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Search for Peripheral K^+ Production in $\pi^- p$ Interactions from 2.75 to 10 GeV/c*

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Upper limits are presented for the differential cross section in the reactions $\pi^- p \to K^+\Sigma^-$ and $\pi^- p \to K^+ Y^{*-}(1385)$ with small momentum transfer from π^- to K^+.

Within the framework of one-particle-exchange models, peripheral K^+ mesons from the reactions

$$\pi^- p \to K^+\Sigma^- \qquad (1)$$

and

$$\pi^- p \to K^+ Y^{*-}(1385) \qquad (2)$$

would require the exchange of an $I=\frac{3}{2}$ strange meson. Since no such meson is known to exist at the present time, these processes are considered "forbidden." They might be expected therefore to be sensitive to s-channel resonances at lower energies and two-meson exchanges, Regge cuts or other more exotic effects at high energies.

In conjunction with the experiment on the reactions

$$\pi^+ p \to K^+\Sigma^+ \qquad (3)$$

and

$$\pi^+ p \to K^+ Y^{*+}(1385) \qquad (4)$$

reported previously,[1] we also searched for fast K^+ mesons in $\pi^- p$ interactions. In the region where s-channel resonances ($N^{*0}_{1/2}$, Δ^0) are known to exist (2.75–4 GeV/c), we collected data at 0.25-GeV/c intervals in beam momentum.[2,3] In addition we ran at 4.5, 6, and 10 GeV/c. Our wire-chamber spectrometer covered the $\frac{1}{2}°$–5° angular range in the laboratory. The experimental arrangement was identical to that of the companion experiment, with one exception: In order to obtain elastic scattering data for calibration purposes, we had to reverse the field in the spectrometer magnet.

The spectrum of the mass recoiling against the K^+ shows no evidence for Σ^- production at any beam-momentum setting. Five sample spectra are shown on Fig. 1, with a corresponding measurement for Σ^+ production. The spectra show a substantially flat background due primarily to multiple interactions and particle misidentification up to $\Lambda\pi$ threshold. At this point events from the reaction

$$\pi^- p \to K^+\pi^-\Lambda \qquad (5)$$

begin to contribute. We estimate the upper limit of the contribution of reaction (1) to these spectra as follows: We define the "Σ^- region" as $1.30 \le \mathrm{MM}^2 \le 1.55$ (GeV/c^2)^2. This choice is dictated by the width of the Σ^+ peak in the companion experiment.[4] We also define a "control region" $0.7 \le \mathrm{MM}^2 \le 1.2$ (GeV/c^2)^2 to establish the background level at the Σ^- mass. The number of events in the Σ^- region after subtraction of the background is our "signal," shown in Table I. The upper limit at 95% confidence level is this signal plus twice its error. Since the detection efficiency of our apparatus depends on the production angle, the values for the differential cross section based on these upper limits depend on the momentum-transfer distribution assumed. We calculated the differential cross section at $t=0$ for reaction (1) assuming the shape $d\sigma/dt = Ae^{5t}$, as suggested by models based on Regge cuts, generated from ρ and K^* exchange. These results also are shown in Table I.[5]

Preliminary results by Akerlof *et al.*[2] indicate that the value of the differential cross section is in fact substantially smaller than our limits at the lower momenta. Direct comparison of our results with bubble-chamber data is somewhat difficult in view of the large difference in angle-dependent efficiency between the two methods. With the assumption of an e^{5t} dependence for the differential cross section the data by Dahl *et al.*[2] give $(d\sigma/dt)_{t=0} = (3.8 \pm 1.9)$ and (1.2 ± 1.2) μb/(GeV/c)^2 at 3.15 and 4.0 GeV/c, respectively, and are thus consistent with our limits for reaction (1).

The analysis of reaction (2) is complicated by the additional background due to reflections of other final states. The dominant contribution comes

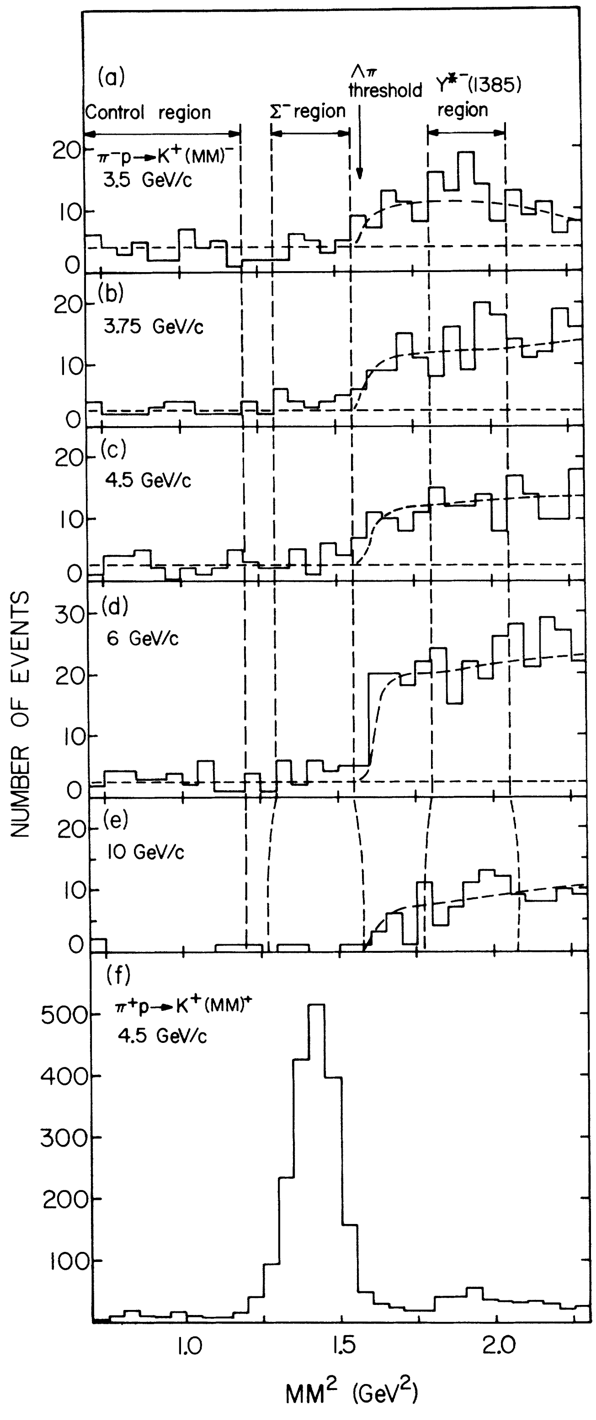

FIG. 1. (a)–(e) Spectra of missing mass squared from the reaction $\pi^-p \to K^+(MM)^-$ at selected beam momenta. The dashed horizontal lines represent the background level determined from the control region. The dashed curves above $\Lambda\pi$ threshold represent reflections from K^* production (see text). (f) Missing-mass-squared spectrum from the reaction $\pi^+p \to K^+(MM)^+$.

from the reaction

$$\pi^-p \to K^{*0}(890)\Lambda, \quad K^{*0}(890) \to K^+\pi^- \qquad (6)$$

although $K^*(1420)$ production and final states involving Σ^0 instead of Λ are also present.[6] While in the case of bubble-chamber experiments these sources of background can be explicitly excluded,[7] we can only estimate their effect on the missing-mass spectrum recoiling against the K^+ in this experiment. This estimate is based on data at 3, 4, and 6 GeV/c from bubble-chamber experiments.[8] Monte Carlo events were generated with these distributions, and were subjected to the geometrical limitations of our apparatus. The shape of the spectrum so generated approximates well the missing-mass-squared distribution. In particular it reproduces the abrupt rise at 1.6 $(\text{GeV}/c^2)^2$, near $\Lambda\pi$ threshold. It is difficult to obtain an absolute normalization for the reflections due to the limited amount of information available on K^* production. Therefore we set the normalization to fit our data outside the Y^{*-}(1385) region. The distributions so obtained are shown on Fig. 1. Although there is some excess of events in the Y^{*-}(1385) region at 3.5 GeV/c and possibly at 3.75 GeV/c, no signal is visible at the higher momenta.

Our estimate on Y^{*-}-production cross sections are summarized in Table II. The momentum-transfer distribution is assumed to be isotropic over the range covered by the apparatus. The upper limits shown take into account the statistical uncertainty at the 2 standard-deviation level, and allow for a renormalization of the background by 33%.

Since the shape of the differential cross section near $|t| = 0$ is quite uncertain, we have no quantitative comparison with the data of Abolins *et al.* and Crennell *et al.*[2] Our results are, however, consistent with the conclusions of these experiments.

The presence of forbidden peripheral processes below 6 GeV/c has been reported for a variety of reactions.[7,9] The corresponding cross sections are generally small ($\lesssim 10\,\mu$b above 3 GeV/c) and fall rapidly with increasing beam momenta. Experiments at higher energy[10] have failed to find a signal for such processes investigated.[11] Reaction (1) is unusual in that the cross section for peripheral K^+ production remains very small, even below 3 GeV/c.[12]

To explain the consistently small upper limits found for this reaction we are forced to one of two possible conclusions: Either the branching ratio of direct-channel resonances into the $K\Sigma$ channel is very small, or there is a systematic cancellation between the two isospin amplitudes contribut-

TABLE I. Upper limits for Σ^- production cross sections, based on events in the momentum-transfer range shown.

P (GeV/c)	Momentum transfer (GeV/c)^2	Events in Σ region (N)	Events in control region ($2B$)	"signal" $[(N-B)\pm\sigma]$	Upper limit $(N-B+2\sigma)$	$d\sigma/dt\|_{t=0}$ [μb/(GeV/c)^2]
2.75	$0.03\le\|t\|\le0.1$	24	61	-6 ± 7	14	<11.5
3.0	$0.03\le\|t\|\le0.1$	22	39	3 ± 6	15	<10.4
3.25	$0.03\le\|t\|\le0.12$	24	43	3 ± 6	15	<6.7
3.5	$0.03\le\|t\|\le0.12$	21	39	2 ± 6	14	<5.0
3.75	$0.03\le\|t\|\le0.12$	22	27	9 ± 6	21	<7.4
4.0	$0.03\le\|t\|\le0.14$	32	51	7 ± 7	21	<4.7
4.5	$0.03\le\|t\|\le0.20$	18	26	5 ± 5	15	<4.0
6.0	$0.02\le\|t\|\le0.26$	21	25	9 ± 5	19	<1.9
10.0	$0.03\le\|t\|\le0.75$	4	6	1 ± 2.5	6	<0.2

TABLE II. Cross section for $Y^{*-}(1385)$ production, based on events in the momentum-transfer range shown.

P (GeV/c)	Momentum transfer (GeV/c)^2	No. of Y^{*-} events	$d\sigma/dt$ [μb/(GeV/c)^2]
3.5	$0.05\le\|t\|\le0.12$	15 ± 12	12 ± 10
3.75	$0.05\le\|t\|\le0.12$	15 ± 15	10 ± 10
4.5	$0.04\le\|t\|\le0.15$	<25	<9
6.0	$0.03\le\|t\|\le0.23$	<40	<3
10.0	$0.03\le\|t\|\le0.72$	<30	<0.3

ing to this reaction, masking the effect of the resonances. Although naively such a cancellation could be considered unlikely, models of duality predict that on the average this cancellation should take place, since the crossed channel is "exotic."

Contributions from Regge cuts above the resonance region are estimated to be considerably smaller than the limits found in this experiment.[13]

Added note. After completion of this work we received a preprint from the Michigan group[14] where final results on reaction (1) from their experiment are presented.

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[3]On reaction (2) we have data only at 3.5, 3.75, 4.5, 6, and 10 GeV/c. At other momenta the efficiency of our K^+ Čerenkov counter was poor for K^+ momenta lower than that for reaction (1).

[4]Because of the poorer resolution at 10 GeV/c, the "Σ region" and the "control region" were enlarged there to $1.27\le MM^2\le1.58$ (GeV/c^2)^2 and $0.6\le MM^2\le1.2$ (GeV/c^2)^2, respectively.

[5]For this calculation we increase the "upper limit" by a factor 1.3 to account for the number of Σ^- events expected outside the "Σ^- region."

[6]Additional but smaller contributions will come from the nonresonant $K^+\pi^-\Lambda$ and $K^+\pi^-\Sigma^0$ final states. The importance of these has been emphasized by E. L. Berger, Phys. Rev. Letters 23, 1139 (1969).

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Photoproduction of Neutral ρ Mesons*

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Results are presented on a series of measurements of ρ-photoproduction from hydrogen, deuterium, and complex nuclei ranging up to lead, at photon energies ranging from 4 to 9 GeV. Detailed dipion mass-spectrum fits are presented, using a Drell-type nonresonant background and its interference with the resonant amplitude, with no other arbitrary backgrounds. For hydrogen and deuterium, the inelastic contributions have been subtracted. The A dependence of the cross sections is analyzed to yield values of $\gamma_\rho^2/4\pi$ and $\sigma_{\rho N}$ at average photon energies of 6.1, 6.5, and 8.8 GeV. The hydrogen-to-deuterium ratios indicate the presence of possible nondiffractive amplitudes at low energies which then decrease with energy.

I. INTRODUCTION

Results are presented on a series of measurements on ρ^0 photoproduction from elements ranging from hydrogen to lead, at average photon energies ranging from 4 to 9 GeV. Some of the data in the present analysis were presented in previous publications.[1] These data have been reanalyzed using a consistent scheme of analysis for all the sets of data. In no case have the cross sections reported in Ref. 1 been changed by more than 9%. However, due mainly to the inclusion of the real part of the ρN scattering amplitude, the values of $\gamma_\rho^2/4\pi$ and $\sigma_{\rho N}$ extracted from the data have changed by about 35%. Here $\gamma_\rho^2/4\pi$ is the direct ρ^0-photon coupling constant and $\sigma_{\rho N}$ the total ρ^0 cross section on a free nucleon.

Dipion mass spectra were measured in detail for several representative nuclei at three energies, 4.4, 6.5, and 8.8 GeV. These mass spectra have been fitted in the mass range ~500 to ~1000 MeV using an interference model[2] and no arbitrary background subtractions. Parameters obtained from these representative fits are found to be fairly independent of the target element at any particular energy, and these parameters are then used for all elements at the same energy to extract the 0° ρ^0-photoproduction cross sections.

The A dependences of the 0° cross sections at each energy (using the elements from deuterium to lead) are then fitted using an optical-model calculation with $\gamma_\rho^2/4\pi$ and $\sigma_{\rho N}$ as free parameters. Two sets of nuclear parameters are used in two independent sets of fits: (i) nuclear radii determined by fitting total nucleon-nucleus cross sections[3] using a consistent optical model, and (ii) nuclear parameters measured by electron-scattering experiments.[4] This second set of parameters agrees well with nuclear parameters determined from high-energy proton-nucleus scattering using an optical-model analysis[5] closely related to the present analysis. The results of these fits using the two different sets of parameters differ from each other by less than 10%. The effective photoproduction cross section from *single nucleons* is obtained from these fits and may be compared with the measured hydrogen cross sections in the same energy range.