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# RANGE, KINETIC ENERGY, AND $B\rho$ FOR $\pi$ AND $\mu$ MESONS IN LEAD

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December 12, 1950

Berkeley, California

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# RANGE, KINETIC ENERGY, AND $B\rho$ FOR $\pi$ AND $\mu$ MESONS IN LEAD

J. De Pangher

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December 12, 1950

## LIST OF SYMBOLS AND FORMULAE

T = kinetic energy of particle in Mev.

R = range of particle in $mg/cm^2$ of material traversed.

R' = range of particle in cm of material traversed.

$B\rho$ = magnetic rigidity in gauss-cm.

v = velocity of particle in cm/sec.

$E_o$ = rest mass energy of particle in Mev.

c = velocity of light in cm/sec $\cong 3 \times 10^{10}$ cm/sec.

$\tanh \phi = \beta = \frac{v}{c}$

e = charge on electron in esu $\cong 4.8 \times 10^{-10}$ esu

$\cosh \phi = 1 + \frac{T}{E_o}$

$B\rho = \frac{10^4 E_o}{3} \sinh \phi$

Subscripts p, $\pi$, and $\mu$ refer to proton, $\pi$-meson, and $\mu$-meson, respectively. The range and kinetic energy for the two mesons listed in the tables were calculated from the formulae:

$$T_\pi = \frac{275}{1837} T_p \qquad T_\mu = \frac{210}{1837} T_p$$

$$R_\pi = \frac{275}{1837} R_p \qquad R_\mu = \frac{210}{1837} R_p$$

The rest mass energy for a $\pi$-meson whose mass is that of 275 electron masses is 140.7 Mev while the rest mass energy for the $\mu$-meson whose mass is that of 210 electron masses is 107.3 Mev.

Values for $T_p$ and $R_p$ were taken from Range-Energy Curves (second revision 1949) by Aron, Hoffman, and Willaims.

KINETIC ENERGY, $B\rho$, AND RANGE IN

LEAD FOR $\pi$-MESONS OF MASS 275

1-200 MEV

| $T_p$ | $R_p$ | $T_\pi$ | $R_\pi$ | $R'_\pi$ | $(B\rho)_\pi$ | $(B\rho)_\pi^{-1}$ |
|---|---|---|---|---|---|---|
| 6 | 151.52 | .898 | $2.268\times10^{1}$ | $2.000\times10^{-3}$ | $5.306\times10^{4}$ | $1.885\times10^{-5}$ |
| 10 | 340.55 | 1.497 | 5.098 | 4.495 | 6.859 | 1.458 |
| 16 | 734.52 | 2.395 | $1.100\times10^{2}$ | 9.695 | 8.688 | 1.151 |
| 20 | 1065.2 | 2.994 | 1.595 | $1.406\times10^{-2}$ | 9.725 | 1.028 |
| 24 | 1447.1 | 3.593 | 2.166 | 1.910 | $1.067\times10^{5}$ | $9.372\times10^{-6}$ |
| 35 | 2745.3 | 5.240 | 4.110 | 3.623 | 1.292 | 7.740 |
| 40 | 3449.0 | 5.988 | 5.163 | 4.552 | 1.383 | 7.231 |
| 45 | 4220.0 | 6.737 | 6.317 | 5.569 | 1.468 | 6.812 |
| 50 | 5056.0 | 7.485 | 7.569 | 6.673 | 1.550 | 6.452 |
| 60 | 6914.8 | 8.982 | $1.035\times10^{3}$ | 9.127 | 1.702 | 5.875 |
| 70 | 9011.4 | 10.48 | 1.349 | $1.189\times10^{-1}$ | 1.844 | 5.423 |
| 130 | $25.981\times10^{3}$ | 19.46 | 3.889 | 3.429 | 2.551 | 3.920 |
| 200 | 53.624 | 29.94 | 7.974 | 7.030 | 3.218 | 3.108 |
| 275 | 90.526 | 41.17 | 1.355 | $1.195\times10^{0}$ | 3.841 | 2.603 |
| 350 | 133.32 | 52.39 | 1.996 | 1.760 | 4.408 | 2.269 |
| 400 | 164.51 | 59.88 | 2.463 | 2.171 | 4.765 | 2.099 |
| 450 | 197.48 | 67.37 | 2.956 | 2.607 | 5.109 | 1.957 |
| 500 | 231.98 | 74.85 | 3.473 | 3.062 | 5.443 | 1.837 |
| 550 | 267.83 | 82.33 | 4.009 | 3.535 | 5.768 | 1.734 |
| 600 | 304.83 | 89.82 | 4.563 | 4.026 | 6.087 | 1.643 |

| $T_p$ | $R_p$ | $T_\pi$ | $R_\pi$ | $R'_\pi$ | $(B\rho)_\pi$ | $(B\rho)_\pi^{-1}$ |
|---|---|---|---|---|---|---|
| 650 | 342.85 | 97.31 | 5.133 | 4.525 | 6.399 | 1.563 |
| 700 | 381.76 | 104.8 | 5.715 | 5.039 | 6.706 | 1.491 |
| 750 | 421.44 | 112.3 | 6.309 | 5.563 | 7.007 | 1.427 |
| 800 | 461.81 | 119.8 | 6.913 | 6.095 | 7.306 | 1.369 |
| 850 | 502.77 | 127.3 | 7.527 | 6.636 | 7.601 | 1.316 |
| 900 | 544.26 | 134.7 | 8.148 | 7.184 | 7.893 | 1.267 |
| 950 | 586.20 | 142.2 | 8.775 | 7.737 | 8.182 | 1.222 |
| 1000 | 628.56 | 149.7 | 9.410 | 8.296 | 8.468 | 1.181 |
| 1100 | 714.28 | 164.7 | $1.069 \times 10^4$ | 9.428 | 9.035 | 1.107 |
| 1200 | 801.09 | 179.6 | 1.199 | $1.057 \times 10^8$ | 9.593 | 1.042 |
| 1300 | 888.73 | 194.6 | 1.330 | 1.173 | $1.015 \times 10^6$ | $9.852 \times 10^{-3}$ |
| 1400 | 977.00 | 209.6 | 1.463 | 1.290 | 1.069 | 9.355 |

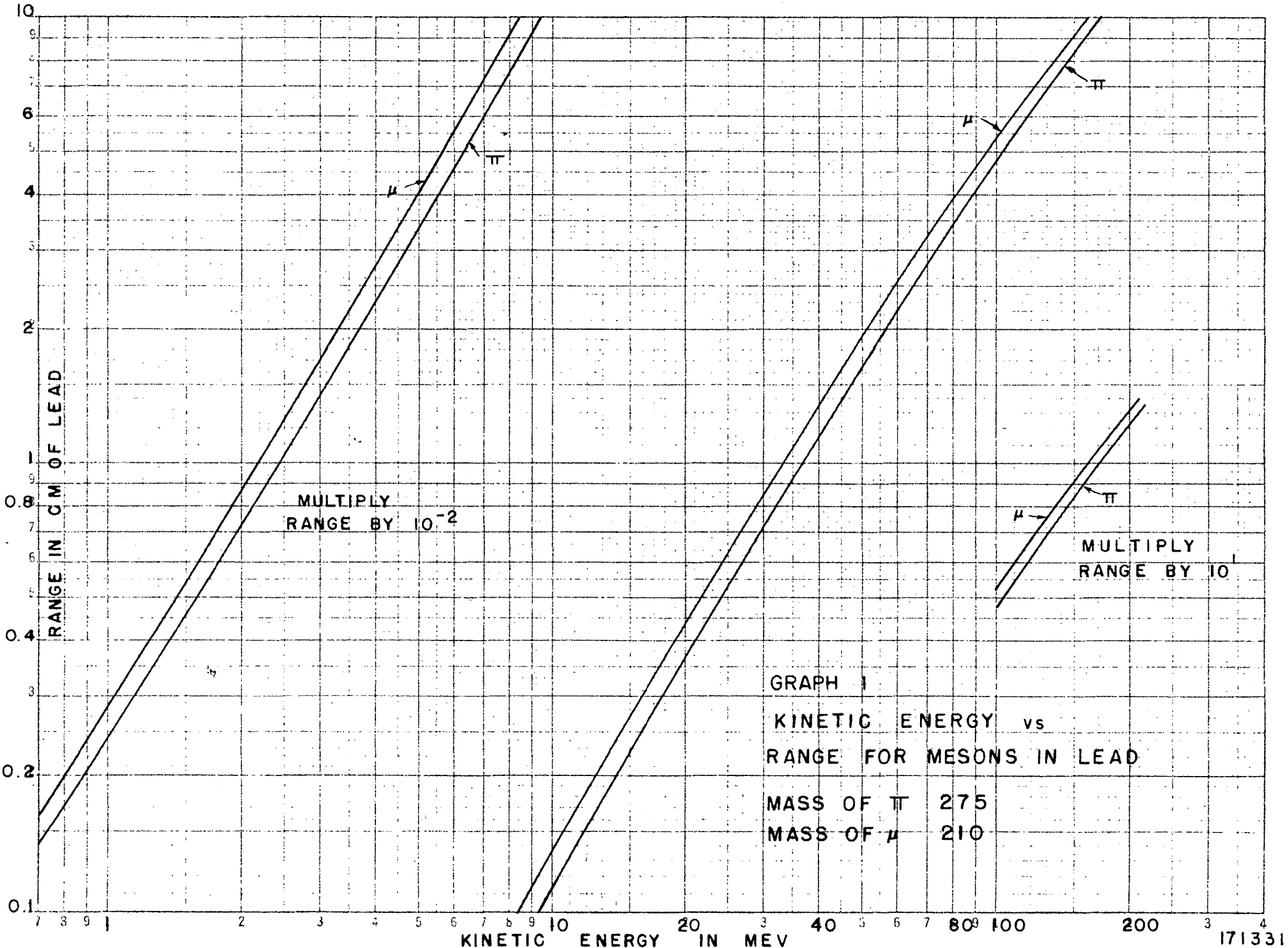
KINETIC ENERGY, $B\rho$, AND RANGE IN

LEAD FOR $\mu$-MESONS OF MASS 210

1-200 MEV

| $T_p$ | $R_p$ | $T_\mu$ | $R_\mu$ | $R'_\mu$ | $(B\rho)_\mu$ | $(B\rho)_\mu^{-1}$ |
|---|---|---|---|---|---|---|
| 8 | 238.23 | .9145 | 2.723x10 | $2.401\times10^{-3}$ | $4.68\times10^{4}$ | $2.136\times10^{-5}$ |
| 10 | 340.55 | 1.143 | 3.893 | 3.433 | 5.233 | 1.911 |
| 18 | 893.29 | 2.058 | $1.021\times10^{2}$ | 9.004 | 7.037 | 1.421 |
| 26 | 1656.6 | 2.972 | 1.894 | $1.670\times10^{-2}$ | 8.475 | 1.180 |
| 35 | 2745.3 | 4.00 | 3.138 | 2.767 | 9.860 | 1.014 |
| 45 | 4220.0 | 5.144 | 4.824 | 4.253 | $1.121\times10^{5}$ | $8.924\times10^{-6}$ |
| 50 | 5056.0 | 5.716 | 5.780 | 5.096 | 1.183 | 8.453 |
| 60 | 6914.8 | 6.859 | 7.936 | 6.997 | 1.299 | 7.697 |
| 70 | 9011.4 | 8.002 | $1.030\times10^{3}$ | 9.083 | 1.407 | 7.107 |
| 80 | $11.333\times10^{3}$ | 9.145 | 1.296 | $1.142\times10^{-1}$ | 1.508 | 6.632 |
| 90 | 13.870 | 10.29 | 1.586 | 1.398 | 1.603 | 6.237 |
| 170 | 40.872 | 19.43 | 4.672 | 4.120 | 2.248 | 4.449 |
| 250 | 77.498 | 28.58 | 8.860 | 7.811 | 2.779 | 3.598 |
| 350 | 133.32 | 40.01 | $1.524\times10^{4}$ | $1.344\times10^{0}$ | 3.365 | 2.972 |
| 450 | 197.48 | 51.44 | 2.258 | 1.990 | 3.900 | 2.564 |
| 550 | 267.83 | 62.87 | 3.062 | 2.700 | 4.403 | 2.271 |
| 600 | 304.83 | 68.59 | 3.485 | 3.072 | 4.646 | 2.152 |
| 700 | 381.76 | 80.02 | 4.364 | 3.848 | 5.119 | 1.954 |
| 800 | 461.81 | 91.45 | 5.279 | 4.655 | 5.577 | 1.793 |
| 900 | 544.26 | 102.9 | 6.222 | 5.486 | 6.025 | 1.660 |

| $T_p$ | $R_p$ | $T_\mu$ | $R_\mu$ | $R'_\mu$ | $(B\rho)_\mu$ | $(B\rho)_\mu^{-1}$ |
|---|---|---|---|---|---|---|
| 1000 | 628.56 | 114.3 | 7.186 | 6.335 | 6.464 | 1.547 |
| 1100 | 714.28 | 125.7 | 8.165 | 7.199 | 6.896 | 1.450 |
| 1200 | 801.09 | 137.2 | 9.158 | 8.074 | 7.323 | 1.366 |
| 1300 | 888.73 | 148.6 | $1.016 \times 10^6$ | 8.958 | 7.745 | 1.291 |
| 1400 | 977.00 | 160.0 | 1.117 | 9.847 | 8.162 | 1.225 |
| 1500 | 1065.71 | 171.5 | 1.218 | $1.074 \times 10^7$ | 8.577 | 1.166 |
| 1600 | 1154.8 | 182.9 | 1.320 | 1.164 | 8.989 | 1.112 |
| 1700 | 1244.0 | 194.3 | 1.422 | 1.254 | 9.396 | 1.064 |
| 1800 | 1333.4 | 205.8 | 1.524 | 1.344 | 9.804 | 1.020 |


RANGE IN CM OF LEAD
KINETIC ENERGY IN MEV
MULTIPLY RANGE BY $10^{-2}$
MULTIPLY RANGE BY $10^{1}$
μ
π
GRAPH 1
KINETIC ENERGY vs
RANGE FOR MESONS IN LEAD
MASS OF π 275
MASS OF μ 210
171331

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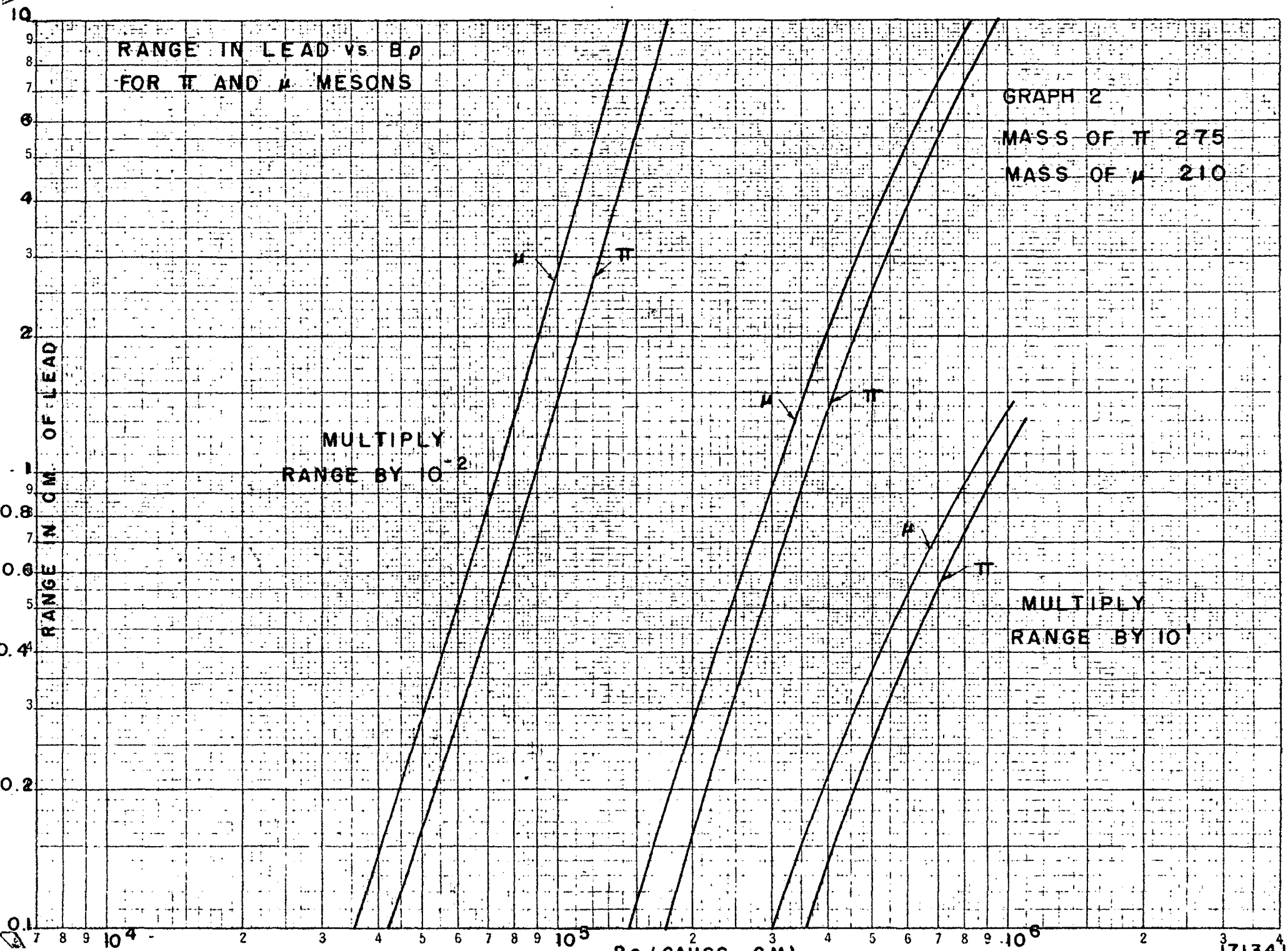

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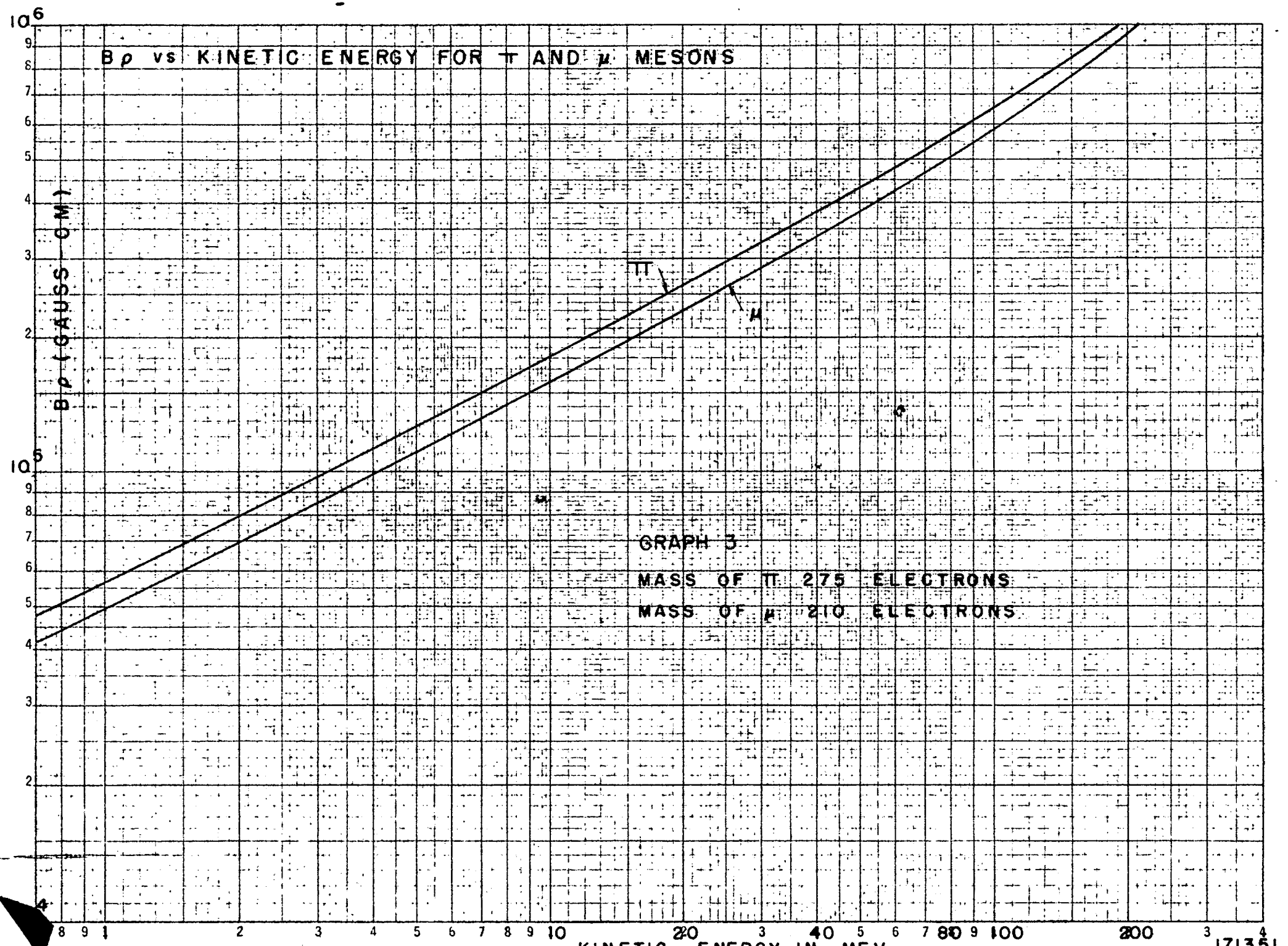

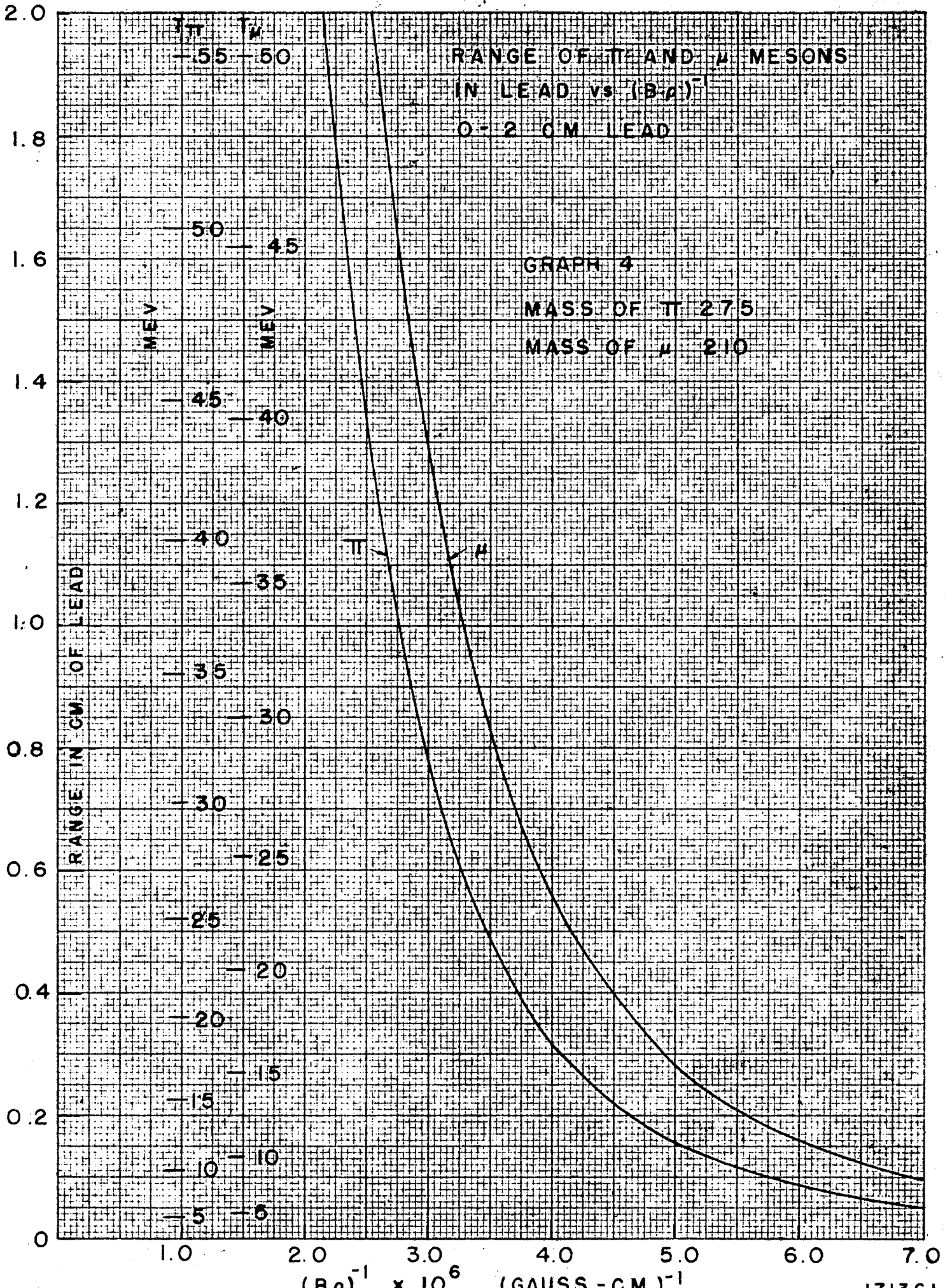


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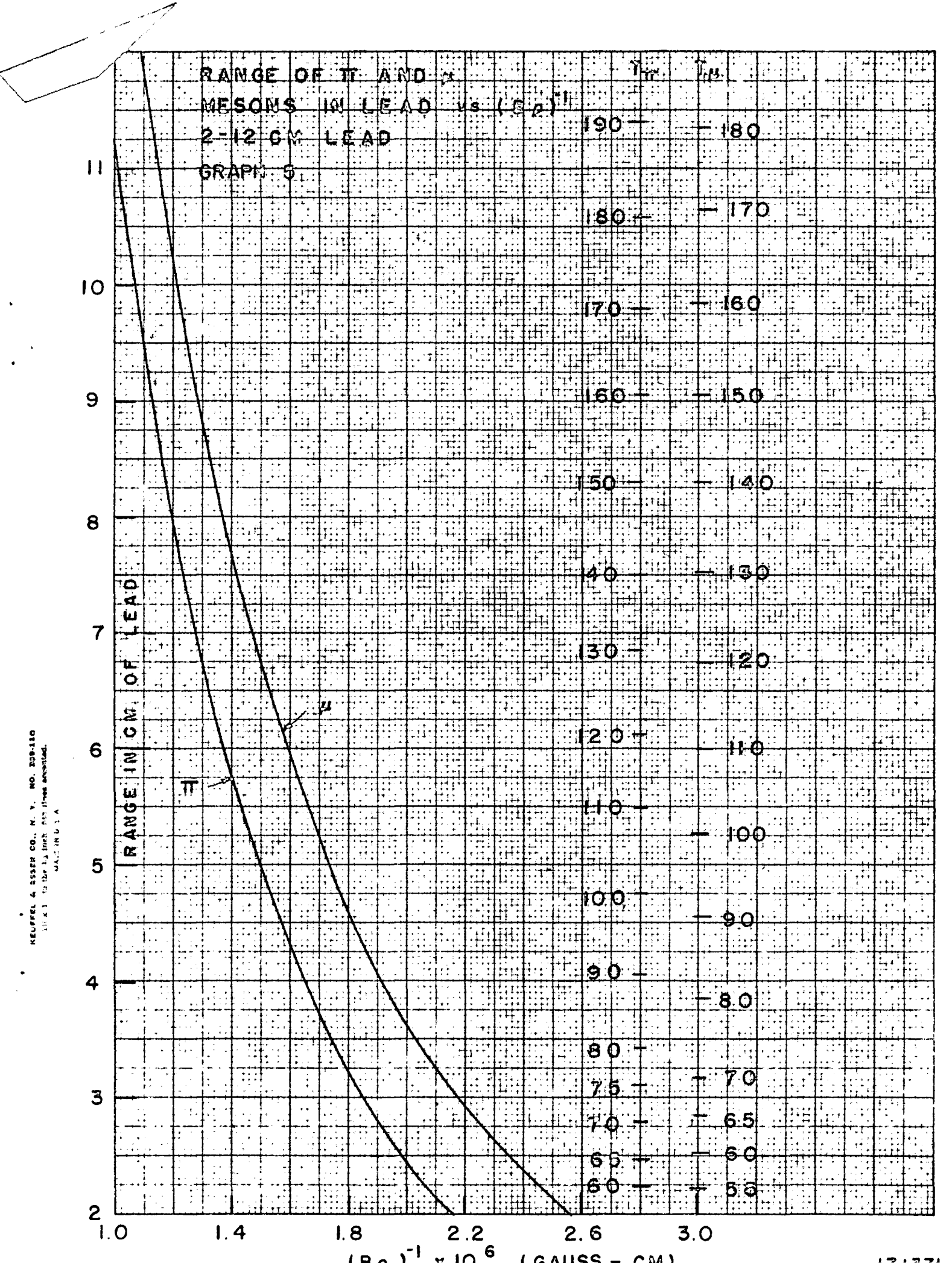
RANGE OF π AND μ MESONS IN LEAD vs (Bρ)⁻¹
2-12 CM LEAD
GRAPH 5
RANGE IN CM. OF LEAD
(Bρ)⁻¹ × 10⁶ (GAUSS - CM)
π
μ
Tπ
Tμ
11
10
9
8
7
6
5
4
3
2
1.0
1.4
1.8
2.2
2.6
3.0
190
180
170
160
150
140
130
120
110
100
90
80
75
70
65
60
180
170
160
150
140
130
120
110
100
90
80
70
65
60
55