DOUBLE–SPIN ASYMMETRY IN EXCLUSIVE ρ^0 MESON PRODUCTION AT COMPASS EXPERIMENT

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Abstract

The longitudinal double–spin asymmetry A_1^ρ extracted from exclusive muoproduction of ρ^0 mesons, $\mu + N \to \mu + N' + \rho^0$, is studied using 2002 and 2003 data from the COMPASS experiment. The studied reaction is incoherent ρ^0 production on polarized deuterons. The dependence of A_1^ρ on Q^2 and $x_{\rm Bj}$ is presented in a wide kinematical range of $3 \times 10^{-3} < Q^2 < 7$ GeV^2 and $5 \times 10^{-5} < x_{\rm Bj} < 0.05$. The presented results are the *first* measurements of A_1^ρ at small Q^2 ($Q^2 < 0.1\,{\rm GeV}^2$) and small $x_{\rm Bj}$ ($x_{\rm Bj} < 3 \times 10^{-3}$). The asymmetry is consistent with zero in the whole studied kinematical range.

The studied reaction is the exclusive muoproduction of the ρ^0 vector meson on the nucleon:

$$\mu + N \to \mu' + N' + \rho^0 , \tag{1}$$

which can be alternatively described in terms of the virtual photoproduction:

$$\gamma^* + N \to \rho^0 + N' . \tag{2}$$

In the above reactions μ, μ', N, N' and γ^* represent the incident and scattered muons, target and recoil nucleons and virtual photon.

The COMPASS target is a mixture of different, basically light, nuclei. In the present work the *incoherent* ρ^0 production is considered, i.e. production on a single nucleon N from any nucleus in the target, in which process the struck nucleon N' remains unexcited and recoils only slightly.

Most of the presently available information on the spin structure of the reaction (2) comes from studying the ρ^0 spin density matrix elements (SDME). They are defined for unpolarized or polarized beam and unpolarized target, and obtained from the analysis of the angular distributions of ρ^0 production and decay [1]. Experimental results on SDME for ρ^0 are provided by various experiments, including the preliminary results from COMPASS [2].

Different information on the reaction (2) can be obtained with polarized both beam and target. In this paper the longitudinal double–spin asymmetry is studied:

$$A_1^\rho = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} , \tag{3}$$

where $\sigma_{1/2\,(3/2)}$ stands for the cross section of the reaction (2). Subscripts $1/2\,(3/2)$ denote absolute values of sums of projections of spins of both the transversally polarized virtual photon and nucleon on the quantization axis (the virtual photon 3-momentum) for spins aligned antiparallel (1/2) and parallel (3/2).

The traditional concepts like Generalized Vector Meson Dominance (GVMD) [3] or, more recently, the Regge approach [4] have been applied to analyse the A_1^ρ asymmetry. In these approaches the exchange of reggeons in the t-channel of the reaction (2) is considered. The A_1^ρ asymmetry can arise either due to exchange of the a_1–trajectory (of unnatural parity P) itself, or due to the interference of amplitudes with exchanges of reggeons with natural (ρ, ω, f, a_2, $\mathbb{P}$ (pomeron) trajectories) and unnatural (π, a_1 trajectories) parity P. A measurable asymmetry can arise even from a small contribution of unnatural parity. No significant asymmetry is expected in case of exchange of the non-perturbative (soft) pomeron, because it has small spin-dependent couplings, as found from data on hadron–nucleon scattering [4].

Perturbative QCD (pQCD) has also been applied to describe the reaction (2). It was demonstrated [5] that exclusive meson production on protons by longitudinally polarized virtual photons (γ_L^*), for which factorization was proved, could be expressed in terms of the generalized parton distributions (GPDs) and meson light cone wave functions. No similar proof exists for transversally polarized virtual photons (γ_T^*). However, the pQCD-inspired model for the spin-independent amplitudes for the reaction (2), using open $q\bar{q}$ pair production and parton–hadron duality concepts, and involving GPDs, was proposed in [6]. This model, able to cope with both γ_L^* and γ_T^*, successfully described various experimental results on the reaction (2). An extension of this model for the spin-dependent amplitudes for the reaction (2) was proposed in [7]. At high W (total energy of the γ^*–N system in its center-of-mass frame), where amplitudes for the reaction (2) with perturbative (hard) pomeron exchanges in the t-channel dominate, this model relates the A_1^ρ asymmetry to the generalized spin-dependent gluon distribution of the proton, approximated by the ordinary gluon distribution ΔG. More recently another pQCD-inspired model involving gluon GPDs have been proposed in [8].

Another prediction for the A_1^ρ asymmetry was proposed in [9]. Using a relation of the reaction (2) to the forward Compton scattering, $\gamma^* p \to \gamma^* p'$, the A_1^ρ asymmetry was related to the inclusive A_1 asymmetry.

The first preliminary experimental results were presented by the HERMES [10] and SMC [11] experiments at the same time. In [10] HERMES showed results for A_1^ρ from the proton target. In [11] SMC presented results for the longitudinal double–spin asymmetry A_{LL} obtained from both the proton and deuteron targets. (A_{LL} is the asymmetry defined for the spin-dependent *muon*–nucleon cross sections for the reaction (1), for its relation to A_1^ρ see Eq. (5) below.) Then only the analysis by HERMES was continued and further results, including also those from a deuteron target, were published in [12, 13]. The similar analysis of A_1^ρ has started at COMPASS and its preliminary results are presented for the first time in this contribution.

The positive muon beam from the CERN M2 beam line, of 160 GeV momentum, average polarization of -0.76, and intensity of 2×10^8 μ/spill, impinges on a polarized double-cell solid-state target. The beam traverses two target cells placed one after the other, each 60 cm long and 3 cm in diameter, in which the target material is polarized in opposite directions, and the polarization is about 0.50. Polarizations of each target cell are reversed frequently during data taking. COMPASS uses ^{6}LiD as polarized deuteron target. A mixture of ^{3}He and ^{4}He (which is used as a coolant) and small amounts of heavier nuclei are also present in the target. The COMPASS setup consists of two high resolution magnetic spectrometers, equipped with various tracking detectors, hadron calorimeters, RICH and muon filters. The COMPASS trigger, comprising several subsystems, allows to cover a very broad range of Q^2 and $x_{\rm Bj}$. For more detailed description of the COMPASS apparatus see [14].

The present analysis is based on the whole data sample taken in 2002 and 2003. The same flux of beam muons has been demanded to pass each target cell. For an event to be accepted it was required to originate in one of the target cells, to have reconstructed beam and scattered muon tracks and to contain only two additional tracks associated with oppositely charged hadrons. In this analysis RICH was not used for particle identification, instead a charged pion mass hypothesis was assigned to each hadron track, and $m_{\pi\pi}$ invariant mass was calculated. The cuts $0.5 < m_{\pi\pi} < 1$ GeV were applied to identify pion pairs from ρ^0 decays. At COMPASS slow recoiling target particles are not detected, and in order to select exclusive ρ^0 events the missing energy was used, defined as $E_{\rm miss} = (m_X^2 - m_{\rm p}^2)/(2\,m_{\rm p})$, where m_X is the mass of the undetected system and $m_{\rm p}$ is the proton mass. The cuts $-2.5 < E_{\rm miss} < 2.5$ GeV were imposed. Also the cuts on p_t^2, the squared transverse momentum of ρ^0 with respect to its parent virtual photon direction, were applied: $0.15 < p_t^2 < 0.5$ GeV^2. The lower cut eliminates events with coherent ρ^0 production on the target nuclei, the upper one allows to suppress a contribution of the non-exclusive background events to the sample. To avoid low efficiency of track reconstruction for low momentum particles and misidentification of events additional cuts $\nu > 30$ GeV and $E_{\mu'} > 20$ GeV were applied.

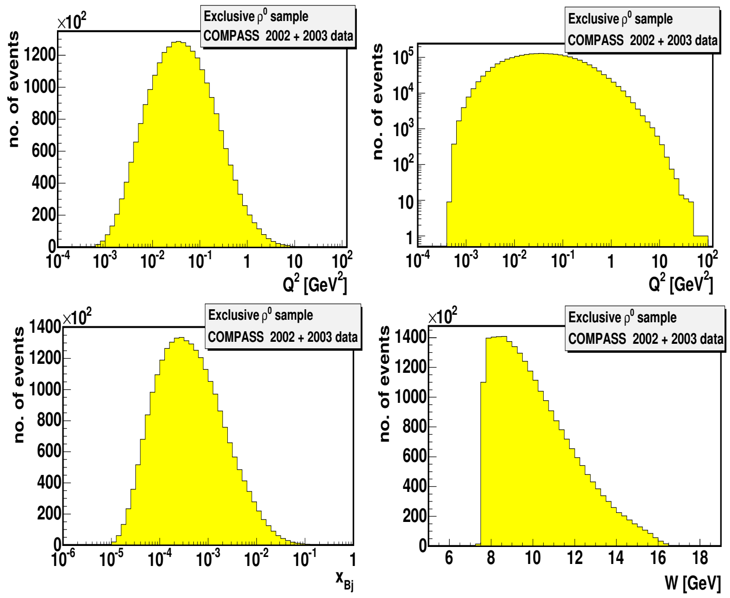

Figure 1: Distributions of Q^2 (linear and logarithmic vertical scales), $x_{\rm Bj}$ and W for the exclusive ρ^0 sample, selected from the 2002 and 2003 data.

After all selections the sample consisted of about 2.44 M events, a large number compared to other experiments studying exclusive ρ^0 leptoproduction. For the final sample the mean values of W and p_t^2 are $\langle\, W\, \rangle = 10.2$ GeV and $\langle\, p_t^2\, \rangle = 0.27$ GeV^2. The distributions of Q^2, $x_{\rm Bj}$ and W are shown in Fig. 1. The distributions of the hadron variables $m_{\pi\pi}$, $E_{\rm miss}$ and p_t^2 after all cuts apart from cuts on the given variable itself are presented in Fig. 2, with vertical arrows showing cuts on the given variable. In top panel of Fig. 2 ($m_{\pi\pi}$) one can see a clear peak of the ρ^0 resonance, centered at 770 MeV, placed on top of a low level background of the non-resonant $\pi^+\pi^-$ pairs. A small bump below 0.4 GeV is due to a contribution of ϕ mesons decaying into K^+K^- channel. In middle panel of Fig. 2 ($E_{\rm miss}$) the pronounced peak centered close to zero is a signature of the exclusive ρ^0 events. A width of this peak is determined by the spectrometer resolution. A part of

E_{miss} distribution right to the peak is due to non-exclusive background events. It continues under the exclusive peak, and a contribution of the non-exclusive background within the imposed cuts was preliminarily evaluated to be around 12%.

For the spin-dependent muon–nucleon cross sections for the reaction (1) the following longitudinal double–spin asymmetry is defined:

$$A_{LL}\,(\mu N \to \mu' N' \rho^0) \;=\; \frac{\sigma_{\uparrow\Downarrow} \;-\; \sigma_{\uparrow\Uparrow}}{\sigma_{\uparrow\Downarrow} \;+\; \sigma_{\uparrow\Uparrow}}\,, \qquad (4)$$

where the arrow pairs $\uparrow\Downarrow$ ($\uparrow\Uparrow$) relate to a case when beam muon and upstream (downstream) target cell polarizations are aligned antiparallel (parallel). This asymmetry is related to the asymmetry A_1^ρ of Eq. (3) as:

$$A_{LL} \;=\; D\,(A_1^\rho \;+\; \eta\,A_2^\rho)\,, \qquad (5)$$

where D is the depolarization factor (fraction of the beam muon polarization taken by the virtual photon), $\eta = \eta(Q^2,\ y,\ m_\mu)$ is a kinematical factor, and m_μ is the muon mass. Values of η are very small in the whole kinematical range considered in this analysis. The A_2^ρ asymmetry is defined as $A_2^\rho = 2\,\sigma_{LT}/(\sigma_{1/2} \,+\, \sigma_{3/2})$, and σ_{LT} is the cross section due to the interference of amplitudes for exclusive ρ^0 production by γ_L^* and γ_T^*. A_2^ρ asymmetry obeys the positivity limit $|\,A_2^\rho\,| < \sqrt{R}$, where $R \,=\, \sigma_L/\sigma_T$ is the ratio of cross sections for exclusive ρ^0 production by γ_L^* and γ_T^*. The product $\eta\sqrt{R}$ is of order $10^{-4} \div 0.05$ (depending on kinematics), which enables to neglect the ηA_2^ρ term in Eq. (5). The effect of this neglect has been included in the total systematic error, giving a very small contribution.

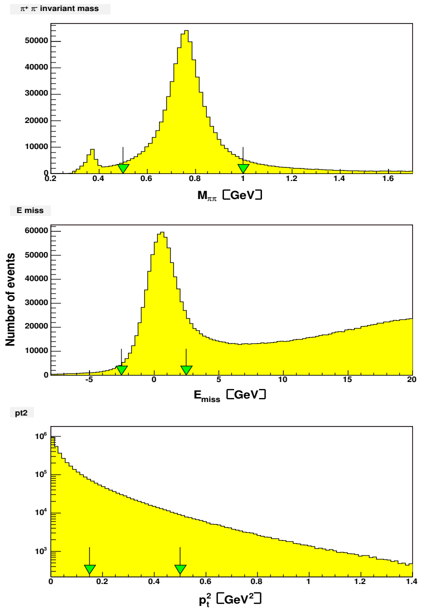

Figure 2: Distributions of $m_{\pi\pi}$, E_{miss} and p_t^2 for the exclusive ρ^0 sample, with no cuts on a shown variable itself. The latter cuts are shown with vertical arrows.

The asymmetry A_1^ρ was extracted from data sets taken before and after target polarization reversal, using the same method as used in COMPASS inclusive A_1 asymmetry analysis [15]. In order to minimize the statistical errors all quantities used in the A_1^ρ calculation are evaluated event by event, and each event is weighed with the factor $w = f D P_{\text{b}}$, where f is the dilution factor and P_{b} is the beam muon polarization.

P_{b} is obtained using its parametrization as a function of the beam muon momentum. D is calculated using the formula:

$$D(Q^2,\ y) \;=\; \frac{y\,[\,(1 \,+\, \gamma^2 y/2)\,(2 \,-\, y) \;-\; 2\,y^2 m^2/Q^2\,]}{y^2\,(1 \,-\, 2m^2/Q^2)\,(1 \,+\, \gamma^2) \;+\; 2\,(1 \,+\, R)\,(1 \,-\, y \,-\, \gamma^2 y^2/4)}\,, \qquad (6)$$

where $\gamma^2 \,=\, Q^2/\nu^2$. For calculation of the cross sections ratio R the formula $R(Q^2) = a_0\,(Q^2)^{a_1}$ was used, with $a_0 = 0.66 \pm 0.05$ and $a_0 = 0.61 \pm 0.09$. This formula was earlier used by the E665 experiment to fit their results on R, and the mentioned a_0 and a_1 values were obtained from this fit [16]. As can be seen in Fig. 3 (left pannel) this parametrization describes well the COMPASS preliminary results on R (circles), moreover in a significantly wider Q^2 range than that of E665. The COMPASS analysis devoted to R and SDMEs [2] is continued, and after including the 2003 data and performing background studies our own parametrization of R will be done.

The dilution factor f is the fraction of polarized deuterons, being the target material for the studied reaction, compared to all nuclei present in the target. It is calculated using the formula:

$$f \;=\; C_1 \cdot f_0 \;=\; C_1 \cdot \frac{n_{\mathrm{D}}}{n_{\mathrm{D}} + \,\Sigma_A\, n_A\, (\,\tilde{\sigma}_A/\,\tilde{\sigma}_{\mathrm{D}})}\,, \tag{7}$$

where $\tilde{\sigma}_{\mathrm{D}}$ and $\tilde{\sigma}_A$ denote the cross section *per nucleon* for the reaction (1) ocurring on deuteron and any nucleus of the atomic mass A present in the COMPASS target. The C_1 factor takes into account that there are two polarized deuterons in a ^{6}LiD molecule, as a ^{6}Li nucleus is to a first approximation composed of a deuteron and an α particle. The measurements of the ratio $\tilde{\sigma}_A/\,\tilde{\sigma}_{\mathrm{D}}$ were taken from the NMC [17], E665 [18] and old experiments on ρ^0 photoproduction on various nuclei [19], and fitted in [20] with the formula:

$$\tilde{\sigma}_A \;=\; \sigma_{\mathrm{p}} \cdot A^{\alpha(Q^2)\,-\,1}, \qquad \text{with} \;\; \alpha(Q^2)\,-\,1 \;=\; -\frac{1}{3}\,\exp\{-Q^2/Q_0^2\}\,. \tag{8}$$

Here σ_{p} is the cross section for the reaction (1) on the free (unbound) proton. The value of the free parameter Q_0^2 obtained from the fit was $Q_0^2 \;=\; 9 \pm 3$ GeV^2. The mentioned experimental results and the fitted curve for α are shown as a function of Q^2 in right panel of Fig. 3, while the dilution factor is presented in middle panel of Fig. 3. The values of f are about 0.36 in most of the Q^2 range, rising to about 0.38 at the highest Q^2.

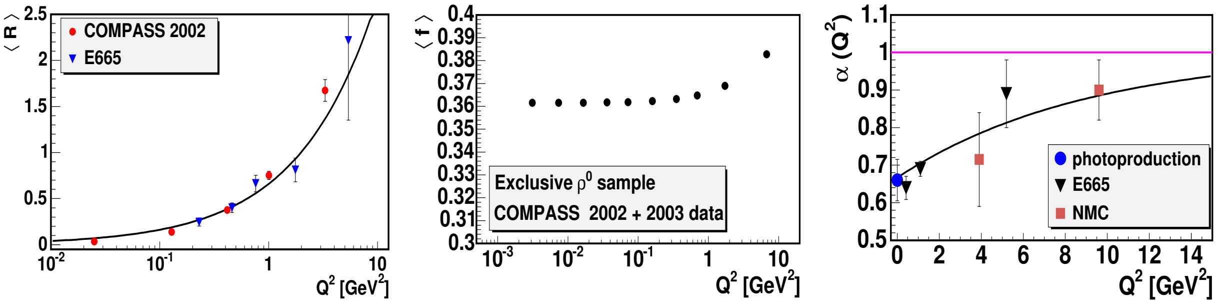

Figure 3: The $R = \sigma_L/\sigma_T$ ratio (left panel), dilution factor f (middle panel) and the power α used to calculate f (right panel) as functions of Q^2. See text for details.

The total systematic error of A_1^ρ takes into account: long-term random variations in the data taking conditions (random false asymmetry); possible false asymmetry arising from different orientations of the target magnetic field, due to different settings of the microwave frequencies used for the dynamic nuclear polarization of the target; overall uncertainties on P_{b} and P_{t}; uncertainties due to changes by 1 standard deviation of the fit parameters entering formulae Eq. (6) and Eq. (7) used to calculate D and f; and a contribution due to neglect of $\eta\sqrt{R}$ term in Eq. (5). The main contribution, more than 90% on average, to the total systematic error comes from the random false asymmetry. The total error, calculated as a quadratic sum of the statistical and systematic errors, is dominated by the statistical error, i.e. $\sigma_{\mathrm{syst}} \approx 60\%\,\sigma_{\mathrm{stat}}$. It has been estimated that background effects should not increase total error by more than about 7% on average.

The preliminary results for the A_1^ρ asymmetry from the COMPASS 2002 and 2003 data are shown (circles) as a function of Q^2 (left panel) and x_{Bj} (right panel) in Fig. 4. Inner (outer) vertical bars denote statistical (total) errors. The results are not background

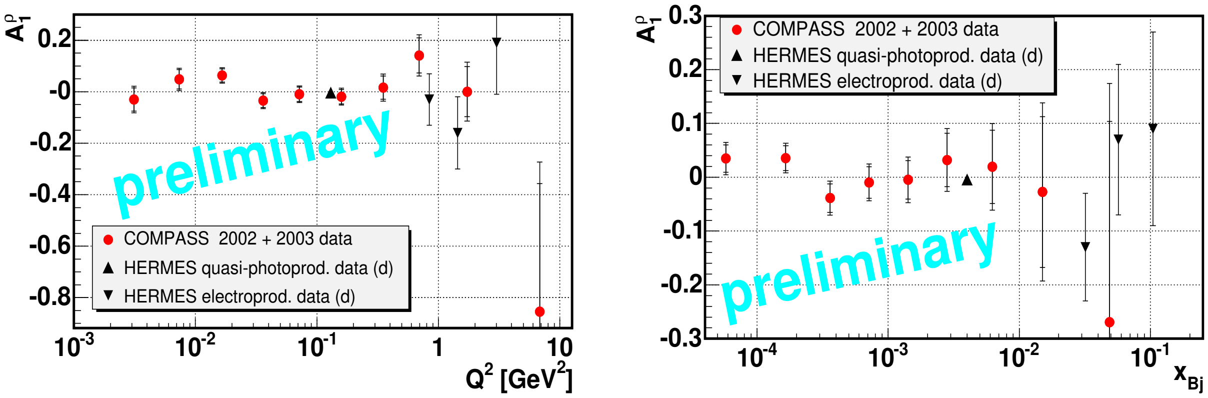

Figure 4: The A_1^ρ asymmetry obtained from the COMPASS 2002 and 2003 data (circles). Compared are results on A_1^ρ from the HERMES experiment obtained from a deuteron target (triangles). See text for details.

corrected yet. The A_1^ρ asymmetry is consistent with zero as a function of both Q^2 and $x_{\rm Bj}$ in their whole ranges. Also the results on A_1^ρ from a deuteron target from the HERMES experiment, taken from [13], are displayed (triangles) for comparison, with vertical bars representing the total errors. It should be noticed that both experiments measured A_1^ρ at different $\langle W \rangle$, equal to about 10 (5) GeV for COMPASS (HERMES). The results from both experiments are consistent within their accuracies. The COMPASS results extend the experimentally covered ranges of both variables by almost two decades down with respect to HERMES results.

The next steps of the reported analysis will comprise including the 2004 COMPASS data, also taken on the deuteron target (which will allow to double the number of events), and further studies of the background effects.

In conclusion, a measurement of the asymmetry A_1^ρ in a wide kinematical range of $3 \times 10^{-3} < Q^2 < 7$ GeV^2 and $5 \times 10^{-5} < x_{\rm Bj} < 0.05$, at $\langle W \rangle \approx 10$ GeV, was done by the COMPASS experiment, based on the data taken in 2002 and 2003 using the deuteron target. In a low Q^2 ($Q^2 < 0.1$ GeV^2) and low $x_{\rm Bj}$ ($x_{\rm Bj} < 3 \times 10^{-3}$) range these measurements are the first ever done. A_1^ρ is consistent with zero in the whole studied kinematical range. This may indicate that in that range the role of the unnatural parity exchanges, due to π or a_1 Regge trajectories exchanged in the t-channel of the reaction (2), discussed in [3, 4], is *small*. The mentioned relation of A_1^ρ to ΔG of model [7] holds only within the range where pQCD can be applied, which for the reaction (2) means $Q^2 \gtrsim 4$ GeV^2 (4 GeV^2 is the lower limit of our highest Q^2 bin). More data are needed to clarify this issue.

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