Transverse target spin asymmetries in exclusive ω muoproduction at COMPASS

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Abstract.
Exclusive production of ω mesons was studied at the COMPASS experiment by scattering 160 GeV/c muons off transversely polarised protons. Five single-spin and three double-spin azimuthal asymmetries were measured in the range of photon virtuality 1 (GeV/c)^2 < Q^2 < 10 (GeV/c)^2, Bjorken scaling variable 0.003 < x_{Bj} < 0.3 and transverse momentum squared of the ω meson 0.05 (GeV/c)^2 < p_T^2 < 0.5 (GeV/c)^2. The results are compared to recent calculations based on Gloskokov-Kroll GPD model with the $\pi\omega$ transition form factor.

1. Introduction

Exclusive leptoproduction of vector meson in the process $\gamma^* + N \to V + N'$ $(V = \rho^0,\ \phi,\ \omega)$ provides information both on reaction mechanism and nucleon structure. This contribution is concentrated on transverse target spin asymmetries obtained in exclusive ω production. Studying these asymmetries give the possibility to constraint Generalized Parton Distribution (GPD). Access to GPDs relies on on factorization property of the process amplitude. The process amplitudes is a convolution of the lepton-quark hard-scattering amplitude with soft part which contains GPDs and vector meson distribution amplitude. At leading twist chiral-even GPDs $\mathrm{H}^{q(g)}$(x, ξ, t), $\mathrm{E}^{q(g)}$(x, ξ, t), $\tilde{H}^{q(g)}$(x, ξ, t), $\tilde{E}^{q(g)}$(x, ξ, t) with helicity of parton unchanged are sufficient to describe exclusive vector mason production on spin 1/2 target. When higher twist effect are included in the Distribution Amplitude, chiral odd GPDs $\mathrm{H}_T^{q(g)}$(x, ξ, t), $\mathrm{E}_T^{q(g)}$(x, ξ, t), $\tilde{H}_T^{q(g)}$(x, ξ, t), $\tilde{E}_T^{q(g)}$(x, ξ, t) with helicity of parton changed, appeard. These GPDs are of special interest as they are related to the total angular momentum of partons in the nucleon by the Ji's relation [1]. GPDs also describe the nucleon as an extended object which correlates longitudinal momenta of parton and transverse spatial coordinates. GPDs H are well constraint by the experimental data. Less is know about GPDs E. Production of exclusive vector meson with unpolarised target is mainly sensitive to GPDs H , with transversely polarised target is also sensitive to GPDs E.
The factorisation of process amplitude is proven rigorously when the lepton-quark interaction is mediated by longitudinely polarised virtual photon. However, phenomenological pQCD-inspired models taking into account parton transverse momenta have been proposed by Goloskokov and Kroll [2, 3, 4], which describe reasonably well the behaviour of the cross sections , spin density

[1] Work supported by the Polish NCN Grant 2015/18/M/ST2/00550

matrix elements (SDMEs), asymmetries for both longitudinal and transverse photons. We referred to as "GK" model. From the very begining it is known that in ω production Unnatural Parity Exchange (UPE) processes play substantial role. In GK model the UPE processes are described by $\pi\omega$ transition form factor.

2. Theoretical formalism

The cross section for exclusive ω muoproduction, $\mu\mathrm{N} \to \mu^{'}\omega\mathrm{N}^{'}$, on a transversely polarised nucleon is given in ref.[5]:

$$
\begin{aligned}
&\left[\frac{\alpha_{em}}{8\pi^3}\frac{y^2}{1-\epsilon}\frac{1-x_{Bj}}{x_{Bj}}\frac{1}{Q^2}\right]^{-1}\frac{\mathrm{d}\sigma}{\mathrm{d}x_{Bj}\mathrm{d}Q^2\mathrm{d}t\mathrm{d}\phi\mathrm{d}\phi_s} = \\
&\quad \frac{1}{2}\left(\sigma_{++}^{++}+\sigma_{++}^{--}\right)+\epsilon\sigma_{00}^{++}-\epsilon\cos(2\phi)\,\mathrm{Re}\,\sigma_{+-}^{++} \\
&\quad -\sqrt{\epsilon(1+\epsilon)}\cos\phi\;\mathrm{Re}\left(\sigma_{+0}^{++}+\sigma_{+0}^{--}\right) \\
&\quad -P_\ell\sqrt{\epsilon(1-\epsilon)}\sin\phi\;\mathrm{Im}\left(\sigma_{+0}^{++}+\sigma_{+0}^{--}\right) \\
&\quad -S_T\quad\Big[\sin(\phi-\phi_s)\,\mathrm{Im}\left(\sigma_{++}^{+-}+\epsilon\sigma_{00}^{+-}\right)+\frac{\epsilon}{2}\sin(\phi+\phi_s)\,\mathrm{Im}\,\sigma_{+-}^{+-} \\
&\qquad +\frac{\epsilon}{2}\sin(3\phi+\phi_s)\,\mathrm{Im}\,\sigma_{+-}^{-+}+\sqrt{\epsilon(1+\epsilon)}\sin\phi_s\;\mathrm{Im}\,\sigma_{+0}^{+-} \\
&\qquad +\sqrt{\epsilon(1+\epsilon)}\sin(2\phi-\phi_s)\,\mathrm{Im}\,\sigma_{+0}^{-+}\Big] \\
&\quad +S_T P_\ell\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_s)\,\mathrm{Re}\,\sigma_{++}^{+-}-\sqrt{\epsilon(1-\epsilon)}\cos\phi_s\;\mathrm{Re}\,\sigma_{+0}^{+-} \\
&\qquad -\sqrt{\epsilon(1-\epsilon)}\cos(2\phi-\phi_s)\,\mathrm{Re}\,\sigma_{+0}^{-+}\Big],
\end{aligned} \tag{1}
$$

where only terms relevant for the present analysis are shown. Defintion of angles ϕ and ϕ_s is shown in Fig 1.

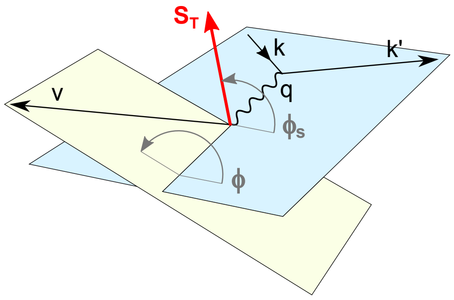

Figure 1. Kinematics of exclusive meson production in the target rest frame. Here **k**, **k**′, **q** and **v** represent the three-momentum vectors of the incident and the scattered muons, the virtual photon and the meson respectively. The component of the target spin vector **S** (not shown) perpendicular to the virtual-photon direction is denoted by $\mathbf{S_T}$.

For a transversely polarised target five single (UT) and three double (LT) spin asymmetries can be defined:

$$
\begin{aligned}
A_{\mathrm{UT}}^{\sin(\phi-\phi_s)} &= -\frac{\mathrm{Im}\left(\sigma_{++}^{+-}+\epsilon\sigma_{00}^{+-}\right)}{\sigma_0}, & A_{\mathrm{LT}}^{\cos(\phi-\phi_s)} &= \frac{\mathrm{Re}\ \sigma_{++}^{+-}}{\sigma_0},\\
A_{\mathrm{UT}}^{\sin(\phi+\phi_s)} &= -\frac{\mathrm{Im}\ \sigma_{+-}^{+-}}{\sigma_0}, & A_{\mathrm{LT}}^{\cos\phi_s} &= -\frac{\mathrm{Re}\ \sigma_{+0}^{+-}}{\sigma_0},\\
A_{\mathrm{UT}}^{\sin(3\phi-\phi_s)} &= -\frac{\mathrm{Im}\ \sigma_{+-}^{-+}}{\sigma_0}, & A_{\mathrm{LT}}^{\cos(2\phi-\phi_s)} &= -\frac{\mathrm{Re}\ \sigma_{+0}^{-+}}{\sigma_0},\\
A_{\mathrm{UT}}^{\sin\phi_s} &= -\frac{\mathrm{Im}\ \sigma_{+0}^{+-}}{\sigma_0}, & &\\
A_{\mathrm{UT}}^{\sin(2\phi-\phi_s)} &= -\frac{\mathrm{Im}\ \sigma_{+0}^{-+}}{\sigma_0}. & & \qquad (2)
\end{aligned}
$$

(3)

Here, σ_0 is the total unpolarised cross section, which is the sum of the cross sections for longitudinally and transversely polarised virtual photons, σ_L and σ_T, respectively:

$$\sigma_0 = \frac{1}{2}\left(\sigma_{++}^{++}+\sigma_{++}^{--}\right)+\epsilon\sigma_{00}^{++} = \sigma_T+\epsilon\sigma_L. \qquad (4)$$

Each asymmetry is related to a modulation of the cross section as a function of and/or (see Eq. 1), which is indicated by the superscript.

3. Experimental data

The results presented in this Contribution are based on the data taken with the transversely polarised NH_3 target in 2010. The ω meson is produced in the following process

$$
\begin{aligned}
&\mu N \to \mu' N' \omega \\
&\qquad\qquad \hookrightarrow \pi^+\pi^-\pi^0 \qquad\qquad \mathrm{BR}\approx 89\% \\
&\qquad\qquad\qquad\qquad \hookrightarrow \gamma\gamma\ . \qquad \mathrm{BR}\approx 99\%
\end{aligned}
$$

Therefore, event containes an incident muon track and three outgoing tracks ($\mu^{'}$ + h^+, h^-), and only two ECAL clusters which are time-correlated with beam. It is checked that clusters are not caused by charged particles.

For exclusive production the missing energy $E_{miss} = 0$. Missing energy is calculated as $E_{miss} = \frac{M_X^2 - M_p^2}{2M_p}$ with $M_X^2 = (p+q-p_{\pi^+}-p_{\pi^-}-p_{\pi^0})^2$ and M_X being missing mass, p, q, p_{π^+}, p_{π^-} p_{π^0} are 4-momenta of proton, γ^* and pions. The E_{miss} distribution is shown in Fig 2. Taking into account spectrometer resolution mising energy has to lie in the interval -3.0 GeV < E_{miss} < 3.0 GeV.

The constraint on squared transverse momentum of ω with respect to virtual photon γ^* momentum, $0.05 < P_T^2 < 0.5$ GeV^2, is applied, to remove coherent production and to suppress non-exclusive background (see Fig 3). Other constraints and mean kinematic values are the following $Q^2 = -q^2 = -(k-k^{'})^2 = 1.0 \div 10.$ GeV^2, $\langle Q^2\rangle = 2.2$ GeV^2, $W = \sqrt{(q+p)^2} > 5.0$ GeV, $\langle W\rangle = 7.1$ GeV, $x_B = \frac{Q^2}{2pq} = 0.003 \div 0.35$, $\langle x_B\rangle = 0.049$

A π^0 meson is recostructed from two calorimeter clusters as described in [6]

The limit on the invariant mass of two photons, $M_{\gamma\gamma}$, depends on the energy $E_{\gamma\gamma}$ of the π^0 candidate:

$$|M_{\gamma\gamma} - M_{\pi^0,\,\mathrm{par}}(E_{\gamma\gamma})| < 3\ \sigma_{\mathrm{par}}(E_{\gamma\gamma}) \qquad (5)$$

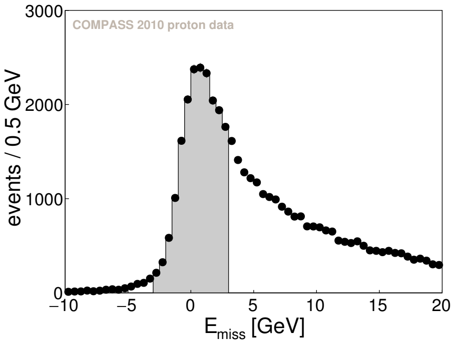

Figure 2. Distribution of E_{miss} . The accepted events are denoted by the shaded area.

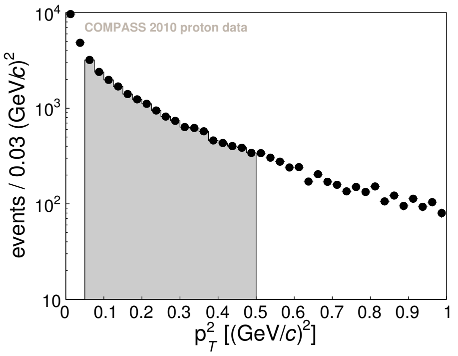

Figure 3. Distribution of P_T^2. The accepted events are denoted by the shaded area.

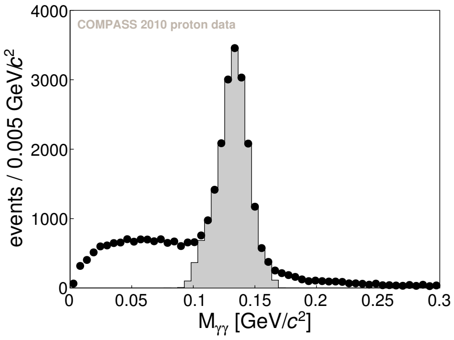

Figure 4. Distribution of the invariant mass of two photons. The accepted events are denoted by the shaded area.

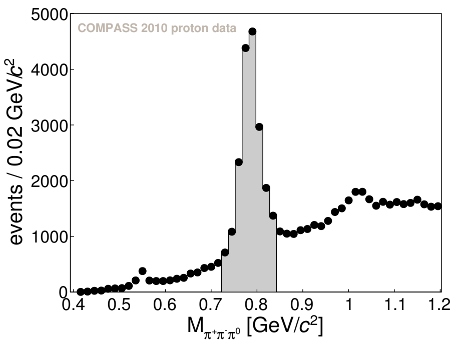

Figure 5. Distribution of $M_{\pi^+\pi^-\pi^0}$. The accepted events are denoted by the shaded area.

Here, position $M_{\pi^0,\,\mathrm{par}}(E_{\gamma\gamma})$ and width $\sigma_{\mathrm{par}}(E_{\gamma\gamma})$ of the π^0 peak are parameterised using semi-inclusive data for π^0 mesons, (see fig. 4)

Events corresponding to incoherent exclusive ω production are selected using additional cuts

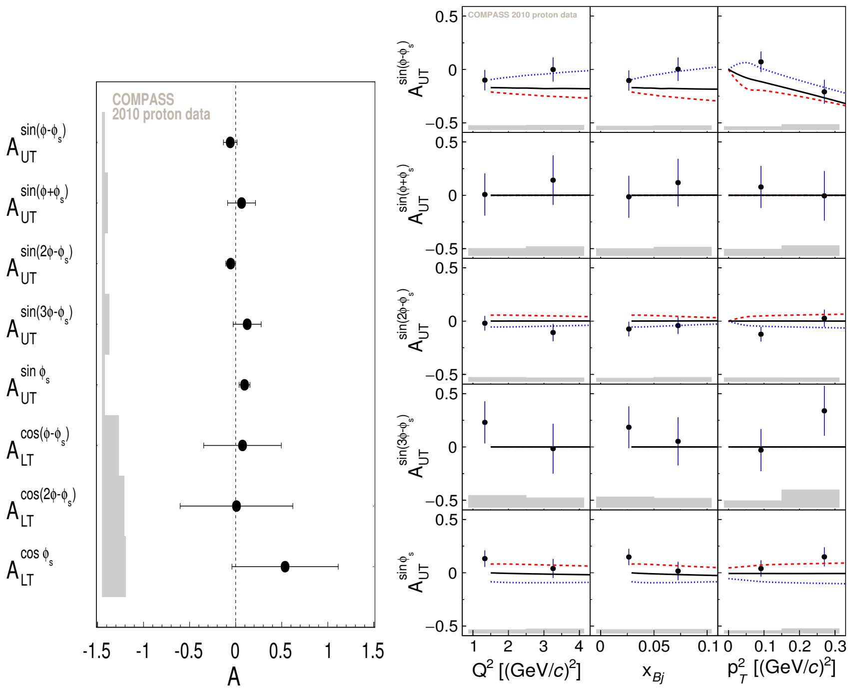

Figure 6. Left: Average azimuthal asymmetries for exclusive ω muoproduction. The error bars (left bands) represent the statistical (systematic) uncertainties. Right: Single spin azimuthal asymmetries as a function of Q^2, x_{Bj} and p_T^2. The curves show the predictions of the GPD-based model [7] for the average Q^2, W and p_T^2 values of the COMPASS data. The dashed red and dotted blue curves represent the predictions with the positive and negative $\pi\omega$ form factors, respectively, while the solid black curve represents the predictions without the pion pole.

on the invariant mass of the $\pi^+\pi^-\pi^0$ system, $M_{\pi^+\pi^-\pi^0}$,

$$\left|M_{\pi^+\pi^-\pi^0} - M_\omega^{\mathrm{PDG}}\right| < 70\ \mathrm{MeV}/c^2, \tag{6}$$

where $M_\omega^{\mathrm{PDG}} = 782.65\ \mathrm{MeV}/c^2$ is the nominal ω resonance mass.

4. Results

Asymmetries were extracted using unbinned maximum likelihood method with simultanous fit of signal and background asymmetries (16 - parameter fit).

The extracted azimuthal asymmetries, for the entire kinematic region, are shown in Fig. 6 (left). In addition, the single-spin asymmetries are measured in bins of Q^2, x_{Bj} or p_T^2 with the results shown in Fig. 6 (right). The double-spin asymmetries are not not shown in separate kinematic bins because of large uncertainties. In Figure 6 (right) the COMPASS results are compared to the calculations of the GK model [7].

The latter are obtained for the average W, Q^2 and x_{Bj} values of the COMPASS data: $W = 7.1\ \mathrm{GeV}/c^2$ and $p_T^2 = 0.17\ (\mathrm{GeV}/c)^2$ for the x_{Bj} and Q^2 dependences, and $W = 7.1\ \mathrm{GeV}/c^2$ and $Q^2 = 2.2\ (\mathrm{GeV}/c)^2$ for the p_T^2 dependence. The predictions are given for three versions of the model: with the pion-pole contribution using a positive or negative $\pi\omega$ transition form factor, and without the pion-pole contribution.

The interpretation of ω results is more challenging , as exclusive ω meson production is significantly influenced by the pion-pole exchange contribution, and at present the sign of $\pi\omega$ transition form factor is unknown. By comparing the COMPASS results with the calculations

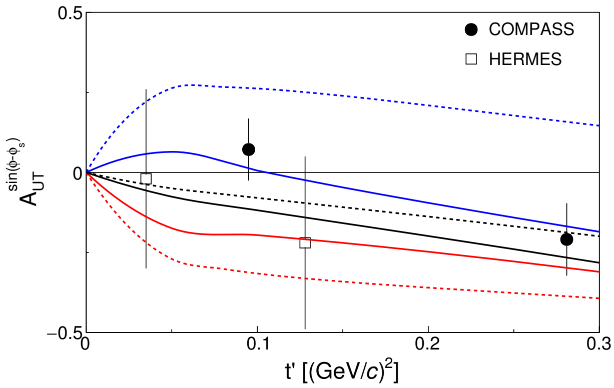

Figure 7. The asymmetry for exclusive ω muoproduction by the COMPASS (filled circles) and HERMES [8] (open squares) collaborations as a function of t'. The curves show the predictions of the GPD-based model [7] given for the average Q^2 and W values of the COMPASS (solid lines) and HERMES (dashed lines) data. For each set of curves, the upper (blue) and lower (red) ones are for the negative and positive $\pi\omega$ form factors, respectively, while the middle (black) one represents the predictions without the pion pole.

of the GK model (see Fig. 6 (right)), one finds that the asymmetries $A_{UT}^{sin(\phi-\phi_S)}$ and $A_{UT}^{sin(2\phi-\phi_S)}$ prefer the negative $\pi\omega$ transition form factor, while the asymmetry $A_{UT}^{sin\phi_S}$ prefers the positive one. The other measured asymmetries are not sensitive to the sign of the $\pi\omega$ form factor. The single-spin azimuthal asymmetries for ω production on transversely polarised protons were measured also by the HERMES collaboration [8]. They conclude that these data seem to favour the positive $\pi\omega$ form factor, although within large experimental uncertainties. A direct comparison of published asymmetry values measured in both experiments in not straightforward, because the HERMES definition of physics asymmetries differs from that given in Eq. 3. Such comparison is only possible for the asymmetry $A_{UT}^{sin(\phi-\phi_S)}$. The results from both experiments are shown as a function of t' in Fig. 7 indicating their compatibility within experimental uncertainties. Note that the COMPASS results cover a wider kinematic range and they have smaller uncertainties, for example for the asymmetry $A_{UT}^{sin(\phi-\phi_S)}$ by a factor larger than two.

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