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Transverse target spin asymmetries in exclusive ρ^0 muoproduction

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Abstract. COMPASS has studied exclusive production of ρ^0 mesons using a 160 GeV/c muon beam and a transversely polarised NH_3 target. Five single-spin and three double-spin azimuthal aymmetries were measured in dependence on Q^2, x_{Bj}, or p_T^2. Except the $\sin\phi_S$ asymmetry, obtained to be $-0.019 \pm 0.008(stat.) \pm 0.003(syst.)$, all others were found to be consistent with zero within experimental uncertainties. Phenomenological GPD-based model calculations agree well with the data and interpret the result as evidence for the existence of chiral-odd, transverse generalised parton distributions.

1. Introduction and formalism

Hard exclusive meson leptoproduction on nucleons (HEMP) can be described in the framework of perturbative Quantum Chromodynamics (pQCD). For incoming longitudinal virtual photons, collinear factorisation holds for the HEMP process amplitude [1, 2]. It factorises into a hard part that is calculable in pQCD and a soft part that contains generalised parton distributions (GPDs) [3–5] and the meson distribution amplitude. For incoming transverse virtual photons, there exists no proof of collinear factorisation. Instead, a phenomenological pQCD-inspired model (see Ref. [6] and references therein) employing parton-transverse-momentum factorisation can be used, in which process amplitudes are constructed from GPDs. Measurements of HEMP hence allow in various ways access to GPDs and thereby to the (spin) structure of the nucleon. At leading twist, the chiral-even GPDs H^f and E^f are sufficient to describe HEMP on a spin 1/2 target, where f denotes a quark of a given flavor or a gluon. There exist also chiral-odd – often called transverse – GPDs, from which in particular H_T^f and $\bar{E}_T^f$ were shown to be required (see Ref. [7] and references therein) for the description of exclusive π^+ electroproduction on a transversely polarised proton target [8]. It was recently shown [6] that the data presented in this contribution are also sensitive to these GPDs.

The cross section for exclusive ρ^0 muoproduction on a transversely polarised target [9], $\mu N \to \mu' \rho^0 N'$, contains eight azimuthal modulations sensitive to the transverse target polarisation, if – a very good approximation at COMPASS kinematics – the sensitivity to the polar angle of the virtual photon

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is neglected. These eight distinct azimuthal dependences give rise to five single-spin asymmetries:

$$A_{\mathrm{UT}}^{\sin(\phi-\phi_s)} = -\frac{\mathrm{Im}(\mathrm{r}_{++}^{+-} + \mathrm{e}\,\mathrm{r}_{00}^{+-})}{\sigma_0}, \qquad A_{\mathrm{UT}}^{\sin(\phi+\phi_s)} = -\frac{\mathrm{Im}\,\sigma_{+-}^{+-}}{\sigma_0},$$
$$A_{\mathrm{UT}}^{\sin(3\phi-\phi_s)} = -\frac{\mathrm{Im}\,\sigma_{+-}^{-+}}{\sigma_0}, \qquad A_{\mathrm{UT}}^{\sin(\phi_s)} = -\frac{\mathrm{Im}\,\sigma_{+0}^{+-}}{\sigma_0},$$
$$A_{\mathrm{UT}}^{\sin(2\phi-\phi_s)} = -\frac{\mathrm{Im}\,\sigma_{+0}^{-+}}{\sigma_0}, \tag{1}$$

and three double-spin azimuthal asymmetries (given in Ref. [10]). Here and in the following, unpolarised (longitudinally polarised) beam is denoted by U (L) and transverse target polarisation by T. The azimuthal angle between the lepton scattering plane and the production plane spanned by virtual photon and produced meson is denoted by ϕ, whereas ϕ_S is the azimuthal angle of the target spin vector about the virtual-photon direction relative to the lepton scattering plane. The symbols $\sigma_{\mu\sigma}^{\nu\lambda}$ in Eq. (1) represent polarised photoabsorption cross sections or interference terms, which are given as products of helicity amplitudes $\mathcal{M}$:

$$\sigma_{\mu\sigma}^{\nu\lambda} = \sum \mathcal{M}^*_{\mu'\nu',\mu\nu}\mathcal{M}_{\mu'\nu',\sigma\lambda}, \tag{2}$$

where the sum runs over $\mu' = 0, \pm 1$ and $\nu' = \pm 1/2$. The helicity amplitude labels appear in the following order: vector meson (μ'), final-state proton (ν'), photon (μ or σ), initial-state proton (ν or λ). For brevity, the helicities -1, $-1/2$, 0, $1/2$, 1 are labelled by only their signs or zero, omitting 1 or 1/2, respectively. Also the dependence of $\sigma_{\mu\sigma}^{\nu\lambda}$ on kinematic variables is omitted. The ϕ-independent part of the cross section for unpolarised beam and target, which is denoted by σ_0, is given as sum of the transverse and longitudinal cross sections:

$$\sigma_0 = \frac{1}{2}(\sigma_{++}^{++} + \sigma_{++}^{--}) + \varepsilon\sigma_{00}^{++}. \tag{3}$$

The virtual-photon polarisation parameter ε describes the ratio of longitudinal and transverse photon fluxes and is given by:

$$\varepsilon = \frac{1 - y - \frac{1}{4}y^2\gamma^2}{1 - y + \frac{1}{2}y^2 + \frac{1}{4}y^2\gamma^2}, \qquad \gamma = \frac{2M_p x_{Bj}}{Q}, \tag{4}$$

where terms depending on m_μ^2/Q^2 are neglected and m_μ denotes the mass of the incoming lepton. The photon virtuality is denoted by Q^2 and the Bjorken scaling variable by x_{Bj}.

2. Results and interpretation

Details on experimental set-up, event selection and background estimation are given in Ref. [10], as also on the extraction of asymmetries including subtraction of the semi-inclusive background using a two-dimensional binned maximum-likelihood fit. The systematic uncertainties of the measurements include the relative uncertainty of target dilution factor (2%), target polarisation (3%), and beam polarisation (5%), from which after quadratic summation an overall systematic normalisation uncertainty of 3.6% is obtained for the asymmetries A_{UT} and 6.2% for A_{LT}. Additional systematic uncertainties are obtained from separate studies of i) a possible bias of the applied estimator, ii) the stability of the asymmetries over data-taking time, and iii) the robustness of the applied background subtraction method and the correction by the depolarization factors [10]. The total systematic uncertainty is obtained as a quadratic sum of these three components and the overall normalization uncertainty.

Average asymmetry values for all eight modulations are shown in the left panel of Fig. 1. For three of them, the experimental precision is as high as $\mathcal{O}$ ($\pm$ 0.01). All average asymmetry values are found to

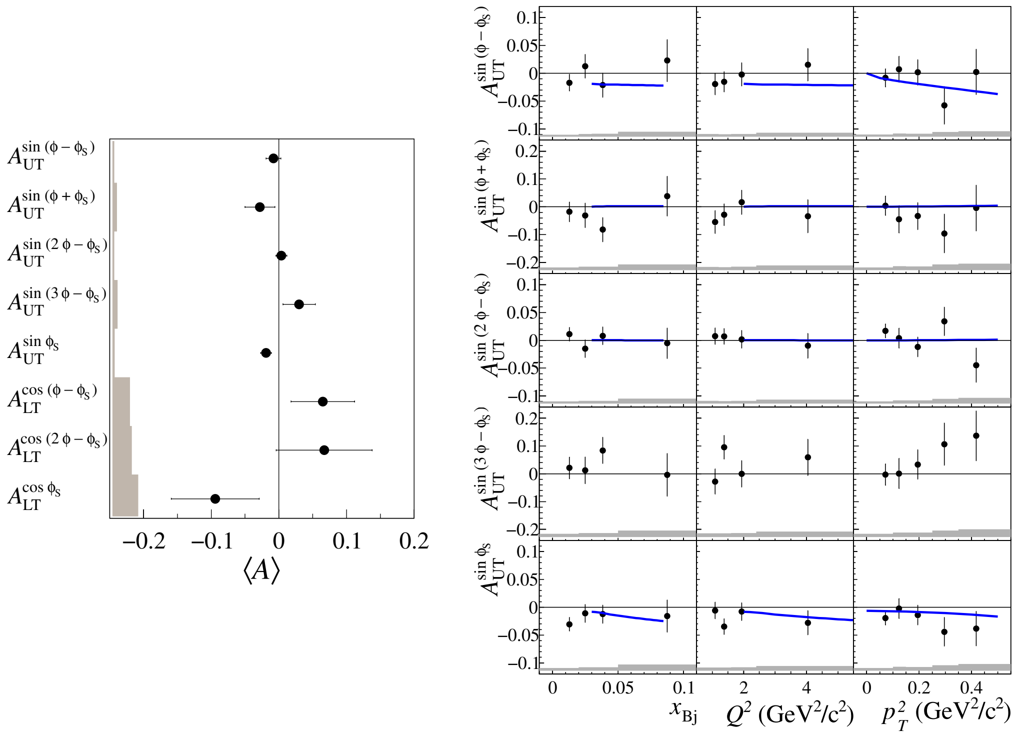

Figure 1. Left: mean values $\langle A \rangle$ and uncertainties for all eight modulations [10]. The error bars (left bands) represent the statistical (systematic) uncertainties. Right: five single-spin azimuthal asymmetries measured with transversely (T) polarised target and unpolarised (U) beam [10]. Error bars (bands) represent statistical (systematic) uncertainties. The curves show the predictions of the GPD model [6], in which the asymmetry $A_{UT}^{\sin(3\phi-\phi_S)}$ is assumed to be zero.

be of small magnitude, below 0.1. Except $A_{UT}^{\sin\phi_S}$, all other average asymmetry values are consistent with zero within experimental uncertainties. In the right panel of Fig. 1, kinematic dependences on x_{Bj}, Q^2, or p_T^2 are shown for the five single-target-spin asymmetries, where p_T is the ρ^0 transverse momentum with respect to the virtual-photon direction.

As already mentioned above, the model of Ref. [6] describes hard exclusive electroproduction of a light vector meson V at small x_{Bj} in the phenomenological "handbag" approach, which also includes twist-3 meson wave functions. Calculations for the set of five $A_{\rm UT}$ and three $A_{\rm LT}$ asymmetries were performed very recently [6]. They are shown in the right panel of Fig. 1 as curves together with the data points. Of particular interest is the level of agreement between data and model calculations for the following four asymmetries, as they involve chiral-odd GPDs:

$$A_{\rm UT}^{\sin(\phi-\phi_s)}\sigma_0 = -2{\rm Im}\left[\epsilon\mathcal{M}^*_{0-,0+}\mathcal{M}_{0+,0+} + \mathcal{M}^*_{+-,++}\mathcal{M}_{++,++} + \frac{1}{2}\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,++}\right], \tag{5}$$

$$A_{\rm UT}^{\sin(\phi_s)}\sigma_0 = -{\rm Im}\left[\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,0+} - \mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+}\right], \tag{6}$$

$$A_{\rm UT}^{\sin(2\phi-\phi_s)}\sigma_0 = -{\rm Im}\left[\mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+}\right], \tag{7}$$

$$A_{\mathrm{LT}}^{\cos(\phi_s)}\sigma_0 = -\mathrm{Re}\Big[\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,0+} - \mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+}\Big]. \quad (8)$$

Here, the dominant $\gamma^*_\ell \to \rho^0_\ell$ transitions are described by helicity amplitudes $\mathcal{M}_{0+,0+}$ and $\mathcal{M}_{0-,0+}$, which are related to chiral-even GPDs H and E, respectively. The subscripts ℓ and t denote the photon and meson helicities 0 and ± 1, respectively. These GPDs are used since several years to describe deeply virtual Compton scattering and HEMP data. The suppressed $\gamma^*_t \to \rho^0_t$ transitions are described by the helicity amplitudes $\mathcal{M}_{++,++}$ and $\mathcal{M}_{+-,++}$, which are likewise related to H and E. By the recent inclusion of transverse, i.e. chiral-odd GPDs, it became possible to also describe $\gamma^*_t \to \rho^0_\ell$ transitions. In their description appear the amplitudes $\mathcal{M}_{0-,++}$ related to chiral-odd GPDs H_T and $\mathcal{M}_{0+,++}$ related to chiral-odd GPDs $\bar{E}_T$, see Ref. [6] and references therein. The double-flip amplitude $\mathcal{M}_{0-,-+}$ is neglected. The transitions $\gamma^*_\ell \to \rho^0_t$ and $\gamma^*_t \to \rho^0_{-t}$ are known to be suppressed and hence neglected in the model calculations.

All measured asymmetries agree well with the calculations of Ref. [6]. In Eq. (5), the first two terms represent each a combination of chiral-even GPDs H and E. The inclusion of chiral-odd GPDs by the third term has negligible impact on the behaviour of $A_{\mathrm{UT}}^{\sin(\phi-\phi_S)}$, as can be seen when comparing calculations of Refs. [12] and [6]. The asymmetry $A_{\mathrm{UT}}^{\sin(\phi-\phi_S)}$ itself may still be of small magnitude, because for GPDs E in ρ^0 production the valence quark contribution is expected to be not large. This is interpreted as a cancellation due to different signs and comparable magnitudes of GPDs E^u and E^d [11]. Also, the small gluon and sea contributions evaluated in Ref. [12] cancel here to a large extent.

The asymmetries $A_{\mathrm{UT}}^{\sin\phi_S}$ and $A_{\mathrm{LT}}^{\cos\phi_S}$ represent imaginary and real part, respectively, of the same difference of two products $\mathcal{M}^*\mathcal{M}$ of two helicity amplitudes, where the first term of this difference represents a combination of GPDs H_T and H, and the second a combination of $\bar{E}_T$ and E. As can be seen in the left panel of Fig. 1, while no conclusion can be drawn on $A_{\mathrm{LT}}^{\cos\phi_S}$ because of larger experimental uncertainties, a non-vanishing value for $A_{\mathrm{UT}}^{\sin\phi_S}$ is measured. The asymmetry $A_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}$ represents the same combination of GPDs $\bar{E}_T$ and E as the second term in $A_{\mathrm{UT}}^{\sin\phi_S}$. The observation of a vanishing value for $A_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}$ implies that the non-vanishing value of $A_{\mathrm{UT}}^{\sin\phi_S}$ constitutes the first experimental evidence from hard exclusive ρ^0 leptoproduction for the existence of transverse GPDs H_T.

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