The New Spin Physics Program of the COMPASS Experiment

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On behalf of the COMPASS Collaboration

3er International Conference on New Frontiers in Physics 2014

02 Aug 2014

FCT Fundação para a Ciência e a Tecnologia

MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

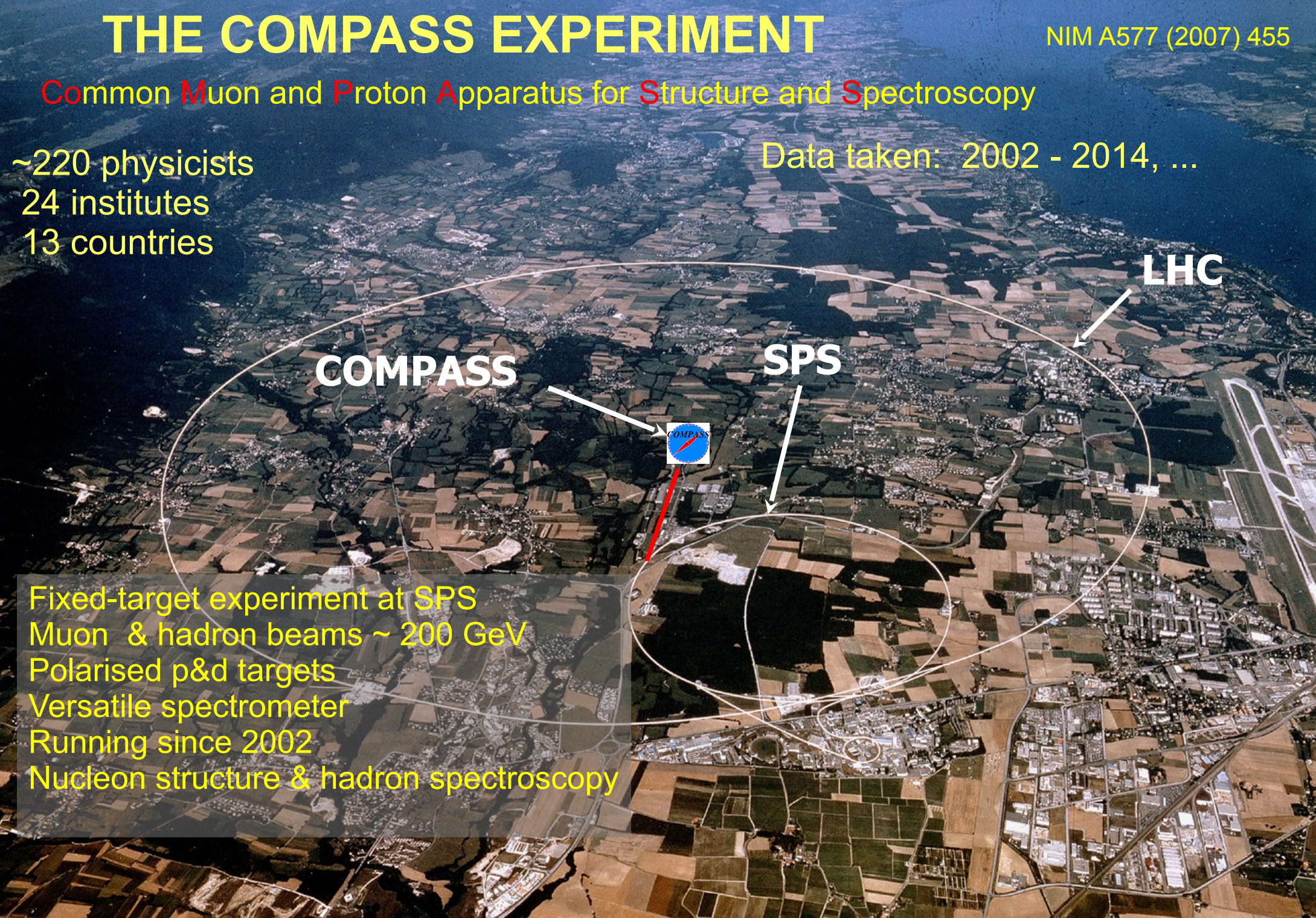
THE COMPASS EXPERIMENT

NIM A577 (2007) 455

Common Muon and Proton Apparatus for Structure and Spectroscopy

~220 physicists
24 institutes
13 countries

Data taken: 2002 - 2014, ...



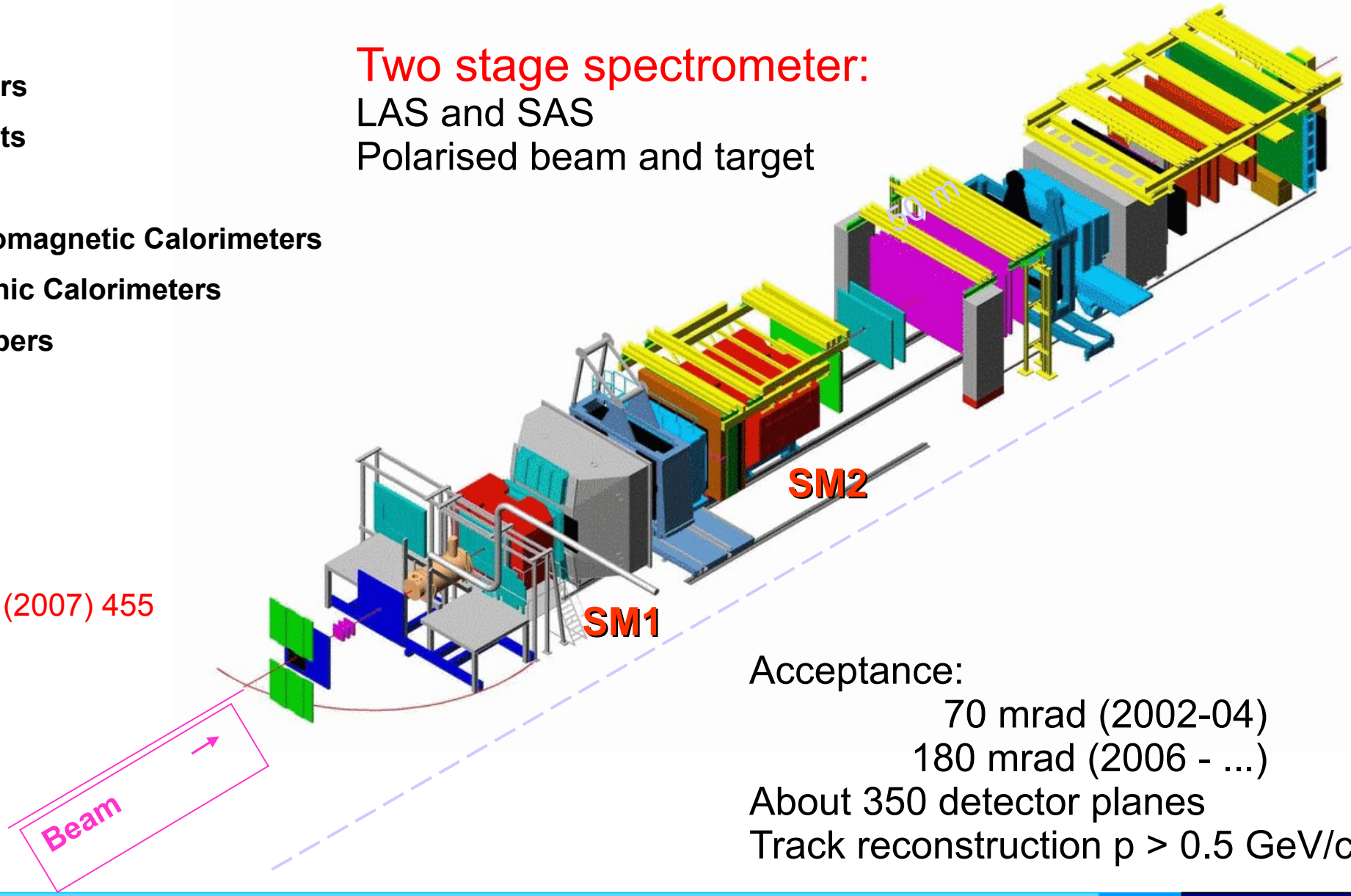
Fixed-target experiment at SPS
Muon & hadron beams ~ 200 GeV
Polarised p&d targets
Versatile spectrometer
Running since 2002
Nucleon structure & hadron spectroscopy

The COMPASS Spectrometer

Common Muon and Proton Apparatus for Structure and Spectroscopy

- Trackers
- Magnets
- RICH
- Electromagnetic Calorimeters
- Hadronic Calorimeters
- Absorbers
- Target

Two stage spectrometer:
LAS and SAS
Polarised beam and target



NIM A577 (2007) 455

Acceptance:
70 mrad (2002-04)
180 mrad (2006 - ...)
About 350 detector planes
Track reconstruction p > 0.5 GeV/c

What COMPASS did

COMPASS (2002 – 2012)

- Muon Program (2002 – 2007, 2010 – 2011):

  Naturally and longitudinally polarised μ+ beam (@ 160 / 200 GeV/c) scattering off longitudinally and transversely polarised targets: ^{6}LiD (d), NH_3 (p)

  - Quarks contribute 30% to the nucleon spin. (PLB647,8)
  - Gluon contribution to the nucleon spin is small (@ $x \sim 0.1$). (PRD 87,052018; PLB676,31)
  - 3 leading twist Parton Distribution Functions (PDFs) (f_1, g_1, h_1) were investigated. (PLB 690, 466; PLB 717, 376, 383)

- Hadron Program (2008 – 2009, 2012):

  Unpolarised hadron beams (π, K, p , @160 / 190 GeV/c) on unpolarised targets (Liquid H_2 , Pb, Ni, Cu and W)

  - Hadron spectroscopy: including searches of exotic hadrons, hybrids and glueballs. (PRL 108,192001; EPJC 73,2581; PRL 104,241803)
  - Pion polarisabilities.

What COMPASS did

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- Hadron Program (2008 – 2009, 2012):

$$S_N = \tfrac{1}{2} = \tfrac{1}{2}\,\Delta\Sigma + \Delta G + L$$

  Unpolarised hadron beams (π, K, p , @160 / 190 GeV/c) on unpolarised targets (Liquid H_2 , Pb, Ni, Cu and W)

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  - Pion polarisabilites.

The new COMPASS-II program

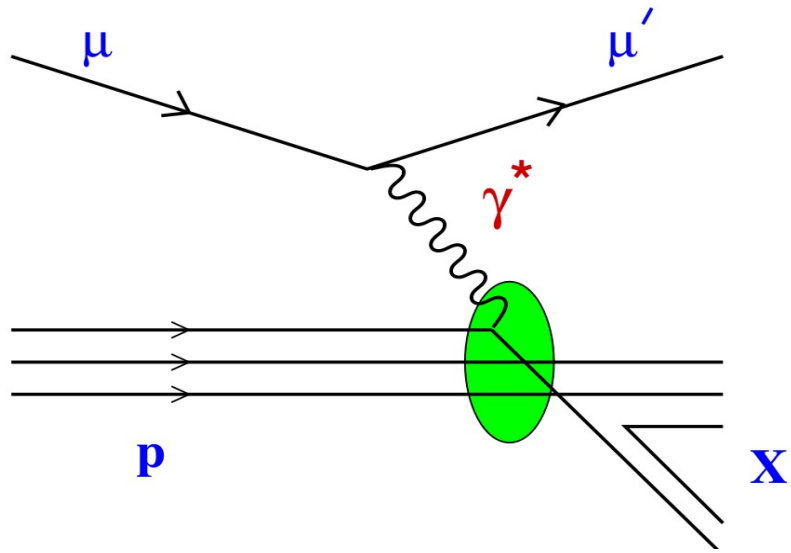
The main idea is to improve the description of the nucleon.

- Semi-Inclusive Deep Inelastic Scattering (SIDIS) studies to improve the Fragmentation Functions (FFs) and the PDFs in the strange sector.
- 3-dimensional description of the nucleon, via Generalised Parton Distribution functions (GPDs), using Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP) studies.
- account for intrinsic transverse momentum of partons, via Transverse Momentum Dependent (TMD) PDFs, using Drell-Yan and SIDIS.
- and low energies of QCD: a test of Chiral Perturbation Theory using Pion and Kaon Polarisabilities.

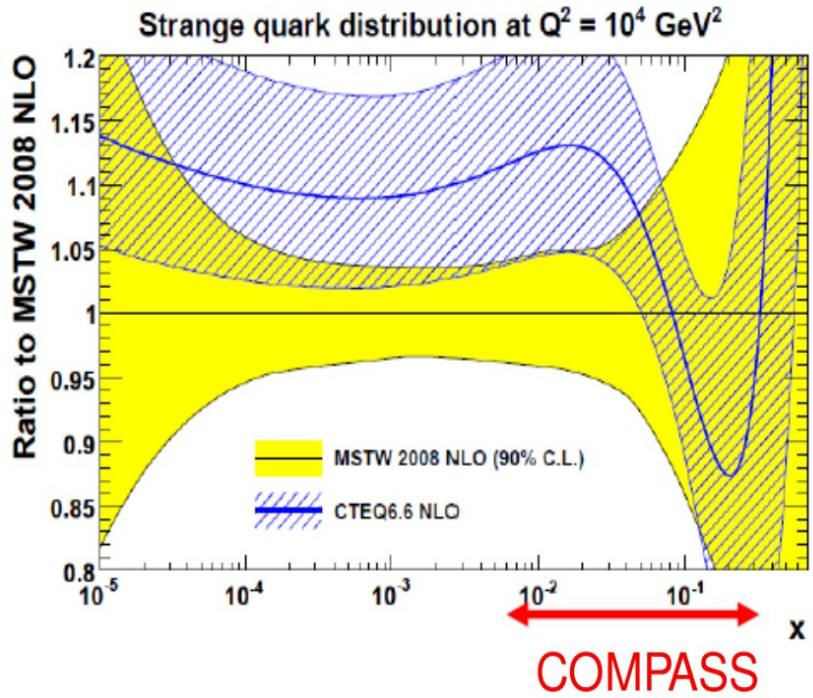
Not covered in this talk

Unpolarised SIDIS

SIDIS is used to extract PDFs and FFs, in particular in the strange sector.



- A liquid hydrogen target will be used to avoid any nuclear effects.
- These data, with PID and charge separation allow to measure hadron multiplicities ($\pi^{\pm}$, π^{0}, $K^{\pm}$, K^{0}, Λ and $\overline{\Lambda}$)
- and combined with previous COMPASS data on ^{6}LiD a very high precision is expected.
- Strong improvement is foreseen for the strange PDF $s(x)$ and FFs



Generalised Parton Distributions (GPDs)

- GPDs give a 3-D picture of the nucleon, by including the transverse position of the constituent quarks.
- GPDs are a generalisation of both nucleon electromagnetic form factors and PDFs.
- They allow to access information on the quarks orbital angular momentum.

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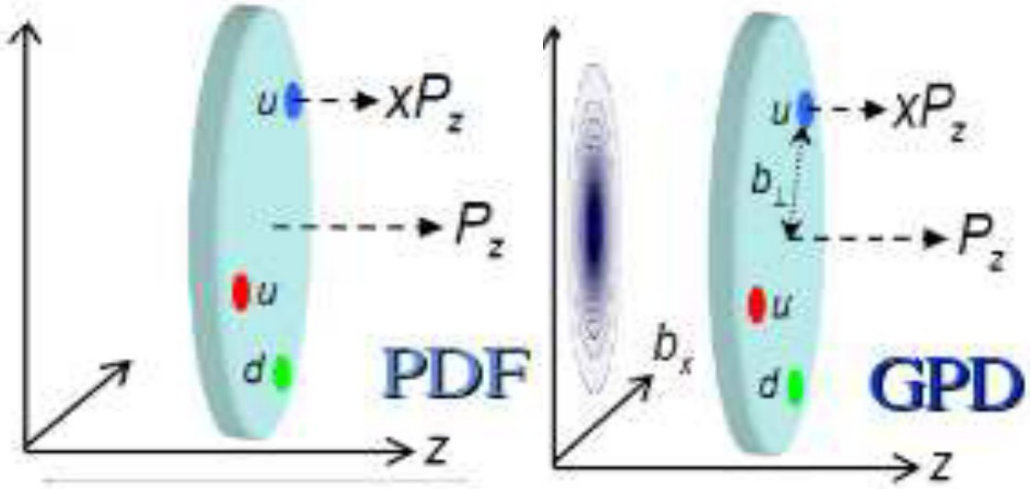
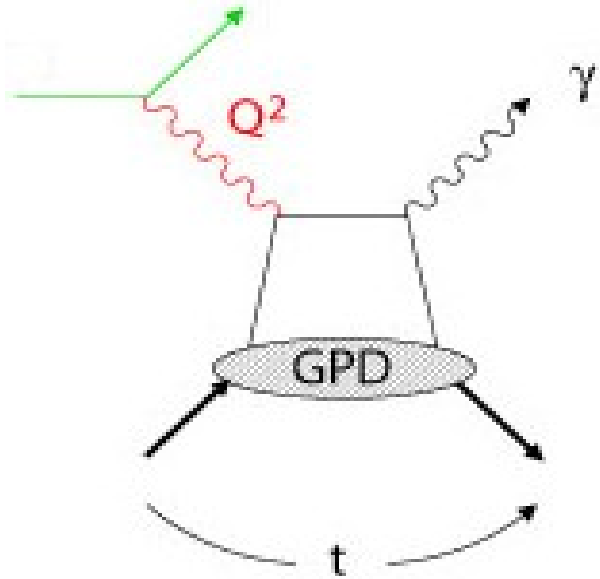
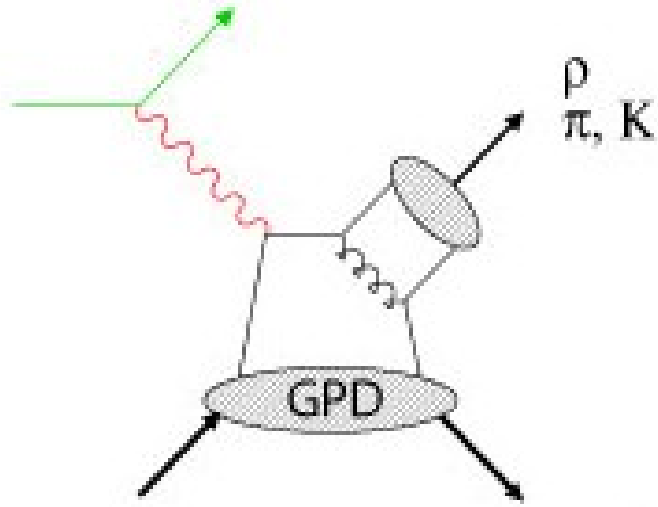


The study of the GPDs can be performed using the DVCS and DVMP mechanisms.



DVCS



DVMP

More about GPDs

- 4 GPDs: $H, E, \widetilde{H}$ and $\widetilde{E}$, for each quark flavour and gluon
- All GPDs depend on 4 variables: x, ξ, t, Q^2 .

- H, E refer to unpolarised distributions
- $\widetilde{H}$, $\widetilde{E}$ refer to polarised distributions

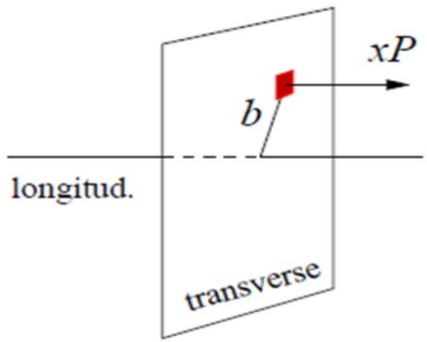
Total quark Angular Momenta

$$J^f = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx\, x\,[H^f(x,\xi,t,Q^2)+E^f(x,\xi,t,Q^2)]$$

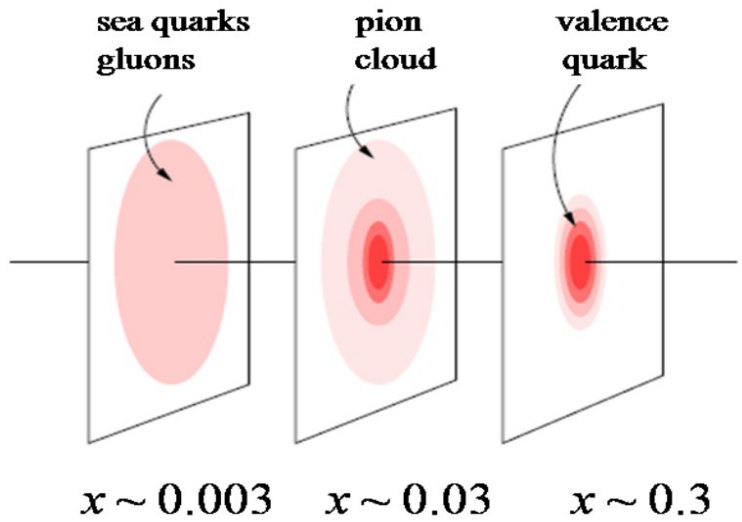
Ji relation
X.-D. Ji, PRL 78 (1997) 610

$\xi=0, \Rightarrow t = -\Delta_\perp^{\,2} \Rightarrow$ no longitudinal transfer.

Fourier trans. of H on $\Delta_\perp$ represents the spatial distribution of the partons as a function of x and $\boldsymbol{b}_\perp$

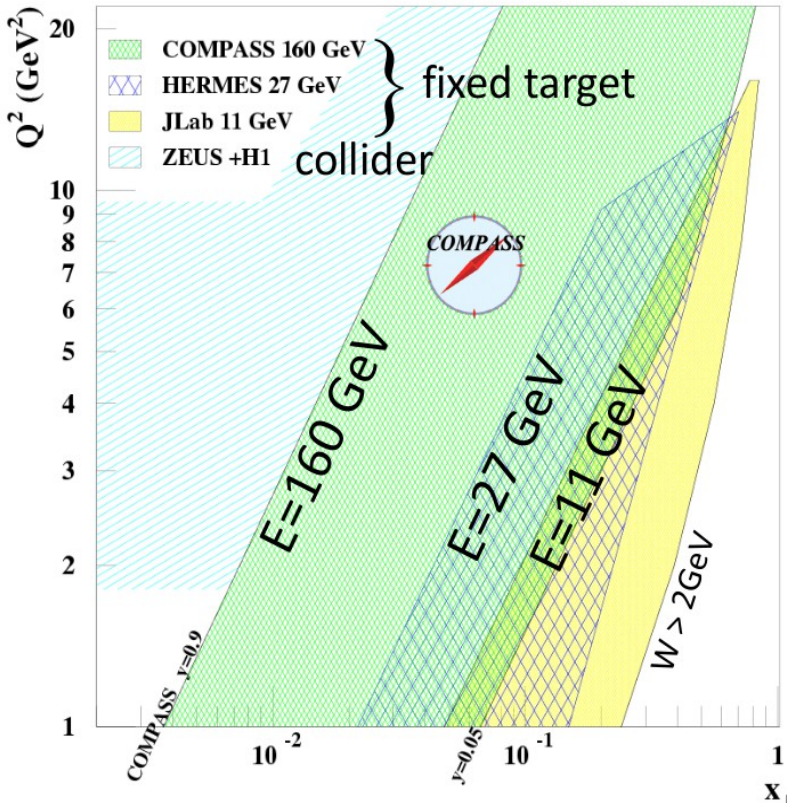


$$q^f(x,\boldsymbol{b}_\perp) = \int \frac{d^2\Delta_\perp}{2\pi} e^{-i\Delta_\perp\cdot\boldsymbol{b}_\perp} H^f(x,0,-\Delta_\perp^2)$$

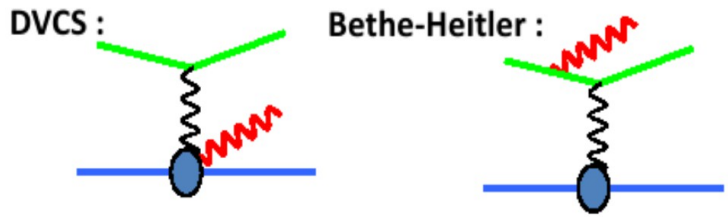


Nucleon tomography

DVCS measurement



DVCS competes with the Bethe-Heitler process



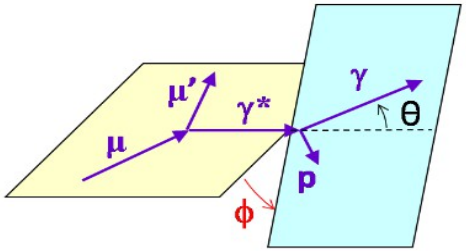
$$d\sigma^{\mu p\to\mu p\gamma} = d\sigma^{BH} + [d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}] + e_\mu[\Re(I) + P_\mu \Im(I)]$$

Observables

$$S_{CS,U} \equiv \mu^{\rightarrow}_{+} + \mu^{\leftarrow}_{-} = 2[d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu \Im(I)]$$

$$D_{CS,U} \equiv \mu^{\rightarrow}_{+} - \mu^{\leftarrow}_{-} = 2[P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu \Re(I)]$$

$$A_{CS,U} \equiv \frac{\mu^{\rightarrow}_{+} - \mu^{\leftarrow}_{-}}{\mu^{\rightarrow}_{+} + \mu^{\leftarrow}_{-}} \qquad \frac{d\sigma^{\mu p\to\mu p\gamma}}{dt} \propto e^{-B(x_B)|t|}$$



These quantities are sensitive to the azimuthal angle between the lepton scattering plane and the photon production plane.

Phase 1: Unpolarised liquid H_2 target $\Rightarrow$ GPD H

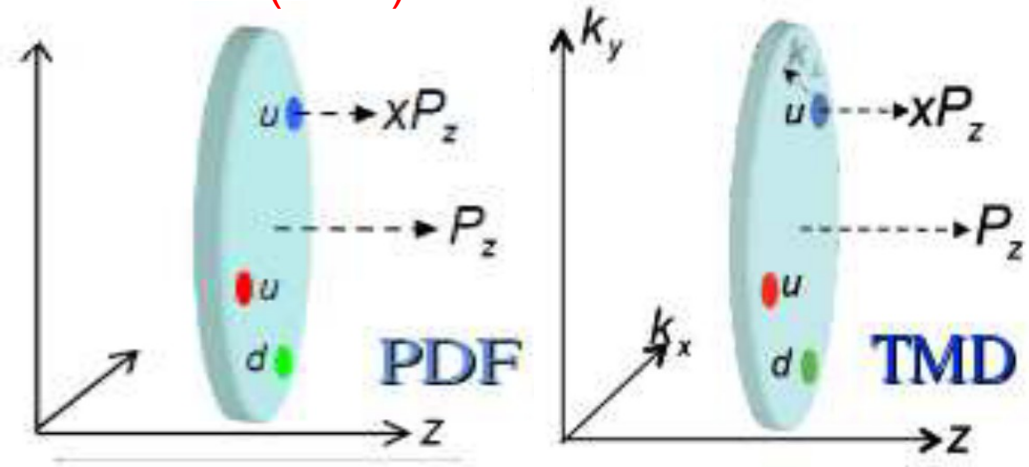
Phase 2: Transversely polarised NH_3 target $\Rightarrow$ GPD E

Transverse Momentum Dependent (TMD) PDFs

JHEP 02 (2007) 093

This new description of the nucleon takes into account the intrinsic transverse momentum k_T .

TMD PDFs allow to access to a 3-D information of the nucleon.

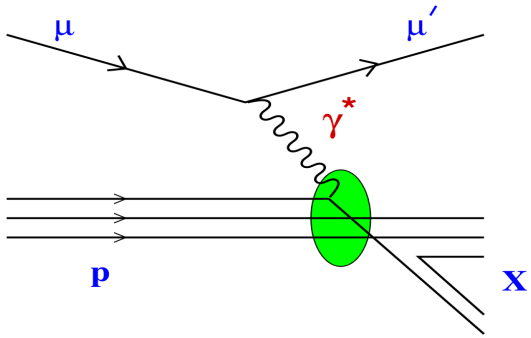


COMPASS can study the TMD PDFs using 2 complementary ways:

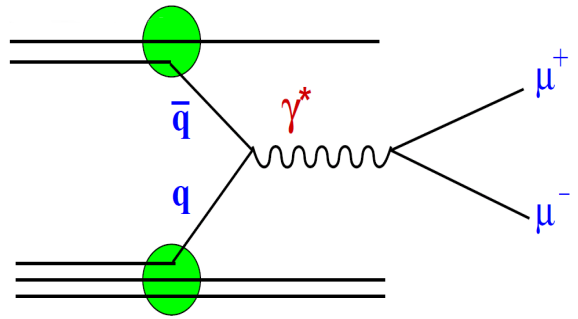
- Semi-inclusive DIS (SIDIS):
  → Polarised muon beam scattering off unpolarised/transversely polarised target;

- Drell-Yan process:
  → Pion beam scattering off unpolarised/transversely polarised target.

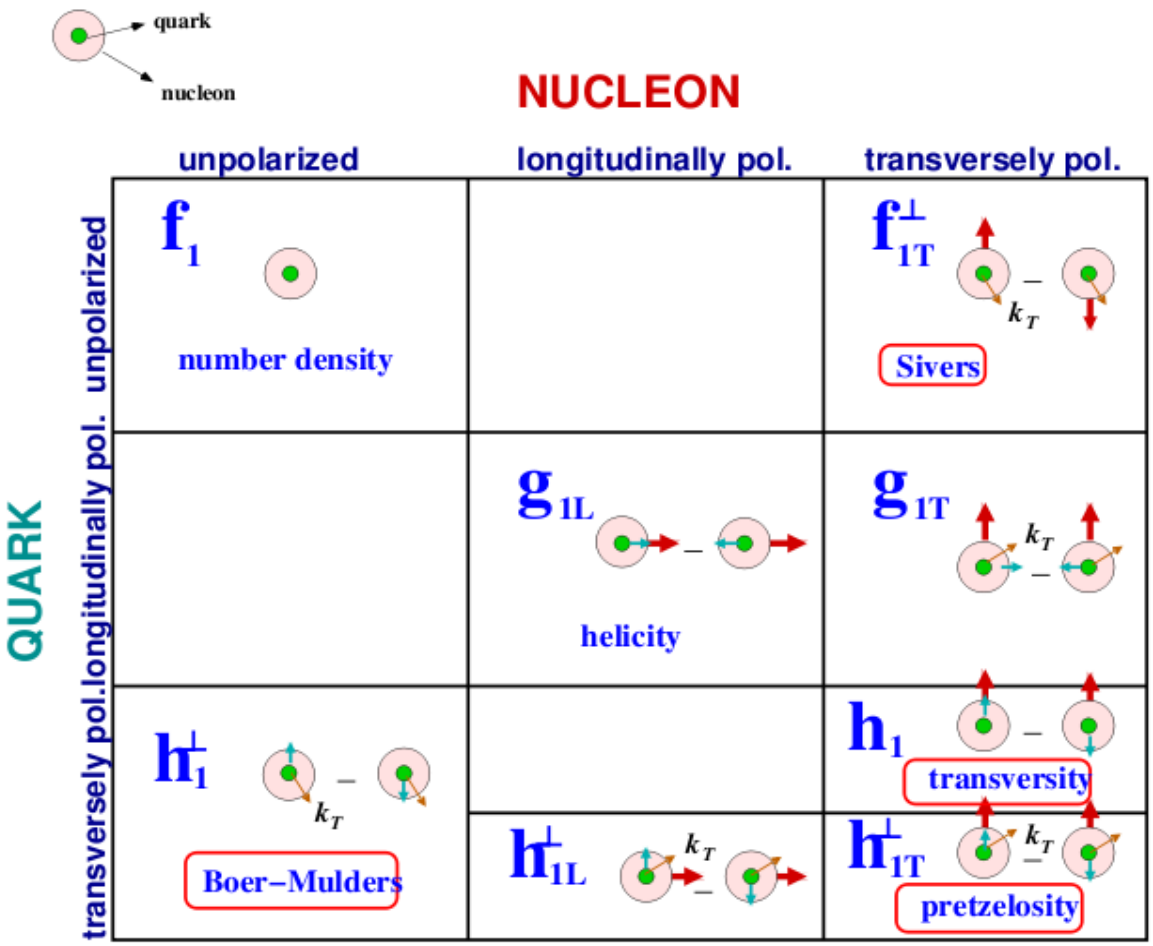
SIDIS



Drell-Yan



TMD PDFs approach

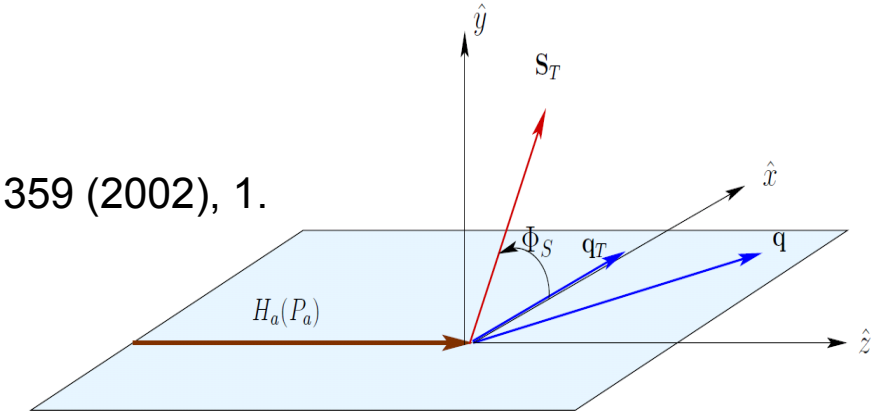


- In LT and taking into account the quarks k_T, 8 PDFs describe the nucleon.
- The TMD approach is valid for

$$\Lambda_{QCD} \ll k_T \ll Q$$

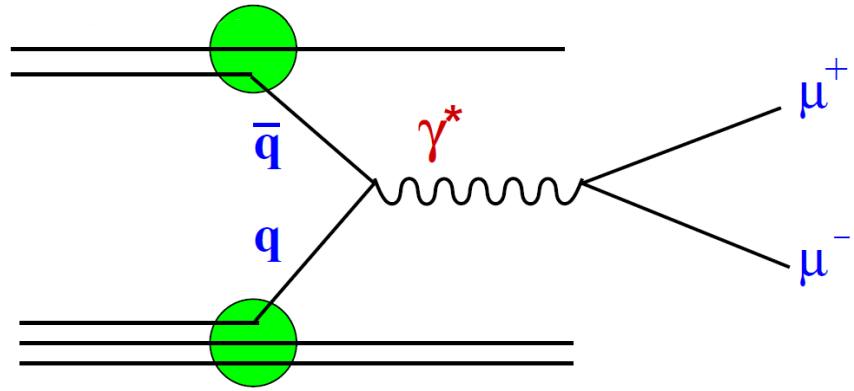
- After a k_T integration only 3 survive: f_1, g_1 and h_1
- TMDs are accessed by measuring azimuthal asymmetries

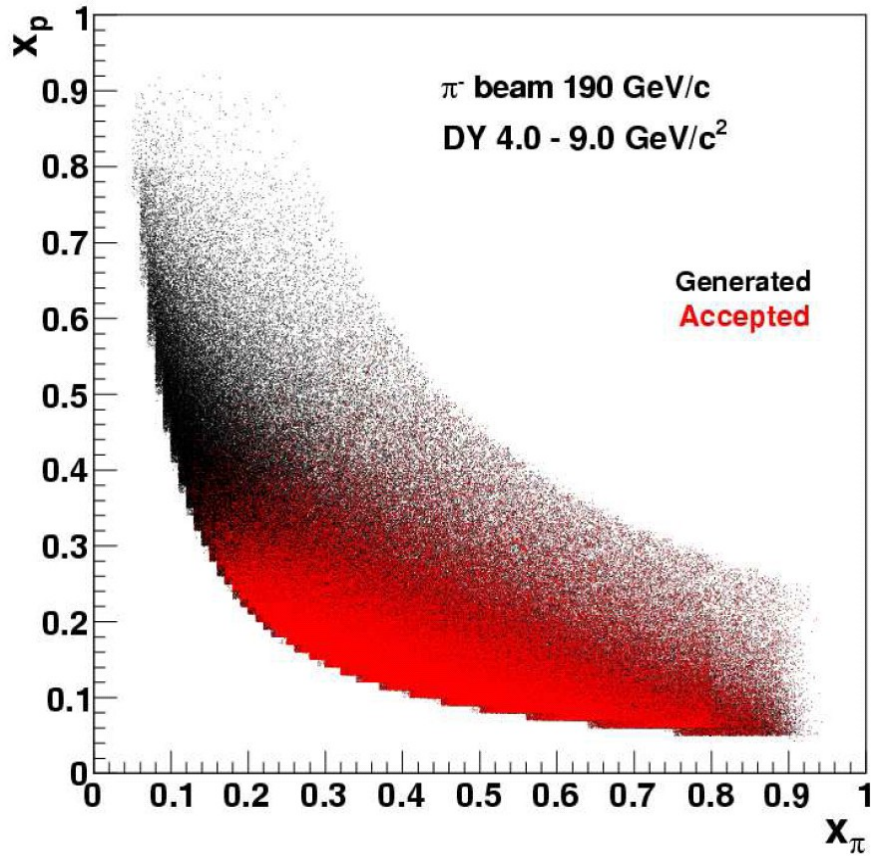
Phys. Rept. 359 (2002), 1.



Drell-Yan measurements

- Drell-Yan (DY) is a clean partonic process. No fragmentation functions are involved.
- Transversely polarised DY gives access to azimuthal modulations on the 4 PDFs: Sivers, Boer-Mulders, pretzelosity and transversity.
- The COMPASS kinematic coverage (in red) for a π beam @ 190 GeV on a trans. polarised NH_3 target, dimuon mass region 4 – 9 GeV .
- COMPASS will be the first experiment to measure the spin dependent PDFs, using polarised DY, with a large acceptance coverage in the valence region of p and π.





Facility	Type	s (GeV^2)	Time - line
RHIC (STAR, PHENIX)	collider, $p^\Uparrow p^\Uparrow$	200^2, 500^2	$>$ 2016
E906 (Fermilab)	fixed target, pp, $pp^\Uparrow$	226	taking data since 2013
J-PARC	fixed target, $pp^\Uparrow$	60 ÷ 100	$>$ 2017
GSI (Panda)	fixed target, $\bar{p}p$	30	$>$ 2020
NICA	collider, $p^\Uparrow p^\Uparrow$, $d^\Uparrow d^\Uparrow$	676	$>$ 2017
COMPASS	fixed target, $\pi^- p^\Uparrow$	300÷400	will start on 2014

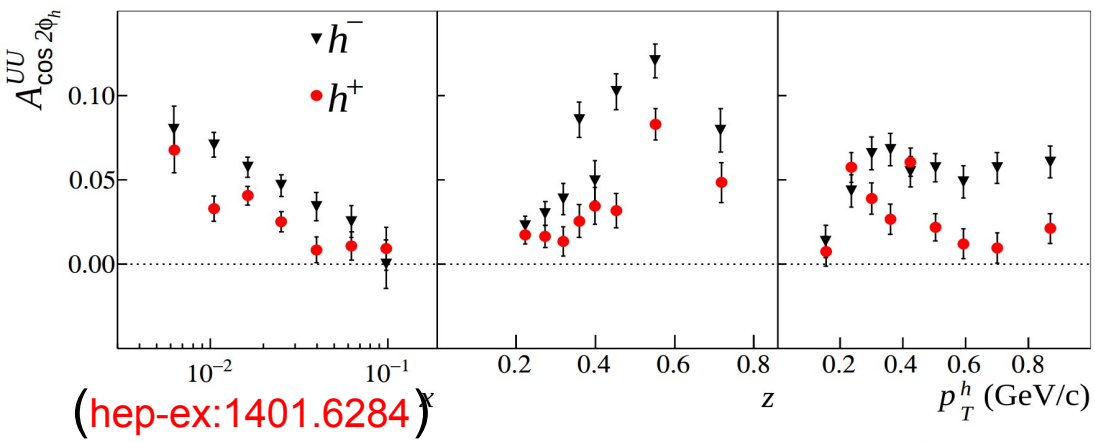
QCD and the TMD PDFs

Sivers and Boer-Mulders are T-odd PDFs ⇒ They are process dependent.

$$f_{1T}^{\perp}(DY) = -f_{1T}^{\perp}(SIDIS) \qquad h_1^{\perp}(DY) = -h_1^{\perp}(SIDIS)$$

Sivers | Boer-Mulders

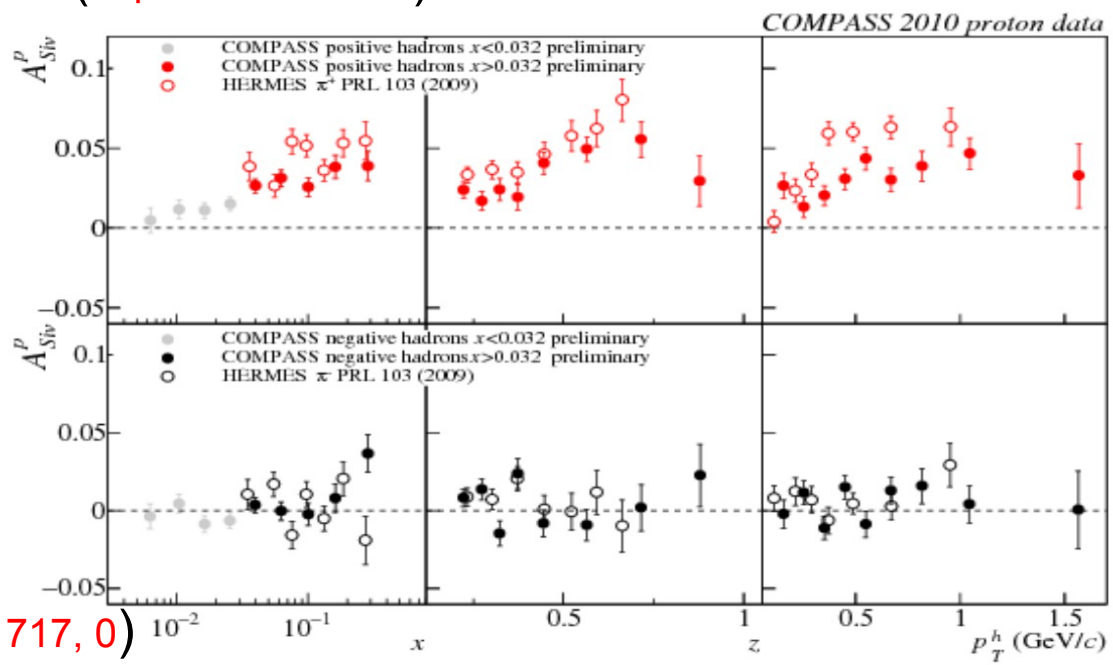
- This T-odd effect indicates a non-zero quark orbital angular momentum.
- The sign change constitutes a crucial test of non-perturbative QCD and of the TMD approach.



(hep-ex:1401.6284)

SIDIS results

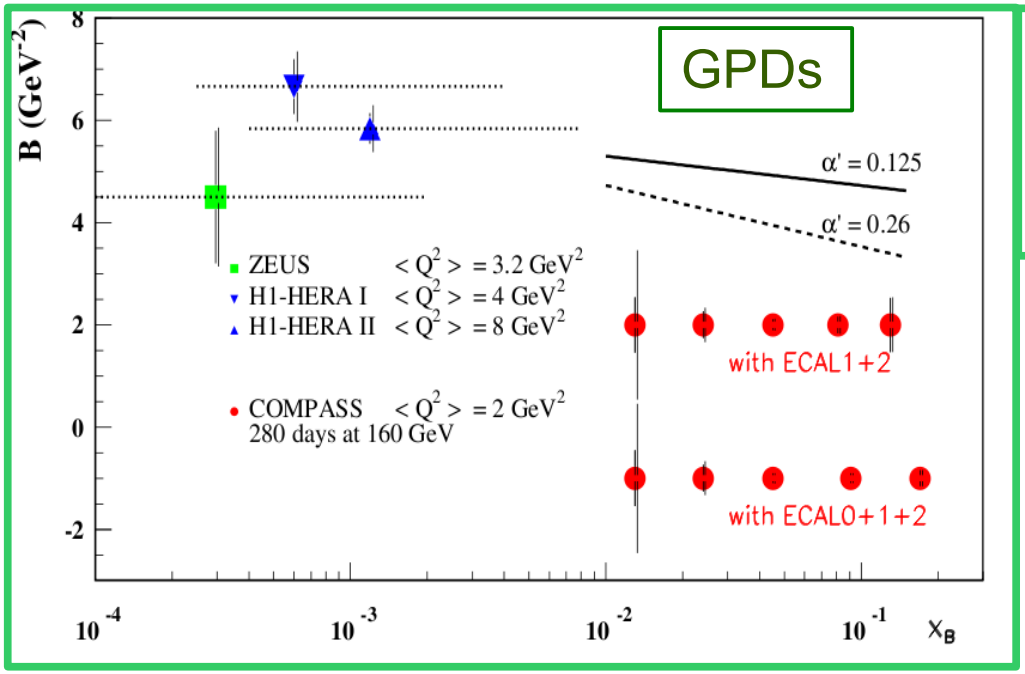
Boer-Mulders TMD is accessed by the asymmetry $A_{LU}^{\cos 2\Phi}$, this function is convoluted with Collins FF. Measured in SIDIS with unpolarised deuteron target



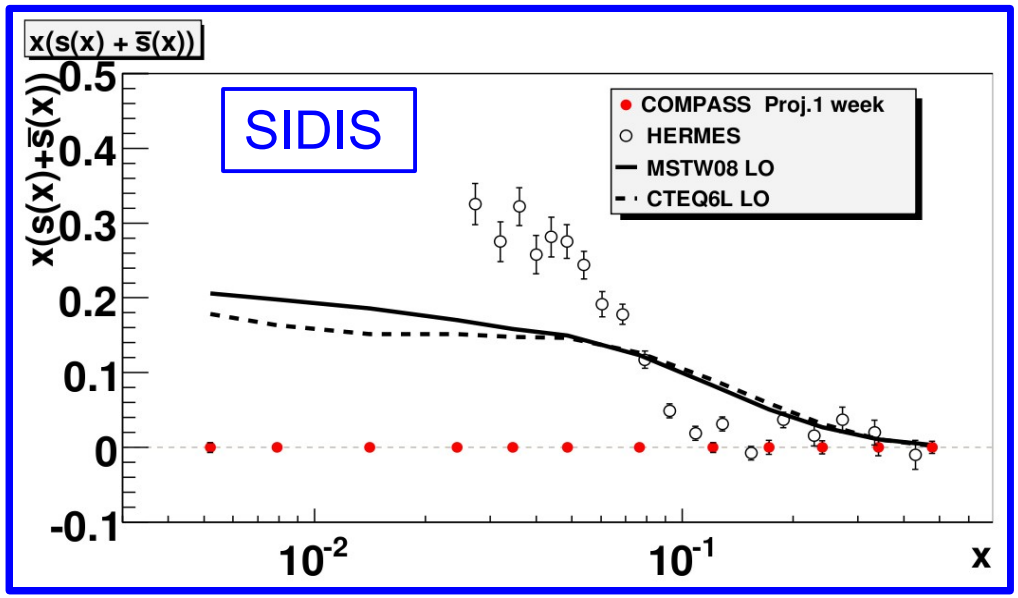
In COMPASS, the Sivers TMD is accessed using a proton target observing $A_{LT}^{\sin\Phi_S}$. Found to be positive for h^+ and zero for h^-, compatible with HERMES.

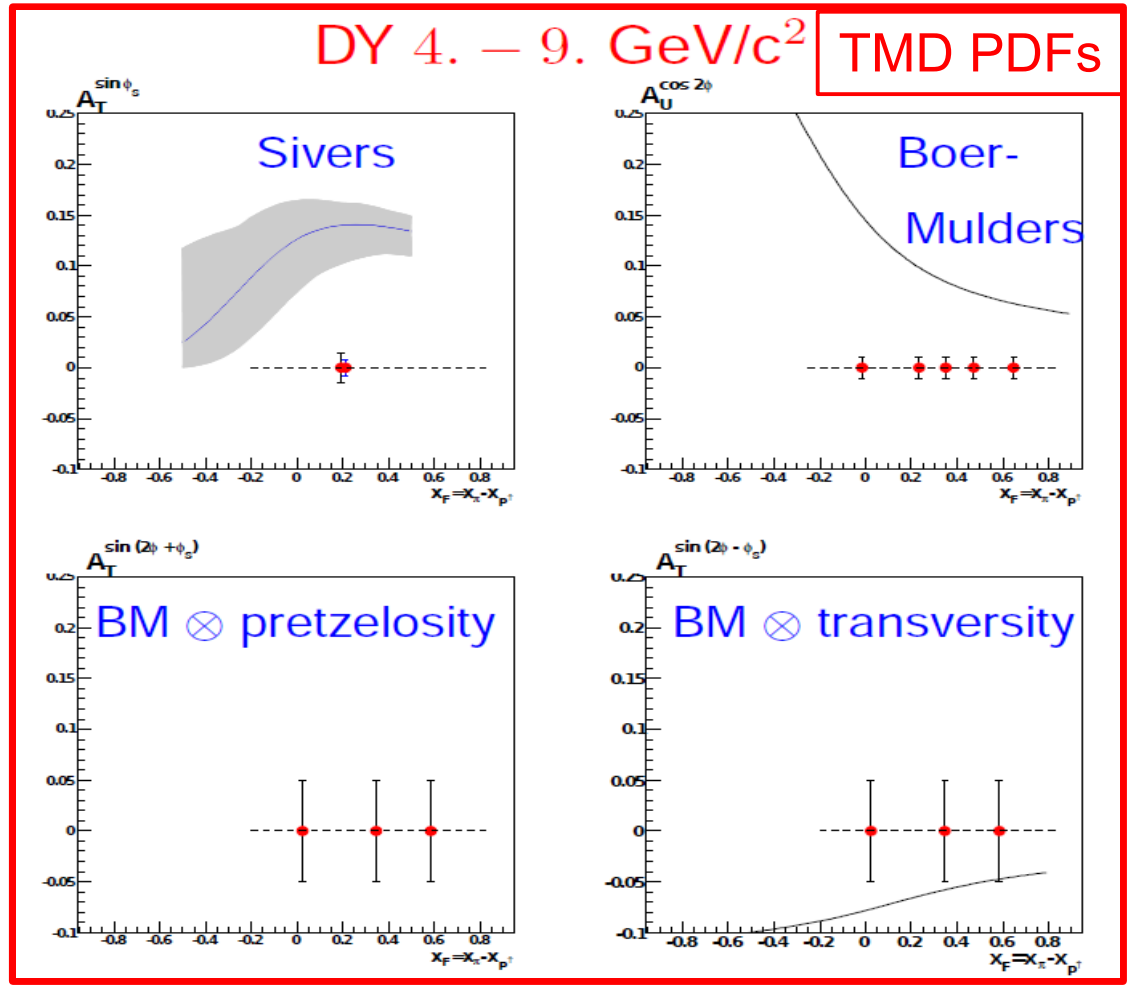
(PLB 717, 0)

Prospects and projections



$$B(x_B) \approx \frac{1}{2}\langle r_\perp^2(x_B)\rangle \qquad \frac{d\sigma^{\mu p \to \mu p \gamma}}{dt} \propto e^{-B(x_B)|t|}$$





Schedule for the future

- Last year: SPS shutdown; new setup installation.
- 2014-15: Drell-Yan data taking.
- 2016-17: GPD and SIDIS data taking.

This program is approved by SPSC/CERN and an extension is foreseen.

COMPASS-II will play an important role in QCD physics for the next 5 years.

Stay tuned!

Backup