Nuclear Transparency in Exclusive ρ^0 Production at HERMES

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Abstract. Exclusive coherent and incoherent electroproduction of the ρ^0 meson from ^{1}H and ^{14}N targets has been studied at the HERMES experiment as a function of coherence length (l_c), corresponding to the lifetime of hadronic fluctuations of the virtual photon, and squared four-momentum of the virtual photon ($-Q^2$). The ratio of ^{14}N to ^{1}H cross sections per nucleon, *called* nuclear transparency, was found to increase (decrease) with increasing coherence length for coherent (incoherent) ρ^0 electroproduction. For fixed coherence length, a rise of nuclear transparency with Q^2 is observed for both coherent and incoherent ρ^0 production, which is in agreement with theoretical calculations of color transparency.

INTRODUCTION

Exclusive electroproduction of ρ^0 mesons from nuclei is considered to be an excellent tool to investigate the properties of elementary particles interacting with the nuclear medium, such as the phenomena of a "shrinking photon" [1, 2, 3] and Color Transparency (CT) [4, 5, 6]. The latter phenomenon is a prediction of perturbative QCD. It suggests that, due to their reduced transverse size, particles produced with high virtuality in exclusive reactions should exhibit a reduced interaction with other hadrons. In particular, the "size" of the hadronic components of the virtual photon at high negative four-momentum transfer squared, Q^2, is conjectured to be smaller than the size of a normal hadron. This would account for the pointlike behavior and the diminished absorption of virtual photons in nuclear interactions, as compared to real photons. In QCD, the reaction amplitudes for exclusive interactions at large momentum transfer are expected to be dominated by components of the photon wave function with small transverse size, which give rise to diminished final state interactions in the nuclear medium. Theoretical models typically describe the exclusive production of light vector mesons as occurring via the fluctuation of the virtual photon into a quark-antiquark pair (or off-shell vector meson), which is scattered onto the mass shell by a diffractive interaction with the target. The corresponding tree level diagram is shown in Fig. 1.

Several experiments in search of CT have been carried out in the past. Although none of these experiments is in conflict with CT, no unambiguous signature for the onset of CT has been found yet. The pioneering searches of CT found an oscillation in the nuclear transparency in quasielastic proton scattering [7], and a nuclear transparency that is compatible with the Glauber model in quasielastic electron scattering [8, 9]. The interpretation of these results in terms of CT is still debatable. First evidence for CT

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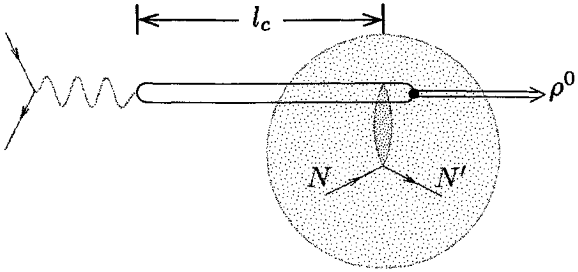

FIGURE 1. Cartoon describing exclusive ρ^0 meson production and illustrating the importance of coherence length, which is the propagation distance of the short-lived quark-antiquark state.

came from quasifree charge exchange scattering data of 40 GeV/c negative pions on carbon [10] as suggested in Ref. [11]. Further evidence for CT comes from Fermilab experiment E791 on the A-dependence of coherent diffractive dissociation of 500 GeV/c pions into di-jets [12]. This result shows a platinum to carbon cross section about ten times larger than expected if soft processes would dominate, which is qualitatively consistent with theoretical calculations of CT effects [13, 14]. Also experiment E665 on exclusive incoherent ρ^0 muoproduction from nuclei [15] gives an indication of CT. However, that signal is of indecisive statistical significance.

EXPERIMENT

The nuclear transparency data were obtained during the 1996-1997 running periods of the HERMES experiment using ^1H and ^{14}N gas targets in the 27.5 GeV HERA positron storage ring at DESY. The HERMES detector is described in detail in Ref. [16]. The scattered positron and the h^+h^- hadron pair arising from the decay $\rho^0 \to \pi^+\pi^-$ were detected and identified in the HERMES forward spectrometer. The ρ^0 production sample was extracted from events with exactly these three detected tracks. A more detailed and comprehensive description of the extraction procedure for exclusive diffractive ρ^0 can be found in Refs. [17, 18]. Here, we only describe the method for extracting the ratio of coherent to incoherent cross sections based on nuclear data. The coherent component of the cross section, where the scattering occurs from the nucleus as a whole, dominates at low $|t'|$ and is absent for the hydrogen target, while the incoherent part, where the ρ^0 meson scatters from a single quasifree nucleon within the target, dominates starting at $|t'| \approx 0.09$ GeV^2. Here, $-t' = -(t - t_{min})$ with t being the four-momentum transfer between the vector meson and target nucleon and $|t_{min}|$ the minimum $|t|$ allowed by the kinematics.

The cross section is therefore approximated with the sum of coherent and incoherent contributions as

$$\frac{d\sigma}{dt} = b_N e^{b_N t'} + R_A b_A e^{b_A t'}, \tag{1}$$

where b_N and b_A are the slope parameters for the nucleon and nucleus, respectively. This yields the first observable, the coherent to incoherent full cross section ratio $R_A = \frac{\sigma_c}{\sigma_{inc}}$. The Monte Carlo generator DIPSI [19] was used to calculate the detector acceptance. There, different diffractive slope parameters and relativistic (non relativistic) Breit-Wigner mass distributions were used as an input parameters. Finally, corrections ($\approx$15%) were applied to the ratios due to the "Pauli blocking" effect [20, 21] for incoherent scattering.

The coherent (incoherent) nuclear transparency is defined as

$$T_{c(inc)} = \frac{\sigma^A_{c(inc)}(Q^2)}{A\sigma^p(Q^2)}, \tag{2}$$

where σ^p refers to scattering from the proton, and A is the atomic number of the nuclear target. For the nuclear transparency measurement, the DIS positron cross section was used as a luminosity measure in addition to the standard luminosity measurement based on Bhabha scattering from atomic electrons. The ratio of the integrated luminosities represents the largest source of kinematics-independent uncertainties. The total estimated systematic uncertainty from all normalization factors is 11%. For incoherent ρ^0 production, nuclear transparency is associated with the probability that the produced ρ^0 meson escapes the nucleus without interaction. For coherent production, measured for the first time at HERMES, such a probabilistic interpretation is not applicable, though T_c is still sensitive to coherence length and color transparency effects.

RESULTS

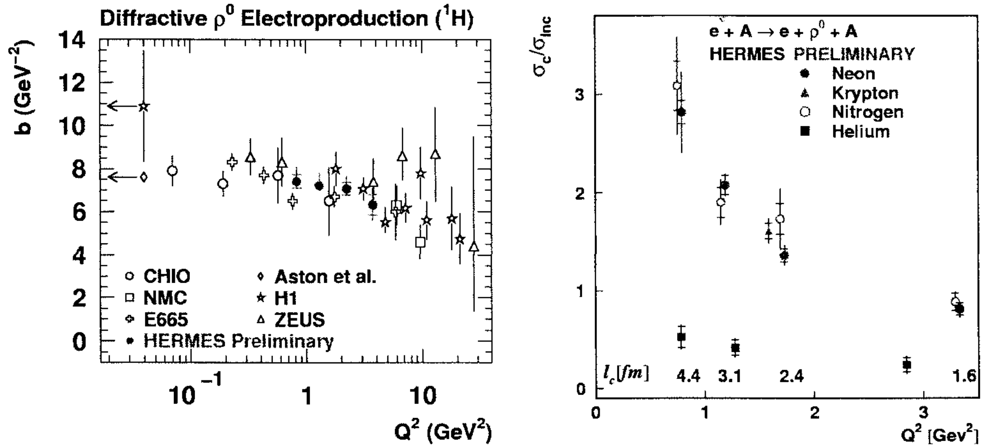

FIGURE 2. *Left panel:* The measured Q^2 dependence of the diffractive slope parameter in exclusive ρ^0 production from a hydrogen target. The compilation of all results including HERMES data is taken from Ref. [22]. *Right panel:* Q^2 dependence of coherent to incoherent cross section ratio (as described by Eq. (1).

In the left panel of Fig. 2 data on the diffractive slope parameter b versus Q^2 for diffractive ρ^0 production from a hydrogen target are presented. This parameter characterizes the rate of exponential decay of the cross section with t. Physically, b is a measure of the transverse size of the interaction region. Fig. 2 (left panel) demonstrates that the virtual photon "shrinks" with increasing virtuality Q^2. When ρ^0 mesons are produced from a nuclear target rather than hydrogen, this shrinkage is one possible source of reduced final state interactions. Another arises from the coherence length $l_c = \frac{2\nu}{Q^2+M_{q\bar{q}}^2}$, which describes the propagation distance of the short-lived quark-antiquark state (see Fig. 1). In the right panel of Fig. 2, the coherent-to-incoherent cross section ratio versus Q^2 is presented. A strong Q^2 dependence is observed, which is likely due to the variation of the coherence length l_c and the nuclear form factor's Q^2 dependence.

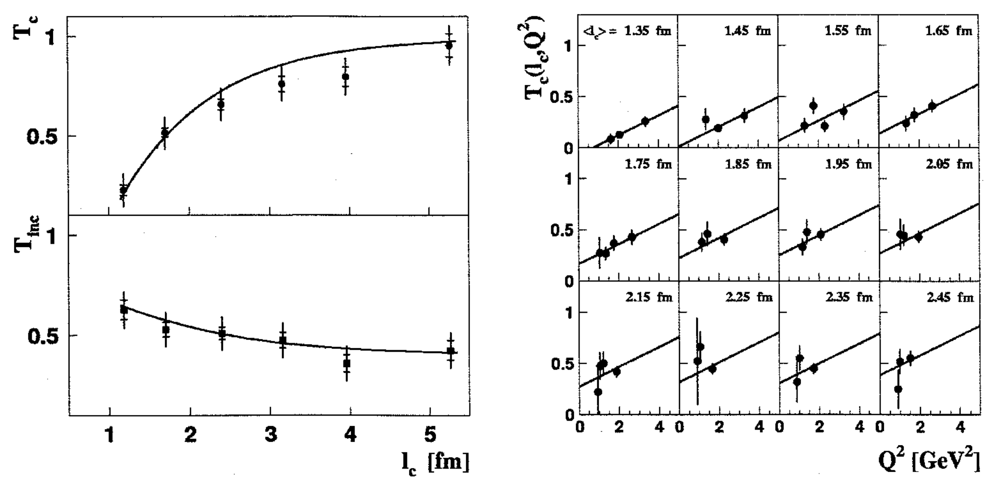

FIGURE 3. *Left panel:* Coherence length dependence of nuclear transparency, for coherent (T_c, top) and incoherent (T_{inc}, bottom) ρ^0 production on nitrogen. The curves are from Ref. [23] and include CT effects. The inner error bars include only statistical uncertainties, while the outer error bars present the statistical and systematic uncertainties added in quadrature. *Right panel:* Q^2 dependence at fixed l_c on nitrogen. The straight line is the result of the common fit.

In Fig. 3 (left panel) results on coherent and incoherent transparency versus l_c [17] are shown. As one can see, both the coherent and incoherent transparencies show a distinct l_c dependence. The incoherent data decrease with increasing l_c, as expected from the effects of initial state interactions. The nuclear transparency for coherent ρ^0 production increases with coherence length as expected from the effects of the nuclear form factor. Good agreement is found between the measured nuclear transparencies, integrated over the available Q^2 region, and calculations including both the coherence length and CT effects [23].

To separate the color transparency effect, which is purely Q^2 dependent, from coherence length effects a two-dimensional analysis was performed: the slope of the data with Q^2 was extracted at fixed l_c. This two-dimensional analysis represents a new approach in the search of CT. Since the combination of statistical significance and Q^2 coverage is largest near $l_c = 2.0$ fm, the region $1.3 < l_c < 2.5$ fm has been chosen for this two-dimensional analysis. To deconvolute the CT and coherence length effects, coherence length bins of 0.1 fm were used. In order to extract the Q^2 dependence, each l_c bin was split into three or four Q^2 bins. The nuclear transparency was extracted in each (l_c,Q^2) sub-bin, and is shown in the right panel of Fig. 3 for coherent ρ^0 production. The data have been fitted with a common Q^2 dependent slope of transparency ratio, presented as lines in Fig. 3 (right panel), resulting in reduced chi-square values close to unity. The Q^2 slopes were found to be 0.070 ± 0.021(stat.) ± 0.017(syst.) for coherent and 0.089 ± 0.046(stat.) ± 0.020(syst.) for incoherent production [18]. According to Ref. [23], a positive slope of the transparency with Q^2, for fixed coherence length, is evidence for CT. Indeed, the results presented here support the CT prediction. If the results are combined, the measured Q^2 slope (0.074 ± 0.023(tot.)) GeV^{-2} is found to differ from zero by more than three standard deviations.

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