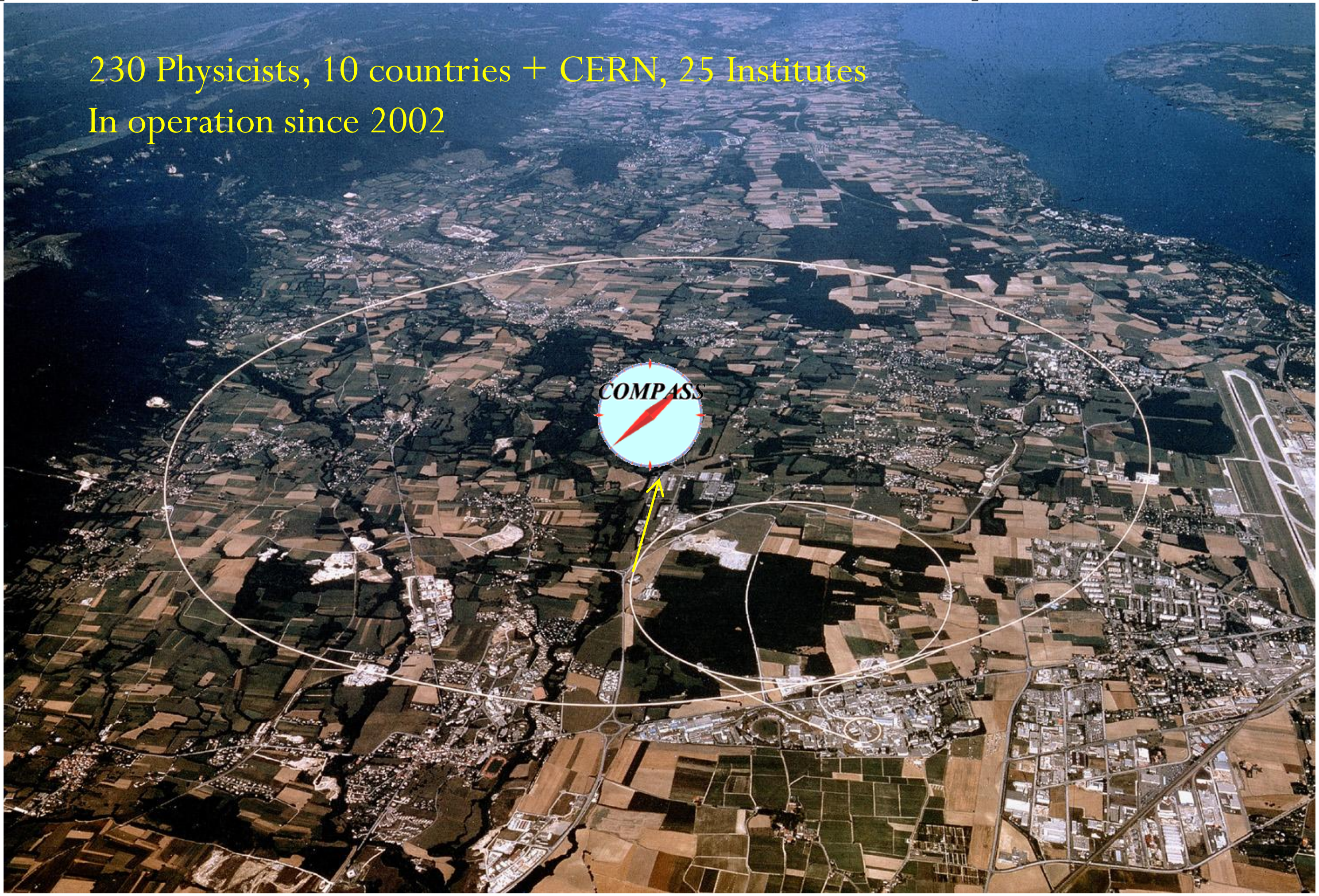
# COMPASS future: COMPASS II

Elena Rocco
CERN

From Quarks and Gluons to Hadrons and Nuclei
16-24 September 2011 – Erice, Sicily

# COMPASS: COmmon Muon and Proton Apparatus for Structure and Spectroscopy



# Current COMPASS Physics Program

Spin decomposition:

$$\frac{1}{2} = \Delta\Sigma + \Delta G + L_{q+g}$$

with $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ (EMC 1988 spin crisis)

Physics with polarised $\mu^+$ (@160GeV/c) on $^6$LiD and $NH_3$ with transversal or longitudinal target polarisation.

- Helicity PDF from double polarised DIS and flavor separation (see Kabuss's talk);
- Gluon polarisation $\Delta G/G$;
- Transversity PDF in transversely polarised SIDIS.(see Bradamante's talk)

Physics with unpolarised hadron beams (@190GeV/c) on: liquid $H_2$, Pb, Ni, Cu and W targets.

- Hadron spectroscopy: search for exotic, hybrids and glueballs;
- Pion polarisabilities

# COMPASS FUTURE:

The COMPASS spectrometer versatility allows to measure:

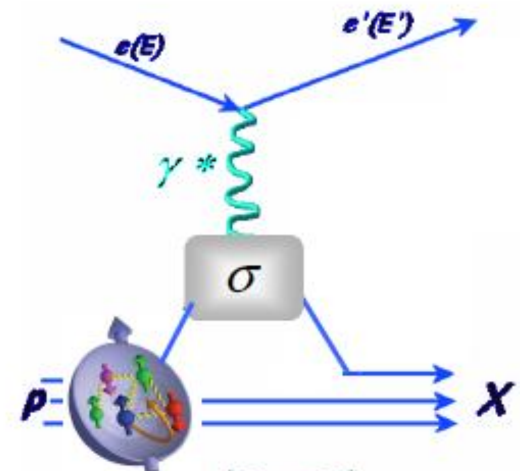
- Generalasided Parton Distributions (GPDs) through Deep Virtual Compton Scattering (DVCS) and Deep Vector Meson Production (DPVM);
- Unpolarised Parton Distribution Functions (PDFs) and Transverse Momentum Dependent (TMD) effects in Semi Inclusive Deep Inelastic Scattering (SIDIS) (here not presented)
- Polarised Drell-Yan (DY) process;
- Primakoff process;

↓

COMPASS II proposal approved by CERN Research Board on 1st December 2010. It is long plan term plan for at least 5 years starting in 2012

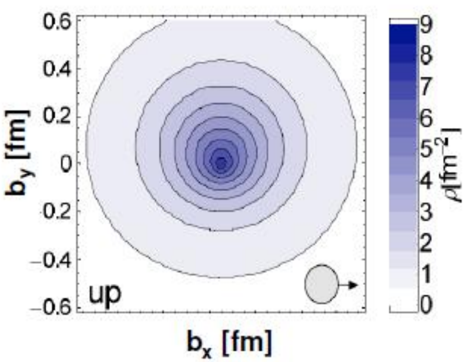
# Nucleon description

## Quantum phase-space nucleon tomography



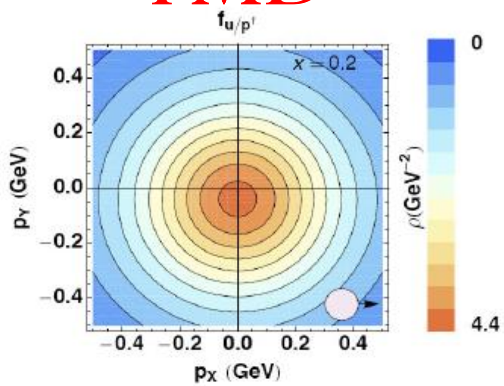

### 3D description

**GPD** | **TMD**



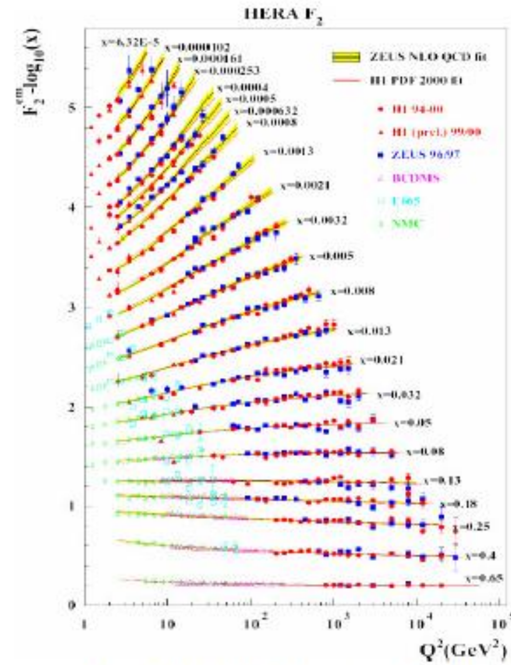

*QCDSF/UKQCD, PRL 98 (07)*

**3D picture in coordinate space**




*A.B., F. Conti, M. Radici, PRD78 (08)*

**3D picture in momentum space**

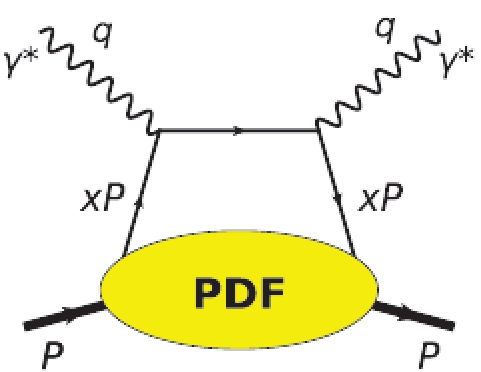


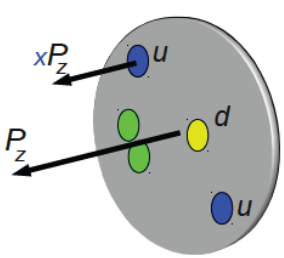

**Longitudinal momentum structure of the nucleon**

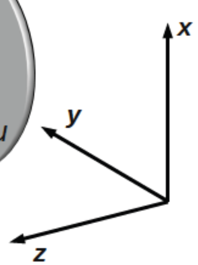
# From PDFs to GPDs:

Deep Inelastic Scattering

μ *p* → μ’ *X*



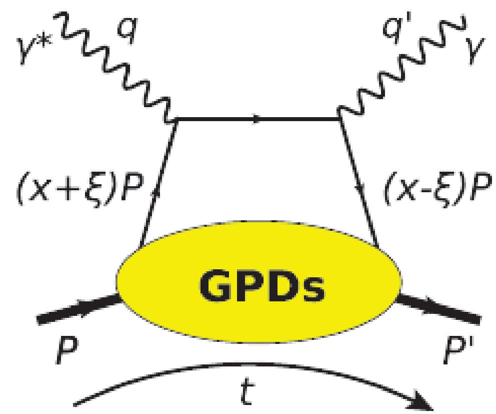



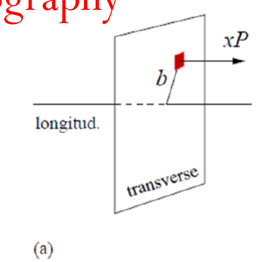

PDFs: $q(x)$, $\Delta q(x)$

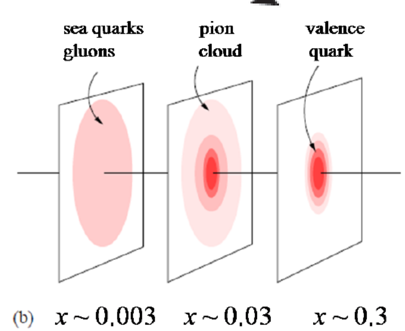
Deeply Virtual Compton Scattering

μ p → μ’ p’ γ




Nucleon Tomography

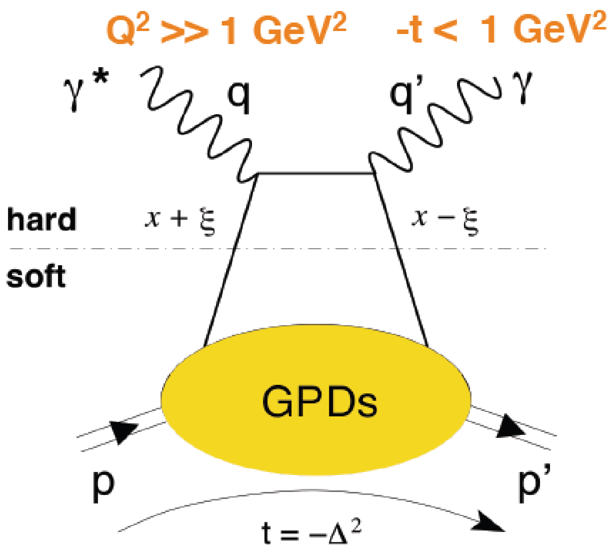


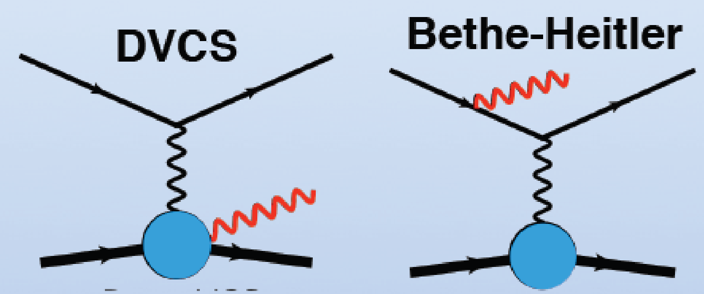




GPDs: $H(x,\xi,t)$, $\tilde{H}(x,\xi,t)$

# Deep Virtual Compton Scattering:

GPDs can be accessed from the hard exclusive DVCS processes




The total cross section is the coherent sum of DVCS and BH

Polarised muon beam with unpolarised target: GPD *H*

$$d\sigma_{(\mu p \rightarrow \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_{\mu} d\sigma^{DVCS}_{pol}$$

$$+ e_{\mu} a^{BH} \mathrm{Re}(I) + e_{\mu} P_{\mu} \mathrm{Im}(I)$$

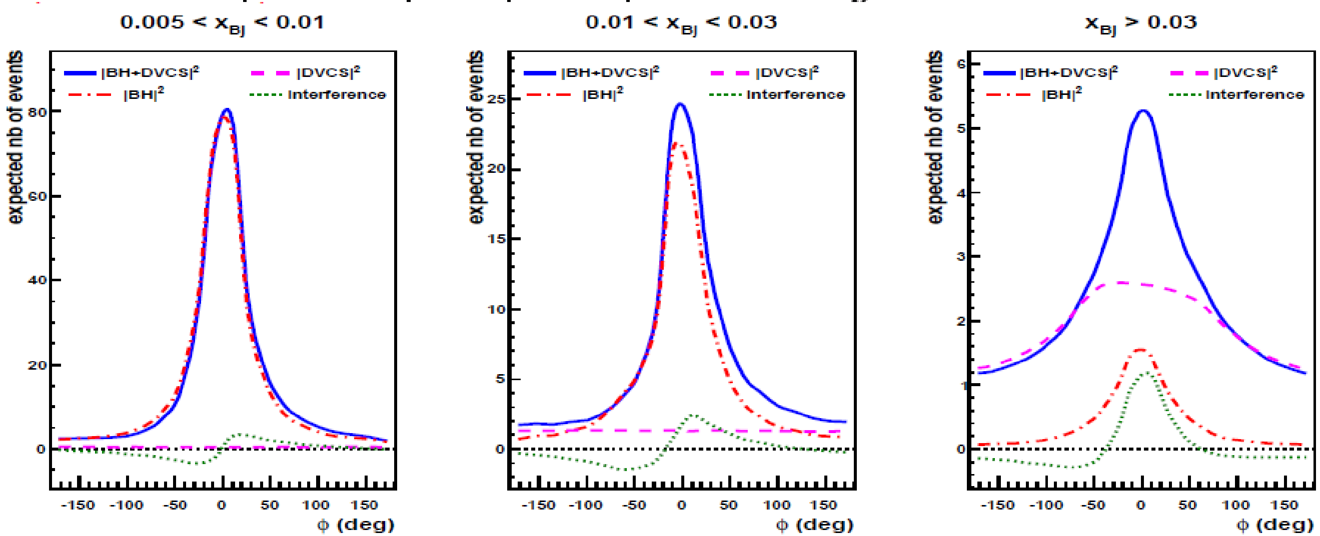
$d\sigma^{BH}$ : well known

$I$ : interference term

# B-H and DVCS cross section at 160GeV

$$d\sigma \propto \left|T^{DVCS}\right|^2 + \left|T^{BH}\right|^2 + InterferenceTerm$$

MonteCarlo

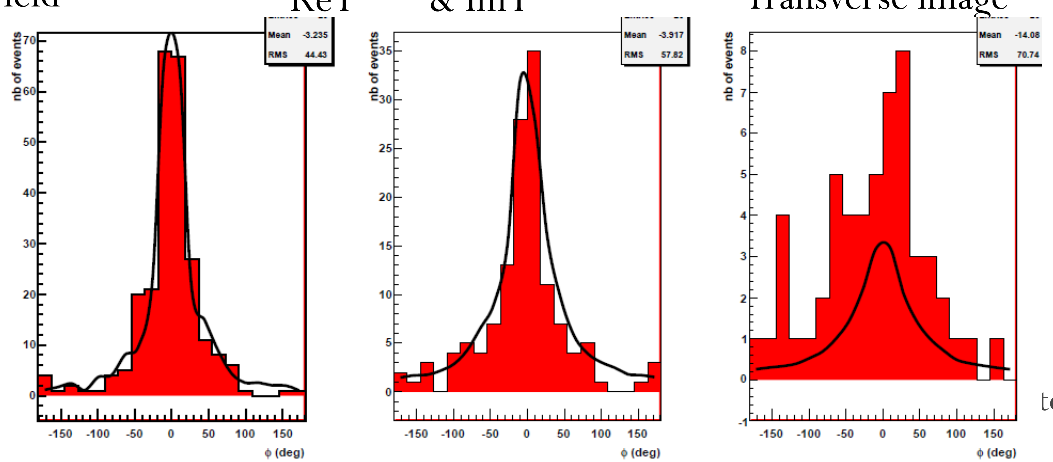



BH dominates
Reference yield

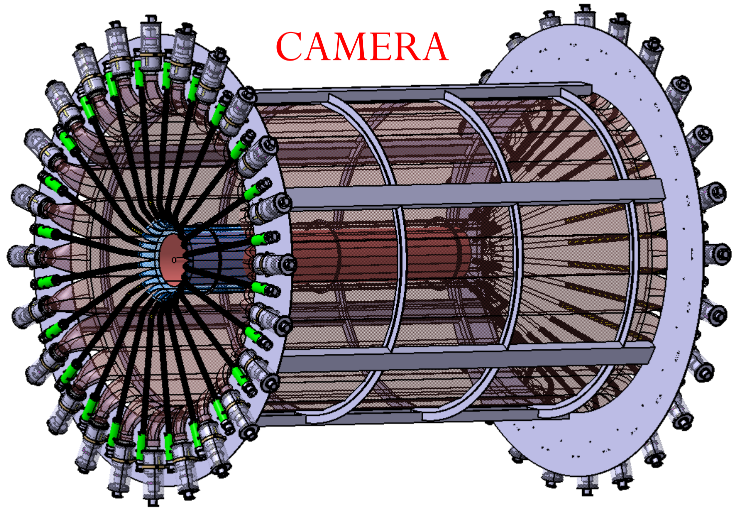
Interference
Re$T^{DVCS}$ & Im$T^{DVCS}$

DVCS dominates
Transverse image

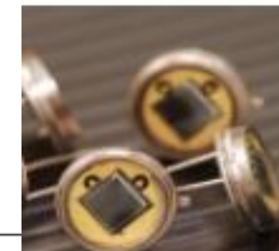
2009 test run! Small target



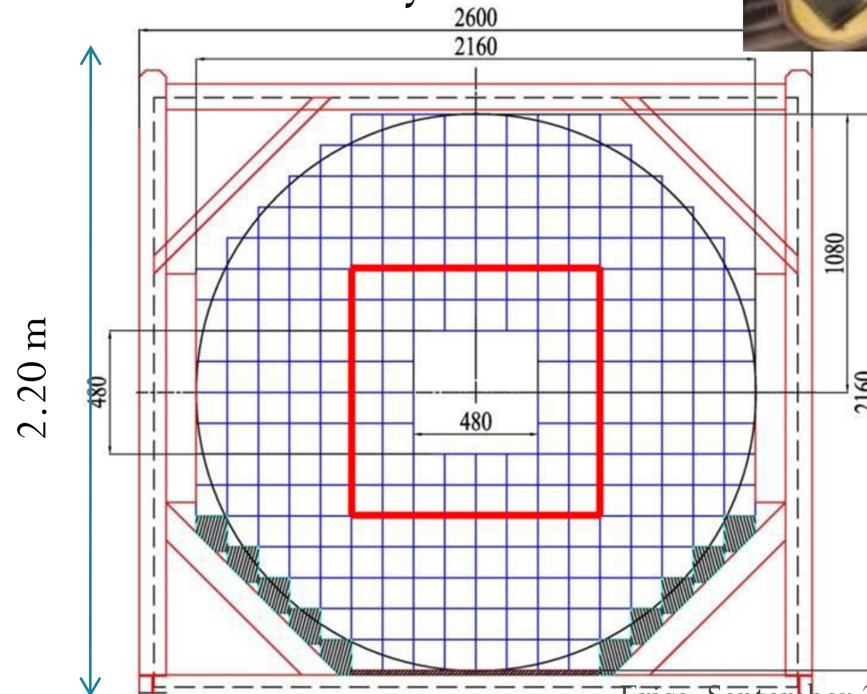
# DVCS @ COMPASS: setup




New ECAL0 large angle calorimeter
Multipixel Avalanche Photodiode Redaout



**ECAL0 248 modules ($12 \times 12$ cm$^2$) of 9 cells read by 9 MAPDs**




- 2.5 m long $LH_2$ target
- 2 barrels 4m long, long scintillators
- ~300 ps timing resolution
- GANDALF project: 1 GHz digitisation PM signal
- ECAL1 and ECAL2 upgrade

# Access to GPD *H*

* Beam Charge and Spin Sum

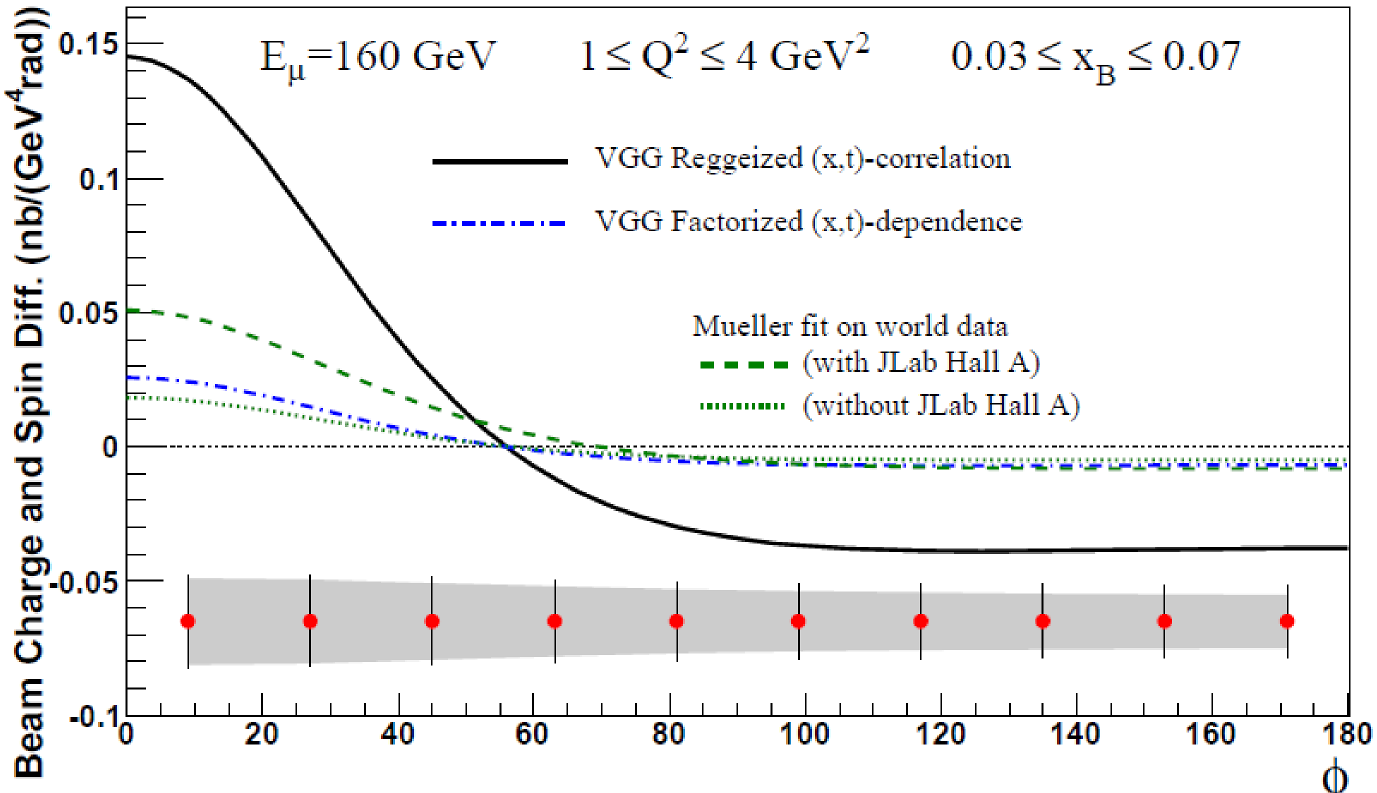
$$S_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} \propto \mathrm{Im}(F_1, H)$$

* Beam Charge and Spin difference

The BH process is independent of the beam charge and polarisation

$$D_{CS,U} = d\sigma^{+\leftarrow} - d\sigma^{-\rightarrow} \propto \mathrm{Re}(F_1, H)$$

# Beam charge and spin difference $D_{CS,U}$

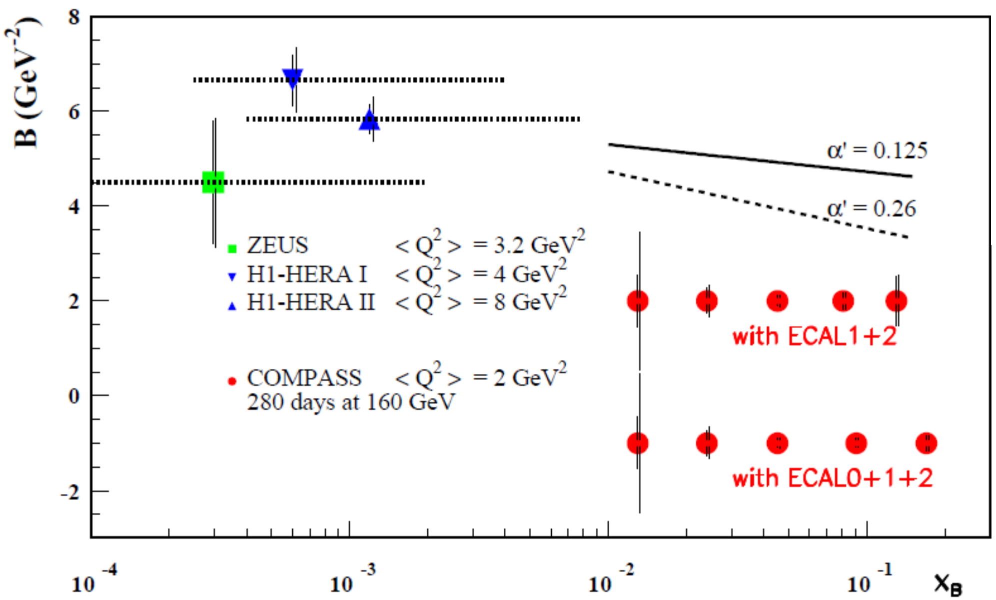


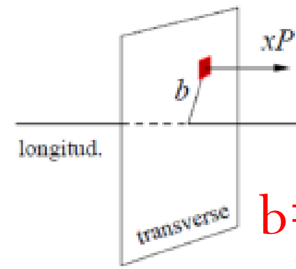

Luminosity=1222pb$^{-1}$

$\varepsilon_{global}$=10%

- ✓Control detector acceptance and beam flux with high precision
- ✓Error band assumes a 3% systematic uncertainty between $\mu^+$ and $\mu^-$
- ✓Use inclusive events and BH for check

# Transverse imaging




b= impact parameter

$$r_\perp = b/(1-x)$$

$r_\perp$ = distance between struck parton and centre of momentum

B ($x_B$) can be extracted without any models

$$\langle r_\perp^2(x_B)\rangle \approx 2 \cdot B(x_B)$$

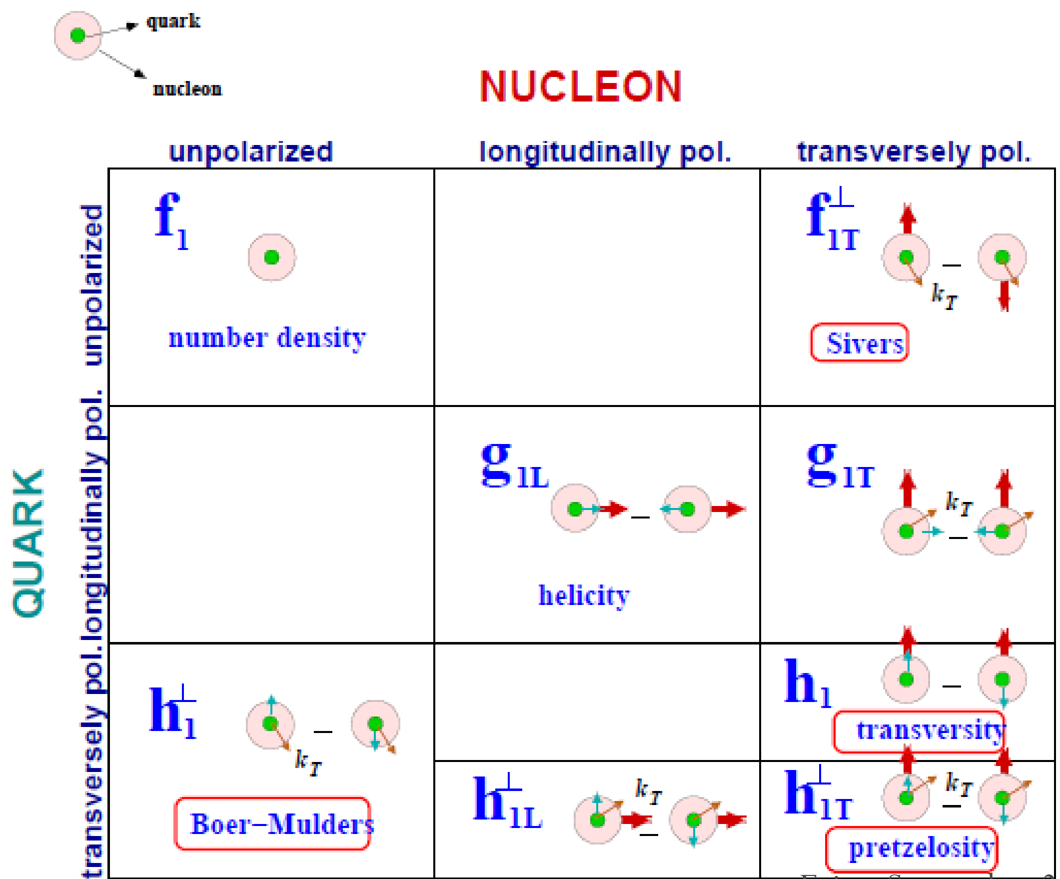
the transverse size of the nucleon

t-slope parameter B($x_B$)

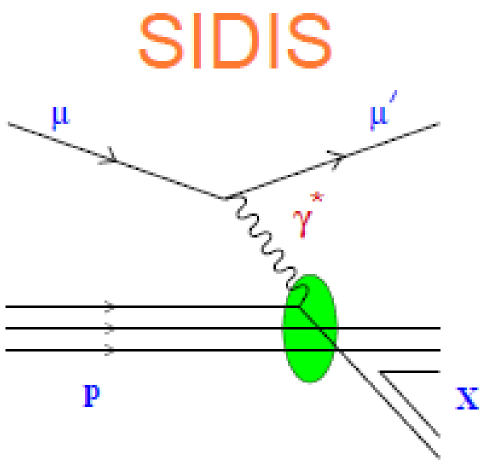
exclusive cross-section

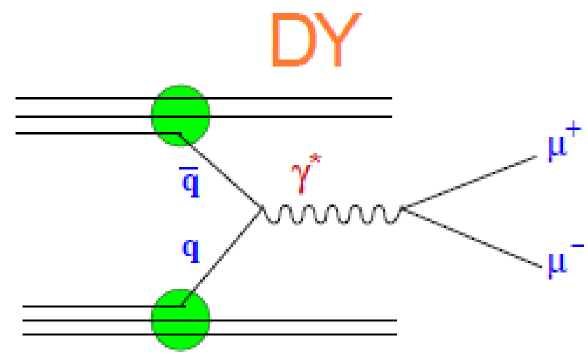
# TMD parton distribution

- 8 intrinsic transverse momentum dependent PDFs at LO
- Asymmetries with different angular dependences on hadron and spin azimuthal angles, $\Phi_h$ and $\Phi_s$
- All measured in COMPASS on $^6$LiD and $NH_3$



# From Semi Inclusive DIS to Drell-Yan




The spin asymmetry is proportional to

$$PDF \otimes FF$$

⇓

$$A_{Sivers}$$

The spin asymmetry is proportional to

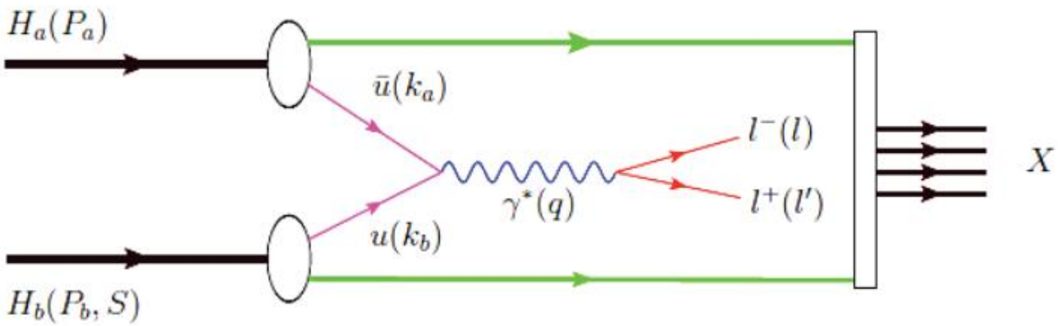
$$PDF \otimes PDF$$

⇓

$$A_{Sivers}$$

# Drell-Yan process and its angular distribution

Quark-anti-quark annihilation with dilepton production




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

- The collinear hypothesis would imply $\lambda=1$ and $\mu=\nu=0$
- NA10(CERN) and E615 (Fermilab) → modulation of cos2$\phi$ up to 30%
- Intrinsic transverse momentum $k_T$ of quarks inside the hadron → Boer-Mulders PDFs interaction between target and beam quarks

# Single Polarised Drell-Yan cross-section

The LO expansion of the single polarised Drell-Yan cross-section is:

$$\frac{d\sigma}{d^4q\,d\Omega} = \frac{\alpha^2}{Fq^2}\hat{\sigma}_u \left\{ \begin{array}{l} \left(1 + D_{\sin^2\theta} A_U^{\cos 2\phi} \cos 2\theta\right) \\ + \left|\vec{S}_T\right| \left[ A_T^{\sin\phi_S} \sin\phi_S + D_{\sin^2\theta} \left( A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) + A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S) \right) \right] \end{array} \right\}$$

$A_U^{\cos 2\phi}$ $(BM)_\pi \otimes (BM)_p$

$A_T^{\sin\phi_S}$ $(f_1)_\pi \otimes (Sivers)_p$

$A_T^{\sin(2\phi+\phi_S)}$ $(BM)_\pi \otimes (Pretz.)_p$

$A_T^{\sin(2\phi-\phi_S)}$ $(BM)_\pi \otimes (Trans)_p$

A: azimuthal asymmetries: convolution of 2 PDFs

D: depolarisation factor

S: target spin component

$\hat{\sigma}_U$ : part of the cross-section surviving integration over $\phi$ and $\phi_s$

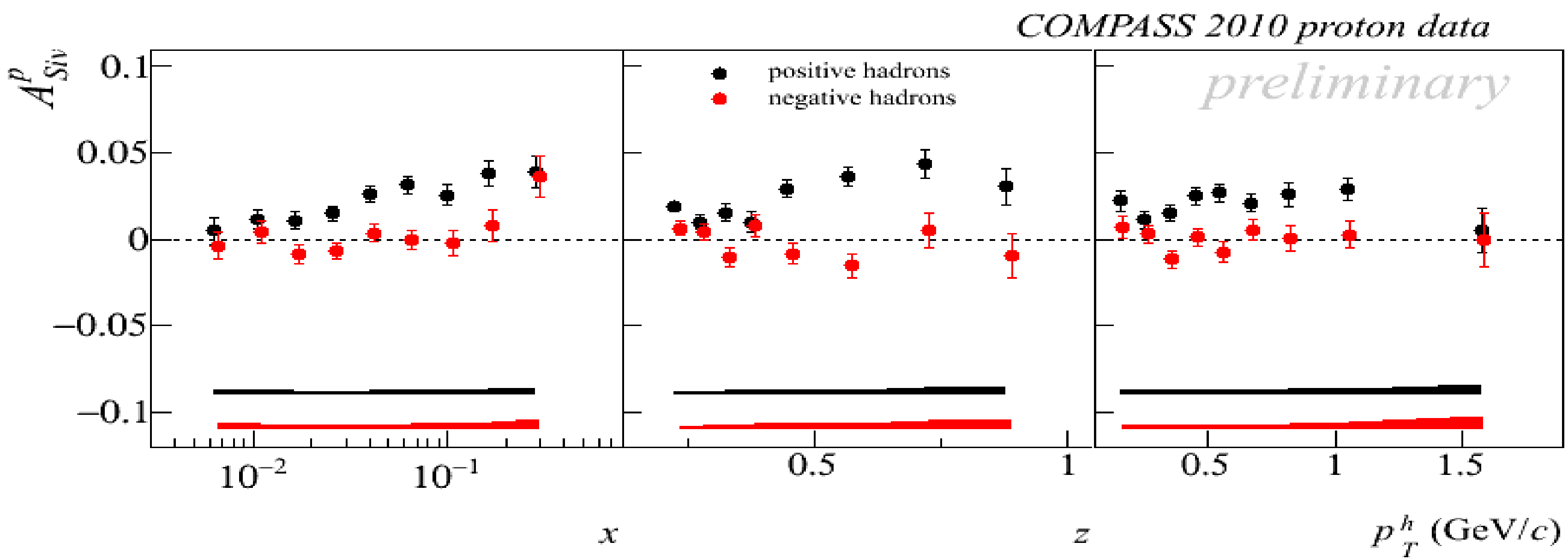
F: $4\sqrt{(P_a.P_b)^2 - M_a^2 M_b^2}$

# Universality of TMD PDFs

Because Sivers and Boer-Mulders PDFs are "time-reversal odd", they are expected to change sign when measured from SIDIS or from DY:

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

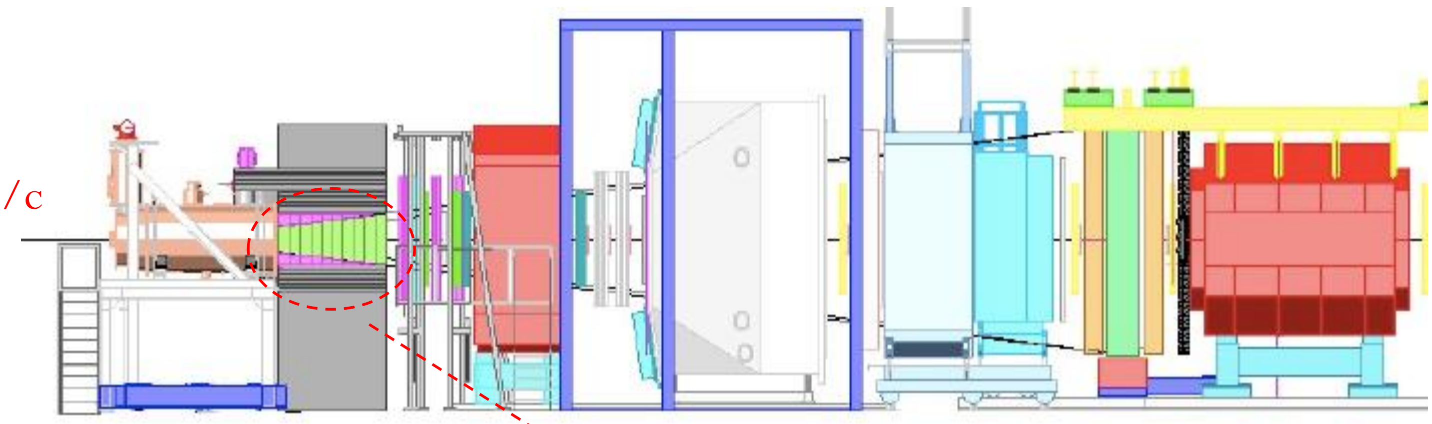
We have the opportunity to test this sign change using the same spectrometer and the transversely polarised target at COMPASS



# DY @ COMPASS: setup

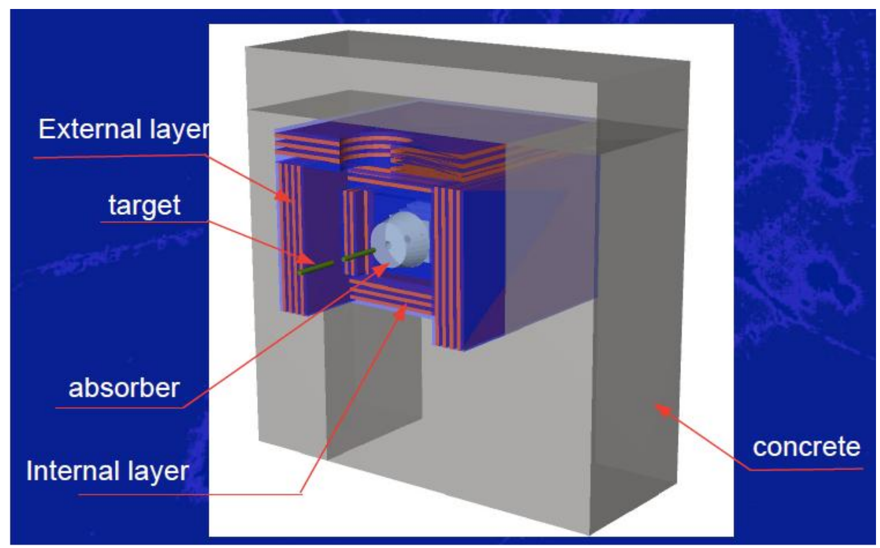
$p^+p^- \rightarrow \mu^-\mu^+X$

$\pi^-$ 190GeV/c



Purpose:

- To stop non-interacting beam particles and secondary hadron flux
- Radio protection issues (max ~$10^8$ pion /s)



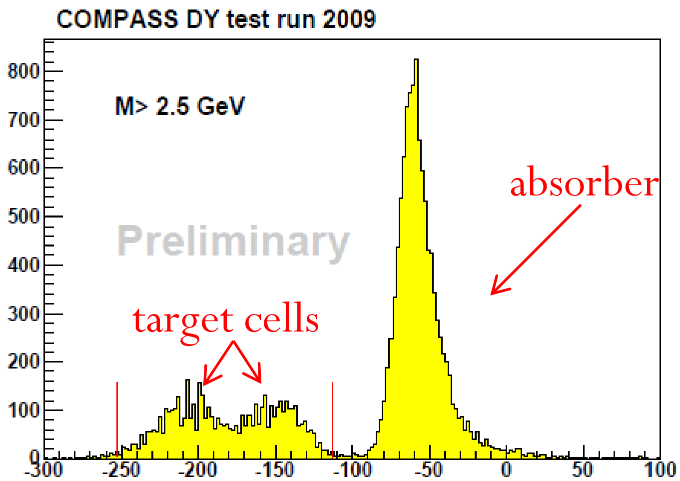

**Key elements:**

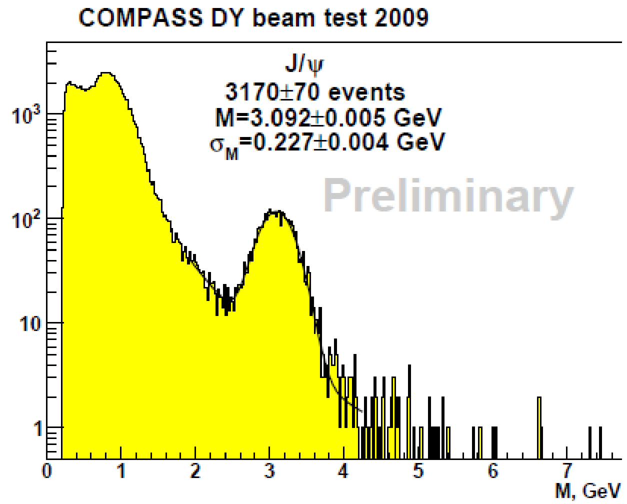
- COMPASS Polarised Target
- Absorber
- Tracking system and beam telescope
- LAS Muon trigger
- RICH and calorimetry for background suppresion

# Drell-Yan test runs

The feasibility of the DY measurement was confirmed by the results of 3 test respectively in: 2007, 2008 and 2009. The most recent one was done using an hadron absorber.

Short data taking was taken, but sufficient to observe J/Ψ peak and DY events as expected from the MonteCarlo simulations and to well distinguish the cells target.



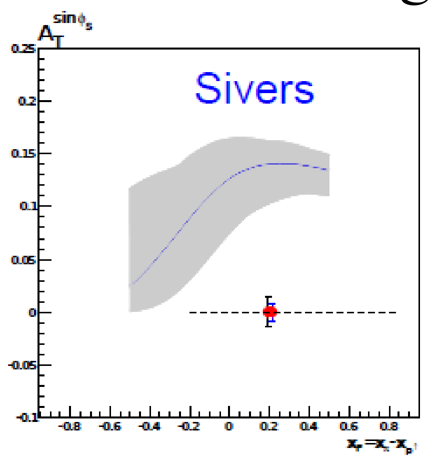



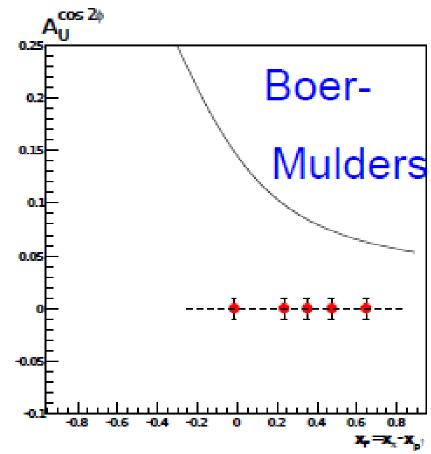
# Drell-Yan statistical error projections

With 2 years of data taking:

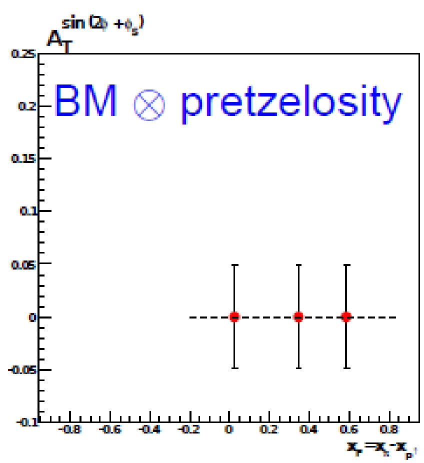
$\mu^+\mu^-$ invariant 4÷9 GeV

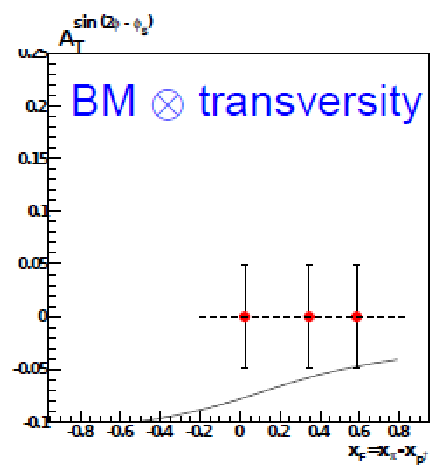
M. Anselmino et al. Phys. Rev. D 79 054010 (2009)



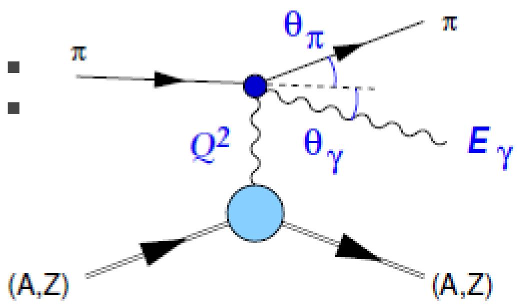

B. Zhang et al. Phys. Rev. D 77, 054011 (2008)




A. N. Sissakian Phys. Part. Nucl. 41 64-100 (2010)

# Primakoff measurement:




$\pi^- \, Z \rightarrow \pi^- \, Z \; \gamma$

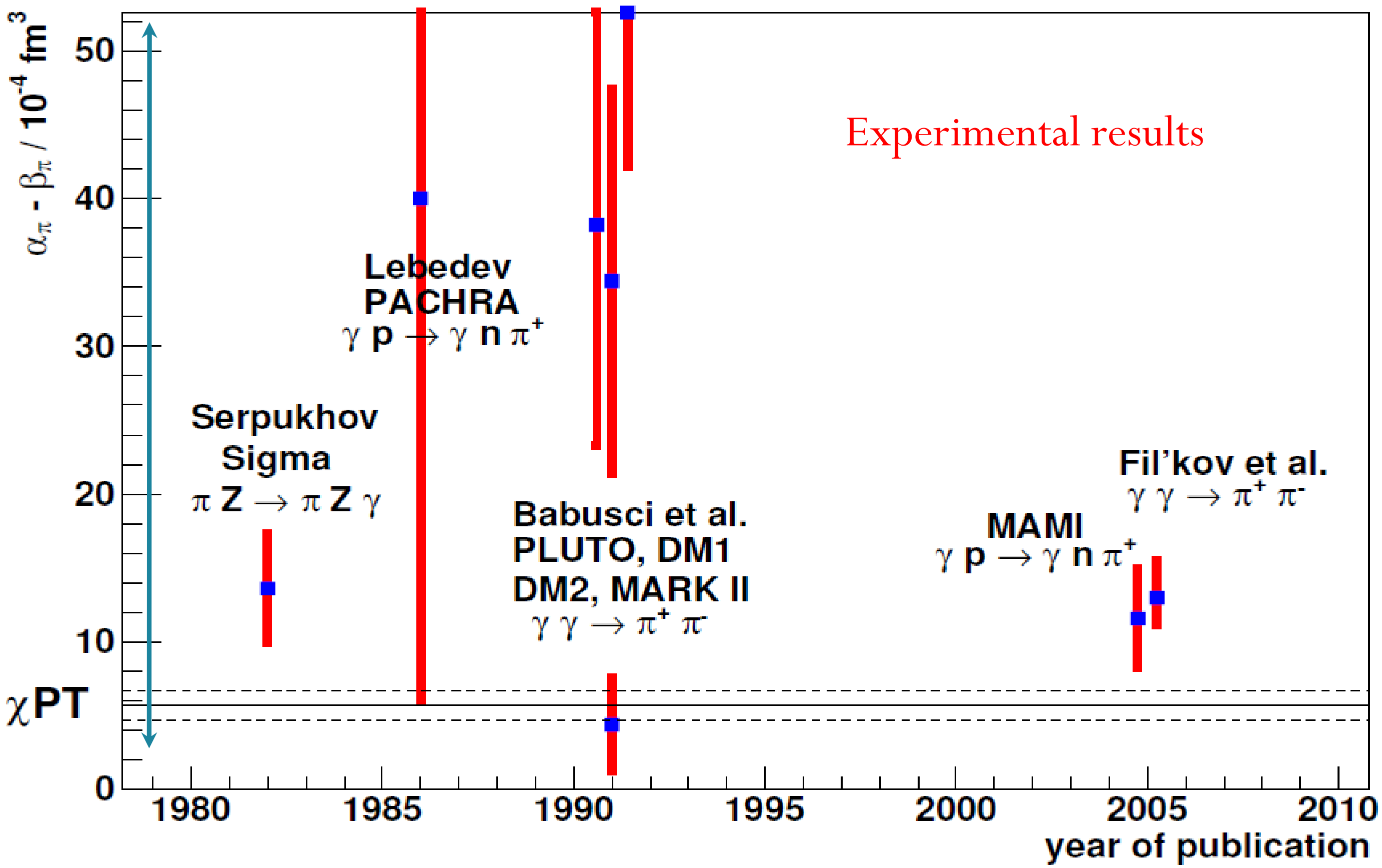
Chiral Perturbation Theory (ChPT) predicts low energy behaviour:

$$\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}} = \left[\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}}\right]_{\text{point}} + C \cdot \frac{s - m_\pi^2}{s^2} P(\alpha_\pi, \beta_\pi)$$

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

ChPT is a low-energy effective field theory based on the approximate chiral symmetry of the **Q**uantum **C**hromo **D**inamycs (QCD) Hamiltonian, possible for small quark masses as ***u***,***d*** and ***s***.

# Polarisability effect

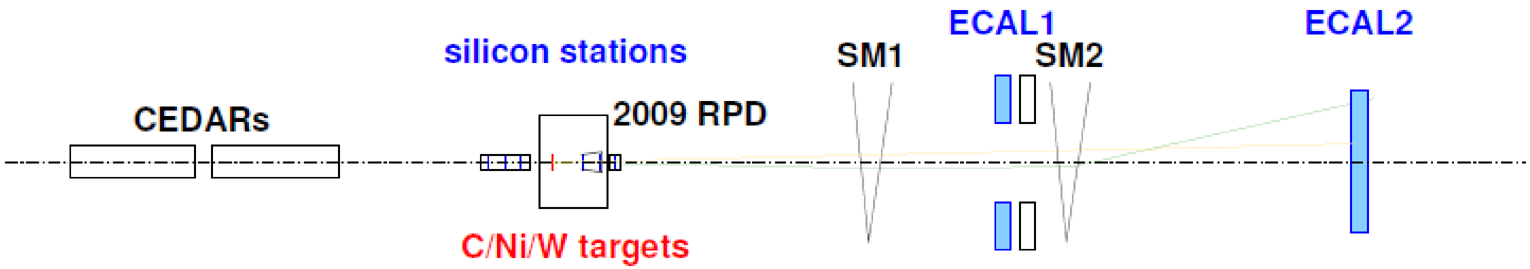



Several theoretical approaches with the ansatz $(\alpha_\pi+\beta_\pi)=0$

→ Experimental measurement needed!!

We will measure independently $\alpha_\pi$ and $\beta_\pi$

# Primakoff at COMPASS: setup




- Pion and muon beams available → same momentum and setup configuration
- Muon is point like particle: Primakoff cross section should correspond to theoretically predicted one
- Study of systematic effect:

Expected total errors

| Days | $\pi$ beam, days | $\mu$ beam, days | Flux $\pi$, $10^{11}$ | Flux $\mu 10^{11}$ | $\alpha_\pi$-$\beta_\pi$ $\sigma_{tot}$ | $\alpha_\pi$+$\beta_\pi$ $\sigma_{tot}$ | $\alpha_2$-$\beta_2$ $\sigma_{tot}$ |
|---|---|---|---|---|---|---|---|
| 120 | 90 | 30 | 59 | 12 | ±0.66 | ±0.025 | ±1.94 |
| | | | | | ChPT prediction | | |
| | | | | | 5.70 | 0.16 | 16 |

Kaon beam 90 days $1.4\text{x}10^{11}$ flux: $\sigma_{tot}(\alpha_k-\beta_k)$ 0.08, (ChPT prediction 1.0)

# Conclusions

COMPASS 2 is on the way and we will provide

- Insight on GPDs through DVCS and DVMP processes;
- Fundamental QCD test for the first-ever polarised Drell-Yan experiment;
- Pion polarisability and kaon polarisability.

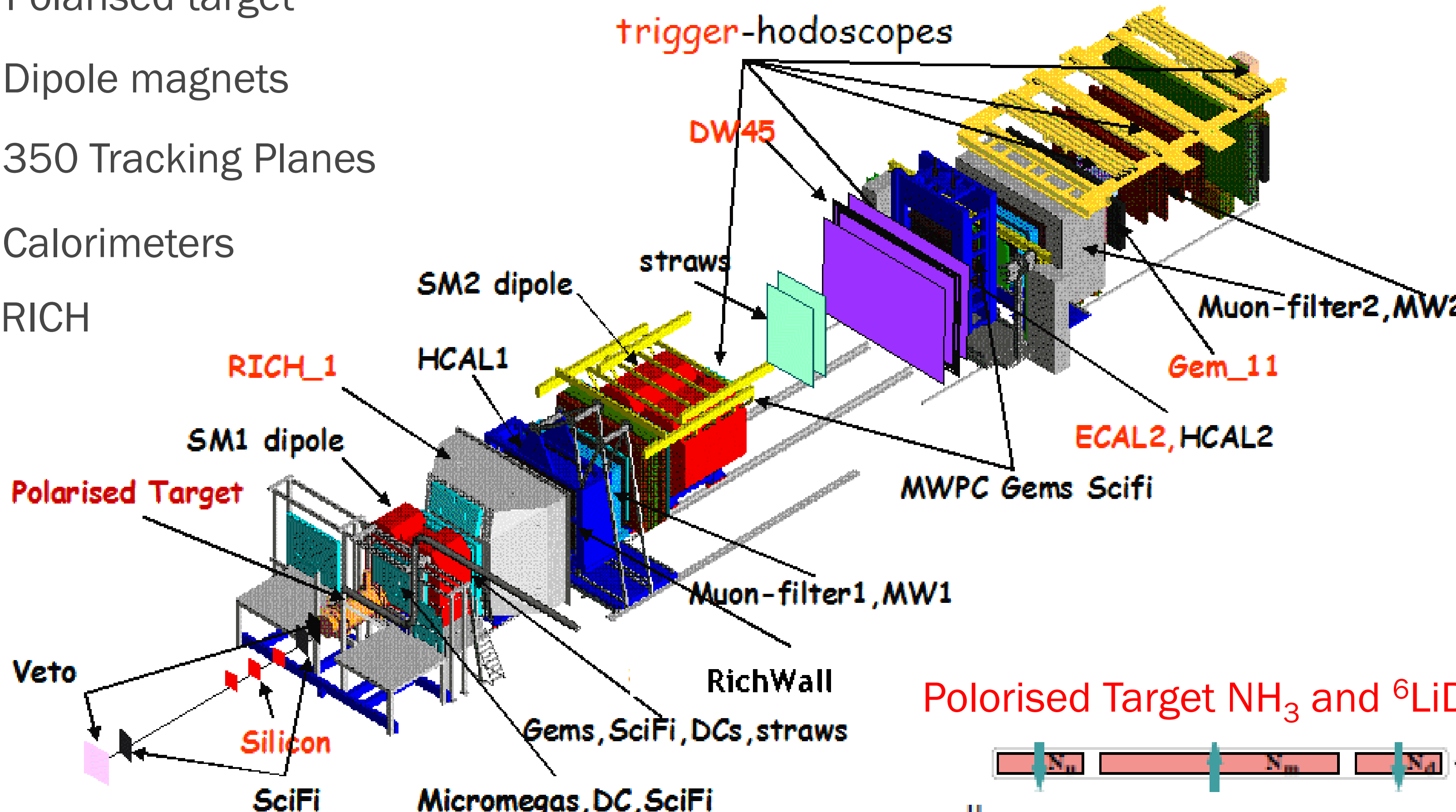
**STAY TUNED!!!**

THANK YOU!

# Spares

# COMPASS Spectrometer

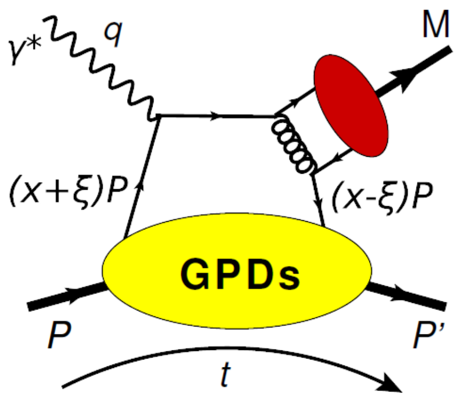
- Polarised target
- Dipole magnets
- 350 Tracking Planes
- Calorimeters
- RICH



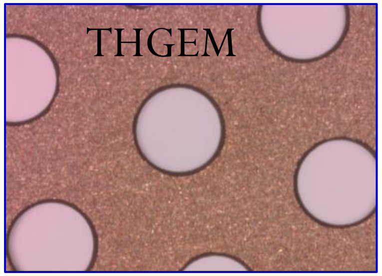

Polorised Target $NH_3$ and $^6LiD$


NIM A 577 (2007) 455-518

# DVCM → RICH upgrade

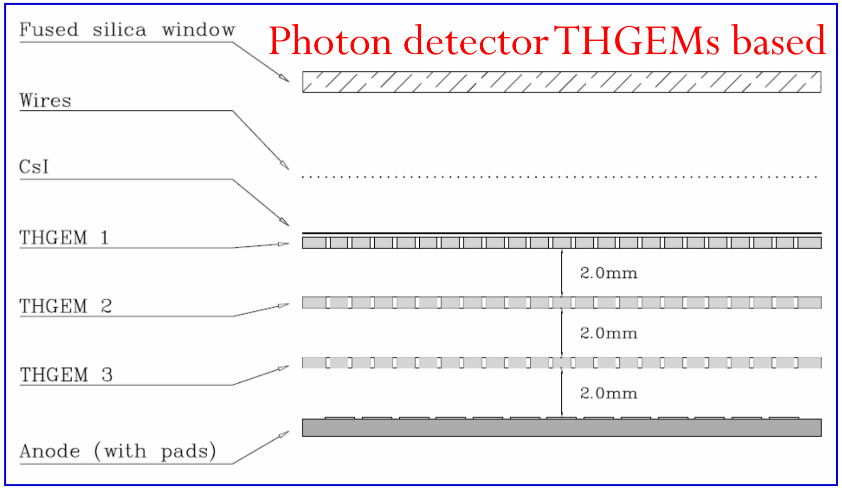



PID needed: RICH-1 upgrade





- Cross-section measurements:
  pseudoscalar → $\widetilde{H}$ & $\widetilde{E}$
  vector meson → H & E
- Vector meson production from transversely polarised target: ∝E/H




Unpolarised data taken w/o RPD in 2002-2004 on $^{6}$LiD and 2007/2010 on $NH_3$

# Azimuthal asymmetries

From the LO DY cross-section we access to 4 azimuthal asymmetries and each asymmetry contains a convolution of 2 PDFs, one from the target and another from beam quarks:

$A_U^{\cos 2\phi}$ Access to Boer-Mulders functions of incoming hadrons;

$A_T^{\sin \phi_S}$ Access to the Sivers function of target nucleon;

$A_T^{\sin(2\phi+\phi_S)}$ Access to Boer-Mulders function of beam hadron and pretzelosity of target nucleon

$A_T^{\sin(2\phi-\phi_S)}$ Access to Boer –Mulders funtion of beam hadron and to transversity of the target nucleon

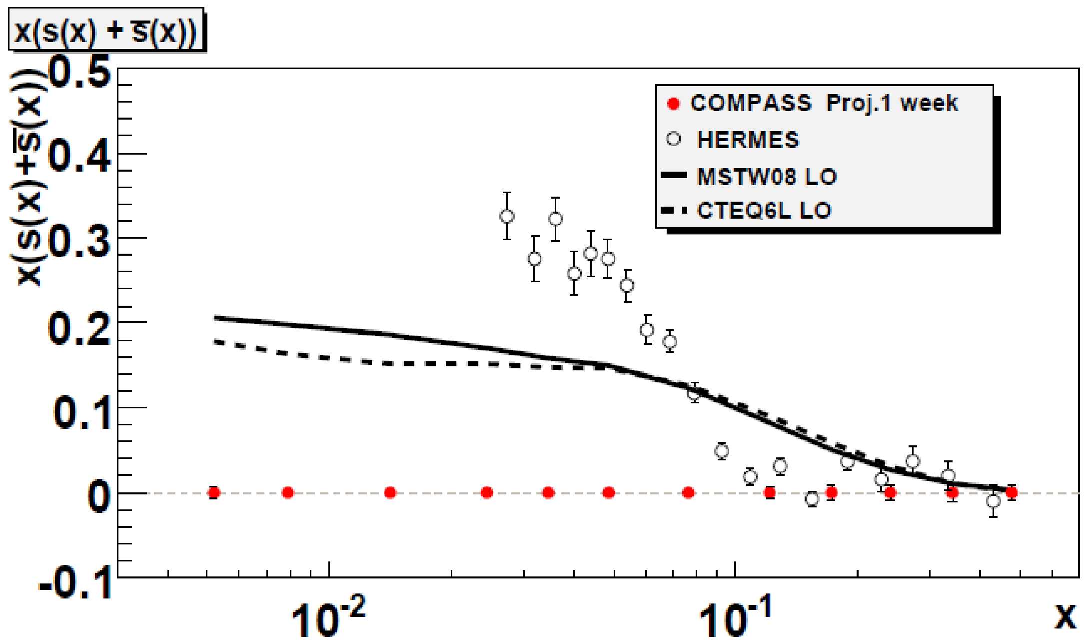
→ ALL TO BE MEASURED EXPERIMENTALLY!!!

# Unpolarised SIDIS measurements(I)

Parallel to the DVCS data taking with $LH_2$ target we can collect data in order to improve:

- Unpolarised PDFs, namely s(x);
- FFs for kaons

GOAL:
Extensive measurement and fine binning in (x, Q2, zpT,..) to provide input to NLO global analysis for PDFs and FFs

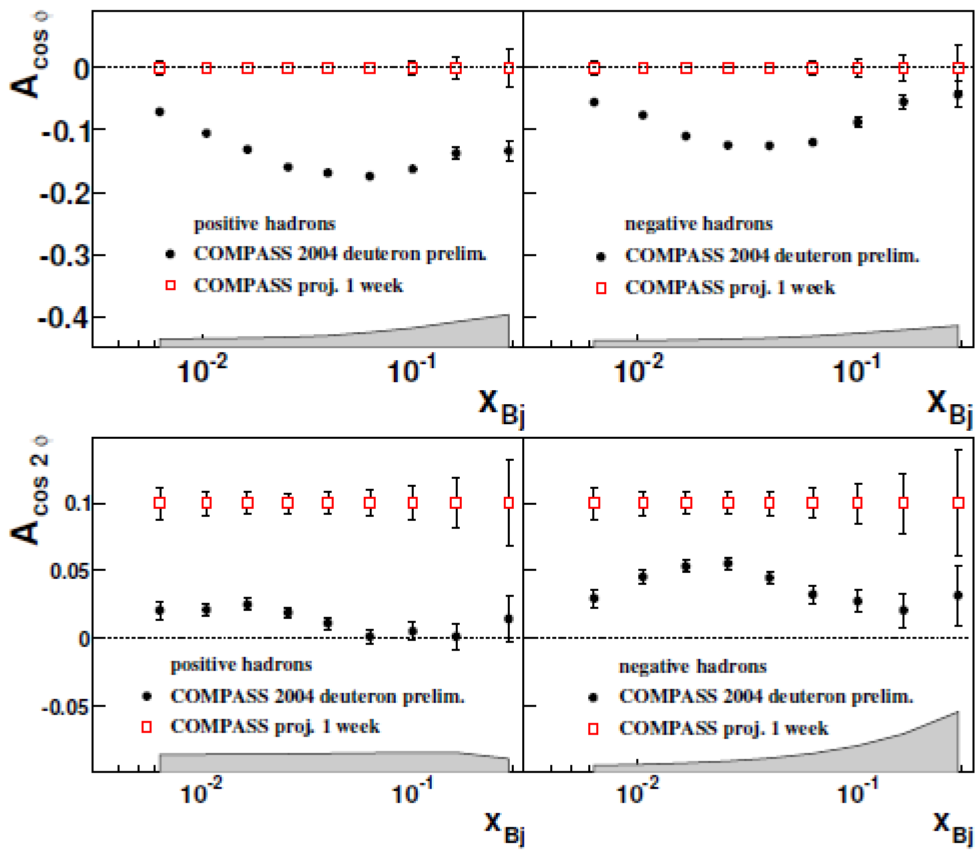





Elena Rocco/CERN

# Unpolarised SIDIS measurements(II)

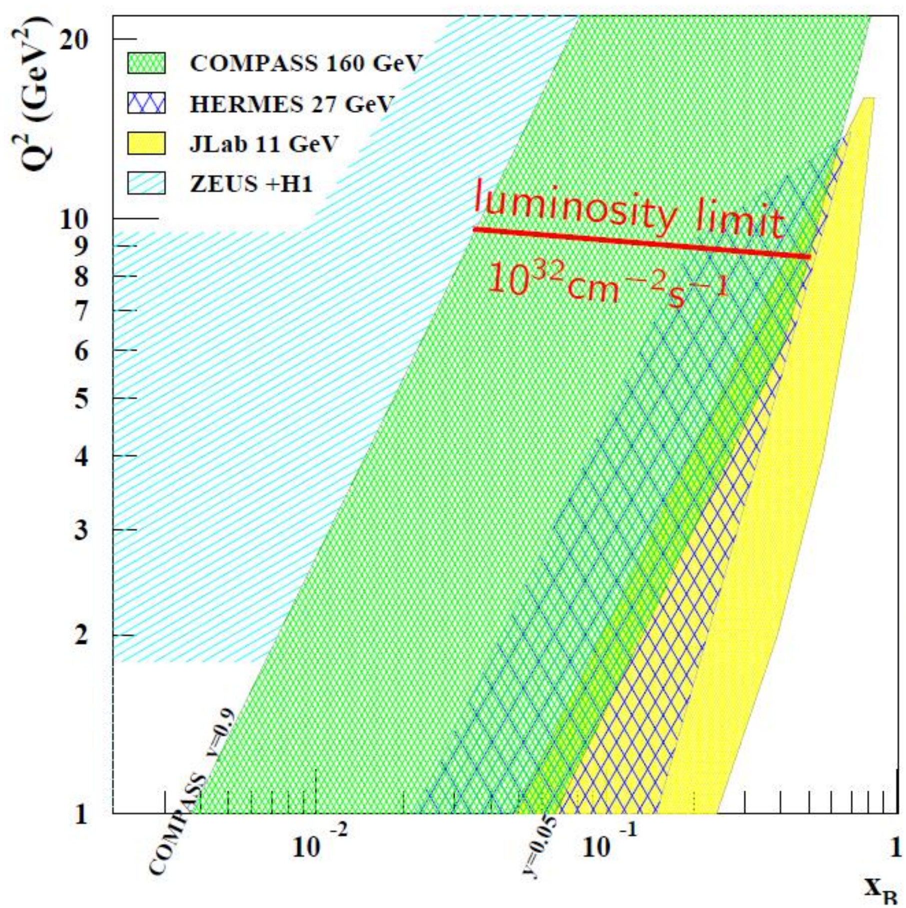
Azimuthal asymmetries in unpolarised SIDIS can reveal quark transverse momentum ($k_T$) effects beyond the collinear approximation




**Cahn effect**

**Boer-Mulders TMD ⊗ Collins FF+ Cahn effect**

# Uniqueness of COMPASS for DVCS




- $m^+$ and $m^-$ beams;
- Momentum 100-190 GeV/c;
- Beam polarisation 80% opposite for $m^+$ and $m^-$
- Coverage of intermediate $x_B$:
  - low $x_B$: pure BH,
  - high $x_B$: DVCS predominance
- Unexplored region between ZEUS+H1 and HERMES+JLAB