EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/79-149
22 November 1979

HYPERNUCLEI WITH SIGMA PARTICLES

R. Bertini[1,2], O. Bing[1], P. Birien[3], W. Brückner[4], H. Catz[5],
A. Chaumeaux[2,3], J.M. Durand[3], M.A. Faessler[4], T.J. Ketel[4],
K. Kilian[4], B. Mayer[3], J. Niewisch[4], B. Pietrzyk[4],
B. Povh[4], H.G. Ritter[4] and M. Uhrmacher[4]

(Heidelberg)-Saclay-Strasbourg Collaboration)*

ABSTRACT

The production of Σ particles in the (K^-,π^-) reaction on ^{9}Be at 720 MeV/c has been studied at the CERN Proton Synchrotron (PS). The missing-mass spectrum shows structures in the Σ region, which have been interpreted as belonging to hypernuclei with sigma particles. An upper limit of 8 MeV for the width of these states has been estimated.

(Submitted to Phys. Letters)

*) This work was supported in part by the Bundesministerium für Forschung und Technologie, Bonn, Germany.

1) CRN, Strasbourg, France.

2) CERN Associate.

3) Département de Physique Nucléaire, CEN Saclay, France.

4) Max-Planck-Institut f. Kernphysik, Heidelberg, Germany, and Physikalisches Institut der Universität, Heidelberg, Germany.

5) CERN Fellow.

In recent experiments [1,2] performed at the CERN Proton Synchrotron (PS) the (K^-,π^-) strangeness exchange reaction has been extensively used to study Λ hypernuclei. Details of the Λ-nucleus interaction have been deduced from these data, which have led to a deeper understanding of the single-particle properties in nuclear matter.

It is quite natural to ask whether a similar spectroscopy is possible with other hyperons, in particular with Σ particles. Obviously, the Σ hyperon can decay by strong interaction in the nucleus, and one cannot expect Σ-hypernuclear states to be as long-lived as the free Σ particle. Nevertheless, Σ-hypernuclear states could be sufficiently narrow to be identified, and therefore we searched for such states during our measurements on Λ hypernuclei.

Using a (K^-,π^-) reaction trigger, three reactions on the neutrons or the protons of the target can occur:

$$K^- + n \rightarrow \Lambda + \pi^- \tag{1}$$

$$K^- + n \rightarrow \Sigma^0 + \pi^- \tag{2}$$

$$K^- + p \rightarrow \Sigma^+ + \pi^- \ . \tag{3}$$

The cross-sections (fig. 1a) [3] for processes (1) and (2) have maxima around a kaon momentum of 720 MeV/c, where the experiment was actually done. The production of Σ^+ particles on the protons (3) is an order of magnitude smaller [3].

Figure 1b shows how the momentum transferred to the hyperons depends on the kaon momentum. It is assumed that the pion is detected in the forward direction within the angular acceptance of the spectrometer SPES II (reaction angles from $0°$ to $6°$). At 720 MeV/c the momentum transferred to the Λ particle (q_Λ) is about 57 MeV/c. Under such kinematical conditions the Λ-hypernuclear spectra are dominated by only a few recoilless transitions to states where the hyperon has the same spin and space quantum numbers as the nucleon it replaces. With increasing q_Λ, quasi-free transitions to other hypernuclear states become important [4]. The situation is less favourable for Σ-hypernuclear production, as the momentum transferred to the Σ particle is about 129 MeV/c at a kaon momentum of 720 MeV/c. This is still low enough for recoilless production to be expected; but even if

Σ-hypernuclear states are narrow, many quasi-free states will appear, which could mask the recoilless production.

Searching for Σ hypernuclei, the most promising target nuclei are the light ones. For these nuclei, one gets in the case of Λ hypernuclei, experimentally [5] and theoretically [4], the highest probability for the recoilless production. As a one-step reaction, the (K^-,π^-) takes place at the surface of the nucleus. This also favours small nuclei, and one can hope that a Σ particle loosely bound to a few-nucleon system may live long enough to build a hypernucleus before it decays via the strong interaction. Finally, in light nuclei only a few hypernuclear states can be reached. We concentrated our search for Σ-hypernuclear states on ^{9}Be, because for $^9_\Lambda$Be the spectrum is dominated by two strong peaks, well separated from each other by 11 MeV. If Σ hypernuclei are built in a similar way to Λ hypernuclei, this signature will be easy to recognize even if the width of these states is larger than that of the hypernuclear states.

The experimental set-up was the same as that used for the spectroscopy of Λ hypernuclei [1]. The over-all energy resolution was about 3 MeV for a target thickness of 2 g/cm^2. In addition to our standard (K^-,π^-) reaction trigger, we used the signal of a scintillation counter which surrounded the target. This counter detected the decay of hyperons or hypernuclear states and eliminated the background coming from the three-body decay of kaons near the target.

Figure 2 shows the spectrum obtained from the (K^-,π^-) reaction on a beryllium target. At the top of the figure we indicate the transformation energy $(M_{Hy} - M_A)$, where M_{Hy} is the mass of the hypernuclear system and M_A the target mass. The Λ-binding energy scale is also given. On the left-hand side of the spectrum one finds the Λ-hypernuclear spectrum which has been discussed earlier [5]. The two strong peaks stem from recoilless production on the neutrons of the $p_{3/2}$ and $s_{1/2}$ shells. The peak at B_Λ = -6 MeV is ascribed to recoilless replacement of the loosely bound neutron in ^{9}Be by a Λ particle, whereas the peak at B_Λ = -17 MeV corresponds to the neutron-Λ exchange in the strongly bound neutron pairs of the $p_{3/2}$ and $s_{1/2}$ shells. Also, the quasi-free produced ground state of $^9_\Lambda$Be can be seen at B_Λ = 7.5 MeV.

Just shifted by the mass difference of about 80 MeV between the Λ and the Σ^0 particles, one finds on the right-hand side of the spectrum a structure that is quite similar to that of the Λ spectrum, consisting of two peaks which we naturally ascribe to Σ-hypernuclear states. Their width is about 8 MeV. Taking into account that the corresponding states in the Λ hypernuclei have about the same width (fig. 3), these 8 MeV are an upper limit for the width of Σ particles in ^{9}Be. The energy integrated cross-section for this structure is about $\frac{1}{4}$ of that for the $^9_\Lambda$Be spectrum, in agreement with the ratio of the cross-sections for the elementary reactions (1) and (2).

The relative intensities of the two Σ-hypernuclear peaks are reversed compared to the Λ-hypernuclear spectrum. The higher momentum transfer in the Σ production (129 MeV/c, instead of 57 MeV/c for Λ production) may be responsible, at least partially, for this effect. This is further supported by the fact that in the $^9_\Lambda$Be spectrum taken at 900 MeV/c kaon momentum [6] -- corresponding to about 70 MeV/c momentum transfer -- the relative strength of the second peak has decreased. We have also inserted this spectrum in fig. 2.

In order to compare the Λ- and Σ-hypernuclear spectra directly, it is convenient to get rid of the hyperon and nuclear mass contributions in the transformation energy ($M_{Hy} - M_A$). For that purpose we use in fig. 3 the scale $\Delta B_{ni} = M_{Hy} - M_A - (M_i - M_n) = B_n - B_i$, where i stands for Λ or Σ^0; M is the mass and B the binding energy of the particles. If the hyperon-nucleus interaction is the same for a Λ or a Σ particle the corresponding hypernuclear states have the same ΔB value. But the Σ-hypernuclear states appear systematically at an excitation about 3 MeV higher, indicating that the Σ-nucleus interaction differs from the Λ-nucleus one. The present data, however, are inadequate for deciding whether the difference in the interaction originates from the different spin-orbit coupling or the central potential of the Λ and Σ particles in the nucleus.

Rather surprisingly, Σ hypernuclei live long enough to observe individual states. In $^9_\Sigma$Be the Σ width is smaller than 8 MeV. This result should be verified as soon as possible. In particular one should try to find out if the Σ lifetime is also longer in heavier hypernuclei and a spectroscopy of these states is possible. If this is the case experimentalists will be challenged to determine the Σ-nucleus interaction in a similar way as was done for the Λ particles and theorists to explain why the strong decay of Σ particles in the nucleus is hindered.

We would like to thank A. Bouyssy, R.H. Dalitz and A. Gal for many stimulating discussions concerning the results. The continuous support of our technician, Z. Kenesei, was essential for the success of the experiment.

REFERENCES

[1] W. Brückner, M.A. Faessler, T.J. Ketel, K. Kilian, J. Niewisch, B. Pietrzyk, B. Povh, H.G. Ritter, M. Uhrmacher, P. Birien, H. Catz, A. Chaumeaux, J.M. Durand, B. Mayer, J. Thirion, R. Bertini and O. Bing, Phys. Lett. 79B (1978) 157.

[2] R. Bertini, O. Bing, P. Birien, W. Brückner, H. Catz, A. Chaumeaux, J.M. Durand, M.A. Faessler, T.J. Ketel, K. Kilian, B. Mayer, J. Niewisch, B. Pietrzyk, B. Povh, H.G. Ritter and M. Uhrmacher, Phys. Lett. 83B (1979) 306.

[3] S.O. Holmgren, private communication.

[4] B. Povh, Z. Phys. A279 (1976) 159.

[5] W. Brückner, M.A. Faessler, T.J. Ketel, K. Kilian, J. Niewisch, B. Pietrzyk, B. Povh, H.G. Ritter, M. Uhrmacher, P. Birien, H. Catz, A. Chaumeaux, J.M. Durand, B. Mayer, R. Bertini, O. Bing and A. Bouyssy, The (K^-,π^-) strangeness exchange reaction on ^{6}Li, ^{7}Li and ^{9}Be, paper presented at the 8th Int. Conf. on High-Energy Physics and Nuclear Structure, Vancouver, 1979.

[6] W. Brückner, B. Granz, D. Ingham, K. Kilian, U. Lynen, J. Niewisch, B. Pietrzyk, B. Povh, H.G. Ritter and H. Schröder, Phys. Lett. 62B (1976) 481.

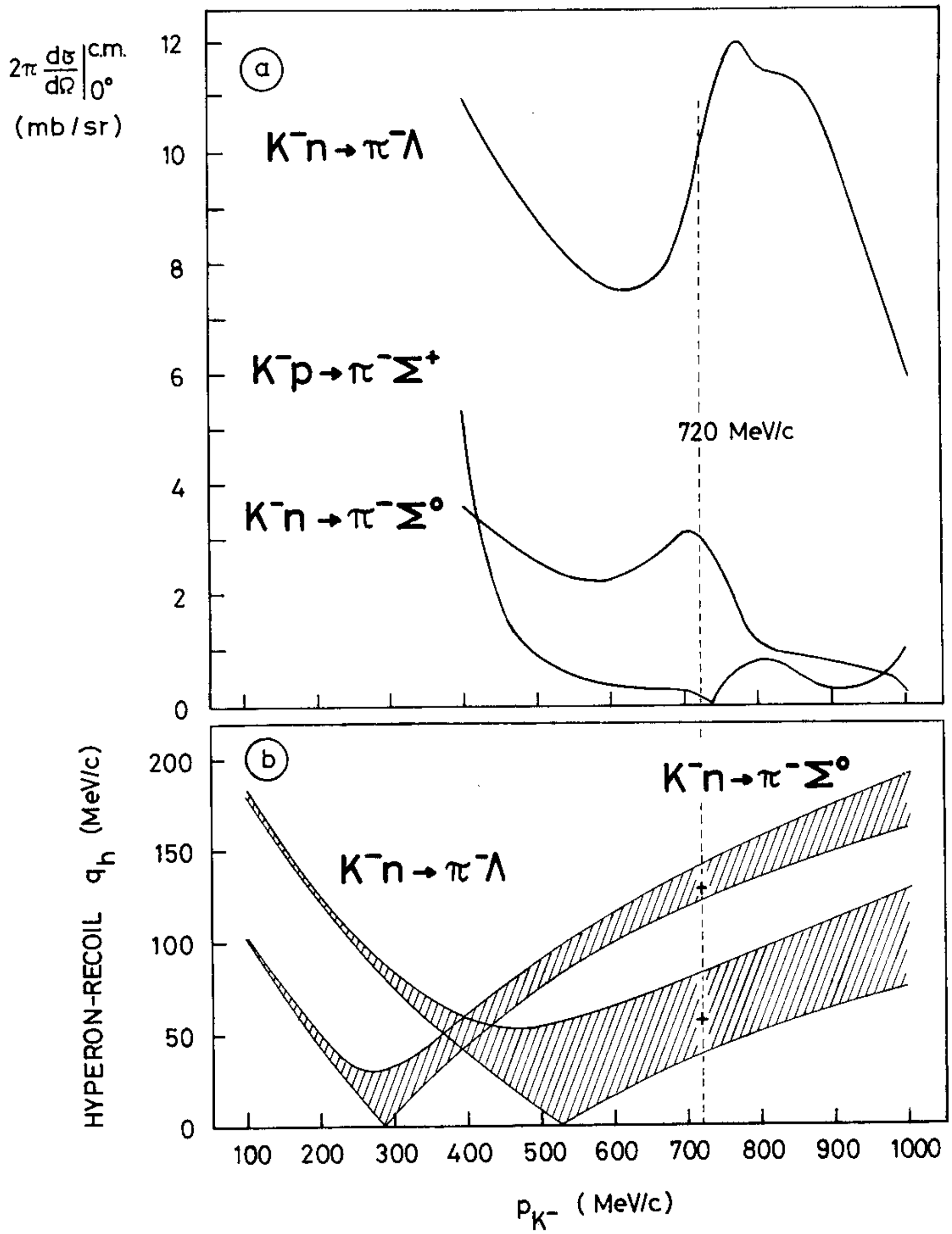
Figure captions

Fig. 1 : a) Cross-sections of the strangeness exchange reactions (1)-(3) as a function of the incident momentum p_K. The curves are taken from ref. [3].

b) Momentum transfer to the hyperons in reactions (1) and (2) as a function of the incident momentum p_K within the acceptance of the spectrometer SPES II (reaction angles from 0° to 6°).

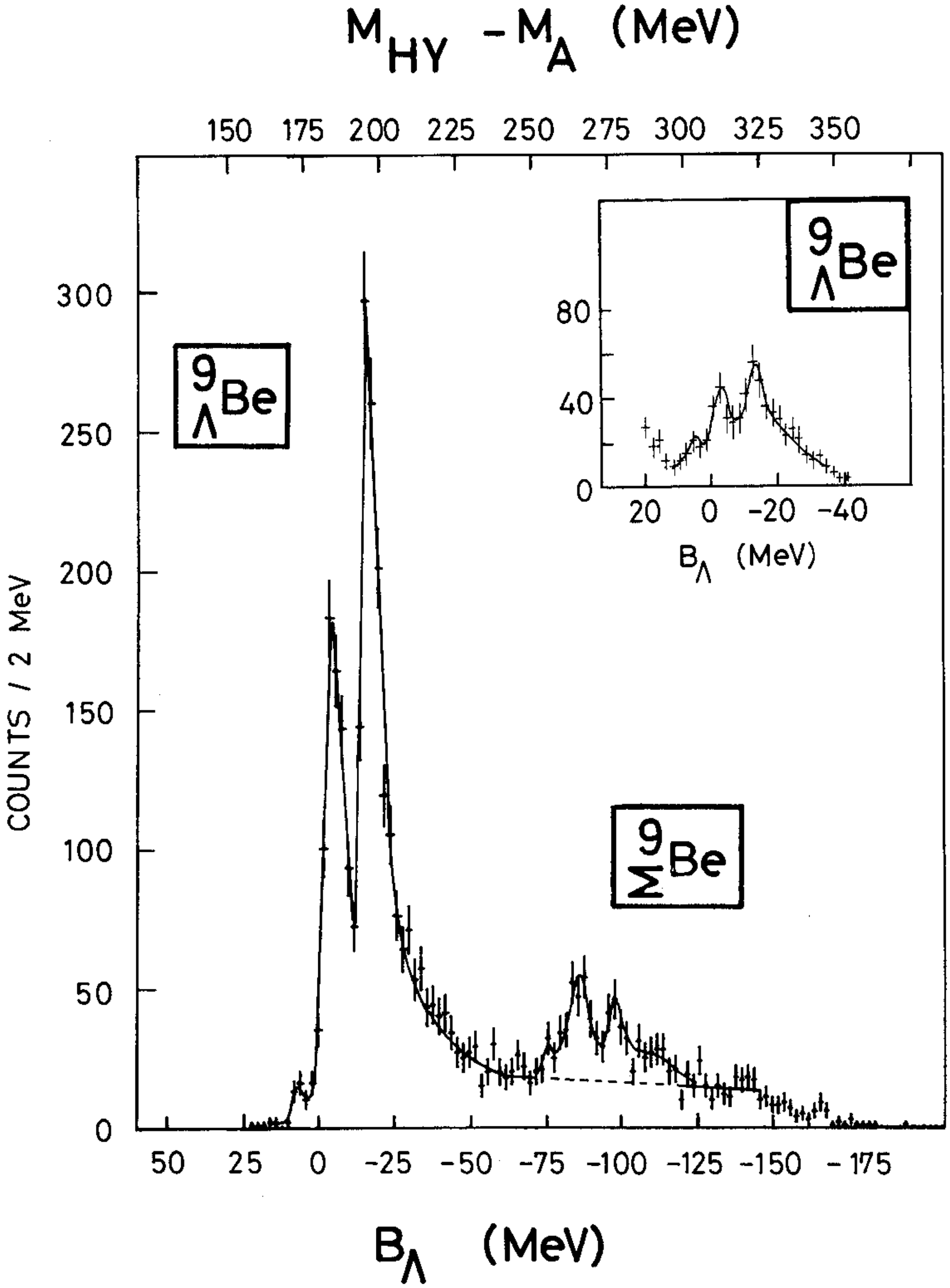
Fig. 2 : Spectrum obtained from the (K^-,π^-) reaction on ^9Be at a kaon momentum of 720 MeV/c. The spectrum is plotted as a function of the transformation energy $(M_{Hy} - M_A)$, that is the difference between the hypernuclear mass and the target mass. Also the Λ-binding energy scale (B_Λ) is given. For comparison the ^9Be spectrum of ref. [6] is inserted, which was taken at a kaon momentum of 900 MeV/c.

Fig. 3 : Λ- and Σ-hypernuclear spectra from the (K^-,π^-) reaction on beryllium as functions of $\Delta B_{n\,Hyperon}$. In the case of the Λ hypernuclei, we calculated $\Delta B_{n\Lambda} = M_{Hy} - M_A - (M_\Lambda - M_A) = B_n - B_\Lambda$; in the case of the Σ hypernuclei we calculated $\Delta B_{n\Sigma^0} = M_{Hy} - M_A - (M_\Lambda - M_A) = B_n - B_{\Sigma^0}$.



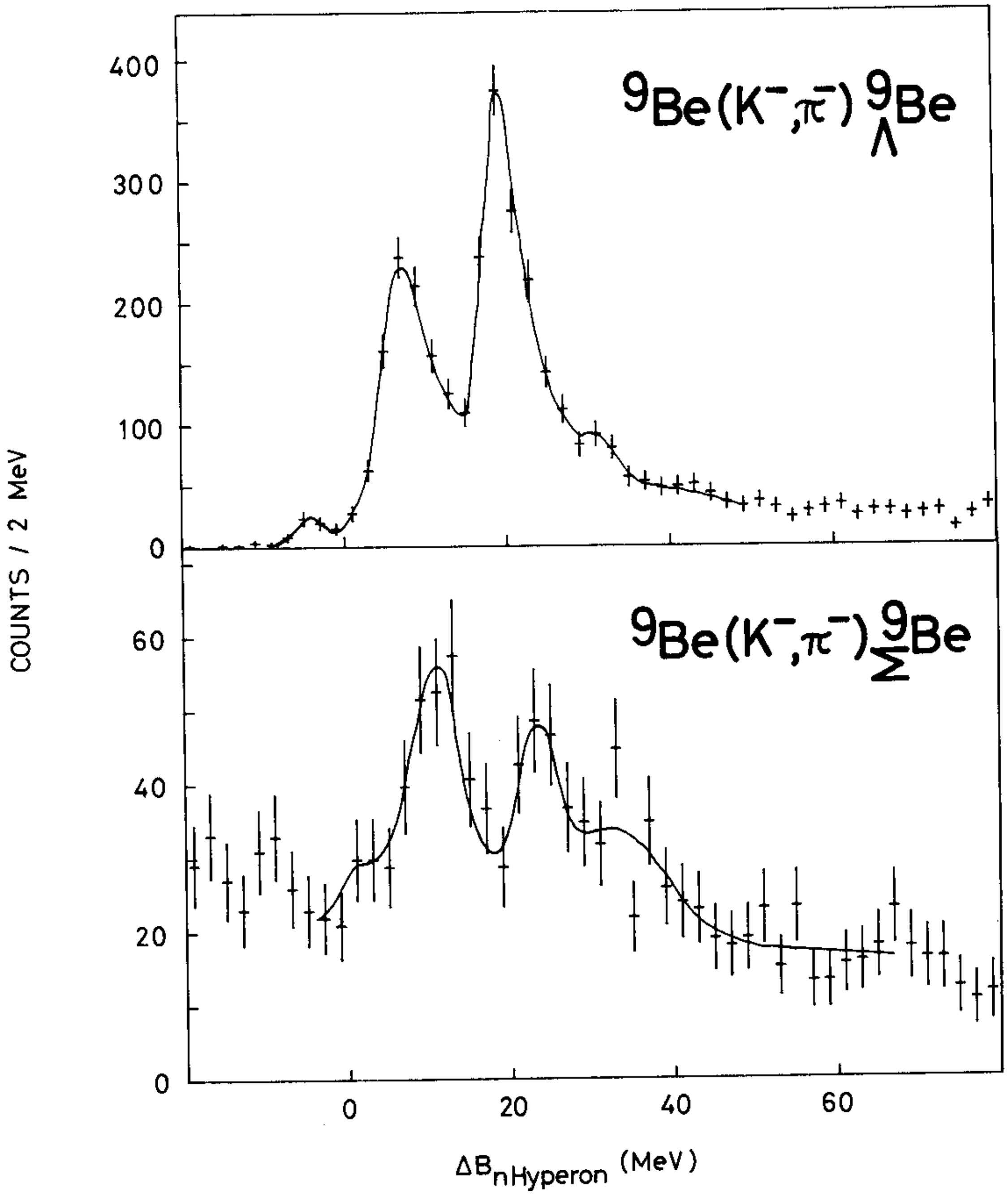
a
$2\pi \frac{d\sigma}{d\Omega}\Big|^{c.m.}_{0°}$
(mb/sr)
12
10
8
6
4
2
0
$K^-n \to \pi^-\Lambda$
$K^-p \to \pi^-\Sigma^+$
$K^-n \to \pi^-\Sigma^0$
720 MeV/c
b
HYPERON-RECOIL q_h (MeV/c)
200
150
100
50
0
$K^-n \to \pi^-\Sigma^0$
$K^-n \to \pi^-\Lambda$
100
200
300
400
500
600
700
800
900
1000
p_{K^-} (MeV/c)

Fig. 1



M_HY - M_A (MeV)
150
175
200
225
250
275
300
325
350
300
250
200
150
100
50
0
COUNTS / 2 MeV
9ΛBe
9ΛBe
80
40
0
20
0
-20
-40
BΛ (MeV)
9ΣBe
50
25
0
-25
-50
-75
-100
-125
-150
- 175
BΛ (MeV)

Fig. 2



$^9Be(K^-,\pi^-)^9_\Lambda Be$
$^9Be(K^-,\pi^-)^9_\Sigma Be$
COUNTS / 2 MeV
400
300
200
100
0
60
40
20
0
0
20
40
60
$\Delta B_{n\,Hyperon}$ (MeV)

Fig. 3