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INTENSITY-MEASUREMENTS OF HIGH ENERGY PROTON BEAMS BY THE REACTION ^{197}Au (p, SPALLATION) ^{149}Tb

by

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ABSTRACT

The reaction ^{197}Au (p, spallation)^{149}Tb is selective to high energy particles due to a threshold energy of about 500 MeV. The use of this reaction for the calibration of high intensity beams was studied. A method to measure the α-decay of ^{149}Tb is described considering the possible sources of systematic errors.

The results from the measurement of the reaction ^{197}Au(p, sp)^{149}Tb are compared with those obtained by the commonly used monitor reaction ^{27}Aℓ (p, 3pn)^{24}Na.

A preliminary measurement of the yield ratio ^{149}Tb/^{24}Na in the fast and slow ejected beam from CPS is reported.

I. INTRODUCTION

Intensities of high energy proton beams are measured usually by current transformers in fast ejected beams, or by secondary emission chambers in slow ejected beams.

The current transformer as well as the secondary emission chamber is sensitive to all charged particles of different momenta. This is also the case for the currently used monitor reactions with threshold energies in the order of a few 10 MeV. In addition these monitor reactions are sensitive to low energy neutrons.

Therefore it is of interest to compare measurements of the usual monitor reactions with reactions occurring at higher threshold energies. Those comparisons are desirable, if high intensity beams are surrounded by a "halo" or the proton beam is contaminated by background particles.

The threshold energy of the reaction ^{197}Au(p, sp.)^{149}Tb is about 500 MeV (BRU 64, CUM 63). The partial cross-section for the α-emitting branch of ^{149}Tb is only known for high energy protons relative to Aℓ^{27}(p, 3pn)^{24}Na (BRU 64, FRA 65). The α-line emitted by ^{149}Tb is measured with a half life of 4.12 h and an energy of 3.95 MeV (BRU 64).

The aim of the study reported here was :

1. to develop a method for the measurement and evaluation of the α-line of ^{149}Tb using thin gold foils.
2. to compare the yields of ^{149}Tb produced from ^{197}Au with ^{24}Na produced from ^{27}Aℓ in the fast and slow ejected beam.
3. to estimate the accuracy of the measurement of relative yields.

II. TECHNIQUE

1. Foils and irradiation

A set of three foils was used to compensate recoil losses of the central foil which was used for the measurements. The thickness of the aluminium foil was $31\,\mu$, that of the gold foil $6.8\,\mu$ ($13.15\ \mathrm{mg/cm^2}$). The choice of the irradiation time was estimated corresponding to 10^{14}-10^{15} protons penetrating the foils. This number of protons was required to obtain sufficient α-decays from ^{149}Tb with a reasonable statistical error.

2. Method of alpha-counting

The alpha-counter consists of a silicon-diode with an efficient surface of about 33 mm diameter. The sample and the diode are mounted in a vacuum vessel which was evacuated to 10^{-1} Torr during the measurement. A bias voltage was applied in order to stop all the alpha-particles with energies < 8 MeV. The energy loss of the numerous beta-particles from the activated gold foil increased only the noice in the lowest channels which have not to be used for α-detection (checked by a highly activated aluminium foil). The noice has thus been cut by setting a lower threshold. The dead time (8-12 %) due to noice was corrected by the automatic clock of the analyser. The sample for the measurement (diameter 10 mm) had a distance of about 10 mm from the counter. The amplified,differentiated and integrated pulses were registered in a 400-channel-analyser (Intertechnique). The calibration of the counter and the efficiency are described in section III.1.

3. Method of gamma-counters

As γ-counter a Na I-crystall (3x3 inches) was used. The pulses from the photomultiplier were amplified and counted in a 1024-channel-analyser (TMC-1024). The sample had been positioned at 17.3 cm from the surface of the Na I-crystall. We used for the measurement absorbers (thickness corresponding to the maximum range of the β-particles of ^{24}Na). The counting efficiency was determined, already for earlier measurements to 0.283 %. For the evaluation the usual routine was applied using the program GAPLOT (HOF 68).

III. TESTS AND MEASUREMENTS

1. The α-spectrometer was calibrated with the ^{239}Pu α-line (5.15 MeV). A pulse generator was used for the subdivisions. The counting efficiency was determined by means of the following standards: ^{239}Pu, ^{233}U, ^{235}U to (39.5 % ± 1 %) of 2π. The resolution measured with a pulse generator is 90 keV (full-width at half height).

2. A mylar foil coated on both sides with a gold layer was exposed to about $5 \cdot 10^{14}$ p/cm^2. Figure 1 shows two α-lines corresponding to α-particles (3.95 MeV) emitted from the top and bottom layer of the "gold-mylar sandwich". The α-particles emitted from the lower surface have lost energy passing through the mylar and top layer of gold (line shift). The asymmetric increased line width is due to α-particles emitted at larger angles.

3. Fig. 2 shows the α-spectrum emitted from a 6.8μ thick gold foil (13.15 mg/cm^2) which represents a thickness slightly larger than the maximum range of 3.95 MeV α-particles. The decay of the α-activity in this foil was followed over 25 hours for α-energies appearing between 2.8 and 4 MeV (Fig. 3). The half life was determined and found to be 4.14 ± 0.03 hours in agreement with the known half life of ^{149}Tb (4.12 hours). The measurement was started several hours after the end of the exposure to avoid the contributions of short living α-emitters*) produced in the foil. We list in Table 1 some α-emitters (with half-life of several hours) produced in gold (FRA 65). However the contribution of the other α-emitters is negligible. The program NUPRO was written which allows for separation of three components with two known and one unknown life time.

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*) See e.g. CHA 66

4. Two intensity measurements were made in the fast and slow ejected beam, respectively. A set of three aluminium and three gold foils were exposed at positions indicated on Fig. 4. The results obtained are given in Table 2. The yield ratio of ^{149}Tb/^{24}Na was measured with the α- and γ-spectrometer, respectively. The difference in the yield ratio is 10 %, which corresponds to the present error in the measurement. From this preliminary result we cannot conclude that the slow ejected beam is less "clean" than the fast ejected.

TABLE 1

Element	α-Energy [MeV]	Half life [h]
^{149}Tb	3.95	4.12
^{151}Tb	3.41	19
^{152}Dy	3.66	2.4
^{153}Dy	3.48	5
^{154}Dy	3.35	13

TABLE 2

	α-Measurement	γ-Measurement
Half life	4.12 h.	15 h.
Energy	3.95 MeV	2.75 MeV
Thickness	6.8 μ	31 μ
Efficiency	19.75 %	0.283 %

	Slow Ejection	Fast Ejection
Yield ratio	0.099 ± 12 %	0.109 ± 12 %

5. The cross-section for ^{197}Au(p, x) ^{24}Na can be calculated relative to the (Aℓ, Na) cross-section by measuring the 2.75 MeV line in the γ-spectrum produced by the gold foil. Two measurements spread over a time larger compared to 15 h. (Half life of ^{24}Na) indicate that this line belongs to ^{24}Na. We obtain

$$\sigma_{(\mathrm{Au,\ Na})} = 16.1 \text{ mb}$$

with a relative error of ± 5 %; we assume in addition an error of 10 % for the absolute Aℓ-Na measurement. Cross-section from 1 to 6 GeV/c are known by Caretto et al. (CAR 58) for this reaction (Fig. 5).

IV. YIELD RATIO, CORRECTIONS AND ACCURACY

The cross-section σ is given as

$$\sigma = \frac{(\mathrm{cpm} \cdot e^{\lambda t})}{\mathrm{Np} \cdot N \cdot R} \cdot \frac{\Delta t}{(1-e^{\lambda \Delta t})} \cdot \frac{1}{\epsilon \cdot b}$$

where

cpm = counts/min. measured and corrected for background
λ = decay constant
N = number of nuclides in the foil/cm^2
Np = number of protons incident
Δt = irradiation time
t = decay time of the nuclide
ϵ = counting efficiency
R = correction factor for the α-particles stopped in the foil (range factor)
b = branching ratio

We define as yield ratio

$$Y = \frac{(\mathrm{cpm}_1 \cdot e^{\lambda_1 t}) / R \cdot N_1 \cdot (1-e^{-\lambda_1 \Delta t}) \cdot \epsilon_1}{(\mathrm{cpm}_2 \cdot e^{\lambda_2 t}) / N_2 \quad (1-e^{-\lambda_2 \Delta t}) \cdot \epsilon_2}$$

where

1 refers to the reaction ^{197}Au (p, sp.) ^{149}Tb measured by the α-decay, and

2 to the reaction ^{27}Aℓ (p, 3pn) ^{24}Na measured by the γ-line.

This ratio is independent of the cross-sections and the branching ratios of the reactions.

The α-measurements had to be corrected for those particles which lost more energy than $\Delta E = E\ (3.95\ \text{MeV}) - E_0$ (e.g. $E_0 = 2.8$ MeV), because only those α-particles, with energies greater than E_0 are used for the evaluation.

The range correction R consists then of two parts :

1. correction of the foil thickness d_F by the ratio $\Delta R/d_F$. $\Delta R = R(E = 3.95\ \text{MeV}) - R(E_0)$. For the range the theoretical values reported by CEA are taken (CEA 66).
2. As ΔR given above is justified only for particles penetrating the foil perpendicular, one had to calculate the correction factor for the different angles taking into account the distance between sample and counter as well as their relative sizes.

Both corrections can be calculated with sufficient precision since the range-energy relation of α-particles in gold is known and the geometry defined. However the angular correction is dependent on the density distribution over the foil. This error is assumed to be ± 6 %. The estimation is based on the calculation of two extreme cases, for the beam distribution.

The correction factor is equal to 1 for the thin foil ("gold sandwich"). Therefore thin gold layers (0.1 to 1 μ) on mylar are preferable for precision measurements. In this case the accurate determination of the gold thickness is critical and the only source of systematic errors. The long irradiation time ($> 5 \cdot 10^{14}$ p/cm^2) required for very thin layers of gold represents a disadvantage.

The influence of the density distribution on the counting efficiency gets less important with decreasing distance between sample and counter. But this distance has to be well defined.

In conclusion, we estimate for the present relative measurements (using "thick" gold foils) an error of about ± 12 %.

This error of relative measurements could be reduced to about 3-4 % by observing the suggestions made above.

V. ACKNOWLEDGEMENTS

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Distribution :

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G. Petrucci

and according to requests

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HOF 68	L. HOFFMANN MPS/Int. MU/EP 68-6

FIGURE CAPTIONS

Fig. 1 : α-spectrum obtained from the thin gold layers(coated on mylar) after irradiation with protons of 24 GeV/c.

Fig. 2 : α-spectrum of a 6.8 μ thick gold foil irradiated with protons of 24 GeV/c.

Fig. 3 : Measurements of the α-decay of ^{149}Tb.

Fig. 4 : Position of the foils in the fast and slow ejected beams.

Fig. 5 : Cross-section ^{197}Au (p, x) ^{24}Na, based on the cross-section ^{27}Aℓ(p, x)^{24}Na.

Fig. 1

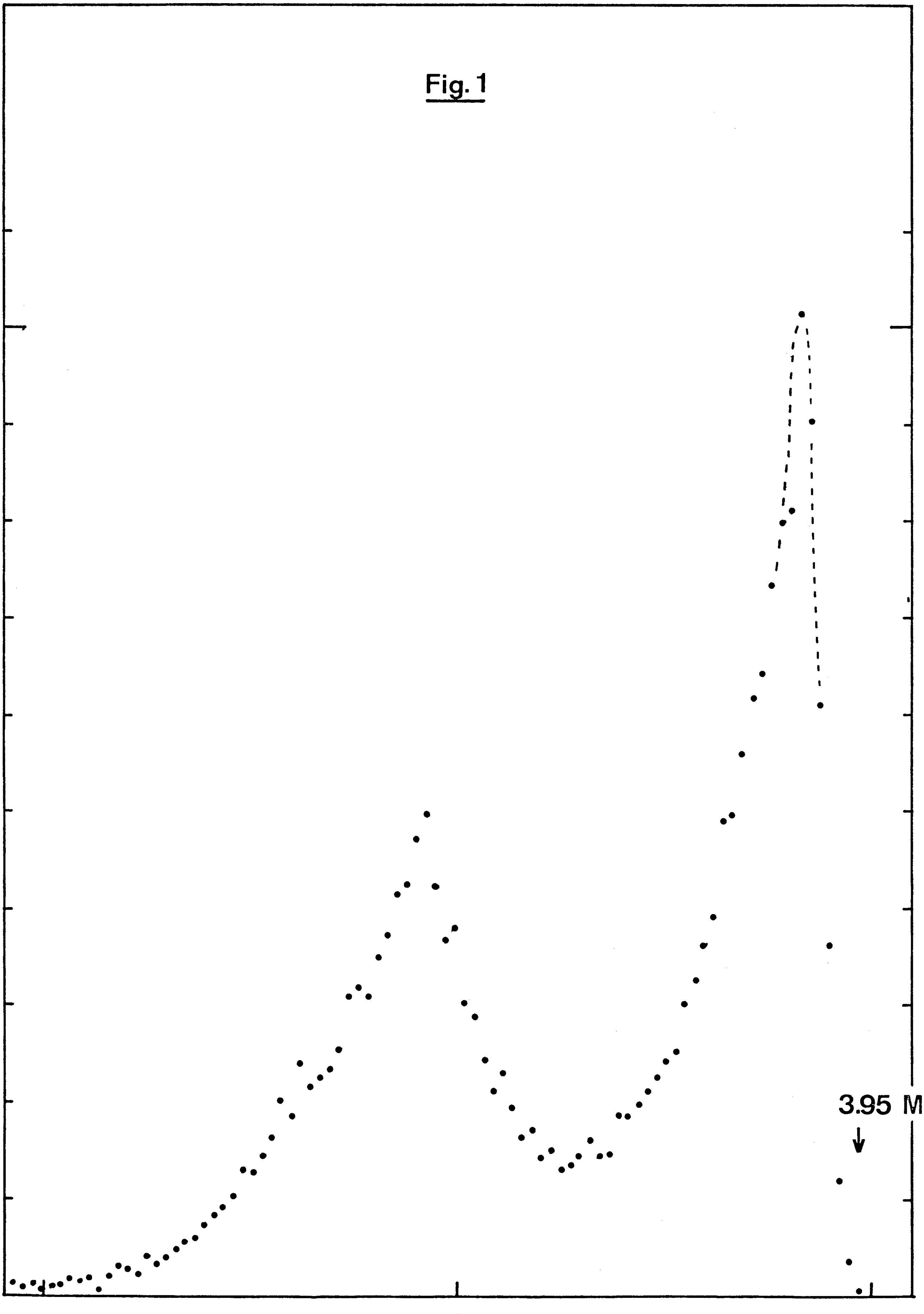


Fig. 2

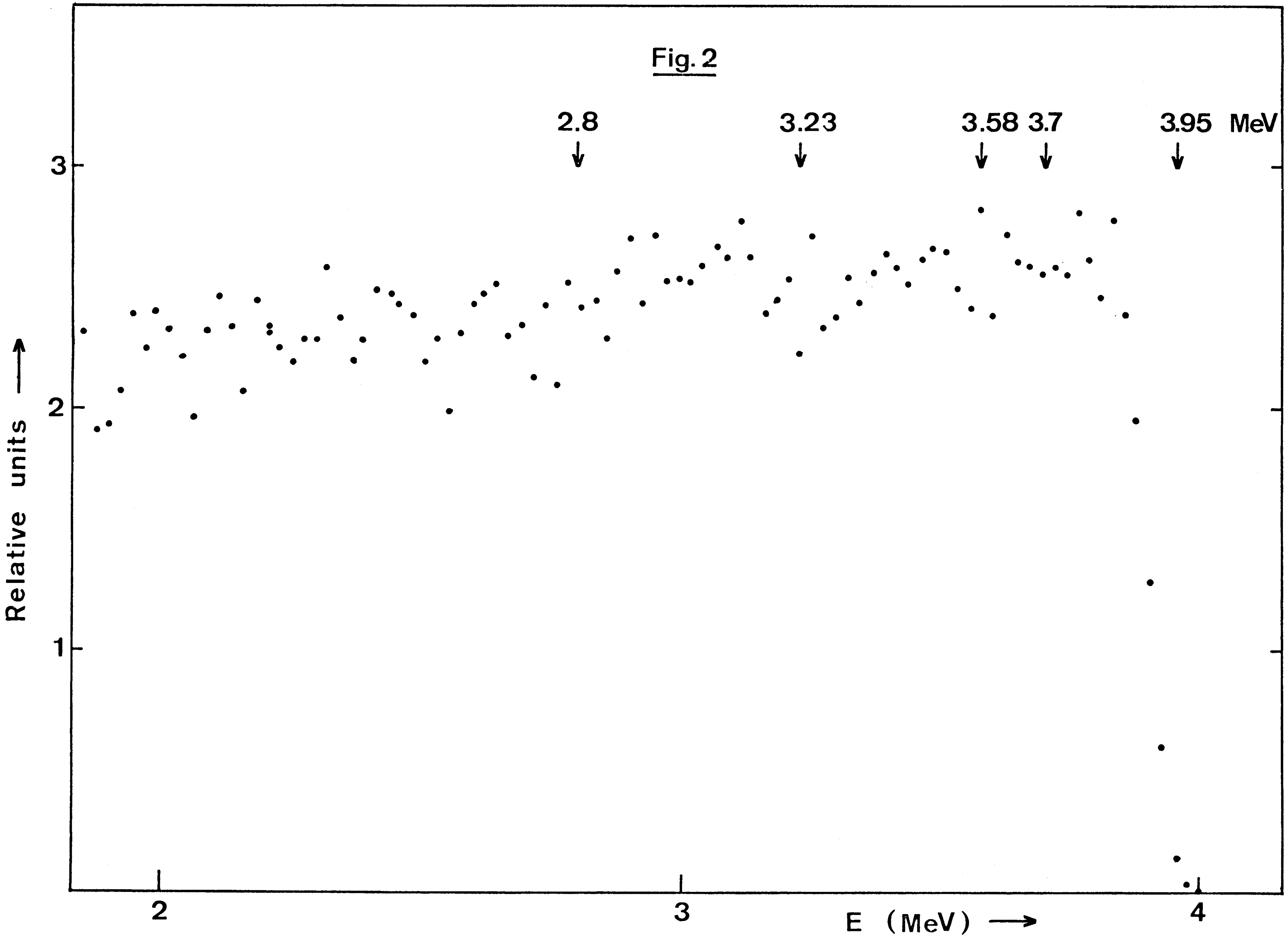
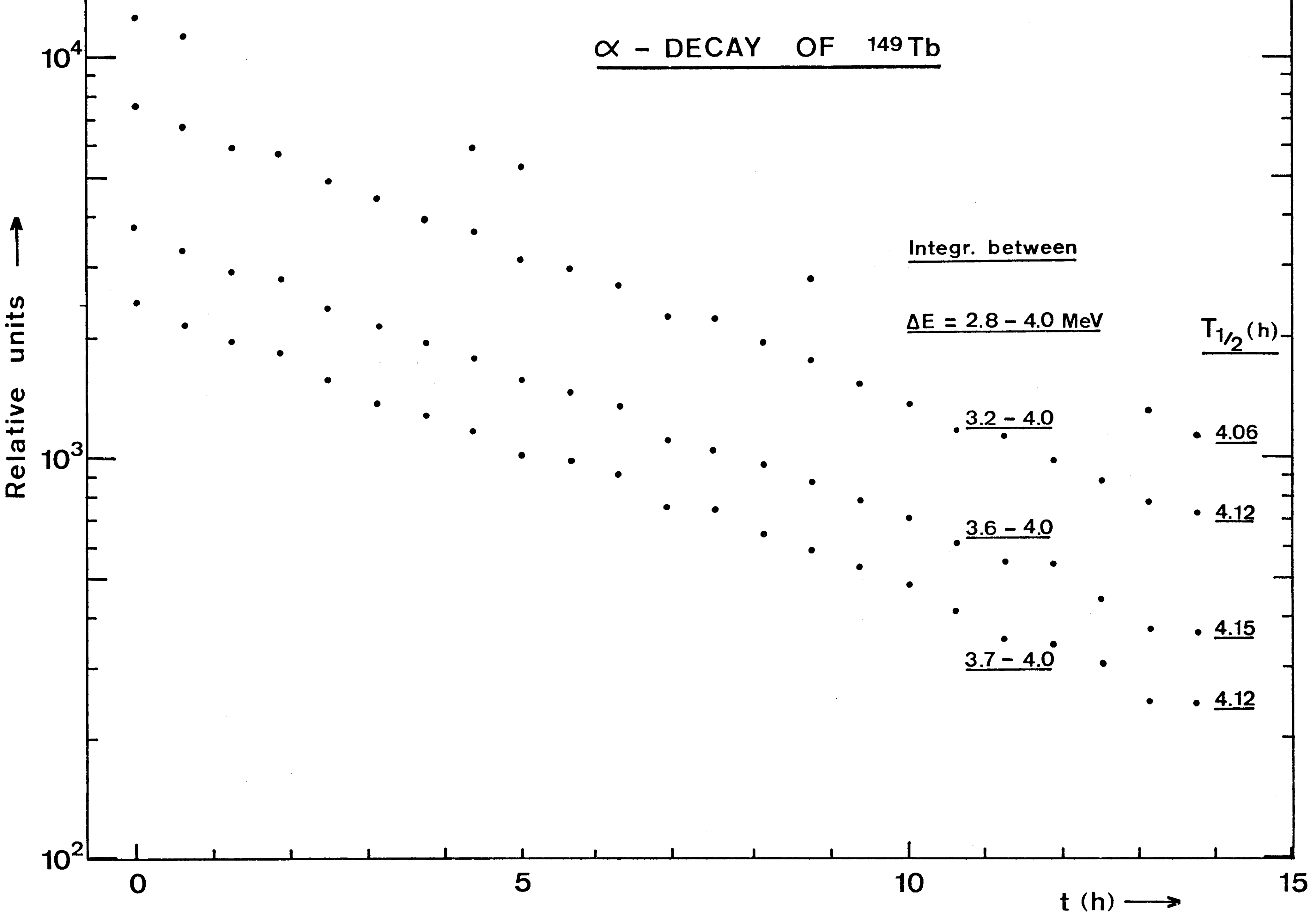
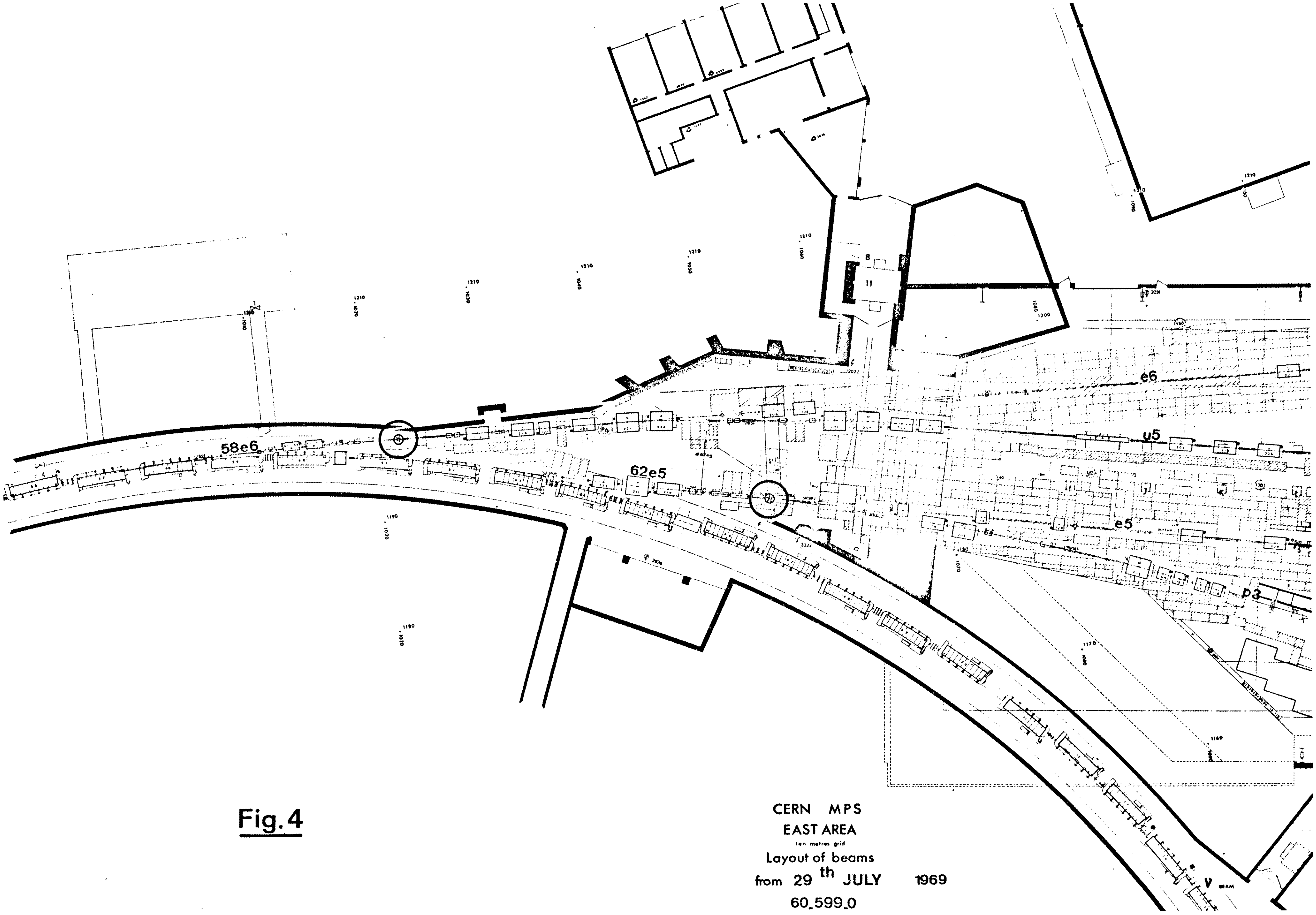


Fig. 3

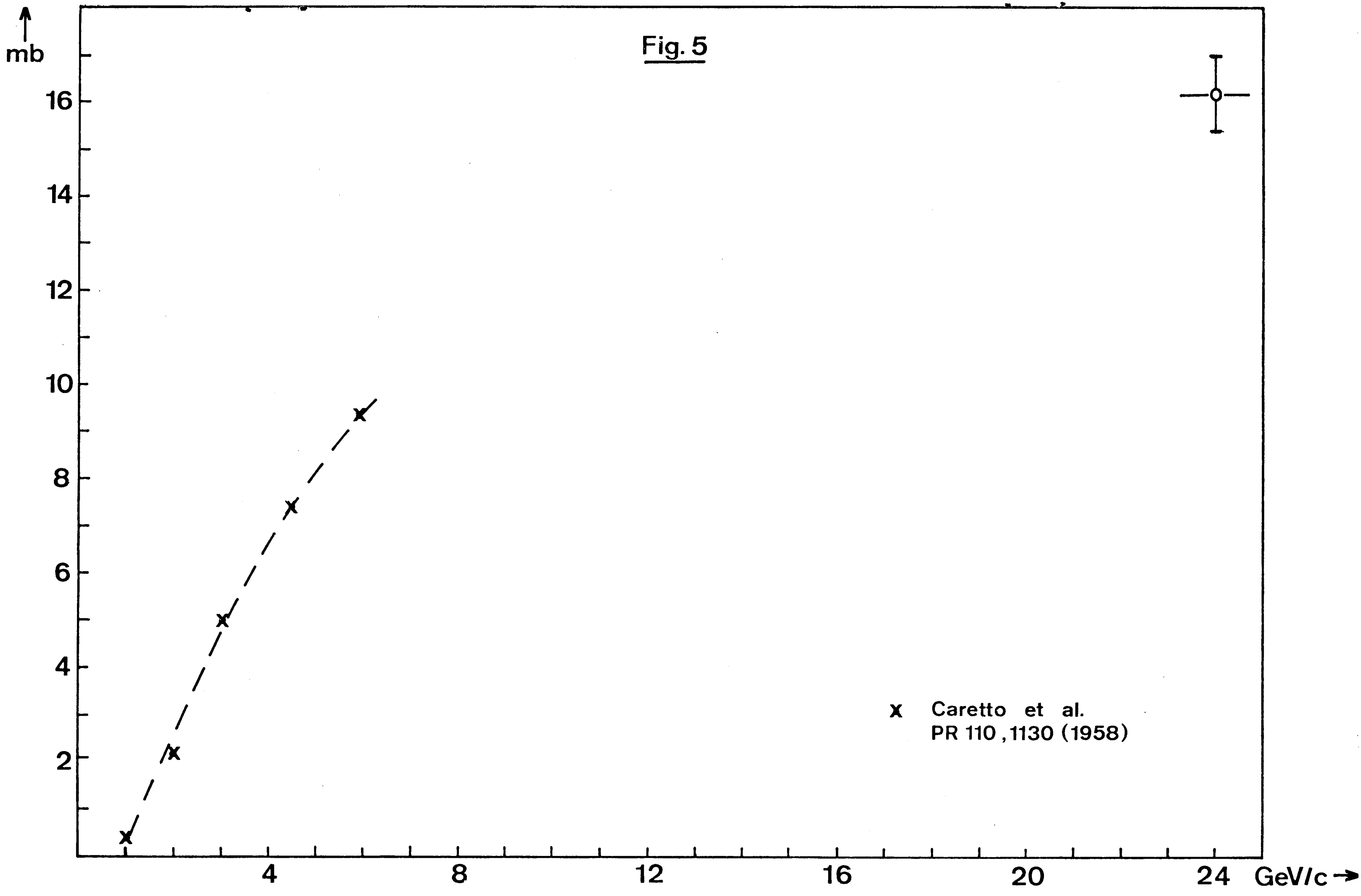

α - DECAY OF ^{149}Tb
Integr. between
ΔE = 2.8 - 4.0 MeV
3.2 - 4.0
3.6 - 4.0
3.7 - 4.0
$T_{1/2}$(h)
4.06
4.12
4.15
4.12
Relative units →
10^4
10^3
10^2
0
5
10
15
t (h) →



CERN MPS
EAST AREA
ten metres grid
Layout of beams
from 29 th JULY 1969
60.599.0

Fig.4

Fig. 5


mb
16
14
12
10
8
6
4
2
4
8
12
16
20
24
GeV/c
x Caretto et al.
PR 110 , 1130 (1958)

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