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FURTHER INVESTIGATION OF THE γ-TRANSITIONS IN $^{4}_{\Lambda}$H AND $^{4}_{\Lambda}$He HYPERNUCLEI

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ABSTRACT

The γ-spectra induced by stopped K^- mesons in ^{6}Li and ^{7}Li targets were obtained in coincidence with the accompanying charged pions and π^0 mesons. The γ-line at (1.04 ± 0.04) MeV observed with charged pions was identified as a γ-transition in $^{4}_{\Lambda}$H, whereas the γ-line at (1.15 ± 0.04) MeV observed with π^0 mesons was ascribed to a γ-transition in $^{4}_{\Lambda}$He. Using these new values for the excitation energies of the 1^+ levels of $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He hypernuclei, the phenomenological ΛN potential for the s-state interaction was recalculated.

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In the experiment described here the identification and the energy determination of γ-transitions from the excited states of $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He hypernuclei was carried out. Preliminary results were reported elsewhere [1,2]. In this experiment, which was a continuation of the two previous experiments [3,4], both $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He γ-transitions could be detected and identified at the same time.

The light hypernuclei were produced using the interaction of K^- mesons [5] stopped in metallic ^{6}Li, ^{7}Li, and Be targets. In this paper the main results obtained with Li targets only will be discussed.

The identification of the $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He γ-rays was possible owing to very frequent (about 50%) two-body mesonic decays of these hypernuclei:

$$^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^- , \qquad E_{\pi^-} = 53\ \mathrm{MeV}$$

$$^{4}_{\Lambda}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + \pi^0 , \qquad E_{\pi^0} = 57\ \mathrm{MeV} .$$

The experimental arrangement and counter dimensions are presented in Fig. 1. The π^0 mesons were identified by detection of their decay γ-rays. These γ-rays were converted into electron cascades in 2 of 21 double Pb-scintillator sandwich counters N_{1-21}. The total thickness of the Pb absorber was equal to 3 radiation lengths, giving about 90% probability of the γ-conversion. The energy of π^0 mesons was obtained from the measurement of the opening angles of the decay γ-rays. The opening angle distribution shows a sharp maximum near its minimum value (corresponding to the π^0 kinetic energy) and for the low-energy π^0 mesons (e.g. 57 MeV) about 86% of all decays are within the interval 20° above the minimum value of this opening angle. The opening angles were determined from the measurement of both the azimuthal and deep angles for each γ-ray. The azimuthal angle was given by the hit counter number, whereas the deep angle was determined from the place of the electron shower in the counter. The scintillation light induced by electrons was collected at both ends of the detector, thus allowing, by means of a time-of-flight (TOF) technique, the determination of the shower position. The TOF resolution (∿ 700 ps, FWHM) and the counter dimensions allowed the measurement of both the azimuthal and the deep angles with an accuracy of ±3.5°. With this angular resolution the energy resolution of the 57 MeV π^0 mesons was expected to be about ±30% (FWHM) and the detection efficiency was about 4%. For the 53 MeV charged pions detected in the range telescope the resolution was ±10% (FWHM) and the efficiency about 3%.

The γ-spectra obtained with the NaI(Tl) counter of 4 in. × 3 in. size are shown in Fig. 2. In the experimental area the single rate for this crystal was about 4×10^5/s, so the energy resolution of the 0.98 MeV ^{8}Li* γ-line observed in the test-spectrum obtained with K^- mesons stopped in a Be target was only 12%. The detection efficiency for the 1 MeV γ-line was $\sim$ 0.2% and the resolving time of the Kγ coincidences was $\sim$ 4 ns (FWHM). The details of the γ-spectrometer and the charged-pion telescope are not discussed here, since they were described in Refs. 3 and 4.

The incidental rate of the (K^-, γ) coincidences did not allow observation of the γ-lines having a production rate lower than 1% per stopped kaon. Therefore, a coincidence of a charged pion or π^0 meson accompanying the K^- interaction in the target was necessary to search for the hypernuclei γ-transitions. The continuous background has largely diminished owing to this triple (K^-, γ, π) coincidence and the discrete structure of the γ-spectra became visible. Furthermore, about (60-70)% of the background, induced by neutrons and pions in the material in the vicinity of the target and NaI detector, could be removed by a (K^-, γ) TOF analysis as it is usually delayed with respect to the γ-rays emitted directly from the target. It turned out that most of the nuclear background γ-transitions creates rather broad maximum in the energy ranges (0.8-1.0) MeV and (1.3-1.5) MeV, being in satisfactory agreement with the most intensive γ-lines of Al, Si, Na and Pb. However, the observation of the γ-lines in the region of 1.1 MeV was only possible if restrictive conditions for kaon and pion counters (e.g. multiplicity 1) were fulfilled and proper energy ranges of π_{ch} and π^0 mesons were chosen.

In Fig. 2a the added γ-spectrum obtained with 4×10^8 K^- stopped in ^{6}Li and 2.3×10^8 K^- stopped in ^{7}Li, and taken in coincidence with charged pions of energy

(48–58) MeV, is shown. In this spectrum the γ-line at (1.04 ± 0.04) MeV, with a production rate of (0.2 ± 0.05)% (statistical error) is observed. Since it is the only maximum correlated with the 53 MeV charged pions and its energy differs by 1 standard deviation only from that observed in Ref. 4, we conclude that it belongs to the ${}^{4}_{\Lambda}$H γ-transition. From this γ-line intensity one can estimate that the production rate of ${}^{4}_{\Lambda}$H hypernuclei is about 0.4% per stopped K^-.

In Fig. 2b the same added γ-spectrum is presented, but the π^0 mesons of energy (45–85) MeV were taken in coincidence. The energy resolution of the π^0 detector (2.5 times worse than that of the charged pion telescope) made it necessary to use a broad energy interval around 57 MeV, thus decreasing the peak-to-background ratio. In this spectrum the only statistically significant maximum was found at (1.15 ± 0.04) MeV and its production rate is about (0.15 ± 0.04)% per stopped K^-. The fact that this γ-line appears for the ${}^{4}_{\Lambda}$He trigger, and that its energy does not correspond to the nuclear background lines observed in other spectra, indicates that it should belong to the ${}^{4}_{\Lambda}$He γ-transition.

In the case of the ^{6}Li target, the same line is also observed if the γ-spectrum is obtained with the π^0 mesons of energy (200–400) MeV (Fig. 2c, $N_{K^-} = 4 \times 10^8$). Such π^0 mesons cannot be correlated with the production or decay of ${}^{4}_{\Lambda}$He hypernuclei. However, the large solid angle ($\sim$ 30%) of the π^0 counter enables one to detect the fictitious π^0 decays resulting from the coincidence of uncorrelated γ-rays from two different π^0 mesons e.g. from the hypernucleus decay and production. Using a Monte Carlo calculation it was found that in the actual set-up the probability of detecting fictitious (200–400) MeV π^0 mesons as a result of such coincidence may be about 6%, if the ${}^{4}_{\Lambda}$He decay π^0 mesons are correlated with ${}^{4}_{\Lambda}$He production π^0 mesons of energy range (90–150) MeV. This value 6% was obtained on the basis that 70% of all ${}^{4}_{\Lambda}$He hypernuclei are decaying with the emission of a π^0 meson, and that π^0 mesons of energy lower than 57 MeV (in the case of many-body ${}^{4}_{\Lambda}$He decays) make contributions to the fictitious (200–400) MeV π^0 mesons similar to those made by the 57 MeV ones. With this efficiency one can estimate that the production rate of the γ-line observed in the spectrum in Fig. 2c is equal to about 0.1%. This corresponds to about 0.15% production rate of all ${}^4_\Lambda$He correlated with the emission of (90-150) MeV π^0 mesons, whereas on the basis of the intensity of the γ-line observed in coincidence with 57 MeV π^0 mesons one obtains the ${}^4_\Lambda$He production rate of about 0.3%. This indicates that only a part (say half) of all ${}^4_\Lambda$He produced would be correlated with high-energy (90-150) MeV π^0 mesons.

Such a strong enhancement of a γ-line with the fictitious π^0 mesons was not observed for similar investigations made for the γ-spectra obtained with K^- stopped in ^{7}Li or ^{9}Be targets. In the case of the ^{7}Li target a broad maximum at (1.08 ± 0.04) MeV was found in the spectrum for the accompanying π^0 mesons of energy (100-180) MeV (Fig. 2d, $N_{K^-} = 2.3 \times 10^8$). This line can be interpreted as a result of the contributions of both ${}^4_\Lambda$H and ${}^4_\Lambda$He γ-transitions.

Using the new values for the excitation energies of ${}^4_\Lambda$H and ${}^4_\Lambda$He hypernuclei, the phenomenological potential proposed by Herndon and Tang [6] for the ΛN s-state interaction was recalculated. This procedure was described in Ref. 3. The present calculations were based on the binding energies of ground states of ${}^4_\Lambda$H and ${}^4_\Lambda$He [$B_\Lambda({}^4_\Lambda H) = (2.09 \pm 0.06)$ MeV, $B_\Lambda({}^4_\Lambda He) = (2.39 \pm 0.04)$ MeV] [7] and on their excitation energies found in this paper. The binding energy of ${}^5_\Lambda$He was not included in this calculation, since the present theoretical approach has not progressed sufficiently to discuss this hypernucleus. The estimated quantities are: the Λp elastic scattering length in singlet and triplet states (a^p_s, a^p_t); the $\chi^2_{\Lambda p}$ values for the Λp elastic scattering cross-section data [8] and the binding energy of ${}^3_\Lambda$H. The ΛN potential is characterized by two parameters (b, $r_{\Lambda N}$), where b is the intrinsic range and $r_{\Lambda N}$ is the hard-core radius. For the calculations the following potential types were used: A (1.5 fm, 0), B (1.5 fm, 0.30 fm), C (1.5 fm, 0.4 fm), D (1.5 fm, 0.60 fm), E (2.0 fm, 0.45 fm) and F (2.0 fm, 0.60 fm). In addition, the calculations were done assuming two values of the Coulomb repulsion of two protons in ${}^4_\Lambda$He: $\Delta_C({}^4_\Lambda He) = 0.25$ MeV used in Herndon and Tang's analysis and $\Delta_C({}^4_\Lambda He) = 0.02$ MeV as estimated recently in Friar and Gibson [9]. The obtained values of $\chi^2_{\Lambda p}$ and $B_\Lambda({}^3_\Lambda H)$ for different ΛN potentials are shown in Fig. 3. The open points correspond to $\Delta_C({}^4_\Lambda He) = 0.25$ MeV, whereas the full points are for

$\Delta_C({}^4_\Lambda\mathrm{He}) = 0.02$ MeV. One can see that for the high Δ_C value three potentials B, C, D are equally good, whereas for the low value of Δ_C only the potentials C and D are good, with higher probability for D. In Table 1 the Λp elastic scattering lengths (a^p_s, a^p_t), are given for the potentials C and D.

As a conclusion we note that the ΛN phenomenological potential can be used to explain both the Λp elastic scattering cross-section and the binding energies of s-shell hypernuclei, even within one standard deviation limit. The calculated scattering lengths and the ${}^3_\Lambda\mathrm{H}$ binding energy do not depend significantly on the accepted Coulomb energy correction of ${}^4_\Lambda\mathrm{He}$.

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REFERENCES

[1] M. Bedjidian, E. Descroix, J.Y. Grossiord, A. Guichard, M. Gusakow, H. Piekarz, J. Piekarz, J.R. Pizzi and J. Pniewski, Abstract contributed to 7th Internat. Conf. on High-Energy Physics and Nuclear Structure, Zurich, 1977.

[2] H. Piekarz, Seminar on the Kaon-Nucleus Interaction and Hypernuclei, Zvenigorod, USSR, Sept. 1977.

[3] A. Bamberger, M.A. Faessler, U. Lynen, H. Piekarz, J. Piekarz, J. Pniewski, B. Povh, H.G. Ritter and V. Soergel, Nucl. Phys. B 60, 1 (1973).

[4] M. Bedjidian, A. Filipkowski, J.Y. Grossiord, A. Guichard, M. Gusakow, S. Majewski, H. Piekarz, J. Piekarz and J.R. Pizzi, Phys. Lett. 62B, 467 (1976).

[5] M. Bedjidian, E. Descroix, J.Y. Grossiord, A. Guichard, M. Gusakow, H. Piekarz, J. Piekarz, J.R. Pizzi and J. Pniewski, CERN Internal Report EP 77-14, (1977).

[6] R.C. Herndon and Y.C. Tang, Phys. Rev. 153 1091 (1967); 159 853 (1967).

[7] M. Jurič, G. Bohm, J. Klabuhn, U. Krecker, F. Wysotzki, G. Coremans-Bertrand, J. Sacton, G. Wilquet, T. Cantwell, F. Esmaal, A. Montwill, D. Kiełczewska, J. Pniewski, T. Tymieniecka and J. Zakrzewski, Nucl. Phys. B52, 1 (1973).

[8] G. Alexander, U. Karshon, A. Shapira, G. Yekutieli, R. Engelmann, H. Filthuth and W. Lunghofer, Phys. Rev. 173, 1452 (1968).

[9] J.L. Friar and B.F. Gibson, Phys. Rev. C 18, 908 (1978).

Table 1

Type of ΛN potential	C		D	
	$r_{\Lambda N} = 0.45$ fm	$b = 1.5$ fm	$r_{\Lambda N} = 0.6$ fm	$b = 1.5$ fm
$\Delta_C({}^{4}_{\Lambda}He)$ [MeV]	0.02	0.25	0.02	0.25
$\chi^2_{\Lambda p}$	12.6	5.8	7.3	8.5
$B_\Lambda({}^{3}_{\Lambda}H)$ [MeV] a)	0.08	0.09	0.06	0.08
$-a^p_s$ [fm]	2.2	2.4	2.3	2.5
$-a^p_t$ [fm]	1.2	1.3	1.2	1.3

a) The experimental value of $B_\Lambda({}^{3}_{\Lambda}H) = (1.13 \pm 0.05)$ MeV [7]

Figure captions

Fig. 1 : The experimental arrangement.

a) A top view of the kaon range telescope, the charged pion range telescope, and the π^0 counter.

b) A side view of the central N_{12} π^0 decay γ-detector.

c) The position of the NaI detectors with respect to the target as seen in a plane perpendicular to the drawing and crossing the K^- beam axis.

Fig. 2 : The γ-spectra obtained with K^- stopped in ^{6}Li and ^{7}Li targets and taken in coincidence with charged pions and π^0 mesons.

a) Added γ-spectrum for ^{6}Li and ^{7}Li targets, $N_{K^-} = 6.5 \times 10^8$, $E_{\pi_{ch}} = (48\text{-}58)$ MeV.

b) Same as A, but $E_{\pi^0} = (45\text{-}85)$ MeV.

c) The γ-spectrum for a ^{6}Li target, $N_{K^-} = 4.2 \times 10^8$, $E_{\pi^0} = (200\text{-}400)$ MeV.

d) The γ-spectrum for a ^{7}Li target, $N_{K^-} = 2.3 \times 10^8$, $E_{\pi^0} = (100\text{-}180)$ MeV.

Fig. 3 : The $\chi^2_{\Lambda p}$ and $B_\Lambda(^3_\Lambda H)$ values for different ΛN phenomenological potentials.

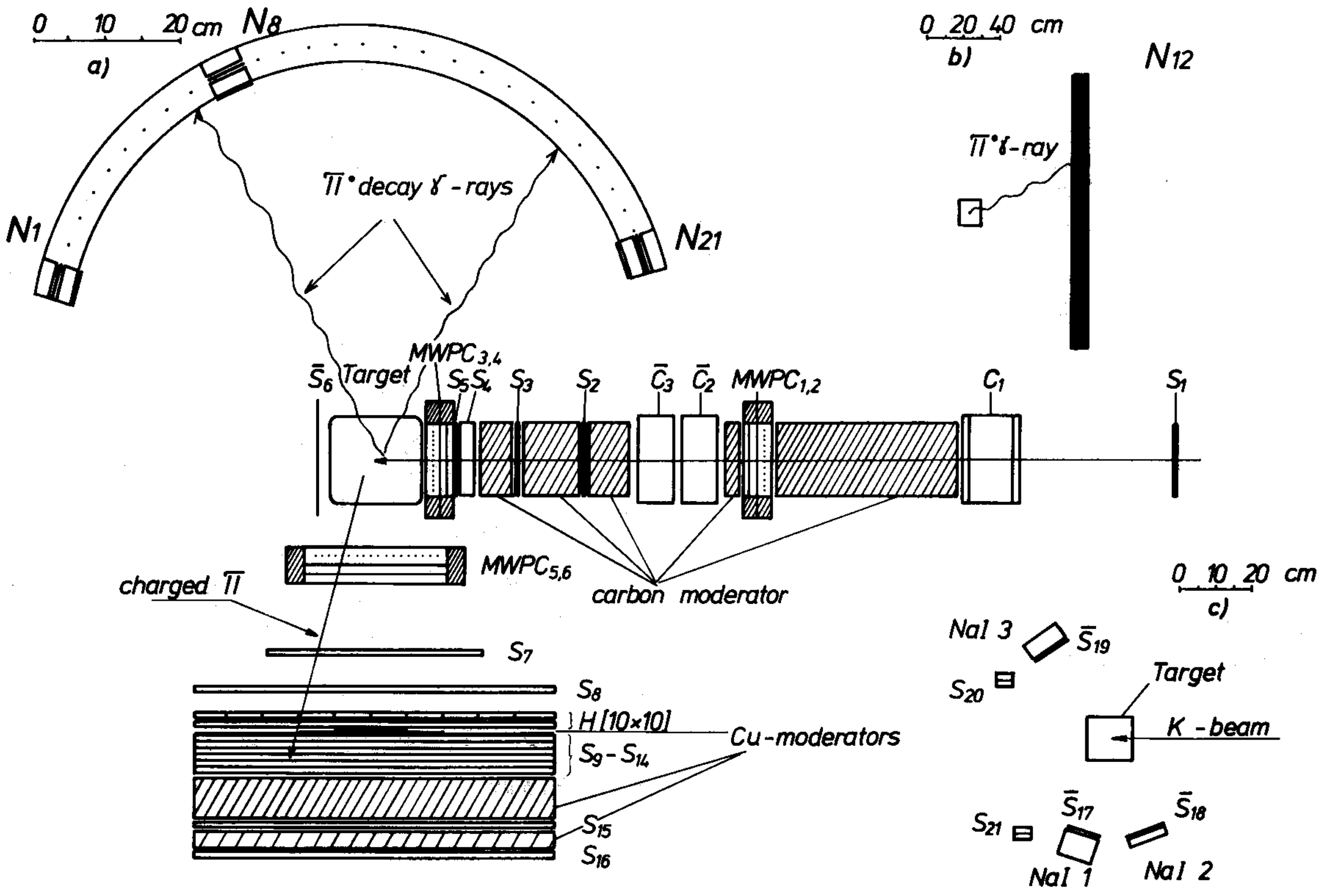

0 10 20 cm
a)
N8
N1
N21
π° decay γ - rays
0 20 40 cm
b)
N12
$\pi^\circ \gamma$-ray
$\bar{S}_6$
Target
MWPC3,4
S_5
S_4
S_3
S_2
$\bar{C}_3$
$\bar{C}_2$
MWPC1,2
C_1
S_1
MWPC5,6
carbon moderator
charged π
S_7
S_8
H [10×10]
$S_9 - S_{14}$
Cu-moderators
S_{15}
S_{16}
0 10 20 cm
c)
NaI 3
$\bar{S}_{19}$
S_{20}
Target
K-beam
S_{21}
$\bar{S}_{17}$
$\bar{S}_{18}$
NaI 1
NaI 2

Fig. 1

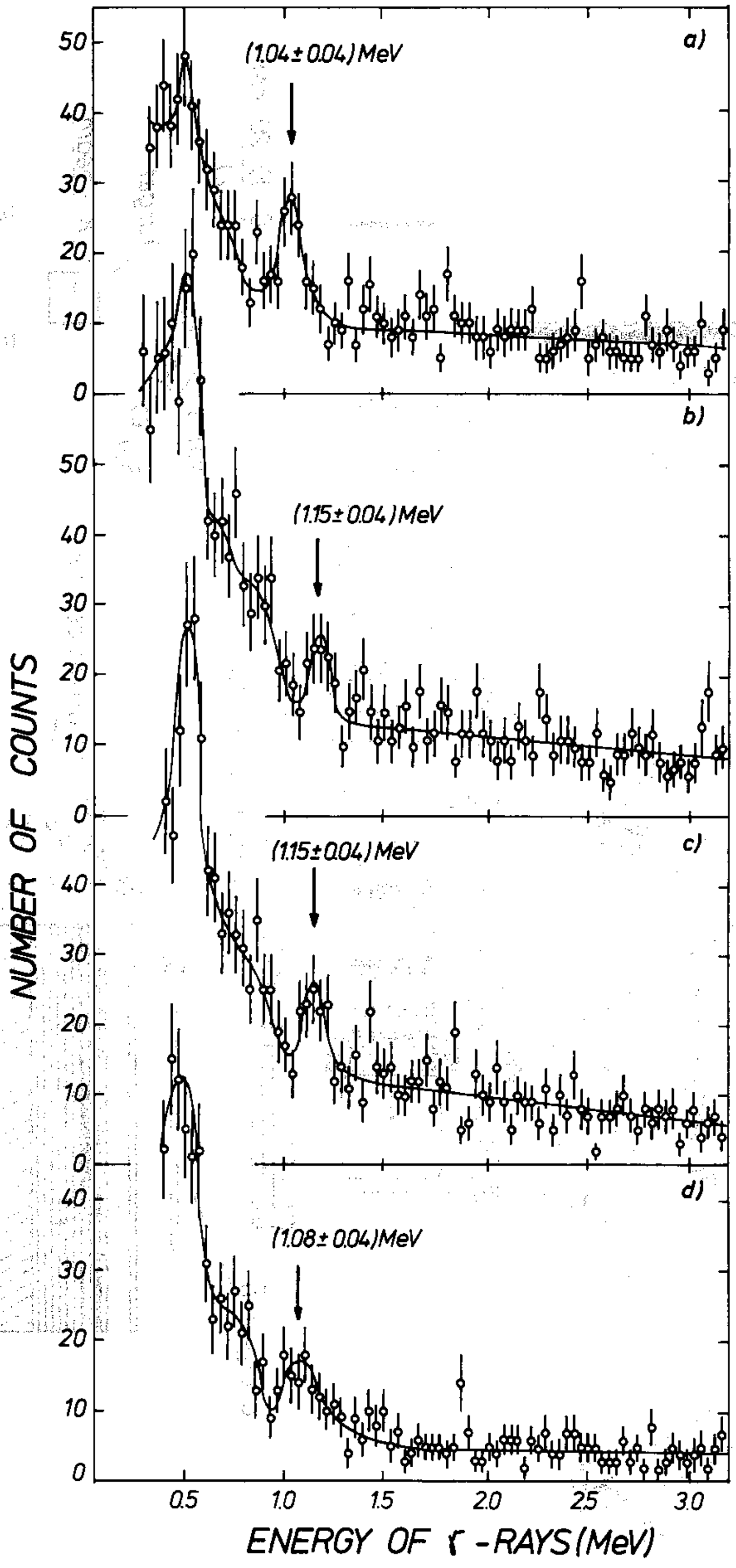
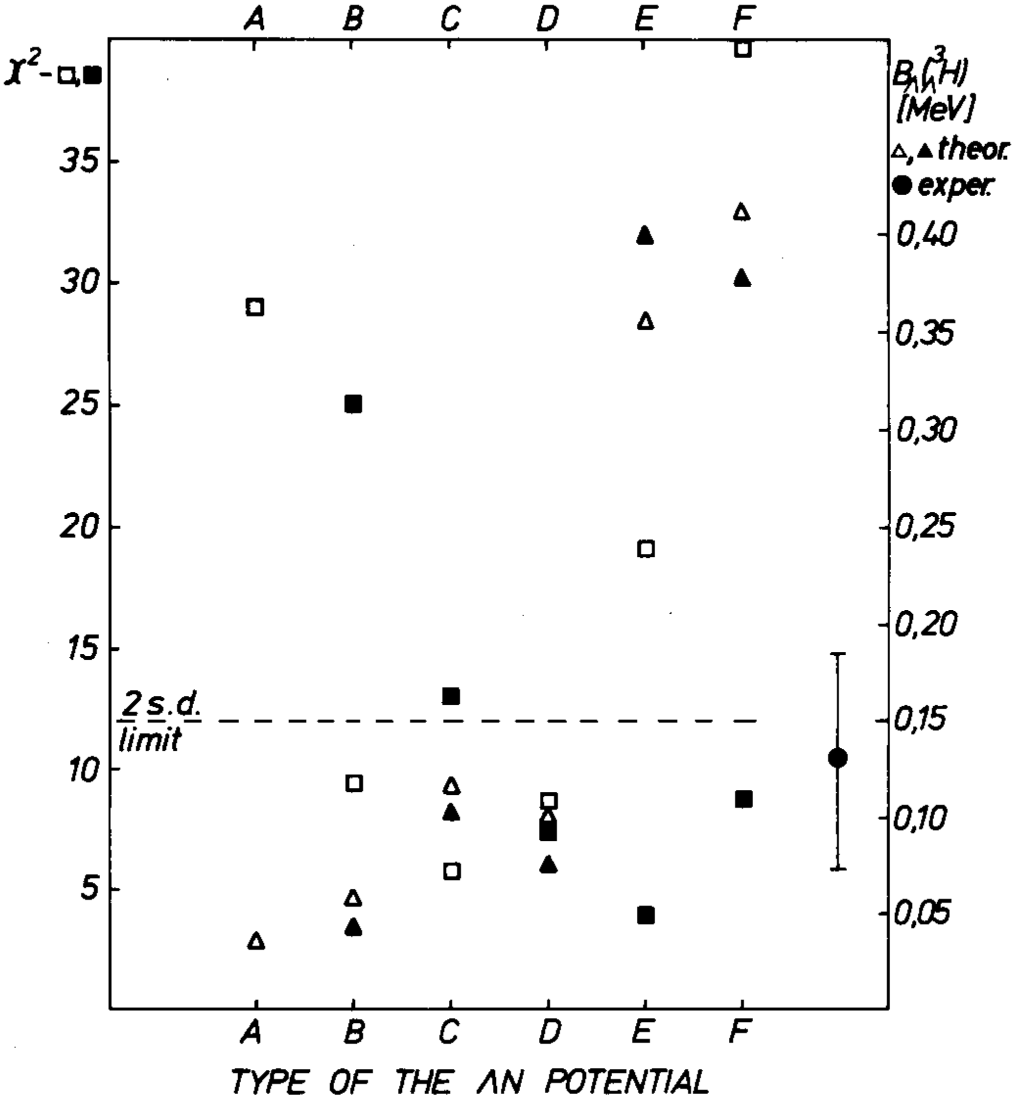

a)
(1.04± 0.04) MeV
b)
(1.15± 0.04) MeV
c)
(1.15± 0.04) MeV
d)
(1.08± 0.04) MeV
NUMBER OF COUNTS
0
10
20
30
40
50
0.5
1.0
1.5
2.0
2.5
3.0
ENERGY OF γ -RAYS (MeV)

Fig. 2



A
B
C
D
E
F
χ^2 - □,■
35
30
25
20
15
10
5
2 s.d. limit
$B_{\Lambda\Lambda}(^3_{\Lambda\Lambda}H)$ [MeV]
△,▲ theor.
● exper.
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
A
B
C
D
E
F
TYPE OF THE ΛN POTENTIAL

Fig. 3