Hard exclusive π^0 production in μp scattering at COMPASS

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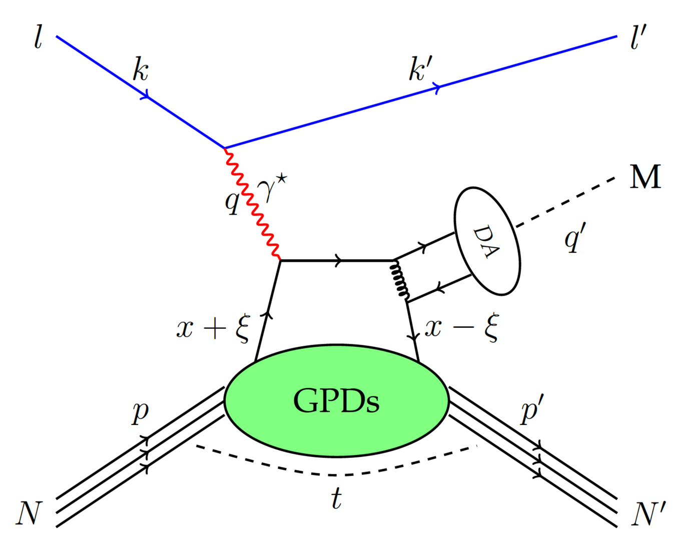
Introduction

General Parton Distributions (GPDs):

- provide a description of a 3D partonic nucleon structure [1, 2, 3]
- combine information from PDFs and Form Factors
- encode the longitudinal momentum fraction and transverse spatial position of a parton in a nucleon
- give access to the total angular momentum carried by a parton, which is expressed by Ji's relation [2]

- **8 GPDs**: 4 helicity-conserving (or chiral even): H^f, $\tilde{H}^f$, E^f, and $\tilde{E}^f$ for particular parton flavour f
- 4 helicity-flip (chiral odd): H_T^f, $\tilde{H}_T^f$, E_T^f, and $\tilde{E}_T^f$
- Measured in various exclusive processes used complementary for accessing different GPDs:
  - Deep Virtual Compton Scattering (DVCS)
  - Hard Exclusive Meson Production (HEMP)

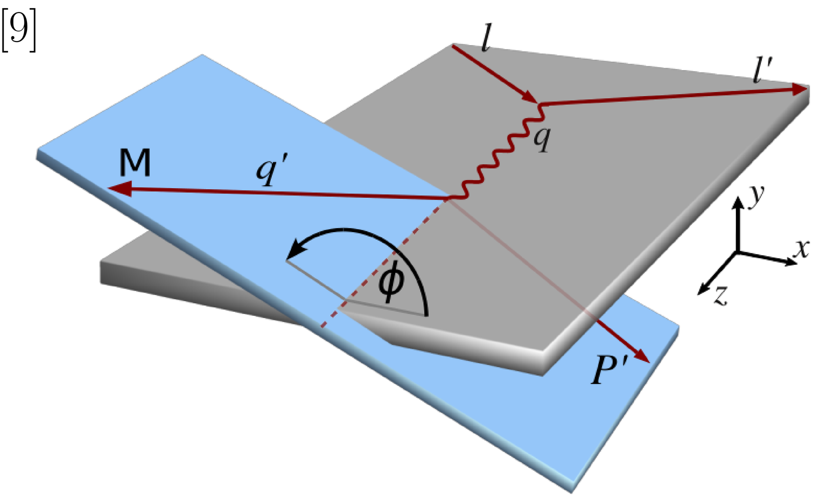


Handbag diagram of HEMP process $lN \to l'N'M$, where $k\,(k')$ denotes the four-momentum of the scattering lepton, q is the four-momentum of the virtual photon γ^*, $p\,(p')$ represents the four-momentum of the target (recoiled) nucleon $N\,(N')$, and M is the produced meson [4].

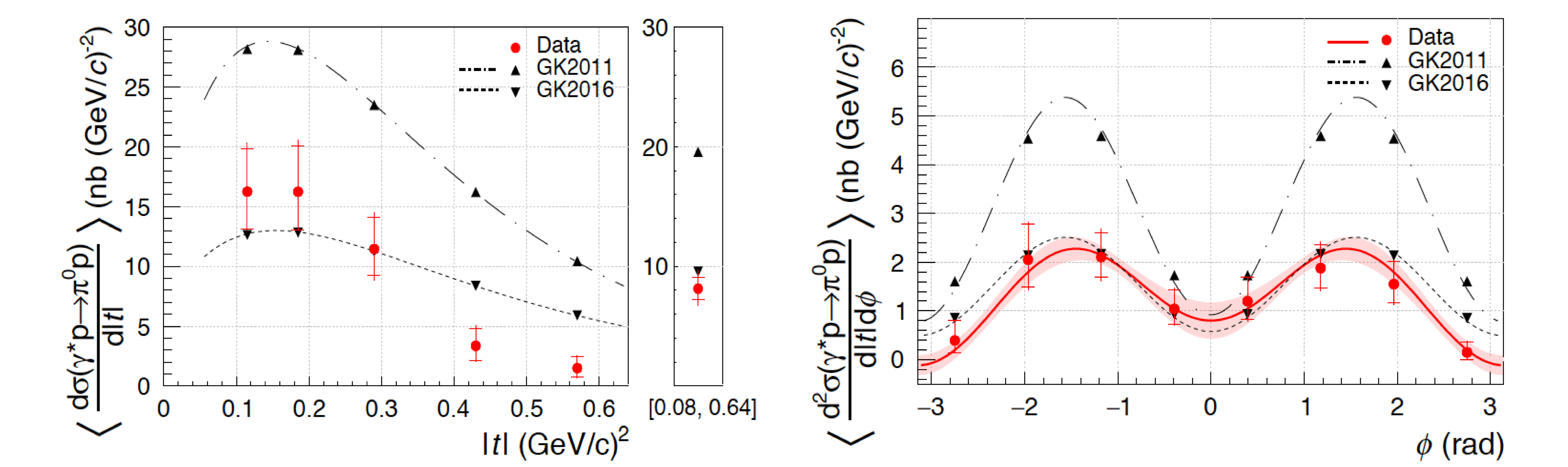
Exclusive π^0 meson production:

- contribution from longitudinally polarised virtual γ^*: Described by GPDs $\tilde{H}^f$ and $\tilde{E}^f$
- contribution from transversely polarised γ^*: expected to be suppressed by a factor of $1/Q$ ($Q = -q$) [5]
- but experimental results from JLab (Hall A, CLASS) suggest quite a significant contribution [6, 7]
- pseudo-scalar meson production described by GPDs $\tilde{H}^f$, $\tilde{E}^f$, H_T^f and $\bar{E}_T^f = 2\tilde{H}_T^f + E_T^f$ (from phenomenological model of ref. [8])
- exclusive π^0 production is sensitive to the chiral-odd GPD $\bar{E}_T^f$

$\Rightarrow$ supported by the current results from 2012 COMPASS data [9]



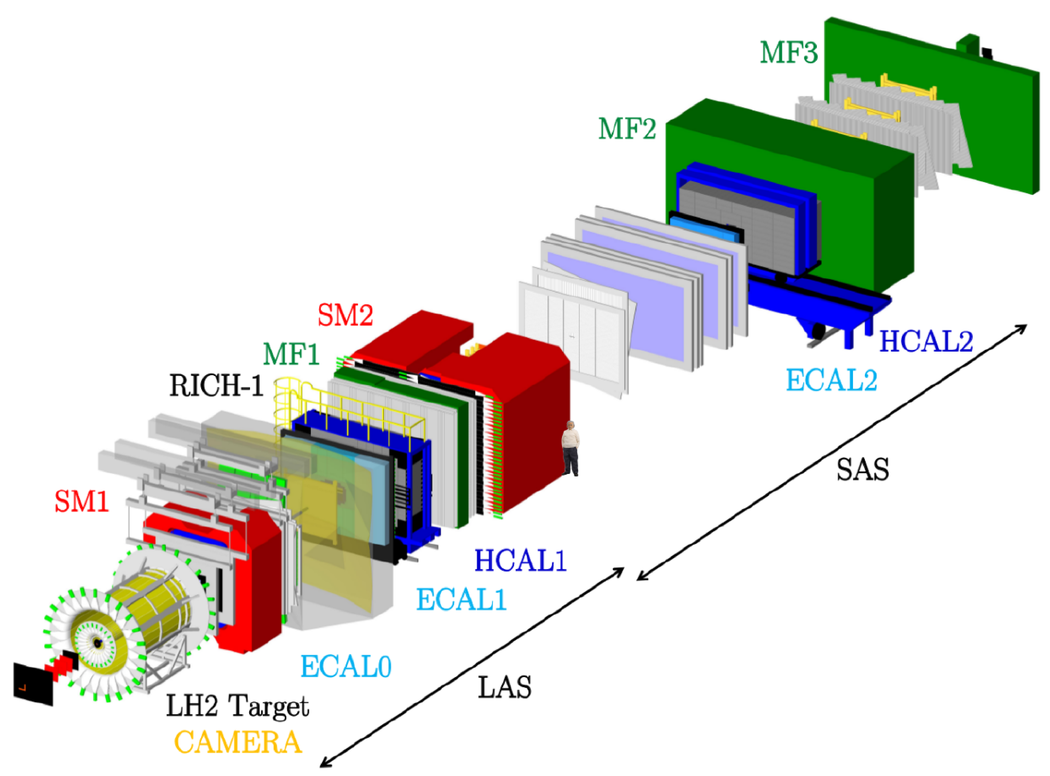
Exclusive π^0 cross-section as a function of ϕ and $|t|$



Left: The $|t|$-dependent differential exclusive π^0 cross section after the integration over ϕ. **Right:** The ϕ-dependent exclusive π^0 cross-section averaged over the measured $|t|$ range. The black dash-dotted line denotes the earlier Goloskokov-Kroll parametrisation [8], the dashed line represents the later version of the GK model adjusted to the new results from [9].

Experimental Methodology

- **COMPASS**: fixed target experiment at the M2 beam-line in CERN North Area
- secondary or tertiary hadron or muon beam from SPS
- two-stage magnetic spectrometer with several tracking stations, muon filters, electromagnetic and hadronic calorimeters, and a RICH detector for PID



- **GPD program**: pilot run in 2012, data-taking in 2016/17
- 2.5 m long liquid hydrogen target and recoiled proton detector (RPD) complementing the COMPASS spectrometer, new electromagnetic calorimeter ECAL0

- **Event selection**: exclusive process $\mu p \to \mu' p_{recoil} \pi^0$
- reconstructed vertex in the target
- two neutral clusters in electromagnetic calorimeters
- recoiled proton measured in the RPD
- over-constrained kinematics of recoiling proton kinematics predicted from the spectrometer with the information from the RPD
- four-momentum balance $M_X^2 = (p_\mu + p_p - p_{\mu'} - p_{p'} - p_{\pi^0})^2$

Formalism

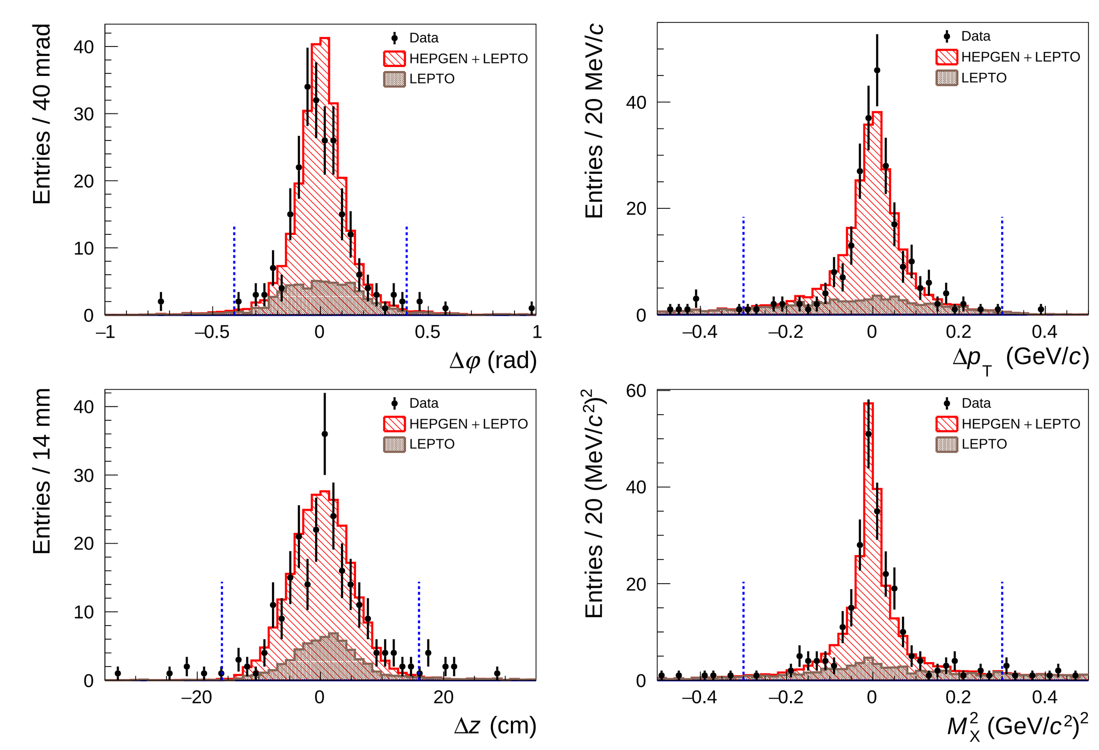
- Differential cross-section of the exclusive meson production by scattering a polarised lepton from an unpolarised proton, reduced to $\gamma^* p$ reaction [9]:

$$\frac{d^2\sigma_{\gamma^* p}^{\leftrightarrows}}{dt\,d\phi} = \frac{1}{2\pi}\Big[\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \epsilon\cos(2\phi)\frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi\frac{d\sigma_{LT}}{dt} \mp |P_l|\sqrt{2\epsilon(1-\epsilon)}\sin\phi\frac{d\sigma'_{LT}}{dt}\Big]$$

- Unpolarised cross-section is obtained by averaging over the two beam polarities:

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

  - ▶ $\sigma_T, \sigma_L, \sigma_{TT}$, and σ_{LT} are the structure functions
    - connected to convolutions of GPDs with the individual hard scattering amplitudes [8, 9]
  - ▶ ϵ is the virtual photon polarisation parameter
  - ▶ subscript T and L represent the contribution of a transversely and longitudinally polarised γ^*, the subscripts TT and LT the interference terms



Distributions of the exclusivity variables: Δp_T and $\Delta\phi$ in the upper row, and Δz and the four-momentum balance in the lower row [4, 9].

Results

The differential cross-section of the exclusive π^0 production was determined from the collected data after correction to a beam luminosity, a spectrometer acceptance, and a bin-wise background subtraction. The analysis was performed on a data sample with the following kinematic range:

$$1 < Q^2 < 5(\mathrm{GeV}/c)^2$$
$$8.5 < \nu < 28\mathrm{GeV}$$
$$0.08 < |t| < 0.64(\mathrm{GeV}/c)^2$$
$$\langle x_B \rangle = 0.093$$

At the leading order, only the σ_L contribution (related to chiral-even GPDs) is expected. However, we measured a large contributions of σ_{TT}, and σ_{LT} (related to chiral-odd GPDs). The results were compared to the predictions of two versions of the Goloskokov-Kroll model [8, 11]. The contributions to the ϕ-dependent exclusive π^0 cross section were extracted by a binned maximum-likelihood fit method:

$$\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} = \left(8.1 \pm 0.9^{+1.1}_{-1.0}\right)\frac{\mathrm{nb}}{(\mathrm{GeV}/c)^2}$$
$$\frac{d\sigma_{TT}}{dt} = \left(-6.0 \pm 1.3^{+0.7}_{-0.7}\right)\frac{\mathrm{nb}}{(\mathrm{GeV}/c)^2}$$
$$\frac{d\sigma_{LT}}{dt} = \left(1.4 \pm 0.5^{+0.3}_{-0.2}\right)\frac{\mathrm{nb}}{(\mathrm{GeV}/c)^2}$$

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