COMPASS - a facility to study QCD

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Hadron 2011
München, 13.-17.11.2011

– COMPASS experiment
– What we have done
– What we want to do

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

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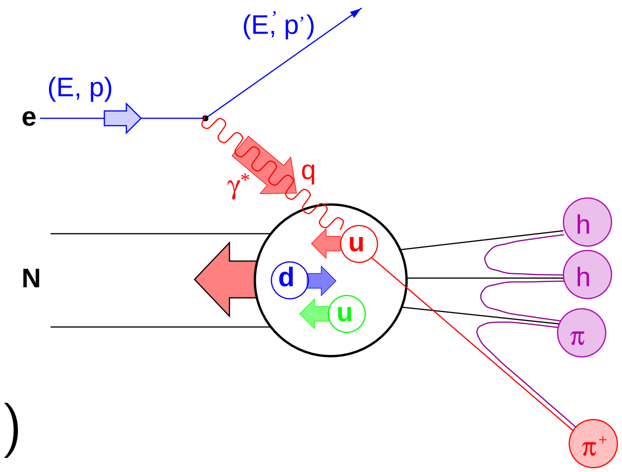
COMPASS

What have we done

COMPASS is data taking since 2002 studying

Nucleon spin puzzle: $S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$



- muon scattering on polarised p(NH_3) and d(^{6}LiD) with long. and transv. target polarisation
- addendum in 2010 (transv. p) and 2011 (long. p)
- all three leading twist PDFs investigated (f_1, g_1, h_1)

Results: quark spin responsible for 30% of nucleon spin
gluon contribution small in x range covered
hardly any information on orbital angular momentum

Hadron spectroscopy

- 190 GeV/c hadron beams (π, p, K) on unpol. targets (liquid H_2, Pb, Ni, Cu ,W)
- searches for exotics, hybrids and glueballs
- pion polarisabilities

What will we do

COMPASS

Improve the 1-dimensional picture of the nucleon

Generalized parton distribution (GPD)

longitudinal momentum structure plus transverse spatial structure
accessible in exclusive reaction like DVCS or DVMP

Flavour separation and fragmentation

in semi-inclusive deep inelastic scattering (SIDIS)
improvement of strange quark distribution and fragmentation

Transverse momentum dependent distributions (TMD)

dynamic picture using intrinsic transverse momenta of partons
accessible in SIDIS and Drell-Yan processes

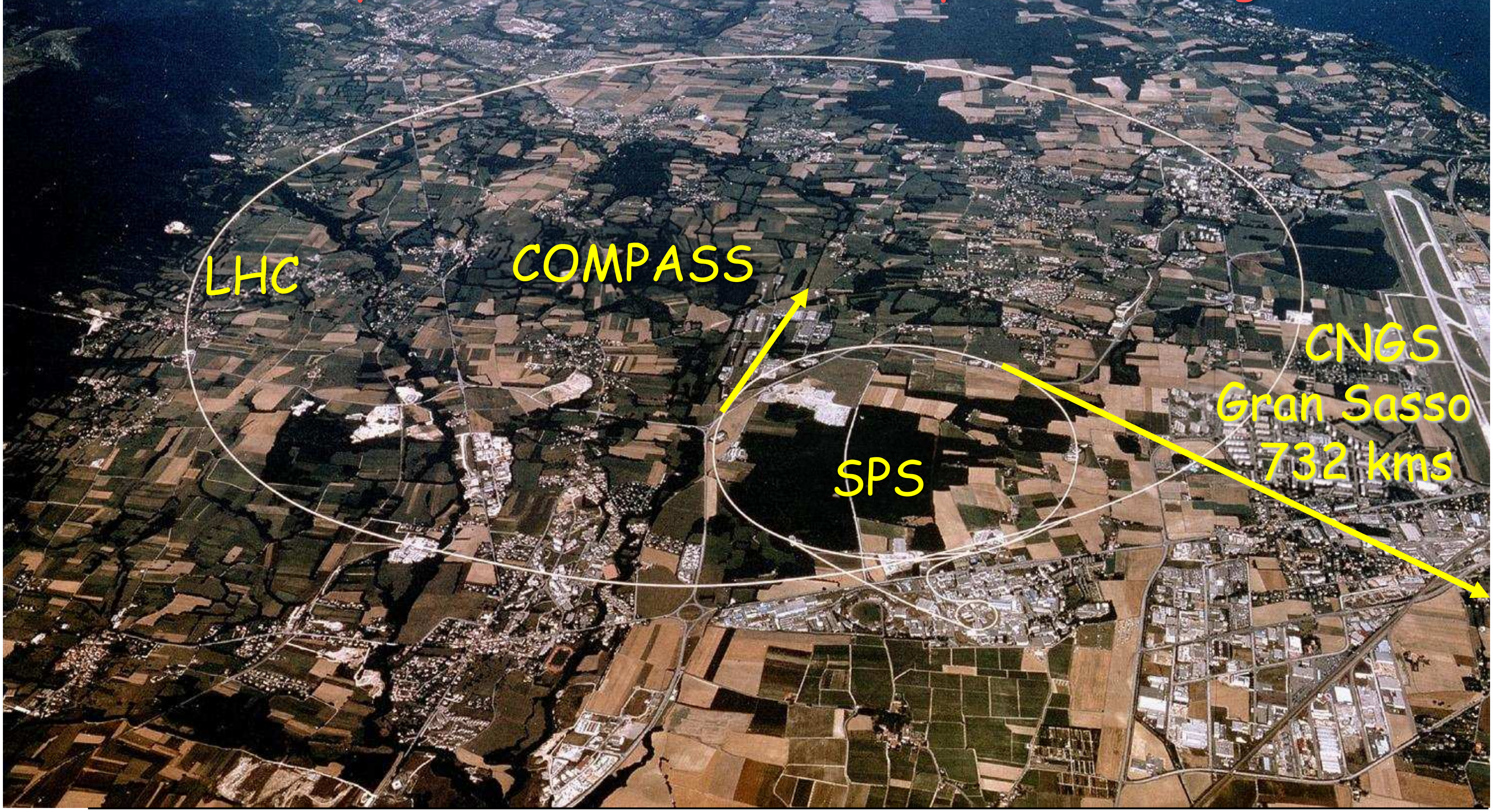
QCD at very low momentum transfers

using Primakoff reactions to access inverse Compton scattering
pion/kaon polarisabilities, testing chiral perturbation theory

COMPASS II proposal:
submitted in May 2010 for 5 years of data taking in the first phase
approved in December 2010 for initially 3 years of data taking

SPS proton beam: $1.4\ 10^{13}$/spill of 4.8s, 400 GeV/c

- Secondary hadron beams (π, K, …): 2.10^{8} /spill, 150-270 GeV/c
- Tertiary muon beam (80% pol): 2.10^{8} /spill, 100-200 GeV/c
  -> Luminosity ~ $5 \times 10^{32}\ cm^{-2}\ s^{-1}$ with polarised targets



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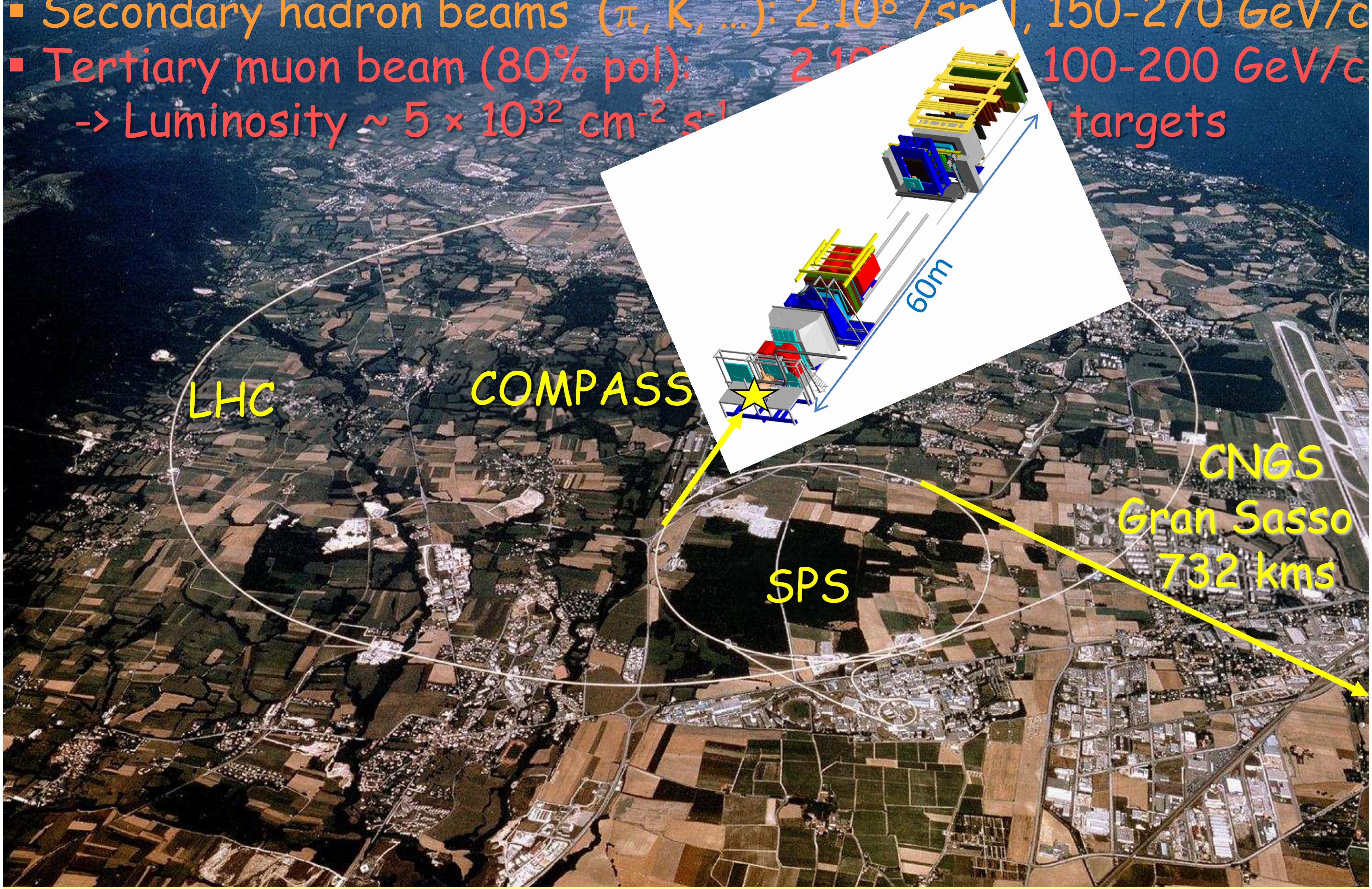
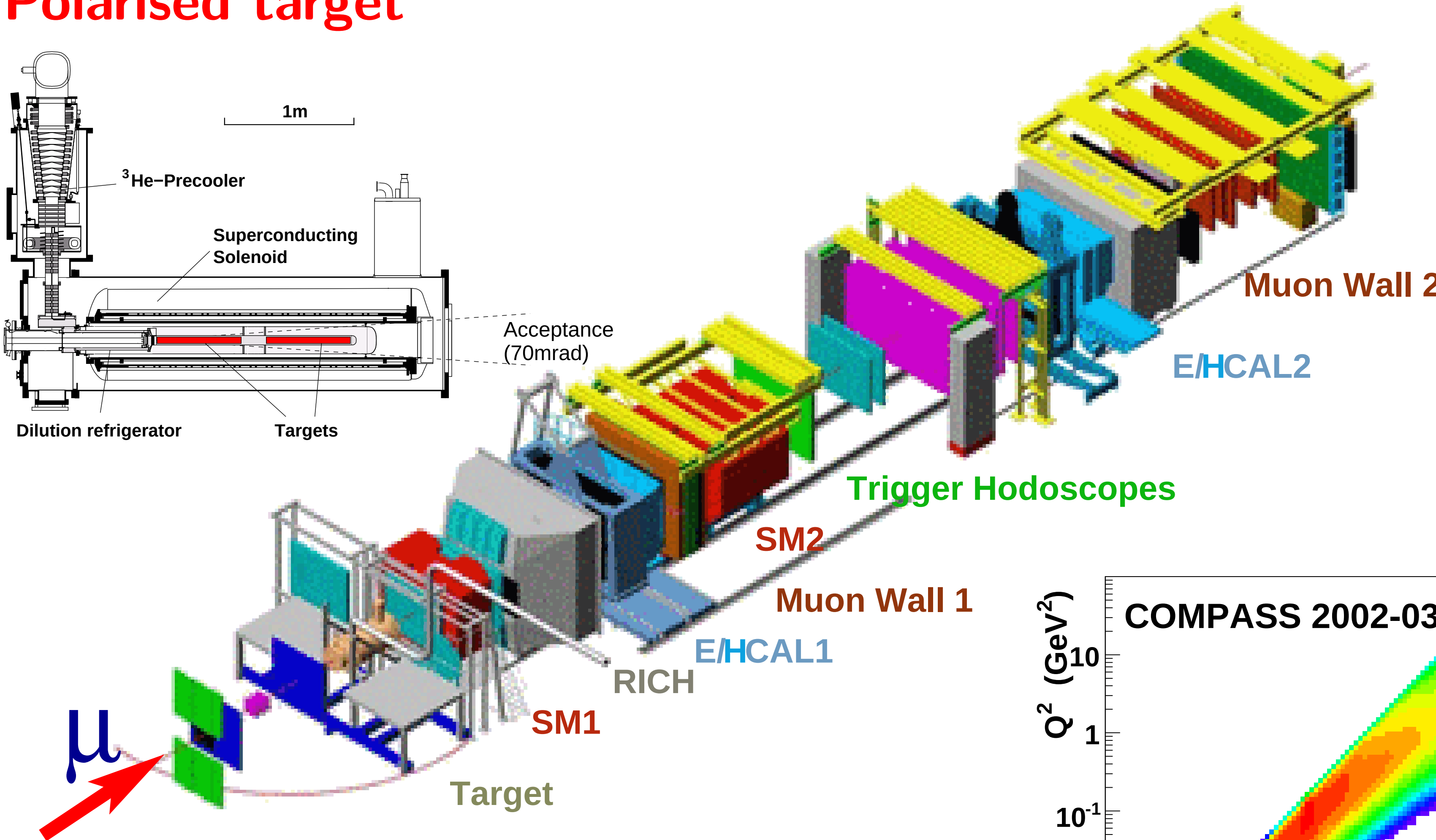
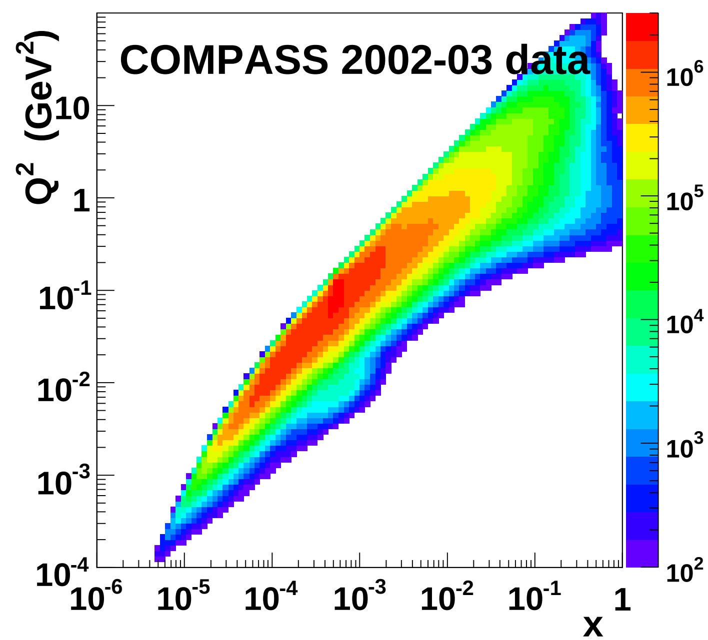


high energy beam(s), broad kinematic range, large angular acceptance

COMPASS spectrometer

Polarised target

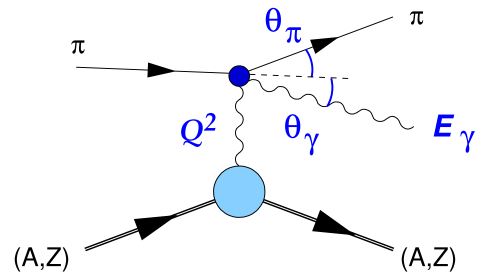




target material: ^{6}LiD, NH_3
polarisation: 50%, 90%

Primakoff experiments with π, K

$$\pi^- Z \to \pi^- Z\gamma$$



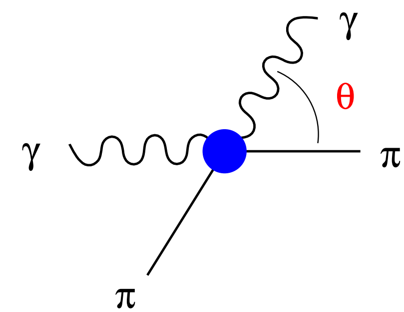
Primakoff

chiral perturbation theory predicts low energy behaviour

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

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

- deviation from pointlike due to pion polarisabilities
- measurements: $\alpha_\pi - \beta_\pi$ (at backward angles), $\alpha_\pi + \beta_\pi$



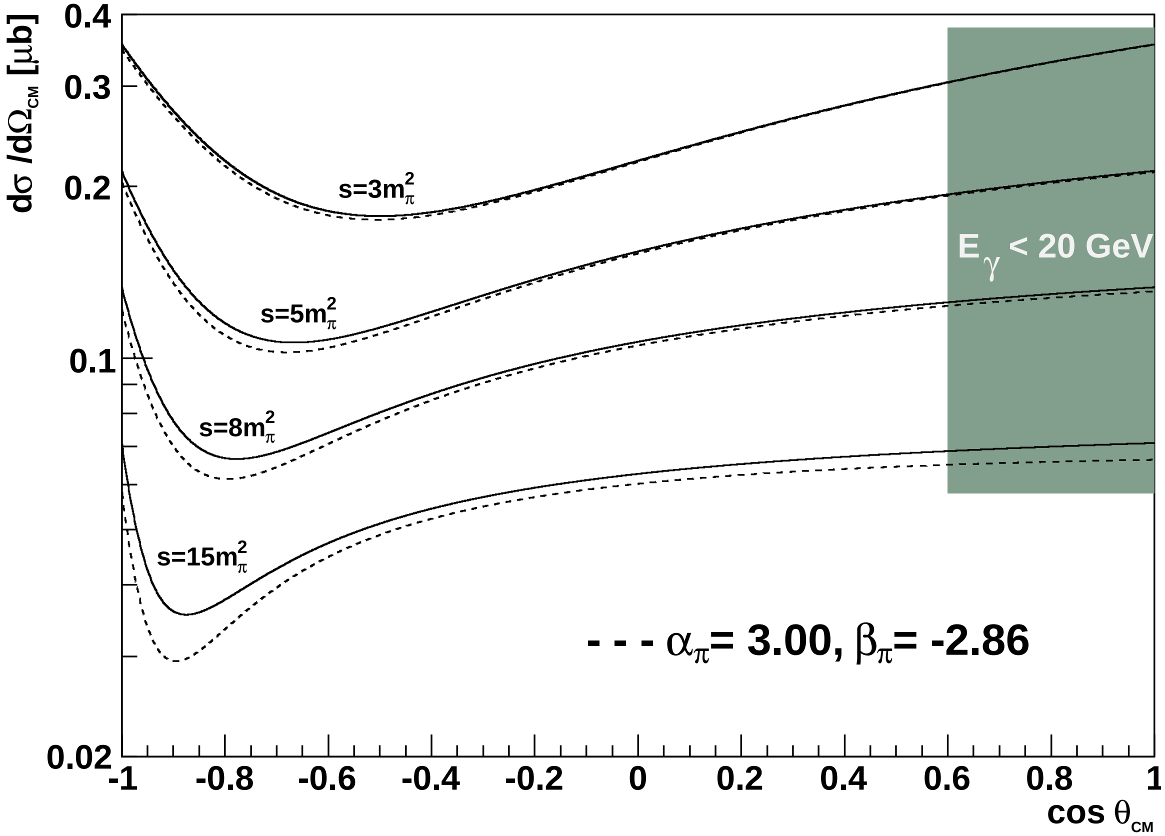
Inverse Compton

2-loop chiral prediction

$$\alpha_\pi - \beta_\pi = (5.7 \pm 1.0)10^{-4}\ \text{fm}^3$$

experiments: $\alpha_\pi - \beta_\pi$ from 4 to $14 \cdot 10^{-4}$ fm^3

Pion polarisability measurement



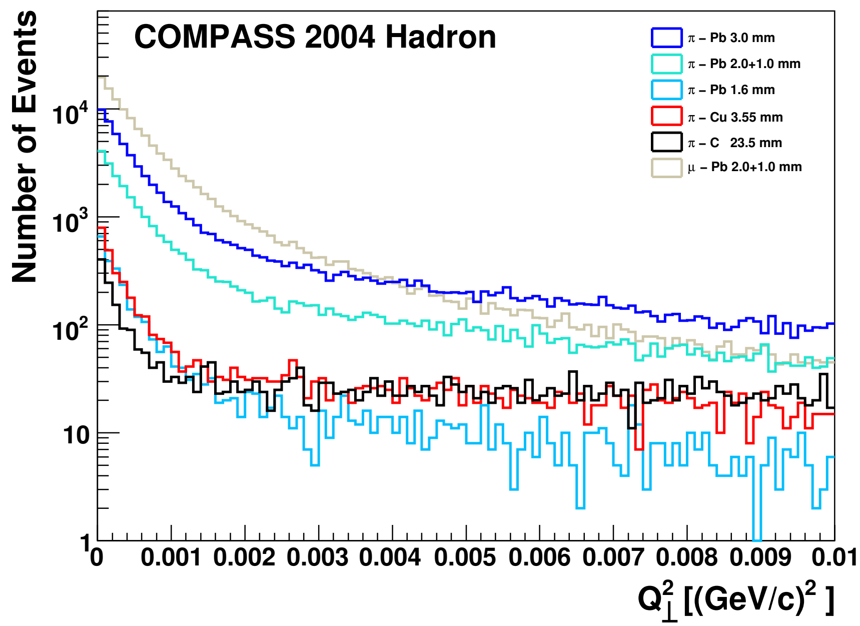
- effect increases with s^2
- effects due to $\alpha_\pi - \beta_\pi$ much larger than for $\alpha_\pi + \beta_\pi$

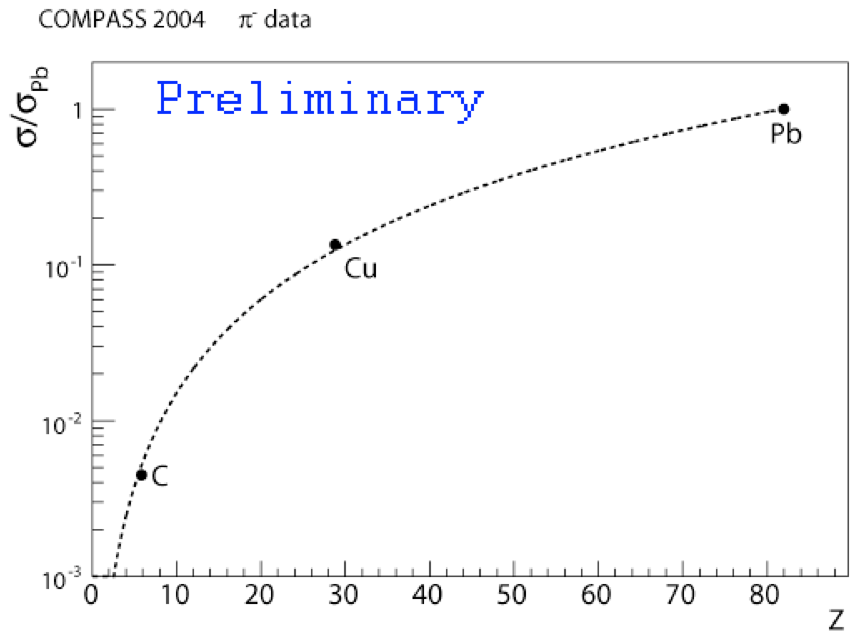
unique at COMPASS :

- kaon component in hadron beam: kaon polarisability accessible
- availability of a muon beam (point like) for comparison and systematics
- switching between pion and muon beam within few hours possible

Projections for polarisabilities

- already two (test)measurements performed, clear signal from Primakoff events

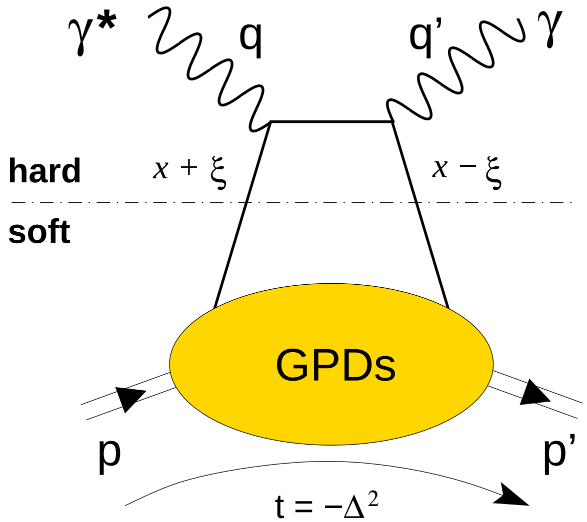




- expected precision of the new measurement:

in 120 d 90 d with π, 30 d of μ beam	$\alpha_\pi - \beta_\pi$ $(10^{-4}$ fm$^3)$	$\alpha_\pi + \beta_\pi$ $(10^{-4}$ fm$^3)$	$\alpha_2 - \beta_2$ $(10^{-4}$ fm$^5)$
2-loop ChPT prediction	5.70 ± 1.0	$.016 \pm 0.10$	16
COMPASS sensitivity	± 0.66	± 0.25	± 1.94

Generalised parton distributions



Factorisation for
Q^2 large, $t < 1$ GeV^2

- **generalised parton distributions for quarks** $H^f, E^f, \widetilde{H}^f, \widetilde{E}^f(x,\xi,t)$
- **limits:**

$$\begin{aligned} q(x) &= H(x,0,0) && \text{normal PDF} \\ F(t) &= \int \mathrm{d}x\, H(x,\xi,t) && \text{elastic form factor} \end{aligned}$$

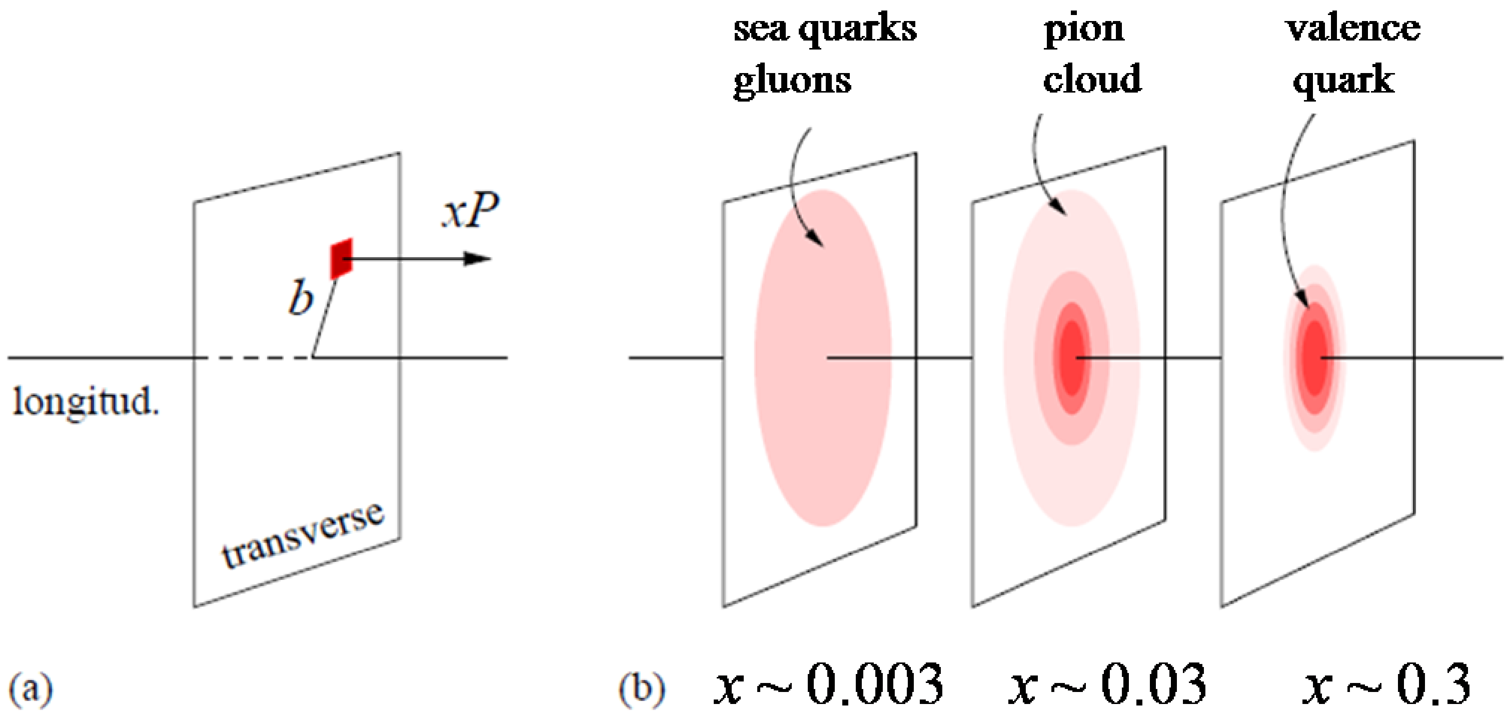
- **Ji's sumrule**

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

J^f: total angular momentum contribution of quark f

Nucleon tomography

- GPDs allow simultaneous measurement of longitudinal momentum and transverse spatial structure



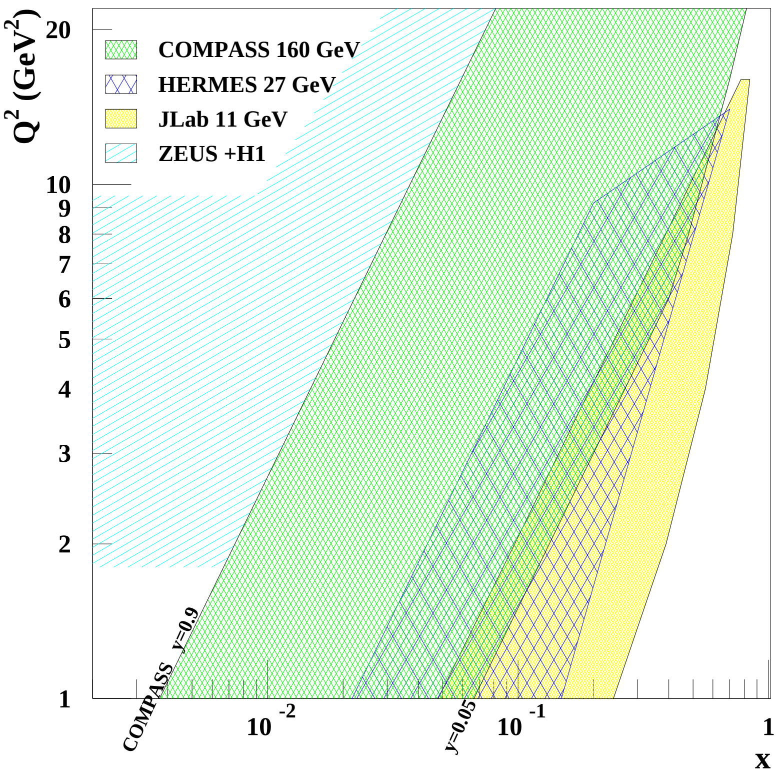
- for $\xi \to 0$: $t = -\boldsymbol{\Delta}_\perp^2$ purely transverse and

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

- $\boldsymbol{b}_\perp$ distance to center of momentum (b in figure is $\boldsymbol{b}_\perp$)

Why GPDs at COMPASS?

- **CERN high energy muon beam:**
  - 100–160 GeV, 80% polarisation
  - μ^+ and μ^- with opposite polarisation



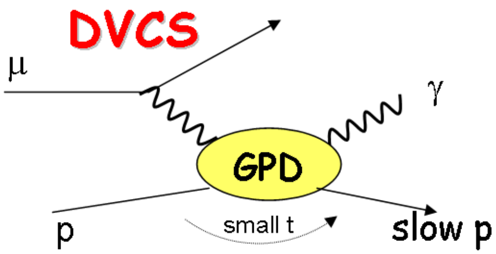
- **unique kinematic range** between HERA and HERMES/JLab
  - intermediate x: $\Longrightarrow$ sea and valence quarks
  - high x limit from acceptance
  - Q^2 up to 8GeV^2 $\Longrightarrow$ limit from cross section with $L = 10^{32}$ cm^{-2}s^{-1}

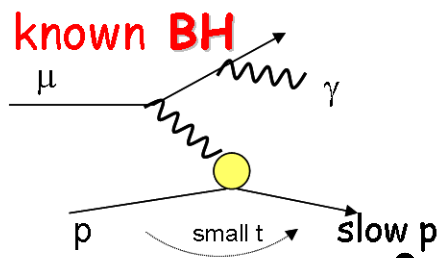
- **planned measurements:**
  - deeply virtual Compton scattering
  - deeply virtual meson production

Phase 1: 2.5 m long unpolarised liquid H_2 target $\Longrightarrow$ **GPD H**
Phase 2: transversely polarised liquid NH_3 target $\Longrightarrow$ **GPD E**

Experimental requirements

$$\mu p \longrightarrow \mu\gamma p$$





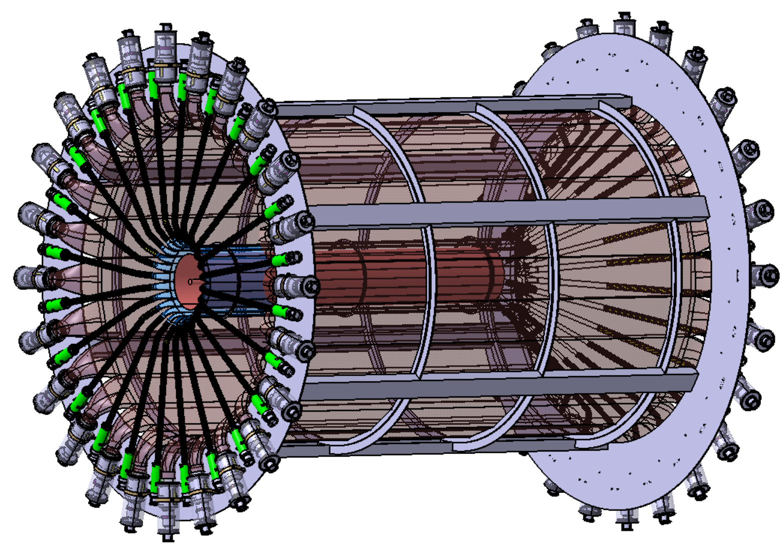
- two competing processes: DVCS and BH
- Bethe-Heitler dominates at low x, used a reference yield
- measurement with μ^+ and μ^- with opposite polarisation

  $$\mathcal{S}_{CS,U} \equiv \mathrm{d}\sigma^{+\downarrow} + \mathrm{d}\sigma^{-\downarrow}$$

  $$\mathcal{D}_{CS,U} \equiv \mathrm{d}\sigma^{+\downarrow} - \mathrm{d}\sigma^{-\uparrow}$$
- yield Re(H) and Im(H)
- additionally deeply virtual meson production

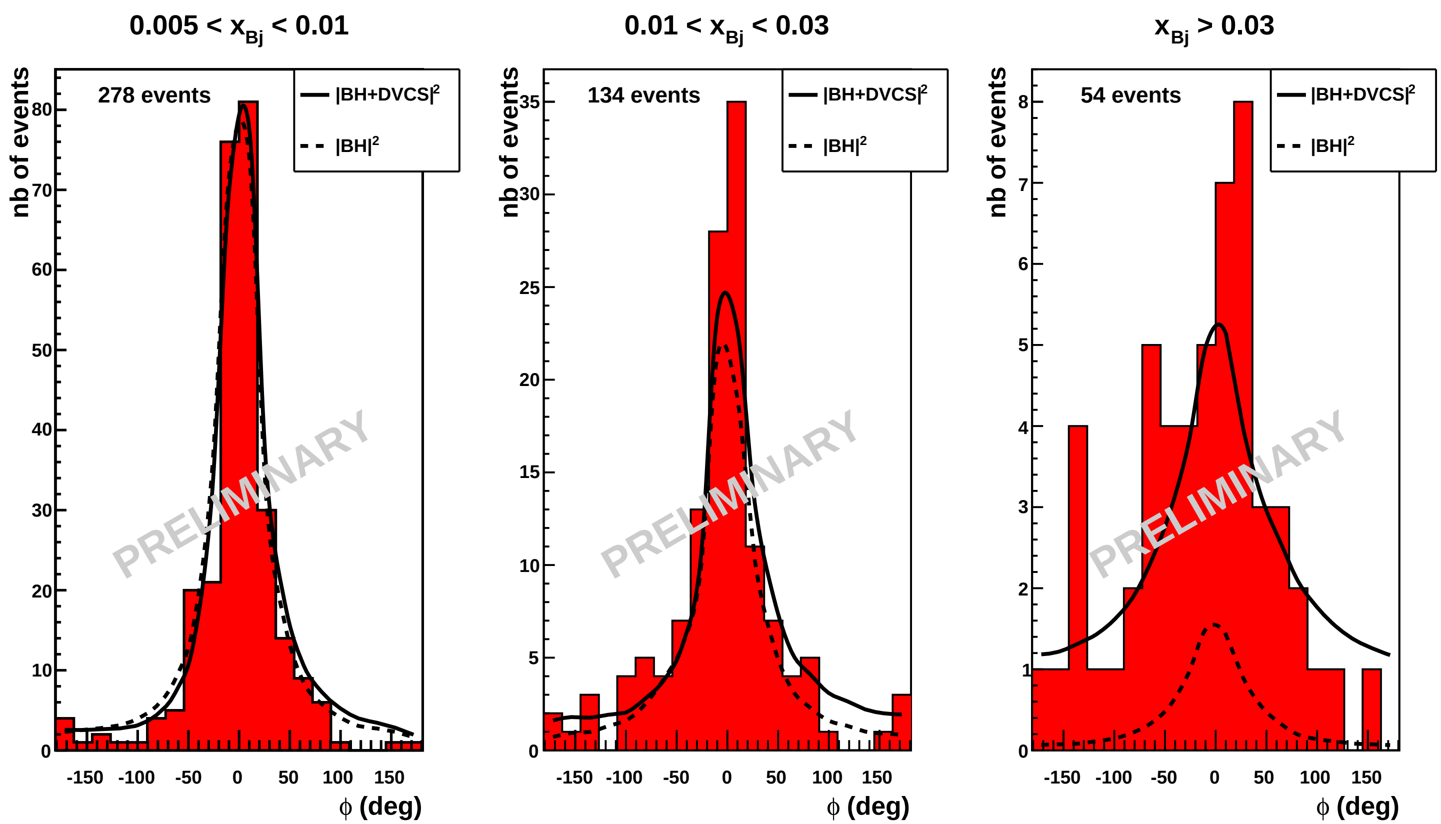
Experimental set-up

- 2.5 m long liquid hydrogen target
- 4 m long recoil proton detector (2 layers)
- 'hermetic' coverage with electro-magnetic. calorimetry



Test measurement 2009

- data taking with μ^+ (8 times more stat.) and μ^- at about nominal intensity
- 40 cm liquid H_2 target and small recoil proton detector
- measure BH events plus relative DVCS and DVMP contributions
- comparison of μ^+ and μ^- data: μ^- flux is factor of 3 lower at 160 GeV
  $\Longrightarrow$ limitation on overall luminosity



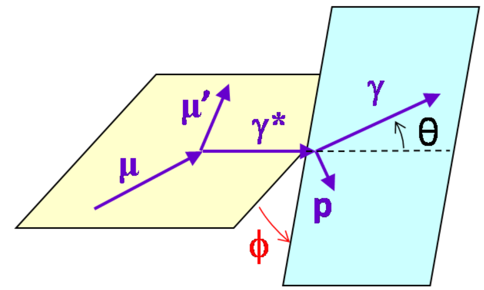
$\Longrightarrow$ clear DVCS signal observed at $Q^2 > 1$ GeV^2, $x > 0.03$

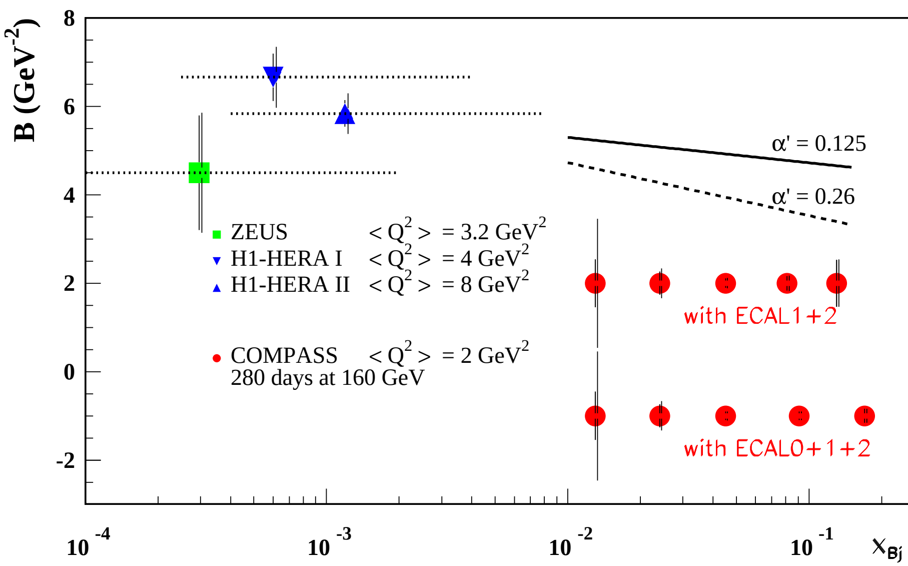
Projected results

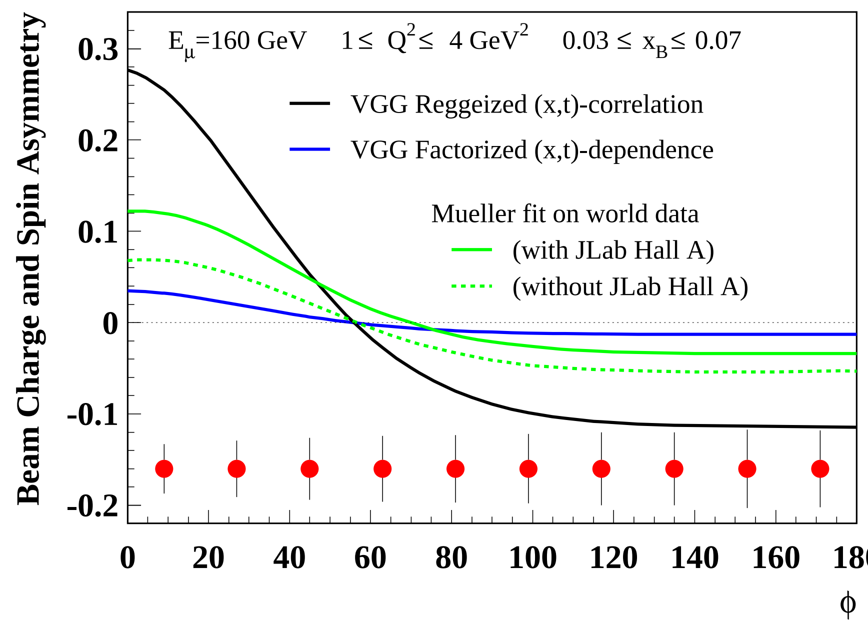
projections with
2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222$ pb^{-1}

- **Transverse imaging**:
  $B(x) \sim 1/2\,\langle r_\perp^2(x)\rangle$
  no model dependence

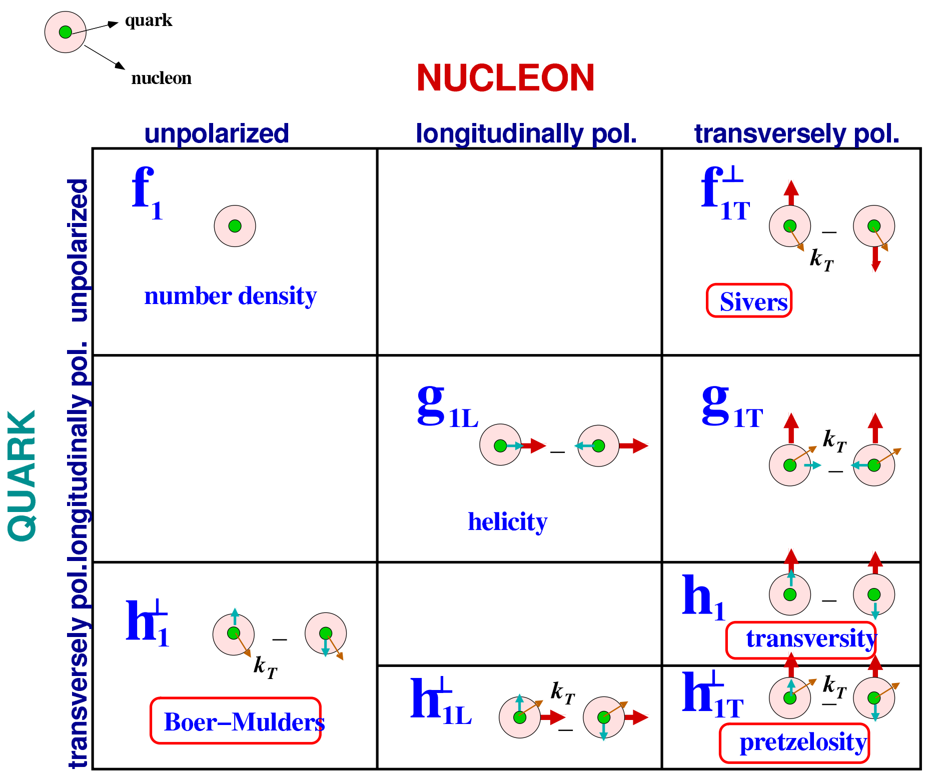
- **Azimuthal dependence**:
  comparison to different models
  $\Longrightarrow c_1^I \propto \mathrm{Re}(F_1\mathcal{H})$







Transverse Momentum Dependent Distributions

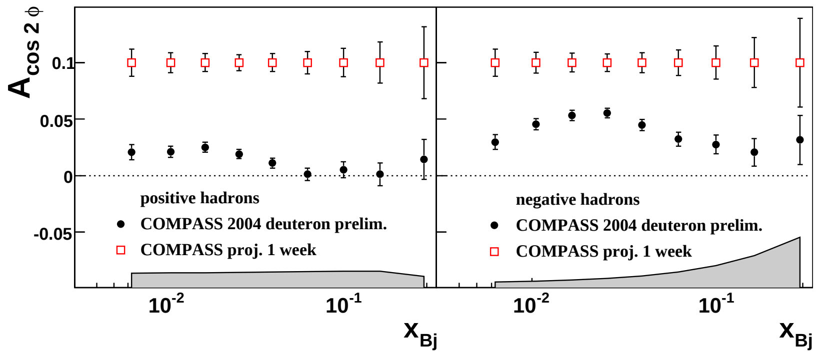


- dynamic picture of the nucleon using intrinsic transverse momentum k_T of partons
- sensitivity to quark orbital angular momentum
- at leading twist:
  full description with 8 TMDs
- 3 survive integration over k_T:
  $\boldsymbol{f}_1$, $\boldsymbol{g}_1$ and $\boldsymbol{h}_1$

- TMDs are accessed by azimuthal asymmetries
- studied in SIDIS using unpolarised and transversely polarised target
- in SIDIS convolution with fragmentation function

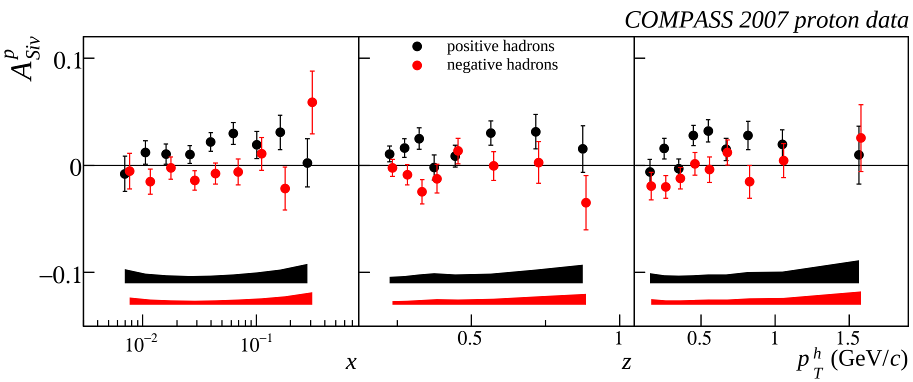
Boer-Mulders and Sivers DF in SIDIS

BM function $h_1^\perp$: correlation of quark k_T and transverse spin in unpol. nucleons



- 2004 data on deuteron target: non-zero Boer-Mulders asymmetry ($A_{LU}^{\cos 2\phi}$)
- Boer-Mulders on proton will be measured in parallel with DVCS

Sivers function $f_{1T}^\perp$: correlation of quark k_T and nucleon transverse spin



- Sivers asymmetry ($A_{LT}^{sin\phi_S}$) measured at COMPASS with pol. deuteron and proton target
- positive asymmetry for $h+$ on proton, but smaller than seen by HERMES

Boer-Mulders and Sivers function are T-odd $\rightarrow$ process dependent

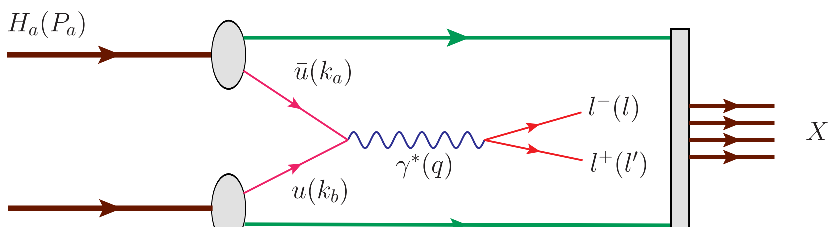
$$h_1^\perp(SIDIS) = -h_1^\perp(DY)$$

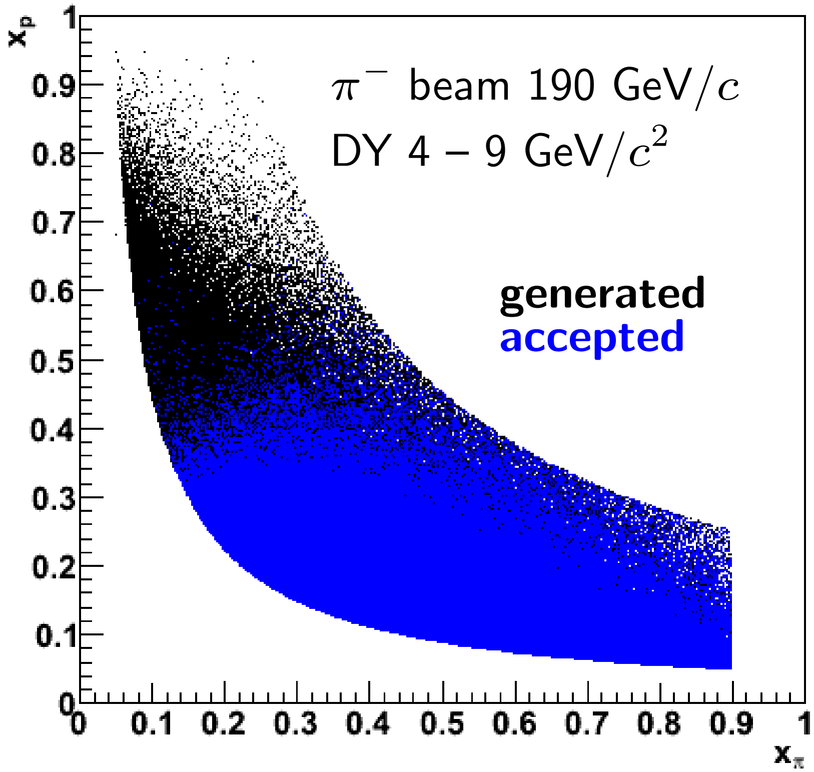
$$f_{1T}^\perp(SIDIS) = -f_{1T}^\perp(DY)$$

$\longrightarrow$ Crucial test of non-perturbative QCD and of TMD approach

Drell-Yan at COMPASS

$$\pi^- p^\uparrow \;\rightarrow \mu^+\mu^- X$$

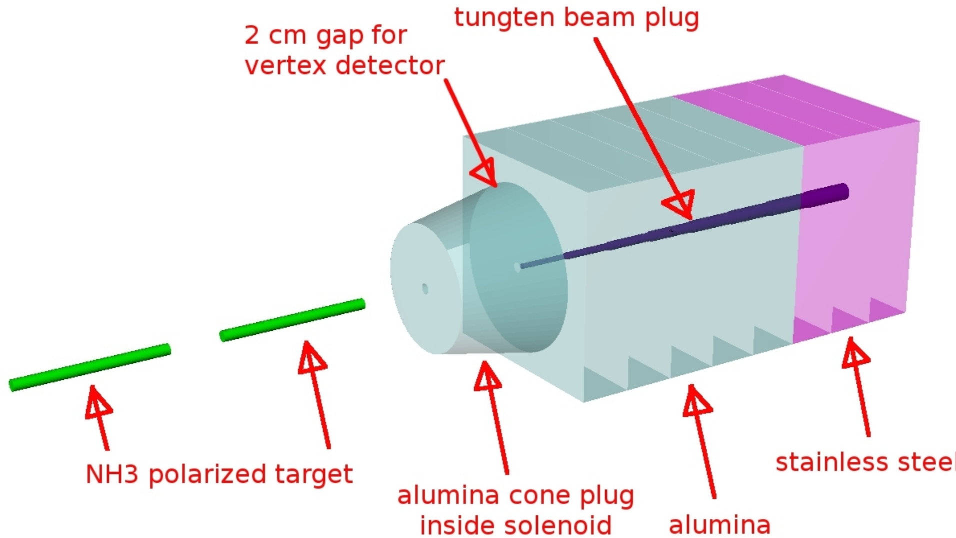




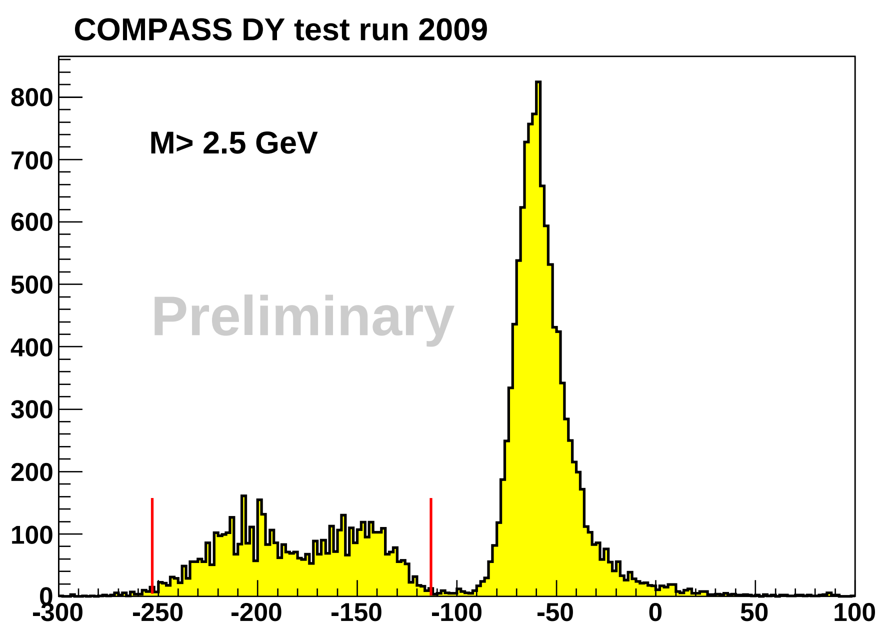
- **DY**: convolution of two TMDs measured
- access to 4 azimuthal modulations: Boer-Mulders, Sivers, pretzelosity and transversity PDFs
- ideal DY measurement: $\bar{p}p$
- good compromise $\pi^- p$
- dominated by annihilation of valence anti-quark from π^- and valence quark from polarised proton
- large acceptance of COMPASS in the valence region of p and π where large SSA are expected

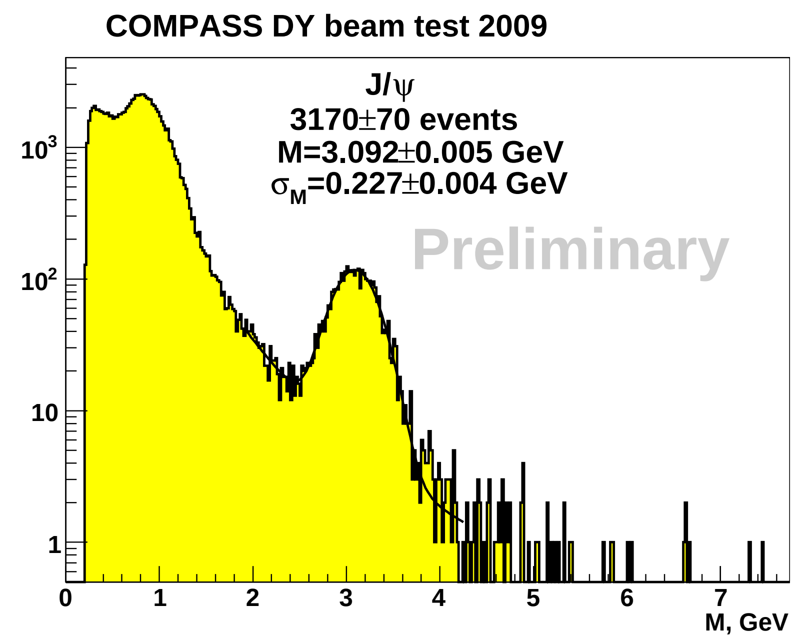
Experimental requirements

- high intensity 190 GeV/c pion beam (up to 10^9/spill)
- transversely polarised NH_3 target
- hadron absorber downstream of target
- dimuon trigger system



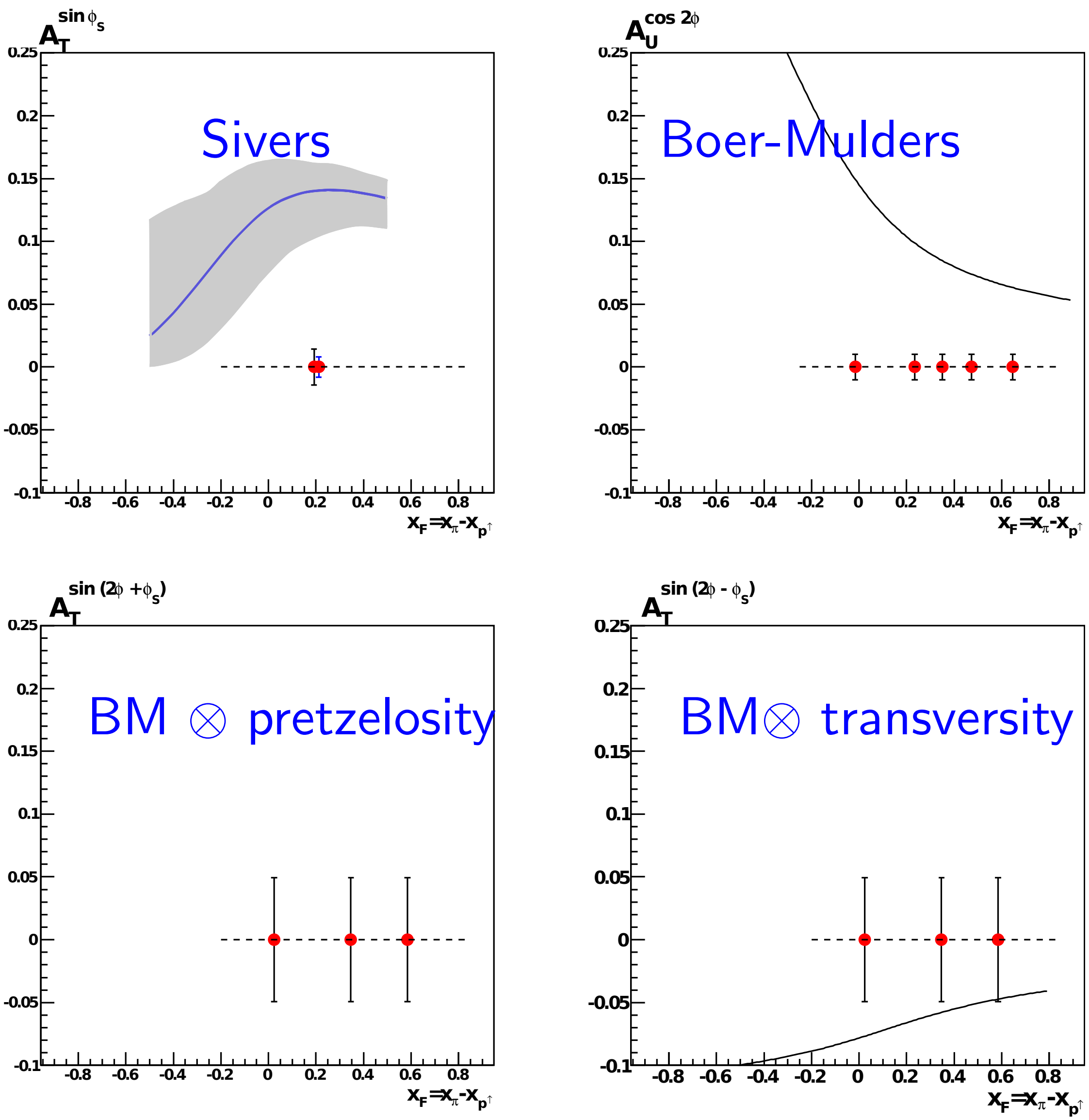
Results from 2009 beam test





Projections for azimuthal asymmetries

$$4\,\mathrm{GeV}/c^2 < M_{\mu^+\mu^-} < 9\,\mathrm{GeV}/c^2$$



projections with
2 years of data
$6 \cdot 10^8\, \pi$ spill $(9.6\ s)$
1.1 m pol. NH_3

- **key measurements**:
  TMD universality,
  change of sign from SIDIS to DY,
  study of J/ψ production mechanism

Conclusions and Outlook

New proposal (COMPASS II) with

- DVCS and DVMP for the study of GPDs in a kinematic region not yet covered by experiments
- in parallel with GPD measurement rich programme in unpolarised DIS and SIDIS
- first polarised Drell-Yan experiment to study TMDs
- measurement of pion (kaon) polarisabilities

$\Longrightarrow$ at least 5 years of data taking, can start from 2012

Program accepted in December 2010 for a first period of 3 years

COMPASS has a great potential in new fields and work is started to get the spectrometer upgraded for the new programmes