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73

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T. Bressani, E. Chiavassa and C. Rubbia[(x)]: A MISSING-MASS EXPERIMENT FOR THE STUDY OF HYPERNUCLEI PRODUCTION BY K^- INTERACTIONS IN FLIGHT.

INTRODUCTION -

Recently an intense beam of K^- of low momentum has been installed at the CERN PS[(1)], and experiments on hypernuclear structures must now be carried with counter techniques. The first one which has been proposed is an investigation of the γ-rays following the capture of a K^- at rest, from a hydrogen-like orbit[(2)].

This kind of experiments can reveal important features of hypernuclear excited states; however, some points have to be stressed.

1) γ-ray spectroscopy is unable to measure the binding energy of the hyperon, usually called B_Λ. The measurement of the B_Λ values for different hypernuclei has been carried out until now with emulsion techniques, from ${}^3_\Lambda H$ to ${}^{13}_\Lambda C$, and it would be interesting to continue these measurements for other hypernuclei.

2) only some states of hypernuclei which are stable against particle decay can be studied by γ-ray spectroscopy, but nothing can be learnt about the highly-excited unstable states, which disintegrate with emission of a nucleon or other heavier particles, the existence of which has been predicted some time ago[(3)]. In fact one of these cases, the 11-MeV state for ${}^{12}_\Lambda C$, has been ascertained[(4)].

3) for hypernuclei heavier than ${}^{12}_\Lambda C$ one should expect high production rates only for the excited states with high angular momenta if

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(x) - CERN

the K^- are captured mainly from the d states[5].

We note that in the capture of a K^- at rest the momentum of the Λ produced is of the order of 250 MeV/c, and that the production of hyper nuclei in two-body reactions falls very fast with the increasing of the mass number (from $\sim 2\%$ for ^4He to $\sim 0.3\%$ for ^{12}C). A process in which a Λ can be formed with a lower momentum is the reaction:

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

with K^- in flight and π^- at forward angles. Fig. 1 gives the main kinematical features of the reaction (1) in the angular range of interest. We see that the momentum of the emitted π^- varies very slowly, and is smaller than the incident K^- momentum p_k until this last one is greater than ~ 550 MeV/c, and greater for $p_k < 550$ MeV/c. The Λ momenta vary faster with the π^- emission angle, but are always less than ~ 80 MeV/c for $\vartheta_{\pi_{Lab.}} < 6^o$. These properties are a consequence of the fact that the reaction (1) is strongly esothermic (Q = 178.19 MeV) and, for $p_k > 550$ MeV/c, the center of mass velocity is greater than the incident K^- velocity, so the Λ emitted backward in the center of mass frame goes forward in the lab. frame.

We propose then to study hypernuclear states using the process:

(2) K^- + (nucleus) $\longrightarrow$ (hypernucleus) + π^-

with K^- in flight and π^- at forward angles.

We recall that this reaction has been proposed by Dalitz[6] as a tool for studying hypernuclear excited states. The determination of the hypernuclear levels can be obtained from direct kinematical analysis (missing mass). If the hypernuclei production rate in the reaction (2) will be high, the observation of γ rays in coincidence will be essential for the determination of more complex decay schemes.

EXPECTED EVENT RATES -

The production of hypernuclei (2) can be described as a result of the reaction (1) on a bound neutron, in which the Λ remains trapped in the parent nucleus. Selecting events in which the π^- is emitted within $\sim 6^o$ from the forward direction, one selects Λ's with a low re coil momentum, as said before. We can very crydely estimate the differen tial cross-section for the reaction (2) $(d\sigma/d\Omega)_{Hyp.}$ by the relation(x):

(x) - We assumed an incoherent production.

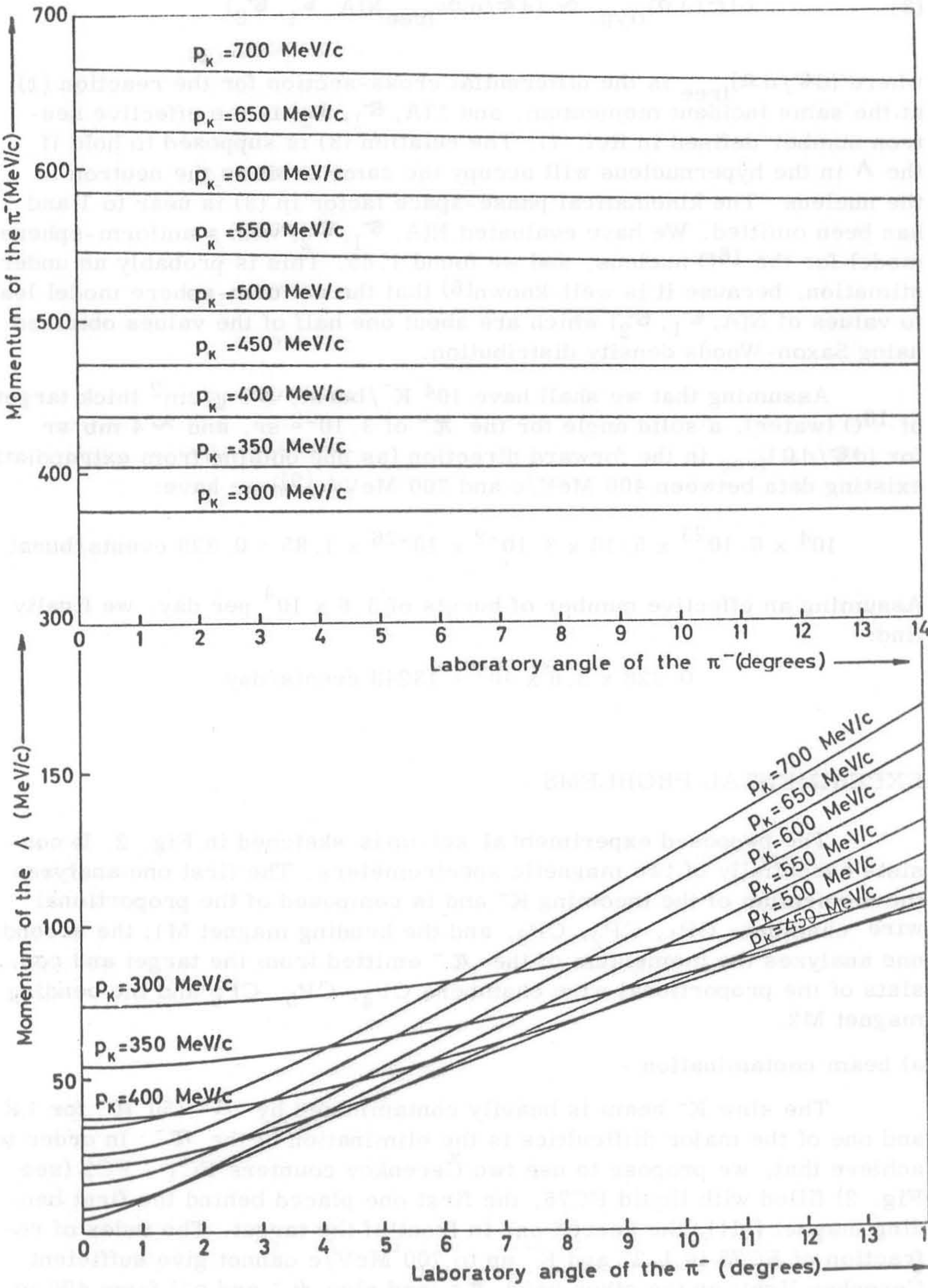

FIG. 1 - Momenta of the Λ and the π^- from the reaction $K^- + n \rightarrow \Lambda + \pi^-$ as a function of the π^- angle, for different incident momenta p_K. All the quantities are in the lab. frame.

(3) $$(d\sigma/d\Omega)_{Hyp.} \simeq (d\sigma/d\Omega)_{free} N(A, \sigma_1, \sigma_2)$$

where $(d\sigma/d\Omega)_{free}$ is the differential cross-section for the reaction (1) at the same incident momentum, and $N(A, \sigma_1, \sigma_2)$ is the effective neutron number defined in Ref. 7). The relation (3) is supposed to hold if the Λ in the hypernucleus will occupy the same orbit as the neutron in the nucleus. The kinematical phase-space factor in (3) is near to 1 and has been omitted. We have evaluated $N(A, \sigma_1, \sigma_2)$ with a uniform-sphere model for the ^{16}O nucleus, and we found 1.85. This is probably an underestimation, because it is well-known(8) that the uniform-sphere model leads to values of $N(A, \sigma_1, \sigma_2)$ which are about one half of the values obtained using Saxon-Woods density distribution.

Assuming that we shall have 10^4 K^-/burst, a 5 g/cm^2 thick target of ^{16}O (water), a solid angle for the π^- of 3.10^{-2} sr, and ~ 4 mb/sr for $(d\sigma/d\Omega)_{free}$ in the forward direction (as one obtains from extrapolating existing data between 400 MeV/c and 700 MeV/c(9)) we have:

$$10^4 \times 6.10^{23} \times 5/18 \times 3.10^{-2} \times 10^{-26} \times 1.85 = 0.328 \text{ events/burst}$$

Assuming an effective number of bursts of 3.6×10^4 per day, we finally find:

$$0.328 \times 3.6 \times 10^4 = 13248 \text{ events/day.}$$

EXPERIMENTAL PROBLEMS -

The proposed experimental set-up is sketched in Fig. 2. It consists essentially of two magnetic spectrometers. The first one analyses the momentum of the incoming K^- and is composed of the proportional wire chambers CP_1, CP_2, CP_3, and the bending magnet M1; the second one analyzes the momentum of the π^- emitted from the target and consists of the proportional wire chambers CP_4, CP_5, CP_6 and the bending magnet M2.

a) beam contamination -

The slow K^- beam is heavily contaminated by π^- (50 π^- for 1 K^-) and one of the major difficulties is the elimination of the π^-. In order to achieve that, we propose to use two Čerenkov counters FC1 - FC2 (see Fig. 2) filled with liquid FC75, the first one placed behind the first bending magnet (M1), the second one in front of the target. The index of refraction of FC75 is 1.27 and K^- up to 700 MeV/c cannot give sufficient Čerenkov light; on the other hand π^- (and also μ^- and e^-) from 400 to 700 MeV/c produce Čerenkov light. Thus a coincidence $(C_1 \overline{FC}_1 \overline{FC}_2 C_2)$ will characterize a K^-. FC1 will have a large radiating thickness, to en

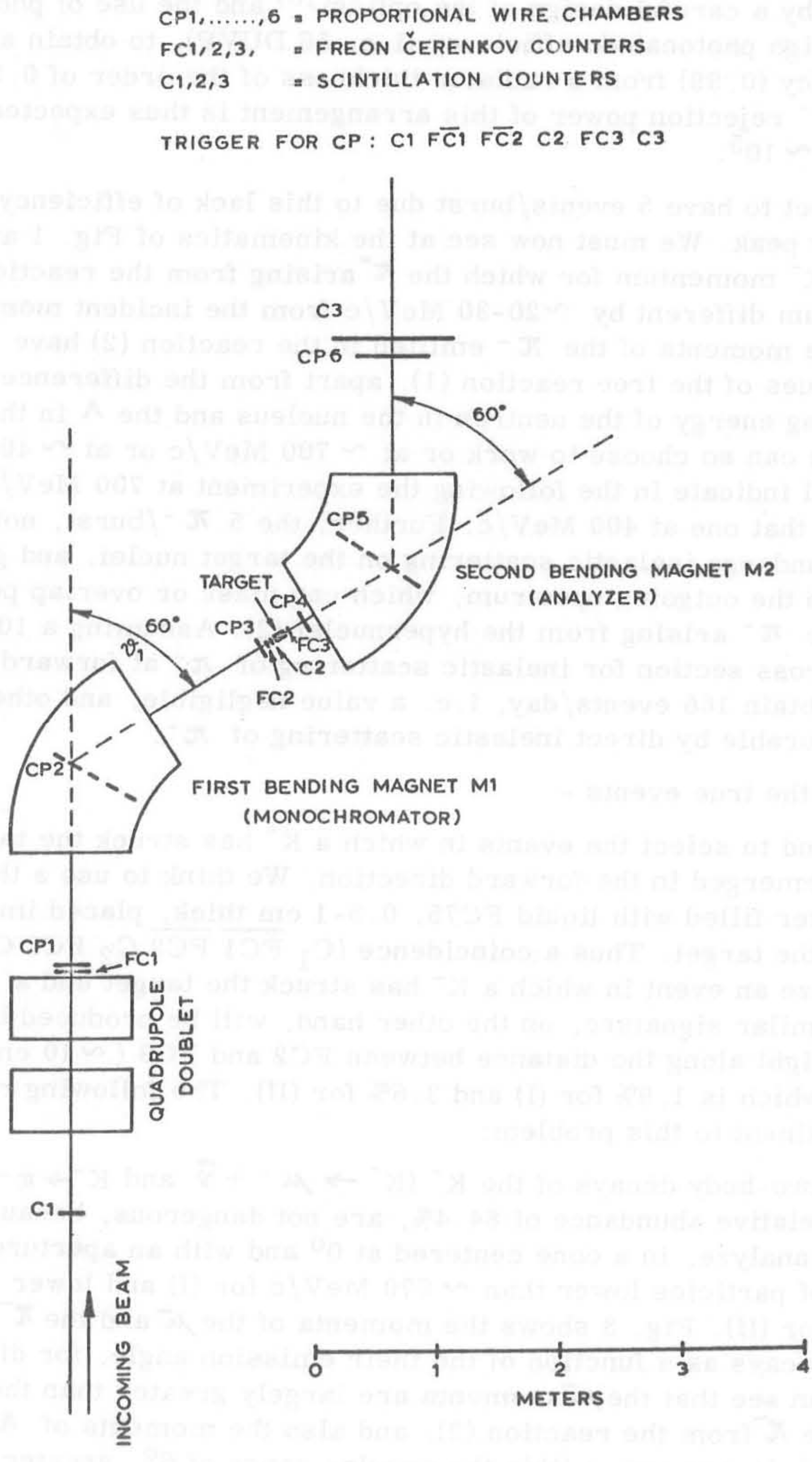

FIG. 2 - Sketch of the proposed experimental set-up.

sure a good efficiency for π^- (0,999); the thickness of FC2 will be necessarily reduced to minimize the production of background events and we can expect, by a careful design of the optics[10] and the use of photomultipliers of high photocatode efficiency (i.e. 56 DUVP), to obtain a reasonable efficiency (0.99) from a radiator thickness of the order of 0.5 - - 1 cm. The π^- rejection power of this arrangement is thus expected to be of the order of $\sim 10^5$.

We expect to have 5 events/burst due to this lack of efficiency, grouped in a narrow peak. We must now see at the kinematics of Fig. 1 and choose an incident K^- momentum for which the π^- arising from the reaction (2) have a momentum different by $\sim$20-30 MeV/c from the incident momentum. We note that the momenta of the π^- emitted in the reaction (2) have values close to the values of the free reaction (1), apart from the difference between the binding energy of the neutron in the nucleus and the Λ in the hypernucleus. We can so choose to work or at $\sim$ 700 MeV/c or at $\sim$ 400 MeV/c. We will indicate in the following the experiment at 700 MeV/c with (I) and with (II) that one at 400 MeV/c. Further, the 5 π^-/burst, not recognized, can undergo inelastic scattering on the target nuclei, and give rise to peaks in the outgoing spectrum, which can mask or overlap peaks produced by the π^- arising from the hypernuclei (2). Assuming a 100 mb/sr value for the cross section for inelastic scattering of π^- at forward angles we shall obtain 166 events/day, i.e. a value negligible, and otherwise easily measurable by direct inelastic scattering of π^-.

b) Signature of the true events -

We intend to select the events in which a K^- has struck the target and a π^- has emerged in the forward direction. We think to use a third Čerenkov counter filled with liquid FC75, 0.5-1 cm thick, placed immediately behind the target. Thus a coincidence ($C_1\ \overline{FC1}\ \overline{FC2}\ C_2\ FC3\ C_3$) will characterize an event in which a K^- has struck the target and a π^- emerged. A similar signature, on the other hand, will be produced by K^- decays in flight along the distance between FC2 and FC3 ($\sim$10 cm), the amount of which is 1.9% for (I) and 3.6% for (II). The following remarks are pertinent to this problem:

(i) the two-body decays of the K^- ($K^- \rightarrow \mu^- + \bar{\nu}$ and $K^- \rightarrow \pi^- + \pi^0$) which total a relative abundance of 84.4%, are not dangerous, because our apparatus will analyze, in a cone centered at 0^o and with an aperture of 6^o, momenta of particles lower than $\sim$ 670 MeV/c for (I) and lower than $\sim$430 MeV/c for (II). Fig. 3 shows the momenta of the μ^- and the π^- from the two-body decays as a function of the their emission angle, for different p_k. We can see that the μ^- momenta are largely greater than the momenta of the π^- from the reaction (2), and also the momenta of π^- arising from K^- decays are, within the angular range of 6^o, greater by almost 20 MeV/c than those of the π^- from the reaction (2).

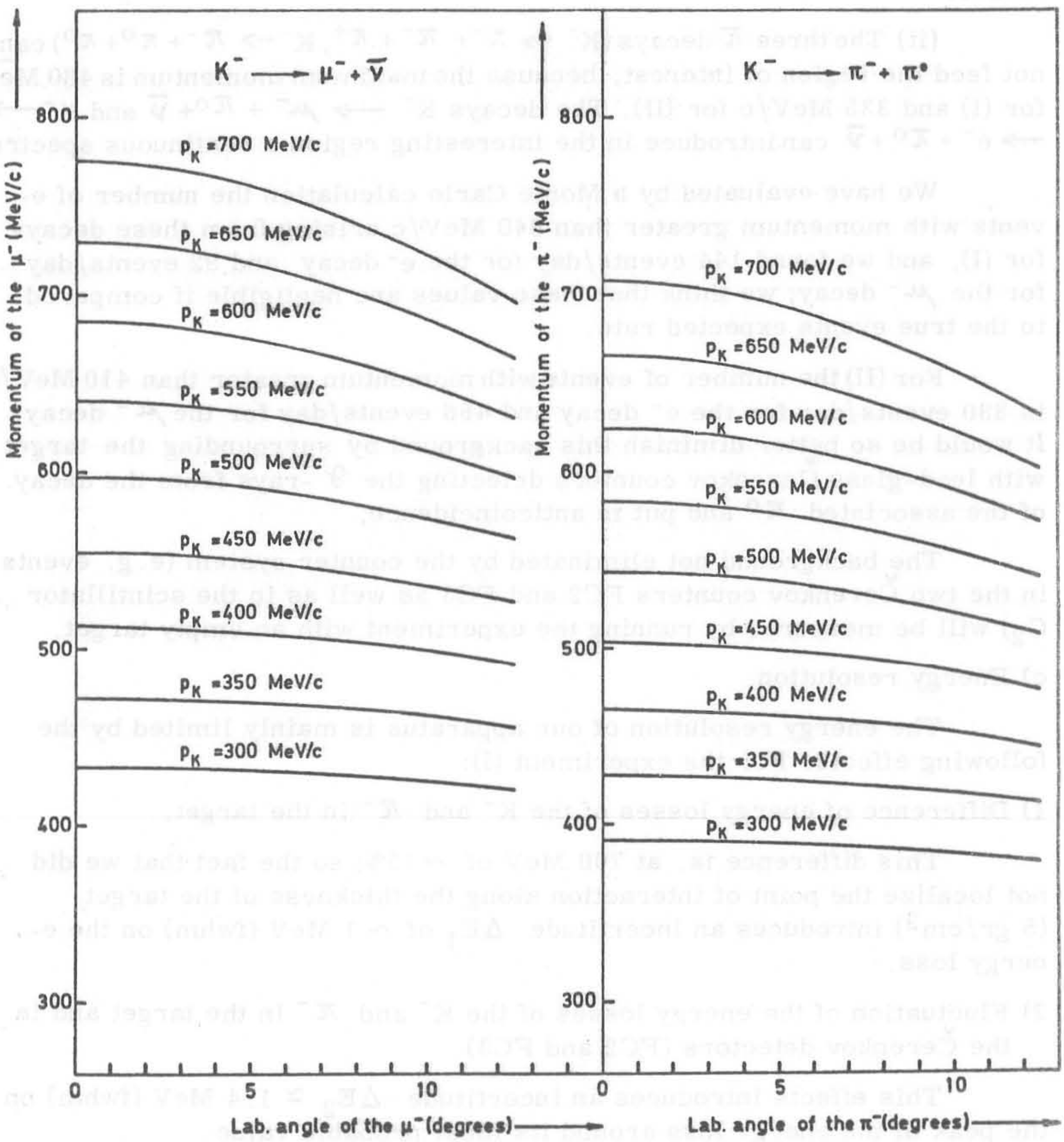

FIG. 3 - Momenta of the μ^- from the decay $K^- \to \mu^- + \bar{\nu}$ and of the π^- from the decay $K^- \to \pi^- + \pi^0$ as a function of their emission angle, for different incident momenta p_K. All the quantities are in the lab. frame.

The r.m.s. projected angle due to multiple Coulomb scattering in the target is of the order of 30', so this effect changes negligibly the above values.

(ii) The three π decays ($K^- \rightarrow \pi^- + \pi^- + \pi^+$, $K^- \rightarrow \pi^- + \pi^0 + \pi^0$) can not feed the region of interest, because the maximum momentum is 480 MeV/c for (I) and 335 MeV/c for (II). The decays $K^- \rightarrow \mu^- + \pi^0 + \bar{\nu}$ and $K^- \rightarrow e^- + \pi^0 + \bar{\nu}$ can introduce in the interesting region a continuous spectrum.

We have evaluated by a Monte Carlo calculation the number of events with momentum greater than 640 MeV/c arising from these decays for (I), and we found 144 events/day for the e^- decay and 92 events/day for the μ^- decay; we think that these values are negligible if compared to the true events expected rate.

For (II) the number of events with momentum greater than 410 MeV/c is 330 events/day for the e^- decay and 466 events/day for the μ^- decay. It would be so better diminish this background by surrounding the target with lead-glass Čerenkov counters detecting the γ-rays from the decay of the associated π^0 and put in anticoincidence.

The background not eliminated by the counter system (e.g. events in the two Čerenkov counters FC2 and FC3 as well as in the scintillator C_2) will be measured by running the experiment with an empty target.

c) Energy resolution.

The energy resolution of our apparatus is mainly limited by the following effects. For the experiment (I):

1) Difference of energy losses of the K^- and π^- in the target.

This difference is, at 700 MeV of $\sim 15\%$; so the fact that we did not localize the point of interaction along the thickness of the target (5 gr/cm^2) introduces an incertitude ΔE_1 of ~ 1 MeV (fwhm) on the energy loss.

2) Fluctuation of the energy losses of the K^- and π^- in the target and in the Čerenkov detectors (FC2 and FC3).

This effects introduces an incertitude $\Delta E_2 \simeq 1.4$ MeV (fwhm) on the peak of the energy loss around its most probable value.

3) Instrumental effect due to the precision with which our system determines the trajectory of a particle. In fact, our system consists of two magnets (each of them with a ~ 1 m long and 30 cm wide gap and a magnetic field of 18 KGa), with two sets of proportional wire chambers with a spatial resolution of $\pm$ 0.5 mm. Thus the momentum resolution will amount to 1.7 MeV for the π^-'s and 1 MeV for the K^-'s.

In conclusion, the total energy resolution on the determination of the hypernuclear levels will be:

$$\Delta E \simeq 2.6 \text{ MeV}$$

This is sufficient for the scope of the experiment.

For the experiment (II):

1) the difference between the specific ionization dE/dx of K^- and π^- of 400 MeV/c is of the order of 90% and the corresponding incertitude on the energy loss, without detection of the interaction point along the beam axis, is too big for a target of 5 gr/cm^2. If a reduction of the true counting rates is acceptable, a target of 1 gr/cm^2 can be used. Alternatively we can use a 5 gr/cm^2 thick target sandwitched with thin scintillators to measure the dE/dx of the particles at different thicknesses of the target. With three scintillators we can divide the target into four sheets, and obtain an incertitude ΔE_1 of $\sim$1.8 MeV (fwhm) on the energy loss.

2) The straggling of K^- and π^- in the sandwitched target introduces an incertitude $\Delta E_2 \simeq 1.9$ MeV (fwhm) on the peak of the energy loss around its most probable value.

3) Using the same features, for the magnetic spectrometer, apart the intensity of the magnetic field, we obtain an experimental resolution of $\sim$1.1 MeV for the π^- and of $\sim$0.7 MeV for the K^-.

In conclusion we expect a total energy resolution of the hypernuclear levels of:

$$\Delta E \simeq 2.9 \text{ MeV}$$

which is about the same as for (I).

One may suspect that the multiple scattering suffered by a particle (K^- or π^-) in traversing the target would affect seriously the energy resolution obtained in the kinematical reconstruction.

It can be easily seen that this is not the case: the error introduced in the determination of the hypernuclear momentum p_H is:

$$\Delta p_H / p_H = 1/2 \tan \vartheta \, \Delta \vartheta$$

where ϑ is the zenithal direction of the outgoing pion with respect to the incoming kaon. Since only events with $\vartheta \leq 6^o$ will be selected, $\Delta p_H/p_H$ will result smaller than 8×10^{-4} thus negligible in comparison with other errors.

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