Fermilab E866: Dimuon Production in *p*-*A* Collisions

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During the past year, the primary focus of the FNAL E866 Collaboration has been finalizing and publishing results of our study of the nuclear dependence of Drell-Yan and charmonium production in 800 GeV/*c* *p*-*A* collisions. The J/ψ production and suppression mechanisms in hadronic collisions are still poorly understood. Many competing effects contribute — parton energy loss and shadowing in the initial state, the relative contributions of color singlet vs. color octet $c\bar{c}$ production, and final state effects including color neutralization and hadronization times, absorption on co-movers or other nucleons, feed-down from higher resonances, and energy loss and multiple scattering of the $c\bar{c}$ pair or the resonant state. It is crucial to investigate these effects in reactions such as proton-nucleus collisions, where no quark-gluon plasma is anticipated, if the suppression of J/ψ production is to be used as a signature for the creation of a quark-gluon plasma in relativistic heavy-ion collisions.

The initial state effects, shadowing and parton energy loss, occur in both Drell-Yan and charmonium production in *p*-*A* collisions, while several of the other effects are expected to demonstrate strong kinematic dependences in charmonium production. Thus, combining high precision measurements of the nuclear dependence of Drell-Yan and charmonium production can help to isolate the various contributions to J/ψ production and suppression.

Preliminary results on the production of Drell-Yan dimuon pairs in 800 GeV/*c* proton-induced collisions on Be, Fe and W targets were presented in last year's *Progess in Research*. A detailed discussion of our final results can be found in [1]. The nuclear dependence of Drell-Yan production in *p*-*A* collisions is well-reproduced by a previous fit to shadowing in deep-inelastic muon scattering off nuclei, leaving little room for any contribution due to energy loss of the incident ultra-relativistic quark passing through cold nuclear matter. Upper limits have been placed on the energy loss of the incident quark by considering the ratios of the Drell-Yan cross section per nucleon in Fe/Be and W/Be vs. the beam parton momentum fraction, after correcting for shadowing. Three different energy loss models were considered. One assumes that parton energy loss is proportional to the parton energy, one assumes that the energy loss is proportional to the thickness of the nuclear medium that the quark penetrates and independent of the energy, and the third assumes that the dE/dx is dominated by coherent gluon radiation which is proportional to the multiple scattering in the nuclear medium. The first two models predict that ΔE should be proportional to $A^{1/3}$, while the latter predicts that the multiple scattering should be proportional to $A^{1/3}$ and ΔE should be proportional to $A^{2/3}$. We conclude that the fractional energy loss of the incident quarks is <0.14%/ fm, that the incident quarks lose energy at a constant rate of <0.44 GeV/fm, and that the contribution to quark energy loss due to coherent gluon radiation is ΔE < 0.046 GeV/fm^2 $\times$ L^2, where L is the quark propagation length through the nucleus. These direct upper limits on energy loss of the incoming parton as it traverses a cold nucleus are tighter than previous constraints and leave little room for a significant contribution to

J/ψ suppression in *p-A* collisions from incident parton energy loss.

The FNAL E866 study of the nuclear dependence of charmonium production [2] provides much broader kinematic coverage and higher statistics than previous measurements. We find that the suppression of J/ψ production is nearly constant in the range $-0.1 < x_F < 0.25$, and becomes greater at larger values of x_F. ψ' production also appears to experience a constant suppression in the range $-0.1 < x_F < 0.25$, where the effect is 4 sigma larger than that seen for the J/ψ. This is the first time a significant difference has been seen between J/ψ and ψ' suppression in *p-A* collisions. We also find that J/ψ and ψ' suppressions demonstrate different x_F dependences, as the ψ' suppression is nearly constant over the range $x_F < 0.55$. We also find significant p_T dependence, which is independent of x_F and similar for the J/ψ and ψ', with strong suppression at small p_T and enhancement in heavy nuclei at large p_T. Comparison of our results to previous measurements at 200 GeV/*c* by NA3 [3] show that the J/ψ nuclear dependence scales with p_T and x_F, but not with x_{targ} or J/ψ p_{LAB}.

The implications of these results is still under investigation. The observed p_T dependence appears to be consistent with multiple scattering of the incident partons and outgoing $c\bar{c}$ pairs. The traditional model of J/ψ suppression in *p-A* collisions assumes that it is due to dissociation of the $c\bar{c}$ into $D\bar{D}$ pairs by interactions of the nascent resonance or J/ψ with the nuclear medium ("absorption"). This model predicts that the ψ' should be more strongly suppressed in central collisions than the J/ψ, as we observe. However, it also predicts that their suppressions should be similar above $x_F \sim 0.1$, when the $c\bar{c}$ pairs hadronize well outside the nucleus. Furthermore, absorption of J/ψ's through interactions with the nuclear medium should scale with the J/ψ p_{LAB}. Our data contradict both of these expectations. The same shadowing fit that reproduces our Drell-Yan data predicts that incident gluon shadowing should be small compared to the size of the nuclear dependence that we observe, which is consistent with the failure of suppression to scale with x_{targ}. Furthermore, as noted above, our Drell-Yan nuclear dependence study indicates that incident parton energy loss is too small to explain the observed effects, while final state $c\bar{c}$ energy loss would lead to a different x_F dependence than we observe. Thus, it appears that no single mechanism can account for our results over the full kinematic region, and several theoretical efforts are underway at present to explain them.

Two other E866 analysis efforts have been underway during the past year — determination of the absolute Drell-Yan dimuon cross sections in *pp* and *pd* and measurement of the polarization of upsilons produced in *p*-Cu collisions. The Drell-Yan cross sections are consistent at the 10-15% level with next-to-leading order calculations using modern parton distribution functions (e.g., MRST, CTEQ5M) that fit the E866 $\bar{d}/\bar{u}$ results. Current results from the latter study are very preliminary, but appear to indicate that the upsilons are polarized in some kinematic regions.

References

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[3] J. Badier *et al.*, Z. Phys. **C20**, 101 (1983).