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PRODUCTION OF DIMUONS IN 16 GeV/c πp INTERACTIONS*

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ABSTRACT

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 for the ρ, ω and the η and ω Dalitz decays. An excess of events is observed in the mass region $\sim 400 - 600$ MeV which is not accounted for by the above-mentioned decays.

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A study of dimuon production by 16 GeV/c π^+ and π^- mesons incident on hydrogen has been performed using the SLAC two-meter streamer chamber.

The data reported is from a total of 10^8 interactions corresponding to 3.9 events per nanobarn × 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 $x_F > 0.3$ region 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) causes 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.

The basic problem in identifying prompt muons at low energies is the decay and "punch through" 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 cm × 15 cm supplemented by two planes of wire chambers to allow more accurate hit locations. Hits which were further than three 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 ($\sim$ 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 punch through 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, 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. Using 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%). Applying 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%.

Making an estimate of the single muon to pion ratio on the basis of the dimuon data reported here requires a model-dependent calculation. We instead calculate a dipion ($\pi^+\pi^-$) 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 ess 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 $3 \pm 1 \times 10^{-5}$.

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, statistical uncertainties regarding the signal shape make a fit to a ρ^0 Breit-Wigner of little value. 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 $\eta\,(\eta \rightarrow \gamma\mu^+\mu^-)$ and $\omega\,(\omega \rightarrow \pi^0\mu^+\mu^-)$. 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 four millibarn total cross section, with an inclusive spectrum similar to the ρ^0,[1] and with a branching ratio for Dalitz decay of 8×10^{-5}.[2] 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 millibarn η inclusive production cross section with a branching ratio for Dalitz decay of 3×10^{-4} was required.[2] 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 $\omega \rightarrow 2\mu$ and $\eta \rightarrow 2\mu$. (See Table I and Fig. 3.) This leads to a Dalitz decay signal about one-third of the maximum possible.

Using either method of estimation, a low mass dimuon signal is observed, which cannot be due to known sources; assuming 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.[3-6] In particular, bremsstrahlung type interactions[4] 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.[6]

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.[7] The ratio of $\mu^+\mu^-/\pi^+\pi^-$ is approximately $1/3 \times 10^{-4}$ which may account for the observed single μ/π ratio[8] in the region $x_F > 0.3$. The ratio of $\sigma(\pi^- p \to \mu^+\mu^-)/\sigma(\pi^+ p \to \mu^+\mu^-)$ in our mass region is $1.28 \pm .23$.

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TABLE I

Data Summary

	π^+	π^-	Combined
Interactions	45.3×10^6	51.1×10^6	96.3×10^6
Sensitivity (events/μbarn)	1,880	1,990	3,870
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 $x_F > 0.3$ (nanobarn)			
$\pi p \rightarrow \mu^+\mu^- X$	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
$\sigma(\pi^- p \rightarrow \mu^+\mu^- X)/\sigma(\pi^+ p \rightarrow \mu^+\mu^- X) = 1.28 \pm 0.23$		$\frac{\sigma(\mu^+\mu^-)}{\sigma(\pi^+\pi^-)} = (3 \pm 1) \times 10^{-5}$	

(a) This number can be compared with the value of 340 ± 70 obtained at 150 GeV/c.[7]

FIGURE CAPTIONS

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.

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

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).

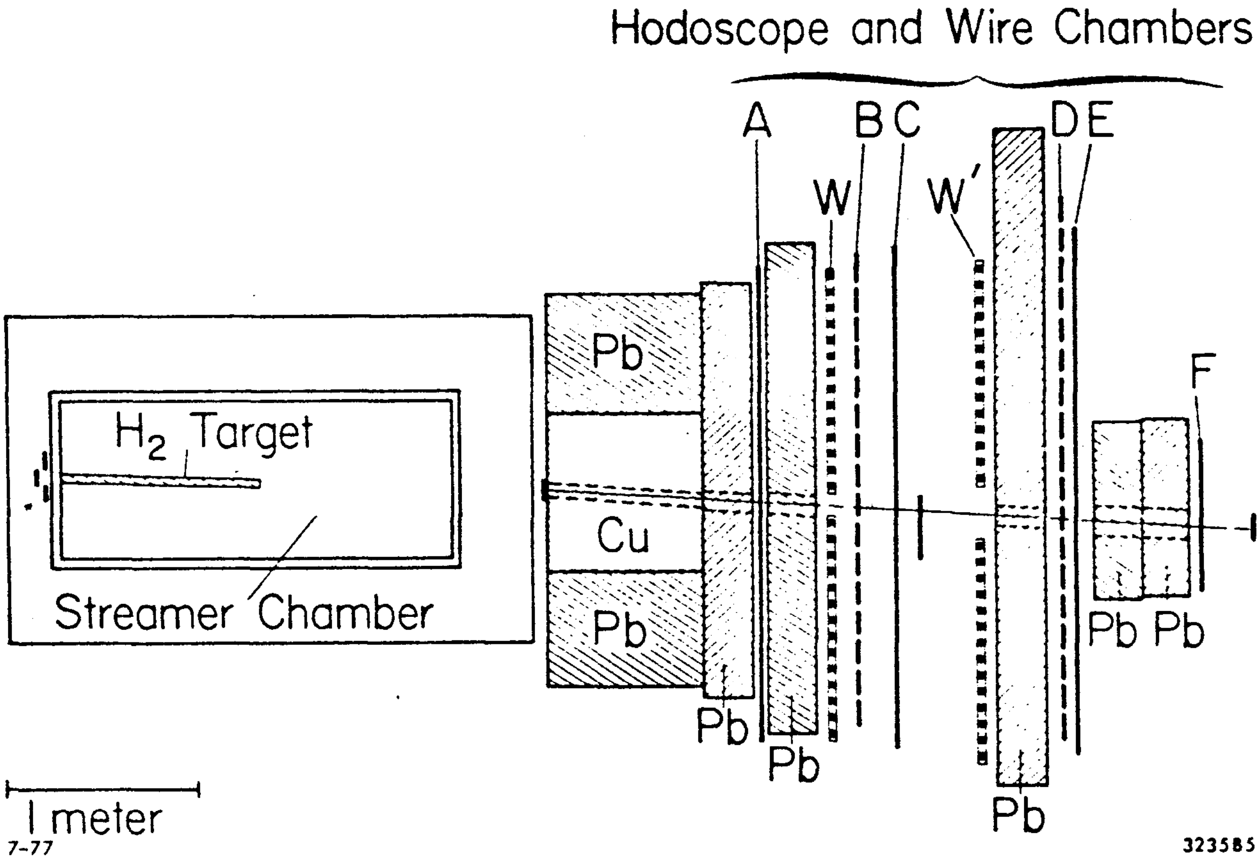
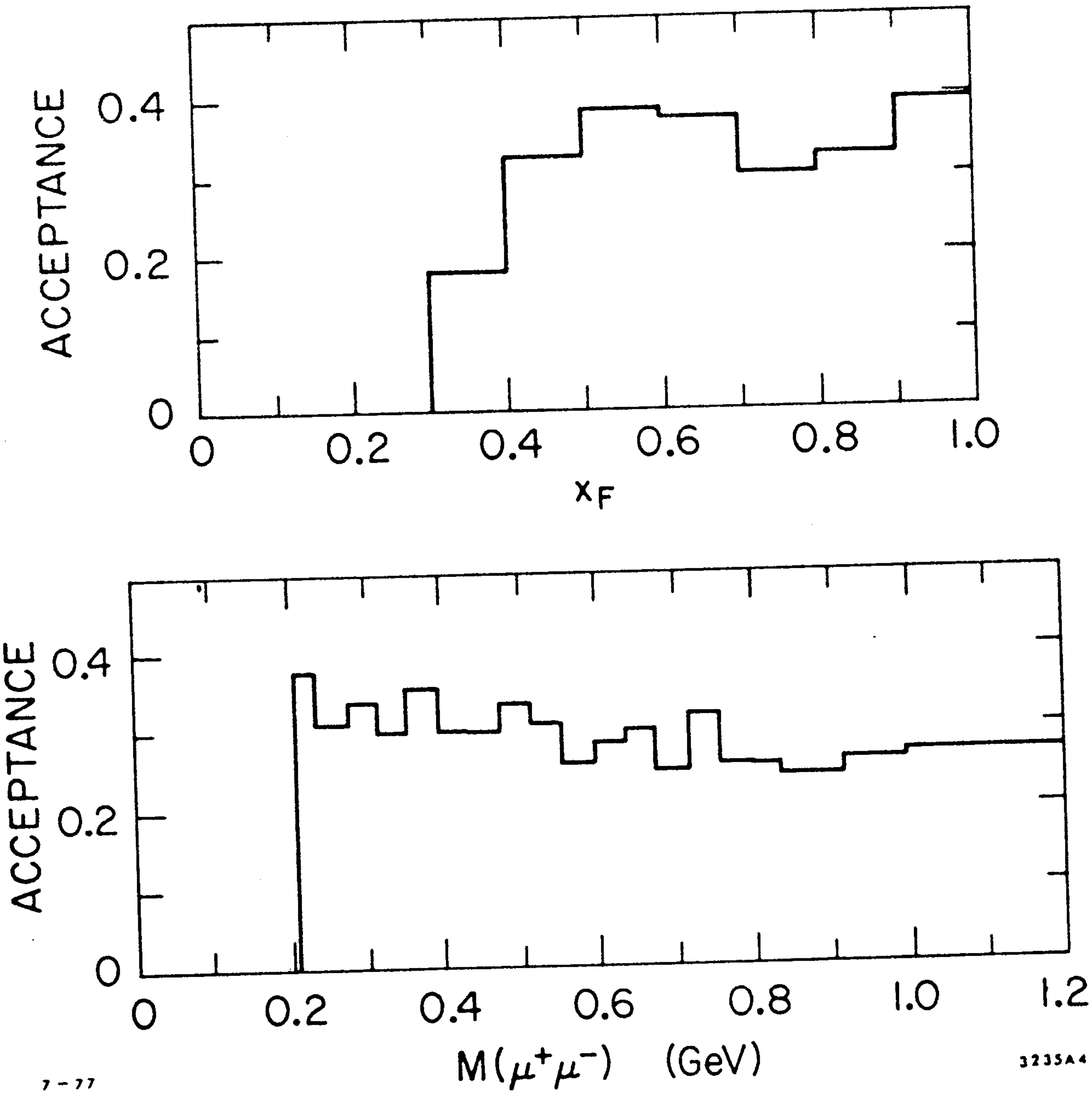
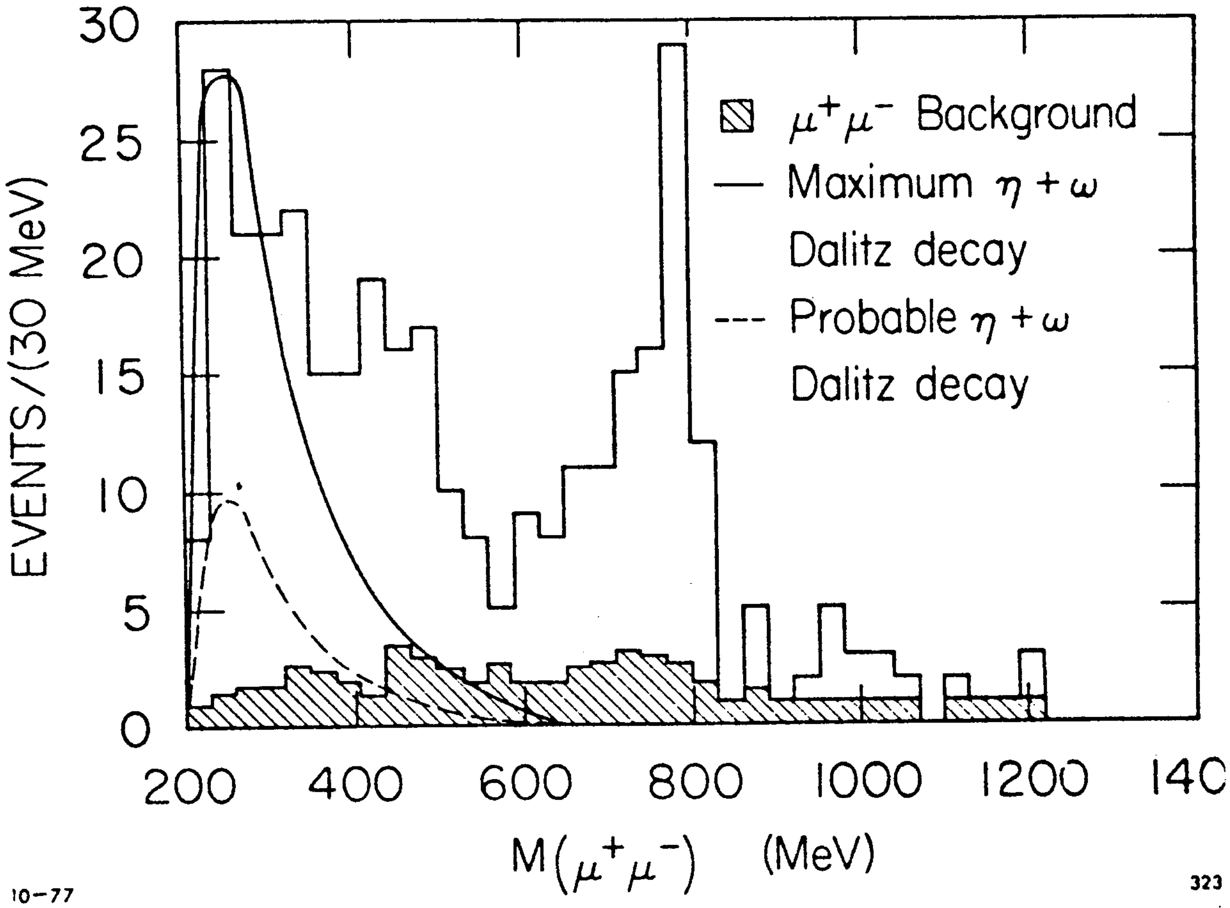

Hodoscope and Wire Chambers
A
B C
D E
W
W'
F
H_2 Target
Streamer Chamber
Pb
Cu
Pb
Pb
Pb
Pb
Pb Pb
1 meter
7-77
323585

Fig. 1



ACCEPTANCE
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
x_F
ACCEPTANCE
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
1.2
$M(\mu^+\mu^-)$ (GeV)
7-77
3235A4

Fig. 2



30
25
20
15
10
5
0
EVENTS/(30 MeV)
200
400
600
800
1000
1200
140C
M($\mu^+\mu^-$) (MeV)
$\mu^+\mu^-$ Background
Maximum $\eta + \omega$
Dalitz decay
Probable $\eta + \omega$
Dalitz decay
10-77
323

Fig. 3