INTERPRETATION OF THE COLOR TRANSPARENCY EXPERIMENTS

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ABSTRACT

We argue that the experimentally measured color transparency ratio is directly related to the interacting hadron wave function at small transverse separation, $b^2 < 1/Q^2$. We show that the present experimental data is consistent with pure scaling behavior of the hadron-hadron and lepton-hadron scattering inside the nuclear medium.
1. Theoretical Formalism

Color transparency, namely reduced attenuation of hadrons in nuclear matter [1] under certain circumstances, has recently received much theoretical study. The basic idea is that the hadrons taking part in large momentum transfer reaction should have small transverse size and therefore should have considerably reduced attenuation in nuclear matter. Although this argument is very reasonable, it necessarily involves non-perturbative physics, since the propagation of the proton after the hard collision is described by the proton wavefunction. Therefore the calculation of the color transparency effect is quite model dependent. However, as we have shown in Ref. [2], it is possible to relate color transparency directly to a hadronic wavefunction. We argue that the simplest basis to discuss color transparency is the fully interacting basis in the presence of the nucleus. By the interacting proton, we mean the exact energy eigenstate that becomes a proton at infinity in interaction with the nucleus. The main advantage of this basis is that there is no mixing of states and the concept of expansion of the hadron disappears. By using the impulse approximation we find for the transparency ratio \( T \),

\[
T = \frac{d\sigma/dt_{\text{nucleus}}}{d\sigma/dt_{\text{free space}}} = \left| \frac{<\tilde{\psi}_{p/A}(b^2 < 1/Q^2) >_x}{<\psi_p(b^2 < 1/Q^2) >_x} \right|^2
\]

where \( \tilde{\psi} \) is the proton wavefunction in transverse separation b space and \( <>_x \) indicates the convolution over the x-variables with the initial distribution amplitude and the known hard scattering kernel. All effects of color transparency, then, are coded into the wave function for the quarks to have \( b^2 < 1/Q^2 \). The above relation is derived for the case of electron nucleus scattering, \( e + A \rightarrow e + p + (A - 1) \). For the case of hadron nucleus experiment, additional complications arise because of Landshoff contributions, which requires some modification of the above formula [3]. The above result can be further simplified if we consider a factorized model of the x- and b-dependence of the wave function, \( \tilde{\psi}_{p/A}(x,b) = \tilde{\psi}_{p/A}(b)\xi(x) \). Then the convolutions over x cancel out to some constants and the transparency is directly proportional to the wave function squared at small separation.

2. Applications

We next turn to the experimental results. As is well known, the results of the Brookhaven experiment [4], studying color transparency in the proton-nucleus collisions, did not show the expected monotonic increase and the eventual saturation of color transparency with increasing energy. The experimental results, instead, showed an oscillation in transparency which could be understood [3] by invoking the Landshoff independent scattering mechanism. In the free space proton-proton elastic scattering the interference between the usual quark counting process, which involve protons with small transverse size, and the Landshoff processes, which in-
volve the normal sized hadrons, leads to the oscillations about the $s^{-9.7}$ behavior for $d\sigma/dt$. In the nucleus, however, the large components are apparently filtered out for large enough $A$ and the entire contribution comes from small sized protons. Thus the transparency ratio $T$ is expected to have an oscillation 180 degrees out of phase with the free space oscillation. This is precisely the behavior seen in the data.

In order to extract information about how nuclear interactions affect the cross-section of mini-hadrons, one can multiply the transparency $T$ by the free space proton-proton cross-section times $s^{-10}$ [4]. The result is expected to be flat with energy in the very high energy limit, with some modification of this behavior at medium energies due to the interaction of the mini-hadrons with the nucleus. The experimental results [4] for this product for the case of the Aluminium nucleus are plotted in Fig.[1]. As expected the result does not show any significant oscillation. However, surprisingly it also shows almost no dependence on energy. This implies that the proton-proton scattering inside the nuclear medium follows the pure $s^{-10}$ scaling behavior, and that the nuclear medium has no effect on the energy dependence.

The above interpretation of the Brookhaven experiment [4] suggests that the SLAC NE18 electron-nucleus scattering experiment would see no change of color transparency with energy. As noted above, the nuclear medium does not modify the pure scaling behavior of the proton-proton elastic scattering. This suggests that the electron-proton scattering inside the nuclear medium may also follow the pure scaling behavior. Since there is no complication due to independent scattering in the free space elastic cross-section for this case, we conclude that the transparency observed in this case should be flat with energy.

The results of the SLAC experiment have not been published so far. However it turns out that it is possible to extract important information from the preliminary results on the fermi motion distribution that were presented at Penn State meeting on high energy probes of QCD [5]. This data actually represents the convolution of the fermi motion with the final state interactions of the outgoing proton. As can be seen from Fig.[2] the data shows no change in going from 1 GeV$^2$ to 3 GeV$^2$, indicating that the final state interactions do not change with energy. This gives evidence that the transparency observed in this experiment will be most likely flat with energy. If this were indeed the case then from our discussion above we would conclude that the results of the Brookhaven and SLAC experiment are consistent with one another and show that the hadron-hadron and lepton-hadron scattering inside nuclear medium follows pure scaling behavior.

Finally we try to get some information about the proton wavefunction from the above discussion which suggests that the transparency for the case of electron-proton scattering inside nucleus is flat with energy. From equation 2 we see that a flat transparency implies that the interacting proton wave function for $b < 1/Q$ does not change with energy.
3. Acknowledgements

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6. References

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