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SEARCH FOR  $S = 2$  BOSON RESONANCES IN THE MASS REGION OF 1.0 TO 3.1 BeV

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IN THE MASS REGION OF  $1.0$  TO  $0.31$  BeV  
by Leon Alexander, Alexander Firestone,  
and Gerson Goldhaber

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SEARCH FOR  $S = 2$  BOSON RESONANCES  
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ABSTRACT

We present results on a search for  $S = 2$  bosons in the final states  $K^+K^+$  ( $I = 1$ ),  $K^0K^+$  ( $I = 1, I = 0$ ) and  $KKn\pi$  ( $n \geq 1$ ) in a 9-BeV/c  $K^+p$  experiment. No statistically significant evidence for such resonances is observed in the mass region 1.0 to 3.1 BeV. The upper limit for the production cross section of the previously reported  $S = 2$  enhancements at 1050 and 1280 MeV is estimated to be 1.5 and 2.0  $\mu\text{b}$ , respectively.

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A feature common to all well-established mesons is that they may be classified in the singlet and octet representations of  $SU(3)$ , and hence may also be described by a quark-antiquark pair in one of the various quark models. For this reason it is of considerable interest to search for "exotic" mesons which cannot belong to the above class of particles. Several experiments have studied the  $K^+K^+$  system in the mass region 1 to 2 BeV in a search for possible resonant states which, if found, could be classified in the  $\overline{10}$  or 27 representations of  $SU(3)$ . Early results indicated possible  $K^+K^+$  resonant states at mass values of 1050 and 1280 MeV,<sup>1</sup> which have not, however, been supported by subsequent investigations.<sup>2</sup> Spin and parity conservation imply that  $S = 2$  boson resonances are allowed to decay into the  $K^+K^+$  system only

if their spin-parity is  $0^+$ ,  $2^+$ , etc.; and are allowed to decay into  $K^0 K^+$  only if their spin-parity is  $0^+$ ,  $1^-$ ,  $2^+$ , etc. Furthermore, it has been pointed out that W-spin selection rules in  $SU(6)_W$  prohibit the decay of many "exotic" resonances into two-body final states.<sup>3</sup> In particular the decay of an  $S = 2$  boson with spin parity  $2^+$  is forbidden [in exact  $SU(6)_W$ ] to decay into  $KK$  or  $KK^*$  (890) final states, but it may decay into three-body final states such as  $KK\pi$ . In this work we have extended the search for  $S = 2$  bosons up to a mass value of 3.1 BeV in  $K^+ p$  interactions at 9 BeV/c leading to final states  $Y^0 KK$  and  $Y^0 KK\pi$  ( $n \geq 1$ ), where  $Y^0$  stands for either a  $\Lambda$  or  $\Sigma^0$  hyperon. The invariant-mass combinations  $KK$  and  $KK\pi$  have been studied in the fitted and unfitted events, and no statistically significant evidence has been found for the existence of any  $S = 2$ ,  $I = 0$ , or  $I = 1$  boson resonances.

The experiment was carried out in 90 000 pictures taken with the 80-inch hydrogen bubble chamber at the Brookhaven National Laboratory alternating-gradient synchrotron, exposed to an rf-separated 9-BeV/c  $K^+$  beam. Events having a visible neutral particle decay ( $V^0$ ) were measured with the Lawrence Radiation Laboratory Flying-Spot Digitizer, and the remeasurements were carried out with a conventional digitizing machine. The events were spatially reconstructed and kinematically fitted to the various possible final-state configurations having  $K^0$  or  $\Lambda$  particles. Those events, kinematically consistent with the interpretation of  $\Lambda$  production, were examined on the scan table by a physicist to check ionization consistency and to resolve kinematical ambiguities. In addition to the well-identified fitted events we have also studied the events in which the  $V^0$  particle was positively identified as  $\Lambda$  decay from kinematical fit and ionization data, but did not yield any kinematic fit to the production point. In this way 51 events were fitted as

$Y^0 K^+ K^+$ , 70 events as  $\Lambda K^+ K^+ \pi^0$ , 133 events as  $\Lambda K^+ K^0 \pi^+$ , and 34 events as  $Y^0 K^+ K^+ \pi^+ \pi^-$ , and 335 events yielded a fit only to the  $\Lambda$  decay.

Of the 51 events identified as  $K^+ p \rightarrow Y^0 K^+ K^+$ , 11 were identified uniquely as the seven-constraint multivertex fit  $K^+ p \rightarrow \Lambda^0 K^+ K^+$ , and 9 were identified uniquely as the five-constraint multivertex fit  $K^+ p \rightarrow \Sigma^0 K^+ K^+$ . The 31 events that are ambiguous between these two hypotheses were assumed in the following analysis to be  $\Lambda K^+ K^+$  events. The cross section for the final state  $Y^0 K^+ K^+$  is  $\sigma = 18 \pm 3 \mu\text{b}$ , where the uncertainty represents the statistical error only. For the three-body events the  $Y^0$  hyperon emerges backward in the production center of mass, as shown in Fig. 1a. The angular correlation between the two final-state  $K^+$  mesons in the overall production c.m. system is shown in Fig. 1b. Although in most of the events one  $K$  meson emerges forward and the other backward in the production center of mass, there is a distinct group of 11 events in which both  $K$  mesons emerge in the forward direction. This group of events suggests the possible contribution of an  $S = 1$  boson-exchange mechanism to the  $Y^0 K^+ K^+$  final state. A Dalitz plot,  $M^2(K_F^+ Y^0)$  versus  $M^2(K_B^+ Y^0)$ , is shown in Fig. 1c, where  $K_F$  and  $K_B$  are the more forward and the more backward  $K$  mesons. There is a low-mass enhancement in the  $(K_B^+ Y^0)$  mass spectrum which may in part be due to the process  $K^+ p \rightarrow K^+ N^{*+}(1688) \rightarrow K^+ K^+ \Lambda$ .<sup>4</sup> No evidence is seen for the production of  $S = 2$  boson resonances in the  $K^+ K^+$ , isospin = 1 system (see Fig. 3).

In the study of the four-body final states  $\Lambda K K \pi$  there are two major problems. The first is to evaluate the contamination in the fitted sample from the underconstrained  $\Sigma^0 K K \pi$  events; the second is to estimate what is the effect of this contamination on the various mass plots and angular distributions. To answer these questions in part we have generated, via

Monte Carlo calculations,<sup>5</sup>  $\Sigma^0 KK\pi$  events which were then processed through the standard geometry and kinematic programs. About 66% of these generated events yield a satisfactory fit to at least one of the  $\Lambda KK\pi$  hypotheses. In Fig. 2a we plot the measured missing mass recoiling against the  $\Lambda$  versus the fitted  $KK\pi$  mass for the 203  $\Lambda KK\pi$  data events. Figure 2b shows a scatter plot of the "measured"  $KK\pi$  mass recoiling against the  $\Sigma^0$  versus the fitted  $KK\pi$  mass recoiling against the  $\Lambda$  for the 864  $\Sigma^0 KK\pi$  Monte Carlo events that yield a fit to the  $\Lambda KK\pi$  hypotheses. From Fig. 2a alone one observes that the fitting procedure to the  $\Lambda KK\pi$  hypotheses essentially does not alter the  $KK\pi$  mass value. Comparison between Fig. 2a and 2b shows that in fact the  $\Sigma^0$  contamination in the data events is small, since the spread in the distribution of the Monte Carlo events is appreciably larger than in the data sample. It is also worthwhile to note from Fig. 2b that a sample of  $\Sigma KK\pi$  events fitted to  $\Lambda KK\pi$  hypotheses increases only slightly the  $KK\pi$  mass, and would therefore still be useful in a search for mass enhancements in the  $KK\pi$  system.

The angular distribution of the  $\Lambda$  hyperon is peaked strongly backward, but a small forward peak is seen in the  $\Lambda K^+ K^0 \pi^+$  events. The angular correlation between the two final-state K mesons in the production c.m. system shows that in the major part of the events one K emerges forward and the other backward. There is not, however, a well-defined separation between these events and the events in which both K mesons emerge forward or both backward. There is evidence for the production of  $Y^*(1385)$  in both  $\Lambda KK\pi$  channels and for some  $K^*(890)$  production in the  $\Lambda K K^0 \pi^+$  final state. The three-particle mass distributions,  $M(\Lambda K\pi)$ , do not reveal any known resonance production. We have examined the pure ( $I = 1$ ) state,  $K^+ K^+$ , and the mixture ( $I = 0, I = 1$ ) state,  $K^+ K^0$ , as well as the doubly charged  $KK\pi$  system, which would be a pure



$I = 1$  state for those events in which the  $Y^0$  is a  $\Lambda$  hyperon. The results are shown in Fig. 3, where for comparison the phase-space distribution is shown on the  $M(KK\pi)$  plot.

Finally we used in the analysis the 335 events in which the  $Y^0$  is unambiguously identified as  $\Lambda$  decay, but no kinematic fit to the production point was satisfactory. From the Monte Carlo calculations it is estimated that  $\sim 88\%$  of the events having  $\Lambda$  or  $\Sigma^0$  in the final state have been identified by the procedures discussed in this work. The missing mass recoiling against the  $\Lambda$ -decay events added to the missing mass of the fitted events is shown in Fig. 3d. The expected phase-space distribution, calculated by using the experimental fraction of three-, four-, and five-body final states with a  $Y^0$  hyperon, is shown as the solid curve.<sup>6</sup> As seen from this sample of 623 events, there is no evidence for the production of  $S = 2$  bosons in either the  $I = 0$  or  $I = 1$  state in the  $KK$  system or in the  $KKn\pi$  systems. We estimate the upper limit of the production cross sections for the reported  $S = 2$  enhancements at 1050 and 1280  $\text{MeV}^1$  to be 1.5 and 2.0  $\mu\text{b}$ , respectively in this experiment.

We thank R. Shutt and the staff of the 80-inch bubble chamber and H. Foelsche and the AGS staff at Brookhaven for helping with the exposure. Thanks are also due to Dr. B. C. Shen for his important contributions in the early stages of this experiment. We acknowledge the valuable support given by our programming and scanning staff, in particular D. V. Armstrong, E. R. Burns, and R. L. Siefer.

## FOOTNOTES AND REFERENCES

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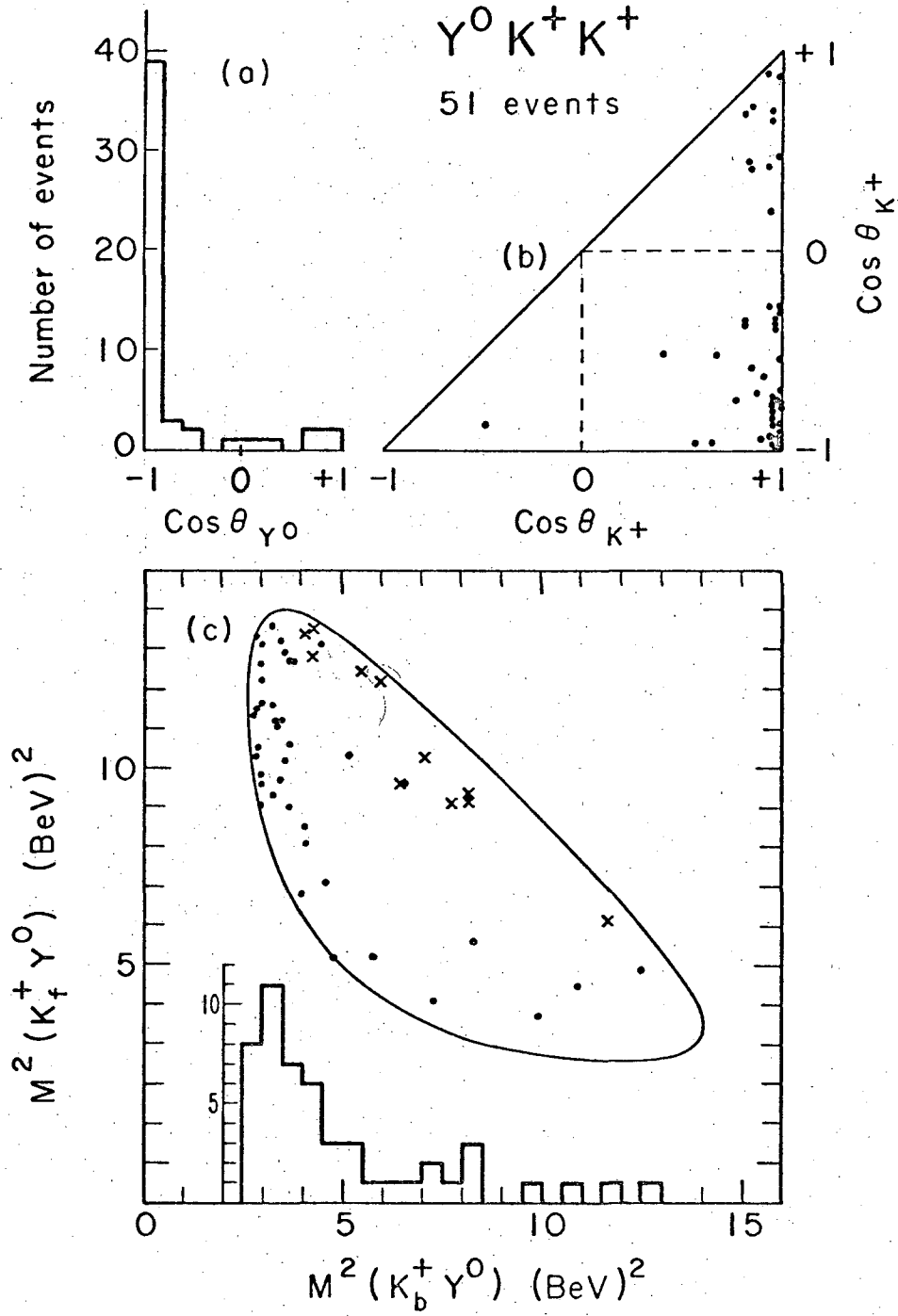
6. In this phase-space calculation we have approximated the five- or more-body final states by the expected phase-space distribution for five-body final states. The excess of events above phase space at the high-mass end of the spectrum in Fig. 3d is most probably due to the neglect of the six- or more-body phase-space distributions.

## FIGURE LEGENDS

Fig. 1. Angular distribution in the production c.m. and Dalitz plot for the  $Y^0 K^+ K^+$  final state. (a) Angular distribution of the  $Y^0$  hyperon; (b) angular correlation of the two final-state  $K^+$  mesons; (c)  $M^2(Y^0 K_f^+)$  versus  $M^2(Y^0 K_b^+)$ . The events marked with an "x" are those for which both  $K^+$  mesons emerge forward in the production c.m. The projection  $M^2(Y^0 K_b^+)$  is also shown.

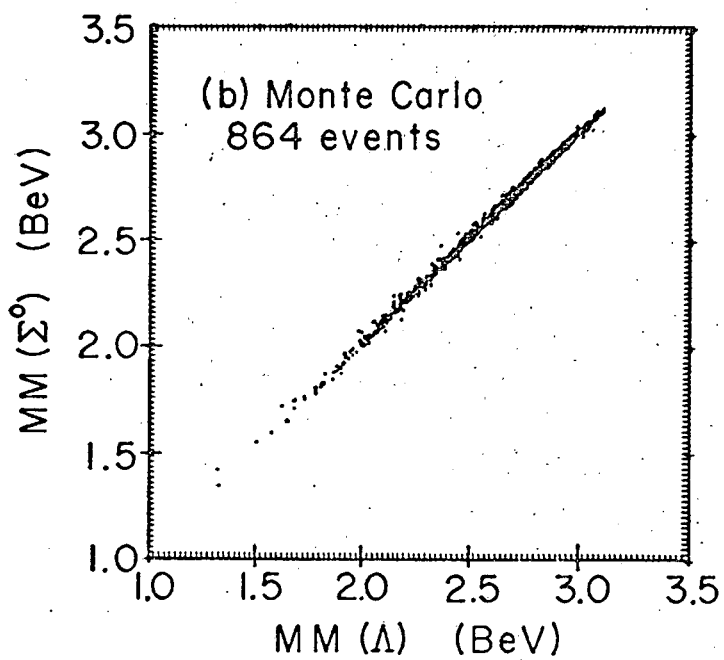
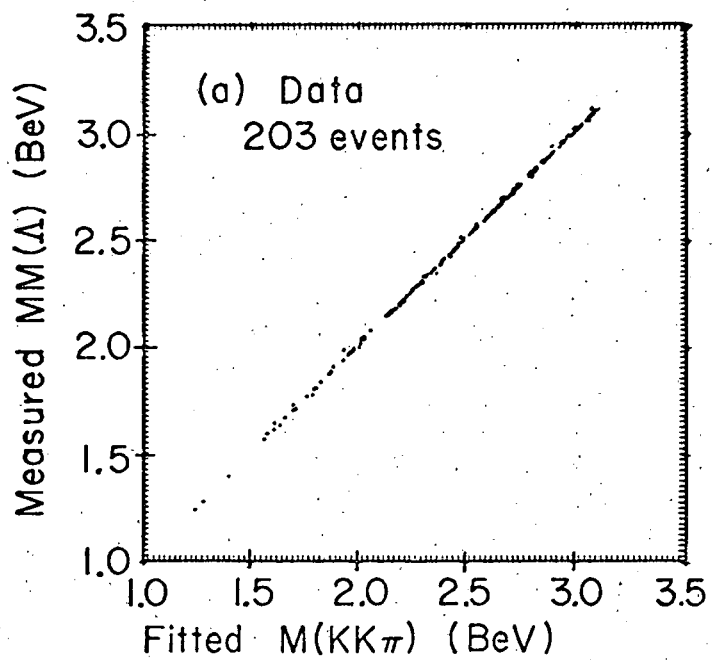
Fig. 2. (a) Scattering plot of fitted  $M(KK\pi)$  versus the measured missing mass recoiling against the  $\Lambda$  hyperon of the 203 data events fitted to the  $\Lambda KK\pi$  hypotheses. (b) Scattering plot of the missing mass recoiling against the  $\Sigma^0$  hyperon versus the fitted missing mass recoiling against the  $\Lambda$  hyperon for 864 generated  $Kp \rightarrow \Sigma^0 KK\pi$  events that fitted the  $\Lambda KK\pi$  hypotheses.

Fig. 3. Invariant mass distributions of various  $B = 0$ ,  $S = 2$  particle combinations. (a)  $M(K^+ K^+)$  of the  $Y^0 K^+ K^+$  final state; shaded area corresponds to events in which both  $K$  mesons emerge forward in the production c.m. (b)  $M(KK)$  of the  $\Lambda KK\pi$  final states; shaded area corresponds to  $M(K^+ K^+)$  and unshaded area to  $M(K^0 K^+)$ . (c)  $M(KK\pi)$  of the final states  $\Lambda KK\pi$ . The solid line is the expected phase-space distribution. (d) Missing mass recoiling against the  $\Lambda$  for both fitted events and events in which only the  $\Lambda$  decay was identified. Solid line represents phase space for a mixture of three-, four-, and five-body final states.



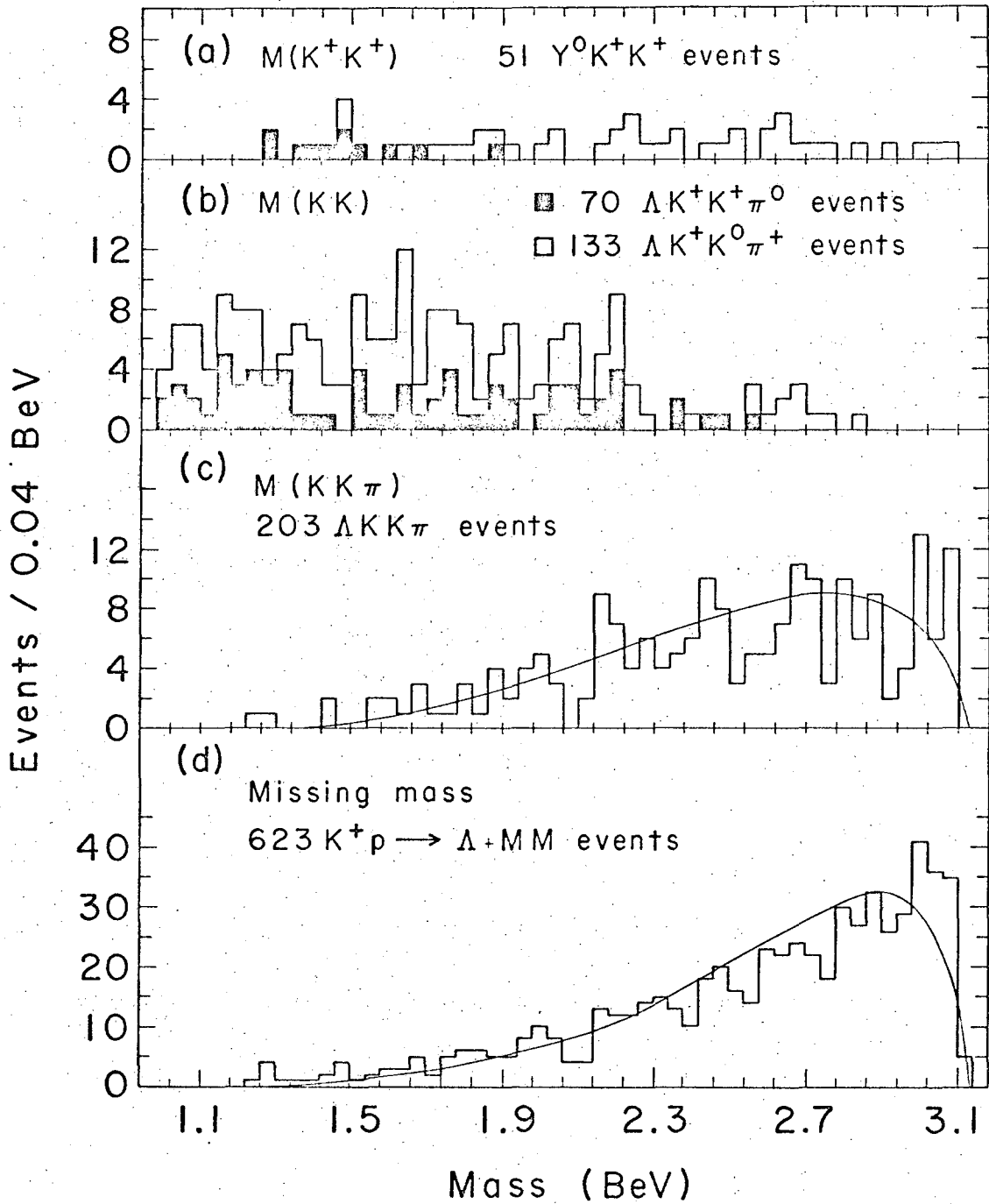
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Fig. 1



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Fig. 2



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Fig. 3

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