Shadowing and Energy Loss in Drell-Yan Dimuon Production

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The Drell-Yan process, where a beam quark (antiquark) fuses with a target antiquark (quark) producing a muon pair, can be used to study the interactions of fast partons penetrating through cold nuclei. Only initial state interactions are important in Drell-Yan since the dimuon in the final state does not interact strongly with the partons in the media. In contrast, resonance production of dimuons, such as those from the J/ψ, depends on interactions in the initial and final states. Gaining a better understanding of Drell-Yan dimuon production in nuclei will help quantify the initial state interactions of the quarks passing through cold nuclear matter. After correcting for the differences between $q\bar{q}$ annihilation and gluon fusion, this will also allow for a cleaner separation of the interactions involved in the more complicated problem of resonance production. Understanding J/ψ resonance production is crucial if it is to be used as a signal for the formation of the quark-gluon plasma in collisions at RHIC or the LHC.

The Drell-Yan process is closely related to deep-inelastic scattering (DIS) of leptons, but unlike DIS it can be used specifically to probe antiquark contributions in target parton distributions. When DIS on nuclei occurs at $x < 0.08$, the cross section per nucleon decreases with increasing nuclear number A due to shadowing. This process should also occur in Drell-Yan dimuon production at small x_2, the momentum fraction of the target parton. Energy loss by partons in the initial state is another process that can lead to a nuclear dependence in the Drell-Yan production process, particularly at large x_1, the momentum fraction of the beam parton. Several groups have developed prescriptions for relating parton energy loss to the size of the nuclear system [1, 2, 3]. Drell-Yan scattering provides a way to test these predictions. During FNAL E866, measurements of Drell-Yan yields on Be, Fe and W were carried out to investigate these questions.

The Drell-Yan events obtained by E866 extend over the ranges $0.01 < x_2 < 0.12$ and $0.21 < x_1 < 0.95$, with $\langle x_2 \rangle = 0.035$ and $\langle x_1 \rangle = 0.46$. They also cover the range $0.13 < x_F < 0.93$ and provide good p_T coverage to 4 GeV/c. Ratios of the cross section per nucleon for Fe to Be and W to Be versus dimuon mass, x_2 and x_F are shown in Fig. 1, along with similar results from E772 for Fe to C and W to C [4]. The figure shows very good agreement between the two experiments, especially given the much smaller $\langle x_2 \rangle$, and hence increased shadowing, of the present data. The reduction in the cross section per nucleon on the heavy targets, characteristic of shadowing, is clearly apparent at small x_2. A similar reduction, part of which could be related to incident parton energy loss, is apparent at large x_F. However, it is important to recognize that the acceptance of the spectrometer coupled to the intrinsic Drell-Yan cross section leads to a strong anti-correlation between x_2 and x_F for the observed events. Therefore, the events that show the cross section reduction at large x_F

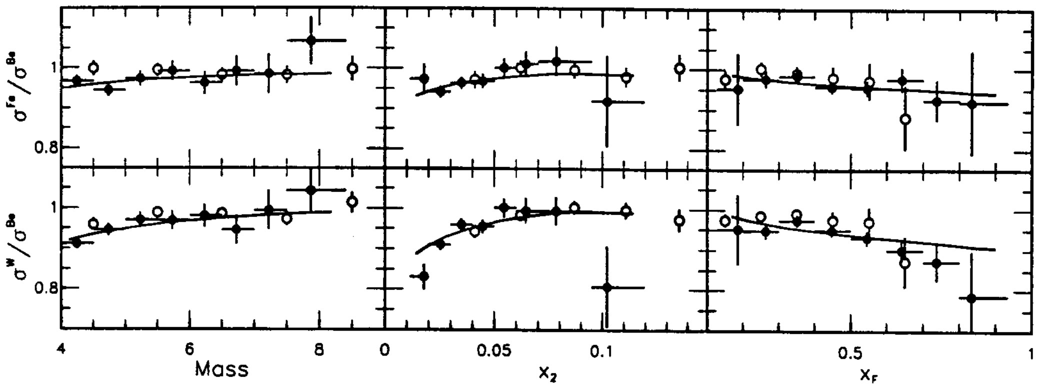

Figure 1: Preliminary ratios of the measured cross section per nucleon for Drell-Yan events versus dimuon mass, x_2 and x_F. The upper (lower) panels show ratios of Fe/Be (W/Be) from the present experiment as solid circles and Fe/C (W/C) from E772 as open circles. The solid curves are the predicted cross section ratios, integrated over the hidden variables, taking shadowing into account.

are in general the same events that appear in the shadowing region.

In order to identify the contributions from shadowing, Fig. 1 also shows the predicted cross section ratios integrated over the experimental acceptance, based on the code EKS98 [5] which has been tuned to fit shadowing observed in DIS and E772. The curves in Fig. 1 are based on the MRST parton distribution functions [6]. Note that most of the data in E772 were taken in the target x range where DIS is dominated by scattering off valence quarks, making the shadowing seen in DIS and Drell-Yan independent processes. In contrast, most of the data in E866 were taken in the domain where DIS is dominated by scattering off sea quarks, so the shadowing seen in the two processes should be quite similar. Both the shape and magnitude of the ratios versus x_2 are well reproduced by the shadowing prediction. Also, most of the A dependence observed in the ratios versus mass and x_F can be explained by shadowing at small x_2. This is the first experimental demonstration that, for sufficiently small x_2 where both Drell-Yan and DIS are dominated by scattering off sea quarks, the shadowing observed in the two processes is quantitatively similar.

Figure 2 shows the cross section ratios versus x_1 after correcting for shadowing event-by-event using the EKS98 code. The cross section ratios versus x_1 can be used to look for a nuclear dependence in the average energy loss by the beam parton as it traverses a nucleus. Several groups have studied energy loss of partons in nuclei recently. Their results can be expressed in terms of energy loss or, equivalently, a change in incident parton momentum fraction Δx_1. Several different parametrizations have been proposed, including [1, 2, 3]:

$$\Delta x_1 = -\kappa_1 x_1 A^{1/3}, \quad (1)$$

$$\Delta x_1 = -\frac{\kappa_2}{s} A^{1/3}, \quad (2)$$

$$\Delta x_1 = -\frac{\kappa_3}{s} A^{2/3}. \quad (3)$$

Given these energy loss expressions, it is possible to obtain empirical values for the κ's by performing simultaneous fits to the Fe/Be and W/Be Drell-Yan cross section ratios versus x_1.

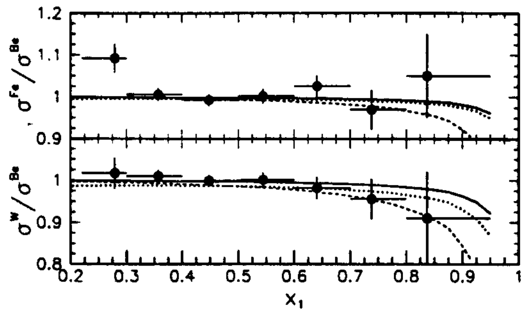

Figure 2: Preliminary ratios of the cross section per nucleon versus x_1 for Fe/Be (upper panel) and W/Be (lower panel), corrected for shadowing. The solid curves are the best fit using the energy loss form (1), and the dashed curves show the 1σ upper limits. The dotted curves show the 1σ upper limits using the energy loss form (3). The 1σ upper limit curves using the energy loss form (2) are essentially the same as for form (3).

The curves corresponding to the fits have been included in Fig. 2. The results set strict limits on the possible energy loss of ultrarelativistic quarks in cold nuclear matter. Both shadowing and initial state energy loss are processes that are common to Drell-Yan production and J/ψ formation, so these results should also further the understanding of J/ψ production, which is required if it is to be used as a signal for quark-gluon plasma formation in relativistic heavy ion collisions.

References

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