Deeply virtual exclusive production of mesons at COMPASS

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Towards improved hadron tomography with hard exclusive reactions

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- Exclusive π^0 production and chiral-odd GPDs
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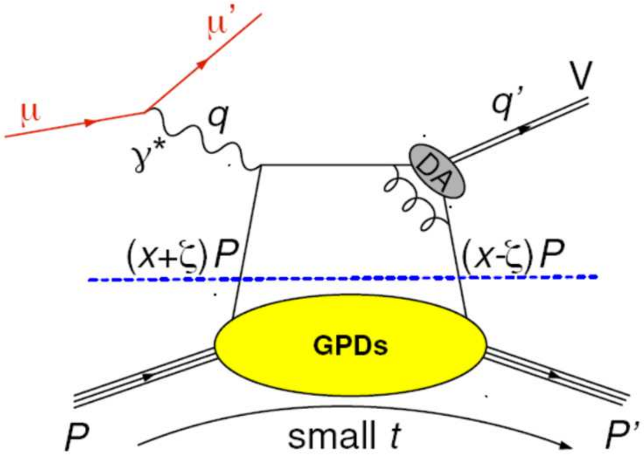
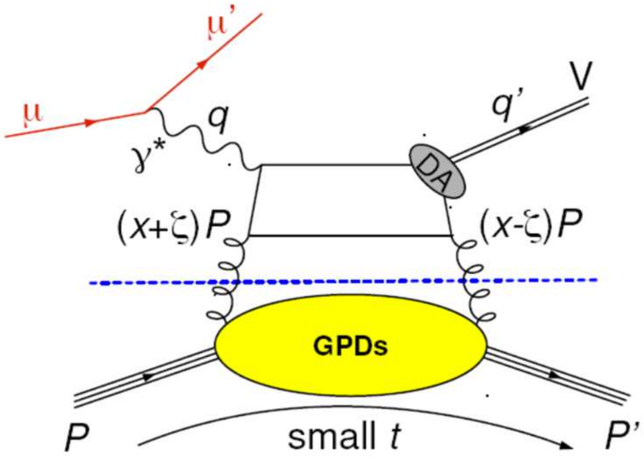
GPDs and Hard Exclusive Meson Production

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:

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

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

$$E_{\varphi} = -\frac{1}{3}E^s - \frac{1}{8}E^g$$

for VMs contribution from gluons at the same order of α_s as from quarks

COMPASS experiment at CERN

Basic ingredients of versatile COMPASS experimental setup

- **secondary beam line M2 from the SPS**

  delivers:
  - high energy polarised μ^+ or μ^- beams
  - negative or positive hadron beams

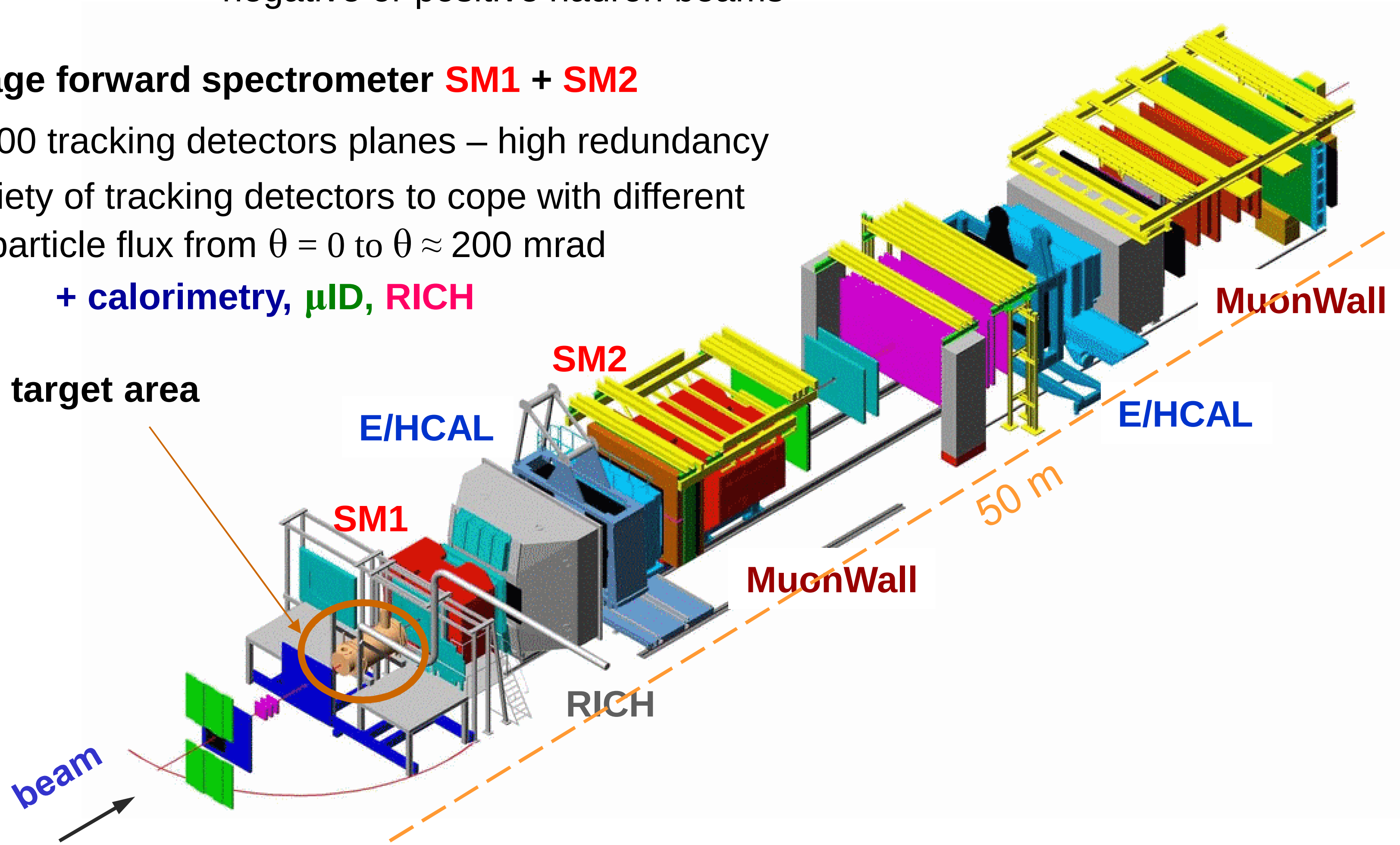
- **two-stage forward spectrometer SM1 + SM2**

  ≈ 300 tracking detectors planes – high redundancy

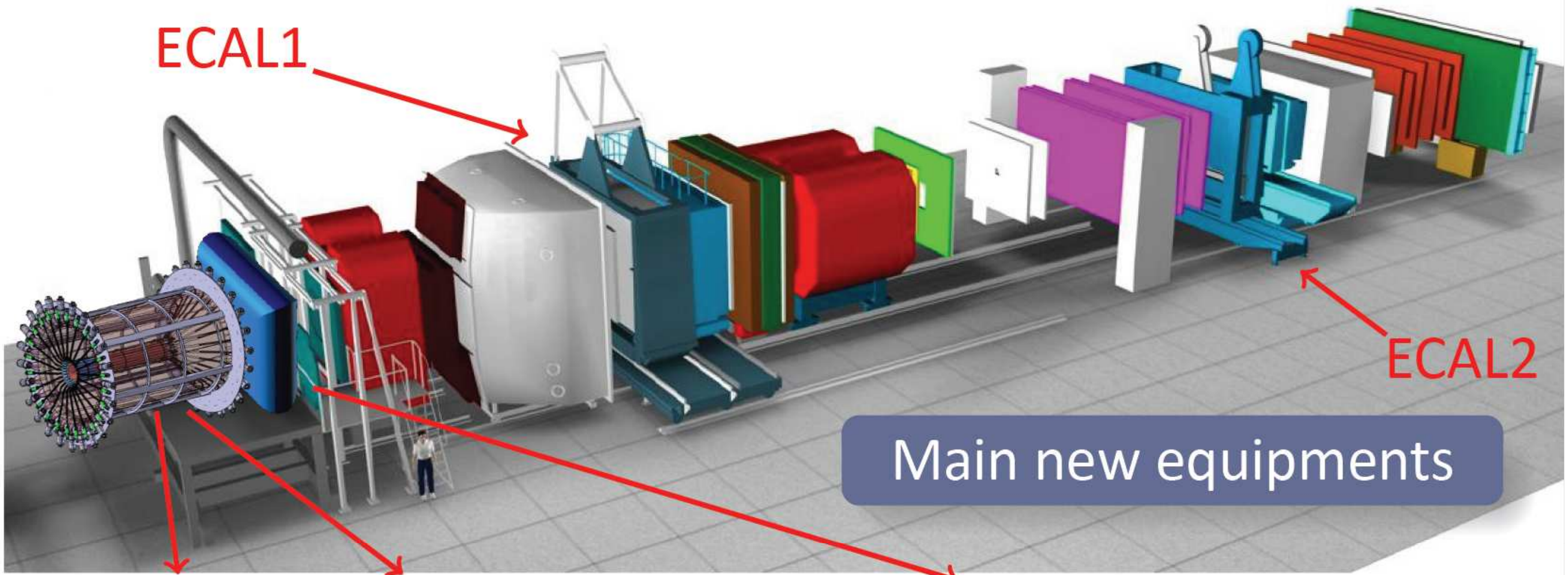
  variety of tracking detectors to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad

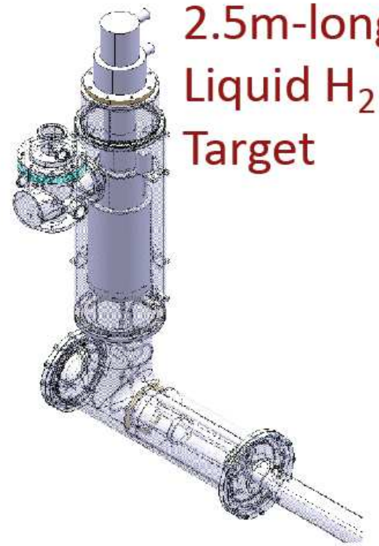
  + calorimetry, µID, RICH

- **flexible target area**



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

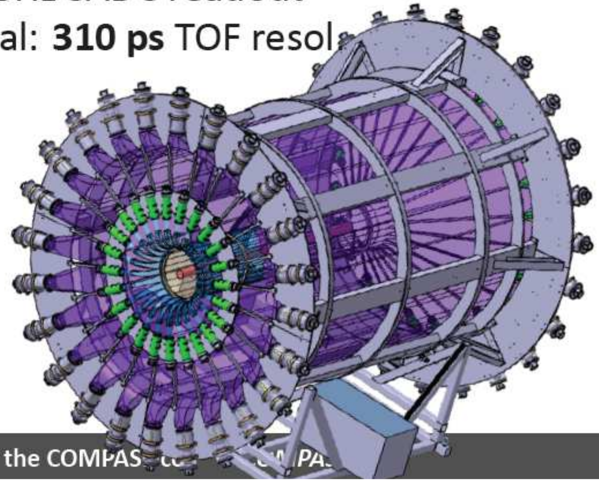




2.5m-long Liquid H_2 Target

Target TOF System

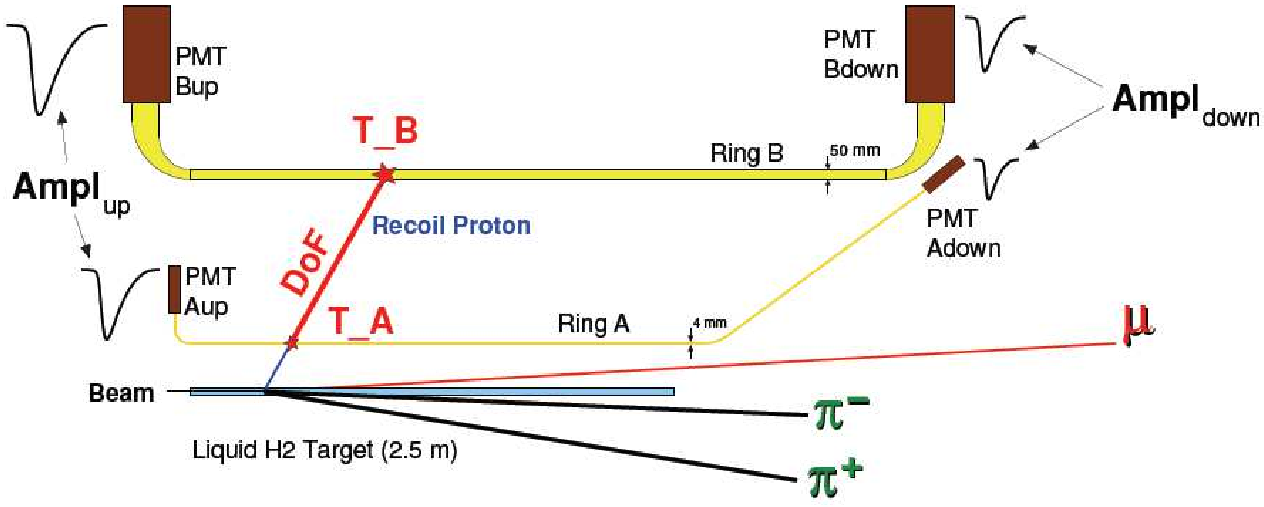
24 inner & outer scintillators
1 GHz SADC readout
goal: **310 ps** TOF resol

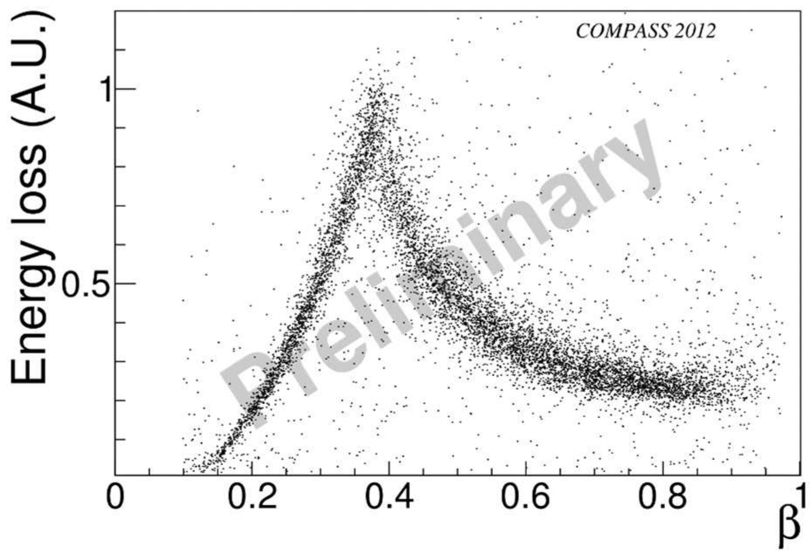


ECAL0 Calorimeter

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

Recoil particle reconstruction in CAMERA





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

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

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

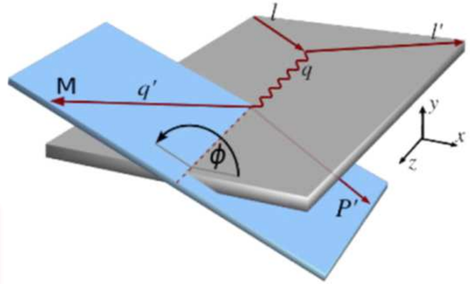
$\beta = DoF / ToF$

- Proton signature clearly visible after exclusivity selections

Hard Exclusive π^0 Production on Unpolarised Protons and Chiral-Odd (quark helicity-flip) GPDs

Exclusive π^0 production on unpolarised protons

$$\left[\frac{\alpha_{em}}{8\pi^3}\frac{y^2}{1-\varepsilon}\frac{1-x_{Bj}}{x_{Bj}}\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_{Bj}\,dQ^2\,dt\,d\phi}=$$



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

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

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

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

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 γ^* p → V p' with photon helicity *m* and target proton helicity *i*

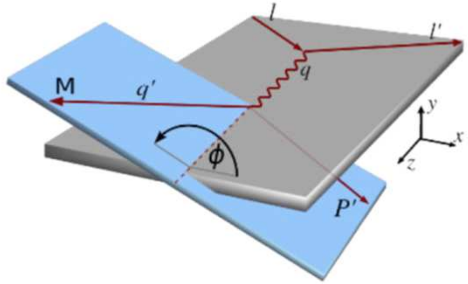
muon polarisation dependence cancels in $S_{CS,U}=[d\sigma(\mu^+)+d\sigma(\mu^-)]/2$

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

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

GPDs in exclusive π^0 production on unpolarised protons

$$\frac{d^2\sigma}{dt\,d\phi} = \frac{1}{2\pi}\left[\frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt} + \varepsilon\cos 2\phi\frac{d\sigma_{TT}}{dt} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi\frac{d\sigma_{LT}}{dt}\right]$$



$$\frac{d\sigma_L}{dt} = \frac{4\pi\alpha}{k'}\frac{1}{Q^6}\left\{(1-\xi^2)\left|\langle\tilde{H}\rangle\right|^2 - 2\xi^2\mathrm{Re}\left[\langle\tilde{H}\rangle^*\langle\tilde{E}\rangle\right] - \frac{t'}{4m^2}\xi^2\left|\langle\tilde{E}\rangle\right|^2\right\}$$

leading twist
at JLAB only few% of $\frac{d\sigma_T}{dt}$

other contributions arise from coupling
of chiral-odd (quark helicity-flip) GPDs to twist-3 pion amplitude

$$\frac{d\sigma_T}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\left[(1-\xi^2)\left|\langle H_T\rangle\right|^2 - \frac{t'}{8m^2}\left|\langle\bar{E}_T\rangle\right|^2\right]$$

def. $\bar{E}_T = 2\tilde{H}_T + E_T$

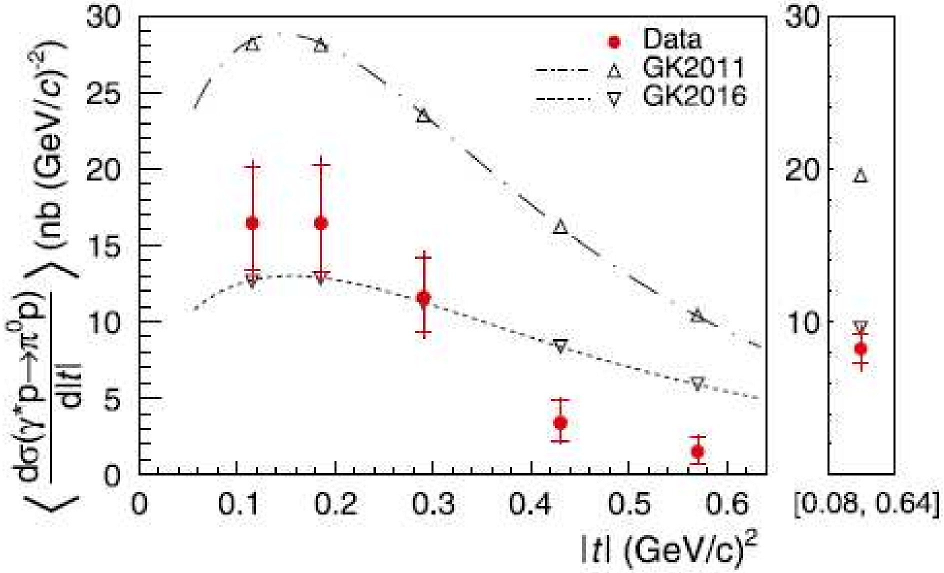
$$\frac{\sigma_{LT}}{dt} = \frac{4\pi\alpha}{\sqrt{2}k'}\frac{\mu_\pi}{Q^7}\xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\mathrm{Re}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

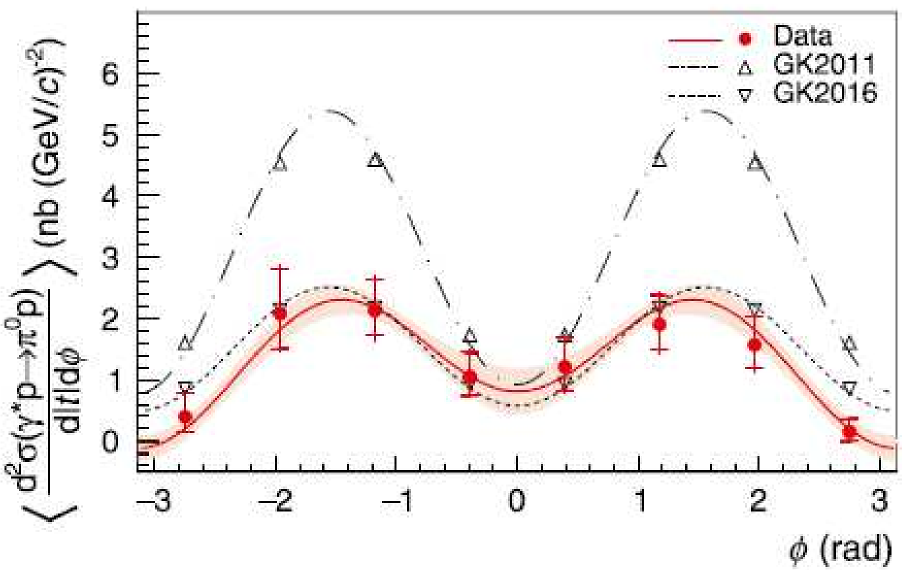
$$\frac{\sigma_{TT}}{dt} = \frac{4\pi\alpha}{k'}\frac{\mu_\pi^2}{Q^8}\frac{t'}{16m^2}\left|\langle\bar{E}_T\rangle\right|^2$$

An impact of $\bar{E}_T$ should be visible in $\frac{\sigma_{TT}}{dt}$

and in a dip at small t' of $\frac{d\sigma_T}{dt}$

Sensitivity for constraining GPD models; an example





8.5 GeV < ν < 28.0 GeV
1.0 (GeV/c)^2 < Q^2 < **5.0** (GeV/c)^2

Data 2012 (pilot run): PLB 805 (2020) 135454

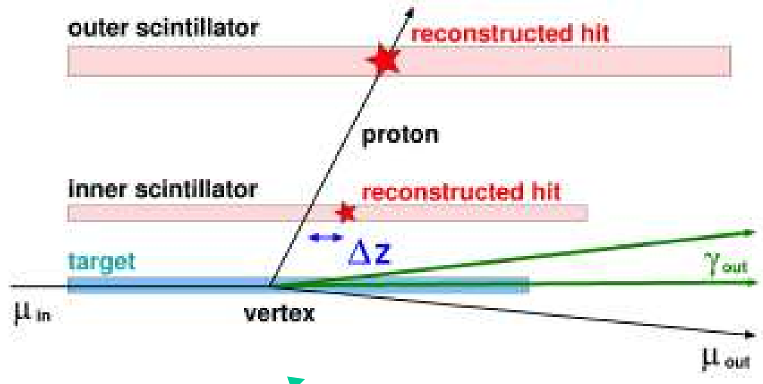
GK2011: EPJA 47 (2011) 112

GK2016: updated GK model, private comm.

Recent preliminary results from exclusive π° analysis of 2016 data

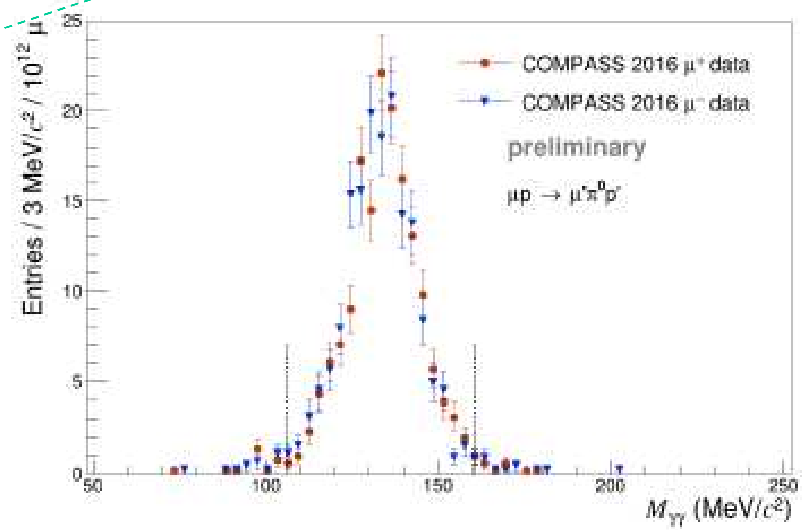
Exclusive π^0 production: Selection

- Incoming and outgoing μ connected to primary vertex
- Two photons in ECALs from π^0 decay
- Recoil proton candidate
- $1 < Q^2 < 8\ (\mathrm{GeV}/c)^2$, $6.4 < \nu < 40$ GeV, $0.08 < |t| < 0.64\ (\mathrm{GeV}/c)^2$

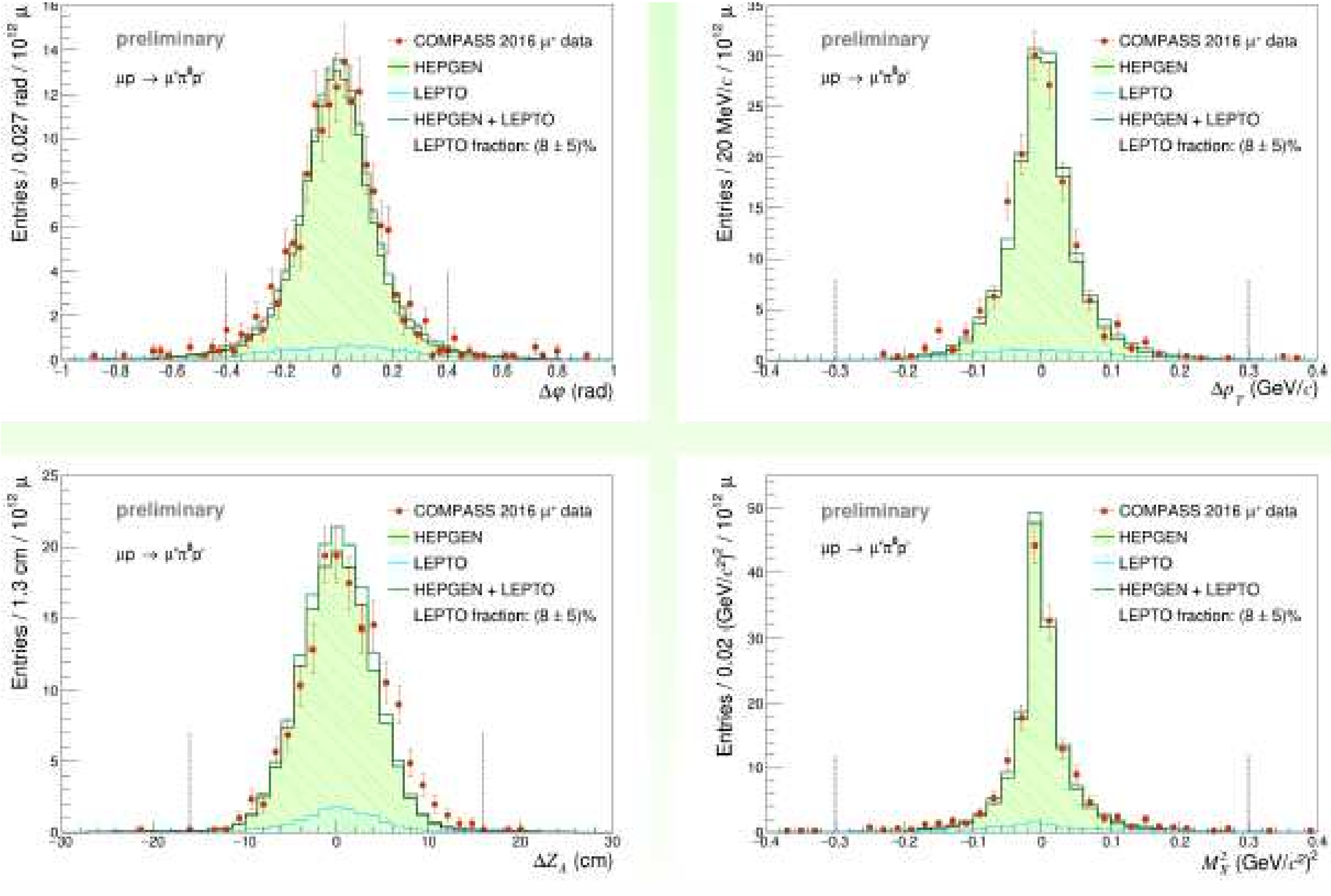


Selections for exclusive π^0 events:

- Transverse momentum constraint: $\Delta p_T = p^p_{T,spect} - p^p_{T,recoil}$
- $\Delta\varphi = \varphi^p_{spect} - \varphi^p_{recoil}$
- Z coordinate of inner CAMERA ring: Δz
- Energy-momentum conservation: $M_X^2 = (p_\mu + p_p - p_{\mu'} - p_{p'} - p_{\pi^0})^2$
- Invariant mass $M_{\gamma\gamma}$ cut
- Kinematic fit of reaction $\mu p \to \mu' p' \pi^0$

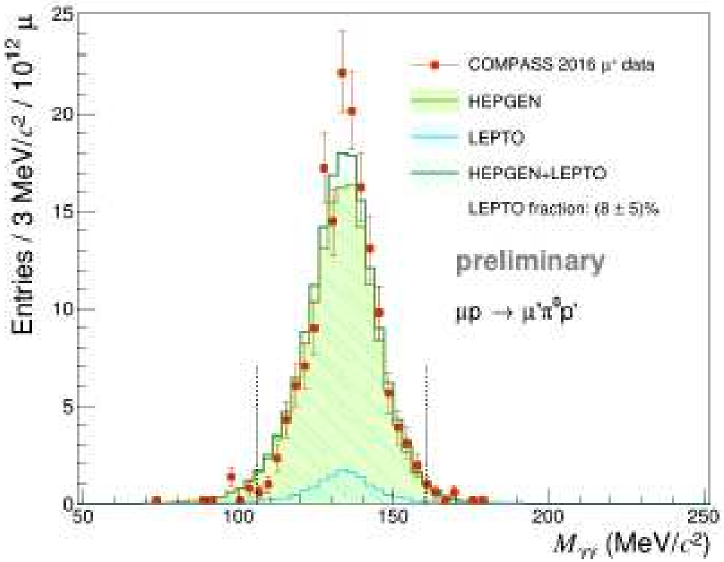


Distributions of „exclusivity variables"



SIDIS background estimate

- Main background of π^0 production $\Rightarrow$ non-exclusive DIS processes
- 2 Monte Carlo simulations with the same π^0 selection criteria:
  - LEPTO for the non-exclusive background
  - HEPGEN++ shape of distributions of exclusive π^0 production (signal contribution)
- Both MC samples normalised to the experimental $M_{\gamma\gamma}$ distribution
- The fraction of background events r_{LEPTO} from fitting MC mixture on the exclusivity distributions



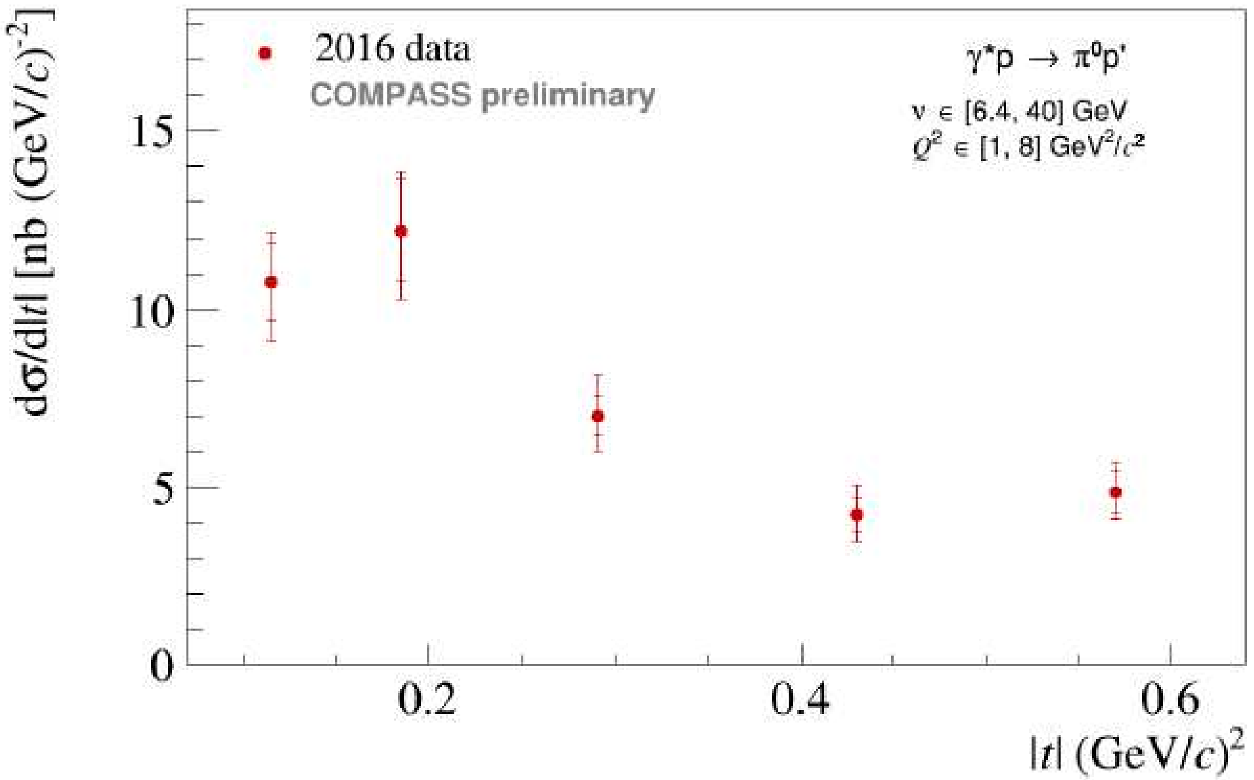
- Fraction of non-exclusive background in data $\Rightarrow$ $(8 \pm 5)\,\%$
- Background fit method is the main source of systematic uncertainty

Exclusive π^0 production cross section as a function of $|t|$

$$\frac{d\sigma}{dt} = \frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt}$$

At small |t| an impact of $\bar{E}_T$ contribution in $\frac{d\sigma_T}{dt}$

- Differential $\gamma^* p \to p'\pi^0$ cross-section as function of $|t|$, integrated over ϕ
- Newest 2016 data release

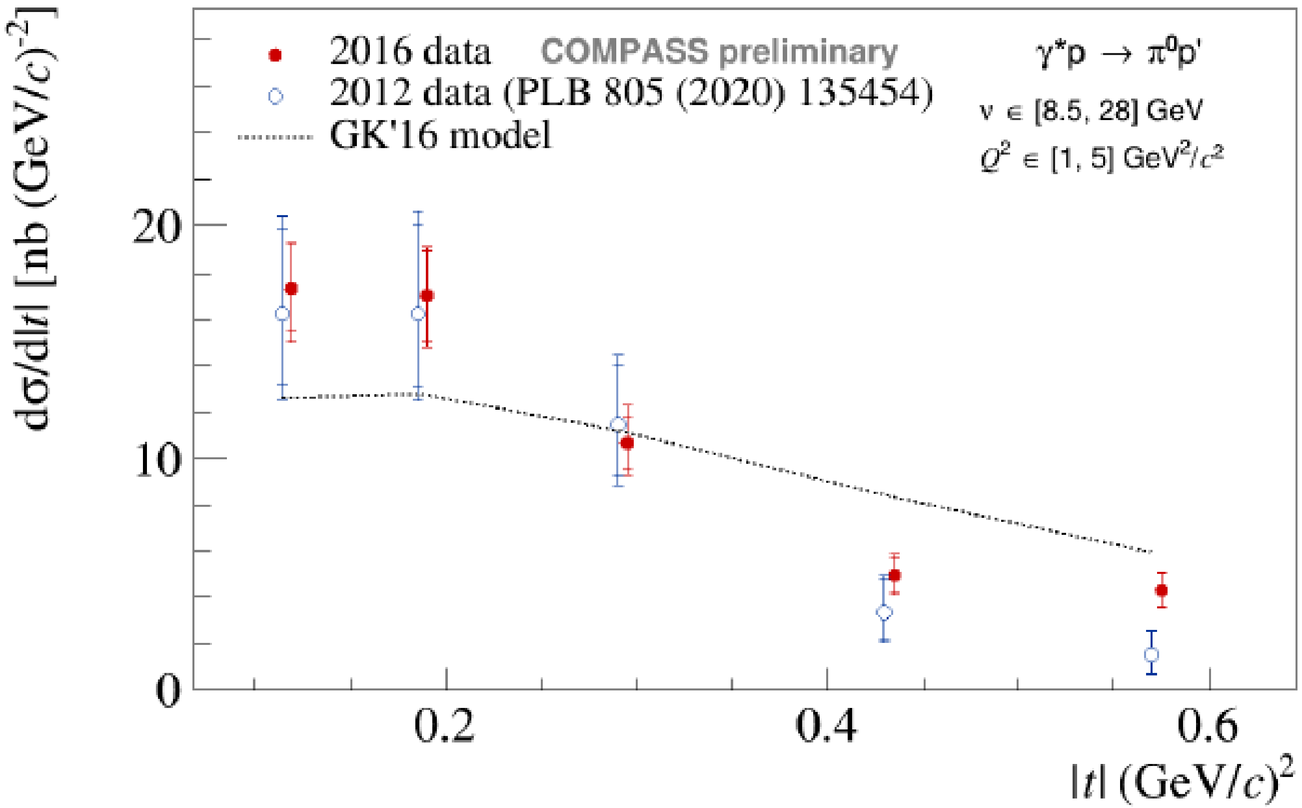


Comparison to the published results from 2012

$$\frac{d\sigma}{dt} = \frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt}$$

For the comparison the 2016 data are shown at the kinematic range of 2012 data

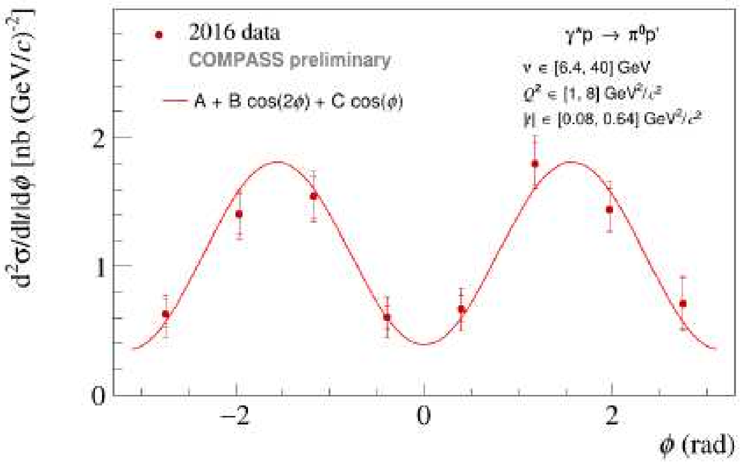
- Newest 2016 data release



Exclusive π^0 production cross section as a function of ϕ

- Newest 2016 data release
- Differential $\gamma^* p \to p'\pi^0$ cross-section as function of ϕ, averaged over $|t|$:

$$\frac{d^2\sigma_{\gamma^* p}}{dt d\phi} = \frac{1}{2\pi}\left[\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \epsilon\cos(2\phi)\frac{d\sigma_{TT}}{dt} + \sqrt{\epsilon(1+\epsilon)}\cos\phi\frac{d\sigma_{LT}}{dt}\right]$$



$$\left\langle \frac{\sigma_T}{|t|} + \epsilon\frac{\sigma_L}{|t|}\right\rangle = (6.9 \pm 0.3_{stat} \pm 0.8_{syst})\frac{nb}{(GeV/c)^2}$$

$$\left\langle \frac{\sigma_{TT}}{|t|}\right\rangle = (-4.5 \pm 0.5_{stat} \pm 0.2_{syst})\frac{nb}{(GeV/c)^2}$$

$$\left\langle \frac{\sigma_{LT}}{|t|}\right\rangle = (0.06 \pm 0.2_{stat} \pm 0.1_{syst})\frac{nb}{(GeV/c)^2}$$

An impact of $\overline{E}_T$ visible in $\frac{\sigma_{TT}}{dt}$

Spin Density Matrix Elements
in Exclusive Vector Meson Production on unpolarised protons

Vector meson spin-density matrix

helicity of vector meson *V*

helicities of virtual photon γ and nucleon *N*

photon spin density matrix ($\mu \to \mu + \gamma^*$); calculable in QED

$$\rho_{\lambda_V \lambda'_V} = \frac{1}{2\mathcal{N}} \sum_{\lambda_\gamma \lambda'_\gamma \lambda_N \lambda'_N} F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} \varrho^{U+L}_{\lambda_\gamma \lambda'_\gamma} F^*_{\lambda'_V \lambda'_N \lambda'_\gamma \lambda_N}$$

(von Neuman)

F helicity amplitudes; describe transitions $\lambda_\gamma, \lambda_N \to \lambda_V, \lambda'_N$, depend on W, Q^2 and p_T

- $\rho_{\lambda_V \lambda'_V}$ decomposes into nine matrices $\rho^{\alpha}_{\lambda_V \lambda'_V}$ corresponding to different photon polarisation states

  α = 0 – 3 - transv., 4 - long,, 5 – 8 - interf.

- Another notation: when contributions from transverse and longitudinal photons cannot be separeted

  notation introduced in (K.Schilling and K. Wolf, NP B 61 (1973) 381)

$$r^{04}_{\lambda_V \lambda'_V} = (\rho^0_{\lambda_V \lambda'_V} + \epsilon R \rho^4_{\lambda_V \lambda'_V})(1+\epsilon R)^{-1},$$

$$r^{\alpha}_{\lambda_V \lambda'_V} = \begin{cases} \rho^{\alpha}_{\lambda_V \lambda'_V} (1+\epsilon R)^{-1}, & \alpha = 1,2,3, \\ \sqrt{R}\rho^{\alpha}_{\lambda_V \lambda'_V} (1+\epsilon R)^{-1}, & \alpha = 5,6,7,8. \end{cases}$$

$R = \sigma_L / \sigma_T$

Vector meson spin-density matrix (2)

Access to helicity amplitudes allows:

- test of s-channel helicity conservation (SCHC) ($\lambda_\gamma = \lambda_V$)
- quantify the role of transitions with helicity flip
- decomposition into Natural (N) Parity and Unnatural (U) Parity exchange amplitudes

$$F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} = T_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} + U_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N}$$

  - e.g. in Regge framework NPE: $J^P = (0^+, 1^-, \ldots)$ (pomeron, ρ, ω, a_2 … reggeons)
    UPE: $J^P = (0^-, 1^+, \ldots)$ (π, a_1, b_1… reggeons)
- tests of GPD models
  - e.g. for SCHC-violating transitions $\gamma_T \rightarrow V_L$ test sensitivity to GPDs with exchanged-quark helicity flip (transversity GPDs)
- extraction of $R = \sigma_L / \sigma_T$ in the case of SCHC violation

- in the COMASS SDME analyses all above-mentioned tasks are adressed

Experimental access to SDMEs

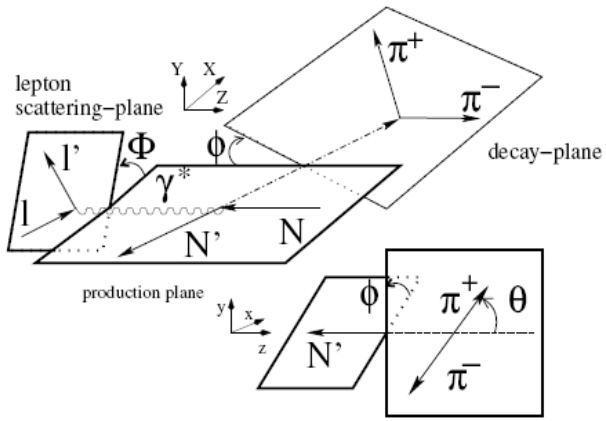
$$W^{U+L}(\Phi,\phi,\cos\Theta) = W^{U}(\Phi,\phi,\cos\Theta) + P_B W^{L}(\Phi,\phi,\cos\Theta) \propto \frac{d\sigma}{d\Phi\, d\phi\, d\cos\Theta}$$

$$\begin{aligned}
W^U = \frac{3}{8\pi^2}\Bigg[& \frac{1}{2}(1 - r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00} - 1)\cos^2\Theta - \sqrt{2}\mathrm{Re}(r^{04}_{10})\sin 2\Theta\cos\phi - r^{04}_{1-1}\sin^2\Theta\cos 2\phi \\
& - \epsilon\cos 2\Phi\left(r^1_{11}\sin^2\Theta + r^1_{00}\cos^2\Theta - \sqrt{2}\mathrm{Re}(r^1_{10})\sin 2\Theta\cos\phi - r^1_{1-1}\sin^2\Theta\cos 2\phi\right) \\
& - \epsilon\sin 2\Phi\left(\sqrt{2}\mathrm{Im}(r^2_{10})\sin 2\Theta\sin\phi + \mathrm{Im}(r^2_{1-1})\sin^2\Theta\cos\phi\right) \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos\Phi\left(r^5_{11}\sin^2\Theta + r^5_{00}\cos^2\Theta - \sqrt{2}\mathrm{Re}(r^5_{10})\sin 2\Theta\cos\phi - r^5_{1-1}\sin^2\Theta\, cos2\phi\right) \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin\Phi\left(\sqrt{2}\mathrm{Im}(r^6_{10})\sin 2\Theta\sin\phi + \mathrm{Im}(r^3_{1-1})\sin^2\Theta\sin 2\phi\right)\Bigg]
\end{aligned}$$

$$\begin{aligned}
W^L = \frac{3}{8\pi^2}\Bigg[& \sqrt{1-\epsilon^2}\left(\sqrt{2}\mathrm{Im}(r^3_{10})\sin 2\Theta\sin\phi + \mathrm{Im}(r^3_{1-1})\sin^2\Theta\sin 2\phi\right) \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos\Phi\left(\sqrt{2}\mathrm{Im}(r^7_{10})\sin 2\Theta\sin\phi + \mathrm{Im}(r^7_{1-1})\sin^2\Theta\sin 2\phi\right) \\
& + \sqrt{2\epsilon(1-\epsilon)}\sin\Phi\Big(r^8_{11}\sin^2\Theta + r^8_{00}\cos^2\Theta \\
& - \sqrt{2}\mathrm{Re}(r^8_{10})\sin 2\Theta\cos\phi \\
& - r^8_{1-1}\sin^2\Theta\cos 2\phi\Big)\Bigg]
\end{aligned}$$

[K. Schilling and G. Wolf, Nucl. Phys. B61, 381 (1973)]

for ρ^0



for ω : angle Θ between direction of ω and normal to decay plane

Data and selected samples

- Data collected within four weeks in 2012
  using 2,5 m long LH2 target
- Data with polarised (|P| ≈ 0.8) μ^+ and μ^- beams taken separately

- Independent analyses of two samples:

(i) $\mu p \rightarrow \mu' p' \rho^0$ ≈ 52 200 evts

$\quad \hookrightarrow \pi^+\pi^-$ $\quad \mathrm{BR} \approx 99\%.$

(ii) $\mu p \rightarrow \mu' p' \omega$ ≈ 3 000 evts

$\quad \hookrightarrow \pi^+\pi^-\pi^0$ $\quad \mathrm{BR} \approx 89\%$

$\quad\quad \hookrightarrow \gamma\gamma$ $\quad \mathrm{BR} \approx 99\%.$

- Results for (i) published in 2023 (EPJC **83**,924 (2023))
- Results for (ii) published in 2021 (EPJC **81**,126 (2021))

Experimental access to SDMEs (2)

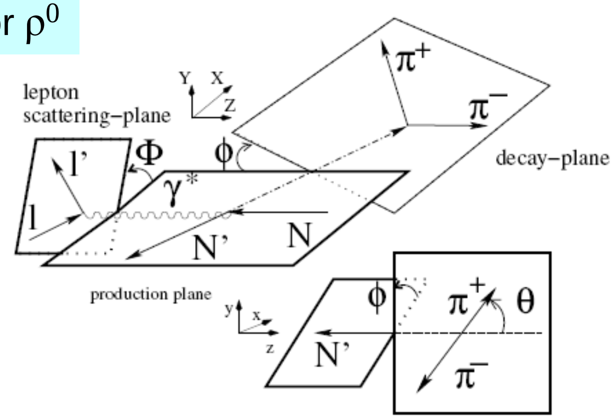
$$W^{U+L}(\Phi,\phi,\cos\Theta) = W^{U}(\Phi,\phi,\cos\Theta) + P_B W^{L}(\Phi,\phi,\cos\Theta) \propto \frac{d\sigma}{d\Phi\, d\phi\, d\cos\Theta}$$

SDMEs: „amplitudes" of decomposition of W^{U+L} in the sum of 23 terms with different angular dependences

[K. Schilling and G. Wolf, Nucl. Phys. B61, 381 (1973)]

15 unpolarised SDMEs (in W^{U}) and 8 polarised (in W^{L})

for ρ^0



for ω angle Θ between direction of ω and normal to decay plane

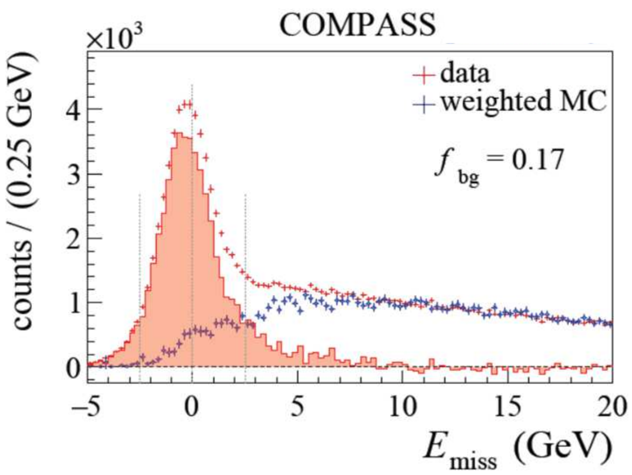
Extraction of SDMEs

- Unbinned ML fit to experimental W^{U+L} taking into account

  • total acceptance

  • fraction of background in the signal window

  • anglar distribution of background W^{U+L}_{bkg} (determined either from LEPTO MC or real data side band)



Results on SDMEs for exclusive ρ^0 production for total kin. range

$1\ GeV^2 < Q^2 < 10\ GeV^2$

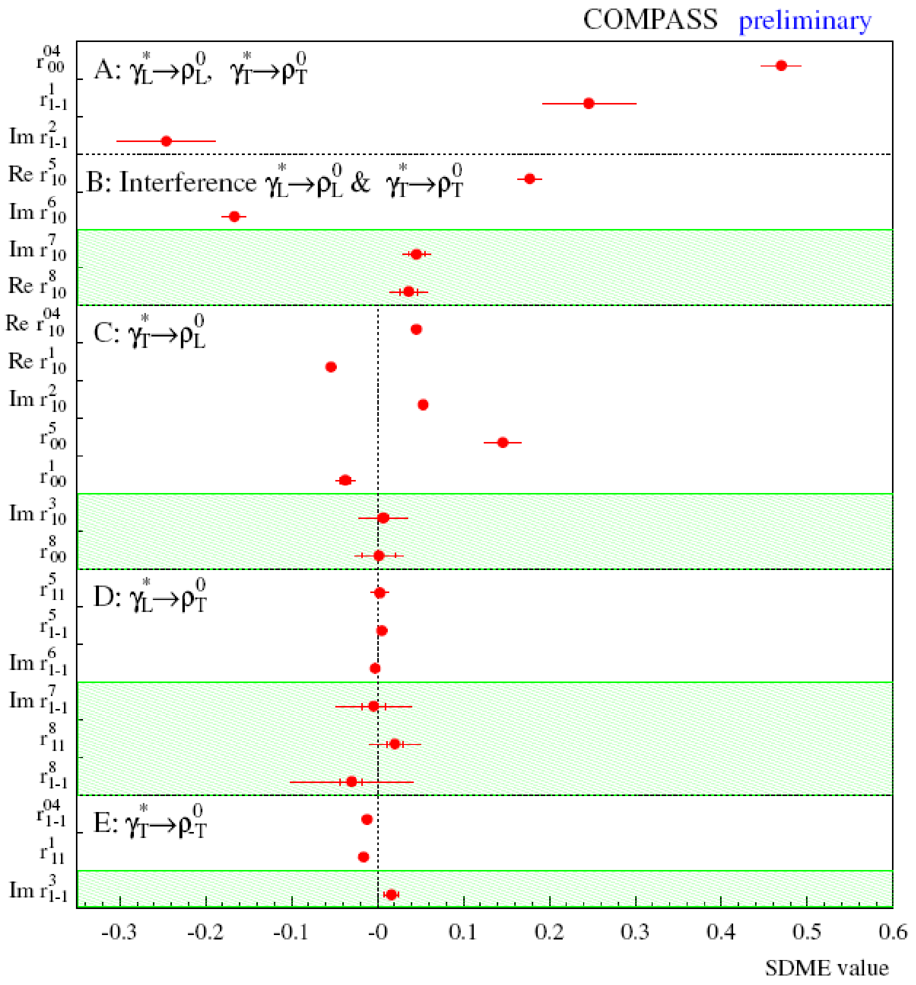
$5\ GeV < W < 17\ GeV$

$0.01\ GeV^2 < p_T^2 < 0.5\ GeV^2$

$< Q^2 > = 2.4\ GeV^2$

$<W> = 9.9\ GeV$

$<p_T^2> = 0.18\ GeV^2$



- SDMEs grouped in clasess: A, B, C, D, E corresponding to different helicity transitions
- SDMEs coupled to the beam polarisation shown within green areas
- if SCHC holds all elements in classes C, D, E should be 0

not obeyed for transitions $\gamma^*_T \to \rho_L$

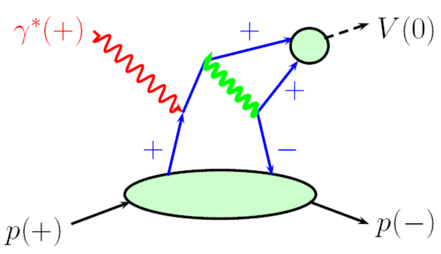
Transitions $\gamma^*_T \to \rho_L$

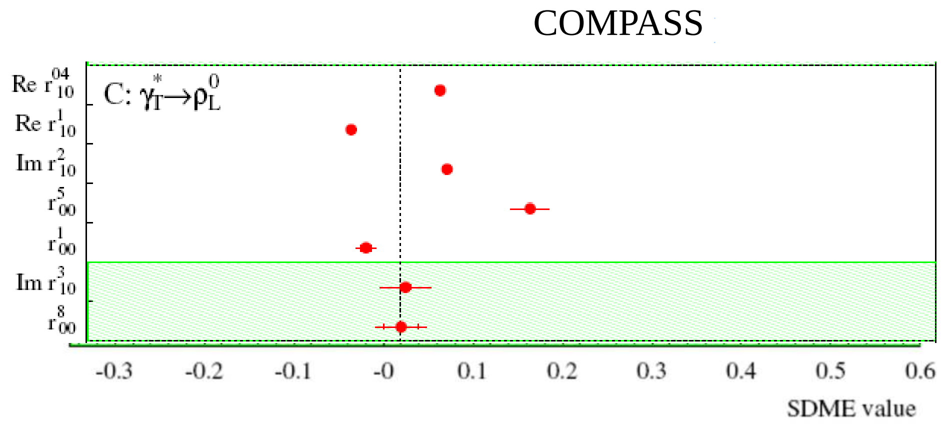
possible GPD interpretation **Goloskokov and Kroll, EPJC 74 (2014) 2725**

contribution of amplitudes depending on chiral-odd ("transversity") GPDs $H_T, \bar{E}_T = 2\tilde{H}_T + E_T$

example

graph for amplitude $F_{0-,++}$

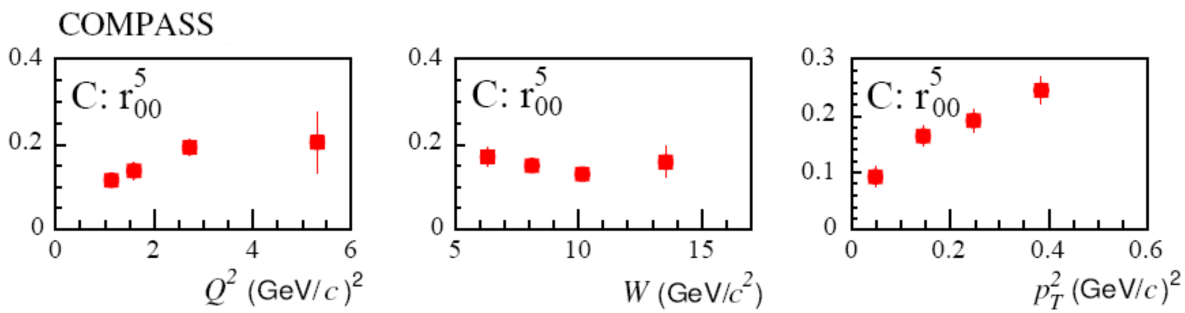




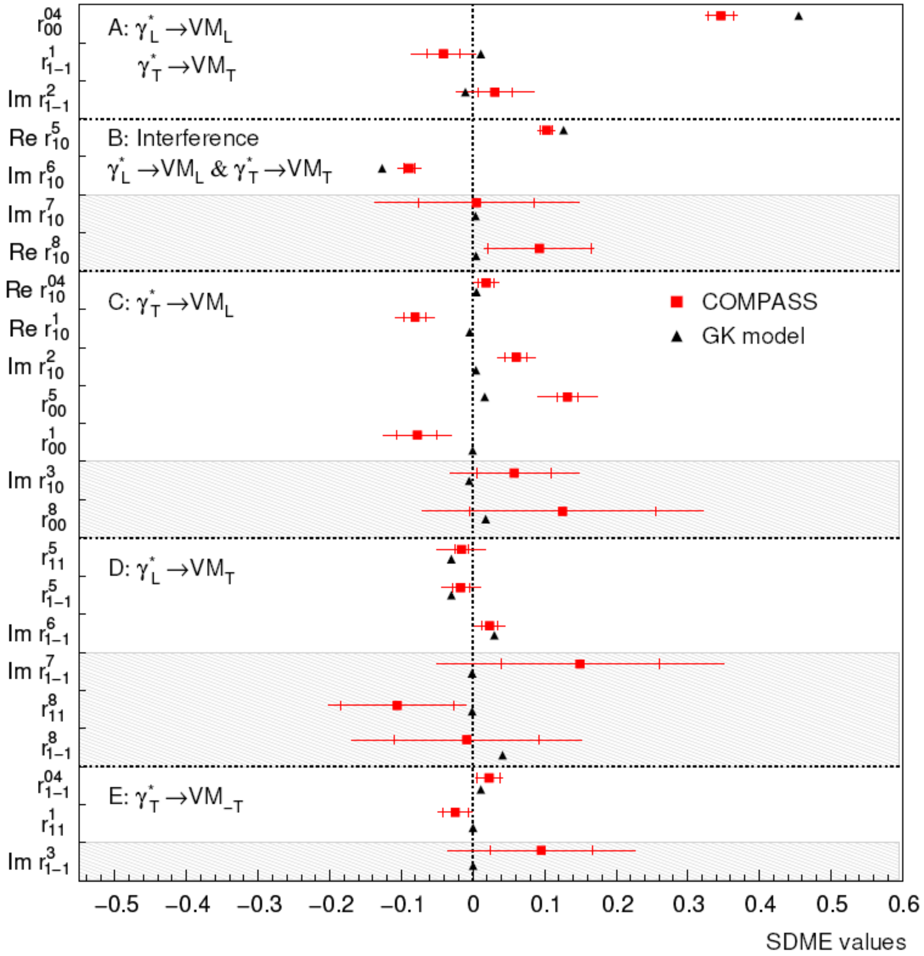
- $r^5_{00} \propto \mathrm{Re}[\langle \bar{E}_T \rangle^*_{LT} \langle H \rangle_{LL} + \frac{1}{2} \langle H_T \rangle^*_{LT} \langle E \rangle_{LL}]$ *Goloskokov and Kroll, ref. above*

interplay of interference of transversity GPDs $H_T, \bar{E}_T = 2\tilde{H}_T + E_T$ with GPDs E and H

for ρ^0 the first term in Eq. (●) dominates, thus r^5_{00} essentially probes $\bar{E}_T$



Results on SDMEs for exclusive ω production for total kin. range



1 GeV² < Q² < 10 GeV²

5 GeV < W < 17 GeV

0.01 GeV² < p_T^2 < 0.5 GeV²

< Q²> = 2.1 GeV²

<W> = 7.6 GeV

<p_T^2> = 0.16 GeV²

GK model, EPJA 50 (2014) 146 (1st version)

parameters constrained mostly by HERMES results for ρ^0 and ω

- COMPASS provides new constraints for parameterisation of the model

- ρ^0 and ω results for class C complementary

● $$r^5_{00} \propto \mathrm{Re}[\langle \bar{E}_T \rangle^*_{LT} \langle H \rangle_{LL} + \frac{1}{2} \langle H_T \rangle^*_{LT} \langle E \rangle_{LL}]$$

$\bar{E}_T$ and H have the same signs for *u* and *d* quarks

H_T and E have opposite signs for *u* and *d* quarks

$< K >_{XY} =$ for ρ^0 $< e_u K_u - e_d K_d + \ldots >_{XY}$

for ω $< e_u K_u + e_d K_d + \ldots >_{XY}$

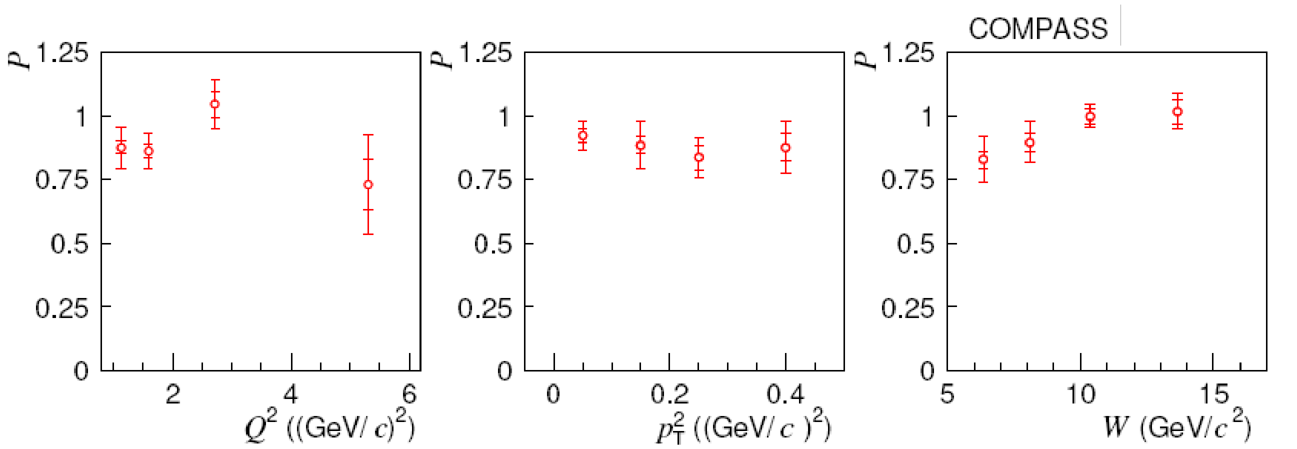
for ω the first term in Eq. (●) still dominates, but sensitivity to H_T is enhanced compared to ρ^0

NPE-to-UPE asymmetry of cross sections

NPE-to-UPE asymmetry of cross sections for transitions $\gamma^*_T \to V_T$

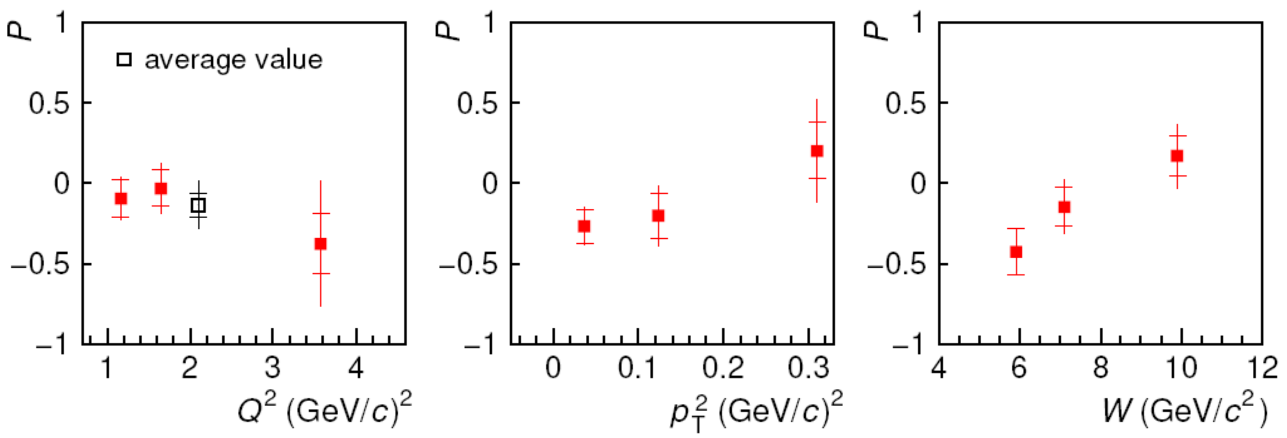
$$P = \frac{2r^1_{1-1}}{1 - r^{04}_{00} - 2r^{04}_{1-1}} \approx \frac{d\sigma^N_T(\gamma^*_T \to V_T) - d\sigma^U_T(\gamma^*_T \to V_T)}{d\sigma^N_T(\gamma^*_T \to V_T) + d\sigma^U_T(\gamma^*_T \to V_T)}$$

ρ^0



- dominance of NPE

ω



- UPE dominates at small W and p^2_T

averaged over kin. range

NPE ≈ UPE

Extraction of *R*

- Most of the previous analyses commonly assumed SCHC hypothesis

In such case $R = \frac{\sigma_L(\gamma_L^* \to V)}{\sigma_T(\gamma_T^* \to V)}$ is approximated by $R' = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1 - r_{00}^{04}}$

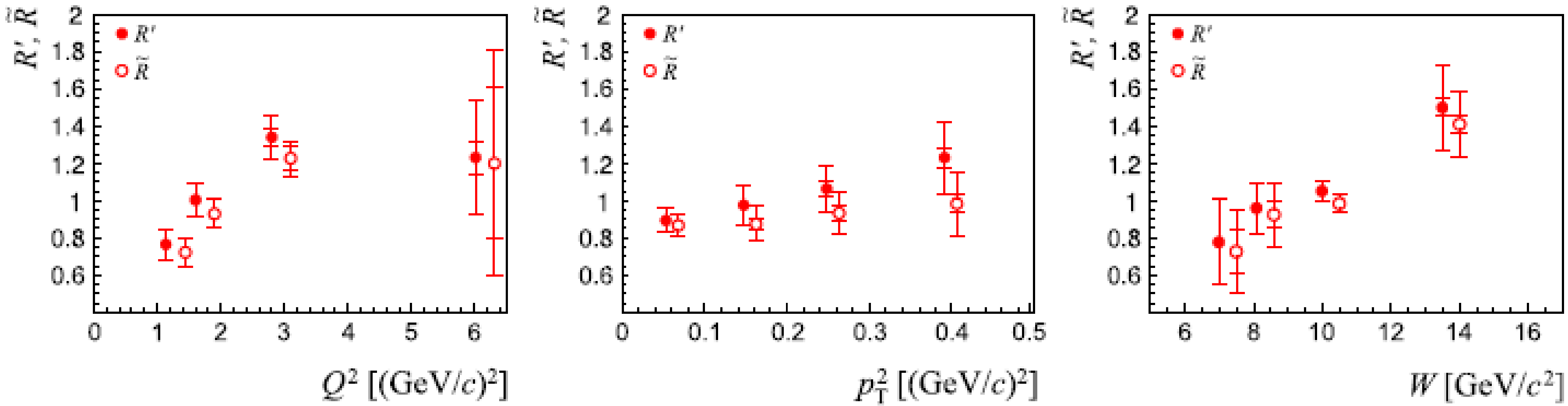
- To include effect of helicity-changing amplitudes one can use $\widetilde{R} = R' - \frac{\eta(1+\epsilon R')}{\epsilon(1+\eta)}$

with $\eta = \frac{(1+\epsilon R')}{N}\widetilde{\sum}\{|T_{01}|^2 + |U_{01}|^2 - 2\epsilon(|T_{10}|^2 + |U_{10}|^2)\}$

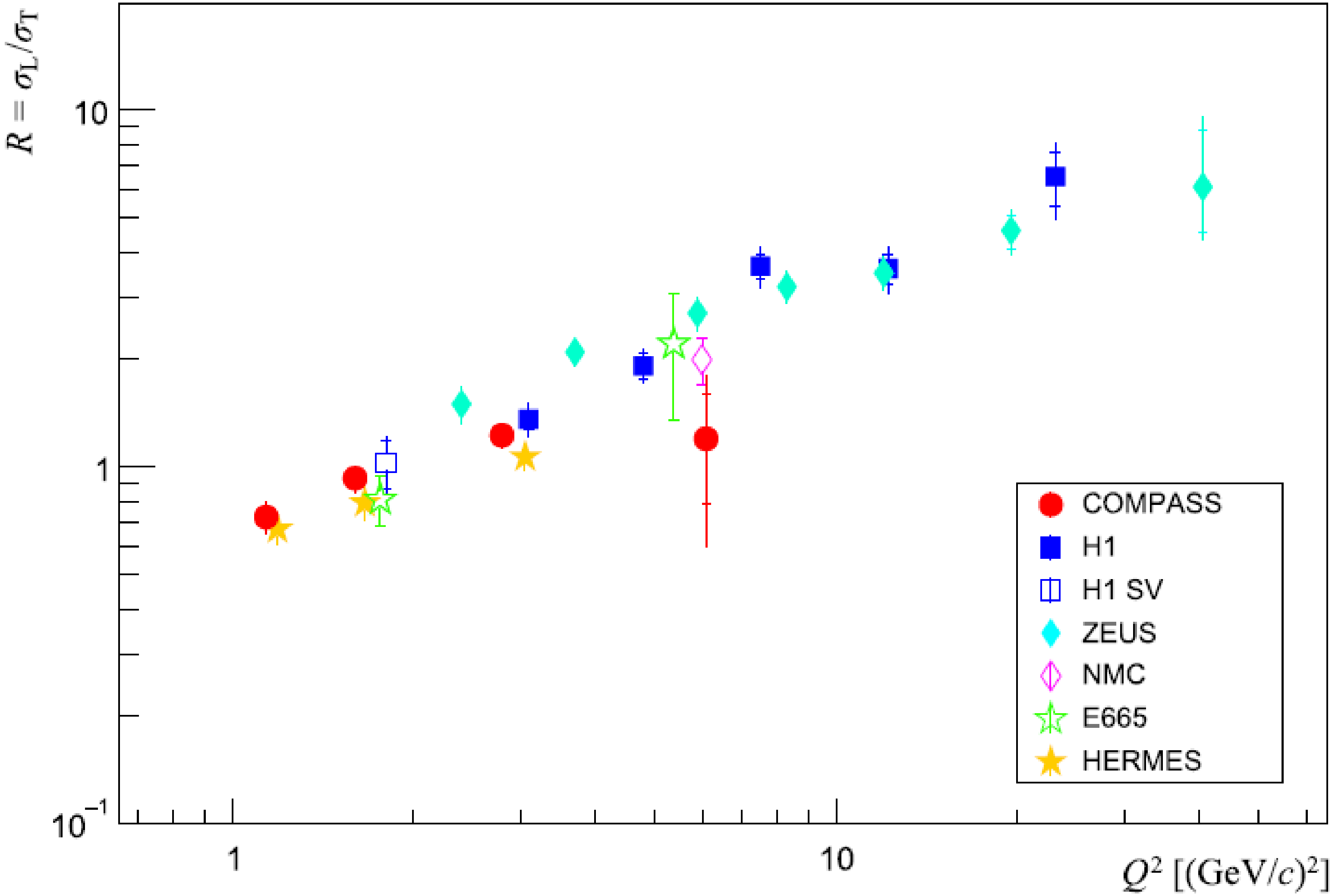
as proposed in A. Airapetian et al. (HERMES Collab.) EPJC **62**, 659 (2009)

η can be approximately estimated as $\eta \approx (1+\epsilon R')(\tau_{01}^2 - 2\epsilon\tau_{10}^2)$ with τ_{01}^2 and τ_{10}^2 denoting fractions of contributions to the cross section from NPE processes $\gamma_T^* \to \rho_L^0$ and $\gamma_L^* \to \rho_T^0$

Comparison between both COMPASS estimates; on average the correction to R' ≈ -0.07



Q^2 dependence of R



- HERMES and COMPASS results corrected for contribution of T_{01} and T_{10}; H1 for contr. of T_{01}
- For other experiments SCHC hypothesis assumed

Outlook

- <u>from the large data sample collected in 2016+2017</u>

  with LH_2 target, RPD and **wide-angle** electromagneric calorimetry

  collected statistic ~ 10 larger than from 2012 test run

Deeply Virtual Compton Scattering:

- t-dependence of DVCS cross section vs. x_{Bj} („proton tomography”)
- mapping GPD H by measurments real and imaginary parts of DVCS

  via ϕ-dependence the μ^+ and μ^- cross sections difference and sum

Hard Exclusive Meson Production:

- differential cross section for π^0 vs. Q^2, ν (W), t(p_T^2), ϕ
- differential cross sections and SDMEs for VMs vs. Q^2, ν (W), t (p_T^2)

Spares

Selection of exclusive ρ^0 sample for SDMEs analysis

$\mu\, p \rightarrow \mu'\, \rho^0\, p'$, with $\rho^0 \rightarrow \pi^+ \pi^-$

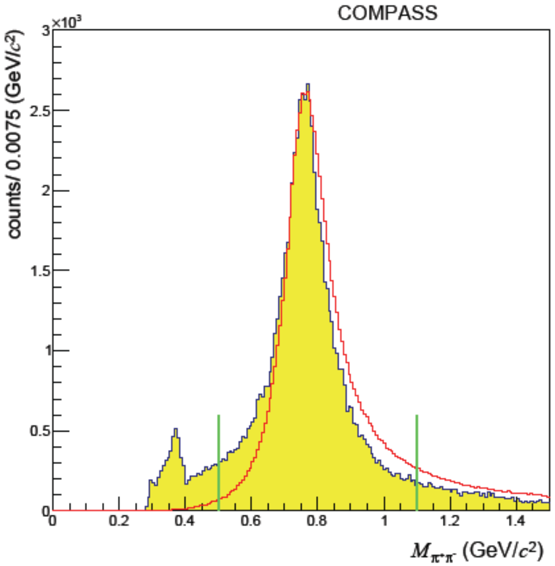
Topological selection: scattered muon
+ two hadrons with opposite charges

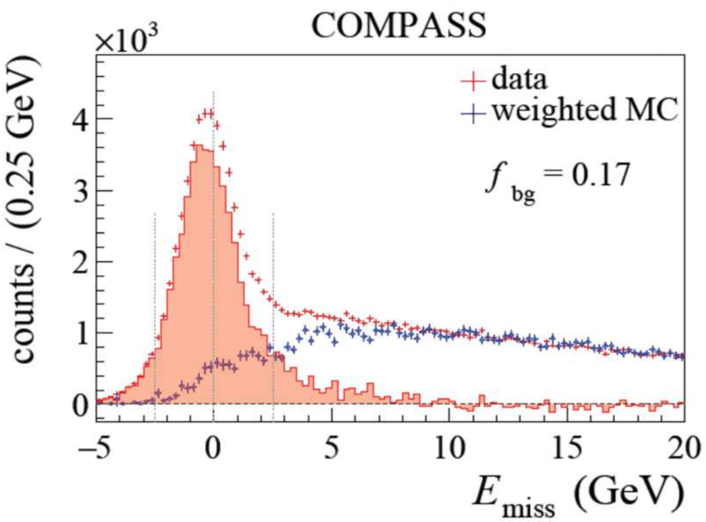
$1 < Q^2 < 10$ GeV/c^2
$W > 5$ GeV
$0.01 < p_T^2 < 0.5$ (GeV/c)^2
$0.1 < y < 0.9$
$\nu > 20$ GeV
$|E_{miss}| < 2.5$ GeV

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

After all selections and cuts
≈ 52 200 evts

Recoil proton detector
not included in selections





Selection of exclusive ω sample for SDMEs analysis

$\mu\, p \rightarrow \mu'\, \omega\, p'$

↳ $\pi^+ \pi^- \pi^0$

↳ $\gamma + \gamma$

Topological selection: scattered muon
+ two hadrons with opposite charges
+ two neutral clusters in calorimeters

Recoil proton detector
not included in selections

$1 < Q^2 < 10$ GeV/c^2

$0.01 < p_T^2 < 0.5$ (GeV/c)^2

$W > 5$ GeV

$0.1 < y < 0.9$

$|E_{miss}| < 3$ GeV

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

After all selections
≈ 3 000 evts