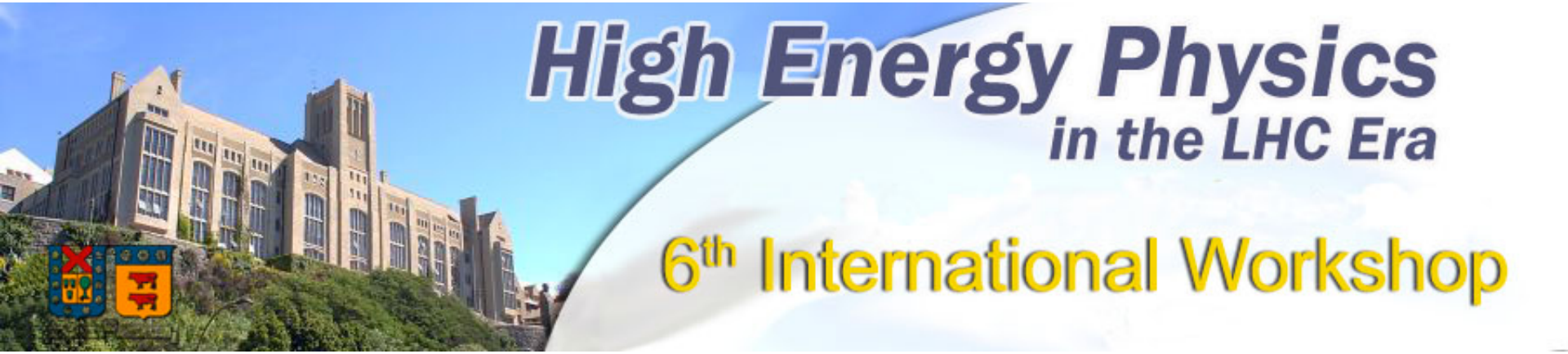
Hadron structure studies with the COMPASS experiment at CERN



Stephane Platchkov

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(for the COMPASS Collaboration)

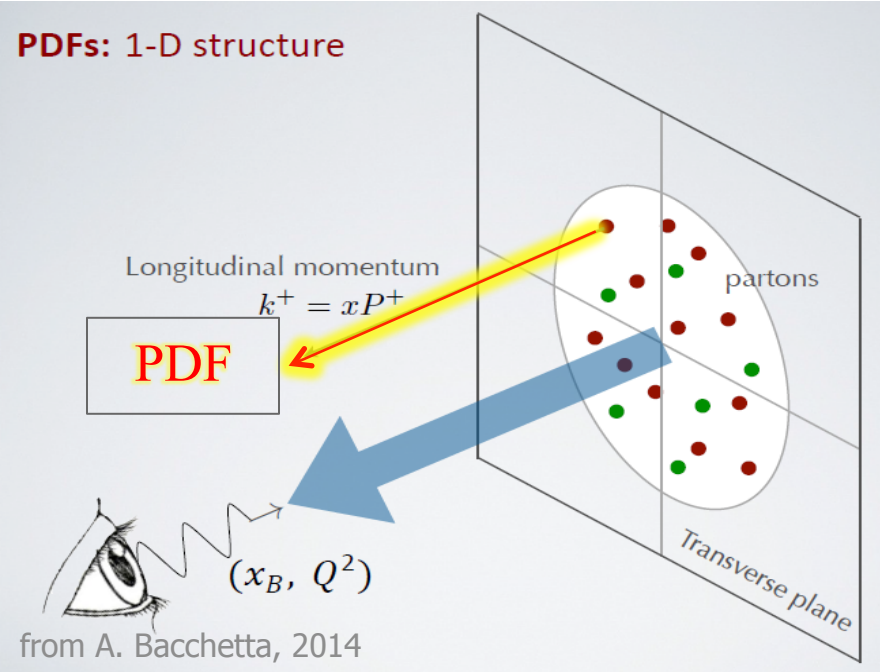
COMPASS experimental program / Outlook

- COMPASS I (2002 – 2011)
  - Longitudinally polarized DIS and SIDIS
  - Transversely polarized SIDIS
- COMPASS II (2012 – 2018)
  - Deeply-Virtual Compton Scattering (DVCS)
  - Massive lepton pairs from Drell-Yan process
- Not covered in this talk
  - Hadron spectroscopy (COMPASS I + II)
  - Pion polarisability (talk by Moinester, Friday)

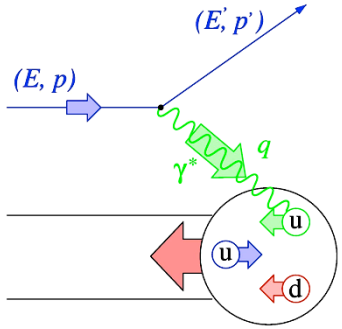
Muon beam

Hadron beams

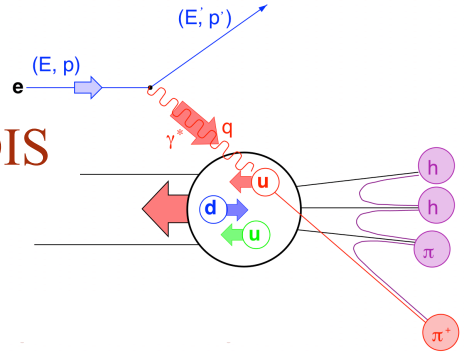
COMPASS – physics and tools



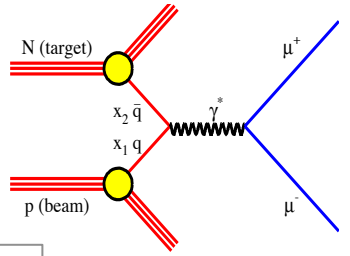
(Polarized)
Deep Inelastic
Scattering (DIS)



Semi-Inclusive DIS

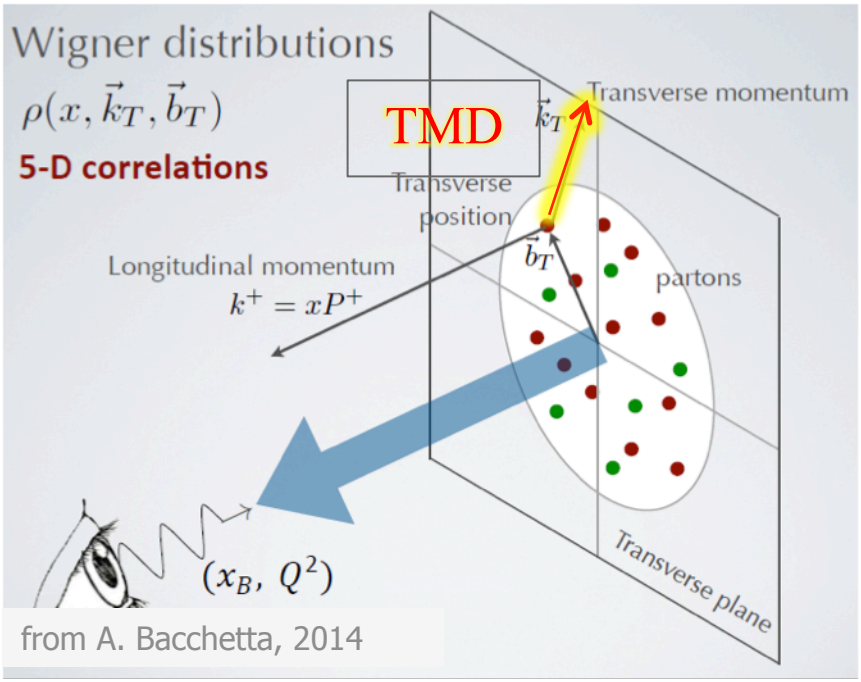


Drell-Yan process

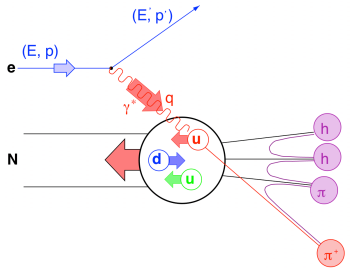


Fundamental non-perturbative quantities:
(pol. and unpol.) Parton Distribution Functions PDF (x)

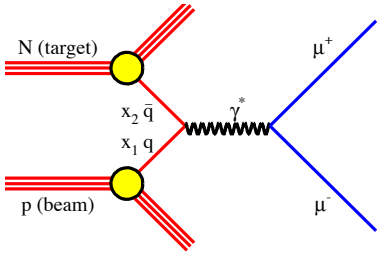
COMPASS – physics and tools



Semi-Inclusive DIS

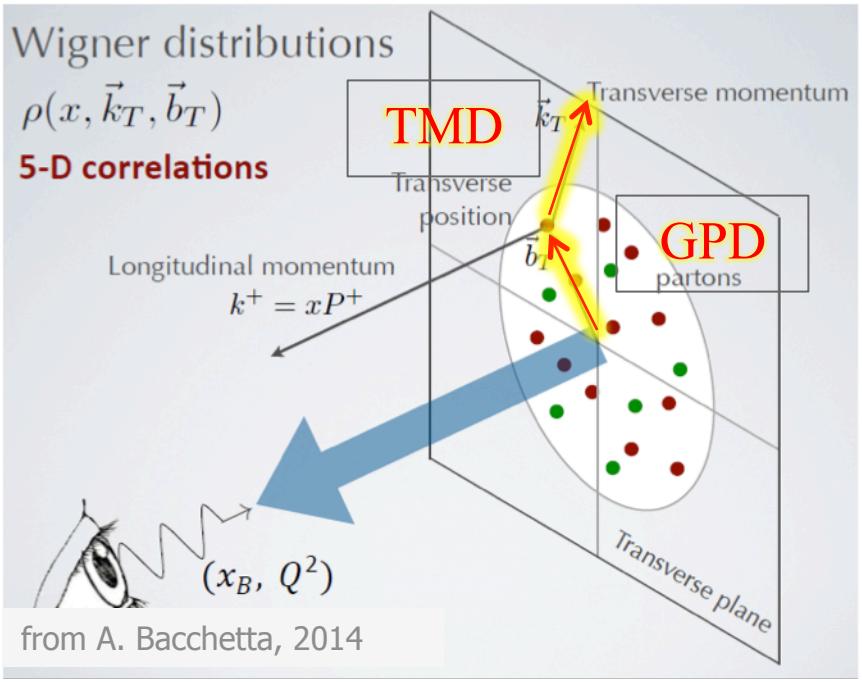


Drell-Yan process

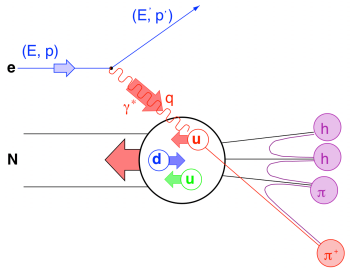


Transverse Momentum Distribution PDFs: TMD PDF (x,k_T): probe the transverse parton momentum dependence

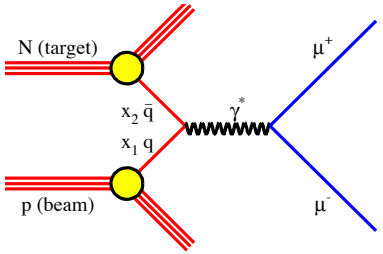
COMPASS – physics and tools



Semi-Inclusive DIS



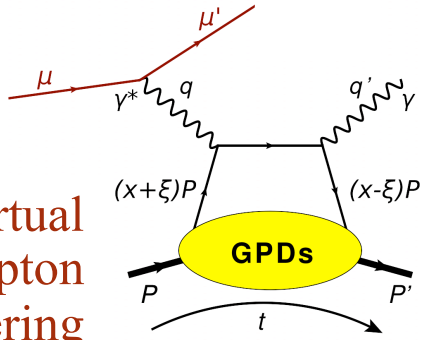
Drell-Yan process



Transversity Momentum Distributions: TMD (x,k_T):
probe the transverse parton momentum dependence

Generalized Parton Distributions : GPD (x,b_T):
probe the transverse parton distance dependence

Deeply Virtual Compton Scattering

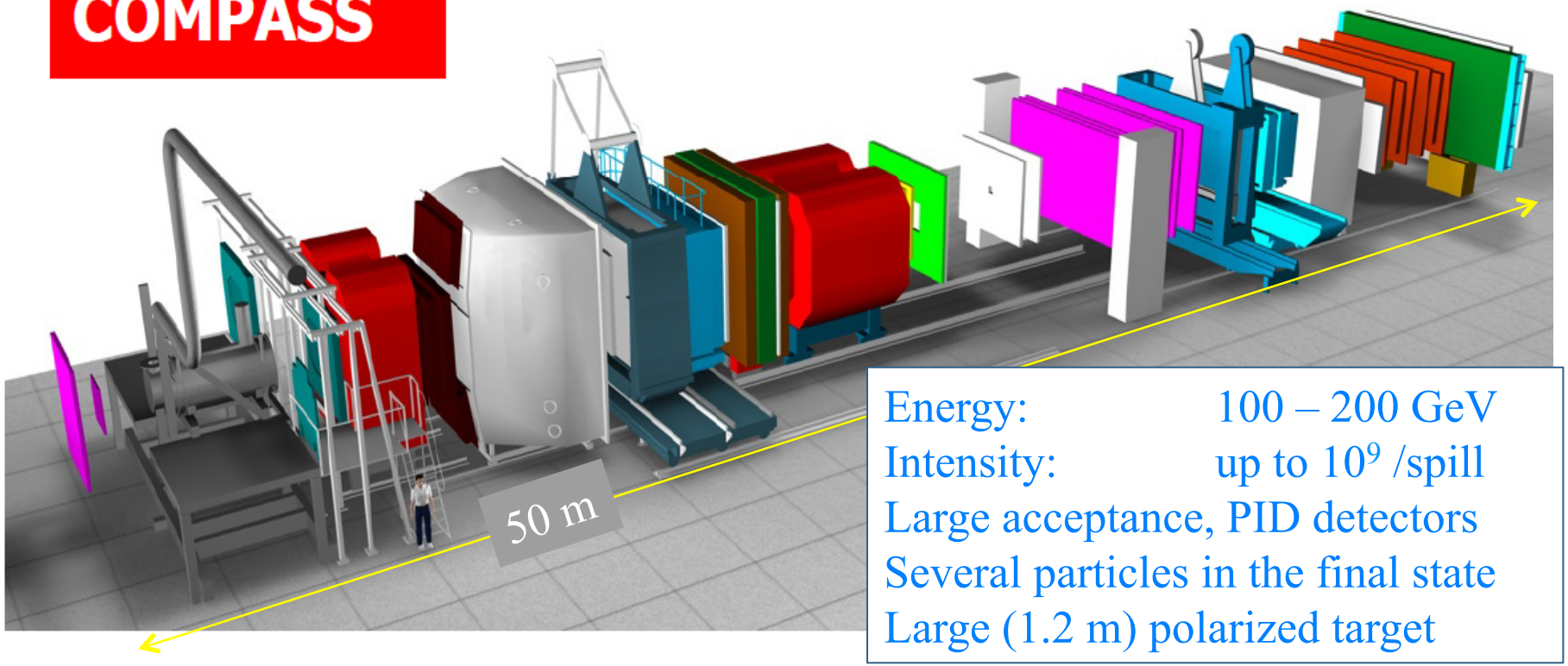


COMPASS explores the multi-dimensional structure of the nucleon
- both in momentum and in configuration space

COMPASS – a fixed target experiment at CERN

IRFU

- A very versatile setup
- Several beams available: μ^+, μ^-, h+, h^-, e^- => Several ways of probing the nucleon structure

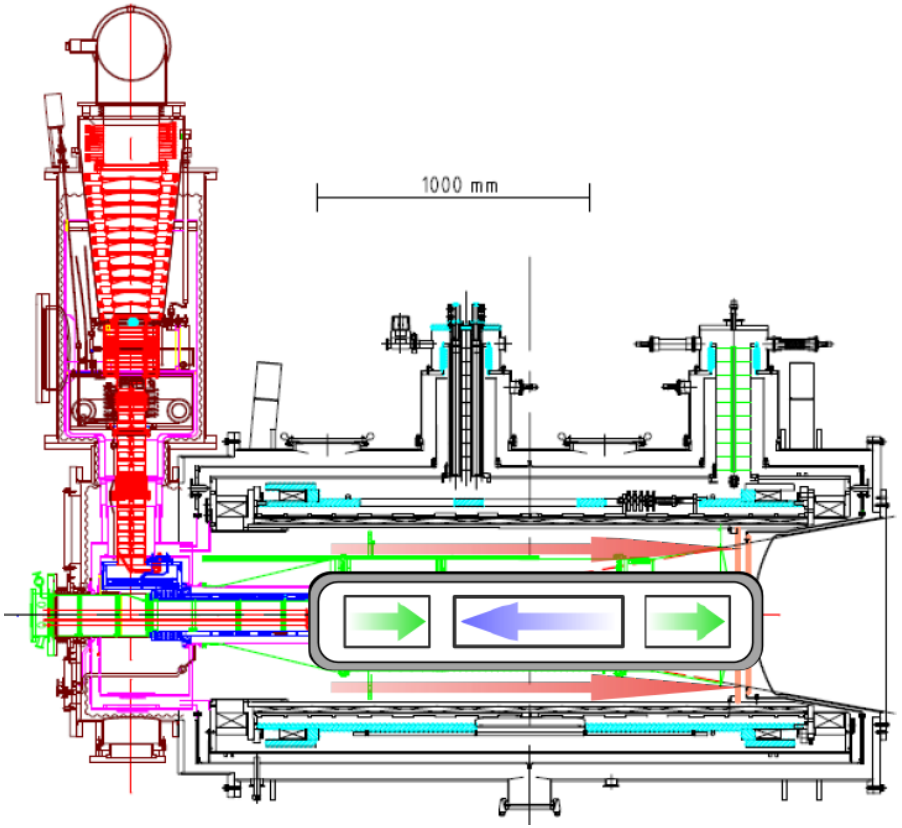


Energy: 100 – 200 GeV
Intensity: up to 10^9 /spill
Large acceptance, PID detectors
Several particles in the final state
Large (1.2 m) polarized target

"Minor" changes to the setup – switch between various physics programs

COMPASS – polarized target

- 3 cells with opposite polarization (to minimize systematics)
- High magnetic field (2.5 T)
- High field uniformity ($<10^{-4}$)
- Very low temperature
- Long or Transv polarization
- Polarizations:
  - Deuteron (^{6}LiD): ~50%
  - Proton (NH_3): ~80%
- Regular polarization reversals



Largest polarized target in the world

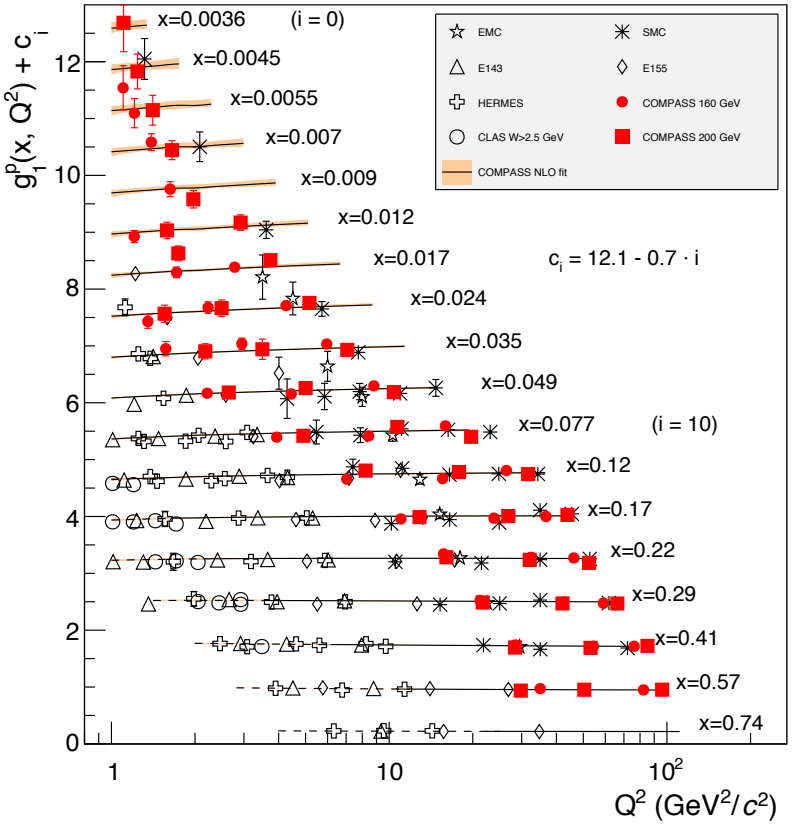
Polarized structure function $g_1(x)$ – world data

IRFU

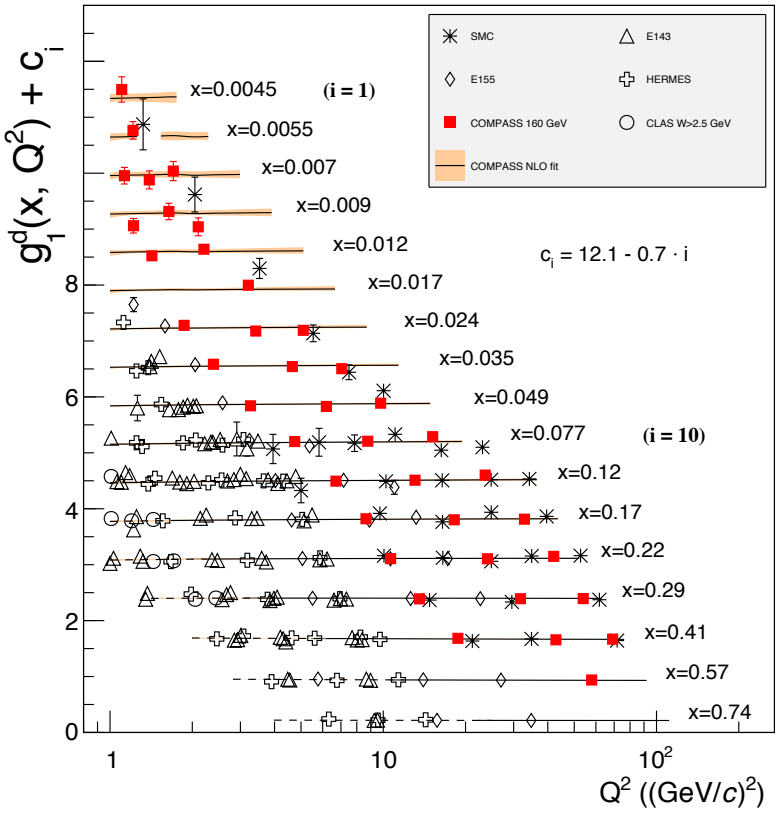
Data are used as input to a global QCD fit

$$g_1(x) = A_1(x)\frac{F_2(x)}{2x(1+R)}$$

PROTON DATA



DEUTERON DATA



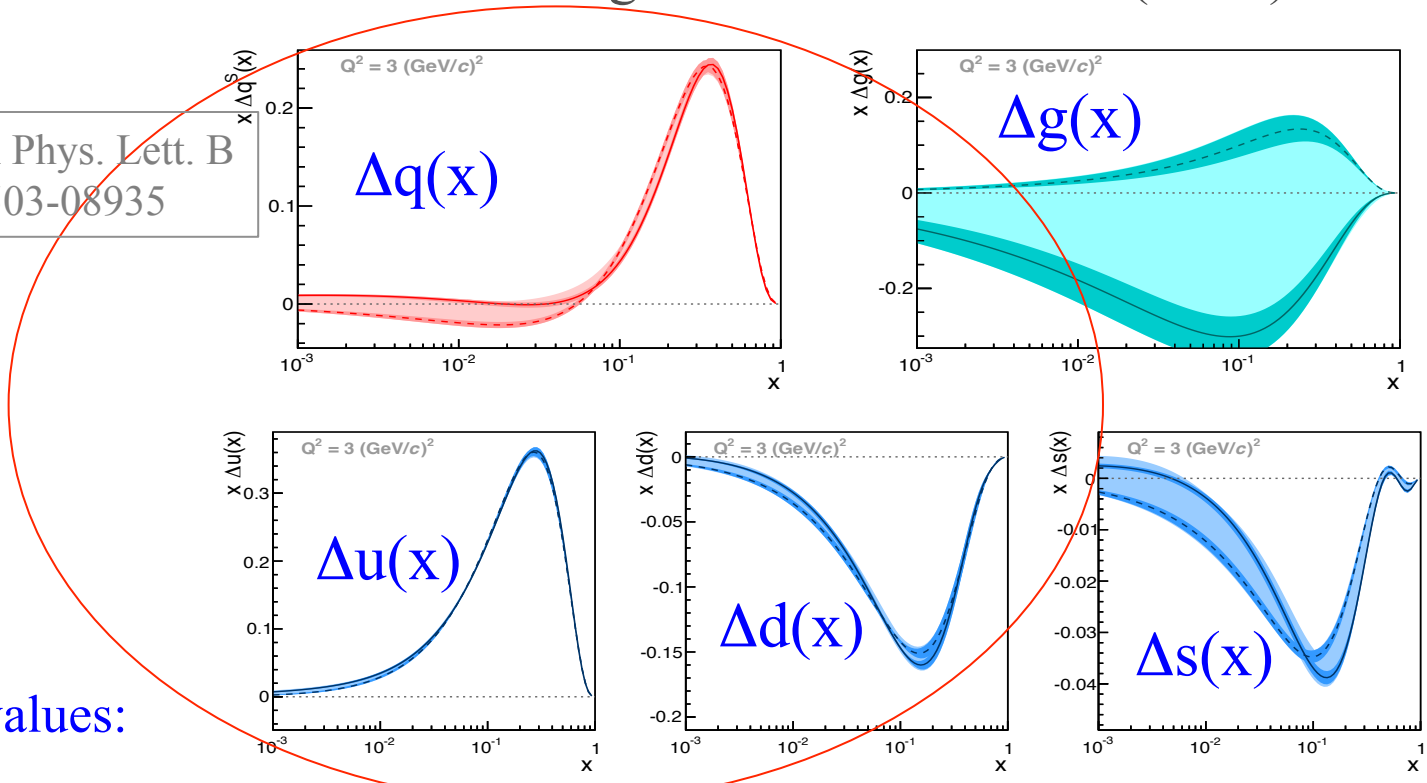
Measurements down to <x>= 0.0035
Thorough study of systematic effects

COMPASS

COMPASS NLO pQCD fit to $g_1(x)$

- Inputs: world data, various functional forms, assume SU(3)
  - ΔG is determined through DGLAP evolution (NLO)

To be publ. in Phys. Lett. B
hep-ex:1503-08935



Integral values:

Quark spin contribution $\Delta\Sigma = 0.30 \pm 0.04$

COMPASS NLO pQCD fit to $g_1(x)$

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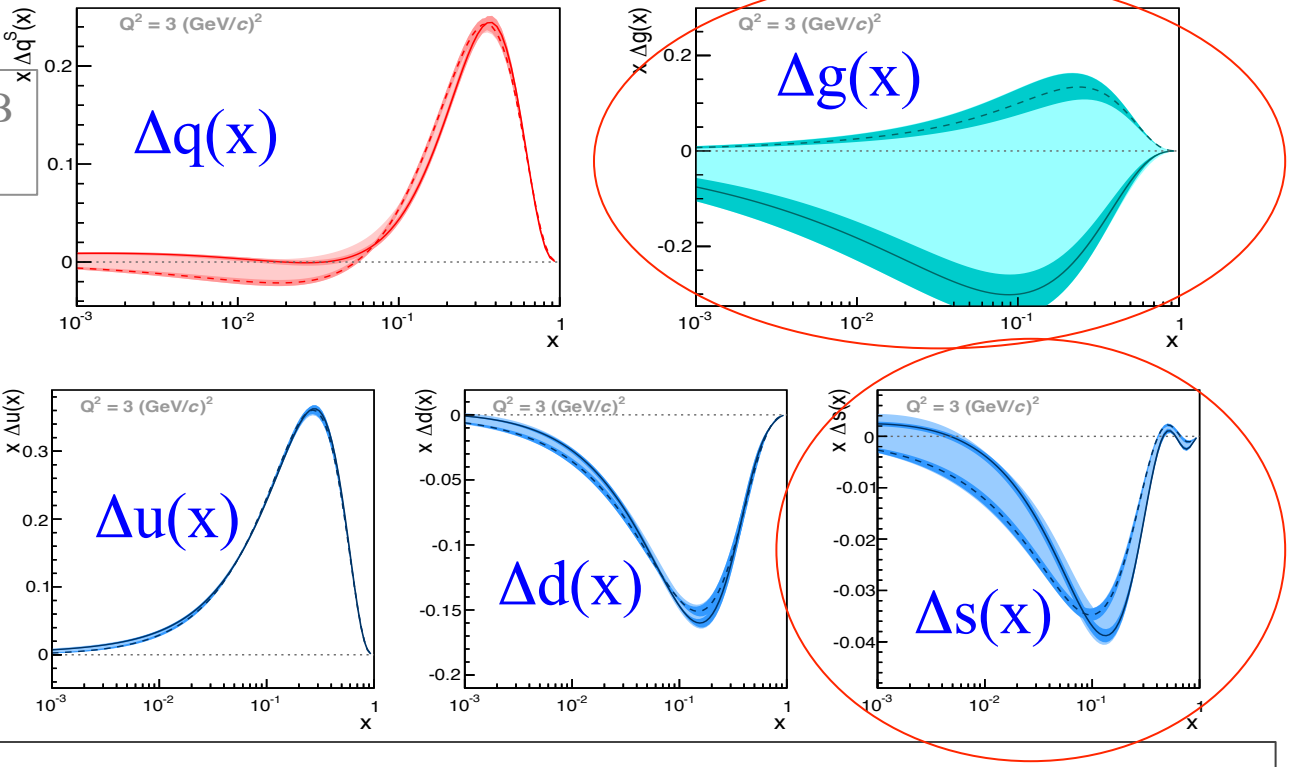


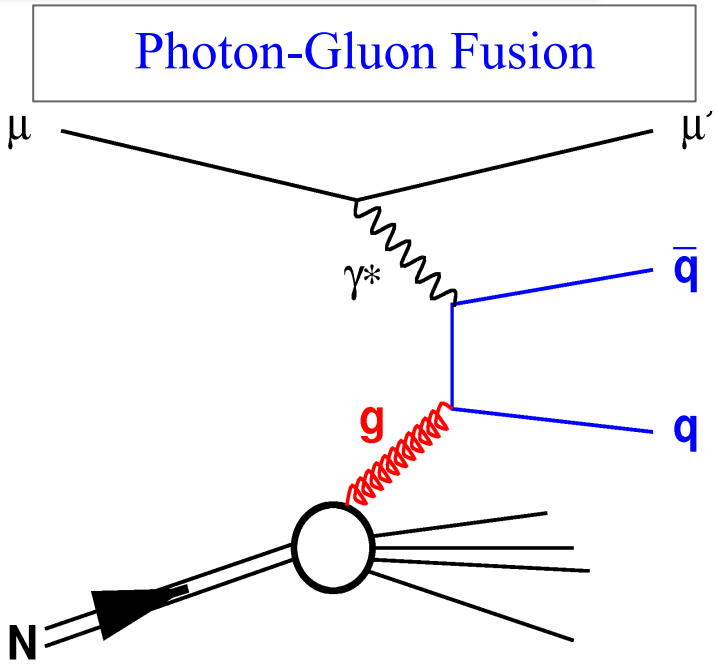
Integral values:

Quark spin contribution $\Delta\Sigma = 0.30 \pm 0.04$
Gluon spin : two classes of solutions, even sign not clear!
Strange quark contribution is negative ! ($\Delta s = -0.095$)

Contribution of gluons to the nucleon spin

- Gluons: spin 1, no charge
- Tool : Photon-Gluon Fusion (PGF)

- Identify the PGF process?



1. Detect charmed quarks: clean signature, but limited statistics
   "Open Charm" method

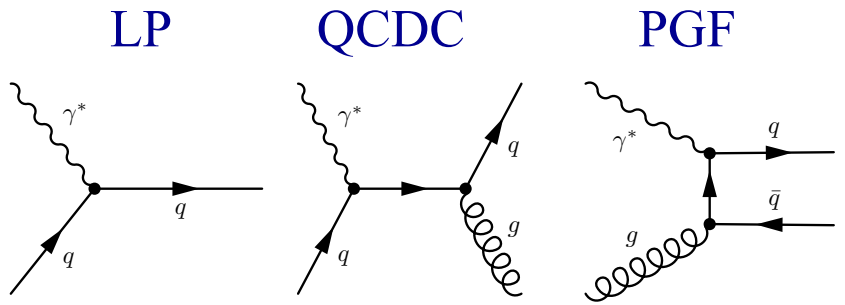
$$\longrightarrow \quad D^0 \to K^-\pi^+ \quad \text{and} \quad D^* \to D^0\pi$$

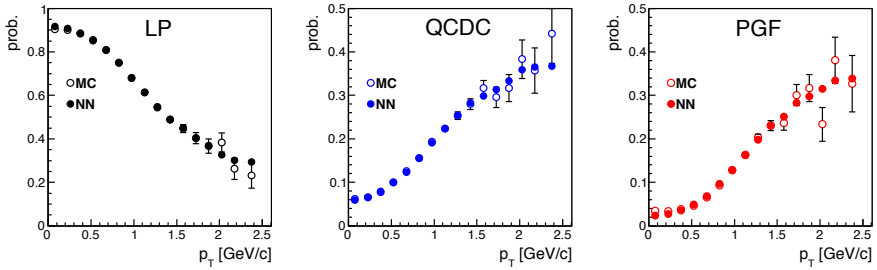
2. Detect light quarks: high statistics, but large physical background
   Hadron "high-p_T" method

$\longrightarrow$ Rely on a Monte-Carlo estimate of the background

Hadron production – "All p_T" method

- Extension of the "high-p_T" method – to all p_T
- Processes: LP, QCDC, PGF; different p_T dependences:
  - Large p_T : PGF, QCDC
  - Small p_T: LP
- Fit all 3 processes simultaneously
- Evaluate model dependence

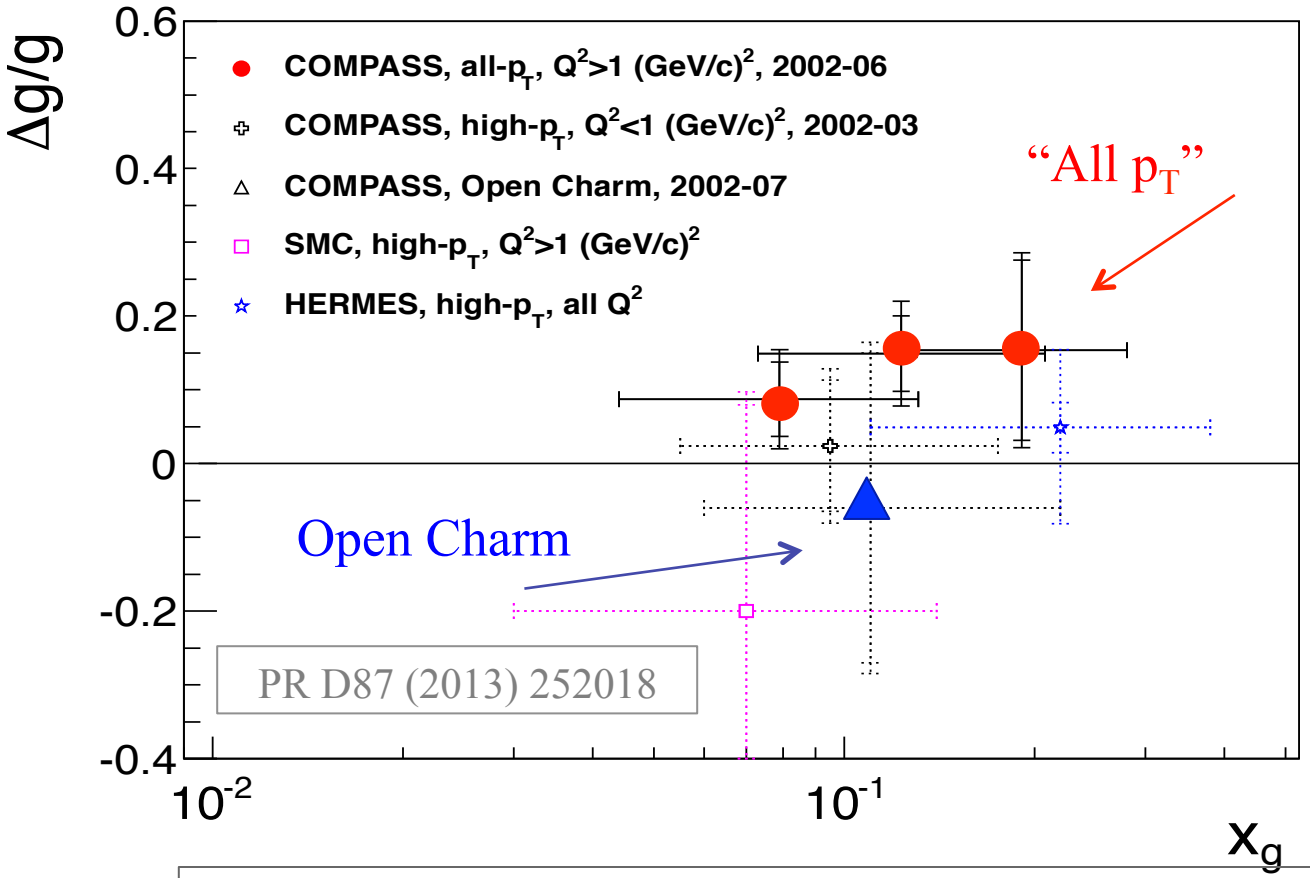




► Improved statistical (and systematic!) errors

to be published:
hep-ex:1512.05053

Δg/g results



to be published:
hep-ex:1512.05053

RHIC results also favor positive Δg/g

$\Delta g/g = +0.113 \pm 0.038\ (stat) \pm 0.036\ (syst)$ @ $\mu^2 = Q^2 = 3\ (GeV/c)^2$

Data suggest positive value of Δg/g (~2σ)
Most precise direct measurements today

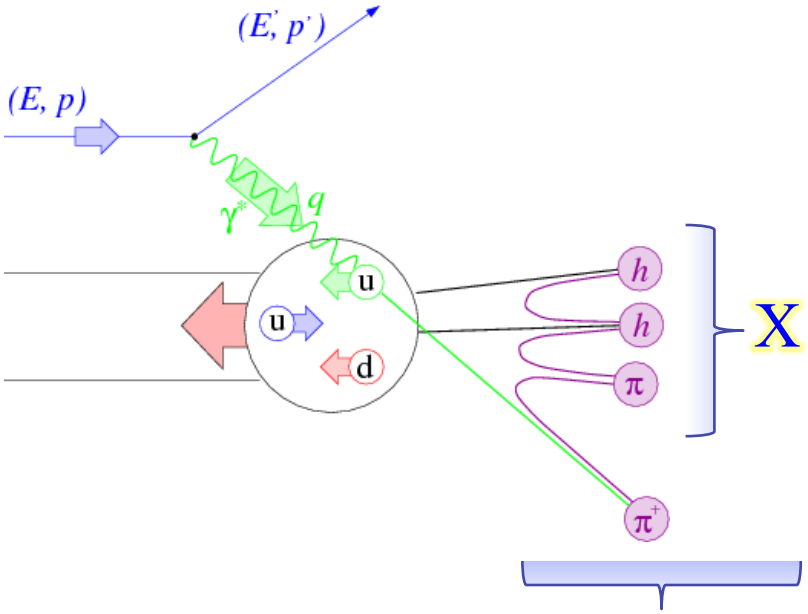
Polarized Semi-Inclusive DIS (SIDIS)

Polarized PDF

$$A_1^h = \frac{\sum_f e_f^2 \Delta q(x,Q^2) D_{1f}^h(z,Q^2)}{\sum_f e_f^2 q(x,Q^2) D_{1f}^h(z,Q^2)}$$

Un-polarized PDF

Fragmentation function: a quark of flavor *f* becomes a hadron *h*

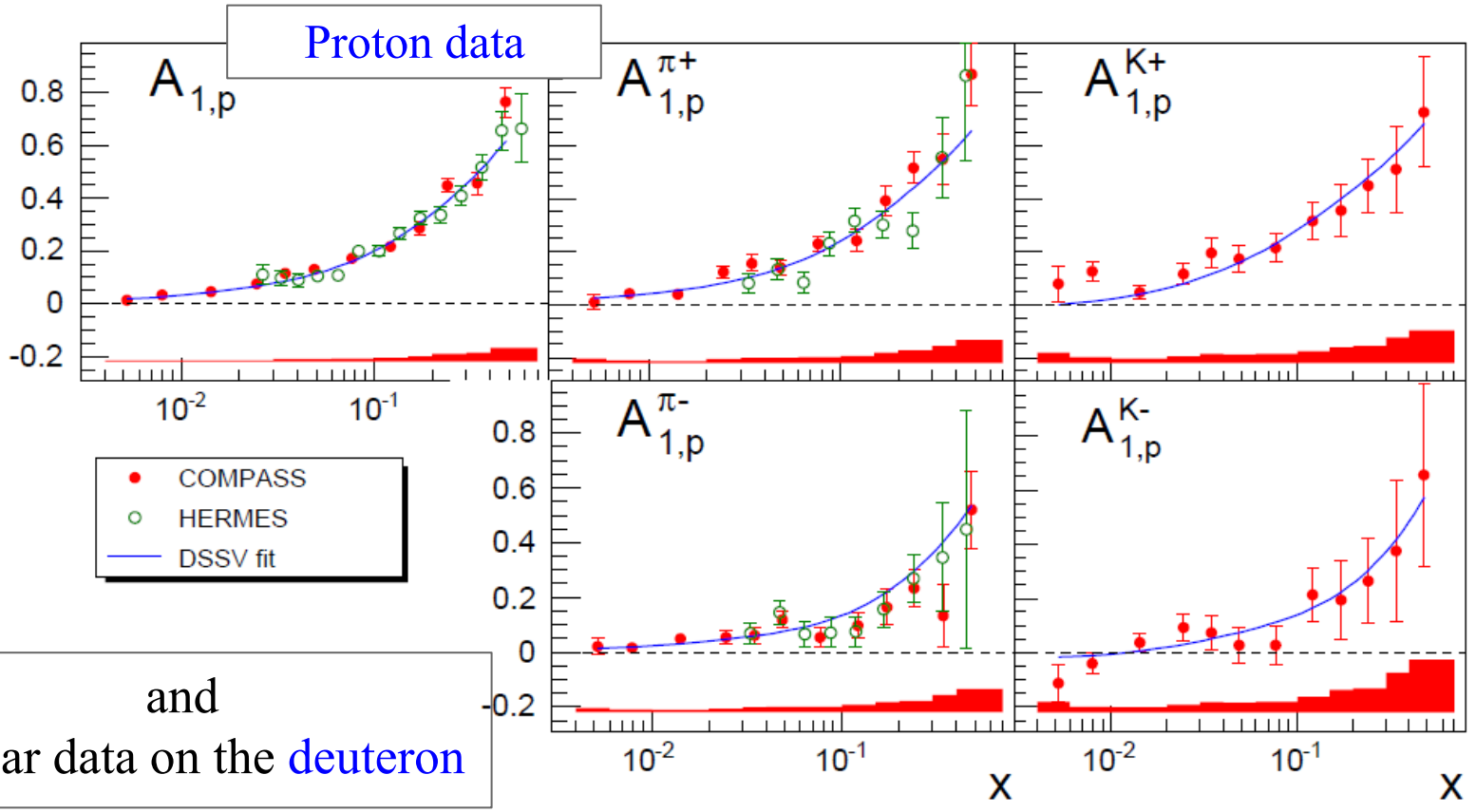


Detected hadron

$$z = \frac{E_h}{E - E'}$$

Polarized SIDIS is sensitive to the shape of the polarized PDFs in the nucleon: Δu(x), Δd(x), Δs(x)

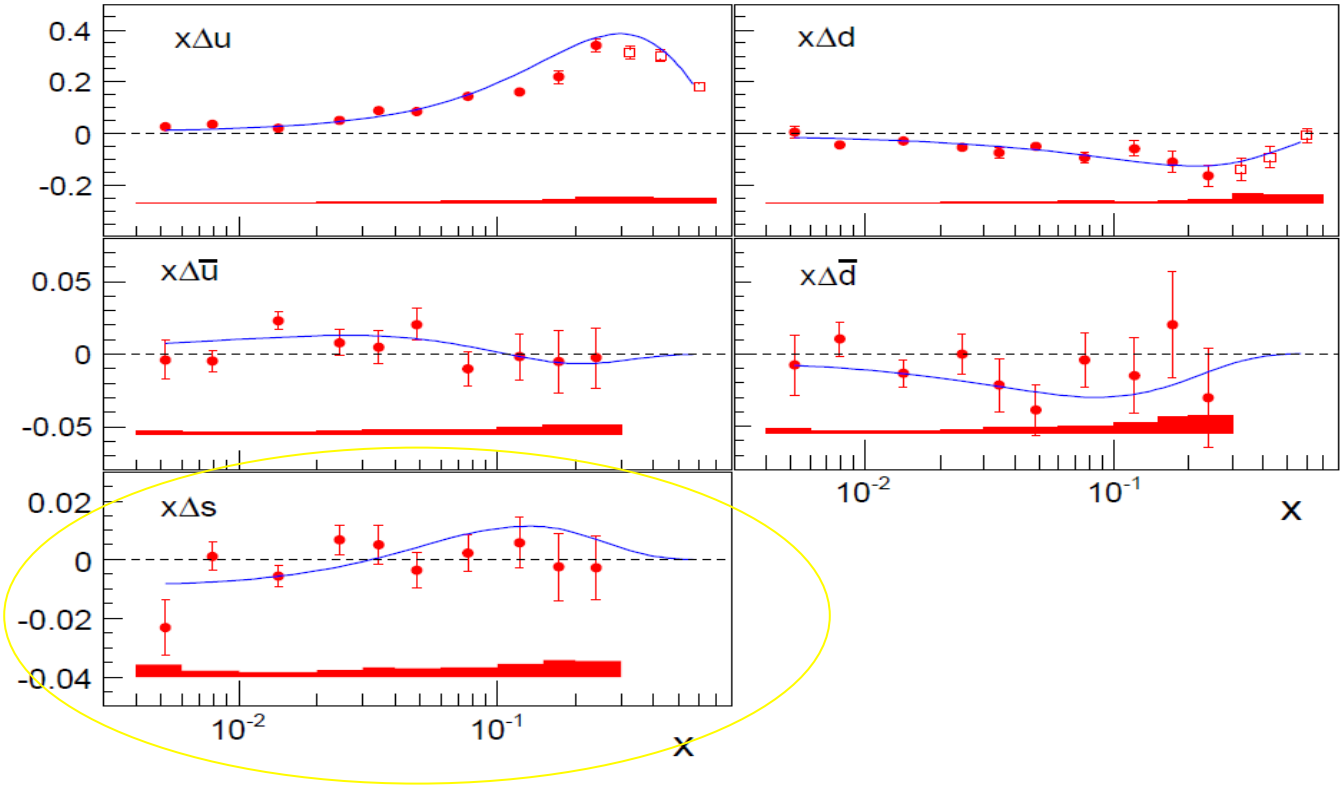
SIDIS asymmetries: World proton data



and
similar data on the deuteron

LO QCD fit to all 10 asymmetries -> simultaneous extraction of : $\Delta u(x)$, $\Delta d(x)$, $\Delta s(x)$ and $\Delta \bar{u}(x)$, $\Delta \bar{d}(x)$, $\Delta \bar{s}(x)$

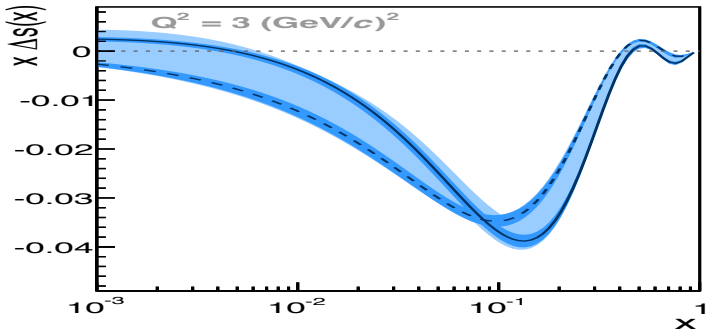
Polarized PDFs as determined by pSIDIS



PL B693 (2010) 227.

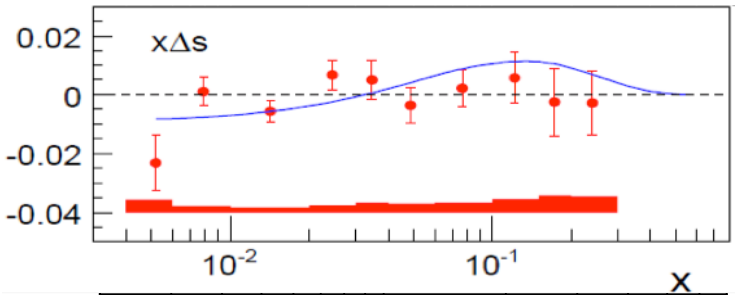
Δu(x), Δd(x), Δū(x), Δd̄(x): as expected from pol. DIS
However: Δs(x) is found to be compatible with zero

The strange quark puzzle



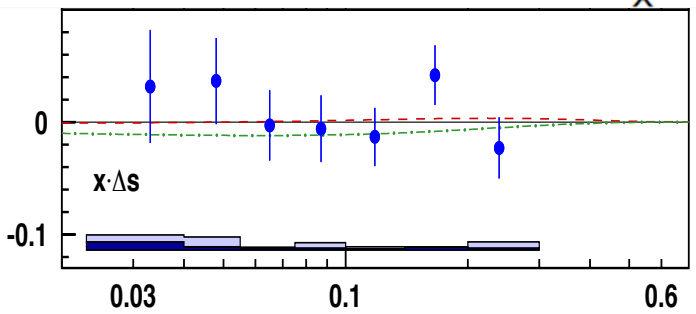
Compass DIS fit
$2\Delta s = -0.09 \pm 0.01 \pm 0.015$

To be publ. in PL B
hep-ex:1503-08935



COMPASS SIDIS
$\Delta s = -0.01 \pm 0.01 \pm 0.02$

Phys. Lett
B693 (2010) 227

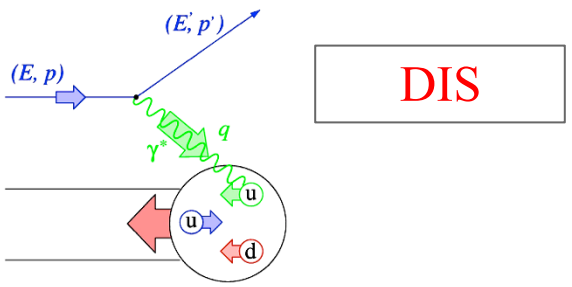


HERMES SIDIS
$\Delta s = +0.001 \pm 0.003 \pm 0.001$*
*measured range

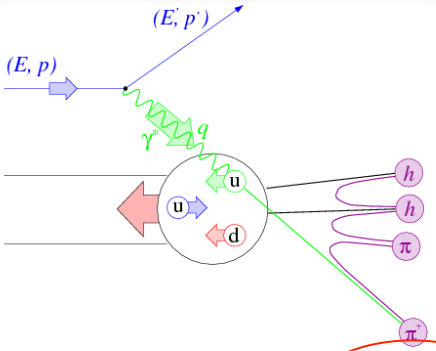
Phys. Rev.
D 71 (2005) 032004

Large disagreement between DIS QCD fits and SIDIS

Δs puzzle: what about Fragmentation Functions?



DIS



SIDIS

Fragmenation Function

$$A_1 = \frac{\sum_f e_f^2 \Delta q(x,Q^2)}{\sum_f e_f^2 q(x,Q^2)}$$

$$A_1^h = \frac{\sum_f e_f^2 \Delta q(x,Q^2) D_{1f}^h(z,Q^2)}{\sum_f e_f^2 q(x,Q^2) D_{1f}^h(z,Q^2)}$$

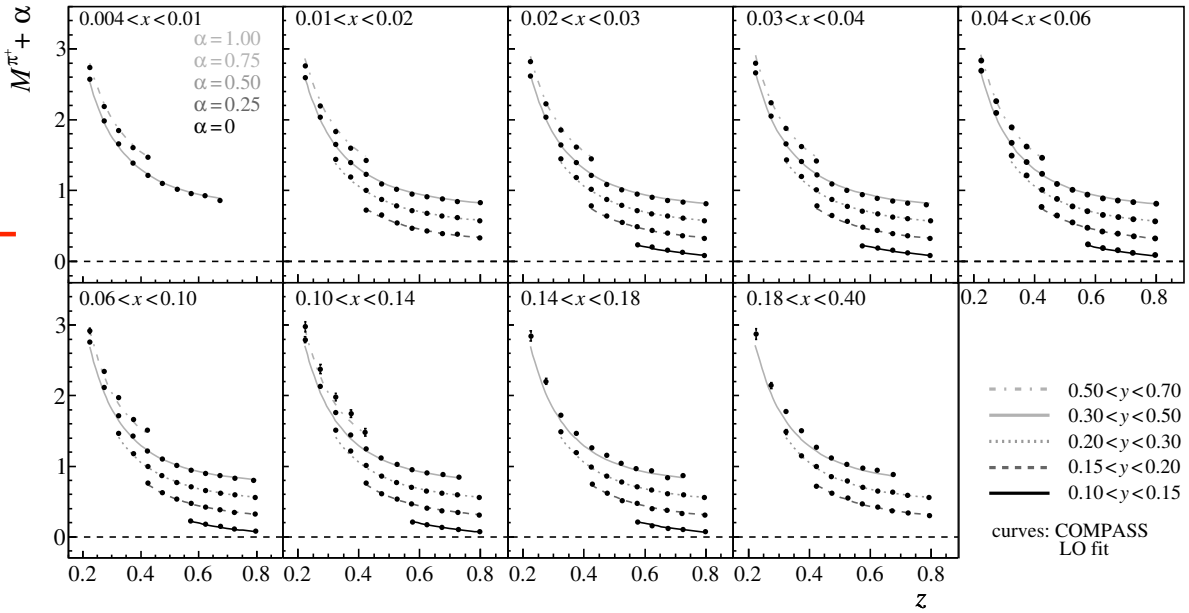
- Independent measurement of $D_f^h(z,Q^2)$: hadron multiplicities (number of hadrons per DIS event)

$$M^K(x,y,z) = \frac{N^K(x,y,z)/\Delta z}{N^{DIS}(x,y)}$$

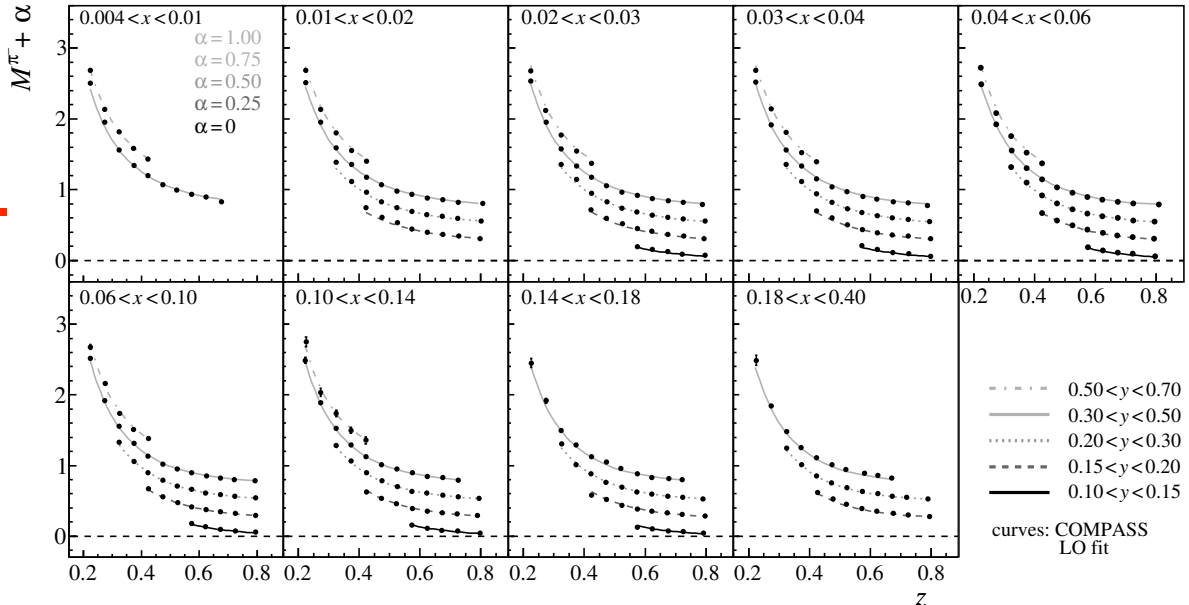
$$M^K = \frac{\sum_f e_f^2 q(x,Q^2) D_f^K(z,Q^2)}{\sum_f e_f^2 q(x,Q^2)}$$

Pion and Kaon FFs are determined through measurements of pion and kaon multiplicities

Pion multiplicities



π^+



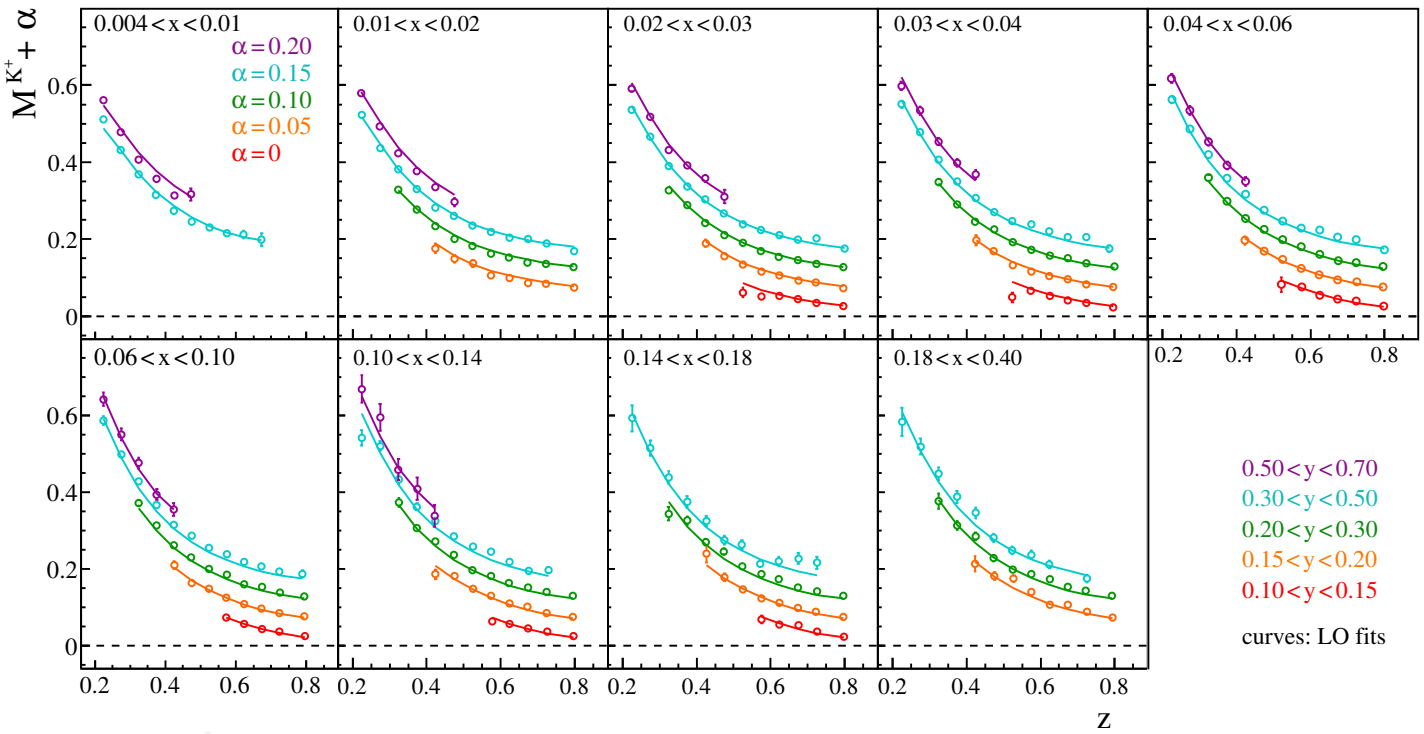
π^-

Compass coll, to be publ. (2016)

About 400 data points per hadron and per charge

Plots for different *x*, as a function of:
z: pion energy fraction
y: virtual photon energy fraction

Kaon (K^+) multiplicities $M^K(z)$: in 9 x bins



Compass coll, in prep. (2016)

Similar results for K^-

$$M^{K^+}(x,z,Q^2) = \frac{2\bar{s}D_{str} + 4(u+d)D_{fav} + (u+d+5(\bar{u}+\bar{d})+2s)D_{unf}}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})}$$

$$M^{K^-}(x,z,Q^2) = \frac{2sD_{str} + 4(\bar{u}+\bar{d})D_{fav} + (5(u+d)+\bar{u}+\bar{d}+2\bar{s})D_{unf}}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})}$$

$$zD_i(z,Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i}(1+\gamma_i(1-z)^{\delta_i}) \qquad i = fav$$

$$zD_i(z,Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i} \qquad i = str, unf, glu$$

QCD (LO) fit to K^+ and K^- kaon multiplicities -> FF

Kaon Fragmentation Function (COMPASS LO fits)

IRFU

Favoured $D^K_{fav} = D^{K\pm}_{fav} = D^{K+}_{u} = D^{K-}_{\bar{u}}$

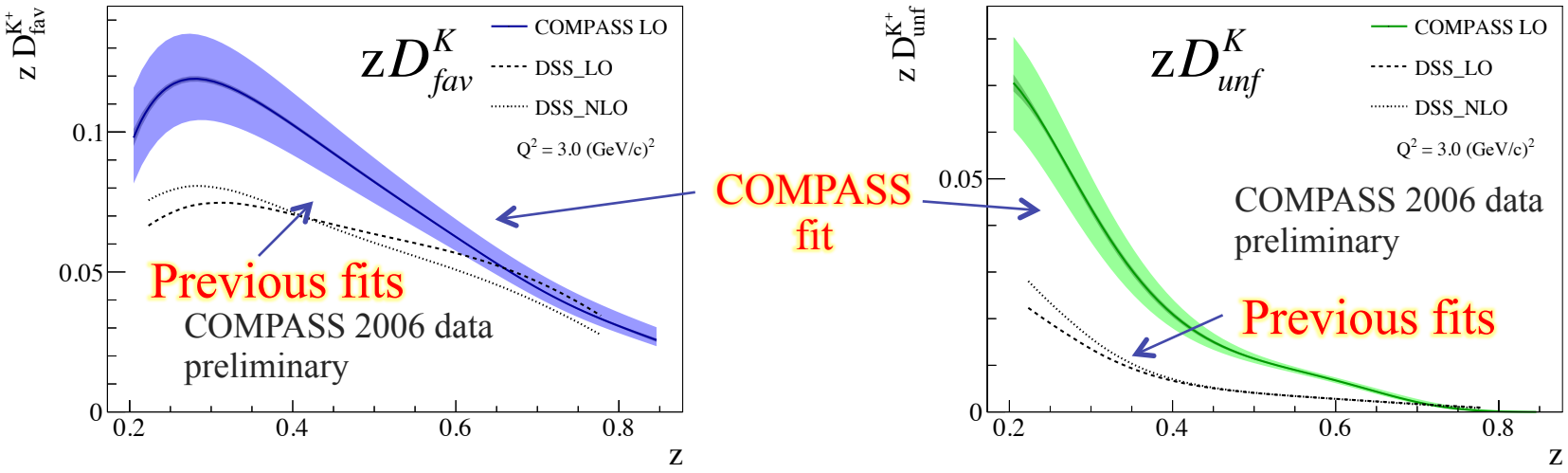
Unfavoured $D^K_{unf} = D^{K\pm}_{unf} = D^{K+}_{\bar{u}} = D^{K+}_{s} = D^{K-}_{u} = D^{K-}_{\bar{s}} = D^{K\pm}_{d} = D^{K\pm}_{\bar{d}}$

Strange $D^K_{str} = D^{K\pm}_{str} = D^{K+}_{\bar{s}} = D^{K-}_{s}$

$K^+ = (u,\bar{s})$
$K^- = (\bar{u},s)$

Favored FF

Unfavored FF



Both FFs are found to be very different from available parametrisations
Strange FF : to be released in the next weeks

Sum of z-integrated kaon multiplicities: $K^+ + K^-$

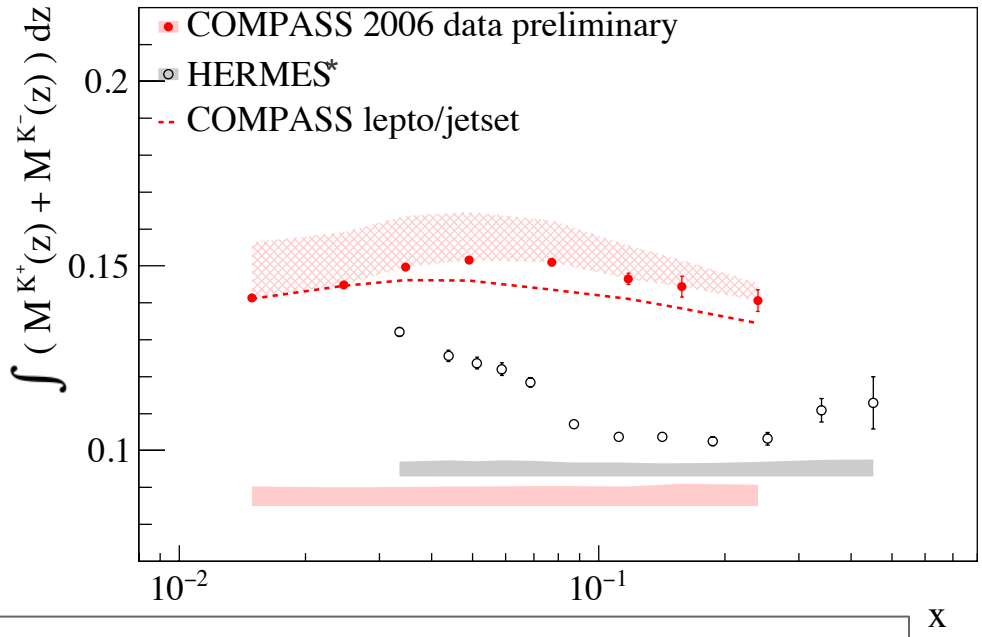
For the isoscalar target, when expressed at LO the sum has a simple form:

$$\frac{dN^{K^+ + K^-}}{dN^{DIS}} = \frac{(u+d+\bar{u}+\bar{d})(4D^K_{fav}+6D^K_{unf})+(s+\bar{s})(2D^K_{str}+2D^K_{unf})}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})} = \frac{Q(x)D^K_Q + S(x)D^K_S}{5Q(x)+2S(x)}$$

$(4D^K_{fav}+6D^K_{unf}) = D^K_Q$ ← contains favoured FF

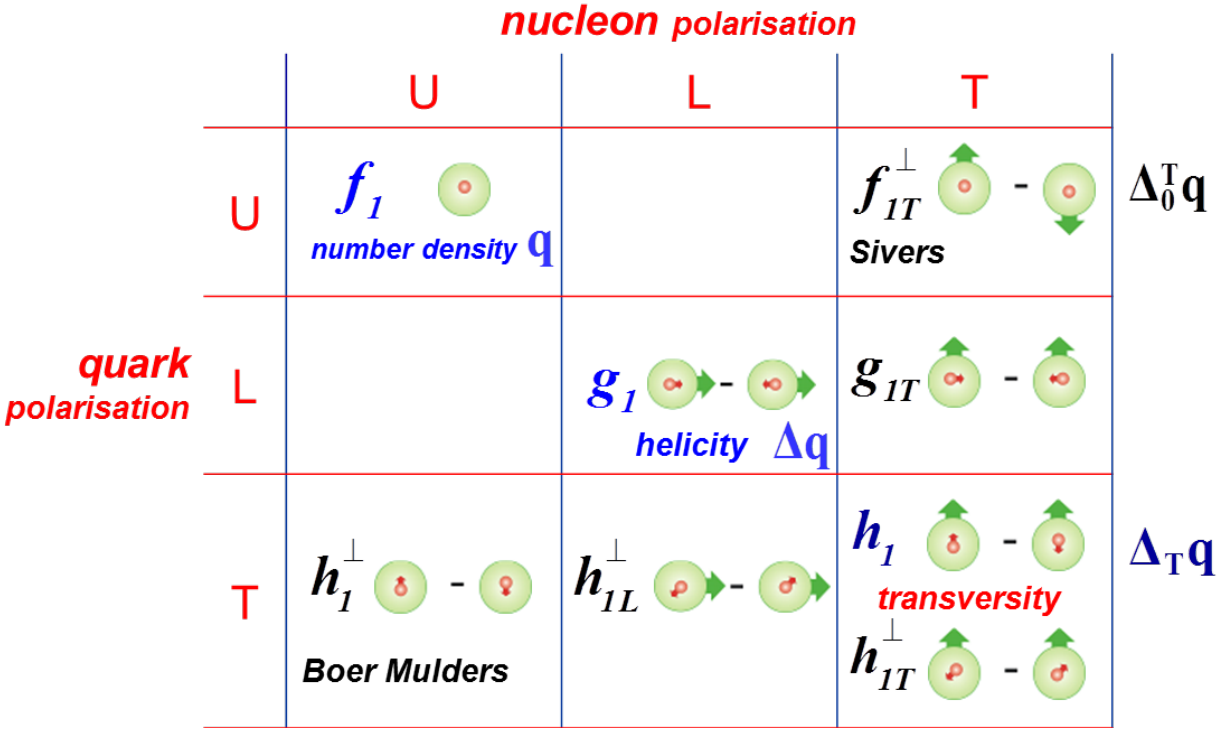
$(2D^K_{str}+2D^K_{unf}) = D^K_S$ ← contains strange FF

Data are averaged over y and integrated over z



Little x dependence. Large disagreement with HERMES data.
Put strong doubts on the HERMES s(x) extraction.

Transverse Momentum Dependent PDFs (LT)



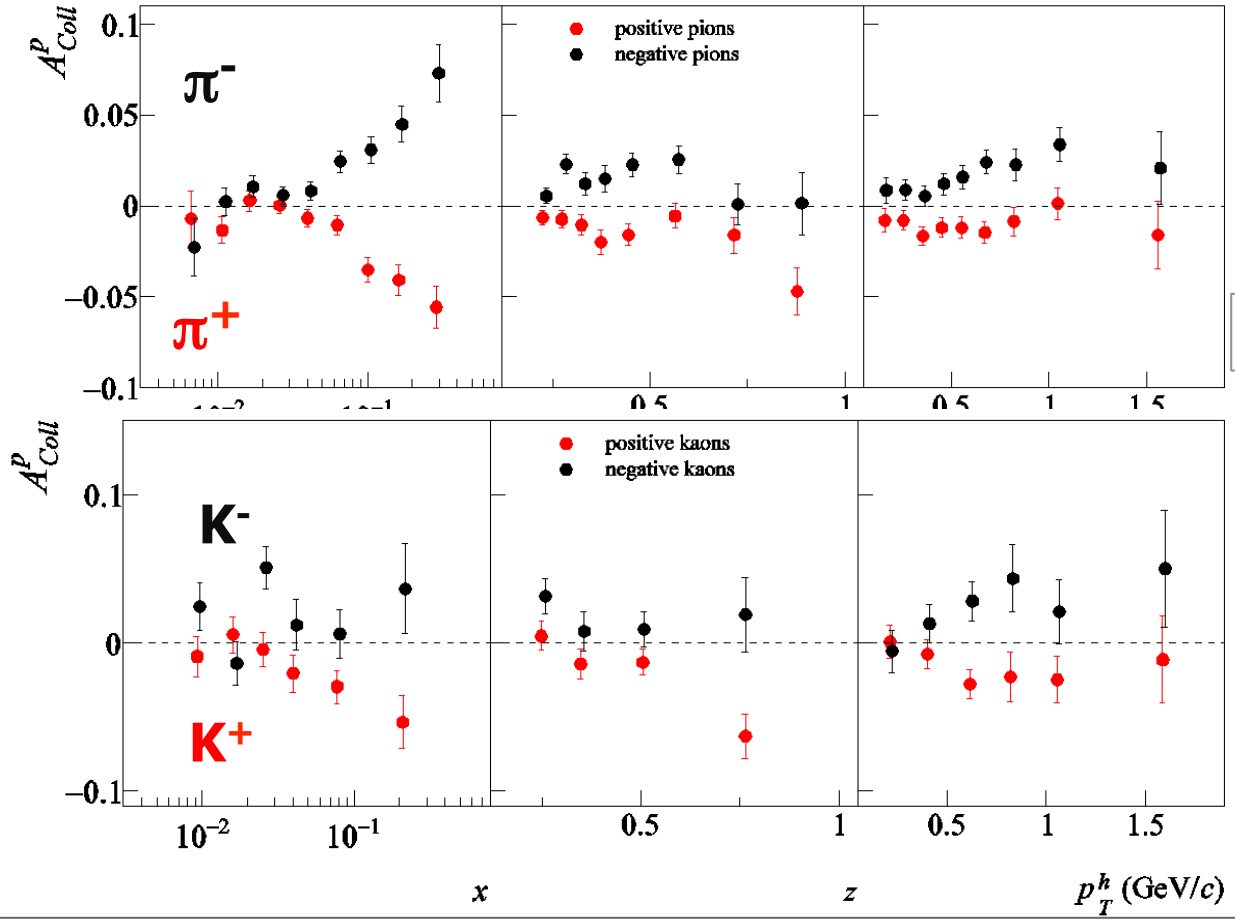
The 5 new TMD PDFs have different azimuthal modulations

- Consider the transverse parton momentum, k_T: 5 new TMD PDFs appear.

Large amount of COMPASS data: longitudinally polarized, transversely polarized, and unpolarized proton and deuteron targets
Last decade: giant steps both experimentally and theoretically

Transverse (Collins) asymmetries - proton

Transversity: correlations between the nucleon transverse spin and the parton transverse spin



pions

PL B744 (2015) 250

kaons

DEUTERON target

PAPERS:

NP B765 (2007) 127

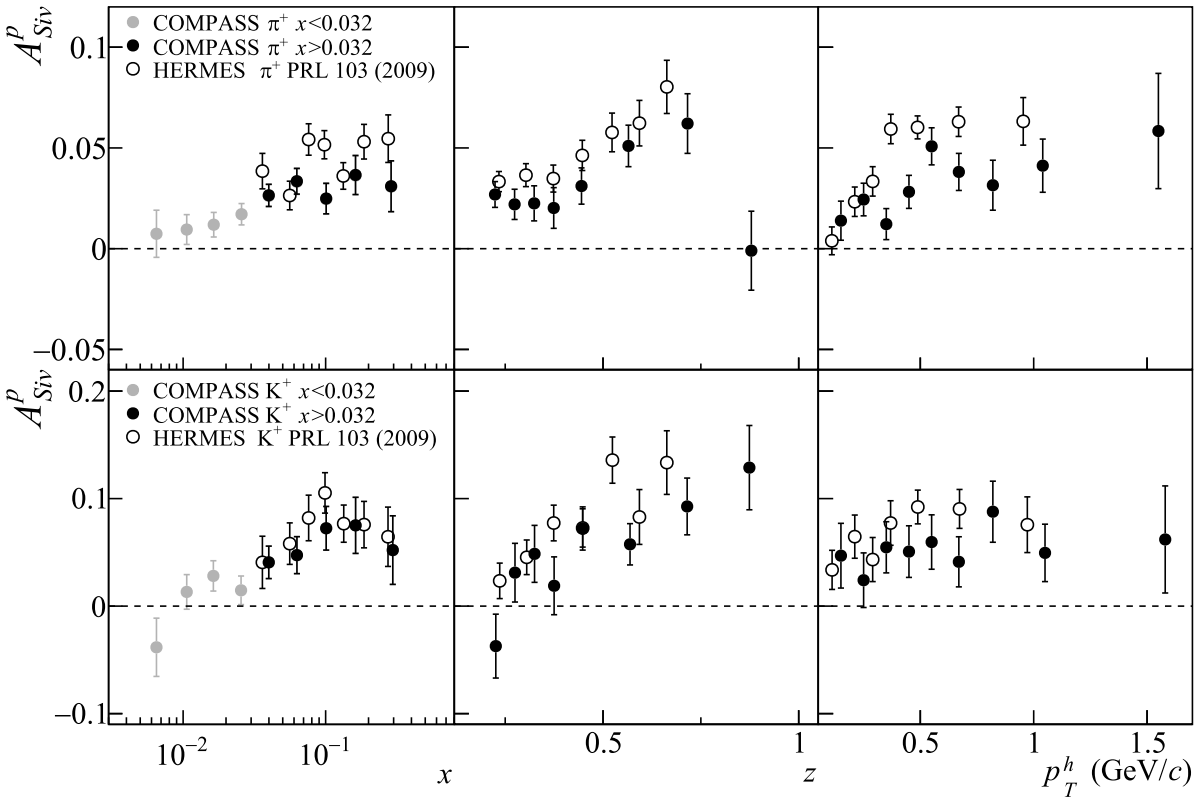
PL B673 (2009) 127

The Collins asymmetries are different that zero in the valence region
Results can be used to determine the Transversity PDF using a QCD fit

Sivers asymmetries – proton target

Sivers: correlations between the nucleon spin and the parton transverse momentum

Positive pions and kaons



Also DEUTERON target:

PL B673 (2009) 127

HERMES:

PRL 103 (2009) 152002

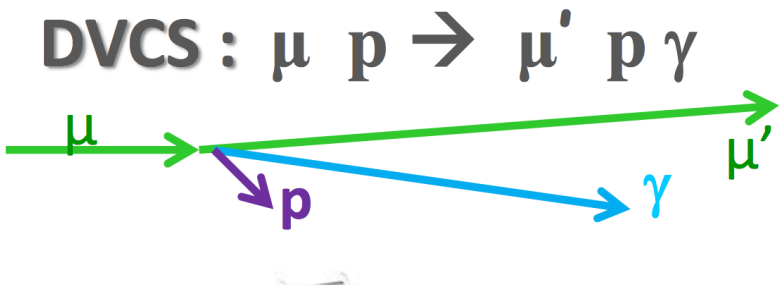
Sivers asymmetries are non zero for positive pions and kaons

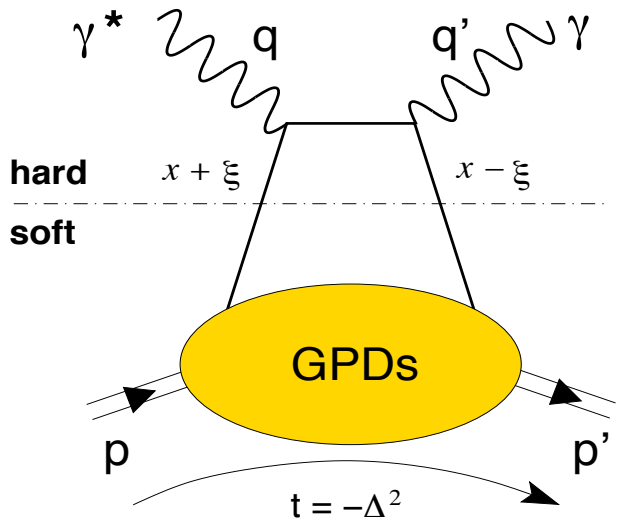
Present status of TMDs: see talk by A. Bacchetta on Monday

Generalized Parton Distributions

- GPDs:
  - Non-perturbative objects
  - Accessed through exclusive reactions

accessed through:
Deeply Virtual Compton Scattering





- 4 GPDs:

$H, \tilde{H}$: conserve nucleon helicity

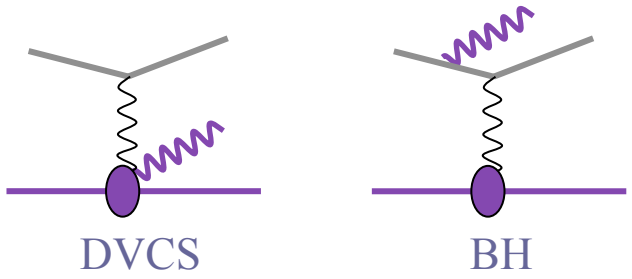
$E, \tilde{E}$: flip nucleon helicity

3 variables:
- x: aver. long; momentum
- ξ: long. mom. difference
- t: four-momentum transfer

GPDs: encode the correlation between the long. momentum x and the transverse position b_T

DVCS cross section for μ^+ and μ^-

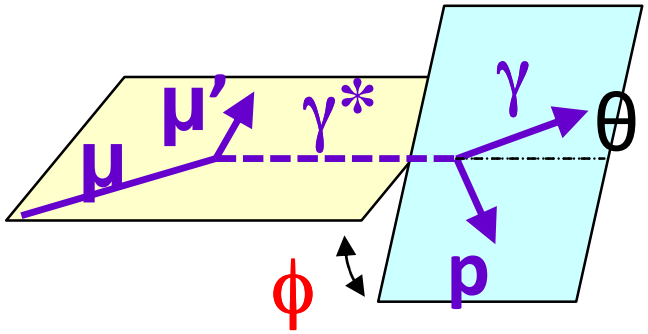
- Cross section for $\mu p \to \mu p \gamma$
  - DVCS and BH (known) processes:



$$d\sigma = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, a^{BH} \mathrm{Re}\, A^{DVCS} + e_\mu P_\mu\, a^{BH}\, \mathrm{Im}\, A^{DVCS}$$

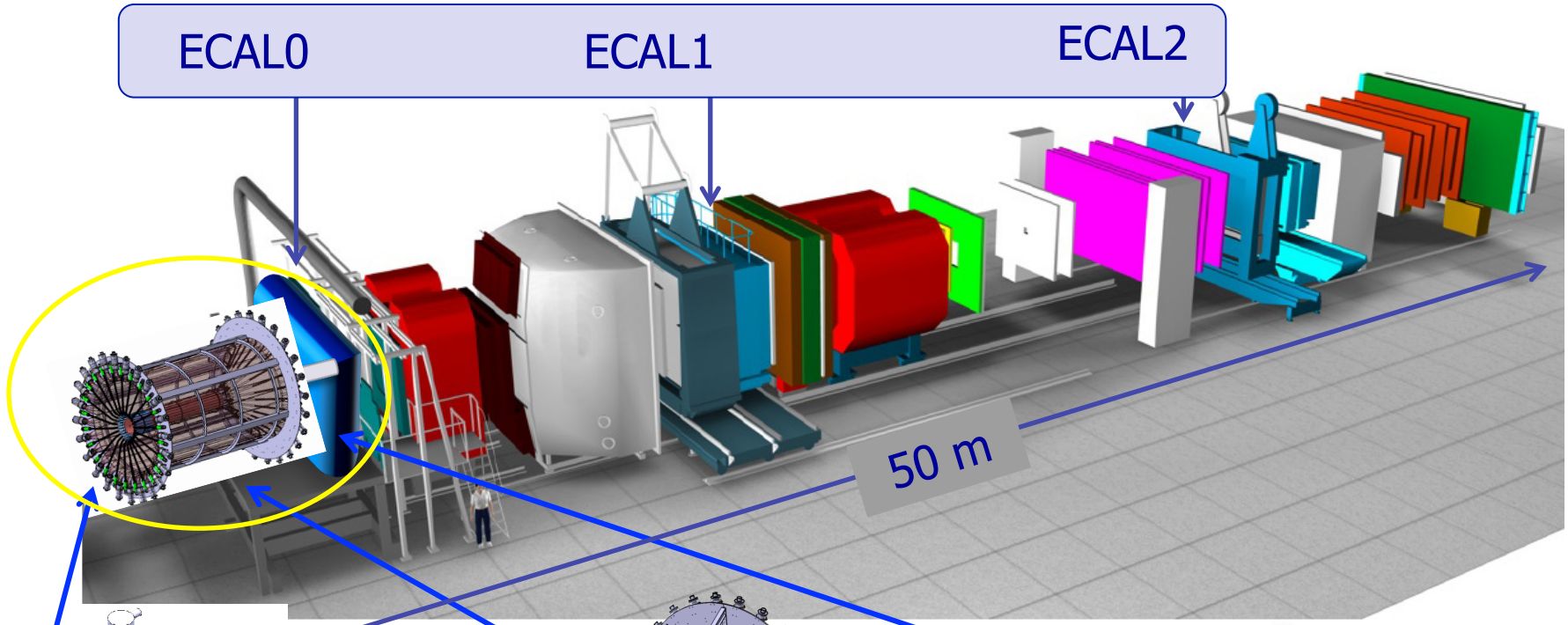
Beam polarization: P_μ beam charge: e_μ

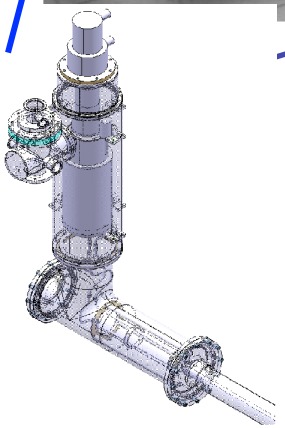
- COMPASS beams: opposite charge/spin
  - Charge-and-Spin Sum
  - Charge-and-Spin Difference



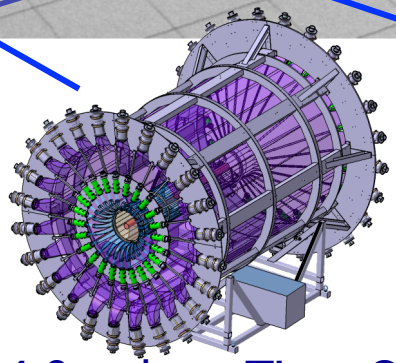
Access both Re($\boldsymbol{H}$) and Im($\boldsymbol{H}$) by measuring the Sum and the Difference

DVCS run – main new equipment

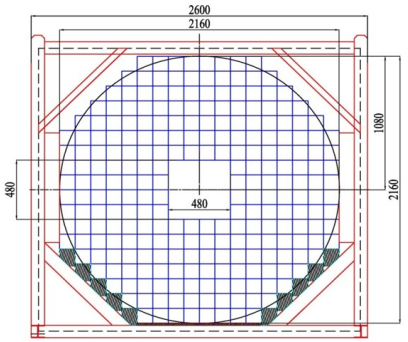




2.5 m long LH target

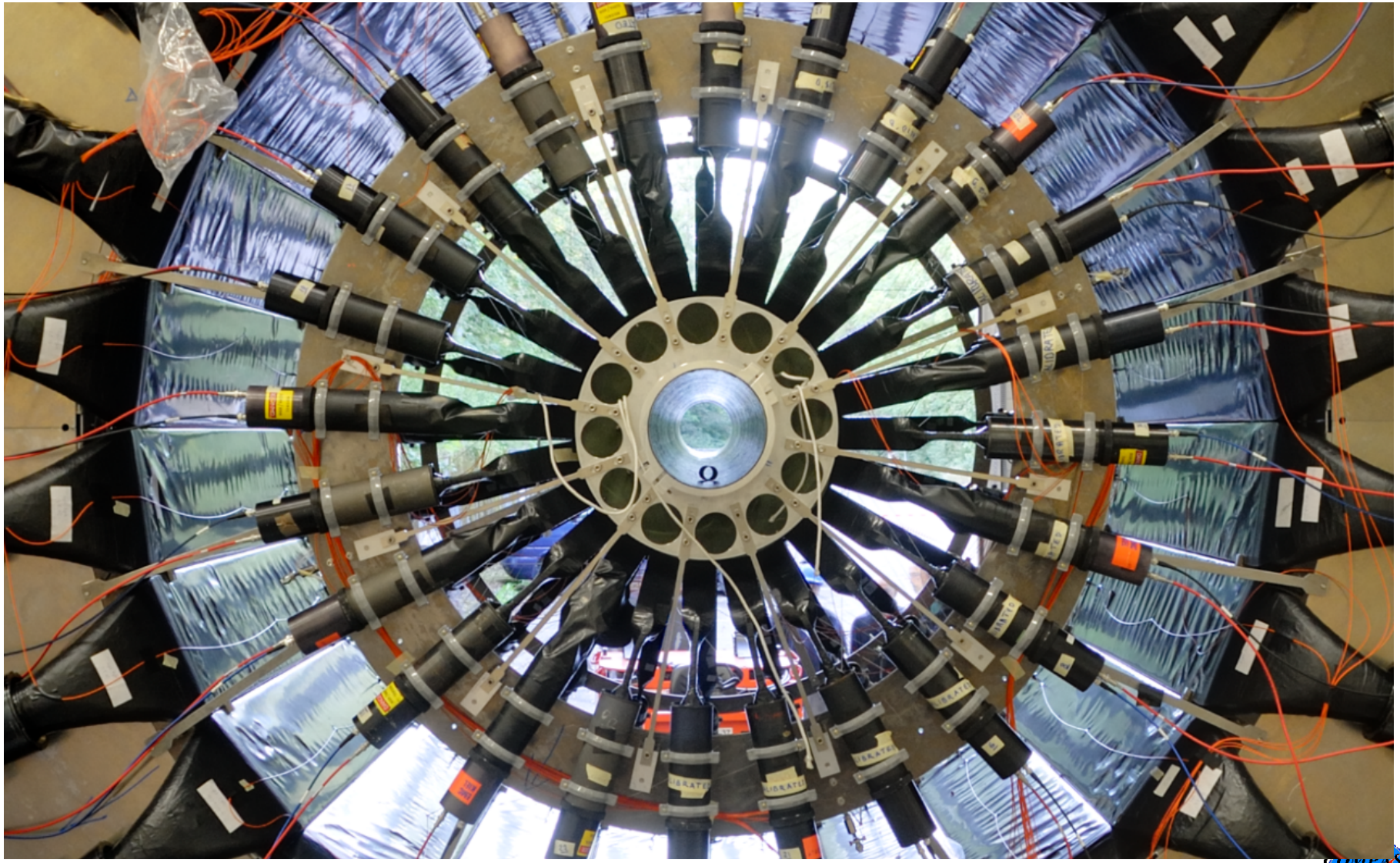


4.0 m long Time-Of-Flight detector: 24 inner and 24 outer slabs



2x2 m^2 electromagnetic calorimeter, ECAL0

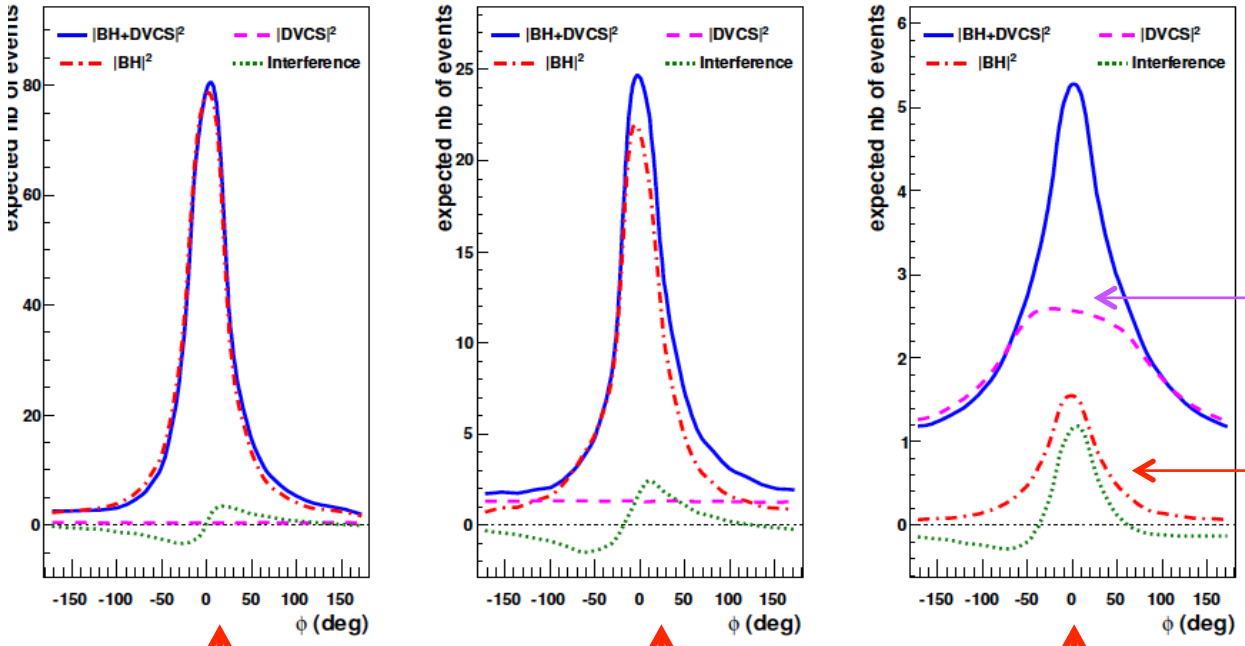
COMPASS “CAMERA” TOF detector

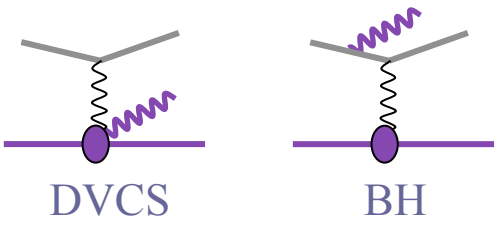


DVCS – the COMPASS x_B regions – SIMULATION

IRFU

$0.005 < x_B < 0.01$ $0.01 < x_B < 0.03$ $x_B > 0.03$

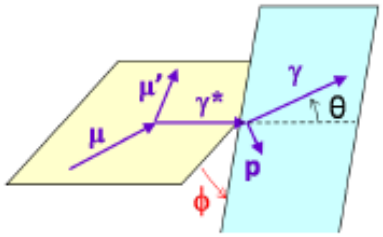




DVCS

BH

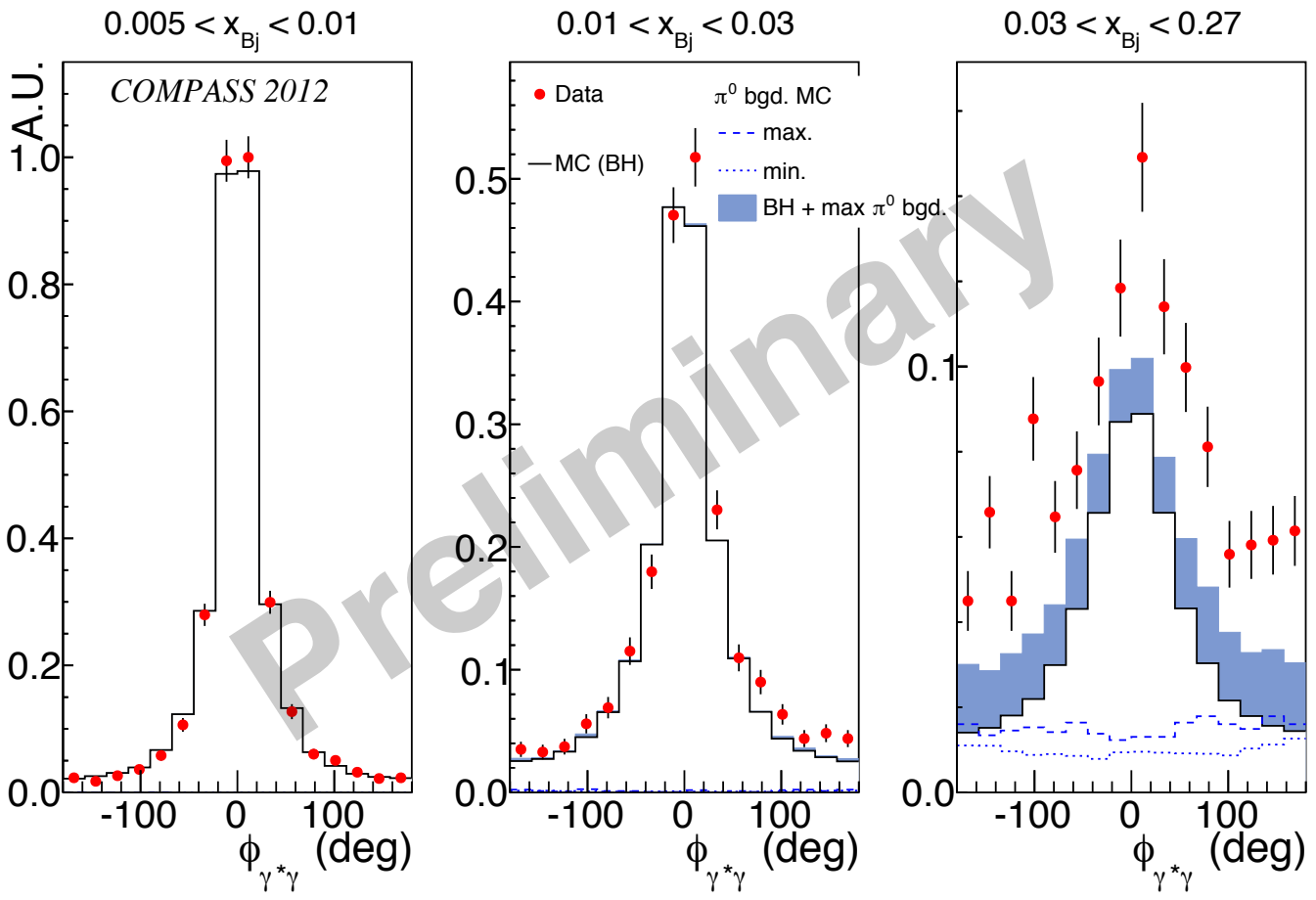
$$d\sigma \propto \left|A^{BH}\right|^2 + \text{Interference} + \left|A^{DVCS}\right|^2$$



Large relative amplitude variation as a function of x

DVCS – the COMPASS x_B regions – REAL DATA

IRFU



2012:
4 weeks
full scale
pilot run

BH dominance | Interference | DVCS dominance

Successful feasibility measurement

COMPASS

DVCS – SUM of μ^+ and μ^- cross sections

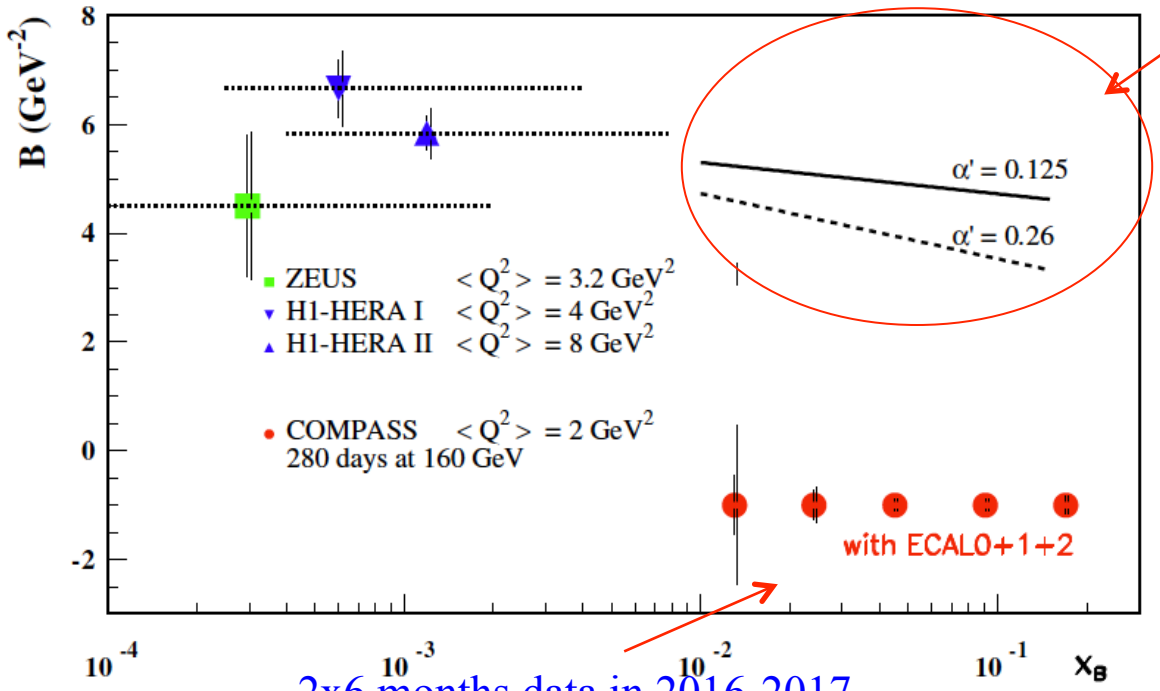
IRFU

$$S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + Ks_1^{Int} \sin\phi$$

Integration over ϕ and BH subtraction $\rightarrow d\sigma^{DVCS}/dt \sim \exp(-B|t|)$

$$r_\perp^2(x_B) = 2B(x_B)$$

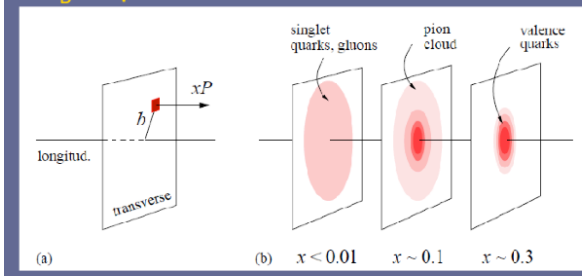
Expected statistics



COMPASS domain

2x6 months data in 2016-2017

x_B-dependent transv. size of nucleon

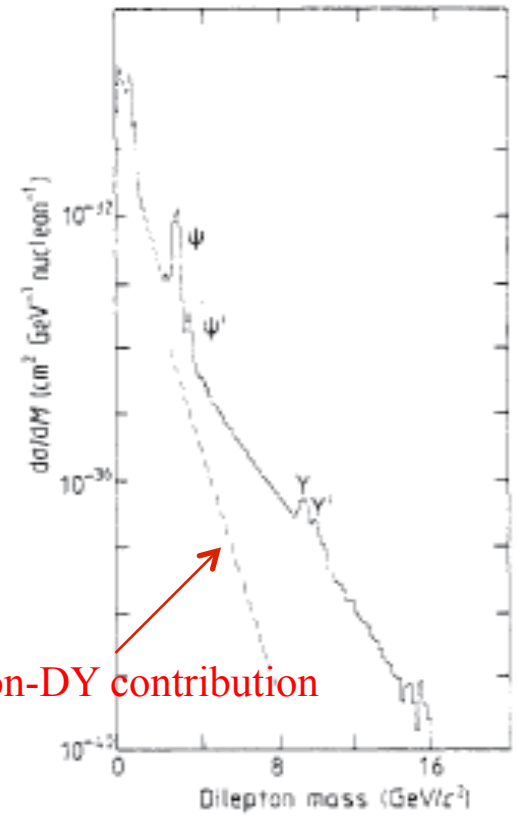


$r_\perp$ parameter from slope of $d\sigma^{DVCS}/dt$

Measurements of GPD: transverse nucleon imaging ("tomography")

Polarized (+ unpolarized) Drell-Yan measurements

Ito et al. PRD 23(1981)604.
(from Kenyon, RPP, 1982)
FERMILAB:



- Drell-Yan cross section:

$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\pi\alpha^2}{9M^4}\frac{x_1 x_2}{x_1 + x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2) + \bar{q}_a(x_1)q_a(x_2)\right]$$

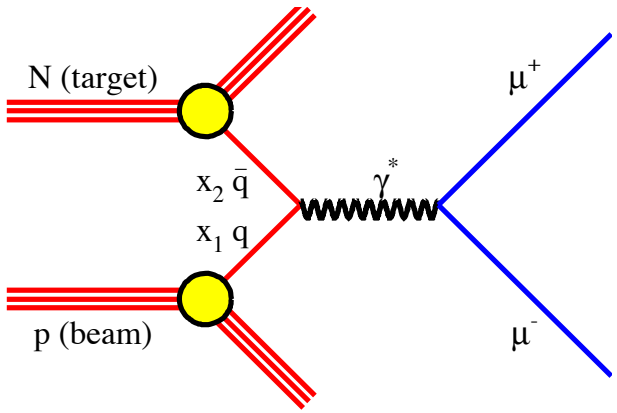
- Features (parton model):
  - Cross section depends on $\tau = M^2/s$
  - Convolution of quark and antiquark PDFs
  - Can be used to determine PDFs in π, K, $\bar{p}$
  - Transverse momentum of $\mu\mu$ pair is small
  - No fragmentation process
- Confirmed in QCD
  - Assumptions: factorization

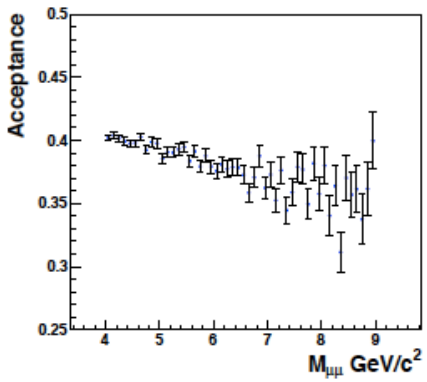
Tung-Mow Yan (SLAC, 1998): *"The process has been so well understood that it has become a powerful tool for precision measurements and new physics"*

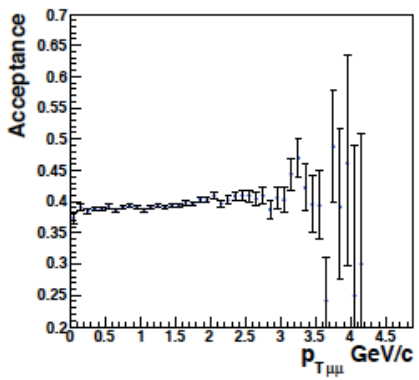
COMPASS exclusive setup advantages

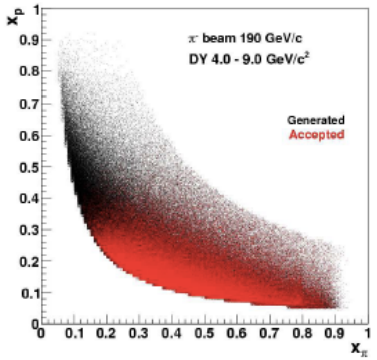
- Hadron (pion + kaon + antiproton) beam
  - With a negative pion beam: ū/u annih.
- Transversely polarized p (NH_3) target
- Large and uniform muon angular acceptance
  - dominated by valence quarks ($x \geq 0.1$)

$$\pi^- \vec{p} \rightarrow \mu^+ \mu^- X$$









COMPASS: only place in the world with high-energy valence antiquark beams

TMDs in Drell-Yan and SIDIS

- SIDIS vs TMD
  - SIDIS: TMD and FF
  - Drell-Yan: two TMDs

$$\sigma^{SIDIS} \propto TMD_p(x,k_T) \otimes D_f^h(z,Q^2)$$

$$\sigma^{DY} \propto TMD_\pi \otimes TMD_p$$

- Factorization and gauge invariance:

Collins, Soper, Sterman,
Adv. Ser. High En Phys. 5, 1988.

  - TMDs (unlike PDFs) can be process dependent ("non-universality")
  - Opposite sign in SIDIS and DY processes for T-odd TMDs:

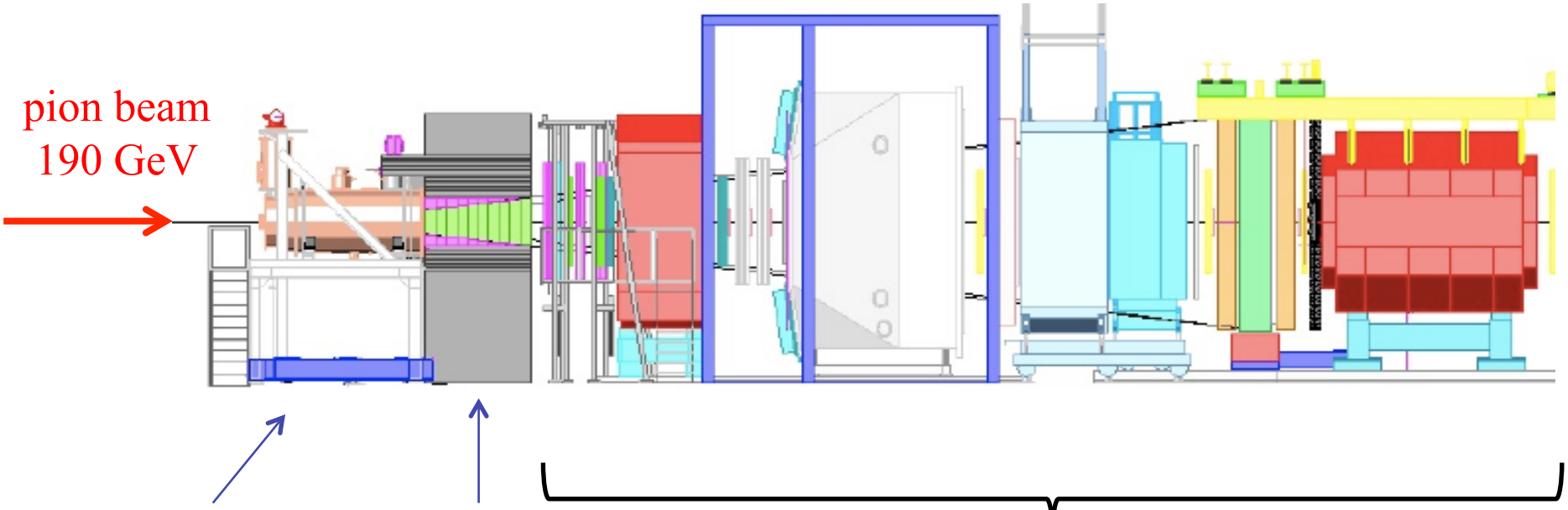
Sivers:
$$f_{1T}^{\perp}(SIDIS) = -f_{1T}^{\perp}(DY)$$

Boer-Mulders:
$$h_1^{\perp}(SIDIS) = -h_1^{\perp}(DY)$$

Crucial test of the QCD factorization approach

NB: Recent results of TSA for W/Z prod:
STAR@RHIC: arXiv: 1511.06003

COMPASS for Drell-Yan setup

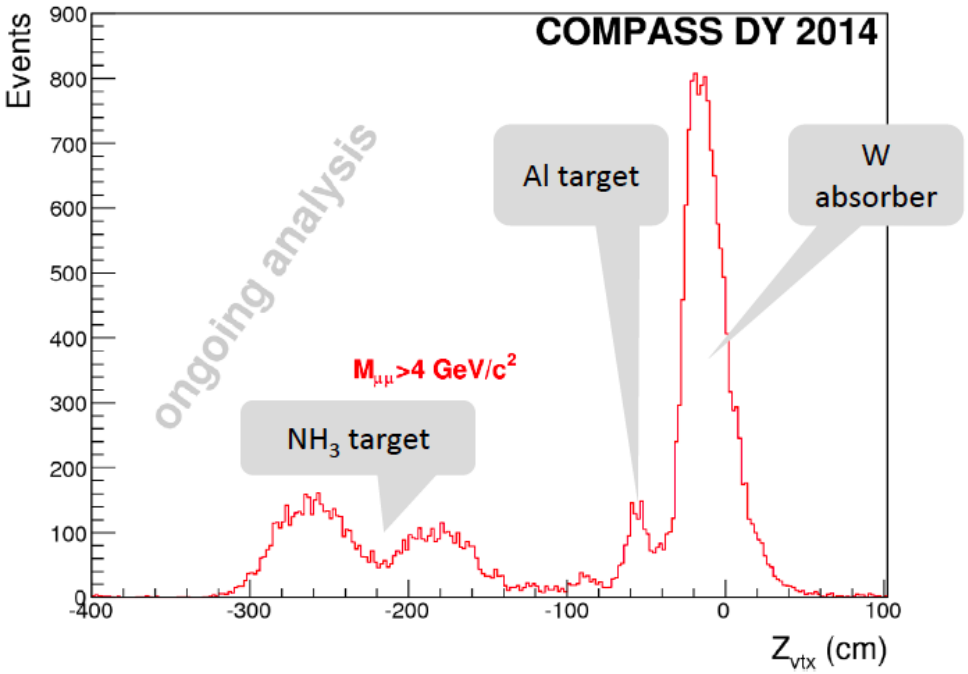


- Small cross sections – high intensity h beam (~10^9/spill of 10 sec)
- Nuclear targets: Al and W

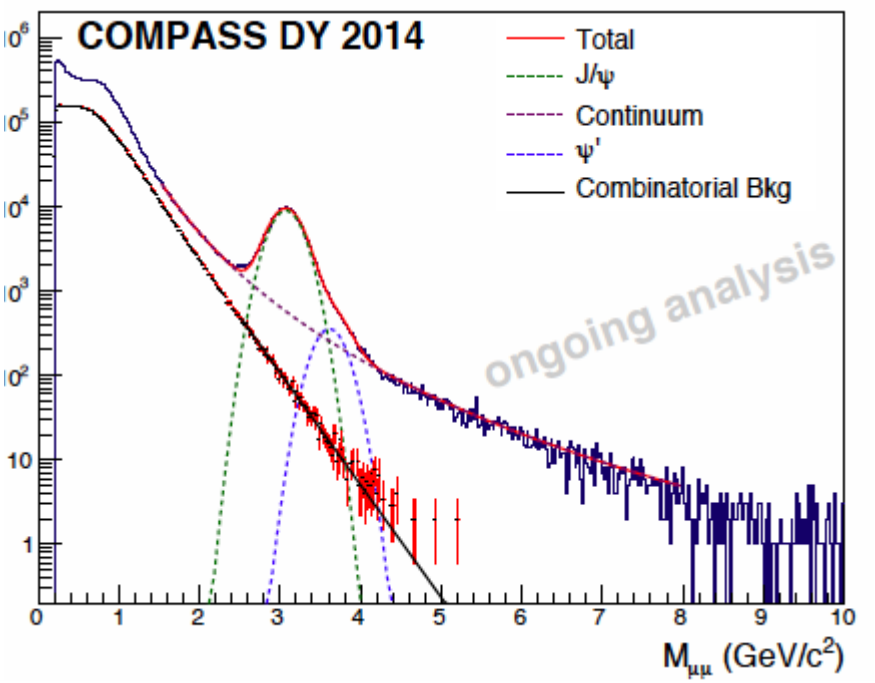
Drell-Yan – pilot run data taking (end 2014)

- 190 GeV negative pion beam, $I \leq 8 \times 10^7$/s, no target polarization, ~2 weeks of data

Z-vertex distribution



High-mass ($M_{\mu\mu} > 4$ (GeV/c)^2 distribution

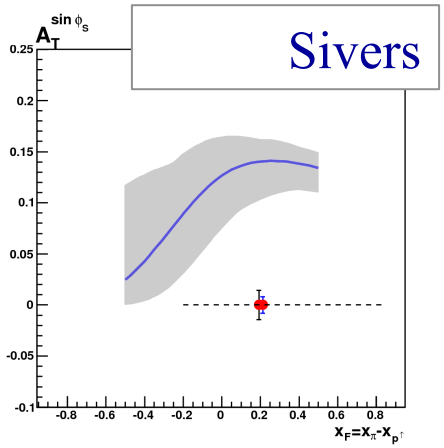


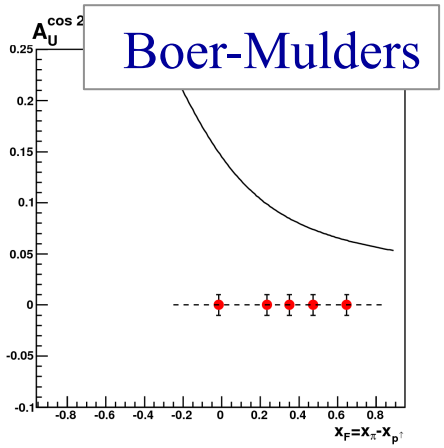
Polarized Drell-Yan – expected results

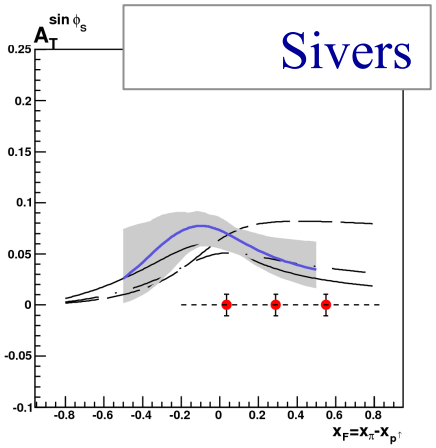
- 280 days of data, 2x55 cm NH_3 target

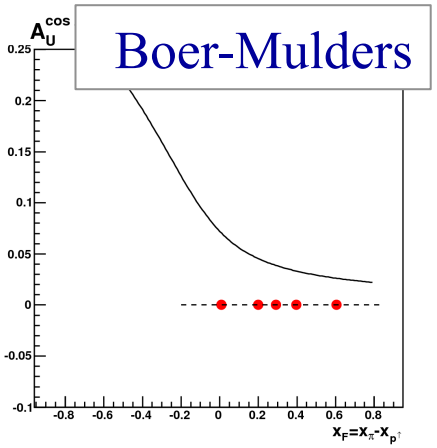
HMR : 4 (GeV/c^2) < Mμμ < 9 (GeV/c^2)

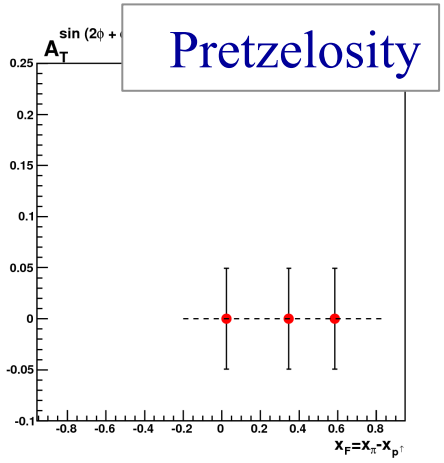
IMR : 2 (GeV/c^2) < Mμμ < 2.5 (GeV/c^2)

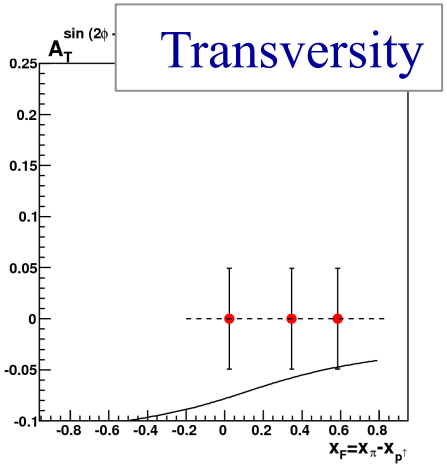


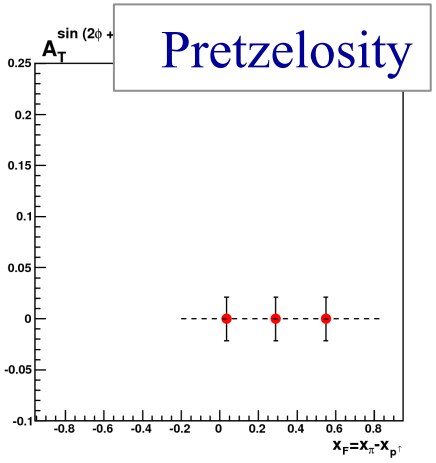


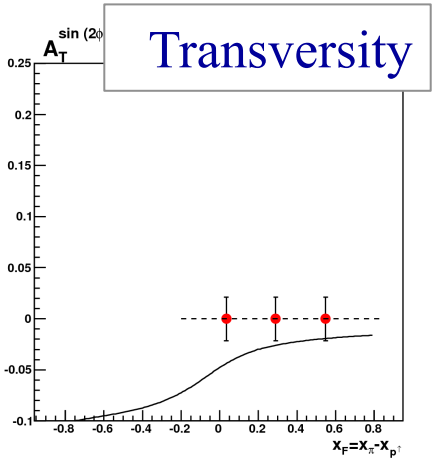












Summary

- COMPASS is the largest fixed-target experiment at CERN
- Unique combination of hadron and muon beams of both polarities
- Avery versatile experimental setup
- Rich physics program dedicated to both nucleon structure and hadron spectroscopy studies

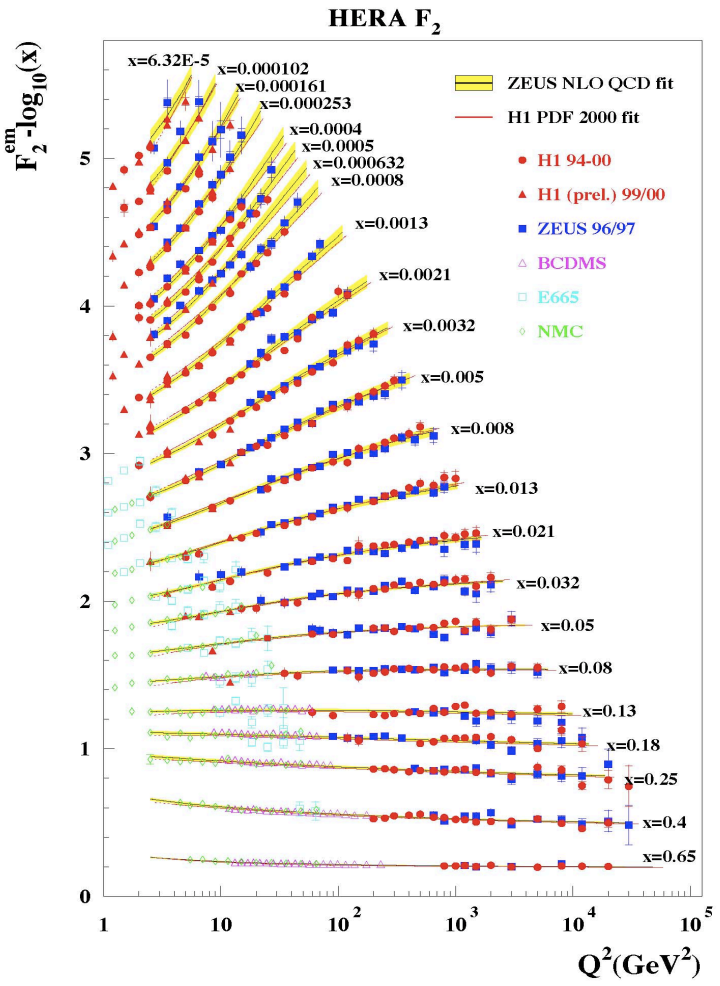
- Present schedule
  - 2015 : Drell - Yan data taking (1st "year" ≈ 140 days)
  - 2016 : DVCS data taking
  - 2017 : DVCS data taking
  - 2018 : Drell-Yan data taking (2nd year)

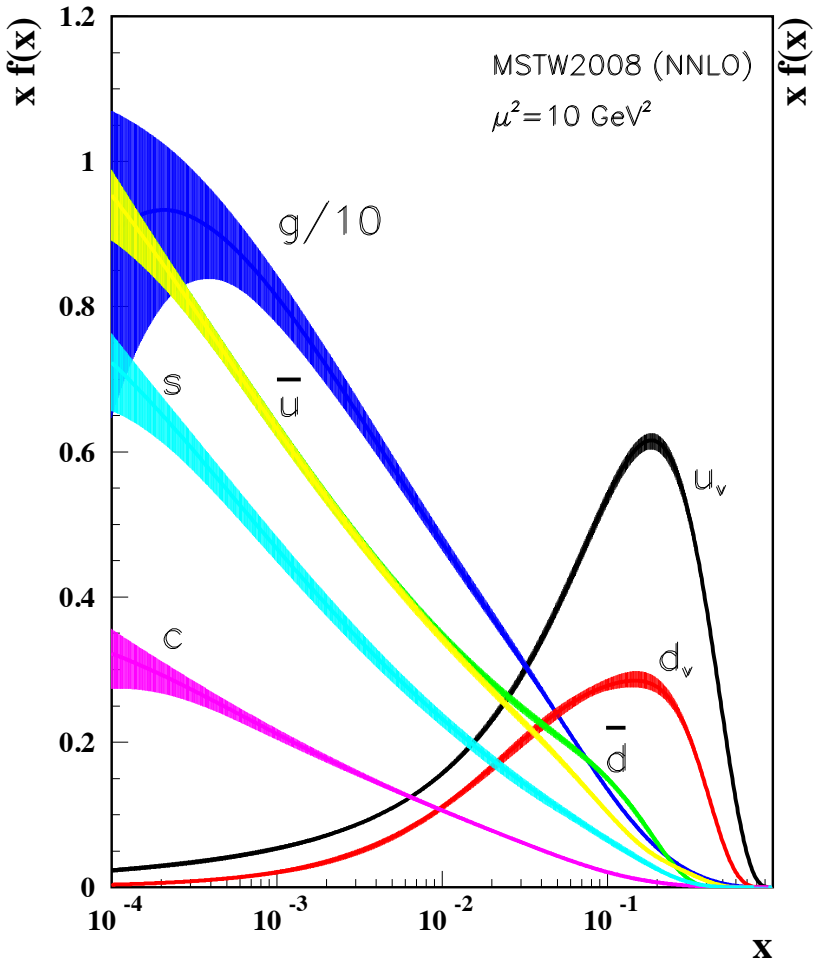
COMPASS physics beyond 2020

- First ideas: submitted to European Strategy Preparatory Group, 2012
  - Spectroscopy: 280 GeV, π, K, $\bar{p}$ separation
  - GPD *E*: Measurements with a polarized target
  - SIDIS: 100 GeV, transv. polarized p and d targets
  - Drell-Yan: Transv pol. d and p targets, unpolarized p, d targets nuclear targets (EMC effect), and π, K, $\bar{p}$ separation

- Dedicated workshop before proposal:
  - Planned in early Spring 2016.
  - New ideas and new collaborators welcome!

Unpolarized DIS measurements and QCD fits

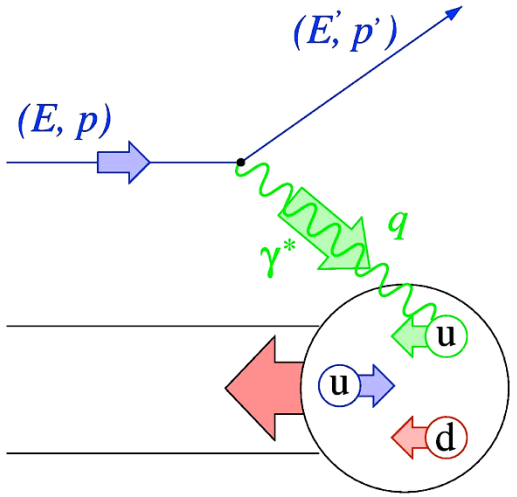




Data span over 5 decades of Q^2 ! –> unpolarized PDFs

Deep-Inelastic Lepton Scattering

- Interaction due to one single photon
- Scattering from nearly free partons
- PDF depend on x only (Bjorken, 1968)
  - Q^2 dependence: QCD evolution
- Polarization: asymmetry measurements:



$$A_{\text{exp}}(x) = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}} \approx DA_1(x);$$

$$g_1(x) = A_1(x)\frac{F_2(x)}{2x(1+R)}$$

Measurements of the (pol) DIS structure functions give access to the (pol) Parton Distribution Functions (PDF)

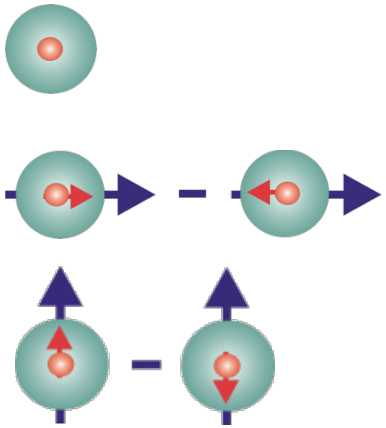
Transversity spin and transverse momentum nucleon structure

- Transversity PDF: correlation between the transverse spin of the quark and the transverse spin of the nucleon.
- Three distribution functions are needed to describe the nucleon longitudinal momentum and spin structure (collinear case)

Momentum distribution $F_1(x)$

Helicity distribution $g_1(x)$

Transversity distribution $h_1(x)$



$$A_{\mathrm{Coll}} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot \Delta_T^0 D_q^h(z, p_T^h)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h(z, p_T^h)}$$

Sum of z-integrated pion multiplicities ($\pi^+ + \pi^-$)

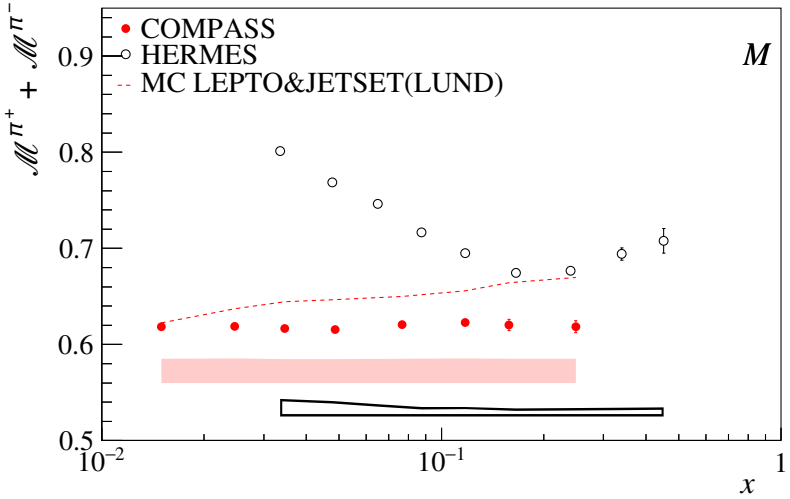
IRFU

- For an isoscalar target, the sum is:

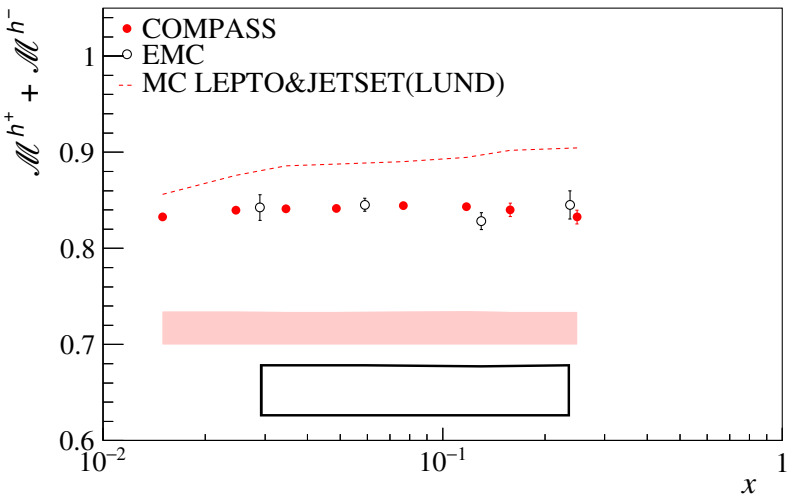
$$M^{\pi^+} + M^{\pi^-} = D_{fav} + D_{unf} + \frac{2S}{5Q + 2S} \cong D_{fav} + D_{unf}$$

$$\begin{cases} Q = u + \bar{u} + d + \bar{d} \\ S = s + \bar{s} \end{cases}$$

Pion multiplicities

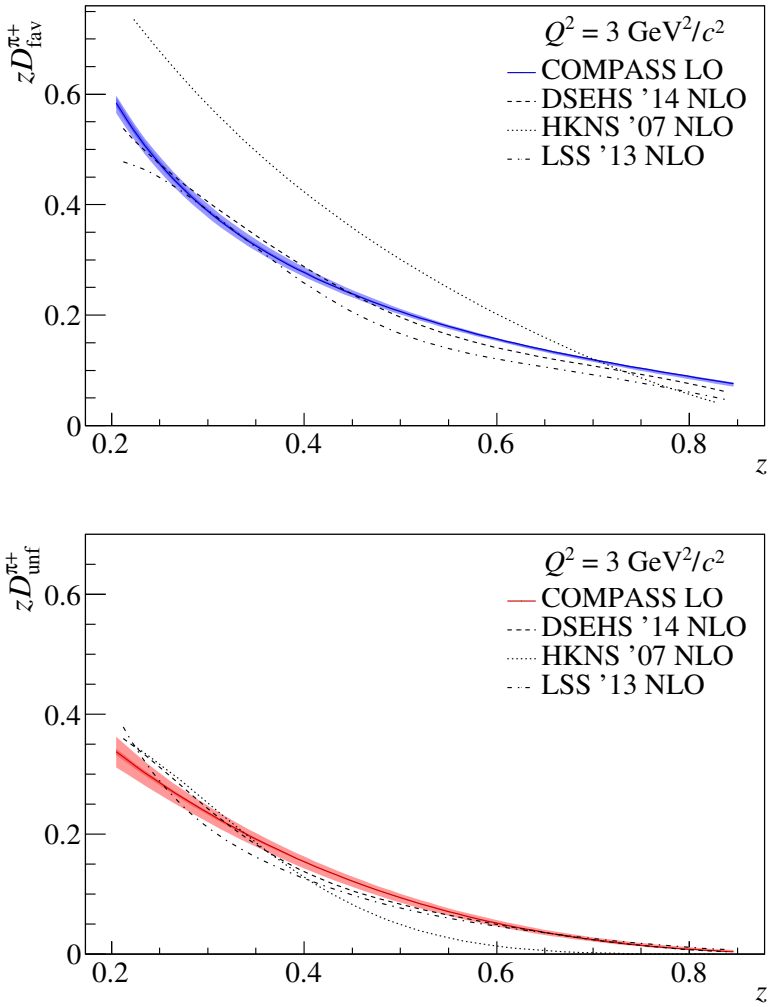


Hadron multiplicities

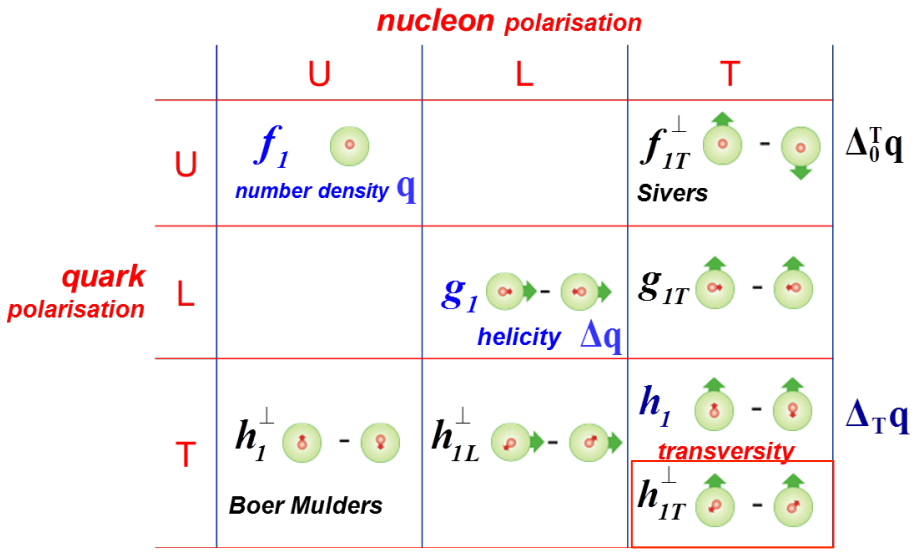


No x dependence observed, neither for pions, nor for hadrons
In agreement with previous EMC results for unidentified hadrons

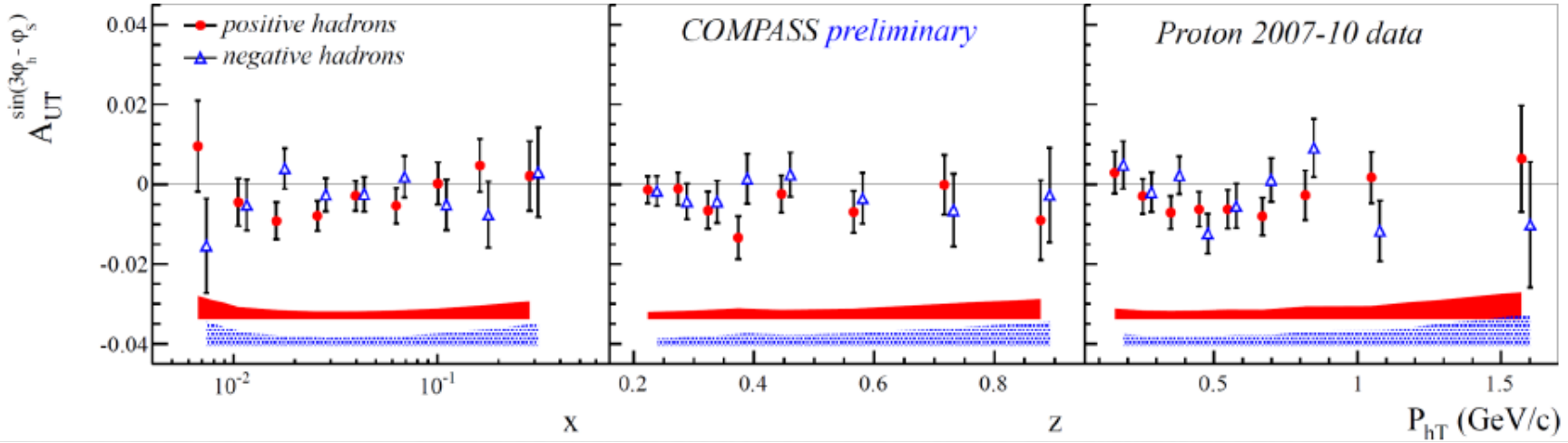
Pion FFs: LO fit results



Other SSA – Pretzelosity TMD



Proton target



DY (polarized) cross section expansion

- Full formalism for two spin ½ hadrons
- COMPASS: access 4 TMDs:
  - Boer-Mulders, Sivers, Pretzelosity, Transversity

Arnold, Metz and Schlegel,
Phys. Rev. D79 (2009) 034005.

- Access 4 TMDs – asymmetry modulations:

Boer-Mulders $A_U^{\cos 2\phi} \propto 1 + \bar{h}_1^{\perp} \otimes h_1^{\perp} \cos 2\phi$

Sivers $A_T^{\sin\phi} \propto S_T \left[\bar{f}_1 \otimes f_{1T}^{\perp} \sin\phi_s \right)\Big]$

Pretzelosity $A_T^{\sin(2\phi+\phi_s)} \propto S_T \left[\bar{h}_1^{\perp} \otimes h_{1T}^{\perp} \sin(2\phi + \phi_s) \right]$

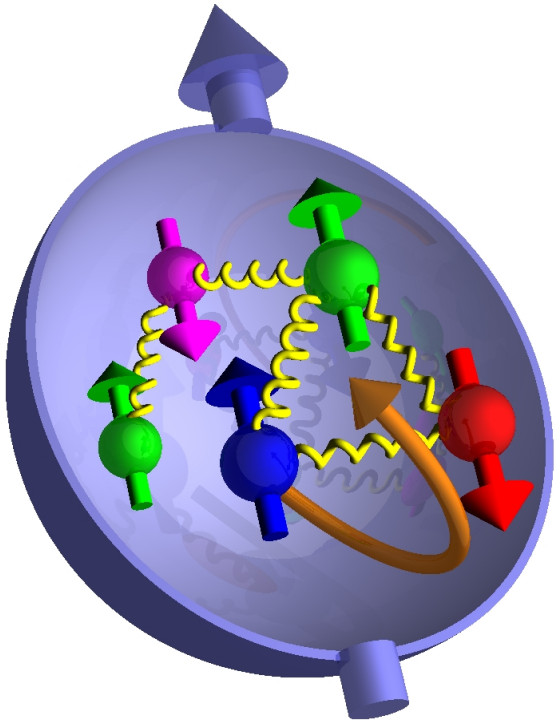
Transversity $A_T^{\sin(2\phi-\phi_s)} \propto S_T \left[\bar{h}_1^{\perp} \otimes h_1 \sin(2\phi - \phi_s) \right]$

Worm-Gear Not possible: needs double polarization

All four TMDs are also measured in SIDIS

Reminder: the proton spin problem

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_q + L_g$$



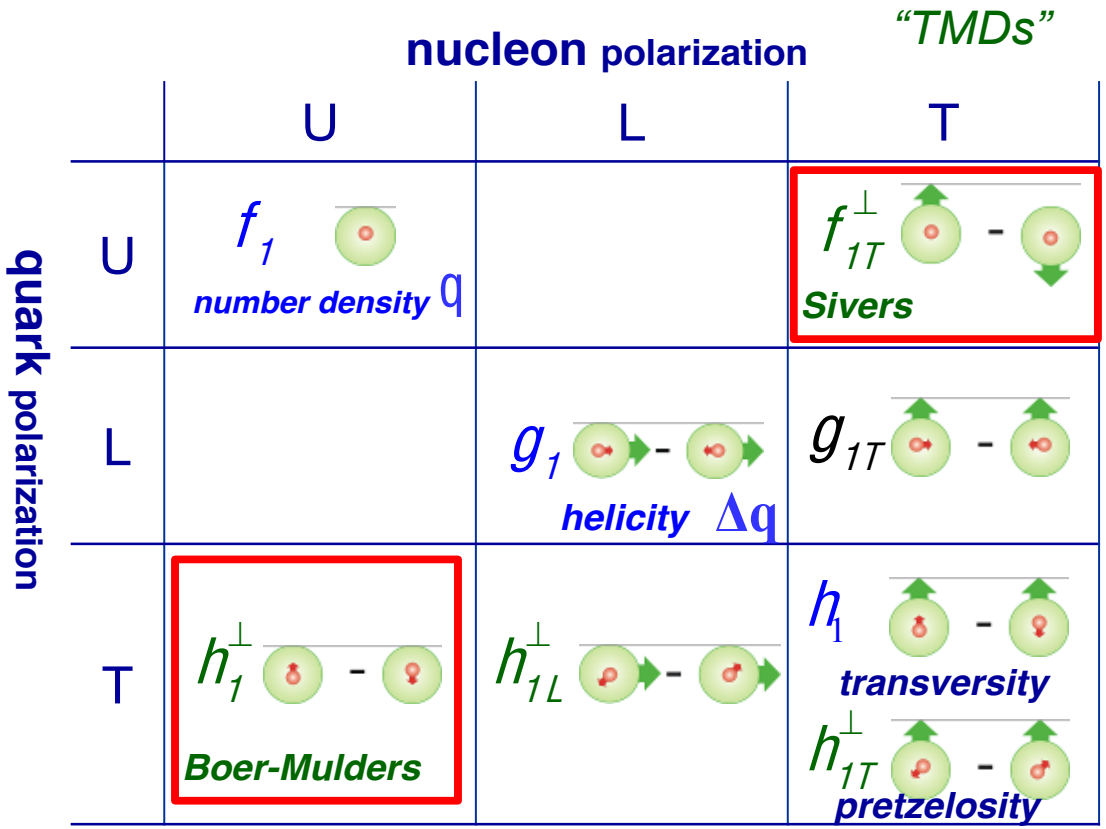
Naive quark model : $\Delta\Sigma = 1.0$

Relativistic quark model : $\Delta\Sigma \approx 0.6$

Experiment : $\Delta\Sigma \approx 0.3$

Physics goals for polarized DIS:
Improve accuracy on $\Delta\Sigma$, measure Δg, try to access L

Transverse Momentum Dependent PDFs



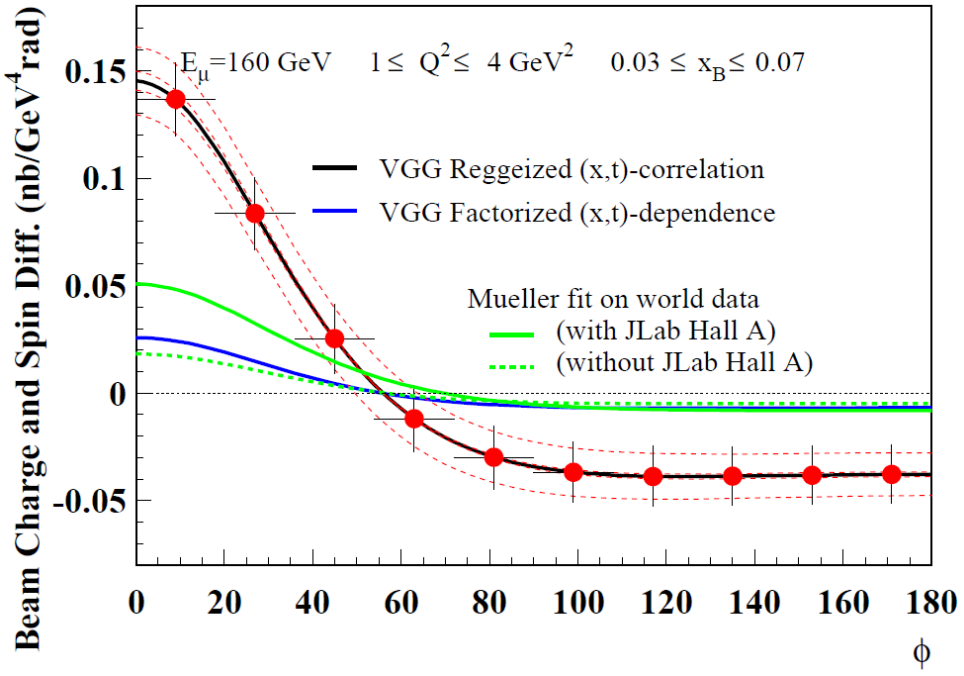
- Sivers: correlation between the quark transverse momentum and the nucleon transverse spin (polarized nucleon)
- Boer-Mulders: correlation between the quark transverse spin and transverse momentum (unpolarized nucleon)

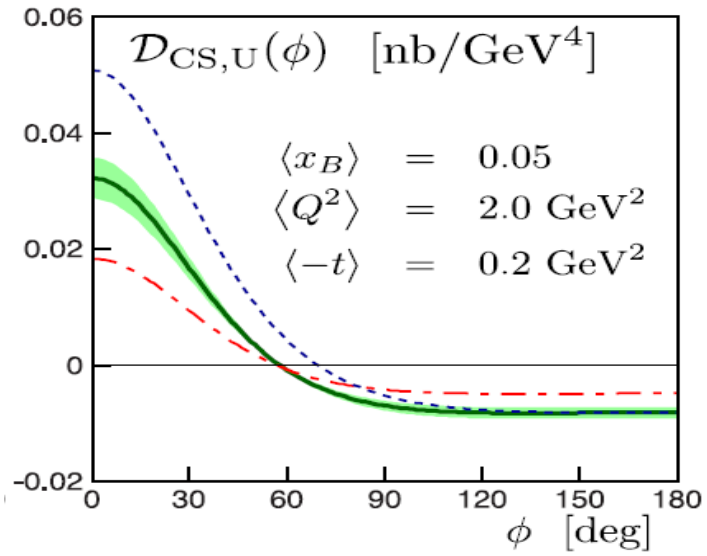
Beam charge and spin difference

$$D_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) - d\sigma(\mu^{-\rightarrow}) \propto c_0^{Int} + c_1^{Int}\cos(\phi)$$

$$c_{0,1}^{Int} \propto Re(F_1\mathcal{H})$$

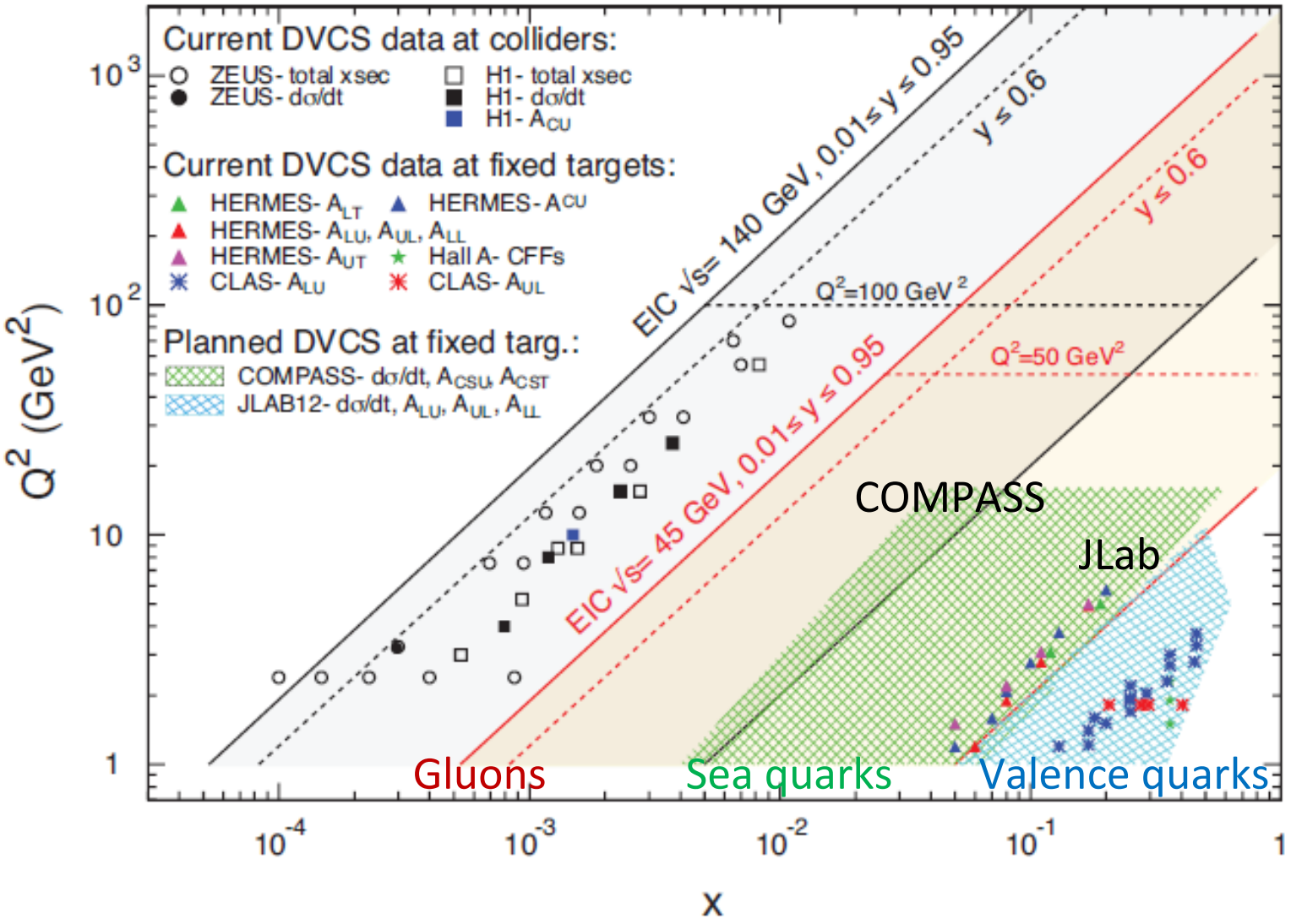
Expected statistics in 2 x 140 days of data taking

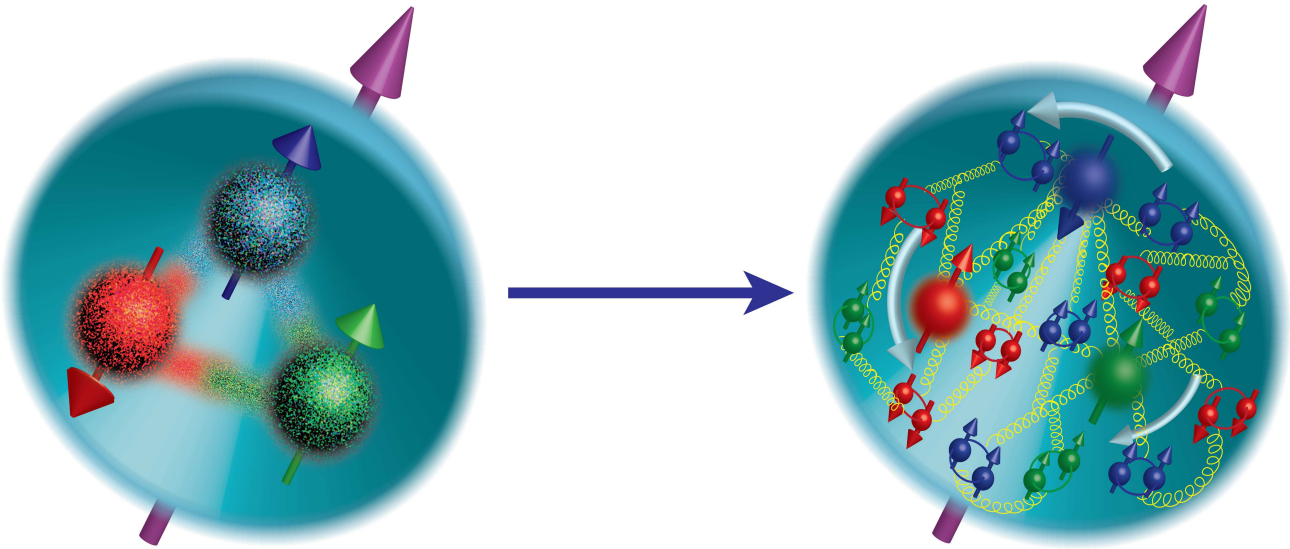




Kroll, Moutarde, Sabatié, EPJC 73(2013)2278

Present and planned GPD measurements





Nucleon spin structure

Transverse Momentum Distribution PDFs

Generalized Parton Distributions

Drell-Yan measurements