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DISCLAIMER

EVIDENCE FOR AN ADDITIONAL RESONANCE IN THE REGION OF THE $K^*(1420)$[†]

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ABSTRACT

We have observed an additional K^* resonance on the low-mass side of the $K^*(1420)$ in the reaction $K^+n \to K^+\pi^-p$ at 12 GeV/c. This resonance has parameters $M \approx 1370$ MeV and $\Gamma < 150$ MeV, and is probably produced by a pion exchange mechanism with $J^P = 0^+$; but the alternate hypotheses of a $J^P = 1^-$ or a $J^P = 2^+$ resonance cannot be ruled out at this time.

In this letter we present evidence for the existence of an additional resonance in the region of the $K^*(1420)$ in the charge exchange reaction $K^+n \to K^+\pi^-p$ at 12 GeV/c. This resonance has parameters $M \approx 1370$ MeV and $\Gamma < 150$ MeV, and will be referred to as $K_N^*(1370)$. It probably has $J^P = 0^+$ and is produced by a pion exchange mechanism, as is the $K^*(1420)$. However, the alternate hypotheses of a $J^P = 1^-$ resonance produced by pion exchange, or a $J^P = 2^+$ resonance produced by a mixture of pion and vector exchanges cannot be ruled out at this time.

Experimental details.—The SLAC 82-inch bubble chamber was exposed to an rf-separated 12-GeV/c K^+ meson beam. Resolution in the beam momentum to within $\Delta p/p = \pm 0.2\%$ is achieved by using the known correlation between beam momentum and transverse position in the bubble chamber.[1] Approximately 500 000 exposures were taken, of which about 85% have been analyzed to date. The experimental details have been reported previously.[2,3]

The film has been scanned for (among other interactions) all events which have three-prong or four-prong topologies, in which all measured four-prongs were required to have at least one track which stops in the bubble chamber. The events were measured on the LRL Flying-Spot Digitizer, and were reconstructed and kinematically fitted in the program SIOUX.

The spectator proton (assumed to be the slower proton in the laboratory frame) has a momentum distribution in agreement with that expected from the Hulthèn wave function for momenta less than 300 MeV/c, and is isotropic in the laboratory frame. For the subsequent analysis only events with $p_{spect} < 300$ MeV/c are accepted. There are 6419 such events for the reaction $K^+d \rightarrow K^+\pi^-pp$, of which 67% are three-prongs and 33% are four-prongs. The cross section for this reaction has been determined to be 400±8 μb, where the quoted error reflects statistical uncertainties only.[4]

<u>Data analysis</u>.—Figure 1 shows the Dalitz plot for the reaction $K^+n \rightarrow K^+\pi^-p$. The outstanding features of this plot include: (1) a large low-mass enhancement in the $p\pi^-$ system, which is associated with several N^* resonances, (2) a $K^*(890)$ band, (3) a $K^*(1420)$ band, (4) a striking depletion of events in a band with $M^2(K^+\pi^-) \sim 2.4$ GeV^2, (5) an excess of events distributed along a band with $M^2(K^+\pi^-) \sim 3$ GeV^2, and (6) a general lack of background events, particularly the absence of any diagonal mass band corresponding to a $M^2(pK^+)$ enhancement. The Particle Data Tables list seven $N^*_{1/2}$ resonances with masses less than 1.8 GeV,[5] several of which could contribute to the low-mass enhancement in the $p\pi^-$ distribution. Except possibly for some structure at $M^2(p\pi^-) \sim 2$ GeV^2, which is probably associated with the P_{11} Roper resonance, none of them can be resolved without cuts in momentum transfer. The Dalitz plot shows that, although there is perhaps some $K^*(1420)N^*$ and $K^*(890)N^*$ interference, the N^* band is not continuous. The depletion of events in a band with $M^2(K^+\pi^-) \sim 2.4$ GeV^2 cuts right across the N^* band, and in addition the lower mass

portion of the N^* band does not persist down to the region between the $K^*(890)$ and $K^*(1420)$. Moreover, the well-known asymmetry in the $K^*(890)$ decay angular distribution, which appears on the Dalitz plot as an asymmetric population density along the $K^*(890)$ band, is not associated with the N^*; i.e., the high density region of the $K^*(890)$ band is approximately the region with $M^2(p\pi^-) < 7\ \mathrm{GeV}^2$, whereas the region attributable to the N^* is only the region with $M^2(p\pi^-) < 3\ \mathrm{GeV}^2$.

Figure 2a shows the mass distribution, $M(p\pi^-)$, in which the N^* enhancement is very clear. Figure 2b shows the mass distribution, $M(K^+\pi^-)$, in which the dominant features are the $K^*(890)$, the $K^*(1420)$, and a higher mass enhancement above 1.6 GeV. This enhancement is due in part to reflections of the N^* peak, but there is evidence for an enhancement in this region when the N^* events are removed. Such an enhancement is consistent in mass and width with the L meson,[6] but we confine our attention for the remainder of this Letter to the region of the $K^*(1420)$.

Evidence for an additional resonance.—In the $K^+\pi^-$ mass distribution (see Fig. 2b) we observe an unusually broad signal from 1.3 to 1.5 GeV which appears at first sight to be due to the $K^*(1420)$ with fitted parameters $M = 1413 \pm 5$ MeV and $\Gamma = 143 \pm 12$ MeV. We note however that the character of the $K\pi$ decay angular distribution changes sharply at 1.4 GeV. Figures 3a and 3b show the $\cos\theta$ distributions in $(K^+\pi^-)$ mass regions, where θ is the Jackson angle, i.e., the angle from the incident K^+ to the final K^+ in the $K^+\pi^-$ rest frame. The distribution in $\cos\theta$ for the high-mass region, 1.4-1.5 GeV (see Fig. 3b), is just that angular distribution expected from the decay of a $J^P = 2^+$ resonance produced by pion exchange. There is no evidence for a significant asymmetry, and the distribution may be fit with D waves with a substantial S-wave background. The $\cos\theta$ distribution for the low-mass region, 1.3-1.4 GeV, however (see Fig. 3a), requires no powers of $\cos\theta$ greater than two to achieve an excellent fit. The parameters for the fits to the angular distributions in both Legendre polynomials, $\sum_{n=0}^{N} a_n P_n(\cos\theta)$, and a power series, $\sum_{n=0}^{N} b_n \cos^n\theta$, are shown in Table I. In order to demonstrate the inconsistency of the angular distributions in the two mass regions, we have tried to fit the theoretical angular distribution, expected from the fit to the entire region, 1.3-1.5 GeV, renormalized to the actual number of events in each region, to the observed angular distributions. This fit has a confidence level of 0.0005 in the 1.3-1.4 GeV region and 0.0001 in the 1.4-1.5 GeV region; thus the two angular distributions are clearly inconsistent.

We have considered the effect of the low $(p\pi^-)$ mass enhancement on the angular distributions. If we subtract the events attributable to this N^* enhancement, the character of the angular distributions is not significantly changed, although the forward peak in the 1.3-1.4 GeV region is slightly reduced, and a small backward asymmetry is introduced into the angular distribution in the 1.4-1.5 GeV region. The excess of events in the overlap of the $K^*(1420)$ band with the $N^*(1560)$ and the $N^*(1680)$ can be seen on the Dalitz plot in Fig. 1.

As an alternate way of presenting the data we plot the $K\pi$ mass distribution for two regions of $\cos\theta$ (see Figs. 2c and 2d): $|\cos\theta| > 0.7$ (polar region), and $|\cos\theta| < 0.7$ (equatorial region). In the polar region the "$K^*(1420)$ peak" is fit with parameters $M = 1439 \pm 5$ MeV, $\Gamma = 105^{+13}_{-12}$ MeV, but in the equatorial region the parameters are $M = 1373^{+6}_{-5}$ MeV and $\Gamma = 150^{+5}_{-14}$ MeV. This large (66 MeV) shift in the central value of the "$K^*(1420)$ peak" with decay angle is obvious from Figs. 2c and 2d.

The possibility that a sharp change at 1.4 GeV in the character of the exchange mechanism producing a <u>single</u> resonance (presumably the $K^*(1420)$) is responsible for this effect is unlikely in view of the fact that a <u>single</u> resonance, produced by two different exchange mechanisms, e.g., π and ρ

exchanges, would show a decay angular distribution characteristic of the particular mix of exchange mechanisms, but that distribution is not expected to be a function of $(K^+\pi^-)$ mass, as is the case here.

Other decay modes.—In a search for possible alternate decay modes of the $K_N^*(1370)$, we have studied the charge exchange reaction $K^+n \rightarrow K^0\pi^+\pi^-p$, in which the K^0 decays visibly in the bubble chamber. In the $K^0\pi^+\pi^-$ mass distribution, shown in Fig. 2e, the $K^*(1420)$ signal is particularly clean, and has been fitted with parameters $M = 1440\pm5$ MeV and $\Gamma = 109\pm24$ MeV. These parameters are very consistent with the parameters obtained for the fit in the polar region in the reaction $K^+n \rightarrow K^+\pi^-p$ (see Fig. 2b). There is thus no evidence for any $K^0\pi^+\pi^-$ peak on the low mass side of the $K^*(1420)$, and hence the $K_N^*(1370)$ has no strong three-body decay mode and is probably not associated with the structure in the Q at about this mass.[7]

Discussion of the $J^P = 0^+$ hypothesis.—The new effect observed here is essentially a striking change in the character of the decay angular distribution at a mass of about 1.4 GeV. The distributions in φ, the decay azimuth in the Jackson frame, are consistent with being flat throughout the $K^*(1420)$ region, as they are expected to be for pion-exchange processes.

If we assume pion-exchange and normalize to the number of observed events in each mass region, we calculate an average of 356±27 S-wave and 19±6 D-wave events in the 1.3-1.4 GeV region, and 234±20 S-wave and 191±22 D-wave events in the 1.4-1.5 GeV region. The amount of D-wave in the 1.3-1.4 GeV region is entirely consistent with that expected from the tail of a Breit-Wigner centered at 1440 MeV with width 100 MeV. Although the hypothesis of S and D waves results in an expected angular distribution symmetric about $\cos\theta = 0$, it is clear from Fig. 3b that the data is asymmetric. Aside from the effects of the crossing N^* bands, an admixture of as little as 1% P-wave to the S and D waves is sufficient to entirely explain the observed asymmetry in this region.

We have also performed a similar analysis on the neighboring (Kπ) mass regions, and have plotted in Fig. 2f the number of S-wave events in each region as a function of $K^+\pi^-$ mass. The rise in the S-wave in the region 1.3-1.4 GeV is more than four standard deviations above the level in the two neighboring regions. The data are thus consistent with a D-wave resonance of $M \sim 1439$ MeV, $\Gamma < 105$ MeV ($K^*(1420)$ and an S-wave resonance of $M \sim 1370$ MeV, $\Gamma < 150$ MeV ($K_N^*(1370)$) (see Ref. 8). The apparent absence of a three-body decay mode for $K_N^*(1370)$ mentioned above might be taken as evidence favoring the $J^P = 0^+$ interpretation since such a resonance cannot decay into three pseudoscalars.

Discussion of the $J^P = 1^-$ hypothesis.—The data in the region 1.3-1.4 GeV may be fit entirely with S and P waves ignoring any D-wave tail of the $K^*(1420)$, with an average of 247±40 S-wave and 128±20 P-wave events. The asymmetry in this region requires the presence of at least a small admixture of P waves; however, because of the intrinsic ambiguity between a P-wave and an S-D interference term, the actual amount of P-wave present is unknown. Thus there is no conclusive evidence for a resonant P-wave, although this possibility cannot be ruled out. Antich et al.[9] have previously suggested the presence of a $J^P = 1^-$ state, or at least an increase in the 1^- contribution to background, in the vicinity of the $K^*(1420)$. These authors observed an asymmetry in the decay distribution of the Kπ system in the reaction $K^+p \rightarrow K^+\pi^-\Delta^{++}$ at 5.5 GeV/c, from which they inferred the presence of P-wave and D-wave interference. In addition, the presence of a large S-wave signal in the region of the dominant D-wave has been observed at the $K^*(1420)$ in the similar reaction $K^+p \rightarrow K^+\pi^-\Delta^{++}$ at 9 GeV/c,[10] and at the f^o in the reaction $\pi^+p \rightarrow \pi^+\pi^-\Delta^{++}$ at 8 GeV/c,[11] although in neither case was there strong evidence for an appreciable P-wave amplitude.

Discussion of the $J^P = 2^+$ hypothesis.—If the $K_N^*(1370)$ were $J^P = 2^+$, its spin density matrix elements have been calculated by the method of moments to be: $\langle\rho_{00}\rangle = 0.45\pm0.05$, $\langle\rho_{11}\rangle = 0.23\pm0.02$ and $\langle \mathrm{Re}\ \rho_{1-1}\rangle = -0.06\pm0.05$. The other spin density matrix elements, e.g., ρ_{22}, are consistent with zero. As in the $J^P = 0^+$ case, the expected angular distribution is symmetric in $\cos\theta$, and therefore a small P-wave background must be invoked to explain the asymmetry. The angular distribution, folded about $\cos\theta = 0$ to eliminate the asymmetry, may be fit with the distribution expected from the spin density matrix elements, but the confidence level for this fit is less than 5%. However this fit may be markedly improved by the addition of a substantial S-wave background. Furthermore, the expected distribution in the Treiman-Yang angle, φ, differs only weakly from isotropy, and within the present statistics no discrimination between the various hypotheses may be made on the basis of the φ distribution. The similarity of the t-distributions in the two regions (see Figs. 3c and 3d) suggests similar production mechanisms and argues to some extent against the substantial vector exchange, which is required to explain the observed angular distribution with a $J^P = 2^+$ object.

Conclusion.—In conclusion we have observed strong evidence for an additional resonance on the low mass side of the $K^*(1420)$, $K^*_N(1370)$ with $M \approx 1370$ MeV and $\Gamma < 150$ MeV. This resonance is probably $J^P = 0^+$ and is produced by pion exchange, but the alternate hypotheses of a $J^P = 1^-$ resonance produced by pion exchange or a $J^P = 2^+$ resonance produced by a mixture of pion and vector exchanges cannot be ruled out at this time.

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8. We have used as the parameters of the $K_N^*(1370)$ and the $K^*(1420)$ the results of the fits to the mass distributions in the polar and equatorial regions. As this achieves only a partial separation of the two resonances the masses quoted should be regarded as approximate and the widths as upper limits.

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Table I. Coefficients of expansion of angular distributions.

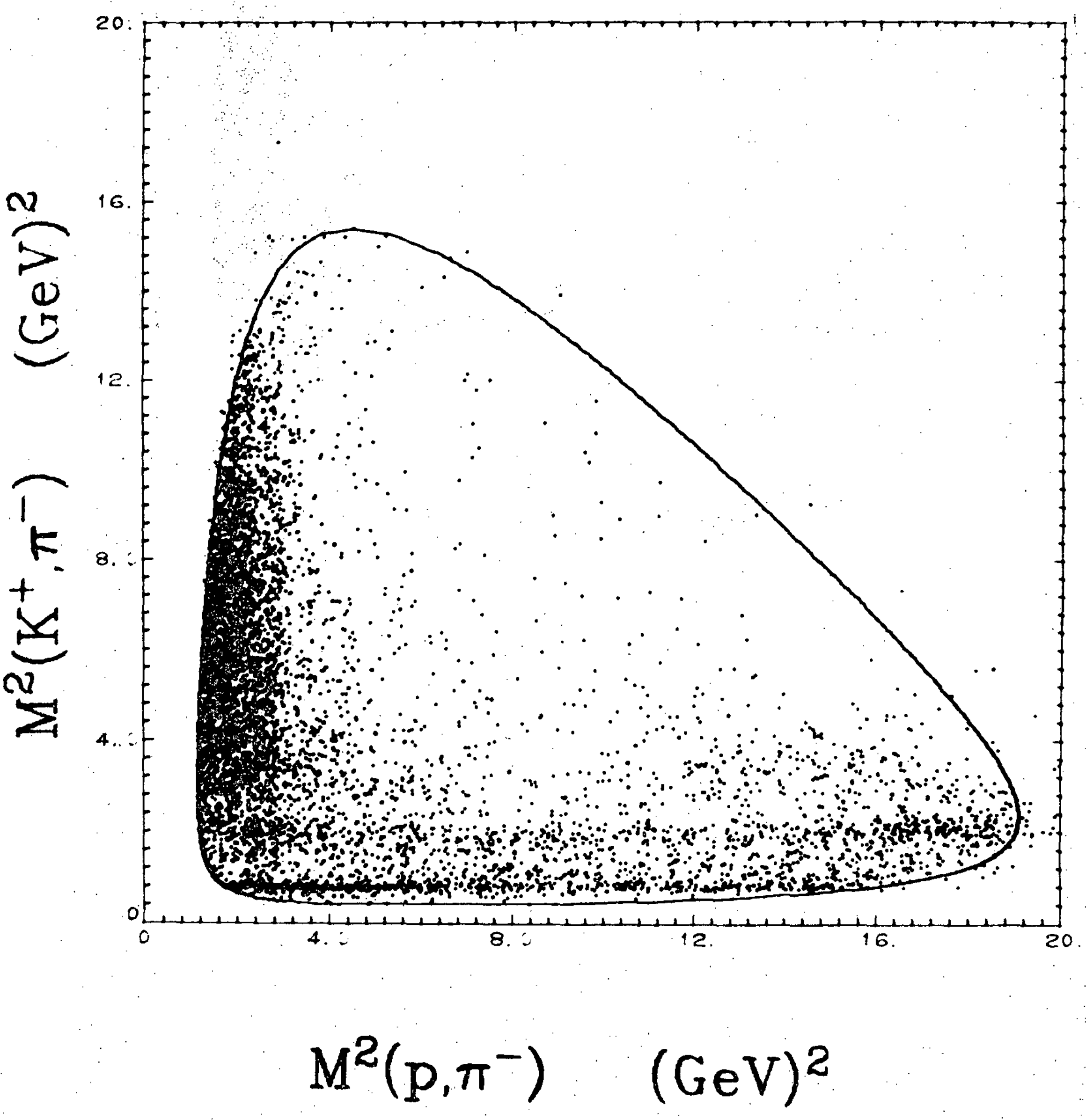
$M(K^+\pi^-)$:	1.3-1.4 GeV	1.4-1.5 GeV
Number of events	375	425
χ^2	13.30	19.00
Degrees of freedom	17	15
Confidence level	72%	21%
Legendre Polynomials		
(a_1/a_0)	0.38±0.10	-0.01±0.11
(a_2/a_0)	0.69±0.11	1.84±0.11
(a_3/a_0)	---	-0.19±0.13
(a_4/a_0)	---	1.06±0.15
Power Series		
(b_1/b_0)	0.57±0.15	1.05±0.30
(b_2/b_0)	1.56±0.25	-2.96±1.03
(b_3/b_0)	---	1.72±0.71
(b_4/b_0)	---	11.17±1.31

FIGURE CAPTIONS

Fig. 1. Dalitz plot, $M^2(K^+\pi^-)$ vs $M^2(p\pi^-)$.

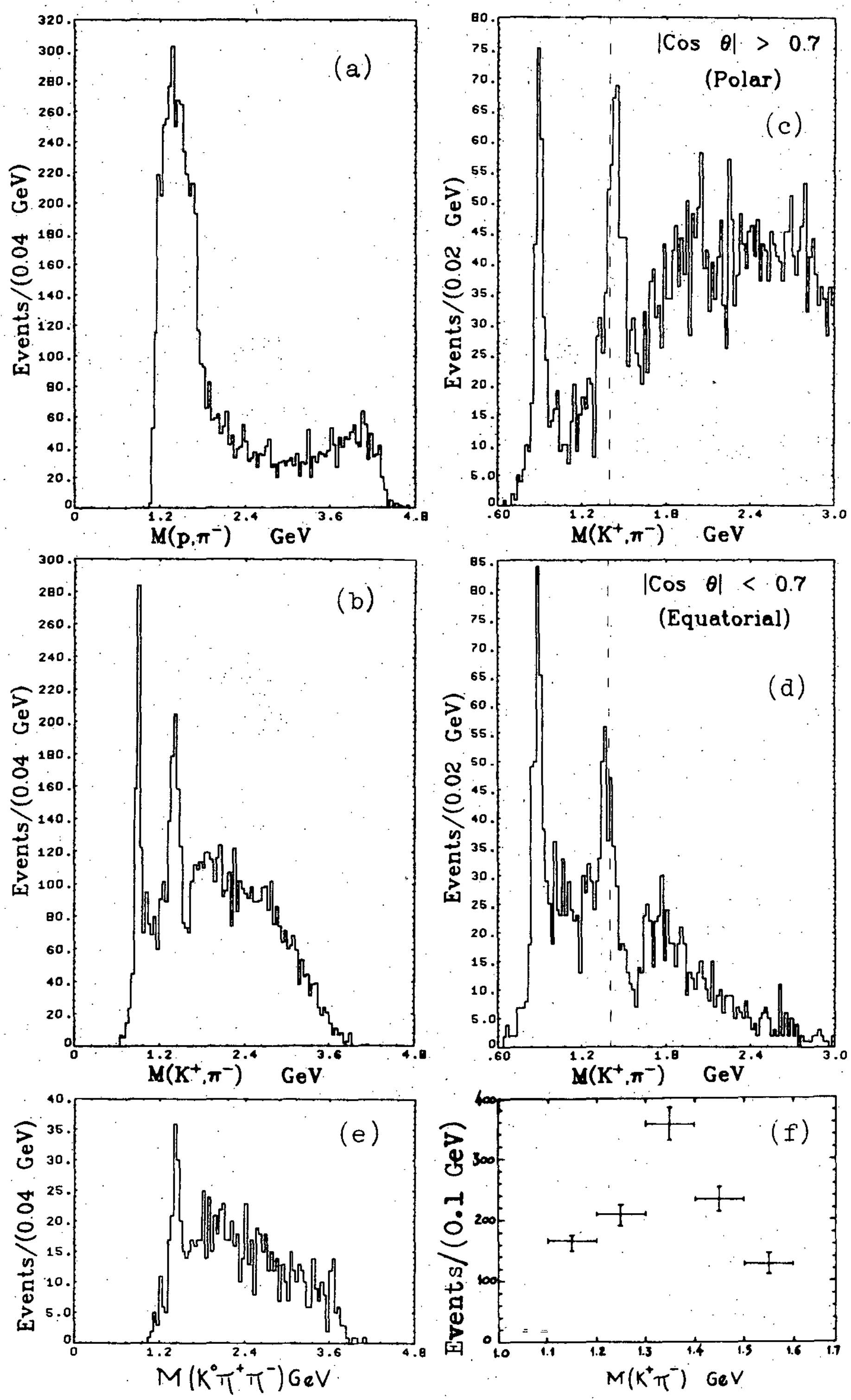
Fig. 2. Distributions in (a) $M(p\pi^-)$ and $M(K^+\pi^-)$ for (b) all events, (c) events with $\cos\theta$ in the polar region, and (d) events with $\cos\theta$ in the equatorial region. (e) $M(K^o\pi^+\pi^-)$ for the reaction $K^+n \rightarrow K^o\pi^+\pi^-p$, and (f) S-wave events as a function of $K^+\pi^-$ mass.

Fig. 3. Distributions in $\cos\theta$ for all events with $M(K^+\pi^-)$ in the range (a) 1.3-1.4 GeV, (b) 1.4-1.5 GeV; and $d\sigma/dt$ vs t for all events with $M(K^+\pi^-)$ in the range (c) 1.3-1.4 GeV, (d) 1.4-1.5 GeV. The straight lines in (c) and (d) are the results of fits to functions of the form $d\sigma/dt = Ae^{Bt}$ with $B = 11.0\pm0.4\ (\text{GeV}/c)^{-2}$ and $B = 9.6\pm0.4\ (\text{GeV}/c)^{-2}$ in the 1.3-1.4 GeV and 1.4-1.5 GeV regions respectively.



XBL 7012-7393

Fig. 1



XBL 712-302

Fig. 2

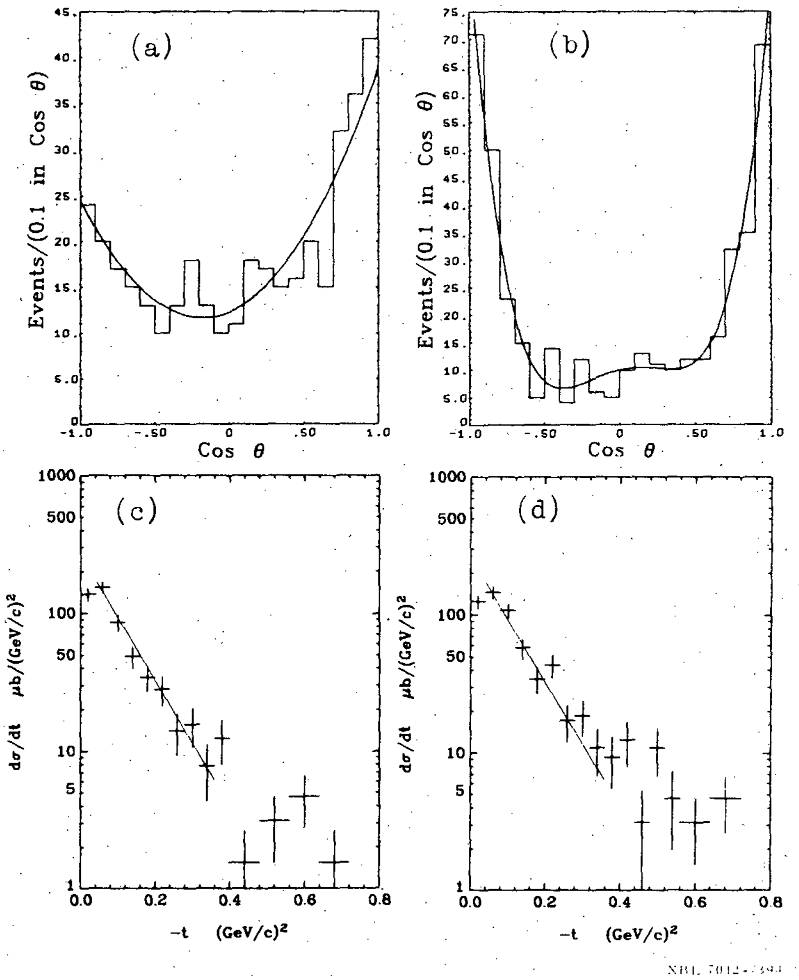


Fig. 3

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