COMPASS - a facility to study QCD

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for the COMPASS collaboration

KHuK Jahrestagung 2010
Bad Honnef, 2./3.10.2010

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

Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg, Lissabon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Turino, Trieste, Warsaw, Yamagata
(30 institutes, 240 physicists)

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Muon beam

Spin dependent structure functions
Gluon polarisation
Polarised quark distributions
Transversity
Lambda polarisation
Vector meson production

Hadron beam

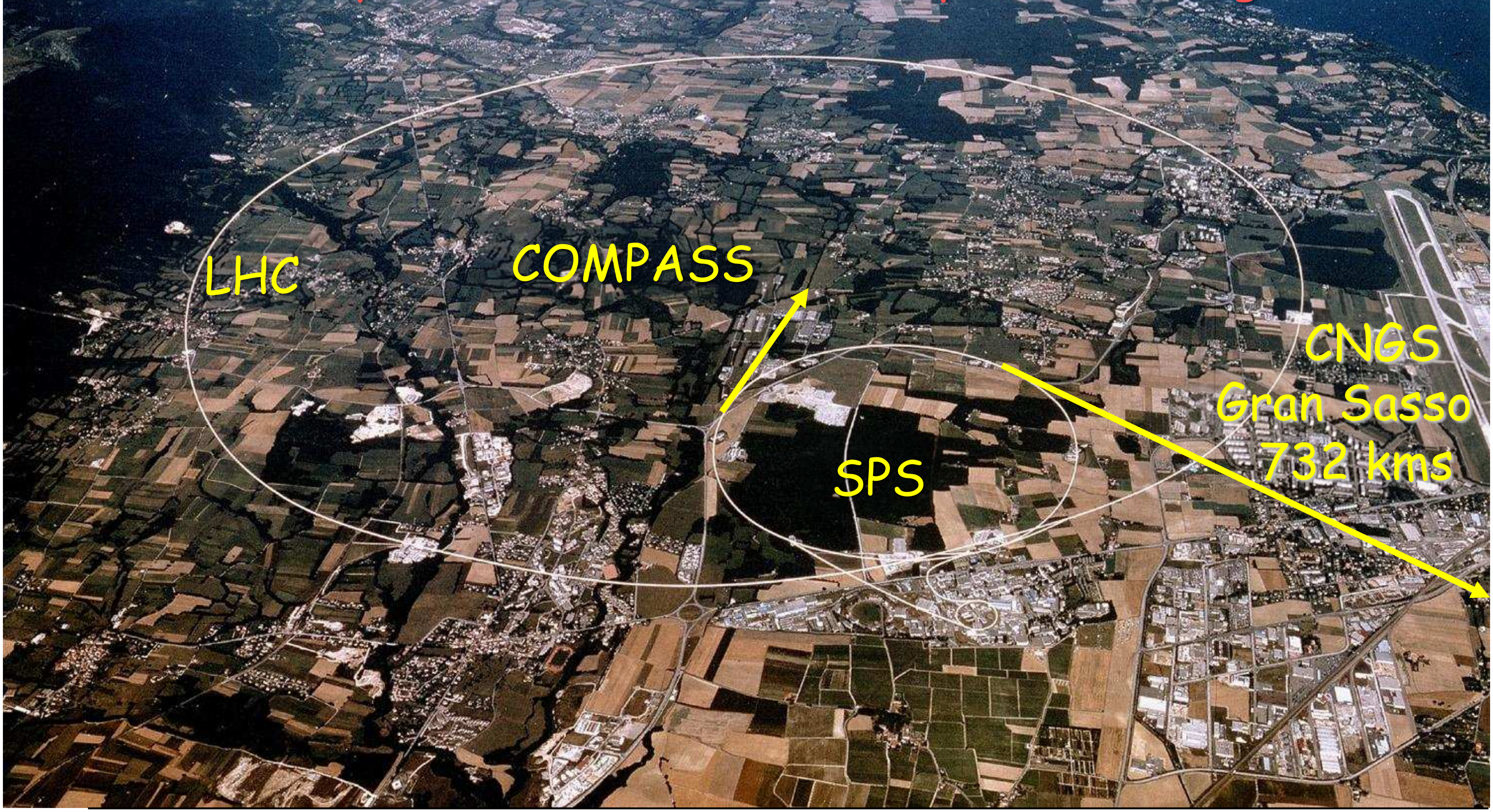
Primakoff scattering
Mesonspectroscopy
- Glueballs
- Hybrids
- Multi-quark states

Charmed baryons

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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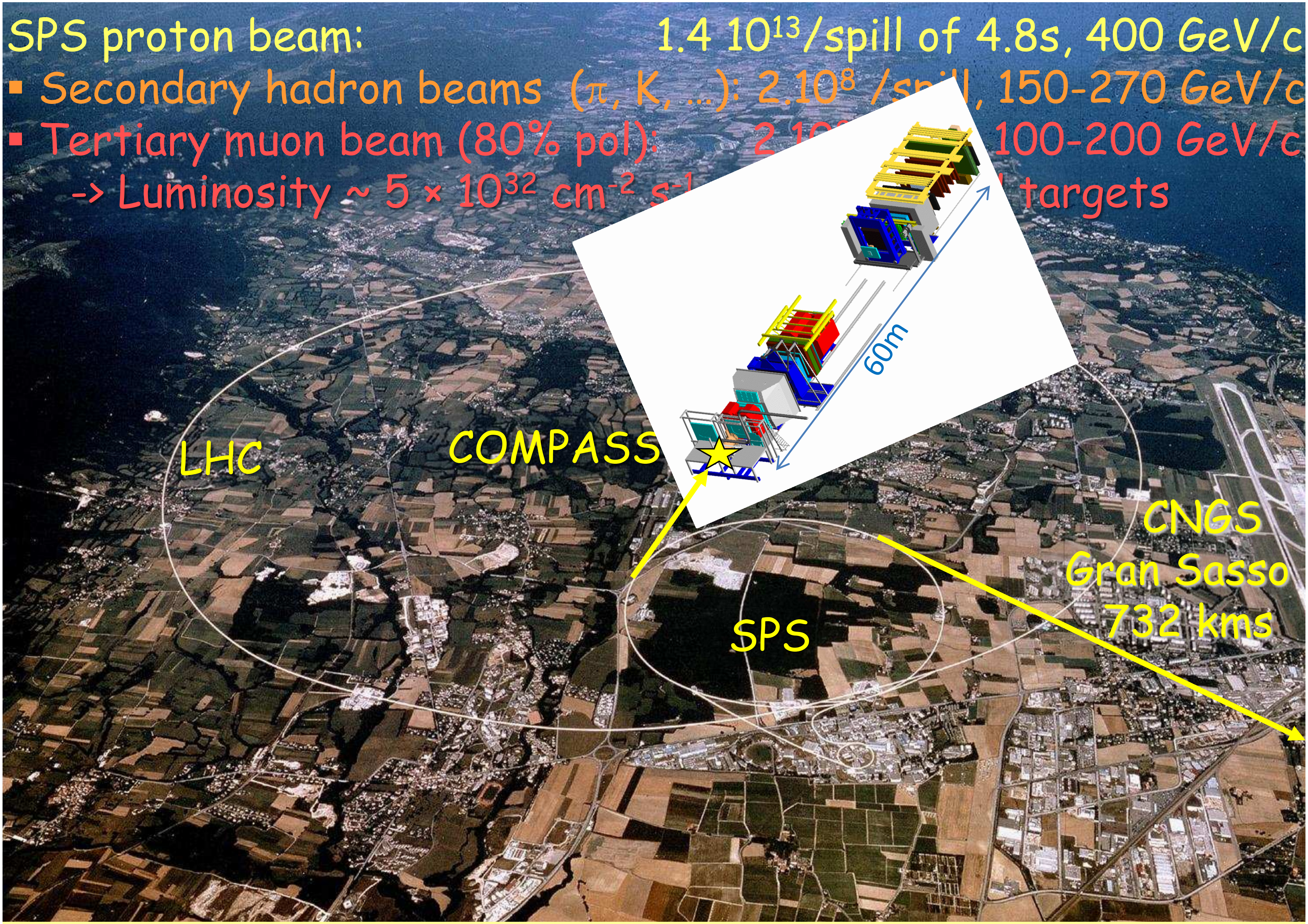
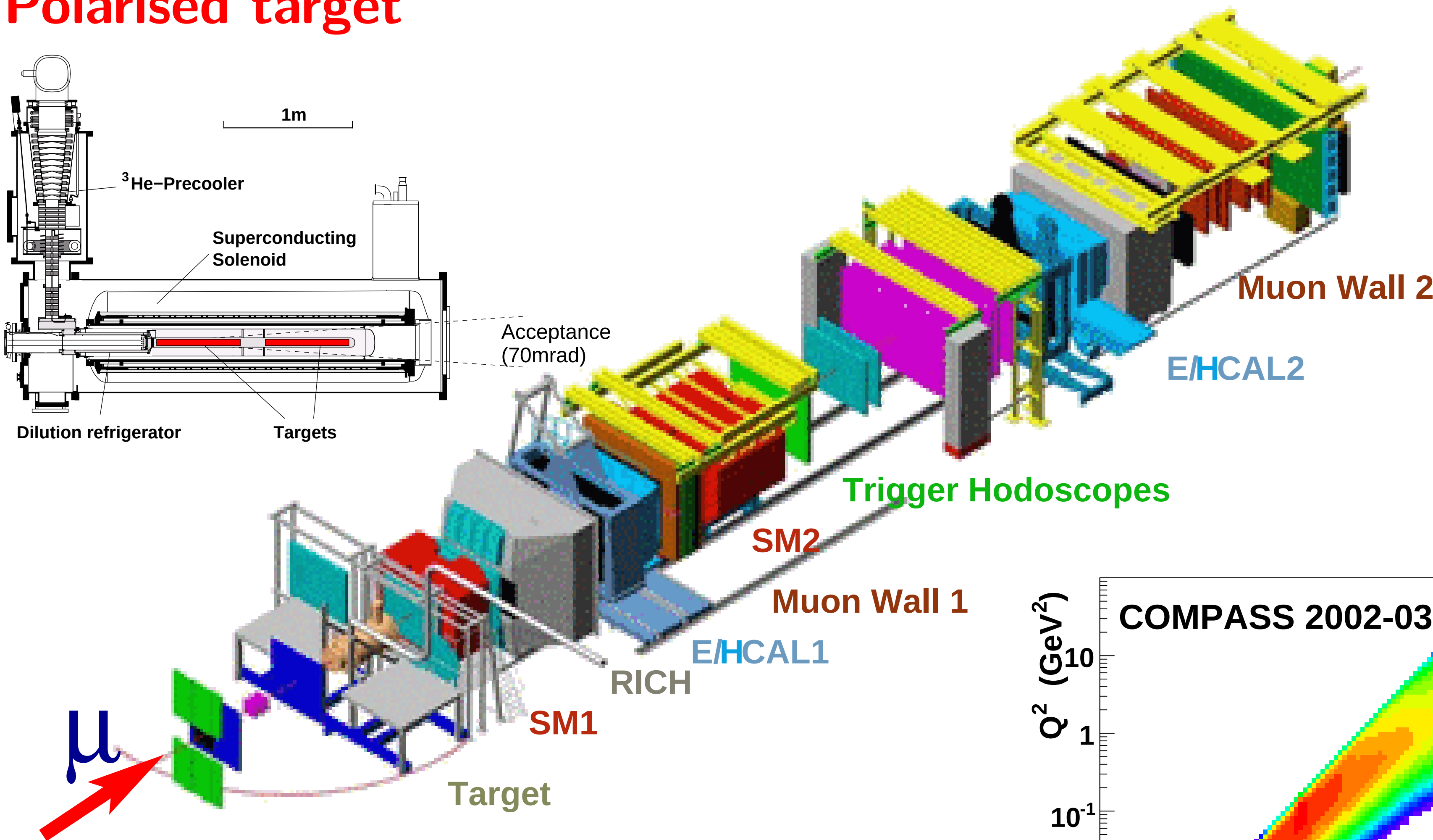
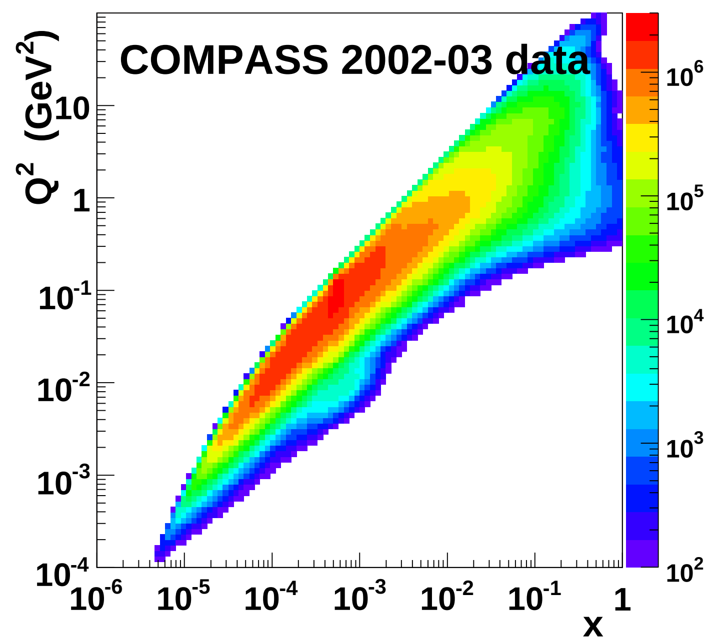


high energy beam(s), broad kinematic range, large angular acceptance

COMPASS spectrometer

Polarised target

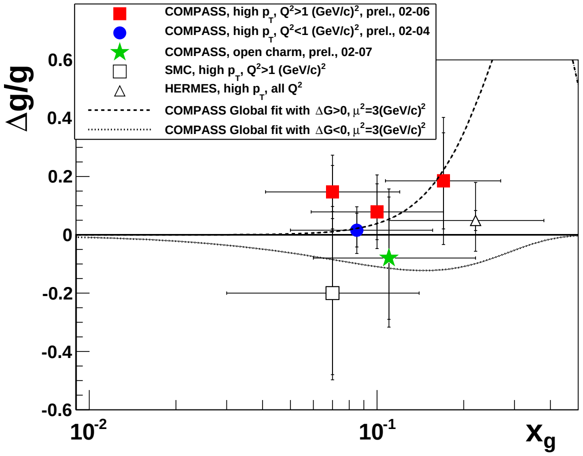




target material: ^{6}LiD, NH_3

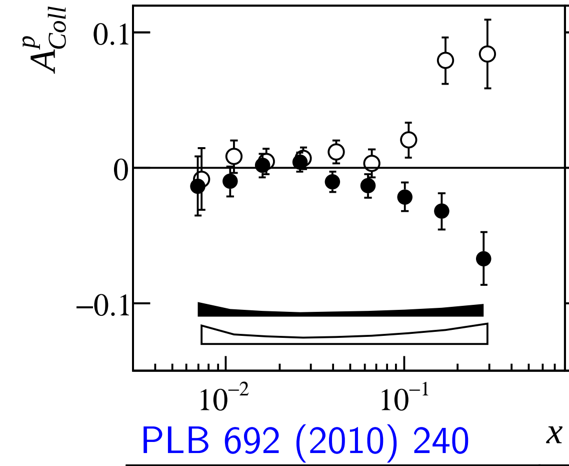
polarisation: 50%, 90%

Spin structure results

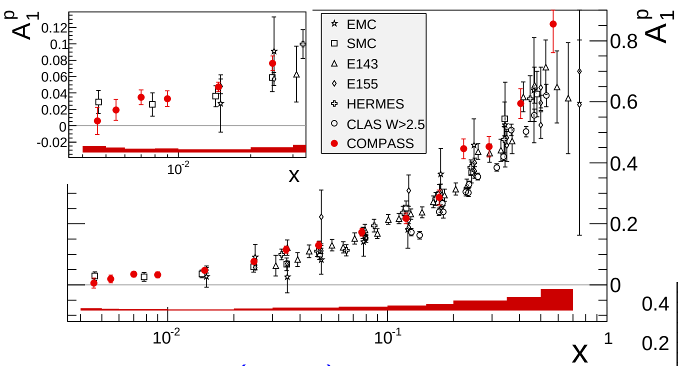


PLB 676 (2009) 31

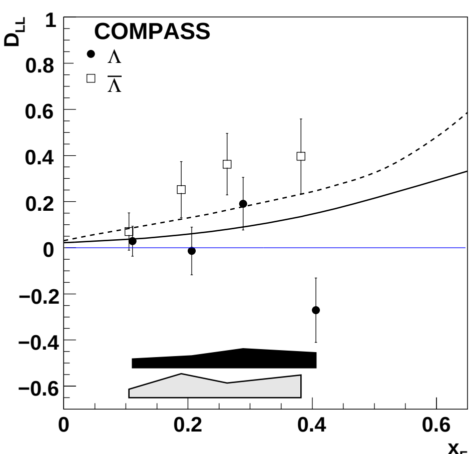
Asymmetries and PDFs
from longitudinal and transverse data (p and d)



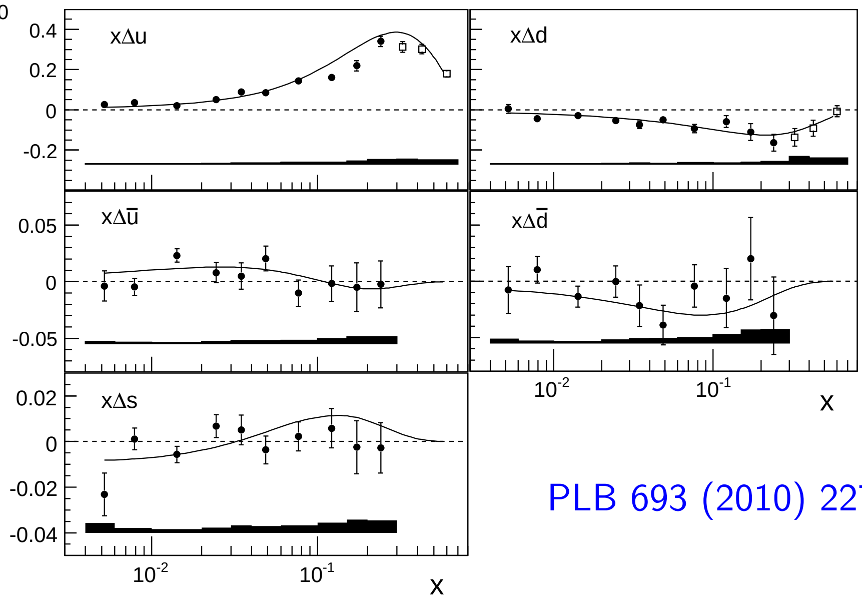
PLB 692 (2010) 240



PLB 690 (2010) 466



EPJC 64 (2009) 171



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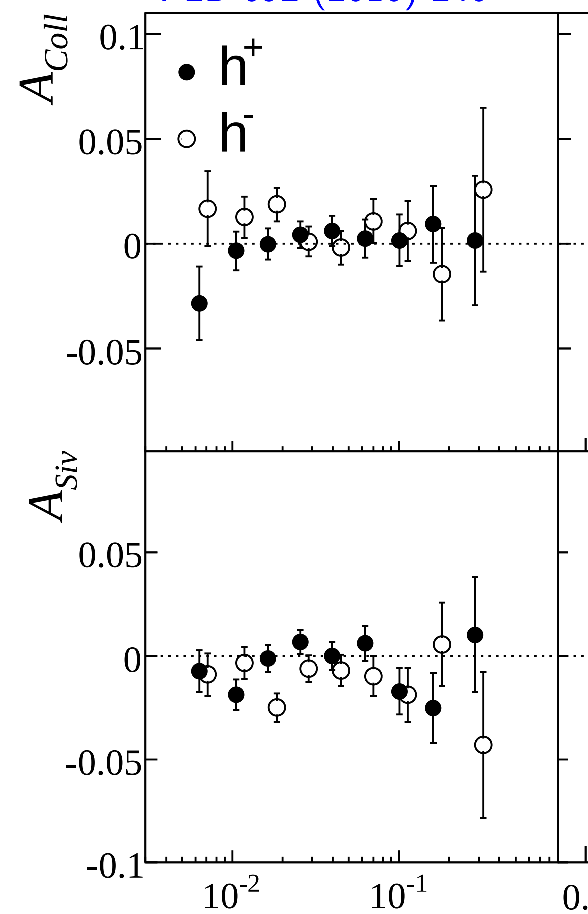


PRL 94 (2005) 202002

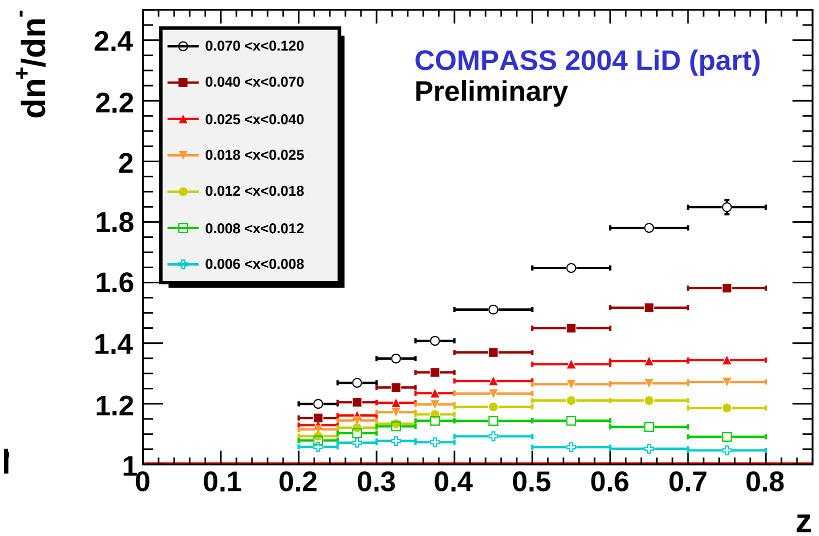
Spin structure

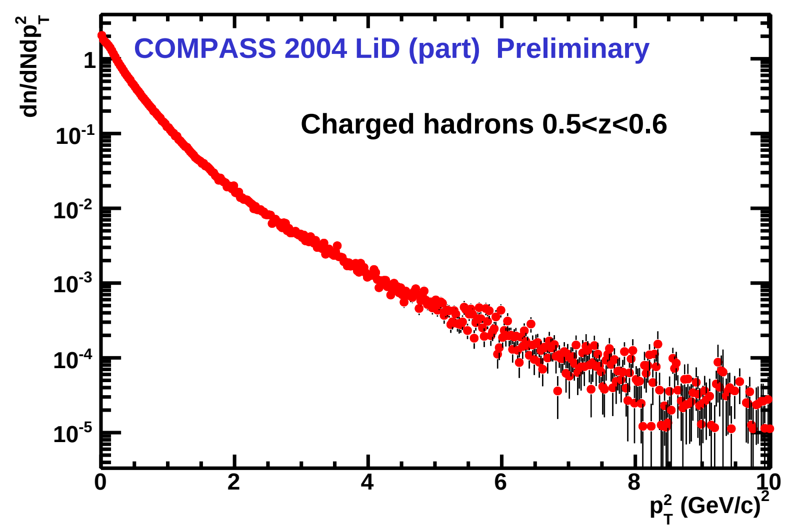
Data

- polarised ^{6}LiD (L,T) data taking 2002-2006
- polarised NH_3 (L,T) data taking 2007

Analysis

- most results published or released for conferences
- analysis of single high p_T hadrons still going on
- focus on unpolarised physics from ^{6}LiD (isoscalar)



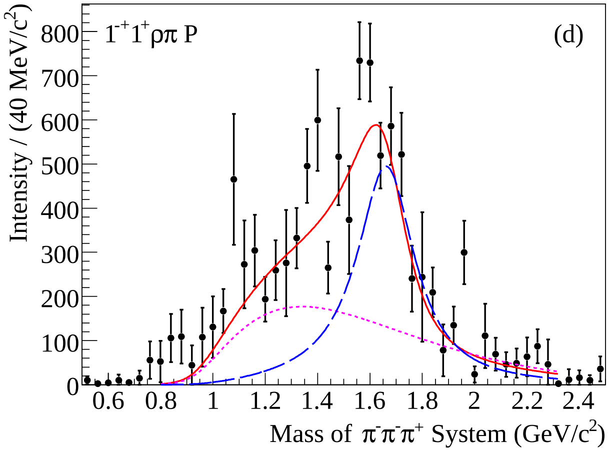


Addendum

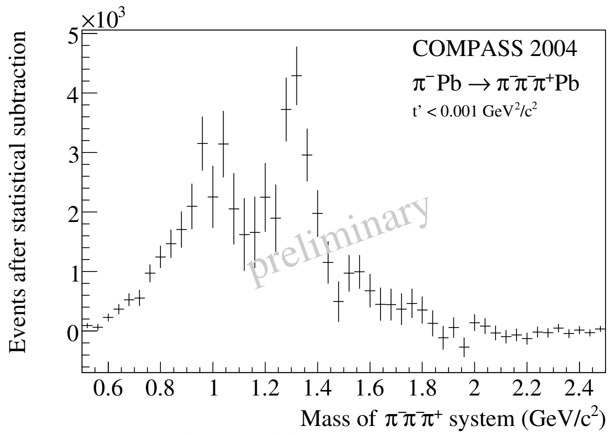
- 2010 NH_3 transversely polarised
  $\rightarrow$ transversity, Sivers DF
- 2011 NH_3 longitudinally polarised
  $\rightarrow$ low x g_1^p, strange quark polarisation

Spectroscopy results

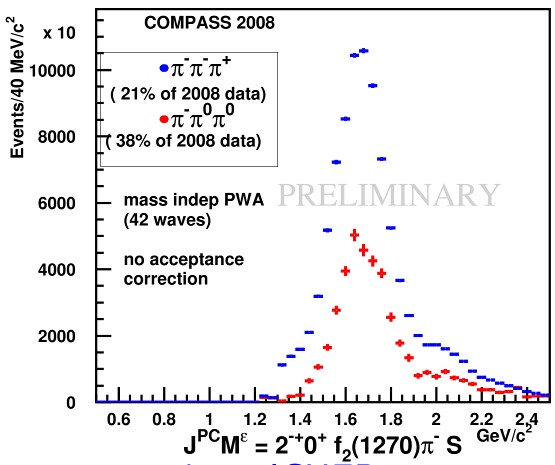
- diffractive, central and Primakoff production
- π beam on Pb in 2004
- π and p beam in 2008/9
- lH_2, Pb, Ni ,W targets



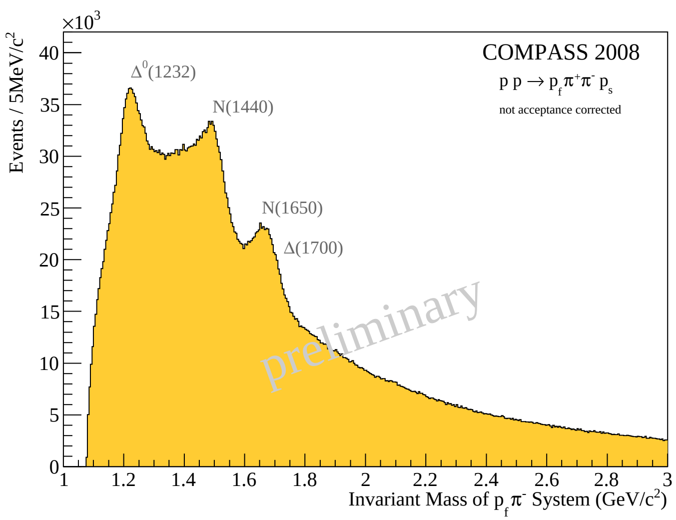
PRL 104 (2010) 241803



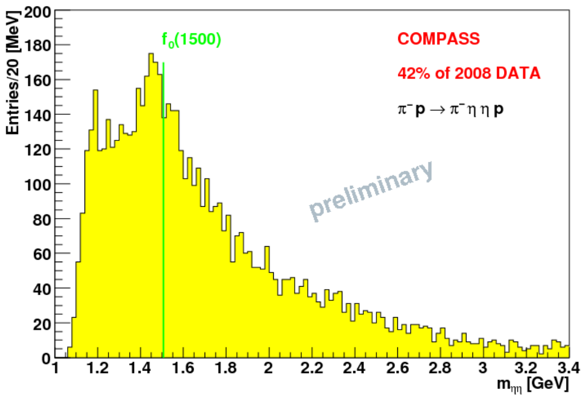
proceedings Hadron2009



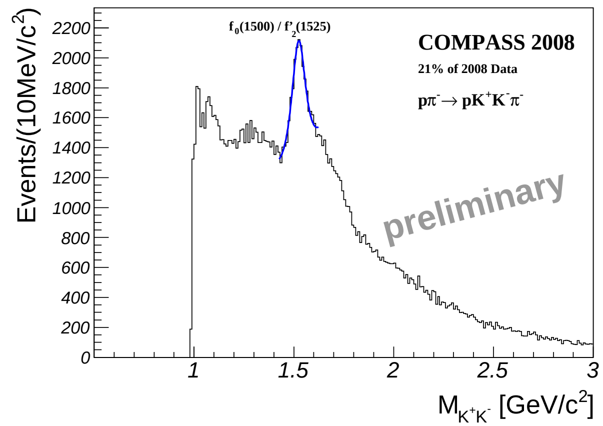
proceedings ICHEP2010



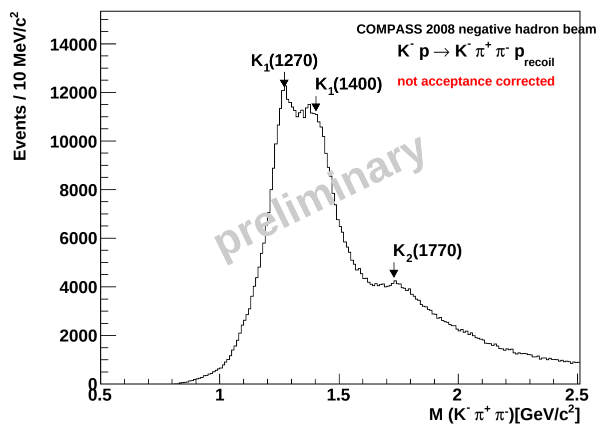
proceedings INPC2010



proceedings HADRON2009



proceedings HADRON2009



proceedings PRAGSPIN 2009

Exploring the 3-dim. phase-space structure of the nucleon

up to now: main focus on Δq quark helicity distributions
$\Delta q_\perp$ transverse quark distributions
(from DIS and SIDS)

$\longrightarrow$ **longitudinal momentum structure of the nucleon**

next step:

Generalised Parton Distributions

$\longrightarrow$ accessible in exclusive reactions like DVCS and DVMP

Transverse Momentum Dependent Distributions

$\longrightarrow$ accessible in SIDIS and Drell Yan processes

in addition:

QCD at very low Q^2: Pion Polarisability

$\longrightarrow$ Primakoff processes

COMPASS II proposal:

submitted in May for 5 years of data taking in the first step
recommended by SPSC in September for initally 3 years of data taking

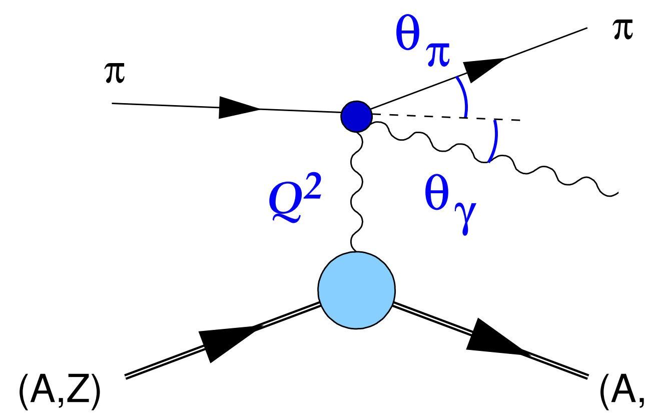
Primakoff experiments with π, K

$$\boxed{\pi^- Z \to \pi^- Z\gamma}$$

- Low energy behaviour predicted by chiral perturbation theory

$$\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}} = \left[\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}}\right]_{\text{point}}$$
$$+C \cdot \frac{s - m_\pi^2}{s^2}\left[(1-\cos\theta_{cm})^2(\alpha_\pi - \beta_\pi) + (1+\cos\theta_{cm})^2(\alpha_\pi + \beta_\pi)\frac{s^2}{m_\pi^4} + \text{h.o.}\right]$$

- deviation from pointlike due to pion polarisabilities
- $\alpha_\pi - \beta_\pi$ measured at backward angles, $\alpha_\pi + \beta_\pi$

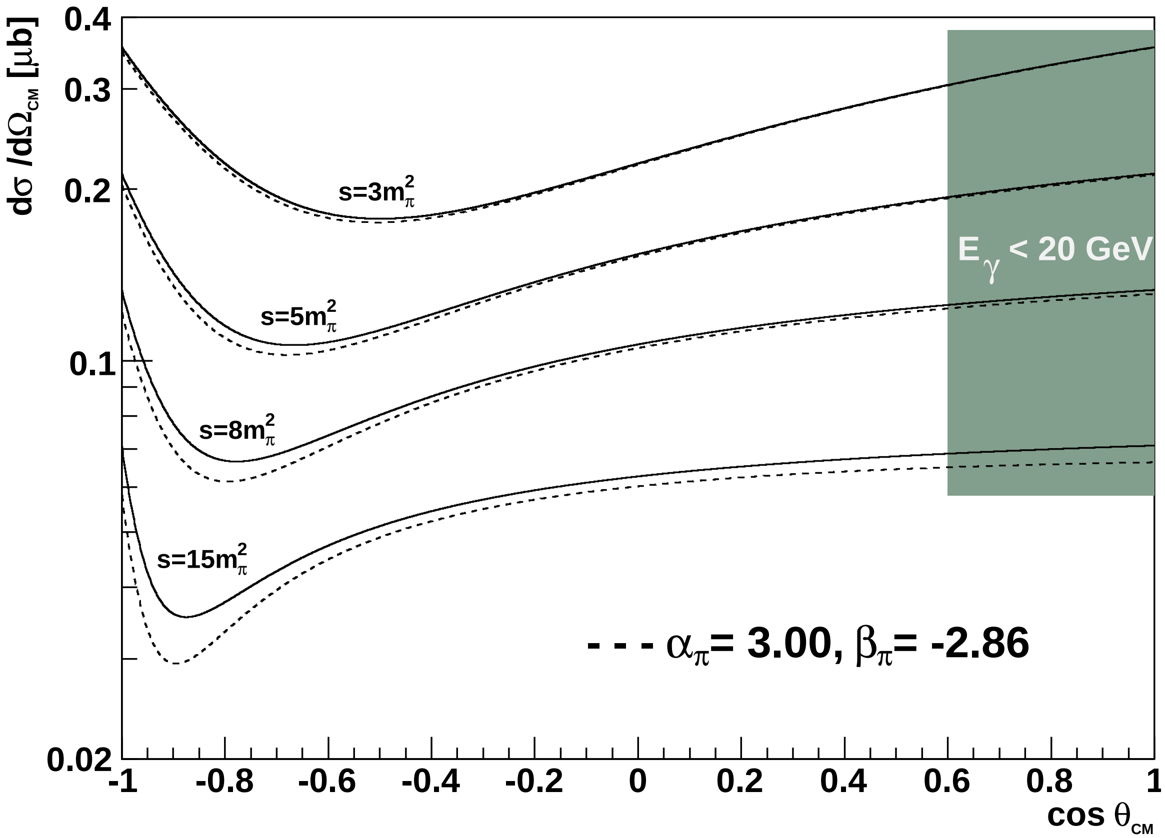


2-loop chiral predictions

$$\alpha_\pi + \beta_\pi = (0.2 \pm 0.1)10^{-4}\ \text{fm}^3$$
$$\alpha_\pi - \beta_\pi = (5.7 \pm 1.0)10^{-4}\ \text{fm}^3$$

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

Pion polarisability measurement



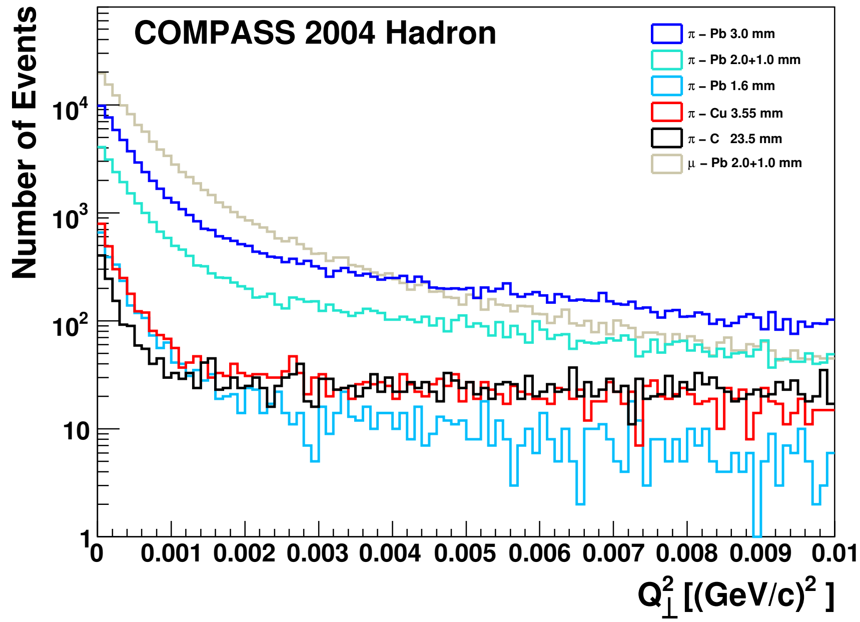
- effect increases with s^2
- effects due to $\alpha_\pi - \beta_\pi$ much larger than for $\alpha_\pi + \beta_\pi$

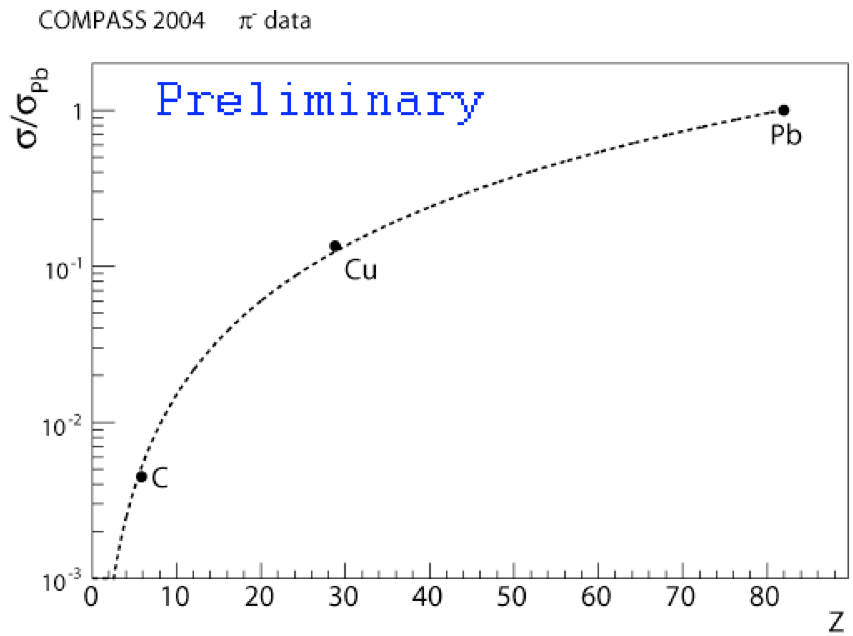
unique at COMPASS:

- availability of a muon beam (point like) for comparison and systematics

Summary for Primakoff

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

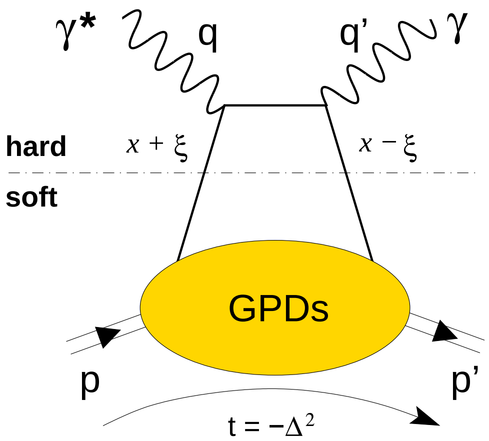




- expected precision of the new measurement:

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

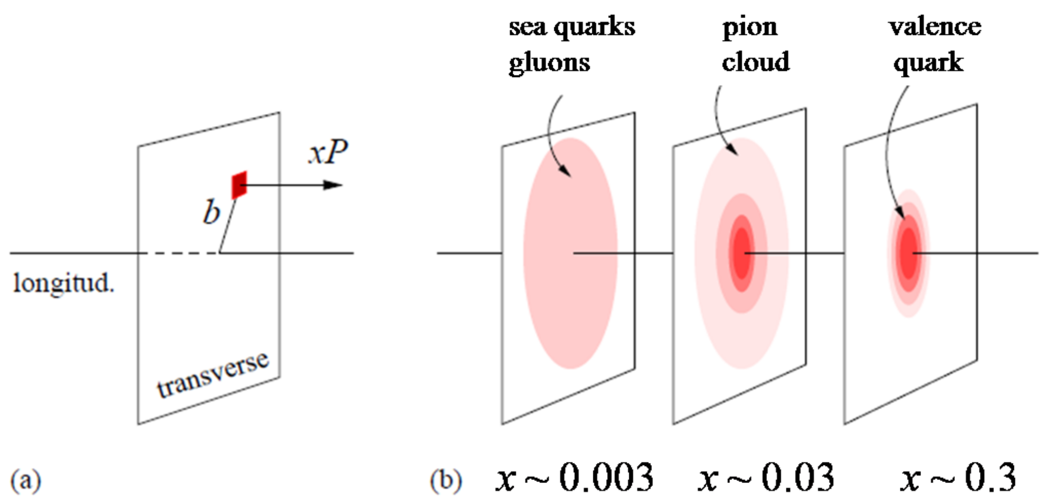
Generalised parton distributions



- **novel concept**: $H^f, E^f, \widetilde{H}^f, \widetilde{E}^f(x,\xi,t)$
- **limits:** $q(x) = H(x,0,0)$ normal PDF
  $F(t) = \int \mathrm{d}x \; H(x,\xi,t)$ elastic form factor
- **Ji's sumrule** for quark total angular momentum

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

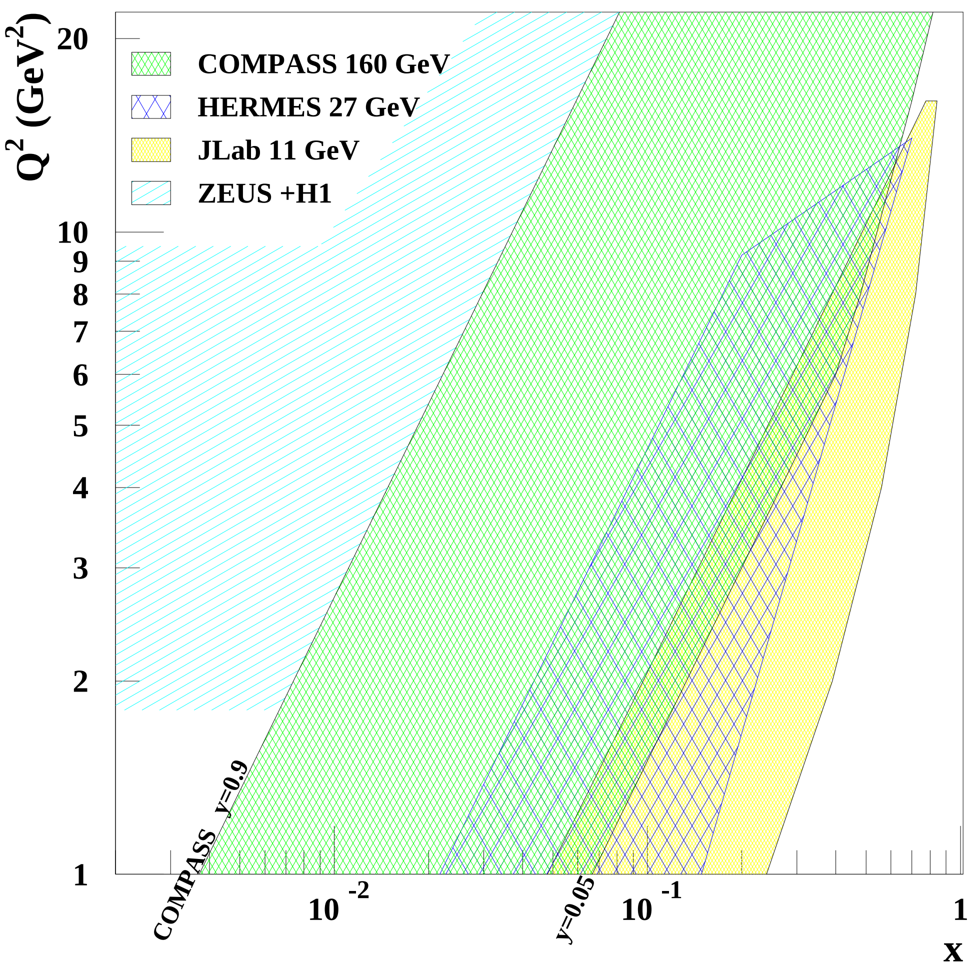
- **Nucleon tomography**: $q^f(x,\boldsymbol{b}_\perp) = \int \frac{\mathrm{d}^2\boldsymbol{\Delta}_\perp}{(2\pi)^2} e^{-i\boldsymbol{\Delta}_\perp\cdot\boldsymbol{b}_\perp} H^f(x,0,-\boldsymbol{\Delta}_\perp^2)$



simultaneous measurement of longitudinal momentum and transverse spatial structure

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_{Bj}: $\Longrightarrow$ sea and valence quarks
  - high x_{Bj} 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

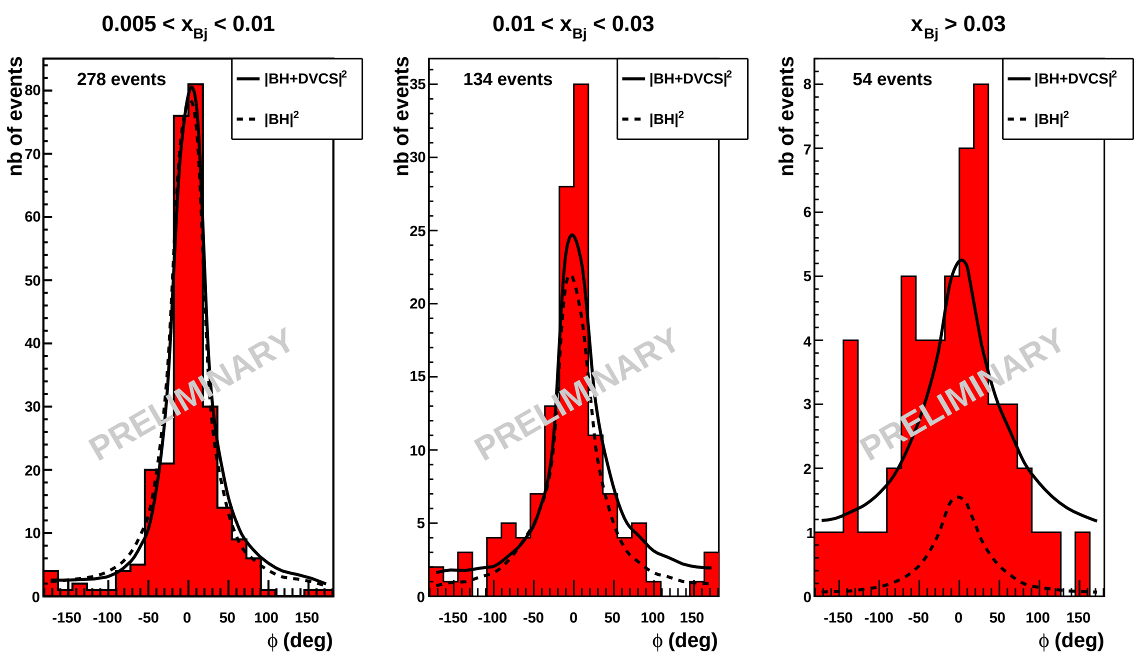
Experimental requirements

Method

- same final state for BH and DVCS
- BH used a reference yield
- measurement with μ^+ and μ^- with opposite pol.
- yields Re and Im part of GPD H

Experimental set-up

- long liquid hydrogen target surrounded by recoil detector (2 layers)
- hermetic coverage with electromagn, calorimeter
- already a few test measurements

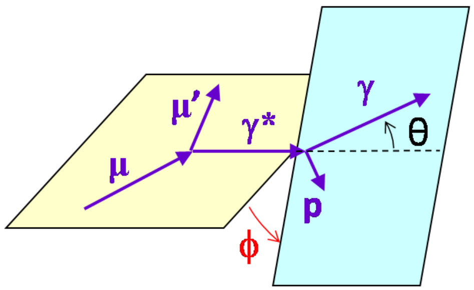


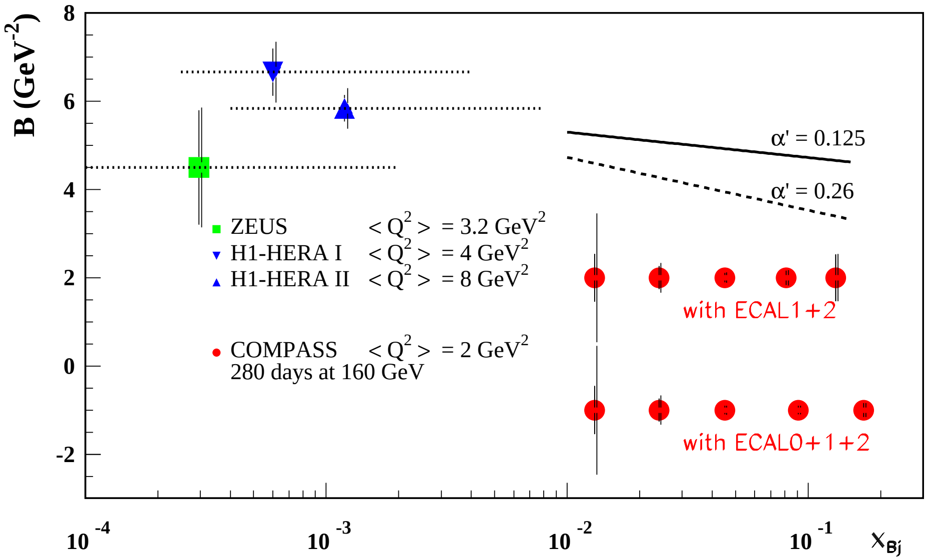
Projected results

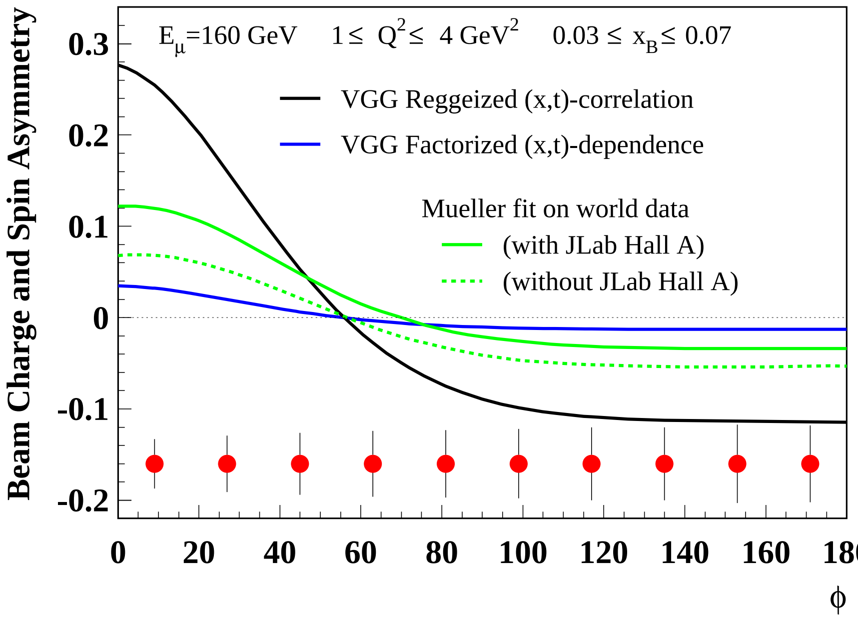
projections with
2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222$ pb^{-1}

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

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







Transverse Momentum Dependent Distributions

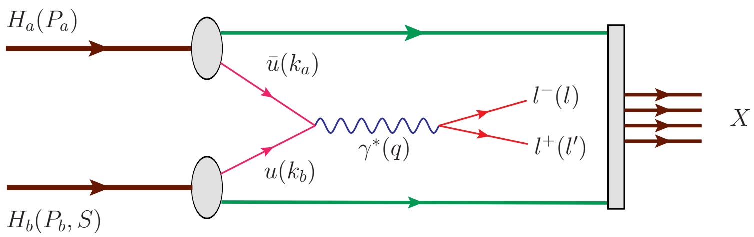
- access to the transverse momentum in the nucleon
- at leading twist 8 TMDs (3 survive integration over k_T: q, Δq and Δq_T)
- **examples of TMDs**:
  - **Boer-Mulders function $h_1^\perp$**:
    correlation of quark k_T and quark transverse spin in unpol. nucleons
  - **Sivers function $f_{1T}^\perp$**:
    correlation of quark k_T and nucleon transverse spin
- Boer-Mulders and Sivers function are T-odd → process dependent

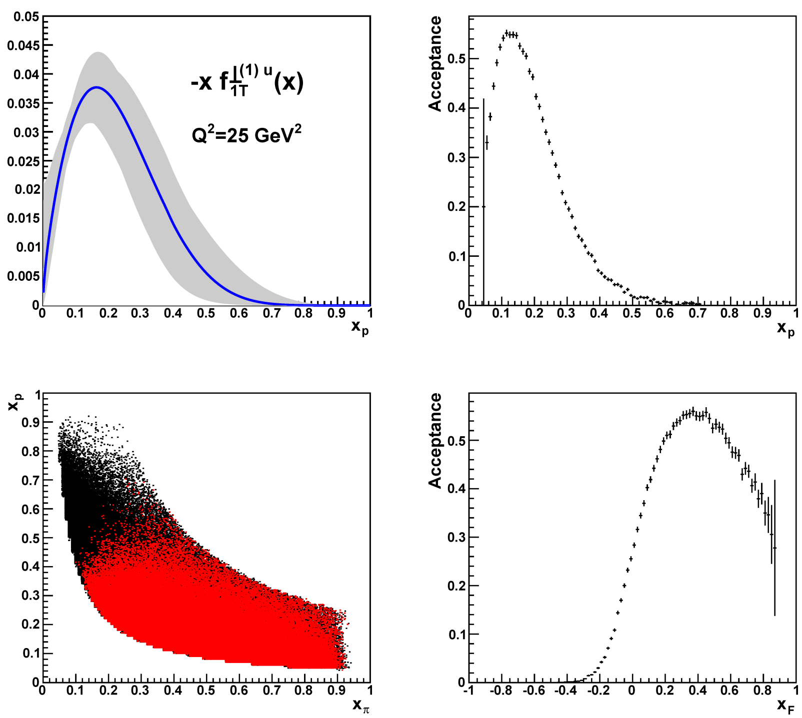
$$\boxed{\begin{aligned} h_1^\perp(SIDIS) &= -h_1^\perp(DY) \\ f_{1T}^\perp(SIDIS) &= -f_{1T}^\perp(DY) \end{aligned}}$$

- needs experimental verification, Sivers measurement needs polarised target

Drell-Yan at COMPASS

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

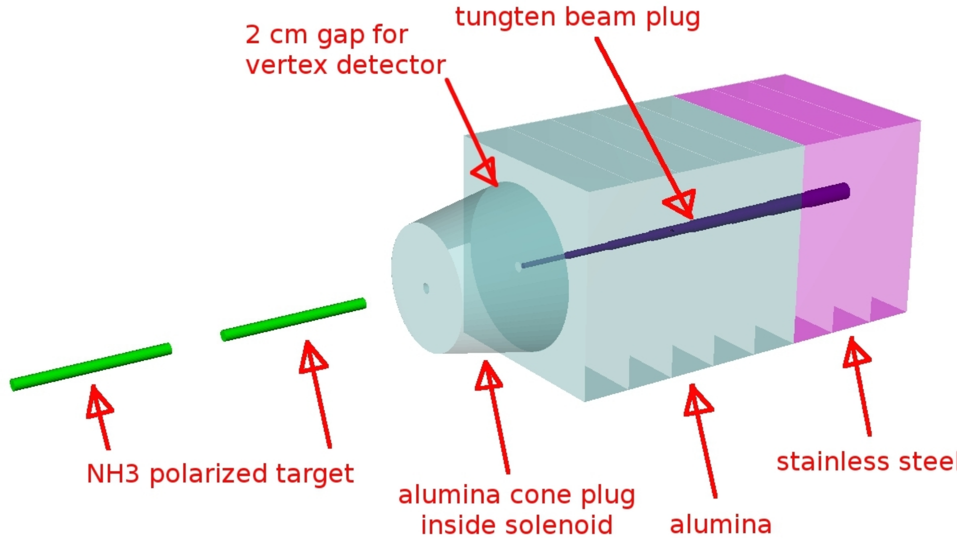


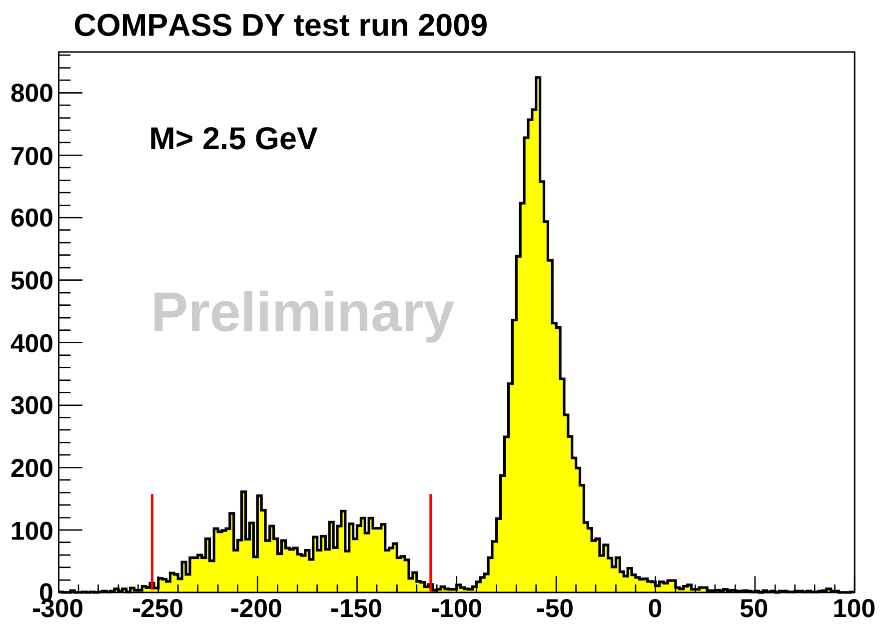


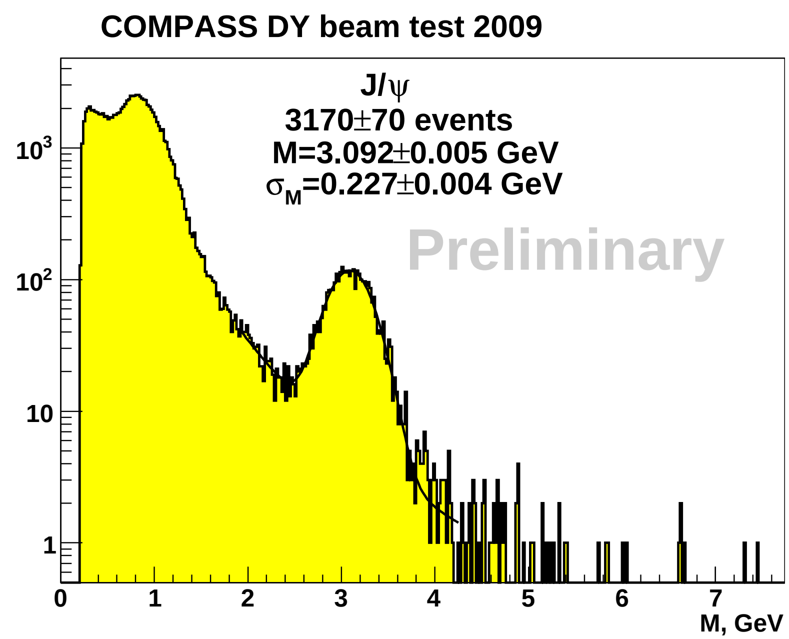
- **DY**: convolution of two TMDs measured, **SIDIS**: TMD convoluted with fragmentation function
- complementary information
- ideal DY measurement: antiproton on proton
- good compromise π^- on protons
- DY dominated by annihilation of valence anti-quark from π^- and valence quark from polarised proton
- large acceptance of COMPASS in the valence region of p and π where large SSA are expected

Experimental requirements

- high intensity pion beam (up to 10^9/spill)
- transversely polarised NH_3 target
- hadron absorber mandatory
- results from 2009 beam test

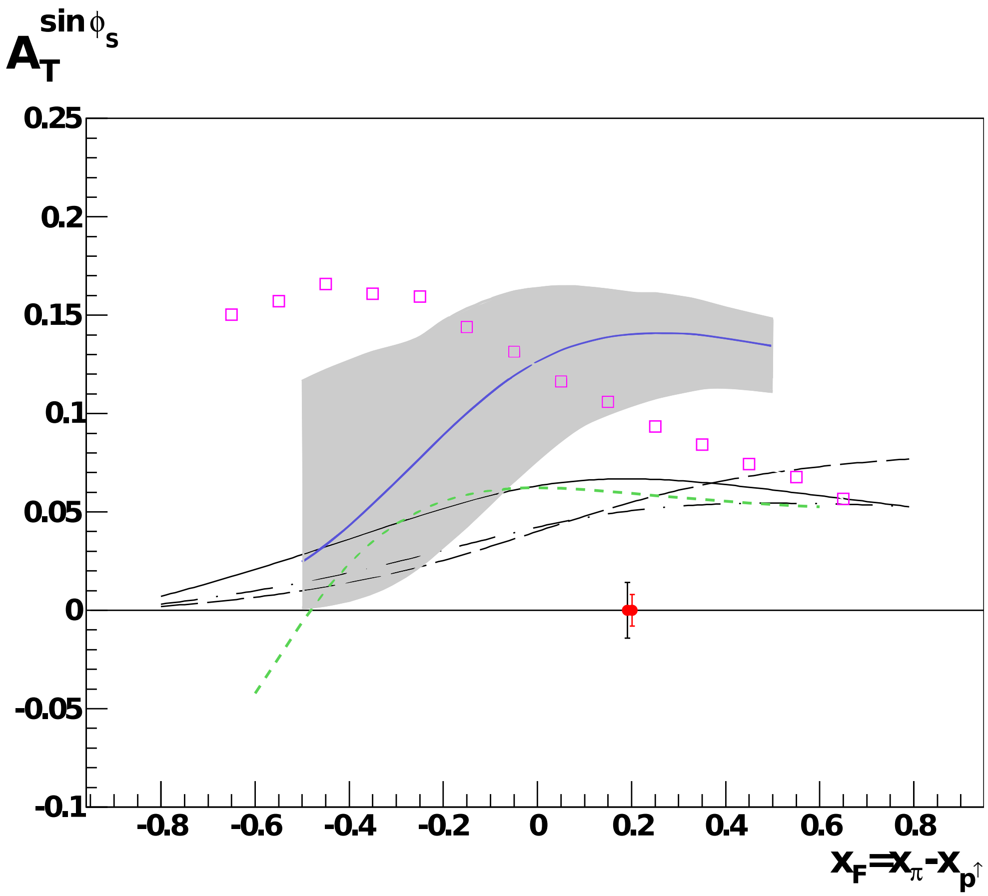






Predictions for Sivers asymmetry

- 3 ranges of study: above J/ψ $4 < M_{\mu^+\mu^-} < 9$ GeV (clean signal), J/ψ, below J/ψ $2 < M_{\mu^+\mu^-} < 2.5$ GeV (large background) prediction are given for high mass range



projections with
2 years of data
$6 \cdot 10^8\, \pi\, \text{spill}\, (9.6\ s)$
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

COMPASS

- rich harvest in results on spin structure and spectoscopy
- PWA of hadron data just starting
- very sucessfull data taking in 2010 for transversity and Sivers DF
- next year will be mainly devoted to longitudinally spin physics

New proposal (COMPASS II)

- for 5 years GPDs, DY and Primakoff processes, already recommended by SPSC
- in parallel with GPD a rich programme in unpolarised DIS and SIDIS

On the long term

- more hadron beam running depending on the results
- DVCS with polarised target discussed
- DY with antiproton beam

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