Program of COMPASS-II at CERN

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COMPASS-II

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–SPSC–2010–014
SPSC-P-340
May 17, 2010

- Charged pion (and kaon) polarisabilities
- Drell-Yan
- Generalised Parton Distributions
- SIDIS (parallel to GPD program)

COMPASS-II Proposal

Approved December 2010, first measurements 2012

The COMPASS Collaboration

wwwcompass.cern.ch/compass/proposal/compass-II_proposal/compass-II_proposal.pdf

COMPASS-II time lines

Part of the COMPASS-II proposal approved and scheduled by CERN

- 2012: pion and kaon polarisabilities (Primakoff) + comissioning and pilot run for DVCS
- 2013-2014: long SPS/LHC shutdown
- 2014-2015: Drell-Yann measurements with transversely polarised protons (NH_3 target)
- 2016-2017: stage 1 of GPD program and in parallel with SIDIS (LH target)

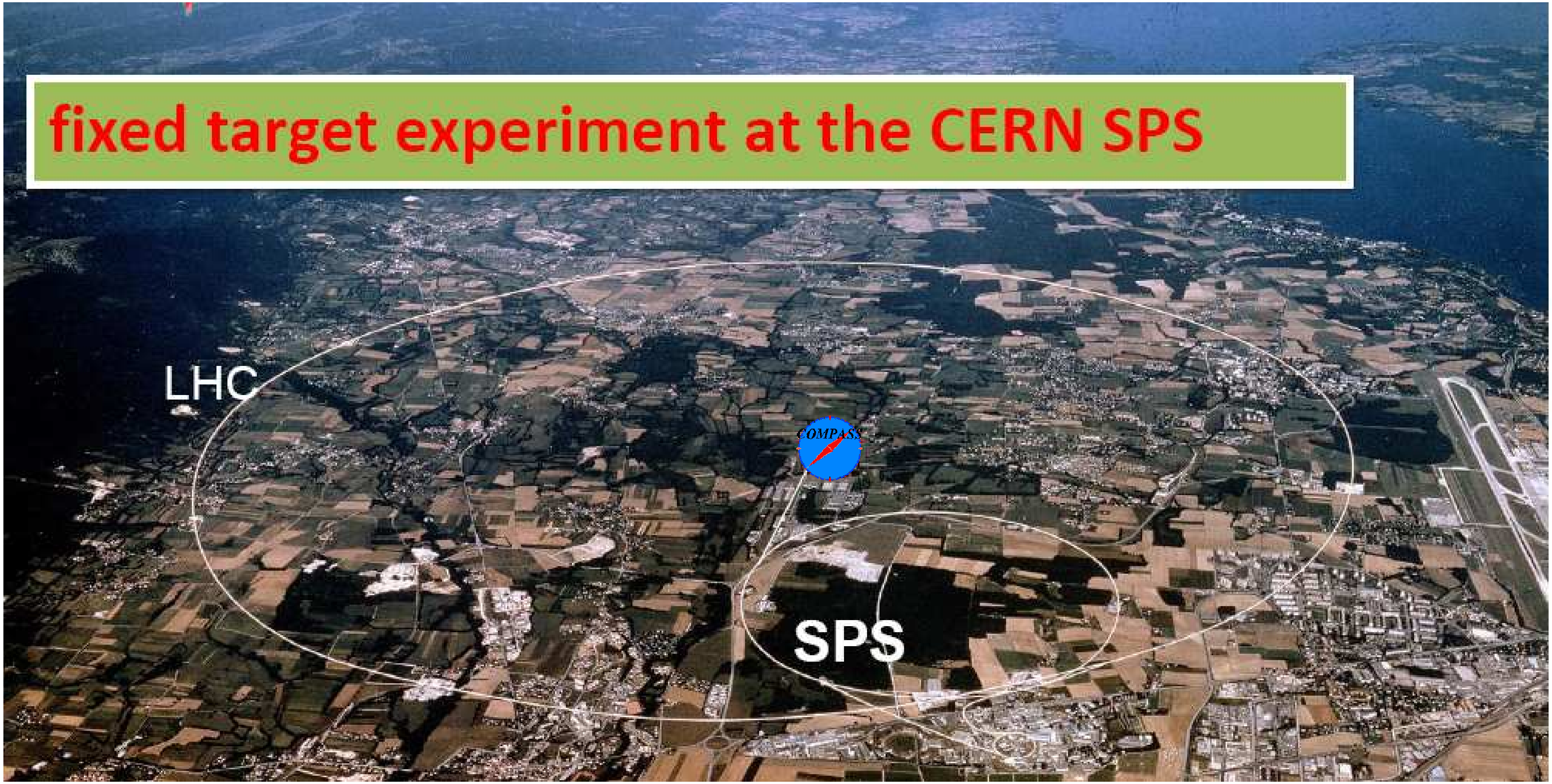
Measurements to be pursued at COMPASS-II > 2017 (subject to an Addendum)

- ✓ Drell-Yann on transversely polarised protons, transversely polarised deuterons, unpolarised protons and nuclear targets
- ✓ stage 2 of GPD program with transversely polarised NH_3 target and RPD
- ✓ SIDIS (high statistics) from transversely polarised deuteron and proton targets
- ✓ hadron program (spectroscopy in diffractive and central production, hybrids and exotics)

COMPASS

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

wide physics program carried on using both muon and hadron beam



COMPASS setup

as in μ run
NIM A 577(2007) 455

- **high energy beam**
- **large angular acceptance**
- **broad kinematical range**

two stages spectrometer

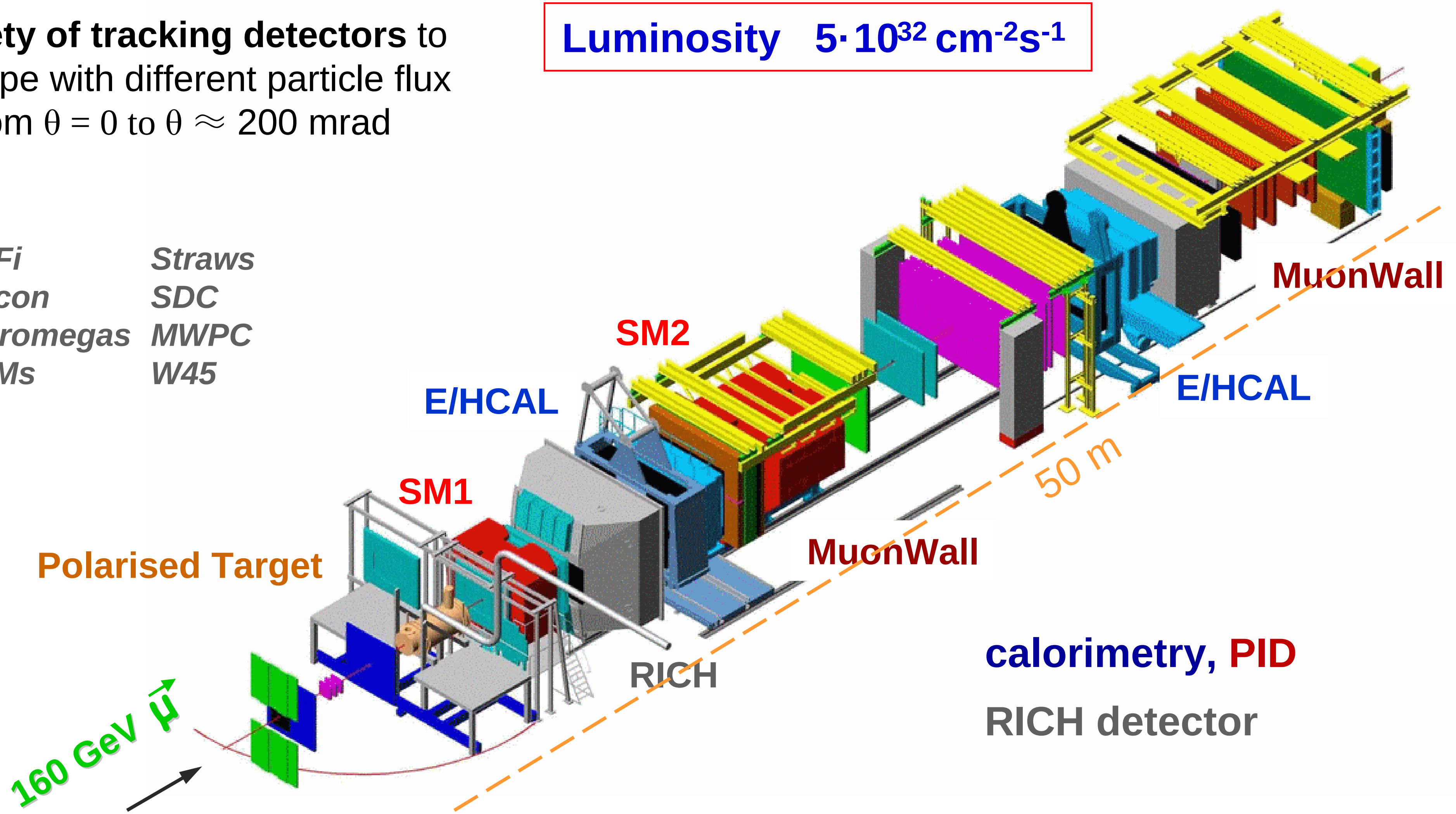
Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors to
cope with different particle flux
from $\theta = 0$ to $\theta \approx 200$ mrad

SciFi *Straws*
Silicon *SDC*
Micromegas *MWPC*
GEMs *W45*

Luminosity $5 \cdot 10^{32}$ cm^{-2}s^{-1}



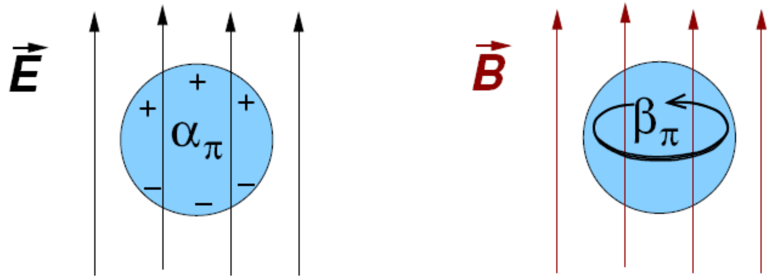
calorimetry, PID

RICH detector

Pion polarisabilities

An important test of χPT

polarisabilities describe the deformation of the pion by an EM field



2-loop ChPT prediction: $\alpha_\pi - \beta_\pi = (5.7 \pm 1.0)\, 10^{-4}\, \text{fm}^3$ $\alpha_\pi + \beta_\pi = (0.2 \pm 0.1)\, 10^{-4}\, \text{fm}^3$

$\pi\, \gamma \longrightarrow \pi\, \gamma$

CMS kinematic variables:

s - total energy squared

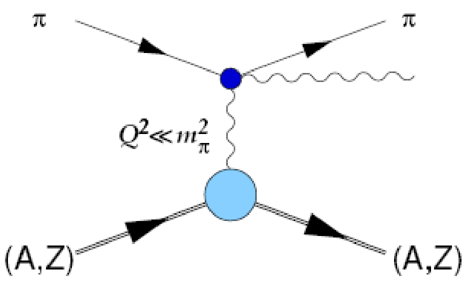
θ_{cm} - scattering angle

$$\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}} = \frac{\alpha^2(s^2 z_+^2 + m_\pi^4 z_-^2)}{s(sz_+ + m_\pi^2 z_-)^2} - \frac{\alpha\, m_\pi^3\, (s - m_\pi^2)^2}{4s^2(sz_+ + m_\pi^2 z_-)} \cdot \mathcal{P}$$

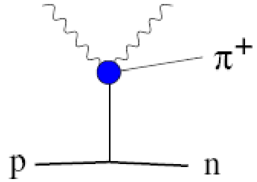
$$\mathcal{P} = z_-^2(\alpha_\pi - \beta_\pi) + \frac{s^2}{m_\pi^4} z_+^2(\alpha_\pi + \beta_\pi) - \frac{(s - m_\pi^2)^2}{24s} z_-^3(\alpha_2 - \beta_2)$$

$z_\pm = 1 \pm \cos\theta_{cm}$ $\alpha = 1/137$ fine structure constant

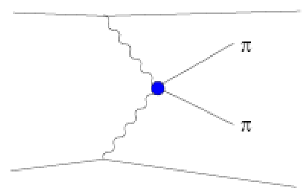
Pion polararisability – world data before COMPASS



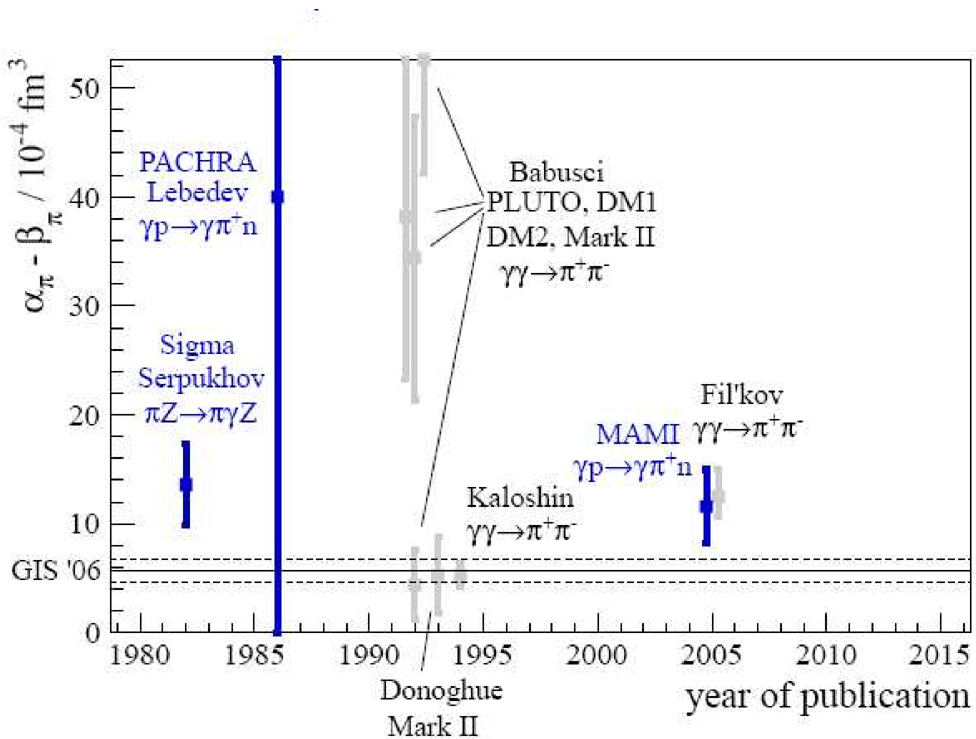
Primakoff process

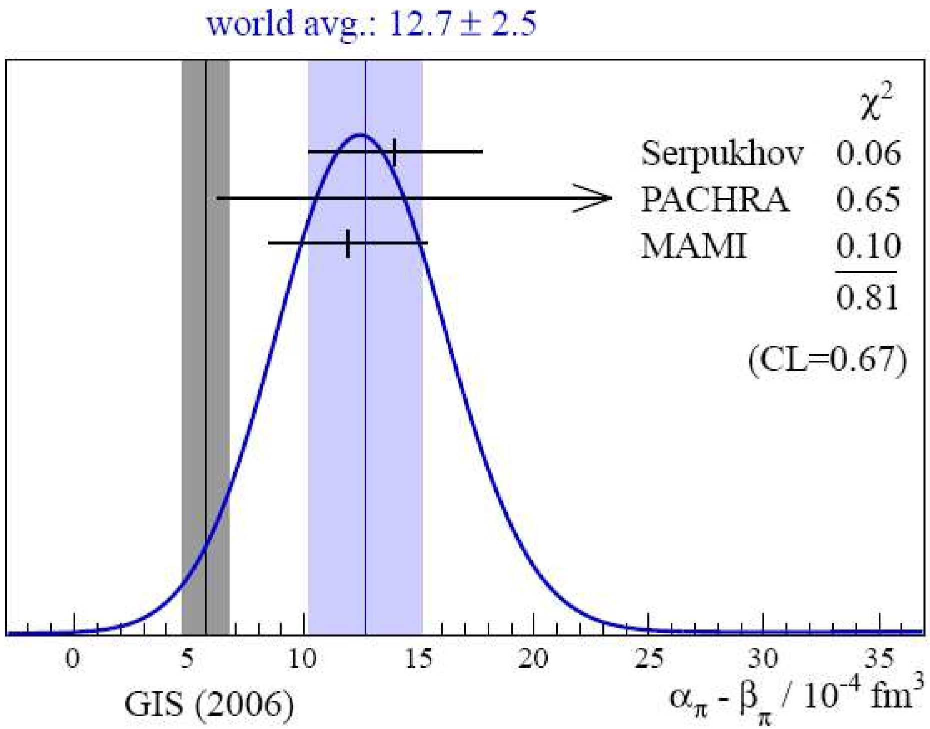


Radiative pion photoproduction



Photon-Photon fusion





GIS'06: ChPT prediction, Gasser, Ivanov, Sainio, NPB745 (2006)

plots from Thiemo Nagel, PhD thesis, TUM 2012

Pion polarisability measurement at COMPASS

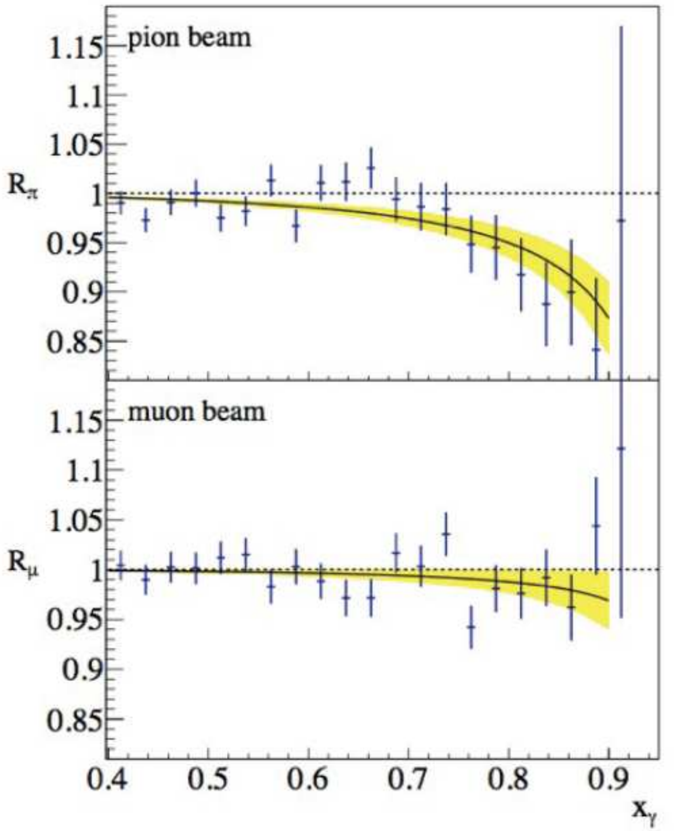
✓ $\pi\,\gamma \rightarrow \pi\,\gamma$ at $\sqrt{s} < 3\,m_\pi$ embedded in the reaction $\pi^-\,\mathrm{Ni} \rightarrow \pi^-\,\gamma\,\mathrm{Ni}$
by 190 GeV pion beam on nickel target
isolating sharp Coulomb peak at $Q^2 < 0.0015$ (GeV/c)^2

✓ assuming $\alpha_\pi = -\beta_\pi$, the ratio of cross sections can be expressed as

$$R = \frac{\sigma(x_\gamma)}{\sigma_{\alpha_\pi=0}(x_\gamma)} = \frac{N_{meas}(x_\gamma)}{N_{sim}(x_\gamma)} = 1 - \frac{3}{2}\cdot\frac{m_\pi^3}{\alpha}\cdot\frac{x_\gamma^2}{1-x_\gamma}\,\alpha_\pi$$

where $x_\gamma = E_{\gamma(lab)}/E_{Beam}$.

✓ α_π obtained from a fit to measured $R(x_\gamma)$ from 2009 data



new

$\alpha_\pi = (2.0 \pm 0.6_{stat} \pm 0.7_{syst})\ 10^{-4}\ \mathrm{fm}^3$

2-loop ChPT prediction $\alpha_\pi = 2.93 \times 10^{-4}\ \mathrm{fm}^3$

⇨ expectation from ChPT confirmed within the uncertainties

control measurements of ‘false’ R with muon beam

$\alpha_\mu = (0.5 \pm 0.5_{stat})\ 10^{-4}\ \mathrm{fm}^3$

⇨ no significant systematic bias

Pion polarisability at COMPASS – conclusions and outlook

- measurement of the pion polarisability via the Primakoff reaction (2009 data)

$$\alpha_\pi = (2.0 \pm 0.6_{stat} \pm 0.7_{syst})\ 10^{-4}\ \text{fm}^3$$

with assumption $\alpha_\pi = -\beta_\pi$

  - new precise experimental determination
  - control of systematics: $\mu\gamma \to \mu\gamma$
  - the expectation for ChPT confirmed within the uncertainties
  - the COMPASS results is in tension with the earlier measurements

- high statistics run 2012 (COMPASS-II)

  - separate determination of α_π and β_π
  - *s*-dependent quadrupole polarisabilities

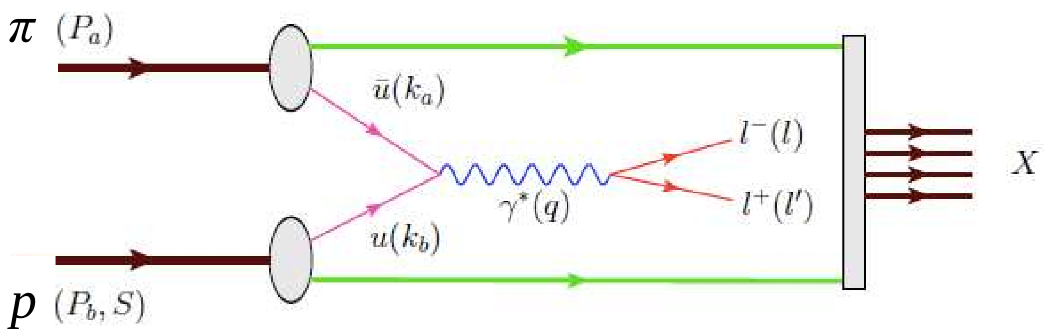
projections for COMPASS-II

	$\alpha_\pi - \beta_\pi$ (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

  - first measurement of the kaon polarisability

DY measurements

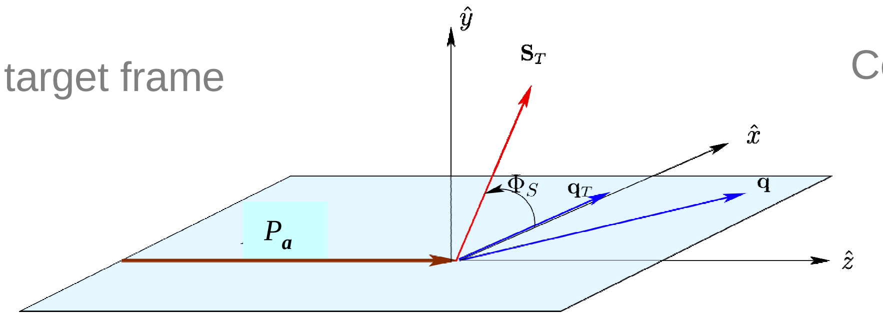
Drell-Yan process in polarised $\pi^- p^\uparrow$ scattering



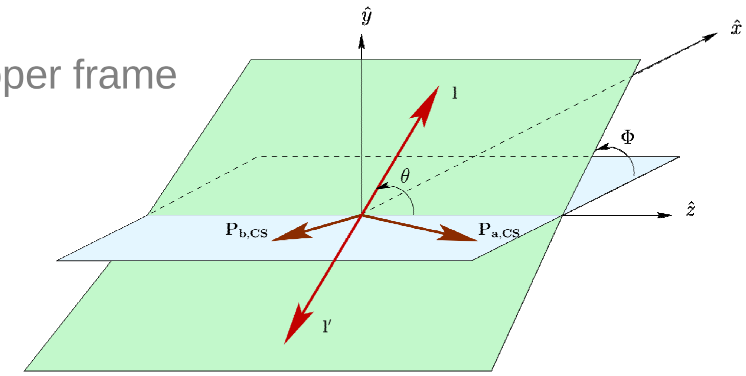
$$
\begin{aligned}
s &= (P_a + P_b)^2, \\
x_{a(b)} &= q^2/(2P_{a(b)} \cdot q), \\
x_F &= x_a - x_b, \\
M_{\mu\mu}^2 &= Q^2 = q^2 = s\ x_a\ x_b, \\
& \mathbf{k}_{Ta(b)} \\
\mathbf{q}_T &= \mathbf{P}_T = \mathbf{k}_{Ta} + \mathbf{k}_{Tb}
\end{aligned}
$$

$$
\frac{d\sigma}{d^4q d\Omega} = \frac{\alpha^2}{Fq^2}\hat{\sigma}_U \{(1 + D_{[\sin^2\theta]} A_U^{\cos 2\phi} \cos 2\phi)
+ |\vec{S}_T|[A_T^{\sin\phi_S} \sin\phi_S + D_{[\sin^2\theta]}(A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S)
+ A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S))]\}
$$

target frame



Collins-Soper frame



- A azimuthal asymmetries
- D depolarisation factors
- S_T transverse component of target spin

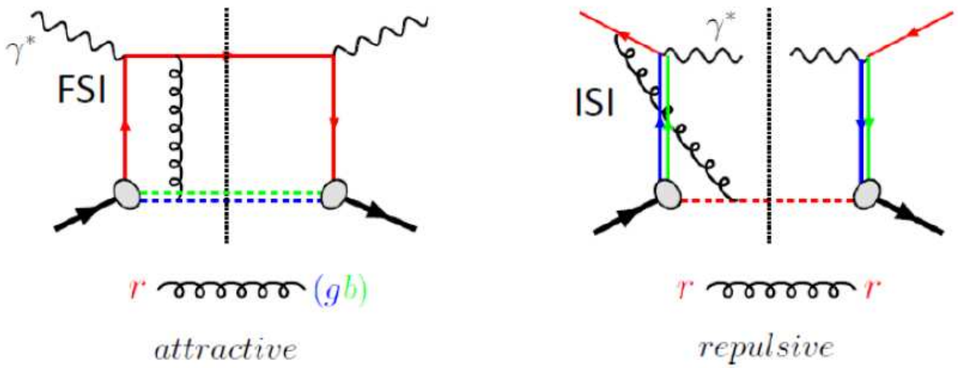
- $F = 4\sqrt{(P_a \cdot P_b)^2 - M_a^2 M_b^2}$
- $\hat{\sigma}_U$ ϕ- and ϕ_s-integrated cross section

Access to TMDs in polarised DY process

- $A_U^{\cos 2\phi}$: $h_1^\perp(\pi) \otimes h_1^\perp(p)$ — Boer-Mulders functions of the incoming hadrons
- $A_T^{\sin \phi_S}$: $f_1(\pi) \otimes f_{1T}^\perp(p)$ — Sivers function of the proton
- $A_T^{\sin(2\phi+\phi_S)}$: $h_1^\perp(\pi) \otimes h_{1T}^\perp(p)$ — BM function of the pion and the Pretzelosity function of the proton
- $A_T^{\sin(2\phi-\phi_S)}$: $h_1^\perp(\pi) \otimes h_1(p)$ — BM function of the pion and the Transversity function of the proton

Why do we need them?

Time-reversal odd behaviour of Sivers and Boer-Mulders TMDs lead to prediction of change of their sign when accessed from SIDIS or DY - restricted unversality



`gauge link changes sign for T-odd TMD', restricted universality of T-odd TMDs

J.C. Collins, PLB536 (2002) 43

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

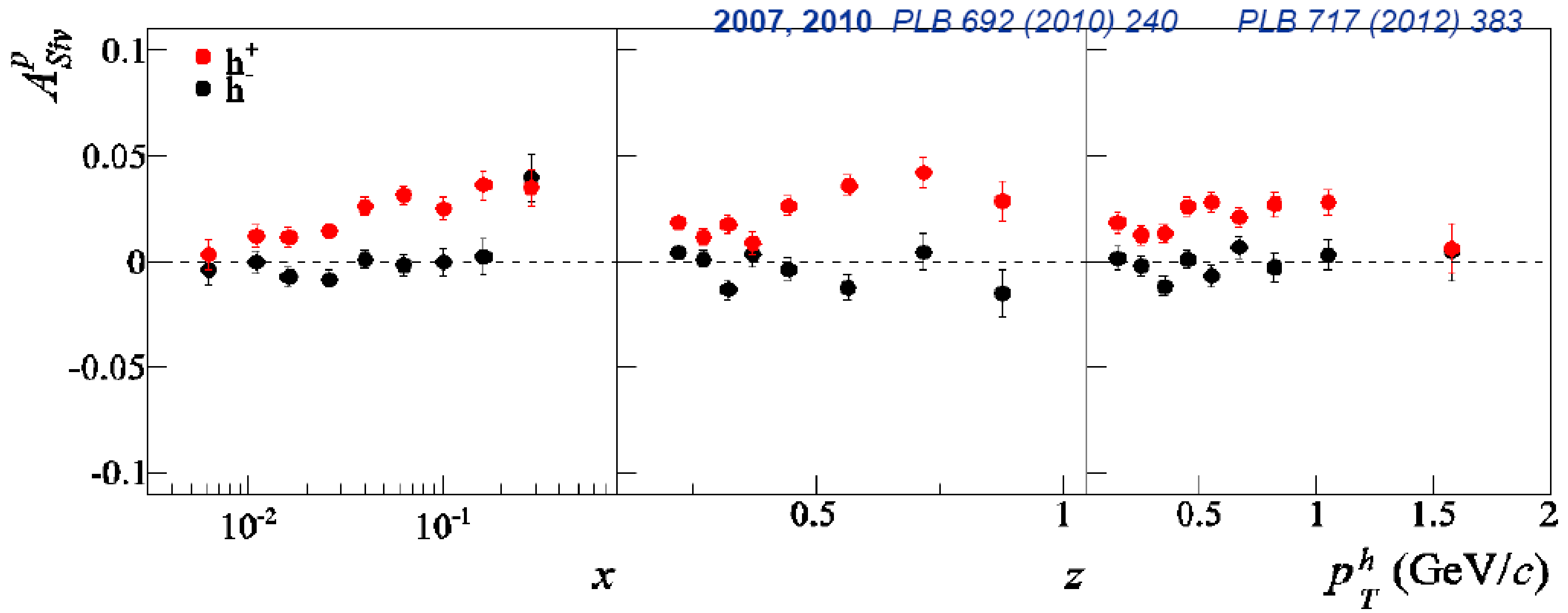
Sivers

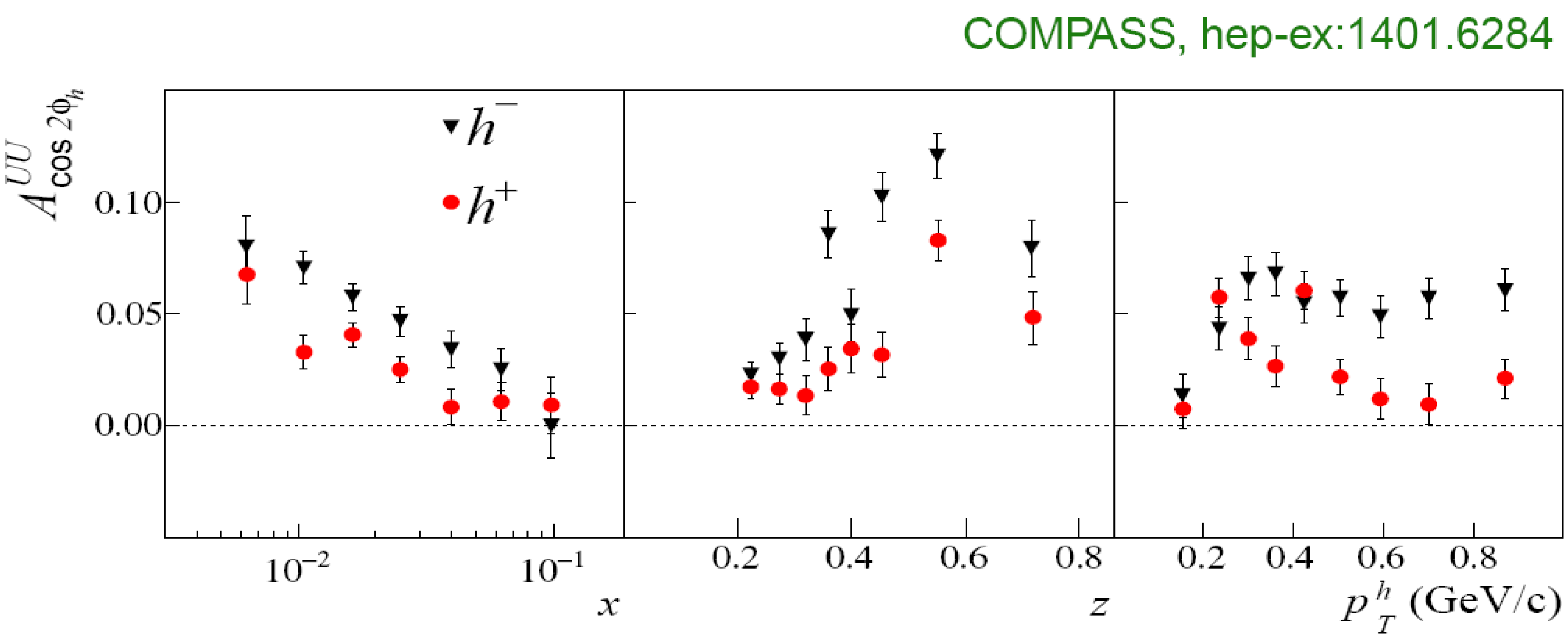
$$h_1^\perp(DY) = -h_1^\perp(SIDIS)$$

Boer-Mulders

Crucial test of the TMD approach

Sivers and BM from SIDIS at COMPASS

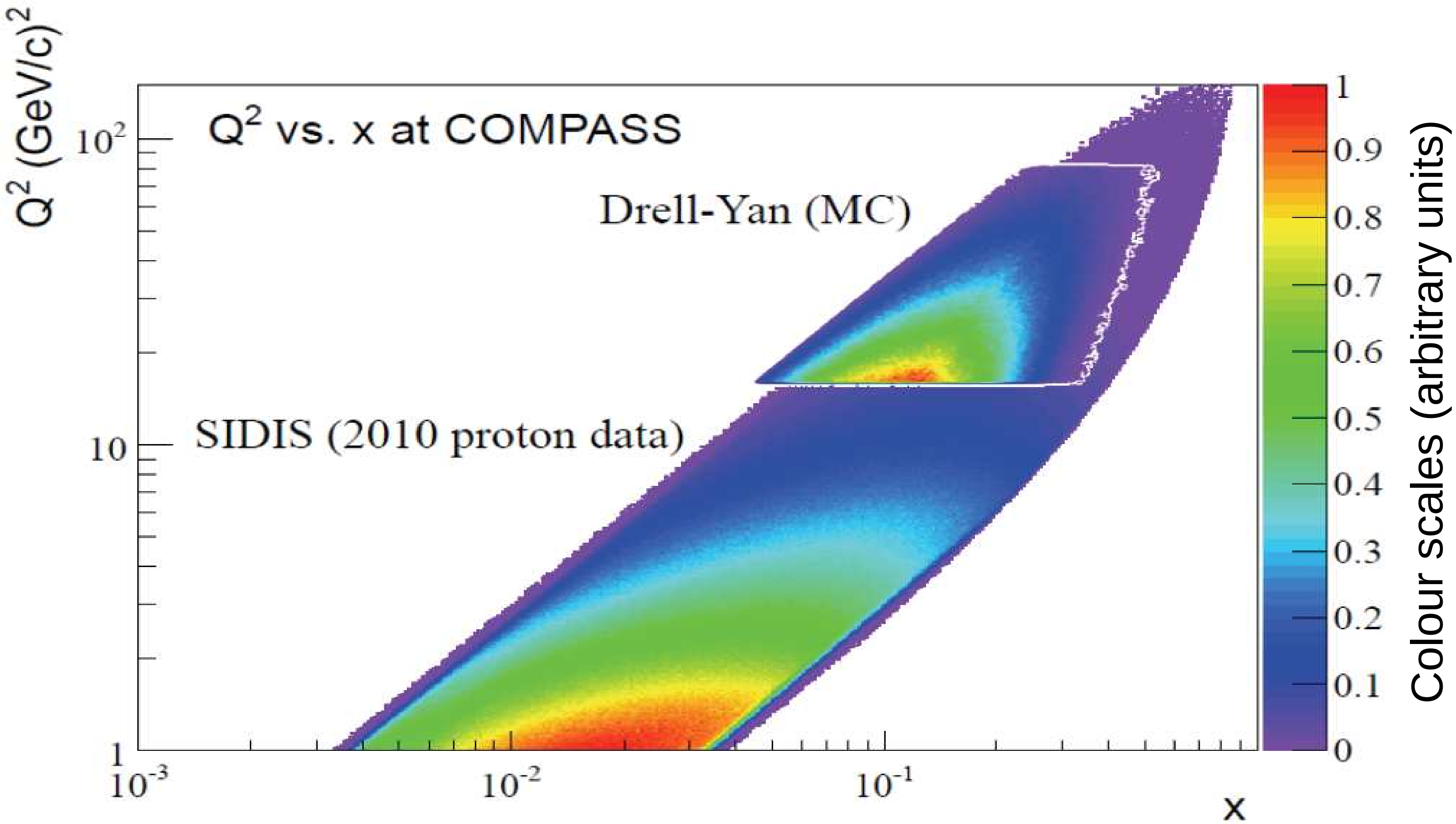




unpolarised isoscalar nucleon target (^{6}LiD)

SIDIS and DY at COMPASS

Kinematic ranges at COMPASS for polarised Drell-Yan ($4 < M_{\mu\mu} < 9$ GeV/c^2) and SIDIS



For h^+ in SIDIS with $Q^2 > 16$: $\delta A_{UT}^{\sin(\phi_h - \phi_s)} \approx$ **0.01** for $z > 0.2$ and $\approx$ **0.007** for $z > 0.1$ sample

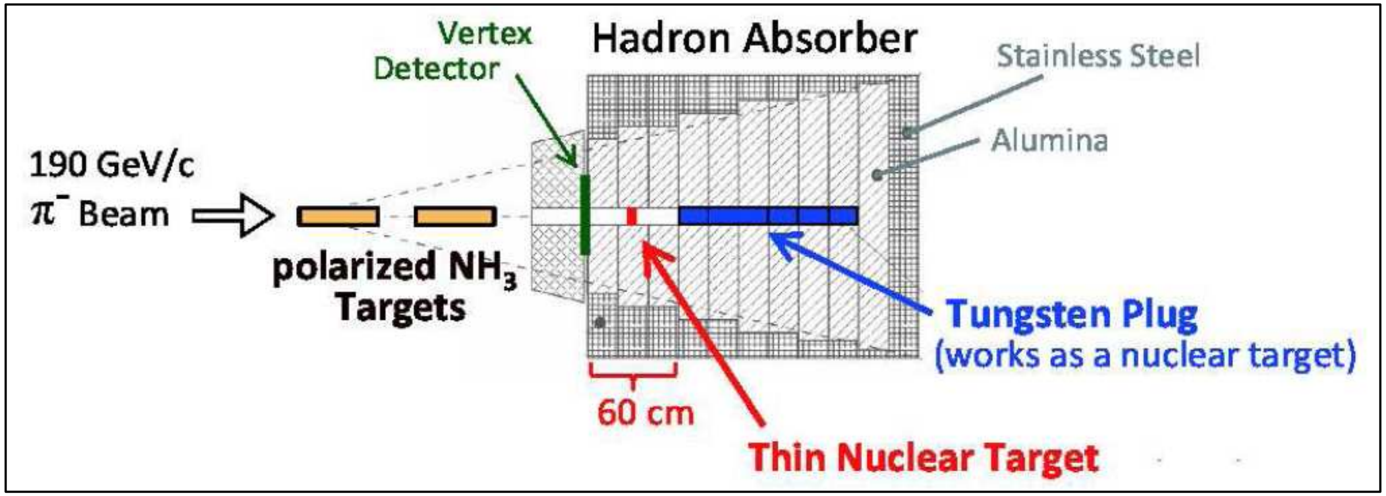
For h^- in SIDIS with $Q^2 > 16$: $\delta A_{UT}^{\sin(\phi_h - \phi_s)} \approx$ **0.012** for $z > 0.2$ and $\approx$ **0.008** for $z > 0.1$ sample

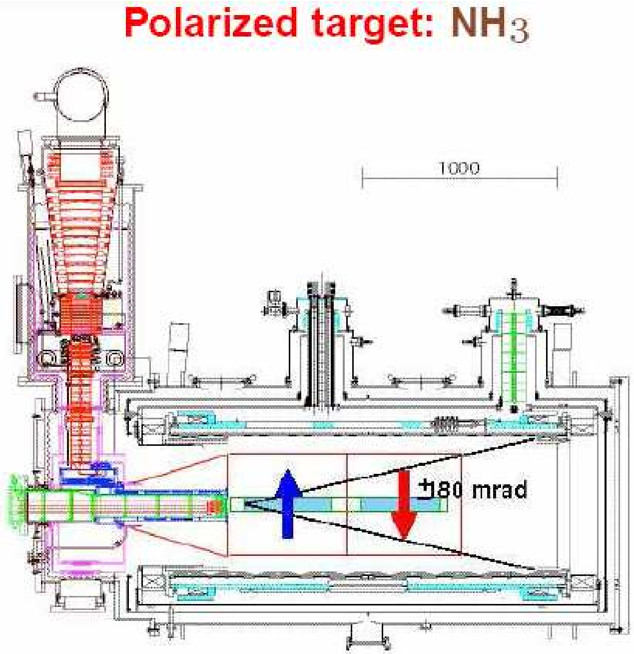
$\delta A_T^{\sin\varphi_s}$ in DY ("high mass" range) with $2.85\ 10^5$ events $\approx$ **0.013** with $5\ 10^5$ events $\approx$ **0.01**

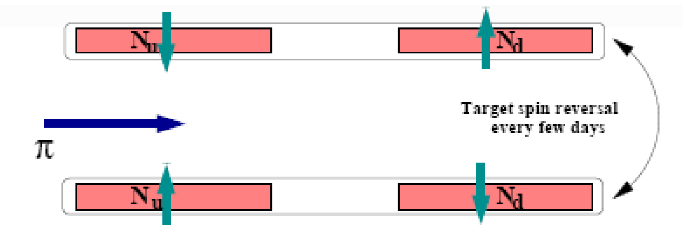
Unique opportunity to access the sameTMDs both via DY and SIDIS with the same spectrometer

Requirements to COMPASS setup for DY

- ✓ small cross section => large luminosity
  => high intensity pion beam 10^8 π^- per sec. on a thick target (~ 1 interaction length)
- ✓ hadron absorber and beam plug in front of the spectrometer
- ✓ NH_3 polarised target => transverse polarisation, spin rotation every few days
- ✓ possible use of a thin nuclear target downstream of PT, inside of the absorber
- ✓ scintillating fibers vertex detector inside of the absorber
- ✓ hodoscope based dimuon trigger system

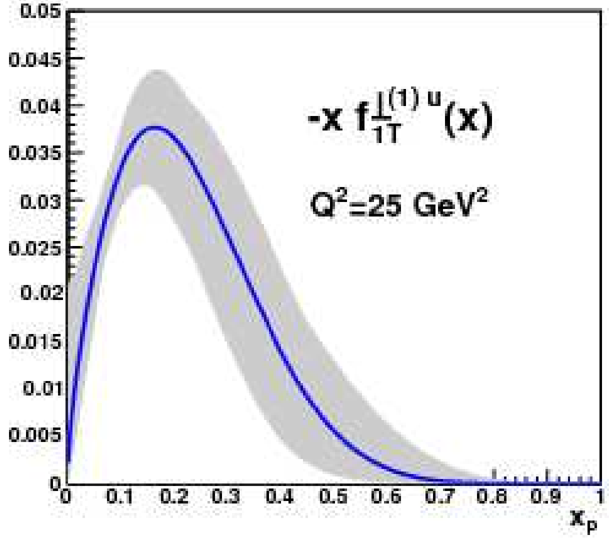


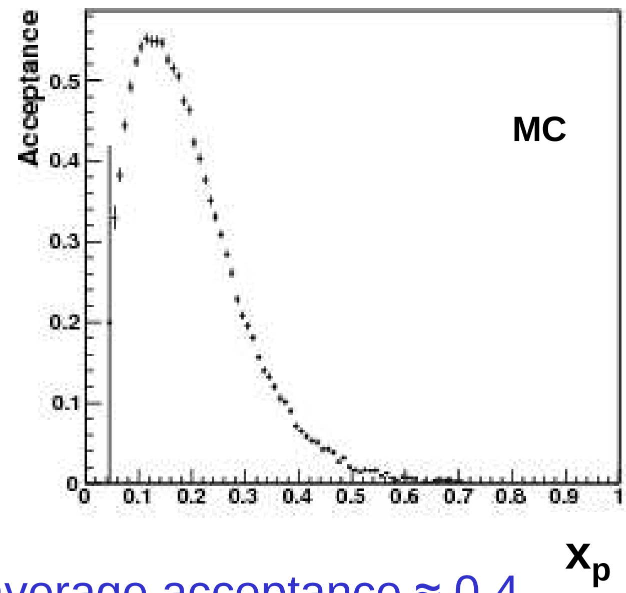




Kinematic range and acceptance for high dimuon mass range

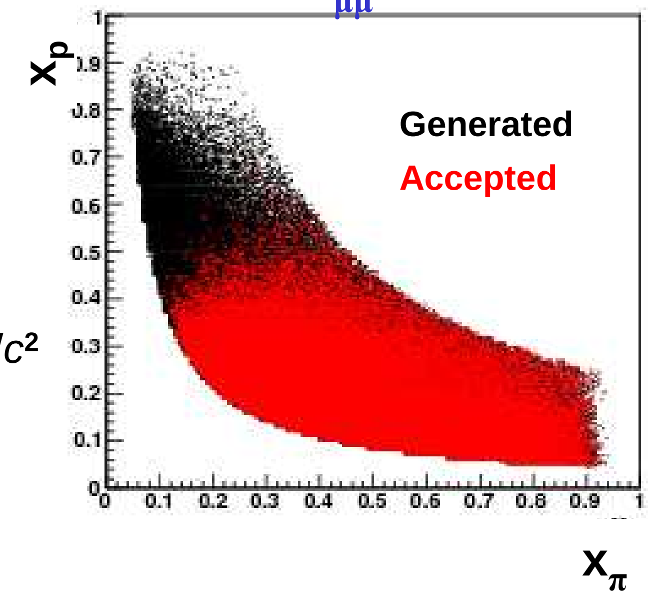
M. Anselmino et al.
PR D79 (2009)

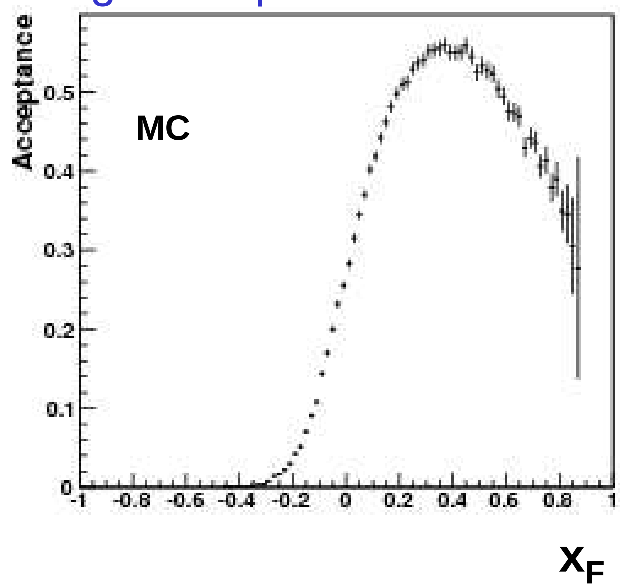




$4.0 < M_{\mu\mu} < 9.0$ GeV/c^2 average acceptance ≈ 0.4

MC
190 GeV π^- beam
DY: 4.0 – 9.0 GeV/c^2





at COMPASS the contribution from valence quarks dominant, mostly u^{val}(p) and $\bar{u}^{\mathrm{val}}(\pi^-)$

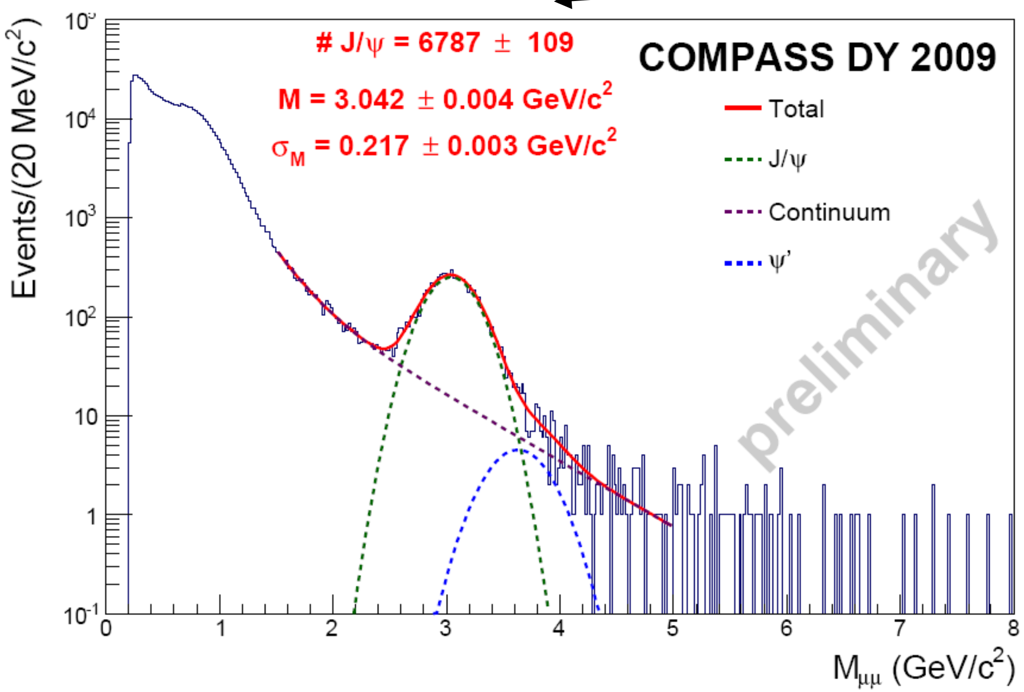
Feasibility test in 2009

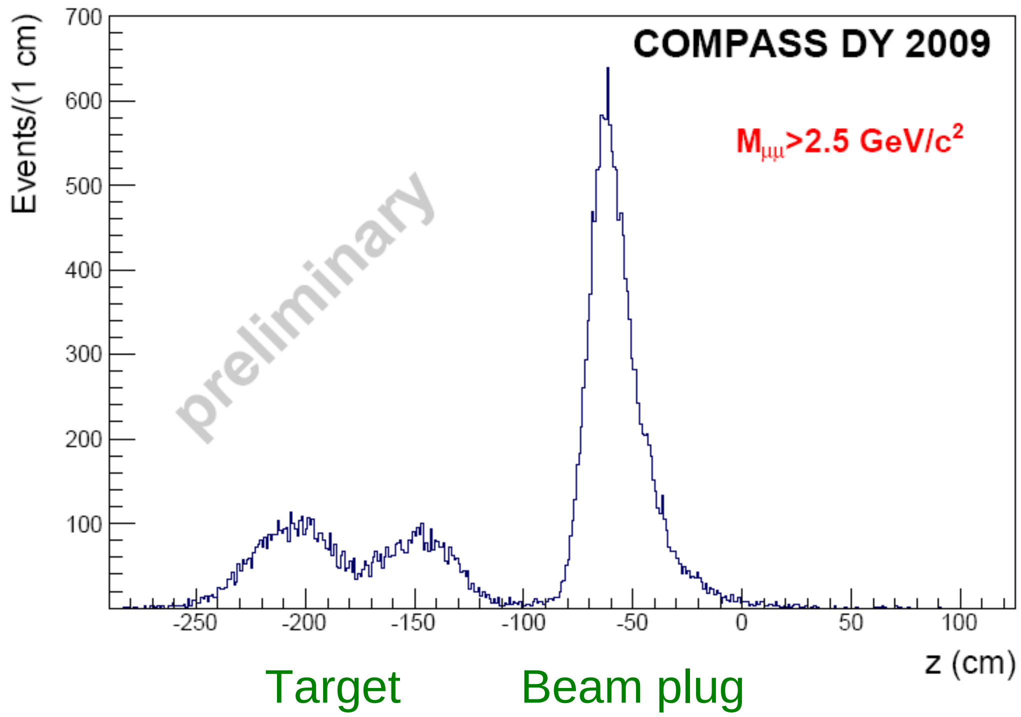
3 days of 190 GeV π^- beam on a polythelyne two-cell target, $I_{\mathbf{beam}}$ = 8x10^{6} π /s

a prototype hadron absorber and beam plug installed

a dimuon trigger based on calorimeter signals

new





- ✓ number of J/ψ, its mass and width in agreement with expectations from MC simulation => validation of MC
- ✓ combinatorial background negligible at high dimuon masses 4 < $M_{\mu\mu}$ < 9 GeV/c^2 , small under J/ψ peak
- ✓ separation of target cells visible
- ✓ expected improvement of vertex resolution with SF vertex detector to be implemented for 2014-2015 run

Recent update of the expected rates and asymmetry uncertainties

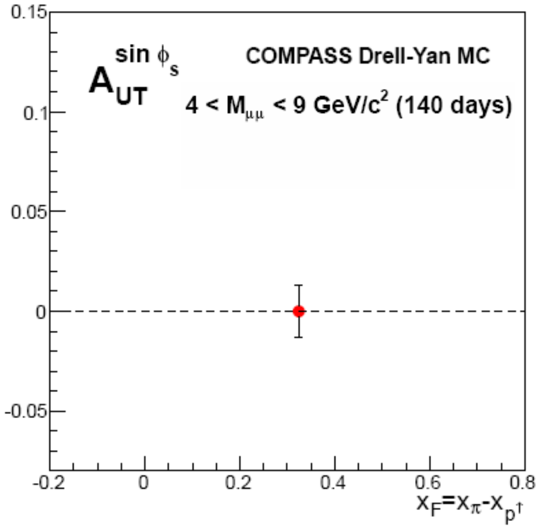
new

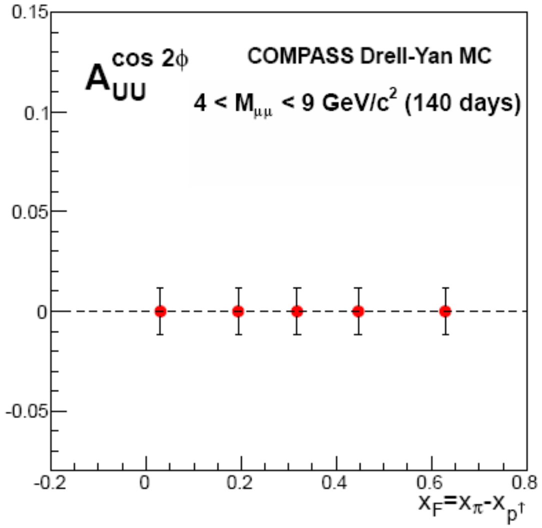
For 2014-2015 expected increase of event rates compared to those in the proposal

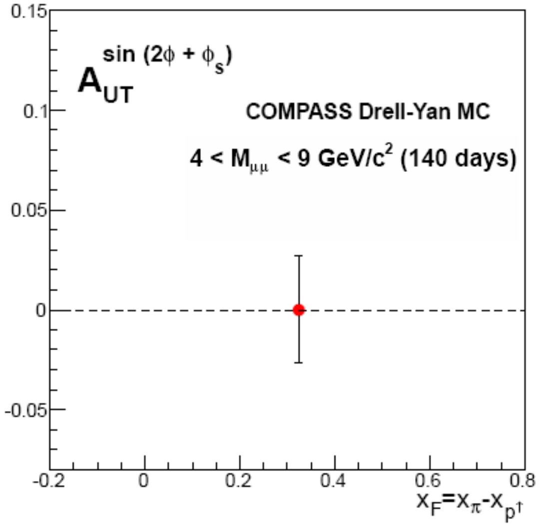
with $I_{\mathbf{beam}}$ = 10^8 particles/s and 9.6s spill every 34 seconds

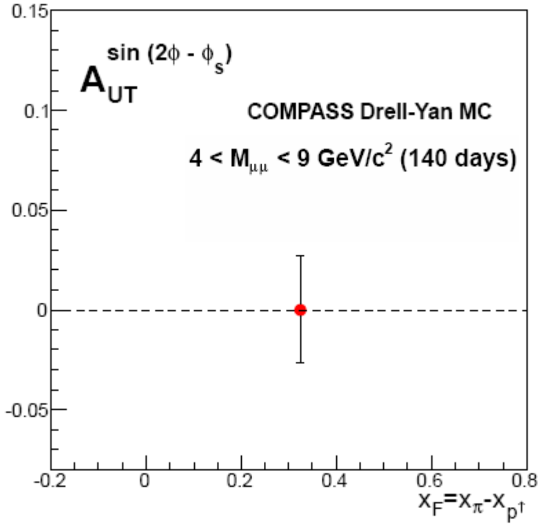
=> 2000 events/day in $4 < M_{\mu\mu} < 9$ GeV/c^2 range, 285 000 events in 140 days

the proposal: 230 000 events in 280 days









statistical errors for 140 days

Asymmetry uncertainties	Dimuon mass (GeV/c^2) $4 < M_{\mu\mu} < 9$
$\delta\, A_U^{\cos 2\phi}$	0.005
$\delta\, A_T^{\sin\phi_S}$	0.013
$\delta\, A_T^{\sin(2\phi+\phi_S)}$	0.027
$\delta\, A_T^{\sin(2\phi-\phi_S)}$	0.027

DY program outlook

- End of 2012 – mid of 2014 preparation of the DY setup

  hadron absorber installation, PT movement in DY position, PT test with refurbished solenoid magnet and new PT infrastructure

- In 2014 two-months polarised DY pilot run from mid October

- Physics data taking in 2015 (~ 140 days)

- A second year for DY planned, after a LS in 2018

  subject of an Addendum to the COMPASS-II proposal with

  - polarised and unpolarised DY measurements with ^{6}LiD target
  - measurements with a liquid hydrogen long target
  - nuclear effects in unpolarised DY

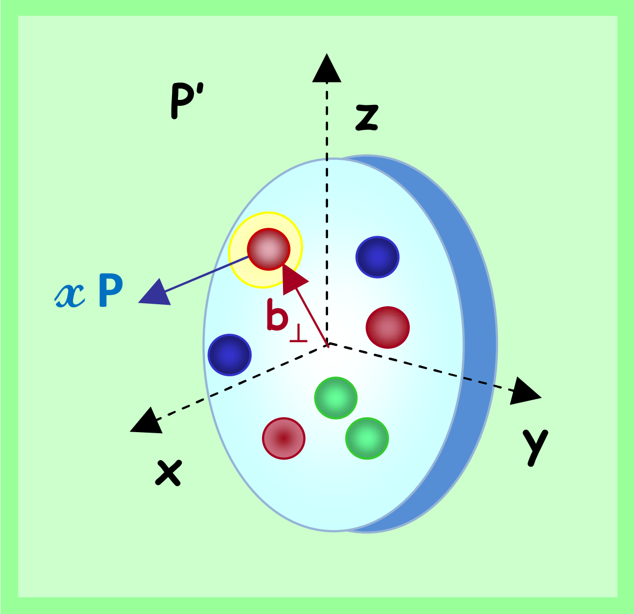
GPD program

Main goals of the GPD program

- GPD a 3-dimensional image of the partonic structure of the nucleon

$$H(x,\ \xi=0,\ t) \rightarrow H(x,\ r_{x,y})$$

probability interpretation
Burkardt

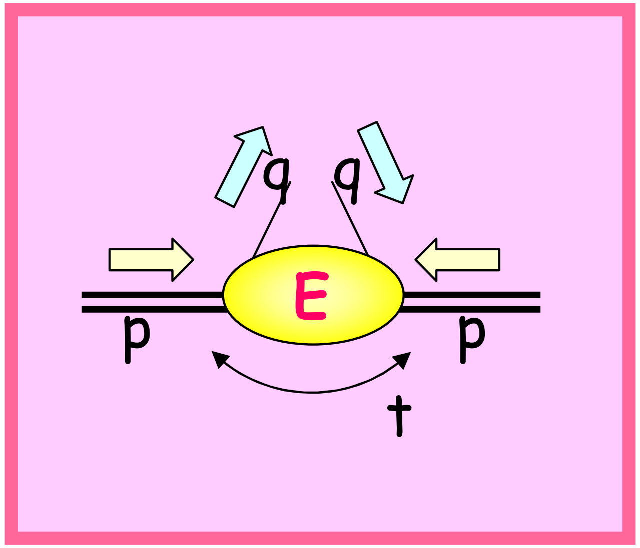


- Contribution to the nucleon spin puzzle

E related to the orbital angular momentum

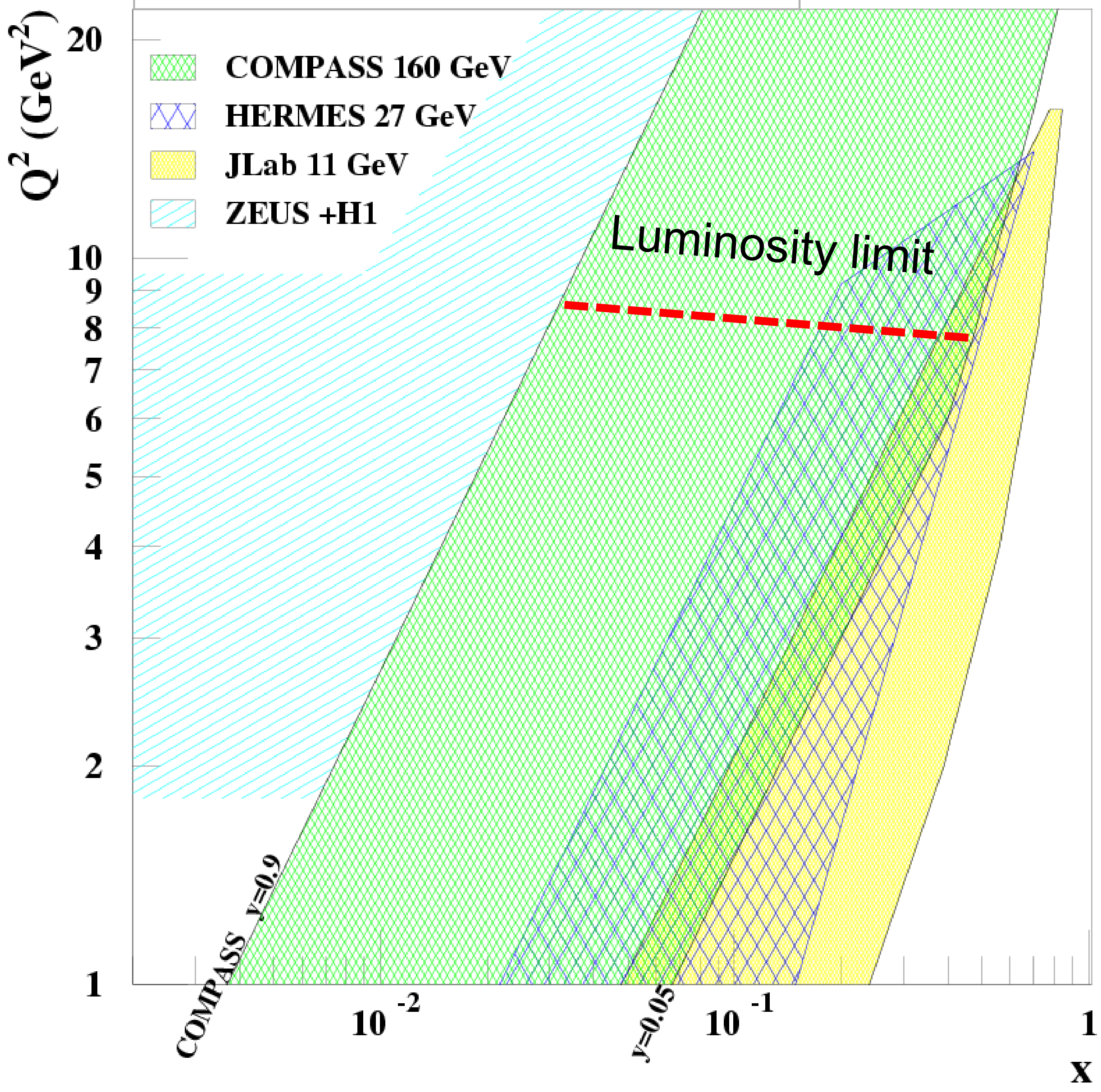
$$2J_q = \int x\ (H^q(x,\xi,0) + E^q(x,\xi,0))\ dx$$

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z^q \rangle + \langle L_z^g \rangle$$



What makes COMPASS unique for GPD studies

kinematic coverage for DVCS



CERN SPS high energy polarised muon beam

- ✓ 100 – 190 GeV
- ✓ polarisation 80%
- ✓ μ^+ and μ^- available
  - opposite polarisation
  - $3.9 \cdot 10^8\ \mu^+$ /spill
  - $I(\mu^+) \approx 2.4\ I(\mu^-)$
- ✓ $L = 10^{32}\ cm^{-2}\ s^{-1}$
  with 2.5 m long LH_2 target

Foreseen measurements

DVCS and HEMP off unpolarised and transversely polarised protons

Kinematic range for DVCS

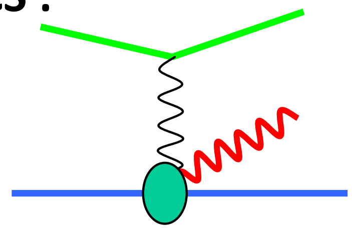
$Q^2 \rightarrow 8\ GeV^2$

$\sim 10^{-2} < x < \sim 10^{-1}$

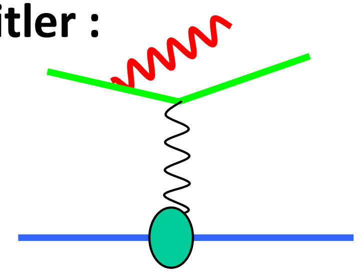
$x \rightarrow 0.20$ with extension of present calorimetry

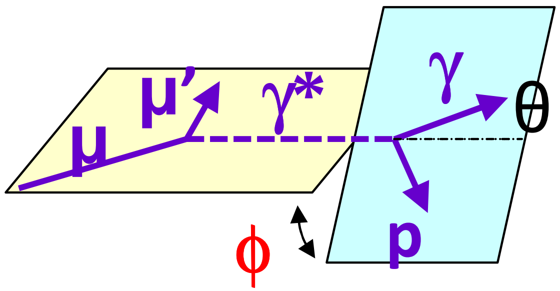
Interplay of DVCS and BH at 160 GeV

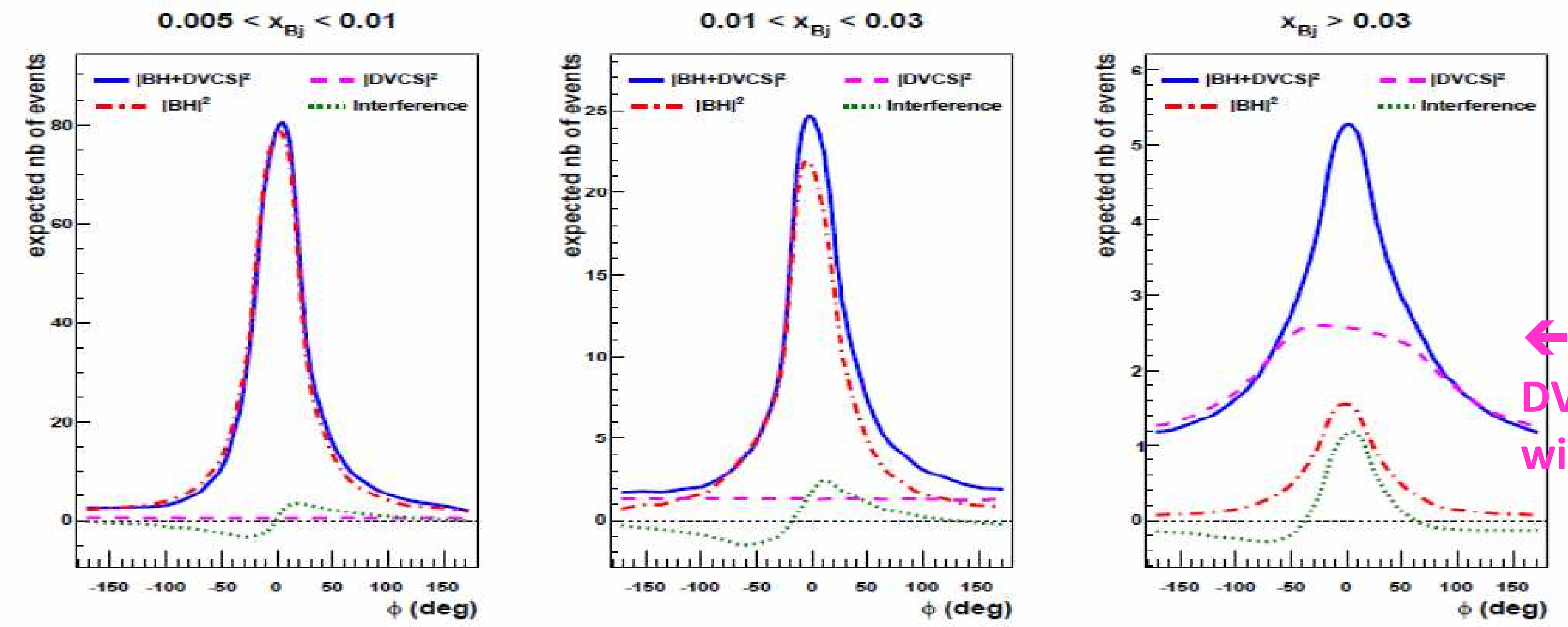
DVCS :



Bethe-Heitler :





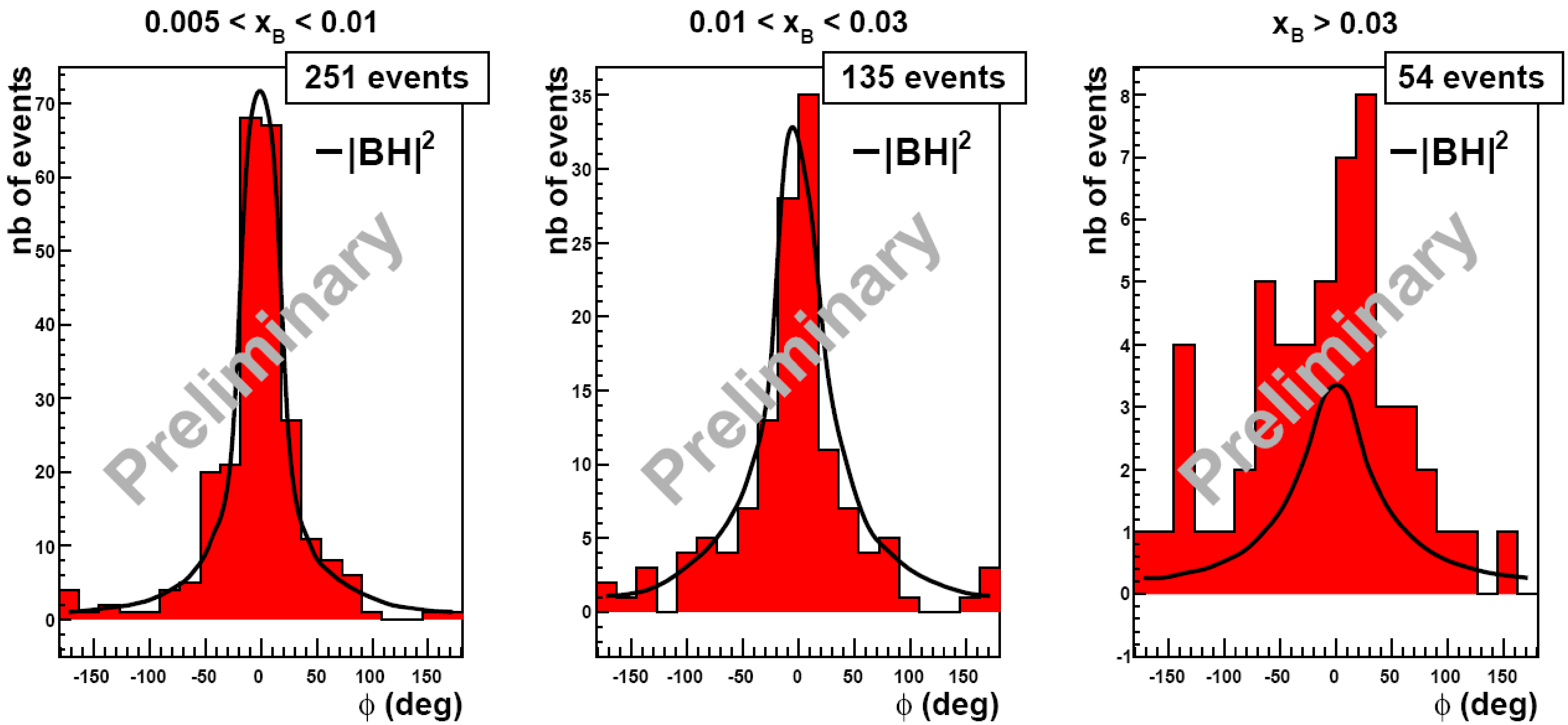


Monte-Carlo Simulation for COMPASS set-up with only ECAL1+2

← non-uniform DVCS acceptance without ECAL0

BH dominates	BH and DVCS at the same level	DVCS dominates
excellent reference yield	access to DVCS amplitude through the interference	study of $d\sigma^{DVCS}/dt$

Exclusive γ production from 2009 DVCS test run



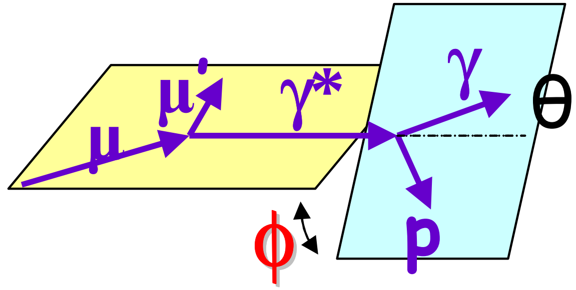
$\epsilon_{\mu p \rightarrow \mu' \gamma p} \approx 35\%$

$\times\, (0.8)^4$ for SPS + COMPASS avail. + trigger eff + dead time

$\varepsilon_{global} \approx 0.14$ confirmed $\varepsilon_{global} = 0.1$ assumed for COMPASS-II projections

54 evts $\approx$ 20 BH
+ 22 DVCS
+ about 12 γ from π^0 (upper limit)

Extraction of DVCS cross section and amplitude



Beam Charge & Spin Sum

$$\mathcal{S}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) = 2(\underline{d\sigma^{BH}} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu\, a^{BH}\, \mathcal{I}m\, T^{DVCS})$$

$$c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi \qquad s_1^{Int}\sin\phi + s_2^{Int}\sin 2\phi$$

$c_0^{DVCS} \longrightarrow d\sigma^{DVCS}/dt$

$s_1^{Int} \longrightarrow \mathcal{I}m(F_1\mathcal{H})$

$\mathcal{I}m\,\mathcal{H}(\xi,t) = H(x=\xi,\xi,t)$

Beam Charge & Spin Difference

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) = 2(e_\mu\, a^{BH}\, \mathcal{R}e\, T^{DVCS} + P_\mu\, d\sigma^{DVCS}_{pol})$$

$$c_0^{Int} + c_1^{Int}\cos\phi + c_2^{Int}\cos 2\phi + c_3^{Int}\cos 3\phi \qquad s_1^{DVCS}\sin\phi$$

$c_{0,1}^{Int} \rightarrow \mathcal{R}e(F_1\mathcal{H})$

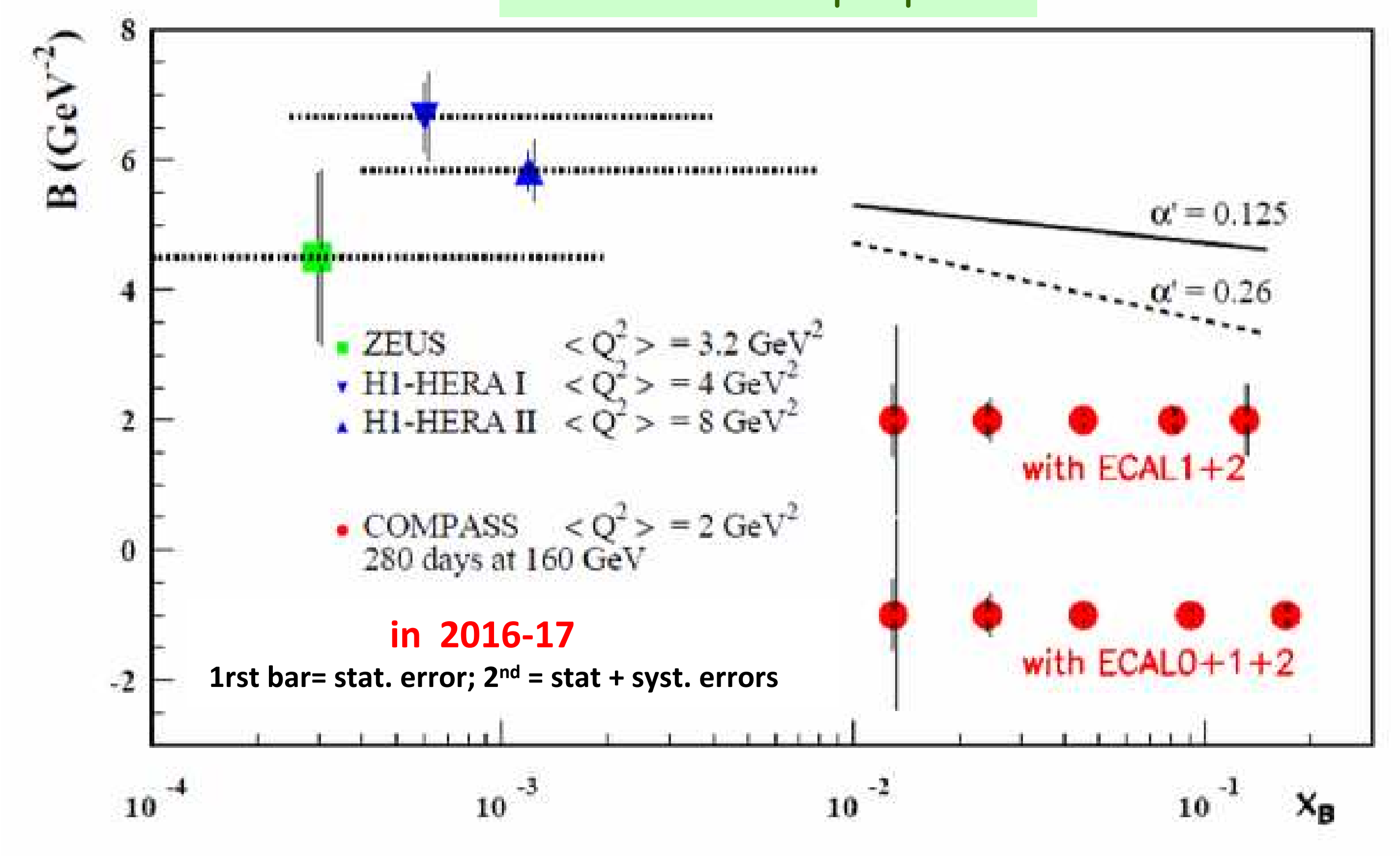
$$\mathcal{R}e\,\mathcal{H}(\xi,t) = \mathcal{P}\int dx\, \frac{H(x,\xi,t)}{x-\xi} = \mathcal{P}\int dx\, \frac{H(x,x,t)}{x-\xi} + \mathcal{D}(t)$$

Transverse imaging of the proton using $d\sigma^{DVCS}/dt$

integrating $\mathcal{S}_{CS,U}$ over ϕ and subtracting BH → $d\sigma_{DVCS}/dt \sim \exp(-B|t|)$

'tomography': $B(x) \Leftrightarrow \langle r_T^2 \rangle(x)$

COMPASS-II proposal



40 weeks of data
160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%

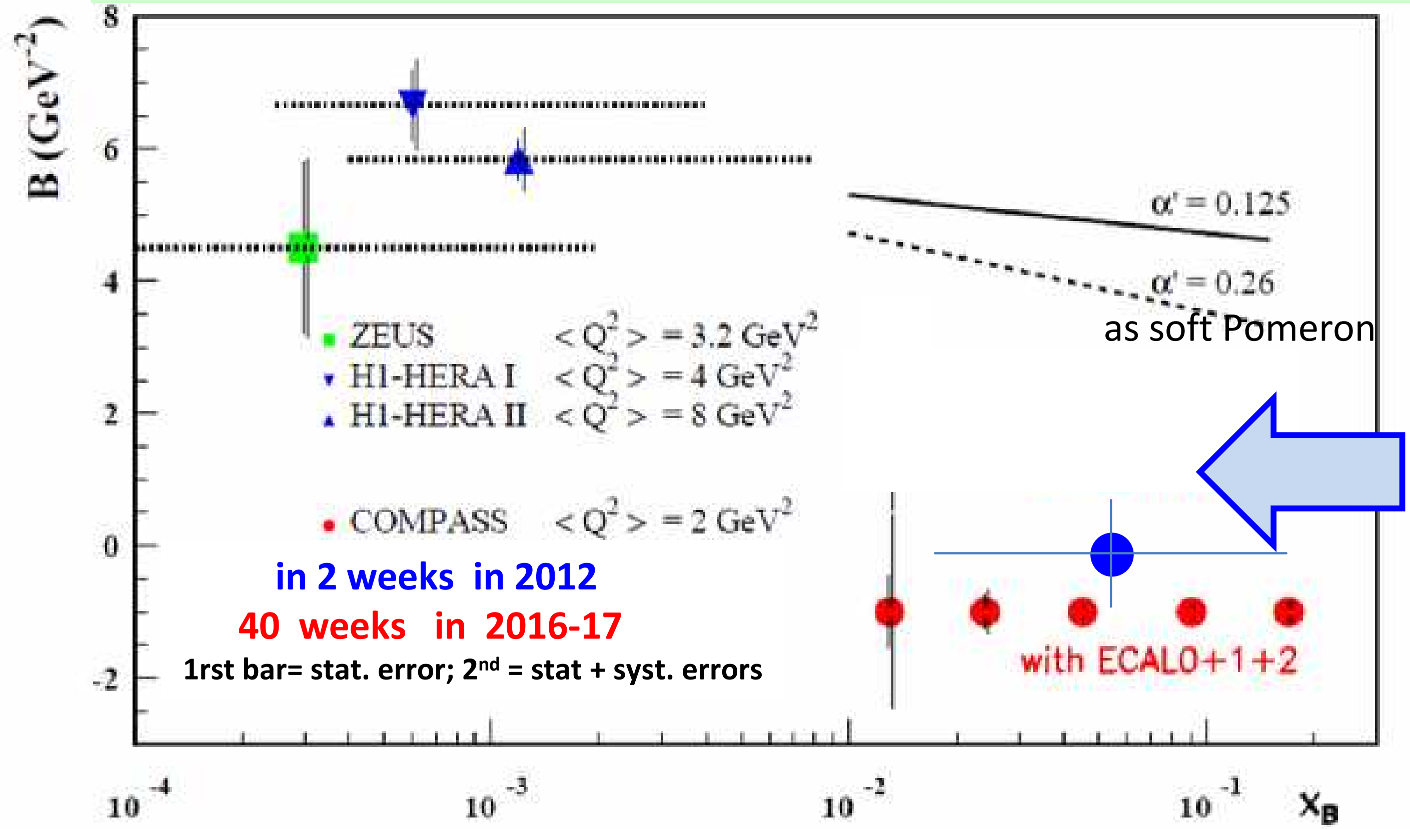
ansatz at small x_B
inspired by
Regge Phenomenology:

$$B(x_B) = b_0 + 2\,\alpha' \ln(x_0/x_B)$$

α' slope of Regge traject

Transverse imaging of the proton using $d\sigma^{DVCS}/dt$

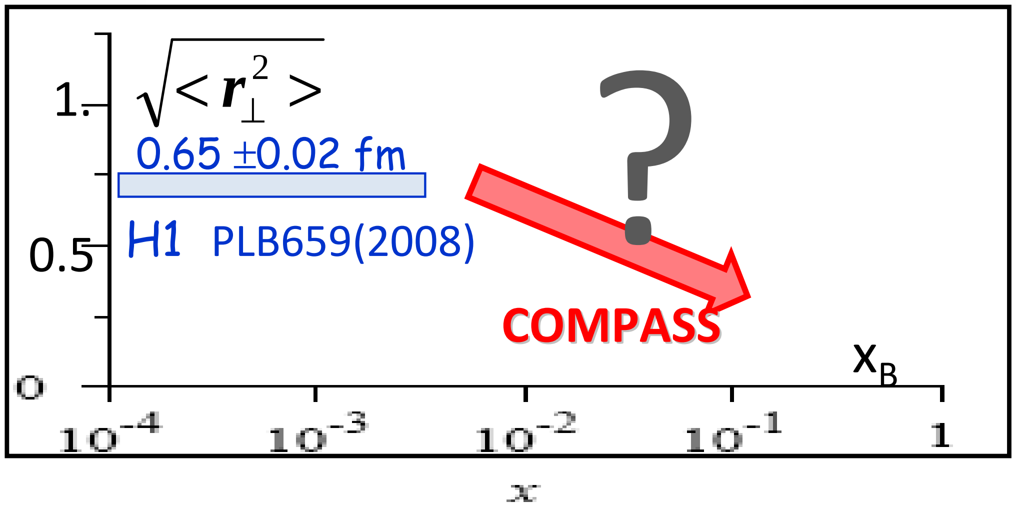
Projection for statistical uncertainty on B-slope from 2012 DVCS pilot run data



DVCS test in 2012

2 weeks of data taking using the 4m long RPD + the 2.5m long LH2 target

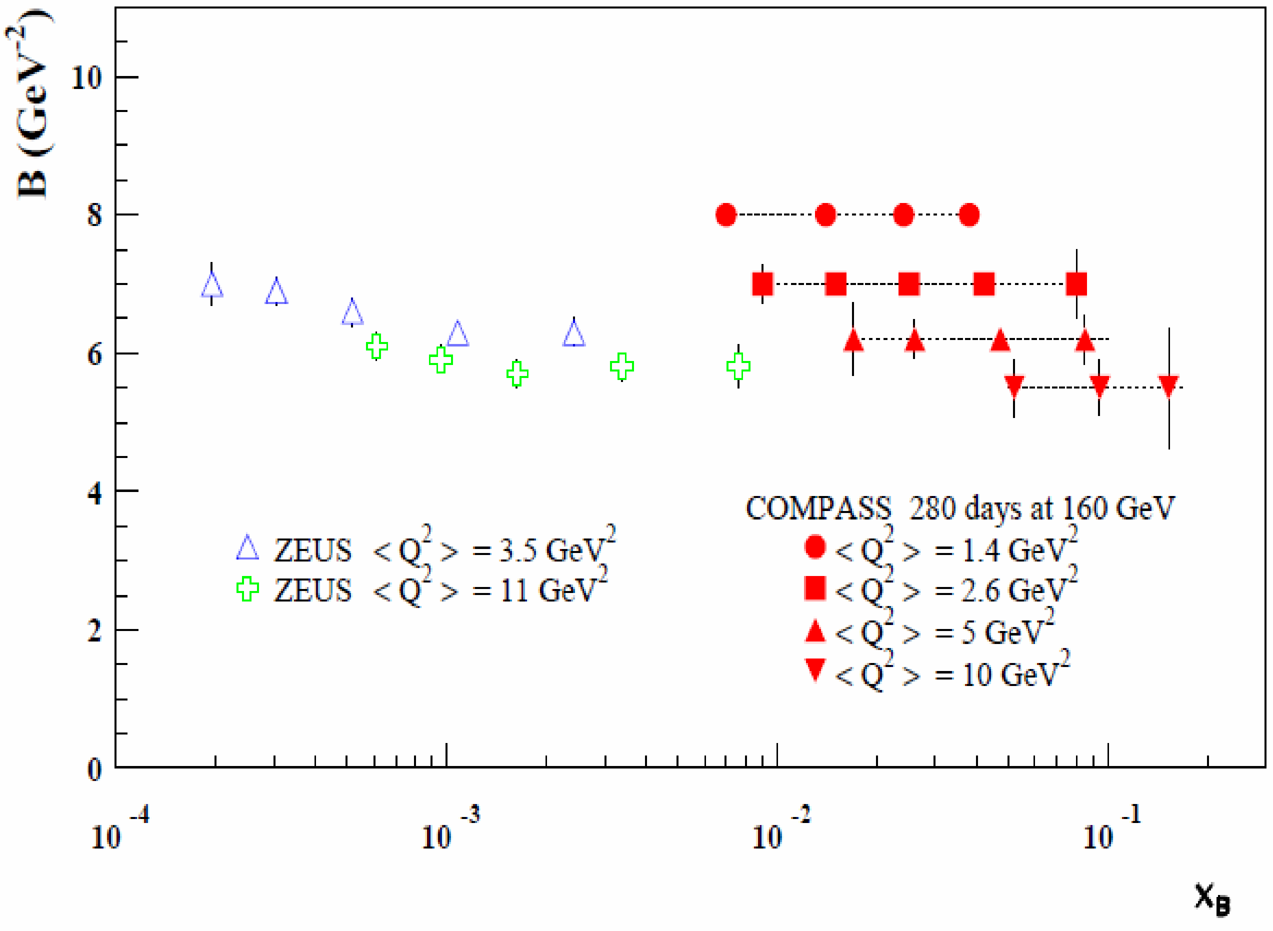
1/20 of the total statistics foreseen in the proposal



From 2012 data expected the first measurement of B-slope for DVCS at an x_{Bj} value above HERA range

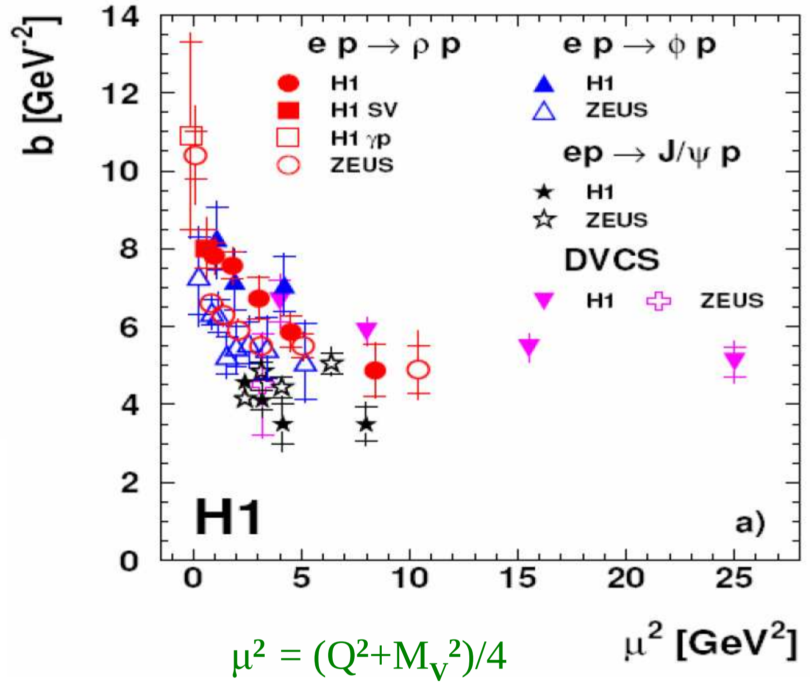
t-slope measurement for exclusive ρ^0 production

$$d\sigma_{\gamma N \to \rho N}/dt \sim \exp(-B|t|)$$



160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%, 280 days
L = $1222 pb^{-1}$

$0.06 < |t| < 0.64$ GeV^2



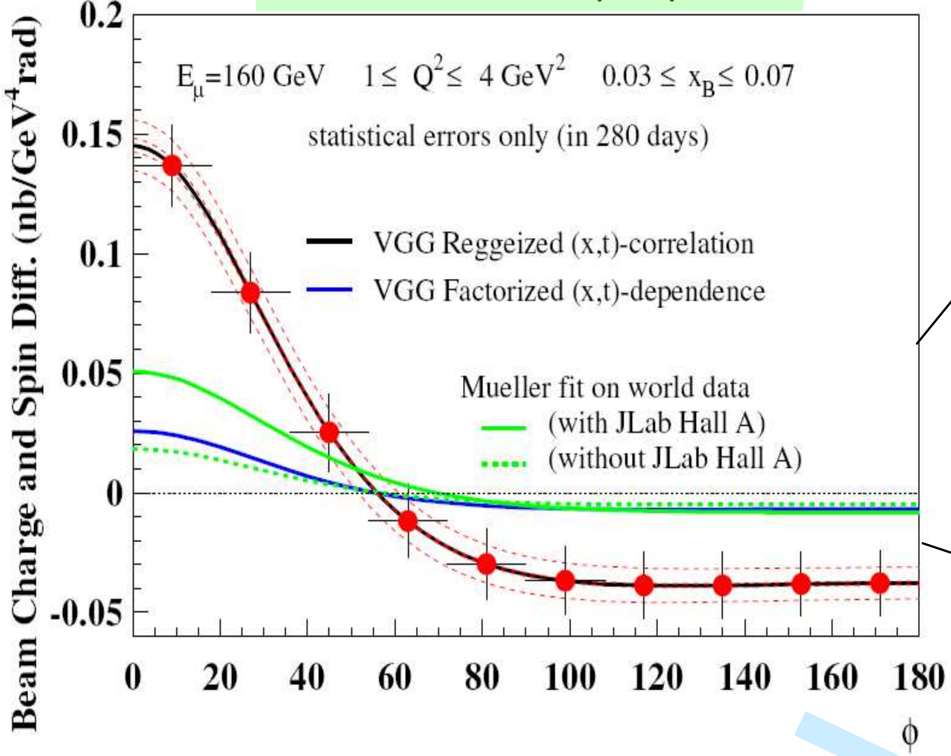
$\mu^2 = (Q^2+M_V^2)/4$
(= Q^2 for DVCS)

At large Q^2 slope B sensitive mostly to the nucleon size

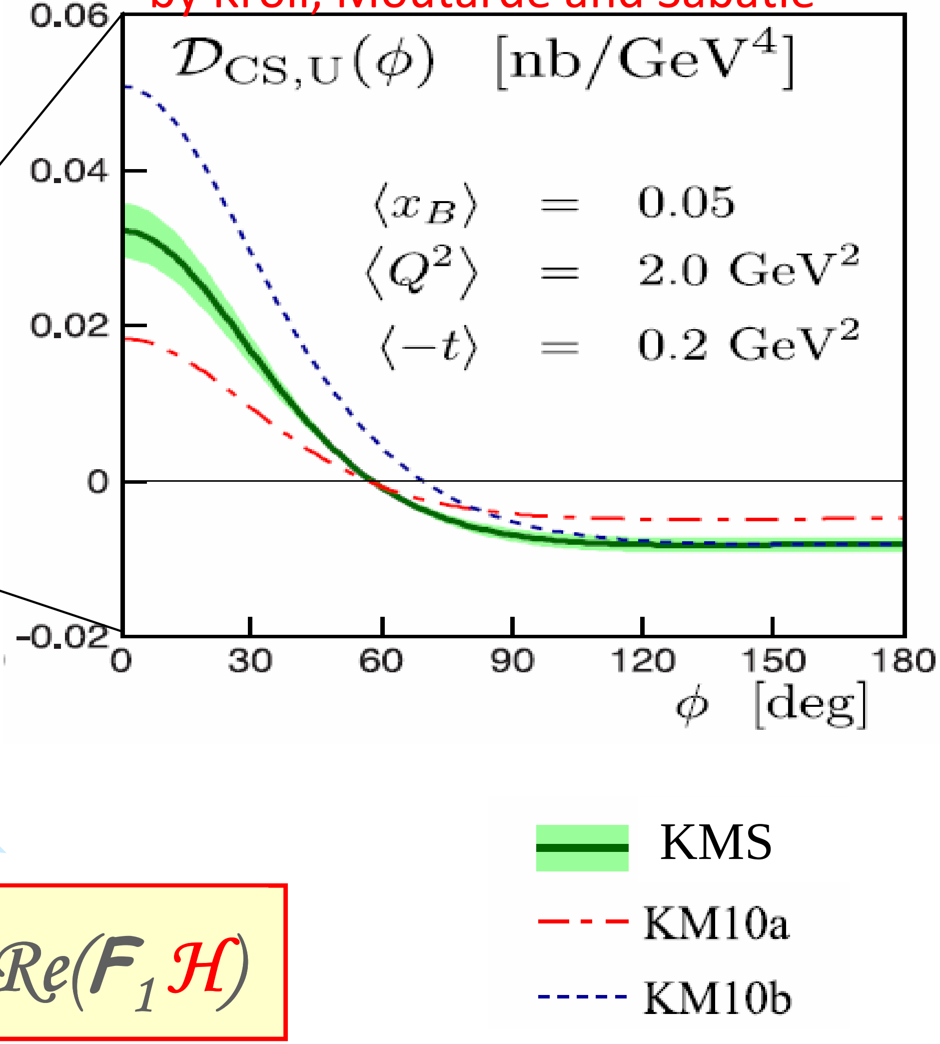
Beam Charge&Spin Difference of cross sections

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) = c_0^{Int} + c_1^{Int}\cos\phi + c_2^{Int}\cos 2\phi + c_3^{Int}\cos 3\phi + s_1^{DVCS}\sin\phi$$

COMPASS-II proposal



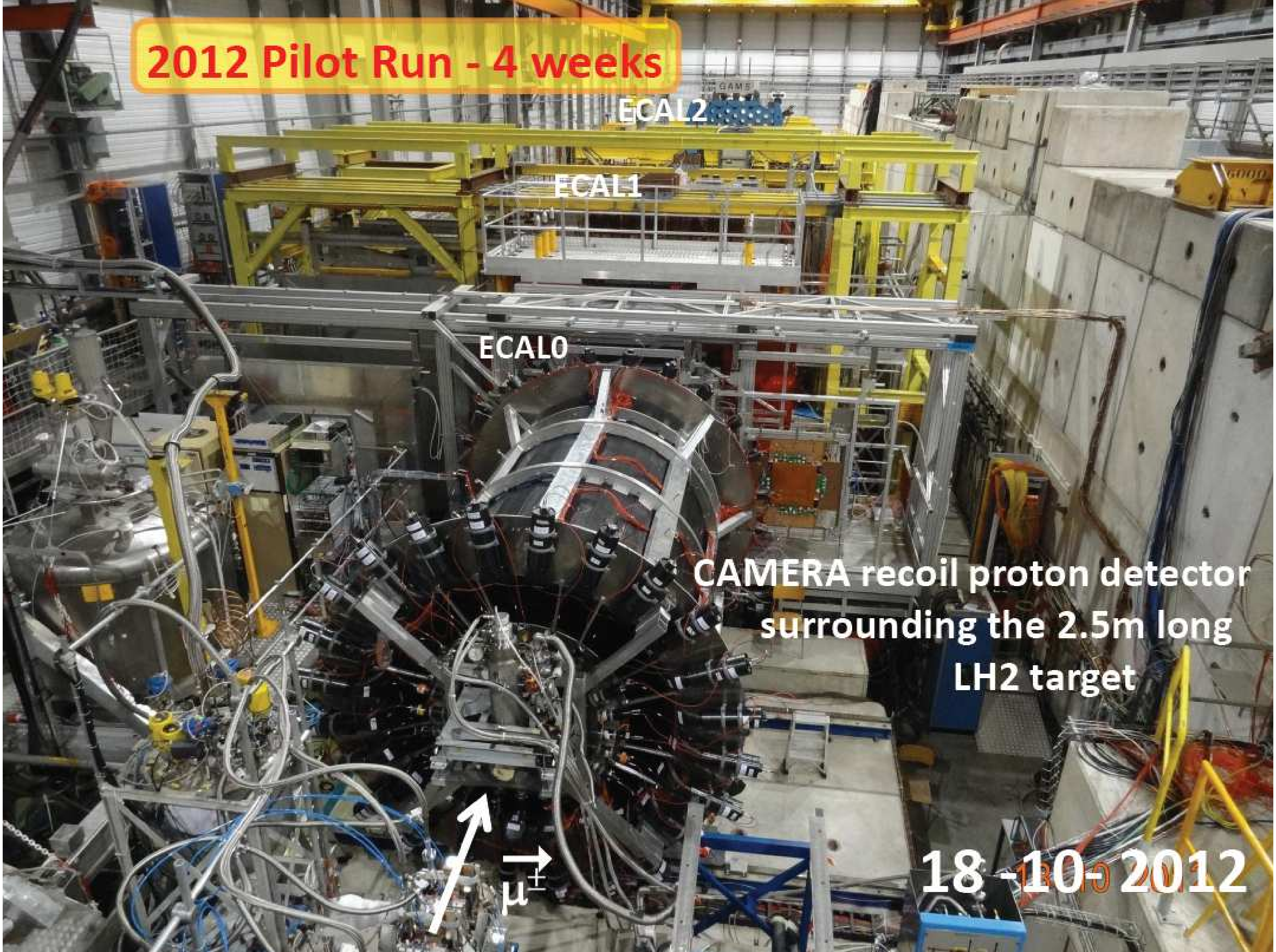
New predictions
by Kroll, Moutarde and Sabatié



0.06 < |t| < 0.64 GeV²

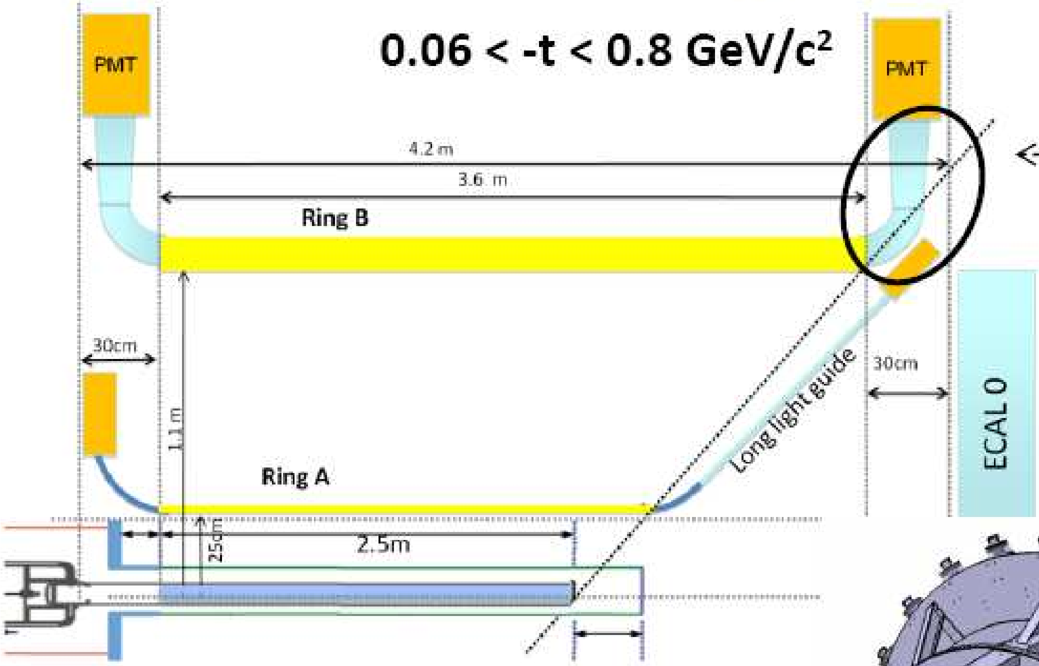
160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%, 280 days
L = 1222pb^{-1}

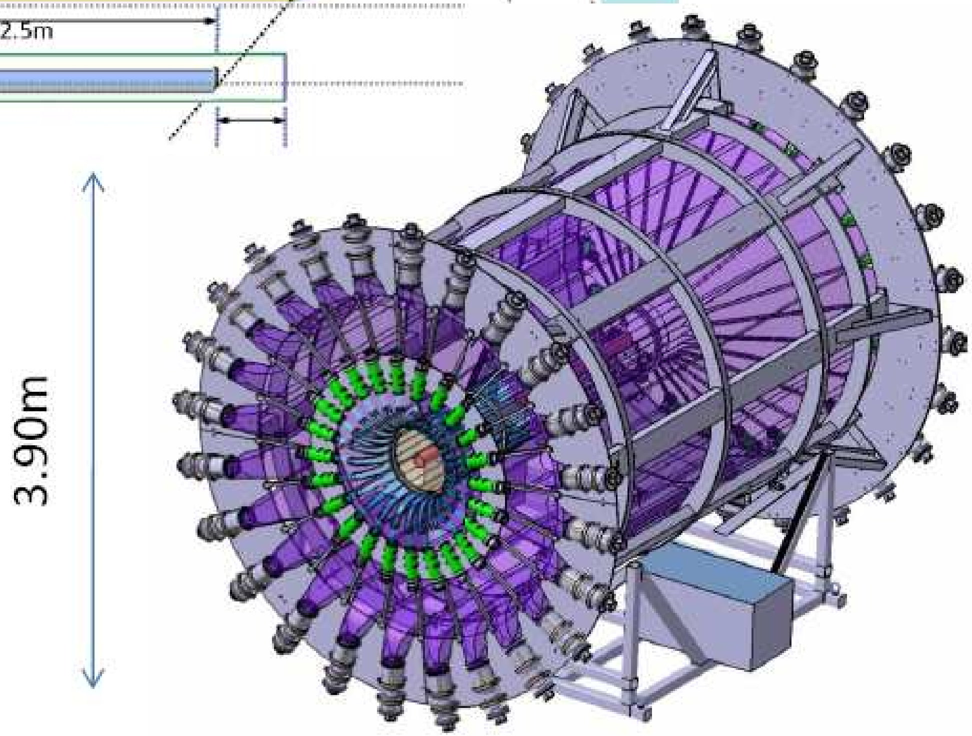
$$c_{0,1}^{Int} \rightarrow \mathcal{R}e(F_1\mathcal{H})$$


2012 Pilot Run - 4 weeks
ECAL2
ECAL1
ECAL0
CAMERA recoil proton detector surrounding the 2.5m long LH2 target
$\vec{\mu}^{\pm}$
18 -10- 2012

Recoil proton detector - CAMERA

ToF between 2 rings of plastic scintillators





Specifications

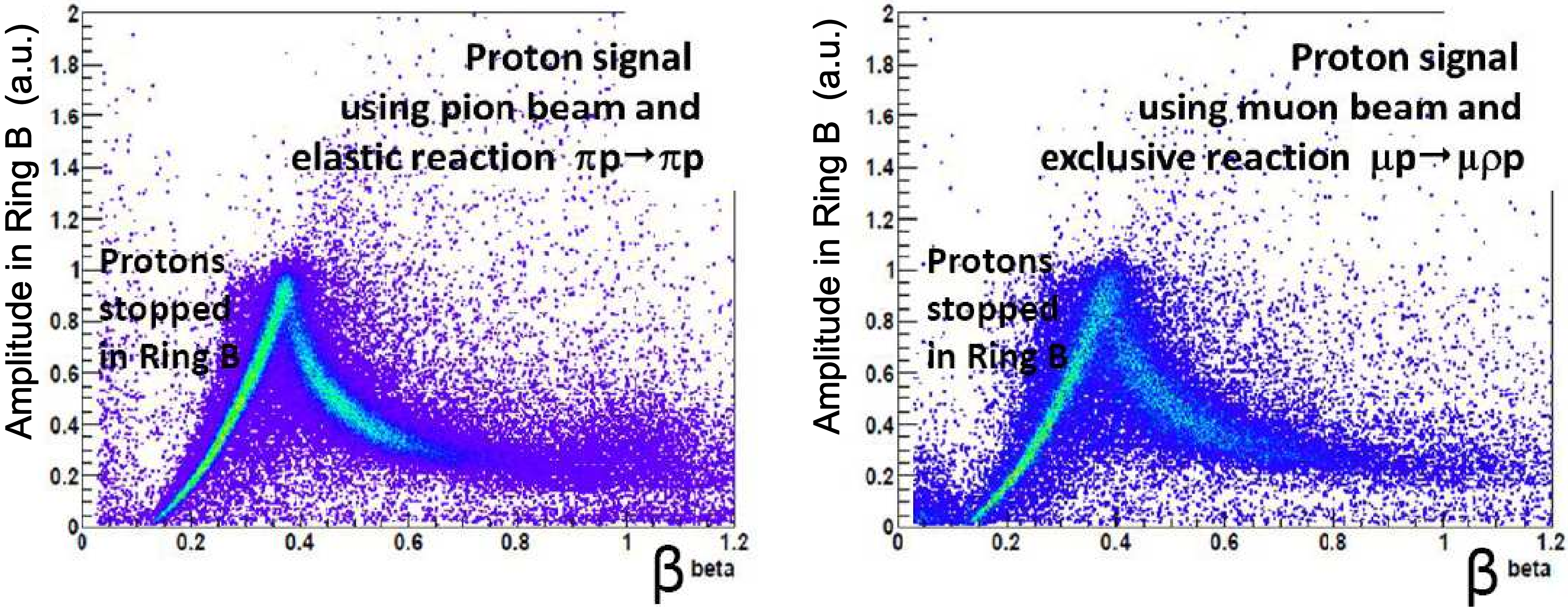
Ring A :

- 4mm thick, 280 cm long
- 350 ps
- Light holding structure

Ring B :

- 5cm thick, 360 cm long
- 160 ps

CAMERA performance in 2012 pilot run



Beyond the dominant GPD H

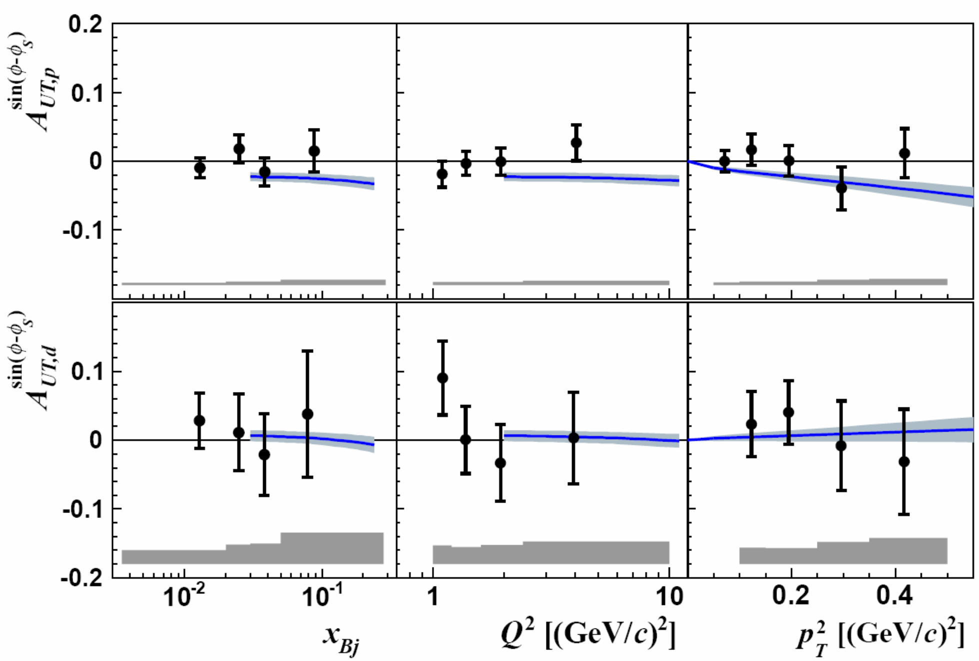
Azimuthal asymmetries for (incoherent) exlusive ρ^0 production on $p^\uparrow$ and $d^\uparrow$

Compass 2002-2010 data with transversely polarised NH_3 and ^6LiD targets

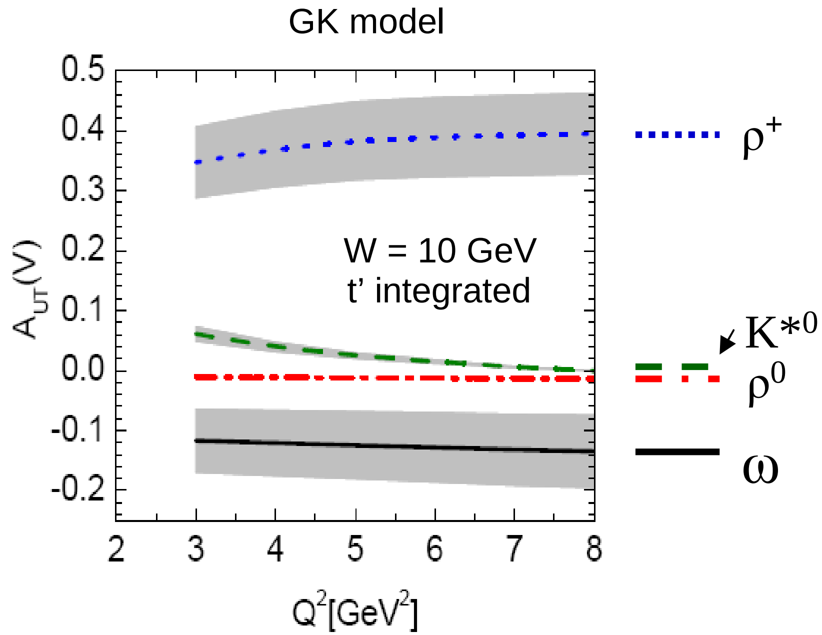
$\mu N^\uparrow \rightarrow \mu \rho^0 N$

without recoil detection, selection with exclusivity cuts
corrections for SIDIS backg.

• **COMPASS,** NP B865 (2012) — **GK model,** EPJ C59(2009)



$W = 8.1$ GeV$/c^2$, $p_T^2 = 0.2$ (GeV$/c)^2$, $Q^2 = 2.2$ (GeV$/c)^2$



$A_{UT}^{\sin(\phi-\phi_S)}$ contains twist-2 terms depending on $E^{q,g}$

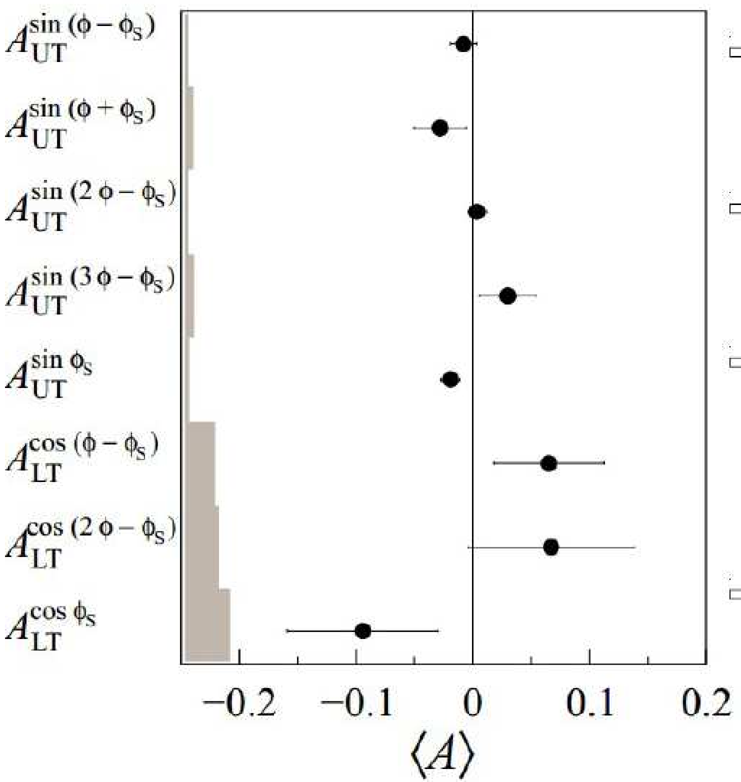
small values expected due to approximate cancellation of contributions from E^u and E^d, $E^u \approx -E^d$

$E^p_{\rho 0} \sim \frac{2}{3} E^u + \frac{1}{3} E^d + \frac{3}{8} E^g$ vs. $E^p_{\omega} \sim \frac{2}{3} E^u - \frac{1}{3} E^d + \frac{1}{8} E^g$ (cf. upper-right plot)

Azimuthal asymmetries for exlusive ρ^0 production on $p^\uparrow$

new

- **COMPASS,** PLB 731 (2014)   asymmetries published also as functions of x_{Bj}, Q^2 and p_T^2



$$\Rightarrow A_{UT}^{\sin(\varphi-\varphi_s)}\sigma_0 = -2\,Im[\epsilon \underbrace{M^*_{0-,0+}}_{\sim E} \underbrace{M_{0+,0+}}_{\sim H} + \underbrace{M^*_{+-,++}}_{\sim E} \underbrace{M_{++,++}}_{\sim H} + \frac{1}{2}\underbrace{M^*_{0-,++}}_{\sim H_T} \underbrace{M_{0+,++}}_{\sim \bar{E}_T}]$$

$$\Rightarrow A_{UT}^{\sin(2\varphi-\varphi_s)}\sigma_0 = -Im[\underbrace{M^*_{0+,++}}_{\sim \bar{E}_T} \underbrace{M_{0-,0+}}_{\sim E}]$$

$$\Rightarrow A_{UT}^{\sin(\varphi_s)}\sigma_0 = -Im[\underbrace{M^*_{0-,++}}_{\sim H_T} \underbrace{M_{0+,0+}}_{\sim H} - \underbrace{M^*_{0+,++}}_{\sim \bar{E}_T} \underbrace{M_{0-,0+}}_{\sim E}]$$

$$\Rightarrow A_{LT}^{\cos(\varphi_s)}\sigma_0 = -Re[\underbrace{M^*_{0-,++}}_{\sim H_T} \underbrace{M_{0+,0+}}_{\sim H} - \underbrace{M^*_{0+,++}}_{\sim \bar{E}_T} \underbrace{M_{0-,0+}}_{\sim E}]$$

M_{Vp',γ^*p} helicity amplitudes
σ_0 unpolarised cross section
$H_T(x, 0, 0) = h_1(x)$
$\bar{E}_T = 2\widetilde{H}_T - E_T$

- asymmetries small, compatible with 0, except

$$A_{UT}^{\sin\varphi_s} = -0.019 \pm 0.008 \pm 0.003$$

- indication of H_T, 'transversity' GPD, contribution
- larger effects for some asymmetries expected for exclusive ω production,   ongoing analysis

DVCS - azimuthal asymmetries from transversely polarized NH_3 target

$$\mathcal{D}_{CS,T} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow})$$
$$\propto Im(F_2\mathcal{H} - F_1\mathcal{E})\,\sin(\phi - \phi_S)\cos\phi + \ldots$$

$$\mathcal{A}^D_{CS,T} \equiv \mathcal{D}_{CS,T}/d\sigma_0$$

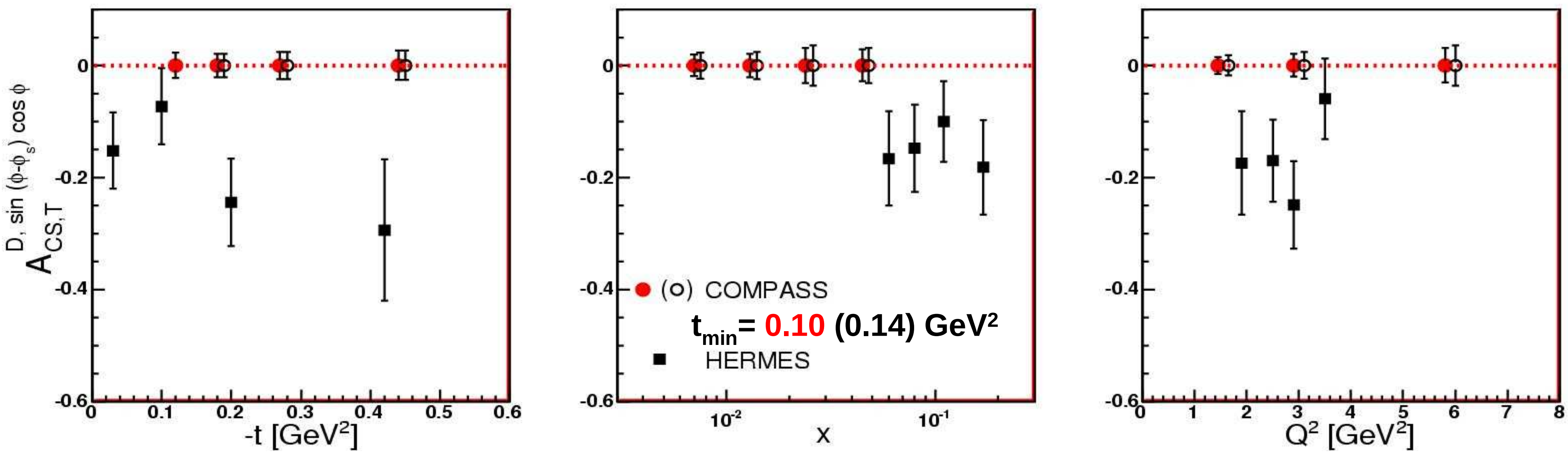
$d\sigma_0$ - unpolarised, charge averaged cross section

160 GeV muon beam
1.2m NH_3 target
$\varepsilon_{global} = 10\%$
with ECAL1+ ECAL2
40 weeks

for $\mu\, p^{\uparrow} \rightarrow \mu\, \gamma\, p$ from NH_3
dilution factor f=0.26

$0.10\ (0.14) < |t| < 0.64\ GeV^2$

COMPASS-II proposal



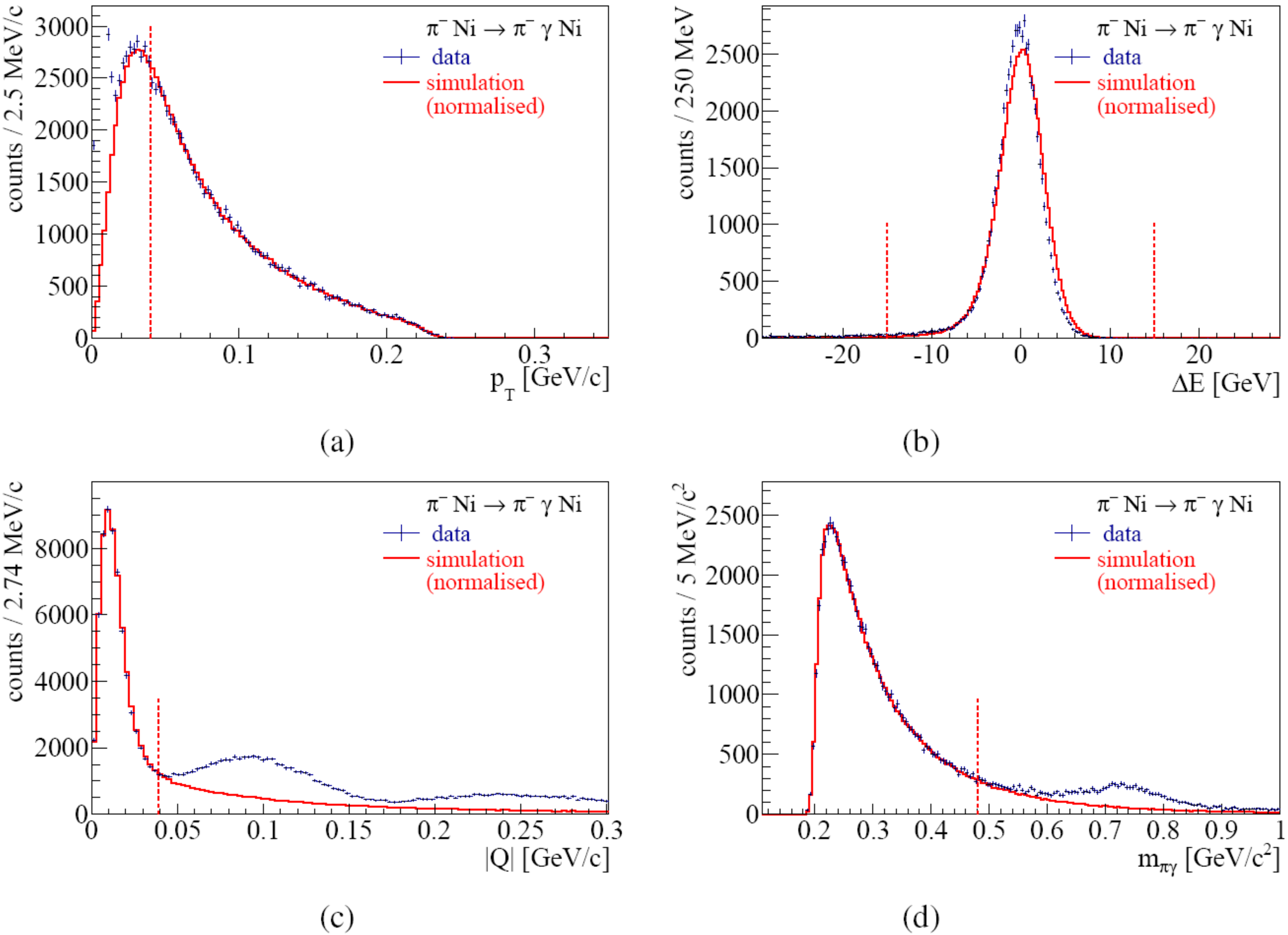
Summary and outlook for GPD program

- COMPASS has a great potential for GPD physics
  - ✓ unique polarised μ^+ and μ^- beams
  - ✓ favourable kinematic domain (x_{Bj})
- Large projects for new apparatus
  - ✓ 4m RPD + large angle ECAL0 (phase 1)
  - ✓ recoil proton detector incorporated into a large polarised target (phase 2)
- Investigation of GPDs with both DVCS and HEMP on unpolarised protons
  - ✓ t-slope of DVCS and HEMP cross section as a function of x_{Bj}
    → transverse distribution of partons
  - ✓ Beam Charge&Spin sum and difference of DVCS cross sections
    → $\mathcal{Re}\, T^{DVCS}$ and $\mathcal{Im}\, T^{DVCS}$ for the GPD H determination
  - ✓ Production of vector mesons ρ^0, ω, φ … → flavour separation for GPD H
  - ✓ Production of π^0 → sensitivity to GPDs $\tilde{E}$ and $\bar{E}_T$ ($\equiv 2\tilde{H}_T + E_T$)
- Transverse Target Spin Asymmetries for DVCS and hard exclusive meson production
  → GPD E and angular momentum of partons
  → also for mesons investigation of chiral-odd GPDs


Thank you !

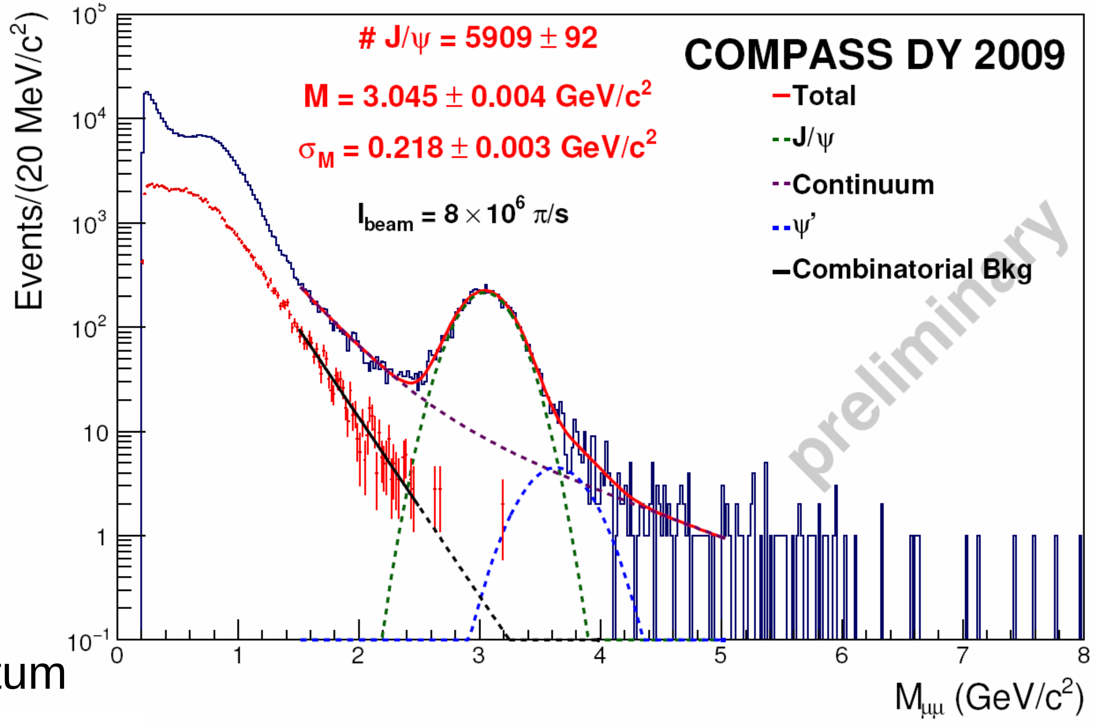
Backup

Selection of pion Compton scattering sample

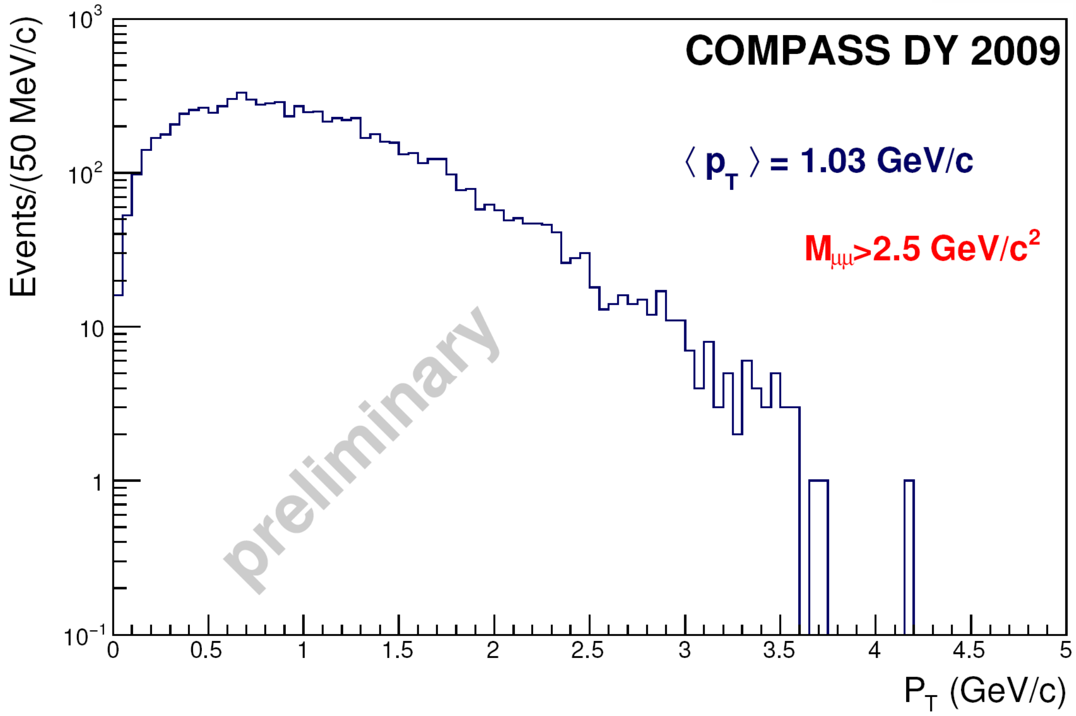


Results from 2009 DY test run

Combinatorial background



Distribution of dimuon transverse momentum



Exclusive ρ^0 production on $p^\uparrow$ and $d^\uparrow$ at COMPASS

$\mu\ N \rightarrow \mu\ \rho^0\ N$

i.e. incoherent process

Transversely polarised protons (target NH_3), 2007, 2010
Transversely polarised deuterons (target ^6LiD), 2003-2004

note: there was no RPD for these data

only two tracks of opposite charge associated to the primary vertex

DIS cuts

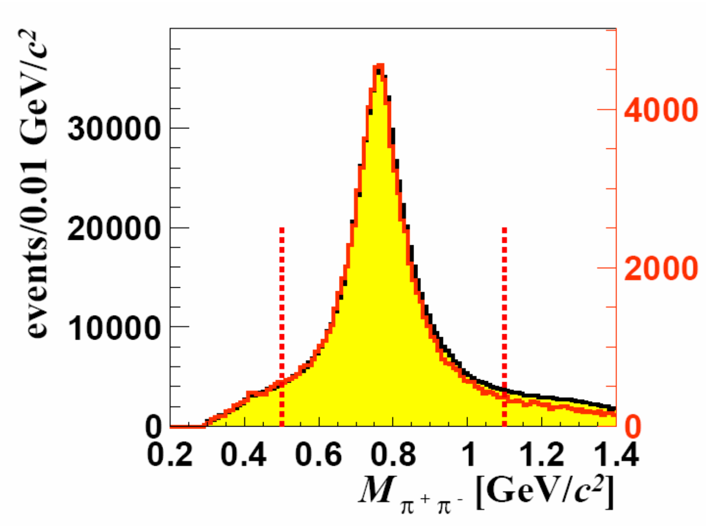
$1 < Q^2 < 10\ \text{GeV}^2$
$0.1 < y < 0.9$
$W > 5\ \text{GeV}$

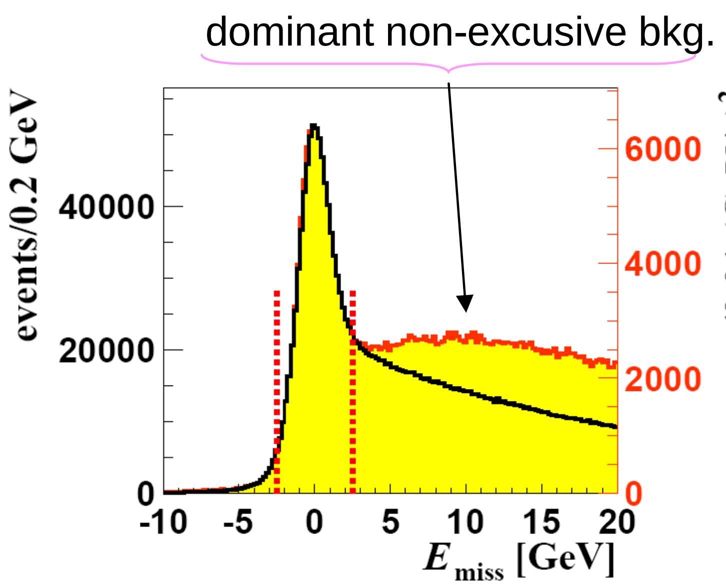
cuts specific for exclusive ρ^0 analysis

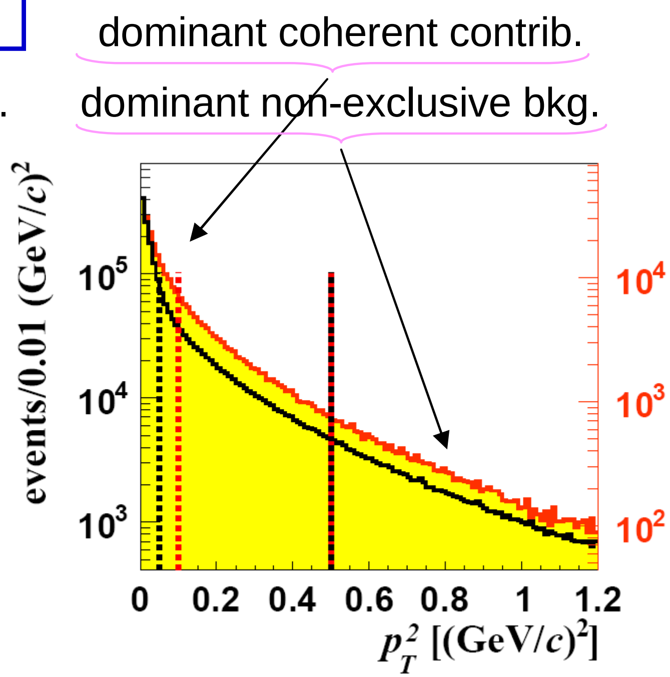
$0.5 < M_{\pi\pi} < 1.1\ \text{GeV}$
$-2.5 < E_{\text{miss}} < 2.5\ \text{GeV}$
$E_{\rho 0} > 15\ \text{GeV}$
$0.05 < p_T^2 < 0.5\ \text{GeV}^2$ [NH_3]
$0.1 < p_T^2 < 0.5\ \text{GeV}^2$ [^6LiD]

$E_{\text{miss}} = (M_X^2 - M_p^2)/(2M_p)$

proton data (797 000 evts)
deuteron data (97 000 evts)



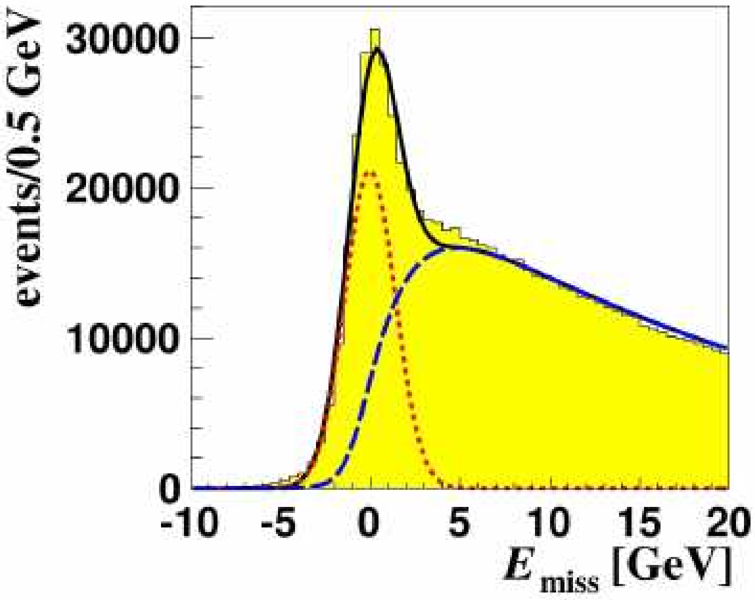




Extraction:
for each kinematic bin

All 8 asymmetries extracted together from a fit of the number of signal events in ϕ, ϕ_S bins for each of the target cell (U+D, C) and polarization state (+,-) → 4 input 2D matrices

Background rejection:
for each kinematic bin, target cell and polarization state



Background asymmetry probed in 7 GeV < E_{miss} < 20 GeV region

shape of semi-inclusive background from MC
(lepto with COMPASS tuning + simulation of spectrometer response + data reconstruction)

MC weighted using agreement between real data and MC for wrong charge combination sample (h^+h^+ + h^-h^-)

$$w(E_{miss}) = \frac{N_{MC}^{h+h+}(E_{miss}) + N_{MC}^{h-h-}(E_{miss})}{N_{RD}^{h+h+}(E_{miss}) + N_{RD}^{h-h-}(E_{miss})}$$

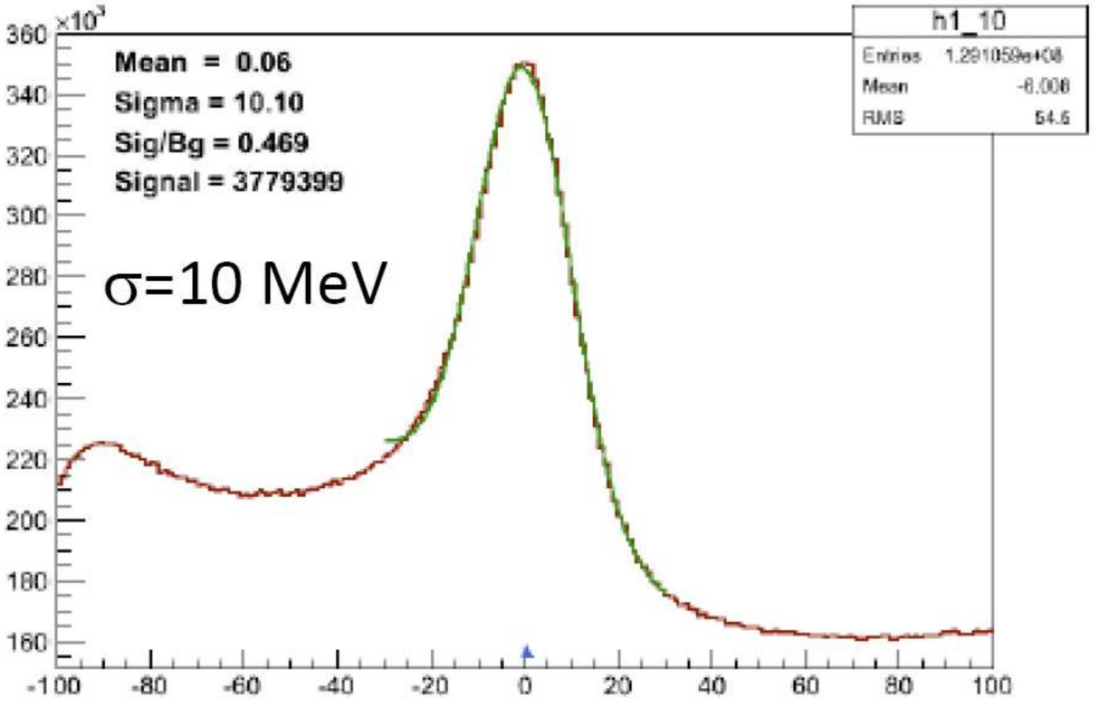
Normalization of MC to the real data using two component fit
Gaussian function (signal) + shape from MC (bkg)

ECAL0 in 2012 DVCS pilot run

56 modules (~1/4 of total) availale for 2012 run
(calibrated with beam on Oct 24, 2012)

Reduced setup in 2012 (1/4 of total)

Invariant $\gamma\gamma$ mass spectra for π^0 production using pion beam



GPD program of Stage 1 with complete ECAL0 is scheduled for 2016-2017