

Production of Dimuons in 16-GeV/c πp Interactions and the Observation of a Low-Mass Continuum of Unfamiliar Origin

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A clear, prompt dimuon signal has been observed in a low-statistics streamer-chamber experiment with 16-GeV/c πp interactions. The good mass resolution makes it possible to identify the contributions from ρ and ω decays and η and ω Dalitz decays. An excess of events is observed in the mass region ~ 400 – 600 MeV which is not accounted for by the above-mentioned decays.

A study of dimuon production by 16-GeV/c π^+ and π^- mesons incident on hydrogen has been performed using the Stanford Linear Accelerator Center (SLAC) two-meter streamer chamber. The data reported are from a total of 10^8 interactions corresponding to 3.9 events/(nb times trigger efficiency). Identification of dimuons was by penetration of both muons through 10 interaction lengths of an absorber corresponding to a muon minimum momentum of 2.4 GeV/c (see Fig. 1). As a result the experiment is sensitive to dimuons with $x_F > 0.3$ ($x_F = P_{\parallel}^*/P_{\max}^*$); see Fig. 2. The

acceptance in the region $x_F > 0.3$ averaged 30% (assuming a uniform decay angular distribution). The events covered a P_T region up to 1.3 GeV/c with an average P_T of 0.43 GeV/c. The small numbers of events (restricted by the SLAC duty cycle) cause data to be primarily in the mass region below 1 GeV but the use of the streamer chamber allows an excellent mass resolution, ~ 25 MeV, and makes possible an examination of the accompanying hadrons.

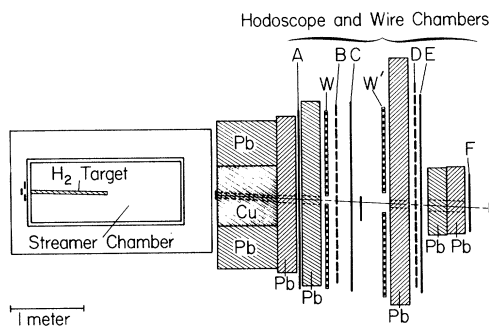


FIG. 1. Plan view of the detection apparatus. Counter planes A, C, E, and F are horizontal counters; planes B and D are vertical counters. W and W' are two x -y planes of magnetostrictive wire chambers. Dashed lines indicate the openings in the lead walls for the unscattered beam.

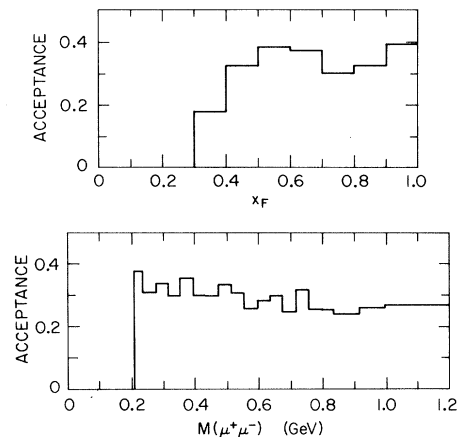


FIG. 2. Acceptance of dimuons as a function of Feynman x (x_F) and invariant mass $M(\mu^+\mu^-)$. In the Monte Carlo calculation, a flat decay angular distribution was assumed.

The basic problem in identifying prompt muons at low energies is the decay and "punchthrough" of hadrons. The method used here for reducing false muon identification was to measure muon candidates in the streamer-chamber photographs (those tracks aiming at the trigger system) and to extrapolate tracks through the trigger system. This system consisted of four planes of scintillation counters arranged throughout the lead absorber in a hodoscope with cell size of approximately $15\text{ cm} \times 15\text{ cm}$ supplemented by two planes of wire chambers to allow more accurate hit locations. Hits which were further than 3 standard deviations of muon multiple scattering from the extrapolated track position were interpreted as originating from hadrons. The counter hodoscope was sufficiently fine grained to allow hadron rejection for low-momentum tracks while the wire chambers were particularly useful for those with high momenta.

In order to estimate the background originating from hadrons remaining after this procedure, we made use of two additional types of data: one produced by triggering on an interacting beam pion and another produced by triggering on interactions with only one track that penetrated the lead (a "single-muon" trigger). The interaction trigger data (~ 2000 events) was used to determine the number and momentum distribution of hadrons incident on the downstream lead wall. The single-muon trigger events, which originate from decay and punchthrough of hadrons in over 90% of the cases, were examined with the same criteria used for the dimuon events. From a sample of 213 000 interactions yielding 460 000 hadrons

of momentum greater than $2.4\text{ GeV}/c$ incident on the absorber, a total of 597 single-muon triggers were found where the triggering track satisfied the muon criteria. Of these, triggers by particles with the same sign as that of the beam predominate. Such dominance is caused in great part by the larger number of beam-sign pions with energy greater than 2.4 GeV incident on the absorber wall. With use of the interaction and the single-muon data, the probability for a pion or decay muon to be misidentified as a prompt muon was computed for three different momentum regions (the average value was 0.13%). By application of this probability to the other secondary hadrons in the single-muon trigger data, the probability for finding background dimuon events was calculated.

The number of observed events together with the results of the background calculation is shown in Table I. The number of events found with the same-sign muons is in reasonable agreement with that calculated, indicating that the background estimate is satisfactory. For the opposite-sign muons this same estimate shows that the background is less than 20%.

An estimate of the single-muon/pion ratio on the basis of the dimuon data reported here requires a model-dependent calculation. We instead calculate a di-pion ($\pi^+\pi^-$) signal from our interaction data in the same x_F region as the dimuon data. The multiplicity in this energy and x_F region is generally two or less and thus the problem of multiple combinations is small. The x_F dependence of the two distributions is the same and the resulting μ/π pair ratio is $(3 \pm 1) \times 10^{-5}$.

TABLE I. Data summary.

	π^+	π^-	Combined
Interactions	45.3×10^6	51.1×10^6	96.3×10^6
Sensitivity (events/ μb)	1880	1990	3870
Dimuons found (background):			
$\mu^+\mu^-$	137(17)	198(44)	335(61)
$\mu^+\mu^+$	15(8)	3(9)	18(17)
$\mu^-\mu^-$	1(1)	22(19)	23(20)
Cross section observed $x_F > 0.3$ (nb)			
$\pi p \rightarrow \mu^+\mu^- X$	250 ± 70^a	320 ± 90	280 ± 70
$\pi p \rightarrow \omega X \rightarrow \mu^+\mu^- X$			30 ± 13
$\pi p \rightarrow \eta X \rightarrow \mu^+\mu^- X$			3 ± 3
$\frac{\sigma(\pi^- p \rightarrow \mu^+\mu^- X)}{\sigma(\pi^+ p \rightarrow \mu^+\mu^- X)} = 1.28 \pm 0.23$		$\frac{\sigma(\mu^+\mu^-)}{\sigma(\pi^+\pi^-)} = (3 \pm 1) \times 10^{-5}$	

^aThis number can be compared with the value of 340 ± 70 obtained at $150\text{ GeV}/c$ (Ref. 1).

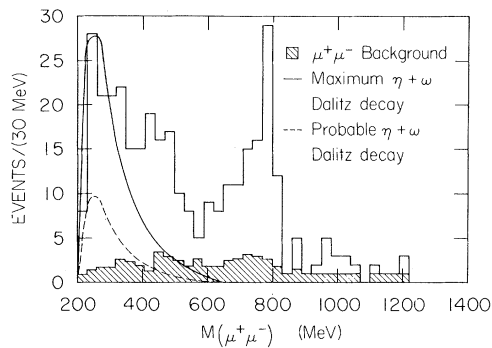


FIG. 3. Invariant mass of the dimuons (unweighted events). The cross-hatched events are the estimate of nonprompt dimuon background. The smooth curves show possible Dalitz decay contributions from η and ω . Not shown are three events of higher mass (1.53, 2.13 and 3.13 GeV).

The invariant mass of $\mu^+\mu^-$ for the sum of π^+p and π^-p interactions is shown in Fig. 3, together with the background estimate of 18%. Although a clear signal in the ρ^0 - ω region is observed, a fit to this region for ρ and ω plus a background continuum gave a stable fit for the ω but the ρ and background contributions were of uncertain size. A dimuon signal is present below the ρ^0 and it is clear that only a portion of it can be due to the Dalitz decays of the η ($\eta \rightarrow \gamma\mu^+\mu^-$) and ω ($\omega \rightarrow \pi^0\mu^+\mu^-$). The ω Dalitz-decay signal has a slightly greater average mass than that due to η Dalitz decay and we illustrate the maximum Dalitz-decay signal possible (see Fig. 3) by assuming the following: ω 's are produced with a 4-mb total cross section, with an inclusive spectrum similar to the ρ^0 ,² and with a branching ratio for Dalitz decay of 8×10^{-5} .³ For the η we assume sufficient production to make the maximum of the combined η and ω Dalitz-decay signal equal to our dimuon signal in the threshold region. A value of 0.7 mb for the η inclusive production cross section with a branching ratio for Dalitz decay of 3×10^{-4} was required.³ Such a method of evaluation clearly maximizes the Dalitz-decay signal since the ω signal used is greater than any reasonable estimate made from the $\omega \rightarrow \mu^+\mu^-$ signal present in our own data.

Alternatively we estimate the probable Dalitz-decay signal using our own data for $\omega \rightarrow 2\mu$ and $\eta \rightarrow 2\mu$ given in Table I and Fig. 3. (By centering 25-MeV wide bins on the η mass we observe a statistically weak signal which we use to estimate the $\eta \rightarrow 2\mu$ contribution.) This leads to a Dalitz-decay signal about one-third of the maximum possible.

By the use of either method of estimation, a low-mass dimuon signal is observed which cannot be due to known sources; under the assumption of an extremely large Dalitz-decay signal, the observed new signal is between 300 and 550 MeV, while with a more self-consistent Dalitz-decay signal it stretches from threshold to 550 MeV.

Theoretical suggestions have been made of possible low-mass enhancements due to parton-parton, pion-parton, and pion-pion annihilation.⁴⁻⁷ In particular, bremsstrahlung-type interactions⁵ can account only for a threshold mass enhancement indistinguishable in shape from a Dalitz-decay type of enhancement. A recent calculation of a more general character shows an enhancement peaking at slightly over 400 MeV and adequate in size to account for the region slightly above threshold.⁷

In summary, we have observed dimuon decays of the ρ^0 and ω plus a low-mass dimuon signal below the ρ^0 which cannot be completely accounted for by the Dalitz decay of the η and the ω . The observed dimuon cross section in the region $M_{\mu\mu} \leq 1.0$ GeV and $x_F > 0.3$ is slightly less than that obtained at 150 GeV/c.¹ The ratio of $\mu^+\mu^-/\pi^+\pi^-$ is approximately $\frac{1}{3} \times 10^{-4}$, which may account for the observed single- μ/π ratio⁸ in the region $x_F > 0.3$. The ratio $\sigma(\pi^-p \rightarrow \mu^+\mu^-)/\sigma(\pi^+p \rightarrow \mu^+\mu^-)$ in our mass region is 1.28 ± 0.23 .

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Search for Production of D^{*-} by Pions near Threshold

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We have searched for production of charmed mesons in the reaction $\pi^- + N \rightarrow D^{*-} + X$, $D^{*-} \rightarrow \pi^- + \bar{D}^0$, $\bar{D}^0 \rightarrow K^+ + \pi^-$ at a beam momentum of 10.5 GeV/c. We measure the cross section times branching ratio to be 7 ± 20 nb/nucleon.

We report here the results of a search for charmed mesons in the reaction

$$\pi^- + N \rightarrow D^{*-} + X, \quad D^{*-} \rightarrow \pi^- + \bar{D}^0, \quad \bar{D}^0 \rightarrow K^+ + \pi^-$$

at a beam momentum of 10.5 GeV/c. Previously we have reported upper limits on inclusive D^0 production by pions of momentum 15.0 GeV/c from an experiment conducted with the same apparatus.¹ In the present experiment we were able to suppress background by requiring, in addition to the D^0 signature, the observation of the pion from the $D^* \rightarrow \pi D$ decay; as a result the present limit is more sensitive than that published earlier by a factor of 5. The decay $D^* \rightarrow \pi^- + \bar{D}^0$ has now been observed at SPEAR, and the Q val-

ue for the decay was measured to be 5.7 ± 0.5 MeV.²

The primary component of the apparatus was the double-arm spectrometer described in detail in Ref. 1. A third arm was added to observe the decay pion, as shown in Fig. 1. For a small value of Q the vector momentum of the decay pion is given approximately by the relation $\vec{p}_\pi = M_\pi \vec{p}_D / M_D$. The acceptance of the double-arm spectrometer restricted the momentum and the direction of the \bar{D}^0 , and therefore of the π^- , to narrow ranges. We placed a 48D48 dipole magnet with magnetic field integral $\int \vec{B} \cdot d\vec{l} \approx 250$ MeV/c and a 32-in. gap about 240 in. downstream of the target. The low-momentum pions were bent out of the

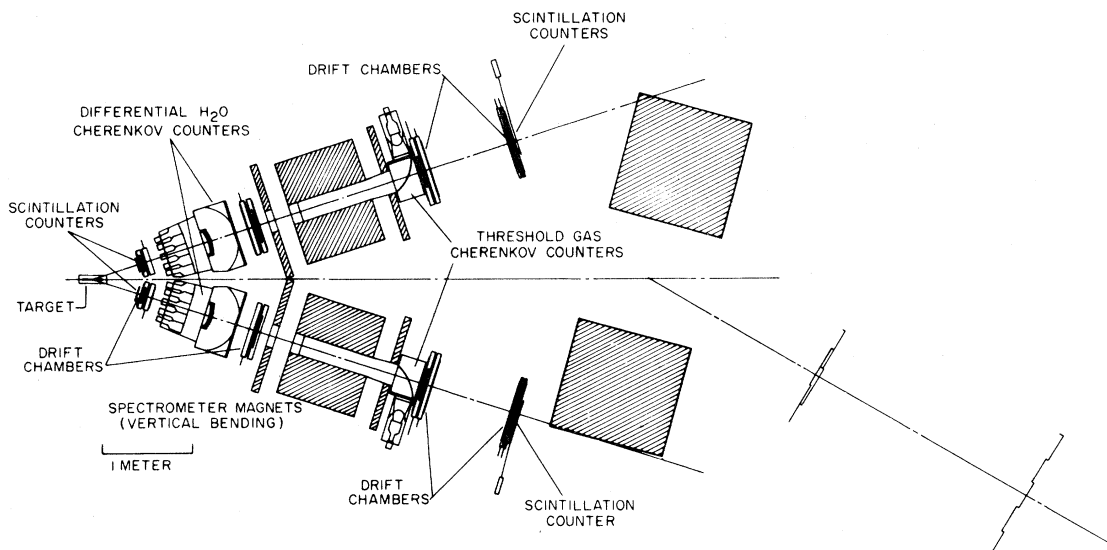


FIG. 1. Plan view of the apparatus. Shown at right is the third arm, including a large-aperture magnet and two hodoscope planes.