

EVIDENCE FOR A NEW STRANGENESS-ONE PSEUDOSCALAR MESON\*

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ABSTRACT

The  $J^P = 0^-$  partial waves of the  $K\pi\pi$  system in the reactions  
 $K^\pm p \rightarrow K^\pm \pi^+ \pi^- p$  at 13 GeV are presented. Structure in intensities and  
relative phase variations suggests the existence of a pseudoscalar reso-  
nance, the  $K'$ , with a mass of  $\sim 1400$  MeV and a width of  $\sim 250$  MeV  
decaying predominantly into  $eK$ .

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The observation of pseudoscalar resonances is of fundamental importance to our understanding of the meson spectrum. Within the quark model<sup>1</sup> higher mass recurrences of these states can occur only as radial excitations of the  $L=0$   $q\bar{q}$  system. Evidence<sup>2</sup> for radial excitations in the meson system is provided by the  $\rho'$  and the  $\psi'$ , although each of these states could have an alternate assignment in the  $L=2$   $q\bar{q}$  supermultiplet. In this paper we present results which suggest the existence of a pseudoscalar, strangeness-one resonance, the  $K'$ , with a mass in the vicinity of 1400 MeV.

The data on which these results are based were obtained in a spectrometer experiment studying the reactions  $K^\pm p \rightarrow K^\pm \pi^+ \pi^- p$  at 13 GeV. The salient features of the experiment<sup>3,4,5</sup> are high statistics, good resolution,  $K/\pi$  identification, and  $K^\pm$  relative normalization uncertainty of  $\pm 2\%$ . We have described previously<sup>3,4</sup> the principal  $J^P=1^+$  and  $2^+$  partial waves<sup>6</sup> of the  $K^\pm \pi^+ \pi^-$  system. In addition to isolating a small, but clear  $K^*(1420)$  signal, we presented evidence for the existence of two axial vector mesons,  $Q_1$  with a mass of  $\sim 1300$  MeV and  $Q_2$  at  $\sim 1400$  MeV.

As they are germane to our discussion of the  $0^-$  waves, we briefly summarize certain features of these  $J^P=1^+$  states. Although their total widths are comparable, they appear to have quite different production and decay properties. The production of  $Q_1$  obeys approximate s-channel helicity conservation, and it seems to decay principally to  $\rho K$ . In contrast  $Q_2$  production satisfies approximate t-channel helicity conservation, while its dominant decay mode is  $K^* \pi$ . The evidence for these different decay modes rests, in part, on the observed phase motion of the  $1^+ \rho K$  waves relative to  $1^+ 0^+ K^* \pi$ : a forward motion of  $\sim 70^\circ$  for  $1.20 \lesssim m(K\pi\pi) \lesssim 1.35$  GeV and a backward motion of  $\sim 50^\circ$  for  $1.35 \lesssim m(K\pi\pi) \lesssim 1.45$  GeV. In addition the  $1^+ \rho K$  mass spectra peak only in the region of

1300 MeV. We infer from these observations that the absolute phase of the  $1^+$   $\rho$ K waves has a Breit-Wigner variation in the 1300 MeV region but is slowly moving by 1400 MeV. On the other hand, the absolute phase of the  $1^+0^+$   $K^*\pi$  wave, associated with the  $Q_2$  meson, would be rapidly moving in the 1400 MeV region. Since we are discussing the possibility of a  $0^-$  resonance in the vicinity of 1400 MeV, it is clearly preferable that the reference wave exhibit limited phase motion in this region. Thus, for the results presented in this letter, we use the  $1^+0^+$   $\rho$ K wave as the reference wave.

In Figs. 1a,b we show the  $0^-0^+$   $\epsilon$ K cross section and relative phase as measured with respect to  $1^+0^+$   $\rho$ K. Cross sections for ambiguous solutions,<sup>3</sup> present only in the  $K^-$  data at low  $K\pi\pi$  mass, are shown by crosses in those cases where they differ significantly from the highest likelihood solutions. For  $K\pi\pi$  masses where either the displayed wave or the reference wave is small in intensity, the relative phase measurement becomes unreliable and is not shown. The  $K^+$  and  $K^-$  data both exhibit a broad ( $\sim 250$  MeV) bump at about 1400 MeV. The points above 1.6 GeV were obtained with the wave set of Ref. 3. While they indicate that all the  $0^-$  waves are decreasing in this region, the qualification must be made that higher spin waves are becoming important beyond 1.6 GeV. Nevertheless a preliminary study of our data in the L-region ( $1.6 < m(K\pi\pi) < 2.0$  GeV) with an extended wave set indicates that all the  $0^-$  waves have decreased in intensity by  $\sim 1.7$  GeV.

The corresponding results for the  $2^+1^+$   $K^*\pi$  wave are shown in Figs. 1c,d. The curves indicate the d-wave Breit-Wigner line shape and phase variation for the  $K^*(1420)$ ,<sup>2</sup> and it is clear that the data are consistent with the expected behavior. In Figs. 1a,b the curves correspond to an s-wave Breit-Wigner parametrization with a mass of 1400 MeV and a width of 250 MeV.<sup>7</sup> Both the  $0^-0^+$   $\epsilon$ K

and the  $2^+1^+K^*\pi$  waves are well described by these parametrizations for intensity and phase. This is strongly suggestive of a resonance interpretation for the  $0^-0^+\epsilon K$  wave.

We turn next to the other significant  $0^-$  partial waves.<sup>8</sup> In contrast to  $0^-0^+\epsilon K$ , the  $0^-0^+K^*\pi$  wave (Figs. 2a,b) is already large by  $\sim 1.23$  GeV and reveals some indication of a two-peak structure. While the lower mass peak at  $\sim 1.23$  GeV is of roughly the same strength in both  $K^+$  and  $K^-$ , the  $K^+$  intensity is greater than that for  $K^-$  in the 1.3-1.5 GeV mass region. This two-peak structure is similar to that for  $1^+0^+K^*\pi$ ,<sup>3</sup> except that for the latter the higher mass peak is stronger for  $K^-$  than for  $K^+$ . The relative phase measured with respect to  $1^+0^+\rho K$  decreases by  $\sim 60^\circ$  for  $1.23 \lesssim m(K\pi\pi) \lesssim 1.35$  GeV, where the  $1^+\rho K$  system resonates, and increases by  $\sim 50^\circ$  for  $1.35 \lesssim m(K\pi\pi) \lesssim 1.56$  GeV. We tentatively interpret these observations in terms of a two-component description of the  $0^-0^+K^*\pi$  wave: a "Deck" background approximately constant in phase and peaking in intensity near 1.23 GeV together with a resonance contribution at  $\sim 1.4$  GeV.

The  $0^-0^+\rho K$  wave (Fig. 2c,d) is about 30% the size of the  $0^-0^+\epsilon K$  wave in intensity and appears to peak at a somewhat higher  $K\pi\pi$  mass. However, since its phase relative to  $1^+0^+\rho K$  shows some forward motion in the 1.4 GeV region, we would conclude that the  $0^-$  resonance may couple weakly to  $\rho K$ .

The momentum transfer ( $t'$ ) dependence of the  $0^-0^+K^*\pi$  and  $0^-0^+\epsilon K$  waves is shown in Fig. 3. The distributions for these waves are considerably steeper than those for the  $1^+0^+K^*\pi$  waves.<sup>4</sup> Parameter values from fits to the data with the expression  $A \exp(bt')$  are given in Table I. The  $0^-0^+\epsilon K$  waves are slightly larger near  $t'=0$  than the  $0^-0^+K^*\pi$  waves. There is an apparent "wrong-sign" cross-over (i.e.,  $b_{K^+} > b_{K^-}$ ) in the  $0^-0^+K^*\pi$  distributions, while none is evident for the  $0^-0^+\epsilon K$  waves, even though the  $K^-$  distribution is somewhat steeper than the

$K^+$ . We note that the presence of a  $0^-0^+ K^* \pi$  cross-over is consistent with the difference between the  $K^+$  and  $K^-$  mass spectra of Fig. 2a,b in the region of 1.4 GeV. However, due to the steepness of these waves, the limited statistics in the last two  $t'$  intervals, and certain technical considerations<sup>9</sup> in our method of analysis, we must at present consider this effect as an intriguing possibility. The difference in the production properties of these waves is presumably related to our previous observation that, whereas the  $0^-0^+ \epsilon K$  wave appears to be purely resonant, the  $0^-0^+ K^* \pi$  wave may require a two-component description.

We have presented evidence for the existence of a  $K\pi\pi$  pseudoscalar resonance, the  $K'$ , of mass  $\sim 1400$  MeV and width  $\sim 250$  MeV. The predominant decay mode is  $\epsilon K$  with weaker couplings to  $K^* \pi$  and, possibly,  $\rho K$ . While it is conceivable that non- $\pi$ -exchange "Deck" mechanisms could describe the  $0^-0^+ \epsilon K$  mass spectrum, they are not expected to yield a phase variation such as that shown in Fig. 1; it is then natural to associate such phase motion with the existence of a  $0^-$  resonance. In contrast "Deck" contributions appear to be significant for the  $K^* \pi$  system, so that a determination of the  $K'$  coupling to  $K^* \pi$  must await a quantitative interpretation of the data in terms of the two-component description mentioned above. Indeed a precise measurement of the  $K'$  mass and width also depends on how much the absolute phase of the  $1^+0^+ \rho K$  reference wave changes in the 1.3 - 1.5 GeV mass region. Nevertheless, the evidence for a  $0^- K\pi\pi$  resonance is already rather persuasive. In the quark model such a state would result from a radial excitation of the  $L=0$ ,  $q\bar{q}$  system and would imply the existence of other pseudoscalar mesons in the 1400 MeV mass region.

# REFERENCES

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2. Particle Data Group, Phys. Lett. 50B, 1 (1974); Rev. Mod. Phys. 47, 535 (1975).
3. G. Brandenburg et al., SLAC-PUB-1697, sub. to Phys. Rev. Lett.
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5. G. Brandenburg et al., to be sub. to Nucl. Instr. and Methods.
6. We label partial waves by  $J^P M^\eta$  Iso, where  $J^P$  is spin, parity;  $M^\eta$  is magnetic substate, exchange naturality; and Iso denotes  $K^*$ ,  $\rho$ ,  $\kappa$  or  $\epsilon$ .
7. Assuming a constant reference phase, we find for the fitted resonance parameters  $m_0 = 1404 \pm 12$  MeV and  $\Gamma_0 = 232 \pm 16$  MeV.
8. We have no difficulty distinguishing  $O^- O^+_{\kappa\pi}$  and  $O^- O^+_{\epsilon K}$ . Since the  $O^- O^+_{\kappa\pi}$  intensity never exceeds  $40 \mu\text{b}/\text{GeV}^3$  below 1.6 GeV, this wave is excluded from the present discussion.
9. The different  $t'$  dependences of individual waves were not imposed. With regard to the mass spectrum, however, the analysis was also done in 40 MeV bins with narrower  $t'$  cuts ( $0-0.06$  and  $0.06-0.2 \text{ GeV}^2$ ). No significant differences from the results presented here were found. See G. Brandenburg et al., to be sub. to Phys. Rev.

TABLE I

Parameter values from fits with  $A \exp(bt')$  to the  $0^-0^+ K^* \pi$  and  $0^-0^+ \epsilon K$  production distributions.

Wave	Beam	$A(\mu b/\text{GeV}^3)$	$b(\text{GeV}^{-2})$	$\chi^2$
$0^-0^+ K^* \pi$	$K^+$	$729 \pm 49$	$13.8 \pm 0.8$	2.9
	$K^-$	$546 \pm 41$	$11.3 \pm 0.7$	5.1
$0^-0^+ \epsilon K$	$K^+$	$1073 \pm 130$	$15.6 \pm 1.6$	3.3
	$K^-$	$1026 \pm 131$	$19.1 \pm 1.7$	1.8

FIGURE CAPTIONS

1. The mass dependence of the  $0^-0^+ \epsilon K$  and the  $2^+1^+ K^* \pi$  waves. Crosses correspond to ambiguous solutions, and  $\phi_{\text{rel}}$  is measured with respect to the  $1^+0^+ \rho K$  wave. The curves correspond to simple Breit-Wigner parametrizations.
2. The mass dependence of the  $0^-0^+ K^* \pi$  and the  $0^-0^+ \rho K$  waves. Crosses correspond to ambiguous solutions, and  $\phi_{\text{rel}}$  is measured with respect to the  $1^+0^+ \rho K$  wave.
3. The momentum transfer dependence of the  $0^-0^+ K^* \pi$  and  $0^-0^+ \epsilon K$  waves. The lines are exponentials with the parameter values given in Table I.

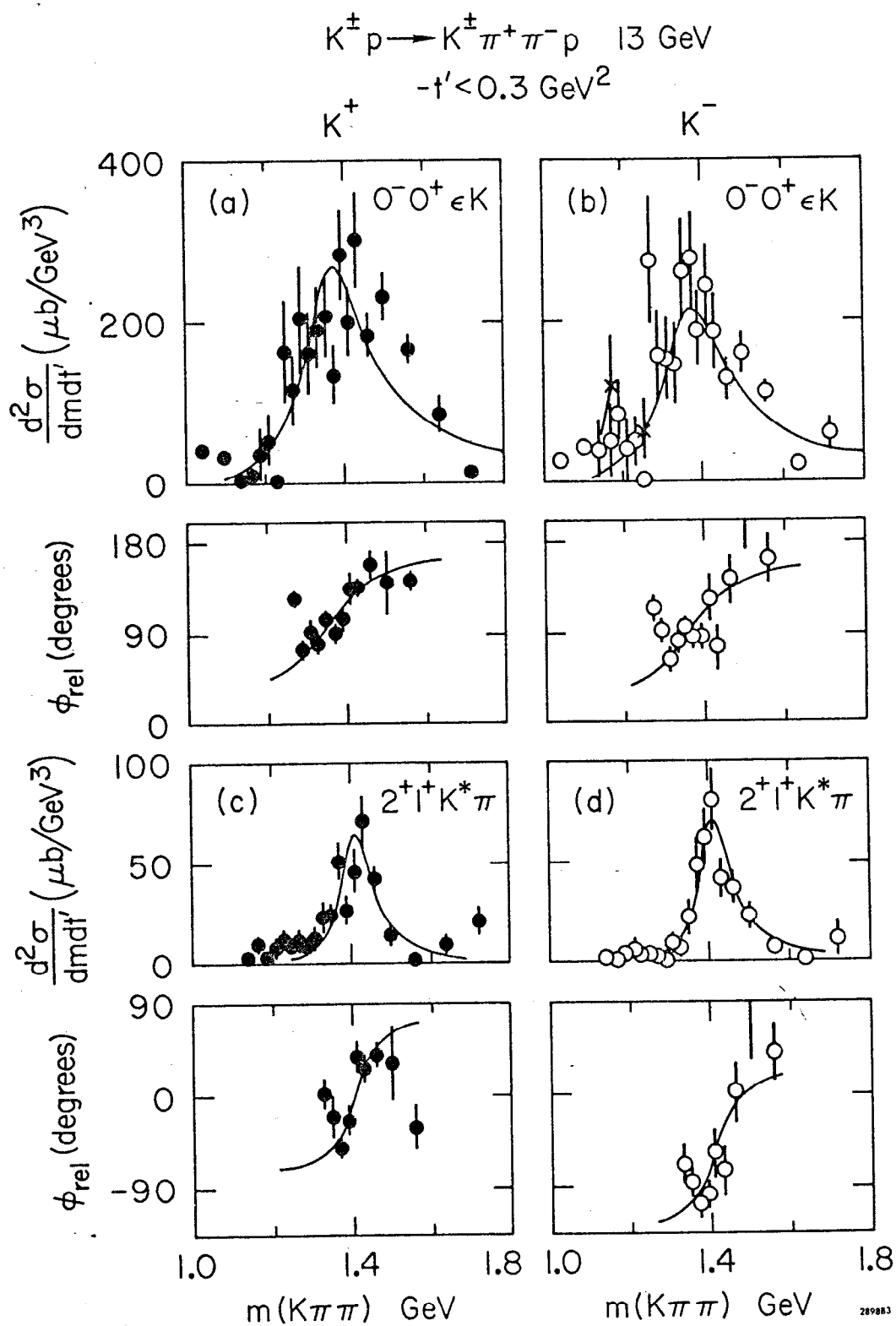


Fig. 1



$$K^{\pm}p \rightarrow K^{\pm}\pi^{+}\pi^{-}p \quad 13 \text{ GeV}$$

$$-t' < 0.3 \text{ GeV}^2$$

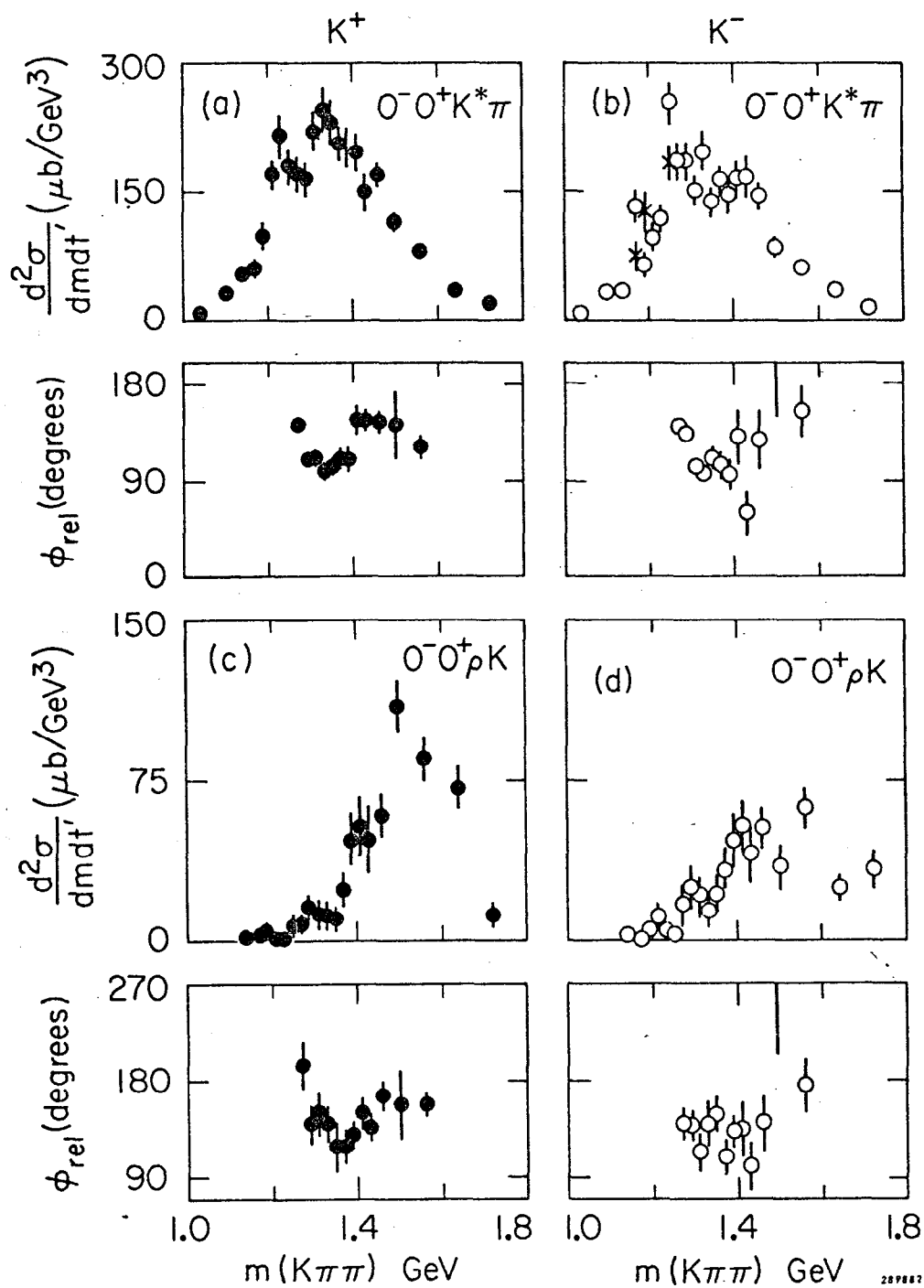


Fig. 2

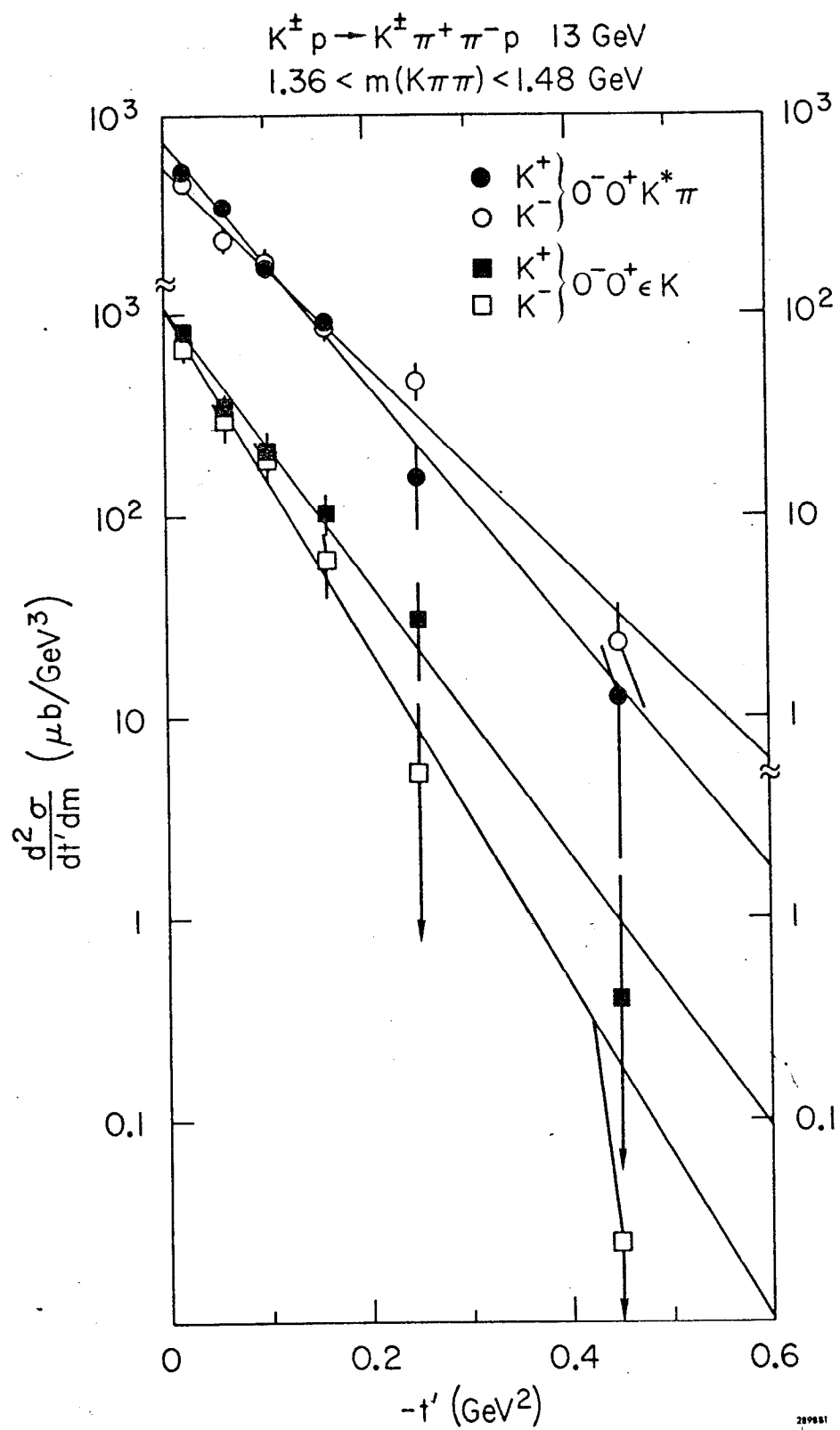


Fig. 3