do the data.

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[7]We have fitted the data using the single-pole functional form

$$\frac{d\sigma}{dt}=F(t)\left(\frac{E_\gamma}{M_p}\right)^{2[\alpha_\omega(t)-1]},$$

where $F(t)$ is a function of t alone, E_γ the incident photon energy, M_p the proton mass, and $\alpha_\omega(t)$ the ω Regge trajectory. When we fitted only those data points where $E_\gamma \geq 2.8$ GeV, we achieved good fits using the above functional form. The fits including data with $E_\gamma < 2.8$ GeV were poor.

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MUON-PAIR DECAY MODES OF THE VECTOR MESONS*

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We wish to present results of a further analysis of data on the production of muon pairs by a negative 12-BeV/c pion and kaon beam at the alternating-gradient synchrotron. A preliminary report of the experiment, which included a brief description of the techniques employed and of the experimental apparatus, was given previously.[1] That Letter discussed the analysis of two-prong events[2] produced in an iron-plate spark chamber and quoted results for the decay mode $\rho^0 \rightarrow \mu^+ + \mu^-$.[3] The present Letter gives four separate determinations of the $\rho^0 \to 2\mu$ branching ratio based on the data taken using carbon as well as the iron target and compares these data with production cross sections taken from both hydrogen and heavy-liquid bubble-chamber data. In addition, angular distributions of the muon pairs, which are presented as a function of four-momentum transfer, suggest the possibility of some ω^0 production. Finally, observation of the decay $\varphi \to 2\mu$ based on events produced with incident K^- mesons is reported.

Determination of the $\rho^0 \to 2\mu$ branching ratio.—We have analyzed events previously measured from data taken during a 16-BeV π^- exposure in a heavy-liquid bubble chamber (C_2F_5Cl).[4] Two of the branching ratios which we report here are determined by comparing the events from our carbon data with production cross sections obtained from the heavy-liquid chamber data. By applying the experimental cutoffs present in our experiment to the bubble-chamber data, we are able to select just those bubble-chamber events which would have been detected in our experiment, thereby measuring the production cross section times the detection efficiency with which our data must be compared. The branching ratios so obtained are shown in the first two entries of Table I. It should be noted that these ratios are relatively free of the systematic error discussed in the previous paper[1] where an optical-model calculation was required to scale the iron cross section measured in our experiment to a cross section for the free proton. In addition, an important correction required when discussing the branching ratio obtained by selecting two-prong events in carbon is not important in the branching ratio determined from the multiprong data. This correction is due to the fact that we estimate that in 25% of the events labeled "two prong," there is an additional π^0 which remains undetected.

In obtaining the ratios using hydrogen bubble-chamber data, it was necessary to calculate experimental efficiencies. These were obtained by making a maximum-likelihood fit to the observed decay angular distributions. The four ratios are in good agreement, but we emphasize that they are not statistically independent and contain systematic errors. Our best estimate is obtained by a weighted average, taking full account of the correlation between the errors of the four methods, giving the branching ratio

$$\frac{\rho^0 \to \mu^+ + \mu^-}{\rho^0 \to \pi^+ + \pi^-} = (5.1 \pm 1.2) \times 10^{-5}.$$

Some further comments concerning our data are necessary in order to support the assumption that the resonance at 750 MeV is the ρ^0 meson. Figure 1 gives the density-matrix parameters ρ_{00}, $\rho_{1,-1}$, and $\mathrm{Re}\rho_{10}$ as a function of the four-momentum transfer for the cut-off two-prong iron and carbon data between 600 and 900 MeV. The parameter ρ_{00}, as measured in our experiment, is in reasonable agreement with an absorption-model calculation[5] based on a one-pion exchange model which is represented on the figure by a dashed line. We conclude from this agreement that our data are primarily ρ^0 production by one-pion exchange, especially at low momentum transfers $[|t| < 0.3\ (\mathrm{BeV}/c)^2]$. At higher momentum transfers the

Table I. Results from four differing determinations of the branching ratio $(\rho^0 \to 2\mu)/(\rho^0 \to 2\pi)$. Each method is not necessarily statistically independent and systematic errors dominate. Experimental efficiencies were determined by applying kinematic limitations to bubble-chamber data for the first two methods and a maximum-likelihood calculation for the second two methods.

Source of muon-pair cross section	Source of pion-pair cross section	Calculated branching ratio $\frac{\rho^0 \to 2\mu}{\rho^0 \to 2\pi} \times 10^5$
Two-prong from C per carbon nucleus	Heavy-liquid bubble chamber	4.4 ± 2.9
Multiprongs from C per carbon nucleus	Heavy-liquid bubble chamber	4.4 ± 1.5
Two-prong from Fe scaled to free proton	Hydrogen bubble chamber[a]	6.1 ± 2.2
Two-prong from C scaled to free proton	Hydrogen bubble chamber[a]	5.2 ± 1.8

[a]Ref. 1.

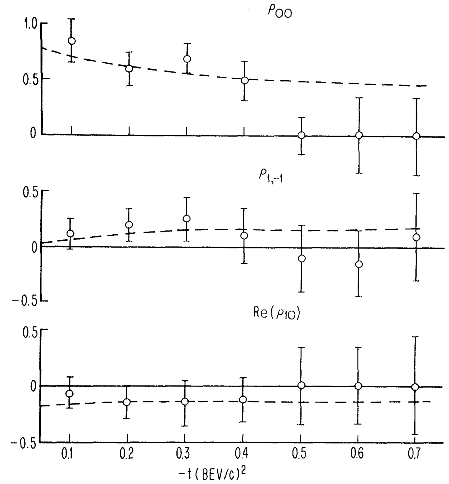

FIG. 1. Decay-correlation matrix elements for combined carbon and iron events in the dimuon mass range $600 < M_{\mu\mu} < 900$ MeV plotted as a function of four-momentum transfer. These matrix elements were obtained by making maximum-likelihood fits to weighted distributions, with the weights proportional to the efficiency of the experimental detection system. The dashed line represents predictions of a one-pion exchange model including absorption.

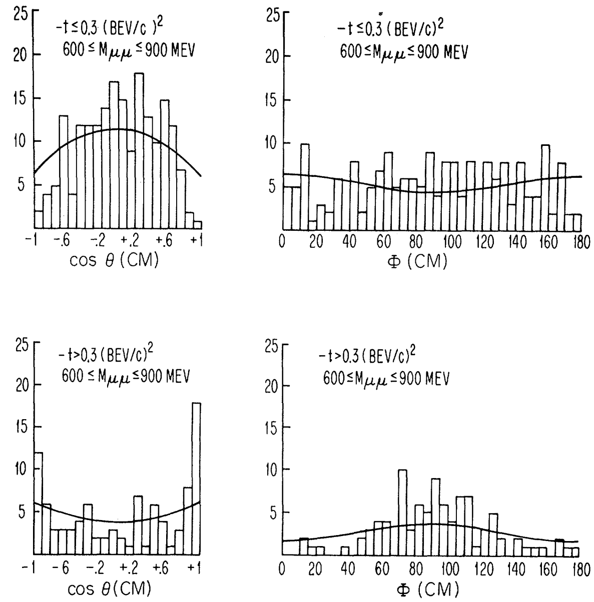

FIG. 2. Distributions of $\cos\theta$ and φ in the dimuon rest system for two-prong carbon events with magnitude $|t| < 0.3$ (BeV/c)^2 and magnitude $|t| > 0.3$ (BeV/c)^2 and dimuon masses in the range $600 < M_{\mu\mu} < 900$ MeV. θ is the polar angle measured from the pion direction; φ is the azimuthal angle (Treiman-Yang angle) measured from the production plane. Continuous curves were calculated using density-matrix elements for all two-prong carbon events in each of the two momentum-transfer ranges.

density matrix elements give evidence for spin-1 exchange, compatible with ω^0 production. This change in vector-meson polarization is clearly seen in the angular distributions of Fig. 2. However, if we construct the effective-mass plot for the data with $|t| > 0.3$ (BeV/c)^2, where ω^0 contamination should be larger, we observe no marked shrinking of the resonance width. Nevertheless we correct the ρ^0 branching ratio for ω^0 contamination, by assuming the ratio of the partial widths $\Gamma(\omega^0 \to 2\mu)/\Gamma(\rho^0 \to 2\mu)$ as predicted by SU(3)[6] and the known ω^0 production cross sections.[7] The correction amounts to $(11 \pm 6)\%$. Finally a Monte Carlo calculation of the contribution to the high momentum-transfer data from the normal two-pion decay mode of the ρ^0 decaying in flight gives less than a 2% contribution ot the data above $|t| = 0.3$ (BeV/c)^2.

Observation of the φ decay mode.—In this section we report on a sample of the data representing those events induced by 12-BeV K^- mesons incident on either carbon or iron and such that the reaction can include any number of particles present in the final state in addition to the muon pair. As discussed in the previous paper, incident K^- mesons were positively identified with a differential Čerenkov counter.[8] Figure 3 shows a histogram of the muon-pair invariant mass observed from these K^- induced events. The histogram has only a few events because of the low K^- flux in the incident beam (~3% of the pion flux). Figure 3 also shows the muon-pair invariant-mass spectrum observed for reactions induced by incident π^- mesons on both carbon and iron scaled down by a factor of 50. A clear peak is seen above this curve in the mass region of about 1050 MeV and with width consistent with our experimental resolution.[1] We attribute this peak to the muon-pair decay mode of the φ meson.

It is well known that φ-production cross sections from π^- mesons are small and that φ mesons are more readily produced with K^- beams, in agreement with SU(3) arguments. In addition, the φ-meson branching ratio into lepton pairs is predicted to be larger than the corresponding branching ratios for the ρ^0 and ω^0 because of the smaller φ width.[6] Since Fig. 3 represents a yield proportional to the product of branching ratio, production cross section,

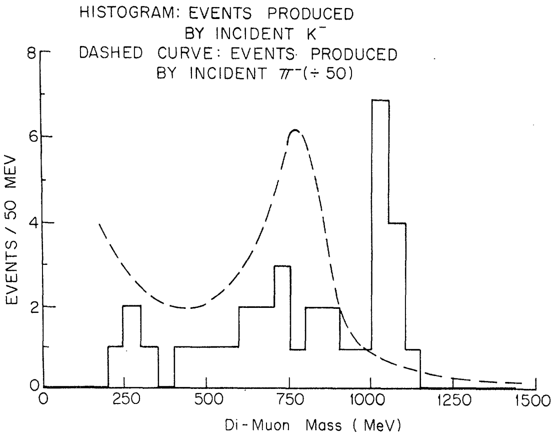

FIG. 3. Dimuon mass spectrum for 34 events produced with 12-BeV/c K^--mesons incident on carbon and iron. For comparison the mass spectrum produced with 12-BeV/c π^- mesons incident on carbon and iron is also shown, scaled down by a factor of 50. (The incident 12-BeV/c beam contained about 3% K^- meson.)

and detection efficiency, one might expect a peaking in the φ-mass region for K-induced events, as is indeed the case.

It is difficult to relate our observed event rate to a branching ratio for the decay mode $\varphi \to 2\mu$ since high-energy φ-production cross sections are unknown at the present time. Bubble-chamber exposures to incident K^- beams in the 10-BeV region can be expected to yield cross sections for φ production in hydrogen in the near future[9] but to our knowledge, no data exist at present. Furthermore, our events come from an undetermined final state and production can occur on either the proton or the neutron. The efficiency for detection of these events in our experiment depends on the angular distributions of the reaction, and the limited statistics introduced large errors in the technique used to calculate this efficiency.[10] We nevertheless employed the method discussed in Ref. 10 to arrive at a cross section for muon-pair events in the φ-mass peak. We find

$$\sigma = 33 \pm 11 \text{ nb/C nucleus.}$$

Because no enhancement of the dimuon mass spectrum in the φ region due to incoming pions was observed, we place an upper limit on production of muon pairs from φ mesons by pions incident on carbon at 12 BeV. We estimate this cross section to be less than 1.0 nb per carbon nucleus.

Conclusions.—We see conclusive evidence for the decay of φ and ρ^0 mesons to muon pairs. The values of the density-matrix parameters describing the dimuon polarization at high four-momentum transfer for the pion data are consistent with the presence of the decay $\omega^0 \to 2\mu$. In addition, we report a new normalization of our data based on the results from a heavy-liquid bubble chamber.

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[2]Our event topology has been divided into two classes, two-prong and multiprong. The two-prong topology represents solely reactions of the type $\pi^- + p \to \mu^+ + \mu^- + n$ except for a contamination of events of the type where either one or more π^0's are also present or where additional charged particles are not seen in our spark chamber target. Multiprong topology represents those events where two, three, or four outgoing charged particles were seen at a vertex and could be accompanied by any number of neutral particles.

[3]The cross section in that paper for production of two-prong events between 600 and 900 MeV and $|t| < 0.3$ $(\text{BeV}/c)^2$ was incorrect due to an error in computation and should be $\sigma_{\text{Fe}} = 87 \pm 14$ nb/Fe nucleus. The present Letter presents results from a more refined analysis of the data. Branching ratios and the free-proton cross section in this paper supersede the previous ones.

[4]We gratefully acknowledge the cooperation of Dr. H. H. Bingham in providing us with the heavy-liquid bubble-chamber data used for our normalization. The data were obtained during a 16-BeV π^- exposure in the Ecole Polytechnique heavy-liquid bubble chamber at CERN.

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[10]As mentioned in our previous publication, a maximum-likelihood technique dependent upon the experimentally observed angular distribution has been used to calculate inefficiencies. A more complete description of this method will be presented in a later publication.