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CHARGED PARTICLE cross sections

NEON TO CHROMIUM

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Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

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Associate Editors

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INTRODUCTION

The present report is a continuation of a projected series titled Charged Particle Cross Sections. The first volume appeared in 1957 as Los Alamos Report LA-2014. The purposes and justifications of such a compilation are many. First and most obvious, it will be of immediate use to experimental theoretical physicists, since no compilation of this type has existed. It should encourage experimenters to make absolute measurements and to raise the quality of such measurements. By presenting existing data in a compact and integrated form, it should stimulate new experiments and theoretical investigations. It may also serve to standardize the notation.

Scope: This volume of the compilation attempts to include the "best" cross sections of all nuclear processes involving charged nuclear projectiles of all energies and targets of the medium-mass elements from neon through chromium. An effort has been made to include all absolute data published in a generally available source before January 1, 1960, although in some cases later or unpublished data may have been used. Only results that are absolute or that can be normalized easily to existing absolute data are included. Data with uncertainties over 100 percent, or with no experimental error limit stated, have been omitted at the discretion of the compiler.

Method of Presentation: It should be noted that the compilation is a graphical representation of experimental data. Tables of results that duplicate information on the curves are not given.

An effort has been made to avoid pitfalls for the reader, such as shifted, overlapping, or other non-monotonic scales, unusual units, and various complex representations. Almost without exception, the units of the ordinate are expressed in some form of barns. In several cases of elastic scattering, the ratio of the experimental cross section to the Rutherford cross section is plotted. Appendix II lists the numerical factors necessary in computing the Rutherford cross section for targets from hydrogen through copper.

It was usually deemed unnecessary to plot angular distributions for these targets in both the laboratory and the center-of-mass coordinate systems, since the difference in cross section due to coordinate transformation was usually only a few percent. If this difference is less than the absolute experimental errors or if the difference in the data plotted in both systems is not readily apparent, only one plot (usually in the C.M. system) is presented.

Excitation functions are presented in the laboratory system except where specifically marked, and the energy scale is always the laboratory energy. Whenever bombarding energies were given in the literature for the C.M. system, they have been transformed nonrelativistically into the laboratory system. Q-values for two-body reactions are taken from the report by Ashby and Catron.[1] Values not given in that reference, such as the Q's of most spallation reactions, were calculated from the masses.[2] In each case, the ground state Q-value is given. Energy level designations are taken whenever possible from Endt and Braams[3] or from Way et al.[4]

Unless otherwise marked, curves are smooth lines representing experimental data. The usual nomenclature is followed in the titles for the graphs: in the title X(a, b)Y, X is the target nucleus, a is the incident particle, b is the fragment to which the cross section refers (usually the light fragment), and Y is the residual nucleus or recoil particle. An effort has been made in each case to indicate which particle was actually observed by placing its symbol furthest to the right in the final parenthesis of the title. That is, where the title is written as X(p, pγ)Y, the cross section refers to the gamma ray. If the proton cross section were shown, the reaction would have been written as X(p, p')Y*. Spallation reactions and other reactions in which the β-activity of one of the product nuclides was observed are written as X(a, b)Y(β)Z.

The sequence of the graphs is according to (1) increasing Z and mass of the target, (2) increasing Z and mass of the projectile, and (3) decreasing Z and mass of the recoil fragment. Further differentiation is given by the energy of the incident particle, excitation functions preceding angular distributions, and ground state preceding excited state reactions. Reactions on targets of normal isotopic

[1]V. J. Ashby and H. C. Catron, Report UCRL-5419 (1959).

[2]A. H. Wapstra, Physica 21, 367 (1955) and ibid. 21, 385 (1955).

[3]P. M. Endt and C. M. Braams, Rev. Mod. Phys. 29, 683 (1957).

[4]K. Way et al., Report TID-5300 (1955).

composition are placed with the graphs for the most abundant stable isotope. Since there are some ambiguous cases, the reader is advised to wander through the pages a bit before giving up the search.

A serious attempt has been made to include with each graph some indication of the absolute error limits for the cross sections. When the error was not stated in the reference and could not be obtained by private communication, the compiler often has made a conservative guess from the information in the reference. The error designation used in this compilation is the probable error. Error bars shown graphically on the experimental points represent counting statistics unless otherwise designated.

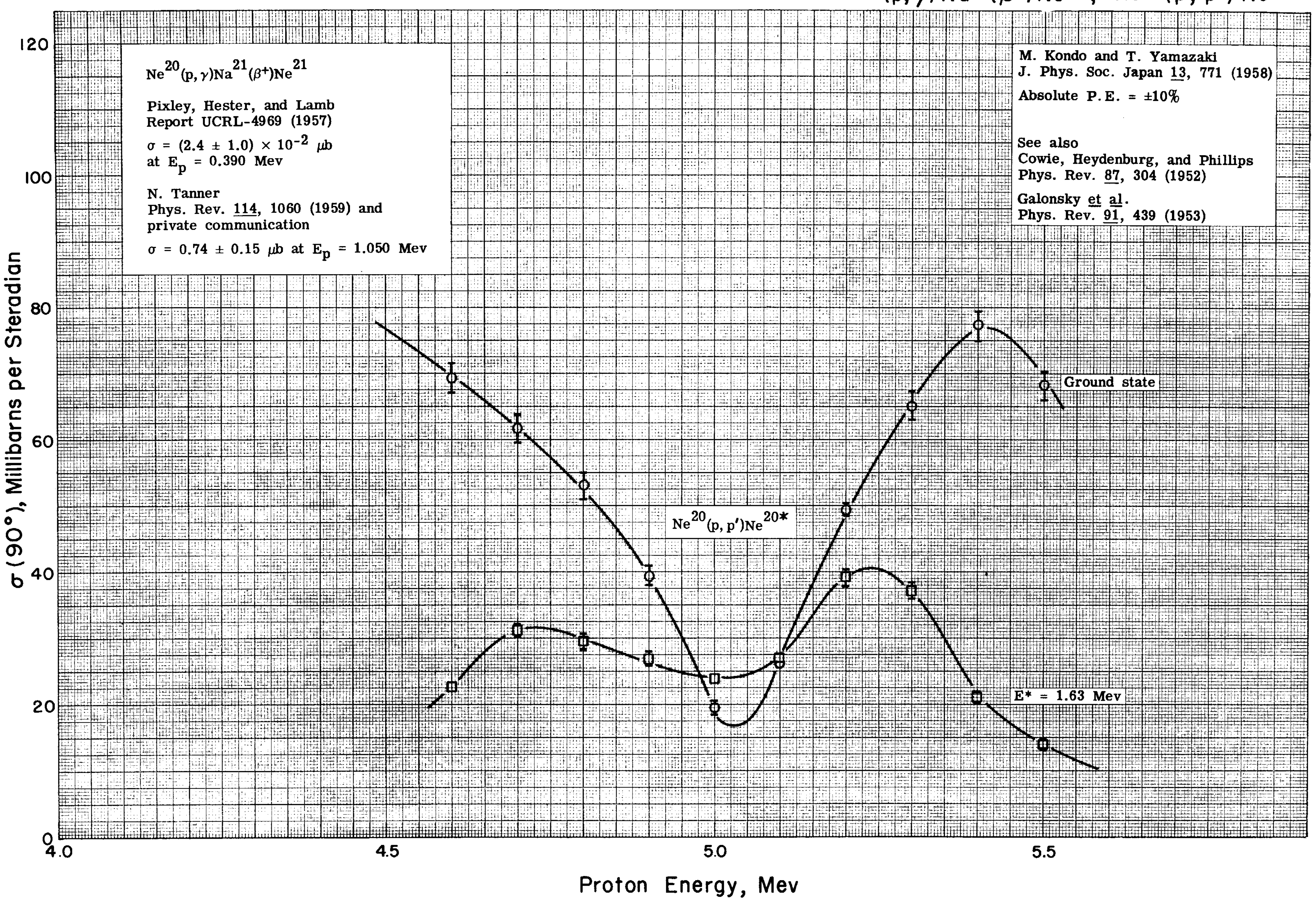
No collected bibliography has been made for the material plotted. References and information of interest have been placed on the page with the data to which they pertain. References containing only relative data or data that was not plotted (usually because of a lack of information on absolute error limits) are collected in Appendix I. These references are listed by reaction and pertain only to those reactions for which no material is plotted.

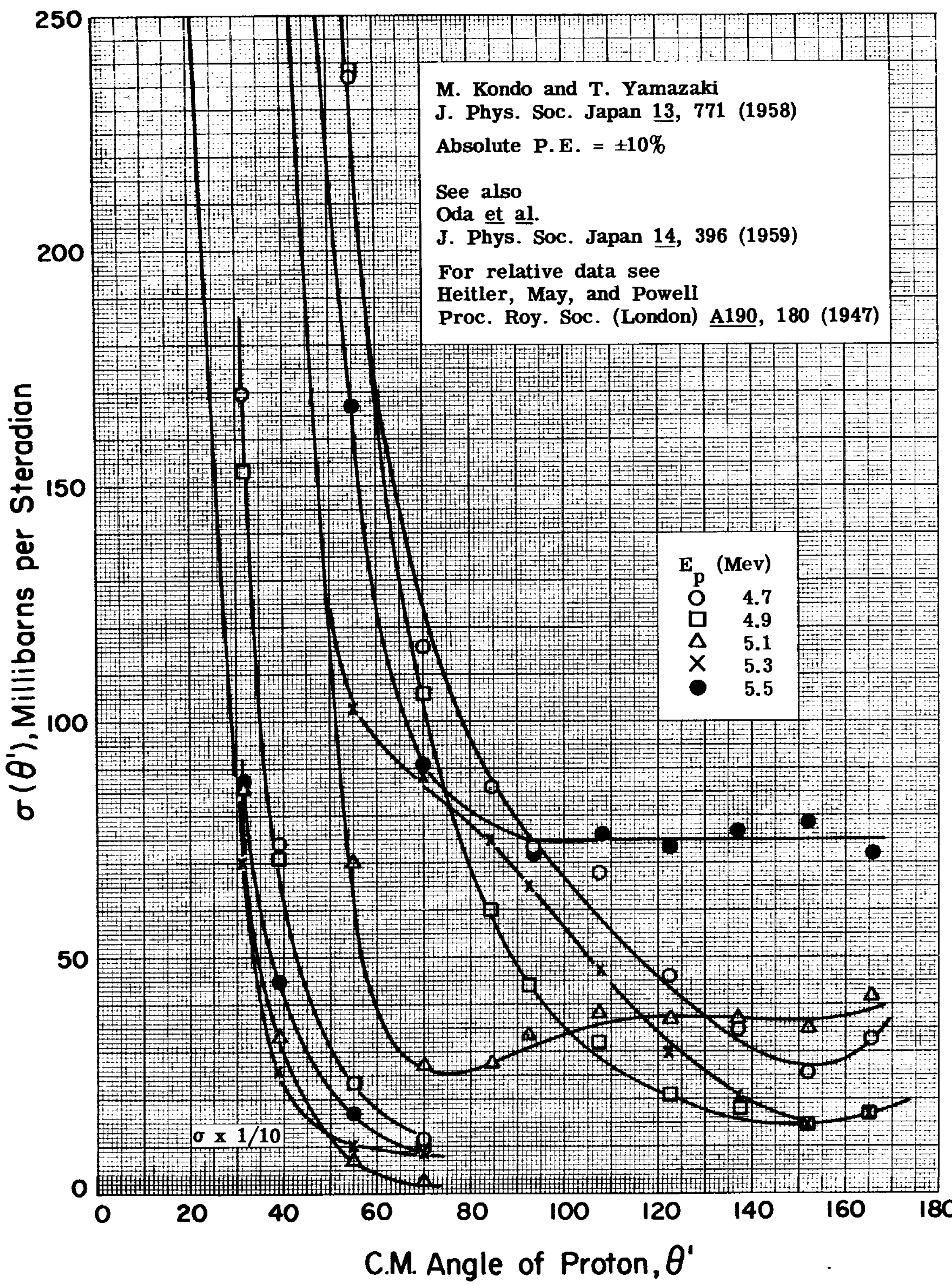
Although due care has been taken, it should be emphasized that anyone desiring very accurate values should always use the original reference. Unavoidable errors in tracing, graph paper distortion, and final reproduction always occur. In extreme cases, where data had to be copied from tiny graphs in journals, errors of 5 percent or more may be expected. Our experience has shown the value of using tabular form for publishing experimental information when accuracy is important.

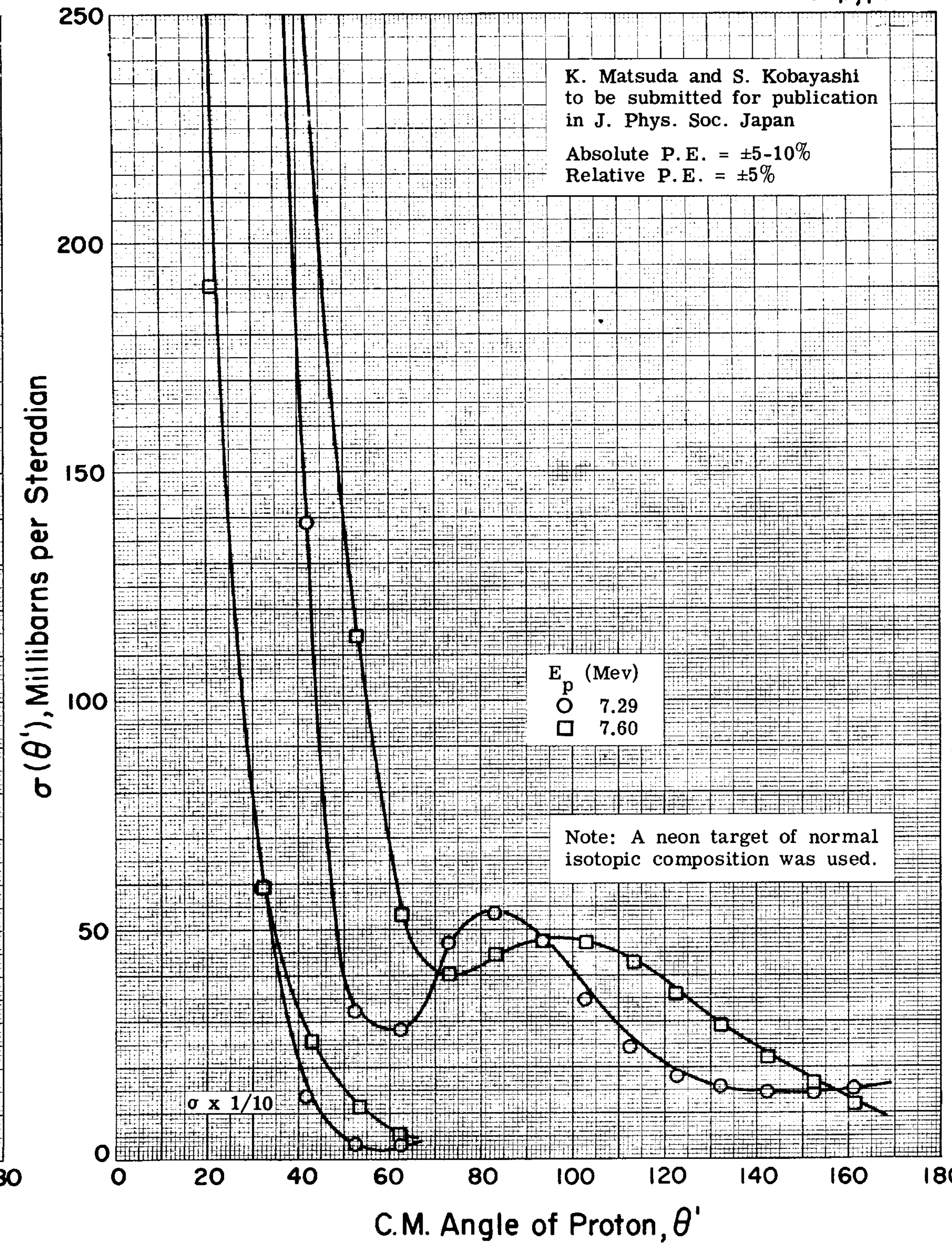
ACKNOWLEDGMENTS

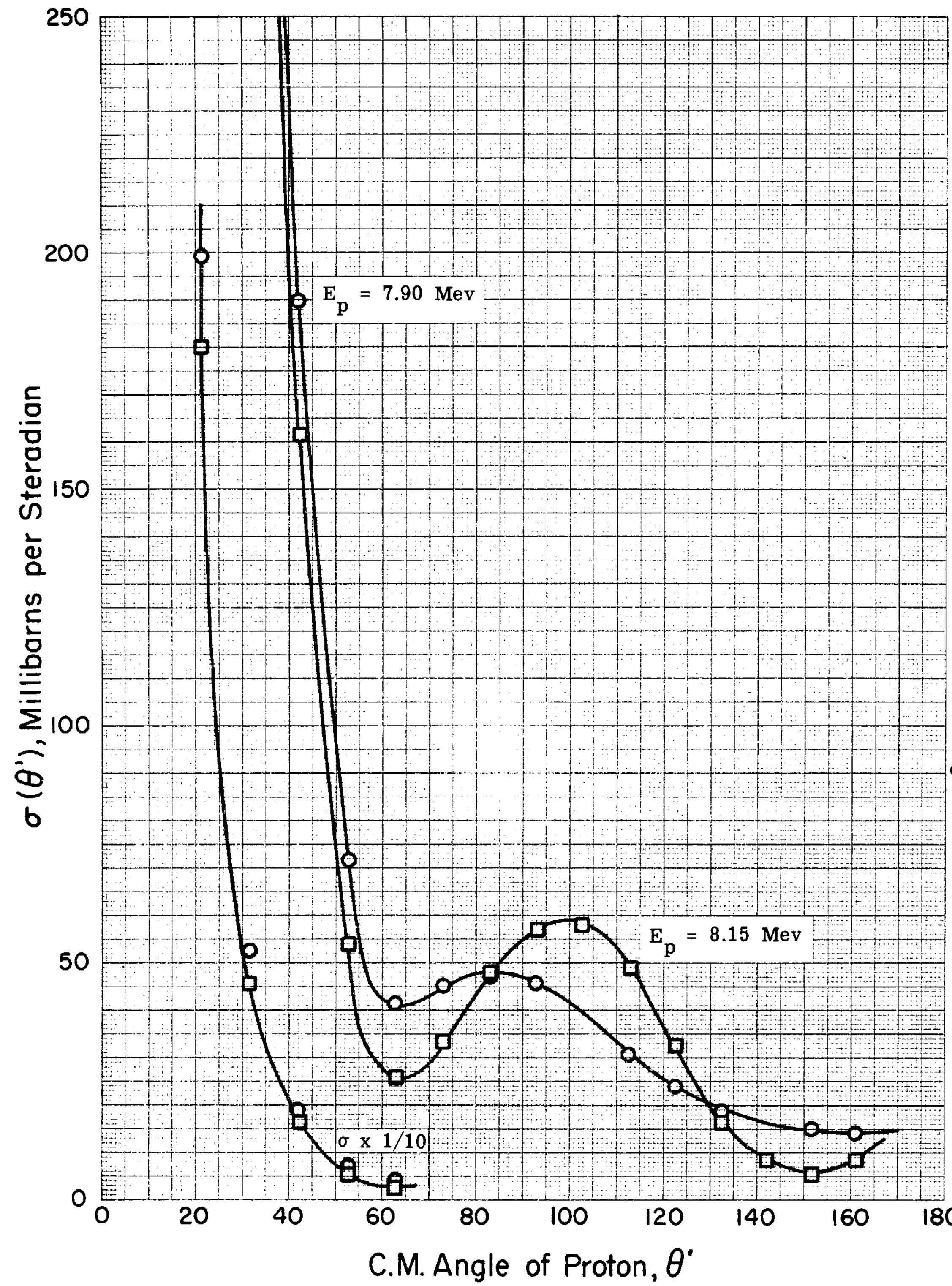
It is a pleasure to acknowledge the help and services of all draftsmen, plotters, calculators, and others who have contributed to this work. Great appreciation is also extended to the numerous correspondents who have furnished unpublished data, error calculations, large graphs, tabular data, and other information.

$Ne^{20}(p,\gamma)Na^{21}(\beta^+)Ne^{21}$; $Ne^{20}(p,p')Ne^{20*}$

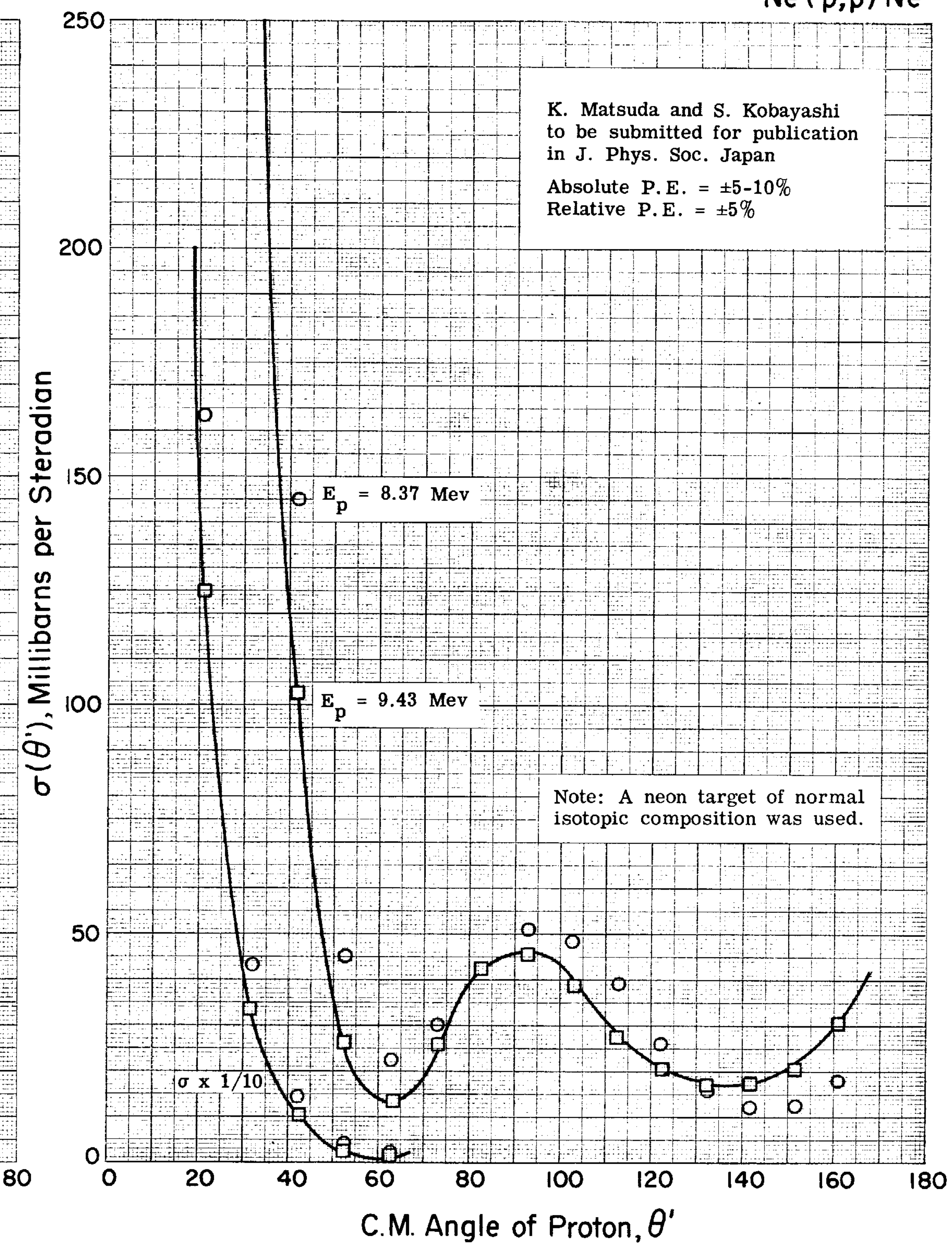



M. Kondo and T. Yamazaki
J. Phys. Soc. Japan 13, 771 (1958)
Absolute P.E. = ±10%
See also
Oda et al.
J. Phys. Soc. Japan 14, 396 (1959)
For relative data see
Heitler, May, and Powell
Proc. Roy. Soc. (London) A190, 180 (1947)
Ep (Mev)
4.7
4.9
5.1
5.3
5.5
σ x 1/10
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

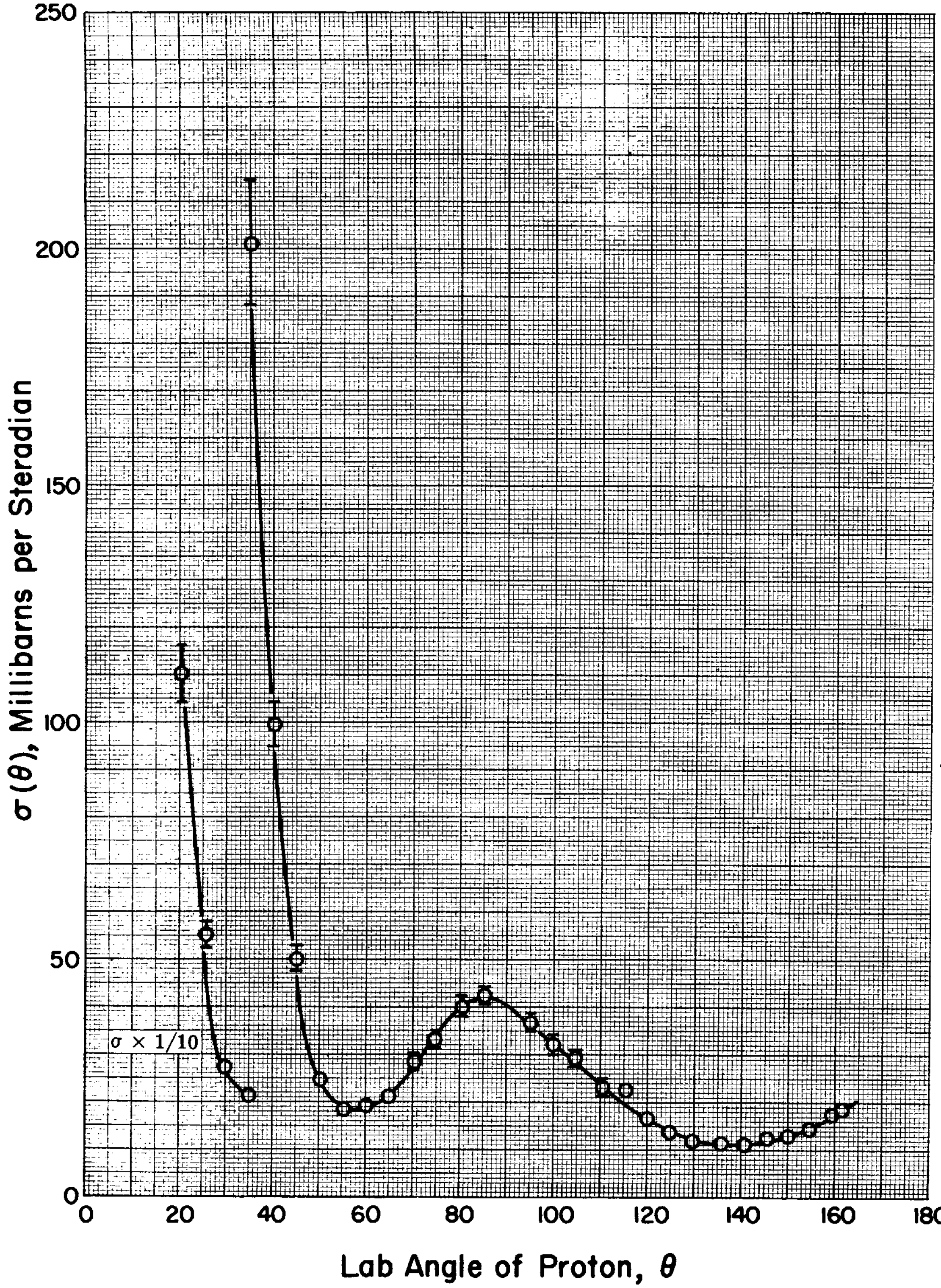

K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%
Ep (Mev)
7.29
7.60
Note: A neon target of normal isotopic composition was used.
σ x 1/10
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

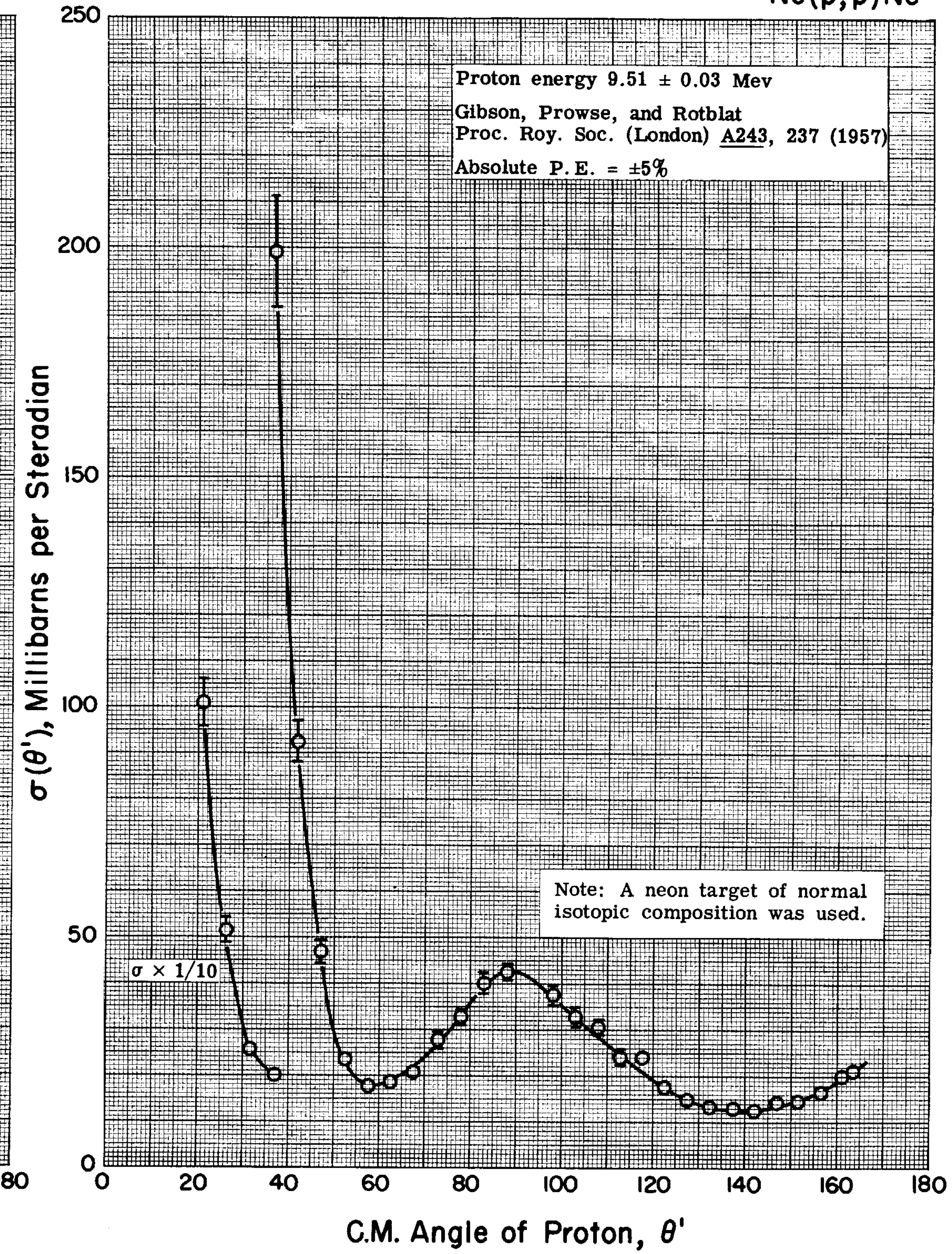


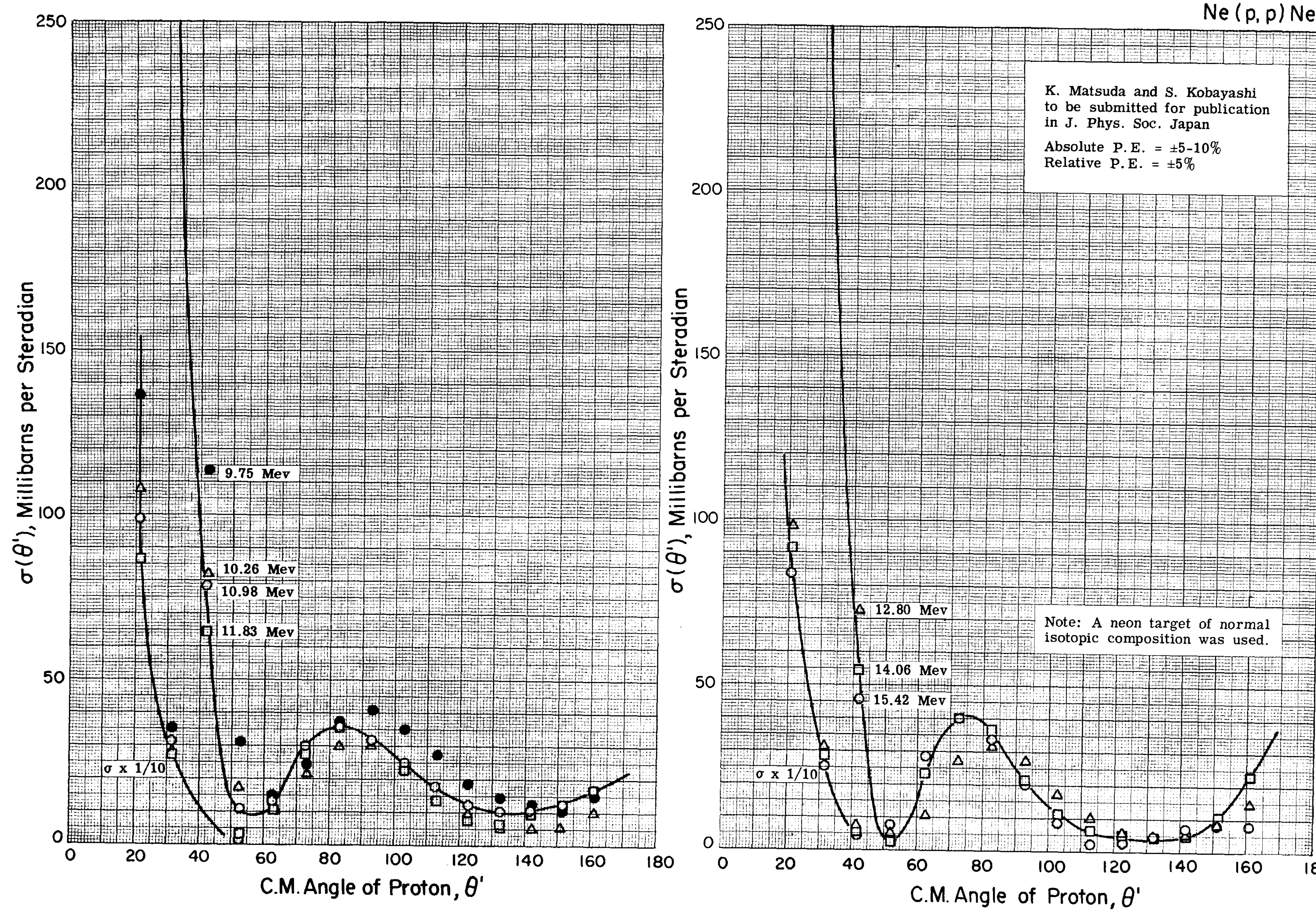
250
200
150
100
50
0
σ (θ'), Millibarns per Steradian
E_p = 7.90 Mev
E_p = 8.15 Mev
σ x 1/10
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'



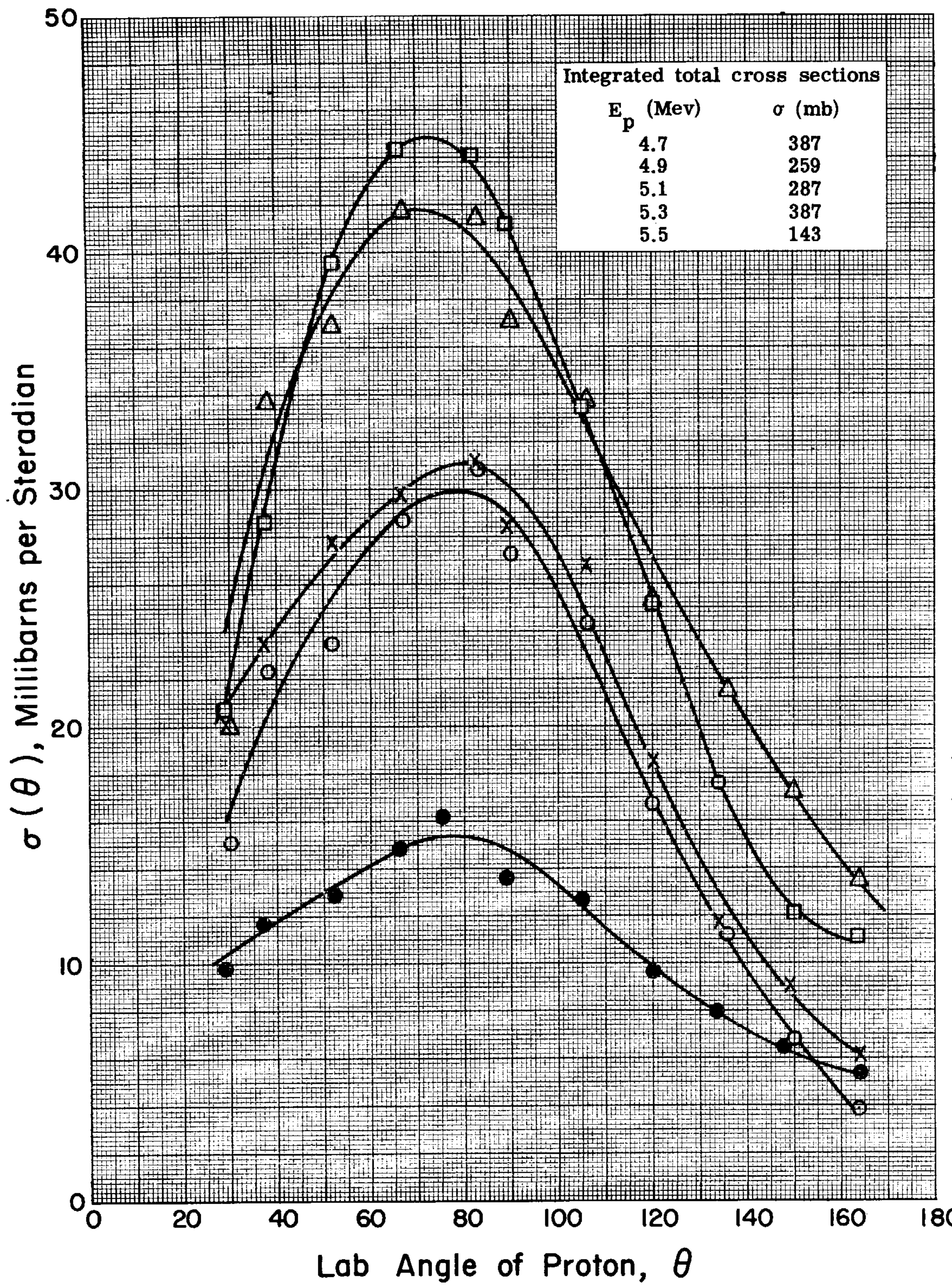
250
200
150
100
50
0
σ (θ'), Millibarns per Steradian
K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%
E_p = 8.37 Mev
E_p = 9.43 Mev
Note: A neon target of normal
isotopic composition was used.
σ x 1/10
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'

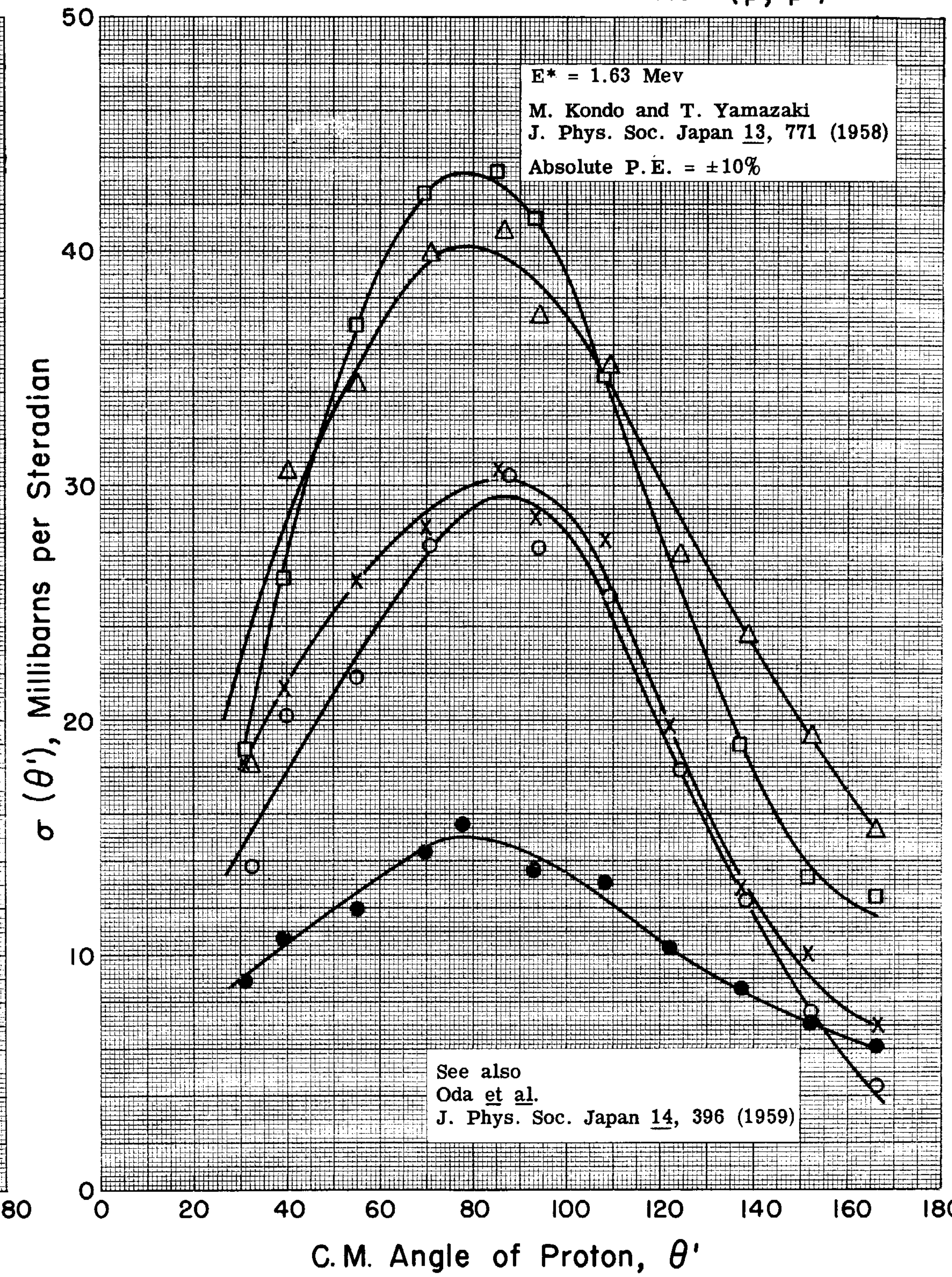

250
200
150
100
50
0
σ (θ), Millibarns per Steradian
σ × 1/10
0 20 40 60 80 100 120 140 160 180
Lab Angle of Proton, θ


Proton energy 9.51 ± 0.03 Mev
Gibson, Prowse, and Rotblat
Proc. Roy. Soc. (London) A243, 237 (1957)
Absolute P.E. = ±5%
Note: A neon target of normal isotopic composition was used.
σ × 1/10
250
200
150
100
50
0
σ (θ'), Millibarns per Steradian
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'

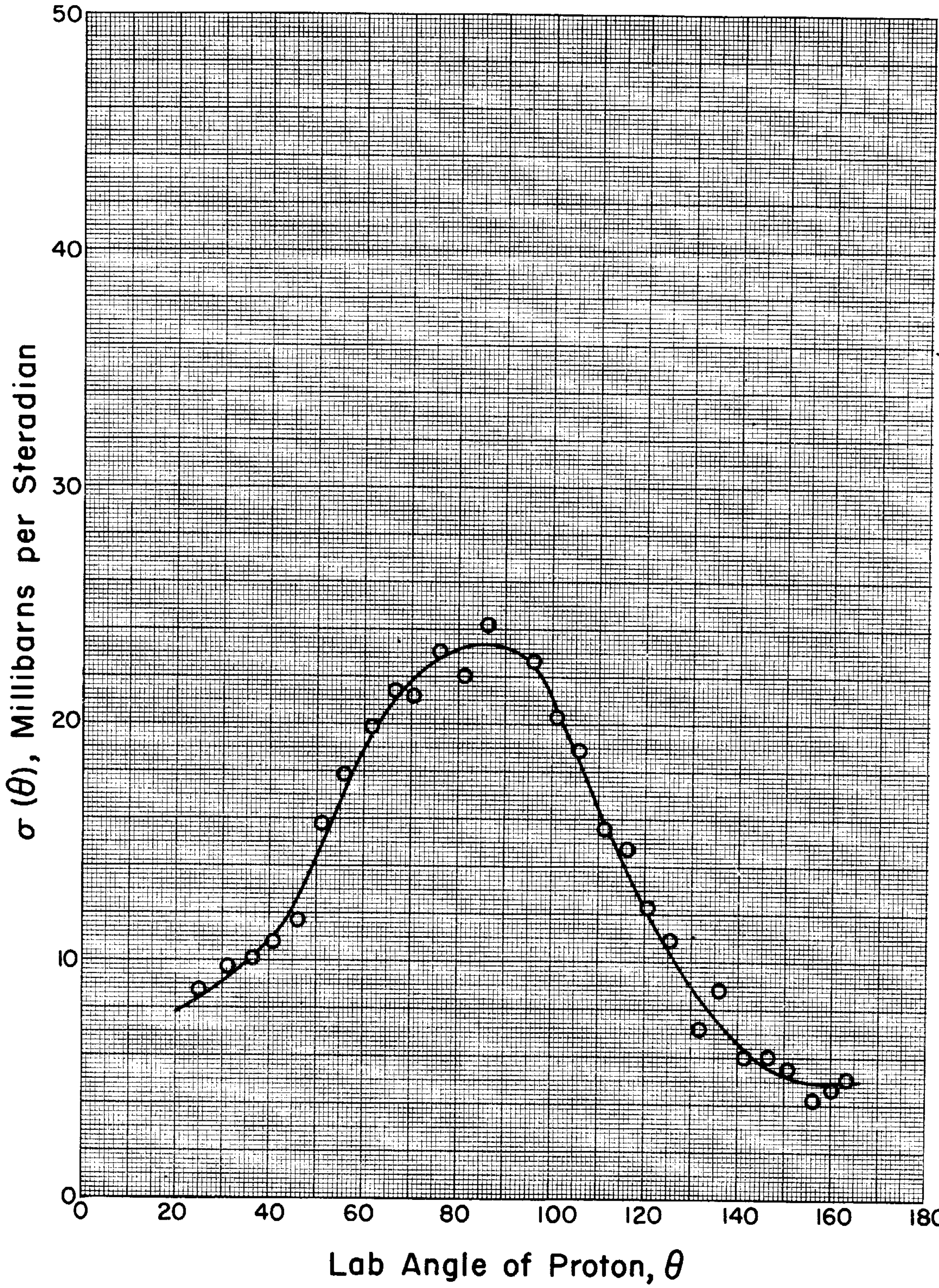

Ne (p, p) Ne
K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%
Note: A neon target of normal
isotopic composition was used.
9.75 Mev
10.26 Mev
10.98 Mev
11.83 Mev
12.80 Mev
14.06 Mev
15.42 Mev
σ x 1/10
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
20
40
60
80
100
120
140
160
180
50
150
200
250

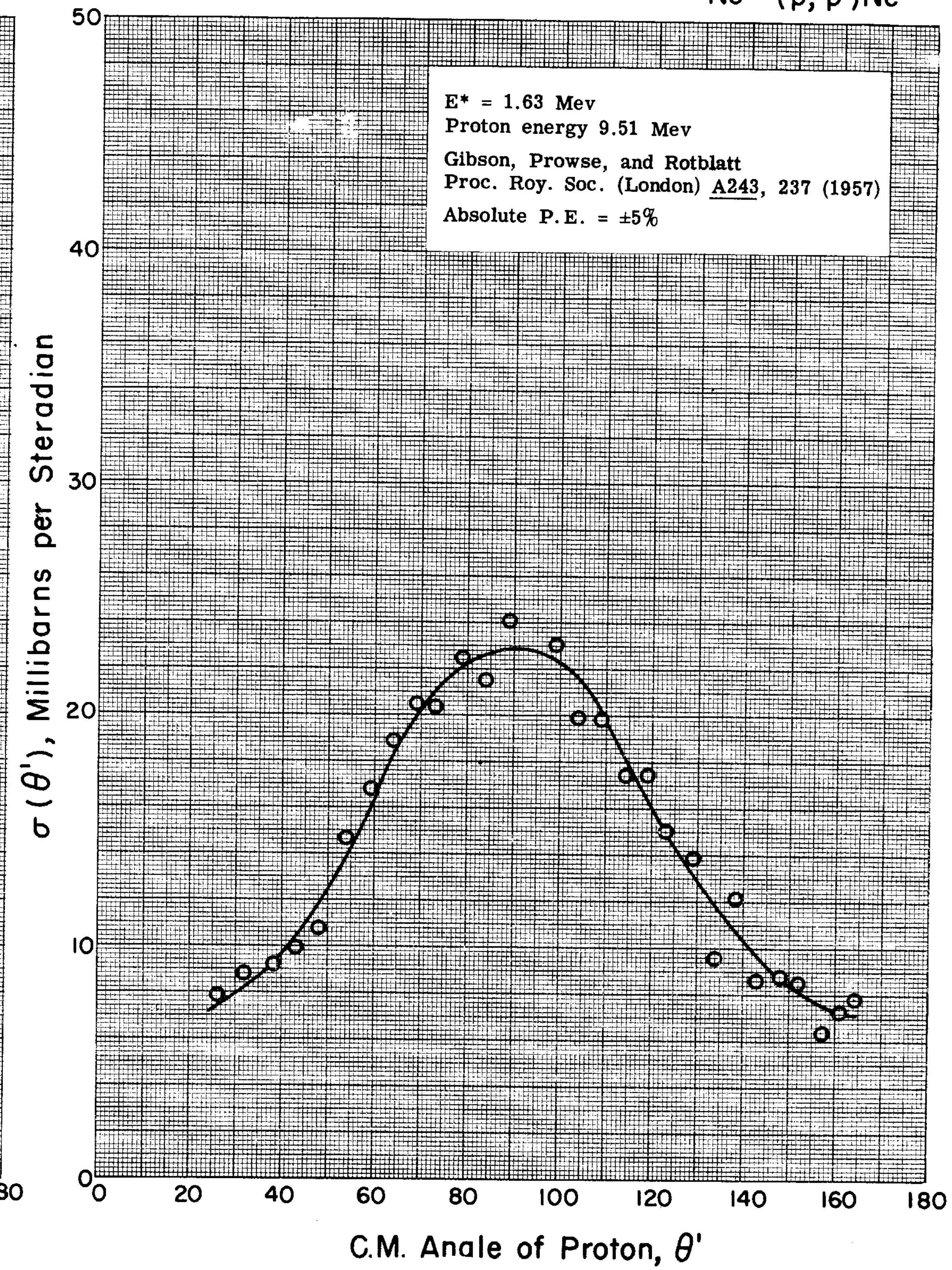
$Ne^{20}(p, p')Ne^{20*}$

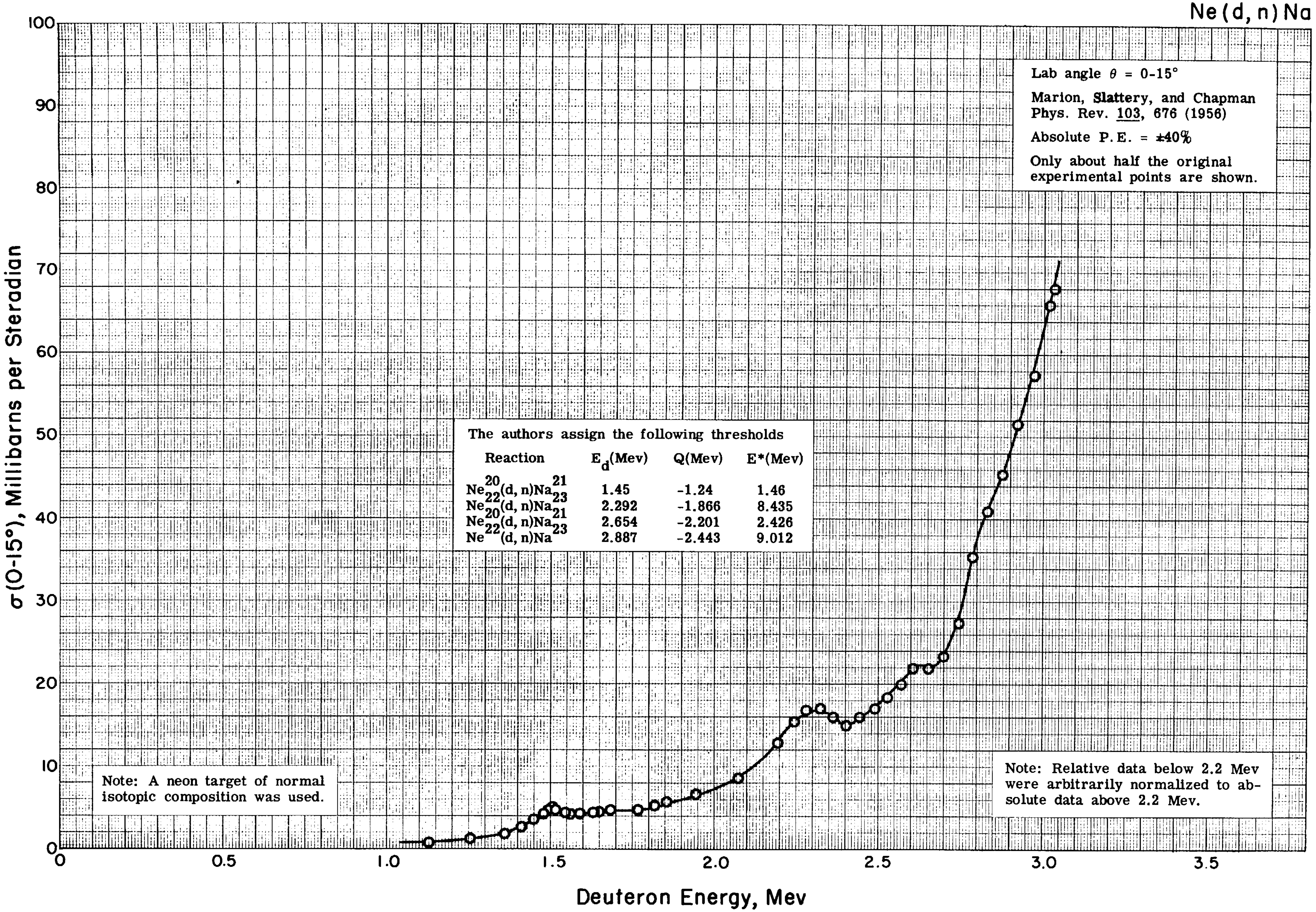

Integrated total cross sections
E_p (Mev) σ (mb)
4.7 387
4.9 259
5.1 287
5.3 387
5.5 143
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ

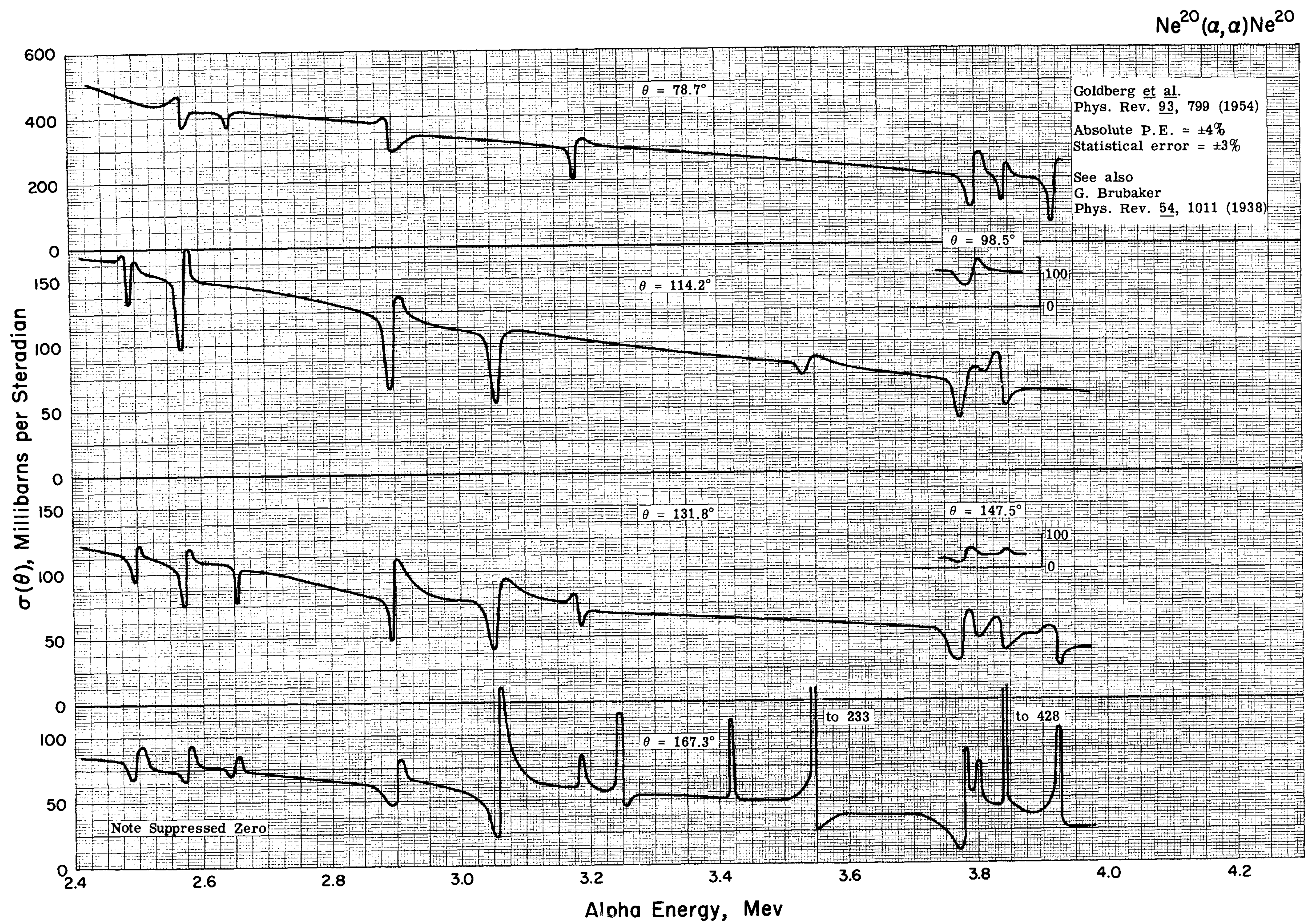

E* = 1.63 Mev
M. Kondo and T. Yamazaki
J. Phys. Soc. Japan 13, 771 (1958)
Absolute P.E. = ±10%
See also
Oda et al.
J. Phys. Soc. Japan 14, 396 (1959)
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

$Ne^{20}(p, p')Ne^{20*}$


50
40
30
20
10
0
σ (θ), Millibarns per Steradian
0
20
40
60
80
100
120
140
160
180
Lab Angle of Proton, θ

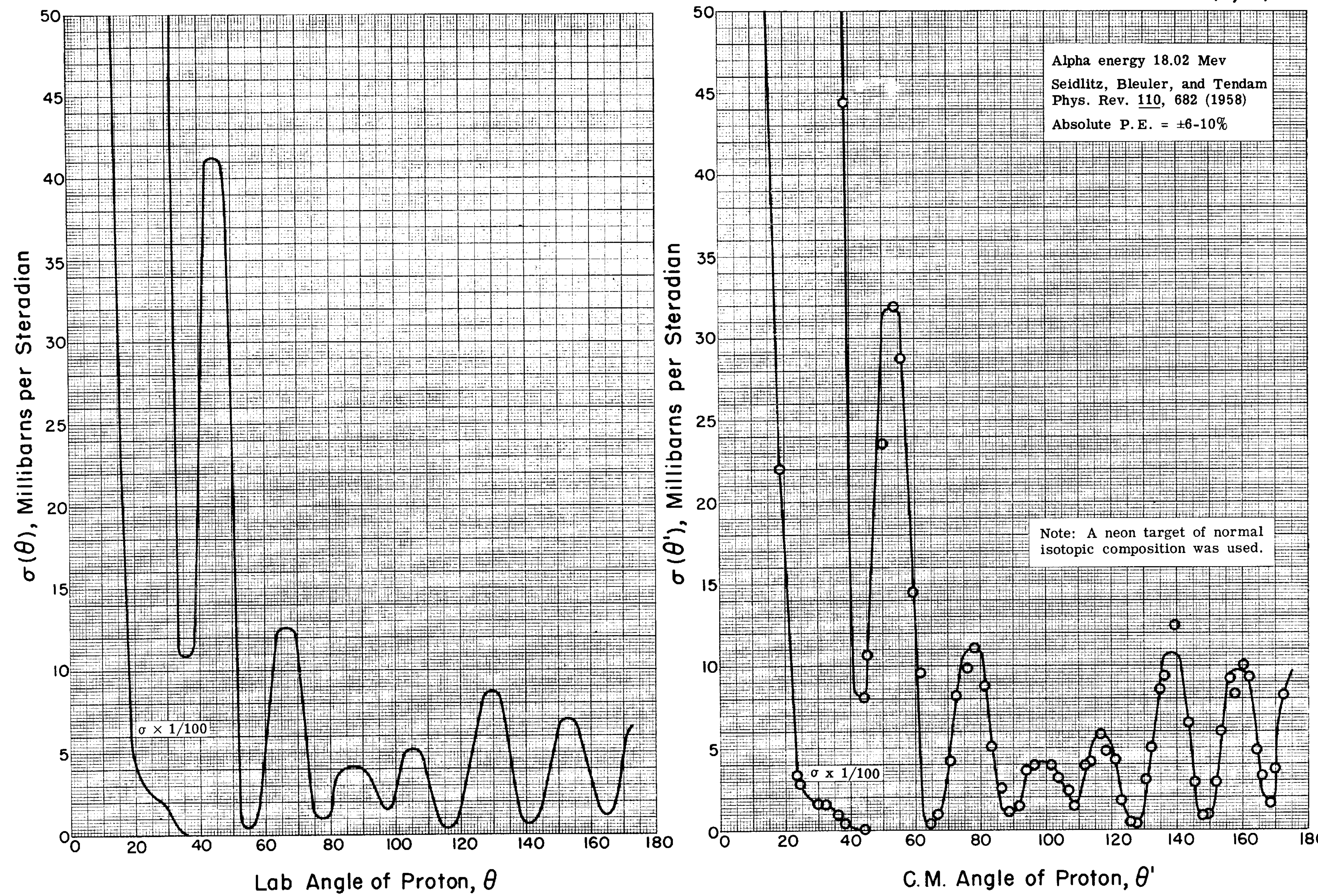

E* = 1.63 Mev
Proton energy 9.51 Mev
Gibson, Prowse, and Rotblatt
Proc. Roy. Soc. (London) A243, 237 (1957)
Absolute P.E. = ±5%
50
40
30
20
10
0
σ (θ'), Millibarns per Steradian
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Proton, θ'


Lab angle θ = 0-15°
Marion, Slattery, and Chapman
Phys. Rev. 103, 676 (1956)
Absolute P.E. = ±40%
Only about half the original experimental points are shown.
The authors assign the following thresholds
Reaction | Ed(Mev) | Q(Mev) | E*(Mev)
Ne20(d, n)Na21 | 1.45 | -1.24 | 1.46
Ne22(d, n)Na23 | 2.292 | -1.866 | 8.435
Ne20(d, n)Na21 | 2.654 | -2.201 | 2.426
Ne22(d, n)Na23 | 2.887 | -2.443 | 9.012
Note: A neon target of normal isotopic composition was used.
Note: Relative data below 2.2 Mev were arbitrarily normalized to absolute data above 2.2 Mev.
σ(0-15°), Millibarns per Steradian
Deuteron Energy, Mev
0
10
20
30
40
50
60
70
80
90
100
0.5
1.0
1.5
2.0
2.5
3.0
3.5

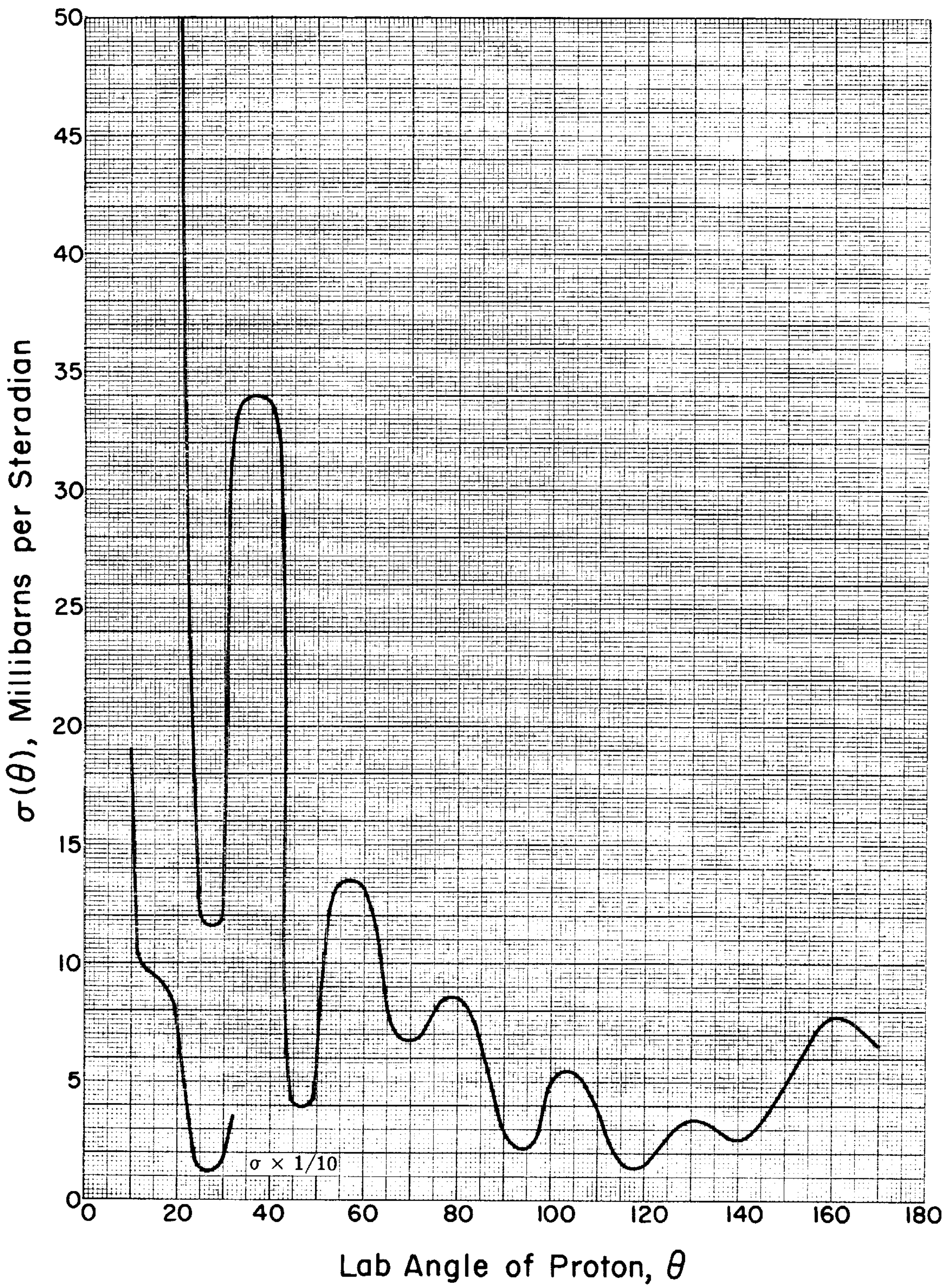


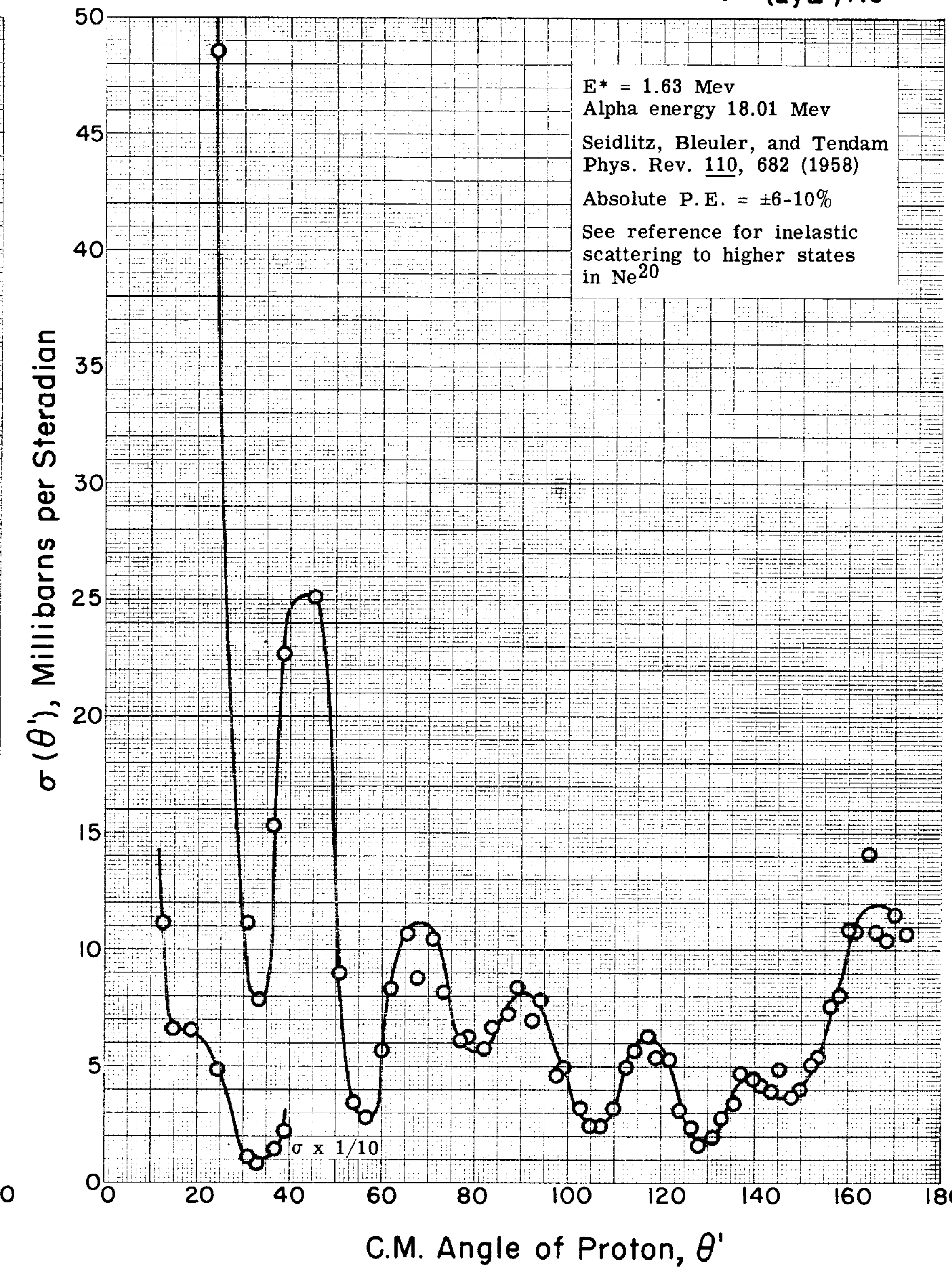
$Ne^{20}(\alpha,\alpha)Ne^{20}$
θ = 78.7°
Goldberg et al.
Phys. Rev. 93, 799 (1954)
Absolute P.E. = ±4%
Statistical error = ±3%
See also
G. Brubaker
Phys. Rev. 54, 1011 (1938)
θ = 98.5°
θ = 114.2°
θ = 131.8°
θ = 147.5°
θ = 167.3°
to 233
to 428
Note Suppressed Zero
σ(θ), Millibarns per Steradian
Alpha Energy, Mev

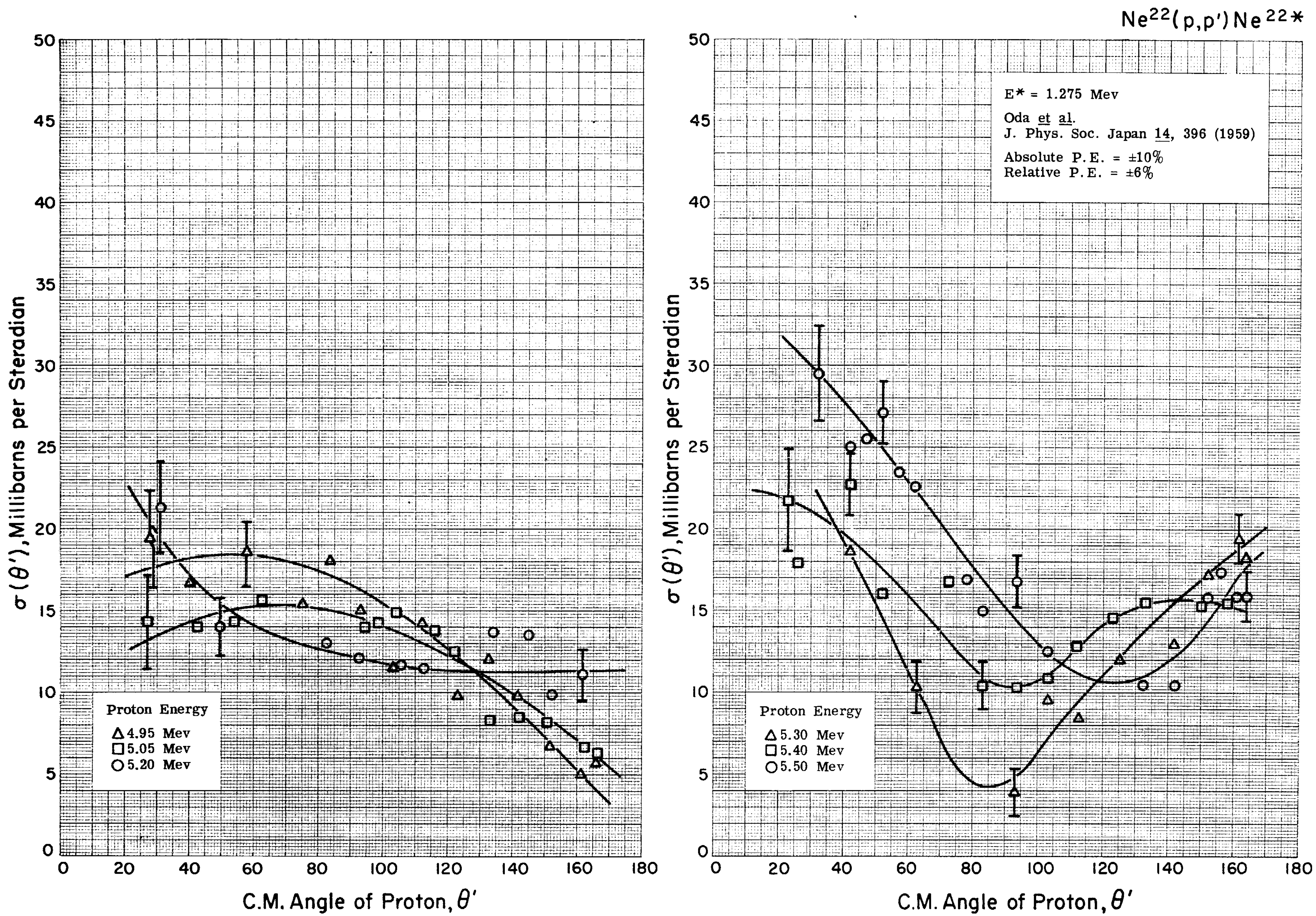
Ne(α, α)Ne


σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
σ × 1/100
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
σ x 1/100
Alpha energy 18.02 Mev
Seidlitz, Bleuler, and Tendam
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±6-10%
Note: A neon target of normal isotopic composition was used.

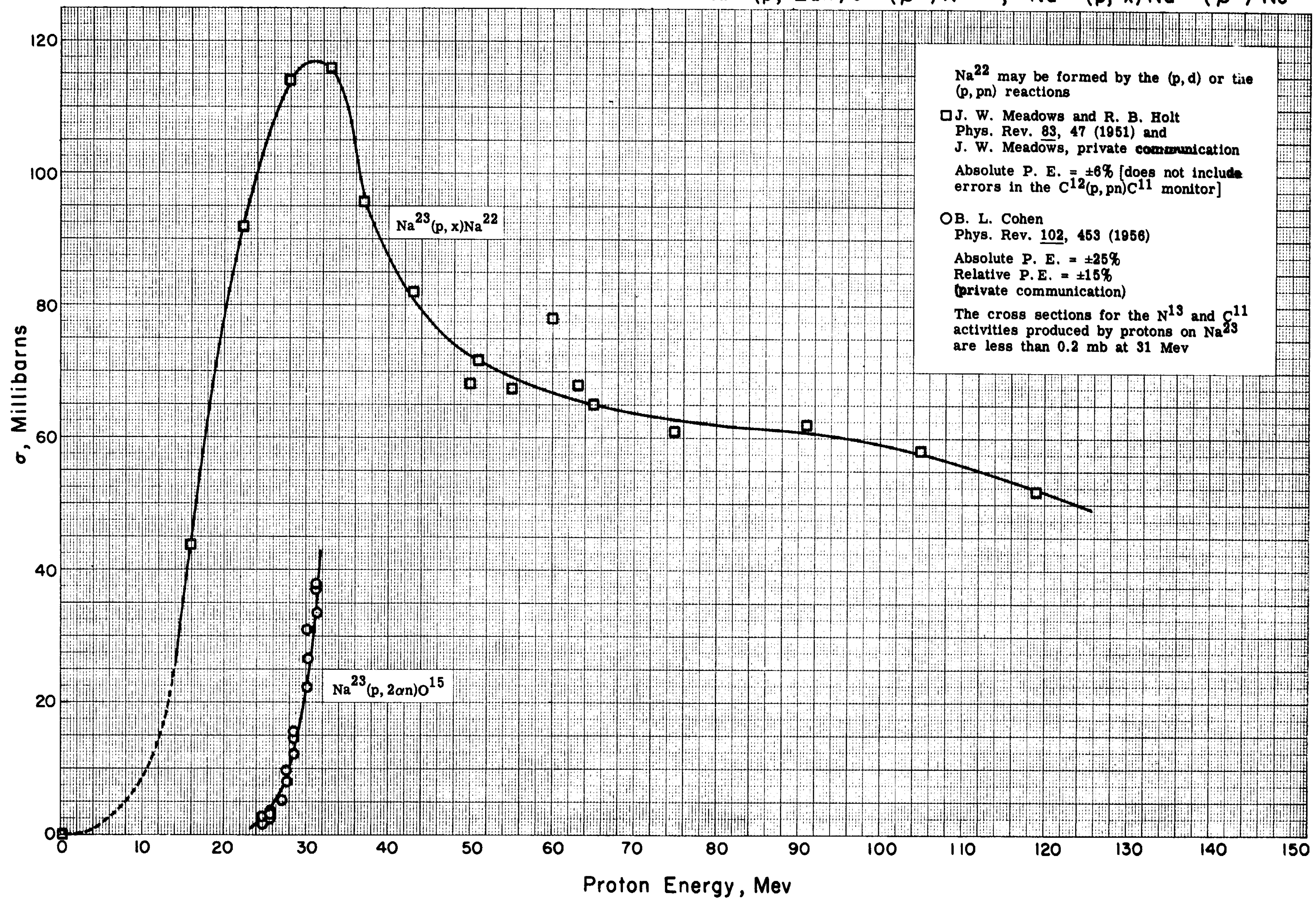
$Ne^{20}(\alpha,\alpha')Ne^{20*}$

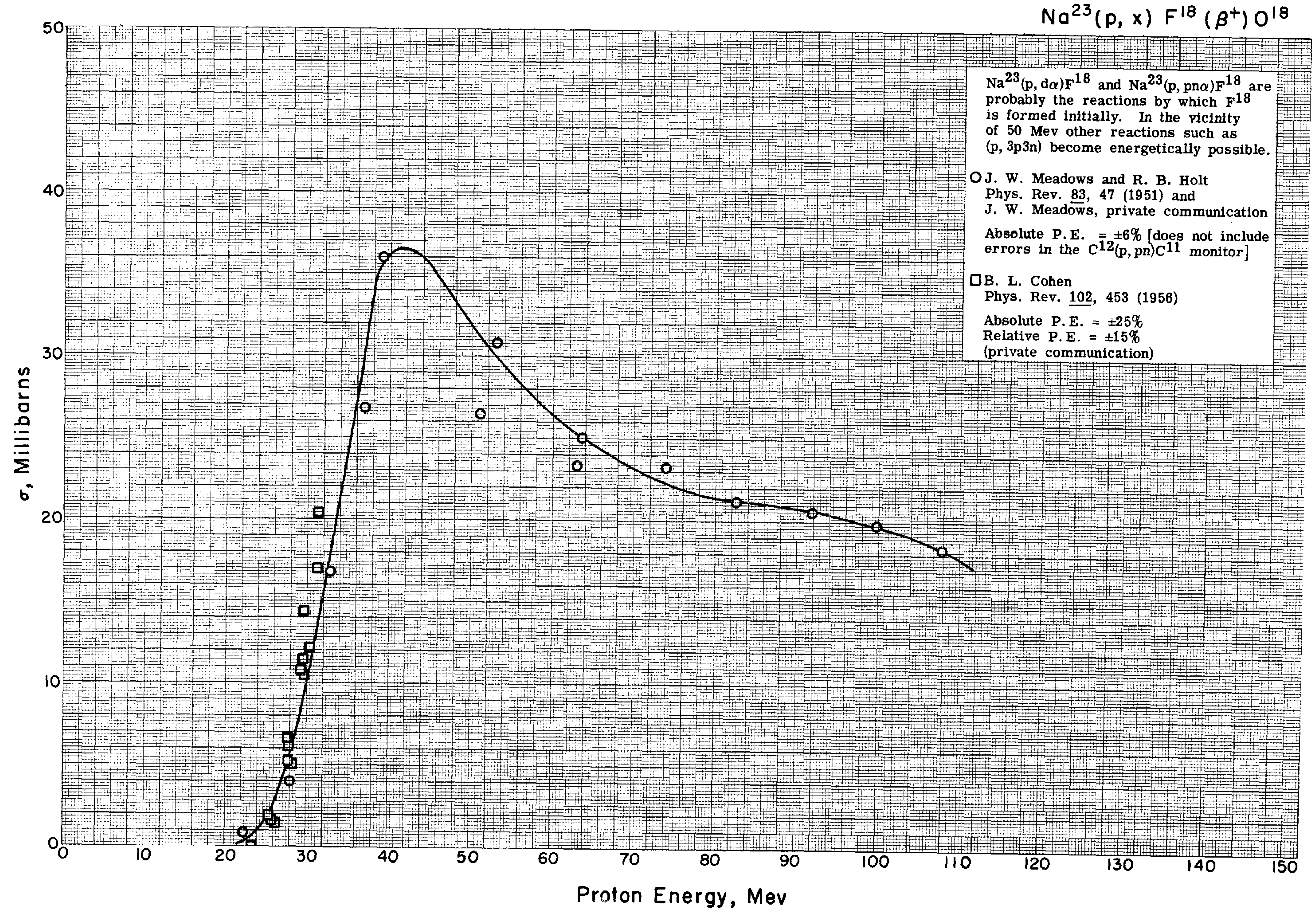





Ne²²(p,p′)Ne²²*
E* = 1.275 Mev
Oda et al.
J. Phys. Soc. Japan 14, 396 (1959)
Absolute P.E. = ±10%
Relative P.E. = ±6%
σ(θ′), Millibarns per Steradian
C.M. Angle of Proton, θ′
Proton Energy
△4.95 Mev
□5.05 Mev
○5.20 Mev
Proton Energy
△5.30 Mev
□5.40 Mev
○5.50 Mev

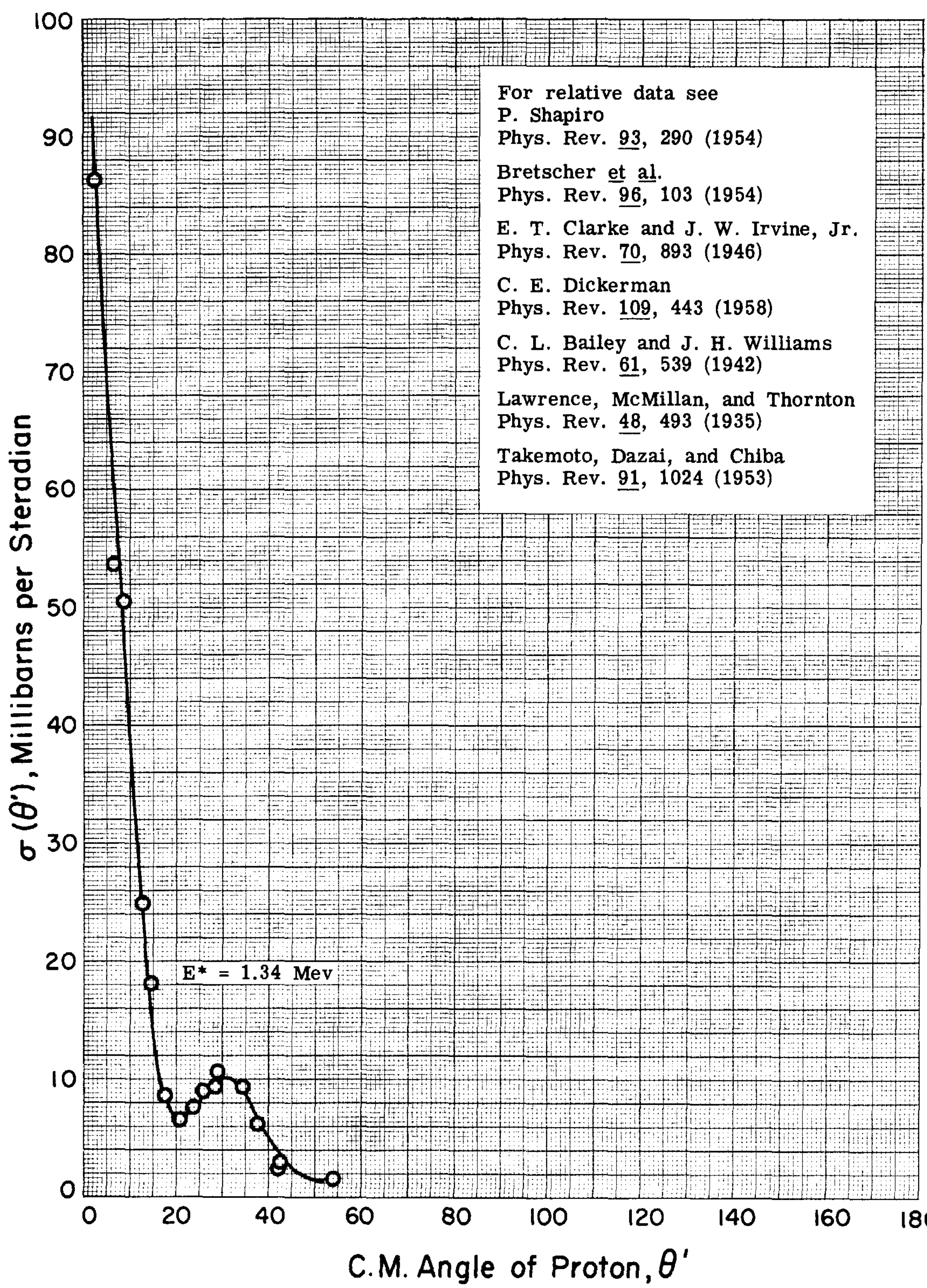
$Na^{23}(p, 2\alpha n)O^{15}(\beta^+)N^{15}$; $Na^{23}(p, x)Na^{22}(\beta^+)Ne^{22}$

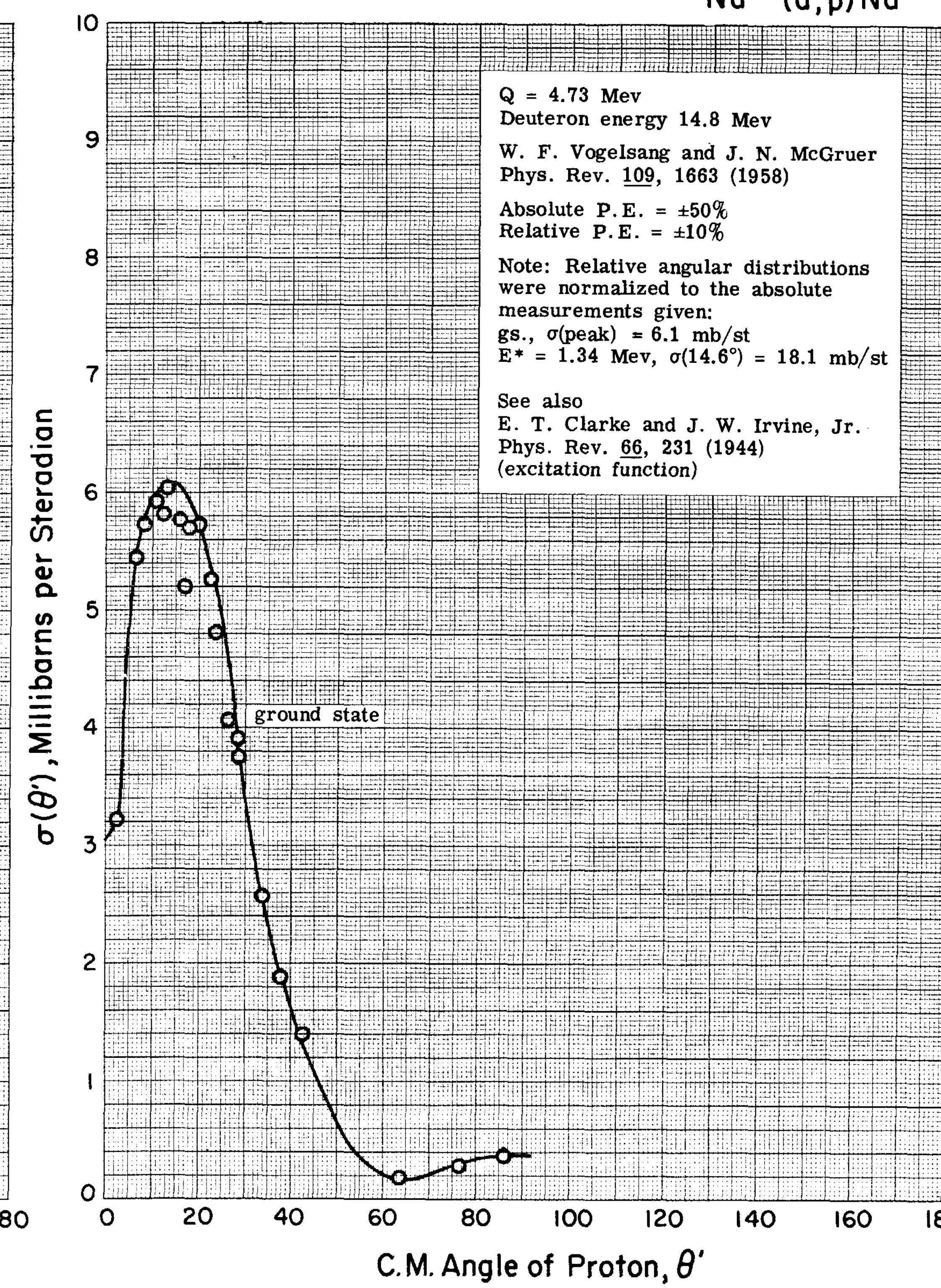




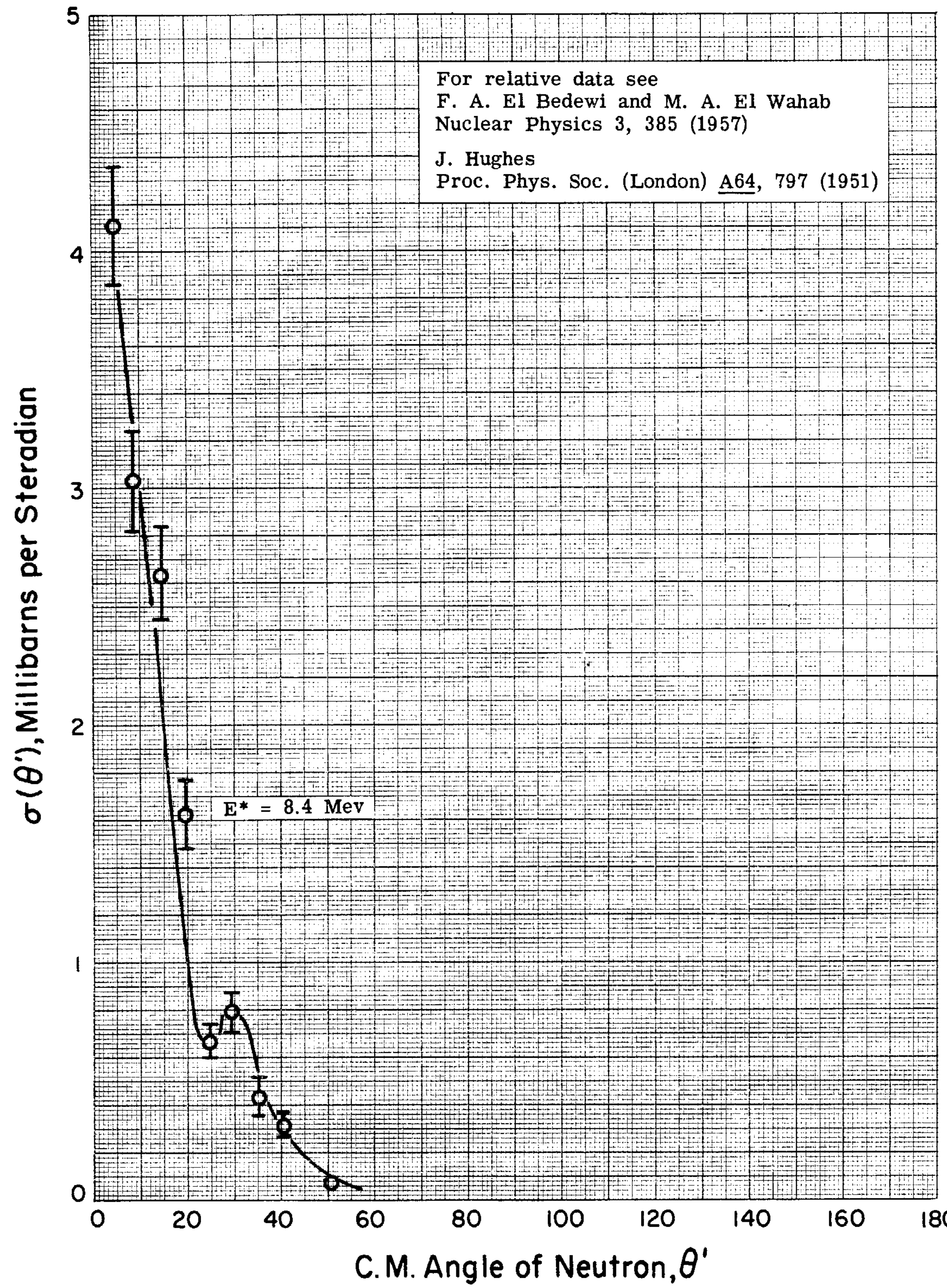
$Na^{23}(p, x)\ F^{18}\ (\beta^+)\ O^{18}$
$Na^{23}(p, d\alpha)F^{18}$ and $Na^{23}(p, pn\alpha)F^{18}$ are probably the reactions by which F^{18} is formed initially. In the vicinity of 50 Mev other reactions such as (p, 3p3n) become energetically possible.
○ J. W. Meadows and R. B. Holt Phys. Rev. 83, 47 (1951) and J. W. Meadows, private communication
Absolute P.E. = ±6% [does not include errors in the $C^{12}(p, pn)C^{11}$ monitor]
□ B. L. Cohen Phys. Rev. 102, 453 (1956)
Absolute P.E. = ±25%
Relative P.E. = ±15%
(private communication)
σ, Millibarns
Proton Energy, Mev

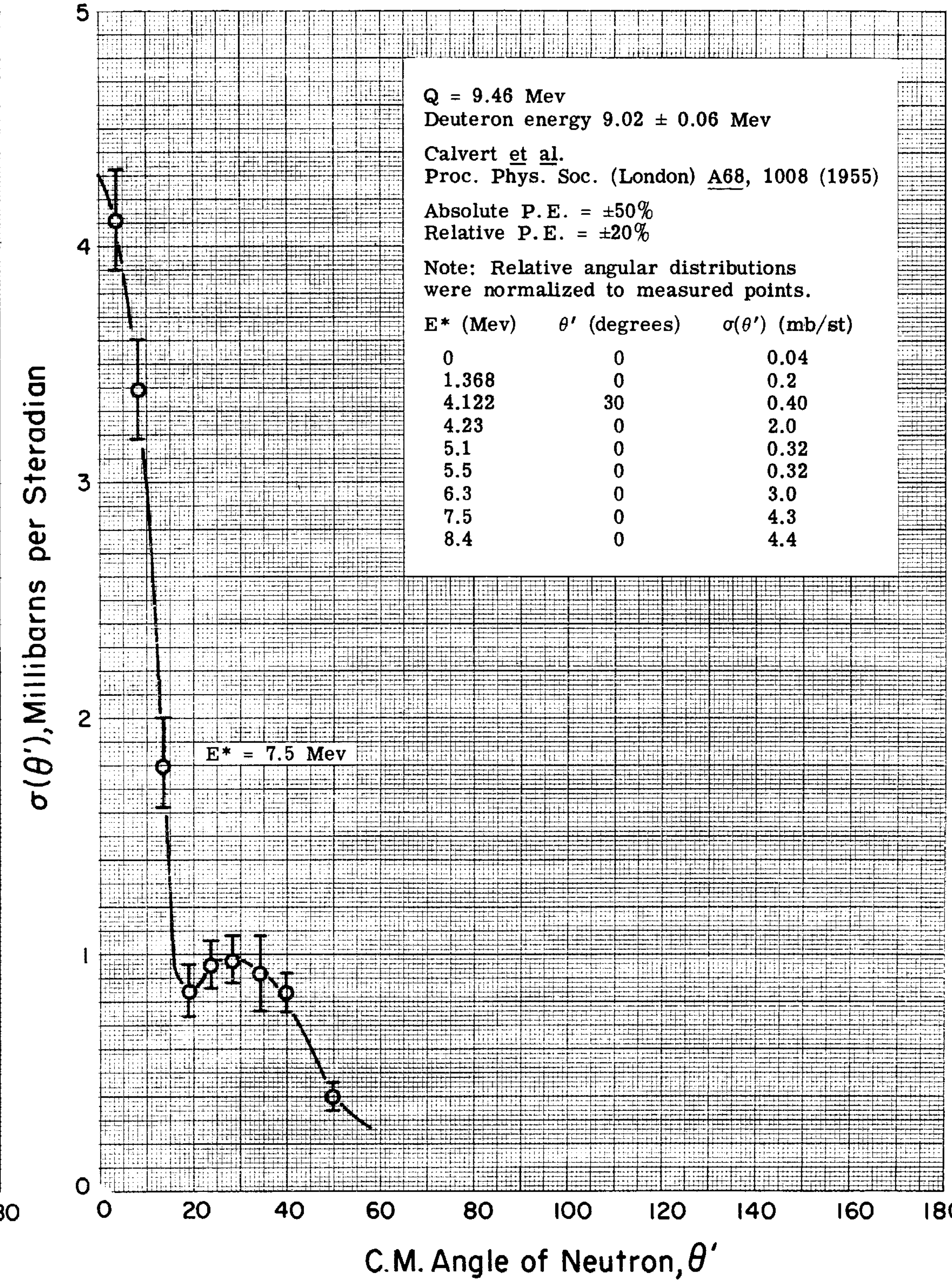
$Na^{23}(d,p')Na^{24*}$


For relative data see
P. Shapiro
Phys. Rev. 93, 290 (1954)
Bretscher et al.
Phys. Rev. 96, 103 (1954)
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 70, 893 (1946)
C. E. Dickerman
Phys. Rev. 109, 443 (1958)
C. L. Bailey and J. H. Williams
Phys. Rev. 61, 539 (1942)
Lawrence, McMillan, and Thornton
Phys. Rev. 48, 493 (1935)
Takemoto, Dazai, and Chiba
Phys. Rev. 91, 1024 (1953)
E* = 1.34 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

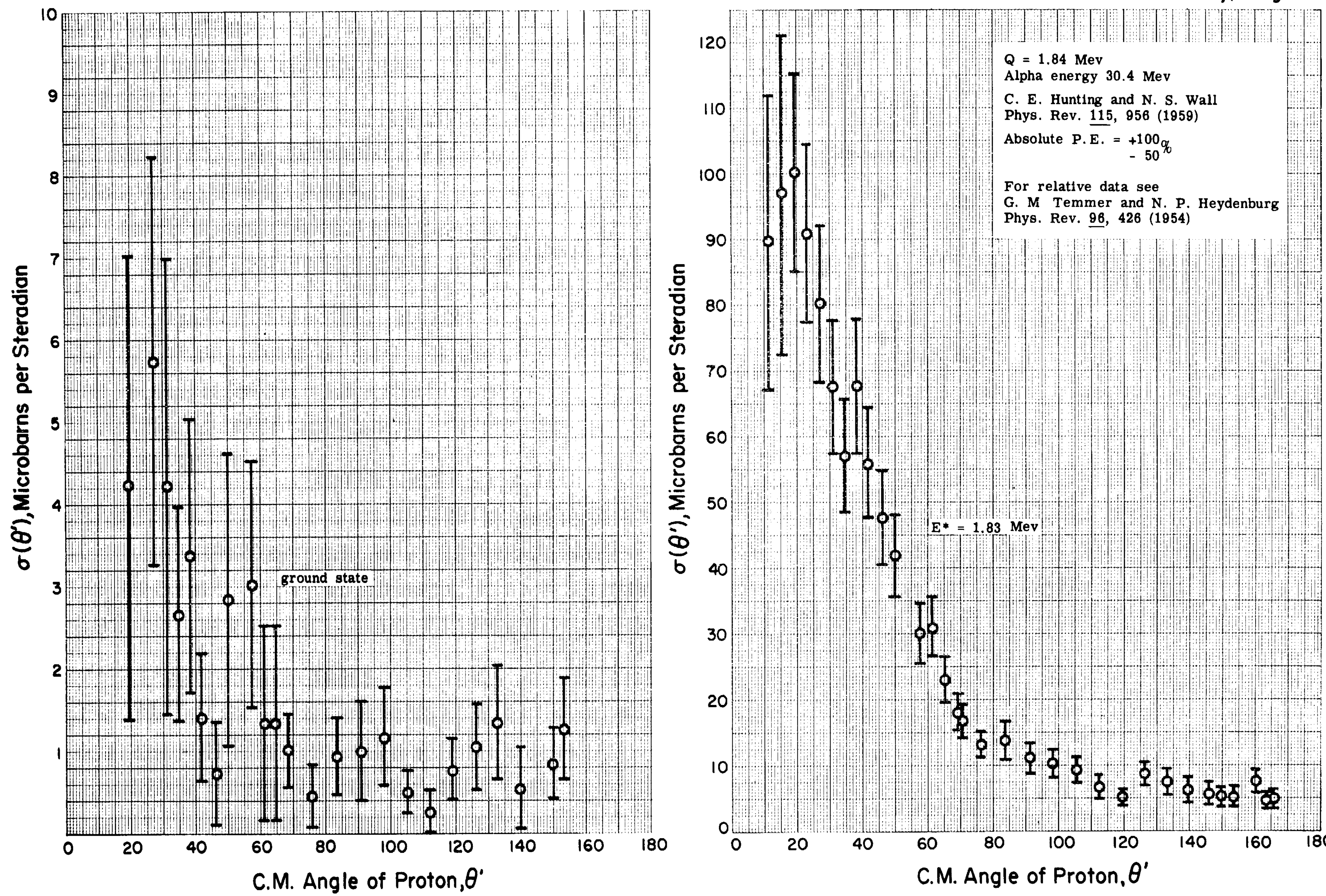

Q = 4.73 Mev
Deuteron energy 14.8 Mev
W. F. Vogelsang and J. N. McGruer
Phys. Rev. 109, 1663 (1958)
Absolute P.E. = ±50%
Relative P.E. = ±10%
Note: Relative angular distributions were normalized to the absolute measurements given:
gs., σ(peak) = 6.1 mb/st
E* = 1.34 Mev, σ(14.6°) = 18.1 mb/st
See also
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 66, 231 (1944)
(excitation function)
ground state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

$Na^{23}(d,n')Mg^{24*}$

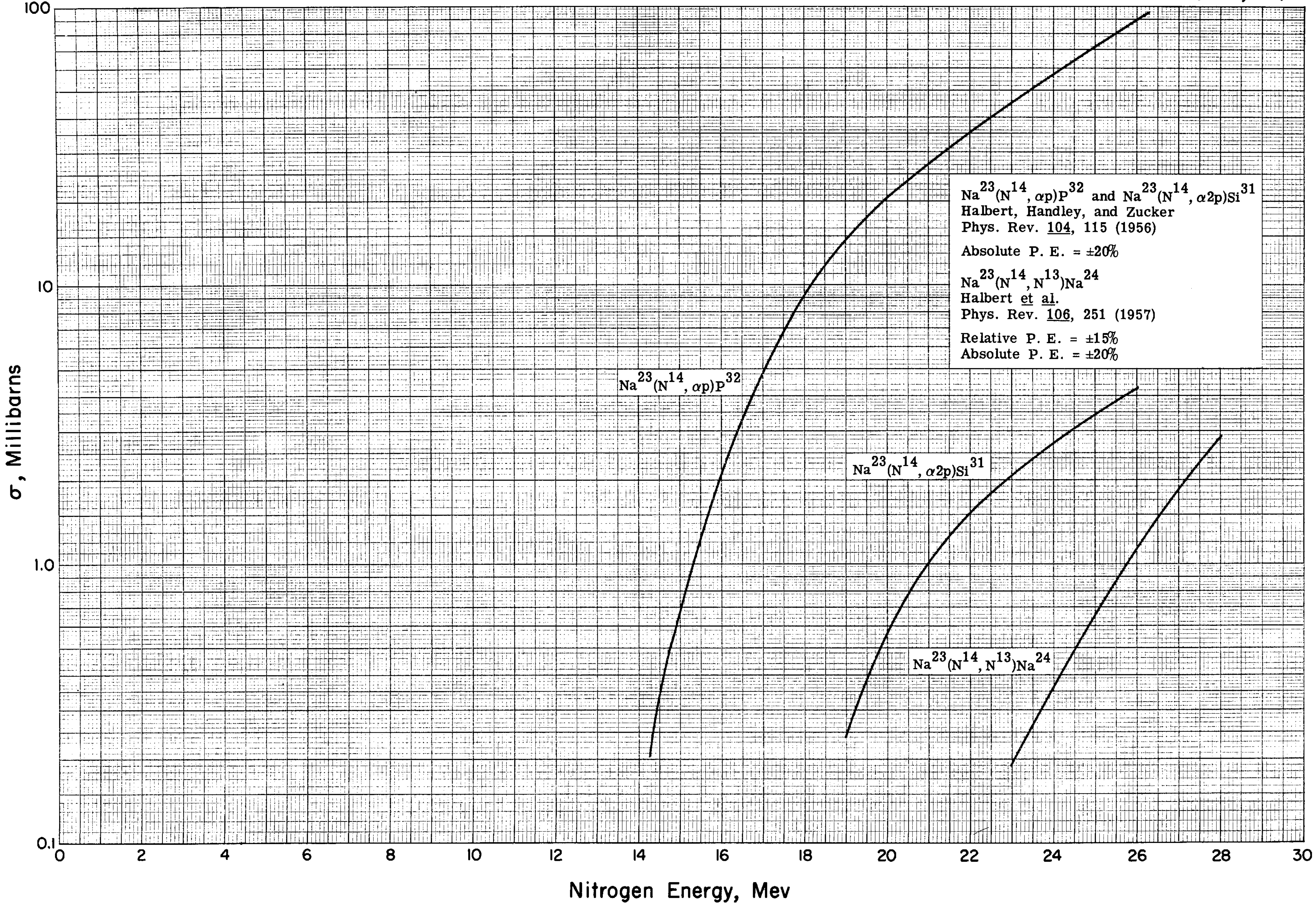

For relative data see
F. A. El Bedewi and M. A. El Wahab
Nuclear Physics 3, 385 (1957)
J. Hughes
Proc. Phys. Soc. (London) A64, 797 (1951)
E* = 8.4 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'
0
1
2
3
4
5
0 20 40 60 80 100 120 140 160 180


Q = 9.46 Mev
Deuteron energy 9.02 ± 0.06 Mev
Calvert et al.
Proc. Phys. Soc. (London) A68, 1008 (1955)
Absolute P.E. = ±50%
Relative P.E. = ±20%
Note: Relative angular distributions were normalized to measured points.
E* (Mev) θ' (degrees) σ(θ') (mb/st)
0 0 0.04
1.368 0 0.2
4.122 30 0.40
4.23 0 2.0
5.1 0 0.32
5.5 0 0.32
6.3 0 3.0
7.5 0 4.3
8.4 0 4.4
E* = 7.5 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'
0
1
2
3
4
5
0 20 40 60 80 100 120 140 160 180

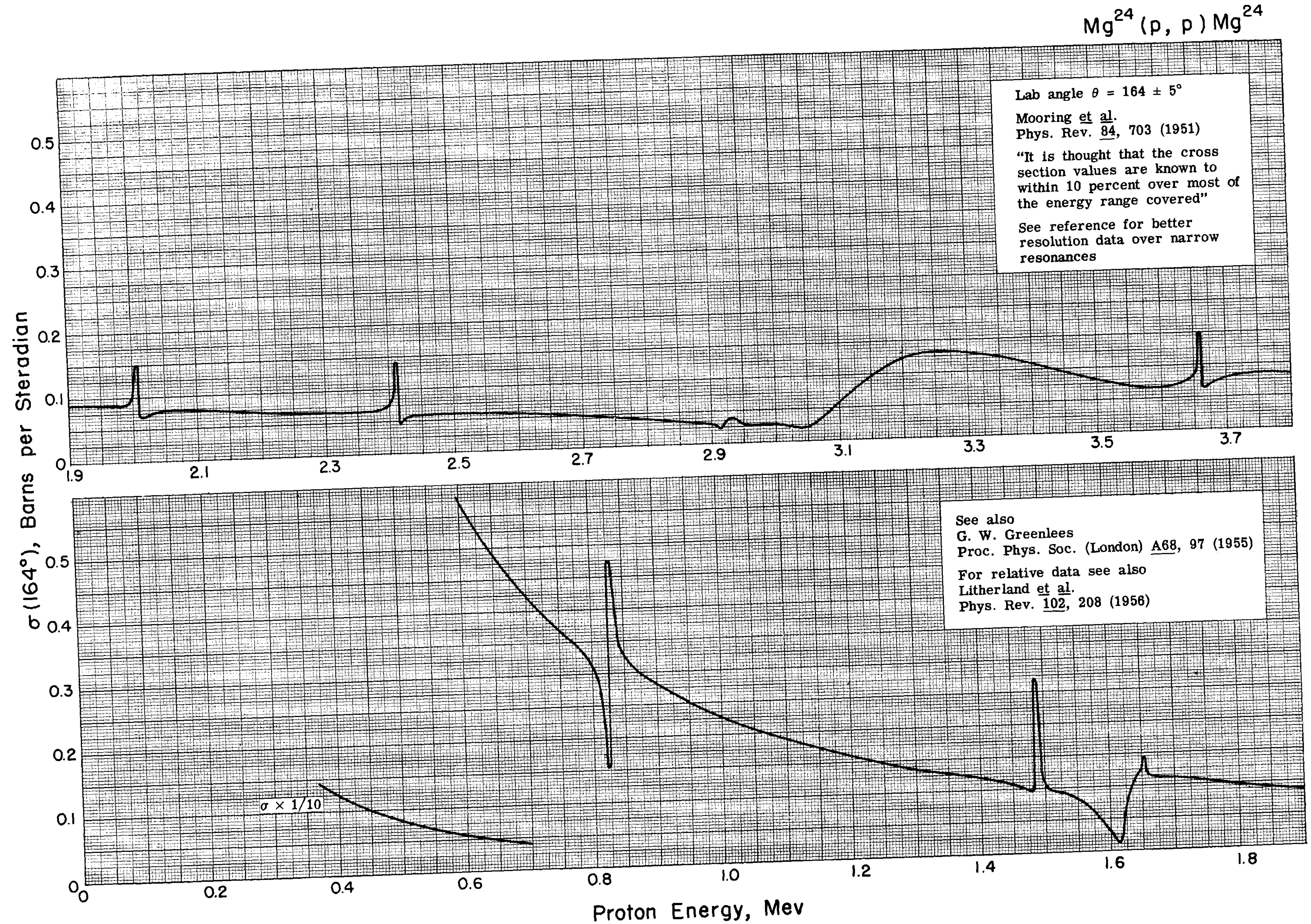
$Na^{23}(\alpha, p')Mg^{26*}$

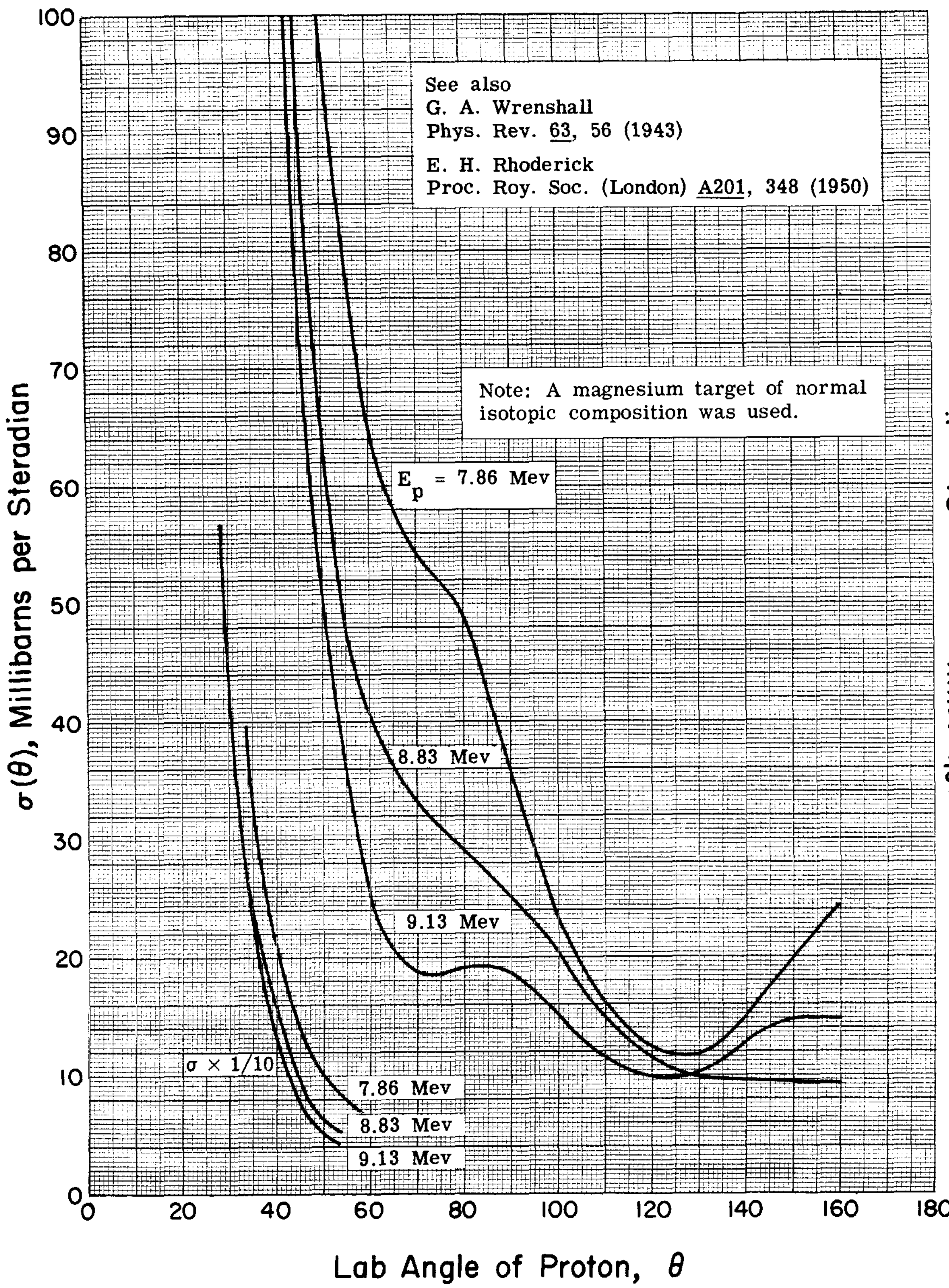


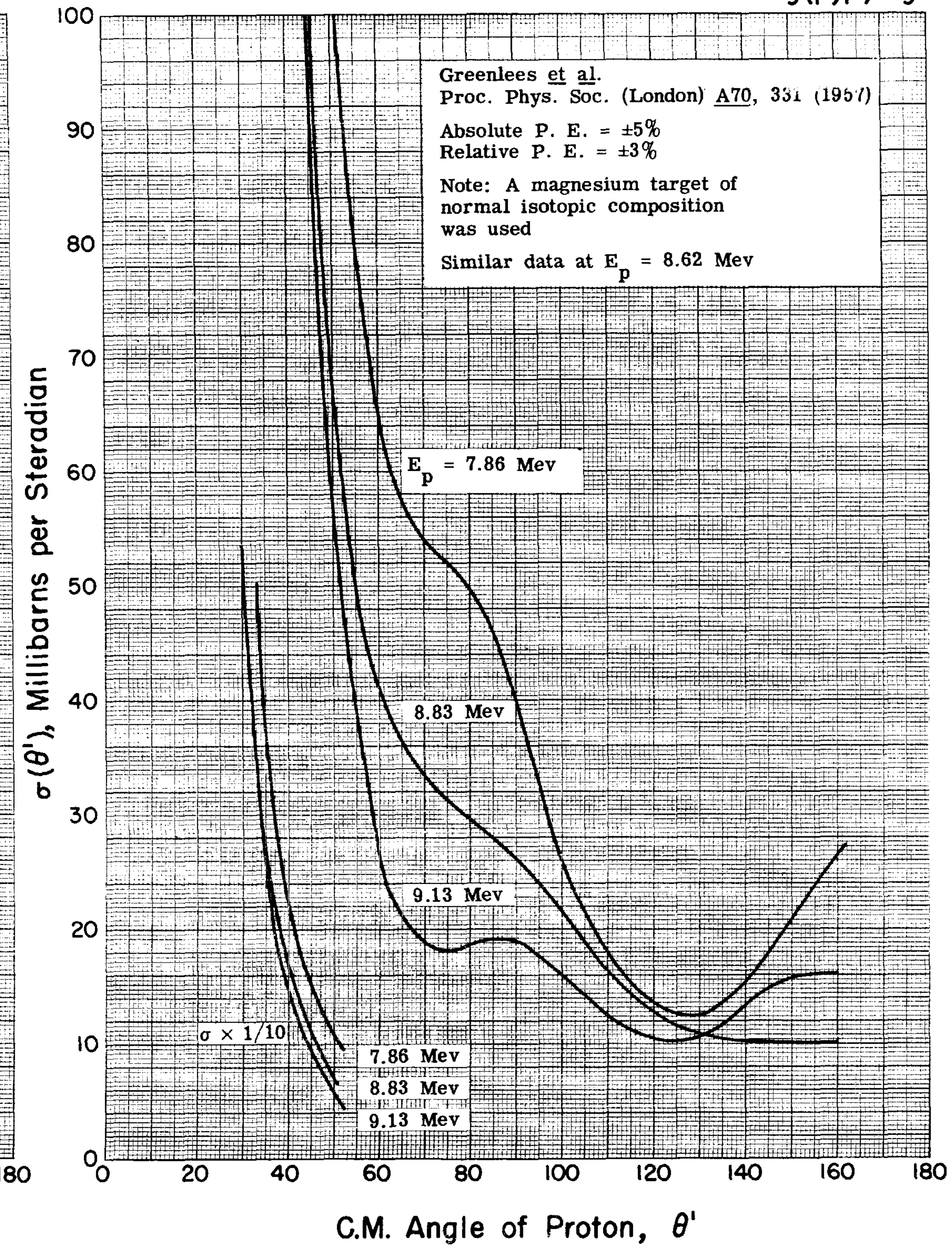
$Na^{23}(N^{14},\ \ )$



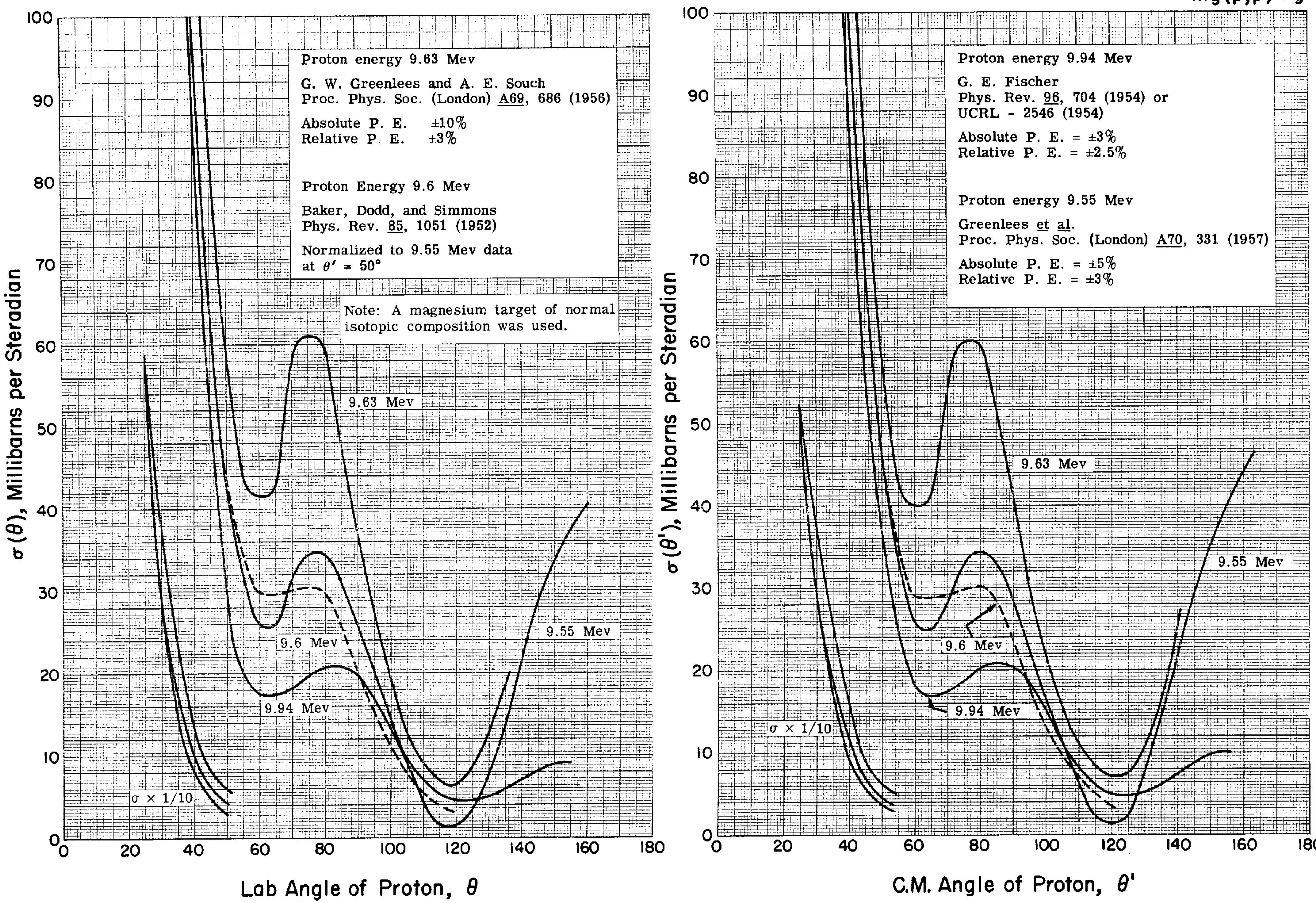
$Na^{23}(N^{14}, \alpha p)P^{32}$ and $Na^{23}(N^{14}, \alpha 2p)Si^{31}$
Halbert, Handley, and Zucker
Phys. Rev. 104, 115 (1956)
Absolute P. E. = ±20%
$Na^{23}(N^{14}, N^{13})Na^{24}$
Halbert et al.
Phys. Rev. 106, 251 (1957)
Relative P. E. = ±15%
Absolute P. E. = ±20%
$Na^{23}(N^{14}, \alpha p)P^{32}$
$Na^{23}(N^{14}, \alpha 2p)Si^{31}$
$Na^{23}(N^{14}, N^{13})Na^{24}$
σ, Millibarns
100
10
1.0
0.1
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Nitrogen Energy, Mev


$Mg^{24}(p, p)Mg^{24}$
Lab angle θ = 164 ± 5°
Mooring et al.
Phys. Rev. 84, 703 (1951)
"It is thought that the cross section values are known to within 10 percent over most of the energy range covered"
See reference for better resolution data over narrow resonances
See also
G. W. Greenlees
Proc. Phys. Soc. (London) A68, 97 (1955)
For relative data see also
Litherland et al.
Phys. Rev. 102, 208 (1956)
σ × 1/10
σ (164°), Barns per Steradian
Proton Energy, Mev


See also
G. A. Wrenshall
Phys. Rev. 63, 56 (1943)
E. H. Rhoderick
Proc. Roy. Soc. (London) A201, 348 (1950)
Note: A magnesium target of normal isotopic composition was used.
E_p = 7.86 Mev
8.83 Mev
9.13 Mev
σ × 1/10
7.86 Mev
8.83 Mev
9.13 Mev
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ

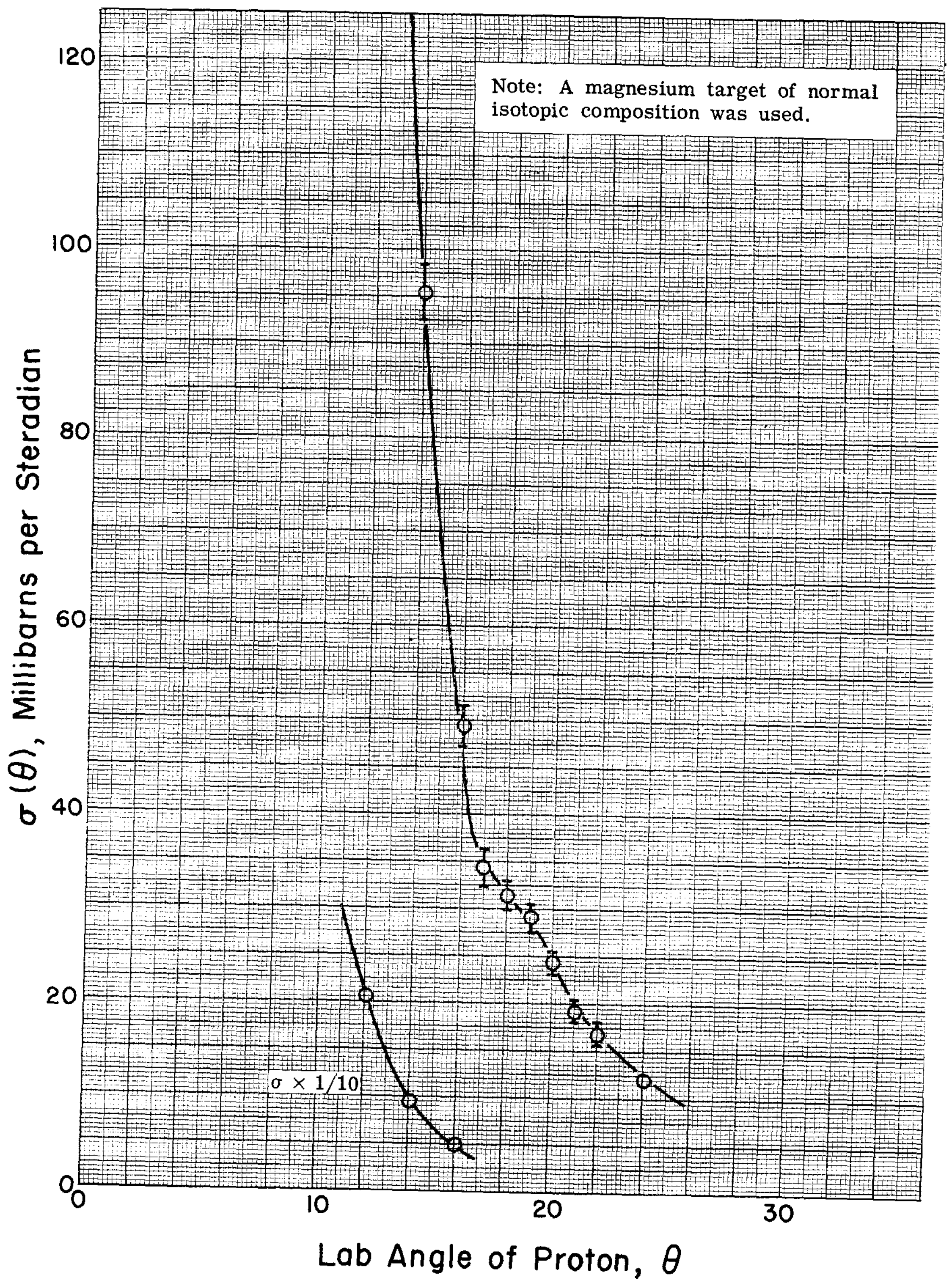

Greenlees et al.
Proc. Phys. Soc. (London) A70, 331 (1957)
Absolute P. E. = ±5%
Relative P. E. = ±3%
Note: A magnesium target of normal isotopic composition was used
Similar data at E_p = 8.62 Mev
E_p = 7.86 Mev
8.83 Mev
9.13 Mev
σ × 1/10
7.86 Mev
8.83 Mev
9.13 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

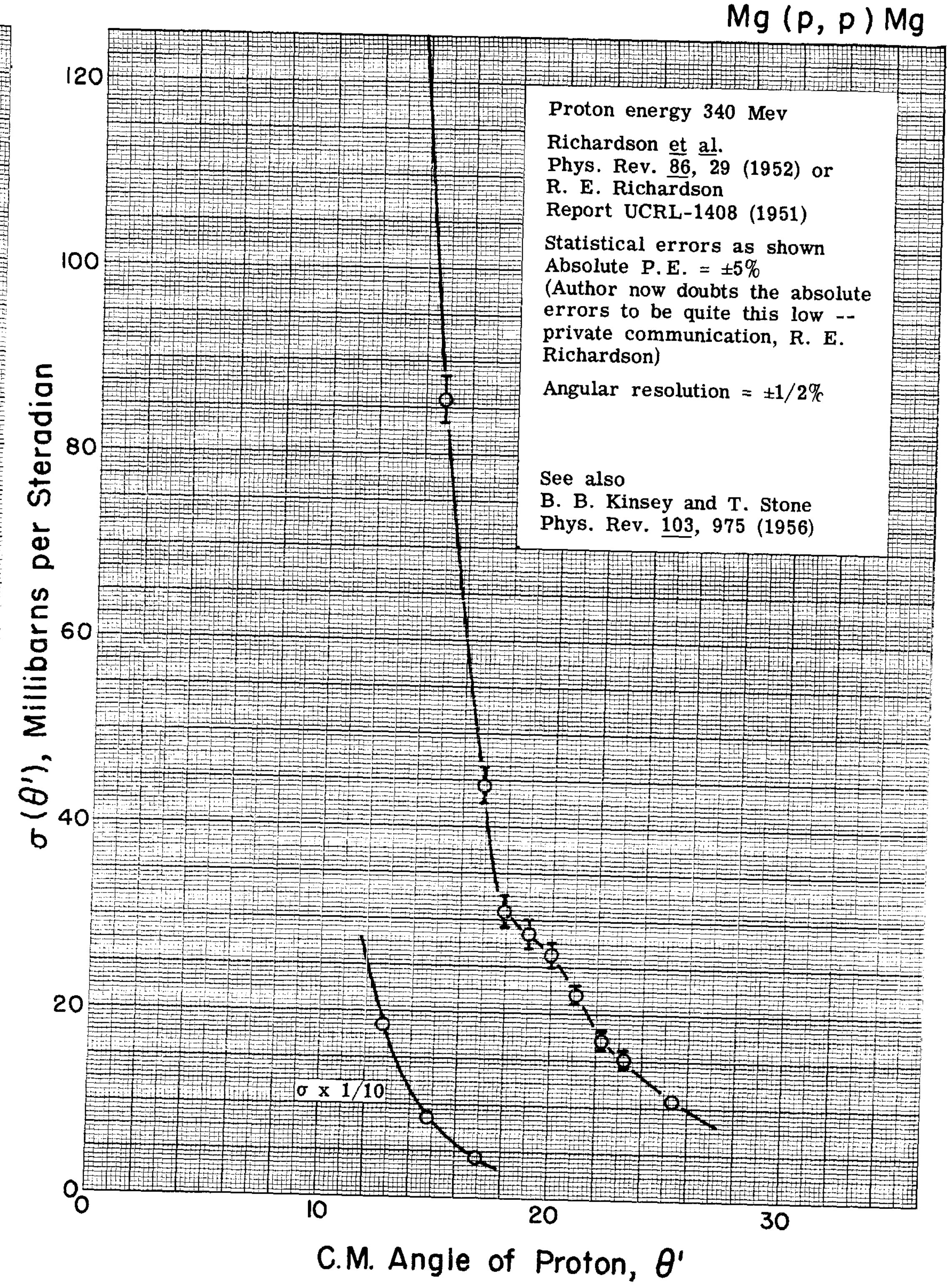
Mg(p,p)Mg



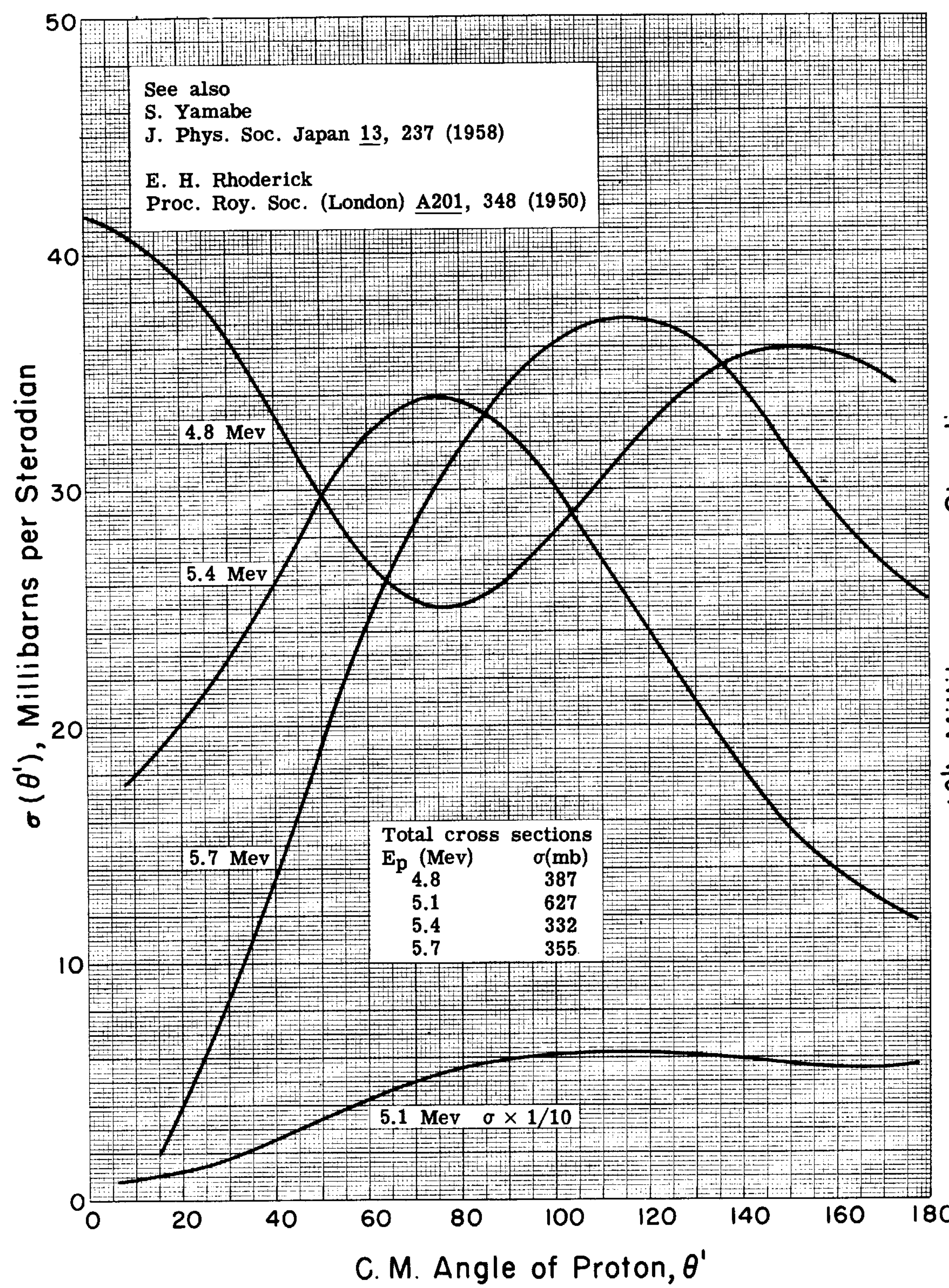
Proton energy 9.63 Mev
G. W. Greenlees and A. E. Souch
Proc. Phys. Soc. (London) A69, 686 (1956)
Absolute P. E. ±10%
Relative P. E. ±3%
Proton Energy 9.6 Mev
Baker, Dodd, and Simmons
Phys. Rev. 85, 1051 (1952)
Normalized to 9.55 Mev data
at θ' = 50°
Note: A magnesium target of normal isotopic composition was used.
9.63 Mev
9.6 Mev
9.55 Mev
9.94 Mev
σ × 1/10
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
Proton energy 9.94 Mev
G. E. Fischer
Phys. Rev. 96, 704 (1954) or
UCRL - 2546 (1954)
Absolute P. E. = ±3%
Relative P. E. = ±2.5%
Proton energy 9.55 Mev
Greenlees et al.
Proc. Phys. Soc. (London) A70, 331 (1957)
Absolute P. E. = ±5%
Relative P. E. = ±3%
9.63 Mev
9.55 Mev
9.6 Mev
9.94 Mev
σ × 1/10
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

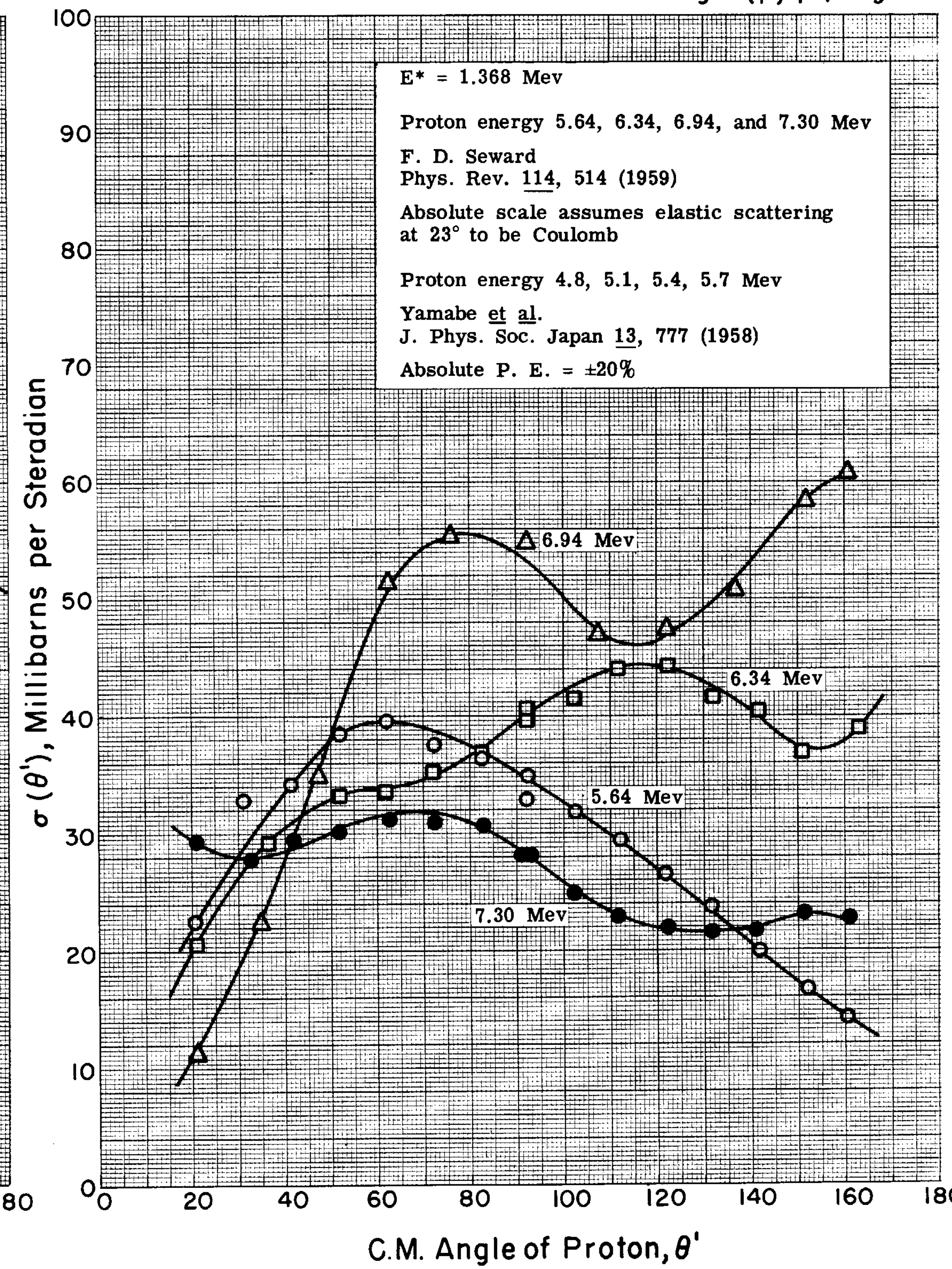
Mg (p, p) Mg


Note: A magnesium target of normal isotopic composition was used.
σ × 1/10
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
20
40
60
80
100
120
10
30

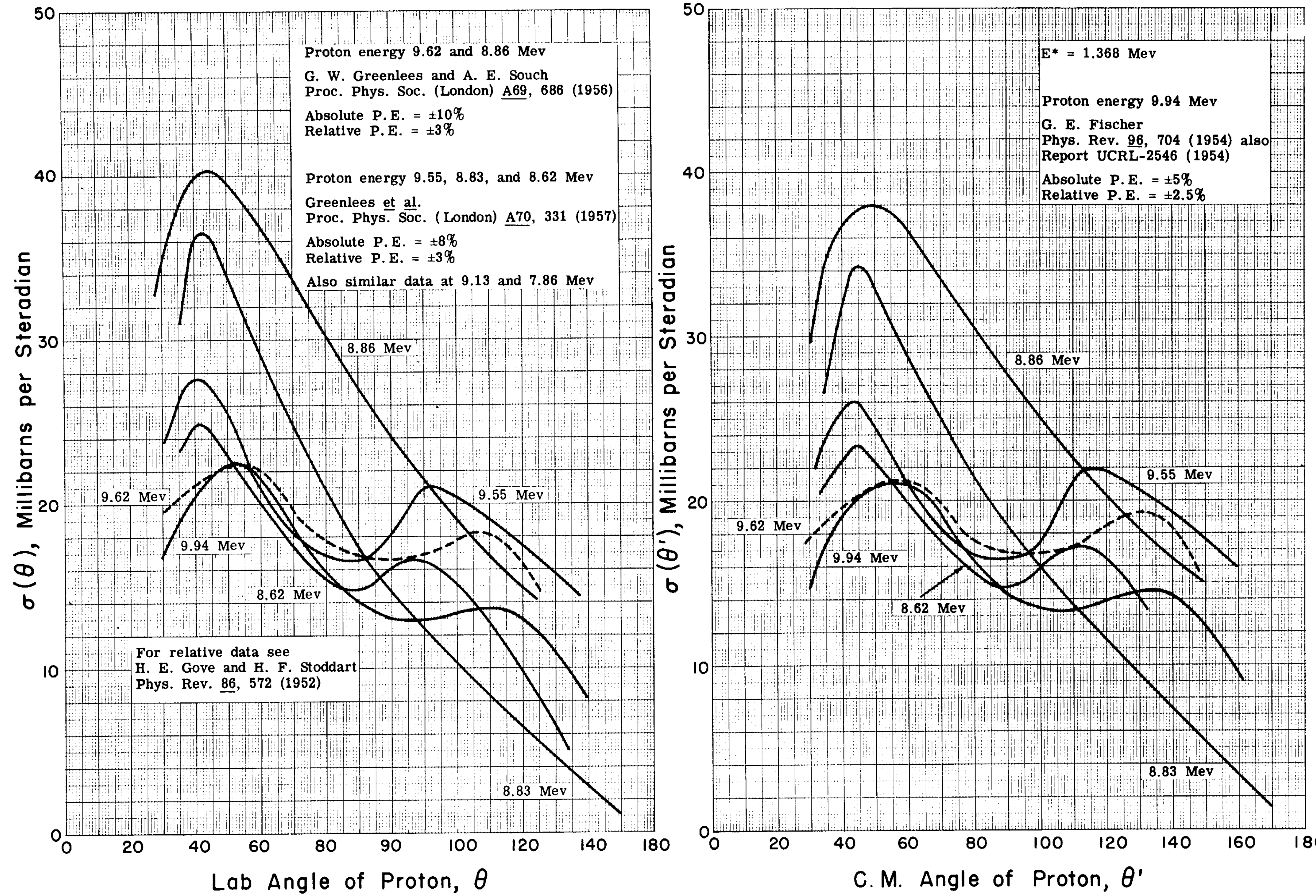

Proton energy 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Statistical errors as shown
Absolute P.E. = ±5%
(Author now doubts the absolute errors to be quite this low -- private communication, R. E. Richardson)
Angular resolution ≈ ±1/2%
See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
σ x 1/10
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
20
40
60
80
100
120
10
30

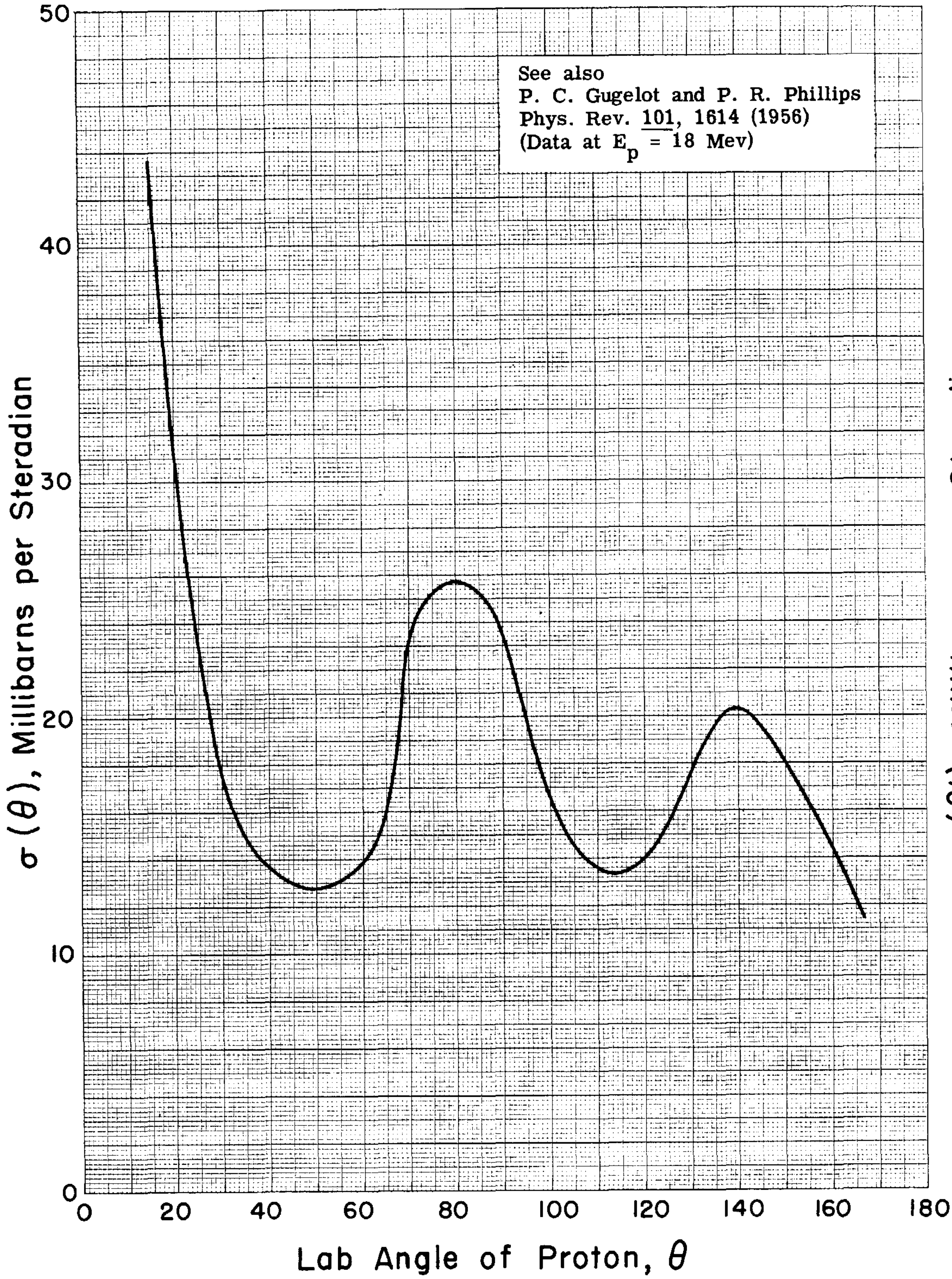
$Mg^{24}(p, p')Mg^{24*}$


See also
S. Yamabe
J. Phys. Soc. Japan 13, 237 (1958)
E. H. Rhoderick
Proc. Roy. Soc. (London) A201, 348 (1950)
4.8 Mev
5.4 Mev
5.7 Mev
5.1 Mev σ × 1/10
Total cross sections
Ep (Mev) σ(mb)
4.8 387
5.1 627
5.4 332
5.7 355
σ (θ'), Millibarns per Steradian
C. M. Angle of Proton, θ'

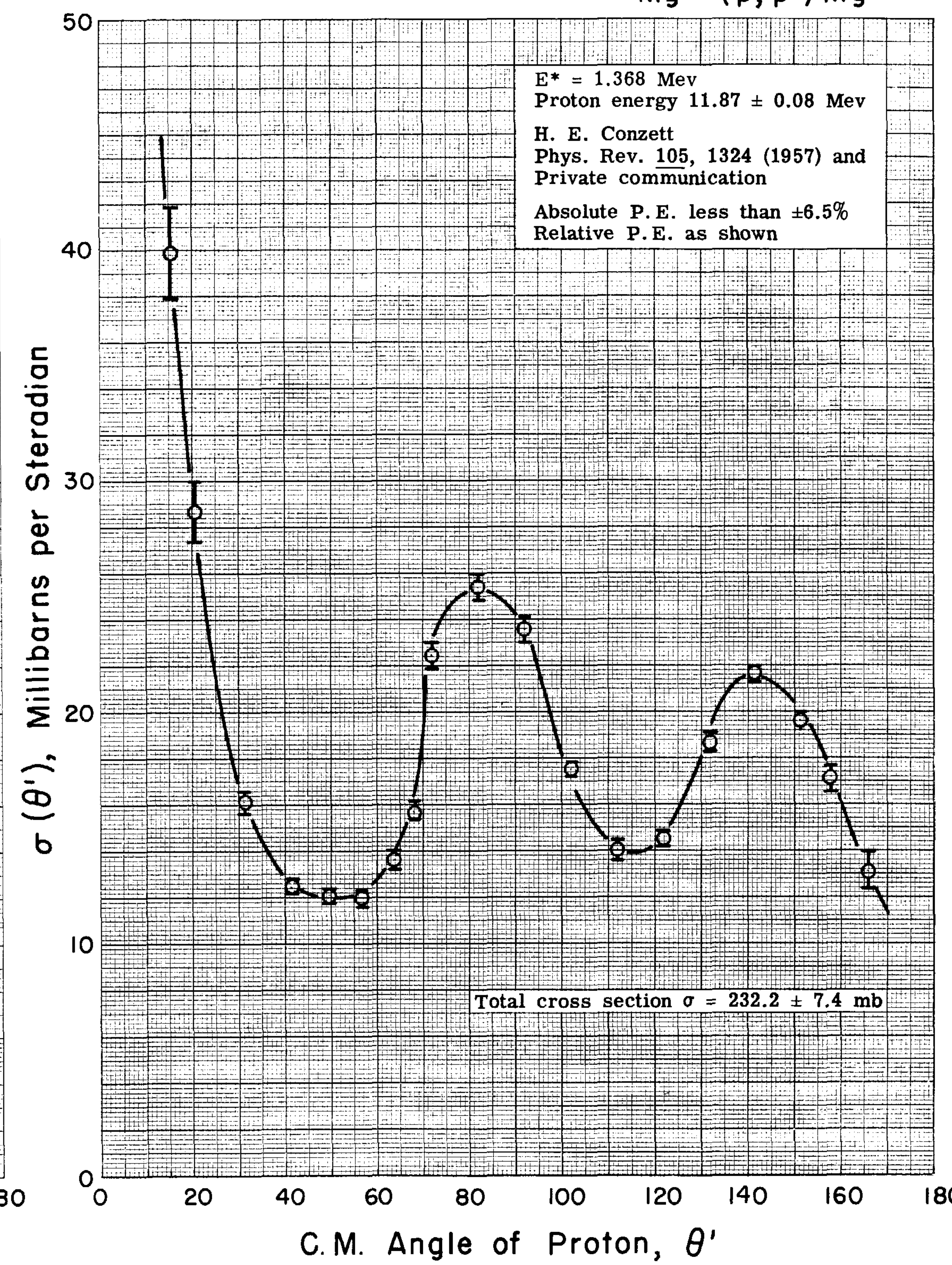

E* = 1.368 Mev
Proton energy 5.64, 6.34, 6.94, and 7.30 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute scale assumes elastic scattering at 23° to be Coulomb
Proton energy 4.8, 5.1, 5.4, 5.7 Mev
Yamabe et al.
J. Phys. Soc. Japan 13, 777 (1958)
Absolute P. E. = ±20%
6.94 Mev
6.34 Mev
5.64 Mev
7.30 Mev
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

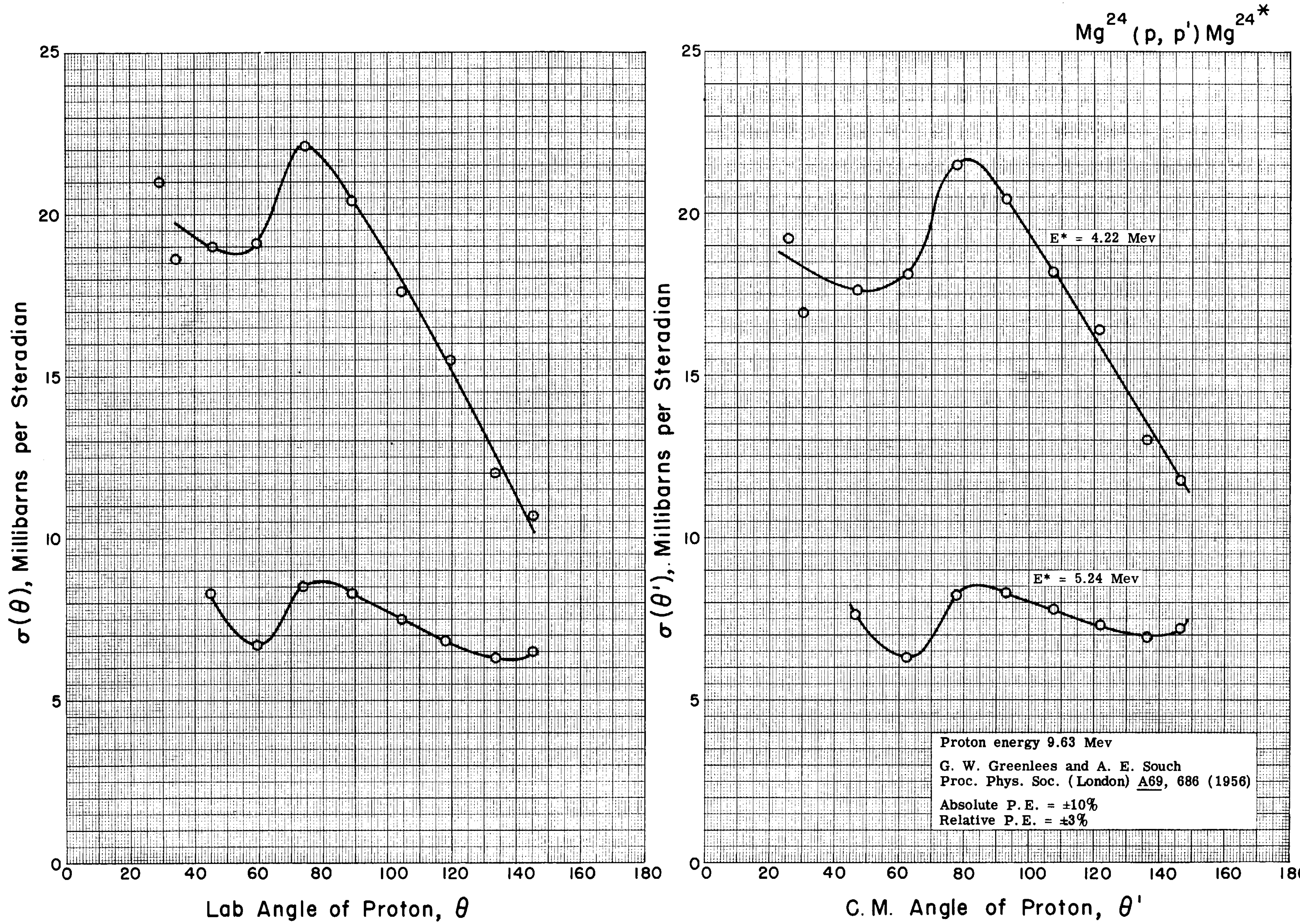
$Mg^{24}(p, p')Mg^{24*}$


Proton energy 9.62 and 8.86 Mev
G. W. Greenlees and A. E. Souch
Proc. Phys. Soc. (London) A69, 686 (1956)
Absolute P. E. = ±10%
Relative P. E. = ±3%
Proton energy 9.55, 8.83, and 8.62 Mev
Greenlees et al.
Proc. Phys. Soc. (London) A70, 331 (1957)
Absolute P. E. = ±8%
Relative P. E. = ±3%
Also similar data at 9.13 and 7.86 Mev
For relative data see
H. E. Gove and H. F. Stoddart
Phys. Rev. 86, 572 (1952)
8.86 Mev
9.62 Mev
9.94 Mev
9.55 Mev
8.62 Mev
8.83 Mev
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
E* = 1.368 Mev
Proton energy 9.94 Mev
G. E. Fischer
Phys. Rev. 96, 704 (1954) also
Report UCRL-2546 (1954)
Absolute P. E. = ±5%
Relative P. E. = ±2.5%
σ(θ'), Millibarns per Steradian
C. M. Angle of Proton, θ'


See also
P. C. Gugelot and P. R. Phillips
Phys. Rev. 101, 1614 (1956)
(Data at E_p = 18 Mev)
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ

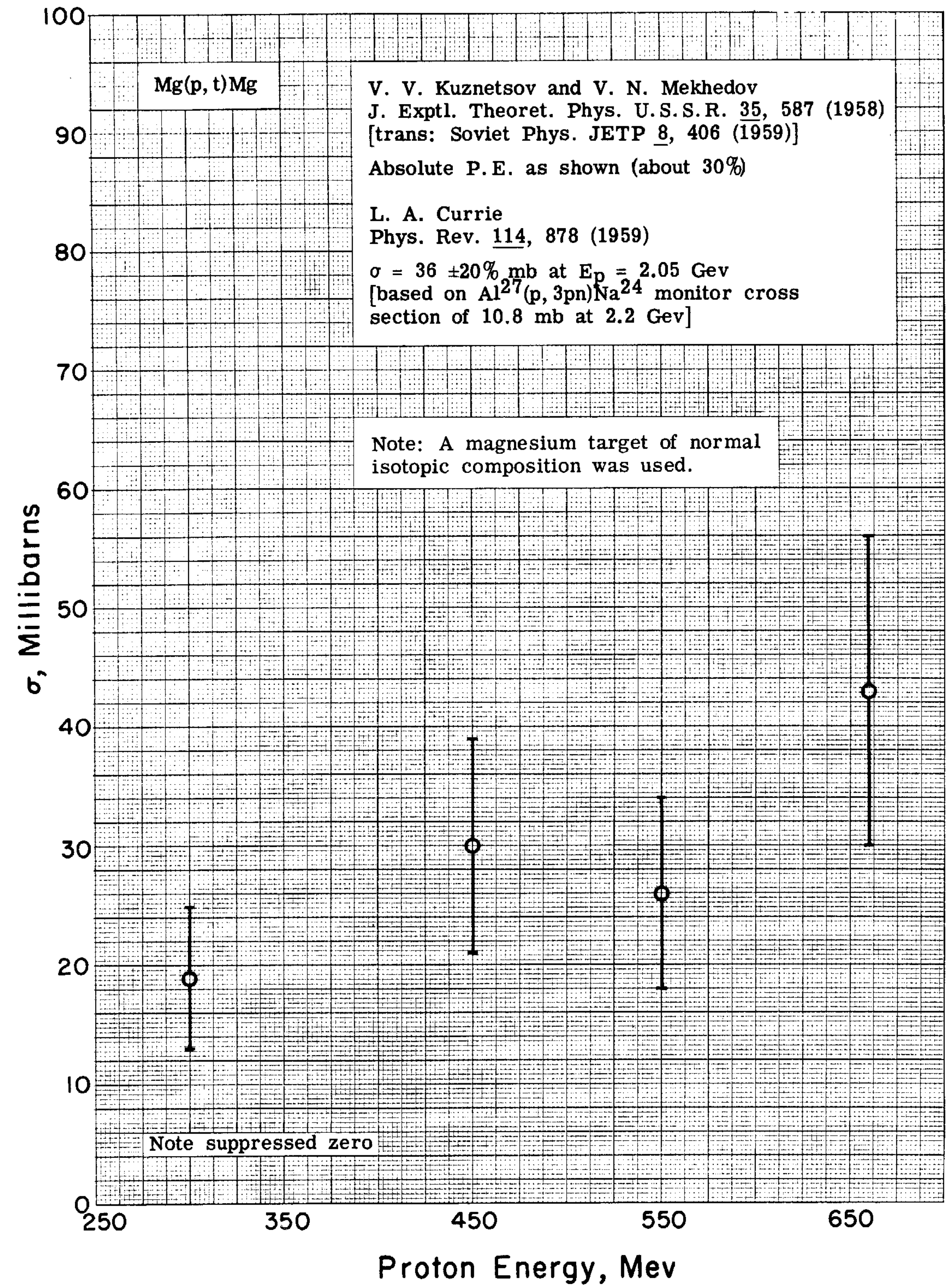
Mg^24 (p, p') Mg^24*

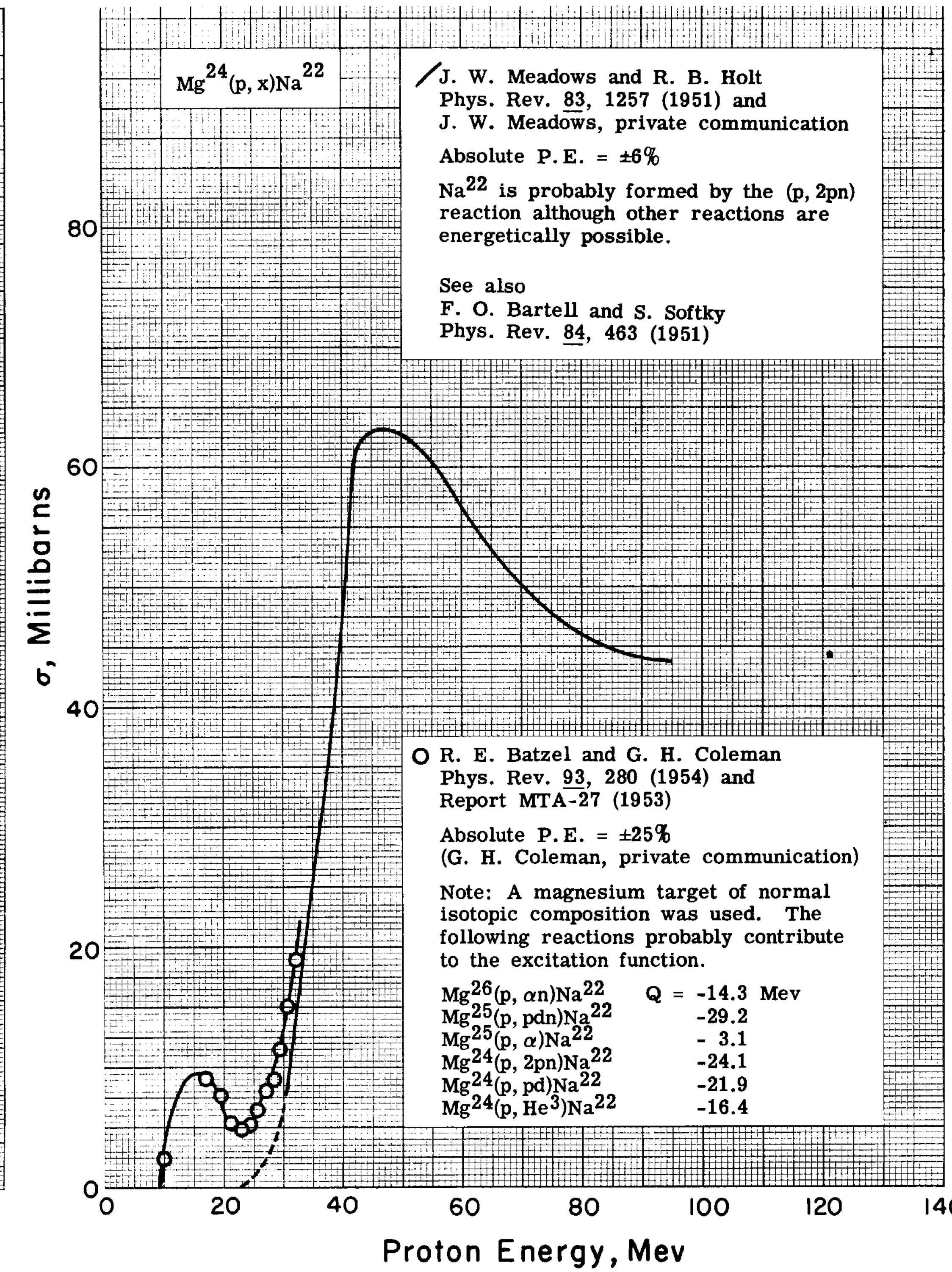

E* = 1.368 Mev
Proton energy 11.87 ± 0.08 Mev
H. E. Conzett
Phys. Rev. 105, 1324 (1957) and
Private communication
Absolute P.E. less than ±6.5%
Relative P.E. as shown
Total cross section σ = 232.2 ± 7.4 mb
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'



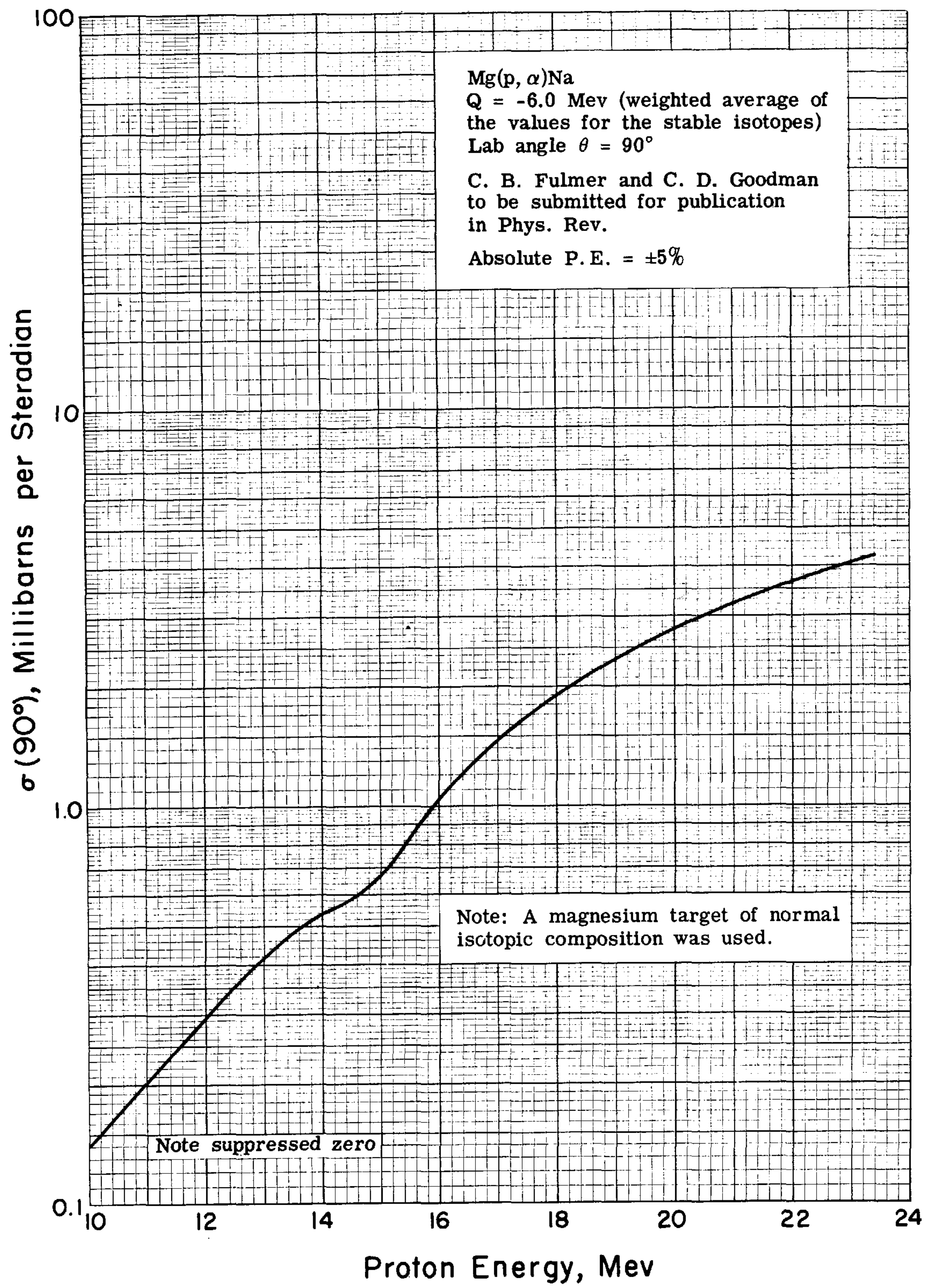
$Mg^{24}(p, p')Mg^{24*}$
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
E* = 4.22 Mev
E* = 5.24 Mev
Proton energy 9.63 Mev
G. W. Greenlees and A. E. Souch
Proc. Phys. Soc. (London) A69, 686 (1956)
Absolute P.E. = ±10%
Relative P.E. = ±3%

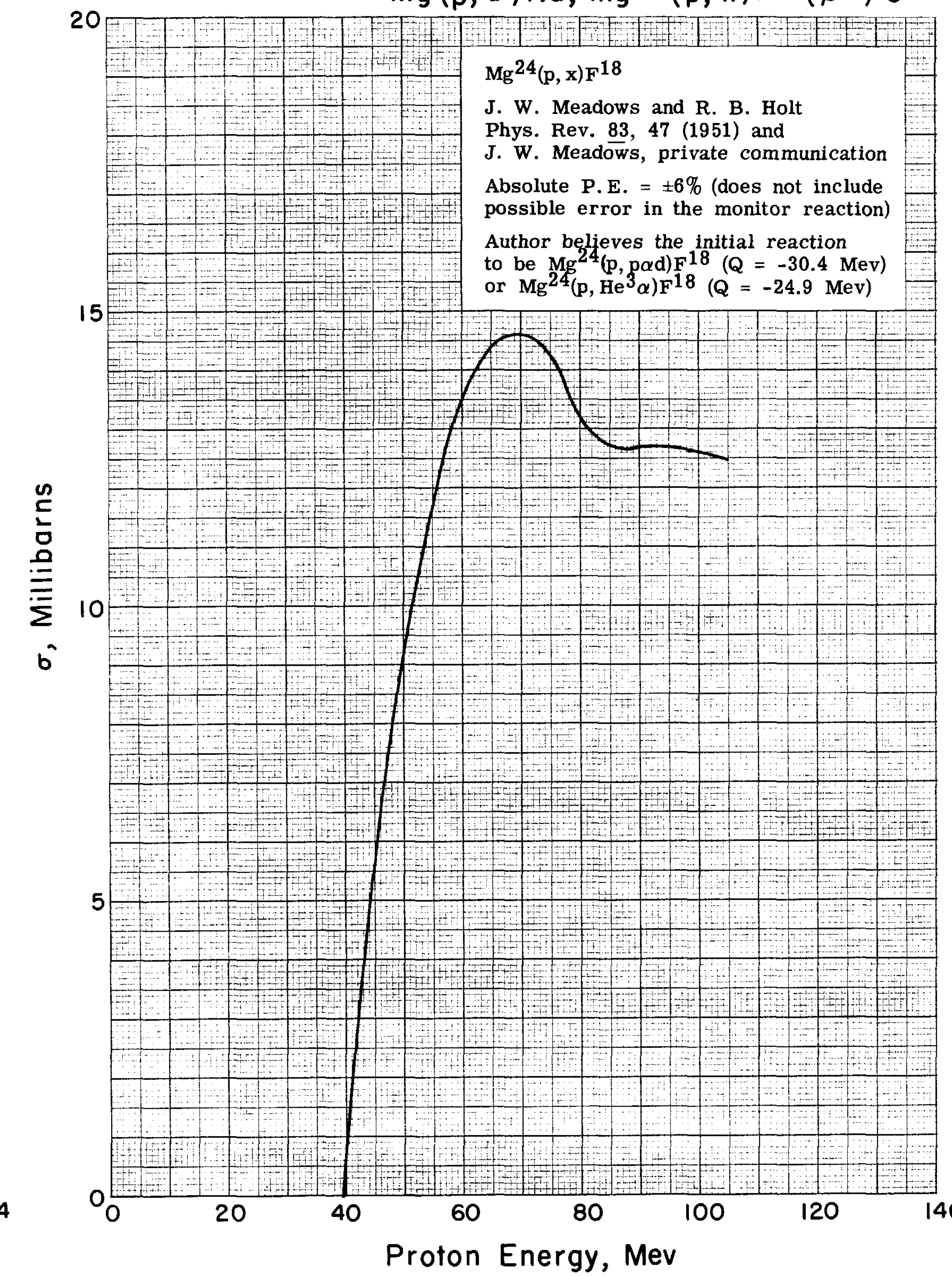
Mg (p, t) Mg ; $Mg^{24}(p, x)Na^{22}(\beta^{+})Ne^{22}$



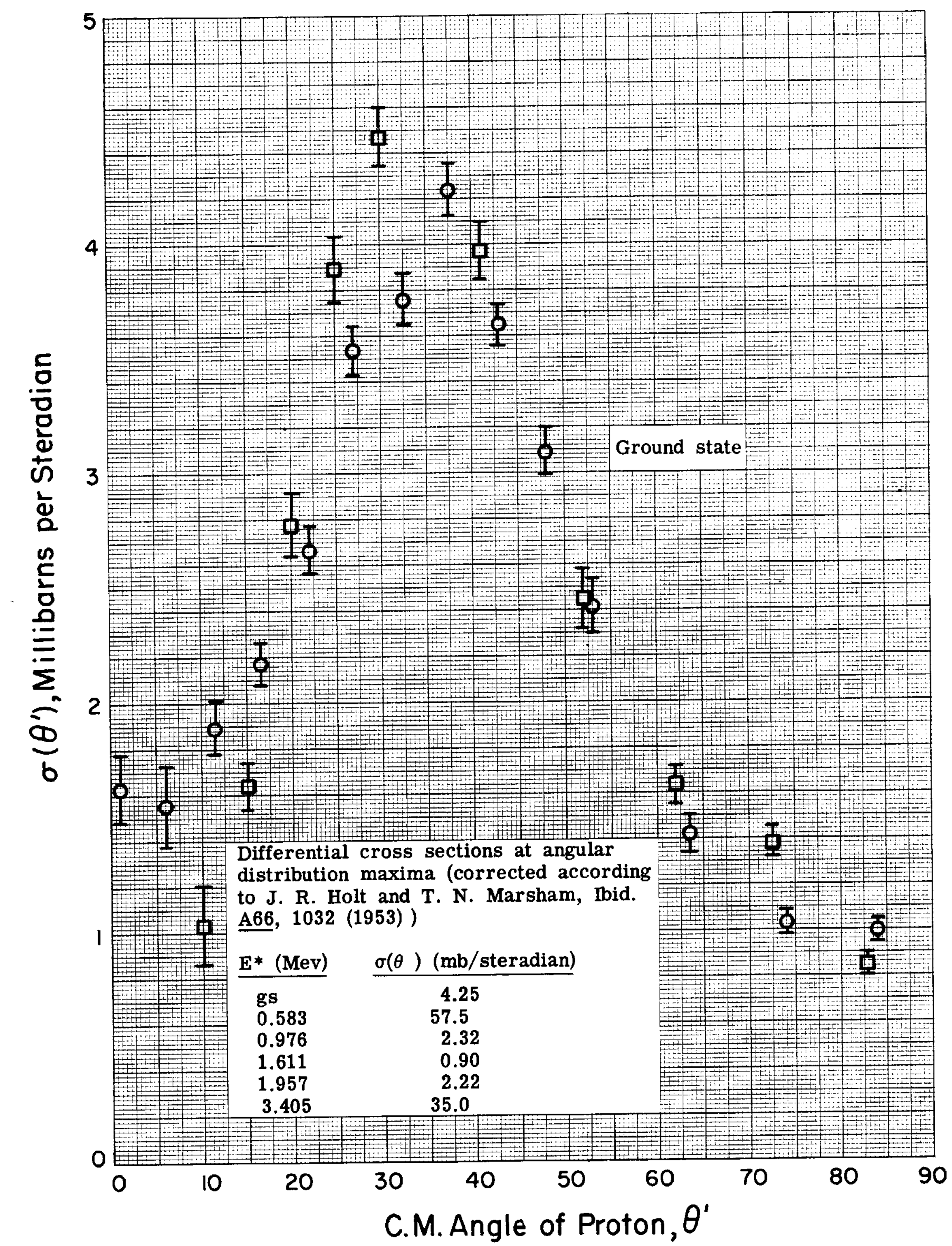


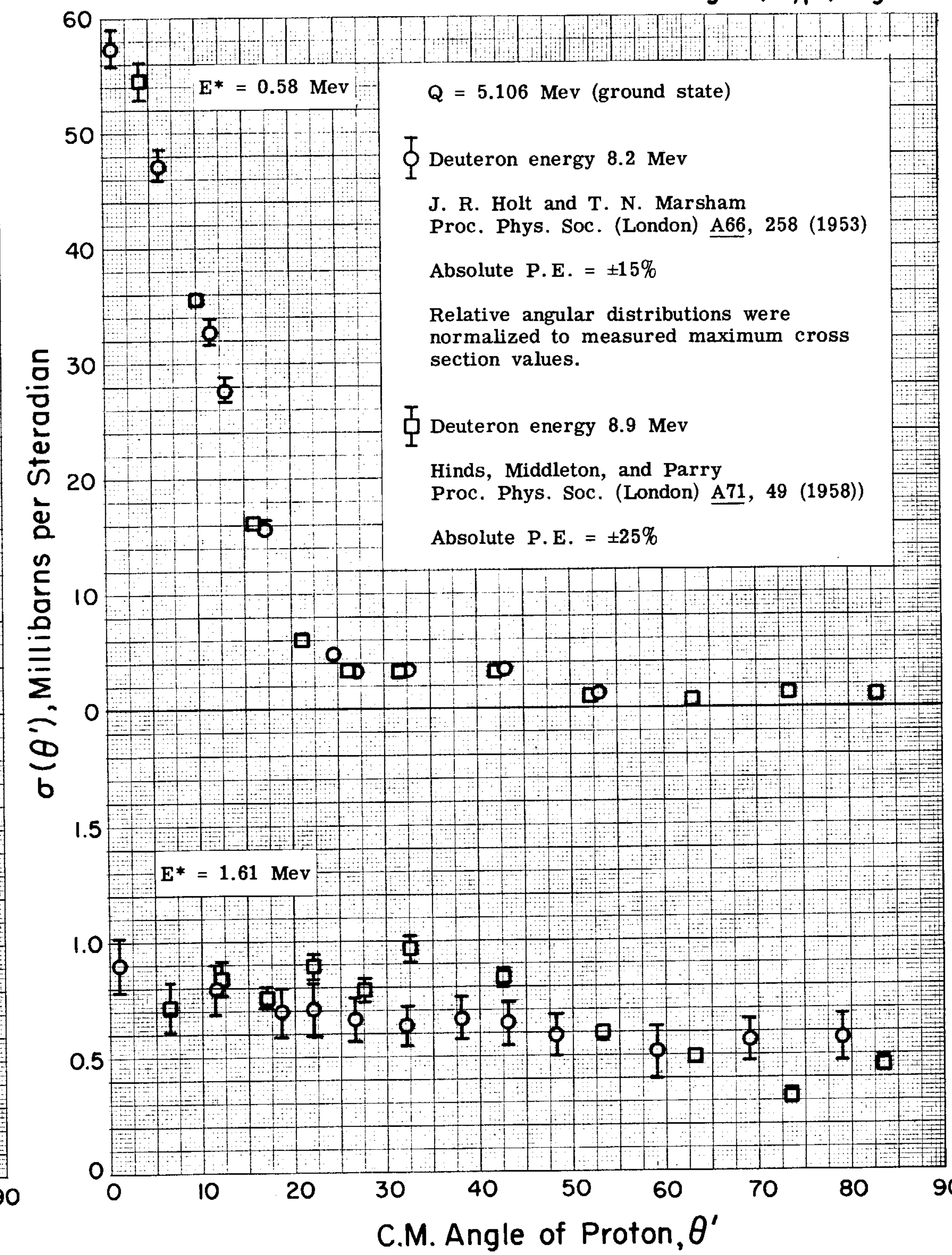
Mg (p, α) Na; Mg^{24} (p, x) F^{18} (β^+) O^{18}



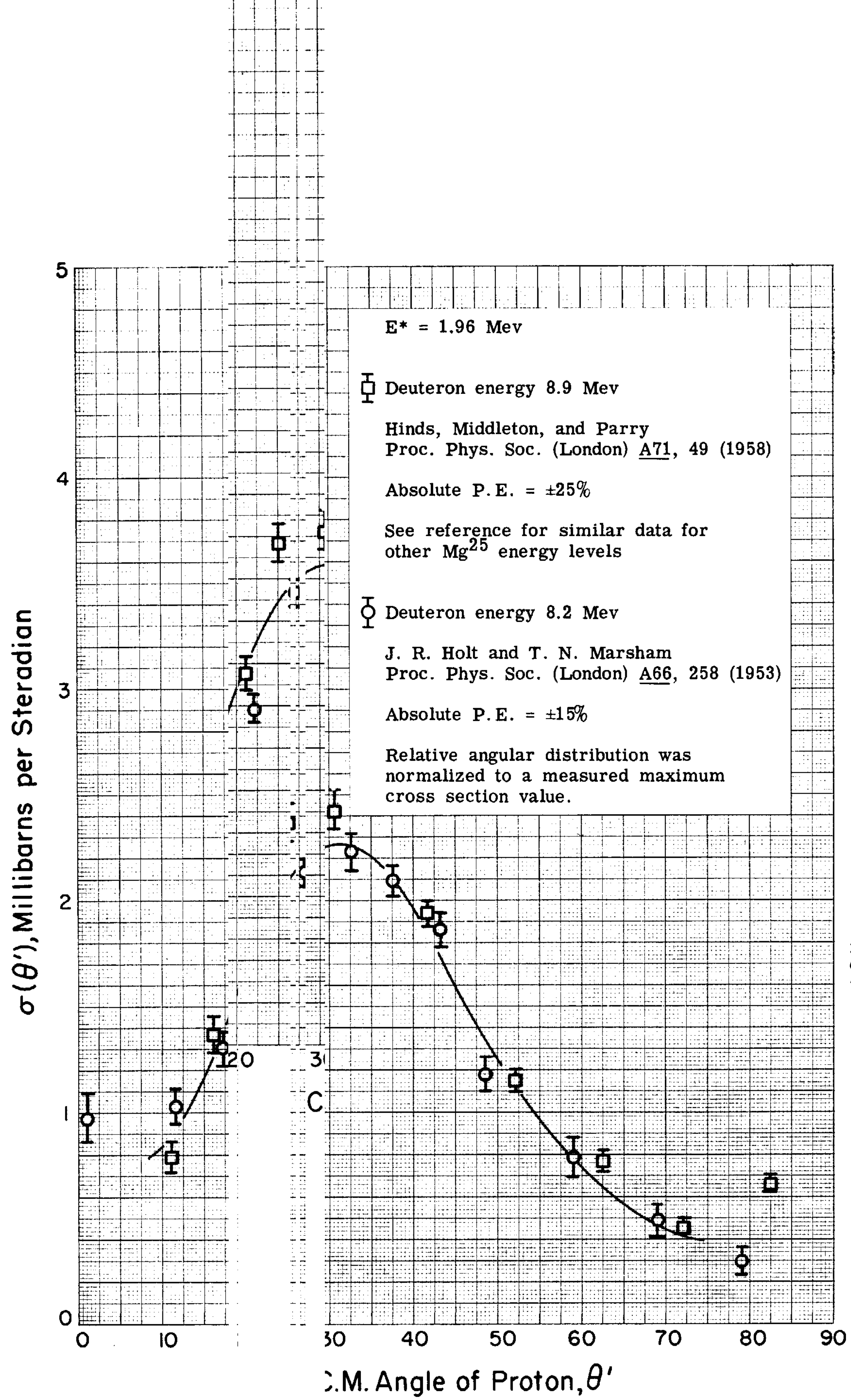


$Mg^{24}(d,p')Mg^{25*}$

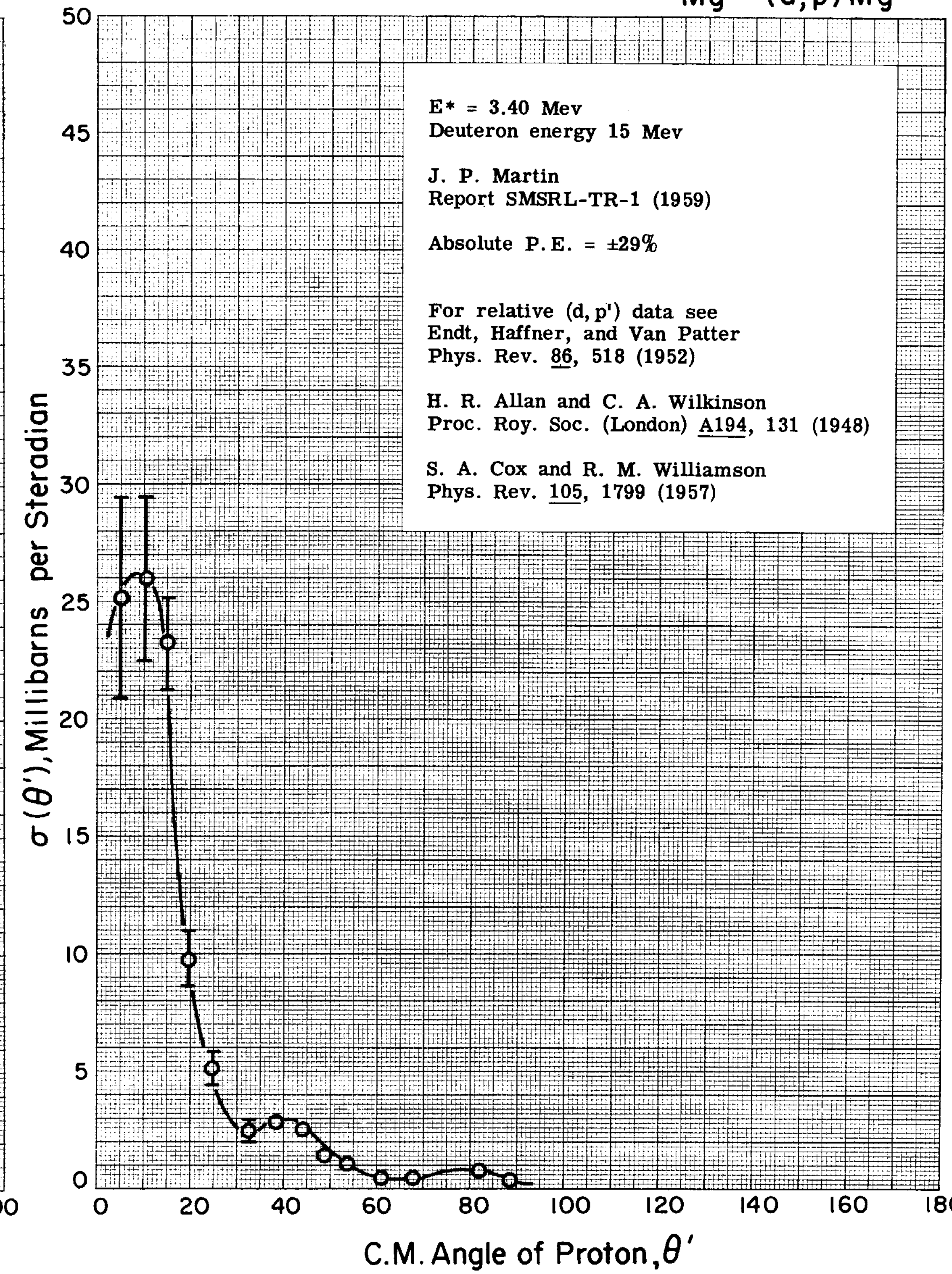

σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
Ground state
Differential cross sections at angular distribution maxima (corrected according to J. R. Holt and T. N. Marsham, Ibid. A66, 1032 (1953))
E* (Mev) σ(θ) (mb/steradian)
gs 4.25
0.583 57.5
0.976 2.32
1.611 0.90
1.957 2.22
3.405 35.0


σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
E* = 0.58 Mev
Q = 5.106 Mev (ground state)
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham Proc. Phys. Soc. (London) A66, 258 (1953)
Absolute P.E. = ±15%
Relative angular distributions were normalized to measured maximum cross section values.
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry Proc. Phys. Soc. (London) A71, 49 (1958))
Absolute P.E. = ±25%
E* = 1.61 Mev

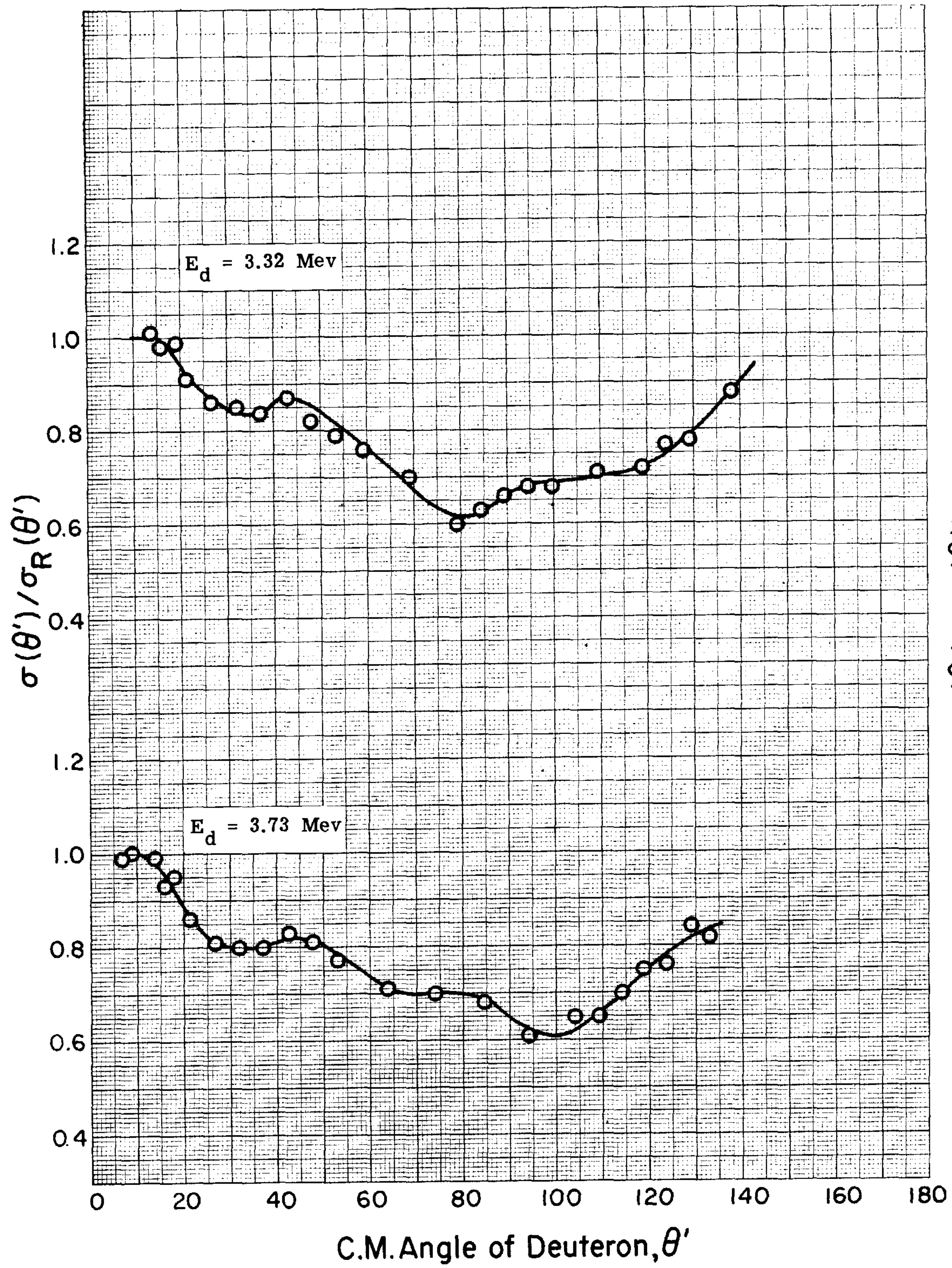
$Mg^{24}(d,p')Mg^{25*}$



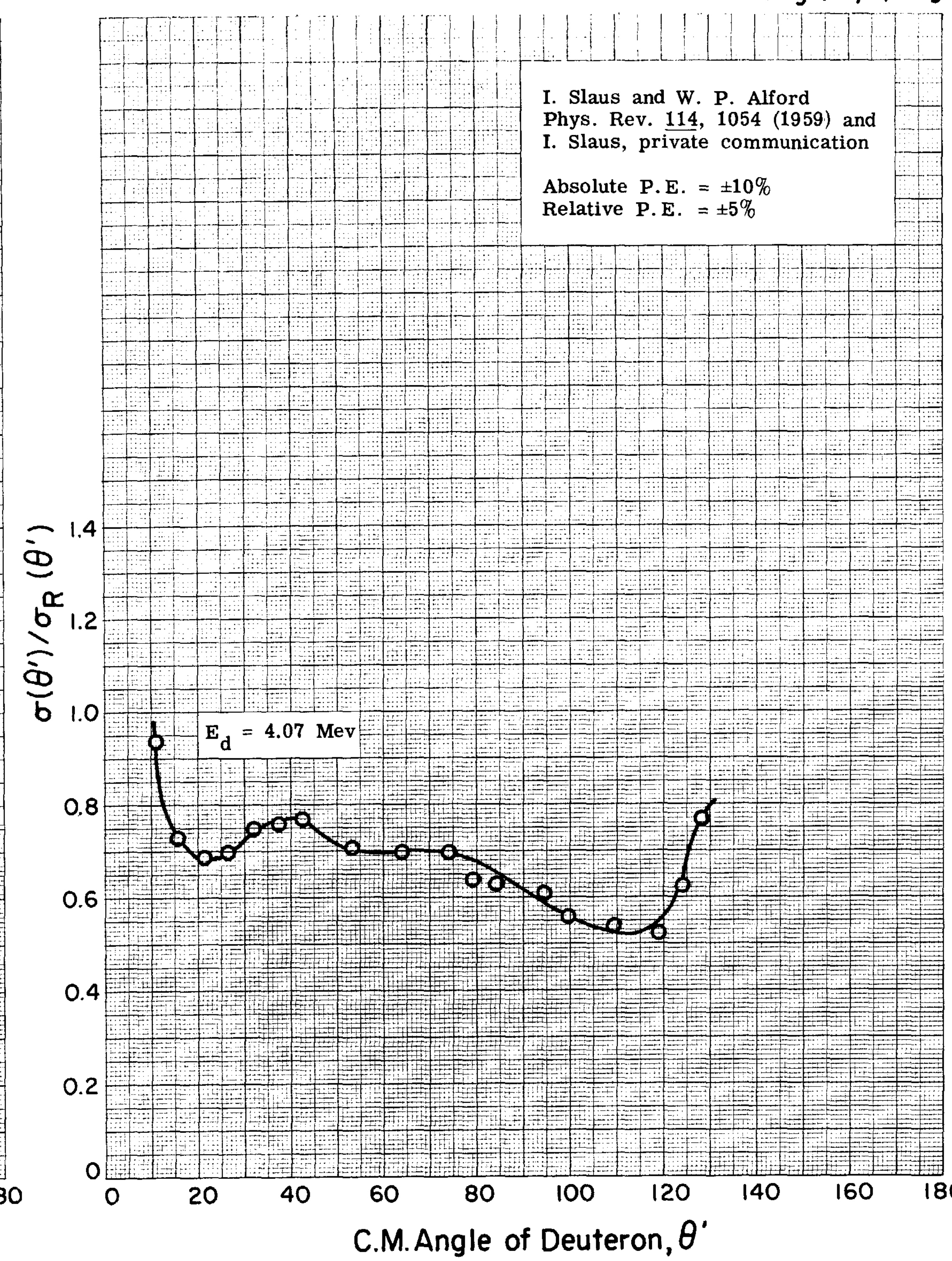
E* = 1.96 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A71, 49 (1958)
Absolute P.E. = ±25%
See reference for similar data for other Mg25 energy levels
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 258 (1953)
Absolute P.E. = ±15%
Relative angular distribution was normalized to a measured maximum cross section value.
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'



E* = 3.40 Mev
Deuteron energy 15 Mev
J. P. Martin
Report SMSRL-TR-1 (1959)
Absolute P.E. = ±29%
For relative (d, p') data see
Endt, Haffner, and Van Patter
Phys. Rev. 86, 518 (1952)
H. R. Allan and C. A. Wilkinson
Proc. Roy. Soc. (London) A194, 131 (1948)
S. A. Cox and R. M. Williamson
Phys. Rev. 105, 1799 (1957)
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

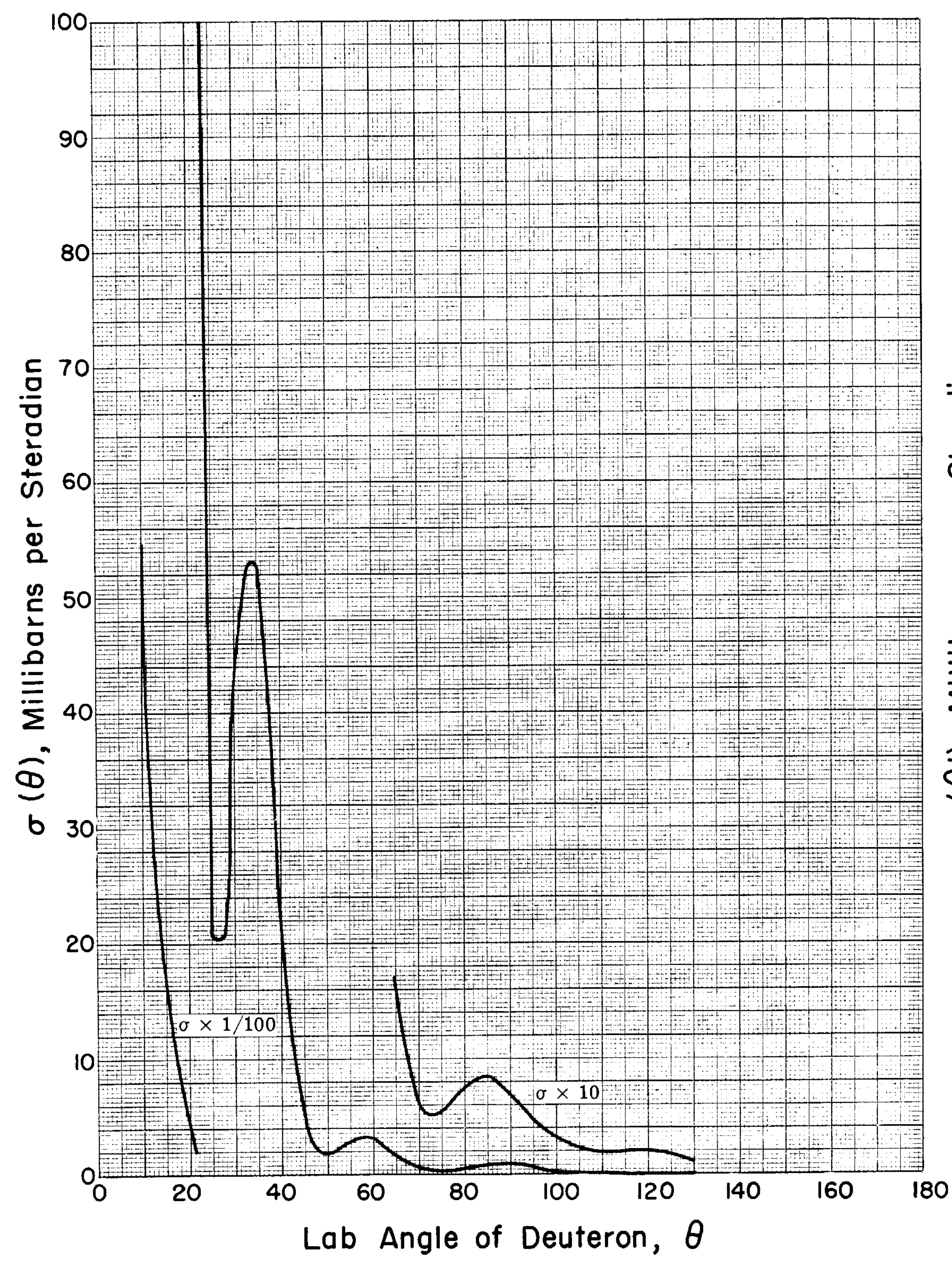


E_d = 3.32 Mev
E_d = 3.73 Mev
σ(θ′)/σ_R(θ′)
1.2
1.0
0.8
0.6
0.4
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Deuteron, θ′

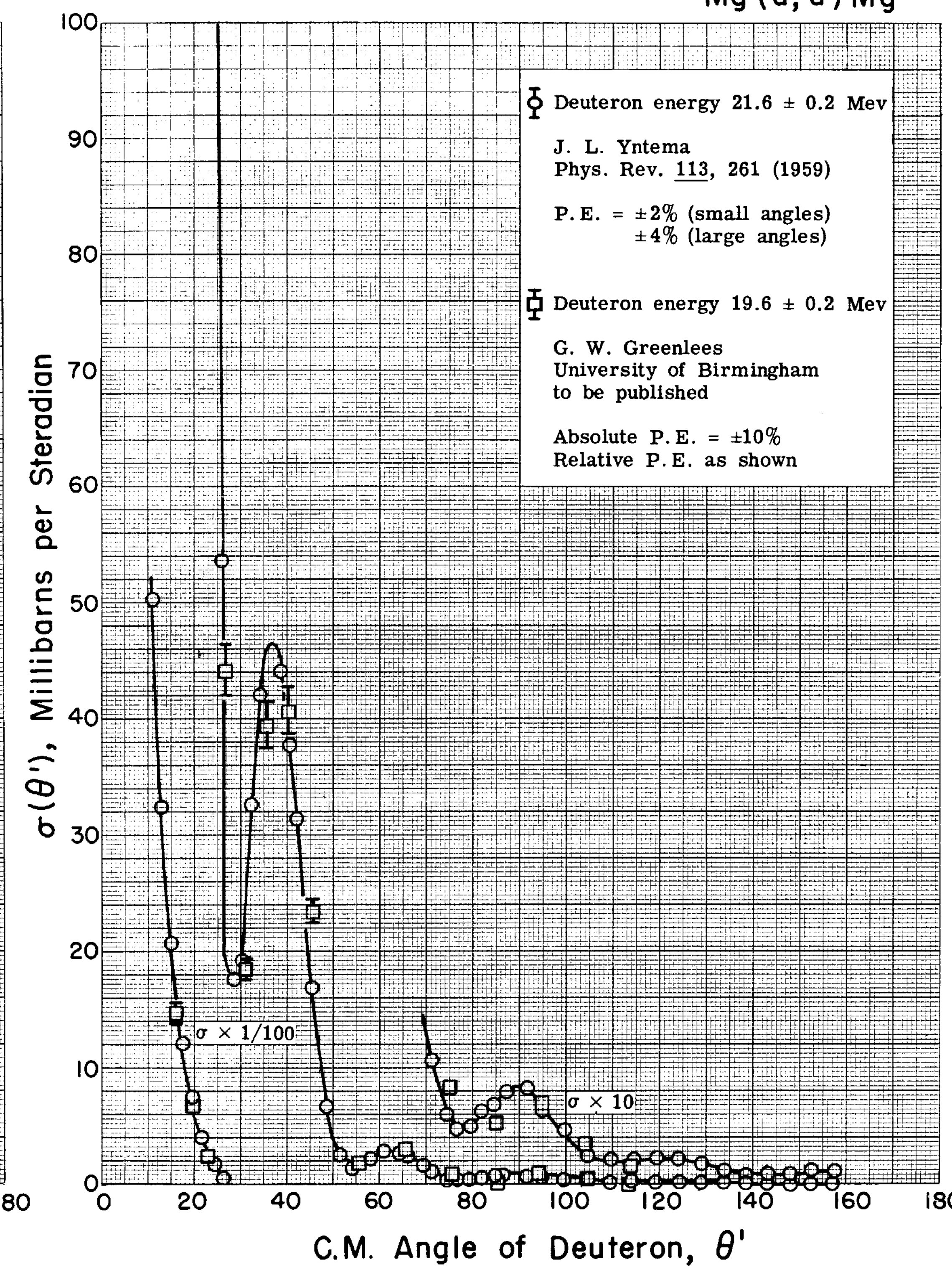


I. Slaus and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication
Absolute P.E. = ±10%
Relative P.E. = ±5%
E_d = 4.07 Mev
σ(θ′)/σ_R(θ′)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Deuteron, θ′

Mg (d, d) Mg

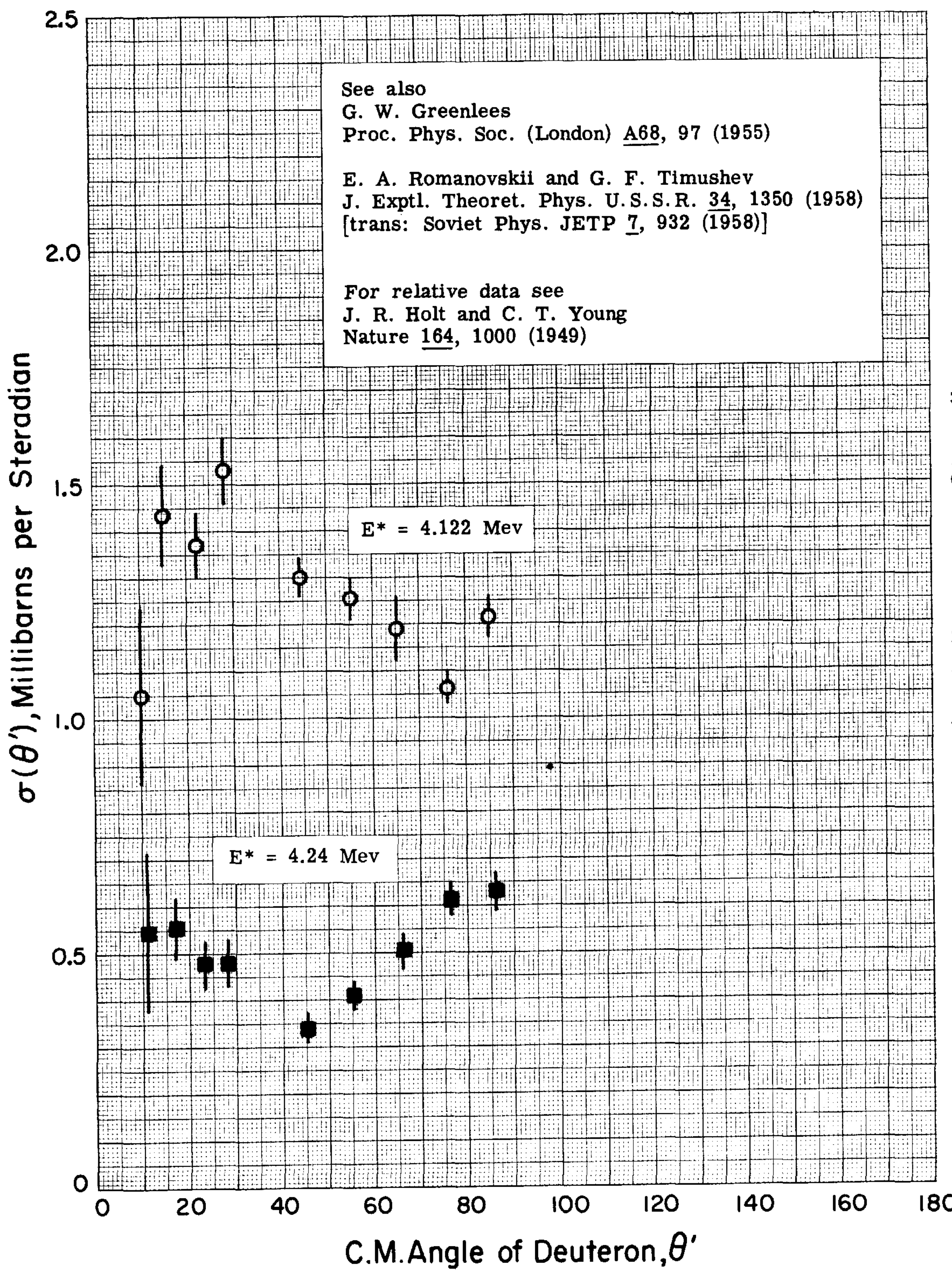


σ (θ), Millibarns per Steradian
Lab Angle of Deuteron, θ
σ × 1/100
σ × 10

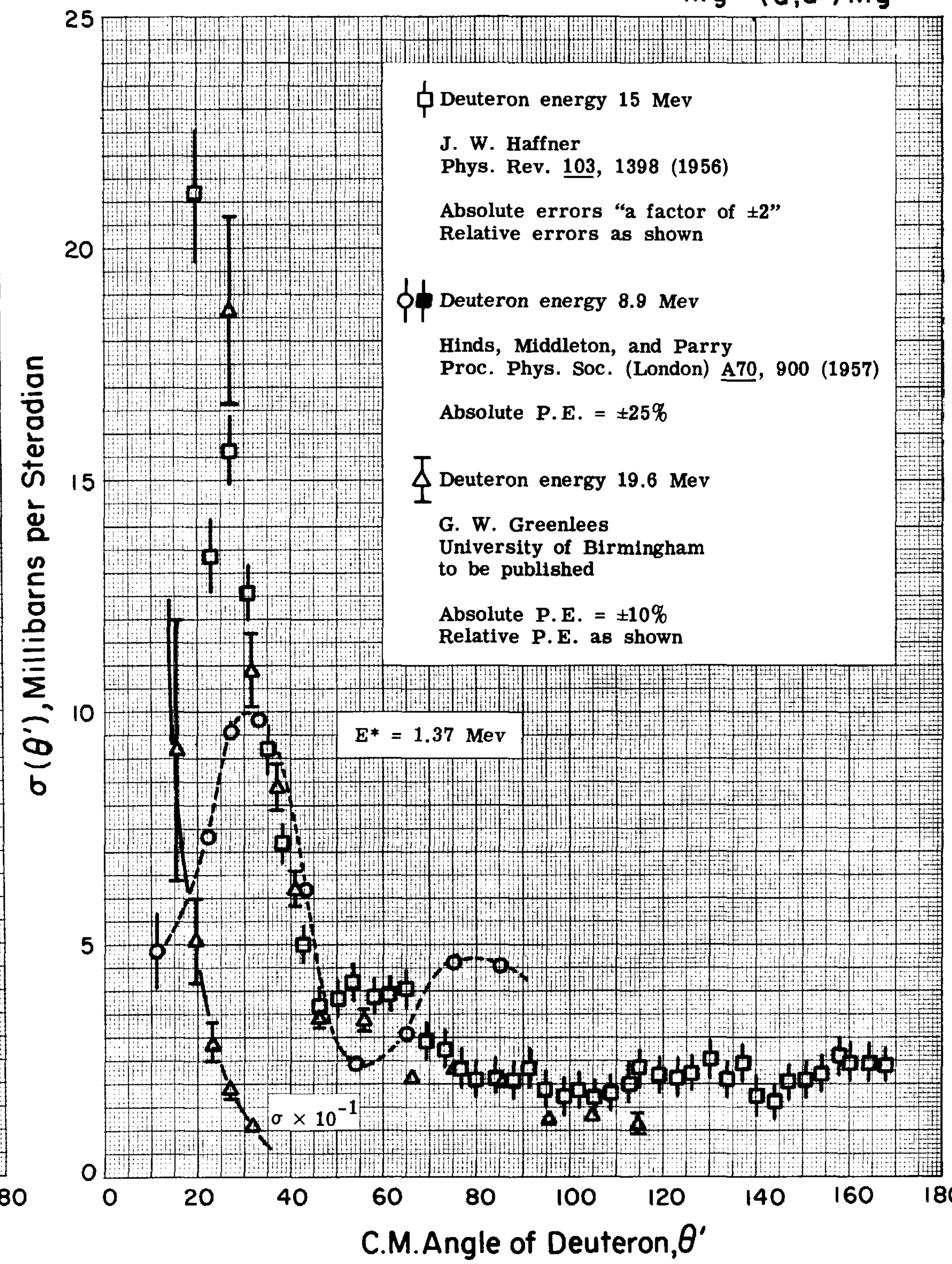


Deuteron energy 21.6 ± 0.2 Mev
J. L. Yntema
Phys. Rev. 113, 261 (1959)
P. E. = ±2% (small angles)
±4% (large angles)
Deuteron energy 19.6 ± 0.2 Mev
G. W. Greenlees
University of Birmingham
to be published
Absolute P. E. = ±10%
Relative P. E. as shown
σ(θ'), Millibarns per Steradian
C.M. Angle of Deuteron, θ'
σ × 1/100
σ × 10

$Mg^{24}(d,d')Mg^{24*}$

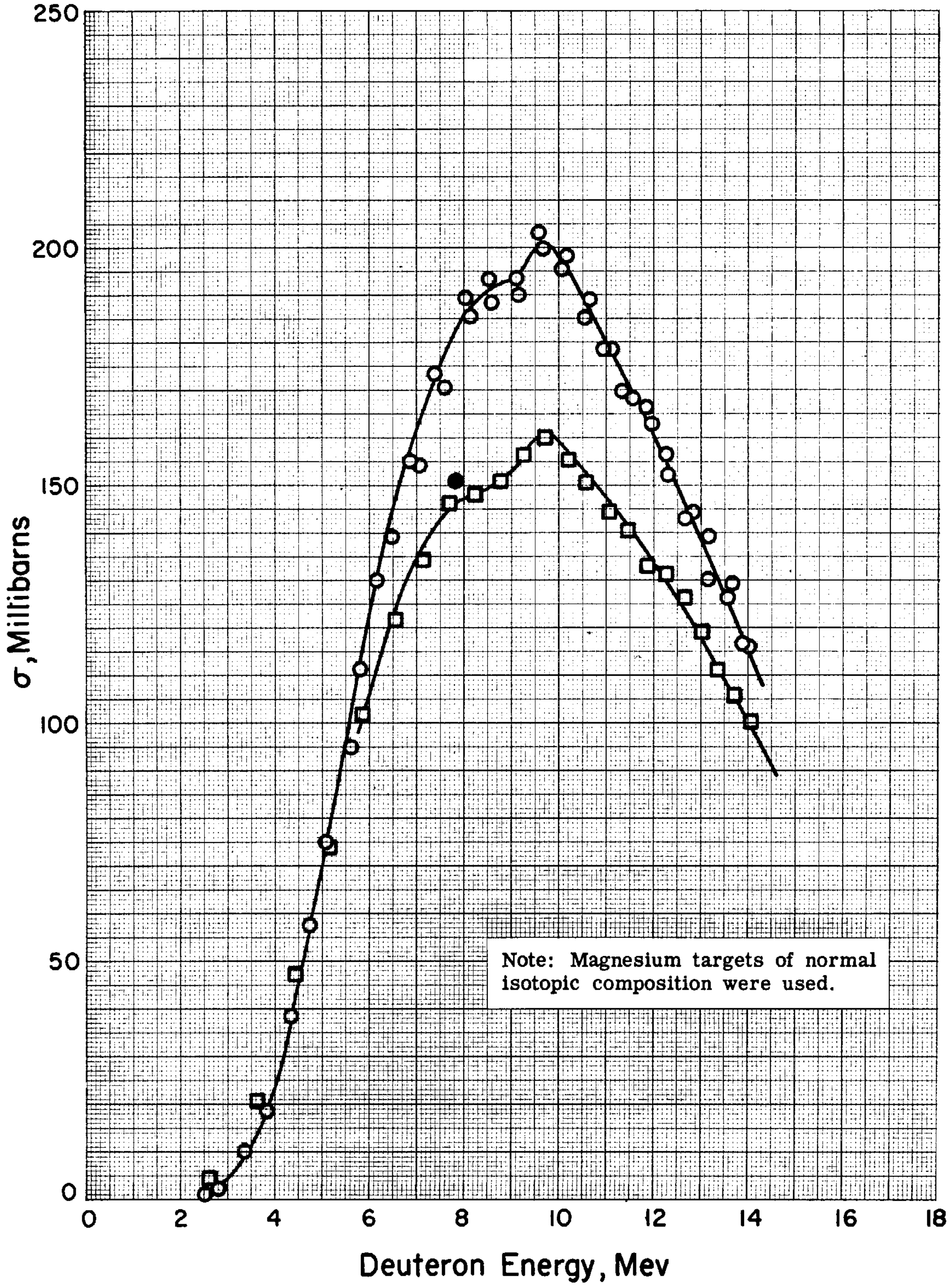


See also
G. W. Greenlees
Proc. Phys. Soc. (London) A68, 97 (1955)
E. A. Romanovskii and G. F. Timushev
J. Exptl. Theoret. Phys. U.S.S.R. 34, 1350 (1958)
[trans: Soviet Phys. JETP 7, 932 (1958)]
For relative data see
J. R. Holt and C. T. Young
Nature 164, 1000 (1949)
E* = 4.122 Mev
E* = 4.24 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Deuteron, θ'



Deuteron energy 15 Mev
J. W. Haffner
Phys. Rev. 103, 1398 (1956)
Absolute errors "a factor of ±2"
Relative errors as shown
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A70, 900 (1957)
Absolute P.E. = ±25%
Deuteron energy 19.6 Mev
G. W. Greenlees
University of Birmingham
to be published
Absolute P.E. = ±10%
Relative P.E. as shown
E* = 1.37 Mev
σ × 10⁻¹
σ(θ'), Millibarns per Steradian
C.M. Angle of Deuteron, θ'

$Mg^{24}(d,\alpha)Na^{22}(\beta^{+})Ne^{22}$



Opposite page
Q = 1.96 Mev

○ Vlasov et al.
Sov. J Atomic Energy 2, 189 (1957)

Absolute P.E. = ±15%

□ J. W. Irvine, Jr. and E. T. Clarke
J. Chem. Phys. 16, 686 (1948)

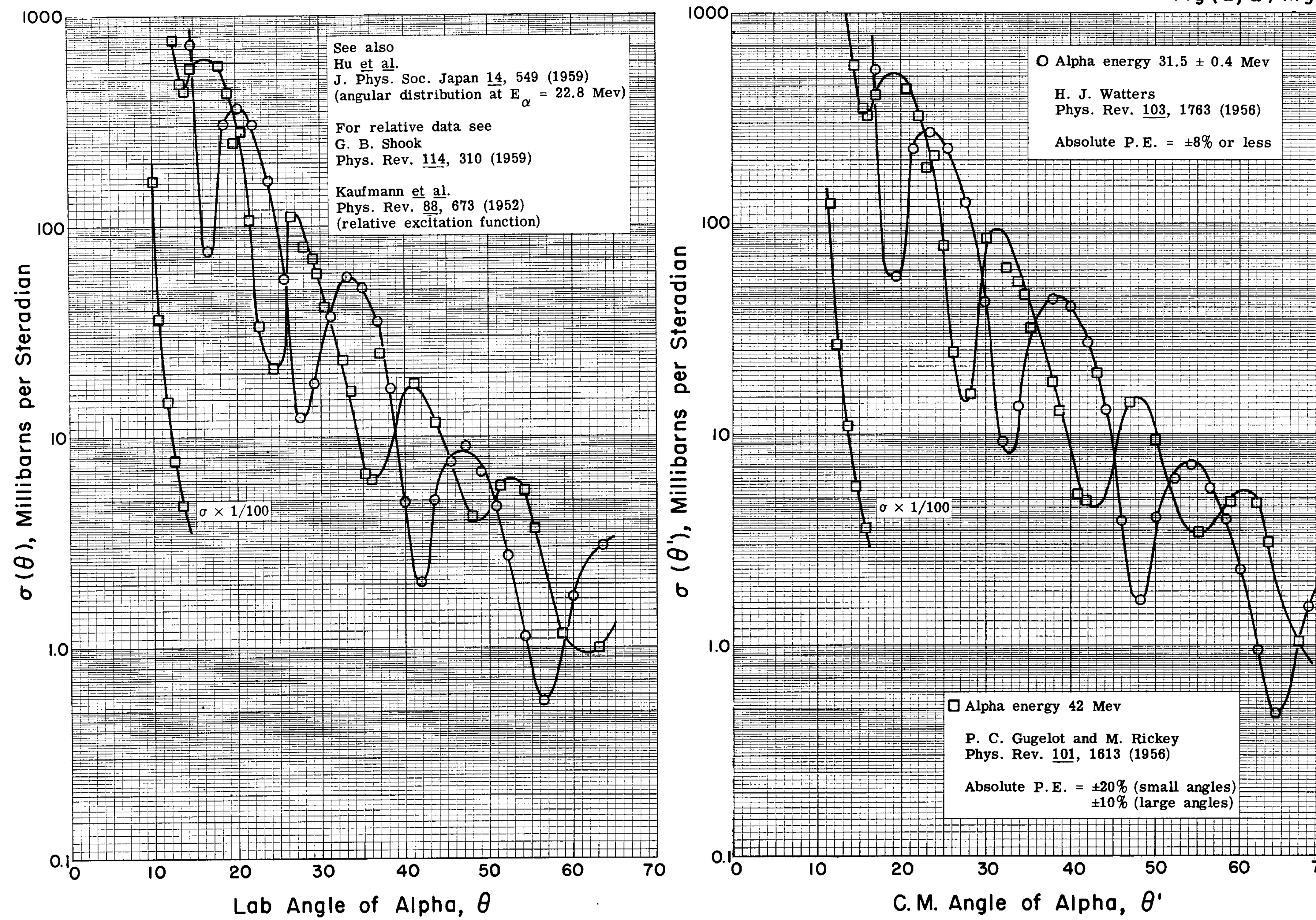
No error stated

● K. L. Hall
Report AECU-3126 (1955) or
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959)

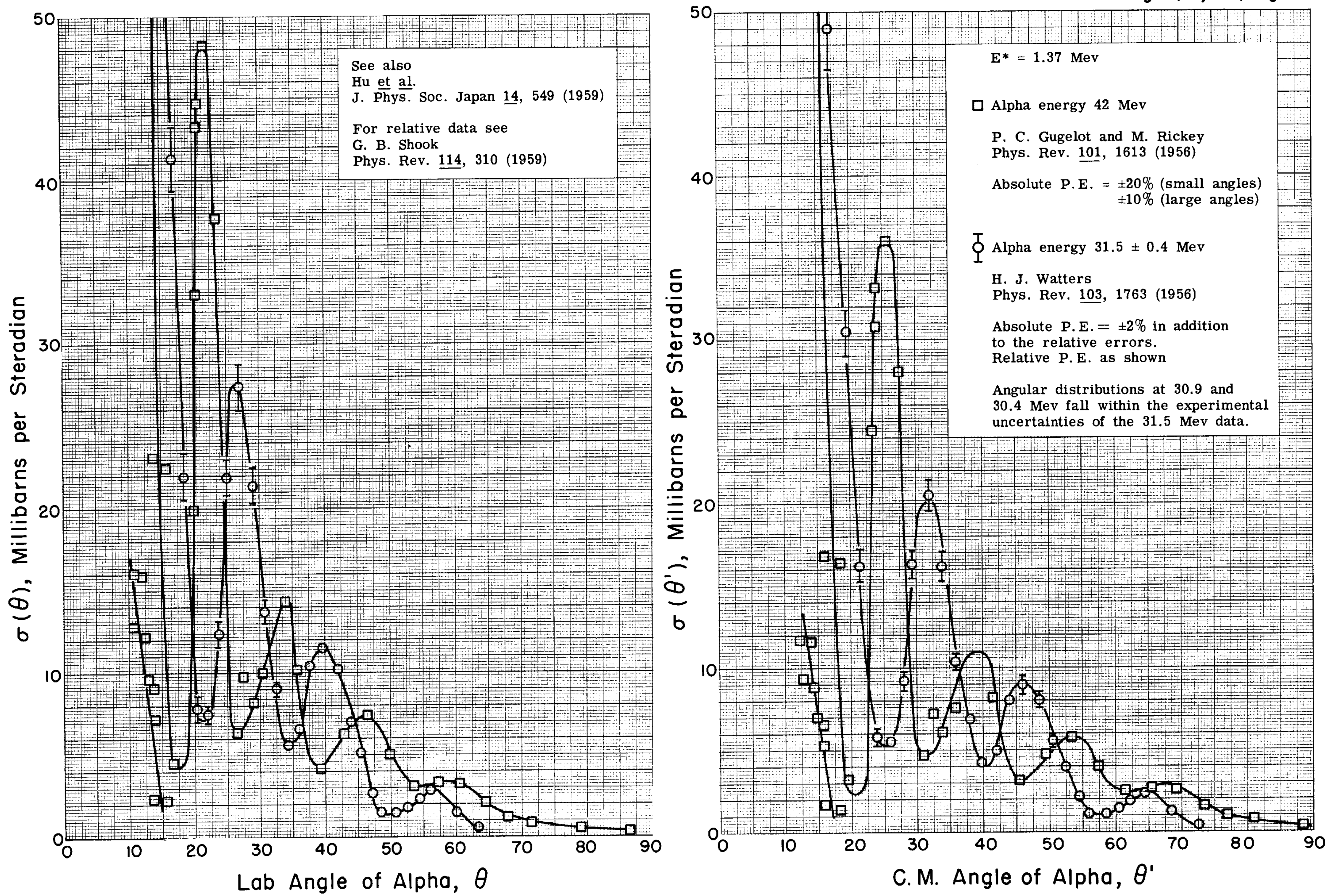
Absolute P.E. = ±2.6%

See also
F. O. Bartell and S. Softky
Phys. Rev. 84, 463 (1951)

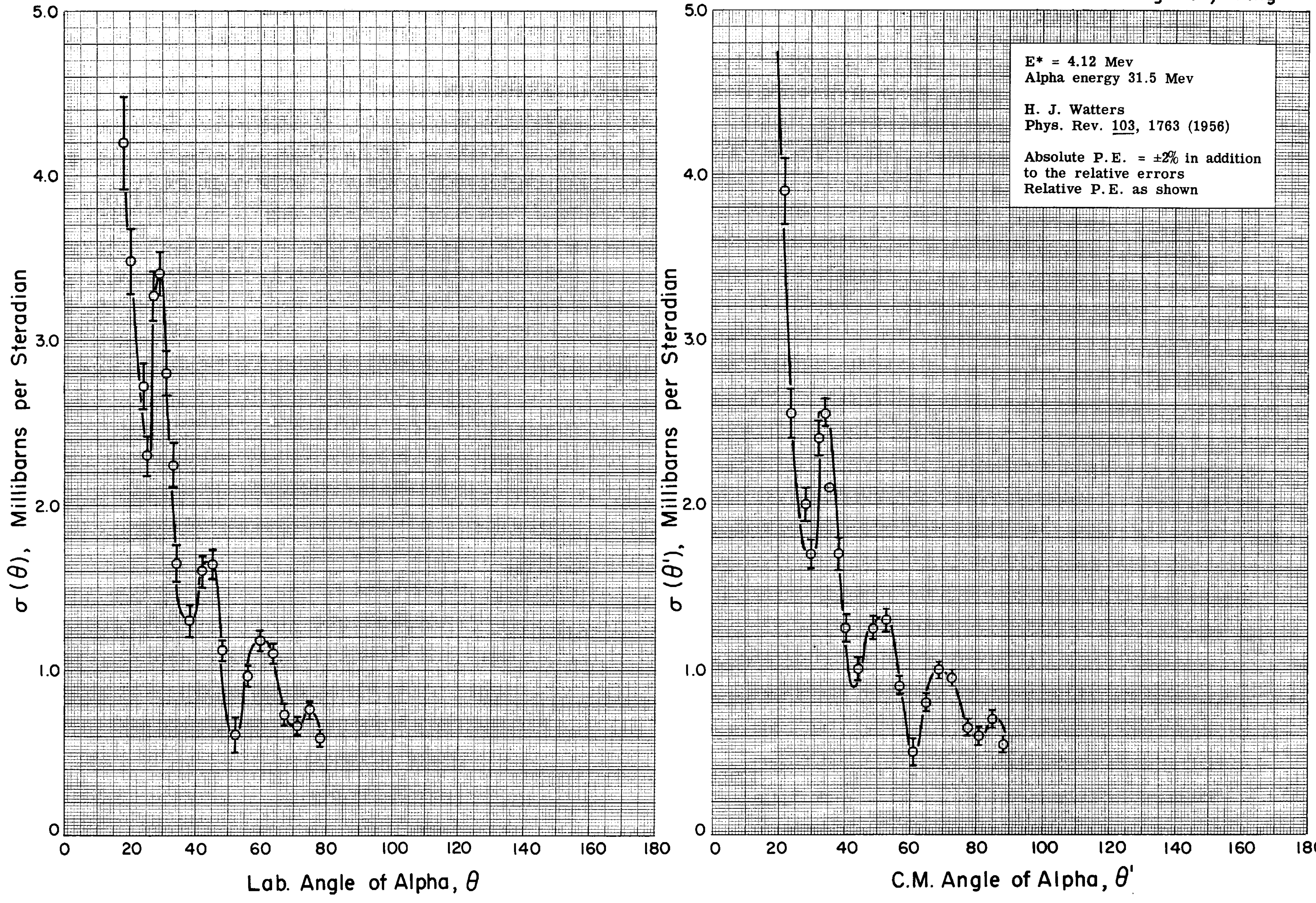
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 69, 680 (1946)

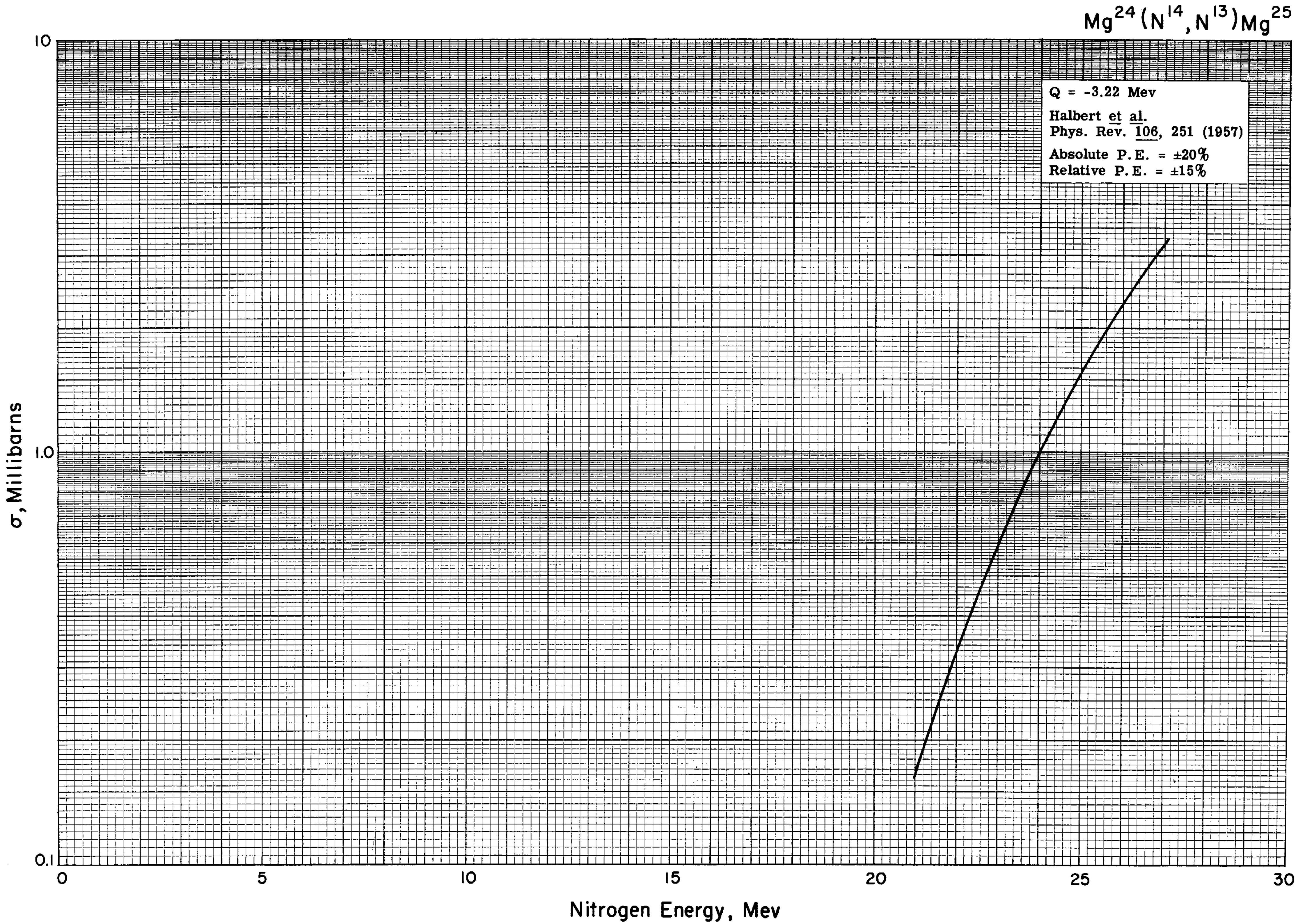

See also
Hu et al.
J. Phys. Soc. Japan 14, 549 (1959)
(angular distribution at Eα = 22.8 Mev)
For relative data see
G. B. Shook
Phys. Rev. 114, 310 (1959)
Kaufmann et al.
Phys. Rev. 88, 673 (1952)
(relative excitation function)
σ × 1/100
σ (θ), Millibarns per Steradian
Lab Angle of Alpha, θ
O Alpha energy 31.5 ± 0.4 Mev
H. J. Watters
Phys. Rev. 103, 1763 (1956)
Absolute P.E. = ±8% or less
□ Alpha energy 42 Mev
P. C. Gugelot and M. Rickey
Phys. Rev. 101, 1613 (1956)
Absolute P.E. = ±20% (small angles)
±10% (large angles)
σ (θ'), Millibarns per Steradian
C.M. Angle of Alpha, θ'

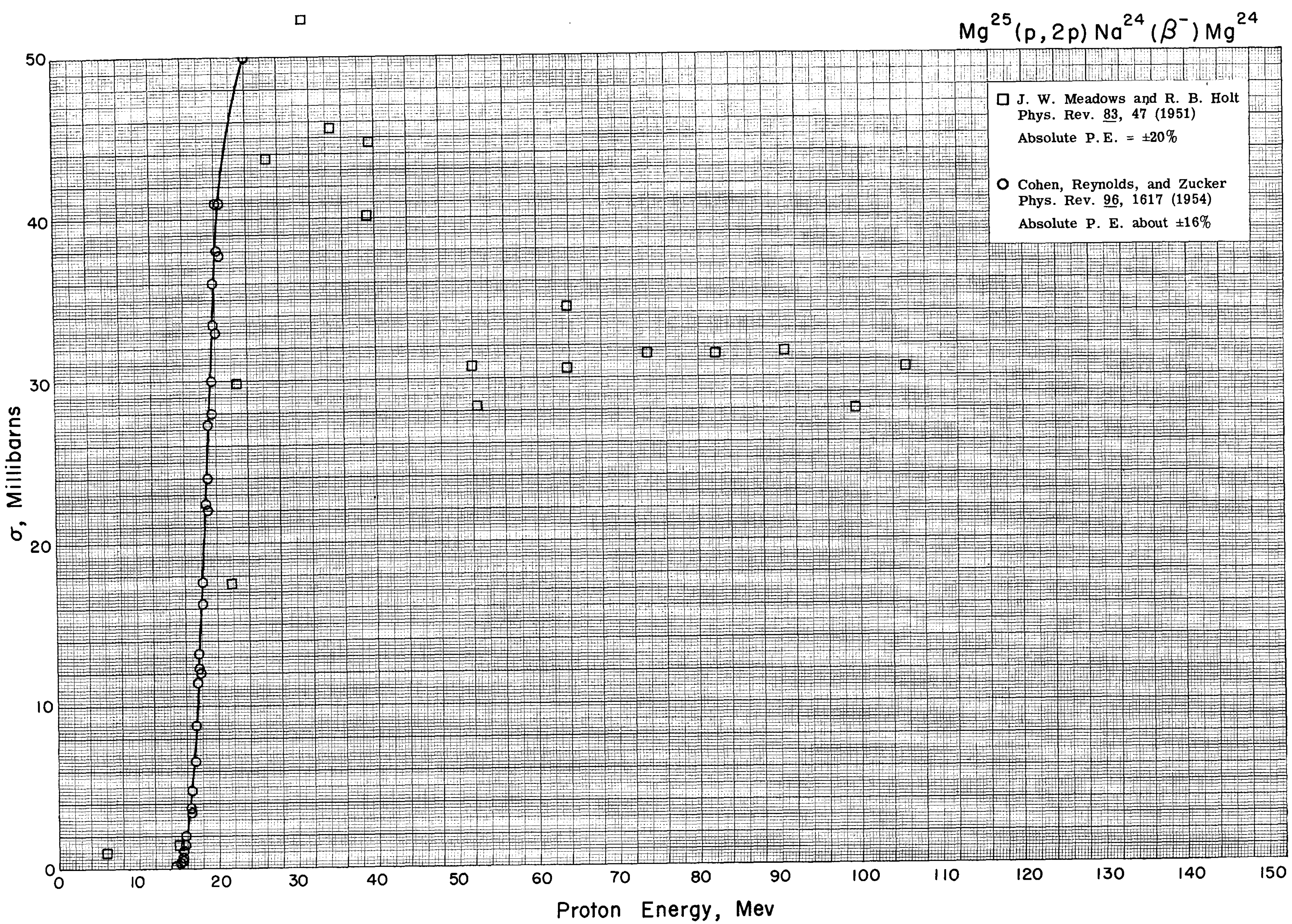
$Mg^{24}(\alpha,\alpha')Mg^{24*}$



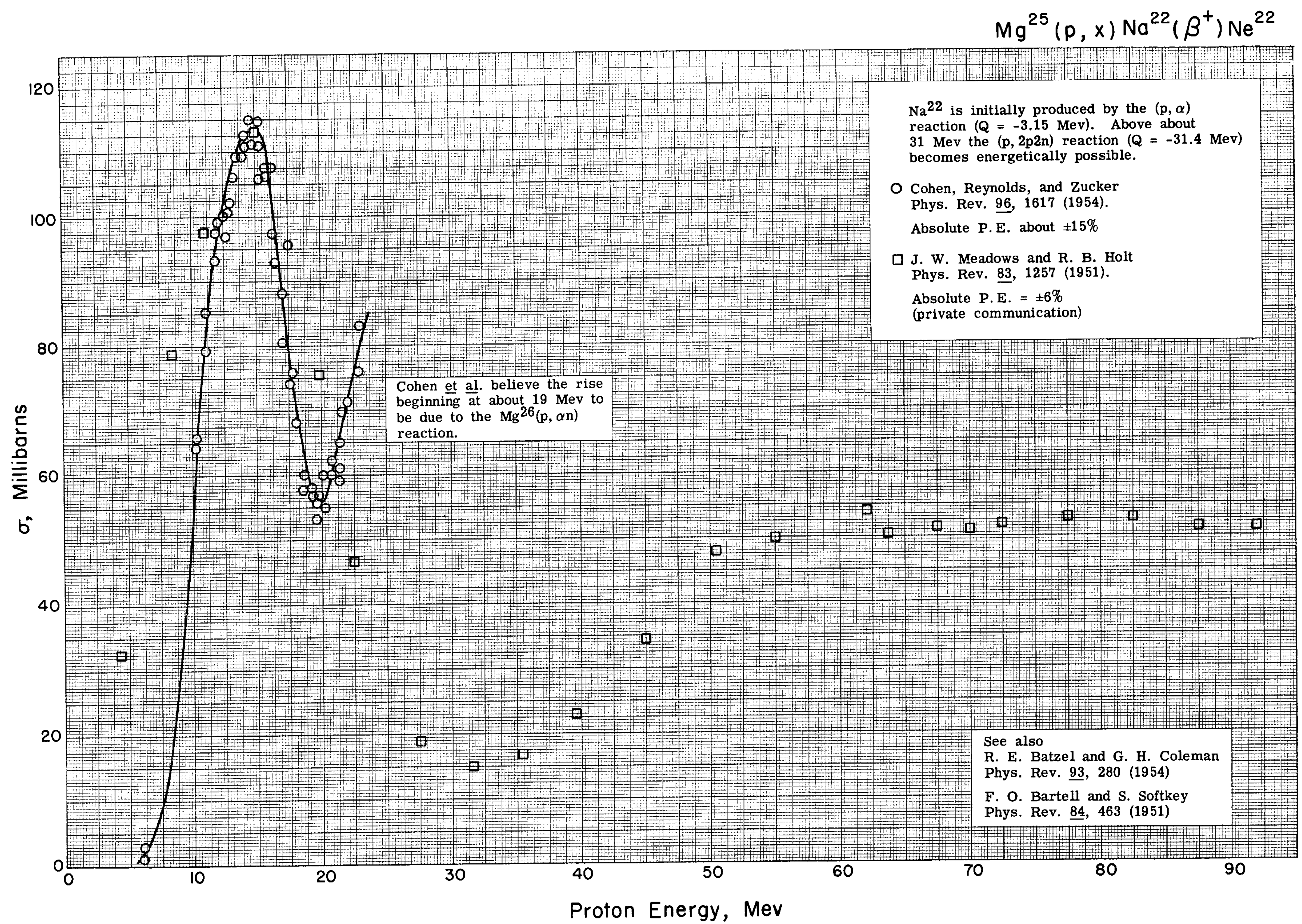
$Mg^{24}(\alpha,\alpha')Mg^{24*}$

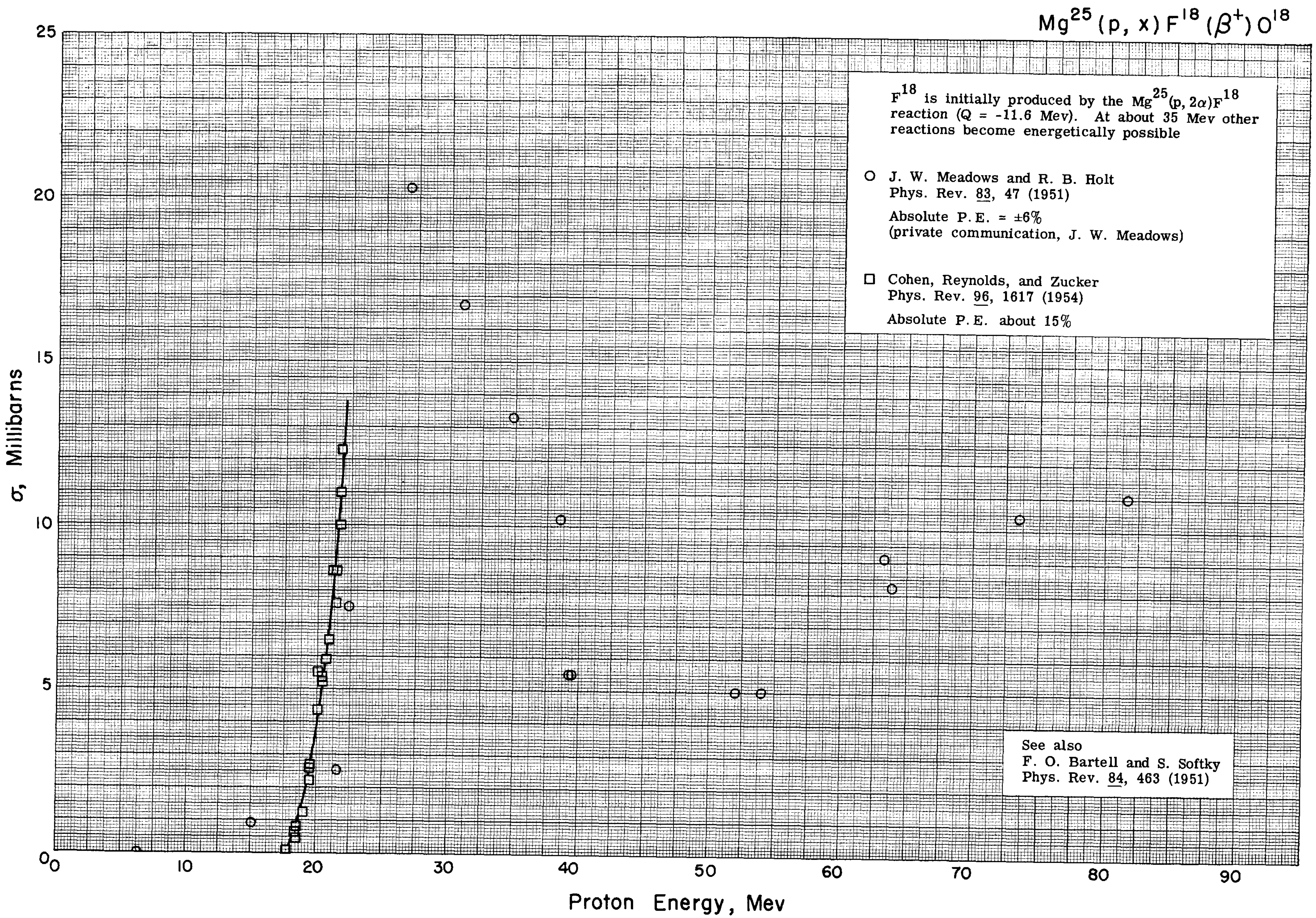



$Mg^{24}(N^{14}, N^{13})Mg^{25}$
Q = -3.22 Mev
Halbert et al.
Phys. Rev. 106, 251 (1957)
Absolute P.E. = ±20%
Relative P.E. = ±15%
σ, Millibarns
10
1.0
0.1
0
5
10
15
20
25
30
Nitrogen Energy, Mev



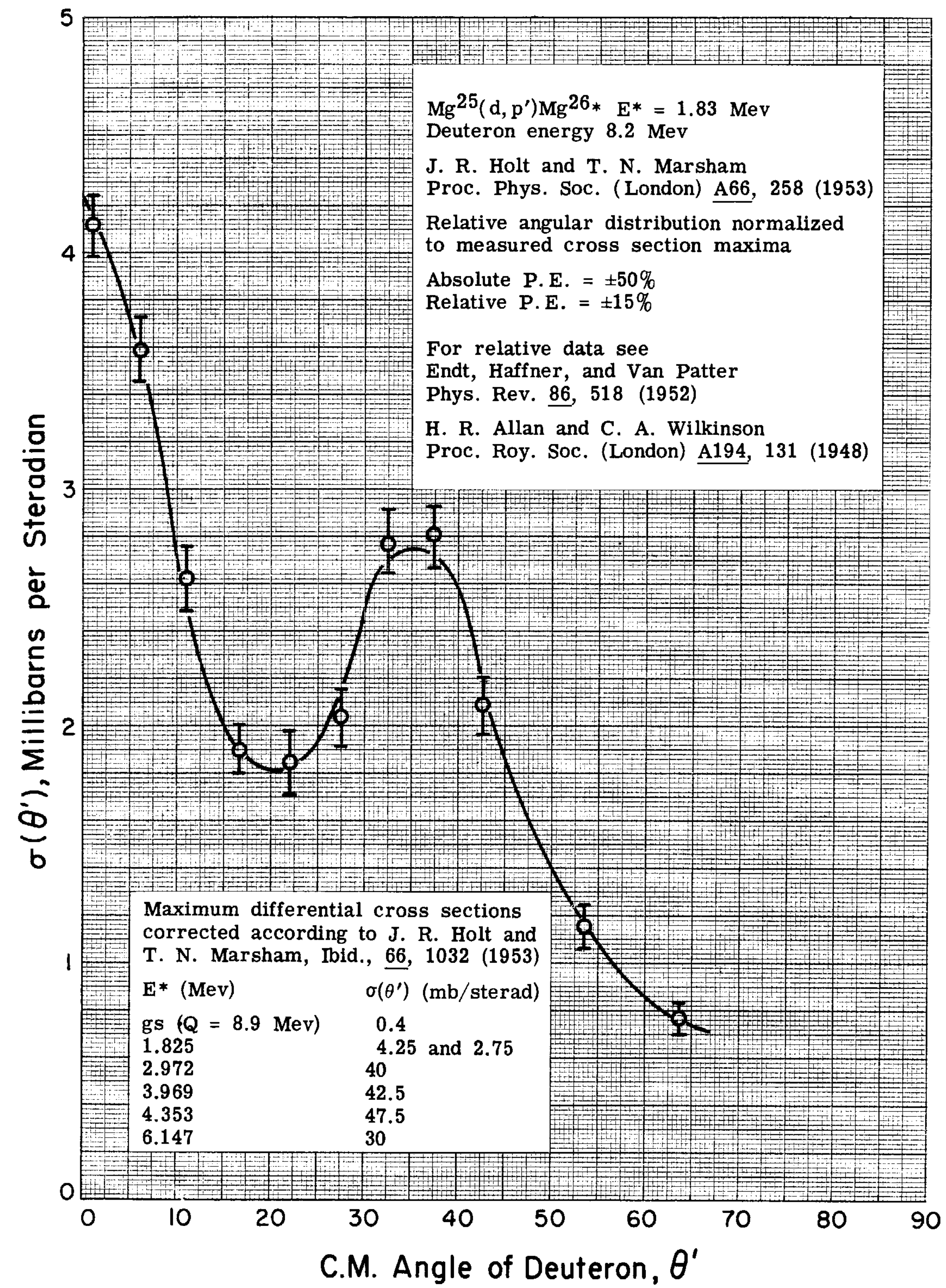
$Mg^{25}(p,2p)Na^{24}(\beta^-)Mg^{24}$
□ J. W. Meadows and R. B. Holt Phys. Rev. 83, 47 (1951)
Absolute P.E. = ±20%
O Cohen, Reynolds, and Zucker Phys. Rev. 96, 1617 (1954)
Absolute P. E. about ±16%
σ, Millibarns
Proton Energy, Mev
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

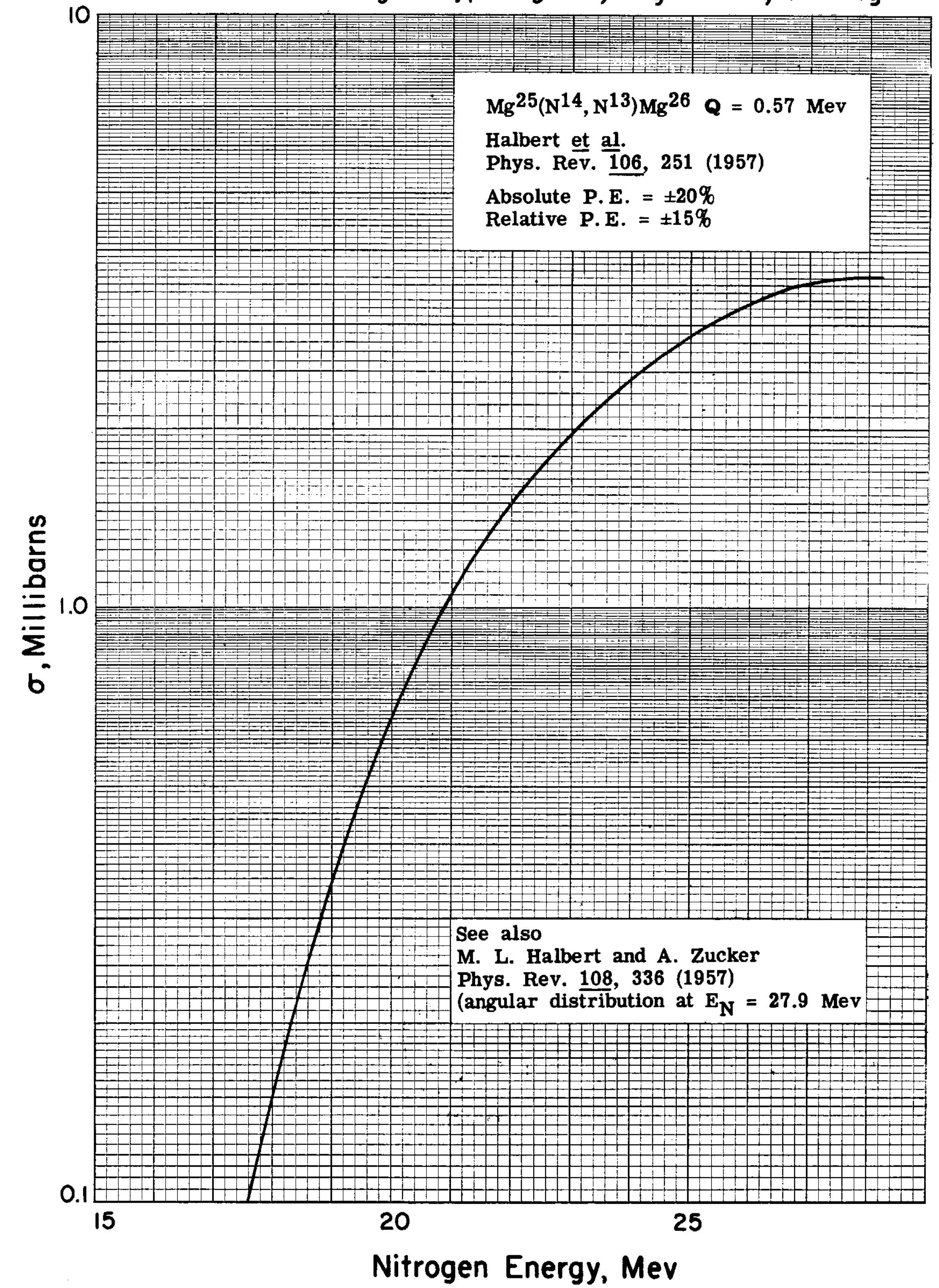

Mg25 (p, x) Na22 (β+) Ne22
Na22 is initially produced by the (p, α) reaction (Q = -3.15 Mev). Above about 31 Mev the (p, 2p2n) reaction (Q = -31.4 Mev) becomes energetically possible.
O Cohen, Reynolds, and Zucker Phys. Rev. 96, 1617 (1954).
Absolute P.E. about ±15%
□ J. W. Meadows and R. B. Holt Phys. Rev. 83, 1257 (1951).
Absolute P.E. = ±6% (private communication)
Cohen et al. believe the rise beginning at about 19 Mev to be due to the Mg26(p, αn) reaction.
See also
R. E. Batzel and G. H. Coleman Phys. Rev. 93, 280 (1954)
F. O. Bartell and S. Softkey Phys. Rev. 84, 463 (1951)
σ, Millibarns
Proton Energy, Mev
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70
80
90



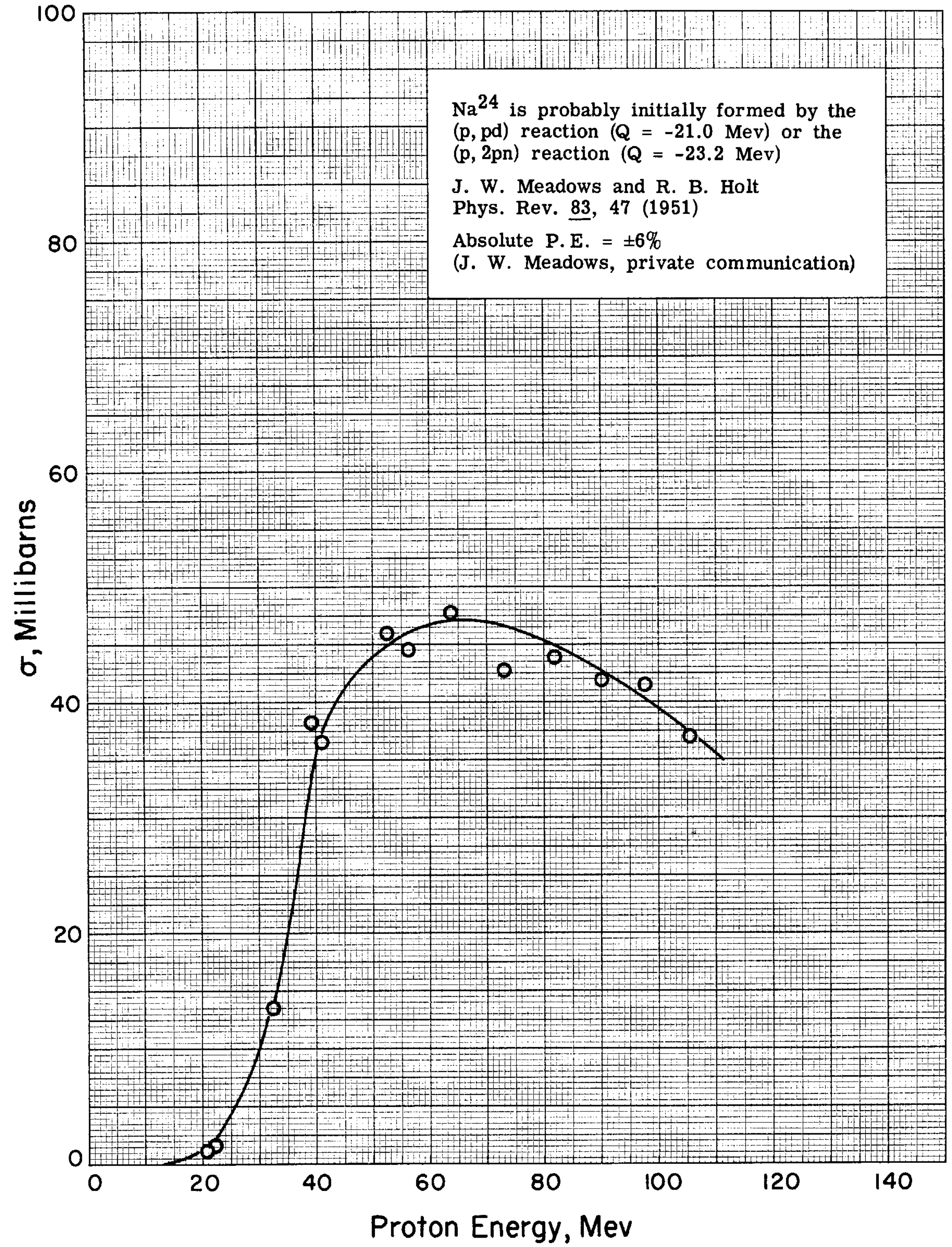
$Mg^{25}(p, x)F^{18}(\beta^+)O^{18}$
F^{18} is initially produced by the $Mg^{25}(p, 2\alpha)F^{18}$ reaction (Q = -11.6 Mev). At about 35 Mev other reactions become energetically possible
○ J. W. Meadows and R. B. Holt Phys. Rev. 83, 47 (1951)
Absolute P.E. = ±6% (private communication, J. W. Meadows)
□ Cohen, Reynolds, and Zucker Phys. Rev. 96, 1617 (1954)
Absolute P.E. about 15%
See also F. O. Bartell and S. Softky Phys. Rev. 84, 463 (1951)
σ, Millibarns
Proton Energy, Mev
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90

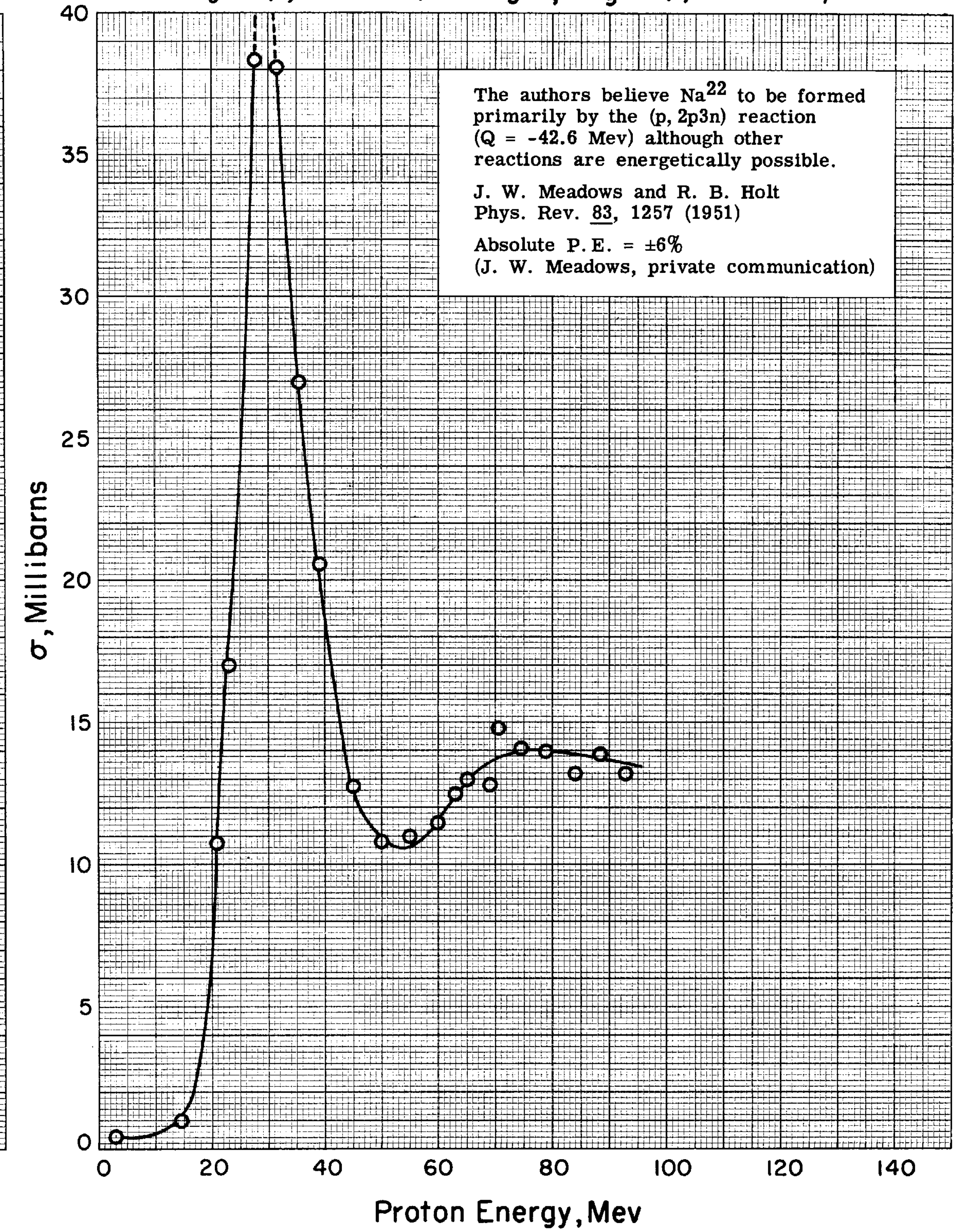
$Mg^{25}(d,p') Mg^{26*}$; $Mg^{25}(N^{14},N^{13}) Mg^{26}$



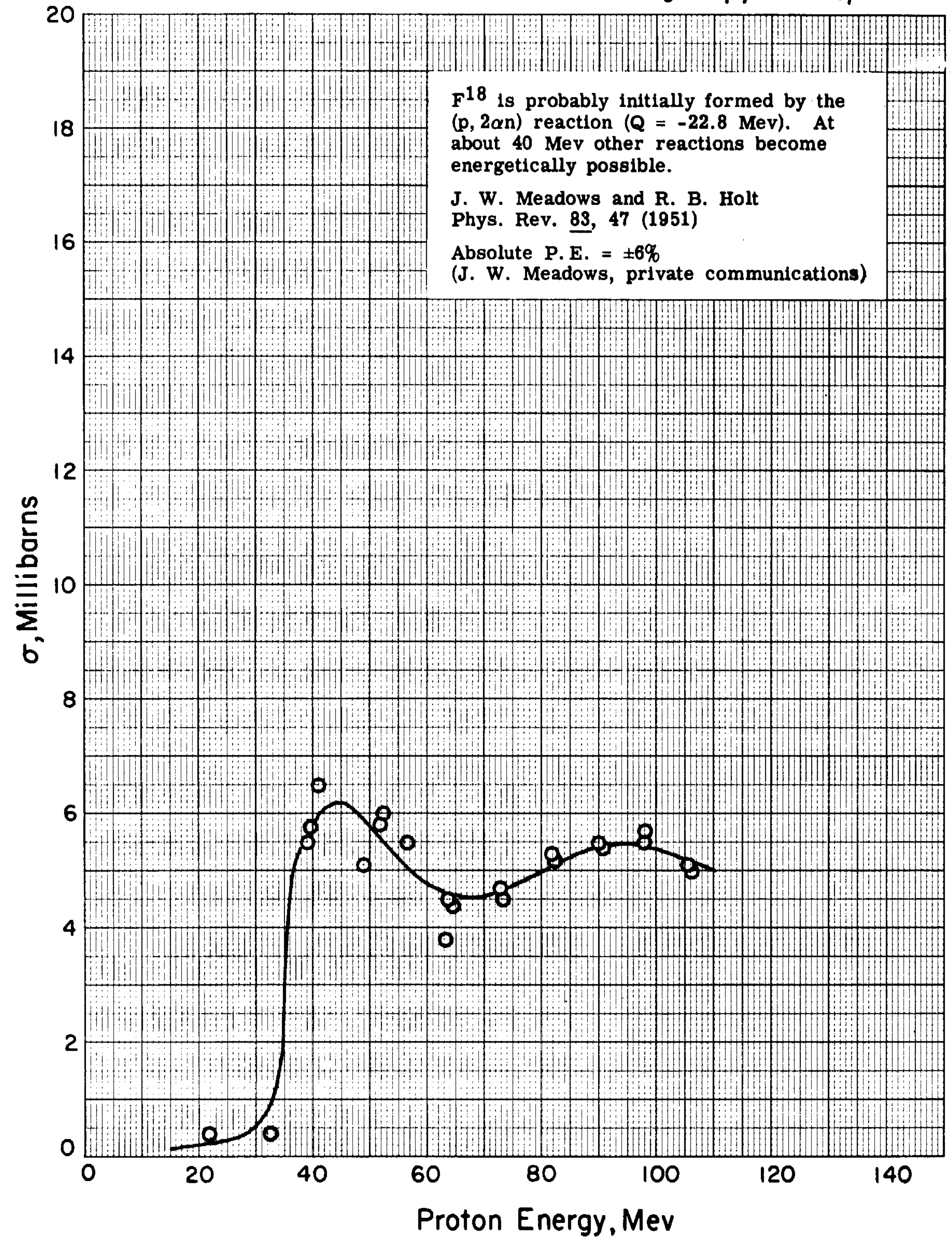


$Mg^{26}(p,x)Na^{24}(\beta^-)Mg^{24}$; $Mg^{26}(p,x)Na^{22}(\beta^+)Ne^{22}$

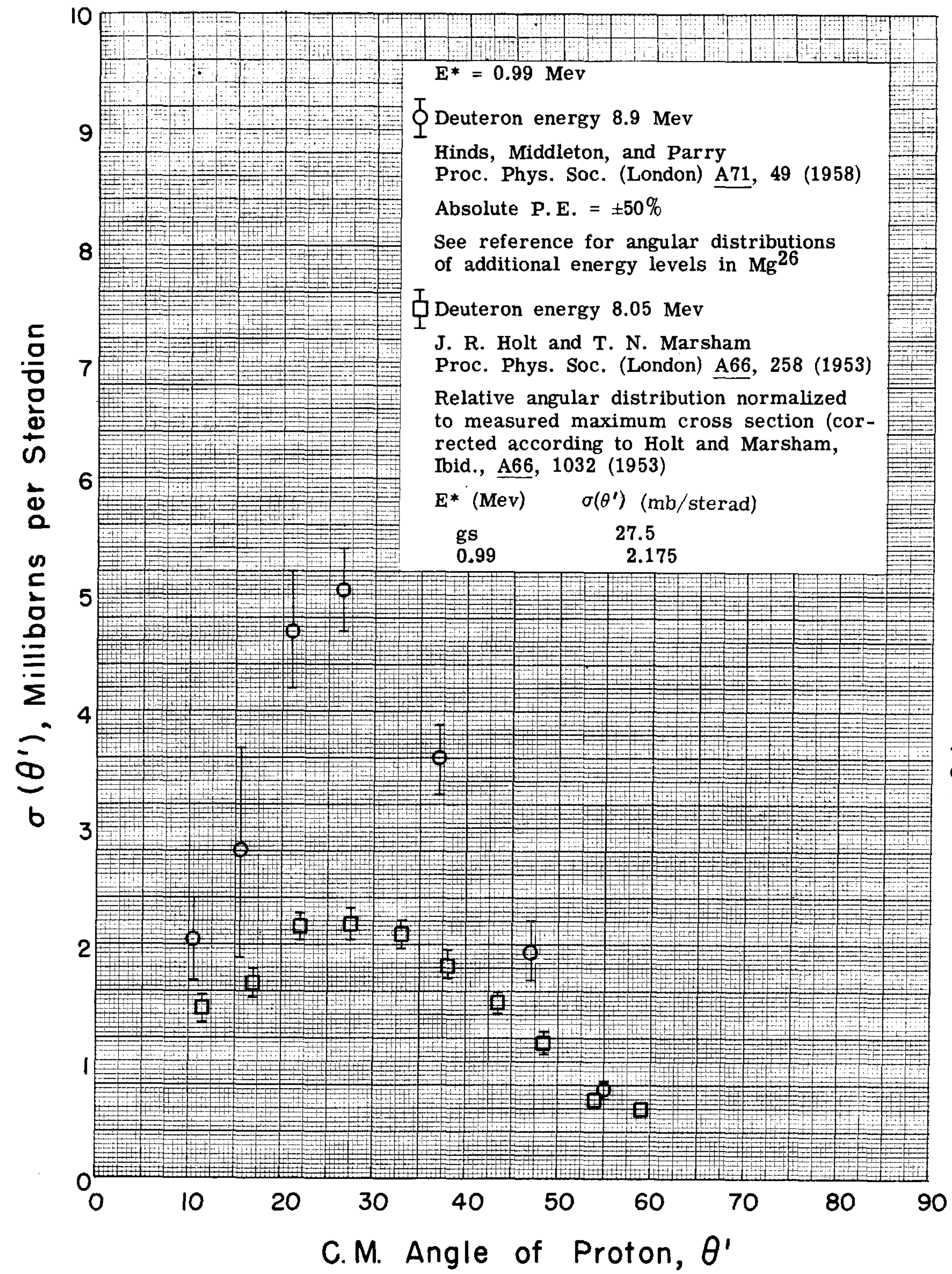




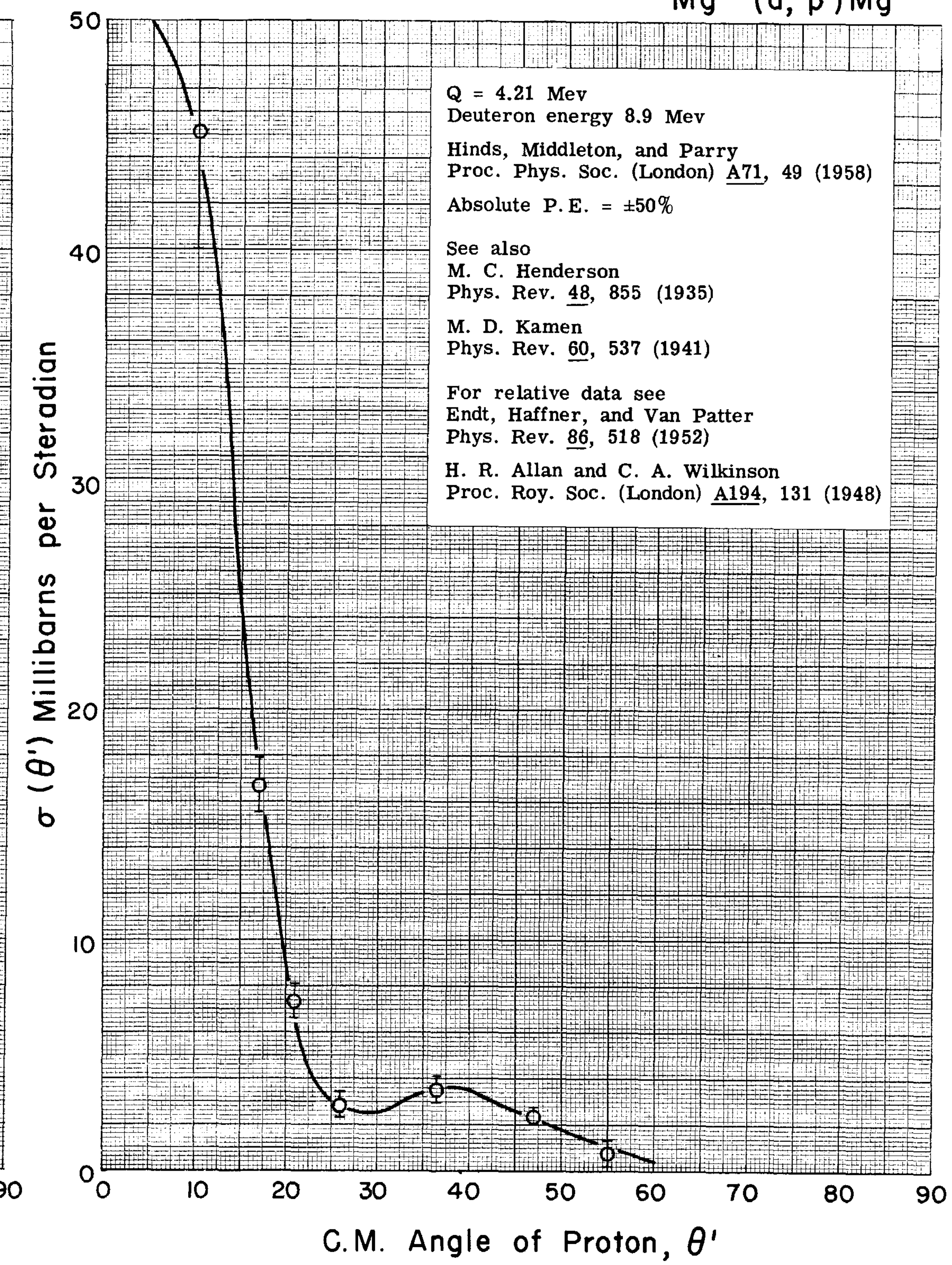
$Mg^{26}(p,x)F^{18}(\beta^+)O^{18}$



$Mg^{26}(d, p')Mg^{27*}$

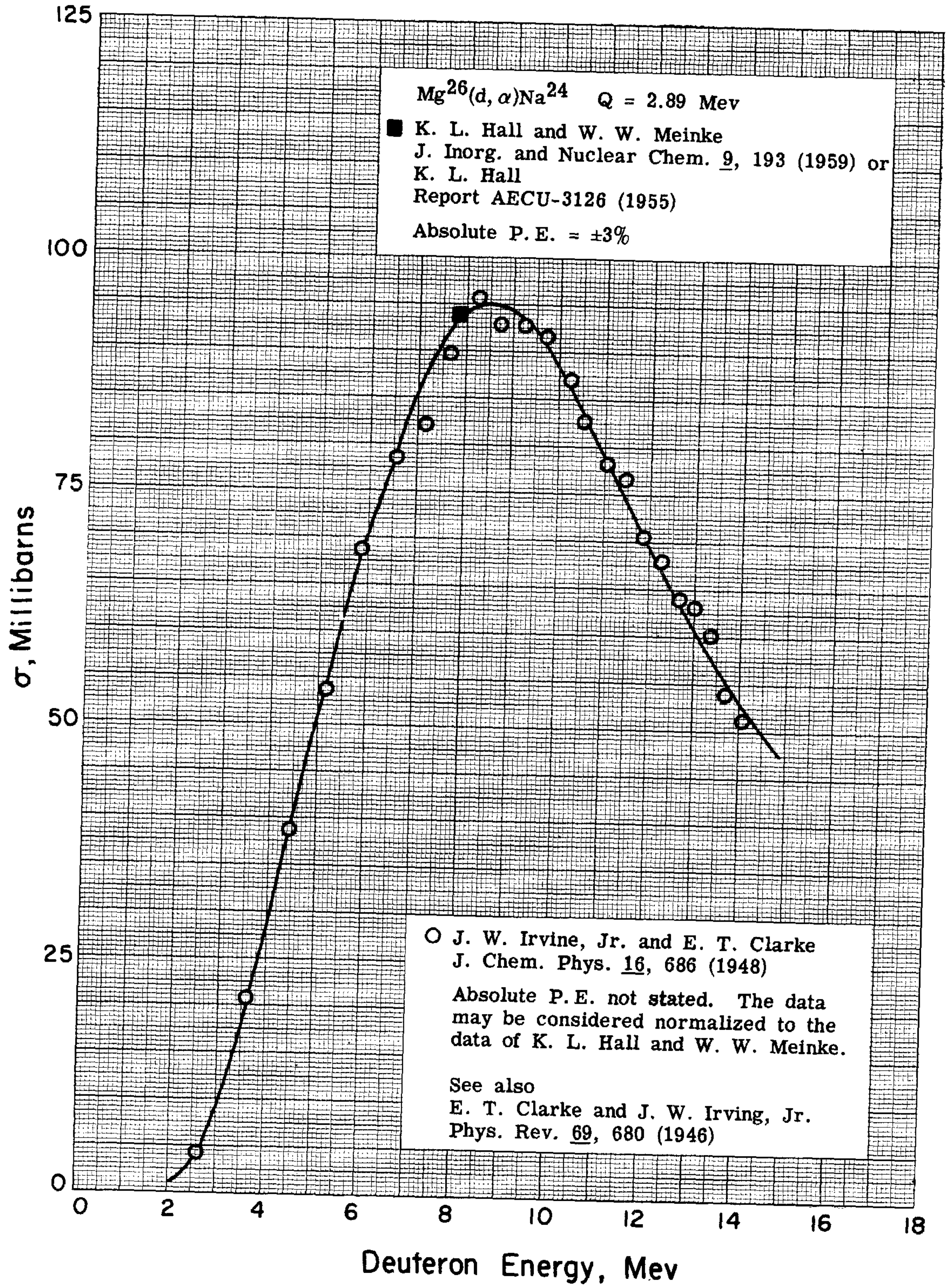


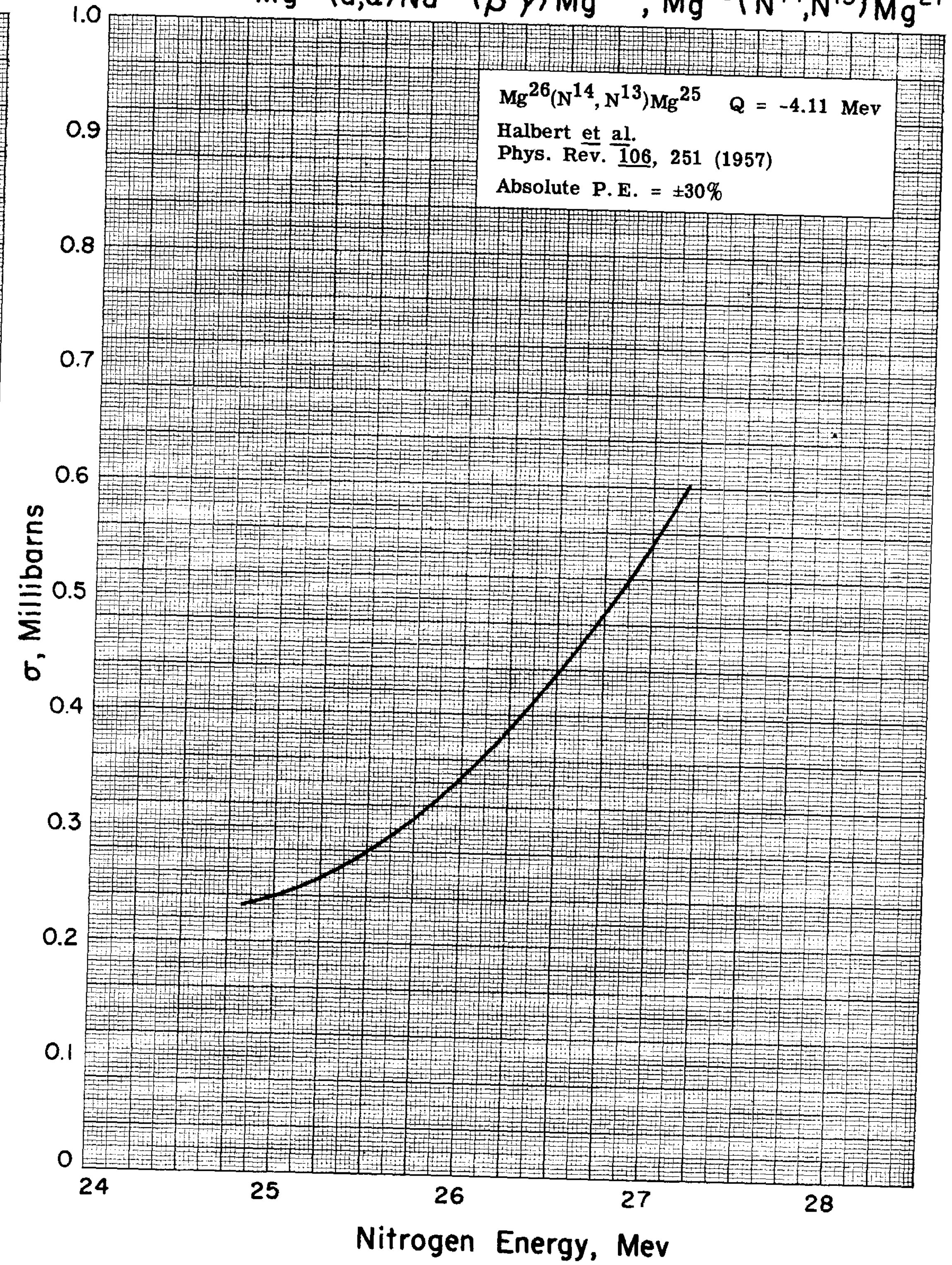
E* = 0.99 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A71, 49 (1958)
Absolute P. E. = ±50%
See reference for angular distributions of additional energy levels in Mg26
Deuteron energy 8.05 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 258 (1953)
Relative angular distribution normalized to measured maximum cross section (corrected according to Holt and Marsham, Ibid., A66, 1032 (1953)
E* (Mev) σ(θ') (mb/sterad)
gs 27.5
0.99 2.175
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'



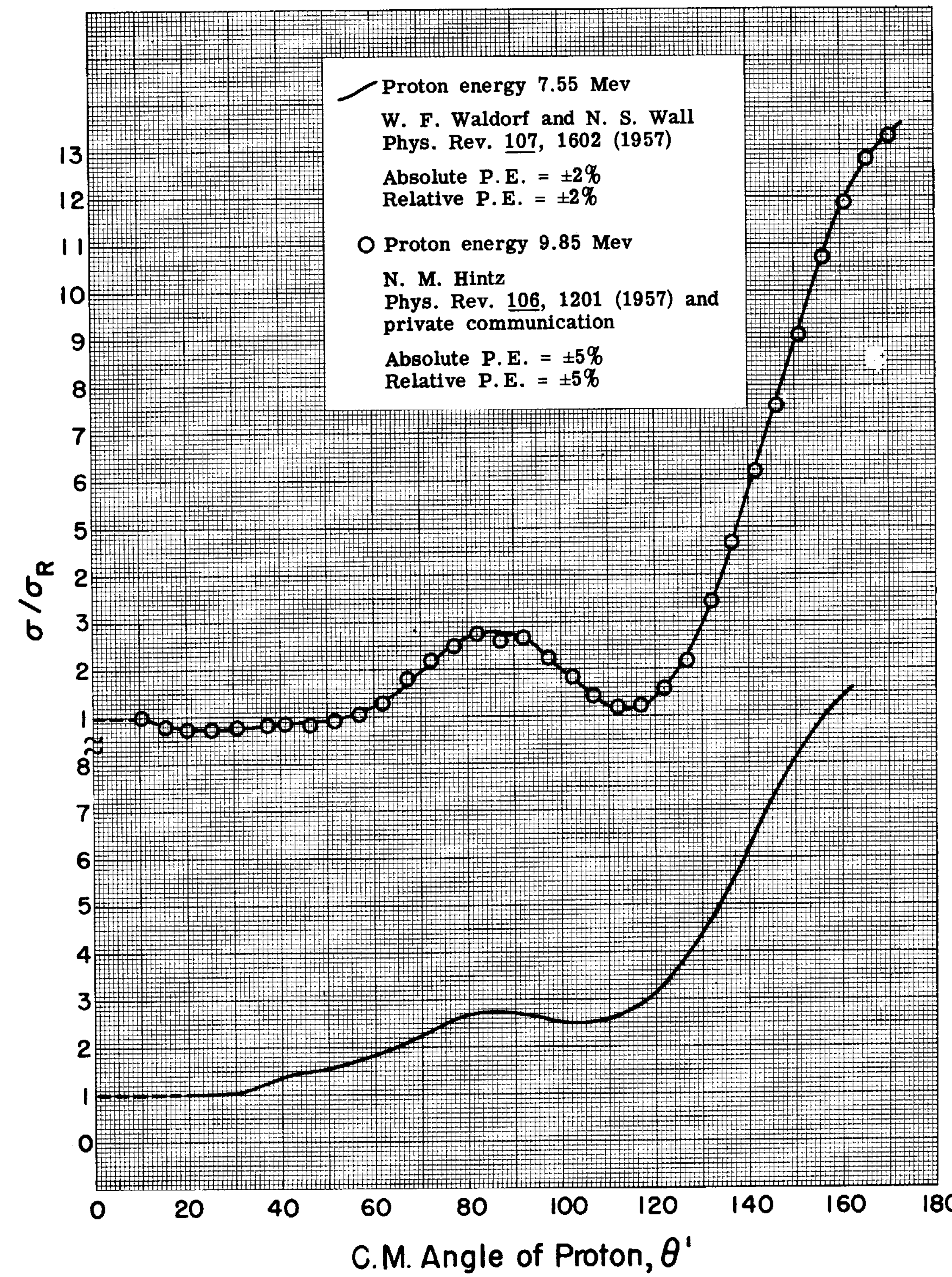
Q = 4.21 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A71, 49 (1958)
Absolute P. E. = ±50%
See also
M. C. Henderson
Phys. Rev. 48, 855 (1935)
M. D. Kamen
Phys. Rev. 60, 537 (1941)
For relative data see
Endt, Haffner, and Van Patter
Phys. Rev. 86, 518 (1952)
H. R. Allan and C. A. Wilkinson
Proc. Roy. Soc. (London) A194, 131 (1948)
σ (θ') Millibarns per Steradian
C.M. Angle of Proton, θ'

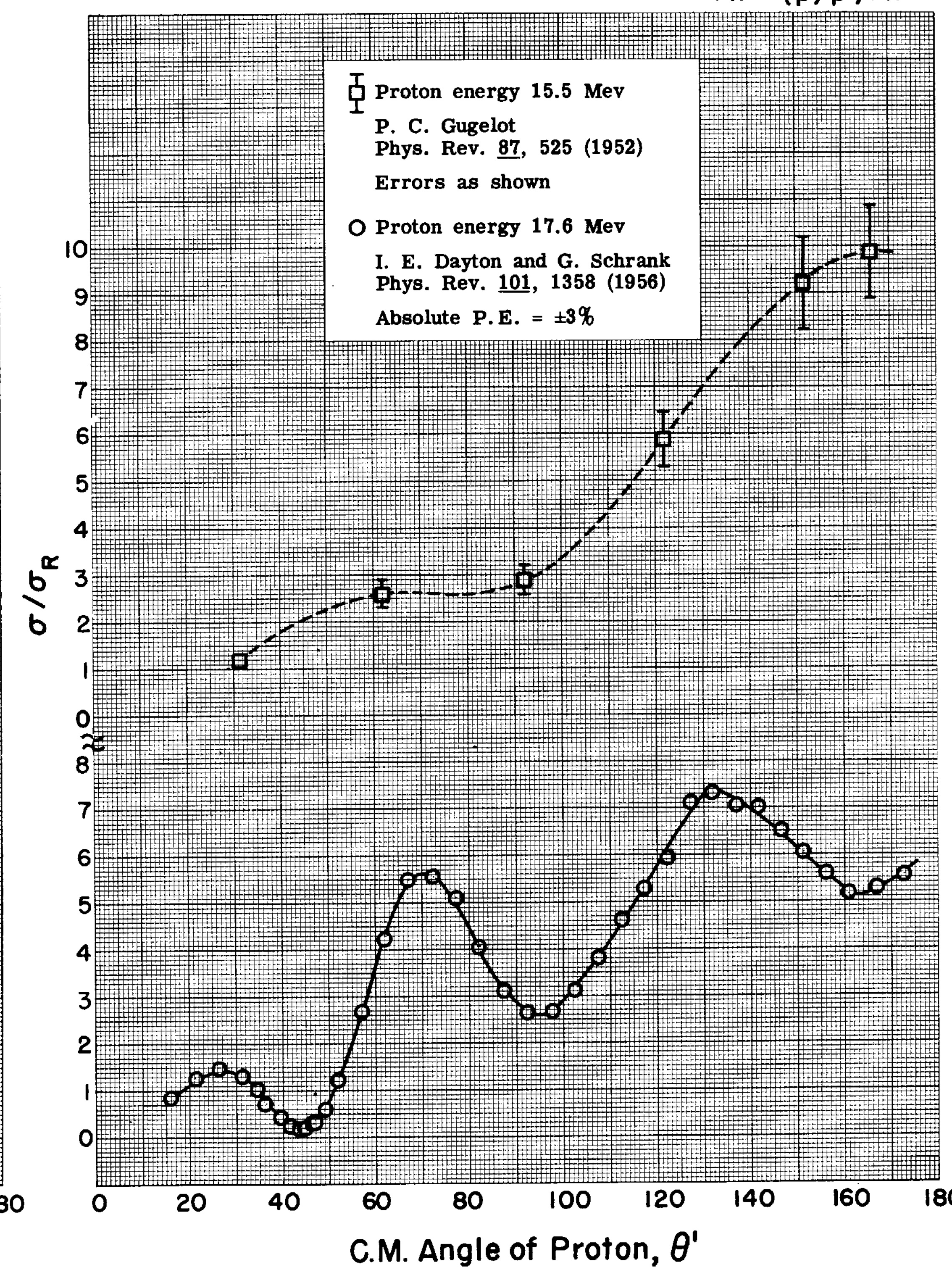
$Mg^{26}(d,\alpha)Na^{24}(\beta^{-}\gamma)Mg^{24}$; $Mg^{26}(N^{14},N^{13})Mg^{27}$

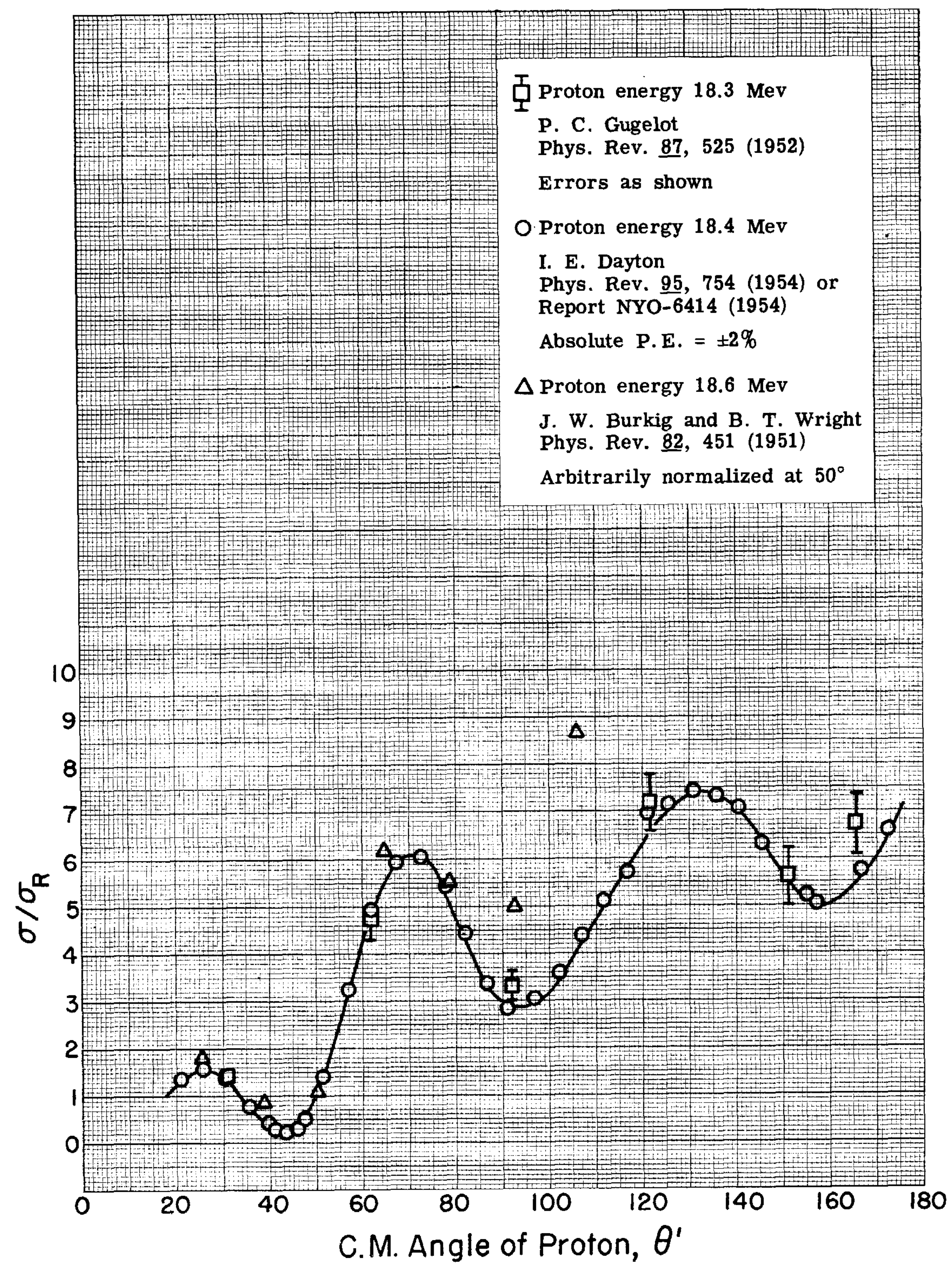


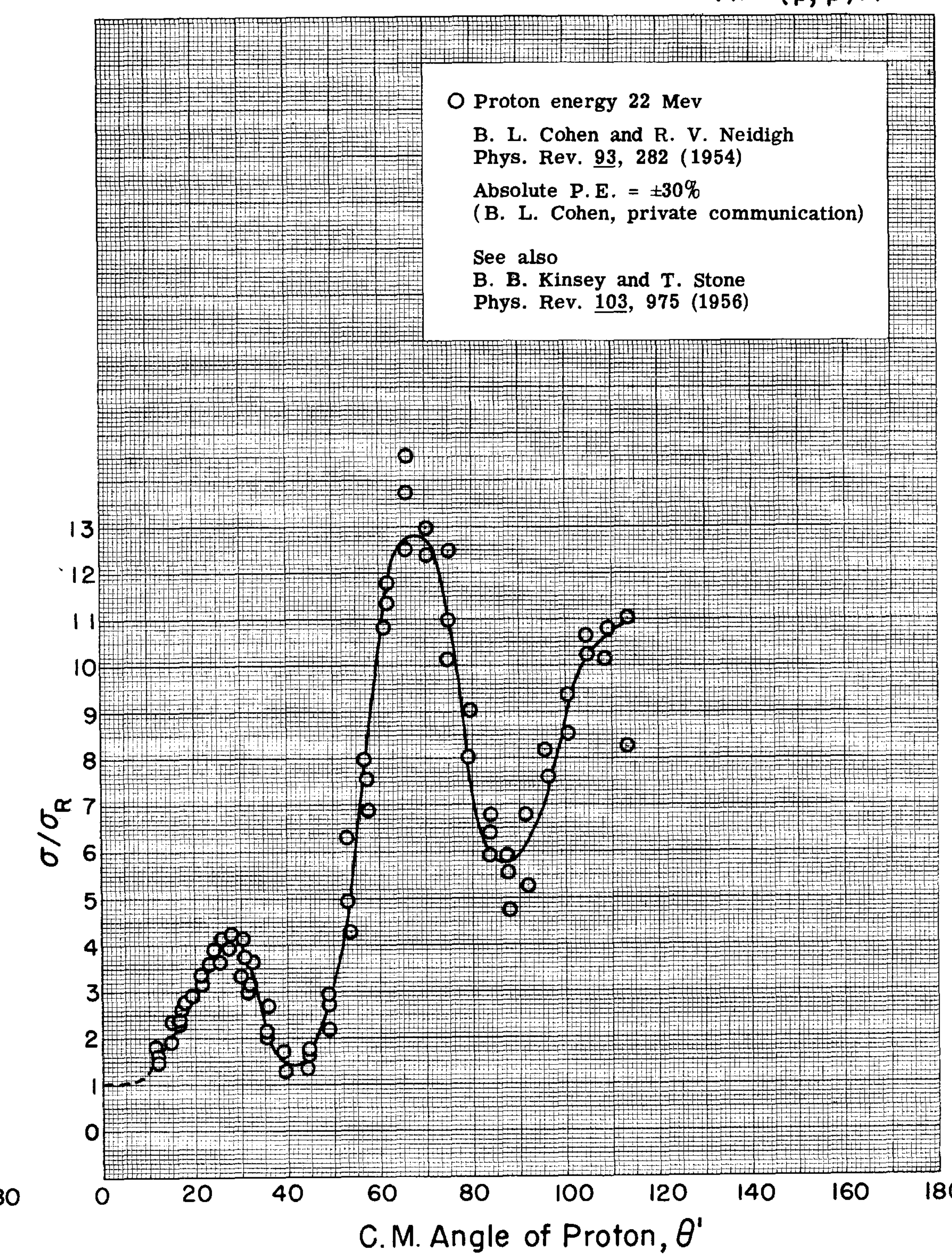


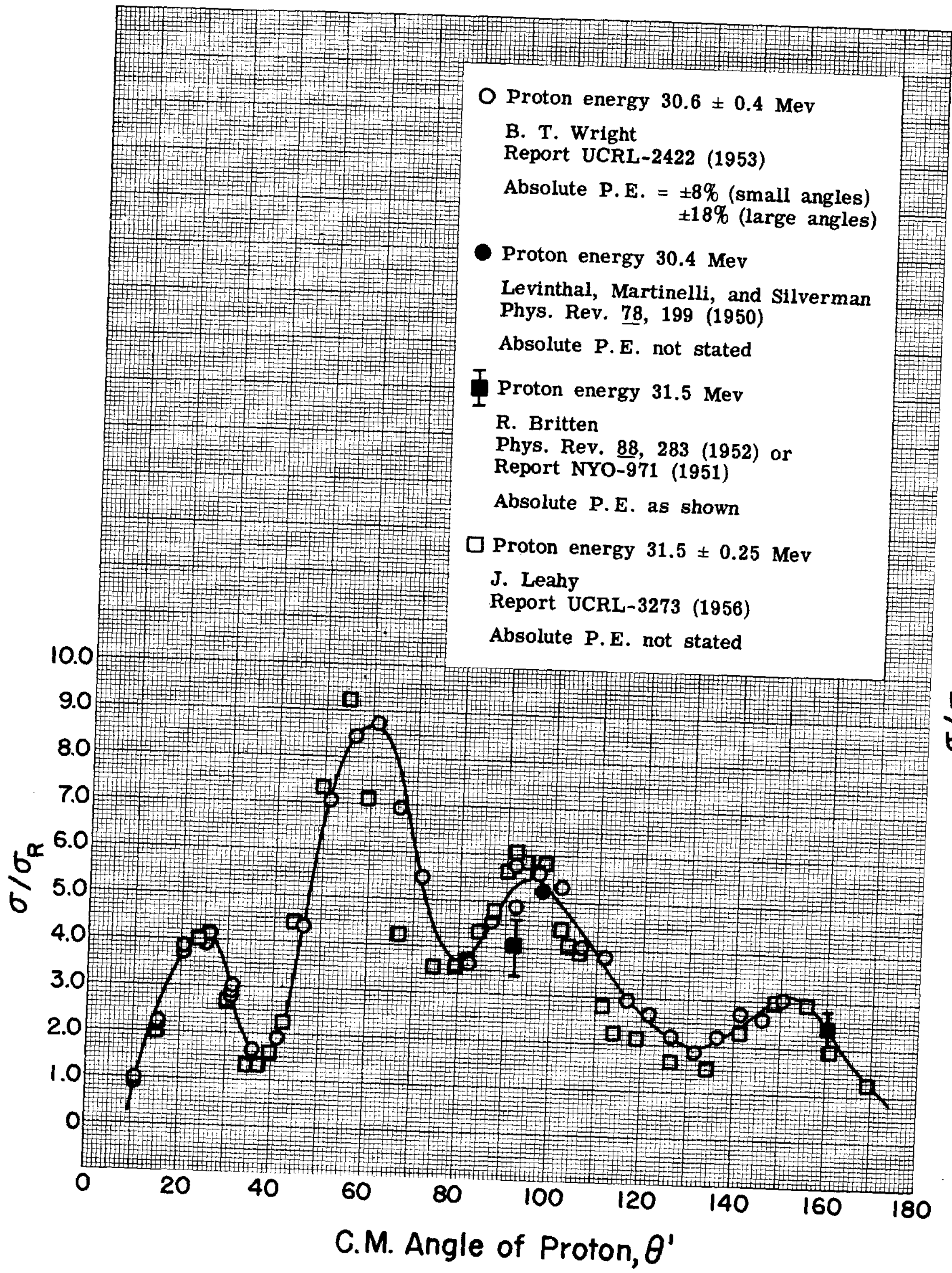
$Al^{27}(p, p)Al^{27}$


Proton energy 7.55 Mev
W. F. Waldorf and N. S. Wall
Phys. Rev. 107, 1602 (1957)
Absolute P.E. = ±2%
Relative P.E. = ±2%
Proton energy 9.85 Mev
N. M. Hintz
Phys. Rev. 106, 1201 (1957) and private communication
Absolute P.E. = ±5%
Relative P.E. = ±5%
σ/σR
C.M. Angle of Proton, θ'

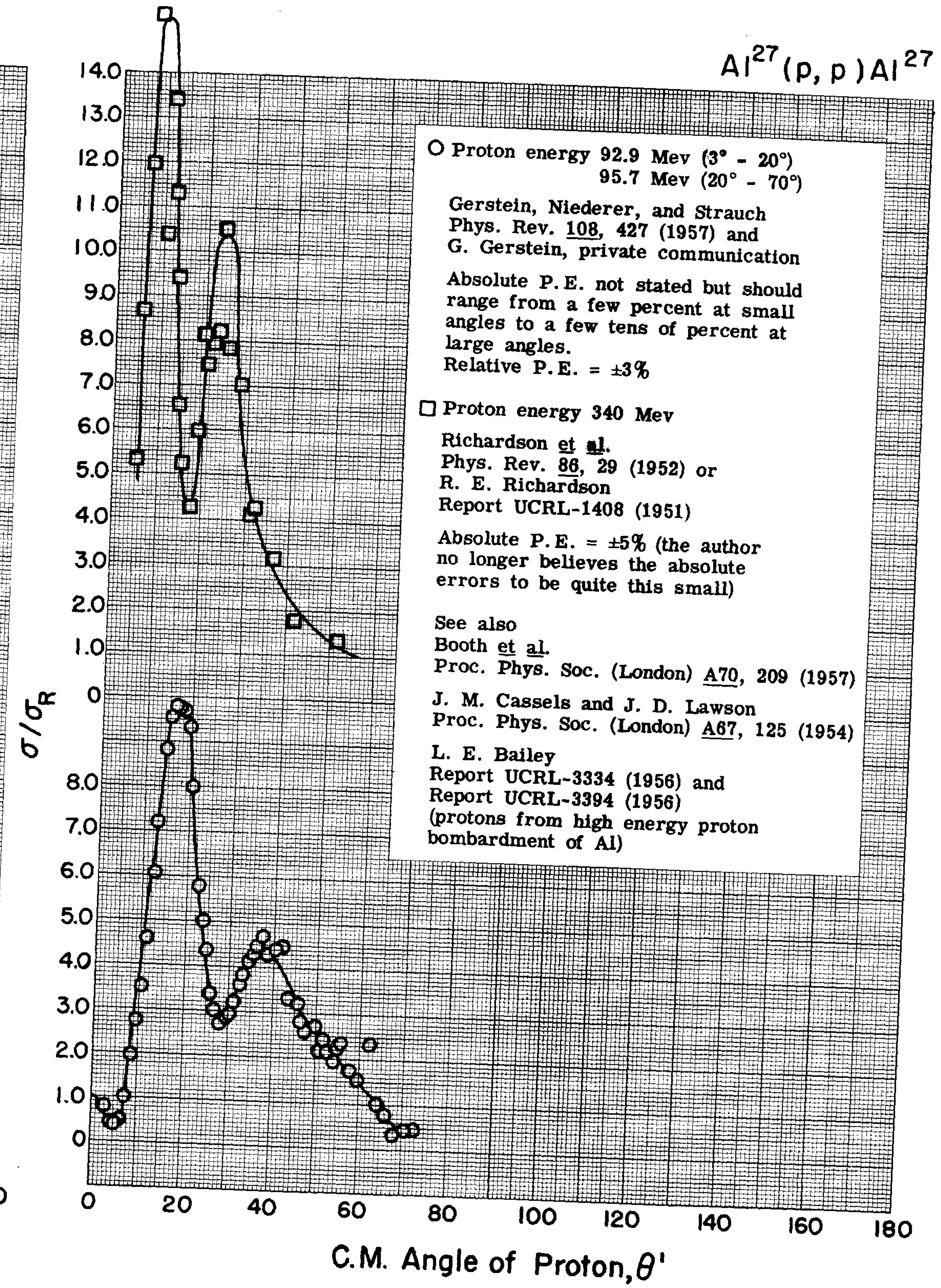

Proton energy 15.5 Mev
P. C. Gugelot
Phys. Rev. 87, 525 (1952)
Errors as shown
Proton energy 17.6 Mev
I. E. Dayton and G. Schrank
Phys. Rev. 101, 1358 (1956)
Absolute P.E. = ±3%
σ/σR
C.M. Angle of Proton, θ'


Proton energy 18.3 Mev
P. C. Gugelot
Phys. Rev. 87, 525 (1952)
Errors as shown
Proton energy 18.4 Mev
I. E. Dayton
Phys. Rev. 95, 754 (1954) or
Report NYO-6414 (1954)
Absolute P.E. = ±2%
Proton energy 18.6 Mev
J. W. Burkig and B. T. Wright
Phys. Rev. 82, 451 (1951)
Arbitrarily normalized at 50°
σ/σR
C.M. Angle of Proton, θ'

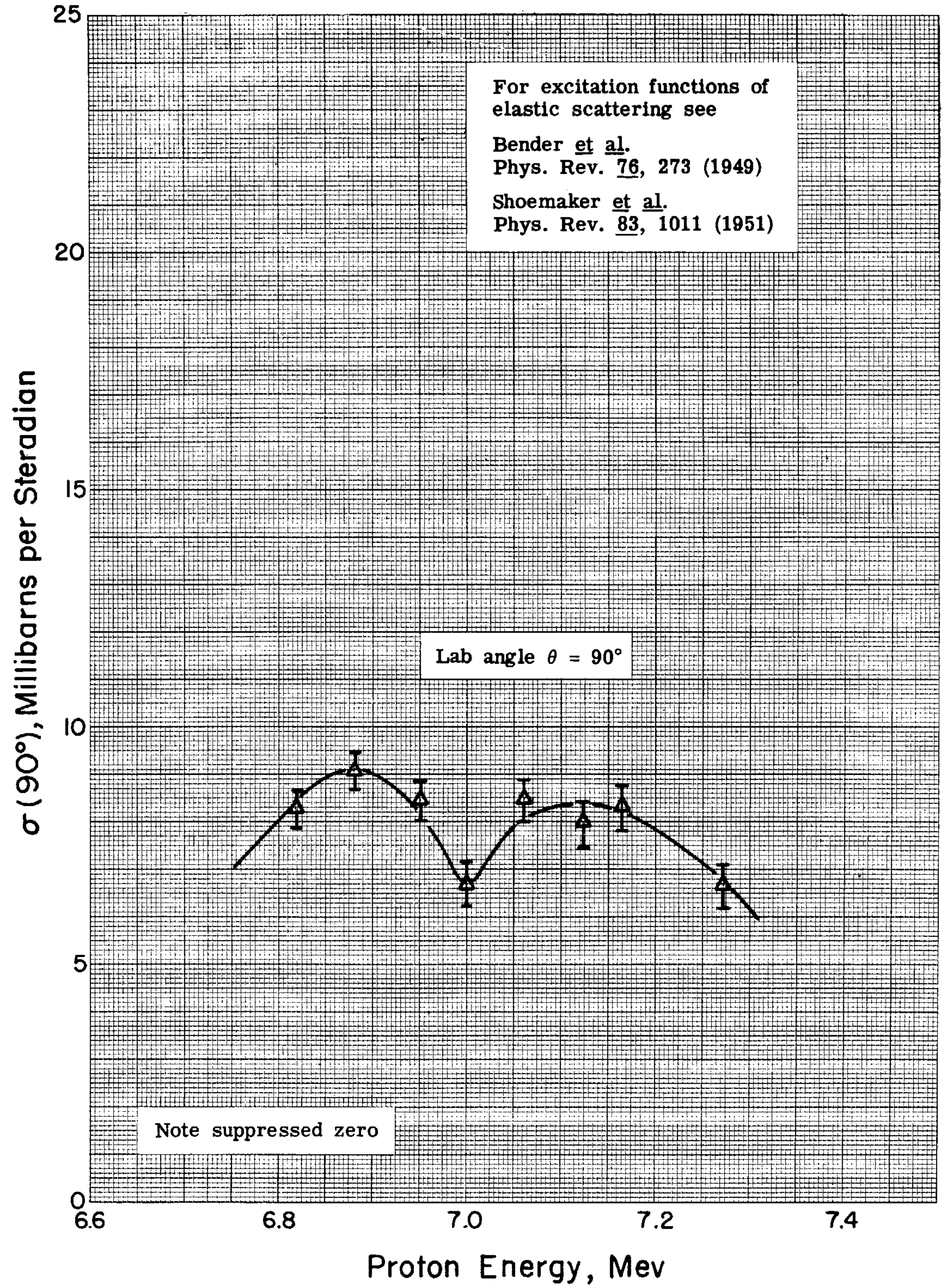

Proton energy 22 Mev
B. L. Cohen and R. V. Neidigh
Phys. Rev. 93, 282 (1954)
Absolute P.E. = ±30%
(B. L. Cohen, private communication)
See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
σ/σR
C.M. Angle of Proton, θ'



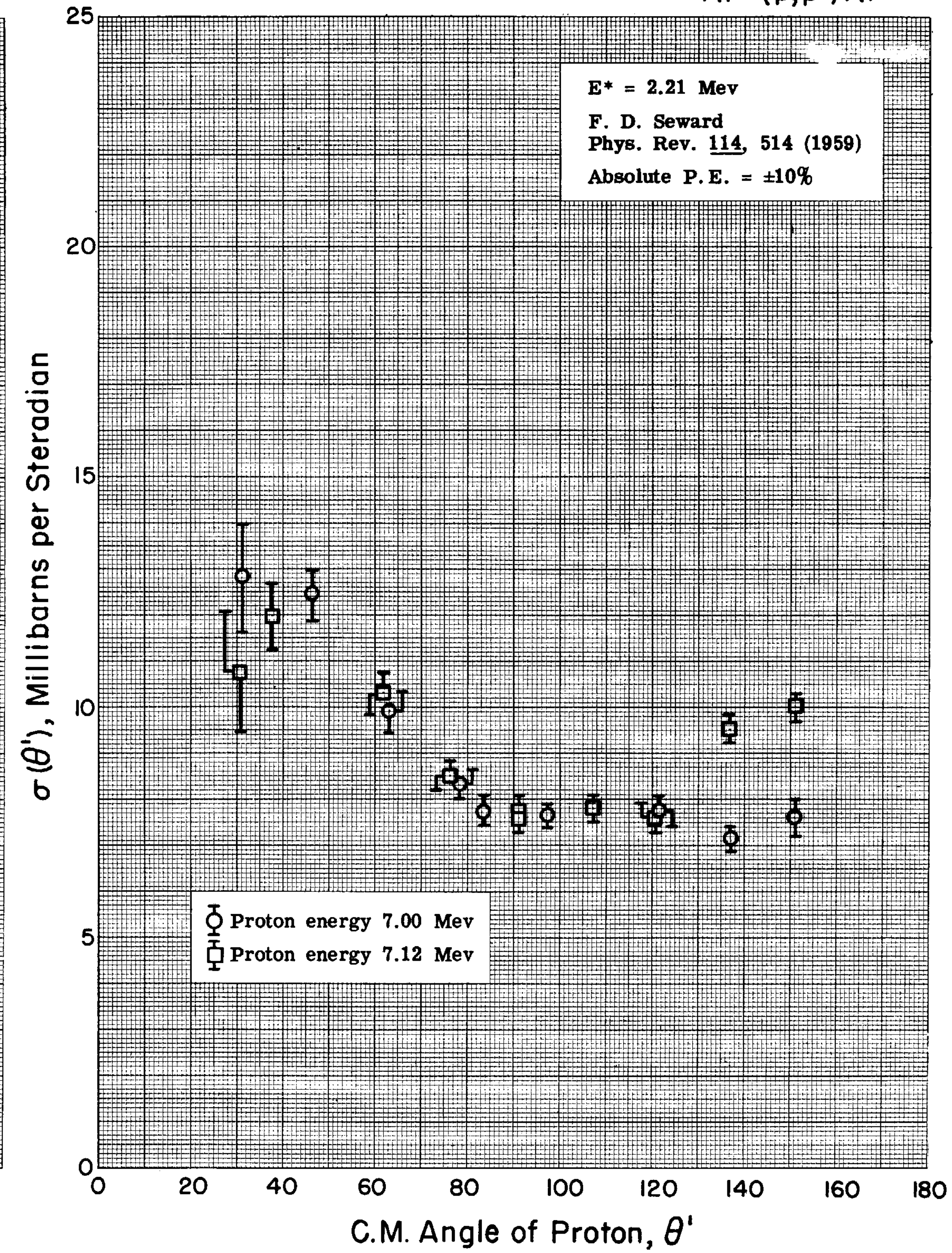
O Proton energy 30.6 ± 0.4 Mev
B. T. Wright
Report UCRL-2422 (1953)
Absolute P. E. = ±8% (small angles)
±18% (large angles)
● Proton energy 30.4 Mev
Levinthal, Martinelli, and Silverman
Phys. Rev. 78, 199 (1950)
Absolute P. E. not stated
■ Proton energy 31.5 Mev
R. Britten
Phys. Rev. 88, 283 (1952) or
Report NYO-971 (1951)
Absolute P. E. as shown
□ Proton energy 31.5 ± 0.25 Mev
J. Leahy
Report UCRL-3273 (1956)
Absolute P. E. not stated
σ/σR
C.M. Angle of Proton, θ'

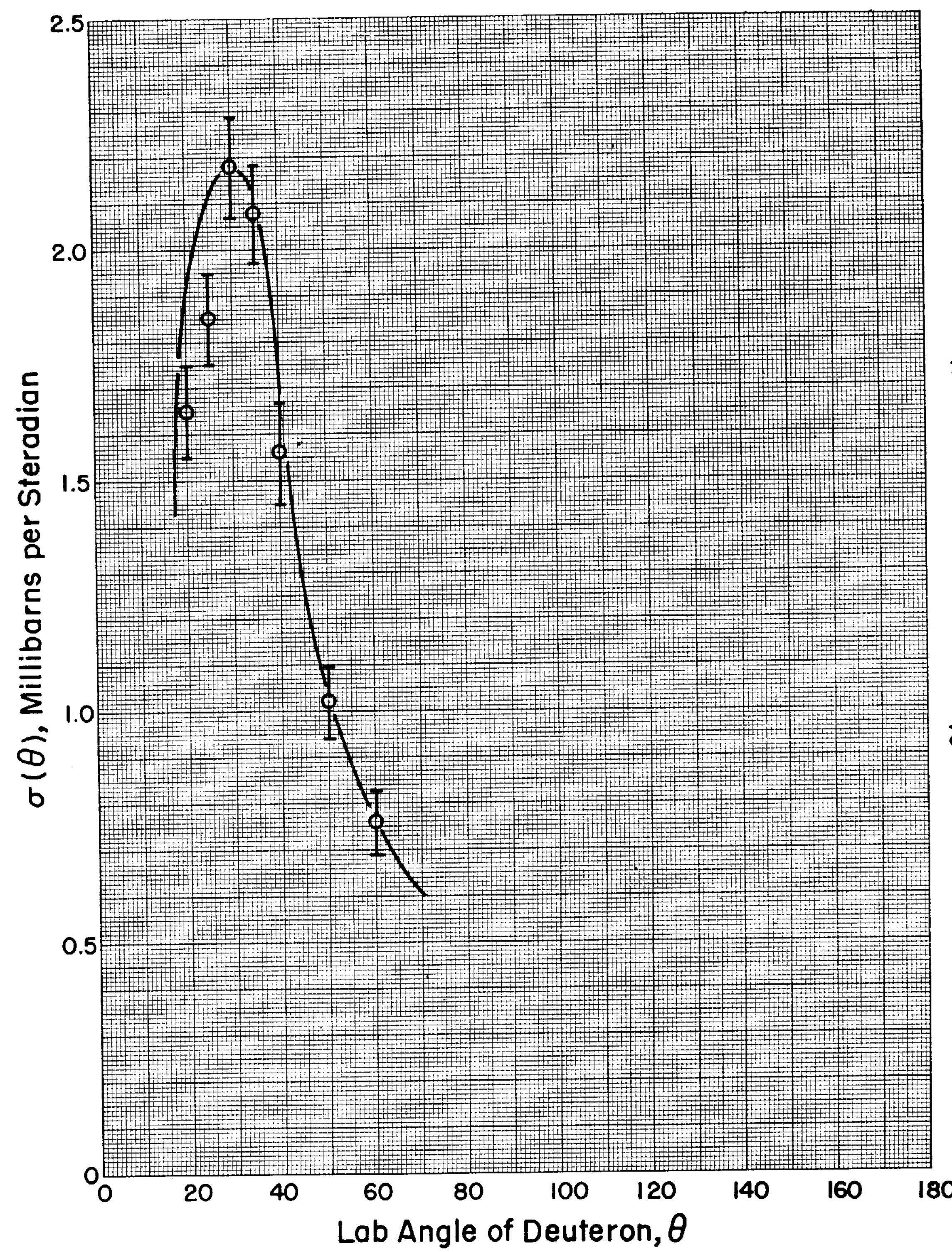


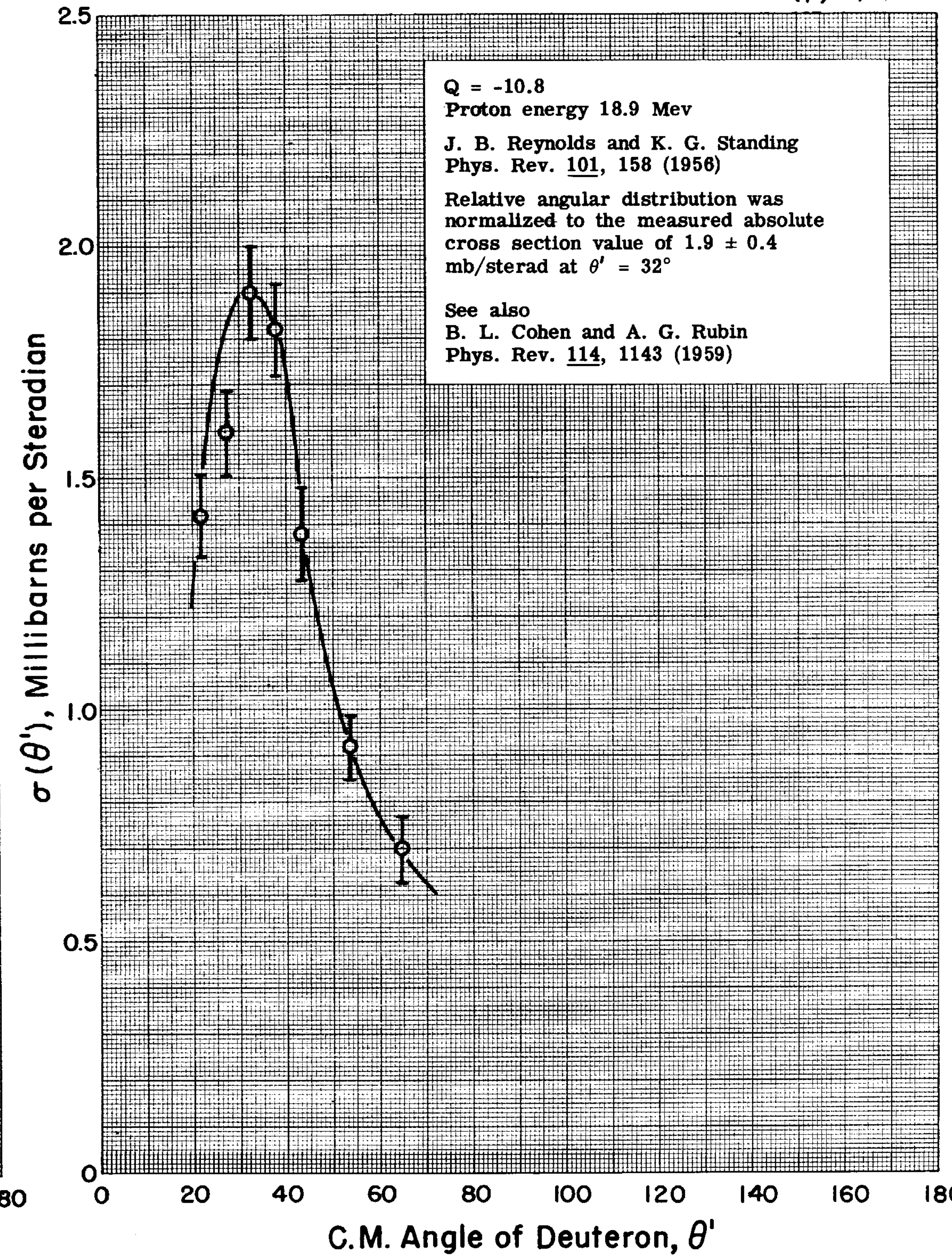
Al27 (p, p) Al27
O Proton energy 92.9 Mev (3° - 20°)
95.7 Mev (20° - 70°)
Gerstein, Niederer, and Strauch
Phys. Rev. 108, 427 (1957) and
G. Gerstein, private communication
Absolute P. E. not stated but should range from a few percent at small angles to a few tens of percent at large angles.
Relative P. E. = ±3%
□ Proton energy 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P. E. = ±5% (the author no longer believes the absolute errors to be quite this small)
See also
Booth et al.
Proc. Phys. Soc. (London) A70, 209 (1957)
J. M. Cassels and J. D. Lawson
Proc. Phys. Soc. (London) A67, 125 (1954)
L. E. Bailey
Report UCRL-3334 (1956) and
Report UCRL-3394 (1956)
(protons from high energy proton bombardment of Al)
σ/σR
C.M. Angle of Proton, θ'


For excitation functions of elastic scattering see
Bender et al.
Phys. Rev. 76, 273 (1949)
Shoemaker et al.
Phys. Rev. 83, 1011 (1951)
Lab angle θ = 90°
Note suppressed zero
σ (90°), Millibarns per Steradian
Proton Energy, Mev
25
20
15
10
5
0
6.6
6.8
7.0
7.2
7.4

Al^{27}(p,p')Al^{27*}


E* = 2.21 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute P.E. = ±10%
Proton energy 7.00 Mev
Proton energy 7.12 Mev
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180



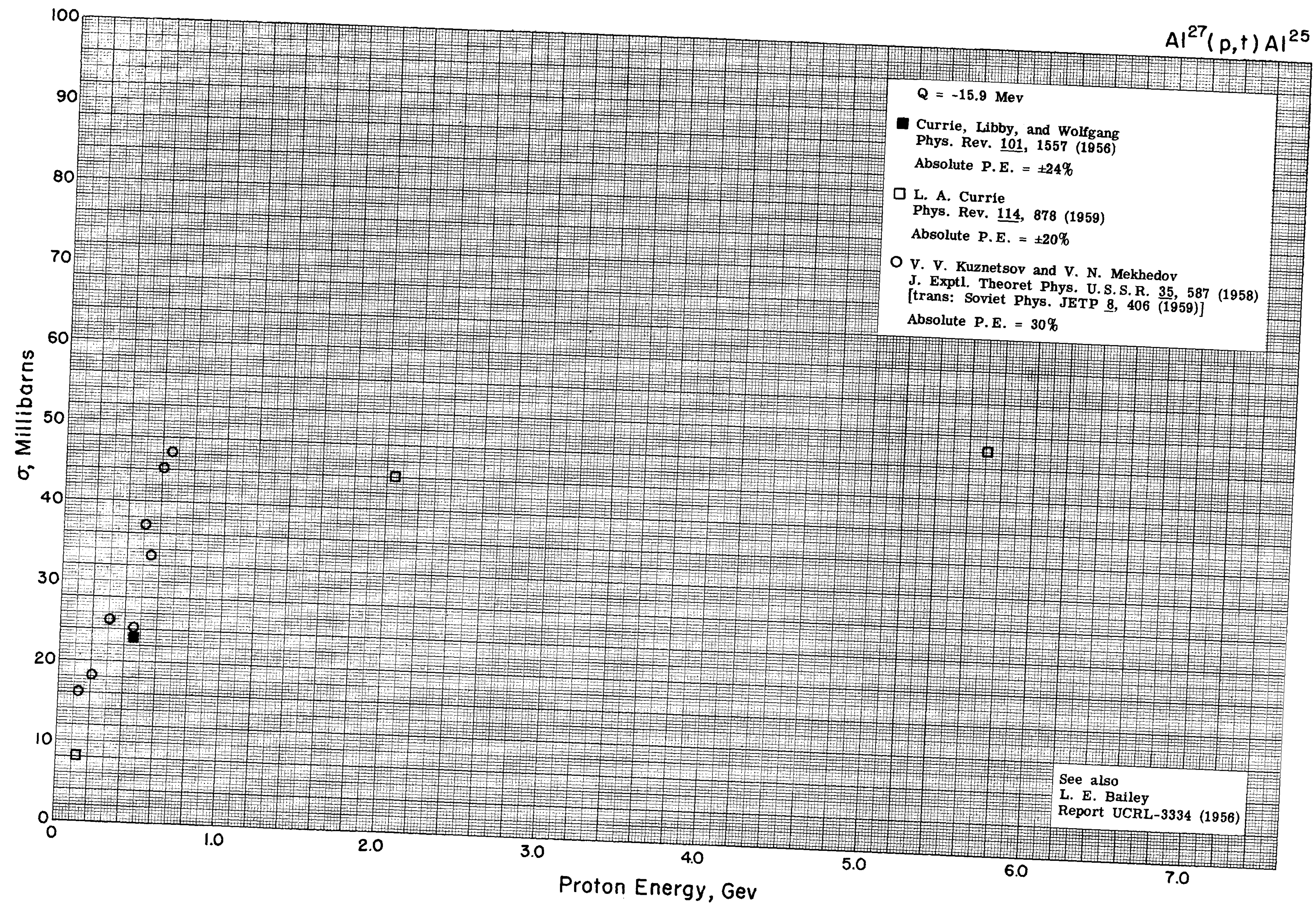


Q = -10.8
Proton energy 18.9 Mev

J. B. Reynolds and K. G. Standing
Phys. Rev. 101, 158 (1956)

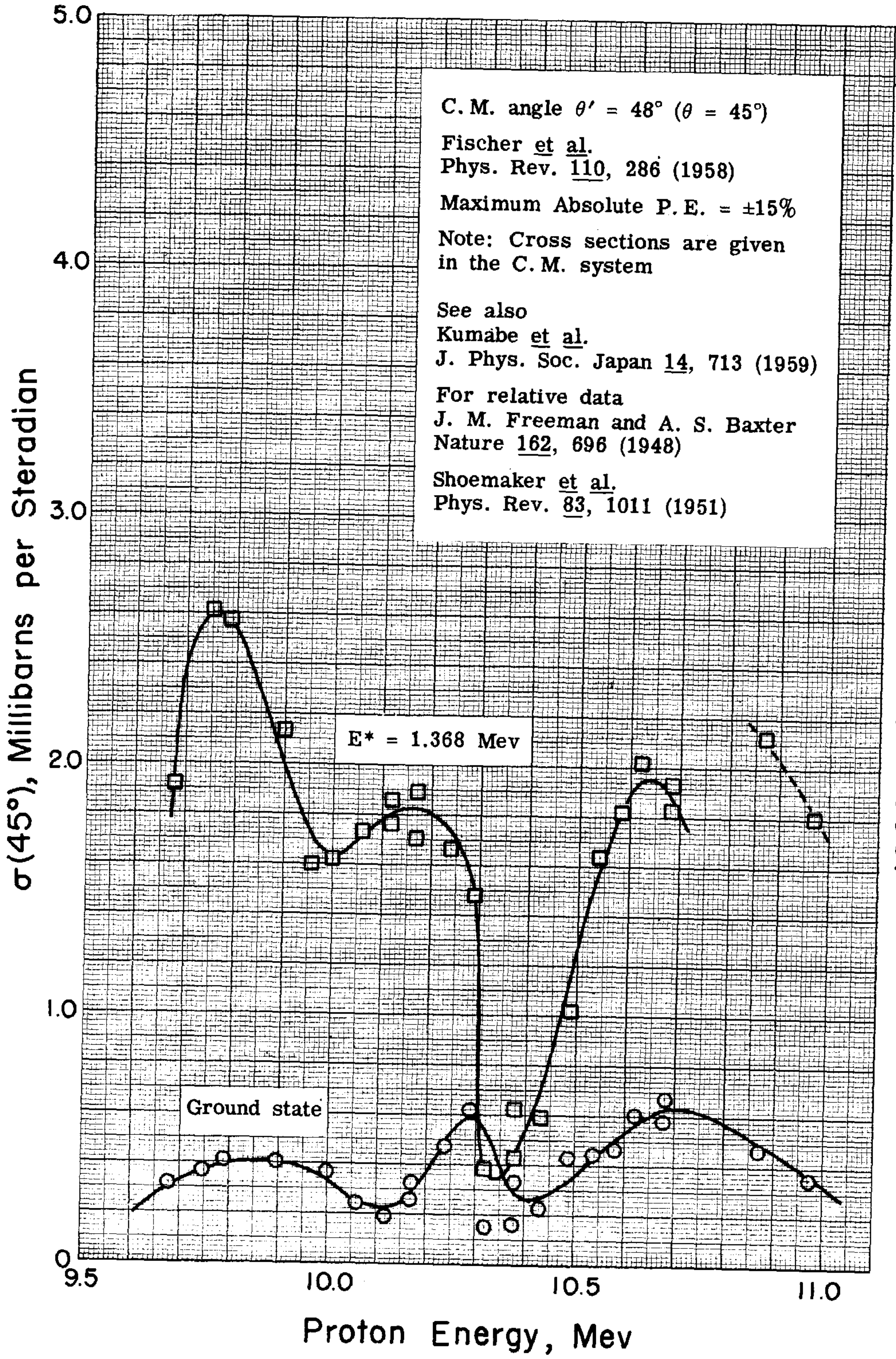
Relative angular distribution was normalized to the measured absolute cross section value of 1.9 ± 0.4 mb/sterad at θ' = 32°

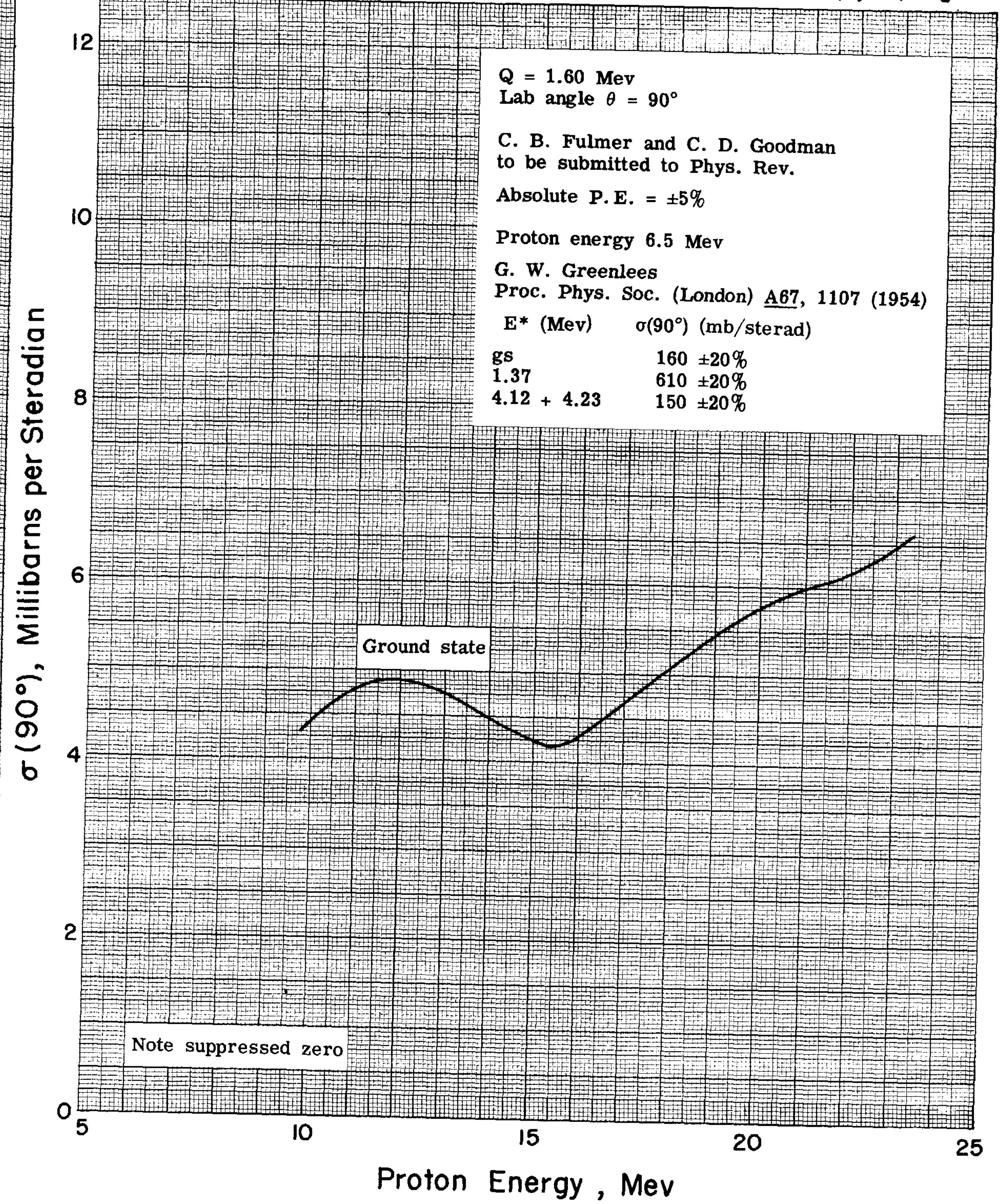
See also
B. L. Cohen and A. G. Rubin
Phys. Rev. 114, 1143 (1959)

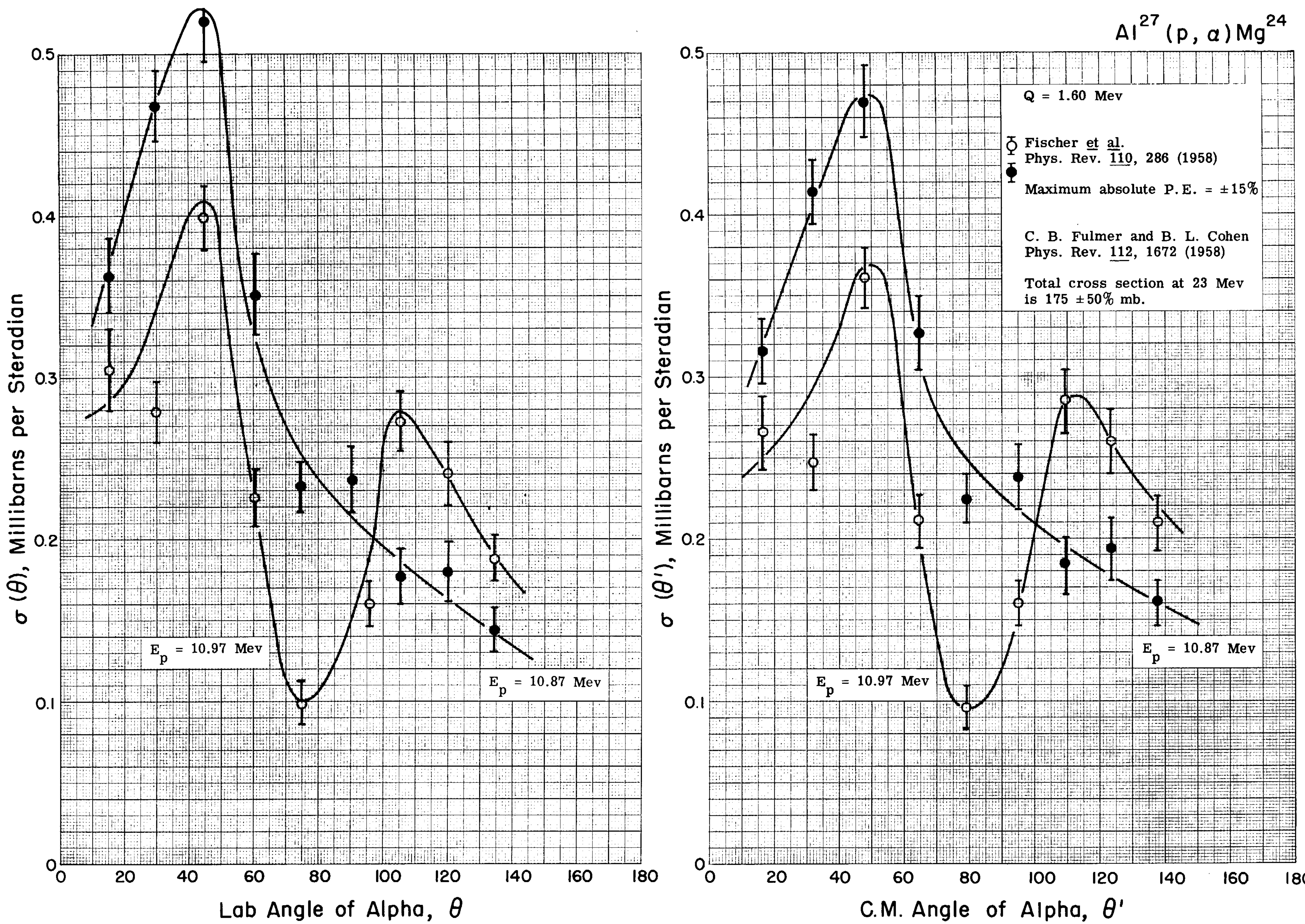


$Al^{27}(p,t)Al^{25}$
Q = -15.9 Mev
■ Currie, Libby, and Wolfgang Phys. Rev. 101, 1557 (1956)
Absolute P.E. = ±24%
□ L. A. Currie Phys. Rev. 114, 878 (1959)
Absolute P.E. = ±20%
○ V. V. Kuznetsov and V. N. Mekhedov J. Exptl. Theoret Phys. U.S.S.R. 35, 587 (1958) [trans: Soviet Phys. JETP 8, 406 (1959)]
Absolute P.E. = 30%
See also L. E. Bailey Report UCRL-3334 (1956)
σ, Millibarns
Proton Energy, Gev
0
10
20
30
40
50
60
70
80
90
100
1.0
2.0
3.0
4.0
5.0
6.0
7.0

$Al^{27}(p,\alpha')Mg^{24*}$

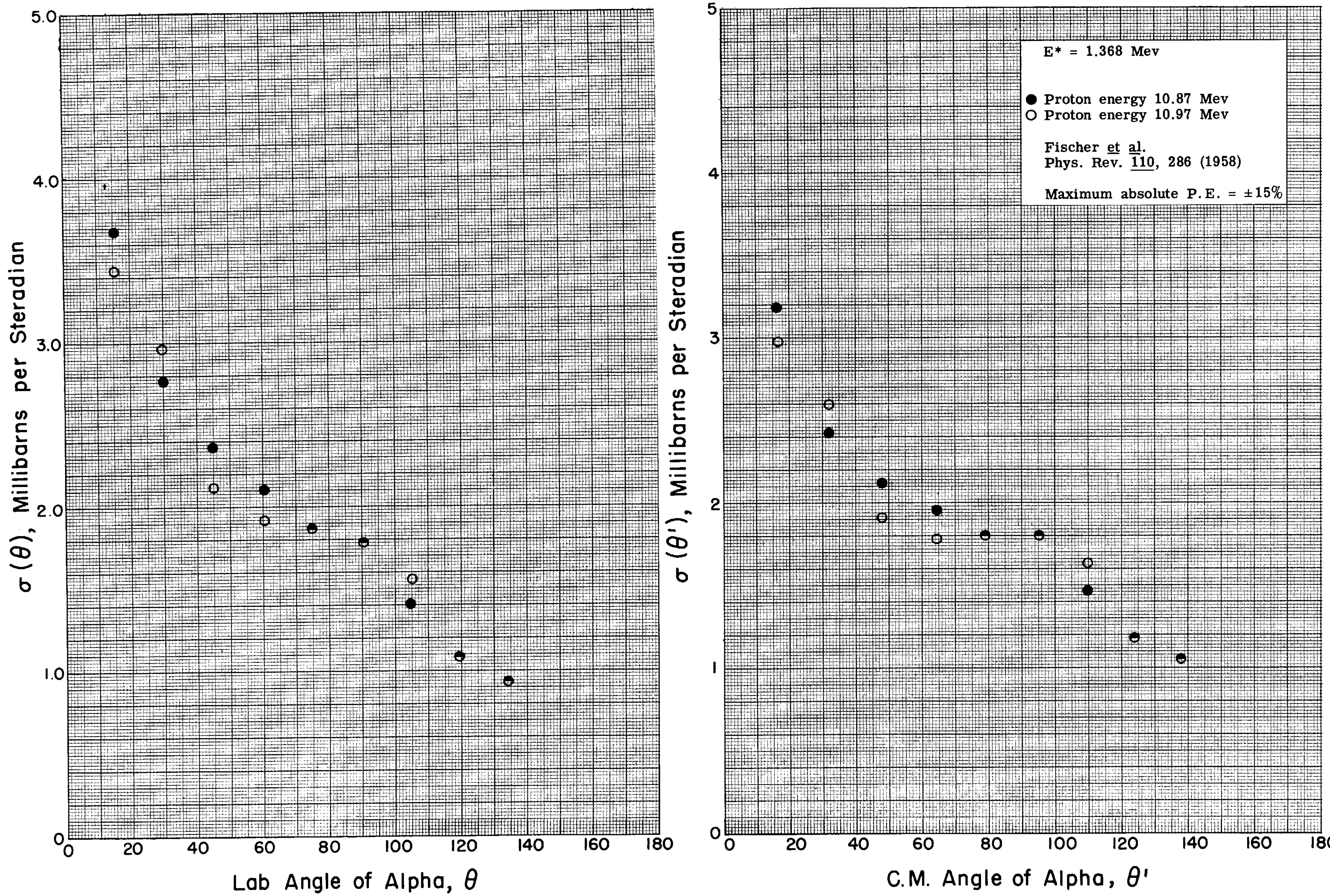


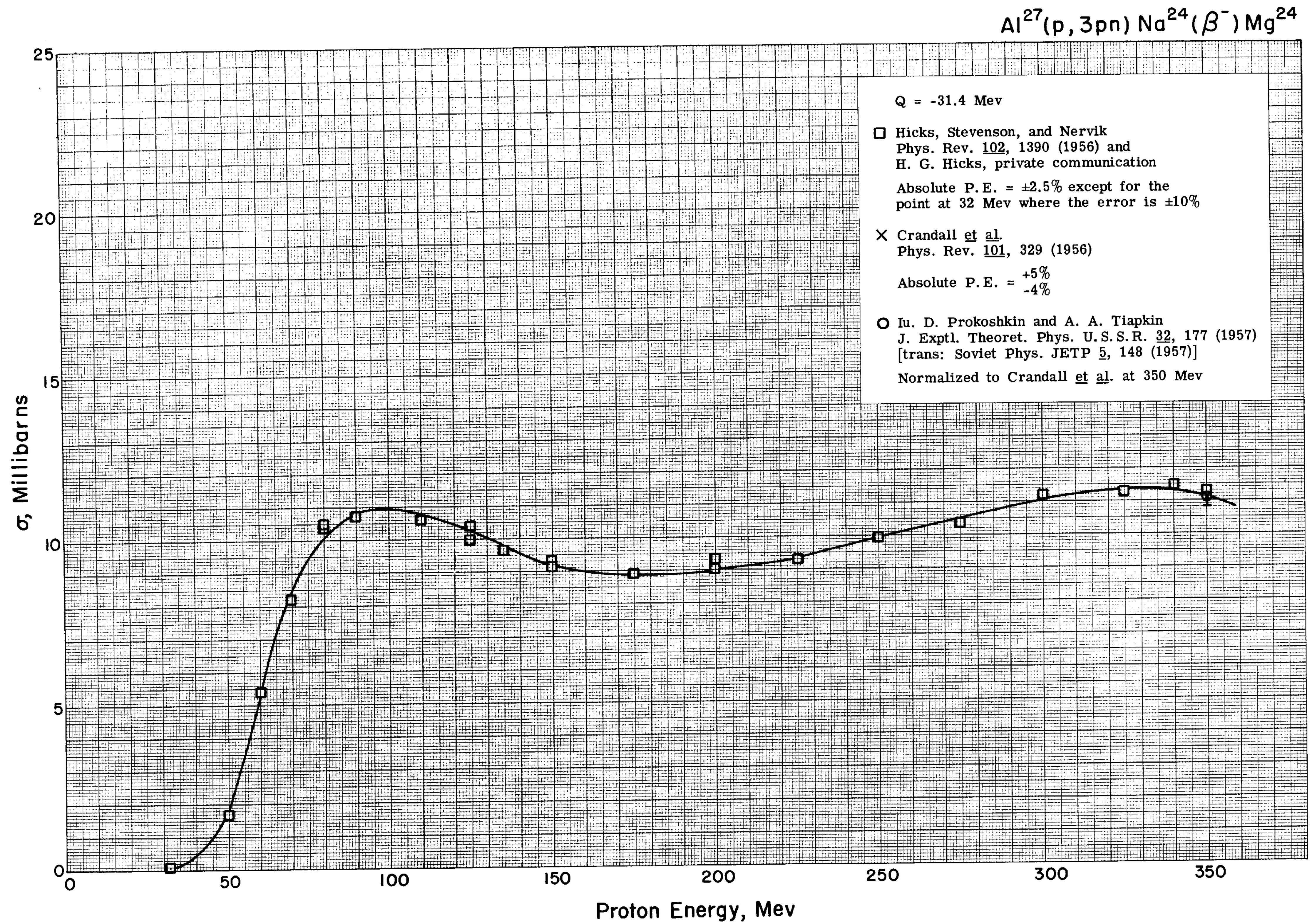




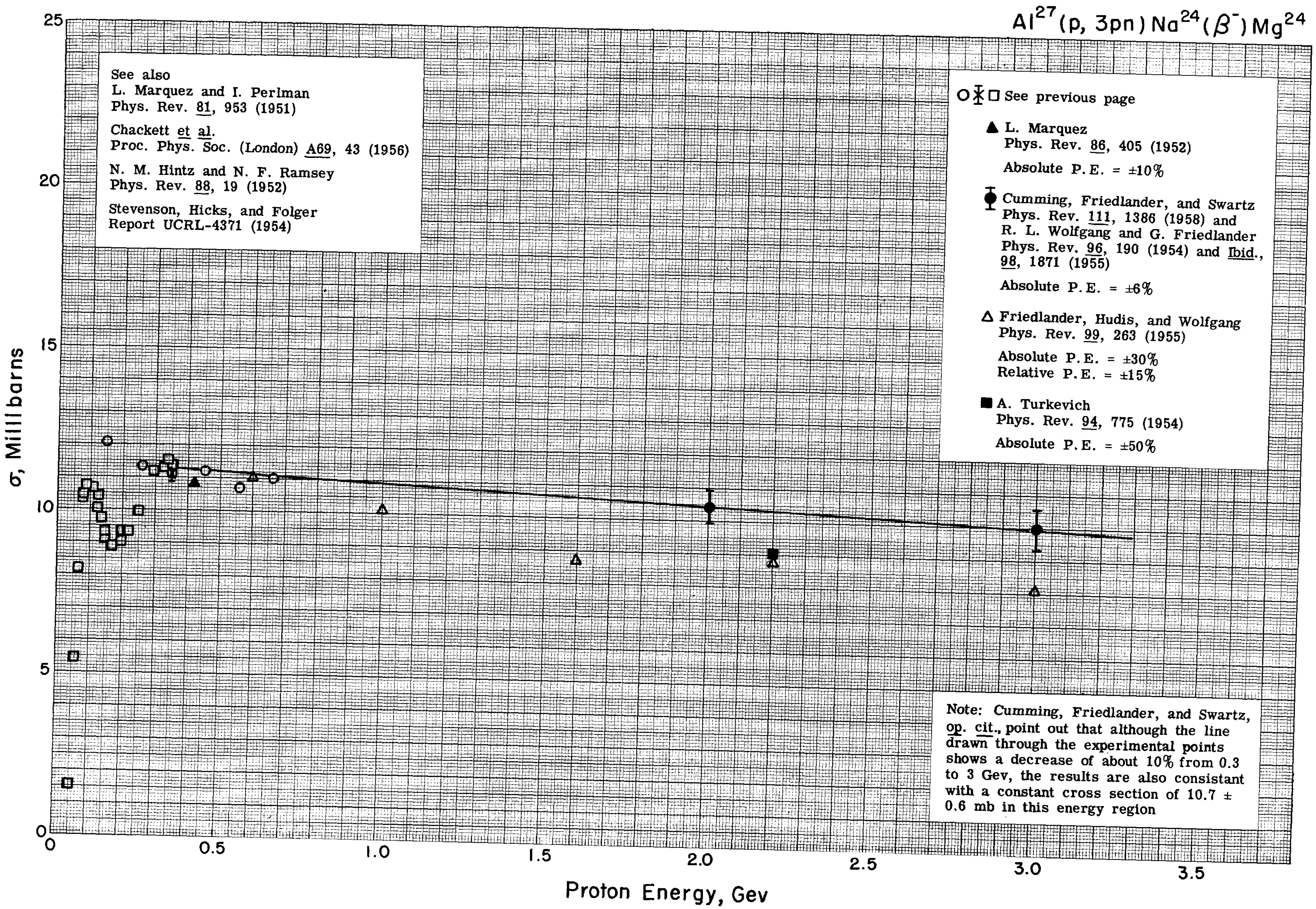
$Al^{27}(p, \alpha)Mg^{24}$
Q = 1.60 Mev
Fischer et al.
Phys. Rev. 110, 286 (1958)
Maximum absolute P.E. = ±15%
C. B. Fulmer and B. L. Cohen
Phys. Rev. 112, 1672 (1958)
Total cross section at 23 Mev
is 175 ±50% mb.
E_p = 10.97 Mev
E_p = 10.87 Mev
σ (θ), Millibarns per Steradian
Lab Angle of Alpha, θ
σ (θ'), Millibarns per Steradian
C.M. Angle of Alpha, θ'

$Al^{27}(p,\alpha')Mg^{24*}$

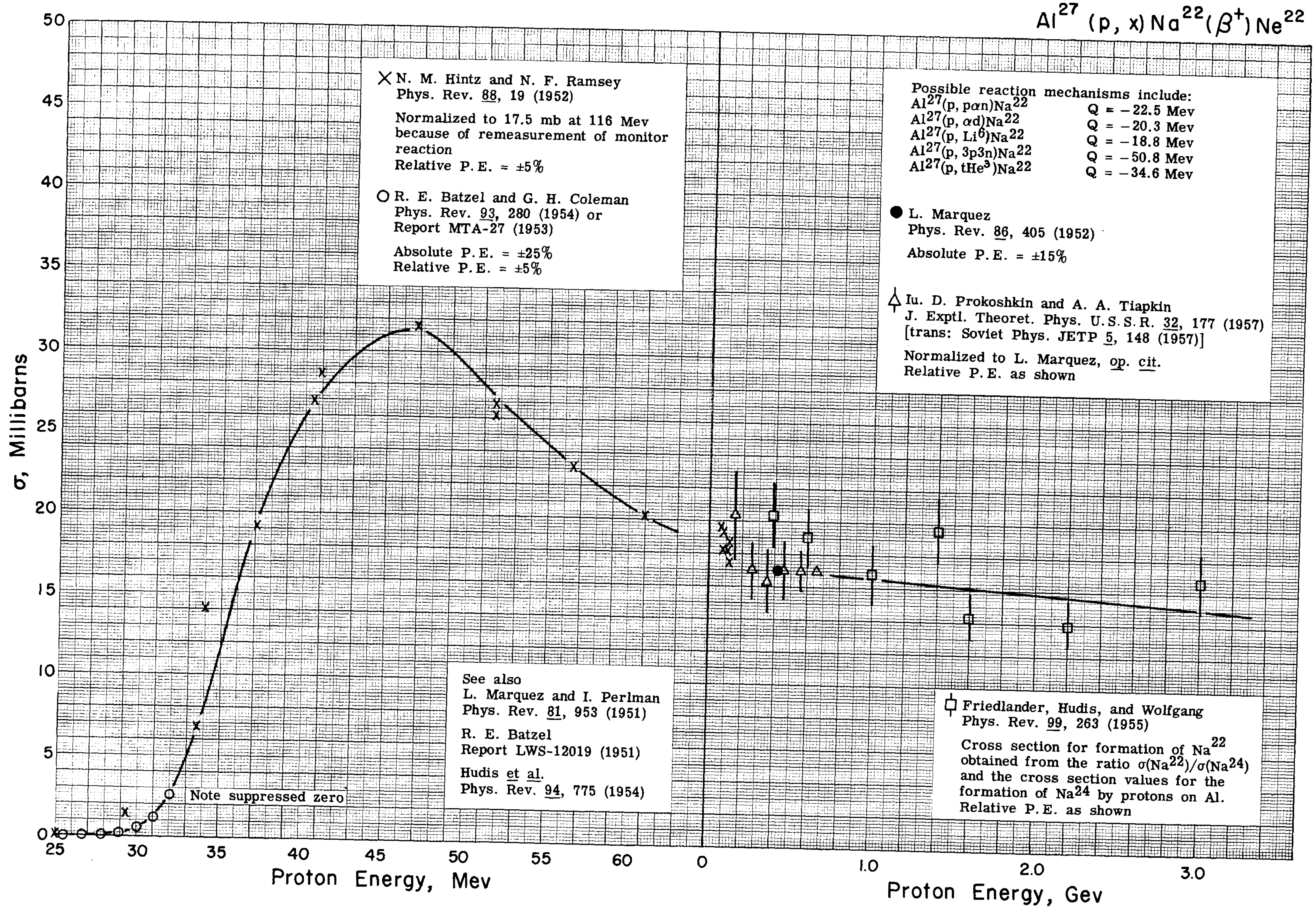




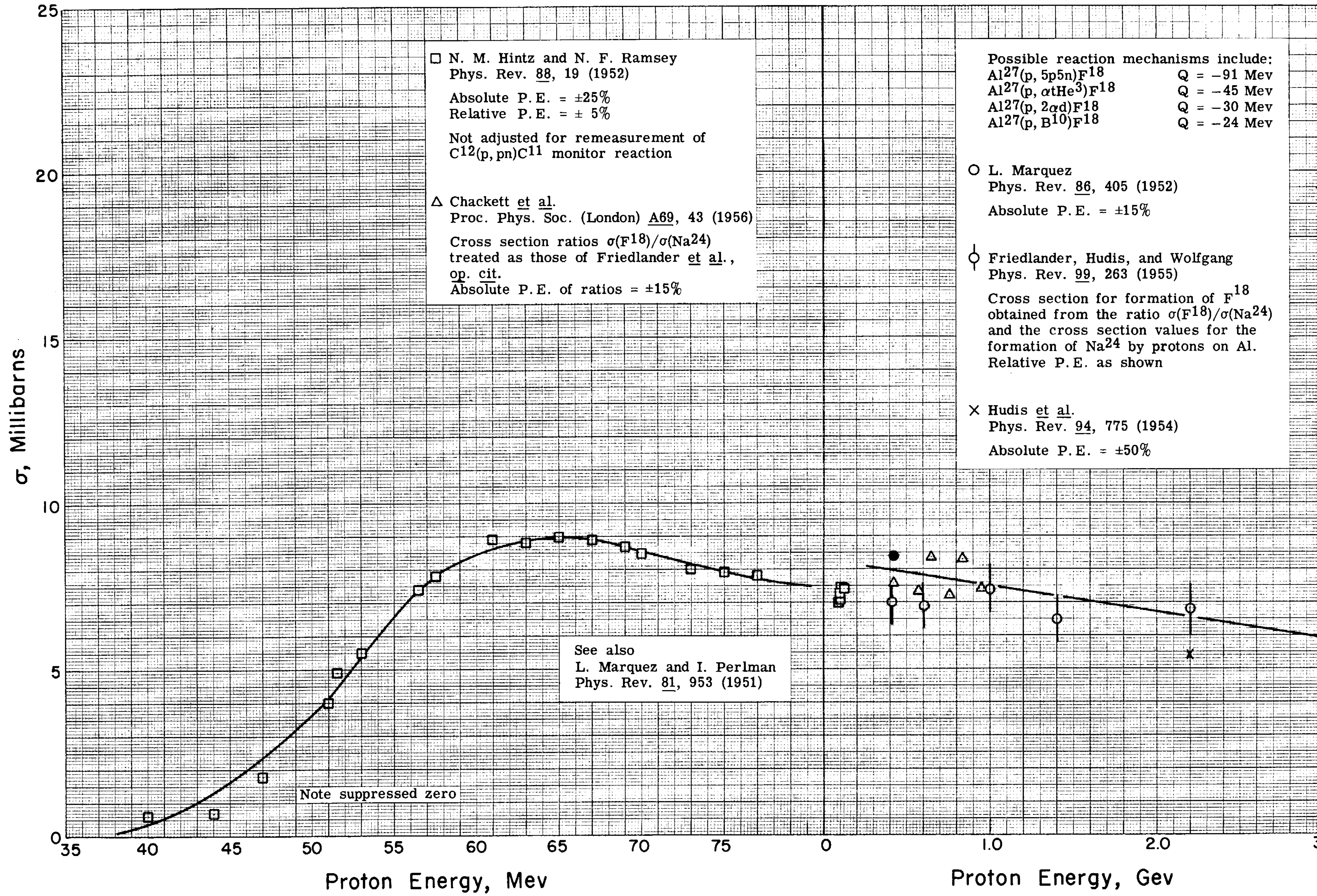
$Al^{27}(p, 3pn)\ Na^{24}(\beta^-)\ Mg^{24}$
Q = -31.4 Mev
□ Hicks, Stevenson, and Nervik
Phys. Rev. 102, 1390 (1956) and
H. G. Hicks, private communication
Absolute P.E. = ±2.5% except for the point at 32 Mev where the error is ±10%
× Crandall et al.
Phys. Rev. 101, 329 (1956)
Absolute P.E. = +5% -4%
○ Iu. D. Prokoshkin and A. A. Tiapkin
J. Exptl. Theoret. Phys. U.S.S.R. 32, 177 (1957)
[trans: Soviet Phys. JETP 5, 148 (1957)]
Normalized to Crandall et al. at 350 Mev
σ, Millibarns
Proton Energy, Mev
0
5
10
15
20
25
0
50
100
150
200
250
300
350


$Al^{27}(p, 3pn)Na^{24}(\beta^-)Mg^{24}$
See also
L. Marquez and I. Perlman
Phys. Rev. 81, 953 (1951)
Chackett et al.
Proc. Phys. Soc. (London) A69, 43 (1956)
N. M. Hintz and N. F. Ramsey
Phys. Rev. 88, 19 (1952)
Stevenson, Hicks, and Folger
Report UCRL-4371 (1954)
See previous page
L. Marquez
Phys. Rev. 86, 405 (1952)
Absolute P.E. = ±10%
Cumming, Friedlander, and Swartz
Phys. Rev. 111, 1386 (1958) and
R. L. Wolfgang and G. Friedlander
Phys. Rev. 96, 190 (1954) and Ibid., 98, 1871 (1955)
Absolute P.E. = ±6%
Friedlander, Hudis, and Wolfgang
Phys. Rev. 99, 263 (1955)
Absolute P.E. = ±30%
Relative P.E. = ±15%
A. Turkevich
Phys. Rev. 94, 775 (1954)
Absolute P.E. = ±50%
Note: Cumming, Friedlander, and Swartz, op. cit., point out that although the line drawn through the experimental points shows a decrease of about 10% from 0.3 to 3 Gev, the results are also consistant with a constant cross section of 10.7 ± 0.6 mb in this energy region
σ, Millibarns
Proton Energy, Gev
0
5
10
15
20
25
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Al^{27} (p, x) Na^{22}(β^+) Ne^{22}



$Al^{27}(p, x)F^{18}(\beta^{+})O^{18}$



$Al^{27}(p, x)N^{13}(\beta^{+})C^{13}$

□ L. Marquez
Phys. Rev. 86, 405 (1952)

Absolute P.E. = ±15%

⊸ Friedlander, Hudis, and Wolfgang
Phys. Rev. 99, 263 (1955)

Cross sections for the formation of N^{13} were obtained from the ratios $\sigma(N^{13})/\sigma(Na^{24})$ and the cross section values for the formation of Na^{24} by protons on Al
Relative P.E. as shown

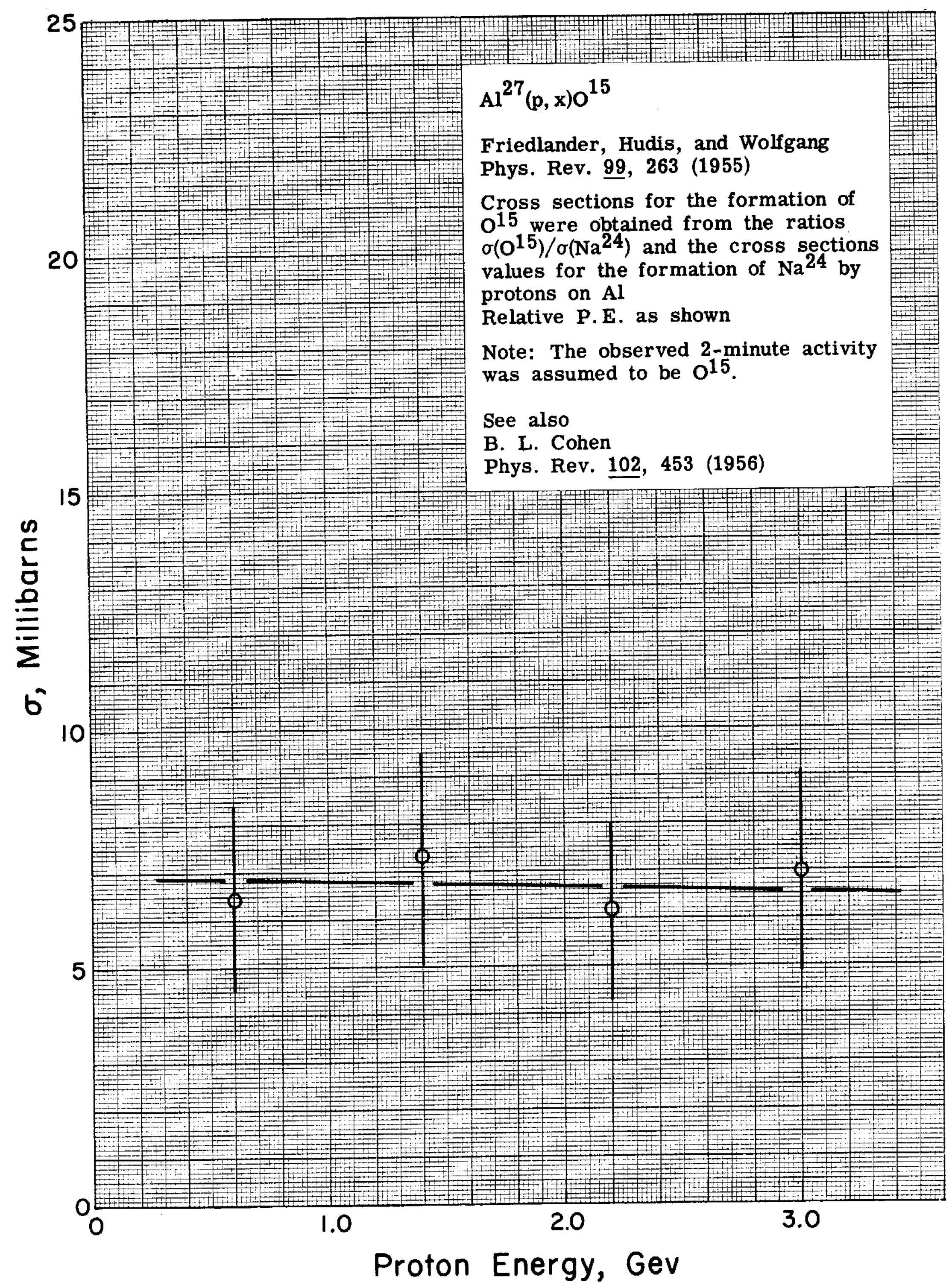
✶ Chackett et al.
Proc. Phys. Soc. (London) A69, 43 (1956)

Preliminary ratio $\sigma(N^{13})/\sigma(Na^{24})$ was treated as those of the above reference

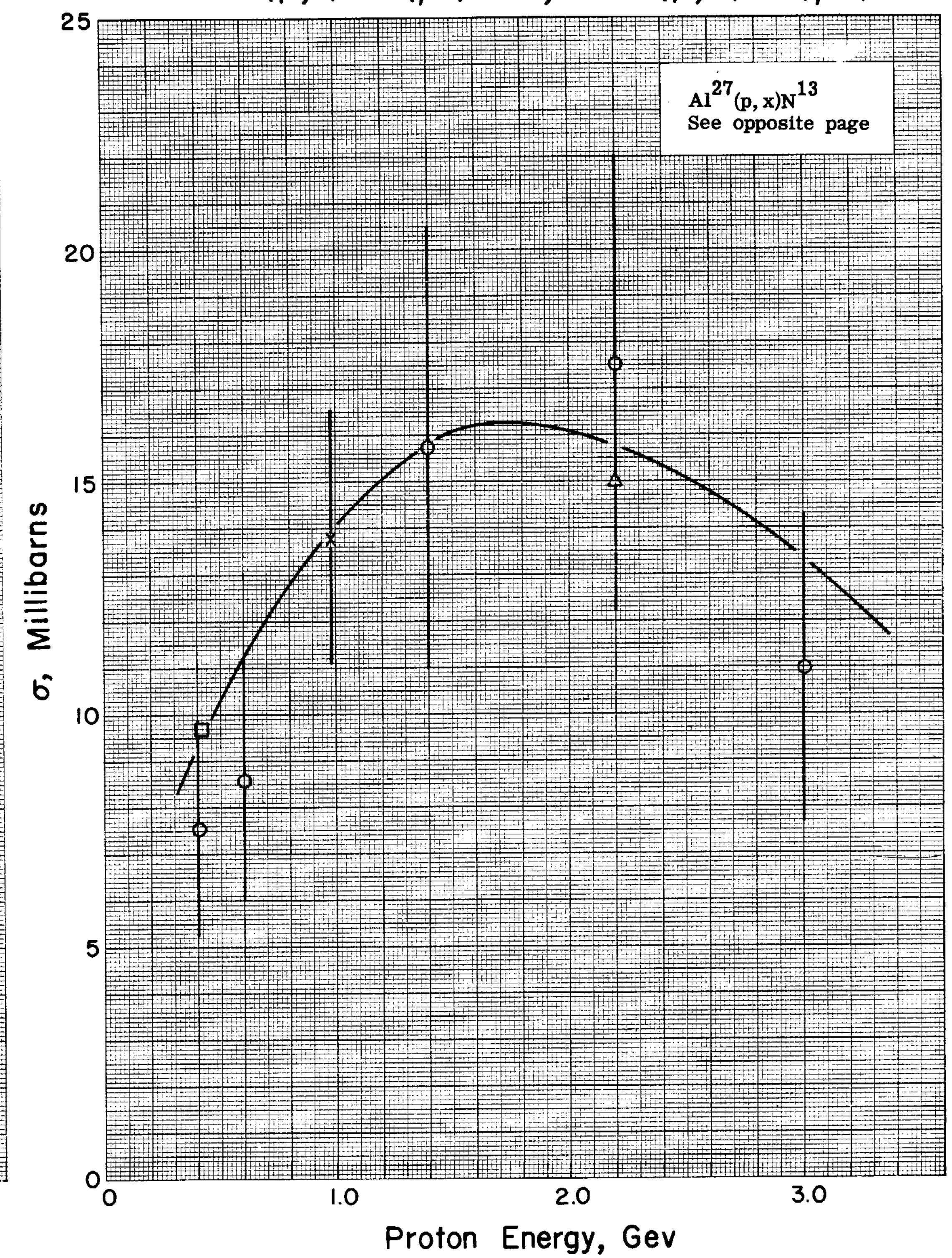
△ Hudis et al.
Phys. Rev. 94, 775 (1954)

Absolute P. E. = ±50%

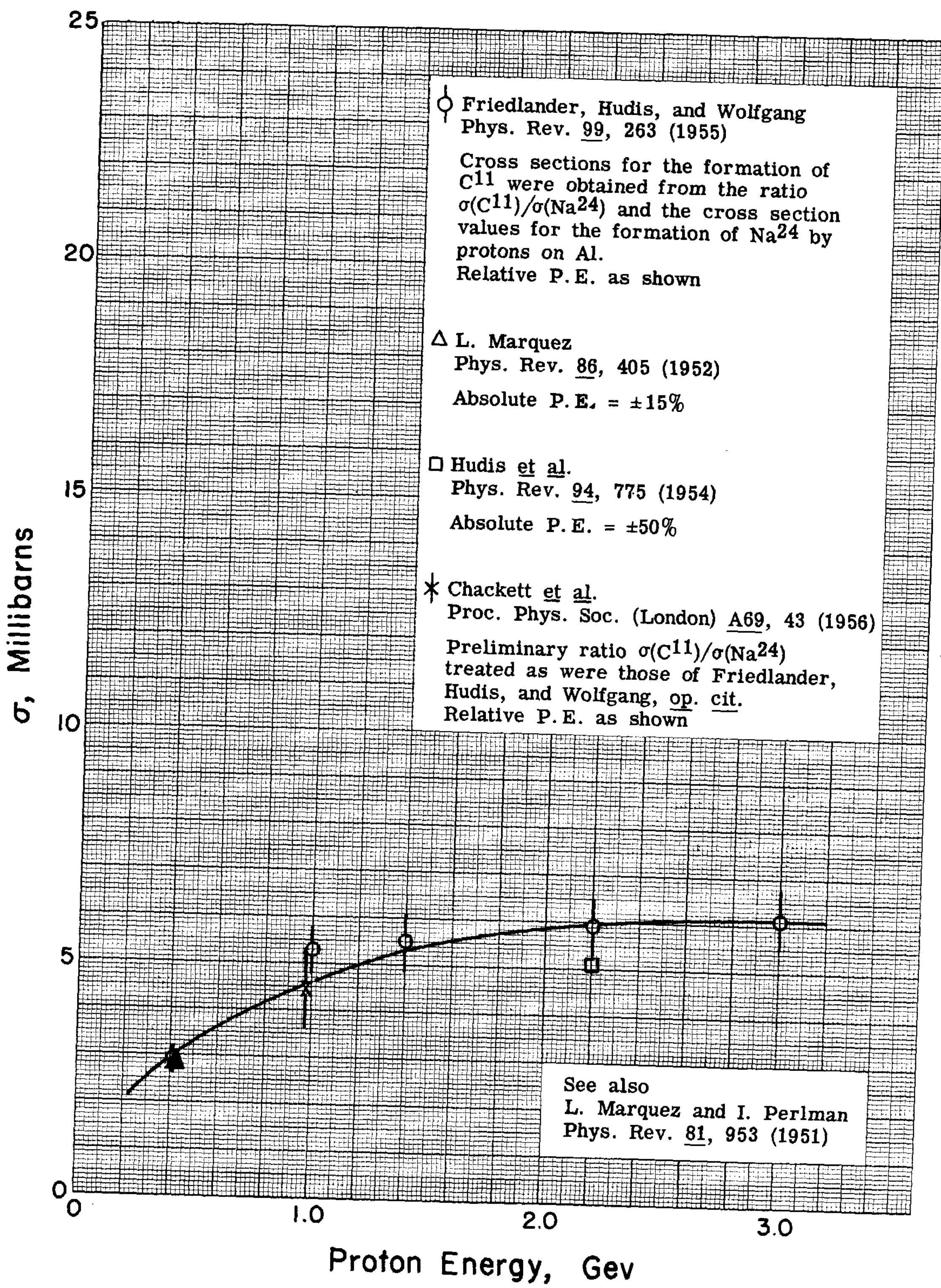
See also
B. L. Cohen
Phys. Rev. 102, 453 (1956)

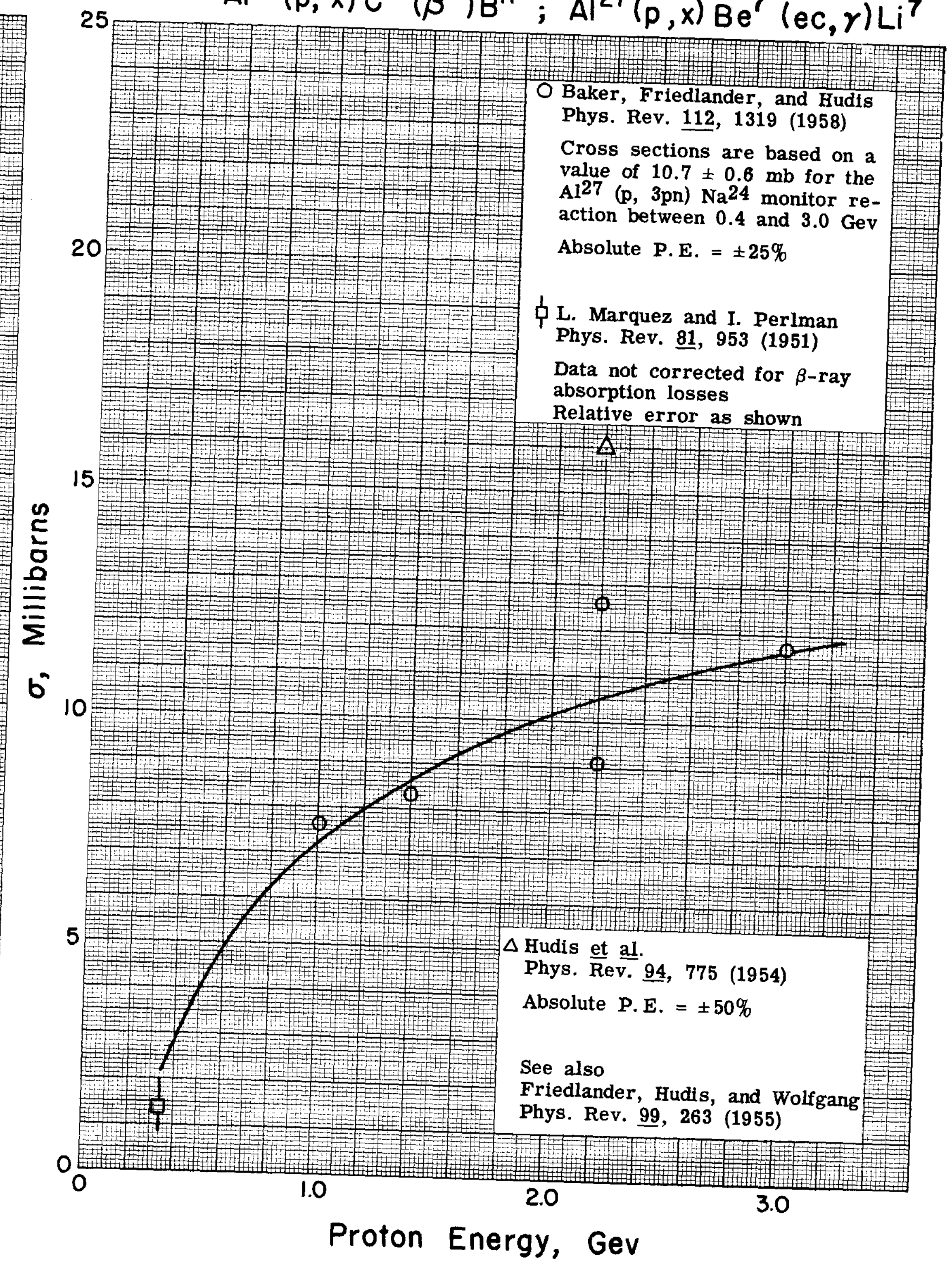


$Al^{27}(p,x)O^{15}(\beta^+)N^{15}$; $Al^{27}(p,x)N^{13}(\beta^+)C^{13}$

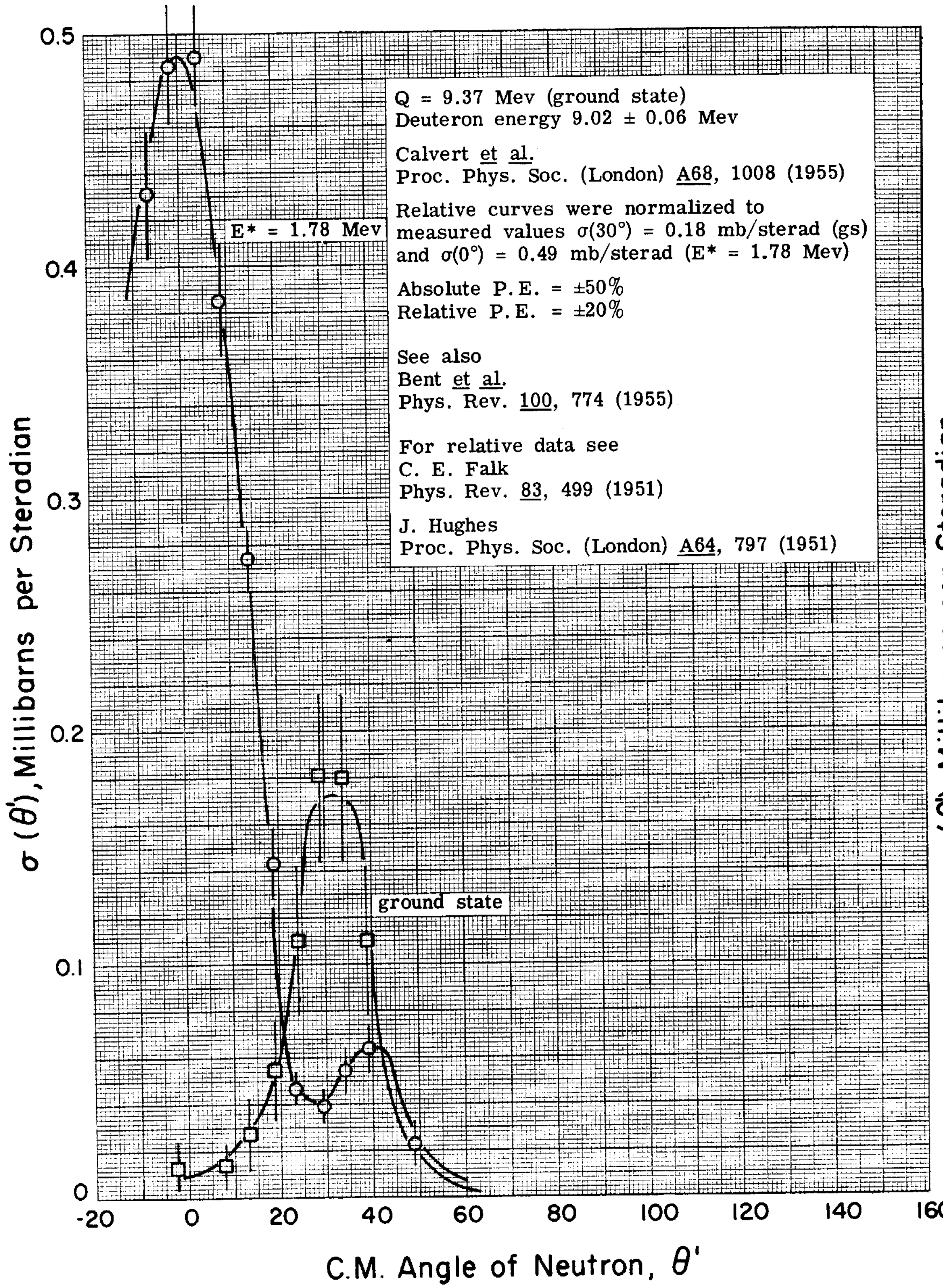


$Al^{27}(p, x)C^{11}(\beta^+)B^{11}$; $Al^{27}(p,x)Be^7(ec,\gamma)Li^7$

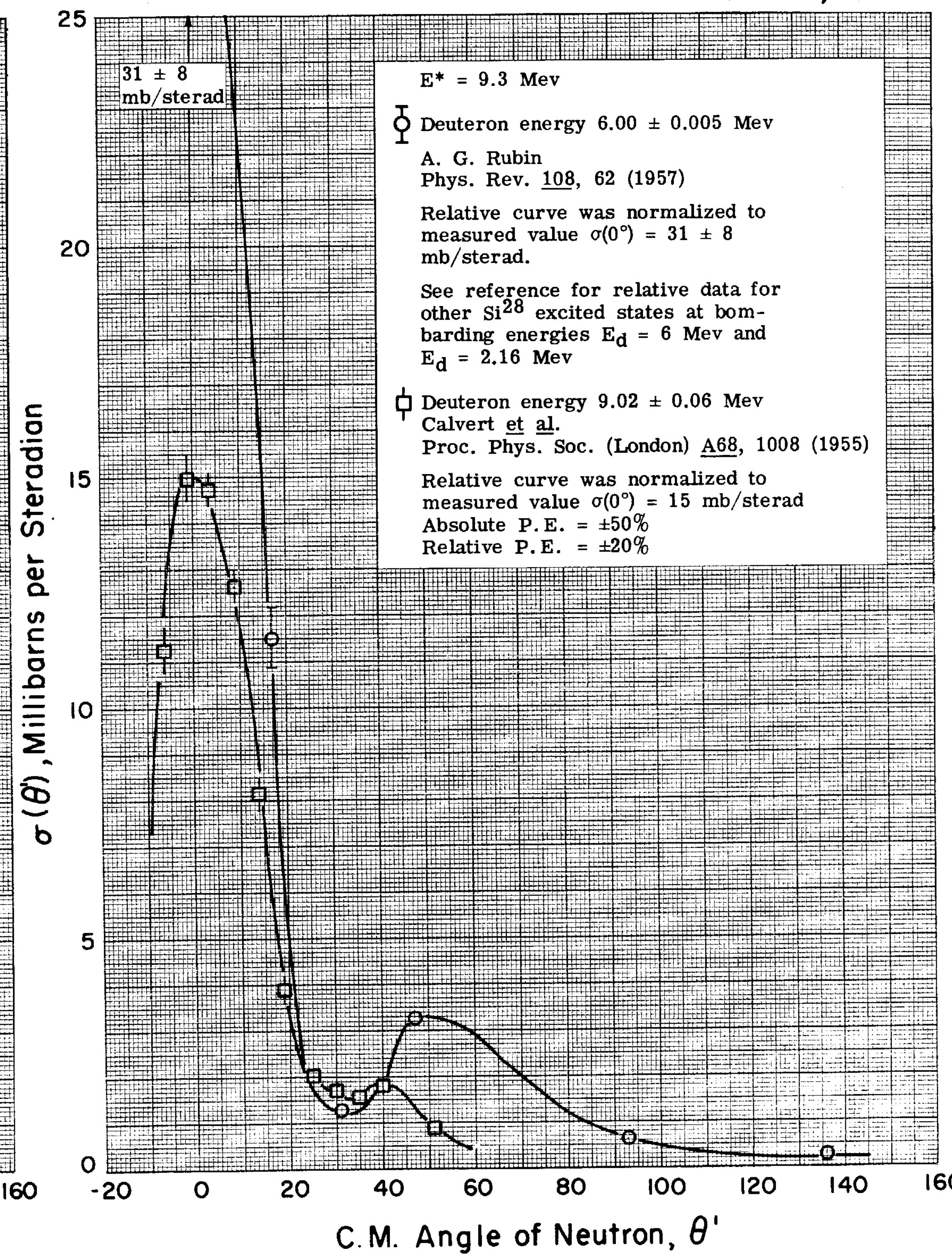




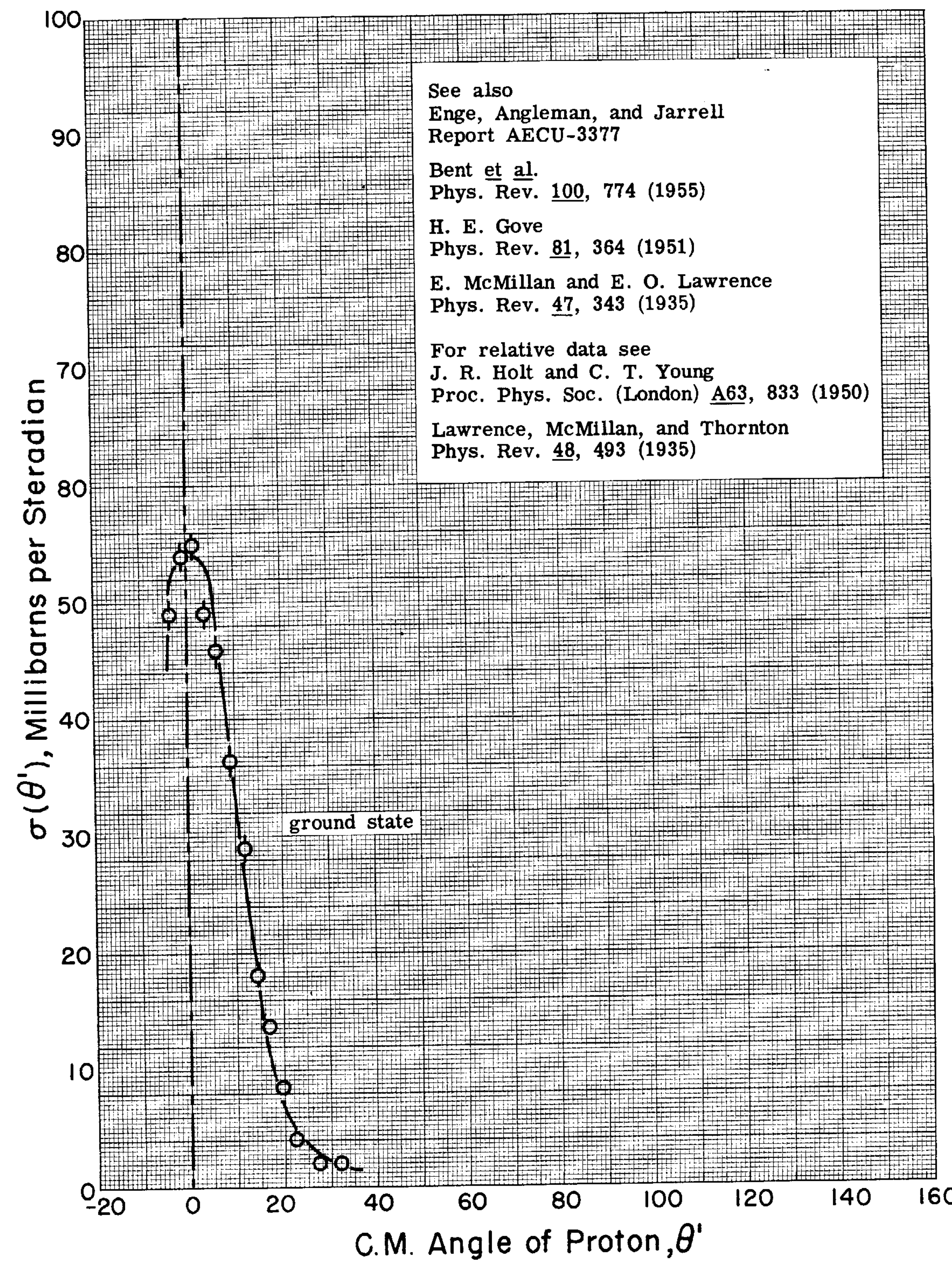
$Al^{27}(d,n')Si^{28*}$

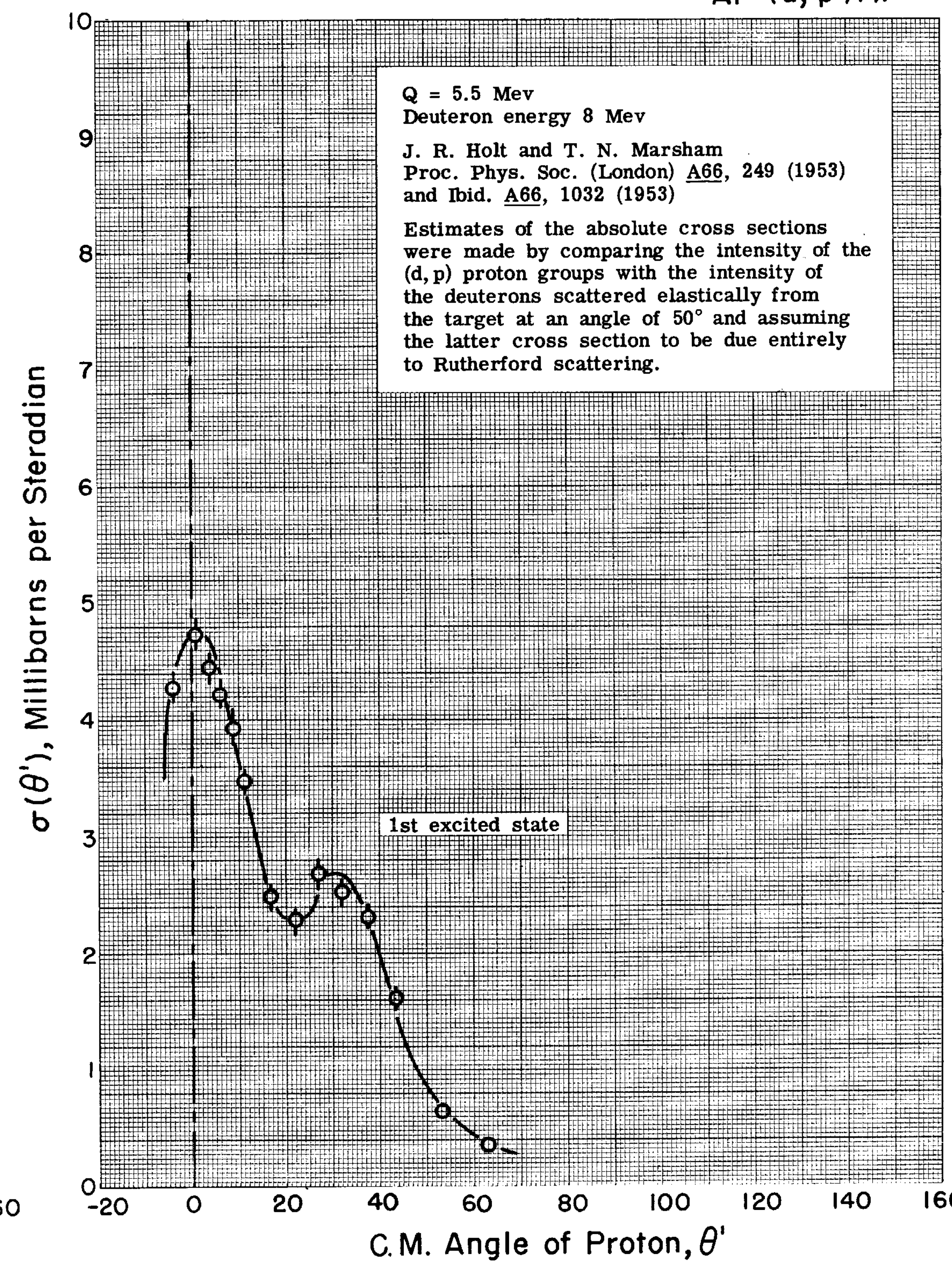


Q = 9.37 Mev (ground state)
Deuteron energy 9.02 ± 0.06 Mev
Calvert et al.
Proc. Phys. Soc. (London) A68, 1008 (1955)
Relative curves were normalized to measured values σ(30°) = 0.18 mb/sterad (gs) and σ(0°) = 0.49 mb/sterad (E* = 1.78 Mev)
Absolute P.E. = ±50%
Relative P.E. = ±20%
See also
Bent et al.
Phys. Rev. 100, 774 (1955)
For relative data see
C. E. Falk
Phys. Rev. 83, 499 (1951)
J. Hughes
Proc. Phys. Soc. (London) A64, 797 (1951)
E* = 1.78 Mev
ground state
σ (θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'

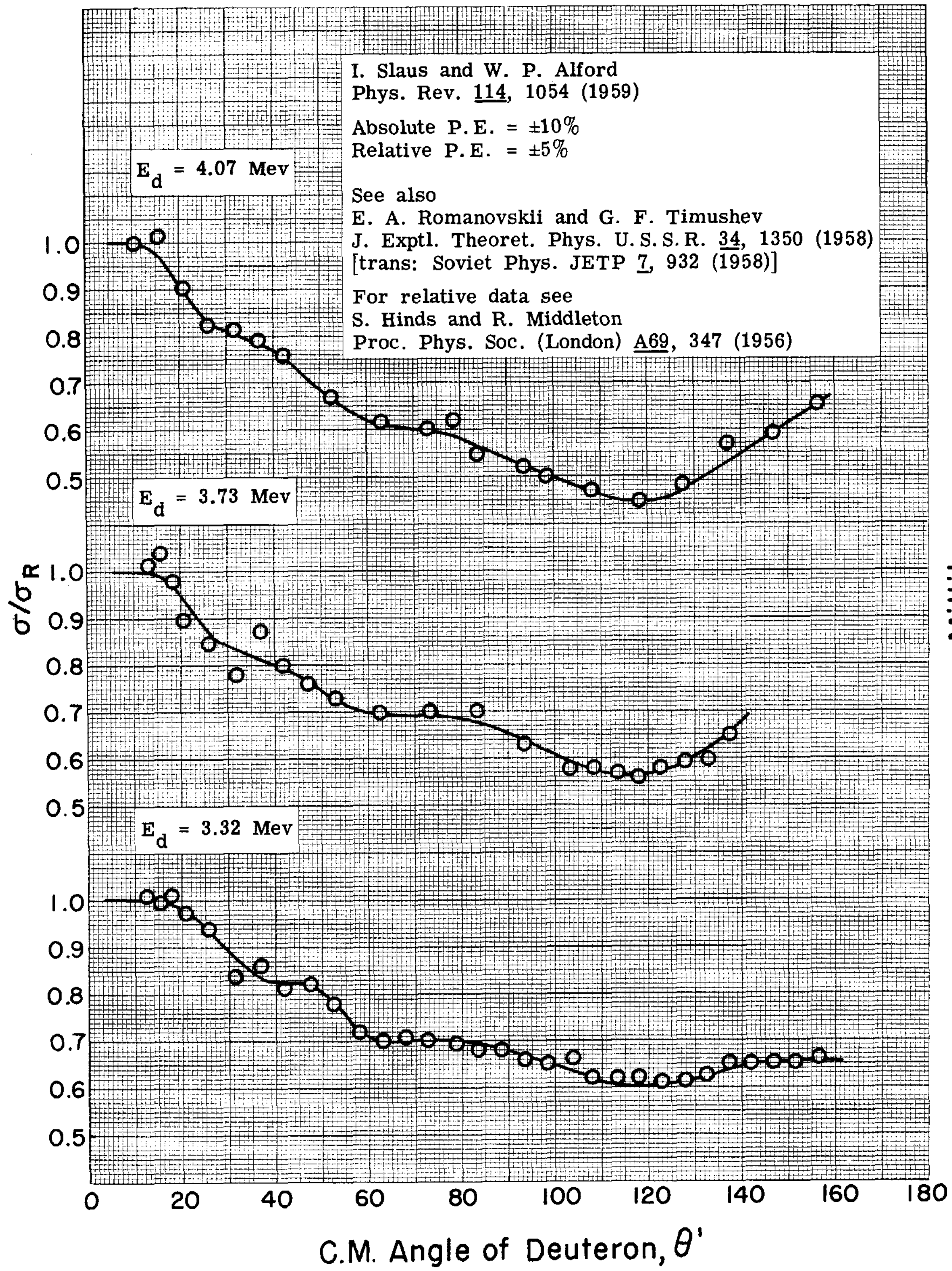


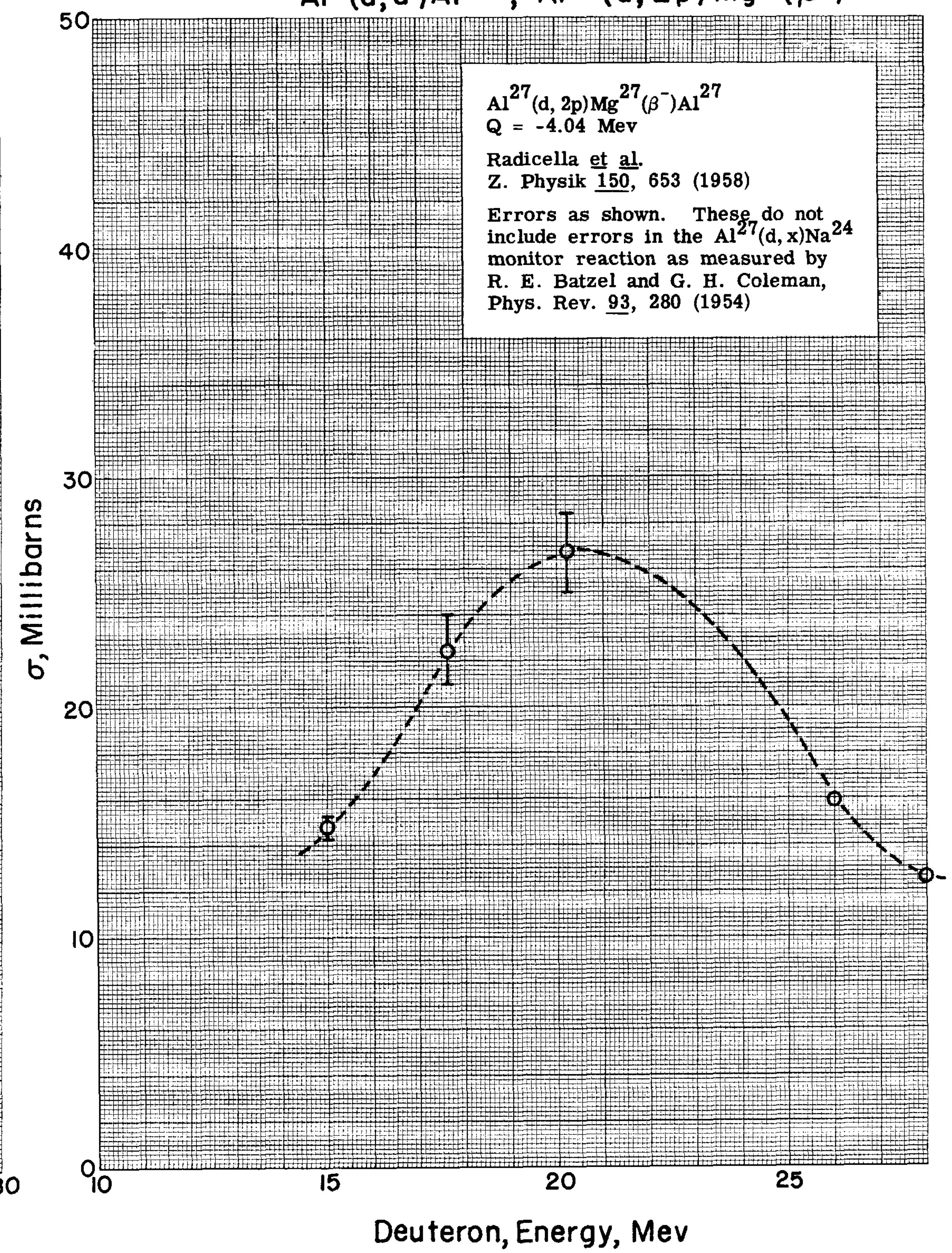
31 ± 8 mb/sterad
E* = 9.3 Mev
Deuteron energy 6.00 ± 0.005 Mev
A. G. Rubin
Phys. Rev. 108, 62 (1957)
Relative curve was normalized to measured value σ(0°) = 31 ± 8 mb/sterad.
See reference for relative data for other Si28 excited states at bombarding energies Ed = 6 Mev and Ed = 2.16 Mev
Deuteron energy 9.02 ± 0.06 Mev
Calvert et al.
Proc. Phys. Soc. (London) A68, 1008 (1955)
Relative curve was normalized to measured value σ(0°) = 15 mb/sterad
Absolute P.E. = ±50%
Relative P.E. = ±20%
σ (θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'


See also
Enge, Angleman, and Jarrell
Report AECU-3377
Bent et al.
Phys. Rev. 100, 774 (1955)
H. E. Gove
Phys. Rev. 81, 364 (1951)
E. McMillan and E. O. Lawrence
Phys. Rev. 47, 343 (1935)
For relative data see
J. R. Holt and C. T. Young
Proc. Phys. Soc. (London) A63, 833 (1950)
Lawrence, McMillan, and Thornton
Phys. Rev. 48, 493 (1935)
ground state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
100
90
80
70
80
50
40
30
20
10
0
-20
0
20
40
60
80
100
120
140
160

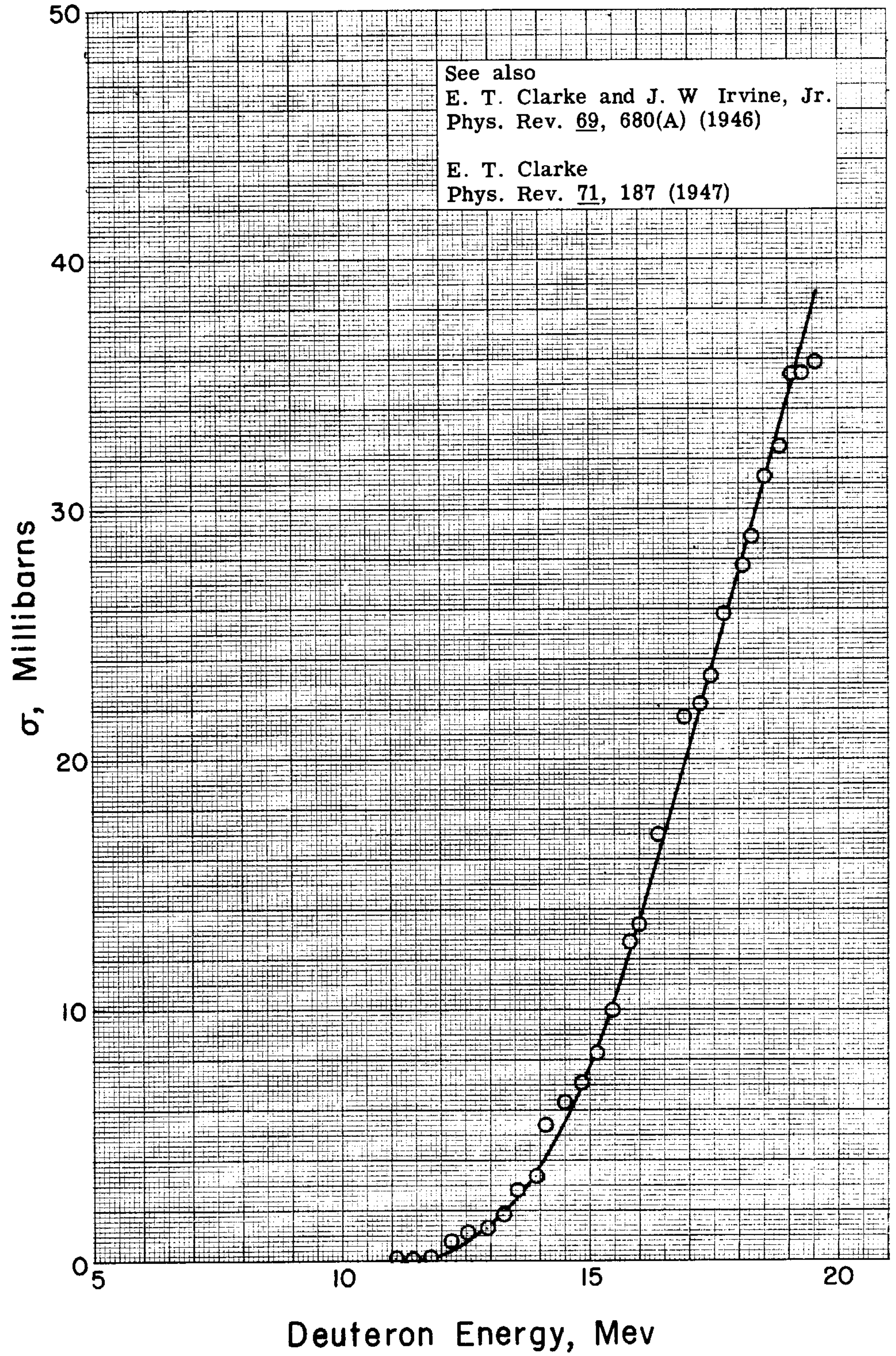

Q = 5.5 Mev
Deuteron energy 8 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 249 (1953)
and Ibid. A66, 1032 (1953)
Estimates of the absolute cross sections were made by comparing the intensity of the (d, p) proton groups with the intensity of the deuterons scattered elastically from the target at an angle of 50° and assuming the latter cross section to be due entirely to Rutherford scattering.
1st excited state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
10
9
8
7
6
5
4
3
2
1
0
-20
0
20
40
60
80
100
120
140
160

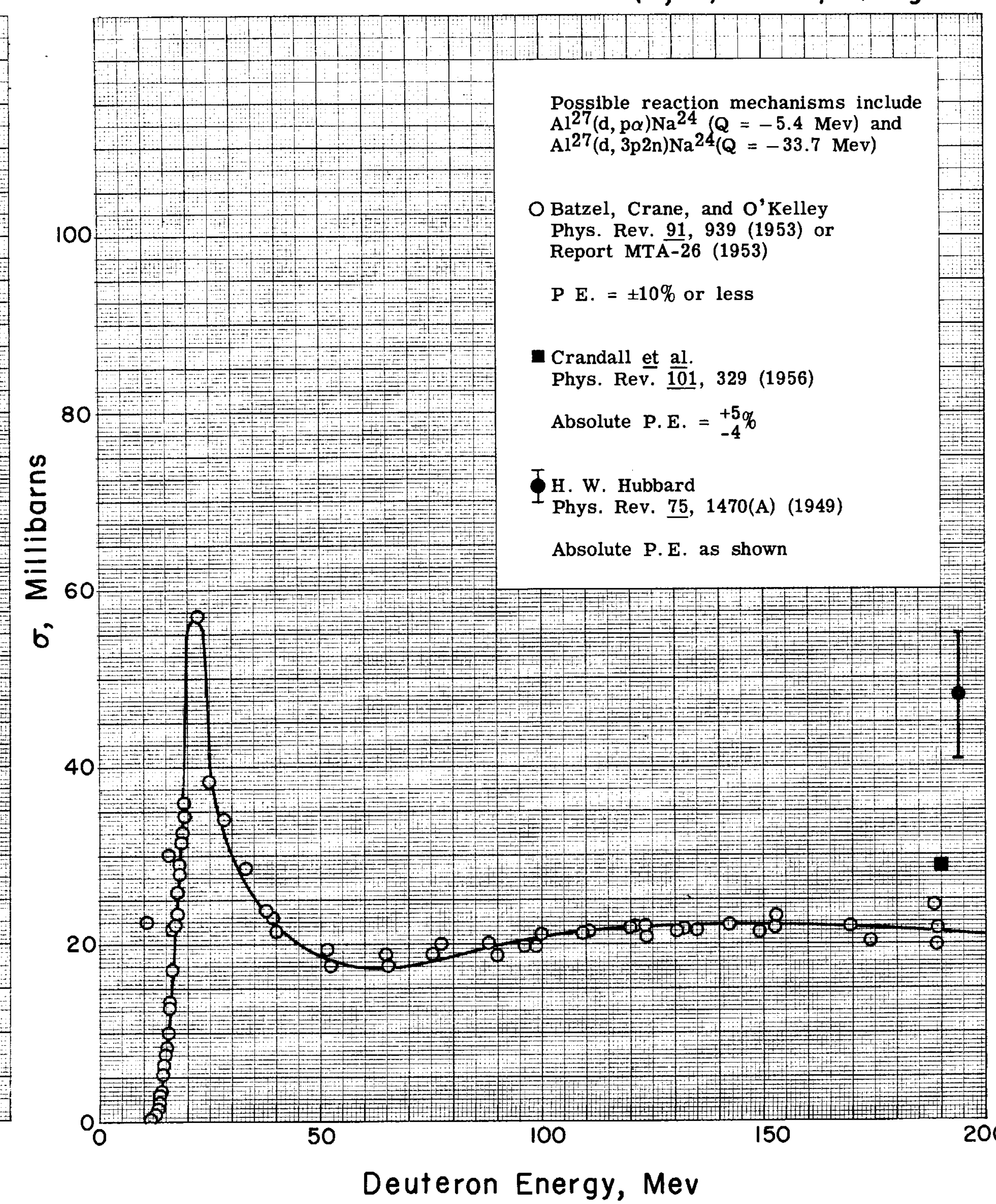
$Al^{27}(d,d)Al^{27}$; $Al^{27}(d,2p)Mg^{27}(\beta^-)Al^{27}$

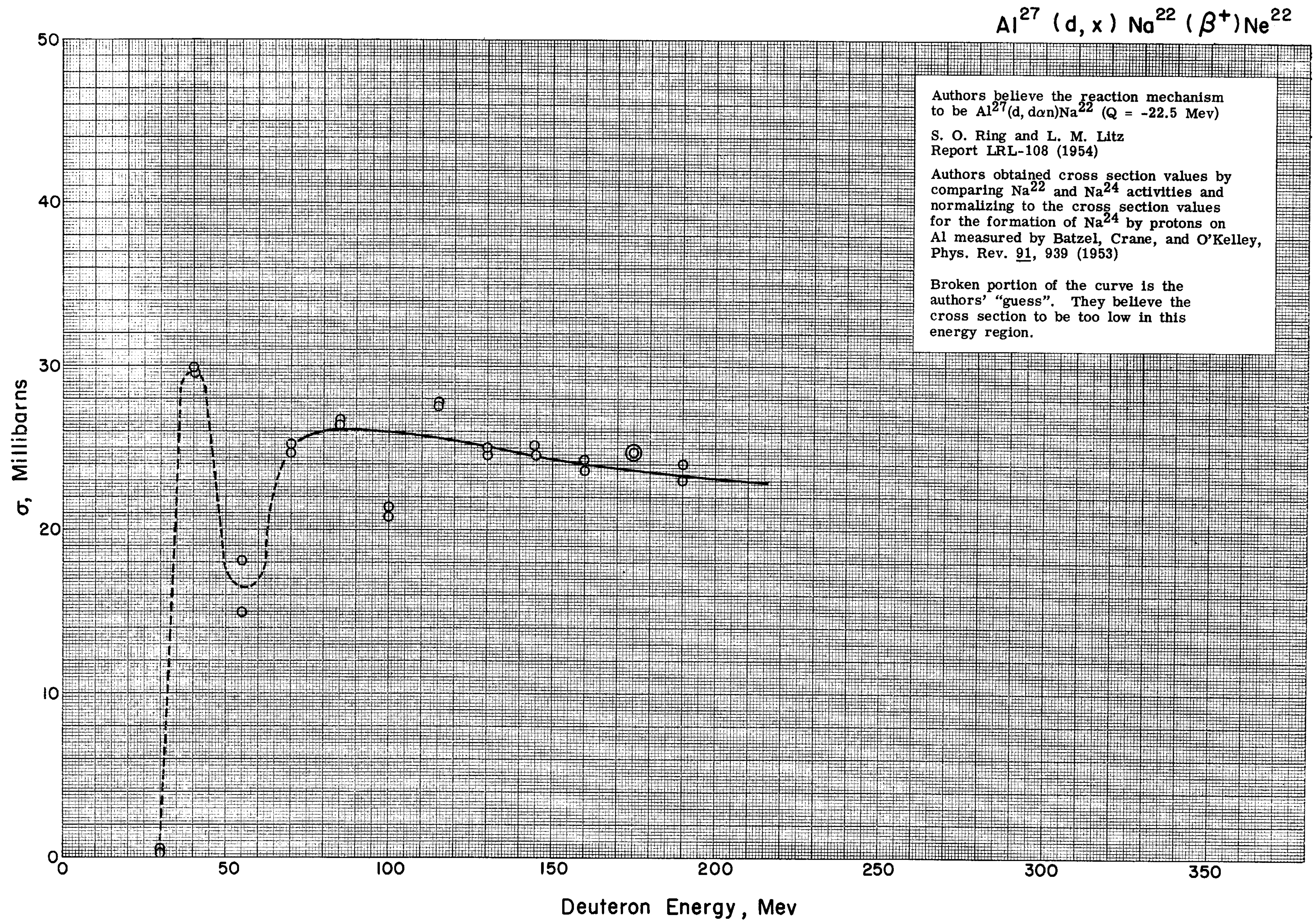


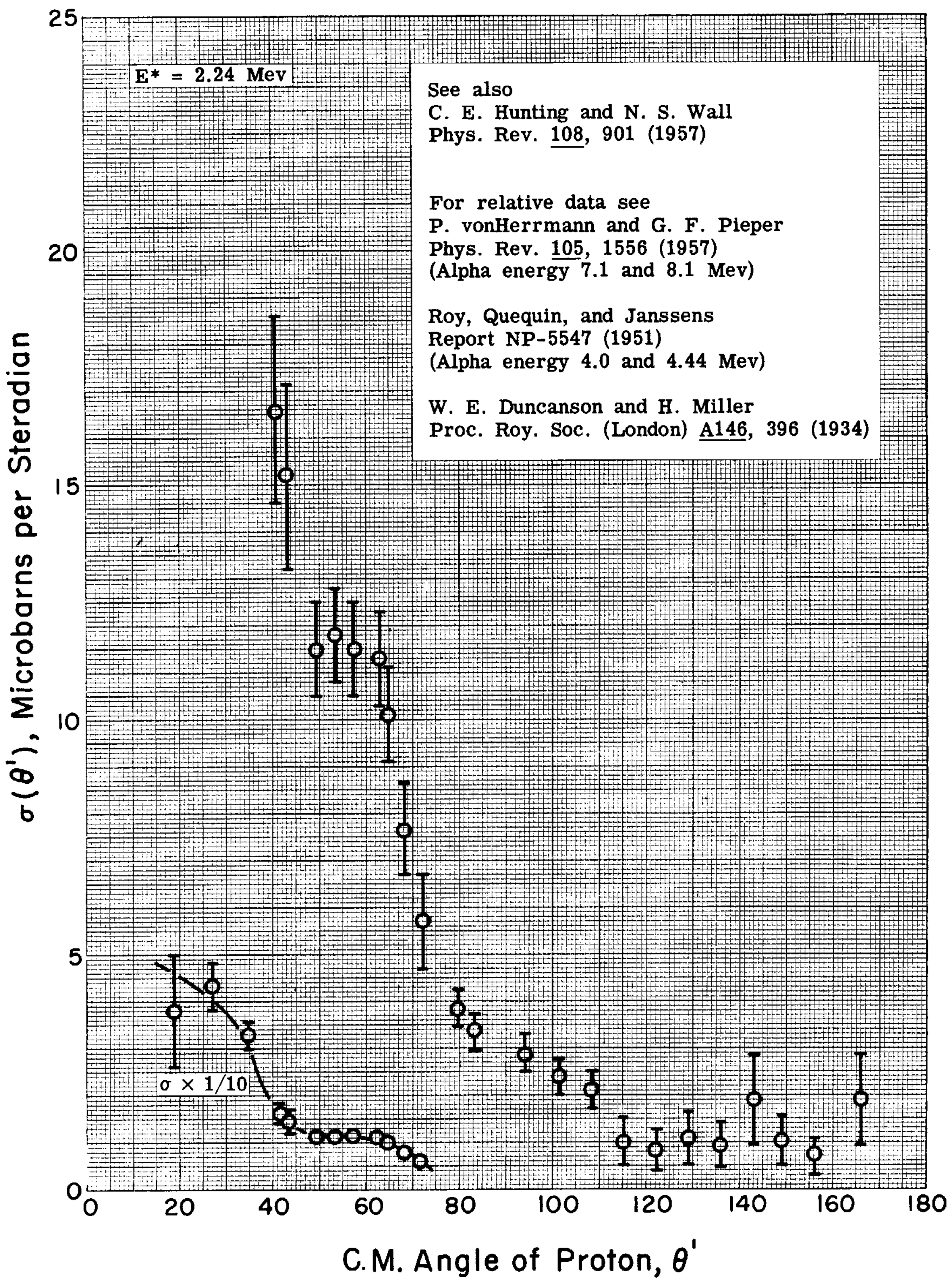


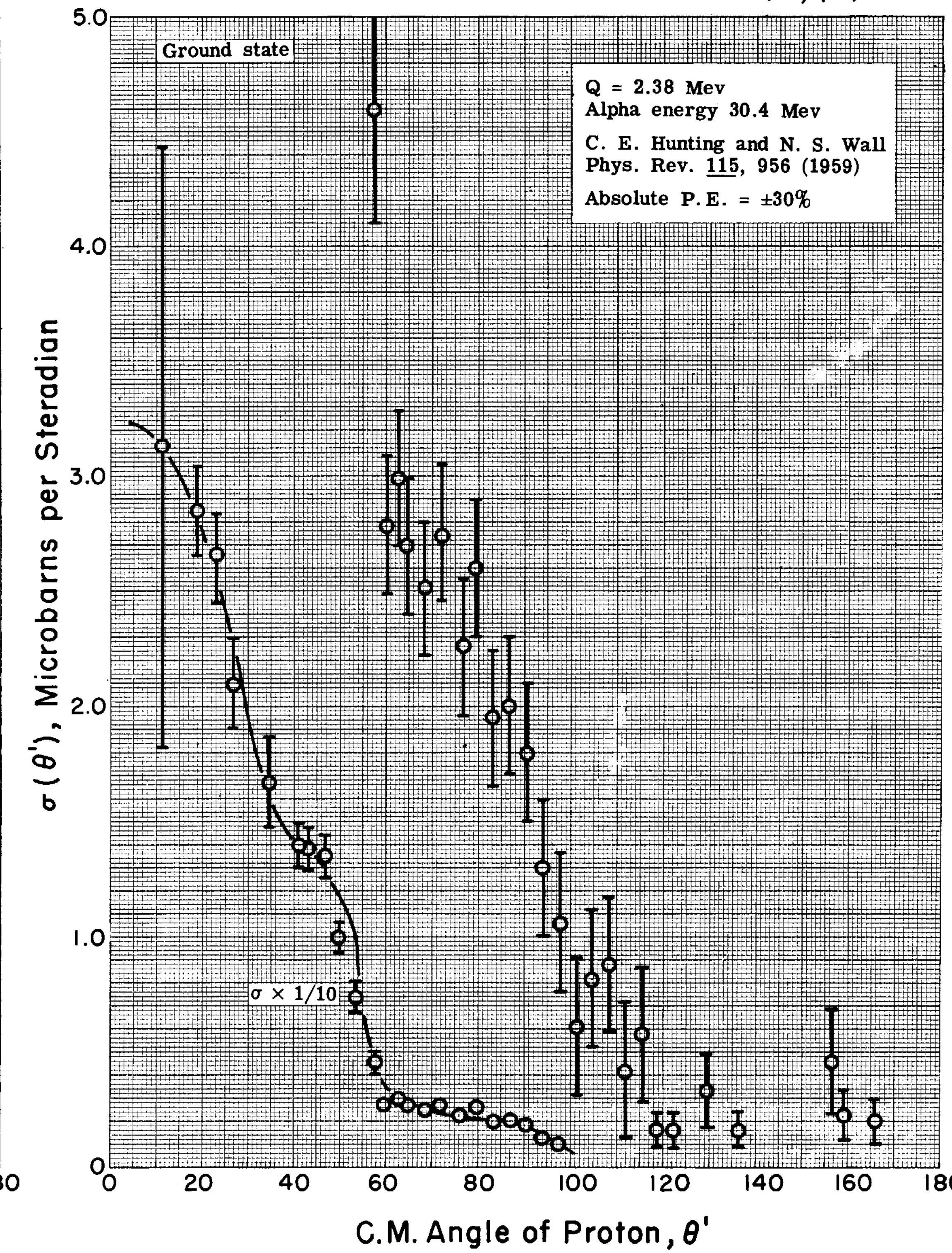
Al^{27} (d, x) Na^{24} (β^-) Mg^{24}



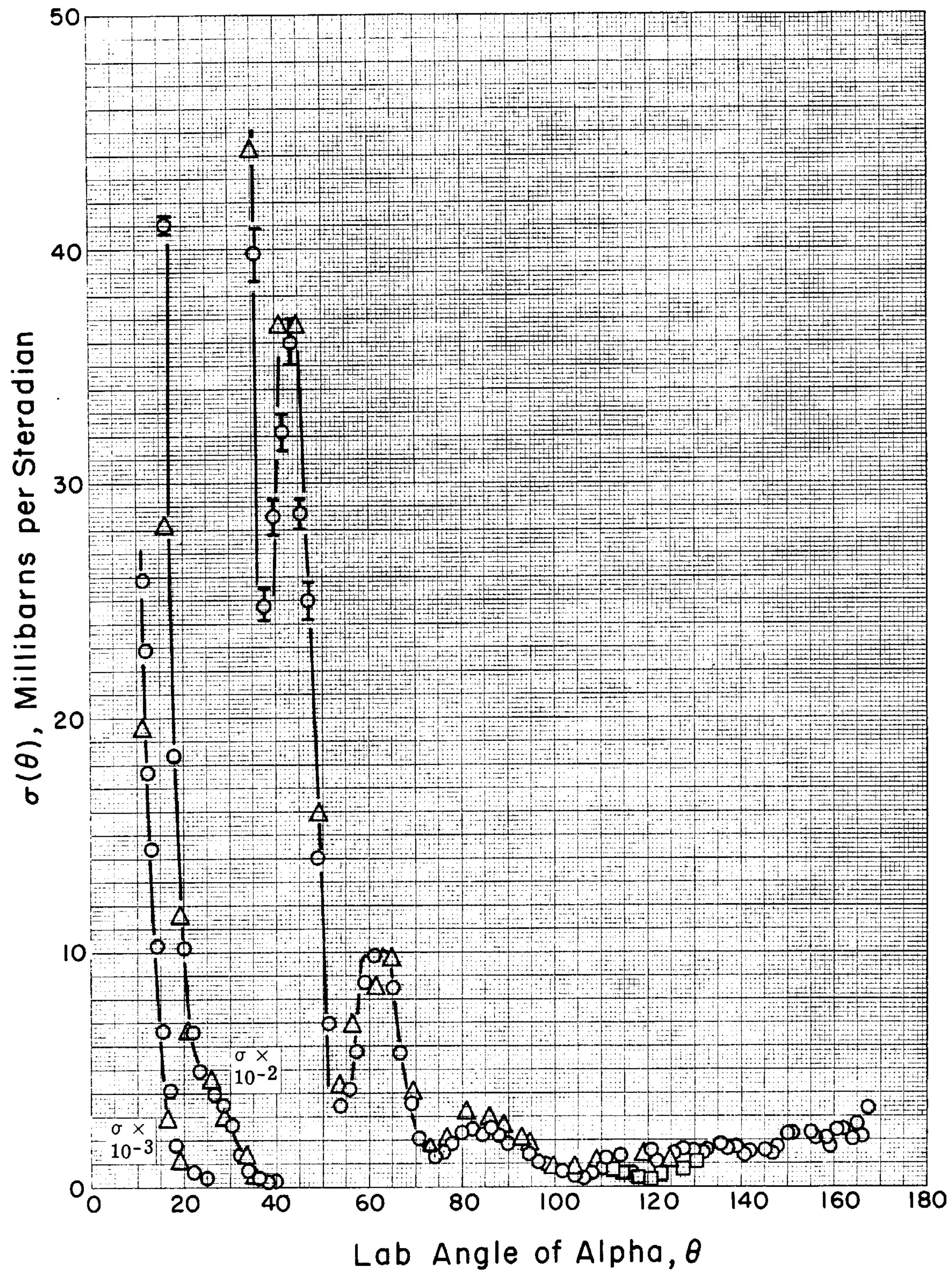


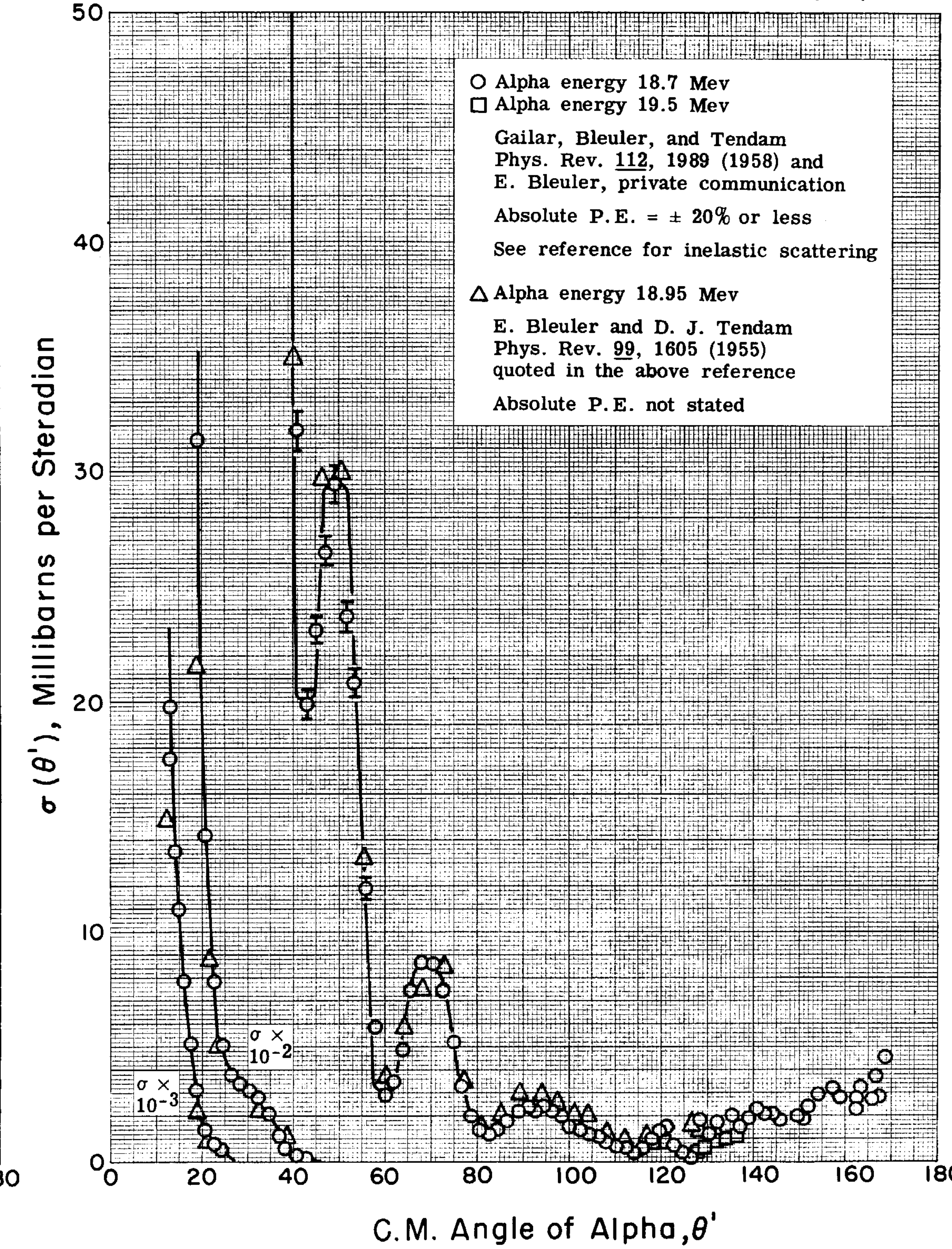

Al^{27} (d, x) Na^{22} (β^+) Ne^{22}
Authors believe the reaction mechanism to be Al^{27}(d, dαn)Na^{22} (Q = -22.5 Mev)
S. O. Ring and L. M. Litz Report LRL-108 (1954)
Authors obtained cross section values by comparing Na^{22} and Na^{24} activities and normalizing to the cross section values for the formation of Na^{24} by protons on Al measured by Batzel, Crane, and O'Kelley, Phys. Rev. 91, 939 (1953)
Broken portion of the curve is the authors' "guess". They believe the cross section to be too low in this energy region.
σ, Millibarns
Deuteron Energy, Mev
0
10
20
30
40
50
0
50
100
150
200
250
300
350

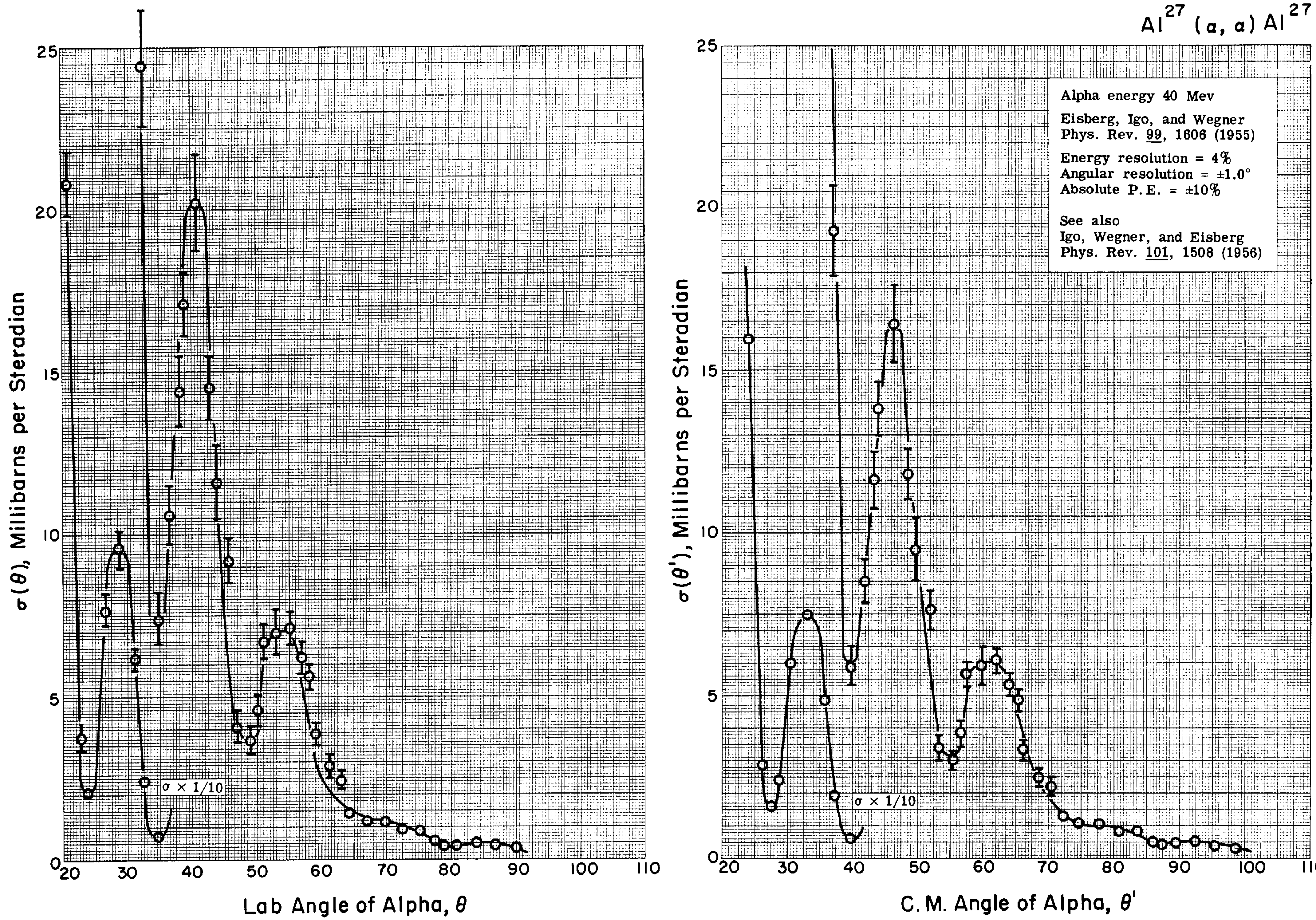

E* = 2.24 Mev
See also
C. E. Hunting and N. S. Wall
Phys. Rev. 108, 901 (1957)
For relative data see
P. vonHerrmann and G. F. Pieper
Phys. Rev. 105, 1556 (1957)
(Alpha energy 7.1 and 8.1 Mev)
Roy, Quequin, and Janssens
Report NP-5547 (1951)
(Alpha energy 4.0 and 4.44 Mev)
W. E. Duncanson and H. Miller
Proc. Roy. Soc. (London) A146, 396 (1934)
σ × 1/10
σ(θ'), Microbarns per Steradian
C.M. Angle of Proton, θ'
0
5
10
15
20
25
20
40
60
80
100
120
140
160
180


Ground state
Q = 2.38 Mev
Alpha energy 30.4 Mev
C. E. Hunting and N. S. Wall
Phys. Rev. 115, 956 (1959)
Absolute P.E. = ±30%
σ × 1/10
σ(θ'), Microbarns per Steradian
C.M. Angle of Proton, θ'
0
1.0
2.0
3.0
4.0
5.0
20
40
60
80
100
120
140
160
180

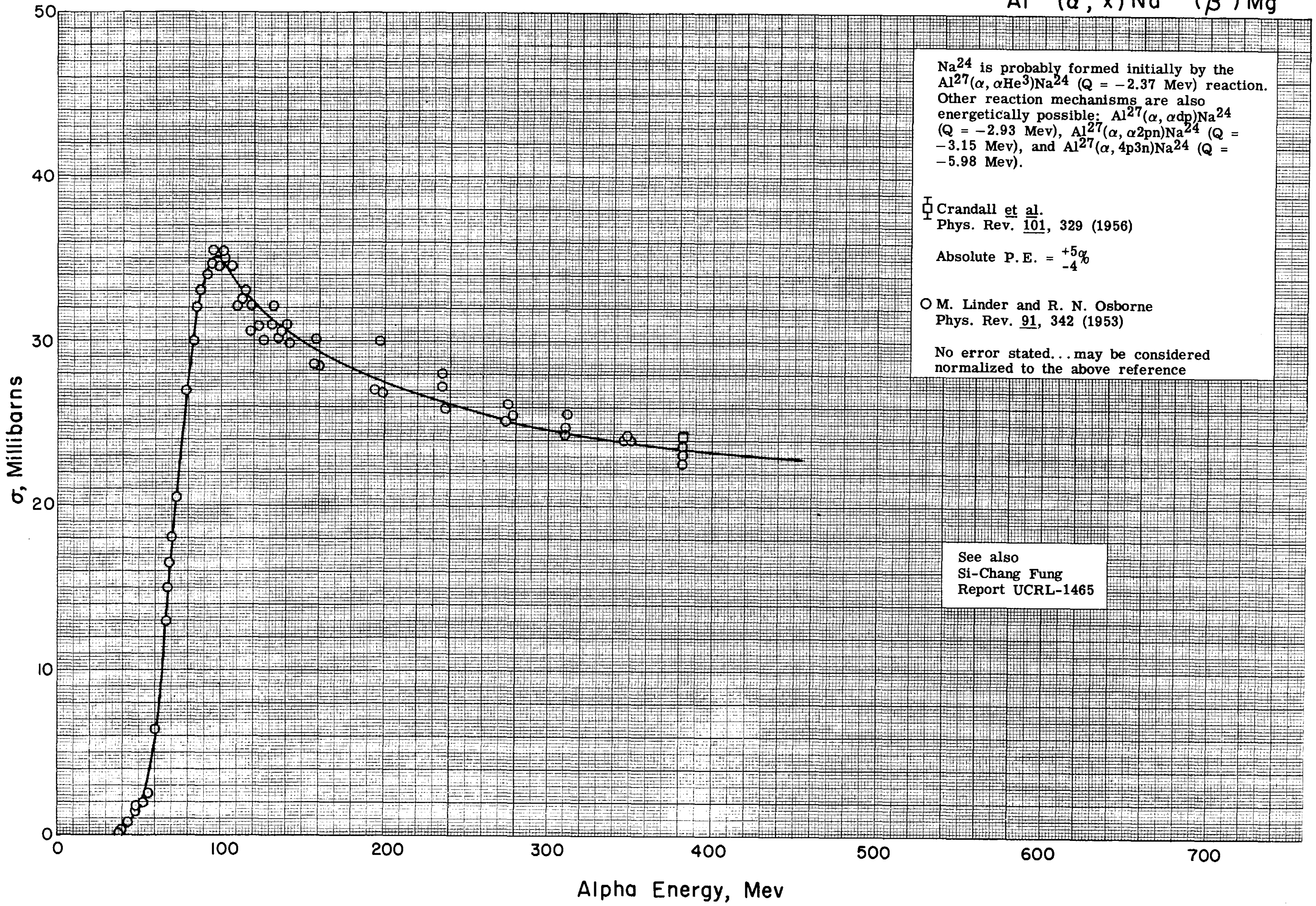
$Al^{27}(\alpha, \alpha)Al^{27}$



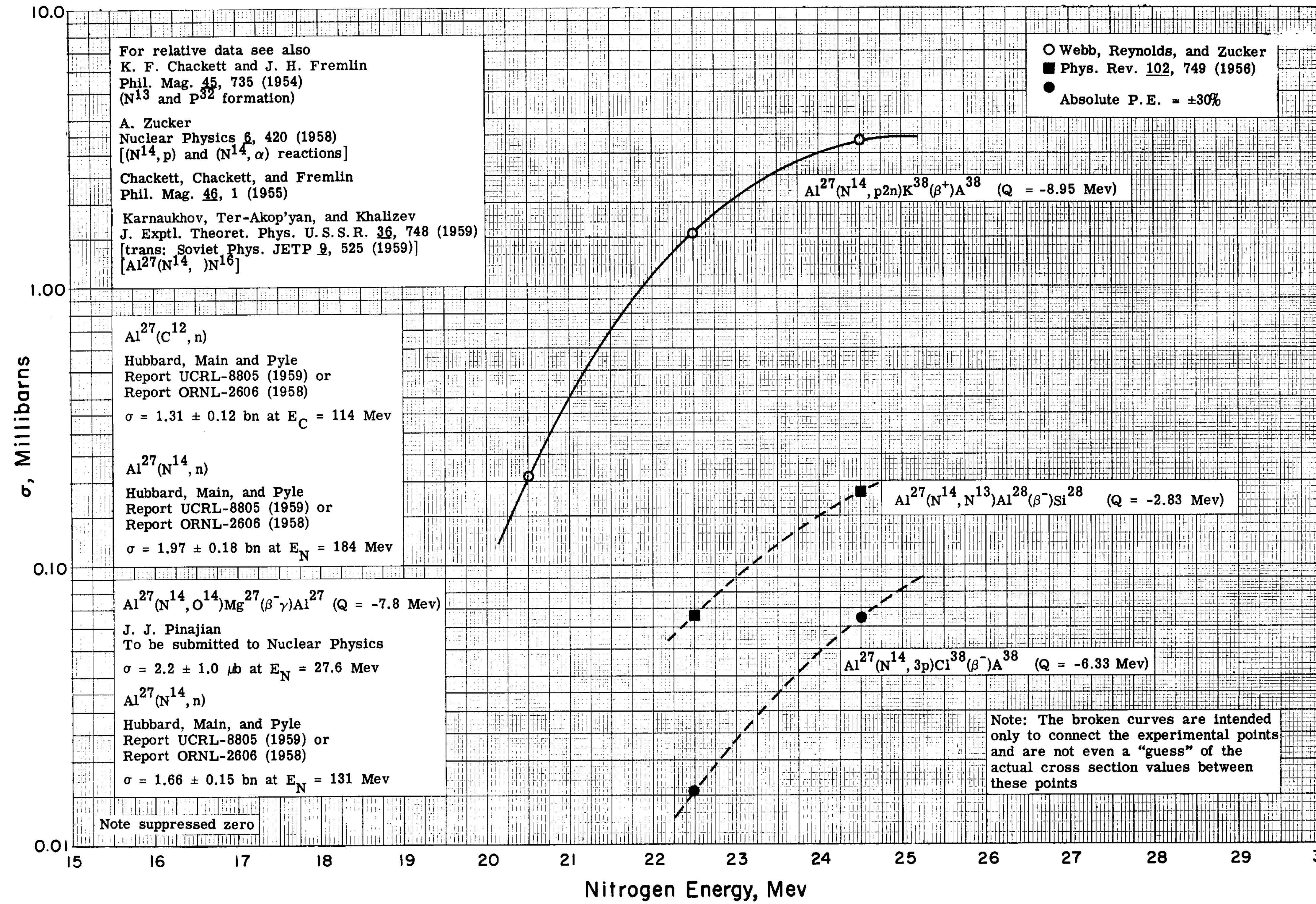



Al^{27} (α, α) Al^{27}
Alpha energy 40 Mev
Eisberg, Igo, and Wegner
Phys. Rev. 99, 1606 (1955)
Energy resolution = 4%
Angular resolution = ±1.0°
Absolute P.E. = ±10%
See also
Igo, Wegner, and Eisberg
Phys. Rev. 101, 1508 (1956)
σ(θ), Millibarns per Steradian
Lab Angle of Alpha, θ
σ(θ'), Millibarns per Steradian
C.M. Angle of Alpha, θ'
σ × 1/10

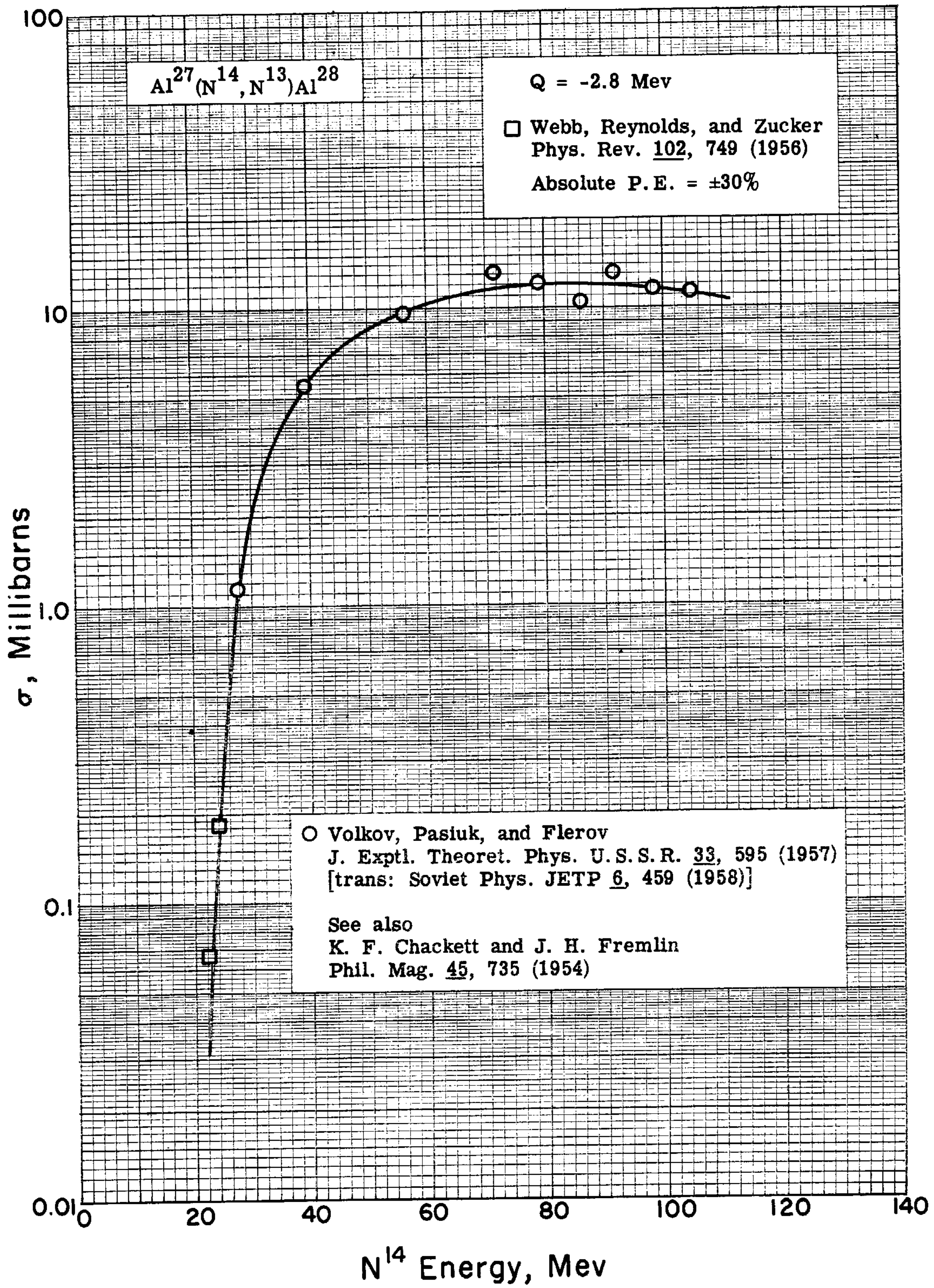
$Al^{27}(\alpha, x)Na^{24}(\beta^-)Mg^{24}$

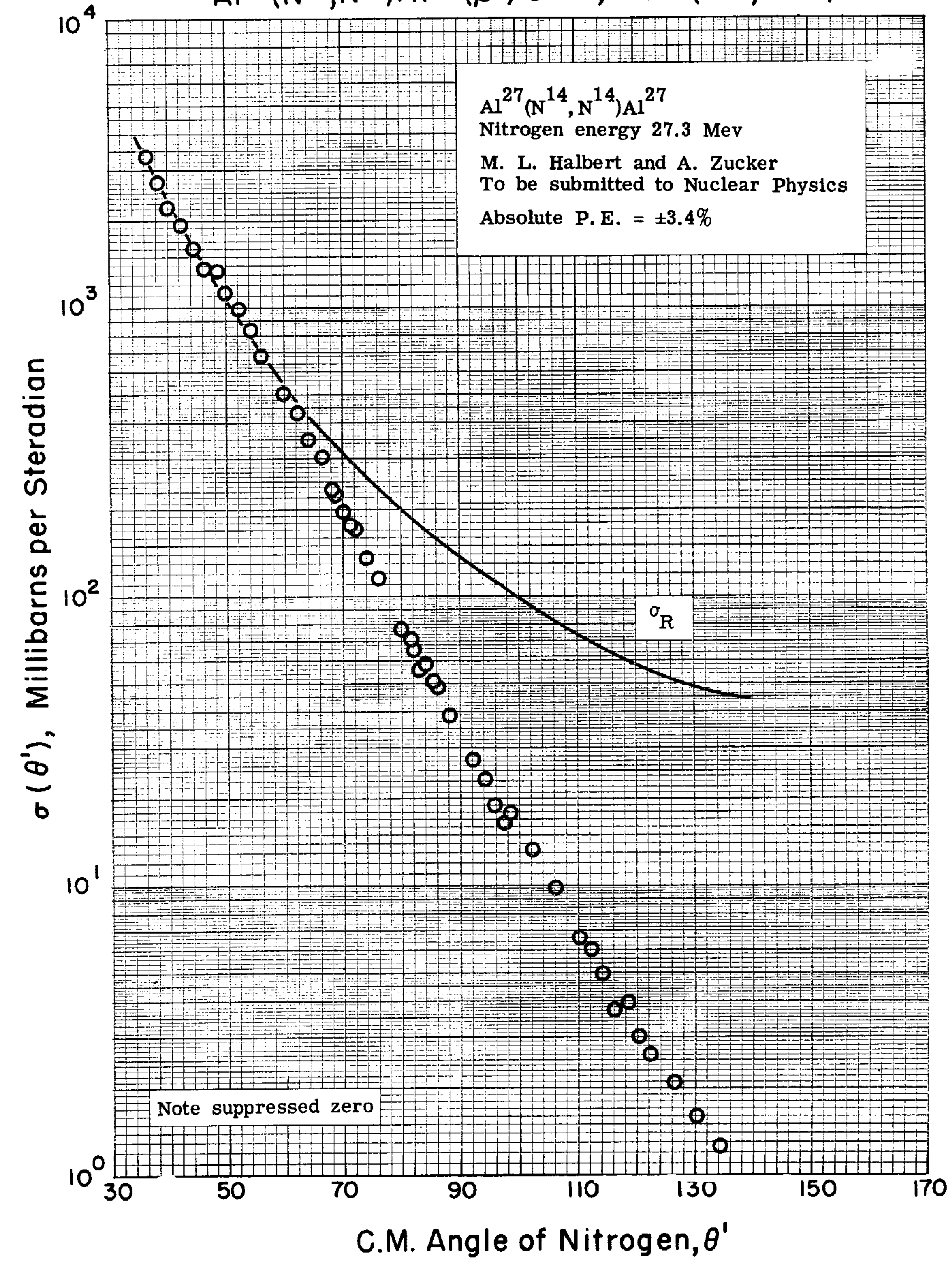


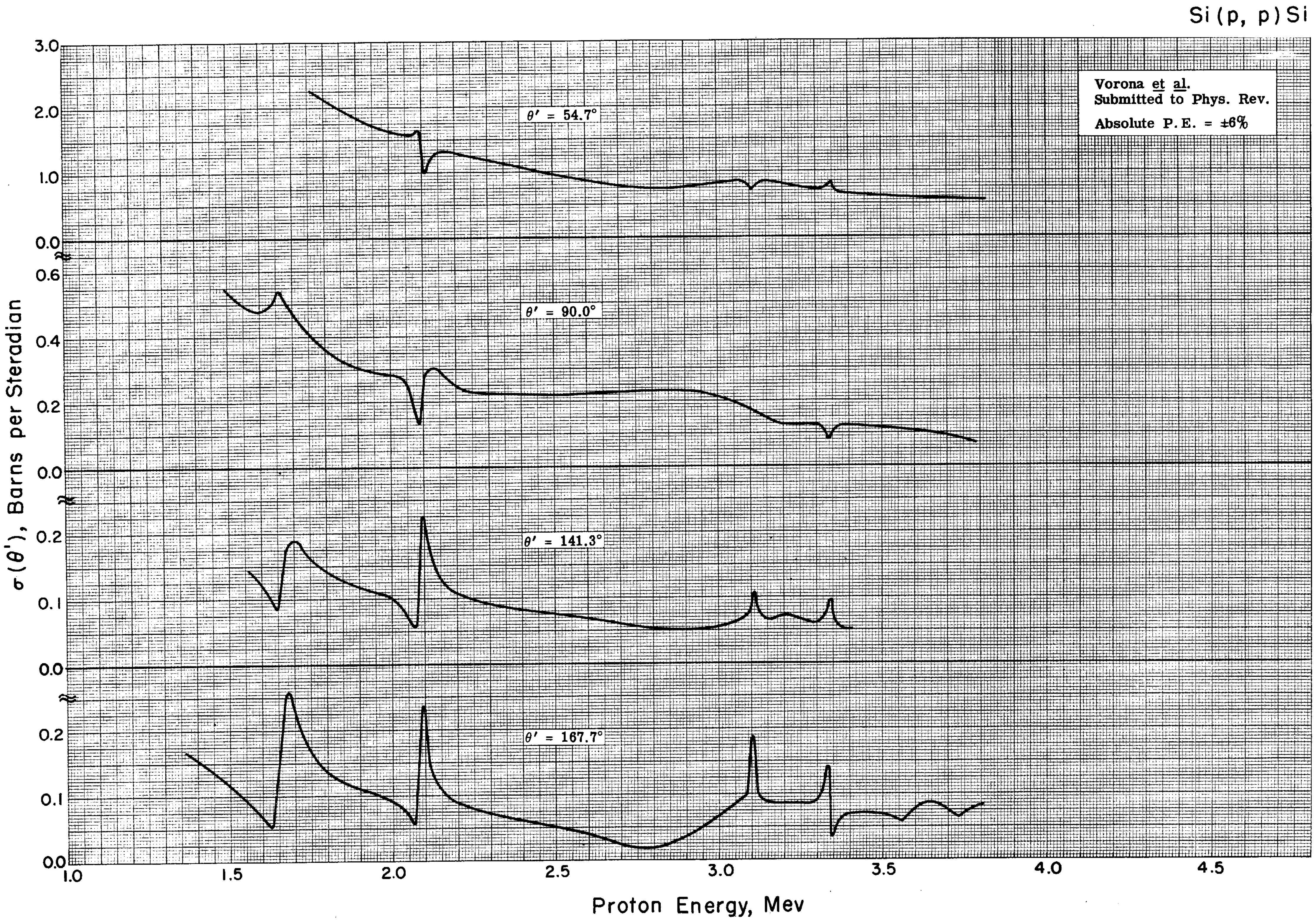
$Al^{27}(C^{12}, n)$; $Al^{27}(N^{14},\ )$

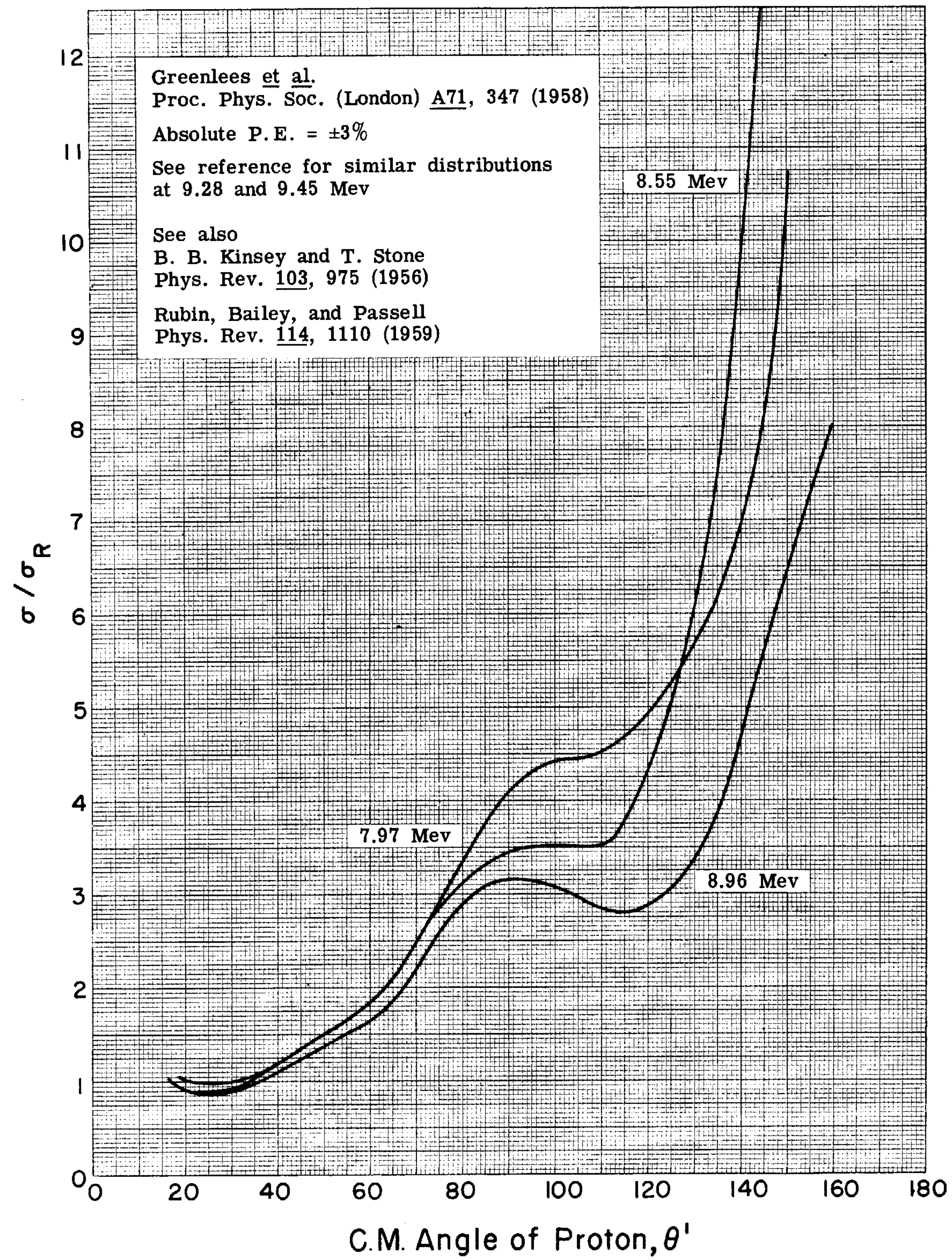


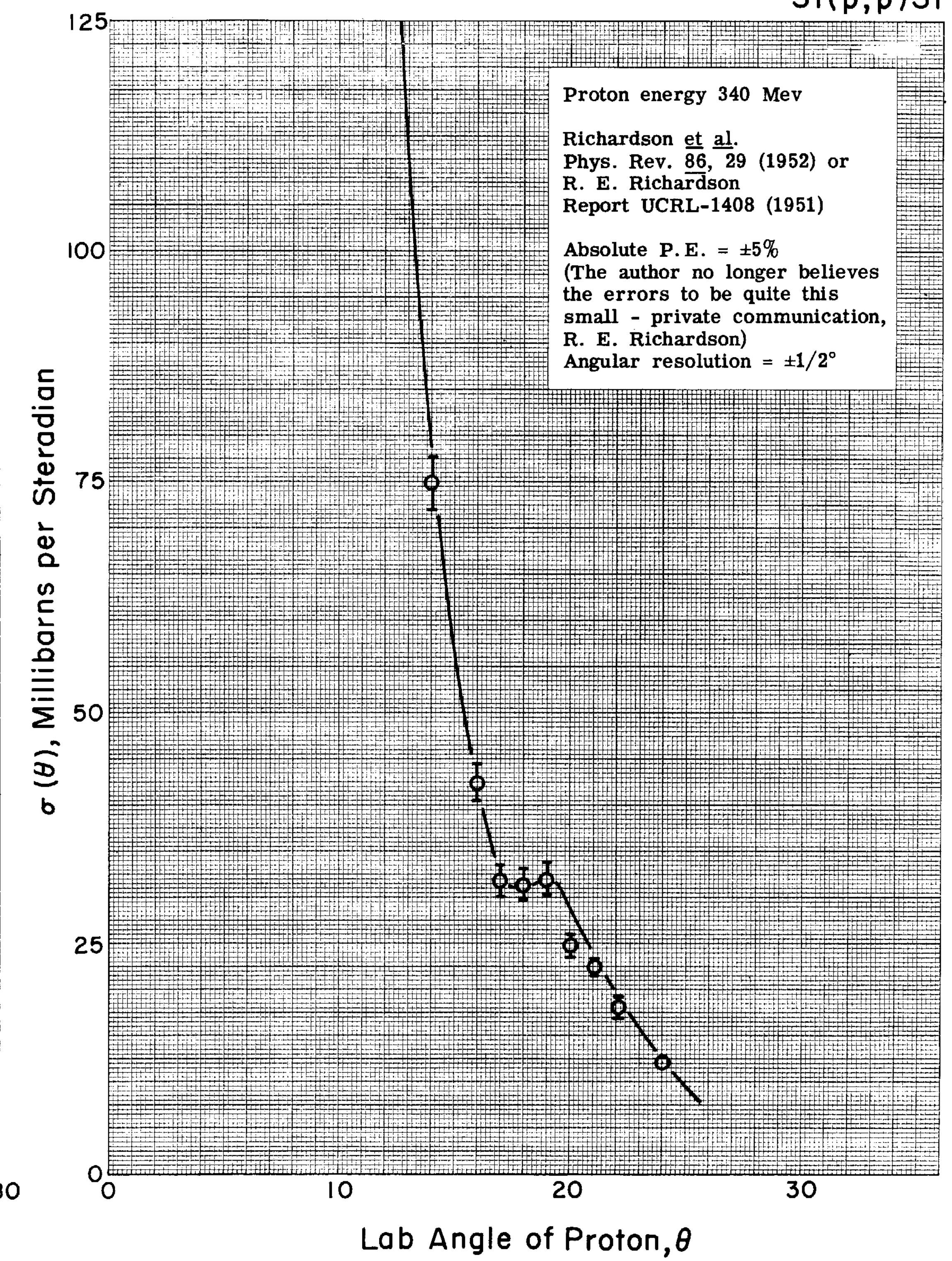
$Al^{27}(N^{14},N^{13})Al^{28}(\beta^-)Si^{28}$; $Al^{27}(N^{14},N^{14})Al^{27}$

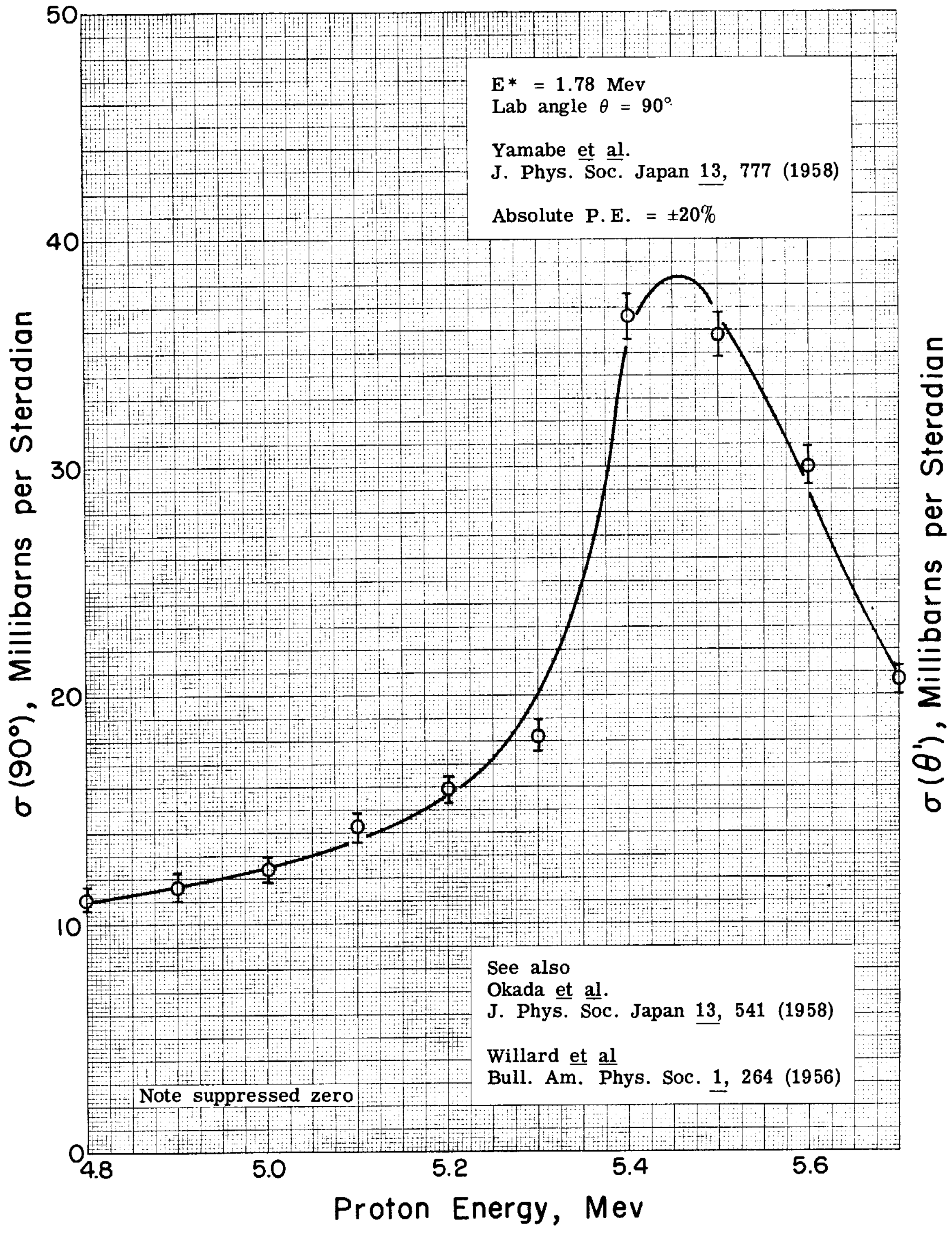




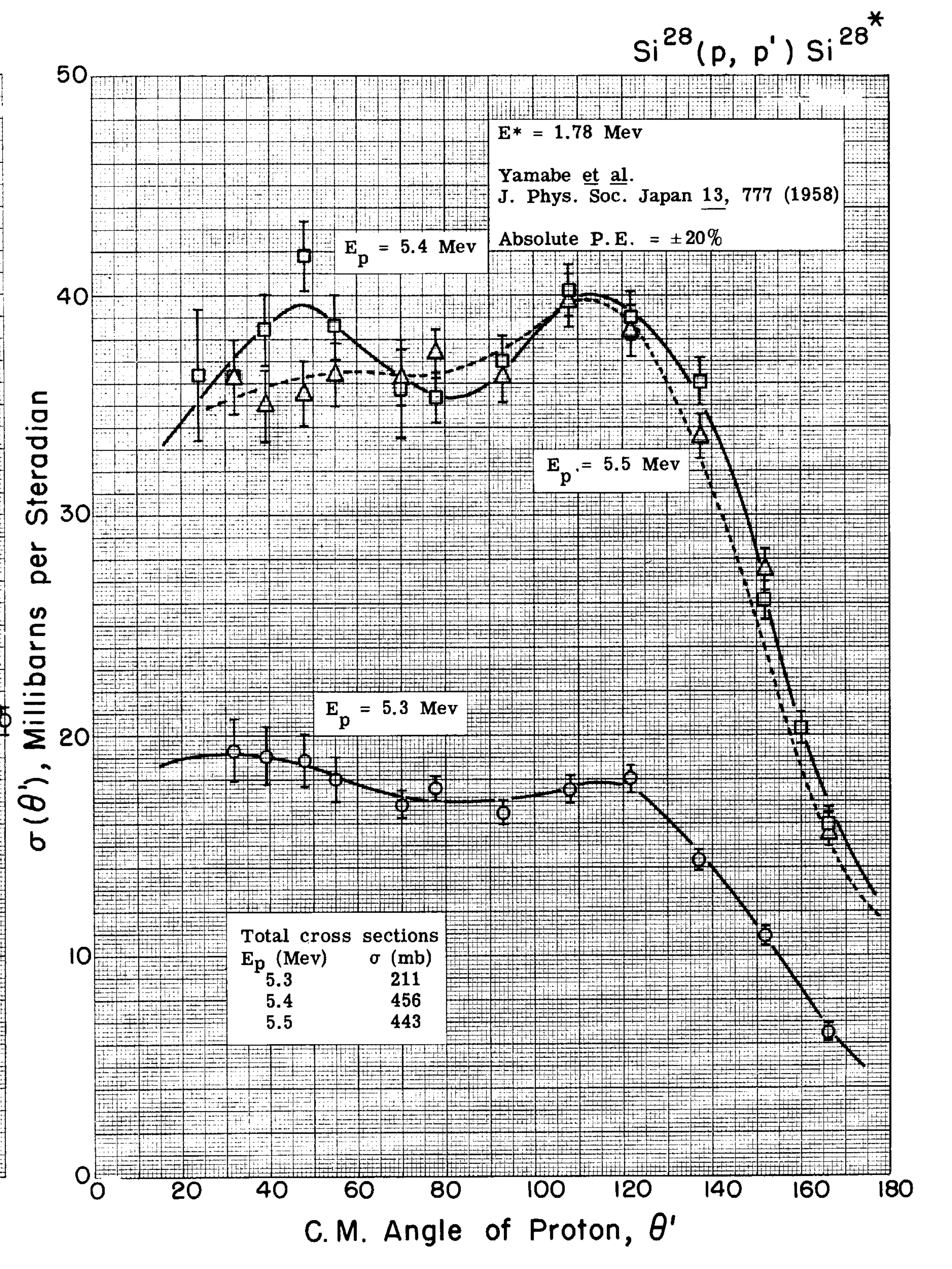

Si(p, p)Si
Vorona et al.
Submitted to Phys. Rev.
Absolute P.E. = ±6%
θ' = 54.7°
θ' = 90.0°
θ' = 141.3°
θ' = 167.7°
σ(θ'), Barns per Steradian
Proton Energy, Mev
3.0
2.0
1.0
0.0
0.6
0.4
0.2
0.0
0.2
0.1
0.0
0.2
0.1
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Greenlees et al.
Proc. Phys. Soc. (London) A71, 347 (1958)
Absolute P.E. = ±3%
See reference for similar distributions at 9.28 and 9.45 Mev
See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
Rubin, Bailey, and Passell
Phys. Rev. 114, 1110 (1959)
8.55 Mev
7.97 Mev
8.96 Mev
σ / σ_R
C.M. Angle of Proton, θ'


Proton energy 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P.E. = ±5%
(The author no longer believes the errors to be quite this small - private communication, R. E. Richardson)
Angular resolution = ±1/2°
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ

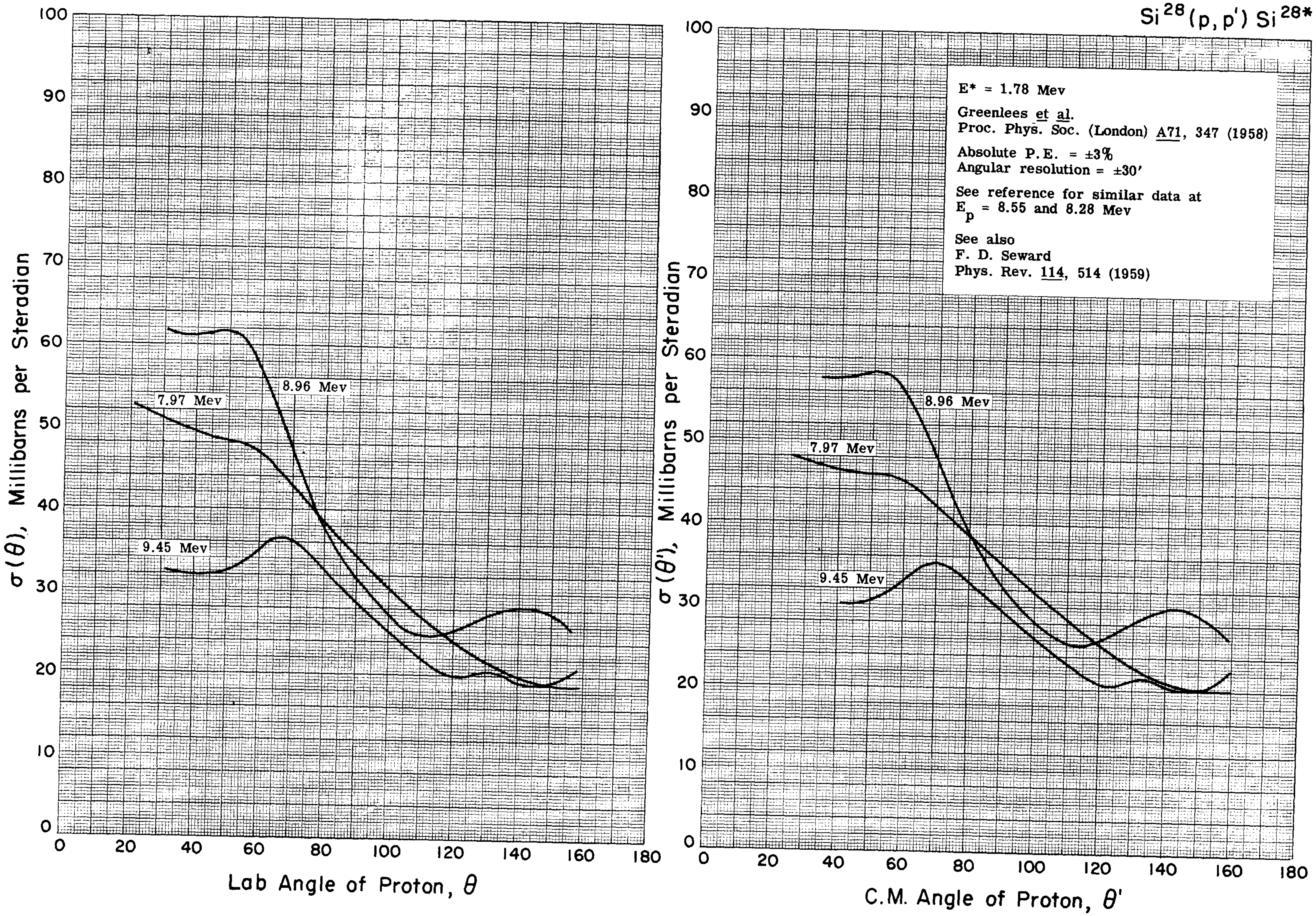


E* = 1.78 Mev
Lab angle θ = 90°
Yamabe et al.
J. Phys. Soc. Japan 13, 777 (1958)
Absolute P.E. = ±20%
See also
Okada et al.
J. Phys. Soc. Japan 13, 541 (1958)
Willard et al
Bull. Am. Phys. Soc. 1, 264 (1956)
Note suppressed zero
σ (90°), Millibarns per Steradian
Proton Energy, Mev

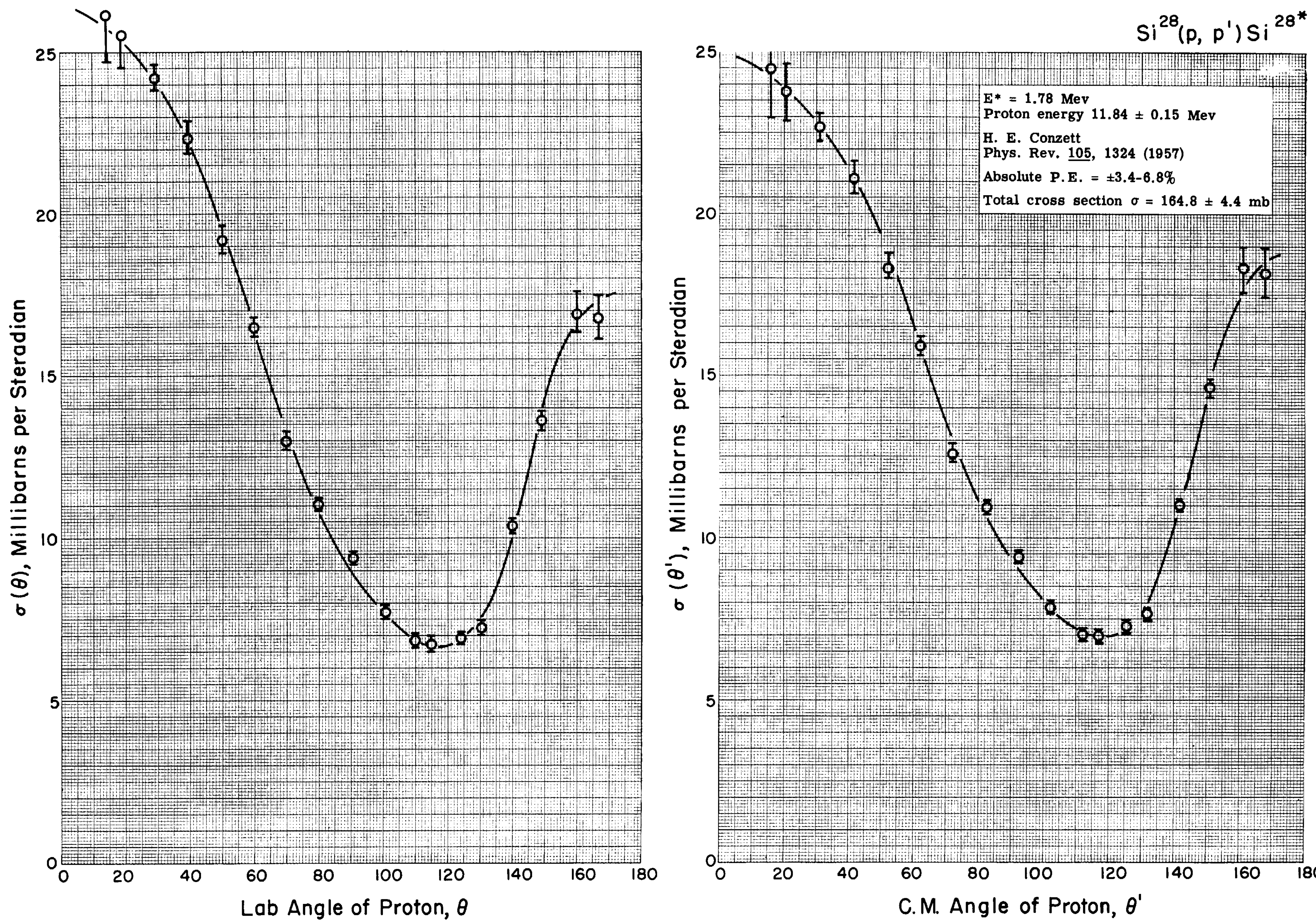


Si28(p, p') Si28*
E* = 1.78 Mev
Yamabe et al.
J. Phys. Soc. Japan 13, 777 (1958)
Absolute P.E. = ±20%
Ep = 5.4 Mev
Ep = 5.5 Mev
Ep = 5.3 Mev
Total cross sections
Ep (Mev) σ (mb)
5.3 211
5.4 456
5.5 443
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

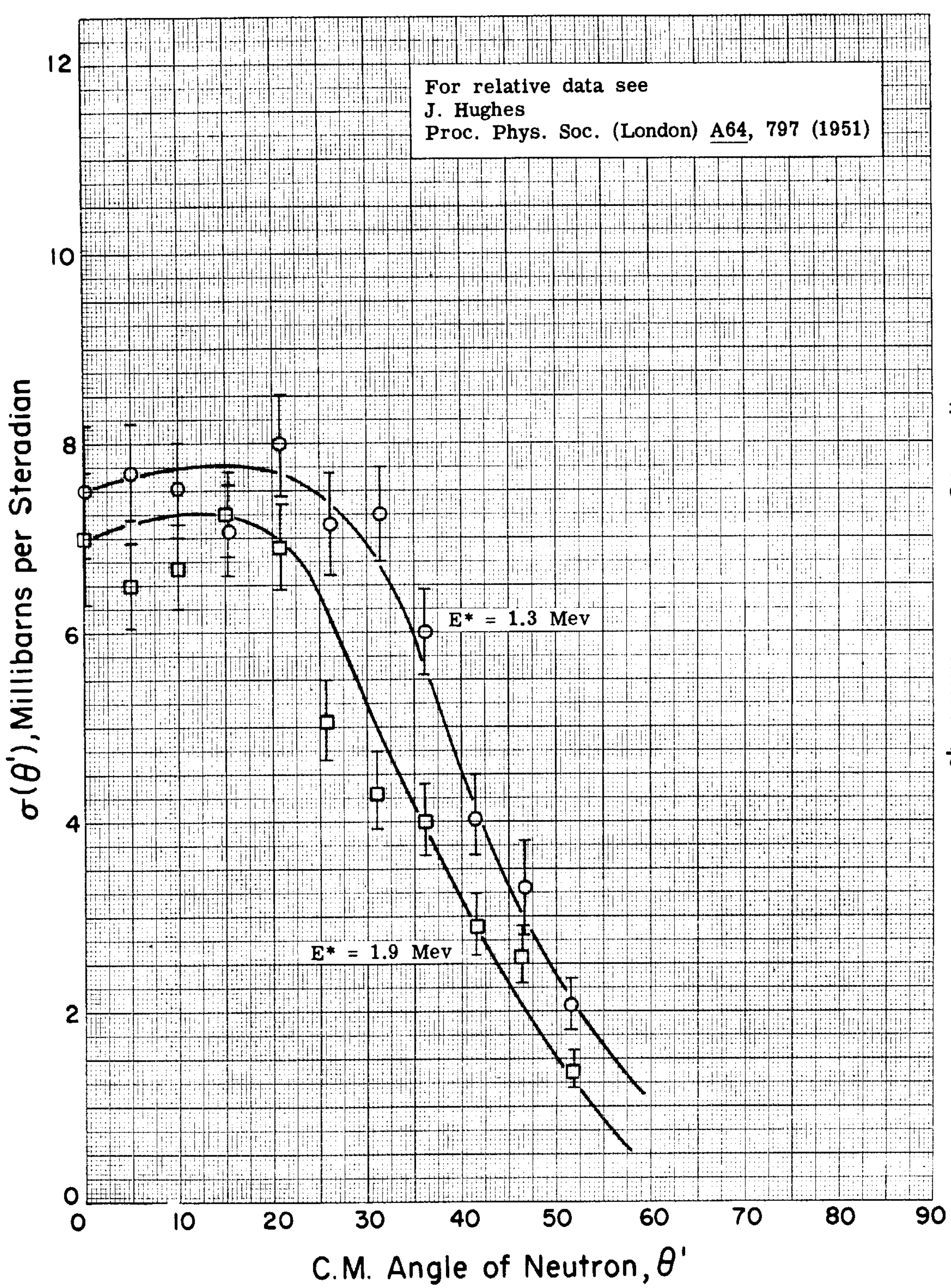
$Si^{28}(p,p')Si^{28*}$

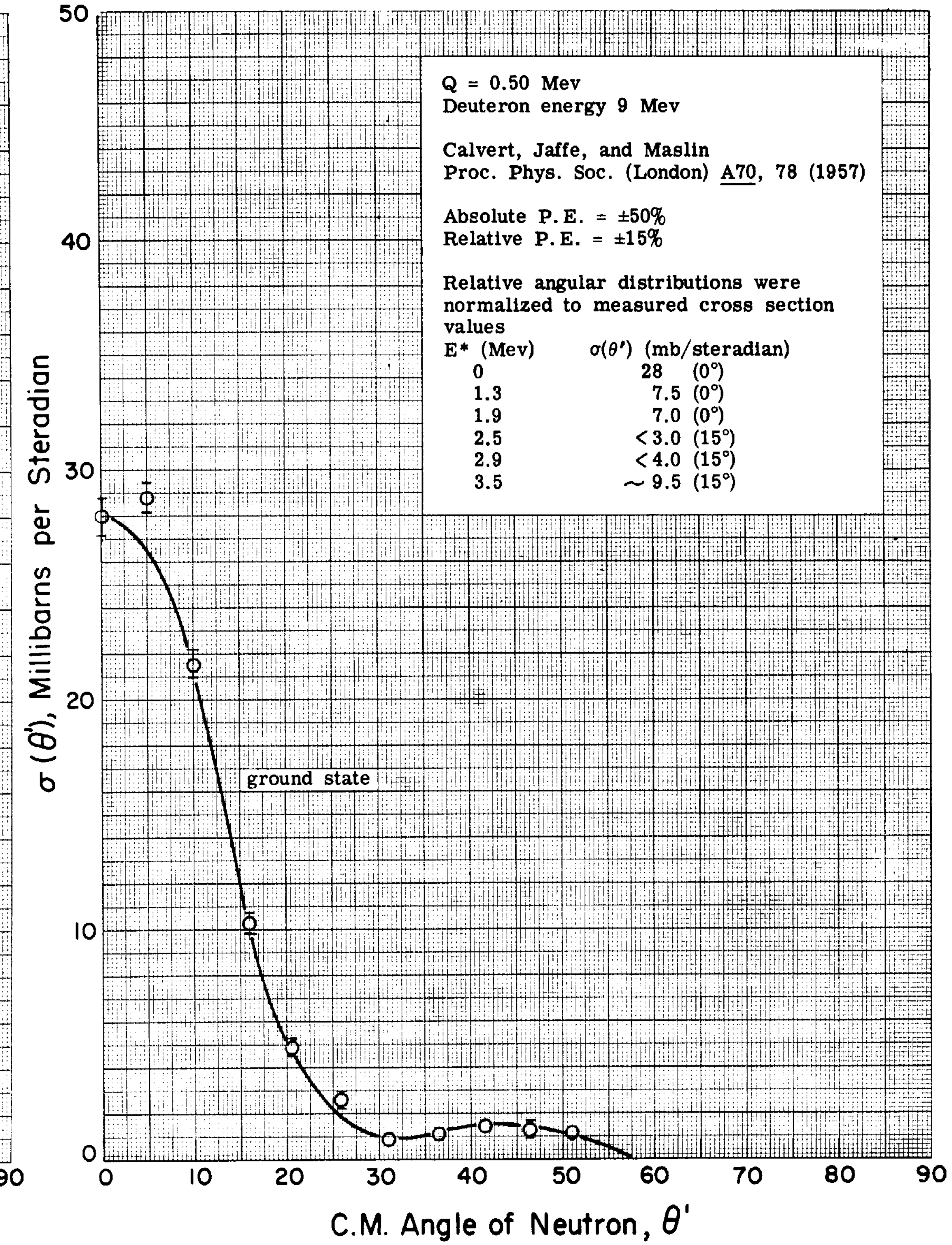


σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
8.96 Mev
7.97 Mev
9.45 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
E* = 1.78 Mev
Greenlees et al.
Proc. Phys. Soc. (London) A71, 347 (1958)
Absolute P.E. = ±3%
Angular resolution = ±30'
See reference for similar data at
E_p = 8.55 and 8.28 Mev
See also
F. D. Seward
Phys. Rev. 114, 514 (1959)

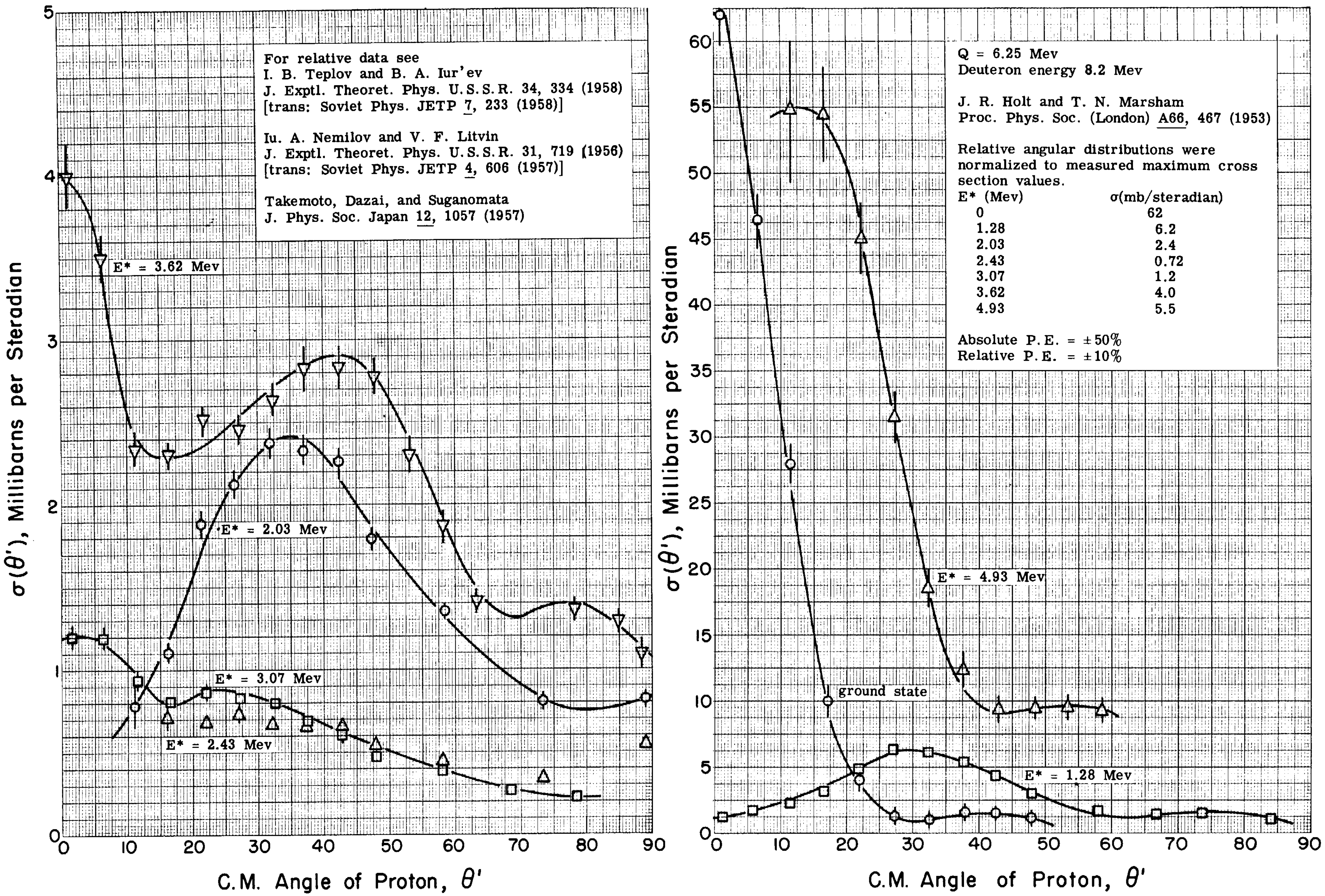


$Si^{28}(p, p')Si^{28*}$
E* = 1.78 Mev
Proton energy 11.84 ± 0.15 Mev
H. E. Conzett
Phys. Rev. 105, 1324 (1957)
Absolute P.E. = ±3.4-6.8%
Total cross section σ = 164.8 ± 4.4 mb
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180


For relative data see
J. Hughes
Proc. Phys. Soc. (London) A64, 797 (1951)
E* = 1.3 Mev
E* = 1.9 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'

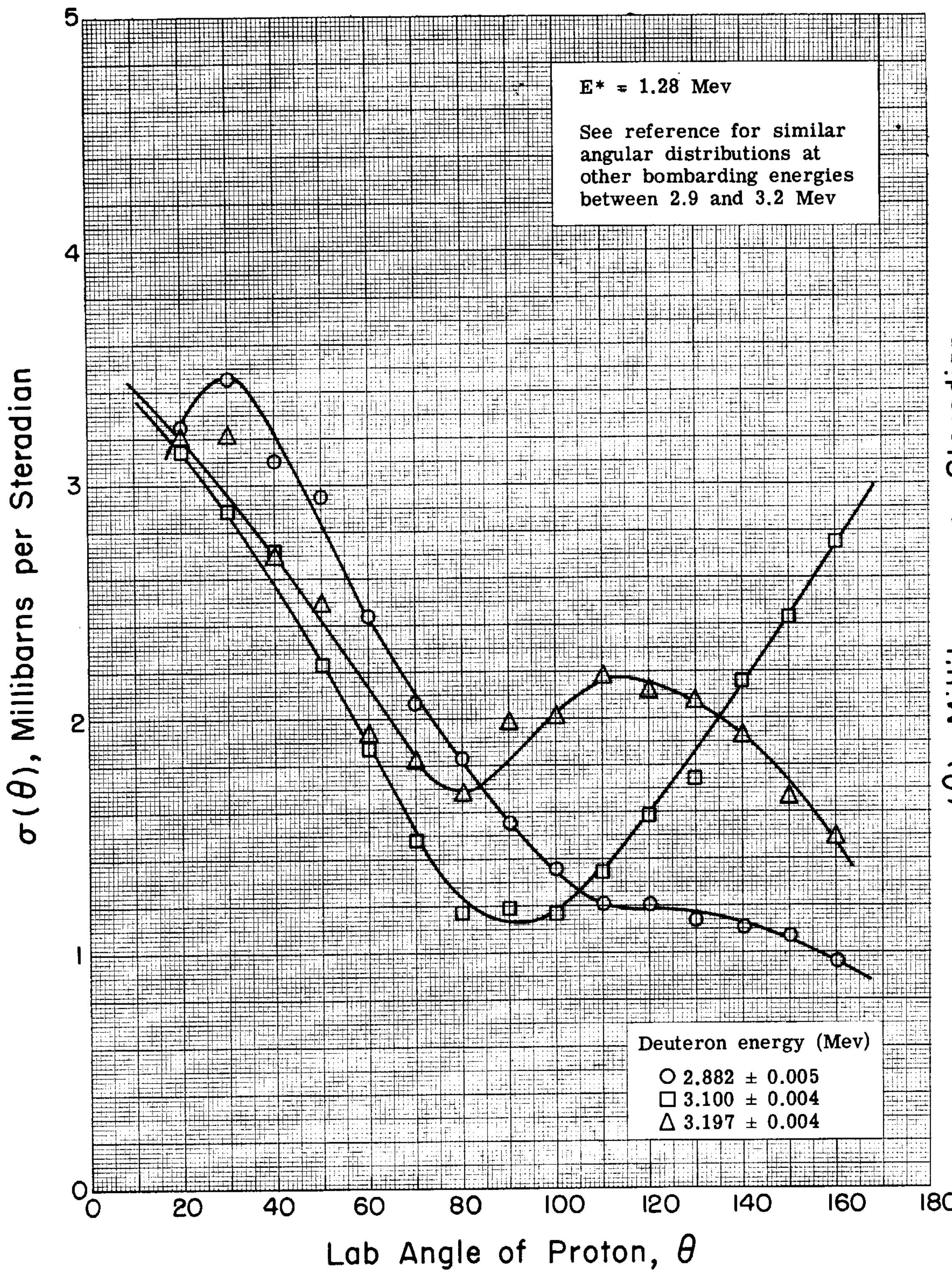

Q = 0.50 Mev
Deuteron energy 9 Mev
Calvert, Jaffe, and Maslin
Proc. Phys. Soc. (London) A70, 78 (1957)
Absolute P.E. = ±50%
Relative P.E. = ±15%
Relative angular distributions were normalized to measured cross section values
E* (Mev) σ(θ') (mb/steradian)
0 28 (0°)
1.3 7.5 (0°)
1.9 7.0 (0°)
2.5 <3.0 (15°)
2.9 <4.0 (15°)
3.5 ~9.5 (15°)
ground state
σ(θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'

$Si^{28}(d,p')Si^{29*}$

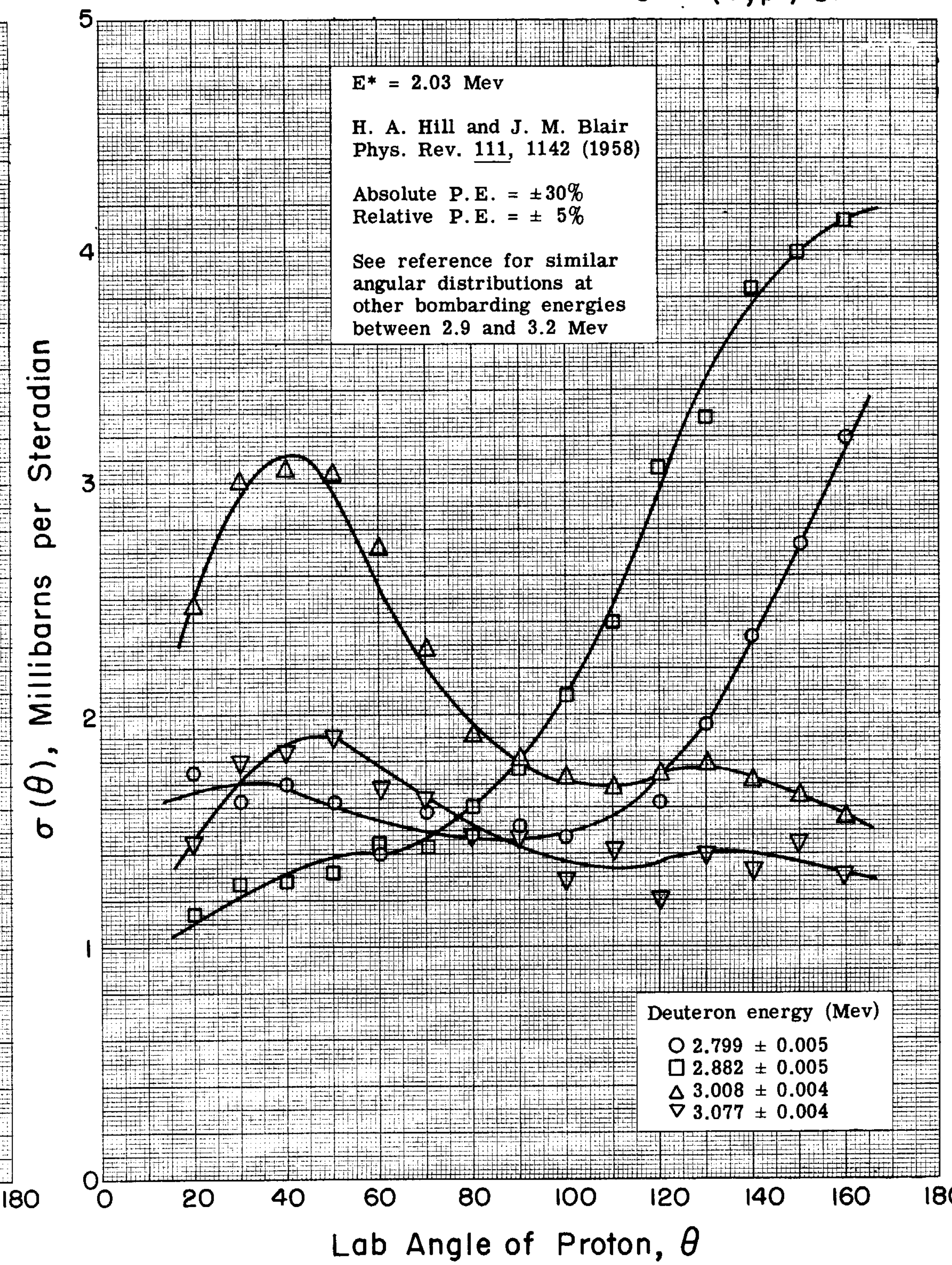


For relative data see
I. B. Teplov and B. A. Iur'ev
J. Exptl. Theoret. Phys. U.S.S.R. 34, 334 (1958)
[trans: Soviet Phys. JETP 7, 233 (1958)]
Iu. A. Nemilov and V. F. Litvin
J. Exptl. Theoret. Phys. U.S.S.R. 31, 719 (1956)
[trans: Soviet Phys. JETP 4, 606 (1957)]
Takemoto, Dazai, and Suganomata
J. Phys. Soc. Japan 12, 1057 (1957)
E* = 3.62 Mev
E* = 2.03 Mev
E* = 3.07 Mev
E* = 2.43 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
Q = 6.25 Mev
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 467 (1953)
Relative angular distributions were normalized to measured maximum cross section values.
E* (Mev) σ(mb/steradian)
0 62
1.28 6.2
2.03 2.4
2.43 0.72
3.07 1.2
3.62 4.0
4.93 5.5
Absolute P.E. = ±50%
Relative P.E. = ±10%
E* = 4.93 Mev
ground state
E* = 1.28 Mev

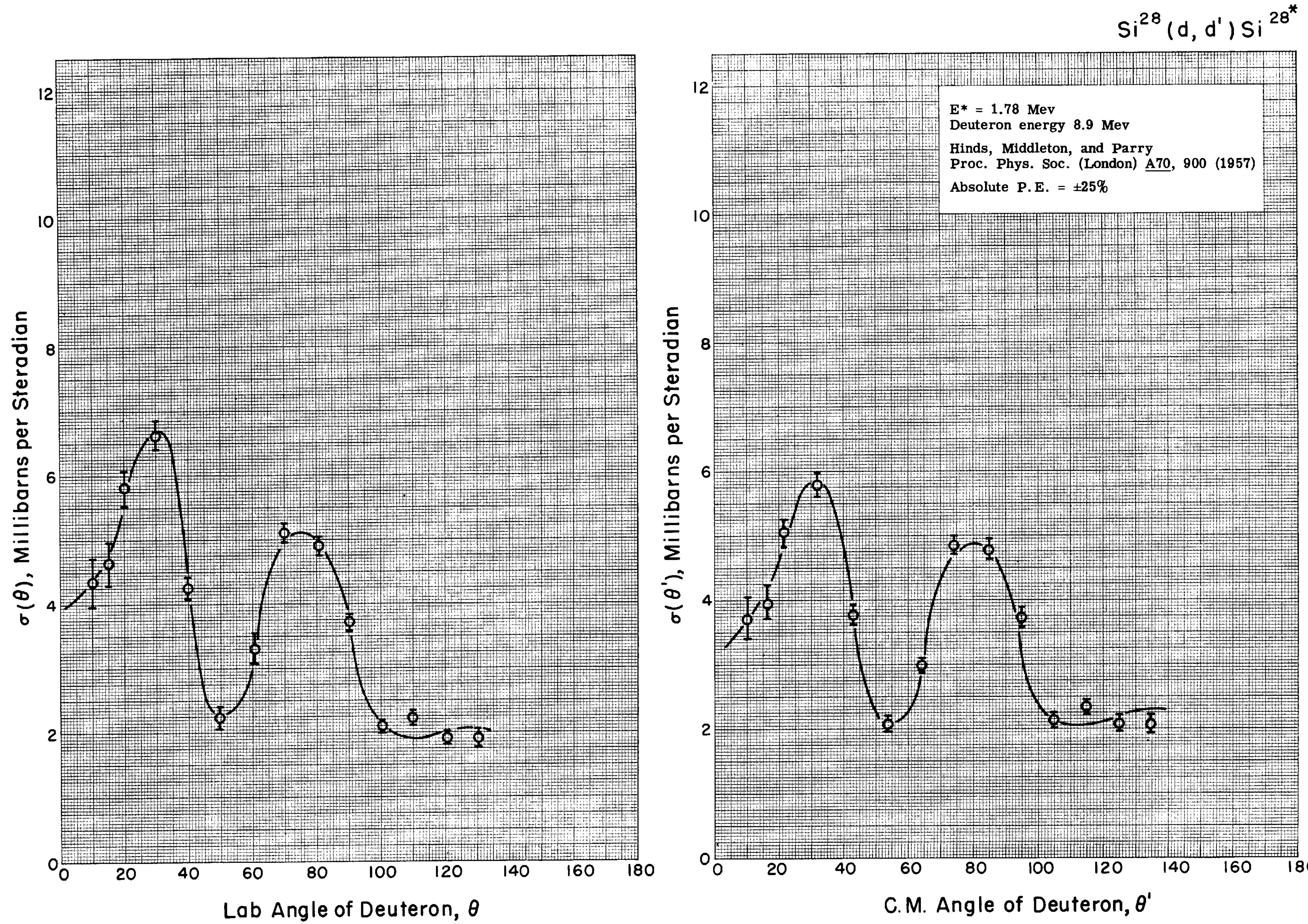
$Si^{28}(d,p')Si^{29*}$



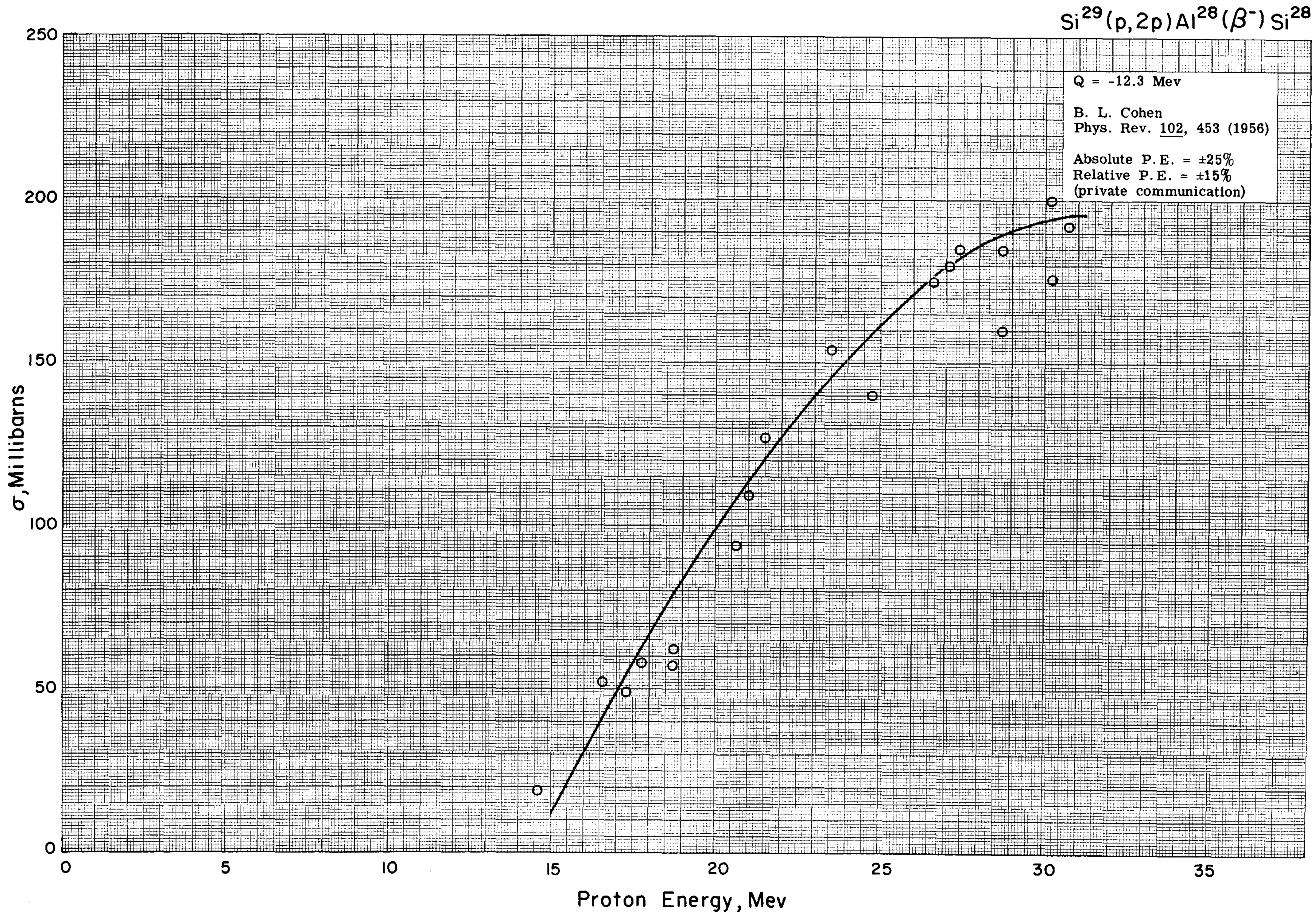
E* = 1.28 Mev
See reference for similar angular distributions at other bombarding energies between 2.9 and 3.2 Mev
Deuteron energy (Mev)
○ 2.882 ± 0.005
□ 3.100 ± 0.004
△ 3.197 ± 0.004
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160
180



E* = 2.03 Mev
H. A. Hill and J. M. Blair
Phys. Rev. 111, 1142 (1958)
Absolute P.E. = ±30%
Relative P.E. = ± 5%
See reference for similar angular distributions at other bombarding energies between 2.9 and 3.2 Mev
Deuteron energy (Mev)
○ 2.799 ± 0.005
□ 2.882 ± 0.005
△ 3.008 ± 0.004
▽ 3.077 ± 0.004
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160
180

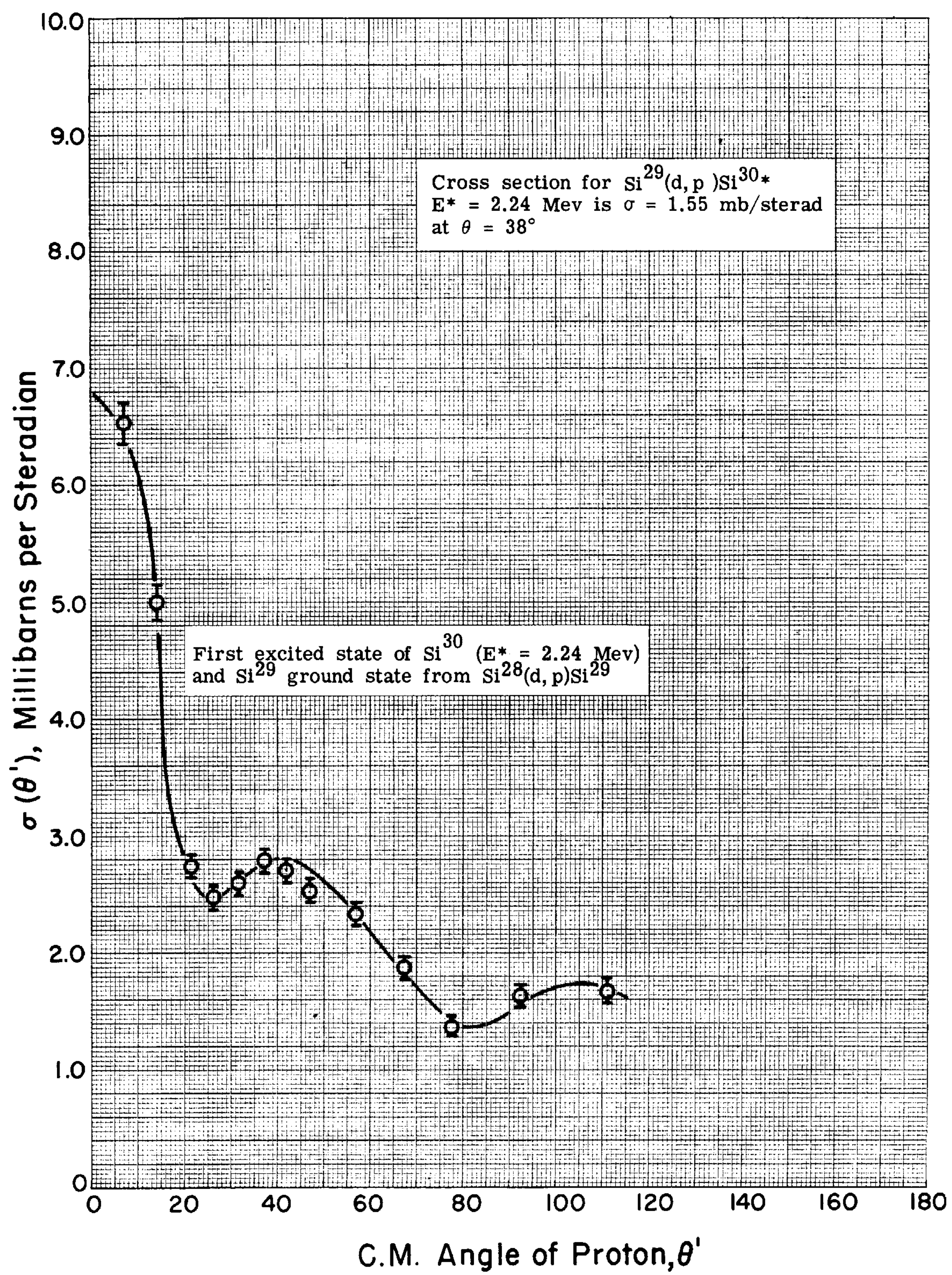


$Si^{28}(d, d')Si^{28*}$
E* = 1.78 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A70, 900 (1957)
Absolute P.E. = ±25%
σ(θ), Millibarns per Steradian
Lab Angle of Deuteron, θ
σ(θ'), Millibarns per Steradian
C.M. Angle of Deuteron, θ'

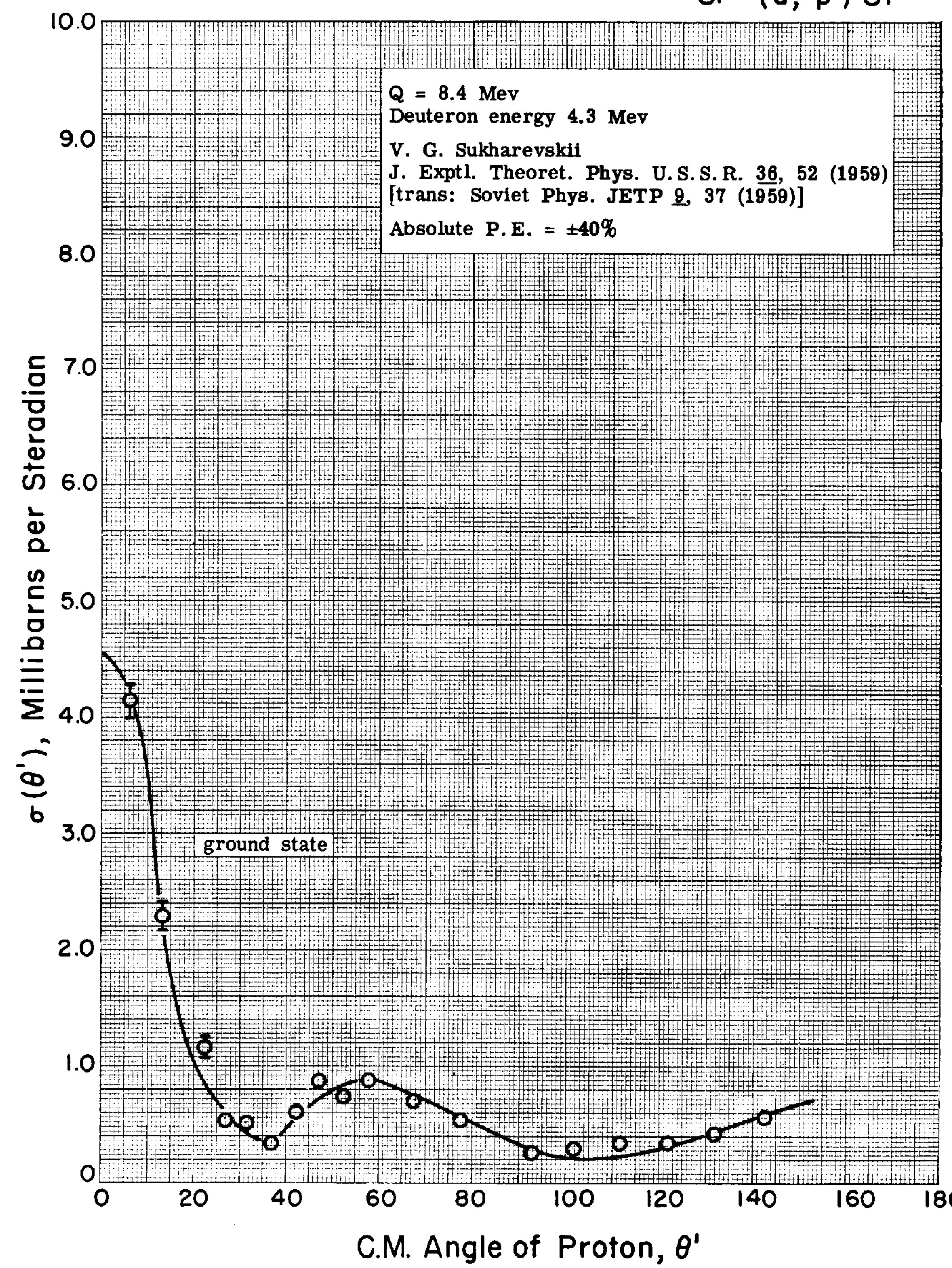


$Si^{29}(p,2p)Al^{28}(\beta^-)Si^{28}$
Q = -12.3 Mev
B. L. Cohen
Phys. Rev. 102, 453 (1956)
Absolute P.E. = ±25%
Relative P.E. = ±15%
(private communication)
σ, Millibarns
0
50
100
150
200
250
0
5
10
15
20
25
30
35
Proton Energy, Mev

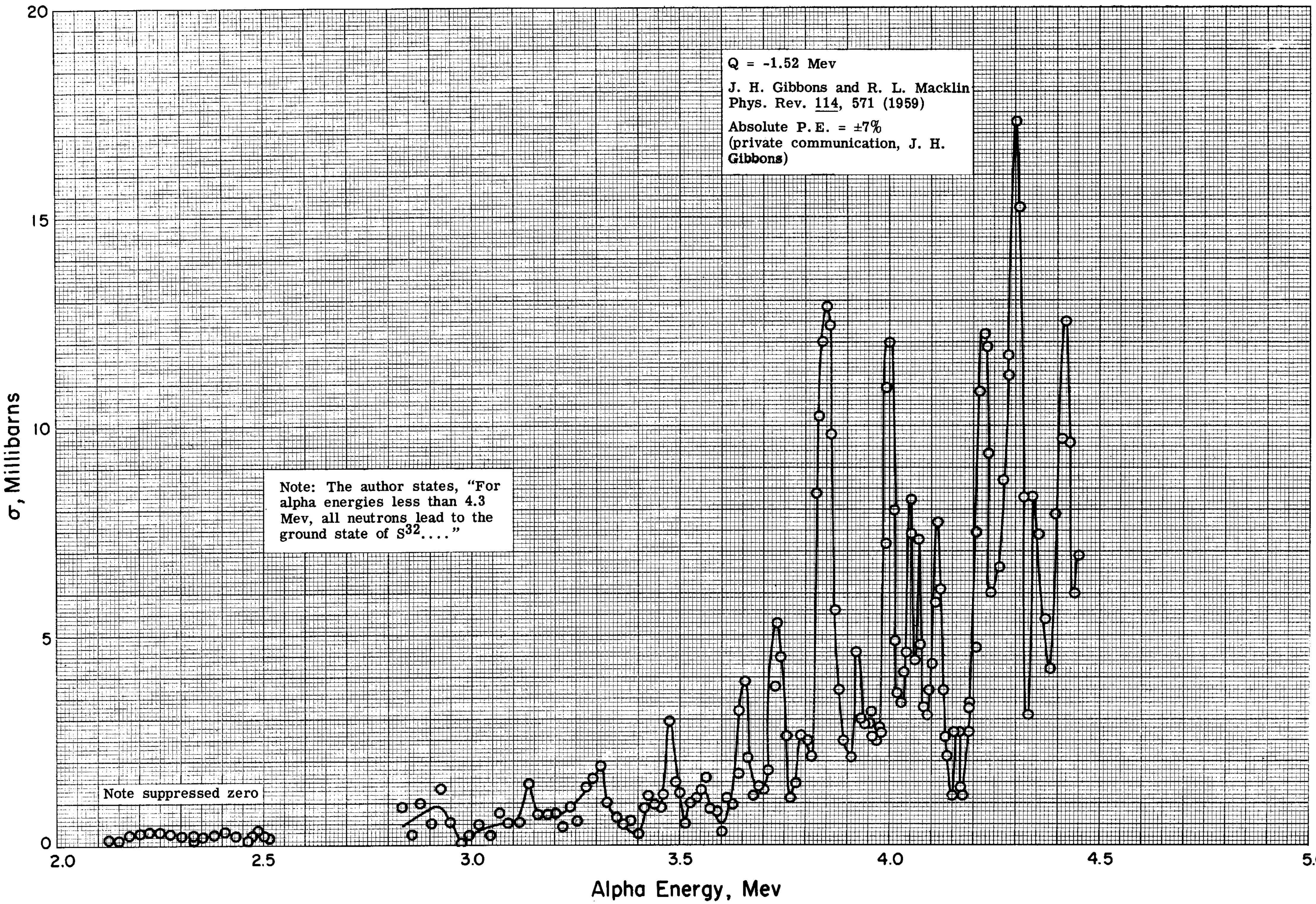
$Si^{29}(d, p') Si^{30*}$



Cross section for $Si^{29}(d, p)Si^{30*}$
E* = 2.24 Mev is σ = 1.55 mb/sterad
at θ = 38°
First excited state of Si^{30} (E* = 2.24 Mev)
and Si^{29} ground state from $Si^{28}(d, p)Si^{29}$
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'



Q = 8.4 Mev
Deuteron energy 4.3 Mev
V. G. Sukharevskii
J. Exptl. Theoret. Phys. U.S.S.R. 36, 52 (1959)
[trans: Soviet Phys. JETP 9, 37 (1959)]
Absolute P.E. = ±40%
ground state
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'


Q = -1.52 Mev
J. H. Gibbons and R. L. Macklin
Phys. Rev. 114, 571 (1959)
Absolute P.E. = ±7%
(private communication, J. H. Gibbons)
Note: The author states, "For alpha energies less than 4.3 Mev, all neutrons lead to the ground state of S32...."
Note suppressed zero
σ, Millibarns
20
15
10
5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Alpha Energy, Mev

$P^{31}(d, n')S^{32*}$
Q = 6.64 Mev
Deuteron energy 9.02 ± 0.06 Mev

Calvert et al.
Proc. Phys. Soc. (London) A68, 1008 (1955)

Absolute P.E. = ±50%
Relative P.E. = ±20%

See also
Bent et al.
Phys. Rev. 100, 774 (1955)

For relative data see
F. A. El Bedewi and M. A. El Wahab
Proc. Phys. Soc. (London) A68, 754 (1955)

$P^{31}(d, p')P^{32*}$
Q = 5.71 Mev
Deuteron energy 4 Mev

I. B. Teplov
J. Exptl. Theoret. Phys. U.S.S.R. 31, 25 (1956)
[trans: Soviet Phys. JETP 4, 31 (1957)]

Absolute P.E. "several tens of percent"

and
I. B. Teplov and B. A. Iur'ev
J. Exptl. Theoret. Phys. U.S.S.R. 34, 334 (1958)
[trans: Soviet Phys. JETP 7, 233 (1958)]

Absolute P.E. = ±30-40%

See also
Bent et al.
Phys. Rev. 100, 774 (1955)

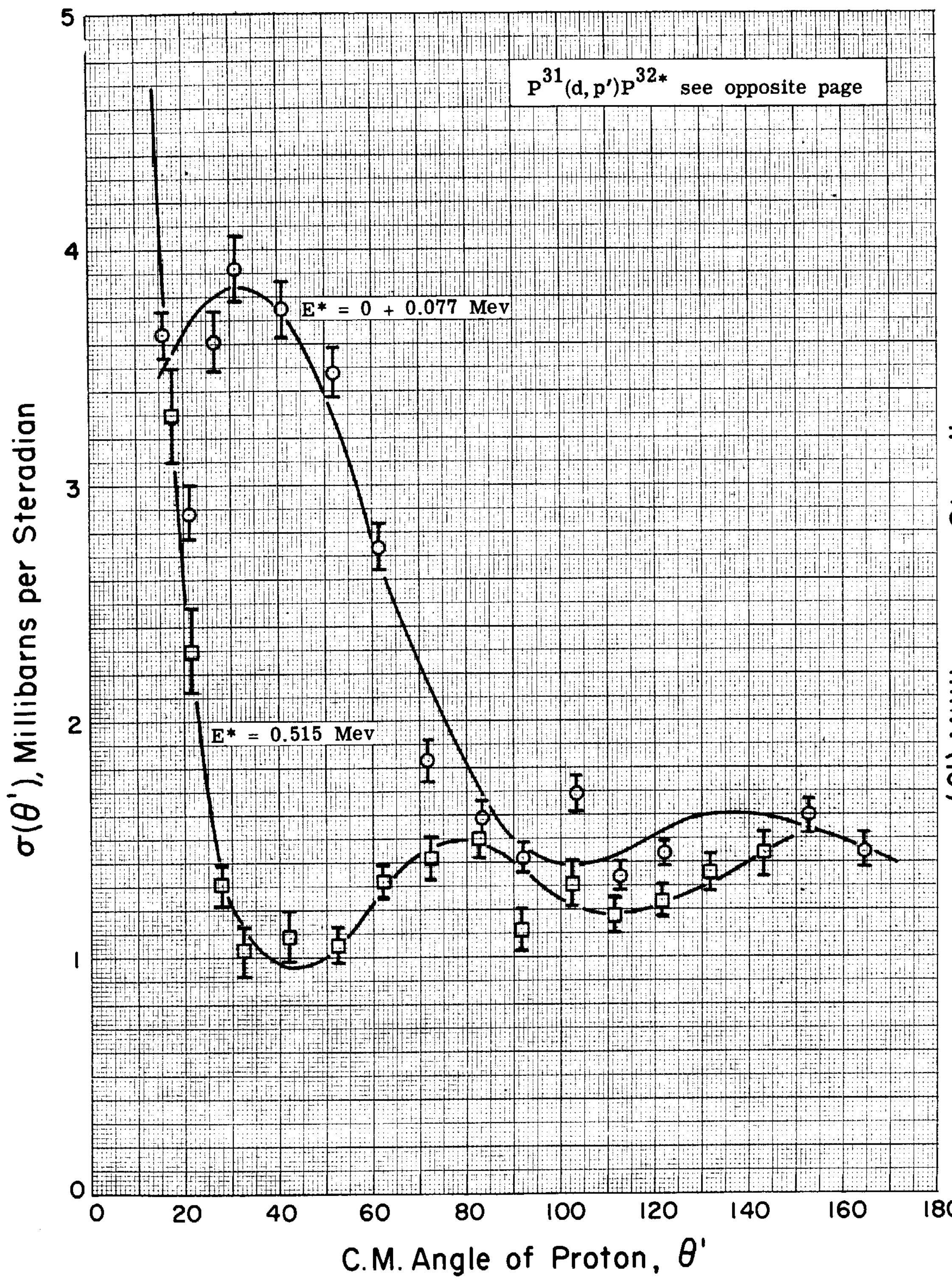
M. D. Kamen
Phys. Rev. 60, 537 (1941)

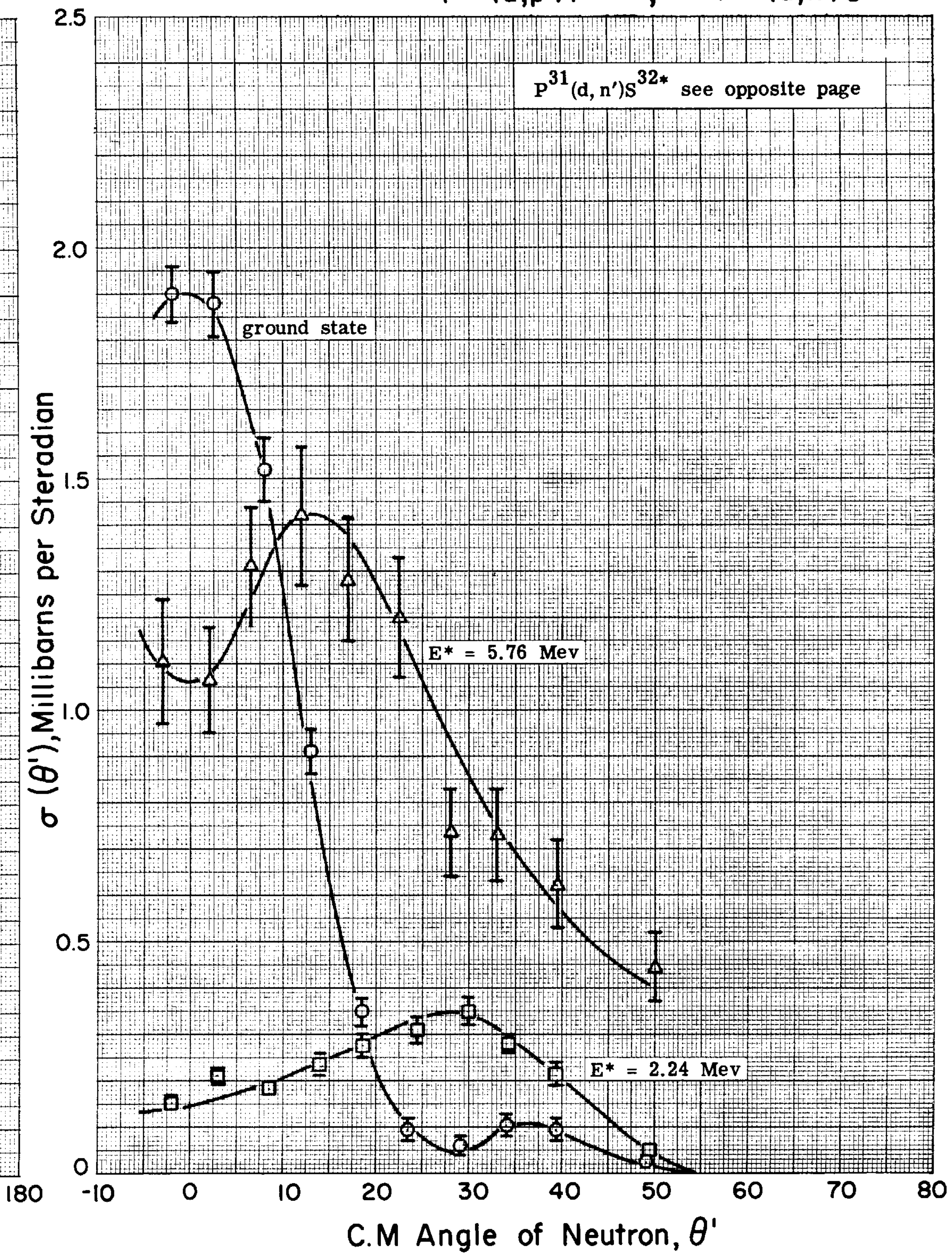
For relative data see
Dalton, Hinds, and Parry
Proc. Phys. Soc. (London) A70, 586 (1957)

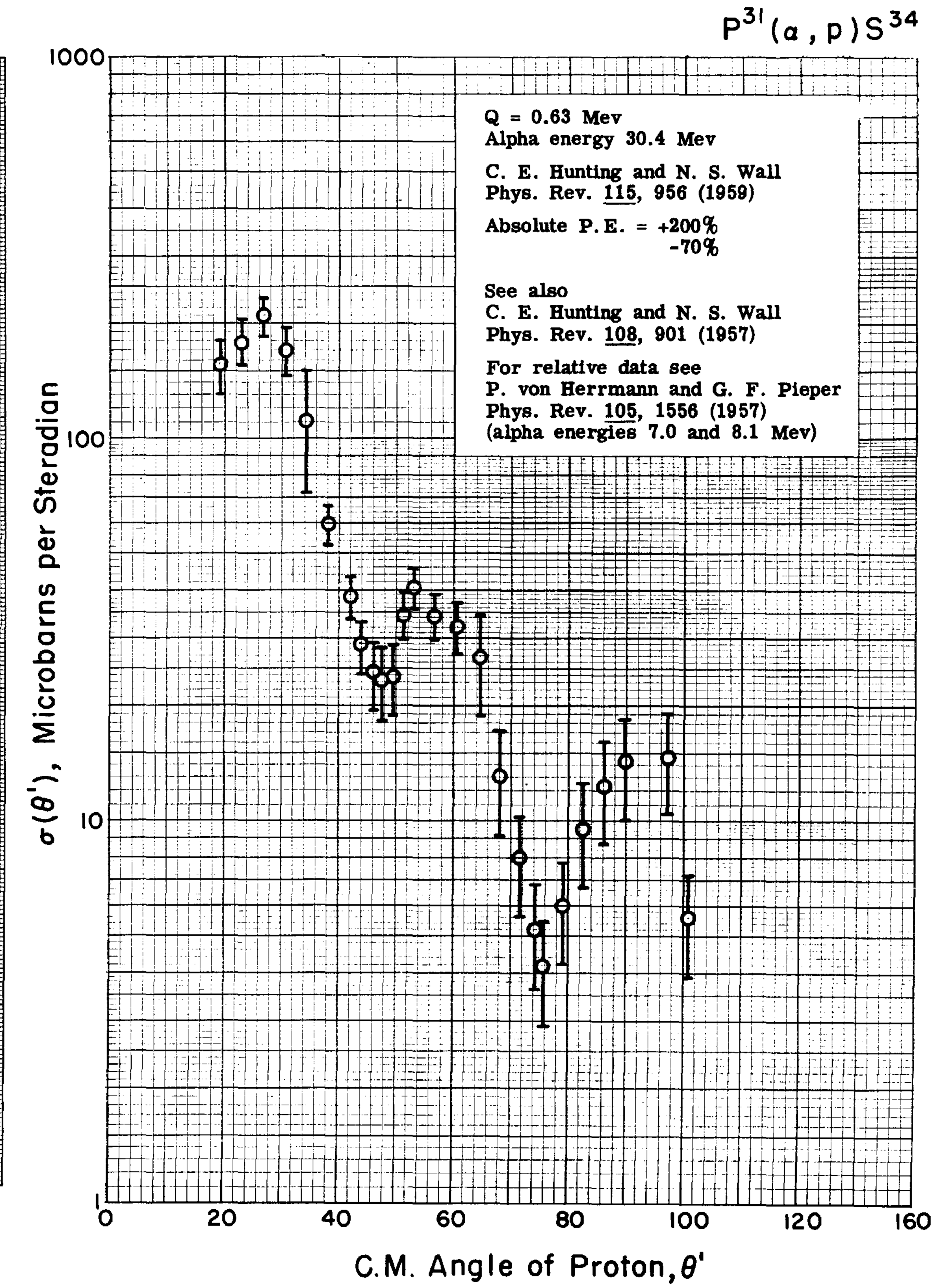
W. C. Parkinson
Phys. Rev. 110, 485 (1958)

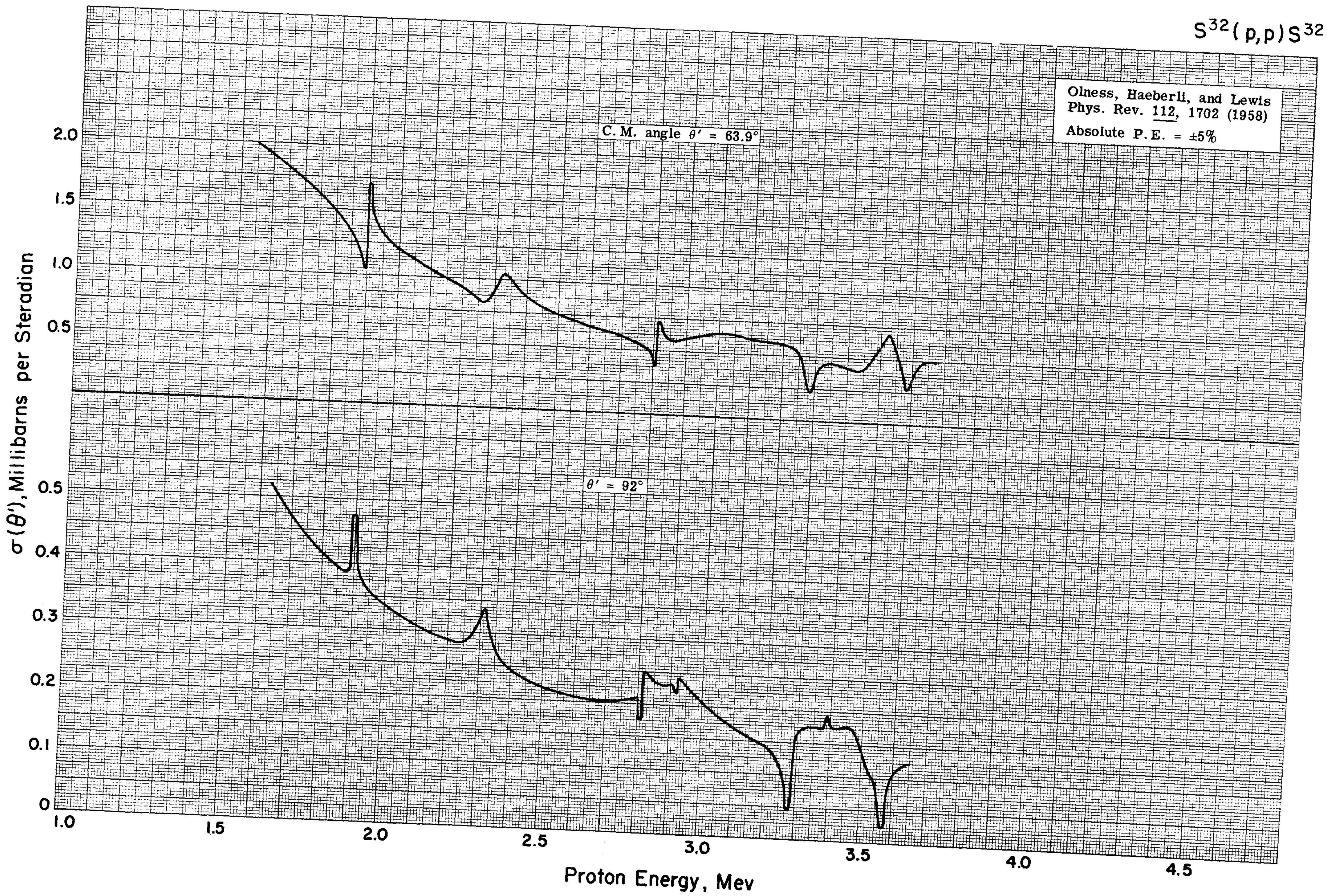
Parkinson, Beach, and King
Phys. Rev. 87, 387 (1952)

$P^{31}(d,p')P^{32*}$, $P^{31}(d,n')S^{32*}$

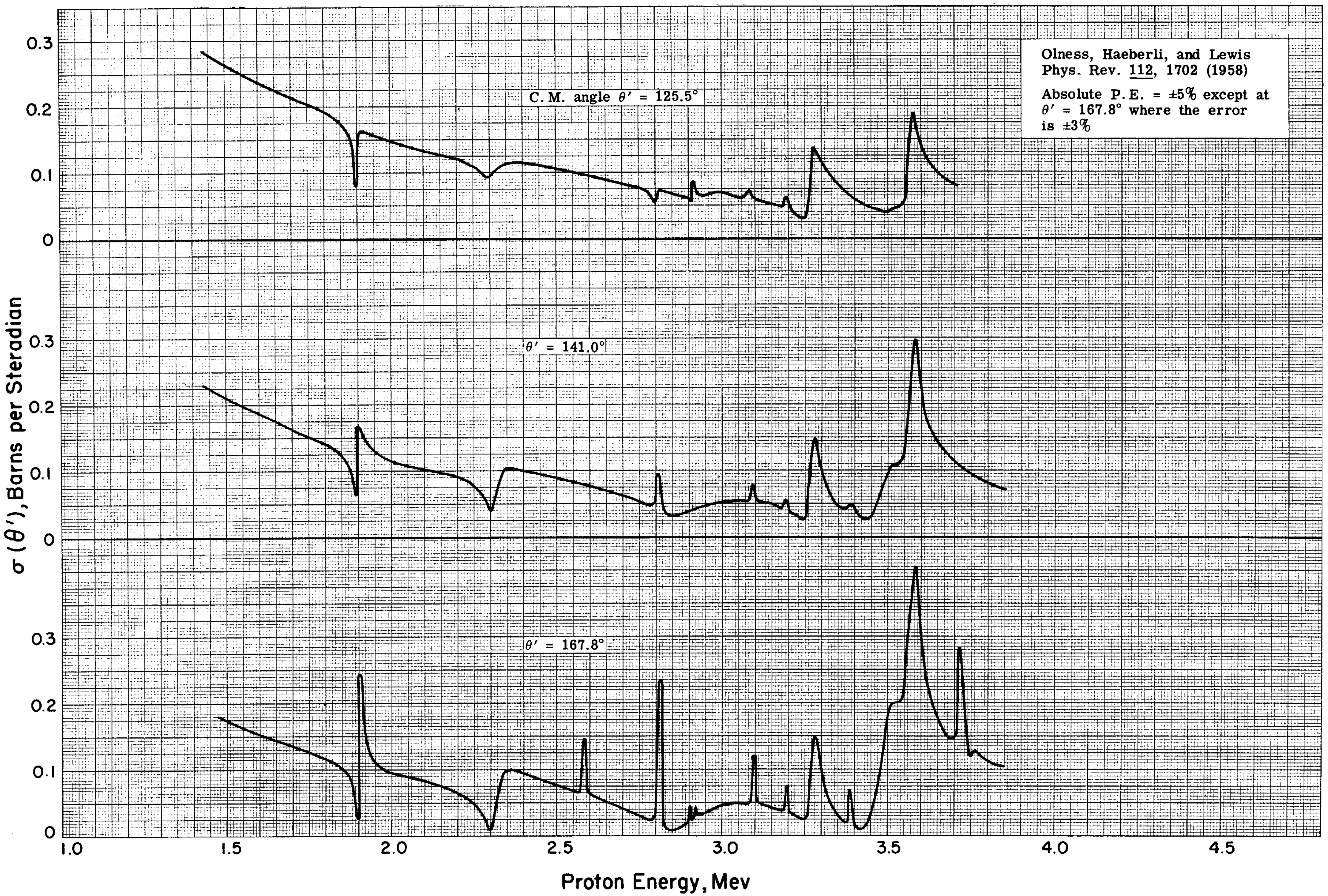


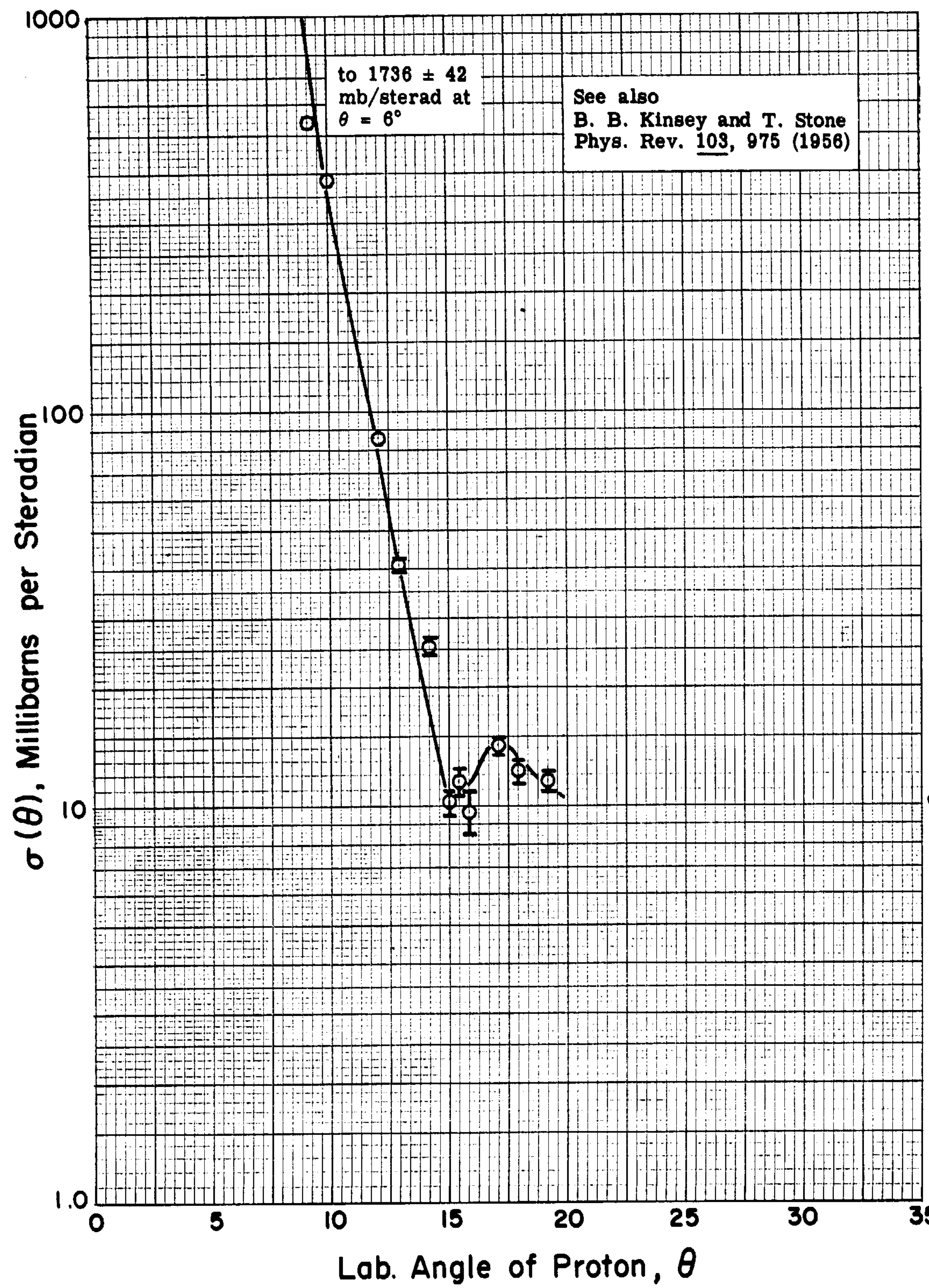


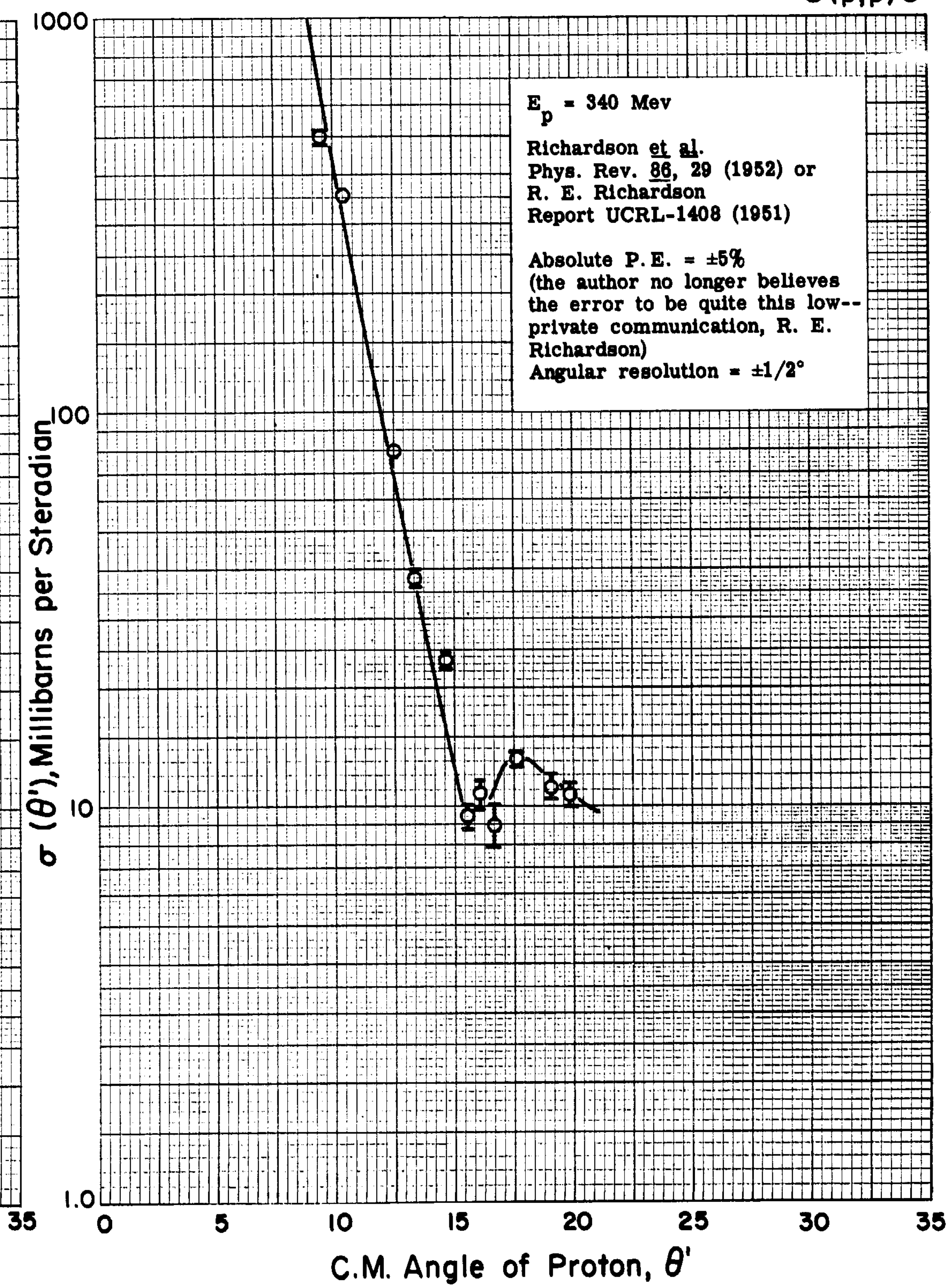

P31(α, p)S34
Q = 0.63 Mev
Alpha energy 30.4 Mev
C. E. Hunting and N. S. Wall
Phys. Rev. 115, 956 (1959)
Absolute P.E. = +200%
-70%
See also
C. E. Hunting and N. S. Wall
Phys. Rev. 108, 901 (1957)
For relative data see
P. von Herrmann and G. F. Pieper
Phys. Rev. 105, 1556 (1957)
(alpha energies 7.0 and 8.1 Mev)
σ(θ'), Microbarns per Steradian
1000
100
10
1
0
20
40
60
80
100
120
160
C.M. Angle of Proton, θ'



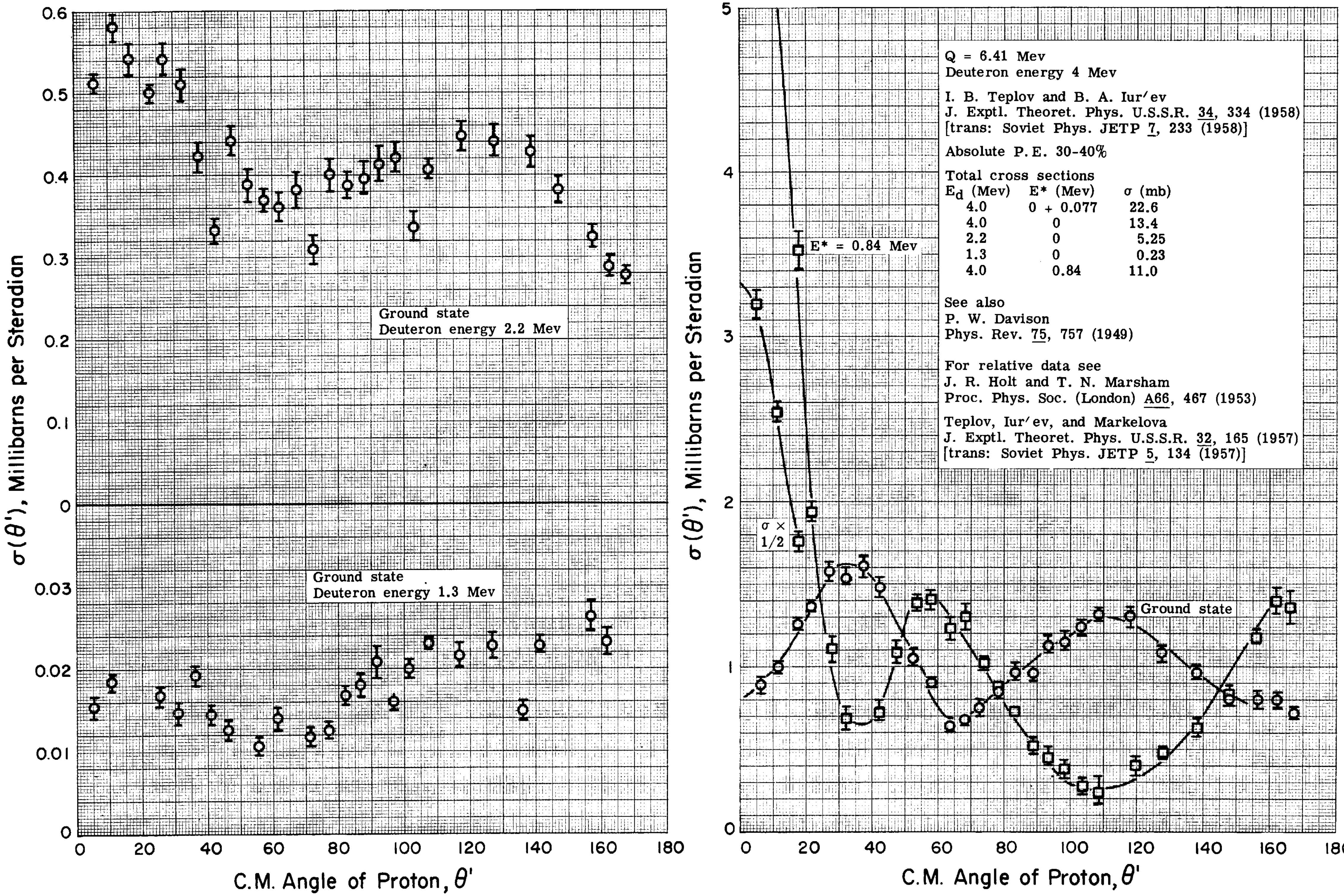
S32(p,p)S32
Olness, Haeberli, and Lewis
Phys. Rev. 112, 1702 (1958)
Absolute P.E. = ±5%
C.M. angle θ' = 63.9°
θ' = 92°
σ(θ'), Millibarns per Steradian
2.0
1.5
1.0
0.5
0.5
0.4
0.3
0.2
0.1
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Proton Energy, Mev


Olness, Haeberli, and Lewis
Phys. Rev. 112, 1702 (1958)
Absolute P.E. = ±5% except at θ' = 167.8° where the error is ±3%
C.M. angle θ' = 125.5°
θ' = 141.0°
θ' = 167.8°
σ (θ'), Barns per Steradian
0
0.1
0.2
0.3
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Proton Energy, Mev

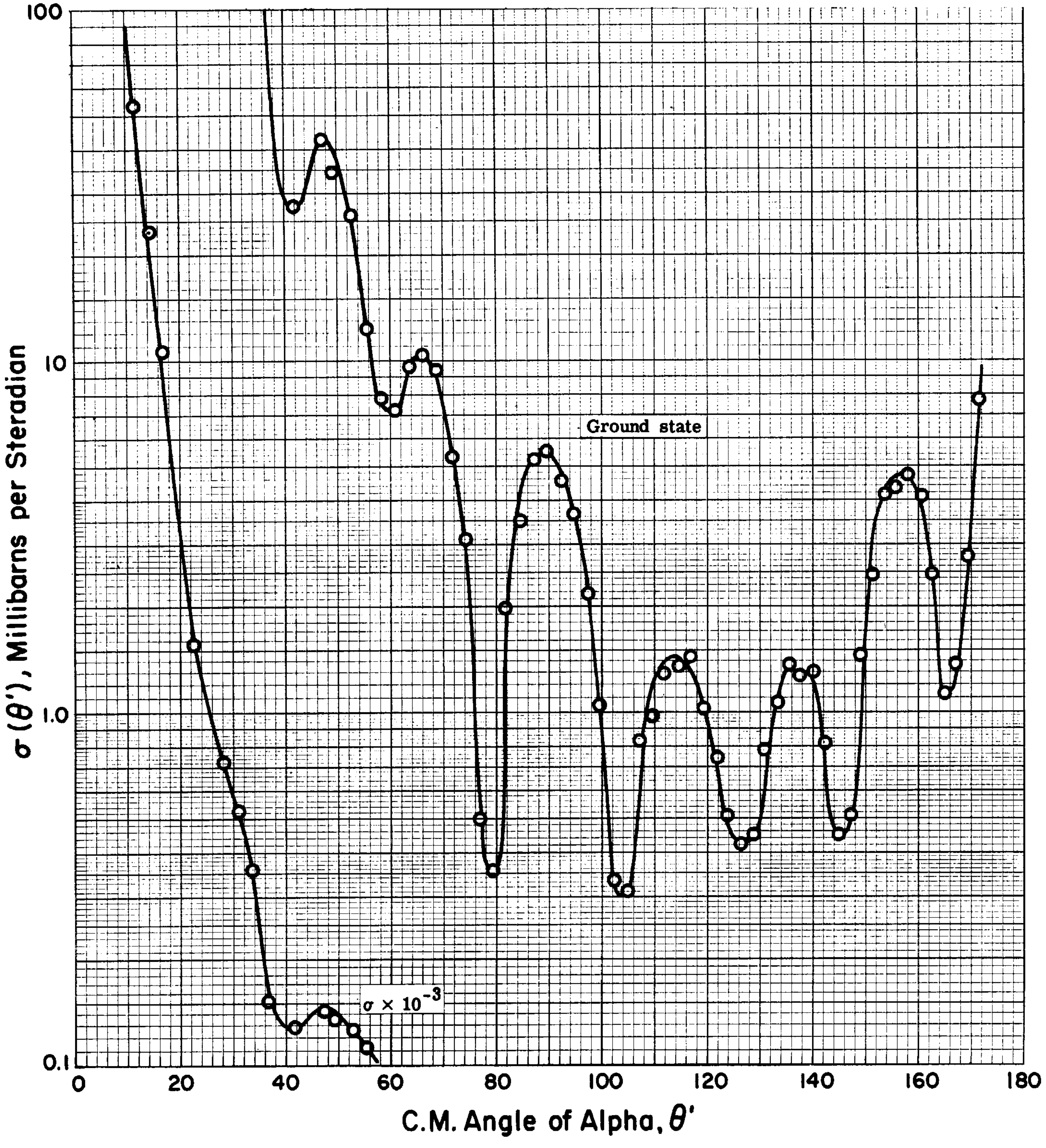

to 1736 ± 42
mb/sterad at
θ = 6°
See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
σ (θ), Millibars per Steradian
Lab. Angle of Proton, θ
1000
100
10
1.0
0
5
10
15
20
25
30
35


Ep = 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P.E. = ±5%
(the author no longer believes
the error to be quite this low--
private communication, R. E.
Richardson)
Angular resolution = ±1/2°
σ (θ'), Millibars per Steradian
C.M. Angle of Proton, θ'
1000
100
10
1.0
0
5
10
15
20
25
30
35

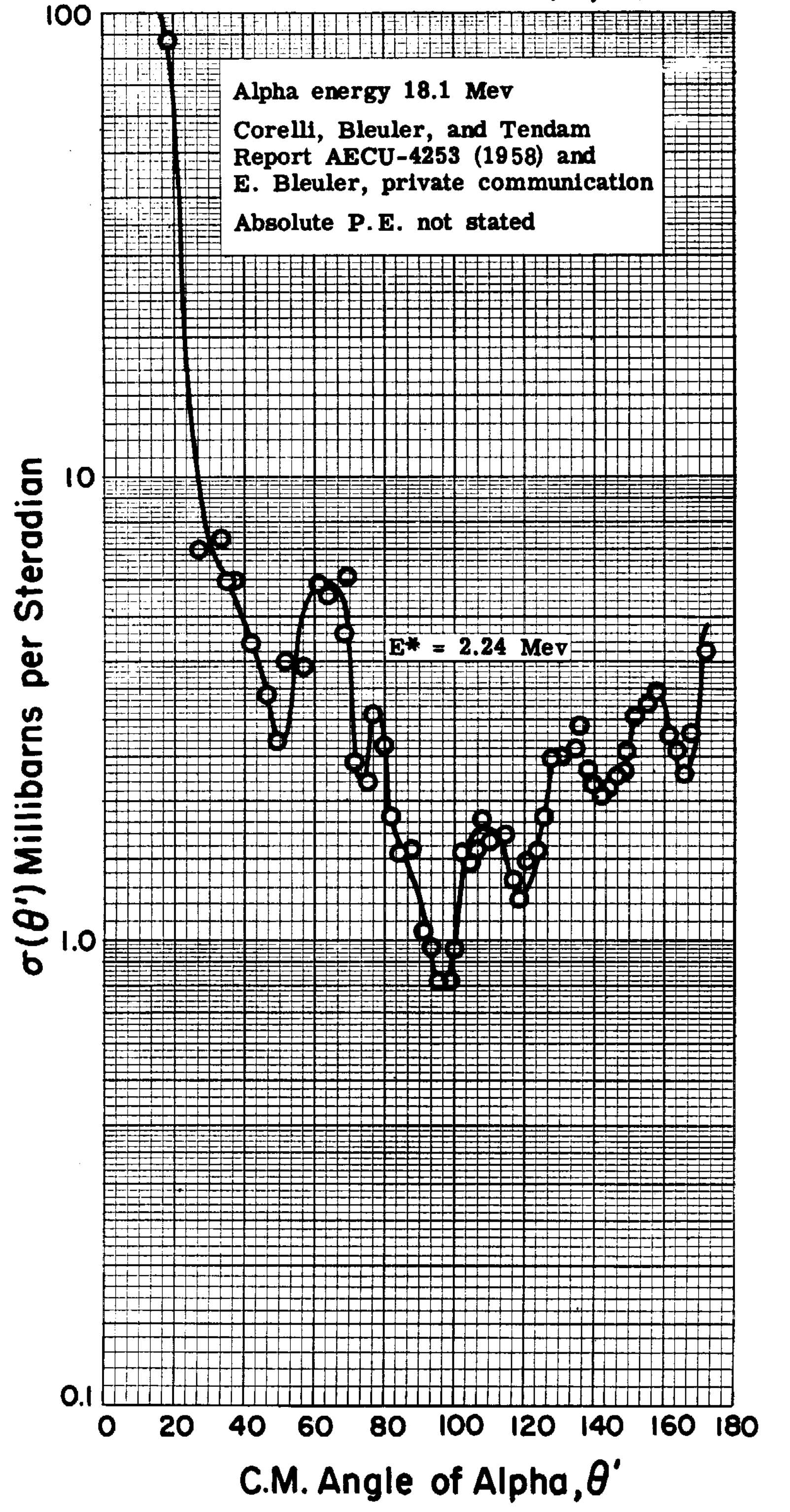
$S^{32}(d,p')\,S^{33*}$

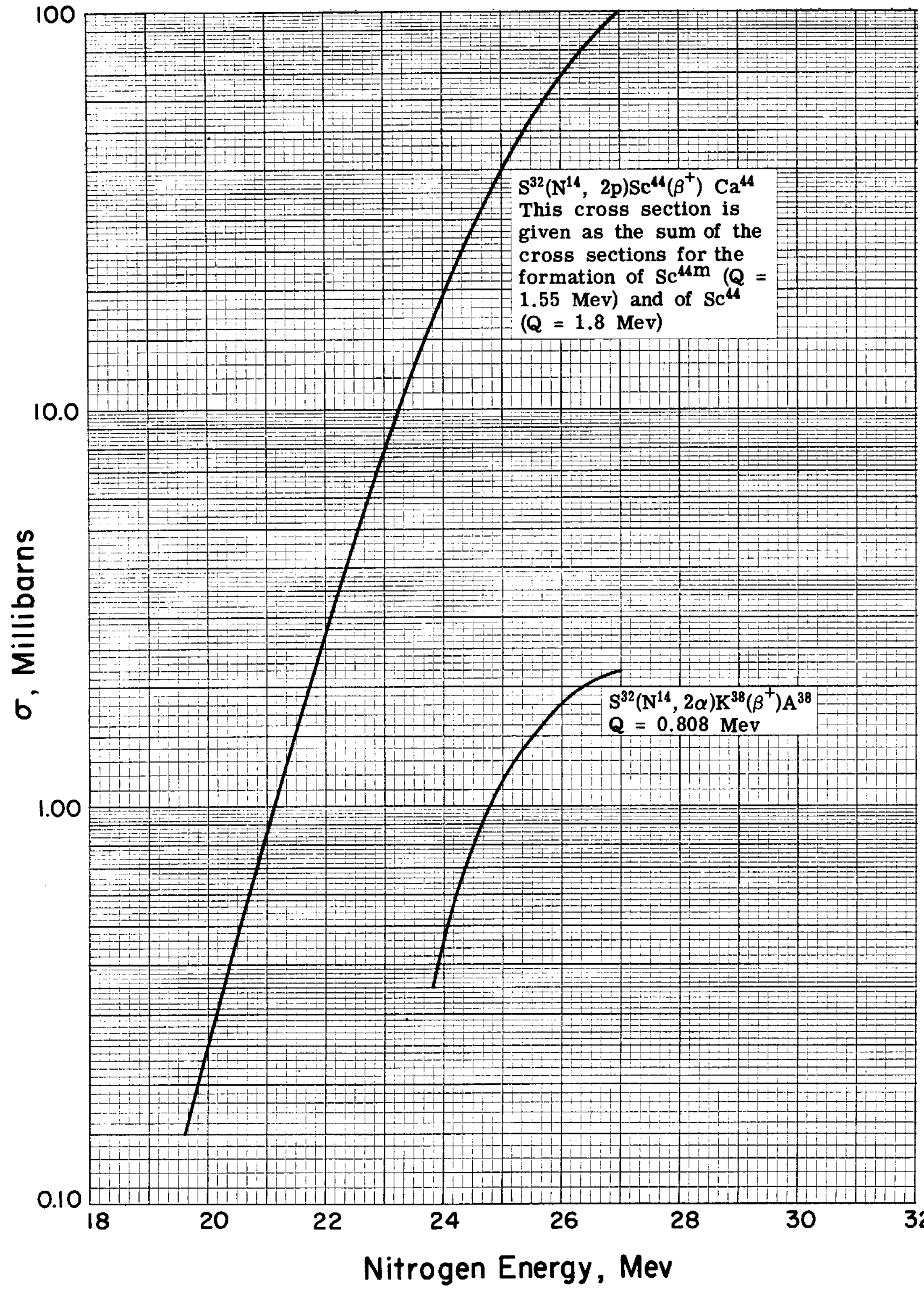


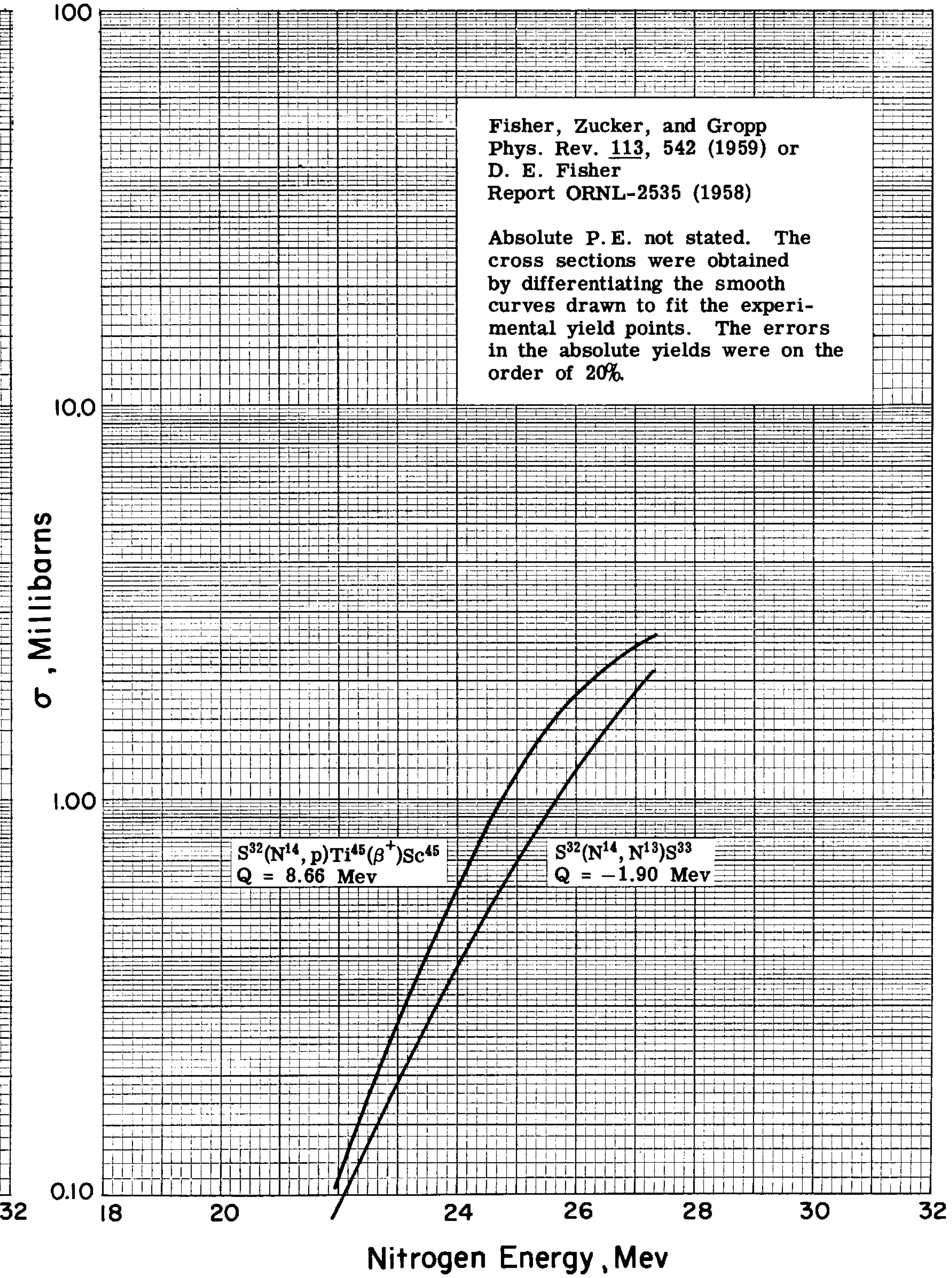
Ground state
Deuteron energy 2.2 Mev
Ground state
Deuteron energy 1.3 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
Q = 6.41 Mev
Deuteron energy 4 Mev
I. B. Teplov and B. A. Iur′ev
J. Exptl. Theoret. Phys. U.S.S.R. 34, 334 (1958)
[trans: Soviet Phys. JETP 7, 233 (1958)]
Absolute P.E. 30-40%
Total cross sections
E_d (Mev) E* (Mev) σ (mb)
4.0 0 + 0.077 22.6
4.0 0 13.4
2.2 0 5.25
1.3 0 0.23
4.0 0.84 11.0
See also
P. W. Davison
Phys. Rev. 75, 757 (1949)
For relative data see
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 467 (1953)
Teplov, Iur′ev, and Markelova
J. Exptl. Theoret. Phys. U.S.S.R. 32, 165 (1957)
[trans: Soviet Phys. JETP 5, 134 (1957)]
E* = 0.84 Mev
σ × 1/2
Ground state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'



$S^{32}(\alpha,\alpha')S^{32*}$



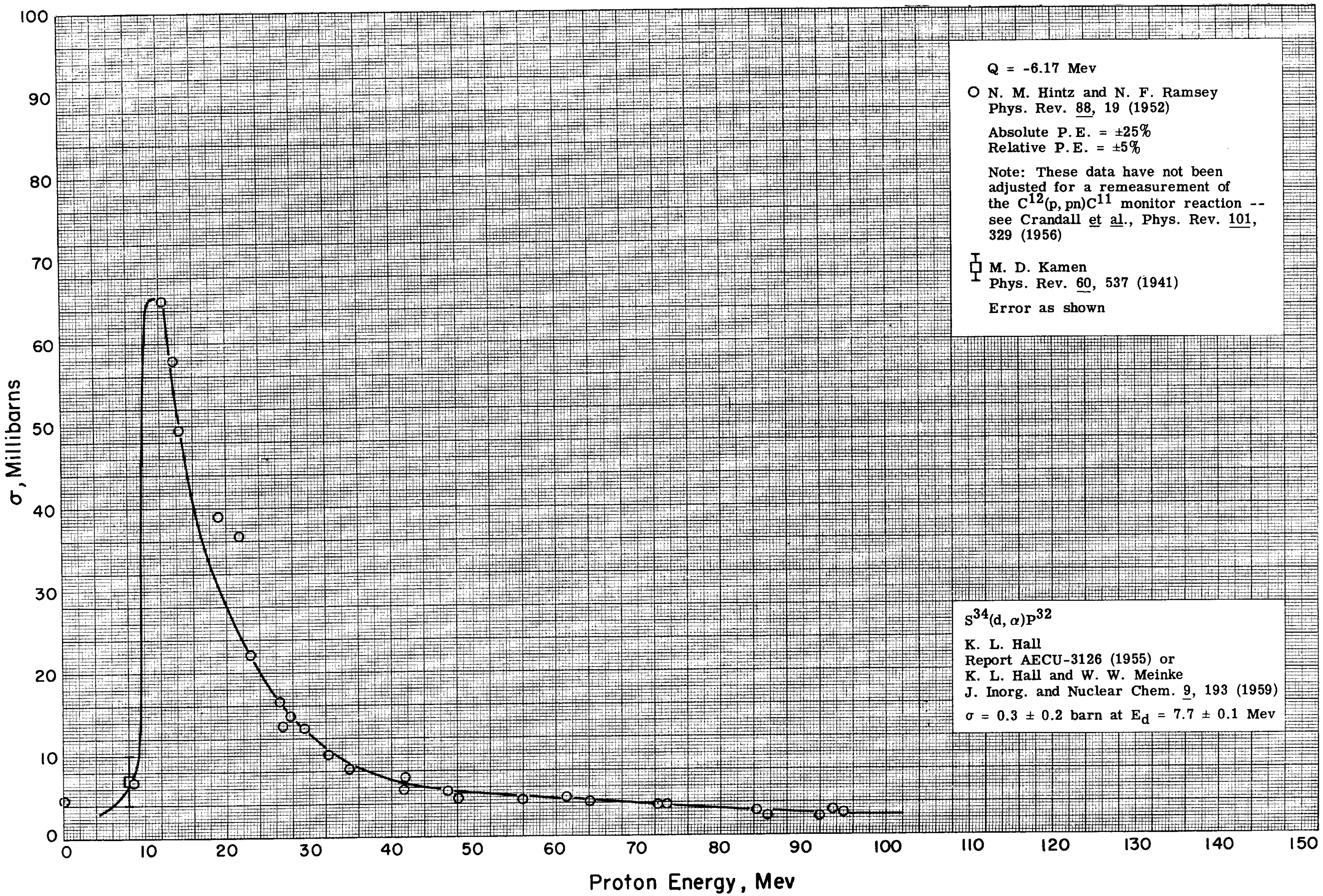




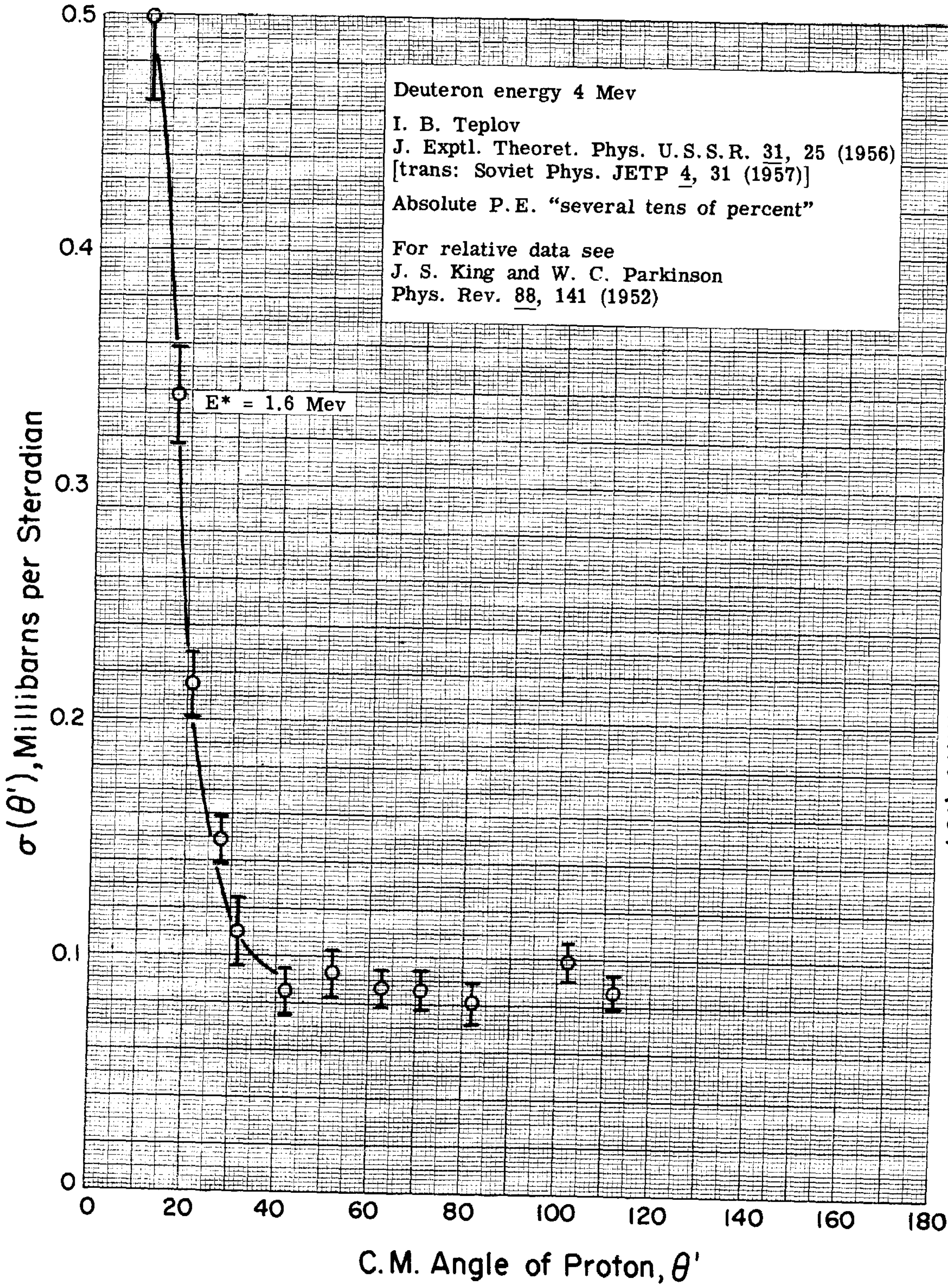
Fisher, Zucker, and Gropp
Phys. Rev. 113, 542 (1959) or
D. E. Fisher
Report ORNL-2535 (1958)

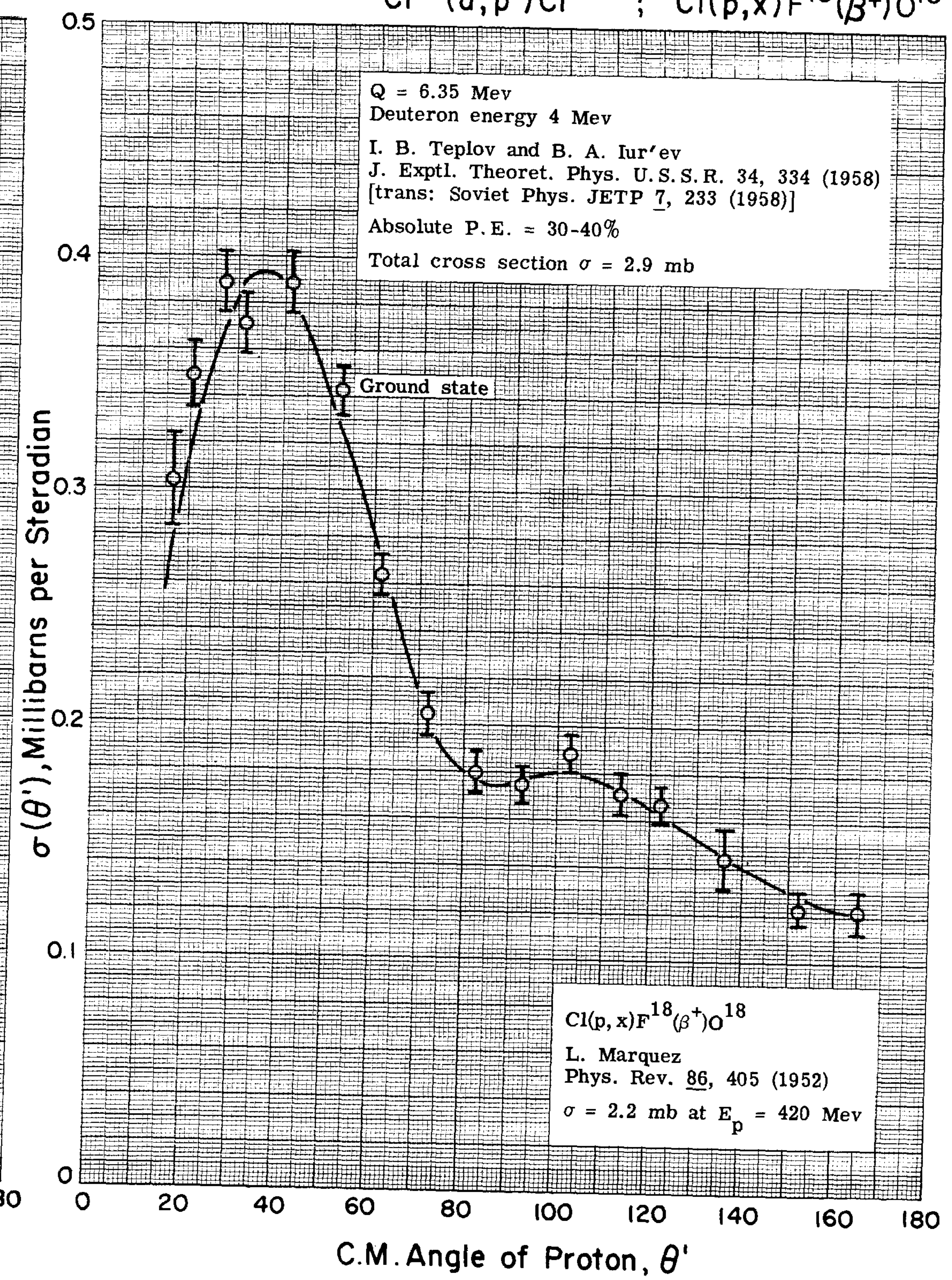
Absolute P.E. not stated. The cross sections were obtained by differentiating the smooth curves drawn to fit the experimental yield points. The errors in the absolute yields were on the order of 20%.

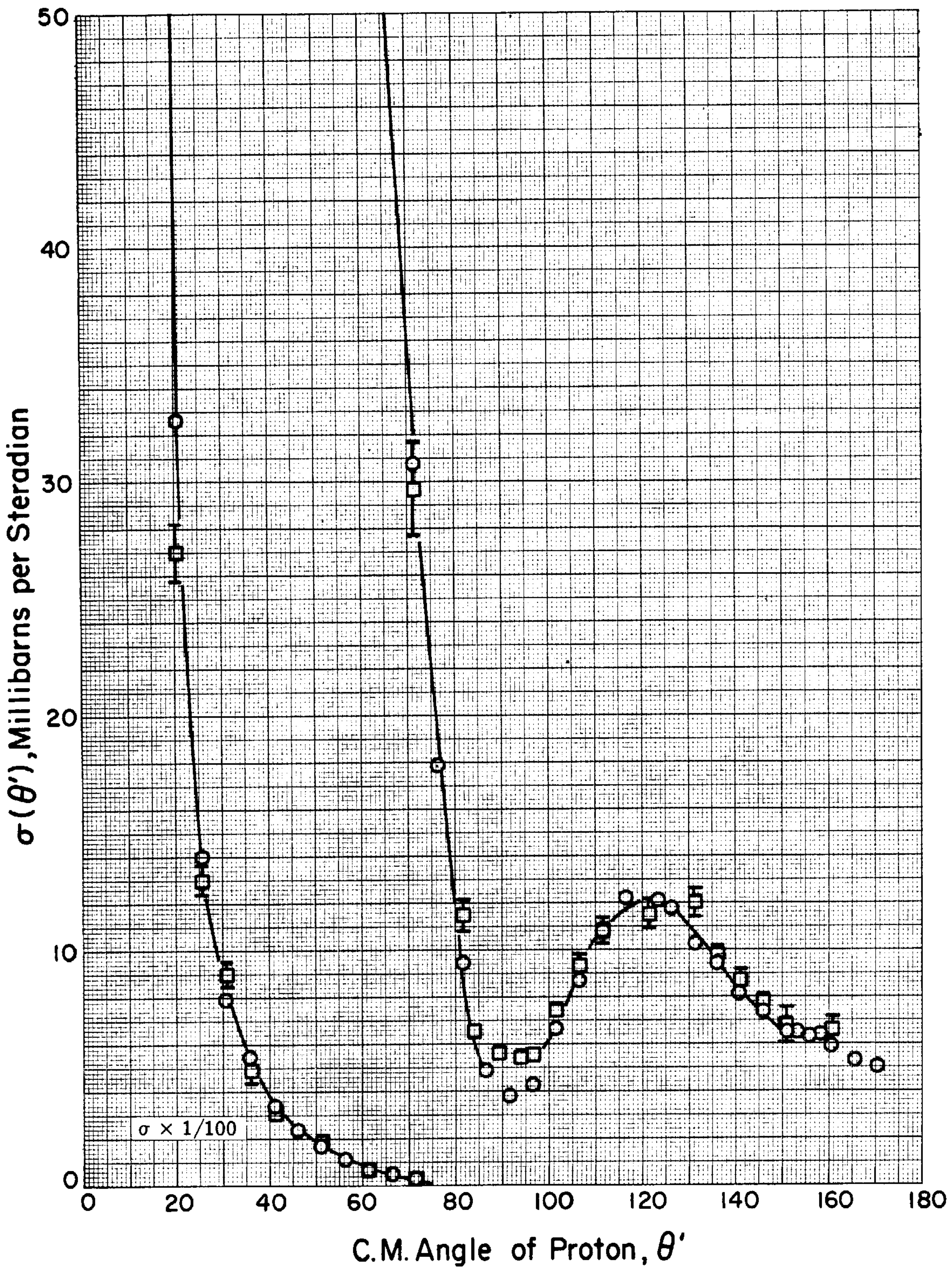
$S^{34}(p,n)Cl^{34}(\beta^+)S^{34}$; $S^{34}(d,\alpha)P^{32}$



$Cl^{35}(d,p')Cl^{36*}$; $Cl(p,x)F^{18}(\beta^+)O^{18}$







□ Proton energy 9.51 Mev

Gibson, Prowse, and Rotblatt
Proc. Roy. Soc. (London) A243, 237 (1957)

Absolute P.E. = ±5%

○ Proton energy 9.72 Mev

N. M. Hintz
Phys. Rev. 106, 1201 (1957)

Absolute P.E. = ±5-7%

Proton energy 0.98 Mev

Bashkin, Carlson, and Douglas
Phys. Rev. 114, 1543 (1959)

$\sigma(159.5°)$ = 478 ± 15 mb/sterad

See also
Freier et al.
Phys. Rev. 110, 446 (1958)

B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)

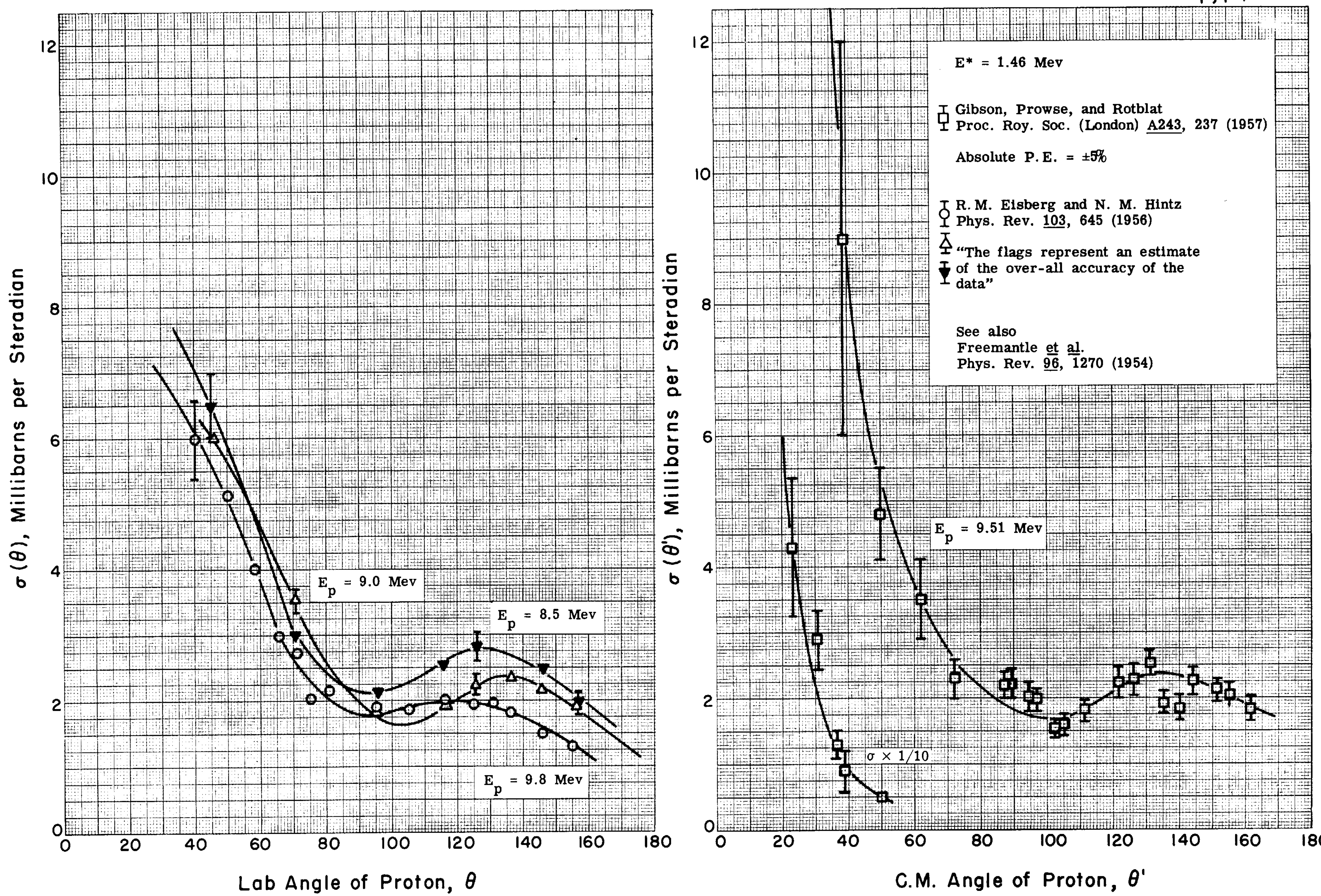
Freemantle et al.
Phys. Rev. 96, 1270 (1954)

$A^{36}(\alpha, p)K^{39}$ Q = -1.29 Mev

Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)

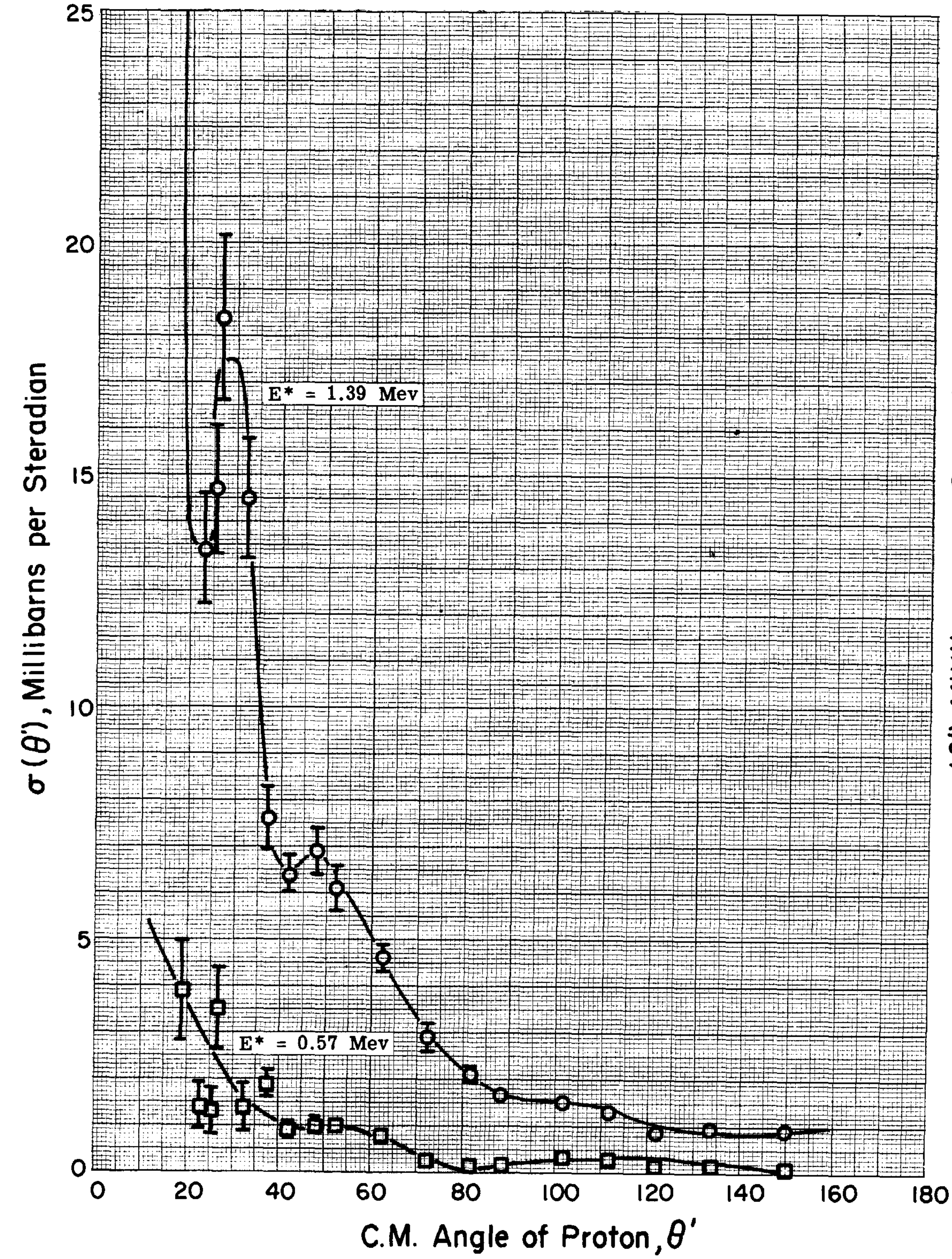
$\sigma(90°)$ = 8.5 ±35% mb at E_α = 7.4 Mev

$A^{40}(p,p')A^{40*}$

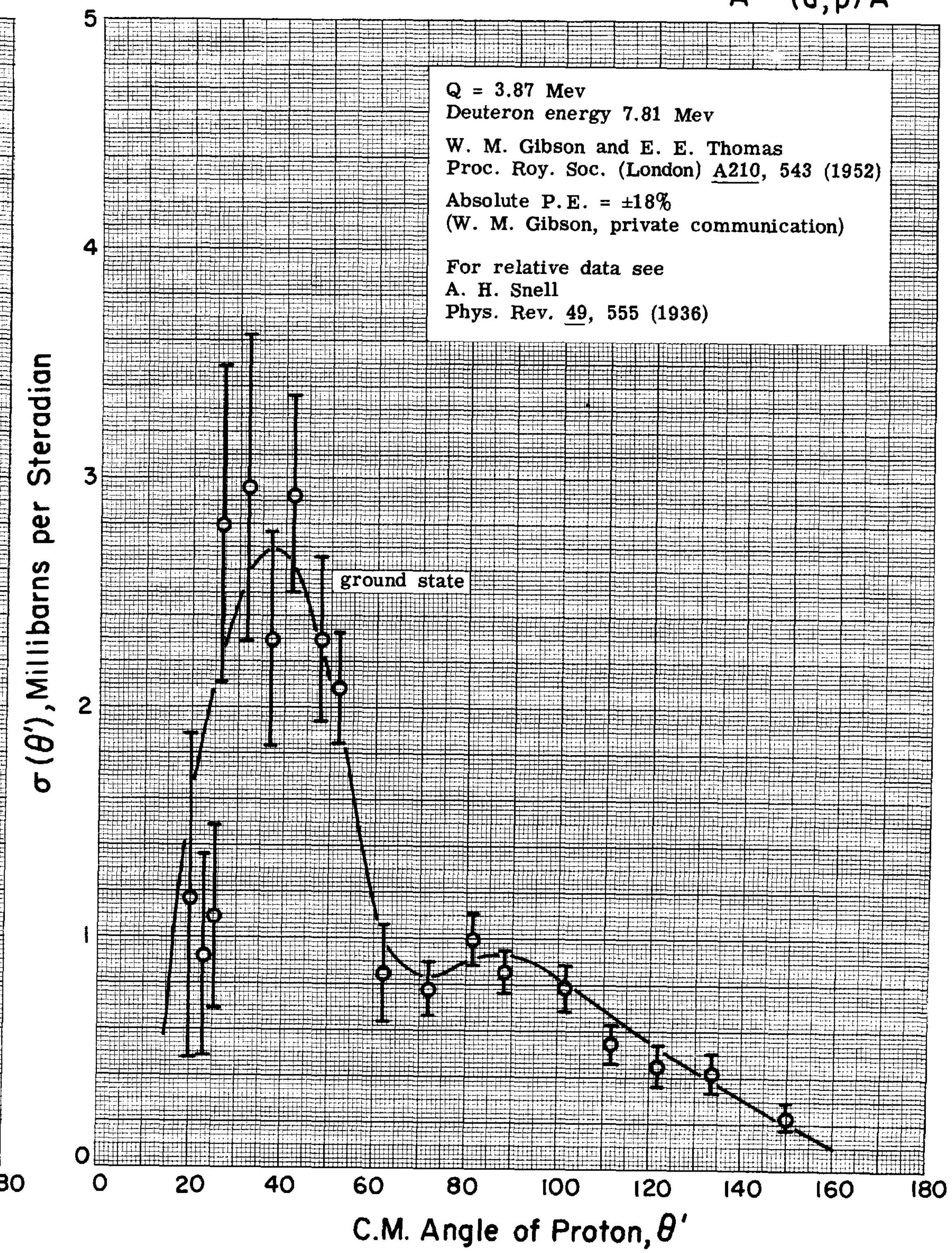


σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
E_p = 9.0 Mev
E_p = 8.5 Mev
E_p = 9.8 Mev
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
E* = 1.46 Mev
Gibson, Prowse, and Rotblat
Proc. Roy. Soc. (London) A243, 237 (1957)
Absolute P.E. = ±5%
R. M. Eisberg and N. M. Hintz
Phys. Rev. 103, 645 (1956)
"The flags represent an estimate of the over-all accuracy of the data"
See also
Freemantle et al.
Phys. Rev. 96, 1270 (1954)
E_p = 9.51 Mev
σ × 1/10

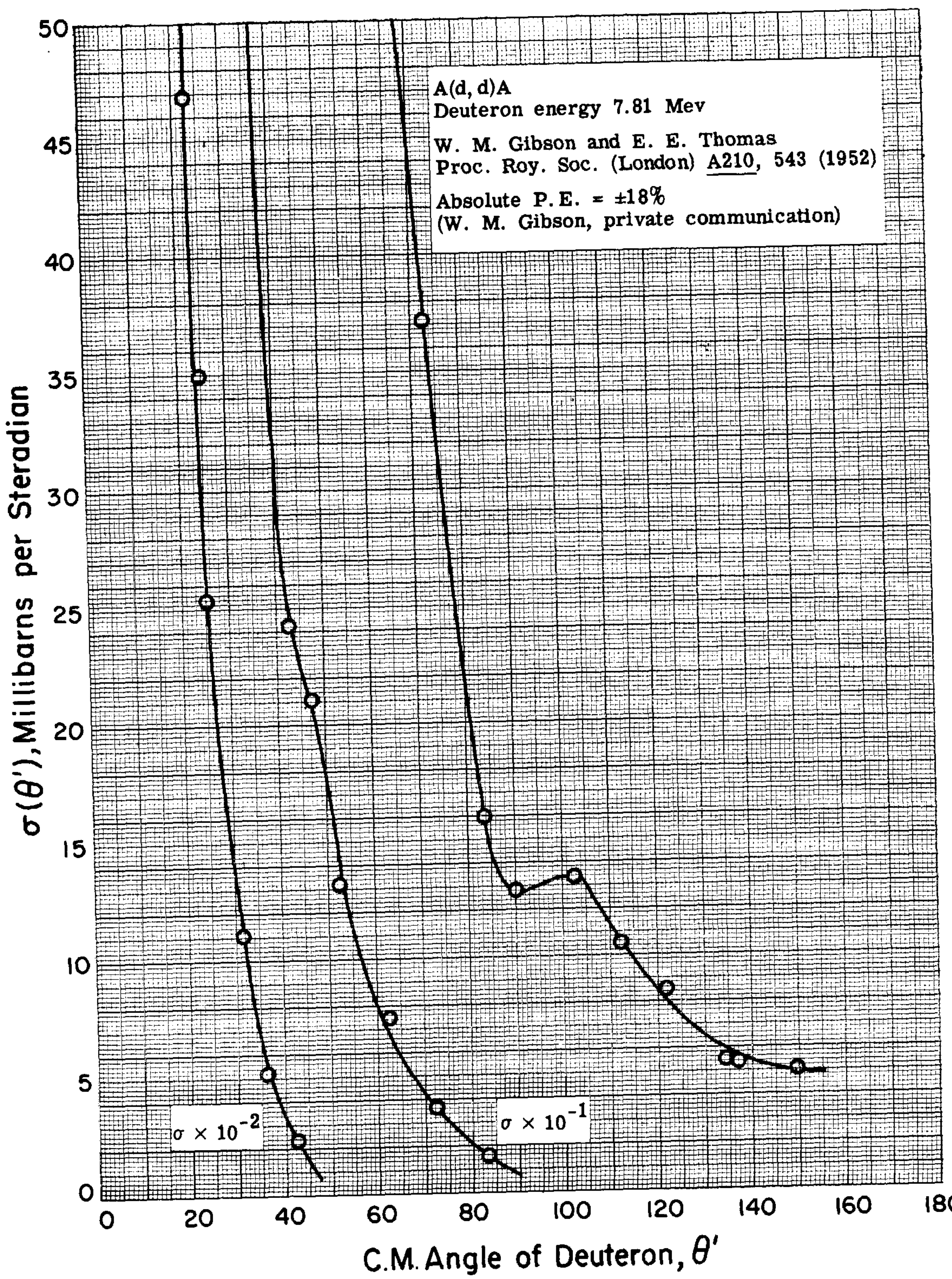
$A^{40}(d,p')A^{40*}$

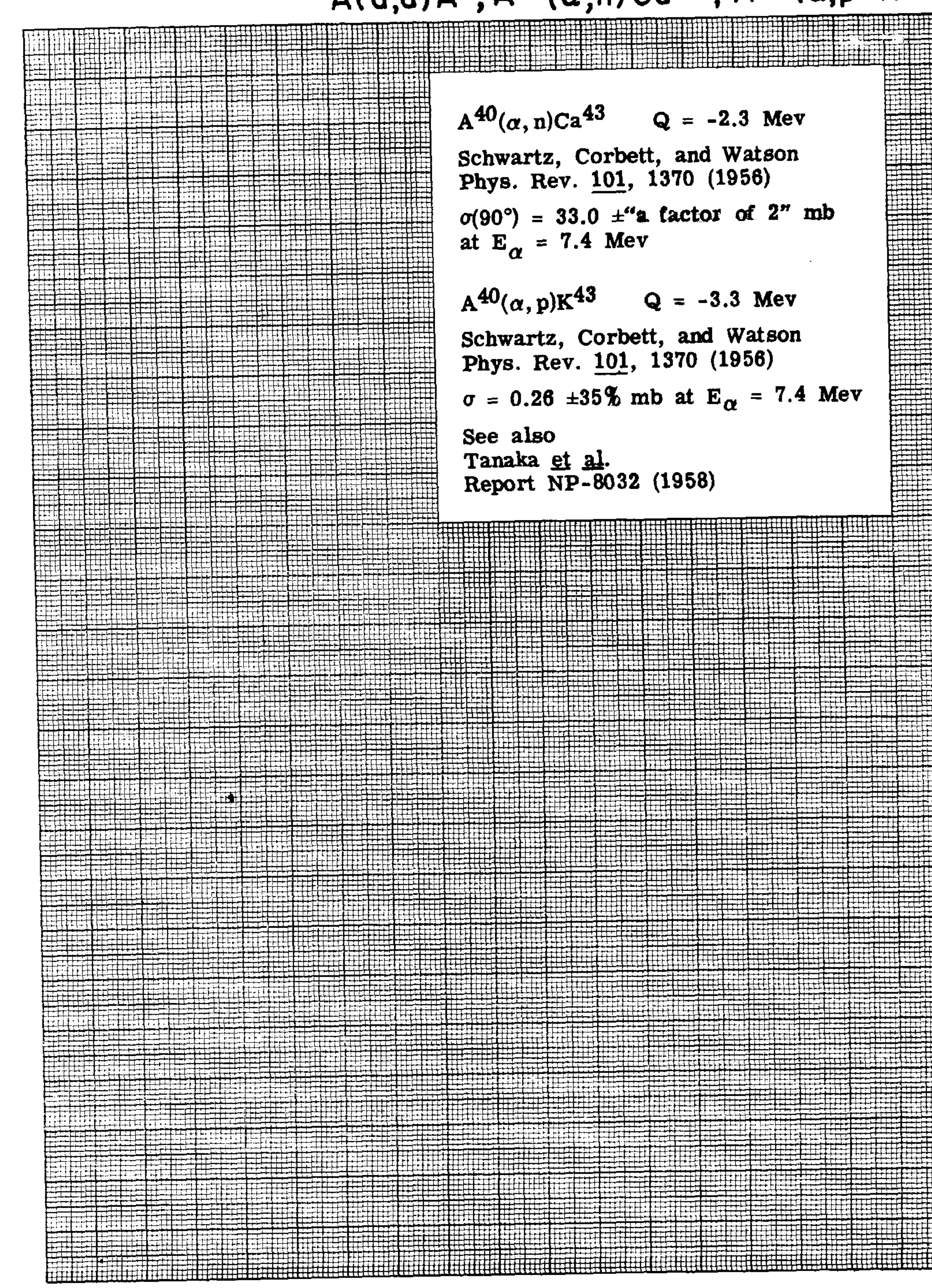


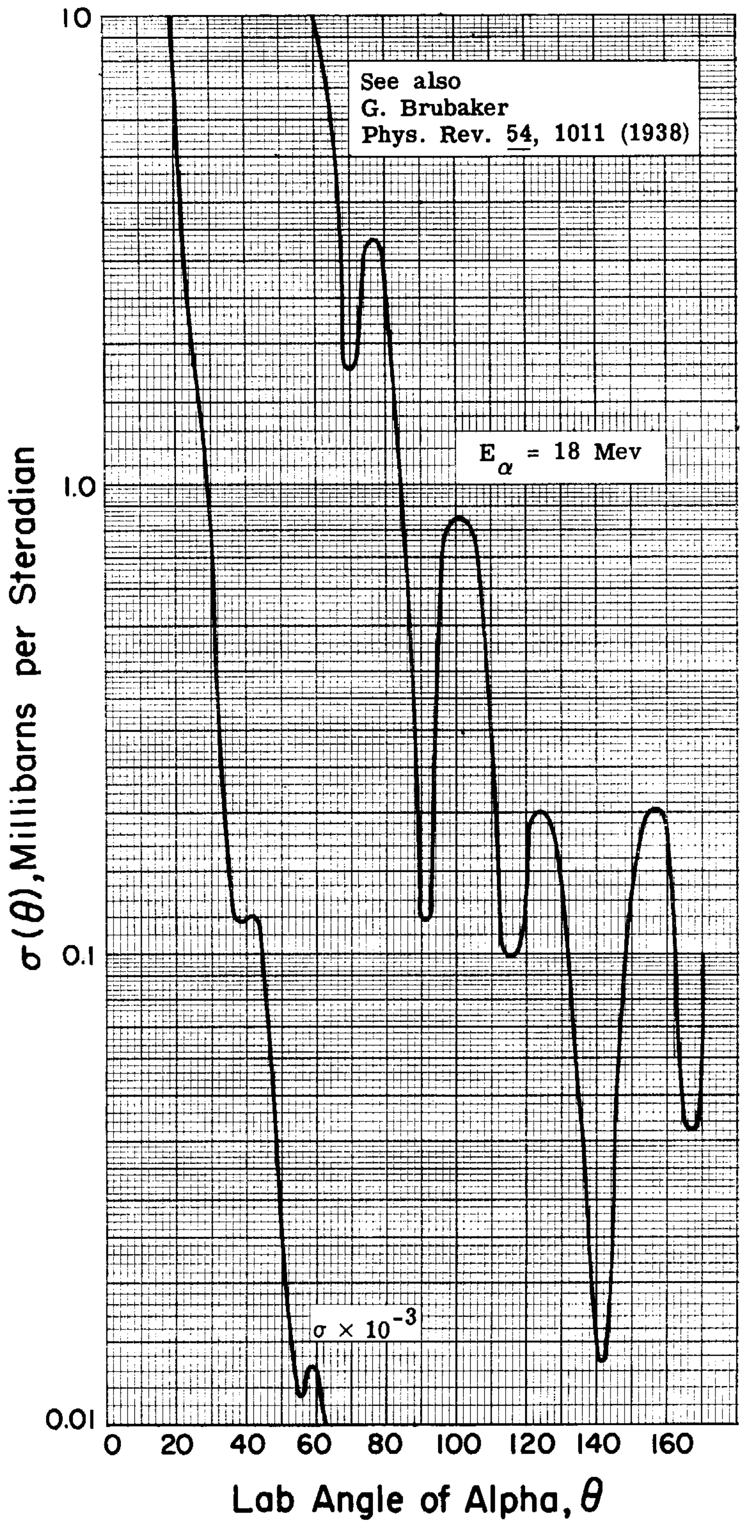
E* = 1.39 Mev
E* = 0.57 Mev
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

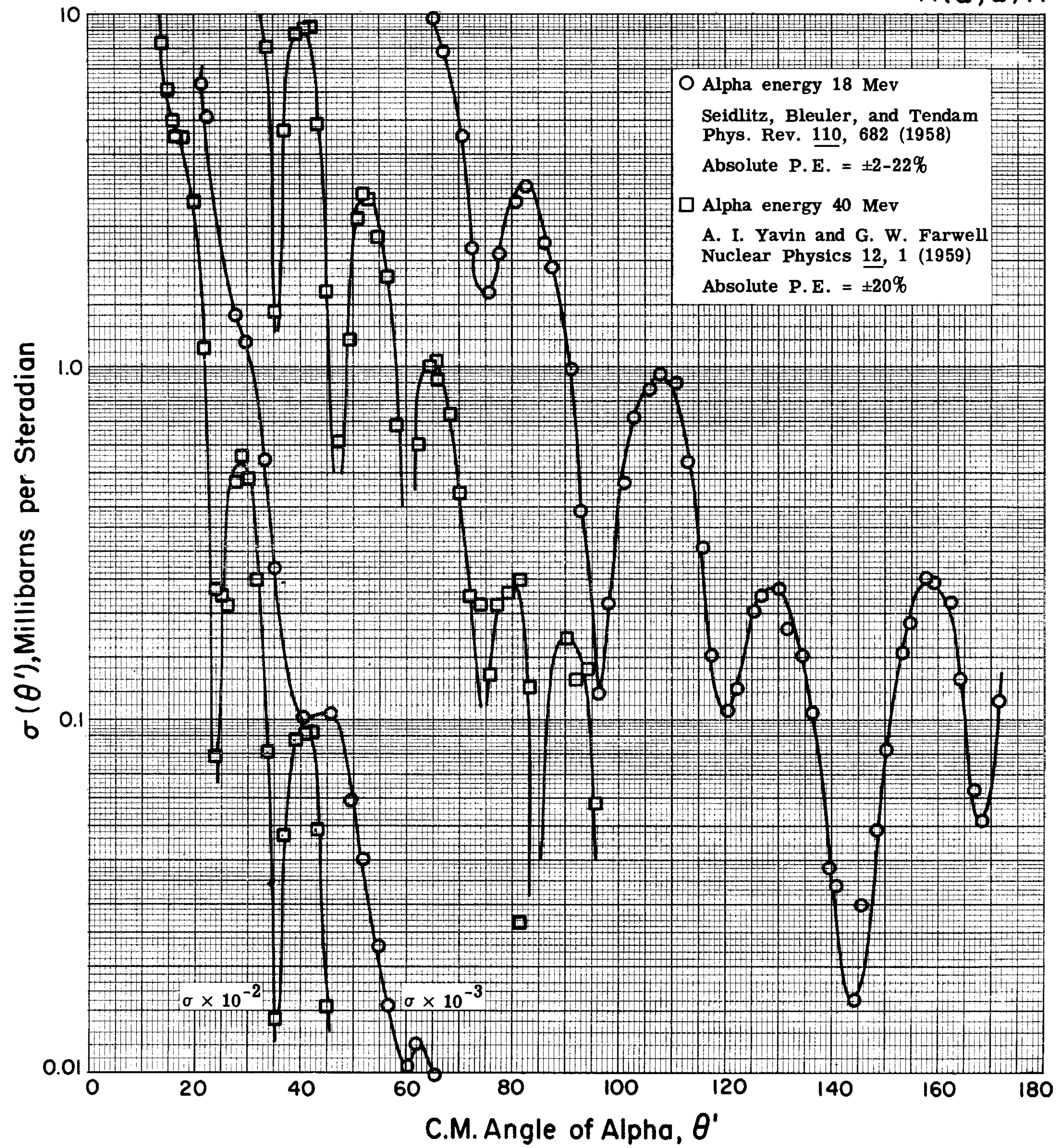


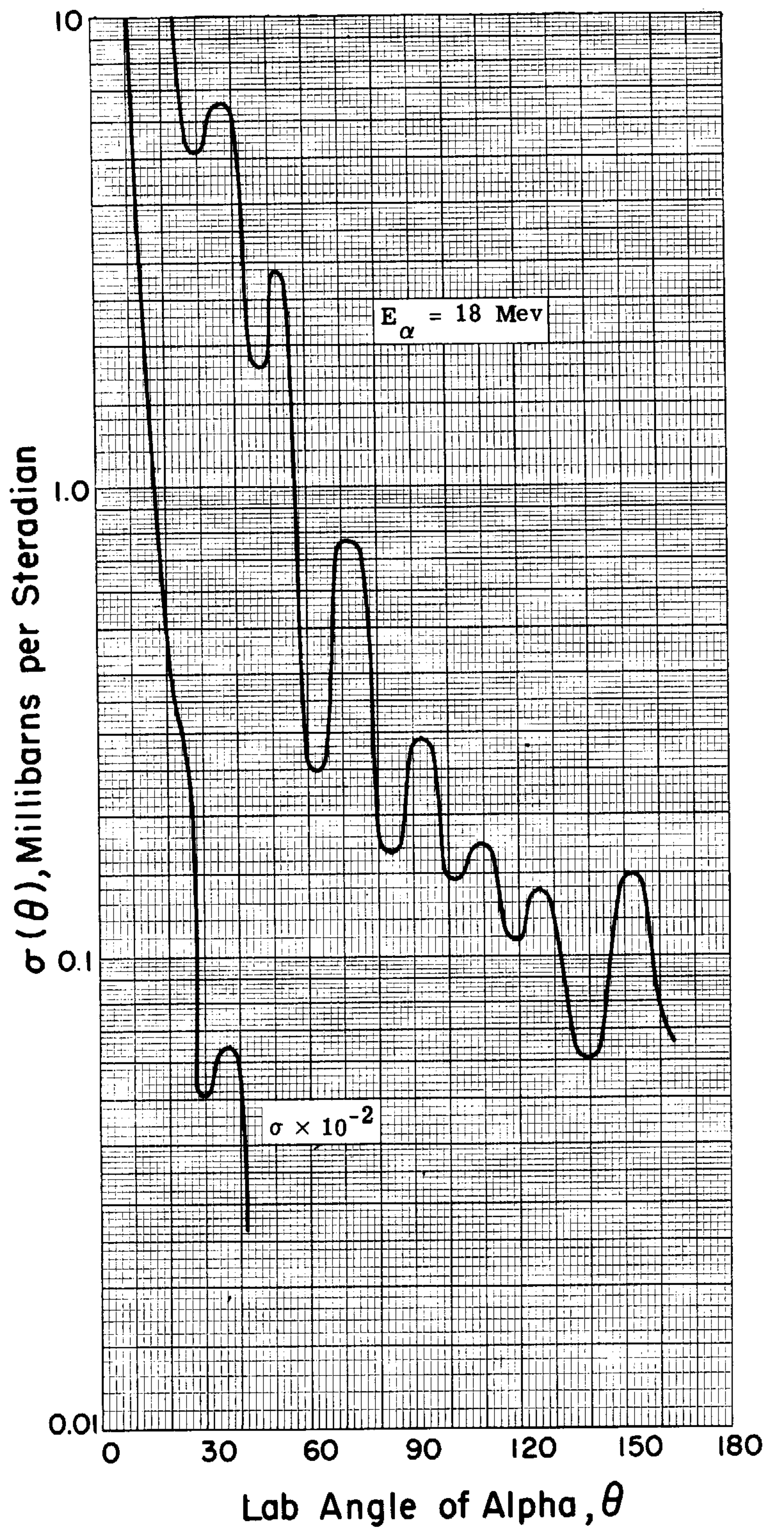
Q = 3.87 Mev
Deuteron energy 7.81 Mev
W. M. Gibson and E. E. Thomas
Proc. Roy. Soc. (London) A210, 543 (1952)
Absolute P.E. = ±18%
(W. M. Gibson, private communication)
For relative data see
A. H. Snell
Phys. Rev. 49, 555 (1936)
ground state
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'


A(d, d)A
Deuteron energy 7.81 Mev
W. M. Gibson and E. E. Thomas
Proc. Roy. Soc. (London) A210, 543 (1952)
Absolute P.E. = ±18%
(W. M. Gibson, private communication)
σ × 10⁻²
σ × 10⁻¹
σ(θ'), Millibarns per Steradian
C.M. Angle of Deuteron, θ'
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120
140
160
180

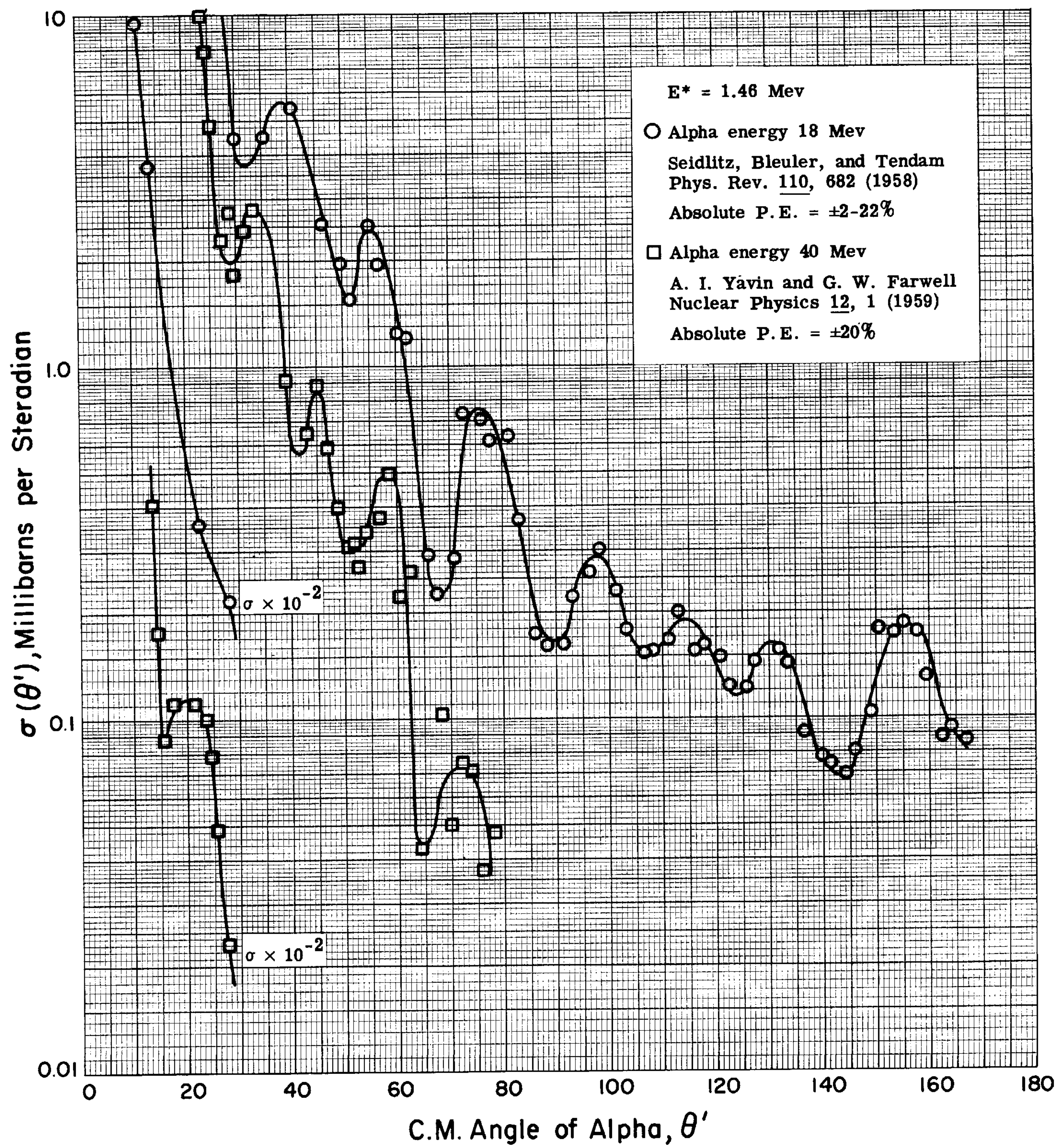

A40(α, n)Ca43 Q = -2.3 Mev
Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)
σ(90°) = 33.0 ±"a factor of 2" mb
at Eα = 7.4 Mev
A40(α, p)K43 Q = -3.3 Mev
Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)
σ = 0.26 ±35% mb at Eα = 7.4 Mev
See also
Tanaka et al.
Report NP-8032 (1958)


See also
G. Brubaker
Phys. Rev. 54, 1011 (1938)
E α = 18 Mev
σ × 10⁻³
σ(θ), Millibarns per Steradian
Lab Angle of Alpha, θ

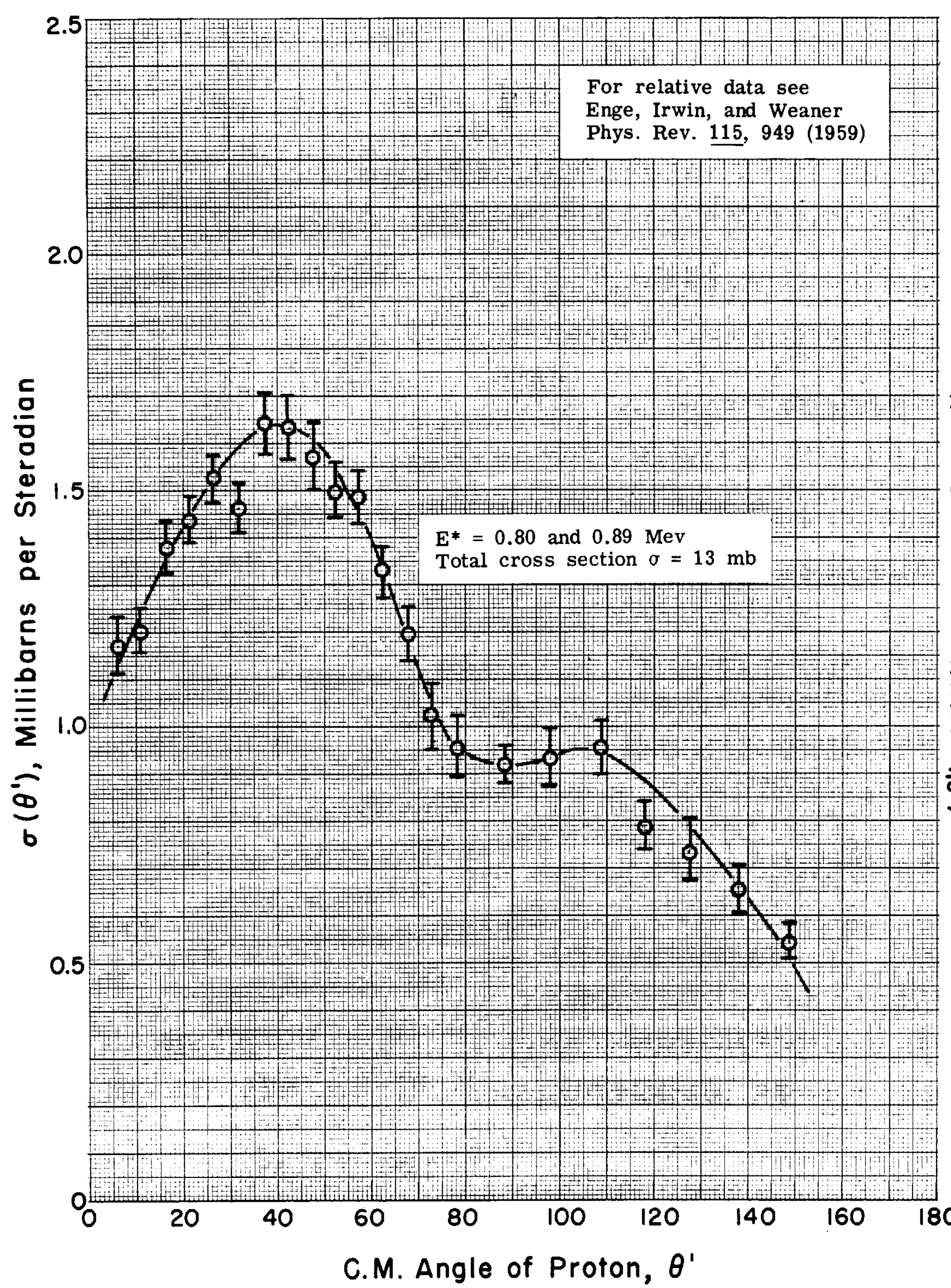

Alpha energy 18 Mev
Seidlitz, Bleuler, and Tendam
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±2-22%
Alpha energy 40 Mev
A. I. Yavin and G. W. Farwell
Nuclear Physics 12, 1 (1959)
Absolute P.E. = ±20%
σ × 10⁻²
σ × 10⁻³
σ(θ'), Millibarns per Steradian
C.M. Angle of Alpha, θ'

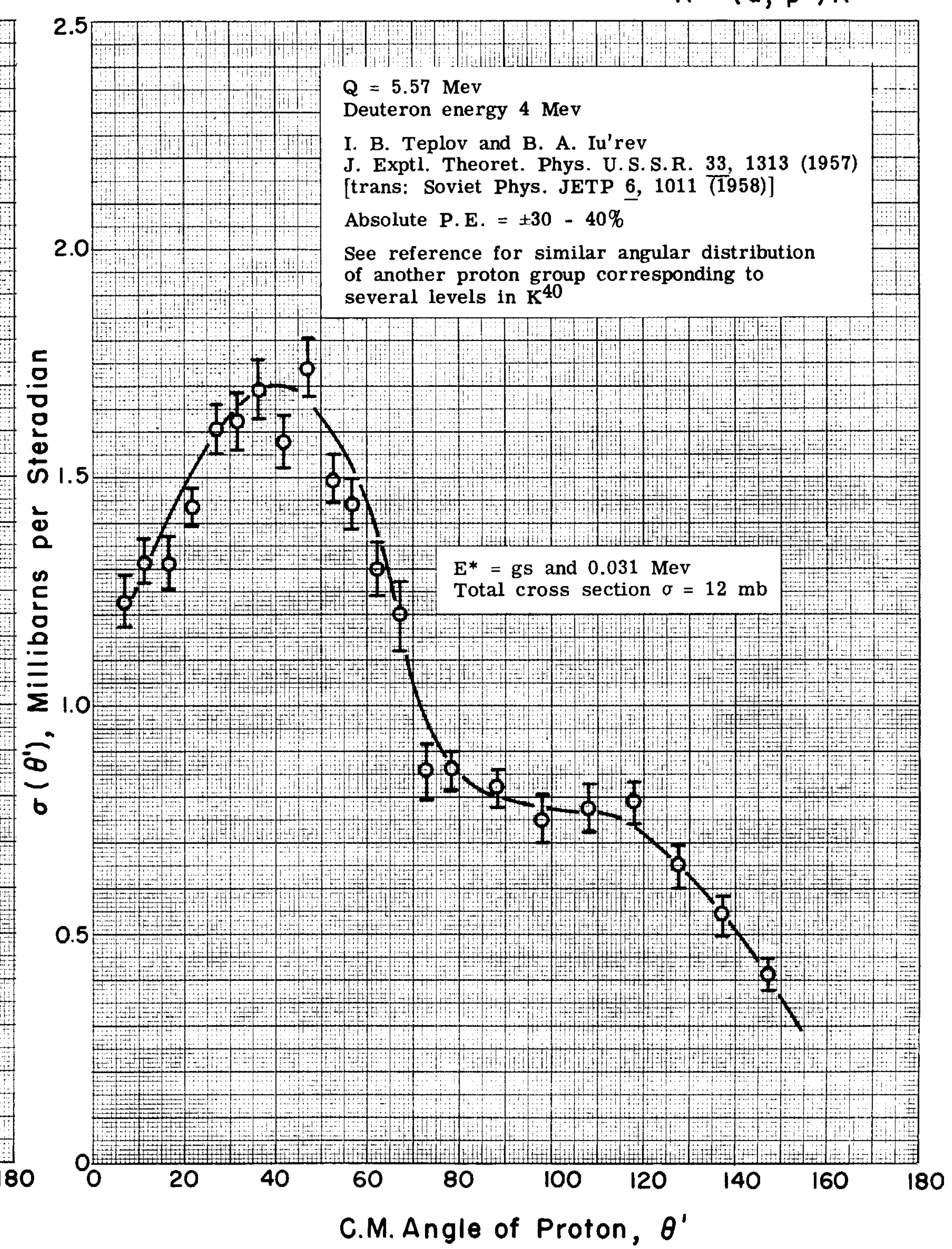


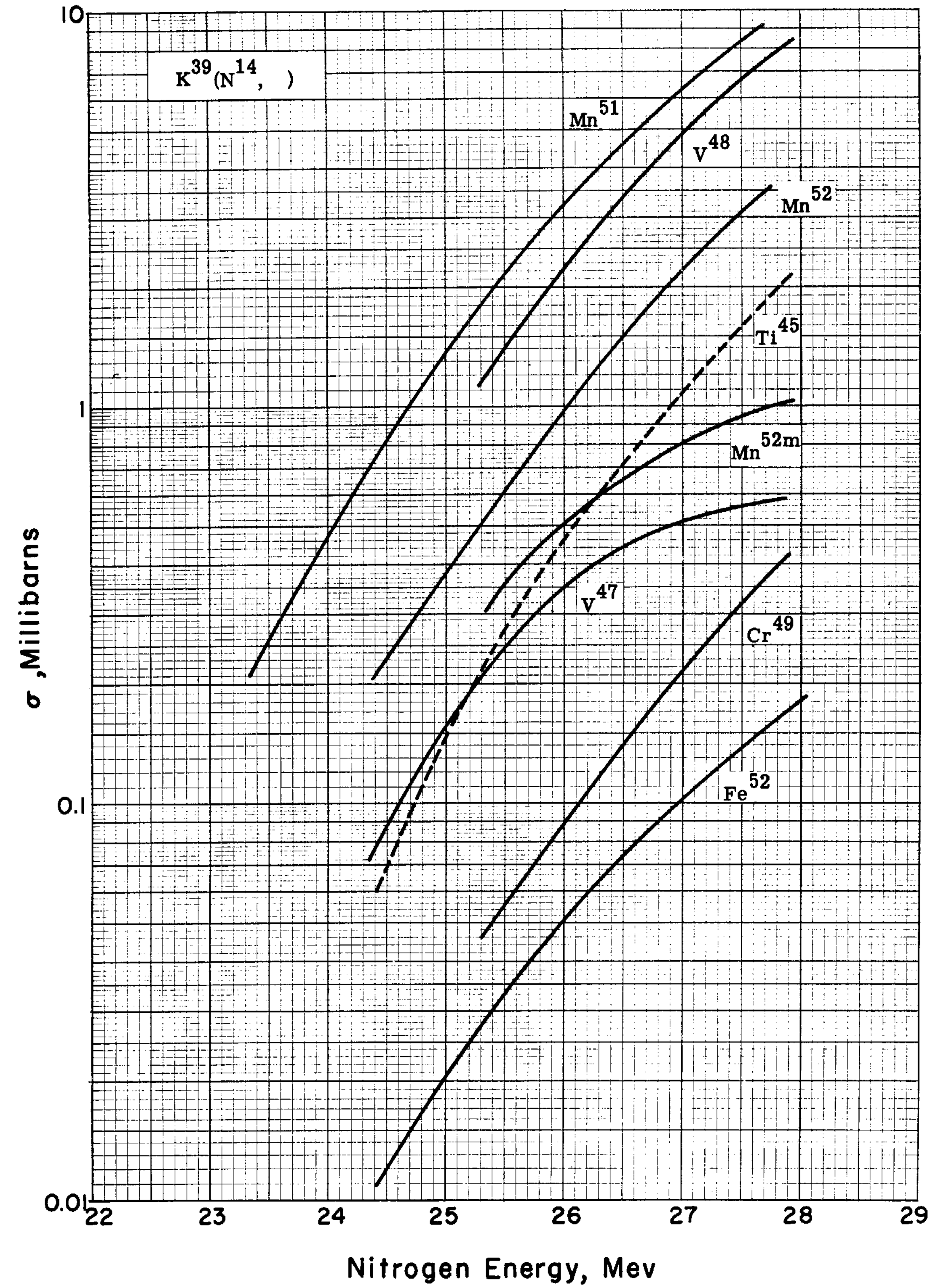
10
1.0
0.1
0.01
0
30
60
90
120
150
180
σ(θ), Millibarns per Steradian
Lab Angle of Alpha, θ
E_α = 18 Mev
σ × 10^-2



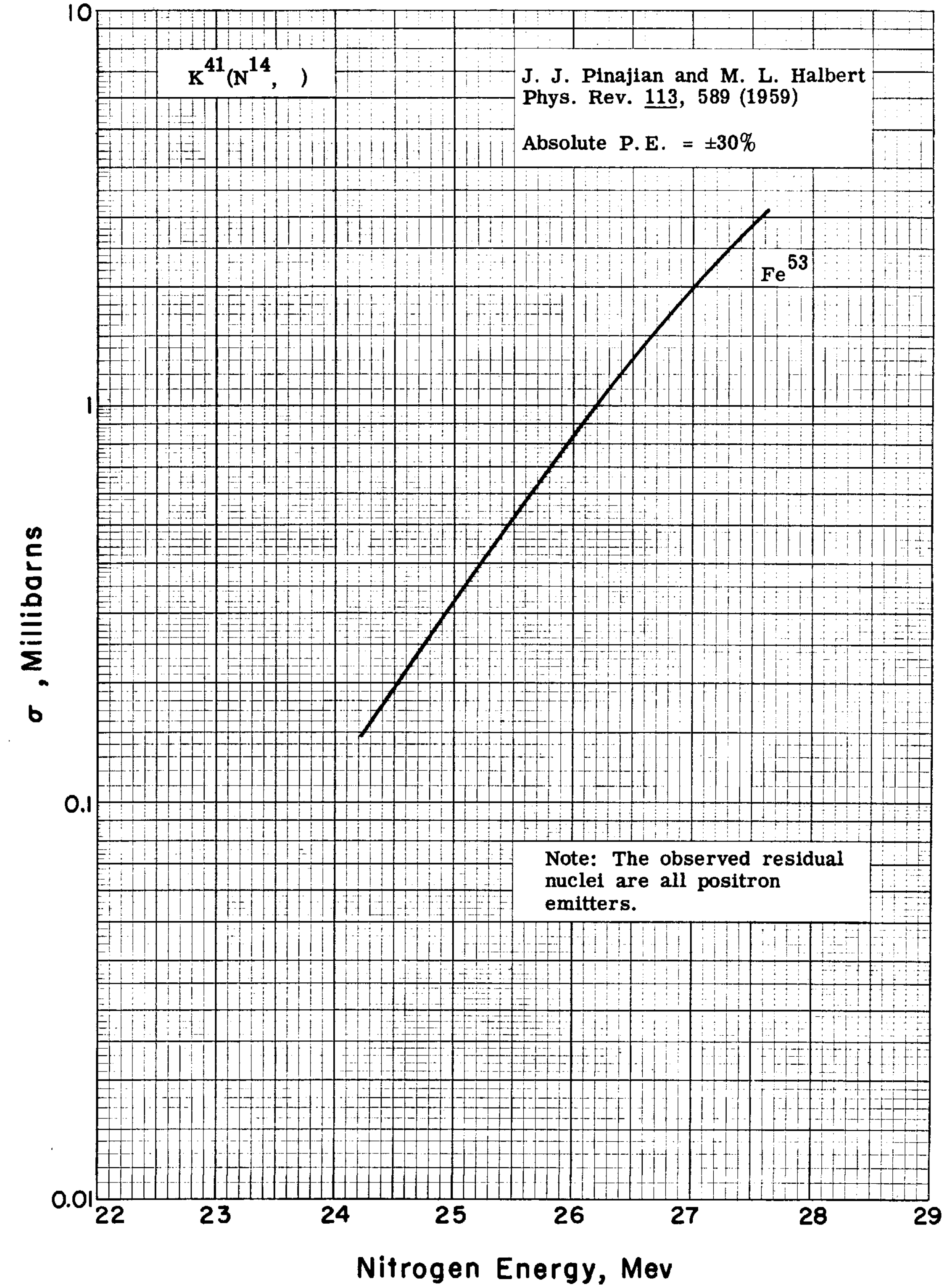
E* = 1.46 Mev
Alpha energy 18 Mev
Seidlitz, Bleuler, and Tendam
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±2-22%
Alpha energy 40 Mev
A. I. Yavin and G. W. Farwell
Nuclear Physics 12, 1 (1959)
Absolute P.E. = ±20%
σ × 10^-2
σ × 10^-2
10
1.0
0.1
0.01
0
20
40
60
80
100
120
140
160
180
σ(θ'), Millibarns per Steradian
C.M. Angle of Alpha, θ'


For relative data see
Enge, Irwin, and Weaner
Phys. Rev. 115, 949 (1959)
E* = 0.80 and 0.89 Mev
Total cross section σ = 13 mb
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'


Q = 5.57 Mev
Deuteron energy 4 Mev
I. B. Teplov and B. A. Iu'rev
J. Exptl. Theoret. Phys. U.S.S.R. 33, 1313 (1957)
[trans: Soviet Phys. JETP 6, 1011 (1958)]
Absolute P.E. = ±30 - 40%
See reference for similar angular distribution
of another proton group corresponding to
several levels in K40
E* = gs and 0.031 Mev
Total cross section σ = 12 mb
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

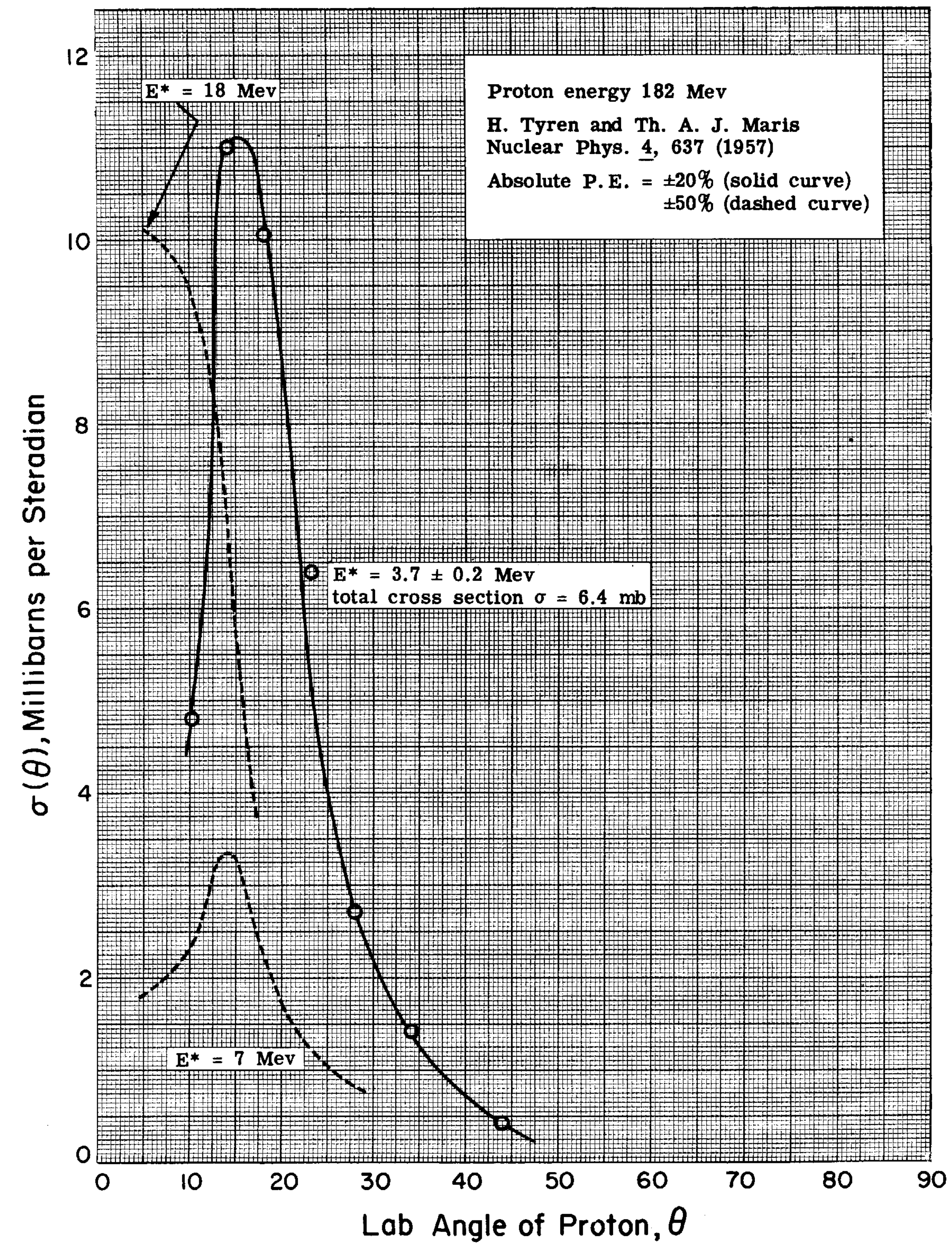


K39(N14,)
Mn51
V48
Mn52
Ti45
Mn52m
V47
Cr49
Fe52
σ, Millibarns
10
1
0.1
0.01
22 23 24 25 26 27 28 29
Nitrogen Energy, Mev

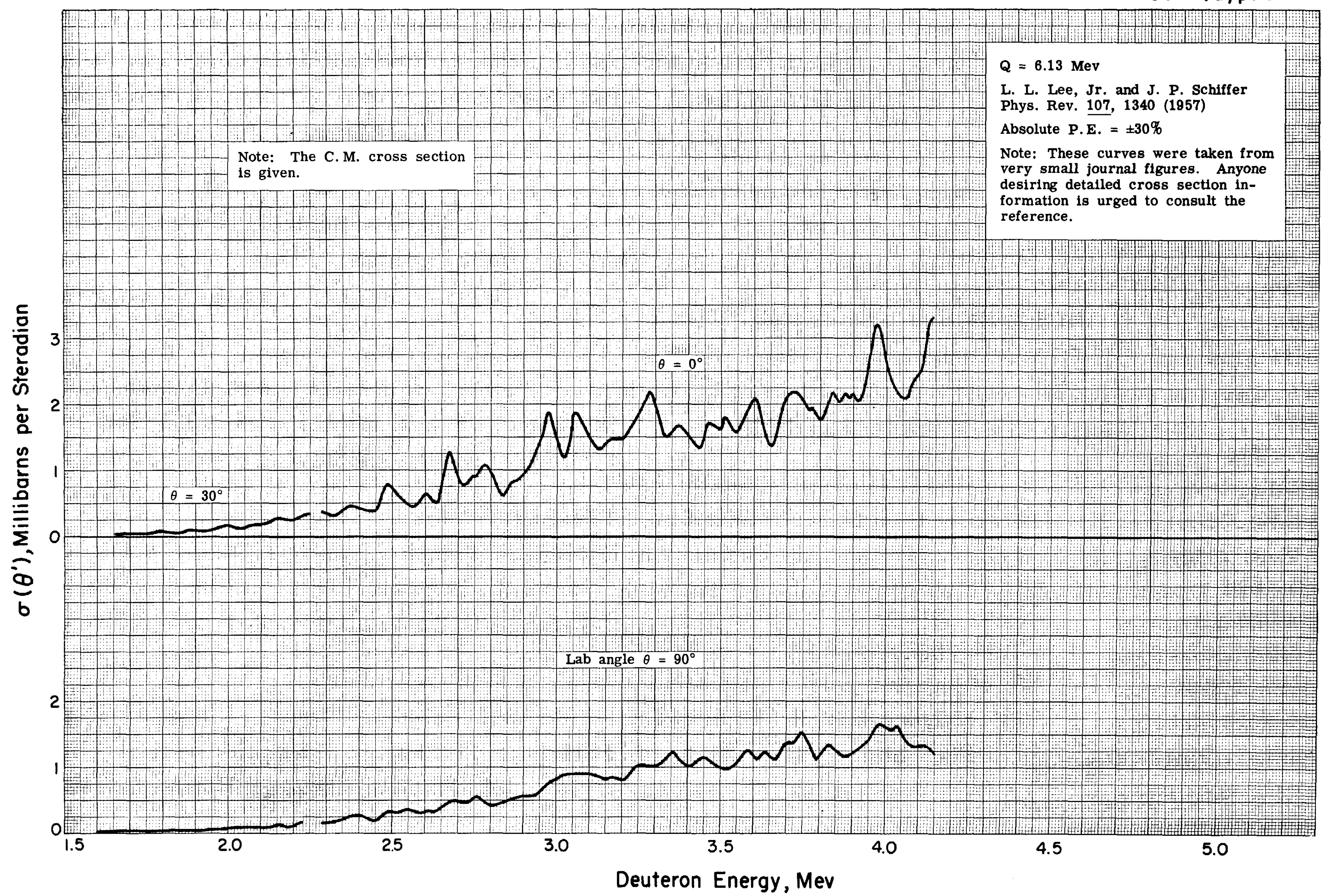


K41(N14,)
J. J. Pinajian and M. L. Halbert
Phys. Rev. 113, 589 (1959)
Absolute P.E. = ±30%
Fe53
Note: The observed residual nuclei are all positron emitters.
σ, Millibarns
10
1
0.1
0.01
22 23 24 25 26 27 28 29
Nitrogen Energy, Mev

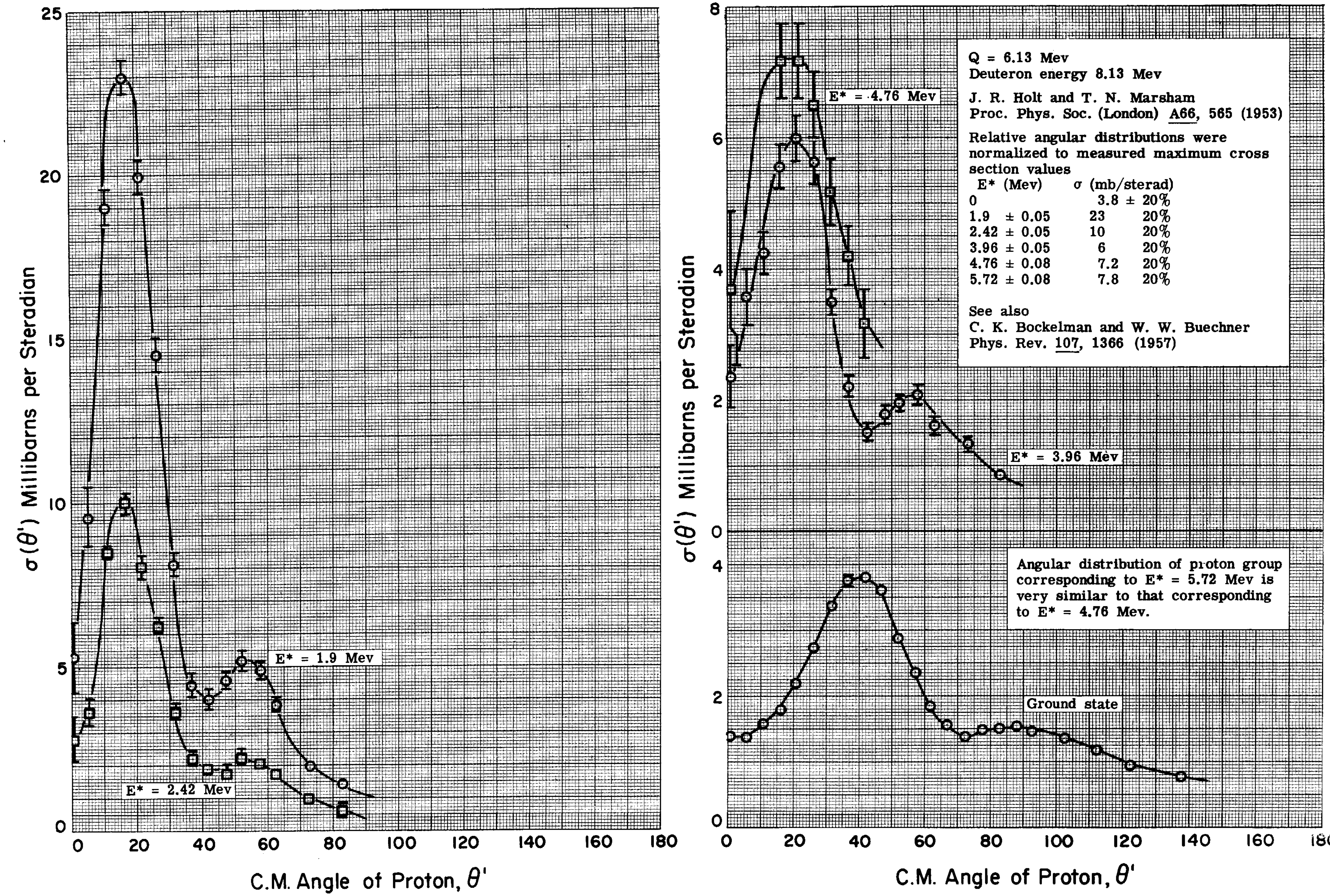
$Ca^{40}(p,p')Ca^{40*}$

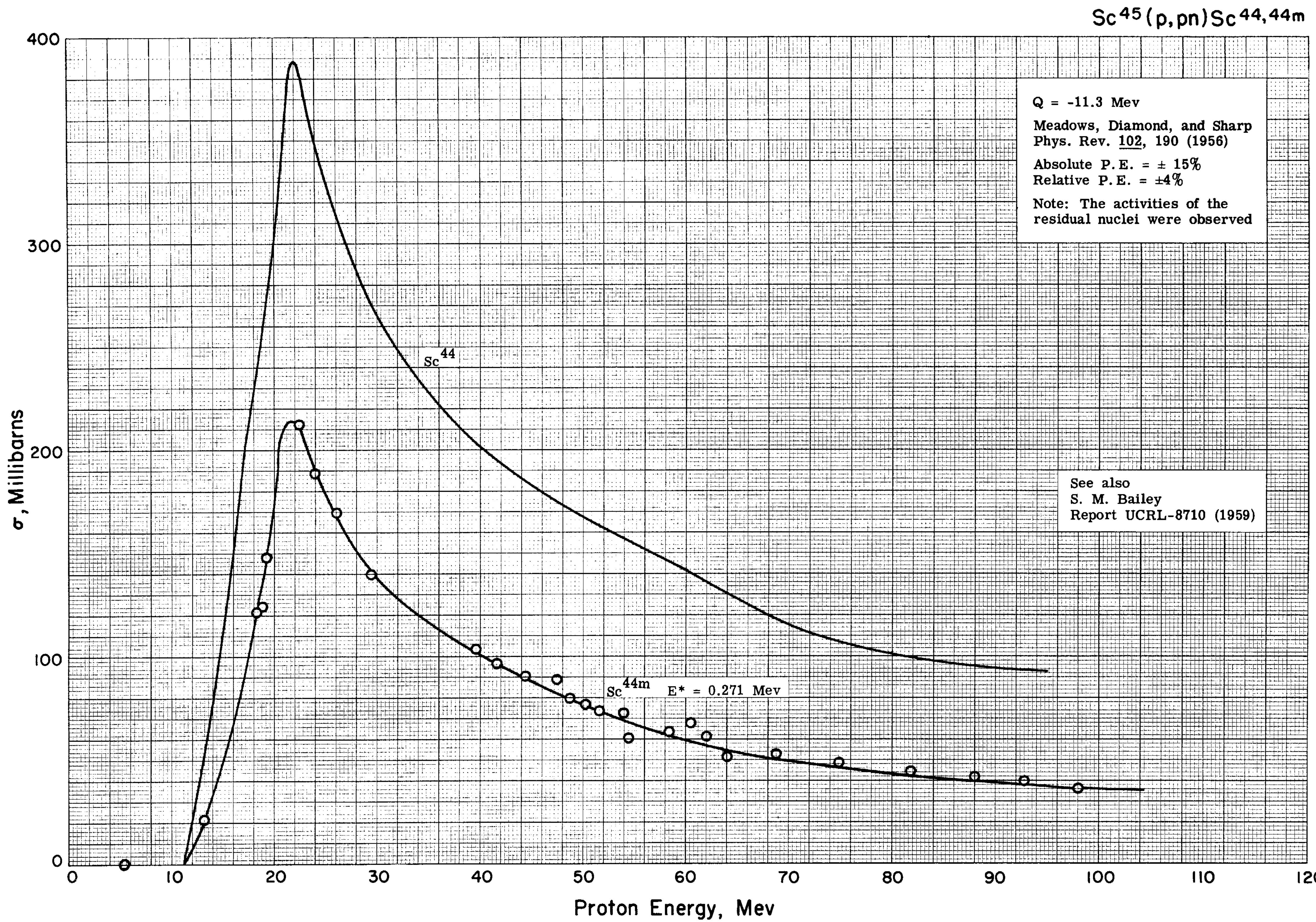


Proton energy 182 Mev
H. Tyren and Th. A. J. Maris
Nuclear Phys. 4, 637 (1957)
Absolute P.E. = ±20% (solid curve)
±50% (dashed curve)
E* = 18 Mev
E* = 3.7 ± 0.2 Mev
total cross section σ = 6.4 mb
E* = 7 Mev
σ (θ), Millibarns per Steradian
0
2
4
6
8
10
12
0 10 20 30 40 50 60 70 80 90
Lab Angle of Proton, θ


Q = 6.13 Mev
L. L. Lee, Jr. and J. P. Schiffer
Phys. Rev. 107, 1340 (1957)
Absolute P.E. = ±30%
Note: These curves were taken from very small journal figures. Anyone desiring detailed cross section information is urged to consult the reference.
Note: The C.M. cross section is given.
θ = 0°
θ = 30°
Lab angle θ = 90°
σ(θ'), Millibarns per Steradian
0
1
2
3
0
1
2
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Deuteron Energy, Mev

$Ca^{40}(d,p') Ca^{41*}$


E* = 1.9 Mev
E* = 2.42 Mev
σ(θ') Millibarns per Steradian
C.M. Angle of Proton, θ'
E* = 4.76 Mev
E* = 3.96 Mev
Ground state
Q = 6.13 Mev
Deuteron energy 8.13 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 565 (1953)
Relative angular distributions were normalized to measured maximum cross section values
E* (Mev) σ (mb/sterad)
0 3.8 ± 20%
1.9 ± 0.05 23 20%
2.42 ± 0.05 10 20%
3.96 ± 0.05 6 20%
4.76 ± 0.08 7.2 20%
5.72 ± 0.08 7.8 20%
See also
C. K. Bockelman and W. W. Buechner
Phys. Rev. 107, 1366 (1957)
Angular distribution of proton group corresponding to E* = 5.72 Mev is very similar to that corresponding to E* = 4.76 Mev.



$Sc^{45}(p,pn)Sc^{44,44m}$
Q = -11.3 Mev
Meadows, Diamond, and Sharp
Phys. Rev. 102, 190 (1956)
Absolute P.E. = ± 15%
Relative P.E. = ±4%
Note: The activities of the residual nuclei were observed
See also
S. M. Bailey
Report UCRL-8710 (1959)
Sc^{44}
Sc^{44m} E* = 0.271 Mev
σ, Millibarns
Proton Energy, Mev
0
100
200
300
400
0
10
20
30
40
50
60
70
80
90
100
110
120

$Ti^{46,47}(d,p)Ti^{47,48}$; $Ti^{47}(p,n)V^{47}(\beta^+)Ti^{47}$; $Ti^{48}(p,n)V^{48}(\beta^+\gamma)Ti^{48}$

$Ti^{46}(d,p)Ti^{47}$ Q = 6.66 Mev
$Ti^{47}(d,p)Ti^{48}$ Q = 9.39 Mev

Deuteron energy 14 Mev

J. A. Harvey
Phys. Rev. 81, 353 (1951)

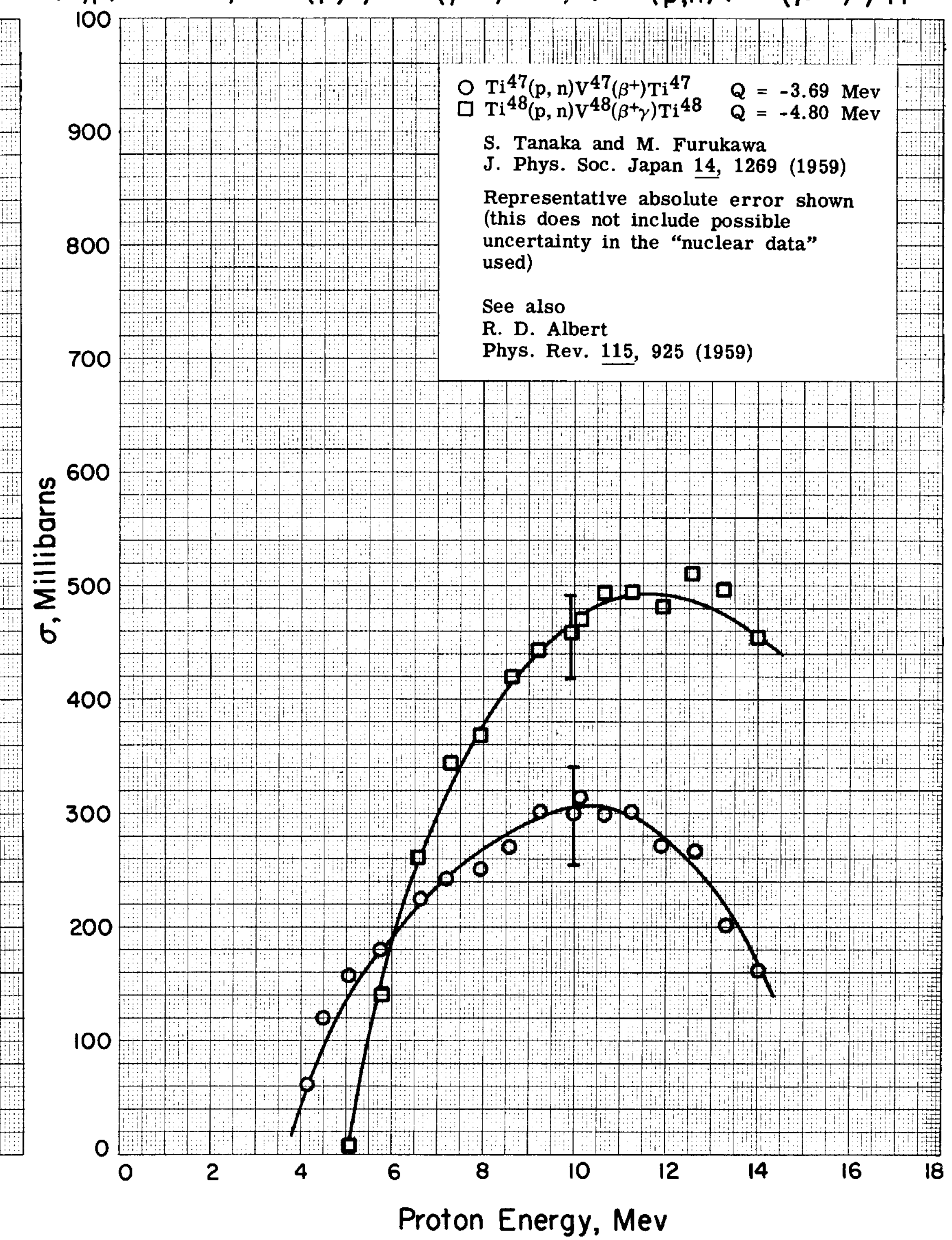
Target	$\sigma(30°)/\sigma_0$
Ti^{46}	0.6 ± 20%
Ti^{47}	0.06 20%

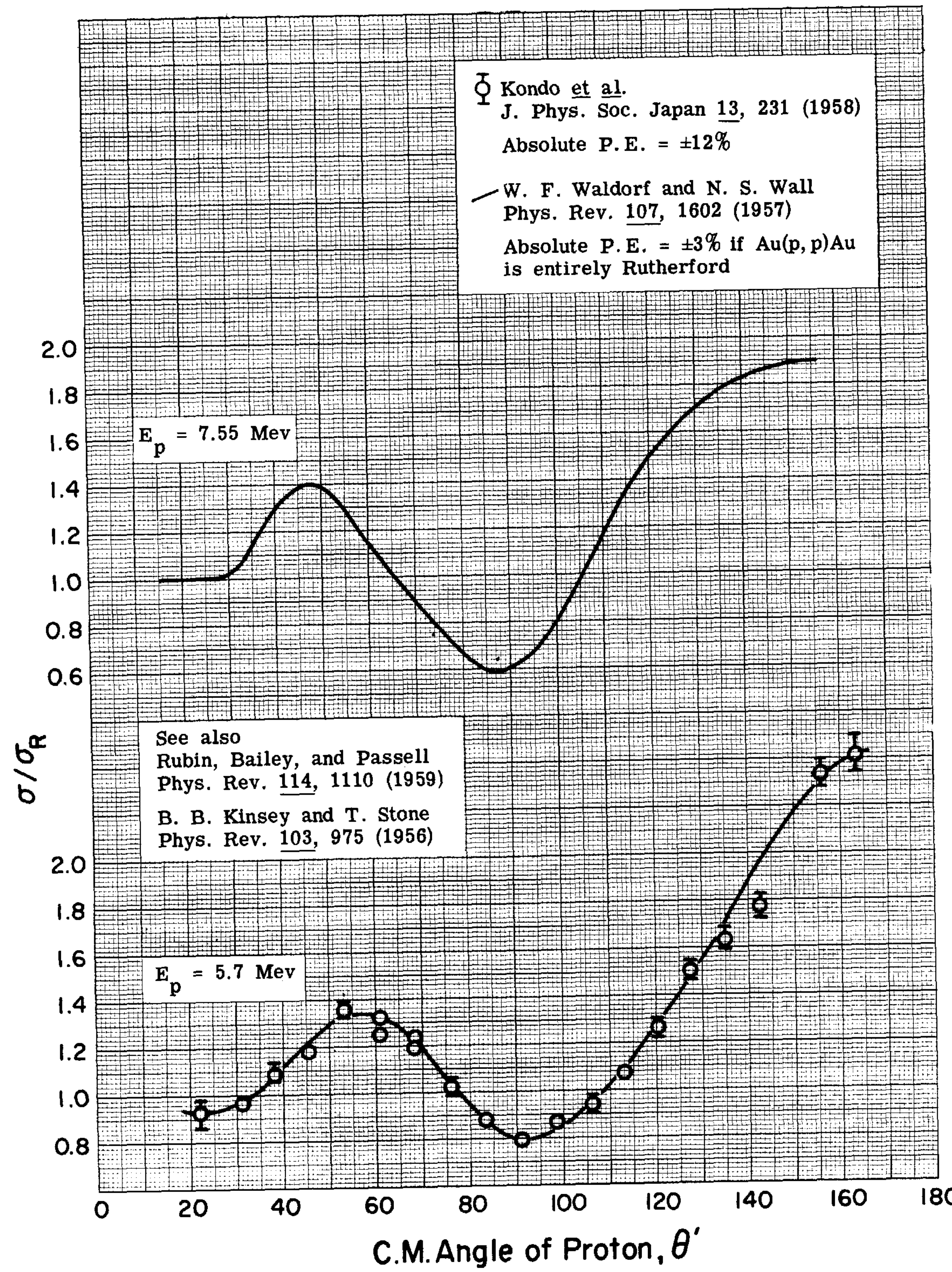
σ_0 = 2.5 ± 1.0 mb/sterad

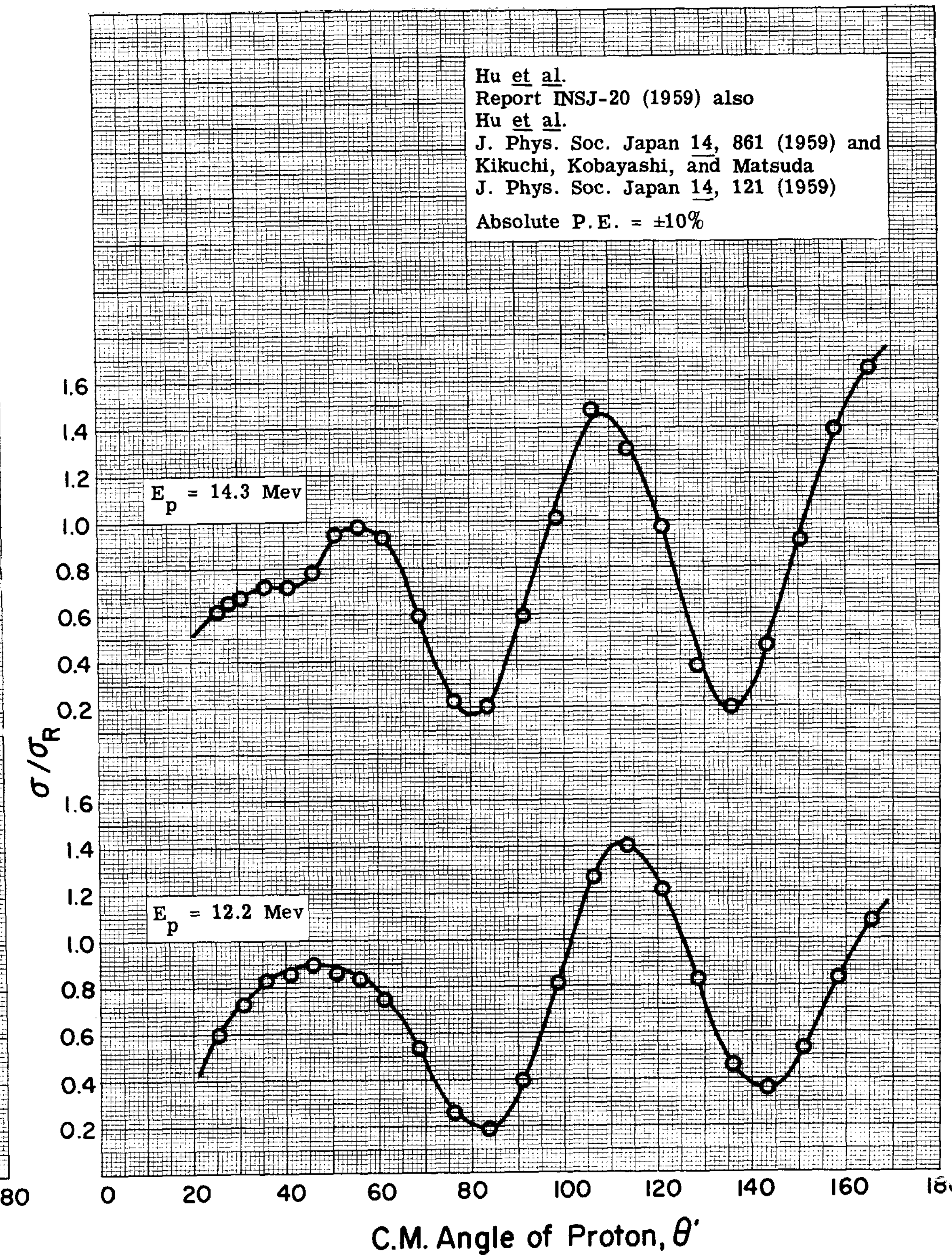
For relative data see
W. W. Pratt
Phys. Rev. 97, 131 (1955)

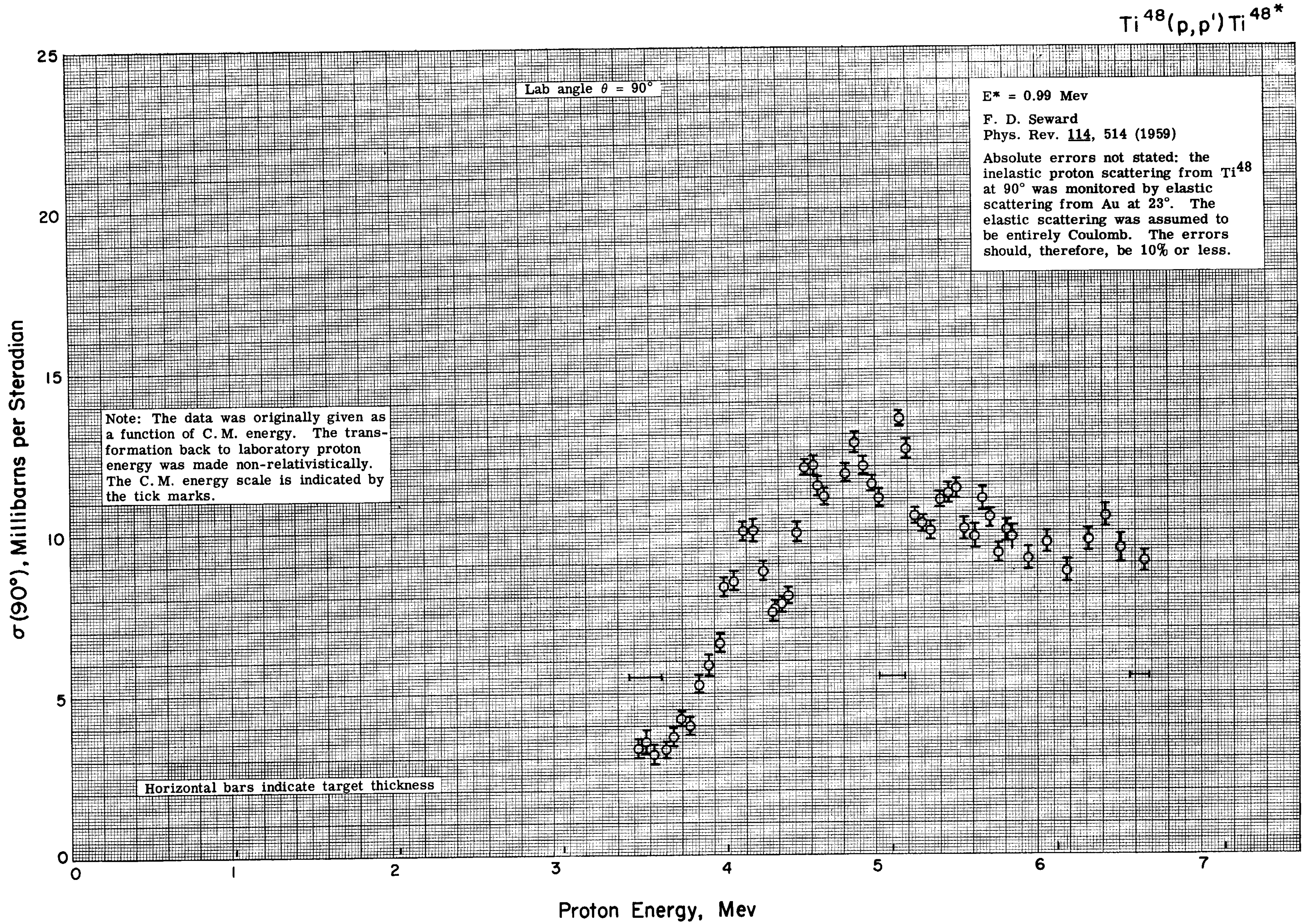
L. L. Lee, Jr. and W. Rall
Phys. Rev. 99, 1384 (1955)

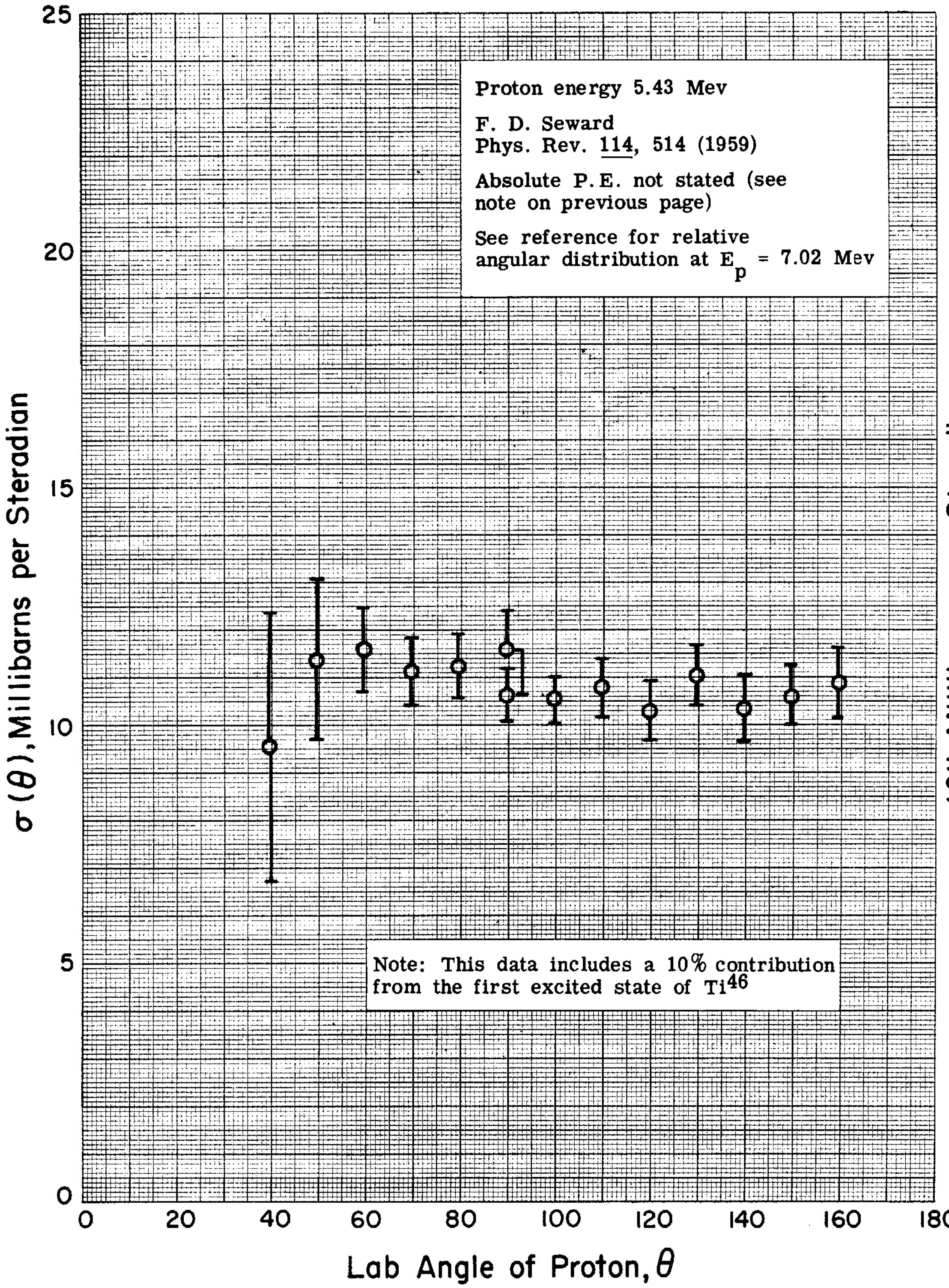
Bretscher *et al.*
Phys. Rev. 96, 103 (1954)

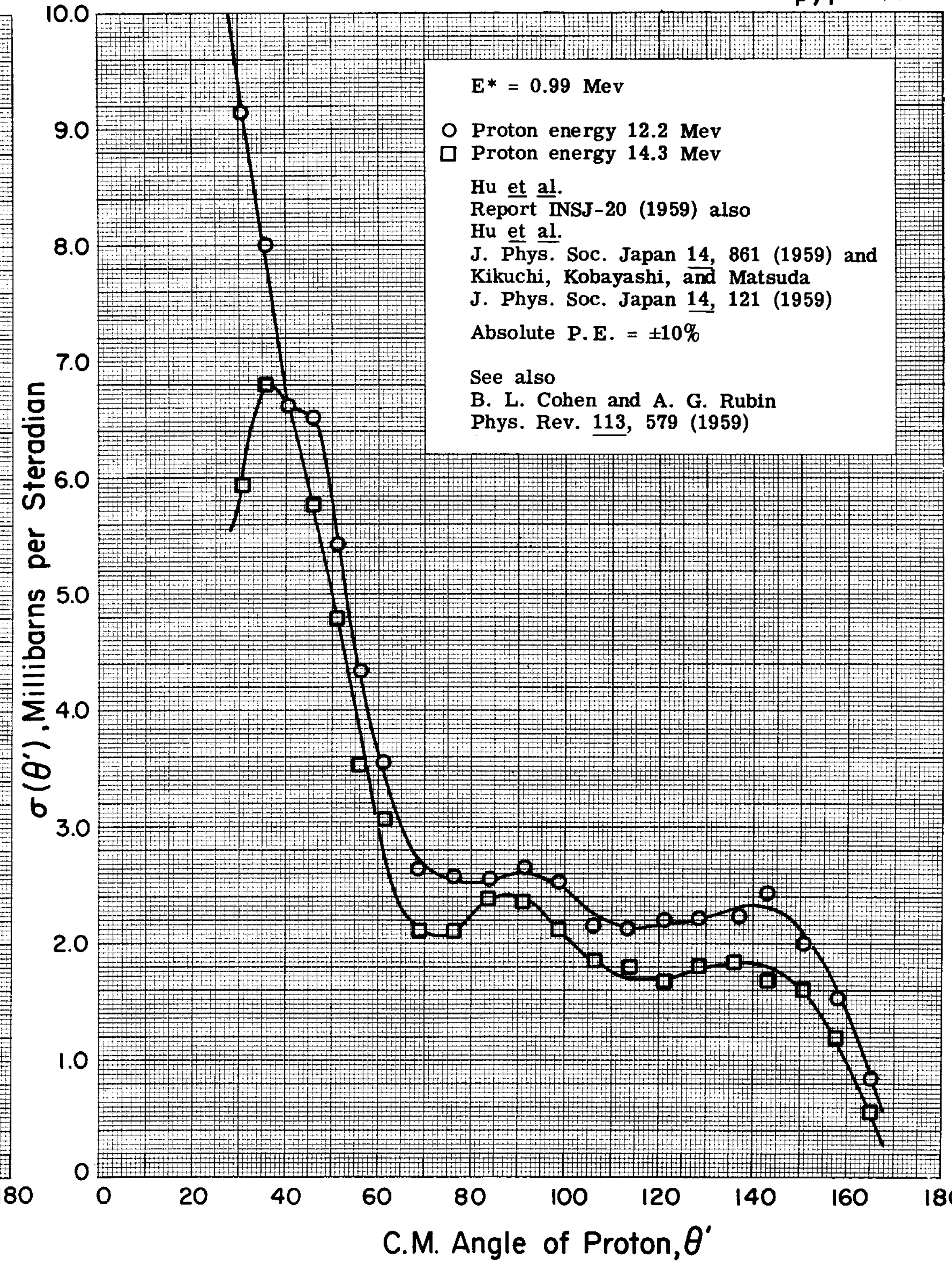



Kondo et al.
J. Phys. Soc. Japan 13, 231 (1958)
Absolute P.E. = ±12%
W. F. Waldorf and N. S. Wall
Phys. Rev. 107, 1602 (1957)
Absolute P.E. = ±3% if Au(p, p)Au is entirely Rutherford
E_p = 7.55 Mev
See also
Rubin, Bailey, and Passell
Phys. Rev. 114, 1110 (1959)
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
E_p = 5.7 Mev
σ/σ_R
C.M. Angle of Proton, θ'

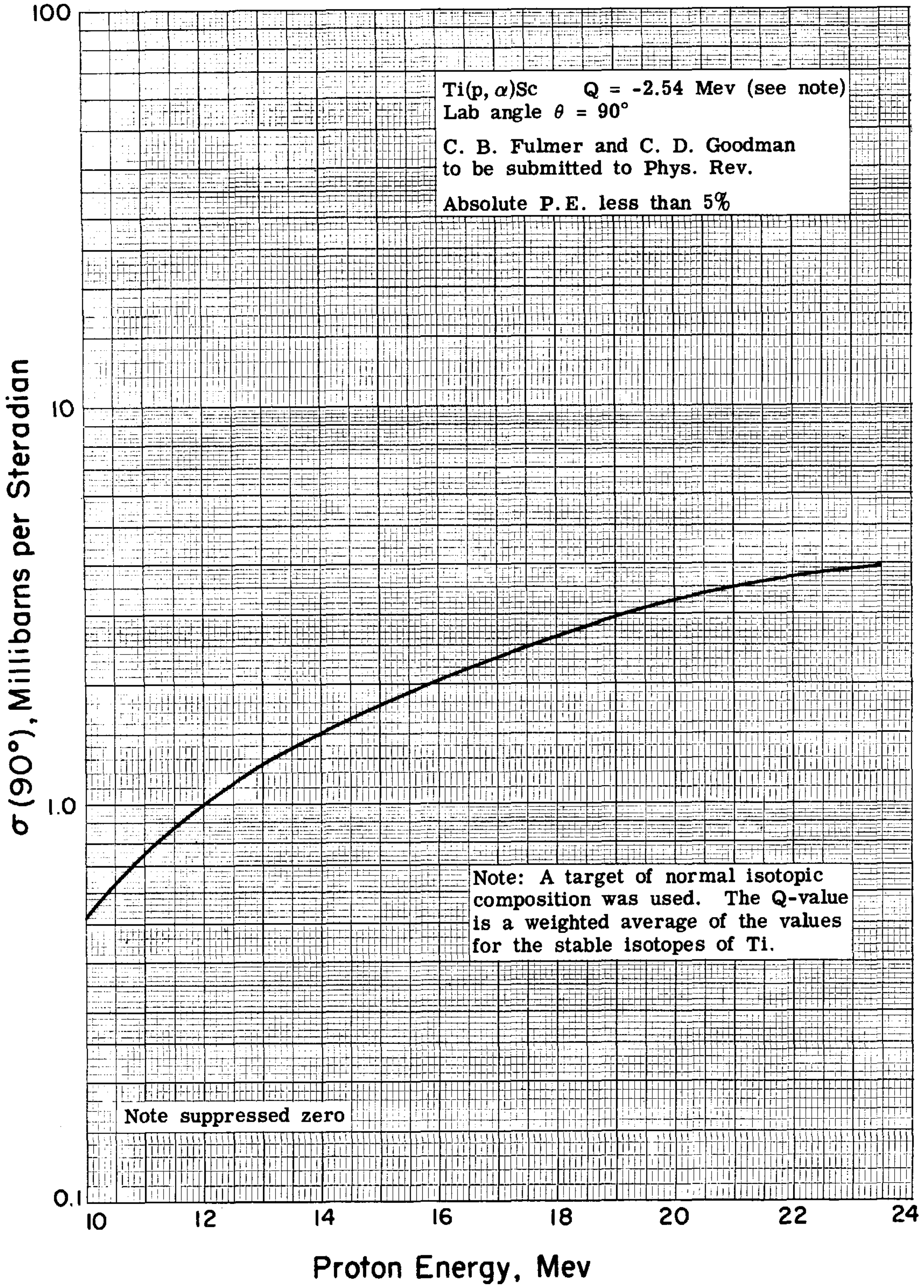

Hu et al.
Report INSJ-20 (1959) also
Hu et al.
J. Phys. Soc. Japan 14, 861 (1959) and
Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)
Absolute P.E. = ±10%
E_p = 14.3 Mev
E_p = 12.2 Mev
σ/σ_R
C.M. Angle of Proton, θ'


Ti 48(p,p')Ti 48*
Lab angle θ = 90°
E* = 0.99 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute errors not stated: the inelastic proton scattering from Ti48 at 90° was monitored by elastic scattering from Au at 23°. The elastic scattering was assumed to be entirely Coulomb. The errors should, therefore, be 10% or less.
Note: The data was originally given as a function of C.M. energy. The transformation back to laboratory proton energy was made non-relativistically. The C.M. energy scale is indicated by the tick marks.
Horizontal bars indicate target thickness
σ (90°), Millibarns per Steradian
Proton Energy, Mev
0
5
10
15
20
25
1
2
3
4
6
7


Proton energy 5.43 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute P.E. not stated (see note on previous page)
See reference for relative angular distribution at E_p = 7.02 Mev
Note: This data includes a 10% contribution from the first excited state of Ti^{46}
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ


E* = 0.99 Mev
○ Proton energy 12.2 Mev
□ Proton energy 14.3 Mev
Hu et al.
Report INSJ-20 (1959) also
Hu et al.
J. Phys. Soc. Japan 14, 861 (1959) and
Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)
Absolute P.E. = ±10%
See also
B. L. Cohen and A. G. Rubin
Phys. Rev. 113, 579 (1959)
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

Ti (p,α) Sc; Ti^{48} (d,p) Ti^{49}



$Ti^{48}(d, p)Ti^{49}$ Q = 5.92 Mev
Deuteron energy 14 Mev

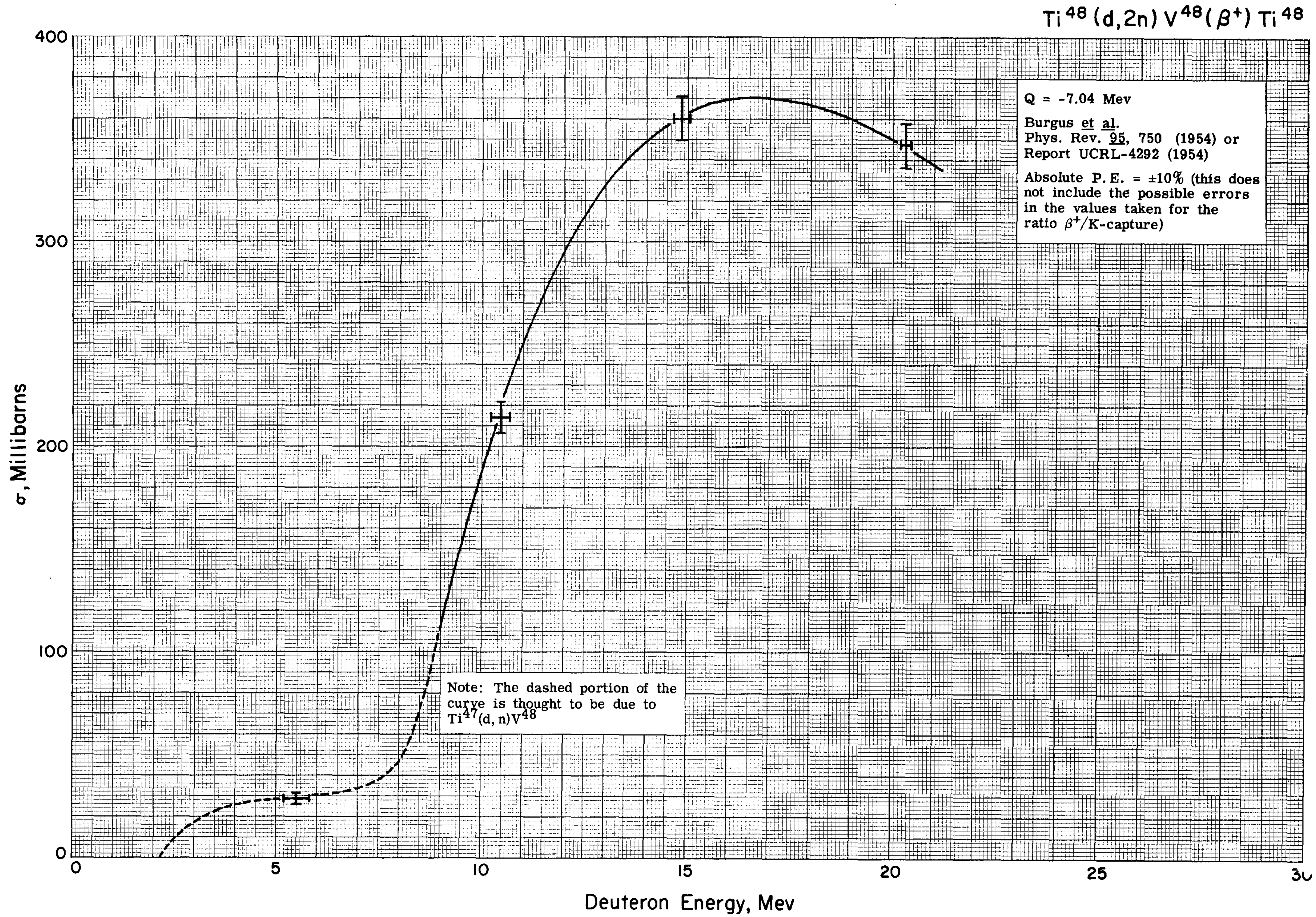
J. A. Harvey
Phys. Rev. 81, 353 (1951)

$\sigma(30°)/\sigma_0$ = 0.4 ±20%
σ_0 = 2.5 ± 1.0 mb/st

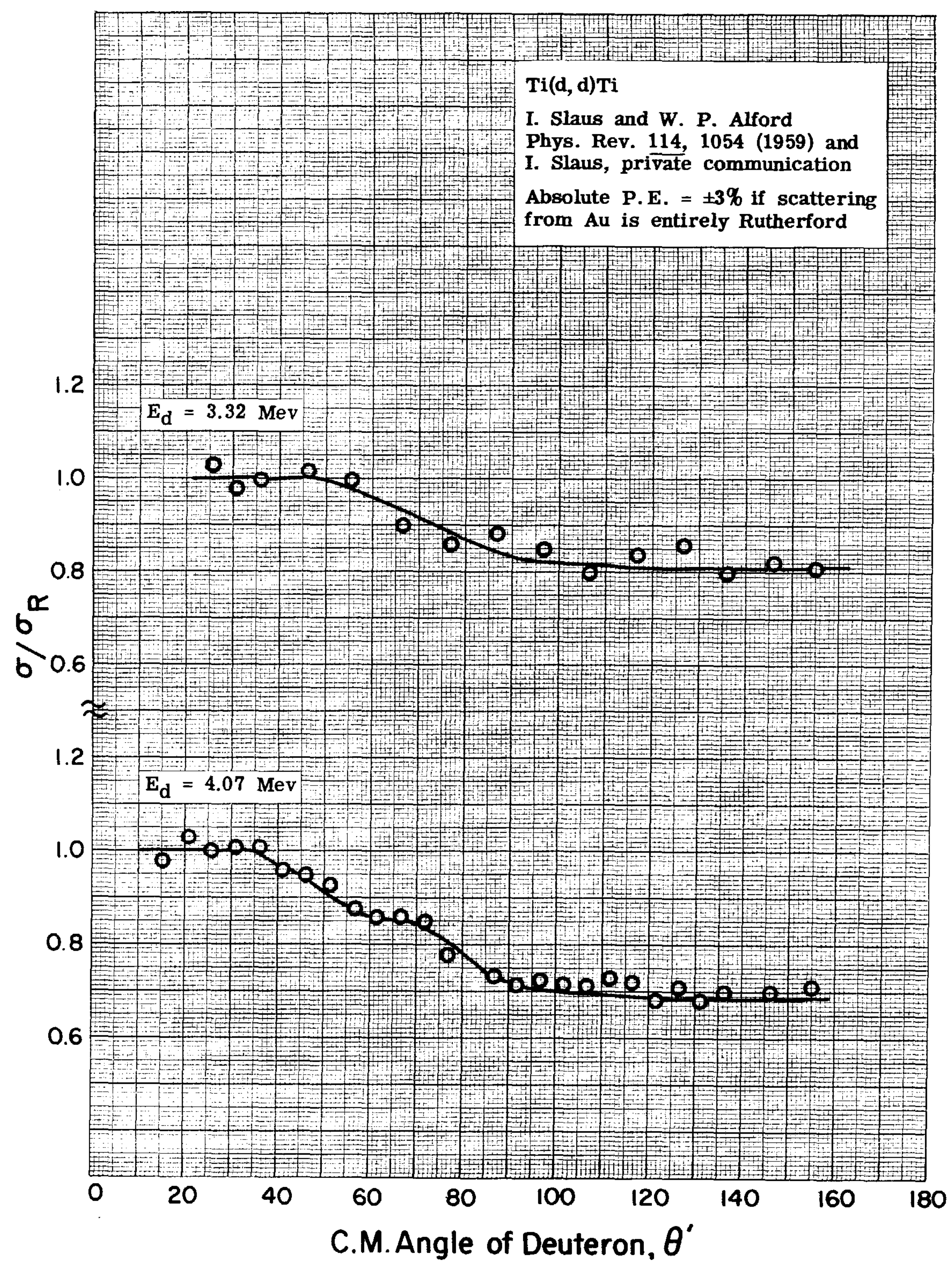
For relative data see
W. W. Pratt
Phys. Rev. 97, 131 (1955)

L. L. Lee, Jr. and W. Rall
Phys. Rev. 99, 1384 (1955)

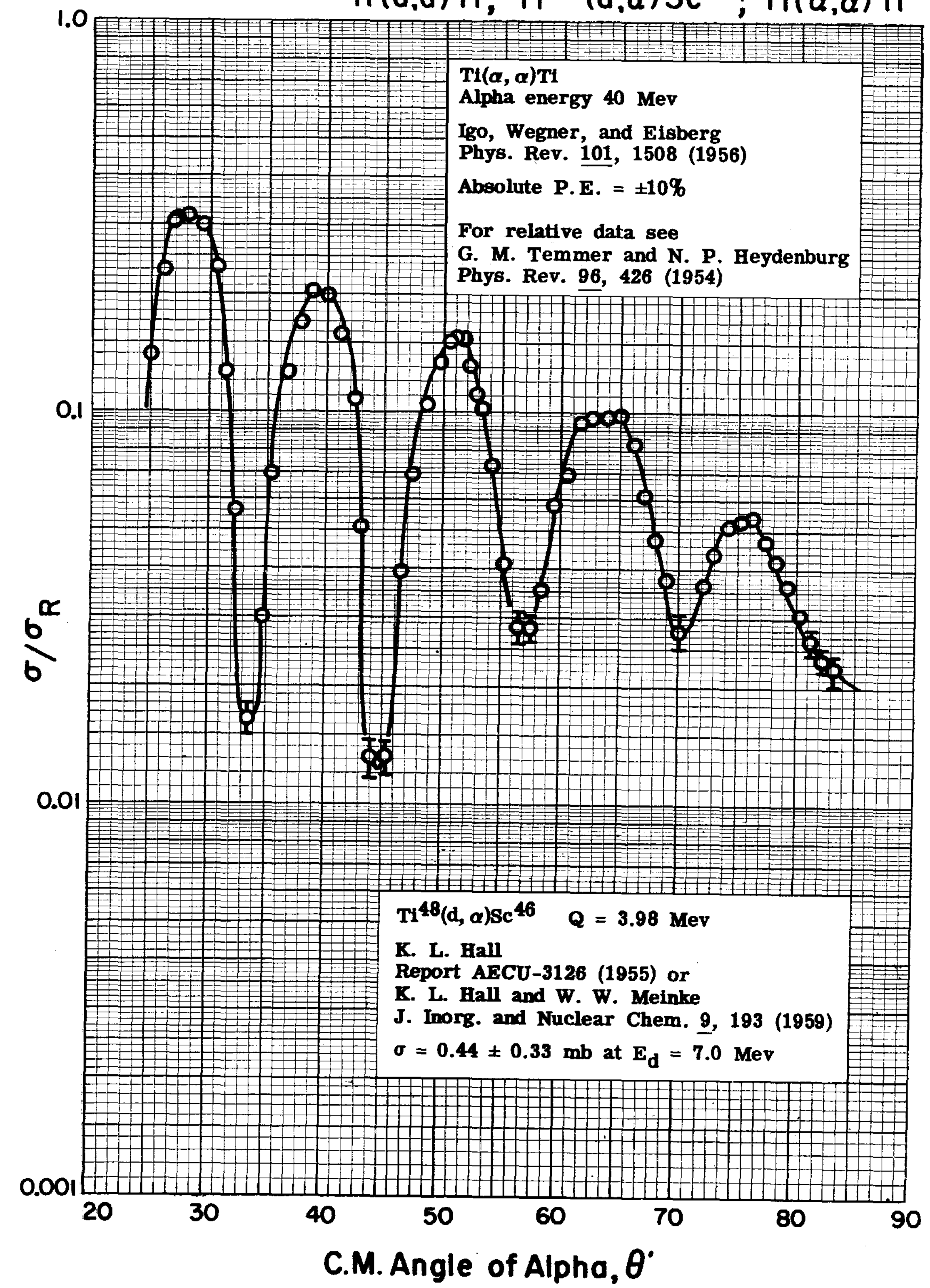
Bretscher *et al.*
Phys. Rev. 96, 103 (1954)



Ti 48 (d,2n) V 48 (β+) Ti 48
Q = -7.04 Mev
Burgus et al.
Phys. Rev. 95, 750 (1954) or
Report UCRL-4292 (1954)
Absolute P. E. = ±10% (this does not include the possible errors in the values taken for the ratio β+/K-capture)
Note: The dashed portion of the curve is thought to be due to Ti47(d, n)V48
400
300
200
100
0
σ, Millibarns
0
5
10
15
20
25
30
Deuteron Energy, Mev

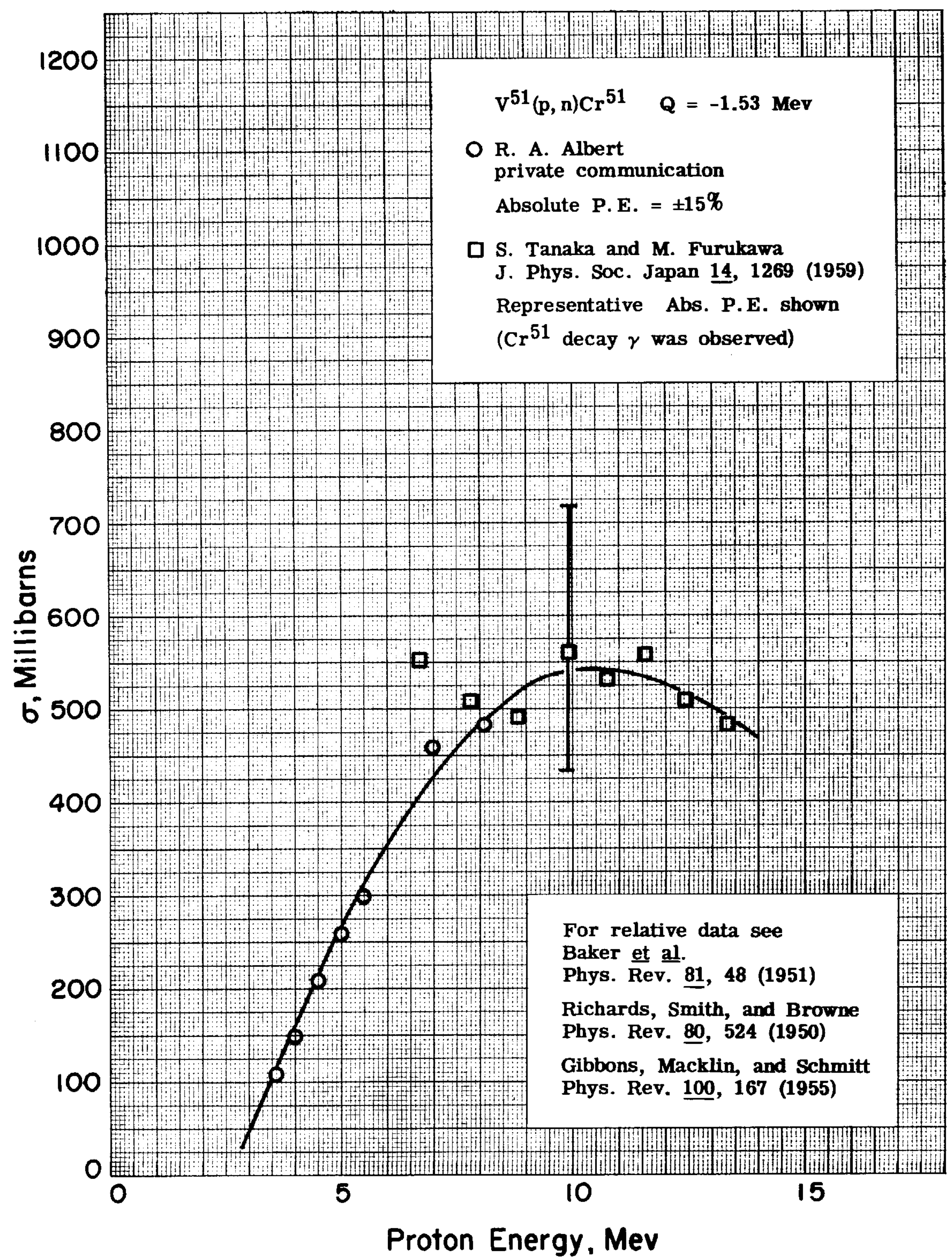


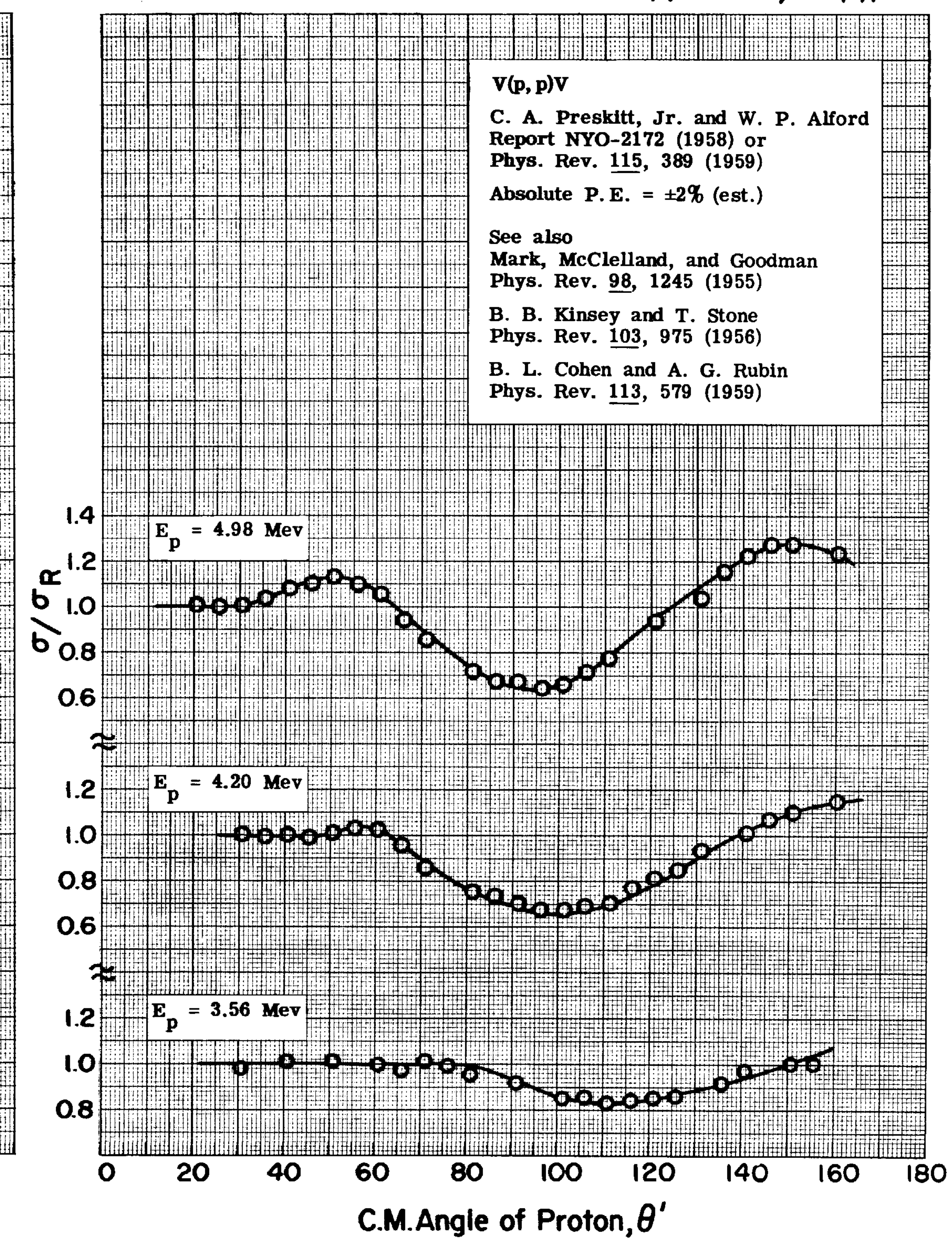
Ti(d, d)Ti
I. Slaus and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication
Absolute P.E. = ±3% if scattering
from Au is entirely Rutherford
Ed = 3.32 Mev
Ed = 4.07 Mev
σ/σR
1.2
1.0
0.8
0.6
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Deuteron, θ'

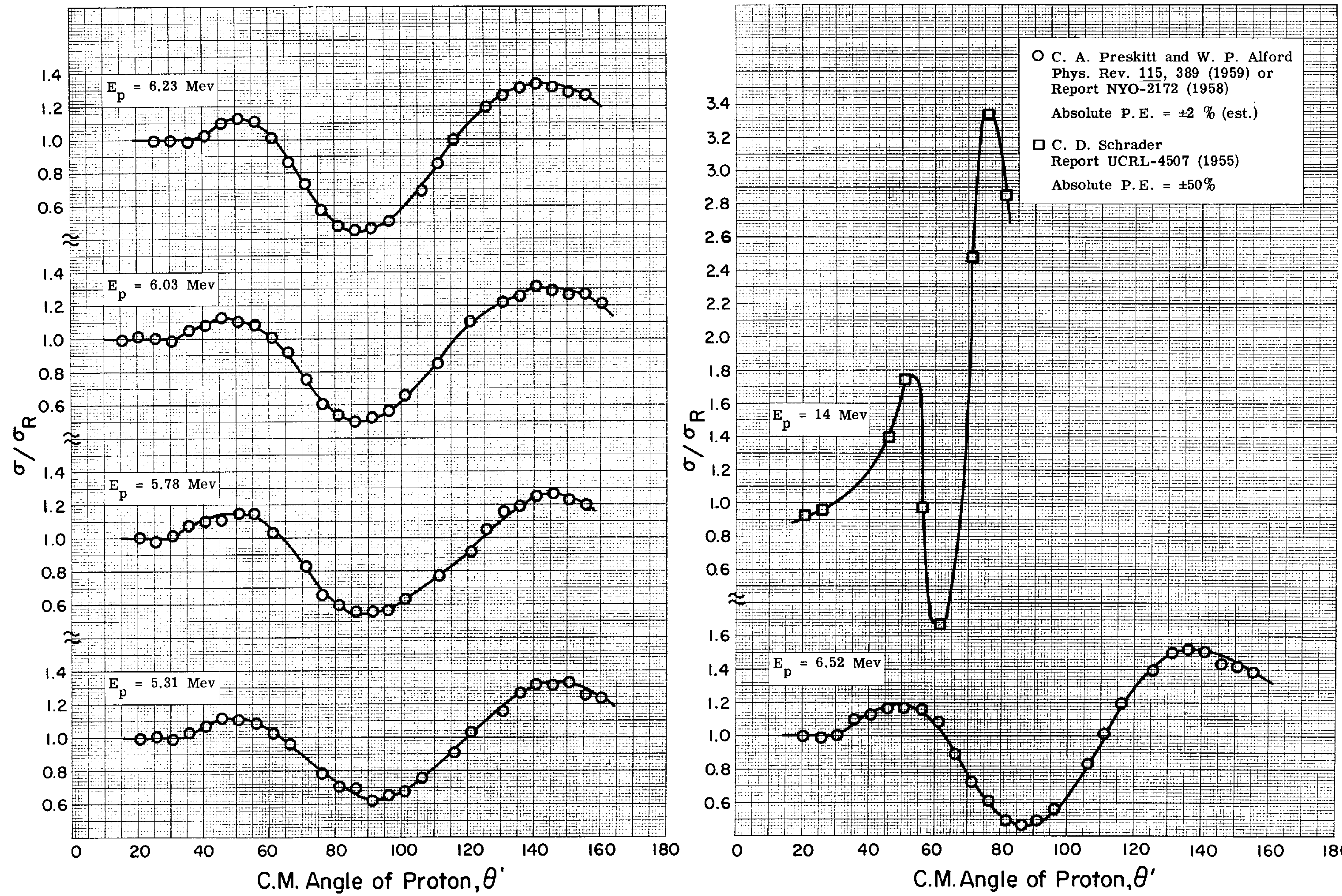


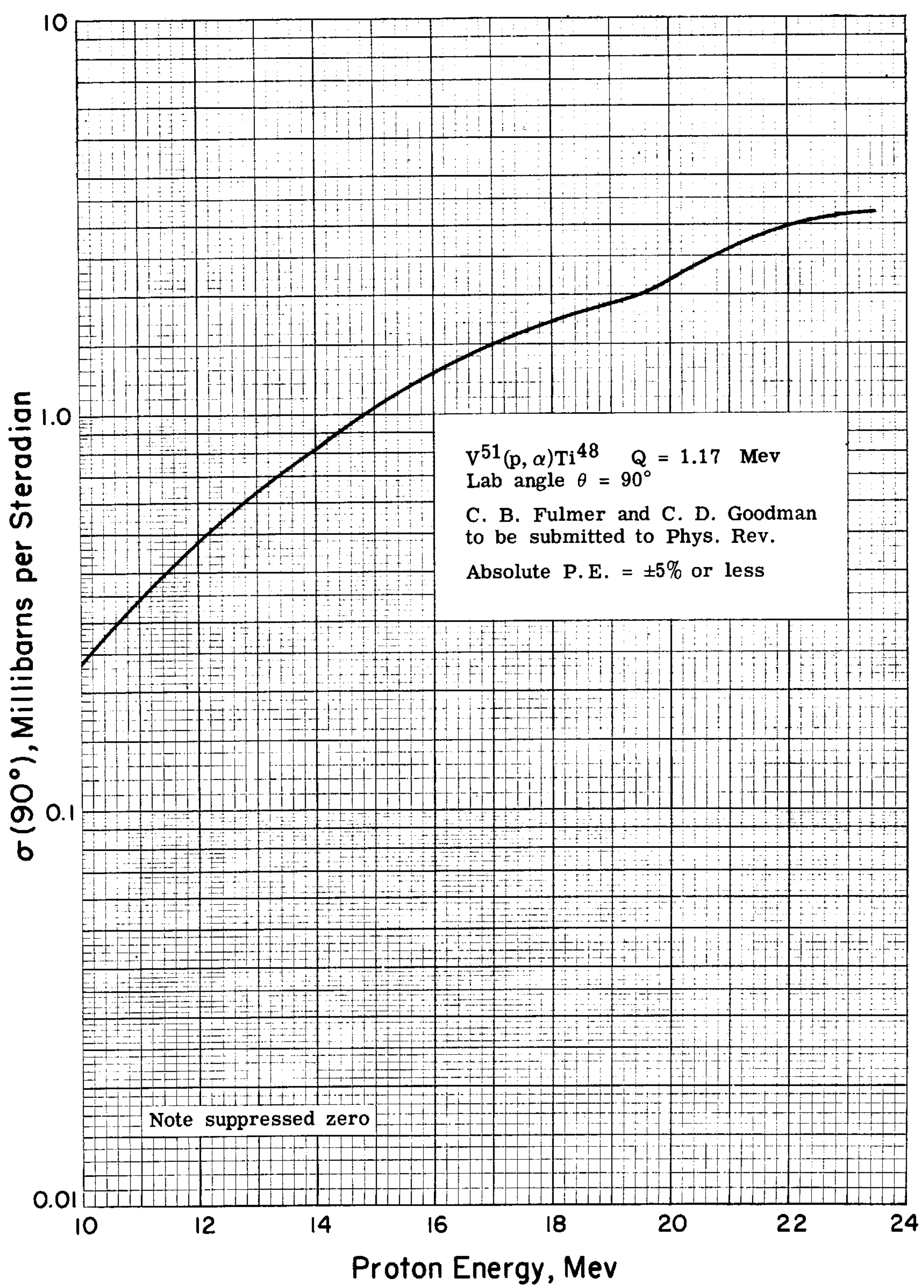
Ti(α, α)Ti
Alpha energy 40 Mev
Igo, Wegner, and Eisberg
Phys. Rev. 101, 1508 (1956)
Absolute P.E. = ±10%
For relative data see
G. M. Temmer and N. P. Heydenburg
Phys. Rev. 96, 426 (1954)
Ti48(d, α)Sc46 Q = 3.98 Mev
K. L. Hall
Report AECU-3126 (1955) or
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959)
σ = 0.44 ± 0.33 mb at Ed = 7.0 Mev
σ/σR
1.0
0.1
0.01
0.001
20
30
40
50
60
70
80
90
C.M. Angle of Alpha, θ'

$V^{51}(p,n)Cr^{51}$; V(p,p)V






σ / σ_R
E_p = 6.23 Mev
E_p = 6.03 Mev
E_p = 5.78 Mev
E_p = 5.31 Mev
E_p = 14 Mev
E_p = 6.52 Mev
C.M. Angle of Proton, θ'
○ C. A. Preskitt and W. P. Alford Phys. Rev. 115, 389 (1959) or Report NYO-2172 (1958)
Absolute P. E. = ±2 % (est.)
□ C. D. Schrader Report UCRL-4507 (1955)
Absolute P. E. = ±50%



V(p, x) (β activity of product nuclides was observed)

Proton energy 170 Mev (most probable energy)

G. Rudstam
Report NP-6191 (1956) also
Phil. Mag. 44, 1131 (1953)
(the first reference contains values corrected for new monitor cross section values)

The absolute error given for each measurement includes 15% error in the absolute monitor)

Proton energies 60, 100, 175, and 240 Mev

C. G. Heininger and E. O. Wiig
Phys. Rev. 101, 1074 (1956)

CROSS SECTION FOR NUCLIDE PRODUCTION IN MILLIBARNS

Nuclide	60 Mev	100 Mev	170 Mev	175 Mev	240 Mev
Cr^{49}	81 ±19	17 ±3	1.7 ±0.4	7.1	2.6 ±0.5
Cr^{48}	3.2 ± 0.9	2.1 ±0.8	0.22 ±0.07	0.26	0.29±0.05
V^{48}	83 ± 4	37 ±7	23 ±4	17 ±5	15 ±5
V^{47}	...	...	4.6 ±0.9	...	...
Ti^{45}	2.4 ± 0.5	5.8 ±1.4	4.8 ±1.2	6.2 ±1.7	10 ±4
Sc^{48}	...	...	4.1 ±1.4	...	...
Sc^{47}	3.1 ± 1.9	11 ±2.	7.6 ±1.5	4.9 ±2.1	7.5 ±2.4
Sc^{46}	11 ± 6	10 ±2	12 ±4	6.4 ±3.0	8.4 ±2.3
Sc^{44m}	...	10 ±4	6.2 ±1.7	4.6 ±2.7	8.0 ±2.5
$Sc^{43}+Sc^{44}$	0.08	20 ±6	9.4 ±2.2	7.3 ±4.0	12 ±4
Ca^{47}	0.011	0.09±0.02	0.087±0.019	0.07±0.04	0.14±0.05
Ca^{45}	0.33	1.0 ±0.5	2.5 ±0.6	1.0 ±0.4	1.7 ±0.7
K^{43}	0.6 ± 0.2	0.7	2.0 ±0.6	1.5 ±0.6	4.1 ±0.9
K^{42}	0.19± 0.15	2.6	3.2 ±0.8	3.6 ±1.2	7.0 ±1.2
Cl^{39}	0.0009	0.36±0.002	0.25 ±0.06	0.20±0.08	1.5 ±0.9
Cl^{38}	0.02± 0.01	0.18±0.02	0.60 ±0.13	1.0 ±0.6	2.4 ±1.1
Cl^{34}	...	...	0.025±0.006	...	0.7 ±0.3
S^{35}	...	0.09	0.46 ±0.13	0.22±0.08	0.4 ±0.2
P^{33}	...	...	0.28 ±0.08	...	0.4
P^{32}	...	...	0.35 ±0.09	0.22±0.05	0.9 ±0.5
Si^{31}	...	...	0.16 ±0.04	...	...
Mg^{28}	...	...	...	0.002	0.009
Mg^{27}	...	...	0.023±0.007	...	...
Na^{24}	...	...	0.024±0.005	...	...

$V^{51}(d,p)V^{52}$ Q = 5.08 Mev

J. A. Harvey
Phys. Rev. 81, 353 (1951)

$\sigma(30°)/\sigma_o$ = 0.6 ±20% at E_d = 14 Mev
σ_o = 2.5 ± 1.0 mb/sterad

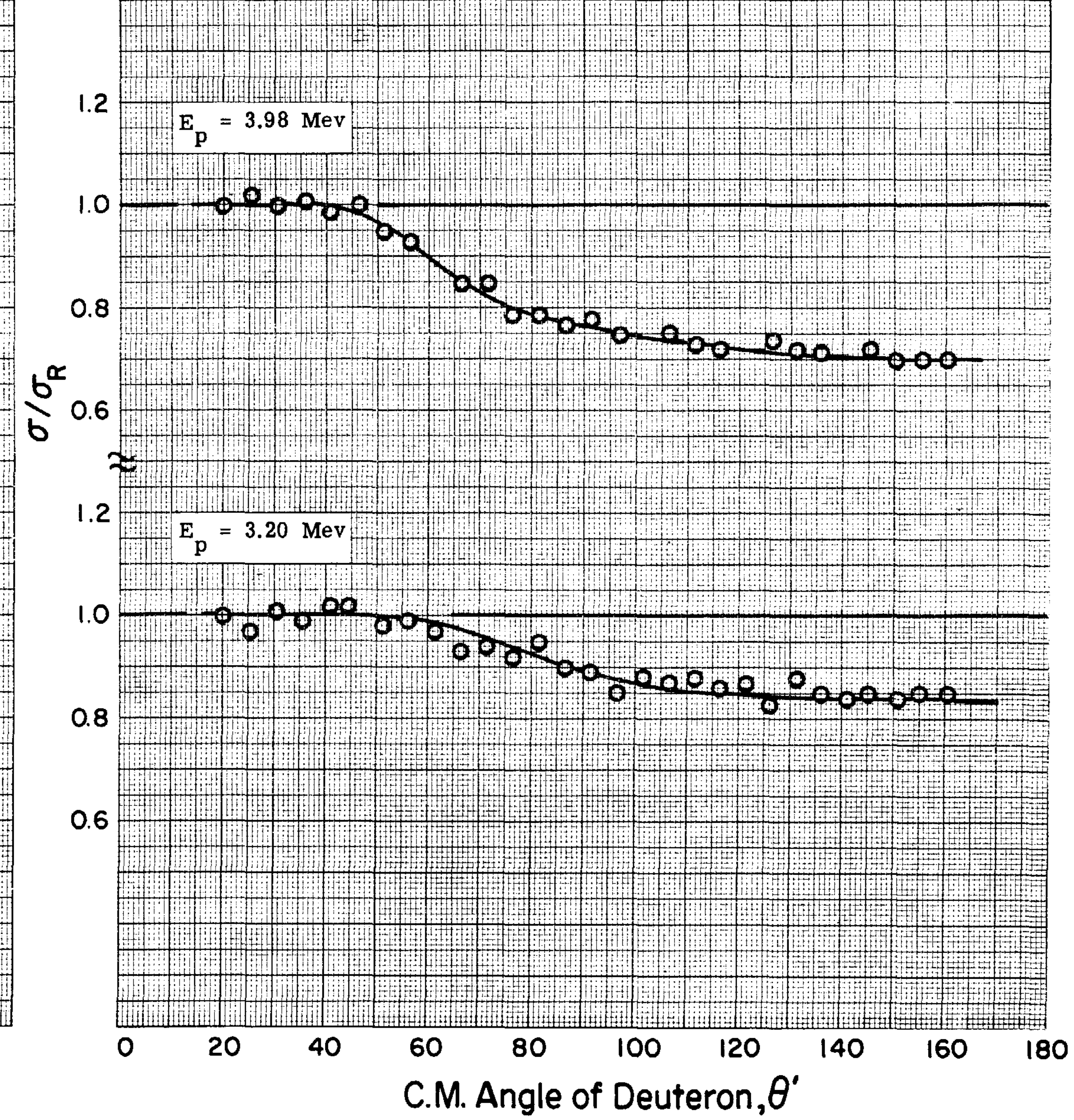
For relative data see
F. A. El Bedewi and S. Tadros
Nuclear Phys. 8, 71 (1958)

J. S. King and W. C. Parkinson
Phys. Rev. 89, 1080 (1953)

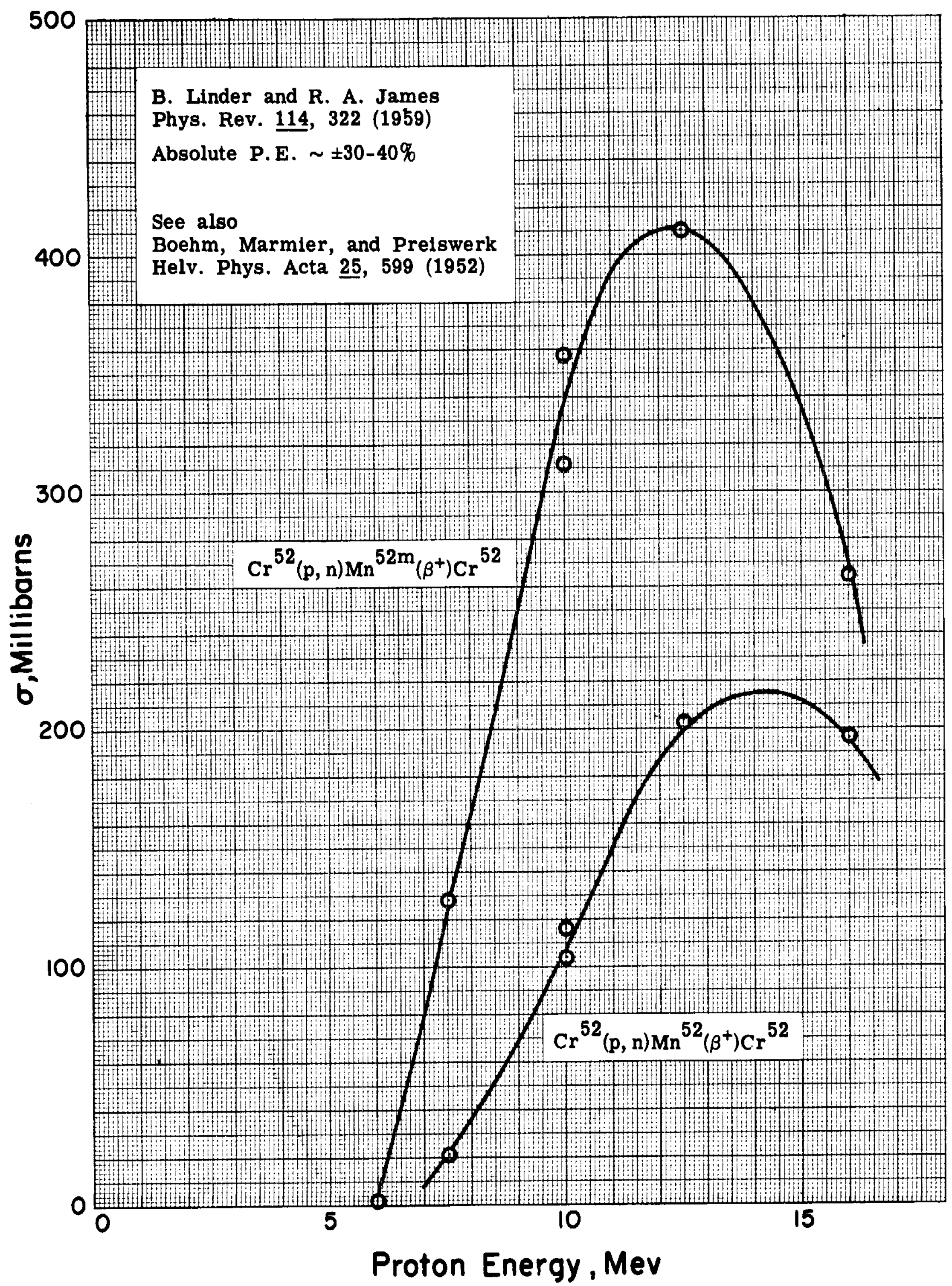
$V^{51}(d,d)V^{51}$

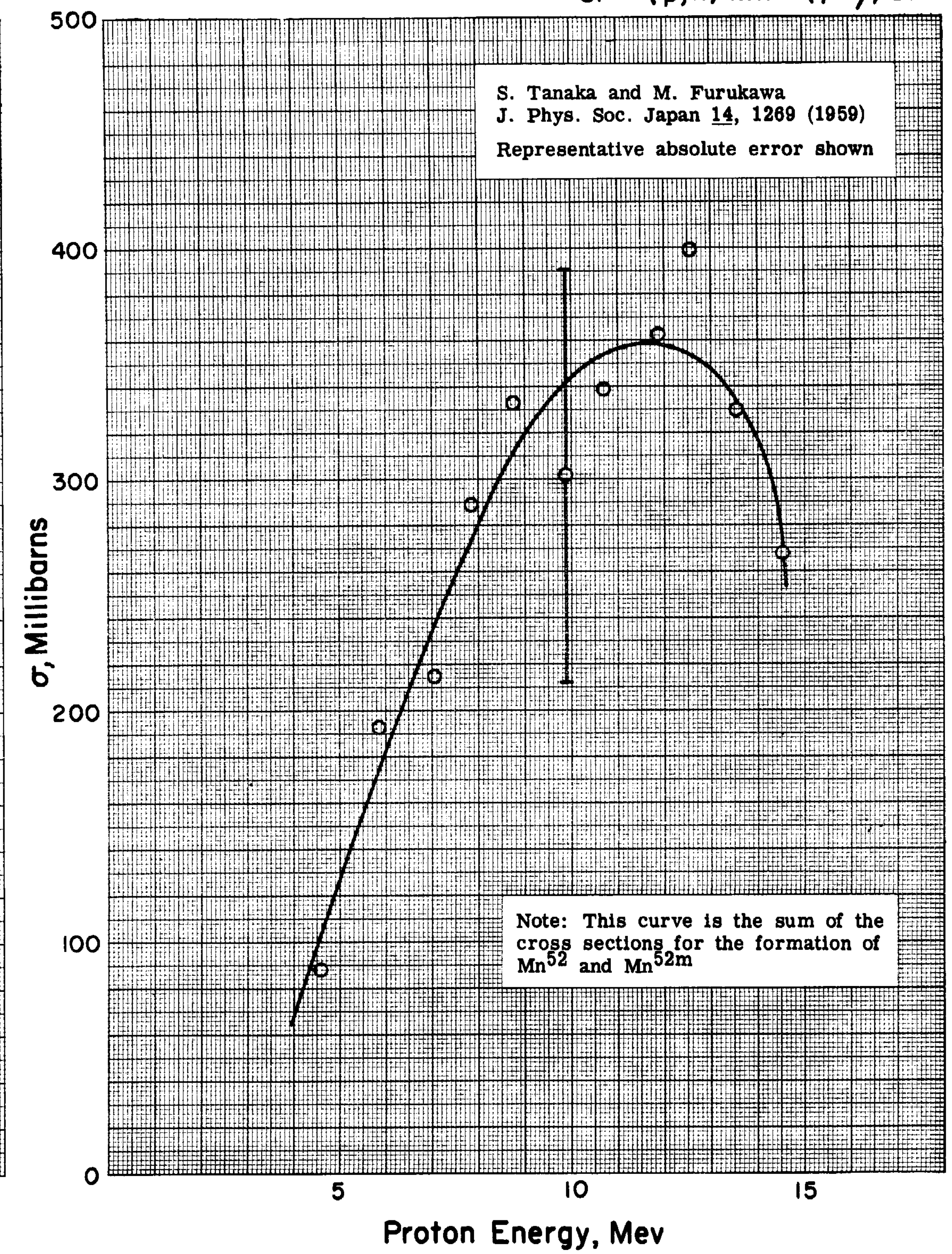
I. Slaus and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication

Absolute P.E. = ±3%

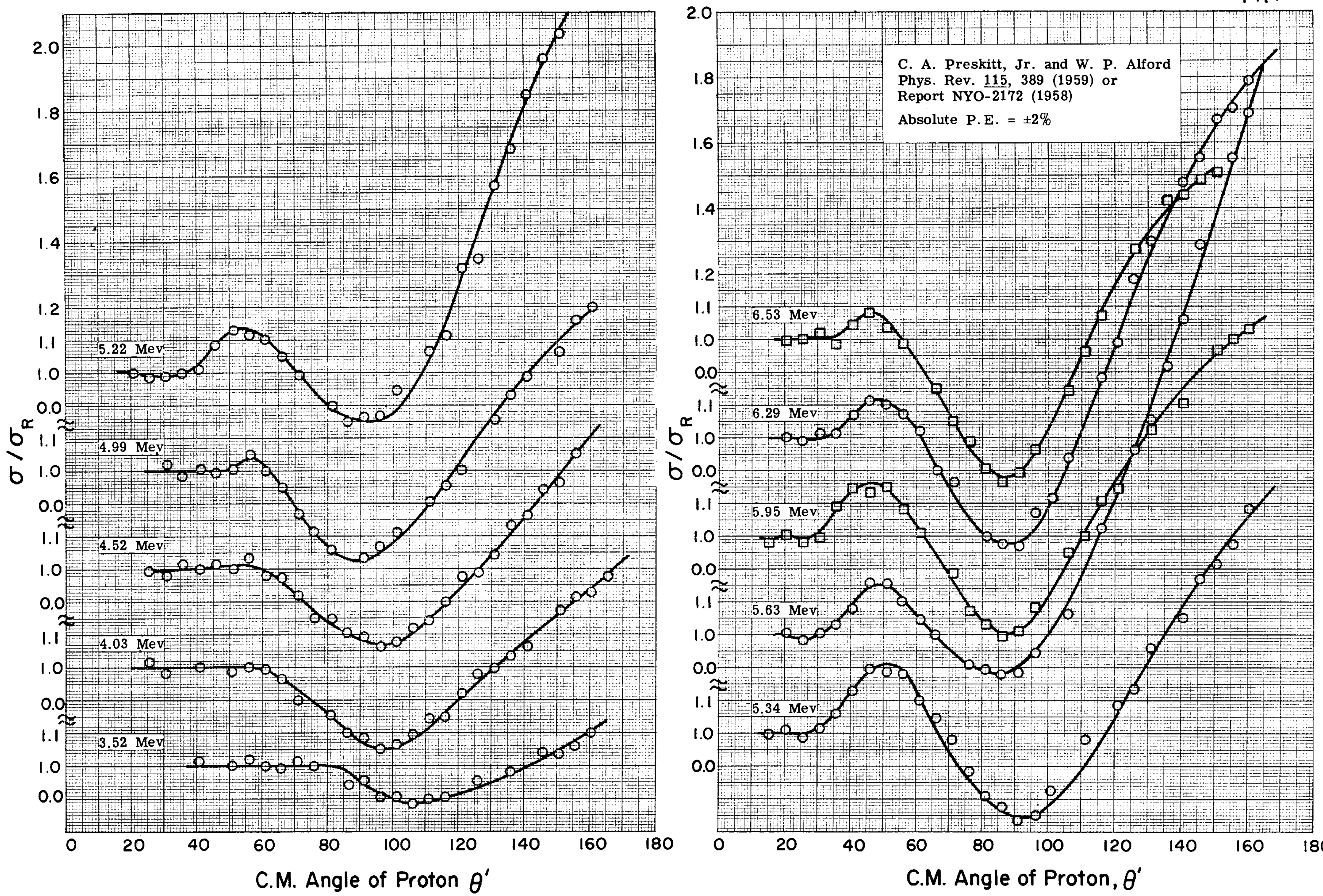


$Cr^{52}(p,n)Mn^{52}(\beta^{+}\gamma)Cr^{52}$

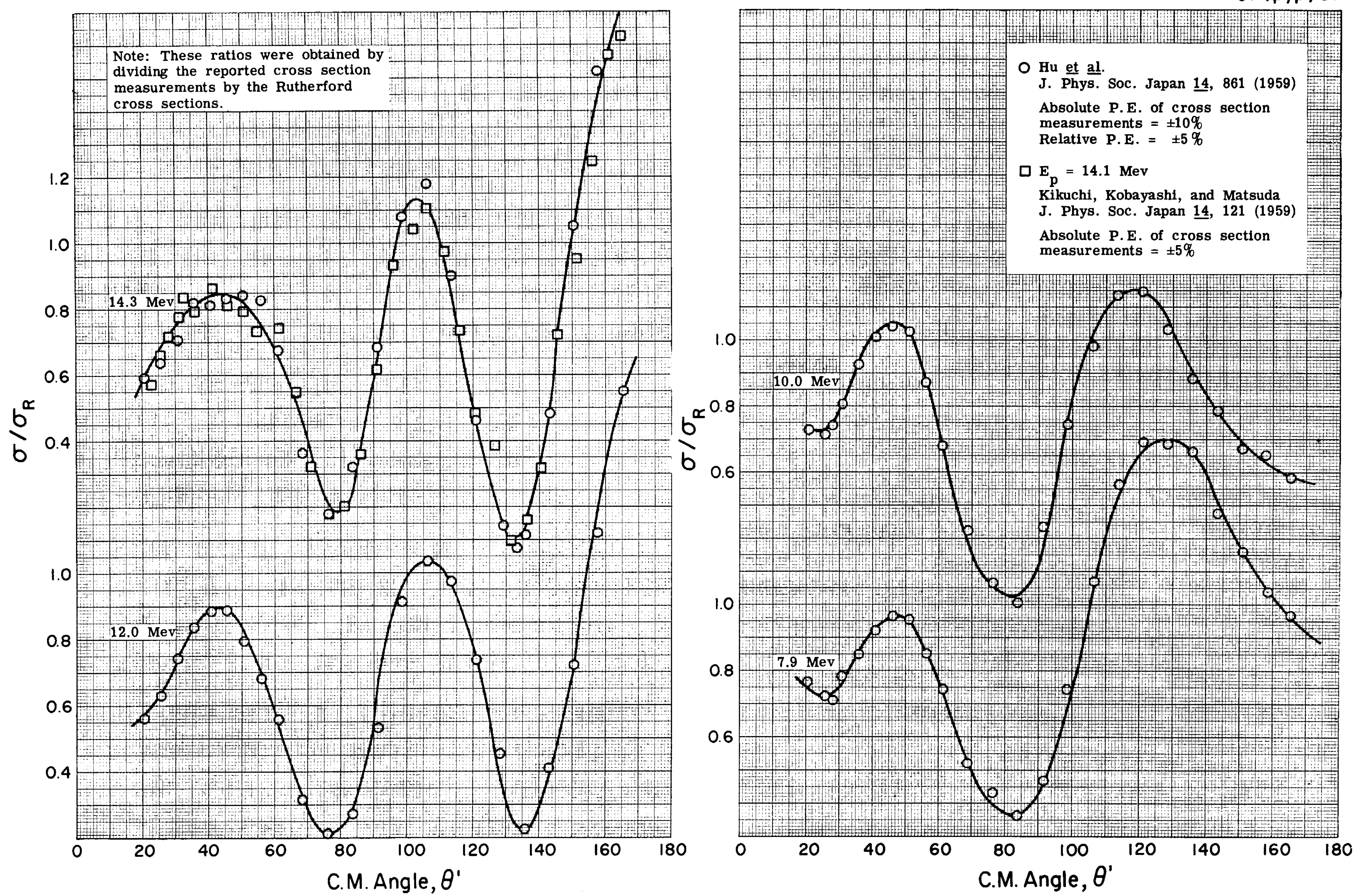




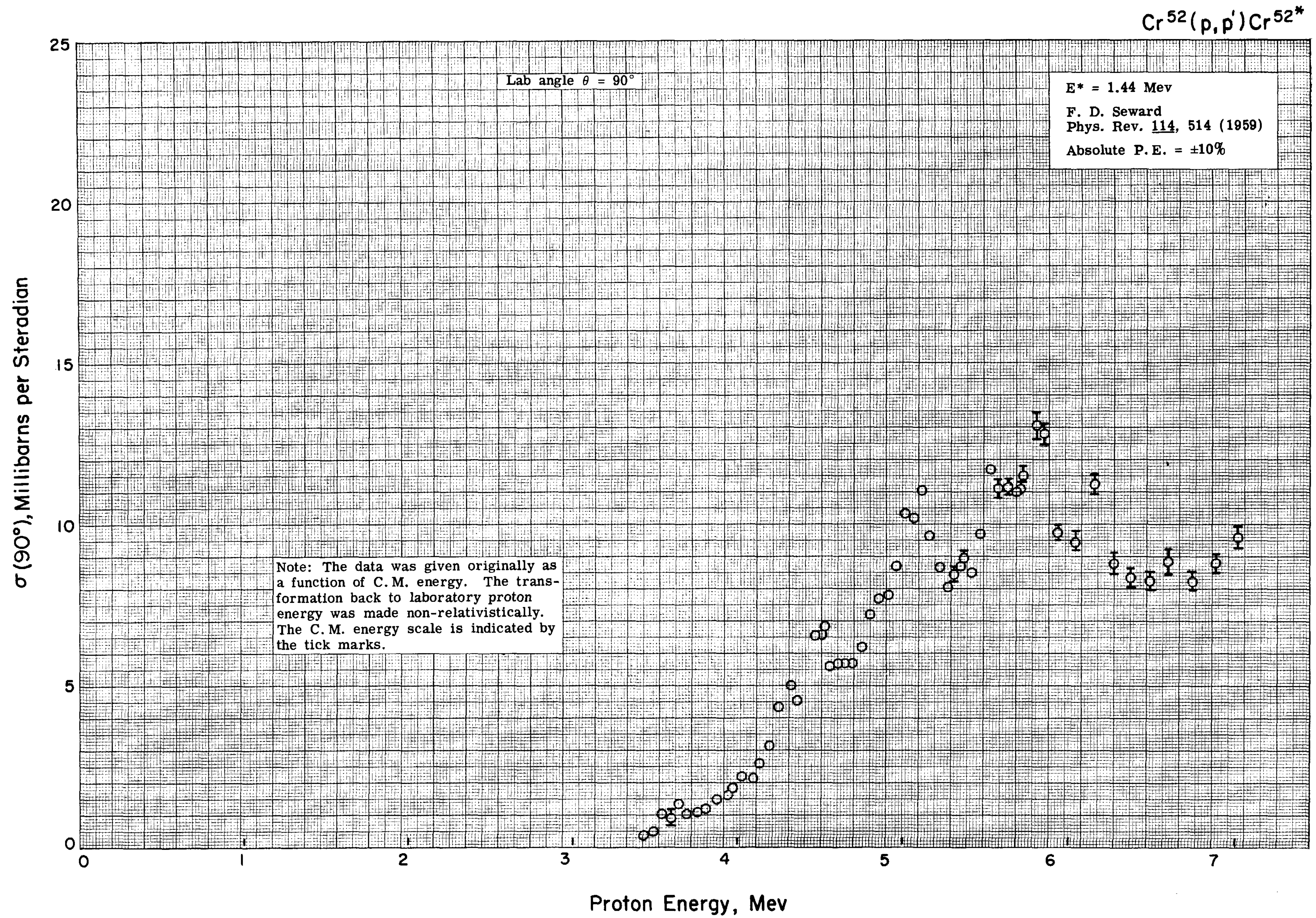
Cr (p, p)Cr



C. A. Preskitt, Jr. and W. P. Alford
Phys. Rev. 115, 389 (1959) or
Report NYO-2172 (1958)
Absolute P.E. = ±2%
5.22 Mev
4.99 Mev
4.52 Mev
4.03 Mev
3.52 Mev
6.53 Mev
6.29 Mev
5.95 Mev
5.63 Mev
5.34 Mev
σ / σR
C.M. Angle of Proton θ'
C.M. Angle of Proton, θ'



Note: These ratios were obtained by dividing the reported cross section measurements by the Rutherford cross sections.
14.3 Mev
12.0 Mev
10.0 Mev
7.9 Mev
σ / σR
C.M. Angle, θ'
○ Hu et al.
J. Phys. Soc. Japan 14, 861 (1959)
Absolute P.E. of cross section measurements = ±10%
Relative P.E. = ±5 %
□ Ep = 14.1 Mev
Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)
Absolute P.E. of cross section measurements = ±5%



Cr^{52}(p,p')Cr^{52*}
Lab angle θ = 90°
E* = 1.44 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute P.E. = ±10%
Note: The data was given originally as a function of C.M. energy. The transformation back to laboratory proton energy was made non-relativistically. The C.M. energy scale is indicated by the tick marks.
σ(90°), Millibarns per Steradian
0
5
10
15
20
25
0
1
2
3
4
5
6
7
Proton Energy, Mev

$Cr^{52}(p, p')Cr^{52*}$
$E^* = 1.44$ Mev

□ Hu et al.
J. Phys. Soc. Japan 14, 861 (1959)
and Report INSJ-20 (1959)

Absolute P. E. = ±15% or less

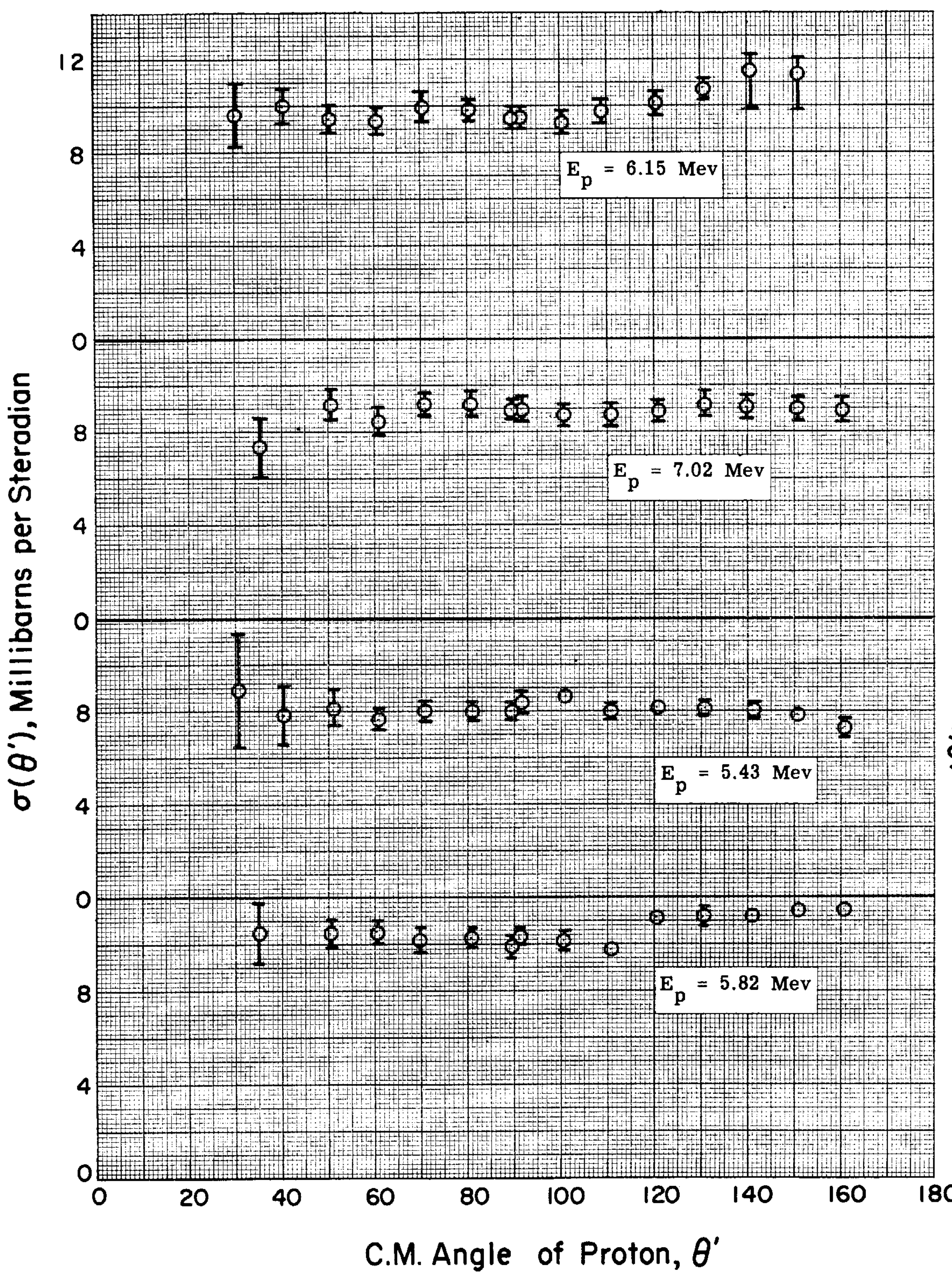
△ Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)

Absolute P. E. = 9-27%

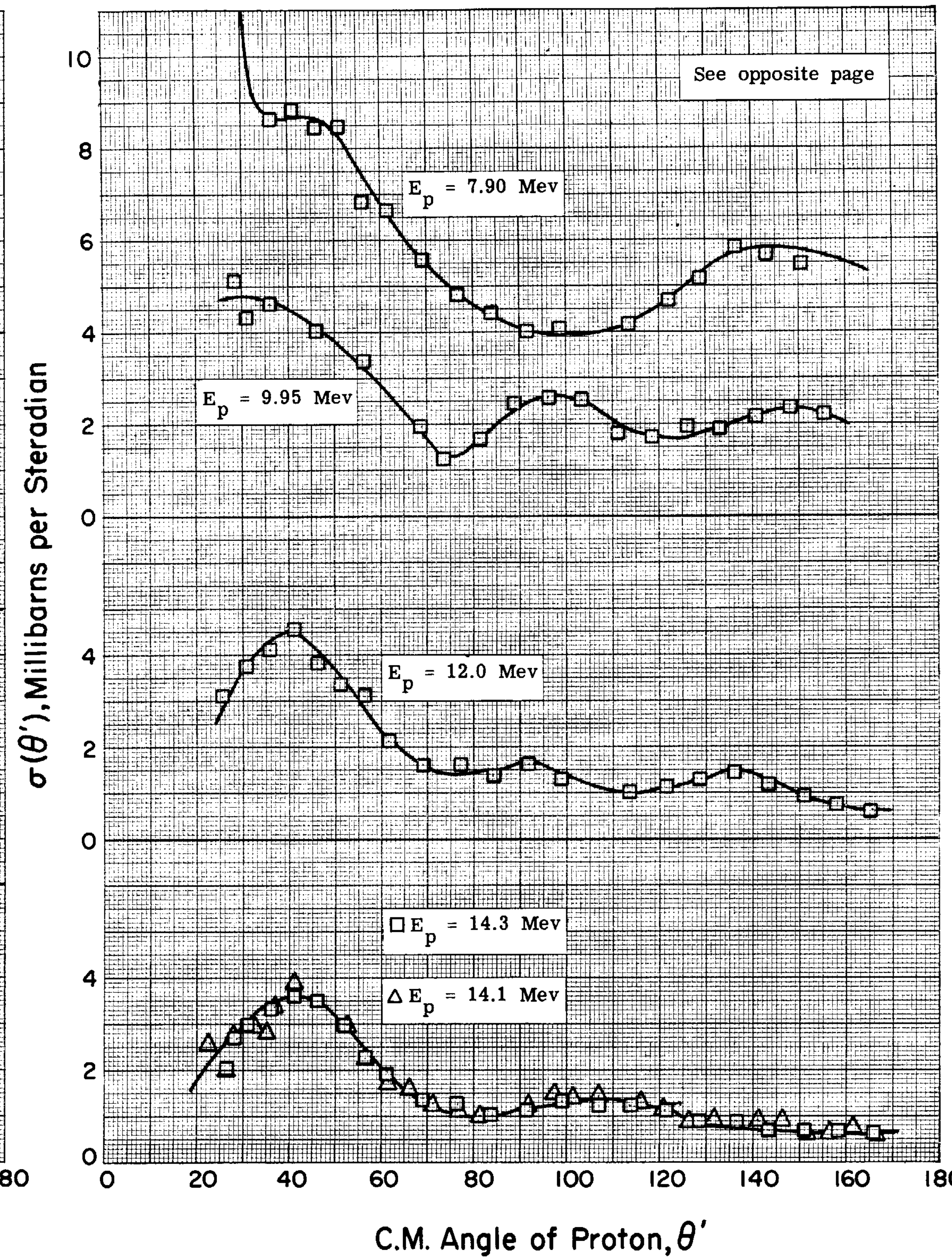
○ F. D. Seward
Phys. Rev. 114, 514 (1959)

Absolute P. E. = ±10%

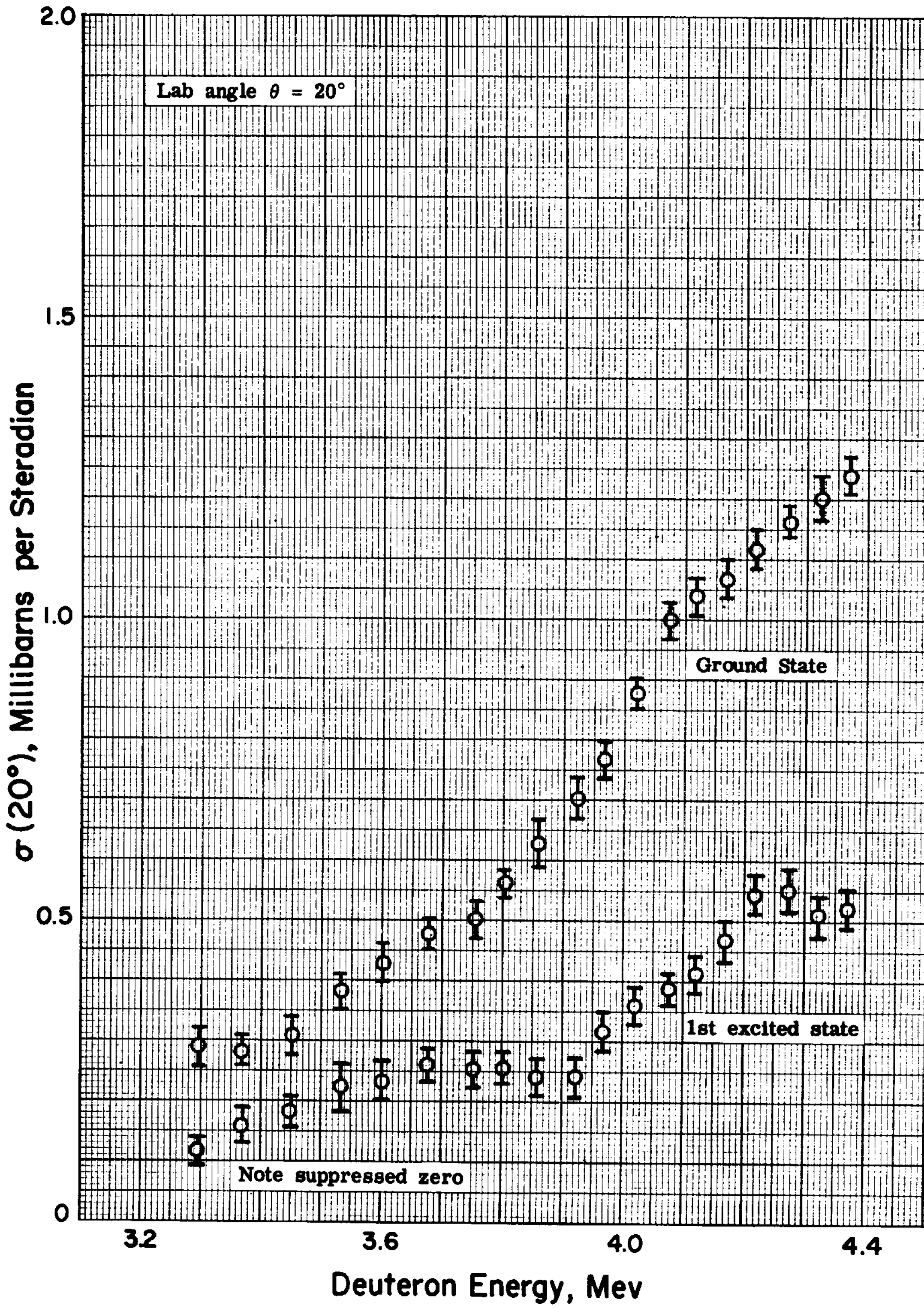
$Cr^{52}(p,p')Cr^{52*}$

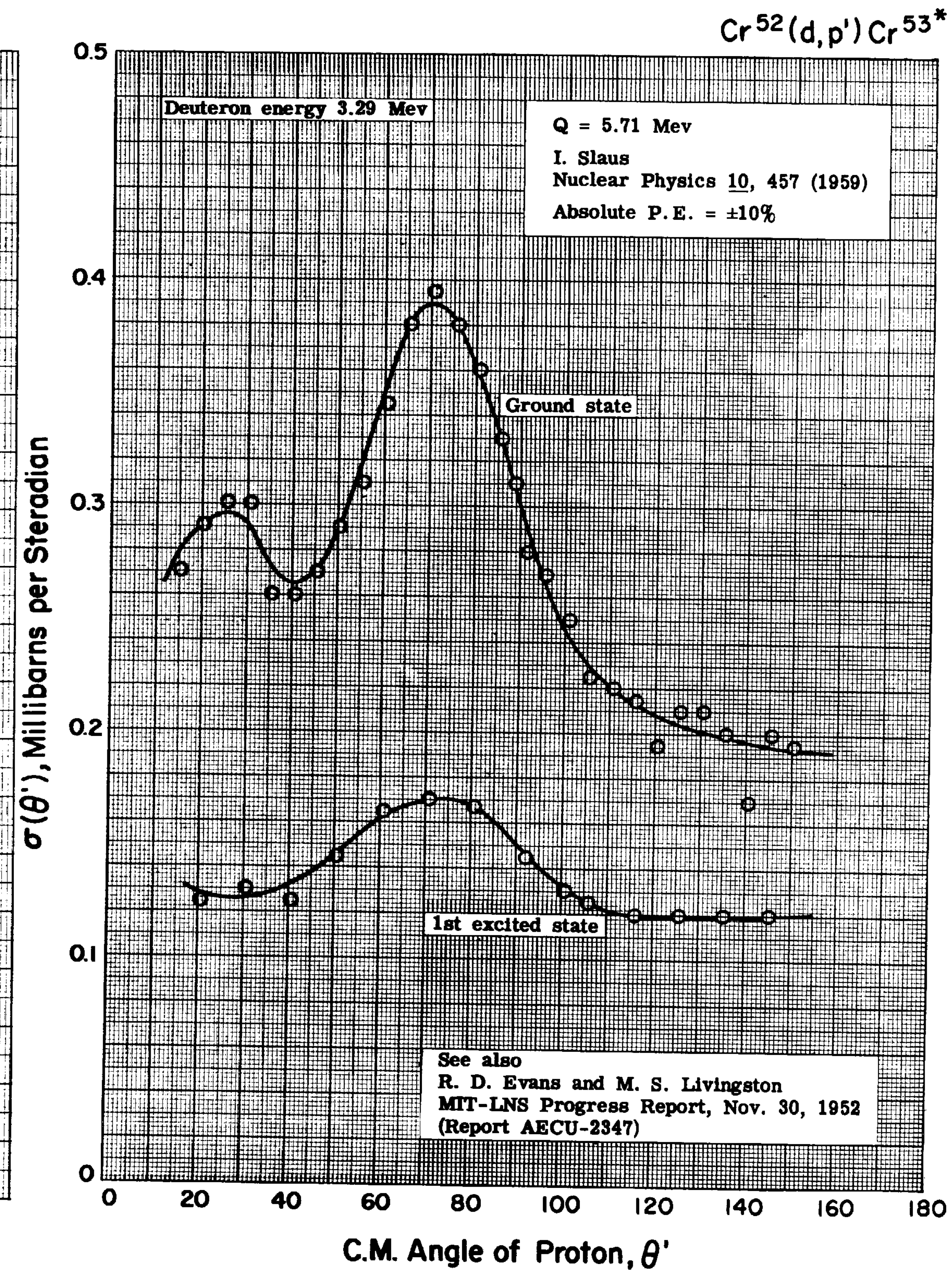


σ(θ'), Millibarns per Steradian
12
8
4
0
8
4
0
8
4
0
8
4
0
E_p = 6.15 Mev
E_p = 7.02 Mev
E_p = 5.43 Mev
E_p = 5.82 Mev
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Proton, θ'

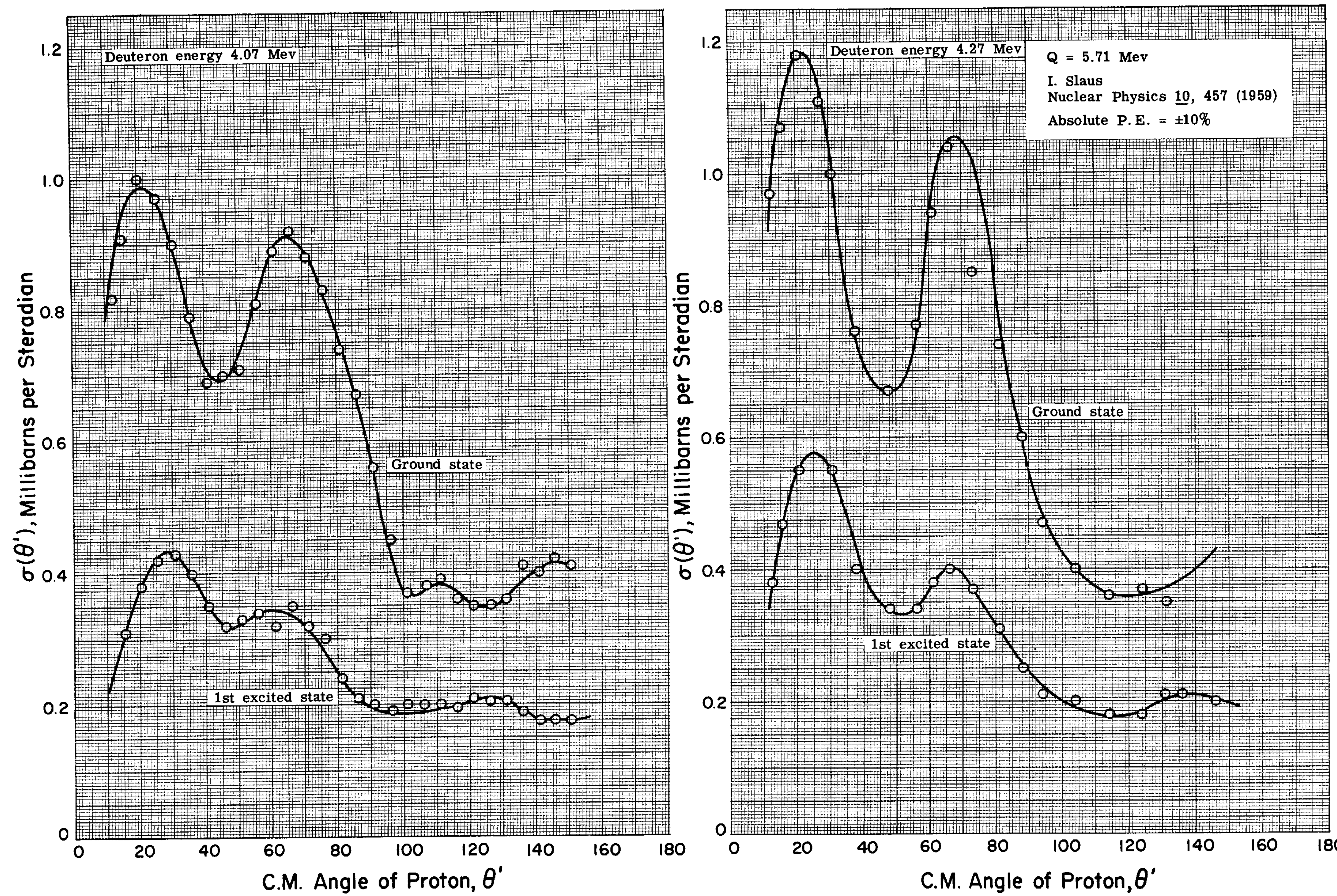


σ(θ'), Millibarns per Steradian
See opposite page
10
8
6
4
2
0
4
2
0
4
2
0
E_p = 7.90 Mev
E_p = 9.95 Mev
E_p = 12.0 Mev
□ E_p = 14.3 Mev
△ E_p = 14.1 Mev
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Proton, θ'

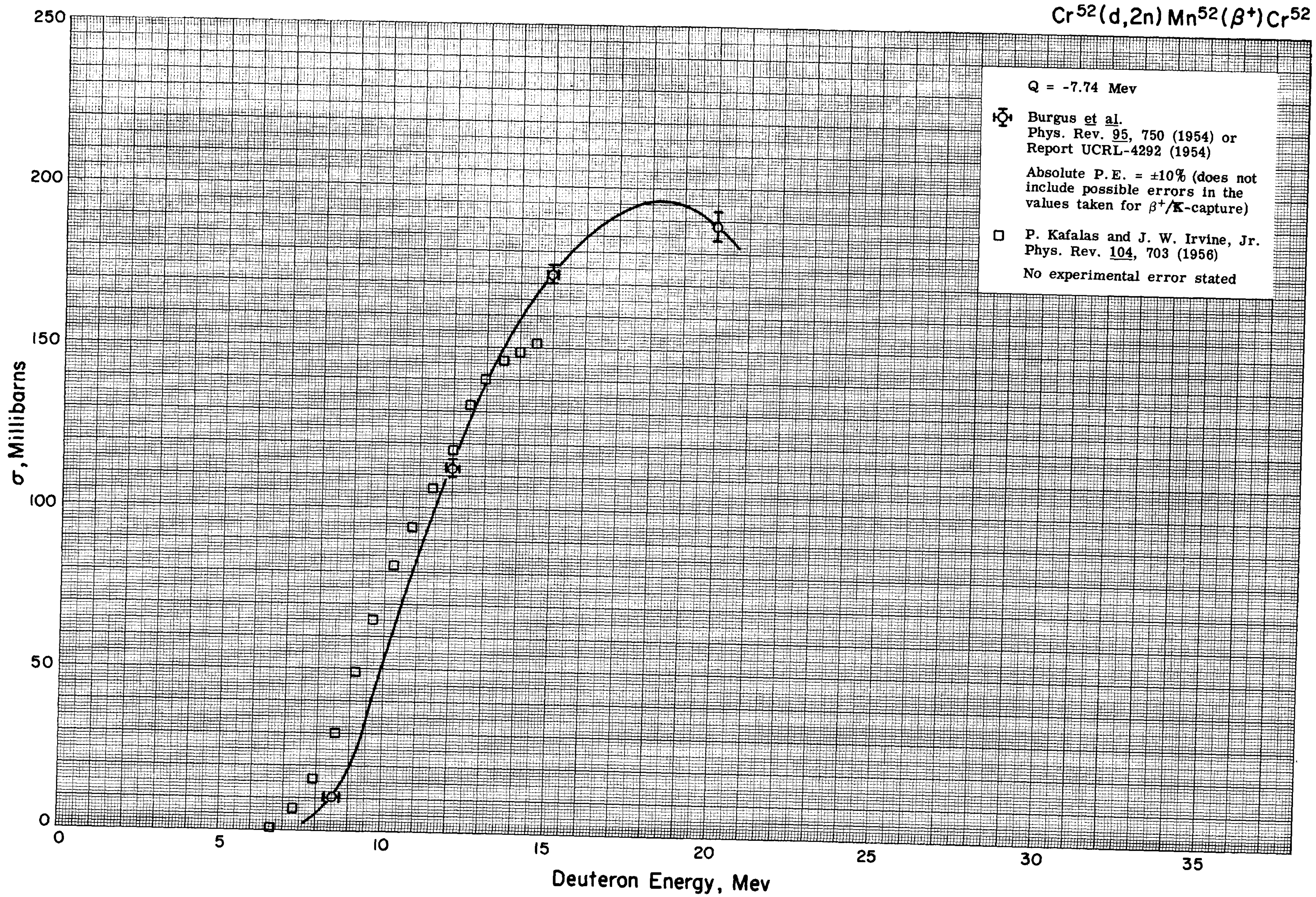

Lab angle θ = 20°
Ground State
1st excited state
Note suppressed zero
σ (20°), Millibarns per Steradian
Deuteron Energy, Mev
2.0
1.5
1.0
0.5
0
3.2
3.6
4.0
4.4


Cr 52 (d, p') Cr 53*
Deuteron energy 3.29 Mev
Q = 5.71 Mev
I. Slaus
Nuclear Physics 10, 457 (1959)
Absolute P.E. = ±10%
Ground state
1st excited state
See also
R. D. Evans and M. S. Livingston
MIT-LNS Progress Report, Nov. 30, 1952
(Report AECU-2347)
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180

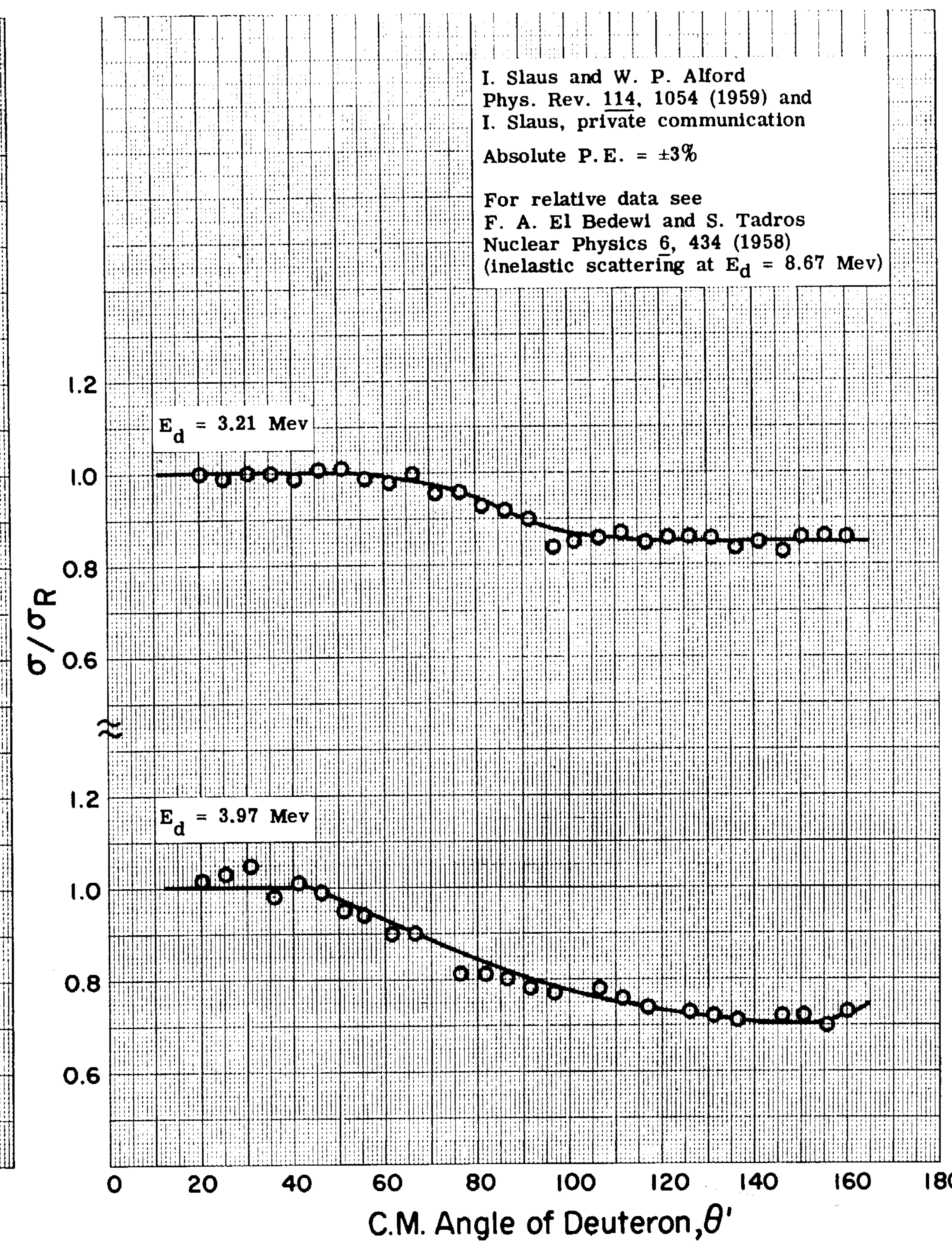
$Cr^{52}(d,p')Cr^{53*}$



Deuteron energy 4.07 Mev
Ground state
1st excited state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
Deuteron energy 4.27 Mev
Q = 5.71 Mev
I. Slaus
Nuclear Physics 10, 457 (1959)
Absolute P.E. = ±10%
Ground state
1st excited state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'



$Cr^{52}(d,2n)Mn^{52}(\beta^+)Cr^{52}$
Q = -7.74 Mev
Burgus et al.
Phys. Rev. 95, 750 (1954) or
Report UCRL-4292 (1954)
Absolute P.E. = ±10% (does not include possible errors in the values taken for β^+/K-capture)
P. Kafalas and J. W. Irvine, Jr.
Phys. Rev. 104, 703 (1956)
No experimental error stated
σ, Millibarns
250
200
150
100
50
0
0
5
10
15
20
25
30
35
Deuteron Energy, Mev


I. Slaus and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication
Absolute P.E. = ±3%
For relative data see
F. A. El Bedewi and S. Tadros
Nuclear Physics 6, 434 (1958)
(inelastic scattering at E_d = 8.67 Mev)
E_d = 3.21 Mev
E_d = 3.97 Mev
σ/σR
1.2
1.0
0.8
0.6
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Deuteron, θ'

Appendix I

BIBLIOGRAPHY OF UNPLOTTED MATERIAL

Most of the references in this bibliography contain only relative data, although references are also listed for data for which no estimate of error limits was given or could be obtained by private communication.

$Ne^{20}(d, p')Ne^{20*}$

R. Middleton and C. T. Tai
Proc. Phys. Soc. (London) A65, 752 (1952)

Burrows et al.
Proc. Phys. Soc. (London) A69, 310 (1956)

$Ne^{20}(d, d')Ne^{20*}$

R. Middleton and C. T. Tai
Proc. Phys. Soc. (London) A65, 752 (1952)

I. J. Van Heerden
Nuclear Physics 6, 55 (1958)

$Ne^{22}(p, \gamma)Na^{23}$

Thornton, Meads, and Collie
Phys. Rev. 109, 480 (1958)

Singh, Davis, and Krone
Phys. Rev. 115, 170 (1959)

Broström, Huus, and Koch
Nature 160, 498 (1947)

$Ne^{22}(d, p')Ne^{23*}$

Burrows et al.
Proc. Phys. Soc. (London) A69, 310 (1956)

$Na^{23}(p, \gamma)Mg^{24}$

Gemmell, Morton, and Smith
Nuclear Physics 10, 45 (1959)

Flack, Rutherglen, and Grant
Proc. Phys. Soc. (London) A67, 973 (1954)

R. Tangen
Kgl. Norske Videnskab Selskabs Skrifter (1946)

W. Gentner
Z. Physik 107, 354 (1937)

P. H. Stelson and W. M. Preston
Phys. Rev. 95, 974 (1954)

H. Casson
Phys. Rev. 89, 809 (1953)

S. C. Curran and J. E. Strothers
Proc. Roy. Soc. (London) A172, 72 (1939)

Teener, Seagondollar, and Krone
Phys. Rev. 93, 1035 (1954)

Grant et al.
Proc. Phys. Soc. (London) A68, 369 (1955)

Prosser et al.
Phys. Rev. 104, 369 (1956)

$Na^{23}(p, n)Mg^{23}$

Blaser et al.
Helv. Phys. Acta 24, 465 (1951)

Willard, Kington, and Bair
Phys. Rev. 86, 259 (1952)

$Na^{23}(p, p)Na^{23}$

Baumann et al.
Phys. Rev. 104, 376 (1956)

G. Dearnaley
Phil. Mag. 1, 821 (1956)

P. H. Stelson and W. M. Preston
Phys. Rev. 95, 974 (1954)

W. G. Read and R. W. Krone
Phys. Rev. 104, 1018 (1956)

Prosser et al.
Phys. Rev. 104, 369 (1956)

$Na^{23}(p, \alpha)Ne^{20}$

Baumann et al.
Phys. Rev. 104, 376 (1956)

Flack, Rutherglen, and Grant
Proc. Phys. Soc. (London) A67, 973 (1954)

J. M. Freeman and A. S. Baxter
Nature 162, 696 (1948)

Prosser et al.
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Appendix II

NUMERICAL FACTORS NECESSARY FOR THE COMPUTATION OF RUTHERFORD CROSS SECTIONS

The Rutherford scattering cross section in the center-of-mass coordinate system is given by $\sigma_R(\theta') = (C/E^2)\ \csc^4(\theta'/2)$ in which C for a given target and projectile is constant and is given by $C = (Z_1 Z_2 e^2/4)^2\ (M_1 + M_2/M_2)^2$, E is the laboratory bombarding energy in Mev, and θ' is the center-of-mass scattering angle. The constant C is given in Table I for the most abundant stable isotopes of the elements from hydrogen through copper. Those entries having no isotopic designation were computed using a weighted average of the masses of the stable isotopes of the target. Values of $\csc^4(\theta'/2)$ are given in Table II for one degree intervals of θ'.

Table I

C (gives σ_R in millibarns/steradian)

Target	(p, p)	(d, d)	(α, α)
H^1	5.1835×10^0	1.1651×10^1	1.2812×10^2
He^4	8.1224	1.1713	8.2936×10^1
Li	1.5295×10^1	1.9412	1.1596×10^2
Li^7	1.5254	1.9320	1.1506
Be^9	2.5631	3.1037	1.7296
B	3.8716	4.5588	2.4327
B^{11}	3.8600	4.5335	2.4094
C^{12}	5.4816	6.3626	3.3185
N^{14}	7.2967	8.3077	4.1994
O^{16}	9.3716	1.0514×10^2	5.1855
F^{19}	1.1640×10^2	1.2840	6.1541
Ne	1.4286	1.5676	7.4447
Ne^{20}	1.4298	1.5701	7.4668
Na^{23}	1.7085	1.8548	8.6461
Mg	2.0238	2.1878	1.0122×10^3
Mg^{24}	2.0262	2.1926	1.0163
Al^{27}	2.3567	2.5292	1.1552
Si	2.7254	2.9172	1.3261
Si^{28}	2.7262	2.9188	1.3275
P^{31}	3.1085	3.3072	1.4872
S	3.5293	3.7473	1.6790
S^{32}	3.5299	3.7486	1.6800
Cl	3.9610	4.1826	1.8553
Cl^{35}	3.9640	4.1889	1.8606
A^{40}	4.4131	4.6325	2.0327
K^{39}	4.9232	5.1742	2.2754
Ca^{40}	5.4482	5.7191	2.5095
Sc^{45}	5.9739	6.2383	2.7111
Ti	6.5388	6.8100	2.9458
Ti^{48}	6.5384	6.8100	2.9451
V^{51}	7.1291	7.4079	3.1899
Cr	7.7564	8.0536	3.4630
Cr^{52}	7.7567	8.0543	3.4636
Mn^{55}	8.3991	8.7039	3.7289
Fe	9.0791	9.4033	4.0243
Fe^{56}	9.0786	9.4023	4.0235
Co^{59}	9.7728	1.0103×10^3	4.3095
Ni	1.0511×10^3	1.0869	4.6369
Ni^{58}	1.0516	1.0878	4.6448
Ni^{60}	1.0504	1.0854	4.6248
Cu	1.1247	1.1600	4.9258
Cu^{63}	1.1250	1.1607	4.9315
Cu^{65}	1.1239	1.1585	4.9133

Table II

$A = \csc^4(\theta'/2)$

θ'	A	θ'	A	θ'	A	θ'	A
0	--	45	4.6626×10^1	90	4.0000	135	1.3726
1	1.7242×10^8	46	4.2903	91	3.8636	136	1.3529
2	1.0779×10^7	47	3.9552	92	3.7352	137	1.3345
3	2.1298×10^6	48	3.6539	93	3.6120	138	1.3162
4	6.7413×10^5	49	3.3812	94	3.4951	139	1.2991
5	2.7626	50	3.1348	95	3.3839	140	1.2826
6	1.3328	51	2.9110	96	3.2784	141	1.2663
7	7.1987×10^4	52	2.7080	97	3.1782	142	1.2511
8	4.2239	53	2.5230	98	3.0822	143	1.2365
9	2.6385	54	2.3541	99	2.9911	144	1.2225
10	1.7332	55	2.1999	100	2.9039	145	1.2086
11	1.1848	56	2.0587	101	2.8211	146	1.1957
12	8.3766×10^3	57	1.9289	102	2.7418	147	1.1830
13	6.0893	58	1.8103	103	2.6659	148	1.1712
14	4.5334	59	1.7009	104	2.5933	149	1.1595
15	3.4452	60	1.6000	105	2.5245	150	1.1489
16	2.6655	61	1.5071	106	2.4579	151	1.1382
17	2.0951	62	1.4211	107	2.3949	152	1.1281
18	1.6699	63	1.3418	108	2.3346	153	1.1185
19	1.3476	64	1.2682	109	2.2762	154	1.1094
20	1.0998	65	1.2000	110	2.2212	155	1.1008
21	9.0671×10^2	66	1.1365	111	2.1678	156	1.0922
22	7.5438	67	1.0776	112	2.1168	157	1.0846
23	6.3299	68	1.0227	113	2.0681	158	1.0769
24	5.3515	69	9.7156×10^0	114	2.0216	159	1.0698
25	4.5566	70	9.2382	115	1.9765	160	1.0630
26	3.9052	71	8.7950	116	1.9335	161	1.0568
27	3.3673	72	8.3777	117	1.8919	162	1.0509
28	2.9195	73	7.9887	118	1.8522	163	1.0451
29	2.5444	74	7.6226	119	1.8144	164	1.0398
30	2.2285	75	7.2817	120	1.7778	165	1.0348
31	1.9607	76	6.9609	121	1.7429	166	1.0303
32	1.7325	77	6.6591	122	1.7092	167	1.0263
33	1.5368	78	6.3752	123	1.6765	168	1.0222
34	1.3685	79	6.1083	124	1.6455	169	1.0185
35	1.2230	80	5.8574	125	1.6155	170	1.0153
36	1.0967	81	5.6216	126	1.5865	171	1.0125
37	9.8644×10^1	82	5.3986	127	1.5590	172	1.0096
38	8.9014	83	5.1882	128	1.5323	173	1.0076
39	8.0537	84	4.9887	129	1.5066	174	1.0056
40	7.3079	85	4.8004	130	1.4823	175	1.0040
41	6.6486	86	4.6227	131	1.4583	176	1.0024
42	6.0627	87	4.4535	132	1.4356	177	1.0012
43	5.5424	88	4.2950	133	1.4137	178	1.0008
44	5.0783	89	4.1431	134	1.3930	179	1.0000

Appendix III

PARTICLE MECHANICS

REFERENCES ON PARTICLE MECHANICS

1. B. G. Carlson, et al., Report AECU-195 (LA-723), January 1949
   Source of the information included in this compilation; notation has been changed for sake of consistency. Includes graphs and tables of elastic scattering of particles of mass 1, 2, 3, and 4 by targets of masses 1 to 16, and of the reactions $T(p,n)He^3$, $T(d,n)He^4$, D(d,p)T, and $D(d,n)He^3$ at E = 6, 8, 10, and 12 Mev. Also Rutherford scattering.

2. Hanson, Taschek, and Williams, Rev. Mod. Phys. 21, 635 (1949)
   Presents formulae in a form convenient for endothermic reactions. Includes nomographs for the reactions $D(d,n)He^3$, $C^{12}(d,n)N^{13}$, $T(d,n)He^4$, $Li^7(p,n)Be^7$, and $T(p,n)He^3$, and plots of neutron energy and solid-angle ratio for $T(d,n)He^4$, $0.5 \leq E_d \leq 3$ Mev.

3. E. Segrè, editor, Experimental Nuclear Physics, John Wiley & Son, Inc., New York, 1953
   (a) K. T. Bainbridge, Part V in Vol. I, p. 669
   Gives equations for Q including relativistic effects. These and other equations may be obtained from the non-relativistic formulae included in this compilation by substituting for each mass M the expression $M + \frac{1}{2}E/c^2$ providing $\frac{1}{2}E/Mc^2 \ll 1$. For excited nuclei use $M + \frac{1}{2}E/c^2 + h\nu/c^2$.
   (b) P. Morrison, Part VI in Vol. II, p. 3
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4. J. Blaton, Kgl. Danske Videnskab. Selskab, Matfys. Medd. 24, No. 20, 1 (1950)
   Gives a geometrical interpretation of the relativistic cases.

5. F. Mariani, Nuovo cimento 8, 297 (1951)
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6. F. J. M. Farley, Nucleonics 12, No. 10, 56 (1954), and erratum, Nucleonics 13, No. 7, 67, (1955)
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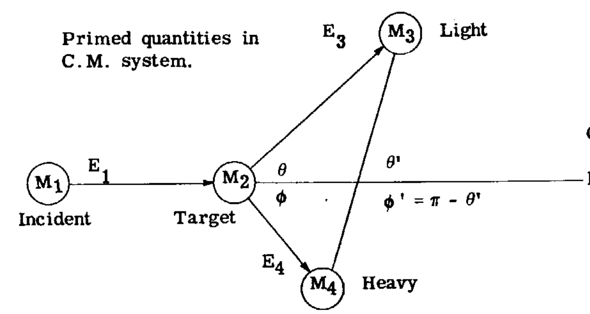
   A mechanical device.

CONVENTIONS AND SYMBOLS

θ	Laboratory angle of observed particle.
θ'	Center-of-mass angle of observed particle.
$\sigma(\theta)$	The differential cross section in the laboratory system.
$\sigma(\theta')$	The differential cross section in the center-of-mass system.
σ	The total cross section of the reaction.
E	Energy, always in the laboratory system. Subscripts p, d, t, etc., refer to protons, deuterons, tritons, etc.
C.M.	Center-of-mass system.
Lab	Laboratory system.
P.E.	Probable error.
Γ	Observed width of a resonance
E_R	Bombarding energy at which a resonance occurs.

REACTIONS



$Q = (M_1 + M_2 - M_3 - M_4)c^2$

$E_T = E_1 + Q = E_3 + E_4$

Define:

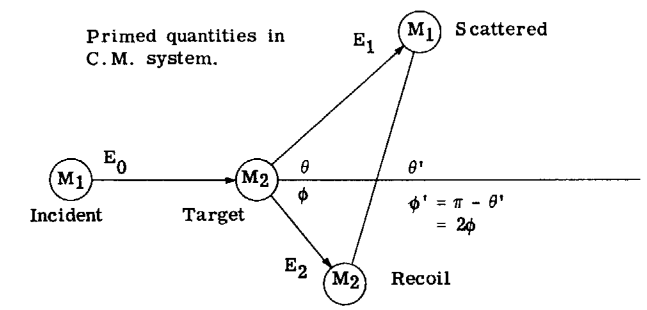
$$A_{14} = \frac{M_1M_4(E_1/E_T)}{(M_1 + M_2)(M_3 + M_4)}, \qquad A_{23} = \frac{M_2M_3}{(M_1 + M_2)(M_3 + M_4)}\left(1 + \frac{M_1}{M_2}\frac{Q}{E_T}\right) = \frac{E'_4}{E_T}$$

$$A_{13} = \frac{M_1M_3(E_1/E_T)}{(M_1 + M_2)(M_3 + M_4)}, \qquad A_{24} = \frac{M_2M_4}{(M_1 + M_2)(M_3 + M_4)}\left(1 + \frac{M_1}{M_2}\frac{Q}{E_T}\right) = \frac{E'_3}{E_T}$$

Note that $A_{14} + A_{13} + A_{23} + A_{24} = 1$

Lab energy of light product:	$\frac{E_3}{E_T} = A_{13} + A_{24} + 2(A_{14}A_{23})^{\frac{1}{2}}\cos\theta'$ $= A_{13}\left[\cos\theta \pm (A_{24}/A_{13} - \sin^2\theta)^{\frac{1}{2}}\right]^2$	Use only plus sign unless $A_{13} > A_{24}$, in which case $\theta_{max} = \sin^{-1}(A_{24}/A_{13})^{\frac{1}{2}}$
Lab energy of heavy product:	$\frac{E_4}{E_T} = A_{14} + A_{23} + 2(A_{14}A_{23})^{\frac{1}{2}}\cos\phi'$ $= A_{14}\left[\cos\phi \pm (A_{23}/A_{14} - \sin^2\phi)^{\frac{1}{2}}\right]^2$	Use only plus sign unless $A_{14} > A_{23}$, in which case $\phi_{max} = \sin^{-1}(A_{23}/A_{14})^{\frac{1}{2}}$
Lab angle of heavy product:	$\sin\phi = \left(\frac{M_3E_3}{M_4E_4}\right)^{\frac{1}{2}}\sin\theta$	C.M. angle of light product: $\sin\theta' = \left(\frac{E_3/E_T}{A_{24}}\right)^{\frac{1}{2}}\sin\theta$
Intensity or solid-angle ratio for light product:	$\frac{\sigma(\theta')}{\sigma(\theta)} = \frac{I(\theta')}{I(\theta)} = \frac{\sin\theta\, d\theta}{\sin\theta'\, d\theta'} = \frac{\sin^2\theta}{\sin^2\theta'}\cos(\theta' - \theta) = \frac{(A_{14}A_{23})^{\frac{1}{2}}(A_{24}/A_{13} - \sin^2\theta)^{\frac{1}{2}}}{E_3/E_T}$	
Intensity or solid-angle ratio for heavy product:	$\frac{\sigma(\phi')}{\sigma(\phi)} = \frac{I(\phi')}{I(\phi)} = \frac{\sin\phi\, d\phi}{\sin\phi'\, d\phi'} = \frac{\sin^2\phi}{\sin^2\phi'}\cos(\phi' - \phi) = \frac{(A_{14}A_{23})^{\frac{1}{2}}(A_{23}/A_{14} - \sin^2\phi)^{\frac{1}{2}}}{E_4/E_T}$	
Intensity or solid-angle ratio for associated particles in the lab system:	$\frac{\sigma(\phi)}{\sigma(\theta)} = \frac{I(\phi)}{I(\theta)} = \frac{\sin\theta\, d\theta}{\sin\phi\, d\phi} = \frac{\sin^2\theta}{\sin^2\phi}\frac{\cos(\theta' - \theta)}{\cos(\phi' - \phi)}$	

ELASTIC SCATTERING



For elastic scattering, all energy and angle ratios are independent of energy and reduce as below:

$$E'_1 = \frac{M_2^2}{(M_1 + M_2)^2}E_0$$

$$E'_2 = \frac{M_1M_2}{(M_1 + M_2)^2}E_0$$

Lab energy of the scattered particle:	$\frac{E_1}{E_0} = 1 - \frac{2M_1M_2}{(M_1 + M_2)^2}(1 - \cos\theta')$ $= \frac{M_1^2}{(M_1 + M_2)^2}\left\{\cos\theta \pm \left[(M_2/M_1)^2 - \sin^2\theta\right]^{\frac{1}{2}}\right\}^2$	Use only plus sign unless $M_1 > M_2$, in which case $\theta_{max} = \sin^{-1}(M_2/M_1)$
Lab energy of the recoil nucleus	$\frac{E_2}{E_0} = 1 - E_1/E_0 = \frac{4M_1M_2}{(M_1 + M_2)^2}\cos^2\phi$	$\phi \leq \pi/2$
Lab angle of recoil nucleus	$\sin\phi = \left(\frac{M_1E_1}{M_2E_2}\right)^{\frac{1}{2}}\sin\theta, \quad \phi = \frac{1}{2}(\pi - \theta')$	$\tan\theta = \frac{\sin 2\phi}{M_1/M_2 - \cos 2\phi}$
C.M. angle of scattered particle:	$\theta' = \theta + \sin^{-1}\left(\frac{M_1}{M_2}\sin\theta\right) = \pi - 2\phi$	$\cos\theta' = 1 - 2\cos^2\phi$
Intensity or solid-angle ratio for scattered particle:	$\frac{\sigma(\theta')}{\sigma(\theta)} = \frac{I(\theta')}{I(\theta)} = \frac{\sin\theta\, d\theta}{\sin\theta'\, d\theta'} = \frac{\sin^2\theta}{\sin^2\theta'}\cos(\theta' - \theta) = \frac{M_1M_2\left[(M_2/M_1)^2 - \sin^2\theta\right]^{\frac{1}{2}}}{(M_1 + M_2)^2(E_1/E_0)}$	
Intensity or solid-angle ratio for recoil nucleus:	$\frac{\sigma(\phi')}{\sigma(\phi)} = \frac{I(\phi')}{I(\phi)} = \frac{\sin\phi\, d\phi}{\sin\phi'\, d\phi'} = \frac{1}{4\cos\phi}$	

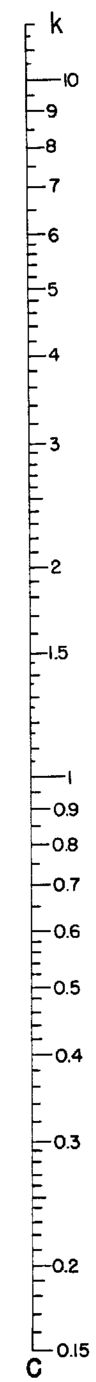
NUCLEAR REACTION NOMOGRAM

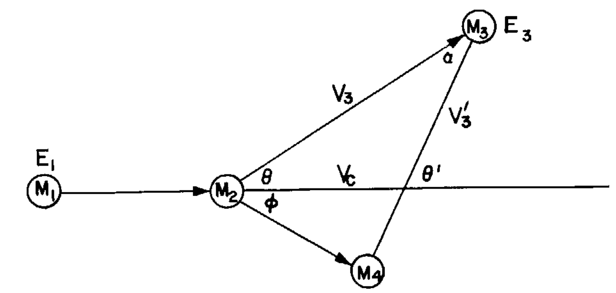
Nuclear Reaction Nomogram

F. J. M. Farley, Nucleonics 12, No. 10, 56 (1954), and Erratum; Nucleonics 13, No. 7, 67 (1955).

This nomogram is based upon the version given in the reference, but with the scales correctly spaced and the notation changed to that adopted in this compilation.

NOTE: If either the energy or intensity ratio falls off of scale D, it is permissible to divide or multiply the value of k' by 10; this changes the answer by a factor of 100. Alternatively, in the case of the energy ratio, one can use the points X or Y on scale A instead of the point 90; the answer will then be multiplied correspondingly by 10 or by 50.





It may be assumed that $M_1 + M_2 = M_3 + M_4 = M$.

1. Calculate $k = V_c/V_3' = (M_1 M_3 E_1 / M^2 E_3')^{1/2}$

   where $E_3' = \left(Q + \frac{M_2}{M} E_1\right) \frac{M_4}{M}$

2. Connect k on scale C with θ on scale A to read α on scale B. $\alpha = \sin^{-1}(k \sin\theta)$ (use equation if k is off scale).
3. Locate $\theta' = \theta + \alpha$ on scale B.
4. Connect θ and θ' to find $k' = V_3/V_3'$.
5. Connect k' with 90^o on scale A, and read $E_3/E_3' = k'^2$ on scale D.
6. Locate $\beta = 90^o - \alpha$ on scale A.
7. Connect β and k' to read on scale D

   $$\sigma(\theta)/\sigma(\theta') = (\sin^2\theta'/\sin^2\theta)\ (1/\sin\beta).$$

Note: When $k > 1$ there are two solutions for $\theta < \theta_{max}$, where θ_{max} is found by connecting k to $\alpha = 90^o$ on scale B.