The GPD program at COMPASS

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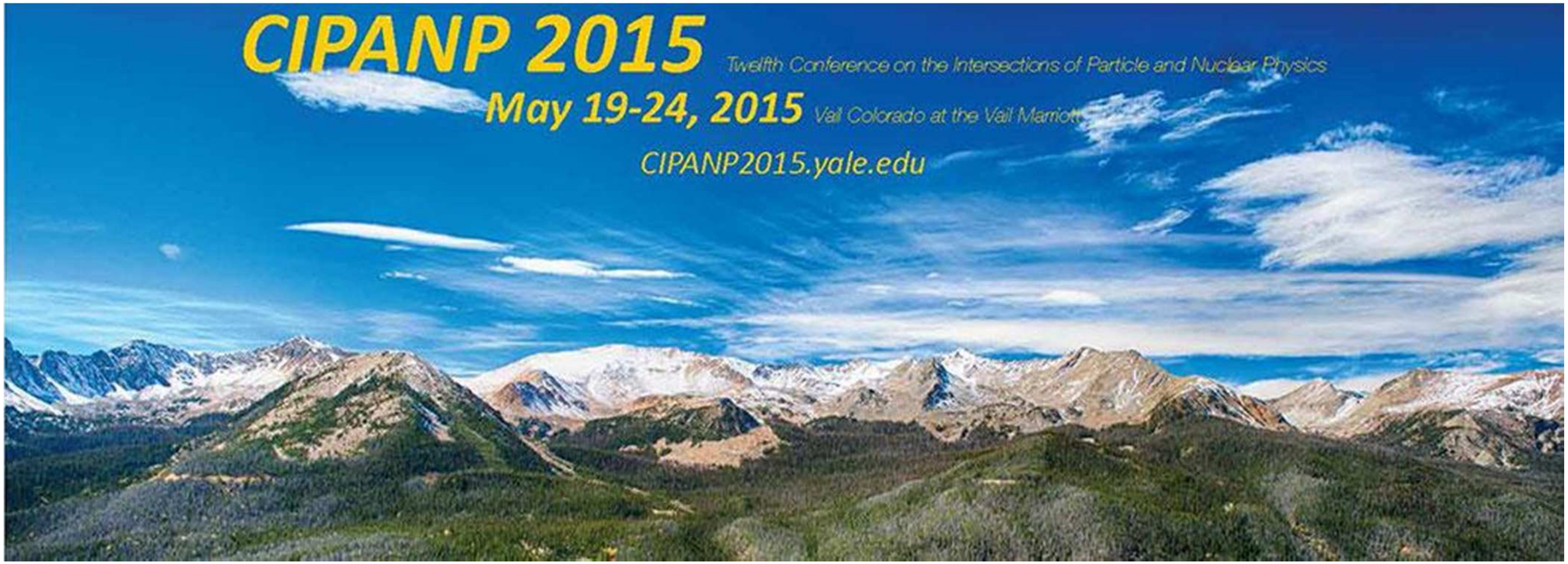


COMPASS GPD program activities

➢ Exclusive vector meson muoproduction from 2002-2010 data

discussed in this talk

with transversely polarised proton/deuteron targets (^{6}LiD, NH_3)

no recoil detector ➡ disadvantage for exclusive measurements

opportunity to get early results which are sensitive to GPDs E and chiral odd GPDs

➢ 'DVCS test' runs in 2008 (1.5 day) and 2009 (10 days)

40 cm LH_2 target and small RPD (used for hadron spectroscopy program)

analyses of the 'DVCS test' data demonstrated feasibility to measure

exclusive γ (DVCS and BH) and exclusive π^0 production at COMPASS

➢ GPD program of COMPASS-II (since 2012)

discussed in this talk

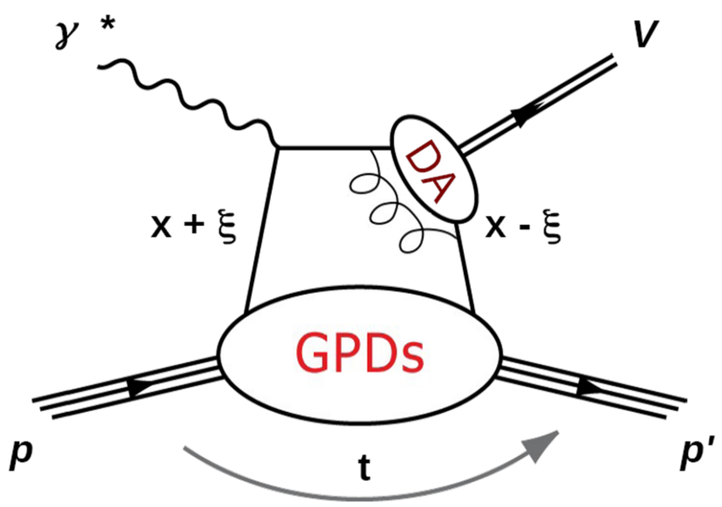
a part of approved new COMPASS proposal

DVCS and HEMP with polarised μ+ and μ- beams at 160 GeV and

unpolarised and transversely polarised proton targets (LH_2 , NH_3)

with large recoil proton detector and large angular coverage by EM calorimetry

GPDs and Hard Exclusive Meson Production



- factorisation proven only for σ_L
  σ_T suppressed by $1/Q^2$
- wave function of meson (DA)
  additional non-perturbative term
- at $Q^2 \approx$ few GeV² higher order pQCD terms important

Chiral-even GPDs
helicity of parton unchanged

$$H^{q,g}(x,\xi,t) \qquad E^{q,g}(x,\xi,t)$$
$$\tilde{H}^{q,g}(x,\xi,t) \qquad \tilde{E}^{q,g}(x,\xi,t)$$

Chiral-odd GPDs
helicity of parton changed (not probed by DVCS)

$$H_T^q(x,\xi,t) \qquad E_T^q(x,\xi,t)$$
$$\tilde{H}_T^q(x,\xi,t) \qquad \tilde{E}_T^q(x,\xi,t)$$

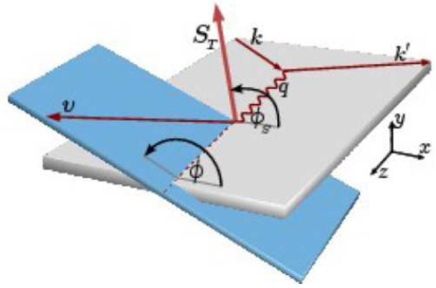
Flavour separation for GPDs
example:

$$E_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u + \frac{1}{3}E^d + \frac{3}{8}E^g\right)$$
$$E_{\omega} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u - \frac{1}{3}E^d + \frac{1}{8}E^g\right)$$
$$E_{\varphi} = -\frac{1}{3}E^s - \frac{1}{8}E^g$$

- *contribution from gluons at the same order of α_s as from quarks*

Spin-dependent cross section for exclusive meson leptoproduction

$$\left[\frac{\alpha_{em}}{8\pi^3}\frac{y^2}{1-\epsilon}\frac{1-x_{Bj}}{x_{Bj}}\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_{Bj}dQ^2dtd\phi d\phi_s}$$



$$= \underbrace{\frac{1}{2}\left(\sigma_{++}^{++}+\sigma_{++}^{--}\right)+\varepsilon\sigma_{00}^{++}} - \varepsilon\cos(2\phi)\,\mathrm{Re}\,\sigma_{+-}^{++} - \sqrt{\varepsilon(1+\varepsilon)}\,\cos\phi\,\mathrm{Re}\,(\sigma_{+0}^{++}+\sigma_{+0}^{--})$$

$$-P_\ell\sqrt{\varepsilon(1-\varepsilon)}\,\sin\phi\,\mathrm{Im}\,(\sigma_{+0}^{++}+\sigma_{+0}^{--})$$

$$-S_L\left[\varepsilon\sin(2\phi)\,\mathrm{Im}\,\sigma_{+-}^{++}+\sqrt{\varepsilon(1+\varepsilon)}\,\sin\phi\,\mathrm{Im}\,(\sigma_{+0}^{++}-\sigma_{+0}^{--})\right]$$

$$+S_L P_\ell\left[\sqrt{1-\varepsilon^2}\,\frac{1}{2}\left(\sigma_{++}^{++}-\sigma_{++}^{--}\right)-\sqrt{\varepsilon(1-\varepsilon)}\,\cos\phi\,\mathrm{Re}\,(\sigma_{+0}^{++}-\sigma_{+0}^{--})\right]$$

$$-S_T\left[\sin(\phi-\phi_S)\,\mathrm{Im}\,(\sigma_{++}^{+-}+\varepsilon\sigma_{00}^{+-})+\frac{\varepsilon}{2}\sin(\phi+\phi_S)\,\mathrm{Im}\,\sigma_{+-}^{+-}+\frac{\varepsilon}{2}\sin(3\phi-\phi_S)\,\mathrm{Im}\,\sigma_{+-}^{-+}\right.$$

$$\left.+\sqrt{\varepsilon(1+\varepsilon)}\,\sin\phi_S\,\mathrm{Im}\,\sigma_{+0}^{+-}+\sqrt{\varepsilon(1+\varepsilon)}\,\sin(2\phi-\phi_S)\,\mathrm{Im}\,\sigma_{+0}^{-+}\right]$$

$$+S_T P_\ell\left[\sqrt{1-\varepsilon^2}\,\cos(\phi-\phi_S)\,\mathrm{Re}\,\sigma_{++}^{+-}\right.$$

$$\left.-\sqrt{\varepsilon(1-\varepsilon)}\,\cos\phi_S\,\mathrm{Re}\,\sigma_{+0}^{+-}-\sqrt{\varepsilon(1-\varepsilon)}\,\cos(2\phi-\phi_S)\,\mathrm{Re}\,\sigma_{+0}^{-+}\right].$$

σ_{mn}^{ij}: helicity-dependent photoabsorption cross sections and interference terms

$$\sigma_{mn}^{ij}\left(x_B, Q^2, t\right) \propto \sum \left(M_m^i\right)^* M_n^j$$

M_m^i: amplitude for subprocess $\gamma^* p \rightarrow V\ p'$ with photon helicity *m* and target proton helicity *i*

$$\epsilon = \frac{1-y-\frac{1}{4}y^2\gamma^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2}$$

$$\gamma = 2x_{Bj}M_p/Q$$

Azimuthal asymmetries of cross section for exclusive meson leptoproduction

5 single spin asymmetries

$$A_{UT}^{\sin(\varphi-\varphi_s)} = -\frac{\mathrm{Im}\left(\sigma_{++}^{+-} + \epsilon\,\sigma_{00}^{+-}\right)}{\sigma_0}$$

$$A_{UT}^{\sin(\varphi+\varphi_s)} = -\frac{\mathrm{Im}\,\sigma_{+-}^{+-}}{\sigma_0}$$

$$A_{UT}^{\sin(2\varphi-\varphi_s)} = -\frac{\mathrm{Im}\,\sigma_{+0}^{-+}}{\sigma_0}$$

$$A_{UT}^{\sin(3\varphi-\varphi_s)} = -\frac{\mathrm{Im}\,\sigma_{+-}^{-+}}{\sigma_0}$$

$$A_{UT}^{\sin\varphi_s} = -\frac{\mathrm{Im}\,\sigma_{+0}^{+-}}{\sigma_0}$$

3 double spin asymmetries

$$A_{LT}^{\cos(\varphi-\varphi_s)} = \frac{\mathrm{Re}\,\sigma_{++}^{+-}}{\sigma_0}$$

$$A_{LT}^{\cos(2\varphi-\varphi_s)} = -\frac{\mathrm{Re}\,\sigma_{+0}^{-+}}{\sigma_0}$$

$$A_{LT}^{\cos\varphi_s} = -\frac{\mathrm{Re}\,\sigma_{+0}^{+-}}{\sigma_0}$$

σ_0 - ‘unpolarised cross section’

$$\sigma_0 = \frac{1}{2}\left(\sigma_{++}^{++} + \sigma_{++}^{--}\right) + \epsilon\,\sigma_{00}^{++} = \sigma_L + \epsilon\,\sigma_T$$

COMPASS setup

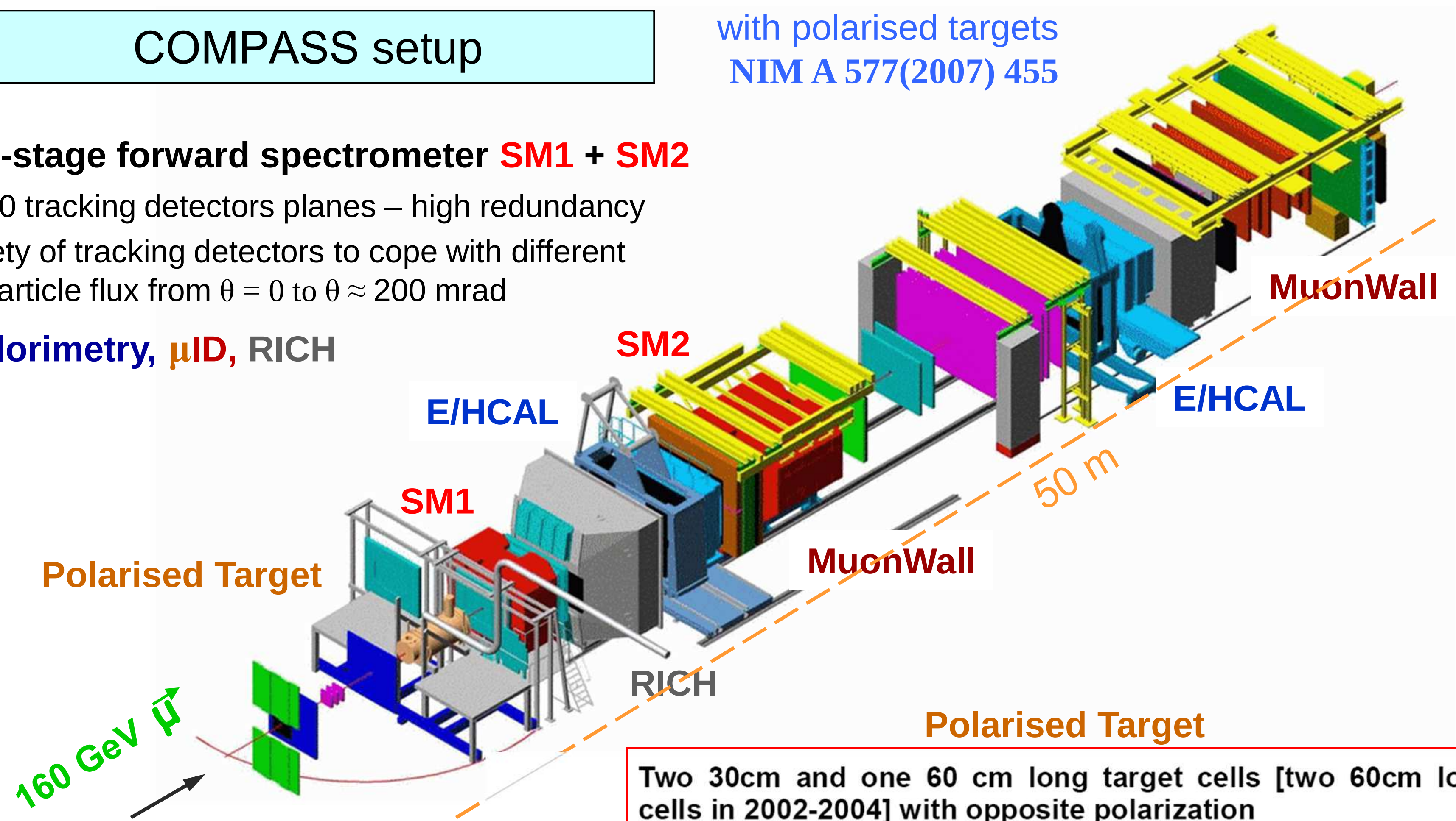
with polarised targets
NIM A 577(2007) 455

two-stage forward spectrometer SM1 + SM2

≈ 300 tracking detectors planes – high redundancy

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

+ calorimetry, µID, RICH



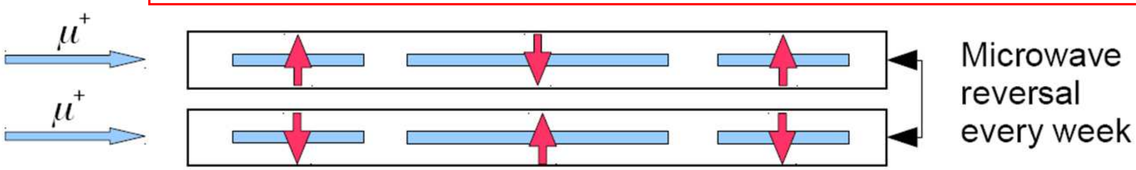
μ^+ beam from SPS
beam polarisation ≈ - 80%

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

Polarised Target

Two 30cm and one 60 cm long target cells [two 60cm long cells in 2002-2004] with opposite polarization

material:	NH_3 (protons)	[^{6}LiD (deuterons)]
polarization:	≈90%	[≈50%]
dilution factor for exclusive ρ^0 production:	≈25%	[≈44%]



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

$\mu N \to \mu \rho^0 N$

i.e. incoherent process

Transversely polarised proton target (NH_3), 2007, 2010
Transversely polarised deuteron target (^6LiD), 2003-2004

note: there was no RPD for these data

only two hadron tracks of opposite charge associated to the primary vertex

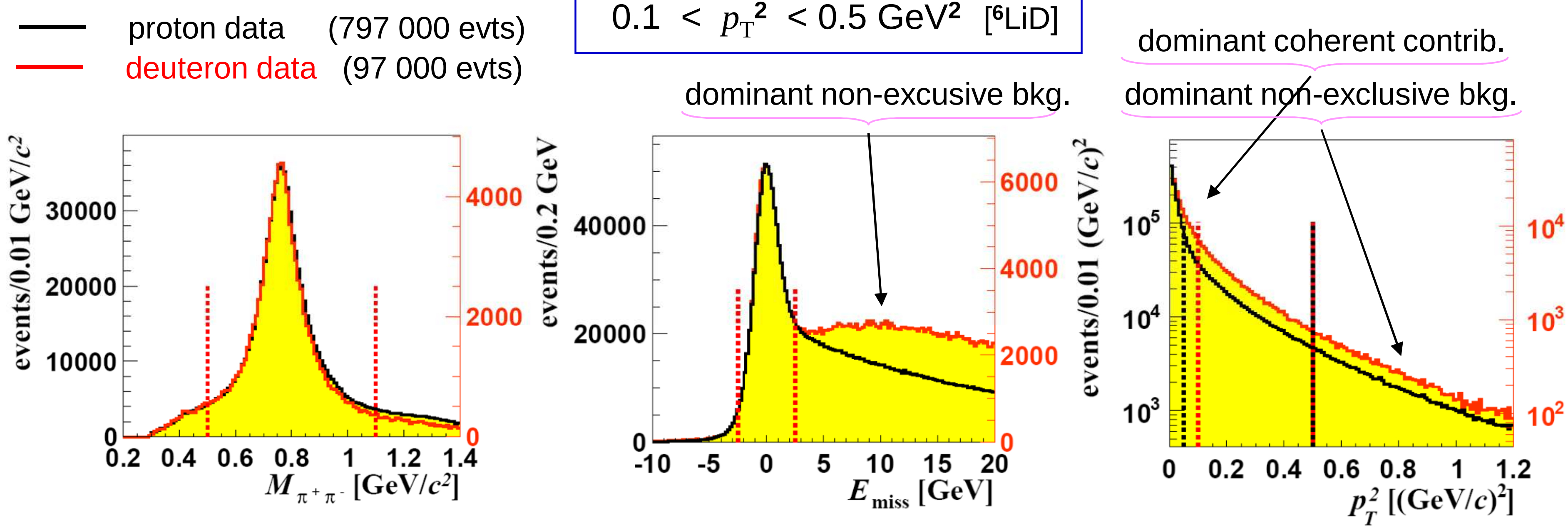
DIS cuts

$1 < Q^2 < 10$ GeV^2
$0.1 < y < 0.9$
$0.003 < x < 0.35$
$W > 5$ GeV

cuts specific for exclusive ρ^0 analysis

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

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



Exclusive ω production on $p^{\uparrow}$ at COMPASS

$\mu N \rightarrow \mu \omega N$

$\hookrightarrow \pi^+ \pi^- \pi^0$

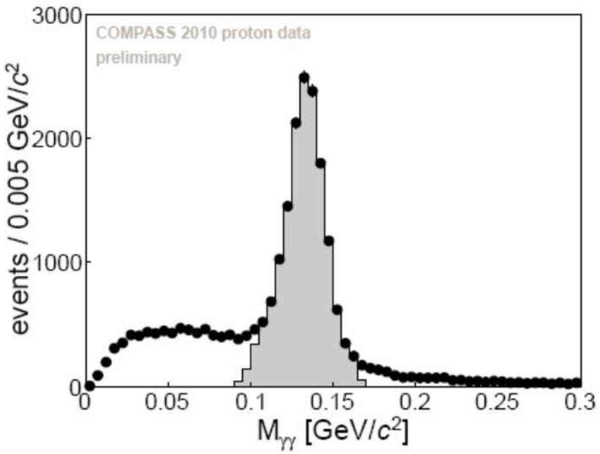
$\hookrightarrow \gamma + \gamma$

Transversely polarised proton target (NH_3), 2010 data

note: there was no RPD for these data

only two hadron tracks of opposite charge associated to the primary vertex

only two ECAL clusters time-correlated with beam and not associated to a charged particle



After selections and cuts ≈ 19 000 evts

$|M_{\pi\pi\pi} - M_{\omega}^{PDG}| < 0.07$ GeV

$-3 < E_{miss} < 3$ GeV

$E_{\omega} > 14$ GeV

$0.05 < p_T^2 < 0.5$ GeV²

$1 < Q^2 < 10$ GeV²

$0.1 < y < 0.9$

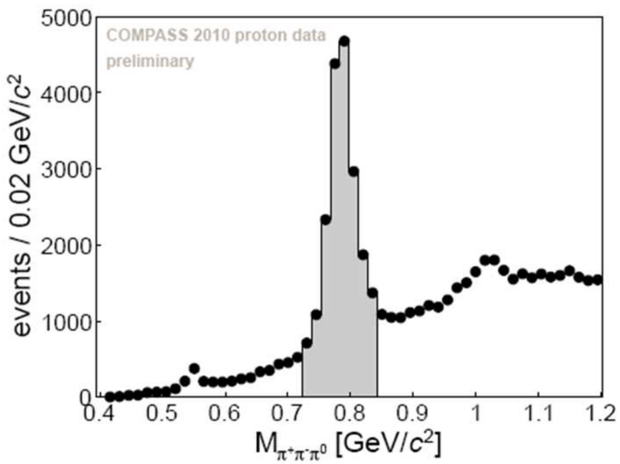
$0.003 < x < 0.35$

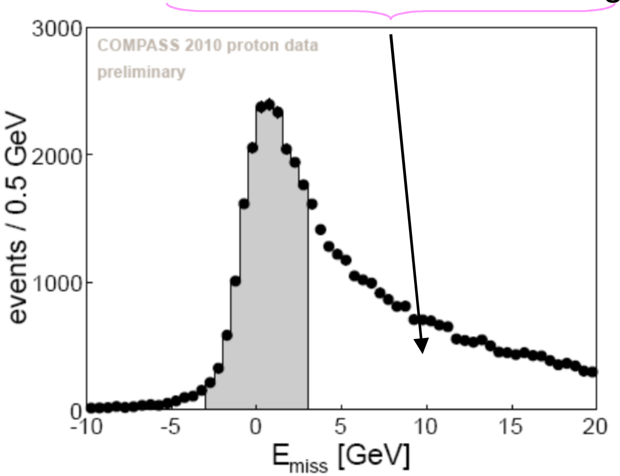
$W > 5$ GeV

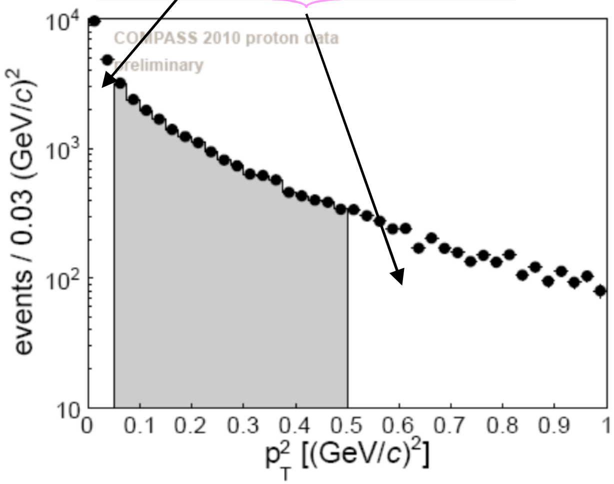
dominant coherent contrib.

dominant non-excusive bkg.

dominant non-exclusive bkg.



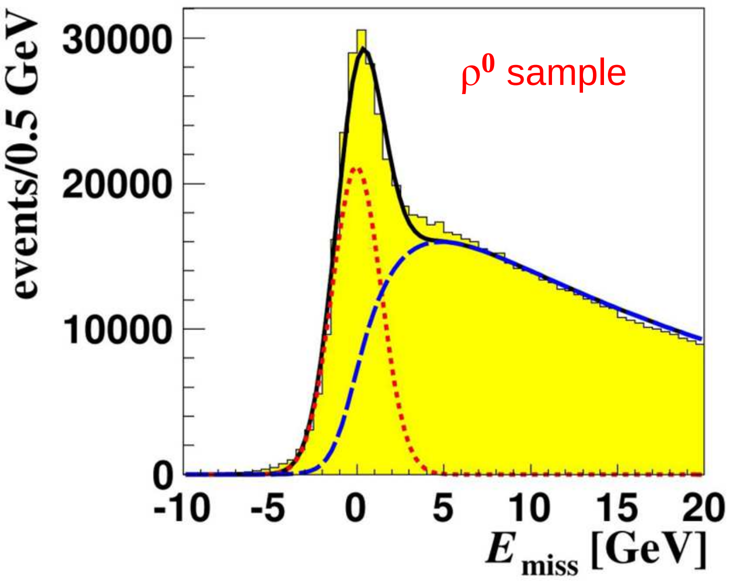




Extraction of asymmetries and subtraction on non-exclusive background

- ρ^0 analysis
  - 1D (deuteron) and 2D (proton) binned maximum likelihood estimator with subtraction of background in (φ, φ_S) bins
- ω analysis
  - Unbinned maximum likelihood estimator with simultaneous fit of signal and background asymmetries

Background rejection:
For each target cell and polarization state



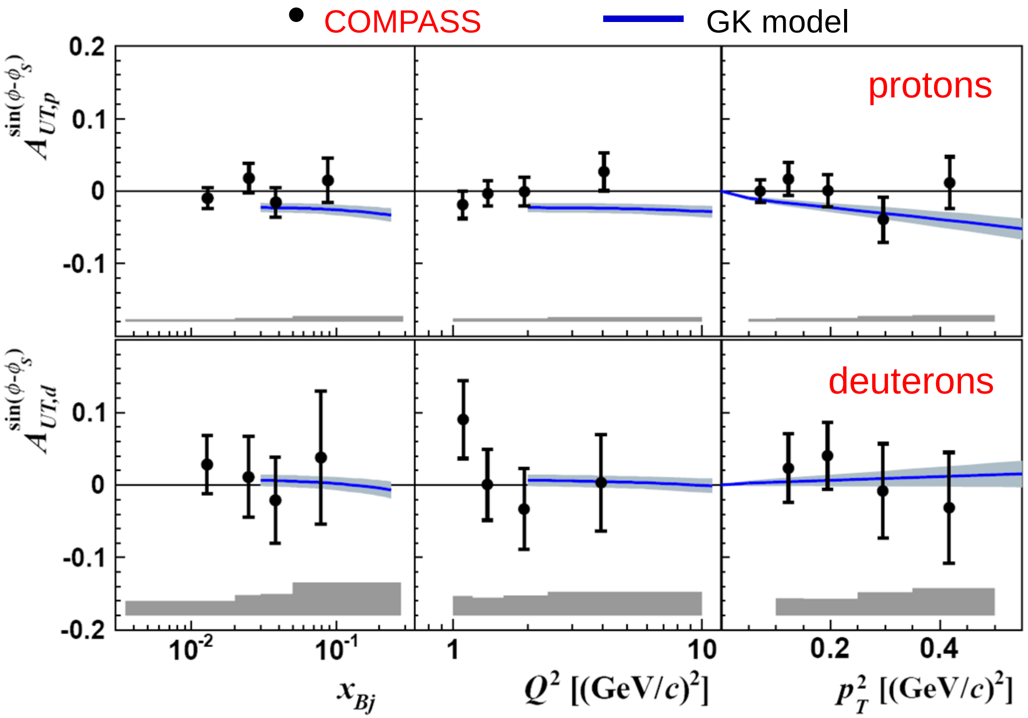
shape of semi-inclusive background from MC
(LEPTO with COMPASS tuning + simulation of spectrometer response + reconstruction as for real data)

MC weighted using ratio between real data and MC for wrong charge combination sample ($h^+h^+\gamma\gamma$ + $h^-h^-\gamma\gamma$)

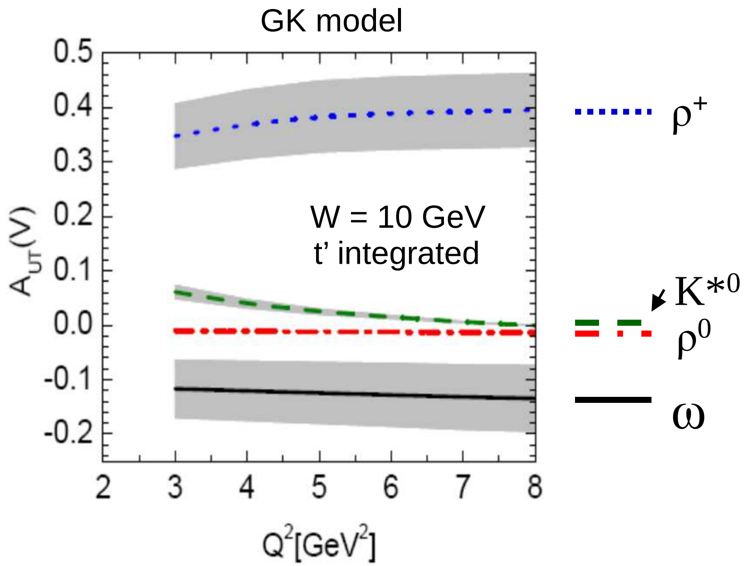
$$w(E_{miss}) = \frac{N_{RD}^{h+h+\gamma\gamma}(E_{miss}) + N_{RD}^{h-h-\gamma\gamma}(E_{miss})}{N_{MC}^{h+h+\gamma\gamma}(E_{miss}) + N_{MC}^{h-h-\gamma\gamma}(E_{miss})}$$

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

Results on $A_{UT}^{\sin(\phi-\phi_s)}$ for exlusive ρ^0 production → **NPB 865 (2012) 1**



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



- $A_{UT}^{\sin(\phi-\phi s)}$ for transversely polarised protons and deuterons small, compatible with 0
- for the proton agreement with HERMES results
  COMPASS results with statistical errors improved by factor 3 and extended kinematic range
- for the deuteron the first measurement
- reasonable agreement with predictions of the GPD model of Goloskokov - Kroll
  [EPJ C59 (2009) 809]

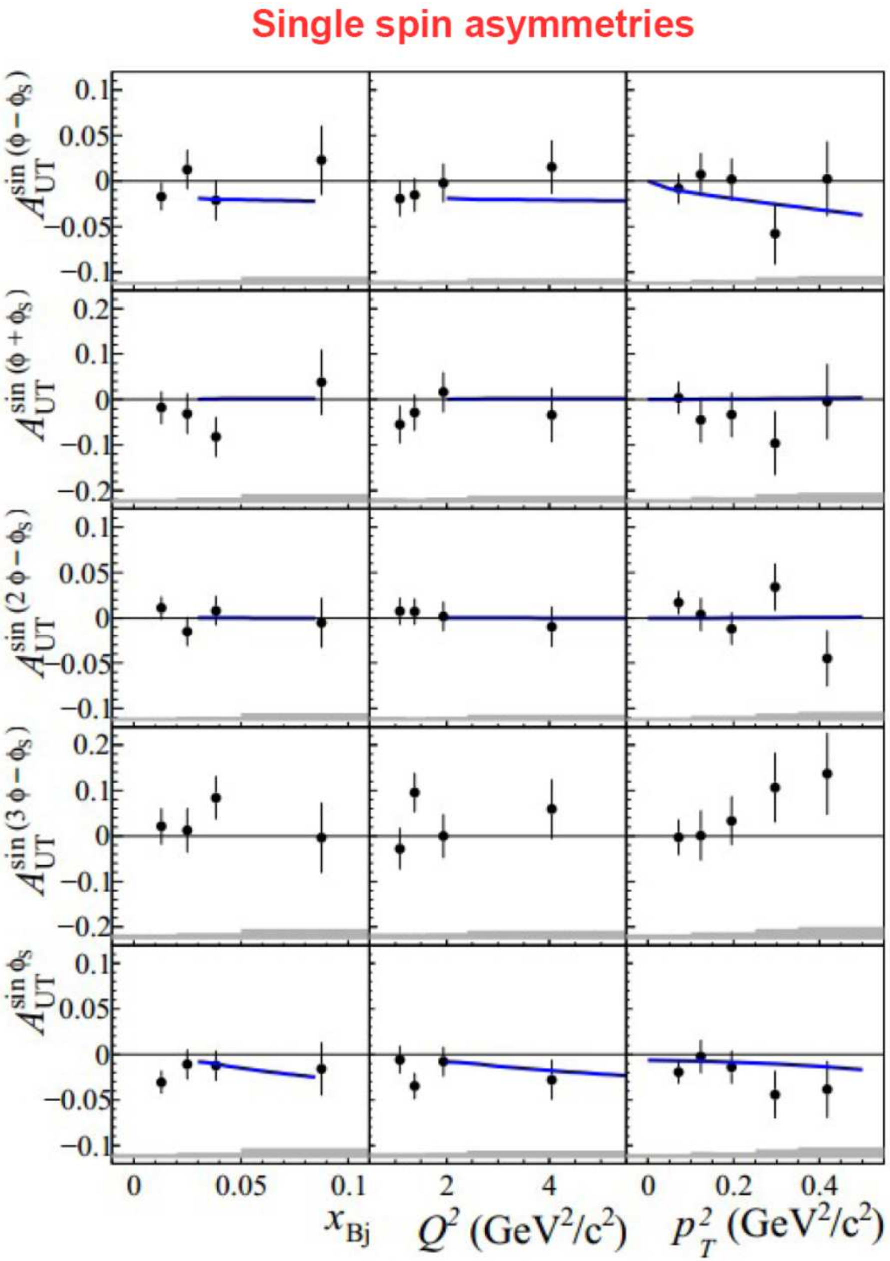
small values expected due to approximate cancellation of contributions from E^u and E^d, $E^u \approx -E^d$

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

Complete set of transverse target spin asymmetries for exlusive ρ^0 production

- Improved method of extraction (2D)
- Simultaneous extraction of
  5 single spin asymmetries and
  3 double spin asymmetries
  for transversely polarised protons

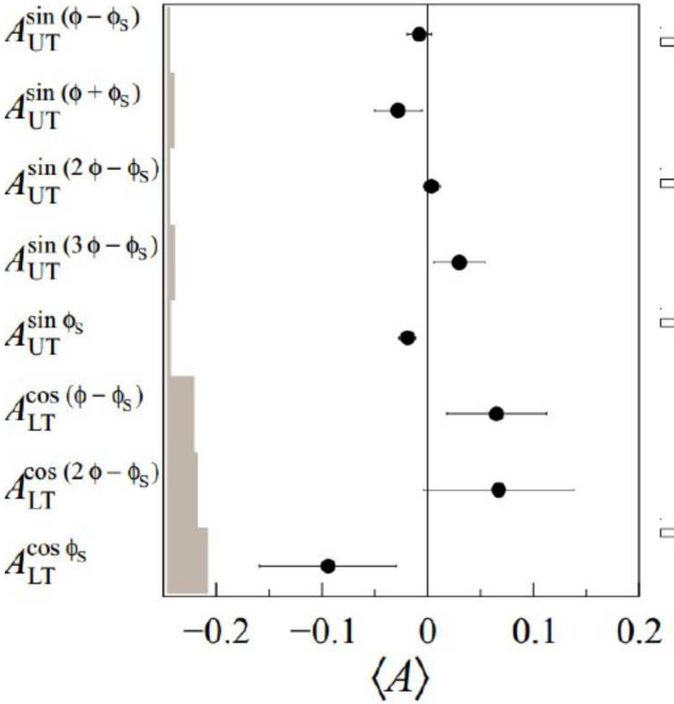
→ **PLB 731 (2014) 19**



—— predictions of GPD model of Goloskokov-Kroll

- reasonable agreement with GK model
  (also for double spin asym.)

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



~E ~H ~E ~H ~H_T ~$\bar{E}_T$

$$A_{UT}^{\sin(\varphi-\varphi_s)}\sigma_0 = -2\,Im[\epsilon M^*_{0-,0+} M_{0+,0+} + M^*_{+-,++} M_{++,++} + \frac{1}{2} M^*_{0-,++} M_{0+,++}]$$

~$\bar{E}_T$ ~E

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

~H_T ~H ~$\bar{E}_T$ ~E

$$A_{UT}^{\sin(\varphi_s)}\sigma_0 = -Im[M^*_{0-,++} M_{0+,0+} - M^*_{0+,++} M_{0-,0+}]$$

~H_T ~H ~$\bar{E}_T$ ~E

$$A_{LT}^{\cos(\varphi_s)}\sigma_0 = -Re[M^*_{0-,++} M_{0+,0+} - M^*_{0+,++} M_{0-,0+}]$$

‹ x_{Bj} › = 0.039, ‹ Q^2 › = 2.0 GeV^2
‹ p_T^2 › = 0.18 GeV^2, ‹ W › = 8.1 GeV^2

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

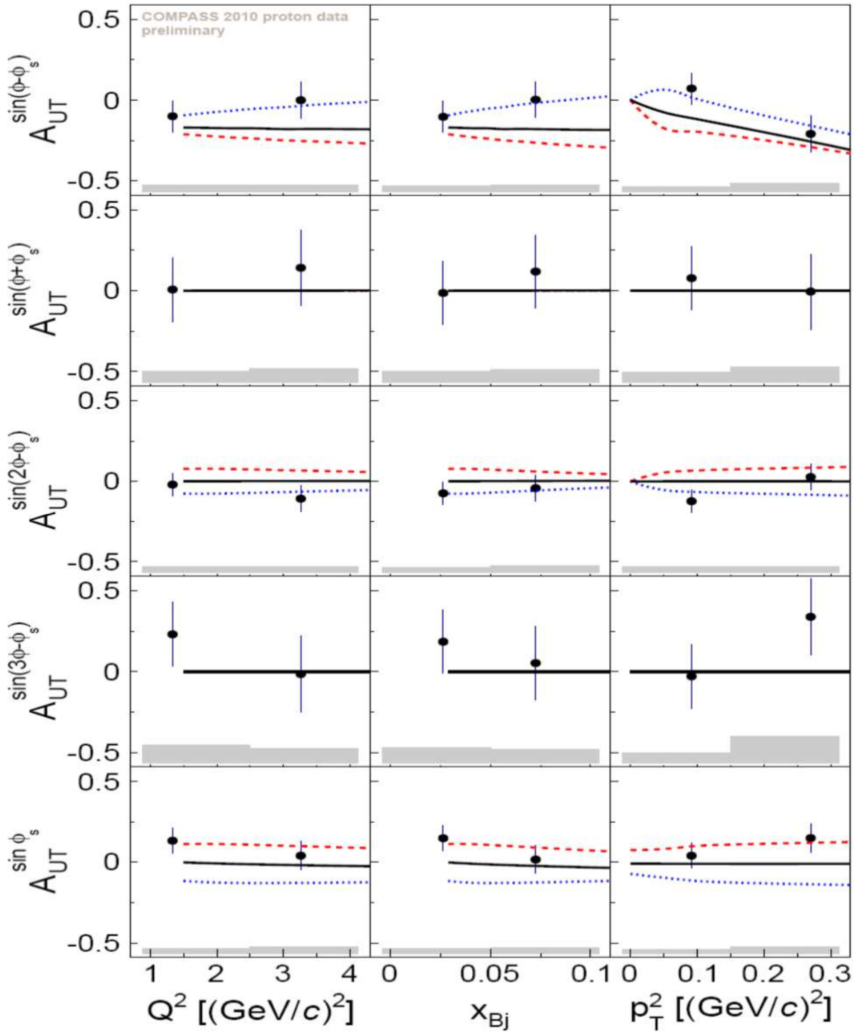
- asymmetries small, compatible with 0, except

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

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

Azimuthal asymmetries for exlusive ω production on $p^{\uparrow}$

Single spin asymmetries

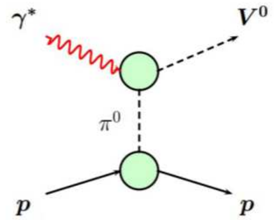


$\langle x_{Bj} \rangle = 0.049$, $\langle Q^2 \rangle = 2.2$ GeV²
$\langle p_T^2 \rangle = 0.17$ GeV², $\langle W \rangle = 7.1$ GeV²

- new result, to be published
- unbinned maximum likelihood method
- extraction of 8 transverse spin asymmetries

comparison to modified GPD model of GK

with added π^0 pole exchange



EPJA 50 (2014) 9, 146

parameters constrained by HERMES SDMEs for ω
except sign of $\pi\omega$ form factor
more sensitivity in azimuthal asymmetries

GK predictions for COMPASS, private com.
- no pion pole
- positive $\pi\omega$ form factor
- negative $\pi\omega$ form factor

- no clear conclusion from the comparison at the moment

COMPASS-II time lines

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

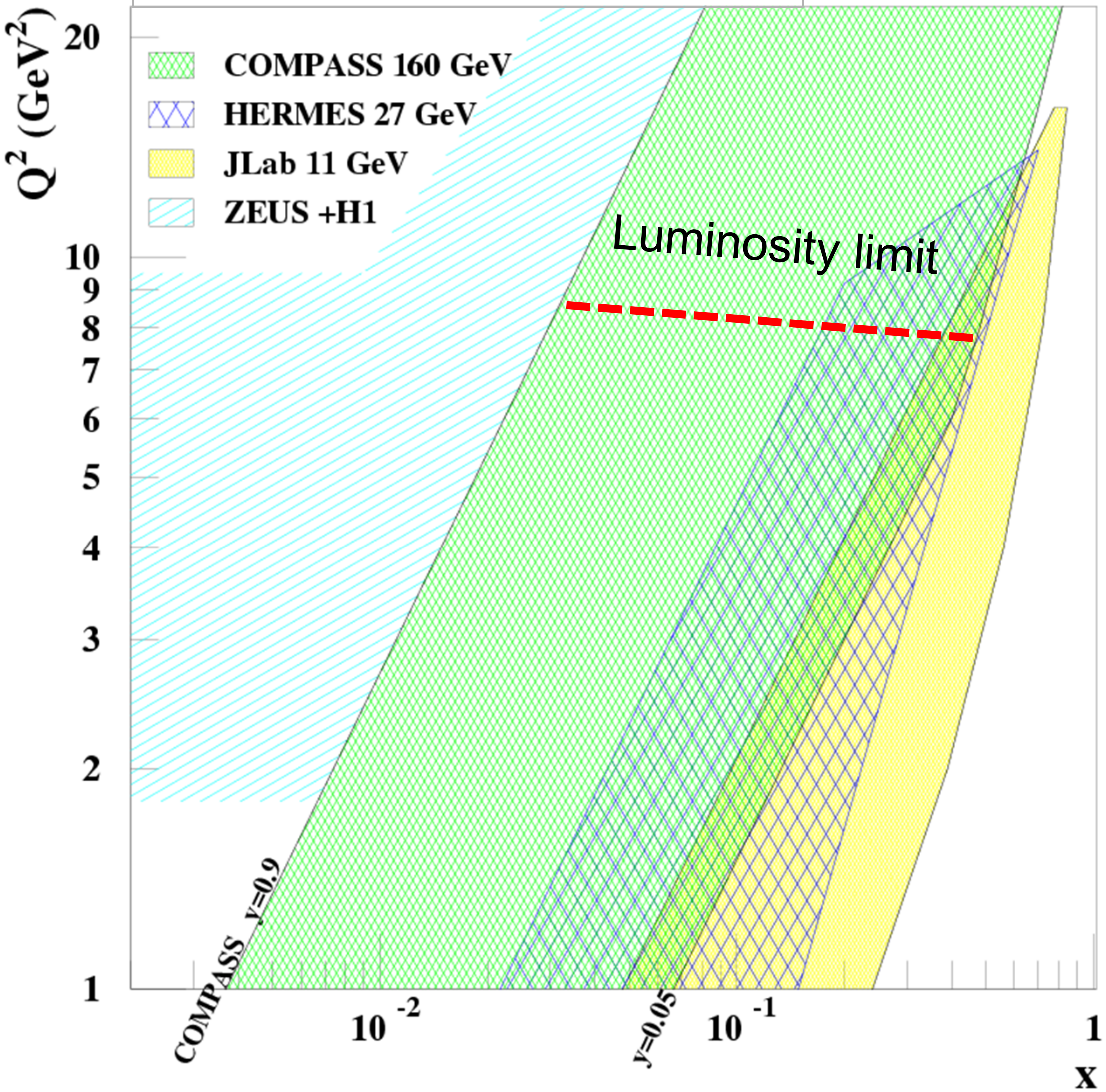
- 2012: pion and kaon polarisabilities (Primakoff) + comissioning and pilot run for DVCS
- 2013-2014: long SPS/LHC shutdown
- 2014-2015: Drell-Yann measurements with transversely polarised protons (NH_3 target)
- 2016-2017: stage 1 of GPD program and in parallel SIDIS (LH target)

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)

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
  - $3.9 \cdot 10^8$ μ^+ /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

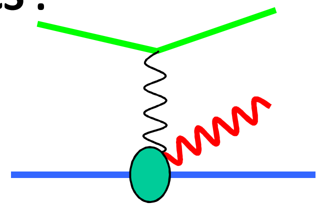
$Q^2 \rightarrow$ 8 GeV^2

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

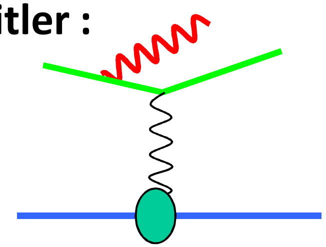
$x \rightarrow$ 0.27 with extension of present calorimetry

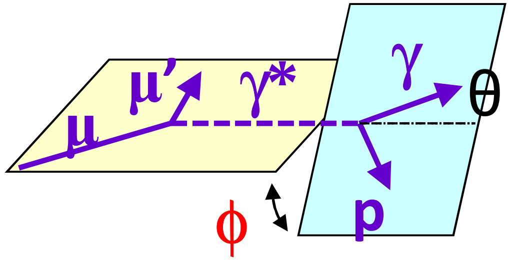
Interplay of DVCS and BH at 160 GeV

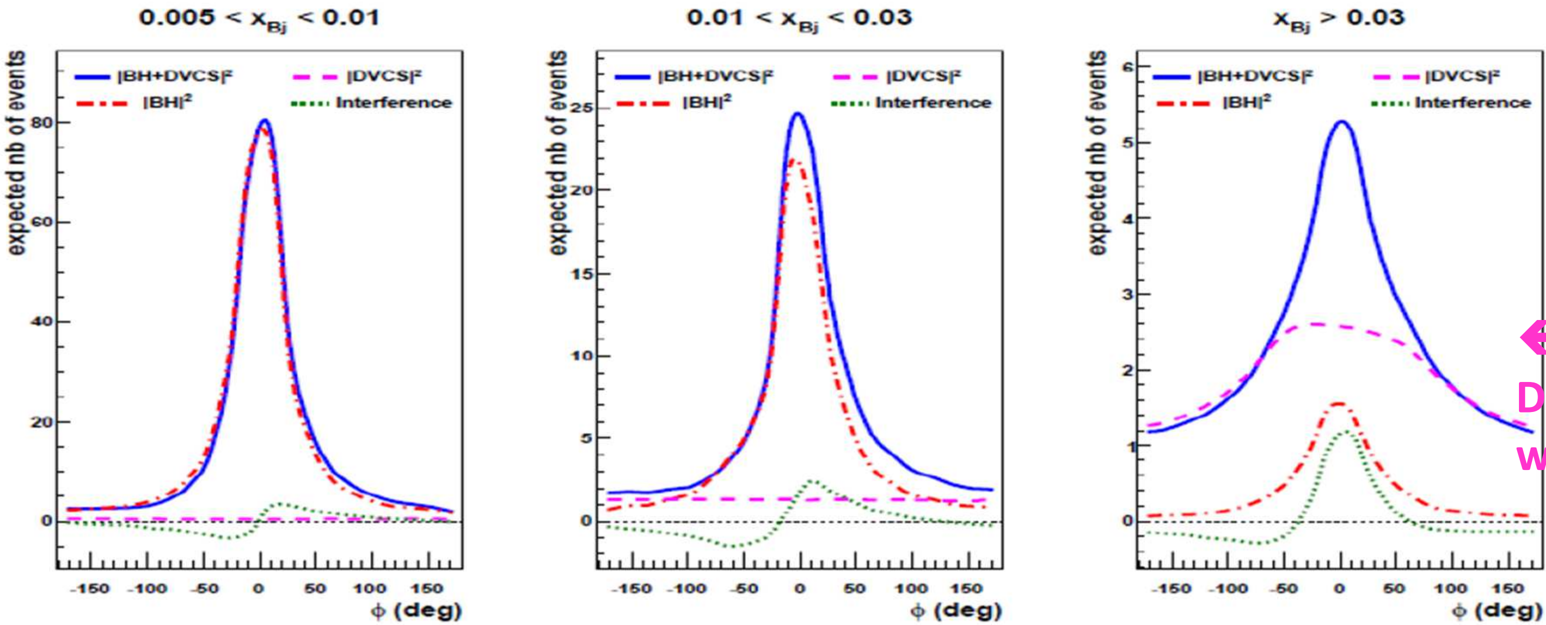
DVCS :



Bethe-Heitler :





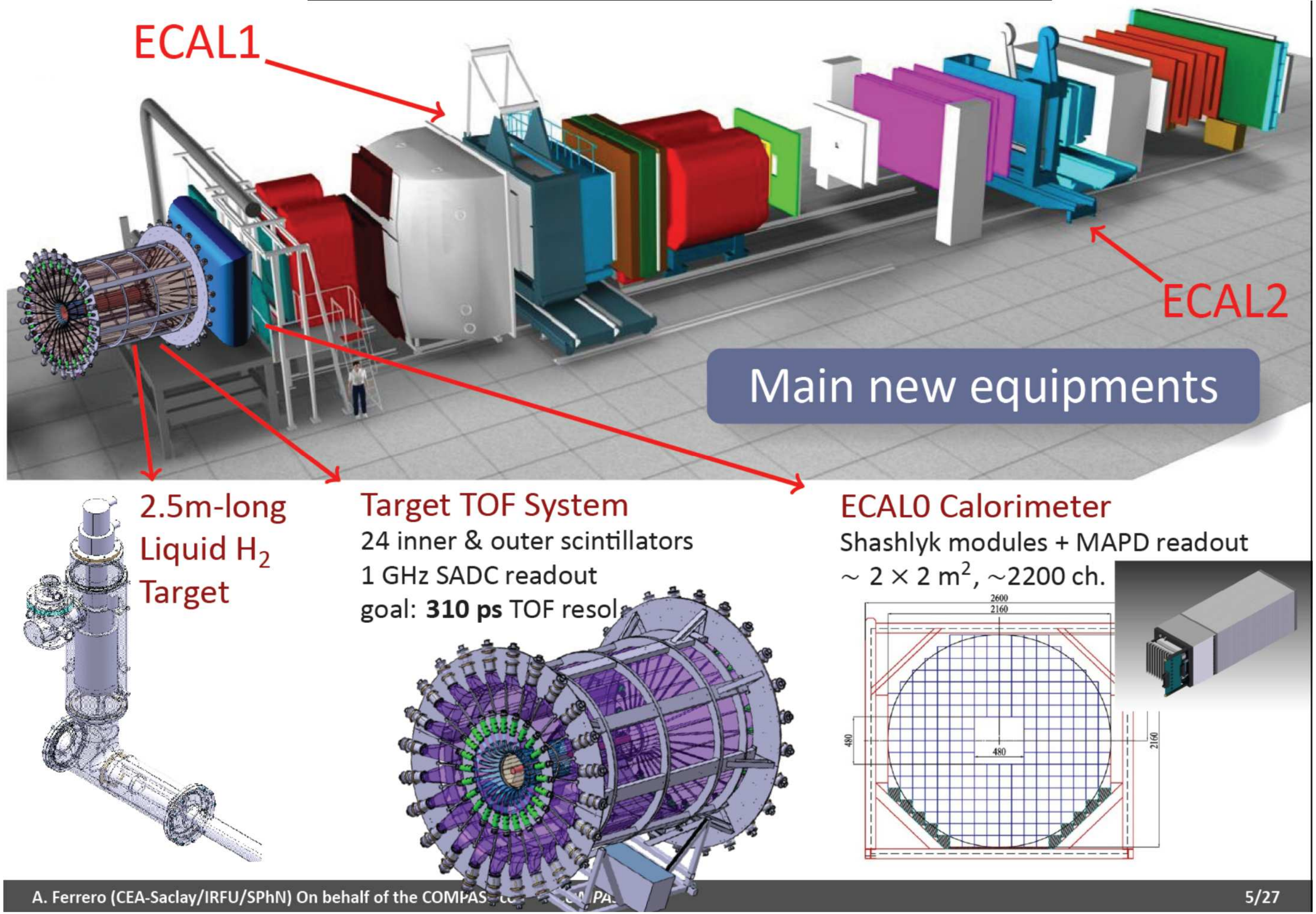


Monte-Carlo Simulation for COMPASS set-up with only ECAL1+2

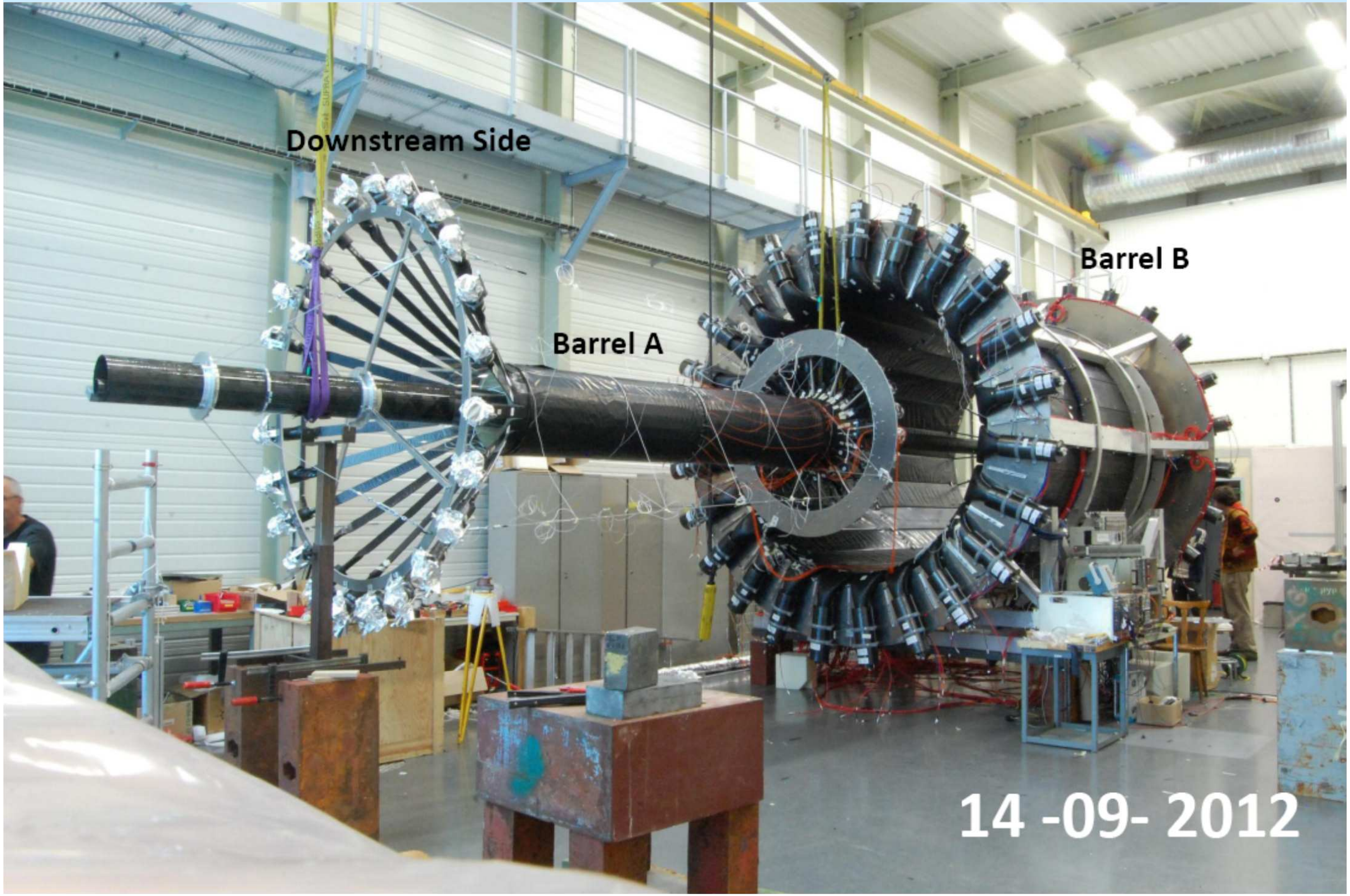
← non-uniform DVCS acceptance without ECAL0

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

The COMPASS set-up for the GPD program



Mounting of CAMERA in clean area at CERN



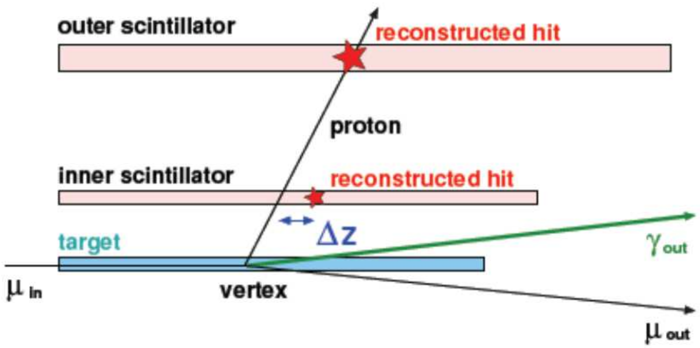
Selection of single photon events

reconstructed vertex in the target volume

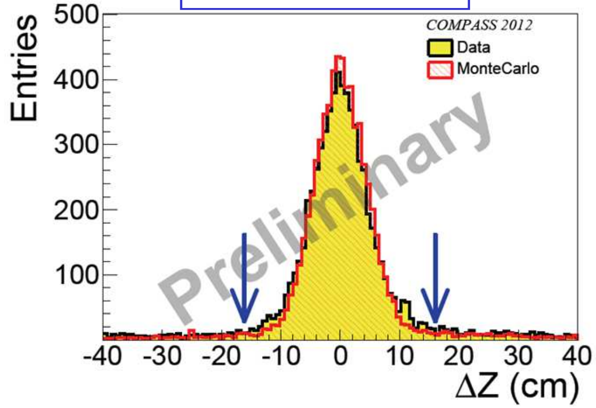
$Q^2 > 1$ GeV^2, $0.05 < y < 0.9$

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

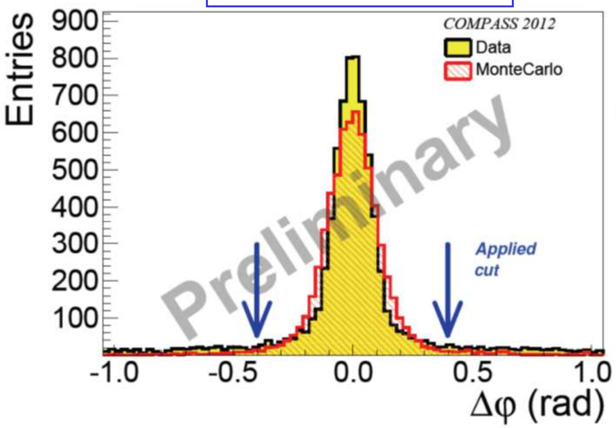
only 1 photon with energy above DVCS threshold



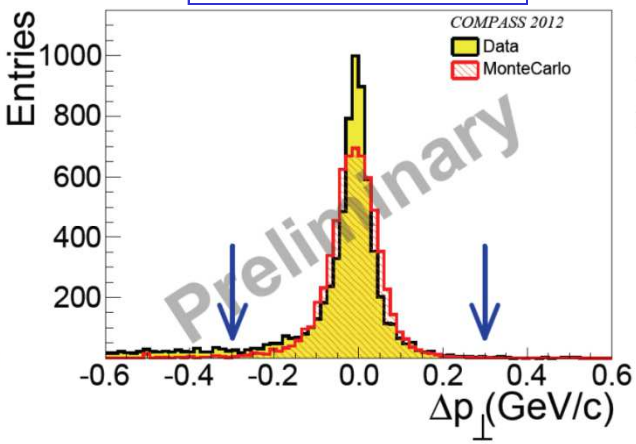
vertex pointing



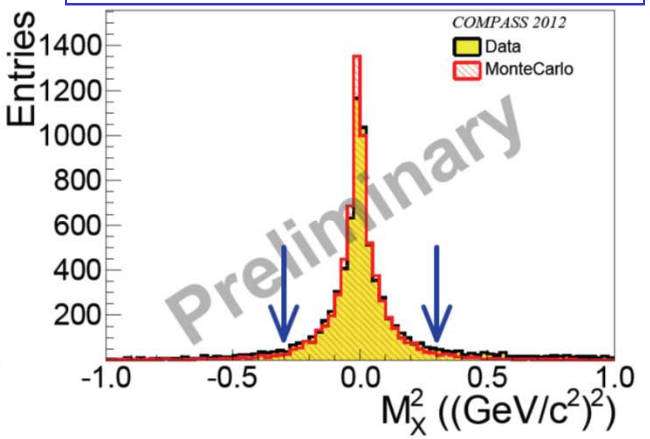
$\Delta\varphi = \varphi^{prot}_{meas} - \varphi^{prot}_{recon}$



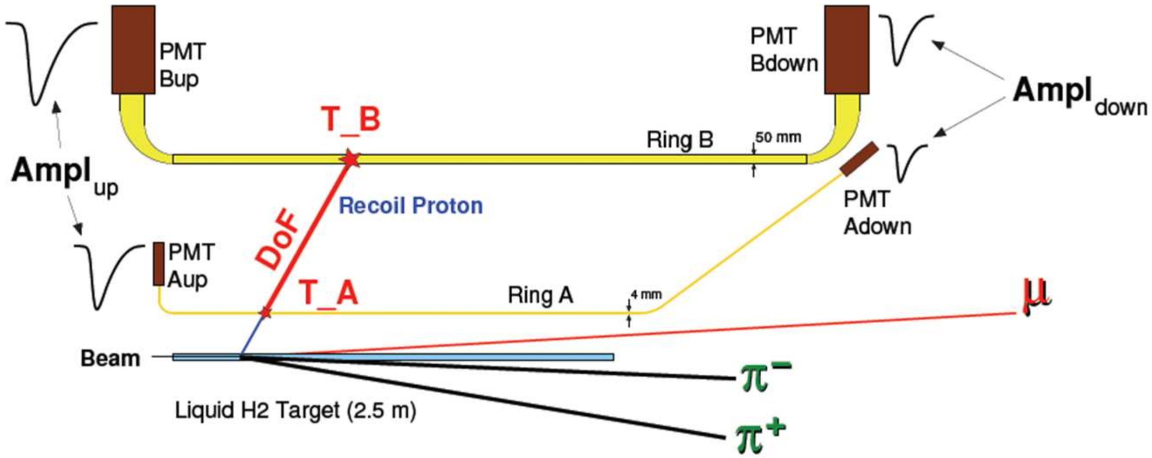
$\Delta p_\perp = p^{prot}_{\perp,meas} - p^{prot}_{\perp,recon}$



$M_X^2 = (p^\mu_{in} + p^p_{in} - p^\mu_{out} - p^p_{out} - p^\gamma)^2$



Recoil particle reconstruction in CAMERA

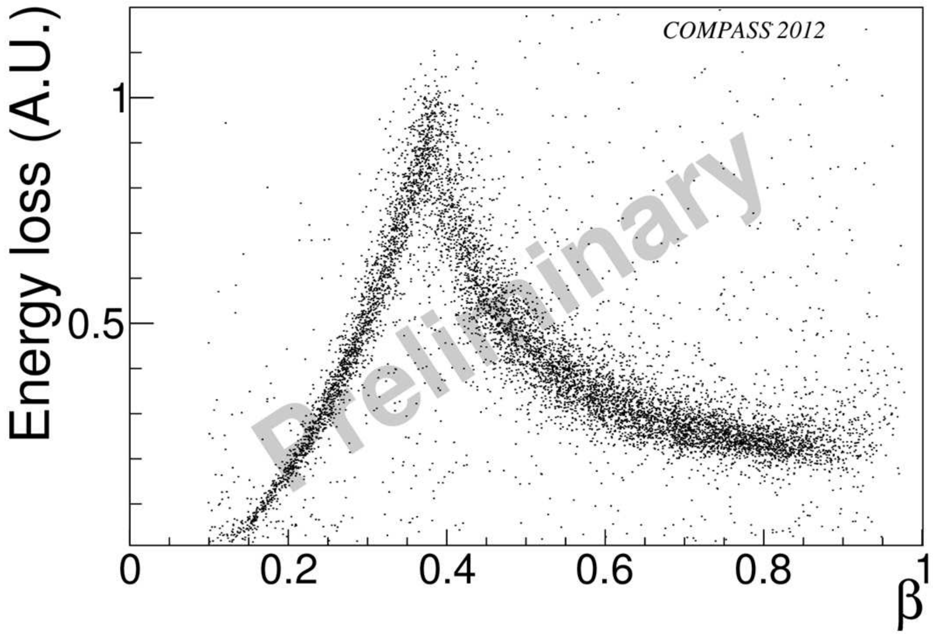


$E_{loss} \sim \sqrt{(Ampl_{up} \times Ampl_{down})}$

$z_{A,B} \sim (t_{up} - t_{down})_{A,B}$

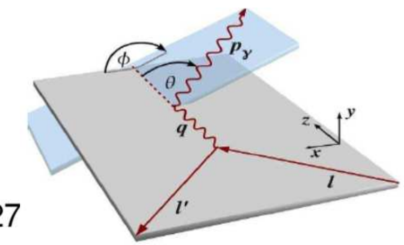
$ToF = (t_{up} + t_{down})_{A,B}$

$\beta = DoF / ToF$

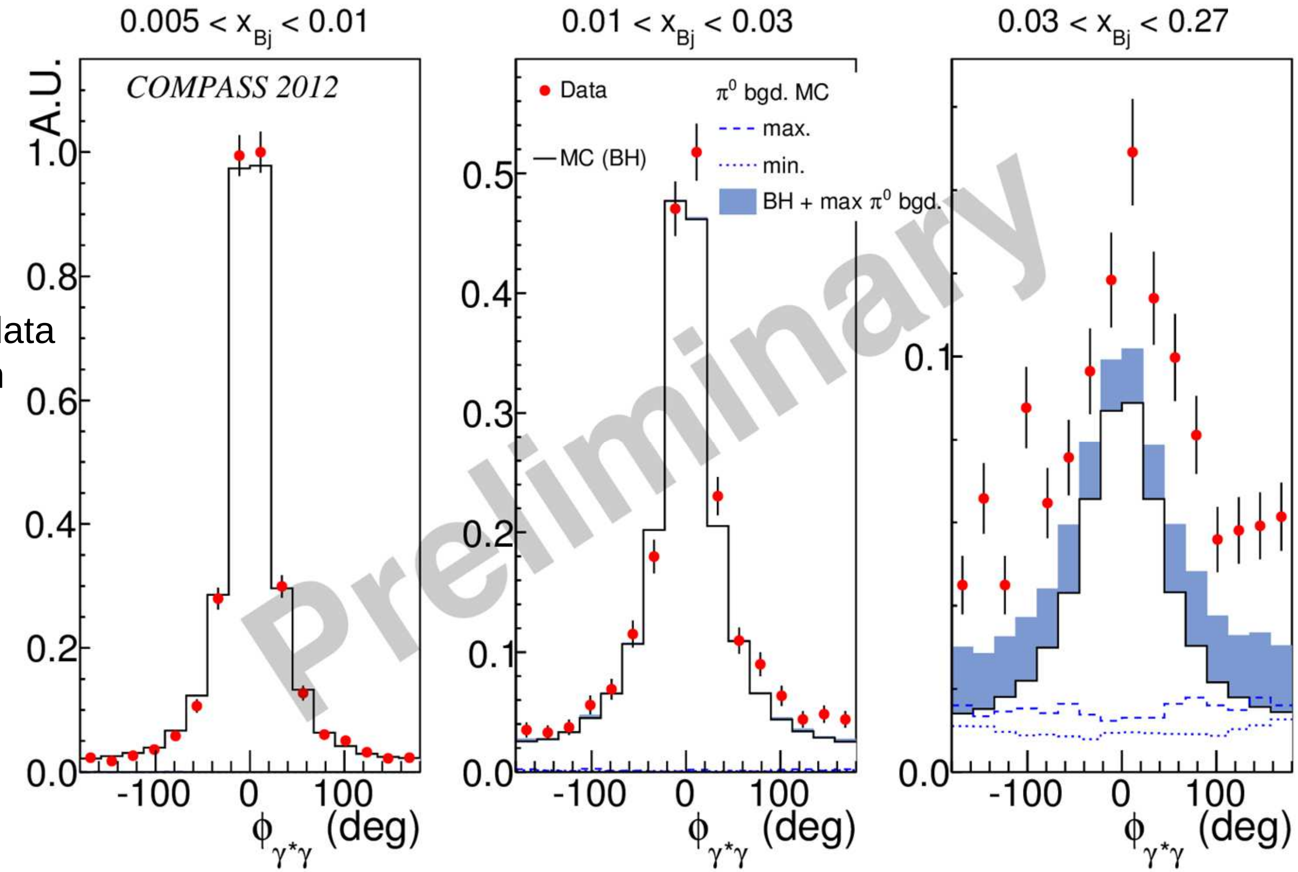


- Proton signature clearly visible after exclusivity selections

Exclusive γ production from 2012 DVCS comissioning run

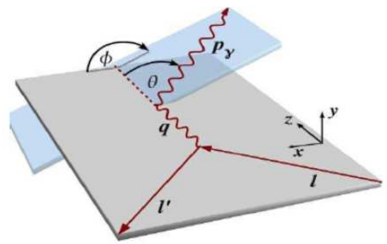


MC (BH) normalised to data in lowest x_{Bj} bin



- dominant BH process at small x_{BJ} clearly visible
- shape of ϕ distribution reproduced well by MC
- first estimates of π^0 background contributing at large x_{BJ}
- at large x_{BJ} an excess of events wrt BH + background

Extraction of DVCS cross section and amplitude



Beam Charge & Spin Sum

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

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

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

$$s_1^{Int} \rightarrow \mathcal{Im}(F_1\mathcal{H})$$

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

Beam Charge & Spin Difference

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

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

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

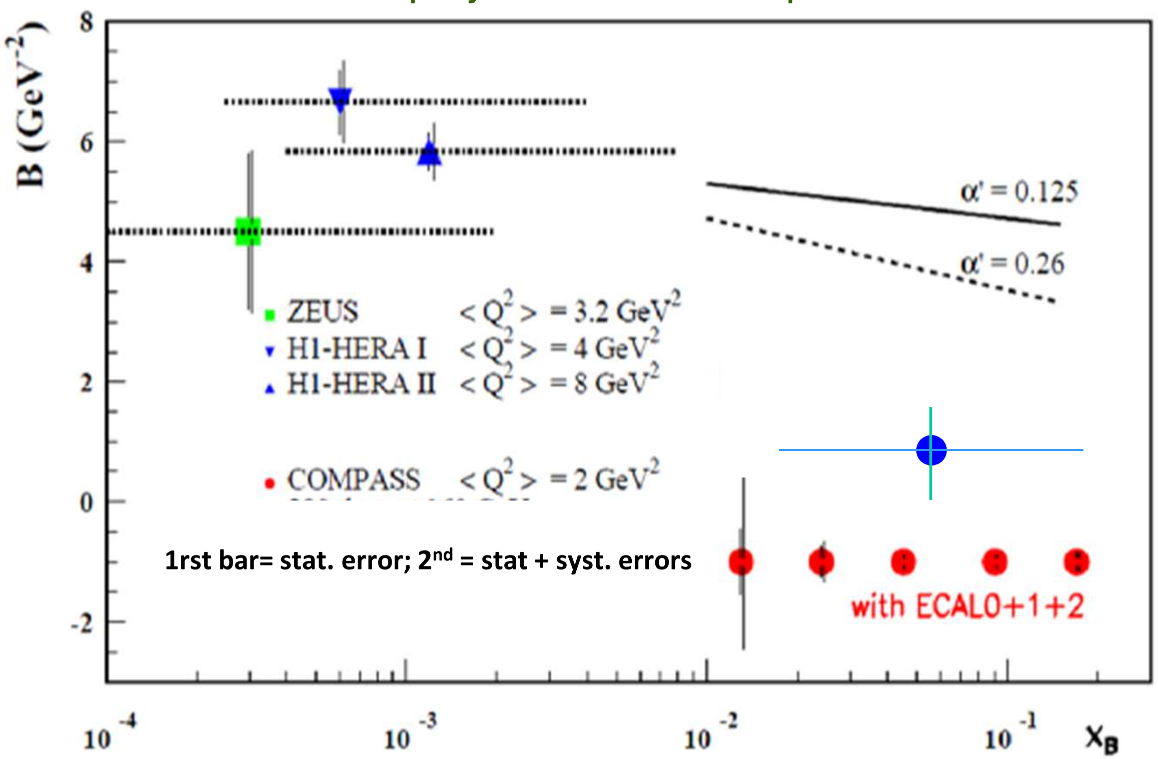
$$\mathcal{Re}\,\mathcal{H}(\xi,t) = \mathcal{P}\int dx\, \frac{H(x,\xi,t)}{x-\xi} = \mathcal{P}\int dx\, \frac{H(x,x,t)}{x-\xi} + \mathcal{D}(t)$$

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 projections for B-slope uncertainties



ansatz at small x_B inspired by Regge Phenomenology:

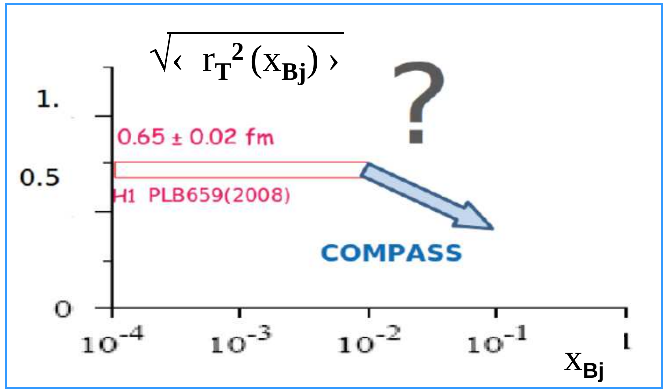
$B(x_B) = b_0 + 2\,\alpha' \ln(x_0/x_B)$

α' slope of Regge traject

from 4 weeks in 2012 DVCS test

with 40 weeks in 2015-16

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



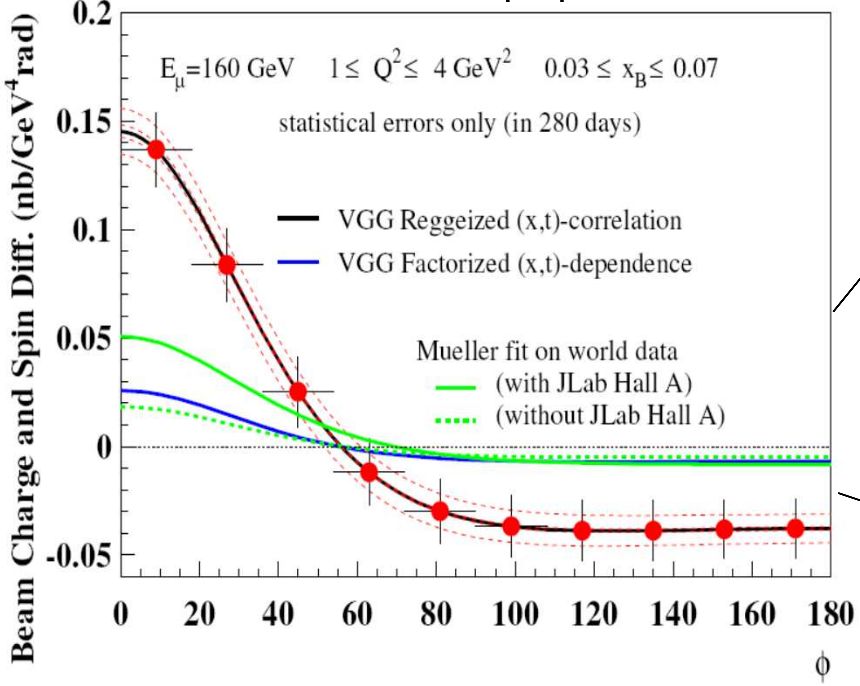
Beam Charge&Spin Difference of cross sections

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) =$$

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

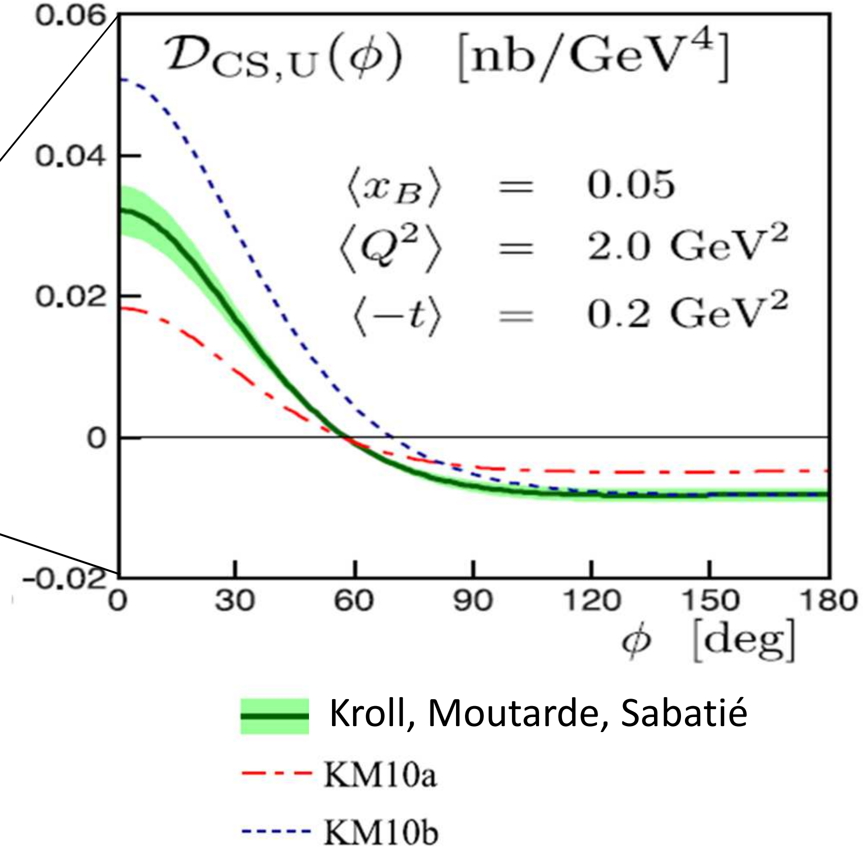
$$c_{0,1}^{Int} \rightarrow \mathcal{R}e(F_1\mathcal{H})$$

COMPASS-II proposal



Systematic error: 3% mostly due to luminosity measurements for μ^+ and μ^-

Kroll, Moutarde and Sabatié



Summary

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

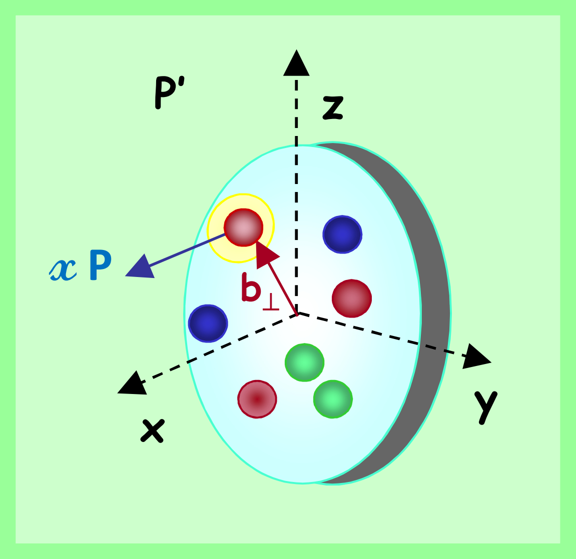
Backup

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

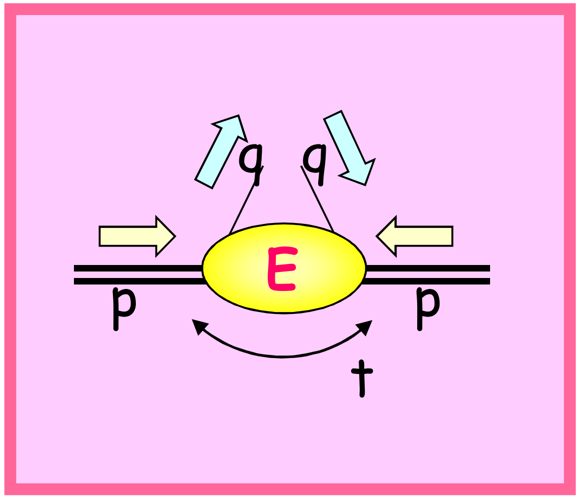


- Contribution to the nucleon spin puzzle

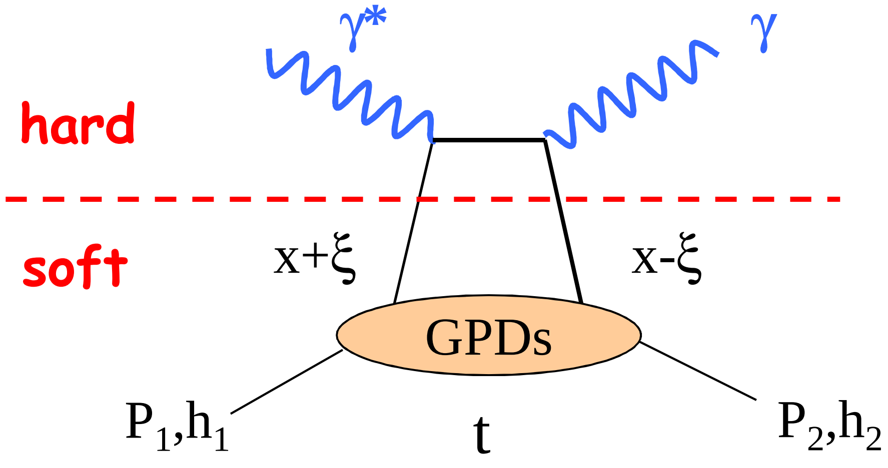
E related to the orbital angular momentum

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

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



Generalized Parton Distributions and DVCS



Factorisation:
Q^2 large, $-t<1$ GeV^2

$$\xi = \frac{x_B}{2 - x_B}$$

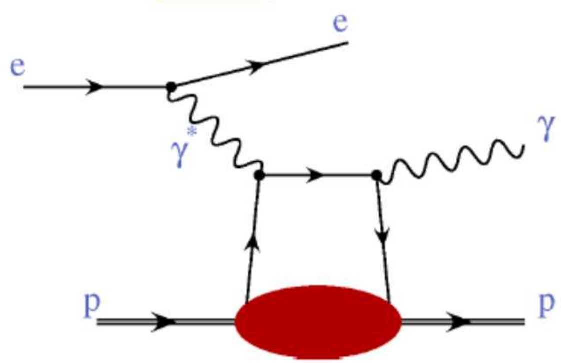
P_i, h_i – proton momentum and helicity

4 Generalised Parton Distributions : $H, E, \tilde{H}, \tilde{E}$ (chiral even)
for each quark flavour and for gluons

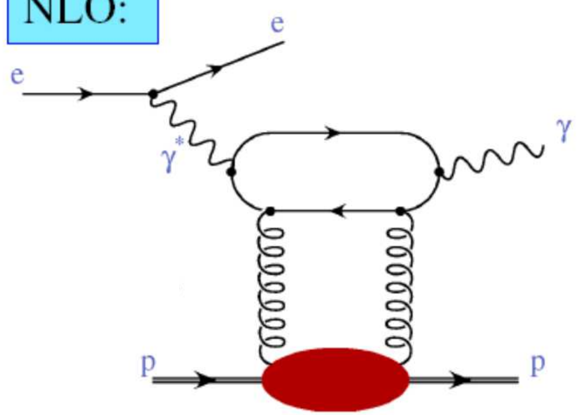
depend on 3 variables: x, ξ, t

for DVCS gluons contribute at higher orders in α_s

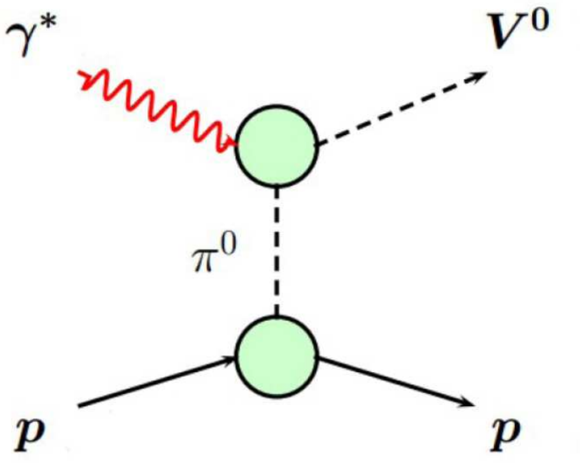
LO:



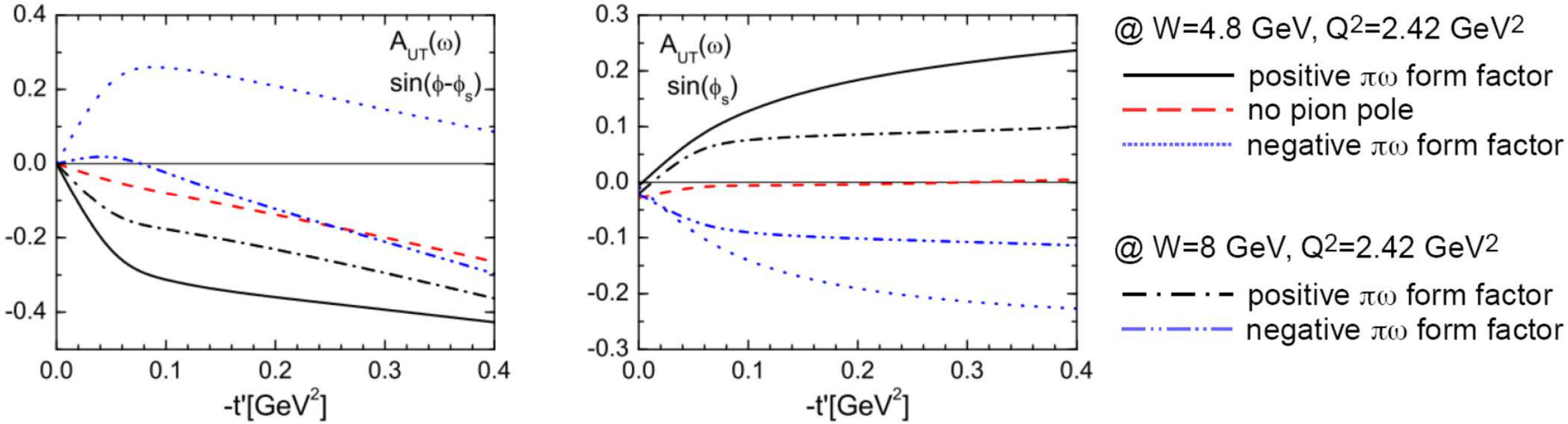
NLO:



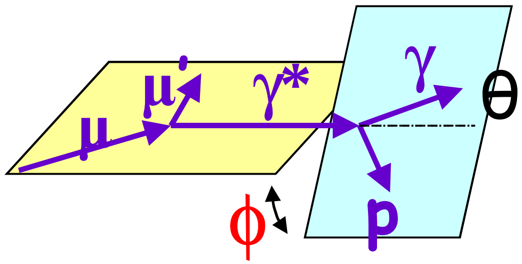
Role of pion exchange



- Effect known since early photoproduction experiments
- At COMPASS kinematics:
  - small for ρ^0 production
  - sizable for ω production
- Unnatural parity exchange process
  → impact on helicity-dependent observables
- Crucial for description of SDMEs for excl. ω production
  → Goloskokov and Kroll, Eur. Phys. J. A50 (2014) 9, 146
- Sign of $\pi\omega$ form factor not resolved from SDMEs data
  → azimuthal asymmetries more sensitive



Azimuthal dependence of exclusive photon xsec.



from Belitsky, Kirchner, Müller :
polarized beam off unpolarized target

$$d\sigma_{(\mu p \to \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}{}_{unpol} + P_\mu\, d\sigma^{DVCS}{}_{pol} + e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS} + e_\mu\, P_\mu\, a^{BH}\, \mathcal{I}m\, A^{DVCS}$$

$$d\sigma^{BH} = \frac{\Gamma(x_B, Q^2, t)}{P_1(\varphi)P_2(\varphi)} \left(c_0^{BH} + c_1^{BH}\cos\varphi + c_2^{BH}\cos 2\varphi\right)$$ ← Known expression

$$d\sigma^{DVCS}_{unpol} = \frac{e^6}{y^2Q^2}\left(c_0^{DVCS} + c_1^{DVCS}\cos\varphi + c_2^{DVCS}\cos 2\varphi\right)$$

$$P_\mu \times \quad d\sigma^{DVCS}_{pol} = \frac{e^6}{y^2Q^2}\left(s_1^{DVCS}\sin\varphi\right)$$

$$e_\mu \times \; a^{BH}\,\Re e\, A^{DVCS} = \frac{e^6}{xy^3 t P_1(\varphi)P_2(\varphi)}\left(c_0^{Int} + c_1^{Int}\cos\varphi + c_2^{Int}\cos 2\varphi + c_3^{Int}\cos 3\varphi\right)$$

$$e_\mu P_\mu \times \; a^{BH}\,\Im m\, A^{DVCS} = \frac{e^6}{xy^3 t P_1(\varphi)P_2(\varphi)}\left(s_1^{Int}\sin\varphi + s_2^{Int}\sin 2\varphi\right)$$

Twist-2 >> Twist-3 Twist-2 gluon

Study of azimuthal asymmetries from transversely polarized NH_3 target

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

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

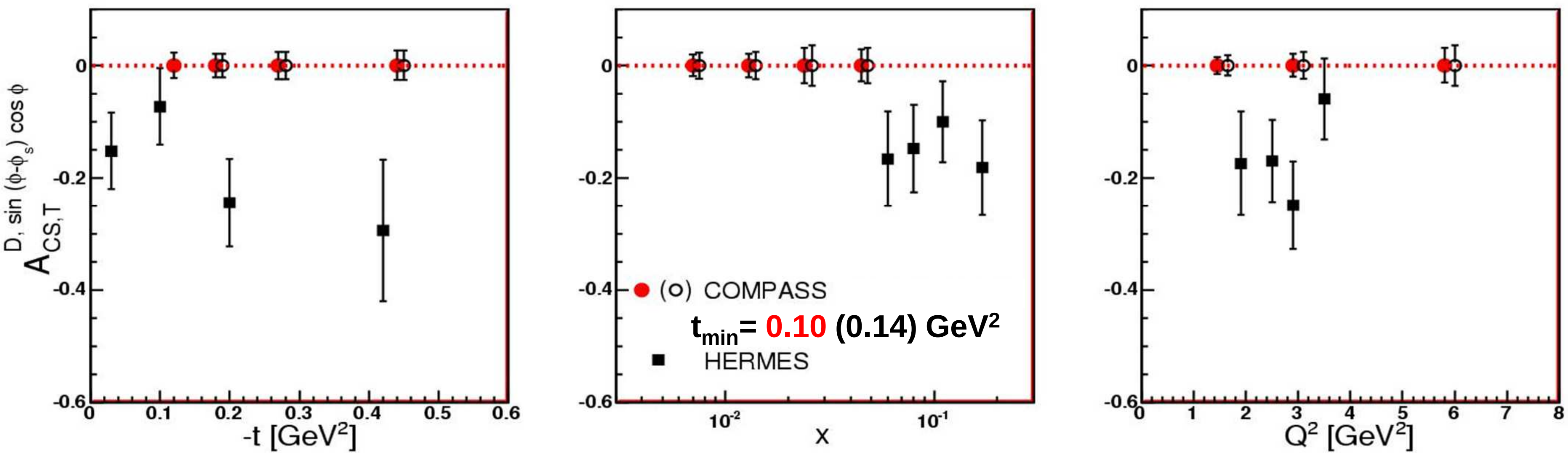
$d\sigma_0$ - unpolarised, charge averaged cross section

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

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

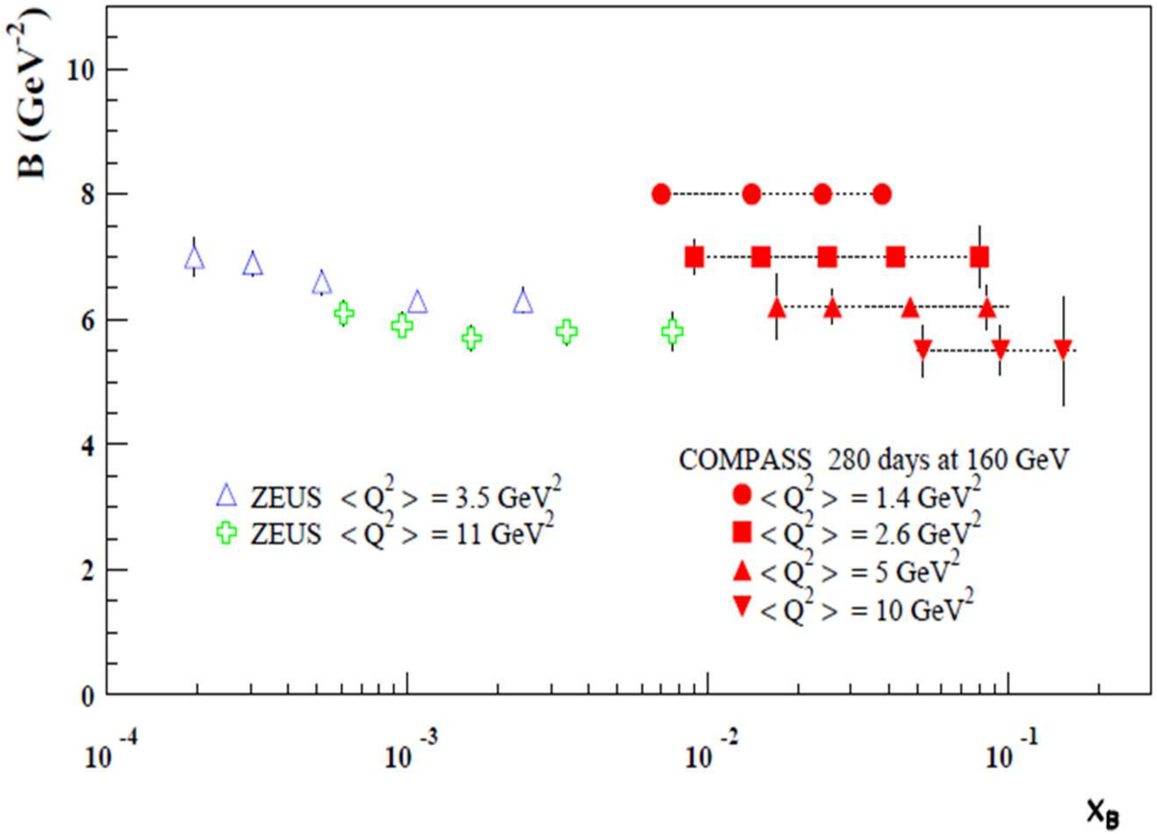
0.10 (0.14) < |t| < 0.64 GeV^2

COMPASS-II proposal



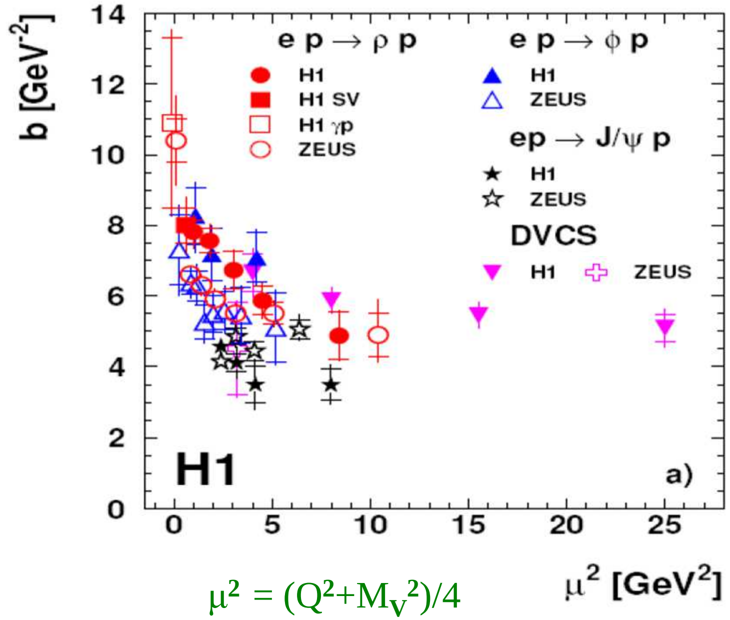
t-slope measurement for exclusive ρ^0 production

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



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



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

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