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CHARGED PARTICLE cross sections

NEON TO CHROMIUM

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CHARGED PARTICLE cross sections
NEON TO CHROMIUM

Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico JUNE 1960

Compiled and edited by
Darryl B. Smith

Associate Editors
Nelson Jarmie and John D. Seagrave

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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all absolute data published in a generally available source before January 1, 1960, although in some cases later or unpublished data may have been used.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 non-relativistically 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

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[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.

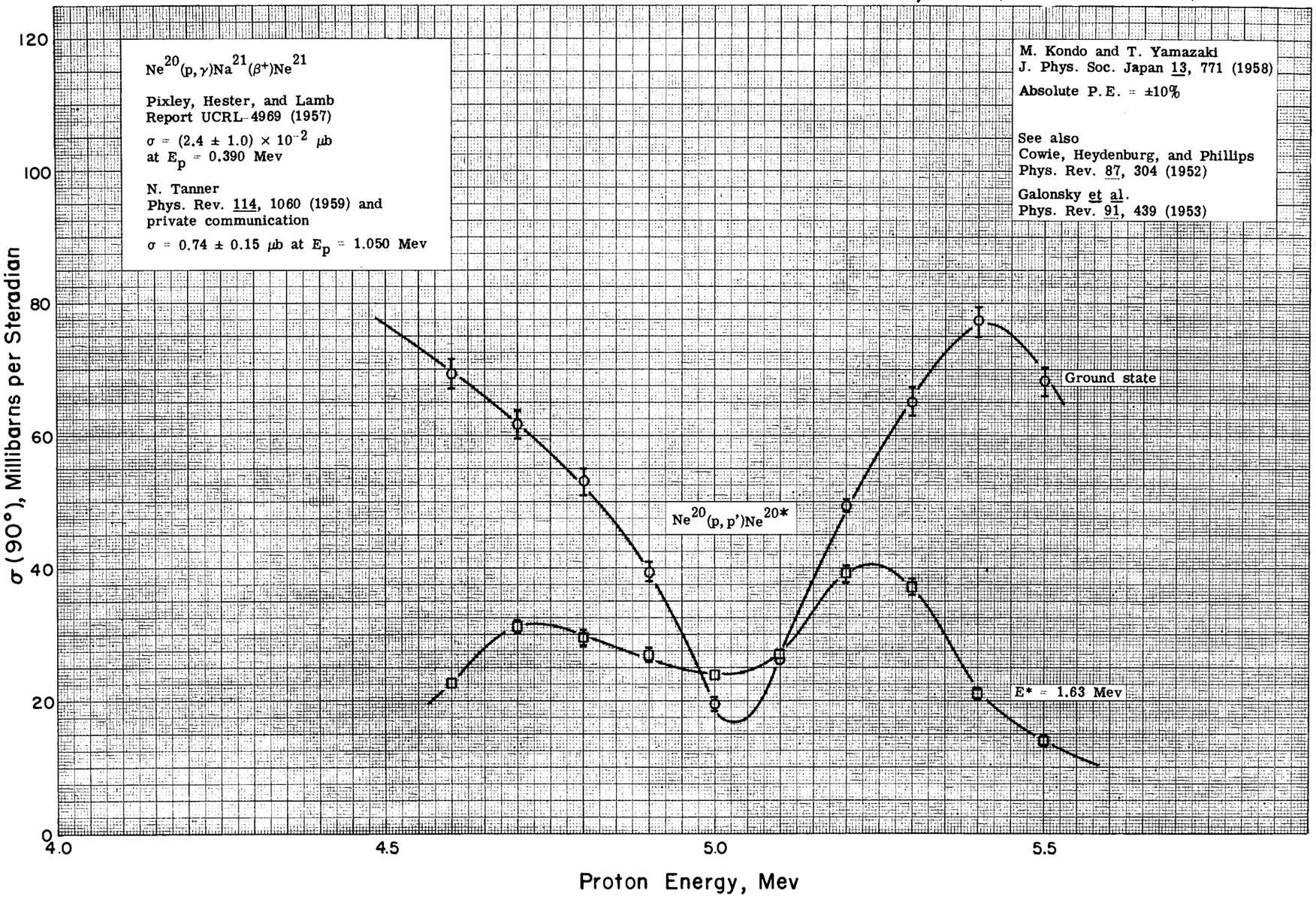
A serious attempt has been made to include with each graph some indication of the absolute error limits for the cross sections. When the error was not stated in the reference and could not be obtained by private communication, the compiler often has made a conservative guess from the information in the 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.

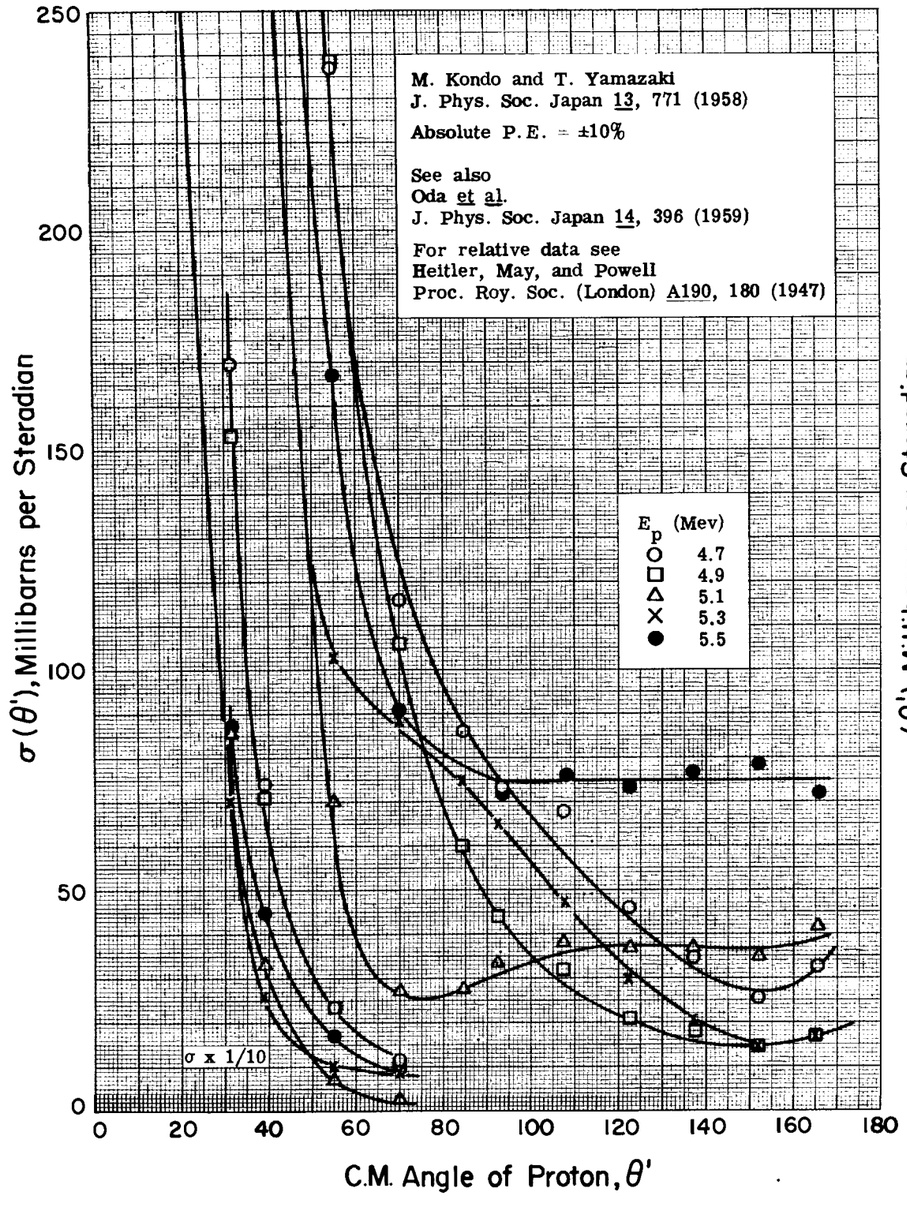
No collected bibliography has been made for the material plotted. References and information of interest have been placed on the page with the data to which they pertain. References containing only relative data or data that was not plotted (usually because of a lack of information on absolute error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

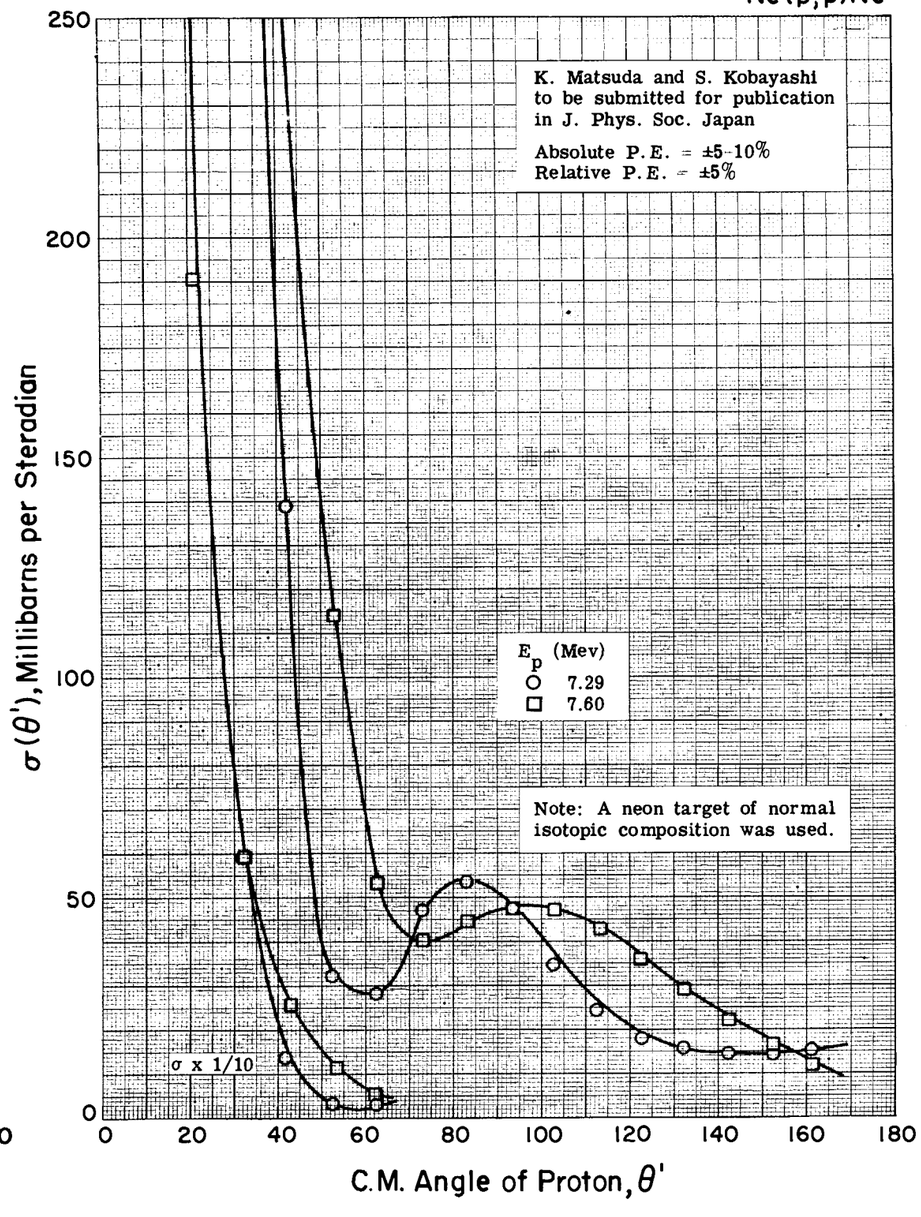
Although due care has been taken, it should be emphasized that anyone desiring very accurate values should always use the original reference. Unavoidable errors in tracing, graph paper distortion, and final reproduction always occur. In extreme cases, where data had to be copied from tiny graphs in journals, 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.

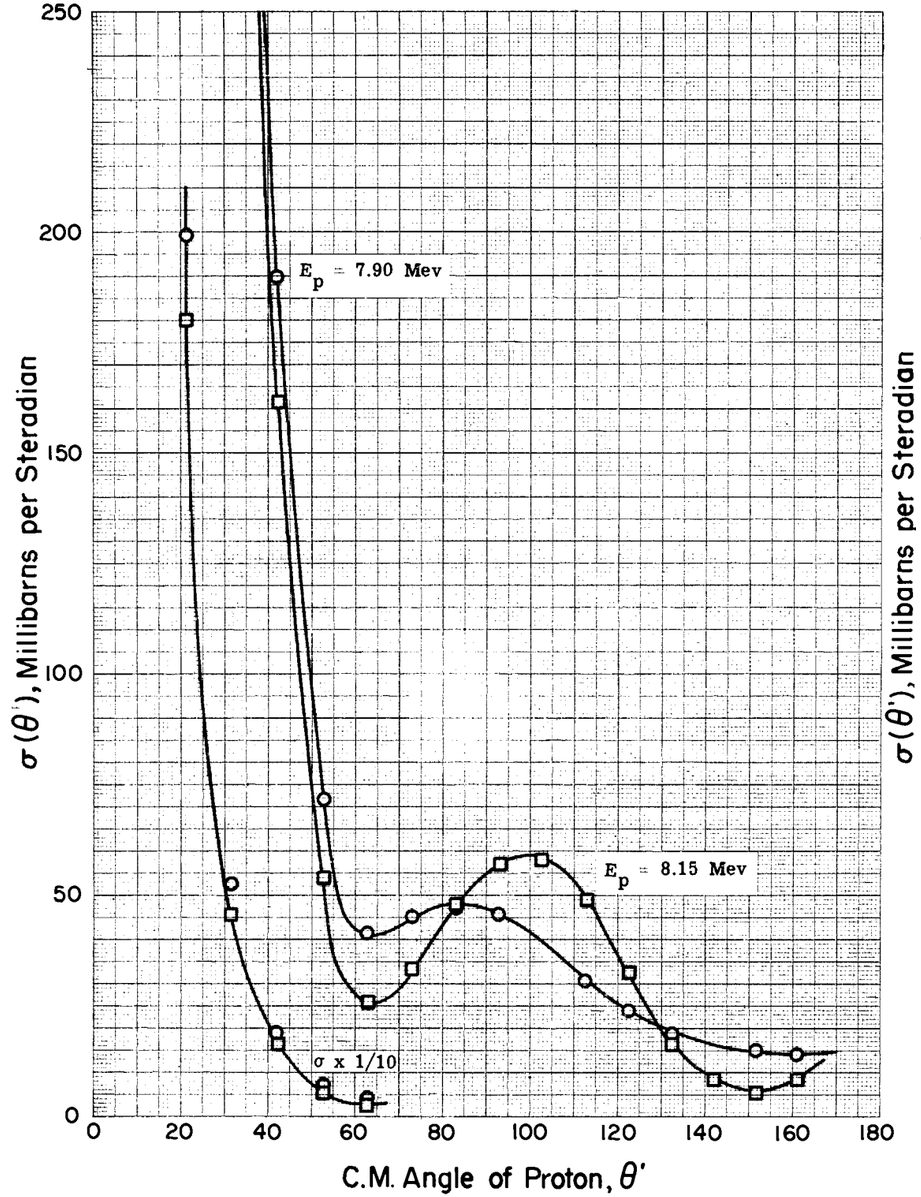
ACKNOWLEDGMENTS

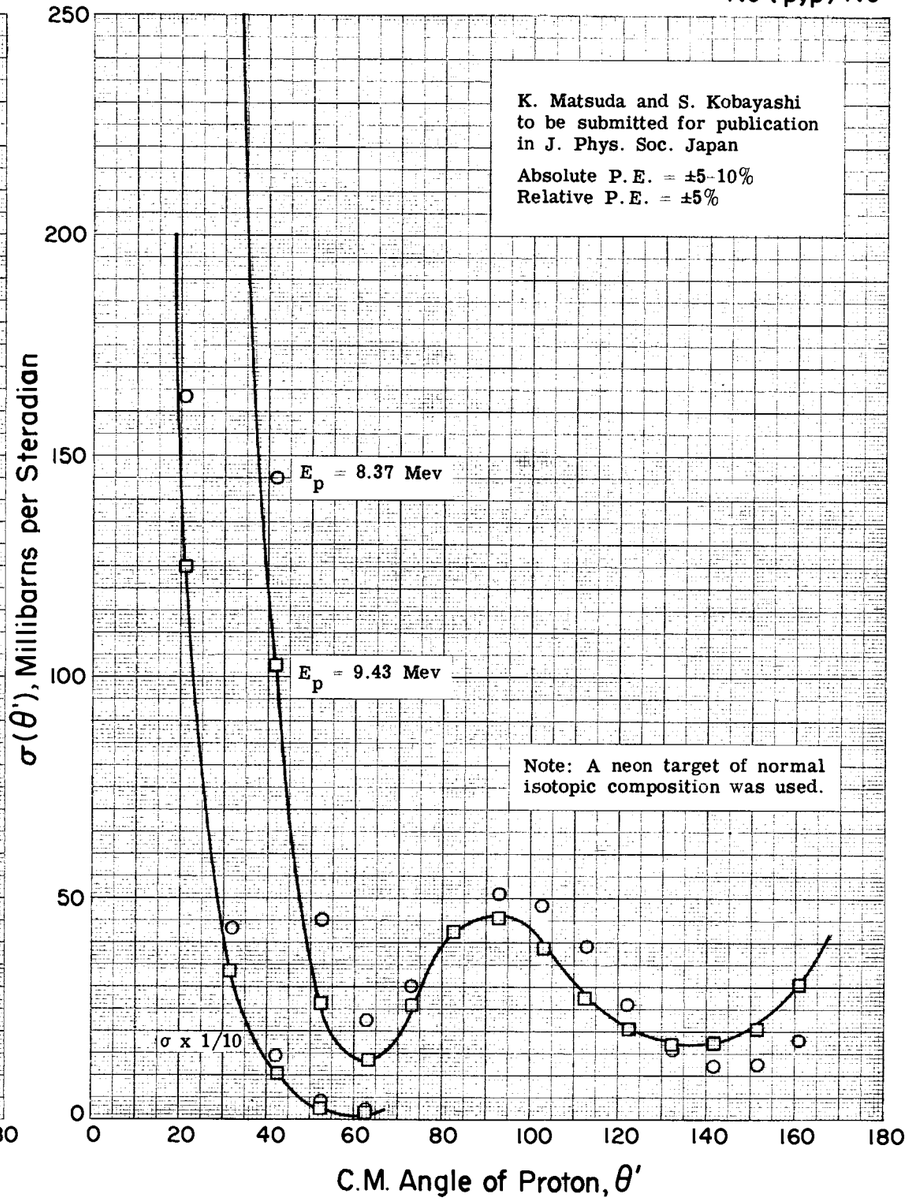
It is a pleasure to acknowledge the help and services of all draftsmen, plotters, calculators, and others who have contributed to this work. Great appreciation is also extended to the numerous correspondents who have furnished unpublished data, error calculations, large graphs, tabular data, and other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

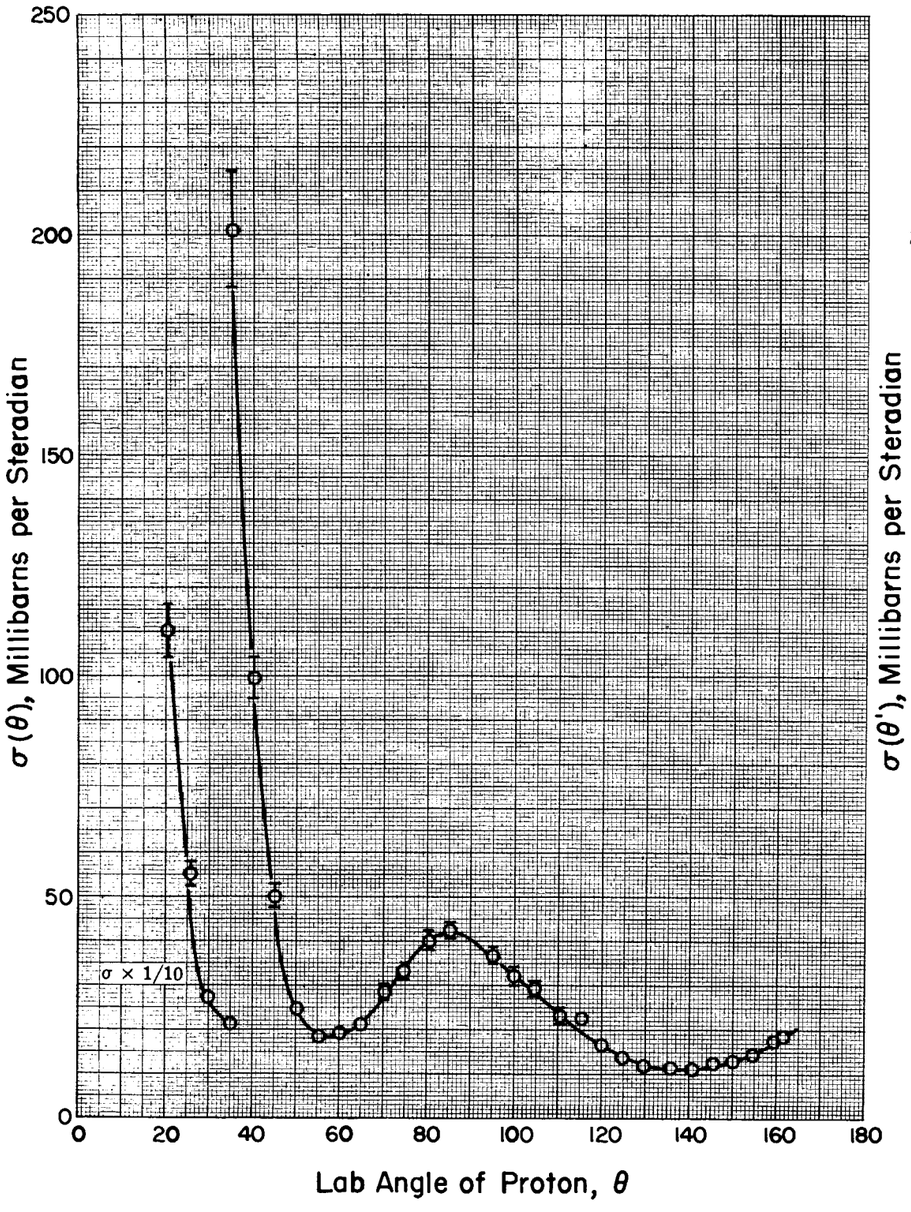

$Ne^{20}(p,\gamma)Na^{21}(\beta^+)Ne^{21}$
Pixley, Hester, and Lamb
Report UCRL-4969 (1957)
$\sigma = (2.4 \pm 1.0) \times 10^{-2}$ μb
at $E_p = 0.390$ Mev
N. Tanner
Phys. Rev. 114, 1060 (1959) and
private communication
$\sigma = 0.74 \pm 0.15$ μb at $E_p = 1.050$ Mev
M. Kondo and T. Yamazaki
J. Phys. Soc. Japan 13, 771 (1958)
Absolute P.E. = ±10%
See also
Cowie, Heydenburg, and Phillips
Phys. Rev. 87, 304 (1952)
Galonsky et al.
Phys. Rev. 91, 439 (1953)
Ground state
$Ne^{20}(p,p')Ne^{20*}$
$E^* = 1.63$ Mev
σ (90°), Millibarns per Steradian
Proton Energy, Mev
0
20
40
60
80
100
120
4.0
4.5
5.0
5.5


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)
E_p (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'
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180

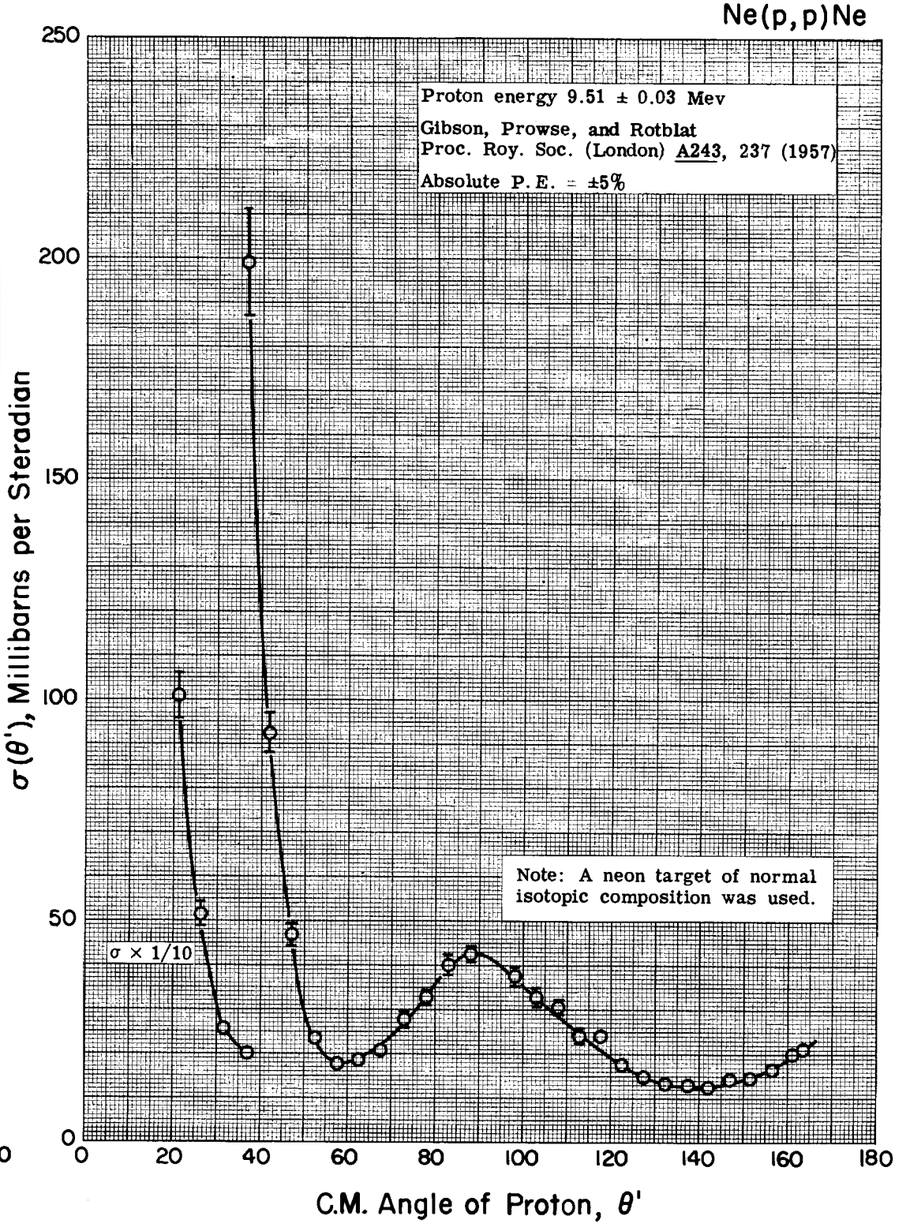

K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%
E_p (Mev)
7.29
7.60
Note: A neon target of normal isotopic composition was used.
σ x 1/10
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180


250
200
150
100
50
0
$\sigma(\theta')$, 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'

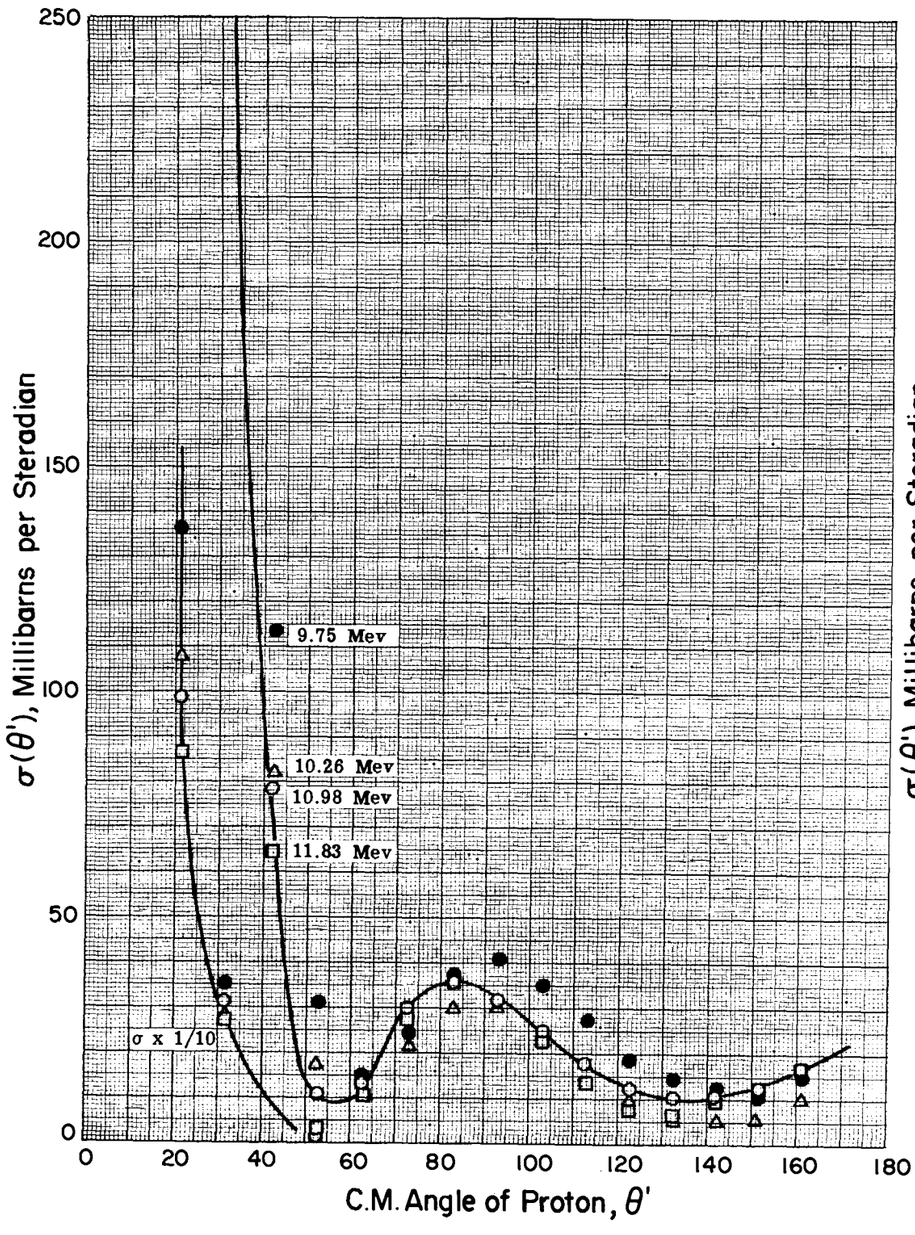

K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%
250
200
150
100
50
0
$\sigma(\theta')$, Millibarns per Steradian
E_p = 8.37 Mev
E_p = 9.43 Mev
Note: A neon target of normal
isotopic composition was used.
σ x 1/10
0 20 40 60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

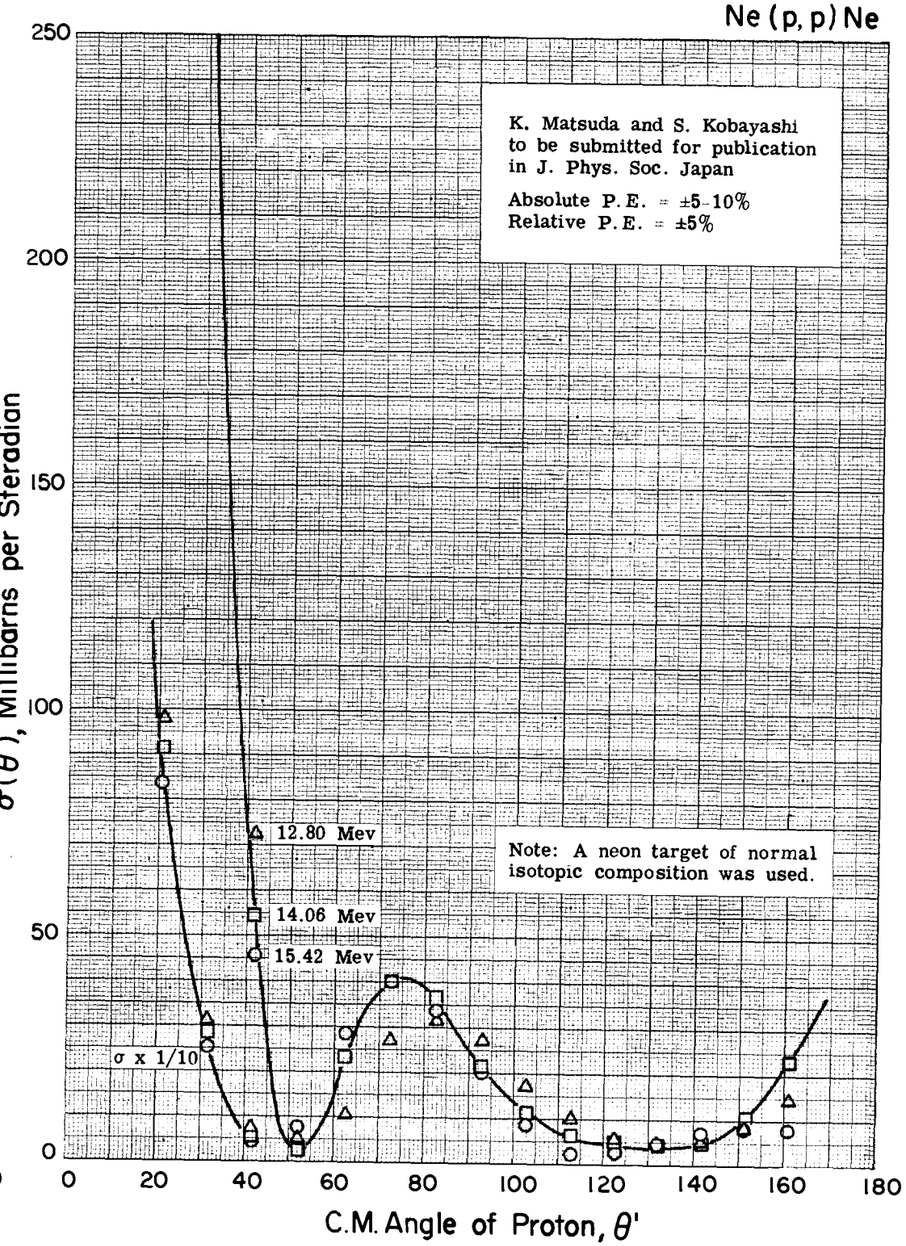


σ(θ), Millibarns per Steradian
250
200
150
100
50
0
σ × 1/10
0
20
40
60
80
100
120
140
160
180
Lab Angle of Proton, θ

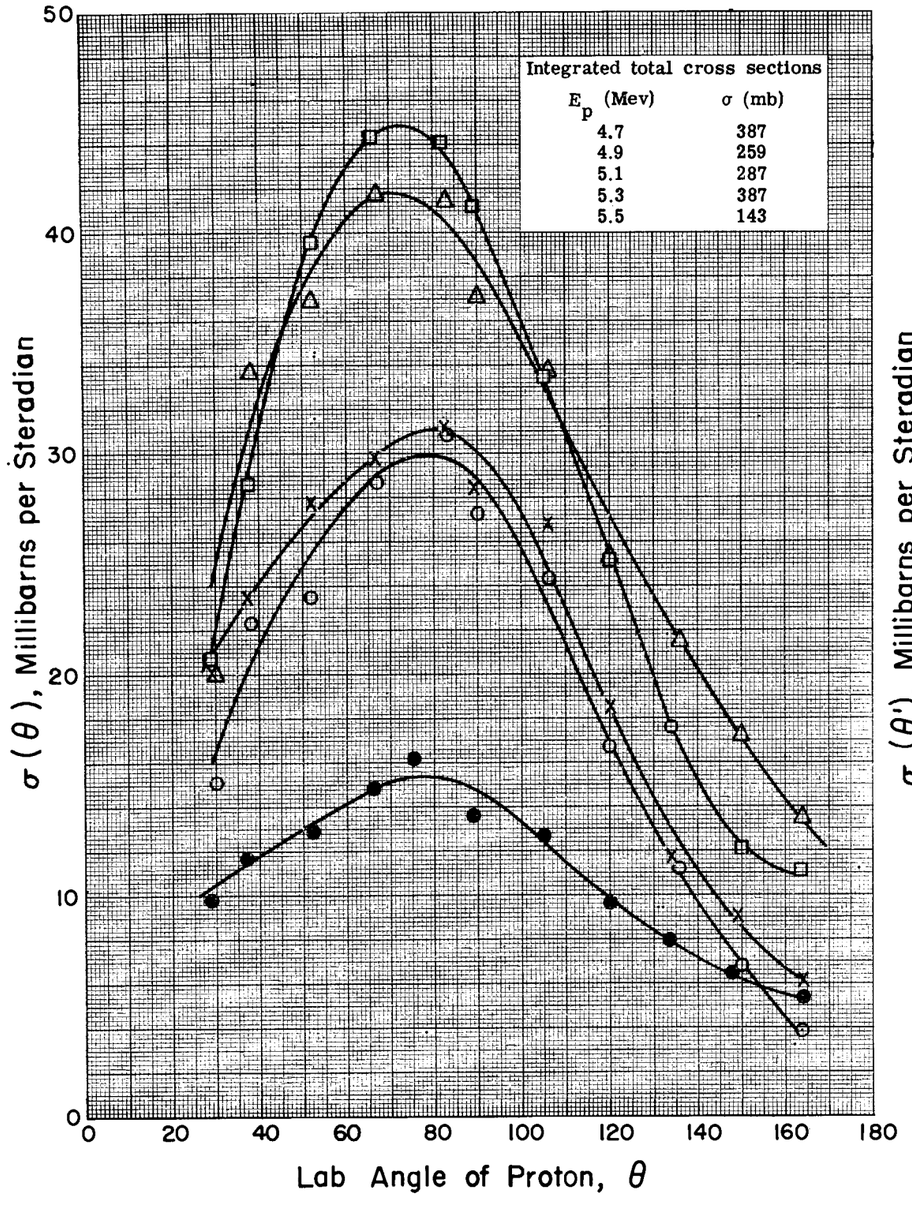


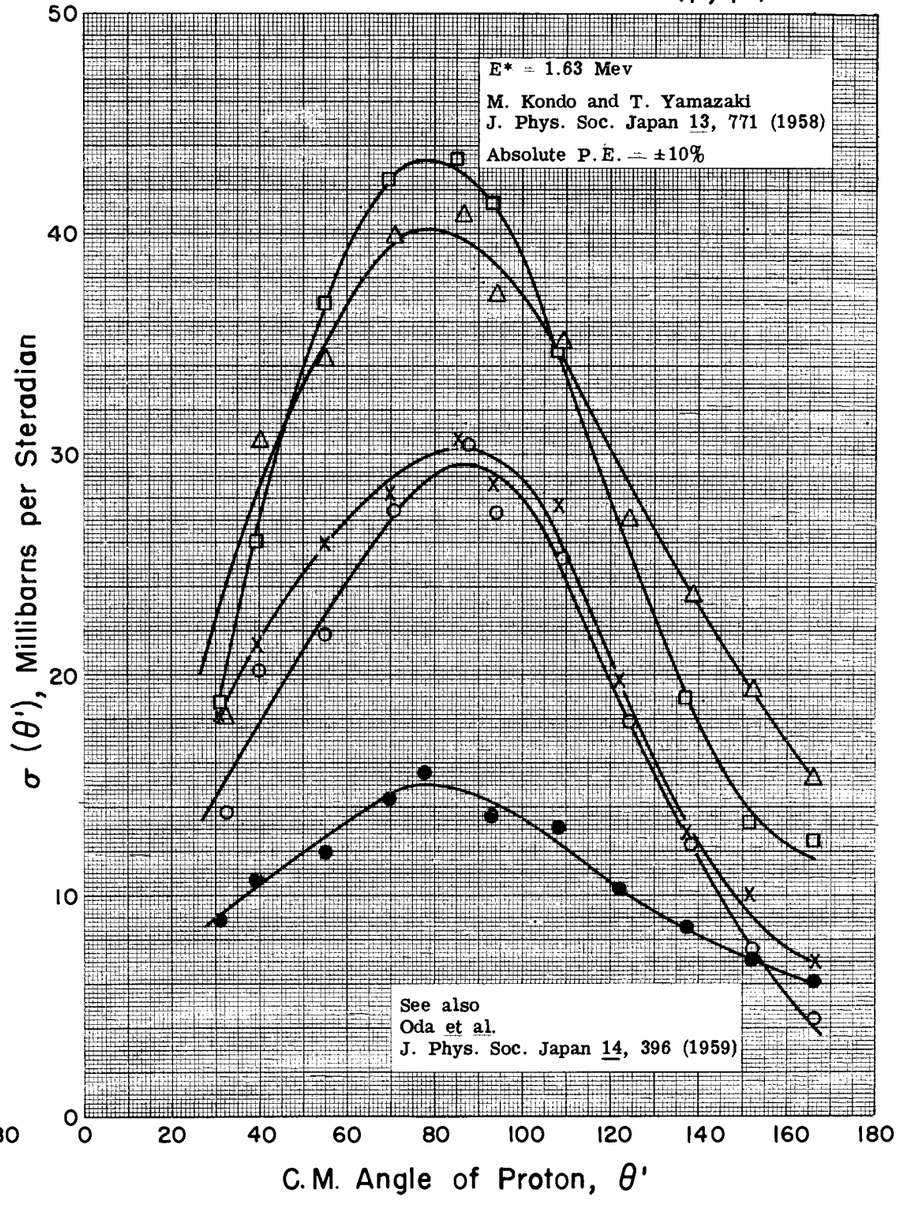
Ne(p,p)Ne
Proton energy 9.51 ± 0.03 Mev
Gibson, Prowse, and Rotblat
Proc. Roy. Soc. (London) A243, 237 (1957)
Absolute P.E. = ±5%
Note: A neon target of normal isotopic composition was used.
σ(θ'), Millibarns per Steradian
250
200
150
100
50
0
σ × 1/10
0
20
40
60
80
100
120
140
160
180
C.M. Angle of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

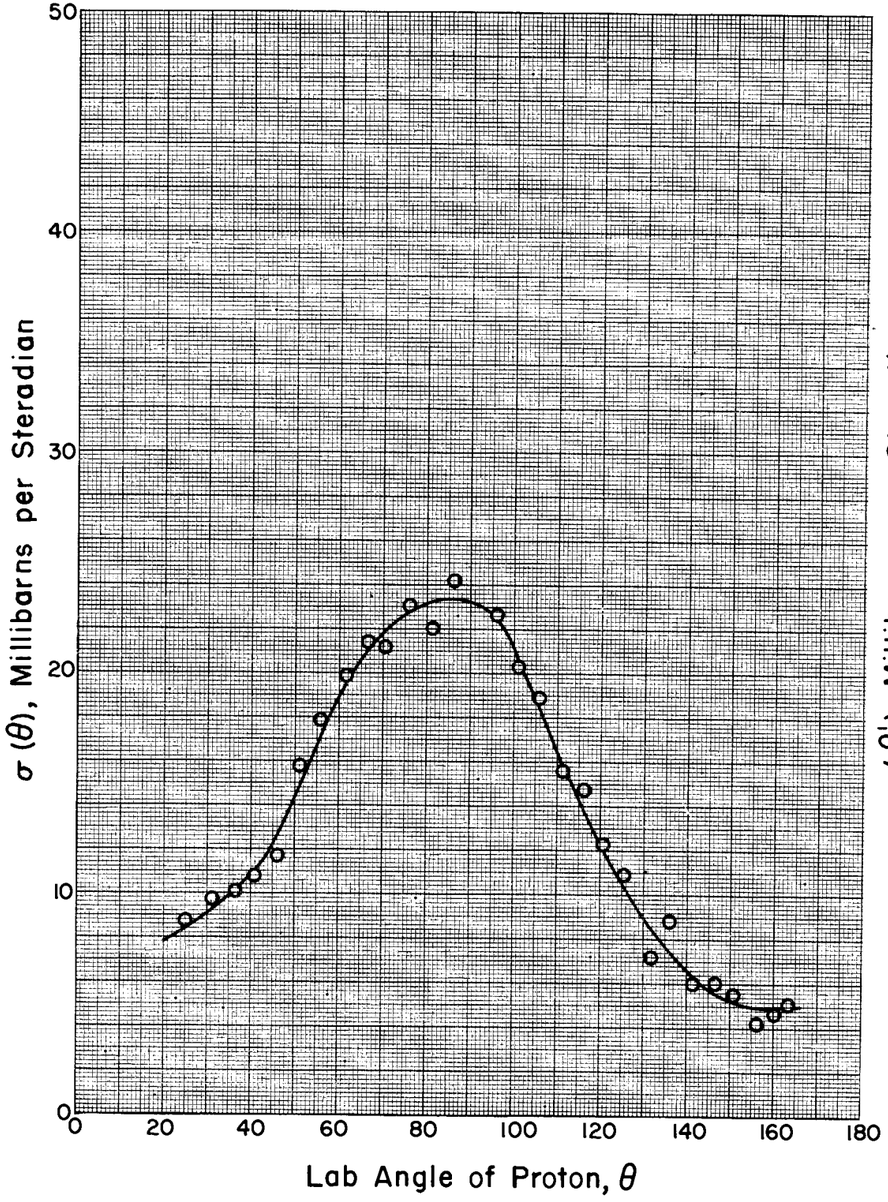

9.75 Mev
10.26 Mev
10.98 Mev
11.83 Mev
σ x 1/10
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
20
40
60
80
100
120
140
160
180
50
150
200
250

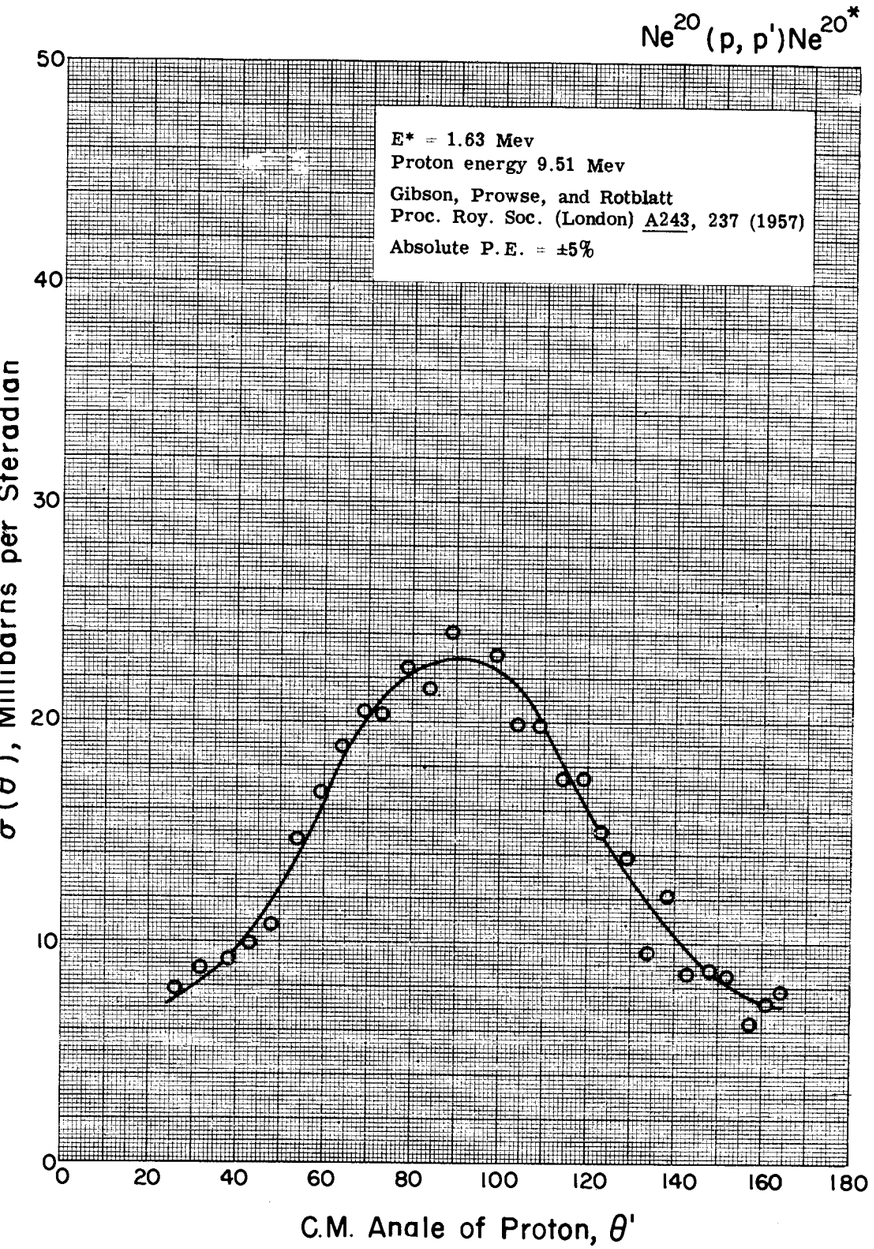

Ne (p, p) Ne
K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%
12.80 Mev
14.06 Mev
15.42 Mev
σ x 1/10
Note: A neon target of normal isotopic composition was used.
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
20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

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

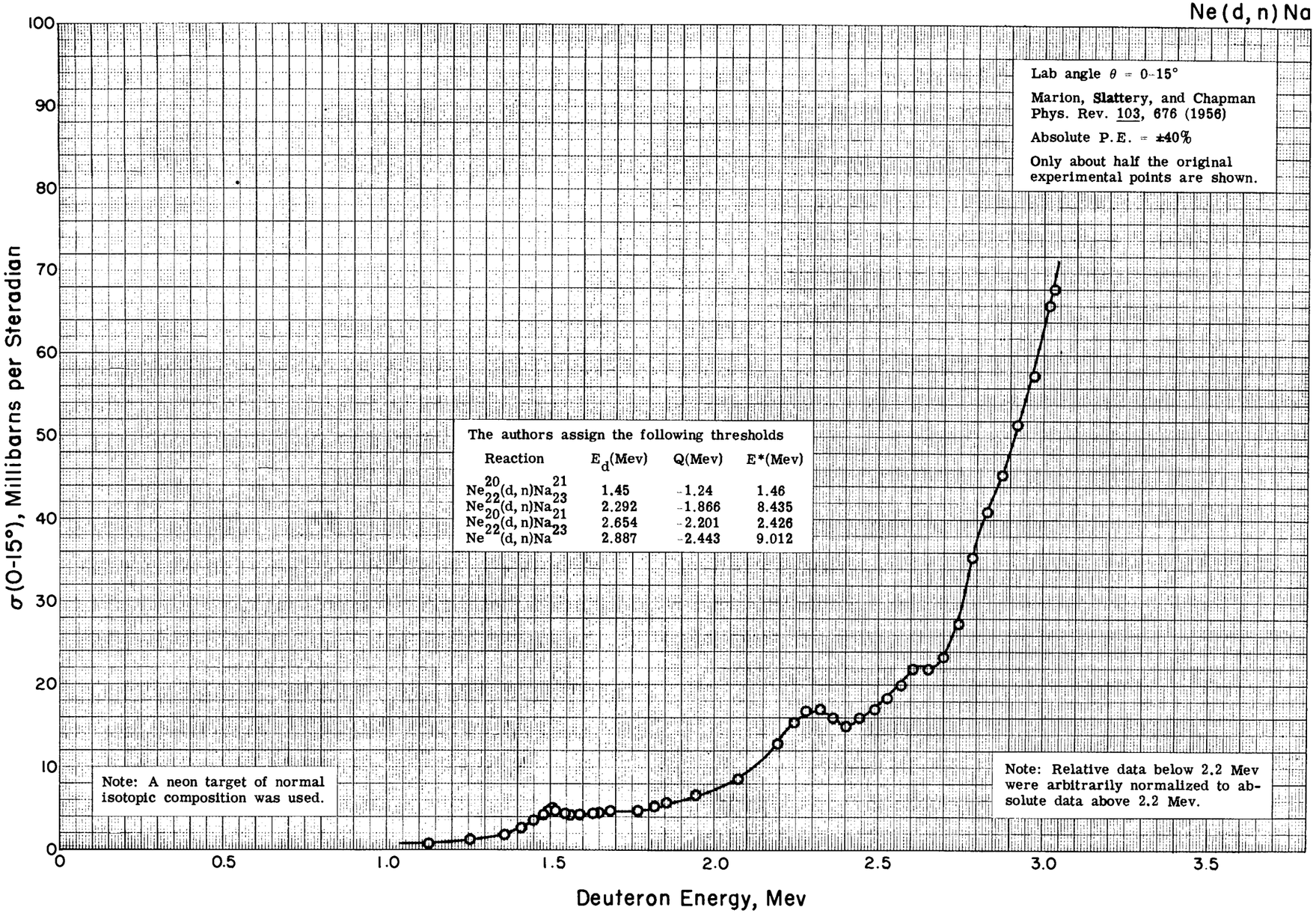

Integrated total cross sections
E_p (Mev) σ (mb)
4.7 387
4.9 259
5.1 287
5.3 387
5.5 143
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
10
20
30
40
50
0 20 40 60 80 100 120 140 160 180

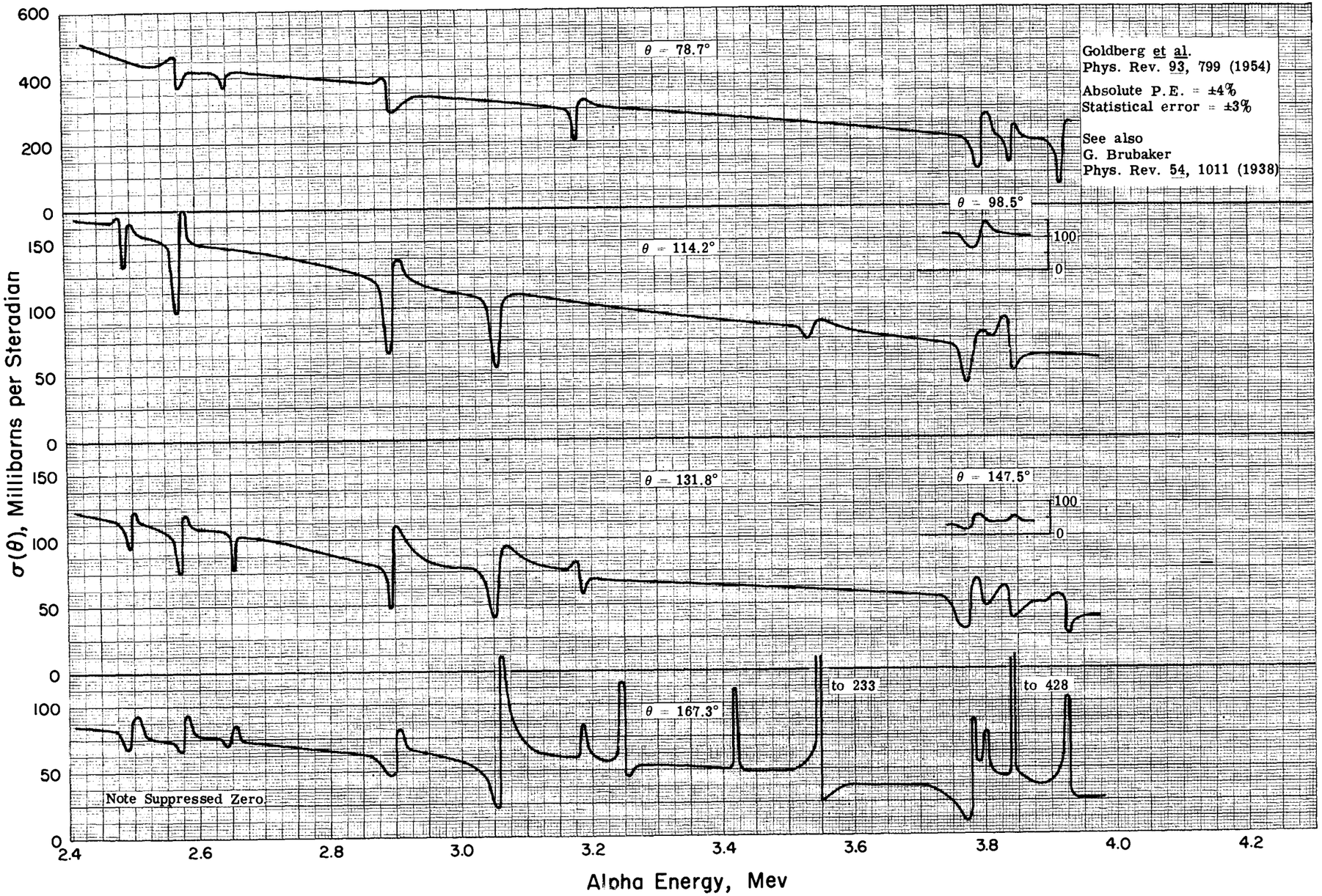

E* = 1.63 Mev
M. Kondo and T. Yamazaki
J. Phys. Soc. Japan 13, 771 (1958)
Absolute P.E. ≈ ±10%
See also
Oda et al.
J. Phys. Soc. Japan 14, 396 (1959)
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
10
20
30
40
50
0 20 40 60 80 100 120 140 160 180


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


Ne20 (p, p')Ne20*
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
0
20
40
60
80
100
120
140
160
180
σ (θ'), Millibarns per Steradian
C.M. Anale of Proton, θ'

Ne(d, n)Na

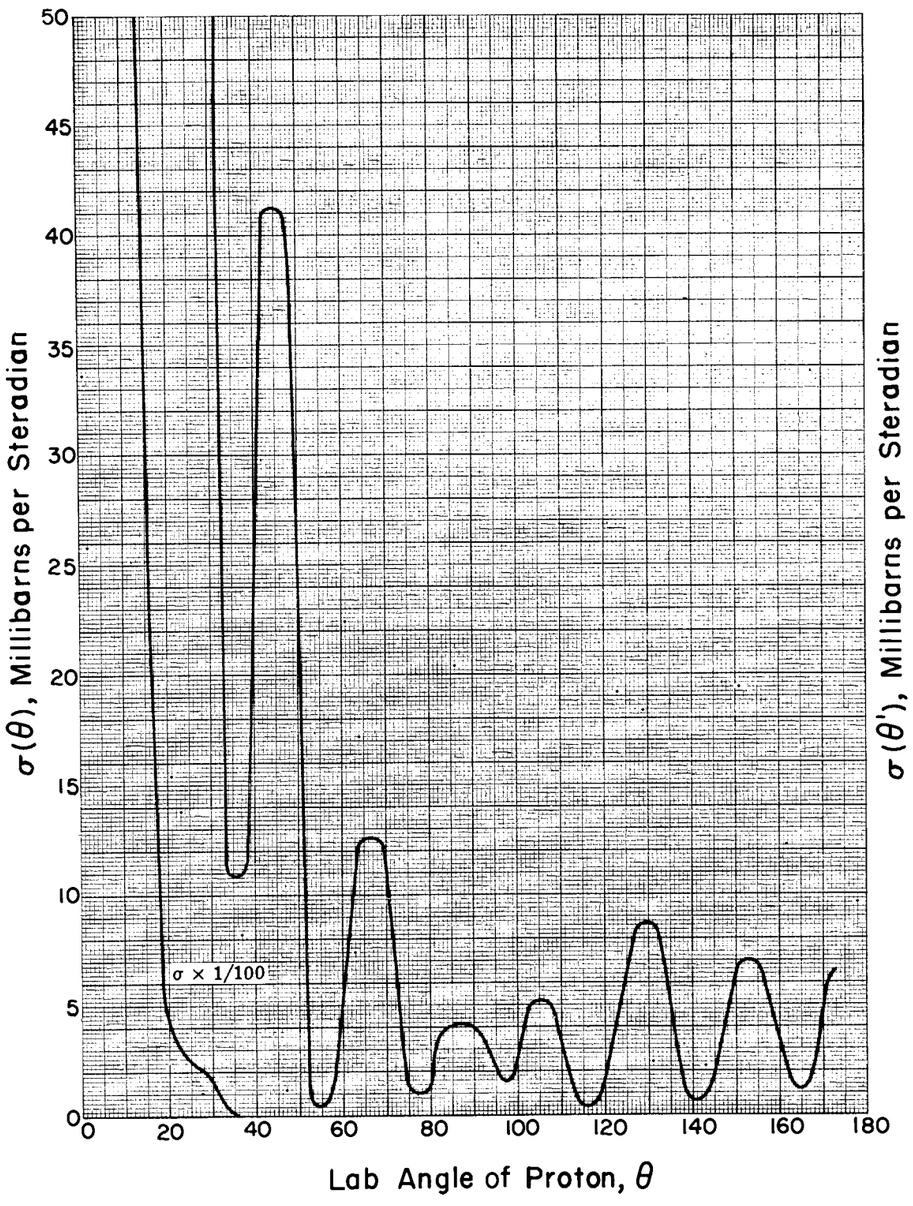

Lab angle θ = 0-15°
Marion, Slattery, and Chapman
Phys. Rev. 103, 676 (1956)
Absolute P.E. = ±40%
Only about half the original experimental points are shown.
The authors assign the following thresholds
Reaction | E_d(Mev) | Q(Mev) | E*(Mev)
$Ne^{20}(d, n)Na^{21}$ | 1.45 | -1.24 | 1.46
$Ne^{22}(d, n)Na^{23}$ | 2.292 | -1.866 | 8.435
$Ne^{20}(d, n)Na^{21}$ | 2.654 | -2.201 | 2.426
$Ne^{22}(d, n)Na^{23}$ | 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

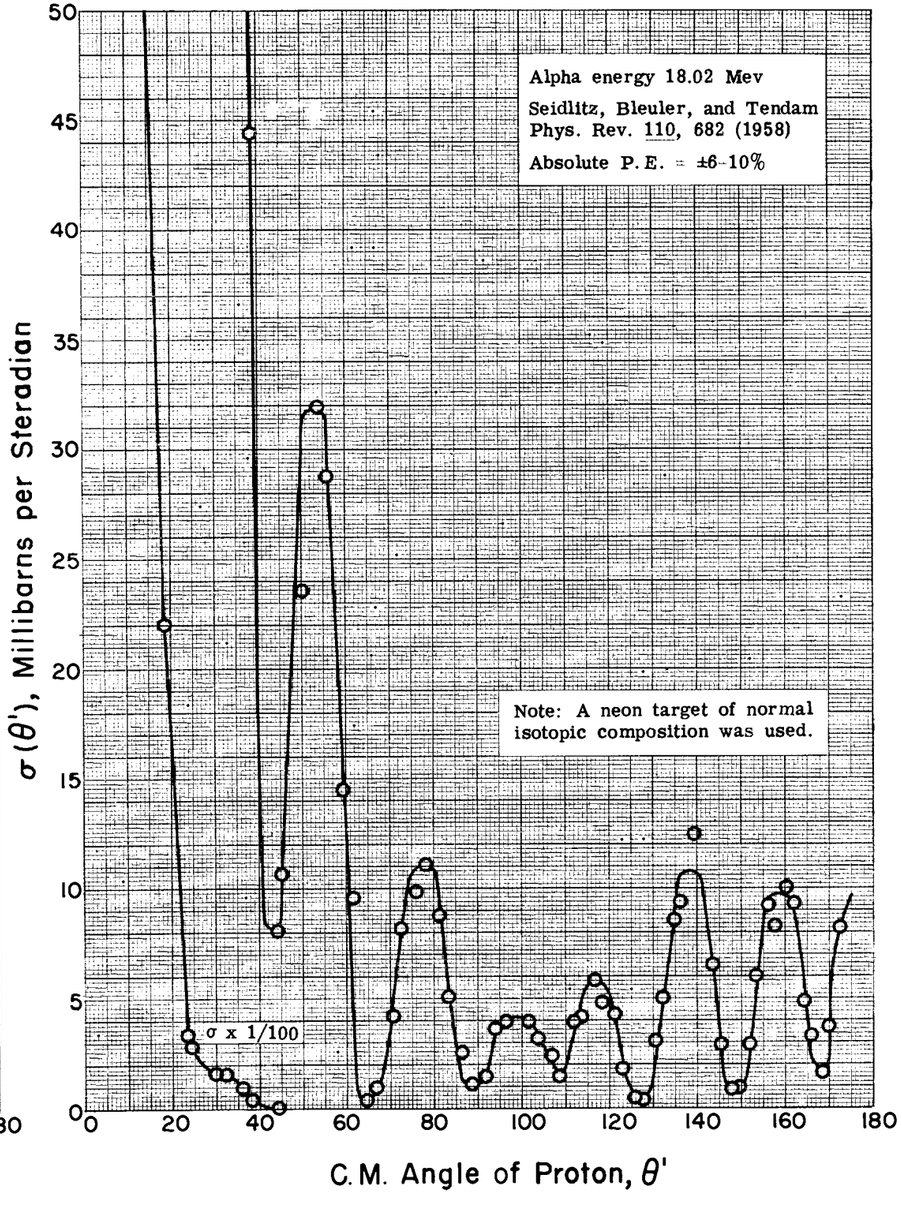


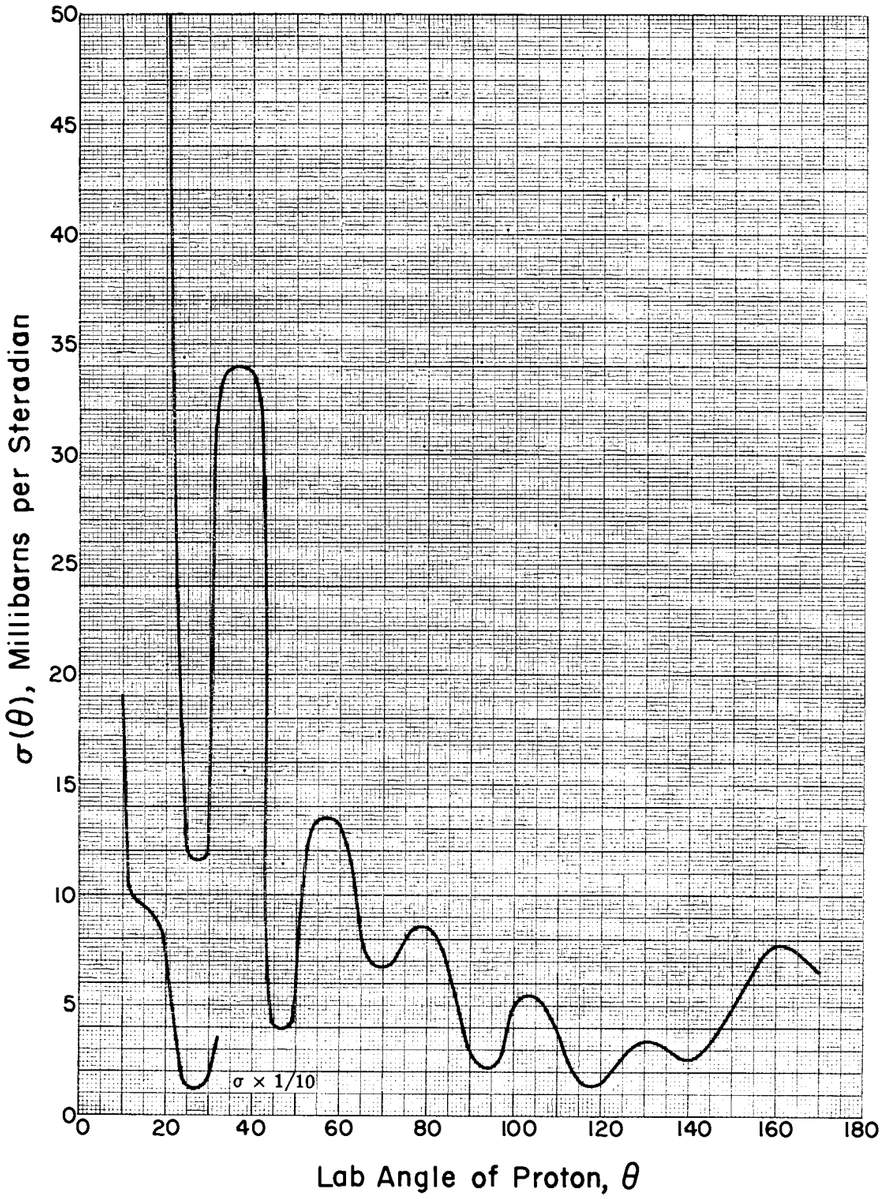
Goldberg et al.
Phys. Rev. 93, 799 (1954)

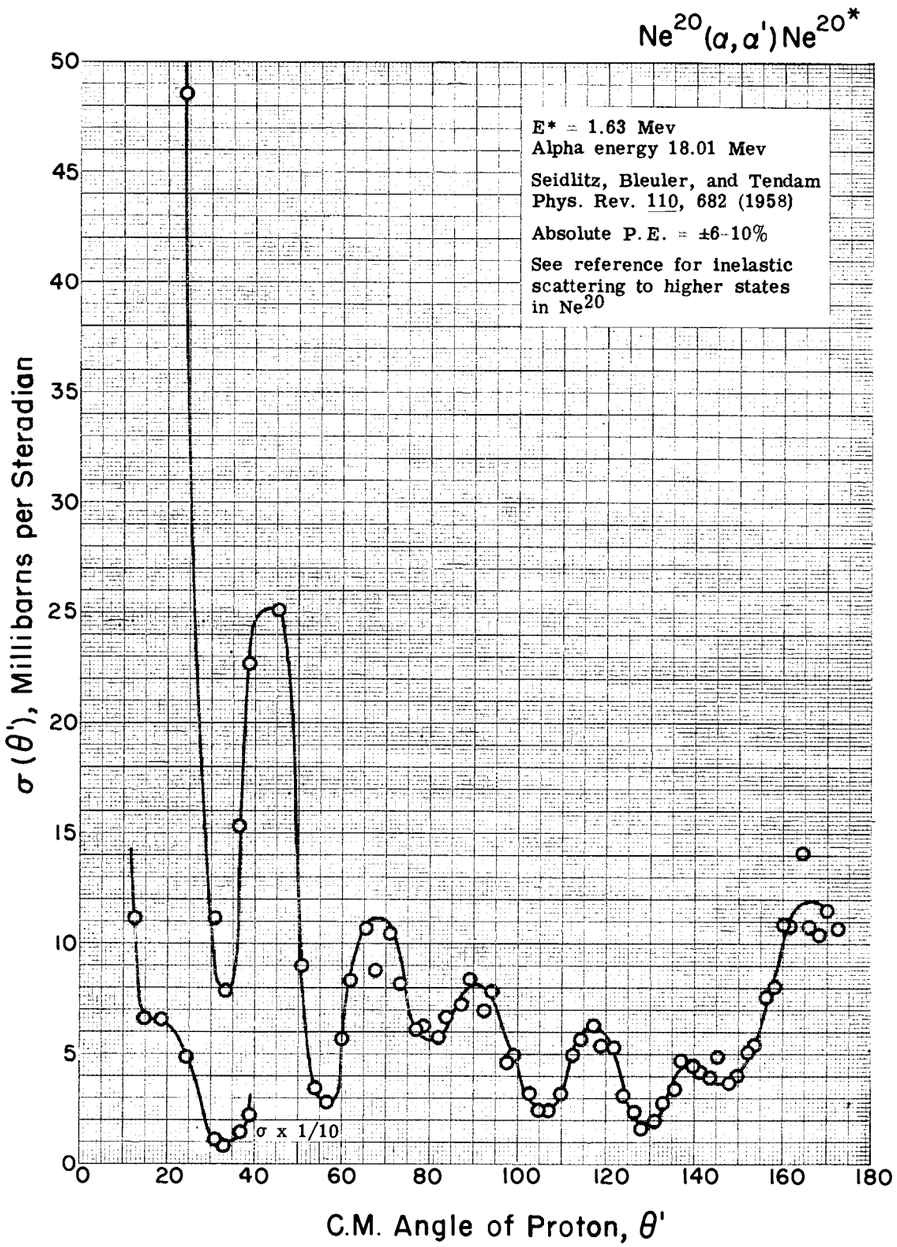
Absolute P.E. = ±4%
Statistical error = ±3%

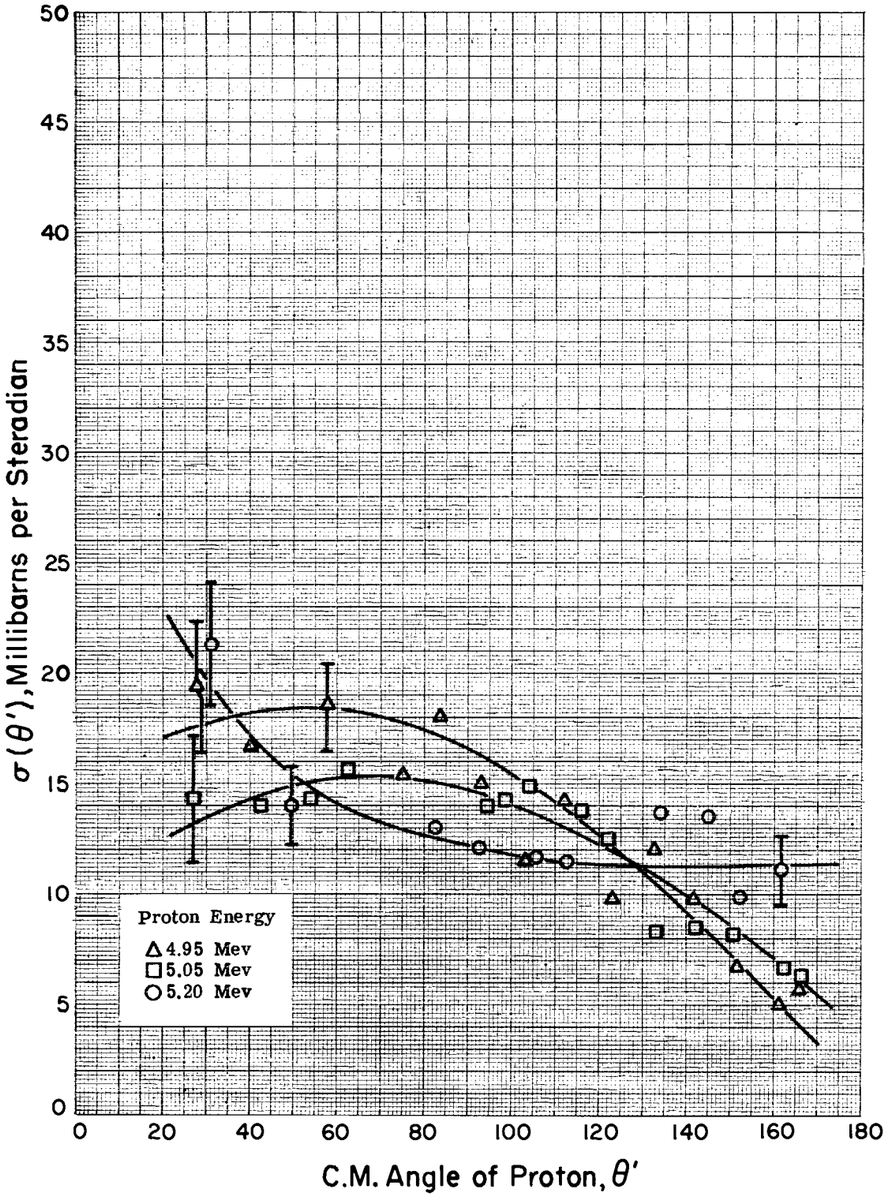
See also
G. Brubaker
Phys. Rev. 54, 1011 (1938)

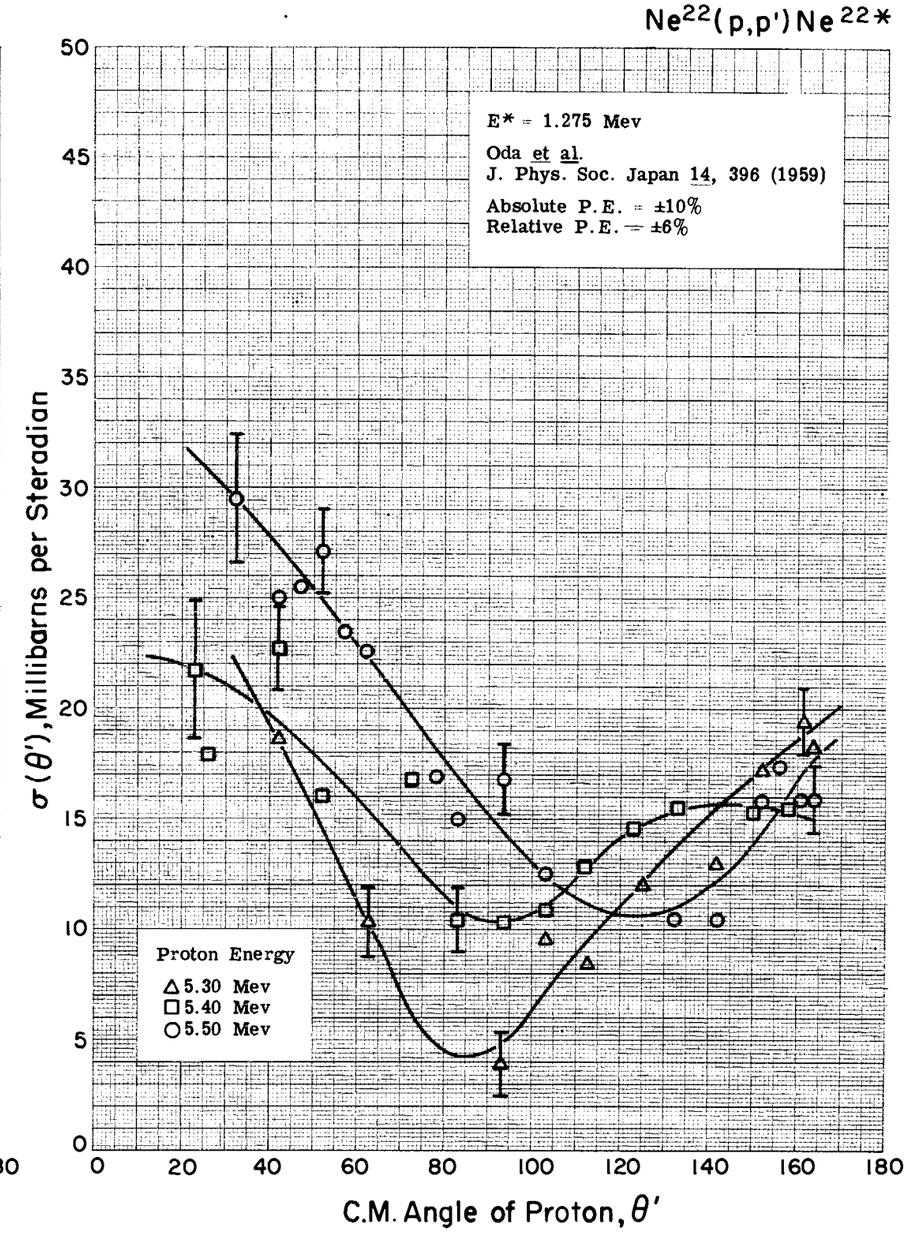

σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
σ × 1/100
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120
140
160
180


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.
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
σ x 1/100
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120
140
160
180

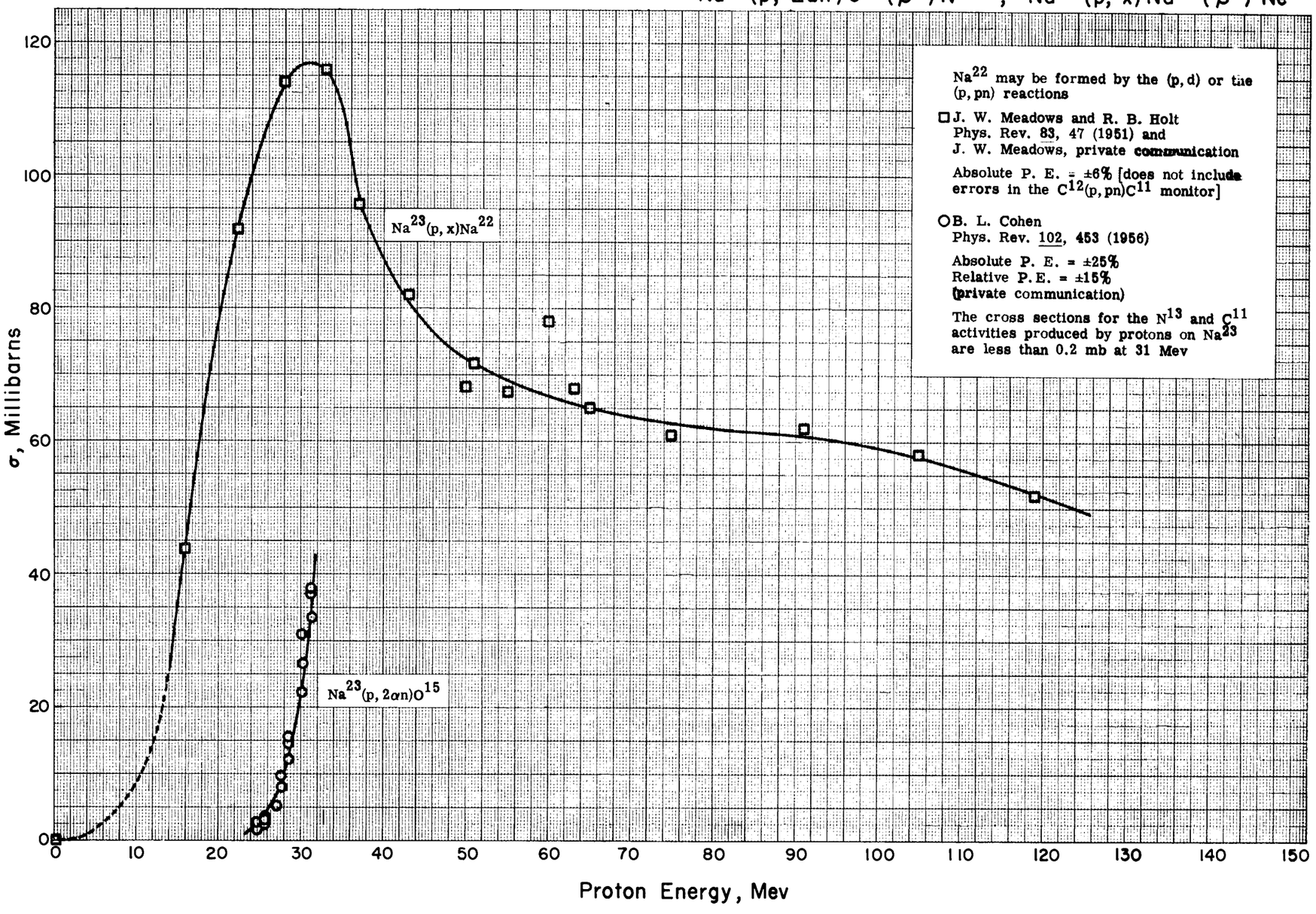

σ(θ), Millibarns per Steradian
50
45
40
35
30
25
20
15
10
5
0
σ × 1/10
0
20
40
60
80
100
120
140
160
180
Lab Angle of Proton, θ


Ne20(α, α')Ne20*
E* = 1.63 Mev
Alpha energy 18.01 Mev
Seidlitz, Bleuler, and Tendam
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±6-10%
See reference for inelastic scattering to higher states in Ne20
σ (θ'), Millibarns per Steradian
50
45
40
35
30
25
20
15
10
5
0
σ x 1/10
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Proton, θ'

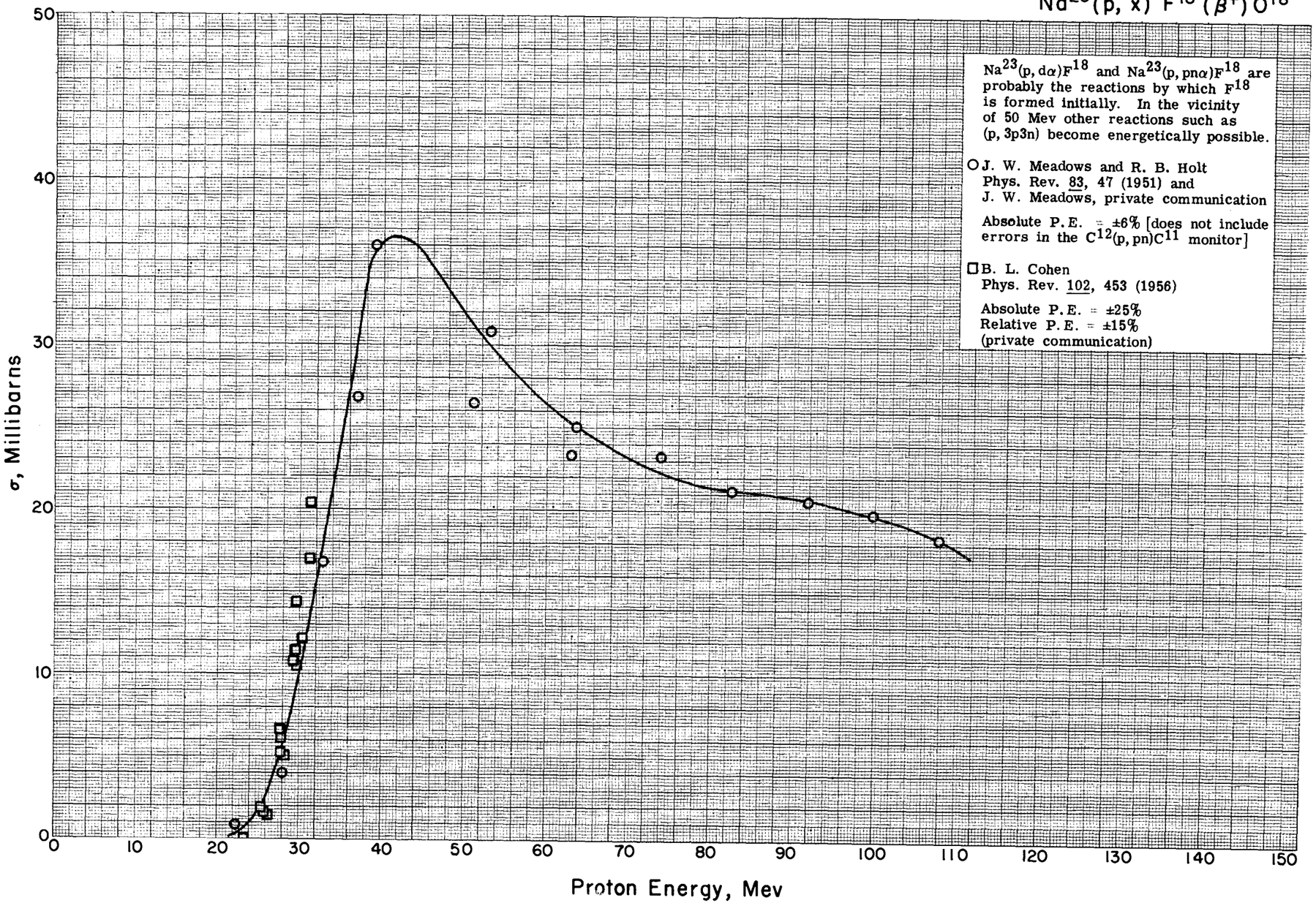

50
45
40
35
30
25
20
15
10
5
0
σ(θ'), Millibarns per Steradian
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'
Proton Energy
△ 4.95 Mev
□ 5.05 Mev
○ 5.20 Mev


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%
50
45
40
35
30
25
20
15
10
5
0
σ(θ'), Millibarns per Steradian
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'
Proton Energy
△ 5.30 Mev
□ 5.40 Mev
○ 5.50 Mev

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



$Na^{23}(p, x)\ F^{18}\ (\beta^+)\ O^{18}$



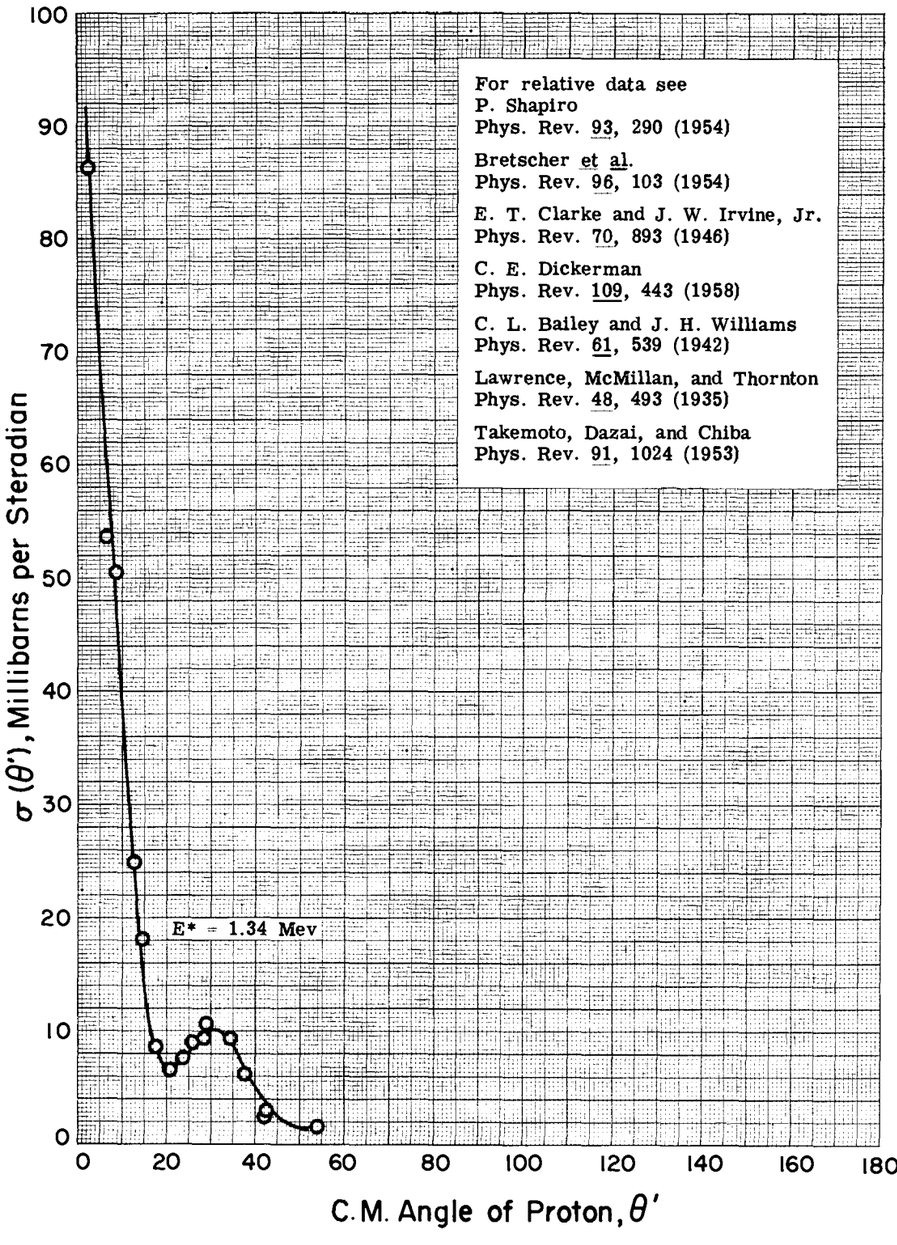
$Na^{23}(p, d\alpha)F^{18}$ and $Na^{23}(p, pn\alpha)F^{18}$ are probably the reactions by which F^{18} is formed initially. In the vicinity of 50 Mev other reactions such as (p, 3p3n) become energetically possible.

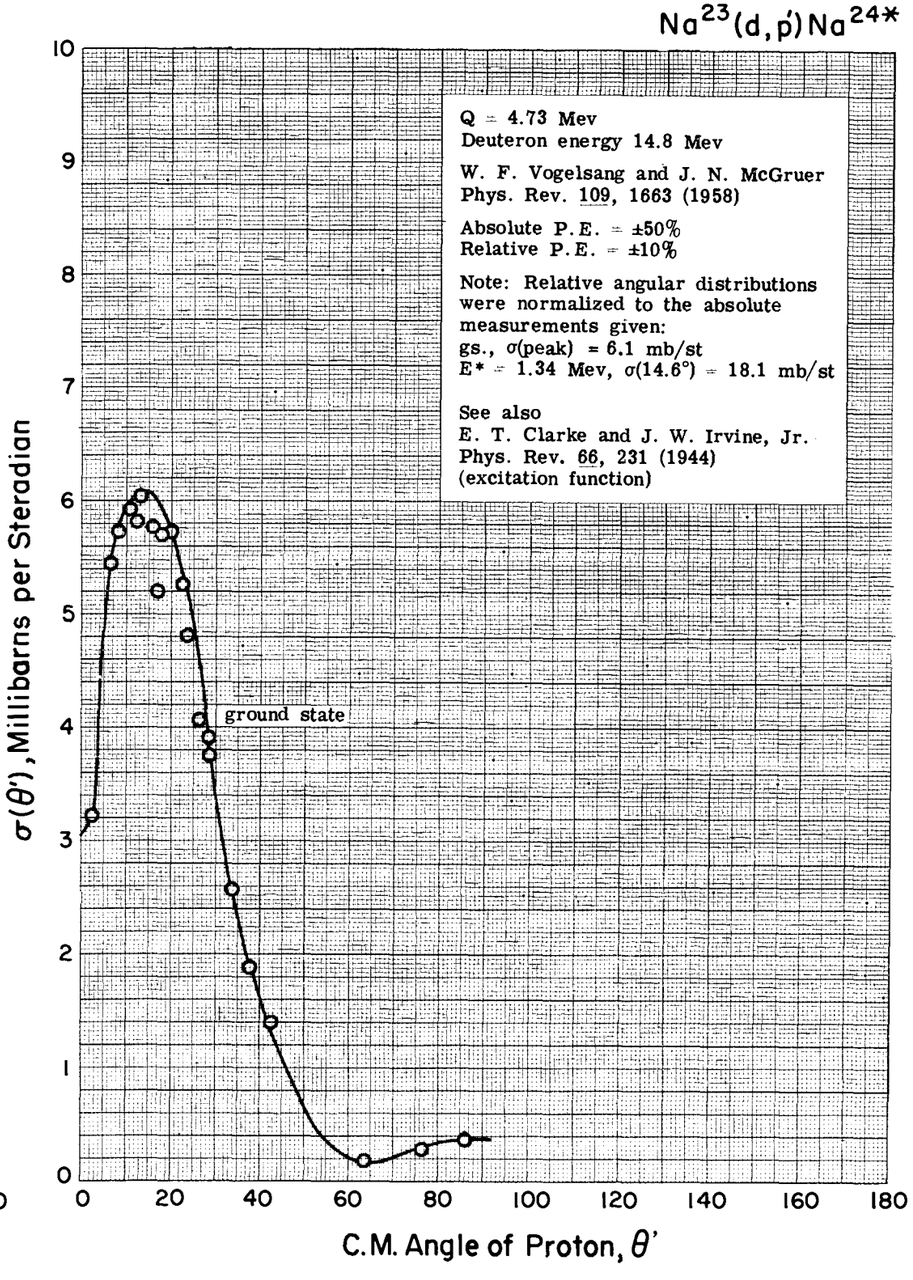
○ J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951) and
J. W. Meadows, private communication

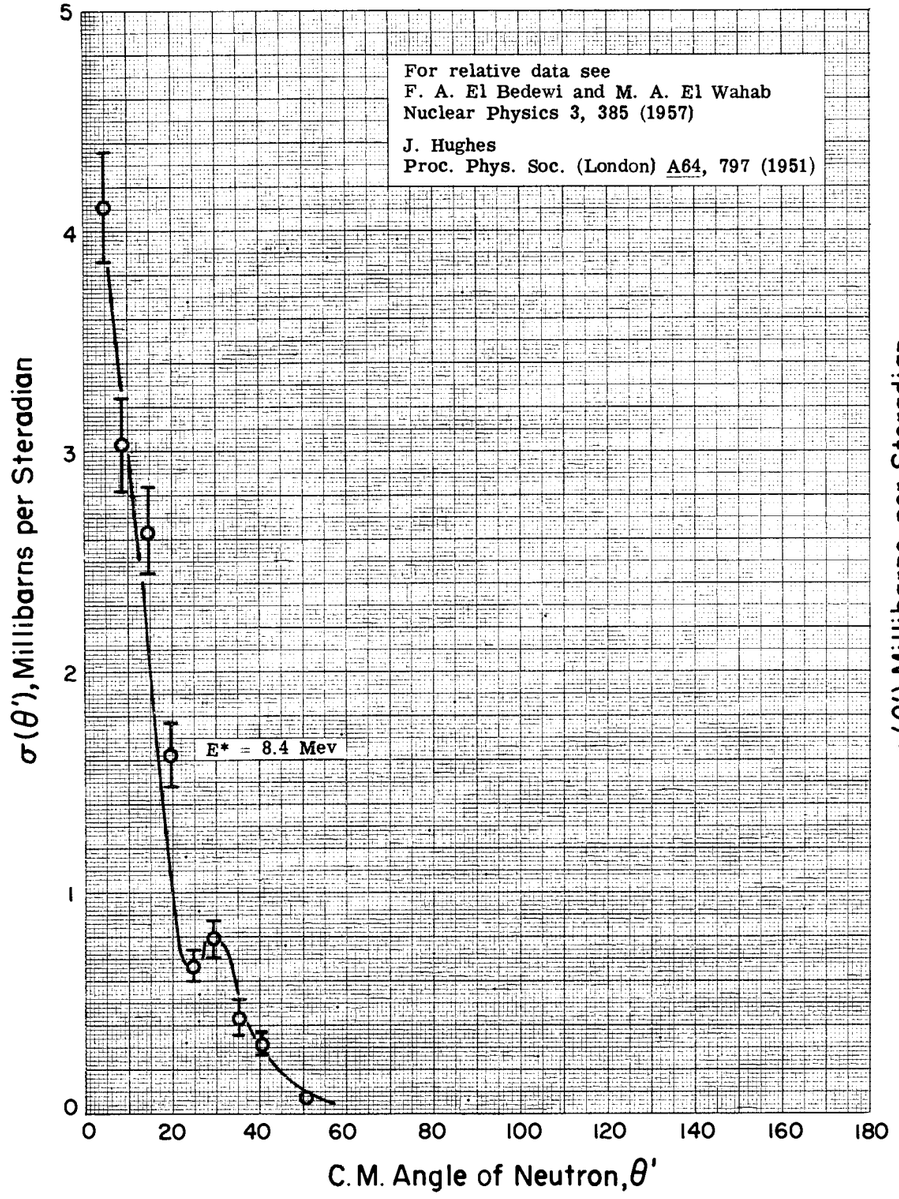
Absolute P.E. = ±6% [does not include errors in the $C^{12}(p, pn)C^{11}$ monitor]

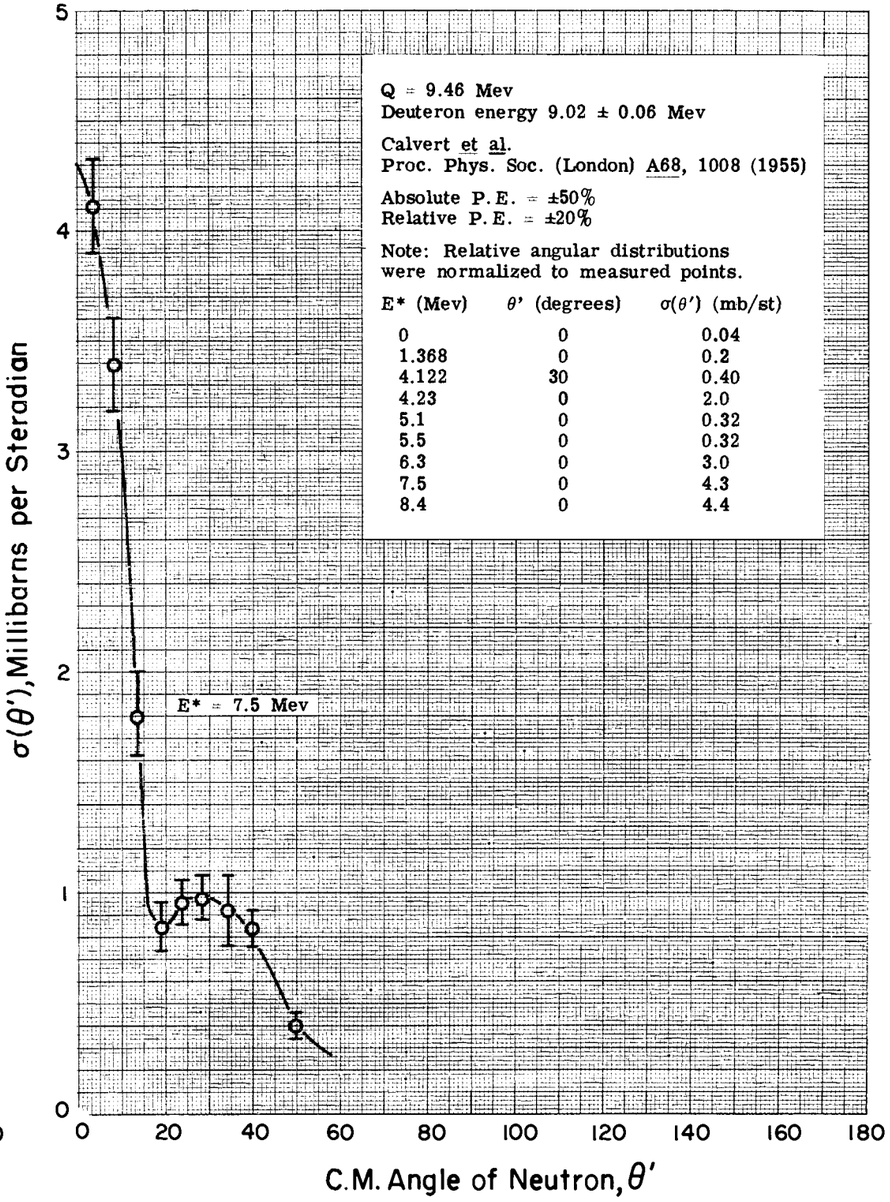
□ B. L. Cohen
Phys. Rev. 102, 453 (1956)

Absolute P.E. = ±25%
Relative P.E. = ±15%
(private communication)

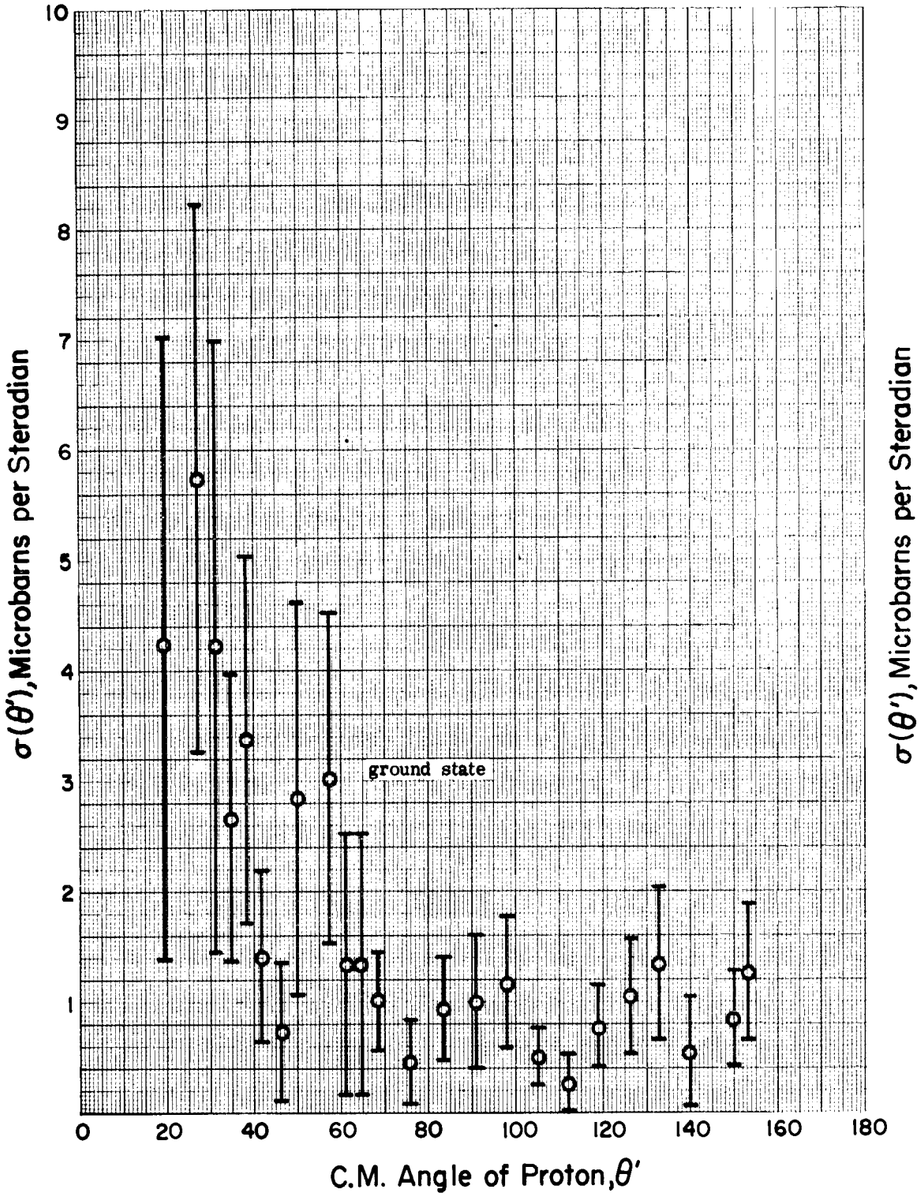

For relative data see
P. Shapiro
Phys. Rev. 93, 290 (1954)
Bretscher et al.
Phys. Rev. 96, 103 (1954)
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 70, 893 (1946)
C. E. Dickerman
Phys. Rev. 109, 443 (1958)
C. L. Bailey and J. H. Williams
Phys. Rev. 61, 539 (1942)
Lawrence, McMillan, and Thornton
Phys. 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'

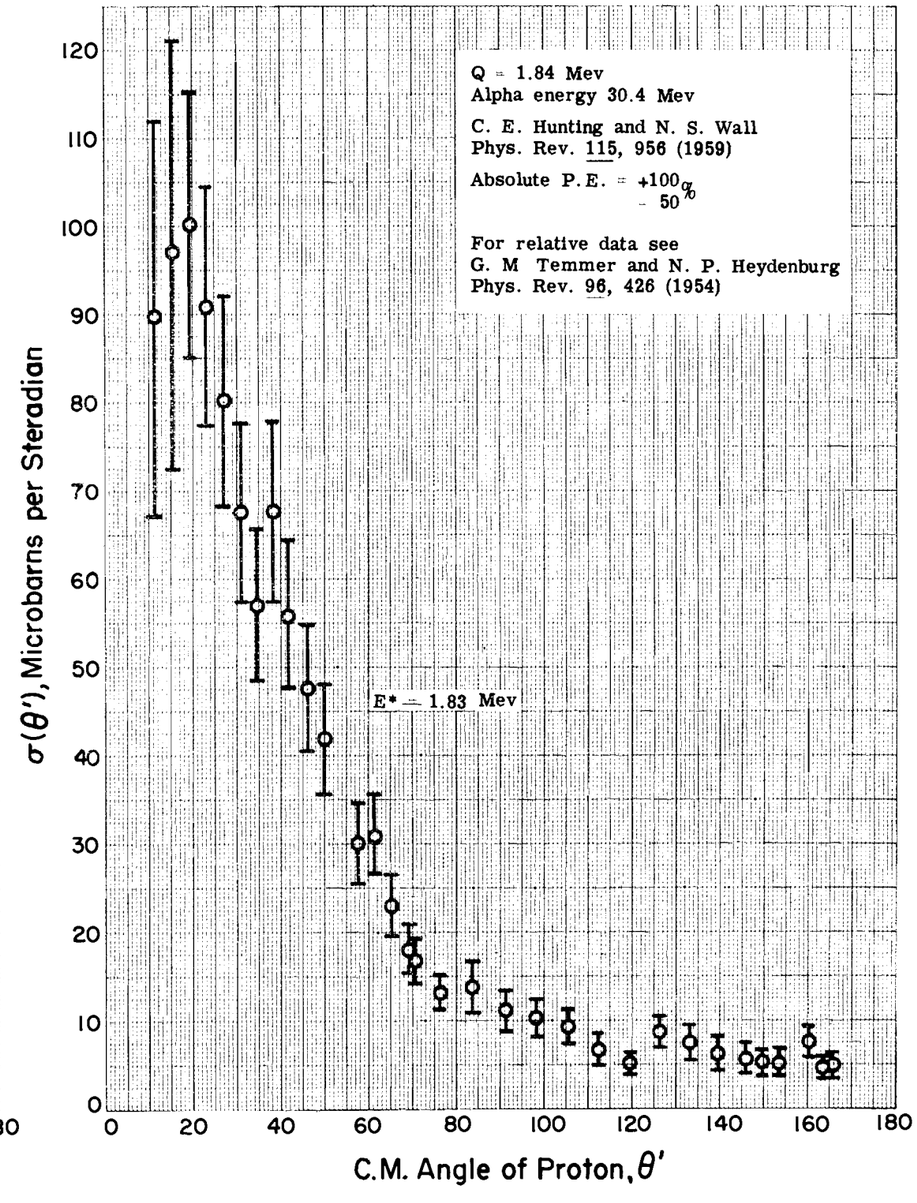

Na23(d,p')Na24*
Q = 4.73 Mev
Deuteron energy 14.8 Mev
W. F. Vogelsang and J. N. McGruer
Phys. Rev. 109, 1663 (1958)
Absolute P.E. = ±50%
Relative P.E. = ±10%
Note: Relative angular distributions were normalized to the absolute measurements given:
gs., σ(peak) = 6.1 mb/st
E* = 1.34 Mev, σ(14.6°) = 18.1 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'

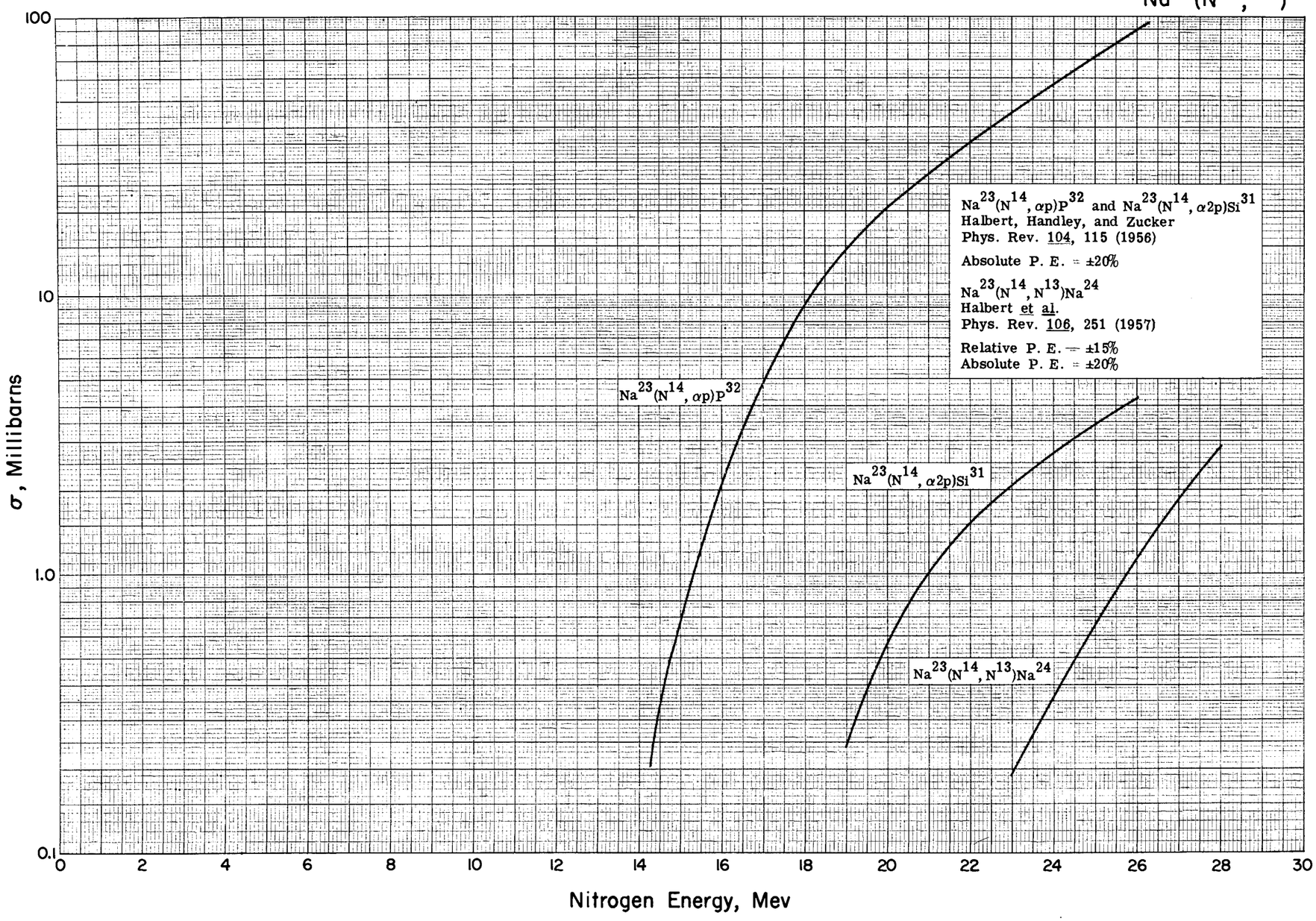


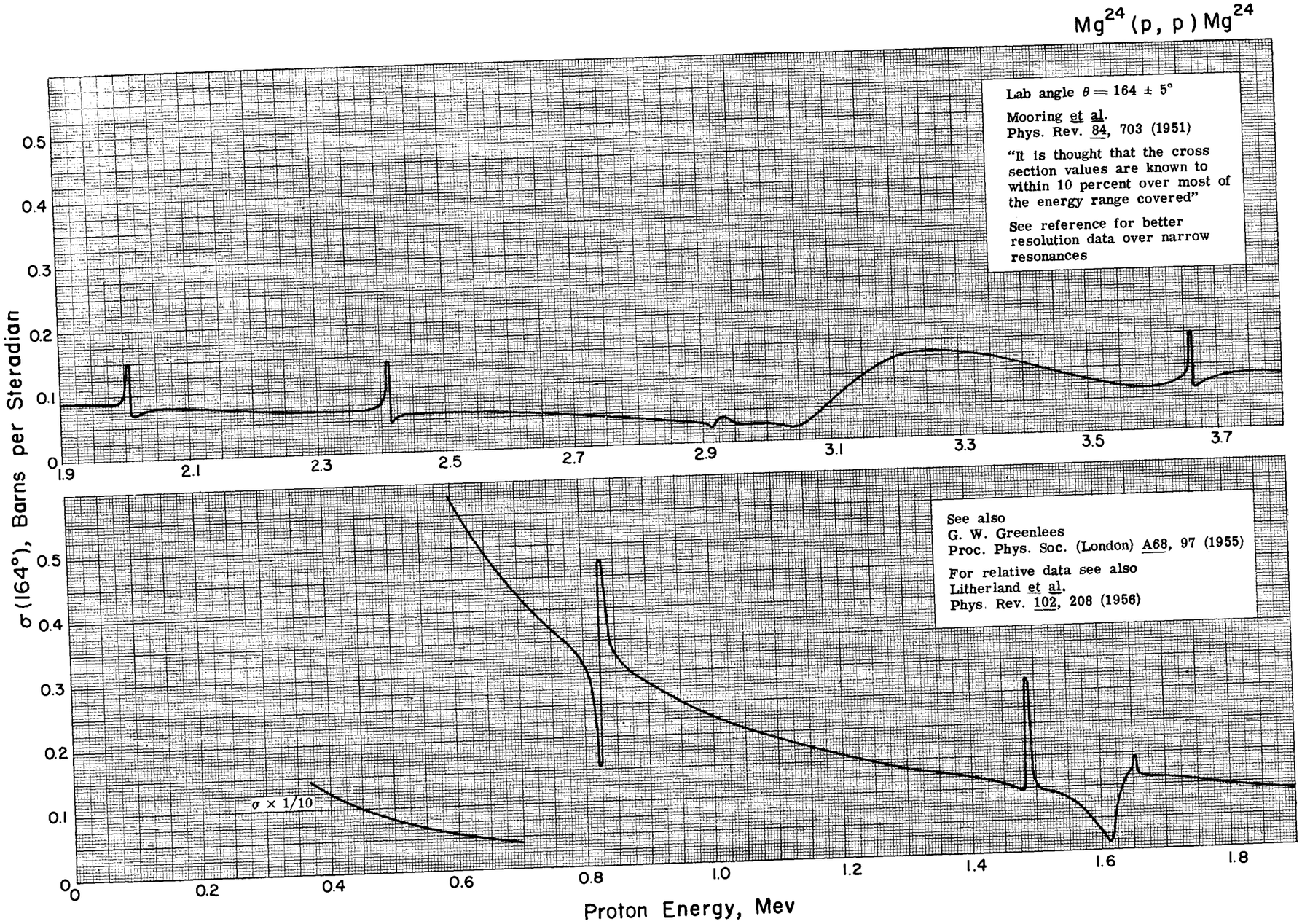


E* (Mev)	θ' (degrees)	σ(θ') (mb/st)
0	0	0.04
1.368	0	0.2
4.122	30	0.40
4.23	0	2.0
5.1	0	0.32
5.5	0	0.32
6.3	0	3.0
7.5	0	4.3
8.4	0	4.4

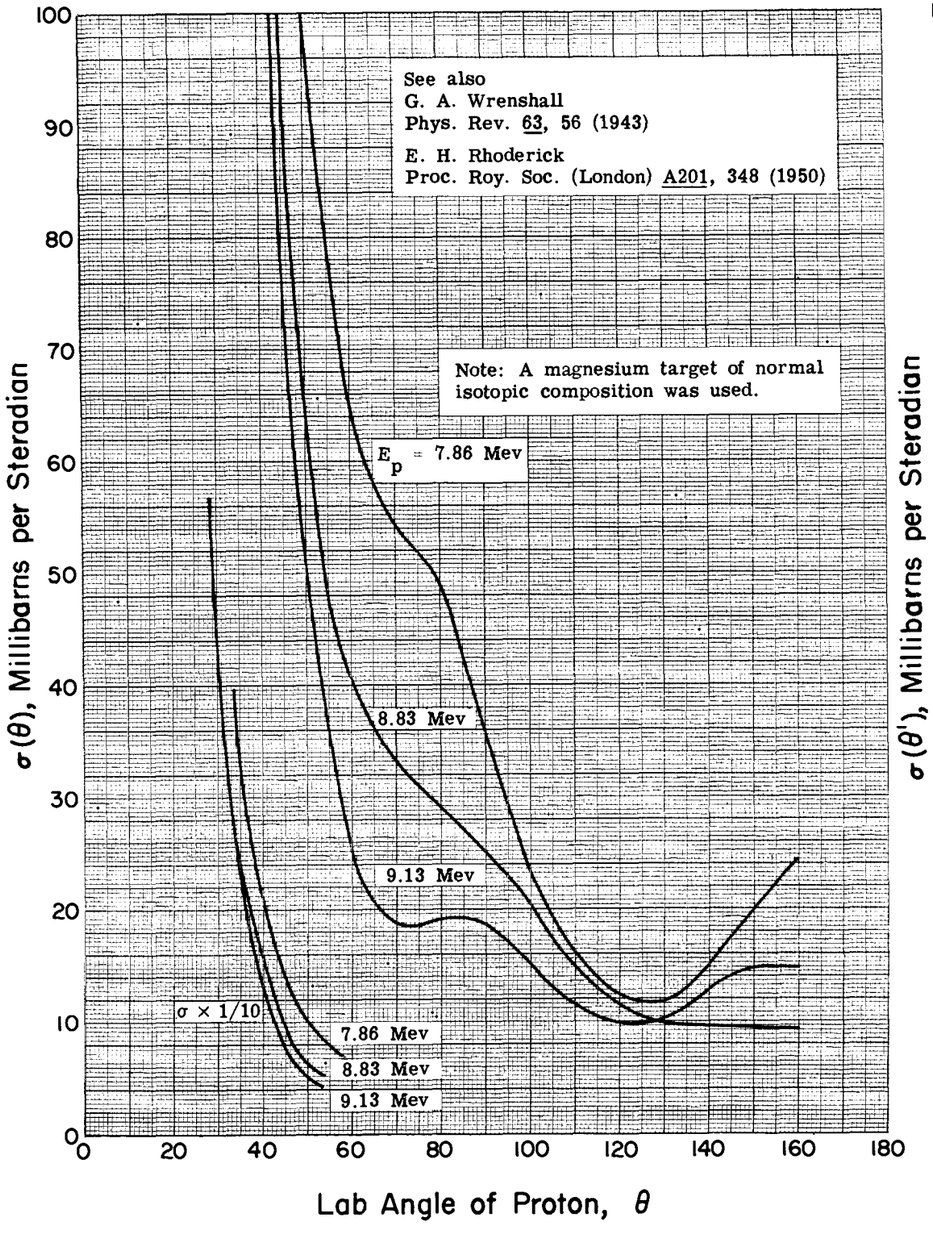

σ(θ'), Microbarns per Steradian
C.M. Angle of Proton, θ'
ground state

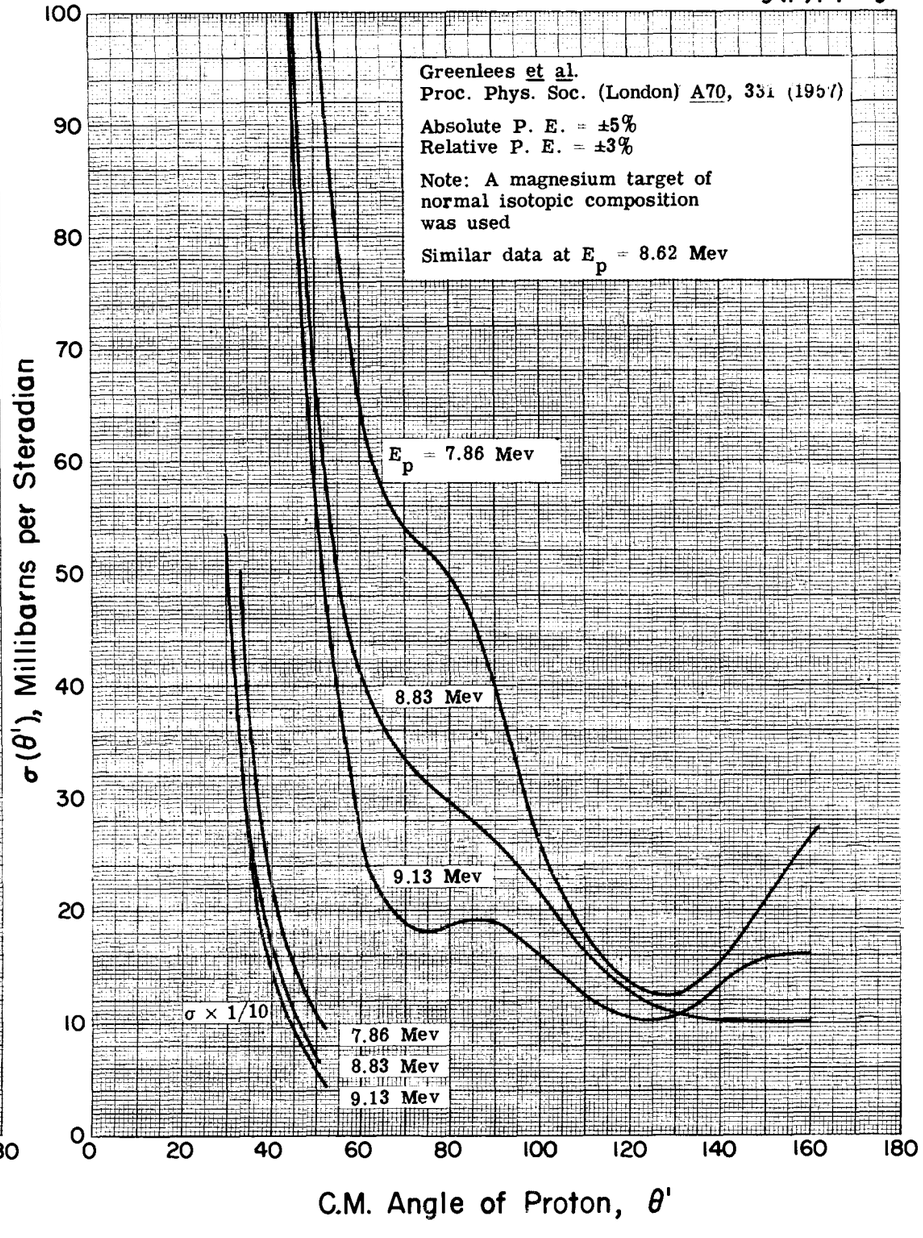

Q = 1.84 Mev
Alpha energy 30.4 Mev
C. E. Hunting and N. S. Wall
Phys. Rev. 115, 956 (1959)
Absolute P.E. = +100% −50%
For relative data see
G. M Temmer and N. P. Heydenburg
Phys. Rev. 96, 426 (1954)
E* = 1.83 Mev
σ(θ'), Microbarns per Steradian
C.M. Angle of Proton, θ'

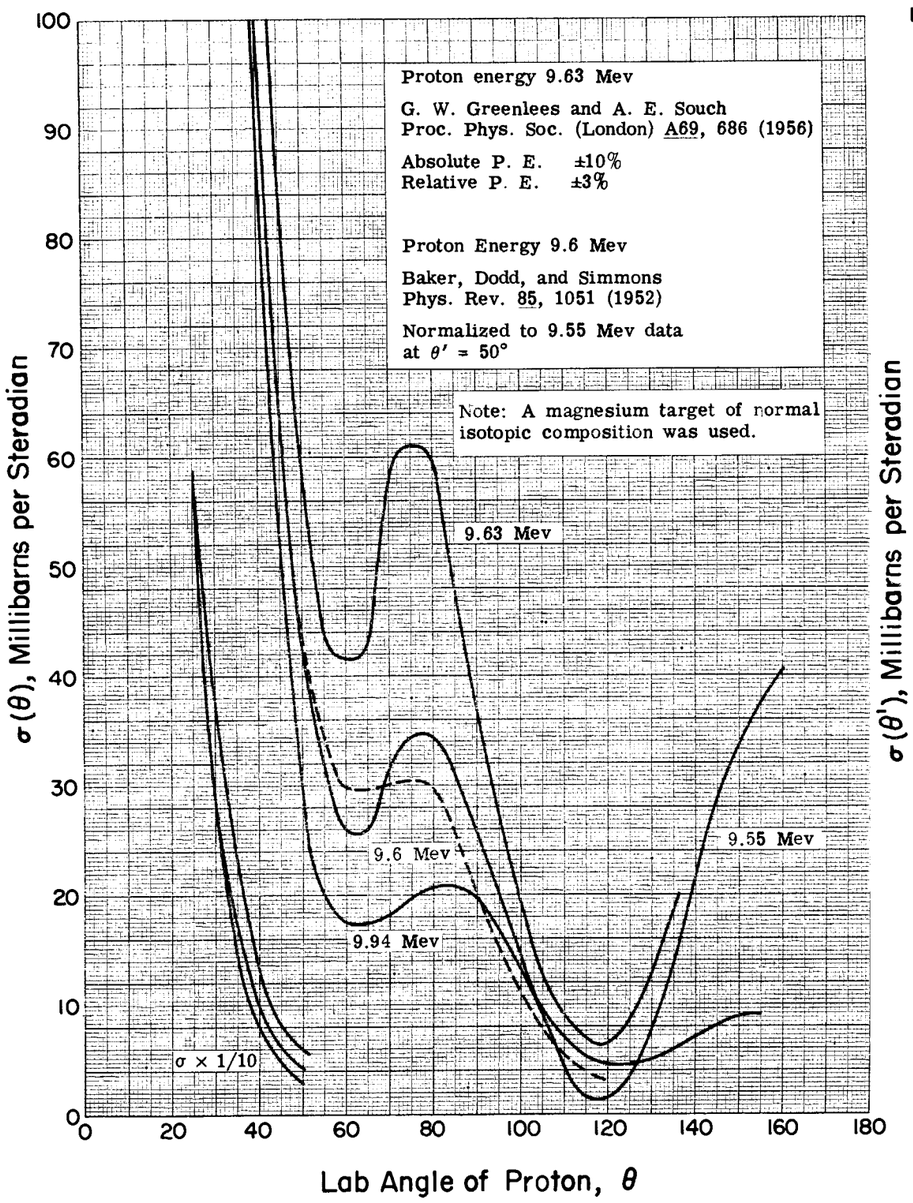

$Na^{23}(N^{14}, \quad)$
$Na^{23}(N^{14}, \alpha p)P^{32}$ and $Na^{23}(N^{14}, \alpha 2p)Si^{31}$
Halbert, Handley, and Zucker
Phys. Rev. 104, 115 (1956)
Absolute P. E. = ±20%
$Na^{23}(N^{14}, N^{13})Na^{24}$
Halbert et al.
Phys. Rev. 106, 251 (1957)
Relative P. E. = ±15%
Absolute P. E. = ±20%
$Na^{23}(N^{14}, \alpha p)P^{32}$
$Na^{23}(N^{14}, \alpha 2p)Si^{31}$
$Na^{23}(N^{14}, N^{13})Na^{24}$
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

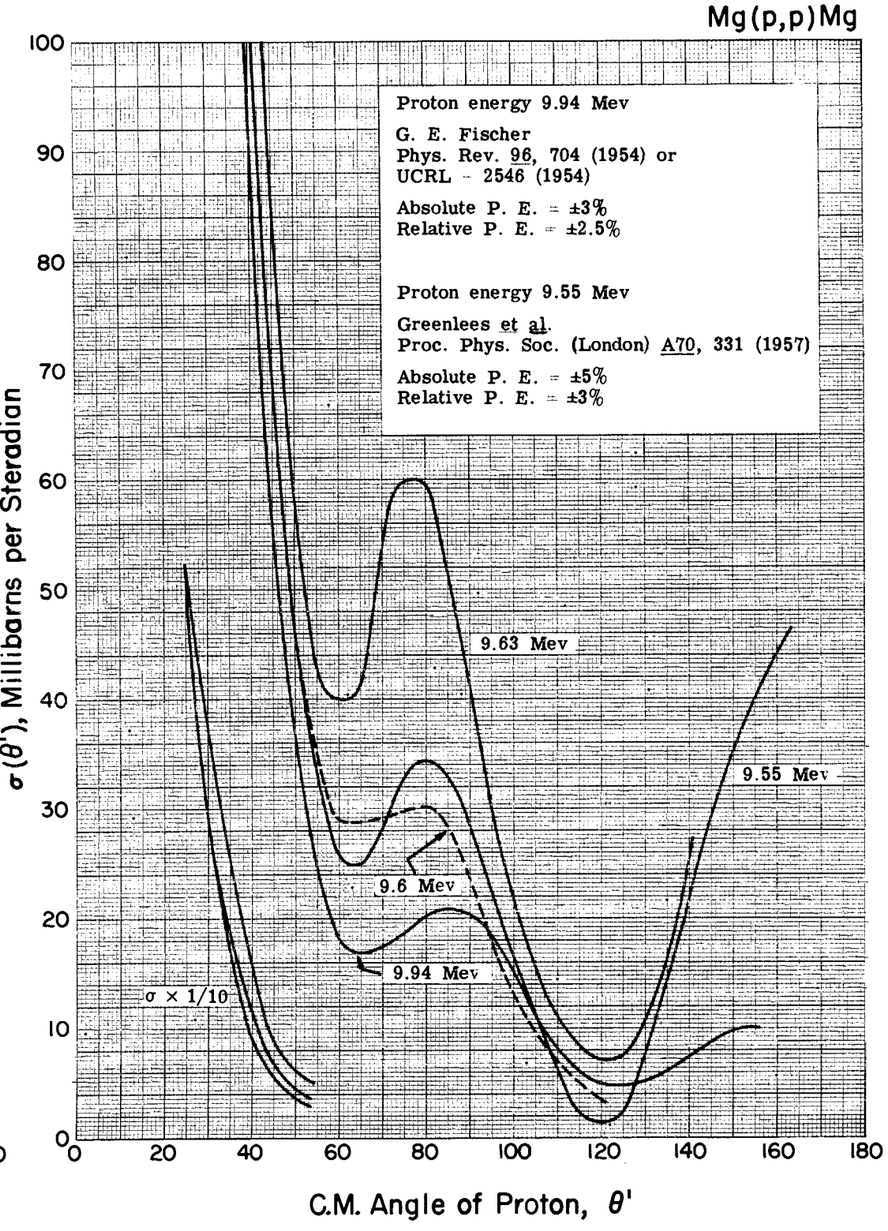


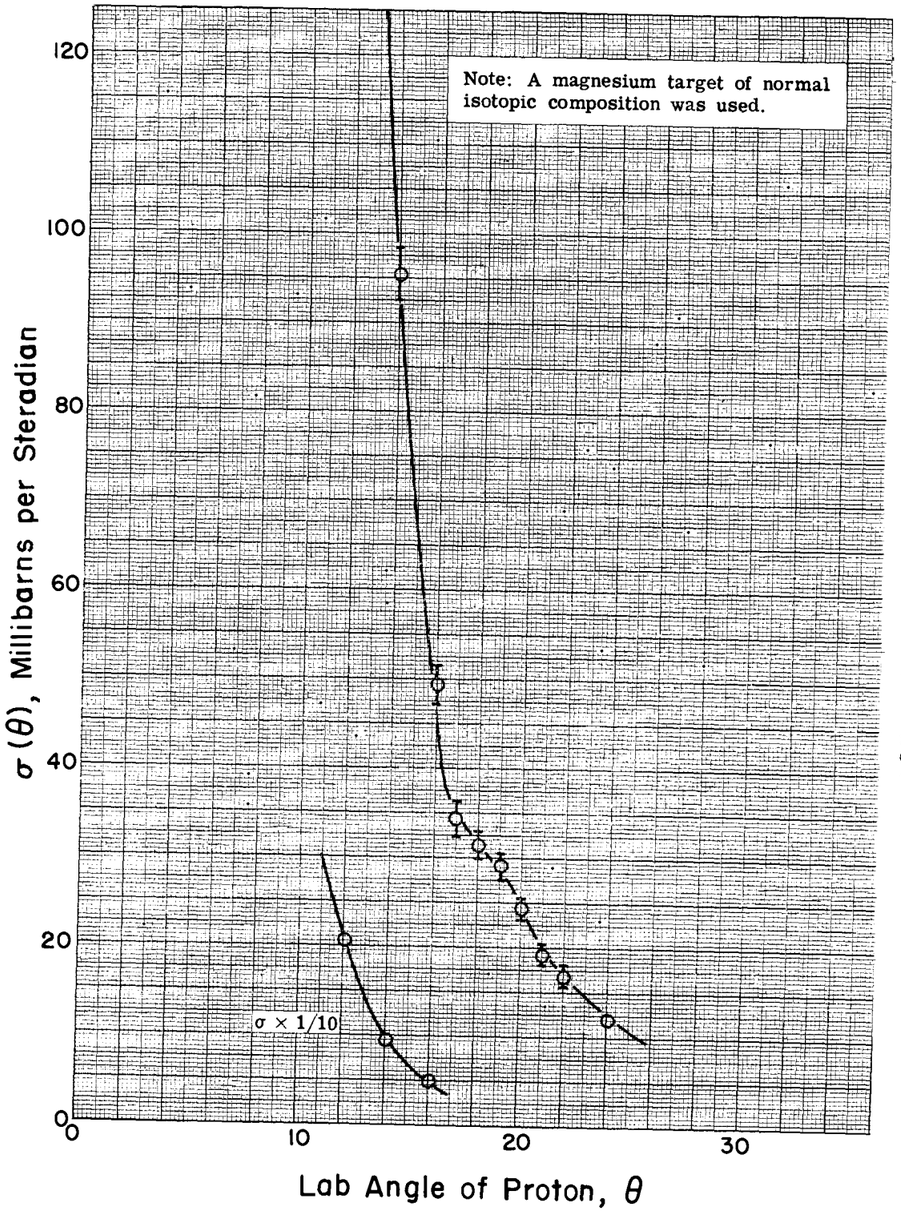
$Mg^{24}(p, p)Mg^{24}$
Lab angle $\theta = 164 \pm 5°$
Mooring et al.
Phys. Rev. 84, 703 (1951)
"It is thought that the cross section values are known to within 10 percent over most of the energy range covered"
See reference for better resolution data over narrow resonances
See also
G. W. Greenlees
Proc.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

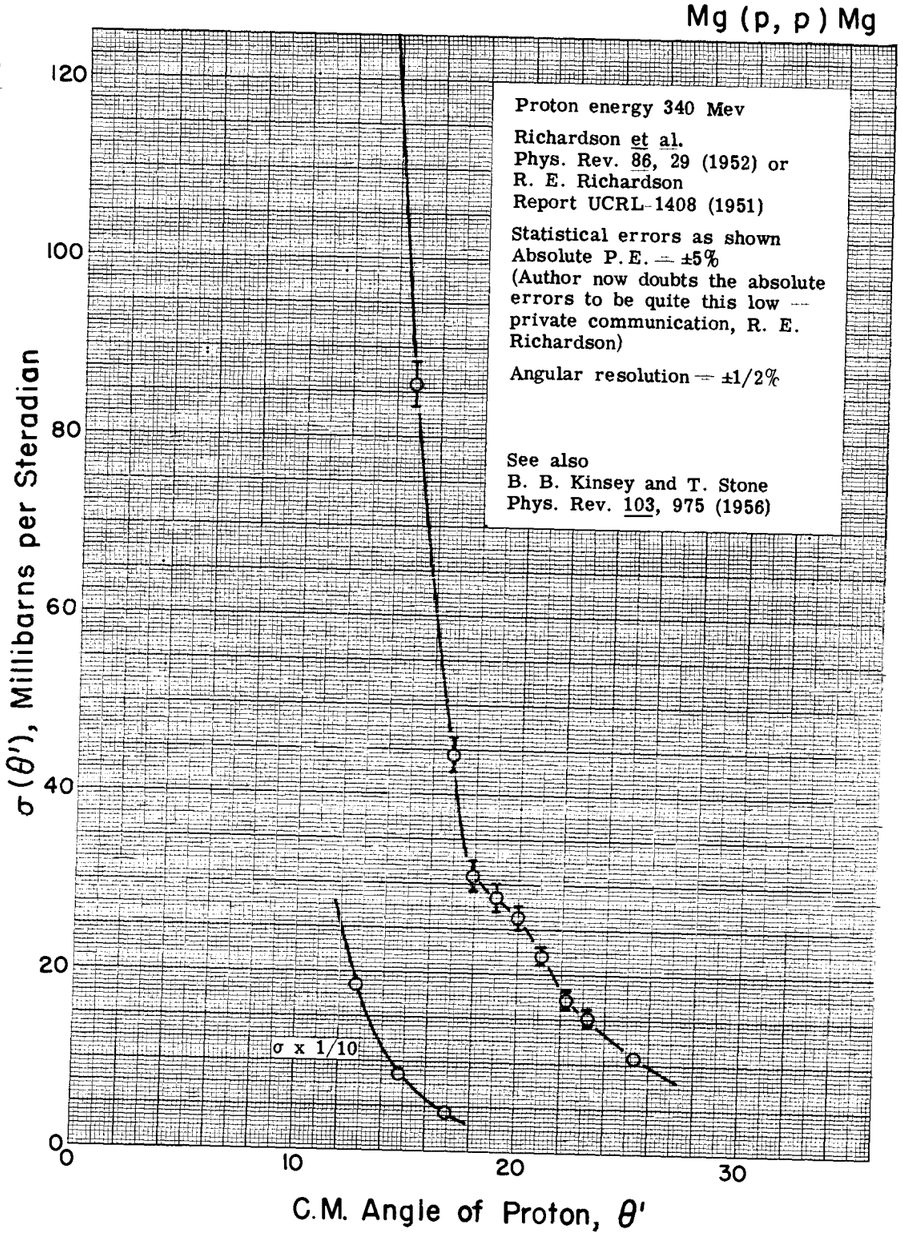

Greenlees et al.
Proc. Phys. Soc. (London) A70, 331 (1957)
Absolute P. E. = ±5%
Relative P. E. = ±3%
Note: A magnesium target of normal isotopic composition was used
Similar data at E_p = 8.62 Mev
E_p = 7.86 Mev
8.83 Mev
9.13 Mev
σ × 1/10
7.86 Mev
8.83 Mev
9.13 Mev
σ(θ'), Millibarns per Steradian
C.M.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

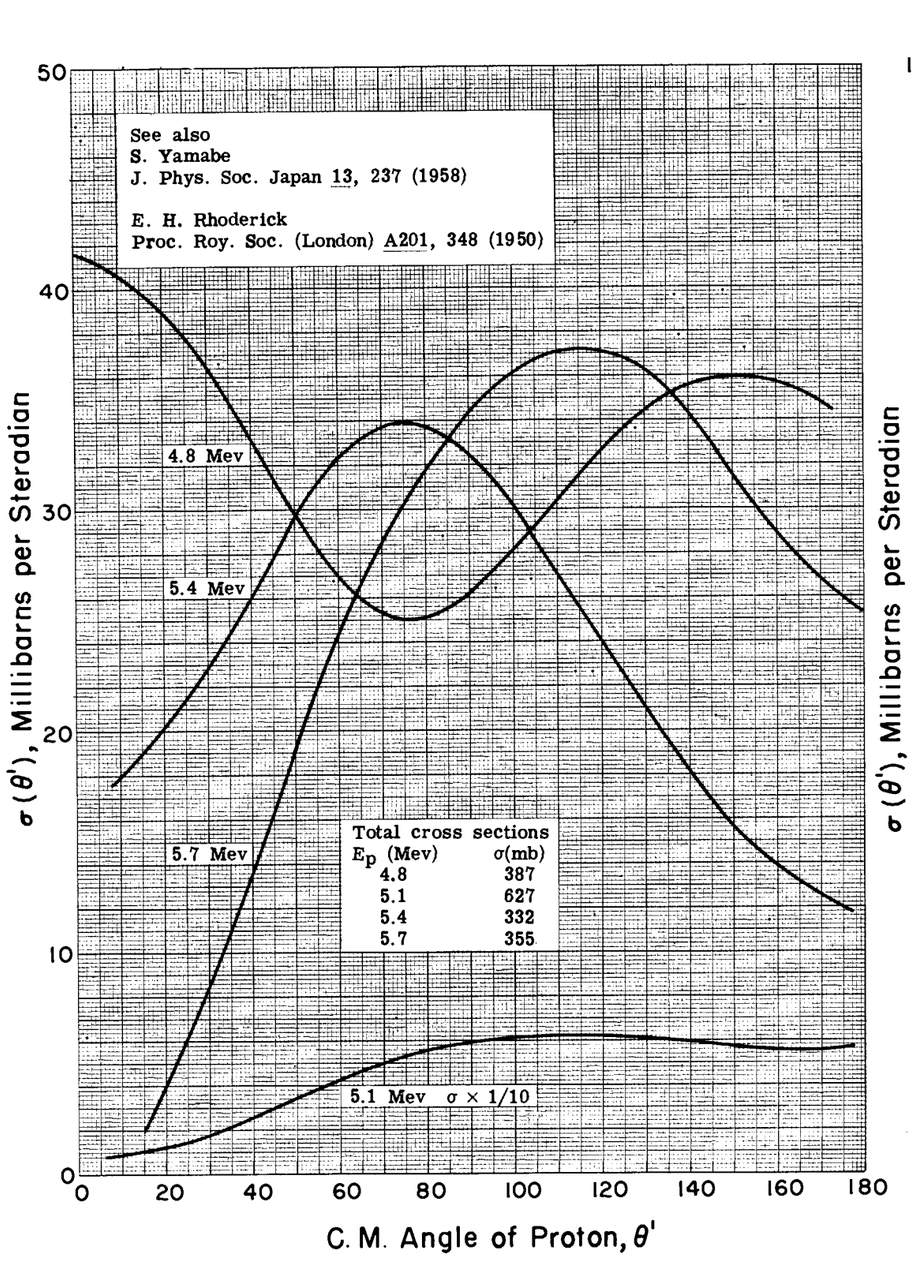

Proton energy 9.63 Mev
G. W. Greenlees and A. E. Souch
Proc. Phys. Soc. (London) A69, 686 (1956)
Absolute P. E. ±10%
Relative P. E. ±3%
Proton Energy 9.6 Mev
Baker, Dodd, and Simmons
Phys. Rev. 85, 1051 (1952)
Normalized to 9.55 Mev data
at θ' = 50°
Note: A magnesium target of normal isotopic composition 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


Mg(p,p)Mg
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'

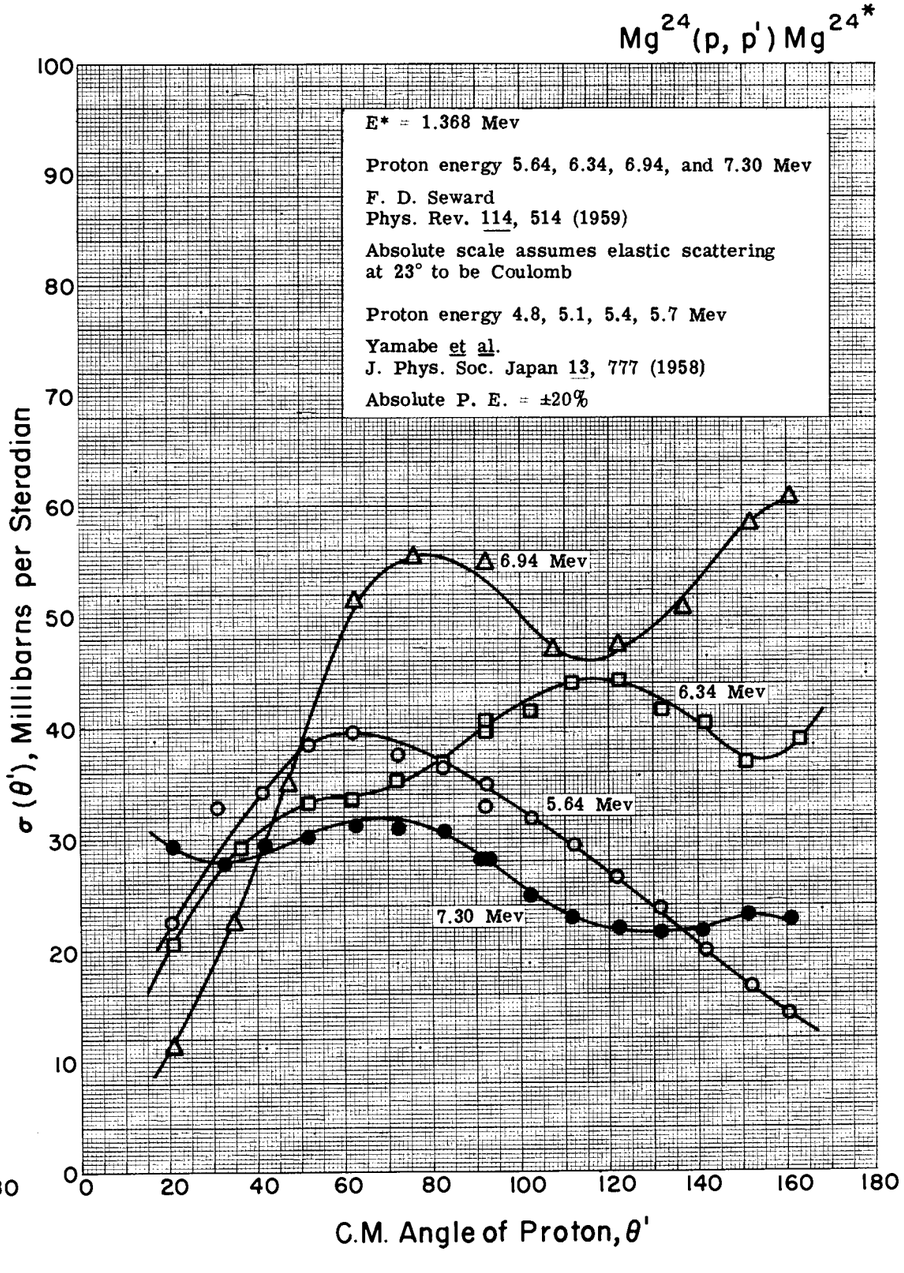

Note: A magnesium target of normal isotopic composition was used.
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
σ × 1/10
0
20
40
60
80
100
120
10
20
30

Mg (p, p) Mg

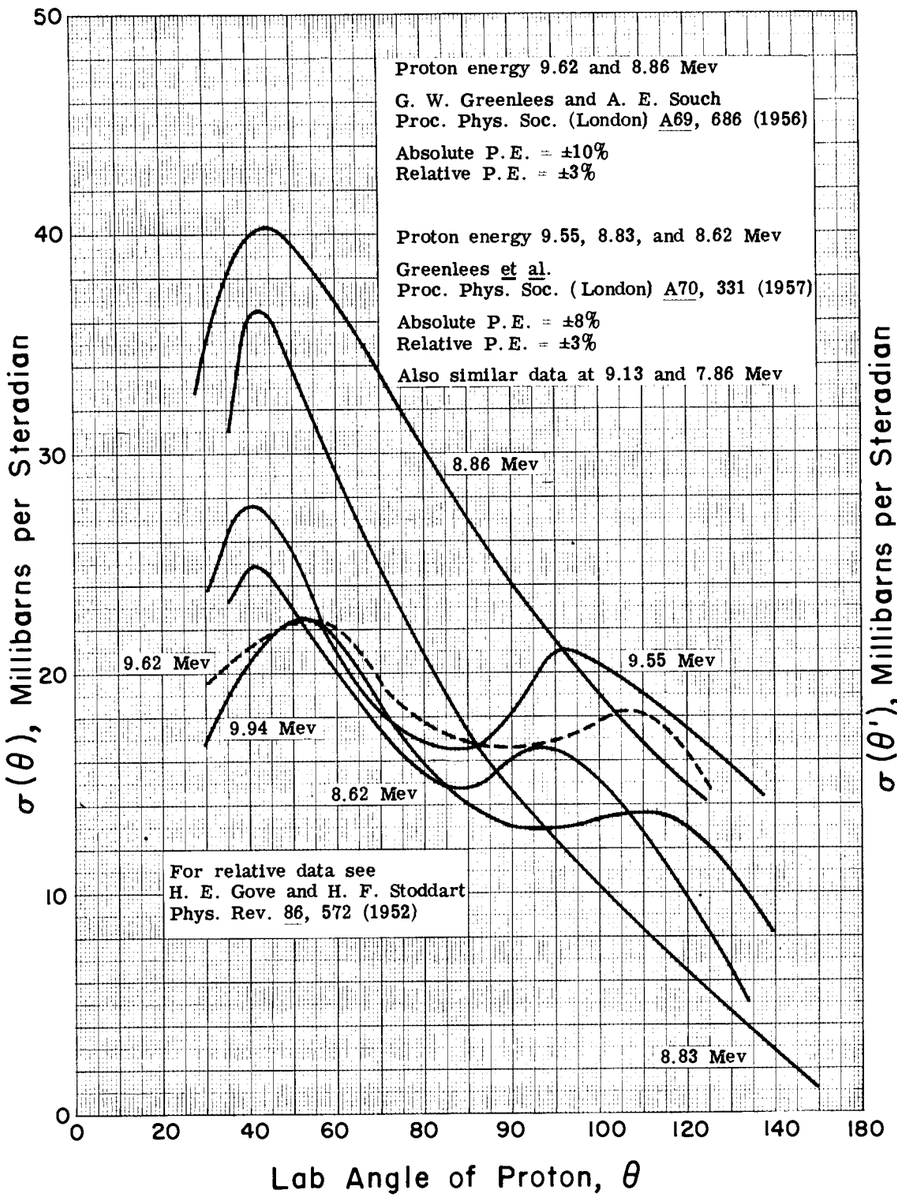

Proton energy 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Statistical errors as shown
Absolute P.E. ≈ ±5%
(Author now doubts the absolute errors to be quite this low — private communication, R. E. Richardson)
Angular resolution ≈ ±1/2%
See also
B. B.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

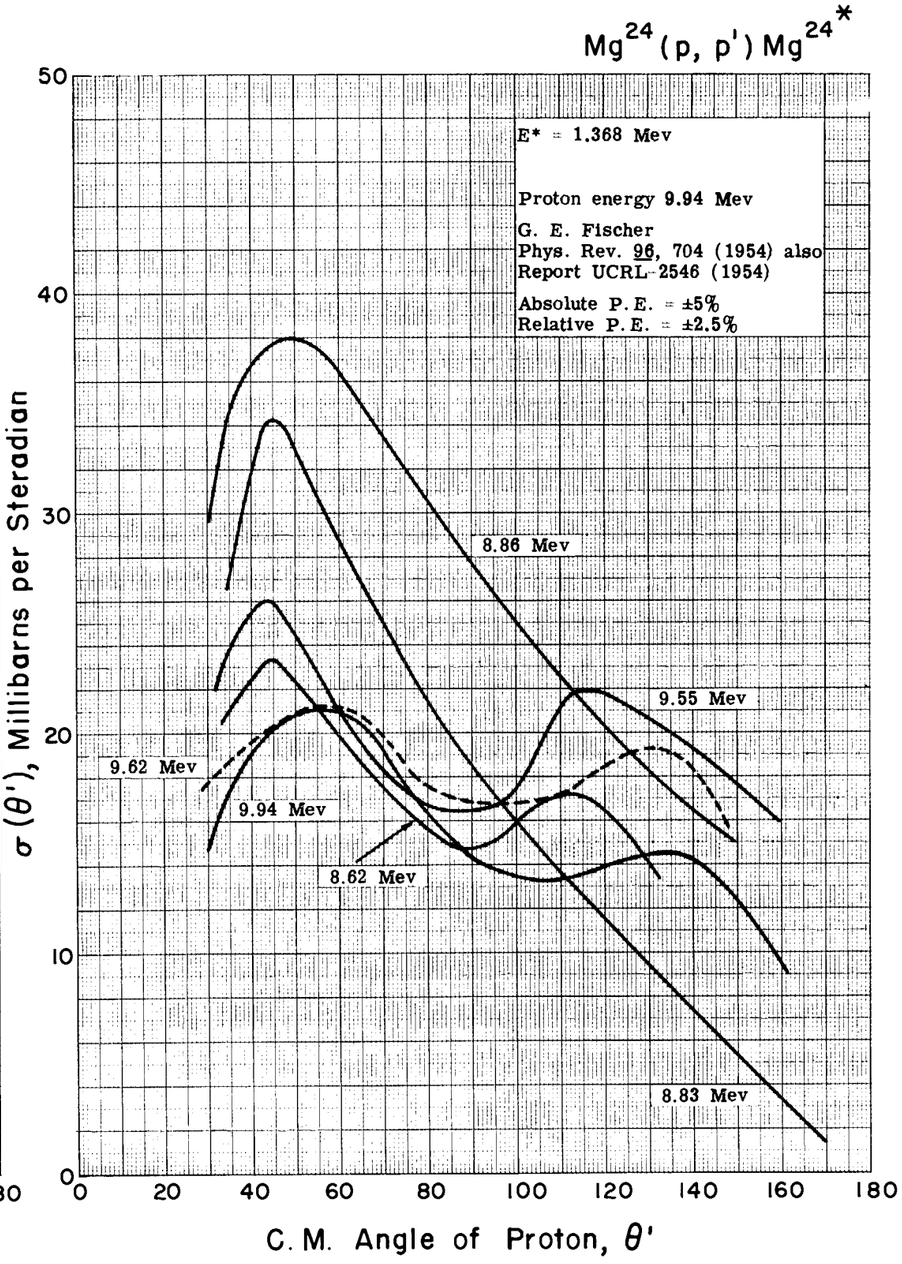


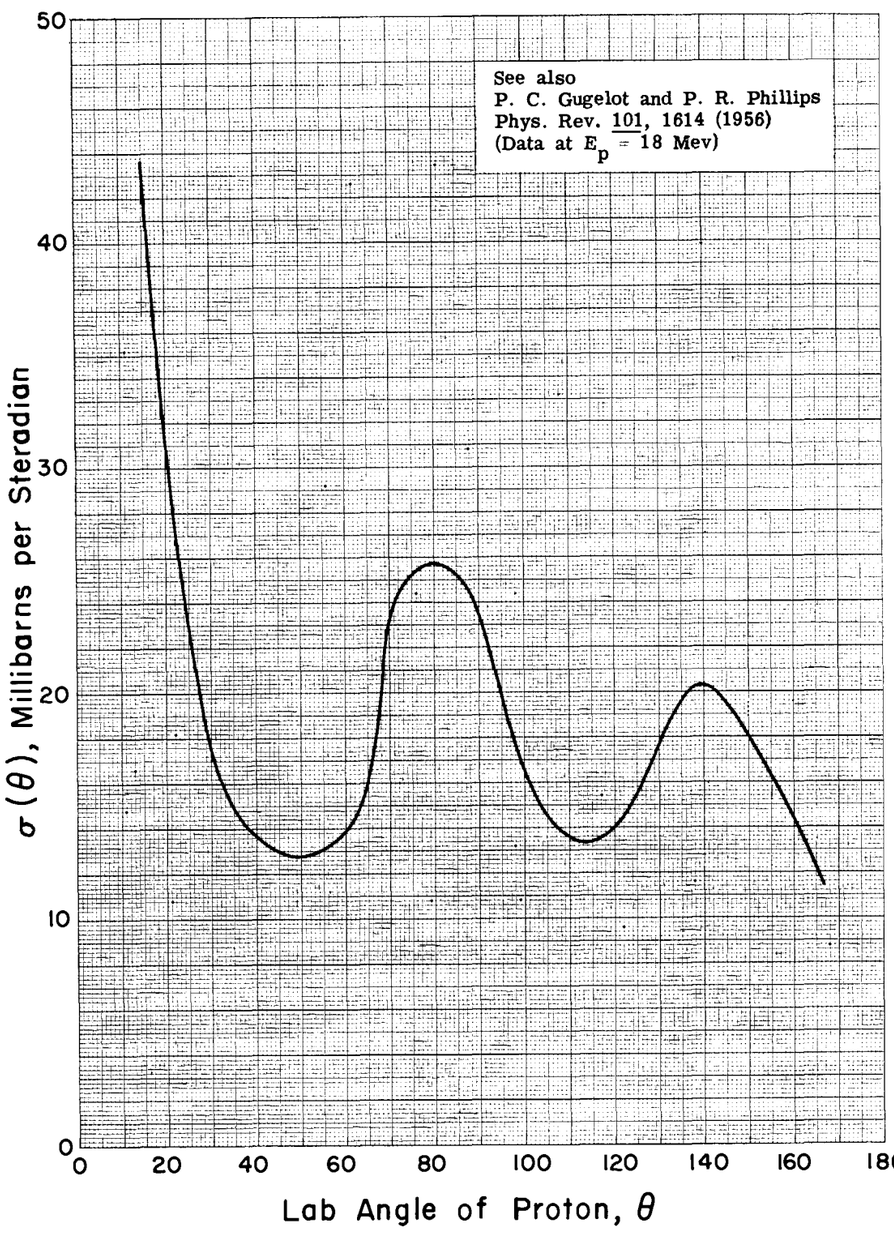
See also
S. Yamabe
J. Phys. Soc. Japan 13, 237 (1958)
E. H. Rhoderick
Proc. Roy. Soc. (London) A201, 348 (1950)
4.8 Mev
5.4 Mev
5.7 Mev
5.1 Mev σ × 1/10
Total cross sections
Ep (Mev) σ(mb)
4.8 387
5.1 627
5.4 332
5.7 355
σ (θ'), Millibarns per Steradian
C. M. Angle of Proton, θ'

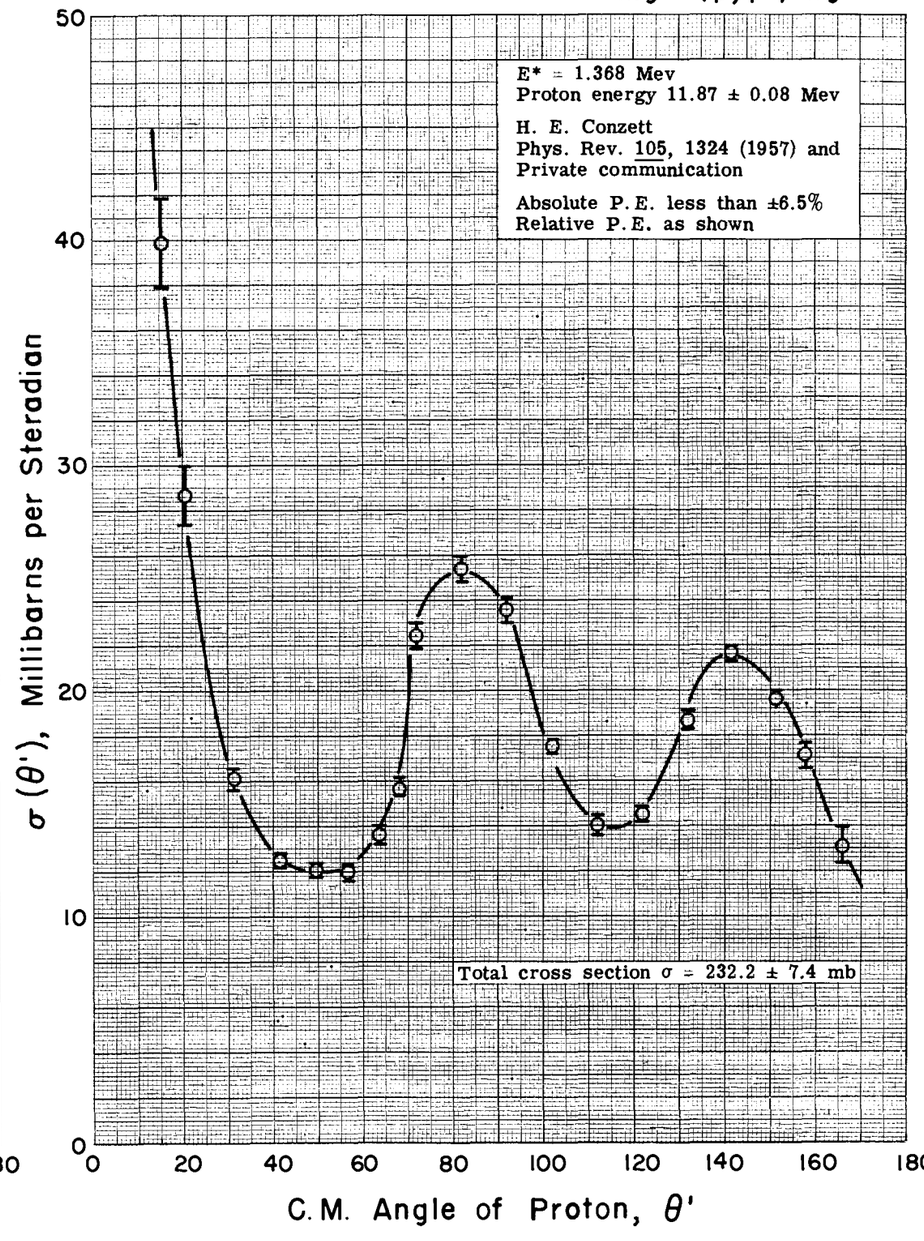


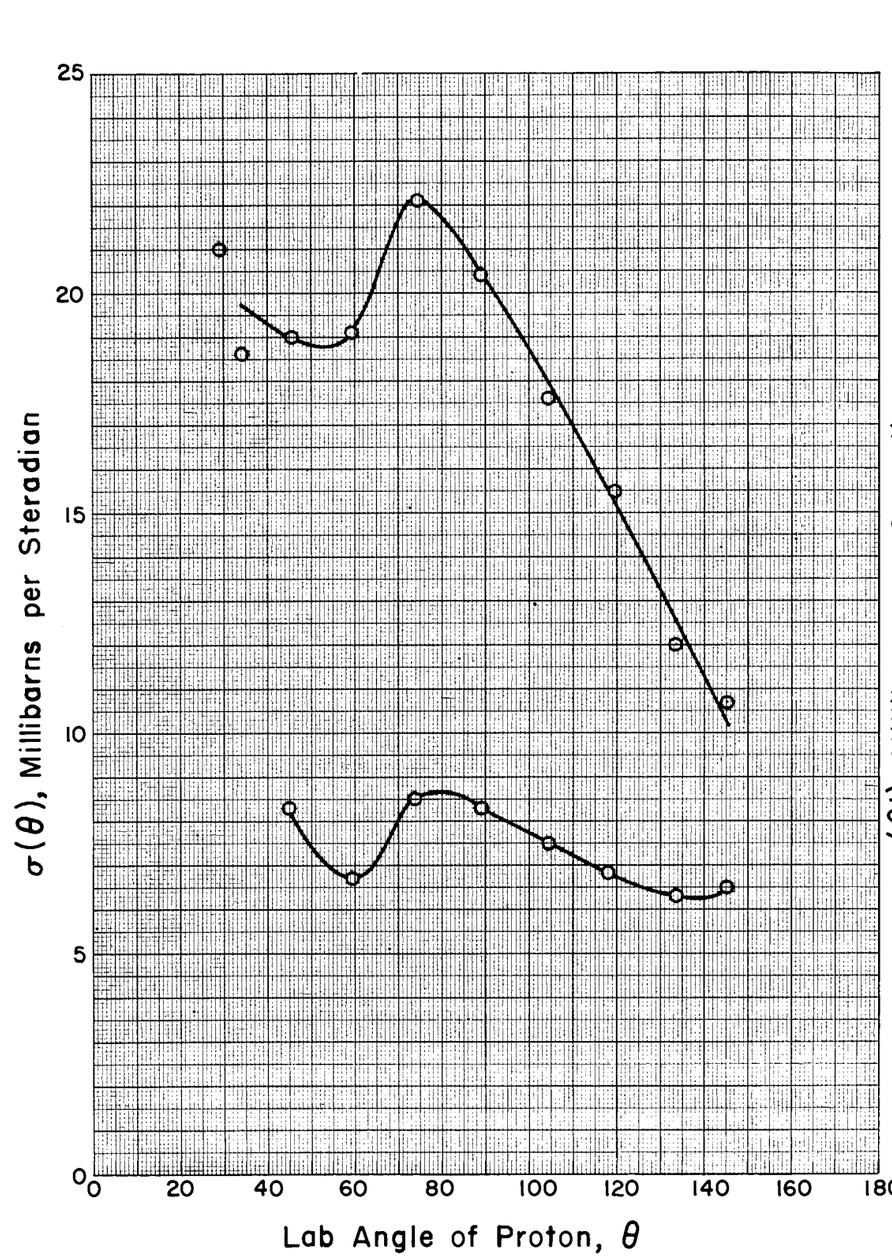
Mg24(p, p')Mg24*
E* = 1.368 Mev
Proton energy 5.64, 6.34, 6.94, and 7.30 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute scale assumes elastic scattering at 23° to be Coulomb
Proton energy 4.8, 5.1, 5.4, 5.7 Mev
Yamabe et al.
J. Phys. Soc. Japan 13, 777 (1958)
Absolute P. E. = ±20%
6.94 Mev
6.34 Mev
5.64 Mev
7.30 Mev
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

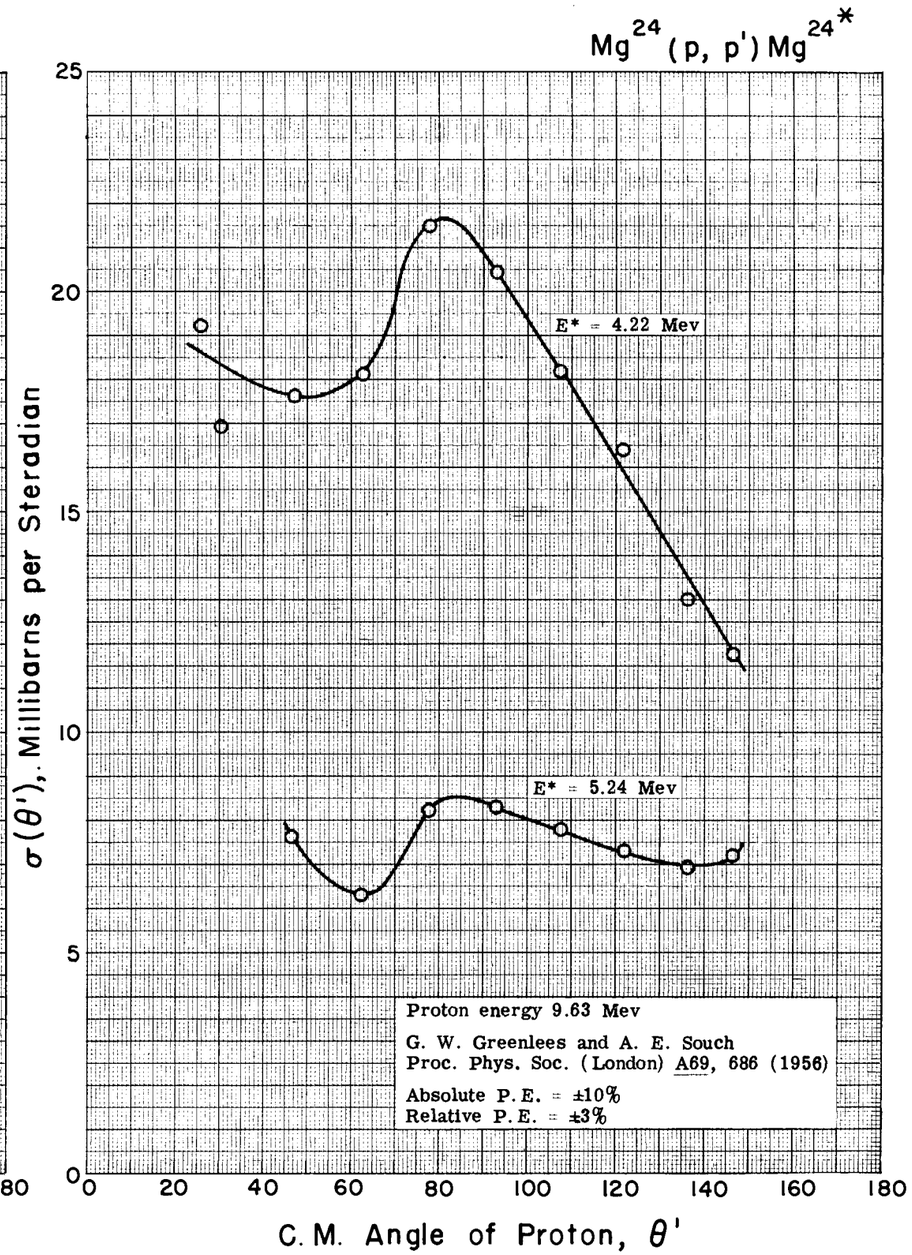

Proton energy 9.62 and 8.86 Mev
G. W. Greenlees and A. E. Souch
Proc. Phys. Soc. (London) A69, 686 (1956)
Absolute P.E. = ±10%
Relative P.E. = ±3%
Proton energy 9.55, 8.83, and 8.62 Mev
Greenlees et al.
Proc. Phys. Soc. (London) A70, 331 (1957)
Absolute P.E. = ±8%
Relative P.E. = ±3%
Also similar data 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
9.55 Mev
9.94 Mev
8.62 Mev
8.83 Mev
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
10
20
30
40
50
0
20
40
60
80
90
100
120
140
180


Mg24(p, p')Mg24*
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%
8.86 Mev
9.55 Mev
9.62 Mev
9.94 Mev
8.62 Mev
8.83 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180

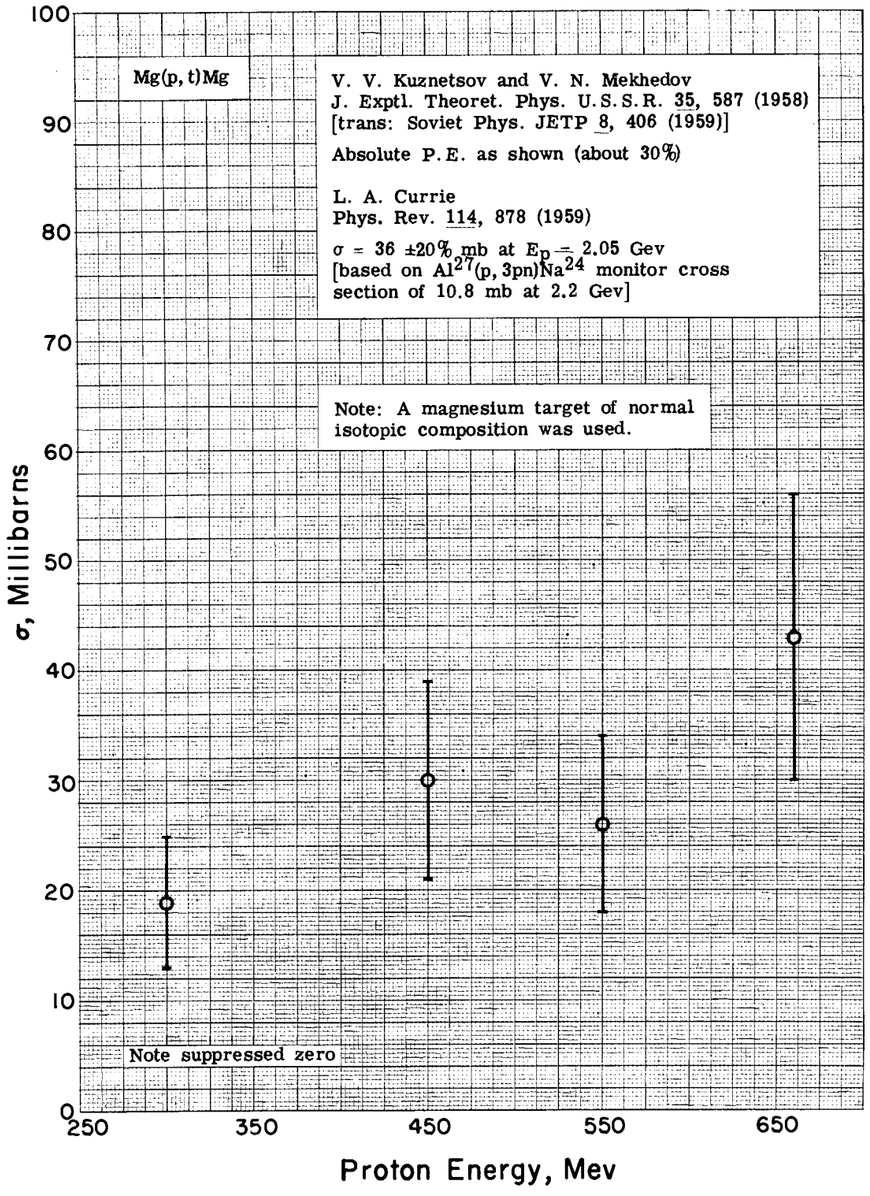

See also
P. C. Gugelot and P. R. Phillips
Phys. Rev. 101, 1614 (1956)
(Data at E_p = 18 Mev)
σ (θ), Millibarns per Steradian
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180
Lab Angle of Proton, θ

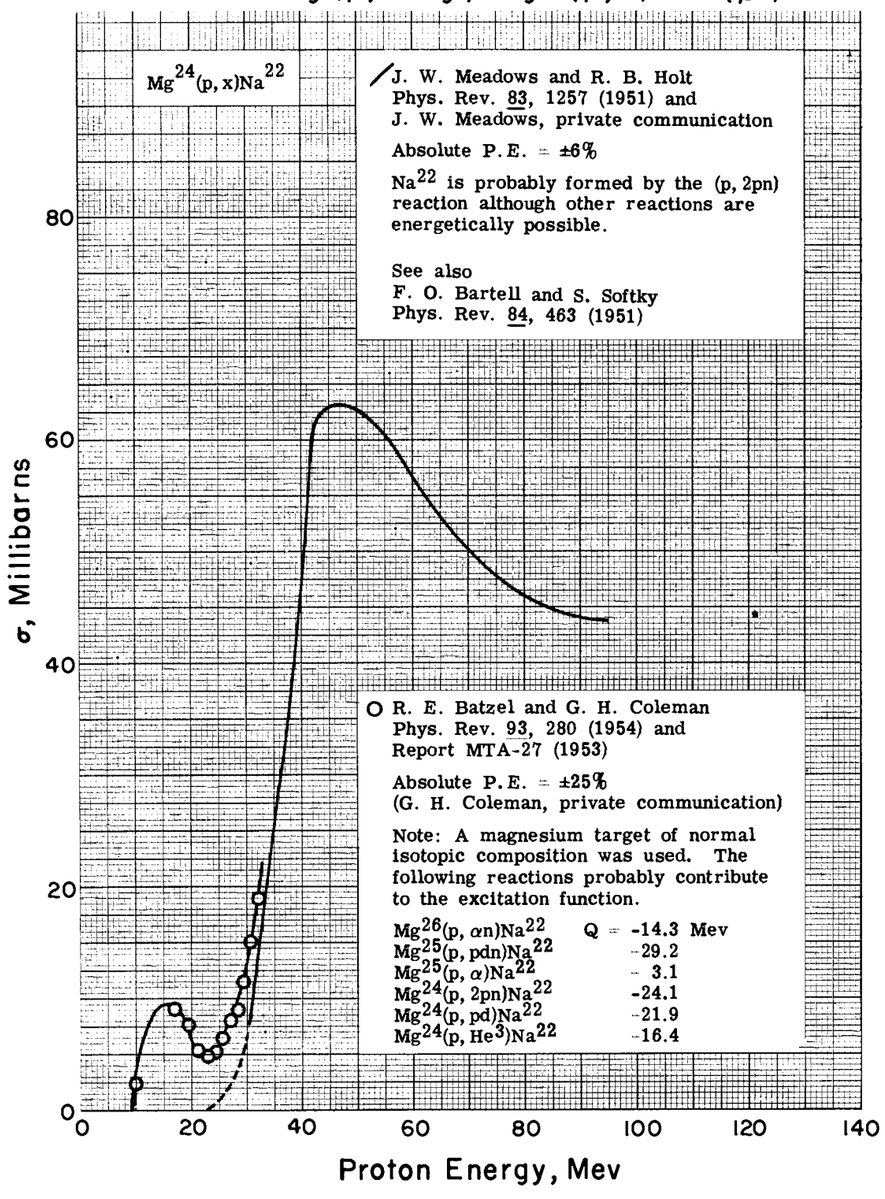

$Mg^{24}(p, p')Mg^{24*}$
E* = 1.368 Mev
Proton energy 11.87 ± 0.08 Mev
H. E. Conzett
Phys. Rev. 105, 1324 (1957) and
Private communication
Absolute P.E. less than ±6.5%
Relative P.E. as shown
σ (θ'), Millibarns per Steradian
0
10
20
30
40
50
Total cross section σ = 232.2 ± 7.4 mb
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Proton, θ'

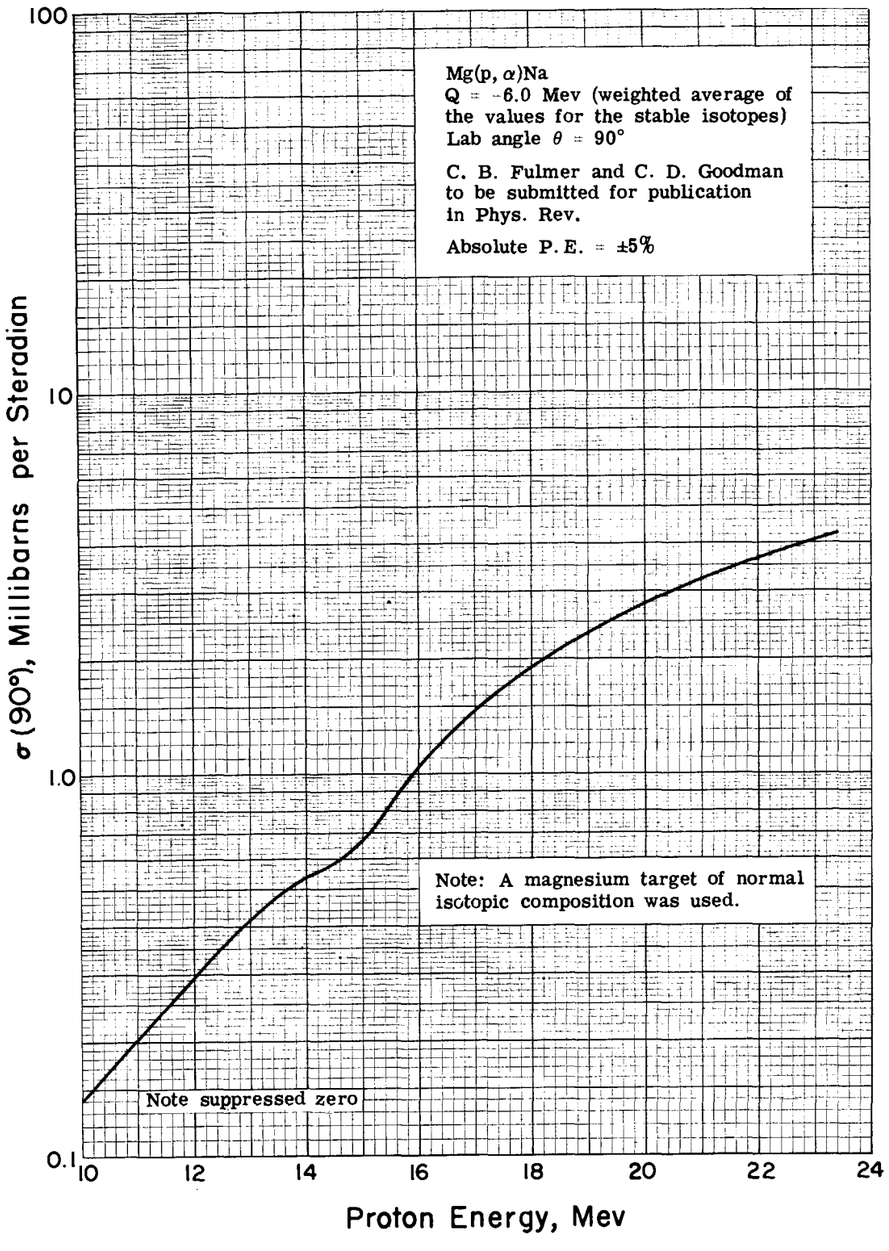

25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ

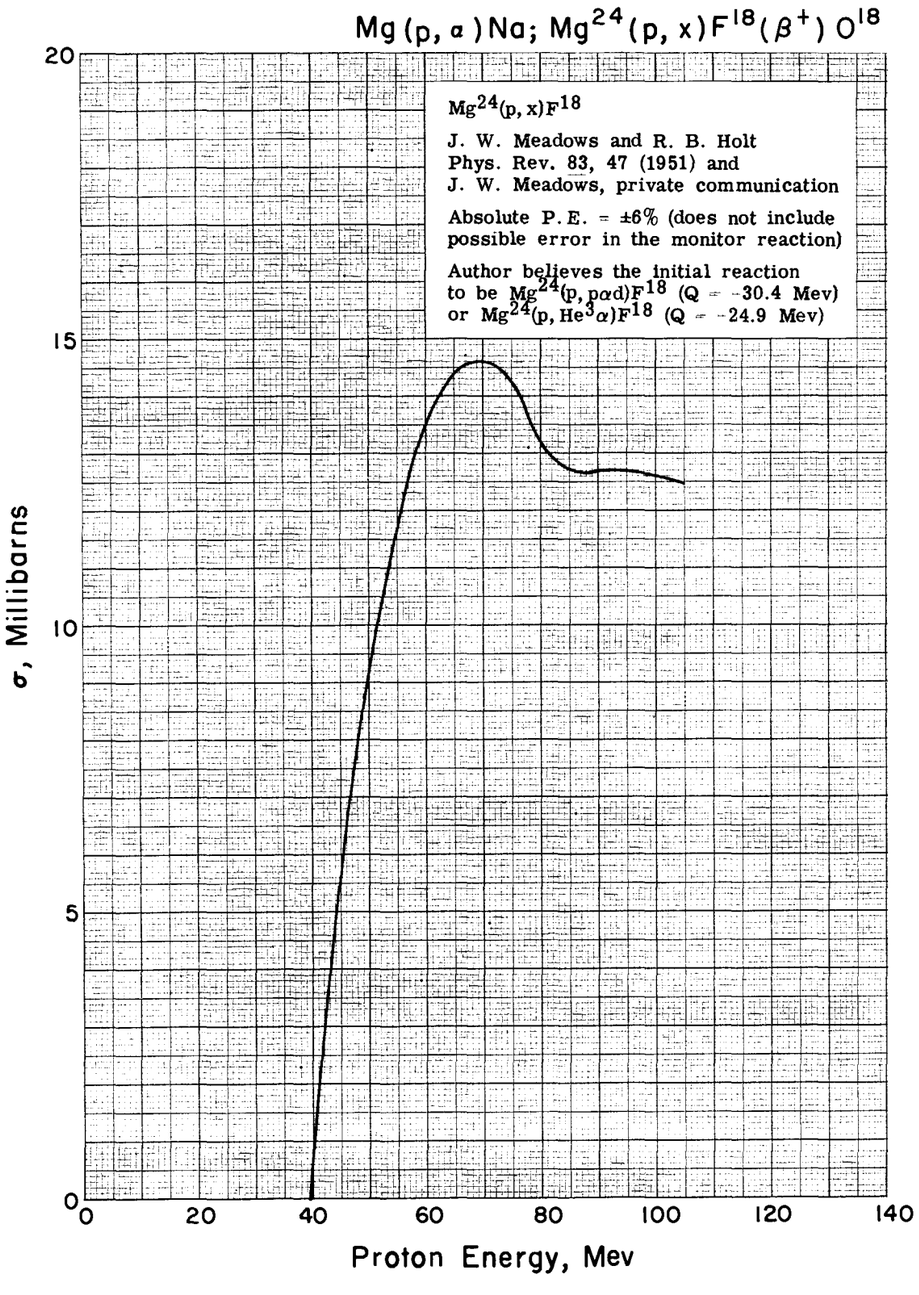

Mg24 (p, p') Mg24*
E* = 4.22 Mev
E* = 5.24 Mev
Proton energy 9.63 Mev
G. W. Greenlees and A. E. Souch
Proc. Phys. Soc. (London) A69, 686 (1956)
Absolute P.E. = ±10%
Relative P.E. = ±3%
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

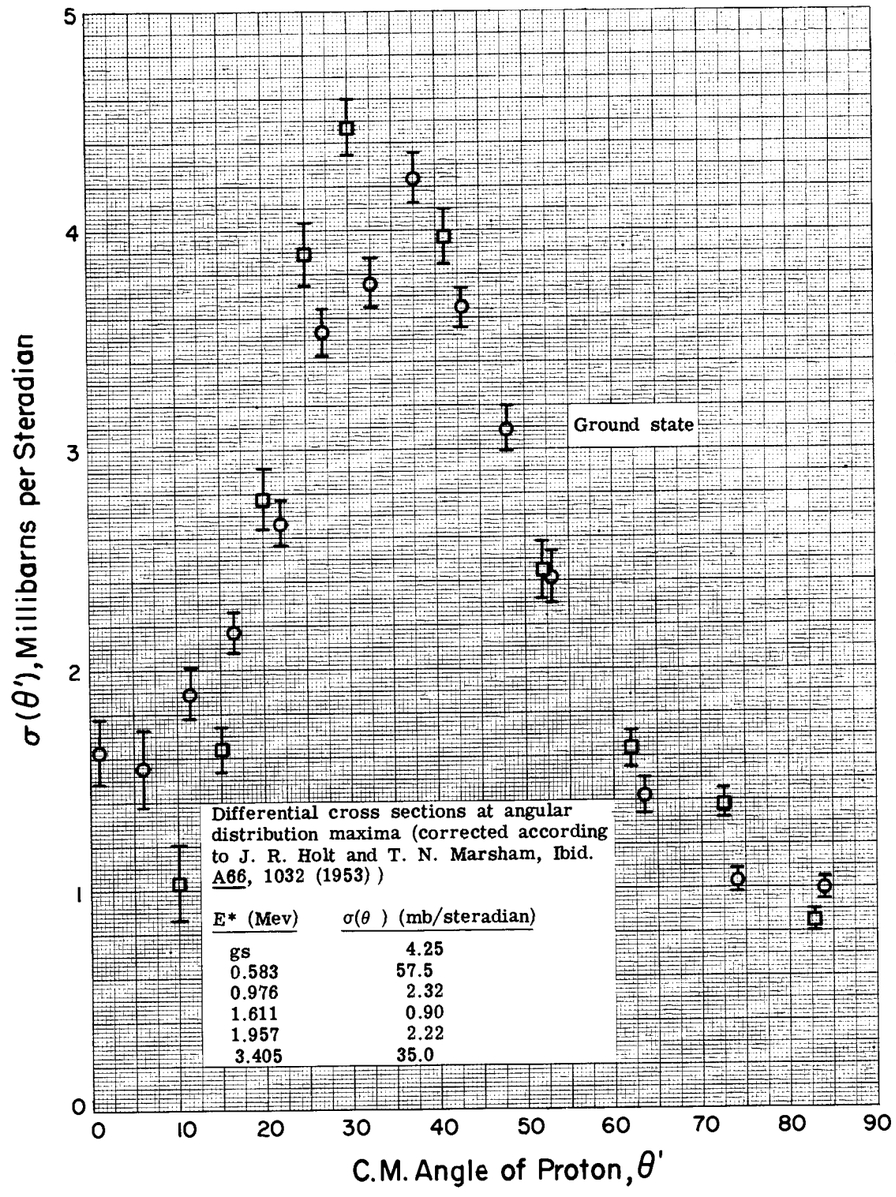
Mg(p,t)Mg ; $Mg^{24}(p,x)Na^{22}(\beta^+)Ne^{22}$

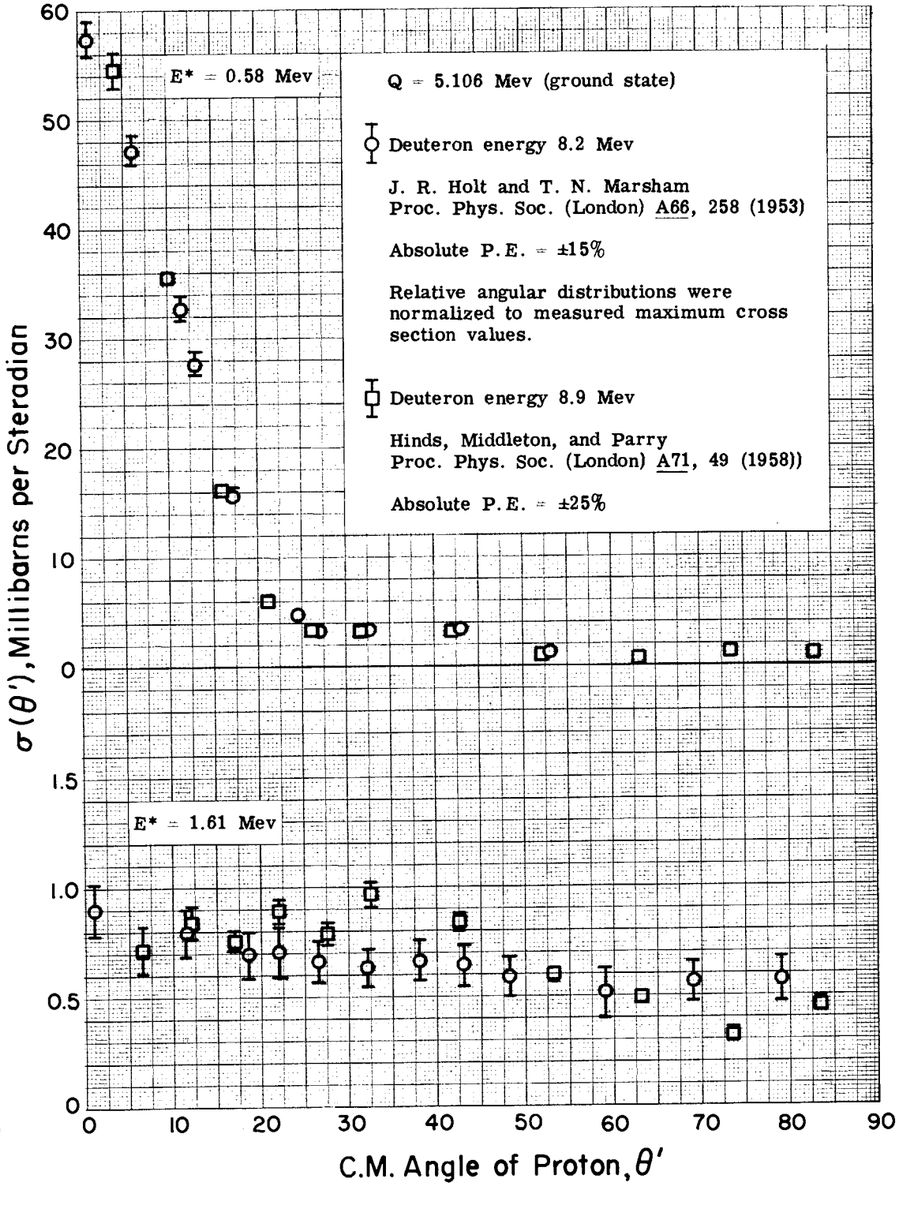


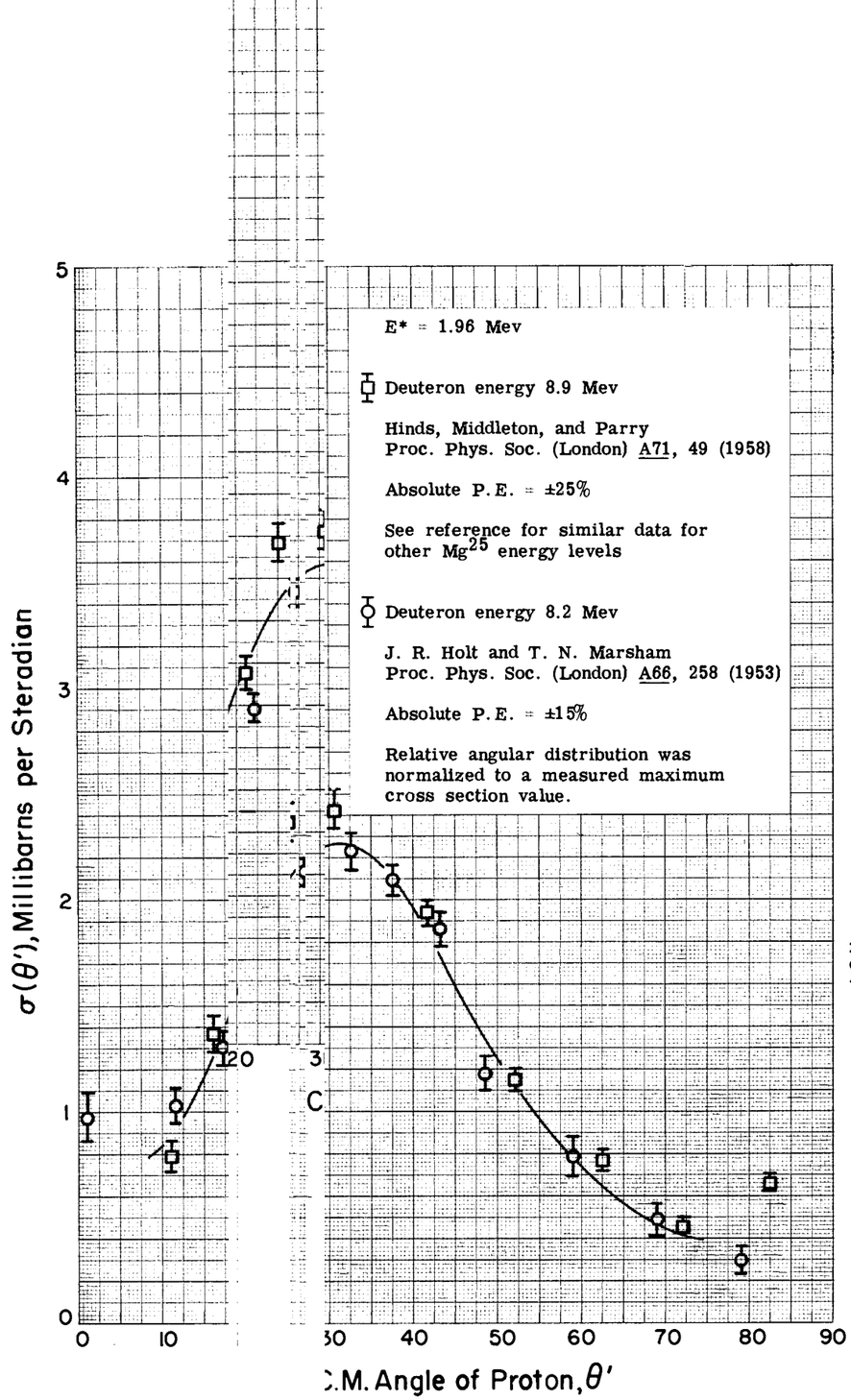


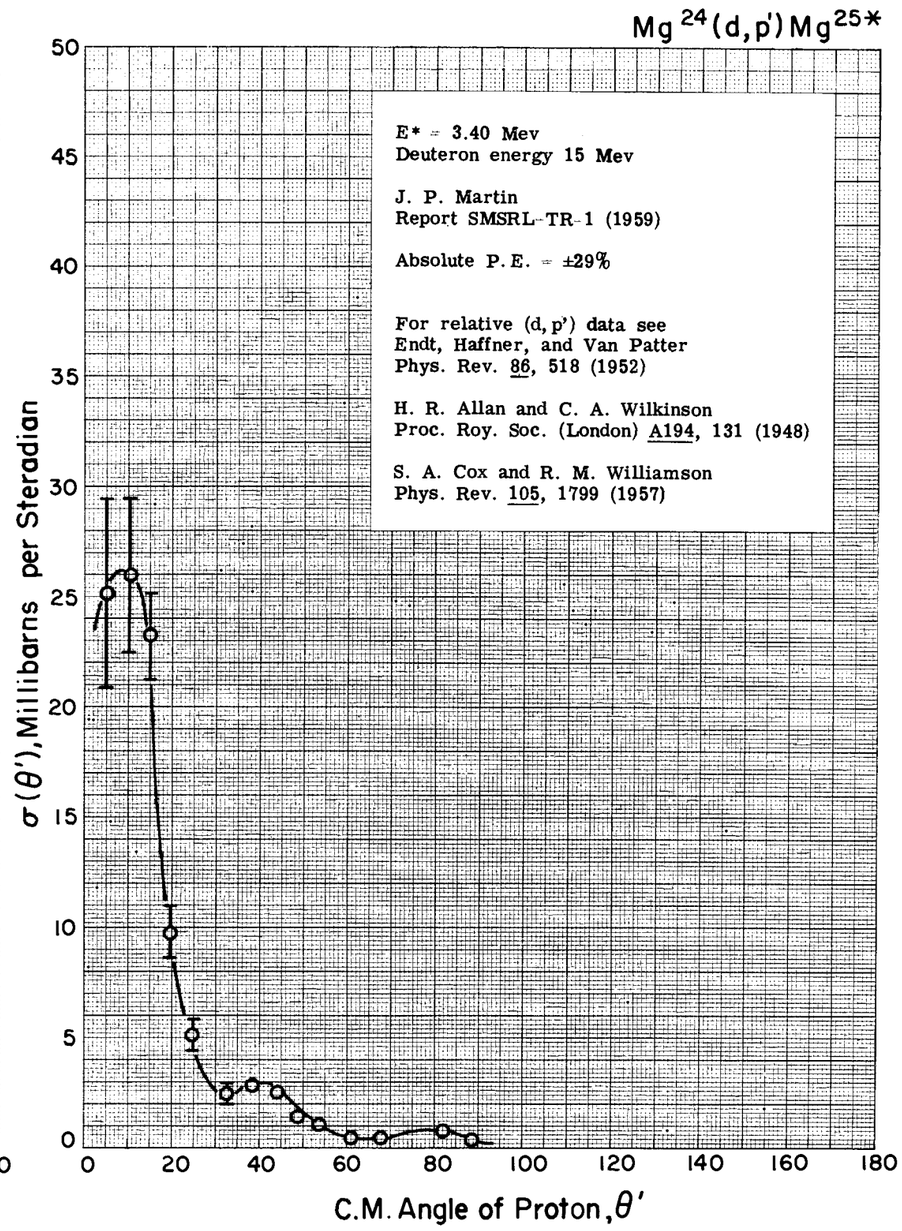

Mg(p, α)Na
Q = −6.0 Mev (weighted average of the values for the stable isotopes)
Lab angle θ = 90°
C. B. Fulmer and C. D. Goodman to be submitted for publication in Phys. Rev.
Absolute P. E. = ±5%
Note: A magnesium target of normal isotopic composition was used.
Note suppressed zero
σ(90°), Millibarns per Steradian
100
10
1.0
0.1
10
12
14
16
18
20
22
24
Proton Energy, Mev

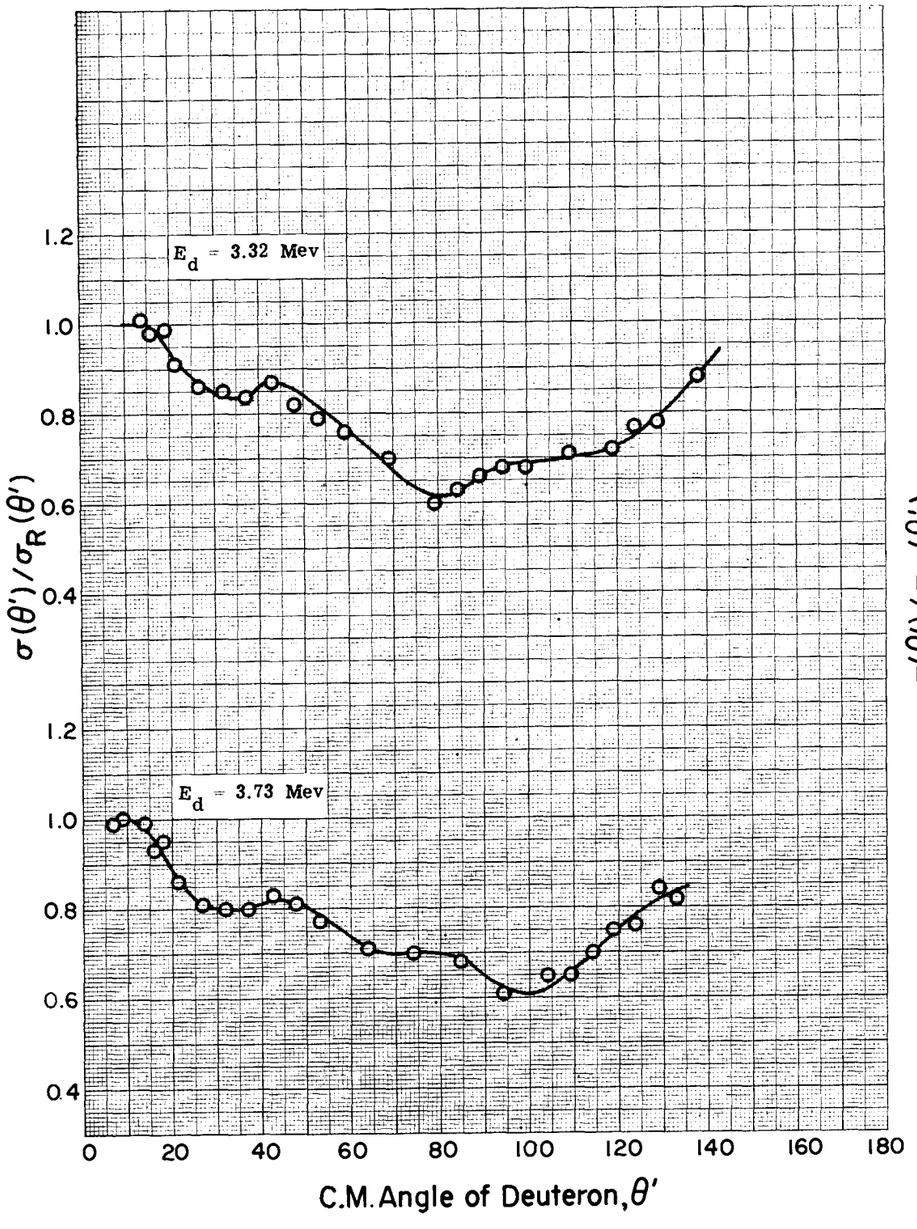

Mg(p, α)Na; Mg24(p, x)F18(β+)O18
Mg24(p, x)F18
J. W. Meadows and R. B. Holt Phys. Rev. 83, 47 (1951) and J. W. Meadows, private communication
Absolute P. E. = ±6% (does not include possible error in the monitor reaction)
Author believes the initial reaction to be Mg24(p, pαd)F18 (Q = −30.4 Mev) or Mg24(p, He3α)F18 (Q = −24.9 Mev)
σ, Millibarns
20
15
10
5
0
0
20
40
60
80
100
120
140
Proton Energy, Mev

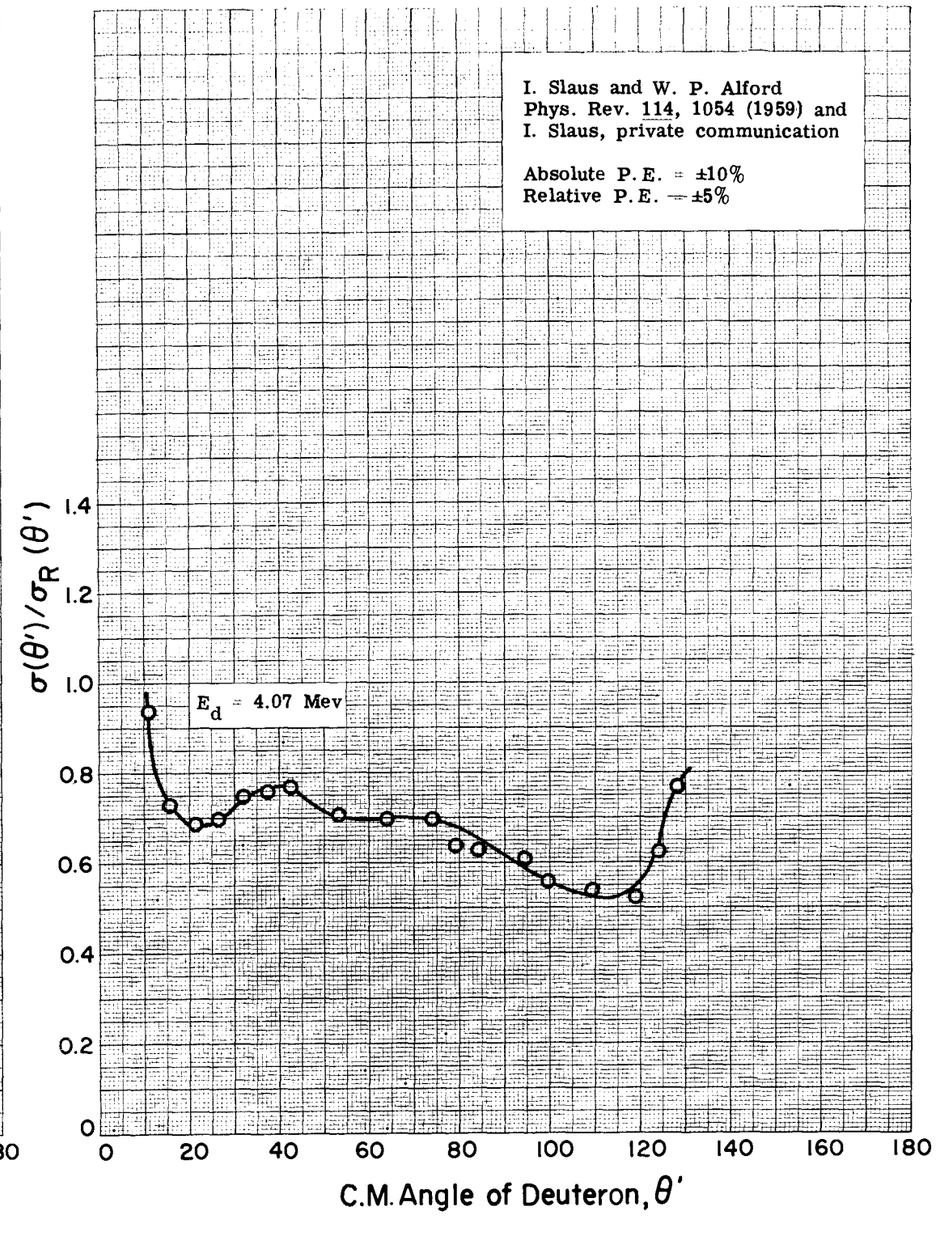

Ground state
Differential cross sections at angular distribution maxima (corrected according to J. R. Holt and T. N. Marsham, Ibid. A66, 1032 (1953))
E* (Mev) σ(θ) (mb/steradian)
gs 4.25
0.583 57.5
0.976 2.32
1.611 0.90
1.957 2.22
3.405 35.0
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

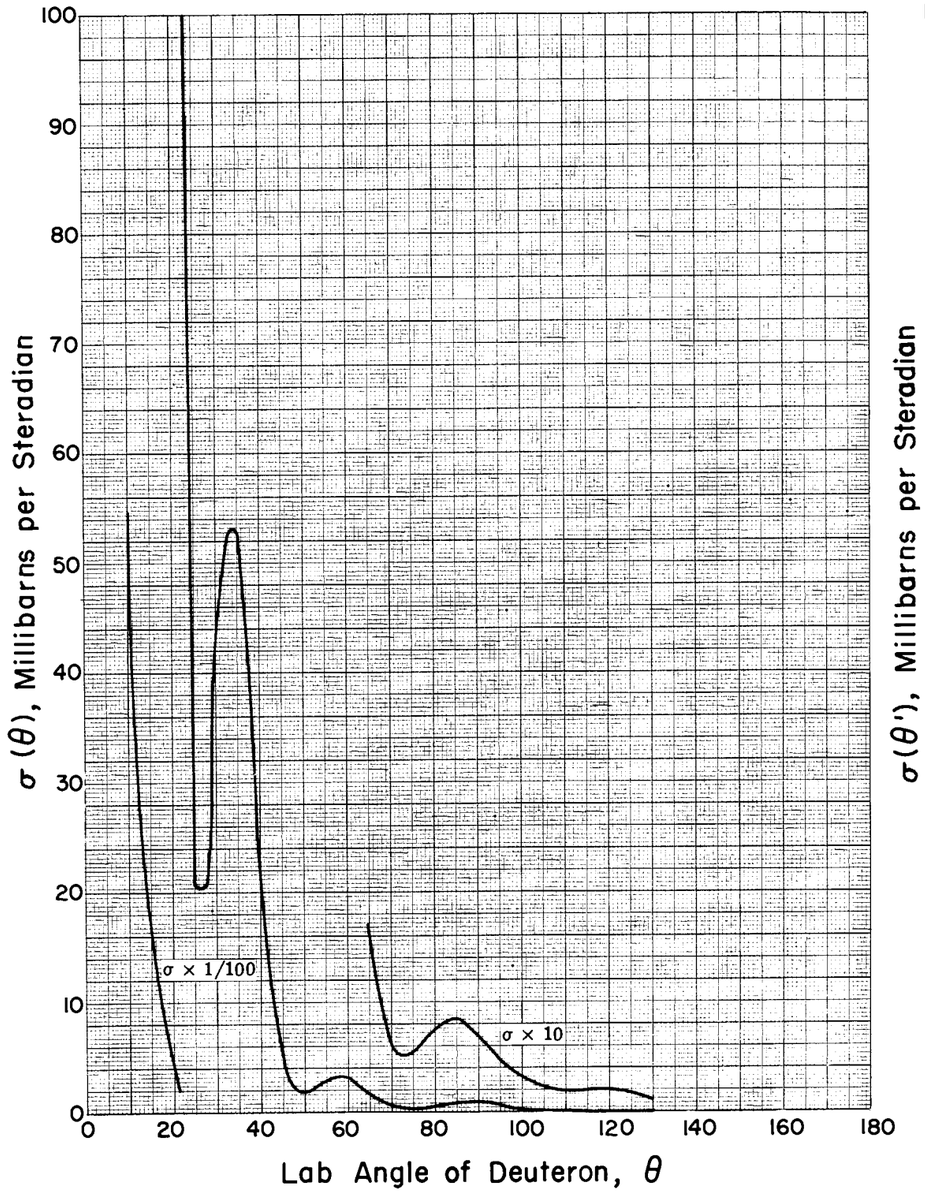

E* = 0.58 Mev
Q = 5.106 Mev (ground state)
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 258 (1953)
Absolute P.E. = ±15%
Relative angular distributions were normalized to measured maximum cross section values.
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc.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

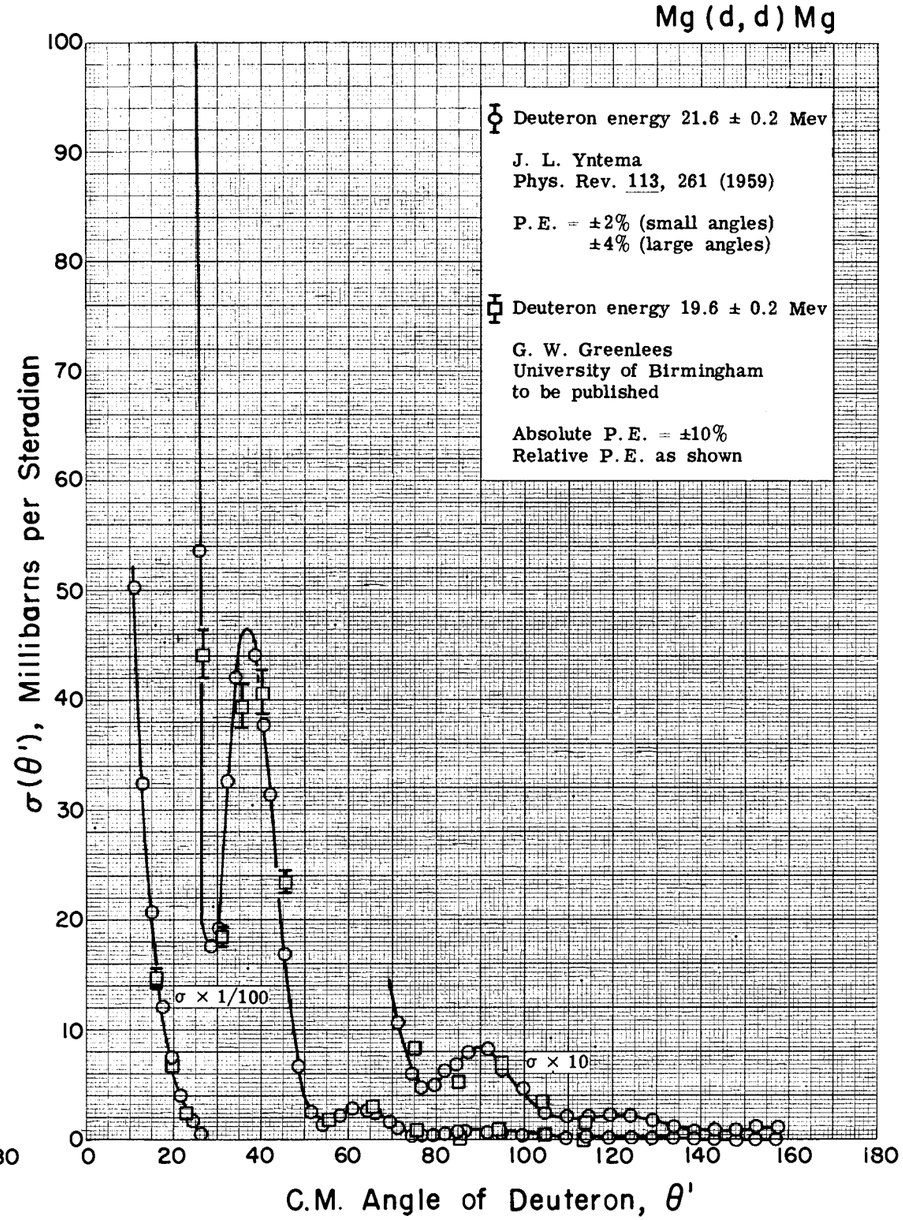

E* = 1.96 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A71, 49 (1958)
Absolute P.E. = ±25%
See reference for similar data for other Mg25 energy levels
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 258 (1953)
Absolute P.E. = ±15%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

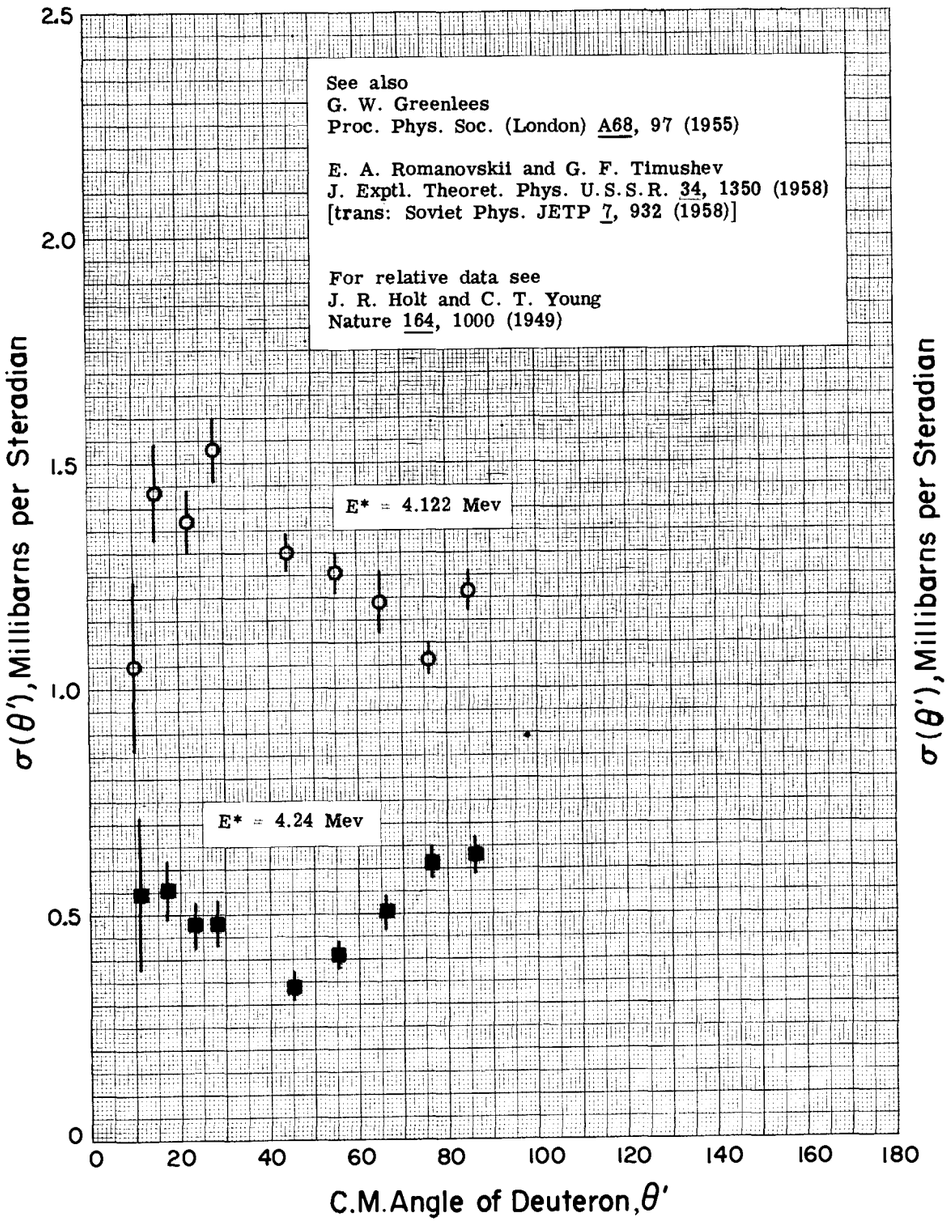

Mg24(d,p')Mg25*
E* = 3.40 Mev
Deuteron energy 15 Mev
J. P. Martin
Report SMSRL-TR-1 (1959)
Absolute P.E. = ±29%
For relative (d, p') data see
Endt, Haffner, and Van Patter
Phys. Rev. 86, 518 (1952)
H. R. Allan and C. A. Wilkinson
Proc. Roy. Soc. (London) A194, 131 (1948)
S. A. Cox and R. M. Williamson
Phys. Rev. 105, 1799 (1957)
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

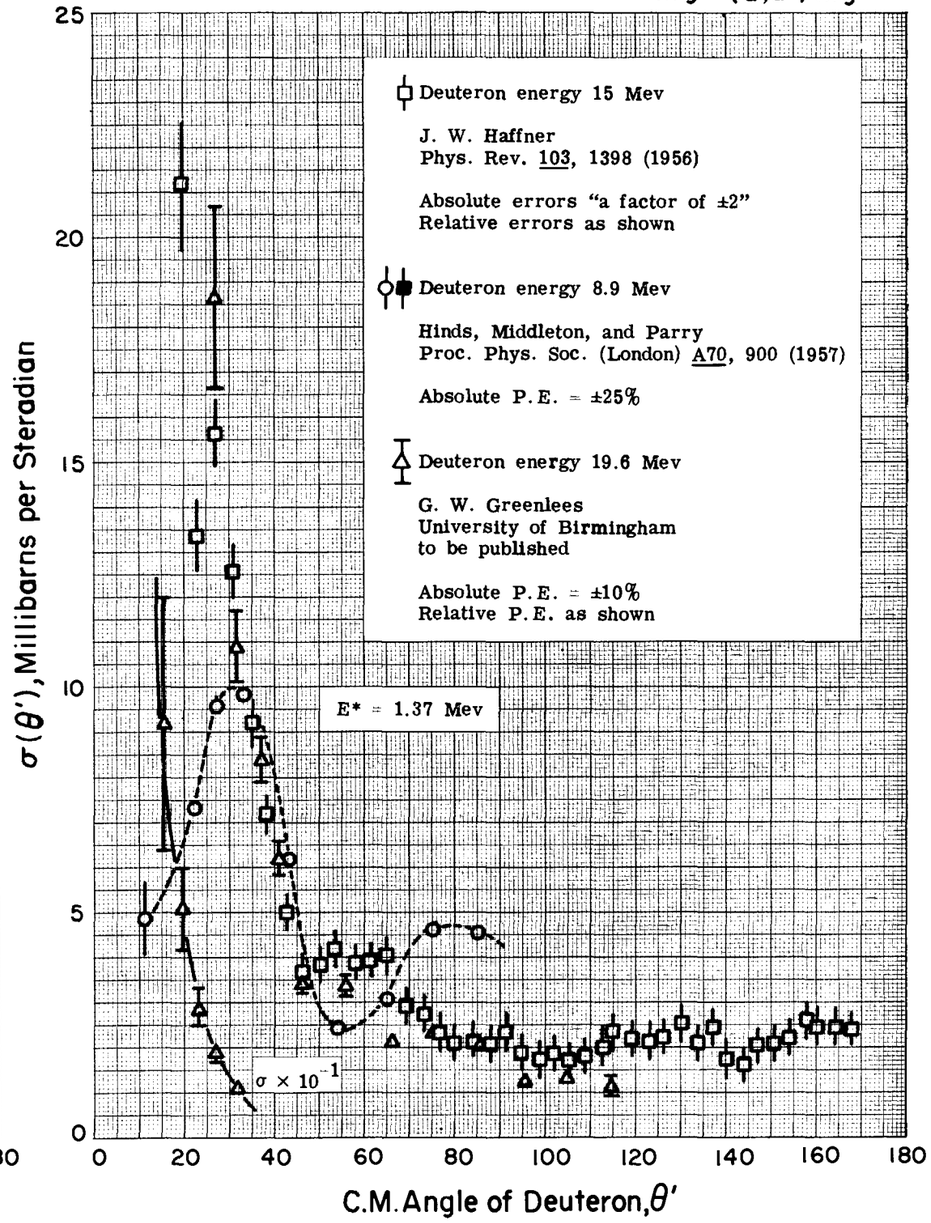

E_d = 3.32 Mev
E_d = 3.73 Mev
$\sigma(\theta')/\sigma_R(\theta')$
C.M. Angle of Deuteron, θ'


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
$\sigma(\theta')/\sigma_R(\theta')$
C.M. Angle of Deuteron, θ'

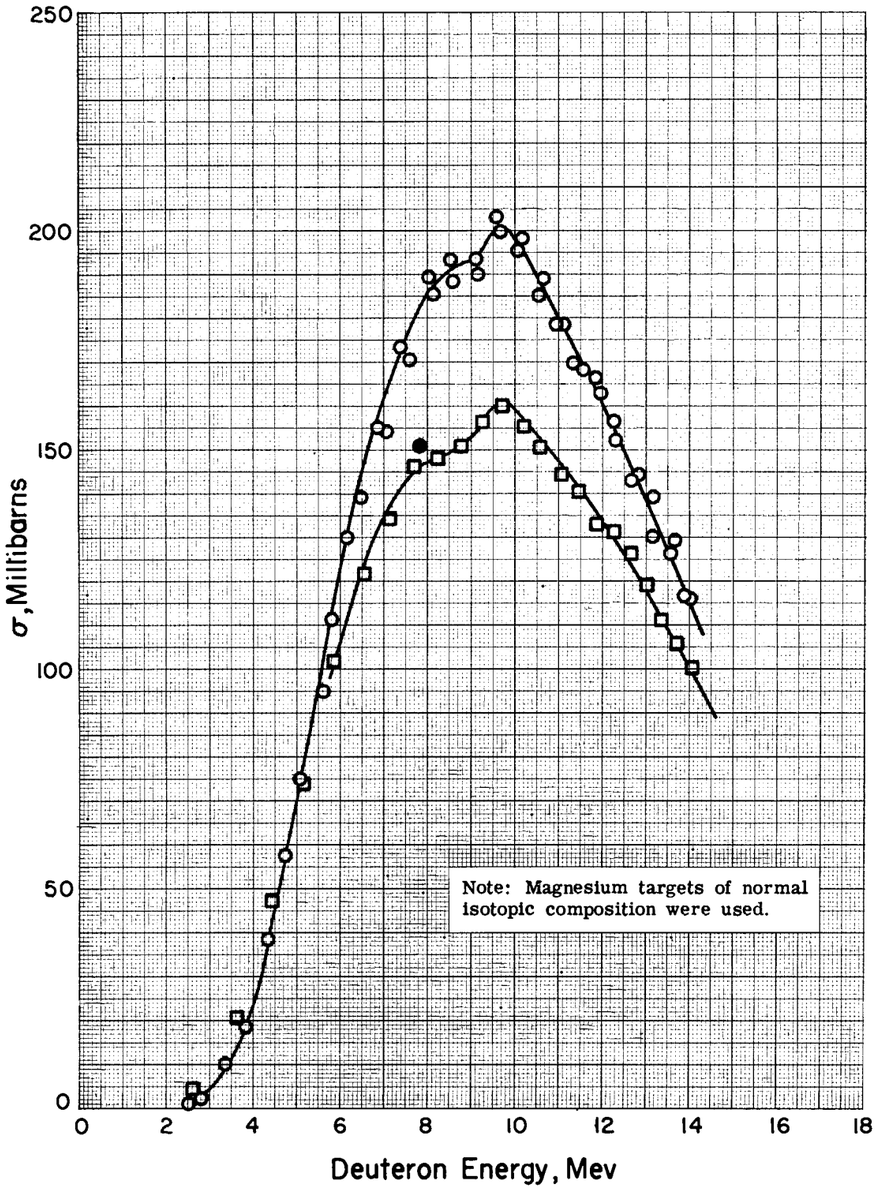

σ (θ), Millibarns per Steradian
Lab Angle of Deuteron, θ
σ × 1/100
σ × 10
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180


Mg (d, d) Mg
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
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180


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'
0
0.5
1.0
1.5
2.0
2.5
0
20
40
60
80
100
120
140
160
180


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'
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180

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



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)

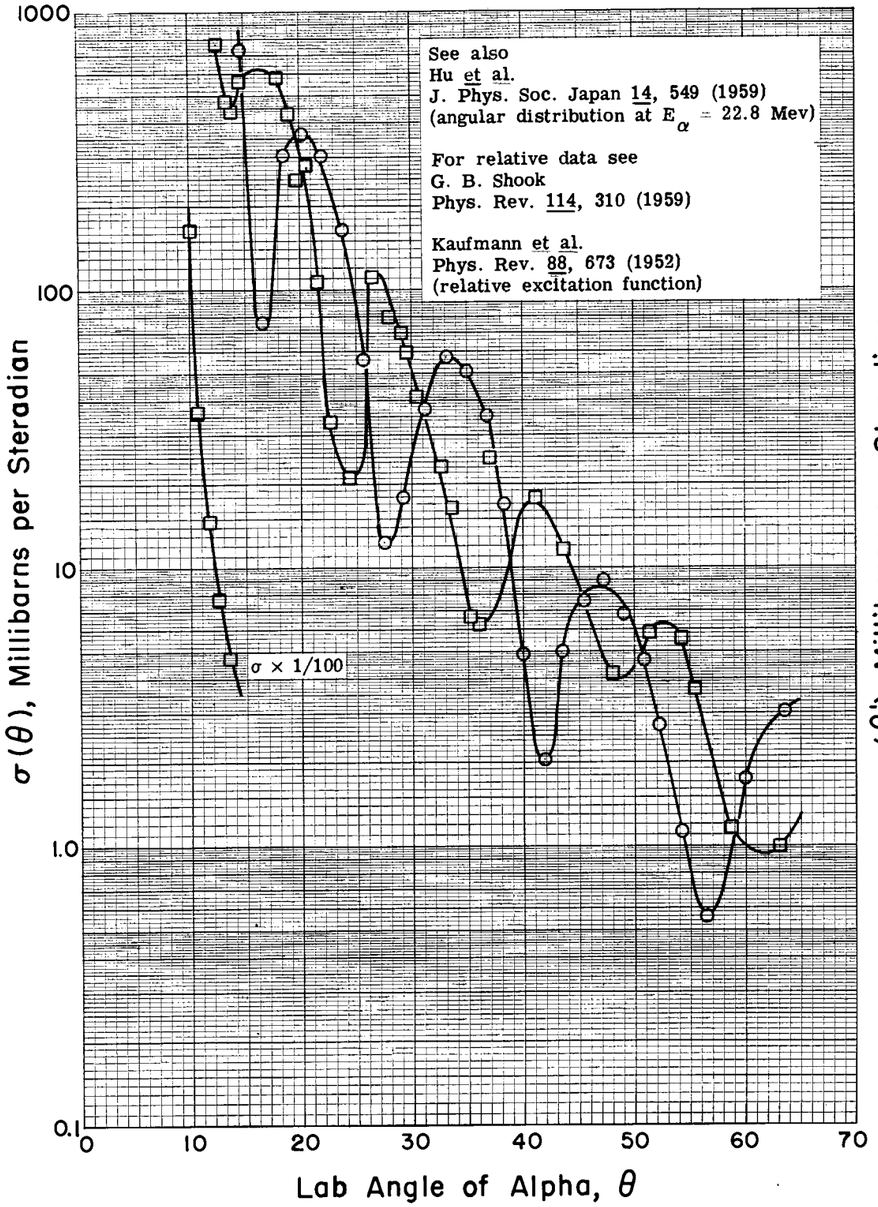
No error stated

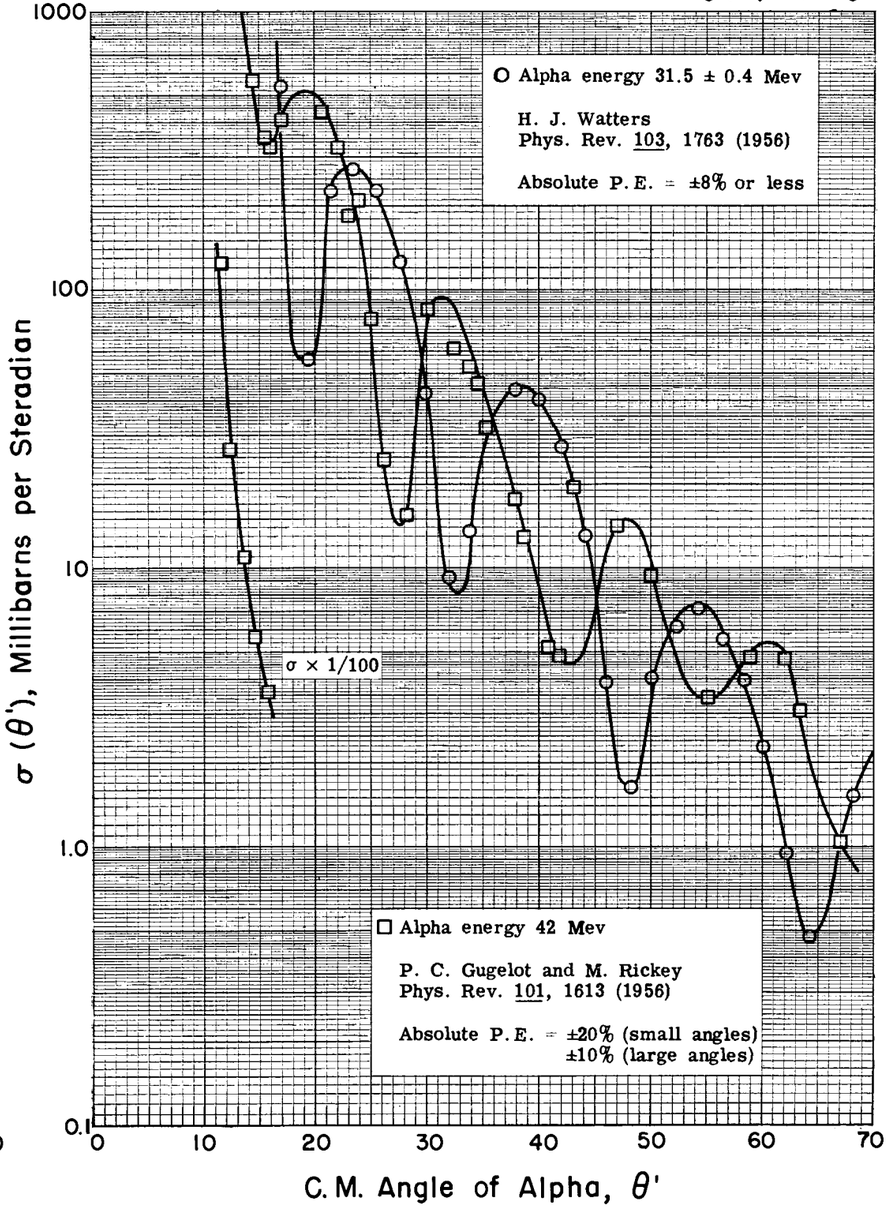
● K. L. Hall
Report AECU-3126 (1955) or
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959)

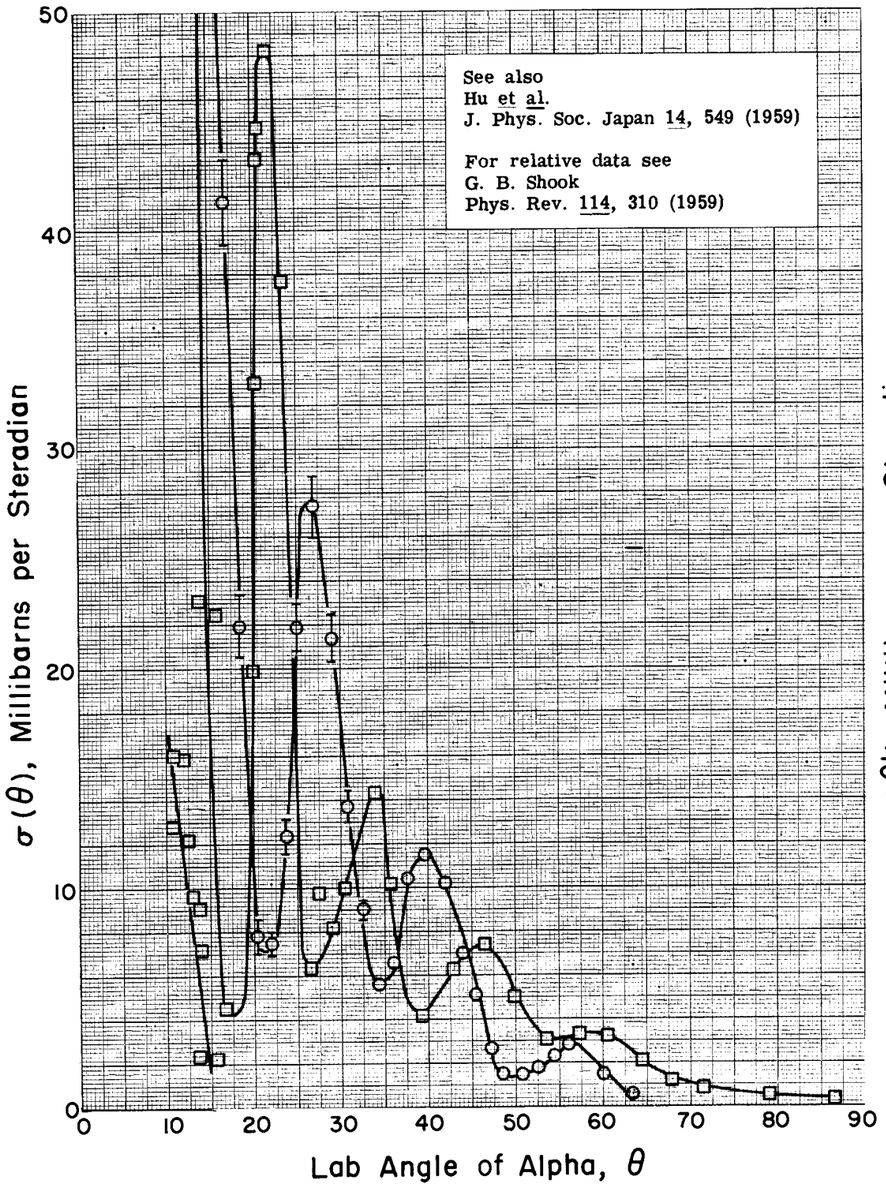
Absolute P.E. = ±2.6%

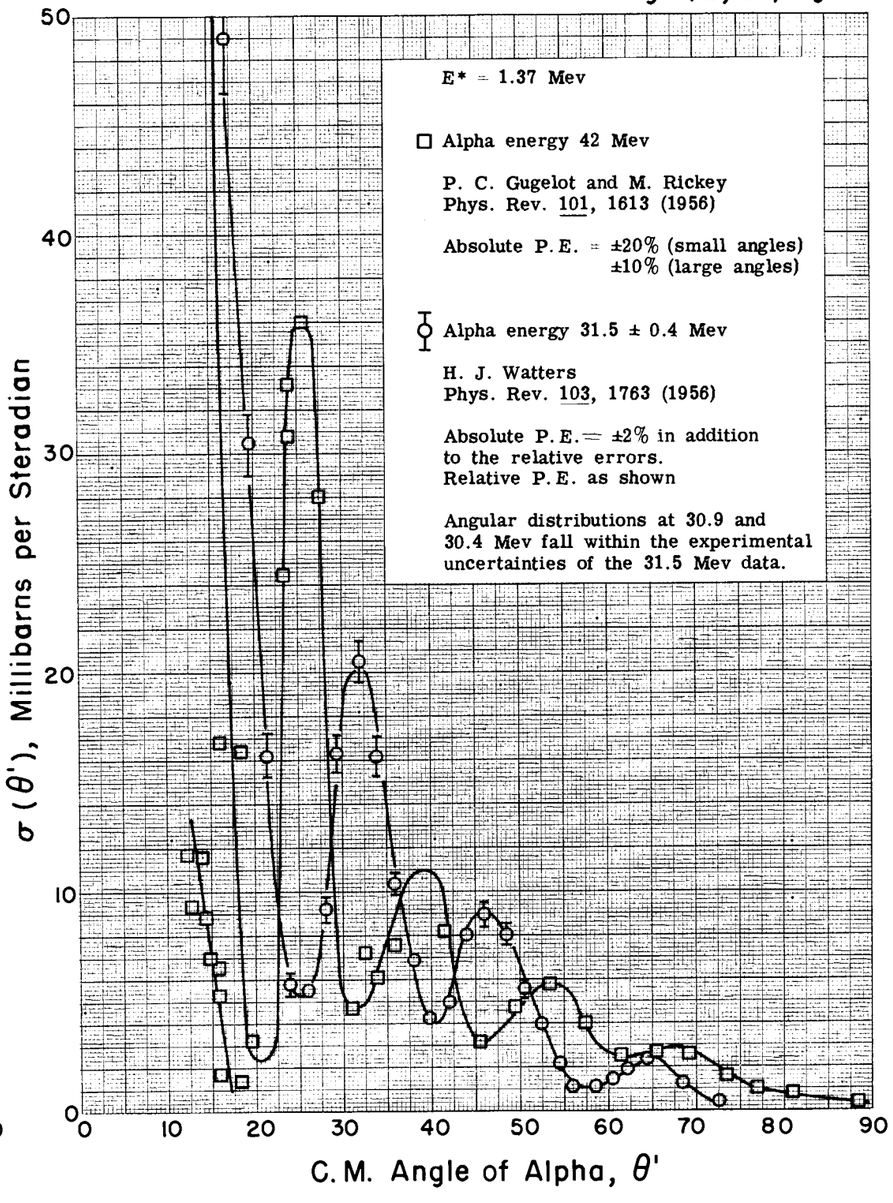
See also
F. O. Bartell and S. Softky
Phys. Rev. 84, 463 (1951)

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

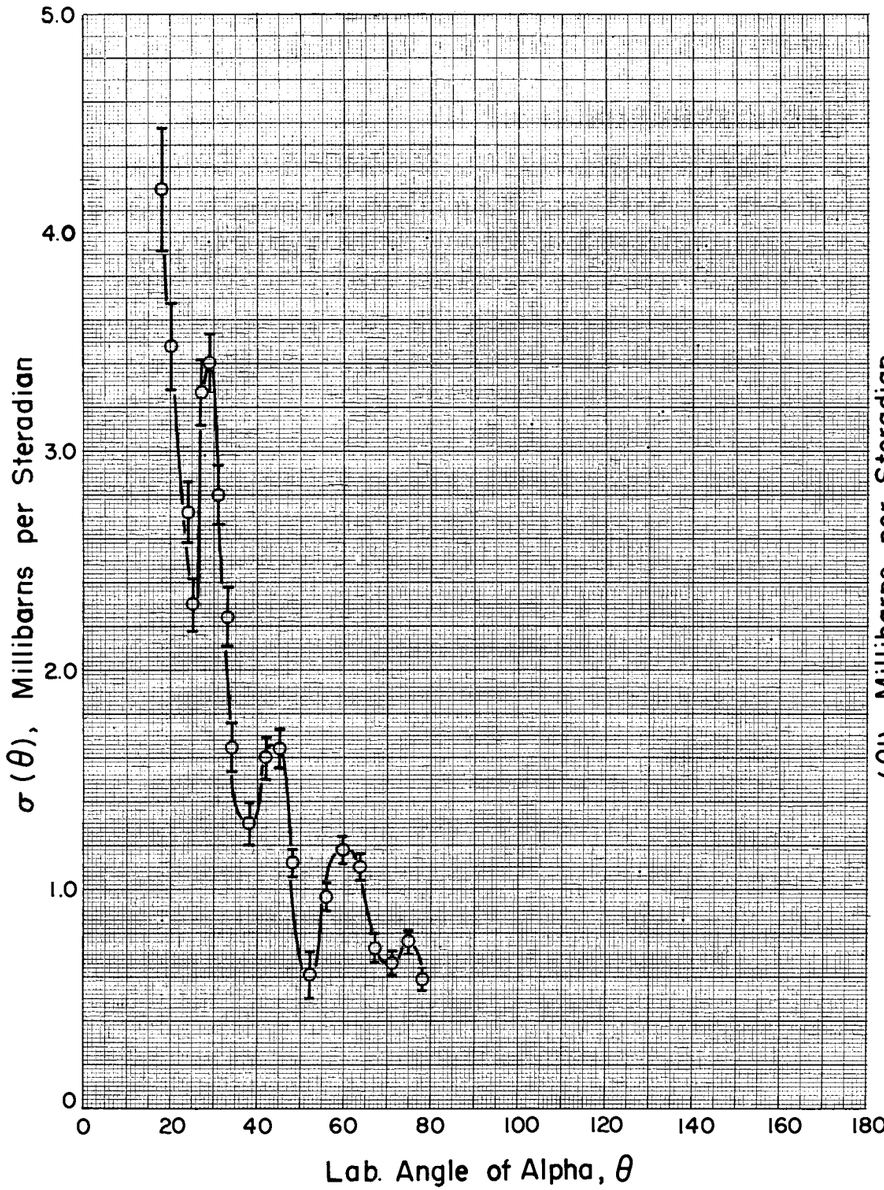

See also
Hu et al.
J. Phys. Soc. Japan 14, 549 (1959)
(angular distribution at E_α = 22.8 Mev)
For relative data see
G. B. Shook
Phys. Rev. 114, 310 (1959)
Kaufmann et al.
Phys. Rev. 88, 673 (1952)
(relative excitation function)
σ × 1/100
σ (θ), Millibarns per Steradian
1000
100
10
1.0
0.1
0
10
20
30
40
50
60
70
Lab Angle of Alpha, θ

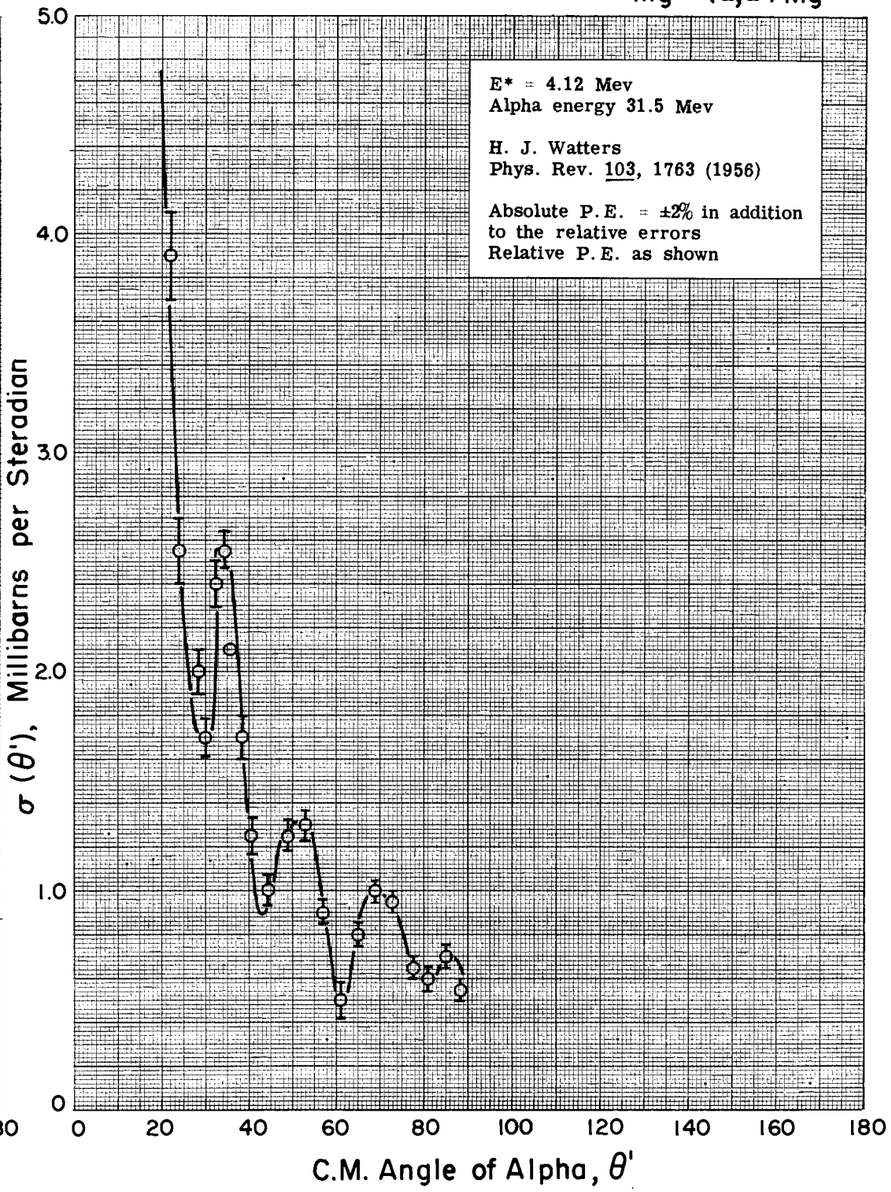

O Alpha energy 31.5 ± 0.4 Mev
H. J. Watters
Phys. Rev. 103, 1763 (1956)
Absolute P.E. = ±8% or less
σ × 1/100
□ Alpha energy 42 Mev
P. C. Gugelot and M. Rickey
Phys. Rev. 101, 1613 (1956)
Absolute P.E. = ±20% (small angles)
±10% (large angles)
σ (θ'), Millibarns per Steradian
1000
100
10
1.0
0.1
0
10
20
30
40
50
60
70
C.M. Angle of Alpha, θ'

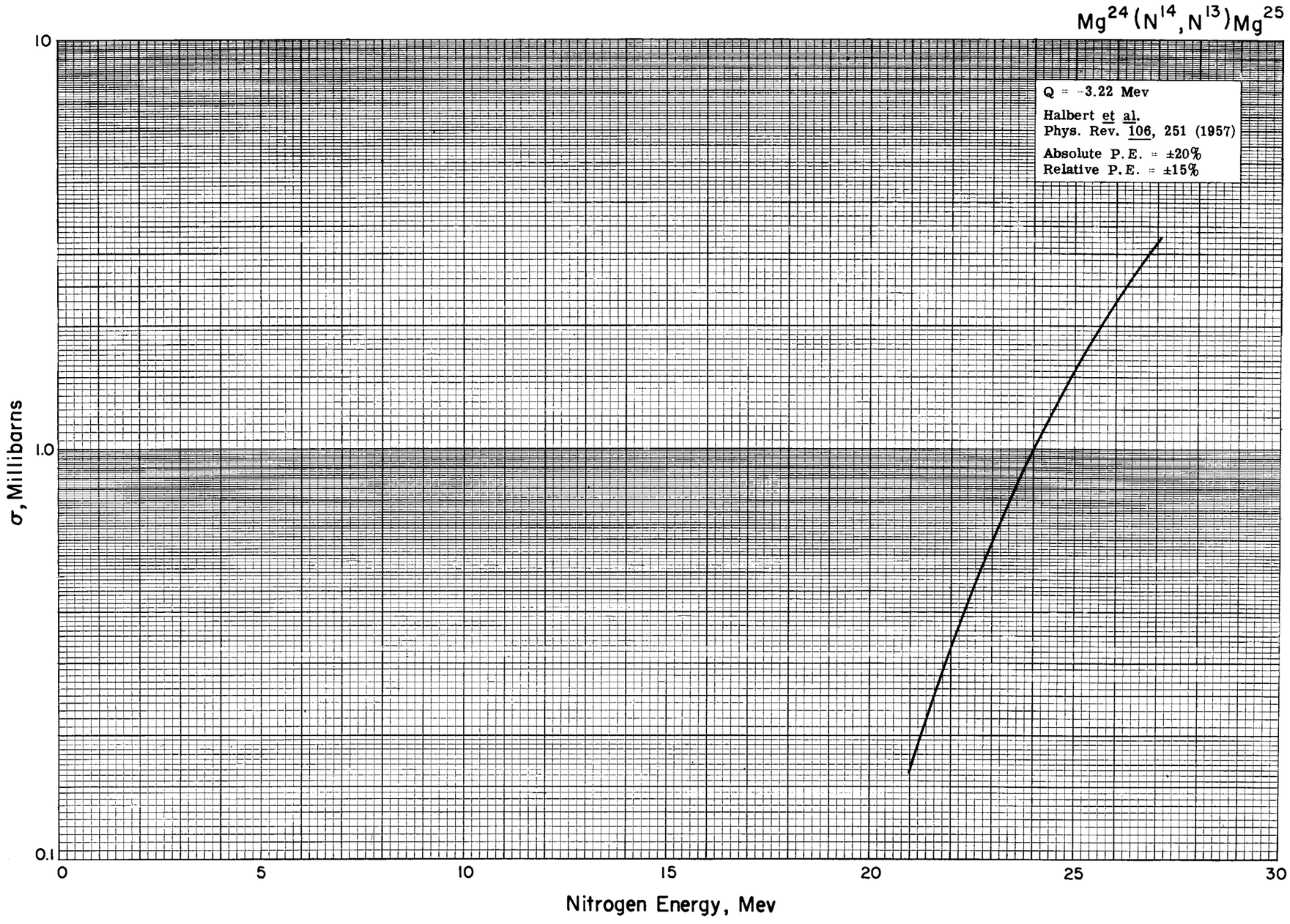

See also
Hu et al.
J. Phys. Soc. Japan 14, 549 (1959)
For relative data see
G. B. Shook
Phys. Rev. 114, 310 (1959)
σ(θ), Millibarns per Steradian
Lab Angle of Alpha, θ
0
10
20
30
40
50
60
70
80
90

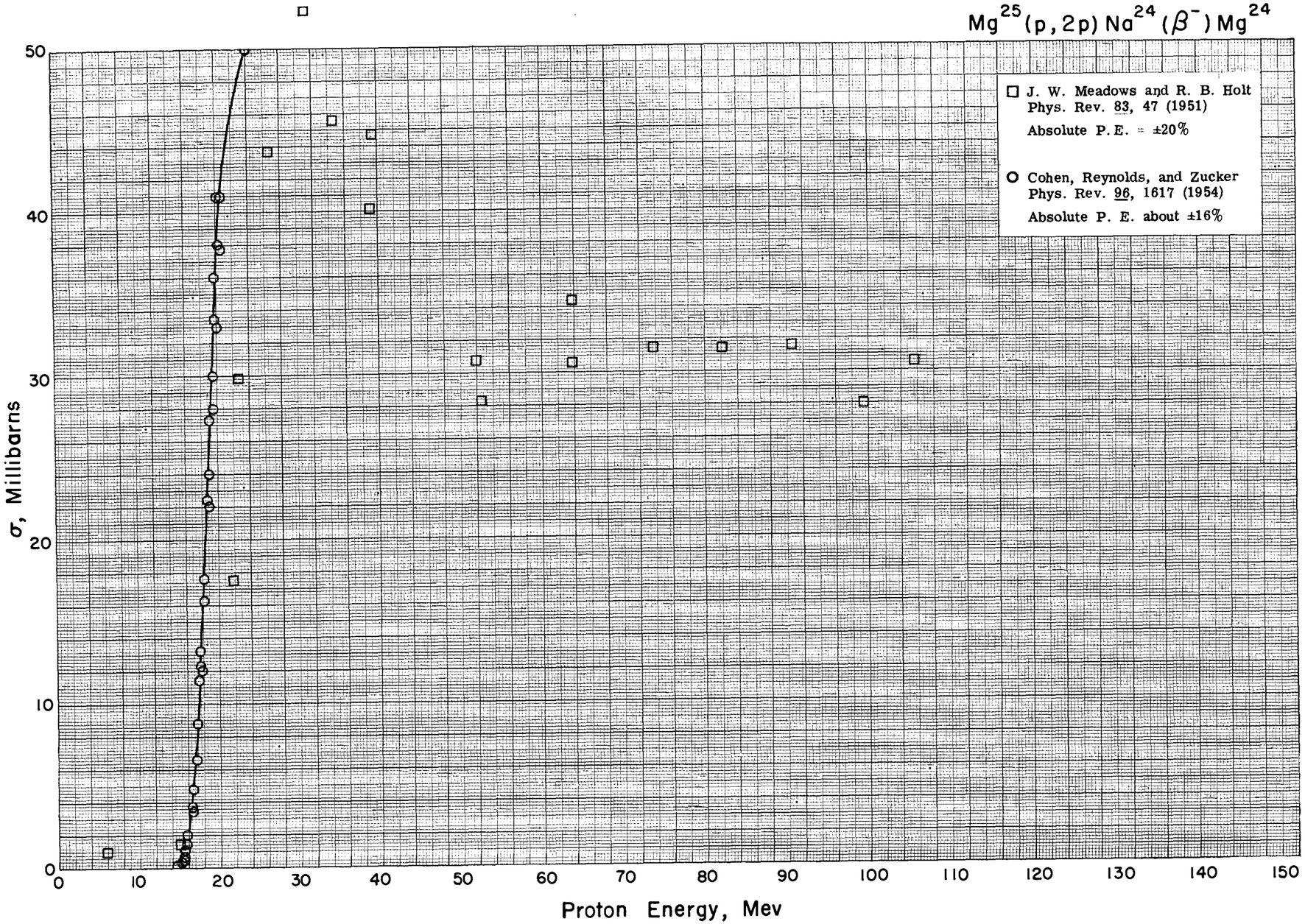

E* = 1.37 Mev
Alpha energy 42 Mev
P. C. Gugelot and M. Rickey
Phys. Rev. 101, 1613 (1956)
Absolute P.E. = ±20% (small angles)
±10% (large angles)
Alpha energy 31.5 ± 0.4 Mev
H. J. Watters
Phys. Rev. 103, 1763 (1956)
Absolute P.E. = ±2% in addition to the relative errors.
Relative P.E. as shown
Angular distributions at 30.9 and 30.4 Mev fall within the experimental uncertainties of the 31.5 Mev data.
σ(θ'), Millibarns per Steradian
C.M. Angle of Alpha, θ'
0
10
20
30
40
50
60
70
80
90

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

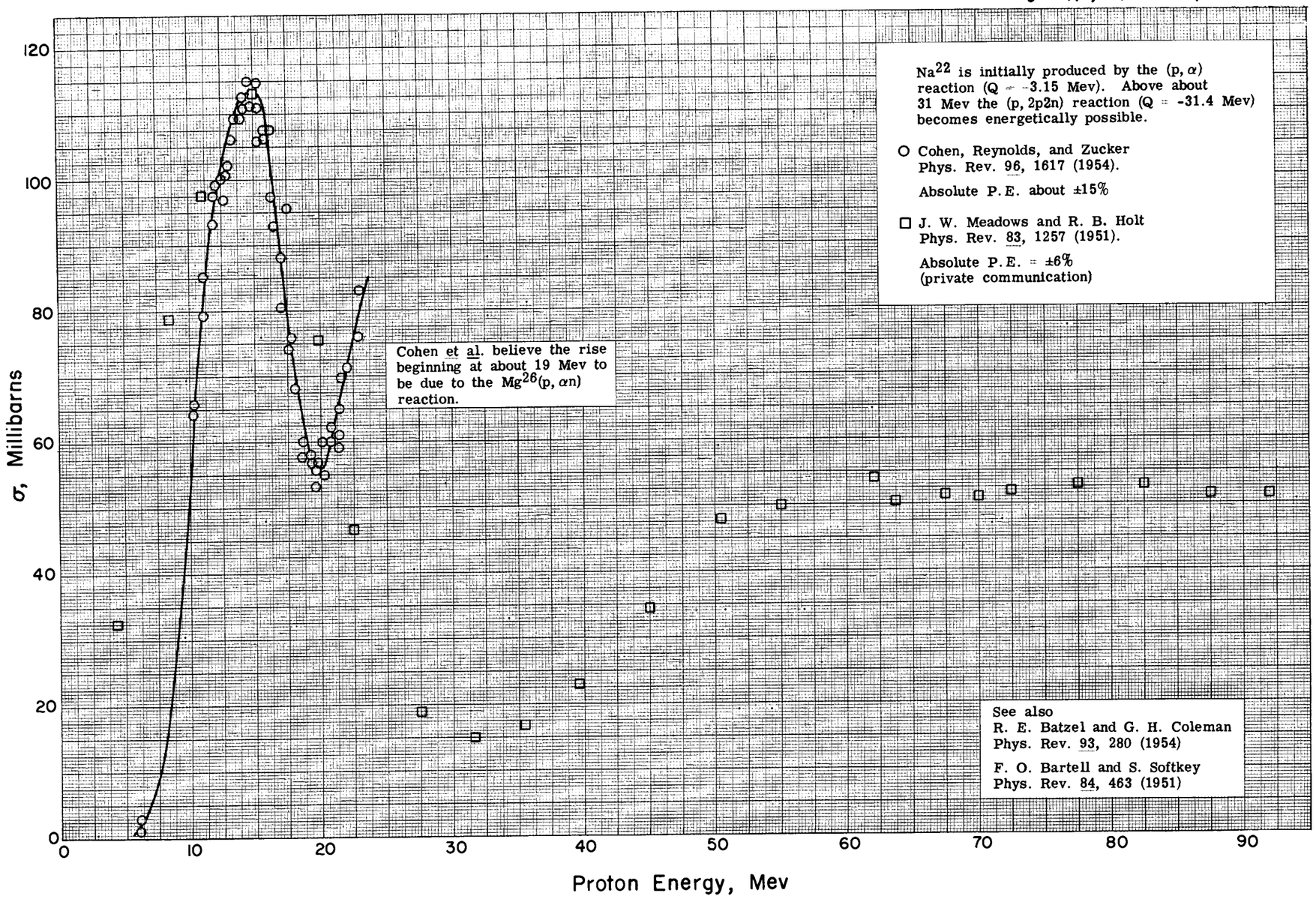


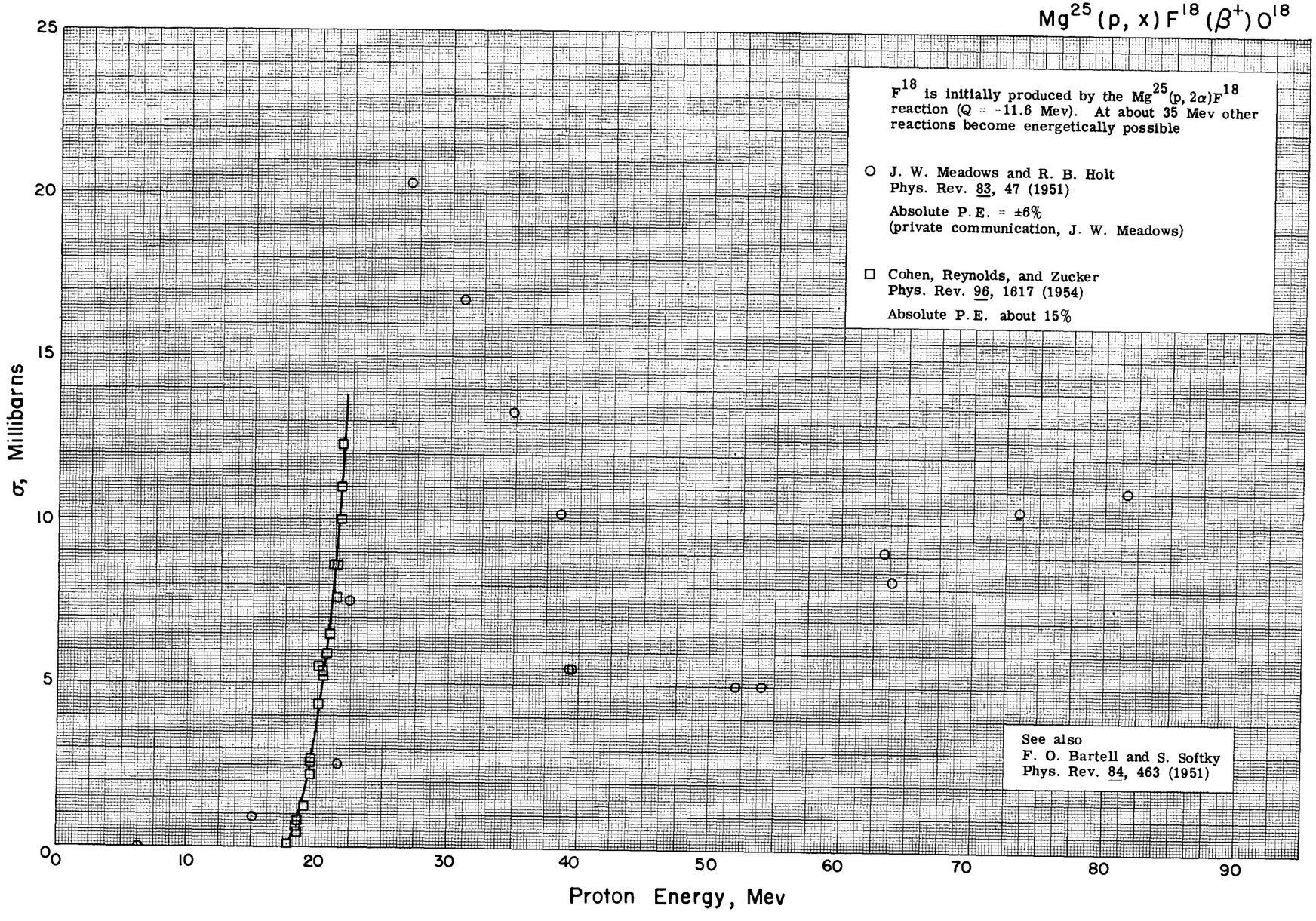



$Mg^{24}(N^{14},N^{13})Mg^{25}$
Q = -3.22 Mev
Halbert et al.
Phys. Rev. 106, 251 (1957)
Absolute P.E. = ±20%
Relative P.E. = ±15%
σ, Millibarns
10
1.0
0.1
0
5
10
15
20
25
30
Nitrogen Energy, Mev

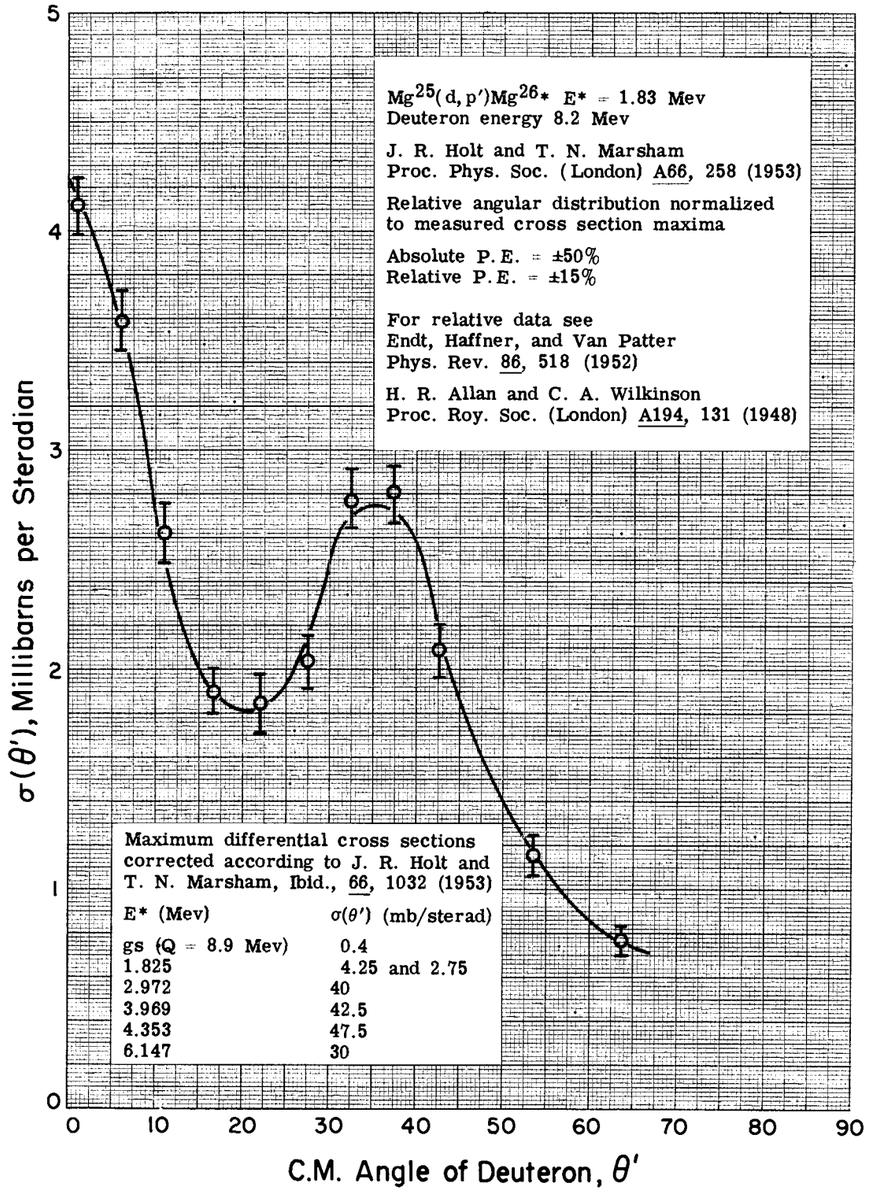

$Mg^{25}(p,2p)Na^{24}(\beta^-)Mg^{24}$
J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951)
Absolute P.E. = ±20%
Cohen, Reynolds, and Zucker
Phys. Rev. 96, 1617 (1954)
Absolute P. E. about ±16%
σ, Millibarns
Proton Energy, Mev
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

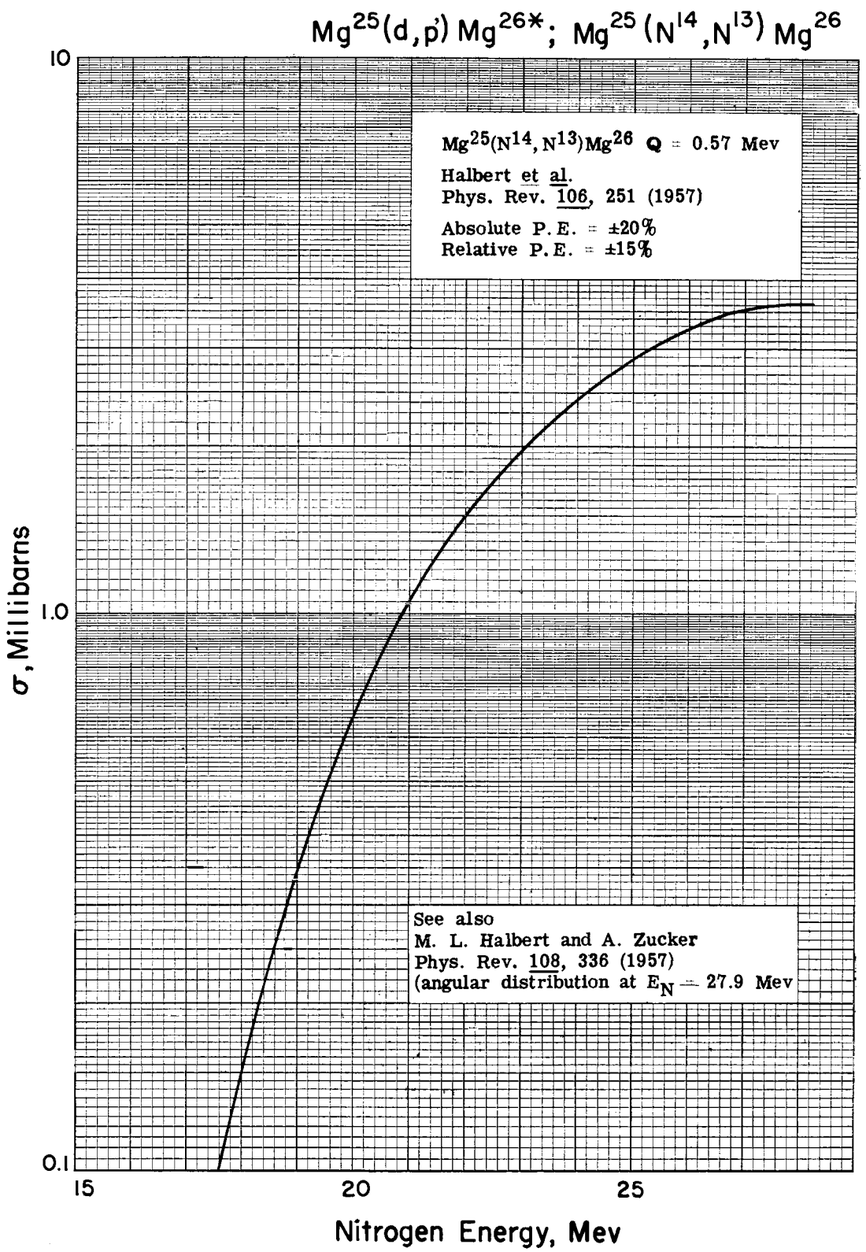
$Mg^{25}(p, x)Na^{22}(\beta^+)Ne^{22}$

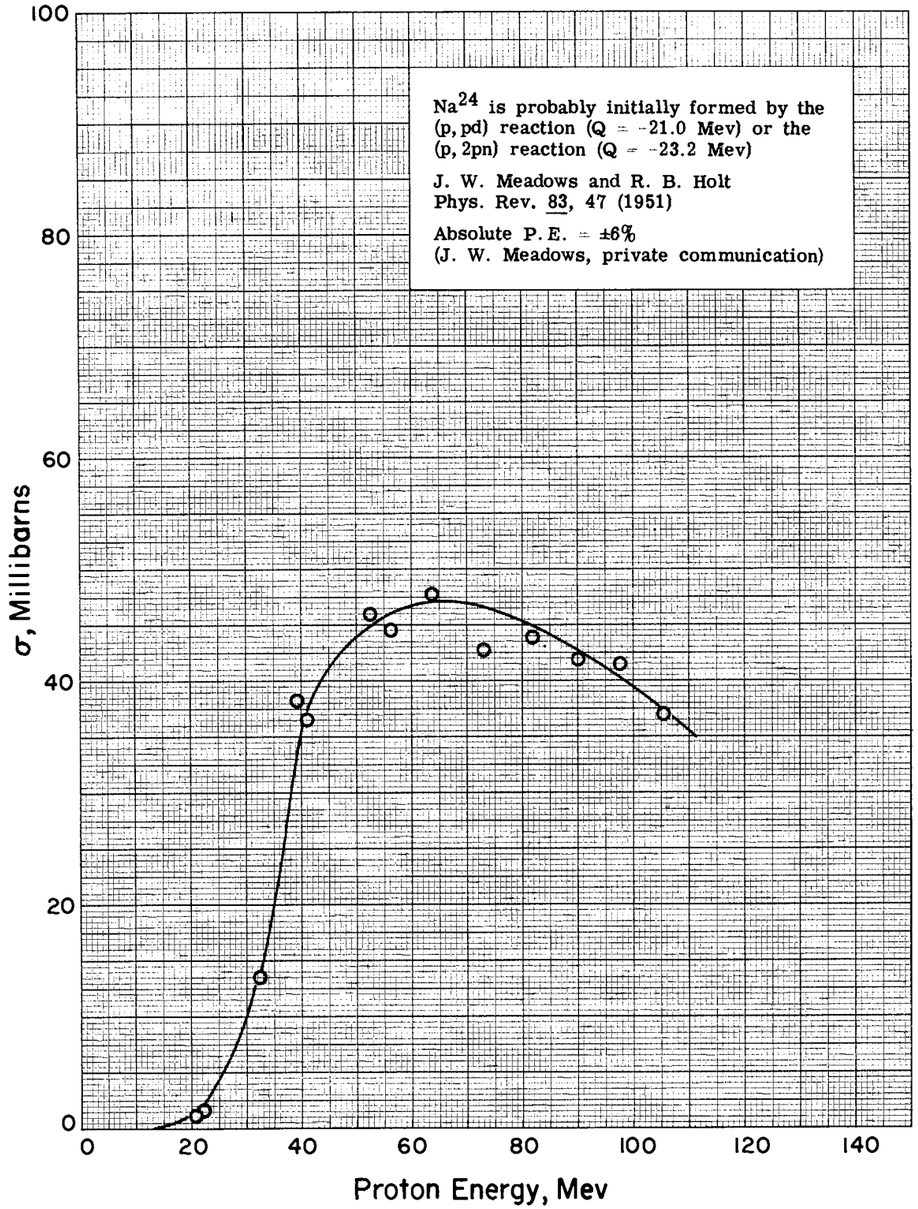


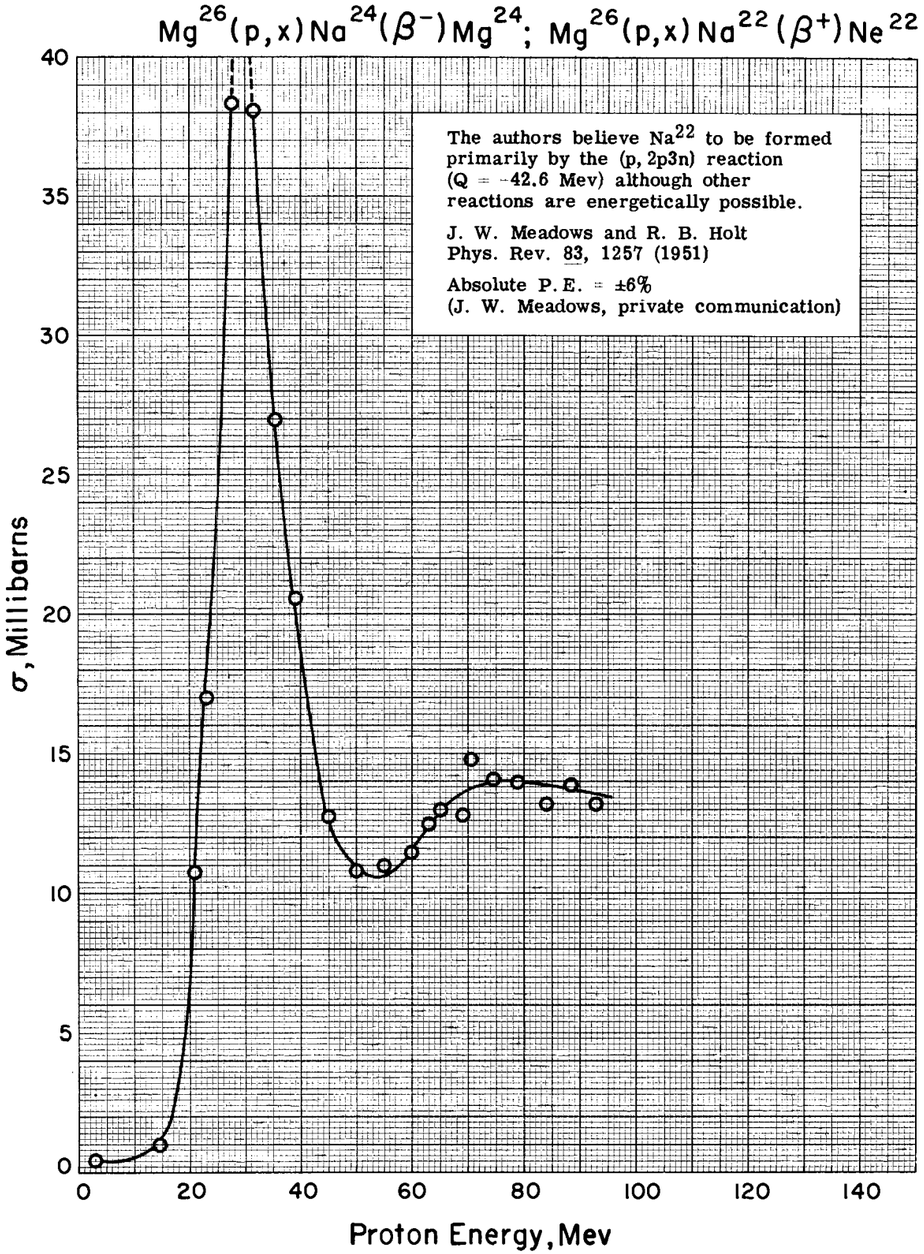


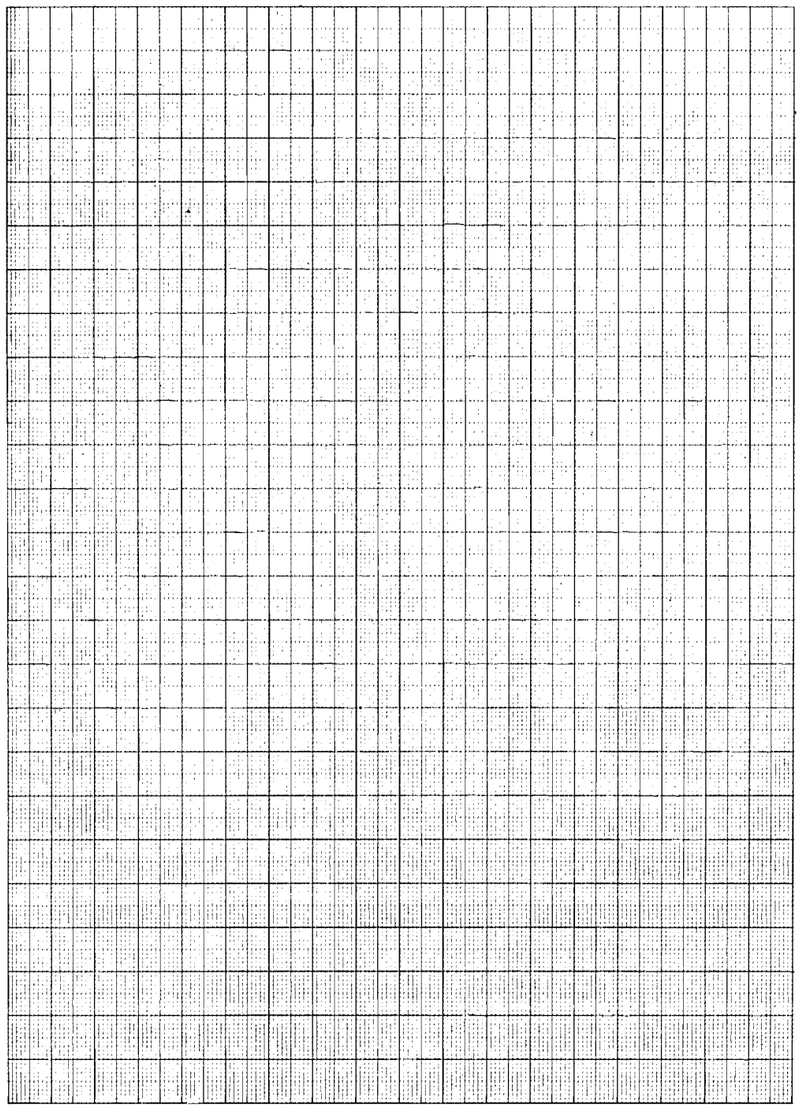
$Mg^{25}(p, x)F^{18}(\beta^+)O^{18}$
F^{18} is initially produced by the $Mg^{25}(p, 2\alpha)F^{18}$ reaction (Q = -11.6 Mev). At about 35 Mev other reactions become energetically possible
○ J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951)
Absolute P.E. = ±6%
(private communication, J. W. Meadows)
□ 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


$Mg^{25}(d,p')Mg^{26*}$ E* = 1.83 Mev
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 258 (1953)
Relative angular distribution normalized to measured cross section maxima
Absolute P.E. = ±50%
Relative P.E. = ±15%
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)
Maximum differential cross sections corrected according to J. R. Holt and T. N. Marsham, Ibid., 66, 1032 (1953)
E* (Mev) σ(θ') (mb/sterad)
gs (Q = 8.9 Mev) 0.4
1.825 4.25 and 2.75
2.972 40
3.969 42.5
4.353 47.5
6.147 30
σ(θ'), Millibarns per Steradian
C.M. Angle of Deuteron, θ'
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90


$Mg^{25}(d,p')Mg^{26*}$; $Mg^{25}(N^{14},N^{13})Mg^{26}$
$Mg^{25}(N^{14},N^{13})Mg^{26}$ Q = 0.57 Mev
Halbert et al.
Phys. Rev. 106, 251 (1957)
Absolute P.E. = ±20%
Relative P.E. = ±15%
See also
M. L. Halbert and A. Zucker
Phys. Rev. 108, 336 (1957)
(angular distribution at E_N = 27.9 Mev
σ, Millibarns
Nitrogen Energy, Mev
0.1
1.0
10
15
20
25


Na^{24} is probably initially formed by the (p, pd) reaction (Q = −21.0 Mev) or the (p, 2pn) reaction (Q = −23.2 Mev)
J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951)
Absolute P. E. = ±6%
(J. W. Meadows, private communication)
σ, Millibarns
Proton Energy, Mev


Mg^{26}(p, x)Na^{24}(β$^-$)Mg^{24}; Mg^{26}(p, x)Na^{22}(β$^+$)Ne^{22}
The authors believe Na^{22} to be formed primarily by the (p, 2p3n) reaction (Q = −42.6 Mev) although other reactions are energetically possible.
J. W. Meadows and R. B. Holt
Phys. Rev. 83, 1257 (1951)
Absolute P. E. = ±6%
(J. W. Meadows, private communication)
σ, Millibarns
Proton Energy, Mev



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

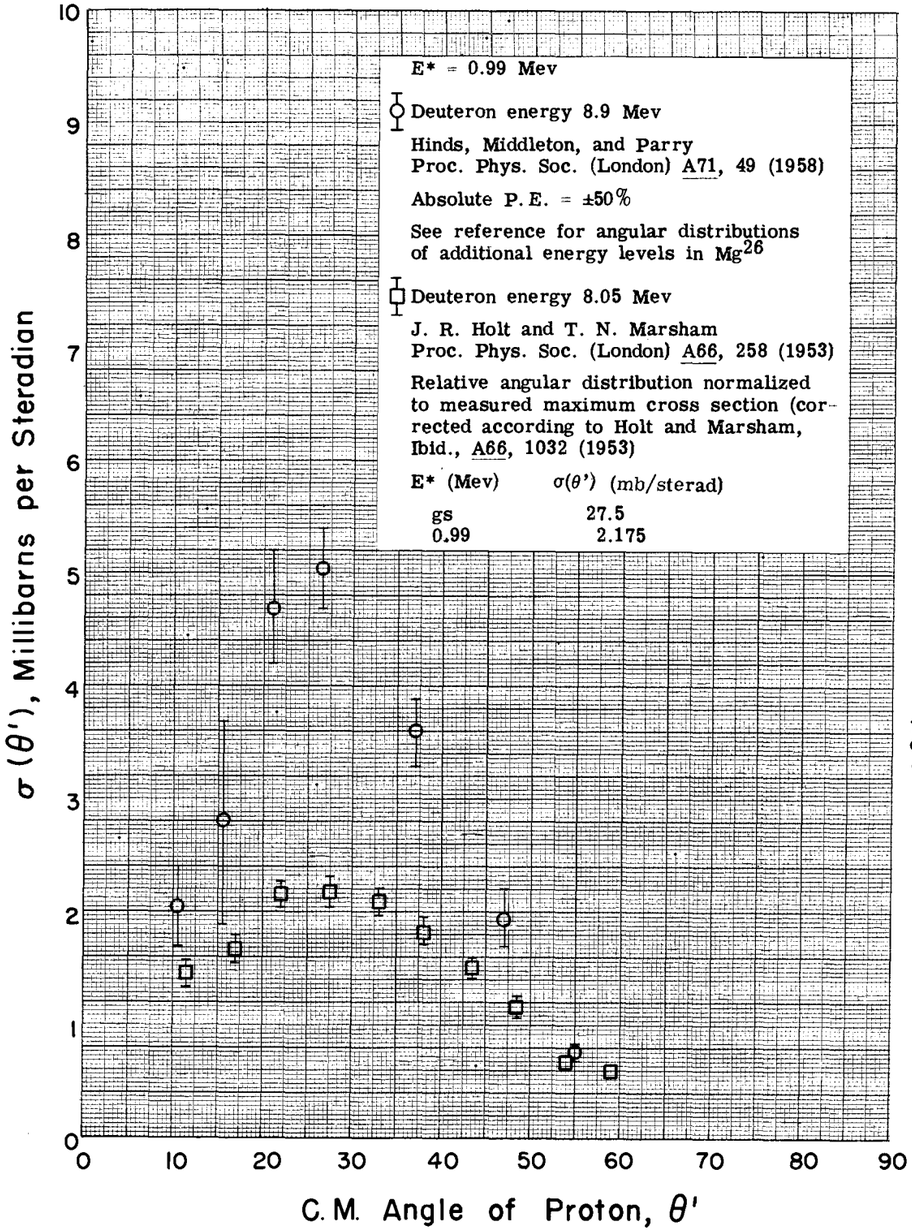
F^{18} is probably initially formed by the $(p, 2\alpha n)$ reaction (Q = -22.8 Mev). At about 40 Mev other reactions become energetically possible.

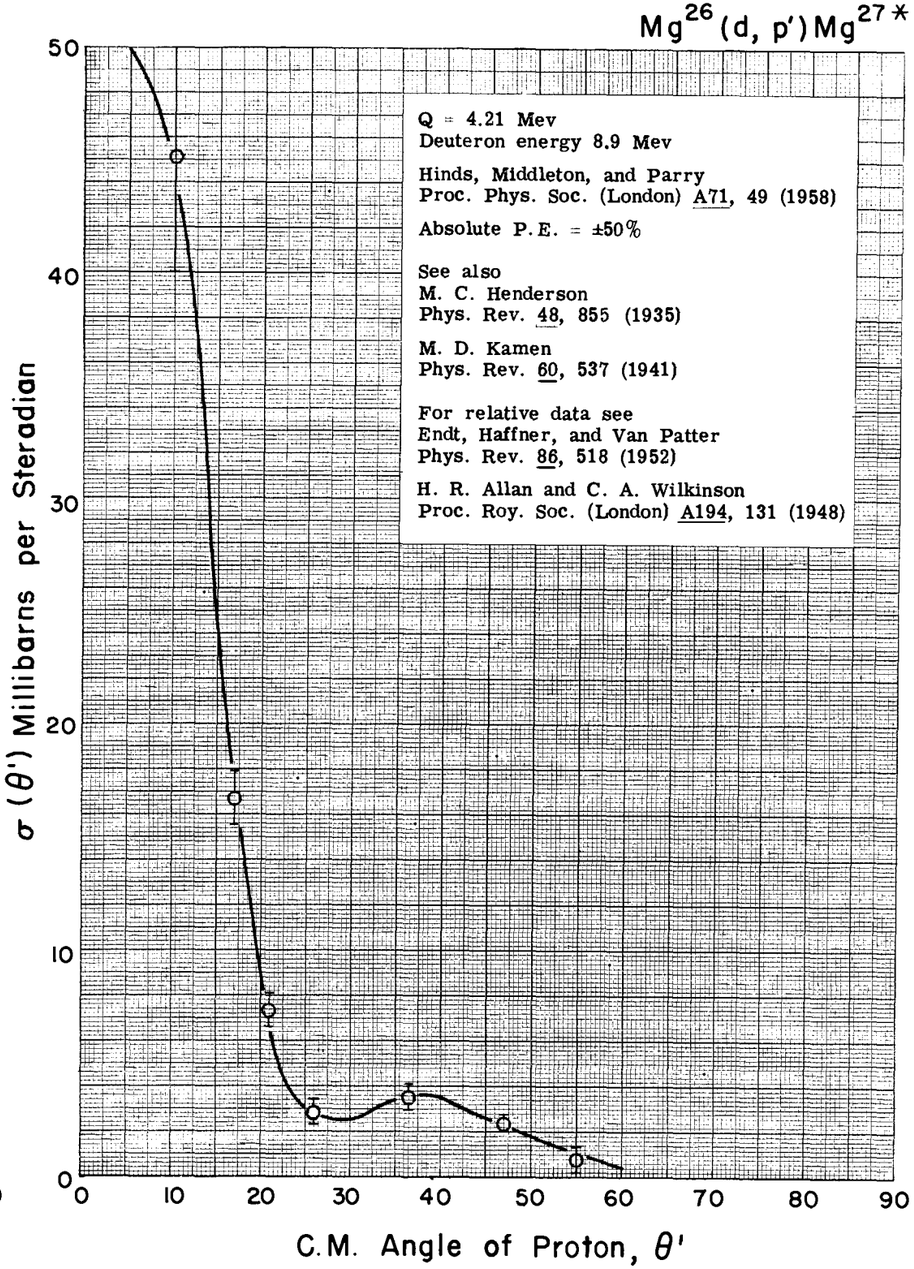
J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951)

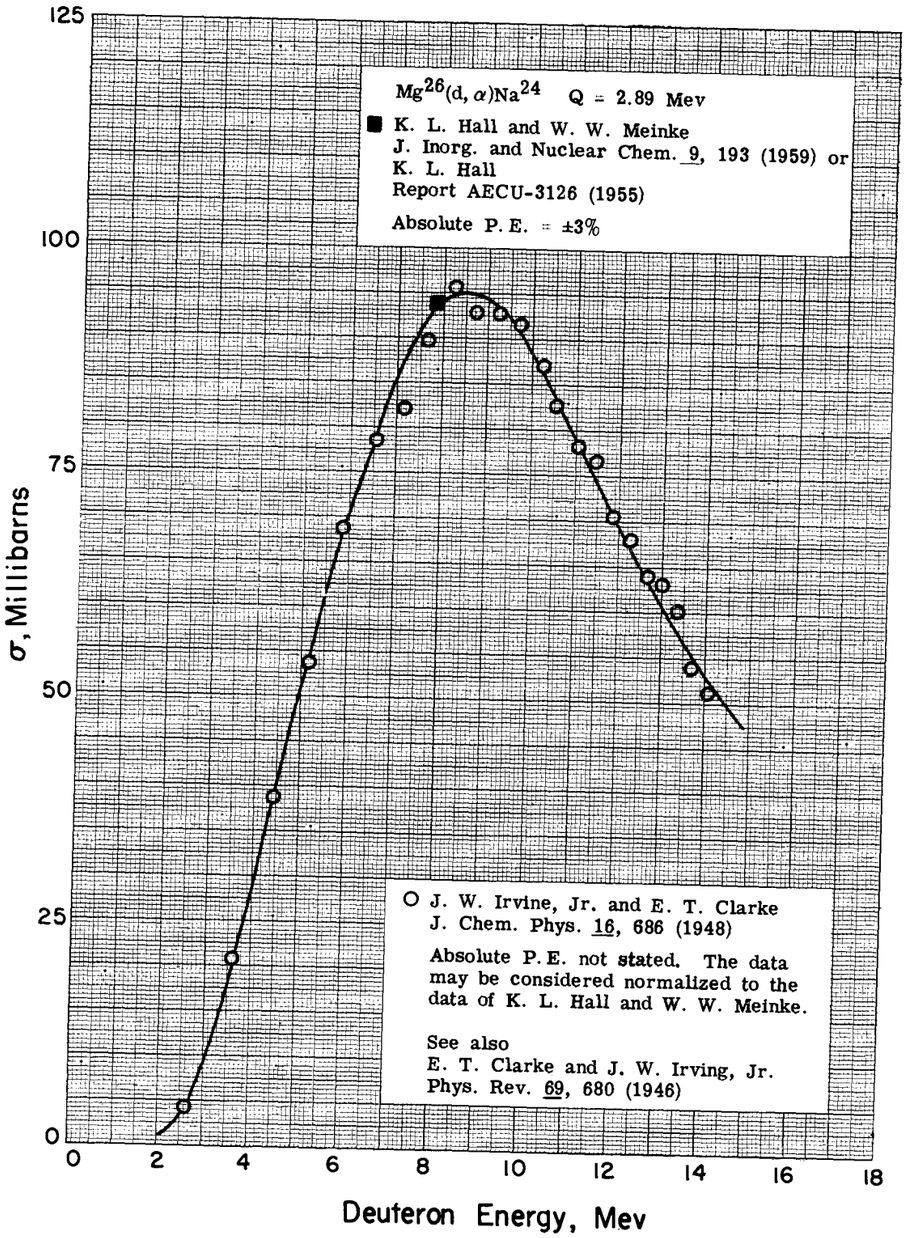
Absolute P.E. = ±6%
(J. W. Meadows, private communications)

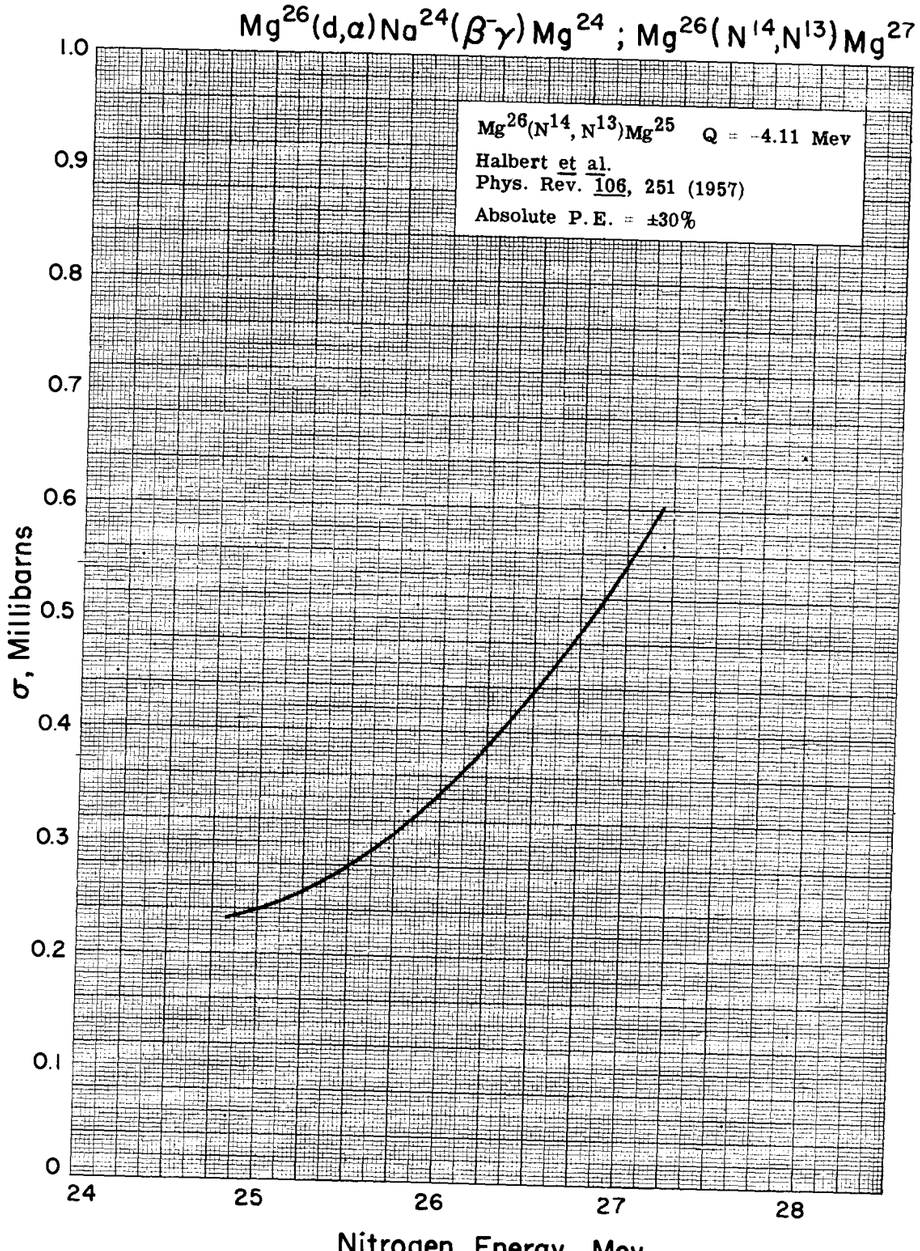
σ, Millibarns

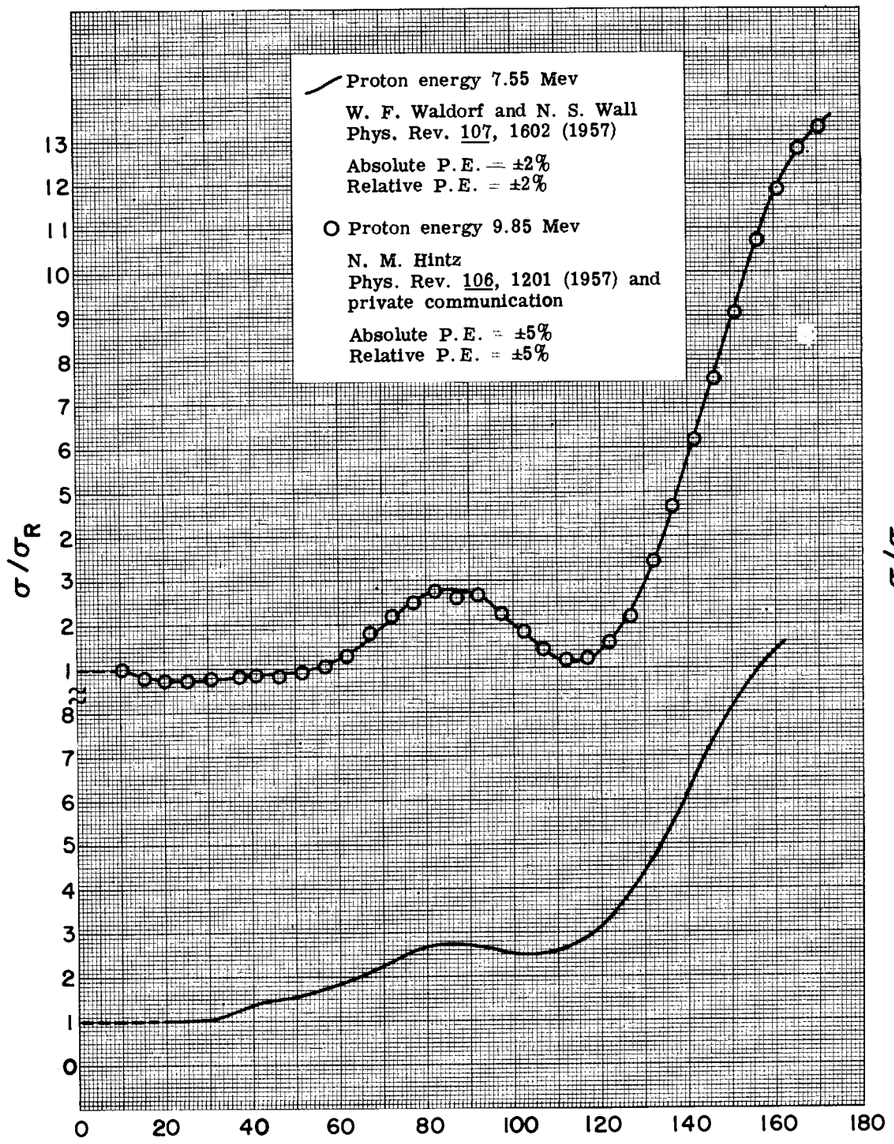
Proton Energy, Mev

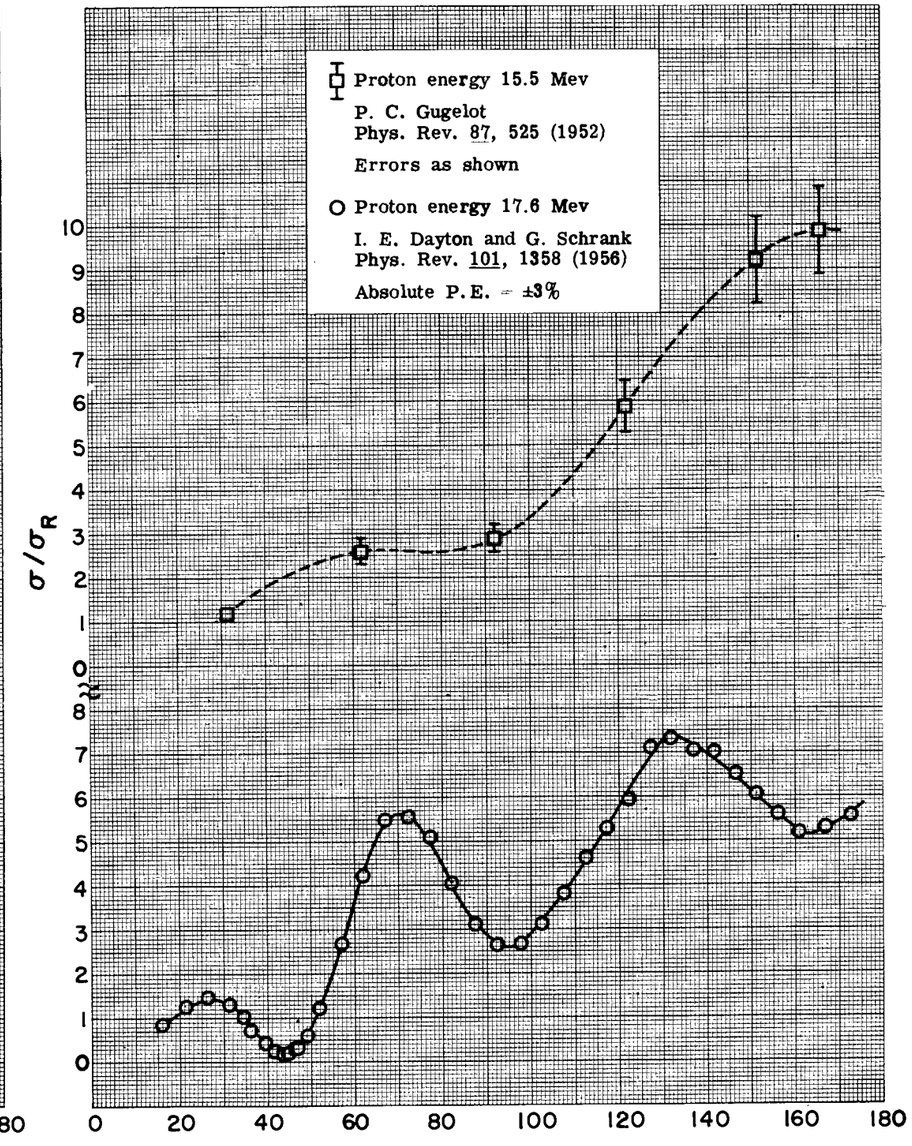

E* = 0.99 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A71, 49 (1958)
Absolute P.E. = ±50%
See reference for angular distributions of additional energy levels in Mg26
Deuteron energy 8.05 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 258 (1953)
Relative 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'

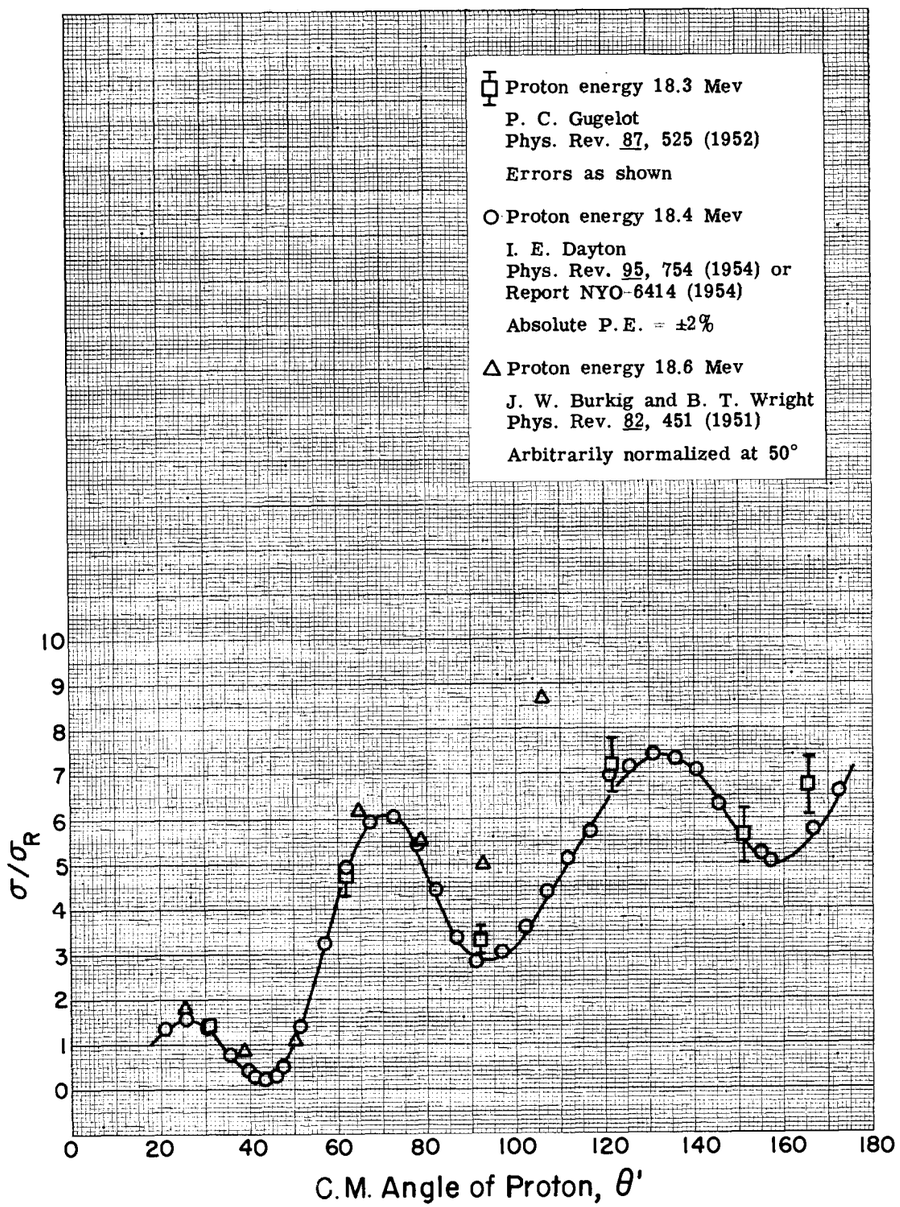

Mg26(d, p')Mg27*
Q = 4.21 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A71, 49 (1958)
Absolute P.E. = ±50%
See also
M. C. Henderson
Phys. Rev. 48, 855 (1935)
M. D. Kamen
Phys. Rev. 60, 537 (1941)
For relative data see
Endt, Haffner, and Van Patter
Phys. Rev. 86, 518 (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'

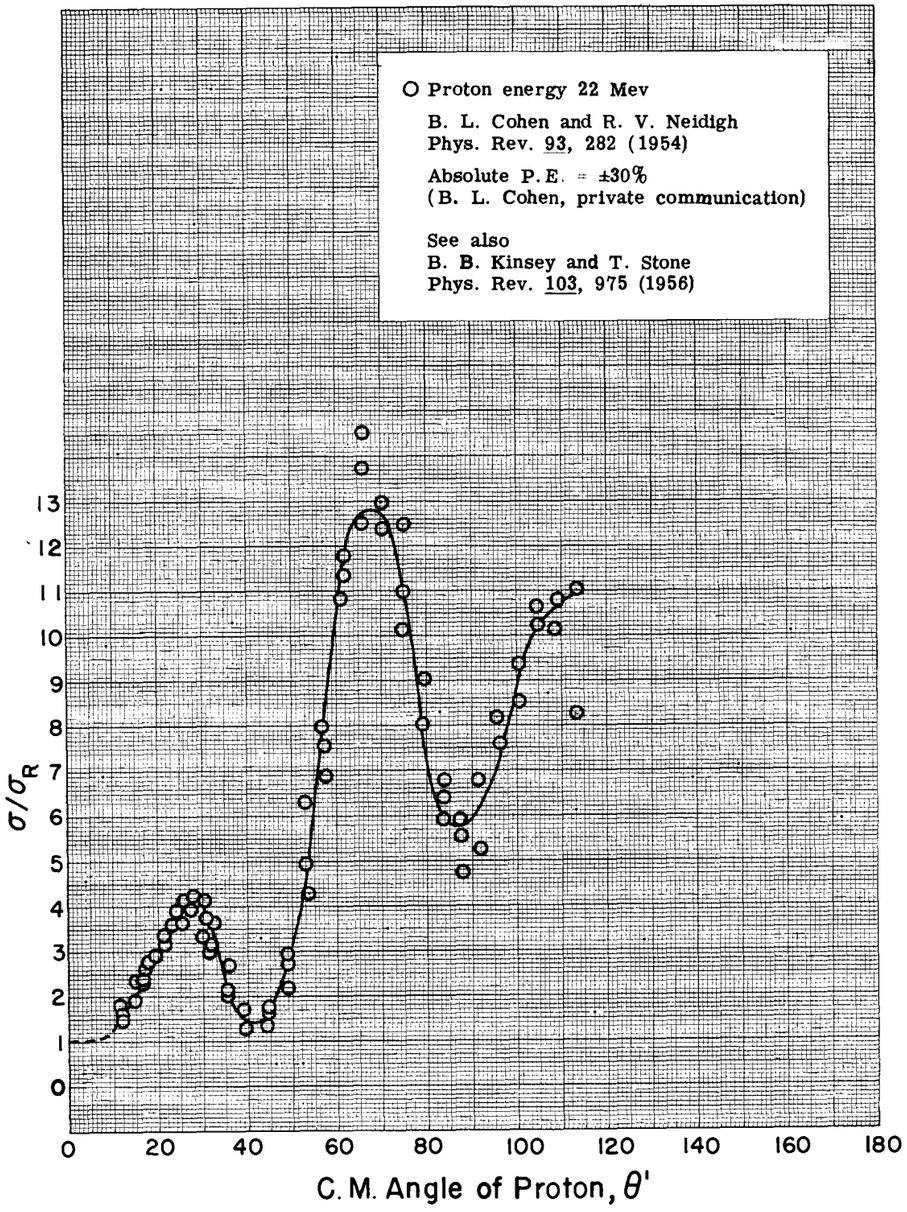

$Mg^{26}(d, \alpha)Na^{24}$ Q = 2.89 Mev
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959) or
K. L. Hall
Report AECU-3126 (1955)
Absolute P. E. = ±3%
O J. W. Irvine, Jr. and E. T. Clarke
J. Chem. Phys. 16, 686 (1948)
Absolute P. E. not stated. The data may be considered normalized to the data of K. L. Hall and W. W. Meinke.
See also
E. T. Clarke and J. W. Irving, Jr.
Phys. Rev. 69, 680 (1946)
σ, Millibarns
Deuteron Energy, Mev
0
25
50
75
100
125
0
2
4
6
8
10
12
14
16
18

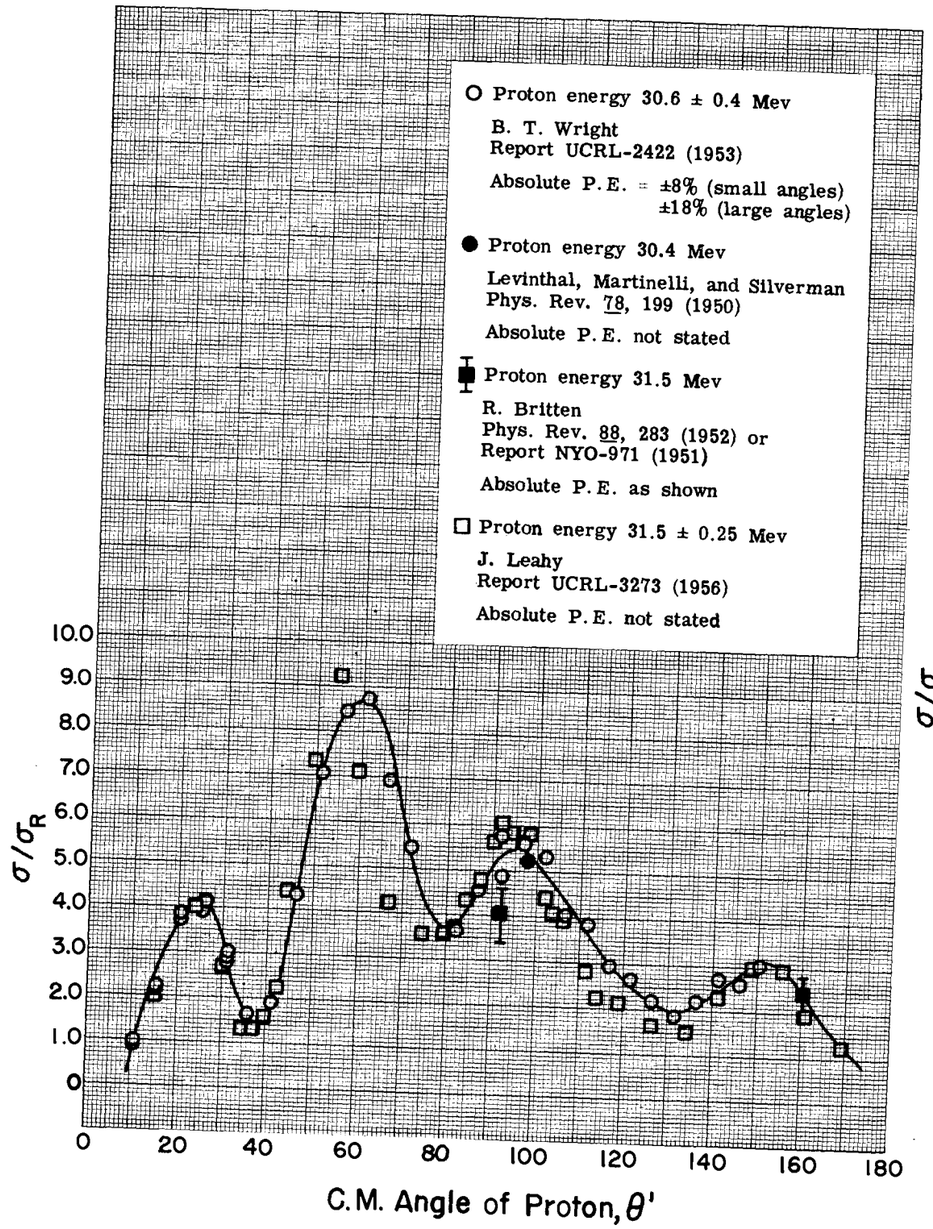

$Mg^{26}(d,\alpha)Na^{24}(\beta^-\gamma)Mg^{24}$; $Mg^{26}(N^{14},N^{13})Mg^{27}$
$Mg^{26}(N^{14}, N^{13})Mg^{25}$ Q = -4.11 Mev
Halbert et al.
Phys. Rev. 106, 251 (1957)
Absolute P.E. = ±30%
σ, Millibarns
Nitrogen Energy, Mev
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
24
25
26
27
28

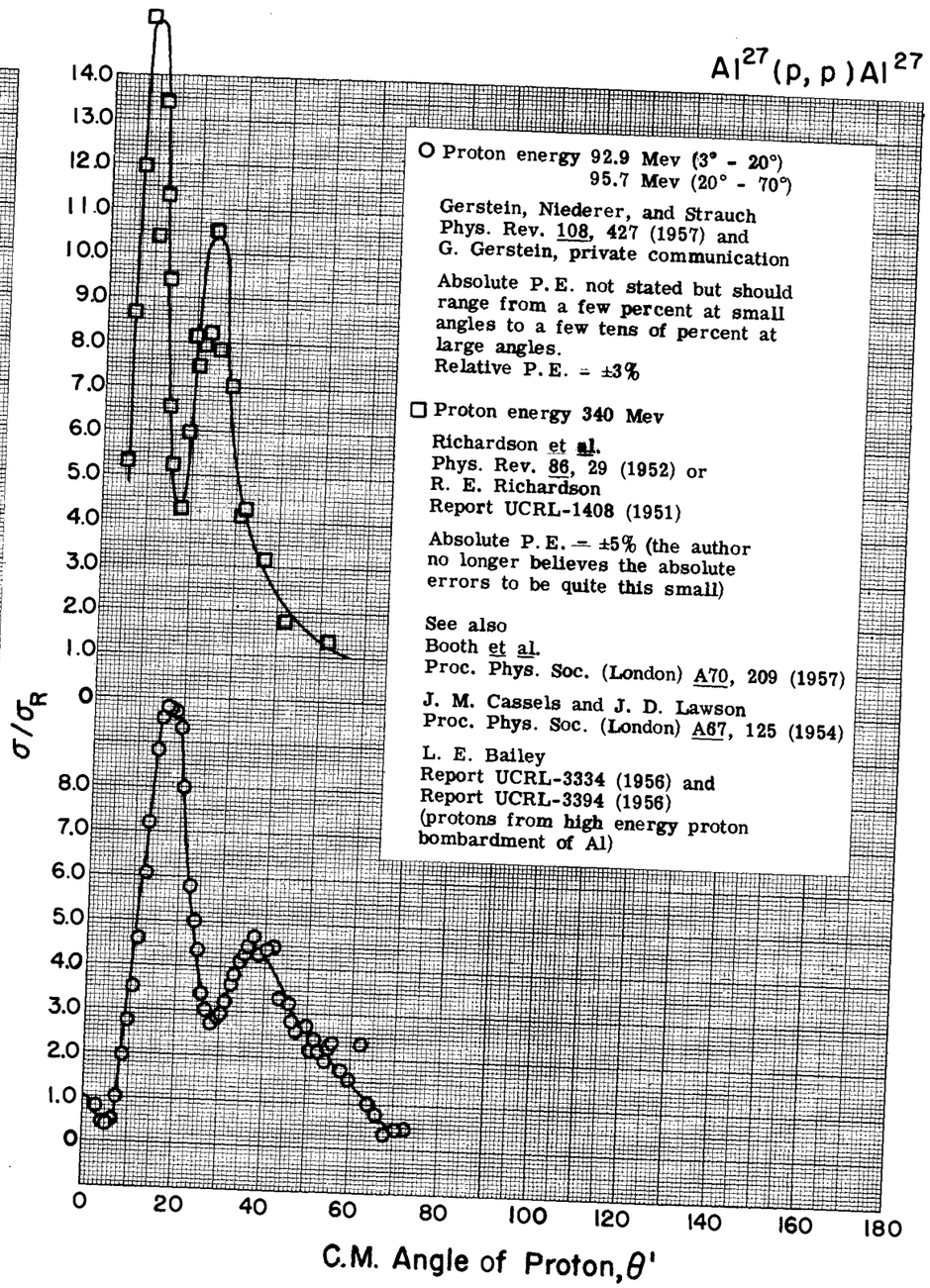

Proton energy 7.55 Mev
W. F. Waldorf and N. S. Wall
Phys. Rev. 107, 1602 (1957)
Absolute P.E. = ±2%
Relative P.E. = ±2%
O Proton energy 9.85 Mev
N. M. Hintz
Phys. Rev. 106, 1201 (1957) and
private communication
Absolute P.E. = ±5%
Relative P.E. = ±5%
σ/σR
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'

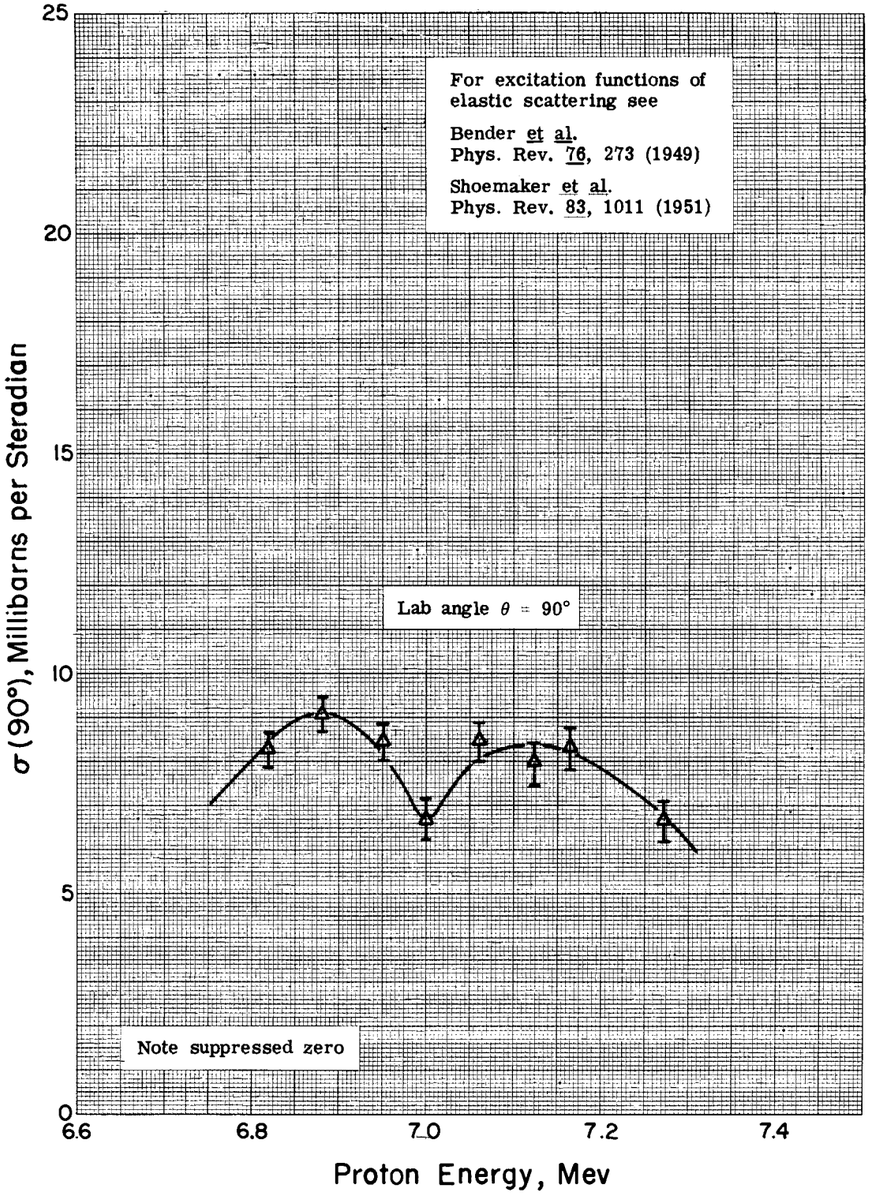

Proton energy 15.5 Mev
P. C. Gugelot
Phys. Rev. 87, 525 (1952)
Errors as shown
O Proton energy 17.6 Mev
I. E. Dayton and G. Schrank
Phys. Rev. 101, 1358 (1956)
Absolute P.E. = ±3%
σ/σR
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Proton, θ'

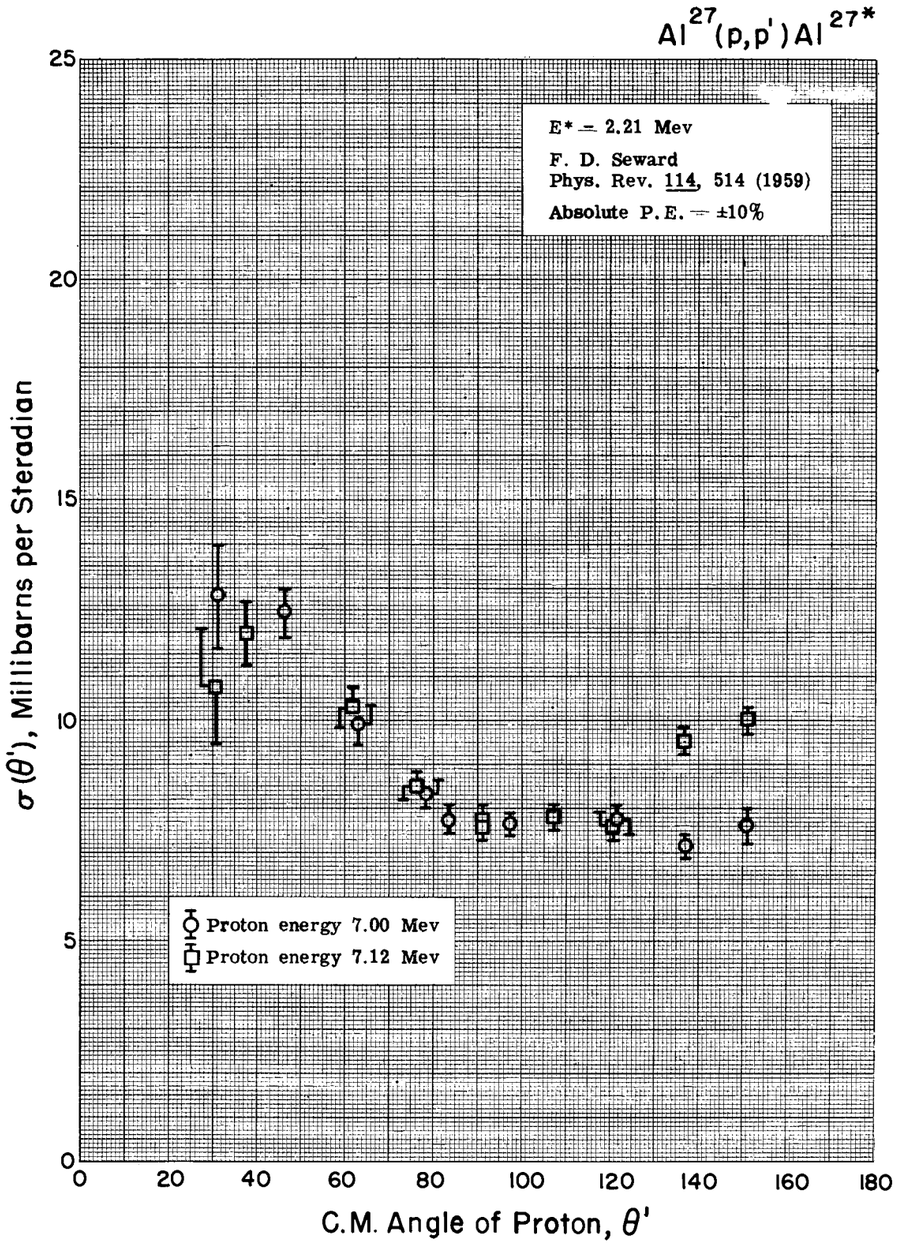

Proton energy 18.3 Mev
P. C. Gugelot
Phys. Rev. 87, 525 (1952)
Errors as shown
Proton energy 18.4 Mev
I. E. Dayton
Phys. Rev. 95, 754 (1954) or
Report NYO-6414 (1954)
Absolute P.E. = ±2%
Proton energy 18.6 Mev
J. W. Burkig and B. T. Wright
Phys. Rev. 82, 451 (1951)
Arbitrarily normalized at 50°
σ/σR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

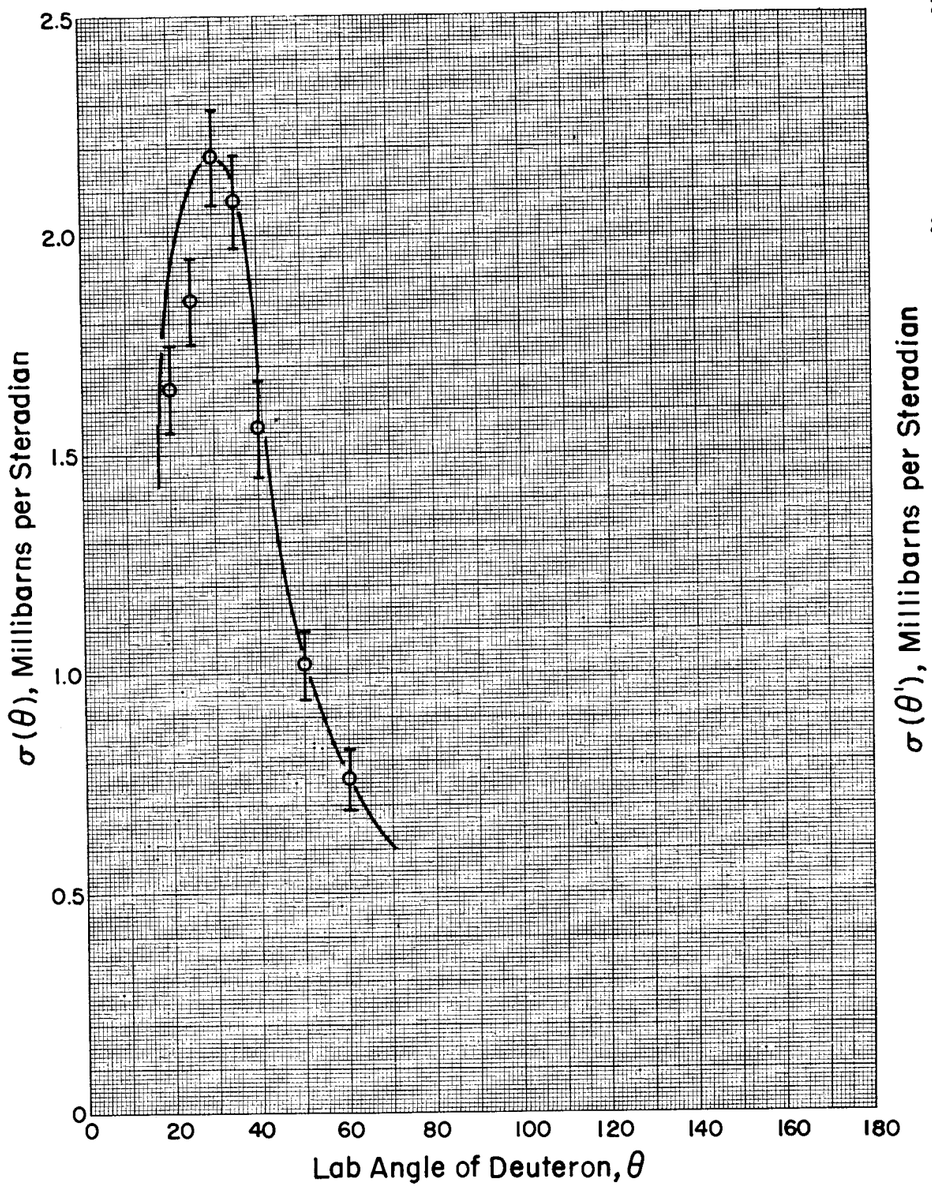

Proton energy 22 Mev
B. L. Cohen and R. V. Neidigh
Phys. Rev. 93, 282 (1954)
Absolute P.E. = ±30%
(B. L. Cohen, private communication)
See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
σ/σR
C.M. Angle of Proton, θ'

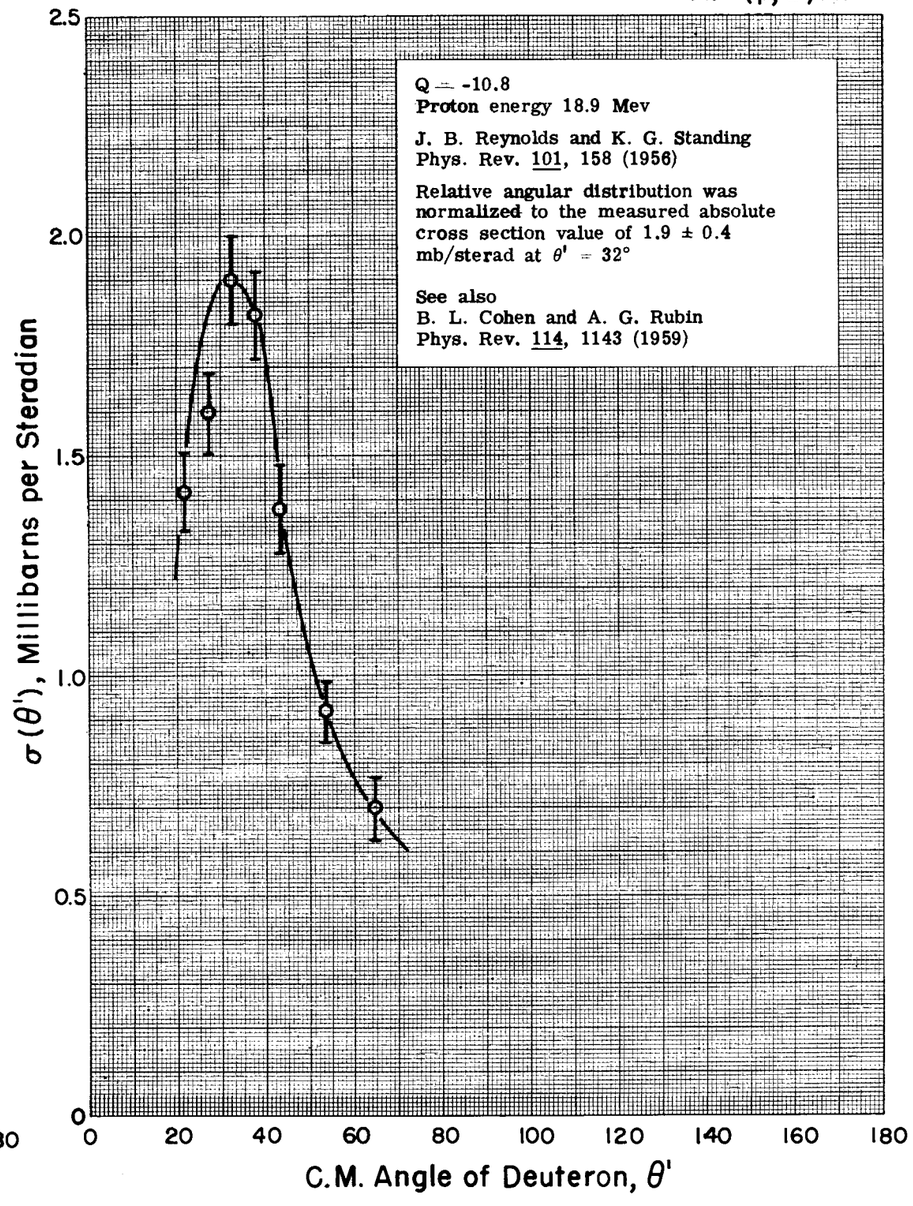

O Proton energy 30.6 ± 0.4 Mev
B. T. Wright
Report UCRL-2422 (1953)
Absolute P.E. = ±8% (small angles)
±18% (large angles)
● Proton energy 30.4 Mev
Levinthal, Martinelli, and Silverman
Phys. Rev. 78, 199 (1950)
Absolute P.E. not stated
Proton energy 31.5 Mev
R. Britten
Phys. Rev. 88, 283 (1952) or
Report 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'

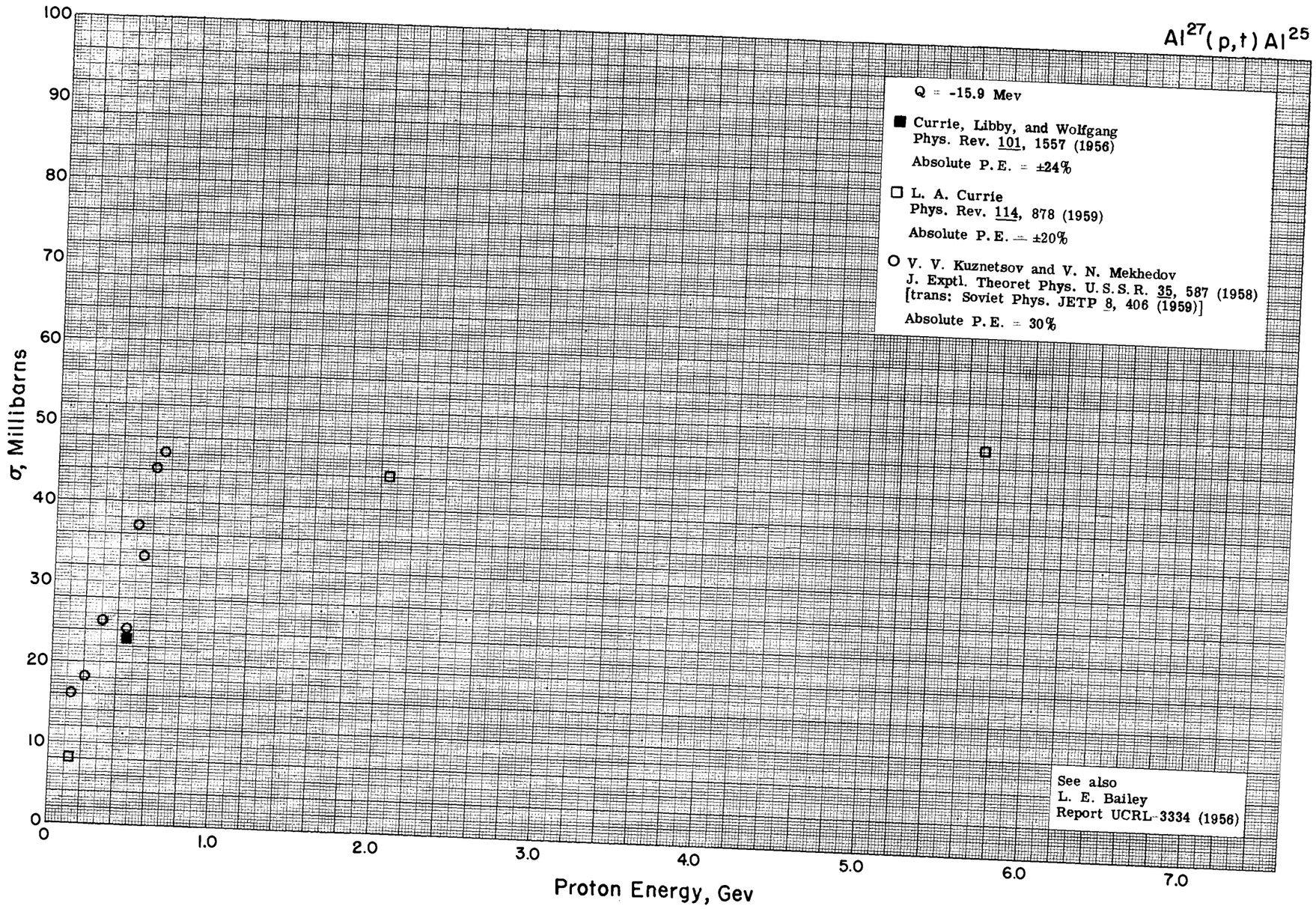

Al27(p, p)Al27
O Proton energy 92.9 Mev (3° - 20°)
95.7 Mev (20° - 70°)
Gerstein, Niederer, and Strauch
Phys. Rev. 108, 427 (1957) and
G. Gerstein, private communication
Absolute P.E. not stated but should range from a few percent at small angles to a few tens of percent at large angles.
Relative P.E. = ±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

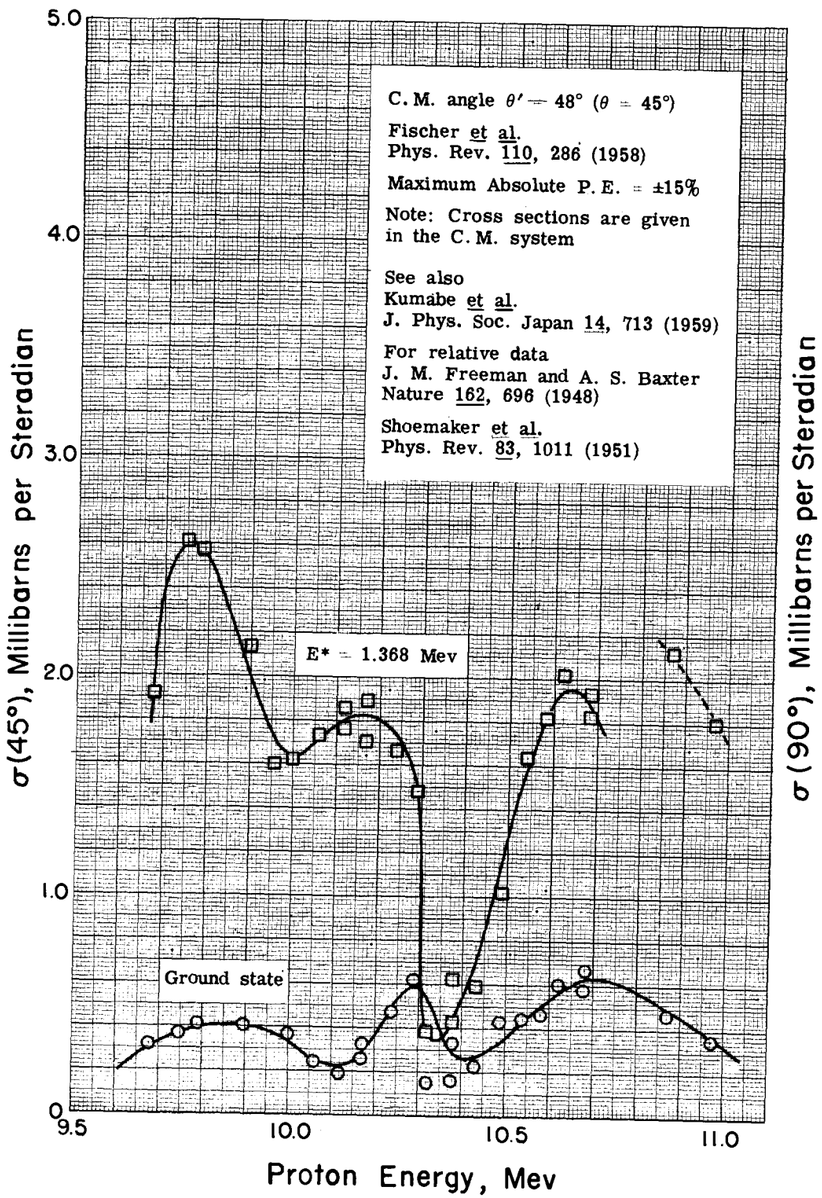

Al27(p,p')Al27*
E* = 2.21 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute P.E. = ±10%
Proton energy 7.00 Mev
Proton energy 7.12 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180

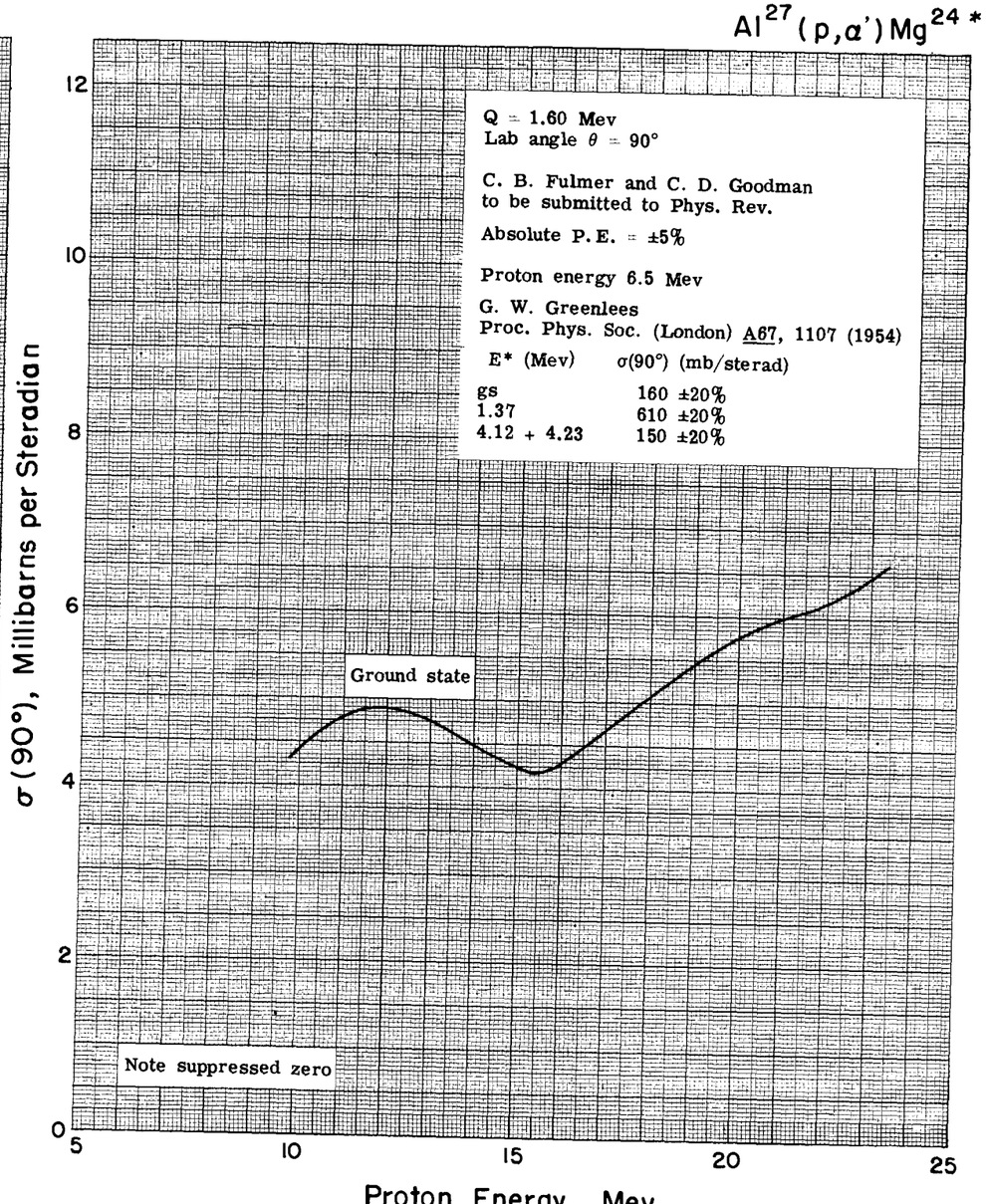

2.5
2.0
1.5
1.0
0.5
0
σ(θ), Millibarns per Steradian
0
20
40
60
80
100
120
140
160
180
Lab Angle of Deuteron, θ

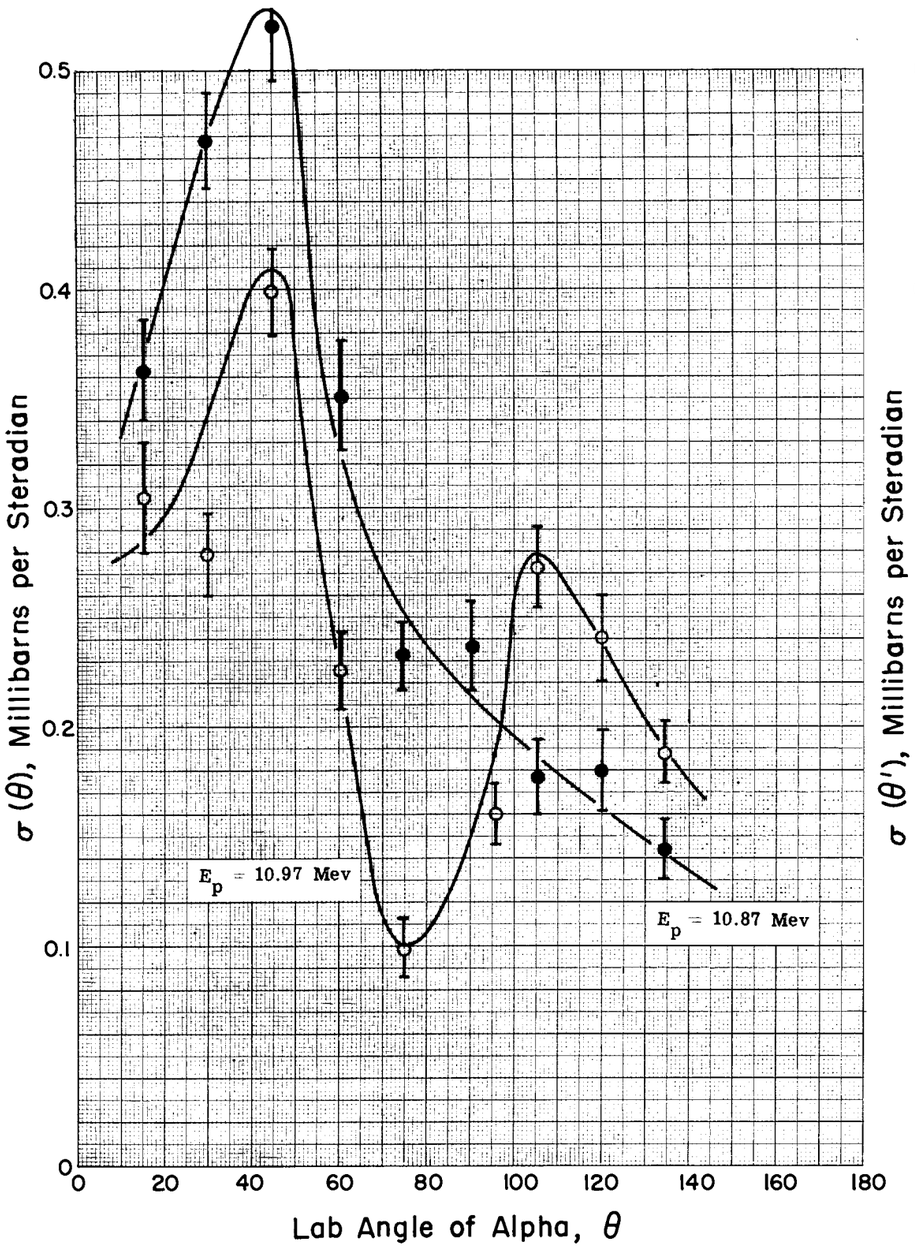

Q = -10.8
Proton energy 18.9 Mev
J. B. Reynolds and K. G. Standing
Phys. Rev. 101, 158 (1956)
Relative angular distribution was normalized to the measured absolute cross section value of 1.9 ± 0.4 mb/sterad at θ' = 32°
See also
B. L. Cohen and A. G. Rubin
Phys. Rev. 114, 1143 (1959)
2.5
2.0
1.5
1.0
0.5
0
σ(θ'), Millibarns per Steradian
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Deuteron, θ'

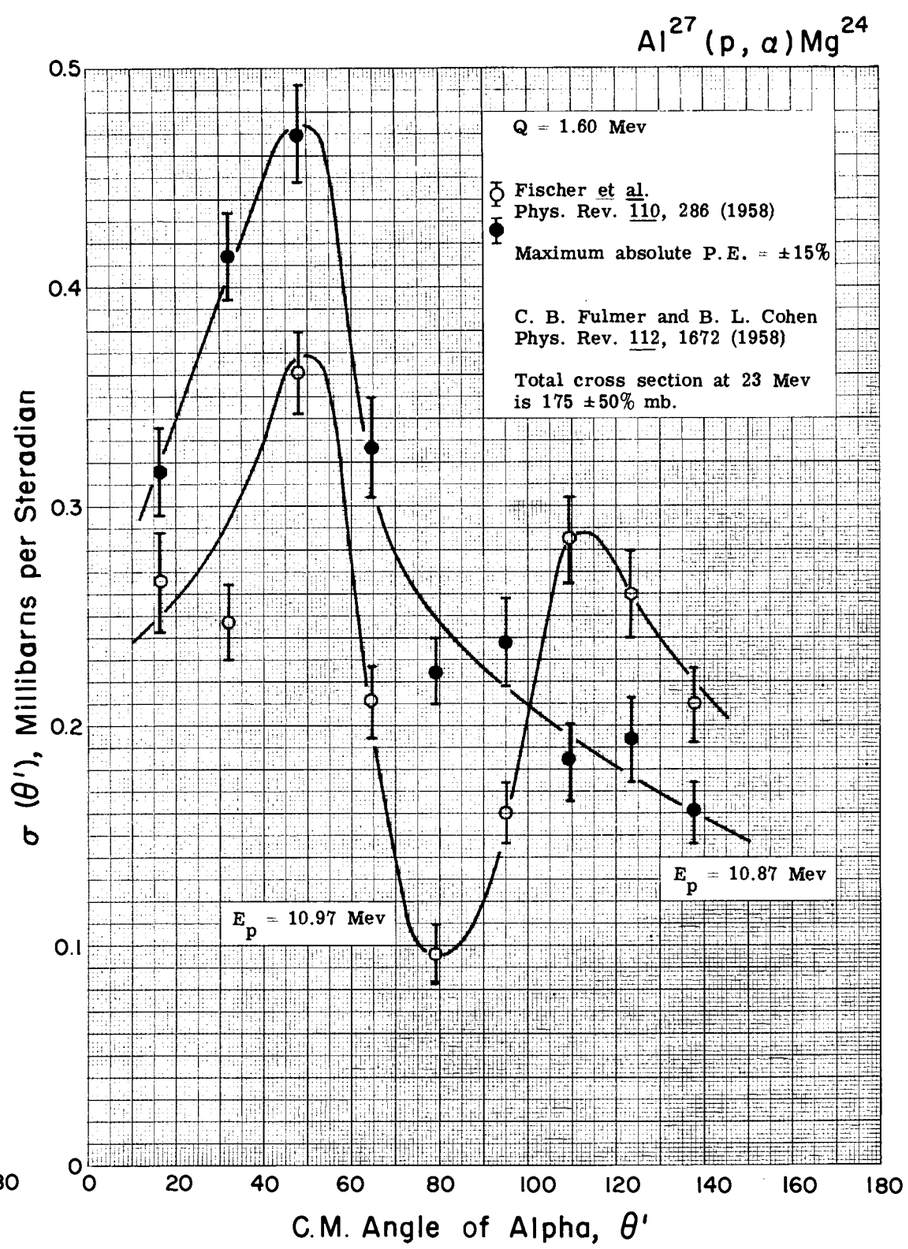

$Al^{27}(p,t)Al^{25}$
Q = -15.9 Mev
Currie, Libby, and Wolfgang
Phys. Rev. 101, 1557 (1956)
Absolute P.E. = ±24%
L. A. Currie
Phys. Rev. 114, 878 (1959)
Absolute P.E. = ±20%
V. V. Kuznetsov and V. N. Mekhedov
J. Exptl. Theoret Phys. U.S.S.R. 35, 587 (1958)
[trans: Soviet Phys. JETP 8, 406 (1959)]
Absolute 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

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

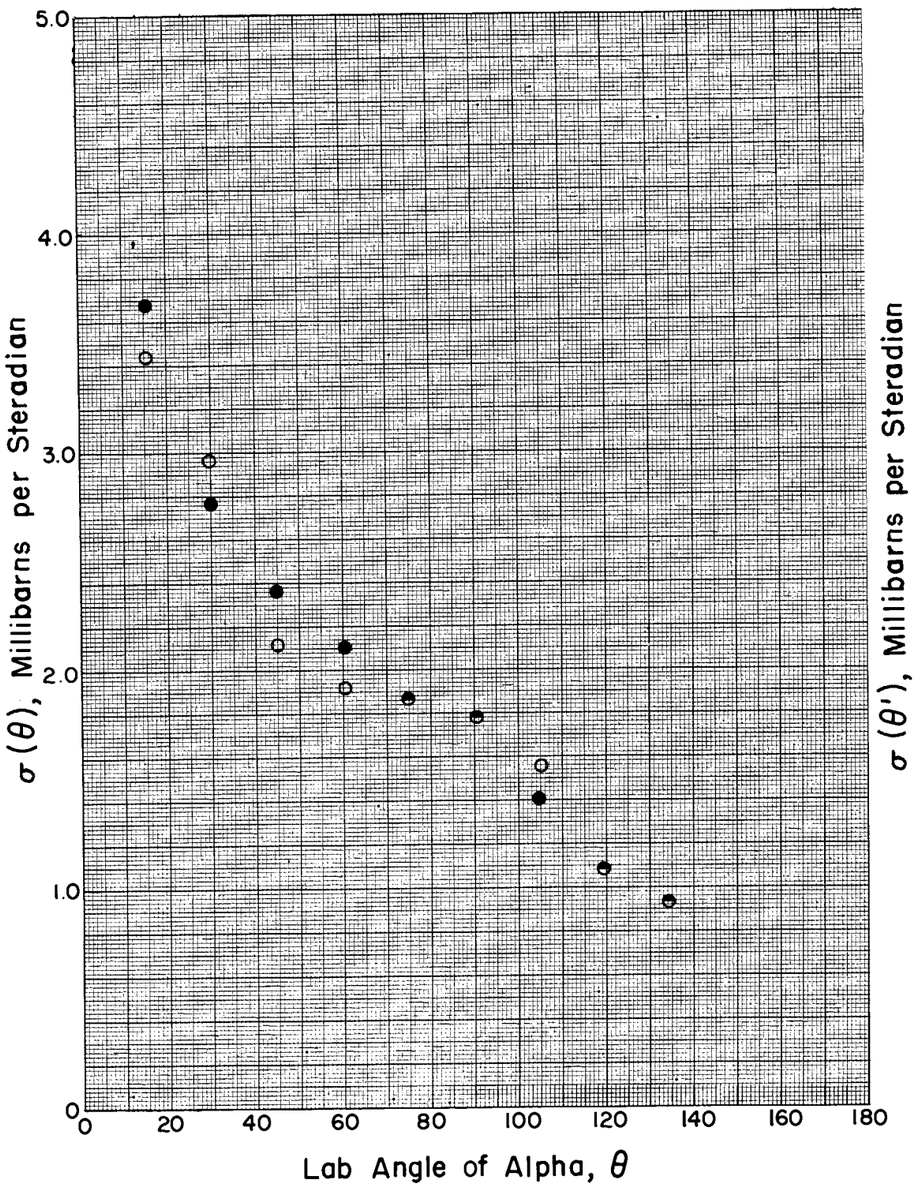


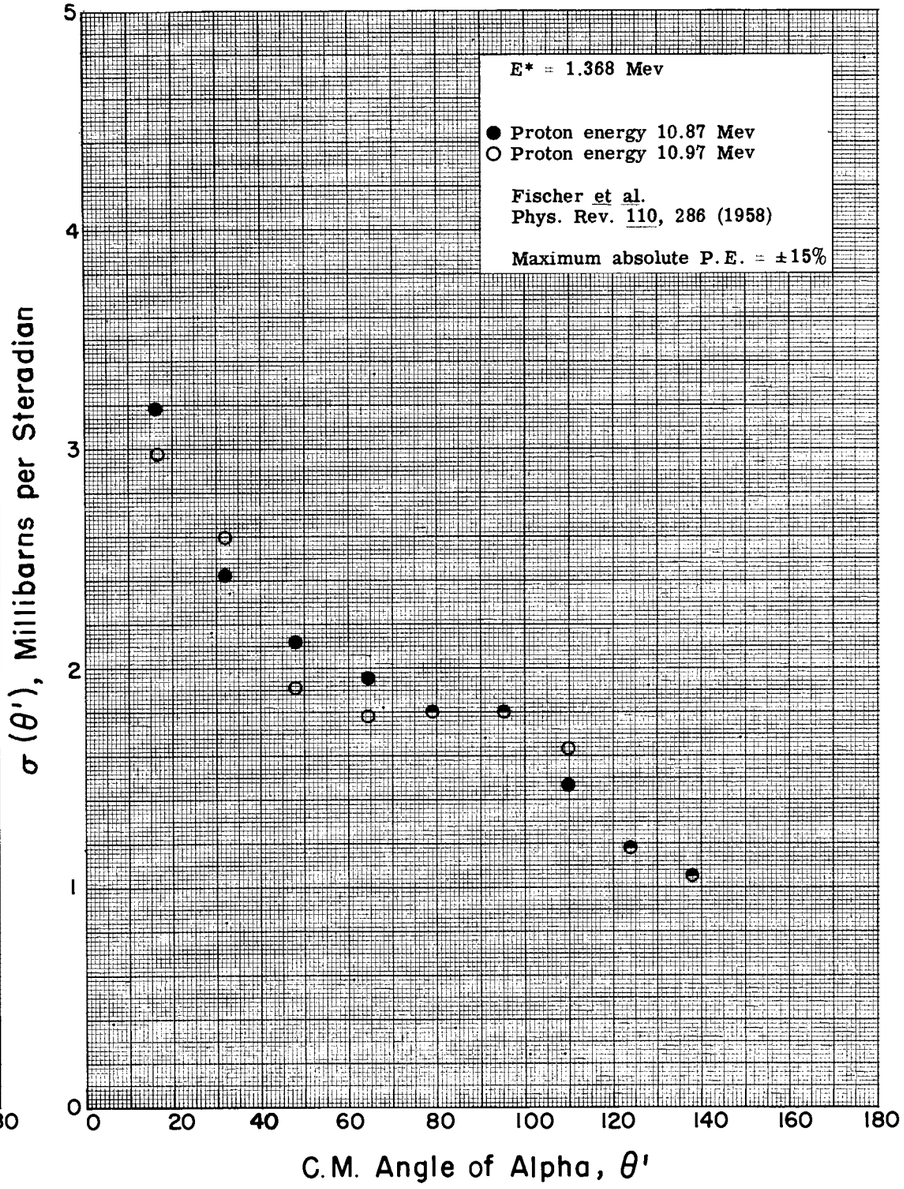



0.5
0.4
0.3
0.2
0.1
0
σ (θ), Millibarns per Steradian
E_p = 10.97 Mev
E_p = 10.87 Mev
0 20 40 60 80 100 120 140 160 180
Lab Angle of Alpha, θ

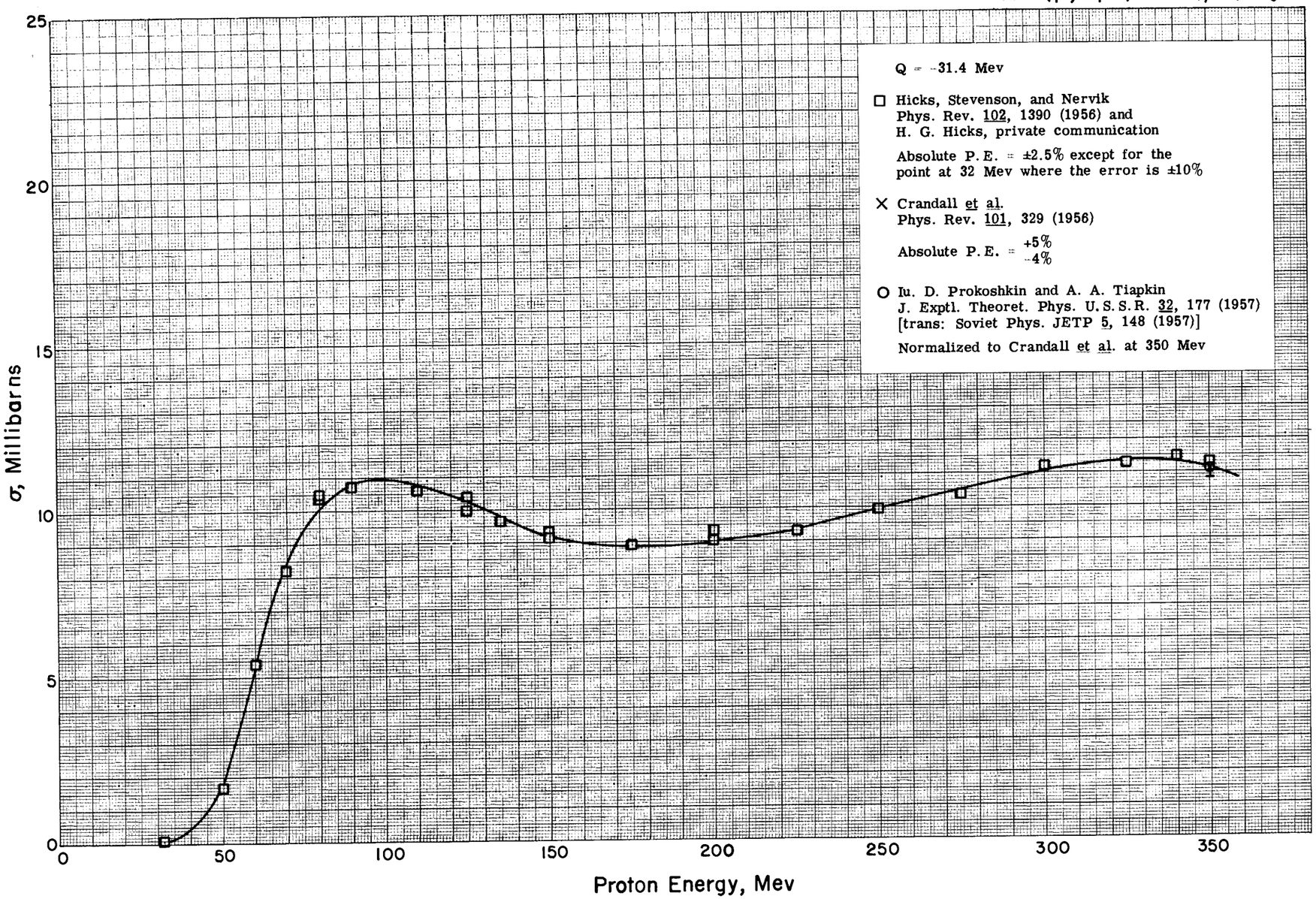

Al^27 (p, α) Mg^24
Q = 1.60 Mev
Fischer et al.
Phys. Rev. 110, 286 (1958)
Maximum absolute P.E. = ±15%
C. B. Fulmer and B. L. Cohen
Phys. Rev. 112, 1672 (1958)
Total cross section at 23 Mev
is 175 ±50% mb.
0.5
0.4
0.3
0.2
0.1
0
σ (θ'), Millibarns per Steradian
E_p = 10.97 Mev
E_p = 10.87 Mev
0 20 40 60 80 100 120 140 160 180
C.M. Angle of Alpha, θ'

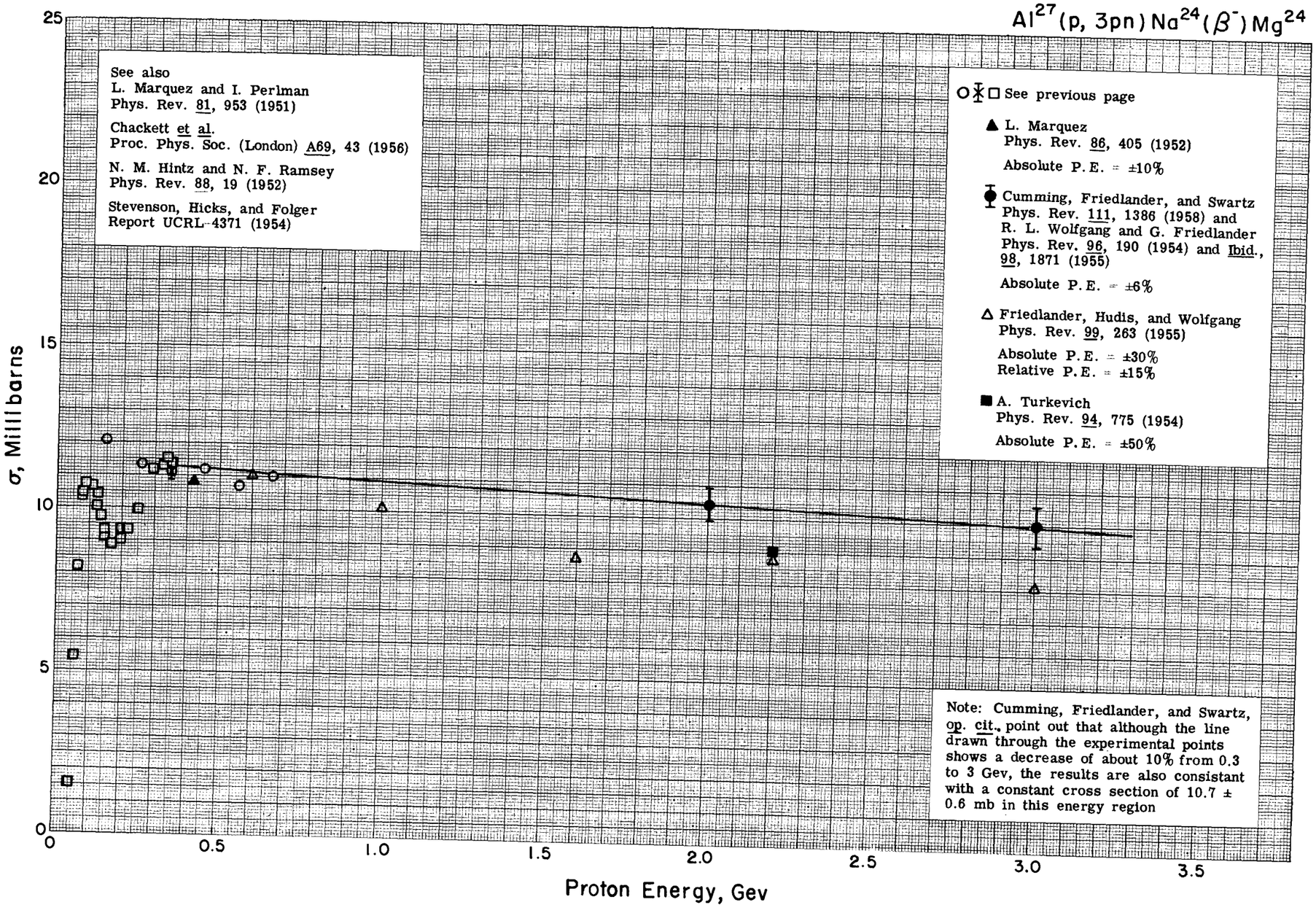
$Al^{27}(p, \alpha')Mg^{24*}$

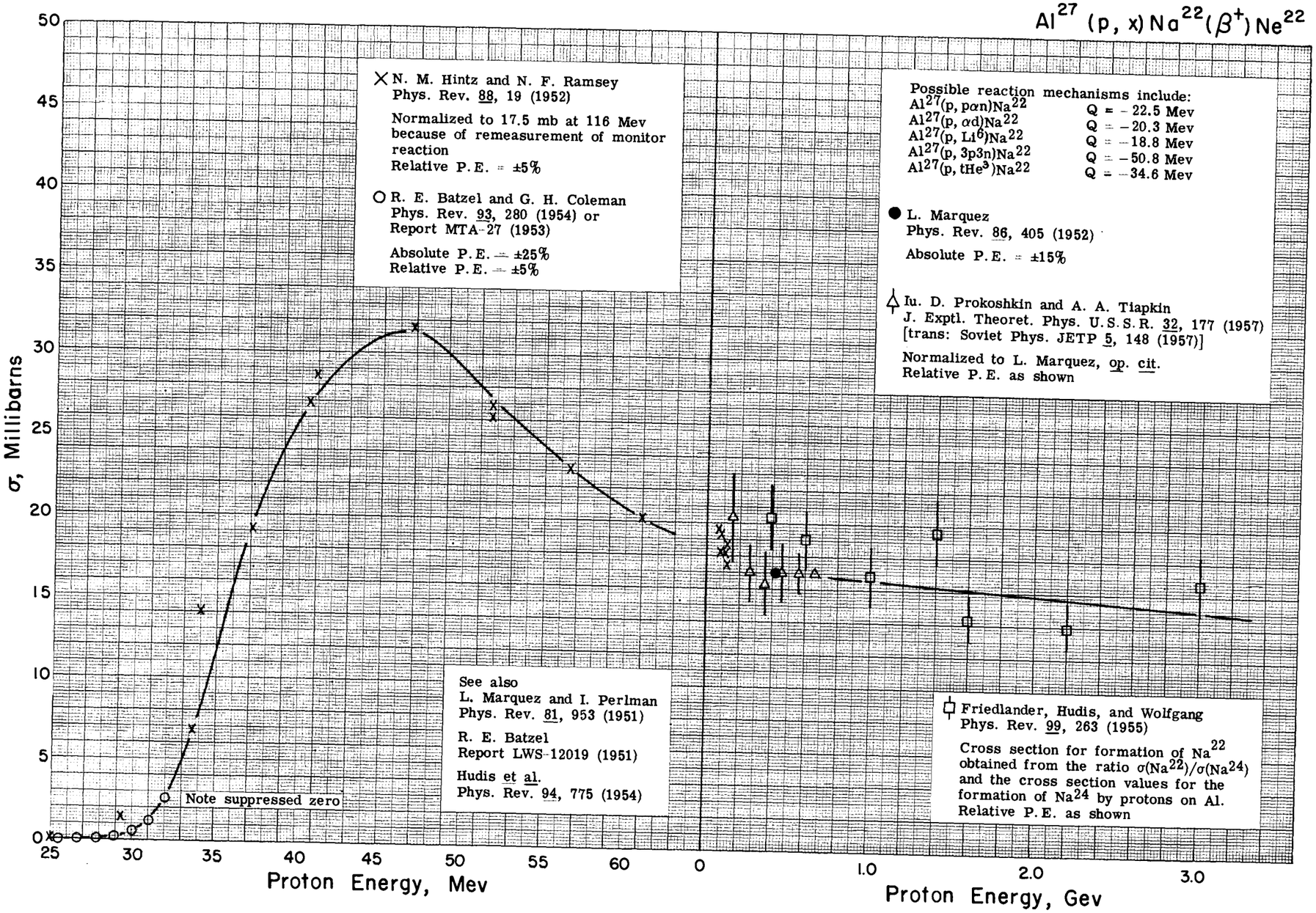




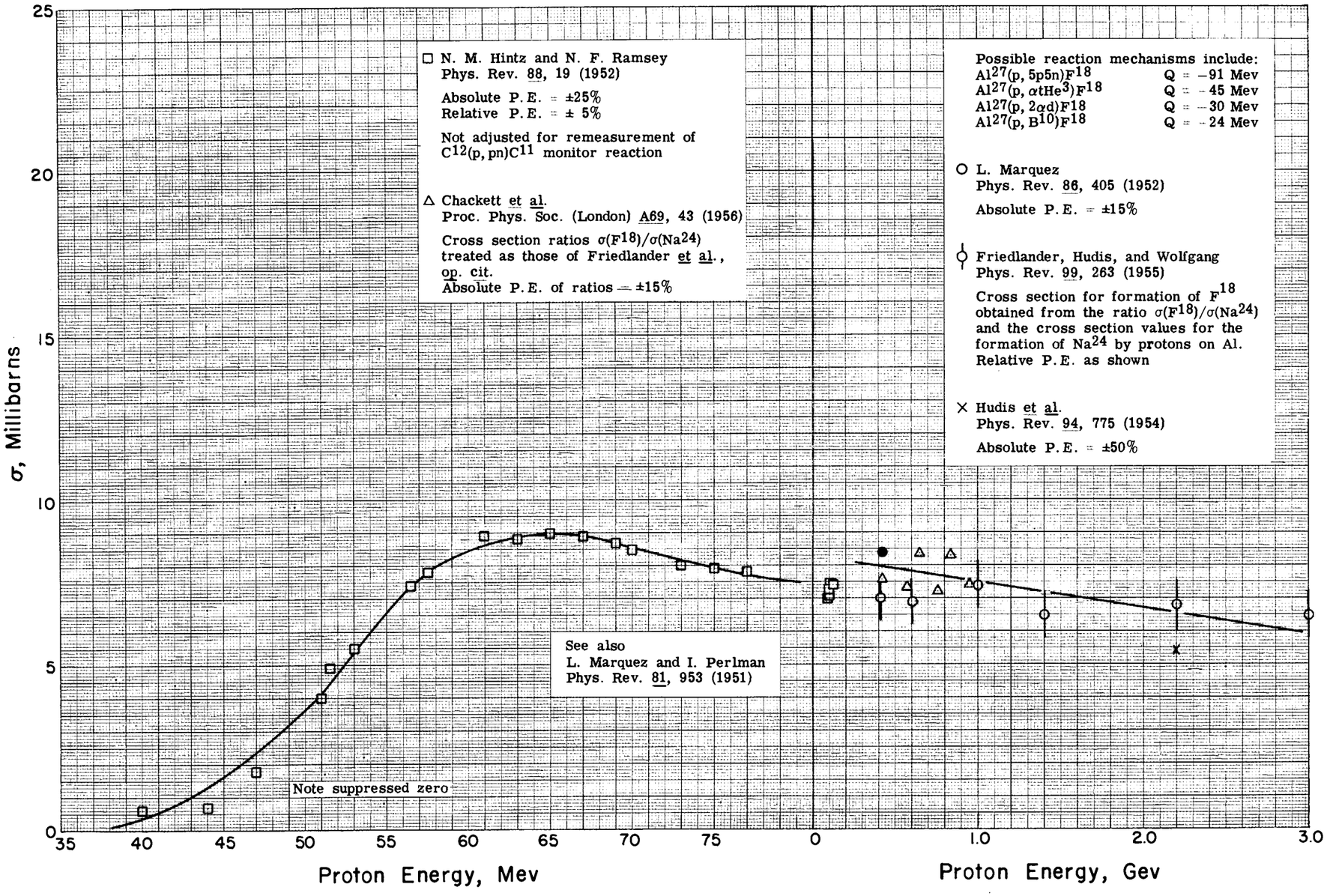
$Al^{27}(p,3pn)\,Na^{24}(\beta^-)\,Mg^{24}$




$Al^{27}(p, 3pn)Na^{24}(\beta^-)Mg^{24}$
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


$Al^{27}(p, x)Na^{22}(\beta^+)Ne^{22}$
σ, Millibarns
Proton Energy, Mev
Proton Energy, Gev
Possible reaction mechanisms include:
$Al^{27}(p, p\alpha n)Na^{22}$ Q = −22.5 Mev
$Al^{27}(p, \alpha d)Na^{22}$ Q = −20.3 Mev
$Al^{27}(p, Li^6)Na^{22}$ Q = −18.8 Mev
$Al^{27}(p, 3p3n)Na^{22}$ Q = −50.8 Mev
$Al^{27}(p, tHe^3)Na^{22}$ Q = −34.6 Mev
N. M. Hintz and N. F. Ramsey
Phys. Rev. 88, 19 (1952)
Normalized to 17.5 mb at 116 Mev because of remeasurement of monitor reaction
Relative P.E. = ±5%
R. E. Batzel and G. H. Coleman
Phys. Rev. 93, 280 (1954) or
Report MTA-27 (1953)
Absolute P.E. = ±25%
Relative P.E. = ±5%
L. Marquez
Phys. Rev. 86, 405 (1952)
Absolute P.E. = ±15%
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 L. Marquez, op. cit.
Relative P.E. as shown
Note suppressed zero
See also
L. Marquez and I. Perlman
Phys. Rev. 81, 953 (1951)
R. E. Batzel
Report LWS-12019 (1951)
Hudis et al.
Phys. Rev. 94, 775 (1954)
Friedlander, Hudis, and Wolfgang
Phys. Rev. 99, 263 (1955)
Cross section for formation of Na^{22} obtained from the ratio $\sigma(Na^{22})/\sigma(Na^{24})$ and the cross section values for the formation of Na^{24} by protons on Al.
Relative P.E. as shown

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



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

□ 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

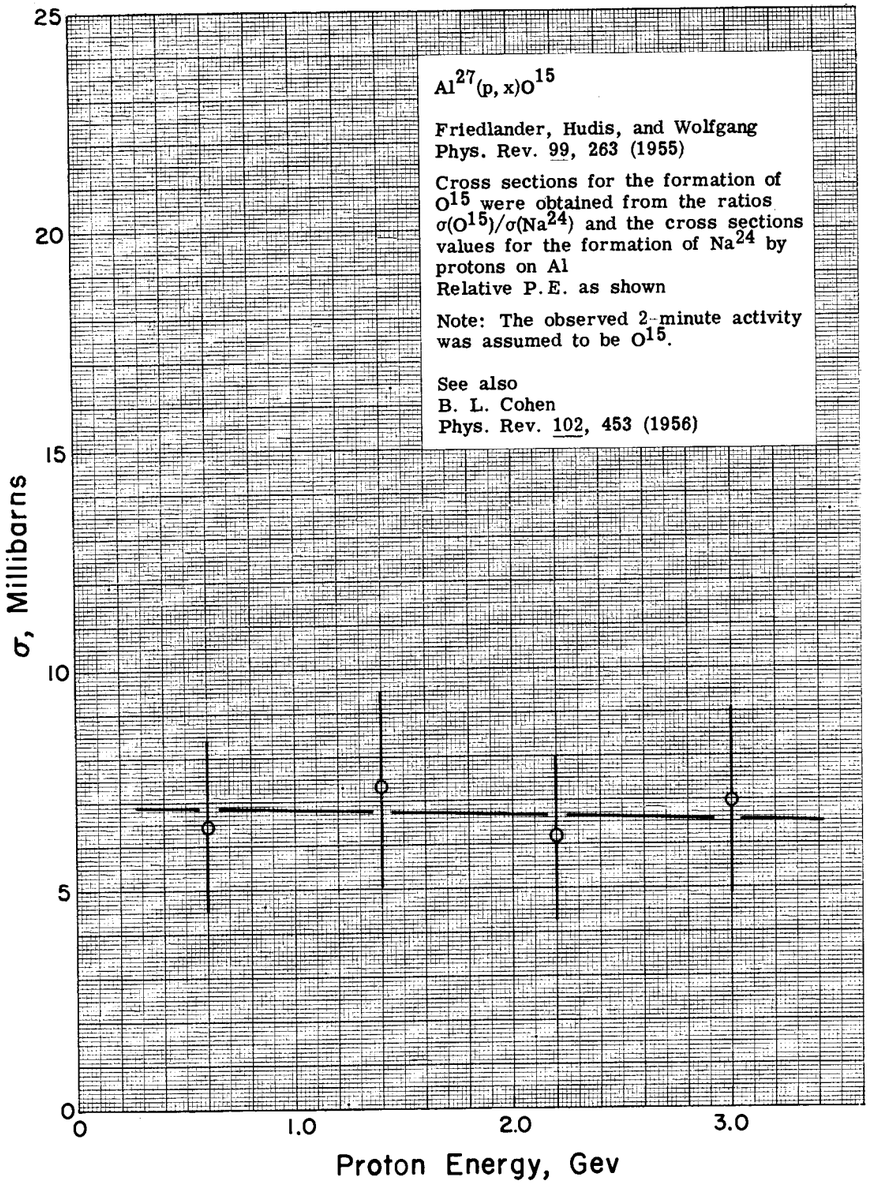
✳ Chackett et al.
Proc. Phys. Soc. (London) A69, 43 (1956)

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

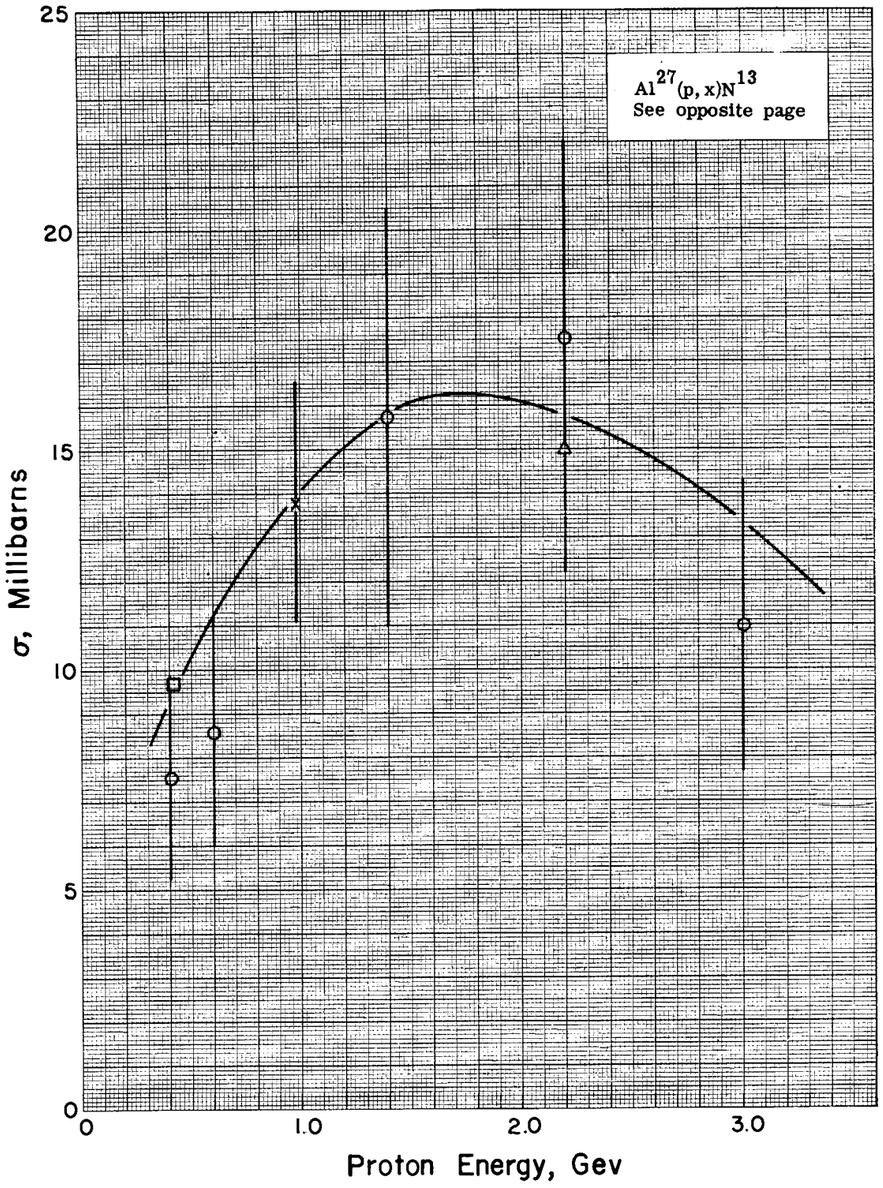
△ Hudis et al.
Phys. Rev. 94, 775 (1954)

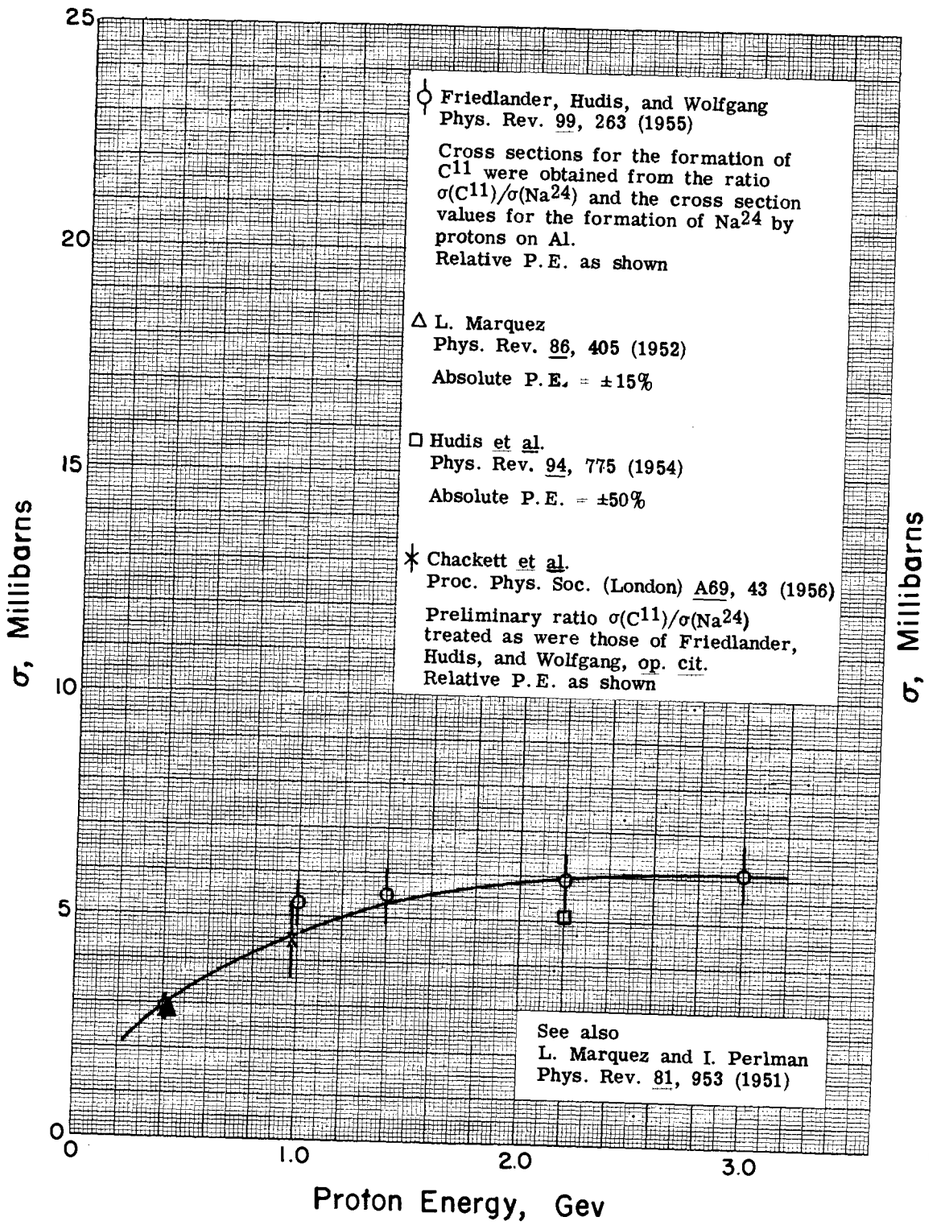
Absolute P.E. = ±50%

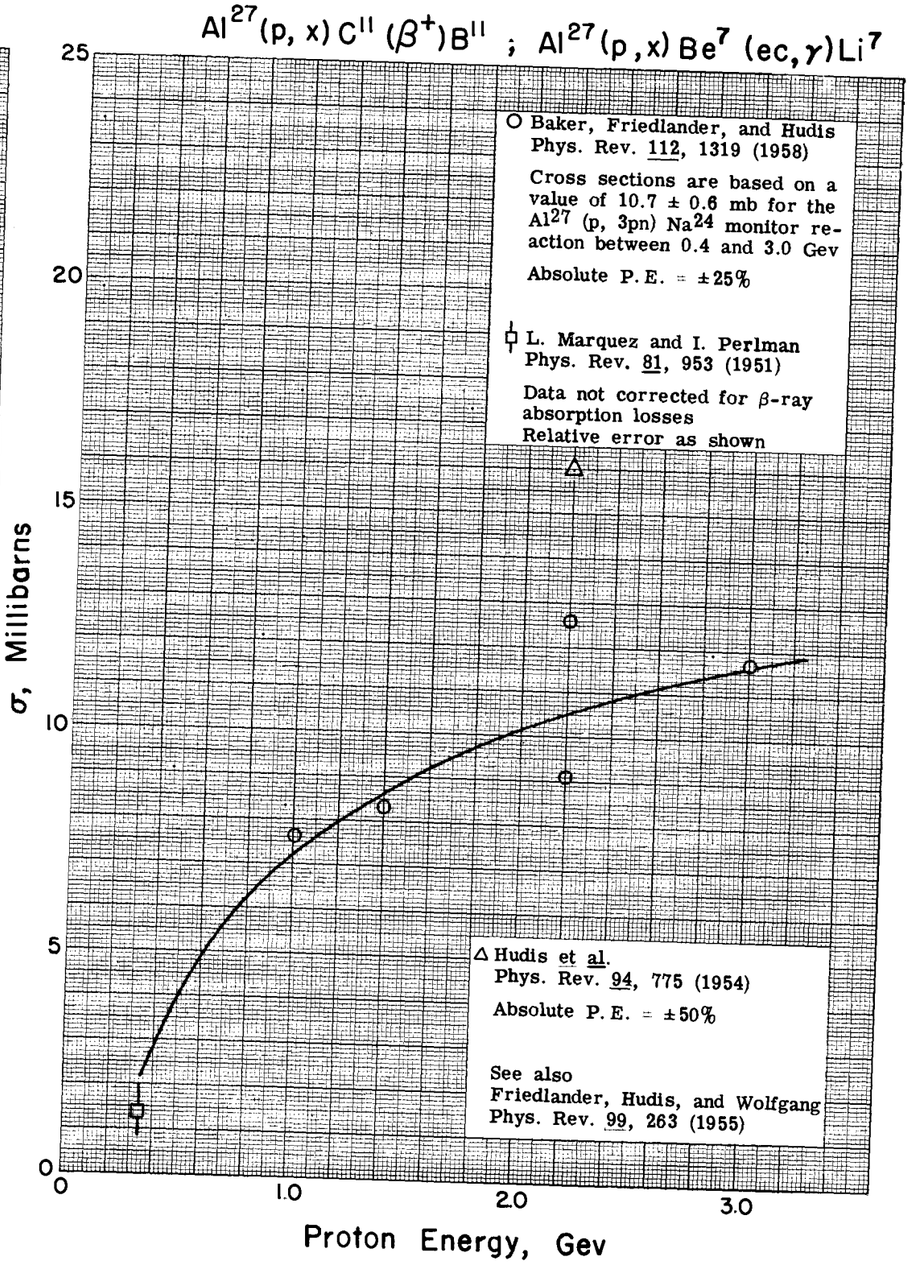
See also
B. L. Cohen
Phys. Rev. 102, 453 (1956)

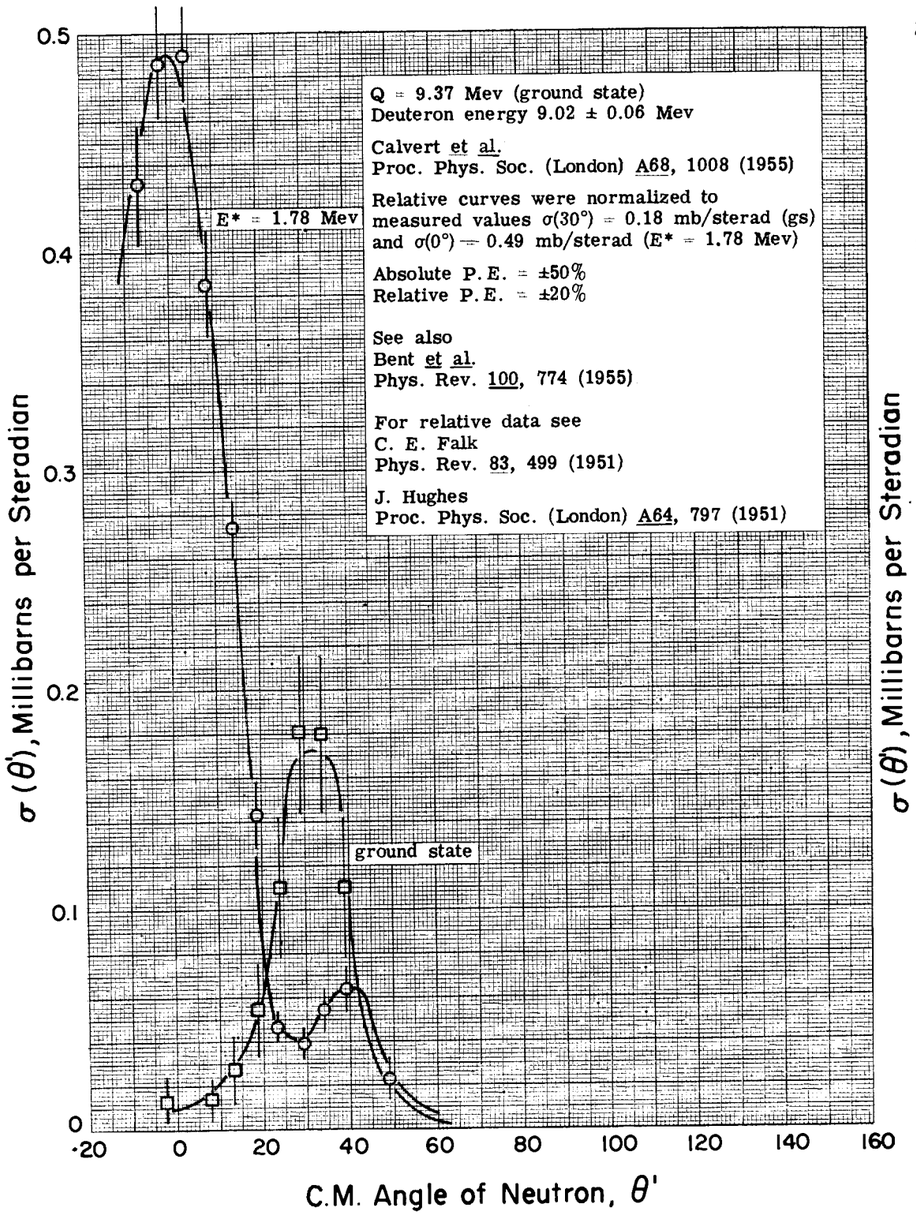


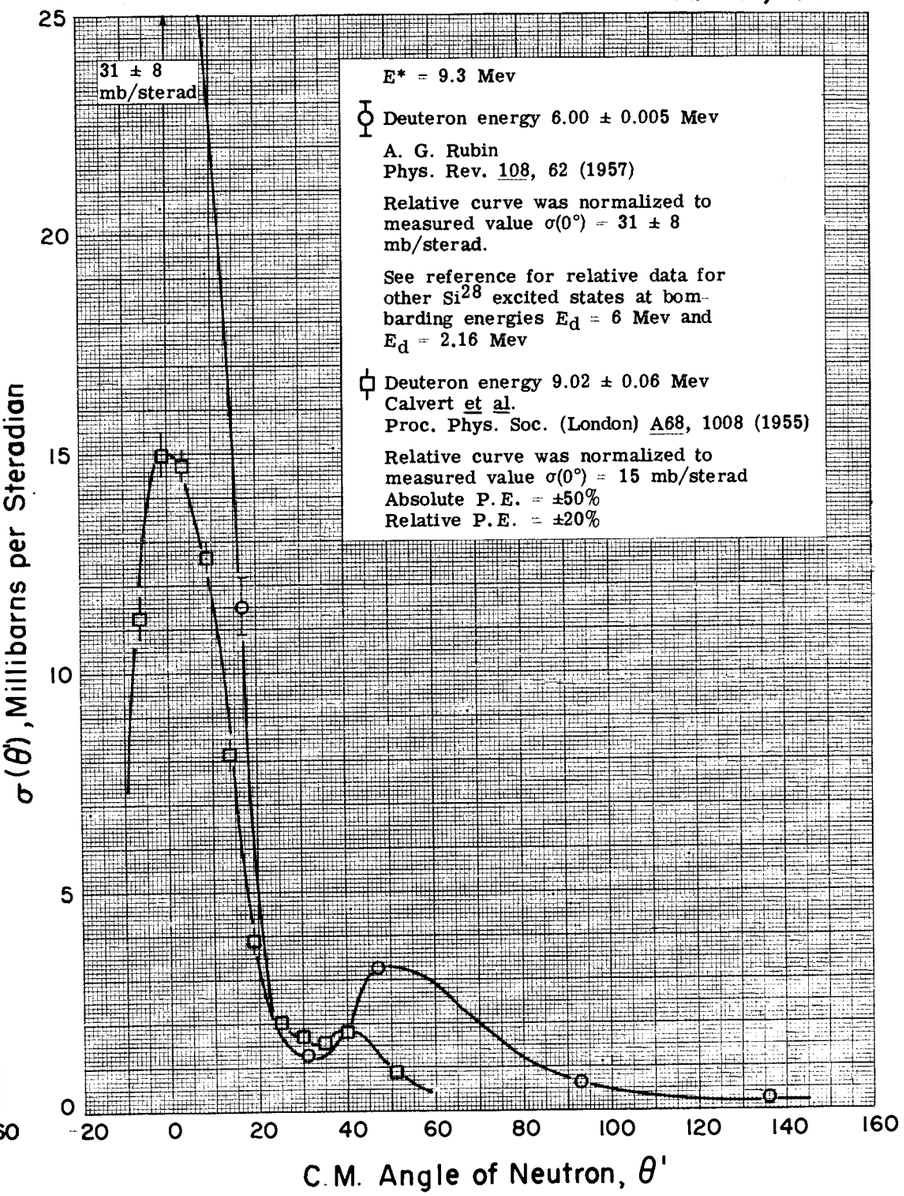
$Al^{27}(p,x)O^{15}(\beta^+)N^{15}$; $Al^{27}(p,x)N^{13}(\beta^+)C^{13}$

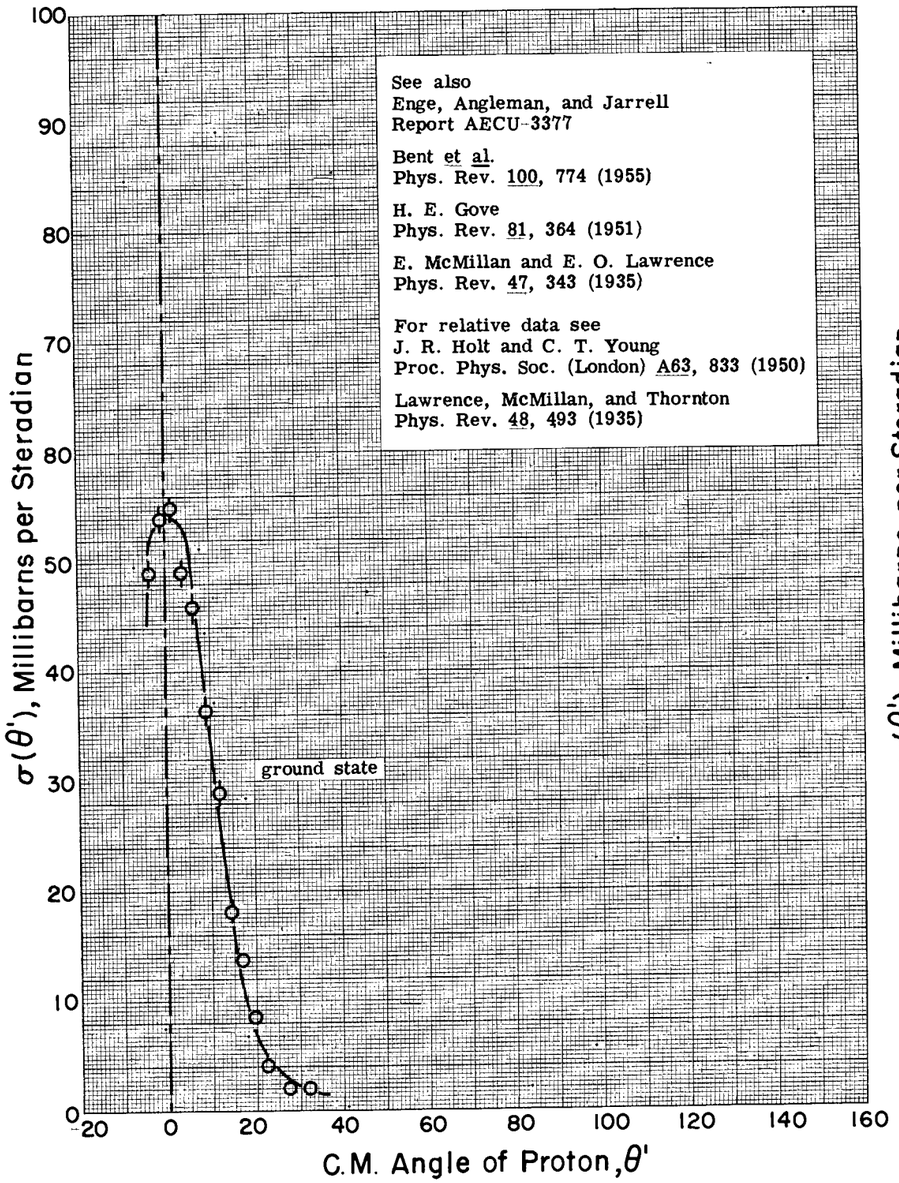


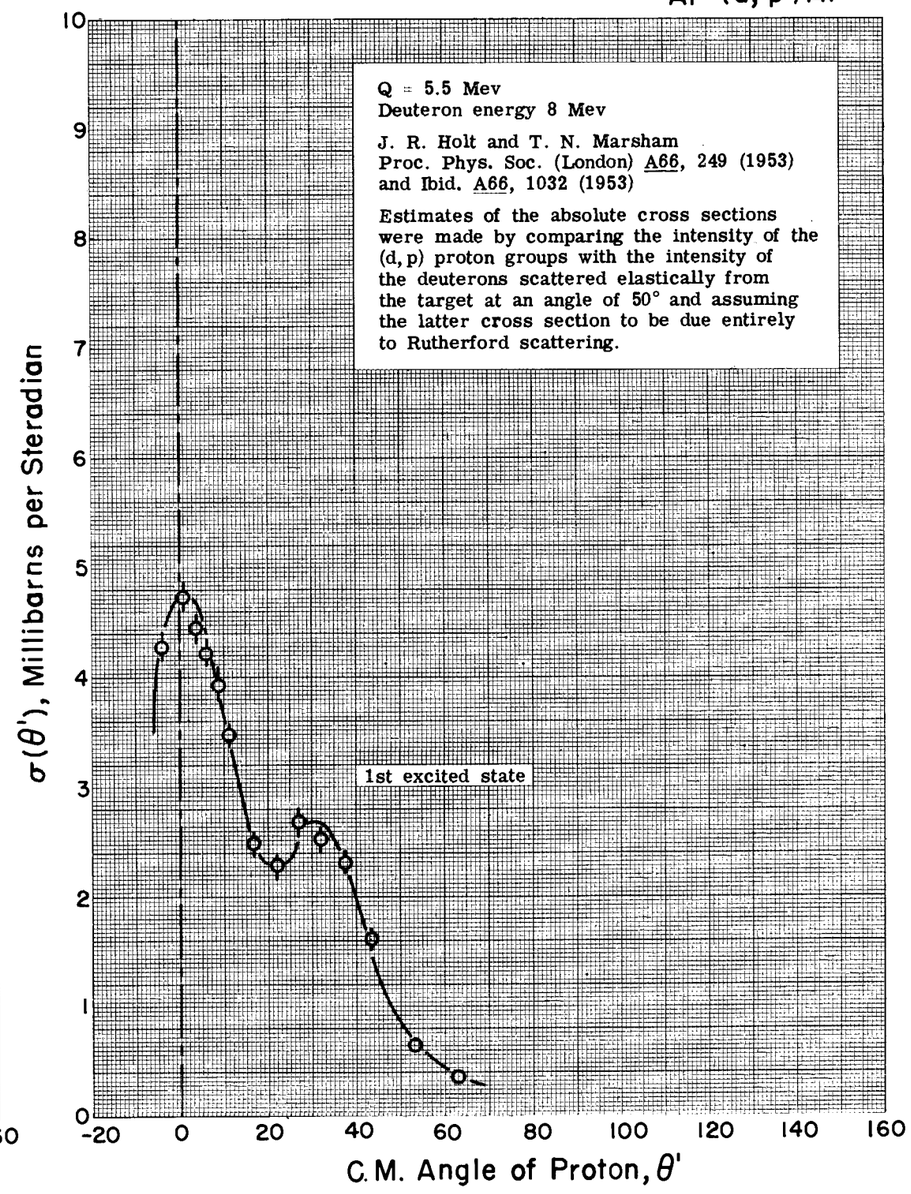

Friedlander, Hudis, and Wolfgang
Phys. Rev. 99, 263 (1955)
Cross sections for the formation of C^{11} were obtained from the ratio $\sigma(C^{11})/\sigma(Na^{24})$ and the cross section values for the formation of Na^{24} by protons on Al.
Relative P.E. as shown
L. Marquez
Phys. Rev. 86, 405 (1952)
Absolute P.E. = ±15%
Hudis et al.
Phys. Rev. 94, 775 (1954)
Absolute P.E. = ±50%
Chackett et al.
Proc. Phys. Soc. (London) A69, 43 (1956)
Preliminary ratio $\sigma(C^{11})/\sigma(Na^{24})$ treated as were those of Friedlander, Hudis, and Wolfgang, op. cit.
Relative P.E. as shown
See also
L. Marquez and I. Perlman
Phys. Rev. 81, 953 (1951)
σ, Millibarns
Proton Energy, Gev
0
5
10
15
20
25
1.0
2.0
3.0


$Al^{27}(p, x)C^{11}(\beta^+)B^{11}$; $Al^{27}(p, x)Be^{7}(ec, \gamma)Li^{7}$
Baker, Friedlander, and Hudis
Phys. Rev. 112, 1319 (1958)
Cross sections are based on a value of 10.7 ± 0.6 mb for the Al^{27} (p, 3pn) Na^{24} monitor reaction between 0.4 and 3.0 Gev
Absolute P.E. = ±25%
L. Marquez and I. Perlman
Phys. Rev. 81, 953 (1951)
Data not corrected for β-ray absorption losses
Relative error as shown
Hudis et al.
Phys. Rev. 94, 775 (1954)
Absolute P.E. = ±50%
See also
Friedlander, Hudis, and Wolfgang
Phys. Rev. 99, 263 (1955)
σ, Millibarns
Proton Energy, Gev
0
5
10
15
20
25
1.0
2.0
3.0

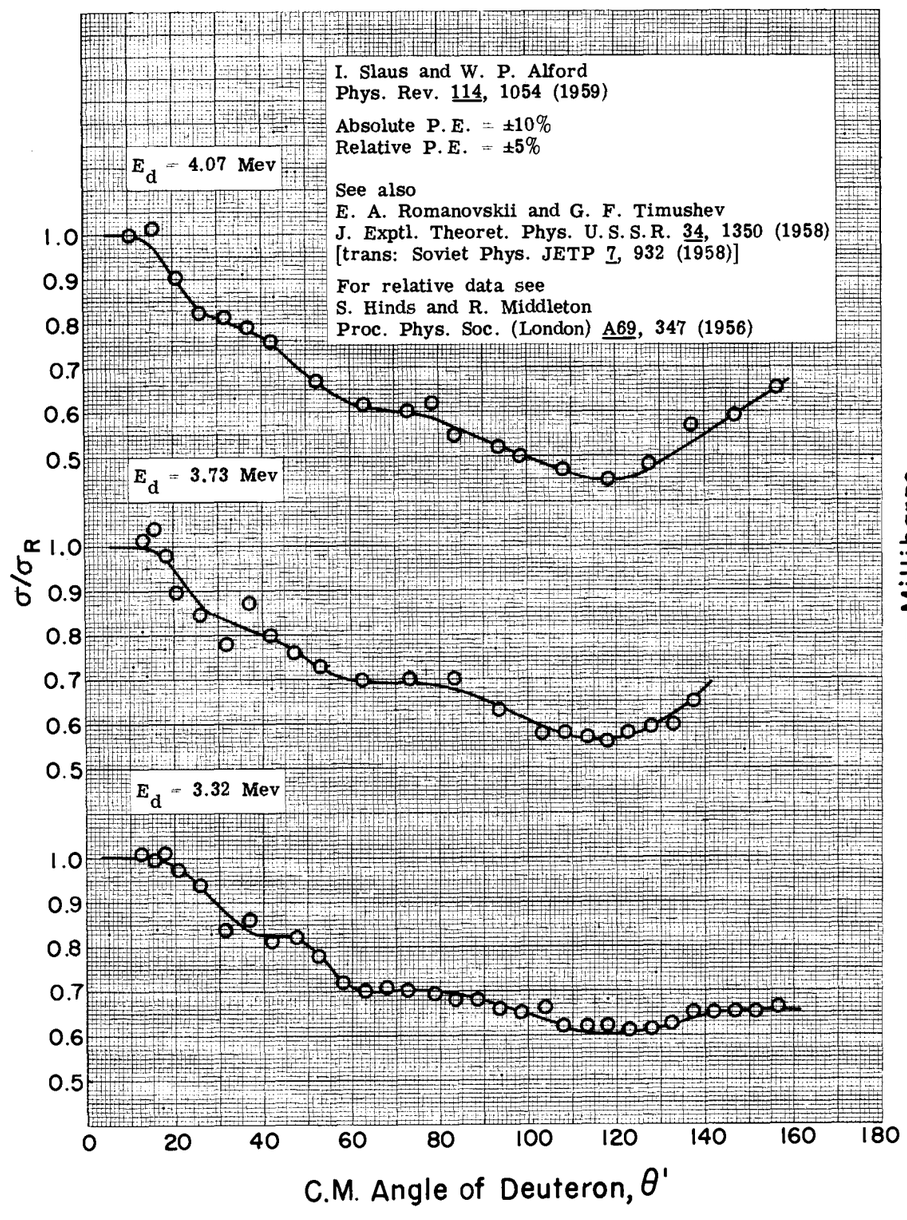

Q = 9.37 Mev (ground state)
Deuteron energy 9.02 ± 0.06 Mev
Calvert et al.
Proc. Phys. Soc. (London) A68, 1008 (1955)
Relative curves were normalized to measured values σ(30°) = 0.18 mb/sterad (gs) and σ(0°) = 0.49 mb/sterad (E* = 1.78 Mev)
Absolute P.E. = ±50%
Relative P.E. = ±20%
See also
Bent et al.
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'
0.5
0.4
0.3
0.2
0.1
0
-20
0
20
40
60
80
100
120
140
160

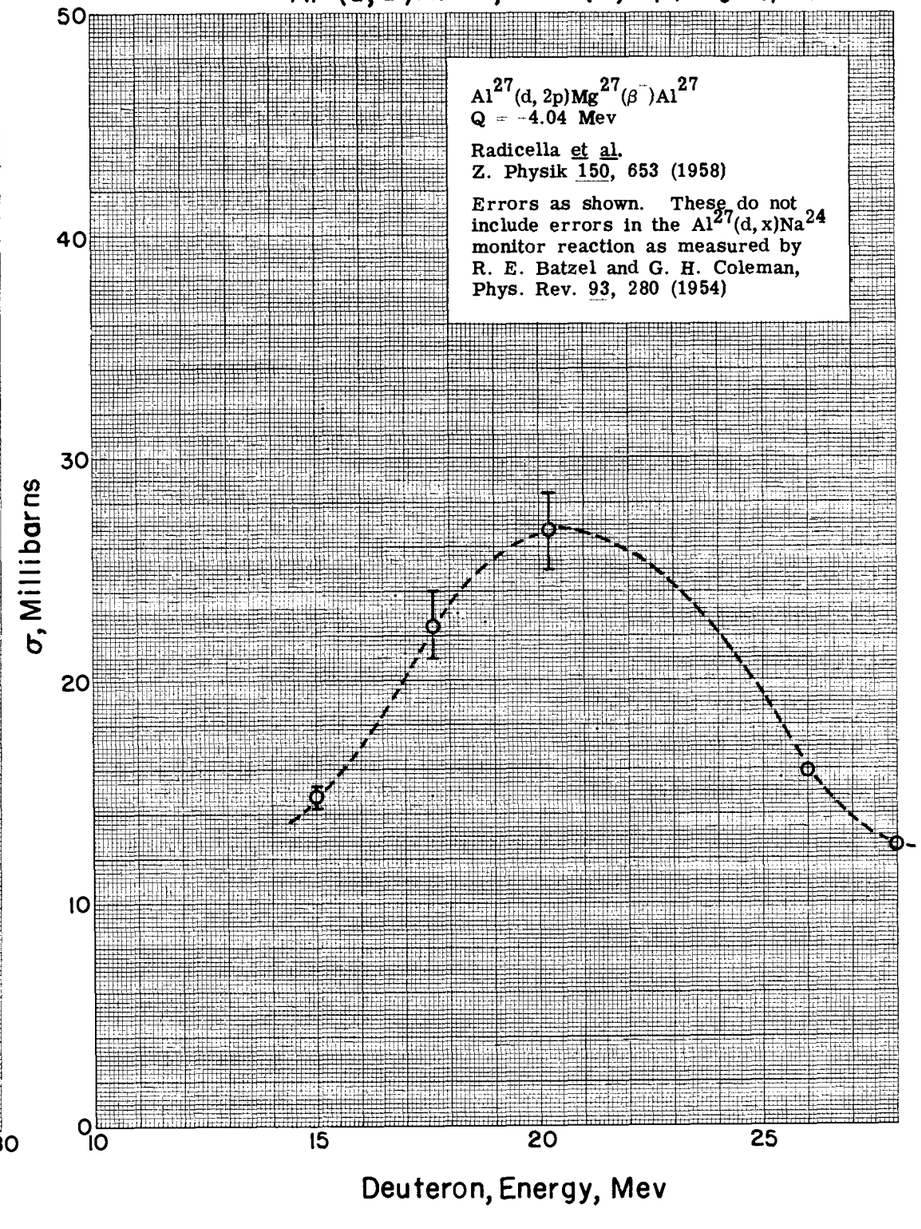

31 ± 8 mb/sterad
E* = 9.3 Mev
Deuteron energy 6.00 ± 0.005 Mev
A. G. Rubin
Phys. Rev. 108, 62 (1957)
Relative curve was normalized to measured value σ(0°) = 31 ± 8 mb/sterad.
See reference for relative data for other Si28 excited states at bombarding energies Ed = 6 Mev and Ed = 2.16 Mev
Deuteron energy 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'
25
20
15
10
5
0
-20
0
20
40
60
80
100
120
140
160

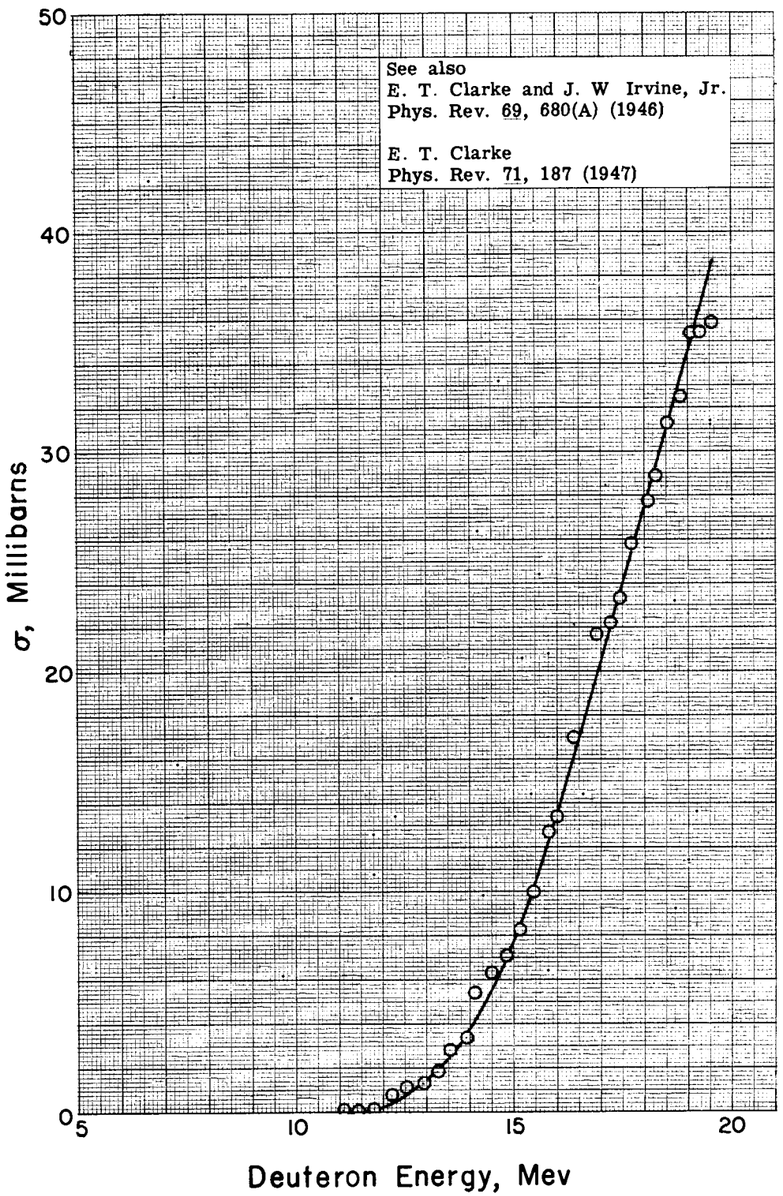

See also
Enge, Angleman, and Jarrell
Report AECU-3377
Bent et al.
Phys. Rev. 100, 774 (1955)
H. E. Gove
Phys. Rev. 81, 364 (1951)
E. McMillan and E. O. Lawrence
Phys. Rev. 47, 343 (1935)
For relative data see
J. R. Holt and C. T. Young
Proc. Phys. Soc. (London) A63, 833 (1950)
Lawrence, McMillan, and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

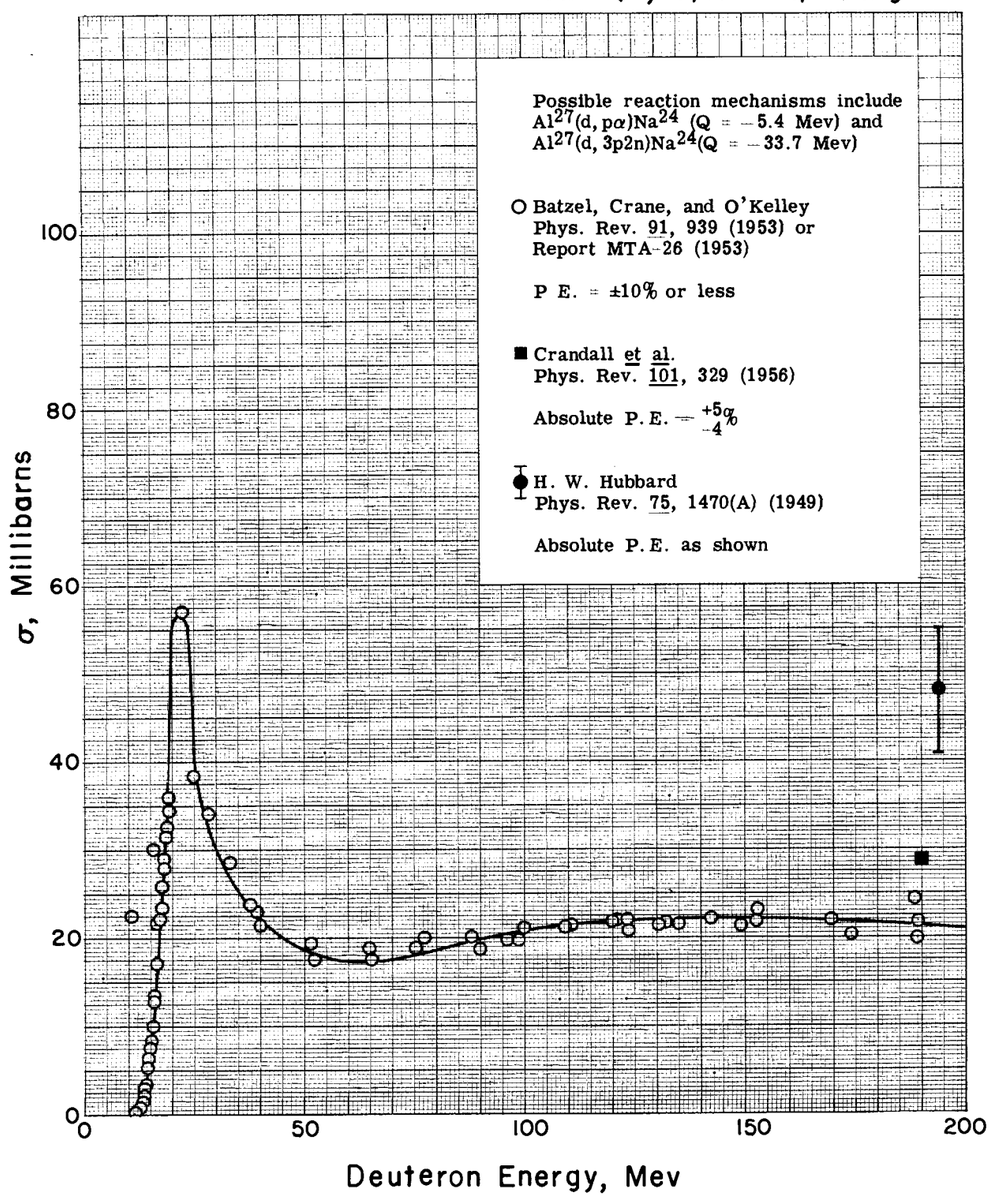

Q = 5.5 Mev
Deuteron energy 8 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 249 (1953)
and Ibid. A66, 1032 (1953)
Estimates of the absolute cross sections were made by comparing the intensity of the (d, p) proton groups with the intensity of the deuterons scattered elastically from 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'

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

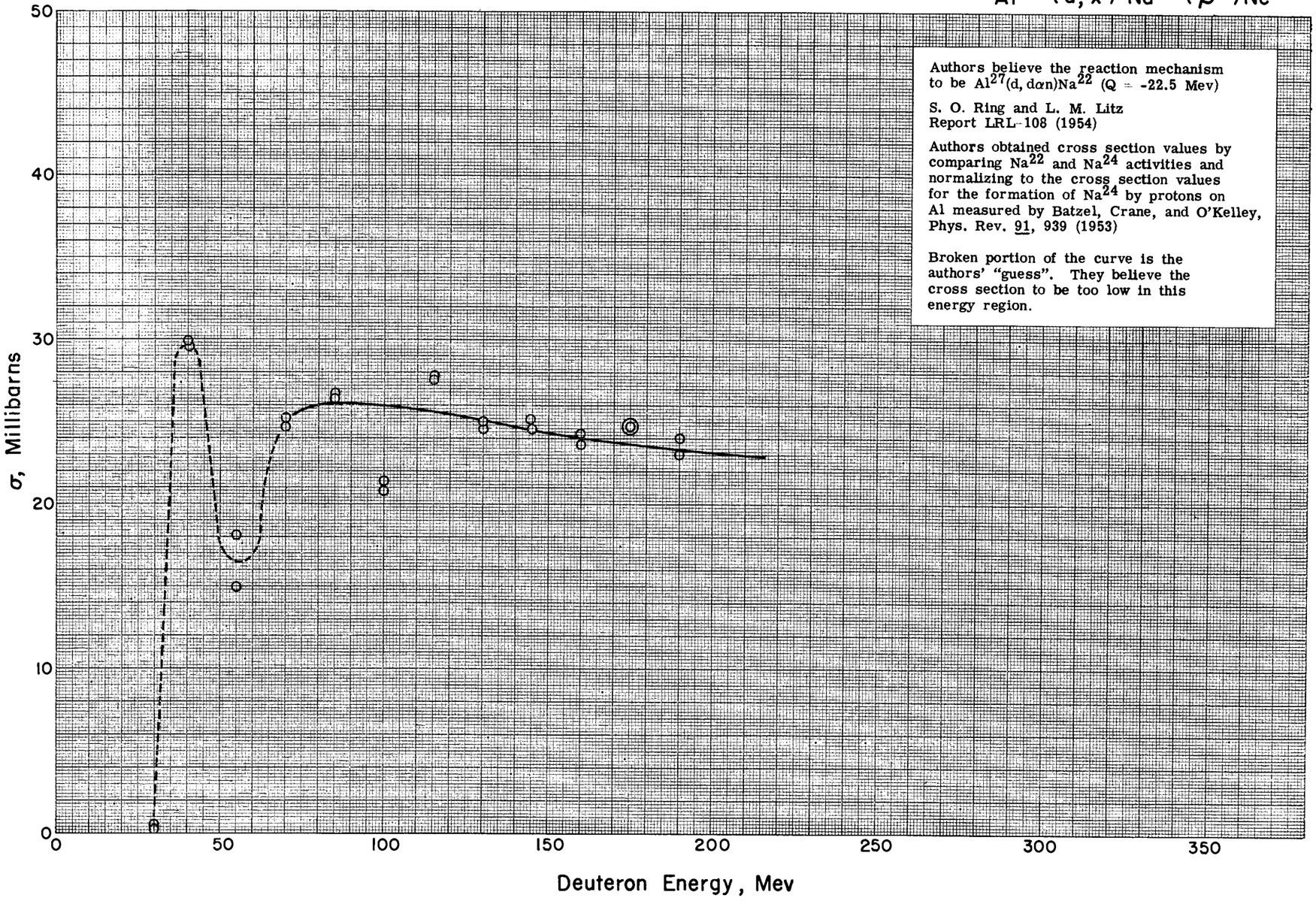





See also
E. T. Clarke and J. W Irvine, Jr.
Phys. Rev. 69, 680(A) (1946)
E. T. Clarke
Phys. Rev. 71, 187 (1947)
σ, Millibarns
Deuteron Energy, Mev


Possible reaction mechanisms include
$Al^{27}(d, p\alpha)Na^{24}$ (Q = −5.4 Mev) and
$Al^{27}(d, 3p2n)Na^{24}$(Q = −33.7 Mev)
O Batzel, Crane, and O'Kelley
Phys. Rev. 91, 939 (1953) or
Report MTA-26 (1953)
P E. = ±10% or less
■ Crandall et al.
Phys. Rev. 101, 329 (1956)
Absolute P.E. = +5 −4 %
H. W. Hubbard
Phys. Rev. 75, 1470(A) (1949)
Absolute P.E. as shown
σ, Millibarns
Deuteron Energy, Mev

Al^{27} (d, x) Na^{22} (β^+) Ne^{22}



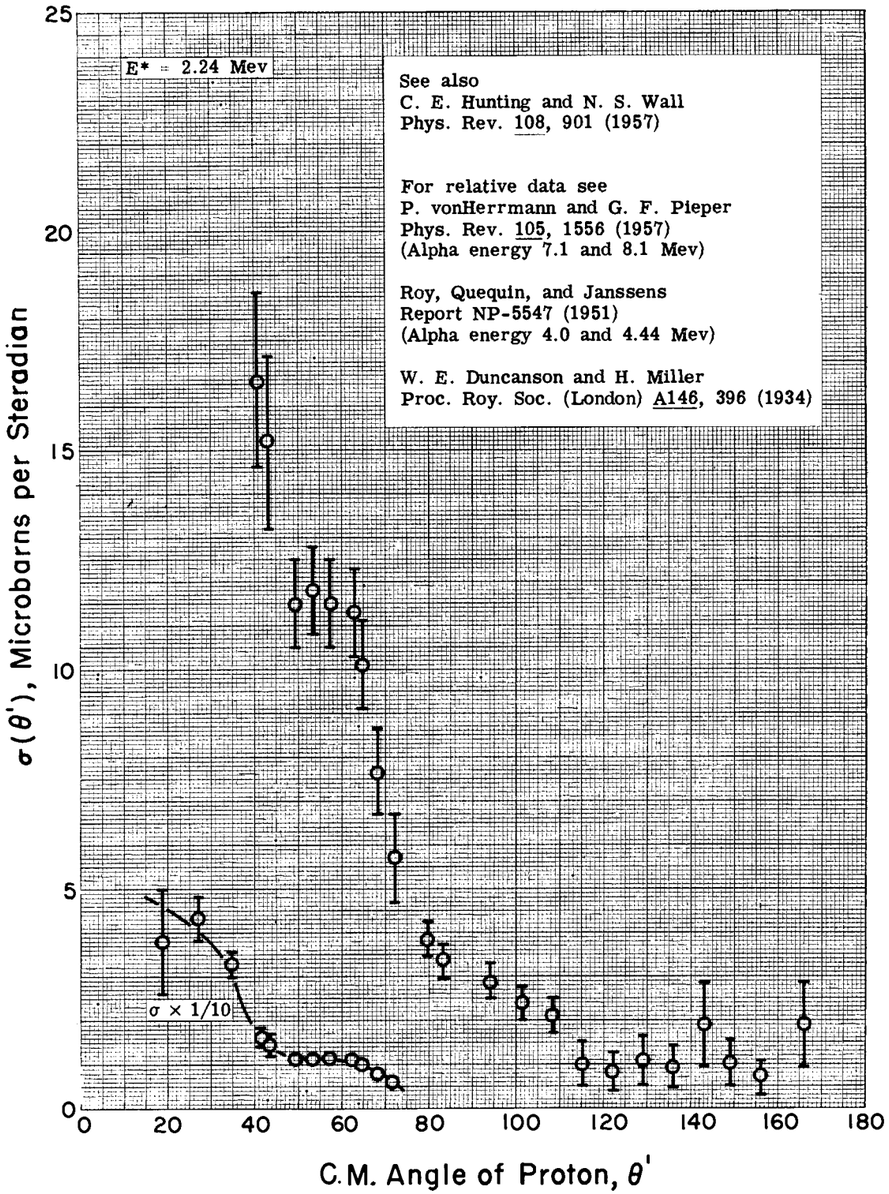
Authors believe the reaction mechanism to be $Al^{27}(d, d\alpha n)Na^{22}$ (Q = -22.5 Mev)

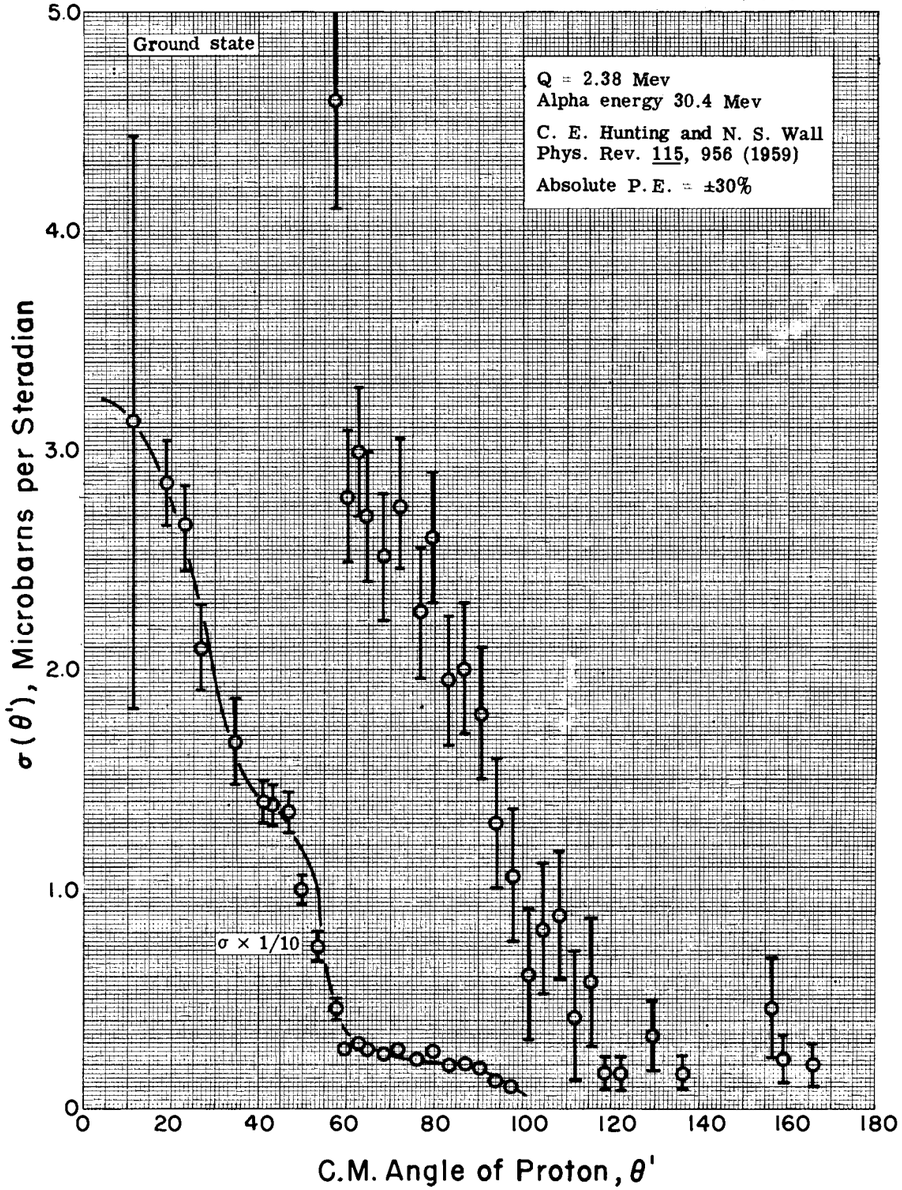
S. O. Ring and L. M. Litz
Report LRL-108 (1954)

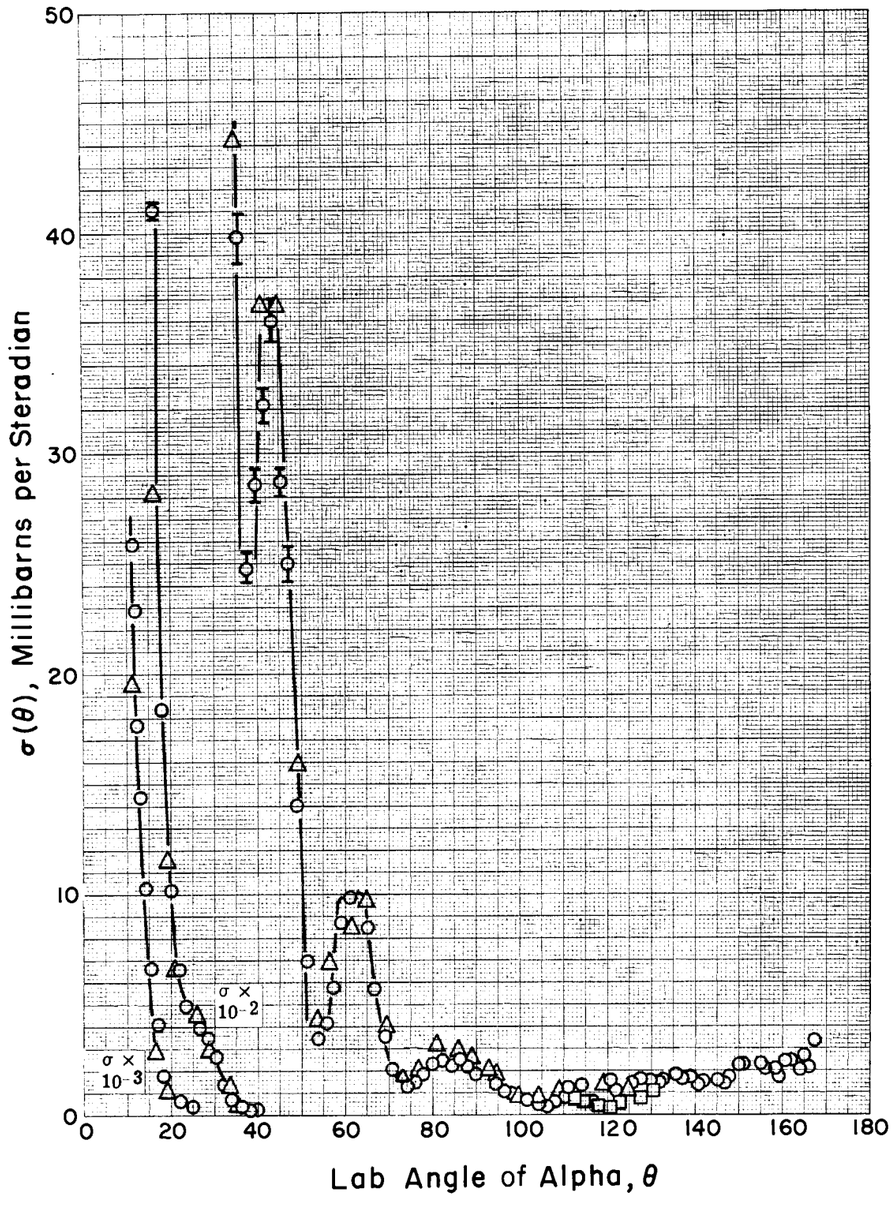
Authors obtained cross section values by comparing Na^{22} and Na^{24} activities and normalizing to the cross section values for the formation of Na^{24} by protons on Al measured by Batzel, Crane, and O'Kelley, Phys. Rev. 91, 939 (1953)

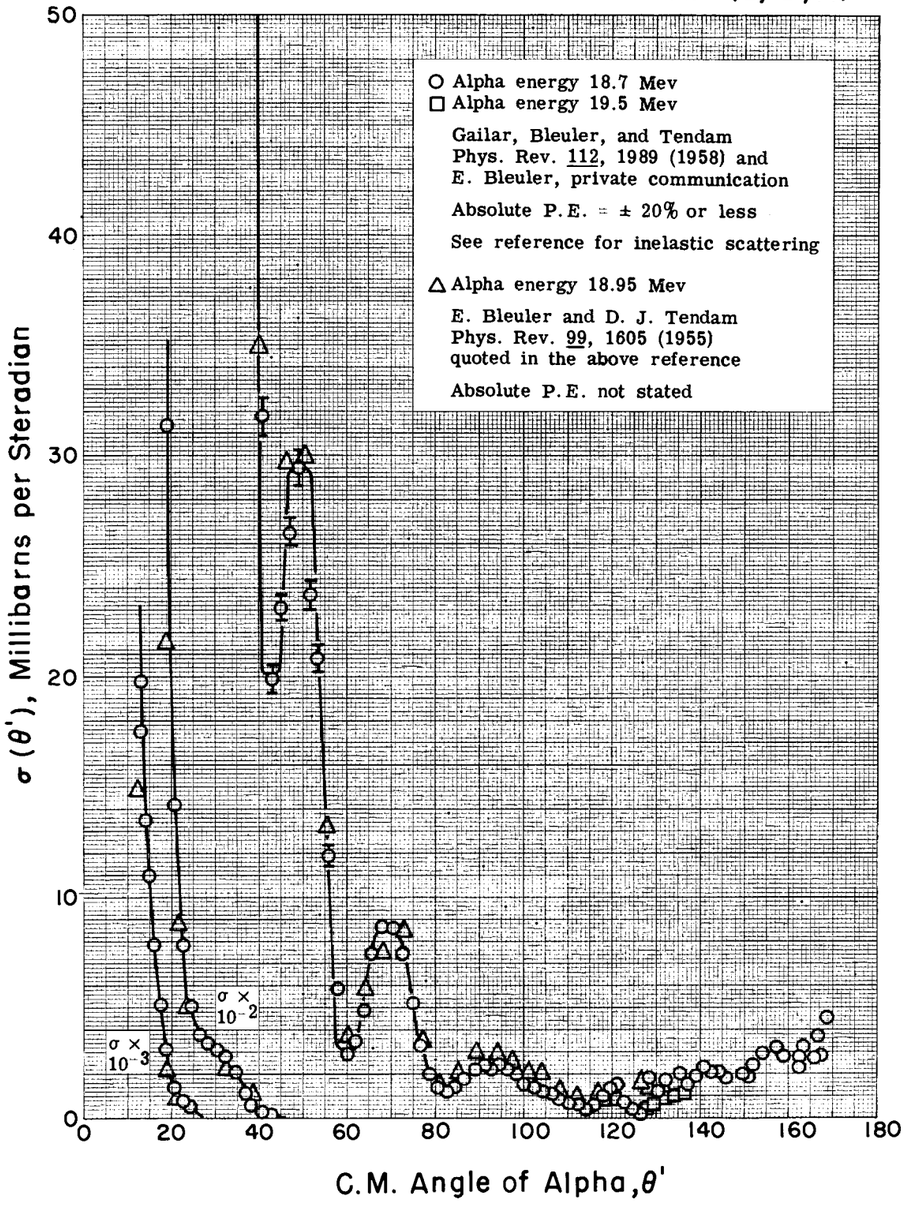
Broken portion of the curve is the authors' "guess". They believe the cross section to be too low in this energy region.

$Al^{27}(\alpha, p')Si^{30*}$









○ Alpha energy 18.7 Mev
□ Alpha energy 19.5 Mev

Gailar, Bleuler, and Tendam
Phys. Rev. 112, 1989 (1958) and
E. Bleuler, private communication

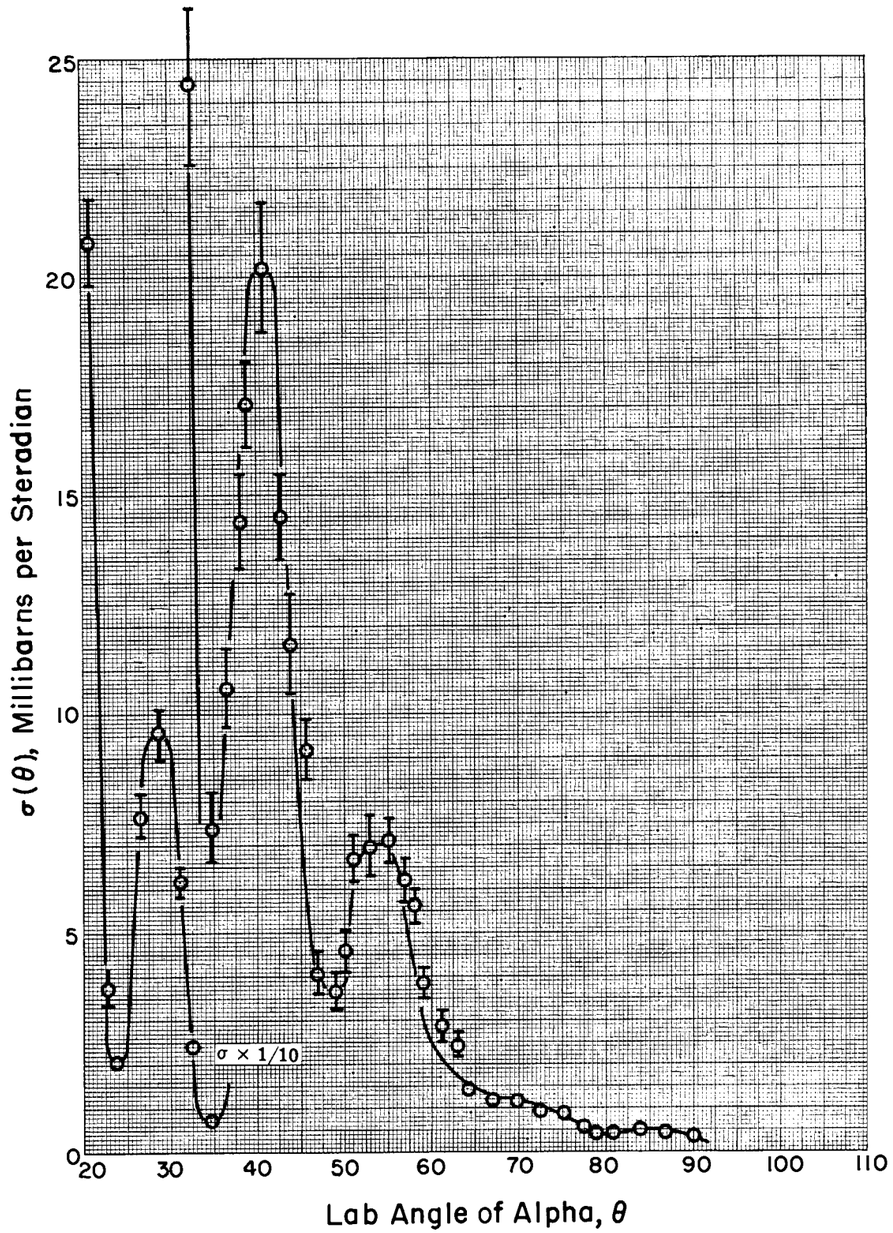
Absolute P.E. = ± 20% or less

See reference for inelastic scattering

△ Alpha energy 18.95 Mev

E. Bleuler and D. J. Tendam
Phys. Rev. 99, 1605 (1955)
quoted in the above reference

Absolute P.E. not stated



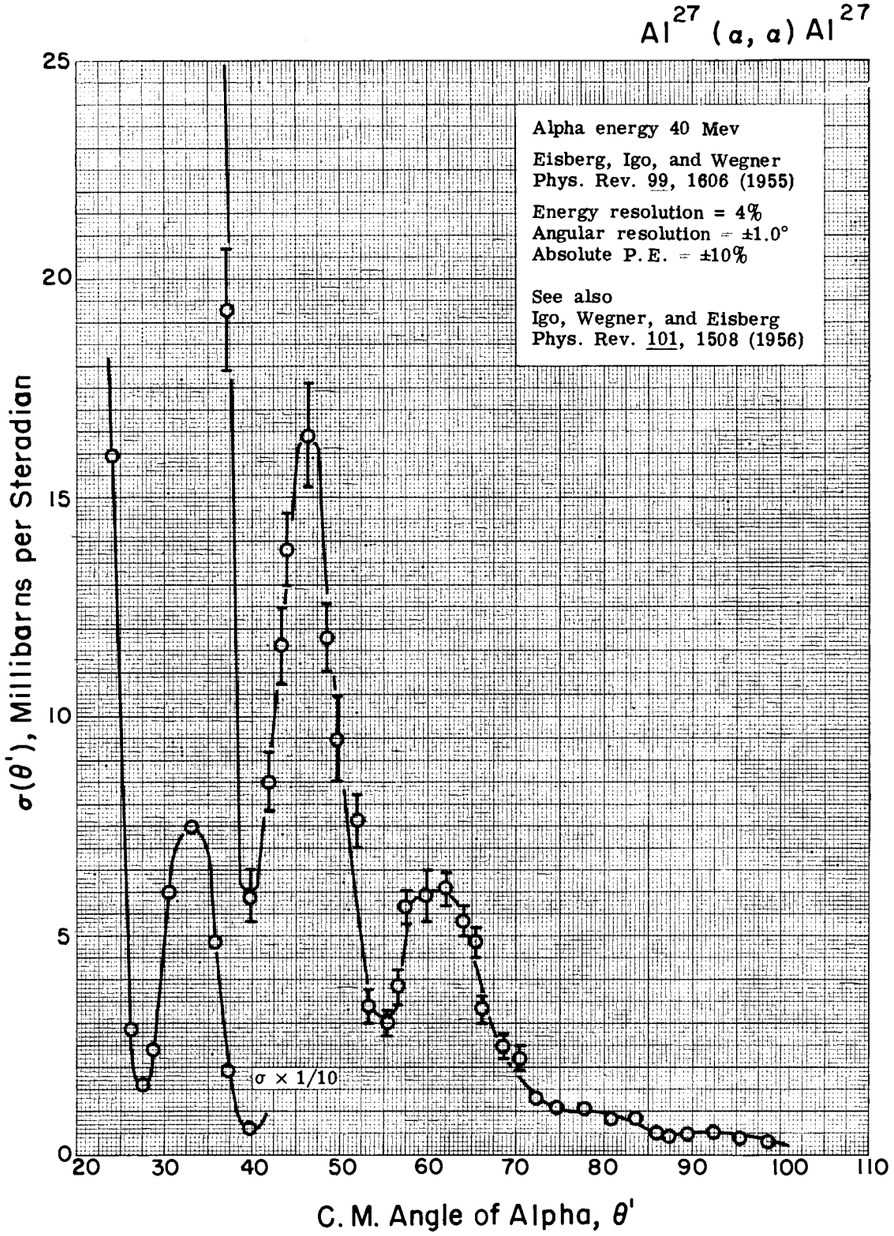
$Al^{27}(\alpha, \alpha)Al^{27}$

Alpha energy 40 Mev

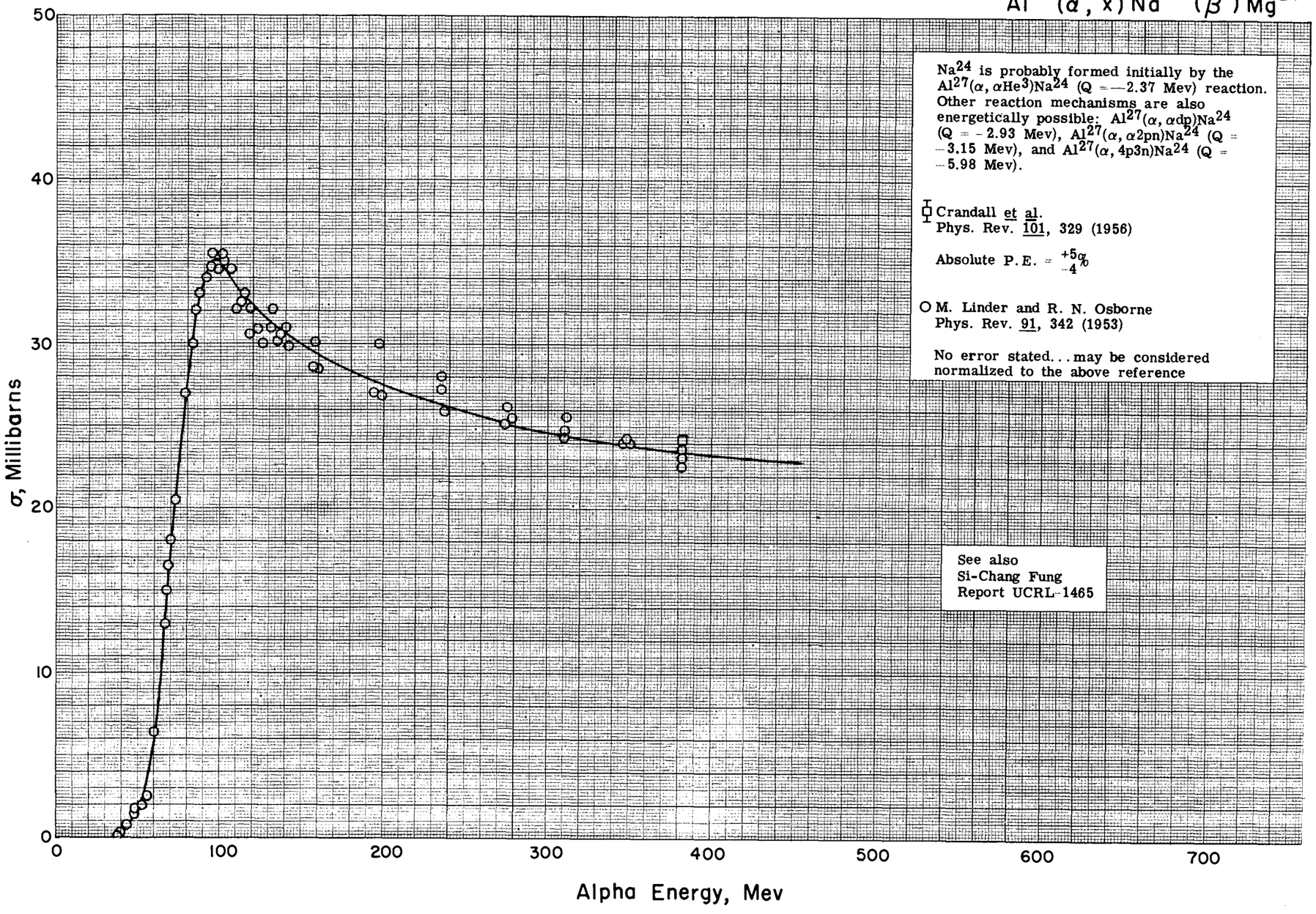
Eisberg, Igo, and Wegner
Phys. Rev. 99, 1606 (1955)

Energy resolution = 4%
Angular resolution = ±1.0°
Absolute P.E. = ±10%

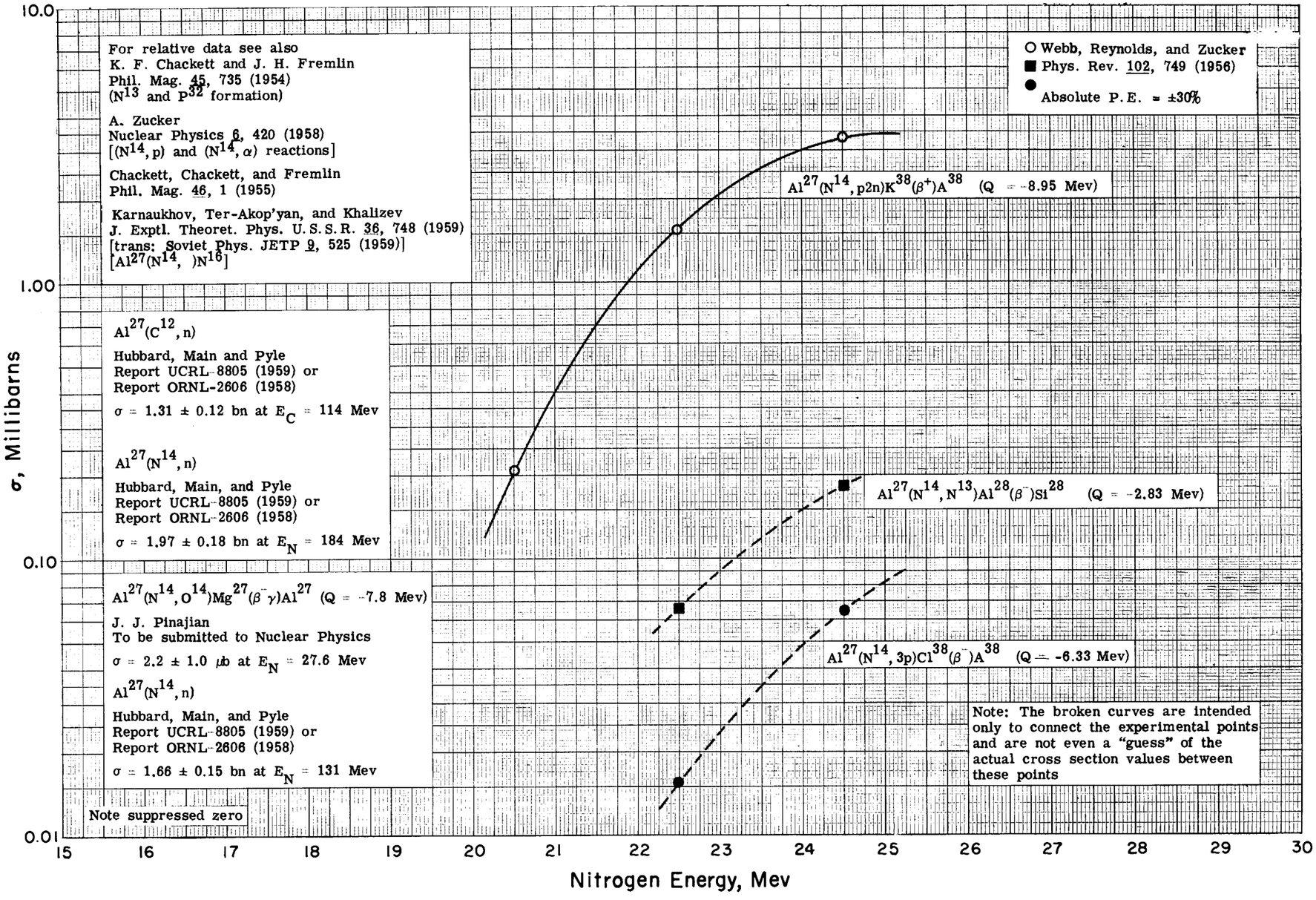
See also
Igo, Wegner, and Eisberg
Phys. Rev. 101, 1508 (1956)

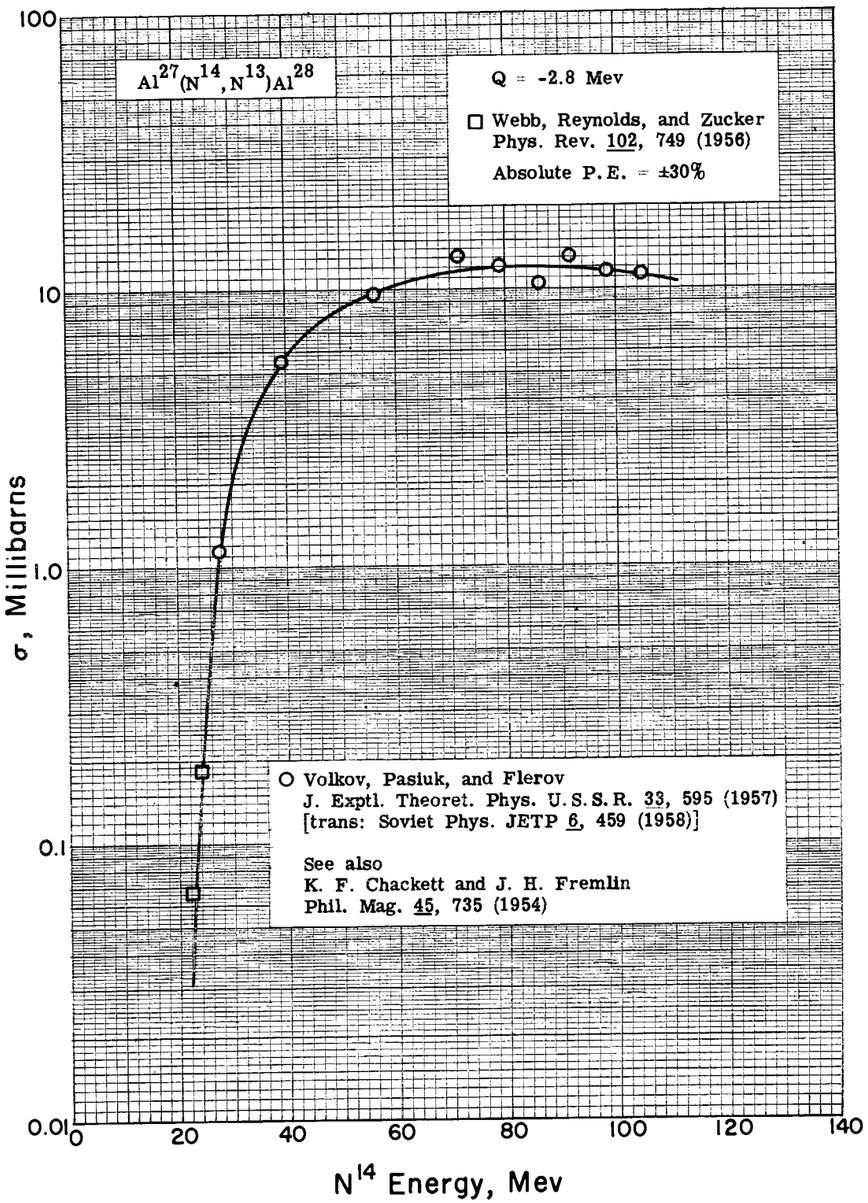


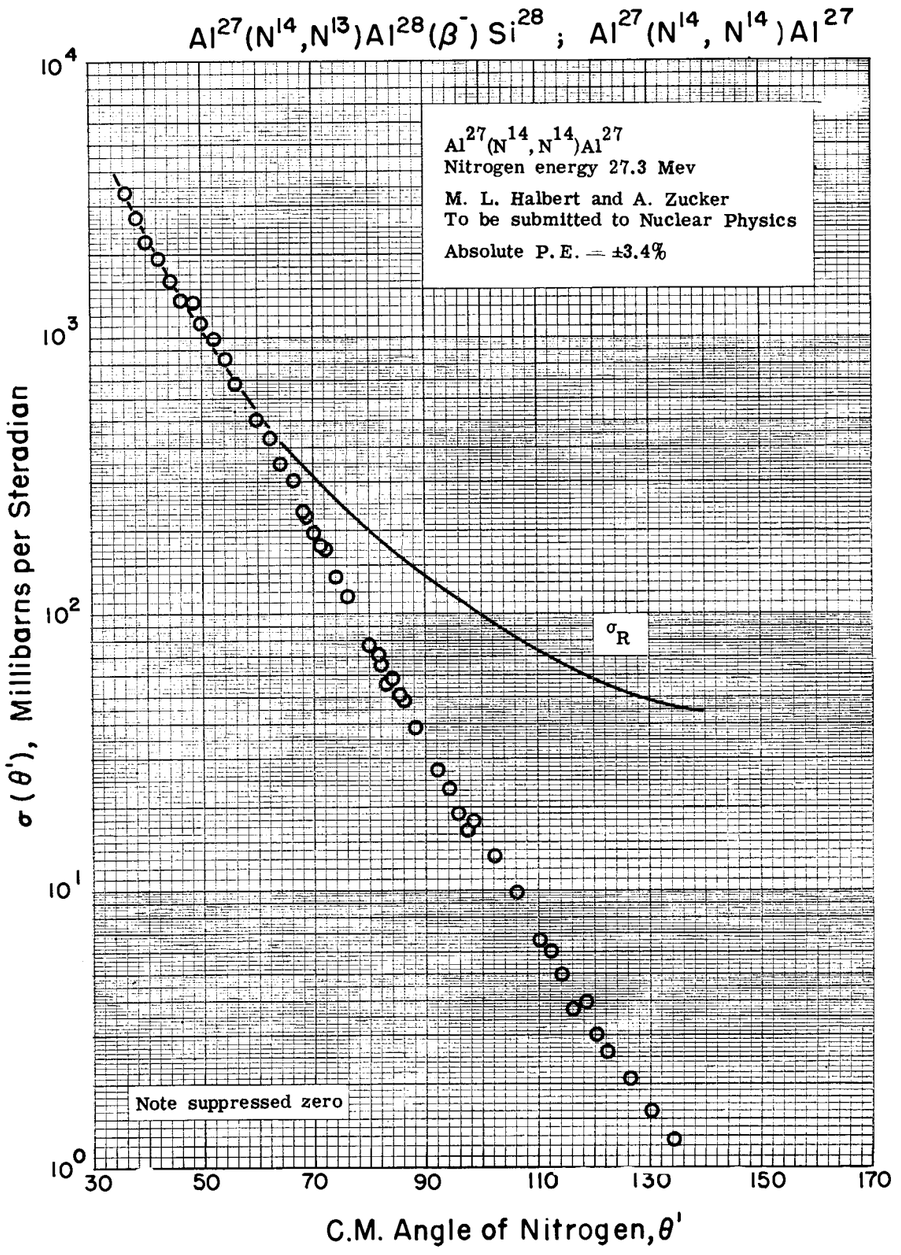
$Al^{27}(\alpha, x)Na^{24}(\beta^-)Mg^{24}$



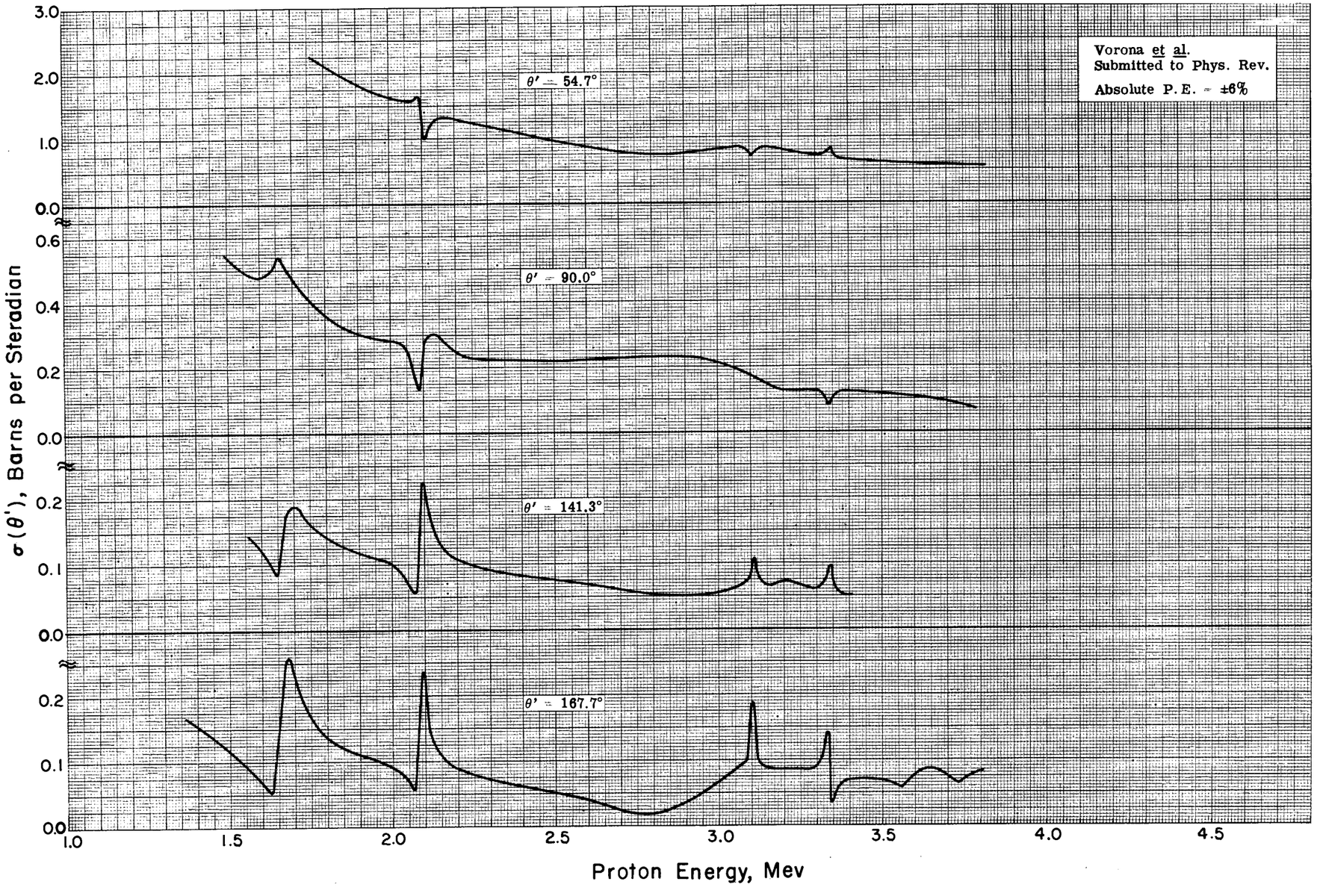
$Al^{27}(C^{12}, n)$; $Al^{27}(N^{14}, \quad)$

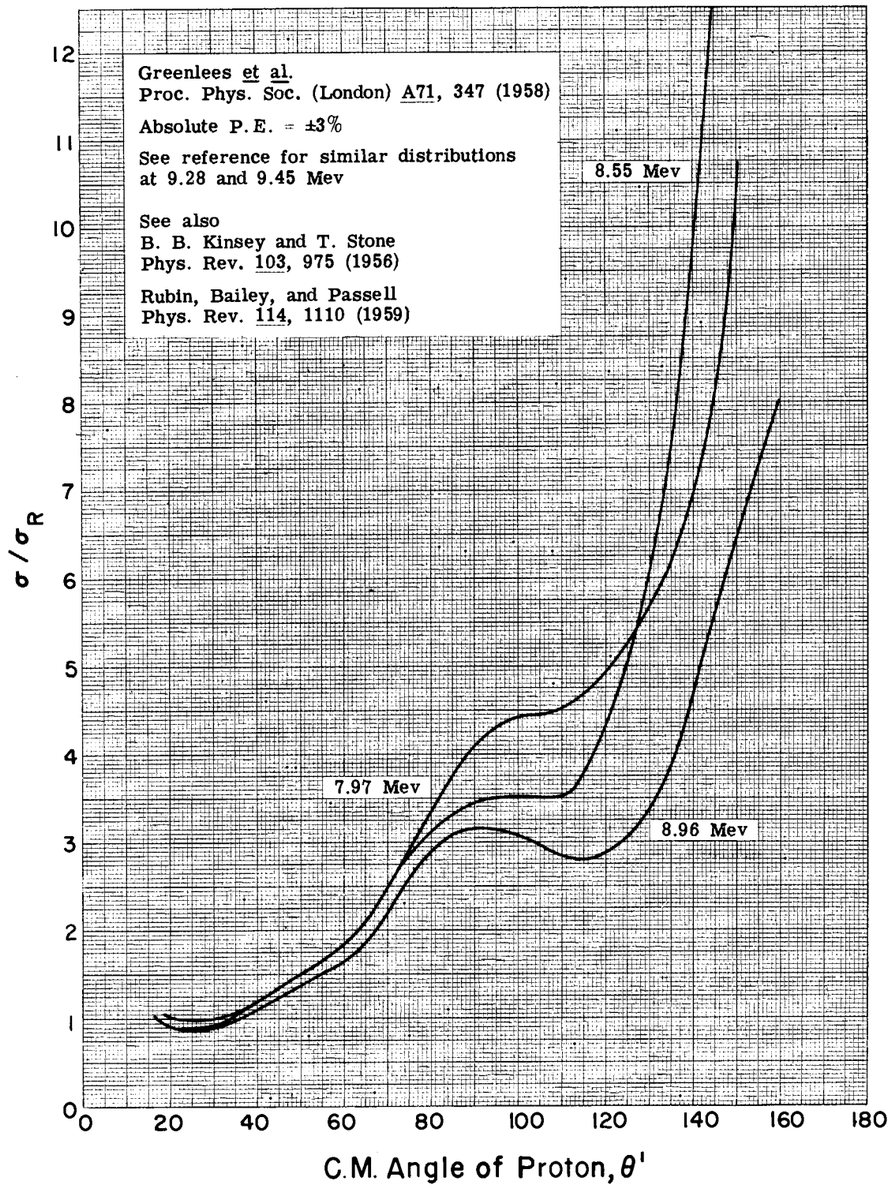


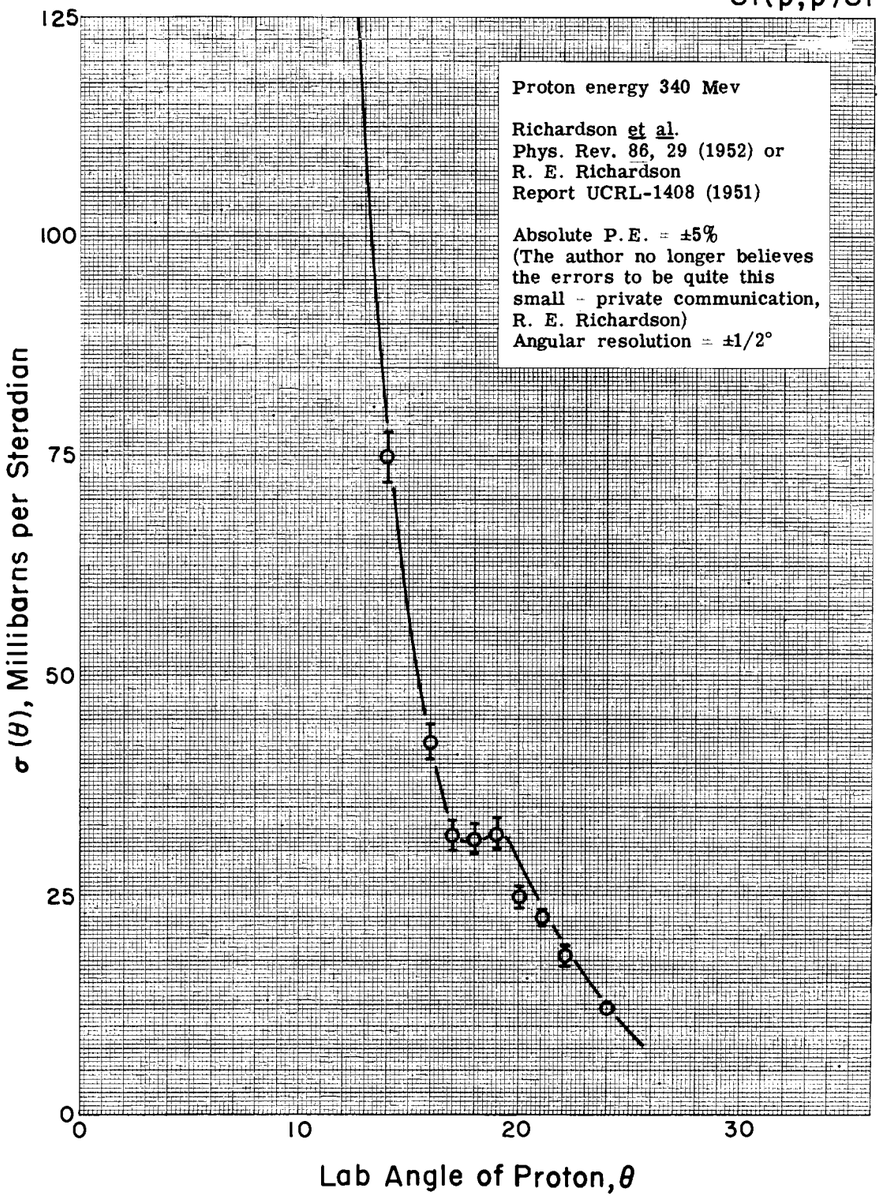

$Al^{27}(N^{14},N^{13})Al^{28}$
Q = -2.8 Mev
□ Webb, Reynolds, and Zucker
Phys. Rev. 102, 749 (1956)
Absolute P.E. = ±30%
O Volkov, Pasiuk, and Flerov
J. Exptl. Theoret. Phys. U.S.S.R. 33, 595 (1957)
[trans: Soviet Phys. JETP 6, 459 (1958)]
See also
K. F. Chackett and J. H. Fremlin
Phil. Mag. 45, 735 (1954)
σ, Millibarns
100
10
1.0
0.1
0.01
0
20
40
60
80
100
120
140
N^{14} Energy, Mev

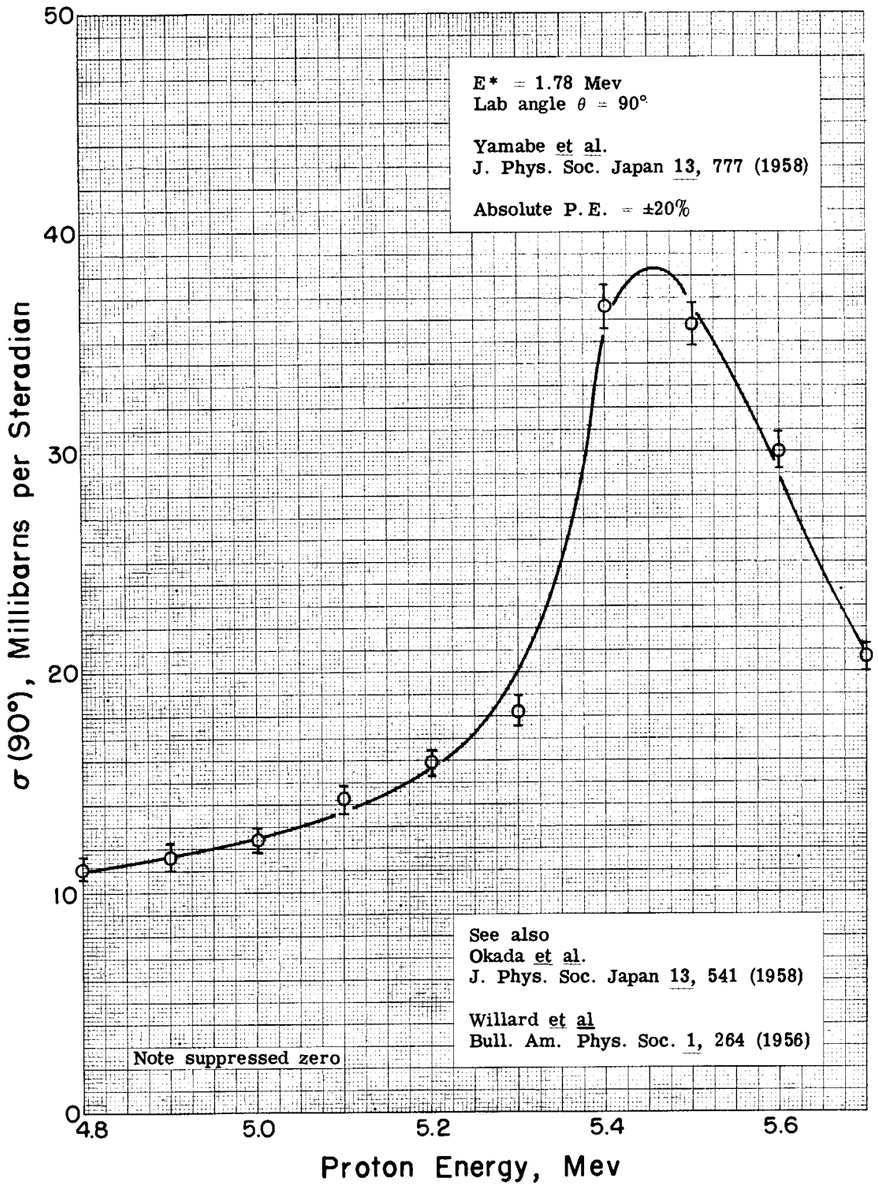

$Al^{27}(N^{14},N^{13})Al^{28}(\beta^-)Si^{28}$; $Al^{27}(N^{14},N^{14})Al^{27}$
$Al^{27}(N^{14},N^{14})Al^{27}$
Nitrogen energy 27.3 Mev
M. L. Halbert and A. Zucker
To be submitted to Nuclear Physics
Absolute P.E. = ±3.4%
σ_R
Note suppressed zero
$\sigma(\theta')$, Millibarns per Steradian
10^4
10^3
10^2
10^1
10^0
30
50
70
90
110
130
150
170
C.M. Angle of Nitrogen, θ'

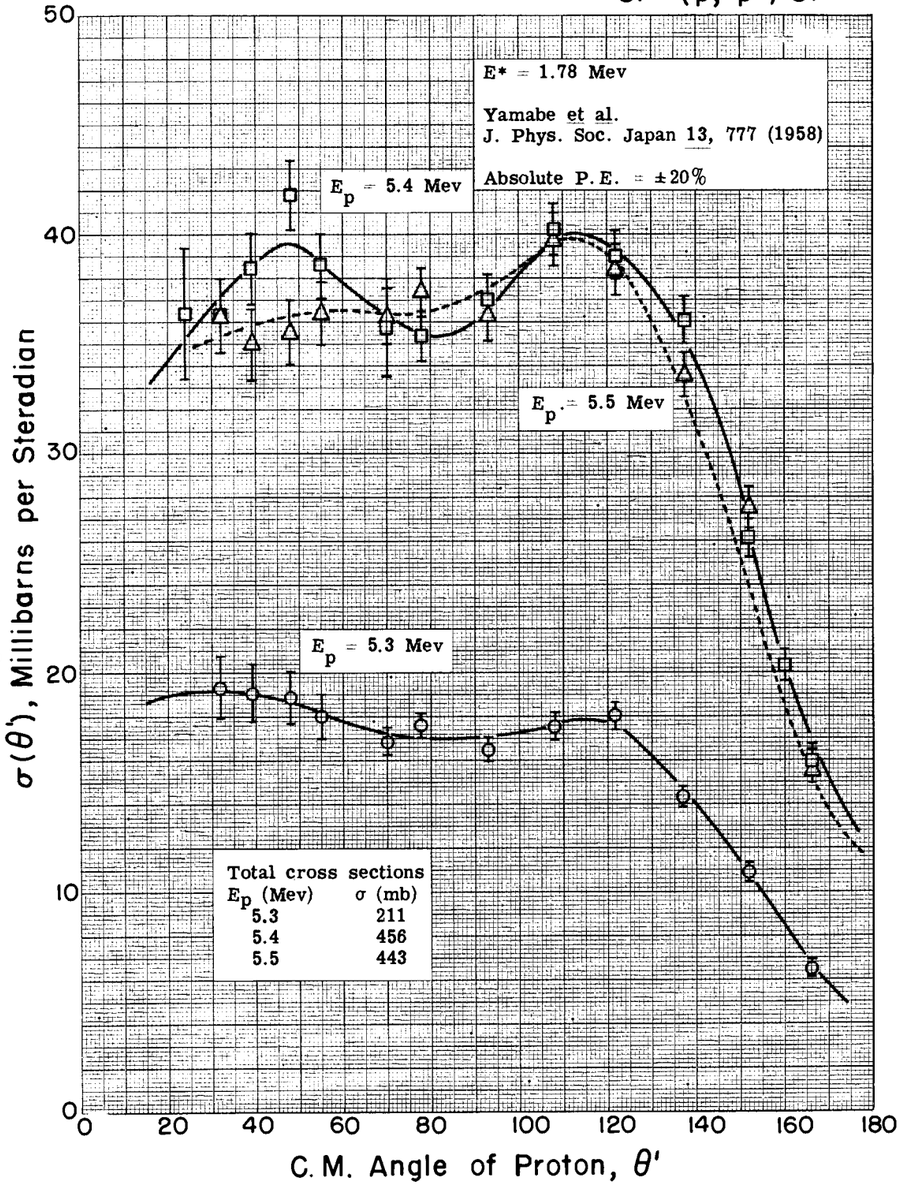
Si(p, p)Si

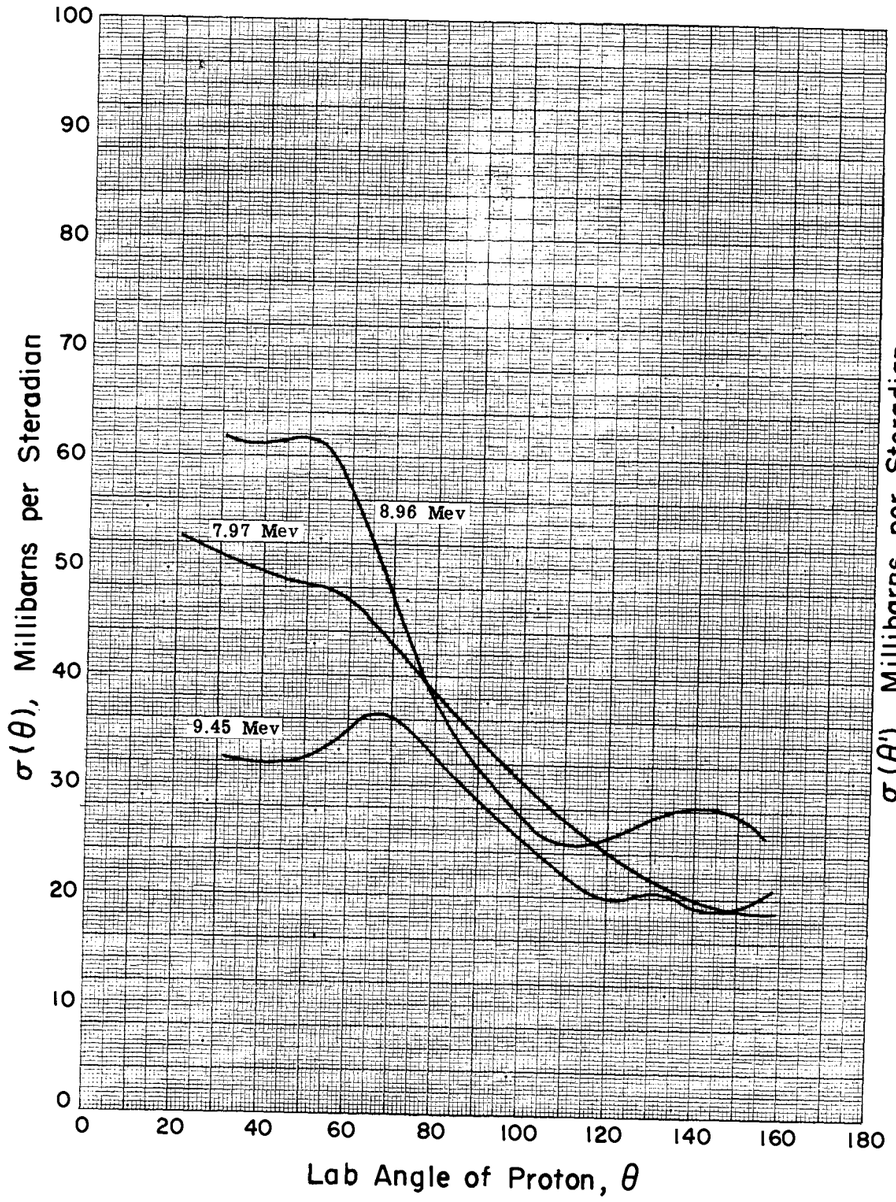

Vorona et al.
Submitted to Phys. Rev.
Absolute P.E. = ±6%
θ' = 54.7°
θ' = 90.0°
θ' = 141.3°
θ' = 167.7°
σ(θ'), Barns per Steradian
3.0
2.0
1.0
0.0
0.6
0.4
0.2
0.0
0.2
0.1
0.0
0.2
0.1
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Proton Energy, Mev


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 / σR
C.M. Angle of Proton, θ'
0
1
2
3
4
5
6
7
8
9
10
11
12
0
20
40
60
80
100
120
140
160
180

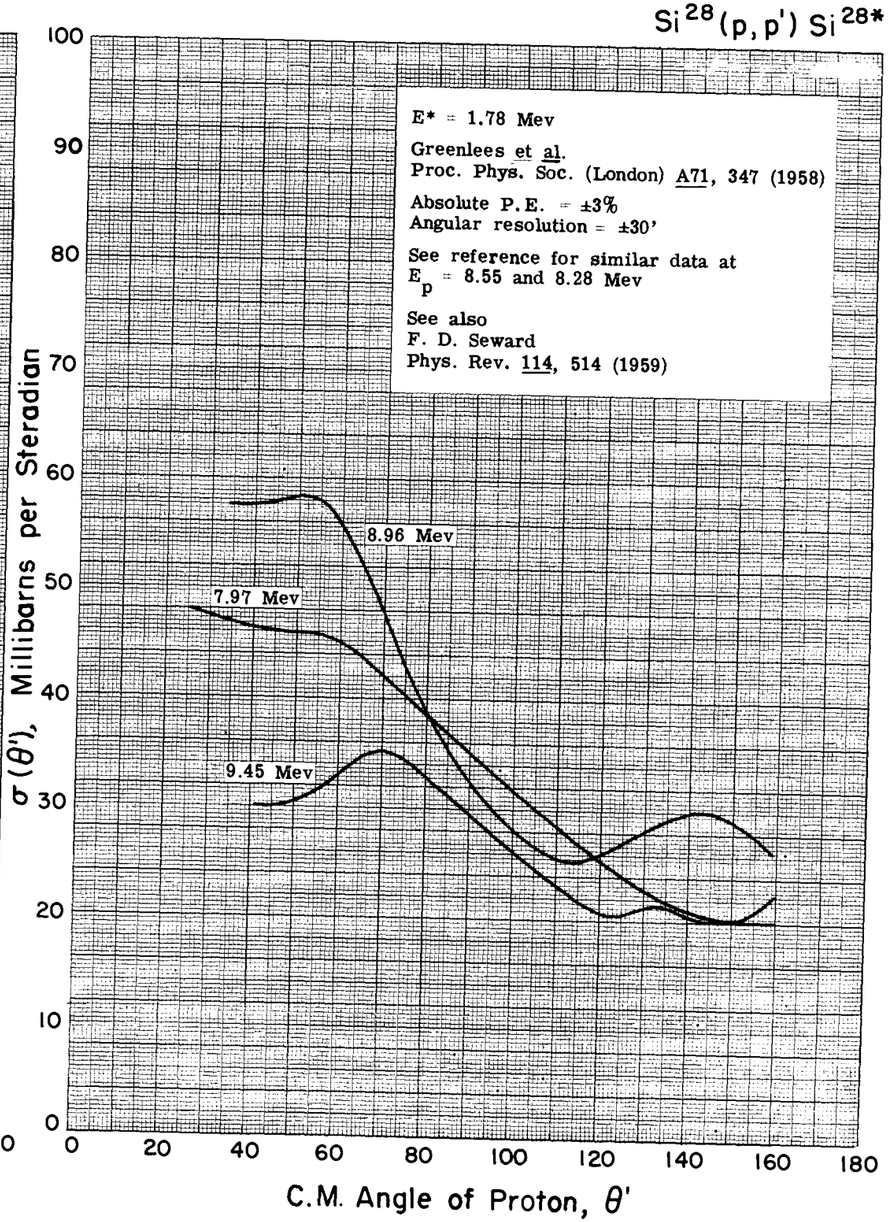

Proton energy 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P.E. = ±5%
(The author no longer believes the errors to be quite this small - private communication, R. E. Richardson)
Angular resolution = ±1/2°
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
25
50
75
100
125
0
10
20
30

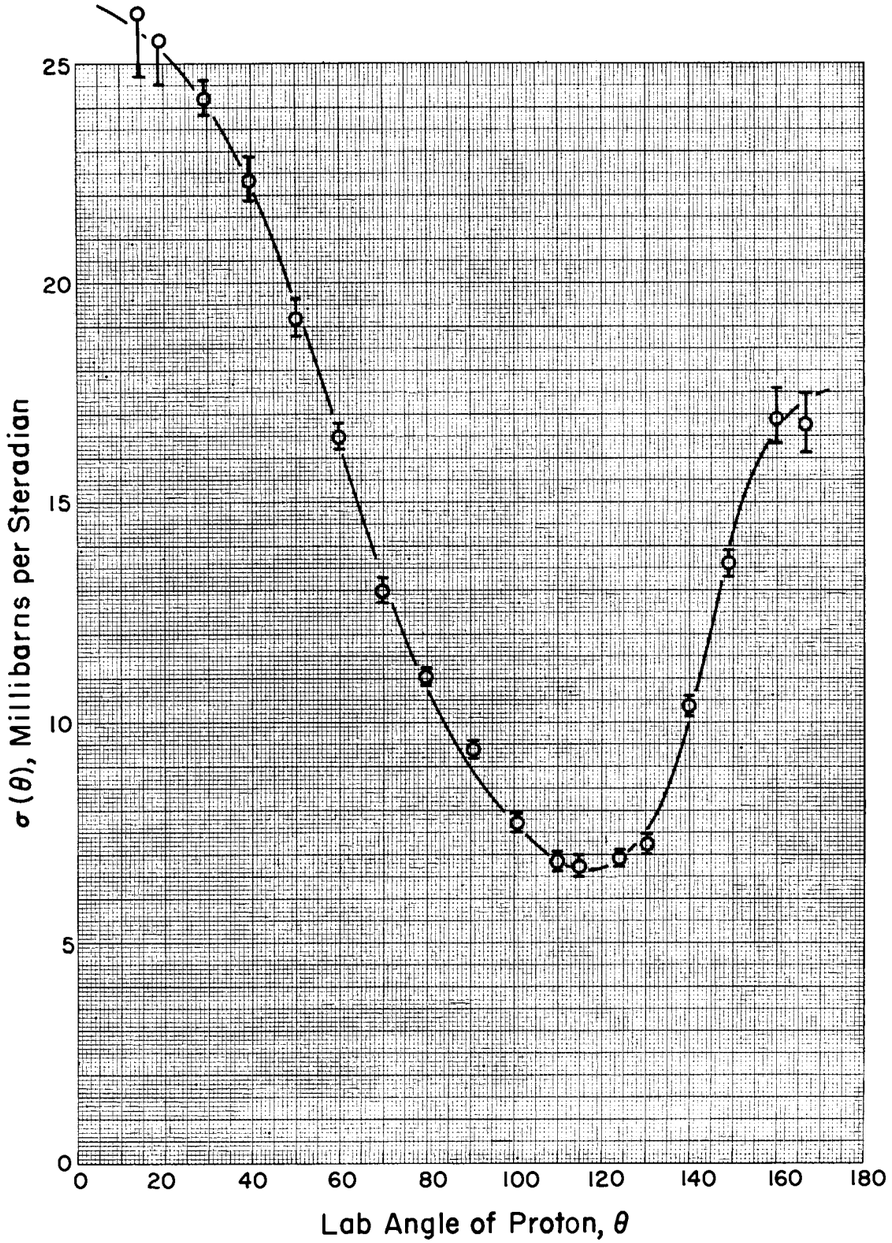

E* = 1.78 Mev
Lab angle θ = 90°
Yamabe et al.
J. Phys. Soc. Japan 13, 777 (1958)
Absolute P.E. = ±20%
See also
Okada et al.
J. Phys. Soc. Japan 13, 541 (1958)
Willard et al
Bull. Am. Phys. Soc. 1, 264 (1956)
Note suppressed zero
σ (90°), Millibarns per Steradian
Proton Energy, Mev
0
10
20
30
40
50
4.8
5.0
5.2
5.4
5.6

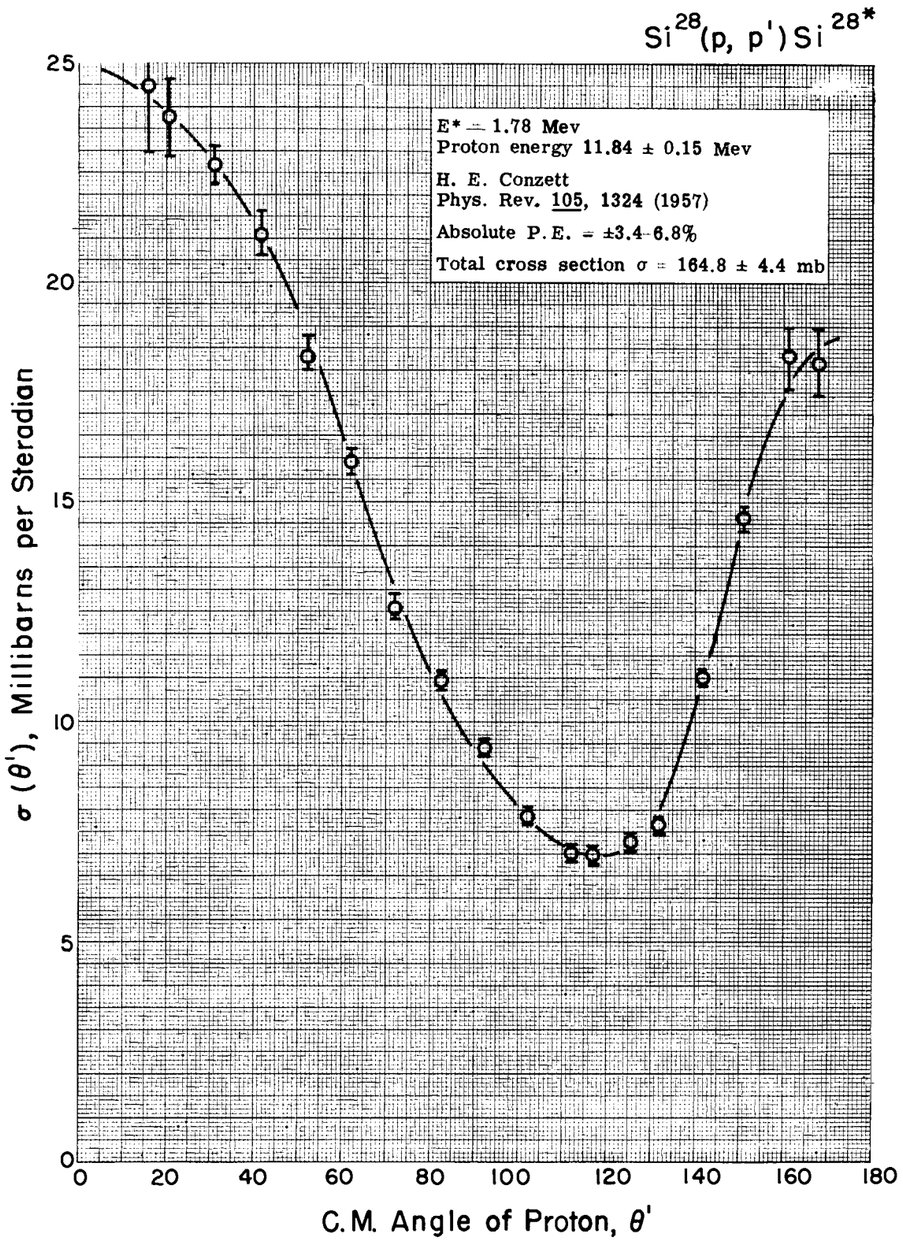

E* = 1.78 Mev
Yamabe et al.
J. Phys. Soc. Japan 13, 777 (1958)
Absolute P.E. = ±20%
E_p = 5.4 Mev
E_p = 5.5 Mev
E_p = 5.3 Mev
Total cross sections
E_p (Mev) σ (mb)
5.3 211
5.4 456
5.5 443
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180

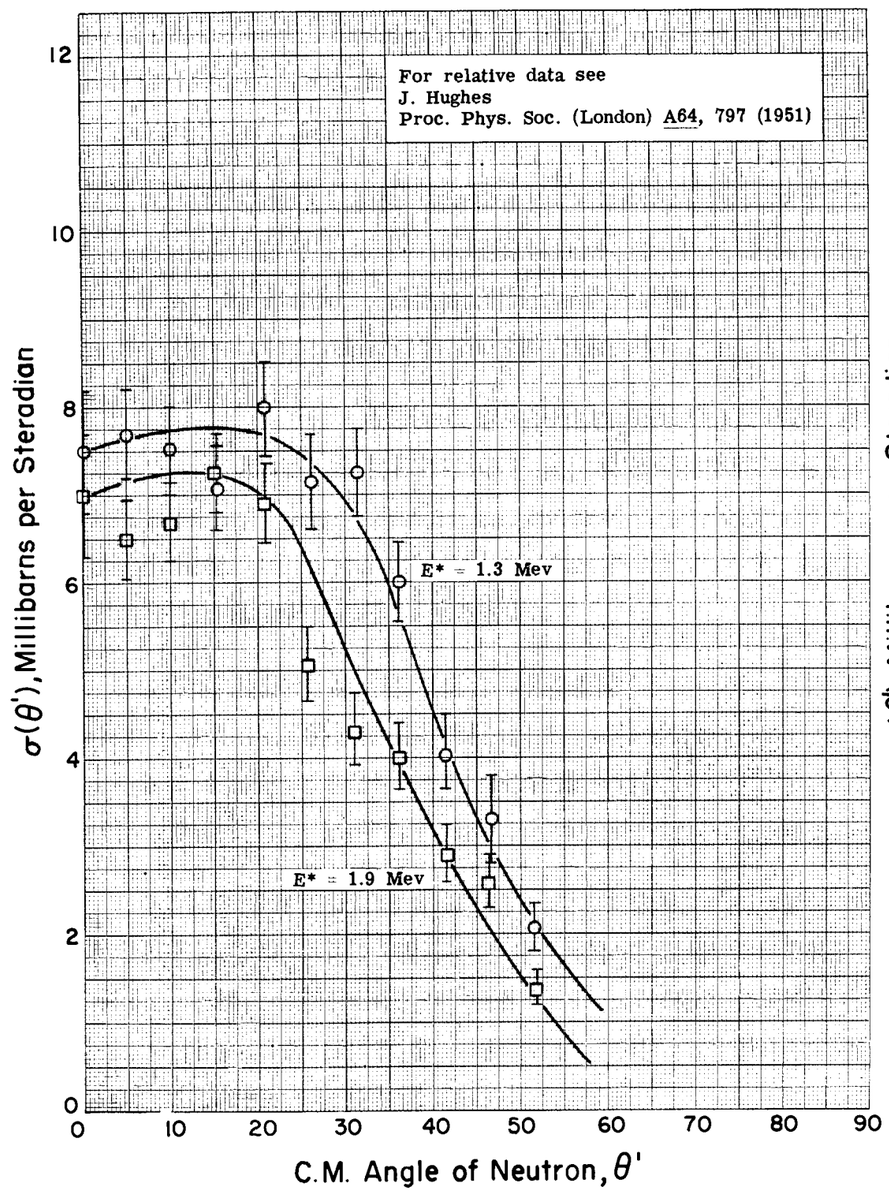

8.96 Mev
7.97 Mev
9.45 Mev
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180

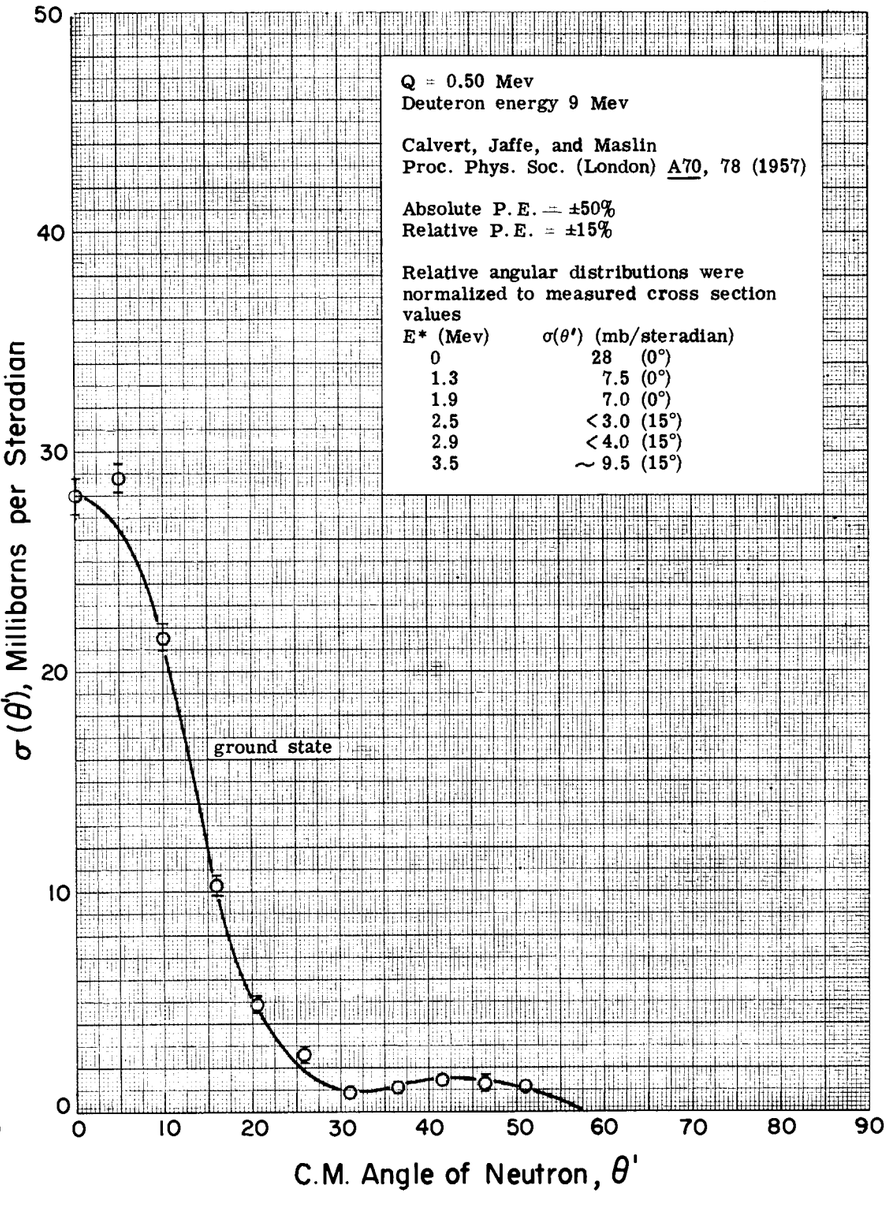
$Si^{28}(p, p')\ Si^{28*}$

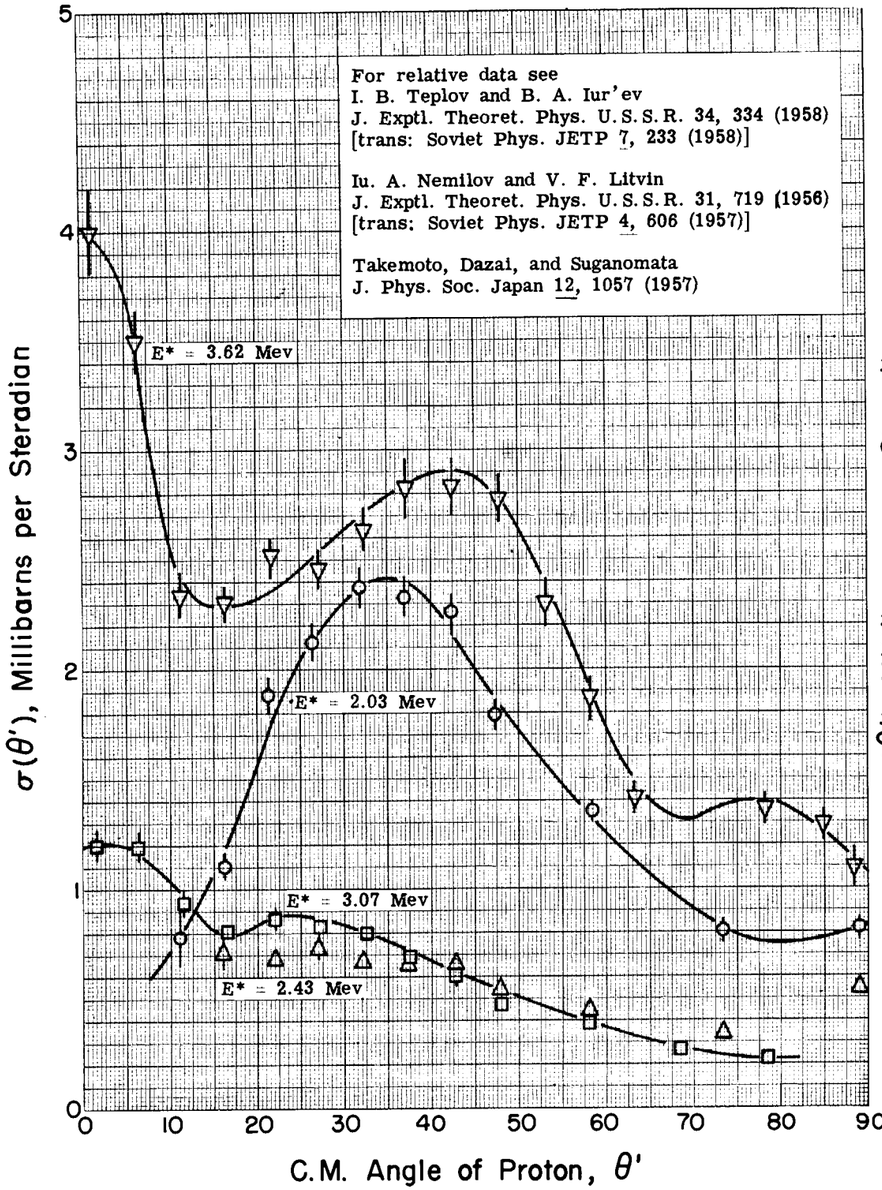

E* = 1.78 Mev
Greenlees et al.
Proc. Phys. Soc. (London) A71, 347 (1958)
Absolute P.E. = ±3%
Angular resolution = ±30'
See reference for similar data at
E_p = 8.55 and 8.28 Mev
See also
F. D. Seward
Phys. Rev. 114, 514 (1959)
8.96 Mev
7.97 Mev
9.45 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180

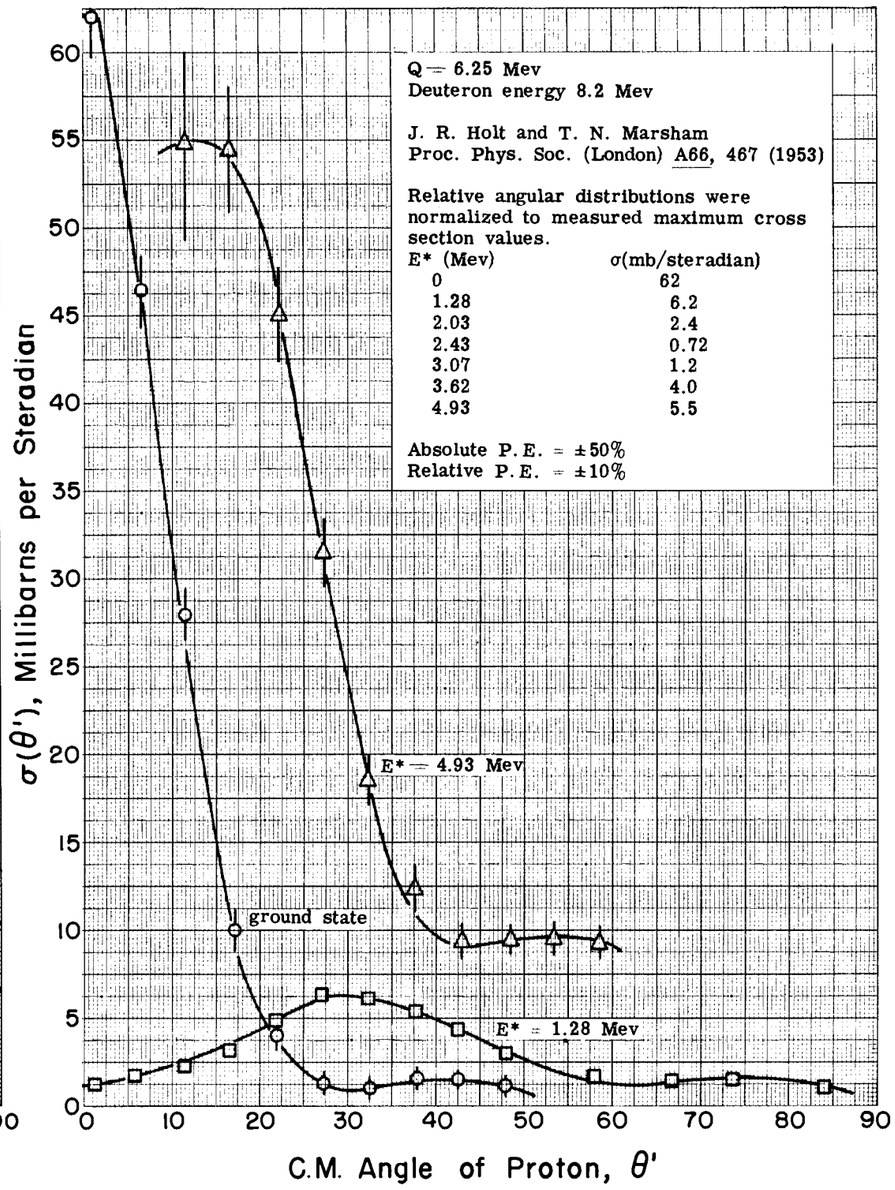

25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ

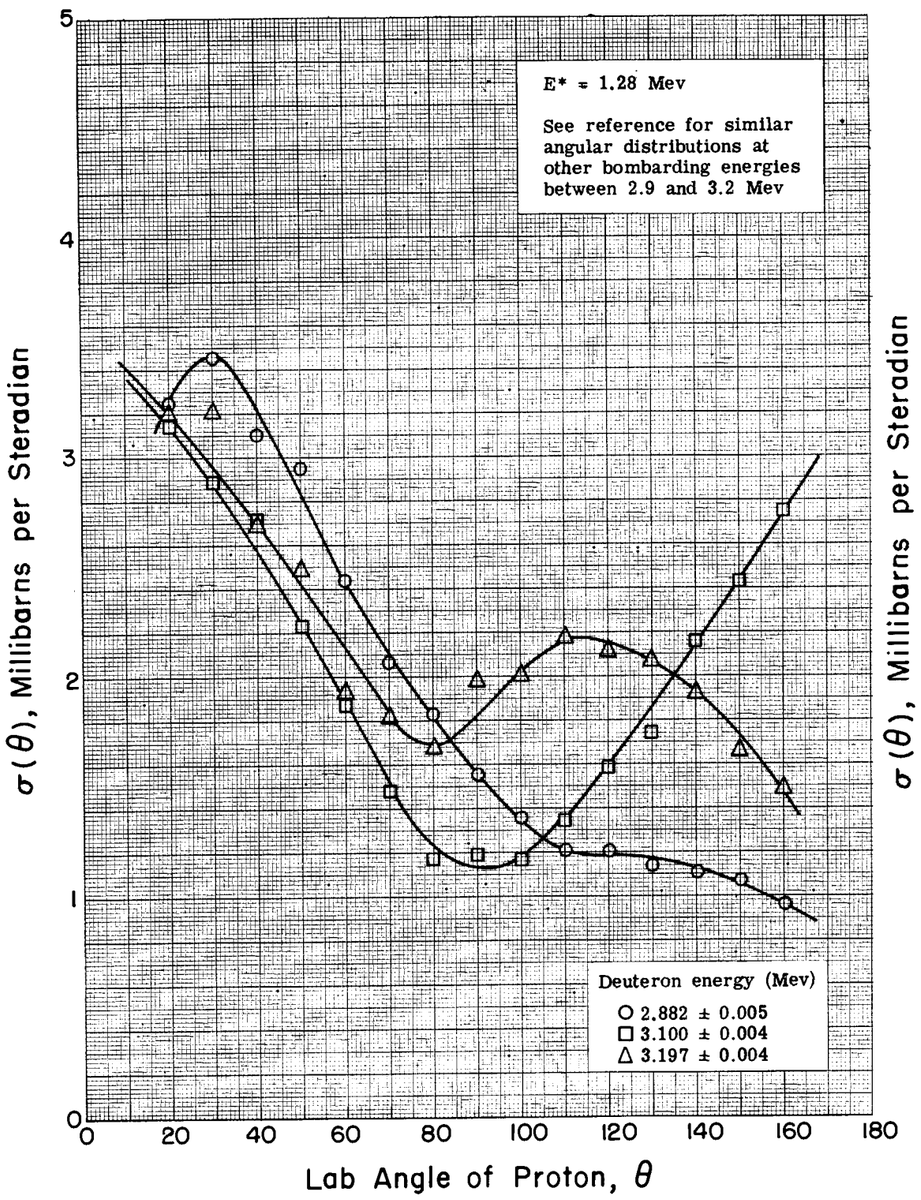

Si28(p, p')Si28*
E* = 1.78 Mev
Proton energy 11.84 ± 0.15 Mev
H. E. Conzett
Phys. Rev. 105, 1324 (1957)
Absolute P.E. = ±3.4-6.8%
Total cross section σ = 164.8 ± 4.4 mb
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'


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'
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90

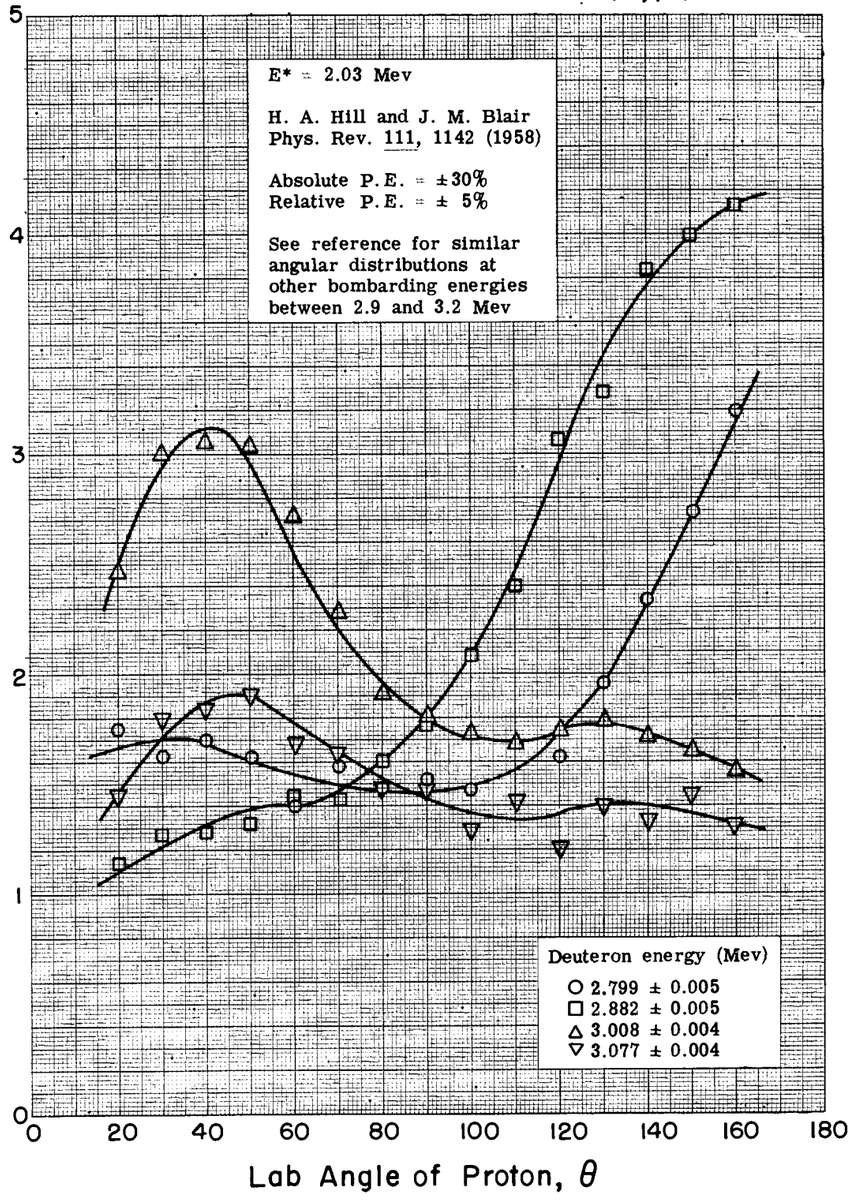

Q = 0.50 Mev
Deuteron energy 9 Mev
Calvert, Jaffe, and Maslin
Proc. Phys. Soc. (London) A70, 78 (1957)
Absolute P.E. = ±50%
Relative P.E. = ±15%
Relative angular distributions were normalized to measured cross section values
E* (Mev) σ(θ') (mb/steradian)
0 28 (0°)
1.3 7.5 (0°)
1.9 7.0 (0°)
2.5 < 3.0 (15°)
2.9 < 4.0 (15°)
3.5 ~ 9.5 (15°)
ground state
σ(θ'), Millibarns per Steradian
C.M. Angle of Neutron, θ'
0
10
20
30
40
50
0
10
20
30
40
50
60
70
80
90

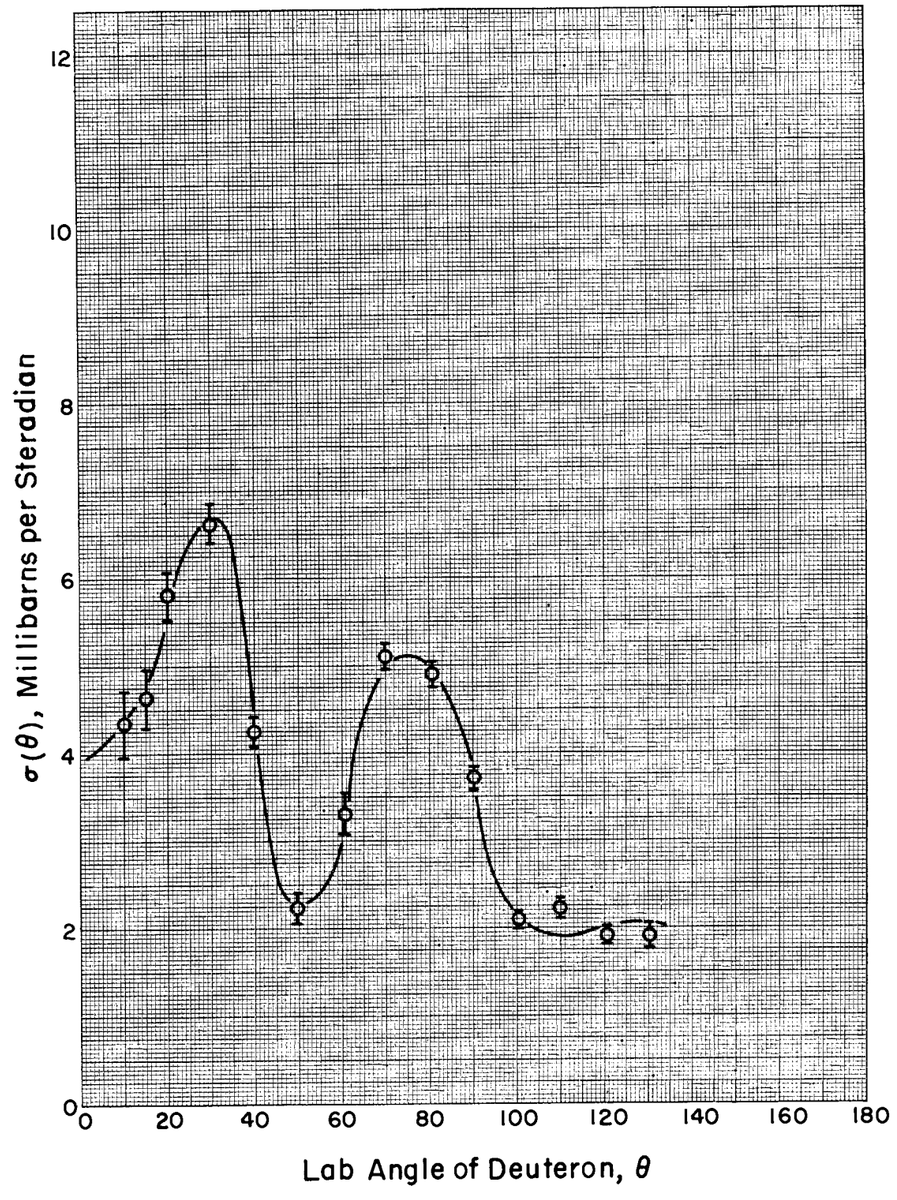

For relative data see
I. B. Teplov and B. A. Iur'ev
J. Exptl. Theoret. Phys. U.S.S.R. 34, 334 (1958)
[trans: Soviet Phys. JETP 7, 233 (1958)]
Iu. A. Nemilov and V. F. Litvin
J. Exptl. Theoret. Phys. U.S.S.R. 31, 719 (1956)
[trans: Soviet Phys. JETP 4, 606 (1957)]
Takemoto, Dazai, and Suganomata
J. Phys. 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'

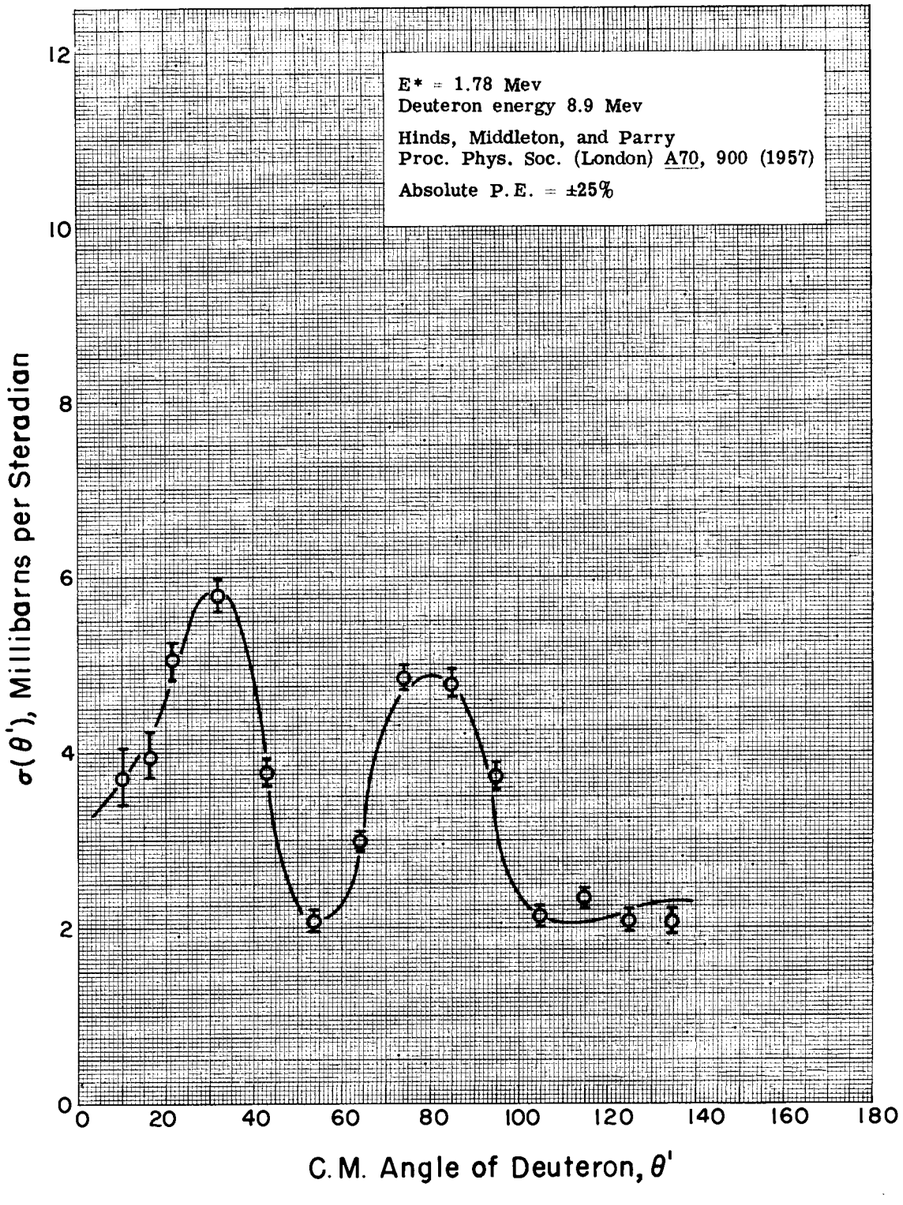

Q = 6.25 Mev
Deuteron energy 8.2 Mev
J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 467 (1953)
Relative angular distributions were normalized to measured maximum cross section values.
E* (Mev) σ(mb/steradian)
0 62
1.28 6.2
2.03 2.4
2.43 0.72
3.07 1.2
3.62 4.0
4.93 5.5
Absolute P.E. = ±50%
Relative P.E. = ±10%
E* = 4.93 Mev
ground state
E* = 1.28 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'


E* = 1.28 Mev
See reference for similar angular distributions at other bombarding energies between 2.9 and 3.2 Mev
Deuteron energy (Mev)
O 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

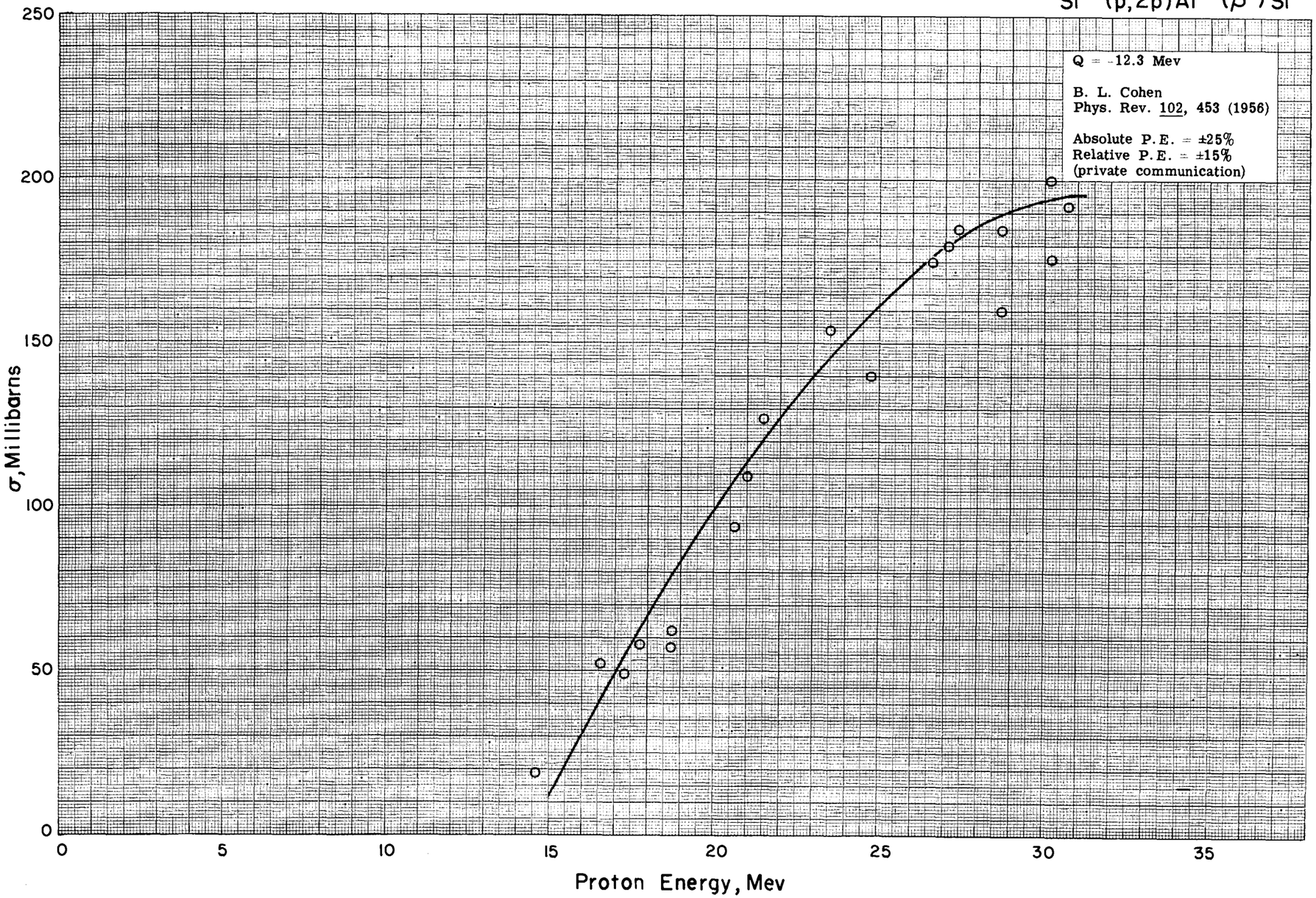
$Si^{28}(d,p')Si^{29*}$

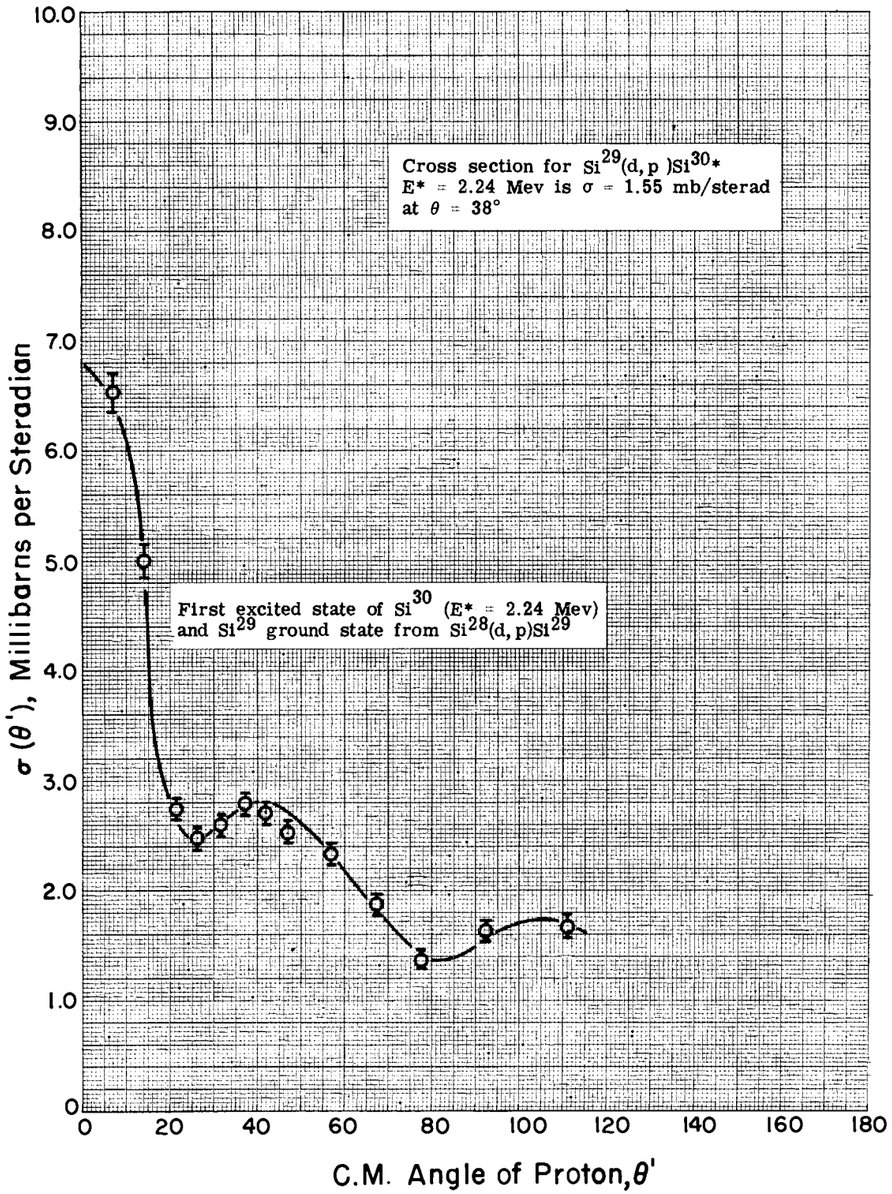

E* = 2.03 Mev
H. A. Hill and J. M. Blair
Phys. Rev. 111, 1142 (1958)
Absolute P.E. = ±30%
Relative P.E. = ± 5%
See reference for similar angular distributions at other bombarding energies between 2.9 and 3.2 Mev
Deuteron energy (Mev)
O 2.799 ± 0.005
□ 2.882 ± 0.005
△ 3.008 ± 0.004
▽ 3.077 ± 0.004
σ(θ),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

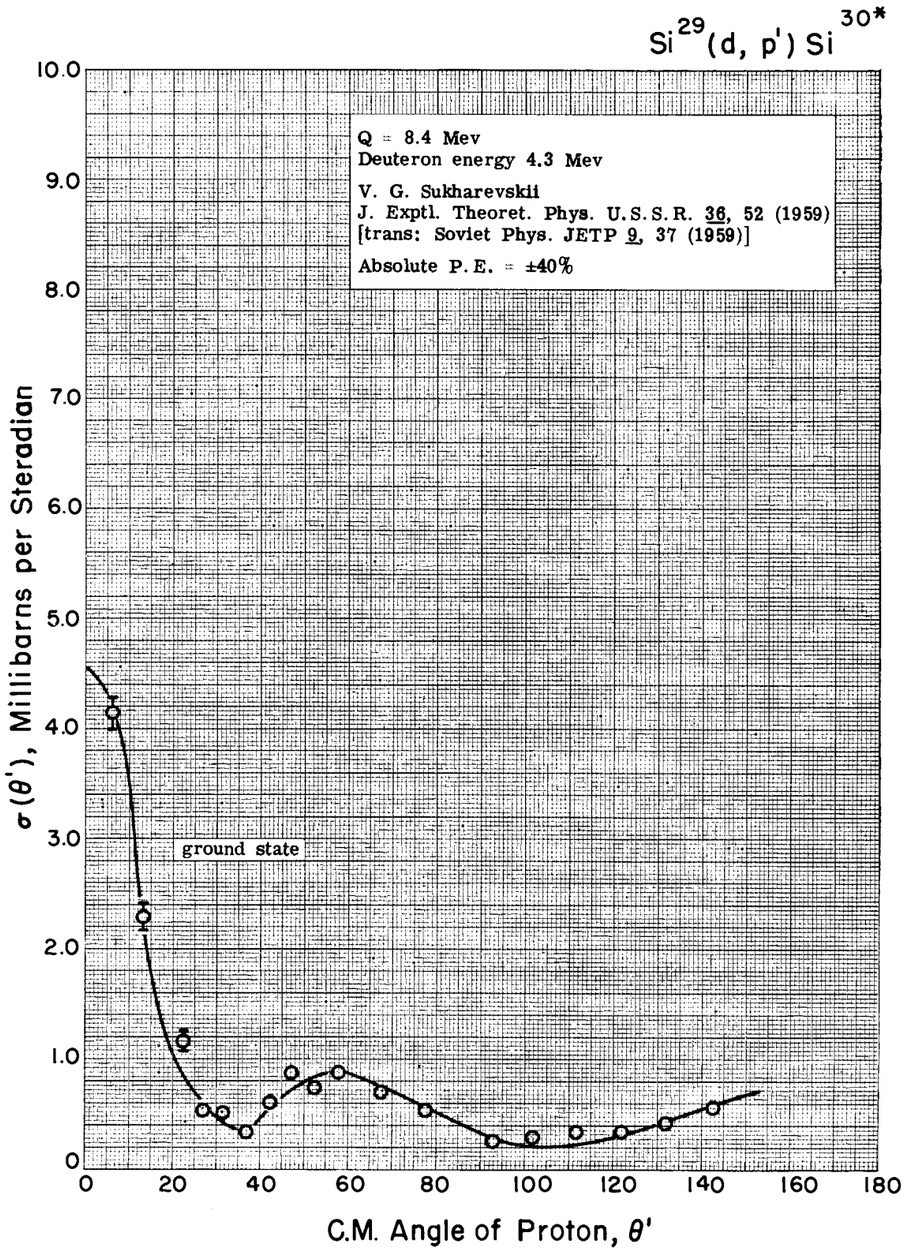

σ(θ), Millibarns per Steradian
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160
180
Lab Angle of Deuteron, θ

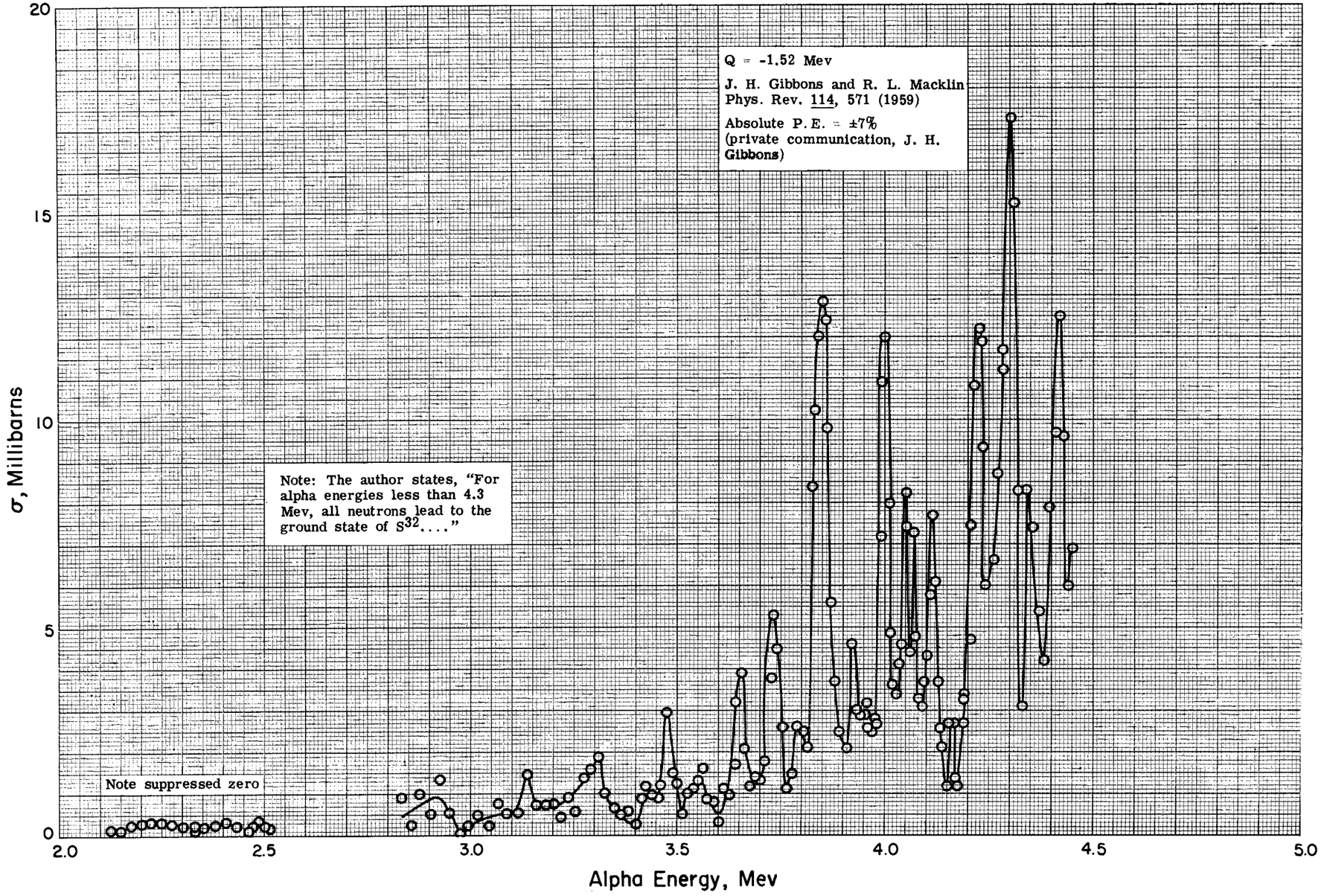

E* = 1.78 Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Proc. Phys. Soc. (London) A70, 900 (1957)
Absolute P.E. = ±25%
σ(θ'), Millibarns per Steradian
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Deuteron, θ'

$Si^{29}(p,2p)Al^{28}(\beta^-)Si^{28}$




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'
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
20
40
60
80
100
120
140
160
180


$Si^{29}(d,p')Si^{30*}$
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'
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
20
40
60
80
100
120
140
160
180


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 S^{32}...."
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%

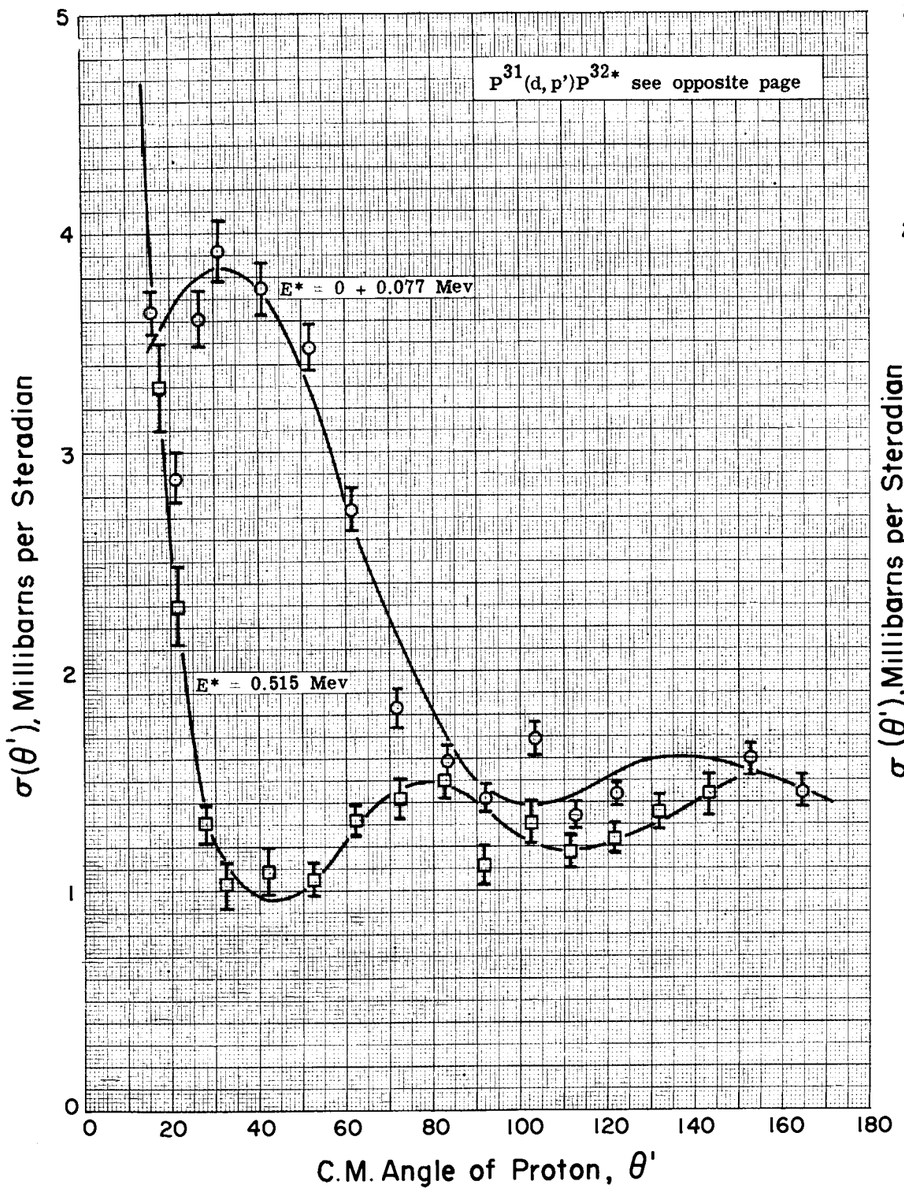
See also
Bent et al.
Phys. Rev. 100, 774 (1955)

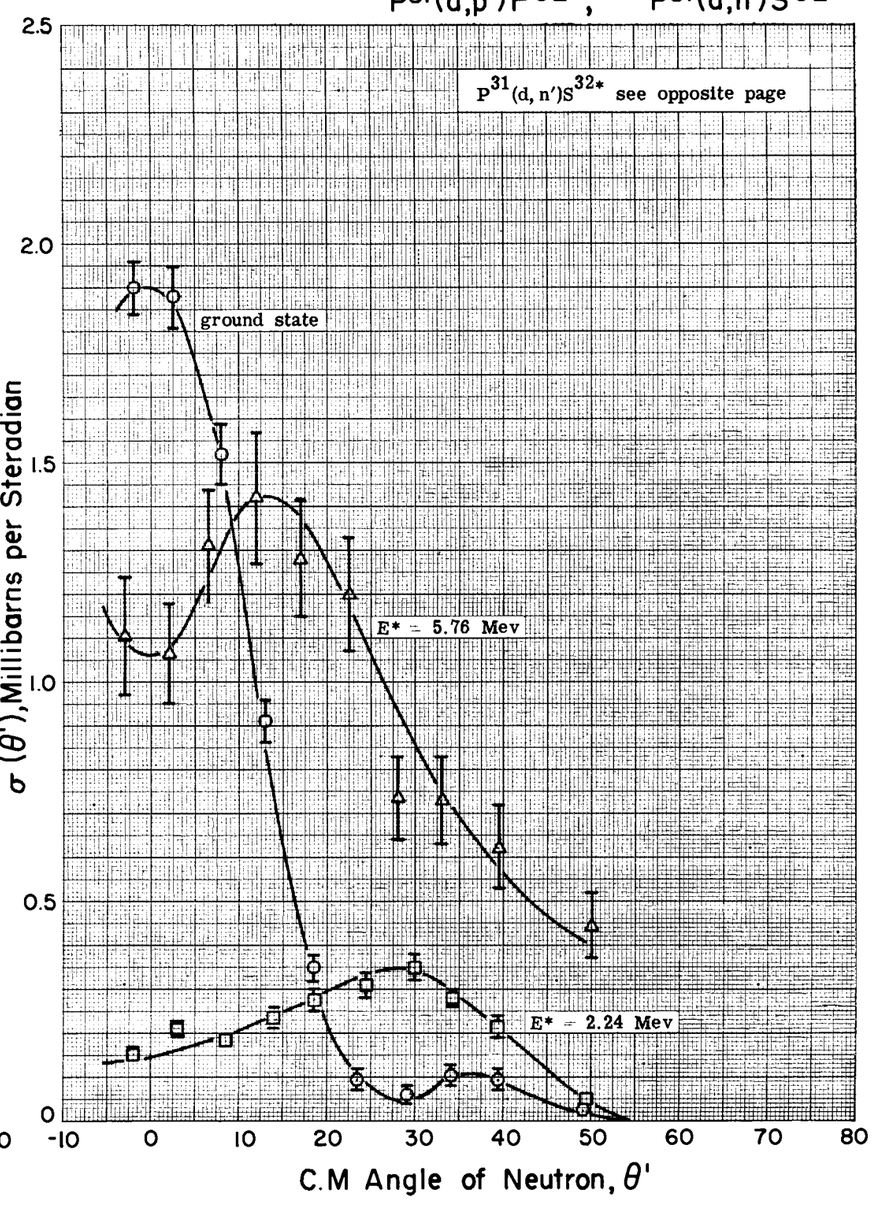
M. D. Kamen
Phys. Rev. 60, 537 (1941)

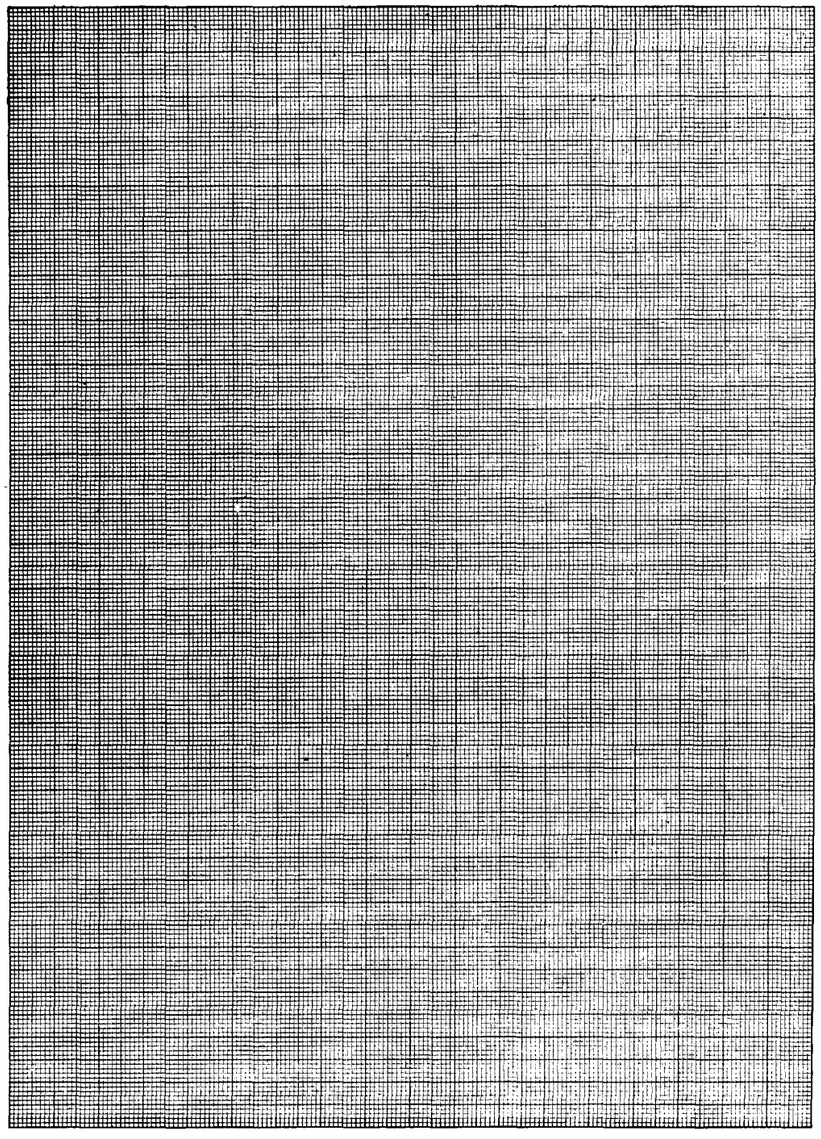
For relative data see
Dalton, Hinds, and Parry
Proc. Phys. Soc. (London) A70, 586 (1957)

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

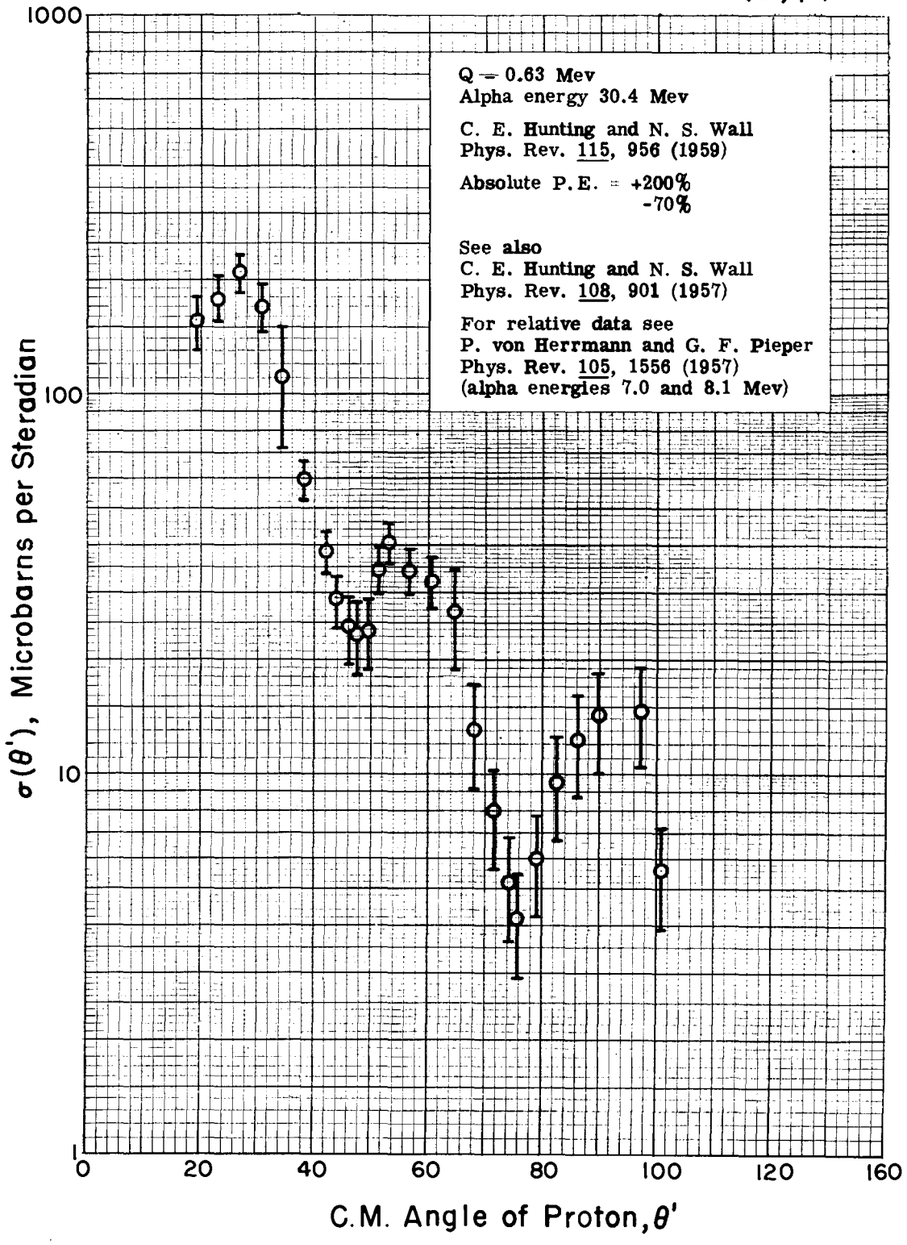
Parkinson, Beach, and King
Phys. Rev. 87, 387 (1952)

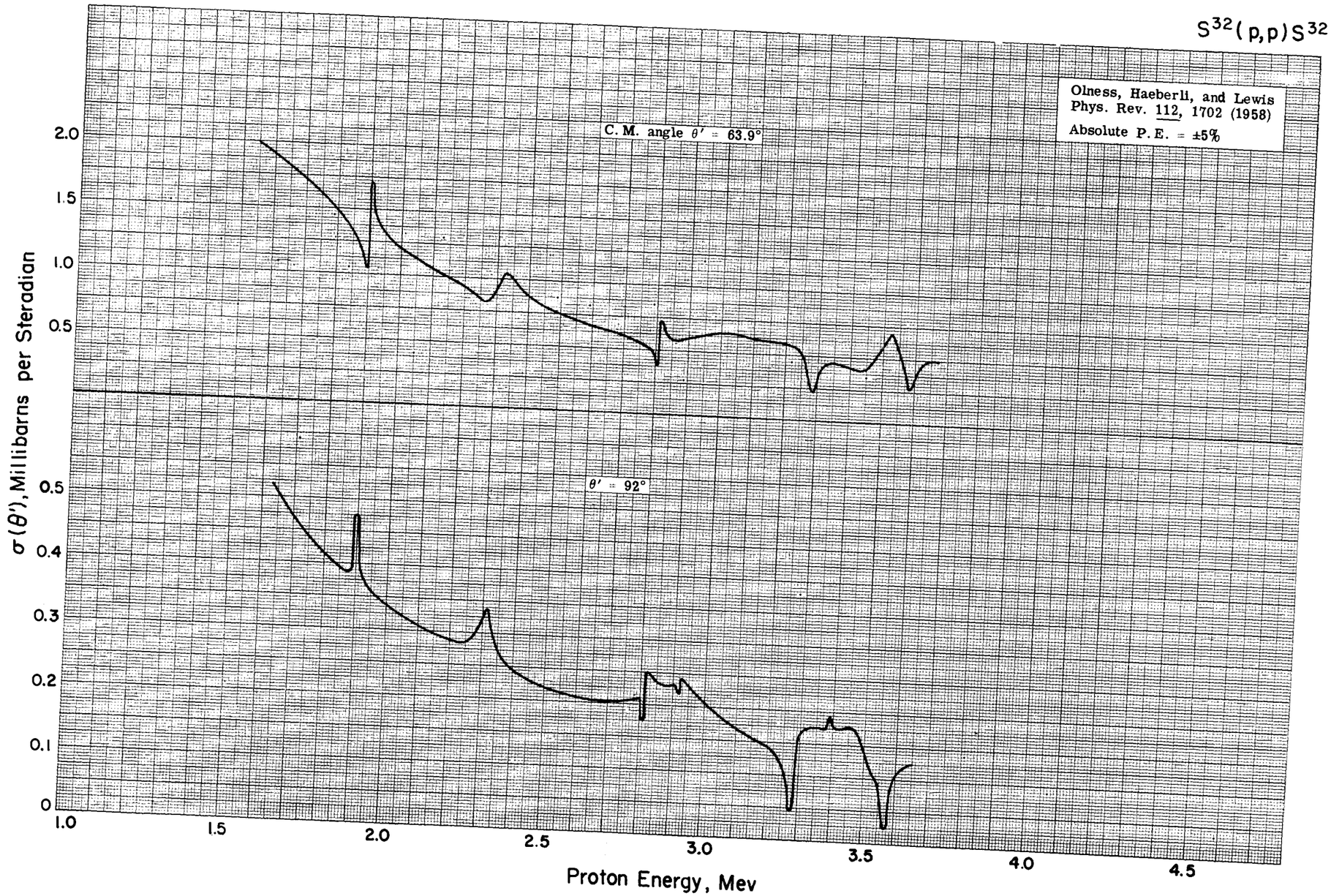

$P^{31}(d, p')P^{32*}$ see opposite page
E* = 0 + 0.077 Mev
E* = 0.515 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
20
40
60
80
100
120
140
160
180
1
2
3
4
5

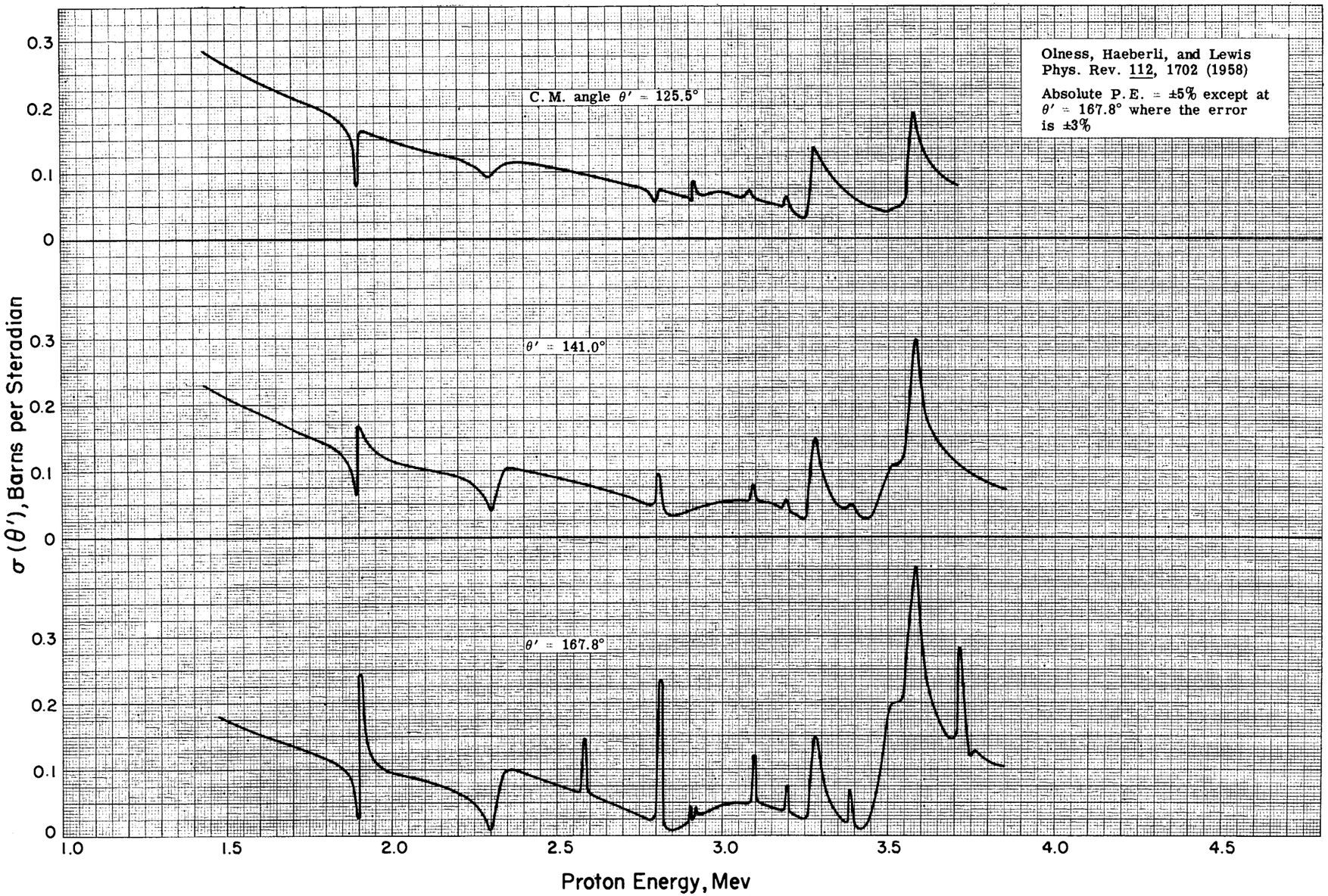

$P^{31}(d,p')P^{32*}$, $P^{31}(d,n')S^{32*}$
$P^{31}(d, n')S^{32*}$ see opposite page
ground state
E* = 5.76 Mev
E* = 2.24 Mev
σ (θ'), Millibarns per Steradian
C.M Angle of Neutron, θ'
-10
0
10
20
30
40
50
60
70
80
0.5
1.0
1.5
2.0
2.5

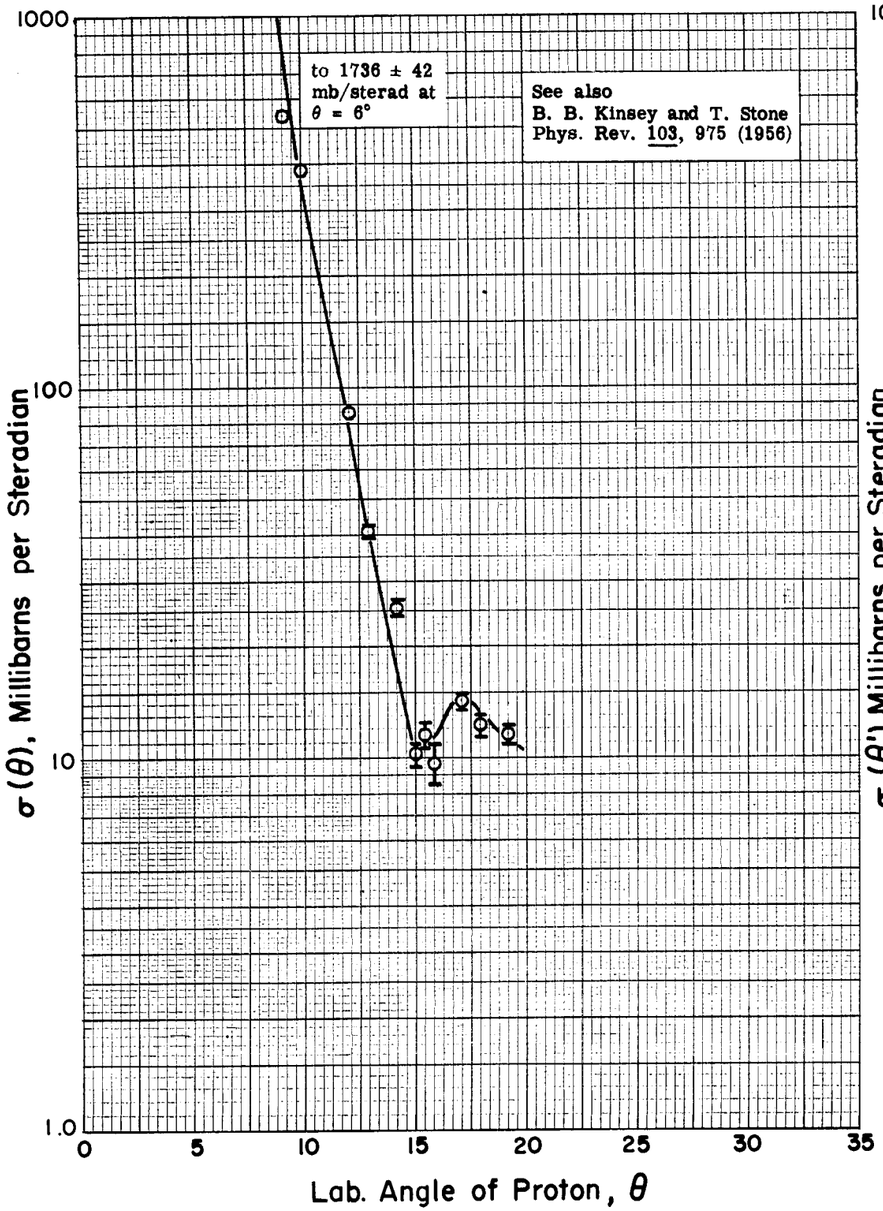


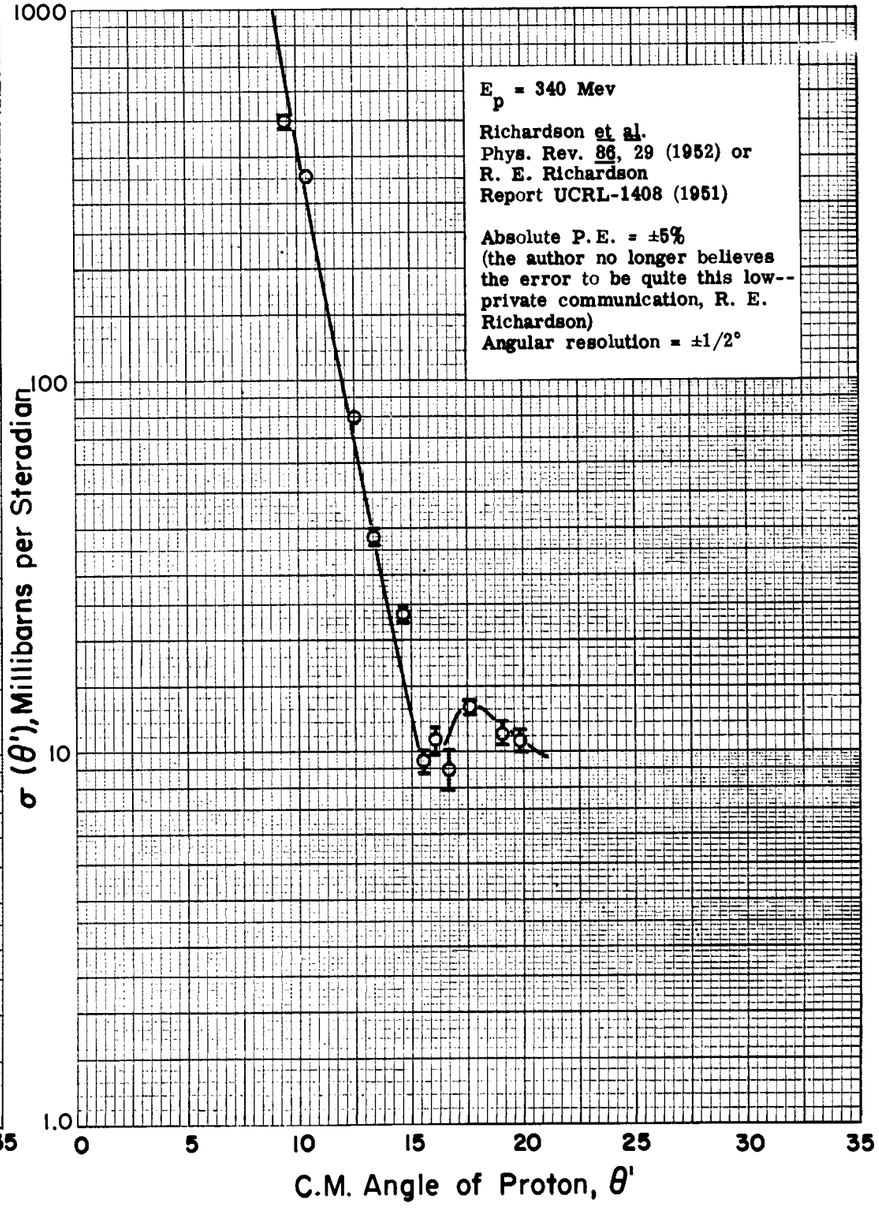
$P^{31}(\alpha, p)S^{34}$

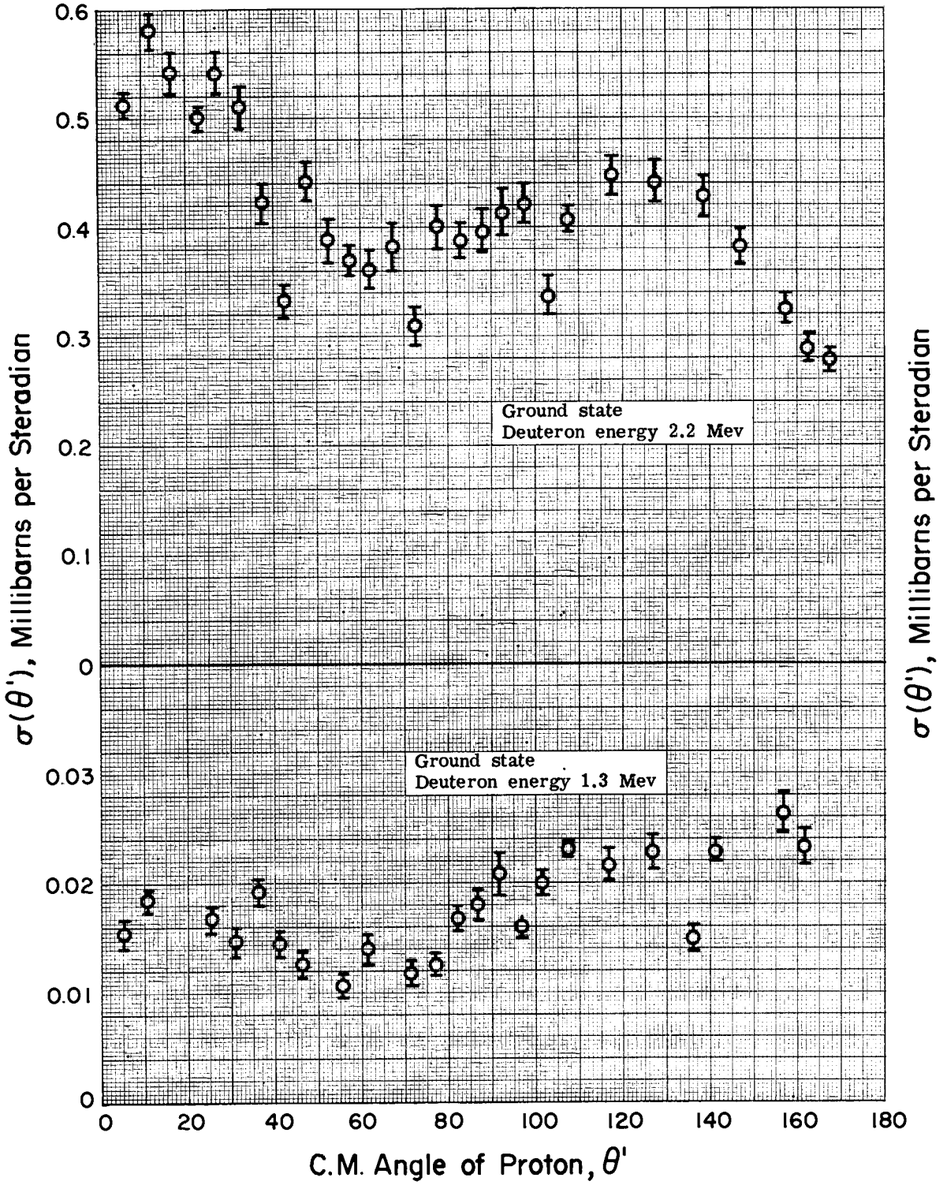


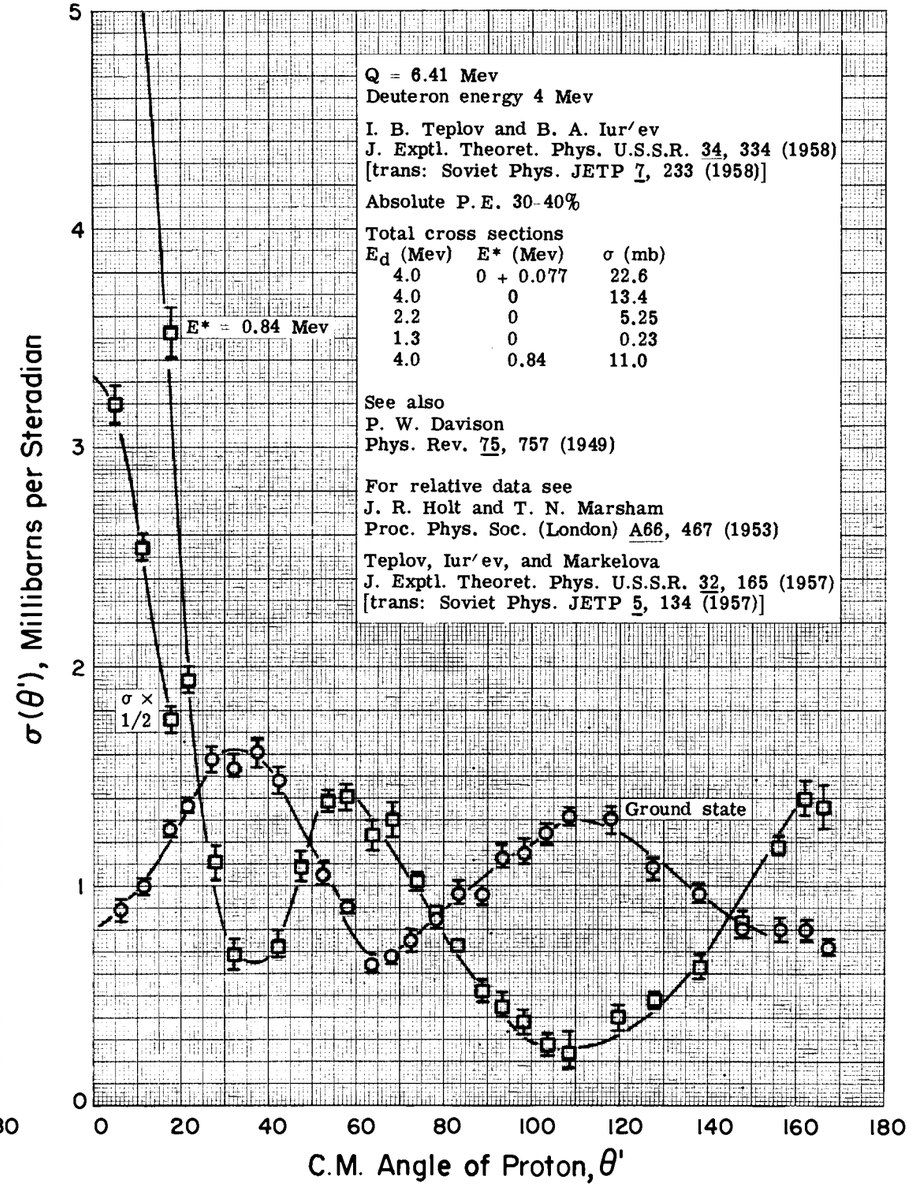

Olness, Haeberli, and Lewis
Phys. Rev. 112, 1702 (1958)
Absolute P.E. = ±5%
C.M. angle θ′ = 63.9°
θ′ = 92°
σ(θ′), Millibarns per Steradian
2.0
1.5
1.0
0.5
0.5
0.4
0.3
0.2
0.1
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Proton Energy, Mev

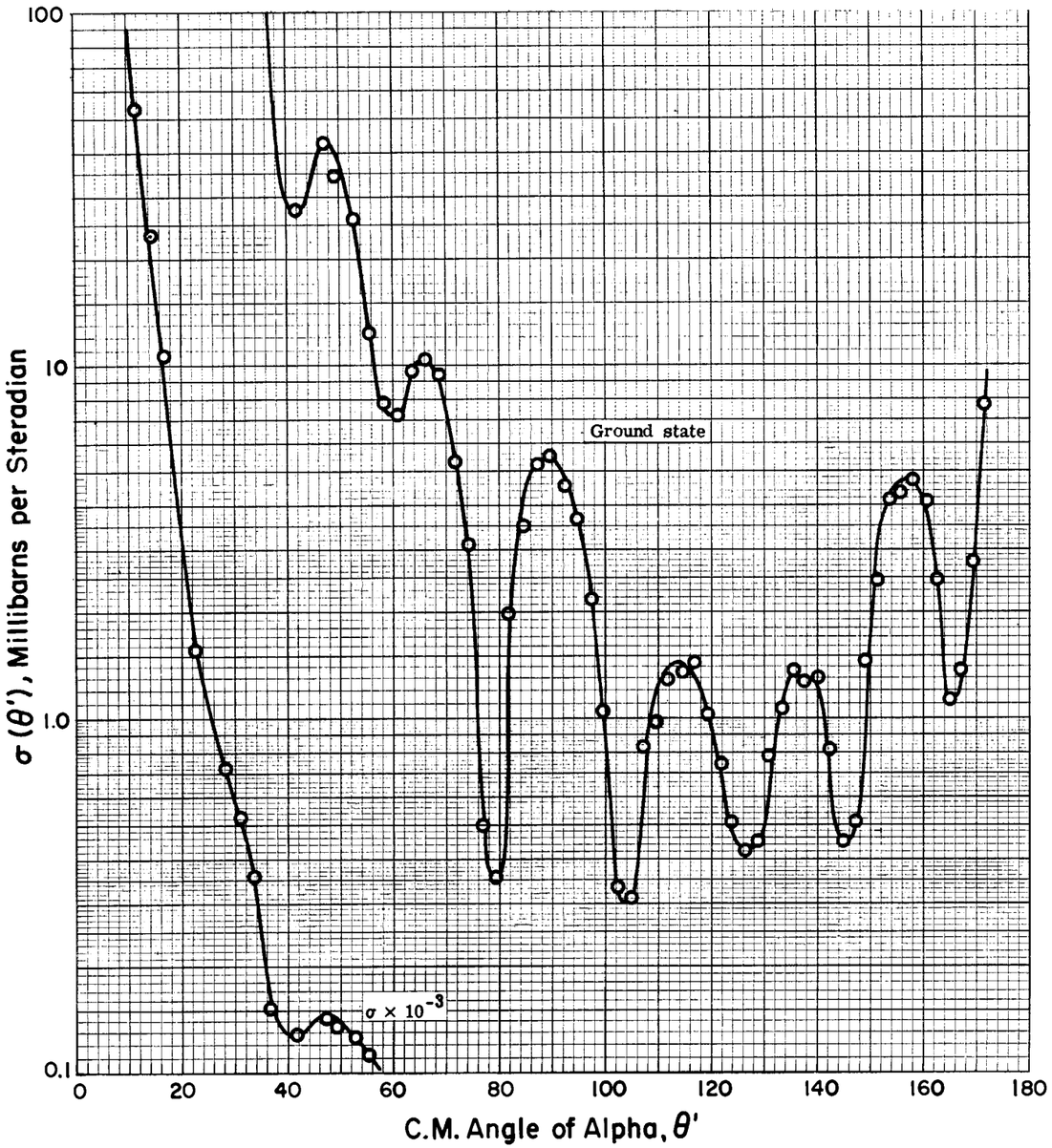

Olness, Haeberli, and Lewis
Phys. Rev. 112, 1702 (1958)
Absolute P.E. = ±5% except at θ′ = 167.8° where the error is ±3%
C.M. angle θ′ = 125.5°
θ′ = 141.0°
θ′ = 167.8°
σ (θ′), Barns per Steradian
0.3
0.2
0.1
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Proton Energy, Mev


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

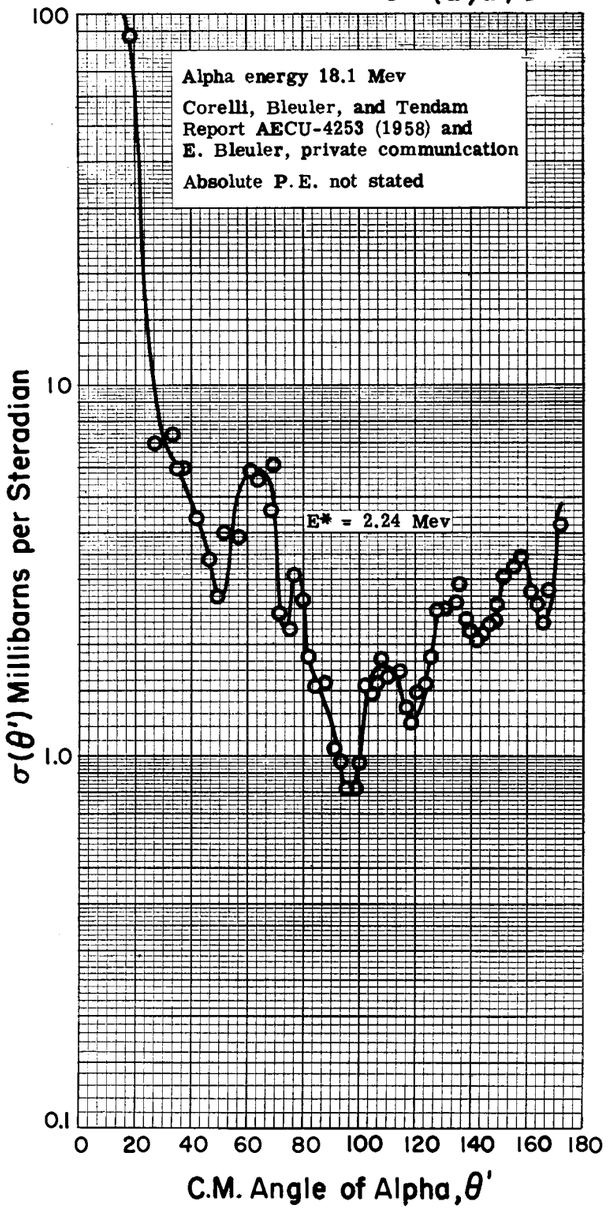

E_p = 340 Mev
Richardson et al.
Phys. Rev. 86, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P.E. = ±5%
(the author no longer believes the error to be quite this low--private communication, R. E. Richardson)
Angular resolution = ±1/2°
σ (θ'), Millibarns per Steradian
1000
100
10
1.0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

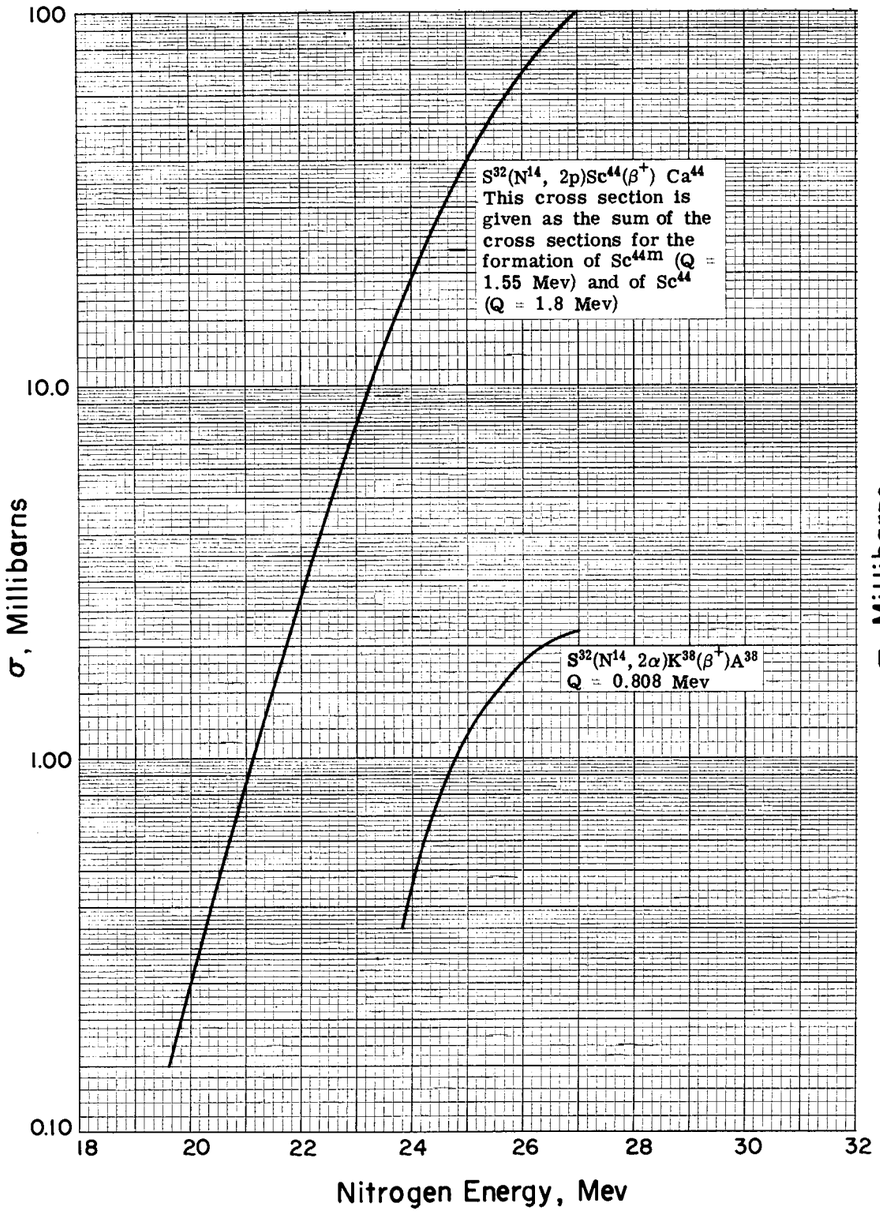

Ground state
Deuteron energy 2.2 Mev
Ground state
Deuteron energy 1.3 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0.6
0.5
0.4
0.3
0.2
0.1
0
0.03
0.02
0.01
0
0 20 40 60 80 100 120 140 160 180


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
Ed (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'
5
4
3
2
1
0
0 20 40 60 80 100 120 140 160 180

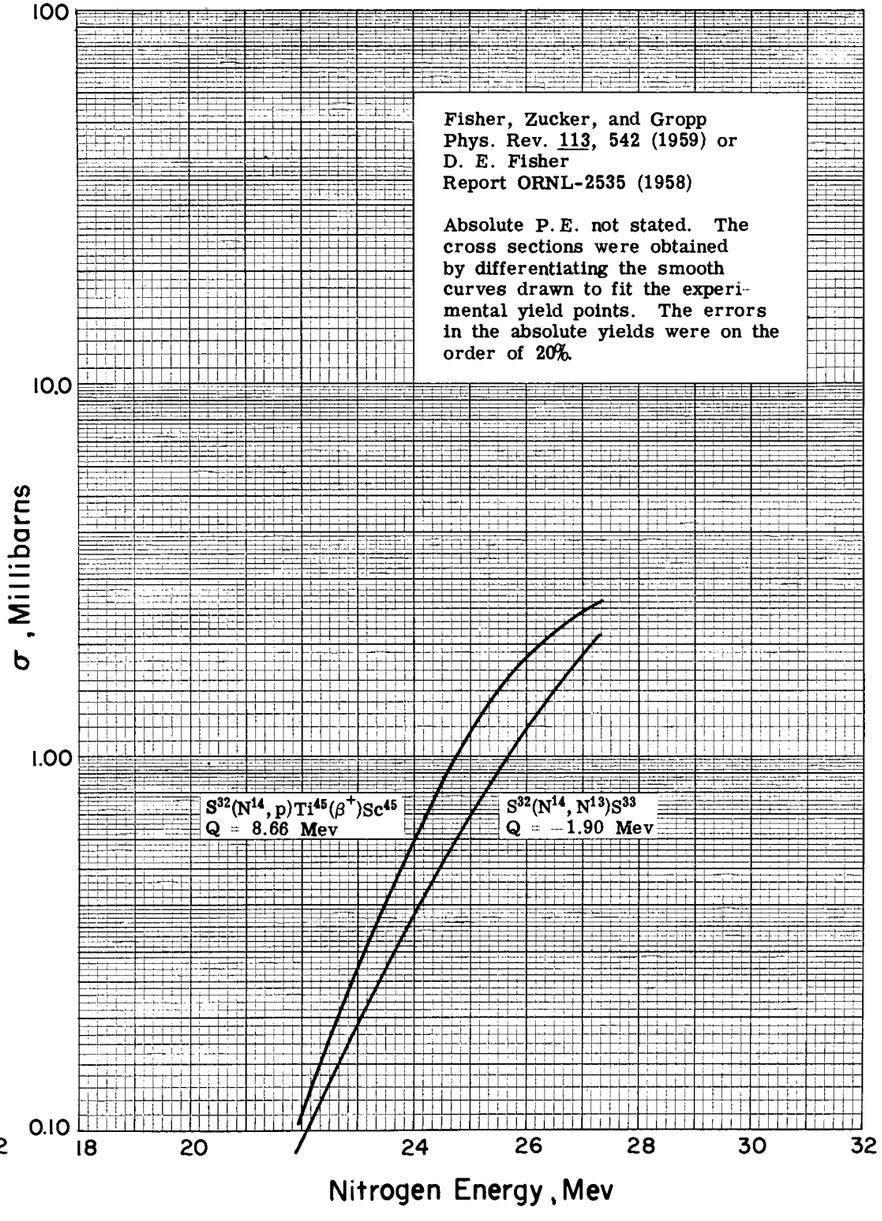


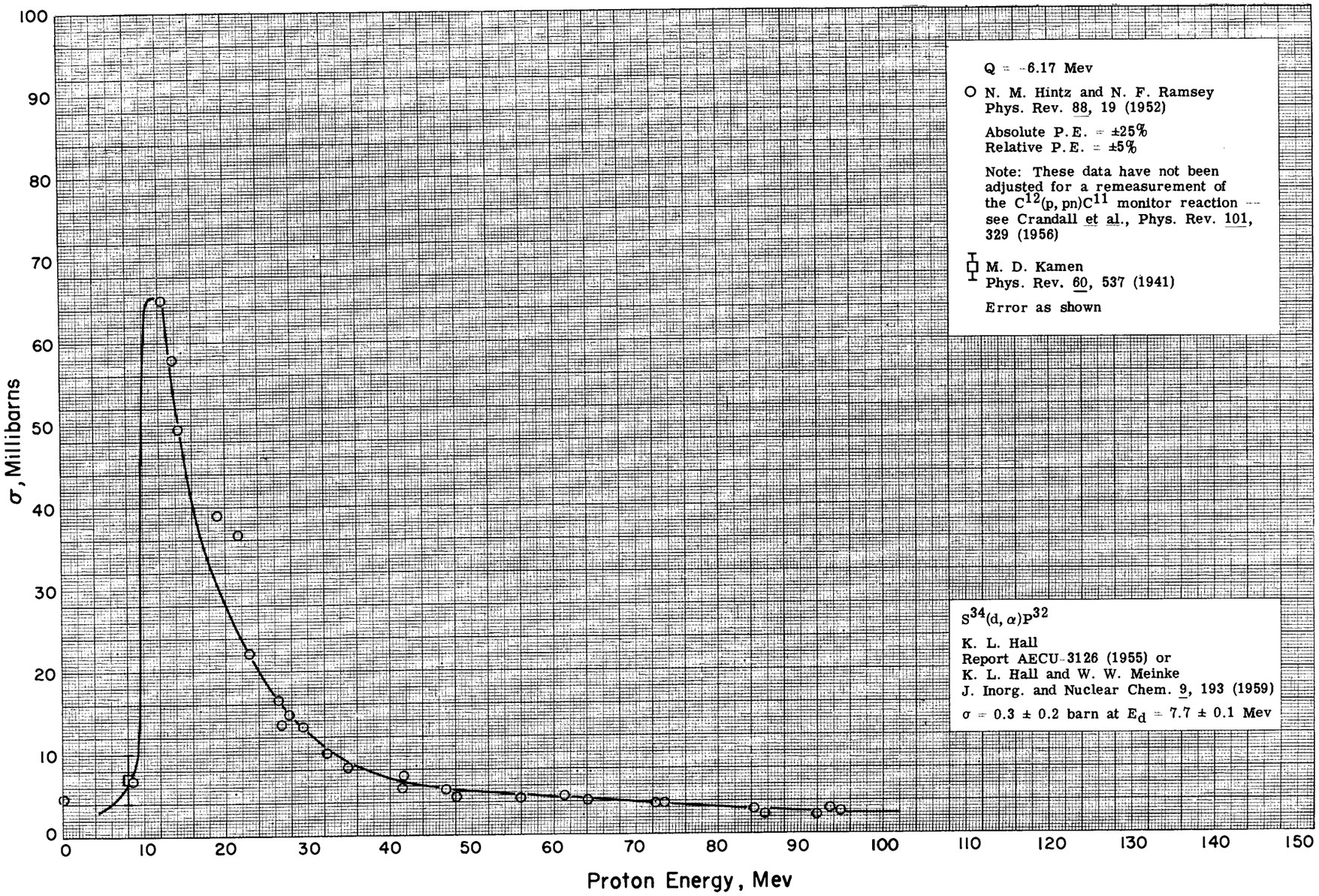
$S^{32}(\alpha,\alpha')S^{32*}$

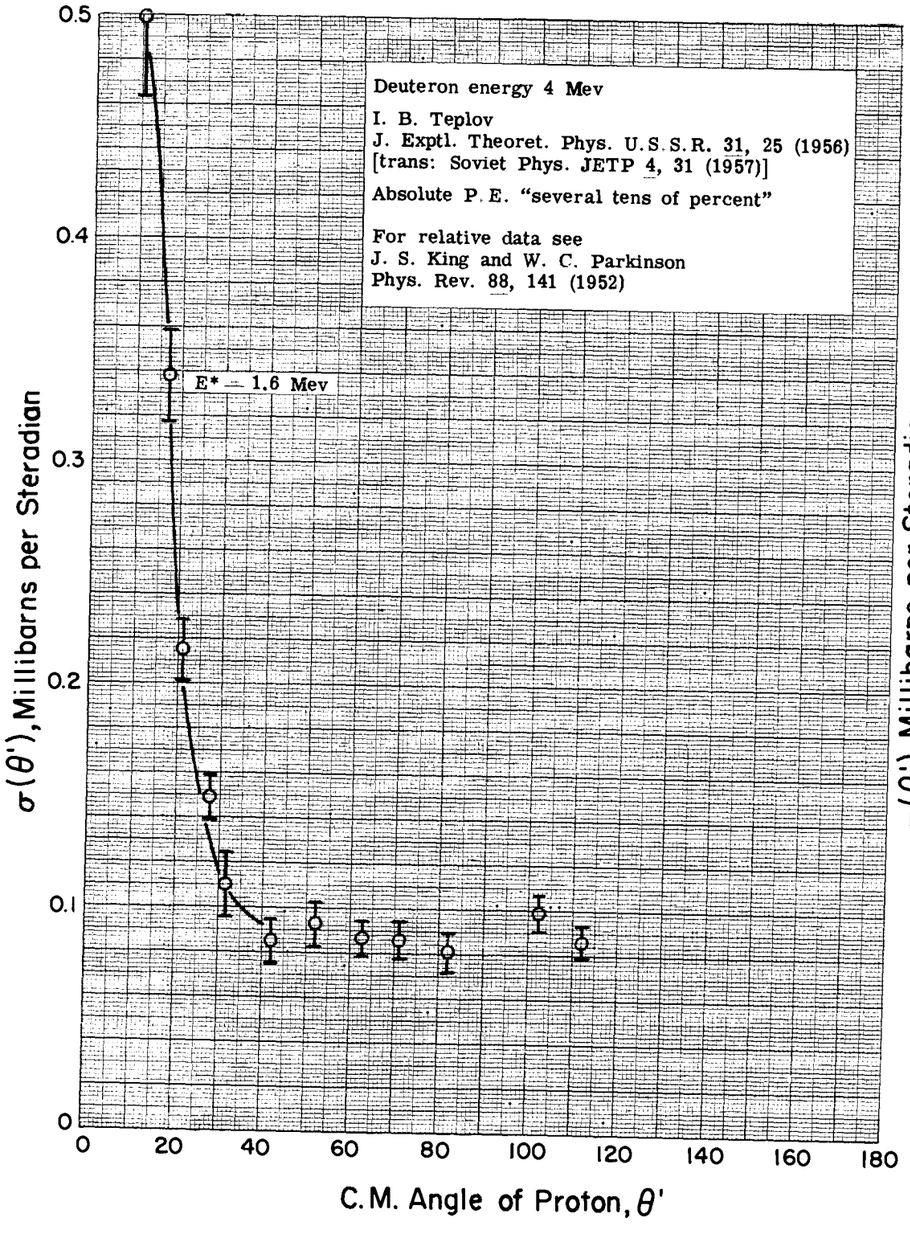


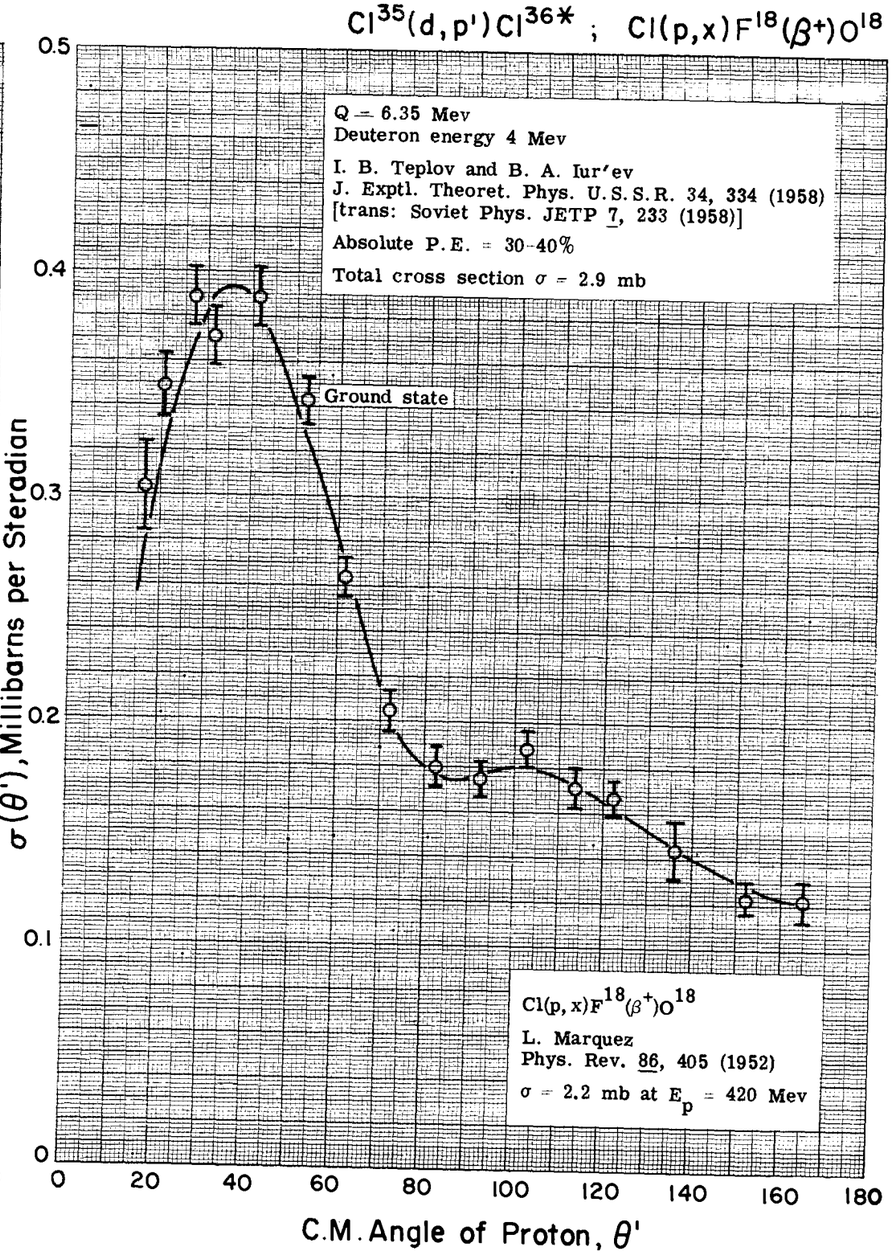

100
10.0
1.00
0.10
σ, Millibarns
$S^{32}(N^{14}, 2p)Sc^{44}(\beta^+)\ Ca^{44}$
This cross section is given as the sum of the cross sections for the formation of Sc^{44m} (Q = 1.55 Mev) and of Sc^{44} (Q = 1.8 Mev)
$S^{32}(N^{14}, 2\alpha)K^{38}(\beta^+)A^{38}$
Q = 0.808 Mev
18
20
22
24
26
28
30
32
Nitrogen Energy, Mev

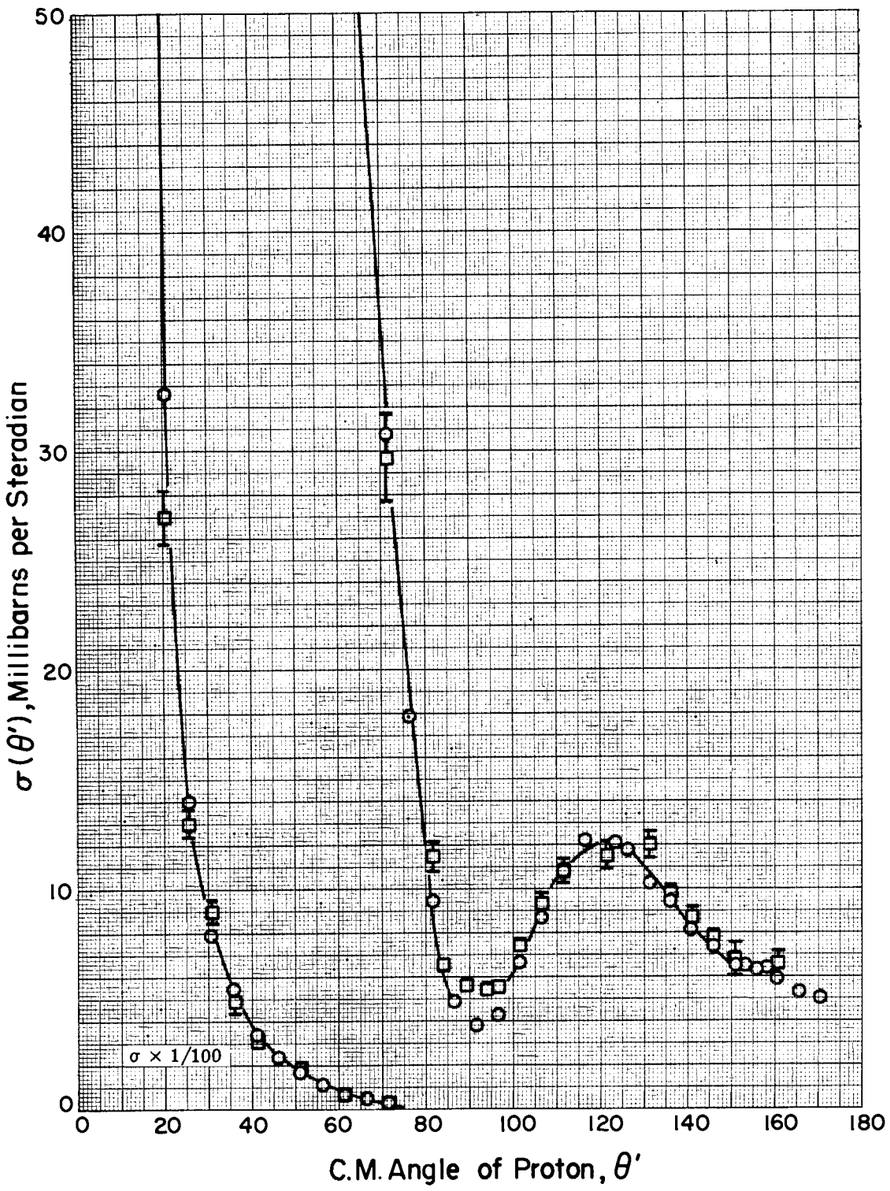
$S^{32}(N^{14},\ )$


100
10.0
1.00
0.10
σ, Millibarns
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%.
$S^{32}(N^{14}, p)Ti^{45}(\beta^+)Sc^{45}$
Q = 8.66 Mev
$S^{32}(N^{14}, N^{13})S^{33}$
Q = −1.90 Mev
18
20
24
26
28
30
32
Nitrogen Energy, Mev


σ, Millibarns
Proton Energy, Mev
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Q = -6.17 Mev
N. M. Hintz and N. F. Ramsey
Phys. Rev. 88, 19 (1952)
Absolute P.E. = ±25%
Relative P.E. = ±5%
Note: These data have not been adjusted for a remeasurement of the $C^{12}(p, pn)C^{11}$ monitor reaction -- see Crandall et al., Phys. Rev. 101, 329 (1956)
M. D. Kamen
Phys. Rev. 60, 537 (1941)
Error as shown
$S^{34}(d, \alpha)P^{32}$
K. L. Hall
Report AECU-3126 (1955) or
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959)
σ = 0.3 ± 0.2 barn at E_d = 7.7 ± 0.1 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"
For relative data see
J. S. King and W. C. Parkinson
Phys. Rev. 88, 141 (1952)
E* = 1.6 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80
100
120
140
160
180


Cl35(d,p')Cl36* ; Cl(p,x)F18(β+)O18
Q = 6.35 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 section σ = 2.9 mb
Ground state
Cl(p,x)F18(β+)O18
L. Marquez
Phys. Rev. 86, 405 (1952)
σ = 2.2 mb at Ep = 420 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80
100
120
140
160
180



Proton energy 9.51 Mev

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

Absolute P.E. = ±5%

O 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)

$\sigma(159.5°) = 478 \pm 15$ mb/sterad

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

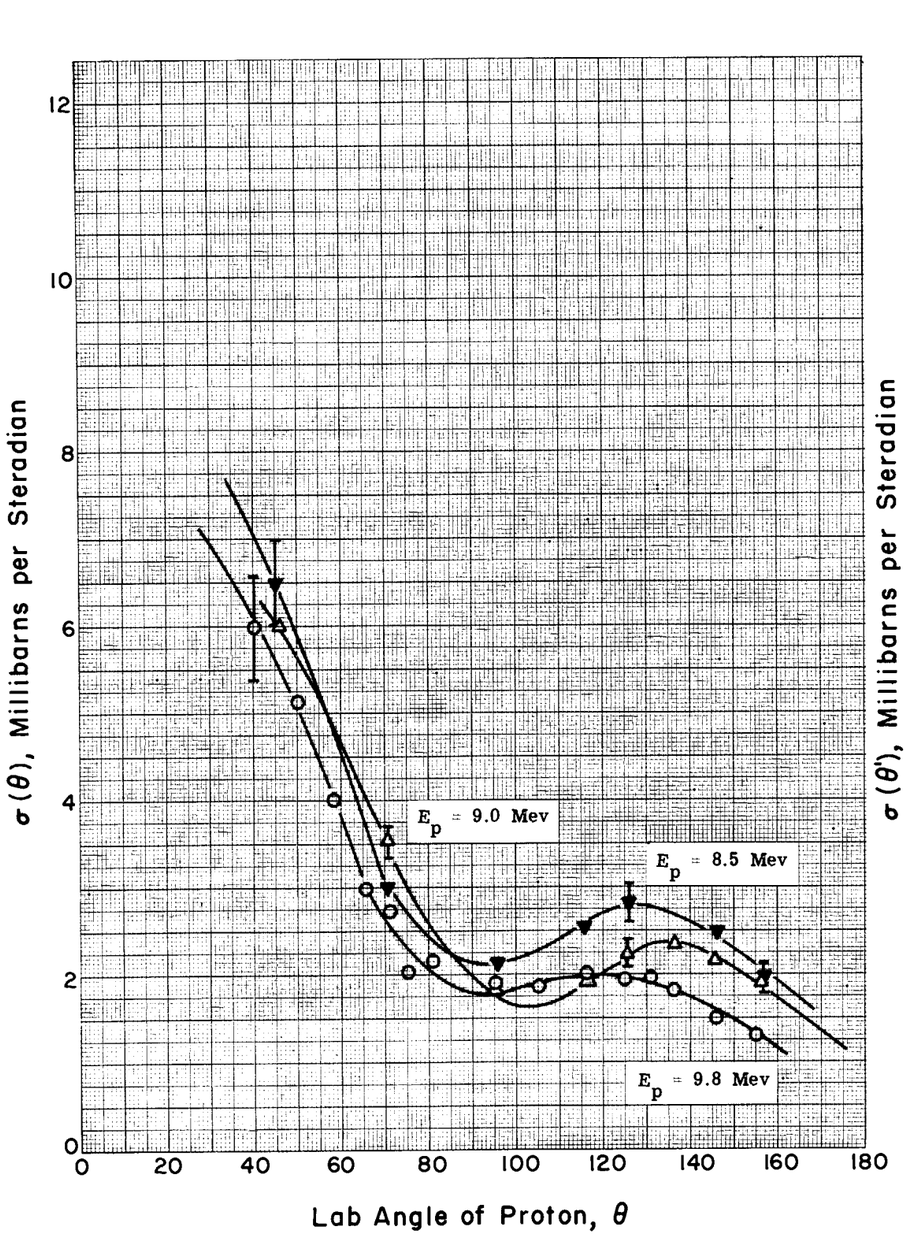
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)

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

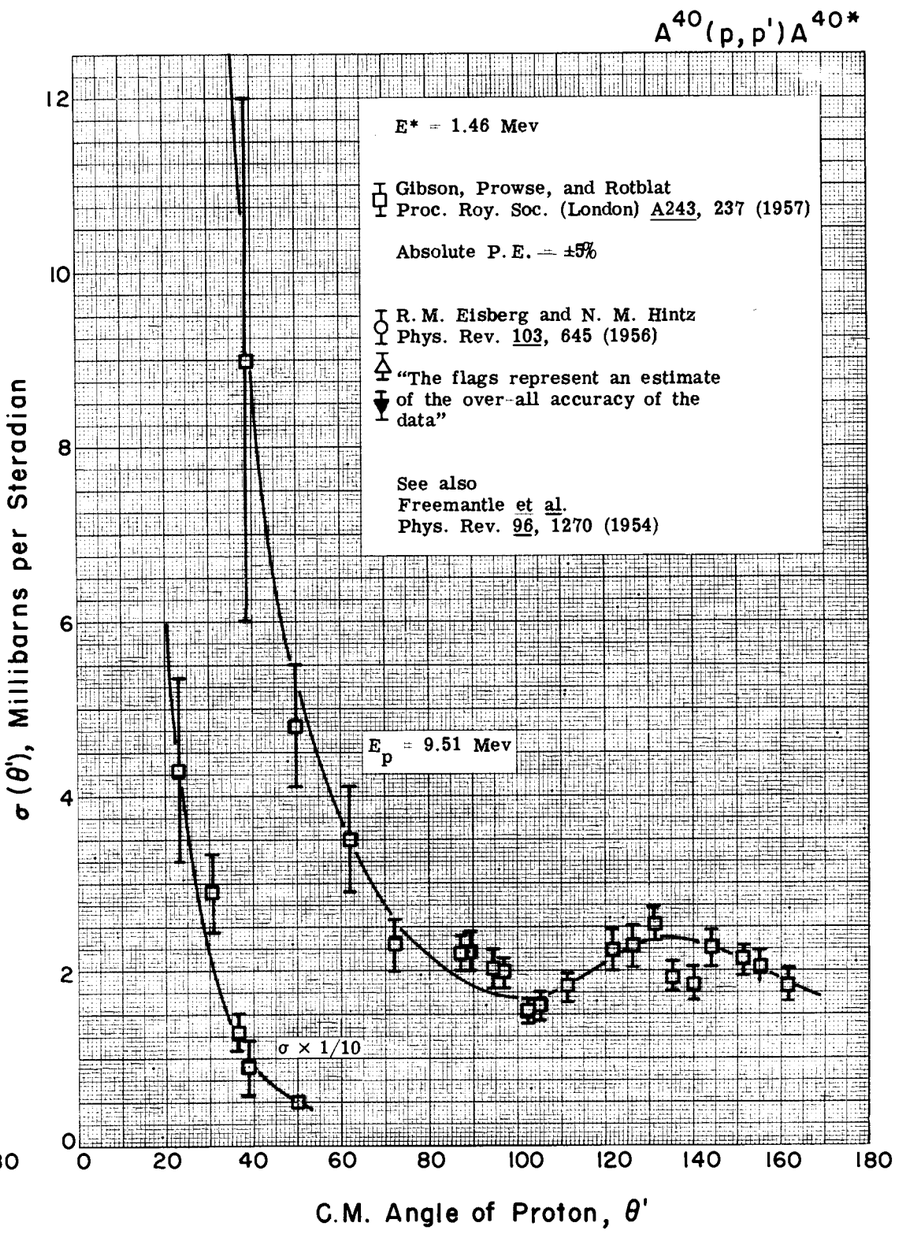
$A^{36}(\alpha,p)K^{39}$ Q = -1.29 Mev

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

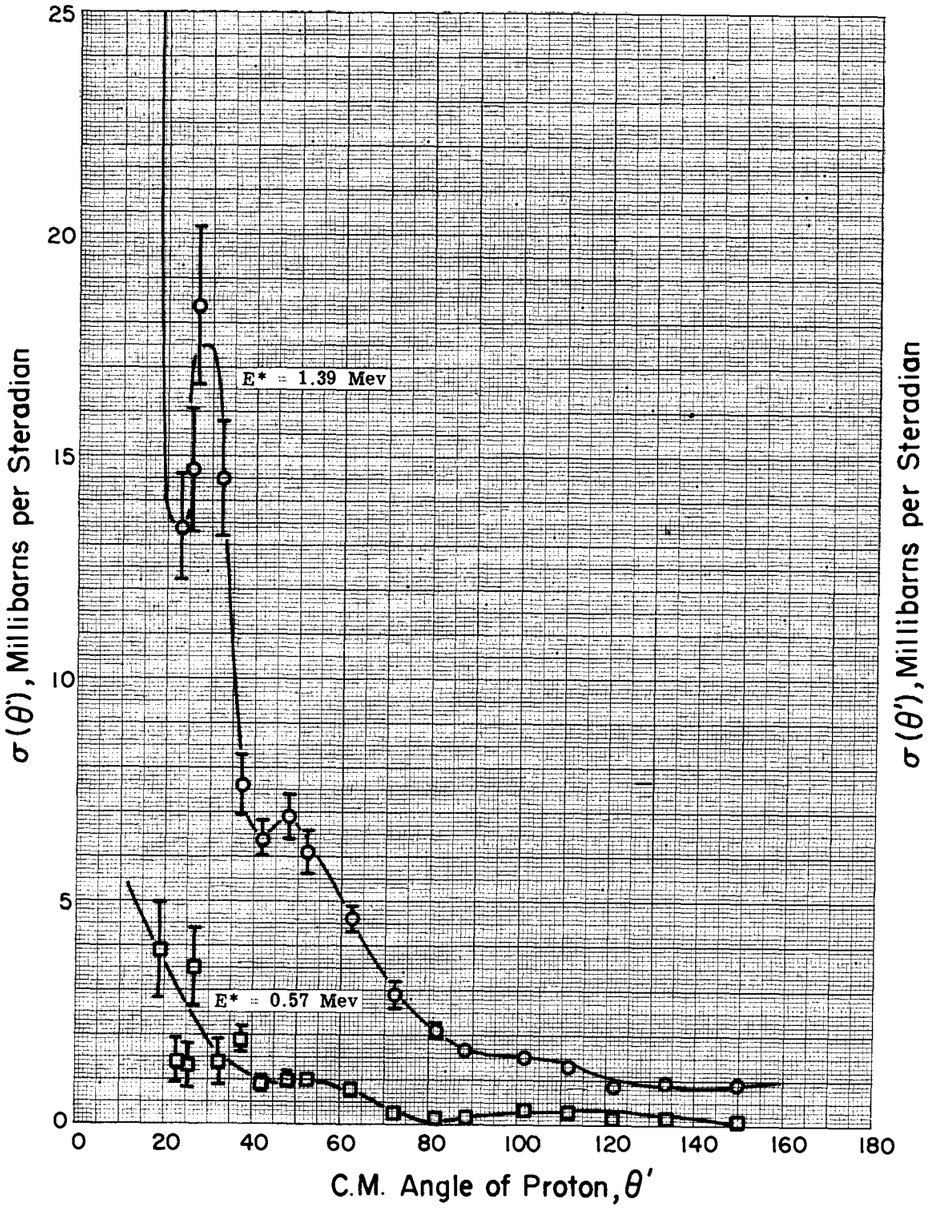
$\sigma(90°) = 8.5 \pm 35\%$ mb at $E_\alpha = 7.4$ Mev



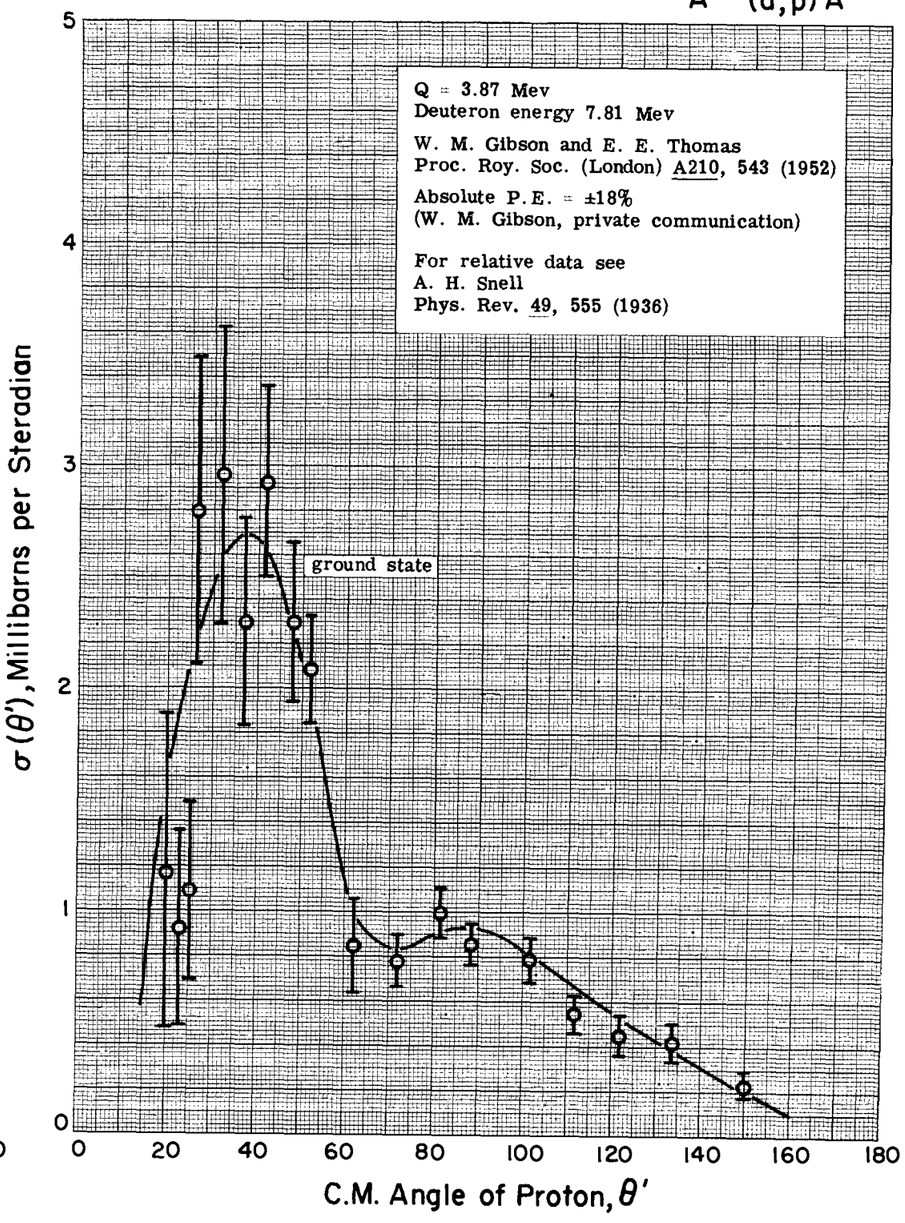
σ (θ), Millibarns per Steradian
Lab Angle of Proton, θ
E_p = 9.0 Mev
E_p = 8.5 Mev
E_p = 9.8 Mev



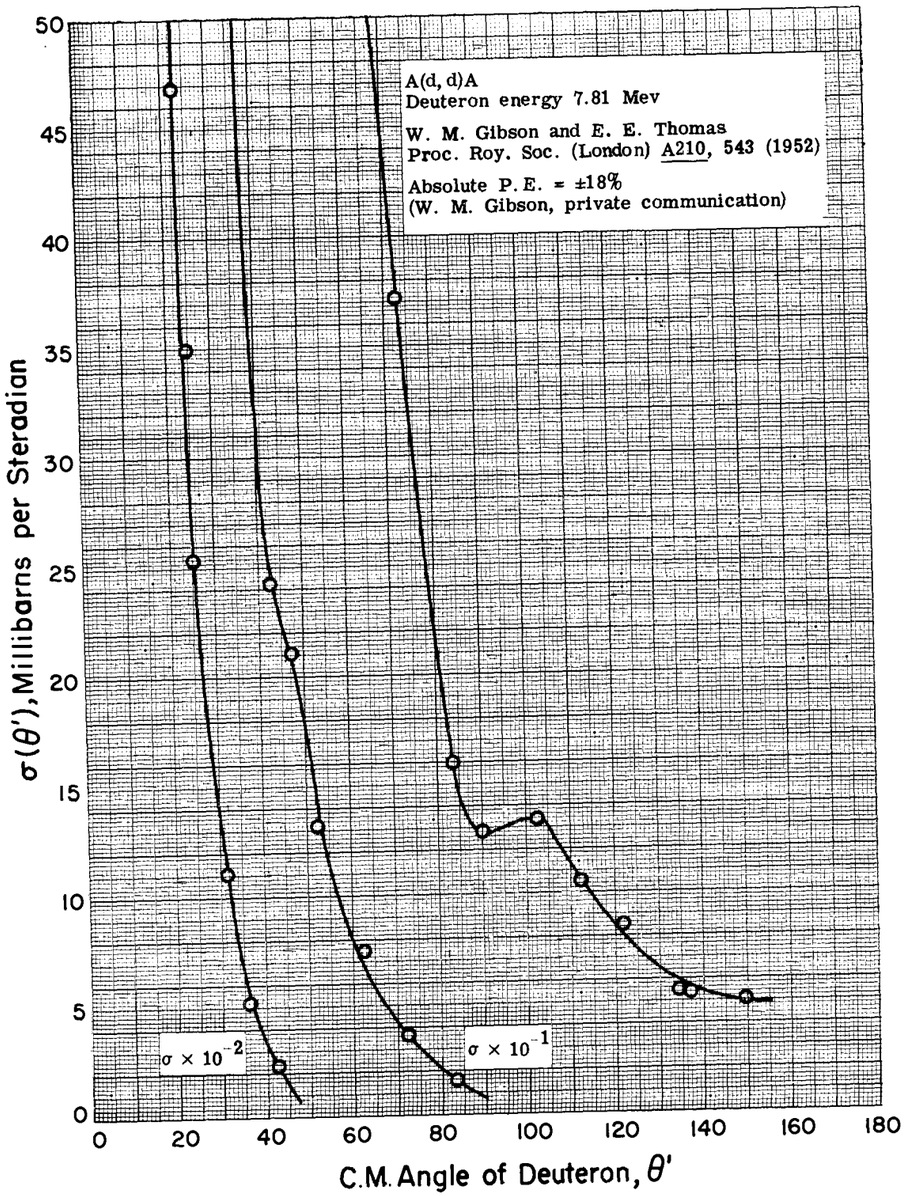
A^40(p,p')A^40*
σ (θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
E* = 1.46 Mev
Gibson, Prowse, and Rotblat
Proc. Roy. Soc. (London) A243, 237 (1957)
Absolute P.E. = ±5%
R. M. Eisberg and N. M. Hintz
Phys. Rev. 103, 645 (1956)
"The flags represent an estimate of the over-all accuracy of the data"
See also
Freemantle et al.
Phys. Rev. 96, 1270 (1954)
E_p = 9.51 Mev
σ × 1/10


E* = 1.39 Mev
E* = 0.57 Mev
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

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


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'
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160
180

$A(d,d)A$; $A^{40}(\alpha,n)Ca^{43}$; $A^{40}(\alpha,p)K^{43}$



$A^{40}(\alpha, n)Ca^{43}$ Q = -2.3 Mev

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

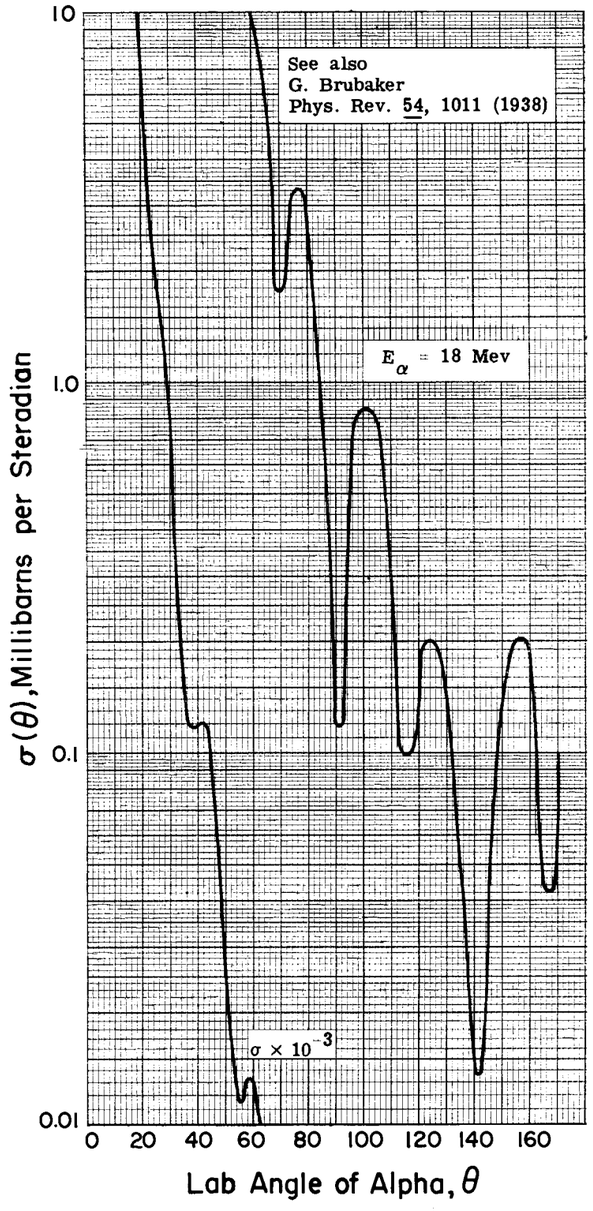
$\sigma(90°)$ = 33.0 ±"a factor of 2" mb at E_α = 7.4 Mev

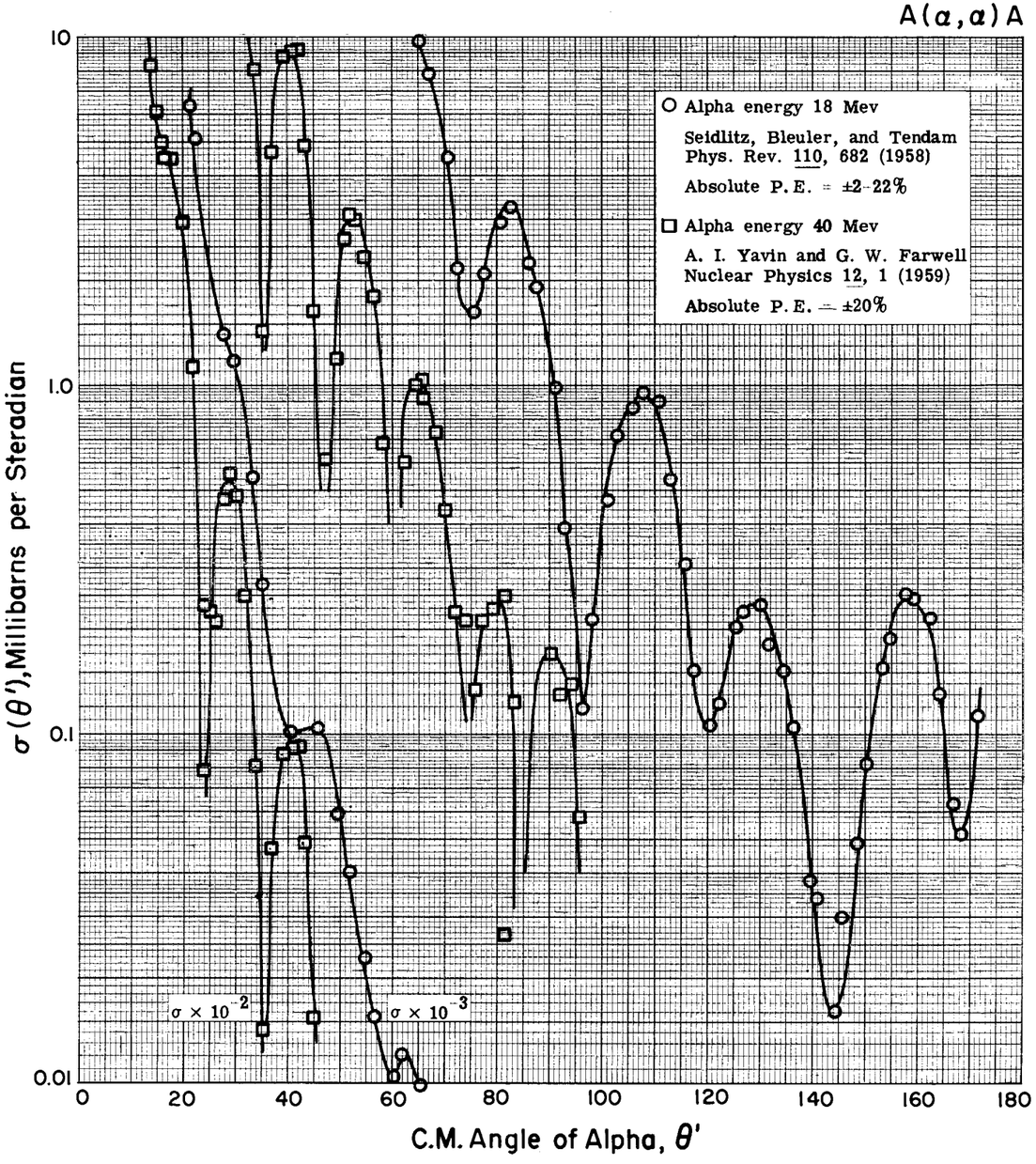
$A^{40}(\alpha, p)K^{43}$ Q = -3.3 Mev

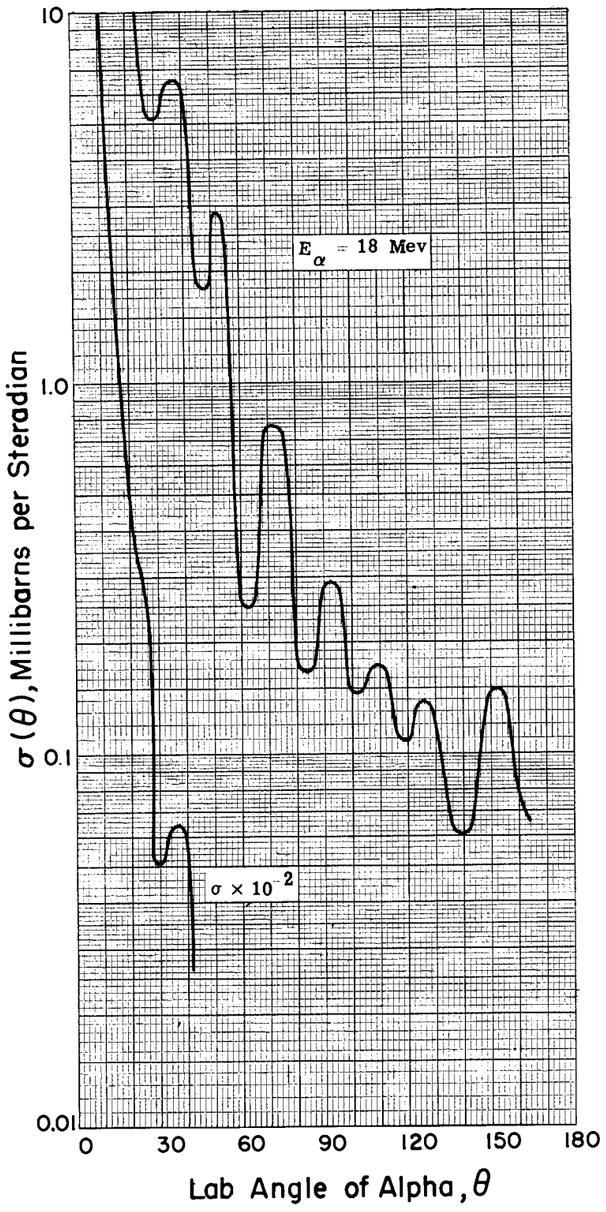
Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)

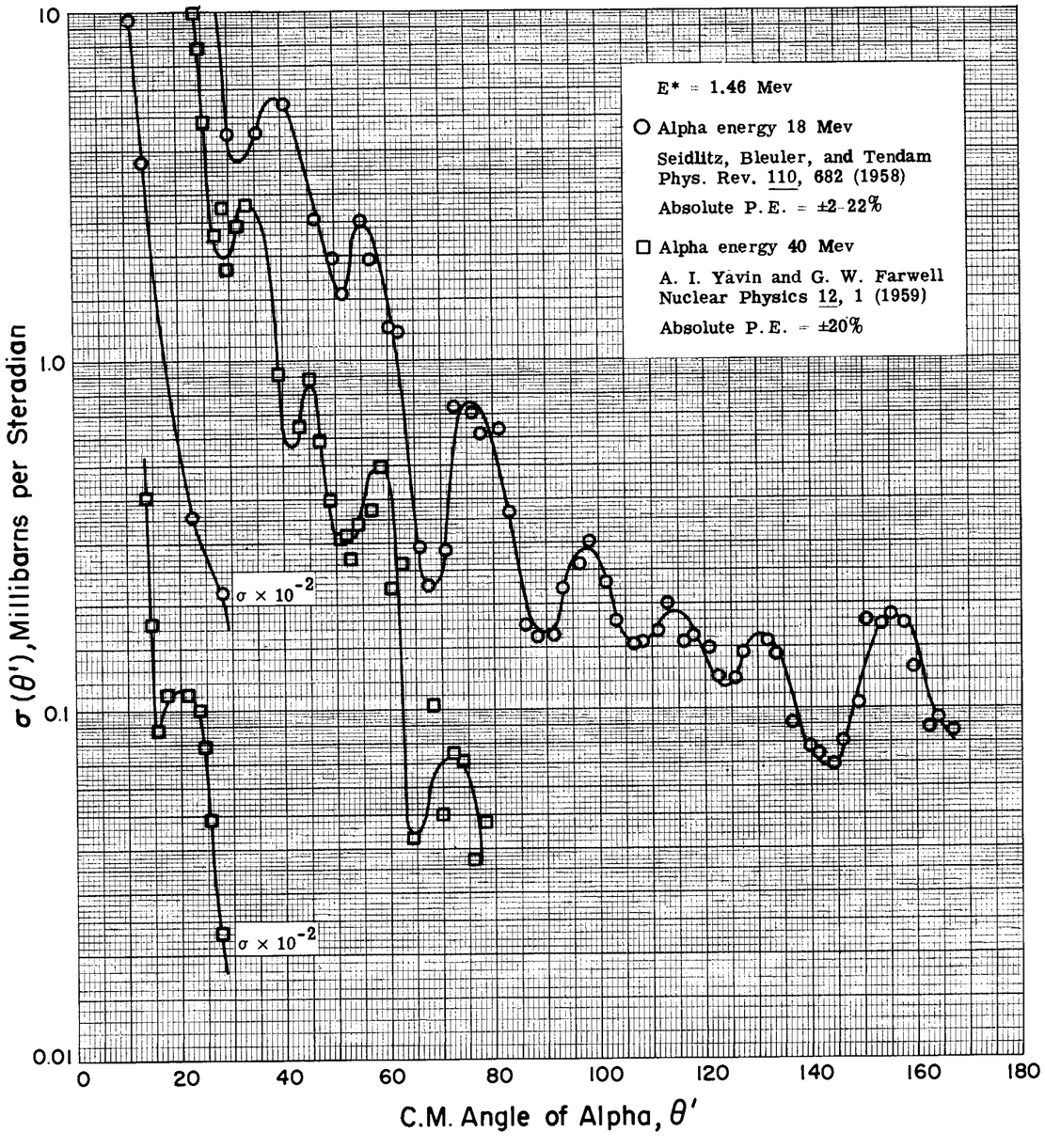
σ = 0.26 ±35% mb at E_α = 7.4 Mev

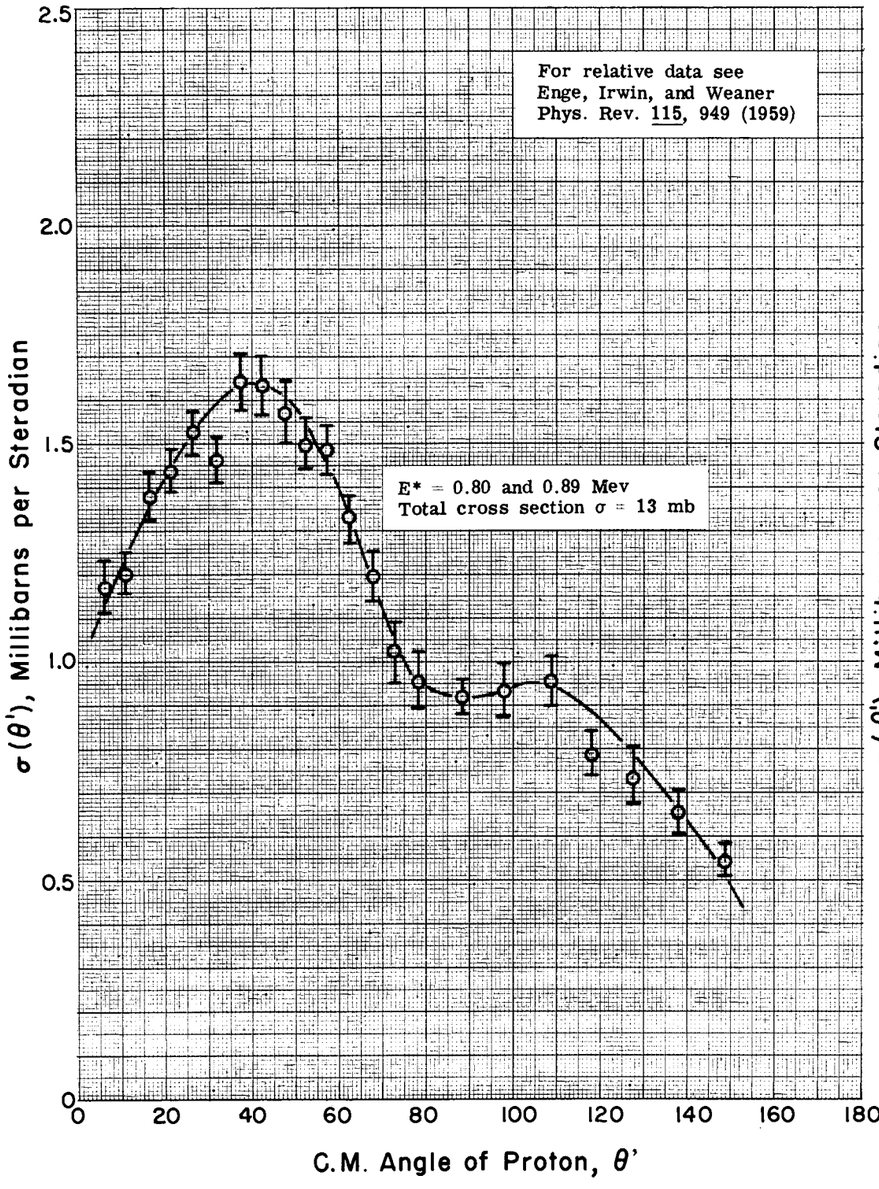
See also
Tanaka et al.
Report NP-8032 (1958)

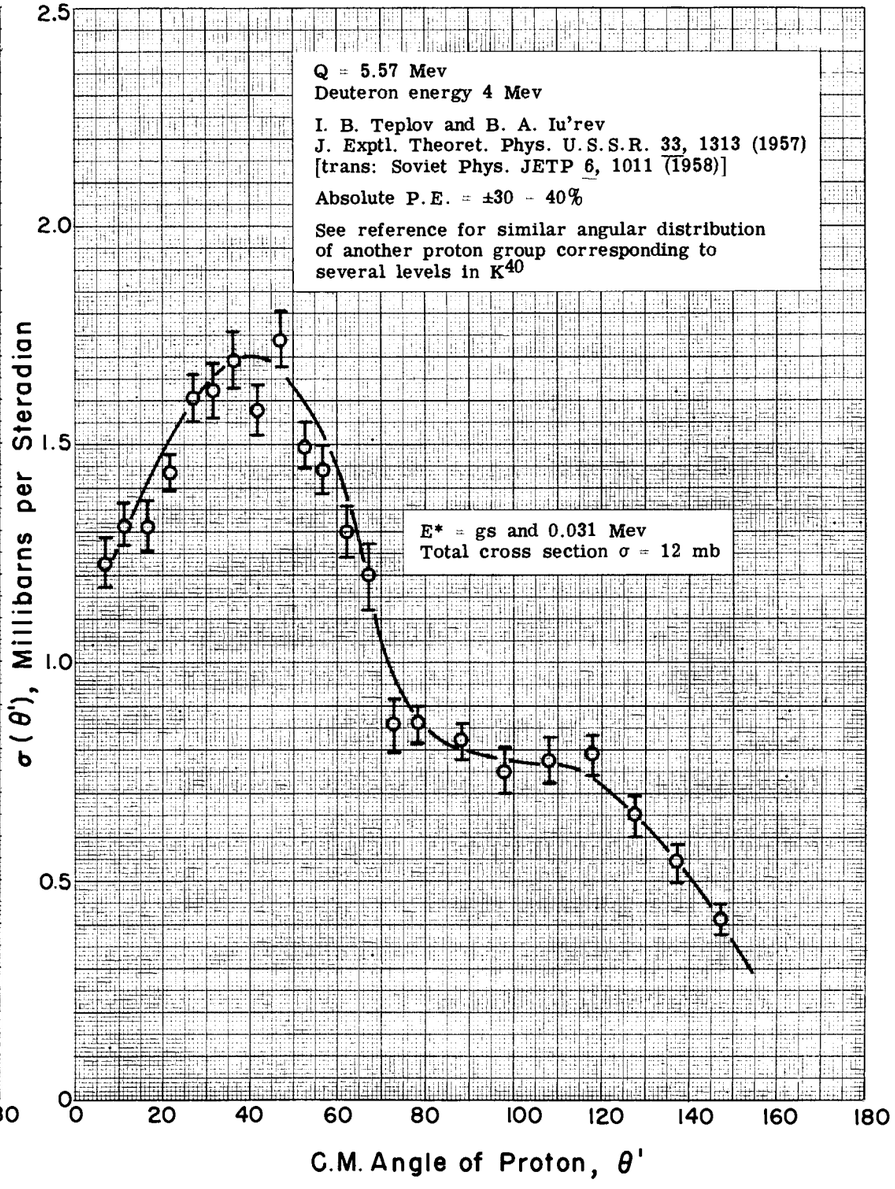

See also
G. Brubaker
Phys. Rev. 54, 1011 (1938)
E_α = 18 Mev
$\sigma \times 10^{-3}$
10
1.0
0.1
0.01
0 20 40 60 80 100 120 140 160
$\sigma(\theta)$, Millibarns per Steradian
Lab Angle of Alpha, θ

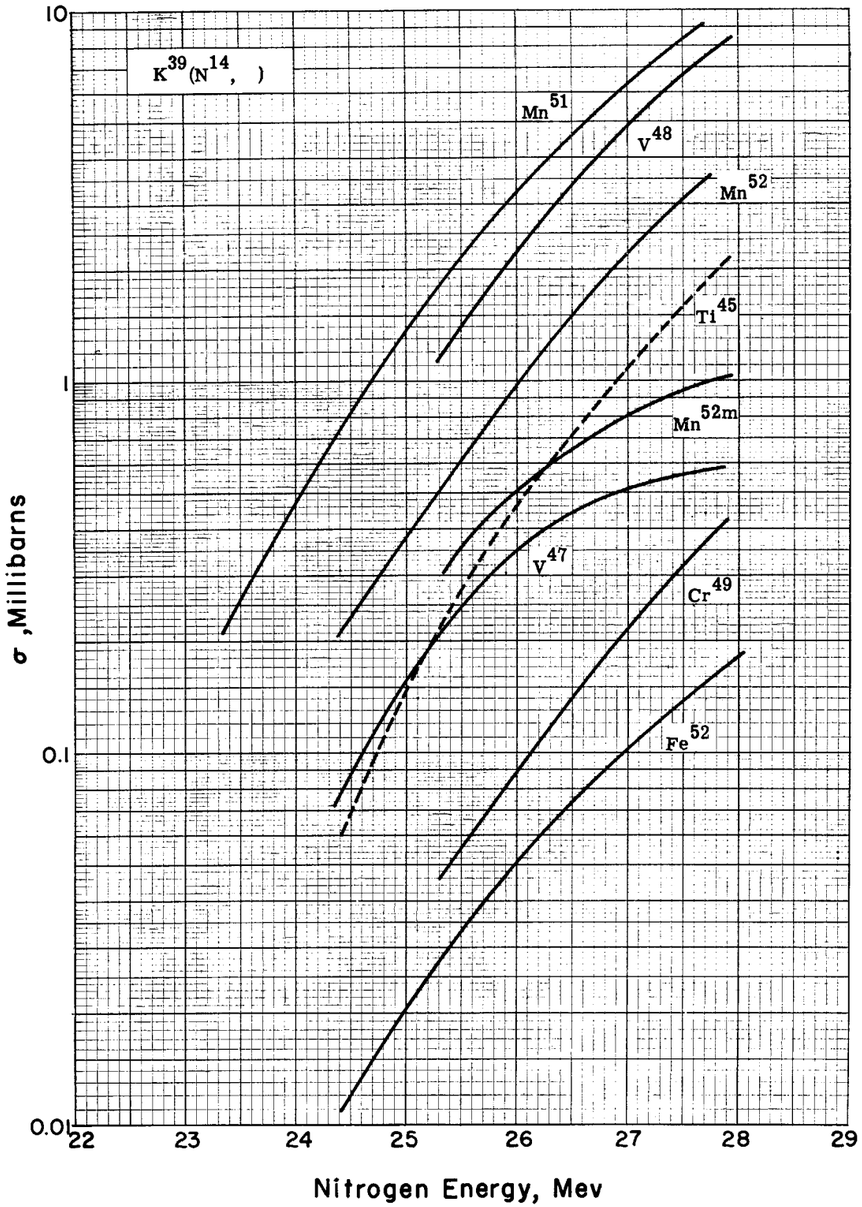

A(α,α)A
Alpha energy 18 Mev
Seidlitz, Bleuler, and Tendam
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±2-22%
Alpha energy 40 Mev
A. I. Yavin and G. W. Farwell
Nuclear Physics 12, 1 (1959)
Absolute P.E. = ±20%
$\sigma \times 10^{-2}$
$\sigma \times 10^{-3}$
10
1.0
0.1
0.01
0 20 40 60 80 100 120 140 160 180
$\sigma(\theta')$, Millibarns per Steradian
C.M. Angle of Alpha, θ'

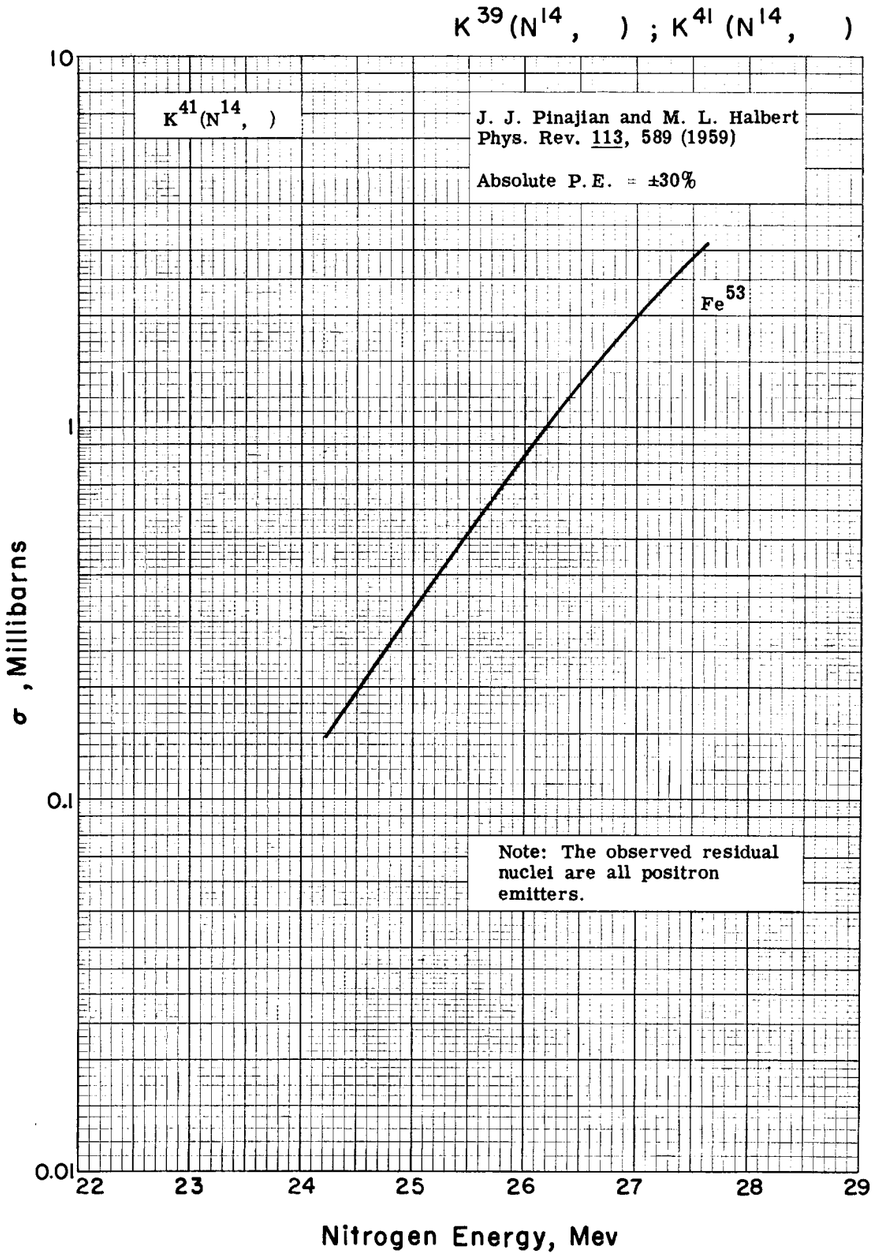

10
1.0
0.1
0.01
$\sigma(\theta)$, Millibarns per Steradian
E_α = 18 Mev
$\sigma \times 10^{-2}$
0
30
60
90
120
150
180
Lab Angle of Alpha, θ

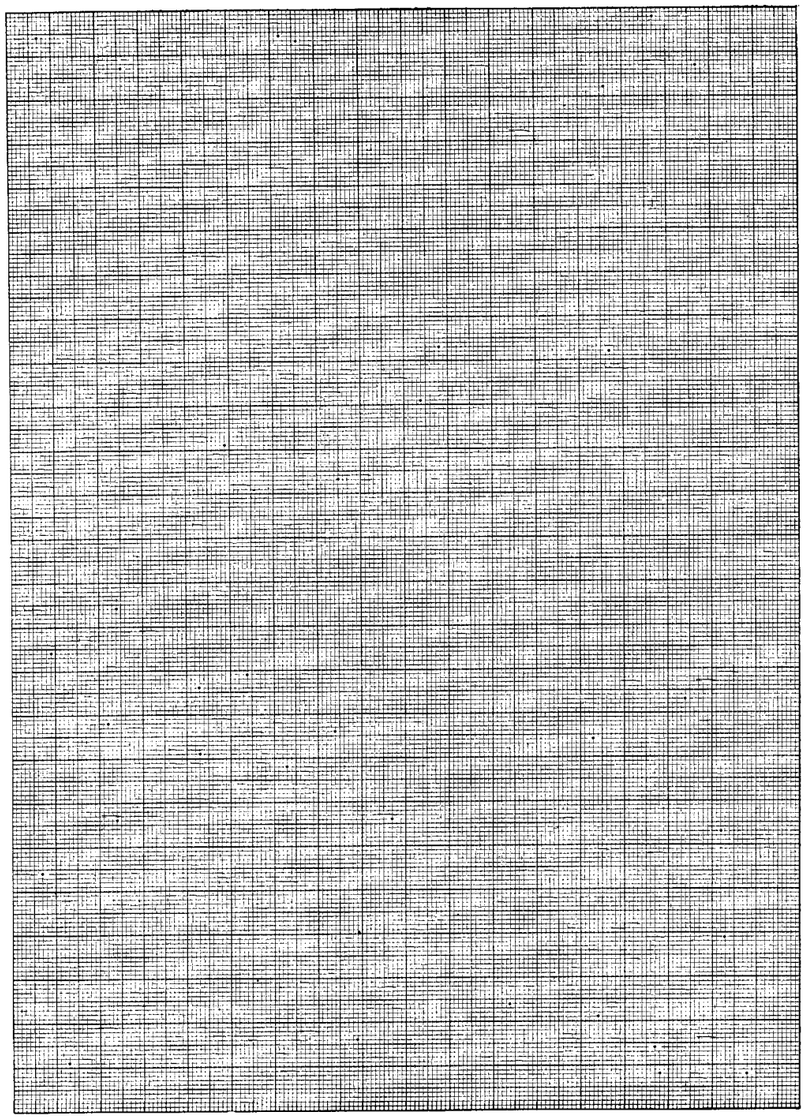

10
1.0
0.1
0.01
$\sigma(\theta')$, Millibarns per Steradian
E^* = 1.46 Mev
O Alpha energy 18 Mev
Seidlitz, Bleuler, and Tendam
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±2-22%
□ Alpha energy 40 Mev
A. I. Yavin and G. W. Farwell
Nuclear Physics 12, 1 (1959)
Absolute P.E. = ±20%
$\sigma \times 10^{-2}$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

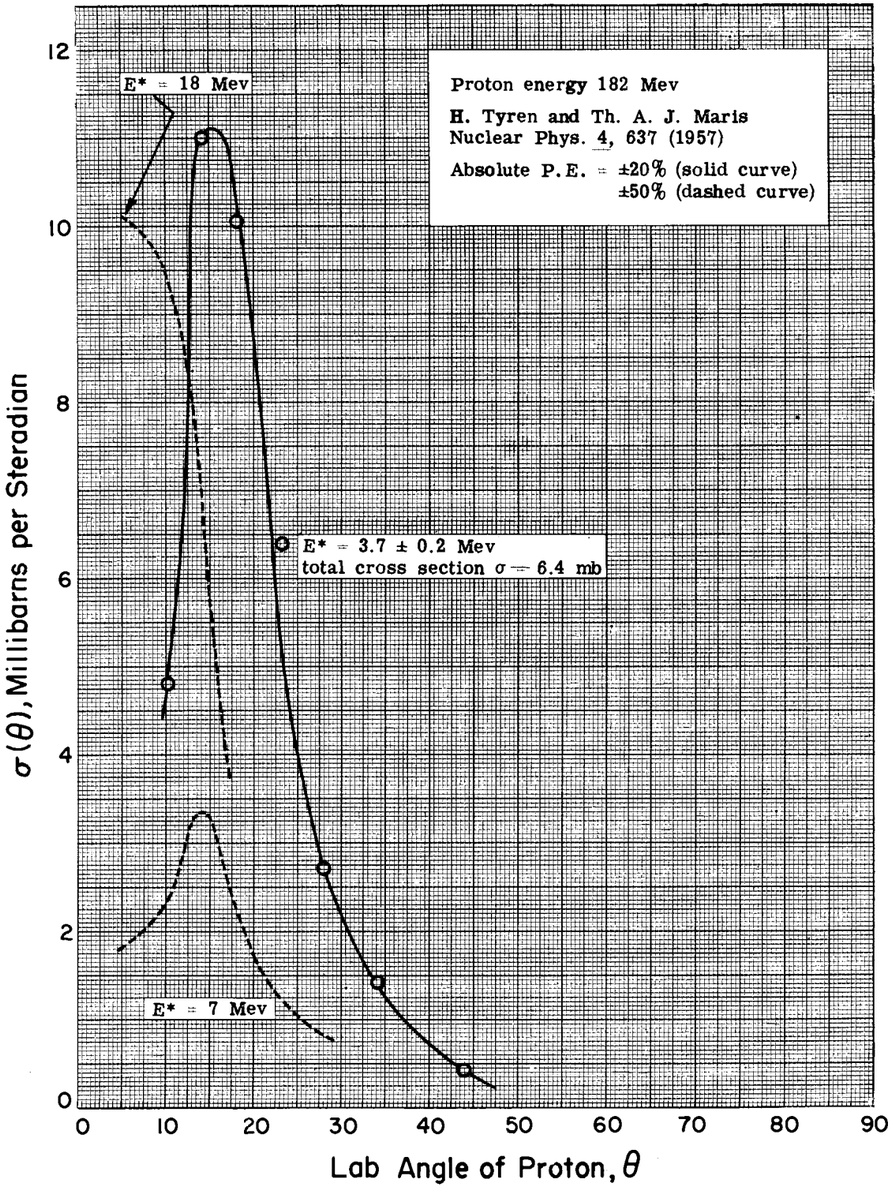

For relative data see
Enge, Irwin, and Weaner
Phys. Rev. 115, 949 (1959)
E* = 0.80 and 0.89 Mev
Total cross section σ = 13 mb
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
0.5
1.0
1.5
2.0
2.5
0
20
40
60
80
100
120
140
160
180

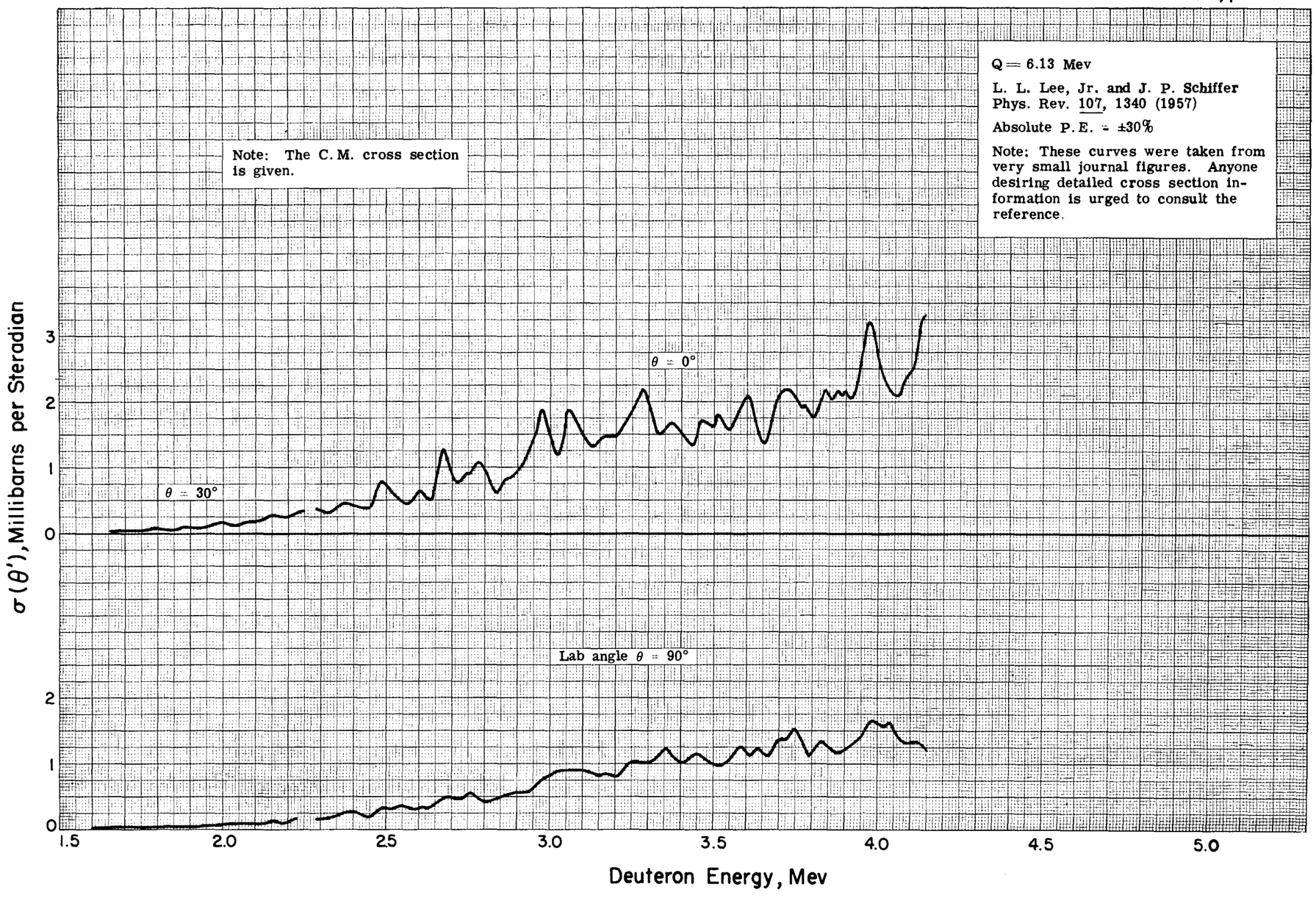

Q = 5.57 Mev
Deuteron energy 4 Mev
I. B. Teplov and B. A. Iu'rev
J. Exptl. Theoret. Phys. U.S.S.R. 33, 1313 (1957)
[trans: Soviet Phys. JETP 6, 1011 (1958)]
Absolute P.E. = ±30 - 40%
See reference for similar angular distribution
of another proton group corresponding to
several levels in K^{40}
E* = gs and 0.031 Mev
Total cross section σ = 12 mb
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
0.5
1.0
1.5
2.0
2.5
0
20
40
60
80
100
120
140
160
180

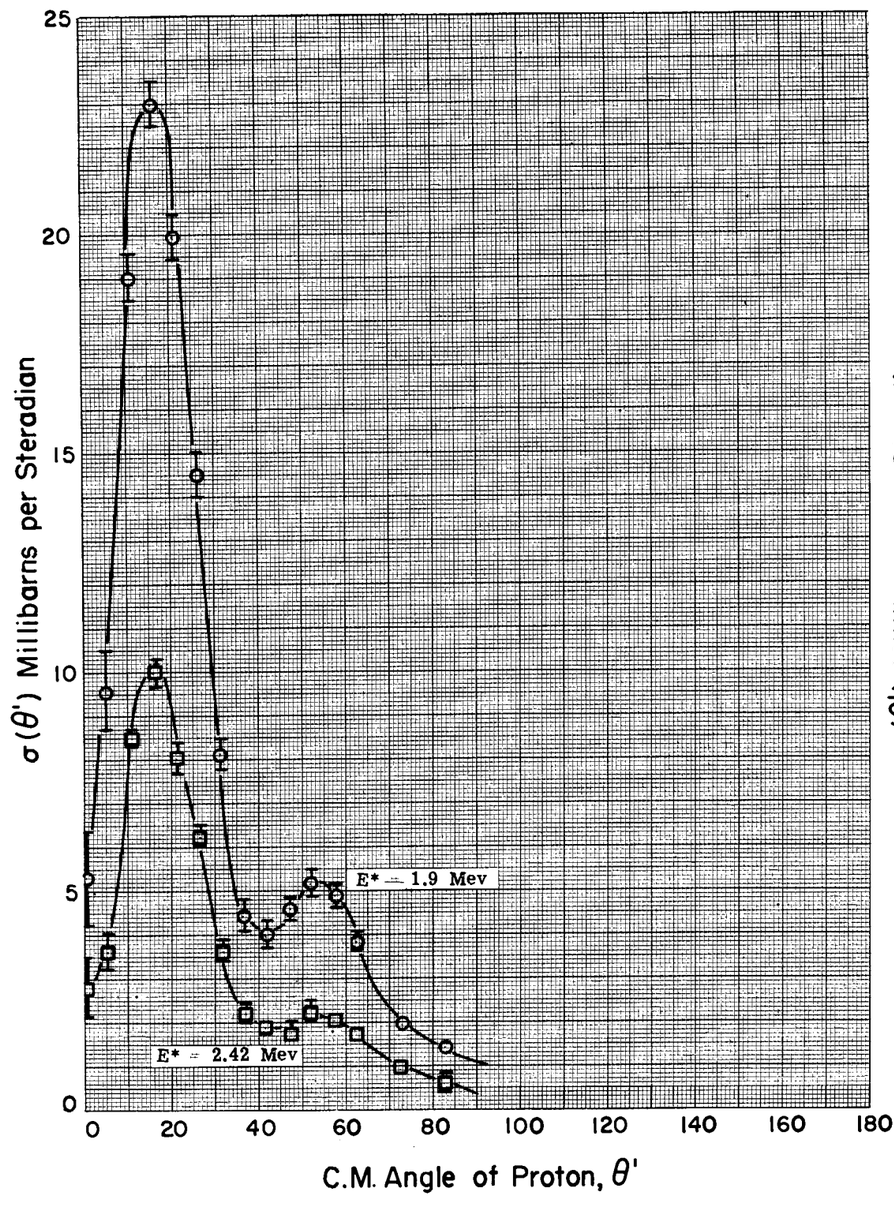

$K^{39}(N^{14}, \quad)$
Mn^{51}
V^{48}
Mn^{52}
Ti^{45}
Mn^{52m}
V^{47}
Cr^{49}
Fe^{52}
10
1
0.1
0.01
σ, Millibarns
22
23
24
25
26
27
28
29
Nitrogen Energy, Mev

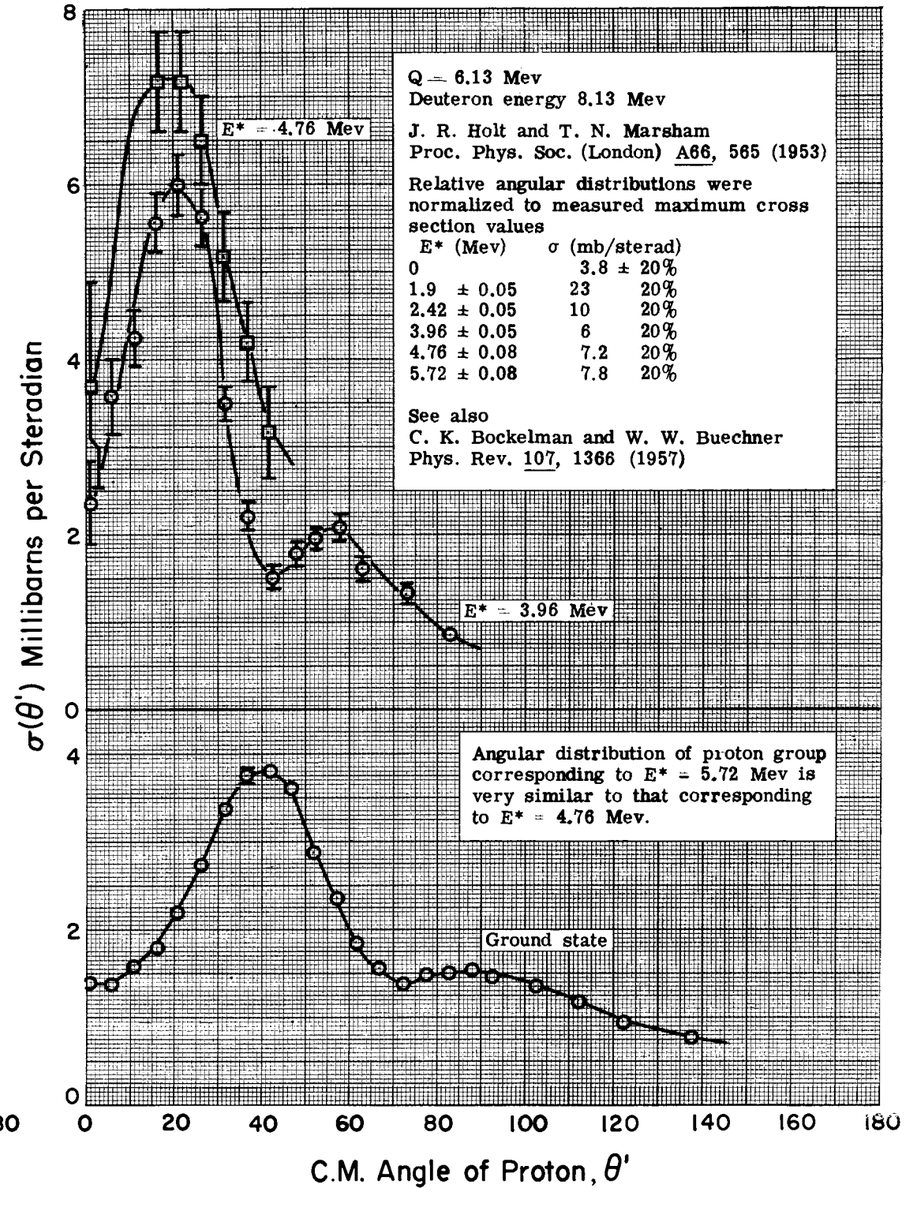

$K^{39}(N^{14}, \quad)$; $K^{41}(N^{14}, \quad)$
$K^{41}(N^{14}, \quad)$
J. J. Pinajian and M. L. Halbert
Phys. Rev. 113, 589 (1959)
Absolute P.E. = ±30%
Fe^{53}
Note: The observed residual nuclei are all positron emitters.
10
1
0.1
0.01
σ, Millibarns
22
23
24
25
26
27
28
29
Nitrogen Energy, Mev




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
Lab Angle of Proton, θ
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90


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
3
2
1
0
2
1
0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Deuteron Energy, Mev





Q = 6.13 Mev
Deuteron energy 8.13 Mev

J. R. Holt and T. N. Marsham
Proc. Phys. Soc. (London) A66, 565 (1953)

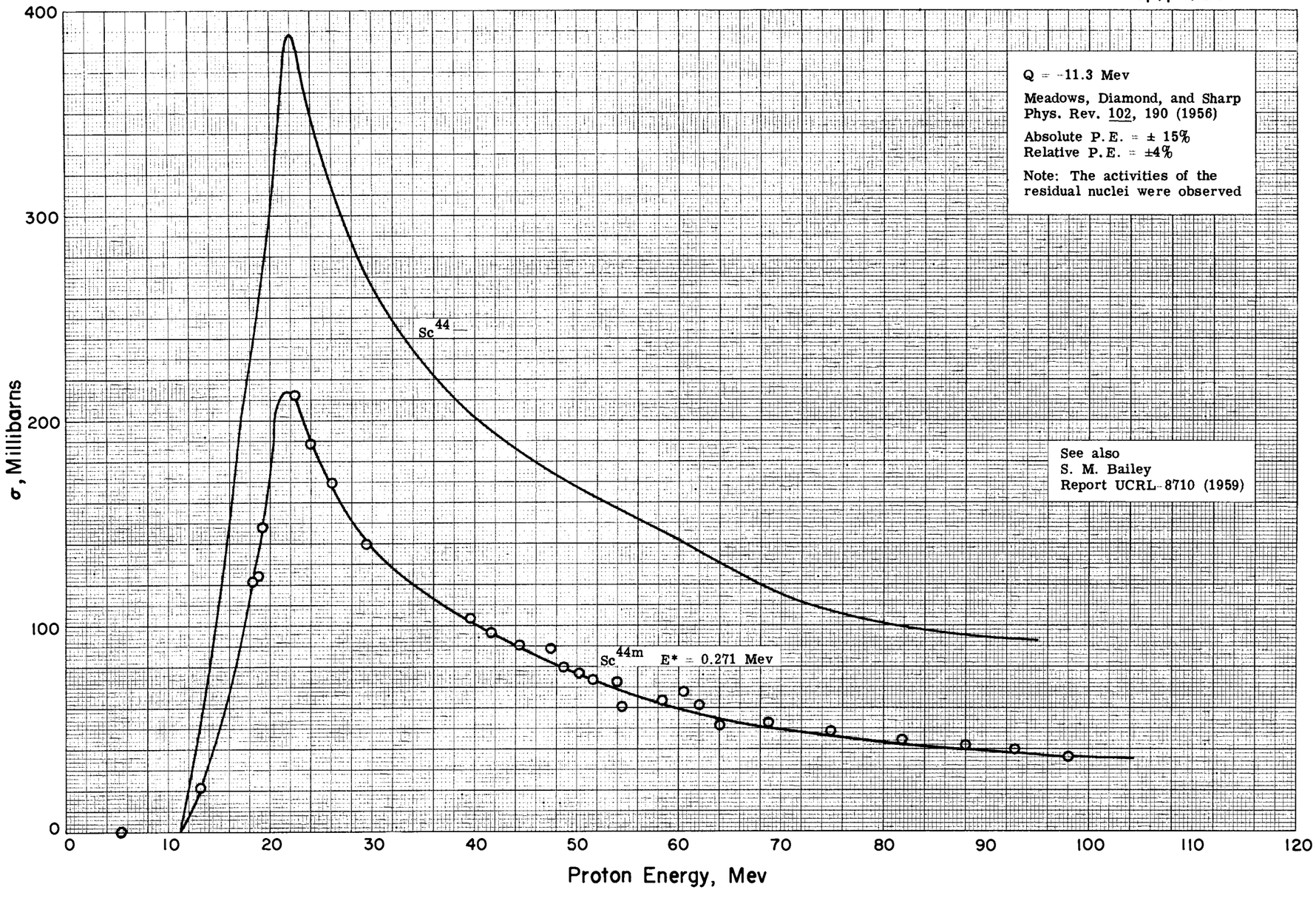
Relative angular distributions were normalized to measured maximum cross section values

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.

$Sc^{45}(p,pn)Sc^{44,44m}$



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

$Ti^{46}(d,p)Ti^{47}$ 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)

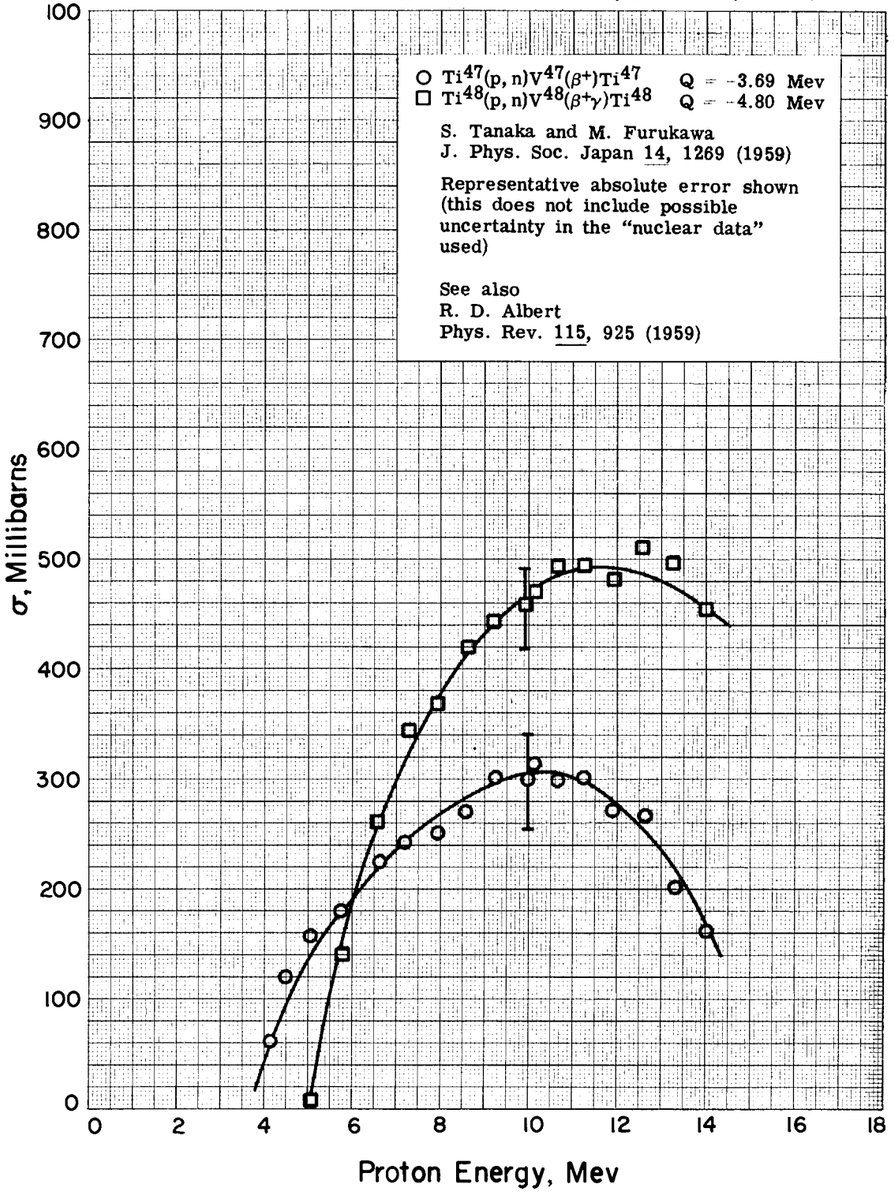
Target	$\sigma(30°)/\sigma_o$
Ti^{46}	0.6 ± 20%
Ti^{47}	0.06 20%

σ_o = 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)

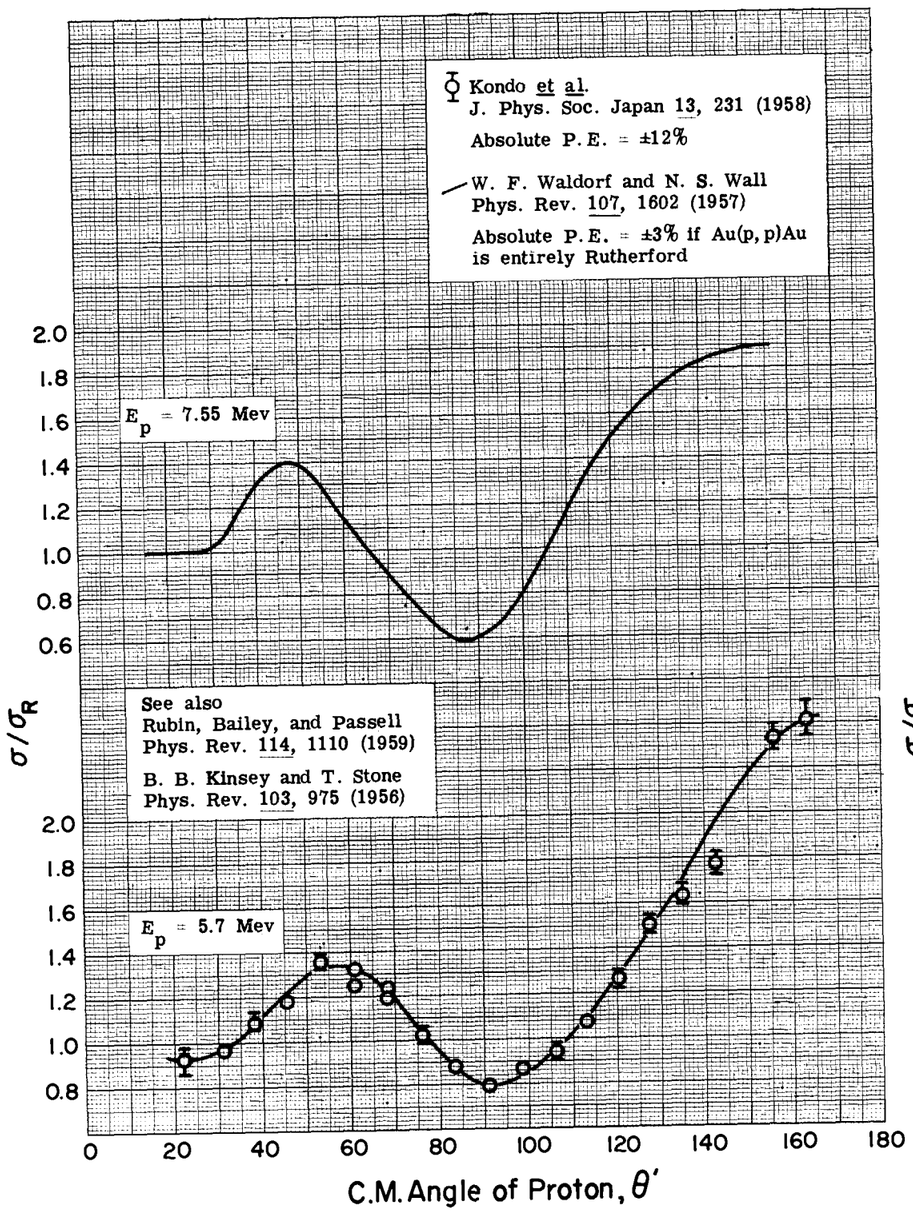


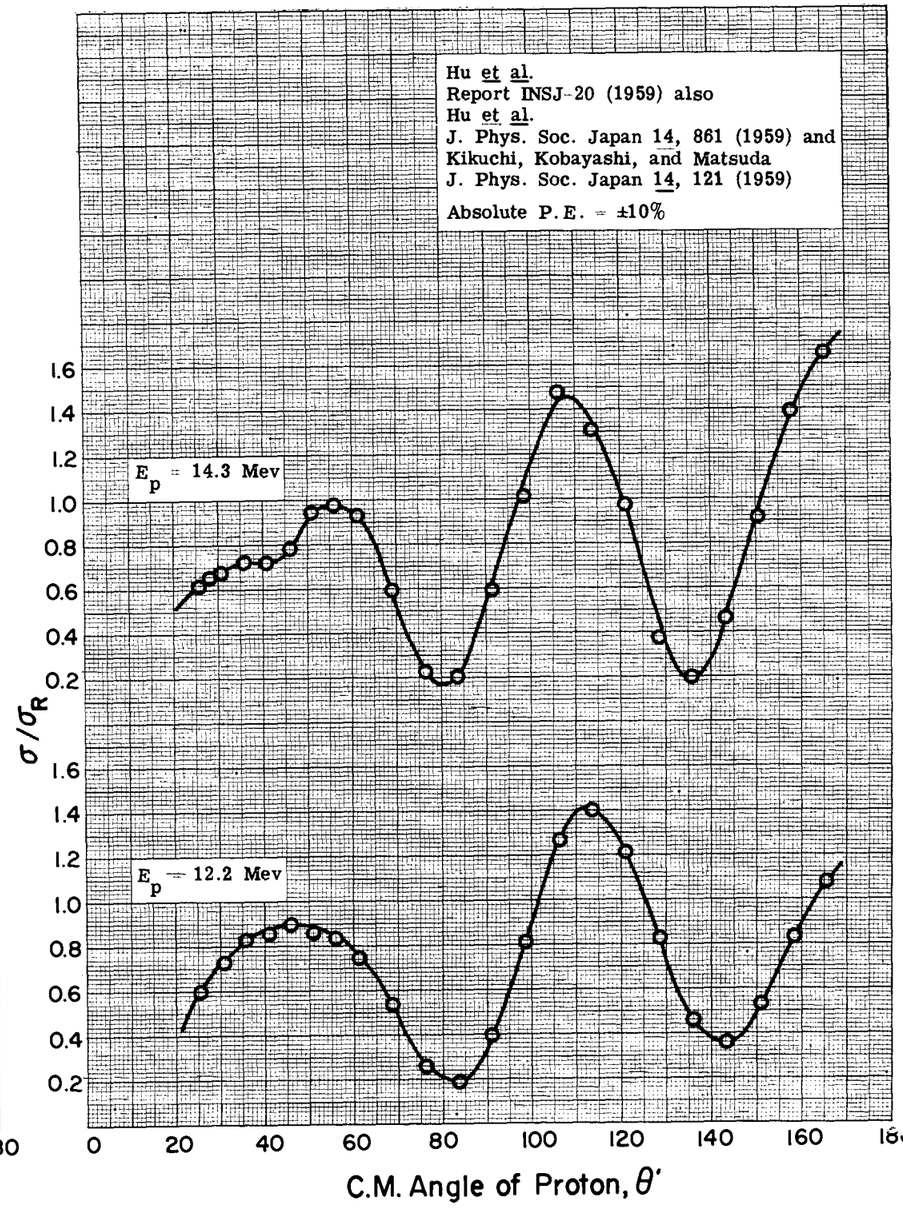
○ $Ti^{47}(p,n)V^{47}(\beta^+)Ti^{47}$ Q = -3.69 Mev
□ $Ti^{48}(p,n)V^{48}(\beta^+\gamma)Ti^{48}$ Q = -4.80 Mev

S. Tanaka and M. Furukawa
J. Phys. Soc. Japan 14, 1269 (1959)

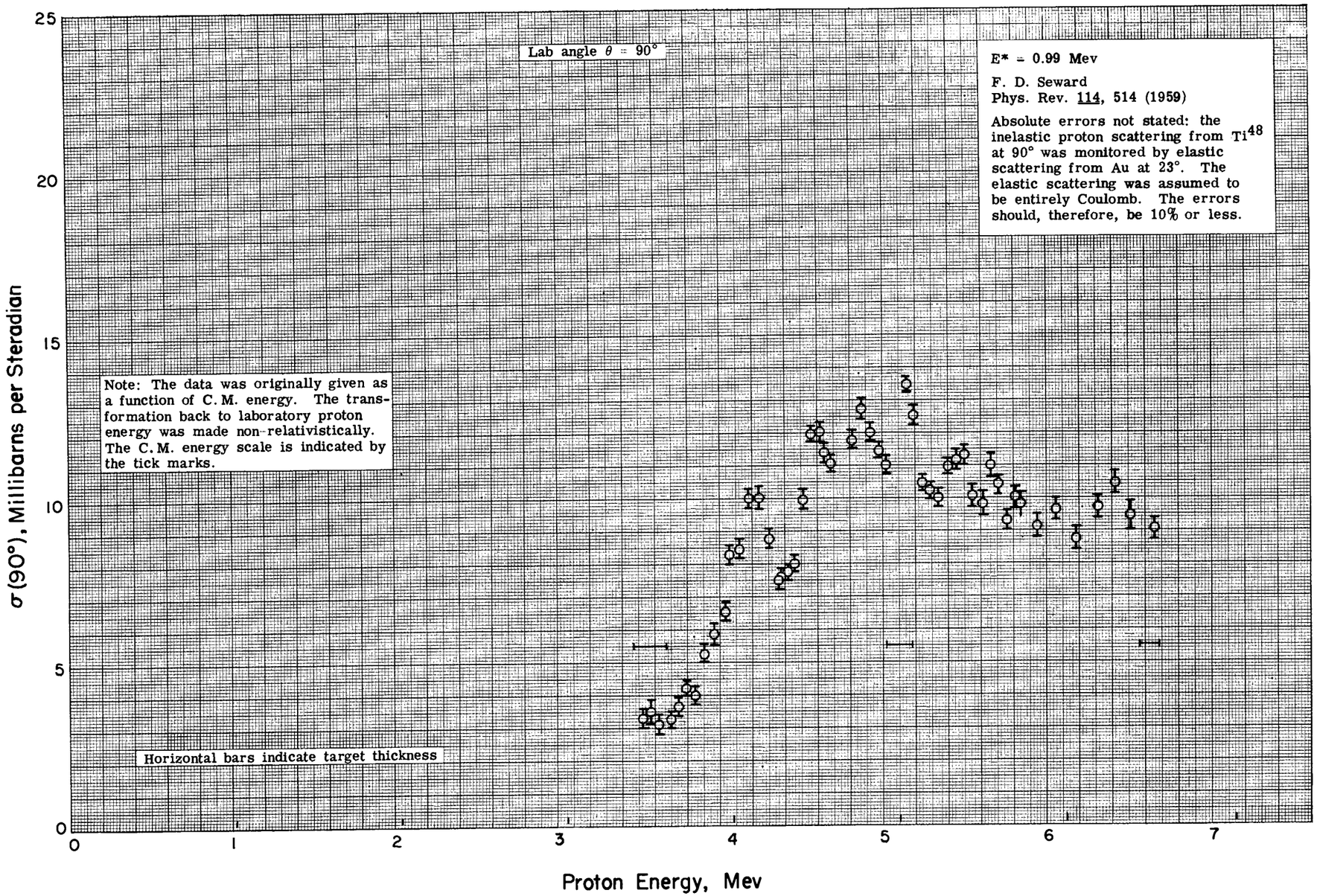
Representative absolute error shown (this does not include possible uncertainty in the "nuclear data" used)

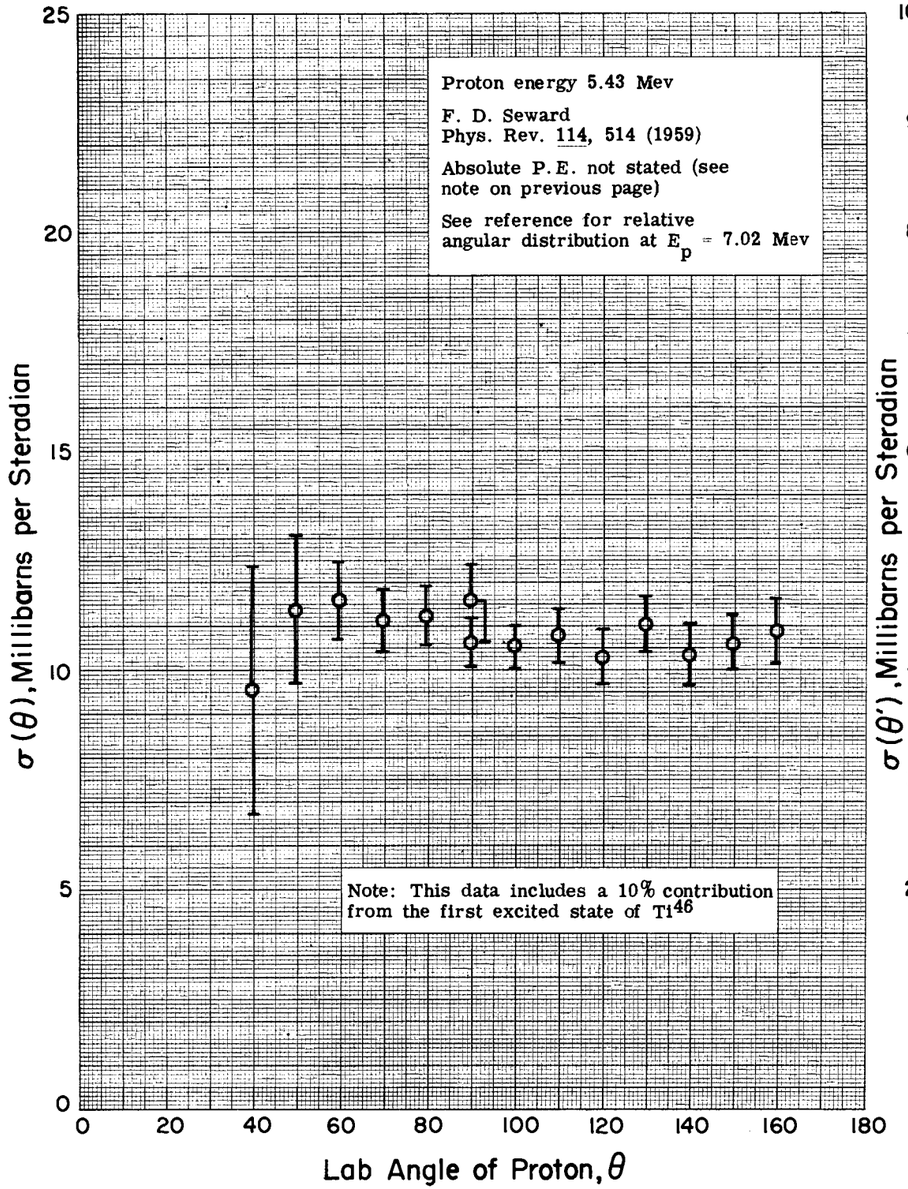
See also
R. D. Albert
Phys. Rev. 115, 925 (1959)

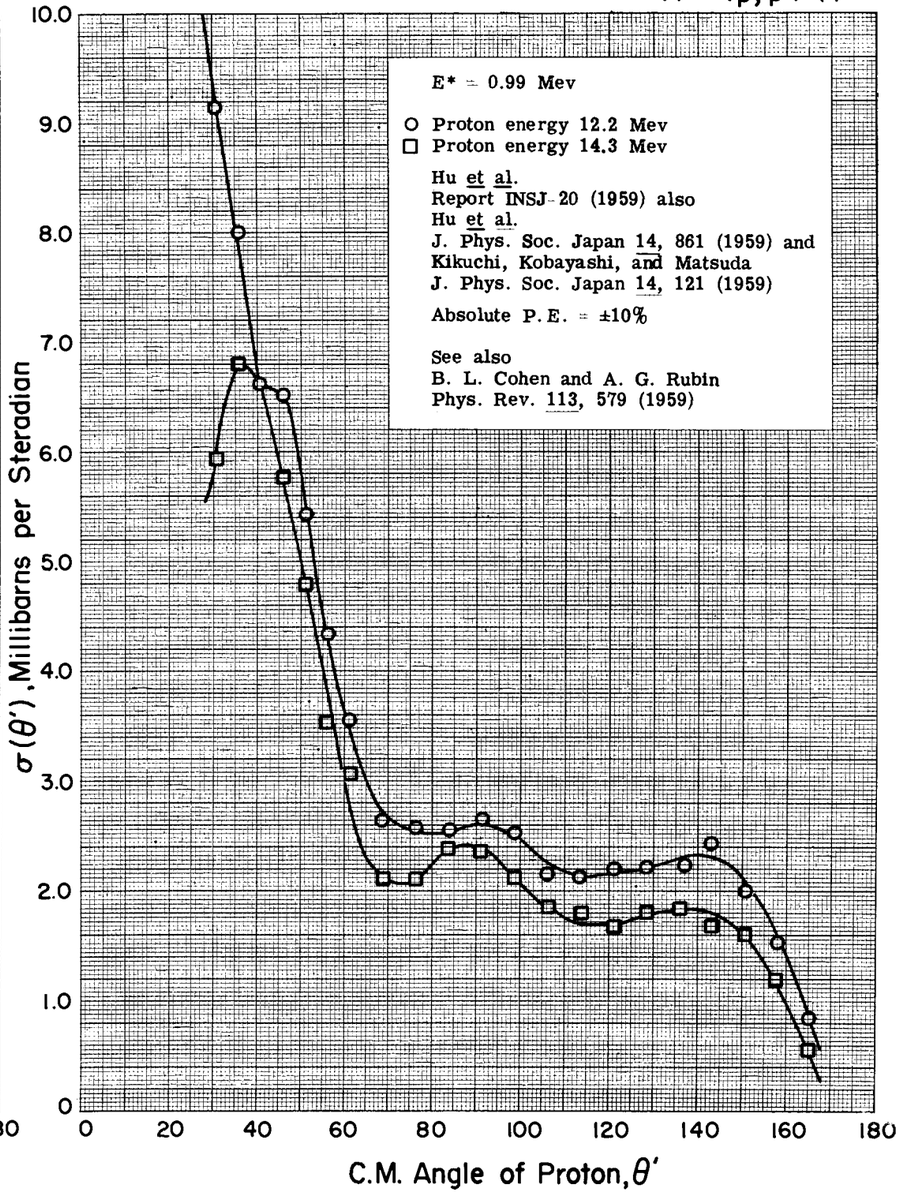

Kondo et al.
J. Phys. Soc. Japan 13, 231 (1958)
Absolute P.E. = ±12%
W. F. Waldorf and N. S. Wall
Phys. Rev. 107, 1602 (1957)
Absolute P.E. = ±3% if Au(p, p)Au is entirely Rutherford
See also
Rubin, Bailey, and Passell
Phys. Rev. 114, 1110 (1959)
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
E_p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

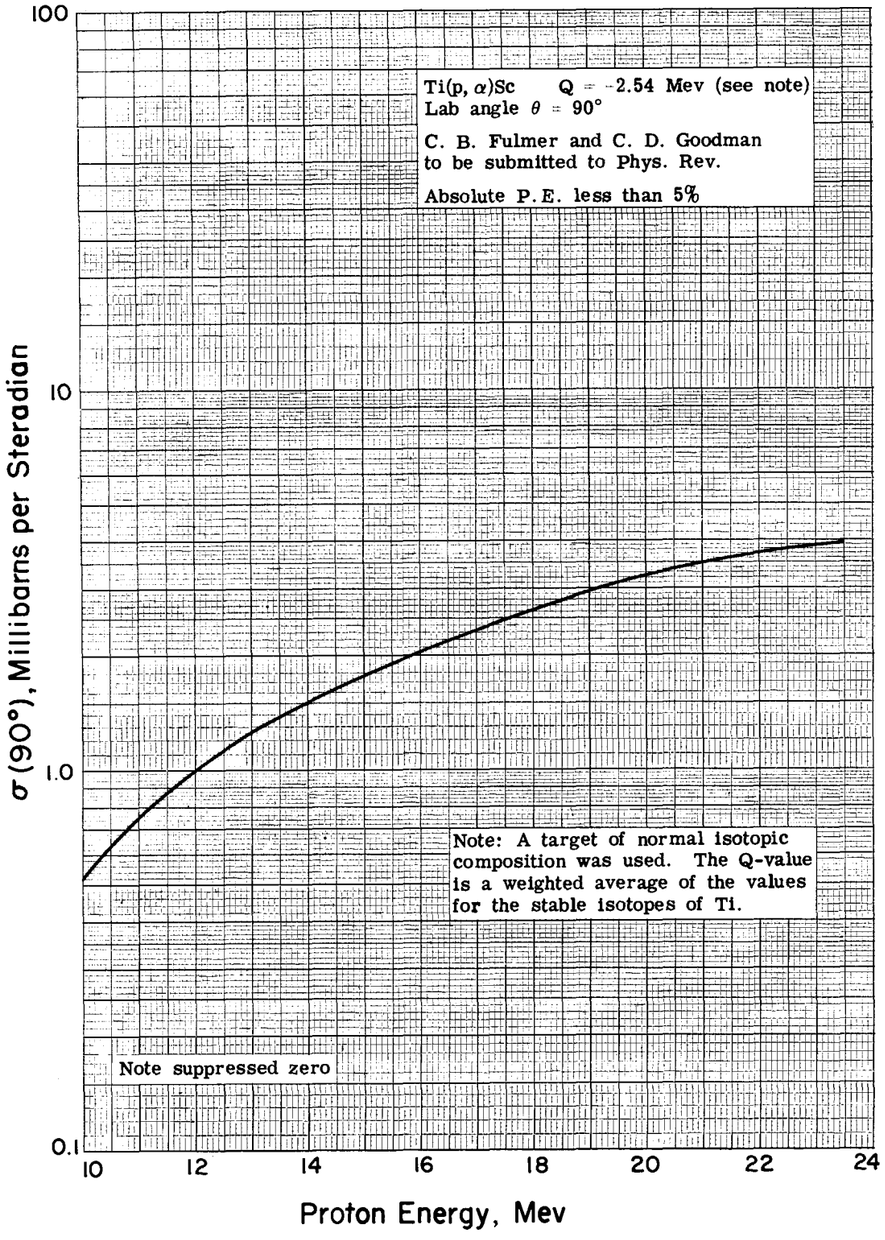

Hu et al.
Report INSJ-20 (1959) also
Hu et al.
J. Phys. Soc. Japan 14, 861 (1959) and
Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)
Absolute P.E. = ±10%
E_p = 14.3 Mev
E_p = 12.2 Mev
σ/σ_R
C.M. Angle of Proton, θ'

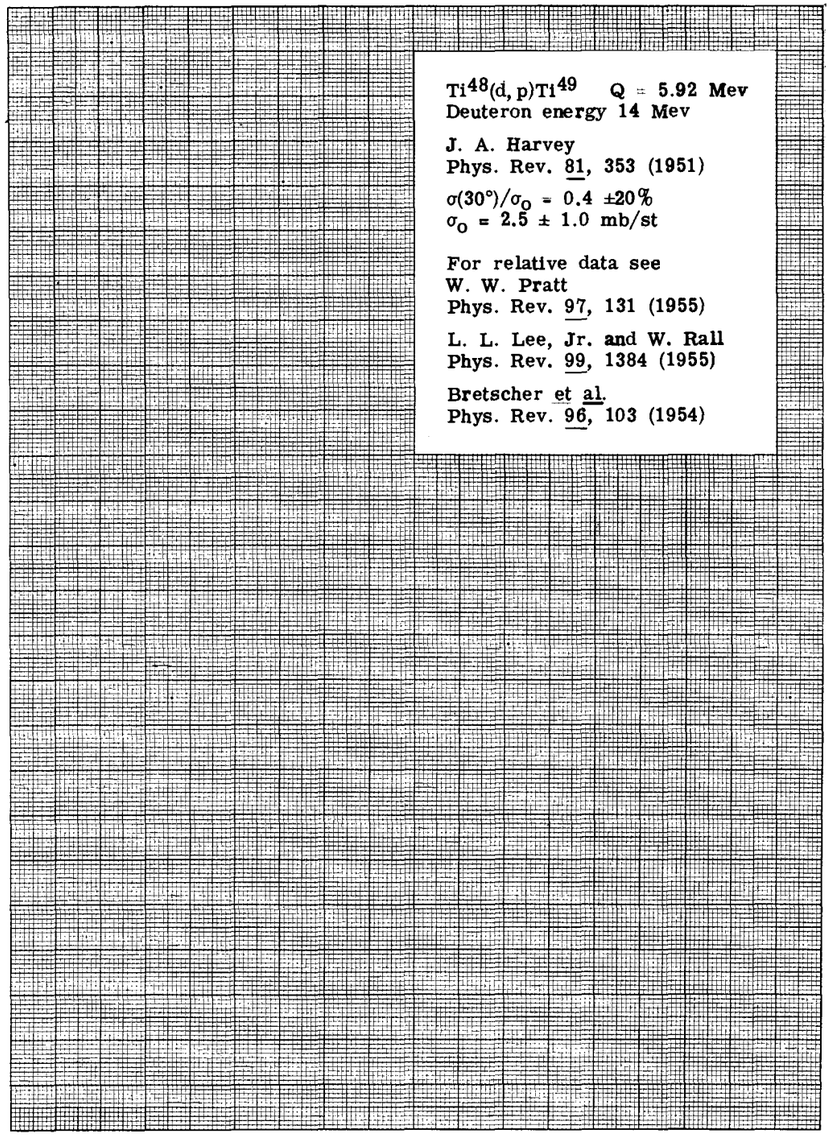
$Ti^{48}(p,p')Ti^{48*}$


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
0
1
2
3
4
5
6
7

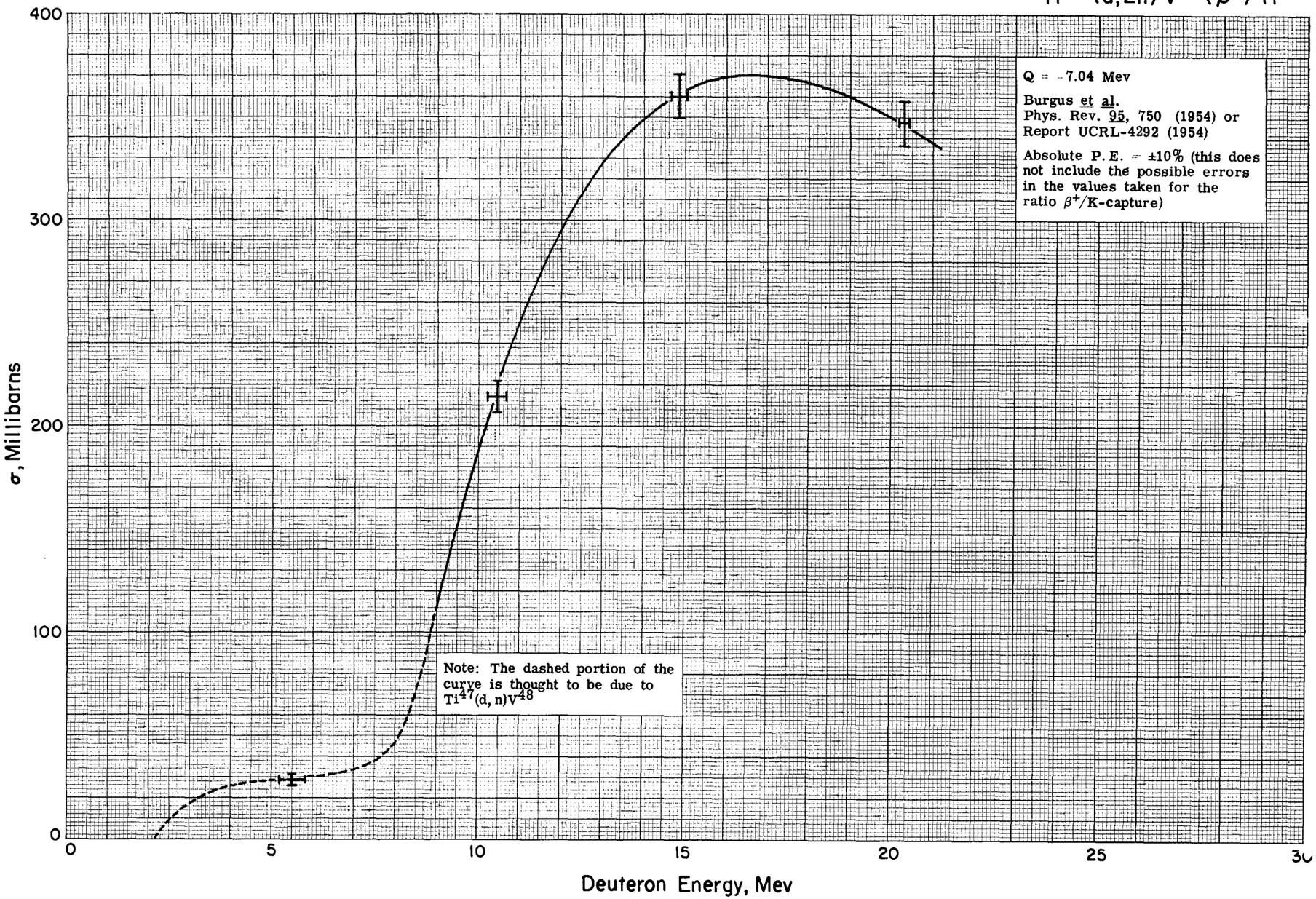

Proton energy 5.43 Mev
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute P.E. not stated (see note on previous page)
See reference for relative angular distribution at E_p = 7.02 Mev
Note: This data includes a 10% contribution from the first excited state of Ti^{46}
σ(θ), Millibarns per Steradian
Lab Angle of Proton, θ
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180

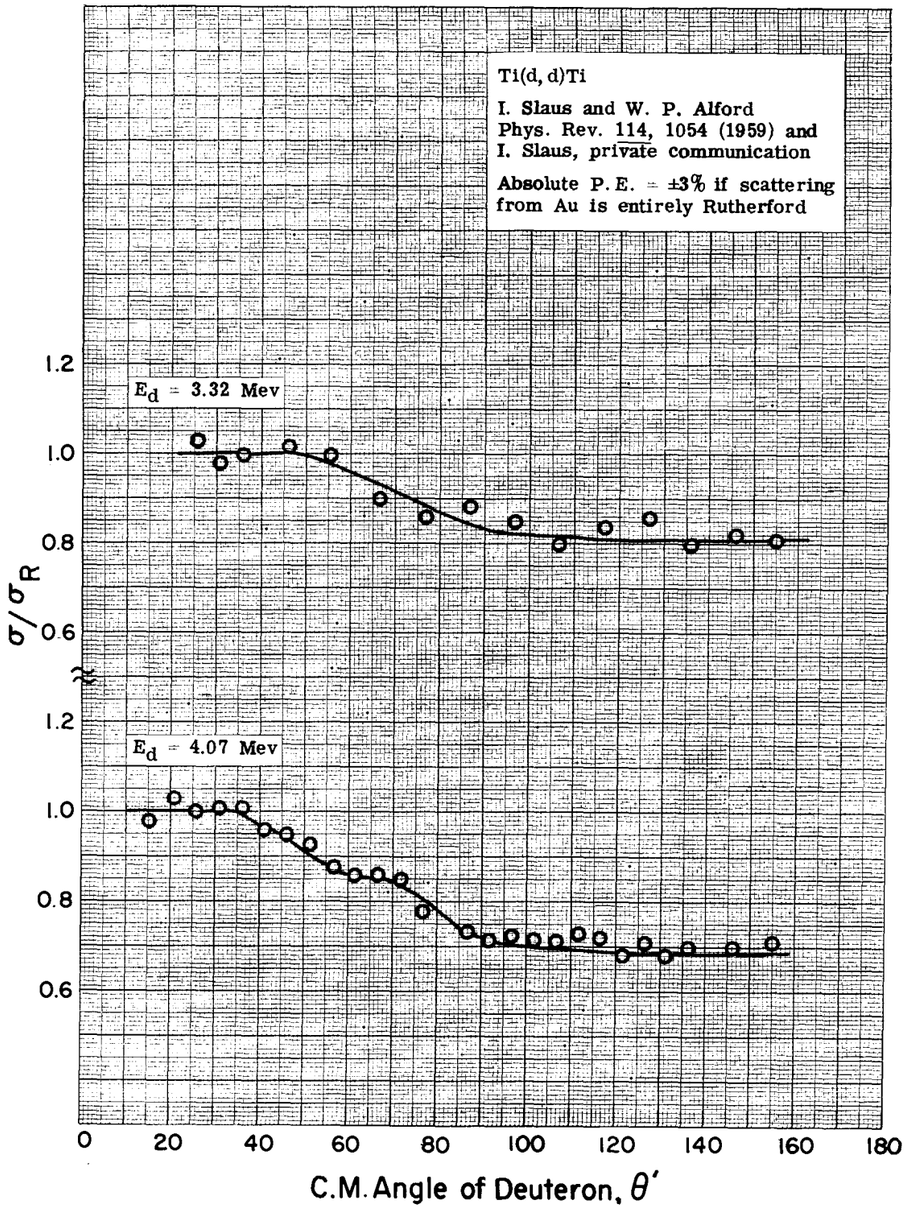

E* = 0.99 Mev
○ Proton energy 12.2 Mev
□ Proton energy 14.3 Mev
Hu et al.
Report INSJ-20 (1959) also
Hu et al.
J. Phys. Soc. Japan 14, 861 (1959) and
Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)
Absolute P.E. = ±10%
See also
B. L. Cohen and A. G. Rubin
Phys. Rev. 113, 579 (1959)
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
20
40
60
80
100
120
140
160
180

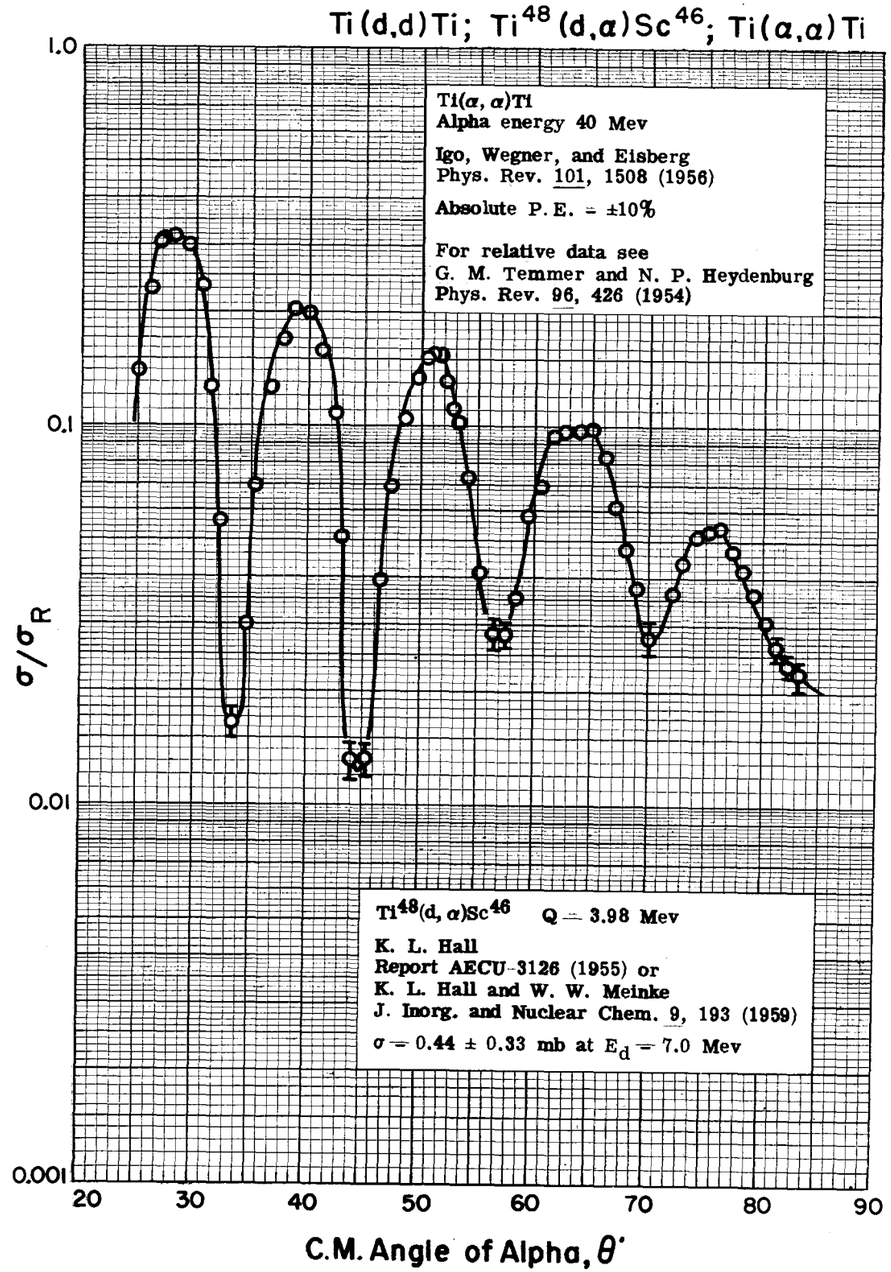

Ti(p, α)Sc Q = −2.54 Mev (see note)
Lab angle θ = 90°
C. B. Fulmer and C. D. Goodman
to be submitted to Phys. Rev.
Absolute P.E. less than 5%
Note: A target of normal isotopic composition was used. The Q-value is a weighted average of the values for the stable isotopes of Ti.
Note suppressed zero
σ(90°), Millibarns per Steradian
100
10
1.0
0.1
10
12
14
16
18
20
22
24
Proton Energy, Mev

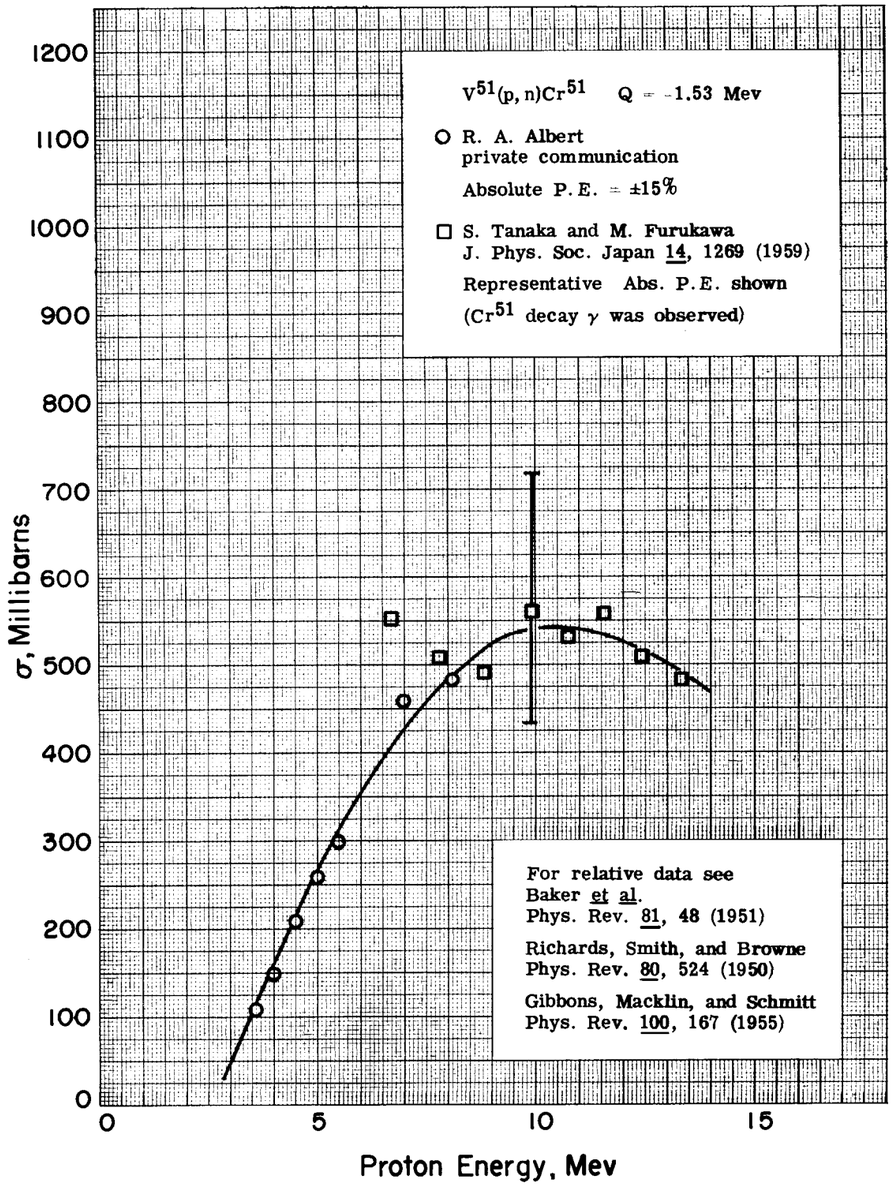

Ti^{48}(d, p)Ti^{49} Q = 5.92 Mev
Deuteron energy 14 Mev
J. A. Harvey
Phys. Rev. 81, 353 (1951)
σ(30°)/$σ_0$ = 0.4 ±20%
$σ_0$ = 2.5 ± 1.0 mb/st
For relative data see
W. W. Pratt
Phys. Rev. 97, 131 (1955)
L. L. Lee, Jr. and W. Rall
Phys. Rev. 99, 1384 (1955)
Bretscher et al.
Phys. Rev. 96, 103 (1954)

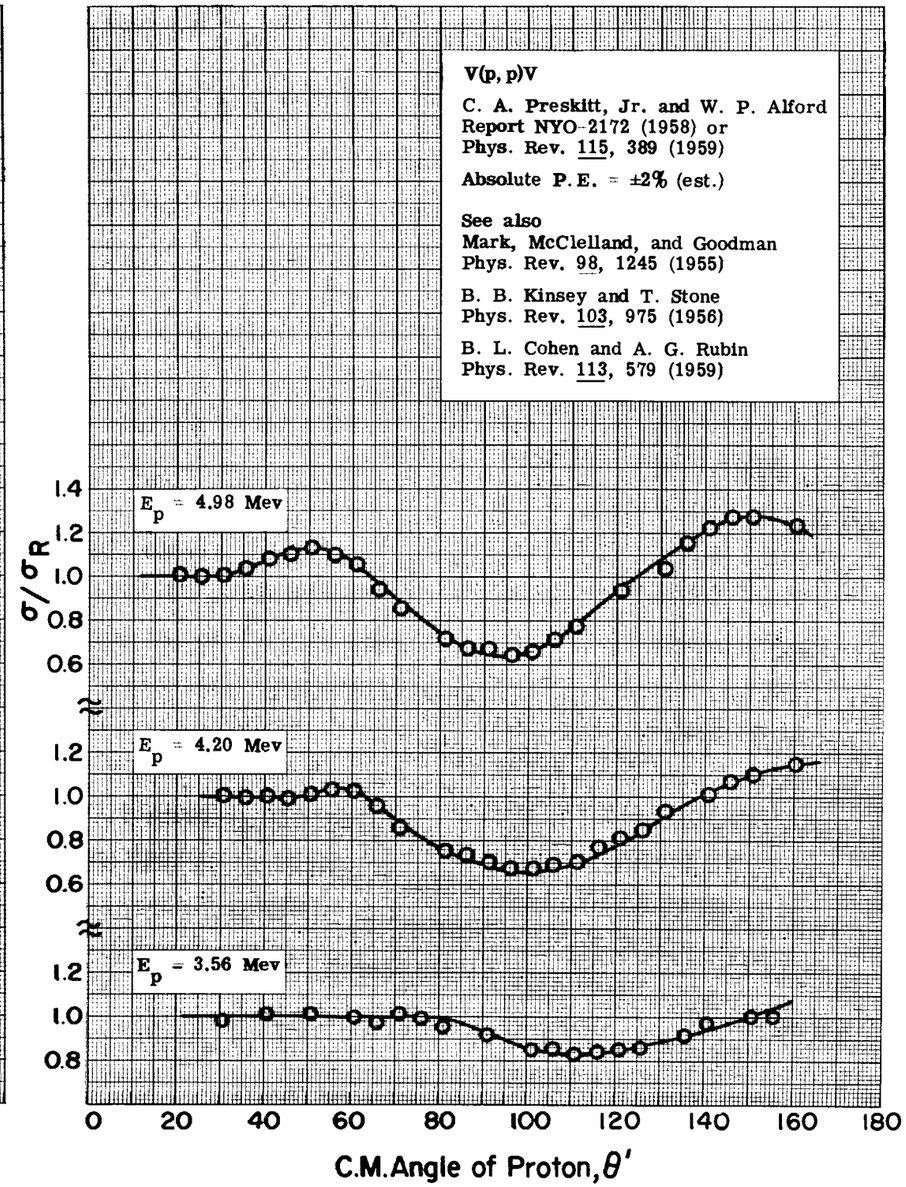
$Ti^{48}(d,2n)V^{48}(\beta^+)Ti^{48}$

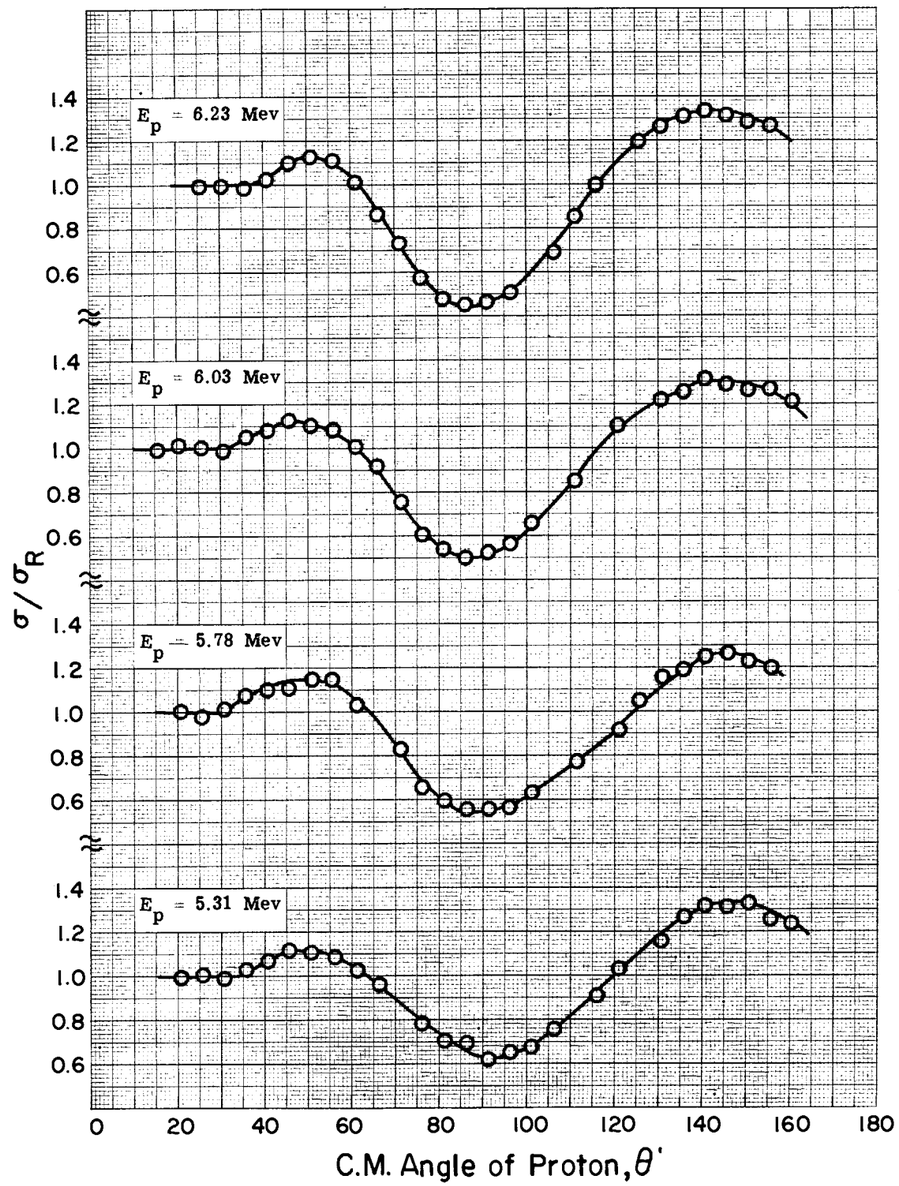


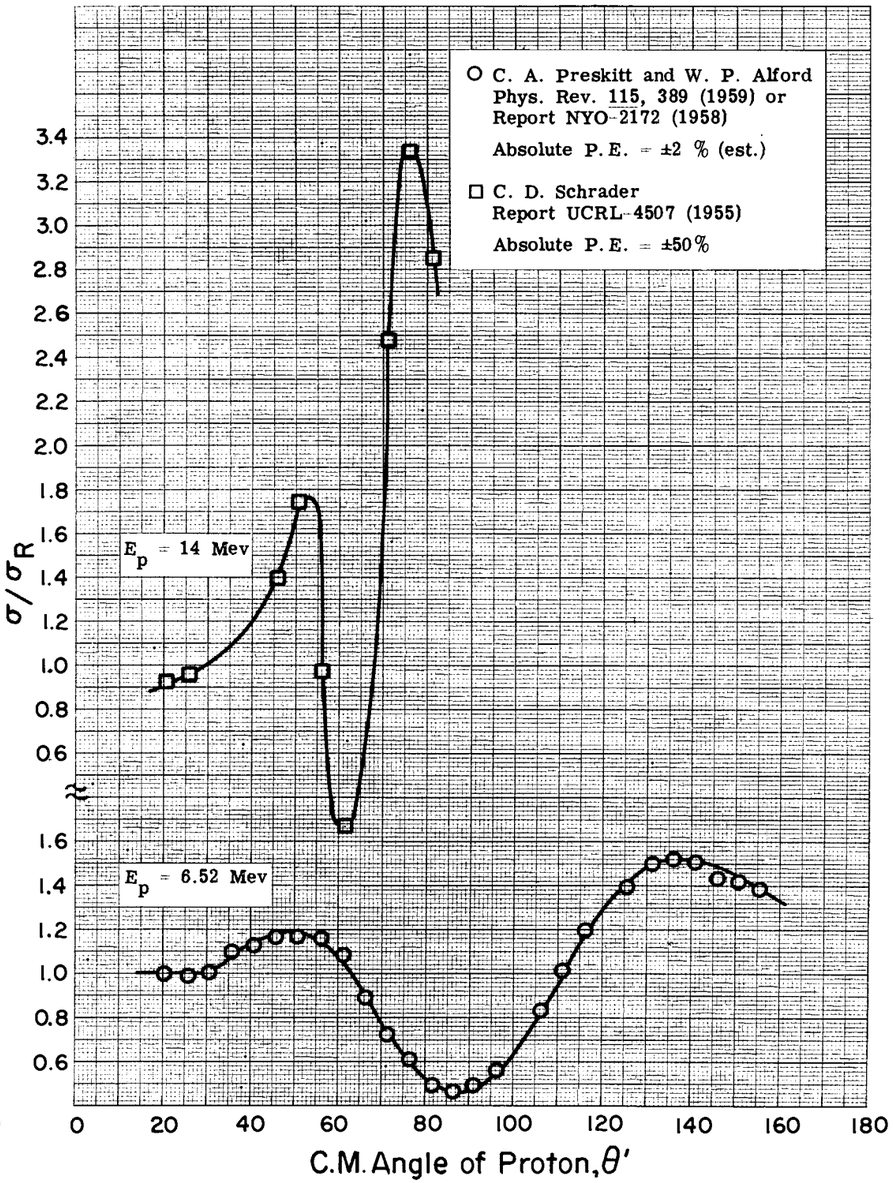

Ti(d, d)Ti
I. Slaus and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication
Absolute P.E. = ±3% if scattering from Au is entirely Rutherford
E_d = 3.32 Mev
E_d = 4.07 Mev
σ/σR
1.2
1.0
0.8
0.6
0
20
40
60
80
100
120
140
160
180
C.M. Angle of Deuteron, θ'

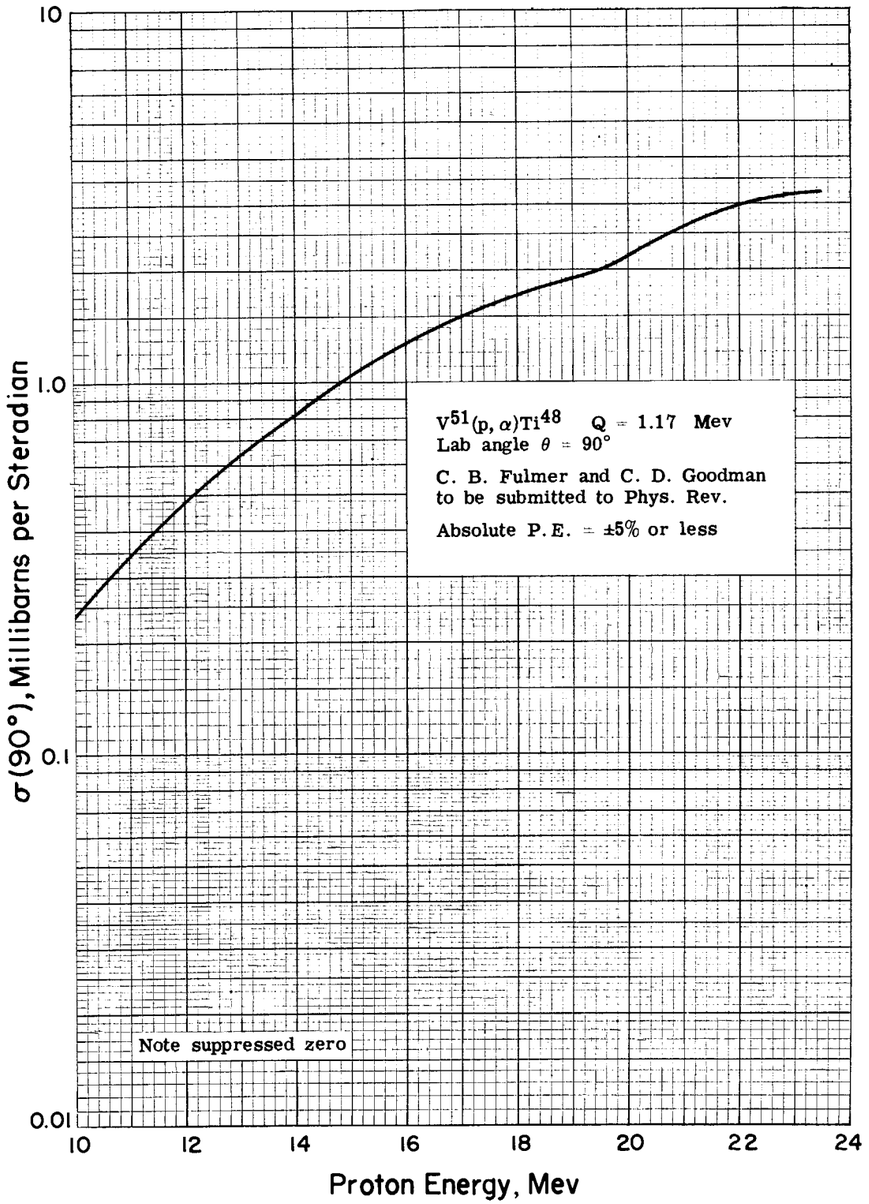

Ti(d,d)Ti; Ti48(d,α)Sc46; Ti(α,α)Ti
Ti(α, α)Ti
Alpha energy 40 Mev
Igo, Wegner, and Eisberg
Phys. Rev. 101, 1508 (1956)
Absolute P.E. = ±10%
For relative data see
G. M. Temmer and N. P. Heydenburg
Phys. Rev. 96, 426 (1954)
Ti48(d, α)Sc46 Q = 3.98 Mev
K. L. Hall
Report AECU-3126 (1955) or
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959)
σ = 0.44 ± 0.33 mb at E_d = 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'


$V^{51}(p,n)Cr^{51}$ Q = -1.53 Mev
O R. A. Albert
private communication
Absolute P.E. = ±15%
□ S. Tanaka and M. Furukawa
J. Phys. Soc. Japan 14, 1269 (1959)
Representative Abs. P.E. shown
(Cr^{51} decay γ was observed)
For relative data see
Baker et al.
Phys. Rev. 81, 48 (1951)
Richards, Smith, and Browne
Phys. Rev. 80, 524 (1950)
Gibbons, Macklin, and Schmitt
Phys. Rev. 100, 167 (1955)
σ, Millibarns
Proton Energy, Mev


V(p, p)V
C. A. Preskitt, Jr. and W. P. Alford
Report NYO-2172 (1958) or
Phys. Rev. 115, 389 (1959)
Absolute P.E. = ±2% (est.)
See also
Mark, McClelland, and Goodman
Phys. Rev. 98, 1245 (1955)
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
B. L. Cohen and A. G. Rubin
Phys. Rev. 113, 579 (1959)
E_p = 4.98 Mev
E_p = 4.20 Mev
E_p = 3.56 Mev
σ/σR
C.M.Angle of Proton, θ'


E_p = 6.23 Mev
E_p = 6.03 Mev
E_p = 5.78 Mev
E_p = 5.31 Mev
σ/σ_R
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%
E_p = 14 Mev
E_p = 6.52 Mev
σ/σ_R
C.M. Angle of Proton, θ'



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

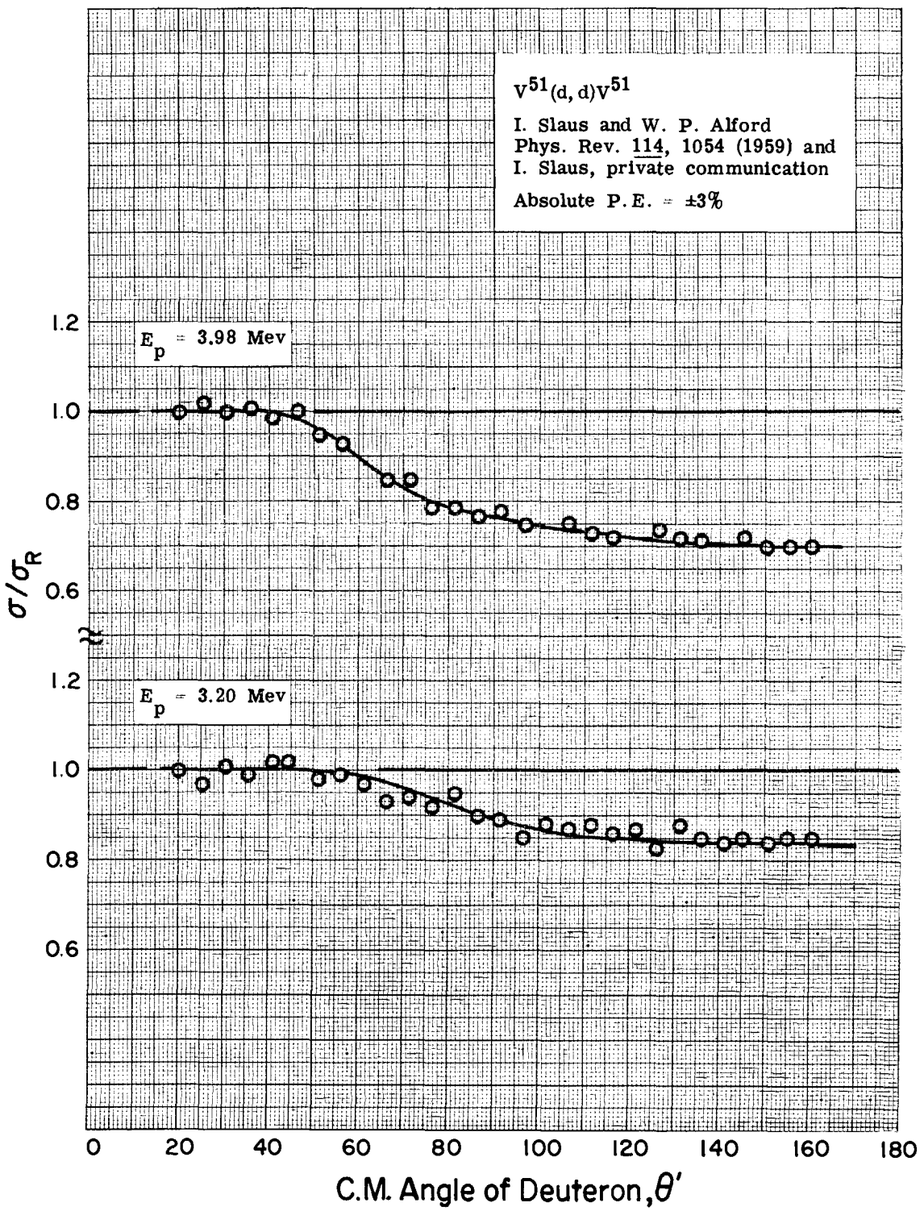
For relative data see
F. A. El Bedewi and S. Tadros
Nuclear Phys. 8, 71 (1958)

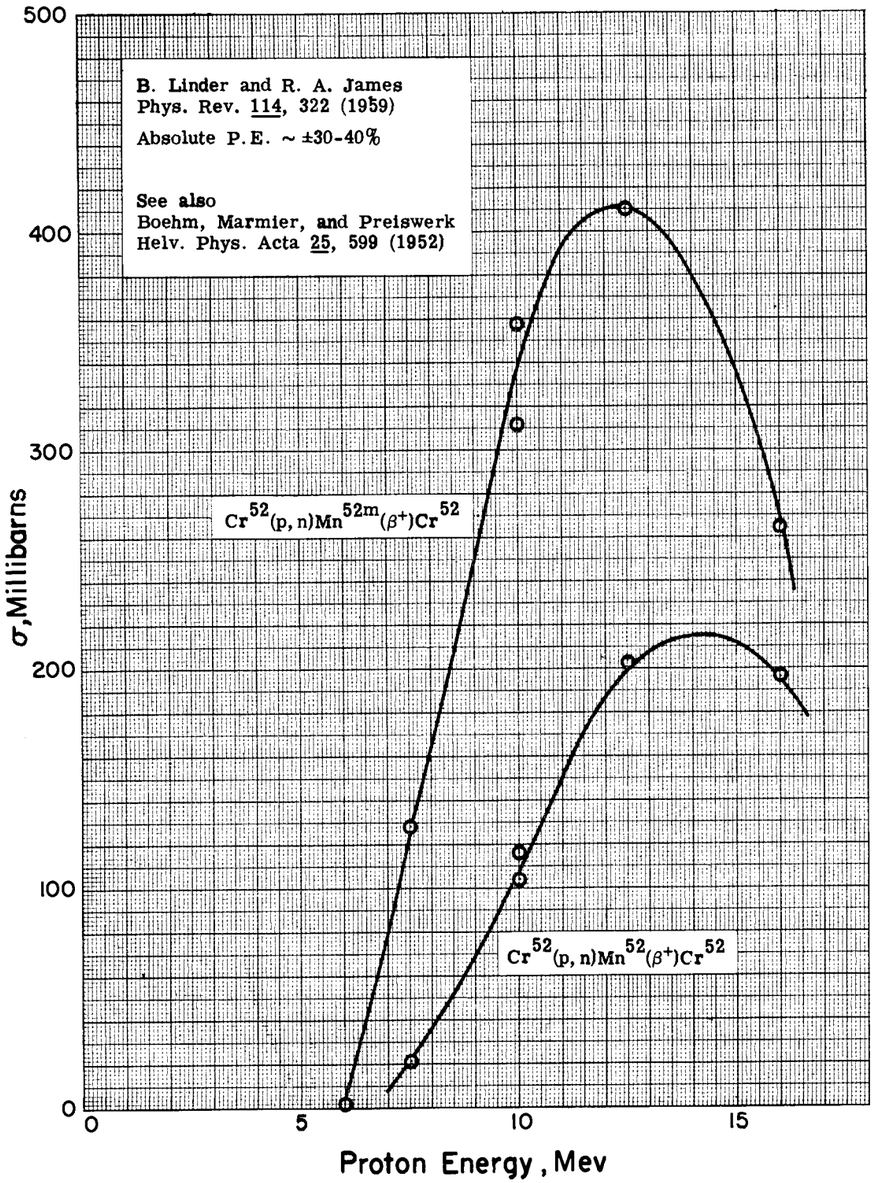
J. S. King and W. C. Parkinson
Phys. Rev. 89, 1080 (1953)

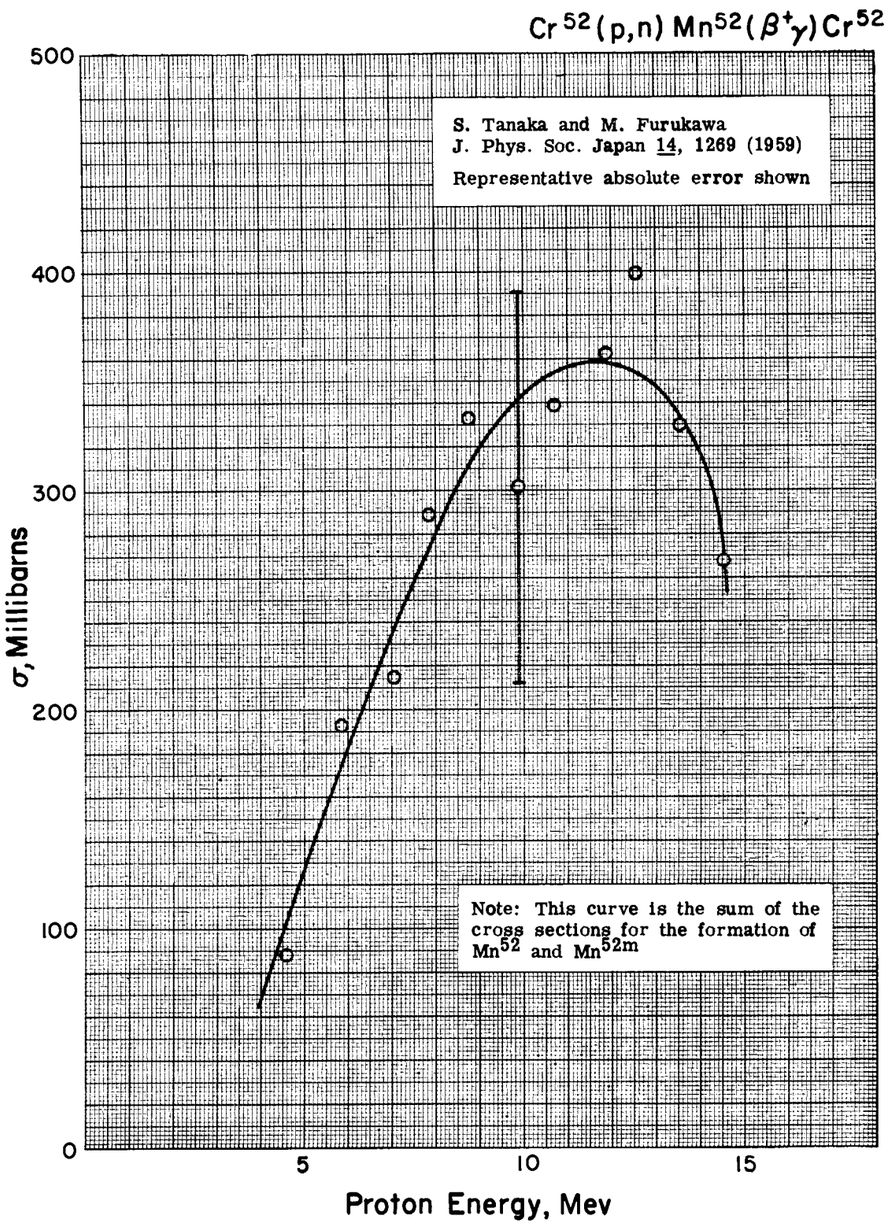
$V^{51}(d, d)V^{51}$

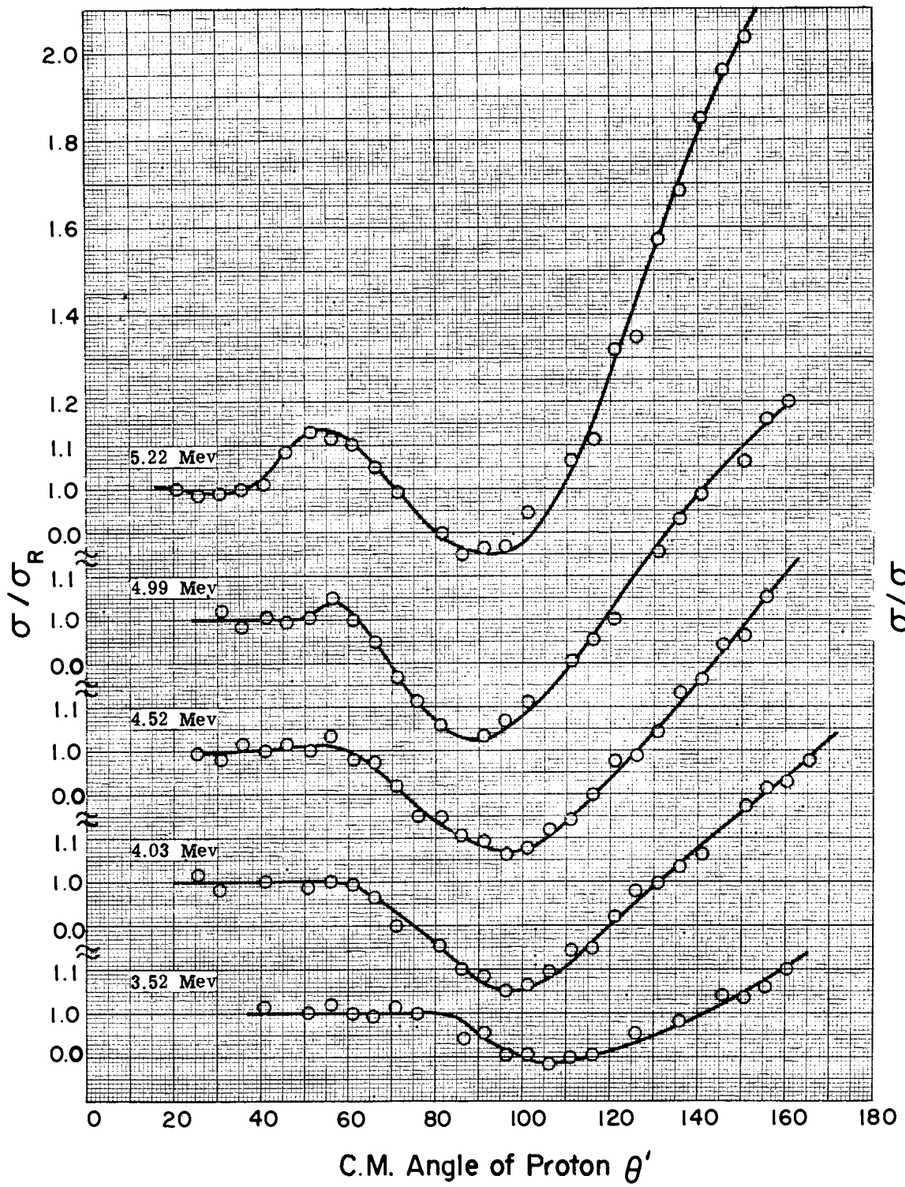
I. Slaus and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication

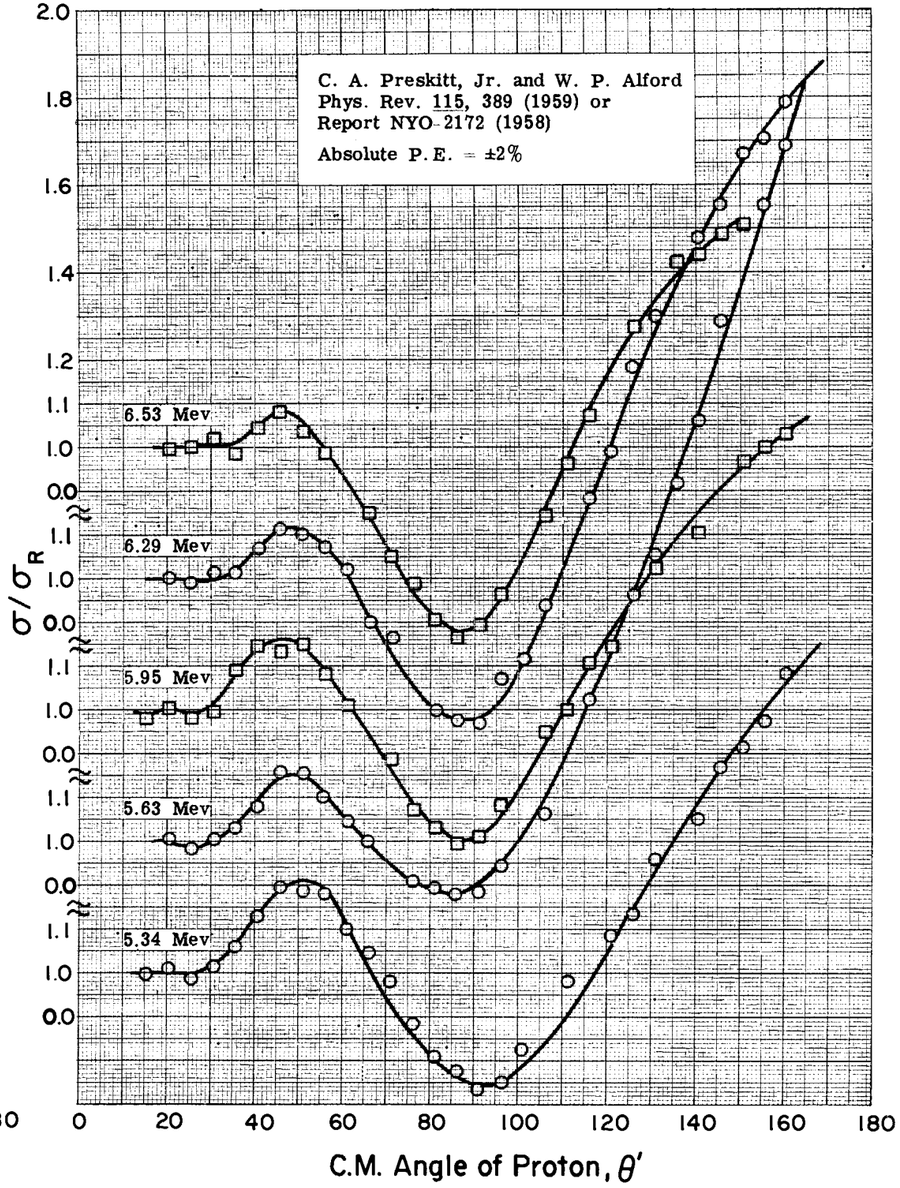
Absolute P.E. = ±3%

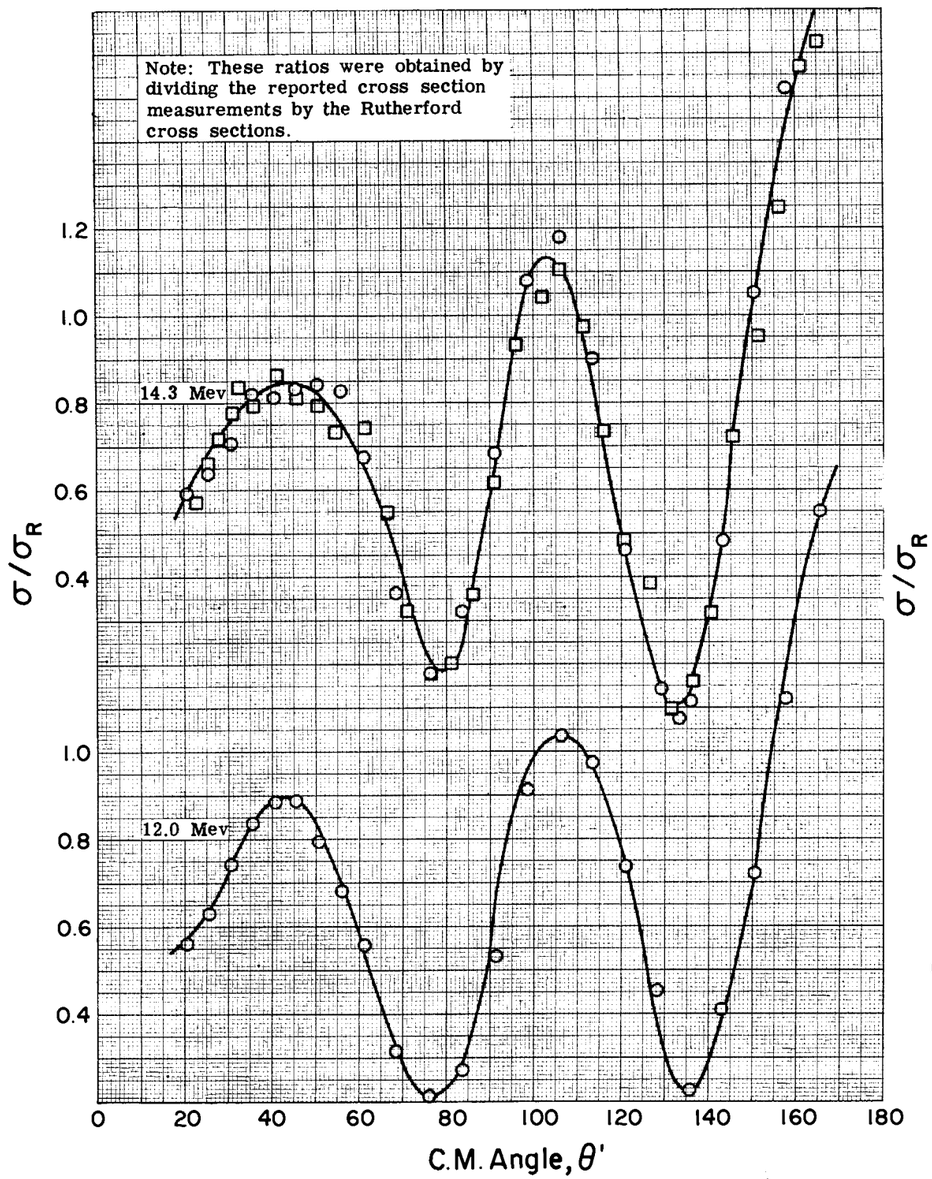


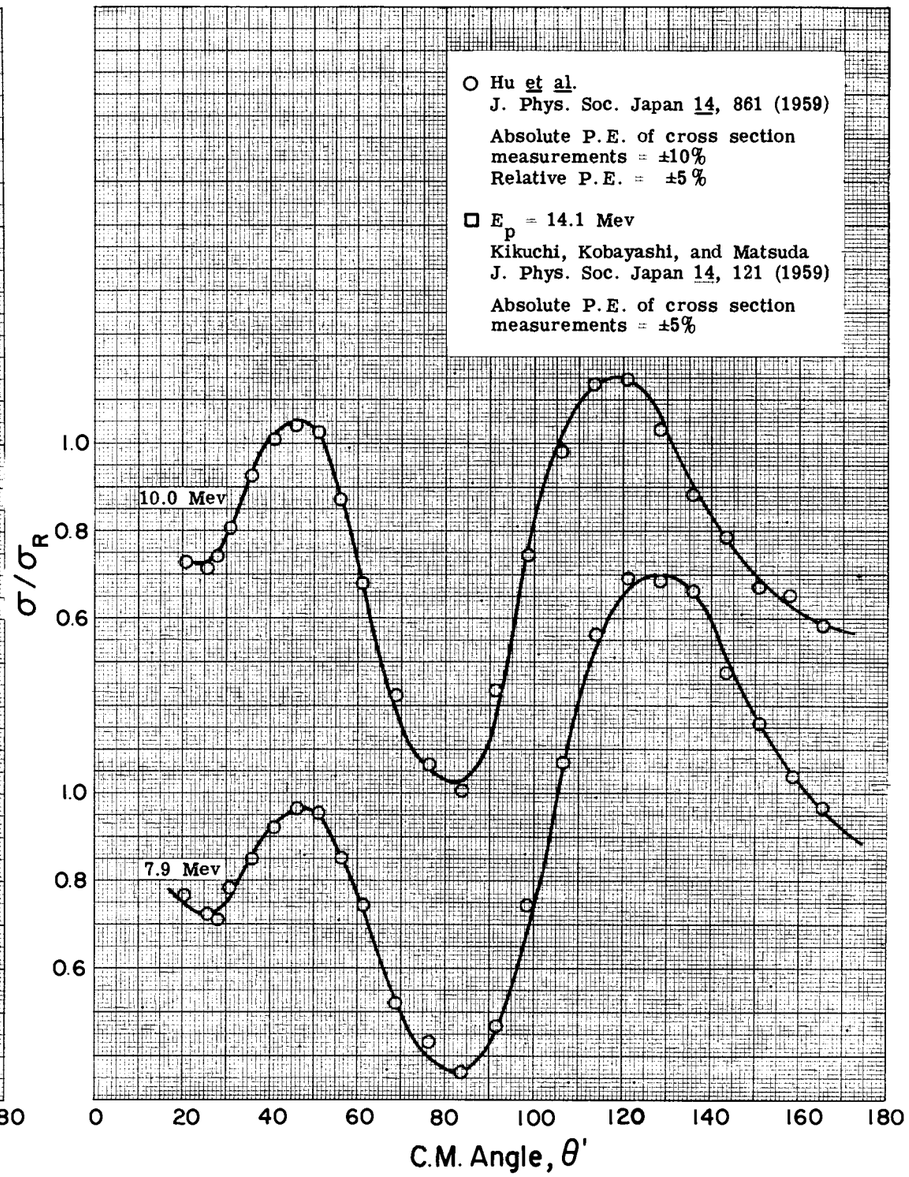

B. Linder and R. A. James
Phys. Rev. 114, 322 (1959)
Absolute P.E. ~ ±30-40%
See also
Boehm, Marmier, and Preiswerk
Helv. Phys. Acta 25, 599 (1952)
Cr52(p, n)Mn52m(β+)Cr52
Cr52(p, n)Mn52(β+)Cr52
σ, Millibarns
Proton Energy, Mev
0
100
200
300
400
500
5
10
15


Cr52(p,n) Mn52(β+γ)Cr52
S. Tanaka and M. Furukawa
J. Phys. Soc. Japan 14, 1269 (1959)
Representative absolute error shown
Note: This curve is the sum of the cross sections for the formation of Mn52 and Mn52m
σ, Millibarns
Proton Energy, Mev
0
100
200
300
400
500
5
10
15

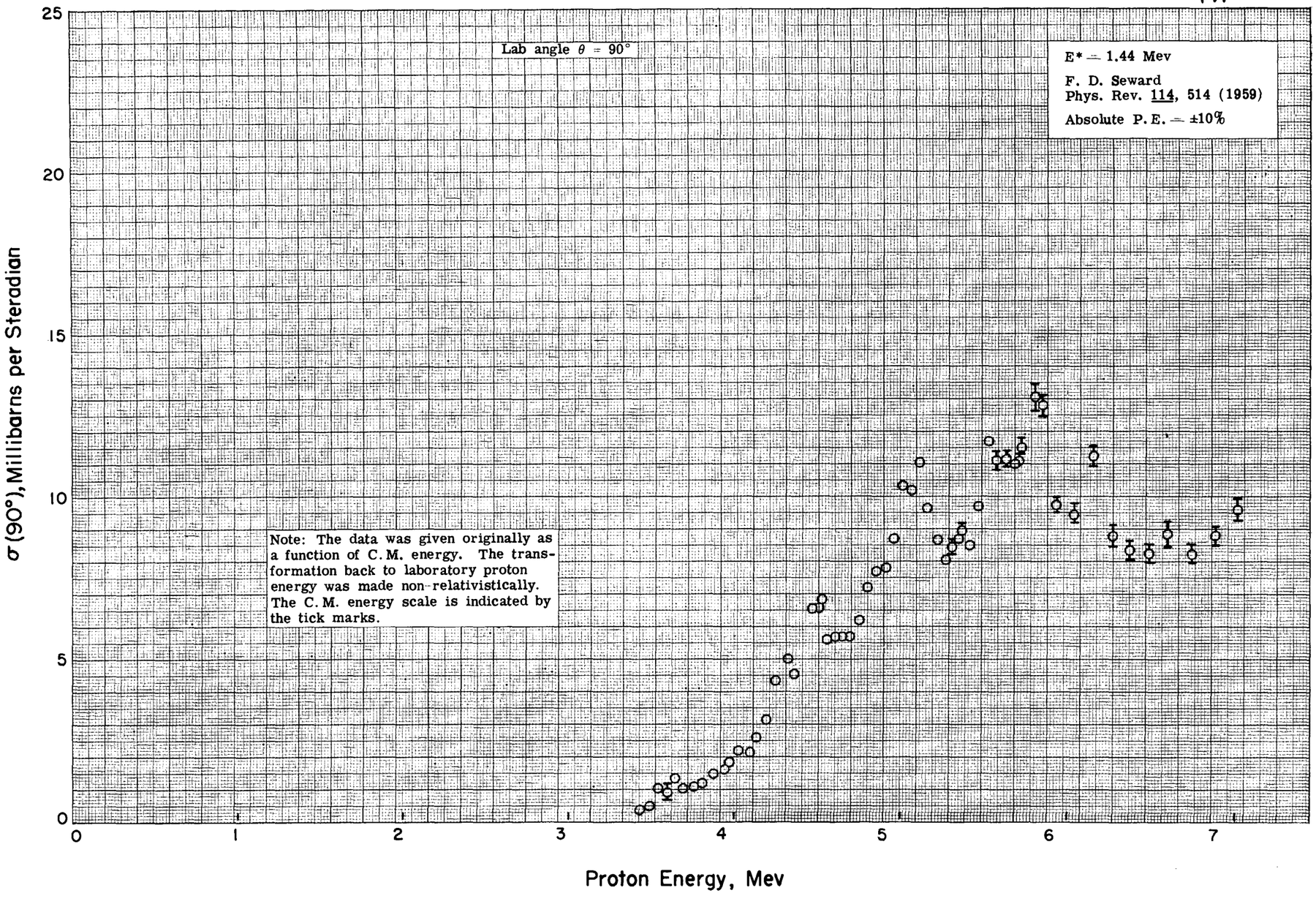

5.22 Mev
4.99 Mev
4.52 Mev
4.03 Mev
3.52 Mev
σ/σR
C.M. Angle of Proton θ′


C. A. Preskitt, Jr. and W. P. Alford
Phys. Rev. 115, 389 (1959) or
Report NYO-2172 (1958)
Absolute P.E. = ±2%
6.53 Mev
6.29 Mev
5.95 Mev
5.63 Mev
5.34 Mev
σ/σR
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
σ/σR
C.M. Angle, θ'
0
20
40
60
80
100
120
140
160
180
0.4
0.6
0.8
1.0
1.2


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%
10.0 Mev
7.9 Mev
σ/σR
C.M. Angle, θ'
0
20
40
60
80
100
120
140
160
180
0.6
0.8
1.0

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


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
Proton Energy, Mev
0
5
10
15
20
25
0
1
2
3
4
5
6
7

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

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

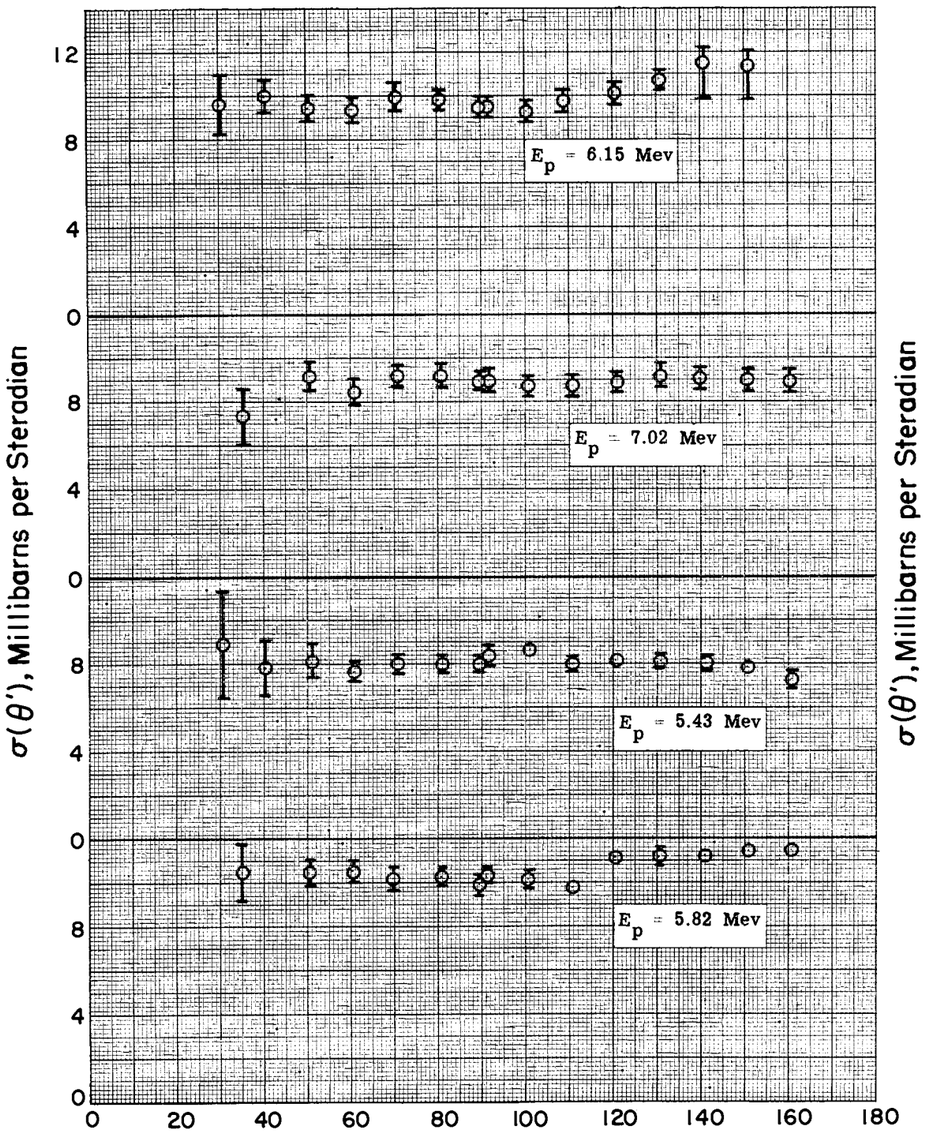
Absolute P.E. = ±15% or less

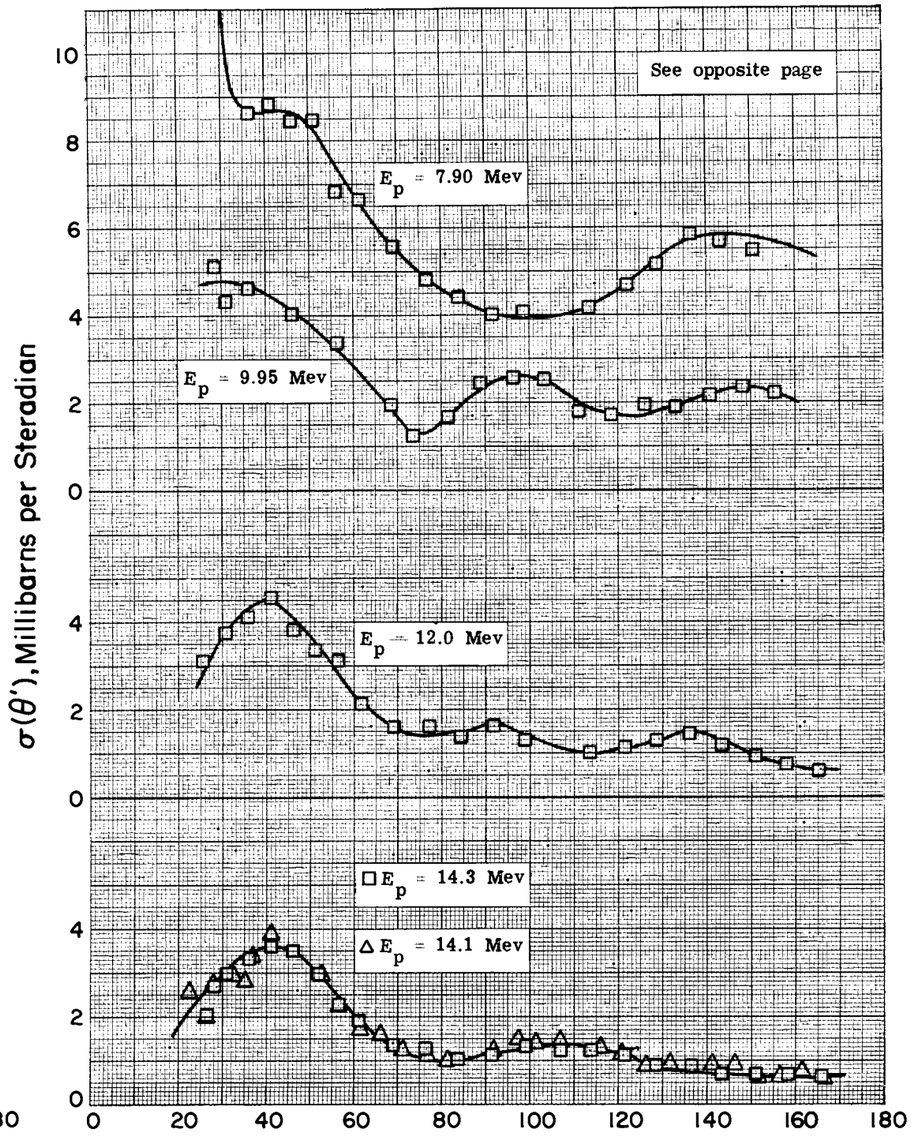
△ Kikuchi, Kobayashi, and Matsuda
J. Phys. Soc. Japan 14, 121 (1959)

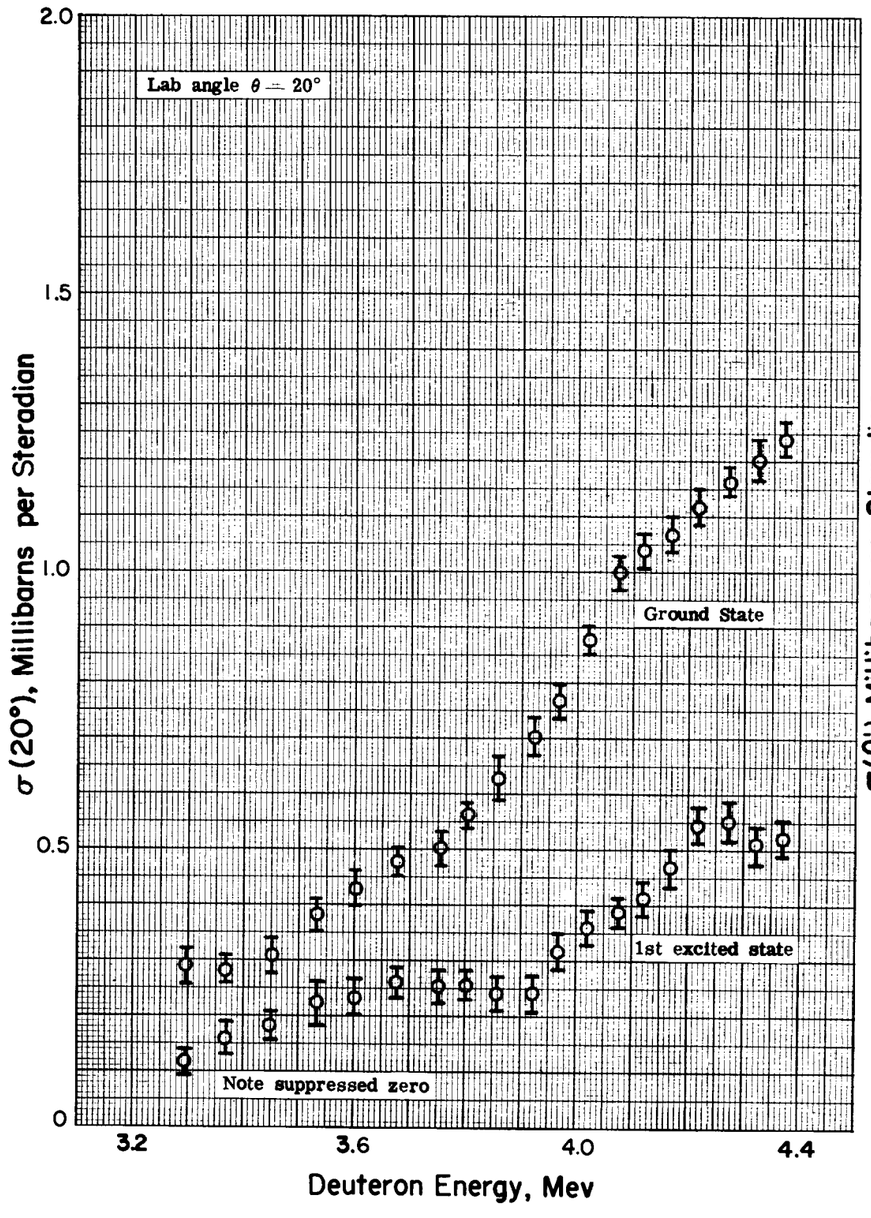
Absolute P.E. = 9-27%

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

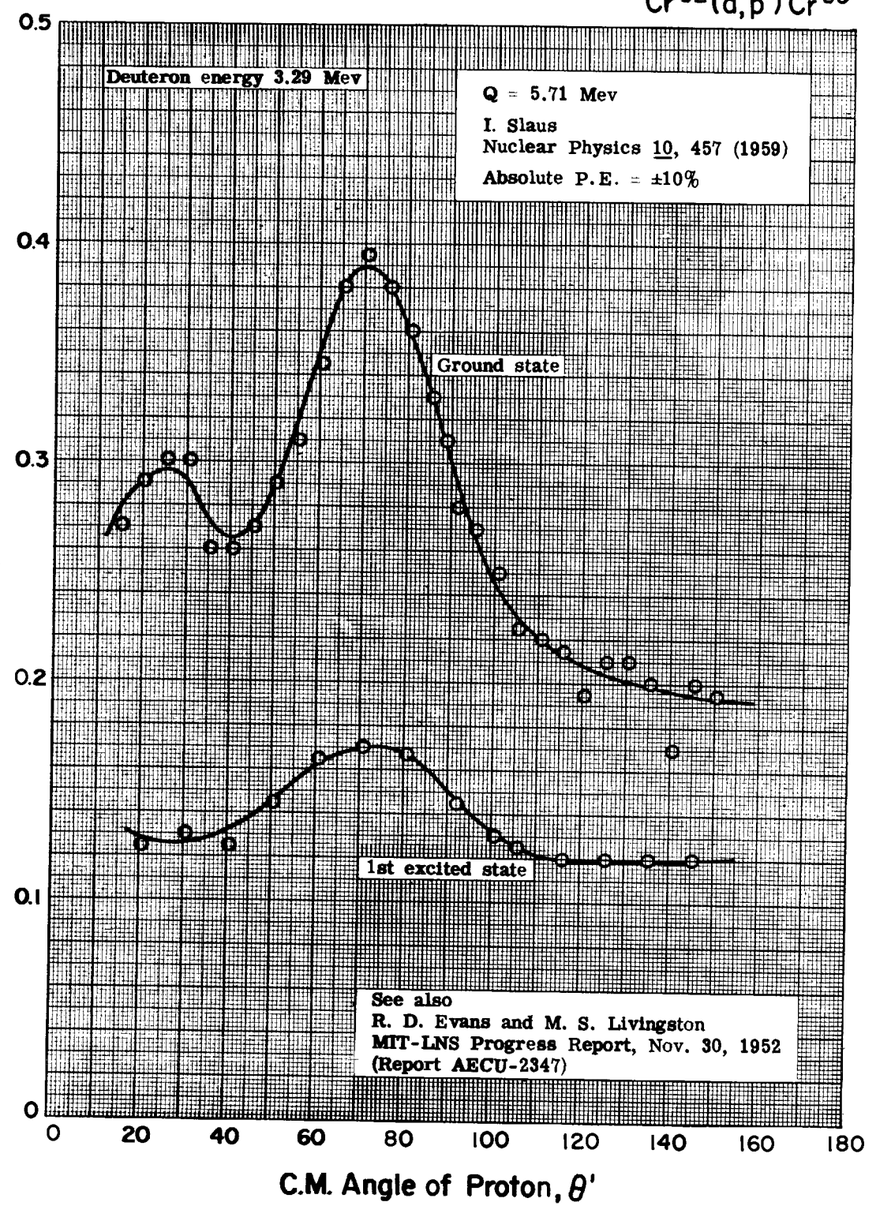
Absolute P.E. = ±10%

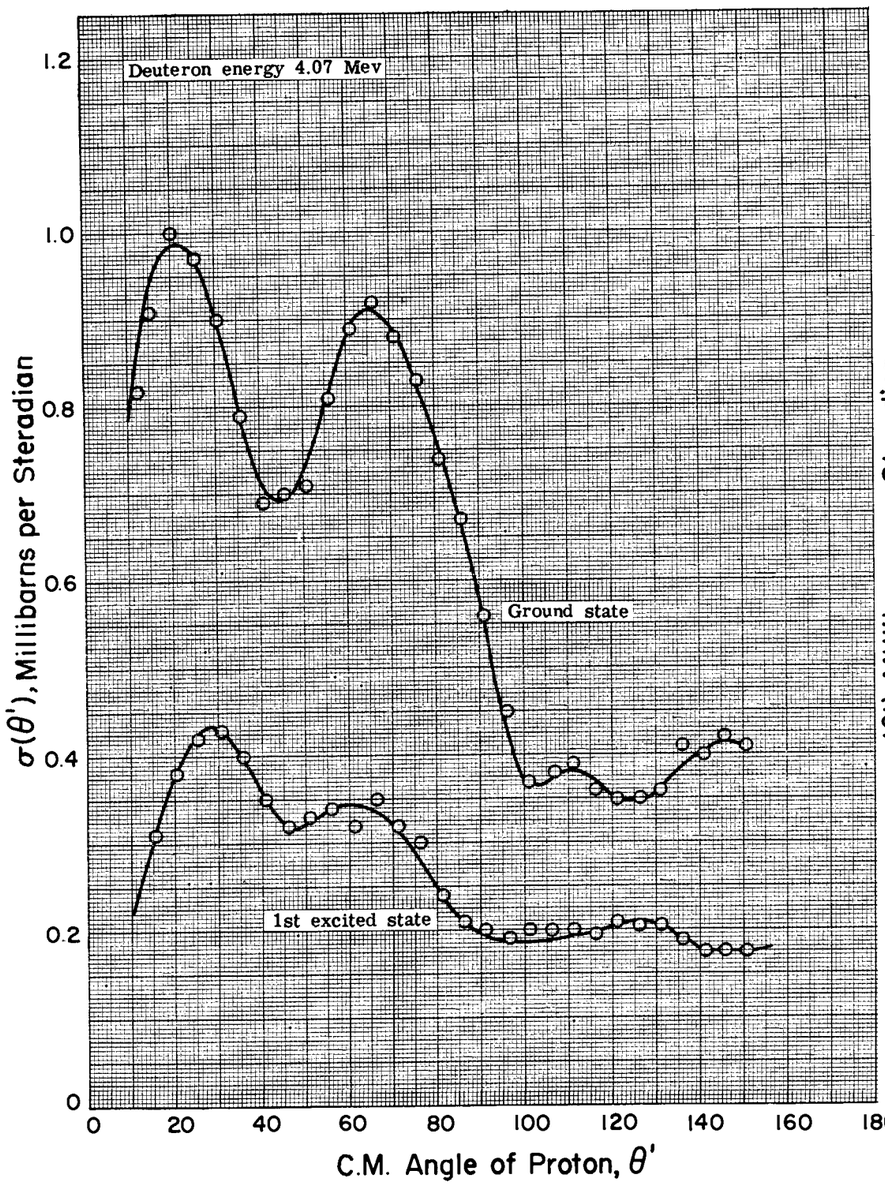

E_p = 6.15 Mev
E_p = 7.02 Mev
E_p = 5.43 Mev
E_p = 5.82 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

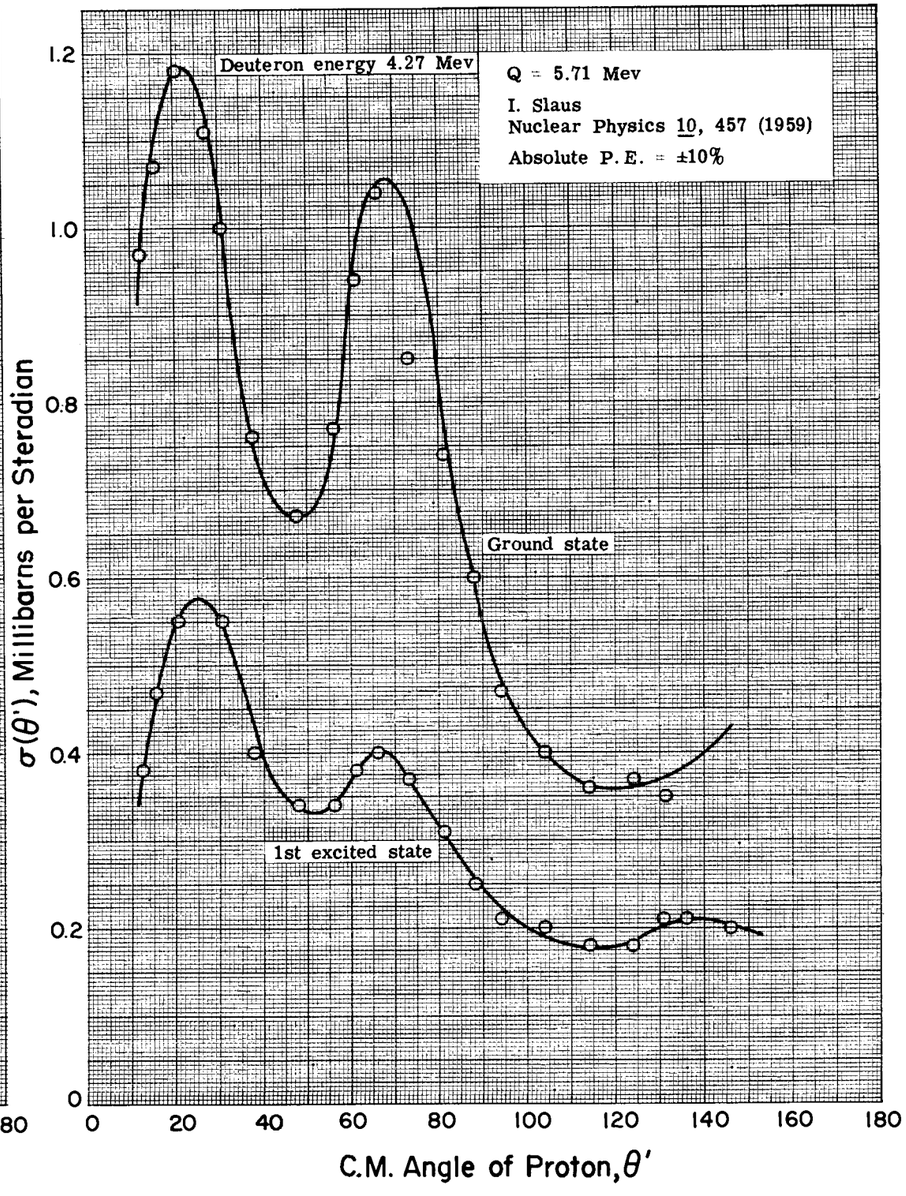

See opposite page
E_p = 7.90 Mev
E_p = 9.95 Mev
E_p = 12.0 Mev
□ E_p = 14.3 Mev
△ E_p = 14.1 Mev
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'

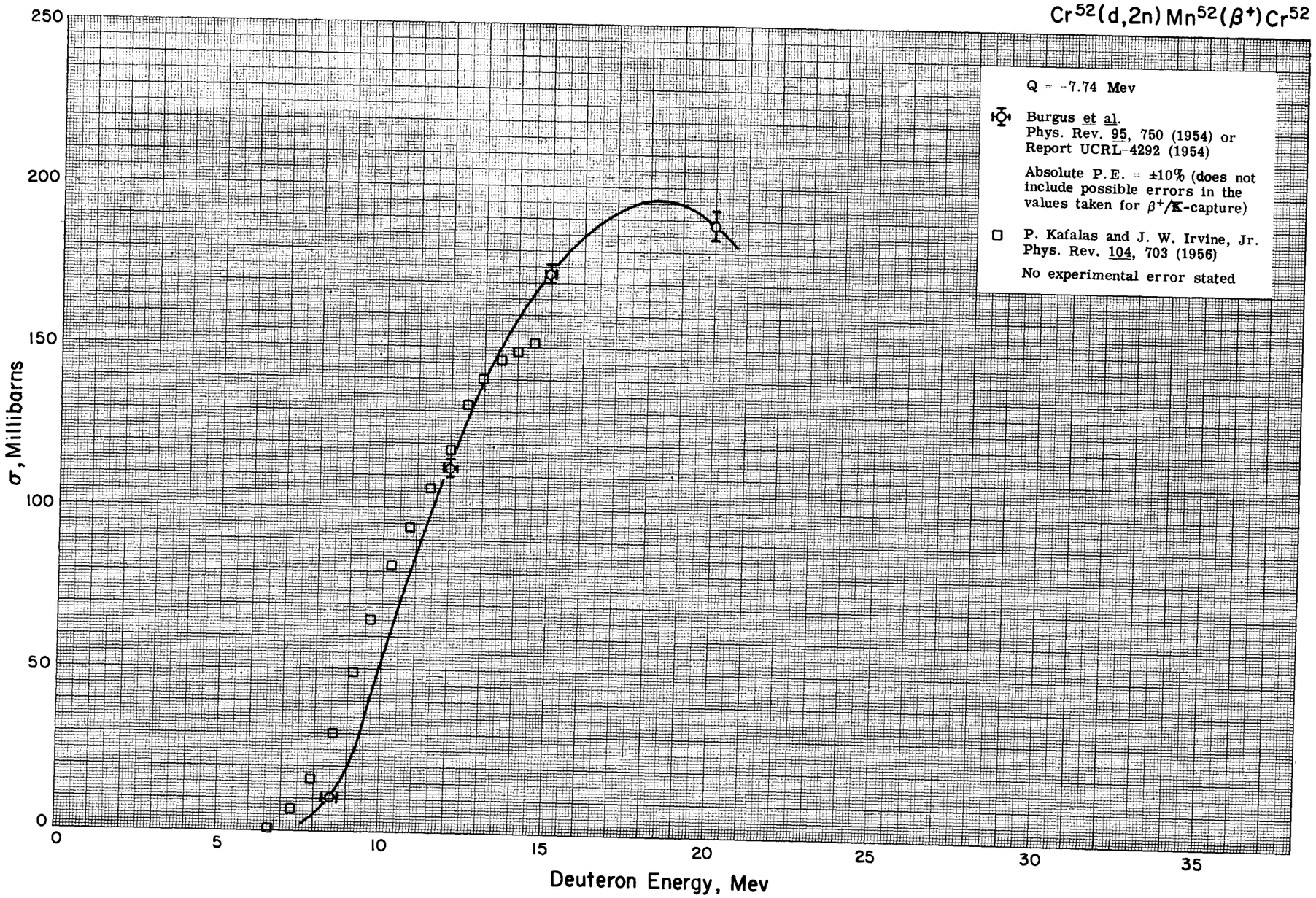

Lab angle θ = 20°
Ground State
1st excited state
Note suppressed zero
σ (20°), Millibarns per Steradian
Deuteron Energy, Mev
2.0
1.5
1.0
0.5
0
3.2
3.6
4.0
4.4

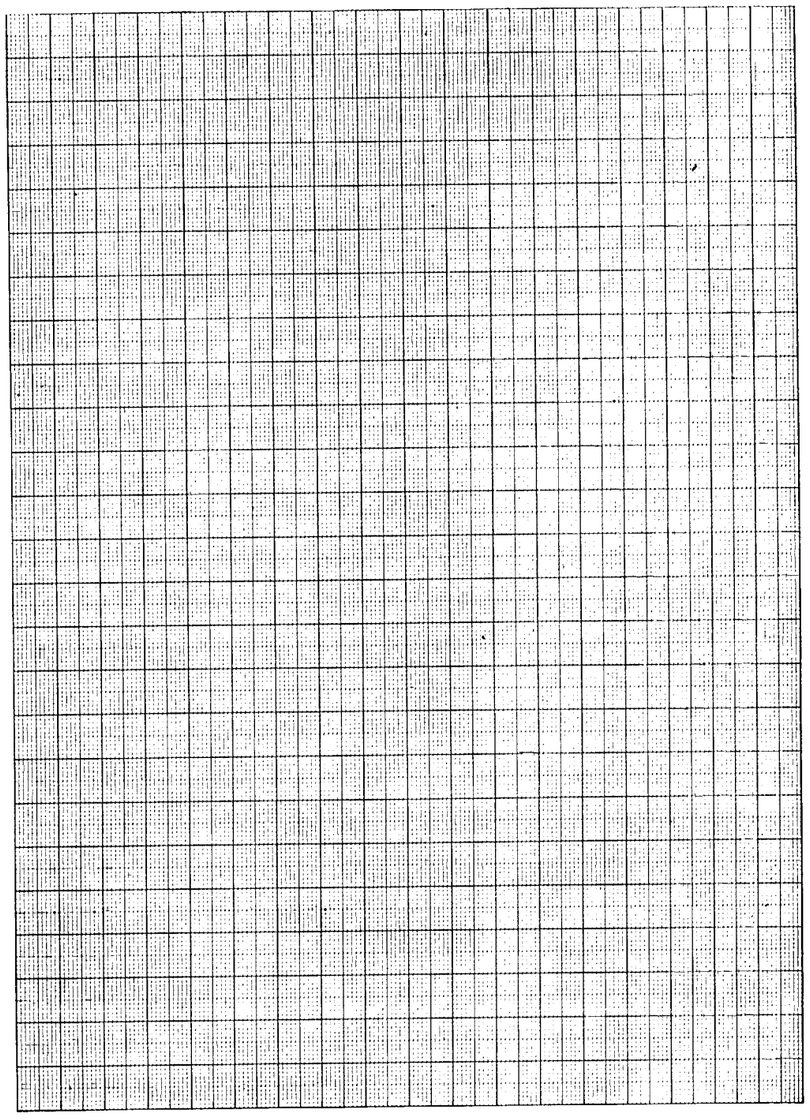
$Cr^{52}(d,p')Cr^{53*}$

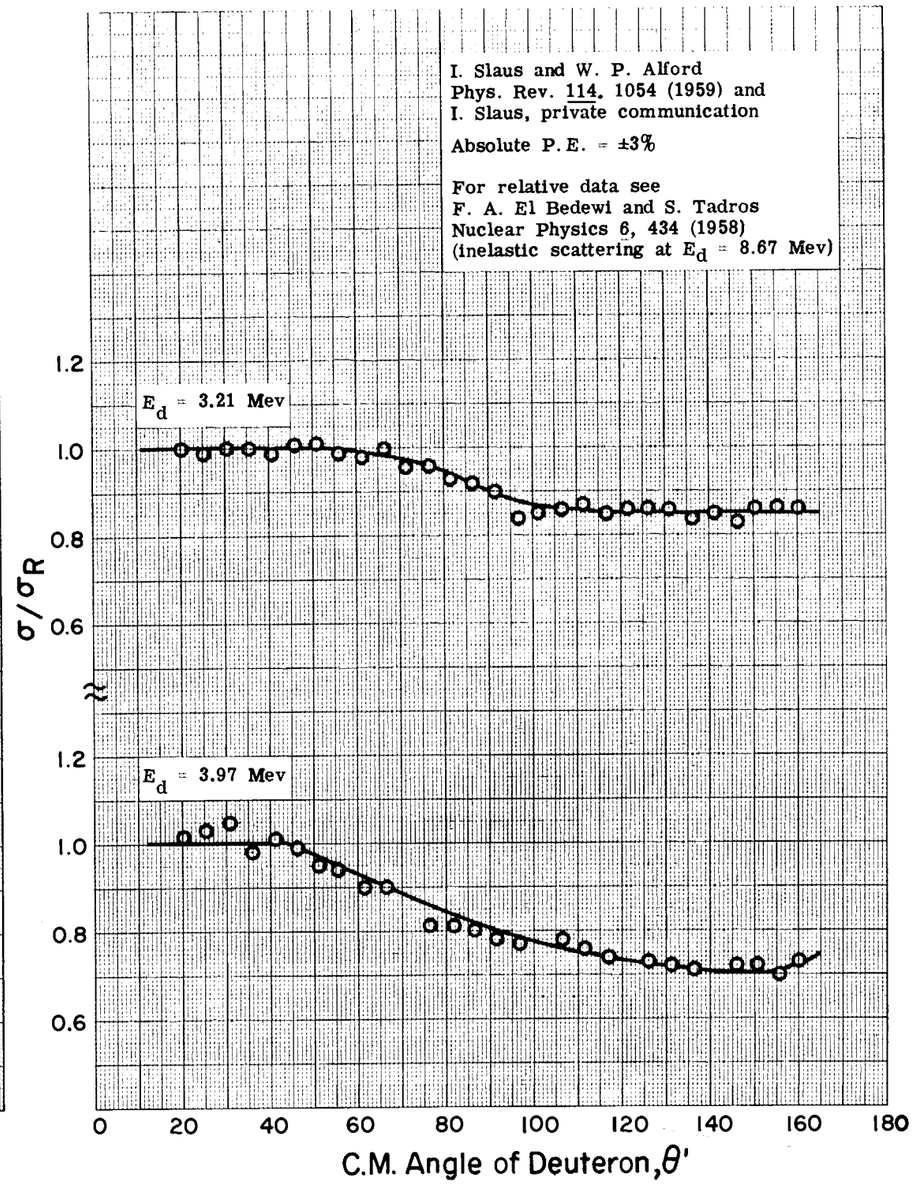

Deuteron energy 3.29 Mev
Q = 5.71 Mev
I. Slaus
Nuclear Physics 10, 457 (1959)
Absolute P.E. = ±10%
Ground state
1st excited state
See also
R. D. Evans and M. S. Livingston
MIT-LNS Progress Report, Nov. 30, 1952
(Report AECU-2347)
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0.5
0.4
0.3
0.2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


Deuteron energy 4.07 Mev
Ground state
1st excited state
σ(θ'), Millibarns per Steradian
C.M. Angle of Proton, θ'
0
0.2
0.4
0.6
0.8
1.0
1.2
0
20
40
60
80
100
120
140
160
180


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'
0
0.2
0.4
0.6
0.8
1.0
1.2
0
20
40
60
80
100
120
140
160
180


$Cr^{52}(d,2n)Mn^{52}(\beta^+)Cr^{52}$
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
0
50
100
150
200
250
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/σ_R
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.

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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			95	3.3839		
6	1.3328	50	3.1348	96	3.2784	140	1.2826
7	7.1987×10^4	51	2.9110	97	3.1782	141	1.2663
8	4.2239	52	2.7080	98	3.0822	142	1.2511
9	2.6385	53	2.5230	99	2.9911	143	1.2365
		54	2.3541			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			105	2.5245		
16	2.6655	60	1.6000	106	2.4579	150	1.1489
17	2.0951	61	1.5071	107	2.3949	151	1.1382
18	1.6699	62	1.4211	108	2.3346	152	1.1281
19	1.3476	63	1.3418	109	2.2762	153	1.1185
		64	1.2682			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			115	1.9765		
26	3.9052	70	9.2382	116	1.9335	160	1.0630
27	3.3673	71	8.7950	117	1.8919	161	1.0568
28	2.9195	72	8.3777	118	1.8522	162	1.0509
29	2.5444	73	7.9887	119	1.8144	163	1.0451
		74	7.6226			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			125	1.6155		
36	1.0967	80	5.8574	126	1.5865	170	1.0153
37	9.8644×10^1	81	5.6216	127	1.5590	171	1.0125
38	8.9014	82	5.3986	128	1.5323	172	1.0096
39	8.0537	83	5.1882	129	1.5066	173	1.0076
		84	4.9887			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
   Gives fully relativistic equations for scattering and for collision with creation of new particles.

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)
   Gives a nomograph for relativistic elastic scattering.

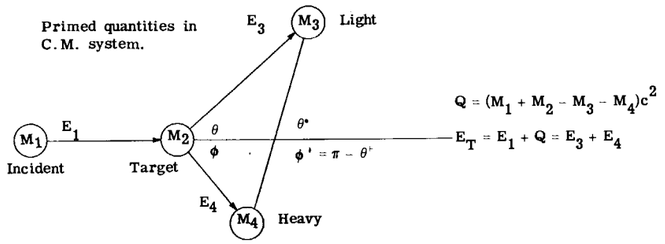
6. F. J. M. Farley, Nucleonics 12, No. 10, 56 (1954), and erratum, Nucleonics 13, No. 7, 67, (1955)
   Source of the nomogram for reaction calculations included in this compilation. Useful for rough preliminary calculations.

7. E. S. Shire, J. Sci. Instr. 32, 391 (1955)
   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



Define:

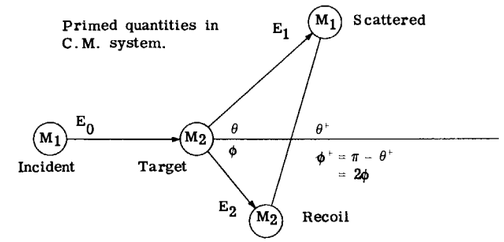
$$A_{14} = \frac{M_1 M_4 (E_1/E_T)}{(M_1 + M_2)(M_3 + M_4)}, \qquad A_{23} = \frac{M_2 M_3}{(M_1 + M_2)(M_3 + M_4)} \left(1 + \frac{M_1}{M_2}\frac{Q}{E_T}\right) = \frac{E_4'}{E_T}$$

$$A_{13} = \frac{M_1 M_3 (E_1/E_T)}{(M_1 + M_2)(M_3 + M_4)}, \qquad A_{24} = \frac{M_2 M_4}{(M_1 + M_2)(M_3 + M_4)} \left(1 + \frac{M_1}{M_2}\frac{Q}{E_T}\right) = \frac{E_3'}{E_T}$$

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:	$\sin\phi = \left(\frac{M_3 E_3}{M_4 E_4}\right)^{\frac{1}{2}} \sin\theta$	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:

$$E_1' = \frac{M_2^2}{(M_1 + M_2)^2} E_0$$

$$E_2' = \frac{M_1 M_2}{(M_1 + M_2)^2} E_0$$

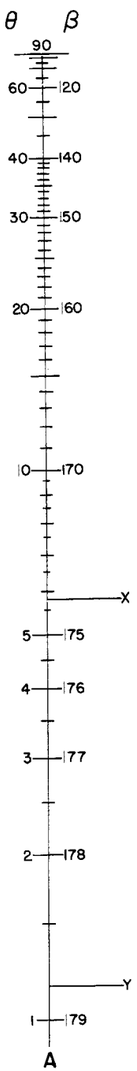
Lab energy of the scattered particle:	$\frac{E_1}{E_0} = 1 - \frac{2M_1M_2}{(M_1 + M_2)^2}(1 - \cos\theta') = \frac{M_1^2}{(M_1 + M_2)^2}\left\{\cos\theta \pm \left[(M_2/M_1)^2 - \sin^2\theta\right]^{\frac{1}{2}}\right\}^2$	Use only plus sign unless $M_1 > M_2$, in which case $\theta_{max} = \sin^{-1}(M_2/M_1)$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

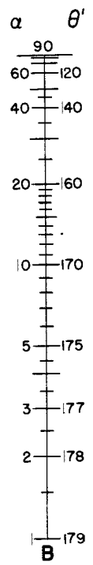
NUCLEAR REACTION NOMOGRAM

Nuclear Reaction Nomogram

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

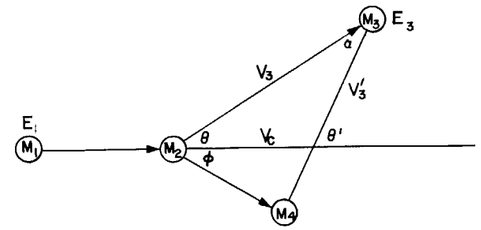
This nomogram is based upon the version given in the reference, but with the scales correctly spaced and the notation changed to that adopted in this compilation.





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 $M_1 + M_2 = M_3 + M_4 = M$.

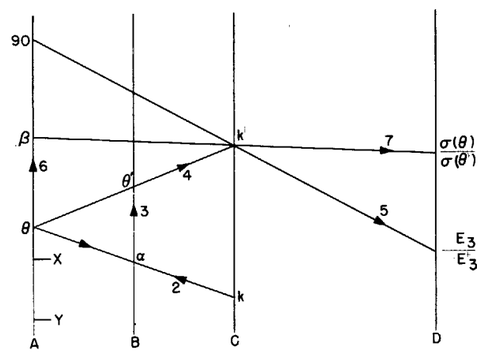
1. Calculate $k = V_c/V_3' = (M_1 M_3 E_1/M^2 E_3')^{1/2}$

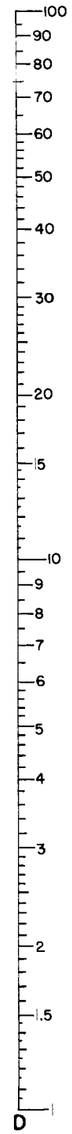
   where $E_3' = \left(Q + \frac{M_2}{M} E_1\right)\frac{M_4}{M}$

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° on scale A, and read $E_3/E_3' = k'^2$ on scale D.
6. Locate $\beta = 90^\circ - \alpha$ 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 $\alpha = 90^\circ$ on scale B.





$\frac{\sigma(\theta)}{\sigma(\theta')}$, $\frac{E_3}{E_3'}$