Investigating the Onset of Color Transparency with CLAS

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Quantum Chromo Dynamics (QCD) predicts that point-like colorless systems will exhibit vanishingly small cross-sections and are thus expected to travel through the nucleus with little attenuation, a phenomenon known as Color Transparency (CT). An increase in nuclear transparency, T_A, for increasing momentum transfer, Q^2, would signal the onset of CT.

We present an experiment with the CLAS detector on exclusive incoherent electro-production on nuclei of the ρ^0 meson, which is a particularly sensitive reaction to study CT. Preliminary results of this experiment show a clear rise in T_A with increasing Q^2, indicating the onset of Color Transparency.[1]

1 Introduction

One of the fundamental predictions of QCD is the phenomenon of Color Transparency (CT), which was first described more than two decades ago [2, 3]. CT describes the process by which a color singlet object with a reduced transverse size has a vanishingly small interaction cross section when propagating through a nucleus. Such a Point Like Configuration (PCL) can be created in a scattering experiment at high momentum transfer (Q^2). See one of the many review articles for details [4, 5, 6].

Experimentally the onset of CT can be observed as a rise in the nuclear transparency, $T_A = \frac{\sigma_A}{A\sigma_N}$ with increasing Q^2. Many experiments have looked for a signal of CT but only a few have observed one. For an overview of the experimental status see [7].

The reaction used in this experiment is incoherent electro-production of ρ^0 mesons off nuclei, which offers many advantages. It is expected that the onset of CT occurs at a lower Q^2 for a meson ($q\bar{q}$) compared to a hadron (qqq)[8]. Also, since the ρ^0 is a vector meson, the production mechanism is well understood by the Vector Meson Dominance model (VMD) as the fluctuation of a photon (which has the same quantum numbers as a vector meson) into a ($q\bar{q}$) pair. The photon at high virtuality Q^2 is expected to produce a pair with small $\sim 1/Q^2$ transverse separation. CT then manifests itself as a vanishing absorption of this ($q\bar{q}$) pair as it propagates through the nucleus [9, 10].

The dynamical evolution of the small size ($q\bar{q}$) pair to a normal sized vector meson is controlled by the time scale called the formation time. In the rest frame of the nucleus this is given by $t_f = \frac{2\nu}{m_{V}'^2 - m_V^2}$, where V' represents the first excited state of the meson and V represents the ground state. This formation time needs to be sufficiently long to be able to observe CT.

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A competing effect to CT in vector meson production is the coherence length effect, which is due to quantum coherence, the destructive interference of the amplitudes for which the interaction takes place on different bound nucleons. The coherence length effect depends on the coherence length, $l_c = \frac{2\nu}{Q^2+m_V^2}$. This effect was recently measured by the HERMES collaboration [11], see Fig. 1. Since this effect competes with the CT signal, it is important to hold the coherence length, l_c, constant. This was done in a later analysis of the same data [12], which shows a rise of T_A with increasing Q^2, but suffers from poor statistics.

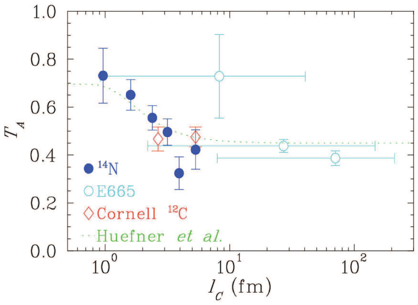

Figure 1: The Coherence Length effect measured by the HERMES collaboration [11]

2 The Experiment

Our experiment was conducted with the CLAS detector in Hall-B at Jefferson Laboratory during the EG2 run period in early 2004. The experiment used an electron beam of 5 GeV and 4 GeV on two targets simultaneously to reduce systematic errors. One of the targets was liquid deuterium and the other target was composed of a foil of either carbon, iron or lead. The targets could be clearly distinguished in the data analysis by use of a cut on the reaction vertex.

We studied the reaction $e+N \rightarrow e'+N+\rho^0 \rightarrow e'+N+\pi^++\pi^-$ by detecting the scattered electron and the two pions which are decay products of the ρ^0. A cut was made on $W > 2$ GeV to select the data above the resonance region. A cut on $t = (q^\mu - P_V^\mu)^2$ of $-t < 0.45$ GeV^2 selected the incoherent electro-production of the ρ^0. A further cut on the missing energy $\Delta E = \nu - E_\rho + t/M_p$ at $|\Delta E| < 0.1 GeV$ ensured proper exclusivity of the reaction. The resulting $\pi^+\pi^-$ invariant mass spectrum shows a clear signal for ρ^0 producion, see Fig. 2. The background processes to our main reaction are delta production and incoherent pion production. These background processes were modeled using the Genoa Monte Carlo generator from which we found the shapes in our spectrum. These processes were then included in the fitting procedure allowing only the relative strength to be varied. The ρ^0 signal was fit with a Breit-Wigner shape. The nuclear transparency was then computed by taking the ratio of the extracted number of counts for the nuclear target divided by the number of counts for the deuterium target and correcting

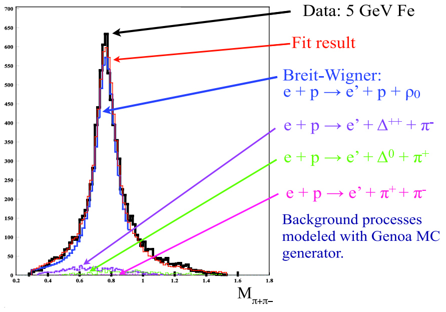

Figure 2: The $\pi^+\pi^-$ invariant mass spectrum, showing a clear signal for the ρ^0 meson. The fit result and background subtraction are indicated on the figure, see text.

for the difference in target thickness and number of nucleons, $T_A = C\frac{2N_A}{AN_D}$.

Plotting the extracted nuclear transparency, T_A versus the coherence length l_c shows that there is no significant dependence on l_c for our data, see Fig. 3. This is not too surprising since our measured l_c range is very short, less than one fermi. The l_c for this data is small due to the relatively low beam energy compared to the HERMES experiment. This means that we do not need to bin in separate bins of constant l_c for this data, since there is no competing coherence length effect.

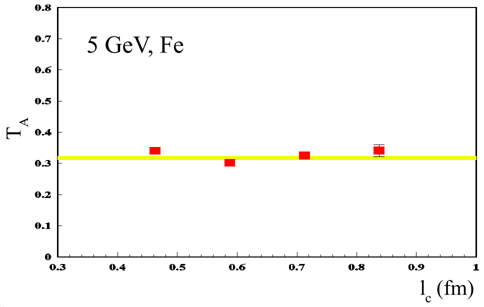

Figure 3: The nuclear transparency, T_A, plotted versus coherence length l_c for the 5 GeV iron data.

A number corrections need to be made on the T_A versus Q^2 graph. The correction for radiative effects is very small since it mostly cancels out in the ratio when computing T_A. The same is true for the corrections for the finite acceptance of the detector. A larger correction is due to pion absorption. When comparing with theoretical calculations, the decay of the ρ^0 into two pions and the subsequent absorption of of these pions in the nucleus or the target material must be taken into account. The Q^2 dependence of this process is very small, so the main effect of the pion absorption correction is to shift all the data points up by a constant amount.

3 Results

Our results are still too preliminary to be reproduced here and should not yet be cited.

The resulting T_A for the 5 GeV data with the iron target were divided into 4 bins in Q^2 ranging from a Q^2 of 0.9 GeV^2 for the central value of the lowest point to 2.5 GeV^2 for the central value of the highest point. The T_A exhibits a clear rise with increasing Q^2, rising nearly linearly over this range from approximately 0.36 to 0.46, which is far more than the statistical errors on the points. If these results withstand the final tests of our analysis, this will be a very clear indication of the onset of Color Transparency.

The data are in good agreement with the calculations by Kopeliovich [10], which almost perfectly describes the data. This model is completely parameter free after an initial fit to fix the parameters for the universal dipole cross section for a $q\bar{q}$ quark dipole with a nucleon [9]. A Glauber Model calculation by H. Lee and B. Mustapha [13] exhibits no rise over this range in Q^2 and clearly fails to describe the data, indicating that the rise in T_A cannot be explained without CT.

To complete this data analysis we will need to do a thorough study of the systematic errors. Additionally we need to continue data analysis on the 4 GeV data set and the runs with the carbon and lead targets.

4 Conclusions and Outlook

We see a clear rise of the nuclear transparency with increasing Q^2 indicating the onset of Color Transparency. These results do not have the ambiguity of the competing coherence length effect because of the very short coherence lengths where this effect is negligible. The model predictions from Kopeliovich [10] describe the data very well.

A new experiment has been approved by the Jefferson Laboratory PAC which will extend this study to higher Q^2, up to 7.5 GeV^2, and also cover a larger range of l_c using the upgraded accelerator and upgraded CLAS detector [7]. This experiment will obtain much higher statistical precision due to the higher luminosity capabilities of the upgraded detector. This will allow us to make a much more detailed study of the Color Transparency phenomenon and the process of vector meson formation and its interaction with the nuclear medium. This will enable us to study in far more detail how the point like configuration dresses with time to form the fully complex asymptotic wave function of the hadron, which puts us at the heart of the dynamics of confinement.

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