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PROPOSAL

SEARCH FOR Σ HYPERNUCLEAR STATES USING THE STRANGENESS EXCHANGE REACTIONS (K^-,π^-) AND (K^-,π^+)

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G E N E V A

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INTRODUCTION

In recent experiments[1,2] performed by our collaboration on the k22 beam 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 led to the deeper understanding of the single particle properties in nuclear matter.

It is quite natural to ask whether a similar spectroscopy is possible for other hypernuclei, in particular Σ hypernuclei. Obviously, the Σ hyperon can decay by strong interaction in the nucleus and we cannot expect long-lived Σ hypernuclear states. Nevertheless, Σ hypernuclear states could be sufficiently narrow to be identified.

It was therefore obvious that we tried also to look for Σ hypernuclei while measuring the Λ hypernuclei. The measurement was rather straightforward as the SPES II spectrometer (used for analysing the pion momenta) has a sufficiently large acceptance to cover the mass region of both Λ and Σ hypernuclei. The (K^-,π^-) and (K^-,π^+) data on ^{9}Be and ^{12}C are shown in Fig. 1 and indicate[3] that some Σ hypernuclear states have widths of less than 8 MeV. Furthermore, when the Σ hypernuclear spectra are compared to the Λ ones we can observe some similarities in their structures (Fig. 2). When the data are plotted in a transformation energy scale, the Σ hypernuclear spectra are shifted by about 3 MeV with respect to the Λ spectra. This indicates that the Σ-nucleus interaction differs from the Λ-nucleus one. It would be very interesting to determine to what extent this difference originates from a different spin-orbit coupling and from a different central potential for Λ and Σ in the nucleus. Much better data are needed for this investigation.

Experiment S154 has been performed at a kaon momentum of 720 MeV/c. At this momentum and if the pion is detected at 0^o, the momentum transferred to the Λ particle (q_Λ) is 50 MeV/c (Fig. 3). Under such kinematical conditions the Λ spectra are dominated by a few strong transitions to narrow hypernuclear states with the same spin and space quantum numbers as the ground state of the target nucleus. With increasing q_Λ, quasifree transitions to numerous hypernuclear states become important.[4] The quantum numbers of these states differ from those of the target nucleus.

The success of the Λ hypernuclear spectroscopy was to a large extent due to the proper choice of kinematical conditions (small q_Λ) so that in addition to the recoilless peaks only a few quasifree transitions were possible. The kinematics for Σ production, however, is quite different (Fig. 3). At 720 MeV/c the momentum transferred to the Σ particle (q_{Σ}) is 130 MeV/c. Even if the Σ hypernuclear states are narrow, so many quasifree states will be produced already in p-shell nuclei as to mask the recoilless Σ transitions. The probability for recoilless production drops fast with increasing transfer momentum as $e^{-aq_{\Sigma}^2}$. Therefore a much lower kaon momentum is necessary to enhance the recoilless Σ production.

At a lower momentum the kaon intensity drops very fast due to K^- decay. Therefore the beam length is the main parameter which determines the beam intensity, e.g. at 400 MeV/c 40% of the kaons decay in one meter. The k22 beam line was 20 m long and gave an intensity of 20 000 $K^-/1.3 \cdot 10^{12}$ at 720 MeV/c kaon momentum. But below 600 MeV/c the intensity was already too marginal to be used for hypernuclear productions. Therefore we propose an experiment which is almost identical to the previous one. The essential improvement, however, will be the use of a shorter beam line.

First studies show that a reasonable intensity can be achieved for kaons of 450 MeV/c by using a beam line of about 10 m length. At this kaon momentum q_{Σ} is 50 MeV/c (Fig. 3), i.e. the same as q_{Λ} in the previous experiment. We propose to measure the strangeness exchange reactions (K^-,π^-) and (K^-,π^+) in the range from 0^o to 5^o on five nuclear targets (^{6}Li, ^{7}Li, ^{9}Be, ^{12}C, ^{16}O). In addition we would like to measure $K^- + n \to \Lambda + \pi$ around 500 MeV/c. At this kaon momentum $q_{\Lambda} = 0$ and the recoilless hypernuclear transition can be more easily identified for heavier targets. We also want to search for possible strange dibaryon states in the reaction $K^- + d \to \Lambda + p + \pi^-$.

EXPERIMENTAL SETUP

Kaon Beam

The conception of the new beam line is based on the search for the shortest possible length. First studies have shown that a beam line of about 10 m length and a maximum kaon momentum of 550 MeV/c is feasible.

For the (K^-,π^-) reaction at 500 MeV/c and below it is of particular importance to have a good pion suppression because beam and background pions and reaction pions have almost equal momentum. Therefore the new beam line has to optimize additionally (i) the K/π separation and (ii) the K spot size at the target. A small spot at the target allows to use a small time-of-flight detector and helps to suppress the unfocused pion background. Studies have demonstrated that both requirements make secondorder corrections of imaging aberrations mandatory. This together with the short length requires the construction of at least two special dipole magnets.

One of the possible solutions for a short beam is shown in Fig. 4. The beam line includes two magnets with 60^{o} deviation each instead of 30^{o} in k22, and three quadrupoles instead of nine. The separation between K and π is improved by the correction of the aberrations. A separator with crossed magnetic and electric fields will save place and avoid the vertical bending of the kaon beam between the electrodes.

Momentum Measurement

The K^{-} momentum is determined by measuring the particle position in the mass/momentum slit with a hodoscope of plastic scintillation counters (like in the k22 and k25 beams) and by the trajectories in the multiwire proportional chambers W1, W2. We are also considering to measure the entrance trajectories by pulsed wire chambers, provided the PS spill can be made 1 sec. instead to 300 msec. now. This would also reduce random coincidences.

The pion spectrometer will be the SPES II of Saclay (momentum acceptance ±18%, angular acceptance 20 msr) or a similar apparatus. The momentum of the pions is determined by the trajectories in the wire chambers W3, W4 and W5, W6, W7.

We are aiming at an overall resolution of 2 MeV/c. The resolution will be determined by the target thickness.

Reaction Trigger

(i) The time of flight between the scintillation counters P1-P2 and P2-P3 defines a K,π event.

(ii) The energy loss in the scintillation counters P1, P2, P3 can be used to discriminate between K and π.

(iii) Liquid-hydrogen Čerenkov counters before and after the target restrict the volume where the reaction can occur. Č1 vetoes beam pions and Č2 triggers reaction pions.

(iv) The vertex of the kaon trajectory measured in front of the target and the pion trajectory measured after the target is required to lie within the target volume.

(v) The measured trajectories at the entrance of the pion spectrometer are compared with their values reconstructed from the exit coordinates.

(vi) Muons and electrons from three-body decays of the kaons will be vetoed by counters at the exit.

Counting Rates

According to measurements taken with the k22 and k25 beams the expected rates for a 10 m beam line and per $3 \cdot 10^{12}$ protons on a 3 cm tungsten production target are:

at 500 MeV/c	75000 K^-	$\pi/K \approx 5$
at 450 MeV/c	40000 K^-	$\pi/K \approx 10$

Our goal is to get about the same statistics for Σ hypernuclei per target that we obtained for Λ hypernuclei at the k22 beam. Taking into account the smaller cross section for Σ production (factor of three) we need about 10^{10} kaons per target and reaction.

40000 K^-/burst amount to about 10^9 K^- per day. Together with calibration measurements each target requires four weeks.

BEAM TIME REQUEST

for setting up	1 period
for Σ hypernuclei	6 periods
for Λ hypernuclei	1 period
for the dibaryon measurement	1 period
total	9 periods

REQUIREMENTS

(i) The beam line is expected to be provided by CERN as well as the power supplies for the spectrometer.

(ii) A PS spill of 1 sec duration should be aimed at during this experiment.

(iii) For the two liquid hydrogen Cerenkov counters and also for the liquid oxygen and deuterium targets we need the target cooling generator now used in S163.

(iv) The spectrometer will be supplied by the Saclay group.

(v) Wire chambers, counters, part of the electronics and on-line computer will be provided by the Heidelberg group.

(vi) From the electronics pool we need electronic modules of a total value of 250 KSF which are at present in experiment S163.

(vii) An off-line cross check of the data and a data concentration requires 40 h of CP time on the IBM computers at CERN. The data analysis will be performed at Heidelberg and Saclay.

TIMETABLE

We intend to run the experiment after the shutdown in 1980.

REFERENCES

(1) W. Brückner et al., Phys. Lett. 79B, 157 (1978)
(2) R. Bertini et al., Phys. Lett. 83B, 306 (1979)
(3) W. Brückner et al., CERN-EP/79-97, to be published
(4) B. Povh, Z. Phys. A279, 159 (1976)

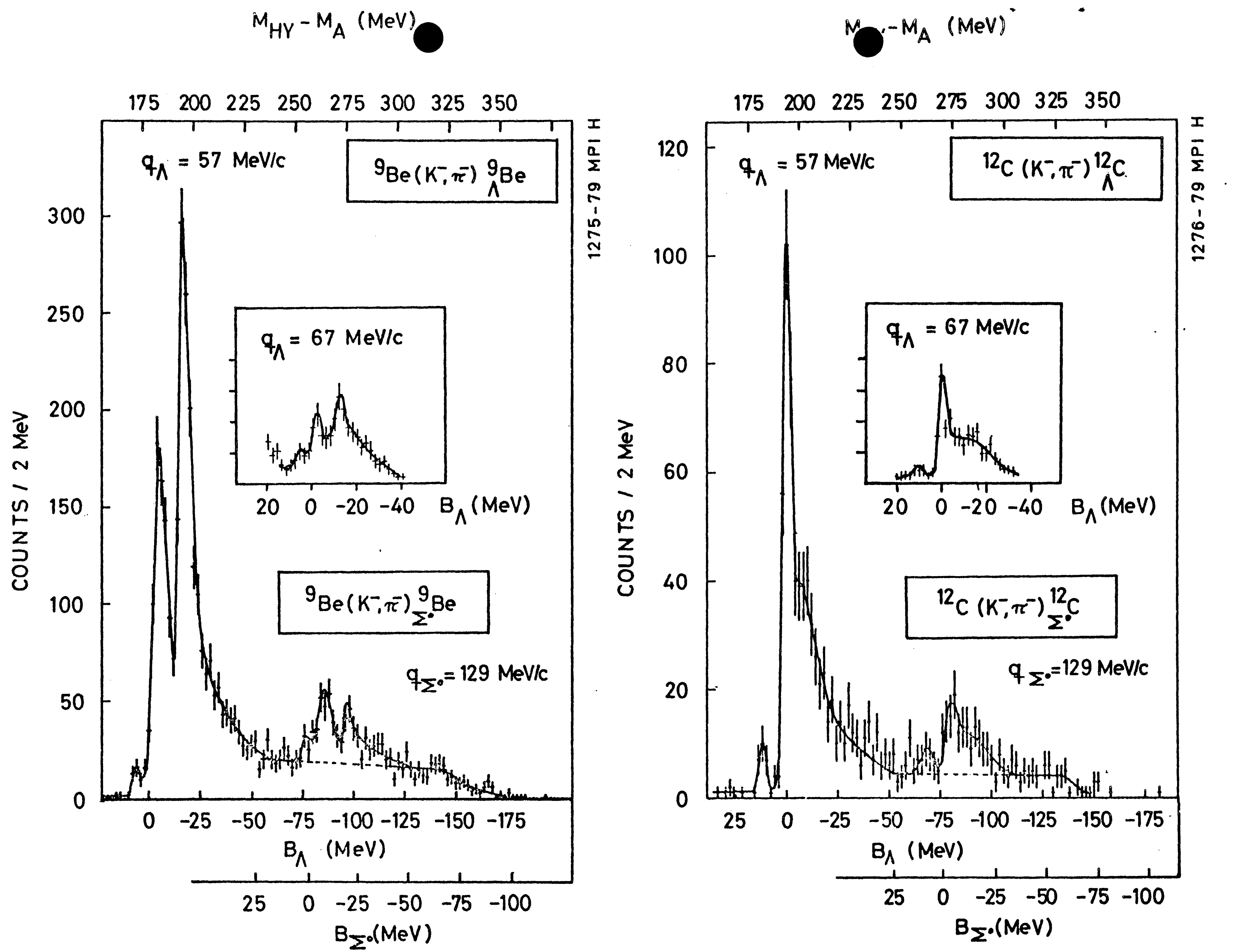
FIGURES

(1) (K^-,π^-) spectra taken at a kaon momentum of 720 MeV/c on ^9Be and ^{12}C. We indicate the transformation energy $M_{HY}-M_A$, where M_{HY} is the mass of the hypernucleus and M_A the mass of the target nucleus. Also the binding energy scales for Λ and Σ^o hypernuclei are given.

(2) Comparison of the Λ, Σ^o, Σ^- hypernuclear spectra on ^9Be. The scale $\Delta B = M_{HY} - M_A - (M_{\Lambda,\Sigma} - M_{n,p})$, where M denotes the masses of the indexed particles.

(3) Kinematics of the $K^- + n \rightarrow \Lambda + \pi^-$ and the $K^- + n \rightarrow \Sigma^o + \pi^-$ reactions. The momentum transferred to the strange particle is plotted as a function of the kaon momentum. The momentum regions of the hypernuclear experiments performed at CERN are indicated.

(4) Experimental setup (P1,P2,P3 - scintillation counters; W1,..., W7 - wire chambers; C_1,C_2 - liquid-hydrogen Cerenkov counters).



$M_{HY} - M_A$ (MeV)
q_Λ = 57 MeV/c
$^9Be(K^-,\pi^-)^9_\Lambda Be$
q_Λ = 67 MeV/c
B_Λ (MeV)
$^9Be(K^-,\pi^-)^9_{\Sigma^0} Be$
q_{Σ^0} = 129 MeV/c
COUNTS / 2 MeV
B_Λ (MeV)
B_{Σ^0} (MeV)
1275-79 MPI H
$M_{HY} - M_A$ (MeV)
q_Λ = 57 MeV/c
$^{12}C(K^-,\pi^-)^{12}_\Lambda C$
q_Λ = 67 MeV/c
B_Λ (MeV)
$^{12}C(K^-,\pi^-)^{12}_{\Sigma^0} C$
q_{Σ^0} = 129 MeV/c
COUNTS / 2 MeV
B_Λ (MeV)
B_{Σ^0} (MeV)
1276-79 MPI H

FIG. 1

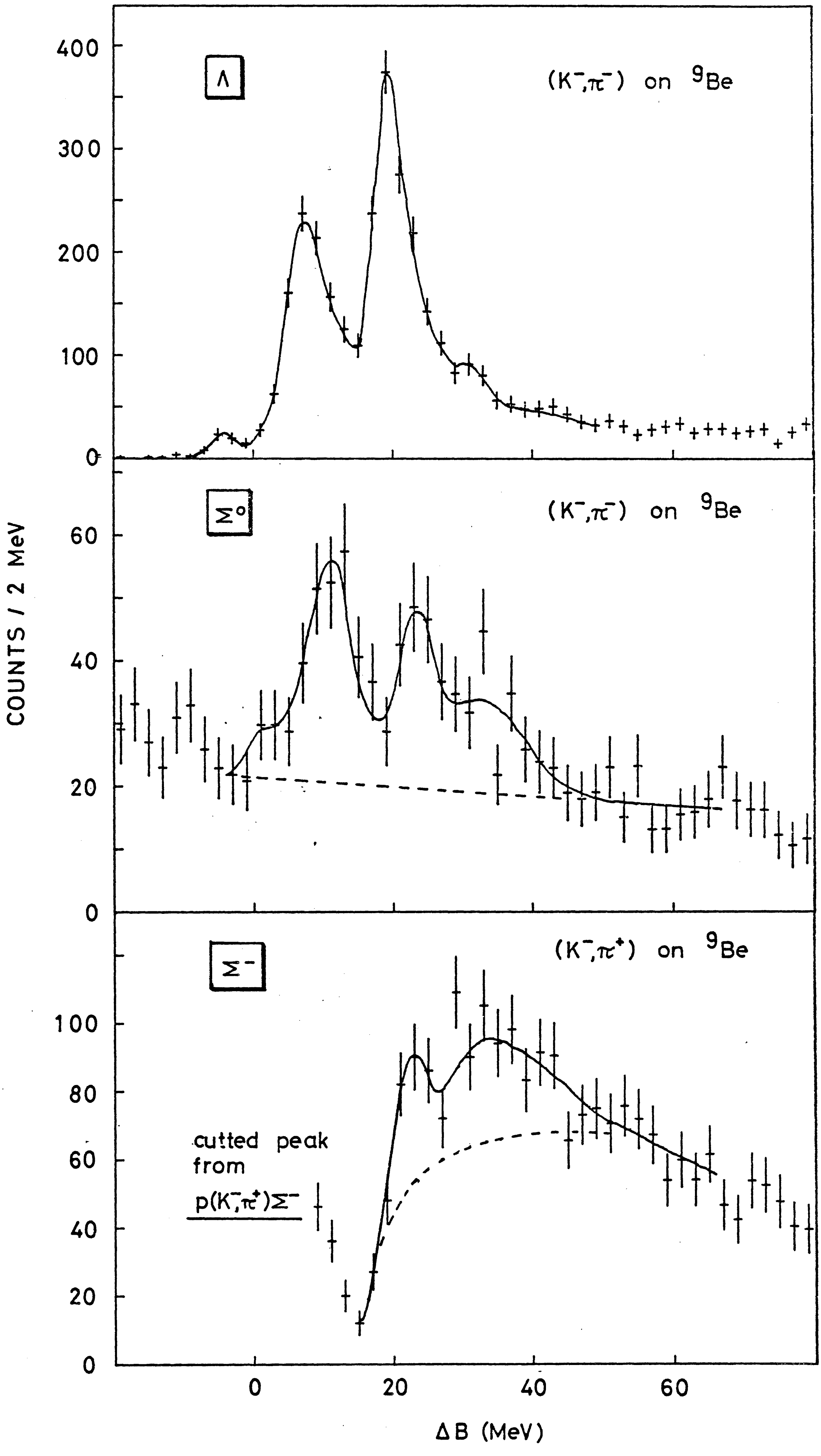

Λ
(K⁻,π⁻) on 9Be
Σ°
(K⁻,π⁻) on 9Be
Σ⁻
(K⁻,π⁺) on 9Be
cutted peak
from
p(K⁻,π⁺)Σ⁻
COUNTS / 2 MeV
400
300
200
100
0
60
40
20
0
100
80
60
40
20
0
0
20
40
60
ΔB (MeV)

FIG. 2

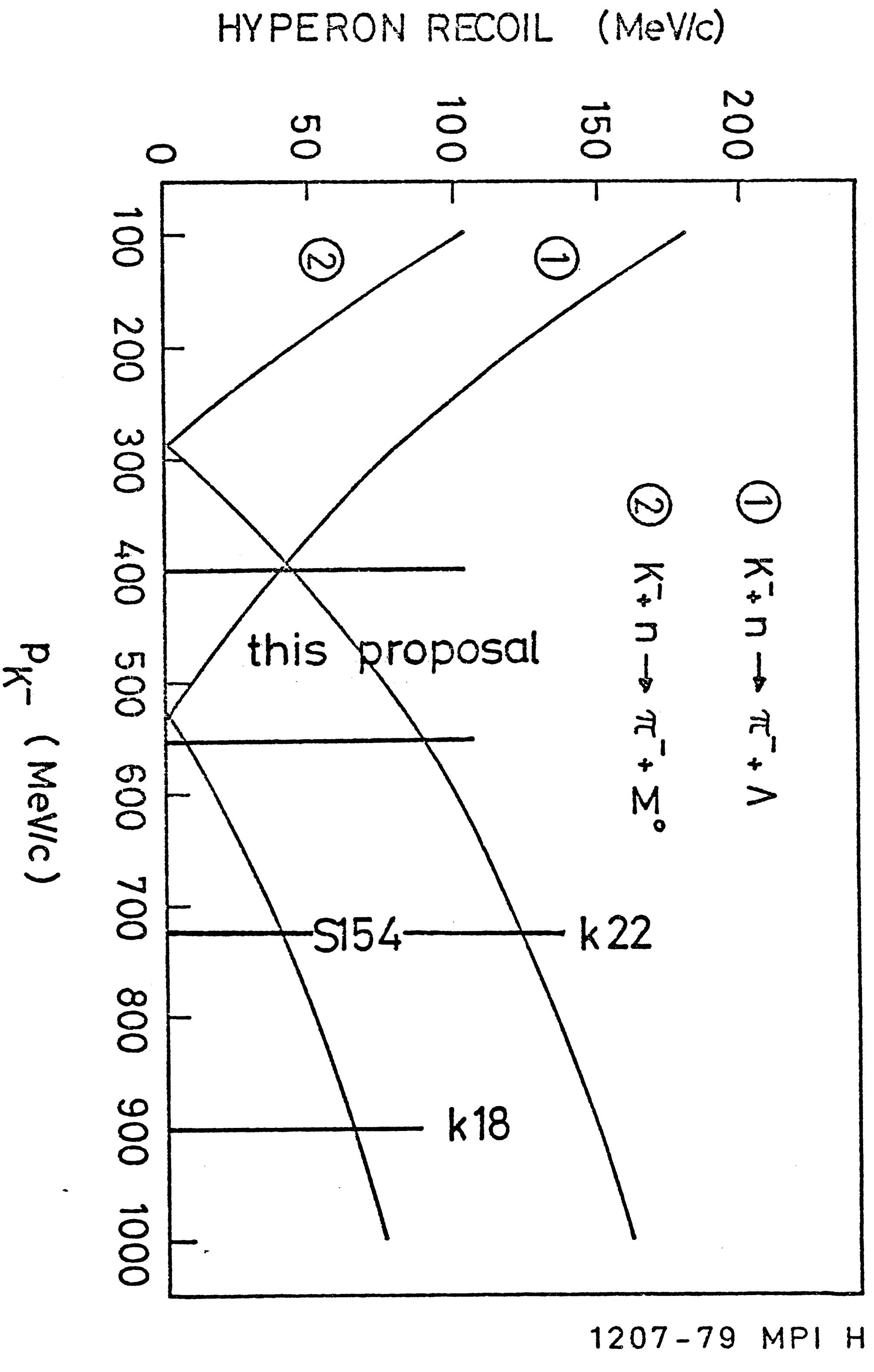

HYPERON RECOIL (MeV/c)
0
50
100
150
200
100
200
300
400
500
600
700
800
900
1000
p_{K^-} (MeV/c)
① $K^- + n \to \pi^- + \Lambda$
② $K^- + n \to \pi^- + M^0$
①
②
this proposal
S154
k22
k18
1207-79 MPI H

FIG. 3

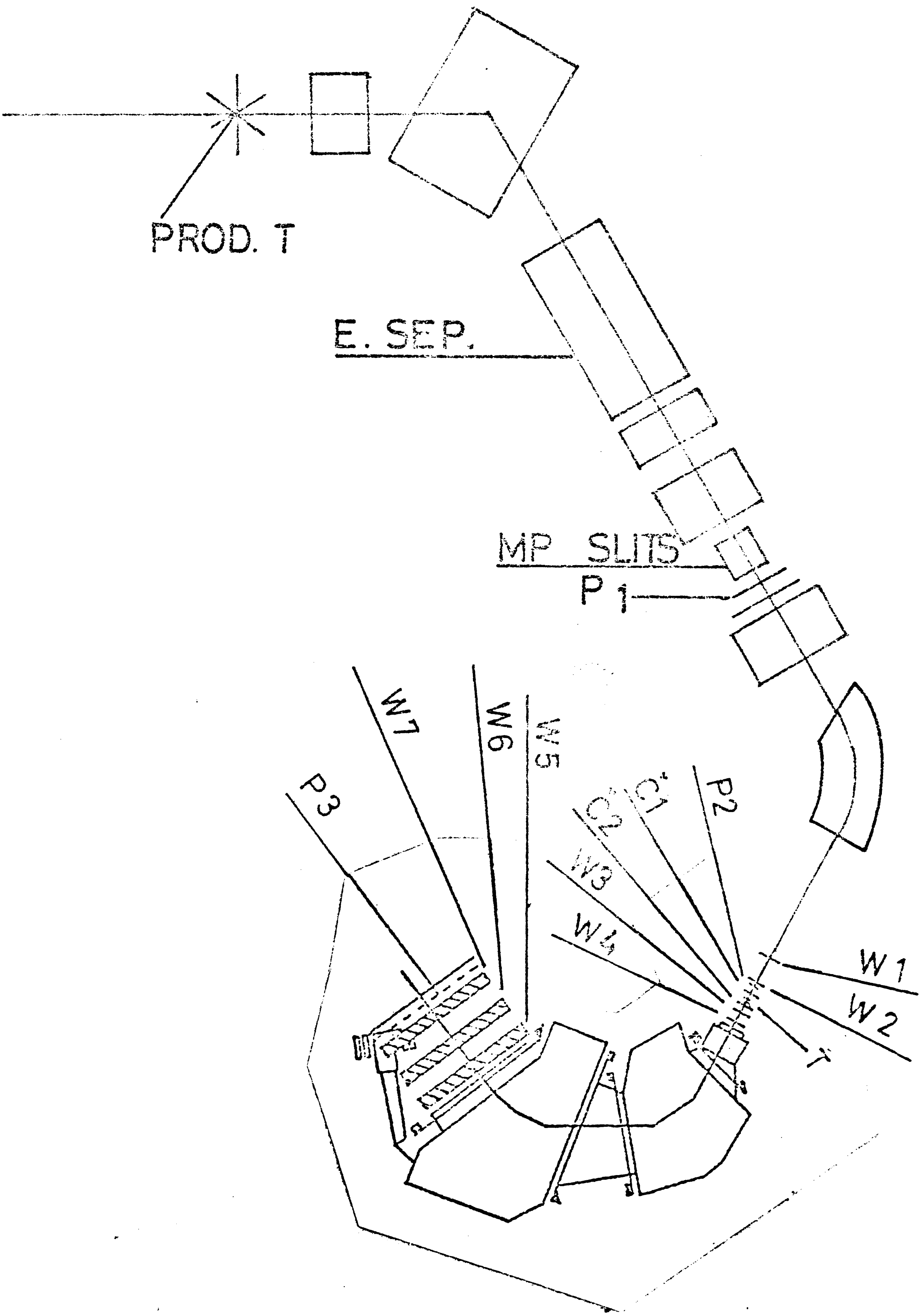


FIG. 4