Limits on the Hadronic Production of Charmed Particles Set by the CP-II Collaboration

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ABSTRACT

Our published measurements have shown that lepton pairs account for the bulk of the single prompt muons produced in p-nucleus collisions. We now use our results to set limits on the $D\bar{D}$ cross section, finding, with 95% confidence, that $\sigma_{D\bar{D}} < 20\mu b$ at $\sqrt{s} = 19.4$ GeV, and $\sigma_{D\bar{D}} < 24\mu b$ at $\sqrt{s} = 27.4$ GeV. These limits are significantly below the recently reported cross sections for charmed particles observed in neutrino "beam dump" experiments. Furthermore, these limits are 5-10 times higher than $\sigma_{D\bar{D}}$ expected from a simple extrapolation of the cross section for J/ψ production.

The search for the hadronic production of charmed particles has featured a lengthy series of null results[1-17] followed by recent reports of evidence for a positive signal[18-22]. Figure 1 summarizes the limits and reported rates for the total cross section, $\sigma_{D\bar{D}}$, where D is D^0 (1865) charmed meson, produced in hadron-nucleus collisions. In obtaining total cross sections from the various experiments, we use 2.2 ± 0.6% as the branching fraction for the decay $D \to K\pi$,[23] and 10.0 ± 1.5% as the total branching fraction for all decays $D \to \mu\nu X$.[24,25,26] When not otherwise specified by the authors, we assume the cross section has a linear dependence on target mass, and a longitudinal momentum dependence $(1-x)^3$, where $x = 2p_L/\sqrt{s}$, in analogy to the production of massive muon pairs.[27] The cross sections reported by the neutrino "beam dump" experiments[18,19,20] are somewhat model dependent, but clearly they have seen a signal of weakly decaying particles. The strong limit of Ref. 11 is only valid for lifetimes in the range 10^{-13} to 10^{-15} sec., but would be, for example, an order of magnitude higher for lifetimes 10^{-2} or 10^{-16} sec.

In previous publications,[28,29] we have shown that the bulk of hadronically produced single prompt muons arise from μ-pairs of electromagnetic origin. Now that the D^0 has been discovered,[30] with known branching ratios to leptons,[24,25,26] and especially in view of recent experiments reporting evidence of prompt neutrinos,[18,19,2] we examine our previous work for evidence of charm production. In sections (1) and (2) we compare the measured production rates of μ-pairs with those of single, prompt muons, and present the results as new limits on the total cross section for $D\bar{D}$ production. In section (3) we give a simple phenomenological argument which indicates $\sigma_{D\bar{D}}$ might be 2-6 μb in the beam energy range 150-400 GeV.

(1) We compare our rates of inclusive muon production from events containing muon pairs[28] in p-Be collisions at 150 GeV/c, to the total prompt muon signal

observed in p-Cu collisions at 400 GeV/c.[31] To make such a comparison, we assume the ratio μ/π from pair sources is the same at 150 GeV/c and 400 GeV/c beams, and for Be and Cu targets. This is justified to the extent that most muon pairs have low mass,[32] and hence have energy and A dependences similar to those of pions.[27] In the comparison (see Fig. 2(b) of Ref. 28) a small excess of prompt muons not of pair origin is observed. To obtain total cross section estimates, we extrapolate the ratio (excess μ^-)/π^- observed at x>0 to $5 \pm 2.5 \times 10^{-5}$ at x = 0. Then since the inclusive cross sections for both μ^- and π^- peak at x = 0, the ratio of total inclusive cross sections is essentially $5 \pm 2.5 \times 10^{-5}$ also. Supposing the excess μ^- to be due to the decay of D^0 (1865) particles, we have $\sigma_{D\bar{D}}/\sigma_{\pi^-} = 5 \pm 2.5 \times 10^{-4}$, using the 10% branching fraction noted above. These single prompt μ^- were produced in 400 GeV/c, p-Cu collisions. In this Letter we assume that charmed particles are produced with a linear A dependence, while pion production varies as $A^{2/3}$. Hence the cross section ratio off single nucleons is reduced by a factor $63.5^{1/3}$ to $\sigma_{D\bar{D}}/\sigma_{\pi^-} = 1.2 \pm 0.6 \times 10^{-4}$ per nucleon. Finally, the inclusive π^- cross section in pp collisions at 400 GeV/c is 100mb[33], so we would nominally obtain from the excess μ^- that $\sigma_{D\bar{D}} = 12 \pm 6$ μb/nucleon. Casting our result into the form of a limit that $\sigma_{D\bar{D}}$ is less than 2 standard deviations above the observed excess, we obtain the 95% confidence limit $\sigma_{D\bar{D}} < 24$ μb/nucleon at $\sqrt{s} = 27.4$ Ge.V. If $\sigma_{D\bar{D}}$ were actually as large as 24 μb, this would require that roughly 2/3 of all prompt muons be due to charmed particle decay, and hence unpaired. We view this as extremely unlikely, and point out that in setting the 24 μb limit we have assumed Gaussian errors. In reality, the errors, mainly in normalizations and extrapolations, have much smaller tails.

(2) In a short "beam dump" experiment with p-Fe collisions at 200 GeV/c, we observed prompt single muons and muon pairs simultaneously.[29] We found a slight

excess of unaccompanied muons over those from muon pairs. As in section (1), we extrapolate to x = 0 to obtain the ratio $\sigma_\mu/\sigma_\pi = 3.5 \pm 2.5 \times 10^{-5}$ for the excess muons. Attributing these to charmed particle decay with a 10% branching fraction and linear A dependence, we have $\sigma_{D\bar{D}}/\sigma_\pi = 9 \pm 6.5 \times 10^{-5}$ per nucleon. At 200 GeV/c, we use[33] 90 mb as the cross section for $(\pi^+ + \pi^-)/2$. Hence $\sigma_{D\bar{D}} = 8 \pm 6$ μb per nucleon. As in section (1), we cannot definitely attribute all of this 8 ± 6 μb cross section to charmed particle production, so we state our result as a 95% confidence limit, or $\sigma_{D\bar{D}} < 20$ μb per nucleon at $\sqrt{s} = 19.4$ GeV.

(3) As an estimate of the expected particle production cross section we suppose

$$\sigma_D/\sigma_{J/\psi} \sim \sigma_K/\sigma_\phi \sim \sigma_\pi/\sigma_\rho$$

At 150 GeV/c we have measured $\sigma_\rho \sim 9$ mb, $\sigma_\phi \sim 660$ μb, and $\sigma_{J/\psi} \sim 100$ nb, all per nucleon.[32] We take[33] $\sigma_\pi \sim 90$ mb and $\sigma_K \sim 10$ mb, so that $\sigma_\pi/\sigma_\rho \sim 10$ and $\sigma_K/\sigma_\phi \sim 15$. Allowing a linear dependence on quark mass we might expect $\sigma_D \sim 45\ \sigma_{J/\psi}$. At the energies considered, significant threshold suppressions are present in the production of very massive particles, so we adopt a simple scaling behavior to get $\sigma_D(\sqrt{s}) = 45\ \sigma_{J/\psi}(.83\sqrt{s})$, noting that $M_{J/\psi}/2M_D = .83$. We suppose $\sigma_{J/\psi}$ varies with energy as B $d\sigma/dx(x=0)$ and normalize to our measurements of $\sigma_{J/\psi}$ at 150 and 225 GeV/c.[32,34] The resulting estimate of $\sigma_{D\bar{D}}$ is shown as the solid curve in Figure 1. A recent parton model calculation[35] involving suitable choices for gluon distribution functions and the strong coupling constant gives very similar predictions, shown as the dashed curve in Fig. 1. Thus our naive expectations for charmed particle production are well below the limits set in sections (1) and (2), and also below the cross sections found there supposing all excess muons are due to charmed particle decay.

In summary, our new limits on the hadronic production of charm particles are comparable to or lower than all previous limits, except that of Ref. 11, and are lower than the cross sections reported in Refs. 18-20. The latter is striking in that our experiment is similar to the neutrino "beam dump" experiments in detecting low transverse momentum leptons in the forward hemisphere, and extrapolating this signal to a total cross section. However, the geometry of the beam dump experiments restricts the transverse momentum of the neutrino to less than 50 MeV/c, while our experiment accepts all p_T. Indeed the average p_T of muons detected by us was 400 MeV/c, which is approximately the value expected from a 3 body decay such as $D \to K\mu\nu$.

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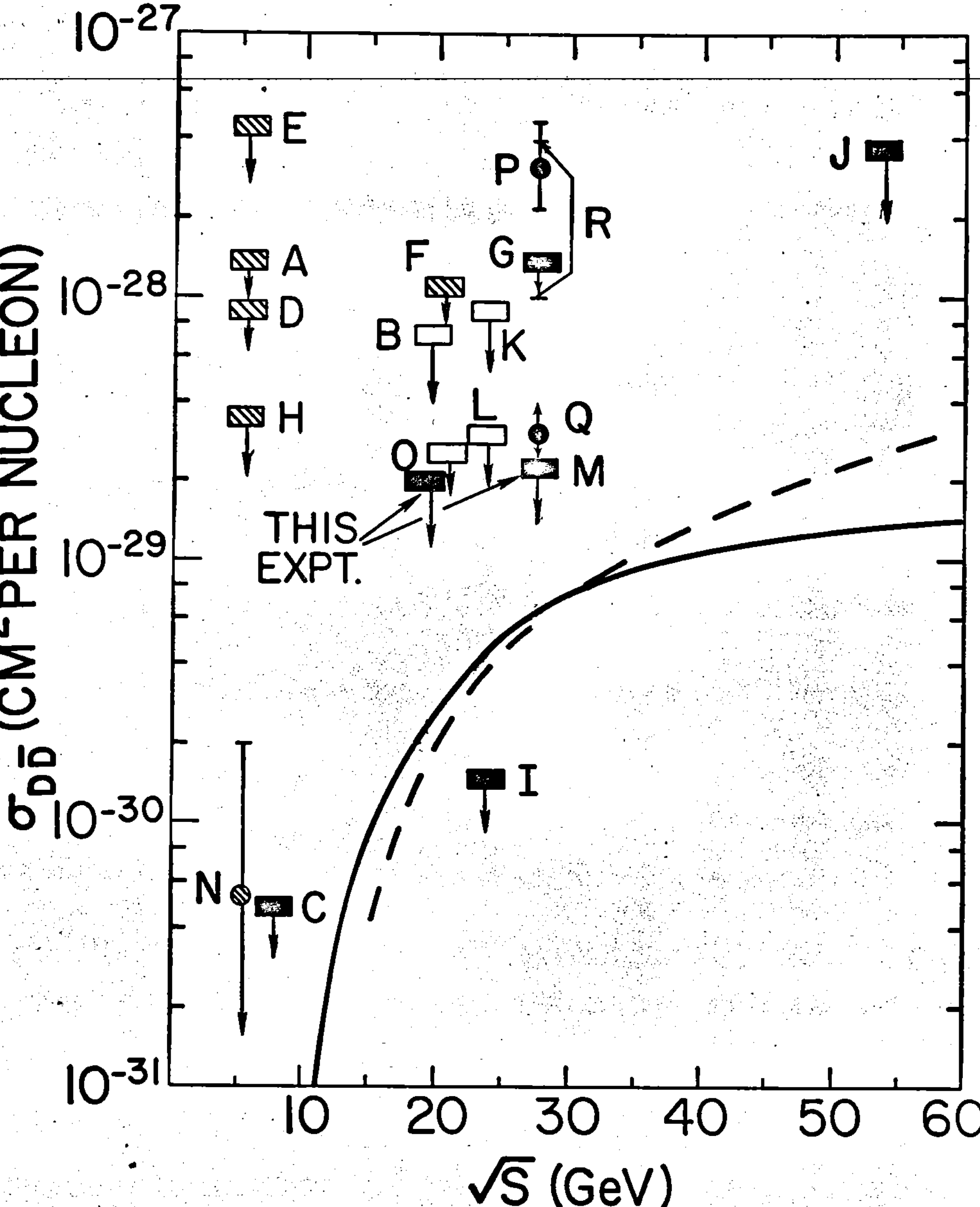
Figure Caption

Figure 1. Total inclusive cross section limits for $D\bar{D}$ production by hadrons. Solid symbols are from proton beams, open symbols from neutron beams, and cross hatched symbols from pion beams. Circular symbols represent reports of positive signals, while box symbols represent upper limits. Data point A is from Ref. 1; B - Ref. 2; C- Ref. 3; D - Ref. 4; E- Ref. 6; F - Ref. 7; G - Ref. 8; H - Ref. 10; I - Ref. 11; J- Ref. 12; K - Ref. 13; L - Ref. 14; M - Ref. 15; N - Ref. 16; O - Ref. 17; P - Ref. 18; Q - Ref. 19; R - Ref. 20. Data point M and one of the limits of this experiment coincide. The solid curve is an estimate of charmed particle production based on J/ψ production as described in section (3). The dashed curve is a parton model calculation from Ref. 35.



10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
$\sigma_{D\bar{D}}$ (CM^2 PER NUCLEON)
E
A
D
H
F
B
K
L
O
P
G
R
Q
M
J
I
N
C
THIS EXPT.
10
20
30
40
50
60
$\sqrt{S}$ (GeV)