Experimental Program of the Future
COMPASS-II Experiment at CERN

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On behalf of the COMPASS Collaboration

co-financed by

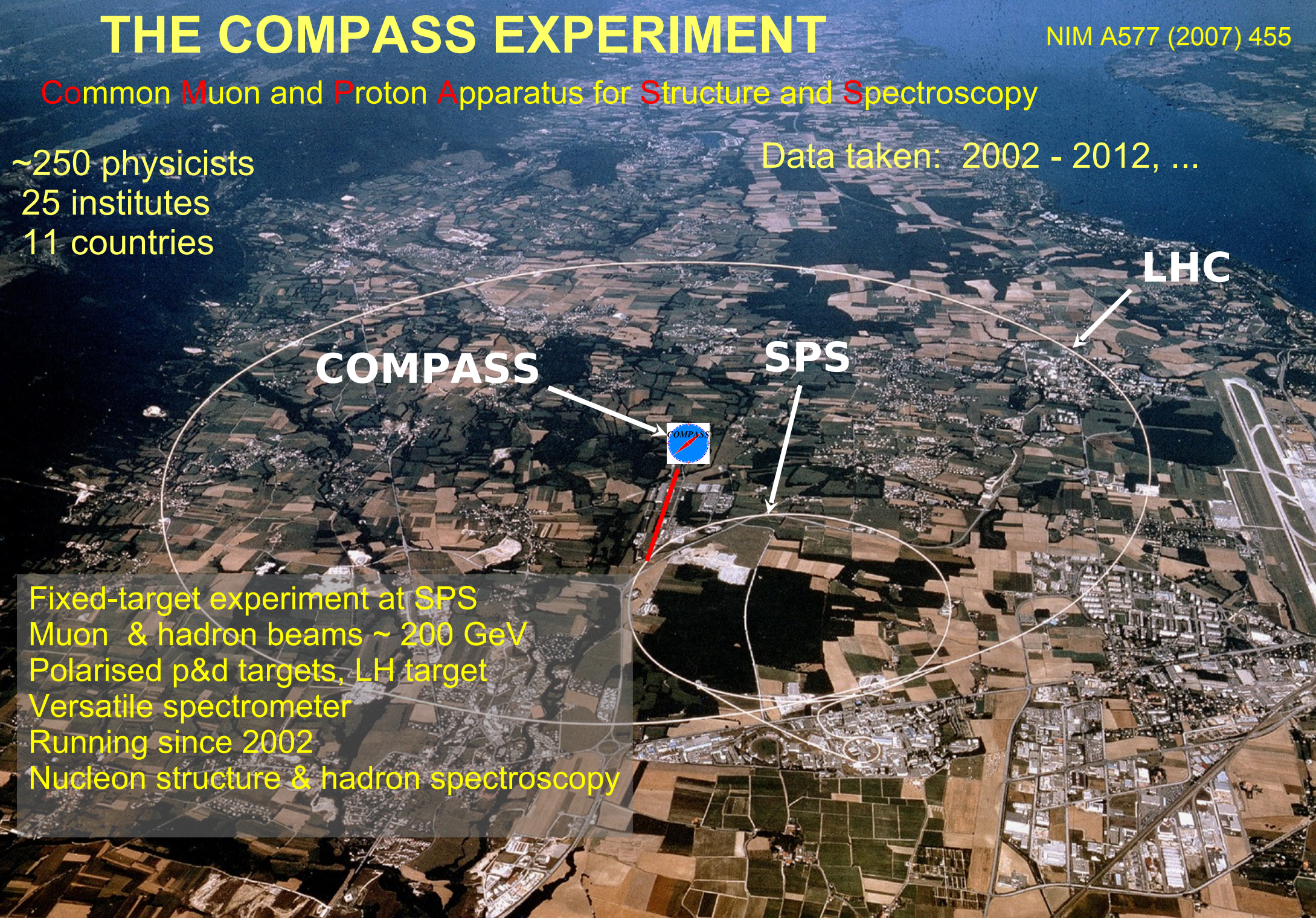
THE COMPASS EXPERIMENT

NIM A577 (2007) 455

Common Muon and Proton Apparatus for Structure and Spectroscopy

~250 physicists
25 institutes
11 countries

Data taken: 2002 - 2012, ...



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

What COMPASS did

COMPASS (2002 – 2012)

- Muon Program:

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

  - Quarks contribute 30% to the nucleon spin. (Phys.Lett.B647,8)
  - Gluon contribution is small to the nucleon spin (@ $x \sim 0.1$).
  - 3 leading twist Parton Distribution Functions (PDFs) (f_1, g_1, h_1) were investigated.

- Hadron Program:

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

  - Hadron spectroscopy: searches of exotics, hybrids and glueballs.
  - Pion polarisabilites.

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

- Hadron Program:

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

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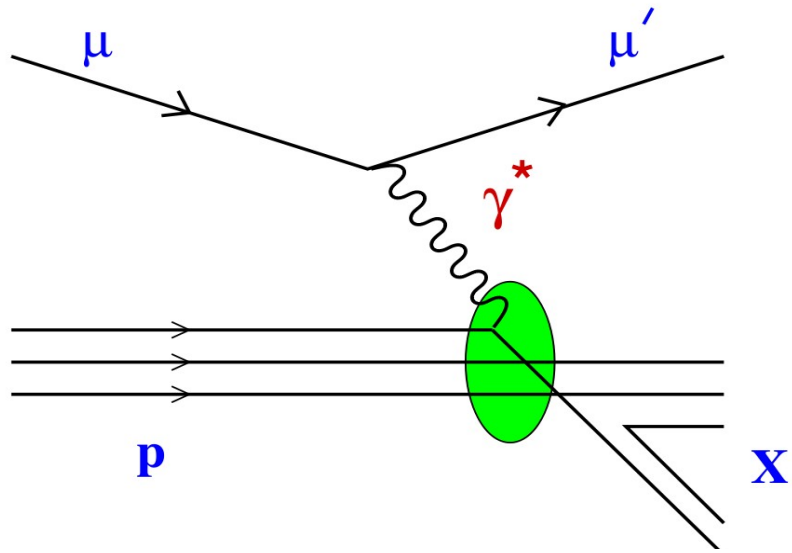
The new COMPASS-II program

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

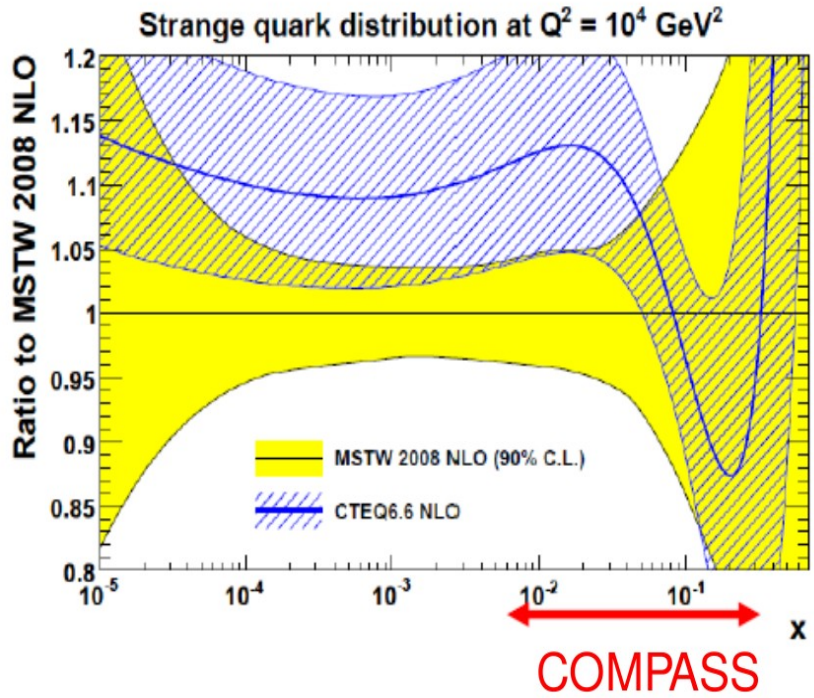
- Semi-Inclusive Deep Inelastic Scattering (SIDIS) studies to improve the Fragmentation Functions (FFs) and the PDFs in the strange sector.
- 3-dimensional description of the nucleon, via Global Parton Distribution functions (GPDs), using Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson 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.

Unpolarised SIDIS

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



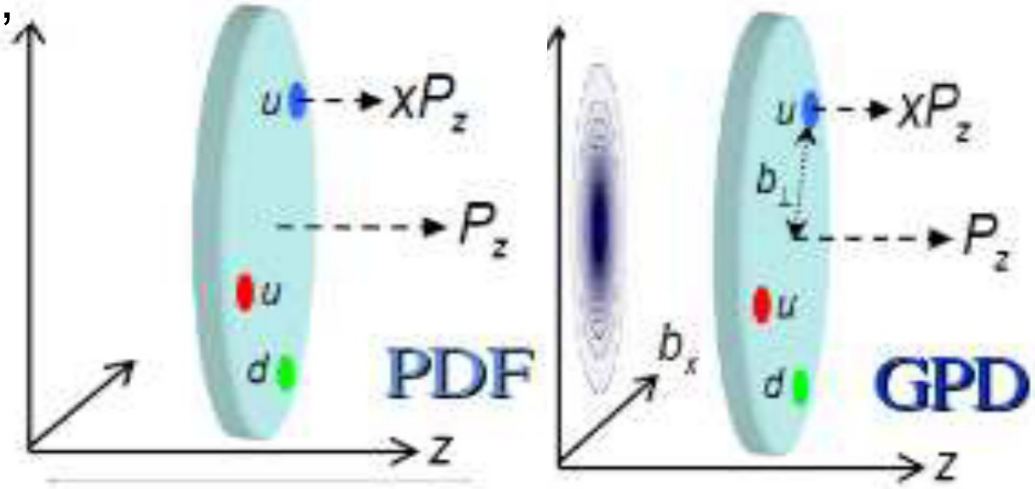
- A liquid hydrogen target will be used to minimise nuclear effects.
- These data together with PID and charge separation allow to measure hadron multiplicities ($\pi^{\pm}$, π^{0}, $K^{\pm}$, K^{0}, Λ and $\overline{\Lambda}$)
- and combined with previous COMPASS data on ^{6}LiD a very high precision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



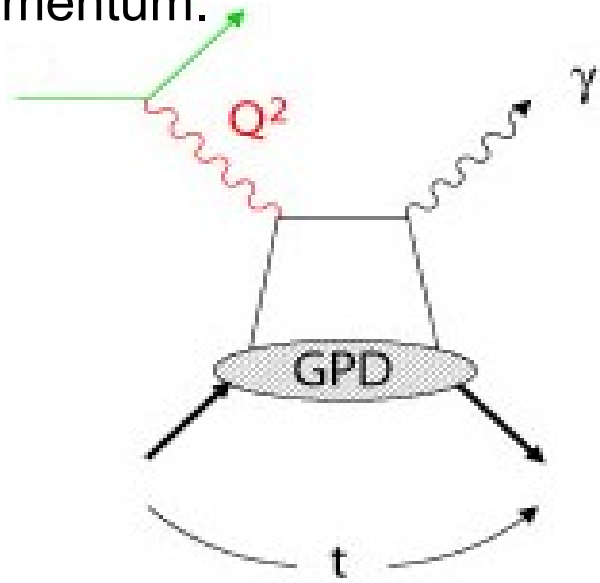
Generalised Parton Distributions (GPDs)

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

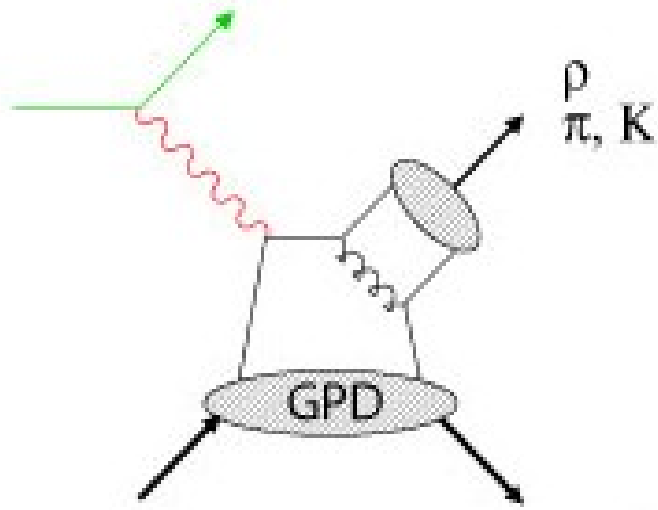
Phys.Lett.B595 (2004) 245



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



DVCS



DVMP

More about GPDs

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

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

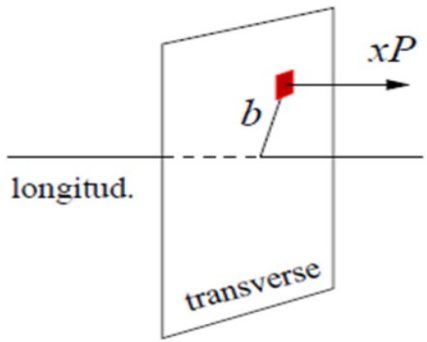
Total quark Orbital Angular Momenta

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

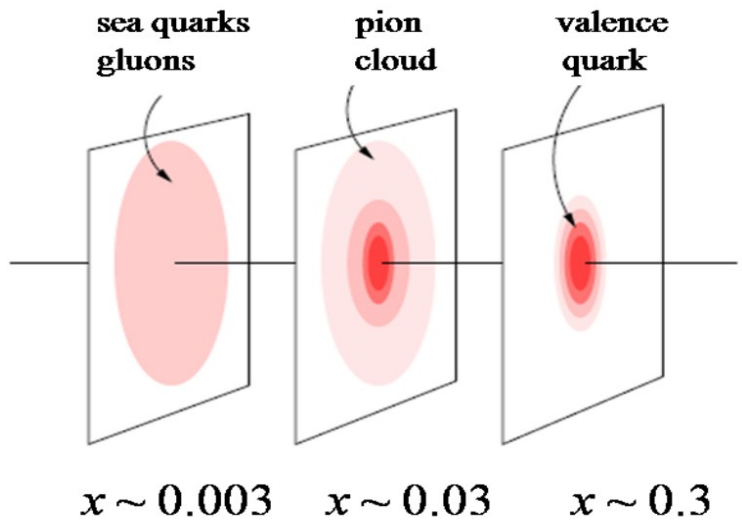
Ji relation
X.-D. Ji, PRL 78 (1997) 610

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

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

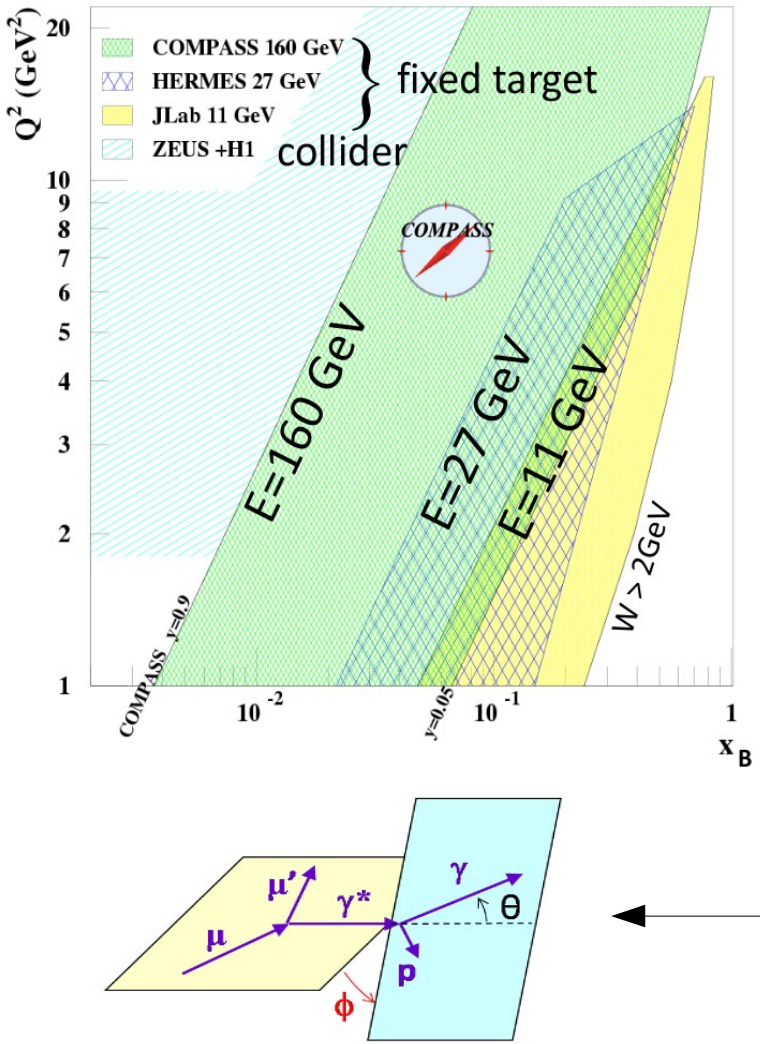


$$q^f(x,\boldsymbol{b}_\perp) = \int \frac{d^2\Delta_\perp}{2\pi} e^{-i\Delta_\perp\cdot\boldsymbol{b}_\perp} H^f(x,0,-\Delta_\perp^2)$$

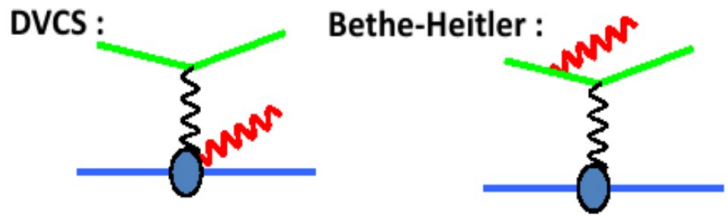


Nucleon tomography

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

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

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

$$A_{CS,U} \equiv \frac{\mu^{\rightarrow}_{+} - \mu^{\leftarrow}_{-}}{\mu^{\rightarrow}_{+} + \mu^{\leftarrow}_{-}}$$

These observables 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

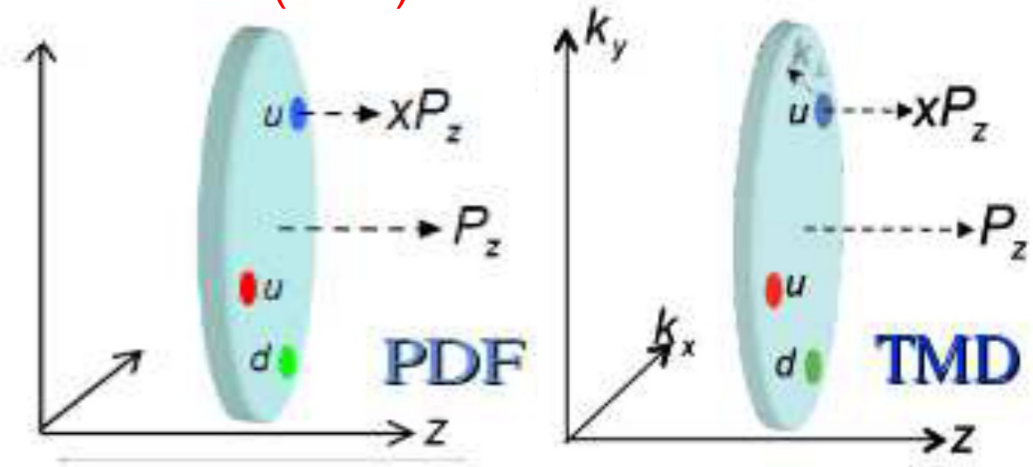
Phase 2: Transversely polarised NH_3 target $\Rightarrow$ GPD E

Transverse Momentum Dependent (TMD) PDFs

JHEP 02 (2007) 093

The description of the nucleon is given by the transverse intrinsic momentum k_T

TMD PDFs allow to access the quarks Orbital Angular Momentum.

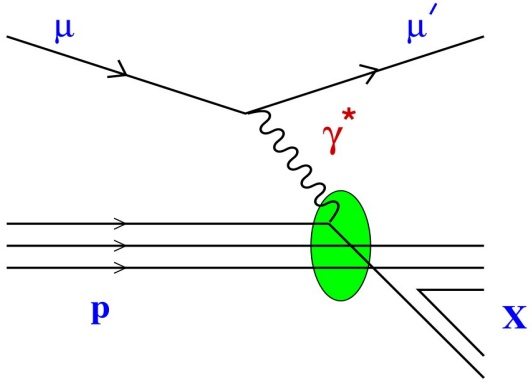


COMPASS can study the TMD PDFs using 2 complementary ways:

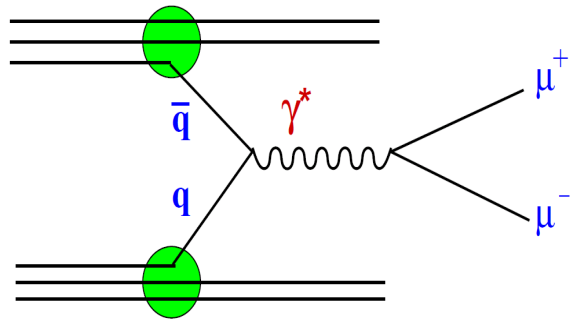
- Semi-inclusive DIS (SIDIS):
  → Polarised beam scattering off unpolarised/transversely polarised target;

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

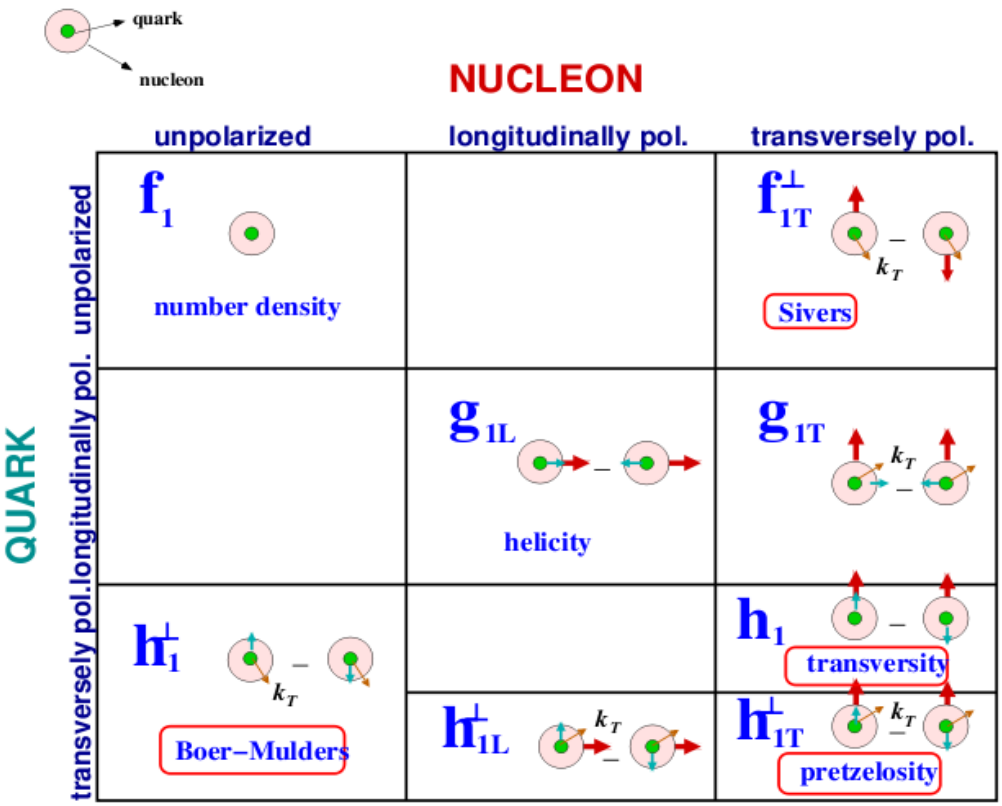
SIDIS



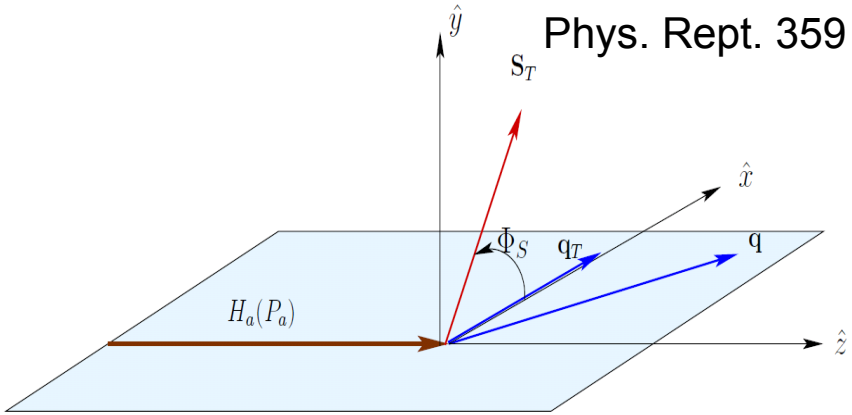
Drell-Yan



TMD PDFs approaches



Phys. Rept. 359 (2002), 1.



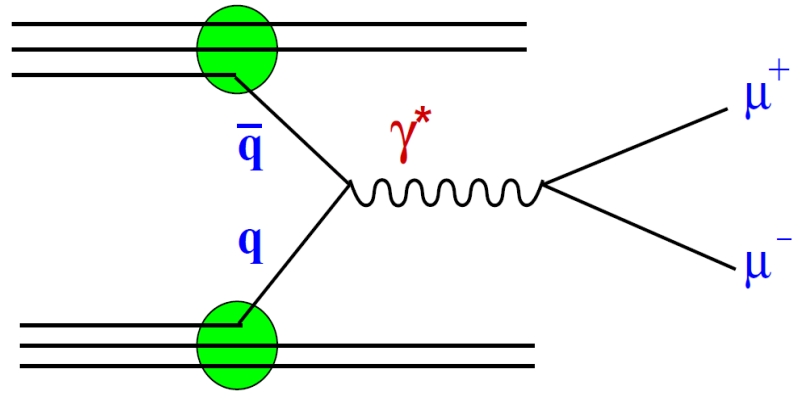
- In LO and considering the quarks k_T, 8 PDFs describe the nucleon.
- The TMD approach is valid for

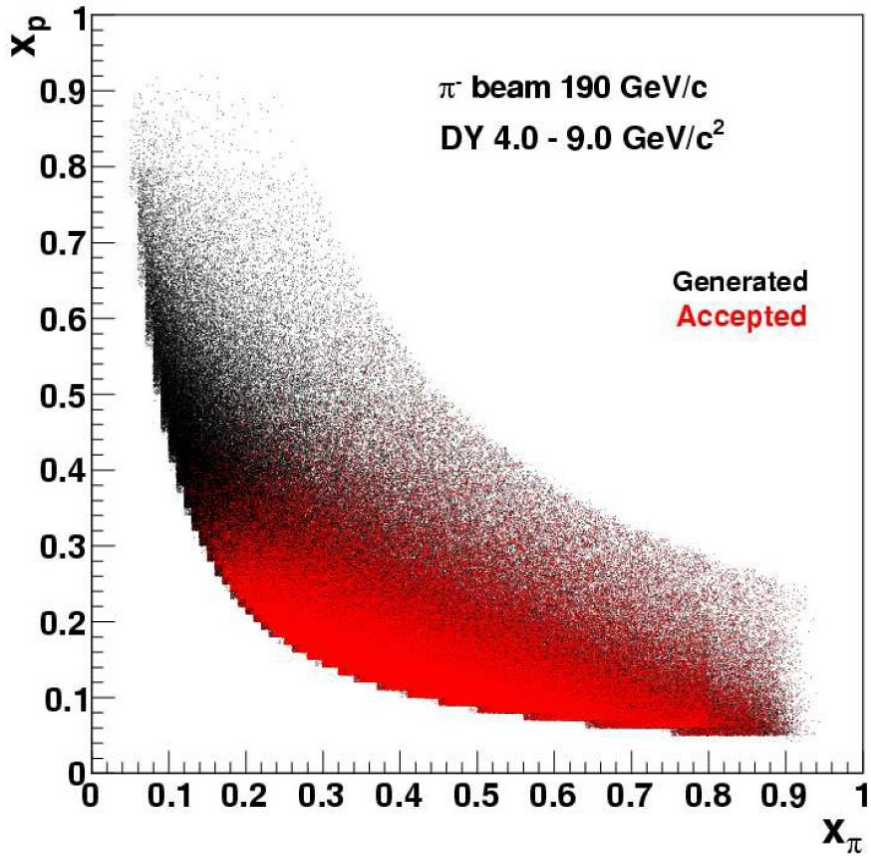
$$\Lambda_{QCD} \ll k_T \ll Q$$

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

Drell-Yan measurements

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



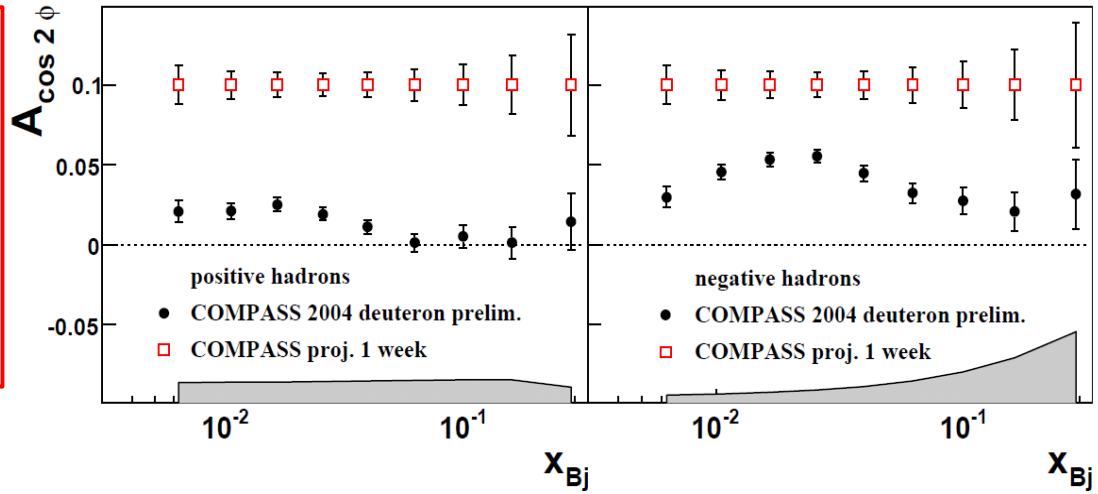


Facility	Type	s (GeV^2)	Time-line
RHIC (STAR, PHENIX)	collider, $p^\Uparrow p^\Uparrow$	200^2, 500^2	> 2014
RHIC(internal target)	fixed target, $p^\Uparrow p^\Uparrow$	500	> 2015
E906 (Fermilab)	fixed target, pp,	226	> 2010
J-PARC	fixed target, $pp^\Uparrow$	$60 \div 100$	> 2015
GSI(PAX)	collider, $\bar{p}^\Uparrow p^\Uparrow$	200	> 2017
GSI (Panda)	fixed target, $\bar{p}p$	30	> 2016
NICA	collider, $p^\Uparrow p^\Uparrow$, $d^\Uparrow d^\Uparrow$	676	> 2014
COMPASS	fixed target, $\pi^- p^\Uparrow$	$300 \div 400$	> 2012

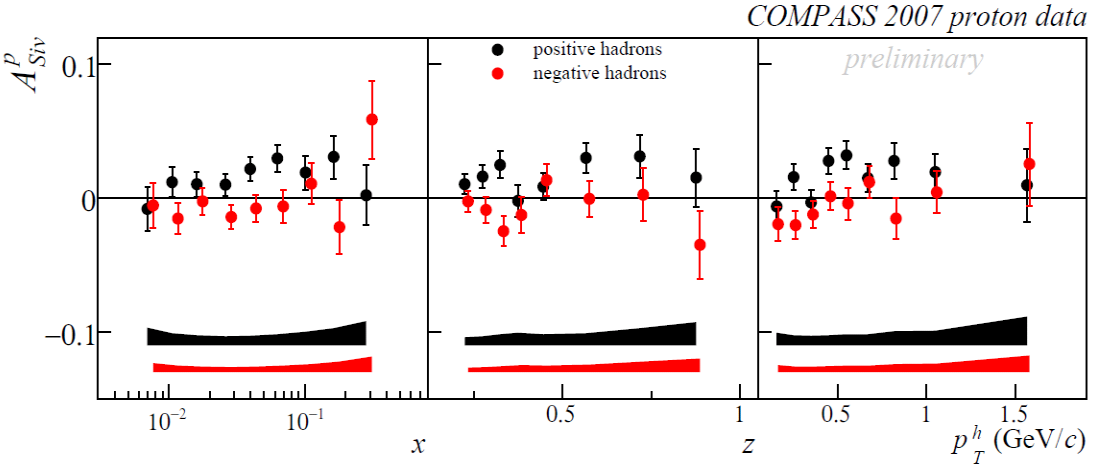
Polarised SIDIS: results and projections

Boer-Mulders asymetry ($A_{LU}^{\cos 2\phi}$): 2004-2006 data on deuteron target shows non-zero asymmetry.

The Boer-Mulders TMD can be measured in parallel with the DVCS.



Sivers asymmetry ($A_{LT}^{\sin\phi_S}$): Measured in deuteron and proton targets. Found to be positive for h^+ on protons but less stronger than HERMES.



Sivers and Boer-Mulders are T-odd PDFs $\Rightarrow$ They are process dependent

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

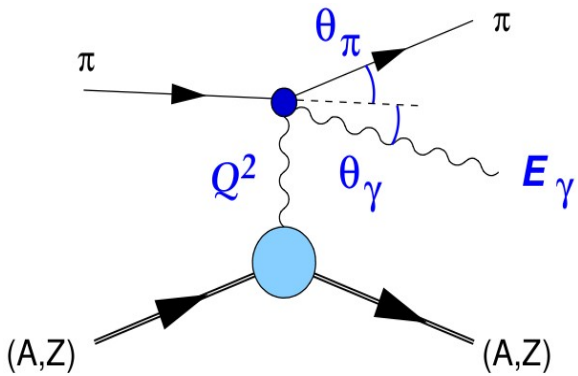
Sivers | Boer-Mulders

Measuring these relations constitutes a crucial test of non-perturbative QCD and of TMD approach

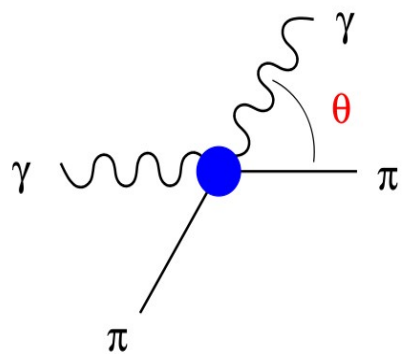
Pion and Kaon Polarisabilities

Chiral Perturbation Theory (ChPT) can be tested using the Goldstone bosons (pions and Kaons) by describing its strong interaction dynamics.

The pions and Kaons inner structure is revealed in its response to the presence of an electromagnetic field ⇒ Pion and Kaon Polarisability



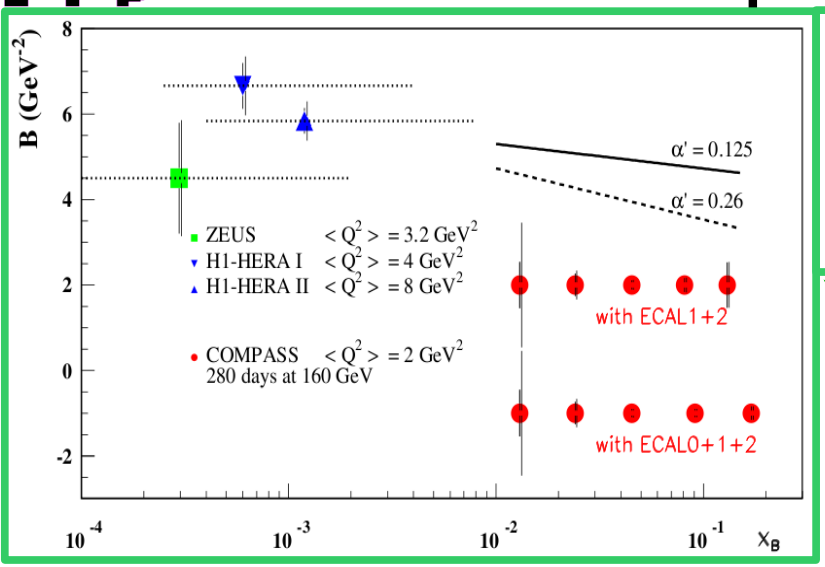
Primakoff



Compton

Studying Primakoff reactions and embedded inverse Compton scattering pion and Kaon polarisability represents a test to ChPT predictions.

Prospects and projections



$$\frac{d\sigma^{\mu p\to\mu p\gamma}}{dt}\propto e^{-B(x_B)|t|}$$

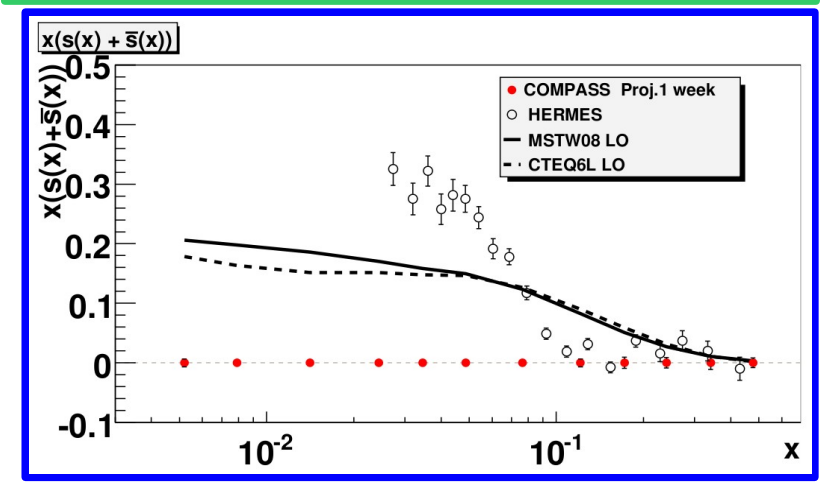
$$B(x_B)\approx\frac{1}{2}\langle r_\perp^2(x_B)\rangle$$

GPDs

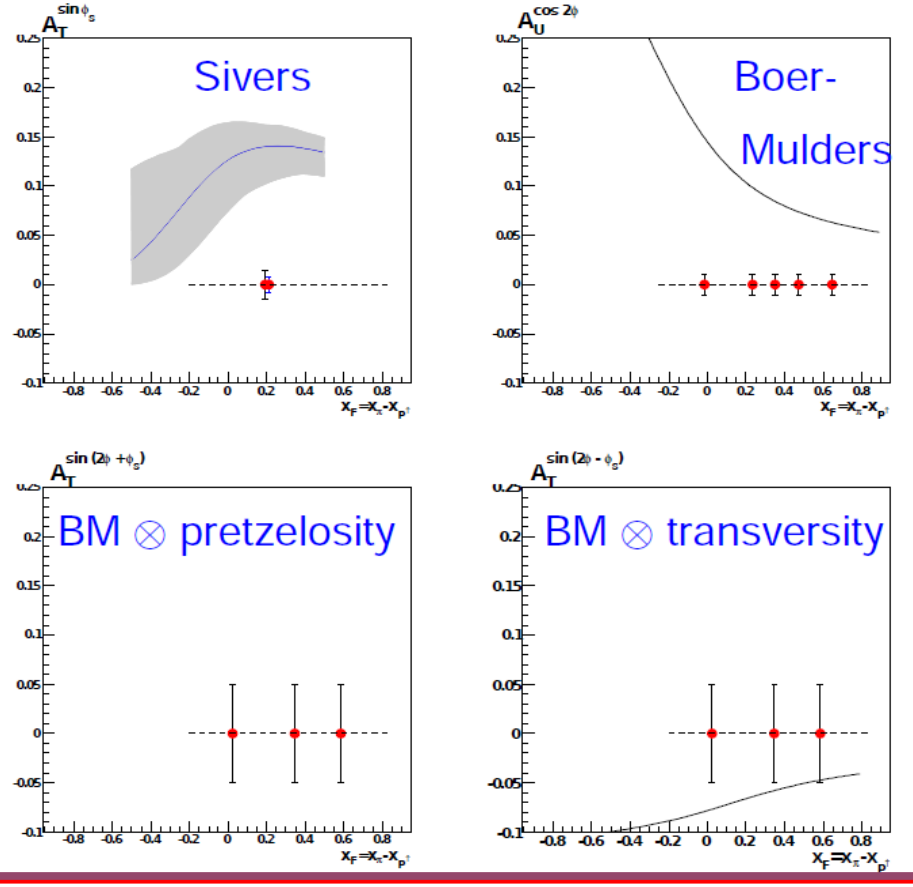
TMD PDFs

SIDIS

ChPT



DY 4. – 9. GeV/c^2



$$P=(1-\cos\theta_{cm})^2(\alpha_\pi-\beta_\pi)$$
$$+(1-\cos\theta_{cm})^2(\alpha_\pi+\beta_\pi)\frac{s^2}{m_\pi^4}$$
$$+(1-\cos\theta_{cm})^3(\alpha_2-\beta_2)\frac{(s-m_\pi^2)^2}{24s}$$

In 120 days (90 with π, 30 with μ beams)	$\alpha_\pi-\beta_\pi$ (10^{-4} fm^3)	$\alpha_\pi+\beta_\pi$ (10^{-4} fm^3)	$\alpha_2-\beta_2$ (10^{-4} fm^3)
2-loop ChPT prediction	5.7 ± 1.0	0.16 ± 0.10	16
COMPASS sensitivity	±0.66	±0.025	±1.94

Schedule for the next years

- 2012: data taking for ChPT tests and GPD studies.
- 2013: SPS shutdown; new setup installation.
- 2014: Drell-Yan data taking.
- 2015-16: 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 to 10 years.

Stay tuned!

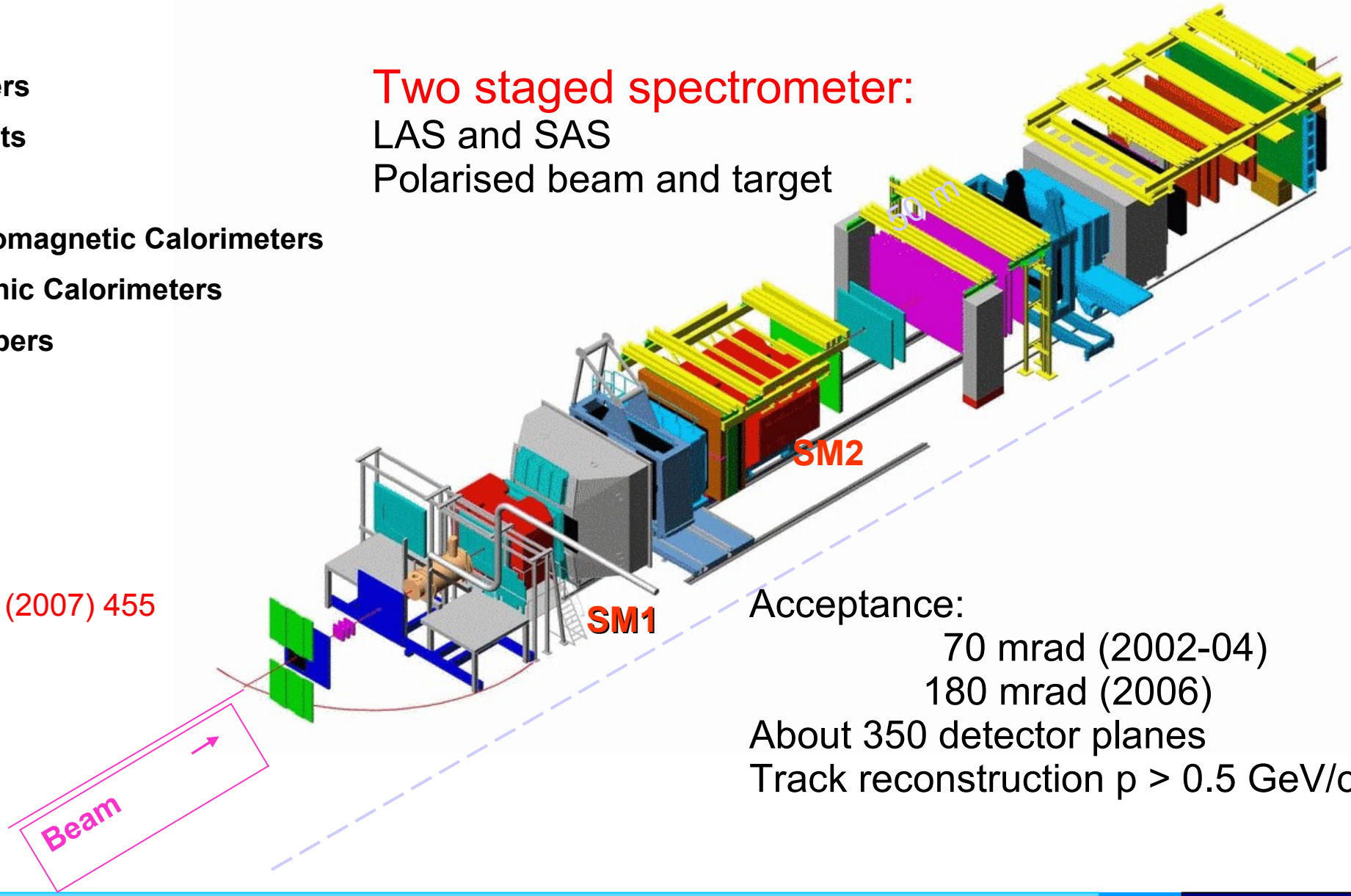
Backup

The COMPASS Spectrometer

Common Muon and Proton Apparatus for Structure and Spectroscopy

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

Two staged spectrometer:
LAS and SAS
Polarised beam and target



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