CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Submitted to
Physics Letters B

CERN/EP/PHYS 78-20
19 July 1978

AN ENHANCEMENT AT THE $\Sigma\bar{K}$ THRESHOLD (1680) MeV OBSERVED IN K^-p REACTIONS AT 4.2 GeV/c

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ABSTRACT

An enhancement in the $(\Sigma\bar{K})$ mass spectrum at threshold is observed in K^-p interactions at 4.2 GeV/c. It appears both in the neutral and negative charge states. Corresponding $\Lambda\bar{K}$ mass distributions show weak evidence for an effect close to this threshold (∿ 1680 MeV). Although the interpretation of the $(\Sigma\bar{K})$ enhancement by itself is ambiguous, a $(\Sigma\bar{K})$-$(\Lambda\bar{K})$ coupled channel analysis gives results compatible with its interpretation as a new Ξ^*.

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(++) The investigation is supported by the Joint Research Program of FOM and ZWO.

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In this letter we report the existence of a threshold enhancement appearing both in neutral and negatively charged $\Sigma\bar{K}$ mass spectra. Weaker evidence is observed in the corresponding $\Lambda\bar{K}$ mass distributions at a mass close to this threshold (∿ 1680 MeV) and thus the enhancement could arise from the decay of a new Ξ^*.

The data come from the high statistics experiment (∿ 133 events/μb) studying K^-p interactions at 4.2 GeV/c in the CERN 2m hydrogen bubble chamber.

The reactions analyzed which give positive evidence for the enhancement are

$\Sigma^+K^-K^+\pi^-$	1806 (3009)	(1)
$\Sigma^oK^-K^o_s\pi^+$	254 (305)	(2)(*)
$\Sigma^+K^-K^o_s\pi^o$	356 (596)	(3)
$\Lambda K^-K^o_s\pi^+$	620 (738)	(4)(*)
$\Lambda K^o_sK^+\pi^-$	502 (588)	(5)(*)

Both the Λ and K^o_s were required to decay into charged particles. The number of events observed in each reaction is given together with (bracketed numbers) those obtained after correcting for scanning losses and decays outside the fiducial volume.

The general procedures on kinematical fits, fiducial volume, decay length cuts and cross section normalization are given in ref. [1].

Kinematical ambiguities in the above channels have been carefully studied, investigating the distributions of the usual parameters (such as missing mass and probabilities). To check a posteriori the quality of the final selected sample we have verified the behaviour of the physical parameters not used in the statistical separation of ambiguities (such as pulls and decay angular distributions). A clear separation with a very low contamination has generally been obtained.

(*) For reactions (1b), (2a) and (2b) only film corresponding to 100 events/μb has been used in the present analysis. This is because insufficient information was kept on DST for the earlier measured events to allow a complete investigation of the kinematical ambiguities which often exist.

The best evidence for the enhancement at threshold comes from reaction (1); the Σ^+K^- weighted mass distribution is given in fig. 1 after eliminating ϕ events ($M(K^+K^-)$ less than 1.03). A prominent narrow enhancement is observed at the Σ^+K^- threshold with a statistical significance of $\sim$ 8 standard deviations above the background given by the broken line. This background curve has been derived, in the indicated region, from the shape of the Σ^+K^+ mass distribution of the same reaction after normalization to the number of Σ^+K^- events outside the enhancement. Effects like the presence of $K^* \to K^+\pi^-$ and $\Xi^* \to \Sigma^+K^-$ which might affect differently the shape of the Σ^+K^- and Σ^+K^+ mass distributions have been verified not to do so to any noticeable extent in the mass region considered. Through a study of the different two- and three-body mass combinations it has also been ascertained that the enhancement is not connected with the abundant production of Y^*'s decaying into $\Sigma^+\pi^-$ or due to the three-body decay, say, of a Ξ^*. The fact that about 70% of the events in the enhancement had a unique kinematical fit shows furthermore that it is not the result of an error in the statistical separation of ambiguities.

Independent confirmation of the $\Sigma\bar{K}$ threshold effect is obtained in reactions (2) and (3). Thus in the Σ^0K^- mass distribution in the forward hemisphere shown in fig. 2(a) from reaction (2) a 4σ effect is seen close to threshold while in the Σ^+K^- distribution from reaction (3) (not shown) a 3σ effect is found. Again a detailed study has led us to the conclusion that the enhancements are not secondary effects.

We notice that while the neutral $\Sigma\bar{K}$ enhancements appear to have a uniform c.m. production angular distribution the negatively charged is concentrated in the forward hemisphere defined with respect to the incident K^- direction.

Threshold enhancements may be described either as resonances or as due to a large scattering length. The two possibilities have been considered for the Σ^+K^- enhancement in the final state $\Sigma^+K^-K^+\pi^-$ where the statistical evidence is the best. Using a maximum likelihood method, the Σ^+K^- mass distribution below 1.76 GeV has been fitted first to the incoherent sum of a relativistic Breit-Wigner function and the previously described background. The experimental mass resolution is good (7 MeV at FWHM) and has not been folded in. The full line in fig. 1 shows the result of the best fit ($\chi^2/ND = 12/11$); it corresponds to an s-wave Breit-Wigner function with the following parameters :

$$M = (1699 \pm 5)\text{MeV}; \qquad \Gamma = (44 \pm 23)\text{MeV}.$$

The number of events in the resonance is 175 ± 35.

Higher wave Breit-Wigner functions gave much worse fits: $\chi^2/ND = 35/11$ for a p-wave function, for instance.

Next the Σ^+K^- amplitude was fitted to a complex scattering length $A = a + ib$ in a zero effective range approximation [2]. The dotted line in fig. 1 represents the best fit obtained ($\chi^2/ND = 15/11$); it corresponds to an s-wave amplitude with the following parameters

$$|a| = (2.6 \pm 0.5)\ \text{fermi}$$

$$b = (0 \pm 0.4)\ \text{fermi}.$$

Higher waves again gave much worse fits, for e.g. $\chi^2/ND = 28/11$ for a p-wave.

Since only the absolute value of a is determined we cannot infer from this fit the nature of the threshold effect. However, $|a|$ is large compared to the range of strong interactions and bigger than b and therefore one possible interpretation, if a is negative, is the existence of an unstable bound state(*). Moreover, the smallness of b suggests that the partial widths into decay modes above threshold should be small. If $a < 0$ the resonance parameters would be [3]

$$M = M_\Sigma + M_{K^-} - E_B = (1675 \pm 5)\text{MeV}$$

$$\Gamma = \frac{2b}{\mu|a|^3} < 10\ \text{MeV}$$

where $E_B = 1/2\ (\mu|a|^2)^{-1}$ is the binding energy of the Σ^+K^- system and μ its reduced mass.

(*) We use the new nomenclature introduced by Dalitz, Dept. of Theoretical Physics, Oxford University, report 40/78.

The analysis of the $\Sigma\bar{K}$ system does not lead to an unambiguous interpretation of the threshold enhancement. To understand better its nature we have looked for effects in the same mass region in other channels. A very qualitative general description of our findings is given first and it is followed by a quantitative evaluation of the $\Lambda\bar{K}$ channels when some positive evidence is found. This can be seen from fig. 2(b) showing the $\Lambda\bar{K}$ mass distribution from reaction (4) for events produced in the forward hemisphere. A shoulder at about 1680 MeV may be apparent together with evidence for production of $\Xi^*(1820)$ and another enhancement at about 1950 MeV. It has to be remembered that because we require both the Λ and the K^0 to decay visibly there is in this channel a loss of sensitivity of $\sim 9/2$. The same is true in reaction (5) from which we show in fig. 3(b) the $\Lambda\bar{K}^0$ mass spectrum after elimination of $\bar{K}^*$ - events $(0.86 \leqslant M(\bar{K}^0\pi^-) \leqslant 0.92$ GeV); also here, only a shoulder is seen below the $\Xi^*(1820)$.

The $\Xi\pi$, $\Xi\pi\pi$ mass distributions in the reactions $K^-p \rightarrow \Xi^-\pi^+K^+\pi^-$, $\Xi^-\pi^+\pi^0K^+\pi^-$, $\Xi^0\pi^-K_s^0\pi^+$, $\Xi^-\pi^+\pi^-\pi^+(K^0)$ and $\Xi^-\pi^+K_s^0\pi^0$ have also been investigated. Abundant $\Xi^*(1530)$ and $\Xi^*(1820)$ is generally found but nowhere did we find an enhancement around a mass of 1680 MeV. In the table summarizing our results, upper limits are given for the effect in these reactions.

Although the evidence from the $\Lambda\bar{K}$ channels is poor we have thought it worthwhile to determine the compatibility of the data with the assumption of a Ξ^* decaying both into $\Sigma\bar{K}$ and $\Lambda\bar{K}$. A coupled channel analysis [4] has been made separately for the negatively charged and neutral systems. The procedure used is illustrated by describing that followed in the Σ^0K^- and ΛK^- analysis. The shape of the background in the $\Sigma\bar{K}$ Threshold mass region was determined by extrapolation of that fitted above 1.76 GeV. Firstly, the $\Lambda\bar{K}$ mass distribution above 1.76 GeV was fitted with an incoherent sum of two Breit-Wigner functions and a polynomial background. The first Breit-Wigner corresponds to the well established $\Xi^*(1820)$; its mass and width were kept fixed (with the experimental resolution folded in) at their well-known values [5]. The parameters of the second(*) Breit-Wigner centred at about 1.950 GeV were left free. In a similar way a fit was made to the Σ^oK^- mass distribution. Secondly, the coupled channel fit was made to the $\Sigma\bar{K}$ and $\Lambda\bar{K}$ mass spectra from their respective thresholds up to 1.74 GeV. In this fit the coupling constant ratio $g^2_{\Sigma^oK^-}/g^2_{\Lambda K^-}$, the mass and the ΛK^- partial width for the enhancement were allowed to vary; the background amplitudes were also allowed to vary although forced to keep the shapes determined in the previous fits.

The full lines in figs 2(a) and 2(b) represent the result of the best fit (χ^2/ND = 45/40) which gave the following values

$$M = (1694 \pm 6)\ \text{MeV};\quad \Gamma = (26 \pm 6)\ \text{MeV};\quad g^2_{(\Sigma\bar{K})^-}\big/g^2_{(\Lambda\bar{K})^-} = (10.5 \pm 4.8)$$

where an isospin factor of 3 has been used to determine $g^2_{(\Sigma\bar{K})^-}$ from the estimated $g^2_{\Sigma^oK^-}$. The dotted line represents the background contribution. The numbers of events in the resonance were found to be

$$N(\Lambda K^-) = 22 \pm 8;\quad N(\Sigma^oK^-) = 23 \pm 6.$$

After the isospin correction to allow for the $\Sigma^-\bar{K}^o$ mode, the following branching ratio is obtained

$$R(\Sigma\bar{K})^-/R(\Lambda\bar{K})^- = 3.1 \pm 1.4.$$

Correcting also for unobserved V^o decays, the production cross section for this negatively charged state is (4.3 ± 1.4)μb.

The Σ^+K^- and $\Lambda\bar{K}^o$ mass spectra were fitted in a similar manner. The result of the best fit (χ^2/ND = 41/44) is shown by the full lines of fig 3(a) and 3(b) while the dotted line represents again the background contribution. This fit gives

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(*) The assumption of a resonant structure at a mass of ∿ 1.95 GeV is not arbitrary; strong indications for it have been found in other experiments and are also found in other channels in this experiment. Our evidence is being put together and will be published soon.

$M = (1684 \pm 5)$ MeV; $\Gamma = (20 \pm 4)$ MeV; $g^2_{(\Sigma\bar{K})^o}/g^2_{(\Lambda\bar{K})^o} = (10 \pm 2.5)$,

(where the estimated $g^2_{\Sigma^+K^-}$ has been multiplied by 3/2 to derive the $g^2_{(\Sigma\bar{K})^o}$ coupling constant) and the following number of events are obtained: $N(\Lambda\bar{K}^o) = 20 \pm 8$; $N(\Sigma^+K^-) = 163 \pm 20$.

Correcting for unobserved V^o neutral decays and using the ratio 3/2 between Clebsch-Gordan coefficients to take into account the $\Sigma^o\bar{K}^o$ contribution, the resulting branching ratio is

$$\frac{R(\Sigma\bar{K})^o}{R(\Lambda\bar{K})^o} = 2.7 \pm 0.9$$

and the total cross section $(3.3 \pm 0.7)\mu$b.

The agreement is therefore good between the two independent determinations of the resonance parameters.

An attempt to determine the spin-parity of the assumed Ξ^* through a study of the decay angular distribution of the $\Sigma\bar{K}$-system in reaction (1) has been inconclusive. Nevertheless, the fact that the fits to the mass distributions were satisfactory only under the s-wave hypothesis and the closeness of the mass to that of the $\Sigma\bar{K}$ threshold would favour qualitatively a $J^P = 1/2^-$ assignment. The state could then be that predicted by Jones et al. [6] at a mass of about 1720 GeV. Indeed, if one takes the $SU(6)_W$ content of this state and the amplitudes derived in the framework of the transformation from constituent to current quarks [7], good agreement is found between the predicted and observed decay rates [8].

In conclusion, a statistically significant effect has been observed in the $\Sigma\bar{K}$ mass distribution close to threshold. An analysis of the enhancement cannot distinguish between its interpretation either as an s-wave scattering length or as a resonance. Observation of weak effects in the $\Lambda\bar{K}$ system at the same mass makes the Ξ^* resonance interpretation plausible. Indeed, a coupled channel analysis is compatible with this interpretation although it does not prove it. The Ξ^* isospin would be 1/2 and a spin-parity $1/2^-$ indicated.

Acknowledgements

We wish to thank Drs F. Buccella, A. Irving and M. Pennington for fruitful discussions. We also wish to thank the operating crews at the CERN Proton Synchrotron and the 2m hydrogen bubble chamber and the designers and constructors of the beam. We are also indebted to the scanning, measuring and computing staffs at our laboratories.

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$\Xi^{*\overset{0}{-}}(1680)$ decay modes and cross sections

	Observed channel	Weighted No of events	Decay mode[(a)]	Cross section (μb)
$\Xi^{*0}(1680)$				
	$\Sigma^+K^-(K^+\pi^-)$	163 ± 20	$(\Sigma\bar{K})^0$	2.3 ± .3
	$\Lambda\,\bar{K}^0_s(K^+\pi^-)$	20 ± 8	$(\Lambda\bar{K})^0$	1. ± 0.4
	$\Xi^-\pi^+(K^+\pi^-)$	< 16	$(\Xi\pi)^0$	< 0.2
	$\Xi^-\pi^+\pi^0(K^+\pi^-)$	< 12	$\Xi^-\pi^+\pi^0$	< 0.1
	$\Xi^{*0}(1530)\pi^0(K^+\pi^-)$	< 10	$(\Xi^*(1530)\pi)^0$	< 0.3
	$\Sigma^+K^-(K^0_s\pi^0)$	15 ± 5	$(\Sigma\bar{K})^0$	0.8 ± 0.3
	$\Xi^-\pi^+(K^0_s\pi^0)$	< 22	$(\Xi\pi)^0$	< 0.9
$\Xi^{*-}(1680)$				
	$\Sigma^0K^-(K^0_s\pi^+)$ (b)	23 ± 6	$(\Sigma\bar{K})^-$	3.2 ± .8
	$\Lambda K^-(K^0_s\pi^+)$ (b)	22 ± 8	$(\Lambda\bar{K})^-$	1.1 ± .5
	$\Xi^0\pi^-(K^0_s\pi^+)$	< 6	$(\Xi\pi)^-$	< 0.6
	$\Xi^-\pi^+\pi^-(K^0_L\pi^+)$	< 10	$\Xi^-\pi^+\pi^-$	< 0.1
	$\Xi^{*0}(1530)\pi^-(K^0_L\pi^+)$	< 8	$\Xi^*(1530)\pi^-$	< 0.2

(a) Corrected for isospin and unseen decay modes.

(b) Forward hemisphere production.

FIGURE CAPTIONS

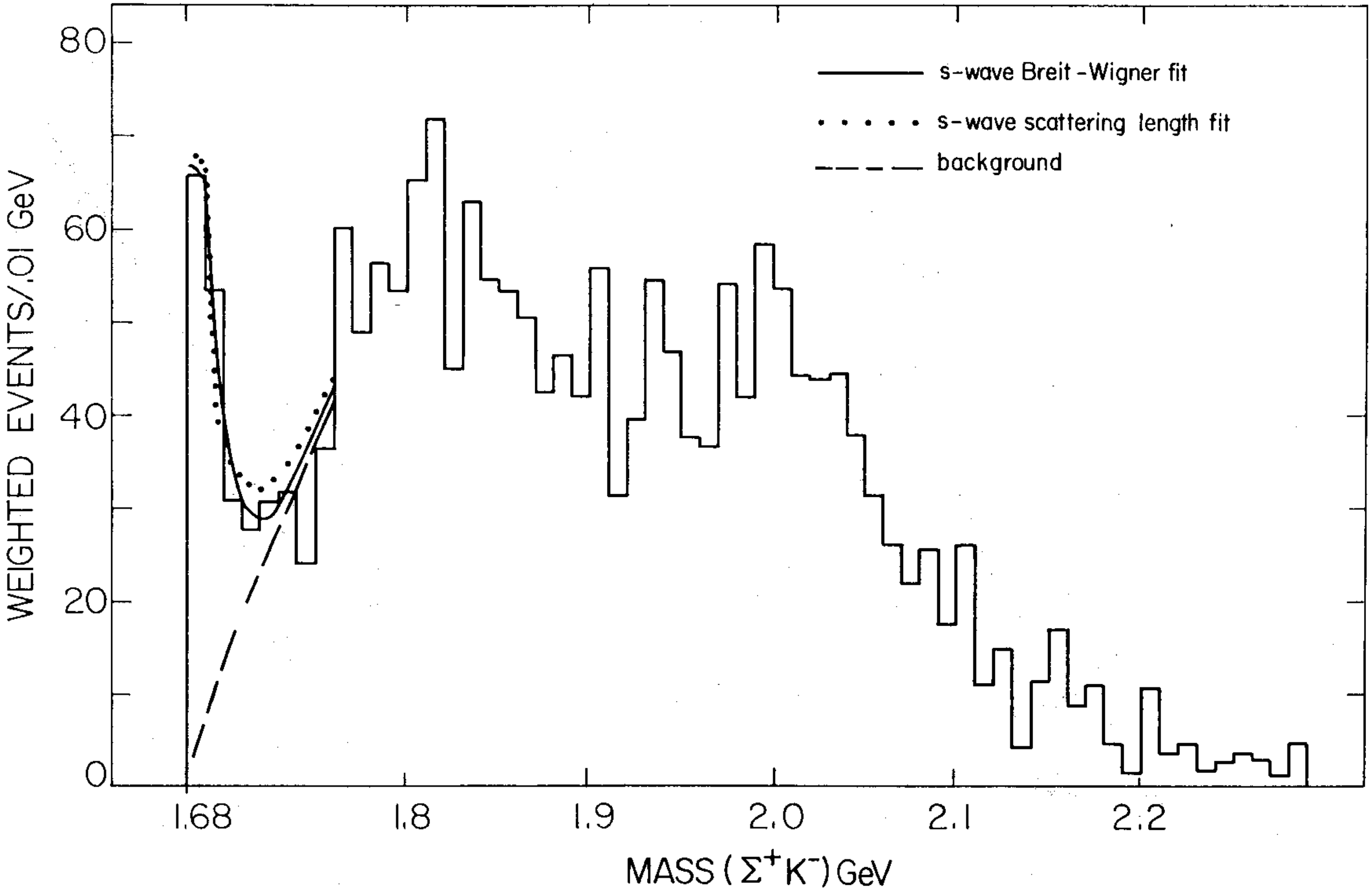
Fig. 1 The Σ^+K^- mass spectrum for the reaction $K^-p \rightarrow \Sigma^+K^-K^+\pi^-$ after elimination of ϕ events (mass (K^+K^-) less than 1.03 GeV). The origin of the curves is indicated.

Fig. 2 (a) The Σ^0K^- mass spectrum for the reaction $K^-p \rightarrow \Sigma^0K^-K_1^0\pi^+$ when the (Σ^0K^-) system is produced in the forward hemisphere. The curves are the result of the coupled channel analysis described in the test.

(b) As above for the $\Lambda\bar{K}^0$ system from the reaction $K^-p \rightarrow \Lambda K^-K^0\pi^+$.

Fig. 3 (a) The Σ^+K^- effective mass below 1.80 GeV from the reaction $K^-p \rightarrow \Sigma^+K^-K^+\pi^-$ together with the curve resulting from the coupled channel analysis.

(b) The $\Lambda\bar{K}^0$ mass spectrum for the reaction $K^-p \rightarrow \Lambda K_1^0K^+\pi^-$ after elimination of events with $0.86 < M(\bar{K}^0\pi^+) < 0.92$ GeV. The curves are the result of the coupled channel analysis described in the text.


s-wave Breit-Wigner fit
s-wave scattering length fit
background
WEIGHTED EVENTS/.01 GeV
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60
40
20
0
1.68
1.8
1.9
2.0
2.1
2.2
MASS (Σ^+K^-) GeV

Fig. 1

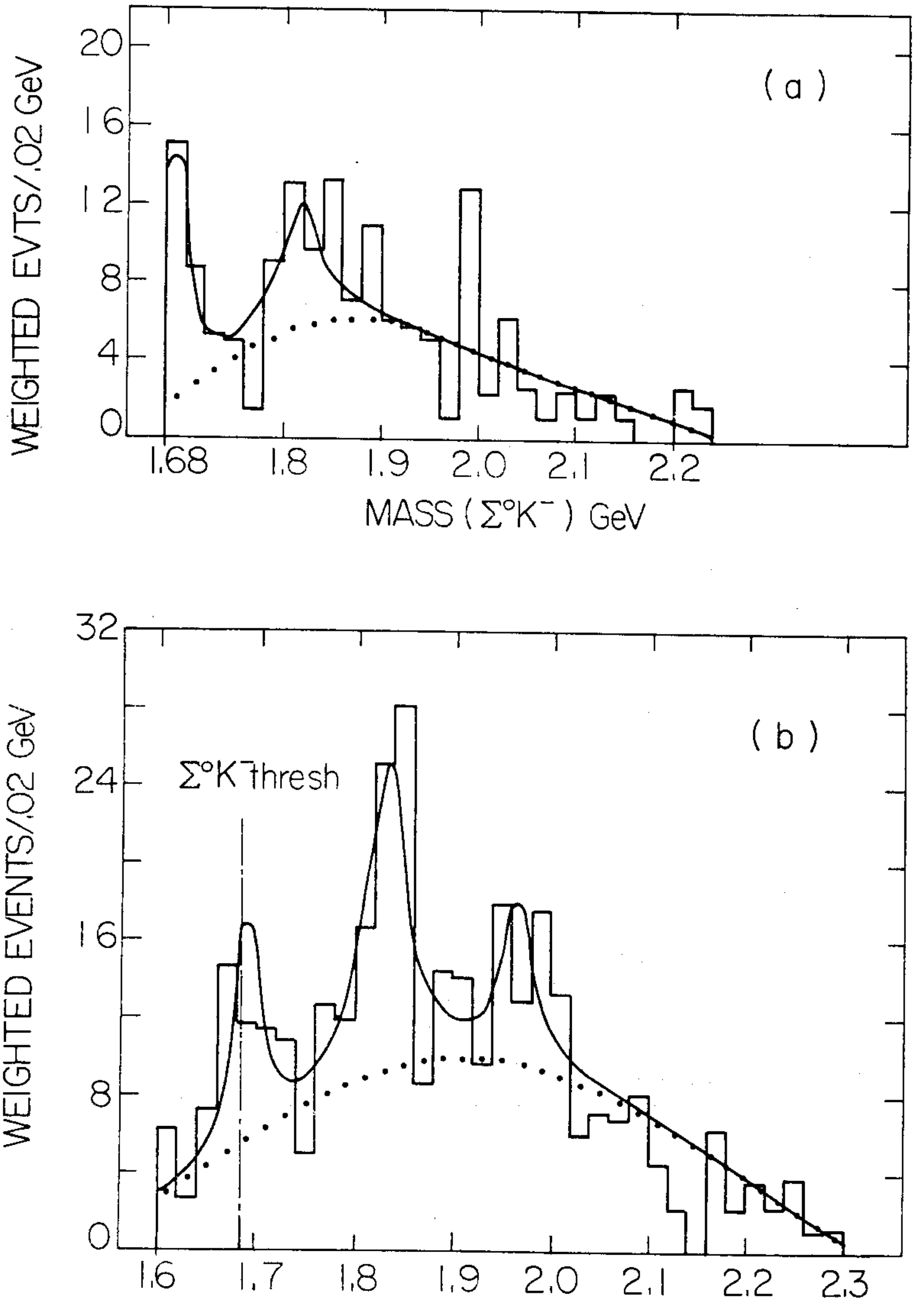
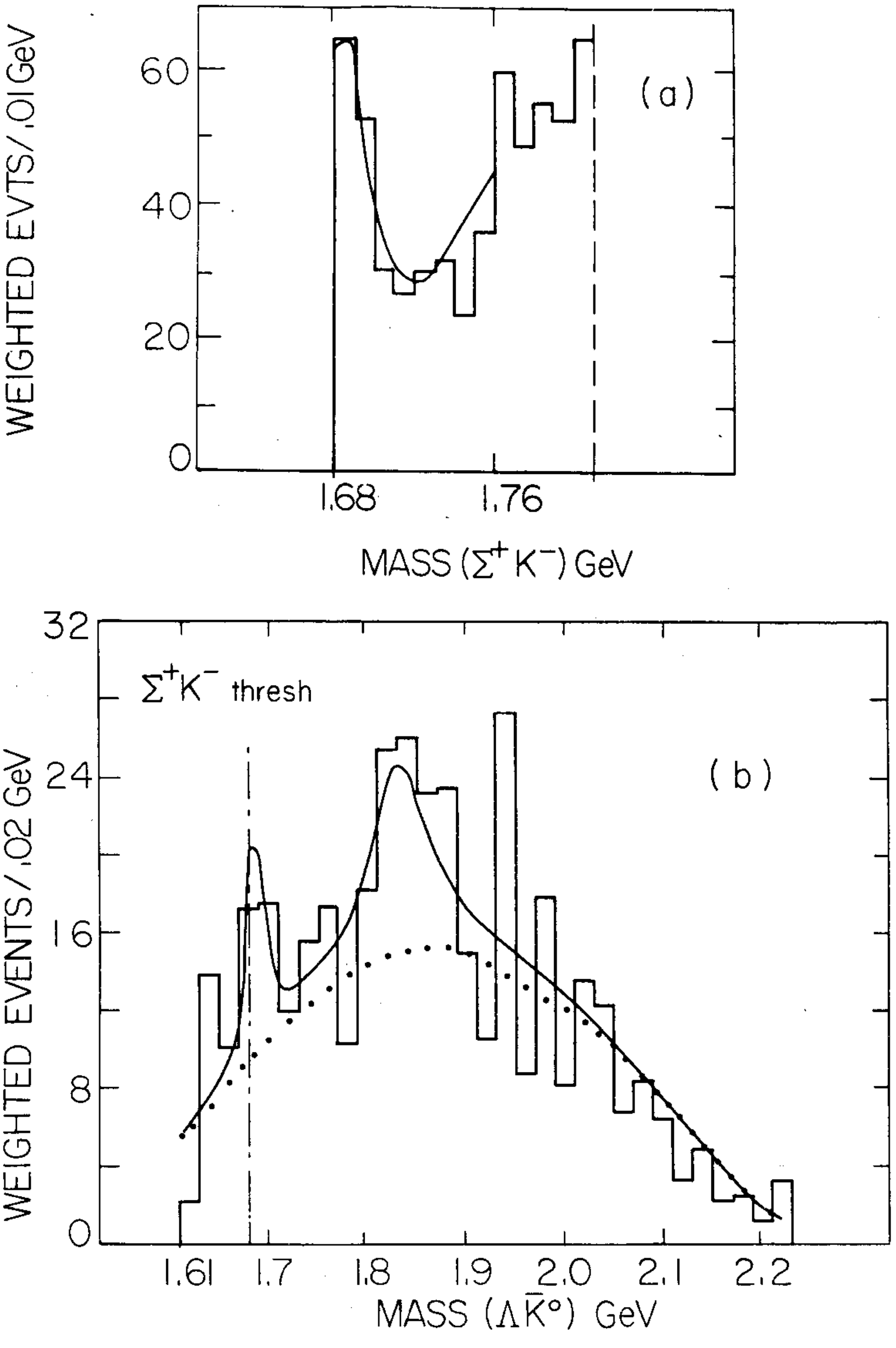

(a)
WEIGHTED EVTS/.02 GeV
20
16
12
8
4
0
1.68
1.8
1.9
2.0
2.1
2.2
MASS (Σ°K⁻) GeV
(b)
WEIGHTED EVENTS/.02 GeV
Σ°K⁻thresh
32
24
16
8
0
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
MASS (ΛK⁻) GeV

Fig. 2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0
20
40
60
(a)
1.68
1.76
MASS (Σ⁺K⁻) GeV
WEIGHTED EVENTS/.02 GeV
0
8
16
24
32
Σ⁺K⁻ thresh
(b)
1.61
1.7
1.8
1.9
2.0
2.1
2.2
MASS (ΛK̄°) GeV

Fig. 3