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PROMPT SINGLE MUON PRODUCTION BY PROTONS ON IRON

A. Bodek,[1] R. Breedon, R.N. Coleman, W. Marsh, S. Olsen, and J.L. Ritchie
University of Rochester, Rochester, New York 14627

B.C. Barish, R.L. Messner, M.H. Shaevitz,[2] and E.J. Siskind[3]
California Institute of Technology, Pasadena, California 91125

F.S. Merritt
University of Chicago, Chicago, Illinois 60637

H.E. Fisk, P.A. Rapidis, and Y. Fukushima
Fermilab, Batavia, Illinois 60510

G. Donaldson and S.G. Wojcicki
Stanford University, Stanford, California 94305

presented by J.L. Ritchie

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ABSTRACT

A new experiment has been performed at Fermilab to measure the hadronic production of prompt single muons. A preliminary analysis of a sample of the data indicates approximately equal production of prompt single μ^+'s and μ^-'s in 350 GeV p-Fe interactions. The observed momentum distributions of prompt single μ^+'s and μ^-'s can satisfactorily be fit by the hypothesis of central production of D mesons with a cross section of 16 ± 4 μb/nucleon.

1. Alfred P. Sloan Foundation Fellow
2. Present address: Columbia University, New York, NY 10027
3. Present address: Brookhaven National Laboratory, Upton, NY 11973

We have performed an experiment at Fermilab to measure the production of prompt single muons in hadronic interactions. Data were taken with both 350 GeV protons and 280 GeV π^-s incident on an iron "beam dump" instrumented with scintillation counters. The density extrapolation technique was employed to separate prompt muons from non-prompt muons originating from decays of long-lived particles such as π's, k's, and hyperons. Prompt dimuons were identified with a very large acceptance muon identifier.

Data were taken in two different triggering configurations. One required only that the produced muon have momentum greater than 8 GeV. This corresponds, for the 350 GeV proton data, to most of the forward hemisphere, allowing a fairly model-independent determination of the charm cross section, if prompt single muons are interpreted as the products of the semi-leptonic decays of charmed hadrons. The other triggering configuration was more restrictive. It required a minimum muon momentum of 20 GeV.

Results are reported here only for the proton data taken with the 20 GeV trigger. (We have analyzed about one-half of this data sample.) Results from the full data set will i) extend the prompt single muon distributions to lower p, ii) reduce the size of the errors, which are dominated by statistics, and iii) allow a comparison between proton induced and pion induced charm production.

The detector[1)] consisted of a beamline spectrometer to measure the momentum of each incoming hadron, a target-calorimeter which served as a variable density "beam dump", a muon identifier and an iron toroid spectrometer. See Figure 1.

The target-calorimeter consisted of 49 steel plates with a scintillation counter on the downstream face of each. The plates were mounted independently on rails so that the spacing between the plates could be varied. Of the 2.4 meters of steel comprising the target-calorimeter, the density of the upstream most 1.7 meters was varied. Data were taken at three different effective densities, ρ, in the ratio 1:2/3:1/2. The most compact density of the target-calorimeter was about 3/4 that of steel.

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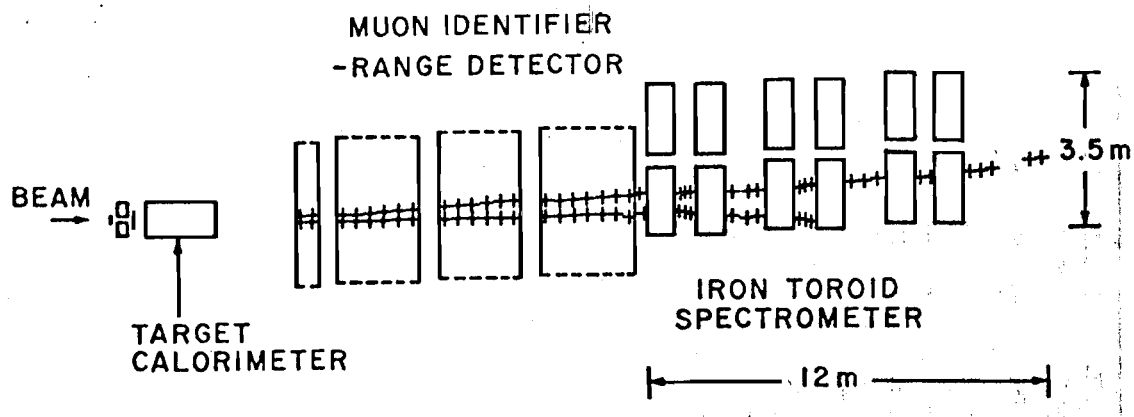

Figure 1. Plan view of the apparatus.

The muon identifier consisted of 42 3mx3m scintillation counters and 21 3mx3m spark chambers sandwiched periodically throughout 4.5 meters of steel. This device allowed identification of muons down to 5 GeV/c in momentum.

The toroid spectrometer, composed of 24 magnetized iron disks of radius 3.6 meters and interspersed with scintillation counters and spark chambers, allowed a determination of muon sign and momentum (with resolution of about 12%). It should be noted that the toroid spectrometer was placed "off-axis" (i.e., displaced laterally from beam center by one-half radius) to avoid a hole in the acceptance for low p_T muons.

Each event was required to pass selection criteria which consisted of a beamline PWC requirement of one and only one incoming hadron with momentum within 2% of beam momentum, a hadronic interaction in the upstream 25cm of the calorimeter, a requirement that muons originate in the target-calorimeter (to remove triggers from halo muons in time with hadrons) and a requirement that the triggering muon traverse the entire toroid system.

Events passing these selection criteria were placed in one of four categories: (i) a single triggering μ^+, (ii) a single triggering μ^-, (iii) dimuon with a triggering μ^+, and (iv) dimuon with a triggering μ^- (note that an event with two muons of opposite sign both of which trigger will fall into both iii and iv). Figure 2 shows the trigger rates of these types of events versus density. The intercepts at $1/\rho = 0$ of the lines drawn through the single μ^+ and μ^- rates are the prompt single μ^+ and μ^- signals, respectively. The difference in the slopes of these two lines is a result of more π^+'s than π^-'s being produced in proton interactions.

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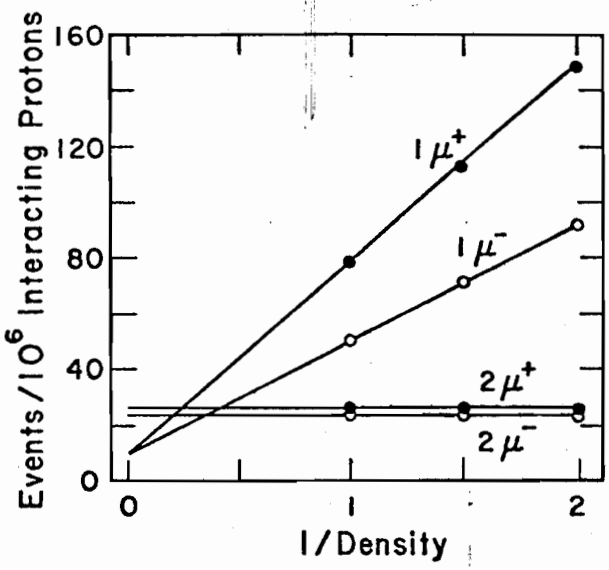

Figure 2. Event rates versus 1/density.

There was a contamination in the single muon sample from highly asymmetric dimuon events because muons of momentum less than 5 GeV were not identified. This background was subtracted with the aid of a Monte Carlo calculation which was normalized to the observed number of identified dimuon events. The resulting prompt single muon distributions versus p are shown in Figure 3a and 3b. The data indicate equal rates for the production of μ^+ and μ^- events. The efficiency corrected prompt single muon rates for p > 20 GeV/c are $(12.2 \pm 3.8)\times10^{-6}$ μ^+'s per interacting proton and $(10.1 \pm 2.6) \times 10^{-6}$ μ^-'s per interacting proton.

A possible source of additional background has not been subtracted in this preliminary analysis. Decays from non-prompt sources which take place in the unexpanded region of the target-calorimeter (recall that 10 interaction lengths are expanded), or in the drift space following the calorimeter, would result in a false prompt single muon signal. In an earlier experiment[2)] with a significantly smaller target-calorimeter, this background was calculated to be small.

The prompt single muon distributions in Figure 3 have been compared with two models of $D\bar{D}$ production. In model A, D's were produced independently according to

$$E \frac{d^3\sigma}{d^3p} = (1 - x)^{\alpha} e^{-\beta p_T}$$

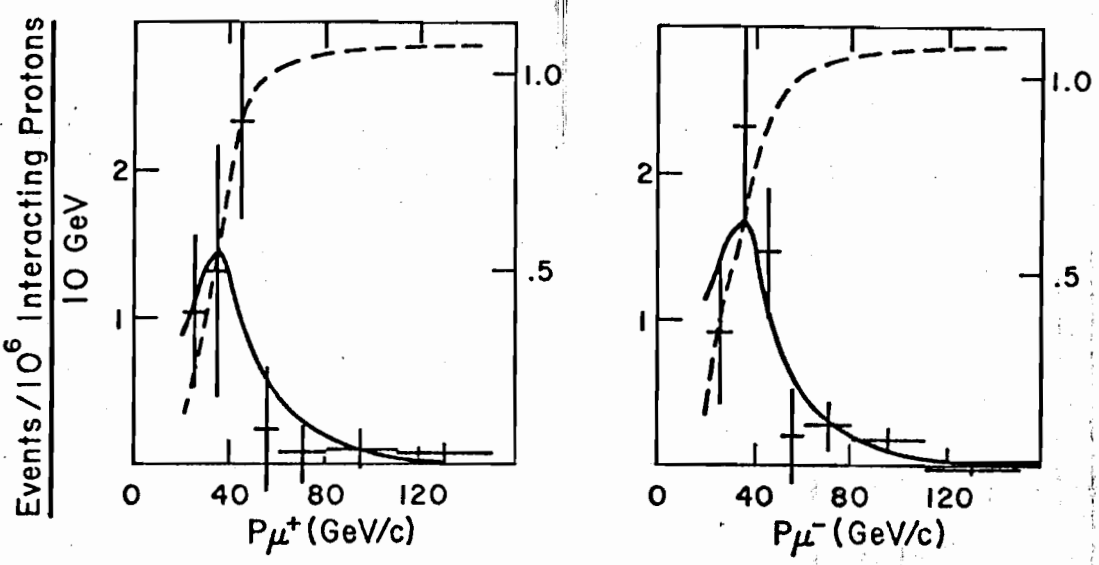

Figure 3. Prompt single muon rates versus momentum for μ^+ (a) and μ^- (b). The rates are not corrected for trigger efficiency. The dashed line is the efficiency. It can be greater 1.0 because it includes resolution smearing effects. The solid line is from the best fit $D\bar{D}$ production model A (see text).

In model B, $c\bar{c}$ pairs were produced with a mass m according to

$$E \frac{d^3\sigma}{d^3p} = \frac{1}{m^3} (1 - x)^{\alpha} e^{-\beta p_T} e^{-\gamma m/\sqrt{s}}$$

and the composite $c\bar{c}$ systems decayed into $D\bar{D}$ pairs. For both models, we have assumed that the semi-leptonic decay modes of the D are $D \to K\mu\nu$ (60%) and $D \to K^*\mu\nu$ (40%). Both of these models adequately fit the data. The best fit with model A was achieved with $\alpha = 4.7 \pm 1.0$ and $\beta = 2.5$ (β was kept fixed). The best fit with model B was achieved with $\alpha = 2 \pm 1.2$, $\beta = 2.5$, and $\gamma = 15$ (β and γ were kept fixed).

It is instructive to plot the rate for producing single muons with momentum p greater than p_{min}. This plot, Figure 4, was obtained by correcting the data in Figure 3 for efficiency and adding the μ^+ and μ^- rates. The corresponding curves calculated from models A and B, discussed above, are similar (the curve for model A is shown in Figure 4). The intercept of these curves at $p_{min}=0$ is simply the total prompt single muon rate. For model A this rate is $(1.9 \pm 0.4) \times 10^{-4}$ and from model B it is $(1.8 \pm 0.6) \times 10^{-4}$. If we assume an 8% average branching ratio and linear A-dependence, these rates correspond to total charm production cross sections of 16 ± 4 μb/nucleon and 15 ± 5 μb/nucleon, respectively. Here the errors are only statistical, and mainly come from the uncertainty in α.

Also shown in Figure 4 is a measurement of the total prompt muon production rate above 8 GeV from an early test run of this experiment[3]. When our new low momentum data is analyzed, it will provide a substantial improvement in this region.

In conclusion the data indicate approximately equal production of prompt μ^+'s and μ^-'s in 350 GeV p-Fe interactions. The data do not confirm results[4] from beam dump experiments which indicate unequal prompt ν_μ and $\bar{\nu}_\mu$ rates. The momentum distribution are adequately described by a central $D\bar{D}$ production model with a cross section of 16 ± 4 μb/nucleon. The data does not indicate a large diffractive charm production cross sections of the magnitude reported[5] by ISR experiments ($\sqrt{s}$ = 60 GeV).

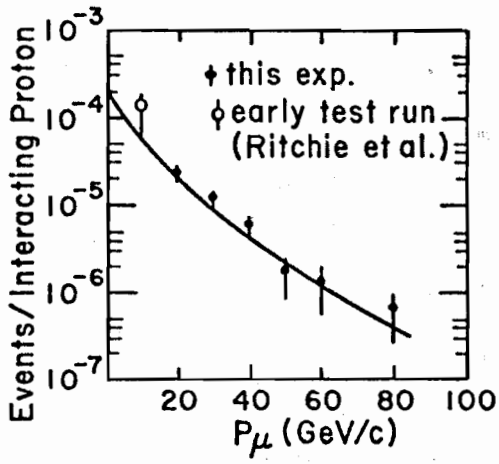

Figure 4. Total prompt single μ rates ($\mu^+ + \mu^-$) with p greater than p_{min}.

REFERENCES

1. Parts of the detector have been used in neutrino experiments by the Caltech-Fermilab-Rochester-Rockerfeller group.
2. K.W. Brown, Ph.D. thesis, Caltech, 1980.
3. J.L. Ritchie, et al., Phys. Rev. Lett. 44 230 (1980).
4. K. Kleinknecht, Proceedings of the XXth International High Energy Physics Conference, Madison, June 1980, p. 237, L. Durand and L.G. Pondrom editors.
5. G. Sagot ibid p. 193, also S. Wojcicki ibid p. 1430.