Diffractive Vector Meson Production at HERMES

N.C.R. Makins
Department of Physics, University of Illinois
Urbana, Illinois 61801, USA

Abstract

The HERMES experiment has reconstructed numerous unstable particle species from its data sets, including the ρ^0 , ϕ, and J/ψ vector mesons. A brief overview of the present status of the analysis of these samples is presented. Specifically discussed are the vector meson production cross-section, spin density matrix elements for ρ^0 production, and A-dependence studies of hadron formation scales.

I. Diffractive vector meson production

Analysis of exclusive diffractive ρ^0 production

Diffractive vector meson production has received considerable theoretical attention in recent years. In this process, a vector meson is created from a virtual boson in an elastic scattering reaction on a nuclear target. Various models have been developed, including the vector dominance model and pictures involving Pomeron exchange.

The ρ^0 meson is reconstructed at HERMES from its decay to two charged pions, whose momenta are required to form an invariant mass between 0.6 and 1.0 GeV. The invariant mass peak is sufficiently clean that no particle identification beyond electron-hadron separation is required. Exclusive ρ^0 production is isolated by requiring that no tracks other than the scattered beam lepton and the two decay pions are observed, and by placing cuts on the missing mass in the final state. The requirement of diffractive production is additionally imposed by restricting the transverse momentum exchanged between the target and the scattered ρ^0 meson. Finally, a subtraction of non-exclusive background is made by fitting the spectrum of inelastic events produced with large transverse momentum.

The vector meson analyses completed to date do not require a polarized target. Consequently, the event samples used in these analyses include scattering from both the polarized and unpolarized targets available at HERMES. During the years 1995 through 1997, scattering from H, D, and ^{3}He targets has been measured. In addition, a brief measurement on ^{14}N was made in 1997.

Vector meson cross sections

Many experiments have measured the cross-section for the production of various vector mesons, at a wide range of kinematics. A representative sample of these measurements for the ρ^0 is shown in Figure 1. The behaviour of the cross-section with W is of particular interest, as it varies dramatically with kinematics. Three distinct regions can be identified. First, at low Q^2 and W values, the cross-section is seen to fall steeply with W. This region is traditionally rather well described by vector dominance and meson exchange models [2][3]. Secondly, at low Q^2 but large W, a slow rise with W is observed. This dependence has been well described by non-perturbative ("soft") Pomeron exchange models [5][4]. Finally, at large values of Q^2 the cross-section begins to rise steeply with W. Similar behaviour is seen in the production cross-section for the heavy J/ψ meson, even down to very low values of Q^2 . In either case, the introduction of a hard scale at the interaction vertex invites the application of perturbative QCD, and models involving the exchange of a "hard" perturbative Pomeron (typically a two-gluon configuration) have been quite successful at describing the measured behaviour in this region [6].

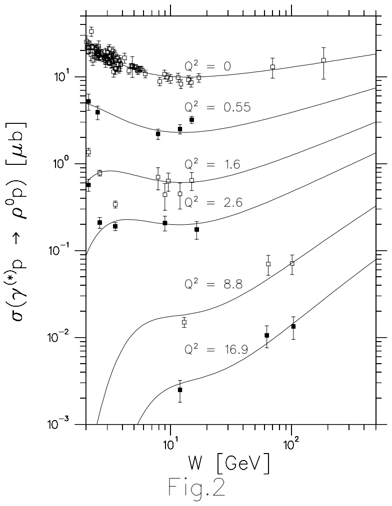

Figure 1: Representative sample of world data on the diffractive ρ^0 production cross-section, superimposed with the multiple-Pomeron model of [1].

The vector meson cross-section remains unmeasured in certain regions of the kinematic plane, notably at high Q^2 and low W. Calculations of two-quark exchange suggest that the cross section should again exhibit a steep W falloff in this region [7]. HERMES is well placed to contribute to our understanding of the transition between these regions, at moderate values of Q^2 and W. Specifically the accessible kinematic range is $0.15 < Q^2 < 5$ (GeV/c)^2 and $4 < W < 6.5$ GeV. The analysis of the ρ^0 cross-section in this region has not yet been completed.

In addition, HERMES will be able to measure the production cross-sections for the ϕ and J/ψ mesons. In the case of the J/ψ , HERMES will make the first measurement in many years of charmonium production near threshold, a region of considerable theoretical uncertainty. A sample of over 100 J/ψ mesons has already been reconstructed, and will be enhanced in forthcoming data taking periods by this year's addition of wide angle muon detectors to the spectrometer.

Spin density matrix elements for the ρ^0

Additional insight into diffractive ρ^0 production can be obtained from a study of the angular distribution of the ρ^0 's $\pi^+\pi^-$ decay products [8]. This angular distribution is a direct consequence of the helicity state of the produced ρ^0 , and can be expressed as a superposition of the three possible states ($\lambda = -1, 0, 1$). In the initial state, the polarization of the virtual photon from which the ρ^0 originates is a well-understood function of kinematics. Thus, one can obtain from the data a transition matrix $T_{\lambda\gamma}$, describing the probability that a virtual photon of helicity γ will fluctuate into a ρ^0 meson of helicity λ.

Models of diffractive vector meson production usually make the assumption of s-channel helicity conservation (SCHC) [9], which effectively diagonalizes the transition matrix $T_{\lambda\gamma}$. If the additional assumption of natural parity exchange is also made, only two independent matrix elements remain.

HERMES has extracted four spin-density matrix elements from the ρ^0 data collected in 1995, providing a partial test of these assumptions. The notation $r^{\alpha}_{\lambda\lambda'}$ is used, where λ, λ' denote helicity states of the ρ^0 and α describes the virtual photon polarization. The matrix element r^{04}_{00} couples $m = 0$ states of the photon and ρ^0 ; the extracted result shows that the ρ^0 polarization changes from predominantly transverse to predominantly longitudinal as Q^2 increases from 0.8 to 3 (GeV/c)^2. The matrix element r^{1}_{1-1} couples linearly polarized photons and ρ^0 's, and under SCHC is directly related to r^{04}_{00}. The data agree well with this relation. Finally, two SCHC-violating matrix elements are extracted. These are r^{04}_{1-1} and r^{3}_{1-1}. Both are found to be consistent with zero, as predicted by SCHC.

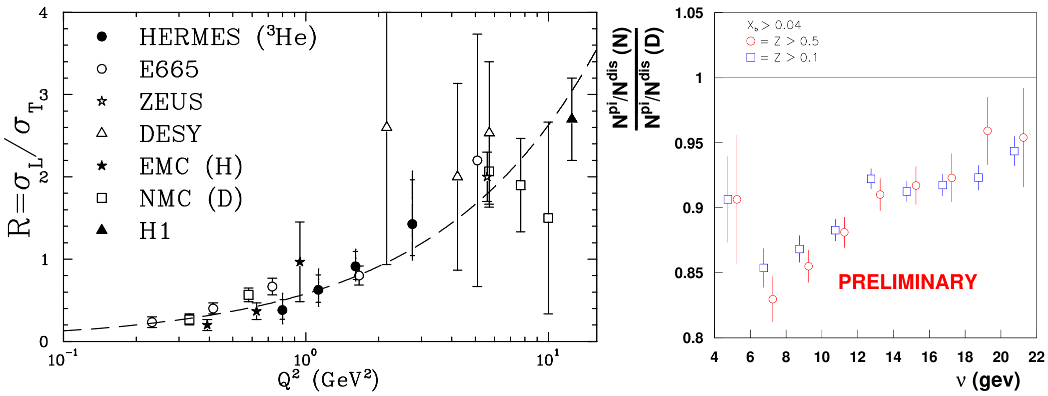

Figure 2: (a) Data from HERMES and other experiments on the ratio $R = \sigma_L/\sigma_T$ for diffractive ρ^0 production. (b) HERMES preliminary result on the attenuation of pion production in ^{14}N compared to D_2.

Finally, the extracted values of r^{04}_{00} yield the quantity $R = \sigma_L/\sigma_T$, at four values of Q^2 . The data are shown in figure 2a. This quantity is expected to exhibit a linear dependence on Q^2 in the vector dominance model. A power-law fit to the world data however suggests a power of about 0.6 rather than 1. Additionally, the overall normalization of R appears to depend significantly on the variable W, yielding different overall constants for the data below and above W = 10 GeV. The new HERMES results fall in the $W < 10$ region, significantly supplementing the existing low statistics measurements from DESY.

II. A-dependence studies

Hadron formation: A-dependence of π production

The fragmentation process which transforms a struck quark into a colourless hadron in a deep-inelastic scattering (DIS) event has been effectively parametrized in various contexts but is still poorly understood. To probe the scales at which this fundamental process occurs, one can measure the production of hadrons from nuclei of different sizes. At different stages of the quark's evolution into a hadron, it can be expected to have different cross-sections for interaction with the nuclear medium. The final state attenuation of deep-inelastically produced hadrons therefore serves as a probe of the fragmentation mechanism, with the nuclear radius providing a scale against which the process can be measured.

The principal quantity under investigation is the scale τ_f over which hadron formation takes place. Two simple models can readily be postulated. One hypothesis is that the hadron formation time is a fundamental constant τ_h, which must simply be Lorentz boosted from the rest frame of the hadron into the lab frame to supply τ_f for a hadron of energy E_h. In this picture, τ_f depends only on the hadron energy and mass. Alternatively, one can imagine that a bare quark behaves like an unstable particle, with an intrinsic "lifetime" τ_q. In this case, the Lorentz boost needed to obtain τ_f is performed in the reference frame of the quark, and depends only on the energy ν transferred to the quark. A possible additional dependence on Q^2 might also arise via the mass of the off-shell quark.

Measurements of the hadron production ratio from heavy targets to that from H_2 and D_2 exist from SLAC[10] and EMC[11]. The ν-dependence of the EMC data in particular demonstrated that single scale models such as those suggested above are inadequate. A second scale τ_c was postulated, representing the time necessary for the quark to form a colour string with the spectator partons.

HERMES has measured the ratio of charged pion production from ^{14}N to that from D. At the kinematics $4 < \nu < 24$, the formation scale τ_f is expected to correspond to the radius of the ^{14}N nucleus. The results are shown in figure 2b as a function of the energy ν transferred to the struck quark. A clear dependence on this variable is observed, as is predicted by the Lorentz boost necessary in both of the simple models described above. The data are also shown with two different cuts in $z = E_h/\nu$. Any dependence on this variable would lend some credence to the first, hadron-based picture of hadron formation. However, no such dependence is observed. HERMES will pursue these studies by varying A (the choice of nuclear target) and by examining the dependence on Q^2 . In addition, the attenuation of different hadronic species will be measured, an endeavour which will be greatly enhanced by the 1998 upgrade of the HERMES Cerenkov detector to a RICH.

References

[1] L.P.A. Haakman *et al.*, Phys. Lett. **B365** (1996) 411.

[2] T.H. Bauer *et al.*, Rev. Mod. Phys. **50** (1978) 261.

[3] A. Donnachie and P.V. Landshoff, Phys. Lett. **B296** (1992) 227.

[4] M.A. Pichowsky and T.-S.H. Lee, Phys. Lett. **B379** (1996) 1.

[5] A.Donnachie and P.V. Landshoff, Nucl. Phys. **B311** (1989) 509;
A.Donnachie and P.V. Landshoff, Phys. Lett. **B348** (1995) 213;
J.R. Cudell, Nucl. Phys. **B336** (1990) 1.

[6] M.G. Ryskin, Z. Phys. **C57** (1993) 89;
J.Nemchik *et al.*, Phys. Lett. **B341** (1994) 228.

[7] M. Guidal, proceedings of this workshop.

[8] K. Schilling, P. Seyboth, and G. Wolf, Nucl. Phys. **B15** (1970) 397;
K. Schilling and G. Wolf, Nucl. Phys. **B61** (1973) 381.

[9] J. Ballam *et al.*, Phys. Rev. Lett. **24** (1970) 960.

[10] L.S. Osborne *et al.*, Phys. Rev. Lett. **40** (1978) 1624.

[11] EMC Collaboration, J. Ashman *et al.*, Z. Phys. **C52** (1991) 1.