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SEARCH FOR Σ HYPERNUCLEI BY MEANS OF THE STRANGENESS-EXCHANGE REACTIONS (K^-,π^-) AND (K^-,π^+)

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ABSTRACT

In the (K^-,π^-) reaction performed at 720 MeV/c on ^{9}Be and ^{12}C, a narrow structure appears around 80 MeV excitation in the hypernuclear spectra, precisely where Σ hypernuclear states could be expected. Especially in ^{9}Be one finds a structure very similar to the Λ hypernuclear states, with peaks narrower than 8 MeV. Those are nearly bound states of Σ^0 in the nucleus.

The spectrum obtained by the (K^-,π^+) reaction on ^{9}Be also shows a structure which could be due to nearly bound states of Σ^- in the nucleus.

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In recent experiments[1,2] the (K^-,π^-) strangeness-exchange reaction has been successfully used to produce Λ hypernuclei. The main advantage of this reaction is the small recoil transferred to the Λ, which replaces a neutron in the same nuclear state without disturbing the residual nucleus. This process is called recoilless Λ production and found to be dominant for light nuclei[1,2]. It is the aim of this paper to show that, for ^9Be and ^{12}C, hypernuclear states exist where the constituent nucleon is replaced by a Σ^0 or a Σ^- particle. These states are sufficiently narrow to allow a study of the Σ-nucleus interaction.

Using a (K^-,π^-) or a (K^-,π^+) reaction trigger the following reactions on neutrons or protons of the nuclear targets may occur:

$$K^- + n \rightarrow \Lambda + \pi^- \qquad (1a)$$

$$K^- + n \rightarrow \Sigma^0 + \pi^- \qquad (1b)$$

$$K^- + p \rightarrow \Sigma^+ + \pi^- \qquad (1c)$$

$$K^- + p \rightarrow \Sigma^- + \pi^+ \qquad (2)$$

Our experiment was done at a kaon beam momentum of 720 MeV/c. At this momentum the cross-section for reaction (1c) is an order of magnitude smaller than that for (1b). Therefore a (K^-,π^-) trigger will show only Λ and Σ^0 hypernuclei. The (K^-,π^+) reaction, on the other hand, cannot produce Λ particles but only Σ^- particles.

The experiment took place at the low-momentum separated K beam (k_{22}) at the CERN Proton Synchrotron (PS). The experimental set-up has been described earlier[1] and consists essentially of two spectrometers, the first one for measuring the K^- momentum and the second one for the momentum of the outgoing pion at about 0°. This second spectrometer is the specially designed SPES II from Saclay. Its large momentum acceptance of $\Delta p/p = \pm 18\%$ gives the unique possibility of measuring simultaneously pions stemming from Λ and Σ^0 hypernuclear production in the same spectrum (see Fig. 1). The over-all energy resolution in this experiment is about 3 MeV, using ^9Be and ^{12}C targets of 2 g/cm^2 thickness. In addition to our (K^-,π^-) reaction trigger we used the signal of a scintillation counter which surrounded the target. This counter detected the fragmentation of a hypernucleus or the decay of the Λ, but not the three-body decay of the kaons near the target which is responsible for a low flat background. The $K \rightarrow 2\pi$ decay background was suppressed by geometrical cuts.

Figure 1 shows the (K^-,π^-) spectra taken on ^{9}Be and ^{12}C. At the top we indicate the transformation energy $(M_{Hy} - M_A)$ which is the Q-value of the strangeness-exchange reaction in transforming a nuclear ground state with mass M_A into a hypernuclear state with mass M_{Hy}. Σ^0 hypernuclei have to be found at a mass 76.87 MeV higher than the Λ hypernuclei. We also indicate the binding energy scales: $B_{\Sigma^0} = 0$ MeV corresponds to $B_\Lambda = -76.87$ MeV. Both spectra show in this region a clear enhancement due to Σ^0 hypernuclear production. The production of Λ hypernuclei is four times stronger than of Σ^0 hypernuclei, which is in agreement with the elementary cross-sections for the reactions (1a) and (1b).

In $^{12}_{\Lambda}$C the strong peak stems from recoilless Λ production on the $1p_{3/2}$ neutrons[1]. In $^{9}_{\Lambda}$Be the peak at $B_\Lambda = -6$ MeV is due to recoilless production on the loosely bound $1p_{3/2}$ neutron, whereas the second peak contains both recoilless strength from the strongly bound $1p_{3/2}$ neutron pair as well as from $1s_{1/2}$ neutrons[3]. Comparing the Λ and the Σ^0 spectra one finds for $^{12}_{\Sigma^0}$C a nearly disappearing recoilless peak. Such a behaviour is expected since the recoilless intensity has to decrease drastically with increased momentum transfer[4]. At 720 MeV/c the momentum transfer for the Σ production is about 130 MeV/c, but for the Λ it is only about 60 MeV/c. The clear similarity between the Λ and the Σ^0 spectra, especially for ^{9}Be, indicates that we see recoilless produced Σ^0 hypernuclear states. Their width of less than 8 MeV is surprisingly narrow, as the Σ particles can decay in nuclear matter via the $(\Sigma + N \rightarrow \Lambda + N)$ reaction, where an energy of about 80 MeV is released. There has been no reliable estimate of the lifetime of Σ particles in nuclei up to now.

The (K^-,π^+) spectrum for ^{9}Be shows a bump of about the same width as the total Σ^0 bump sitting above a shoulder which might be produced by free Σ^- production. In this bump one may see a small peak, which is statistically weak but nevertheless at the expected mass for recoilless produced Σ^- hypernuclear states. In order to compare Λ, Σ^0 and Σ^- hypernuclear spectra, one has to get rid of the hyperon and nuclear mass contribution in the transformation energy $(M_{Hy} - M_A)$. For that purpose we use in Fig. 2 the scale $\Delta_B = M_{Hy} - M_A - (M_{\Lambda,\Sigma} - M_{n,p}) = B_{n,p} - B_{\Lambda,\Sigma}$, where M means the masses and B the binding energy of the indexed particles. The peaks in the Σ^0 spectra are shifted by about 3 MeV towards higher Δ_B values. This indicates that the Σ-nucleus interaction differs from the Λ-nucleus one.

The Σ^- spectra are produced on the target protons. As expected, the Σ^- spectrum on the ^{9}Be target shows only one recoilless peak at a position where the Λ and the Σ^0 spectra contain the peak stemming from recoilless production on the $1p_{3/2}$ neutron pair and on the $1s_{1/2}$ neutrons.

So we conclude that the Σ-nucleus potential appears to be the same for Σ^0 and Σ^- hypernuclei. The data, however, are inadequate for deciding whether the difference between the Λ- and Σ-nucleus potential originates, from a different spin-orbit coupling or from a different central potential felt by the Λ and the Σ particles in the nucleus. Measurements at much lower kaon momentum are necessary to enhance the recoilless Σ production, but kaon beams with sufficient intensities at 300-400 MeV/c do not exist at present.

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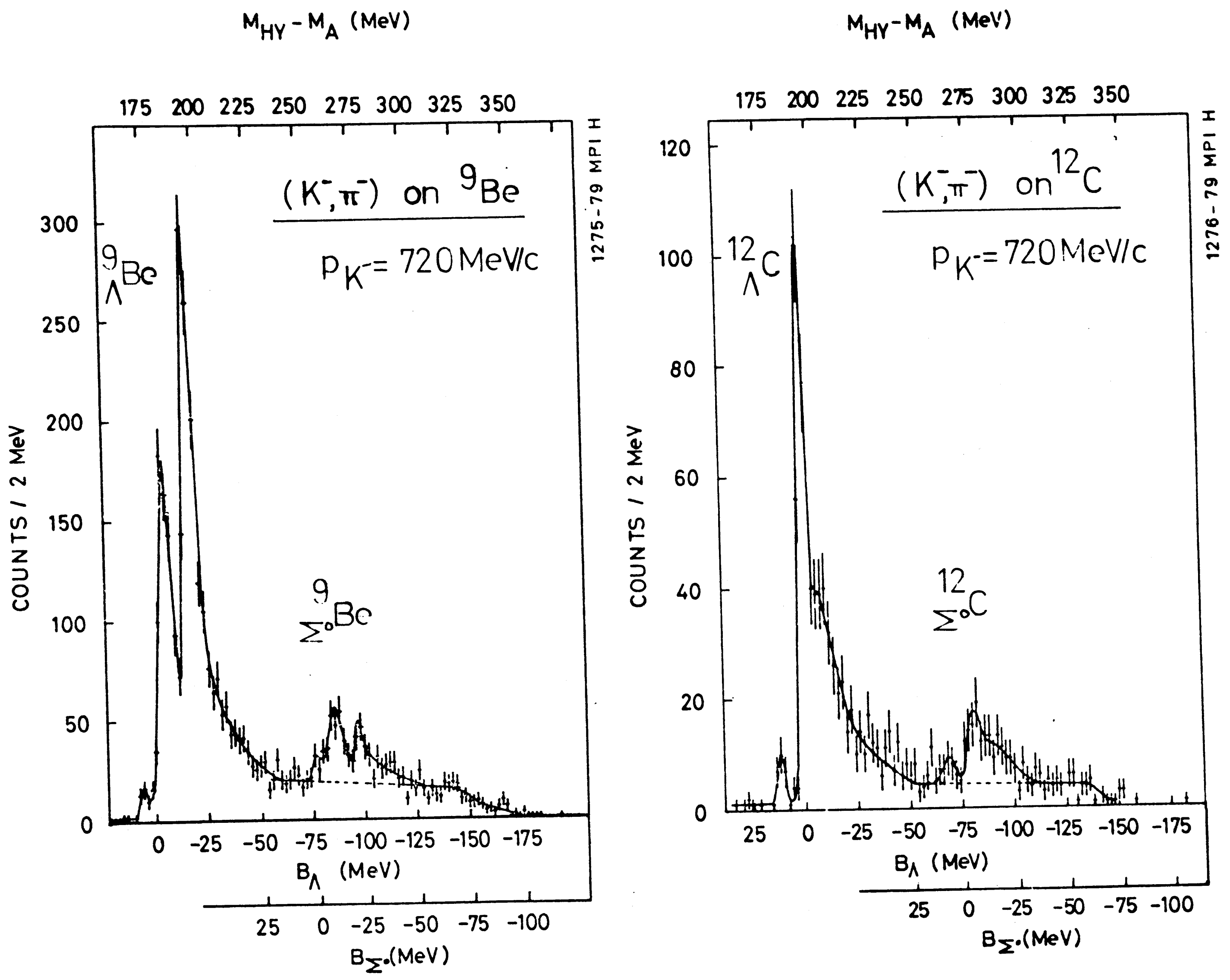
Figure captions:

Fig. 1 : (K^-,π^-) spectra taken at a kaon momentum of 720 MeV/c on ^{9}Be and ^{12}C. The transformation energy and the different binding energy scales are given.

Fig. 2 : Comparison of the Λ, Σ^0 and Σ^- hypernuclear spectra on ^{9}Be in the Δ_B scale.



M_HY - M_A (MeV)
175 200 225 250 275 300 325 350
(K⁻,π⁻) on 9Be
p_K⁻ = 720 MeV/c
9ΛBe
9Σ°Be
COUNTS / 2 MeV
0 50 100 150 200 250 300
0 -25 -50 -75 -100 -125 -150 -175
BΛ (MeV)
25 0 -25 -50 -75 -100
BΣ° (MeV)
1275-79 MPI H
M_HY - M_A (MeV)
175 200 225 250 275 300 325 350
(K⁻,π⁻) on 12C
p_K⁻ = 720 MeV/c
12ΛC
12Σ°C
COUNTS / 2 MeV
0 20 40 60 80 100 120
25 0 -25 -50 -75 -100 -125 -150 -175
BΛ (MeV)
25 0 -25 -50 -75 -100
BΣ° (MeV)
1276-79 MPI H

Fig. 1

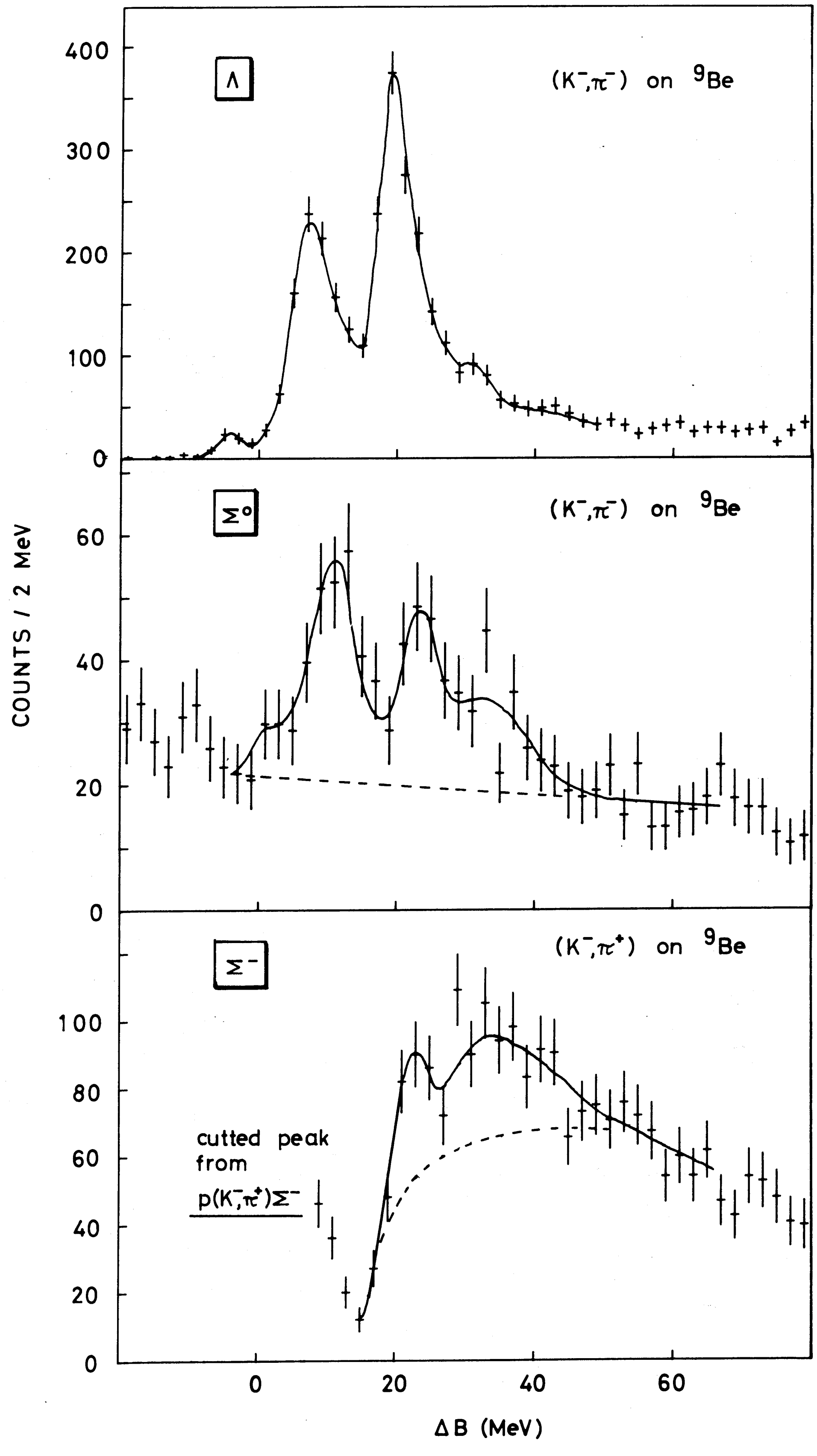

Λ
(K⁻,π⁻) on 9Be
Σ°
(K⁻,π⁻) on 9Be
Σ⁻
(K⁻,π⁺) on 9Be
cutted peak
from
p(K⁻,π⁺)Σ⁻
COUNTS / 2 MeV
ΔB (MeV)
0
20
40
60
100
200
300
400
80

Fig. 2