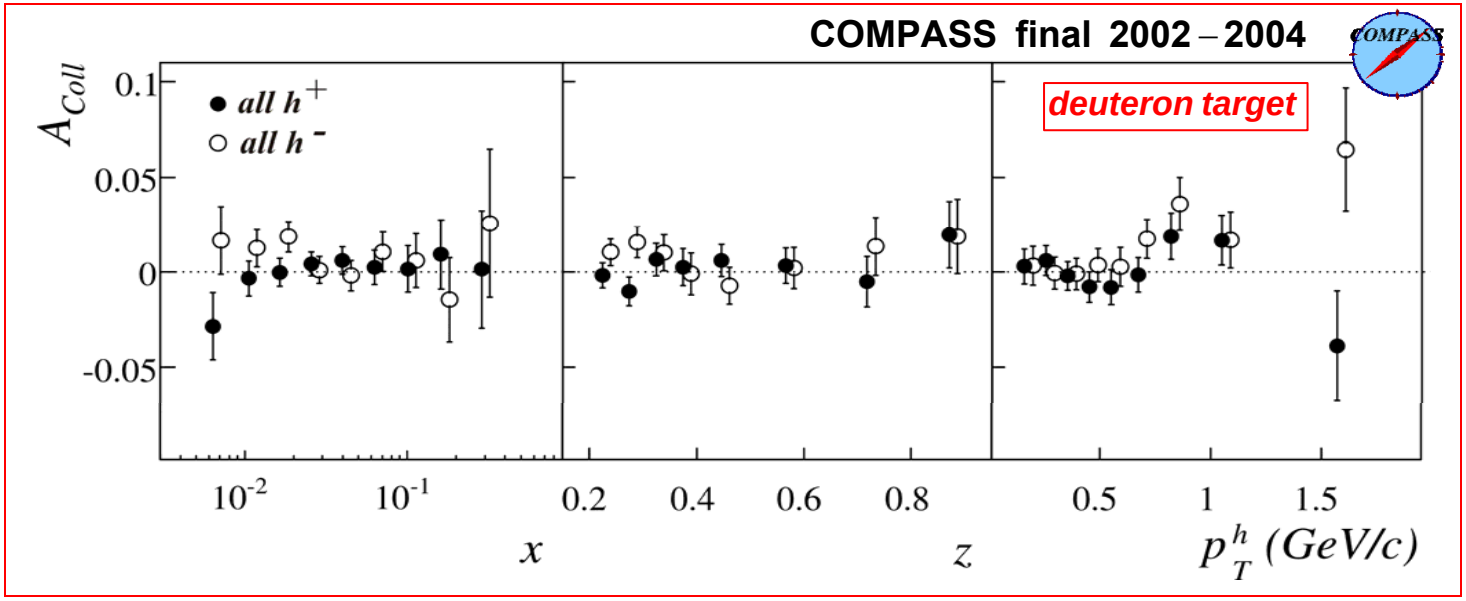
- ~ zero asymmetries measured by COMPASS on d over the whole x-range understood as u – d cancellation



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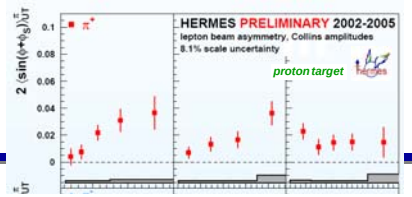

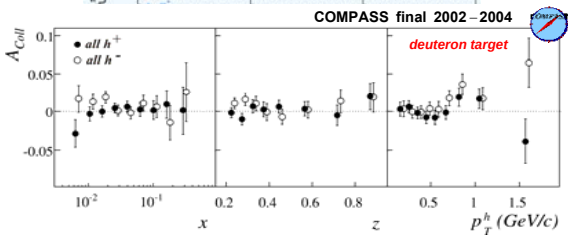

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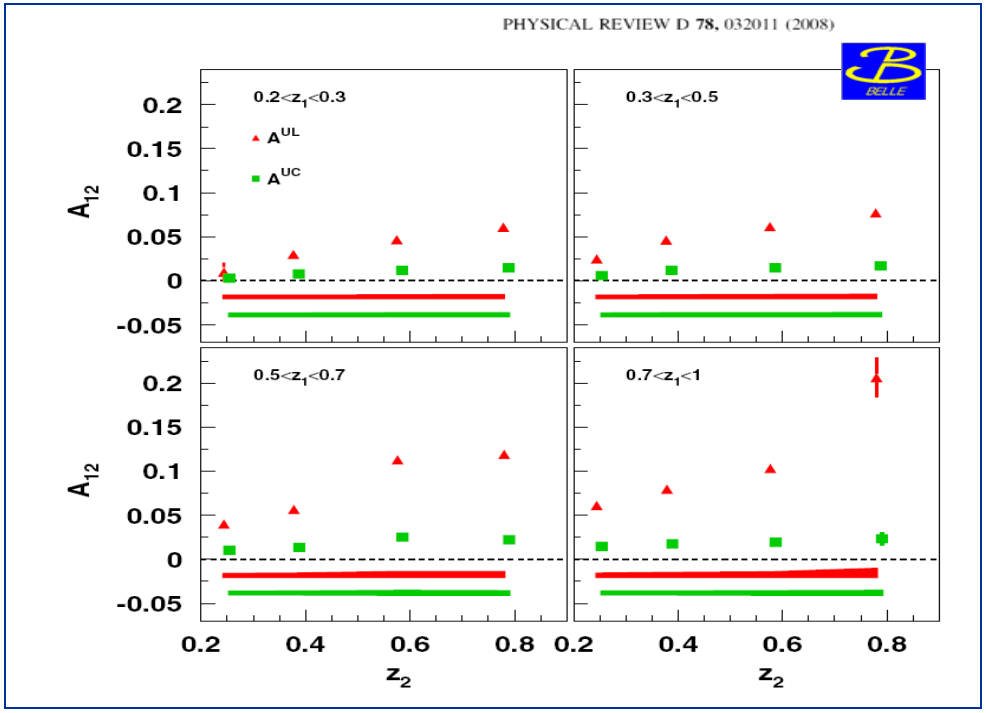
independent measurement of Collins effect using

BELLE $e^+e^- \to \pi^+\pi^- X$ data
(first measurements from LEP data)



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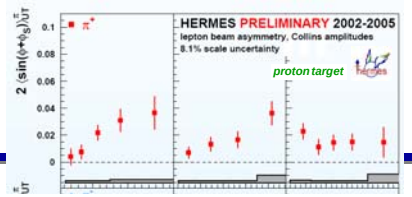

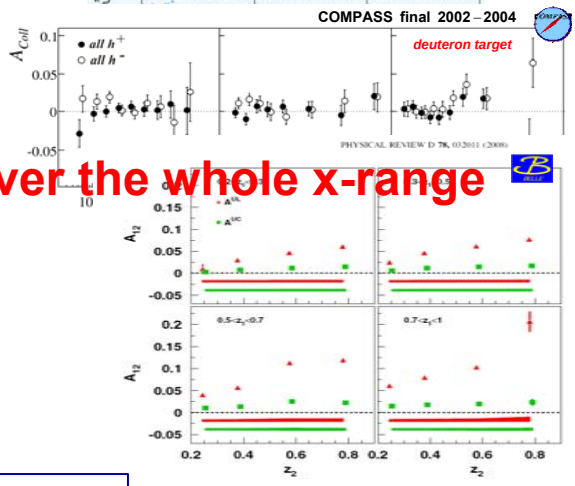

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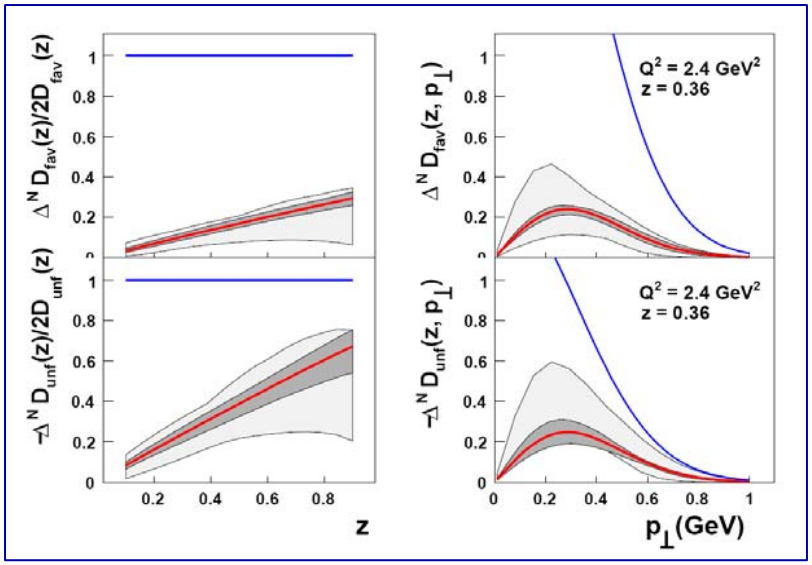
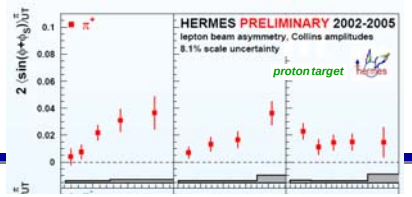
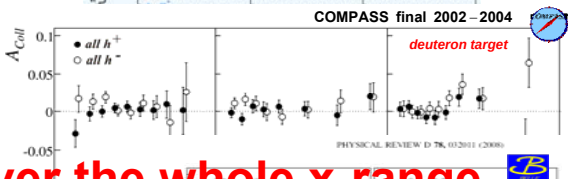
HERMES $e^- p$
COMPASS $\mu^+ d$
BELLE $e^+ e^-$



M. Anselmino et al., arXiv :0812.4366v 1[hep -ph] 23 Dec 2008

Collins asymmetry





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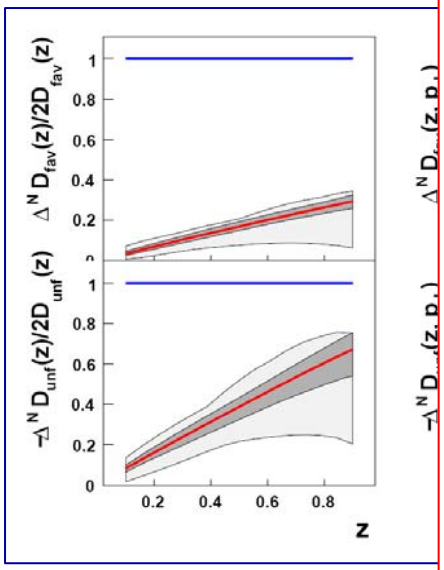
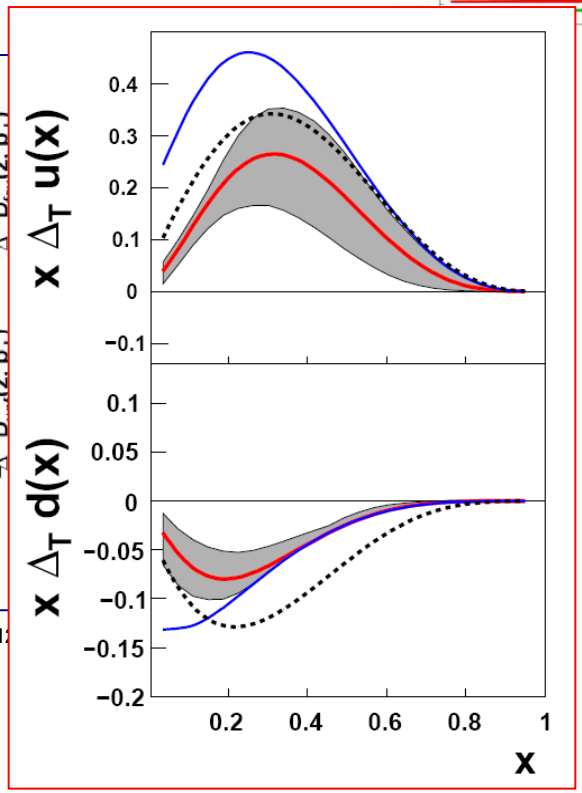
a major result !



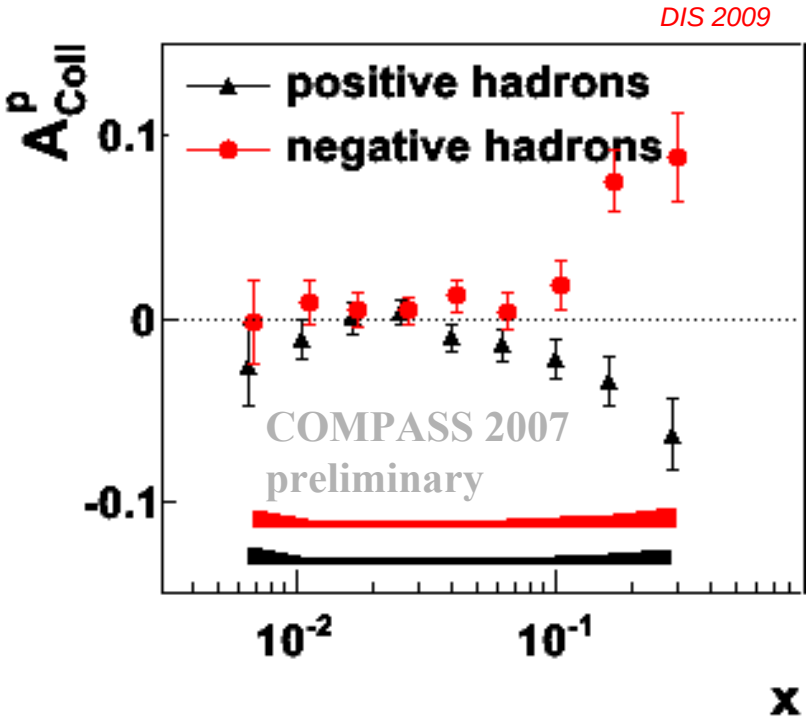
M. Anselmino et al., arXiv:081



Collins asymmetry

new preliminary results

from COMPASS <u>proton</u> target run in 2007
(much interest in the international community)



large signal in the valence region

Collins asymmetry

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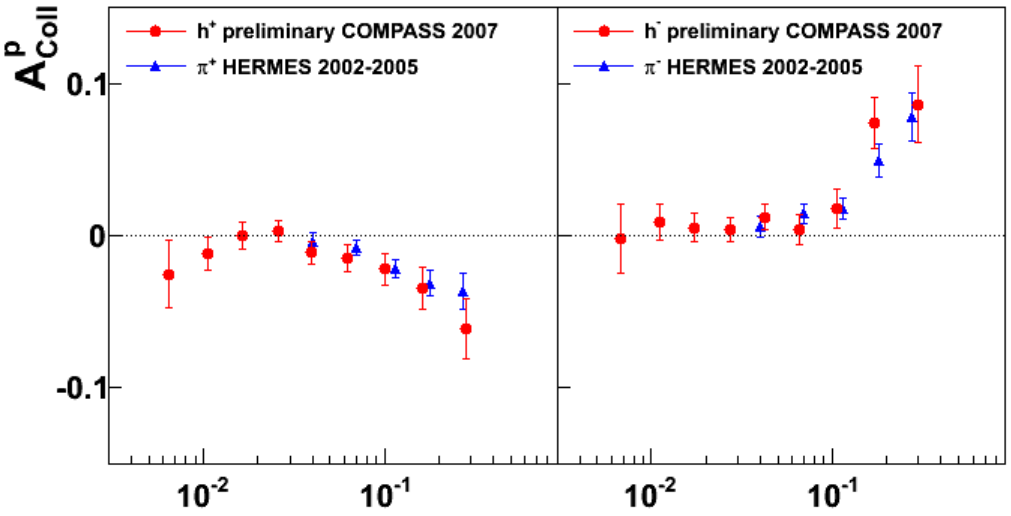
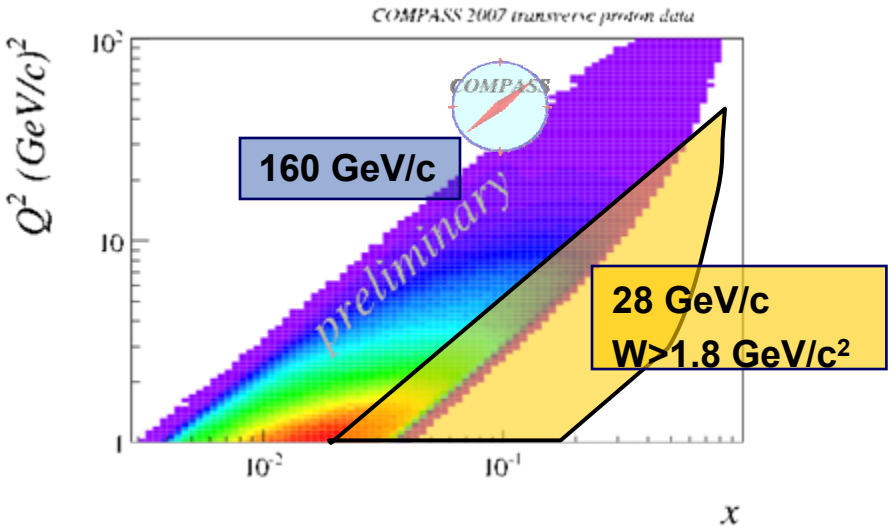
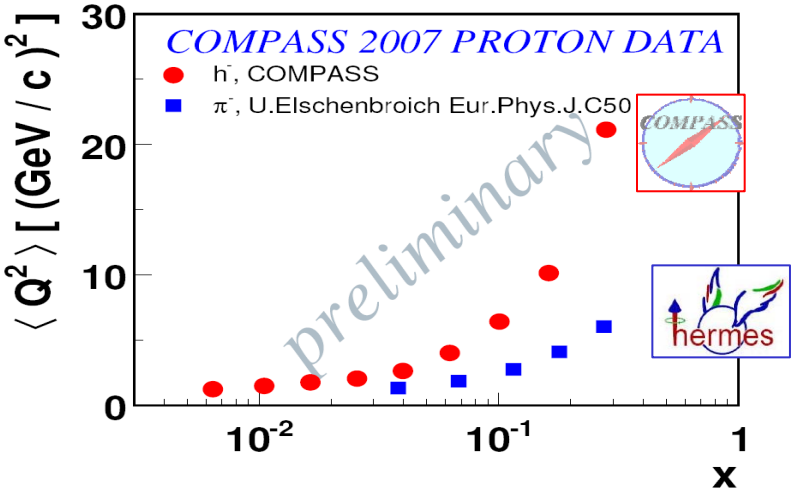


good agreement with HERMES in the x overlap region

an important and not obvious result,

given the different energies of HERMES and COMPASS





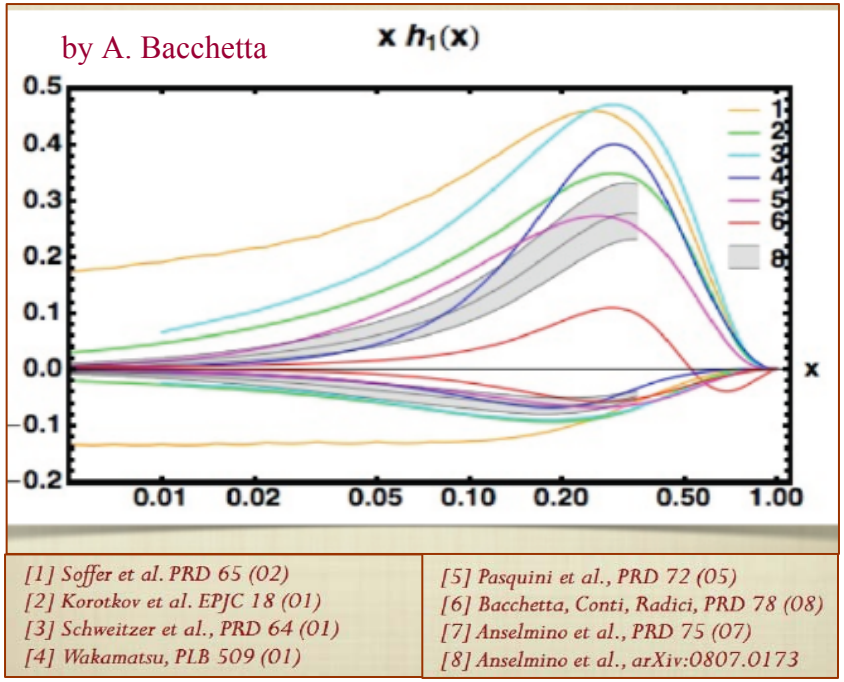
Collins asymmetry

conclusion:

transversity is different from zero and

can be measured in SIDIS thanks to the "Collins effect"

the work has just started



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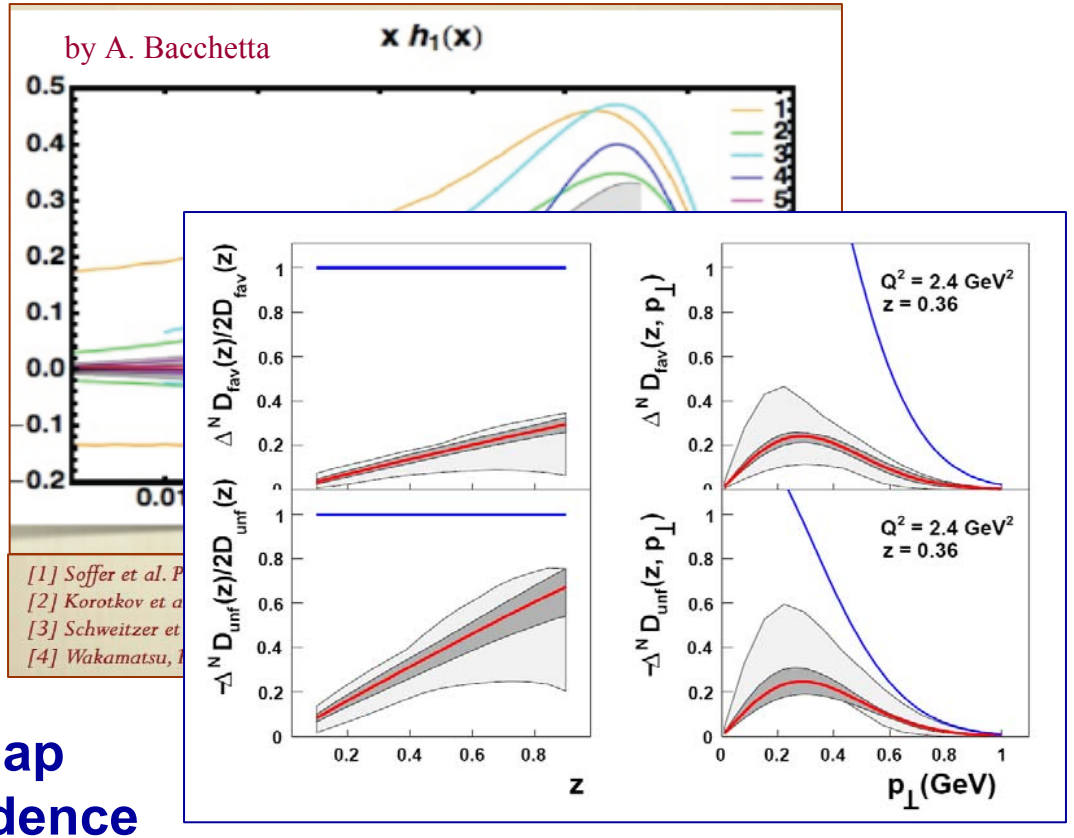
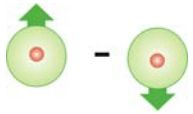
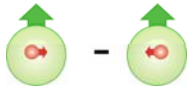
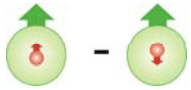
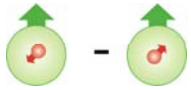


more data are needed to map the Q^2, x, z and $p_\perp$ dependence

Structure of the Nucleon

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

nucleon polarization

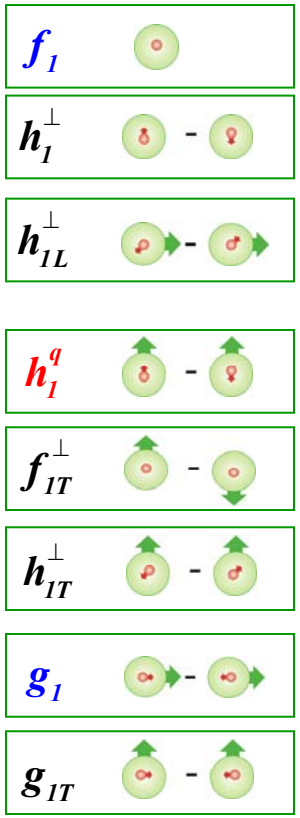
quark polarization	U	L	T
U	f_1  *number density*		$f_{1T}^{\perp}$ 
L		g_1  *helicity*	g_{1T} 
T	$h_1^{\perp}$ 	$h_{1L}^{\perp}$ 	h_1  *transversity* $h_{1T}^{\perp}$ 

"TMDs"
interesting properties

SIDIS cross-section

leading order

Collins asymmetry



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

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

unpol

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

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

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

SIDIS cross-section

presently, the most "famous" TMD 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)

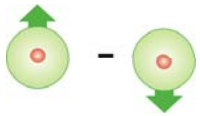
- **and** $h_{1T}^{\perp}$ 

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

$$d^6\sigma \approx \frac{4\pi\alpha^2 sx}{Q^4}\cdot$$
$$\{[1+(1-y)^2]\sum_q e_q^2 f_1^q(x)D_1^q(z,p_{h\perp}^2)$$
$$+(1-y)\frac{p_{h\perp}^2}{4z^2M_NM_h}\cos(2\phi_h)\sum_q e_q^2 h_1^{\perp(1)q}(x)H_1^{\perp q}(z,p_{h\perp}^2)$$
$$-|S_L|(1-y)\frac{p_{h\perp}^2}{4z^2M_NM_h}\sin(2\phi_h)\sum_q e_q^2 h_{1L}^{\perp(1)q}(x)H_1^{\perp q}(z,p_{h\perp}^2)$$
$$-|S_T|(1-y)\frac{p_{h\perp}}{zM_h}\sin(\phi_h+\phi_S)\sum_q e_q^2 h_1^q(x)H_1^{\perp q}(z,p_{h\perp}^2)$$
$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{p_{h\perp}}{zM_N}\sin(\phi_h-\phi_S)\sum_q e_q^2 f_{1T}^{\perp(1)q}(x)D_1^q(z,p_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{p_{h\perp}^3}{6z^3M_N^2M_h}\sin(3\phi_h-\phi_S)\sum_q e_q^2 h_{1T}^{\perp(2)q}(x)H_1^{\perp q}(z,p_{h\perp}^2)$$
$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_q e_q^2 g_1^q(x)D_1^q(z,p_{h\perp}^2)$$
$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{p_{h\perp}}{zM_N}\cos(\phi_h-\phi_S)\sum_q e_q^2 g_{1T}^{(1)q}(x)D_1^q(z,p_{h\perp}^2)\}$$

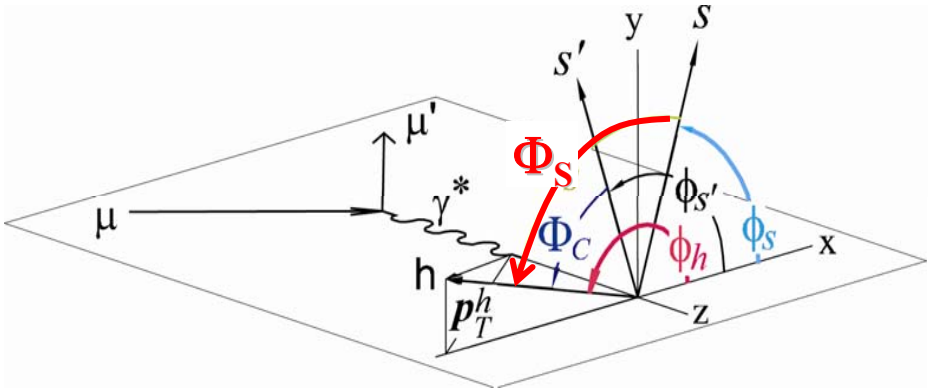
all important for assessing the orbital angular momentum of the quarks

Sivers function

$f_{1T}^{\perp}$  correlates the nucleon spin and the quark k_t
(transversely polarised nucleon)

- **proposed in 1990**
- **initially thought to be zero** (Collins, 1993)
- **resurrected in 2002** (Brodsky, Hwang, Schmitt) **– *FSI, gauge link …***

- **if different from zero, it should be responsible of a modulation in $\Phi_S = \phi_h - \phi_S$ of the hadron produced inclusively on a transversely polarized target**



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

SIDIS cross-section

the Collins and the Sivers terms depend on *different angles* and both asymmetries can be extracted from the same data (as done by COMPASS and HERMES)

all the structure functions can be extracted simultaneously from the different azimuthal modulations

Collins asymmetry

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

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

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

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

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

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

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

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

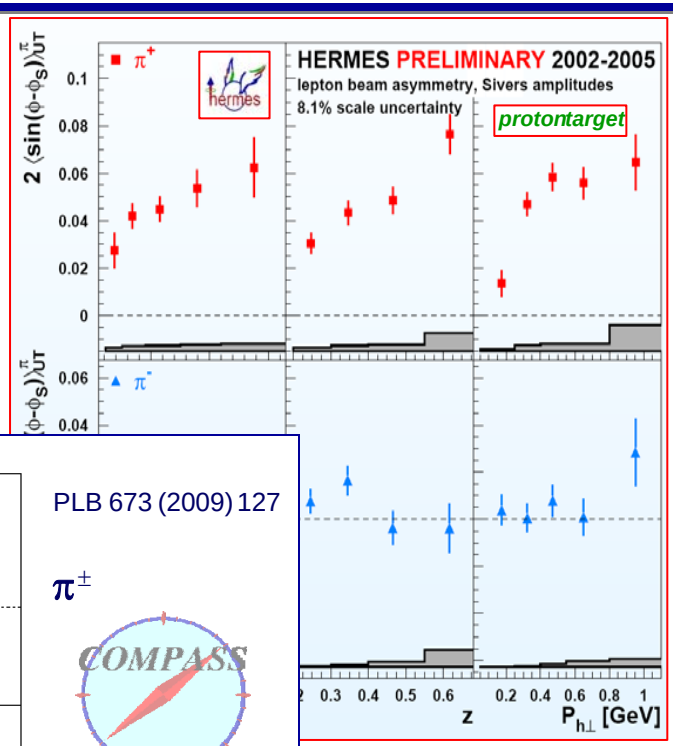
$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{p_{h\perp}}{zM_N}\cos(\phi_h-\phi_S)\sum_q e_q^2 g_{1T}^{(1)q}(x)D_1^q(z,p_{h\perp}^2)\}$$

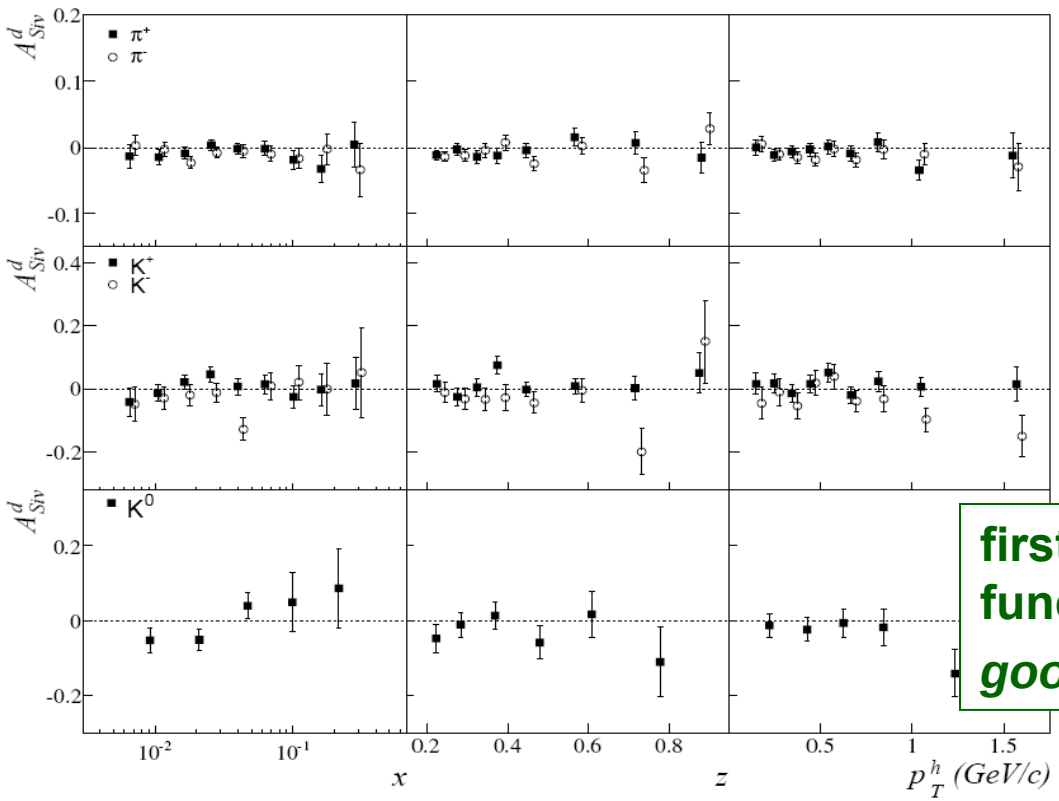
Sivers asymmetry

Sivers asymmetry

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)





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$\pi^{\pm}$

COMPASS

$K^{\pm}$

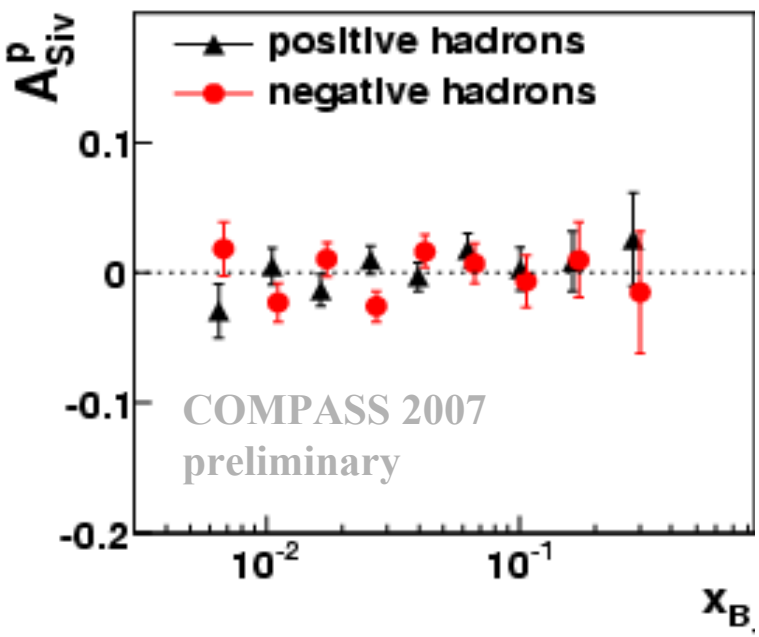
first extractions of the Sivers function from pion SIDIS data

good fits to the existing data

Sivers asymmetry

COMPASS preliminary results from 2007 proton data

Transversity 2008

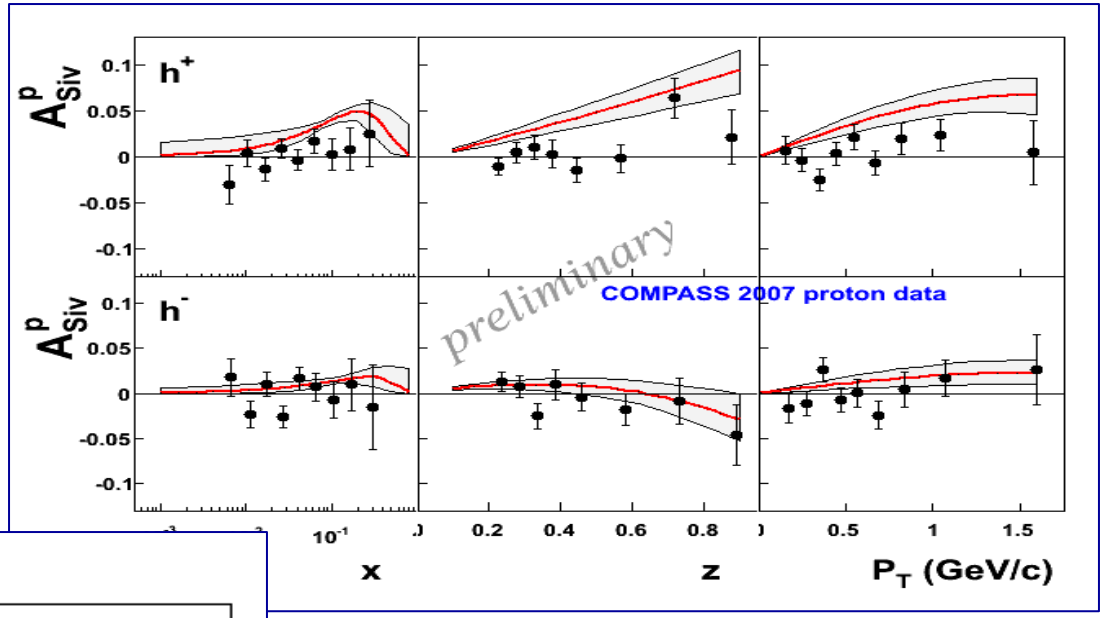


- no signal over the whole x range
- marginal compatibility with HERMES π^+ data

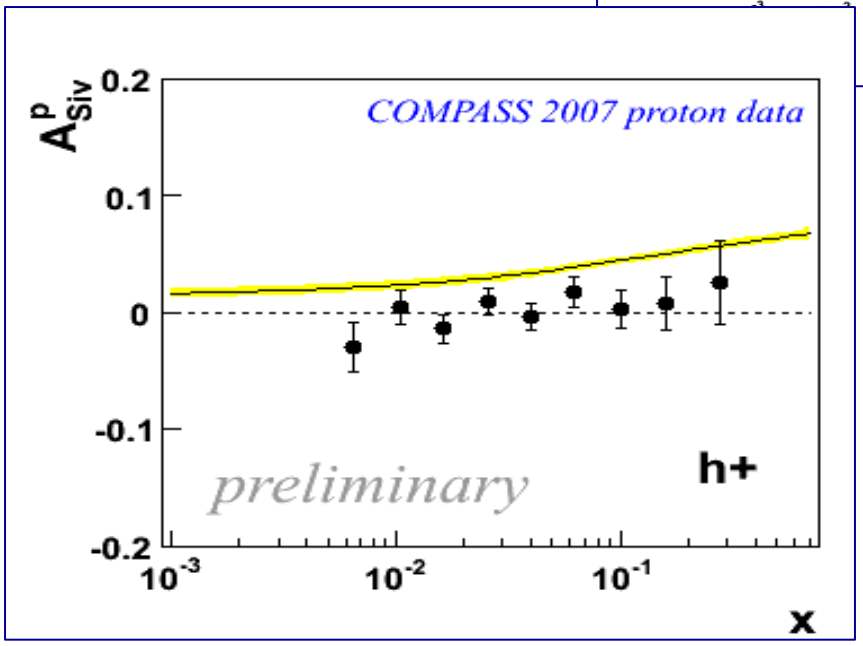
an “intriguing result”

comparison with recent predictions

based on HERMES p data from Anselmino et al.



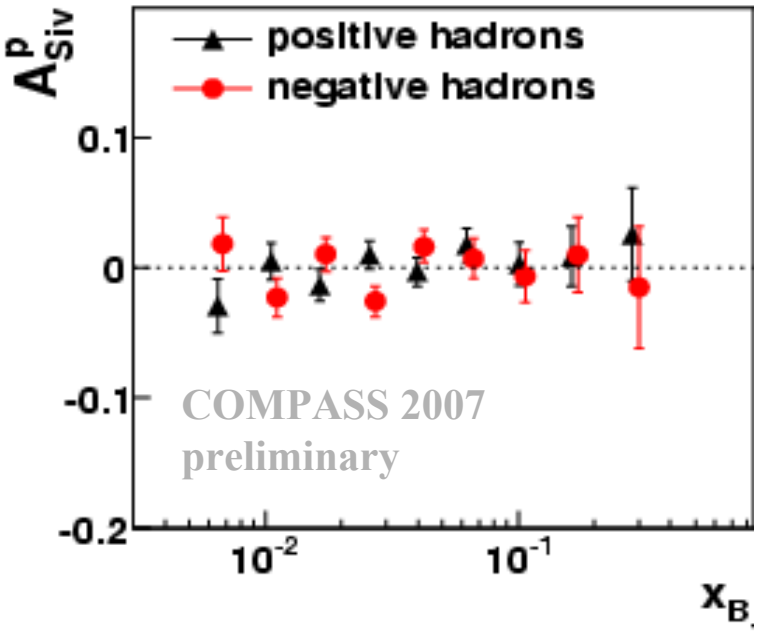
from Goeke et al.



Sivers asymmetry

COMPASS preliminary results from 2007 proton data

Transversity 2008



- **no signal over the whole x range**
- **marginal compatibility with HERMES π^+ data**

an "intriguing result"

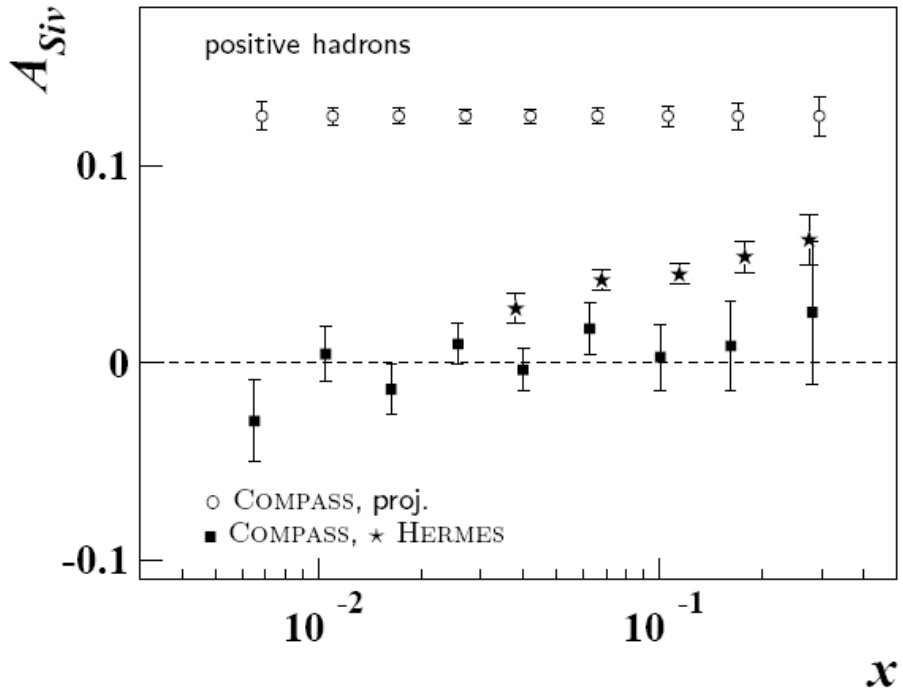
new high energy data are necessary to clarify the energy dependence suggested by the COMPASS result

new data will also allow to perform precise measurements of the K Sivers asymmetry

Transverse Spin Effects in SIDIS

one year (150 days) **of data taking at COMPASS with the transversely polarised proton target, and the present spectrometer and muon beam, will allow to improve the knowledge of transversity and will clarify the Sivers issue**

projected statistical errors for the Sivers asymmetry



★ HERMES π^+, DIS2007

■ COMPASS h^+, Transversity 2008

○ **COMPASS h^+, projection**
160 Gev
proton target

Transverse Spin Effects in SIDIS

one year (150 days) **of data taking at COMPASS with the transversely polarised proton target, and the present spectrometer and muon beam, will allow to improve the knowledge of transversity and will clarify the Sivers issue**

REQUEST TO CERN SPSC:

(CERN-SPSC-2009-003 SPSC-I-238, 21 January 2009; CERN-SPSC-2009-025/M-769, Addendum2 to the COMPASS Proposal, June 2009)

run one full year with transversely polarised proton target in 2010, to perform new precise measurements of transverse spin effects in SIDIS

and one full year with longitudinally polarised proton target

agreed!

this new measurement will mostly conclude the exploratory phase of transverse spin effects in SIDIS

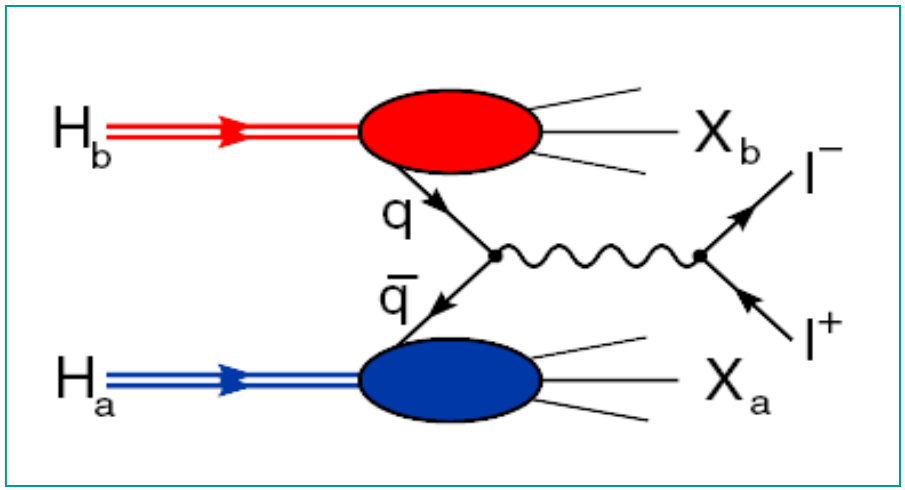
more systematic measurements in SIDIS will be needed in future, and CERN can have an important role

→ ***F. Kunne talk***

OUTLINE

- the COMPASS experiment
- the spin structure of the nucleon
- transverse spin effects in SIDIS
  - transversity and Collins asymmetry
  - Sivers function and asymmetry
  - future measurements at COMPASS
- **transverse spin effects in Drell-Yan**
  - **spin asymmetries**
  - **COMPASS plans**

The Drell-Yan process



in hadron-hadron scattering a quark and an antiquark annihilate in a timelike virtual photon which decays in a lepton pair

the phase-space is defined by the variables x_1 and x_2

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

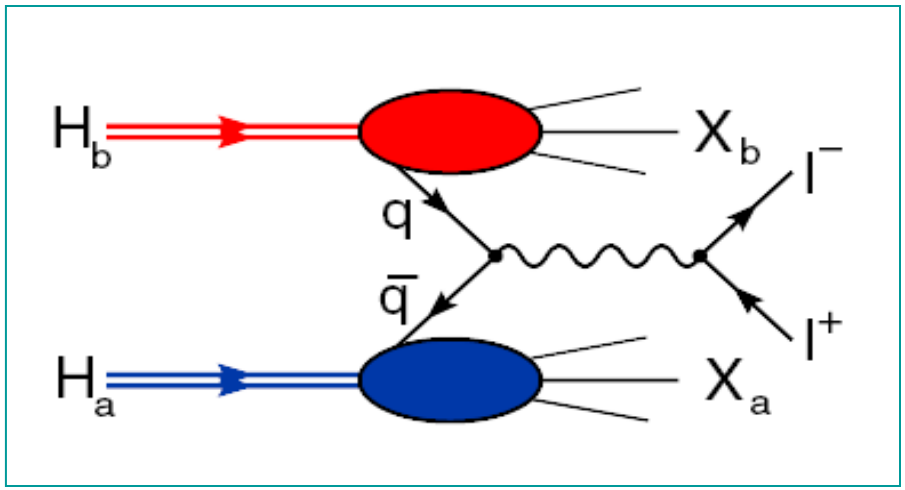
$$\tau = \frac{M^2}{s} = x_1 \cdot x_2$$

$\sqrt{s}$ total energy

p_L longitudinal momentum of the lepton pair

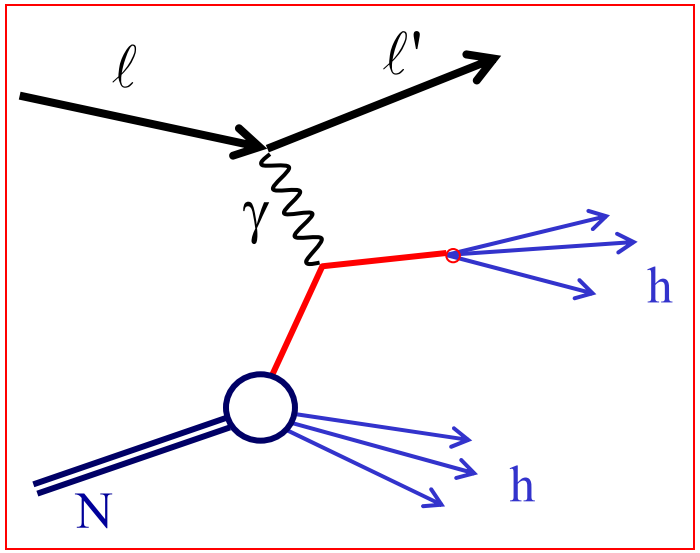
M invariant mass of the lepton pair

The Drell-Yan process



DY
cross section
~ convolution of PDFs

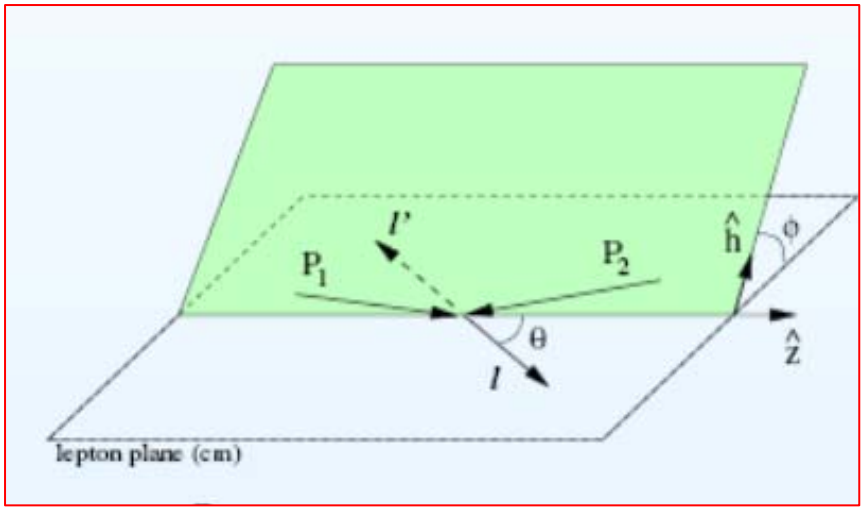
complementary information



SIDIS
cross section
~ convolution of PDF and FF

The Drell-Yan process

to access TMDs
measurement of azimuthal
distributions of the lepton plane



Collins-Soper frame

θ, ϕ

angular distribution (unpolarized)

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

at LO and in the collinear approximation one gets

$$\lambda = 1$$
$$\nu = \mu = 0$$

QCD corrections:

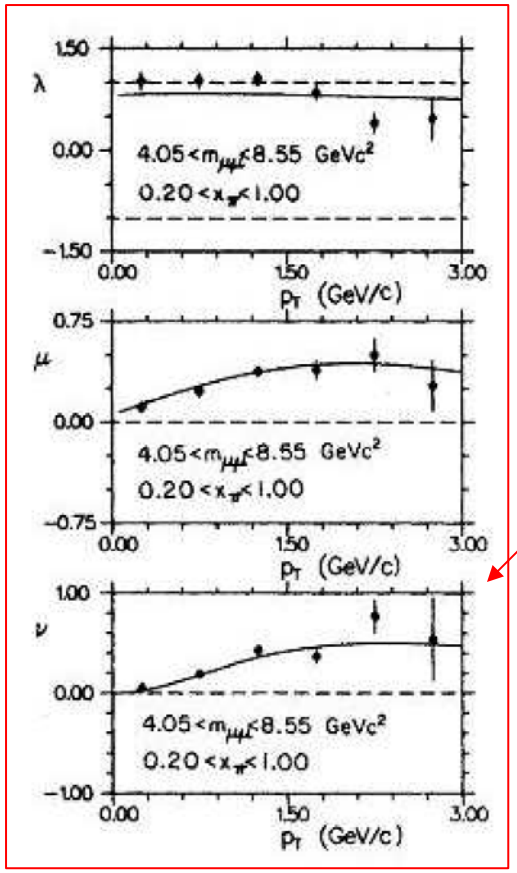
Lam-Tung sum rule

$$1 - \lambda - 2\nu = 0$$

The Drell-Yan process

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

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



E615, Conway et al (1989)

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

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

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

↑ Boer-Mulders ↑

The Drell-Yan process

a long history of successful DY experiments

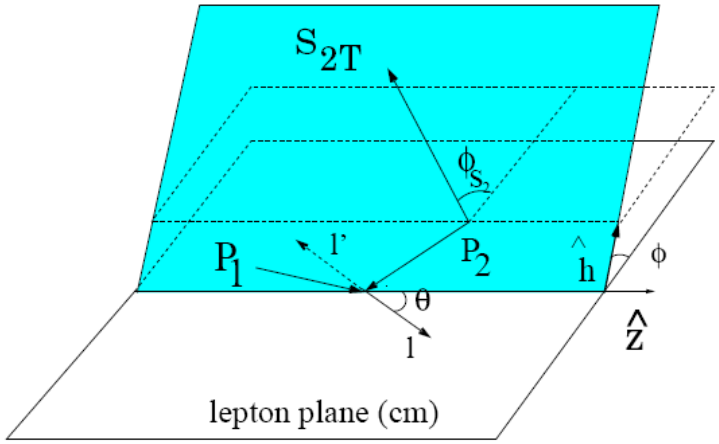
Experiment	Beam (GeV/c)	Targets	Physics
NA3	$\pi^{\pm}$ 150/200/280	H_2, Pt	π, K PDFs
NA10	π^{-} 140/194/284	D, W	π PDFs, Boer-Mulders PDF
E615	π^{-} 252	W	π, K PDFs, Boer-Mulders PDF
NA51	p 450	H_2, D	$\bar{d}/\bar{u}$ asymmetry in proton
E866	p 800	H_2, D	$\bar{d}/\bar{u}$ asymmetry in proton

up to now, none with beam and/or polarized target to access the spin dependent PDFs

COMPASS can do it

The Drell-Yan process

on a transversely polarized target



Collins-Soper frame

θ, ϕ

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

→ access spin dependent TMDs

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

↑ 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

sum over q (qbar) flavour

The Drell-Yan process in π^- p

in the valence region, u quark-dominance

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

where $f = h_1^\perp, f_1, f_{1T}^\perp, h_1, h_{1T}^\perp$

- → **extraction of the u-quark Sivers function**
- → **model dependent extraction of transversity and Boer-Mulders functions**

Testing non-perturbative QCD

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

→ **check the predictions:**

$$f_{1T}^\perp(DY) = -f_{1T}^\perp(SIDIS)$$

$$h_1^\perp(DY) = -h_1^\perp(SIDIS)$$

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

STRONG PHYSICS CASE

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
- a muon detection system
- spectrometer with wide angular acceptance

COMPASS plans

measurement of DY with high energy π^- beam and transversely polarised NH3 target soon

(LoI, CERN-SPSC-2009-003 SPSC-I-238, 21 January 2009, Proposal in preparation)

not an easy experiment in the COMPASS environment

- **many MC simulations**
- **test beam in 2007**
- **test beam in 2008**
- ***test beam in 2009***

Drell-Yan at COMPASS

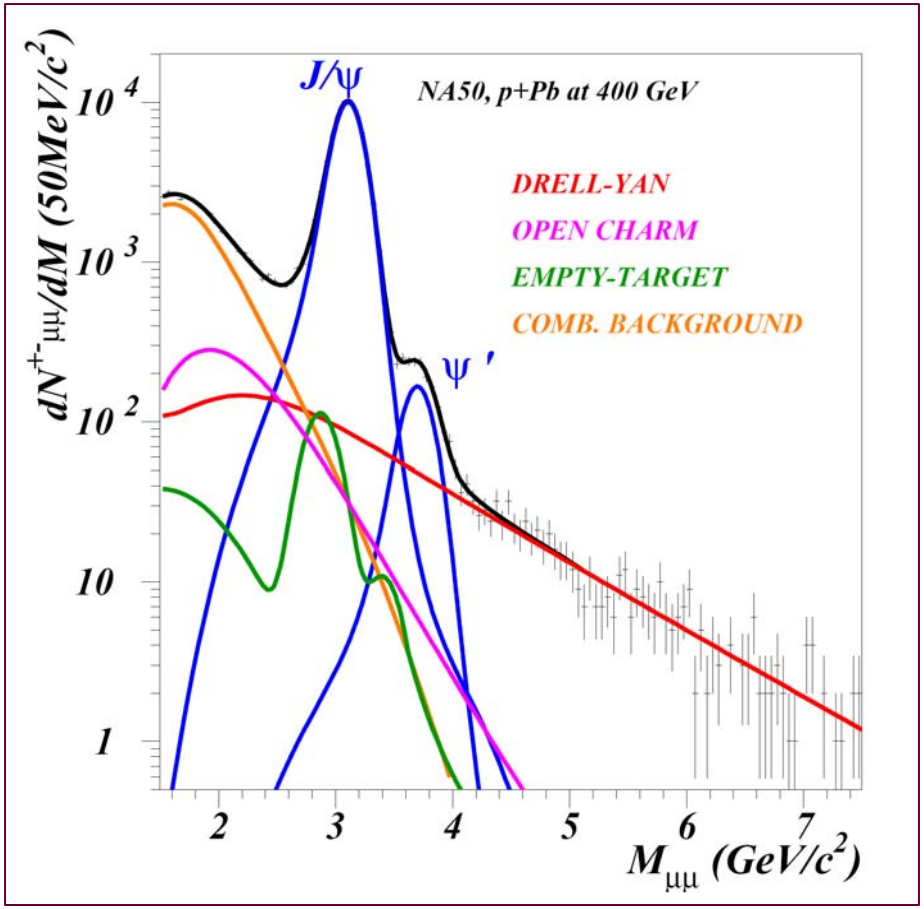
signal and background

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

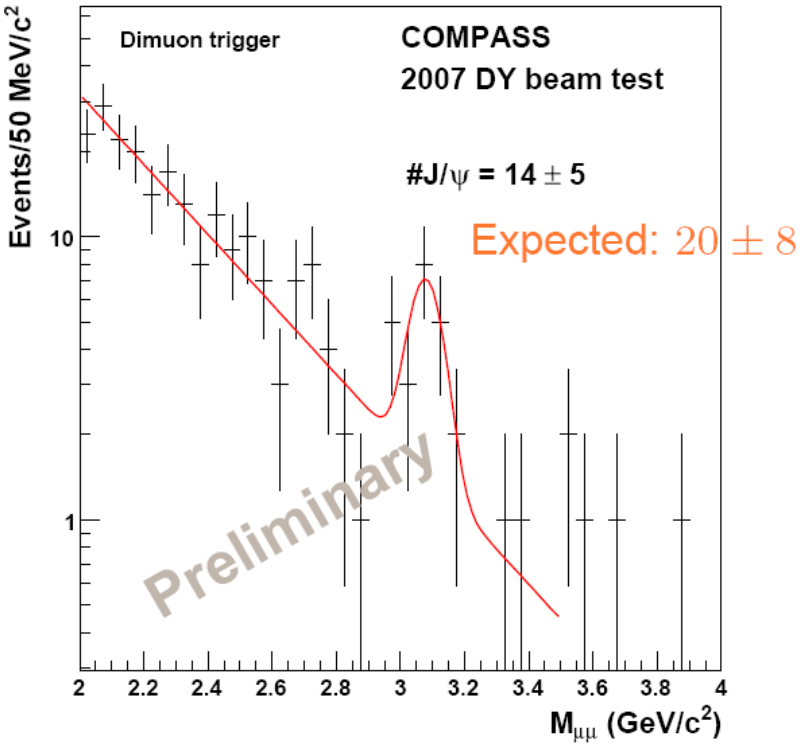
M > 4 GeV/c^2: safe region to study Drell-Yan

Drell-Yan at COMPASS

beam tests

2007: 160 GeV/c π^- beam, NH_3 target, no absorber
to test the feasibility of the measurement

~ 90000 dimuon events in <12 hours of data taking

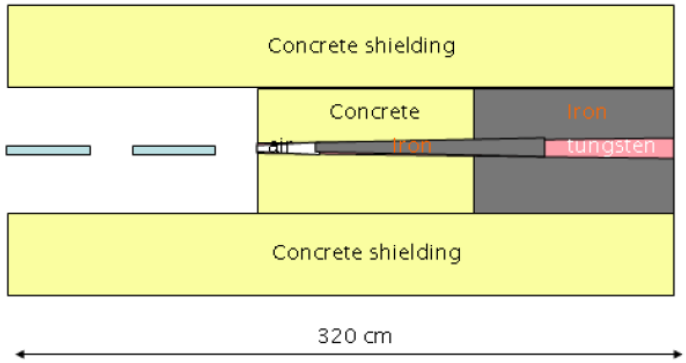


Drell-Yan at COMPASS

beam tests

2008: 160 GeV/c π^- beam, at higher beam intensity

→ *too high detector occupancy: absorber*



2009: an prototype absorber will be placed after the (dummy) target to
check detectors occupancy,
extent of the combinatorial background,
mass and vertex resolution, and
radiation issues

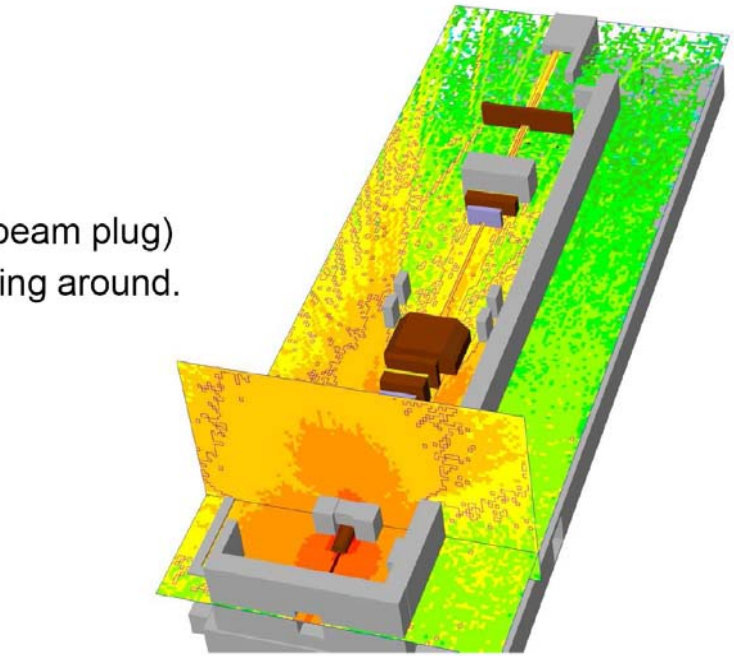
Drell-Yan at COMPASS

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**

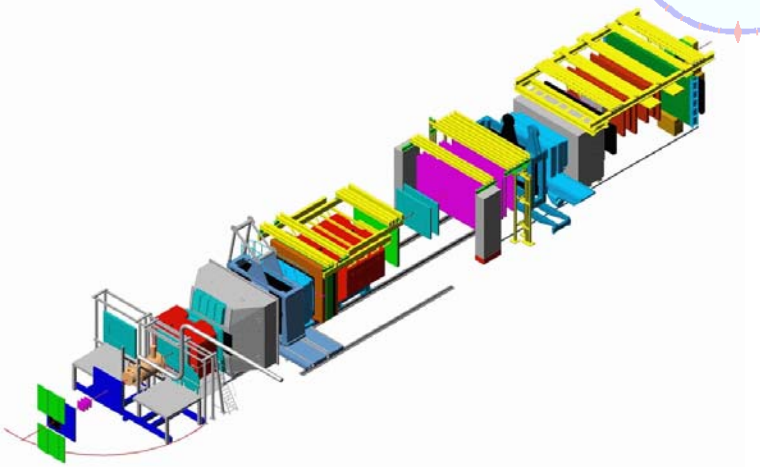
Simulations from Heinz Vincke (Rad-Prot/CERN)

Beam I=8×10^7 π^-/s
Absorber (Al_2O_3 with W beam plug)
of 1.5 m. Concrete shielding around.



Drell-Yan at COMPASS

experimental apparatus



~ the existing one
with the existing PT, plus

- an absorber just after the target

- an improved muon trigger in the LAS
  in ~50% of the events, both the muons are detected in the LAS
  new hodoscopes already being built and to be used in the new SIDIS measurements

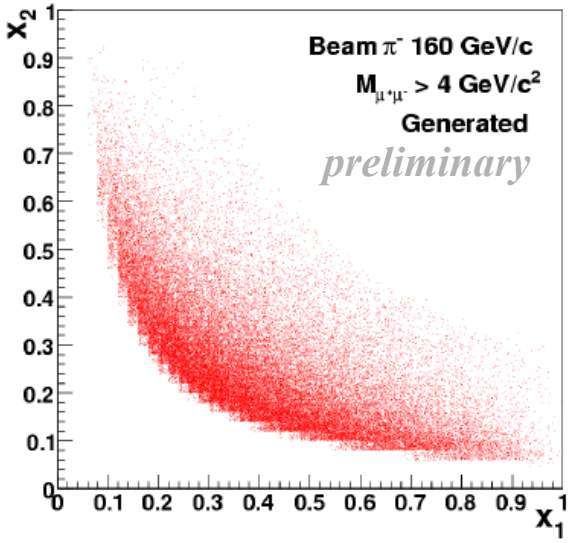
Drell-Yan at COMPASS

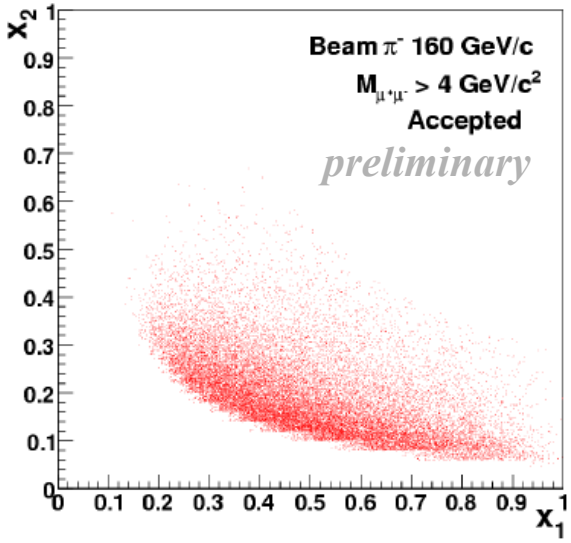
expected precision

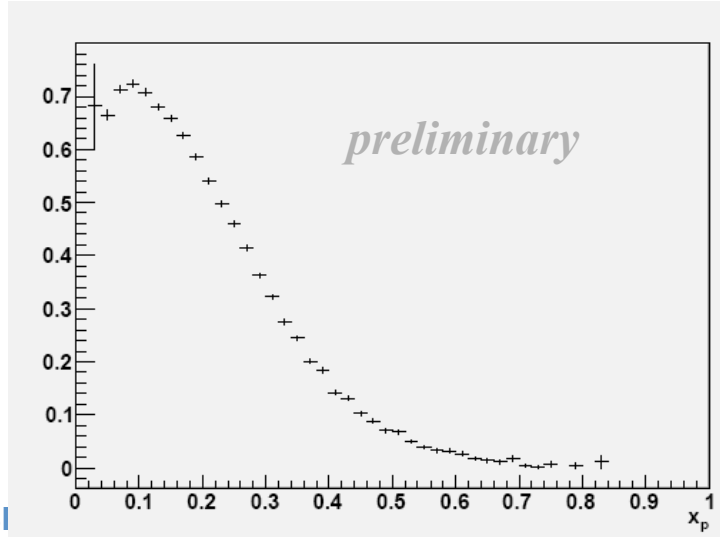
π^- beam of 190 GeV/c

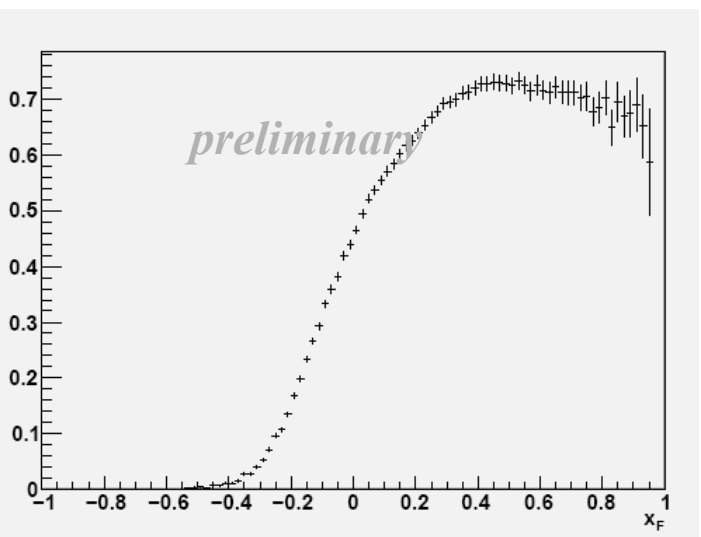
the acceptance

is higher in the valence quarks region, where SSA are expected to be larger









Drell-Yan at COMPASS

expected precision

π^- beam of 190 GeV/c

with

- the transversely polarized NH_3 target (120 cm long) and
- a beam intensity of $6 \cdot 10^7$ particles/second,

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

in two years of data taking

one can collect more than 200000 DY events in the region

$4 < M\mu\mu < 9$ GeV/c^2

the statistical error in the measured asymmetries is expected to be

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

Drell-Yan at COMPASS

expected precision

π^- beam of 190 GeV/c

two years of data taking

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

4 < M < 9 GeV/c²

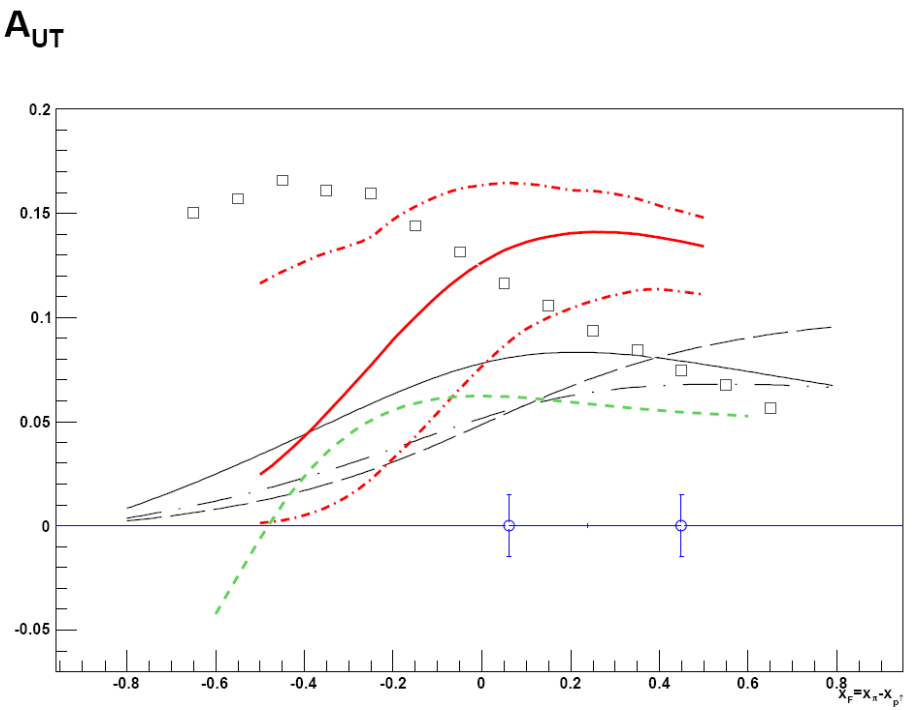
– solid and dashed: Efremov et al, PLB612(2005)233;

– 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?

would be possible in the future

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

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

- **extraction of the Sivers function**

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

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

Drell-Yan at COMPASS - conclusion

- **DY is a well understood process**
  it provides unique information of the hadron structure and dynamics, and of TMD PDFs, complementary to SIDIS
- **COMPASS allows to 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 prediction on the sign of the Sivers function

Proposal in preparation

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

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

COMPASS plans – short term

Starting in 2010:

- **SIDIS measurements with transversely pol protons (1 year)**
- **SIDIS measurements with longitudinally pol protons (1year)**

Proposal in preparation

- **DY on transversely polarised p target**
- **DVCS with LH target and polarised p target**

Hadron program: not over
further measurements mainly depending on the results from the 2008-2009 data taking