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K^{*0} PRODUCTION IN K^+d INTERACTIONS AT 12 GeV/c*

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In this paper we report preliminary results on the interactions of 12-GeV/c K^+ mesons in deuterium. 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] Through the use of a gas Čerenkov counter, pion contamination in the beam is reduced essentially to zero. Approximately 500,000 exposures were taken, of which about 60% have been analyzed to date. The experimental details have been reported previously[2] in a study of the elastic charge exchange reaction $K^+n \to K^0p$. In the present paper we report on the charge exchange reactions $K^+n \to K^+\pi^-p$ and $K^+n \to K^0\pi^+\pi^-p$.

The film has been scanned for all events which have three-prong or four-prong topologies, both with and without associated V^0 decays. In addition, 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. For those events with invisible spectators (three-prongs), the spectator was assigned a momentum of zero with errors $\Delta p_x = \Delta p_y = \pm 30$ MeV/c, and $\Delta p_z = \pm 40$ MeV/c. All events which fit the four-constraint hypothesis, either $K^+d \to K^+\pi^-pp$ or $K^+d \to K^0\pi^+\pi^-pp$, with χ^2 probability greater than 0.1% were accepted.

The spectator proton (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. For the subsequent analysis only events with $p_{spect} < 300$ MeV/c are accepted. There are 4260 and 510 such events for the reactions $K^+d \rightarrow K^+\pi^-pp$ and $K^+d \rightarrow K^0\pi^+\pi^-pp$ respectively, of which 67% are 3-prongs and 33% are 4-prongs in each case. The cross sections for these reactions have been determined to be 399±8 μb for $K^+d \rightarrow K^+\pi^-pp$ and 212±12 μb for $K^+d \rightarrow K^0\pi^+\pi^-pp$. Here the quoted errors reflect statistical uncertainties only.

I. GENERAL FEATURES OF THE REACTION $K^+n \rightarrow K^+\pi^-p$

Figure 1 shows the Dalitz plot for the reaction $K^+n \rightarrow K^+\pi^-p$. The outstanding features of this plot include the following: (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 asymmetrically distributed along a band with $M^2(K^+\pi^-) \sim 3$ GeV^2, and (6) a general lack of background events. The Particle Data Tables list seven $N^*_{1/2}$ resonances with masses less than 1.8 GeV,[3] 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 t. The Dalitz plot shows that, although there is perhaps some $K^*(1420)N^*$ and $K^*(890)N^*$ constructive 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 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, appears not to be associated with the N^*; i.e., the high density region of the $K^*(890)$ band is roughly the region with $M^2(p\pi^-) < 7\ GeV^2$, whereas the region attributable to the N^* is only the region with $M^2(p\pi^-) < 3\ GeV^2$.

Figure 2 shows the distribution in $M(p\pi^-)$ in which the N^* enhancement is very clear. Figure 3 shows the same $M(p\pi^-)$ distribution with cuts (a) $t < 0.3\ (GeV/c)^2$ and (b) $t > 0.3\ (GeV/c)^2$. The N^* peak is sharply shifted between the two; the P_{11} Roper resonance is apparently produced primarily at low t, while higher N^*'s are produced at higher t values.

II. $K_N^*(1250)$

Figure 4a shows the mass distribution $M(K^+\pi^-)$ for all the events in the sample. In addition to the features noted already, there is a sharp spike at a mass of $M(K^+\pi^-) = 1250$ MeV. Figure 4b shows the data with the N^* peak removed ($M(p\pi^-) > 1.8$ GeV) and the low t region selected ($t_{K\to K\pi} < 0.2\ (GeV/c)^2$). The enhancement is about 5 standard deviations above background in this distribution. A fit to the data of a Breit-Wigner line shape gives the following values for the parameters of this $K^*(1250)$ resonance, $M = 1247\pm5$ MeV and $\Gamma = 20^{+9}_{-6}$ MeV, with a $\chi^2 = 3.95$ for six degrees of freedom. The results of this fit are shown as a smooth curve in Fig. 2c. In a compilation by W. P. Dodd et al.,[4] a K^* resonance at approximately this mass was observed; however, the width reported in that case was 70 MeV. If the large t region is selected, i.e., $t_{K\to K\pi} > 0.2\ (GeV/c)^2$, the $K^*(1250)$ does not appear significantly above the background, but there is some evidence for structure in the region 1 GeV < $M(K^+\pi^-) < 1.2$ GeV. Evidence for two enhancements in this region have been reported; a $K^*(1080)$ (Ref. 5) and a $K^*(1160)$ (Ref. 6). However the statistical significance of any peaks in this region is marginal in the sample analyzed to date in this experiment.

Figure 5 shows the decay angular distributions, $\cos\theta$ and φ, and the distribution in momentum transfer, $t_{K\rightarrow K\pi}$ for the region of the $K^*(1250)$ and for two neighboring regions. The region of the $K^*(1250)$ has been defined as the 40-MeV band, 1.19-1.23 GeV (see Fig. 4c). The neighboring regions have also been taken as 40 MeV wide on either side of the $K^*(1250)$ region. The angle θ is the angle between the incident K^+ and the outgoing K^+ in the $K^+\pi^-$ rest frame (Jackson angle), and the angle φ is the azimuth of the outgoing K^+ about the incident K^+ axis in the $K^+\pi^-$ rest frame (Treiman-Yang angle). No cuts have been made in this data except for the indicated mass cut; specifically, $M(p\pi^-) > 1.8$ GeV has not been selected here, because such a cut is equivalent to a cut on θ, i.e., a cutting out of forward K^+ ($\cos\theta \sim +1$) events.

In the $K^*(1250)$ region, the distribution is consistent either with isotropy or with a polynomial in $\cos\theta$ of order 2. There is no evidence for any term in $\cos^n\theta$ where $n > 2$. We have fit the data to a function of the form $a_o + a_1P_1(\cos\theta) + a_2P_2(\cos\theta)$, where the $P_i(\cos\theta)$ are the Legendre polynomials in $\cos\theta$. We obtain a $\chi^2 = 22.9$ for 17 degrees of freedom, and the best fit normalized parameters are $(a_1/a_o) = 0.28\pm0.19$ and $(a_2/a_o) = 0.86\pm0.22$. In the region below the $K^*(1250)$ there is no evidence for any deviation from isotropy, and in fact in that region we obtain parameters $(a_1/a_o) = 0.31\pm0.23$ and $(a_2/a_o) = -0.11\pm0.29$, but a fit to an isotropic distribution $(a_1 = a_2 = 0)$ yields a $\chi^2 = 11.8$ for 19 degrees of freedom. In the region above the $K^*(1250)$ the data are consistent with isotropy, but there is some evidence for an asymmetry in this region; however this may be due to the effects of the tail of the $K^*(1420)$ which is becoming important at 1.3 GeV. The best fit parameters in this region are $(a_1/a_o) = 0.62\pm0.21$ and $(a_2/a_o) = 0.41\pm0.20$.

A least squares fit to the t distribution in the $K^*(1250)$ region (Fig. 5h) yields a slope of $12.5\pm1.5\ (\text{GeV}/c)^{-2}$, which is certainly consistent with slopes generally observed for pion exchange processes. If the $K^*(1250)$ is in fact produced primarily by pion exchange, then we may say that its spin-parity must be either $J^P = 0^+$ or 1^-, as there is no evidence for any terms higher than $\cos^2 \theta$ in the decay angular distribution. At the present level of statistics we cannot distinguish between $J^P = 0^+$ and $J^P = 1^-$, but the value $(a_2/a_o) = 0.86 \pm 0.22$ in the $K^*(1250)$ region tends to favor the $J^P = 1^-$ interpretation as this parameter would be zero for a $J^P = 0^+$ resonance produced by pion exchange. The $K^*(1250)$ does not have a large branching fraction into three-body final states. This is discussed in Section IV, where the reaction $K^+n \rightarrow K^o\pi^+\pi^-p$ is studied.

III. EVIDENCE FOR A $J^P \neq 2^+$ SIGNAL ON THE LOW MASS SIDE OF $K^*(1420)$

In the $K^+\pi^-$ mass distribution (see Fig. 4) we observe a rather broad signal from 1300 to 1500 MeV which appears to be due to the $K^*(1420)$ with $M \sim 1385$ MeV and $\Gamma \sim 140$ MeV. We note however that the character of the $K\pi$ decay angular distribution changes sharply at 1400 MeV. Figure 6 shows the $\cos \theta$ distributions where θ is the Jackson angle in the region of the $K^*(1420)$. The distribution in $\cos \theta$ for the high mass side 1400-1500 MeV (Fig. 6b) is just that distribution expected from the decay of a $J^P = 2^+$ object produced by pseudoscalar exchange. There is no evidence for any asymmetry, and the distribution may be fit with D waves with some S-wave background. The $\cos \theta$ distribution for the 1300-1400 MeV region, shown in Fig. 6a, can be fitted with S and P waves only and requires no D waves. This sharp change in character of the decay angular distribution can be further noted from Fig. 7 where we show the $K^+\pi^-$ mass spectrum for three regions in $\cos \theta$: $0.7 < \cos \theta \leq 1$ (forward), $-0.7 < \cos \theta \leq 0.7$ (equatorial), and $-1 < \cos \theta < -0.7$ (backward) decay. We note that the entire "$K^*(1420)$" peak appears in the forward region, a peak at ~ 1360 MeV appears in the equatorial region, and a peak at ~ 1420 MeV appears in the backward region. One interpretation of this data would include the presence of a $J^P = 0^+$ or 1^- signal at ~ 1360 MeV with a width of $\Gamma \sim 60$ MeV in addition to the $K^*(1420)$. The possibility that a change in the character of the exchange mechanism at 1400 MeV is responsible for this effect appears to be unlikely in view of the fact that the t distributions for the two mass regions appear identical (see Fig. 8).

Further evidence for a sharp break at 1400 MeV can be seen in a comparison of the $(K^+\pi^-)$ mass distribution in this reaction with the $(K^o\pi^+\pi^-)$ mass distribution in the final state $K^o\pi^+\pi^-p$. This is discussed in Section IV.

We note that Antich et al.[7] 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 $K^*(1420)$. This work is based on a study of the decay distributions of the $K\pi$ system in the reaction $K^+p \rightarrow K^+\pi^-\Delta^{++}$ at 5.5 GeV/c.

IV. $K^+n \rightarrow K^o\pi^+\pi^-p$

In Fig. 9 we show the distribution in $M(K^o\pi^+\pi^-)$ for the reaction $K^+n \rightarrow K^o\pi^+\pi^-p$. The most striking features of this distribution are the $K^*(1420)$ peak and the complete absence of any signal below the $K^*(1420)$. The well-known Q enhancement in $K\pi\pi$ is evidently not produced in a charge exchange reaction off the neutron as was noted earlier for other charge exchange reactions.[8,9] The $K^*(1250)$ is also not produced in this reaction which indicates its branching ratio into three-body final states is small, and thus is not associated with the structure in the Q at about the same mass. We have calculated the ratio $R = (K^o\pi^+\pi^-)/(K^+\pi^-)$ as a function of the invariant mass of all the mesons in each final state, where the number of $K^o\pi^+\pi^-$ events have been corrected for the neutral decay mode and the K_2 decay of the K^o. We note that in the 1280 to 1400 MeV mass region $R = 0.27 \pm 0.06$, while in the 1400 to 1520 MeV mass region $R = 0.60 \pm 0.09$. This is further evidence for the sharp change at 1400 MeV which cannot be explained by two-body and three-body phase space differences.

In addition, the $(K^0\pi^+\pi^-)$ mass distribution in Fig. 9b shows a peak at a mass of about 2.1 GeV. This peak is currently being investigated.

V. ACKNOWLEDGMENTS

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*Work supported by the U.S. Atomic Energy Commission.

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FIGURE CAPTIONS

Fig. 1. Dalitz plot $M^2(p\pi^-)$ vs $M^2(K^+\pi^-)$ for the reaction $K^+n \to K^+\pi^-p$.

Fig. 2. $M(p\pi^-)$ for the reaction $K^+n \to K^+\pi^-p$.

Fig. 3. $M(p\pi^-)$ for the reaction $K^+n \to K^+\pi^-p$ with (a) $t < 0.3\ (\text{GeV}/c)^2$ and (b) $t > 0.3\ (\text{GeV}/c)^2$.

Fig. 4. $M(K^+\pi^-)$ for the reaction $K^+n \to K^+\pi^-p$ with (a) no cuts, (b) $M(p\pi^-) >$ 1.8 GeV and $t_{K\to K\pi} < 0.2\ (\text{GeV}/c)^2$, and (c) same as (b) in 10-MeV bins. The smooth curve in (c) is the result of a fit to a Breit-Wigner shape. See text.

Fig. 5. (a) $\cos\theta$, the $K\pi$ decay angle, (b) φ, the Treiman-Yang angle, and (c) $t_{K\to K\pi}$ in three mass regions: (i) below the $K^*(1250)$, (ii) in the $K^*(1250)$, and (iii) above the $K^*(1250)$.

Fig. 6. $\cos\theta$, the $K\pi$ decay angle for events in the $K^*(1420)$ region with (a) 1.3 GeV $< M(K^+\pi^-) <$ 1.4 GeV and (b) 1.4 GeV $< M(K^+\pi^-) <$ 1.5 GeV. The data have been selected with $t < 0.2\ (\text{GeV}/c)^2$.

Fig. 7. $M(K^+\pi^-)$ for (a) $0.7 < \cos\theta < 1$, (b) $-0.7 < \cos\theta < +0.7$ and (c) $-1 < \cos\theta < -0.7$. The data have been selected with $t < 0.2\ (\text{GeV}/c)^2$.

Fig. 8. $d\sigma/dt$ vs t for the low and high $K^*(1420)$ regions.

Fig. 9. $M(K^o\pi^+\pi^-)$ for the reaction $K^+n \to K^o\pi^+\pi^-p$. The insert shows the same distribution with $M(p\pi^-) < 1.32$.

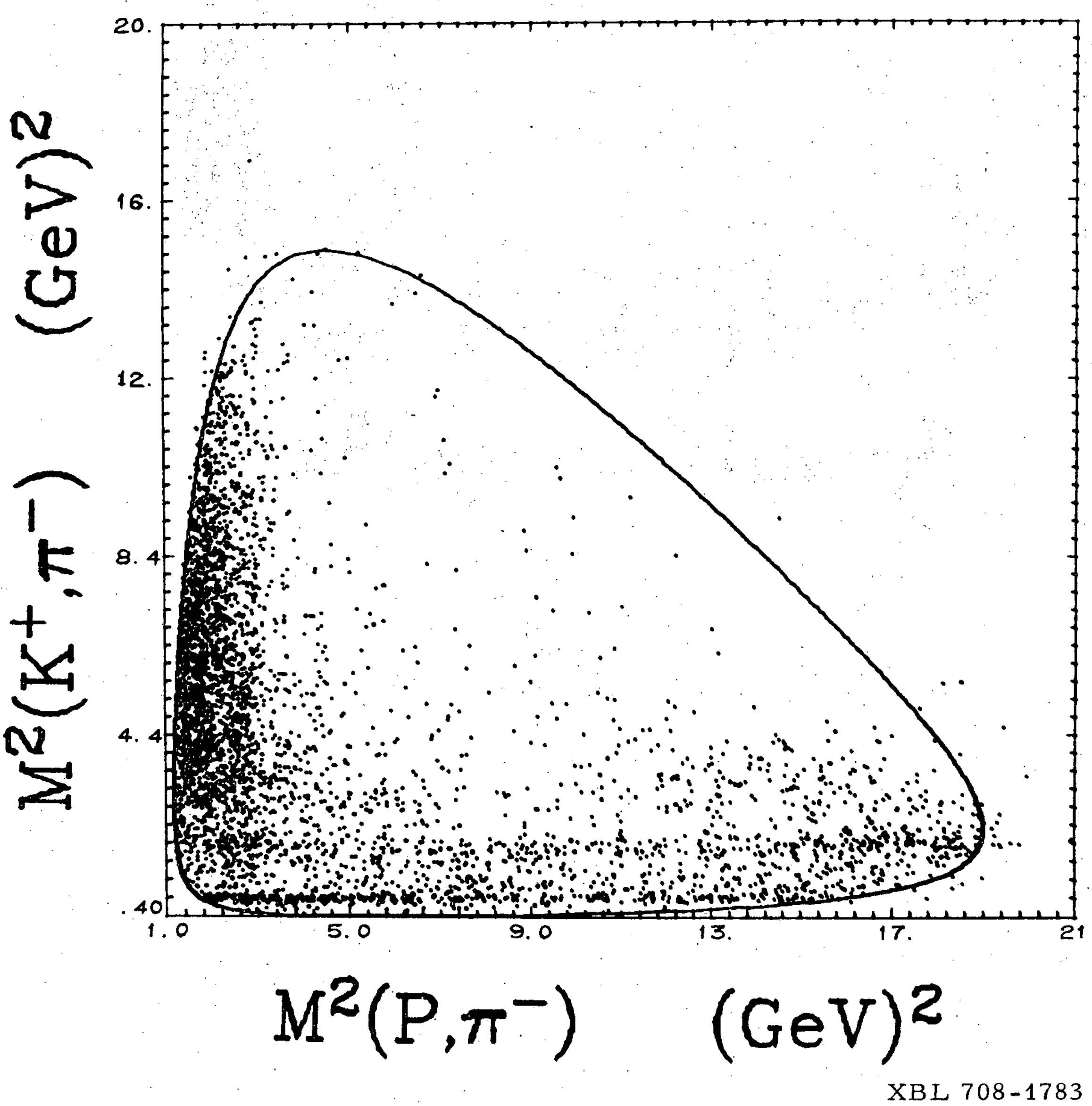
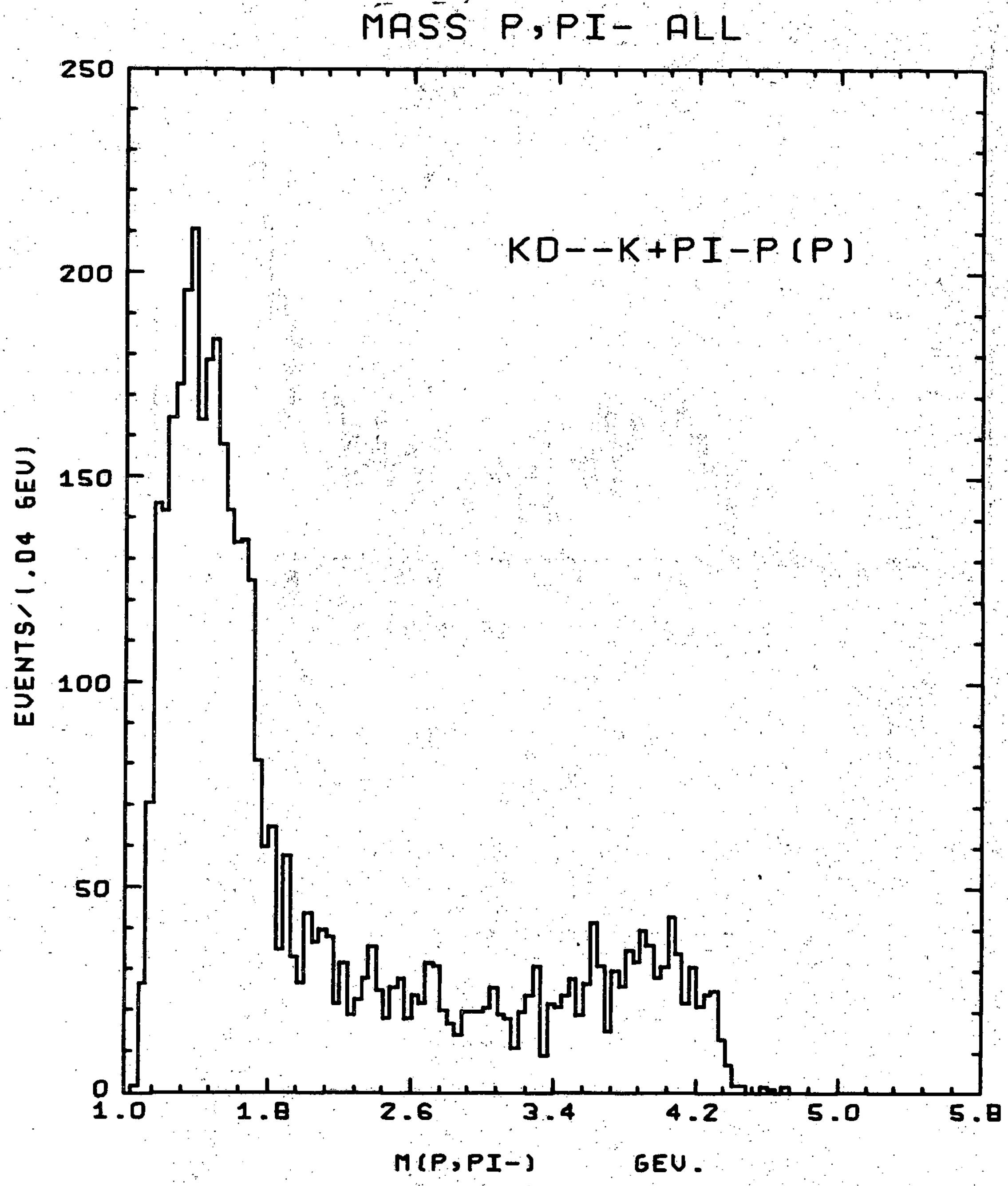
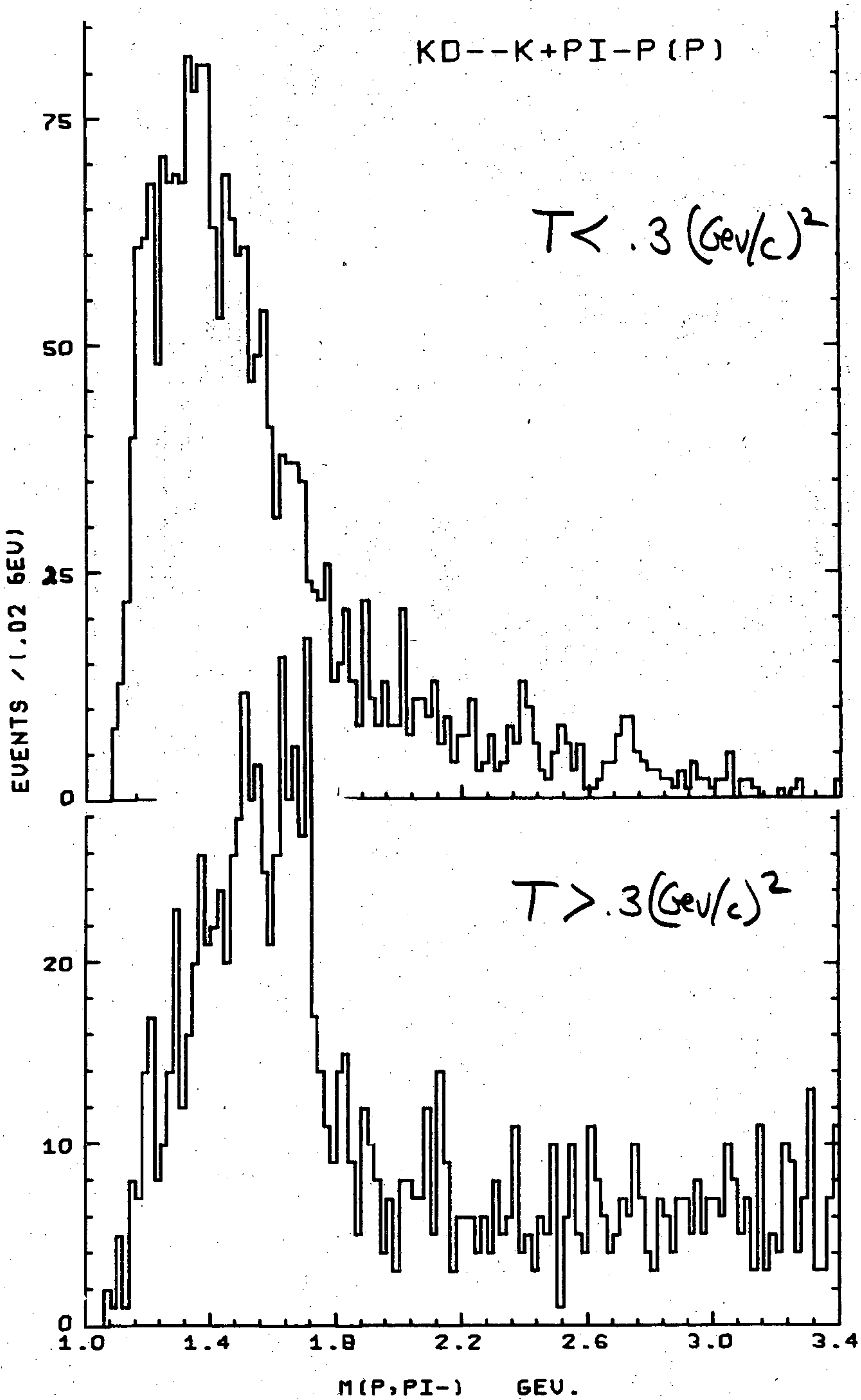

20.
16.
12.
8.4
4.4
.40
1.0
5.0
9.0
13.
17.
21.
$M^2(K^+,\pi^-)$ $(GeV)^2$
$M^2(P,\pi^-)$ $(GeV)^2$
XBL 708-1783

Fig. 1



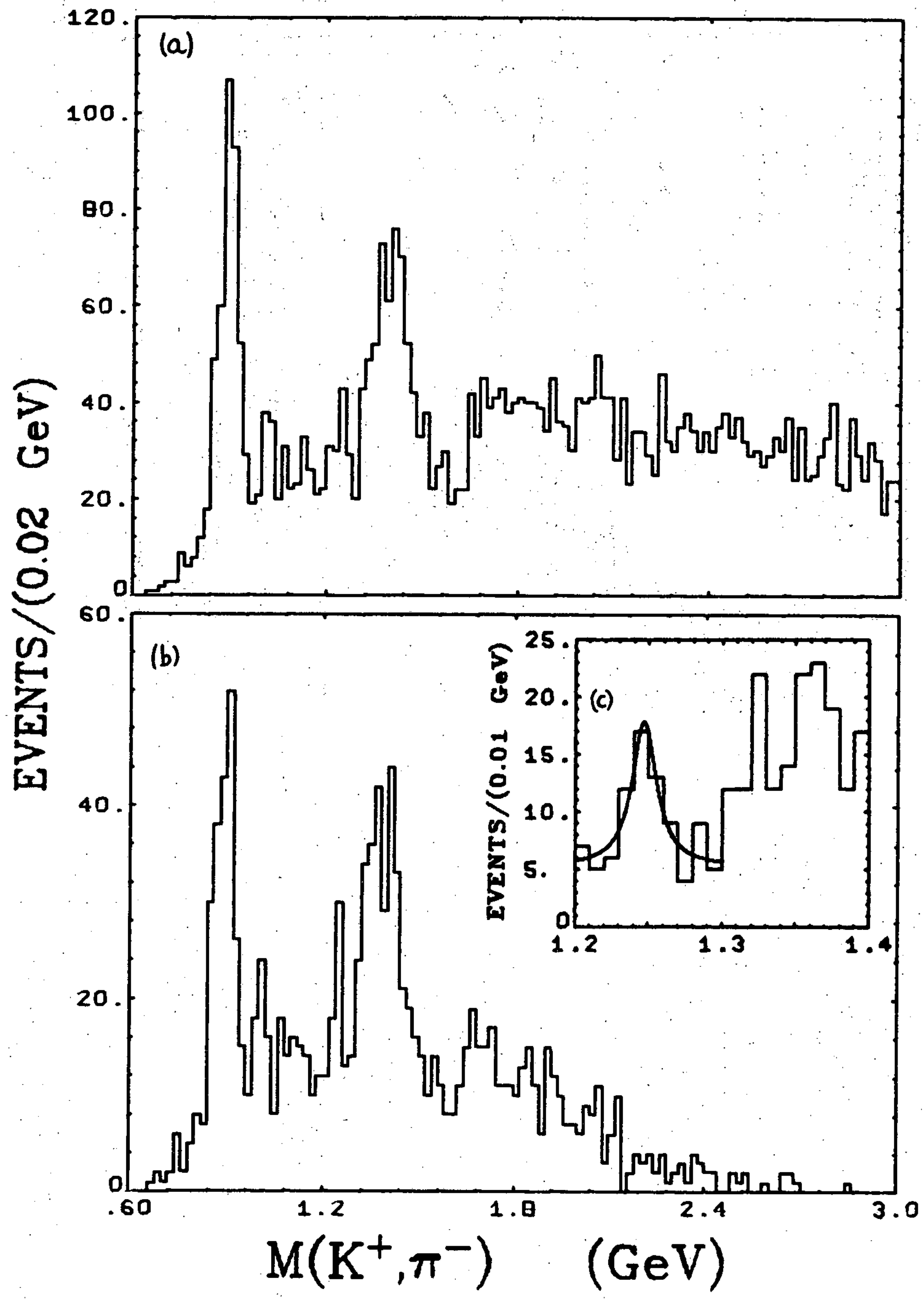
XBL 708-1807

Fig. 2



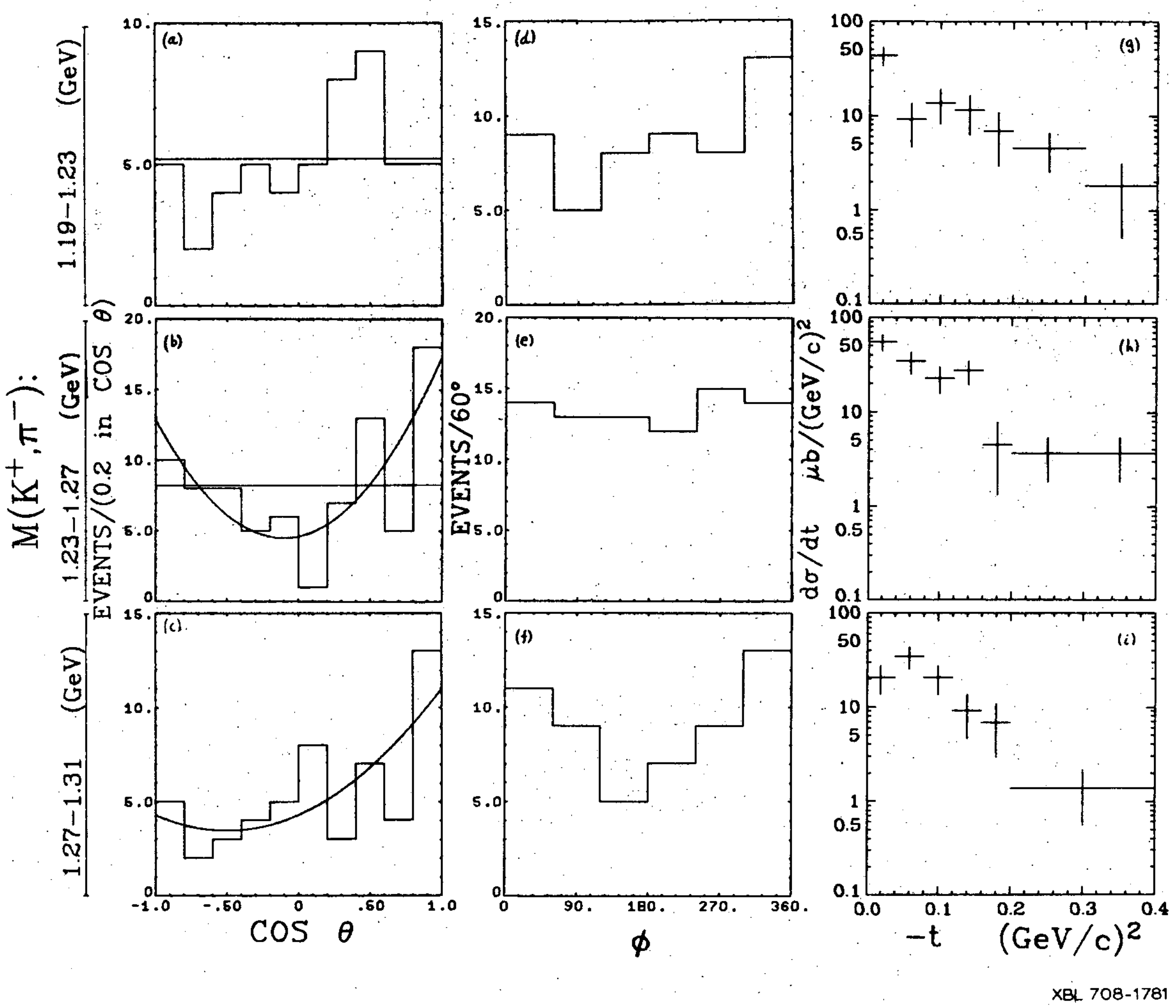
XBL 708-1802

Fig. 3



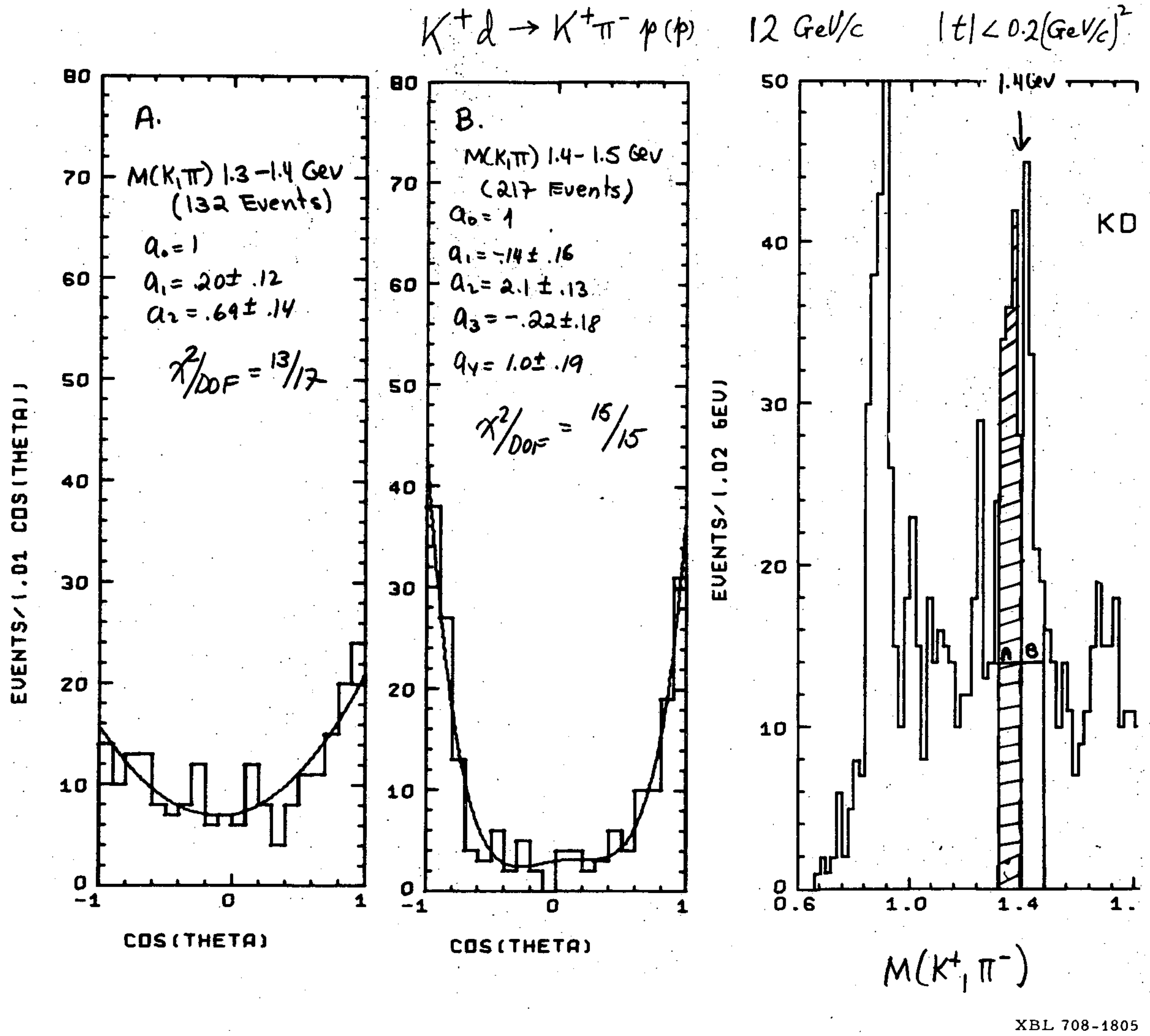
XBL 708-1782

Fig. 4



M(K+,π−):
1.19−1.23 (GeV)
1.23−1.27 (GeV)
1.27−1.31 (GeV)
EVENTS/(0.2 in COS θ)
EVENTS/60°
dσ/dt μb/(GeV/c)2
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
COS θ
φ
−t (GeV/c)2
XBL 708-1781

Fig. 5



K+d → K+π− p(p) 12 GeV/c |t| < 0.2 (GeV/c)2
A.
M(K,π) 1.3 – 1.4 Gev
(132 Events)
a0 = 1
a1 = .20 ± .12
a2 = .69 ± .14
χ2/DOF = 13/17
B.
M(K,π) 1.4 – 1.5 Gev
(217 Events)
a0 = 1
a1 = -.14 ± .16
a2 = 2.1 ± .13
a3 = -.22 ± .18
a4 = 1.0 ± .19
χ2/DOF = 16/15
EVENTS/(.01 COS(THETA))
COS(THETA)
1.4 GeV
KD
EVENTS/(.02 GEV)
M(K+, π−)
XBL 708-1805

Fig. 6

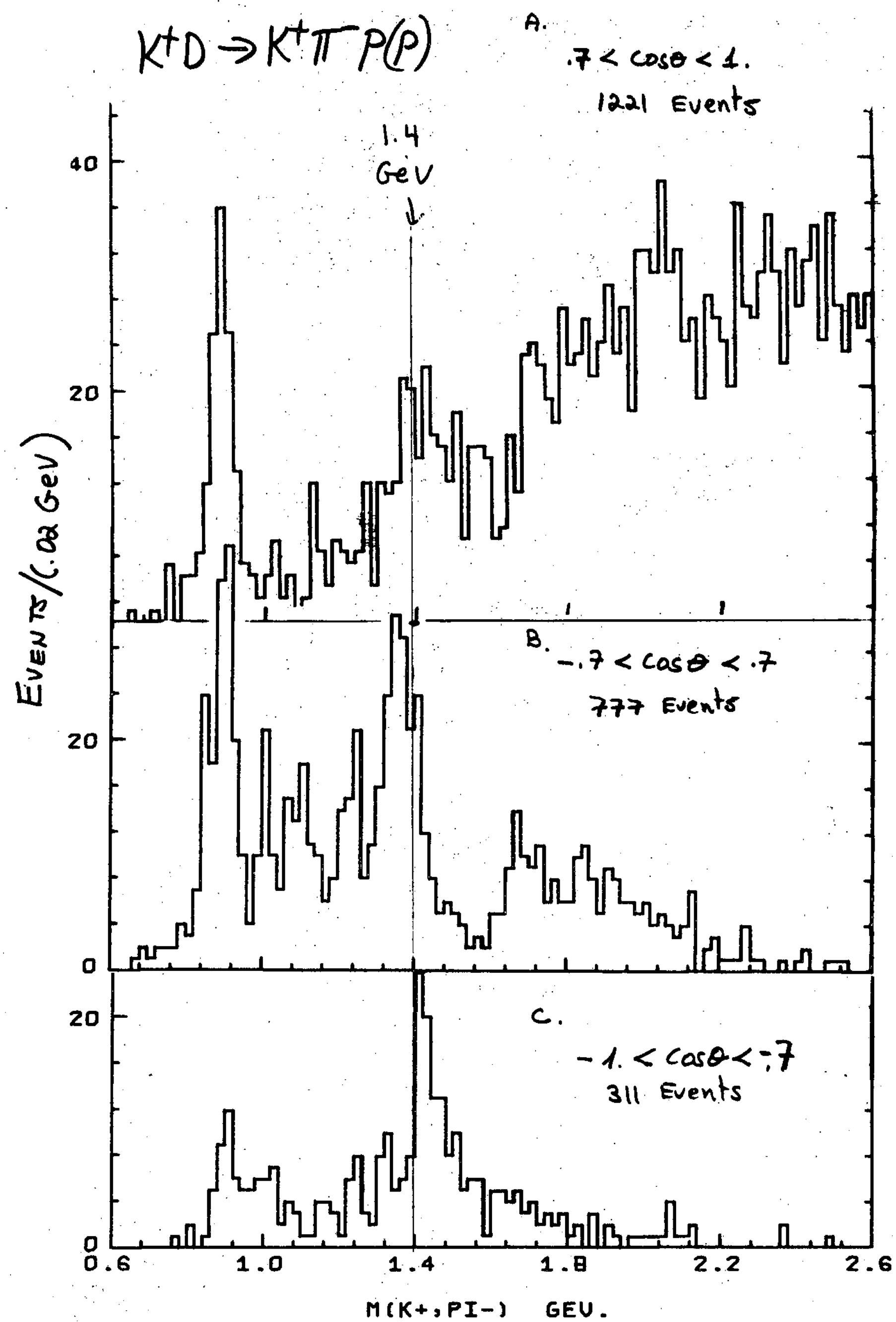


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Fig. 7

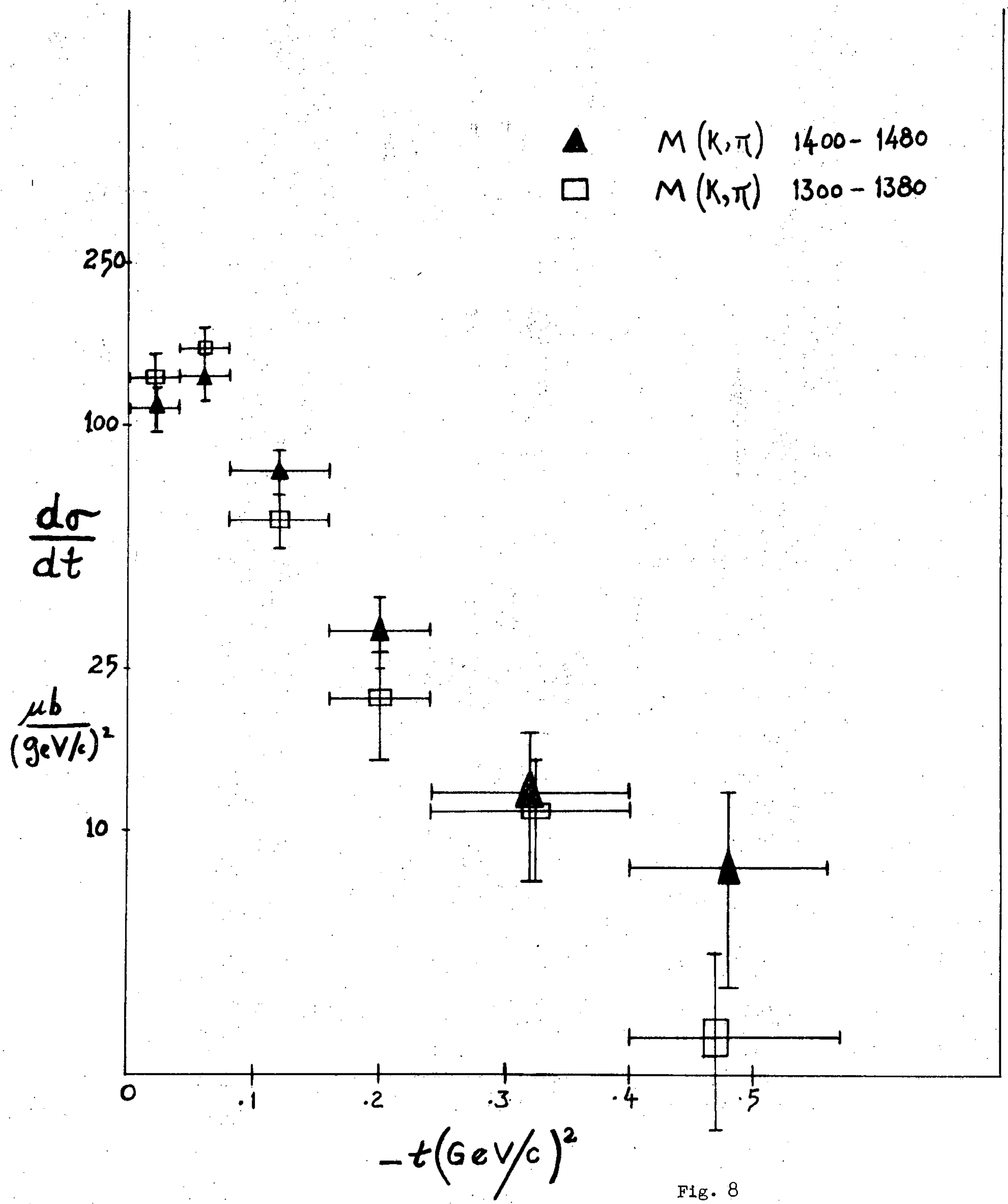
M (K,π) 1400 - 1480
M (K,π) 1300 - 1380
250
100
25
10
dσ/dt
μb/(GeV/c)²
0
·1
·2
·3
·4
·5
-t (GeV/c)²

Fig. 8

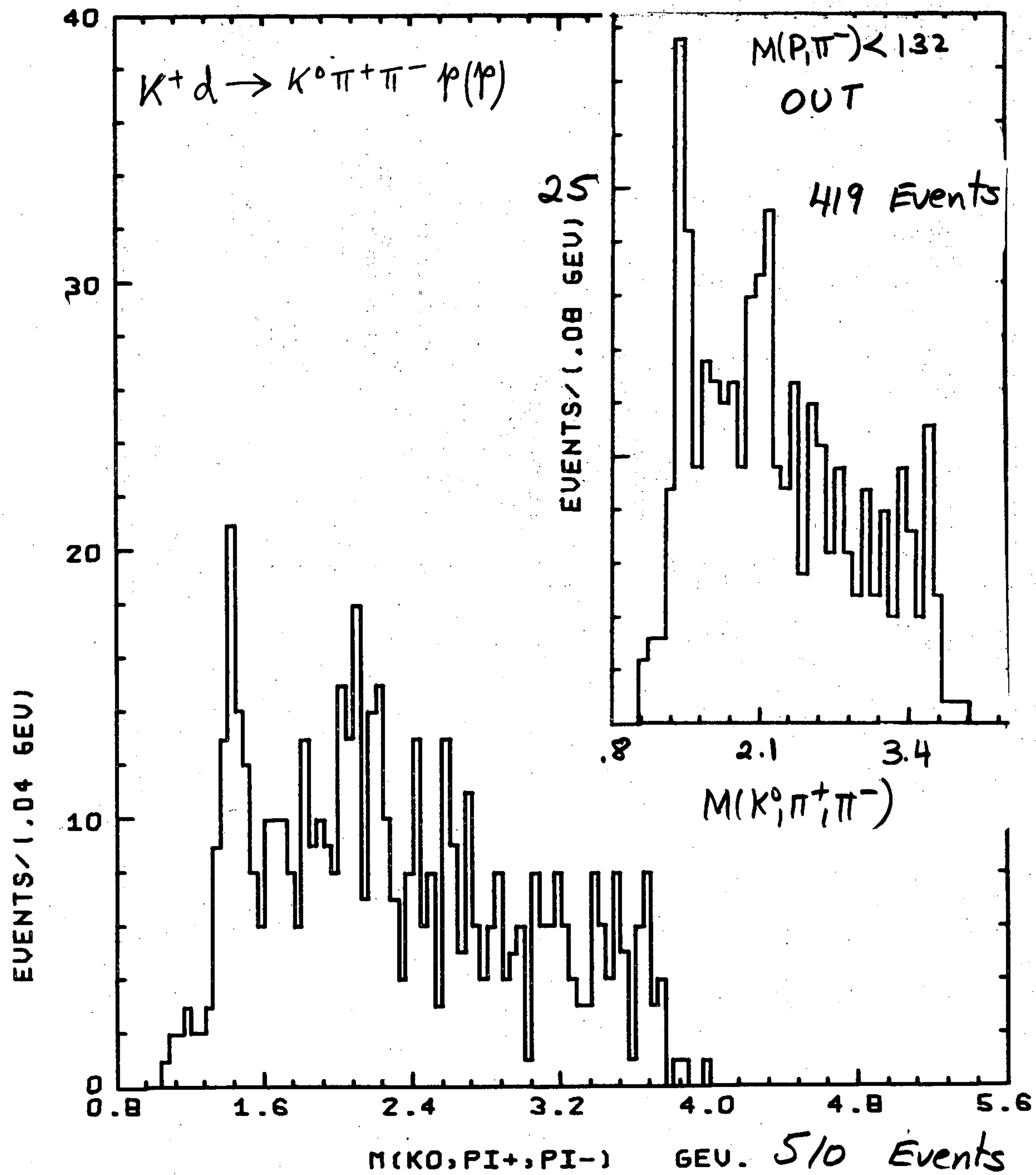

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Fig. 9

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