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RESCATTERING AND ENERGY LOSS OF FAST PARTONS IN NUCLEAR MATTER*

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ABSTRACT

We compare nuclear rescattering and energy loss effects as seen in dijet production in Fermilab fixed target experiment E609 with theoretical estimates and with data from Drell-Yan dilepton production. Possible explanations for these effects being unusually large in dijet production are briefly discussed.

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1. Uncertainty Principle Relation

When a fast parton traverses nuclear matter, it may scatter and consequently suffer energy loss. Recently, Brodsky and Hoyer (BH) have emphasized[1] that scattering with gluon radiation and the resulting parton energy loss are related to each other by the uncertainty principle, yielding

$$\frac{dE}{dz} \leq \frac{1}{2}(k_T)^2 \qquad (1)$$

Here k_T is the parton transverse momentum imparted by a radiative scattering, dE is the parton energy loss, and dz is the length of the scattering region (nucleus). The essential physics of eq. 1 is that the formation length of the emitted gluon radiation must not be larger than the nuclear size. This physics is closely related to that of the Landau-Pomeranchuk-Migdal (LPM) effect[2].

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BH then estimated that k_T (nuclear) for an incident or final state parton scattering radiatively within nuclear matter is expected to be about 0.3 GeV/c in cold nuclear matter. Using this value in eq. 1 yields the result that

$$\frac{dE}{dz} \leq 0.25 \text{ GeV/fm}. \qquad (2)$$

BH also expect a comparable contribution to $\frac{dE}{dz}$ from parton elastic scattering in nuclear matter.

2. Experimental Values from E609

Using data from our studies of dijet production in 400 GeV/c pA collisions in Fermilab experiment E609, we have extracted "experimental" values for k_T (nuclear)[3] and for $\frac{dE}{dz}$ (nuclear)[4] which are much larger than those given above. The E609 values are the only published measurements of k_T (nuclear) and $\frac{dE}{dz}$ for hard collisions in nuclei yielding dijets (or dihadrons), and were obtained in the following ways:

k_T (nuclear) - In a quantitative study of the coplanarity of pA dijet events with $p_T \approx 5$ GeV/c, we found[3] that a heavy nucleus yields events which are much less coplanar than those from a proton target. When this effect is parametrized in terms of an additional nuclear scattering for each of the outgoing partons, the surprisingly large value of k_T (nuclear) $\approx$ 1.8 GeV/c per outgoing parton is obtained.

$\frac{dE}{dz}$ (nuclear) - By comparing the total forward energy flow in the laboratory system for p-Pb and p-p dijet events, we found that about 50 GeV of the initial state laboratory energy of 400 GeV goes into nuclear energy loss[4]. This can be interpreted as a nuclear energy loss of about 2.5 GeV/fermi for each of the partons, again substantially larger than might be expected (from say a string tension of 1 GeV/fermi).

Note that the above E609 values, although they are both large, are consistent with each other in the sense that they do satisfy eq. (1). Of course, our E609 value for $\frac{dE}{dz}$ would violate eq. 1 if k_T were actually about 0.3 $\frac{\text{GeV}}{\text{c}}$.

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3. Discussion

Since the numerical conclusions of BH are quite different from the results of our analyses of E609 data, one should be cautious about using any of the above numerical results until the reasons for the differences are understood.

It seems clear that a key physics question at issue is why the nuclear contribution to k_T is about 0.4 GeV/c for Drell-Yan experiments [5], as compared to our E609 result of 1.8 GeV/c for dijets (in a similar kinematic situation). As we have described elsewhere[6], there is other evidence in addition to E609 results that k_T (nuclear) is indeed large for hard dijet and dihadron events at Fermilab fixed target energies.

We have previously pointed out[3] this striking difference in k_T (nuclear) between Drell-Yan and dijet production in nuclei, but do not know of any theoretical model which provides insight into this difference. The fact that the Drell-Yan process involves only an initial state parton traversing the nucleus, whereas dijet production has final state partons which may scatter in nuclear matter, does not seem to offer any direct explanation of the difference in k_T (nuclear) for the two processes, within existing perturbative QCD models[7].

Here we shall offer a different speculation, that the difference might be due to the essentially longitudinal flow of color for the Drell-Yan case (and thus perhaps also for large x, low p_T particle production). By contrast, the strong transverse flow of color change in dijet final states could lead to large scattering and consequent energy loss of the "string" as it moves through the nucleus[8]. This would presumably be a non-perturbative process, even though this value of k_T would be too large for a non-perturbative effect, if it resulted from a single scattering. This speculation could be tested by measuring k_T (nuclear) for single jet and dijet production by the virtual photon in deep inelastic lepton scattering. If this speculation is correct, the nuclear k_T values for these processes would be comparable to those given above for hadron-induced Drell-Yan and dijet reactions, respectively.

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