Double–Spin Asymmetry in Exclusive Vector Meson Production at HERMES

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The double–spin asymmetries A_1^ρ, A_1^Φ and $A_1^{J/\psi}$ in exclusive vector meson production have been measured at HERMES, using a longitudinally polarized positron beam and a longitudinally polarized hydrogen target. The analysis is focused on the ρ meson, because of its superior statistics. A significant positive asymmetry A_1^ρ was found, while the asymmetries for the Φ and J/ψ mesons are consistent with zero.

Spin dependence in vector meson production has been a field of interest for a long time. Spin density matrix elements of the vector meson are measured via angular distributions in diffractive production and only a small deviation from s-channel-helicity conservation (SCHC) could be observed [1–3]. So far, only the spin transfer from the virtual photon to the final state vector meson has been considered; the spin state of the target has not been taken into account.

The theoretical understanding of double–spin asymmetries in diffractive processes is limited. For the J/ψ only small asymmetries are predicted by models describing the elastic process as exchange of two gluons [4]. For the lighter vector mesons ρ and Φ, the naive expectation from Pomeron exchange is a zero asymmetry. No previous data exist on double–spin asymmetries in diffractive vector meson production.

The HERMES experiment has the possibility to analyse vector meson production because of its acceptance and its particle identification capabilities [5]. It uses the longitudinally polarized HERA positron beam, and in 1996 and 1997 a longitudinally polarized hydrogen target. Their respective polarizations were 0.55 ± 0.02 and 0.86 ± 0.04, where the errors are purely systematic. The internal hydrogen gas target has the advantage of no dilution by unpolarizable material, and no nuclear effects.

Four decay channels have been analysed: $\rho \to \pi^+\pi^-$, $\Phi \to K^+K^-$, and the two di–leptonic decays $J/\psi \to e^+e^-$, $J/\psi \to \mu^+\mu^-$. Within the selection criteria described below, about 2800 ρ, 200 Φ, and 20 J/ψ events were found. For ρ's and Φ's the scattered positron is detected and the complete event kinematics can be reconstructed, while for most of the J/ψ events, the scattered positron remains undetected within the beam pipe. The analysis is focused on the ρ meson, because of its superior statistics.

For the analysis of exclusive ρ production, events are selected with exactly 3 tracks – two opposite charged hadrons and a positron. The invariant mass in the two pion hypothesis is required to be in the range $0.62 < M_{inv}(\pi,\pi) < 0.92$ GeV. Vertex cuts ensure that the three tracks originate from a common vertex within the target. In an exclusive event ($e + T \to VM + X$) the target nucleon stays intact ($T = X$) and no energy $\Delta E = (M_X^2 - M_T^2)/2M_T$ is transfered to the target; thus a cut of $|\Delta E| < 0.6$ GeV is applied.

Non–diffractive background is suppressed by a requirement $-t' \sim p_t^2 < 0.4$. The remaining background is dominated by DIS events which are subtracted using a Monte Carlo simulation based on LEPTO [6]. In order to remove possible asymmetry contributions ($A_1^{DIS} \sim 0.1$ at the average $x_{Bj} \sim 0.07$), the background subtraction is performed separately per spin configuration and kinematical bin. Background from mis-reconstructed Φ events is excluded by the cut on the invariant mass $M(\pi,\pi)$. Diffractive double–dissociative processes make an estimated

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3-6% contribution to the signal region $|\Delta E| < 0.6$ [7]. Background from the ω interference and non-resonant pion pair production can not be separated in principle and remains in the data. The asymmetry contribution of spin dependent radiative processes is expected to be negligible.

The longitudinal asymmetry $A_{\parallel}$ is given by

$$A_{\parallel} = \frac{N^- L^+ - N^+ L^-}{N^- L_p^+ + N^+ L_p^-} \qquad (1)$$

with $N^{\pm}$ being the (background corrected) numbers of events for the parallel (+) and antiparallel (-) beam-target spin configuration, and $L^{\pm}$, $L_p^{\pm}$ the corresponding integrated luminosities, the latter weighted with beam and target polarizations. The virtual photon asymmetry A_1 is related to the experimental asymmetry $A_{\parallel}$ by the effective polarization D of the virtual photon

$$A_1 = \frac{A_{\parallel}}{D} - \eta A_2 \quad \approx \frac{A_{\parallel}}{D}, \qquad (2)$$

$$D = \frac{1-(1-y)\epsilon}{1+\epsilon R}, \quad \text{and} \quad \epsilon \approx \frac{1-y}{1-y+y^2/2}, \qquad (3)$$

where D has an average value of about 0.4 for ρ and Φ and unity for J/ψ production at HERMES. The ratio $R = \sigma_L/\sigma_T$ for ρ production has been measured at HERMES and a fit as a function of Q^2 is used for this analysis [8].

A significant positive asymmetry A_1 in exclusive ρ production is observed at the HERMES experiment. Figure 1 shows the extracted asymmetry A_1^{ρ} versus Q^2 and W^2. Other dependences have been investigated as well, but within the statistical uncertainty no significant trend can be seen in any kinematical variable.

Systematic studies included variation of the event selection, checks of possible acceptance effects, and different methods of background subtraction: based on data, Monte Carlo or empirical fits [9]. A preliminary systematic uncertainty of $\delta A_1^{\rho} = \pm 0.035$ was assigned. Added in quadrature is a systematic uncertainty of 6% on A_1 due to the uncertainties in the beam and target polarization measurements. The resulting experimental systematic uncertainty is indicated by the dark bands in Figure 1.

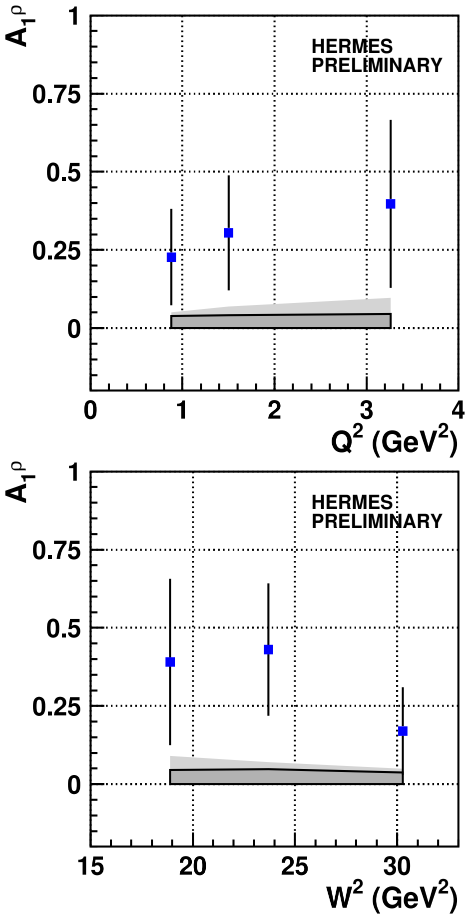

Figure 1. Asymmetry A_1^{ρ} versus Q^2 and W^2.

In Equation 2, a contribution from the transverse asymmetry A_2 is suppressed by a kinematical factor $\eta = \frac{2\gamma(1-y)}{2-y}$; $\gamma^2 = \frac{Q^2}{\nu^2}$. In DIS this contribution is small and usually neglected. In vector meson production, A_2 is unmeasured and hence a systematic uncertainty ηA_2 is assigned. The average η is 0.05 and A_2 obeys the positivity limit $|A_2| < \min(\sqrt{R}, 1)$. This theoretical uncertainty is added in quadrature to the experimental uncertainty, resulting in the light grey shaded bands in Figure 1.

The analysis of exclusive $\Phi \to K^+K^-$ production follows closely the ρ analysis. Similar cuts are used to select the event sample with an invariant mass between $1.012 < M_{inv}(K,K) < 1.028$ GeV. Additionally, the identification of at least one non–pion by the Cherenkov detector is required. Due to the statistics of about 200 Φ events the systematic studies have been limited. An asymmetry consistent with zero within the statistical uncertainty was obtained.

The spectrometer is naturally suited in terms of particle identification and trigger to detect the decay $J/\psi \to e^+e^-$. The decay channel $J/\psi \to \mu^+\mu^-$ is accessible via a track multiplicity trigger, and muon identification is achieved by requiring minimum ionising signals in the calorimeter and the pre-shower detector. HERMES is restricted to J/ψ production near threshold by the beam energy of 27.5 GeV, and about 20 J/ψ's combined from both decay channels have been extracted using the polarized hydrogen target.

For most J/ψ events the scattered positron remains inside the beam pipe, preventing the full reconstruction of the event kinematics and the separation of different production mechanisms. The contribution of inelastic processes was estimated to be $20-30\%$ [10]. A fit to the invariant mass spectrum separately for each spin configuration was used to determine the number of events over background, and the asymmetry $A_1^{J/\psi}$ was found to be consistent with zero.

Figure 2 compares the asymmetry A_1 for ρ, Φ and J/ψ production. A positive asymmetry for exclusive ρ production at an average $< W^2 >= 24$ GeV^2 and $< Q^2 >= 1.7$ GeV^2 has been observed. Combining all data, a value with a statistical significance of 3σ is obtained: $A_1^\rho = 0.30 \pm 0.11(stat.) \pm 0.04(syst.exp.) \pm 0.05(syst.theor.; A_2)$. Within their statistical uncertainties the asymmetries A_1^Φ and $A_1^{J/\psi}$ are consistent with zero; their systematic uncertainties have been neglected.

Since there exists no clear interpretation of the observed asymmetry in exclusive ρ production yet, several questions arise: Can A_1^ρ be related to ΔG via models involving gluon exchange? Is there a relation to spin density matrix elements ? The angle dependence of A_1^ρ is currently being investigated. Is there a possible relation of A_1^ρ to off–forward parton distributions [11]? The HERMES kinematics lies in the transition region

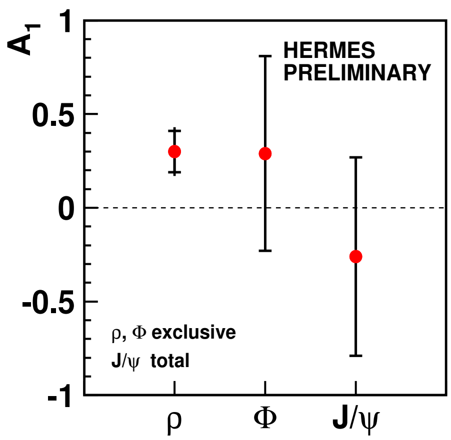

Figure 2. Asymmetry A_1 for ρ, Φ and J/ψ.

between Reggeon and Pomeron exchange; the ρ cross section agrees with predictions from models dominated by quark exchange [8,12]. The W^2 or Q^2 dependence of A_1^ρ may help to distinguish between different models of diffractive ρ production.

In summary, a significant nonzero asymmetry in ρ production is an unexpected exciting result, presently without theoretical explanation.

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