## Chapter IV

## ANALYSES OF DATA AND RESULTS

The scanned volume of emulsion in each thickness of lead absorber is shown in Table I.

Table I. Scanned volume of emulsion in each thickness of lead absorber.

| Thickness of Lead Absorber | Scanned Volume ($cm^3$) |
|---|---|
| 0 cm | 3.0 |
| 1 cm | 4.5 |
| 2 cm | 4.5 |
| 3 cm | 4.5 |

The numbers of grain counted tracks classified according to the origins and the efficiency of scanning are shown in Tables II and III.

Table II. The number of particles in emulsion in each thickness of lead absorber.

| Thickness of Lead Absorber | Number of Particles | | |
|---|---|---|---|
| | Coming into the Emulsion | Originating from Neutral Particle Collision | Originating from Stars |
| 0 cm | 77 | 0 | 9 |
| 1 cm | 112 | 8 | 25 |
| 2 cm | 125 | 7 | 16 |
| 3 cm | 117 | 6 | 10 |

Table III. Efficiency of Scanning.

| Plate No. | Number of Events in First Scanning | Number of Events in Second Scanning | Number of Common Events in Two Scannings | Efficiency (%) |
|---|---|---|---|---|
| 3 cm Pb-1 | 38 | 45 | 38 | 91.6 |
| 3 cm Pb-2 | 50 | 47 | 45 | 92.8 |
| 3 cm Pb-3 | 45 | 42 | 41 | 94.3 |
| 2 cm Pb-1 | 47 | 43 | 42 | 93.3 |
| 2 cm Pb-2 | 49 | 47 | 45 | 93.8 |
| 2 cm Pb-3 | 50 | 46 | 45 | 93.8 |
| 1 cm Pb-1 | 45 | 41 | 40 | 93.0 |
| 1 cm Pb-2 | 49 | 50 | 45 | 90.9 |
| 1 cm Pb-3 | 42 | 41 | 37 | 89.2 |
| 0 cm Pb-1 | 38 | 44 | 38 | 92.7 |
| 0 cm Pb-2 | 50 | 48 | 45 | 91.9 |

For each thickness of lead absorber the average grain density per 100 microns is plotted against the range on a log-log scale as shown in Fig II-V. The points due to different particles are gathered in different regions. From . characteristics of tracks, a group of points on each log-log scale is expected to be corresponding to protons. These points are chosen to fit the least square lines

$$\log n_g = a + b \log R.$$

The equations of the lines expected to be corresponding to proton in each thickness of absorber are

$$\log n_g = 3.2511 - 0.4472 \log R$$

for protons in the emulsion without lead absorber,

$$\log n_g = 3.1376 - 0.3696 \log R$$

for protons in the emulsion with 1 cm lead absorber,

$$\log n_g = 3.1686 - 0.3683 \log R$$

for protons in the emulsion with 2 cm lead absorber, and

$$\log n_g = 3.1601 - 0.3699 \log R$$

for protons in the emulsion with 3 cm lead absorber.

When the above equations are obtained the ratio of the ranges of the unknown particles and the expected proton can be determined. For a thickness of absorber, the track of a particle has been measured. Ranges and grain densities per 100 microns are measured to be $R_1$ and $n_{g1}$ respectively. By substituting the values of $n_{g1}$ in the equation of proton in the same thickness of absorber, the values of ranges $R_p$, which have the same grain densities as the ranges $R_1$ of the unknown particle, are obtained. That is $R_1$ and $R_p$ are ranges of unknown particle and proton having the same velocity. Using the relation $\frac{R_1}{R_p} = \frac{M_1}{M_p}$, the mass of the unknown particle in proton mass unit is determined.

Having obtained the masses of the particles in units of expected proton mass, these values of masses are tabulated to construct histograms. The histograms in Fig VI are constructed by using the interval $0.0272 m_p$ or $50 m_e$. In constructing the histograms here, the masses of particles from stars and those produced by the collision of neutral particles with nuclei in the emulsion have been included to give more accuracy. The scattered values of masses are excluded.

The mean values of masses that have peaks in histograms in each thickness of absorber comparing to the masses of particles in proton mass units obtained from Leighton's Principles of Modern Physics, are shown in Table IV.

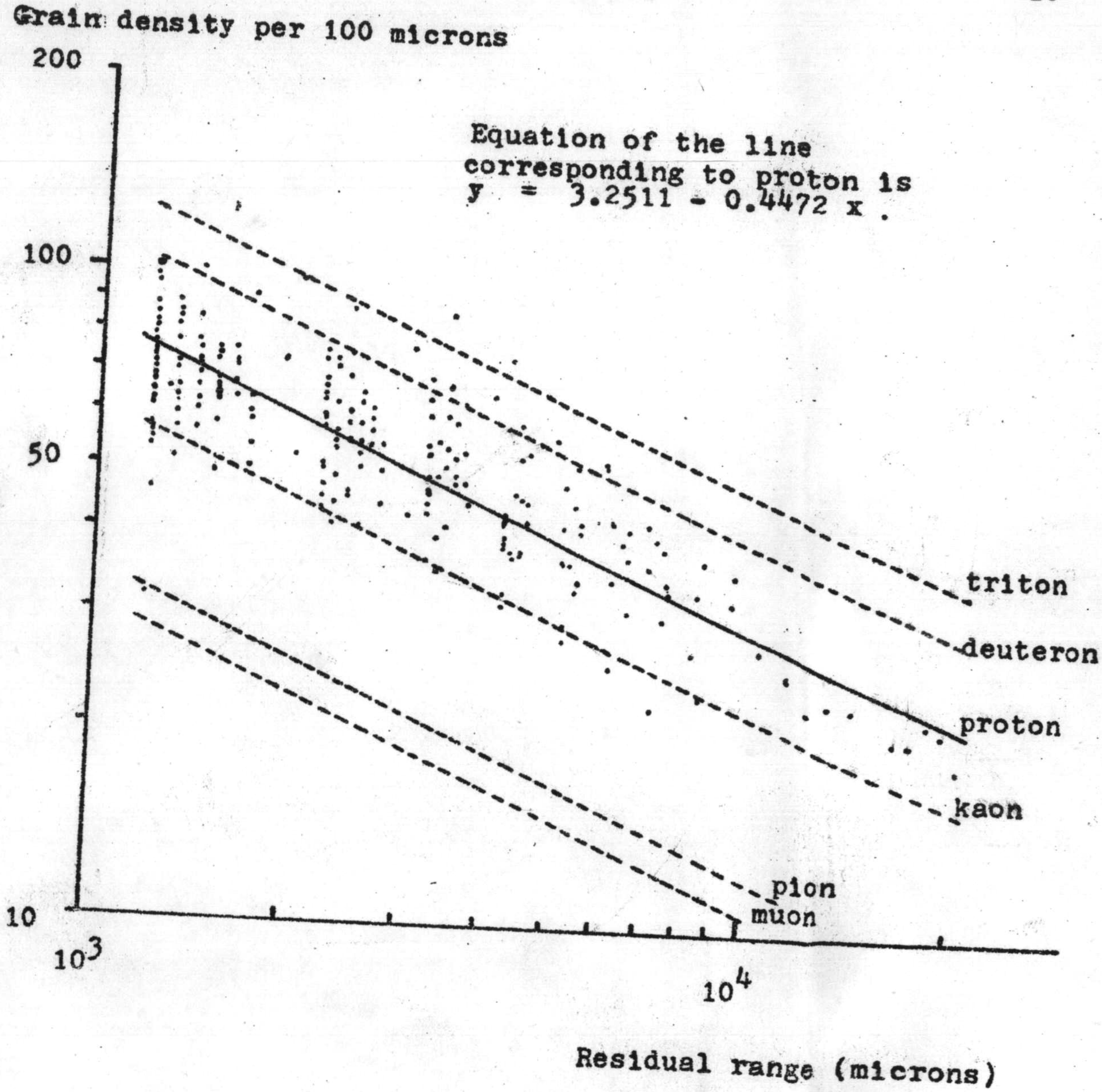


Fig II. A plot of residual range and grain density per 100 microns of events in the emulsion without lead absorber.

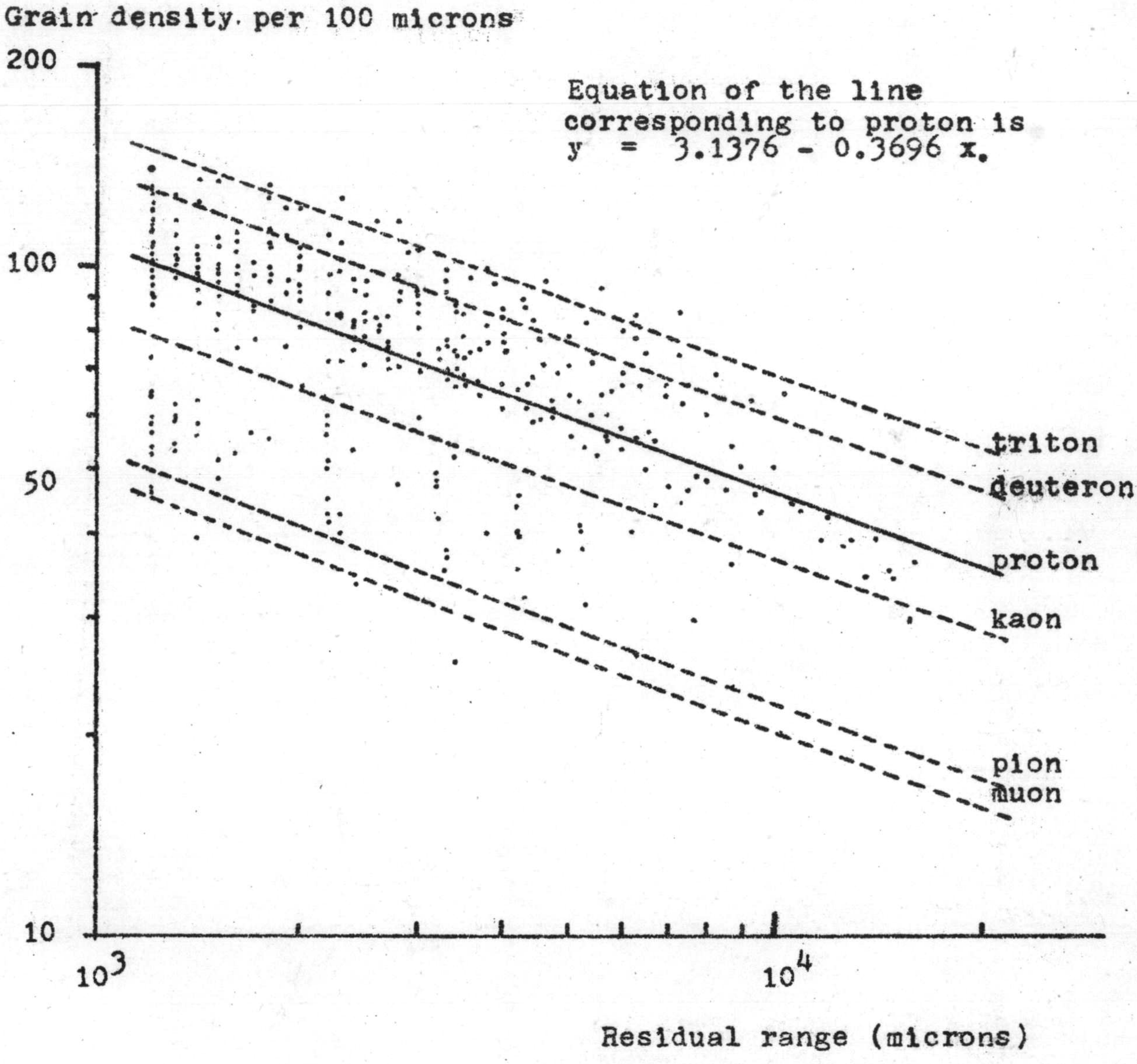


Fig III. A plot of residual range and grain density per 100 microns of events in the emulsion with 1 cm lead absorber.

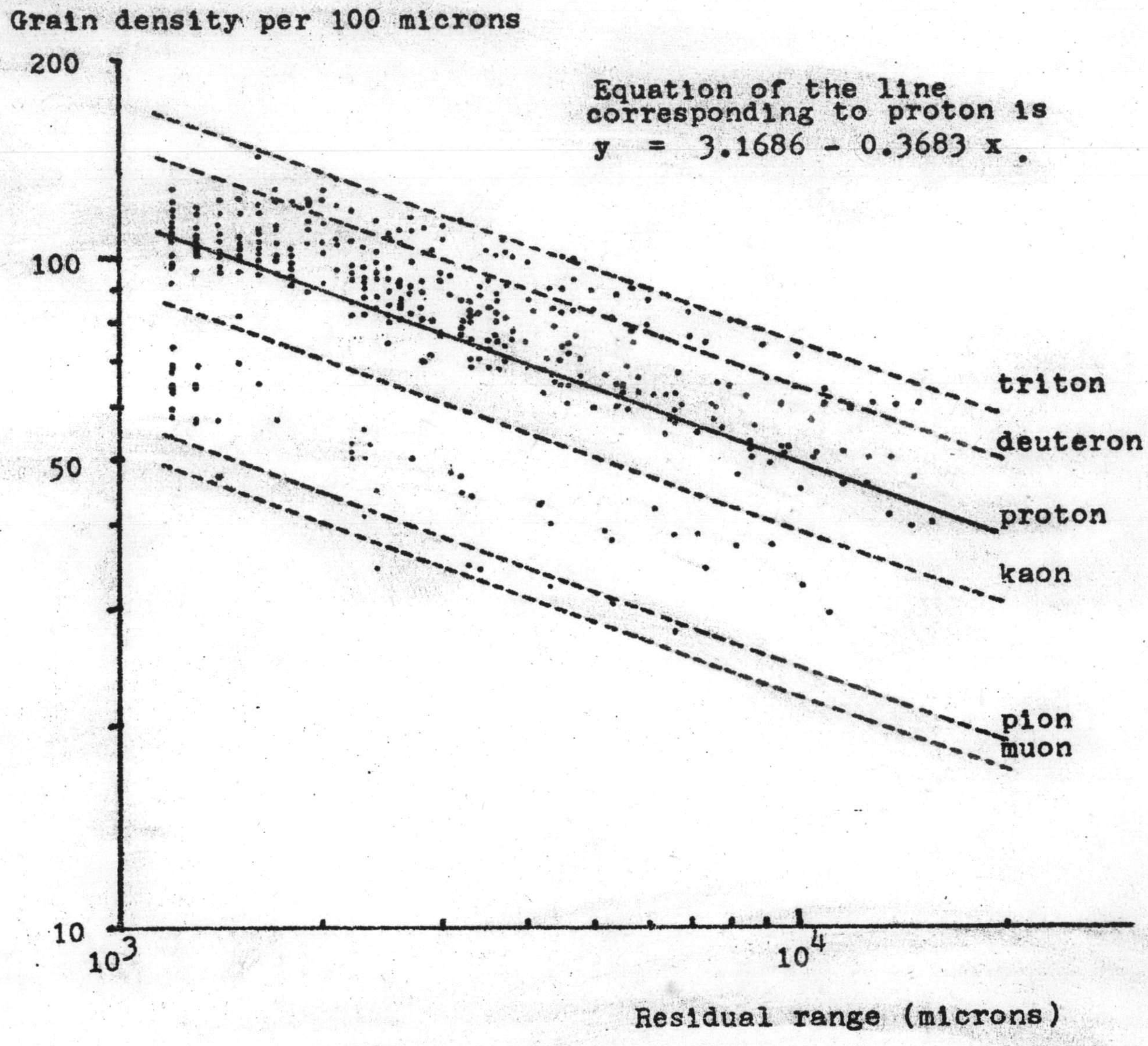


Fig IV.A plot of residual range and grain density per 100 microns of events in the emulsion with 2 cm lead absorber.

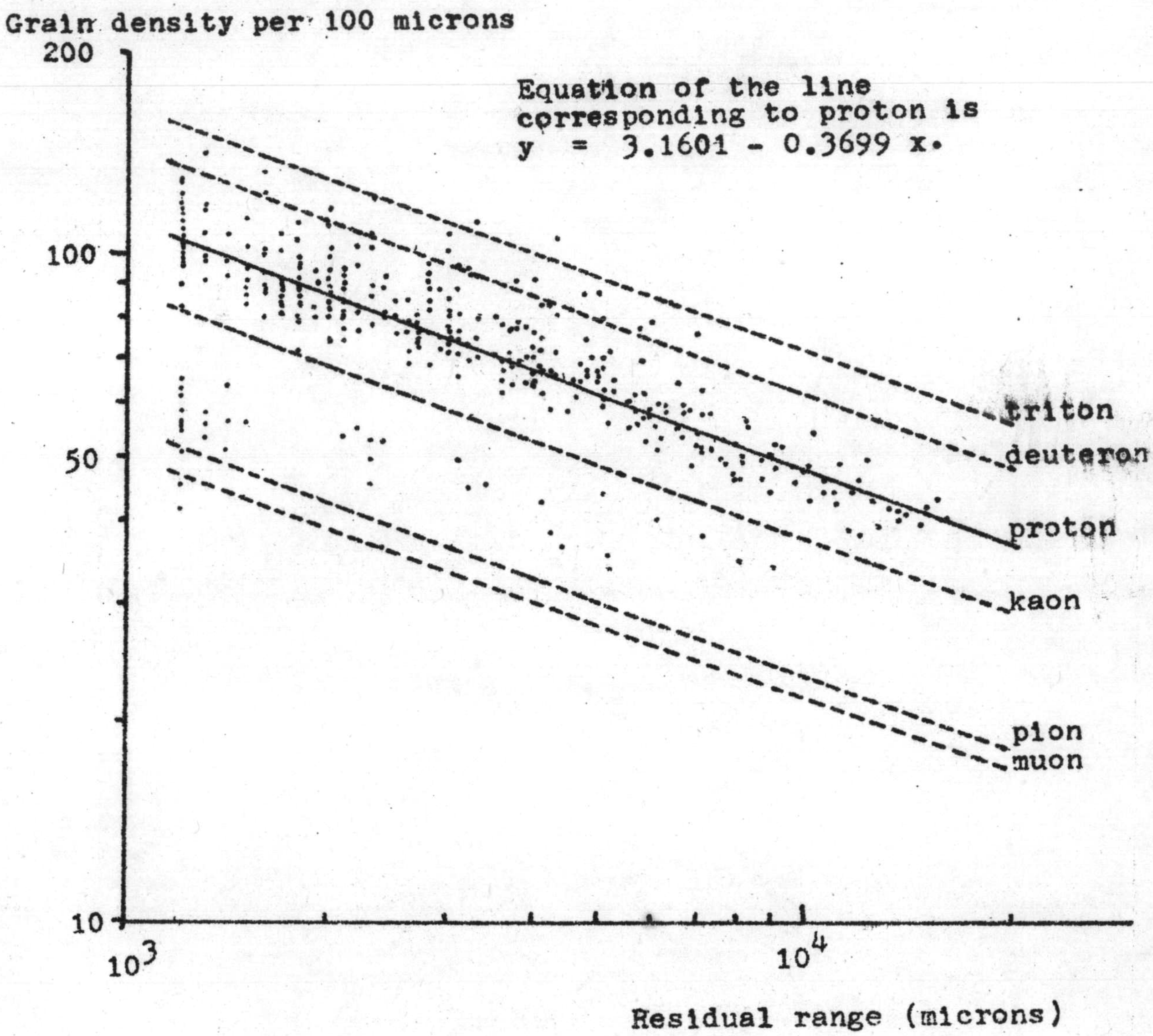


Fig V. A plot of residual range and grain density per 100 microns of events in the emulsion with 3 cm lead absorber.

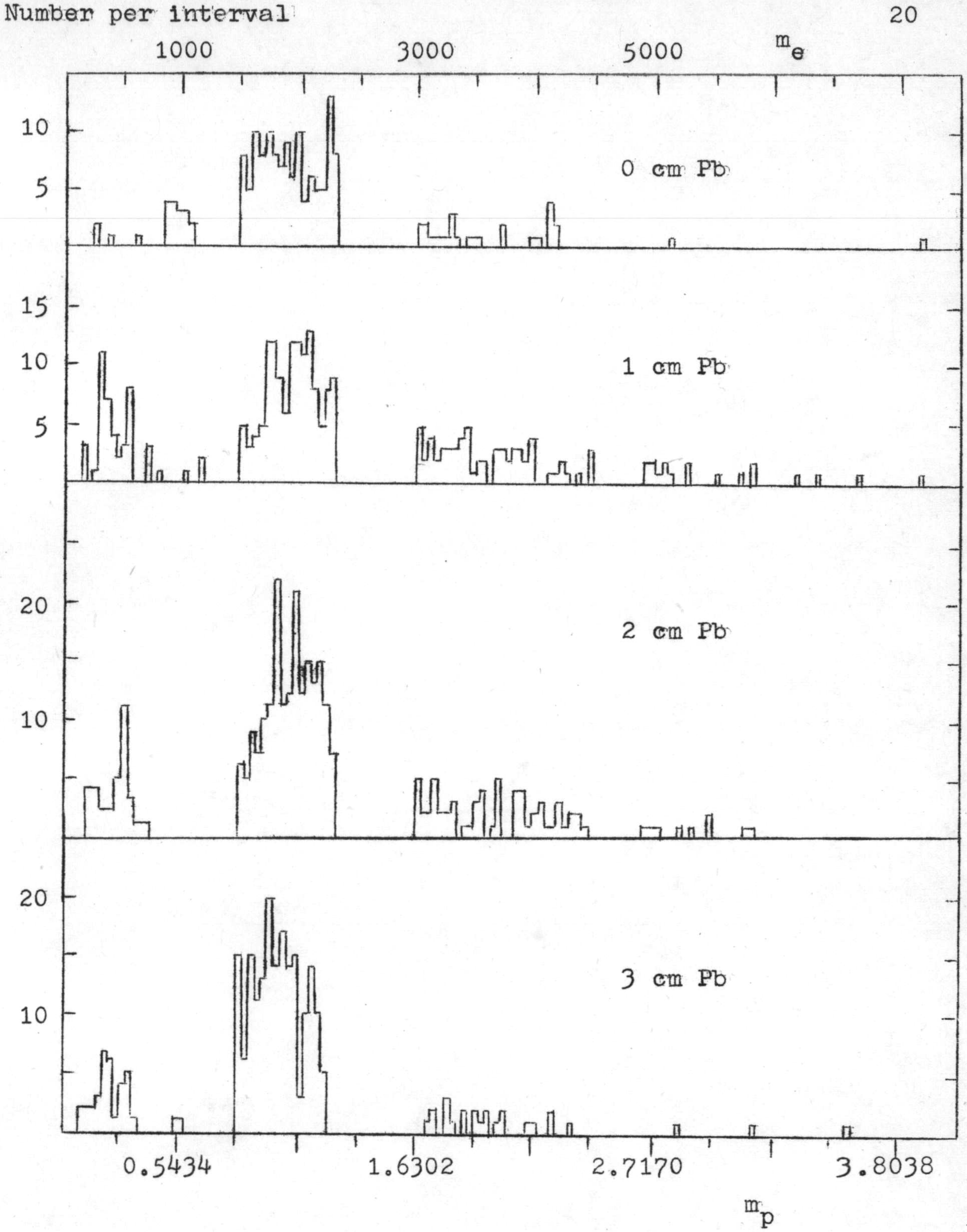


Fig VI. Mass spectrum of particles in the emulsion in each thickness of lead absorber.

Table IV. Comparison of masses having peaks in histograms and masses from Leighton's Principles of Modern Physics.

| Thickness of Lead Absorber | Masses from Peaks in Histograms | Masses in Proton Mass Units |
|---|---|---|
| 0 cm | 0.5212 ± 0.0043 | $m_K$ = 0.5264 |
| | 1.0315 ± 0.2992 | $m_p$ = 1.0000 |
| | 1.9386 ± 0.2690 | $m_d$ = 2.0014 |
| 1 cm | 1.0505 ± 0.2614 | $m_p$ = 1.0000 |
| | 1.8848 ± 0.2310 | $m_d$ = 2.0014 |
| | 3.0197 ± 0.4179 | $m_t$ = 3.0028 |
| 2 cm | 1.0505 ± 0.0652 | $m_p$ = 1.0000 |
| | 1.9864 ± 0.2755 | $m_d$ = 2.0014 |
| | 2.9000 ± 0.2000 | $m_t$ = 3.0028 |
| 3 cm | 0.9967 ± 0.1926 | $m_p$ = 1.0000 |
| | 1.9587 ± 0.2217 | $m_d$ = 2.0014 |



The uncertainties in Table IV are taken from half-width of the Gaussian distribution.

In emulsion without lead absorber, there exist the masses 0.5215 ± 0.0043$m_p$, 1.0315 ± 0.2992$m_p$ and 1.9386 ± 0.2690$m_p$ which agree with masses of kaon (0.5264$m_p$), proton and deuteron (2.0014$m_p$). In emulsions with lead absorbers, there exist the masses about 1, 2 and 3$m_p$ which agree with masses of proton deuteron and triton.

The comparison in Table IV confirms the inspection from the characteristics of the tracks that the chosen protons are really protons.

From the histograms, the number of particles coming into emulsions, in different intervals of masses is shown in Table V. The unit of mass from now on is in electron mass unit ($m_e$) obtained by 1840 X proton mass unit.

Table V. Number of particles coming into emulsions in different mass intervals.

| Mass Interval ($m_e$) | Number of Particles Coming into Emulsion with Lead Absorber of Thickness | | | |
|---|---|---|---|---|
| | 0 cm | 1 cm | 2 cm | 3 cm |
| 150-250 | 0 | 3 | 1 | 4 |
| 280-380 | 3 (5) | 14 | 9 | 17 |
| 480-580 | 0 | 11 | 12 | 8 |
| 700-1150 | 4 (6) | 3 | 0 | 2 |
| 1500-2250 | 59 (89) | 57 | 81 | 73 |
| 2950-4500 | 11 (17) | 18 | 18 | 13 |
| 4900-7200 | 0 | 6 | 4 | 0 |

The numbers in parentheses correspond to the number of particles coming into emulsion without lead absorber normalized to be number of particles in emulsion of volume 4.5 $cm^3$.

The distribution of mass due to error is assumed to be Gaussian (see Appendix I), except some values of masses when judged from histograms are not suitable for Gaussian distribution. The uncertainties of the mean masses are taken from the half-width of the distribution. The uncertainties of masses which are not Gaussian distributions are taken from the mean values of the deviation from the mean values of masses. The values of masses in units of $m_e$ in each thickness of absorber are shown in Table VI.

Table VI. Masses of the observed particles when assuming the error of measurement to be Gaussian, and the resolution of measurement.

| Thickness of Lead Absorber | Masses | Resolution of Measurement (M/Δ M) |
|---|---|---|
| 0 cm | 959 ± 80 | 5.98 |
| | 1898 ± 551 | 1.72 |
| | 3567 ± 495 | 3.60 |
| 1 cm | 356 ± 42* | |
| | 543 ± 22* | |
| | 911 ± 160* | |
| | 1933 ± 484 | 4.02 |
| | 3468 ± 425 | 4.08 |
| | 5553 ± 769 | 3.62 |
| 2 cm | 282 ± 32* | |
| | 527 ± 46* | |
| | 1933 ± 120 | 8.08 |
| | 3655 ± 507 | 3.60 |
| | 5336 ± 368 | 7.86 |
| 3 cm | 375 ± 39* | |
| | 538 ± 44* | |
| | 1834 ± 361 | 2.50 |
| | 3604 ± 408 | 4.42 |

* The uncertainties are taken from the mean deviation from mean values.

The ratio $M/\Delta M$ in Table VI is the resolution of the measurement. The resolution of measurement of masses in Table VI is given only for the masses with the Gaussian distribution.

Table VII shows the mean energies of masses found in emulsions. These energies are derived from table of range and energy in emulsion.[1] For proton, deuteron and triton, the energy can be found directly from the table. For other particles, the energy is derived from table of range and energy for proton and using the relation[2]

$$R_M(E) \quad = \quad \frac{M}{M_p} R_p\left(\frac{M_p}{M} E\right).$$

Fig VII shows the energy spectrum of proton in emulsion with different thicknesses of lead absorber.

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[1] J.P. Gerber and P. Volmer, Courbes Parcours Energie des Noyaux Legers (Z ≤ 10) dans les Emulsions Ionographiques, C.N.R.S., stencil.

[2] E. Segrè, Experimental Nuclear Physics, (New York: John Wiley and Sons, Inc., 1953), p.178.

Table VII. Mean energies of particles in emulsions.

| Thickness of Lead Absorber | Mean Energies (keV) of | | | | | | |
|---|---|---|---|---|---|---|---|
| | proton | deuteron | triton | kaon | mass 150-250$m_e$ | mass 280-380$m_e$ | mass 480-580$m_e$ |
| 0 cm | 27,725 | 42,752 | | 29,691 | | | |
| 1 cm | 29,885 | 42,852 | 66,090 | 23,756 | 10,608 | 14,143 | 17,139 |
| 2 cm | 28,511 | 42,917 | 61,363 | | | 13,962 | 17,351 |
| 3 cm | 30,913 | 46,160 | | 17,752 | 9,629 | 12,118 | 20,830 |

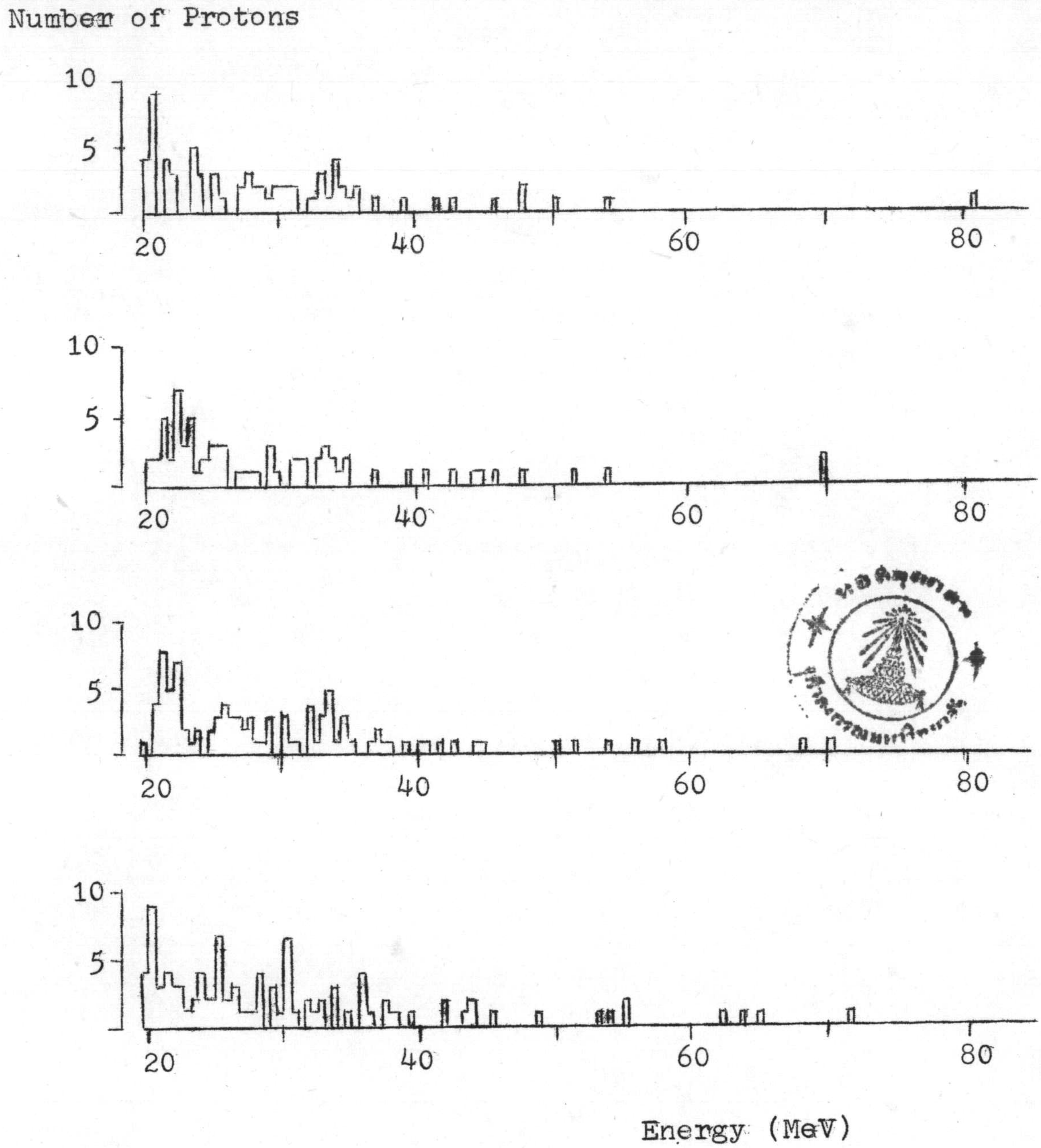


Fig VII. Energy spectrum of proton in emulsions in each thickness of absorber.

Two special events are observed in plates 0 cm Pb-2 and 2 cm Pb-3. From Tables VIII and IX, the event in the plate 0 cm Pb-2 is the capture event. From Tables X and XI, the event in the plate 2 cm Pb-3 is the decay event.

Table VIII. Ranges and average grain density of a proton produced by capture in the plate 0 cm Pb-2.

| R (microns) | 1200 | 2200 | 3200 | 4200 |
|---|---|---|---|---|
| $n_g$ | 69.4 | 57.2 | 46.0 | 42.9 |

The equation derived from range and grain density of the proton produced by capture is

$$\log n_g = 3.0833 - 0.4024 \log R.$$

Table IX. Ranges and grain density of the captured particle and the ratio of ranges at the same grain density of the captured particle and the produced proton.

| R | $n_g$ | $R_p$ | $R/R_p$ |
|---|---|---|---|
| 100 | 95 | 559.1 | 329 |
| 200 | 77 | 942.3 | 390 |
| 300 | 67 | 1131.4 | 415 |

$R/R_p$ is in units of electron mass.

The values of mass from Table IX fall in the region of pion in the histogram. Hence the captured particle is a pion.

Table X. Ranges and average grain density of the decaying particle in the plate 2 cm Pb-3.

| R (microns) | 1300 | 2300 | 3300 | 4300 | 5300 | 6300 |
|---|---|---|---|---|---|---|
| $n_g$ | 57.0 | 42.5 | 35.0 | 32.5 | 30.8 | 28.0 |

The equation derived from the range and grain density of the decaying particle is

$$\log n_g = 3.1100 - 0.4389 \log R.$$

Table XI. Ranges and grain density of the product and the ratio of ranges at the same grain density of the decaying particle and the product.

| R | $n_g$ | $R_1$ | $R/R_1$ | m (units of $m_e$) |
|---|---|---|---|---|
| 200 | 106 | 296.08 | 0.6755 | 172.8 |
| 300 | 87 | 464.41 | 0.6460 | 165.2 |
| 400 | 79 | 578.64 | 0.6913 | 176.8 |
| 500 | 68 | 814.15 | 0.6141 | 157.1 |

R and $R_1$ are ranges of product and decaying particle respectively. m is the mass of the product.

The decaying particle has the mass $255.8 \pm 6.9m_e$ which is very close to the mass of pion. The mass of the product is $168.0 \pm 6.8m_e$ which is very much in error to compare to the mass of muon ($206m_e$). But the range of the product is 500 microns, it is in the interval of the decayed muon from pion at rest which is about 600 microns.[3] Hence the event may be predicted as muon produced by the decay of pion at rest.

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[3] C.F. Powell, P.H. Fowler and D.H. Perkins, <u>The Study of Elementary Particles by the Photographic Method</u>, (London: Pergamon Press, 1959), p. 80.