Hard exclusive processes in muon scattering at COMPASS

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Various faces of QCD 2

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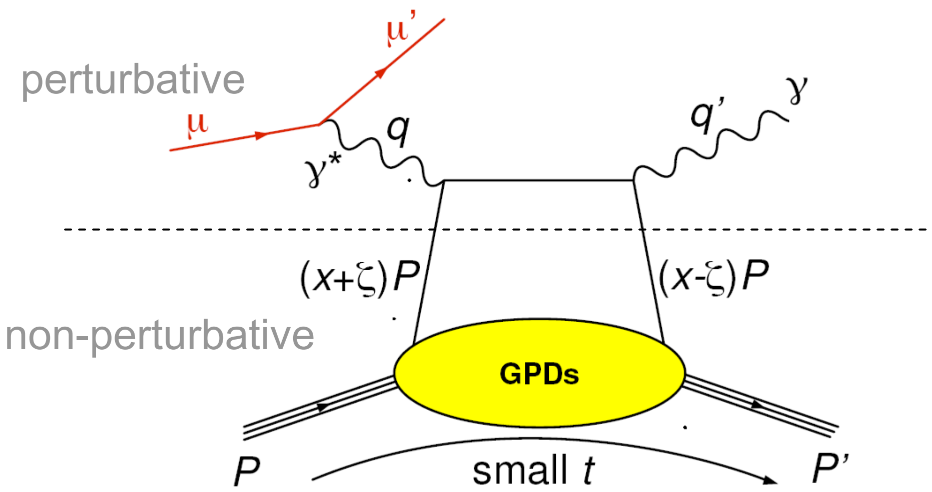
Generalised Parton Distributions (GPDs)

- Provide comprehensive description of 3-D partonic structure of the nucleon
  one of the central problems of non-perturbative QCD
- GPDs can be viewed as correlation functions between different partonic states
- 'Generalised' because they encompass 1-D descriptions by PDFs or by form factors

(the simplest) example: Deeply Virtual Compton Scattering (DVCS)

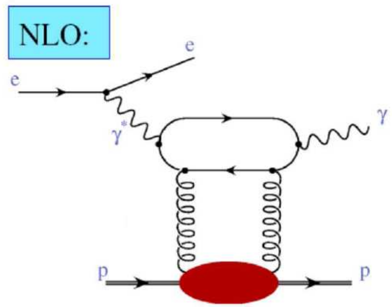


Factorisation for large Q^2 and | t | ‹‹ Q^2

4 GPDs for each **quark flavour**

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

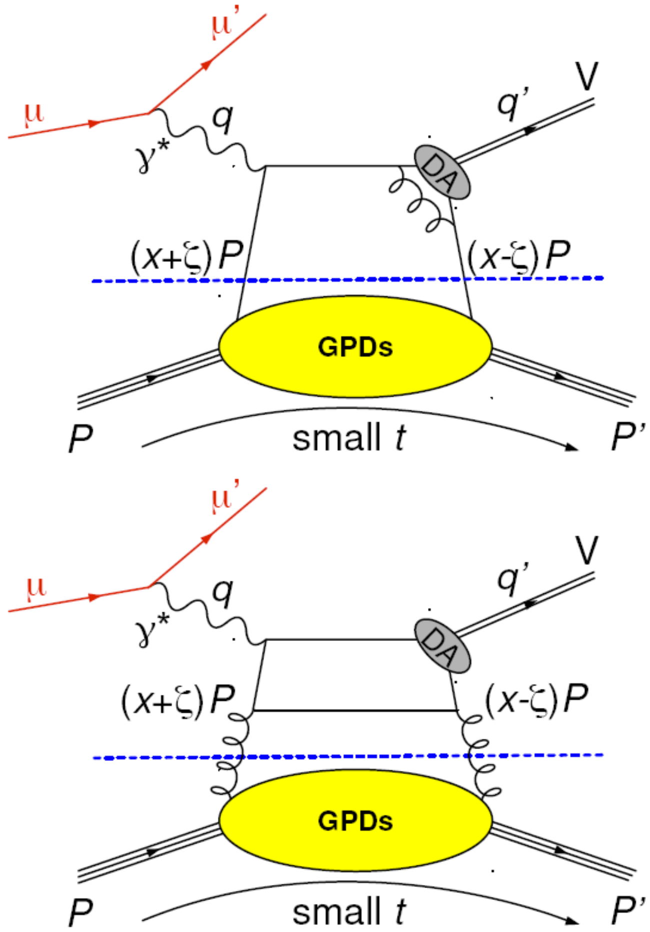
for DVCS **gluons** contribute at higher orders in α_s



GPDs and Hard Exclusive Meson Production

quark contribution

gluon contribution



- factorisation proven only for σ_L
  σ_T suppressed by $1/Q^2$
- wave function of meson (DA)
  additional non-perturbative term

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:

$$E_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^{u(+)} + \frac{1}{3}E^{d(+)} + \frac{3}{4}E^g/x\right)$$
$$E_{\omega} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^{u(+)} - \frac{1}{3}E^{d(+)} + \frac{1}{4}E^g/x\right)$$
$$E_{\phi} = -\frac{1}{3}E^{s(+)} + \frac{1}{4}E^g/x$$

Diehl, Vinnikov
PLB, 2005

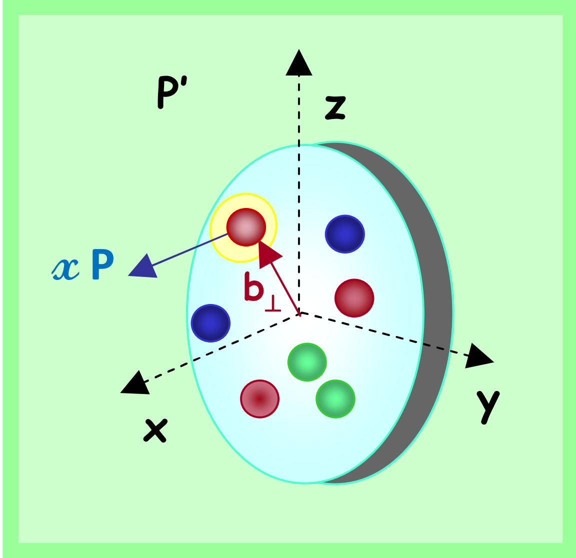
- *contribution from gluons at the same order of α_s as from quarks*

Most appealing aims of the GPD program

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

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

probability interpretation (Burkardt)



this talk

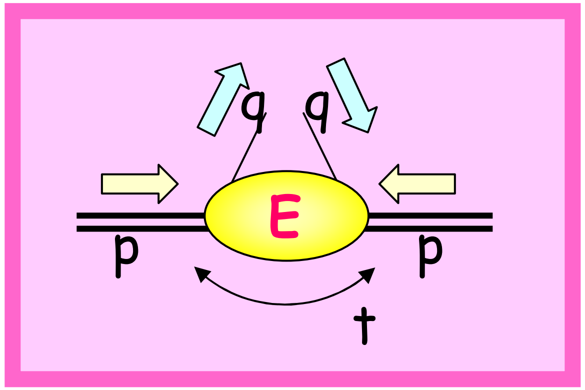
> ➢ t-dependence of pure DVCS cross section on unpolarised protons

- Contribution to the nucleon spin puzzle

  GPD E related to the orbital angular momentum

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

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



this talk

> ➢ Exclusive vector meson production on transversely polarised protons and deuterons

COMPASS QCD facility at CERN (SPS)

COmmon Muon Proton Apparatus for Structure and Spectroscopy

~240 physicists, 12 countries + CERN, 24 institutions

COMPASS setup

1\. **High energy secondary hadron and polarised muon beams from SPS M2 beam line**

2\. **Two stages forward spectrometer**

Large Angle Spectrometer (SM1)

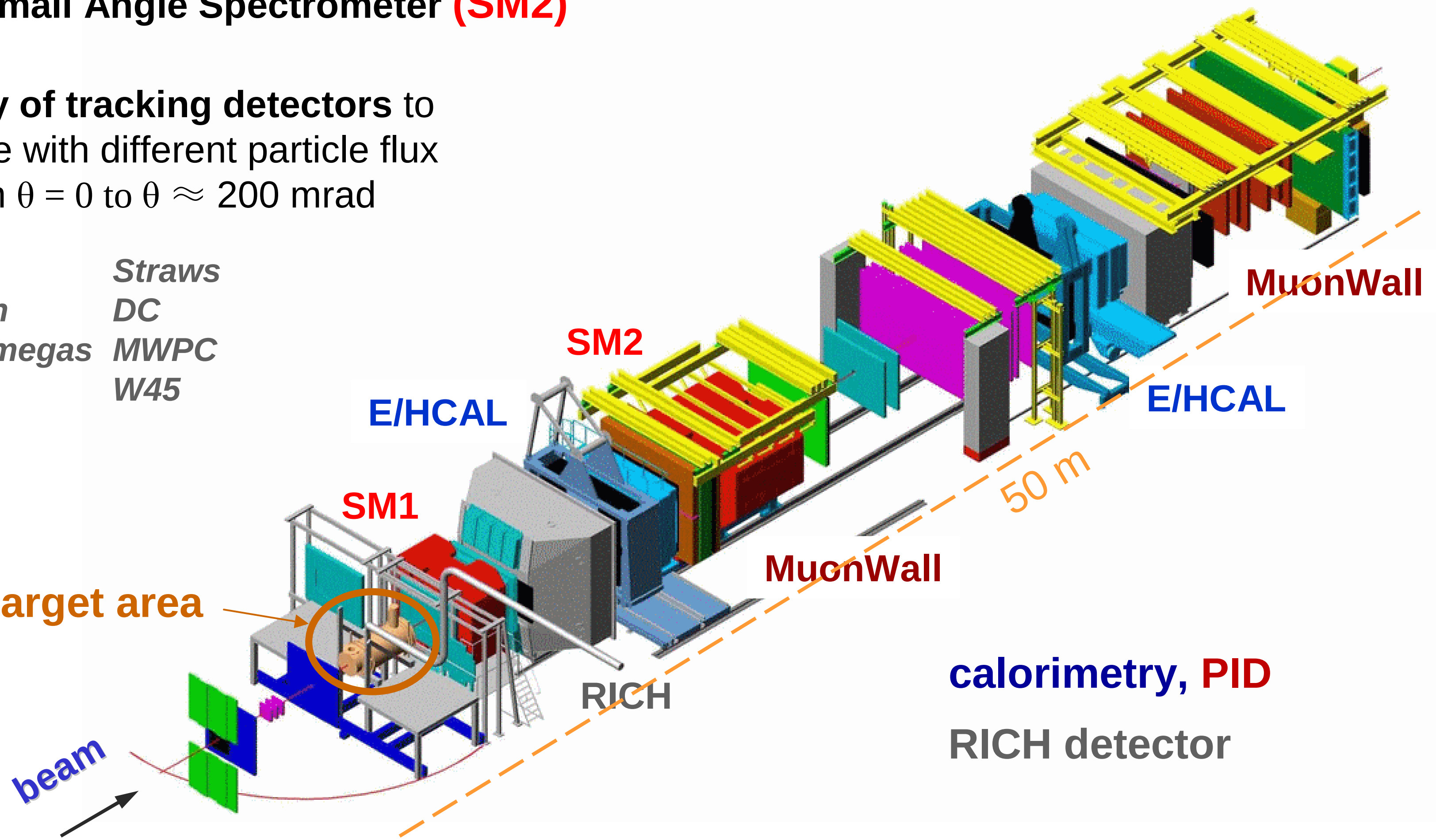
Small Angle Spectrometer (SM2)

- **large angular acceptance**
- **broad kinematic range**

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

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

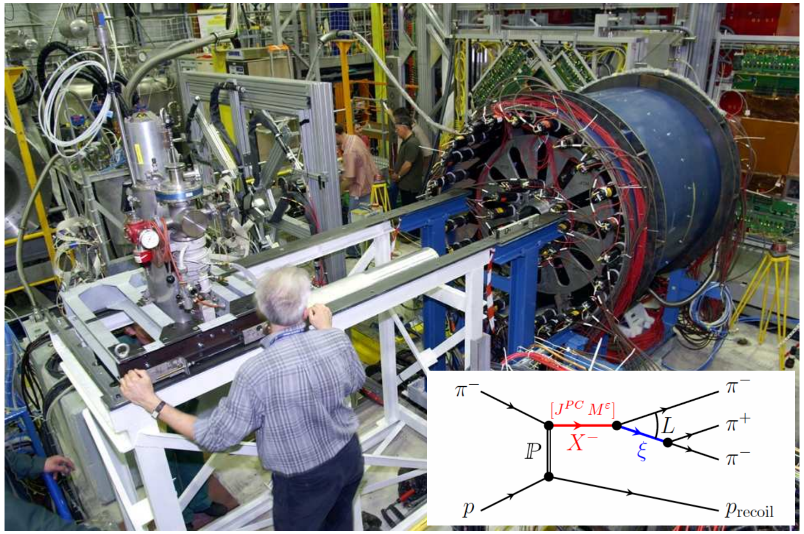
3\. **Flexible target area**



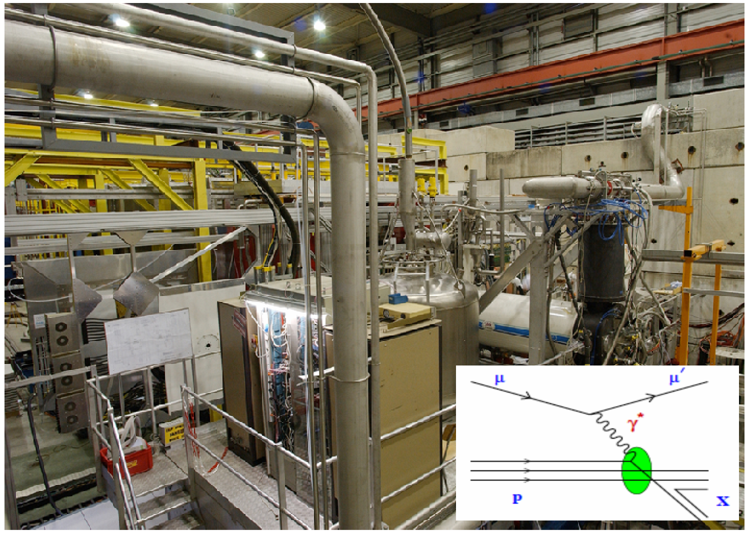
calorimetry, PID

RICH detector

Versatility; Four *(programs)* in One *(experiment)*



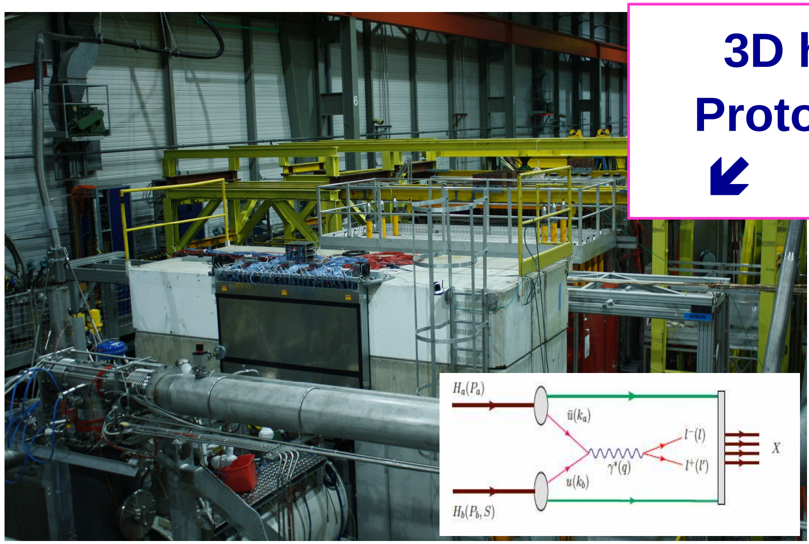
COMPASS-I
2002-2011



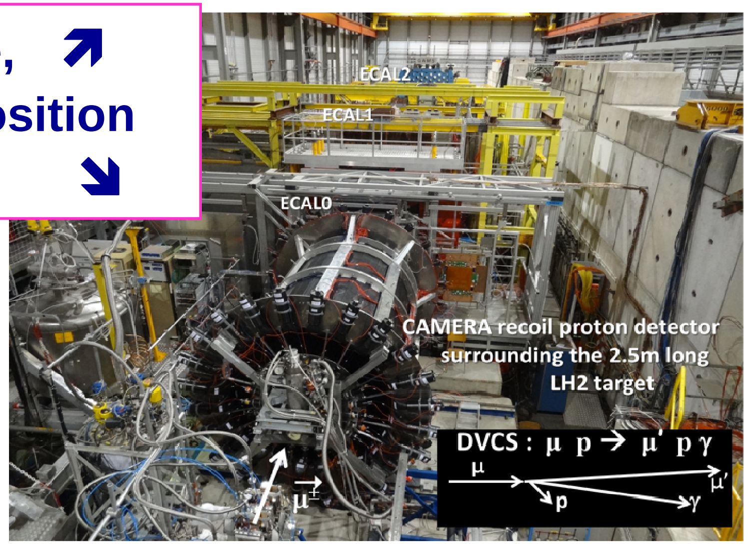
hadron spectroscopy & exotic states
π and K polarisabilities, chiral dynamics

polarised SIDIS

3D hadron structure,
Proton spin decomposition
(spin crisis)



COMPASS-II
2012-..



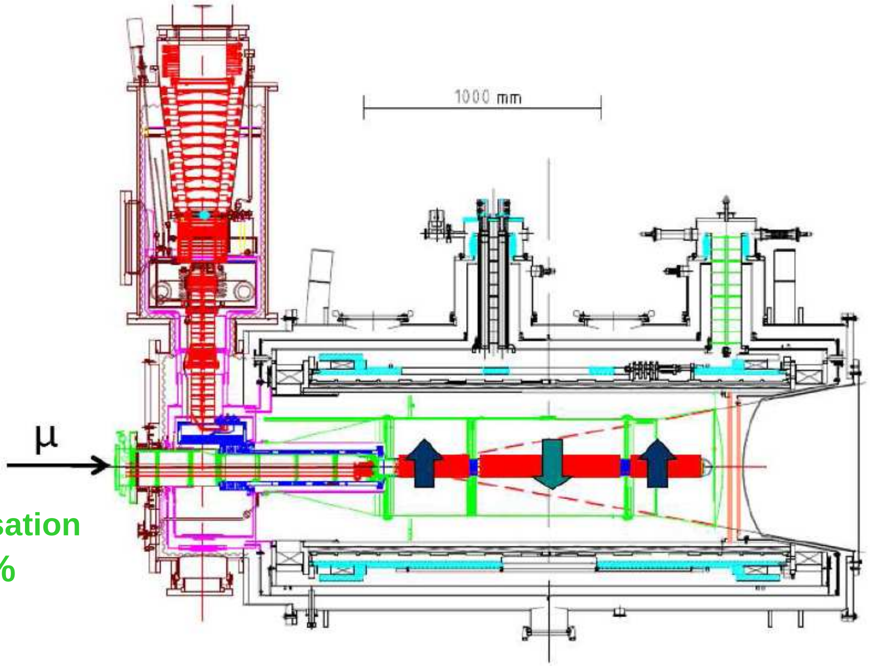
Polarised Drell-Yan

DVCS (GPDs) + unp. SIDIS

Exclusive ρ^0 and ω production

on transversely polarised protons and deuterons

COMPASS polarised target



μ^+ polarisation
≈ -80%

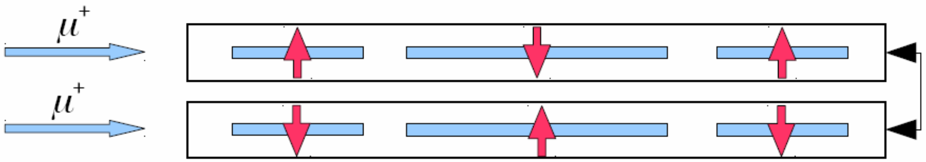
^3He - ^4He dilution refrigirator (T~50 mK)

solenoid 2.5 T
dipole magnet 0.6 T

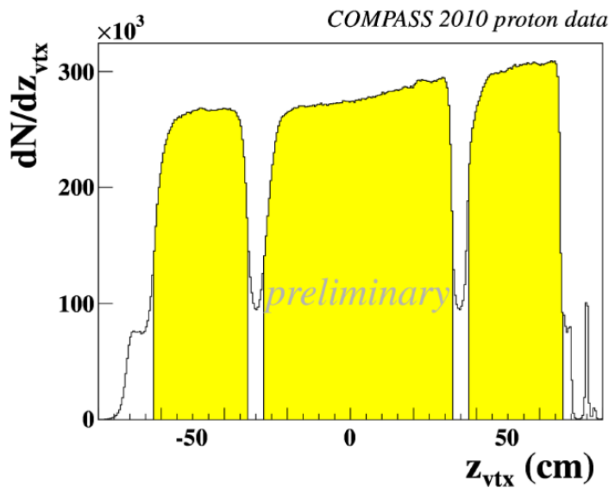
Two 30cm and one 60 cm long target cells [two 60cm long cells in 2002-2004] with opposite polarization

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

Luminosity $5\cdot10^{32}$ cm^{-2}s^{-1}

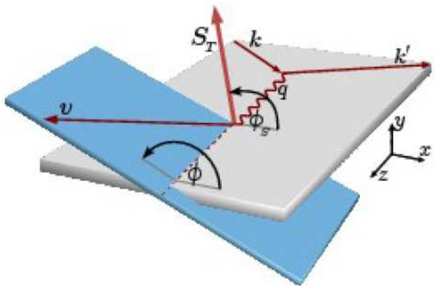


Microwave
reversal
every week



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’

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

Selections for exclusive ρ^0 sample (similar selections for ω)

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

$\rho^0 \rightarrow \pi^+ \pi^-$

NH_3 target – transversely polarised protons

All charged particles measured <u>except recoil nucleon</u>

$1\ (\mathrm{GeV}/c)^2 < Q^2 < 10\ (\mathrm{GeV}/c^2$

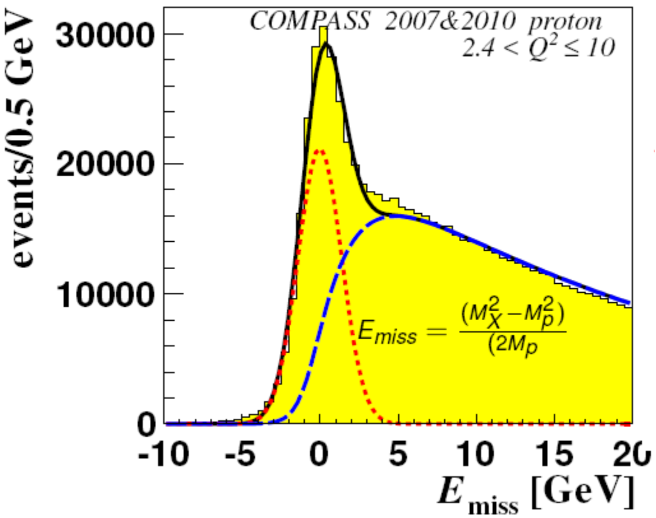
$W > 5\,(\mathrm{GeV}/c^2)$

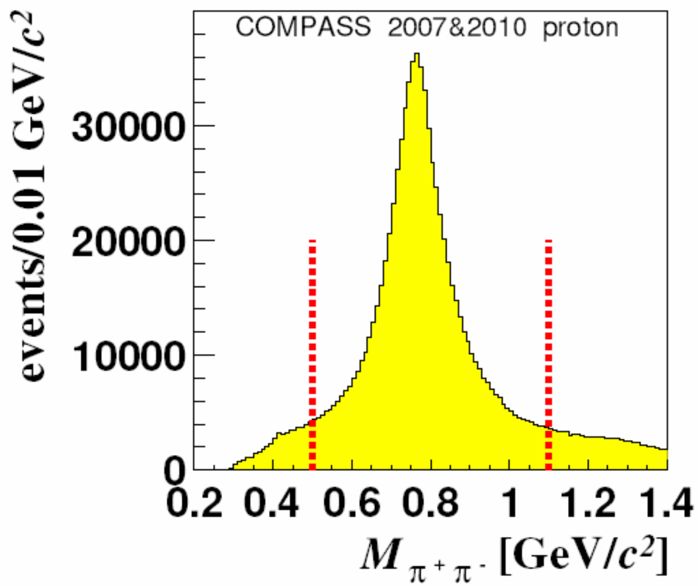
$0.1 < y < 0.9$

$0.003 < x_{Bj} < 0.35$

$|E_{miss}| < 2.5 GeV$

$0.1 (\mathrm{GeV}/c)^2 < p_T^2 < 0.5 (\mathrm{GeV}/c)^2$





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

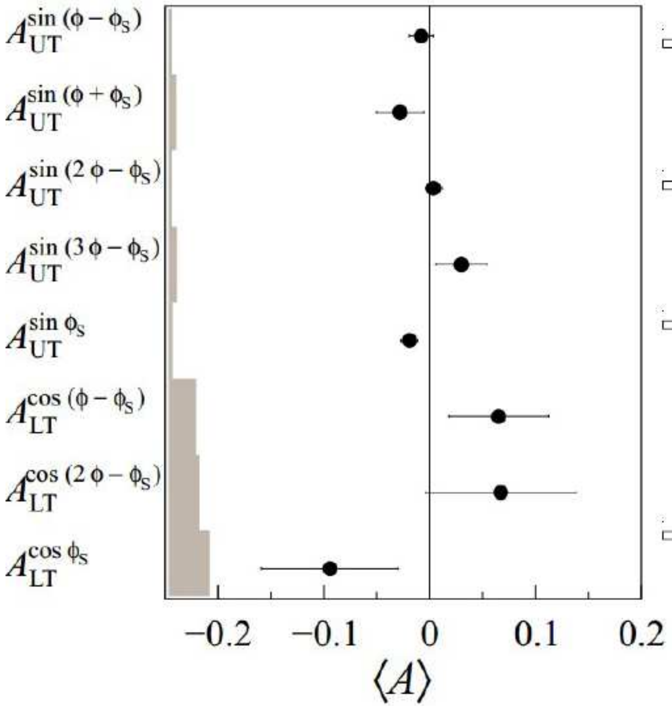
MC weighted using ratio between real data and MC for wrong charge combination sample $(h^+h^+ + h^-h^-)$

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

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

Transverse target spin asymmetries for exlusive ρ^0 production on $p^\uparrow$

PLB 731 (2014) 19



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

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

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

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

$\langle x_{Bj} \rangle = 0.039$, $\langle Q^2 \rangle = 2.0\ \mathrm{GeV}^2$
$\langle p_T^2 \rangle = 0.18\ \mathrm{GeV}^2$, $\langle W \rangle = 8.1\ \mathrm{GeV}^2$

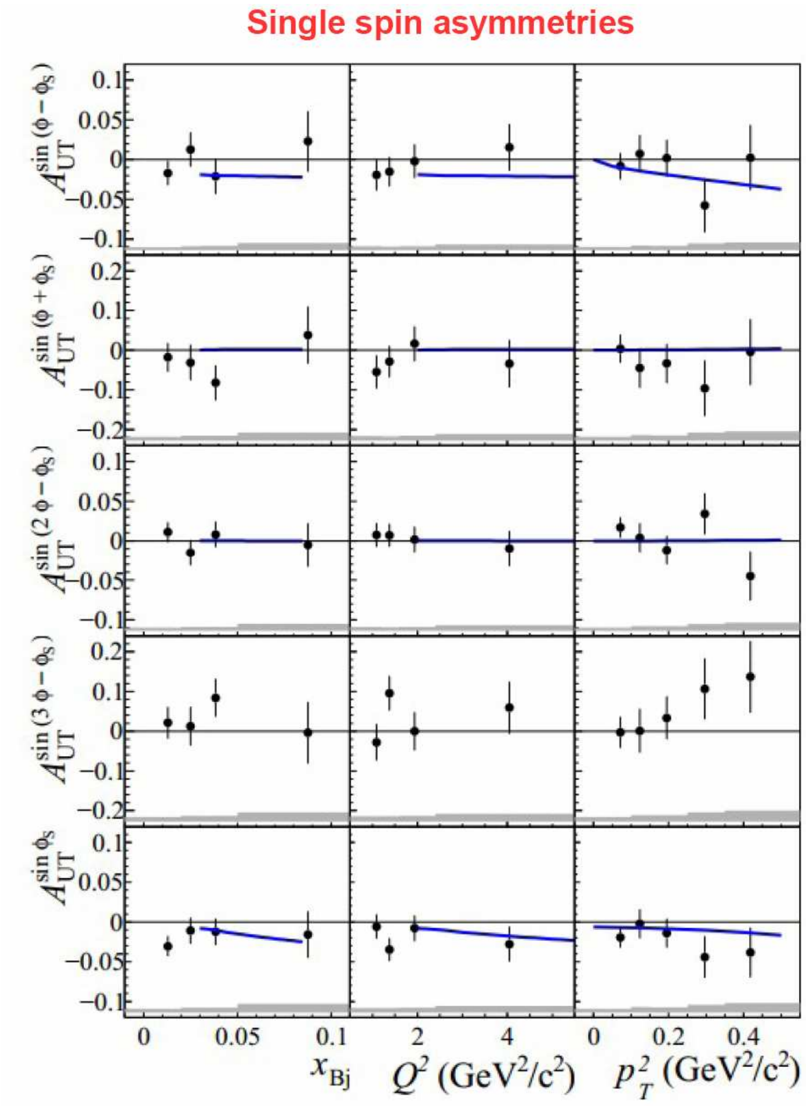
$M_{Vp', \gamma^* p}$ helicity amplitudes
σ_0 unpolarised cross section
$H_T(x, 0, 0) = h_1(x)$
$\bar{E}_T = 2\widetilde{H}_T - E_T$

- 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

Transverse target spin asymmetries for exlusive ρ^0 production on $p^\uparrow$



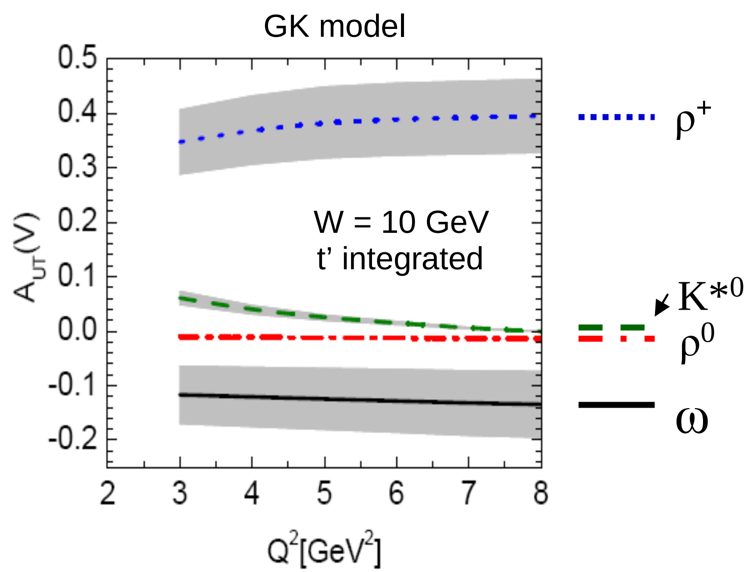
predictions of GPD model of Goloskokov-Kroll

- reasonable agreement with GK model (also for not-shown double spin asym.)

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

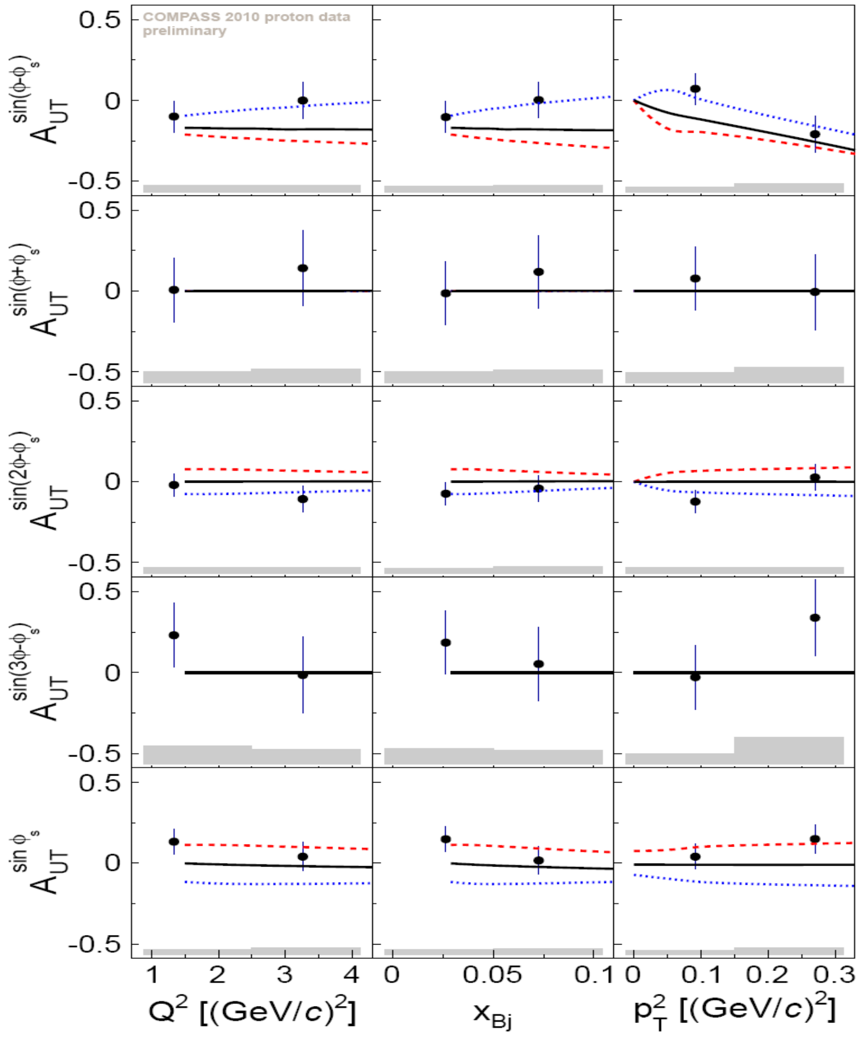
its small values due to approximate cancellation of contributions from E^u and E^d, $E^u \approx -E^d$

- larger effects expected for exclusive ω production



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

Single spin asymmetries

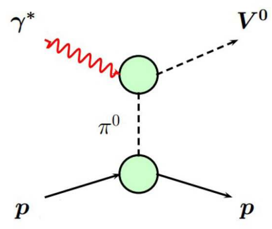


$\langle x_{Bj} \rangle = 0.049$, $\langle Q^2 \rangle = 2.2$ GeV^2
$\langle p_T{}^2 \rangle = 0.17$ GeV^2, $\langle W \rangle = 7.1$ GeV^2

- new result, subm. to Nucl.PB

comparison to modified GPD model of GK

with added π^0 pole exchange



EPJ A50 (2014) 146

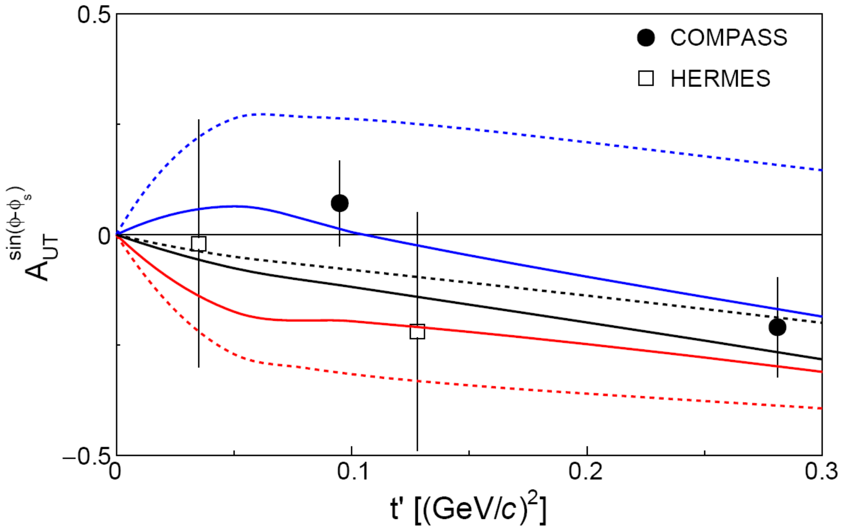
parameters constrained by HERMES SDMEs for ω
except sign of $\pi\omega$ transition form factor
more sensitivity in azimuthal asymmetries

GK predictions for COMPASS, private com.

- no pion pole
- positive $\pi\omega$ form factor
- negative $\pi\omega$ form factor

- when 'global' comparison to the data
  no clear preference for any version

Comparison to HERMES asymmetries for ω production on p↑



COMPASS <W> = 8 GeV   HERMES <W> = 4.8 GeV ← **EPJ C75 (2015) 600**

no pion pole

positive πω form factor

negative πω form factor

✓ Note: contribution of pion pole decreases with W

→ each experiment to be compared to corresp. predictions

✓ COMPASS uncertainties smaller by a factor > 2

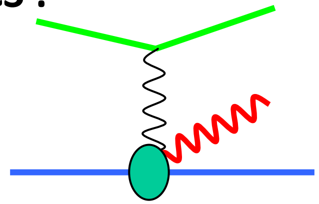
✓ within large errors combined HERMES data compatible with all 3 scenarios

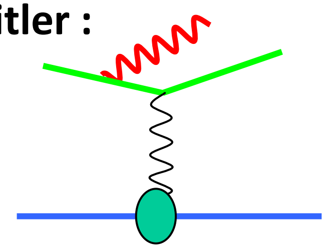
✓ Future measurements at JLab12 **EPJ A48 (2012) 187**

expected to resolve the issue of πω transition form factor

Deeply Virtual Compton Scattering off unpolarised protons

Exclusive single photon production cross section

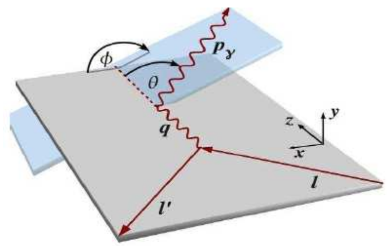




cross-sections on proton for $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam with opposite charge & spin (e_μ& P_μ)

$$d\sigma_{(\mu p\rightarrow\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}{}_{unpol} + P_\mu\, d\sigma^{DVCS}{}_{pol}$$
$$+ e_\mu\, a^{BH}\, \mathcal{Re}\, A^{DVCS} + e_\mu\, P_\mu\, a^{BH}\, \mathcal{Im}\, A^{DVCS}$$

Extraction of DVCS cross section and amplitude



Beam Charge & Spin Sum

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

$c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi$

$s_1^{Int}\sin\phi + s_2^{Int}\sin 2\phi$

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

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

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

Beam Charge & Spin Difference

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

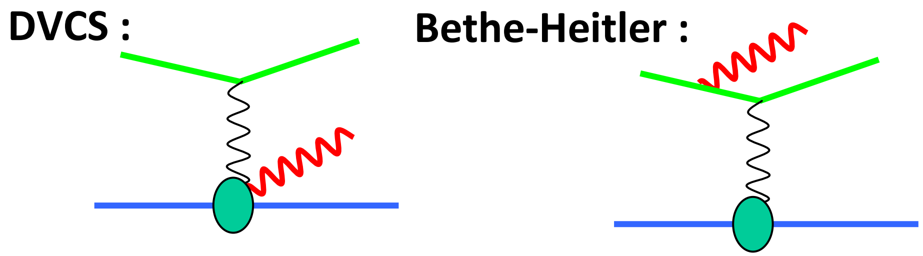
$c_0^{Int} + c_1^{Int}\cos\phi + c_2^{Int}\cos 2\phi + c_3^{Int}\cos 3\phi$

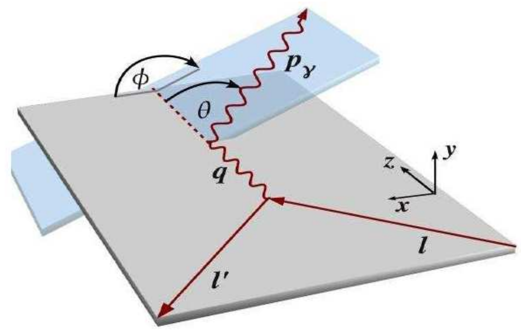
$s_1^{DVCS}\sin\phi$

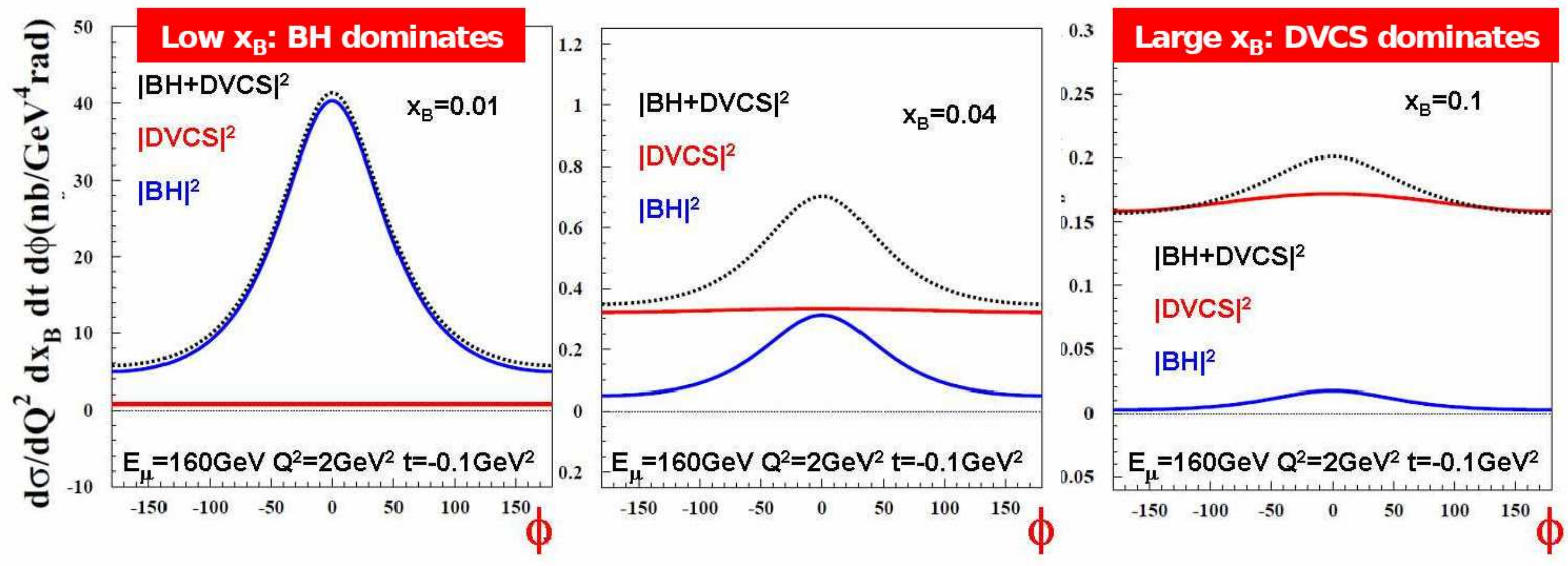
$\boxed{c_{0,1}^{Int}} \longrightarrow \mathcal{R}e(F_1\mathcal{H})$

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

Interplay of DVCS and BH at 160 GeV







BH dominates

excellent reference yield

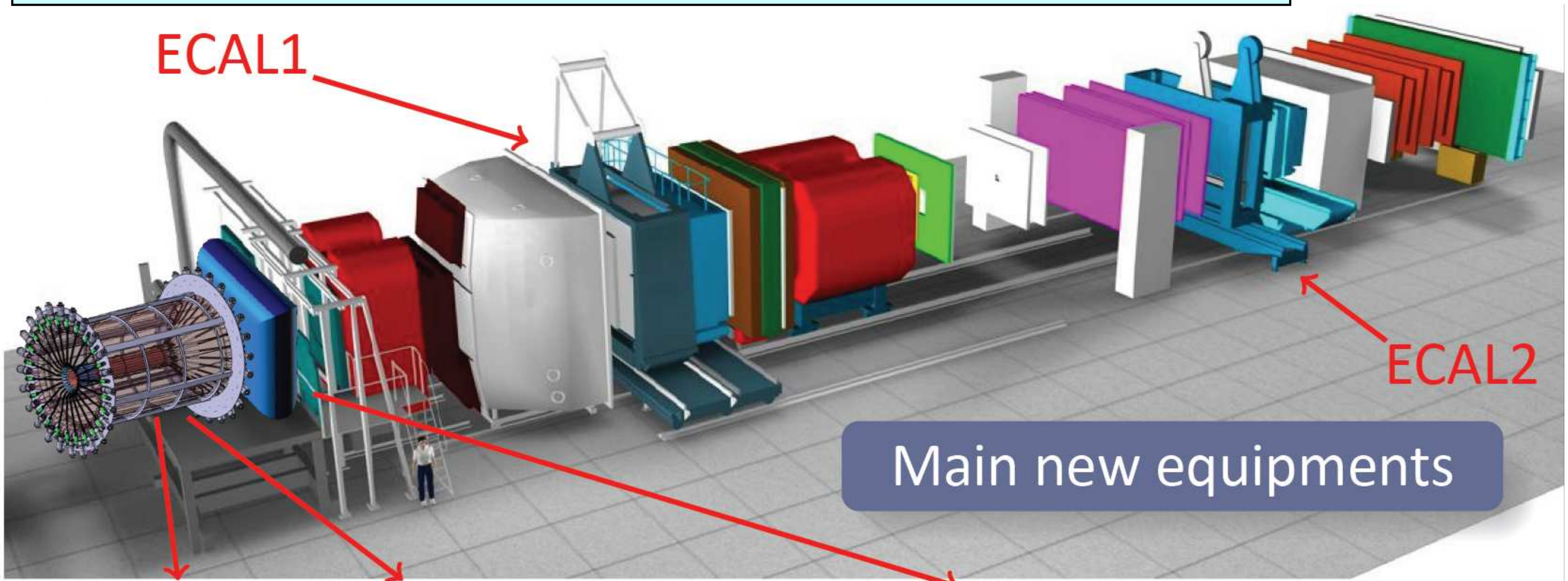
BH and DVCS at the same level

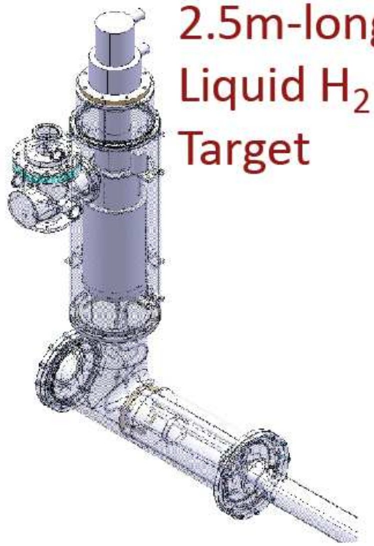
access to DVCS amplitude through the interference

DVCS dominates

study of $d\sigma^{DVCS}/dt$

The COMPASS set-up for the GPD program (starting from 2012)

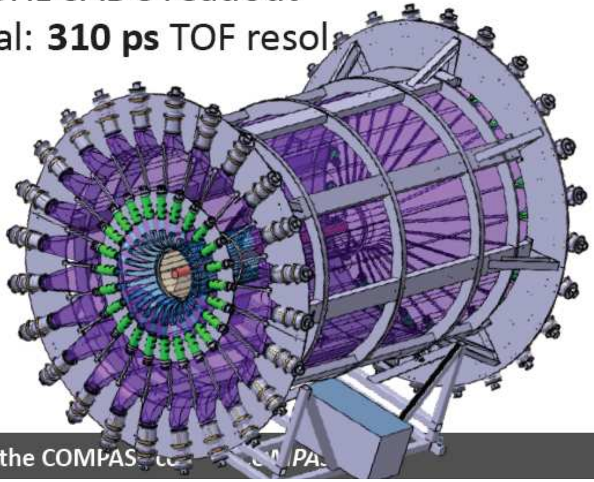




2.5m-long
Liquid H_2
Target

Target TOF System

24 inner & outer scintillators
1 GHz SADC readout
goal: **310 ps** TOF resol

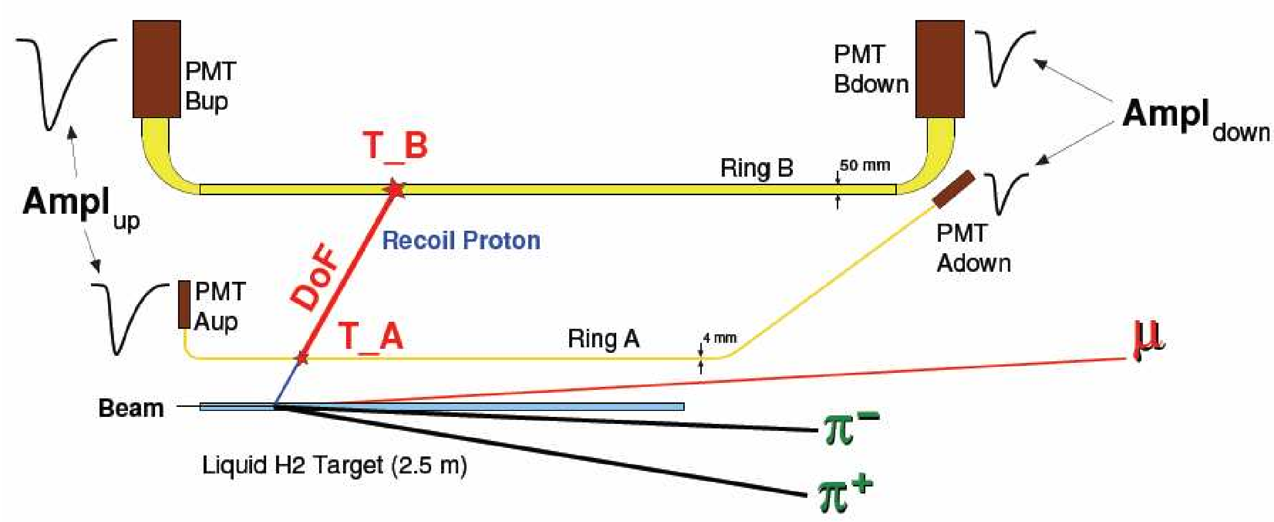


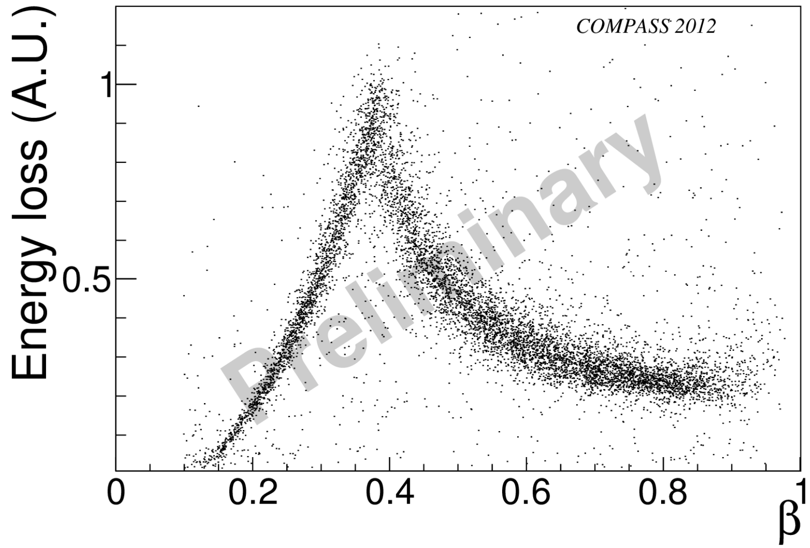
ECAL0 Calorimeter

Shashlyk modules + MAPD readout
$\sim 2 \times 2$ m^2, $\sim$2200 ch.

Mounting of Recoil Proton Detector ('CAMERA') in clean area at CERN

Recoil particle reconstruction in CAMERA





$E_{\mathbf{loss}} \sim \sqrt{(\mathrm{Ampl}_{\mathbf{up}} \times \mathrm{Ampl}_{\mathbf{down}})}$

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

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

$\beta = \mathrm{DoF} / \mathrm{ToF}$

counting rate: > 5 MHz in ring A
~ 1 MHz in ring B

- Proton signature clearly visible after exclusivity selections

Selection of exclusive single photon events

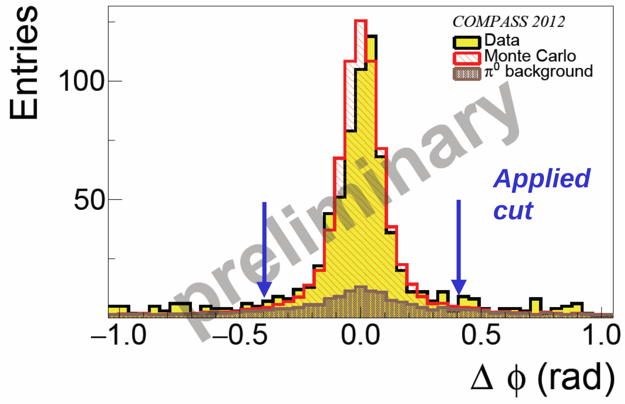
reconstructed vertex in the target volume

1 GeV² < Q² < 5 GeV², 10 GeV < ν < 32 GeV

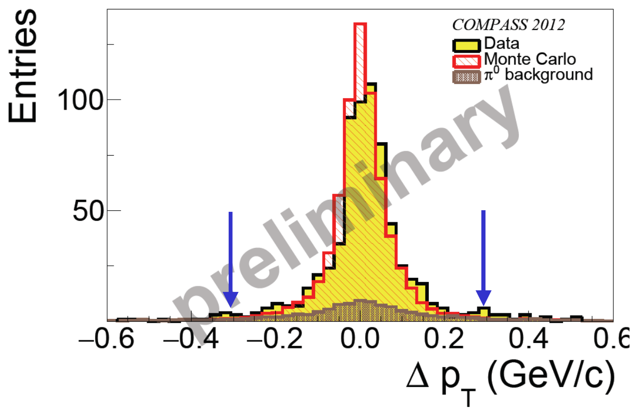
0.08 GeV² < | t | < 0.64 GeV²

1 single photon with energy above DVCS threshold ← $E_{Ecal(0,1,2)}$ > (4,5,10) GeV

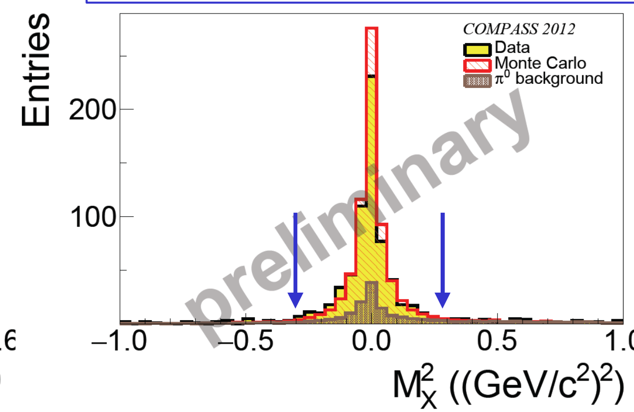
$$\Delta\varphi = \varphi^{prot}_{meas} - \varphi^{prot}_{recon}$$

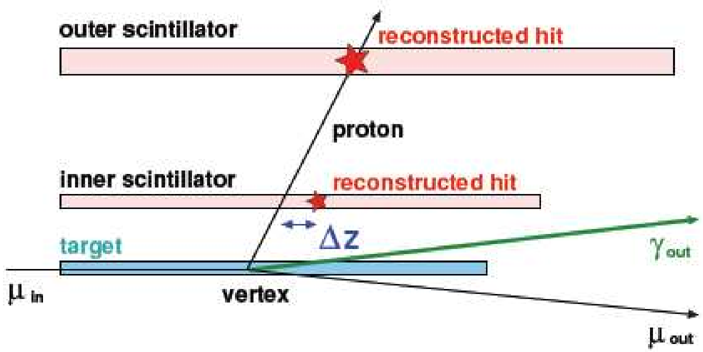


$$\Delta p_\perp = p^{prot}_{\perp,meas} - p^{prot}_{\perp,recon}$$

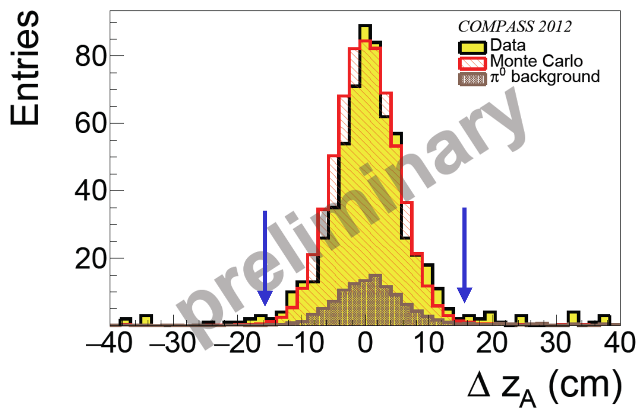


$$M_X^2 = (p_{in}^{\mu} + p_{in}^{p} - p_{out}^{\mu} - p_{out}^{p} - p^{\gamma})^2$$





vertex pointing

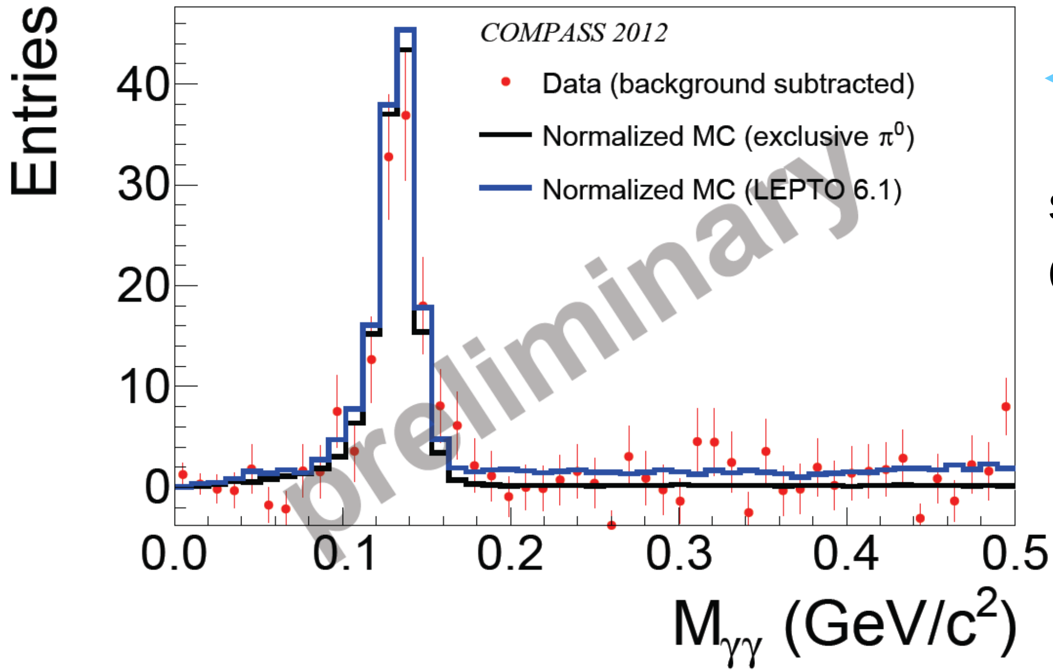


Estimate of π^0 background

Major source of background for exclusive photon events

Two cases:

- Visible; detected second γ (below DVCS threshold) => events rejected from final sample
- Invisible; one γ lost => estimated from MC normalised to π^0 peak for 'visible' sample



'Visible' sample

Semi-inclusive (LEPTO MC) or exclusive

(HEPGEN MC based on Goloskokov-Kroll model)

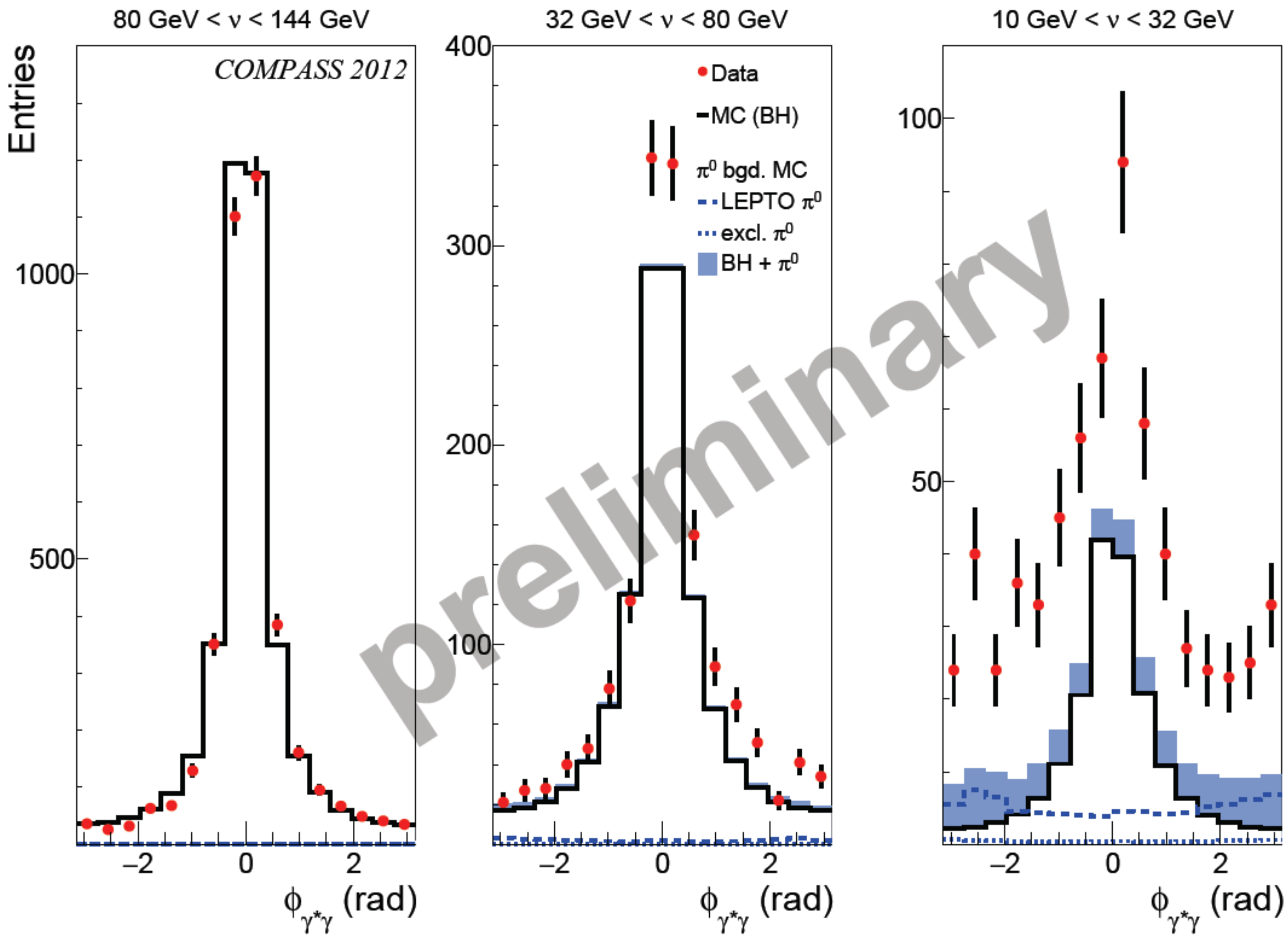
π^0 contribution normalised to $M_{\gamma\gamma}$ peak

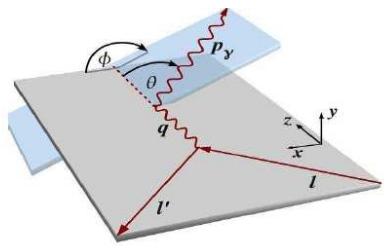
'Invisible' sample

Relative contributions from both processes to π^0 background estimated from combined fits

to the distributions of 'exclusivity variables' (M_X^2, $\Delta\phi$, Δp_T) and $E_{miss} = \nu - E_\gamma + t/(2m_p^2)$

Exclusive γ production from 2012 DVCS comissioning run





for normalization of BH MC to the data beam flux measurement used

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

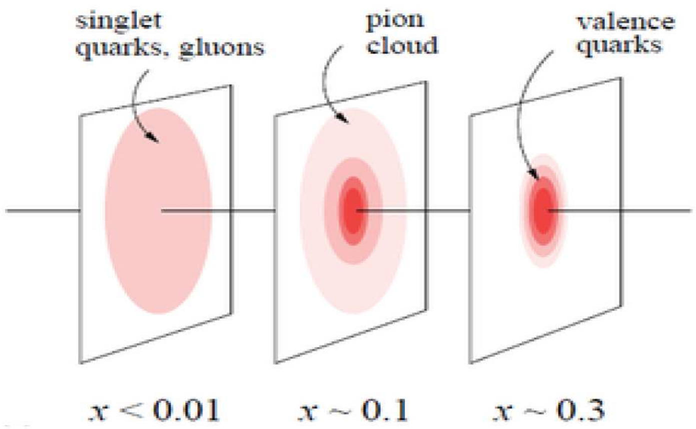
Signal of DVCS

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

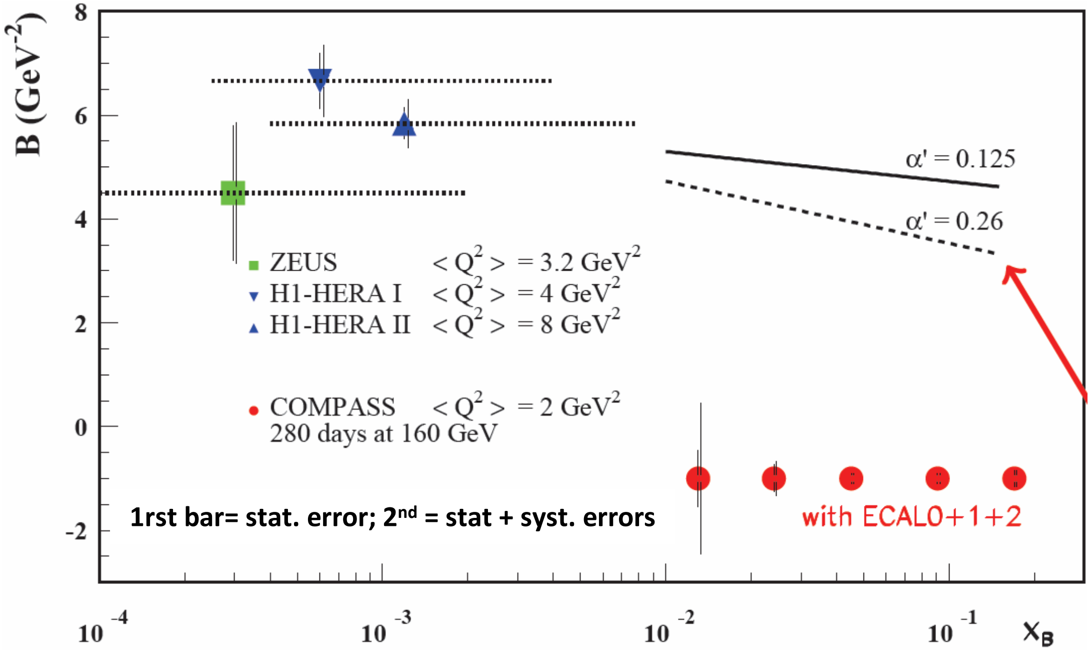
- Measure $S_{CS,U} = (d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow})$
- Subtract Bethe-Heitler (BH)
- Integrate over ϕ

$d\sigma_{DVCS}/dt \sim \exp(-B|t|)$

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



Predictions from COMPASS-II proposal for 40 weeks in 2016-17

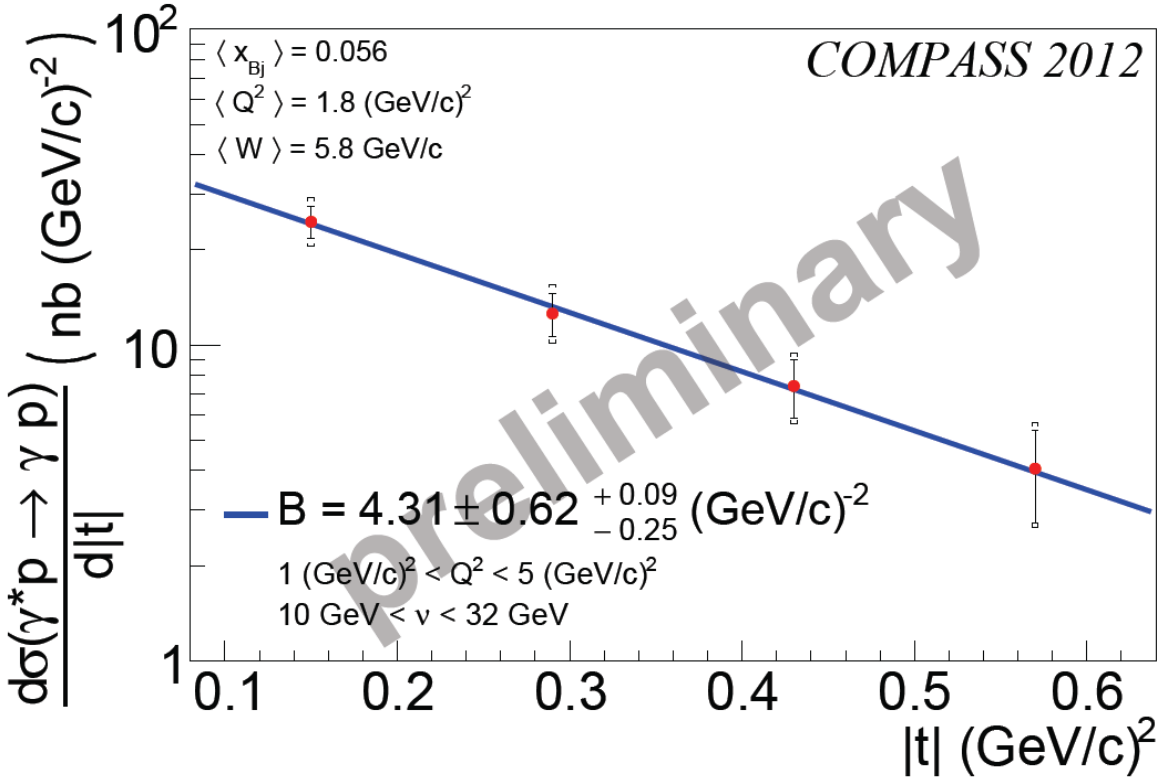


ansatz at small x_B inspired by Regge Phenomenology:

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

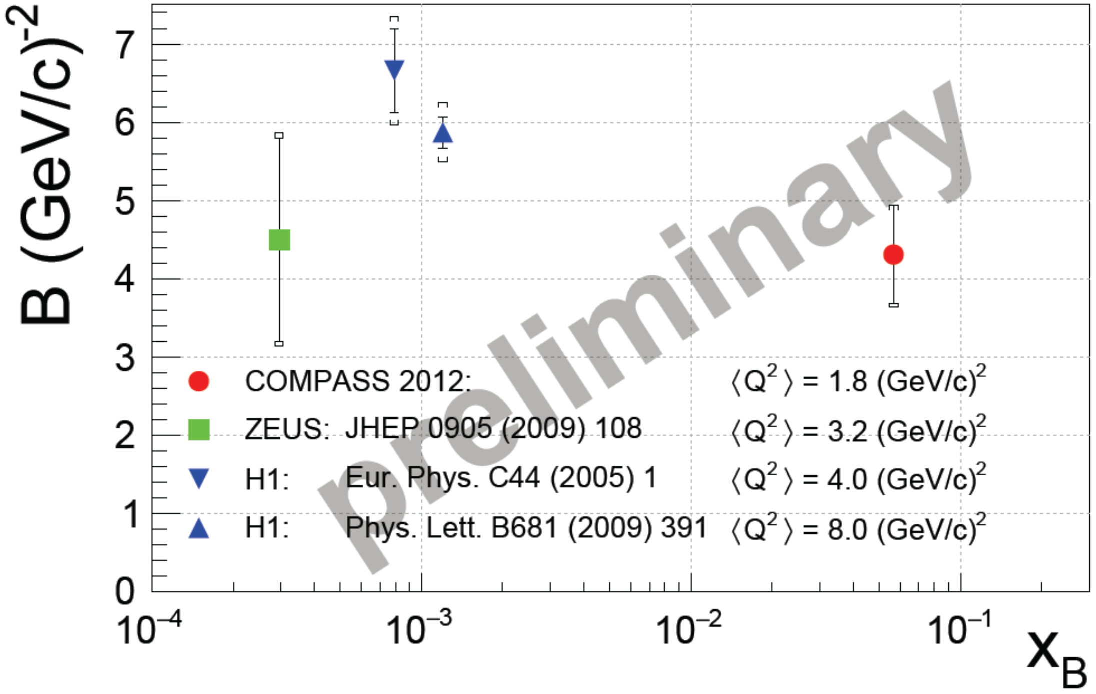
α' slope of Regge traject.

DVCS cross section and t-slope



Comparison of t-slope B to HERA results

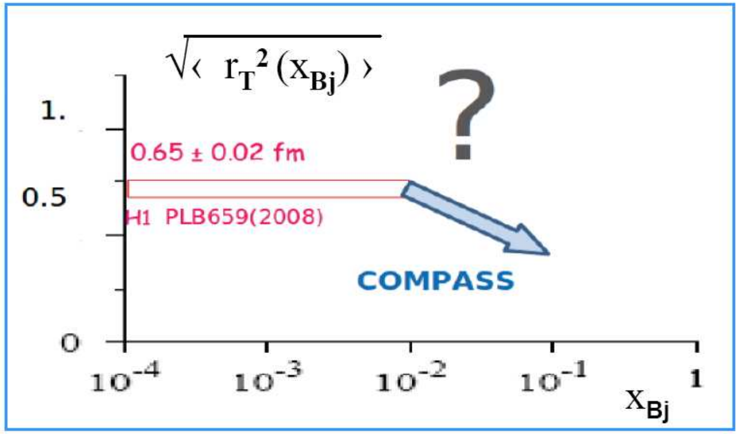
Model independent result



From 3 weeks of 2012 commissioning data

the first measurement of B-slope for DVCS

at x_{Bj} above HERA range



COMPASS-II time lines

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

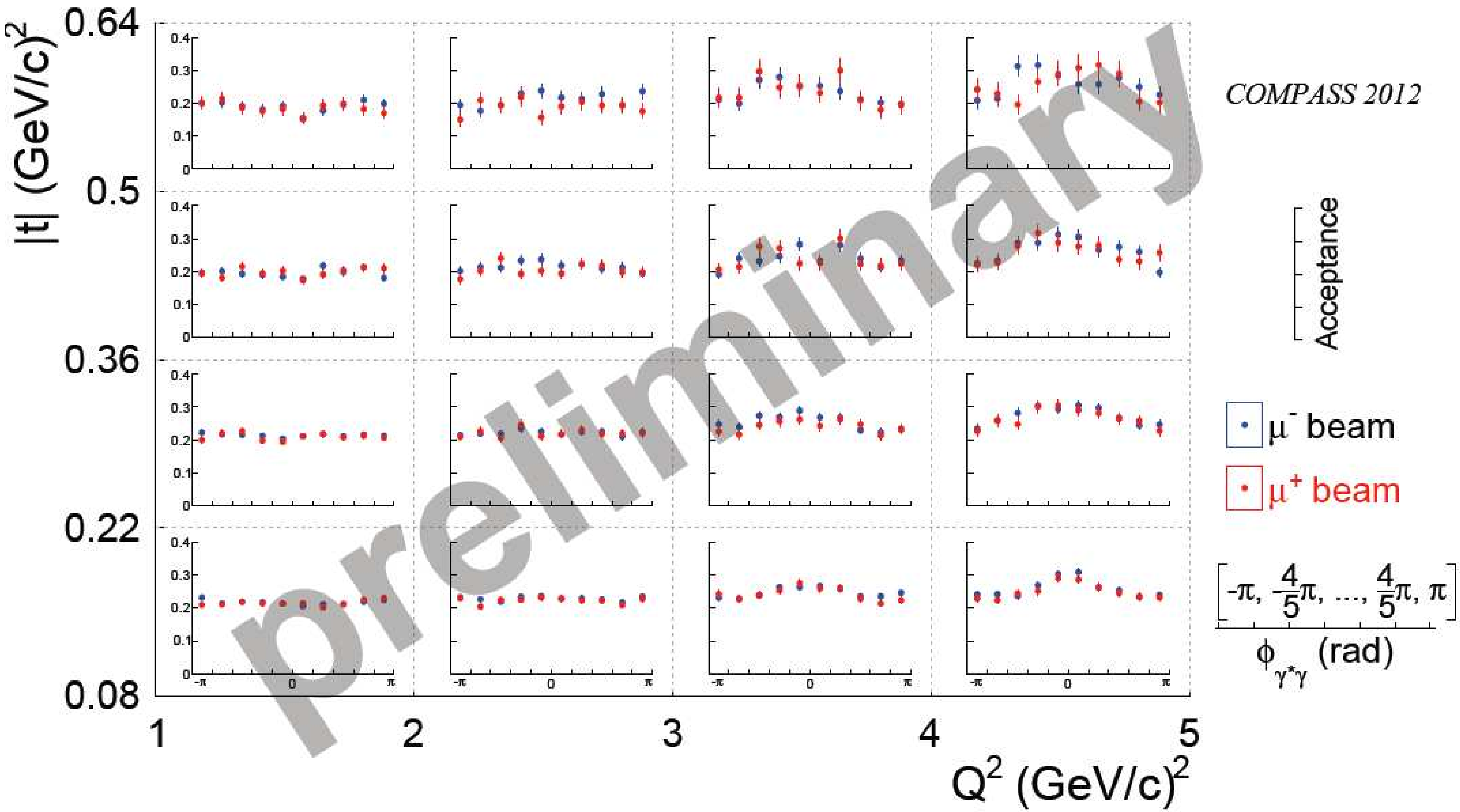
- 2012: pion and kaon polarisabilities (Primakoff) + comissioning and pilot run for DVCS
- 2013-2014: long SPS/LHC shutdown
- 2014-2015: Drell-Yan measurements with transversely polarised protons (NH_3 target)
- 2016-2017: stage 1 of GPD program and in parallel SIDIS (LH target)
- 2018: Drell-Yan measurements with transversely polarised protons (NH_3 target)

Measurements to be pursued at COMPASS-II > 2020 (subject to a new proposal)

- ✓ stage 2 of GPD program with transversely polarised NH_3 target and RPD
- ✓ SIDIS (high statistics) from transversely polarised deuteron and proton targets
- ✓ Drell-Yan on transversely polarised deuterons, unpolarised protons and nuclear targets
- ✓ hadron spectroscopy program with high-intensity separated kaon and antiproton beams

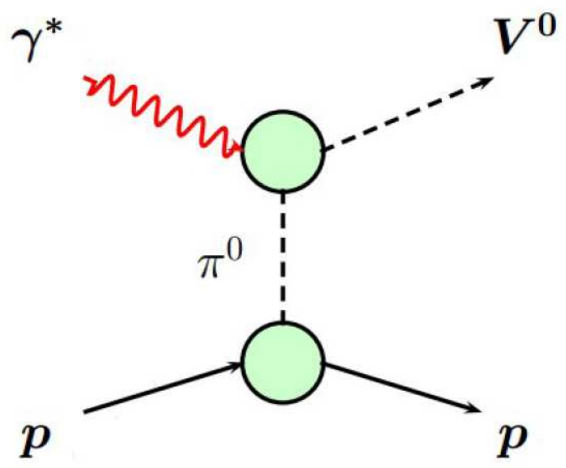
Backup

COMPASS acceptance for DVCS (1)

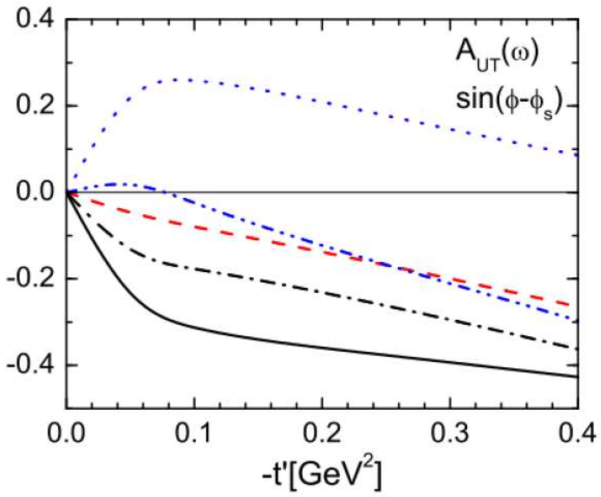


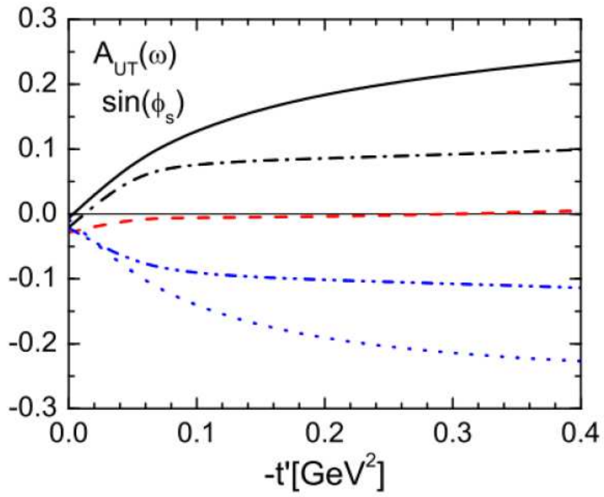
Symmetric acceptance in ϕ leads to cancellation of the interference terms when integrated over ϕ

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





@ W=4.8 GeV, Q^2=2.42 GeV^2
positive $\pi\omega$ form factor
no pion pole
negative $\pi\omega$ form factor

@ W=8 GeV, Q^2=2.42 GeV^2
positive $\pi\omega$ form factor
negative $\pi\omega$ form factor