Title

RECENT ADVANCES IN PARTICLE IDENTIFIERS AT BERKELEY

Authors

Goulding, F.S.
Landis, D.A.

Publication Date

1967-05-01

University of California

Ernest O. Lawrence Radiation Laboratory

RECENT ADVANCES IN PARTICLE IDENTIFIERS AT BERKELEY

F. S. Goulding and D. A. Landis

May 1967

Berkeley, California

DISCLAIMER

Submitted to Gatlinburg Conference
On Semi-Conductor Detectors and
Associated Circuits, May, 1967

UCRL-17555
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

RECENT ADVANCES IN PARTICLE IDENTIFIERS AT BERKELEY

F. S. Goulding and D. A. Landis

May 1967

FOREWARD

This is one of a series of papers presented at the Gatlinburg Conference on Semi-Conductor Detectors and Associated Circuits (May, 1967). Taken together, the papers represent a general summary of some of the recent advances in this area at LRL, Berkeley.

RECENT ADVANCES IN PARTICLE IDENTIFIERS AT BERKELEY*

By F. S. Goulding and D. A. Landis

The purpose of this brief note is to summarize the recent advances made at Berkeley in techniques of particle identification using semi-conductor detectors and to discuss the performance of identifiers. Attention is restricted to particles (p, d, t, α---C ions) in the energy range 5 to 100 MeV (depending upon the type of particle) but the identification method used has proved to be very versatile and may be applied with appropriate restrictions to ranges outside the scope of this paper.

The most significant result of the development of these particle identifiers is to be seen in the fact that particle identification has now become commonplace in experiments in this energy range at Berkeley. The technique is being used at the 88" variable-energy cyclotron and at the heavy ion linear accelerator in nuclear reaction experiments, and also on the Bevatron in nuclear spallation work.

The major step taken in this program was the decision to use a power-law approximation to the range-energy relationship instead of the more common Bethe's equation. Examination of range-energy curves for a wide variety of particles reveals that they can closely be represented by:

$$R = aE^b \qquad (1)$$

where R is the particle range and E is its energy (a and b are constants)

If a particle passes through a transmission detector of thickness T, depositing energy ΔE in this detector, and stops in a second detector, depositing energy E in it, it is easy to show that

$$\frac{T}{a} = (E + \Delta E)^b - E^b \qquad (2)$$

*This work was carried out as part of the program of the Nuclear Chemistry Instrumentation Group of the Lawrence Radiation Laboratory supported by AEC Contract No. W-7405-eng-48.

The quantity a is a constant for a given type of particle but it is different for each of the interesting particles (it is almost proportional to $\frac{1}{MZ^2}$ and no two light isotopes have similar values of MZ^2). Therefore, calculation of $\frac{T}{a}$ gives a value dependant only on the type of particle and not on its energy. Using the E and ΔE signals which are available from the two detectors, a function generator based on the logarithmic relationship between base-emitter voltage and collector current of a transistor can be designed to calculate $\frac{T}{a}$ in a few microseconds. This technique is described in more detail in Reference 1 and a typical distribution of the identifier output is shown in Fig. 1. This figure is designed to illustrate a limitation of the dual-counter identifier. In this case, we were interested in studying the $^{12}C(^{3}He,{}^{6}He)^{9}C$ reaction and therefore in selecting ^{6}He particles. The pronounced shoulder on the predominant ^{4}He group resulted in a large amount of contamination of the ^{6}He energy spectrum as shown in Fig. 2. The problem arises in two ways:

a) Landau collisions in the ΔE detector produce excessively high ΔE signals for a small fraction of the events. This causes the identifier output to be higher in these cases;

b) Chance coincidences have a similar effect.

To reduce these problems an extra ΔE detector is mounted in front of the detector telescope and a reject detector is added at the back to allow rejection of many uninteresting particles. Using the two ΔE signals and the E signal, two identification outputs are derived; they are compared, and if the results do not agree, the event is rejected. This is the basis of the triple-counter identifier.[(2)]

Fig. 4 shows a typical output spectrum from the triple-counter unit, in which the seperation of the different particle groups is seen to be much clearer than the equivalent dual-counter example (Fig. 1). A direct comparison can be made by looking at the ^{6}He energy spectrum in Fig. 4 obtained with the triple-counter and that obtained with the dual-counter in Fig. 2. The background due to α-contamination is virtually zero in Fig. 4 while it is large enough to make interpretation of the data difficult in Fig. 2.

As is usual with any improvement in technique, the experimentalist finds a new experiment to tax the technique to its limit. In this case, the study of very low yield reactions such as (^{4}He,^{8}He) was the trial. In Fig. 5, a typical identifier spectrum obtained from bombarding ^{26}Mg with 80 MeV α-particles is shown. The peak due to ^{8}He particles is seen and, by gating on this peak, the ^{8}He energy distribution can be determined (see Fig. 6). Since the masses of ^{26}Mg, ^{22}Mg and ^{4}He and the beam energy are known, the mass of ^{8}He can be calculated. The first mass determination of ^{8}He was the primary purpose of the experiment. About 20 ^{8}He events were observed in 10 days, during which 10^{9} to 10^{10} α-particles passed through the counter telescope. This ratio illustrates the severity of the particle selection problem in these low-yield reaction experiments.

The next extension in the use of the identifier was to the identification of somewhat heavier ions.(3) To achieve the best results, a small amount of adjustment of the power law (i.e., b of equation 1) is provided. For light ions such as protons, b = 1.73 while b = 1.65 is a better match for carbon ions.

Fig. 7 shows the heavy ion performance of the dual-counter identifier and Fig. 8 shows the improved performance of the triple-counter unit. While carbon ions are the heaviest yet looked at by this method, the problem of making very thin ΔE detectors is a major cause of this limitation--not just the identifier performance (our thinnest ΔE detector is 8μ thick but about 25μ is more common).

A new area of application for the identifier has recently opened up.[(4)] Studies of the spallation products produced by bombardment of heavy elements with high-energy particles have previously required elaborate micro-chemistry and short-lived products have not been studied. A typical identifier spectrum for the products of the bombardment of a uranium target by 5.3 GeV protons is shown in Fig. 9. This experiment was unique in that it made possible the simultaneous discovery of three isotopes ^{11}Li, ^{14}B and ^{15}B. The stability of ^{15}B was previously predicted, ^{14}B was predicted to be marginally stable, while ^{11}Li was expected to be unbound. The curves in Fig. 4 were the results of two experiments at different angles (and therefore counting rates) to demonstrate that chance coincidence were not responsible for the peaks of interest.

In Fig. 9, we observe that the heavier boron ions spill over into the light carbon region--a completely predictable behaviour in this heavy ion region. This tends to result in a confusing picture in the ^{14}B, ^{9}C, ^{15}B region and similar problems will exist in the C, N and higher regions. To help to resolve this confusion we now propose to include time of flight measurements in the system. By moving the front ΔE detector ~20cm in front of the remainder of the telescope, times of flight ~5ηsec result (see Fig. 10). We estimate that we can measure this time with ±0.5ηsec accuracy. Using a simple analogue calculation,* the mass of the particle can be derived at the same time as the normal particle

---

*Mass = $\dfrac{\frac{2E.t^2}{2}}{d}$ where E = particle energy
t = time of flight
d = flight path

identifier computes its identification signal. These can be combined into a two dimensional picture as seen in Fig. 11. We can see that this presentation easily separates the light carbon ions from the heavy boron ions despite the rather poor timing accuracy assumed here.

(Note that we have restricted attention to ion energies <100 MeV. In the spallation process a continuous range of energies is encountered.)

Acknowledgements

This work owes its origin and development to the unusually close collaboration between two experimental groups and ourselves. We owe a debt of gratitude to a number of experimenters, particularly J. Cerny, and S. Cosper, and R. H. Pehl in connection with the nuclear reaction experiments and to E. Hyde and A. Poskanzer for the spallation experiments. The success of the program emphasises the importance of close collaboration between workers in several areas such as detector production, electronic design, computer programming and experimental physics. An essential part of the program is the development and production of ultra-thin diffused detectors by M. Roach and R. Lothrop.

References

(1) F. S. Goulding, D. A. Landis, J. Cerny, R. H. Pehl, IEEE Trans. on Nucl. Sci. NS-11, 399 (1964).

(2) F. S. Goulding, D. A. Landis, J. Cerny, R. H. Pehl, IEEE Trans. on Nucl. Sci. NS-13, 514 (1966).

(3) J. Cerny, et al, Nucl. Instr. and Methods, 45, 337 (1966).

(4) A. M. Poskanzer, et al, UCRL-17261 (1966).

Figures

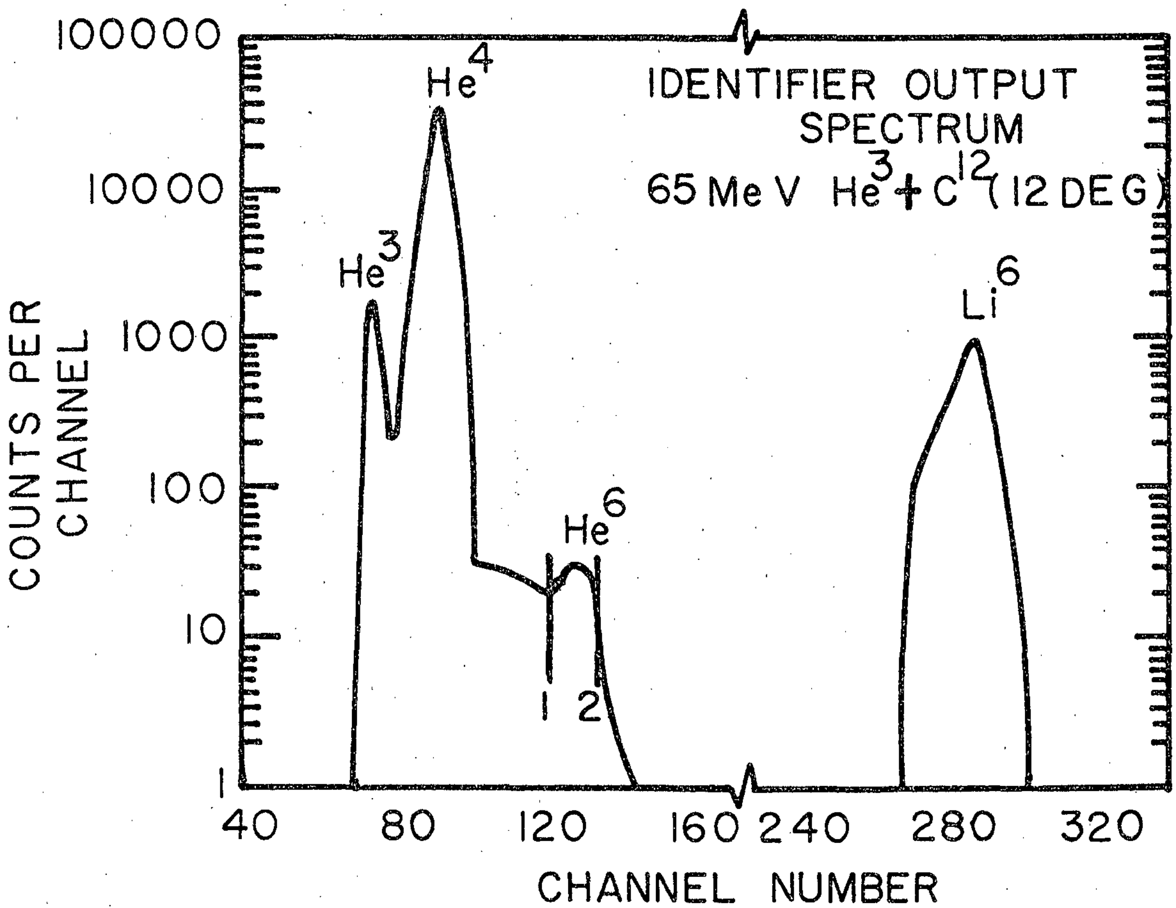


Fig. 1. MUB-9628

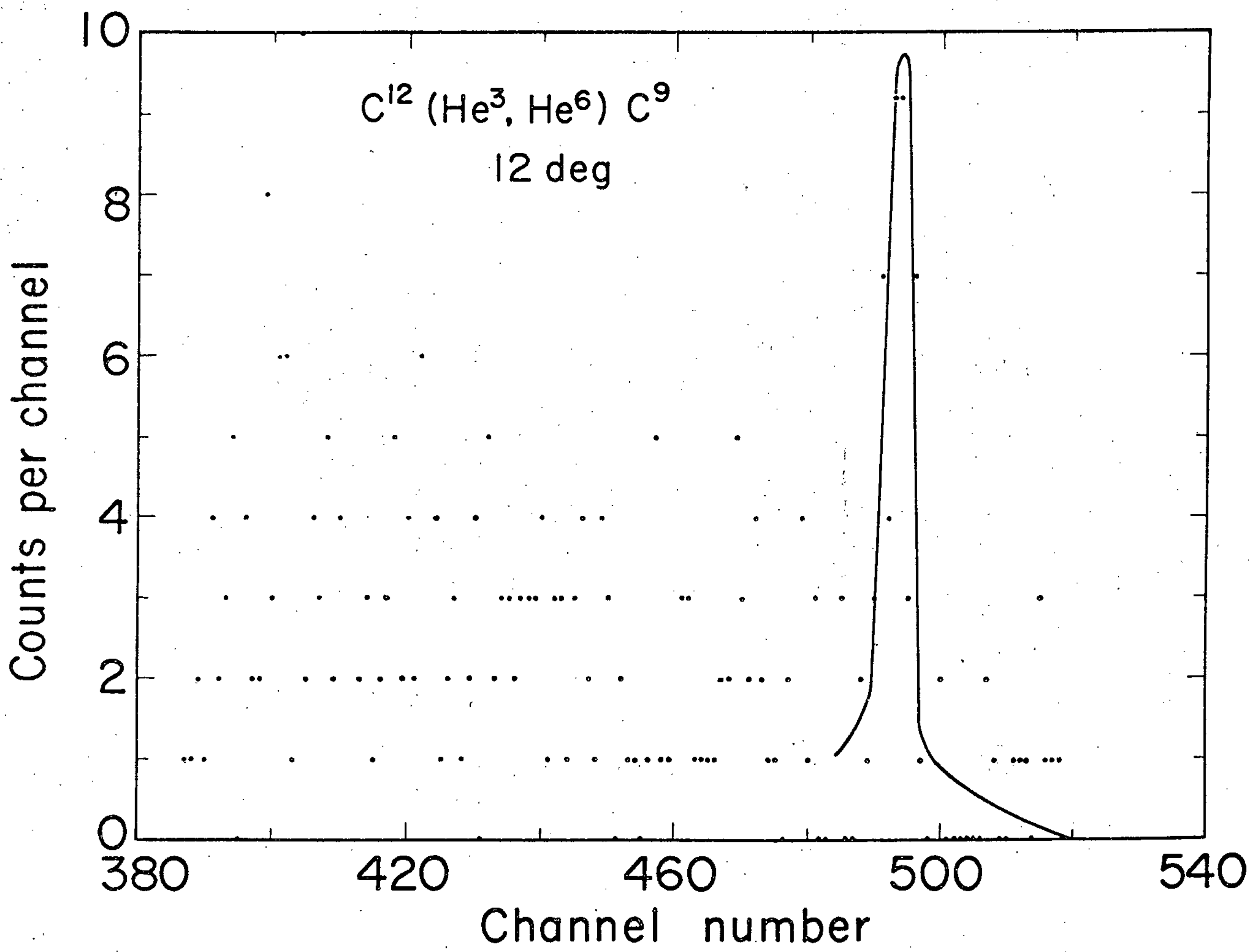


Fig. 2.

MUB-4506

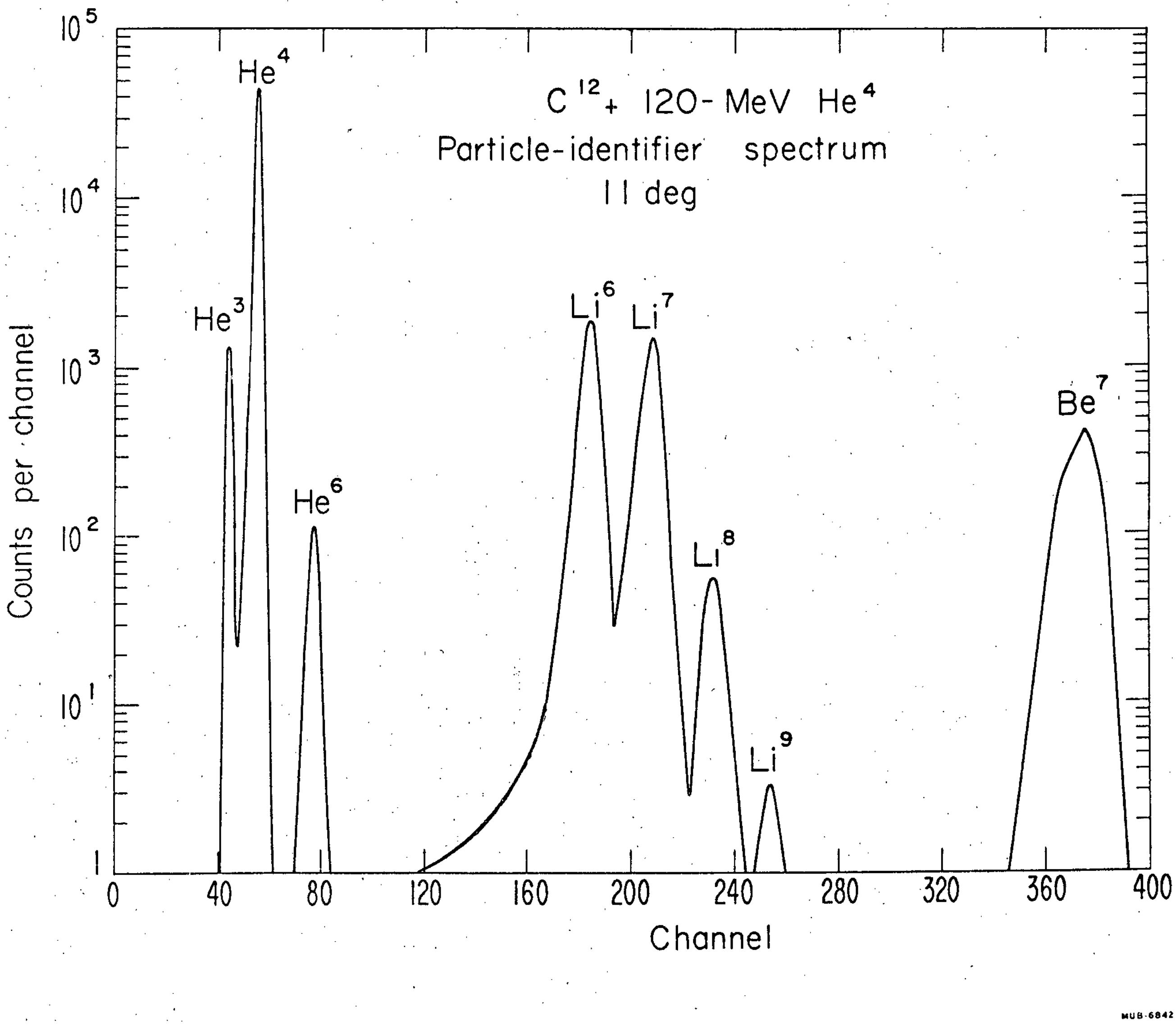

C 12 + 120-MeV He 4
Particle-identifier spectrum
11 deg
He 4
He 3
He 6
Li 6
Li 7
Li 8
Li 9
Be 7
Counts per channel
Channel
10 5
10 4
10 3
10 2
10 1
1
0
40
80
120
160
200
240
280
320
360
400
MUB-6842

Fig. 3.

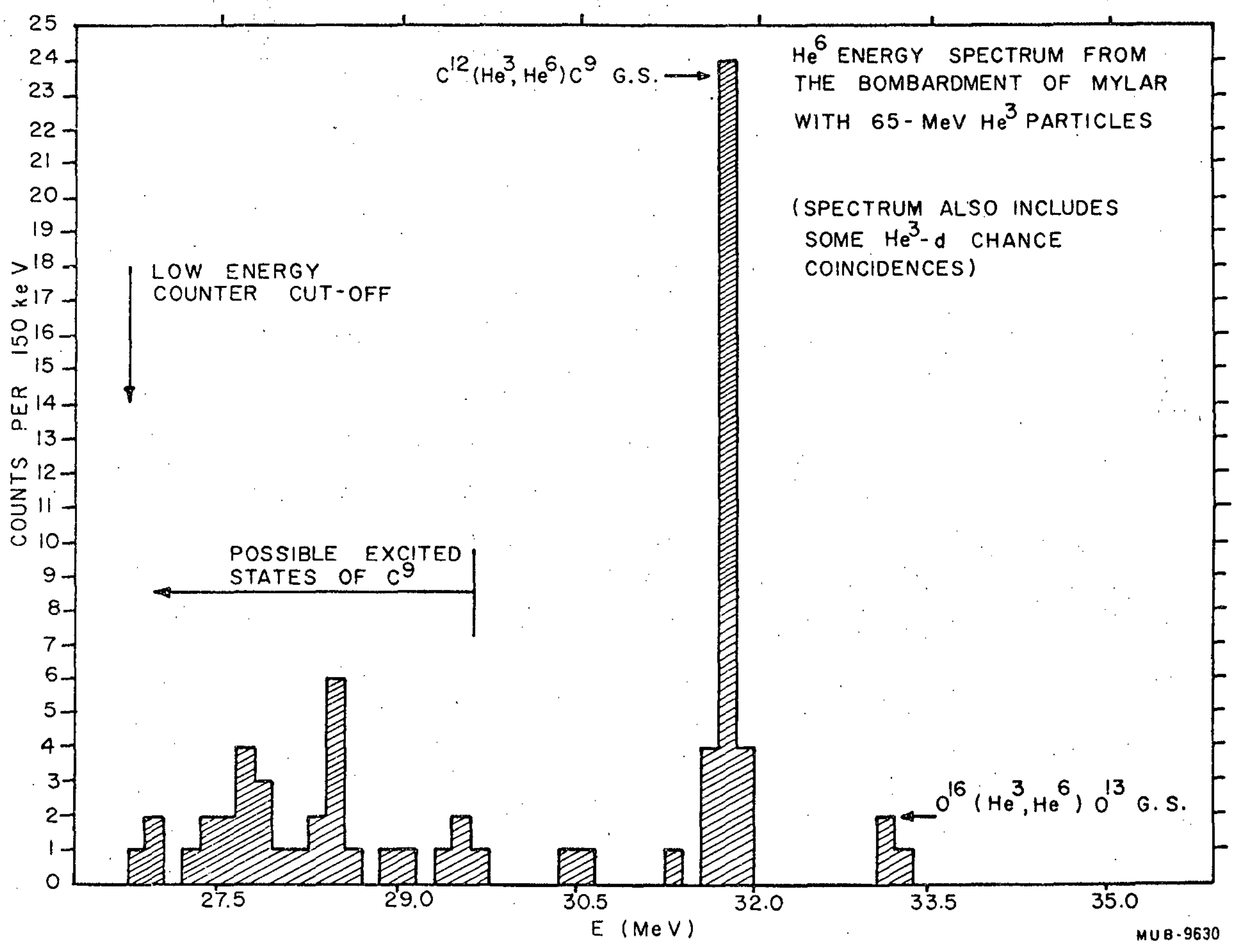
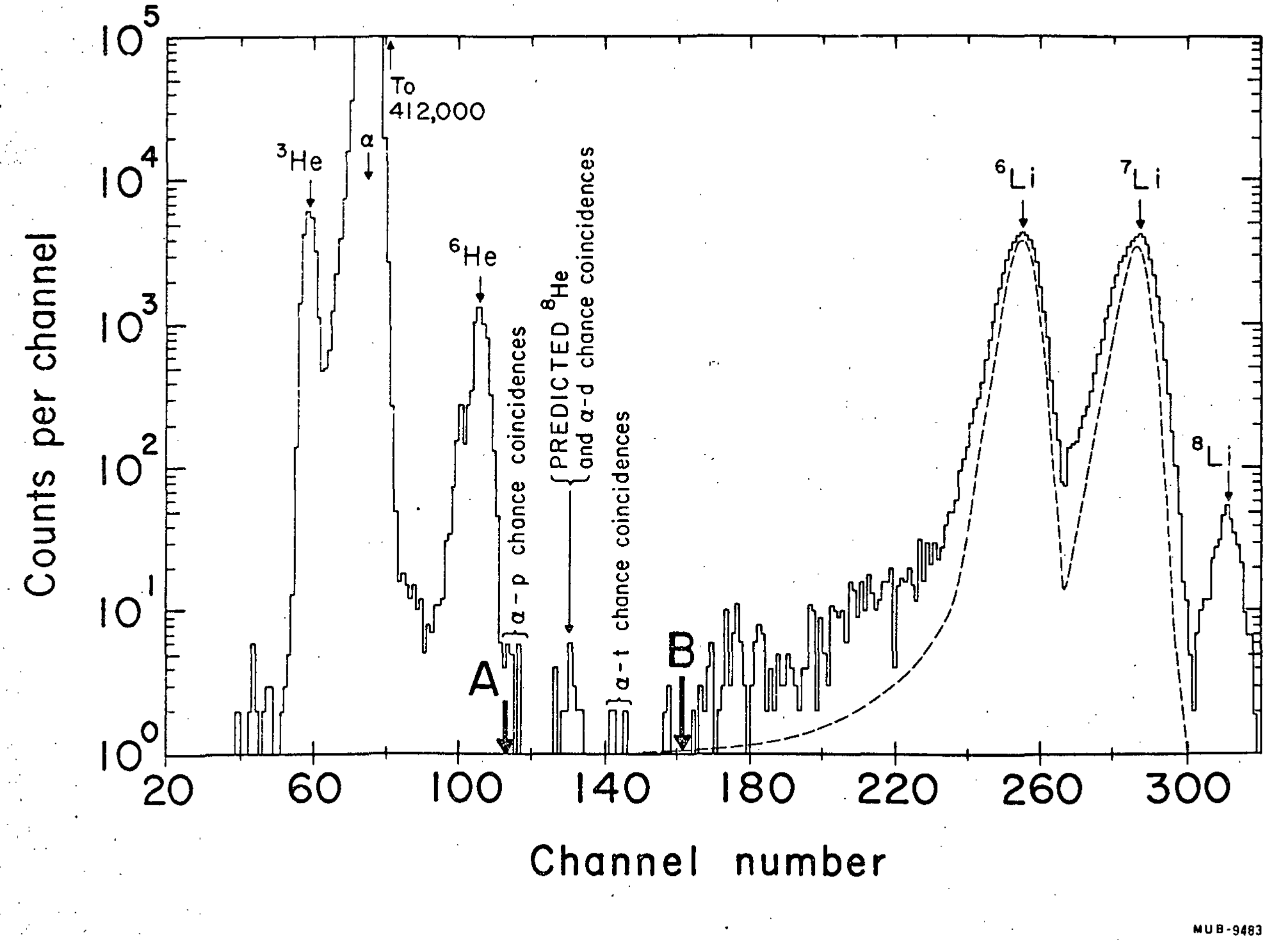
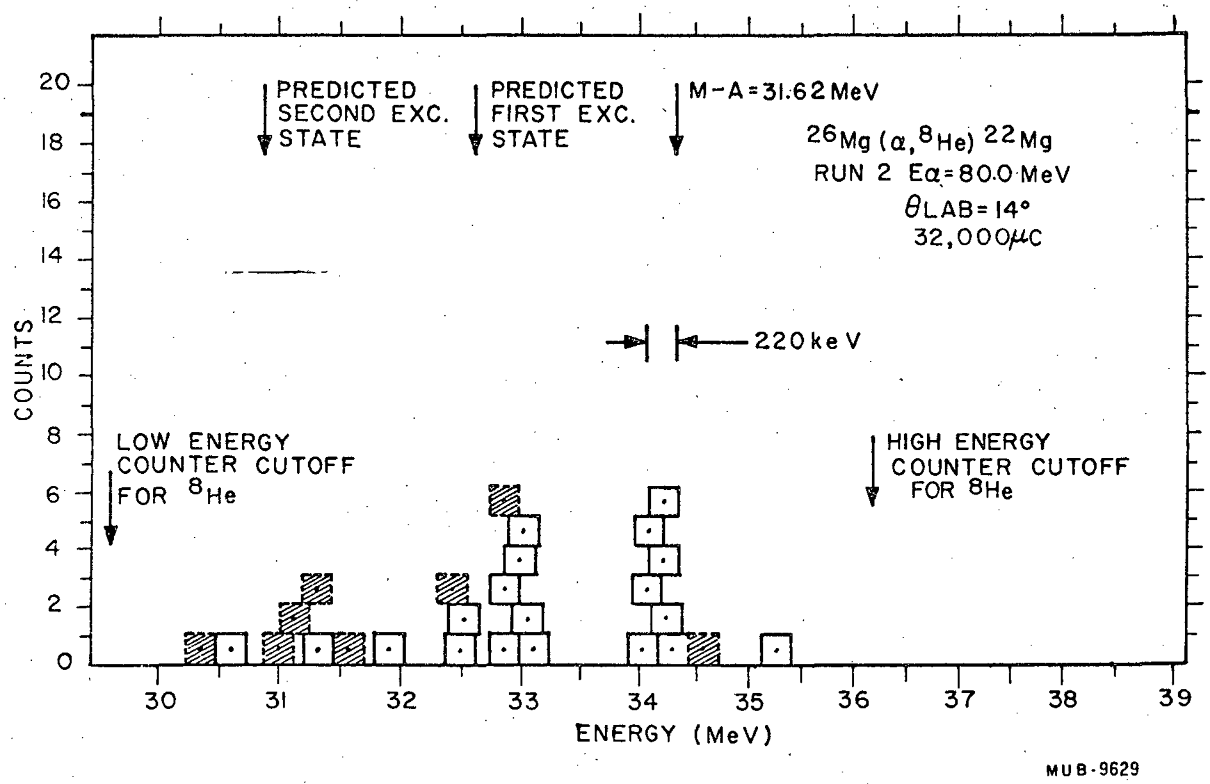

25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
COUNTS PER 150 keV
$C^{12}(He^3, He^6)C^9$ G.S.
He^6 ENERGY SPECTRUM FROM THE BOMBARDMENT OF MYLAR WITH 65-MeV He^3 PARTICLES
(SPECTRUM ALSO INCLUDES SOME He^3-d CHANCE COINCIDENCES)
LOW ENERGY COUNTER CUT-OFF
POSSIBLE EXCITED STATES OF C^9
$O^{16}(He^3, He^6)O^{13}$ G.S.
27.5
29.0
30.5
32.0
33.5
35.0
E (MeV)
MUB-9630

Fig. 4.



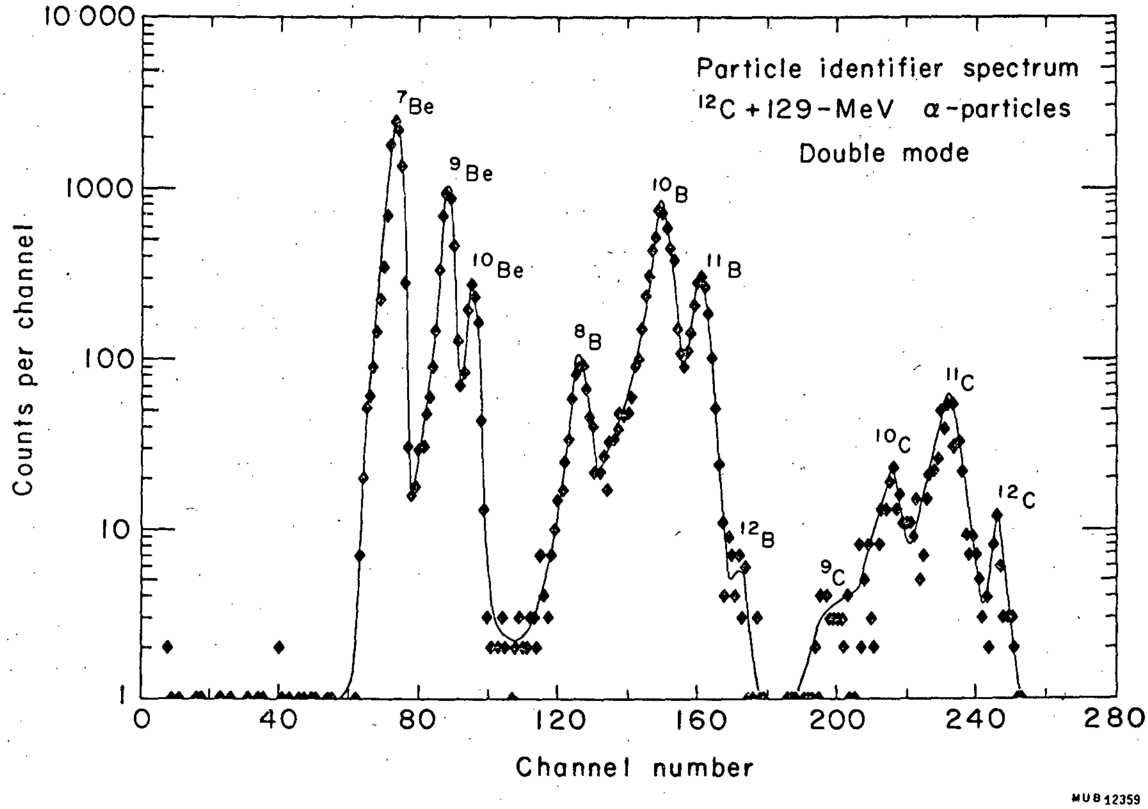
Counts per channel
Channel number
To 412,000
^{3}He
α
^{6}He
α-p chance coincidences
PREDICTED ^{8}He
and α-d chance coincidences
α-t chance coincidences
A
B
^{6}Li
^{7}Li
^{8}Li
MUB-9483

Fig. 5.



PREDICTED SECOND EXC. STATE
PREDICTED FIRST EXC. STATE
M-A=31.62 MeV
26Mg (α, 8He) 22Mg
RUN 2 Eα=80.0 MeV
θLAB=14°
32,000μC
220 keV
LOW ENERGY COUNTER CUTOFF FOR 8He
HIGH ENERGY COUNTER CUTOFF FOR 8He
COUNTS
ENERGY (MeV)
MUB-9629

Fig. 6.



Particle identifier spectrum
12C + 129-MeV α-particles
Double mode
7Be
9Be
10Be
8B
10B
11B
12B
9C
10C
11C
12C
Counts per channel
Channel number
10 000
1000
100
10
1
0
40
80
120
160
200
240
280
MUB 12359

Fig. 7.

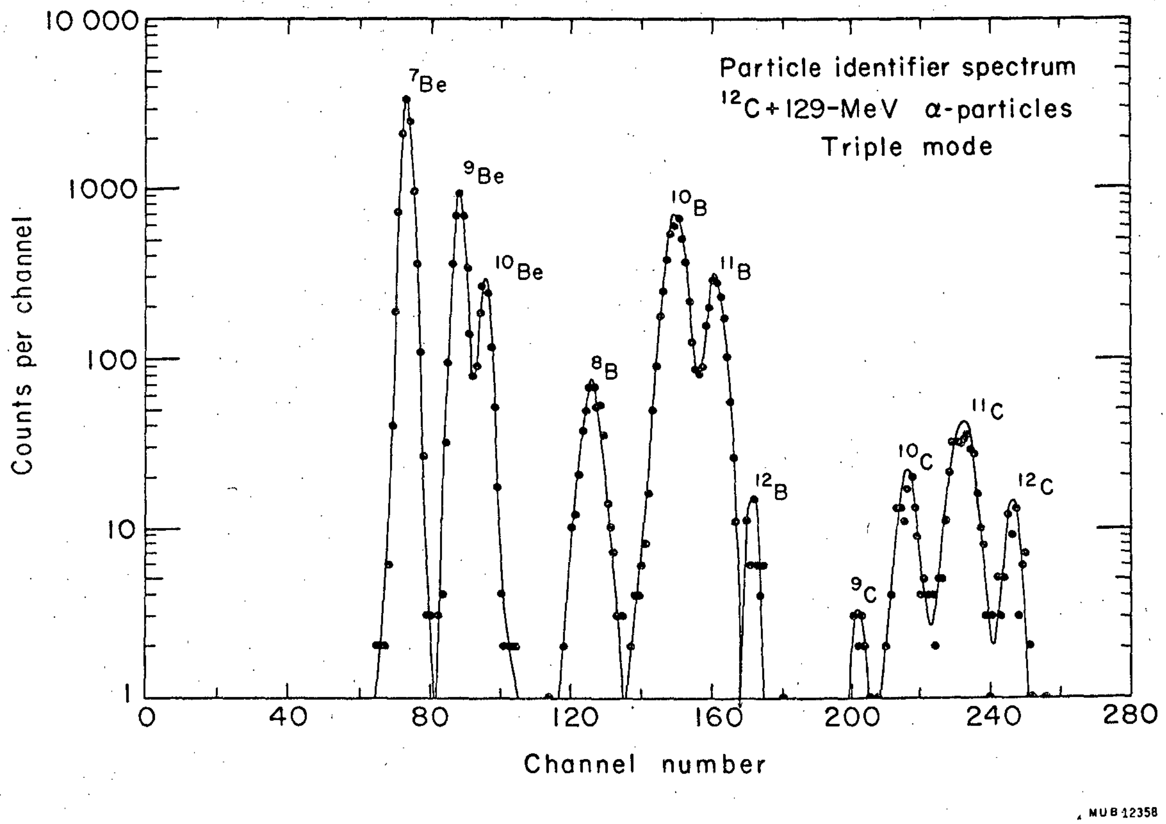

Particle identifier spectrum
$^{12}C + 129$-MeV α-particles
Triple mode
^{7}Be
^{9}Be
^{10}Be
^{8}B
^{10}B
^{11}B
^{12}B
^{9}C
^{10}C
^{11}C
^{12}C
Counts per channel
Channel number
10 000
1000
100
10
1
0
40
80
120
160
200
240
280
MUB 12358

Fig. 8.

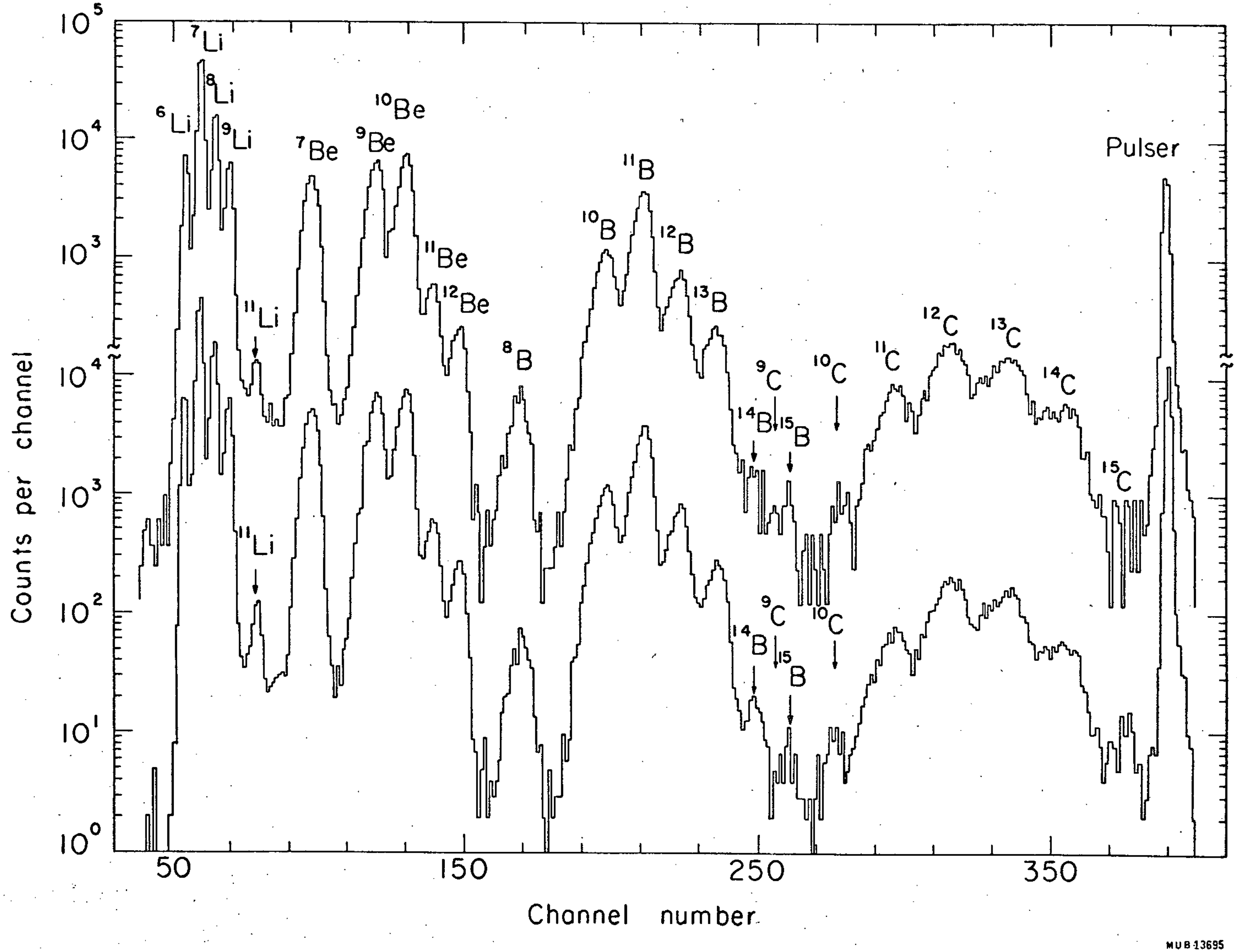
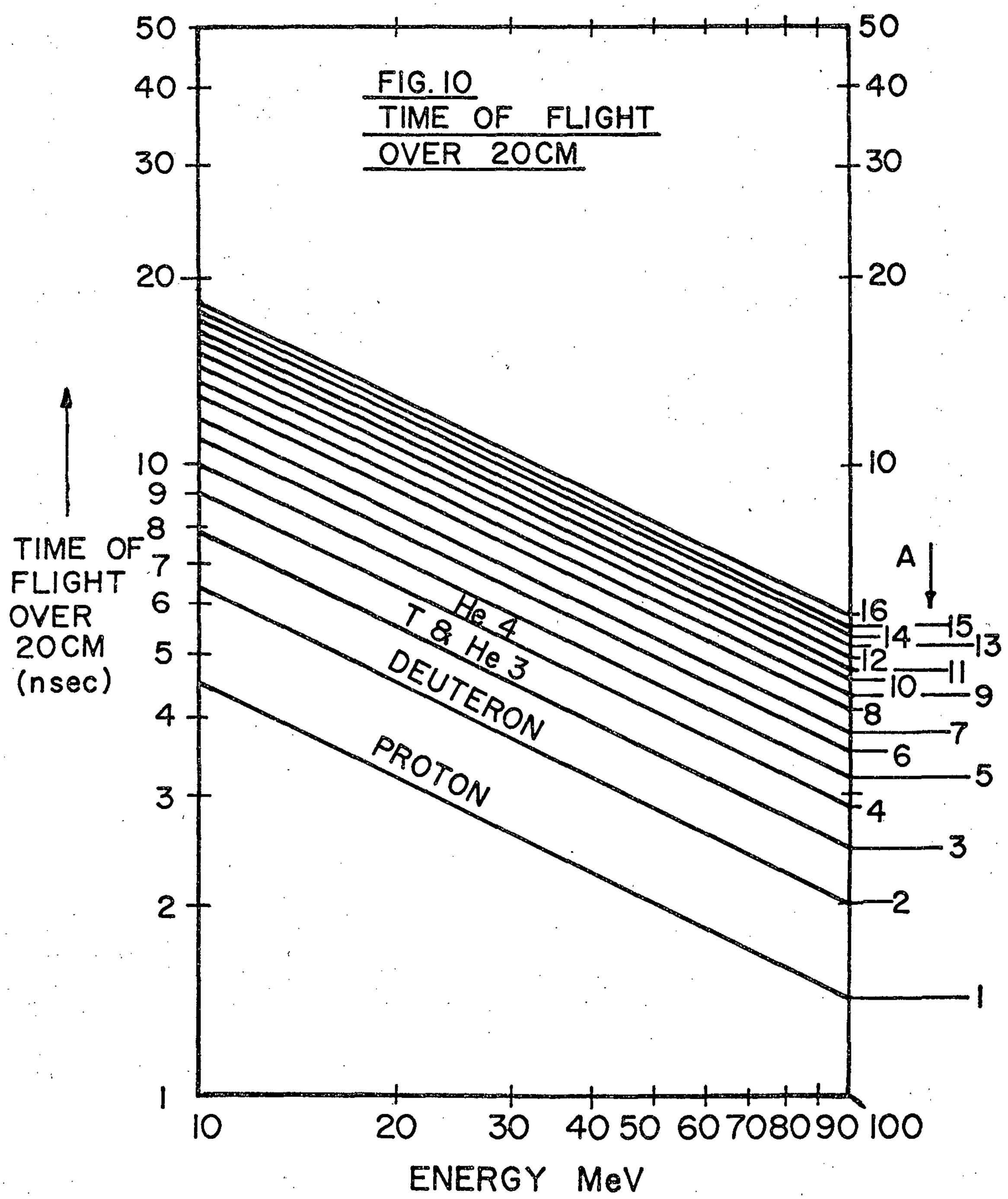


Fig. 9.

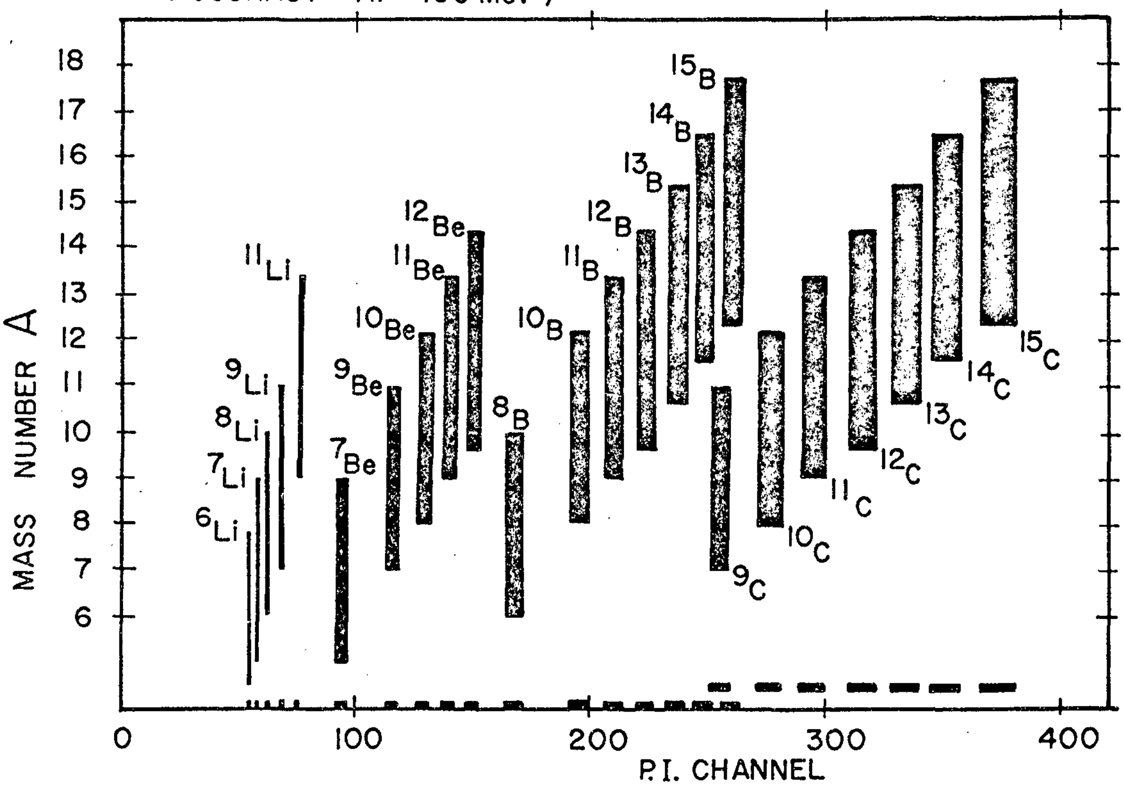
UCRL-17555



XBL 675-1458

Fig. 10.

FIG. 11
TWO DIMENSIONAL PICTURE OF P.I. OUTPUT COMBINED WITH TIME OF FLIGHT.
(ASSUMING 20CM FLIGHT PATH AND ±0.5N SEC ACCURACY AT 100 MeV)



XBL 675-1459

Fig. 11.