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PHYSICS I COMMITTEE

LETTER OF INTENTION

A STUDY OF THE EXCITED STATES OF ${}^{4}_{\Lambda}H$ AND ${}^{4}_{\Lambda}He$ HYPERNUCLEI

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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PHYSICS III COMMITTEE

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A STUDY OF THE EXCITED STATES OF $^{4}_{\Lambda}H$ AND $^{4}_{\Lambda}He$ HYPERNUCLEI

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As it was pointed out in ref. 1 we are interested in a continuation of the hypernuclear γ-spectroscopy studies. The experiment recently performed at CERN by the CERN-Heidelber Warsaw Collaboration (2,3) has shown that features of the ΛN s-state interaction can be examined by this method. The present letter outlines the physical basis and the experimental precedure of a new experiment. Discussions are in progress with other groups with a view of setting up a collaboration of sufficient strength to perform the experiment.

I. Physical basis of the proposed experiment

In the experiment described in ref. 2 and 3, the first hypernuclear γ-transitions ascribed to the mass number 4 hypernuclei ($^{4}_{\Lambda}H$, $^{4}_{\Lambda}He$) have been distinguished. In the γ-spectra obtained from ^{6}Li and ^{7}Li targets irradiated with stopping K^{-}-mesons, two γ-lines at 1.09 MeV and 1.42 MeV have been observed. The first one was firmly established as a hypernuclear line whereas the identification of the second one might still be questioned. Nevertheless, it was proved that both lines considered as hypernuclear lines cannot be ascribed to any other hypernuclei but $^{4}_{\Lambda}H$ and $^{4}_{\Lambda}He$.

The observation of the 1.09 MeV line made it possible to reconsider the properties of the ΛN interaction in terms of various phenomenological hard core potentials with attractive wells of exponential shape outside the core. As the input data the binding energies of $^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$ and $^{4}_{\Lambda}He$ were used, in addition to the 1.09 MeV γ-transition energy which was alternatively ascribed to the excitation of either the $^{4}_{\Lambda}H$ or the $^{4}_{\Lambda}He$ hypernucleus. Knowing the binding energy values of the ground and excited states of the s-shell hypernuclei, one can determine the appropriate Λ-nucleus well depth parameters for these states. This can be achieved by means of the interpolation formulas obtained by Herndon and Tang[4)] with the variational method. Each of these formulas connects the binding energy of a hypernucleus with the Λ-core nucleus potential well depth parameter. The ΛN potential depths are the linear combinations of the corresponding Λ-core nucleus potential depths. Having the Λp potential parameters, one can estimate the Λp elastic scattering cross-sections and compare them with the experimental data obtained at low energies[3)]. The results of these calculations are shown in Fig. 1. It is seen that only the ΛN potentials, marked C and D, with core radii d = 0,45 fm and 0.60 fm and an intrinsic range b = 1.5 fm can be fitted to the experimental data. This is inconsistent with what was obtained in ref. 4 (d = 0.45 fm, b = 2.0 fm) when the excitation energy of mass number 4 hypernuclei was not known. The new experimental data made it possible to use a more general form of the charge symmetry breaking term in ΛN interaction containing both spin-dependent and spin-independent parts. The spin-independent part turned out to be significant.

The estimated values of the singlet and triplet state scattering parameters a_s and a_t differ markedly for both Λn and Λp potentials. This indicates a rather strong spin-dependence of the ΛN interaction. In addition to this - at present still rather simple approach - for both assignments of the 1.09 MeV line, the excitation energy of a second mass number 4 hypernucleus has been predicted to be higher than 1 MeV for all fitted potentials.

The confirmation of the existence of a hypernuclear line at 1.42 MeV and the proper assignment of both these lines to ${}^4_\Lambda H$ and ${}^4_\Lambda He$ would make it possible to gain better information about the ΛN potential parameters.

II. Experimental programme

The aim of the proposed experiment is the identification of the 1.42 MeV line and the proper assignment of the 1.09 MeV line to one of the mass number 4 hypernuclei : ${}^{4}_{\Lambda}H$ or ${}^{4}_{\Lambda}He$.

In the vicinity of the 1.42 MeV line, a background line at 1.32 MeV was also present. It has been found that this line was due to the interaction of fast secondary neutrons with ${}^{23}Na$, a constituent of the γ-detector[3]. The 1.32 MeV line was observed in a spectrum slightly delayed with respect to the lines attributed to γ-rays emitted directly from the target. The delay time amounted to about 2 ns in the previous experiment, where the distance between the γ-detector and the target was equal to 15 cm only. In the proposed experiment this distance will be enlarged to 45 cm to increase the delay time up to 5-6 ns. This enlargement seems to be sufficient for a good separation of the 1.42 MeV and 1.32 MeV lines, tentatively ascribed to a γ-transition in the target or to the fast neutron interaction with the γ-detector, respectively.

A correct assignment of the 1.09 MeV line to the γ-transition in either the ${}^{4}_{\Lambda}H$ or ${}^{4}_{\Lambda}He$ hypernucleus can be done if the γ-spectra are taken in coincidence with decay pions. The decay of the ${}^{4}_{\Lambda}H$ hypernucleus is accompanied in 50 % of all the cases by the emission of a π^--meson with the kinetic energy of 53 MeV. The relative intensity measurements of the 1.09 MeV line observed both in coincidence with the 53 MeV pions and without it should lead to the proper assignment of this line.

III. Experimental set-up

3.1 K^--beam

In the proposed experiment the solid angle subtended by the γ-detector will be diminished by a factor of about 10 as compared with the previous set-up[2,3]. The same statistics of the observed hypernuclear events can still be obtained with the 10 times more intense K^--beam e.g. with the short version of the K12 beam where 7000 K^-/burst could be stopped in the target. (The background conditions are discussed separately).

3.2 Counters and electronics

A schematic diagram of the experimental set-up is presented in Fig. 2. A telescope consisting of the veto-Čerenkov counter $\bar{C}_1$ and three plastic scintillation counters S_{1-3} will be used for the K-meson identification. A threshold Čerenkov veto-counter made of plexiglass has a high rejection power (> 99,5 %) for the 500 MeV/c pions. A further improvement of the kaon-to-pion ratio can be achieved with the help of the scintillation counters S_{1-3} which are only sensitive to a given energy loss of the passing kaons. The Cu and C degraders for the kaon beam are placed between the telescope counters. The beam will be stopped both in ^{6}Li and ^{7}Li targets.

The NaI(Tℓ) crystal, of the size 4" x 3", will be used as a γ-detector. The aluminium cover of the crystal has been made especially thin to reduce the background induced by neutrons. Seven XP1010 phototubes will collect the scintillation photons produced in the crystal. It is more advantageous to use a great number of small tubes instead of a one large tube since high counting rates are expected.

A range telescope will be used to detect the 53 MeV decay pions to be expected in the case of the $^4_\Lambda$H hypernucleus. The pions emitted from the target will pass through the hodoscope counters $H^{(2)}$ (Fig. 2), arranged in a 5 x 5 matrix, a properly shaped Cu-degrader to reduce the differences in ranges for various directions and another hodoscope counters $H^{(3)}$, arranged in a 10 x 10 matrix. Finally the pions will be stopped in six layers of the plastic counters S_{6-11}. The hodoscope counters $H^{(2)}$ and $H^{(3)}$ and the counters S_{6-11} will make it possible to determine the range and the direction of the passing pions. Some corrections for the energy loss of the pions in the target can also be done in this way. The numbers of the fired hodoscope counters and those of the S_{6-11} counters will be registered on the magnetic Kennedy tape together with the two-dimension time-energy γ-spectra. Thus the off-line analysis of the γ-spectra in coincidence with pions from the energy range of 50 MeV to 56 MeV becomes possible.

The γ-spectra taken in coincidence with only K-mesons stopped in the target will be registered by the two-dimension analyser TRIDAC-C.

3.3 Counting rates and background

The increased intensity of the kaon beam compensates for the reduction of the counting rates obtained with a smaller angle subtended by the γ-detector in the proposed set-up. Therefore the rates observed in a given time unit and ascribed to the hypernuclear lines will not be changed with respect to those obtained previously[2,3]. In a week of the machine time (ca 100h) one should register about 5000 γ-quanta corresponding to the 1.09 MeV line in the case of the ^{7}Li target and some 1500 counts for each of the two lines, the 1.09 MeV and the 1.42 MeV, in the case of the ^{6}Li target.

In a short version of the K12 beam, the total background counting rate observed in the γ-detector is expected to be about 2 x 10^5 counts per second. It will be twice as high as the rate measured previously with the extended version of the K12 beam and the γ-detector placed at a distance of 15 cm from the beam axis. In addition, with the increased intensity of the beam, one may expect an increase of the incidental counts which, however, should be compensated when the time-of-flight base is much larger. (The rate of the incidental events in the previous experiment did not exceed 1 %). Thus one should expect that the detection of the hypernuclear γ-spectra will be feasible under the new experimental conditions.

In a 100 hour run, the total number of the 1.09 MeV γ-quanta observed for the ^{7}Li target in coincidence with the 53 MeV decay pions should amount to 500 if they are emitted from the $^{4}_{\Lambda}H^*$ and to 50 only if it were the $^{4}_{\Lambda}He^*$ hypernucleus. These predictions can be deduced from an evaluation of the solid angle ($\sim$20 %) subtended by the range telescope for the 53 MeV pions. Here account has also been taken of the above mentioned reduction of the effect by the factor of about 10 and of the 53 MeV pion decay rate of the $^{4}_{\Lambda}H$ hypernucleus.

IV. Machine time and manpower

Nine weeks of the machine time in the second half of 1973 would be desired.

Four physicists and a technician from Warwaw could participate in the experiment during the running time. A collaboration with another group at CERN is indispensable to perform this experiment and the preliminary discussions on this point have already been started.

REFERENCES

1. J. Pniewski, Letter of Intention PH III-72/7.

2. A. Bamberger et al., Physics Letters, 36B (1971) 412.

3. A. Bamberger et al., Excited States of Light Hypernuclei, to be published.

4. R.C. Herndon and Y.C. Tang, Phys. Rev. 159 (1967) 853.

FIGURE CAPTIONS

Fig. 1 : Λ-p total cross-section as a function of the c.m. energy. The lines are calculated by Bamberger et al.[3] for various ΛN potentials fitted to the elastic scattering and hypernuclear data and to the excitation energy $E\gamma$ = 1.09 MeV ascribed to (a) - ${}^{4}_{\Lambda}H^{*}$, (b) - ${}^{4}_{\Lambda}He$.

Fig. 2 : The experimental set-up.

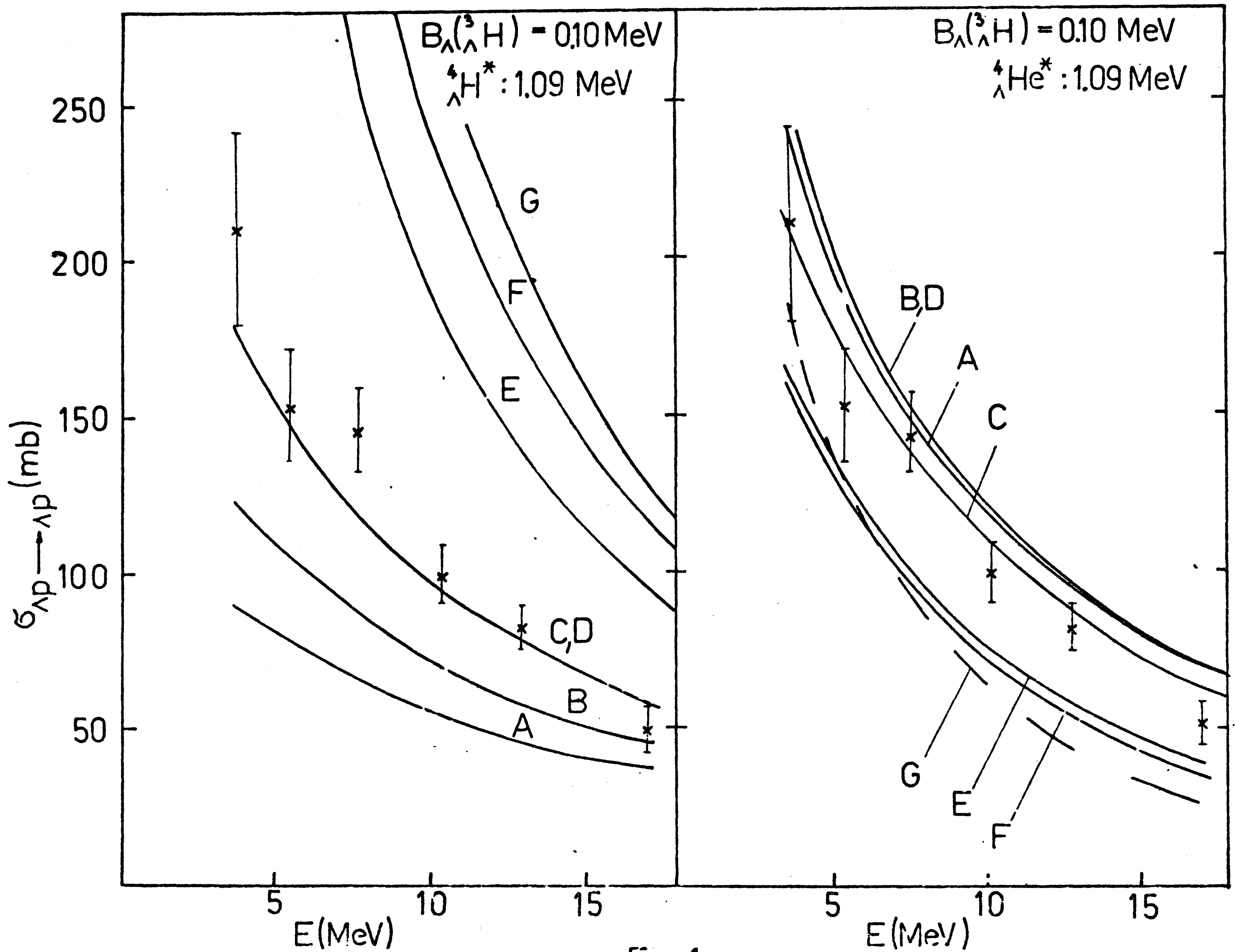
B_Λ(³_ΛH) = 0.10 MeV
⁴_ΛH* : 1.09 MeV
B_Λ(³_ΛH) = 0.10 MeV
⁴_ΛHe* : 1.09 MeV
σ_Λp→Λp (mb)
250
200
150
100
50
5
10
15
E(MeV)
A
B
C,D
E
F
G
B,D
C

Fig 1

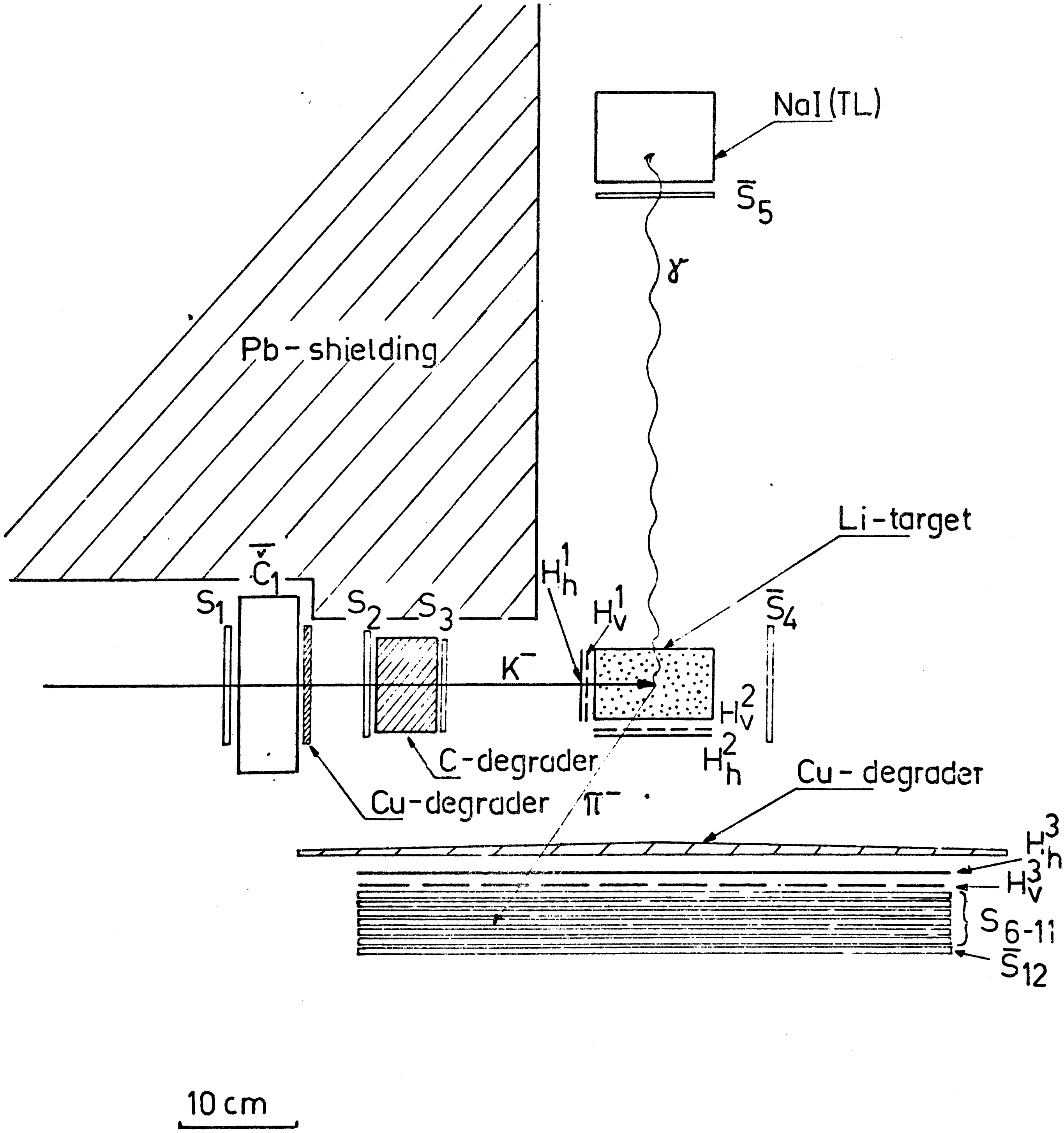
NaI (TL)
$\bar{S}_5$
γ
Pb - shielding
Li - target
$\check{\bar{C}}_1$
S_1
S_2
S_3
H_h^1
H_v^1
$\bar{S}_4$
K^-
H_v^2
H_h^2
C - degrader
Cu - degrader
π⁻
Cu - degrader
H_h^3
H_v^3
S_{6-11}
$\bar{S}_{12}$
10 cm

Fig 2