PROCEEDINGS OF SCIENCE

Exclusive ρ^0 muoproduction on transversely polarised protons and deuterons

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The theoretical framework of Generalized Parton Distributions (GPDs) provides a dynamical and geometrical picture of the nucleon. In addition to the longitudinal momentum information of partons they contain information on the transverse localisation of the constituents. The exclusive production of ρ^0 mesons off a transversely polarised target allow to constrain the GPD E which is connected, according to Ji's sum rule, with the total angular momentum of quarks and gluons. At the COMPASS experiment at CERN measurements were performed by scattering a 160 GeV/c muon beam off transversely polarised ^{6}LiD (2003, 2004) and NH_3 (2007, 2010) targets. From these data the transverse target spin azimuthal asymmetries $A_{\mathrm{UT}}^{\sin(\phi-\phi_S)}$ for proton and deuteron are extracted.

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1. Introduction

The concept of Generalized Parton Distributions (GPDs) provides an extensive description of the internal quark-gluon structure of the nucleon [1 – 3]. It combines the well know form factors and the parton density distributions and allows for a 3-dimensional tomographic picture of the nucleon. GPDs can be experimentally probed via the hard exclusive radiation of a real photon (Deep Virtual Compton Scattering, DVCS) or the hard emission of an exclusive meson (Hard Exclusive Meson Production, HEMP). Both processes are characterized by an intact nucleon in the final state. The measurements of the two channels allow for accessing independent and complementary information towards a full flavour decomposition of GPDs. At leading twist, meson production is described by 4 types of GPDs H, E, $\tilde{H}$, $\tilde{E}$ for every quark family and the gluon. Each of the GPDs depends on three variables: x the average and ξ half the difference of the longitudinal momenta carried by the struck parton in the initial and final states and t the squared four-momentum transfer to the target nucleon.
For the hard exclusive production of a meson by longitudinal polarised photons the factorisation theorem is valid which allow for a separation of the amplitude into a hard part, described by perturbative QCD and a soft part [4]. The non-perturbative part enfolds the structure of the nucleon described by GPDs and the structure of the emitted meson depicted by the distribution amplitude (DA).

2. The COMPASS experiment

The COMPASS experiment, situated at the SPS M2 beam line at CERN, is a fixed-target experiment with a rich physics program focused on the spin structure of nucleons and hadron spectroscopy [5]. The two stage spectrometer is designed to reconstruct scattered muons and produced hadrons in a wide kinematic range. Each stage is equipped with an open field dipole magnet, different tracking detectors and one hadronic and electromagnetic calorimeter. In Addition a RICH allow for charged particle identification. In 2006 a new target magnet was installed increasing the acceptance from ± 70 mrad to ± 180 mrad.
The presented measurements were performed using a μ^+ beam with an intensity of $\sim 2 \cdot 10^8$ muons per SPS cycle and a momentum of $\sim$ 160 GeV/c. It is based on data taken during the years 2003, 2004 with a ^{6}LiD target (deuterons) and 2007, 2010 with a NH_3 target (protons). Both targets are transversely polarised with respect to the beam direction and are composed of different target cells, arranged along the beam axis. The ^{6}LiD target is a two cell target, where each target cell is 60 cm long and polarised in opposite direction. The NH_3 target has three target cells, of 30 cm, 60 cm and 30 cm length, were the spin directions in neighbouring cells are opposite. The achieved polarisation is about $P_T \sim 50\%$ for deuterons and $P_T \sim 80\%$ for protons with relative uncertainties of 5% and 3% respectively. The fraction of the polarisable material in the target weighted by the cross section is quantified by the dilution factor f, where f is $\sim 45\%$ for ^{6}LiD and $\sim 25\%$ for the NH_3 target. The setup allows the measurement of both spin polarisation states at the same time. Systematic effects of the acceptance are further reduced by rotating the spin direction periodically about every week.

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3. Hard exclusive ρ^0 production

The cross section of the analysed process $\mu N \to \mu N \rho^0$ is described in the COMPASS kinematic region by

$$\left[\frac{\alpha_{em}}{8\pi^3}\frac{y^2}{1-\varepsilon}\frac{1-x_B}{x_B}\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_B dQ^2 d\phi d\phi_s} \simeq \sigma_0\left(1 - S_T A_{\mathrm{UT}}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S)\right) + \dots ,$$

where only the terms relevant for this analysis are shown explicitly [6]. The unpolarised cross section is given by σ_0, ε is the virtual photon polarisation parameter and S_T the transverse component of the target spin vector respective to the direction of the virtual photon. The azimuthal angle between the lepton scattering plane and the plane containing the virtual photon and the produced meson is denoted by ϕ, and ϕ_S is the azimuthal angle of the target spin vector around the virtual photon direction relative to the lepton scattering plane. The transverse target spin azimuthal asymmetry

$$A_{\mathrm{UT}}^{\sin(\phi-\phi_S)} \propto \sqrt{|t-t_0|}\frac{\mathrm{Im}(\mathscr{E}^\star\mathscr{H})}{|\mathscr{H}|^2} \tag{3.1}$$

is connected to $\mathscr{E}$ and $\mathscr{H}$ which are weighted sums of convolutions of the GPDs E and H with the DA of the produced meson and a hard scattering kernel [6]. Here t_0 describes the minimal kinematically allowed $|t|$ while U and T refer to an unpolarised beam and a transversely polarised target. The asymmetry is sensitive to the poorly known GPD E. This GPD is connected, according to Ji's sum rule, with the total angular momentum of quarks and gluons [3].

4. Event selection and background estimation

The essential steps of the event selection are described in the following. The considered events have an incoming and a scattered muon track and two oppositely charged hadron tracks associated to a vertex in the target region. In order to select a sample in the deep inelastic scattering region cuts on the photon virtuality $Q^2 > 1$ (GeV/c)^2, $0.003 < x_{Bj} < 0.3$, the fractional energy of the virtual photon $0.1 < y < 0.9$ and the invariant mass of the $\gamma^* - N$ state $W > 5$ GeV/c^2 are applied. The ρ^0 meson is selected in the invariant mass range of 0.5 GeV/$c^2 < M_{\pi^+\pi^-} <$ 1.1 GeV/c^2, where for each hadron the pion mass hypotheses is assigned. This cut is optimised with regard to a high yield and purity of a resonant ρ^0 production compared to the non-resonant $\pi^+\pi^-$ production. The measurements are performed without the detection of the recoiled proton in the final state. The exclusivity selection of the events is based on cuts on the missing energy

$$E_{\mathrm{miss}} = \frac{(p+q-v)^2 - p^2}{2\cdot M_P} = \frac{M_X^2 - M_P^2}{2\cdot M_P}, \tag{4.1}$$

where M_p is the rest mass for the proton and M_X the mass of the not detected recoiled system. M_X is calculated with the four-momentum of proton p, photon q and meson v. For exclusive events E_{miss} is about 0. To accomodate for the finite experimental resolution we consider events in the range - 2.5 GeV $< E_{\mathrm{miss}} <$ 2.5 GeV. The number of non-exclusive events can be further reduced by a cut on the squared transverse momentum of vector meson with respect to the virtual photon direction $p_T^2 < 0.5$ GeV^2/c^2, the energy of ρ^0 in laboratory system $E_{\rho^0} > 15$ GeV and $Q^2 < 10$

target	$\langle Q^2 \rangle$ (GeV^2/c^2)	$\langle x_{Bj} \rangle$	$\langle y \rangle$	$\langle W \rangle$ (GeV/c^2)	$\langle p_T^2 \rangle$ (GeV^2/c^2)
^{6}LiD	1.99	0.032	0.27	8.56	0.23
NH_3	2.15	0.039	0.24	8.13	0.18

Table 1: Mean values for the most important kinematic variables.

GeV^2/c^2. A cut on $p_T^2 > 0.1$ GeV^2/c^2 and $p_T^2 > 0.05$ GeV^2/c^2 for ^{6}LiD and NH_3 respectively is used to suppress coherently produced events. After all applied cuts the final samples for incoherent exclusive ρ^0 production consist of about 97000 and 797000 events for the ^{6}LiD and NH_3 targets, respectively. The mean values for the kinematic variables Q^2, x_{Bj}, y, W and p_T^2 are given in Tab. 1. In order to correct for semi-inclusive events the E_{miss} shape of the background is parametrised for each individual target cell in every kinematic bin of Q^2, x_{Bj} and p_T^2 using a Monte-Carlo (MC) LEPTO sample with the COMPASS tuning of the JETSET parameters [7]. The h^+h^- MC sample is weighted in every E_{miss} bin i by the ratio of numbers of like-sign events from data and MC

$$w_i = \frac{N^{h^+h^+}_{\text{i,data}}(E_{\text{miss}}) + N^{h^-h^-}_{\text{i,data}}(E_{\text{miss}})}{N^{h^+h^+}_{\text{i,MC}}(E_{\text{miss}}) + N^{h^-h^-}_{\text{i,MC}}(E_{\text{miss}})},$$

which improves the agreement between data and MC significantly. The approach is supported by the observation that the weights calculated for the ρ^0 sample and for the like-sign sample are comparable for large E_{miss}. In every bin required for the asymmetry extraction, i.e the kinematic bins Q^2, x_{Bj}, and p_T^2 and 12 bins in $\phi - \phi_S$, individually for each target cell and spin orientation, a signal plus background fit is performed, with a Gauss function for the signal and the background shape fixed by MC. As an example, the E_{miss} distribution integrated over the angle $\phi - \phi_S$, target cells and polarisation states for the highest Q^2 bin is depicted in Fig. 4. The total amount for the semi-inclusive background is estimated as 18% (^{6}LiD) and 22% (NH_3), respectively. Apart of the discussed semi-inclusive fraction of the background the final sample comprise diffractive events where the recoiled nucleon is in an excited N*- or Δ-state (14%), visible as an enhancement right from the signal peak in Fig. 4. Furthermore coherently produced ρ^0 mesons ($\sim$ 8% for ^{6}LiD, $\sim$ 12% for NH_3) and non-resonant $\pi^+\pi^-$-pairs ($<$ 2%) contributes. We do not apply a correction for these contributions.

5. Results

The asymmetry is extracted from the final sample, after the subtraction of semi-inclusive background, using a one dimensional maximum likelihood fit. The number of exclusive ρ^0 mesons for a given bin j of $\phi - \phi_S$ and target cell (ncell) can be written as

$$N^{\pm}_{j,ncell} = c^{\pm}_{j,ncell}\left(1 \pm f|P_T|A_{\text{UT}}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S)\right), \tag{5.1}$$

where f is the target dilution factor, P_T the target polarisation and $c^{\pm}_{j,ncell}$ is a product of the spin-averaged cross section, the muon flux, the number of target nucleons and the product of acceptance and efficiency of the spectrometer. For the data taken with the three cell NH_3 target the events of the

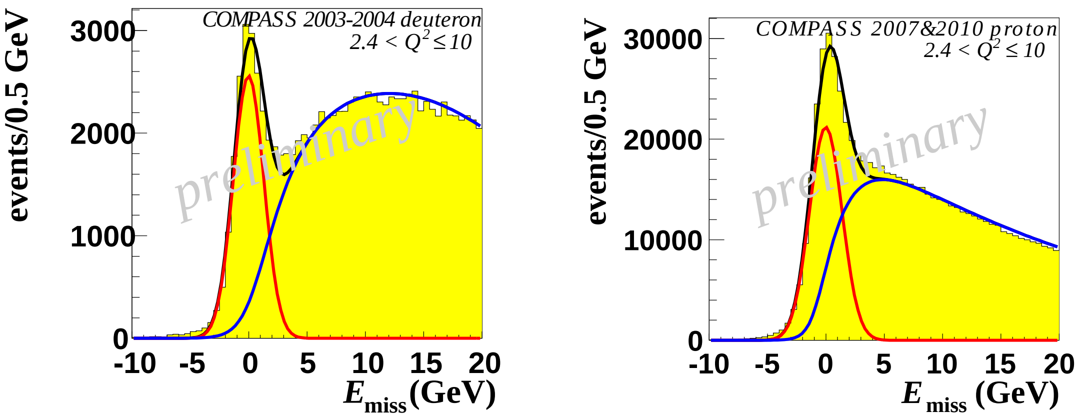

Figure 1: The E_{miss} distributions in the range 2.4 (GeV$^2/c^2$) $< Q^2 \leq 10.0$ (GeV$^2/c^2$), together with signal (red line) plus background (blue line) fits for the ^{6}LiD (left) and NH_3 (right) samples.

two outer cells are summed up. The asymmetry is extracted using at the same time the information coming from both cells in two consecutive periods with opposite spin configuration $\pm$.

The results for $A_{\text{UT}}^{\sin(\phi-\phi_S)}$ as a function of x_{Bj}, Q^2 and p_T^2 are shown in Fig. 2. As sources of systematic effects the bias of the applied estimator of the asymmetry, data stability in time, false asymmetries and the uncertainties of target dilution factor and target polarisation value are investigated. For systematic effects related to the background subtraction the sensitivity to the Monte-Carlo description used for the parametrisation of the background shape and the compatibility of results after background subtraction are studied. The overall systematic error is estimated for every kinematic bin i to $\sigma_i^{sys} = 0.5\sigma_i^{stat}$ for deuteron data and $\sigma_i^{sys} = 0.25\sigma_i^{stat}$ for proton data, depicted as grey bands in Fig. 2. For both targets the asymmetries are found to be small and compatible with 0 within statistical uncertainties. Averaged over COMPASS kinematical region the values are $A_{\text{UT,d}}^{\sin(\phi-\phi_S)} = 0.02 \pm 0.03 \pm 0.02$ and $A_{\text{UT,p}}^{\sin(\phi-\phi_S)} = -0.002 \pm 0.010 \pm 0.003$.
The blue lines in Fig. 2 show the predictions given by the GPD model of Goloskokov and Kroll [8]. The model includes both longitudinal and transverse virtual photons for $W = 8.1$ GeV/c^2, $Q^2 = 2.2$ GeV$^2/c^2$ and $p_T^2 = 0.2$ GeV$^2/c^2$ and with $E^g \simeq E^s \simeq 0$. The indicated theoretical error bands reflect uncertainties in the GPD parametrisation. The small value of the asymmetry for ρ^0 may be due to an approximate cancellation of two sizable and comparable contributions of opposite sign from GPDs E for valence u and d quarks, $E^u \approx -E^d$.

6. Summary

GPDs provide a dynamical and geometrical picture of the nucleon. Experimentally the asymmetry $A_{\text{UT}}^{\sin(\phi-\phi_S)}$ can be determined and allow to constrain the GPD E. This talk presented $A_{\text{UT}}^{\sin(\phi-\phi_S)}$ for transversely polarised deuterons (^{6} LiD target) and protons (NH_3 target). The measurement was performed at the COMPASS experiment during the year 2003, 2004 and 2007, 2010. Both asymmetries, which are shown as a function of x_{Bj}, Q^2 and p_T^2, are small and compatible with 0. The results for the transversely polarised deuterons were measured for the first time. The proton results are compatible with HERMES although the COMPASS measurement is more precise by a factor

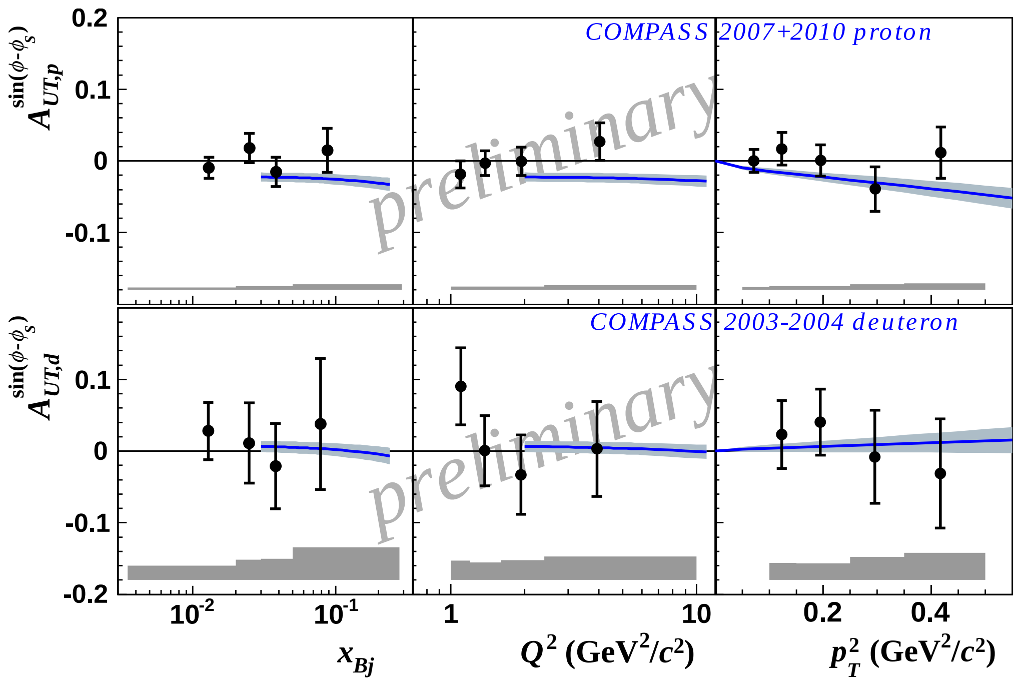

Figure 2: Transverse target spin asymmetry $A_{\mathrm{UT}}^{\sin(\phi-\phi_S)}$ measured on proton (upper) and deuteron (lower) as a function of x_{Bj}, Q^2 and p_t^2. Error bars show statistical uncertainties, while the systematic ones are represented by bands at the bottom. The blue curves indicate the predictions of the GPD model [8].

of about 3 and covers a larger kinematic domain. The results agree with predictions of the GPD model [8].

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