Production of Leptons in Coincidence with Prompt Muons

R. M. Edelstein, G. Ginther, R. Lipton, J. M. McQuade,[a] J. Russ, and L. Spiegel
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

and

D. E. Johnson
Fermilab, Batavia, Illinois 60510

and

D. Buchholz, L. M. Cremaldi,[b] S. Delchamps, H. S. Mao,[c] J. L. Rosen,
W. K. Sakumoto, R. A. Schluter, S. B. Sontz, and C. Winter
Northwestern University, Evanston, Illinois 60201

and

J. Bishop, N. Biswas, N. Cason, L. Dauwe,[d] V. Kenney, A. Kreymer,[d]
P. Mooney, R. Pemper,[e] R. Ruchti, and W. Shephard
University of Notre Dame, Notre Dame, Indiana 46556
(Received 16 May 1984)

Muon and electron production in association with prompt muons has been studied in a 200-GeV/c π^--Be interaction at Fermilab. The prompt dimuon cross section was found to be 3.3 ± 0.6 μb per nucleon. The cross section for muon-electron production was found to be 0.12 ± 0.04 μb. The relative yields of prompt muons at low x_F and moderate p_t from charm and electromagnetic sources are also reported.

PACS numbers: 13.85.Qk, 14.40.Jz

Measurements of prompt muon, electron, and neutrino production furnish important information on hadronic charm production. Most previous prompt lepton studies have been based on single-lepton production or on the production of two leptons of the same flavor.[1-7] In such experiments distinction between lepton pairs arising from electromagnetic decay processes, such as Drell-Yan production and vector-meson decay, and those coming from the production and weak decay of heavy quarks is difficult. In this experiment we triggered on a muon with Feynman x (x_F) between 0 and 0.3 and transverse momentum between 0.4 and 1.2 GeV/c and identified accompanying muons and electrons. This allowed us to compare directly the yields from electromagnetic and weak prompt lepton sources.

The experiment was performed in the M1 beam line at Fermilab with a 200-GeV/c π^- beam. Our spectrometer (Fig. 1) was separated into two arms: a muon trigger arm which subtended +40 to +150 mrad vertically and a large-acceptance forward arm

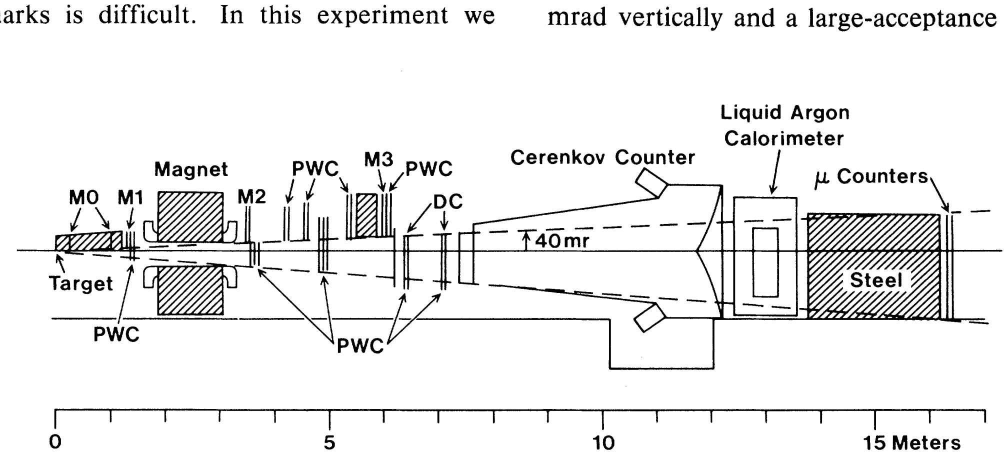

FIG. 1. Elevation view of the E515 spectrometer.

which subtended +40 to −80 mrad vertically and ±200 mrad horizontally. The trigger arm was instrumented with hodoscopes and a set of 6-mm proportional wire chambers (PWC). A trigger required hits in each of four trigger-arm hodoscopes in coincidence with a beam particle striking a 3-cm beryllium target. Muons needed a momentum of at least 5 GeV/c to penetrate the trigger-arm absorber. The forward arm was instrumented with PWC, drift chambers, a lead liquid-argon shower calorimeter (LAC), and two hodoscopes located downstream of a 2.9-m steel filter. A large-aperture dipole magnet provided a transverse momentum kick of 0.8 GeV/c.

In the off-line analysis trigger muons were identified by linking tracks in the trigger-arm PWC with hits in the M1 hodoscope and target points. Muon momentum was determined to within 25% by a least-squares fit that took into account energy loss and multiple scattering in the absorber. A final sample of 2.6×10^5 muon triggers was used in further analysis.

Muons in the forward arm were identified by associating hits in the forward-muon hodoscopes with extrapolated tracks. Electrons were identified with the 1.2×2.4-m^2 LAC which was segmented into 1.25-cm strips in the x and y views and longitudinally into two twelve-radiation-length halves. Off-line electron identification required that electron candidates pass cuts on (1) the transverse shower profile, (2) the front-to-back half-energy ratio, (3) the shower-track matchup, and (4) have a shower energy within two standard deviations ($\sigma/E=0.22/\sqrt{E}$) of the track momentum.[8,9] Electron identification efficiencies were determined with e^+e^- pairs from photon conversions. The LAC was found to be 15% less efficient for e^+ than e^-, because of the small-angle neutral particles which impacted on the positron side of the detector.

In the following analysis we assume that same-sign trigger-arm–forward-arm dilepton pairs arise from nonprompt sources and opposite-sign pairs arise from a combination of prompt and nonprompt sources. We then subtract same-sign pair yields from opposite-sign yields (with corrections described below) to isolate the prompt signal. In all cases we subtract forward-arm leptons of equal signs to cancel systematic errors due to uncertainties in forward-arm lepton detection efficiency. A charge asymmetry in the trigger arm may contribute to the dilepton signal. We measure this asymmetry to be less than 3%.

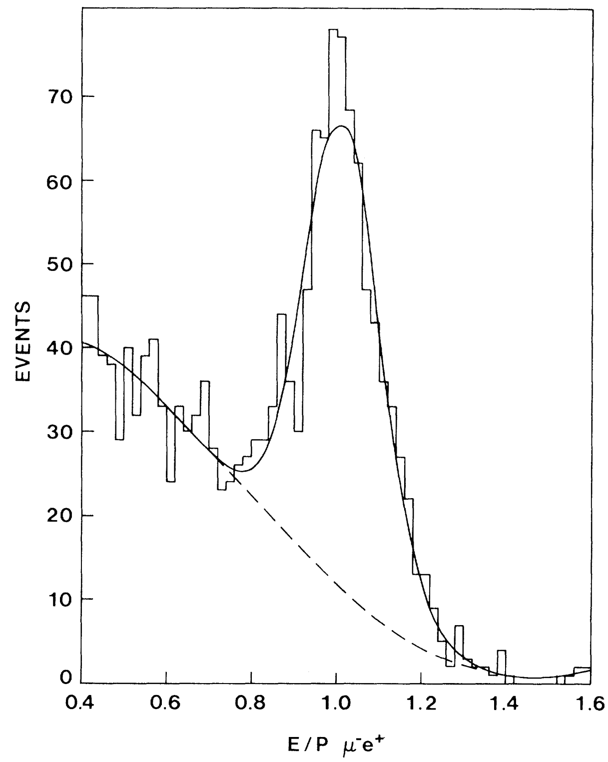

FIG. 2. Energy as measured in the liquid-argon calorimeter divided by momentum as measured in the spectrometer for electrons detected in coincidence with a trigger μ^- with cuts 1–3 applied. The solid line is the fit described in the text. The dashed line is the background function only.

We use the following equation to calculate the prompt muon yield:

$$N(\mu\mu)_{\rm prompt}=\{N(\mu\mu)_{\rm opp}-N(\mu\mu)_{\rm same}-P_d\epsilon_\mu[N(\mu h)_{\rm opp}-N(\mu h)_{\rm same}]\}/\epsilon_{\mu\mu},$$

where $N(\mu\mu)$ are the trigger-arm–forward-arm muon pair yields corrected for accidentals, P_d is the probability that a forward-arm hadron will decay into a muon, $N(\mu h)$ is the trigger-muon–forward-hadron pair yield, ϵ_μ is the forward-arm muon detection efficiency, and $\epsilon_{\mu\mu}$ is the joint trigger-arm–forward-arm muon detection efficiency. The term involving P_d is included to remove any μ-hadron charge correlations. The detector acceptance was modeled with use of the parametrization of Anderson *et al.*[4] If one assumes symmetry about $x_{\rm F}=0$ and linear mass number (A) dependence, the total prompt dimuon cross section is found to be 3.3 ± 0.6 μb per nucleon.

The number of prompt muon-electron pairs is calculated in a similar manner. In the absence of D^0-$\bar{D}^0$ mixing, charm contributes only to the observed opposite-sign yields. Electrons from photon conversions and Dalitz decays of π^0s contribute both to same-sign and opposite-sign yields. Electrons from reconstructed photon conversions are removed from the data. The yield of electrons is determined by fitting the E/P curves for each sign combination to a Gaussian electron peak plus a background function. The fit for $\mu^- e^+$ pairs is shown in Fig. 2. If $N(\mu^- e^-)$ and $N(\mu^+ e^-)$ represent the yields of $\mu^- e^-$ and $\mu^+ e^-$ pairs then the number of prompt $\mu^+ e^-$ pairs is

$$N(\mu^+ e^-)_{\text{prompt}} = [N(\mu^+ e^-) - N(\mu^- e^-)]/\epsilon_e,$$

where ϵ_e is the detection efficiency for electrons. A parallel calculation is made for $\mu^- e^+$ pairs. The results are presented in Table I. The errors shown include the uncertainty in the fits and trigger-muon charge symmetry as well as statistical contributions. There is a larger yield in the $\mu^+ e^-$ sample than in $\mu^- e^+$. It is not clear whether this represents a real production asymmetry or is simply a statistical fluctuation.

The prompt muon-electron production cross section is calculated given the assumption that the pairs result from $D\bar{D}$ production and subsequent semileptonic decay. We model associated $D\bar{D}$ production as

$$d^3\sigma/d^3p \propto e^{-5M}(1-x_F)^N e^{-bP_t},$$

where M represents the invariant mass of the $D\bar{D}$ pair. Half of the D decays were assumed to proceed through $K\mu\nu$ and the rest through $K^*\mu\nu$. The electron momentum and transverse momentum spectra for the above model are shown in Fig. 3 along with data points obtained by subtracting same-sign from opposite-sign μe yields. If we assume values of 5 for N, 2 for b, and linear A dependence, the prompt μe cross section is 0.12 ± 0.04 μb per nucleon. Under the assumption of an average semileptonic branching ratio of 8%, the total

TABLE I. Yields of muon-electron pairs. The second column is corrected for electron detection efficiency.

	Raw μe Yield	Corrected Yield
$\mu^- e^+$	625 ± 40	2232 ± 142
$\mu^+ e^+$	563 ± 38	2010 ± 135
$\mu^- e^+_{\text{prompt}}$		222 ± 213
$\mu^+ e^-$	1131 ± 55	2632 ± 126
$\mu^- e^-$	862 ± 50	1981 ± 116
$\mu^+ e^-_{\text{prompt}}$		651 ± 194

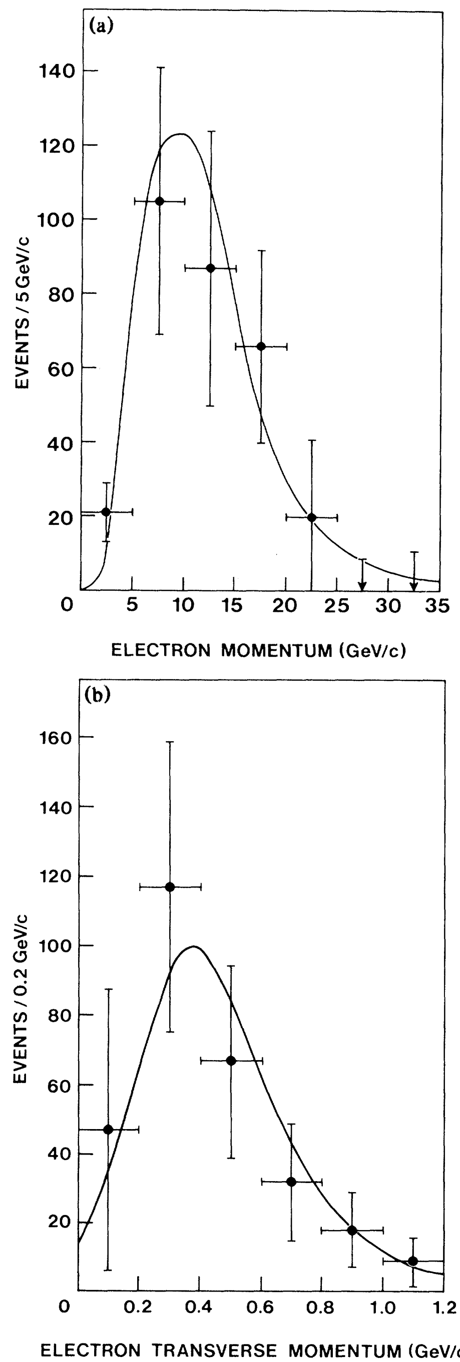

FIG. 3. Excess opposite-sign μe events as a function of (a) electron momentum and (b) transverse. These yields have not been corrected for efficiency. Only statistical errors are shown. The solid lines represent the Monte Carlo models discussed in the text.

charm production cross section $\sigma(c\bar{c})$ is 18 ± 6 μb per nucleon. Varying N between 3 and 5 and b between 1 and 3 produces a 40% change in the calculated cross sections.

The trigger-arm muon yield due to charm $N(\mu)_{\text{charm}}$ can be extracted from our data as follows:

$$N(\mu)_{\text{charm}} = N(\mu e)_{\text{prompt}}/\alpha_{e,\text{charm}},$$

where $\alpha_{e,\text{charm}}$ is the probability for detecting an electron from charm decay in the LAC given a trigger muon from charm. The prompt muon yield due to electromagnetic sources $N(\mu)_{\text{em}}$ can be isolated by using the following relation:

$$N(\mu\mu)_{\text{prompt}} = \frac{N(\mu)_{\text{charm}}}{\alpha_{\mu,\text{charm}}} + \frac{N(\mu)_{\text{em}}}{\alpha_{\mu,\text{em}}},$$

where $\alpha_{\mu,\text{em}}$ is the probability for detecting a forward-arm muon given a trigger muon from an electromagnetic source and $\alpha_{\mu,\text{charm}}$ is the similar probability given a trigger muon from charm decay. These probabilities were calculated with use of the above models for charm and electromagnetic dimuon production and under the assumption of an average 8% semileptonic branching ratio for charm. The sum of $N(\mu)_{\text{charm}}$ and $N(\mu)_{\text{em}}$ indicates that $\frac{1}{3}$ of our final muon trigger sample is of prompt orgin. Within the prompt sample,

$$N(\mu)_{\text{em}}/N(\mu)_{\text{charm}} = 0.56 \pm 0.17 \pm 0.22,$$

where the last number is our estimate of the systematic error in the calculated probabilities. The results indicate that a significant fraction of the prompt muons in the kinematic range of our trigger (p_t near 0.6 GeV/c and low x_{F}) are from weak decay.

We wish to thank the staff of the Meson Department and the Accelerator Division at Fermilab. We also wish to thank the technical staffs at our home institutions for their invaluable support. This work was supported by the U. S. Department of Energy and the National Science Foundation.

[a]Current address: 3M Company, St. Paul, Minn. 55144.

[b]Current address: University of Colorado, Boulder, Colo. 80302.

[c]Permanent address: Institute of High Energy Physics, Beijing, China.

[d]Current address: Fermilab, Batavia, Ill. 60510.

[e]Current address: Houston Baptist University, Houston, Tex. 77074.

[1]F. W. Busser *et al.*, Phys. Lett. **53B**, 212 (1974).

[2]L. Baum *et al.*, Phys. Lett. **60B**, 485 (1976).

[3]K. W. Brown *et al.*, Phys. Rev. Lett. **43**, 410 (1979).

[4]K. J. Anderson *et al.*, Phys. Rev. Lett. **37**, 799 (1976).

[5]A. Bodek *et al.*, Phys. Lett. **113B**, 77 (1982).

[6]A. G. Clark, *et al.*, Phys. Lett. **77B**, 339 (1982).

[7]A. Bodek, University of Rochester Report No. UR-730, 1979 (unpublished).

[8]J. M. McQuade, Ph.D. dissertation, Carnegie-Mellon University, 1983 (unpublished).

[9]L. M. Cremaldi, Ph.D. dissertation, Northwestern University, 1983 (unpublished).