Hard Exclusive ϕ meson leptoproduction at HERMES

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The HERMES experiment at DESY, Hamburg collected a set of data on hard exclusive vector meson (ρ^0, ϕ , ω) leptoproduction using the 27.6 GeV self-polarized lepton beam of HERA accelerator and a longitudinally or transversely polarized or unpolarized gas target. The latest results for spin density matrix elements of exclusive ϕ meson production using the full statistics collected at HERMES are presented. Conclusions on the helicity amplitudes, which are related to spin density matrix elements, are also presented.

1 Introduction

Electroproduction of vector mesons (V) from scattering the beam lepton (e) on the nucleon target (N) can be described by the equation $e + N \rightarrow e' + V + N'$, with the following decay of the vector meson to two oppositely charged kaons in case of ϕ meson production. In perturbative Quantum Chromo Dynamics (pQCD) exclusive meson production can be considered as an interaction with the target nucleon of a qq pair into which the virtual photon has fluctuated. Therefore, in the single photon approximation, the last equation can be represented as $\gamma^* + N \rightarrow V + N'$. The spin state of the final vector meson produced is determined by the spin density matrix. The decay angular distribution of the ϕ meson, which can be reconstructed via measurement of all the reaction kinematics, also can be decomposed in terms of the model-independent quantities - spin density matrix elements (SDMEs) [1]. With the HERMES experimental configuration (longitudinally polarized beam and unpolarized target) 15 so-called unpolarized SDMEs and 8 beam-polarization dependent SDMEs can be determined. The set of 23 SDMEs for the ϕ meson is presented here in the Wolf-Schilling representation [1]. Using the measured SDMEs, the hypothesis of s-Channel Helicity Conservation (SCHC), which is the conservation of helicity in the $\gamma^* \rightarrow V$ transition, can be tested. If SCHC holds, SDMEs responsible for helicity-flip transitions are zero. SDMEs can be expressed through bilinear products of helicity amplitudes, defined in the "hadronic" center of mass system of virtual photon and target nucleon [2]. Since the spin density matrix elements are dimensionless they may be expressed through ratios of amplitudes rather than amplitudes themselves. In contrast to SDMEs, the number of helicity amplitudes does not depend on the beam and target polarization. Therefore the helicity amplitudes provide more a general description of vector meson electroproduction than SDMEs.

2 Data

The exclusive ϕ meson event sample used in the analysis was selected by requiring the existence of three tracks: a lepton and two oppositely charged kaon tracks. Certain kinematic restrictions were applied to the momentum transfer Q^2, the inelasticity y and the invariant mass of the excited photon-nucleon system W. Exclusivity of the sample was achieved via restrictions on the invariant mass of the ϕ meson, the squared transverse 4-momentum transfer t', and the missing energy of the reaction ΔE, calculated as $\Delta E = (M_x^2 - M_p^2)/(2M_p)$, where M_x is the missing mass of the recoil particle, and M_p is target mass. The background fraction was estimated using the PYTHIA monte Carlo and was found to be of the order of 2-3%.

3 Extraction of SDMEs

The 3-dimensional angular distribution of the scattered lepton and the decay products can be expressed in terms of SDMEs and the following angles (see detailed definition in [3]): Φ which is the angle between φ meson production plane and the lepton scattering plane in the center of mass system of virtual photon and target nucleon; θ and ϕ which are the polar and azimuthal angles of the decay K^+ in the vector meson rest frame. The distribution of these angles is calculated for two sets - a measured data set, whose angular distributions are generated by SDMEs and therefore is not flat; and a data set generated by a Monte Carlo simulation whose angular distribution does not contain SDMEs and is affected by detector geometry only. Then the maximum likelihood function, which contains the Monte Carlo decay angular distribution for normalization and the data angular distribution, are fit by (for the present analysis MINUIT package was used), using the SDMEs are treated as fit parameters.

4 Results

In Fig 1 twenty three ϕ SDMEs for the ϕ (red) and ρ (black) mesons are presented. Usage of almost the whole HERMES statistics for the ϕ meson allow the separation for hydrogen and deuterium targets. SDMEs are divided into 5 classes according to the transition processes. Shadowed areas denote polarized SDMES. The inner error bars represent statistical uncertainties, while the outer error bars represent total uncertainties, obtained as the sum of squared statistical and systematic uncertainties. The average kinematics are $< Q^2 >= 1.956$ GeV^2, $< W^2 >= 21.89$ GeV^2, $< x >= 0.088$, $< t' >= -0.12$ GeV^2. The SDMEs are multiplied by certain kinematic factors in order to facilitate comparison with the corresponding helicity amplitude. The large SDME values of classes A and B corresponding to the helicity-conserving transitions, support the SCHC hypothesis. The SDMEs of class A have dominant contributions proportional to the helicity amplitudes $|T_{00}|^2$ or $|T_{11}|^2$. For the ϕ meson, the SDMEs of the class A are 10-20% larger than those of ρ meson, which implies that the corresponding amplitude ratio T_{11}/T_{00} is larger for ϕ meson than for ρ. Several relations between SDMEs of classes A and B allow conclusions to be drawn on the validaty of SCHC (see Eqs. (78-83) in Ref. [4]). The relations $r^1_{1-1} = -Imr^2_{1-1}$ and $Rer^5_{10} = -Imr^6_{10}$ are fulfilled for both the ϕ and ρ mesons. The relation $Rer^8_{10} = Imr^7_{10}$ is fulfilled for ρ, while for ϕ no conclusion can be made due to the large uncertainties. Class B SDMEs correspond to the interference of the class A SDMEs. SDMEs of classes C, D, E are responsible for SCHC-violating transitions. For both ϕ and ρ mesons the most significant deviations from zero are observed in C class. This class contains SDMEs with dominant terms that are products of the s-chanel helicity non-conserving amplitude T_{01} and helicity conserving amplitudes T_{00} and T_{11}. In D and E classes ϕ and ρ meson SDMEs fluctuate about zero, supporting SCHC. They are composed of SDMEs in which the main terms contain a product of T_{10} (for single helicity flip) or T_{1-1} (for double helicity flip), respectively, with T^*_{11}. From the relations between SDMEs cited above a conclusion on the amplitudes hierarchy for the ϕ meson can be drawn, namely, $|T_{00}| \sim |T_{11}| >> |T_{01}|, |T_{10}| \approx |T_{1-1}| \approx 0$.

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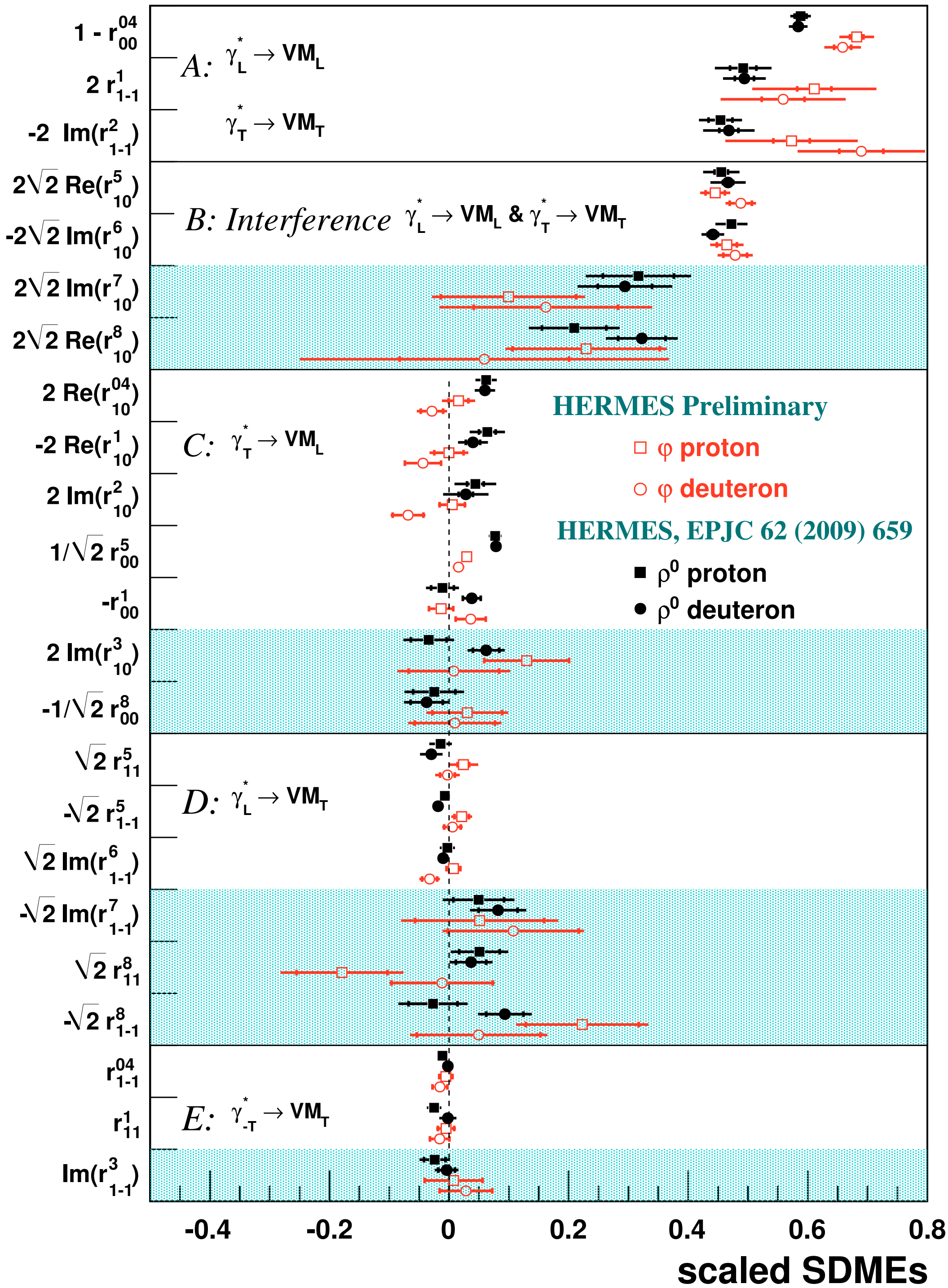

Figure 1: The 23 SDMEs for the ϕ and ρ mesons.