KERNFORSCHUNGSZENTRUM
KARLSRUHE

JUNE 1968

KFK 1000
EUR 3963 e
EANDC (E)-111 "U"

INSTITUT FÜR ANGEWANDTE KERNPHYSIK

HIGH RESOLUTION TOTAL NEUTRON CROSS-SECTIONS BETWEEN 0.5 - 30 MeV

S. Cierjacks, P. Forti, D. Kopsch, L. Kropp, J. Nebe, H. Unseld

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Work performed within the association in the field of fast reactors between the European Atomic Energy Community and Gesellschaft für Kernforschung mbH, Karlsruhe

Introduction

This report entitled

'High Resolution Total Neutron Cross Sections between 0.5 - 30 MeV'

is published in one and the same edition as an external report of the Kernforschungszentrum Karlsruhe, as an Euratom-report and as an EANDC-report under the reference numbers KFK 1000, EUR 3963 e and EANDC (E)-111 "U" respectively.

The book is a compilation of experimental results taken with the large neutron spectrometer of the Institut für Angewandte Kernphysik of the Kernforschungszentrum Karlsruhe. It is published to be of use to nuclear and reactor physicists interested in total neutron cross sections and in particular to those concerned with the behavior of fast neutrons in nuclear reactors and in neutron shields. The presentation of experimental information in this report is graphical only. Numerical values of the data included in this report are available on request from the ENEA Neutron Data-Compilation Centre, 91 Gif-sur-Yvette B.P. 9.

At the time of edition cross section data of the following nine elements C, O, Na, Al, S, Ca, Fe, Tl and Bi are available. In addition to these results the compilation will be supplemented with any further data on atomic and isotopic total neutron cross sections to be measured with the same facility. To facilitate the completion of this compilation the kind of this report is of 'ring-book' type. So any further data can be added easily.

The high resolution total neutron cross sections were measured using the fast neutron time-of-flight facility at the Karlsruhe isochronous cyclotron, described elsewhere[1]. Neutron production was achieved by (d,nx) reactions in a thick natural uranium target by bombardment of 45 ± 5 MeV deuterons from the internal beam of the cyclotron. Bursts of high energy deuterons and of 1 nsec duration yield a broad neutron spectrum capable to obtain useful neutron data in the energy region mentioned above. Time-of-flight assignments were made with a digital time sorter[2],[3]. Typically 2 x 8000 time channels of 1 nsec channel width were used.

By timin g the neutrons over a 57 m flight path a total resolution of the spectrometer of about 0, 03 nsec/m was obtained.
The experimental work reported here has been performed partially in the frame work of the Karlsruhe Fast Breeder Reactor Project.

Arrangement and Graphs

The arrangement of this book is as follows: Information on the various elements is placed in order of their atomic number. On the first page for each element there is a detailed description of the experimental conditions, e.g. sample thickness, purity of the material, accurate length of the flight path, time resolution, isotopic abundance etc.. The following two pages show a survey presentation on a double-logarithmic scale to give a rough information about the mean behaviour of the excitation function. The succeeding pages contain a detailed display of the data on a linear scale with the exception of some regions with a smooth energy dependence. The arrangement of the plots is in order of increasing energy.

The absolute total cross section in barn is plotted as a function of the incident neutron energy in MeV. Both the double-logarithmic and the linear representation of the data are plotted on close-meshed grids for ease of reading off the cross section as well as the energy values. In the detailed linear representation a curve is drawn through the data on each of the graphs. The curve is merely our own idea of a reasonable fit to the data; it serves as an 'eye-guide' only.

The data are presented as clear and uniform a manner as was consistent with the representation of the time-of-flight results on a linear energy scale. To accommodate on the fact of increasing resolution with decreasing energy the total energy range was divided for all elements uniformly into the following subintervals: 0.5-0.6, 0.6-0.7, 0.7-0.9, 0.9-1.2, 1.2-1.5, 1.5-2.0, 2.0-3.0, 3.0-4.5, 4.5-7.0, 7.0-12, and 12-32 MeV.

In addition to the energy scale also the ordinate scale changes from one graph to the other to account for the large differences in the fluctuation amplitudes occuring over the wide range of data.
Indication for these facts are not included in the graphs, except for the case that the ordinate scale does not start at zero. This is expressed by the notation "zero suppressed".

The statistical accuracy varying with energy is indicated by conventional error bars generally shown several times in each graph. The error bars are not shown in the figures if these are smaller than the size of the open circles representing data points. In some cases the original data were smoothed with a function given by the time distribution of the γ-peak to reduce the point scatter. Those regions are characterized by special symbols.
Neither the survey nor the detailed representation of the data contain any comparison with the results from other laboratories. Because of the large amount of the actual data this would give rise to a loss of all perspective and would considerably complicate the expeditious distribution of further data.

Notation

The notation used in this report is as follows

σ_T = total cross section in barn
E_n = energy of the incident neutron in MeV (lab. syst.)
n = sample thickness in at/barn
p = chemical purity of the sample in weight percent
l = lenght of the flight path in meter
Δt = total time uncertainty of the spectrometer in nsec (FWHM of the γ-peak)
i = isotopic abundance of the sample (e.g. natural or enriched)

Acknowledgements

The authors are indebted to Prof. K.H. Beckurts for his permanent interest in the experimental program and for promoting this work. We are also grateful to all members of the cyclotron crew headed by Dr. G. Schatz and Mr. G. Schulz, especially to Mr. H. Schweickert, Mr. M. Lösel and Mr. W. Linder. We wish to thank Mr. G. Gagel for building the hardware and Mrs. D. Jenet for several computer programs used in this experiment. The help of the data handling group of our institute headed by Dr. O. Abeln and the assistance of the data processing group headed by Mr. H. Stittgen is gratefully acknowledged. The production of the tables by the Reprografie Division of the Kernforschungszentrum headed by Mr. G. Burg had been largely responsible for the representation of the data as a compilation.

References

1. S. Cierjacks, B. Duelli, P. Forti, D. Kopsch, L. Kropp, M. Lösel, J. Nebe, H. Schweickert and H. Unseld, Rev. Sci. Instr. (to be published)

2. I. De Lotto, E. Gatti and F. Vaghi, Proceedings of a Conference on Automatic Acquisition and Reduction of Nuclear Data, organized by EANDC in collaboration with Gesellschaft für Kernforschung mbH., Karlsruhe, July 1964, ed. by K.H. Beckurts, W. Gläser and G. Krüger, published by Gesellschaft für Kernforschung mbH., p. 291 (1964)

3. C. Cottini, I. De Lotto, D. Dotti, E. Gatti and F. Vaghi, Energia Nucleare Vol. 14, No. 12, 704 (1967)

C

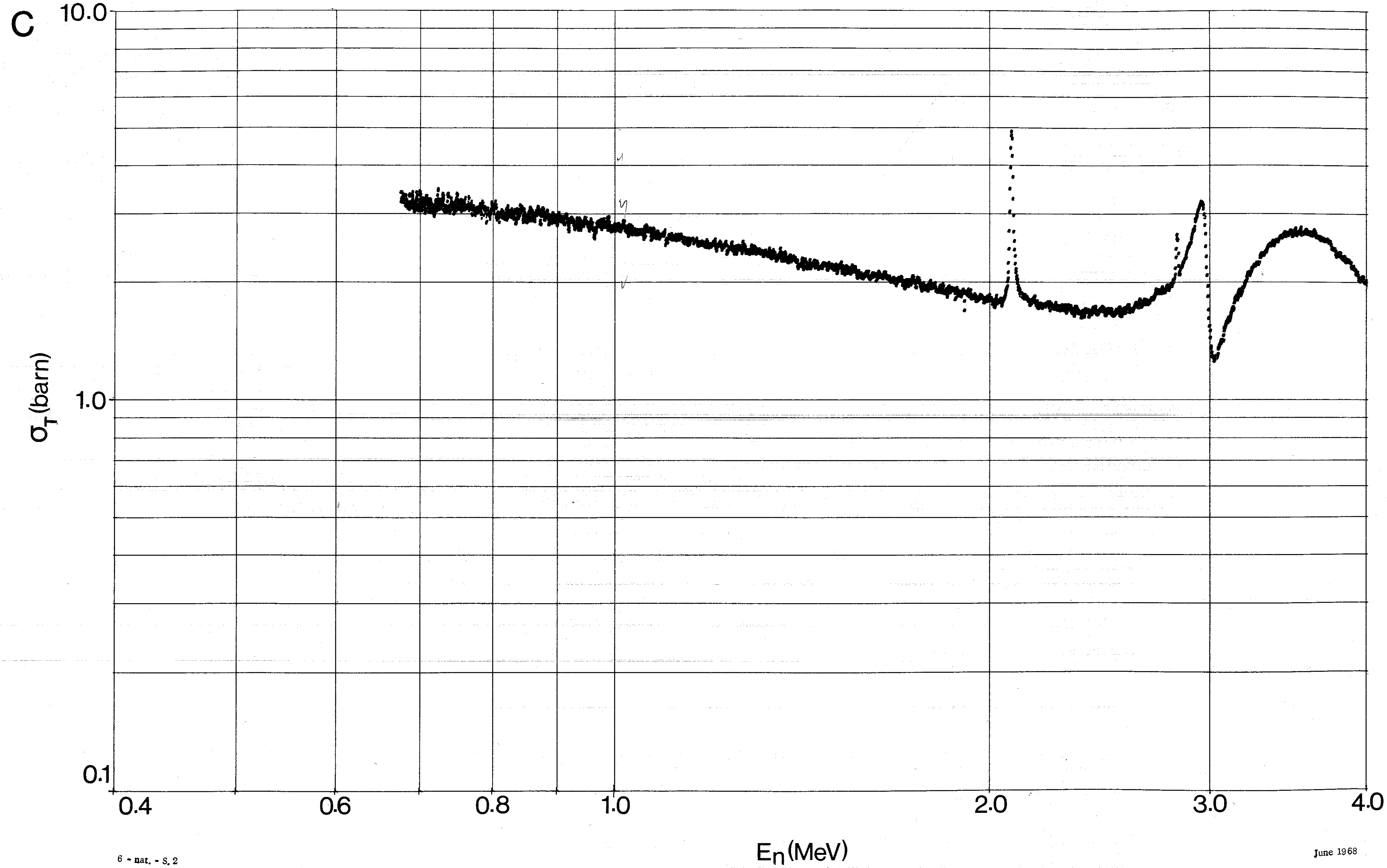
n = 0.2034 at/barn

p = 99.9998 %

l = 57.393 m

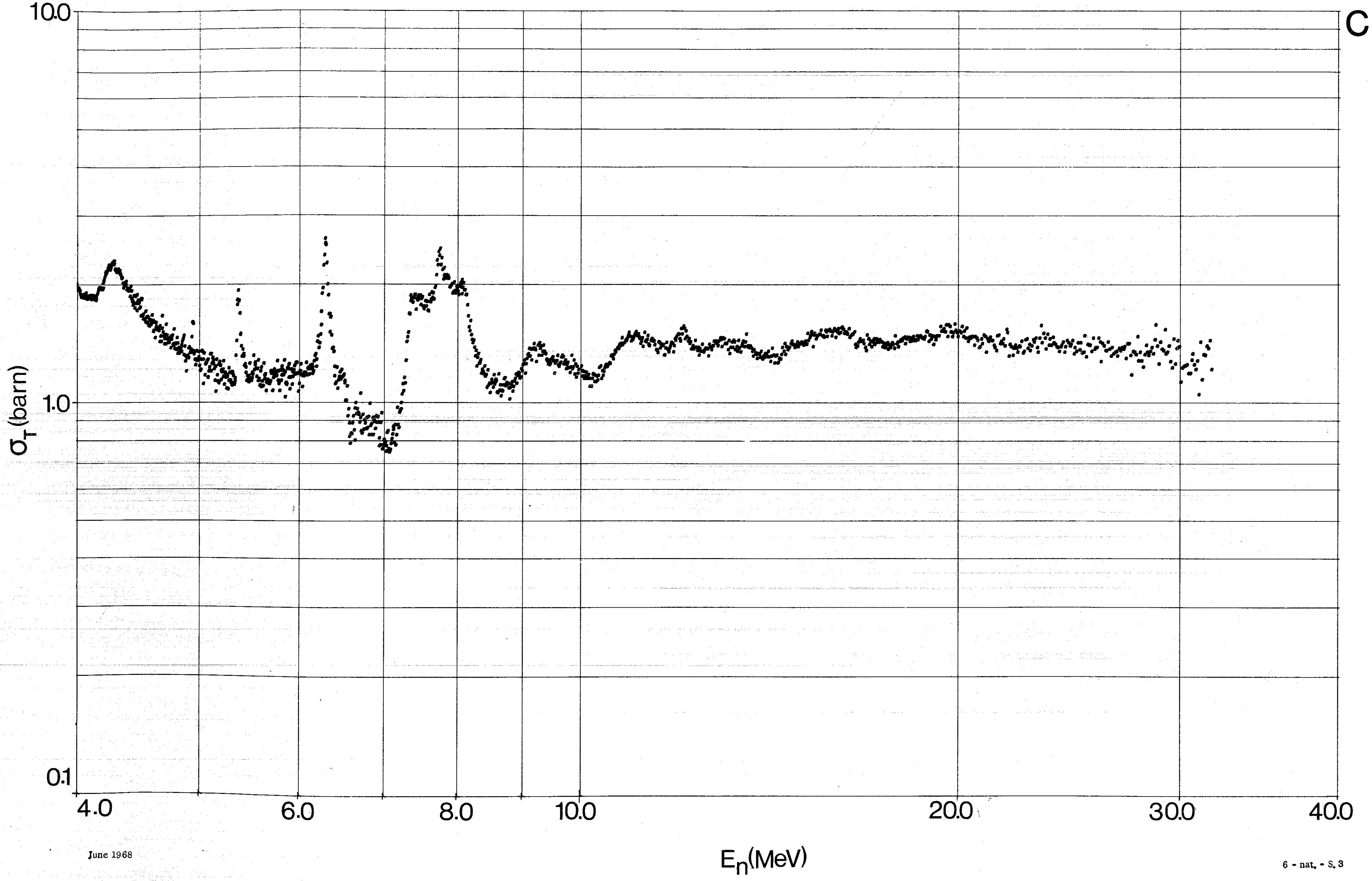
Δt = 2.5 nsec

i : natural



6 - nat. - S. 2

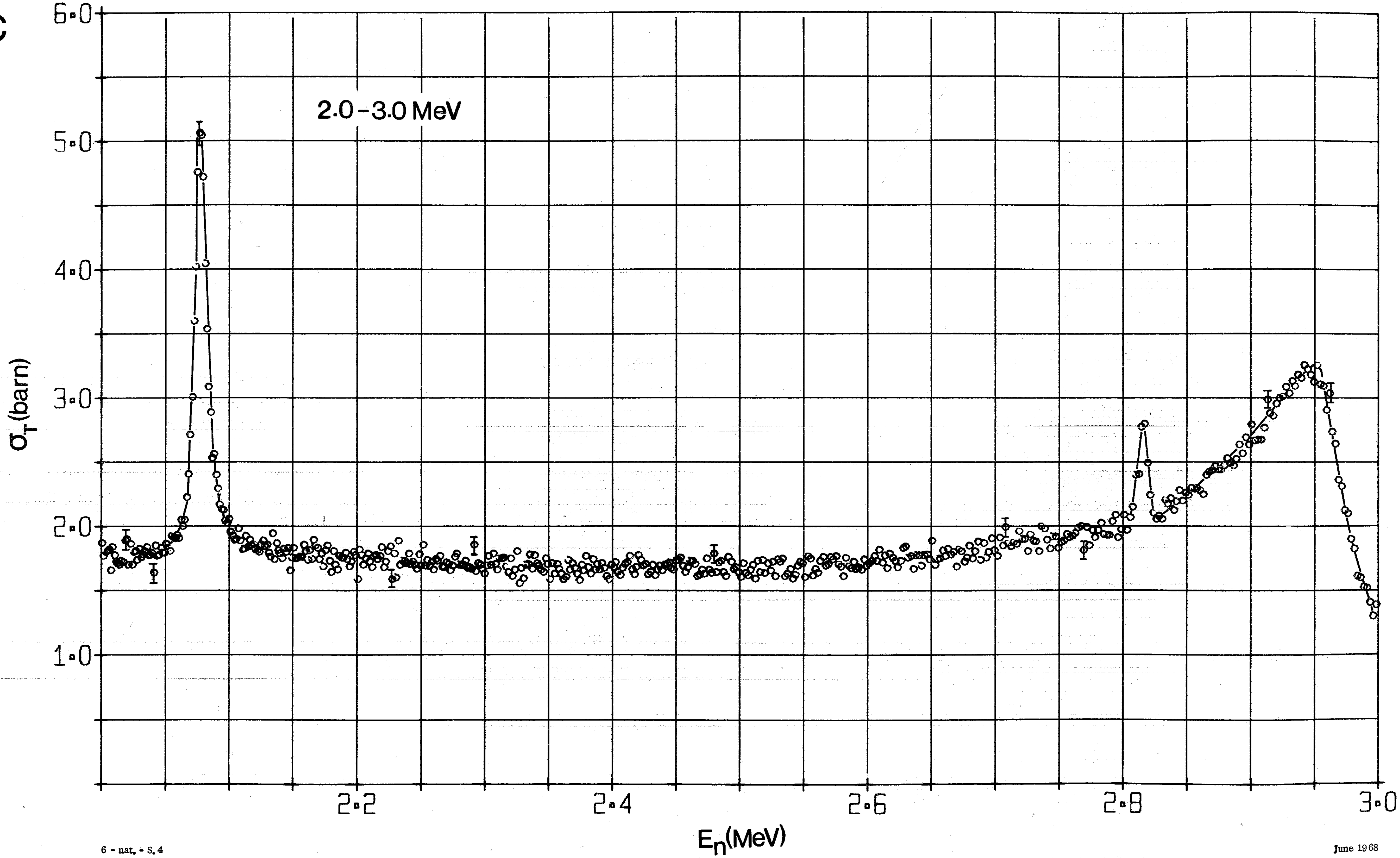
June 1968

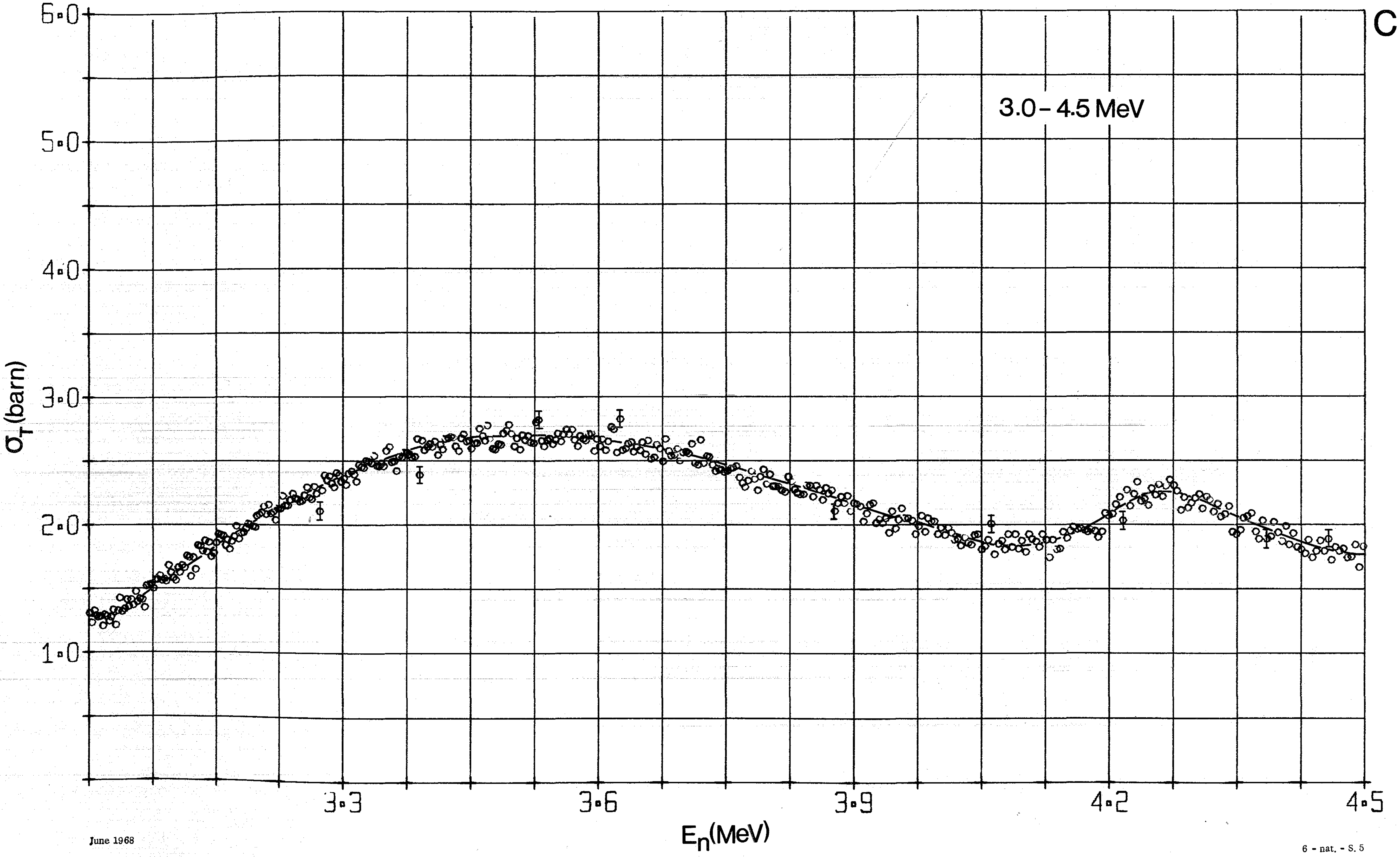


June 1968

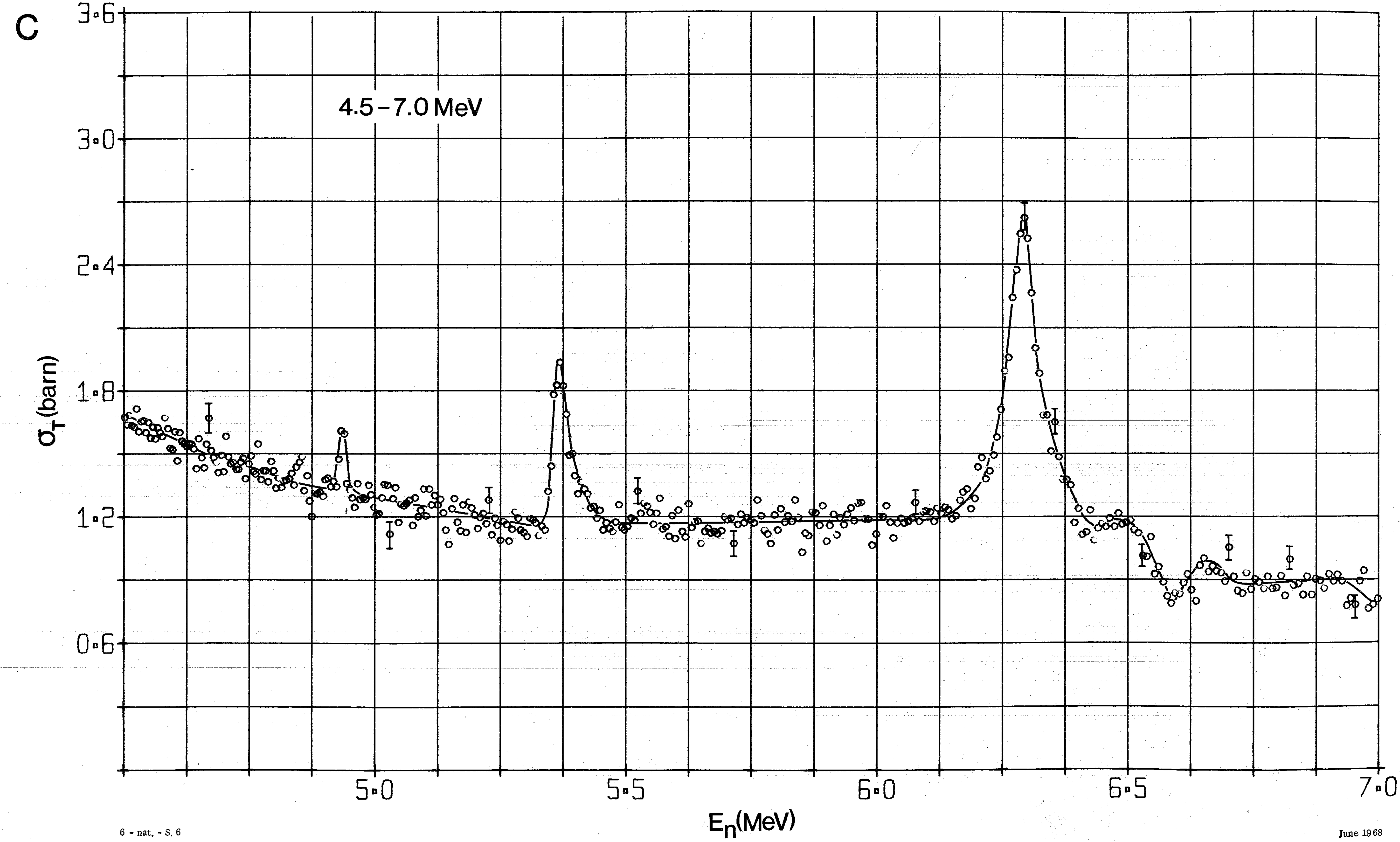
6 - nat. - S. 3

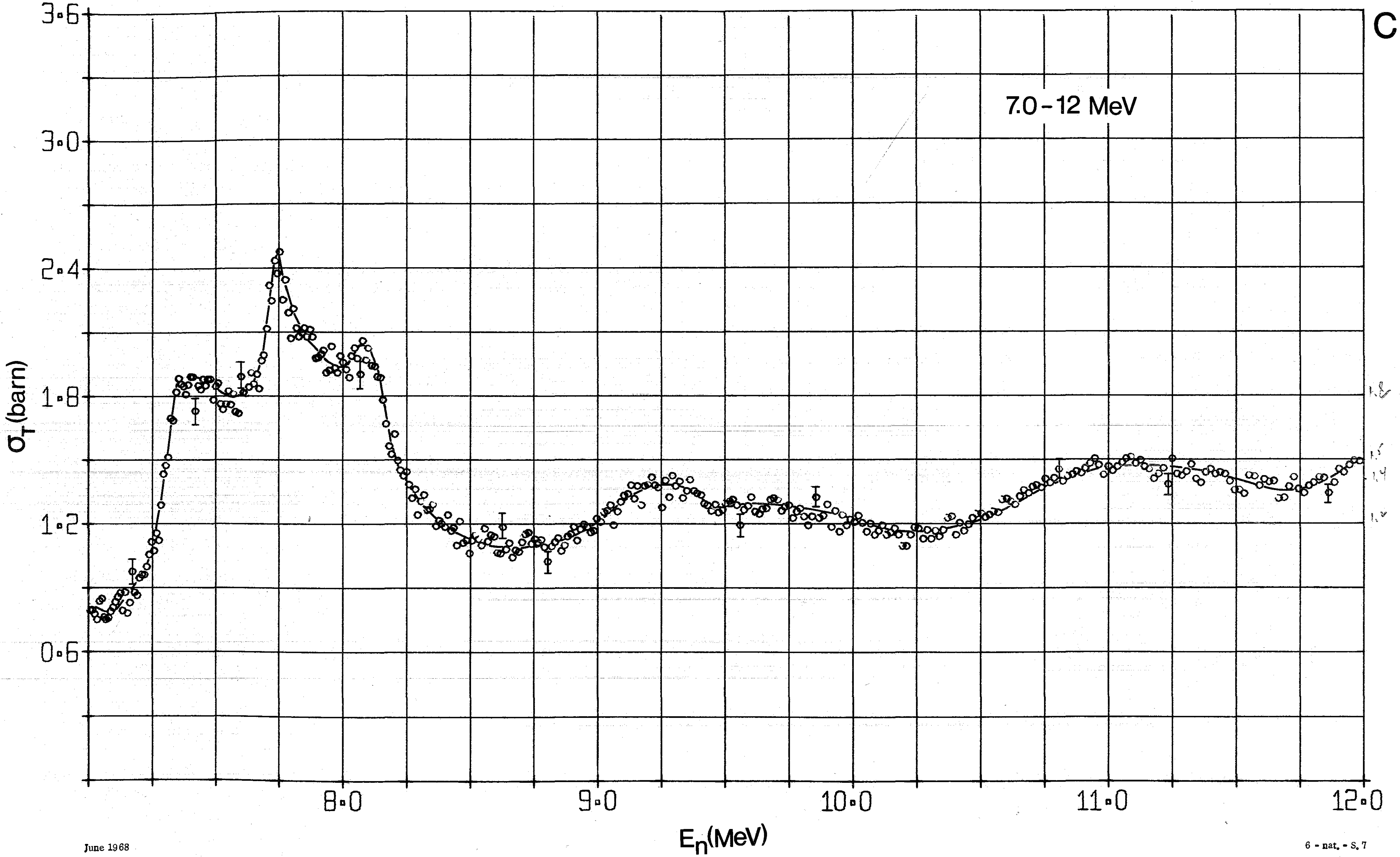
C



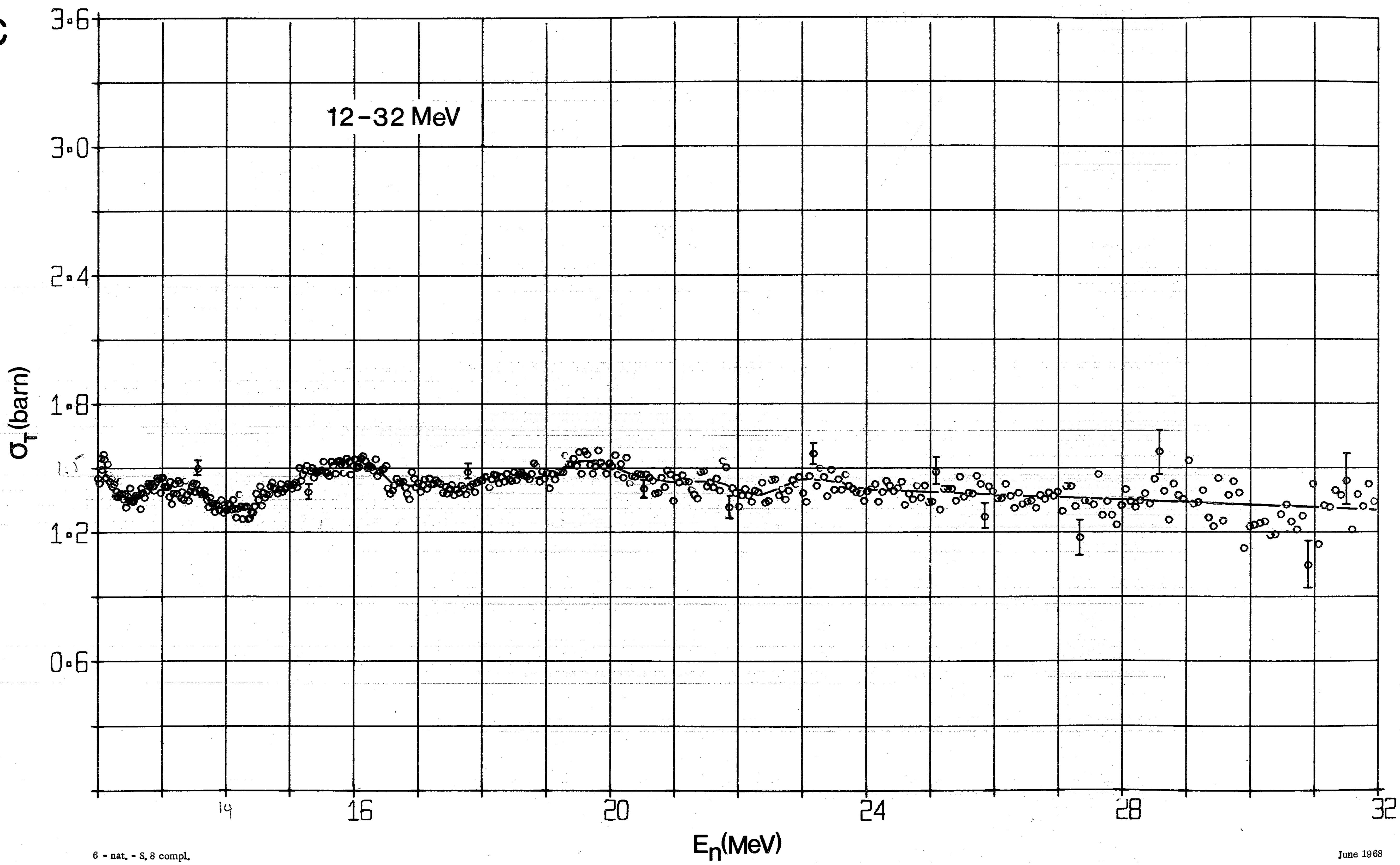


June 1968


C
4.5-7.0 MeV
3·6
3·0
2·4
1·8
1·2
0·6
σ_T (barn)
5·0
5·5
6·0
6·5
7·0
E_n(MeV)


C
7.0 - 12 MeV
3·6
3·0
2·4
1·8
1·2
0·6
σ_T (barn)
8·0
9·0
10·0
11·0
12·0
E_n(MeV)

C



6 - nat. - S. 8 compl.

June 1968

n = 0.3292 at/barn

p = 98.9 %

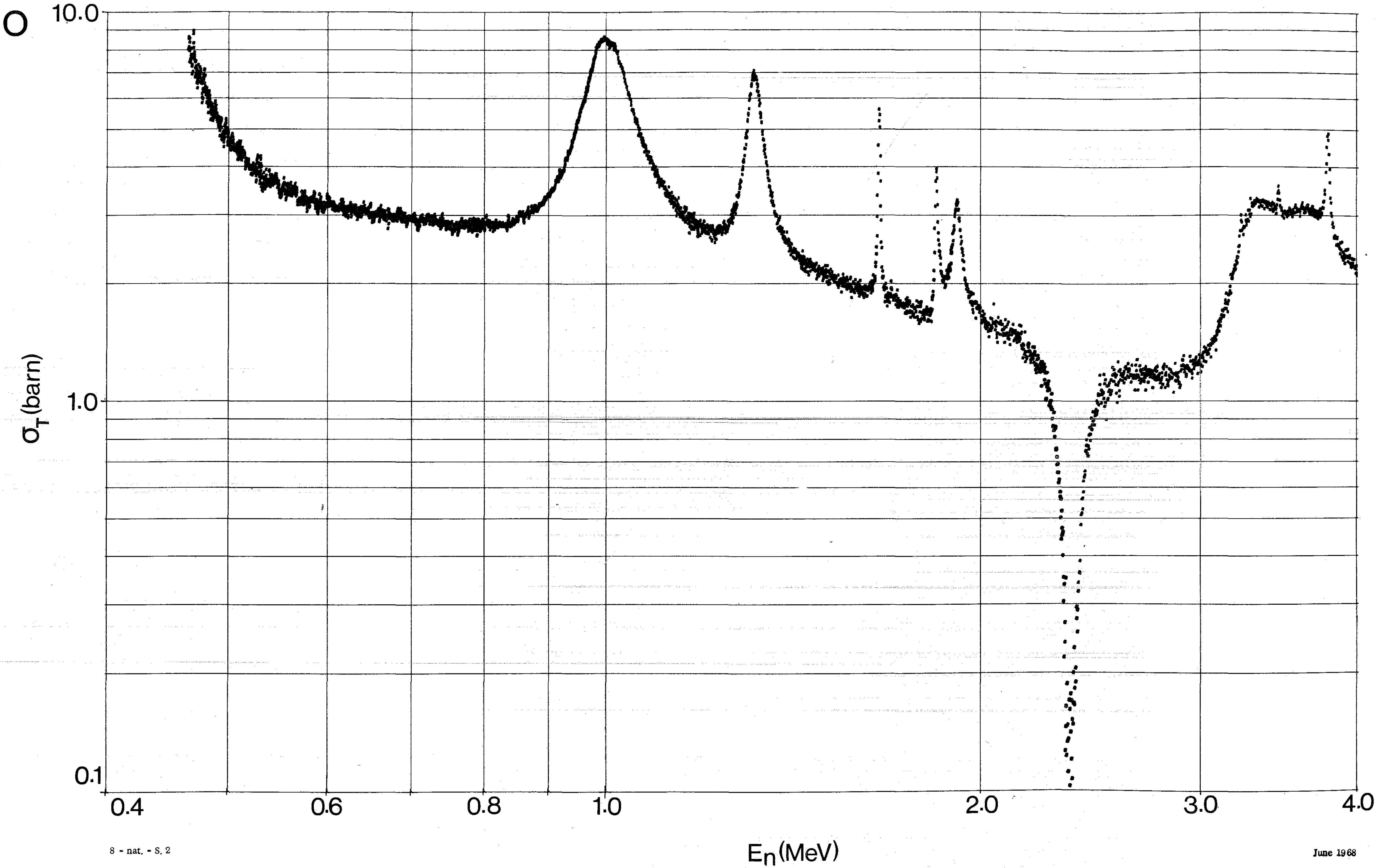
l = 57.238 m

Δt = 3.6 nsec

i : natural

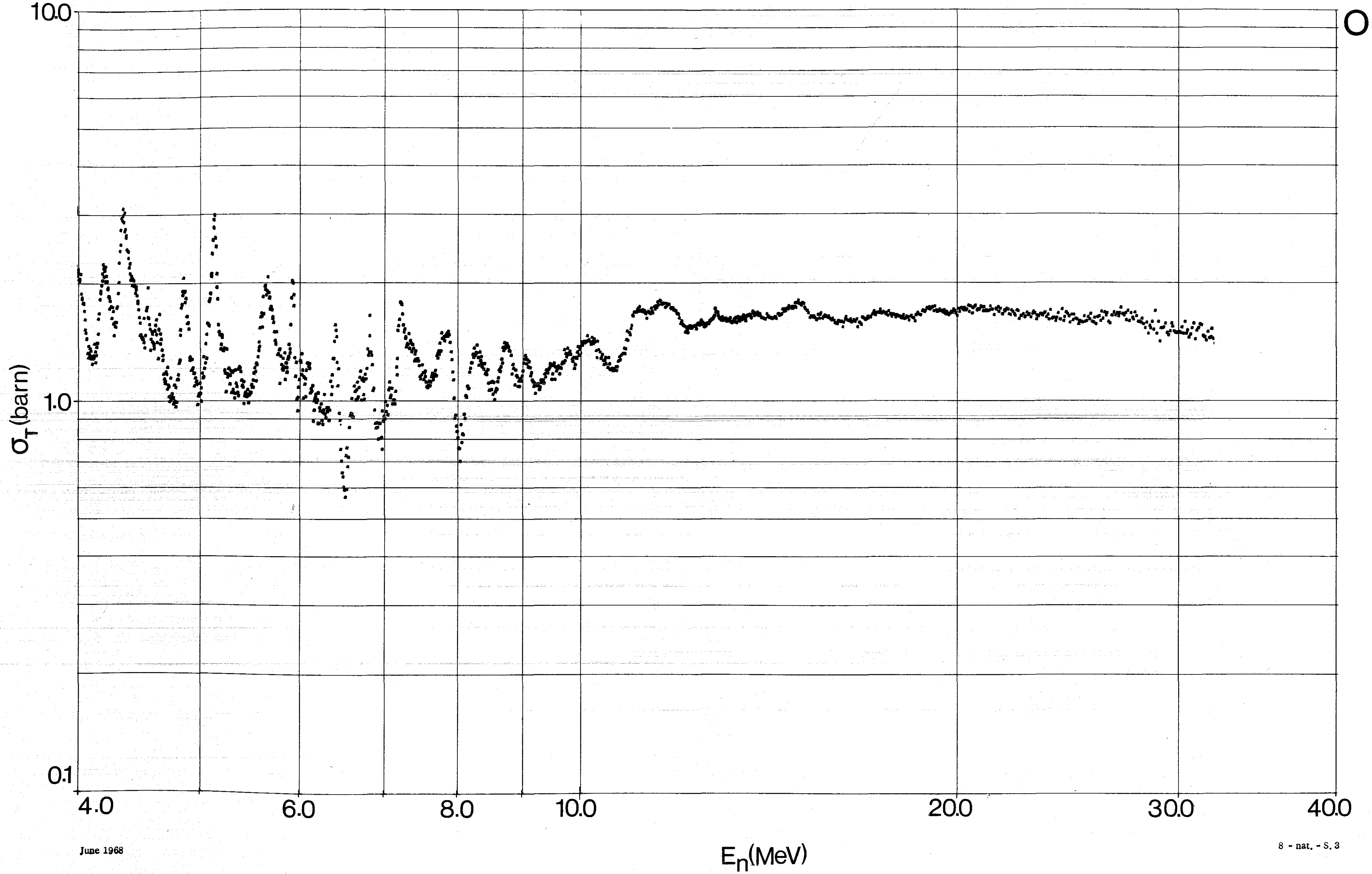
Al_2O_3 versus Al

O



8 - nat. - S. 2

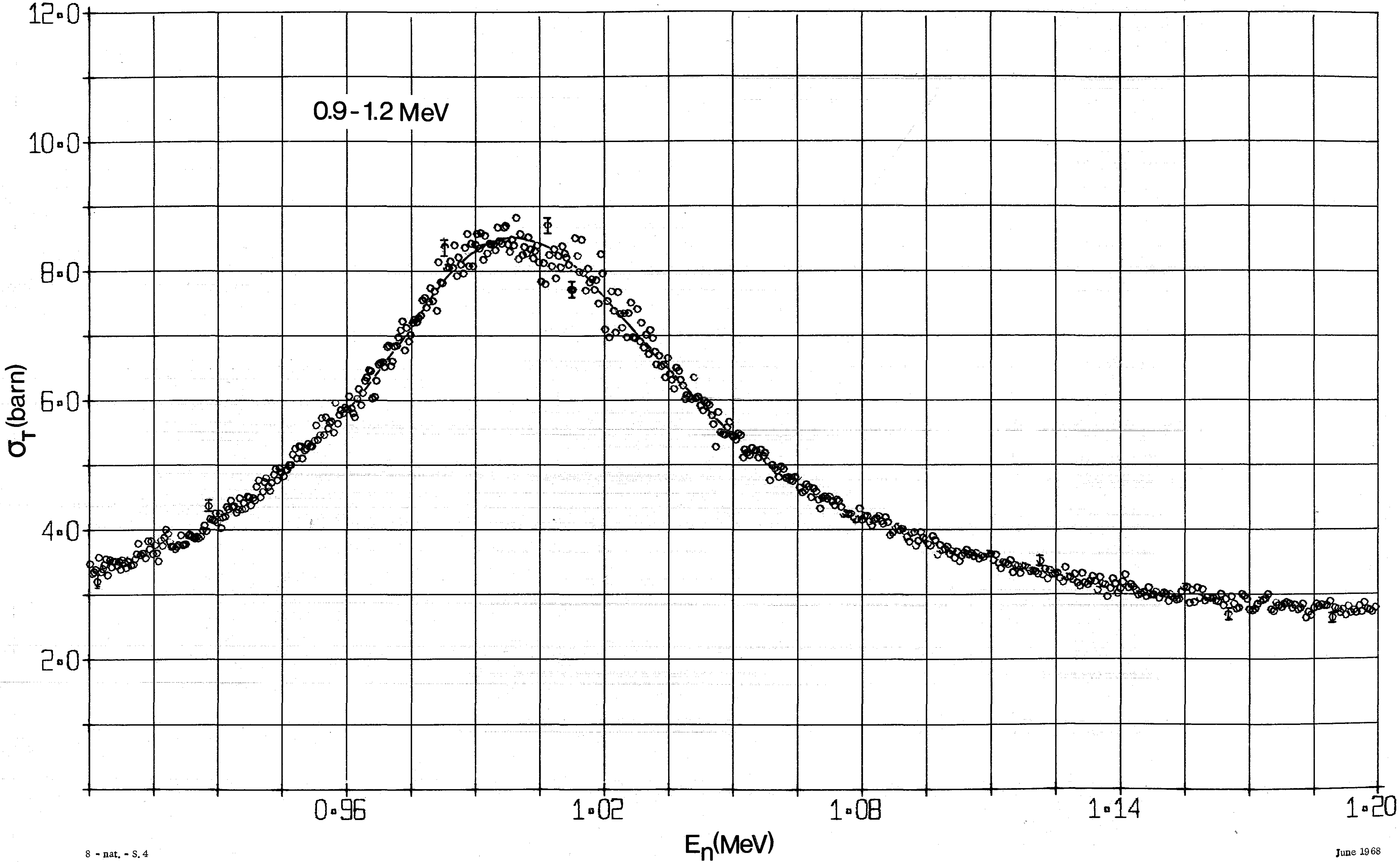
June 1968



June 1968

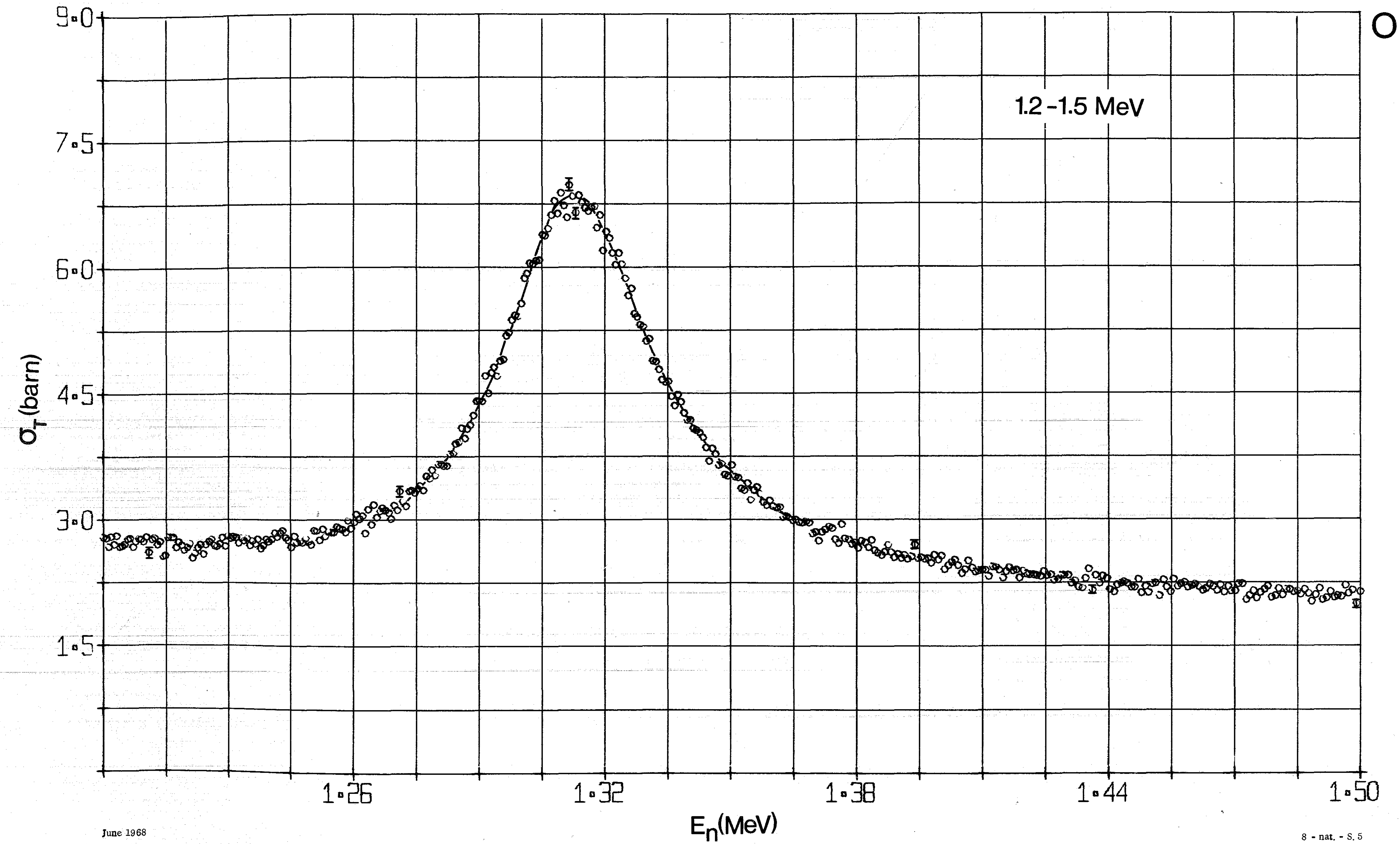
8 - nat. - S. 3

O

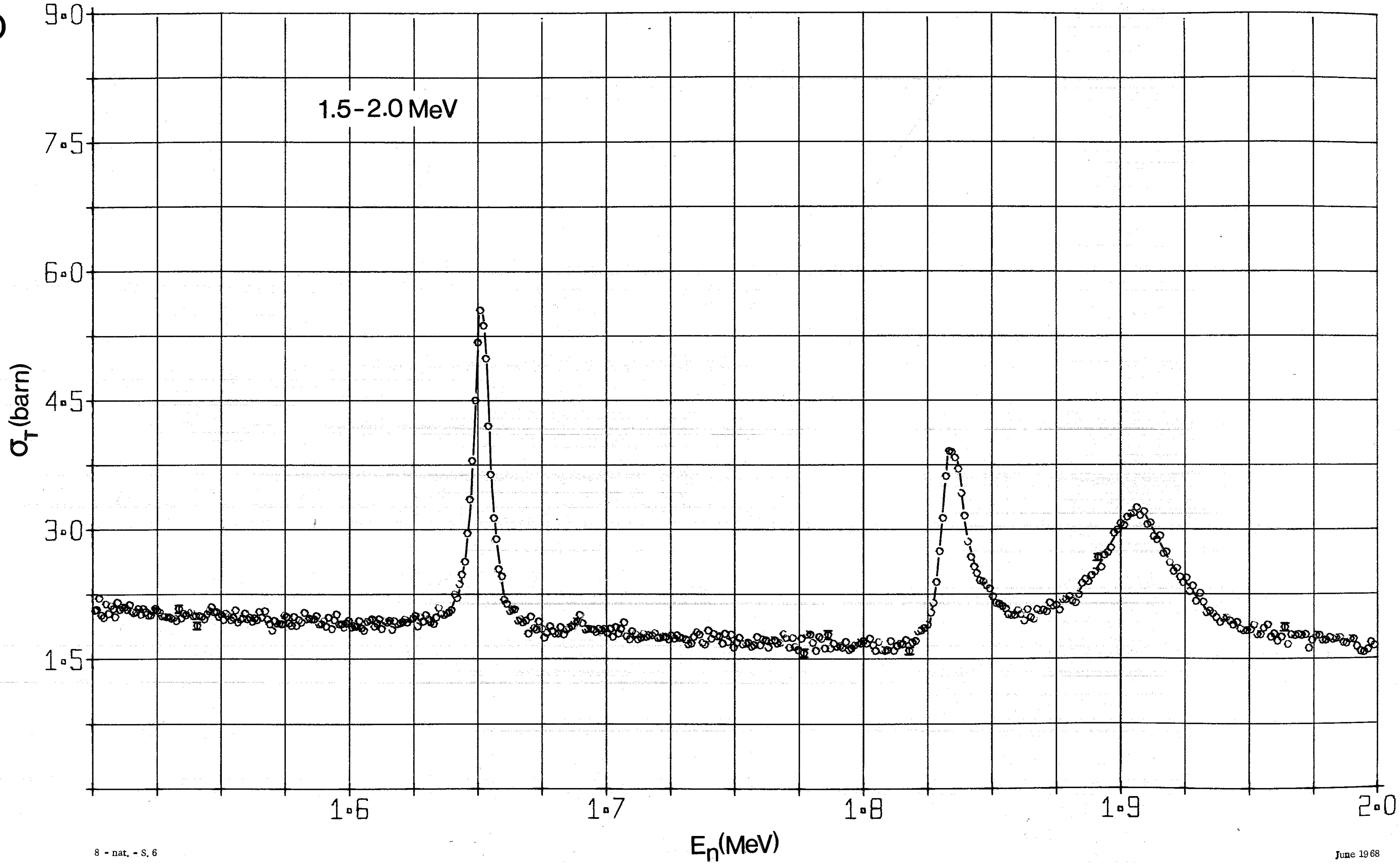


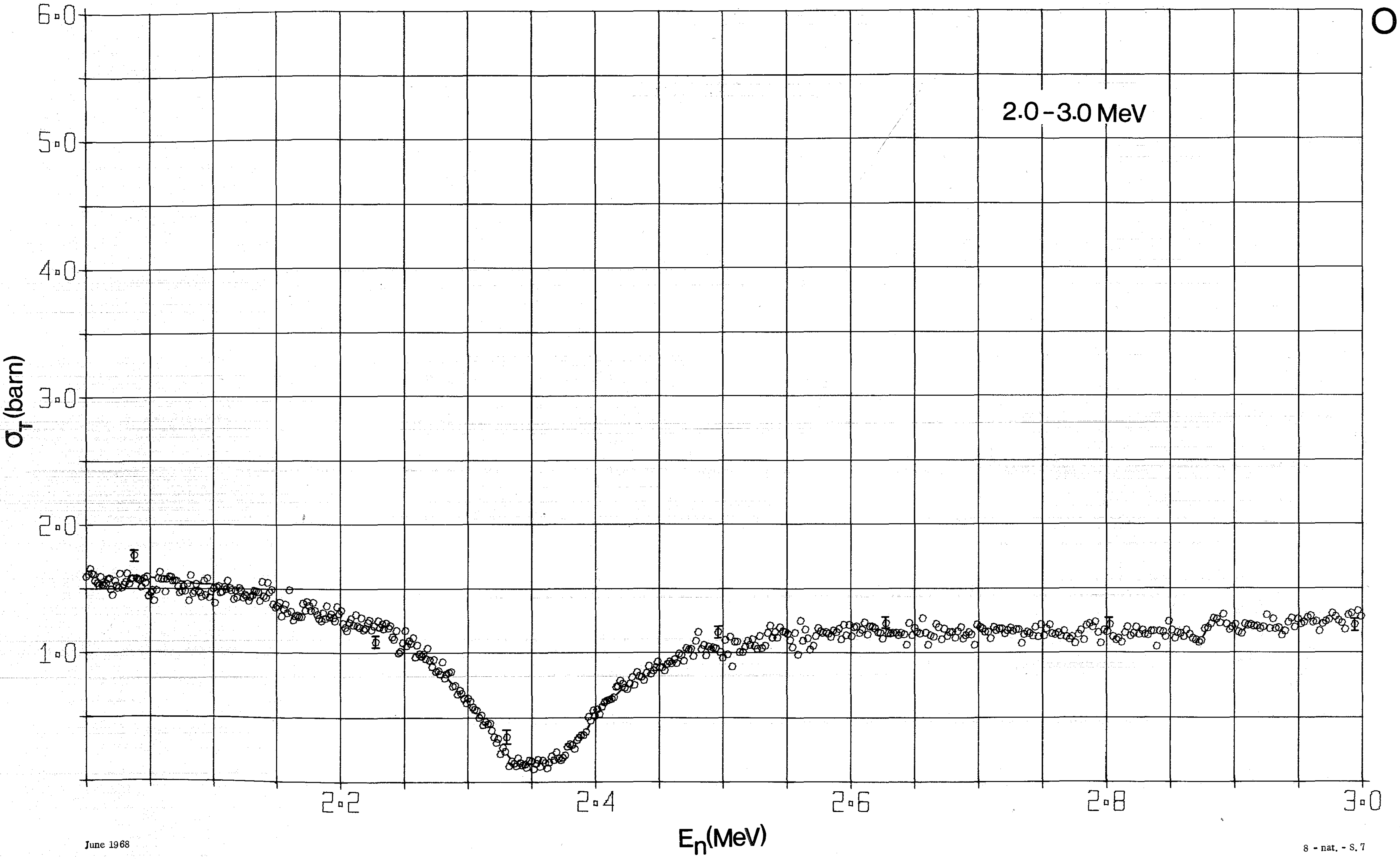
8 - nat. - S. 4

June 1968

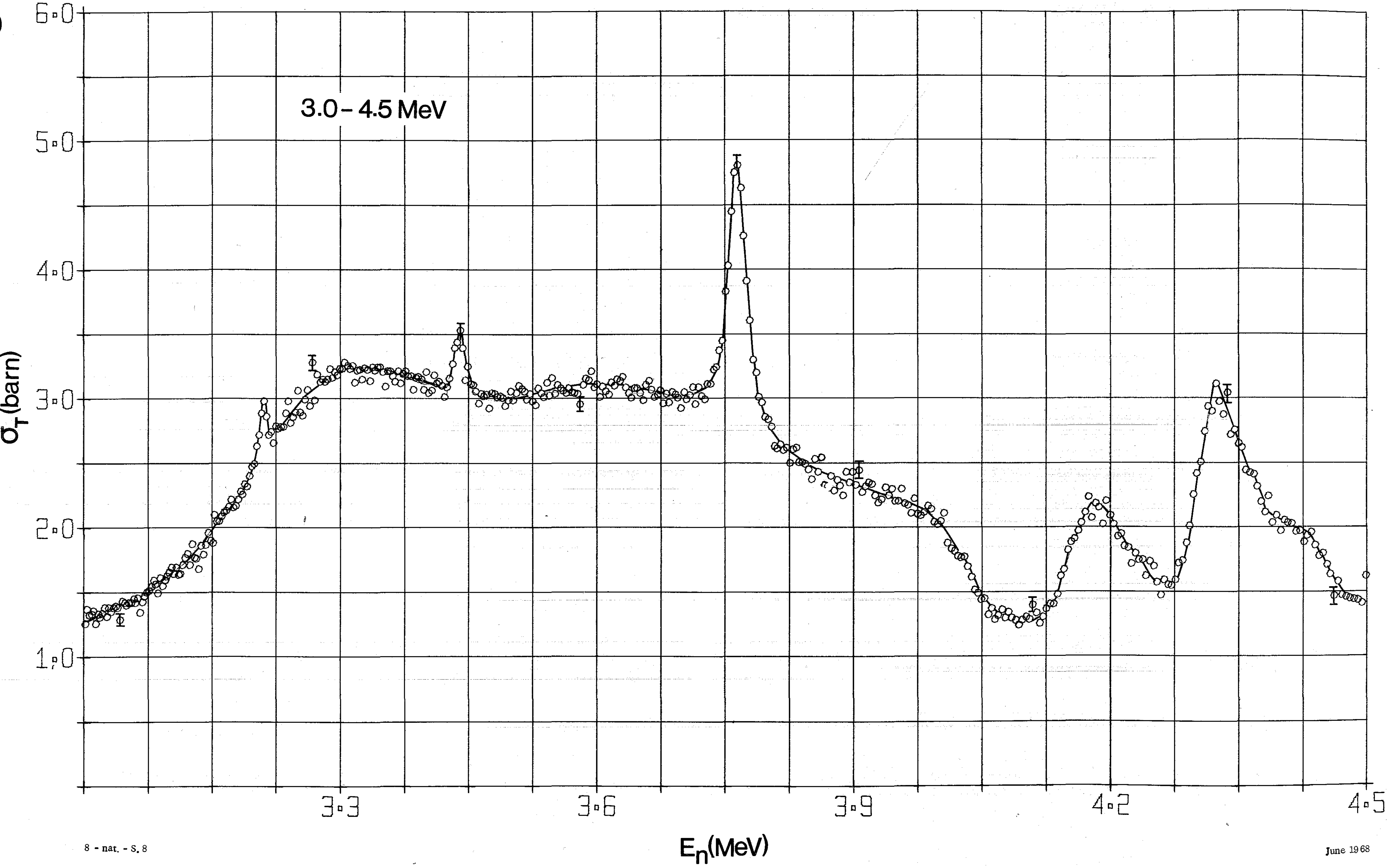

O
1.2 -1.5 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σ_T (barn)
1·26
1·32
1·38
1·44
1·50
E_n(MeV)

O



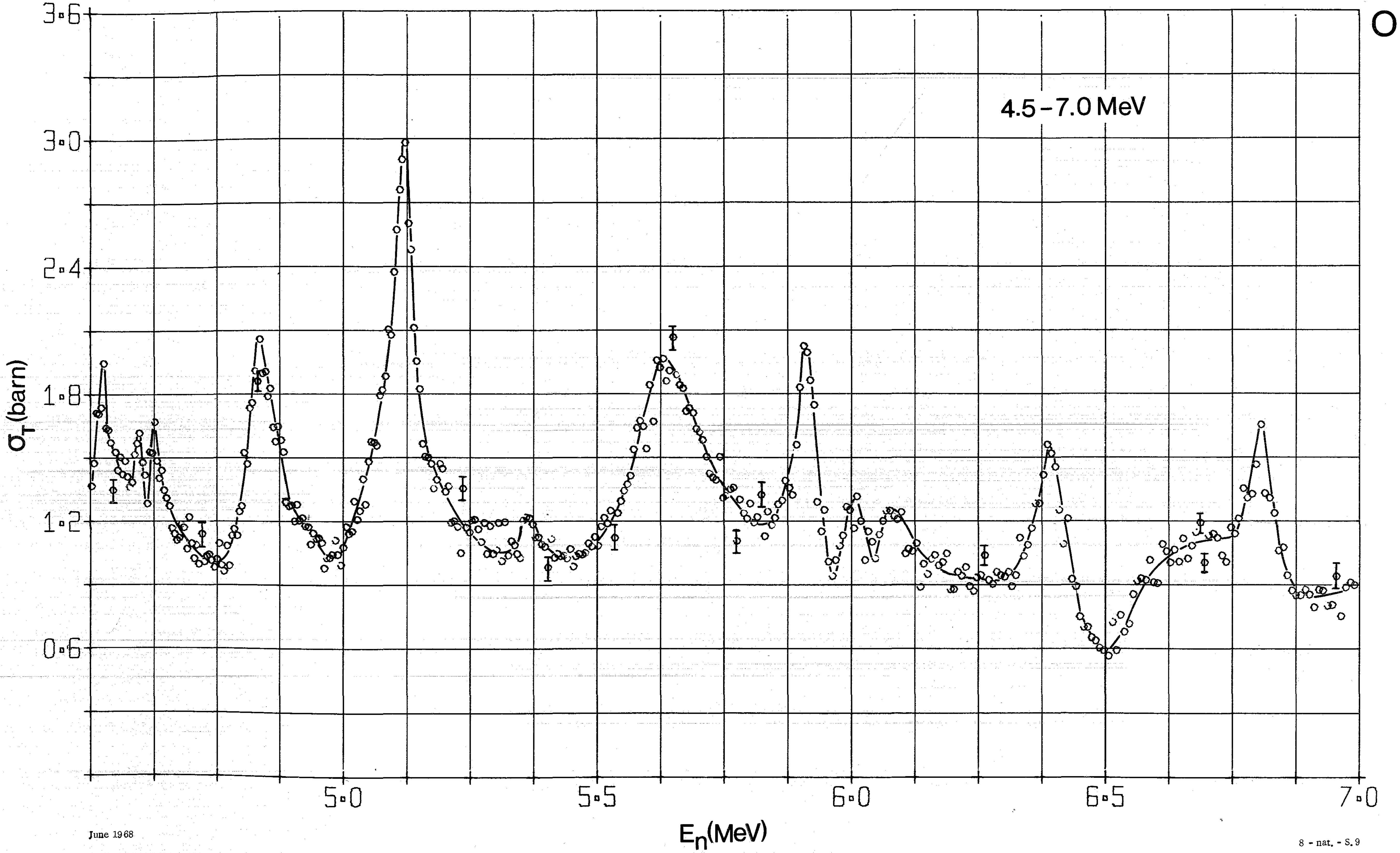

O
2.0 - 3.0 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σ_T (barn)
2·2
2·4
2·6
2·8
3·0
E_n(MeV)

O



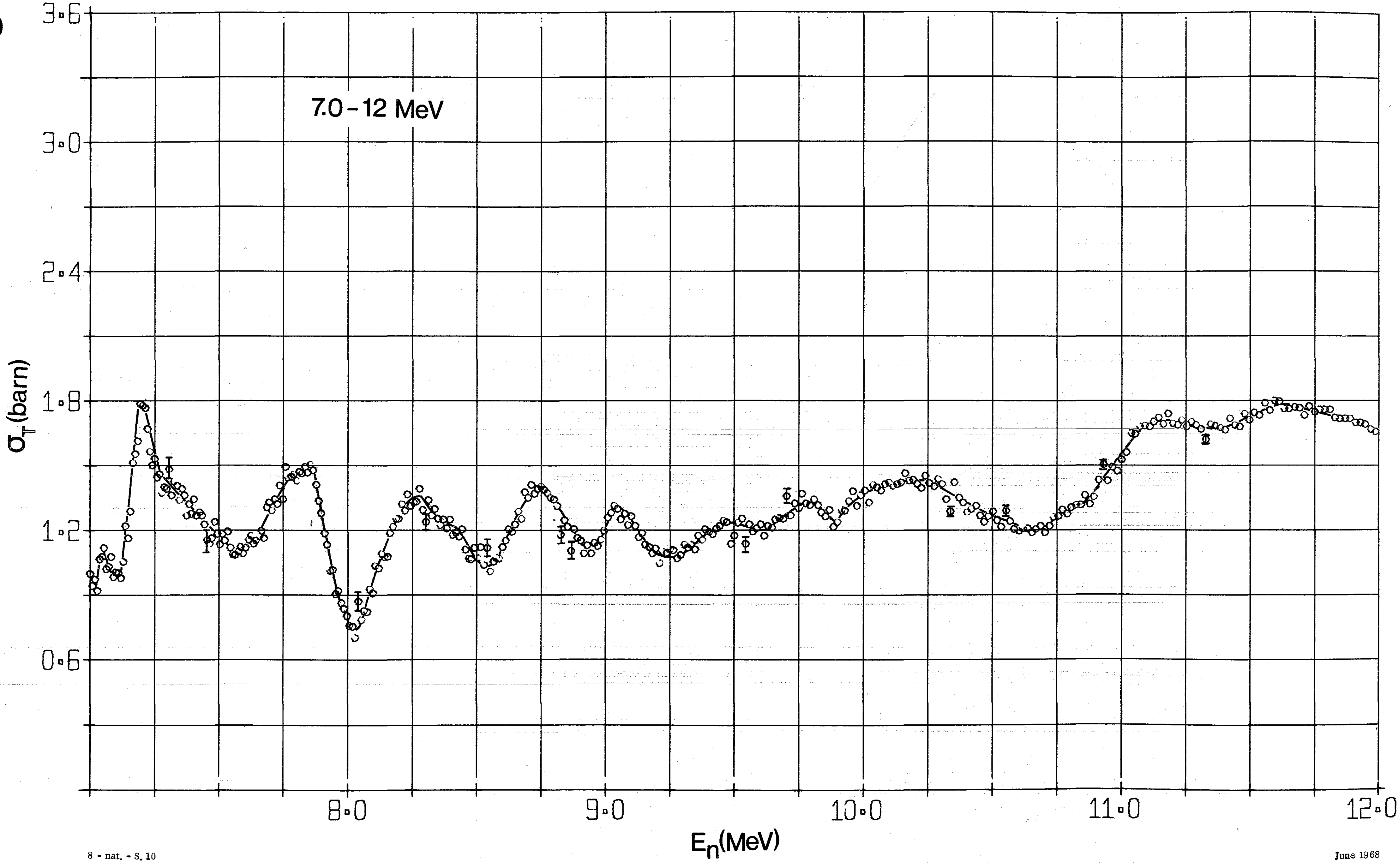
8 - nat. - S. 8

June 1968

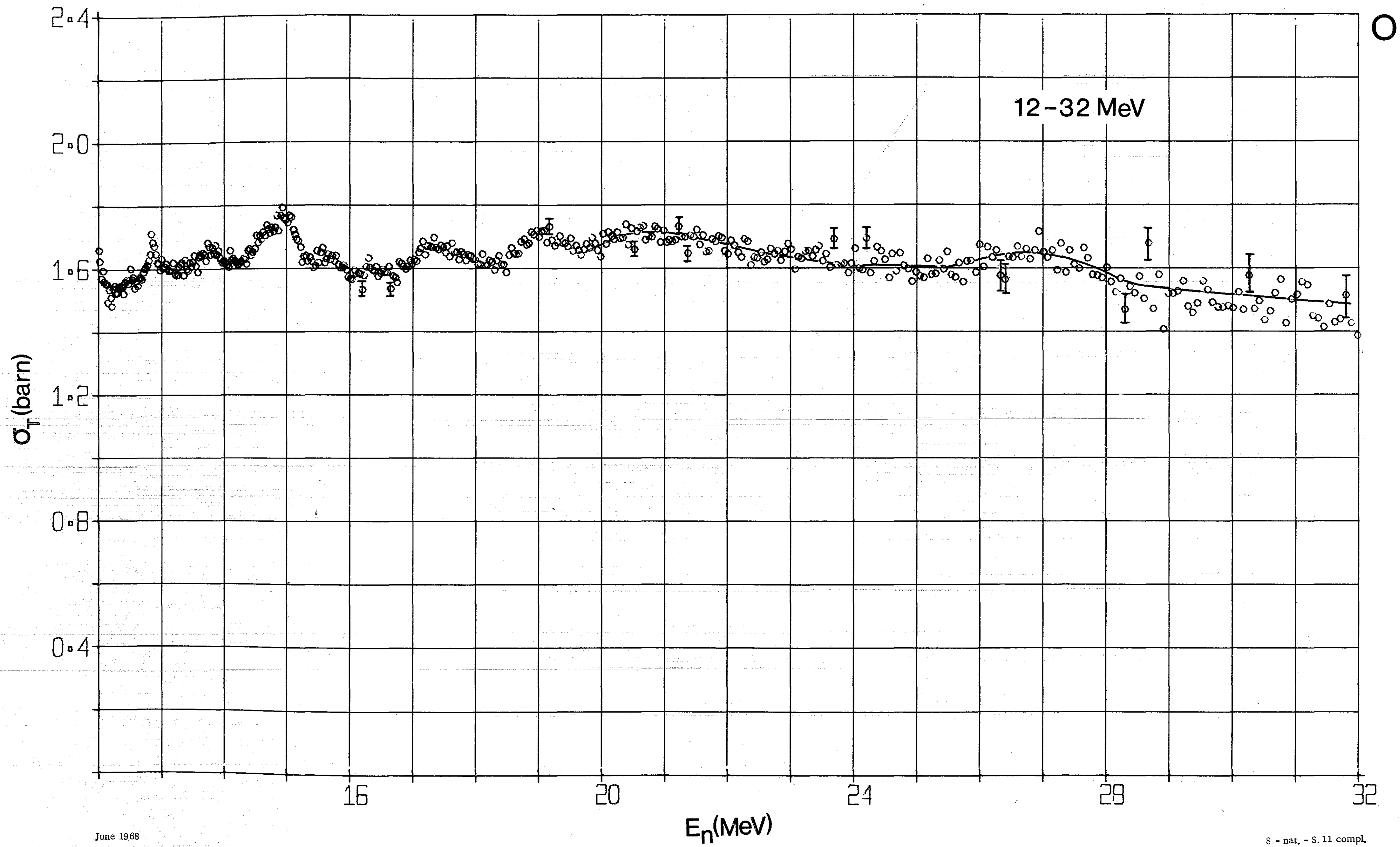


June 1968

O

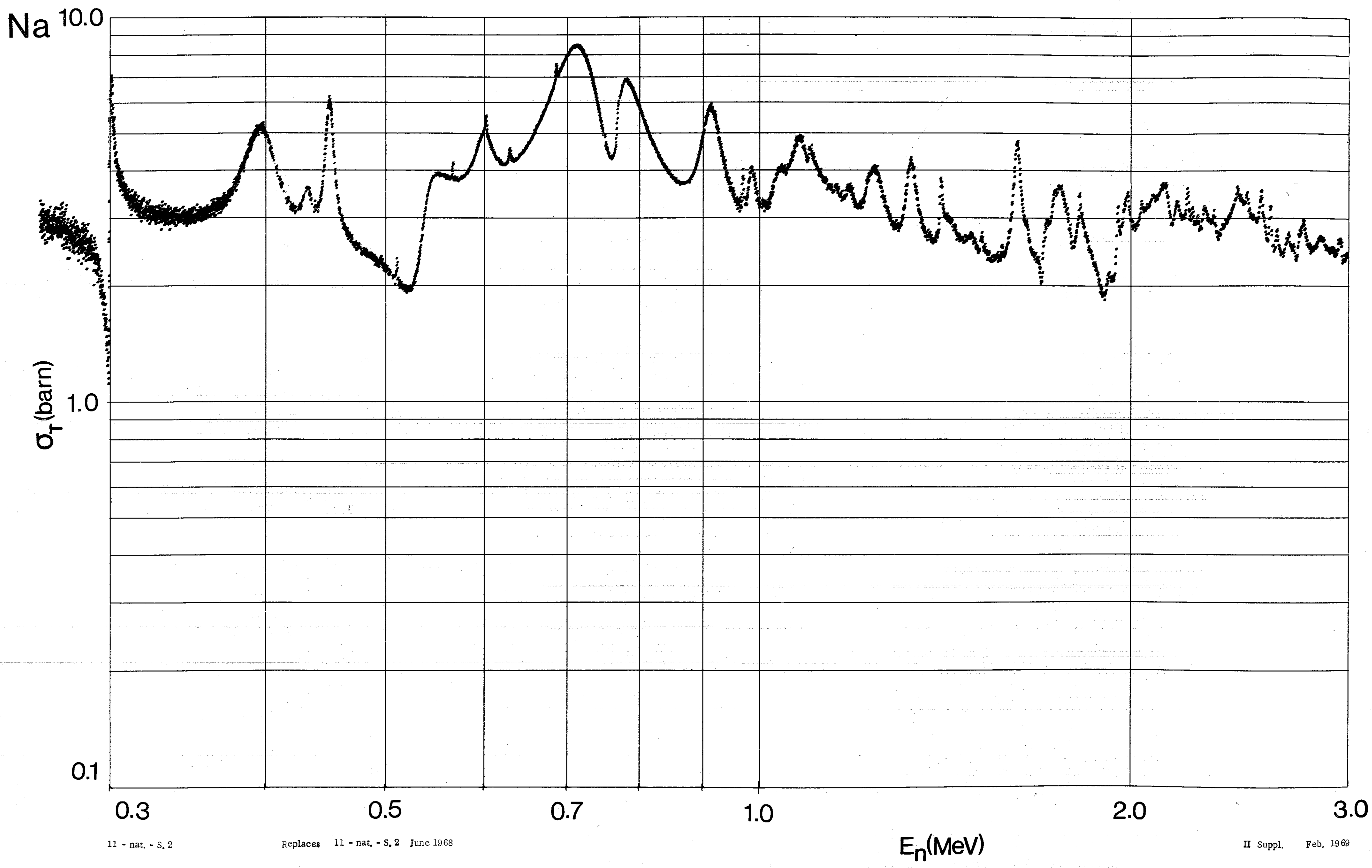


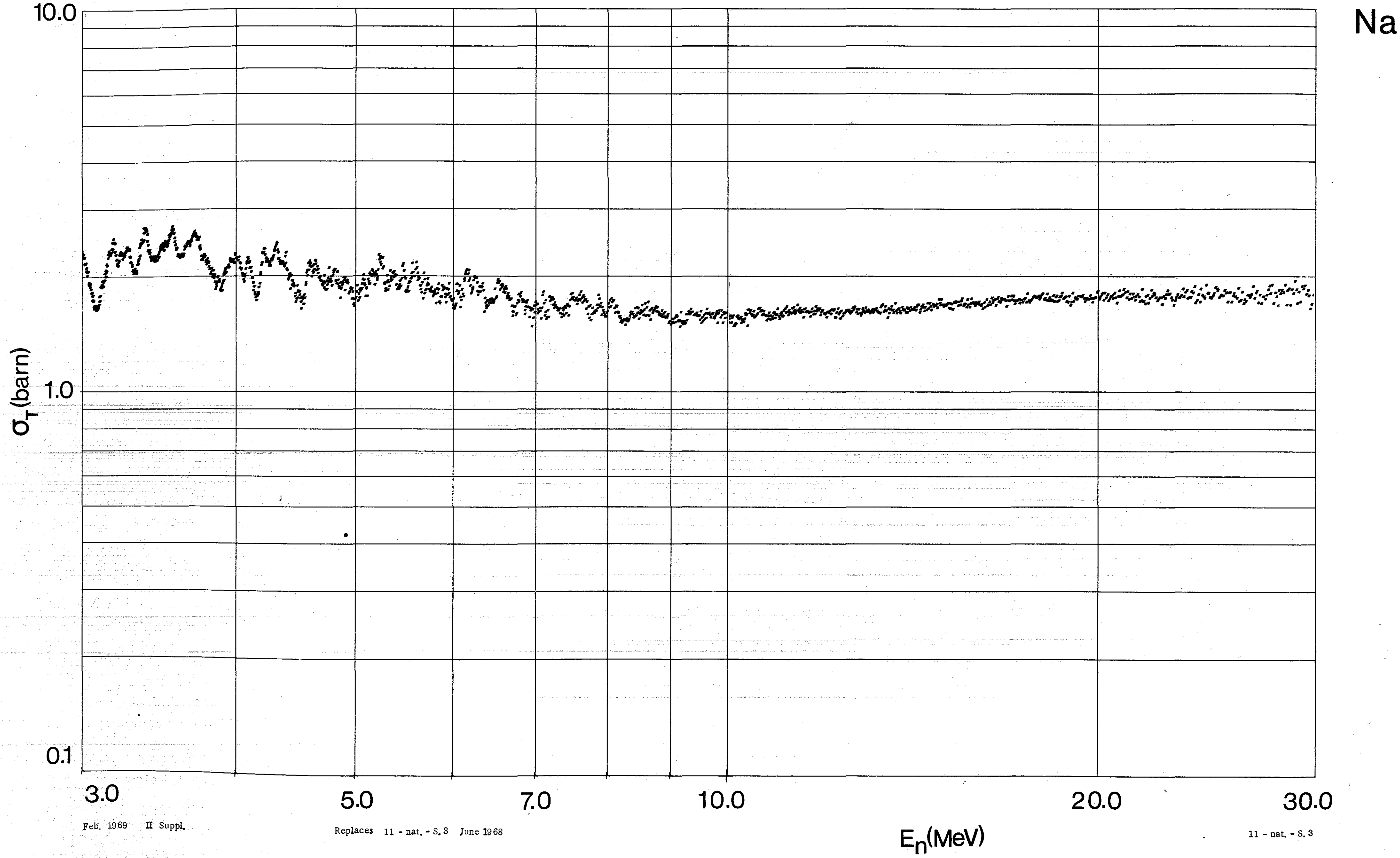
June 1968


O
12-32 MeV
2·4
2·0
1·6
1·2
0·8
0·4
σ_T (barn)
16
20
24
28
32
E_n(MeV)

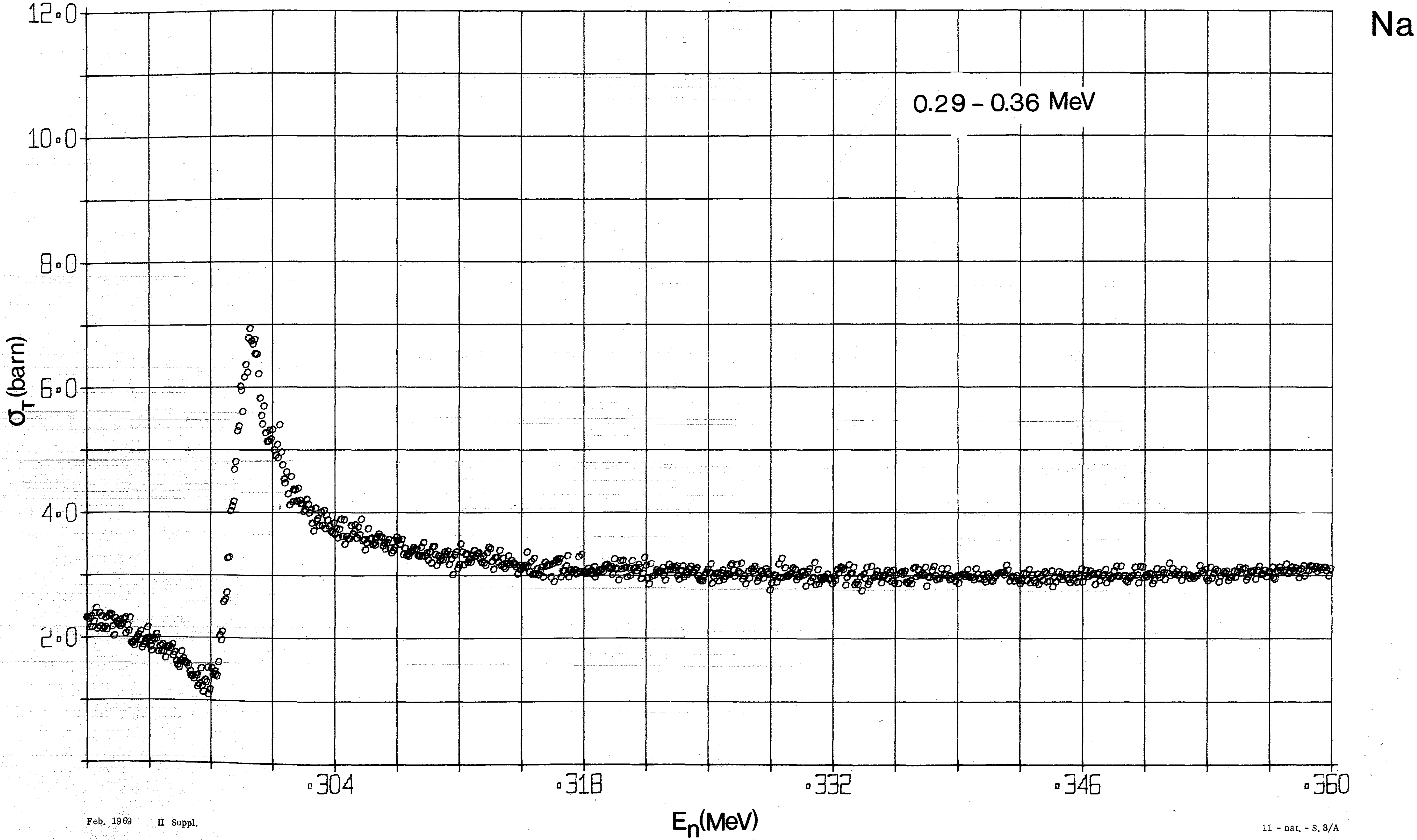
Na

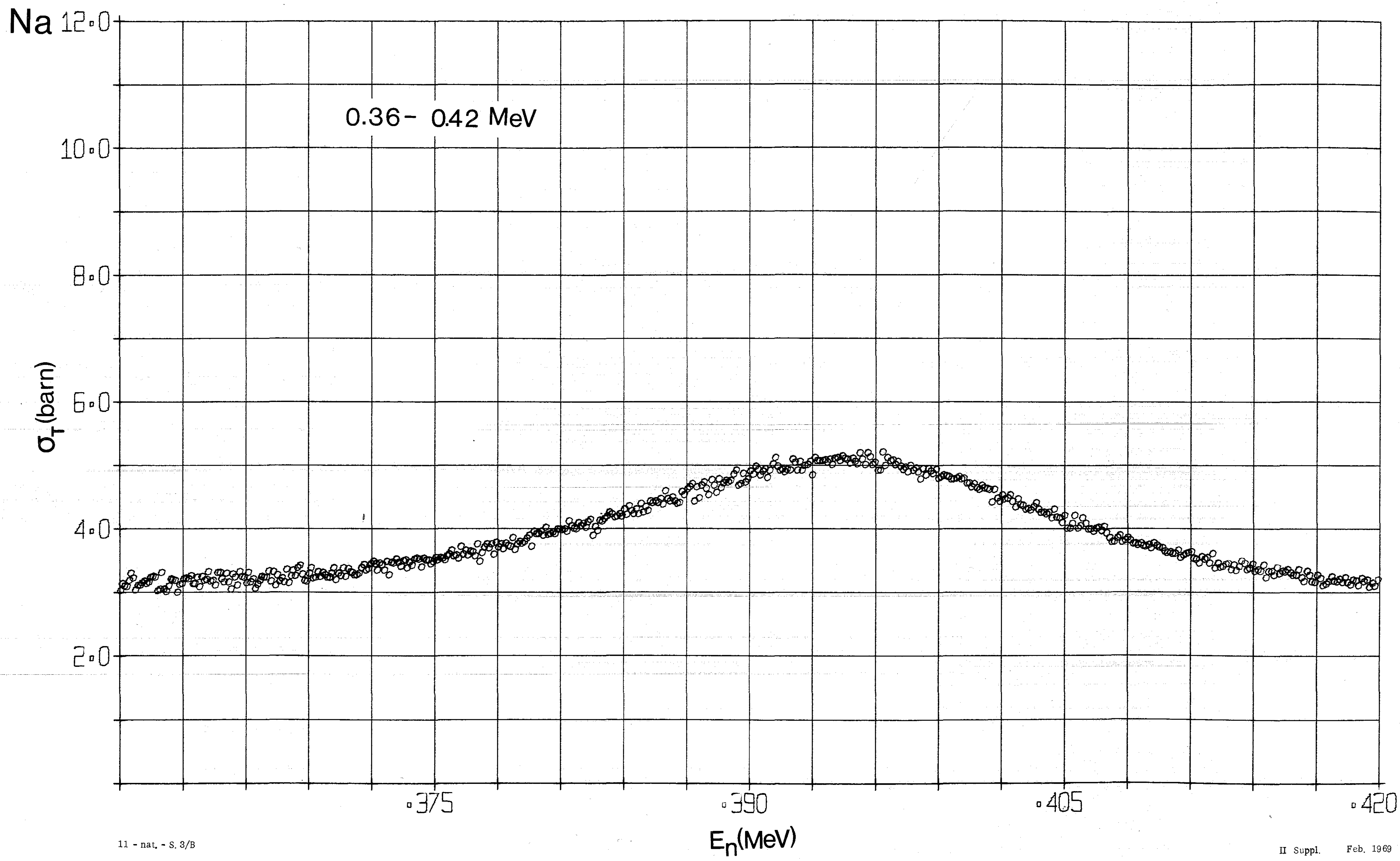
n	=	0.2328	At/barn	
p	=	99.998	%	
l	=	57.540	m	(0.3 - 0.9 MeV)
l	=	57.228	m	(0.9 - 32 MeV)
Δt	=	3.7	nsec	(0.3 - 0.9 MeV)
Δt	=	2.7	nsec	(0.9 - 32 MeV)
i	:	natural		

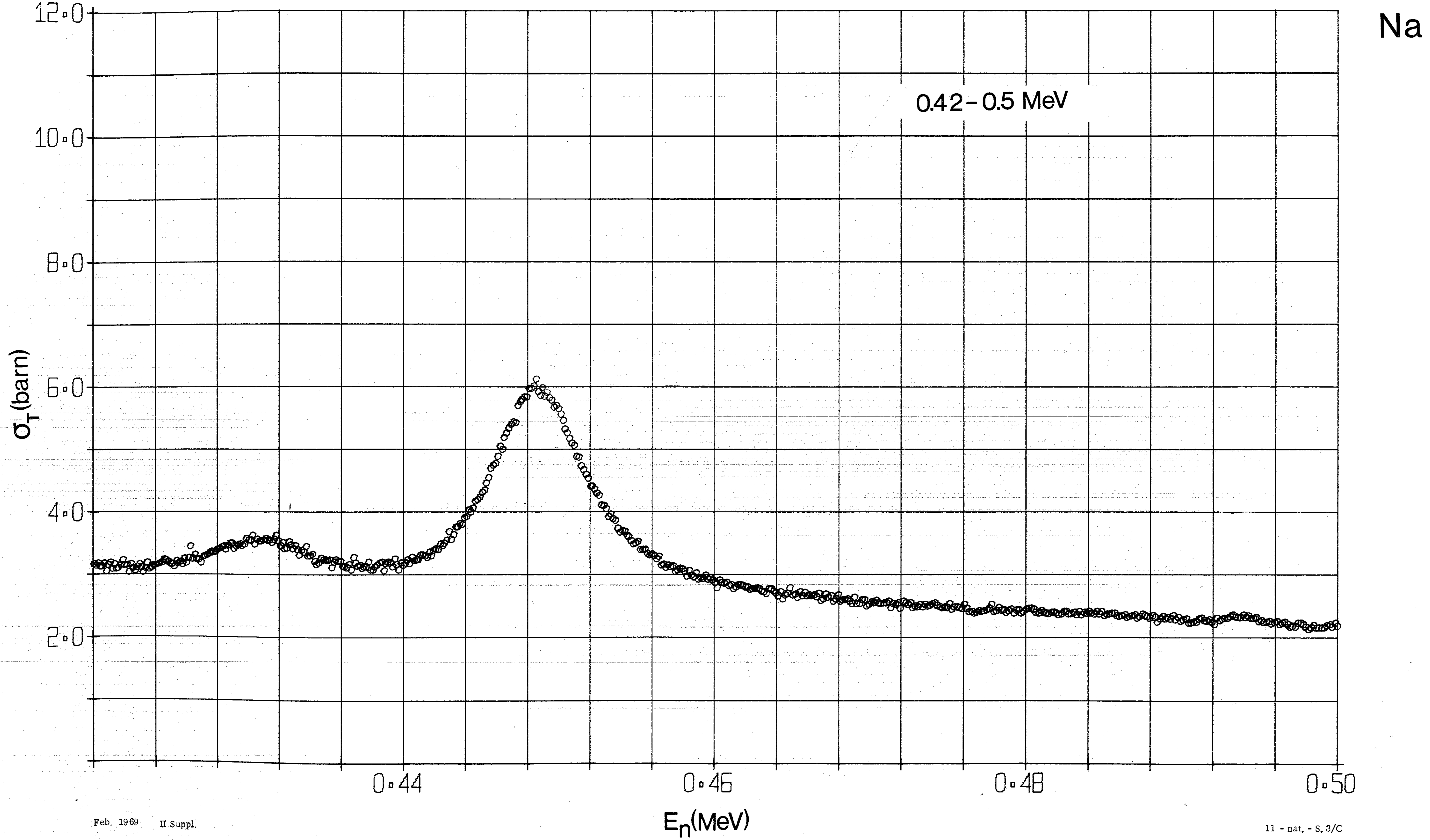

Na
10.0
1.0
0.1
σ_T(barn)
0.3
0.5
0.7
1.0
2.0
3.0
E_n(MeV)



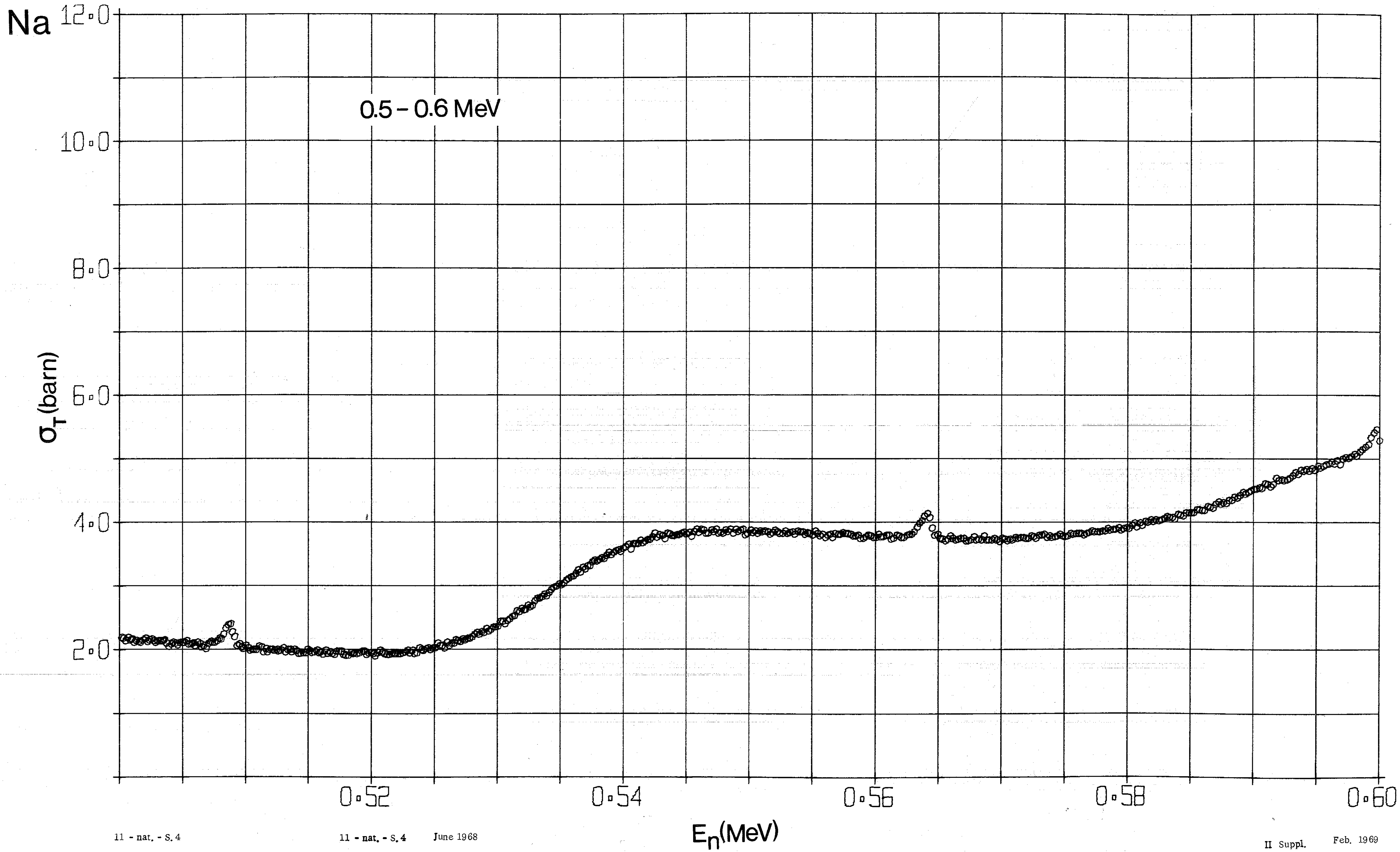
Na
10.0
1.0
0.1
σ_T(barn)
3.0
5.0
7.0
10.0
20.0
30.0
E_n(MeV)


Na
0.29 - 0.36 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σT (barn)
.304
.318
.332
.346
.360
En(MeV)

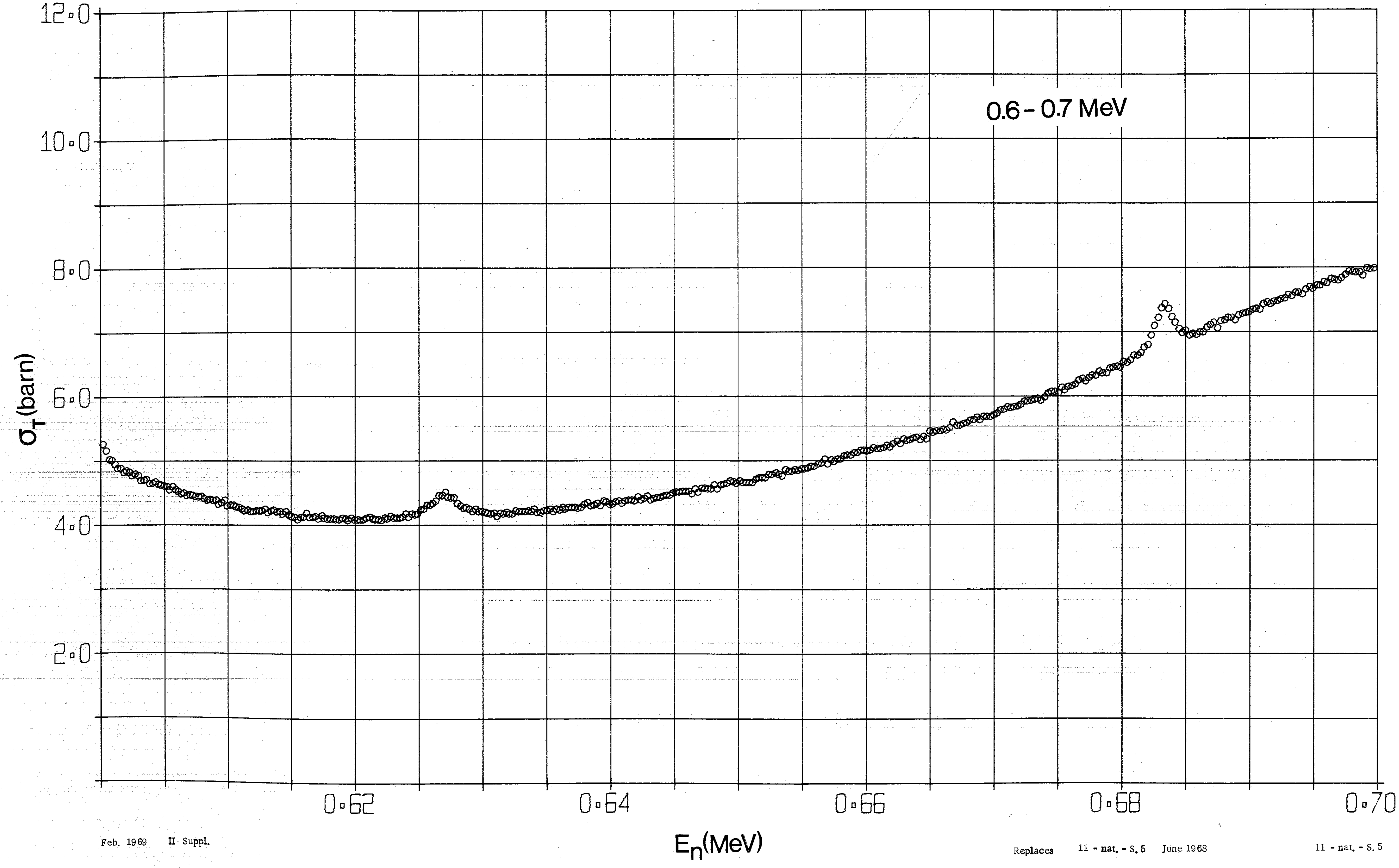

Na
0.36- 0.42 MeV
σT (barn)
12.0
10.0
8.0
6.0
4.0
2.0
.375
.390
.405
.420
En(MeV)



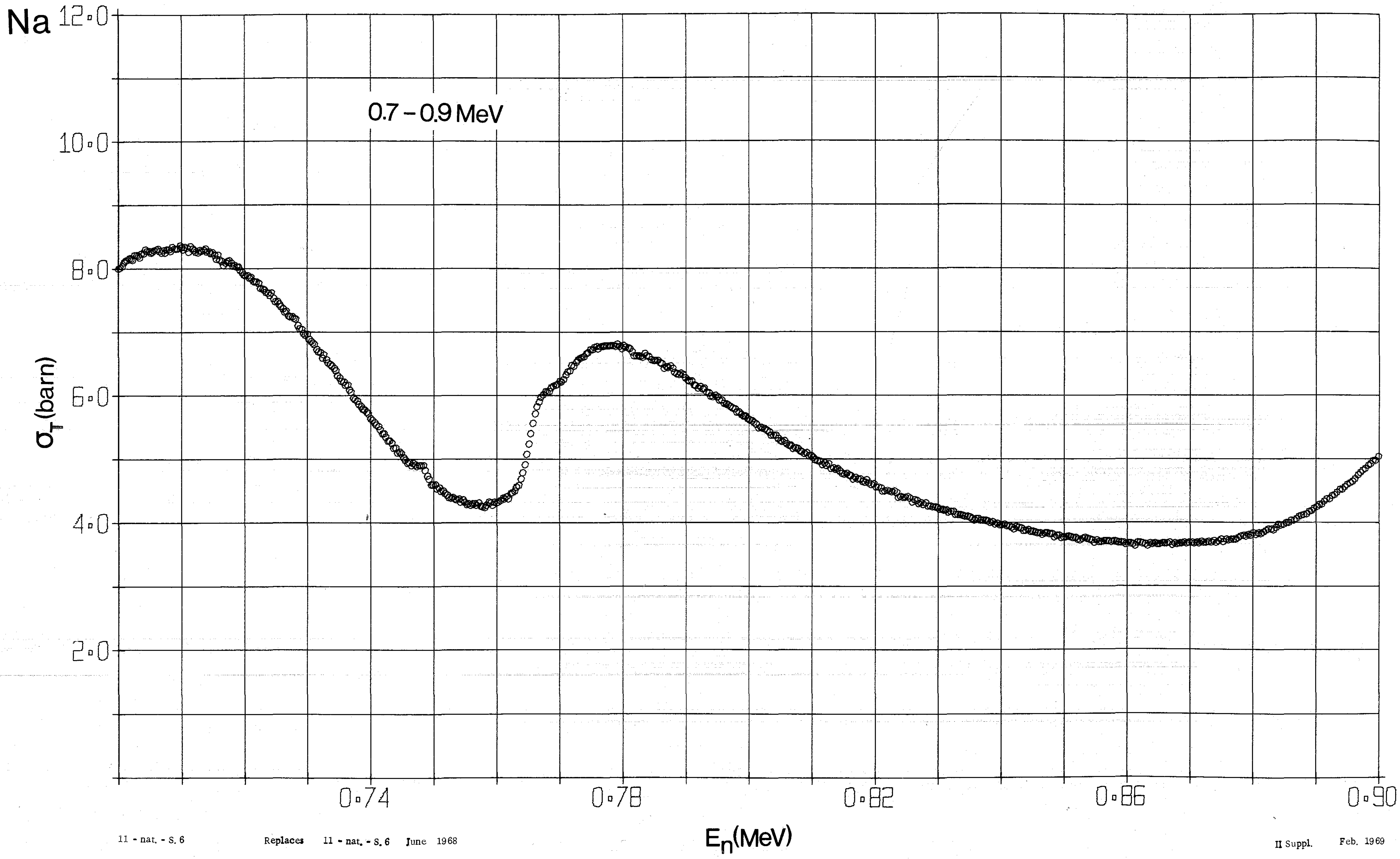
Na
0.42-0.5 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σT (barn)
0.44
0.46
0.48
0.50
En(MeV)

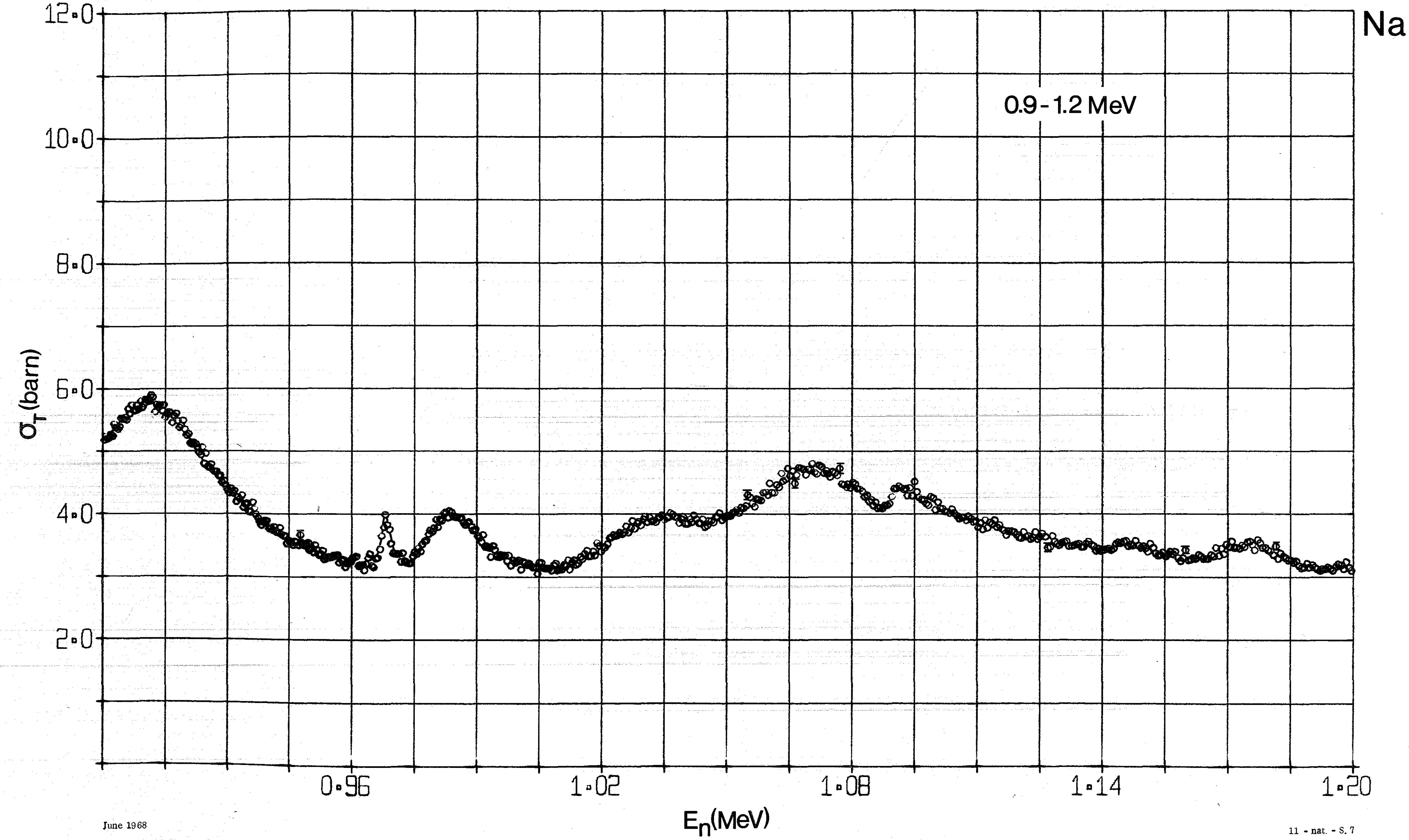

Na
0.5 - 0.6 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σT (barn)
0.52
0.54
0.56
0.58
0.60
En(MeV)

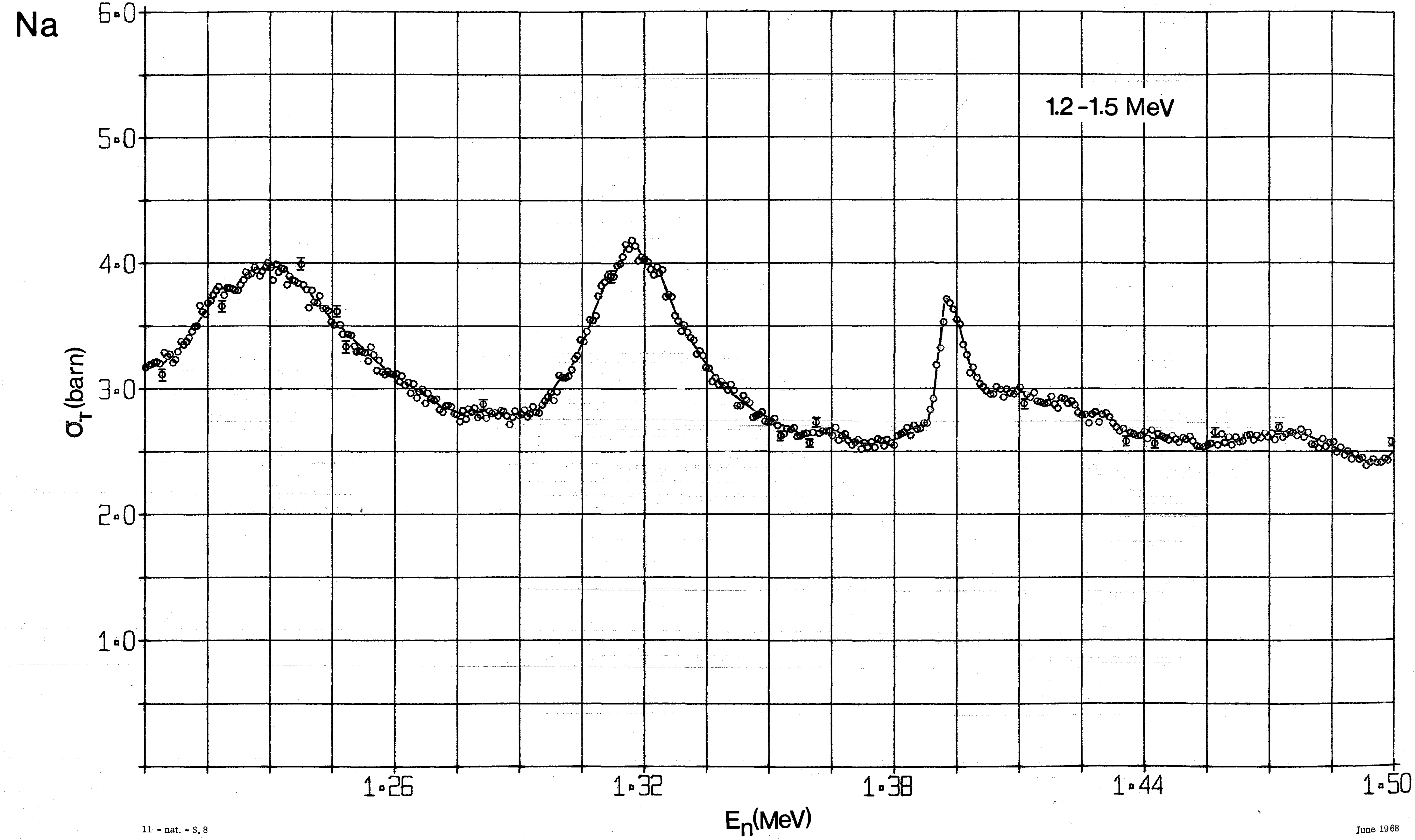
Na

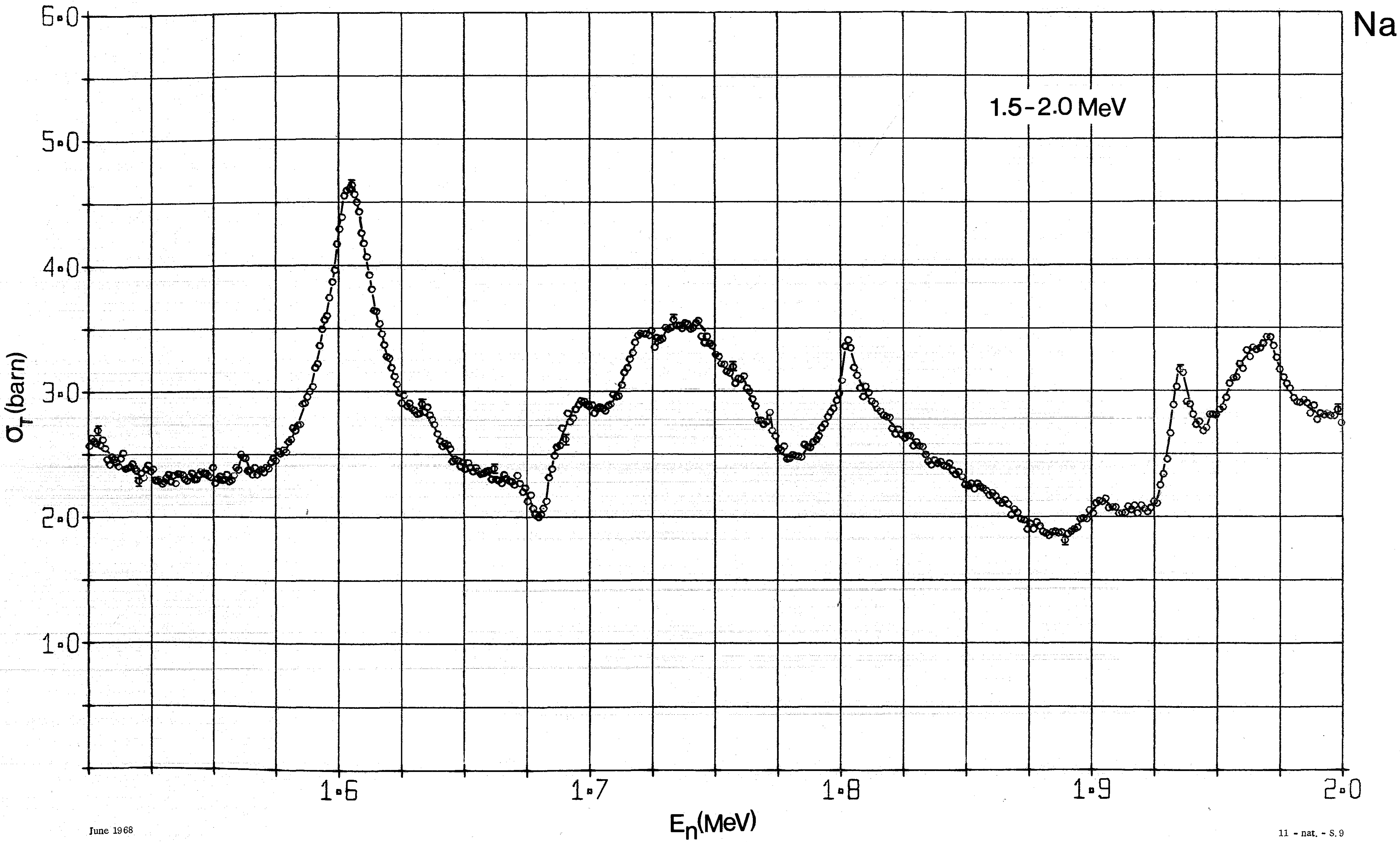


0.6 - 0.7 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σ_T(barn)
0.62
0.64
0.66
0.68
0.70
E_n(MeV)

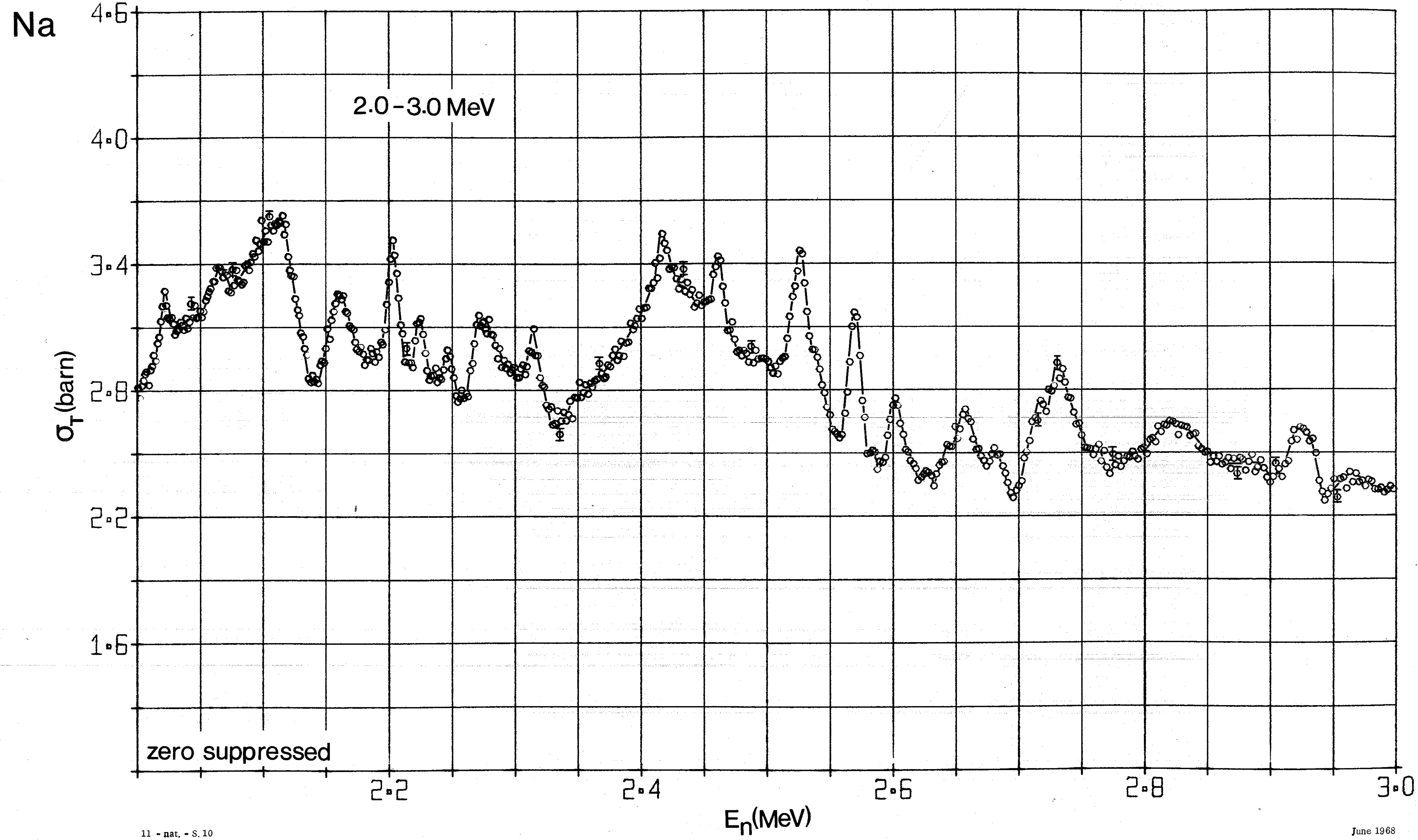

Na
12·0
10·0
8·0
6·0
4·0
2·0
0.7 - 0.9 MeV
σT (barn)
0·74
0·78
0·82
0·86
0·90
En(MeV)


Na
0.9 - 1.2 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σ_T (barn)
0.96
1.02
1.08
1.14
1.20
E_n(MeV)


Na
1.2 - 1.5 MeV
6.0
5.0
4.0
3.0
2.0
1.0
σT (barn)
1.26
1.32
1.38
1.44
1.50
En(MeV)
11 - nat. - S. 8
June 1968

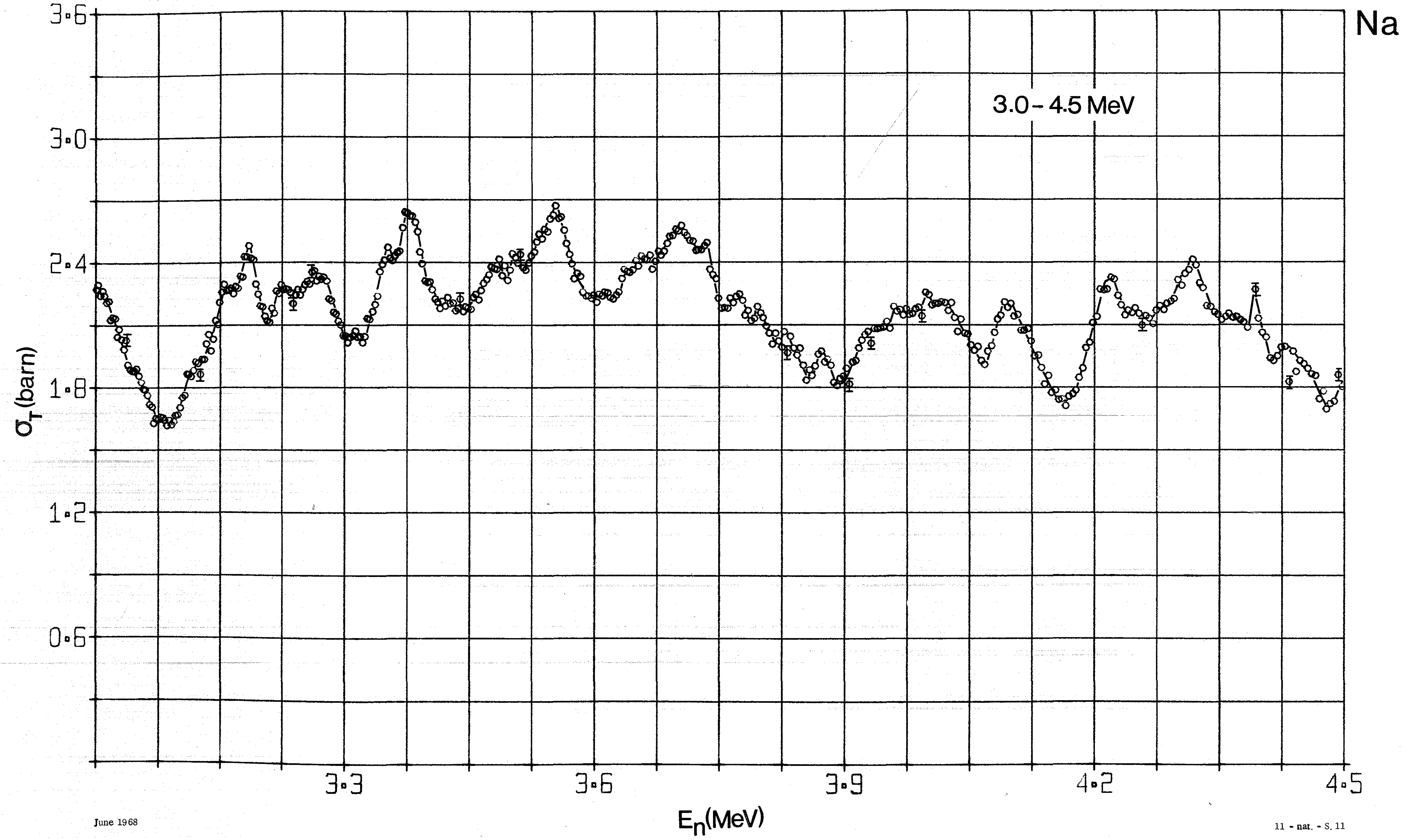


June 1968

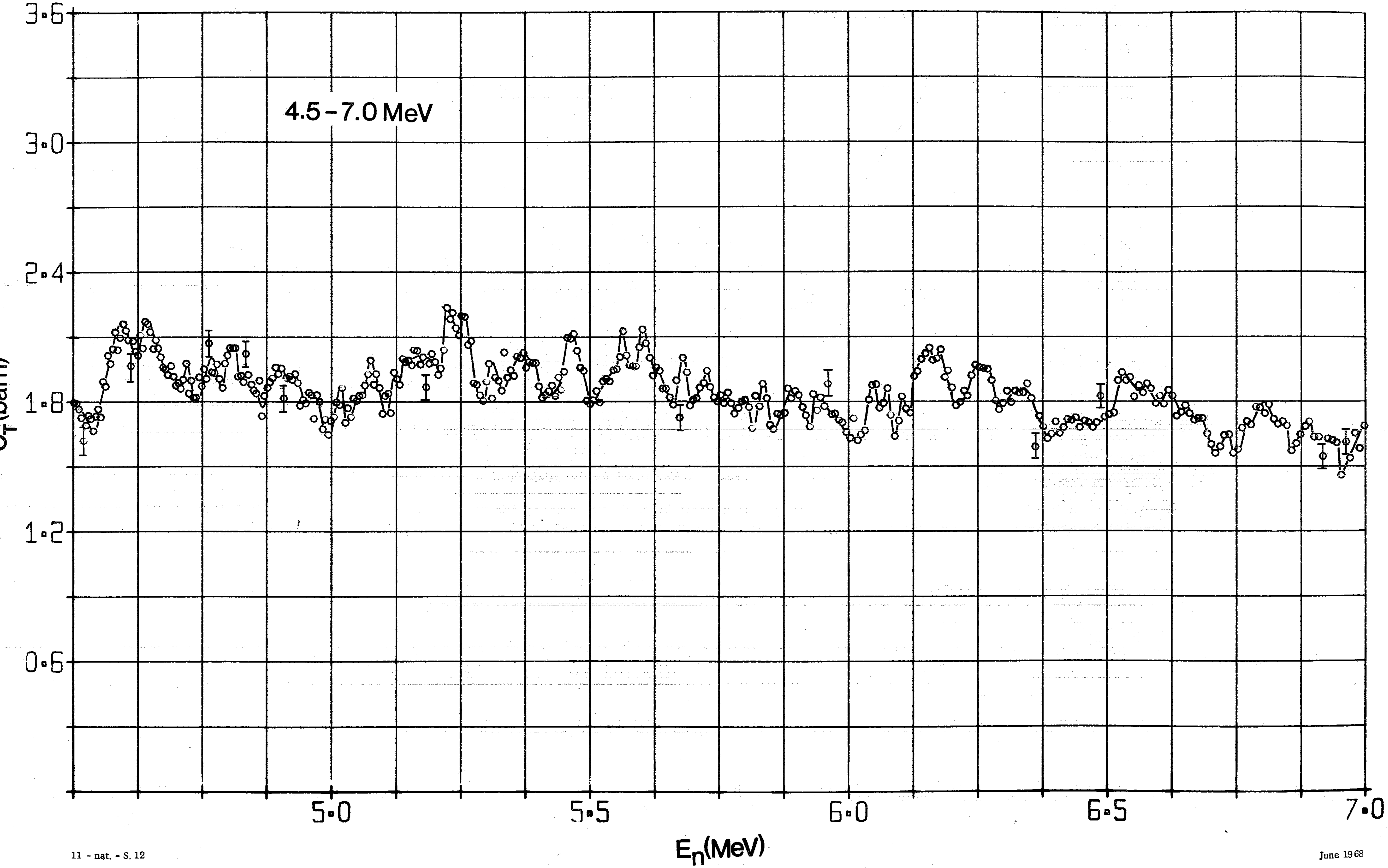


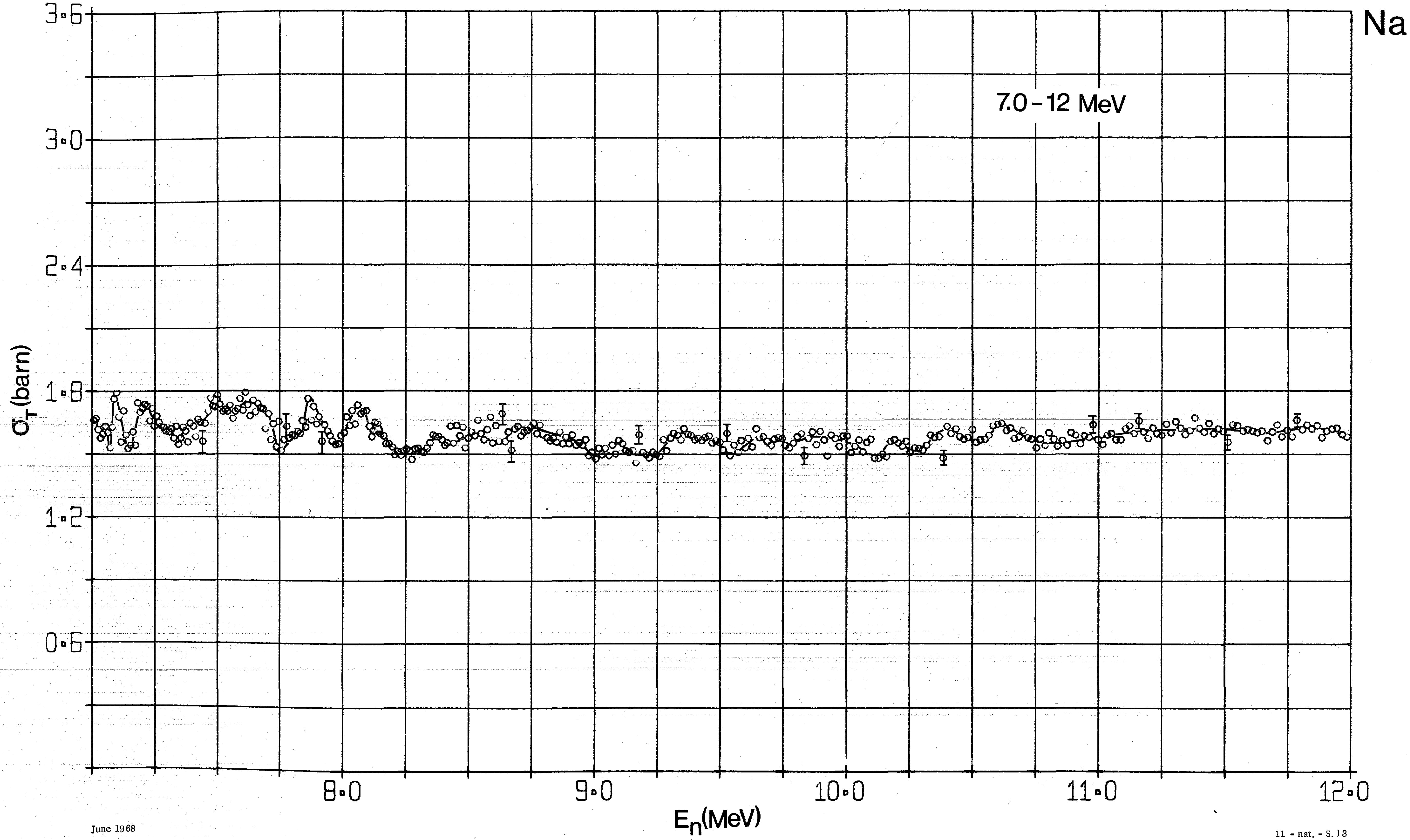
11 - nat. - S. 10

June 1968

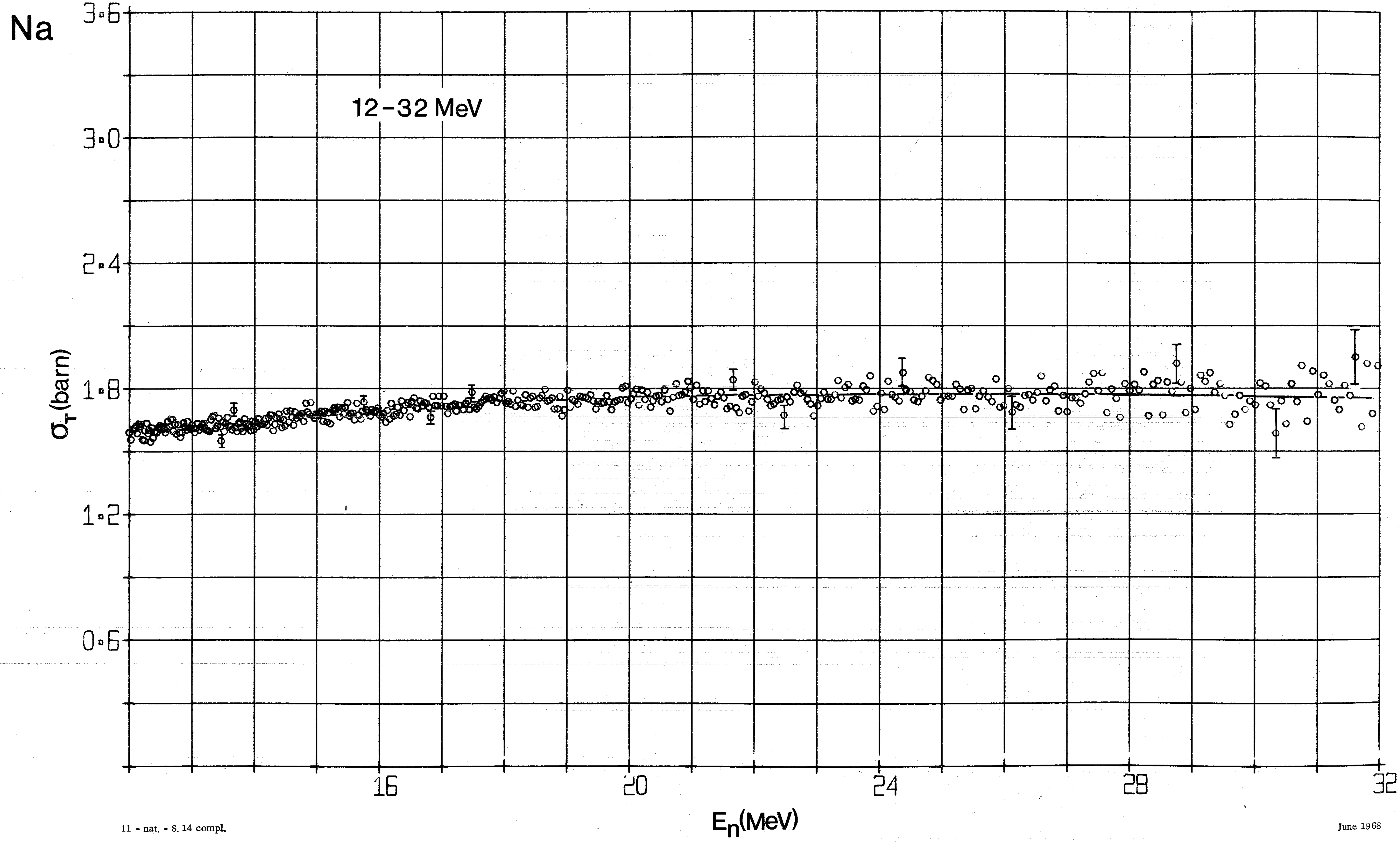

Na
3.0 - 4.5 MeV
3·6
3·0
2·4
1·8
1·2
0·6
σT (barn)
3·3
3·6
3·9
4·2
4·5
En(MeV)

Na





June 1968



11 - nat. - S. 14 compl.

June 1968

Al

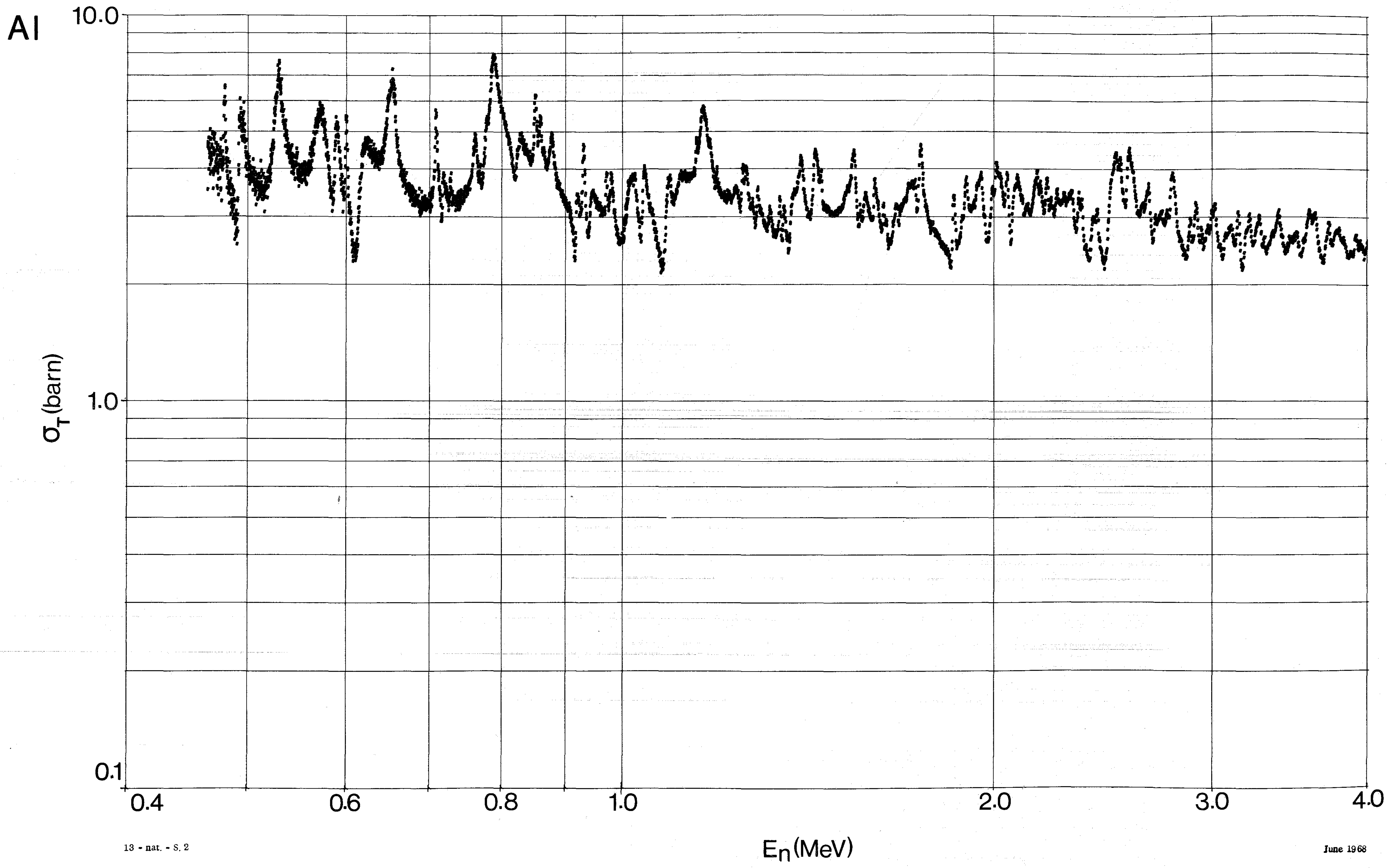
n = 0.2195 at/barn

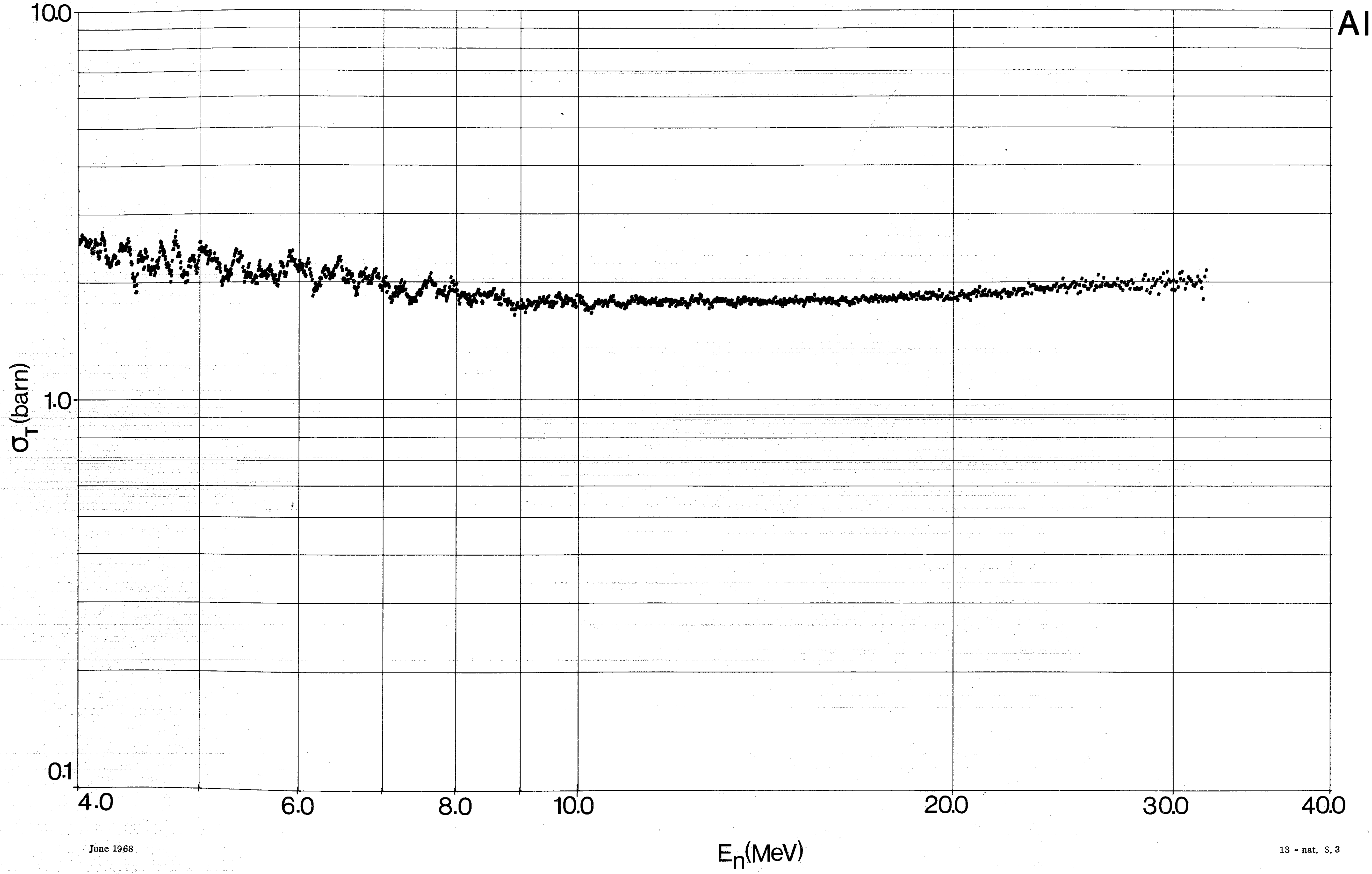
p = 99,5 %

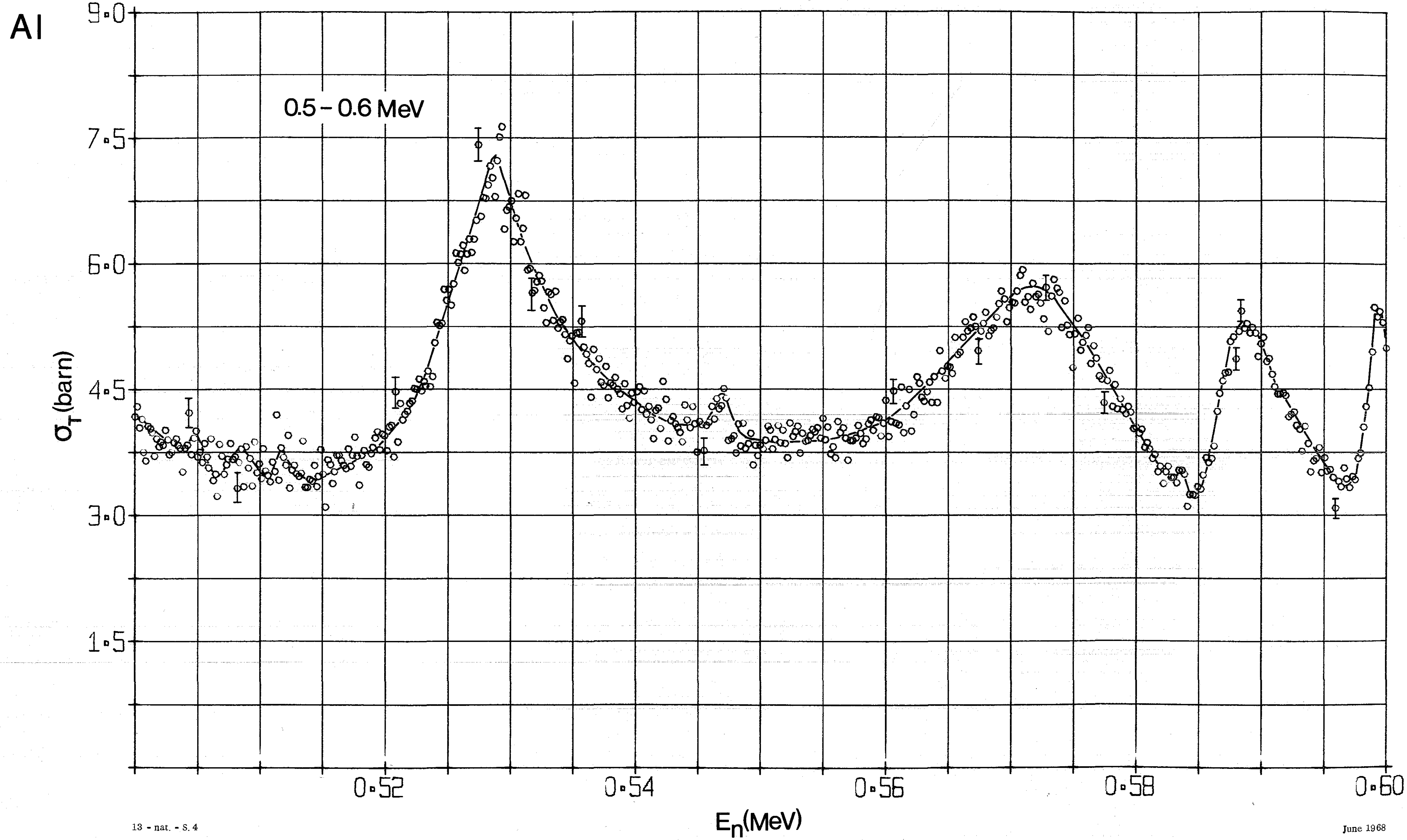
l = 57,228 m

Δt = 2,7 nsec

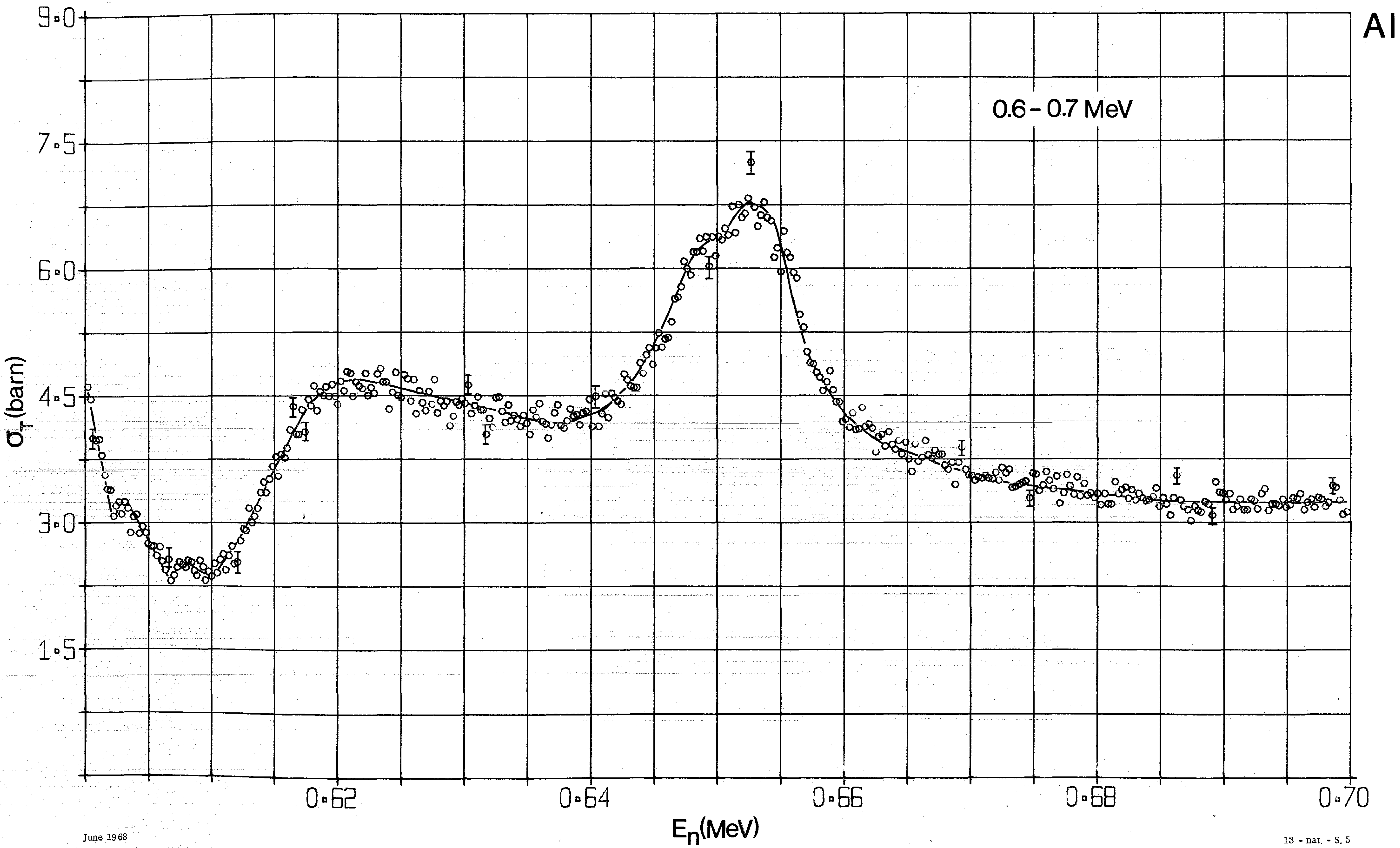
i : natural


Al
10.0
1.0
0.1
σT (barn)
0.4
0.6
0.8
1.0
2.0
3.0
4.0
En (MeV)

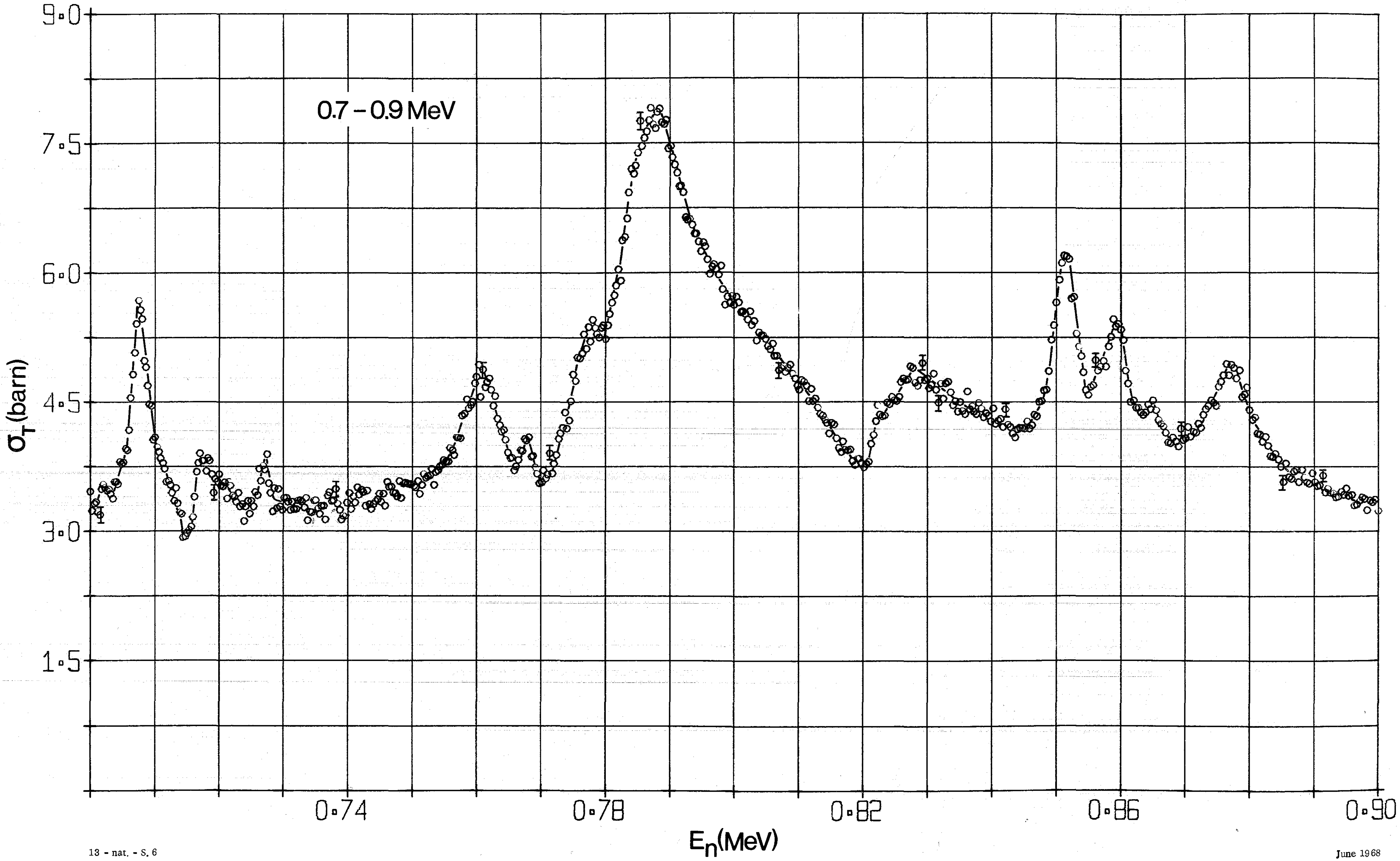

10.0
1.0
0.1
Al
σ_T (barn)
4.0
6.0
8.0
10.0
20.0
30.0
40.0
E_n(MeV)

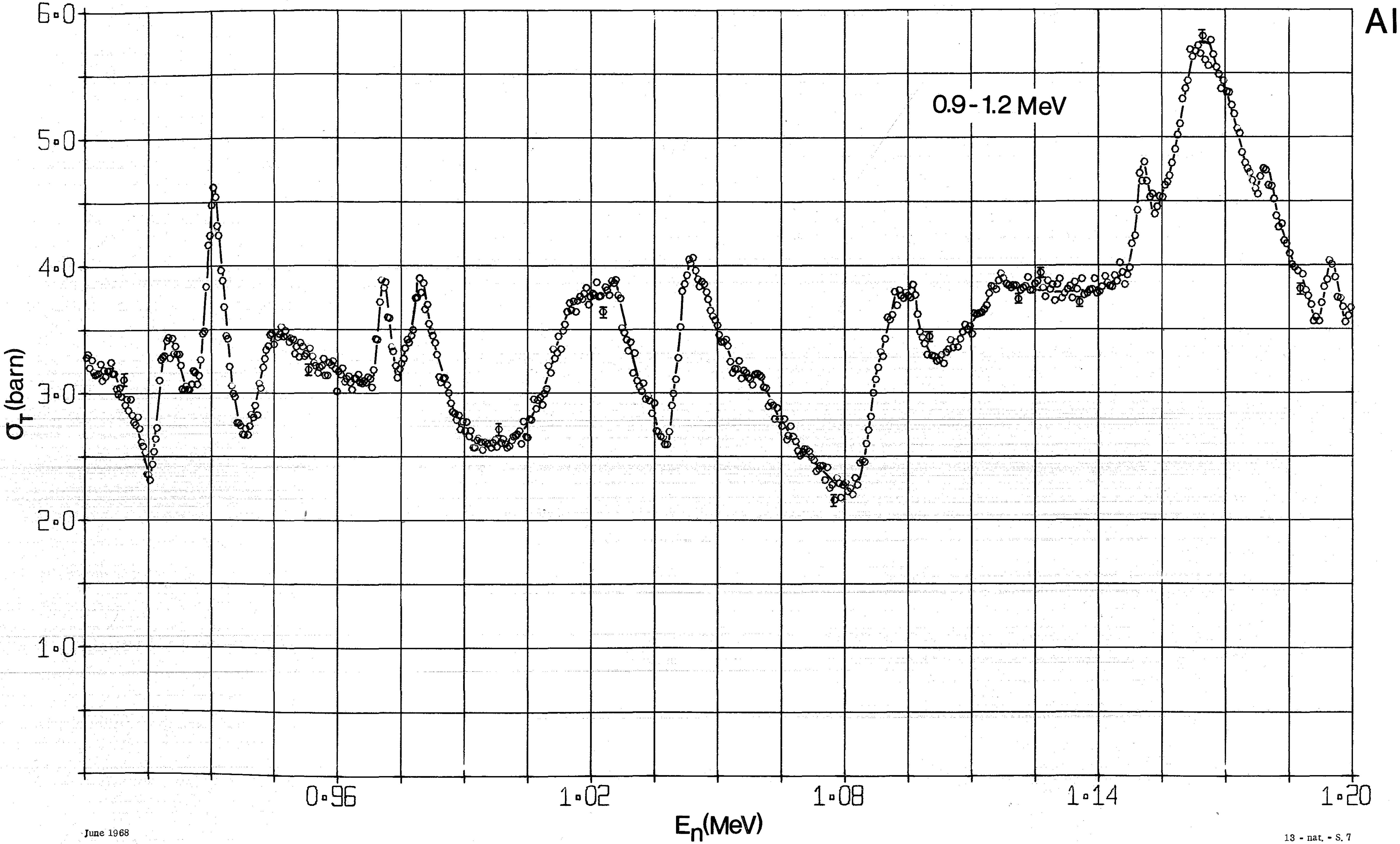


Al
0.5 – 0.6 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σT (barn)
0·52
0·54
0·56
0·58
0·60
En(MeV)

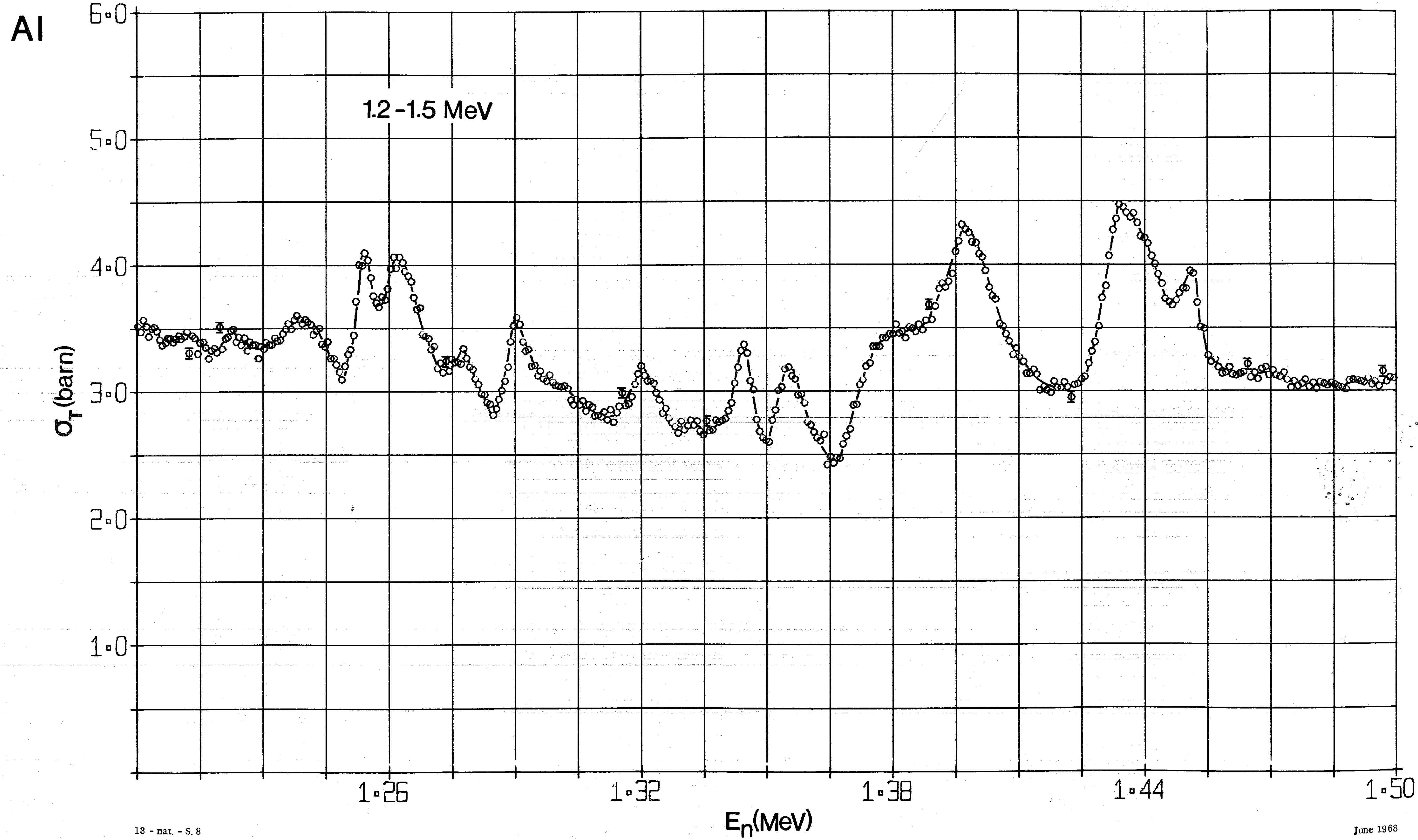

Al
0.6 - 0.7 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σT (barn)
0·62
0·64
0·66
0·68
0·70
En(MeV)

Al



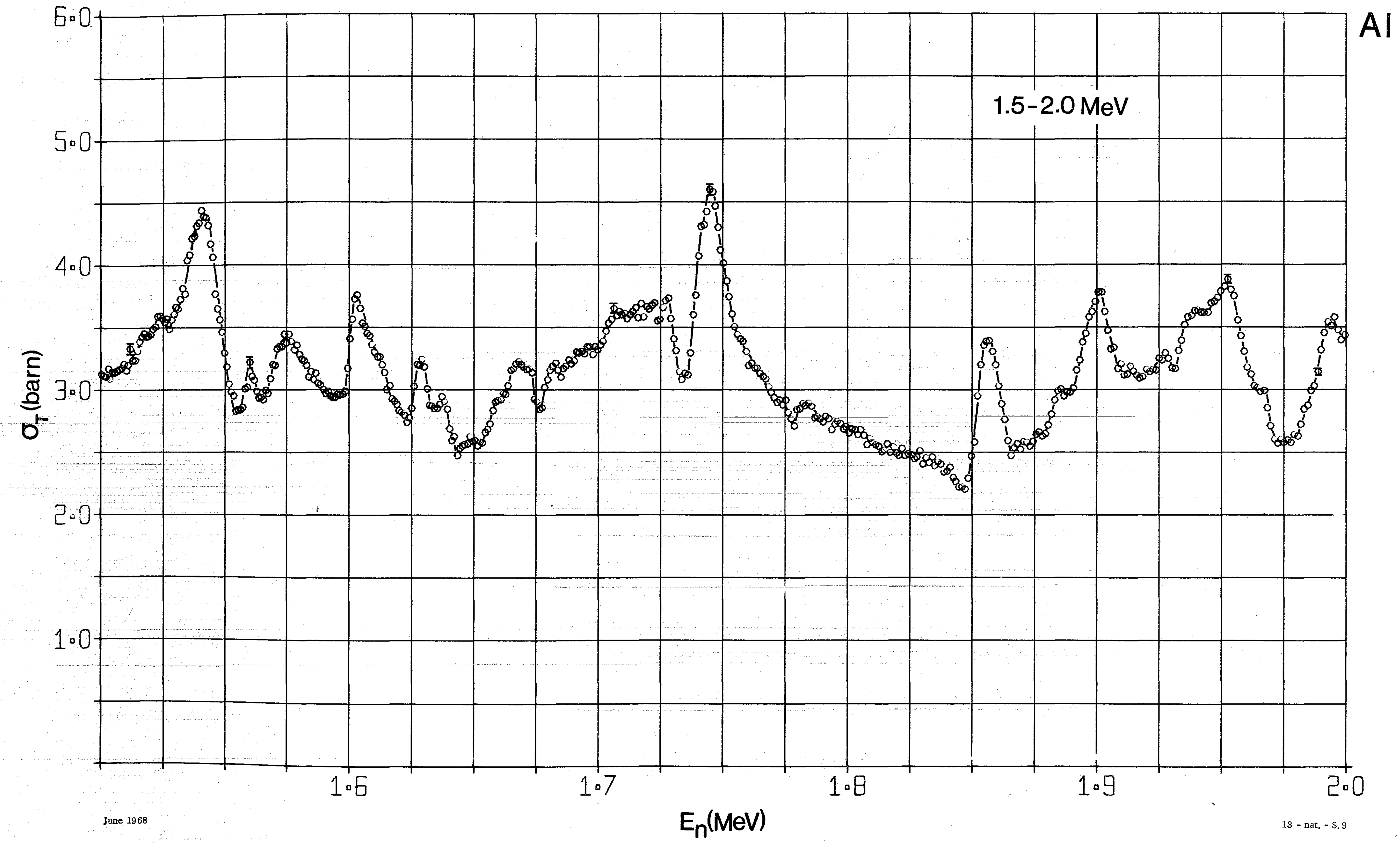


June 1968



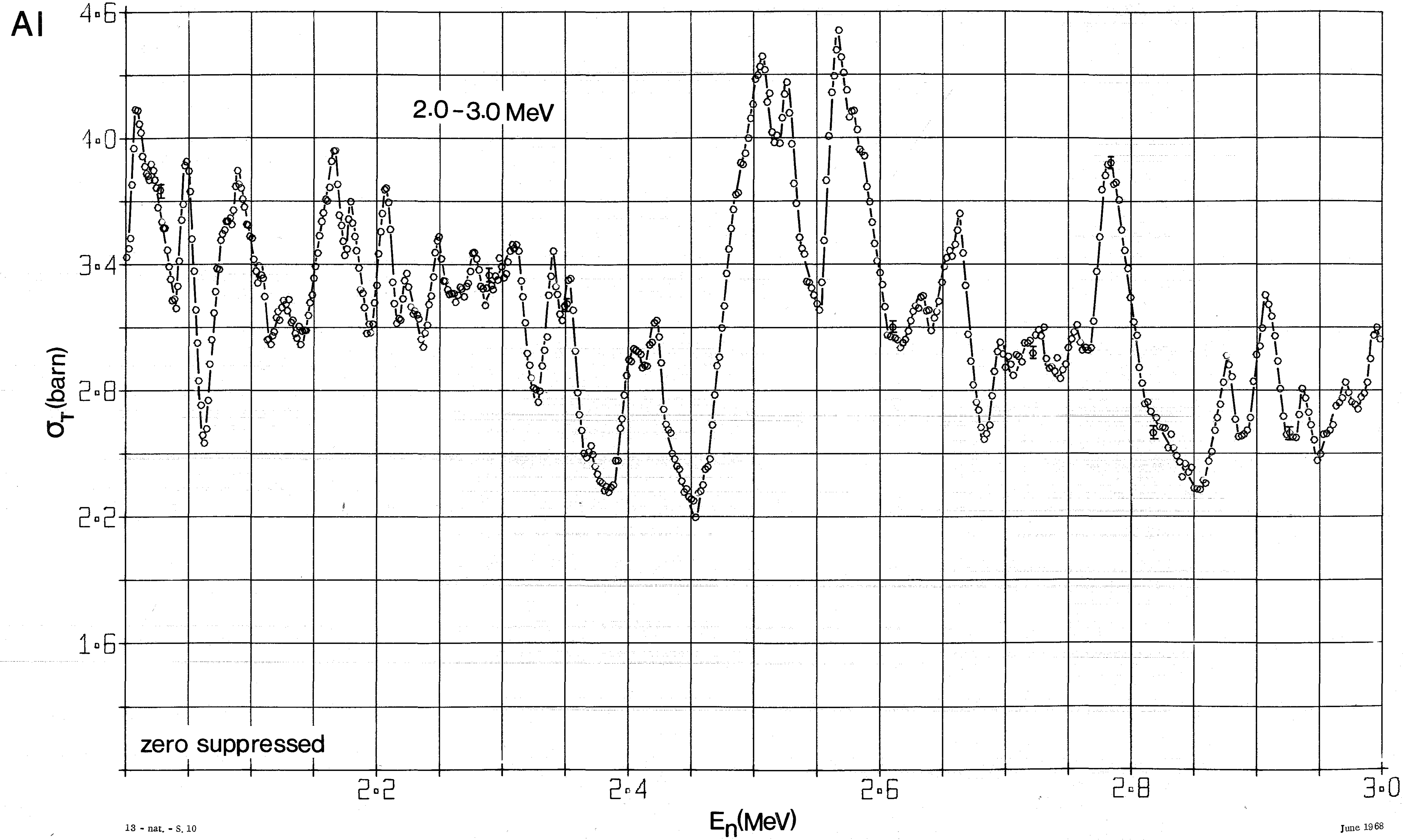
13 - nat. - S. 8

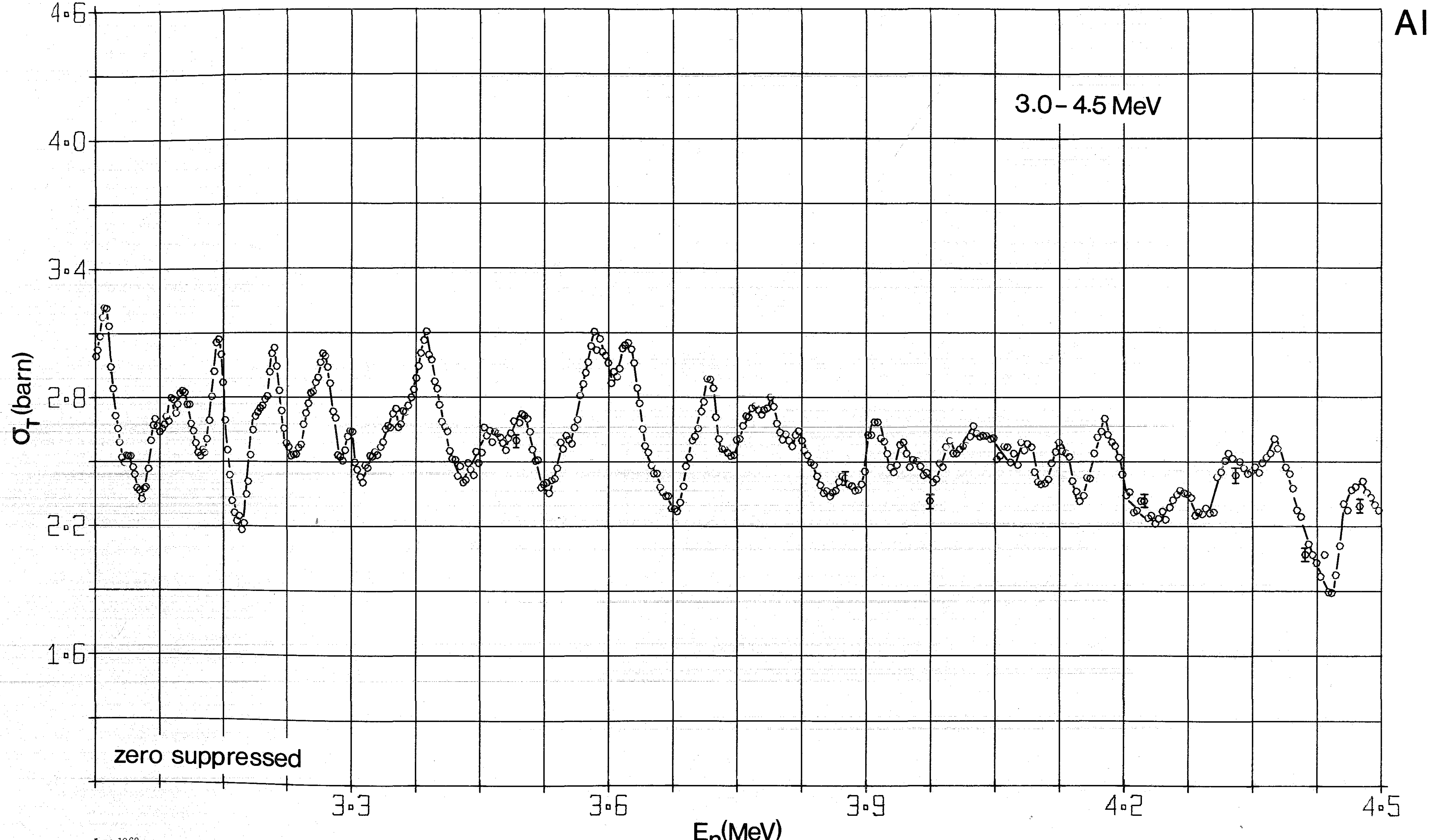
June 1968

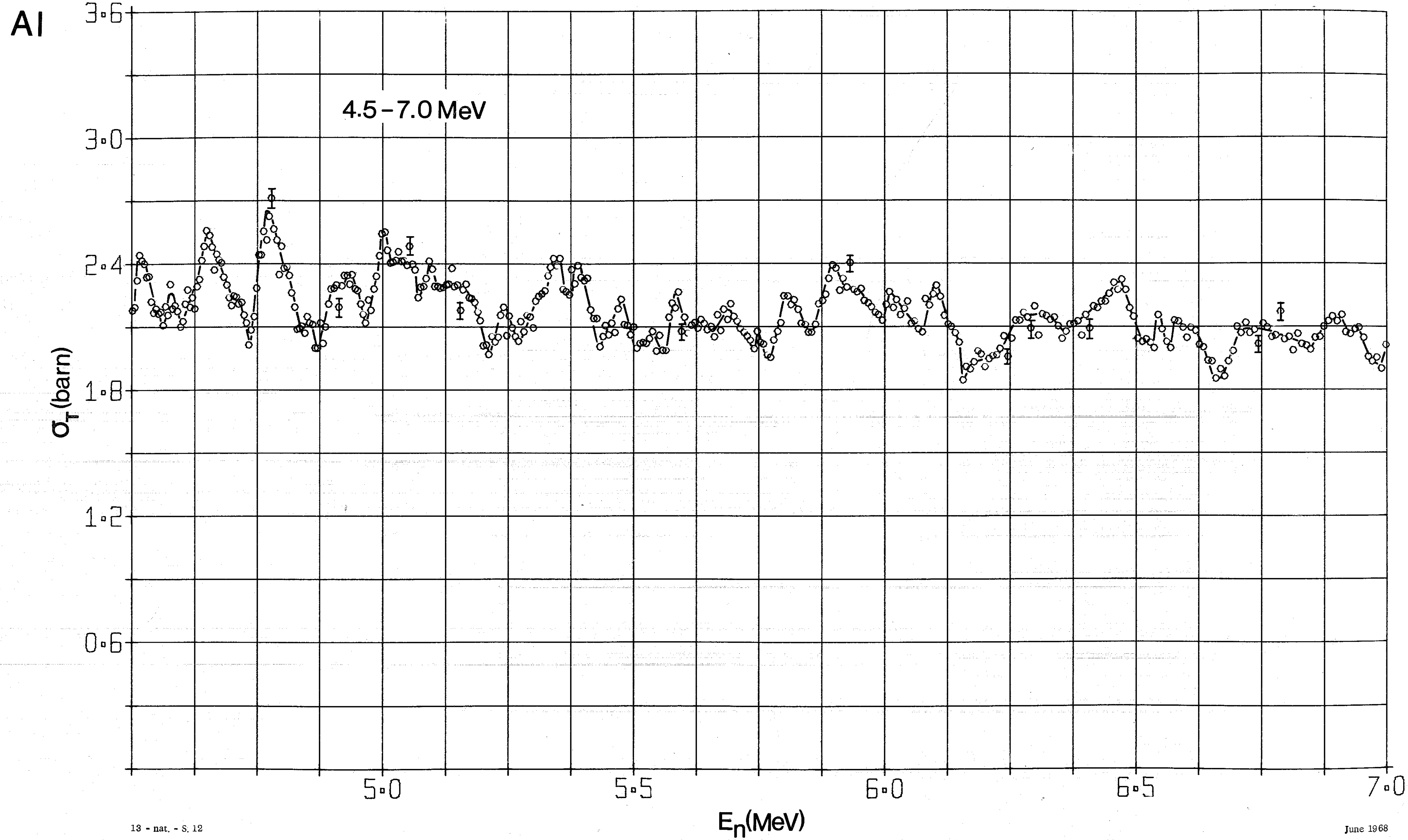


June 1968

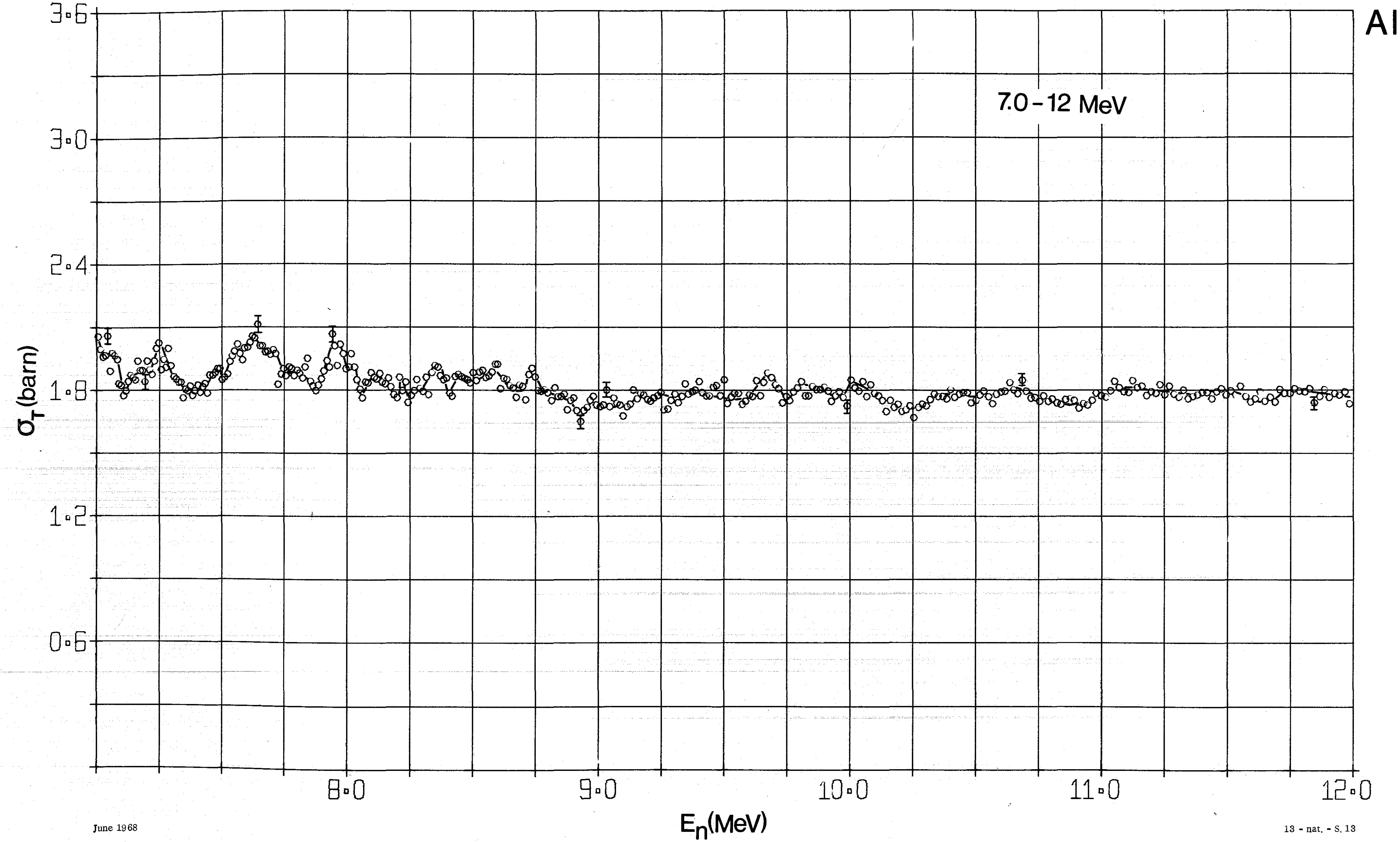
13 - nat. - S.9


Al
2.0 - 3.0 MeV
zero suppressed
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
2·2
2·4
2·6
2·8
3·0
E_n(MeV)

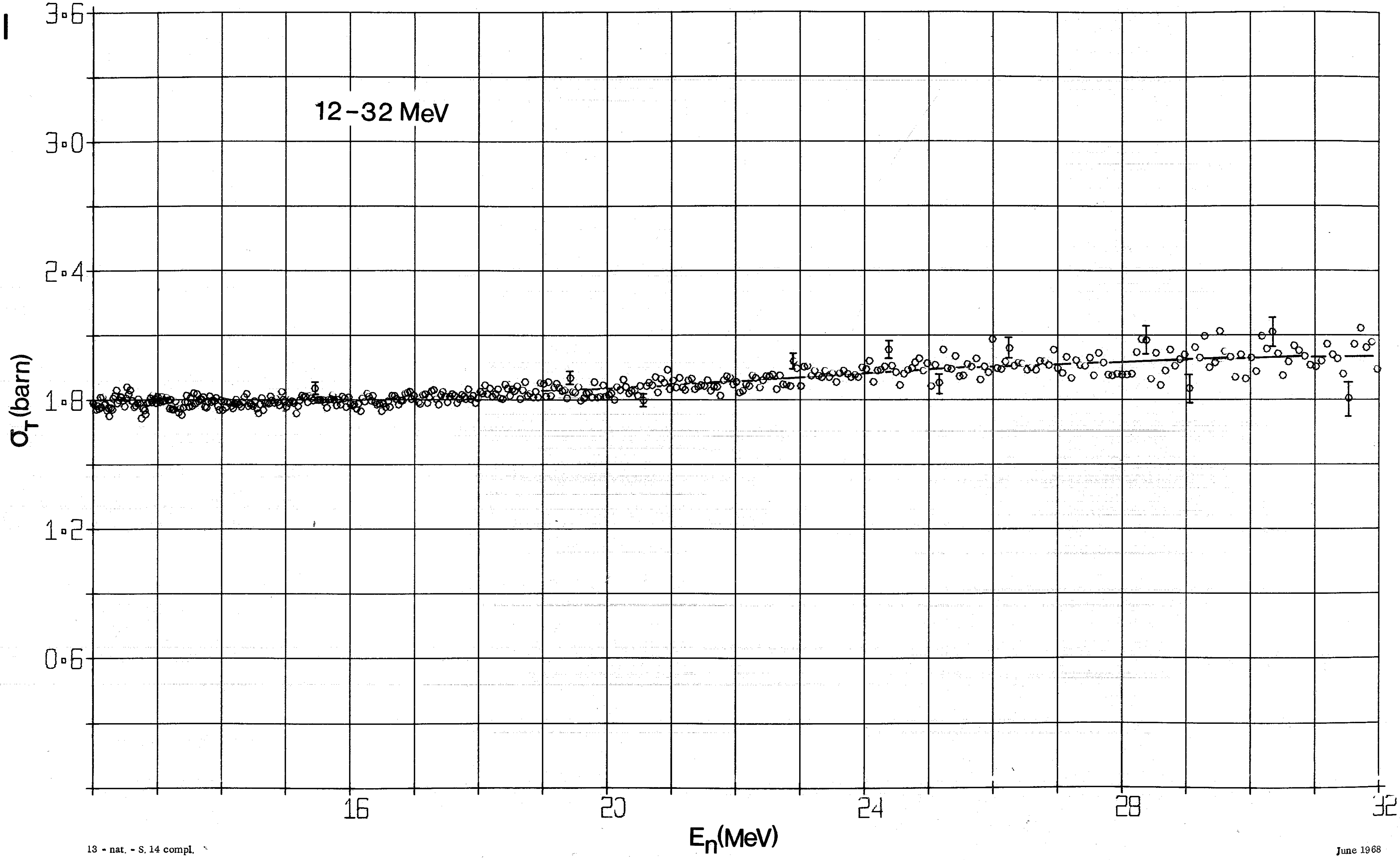

Al
3.0 - 4.5 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
E_n(MeV)



Al
4.5-7.0 MeV
3·6
3·0
2·4
1·8
1·2
0·6
σT (barn)
5·0
5·5
6·0
6·5
7·0
En(MeV)


Al
7.0 - 12 MeV
3.6
3.0
2.4
1.8
1.2
0.6
σ_T (barn)
8.0
9.0
10.0
11.0
12.0
E_n(MeV)

Al

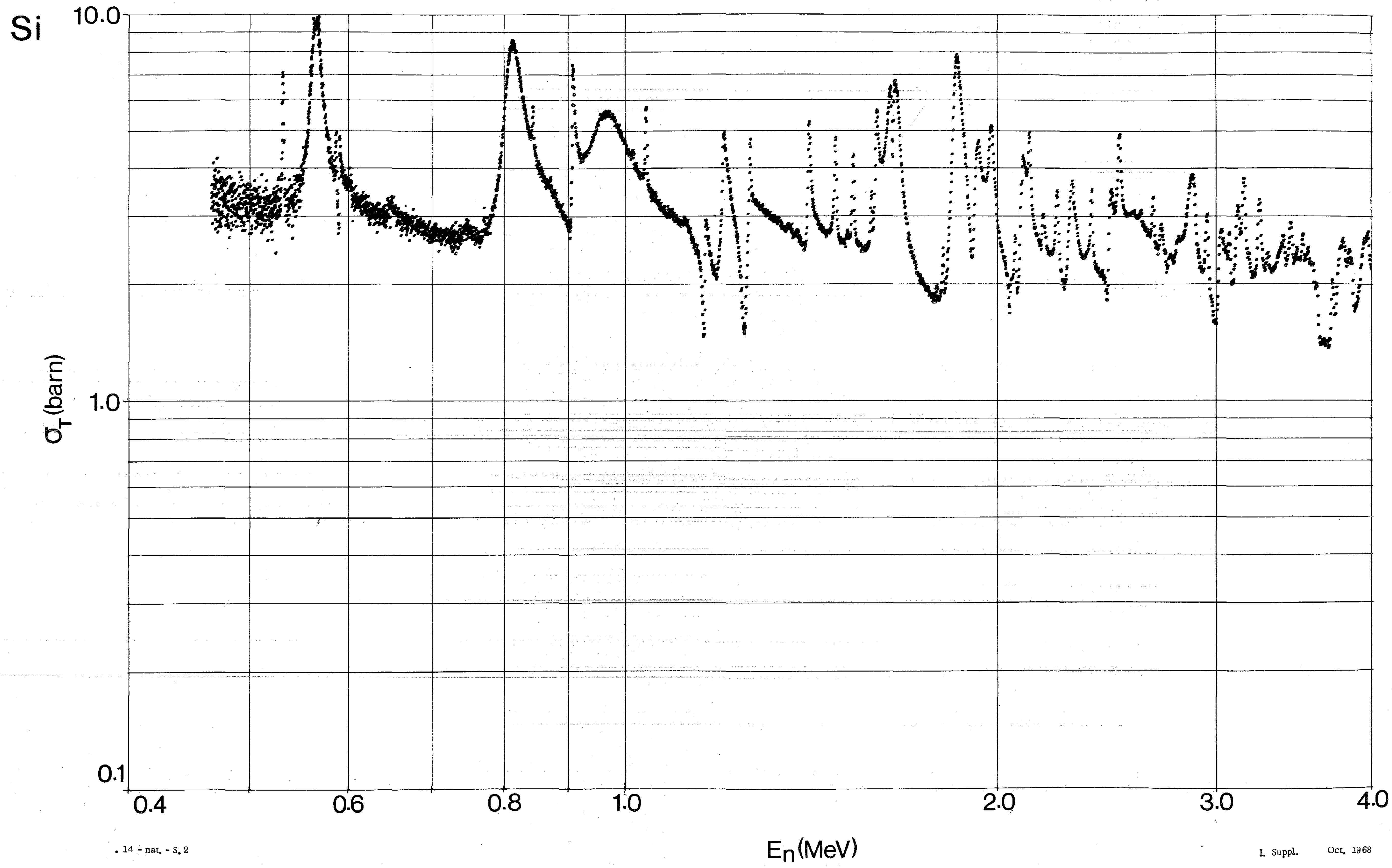


13 - nat. - S. 14 compl.

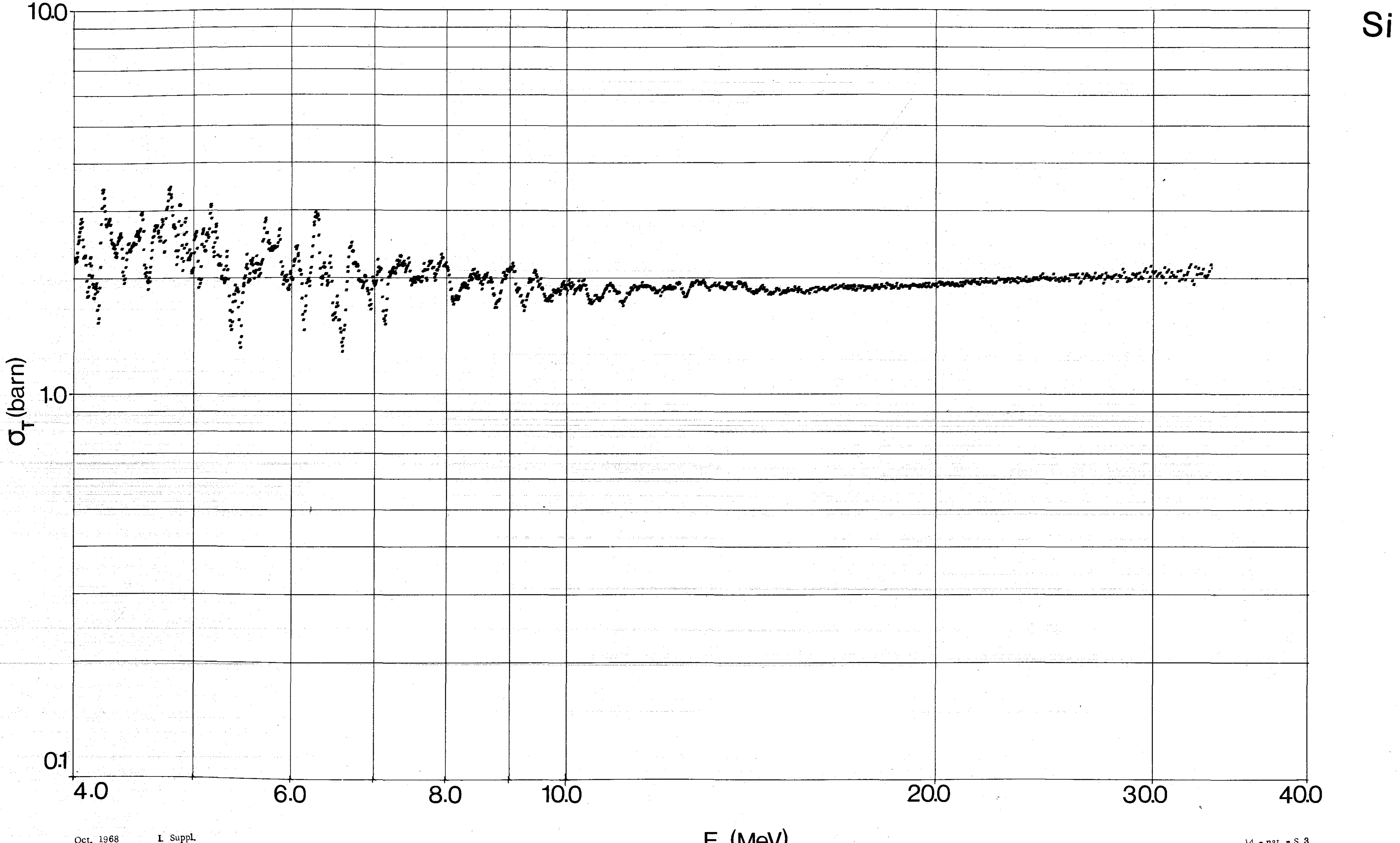
June 1968

Si

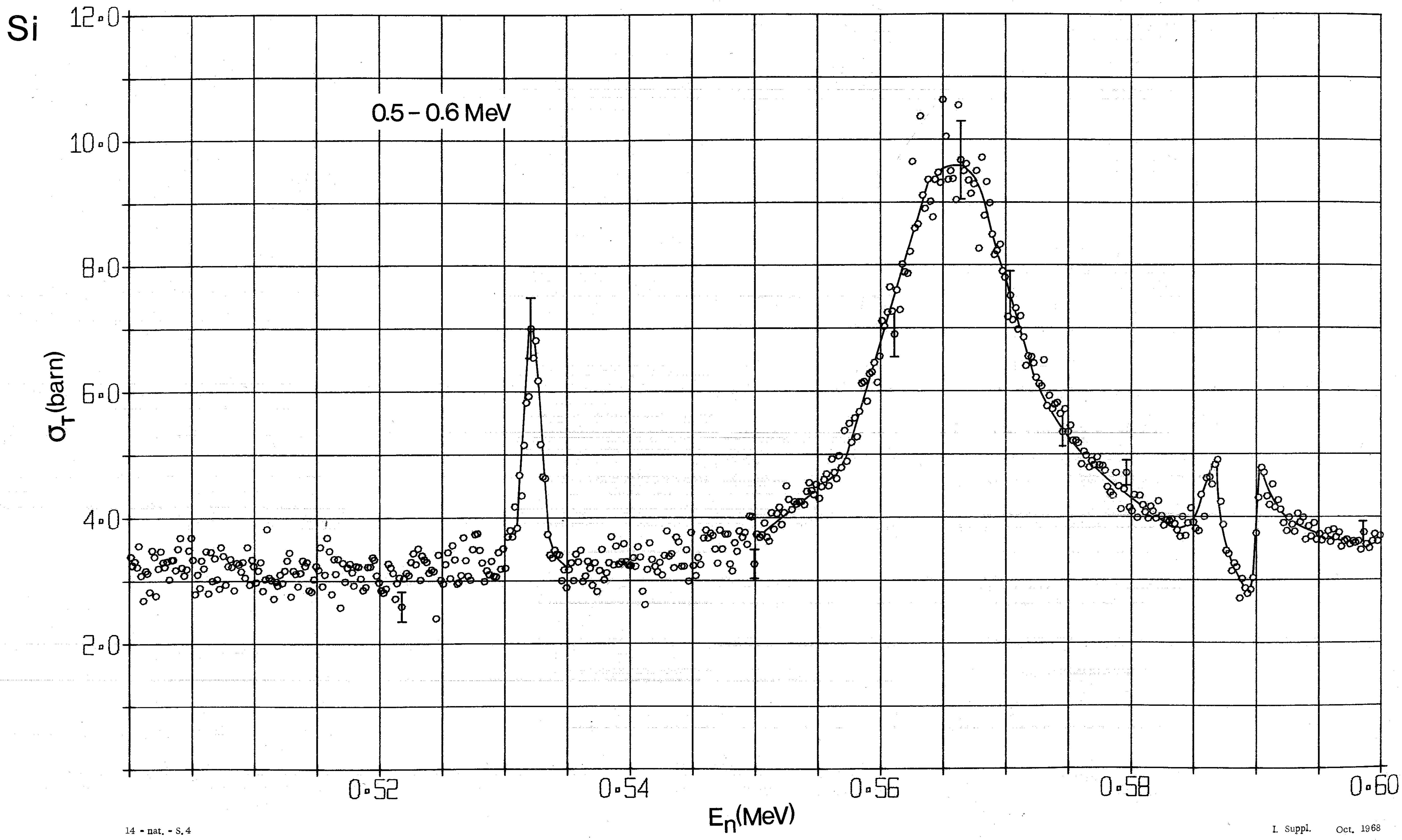
n	=	0.2363	At/barn
p	=	99.5	%
l	=	57.394	m
Δt	=	2.8	nsec
i	:	natural	



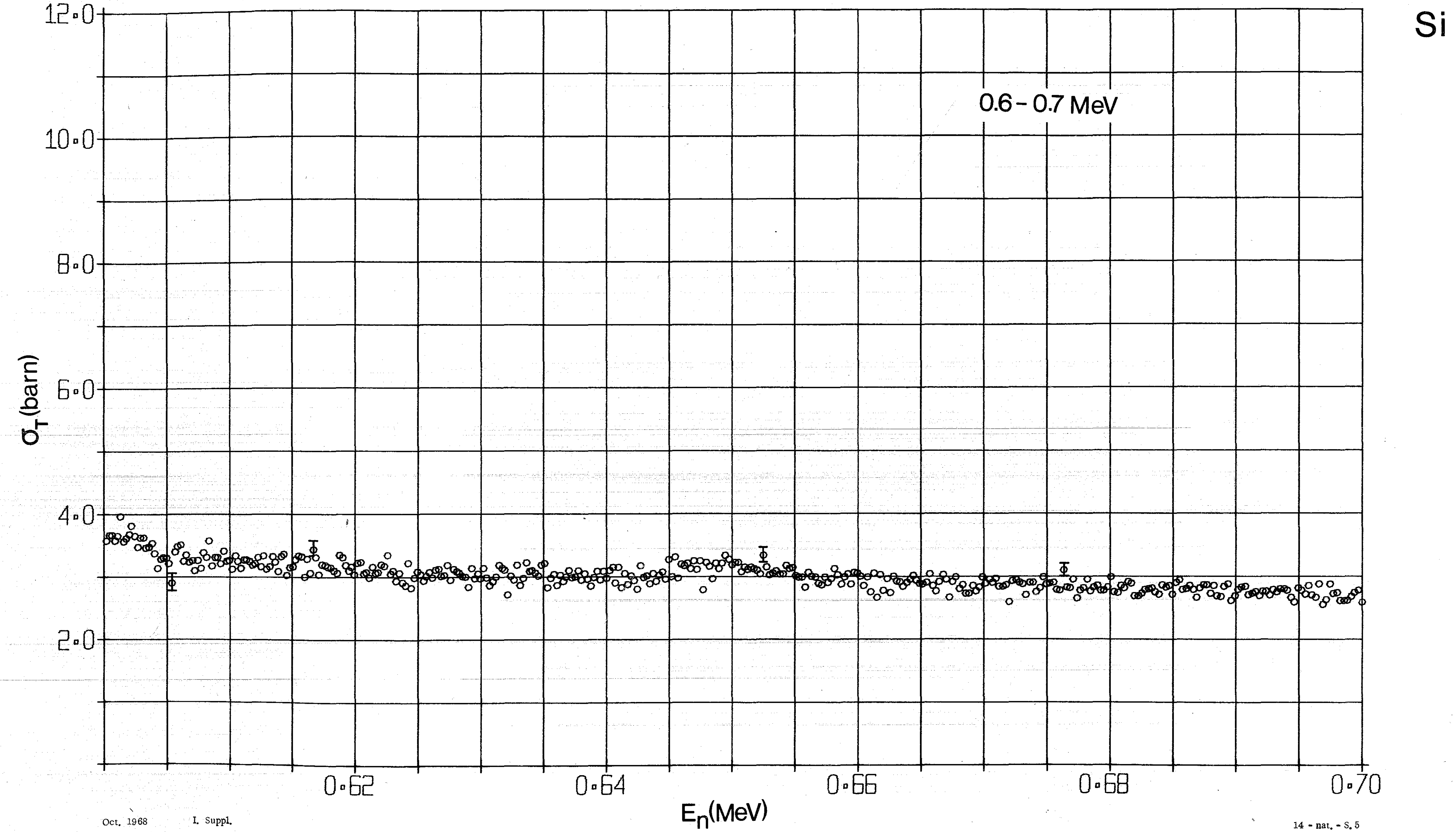
Si
10.0
1.0
0.1
σ_T (barn)
0.4
0.6
0.8
1.0
2.0
3.0
4.0
E_n (MeV)

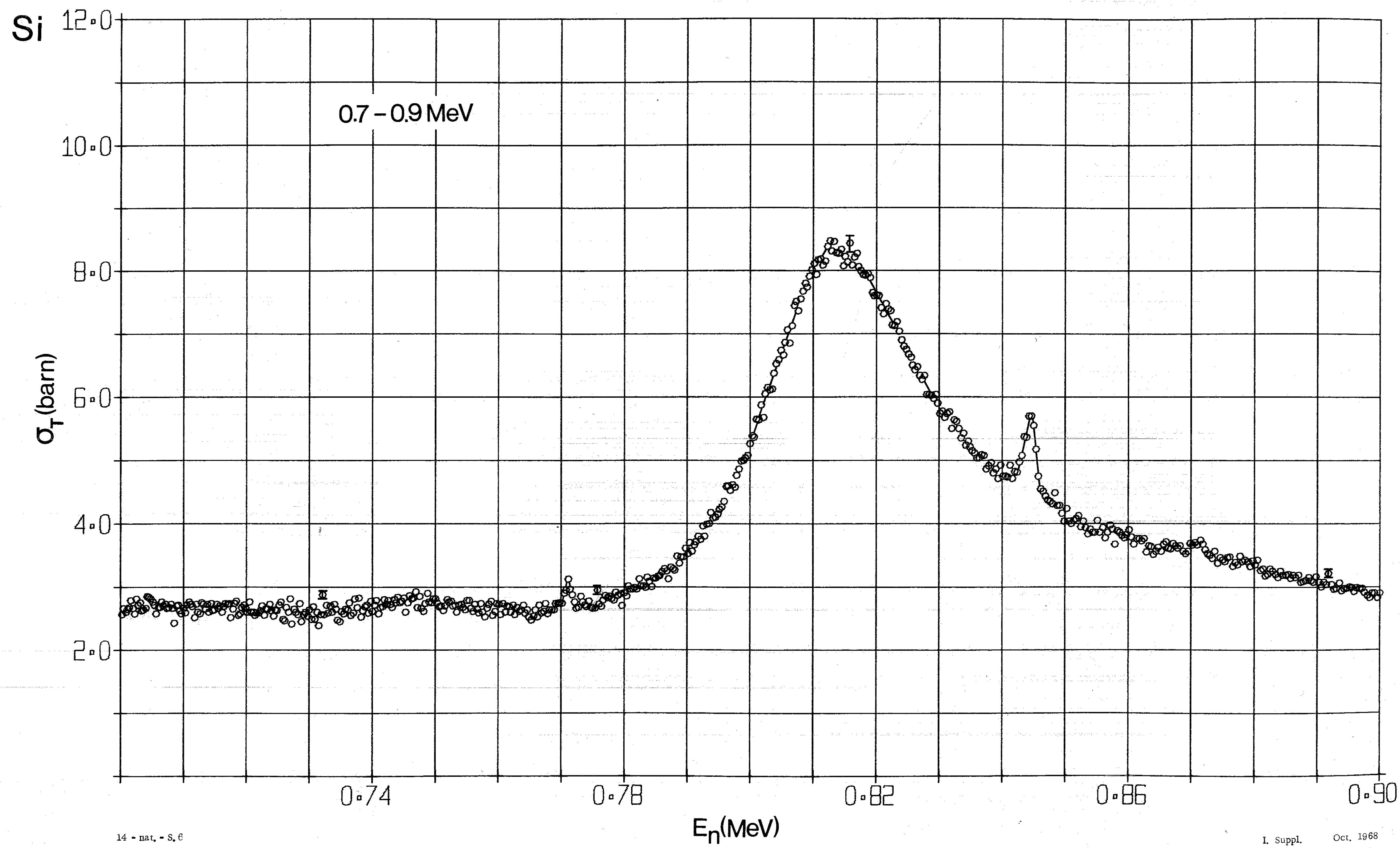


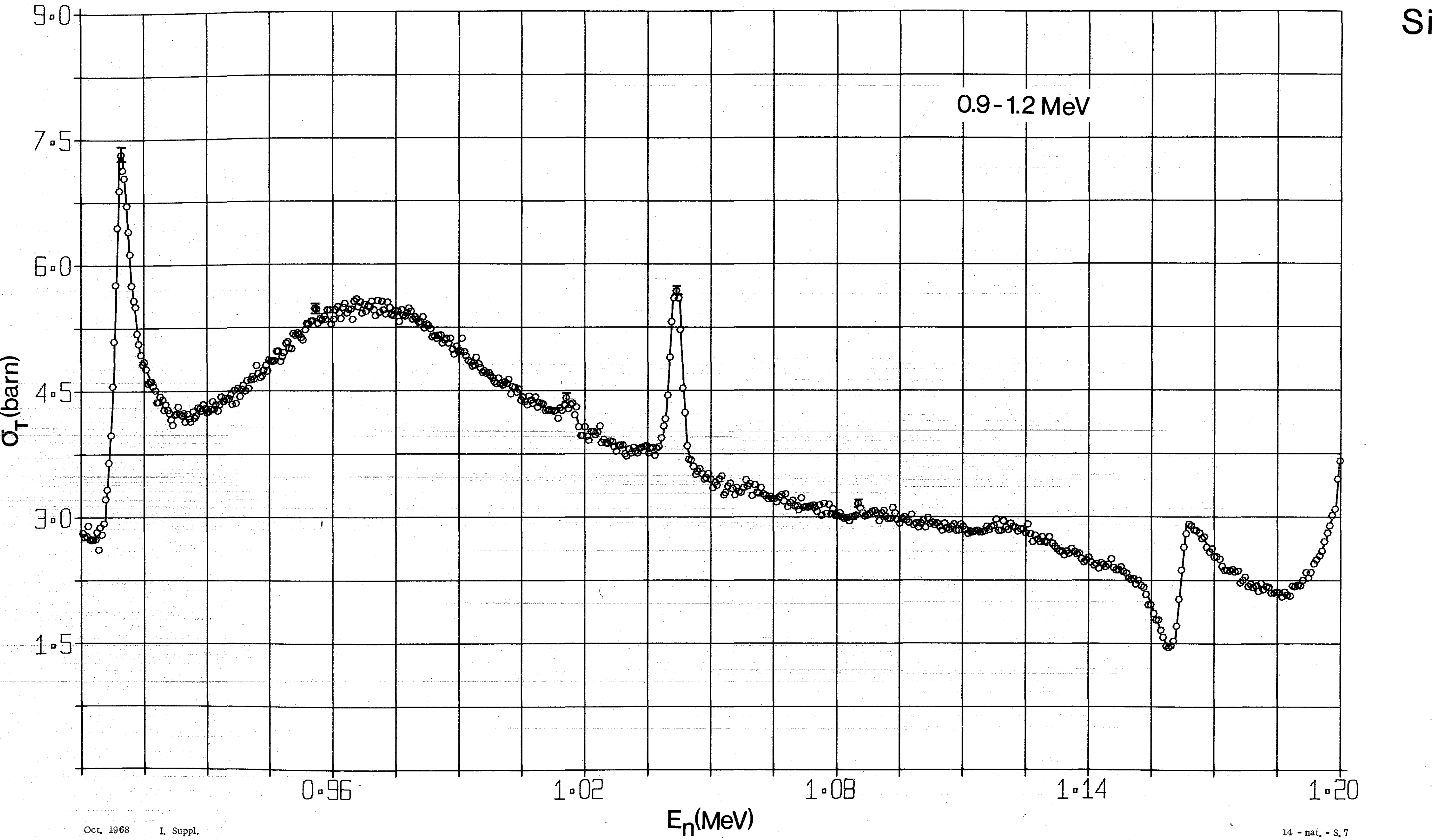
Si
10.0
1.0
0.1
σ_T (barn)
4.0
6.0
8.0
10.0
20.0
30.0
40.0
E_n(MeV)

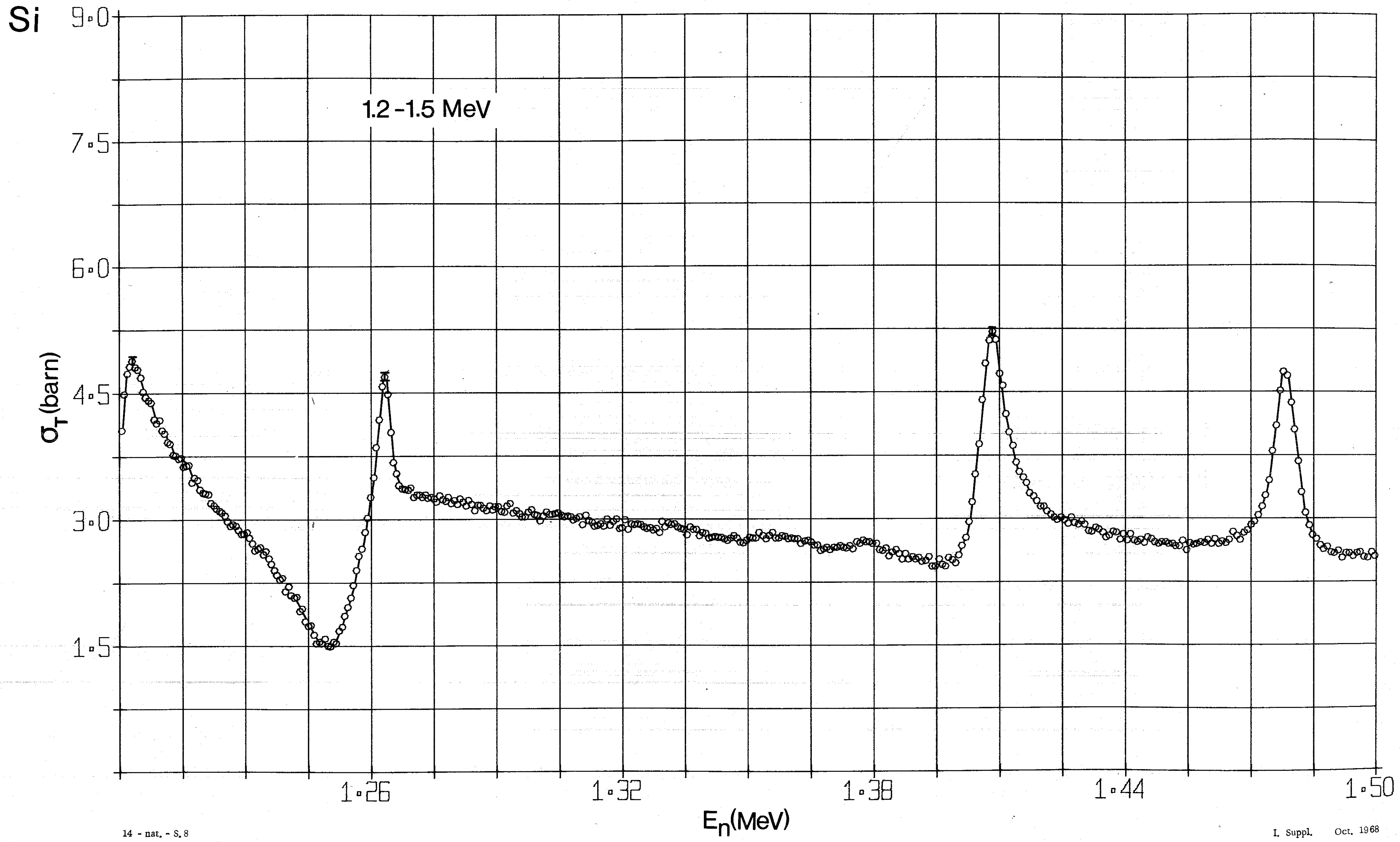


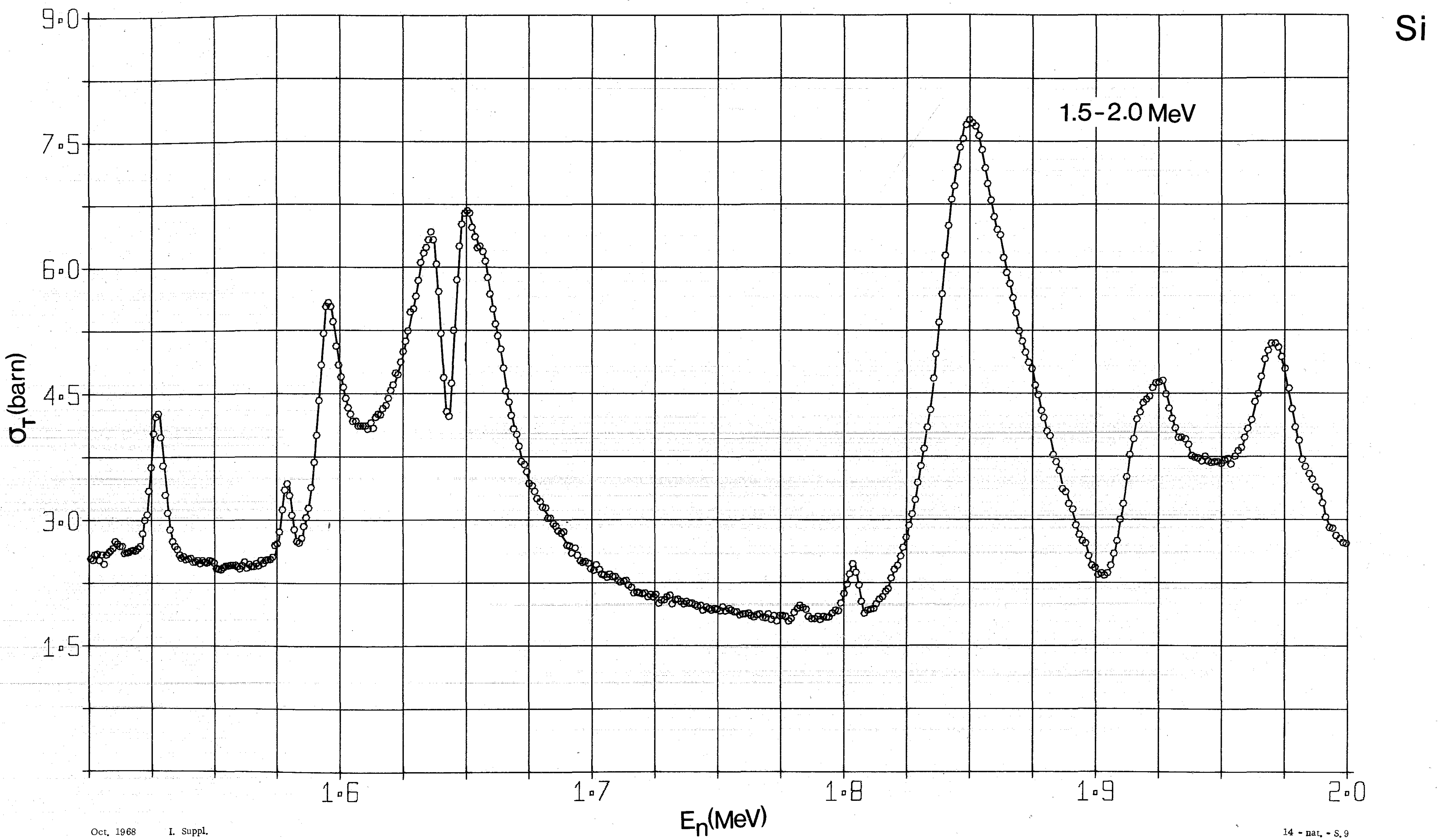
Si
0.5 - 0.6 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σT (barn)
0.52
0.54
0.56
0.58
0.60
En(MeV)

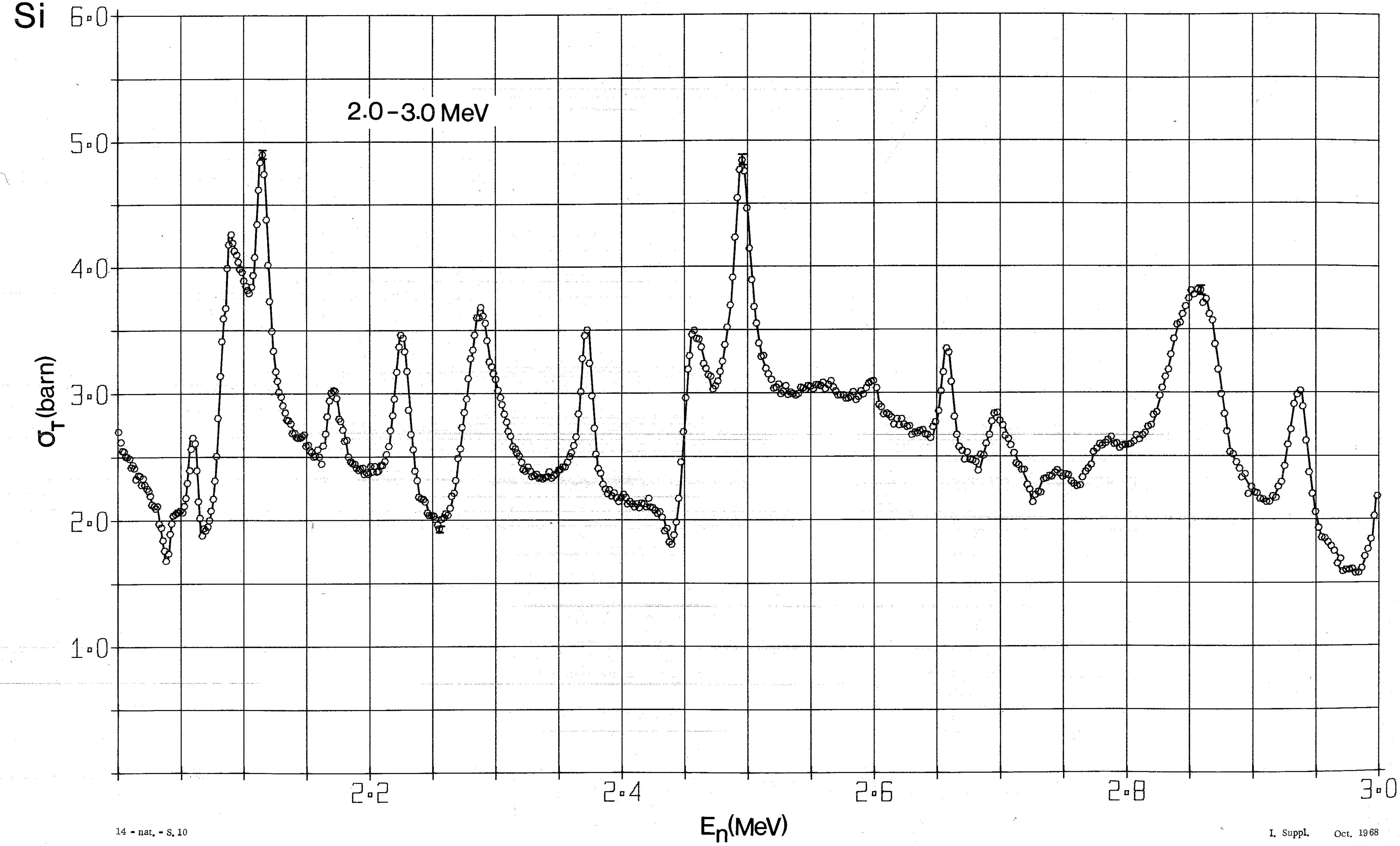

Si
0.6 - 0.7 MeV
12.0
10.0
8.0
6.0
4.0
2.0
σT (barn)
0.62
0.64
0.66
0.68
0.70
En(MeV)


Si
12.0
10.0
8.0
6.0
4.0
2.0
0.7 – 0.9 MeV
σT (barn)
0.74
0.78
0.82
0.86
0.90
En(MeV)

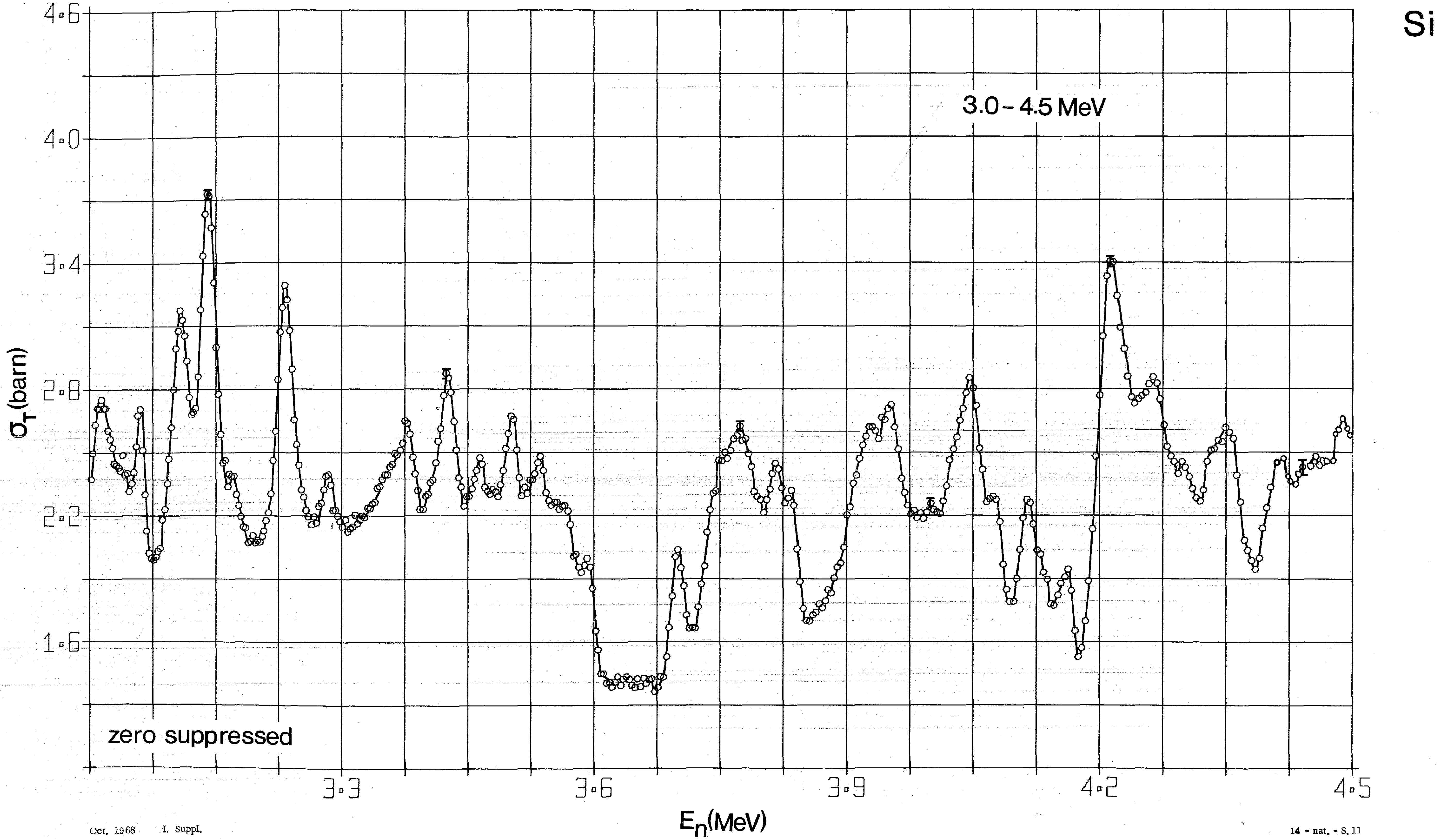

Si
0.9-1.2 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σ_T (barn)
0·96
1·02
1·08
1·14
1·20
E_n(MeV)

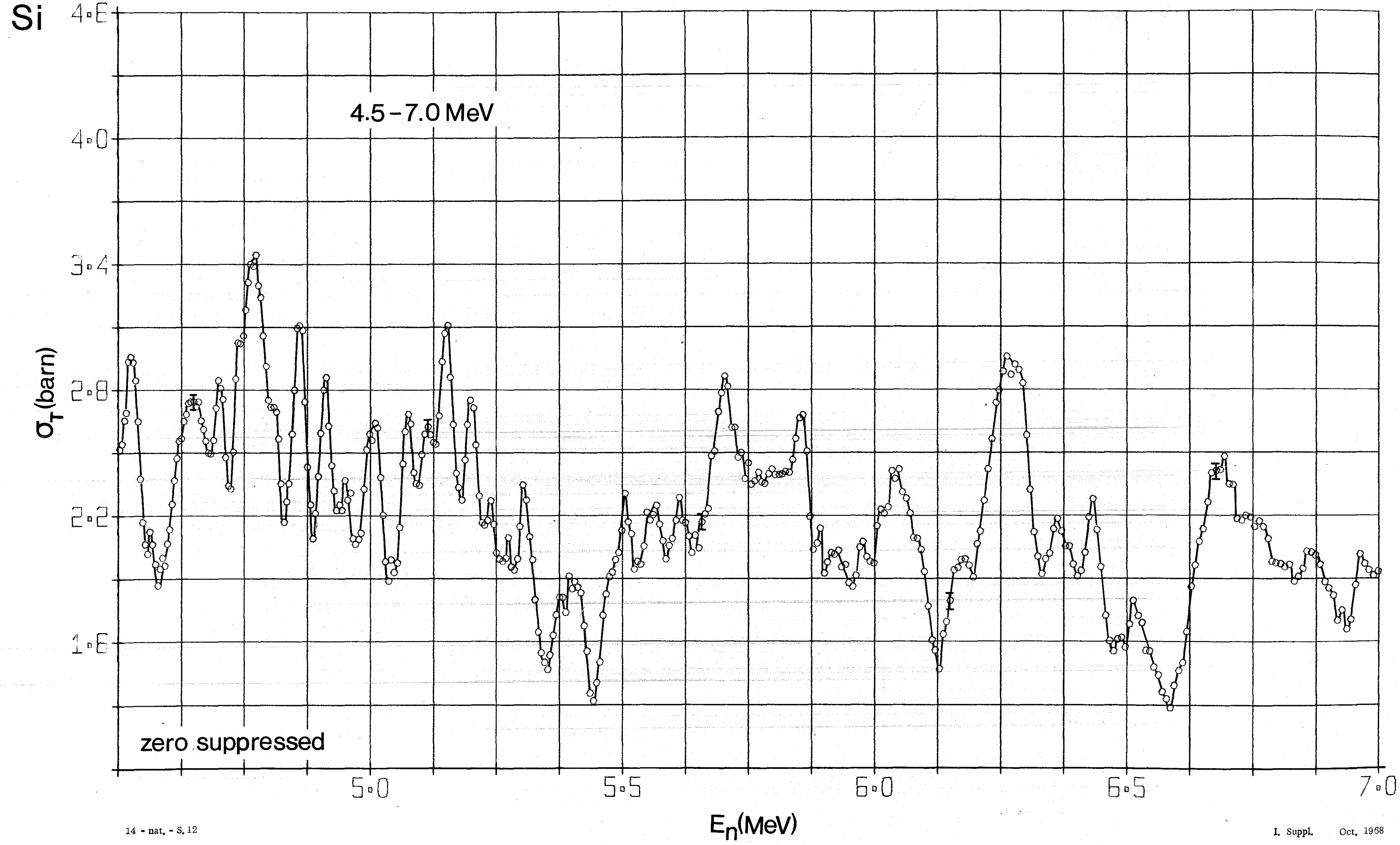

Si
9·0
7·5
6·0
4·5
3·0
1·5
1.2 -1.5 MeV
σT (barn)
1·26
1·32
1·38
1·44
1·50
En(MeV)


Si
1.5-2.0 MeV
9.0
7.5
6.0
4.5
3.0
1.5
σ_T (barn)
1.6
1.7
1.8
1.9
2.0
E_n(MeV)

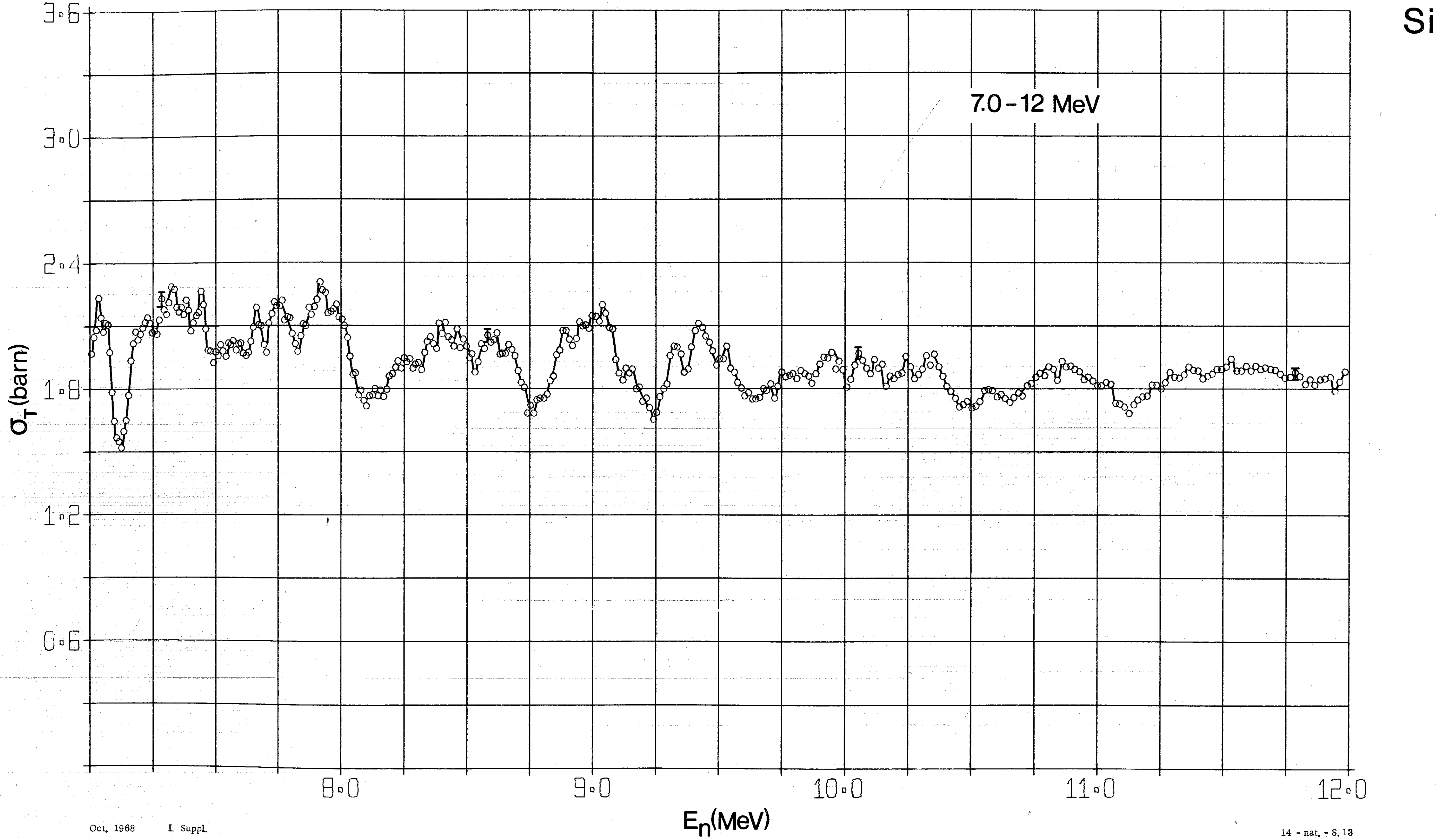


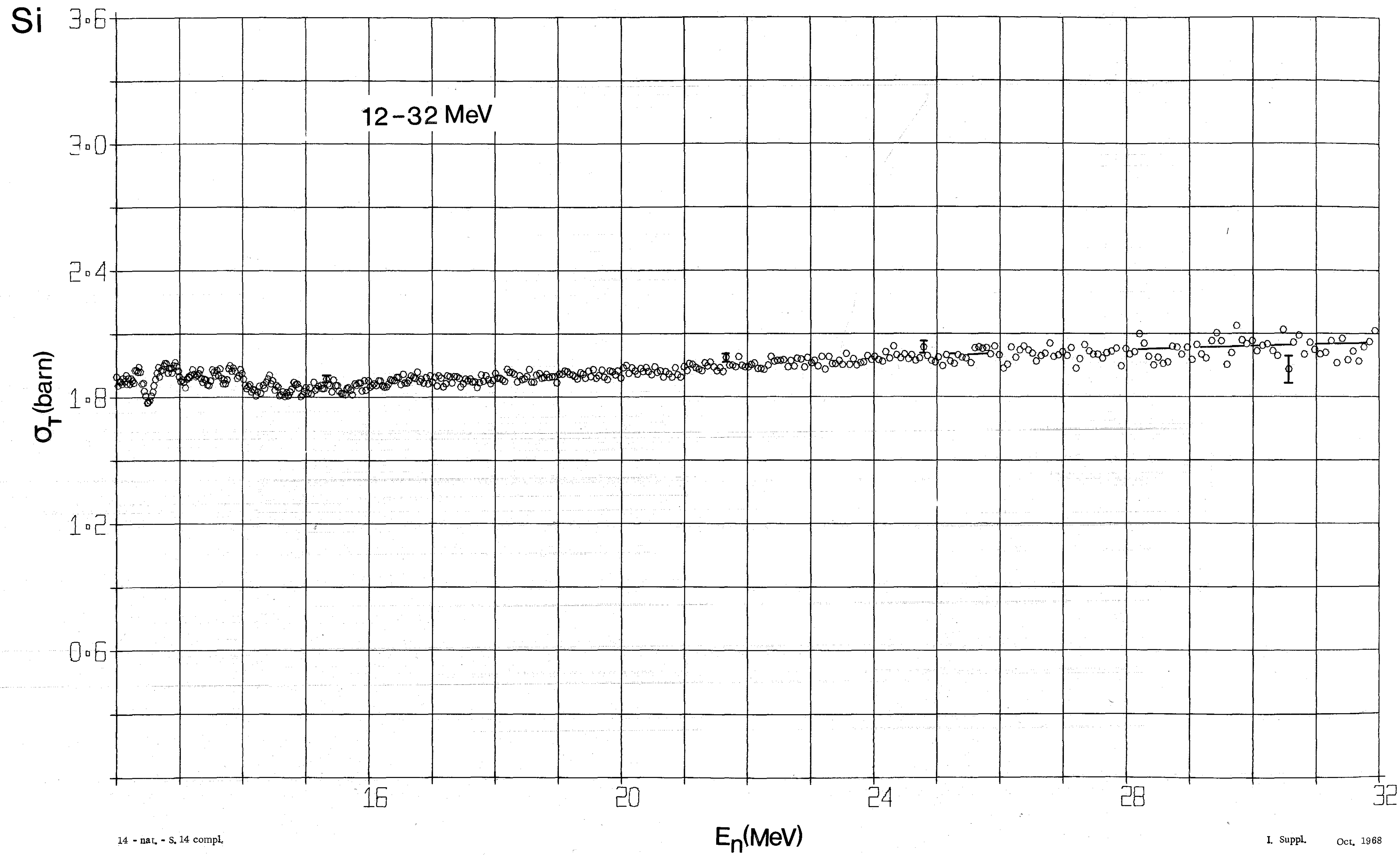
Si
2.0-3.0 MeV
6.0
5.0
4.0
3.0
2.0
1.0
σT(barn)
2.2
2.4
2.6
2.8
3.0
En(MeV)


Si
3.0 - 4.5 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σT (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
En(MeV)



Si
4.5-7.0 MeV
zero suppressed
4·6
4·0
3·4
2·8
2·2
1·6
σ_T(barn)
5·0
5·5
6·0
6·5
7·0
E_n(MeV)


Si
7.0 - 12 MeV
3·6
3·0
2·4
1·8
1·2
0·6
σT (barn)
8·0
9·0
10·0
11·0
12·0
En(MeV)



Si
3·6
3·0
2·4
1·8
1·2
0·6
12-32 MeV
σ_T(barn)
16
20
24
28
32
E_n(MeV)

S

n = 0.3006 at/barn (0.5 - 4.4 MeV)

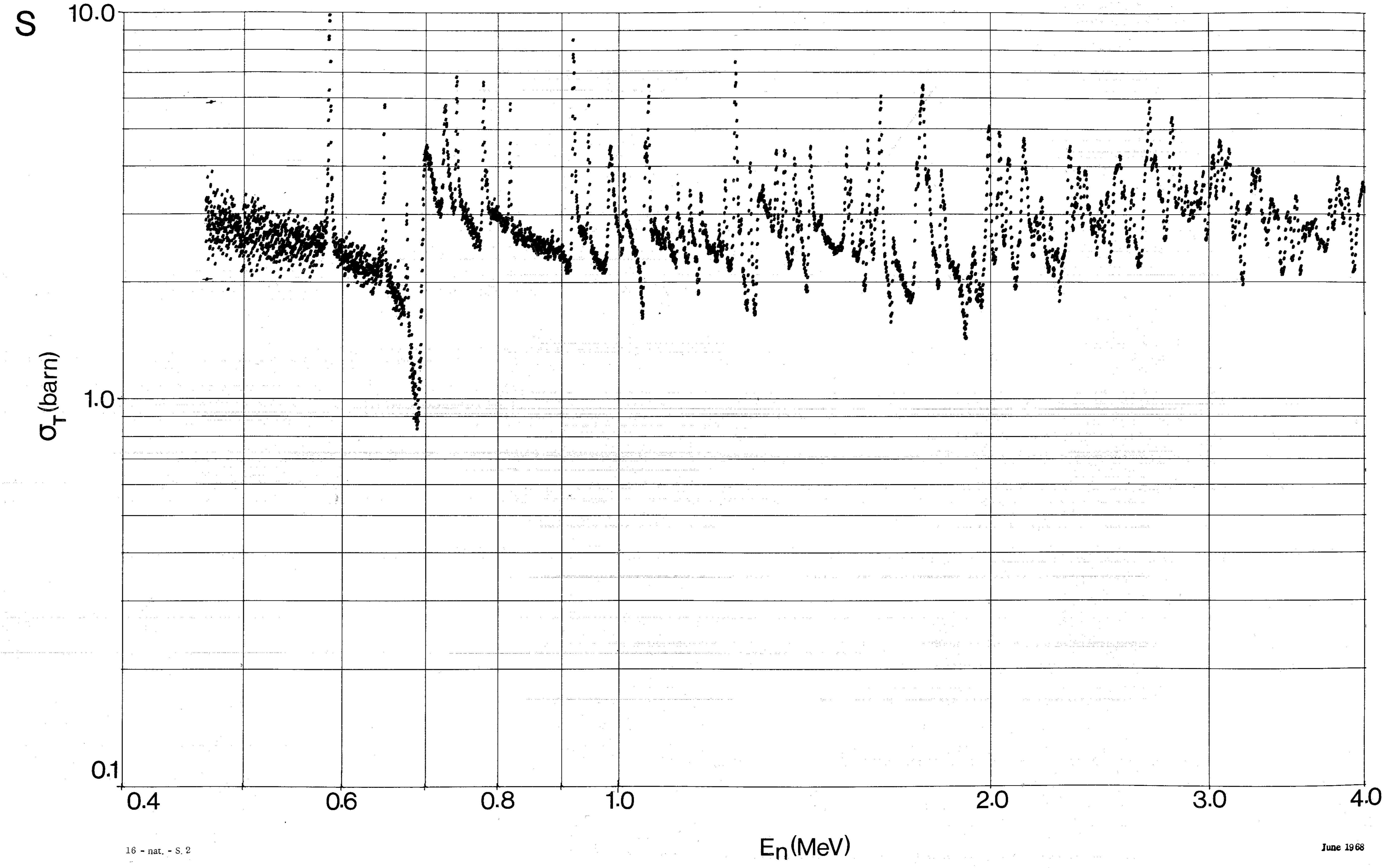
n = 0.1033 at/barn (4.4 - 32.0 MeV)

p = 98.0 %

l = 57.394 m

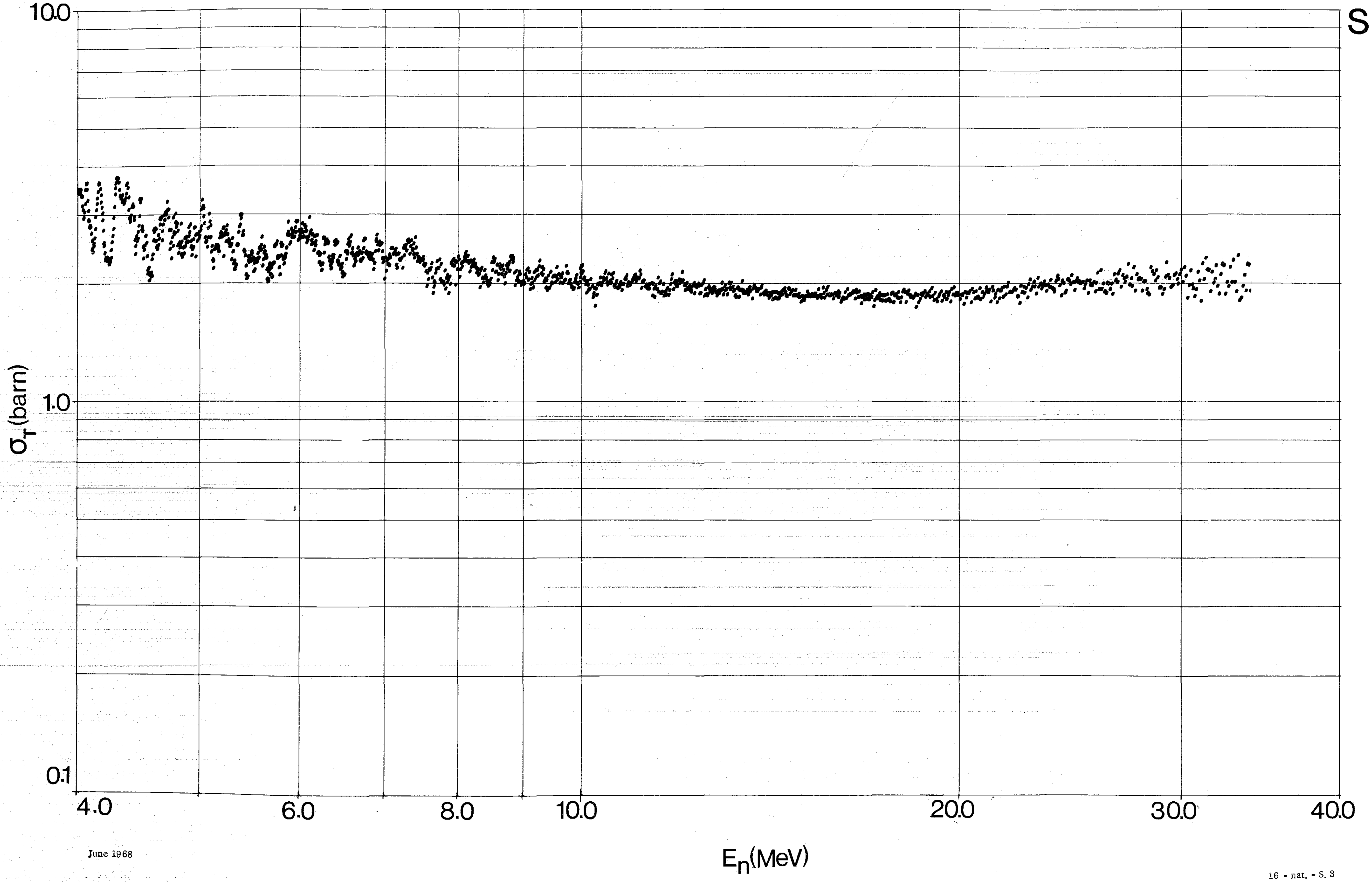
Δt = 2.6 nsec

i : natural

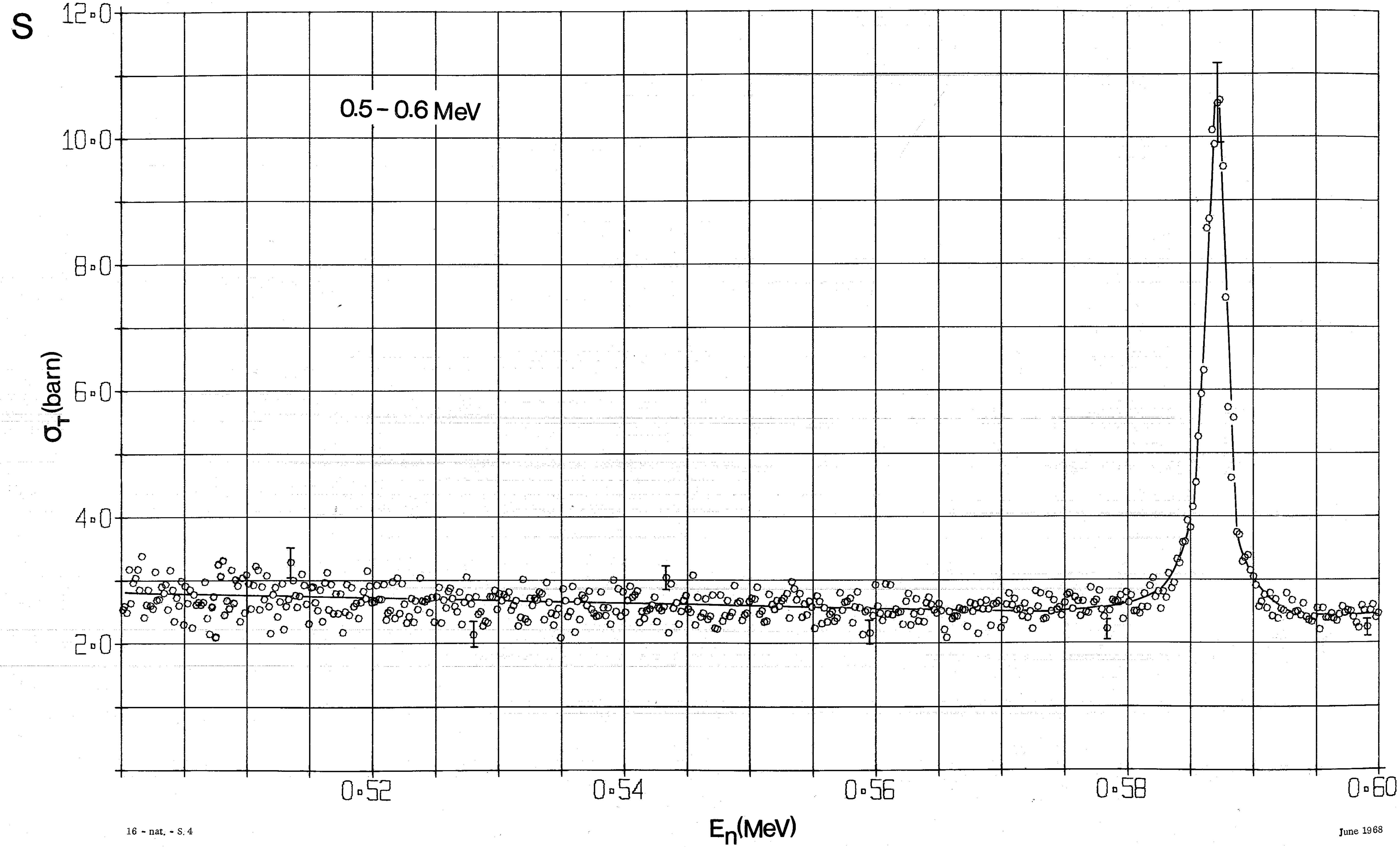


16 - nat. - S. 2

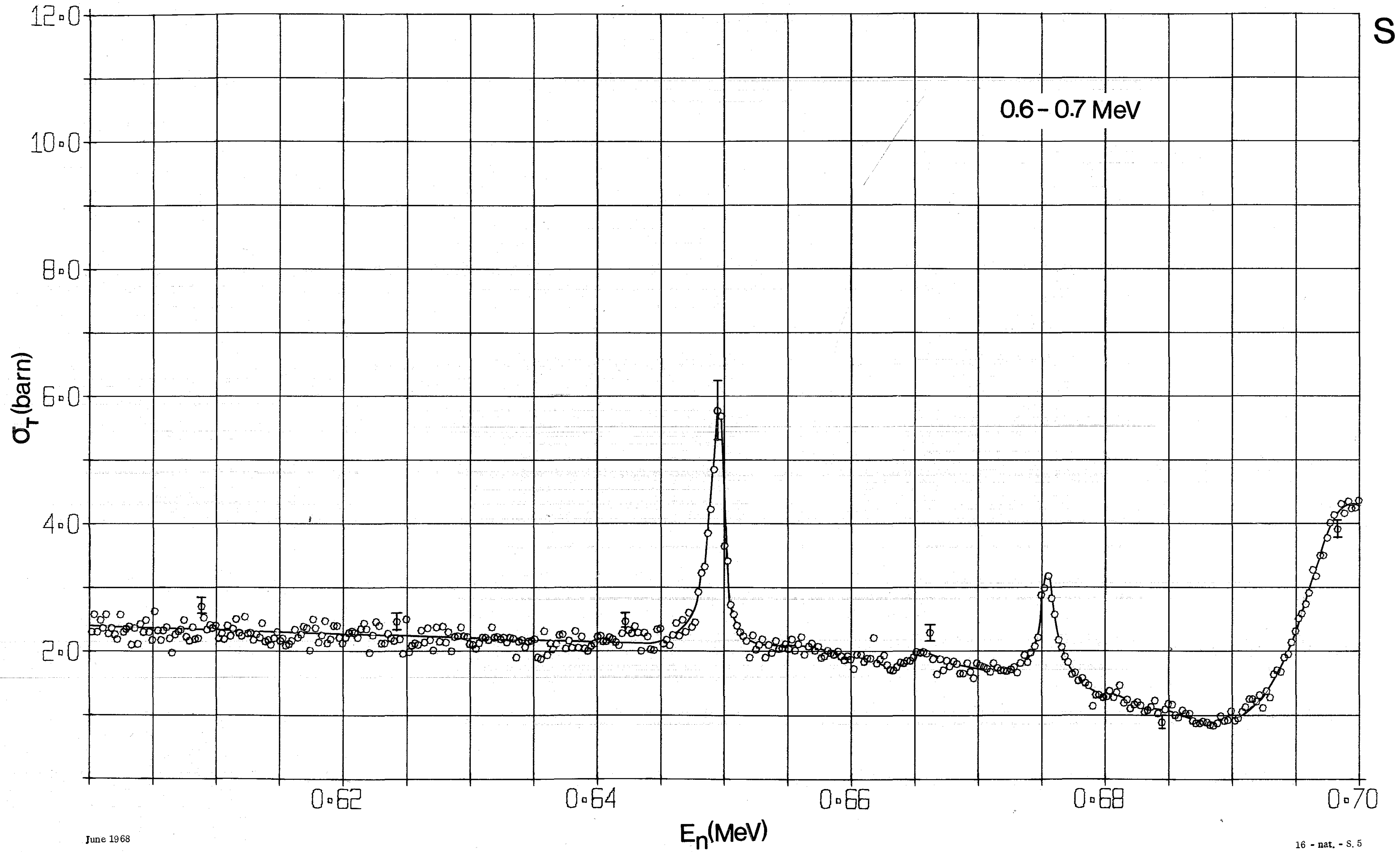
June 1968



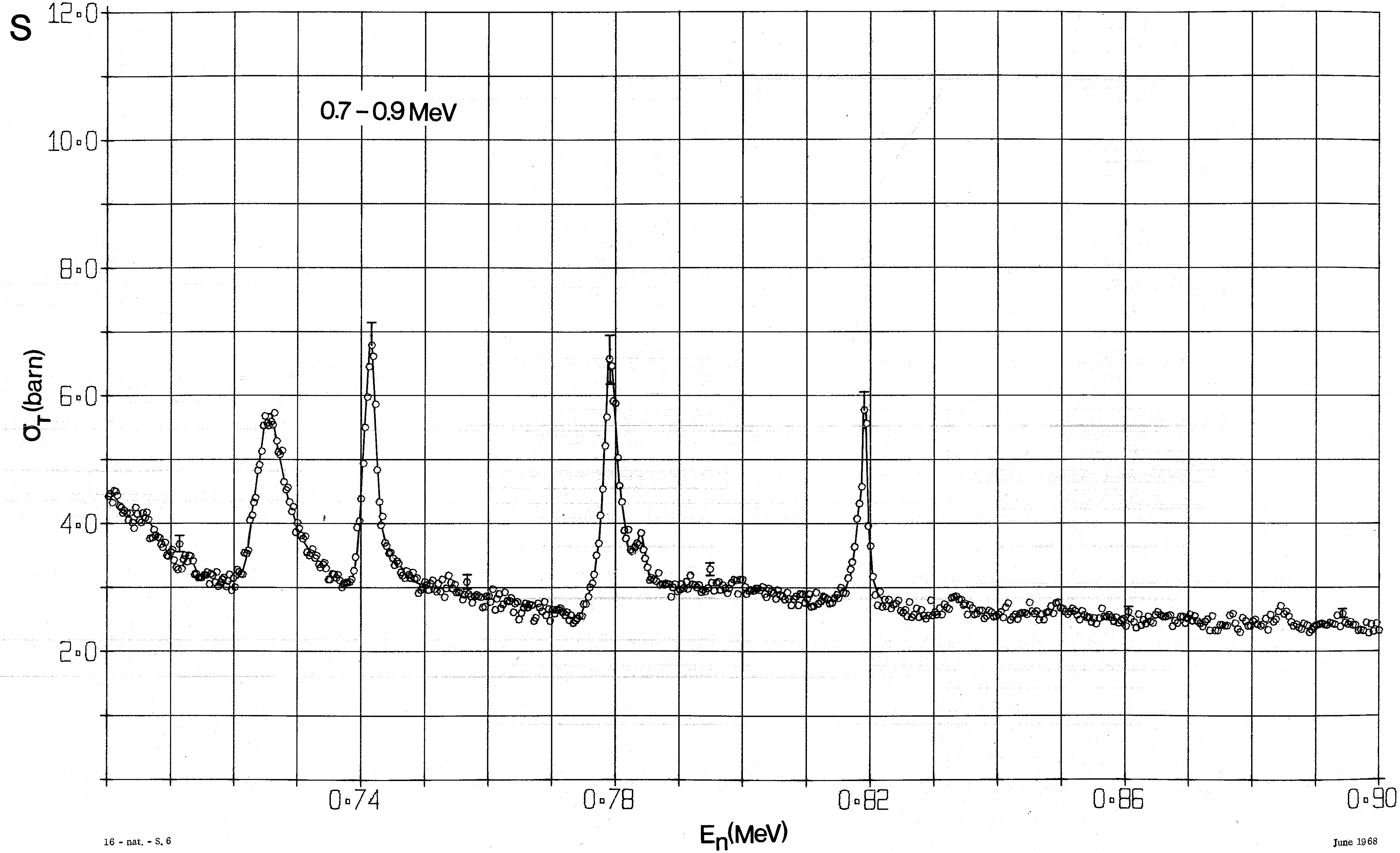
June 1968

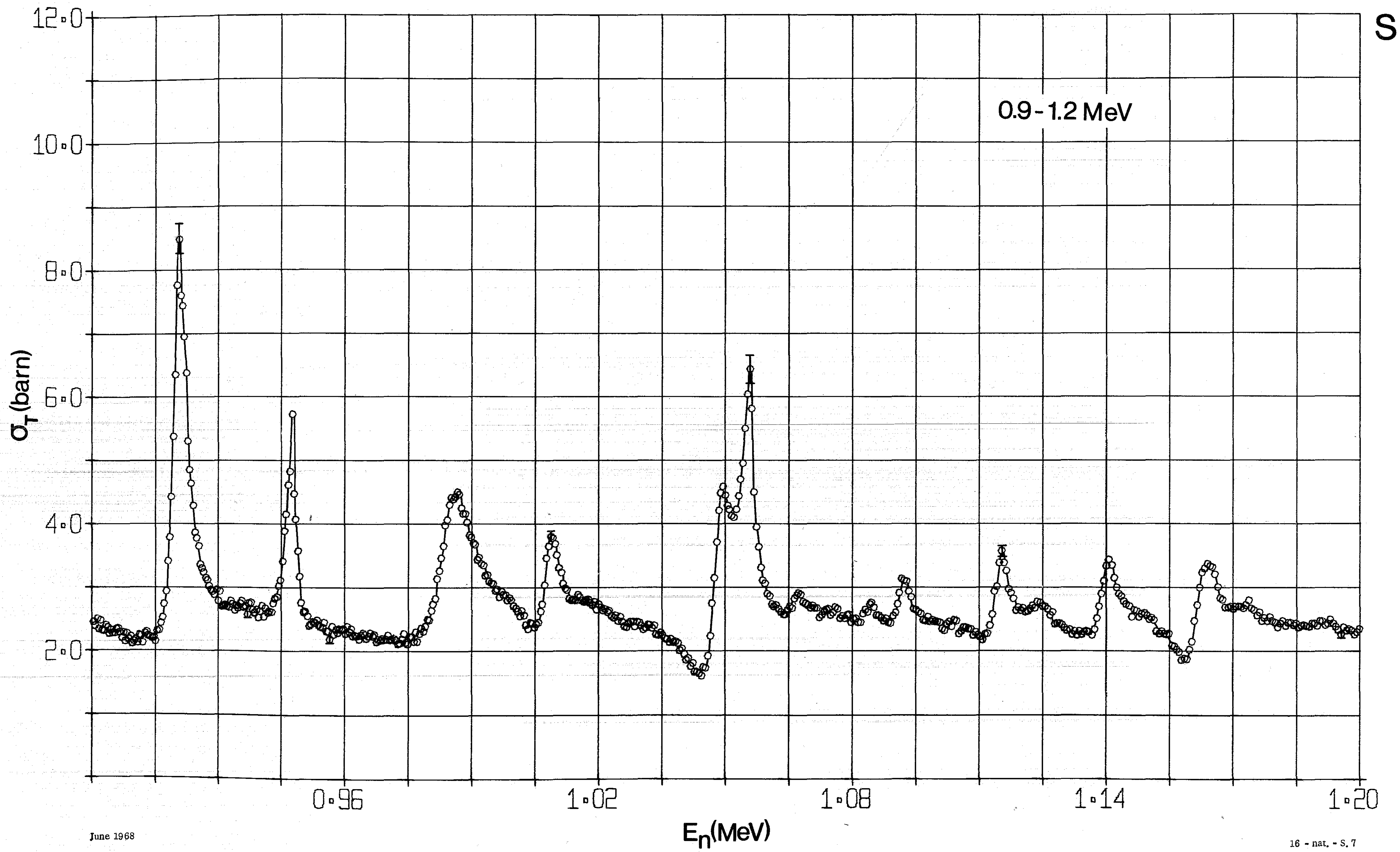


June 1968



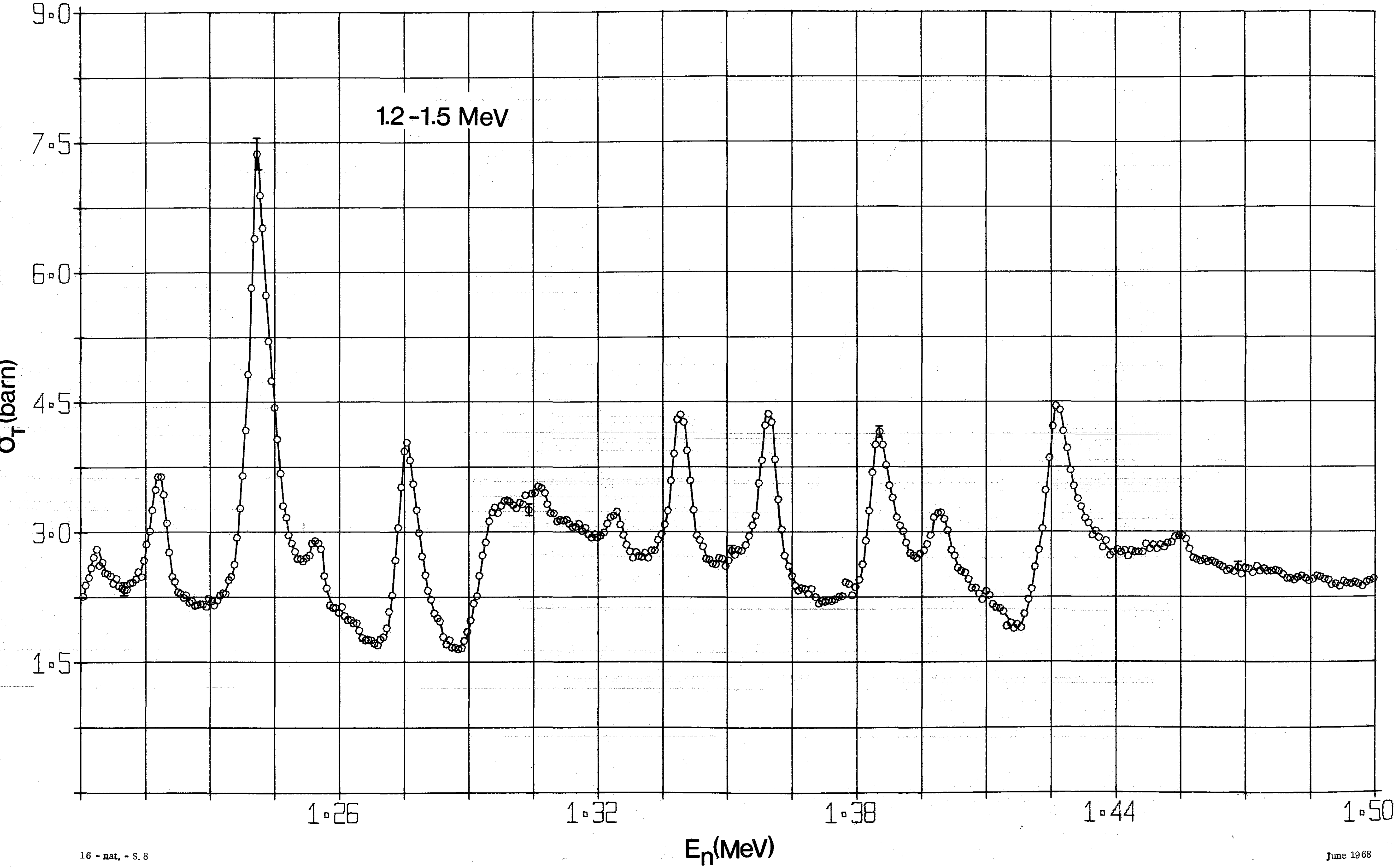
June 1968


S
0.7 – 0.9 MeV
σ_T (barn)
12·0
10·0
8·0
6·0
4·0
2·0
0·74
0·78
0·82
0·86
0·90
E_n(MeV)



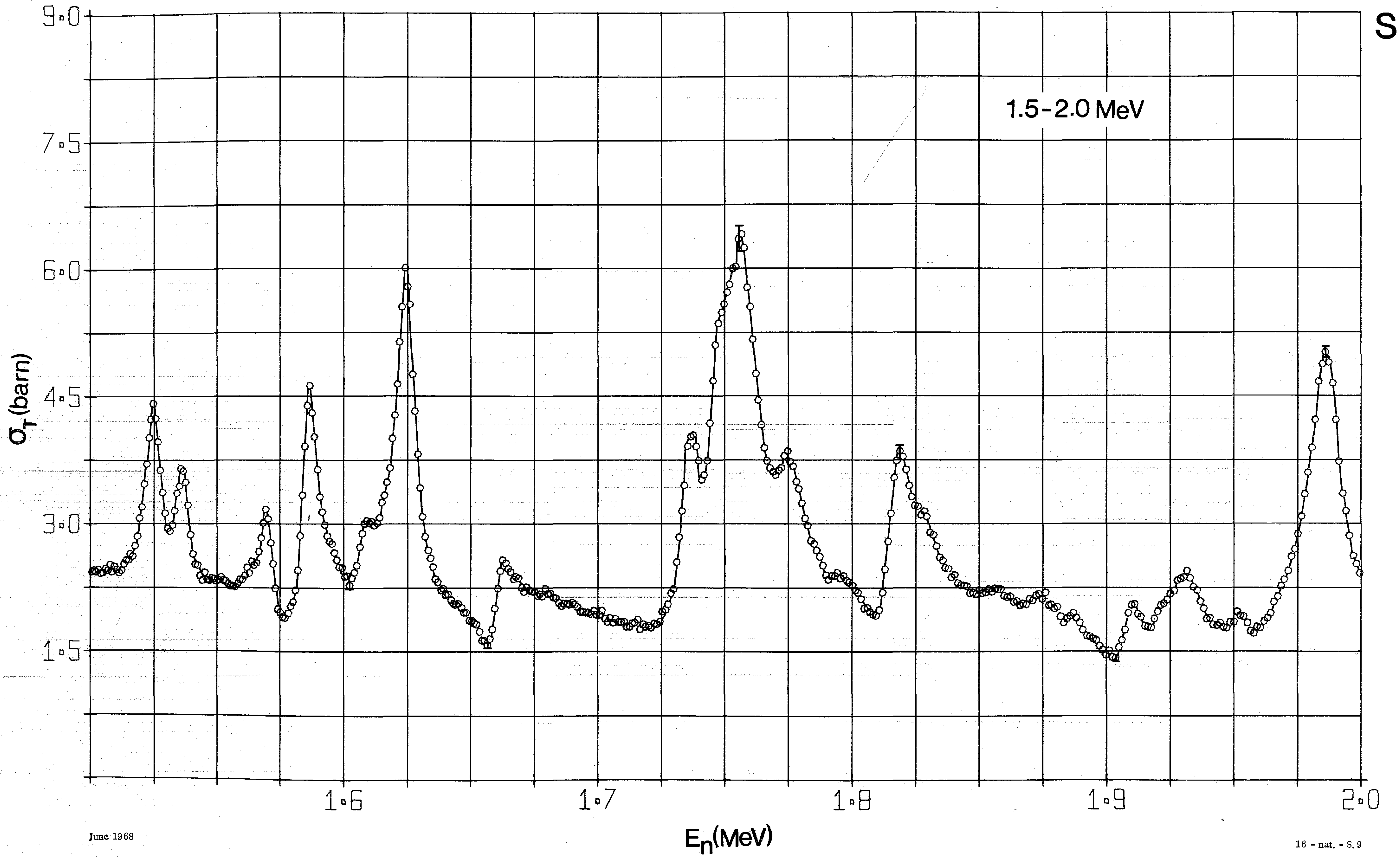
S
0.9 - 1.2 MeV
12·0
10·0
8·0
6·0
4·0
2·0
σT (barn)
0·96
1·02
1·08
1·14
1·20
En(MeV)

S

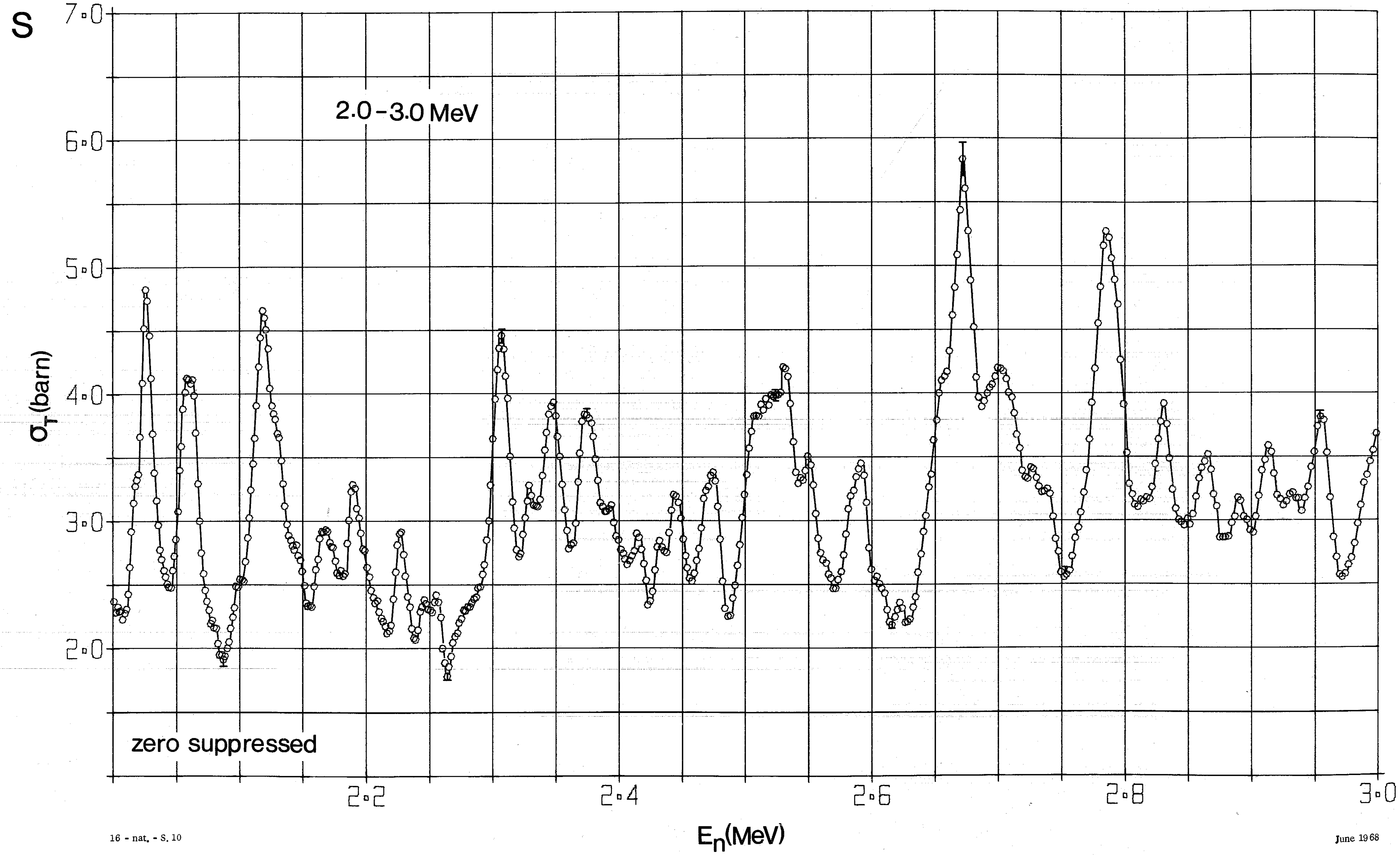


16 - nat. - S. 8

June 1968

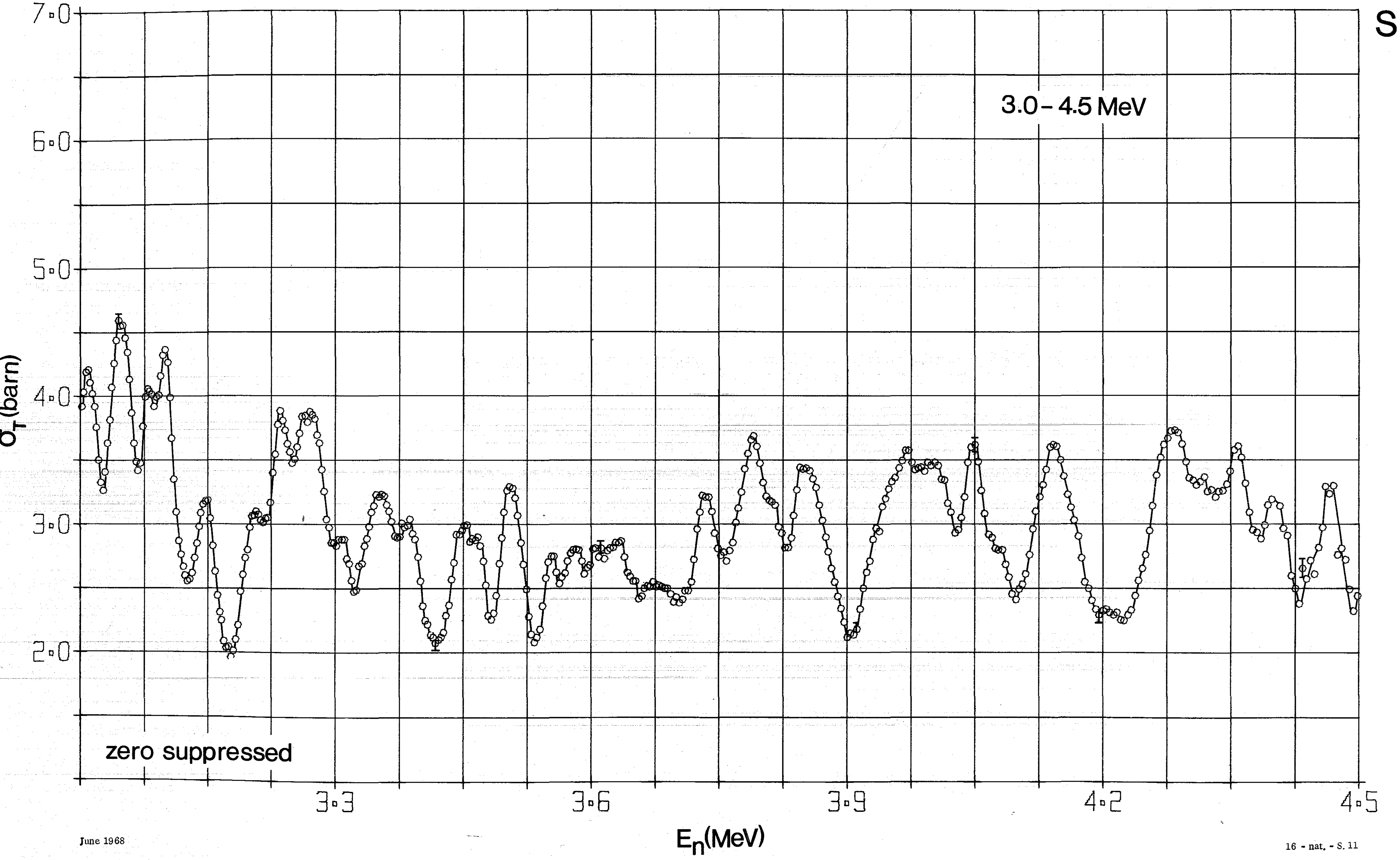


June 1968

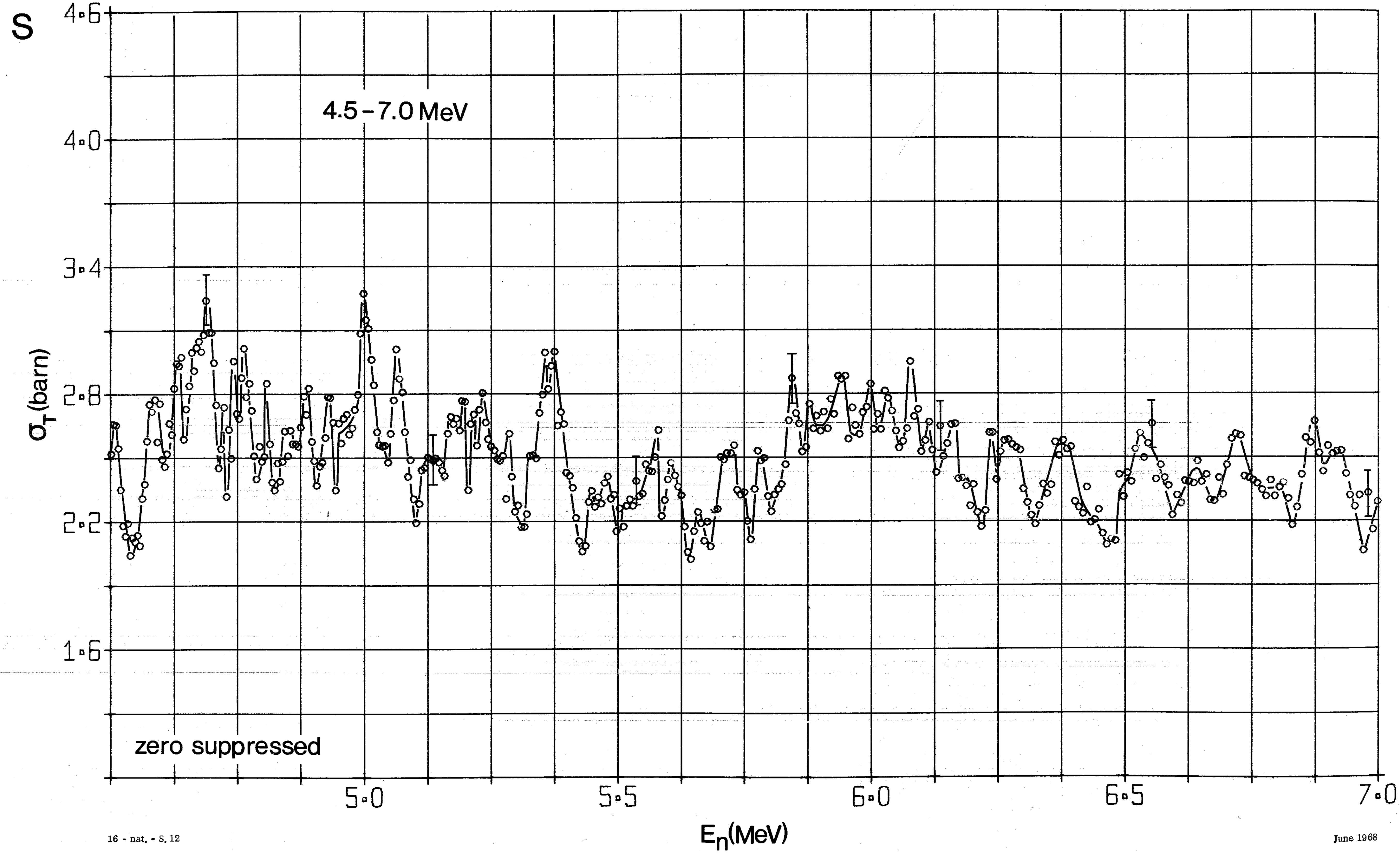


16 - nat. - S. 10

June 1968

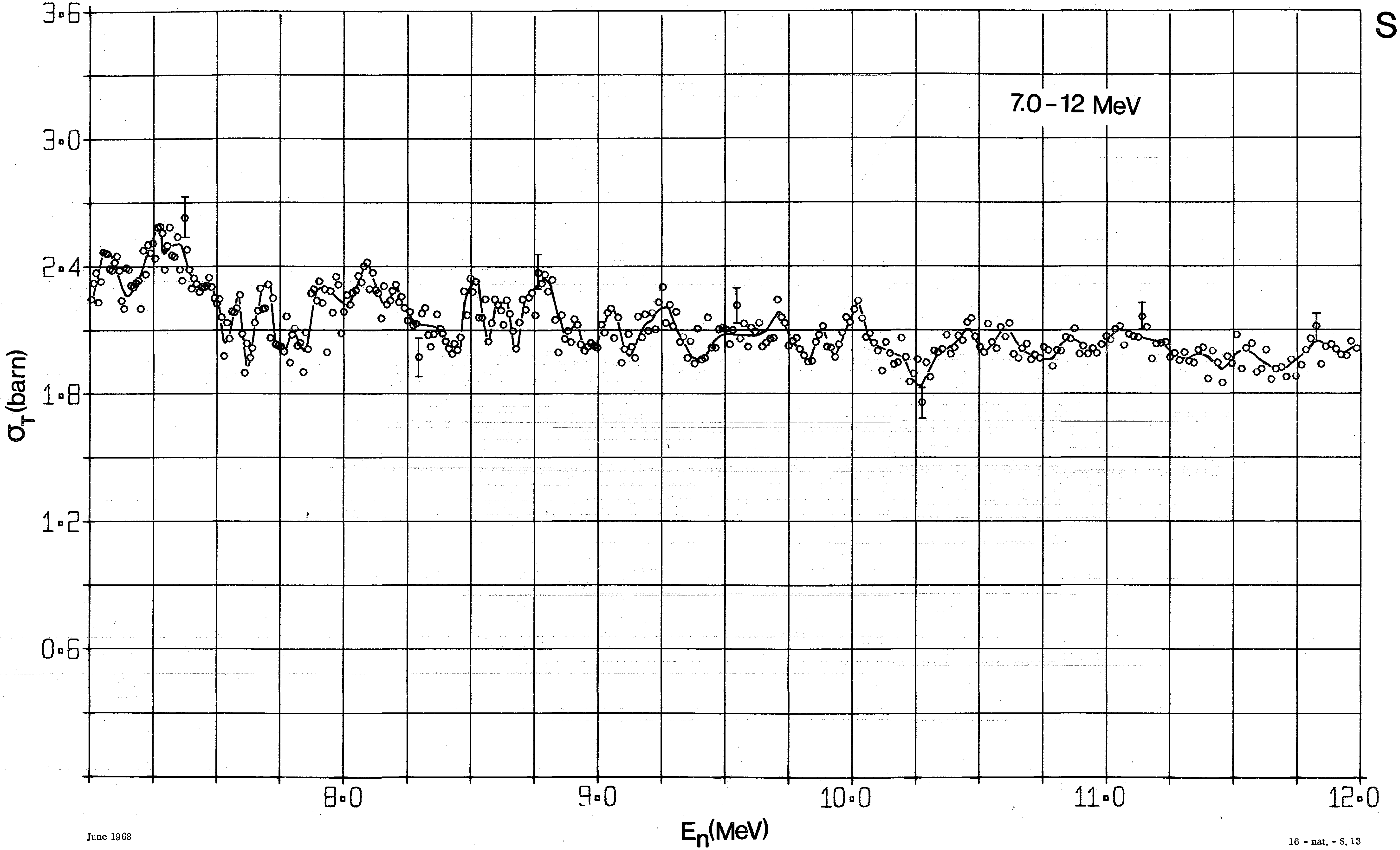


S
3.0 - 4.5 MeV
7·0
6·0
5·0
4·0
3·0
2·0
σ_T (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
E_n(MeV)



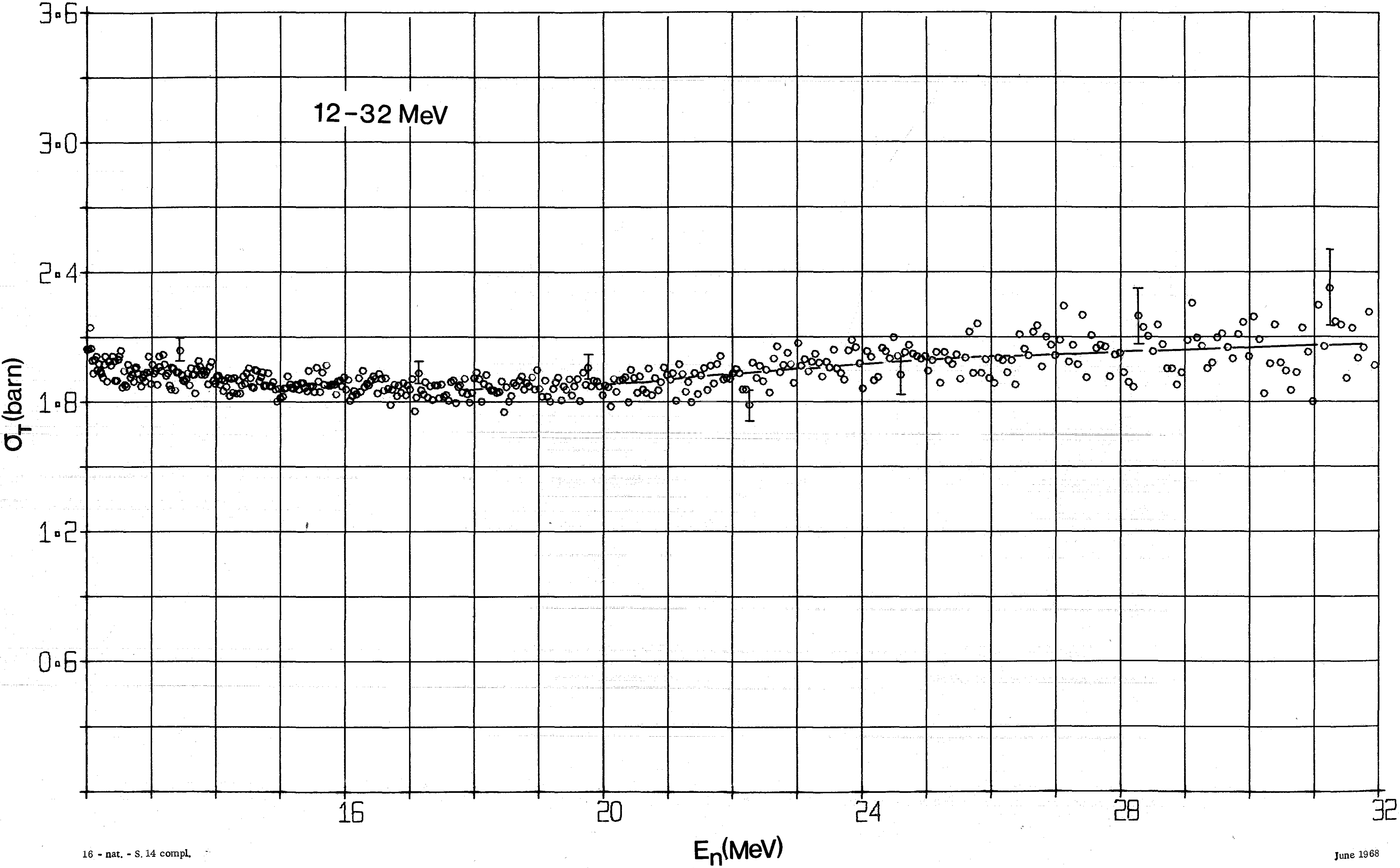
16 - nat. - S. 12

June 1968



June 1968

S



16 - nat. - S. 14 compl.

June 1968

Cl

n = 0.2620 At/barn

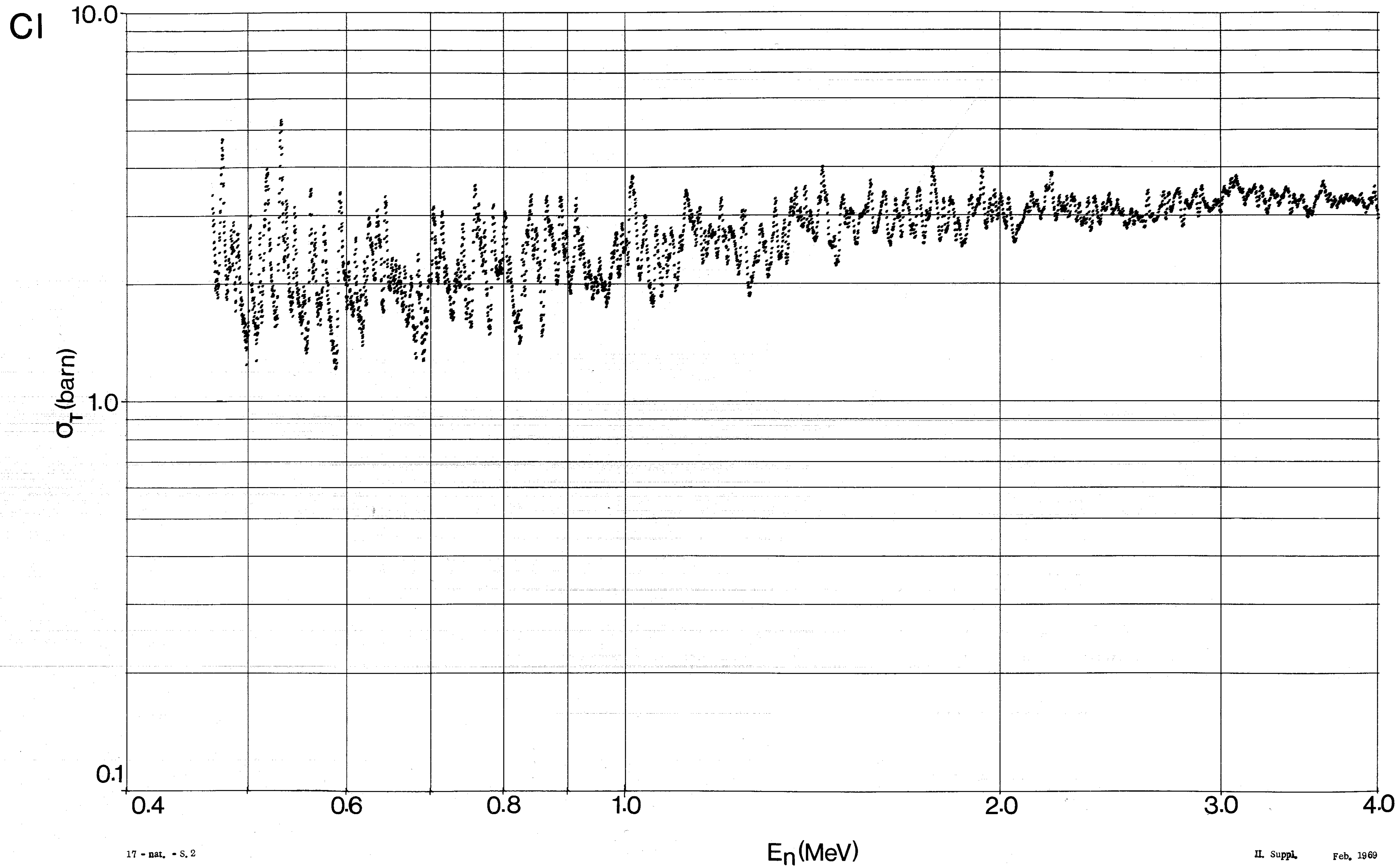
p = 99.0 %

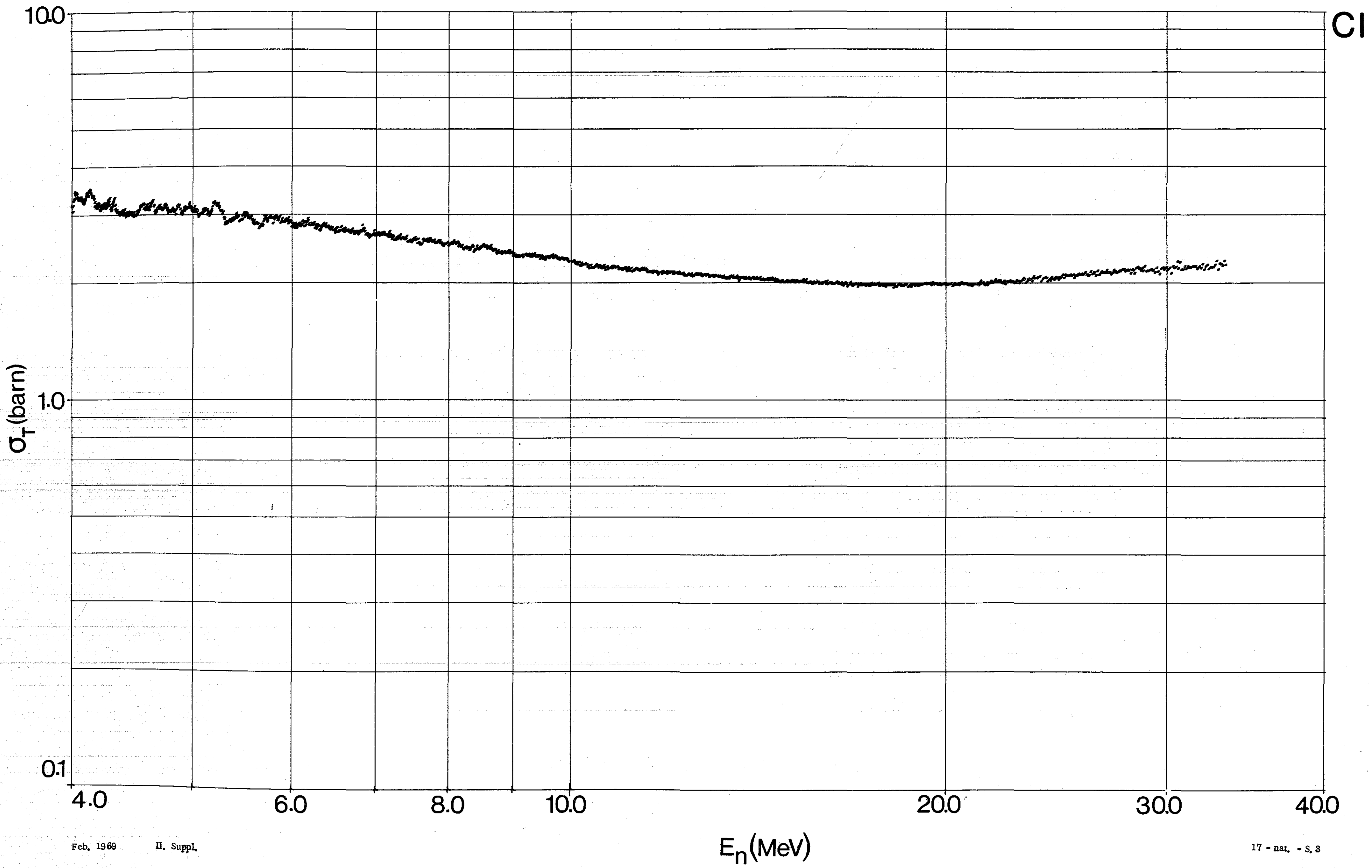
l = 57.540 m

Δt = 4.5 nsec

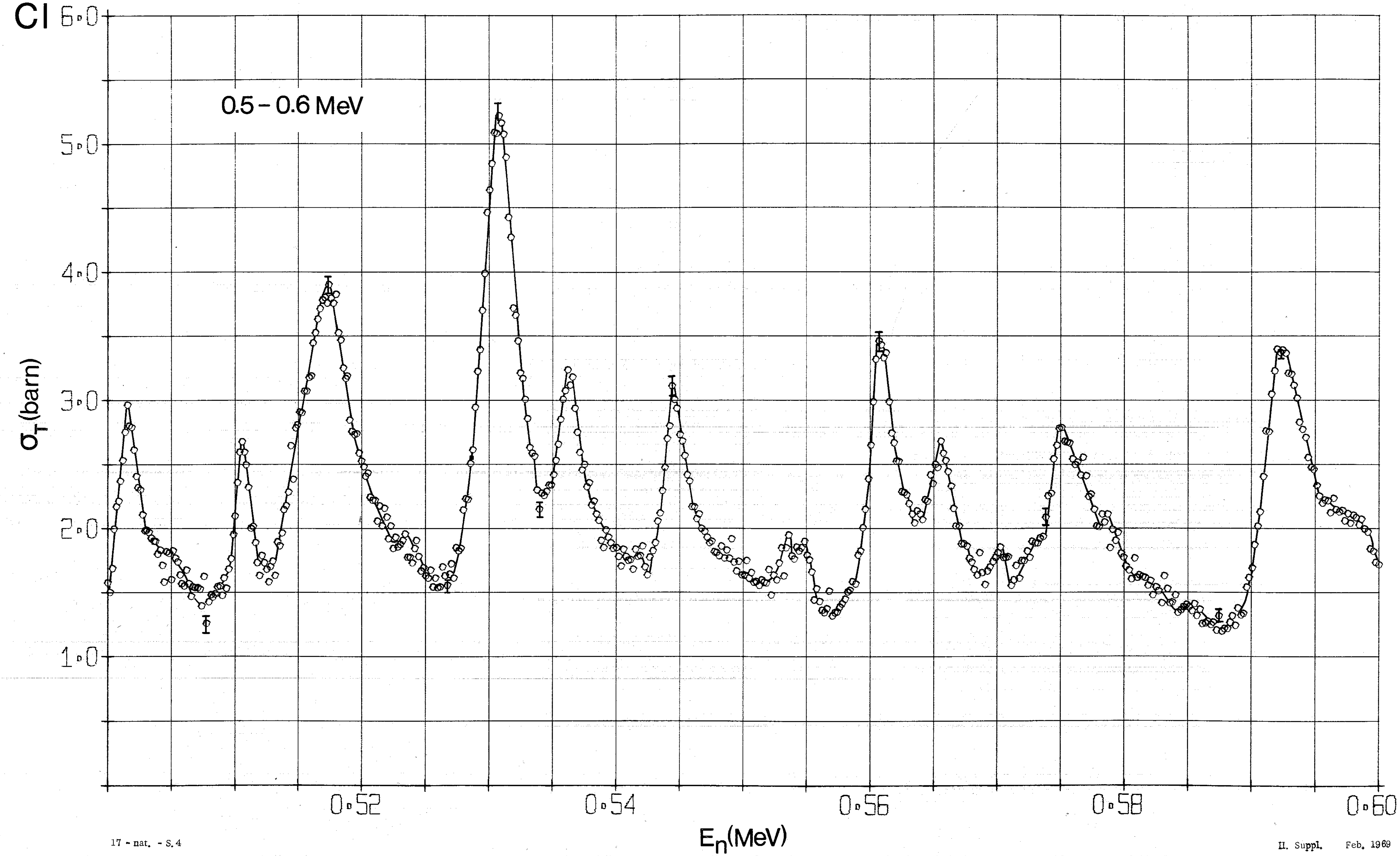
i : natural

CCl_4 versus C

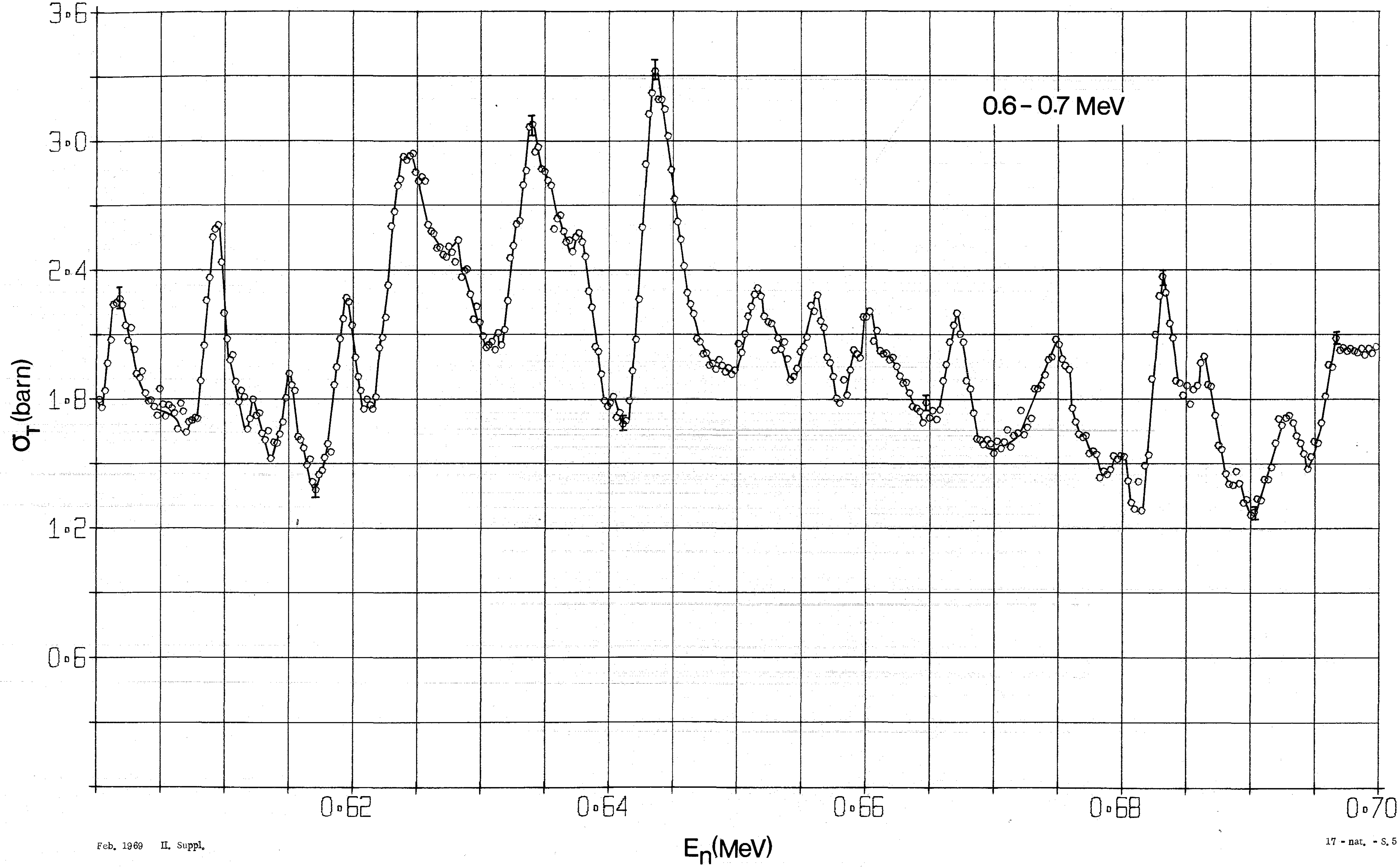

Cl
10.0
1.0
0.1
σT (barn)
0.4
0.6
0.8
1.0
2.0
3.0
4.0
En (MeV)

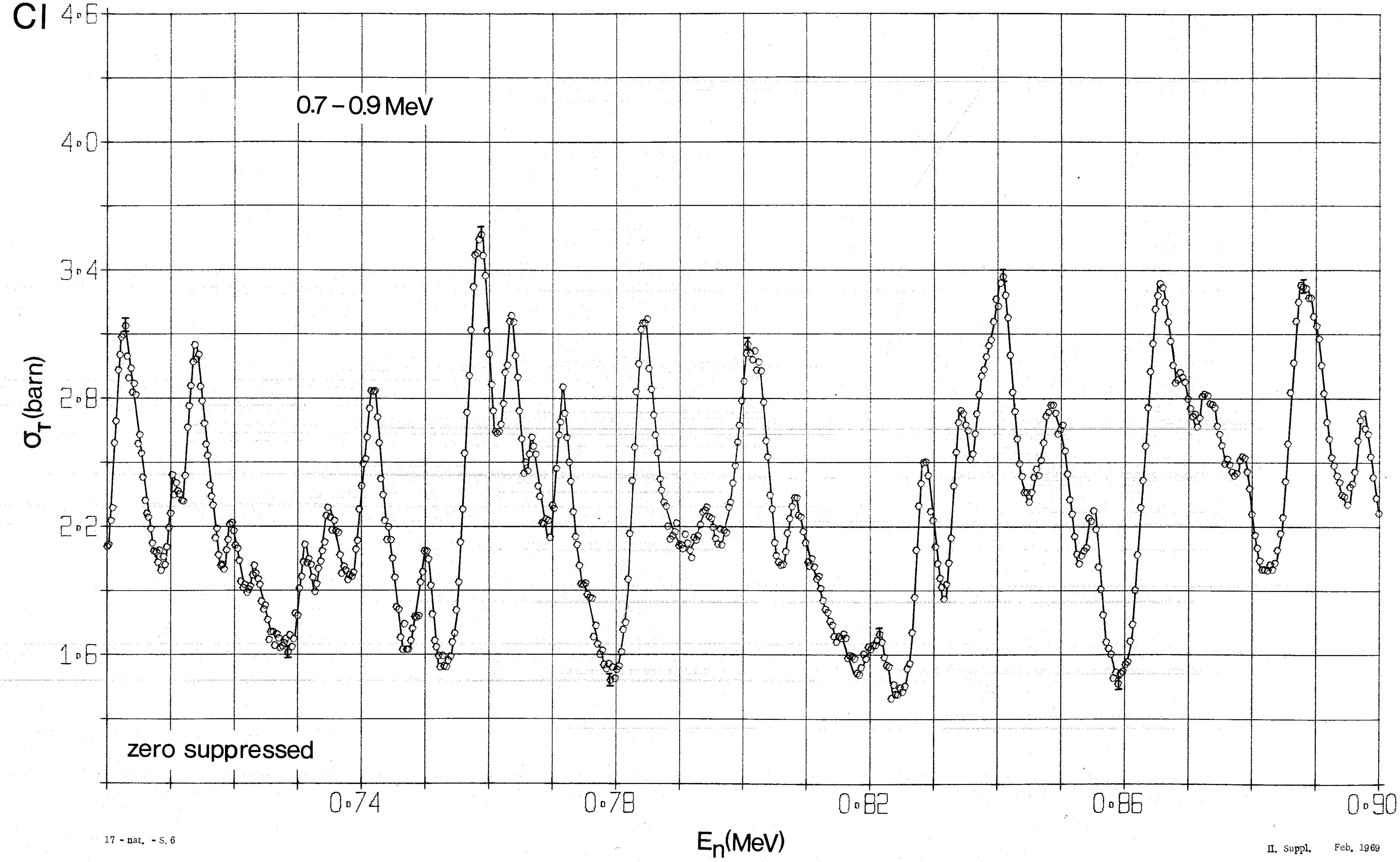


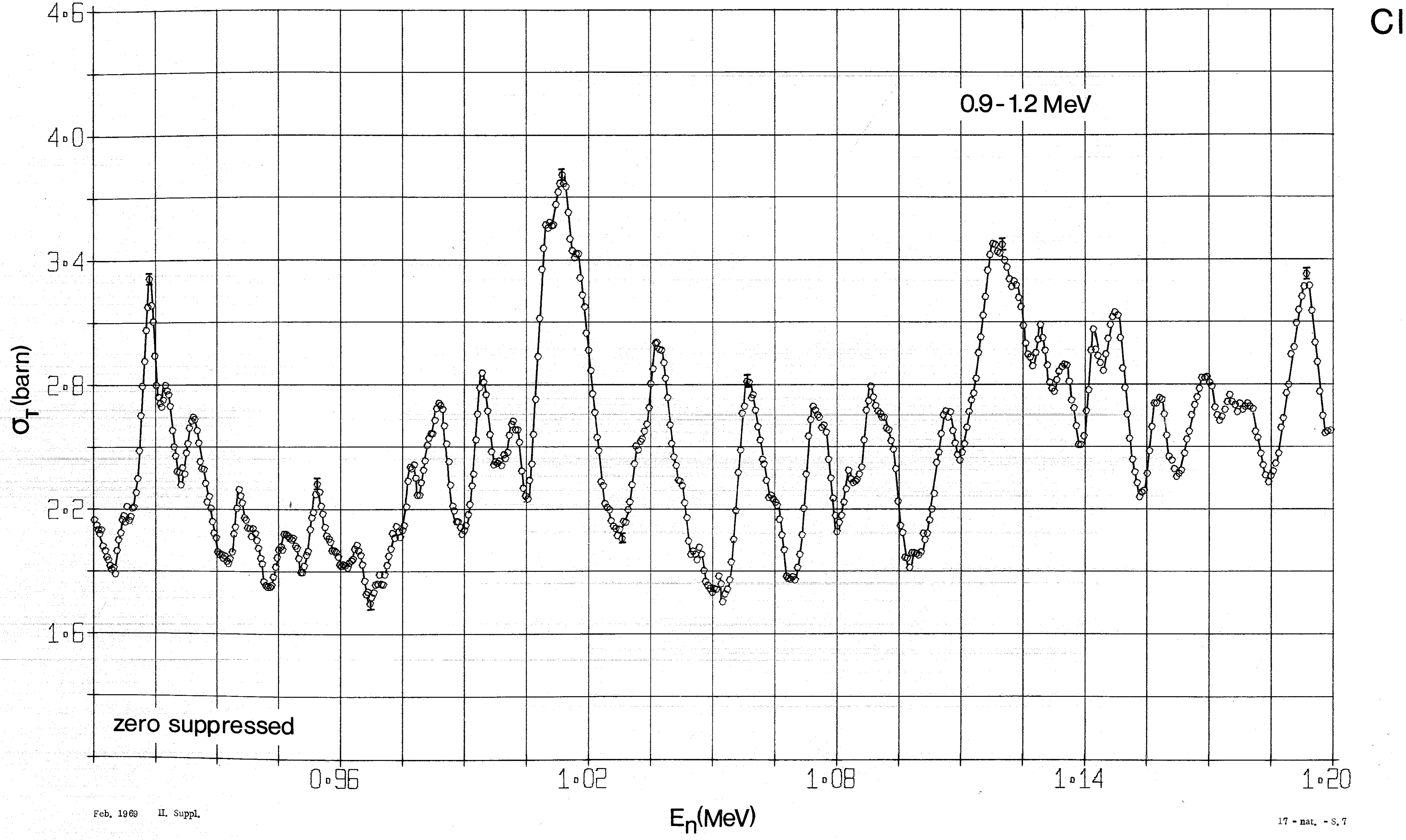
Cl
10.0
1.0
0.1
σ_T (barn)
4.0
6.0
8.0
10.0
20.0
30.0
40.0
E_n(MeV)


Cl
0.5 - 0.6 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σT (barn)
0·52
0·54
0·56
0·58
0·60
En(MeV)

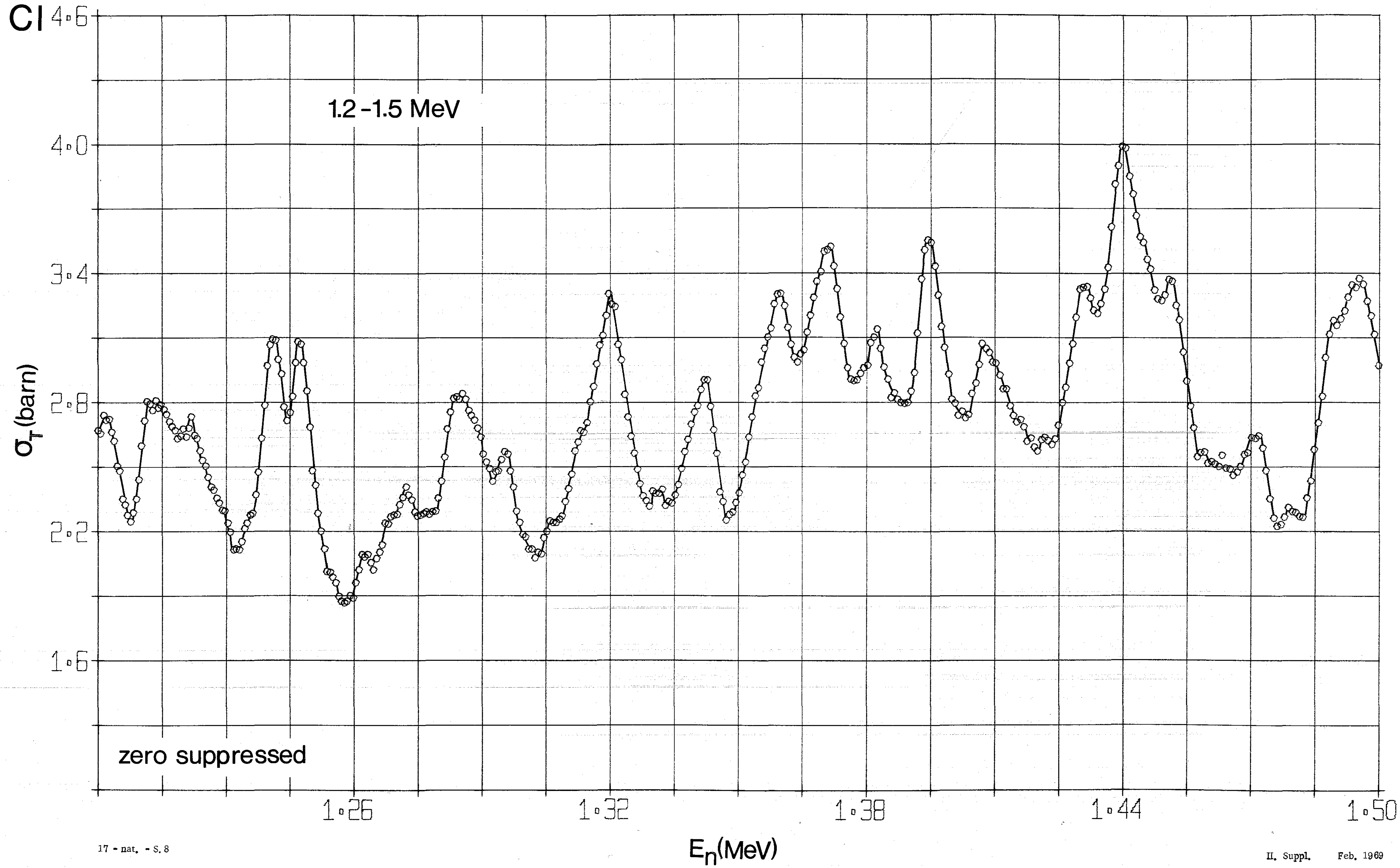
Cl




Cl
4·6
4·0
3·4
2·8
2·2
1·6
0.7 – 0.9 MeV
σT (barn)
zero suppressed
0·74
0·78
0·82
0·86
0·90
En(MeV)

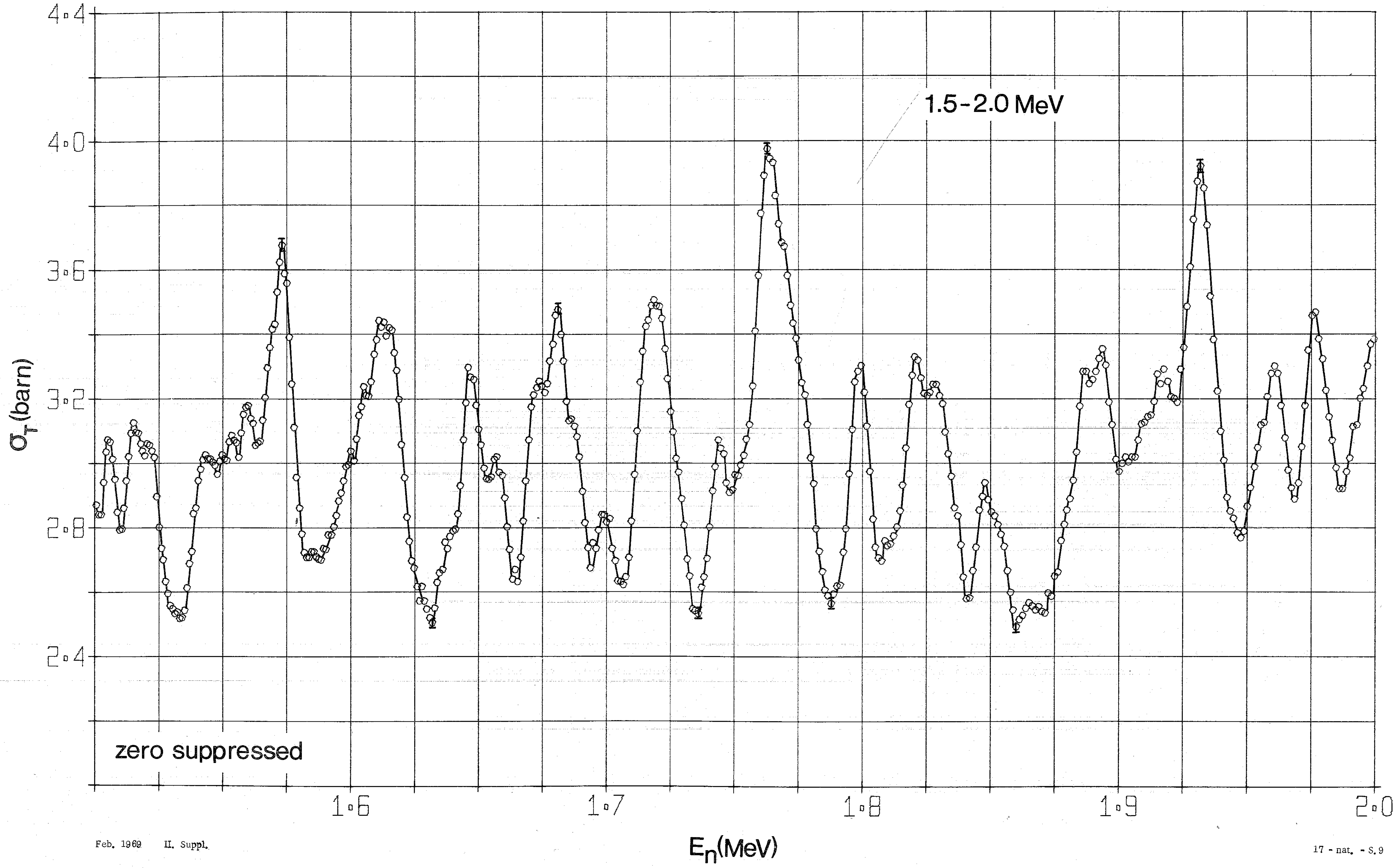


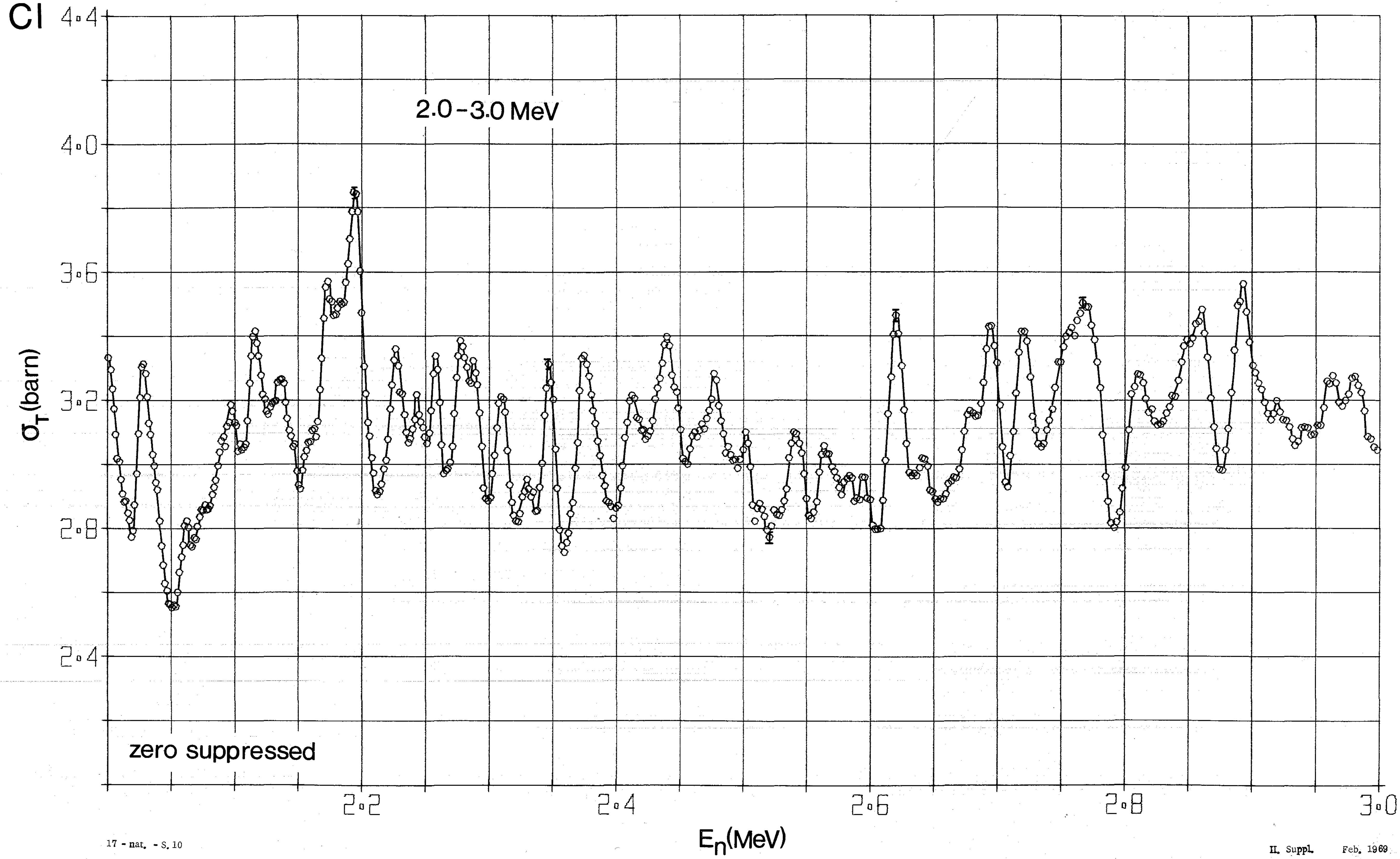
Cl
0.9 - 1.2 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
zero suppressed
0·96
1·02
1·08
1·14
1·20
E_n(MeV)

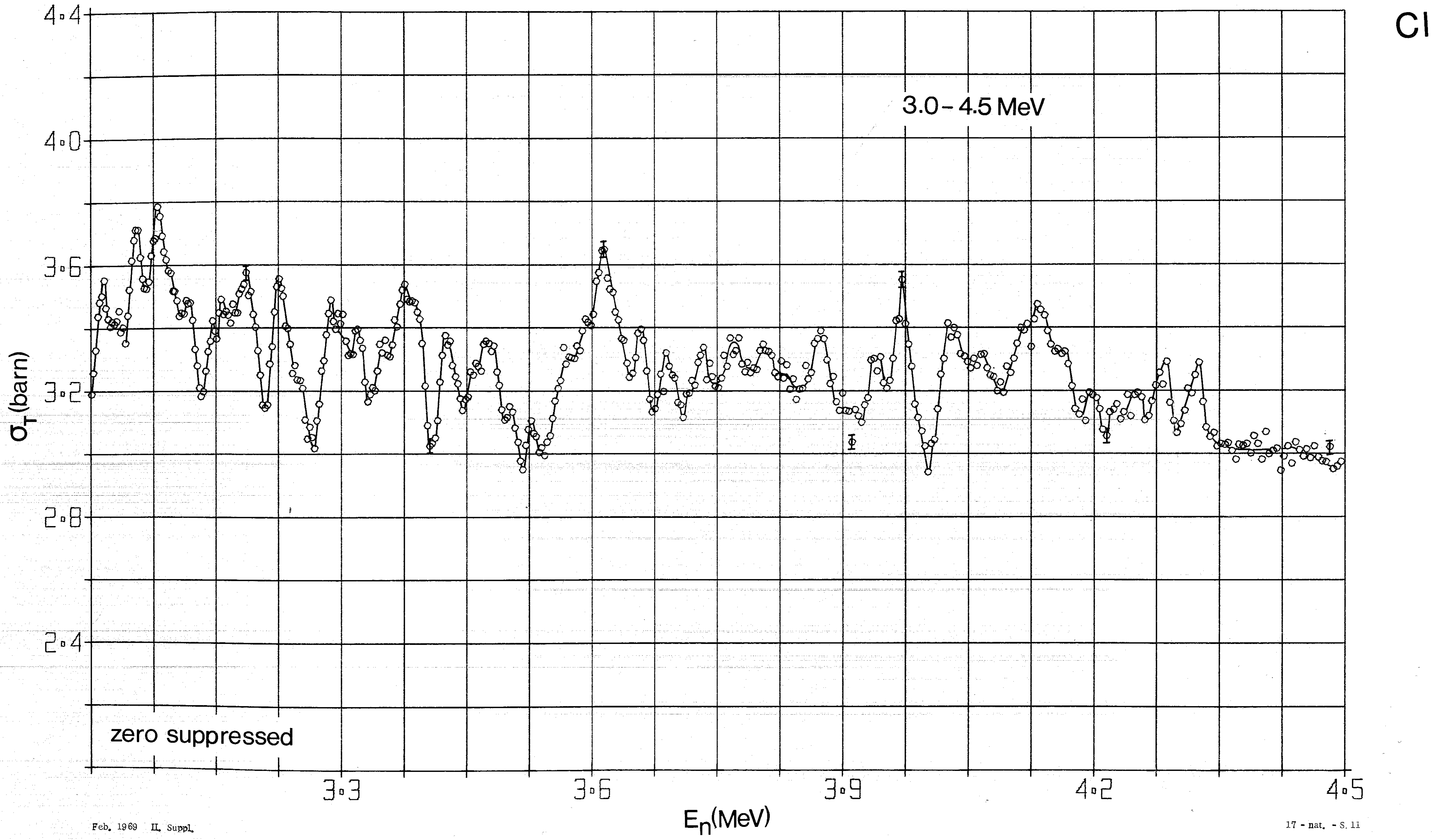


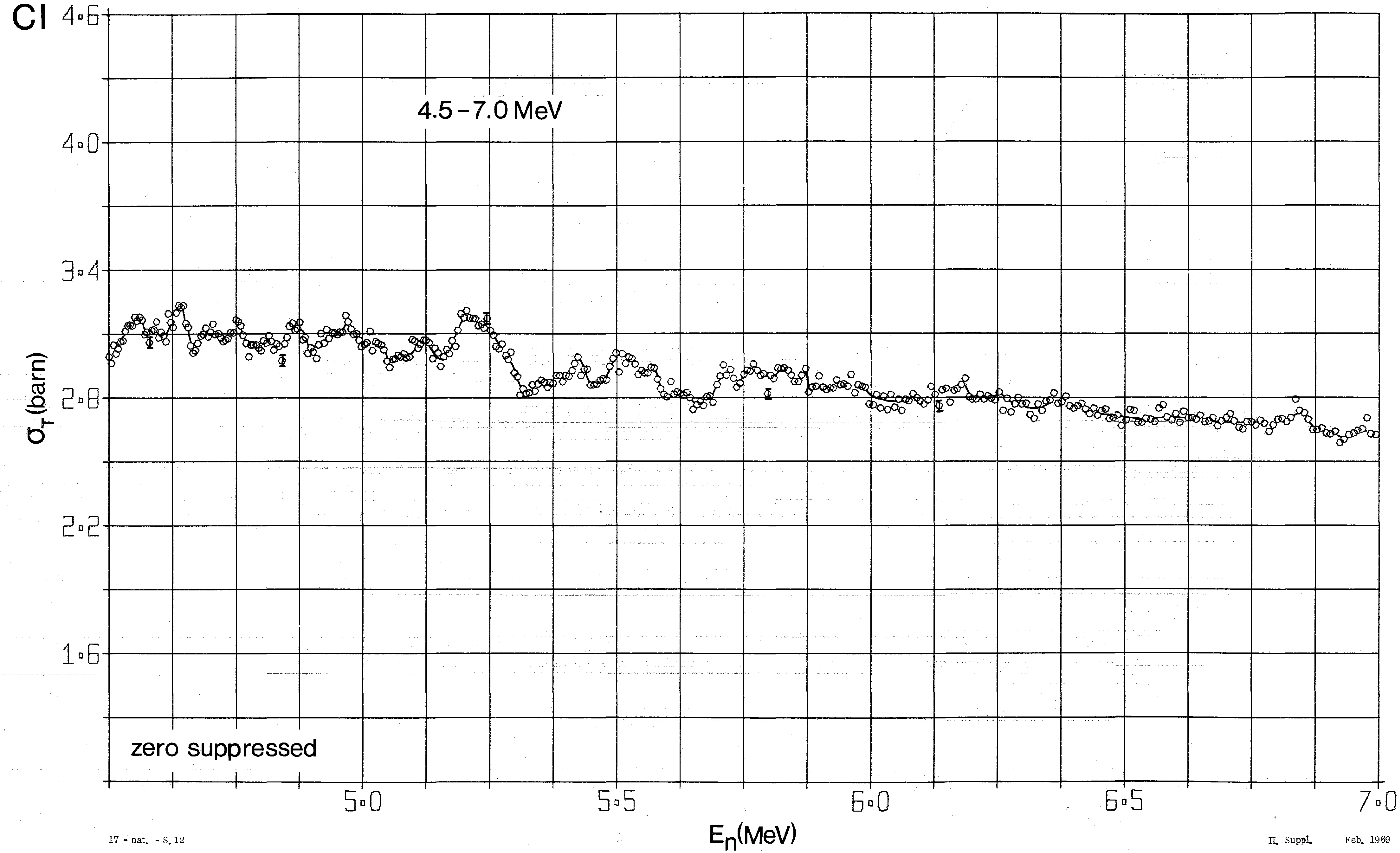
Cl
4·6
4·0
3·4
2·8
2·2
1·6
1.2 -1.5 MeV
zero suppressed
σ_T (barn)
1·26
1·32
1·38
1·44
1·50
E_n(MeV)

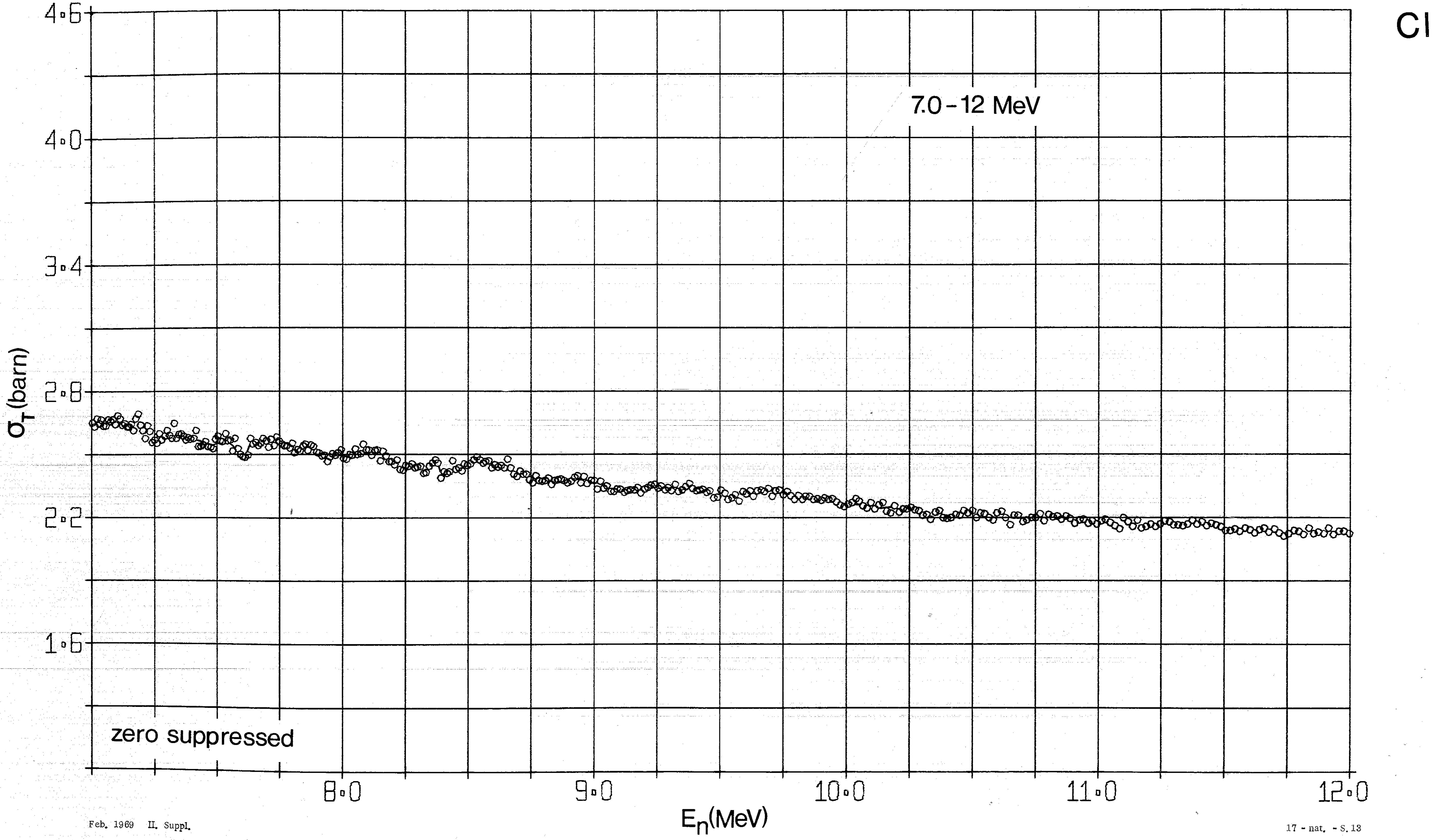
Cl


1.5-2.0 MeV
4·4
4·0
3·6
3·2
2·8
2·4
σT (barn)
zero suppressed
1·6
1·7
1·8
1·9
2·0
En(MeV)

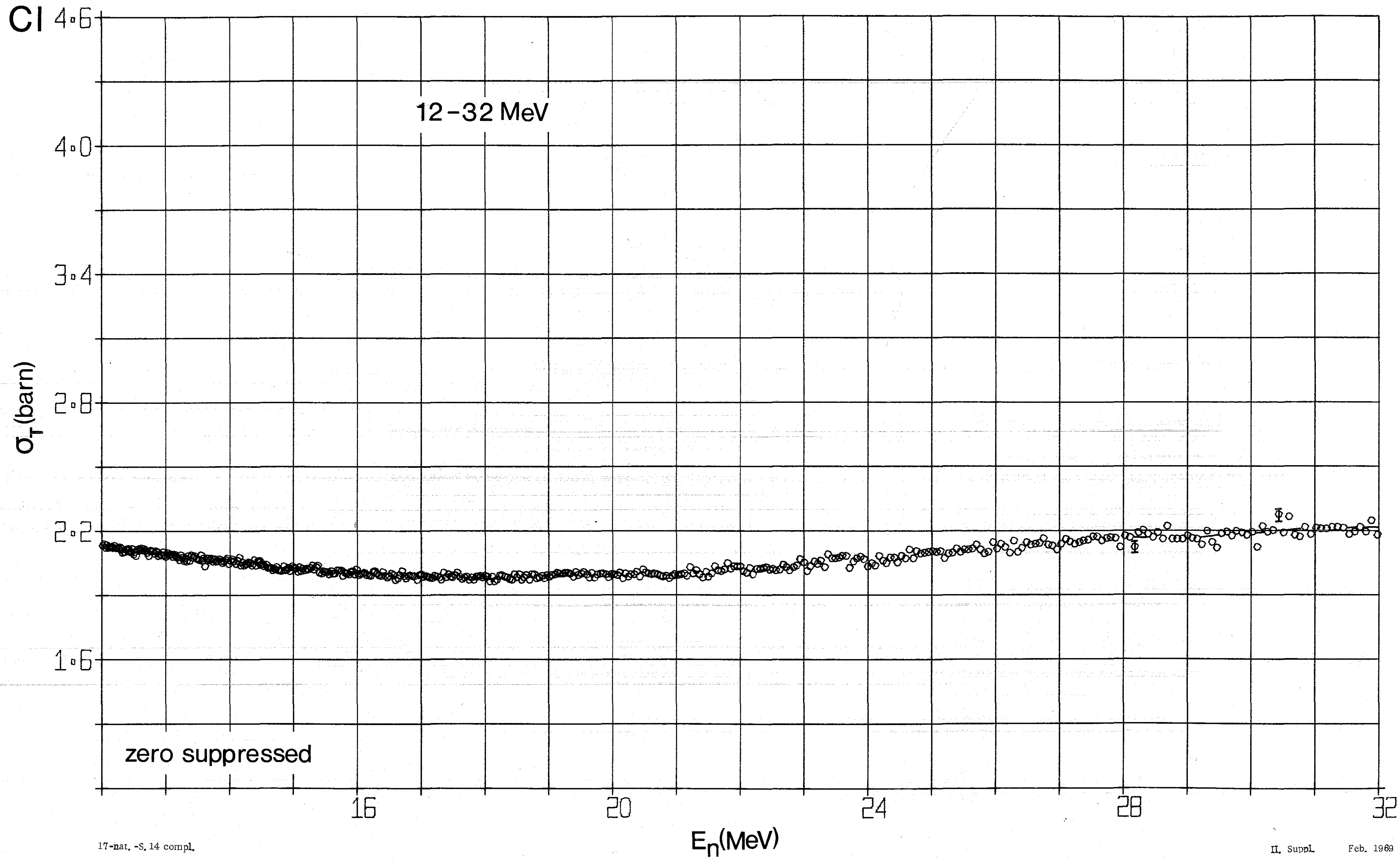

Cl
4·4
4·0
3·6
3·2
2·8
2·4
2.0-3.0 MeV
σ_T(barn)
zero suppressed
2·2
2·4
2·6
2·8
3·0
E_n(MeV)


Cl
3.0 - 4.5 MeV
4·4
4·0
3·6
3·2
2·8
2·4
σT (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
En(MeV)


Cl
4.5-7.0 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σT(barn)
zero suppressed
5·0
5·5
6·0
6·5
7·0
En(MeV)

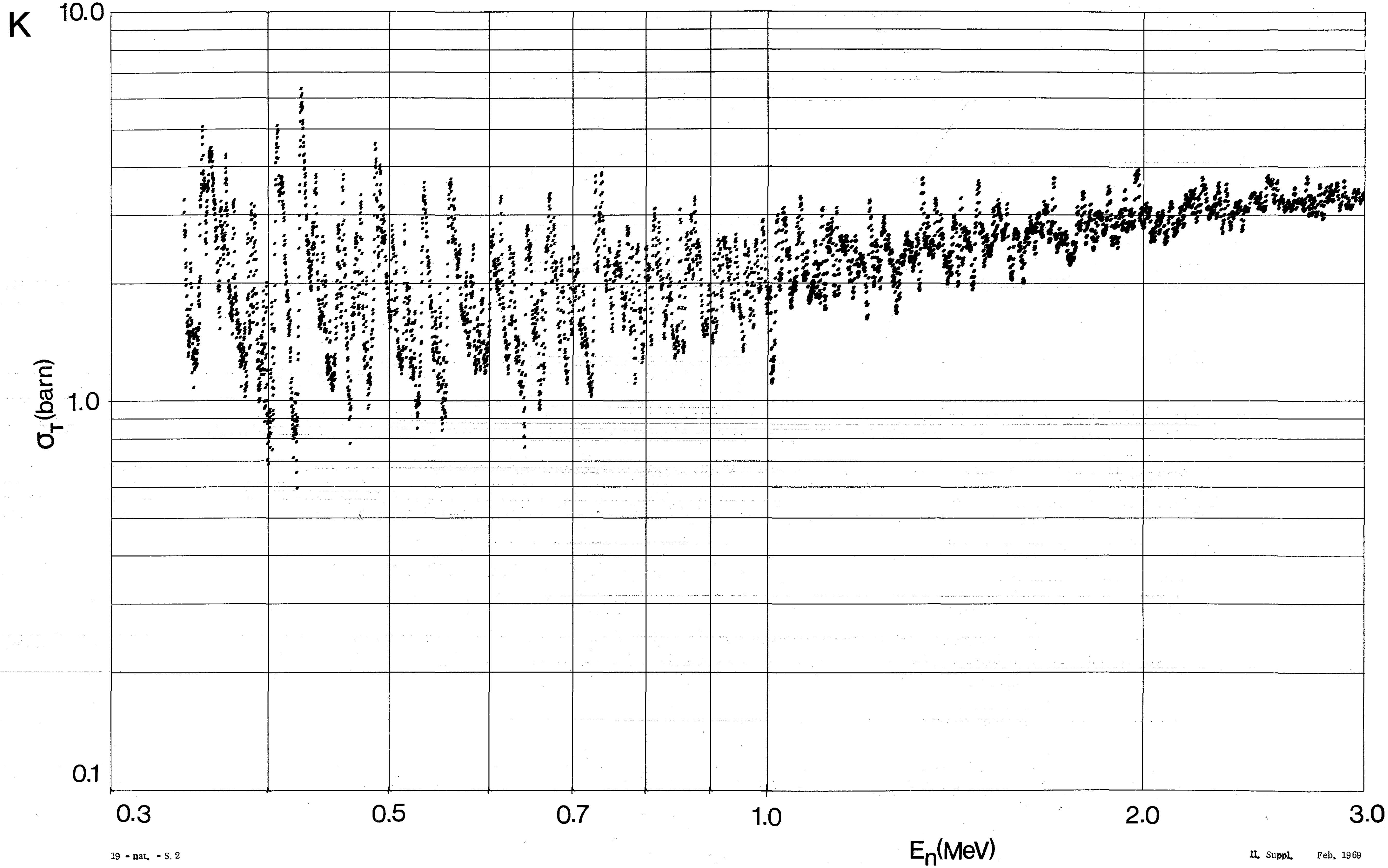


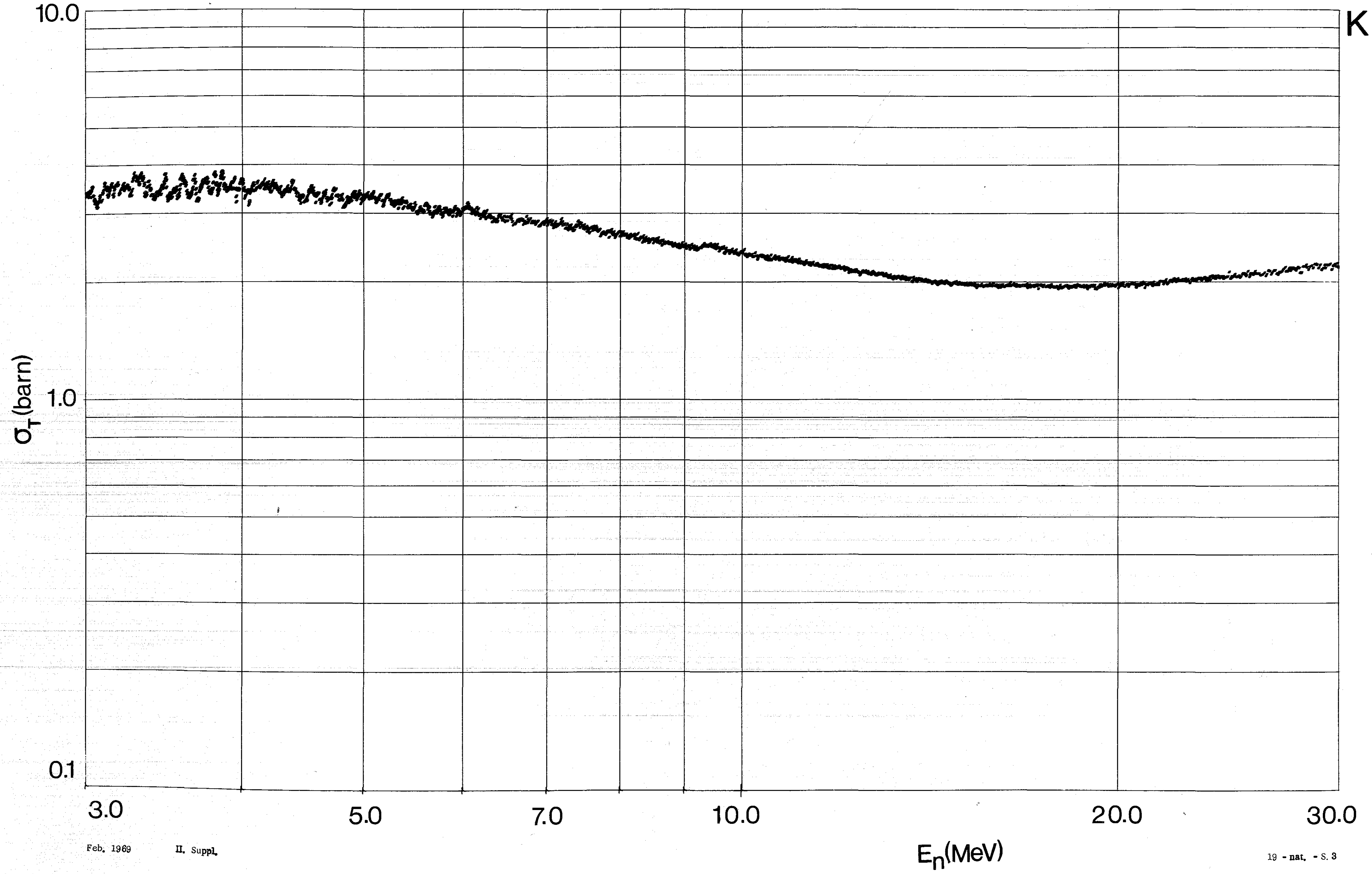
Cl
7.0 - 12 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T(barn)
zero suppressed
8·0
9·0
10·0
11·0
12·0
E_n(MeV)


Cl
4·6
4·0
3·4
2·8
2·2
1·6
12-32 MeV
σ_T(barn)
zero suppressed
16
20
24
28
32
E_n(MeV)

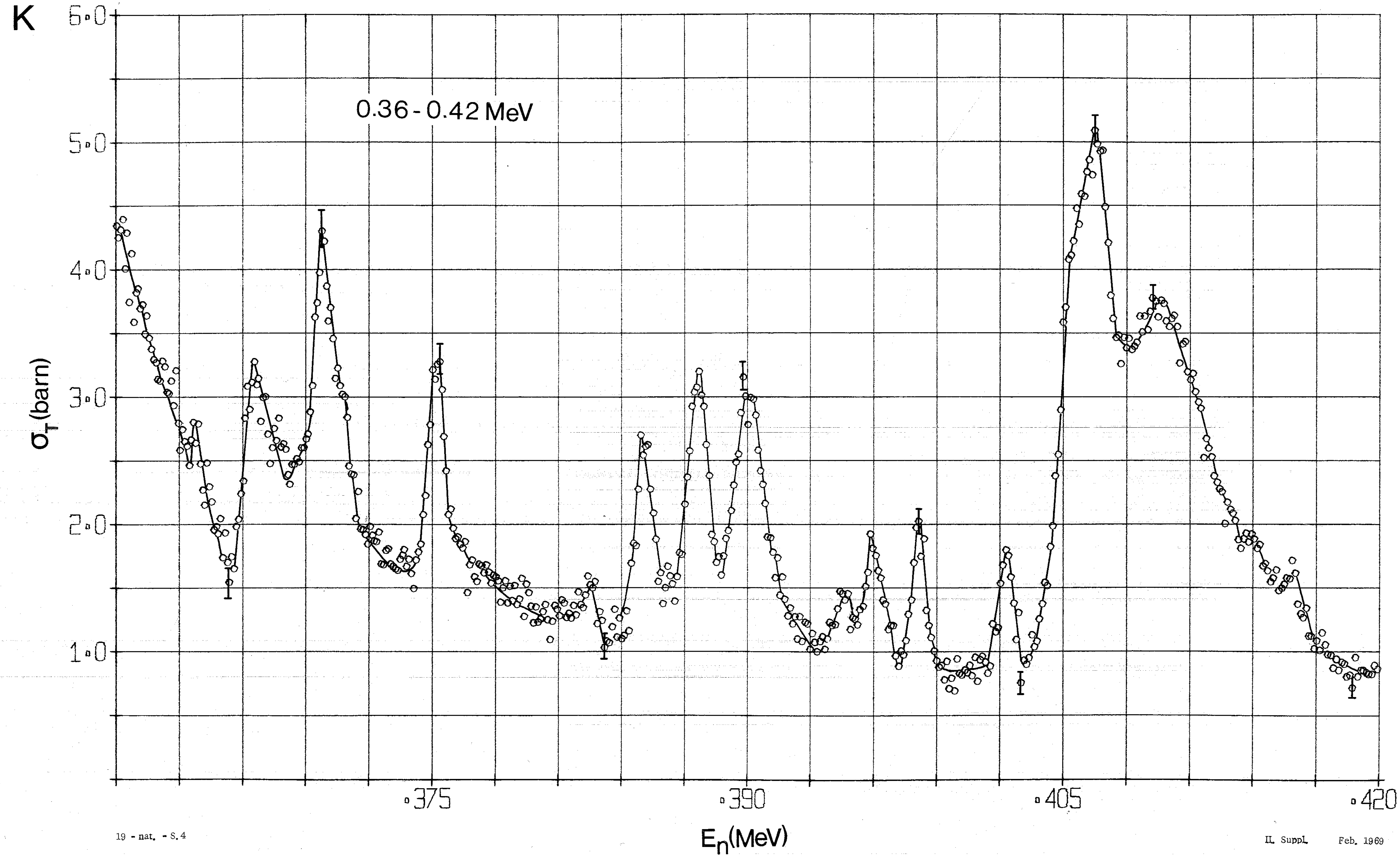
K

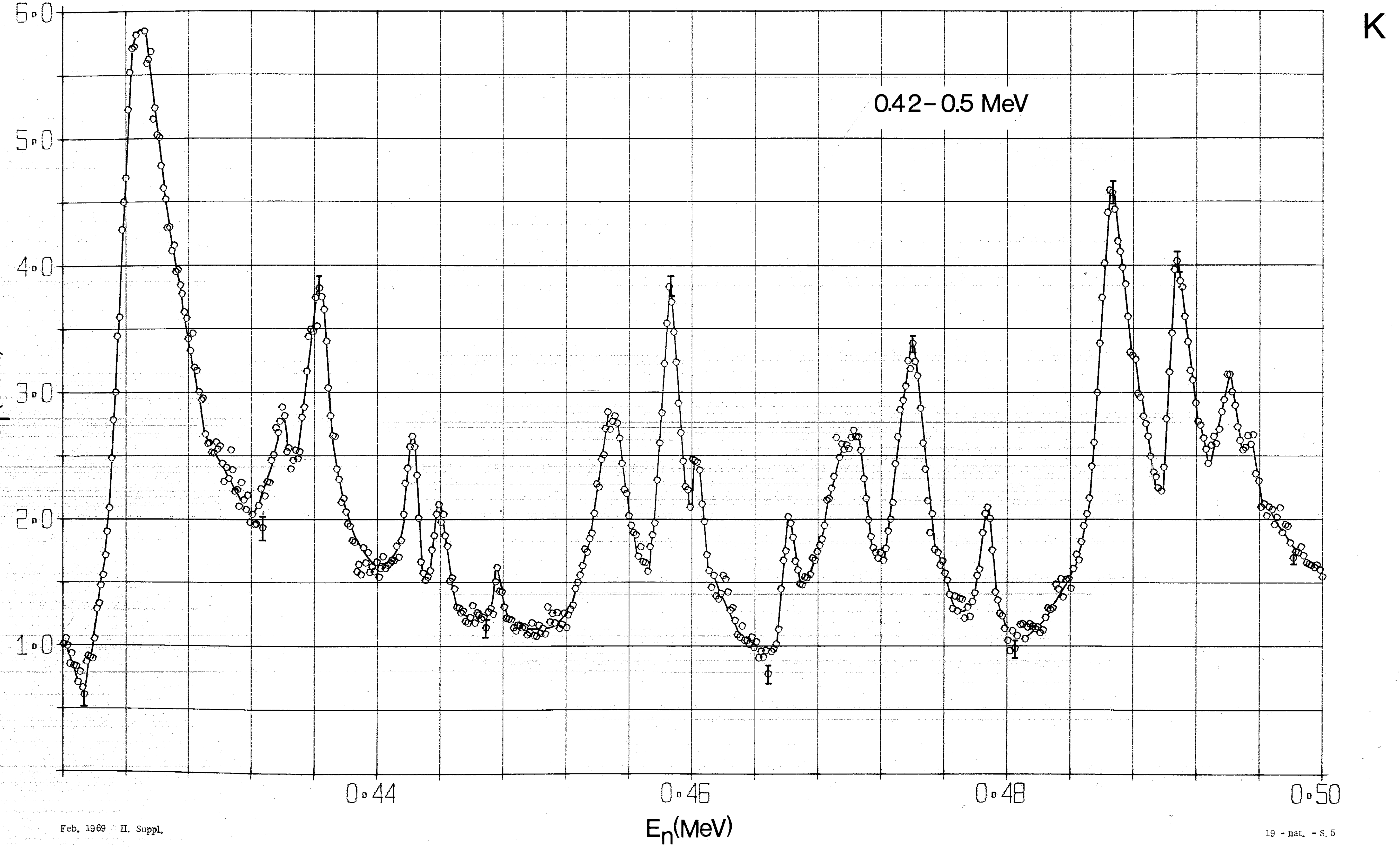
n	=	0.1860	At/barn
p	=	99.9	%
l	=	57.540	m
Δt	=	3.7	nsec
i	:	natural	


K
10.0
1.0
0.1
σT(barn)
0.3
0.5
0.7
1.0
2.0
3.0
En(MeV)

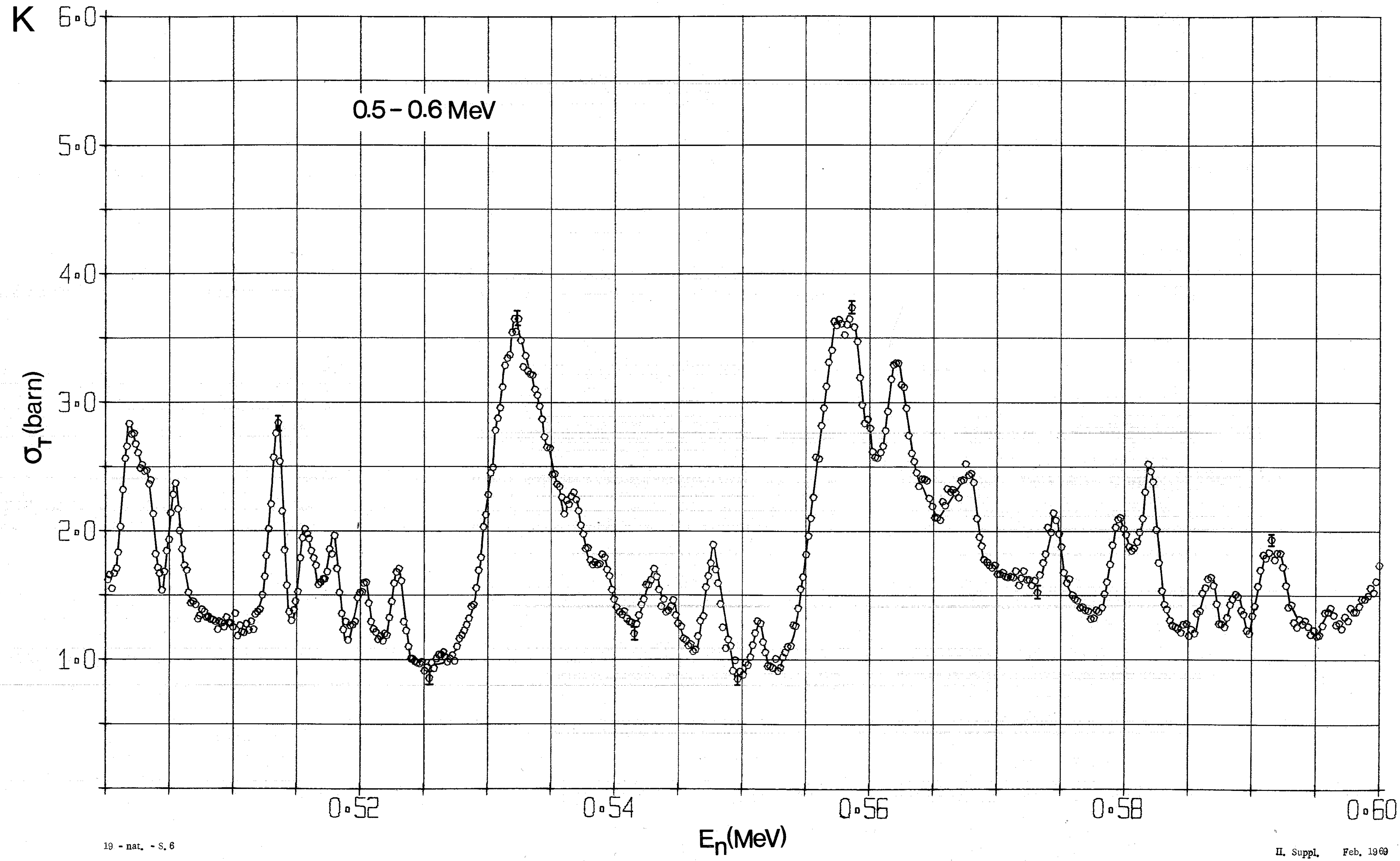


K
10.0
1.0
0.1
σT (barn)
3.0
5.0
7.0
10.0
20.0
30.0
En(MeV)

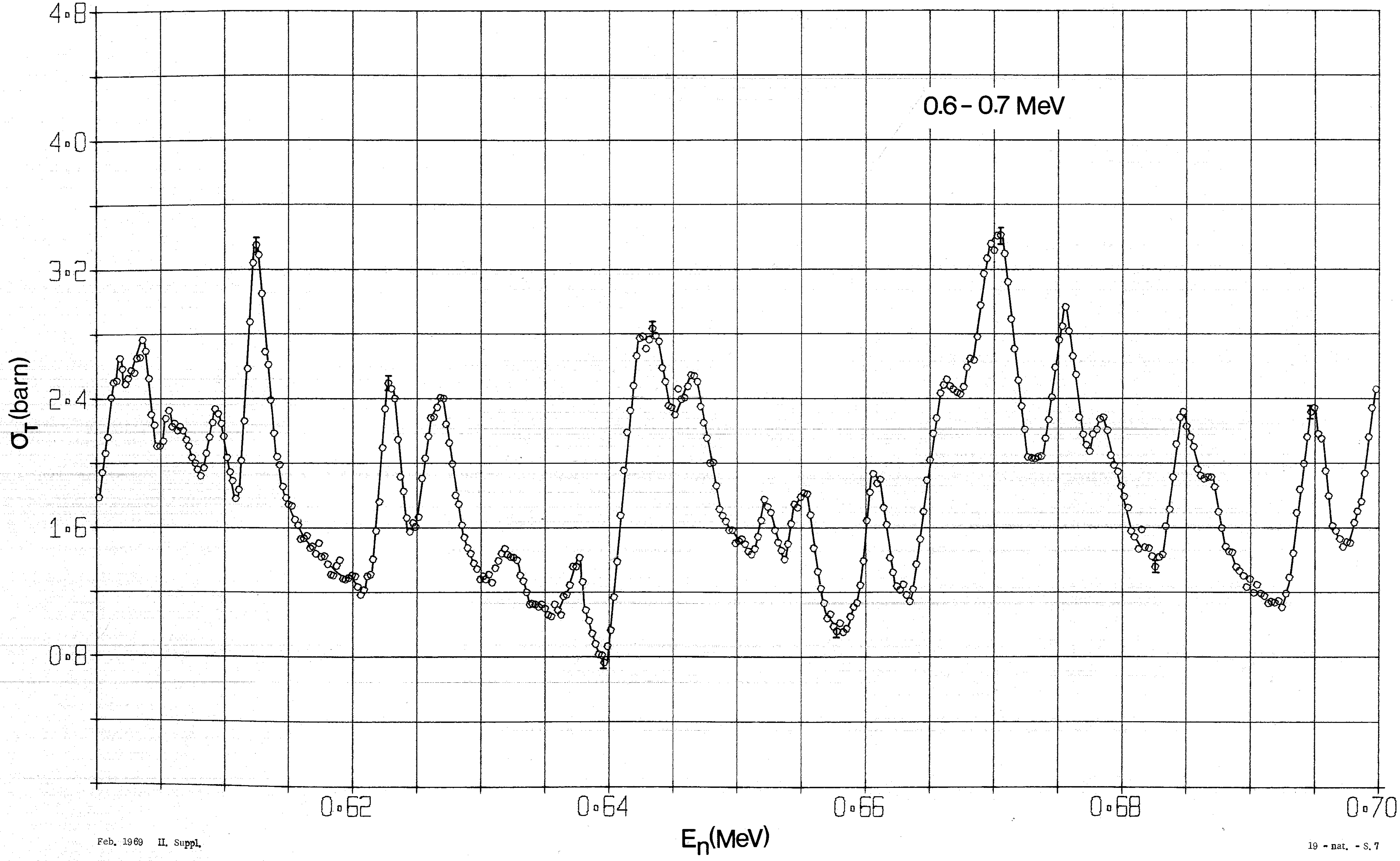

K
0.36 - 0.42 MeV
σT (barn)
6.0
5.0
4.0
3.0
2.0
1.0
.375
.390
.405
.420
En(MeV)

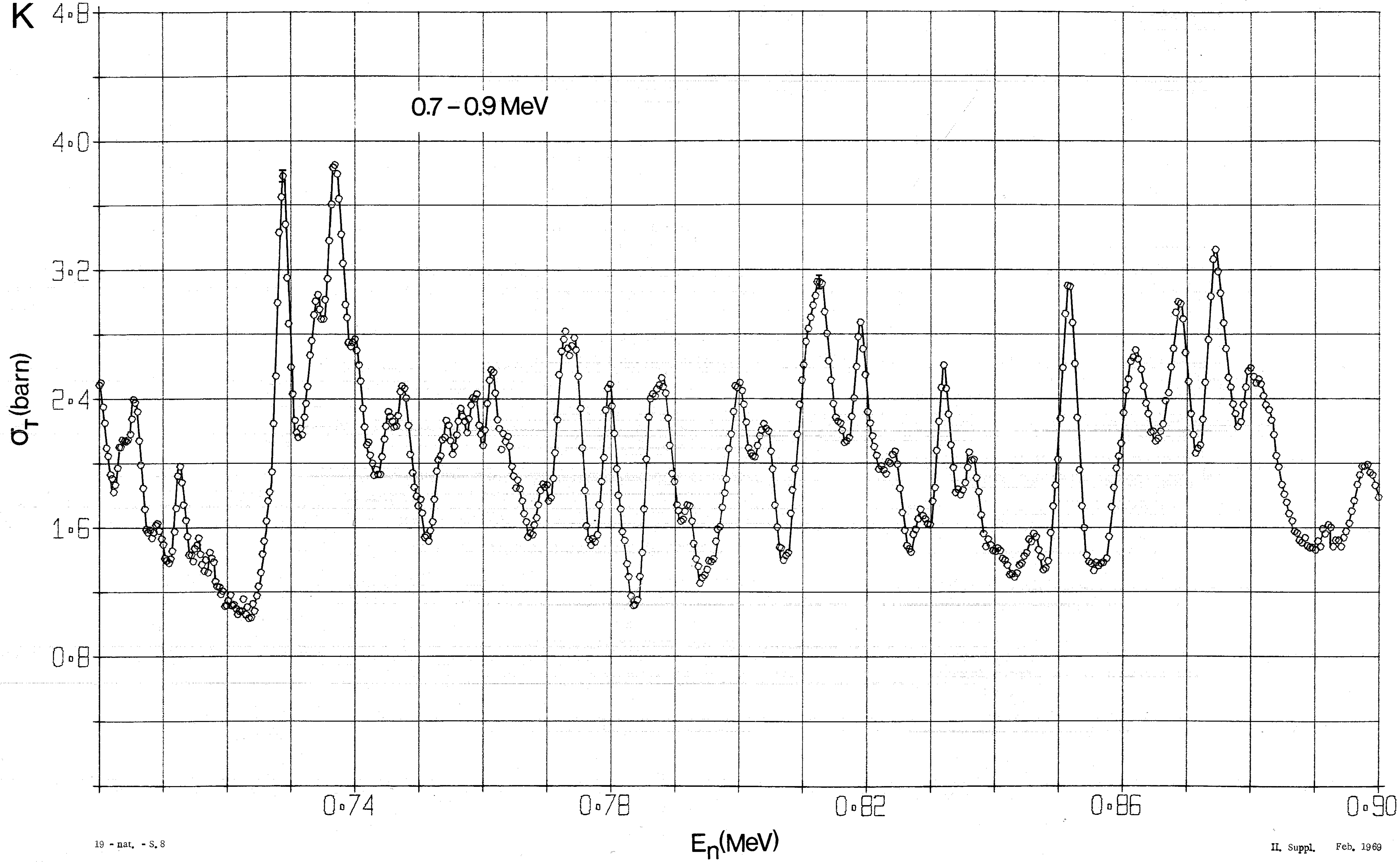


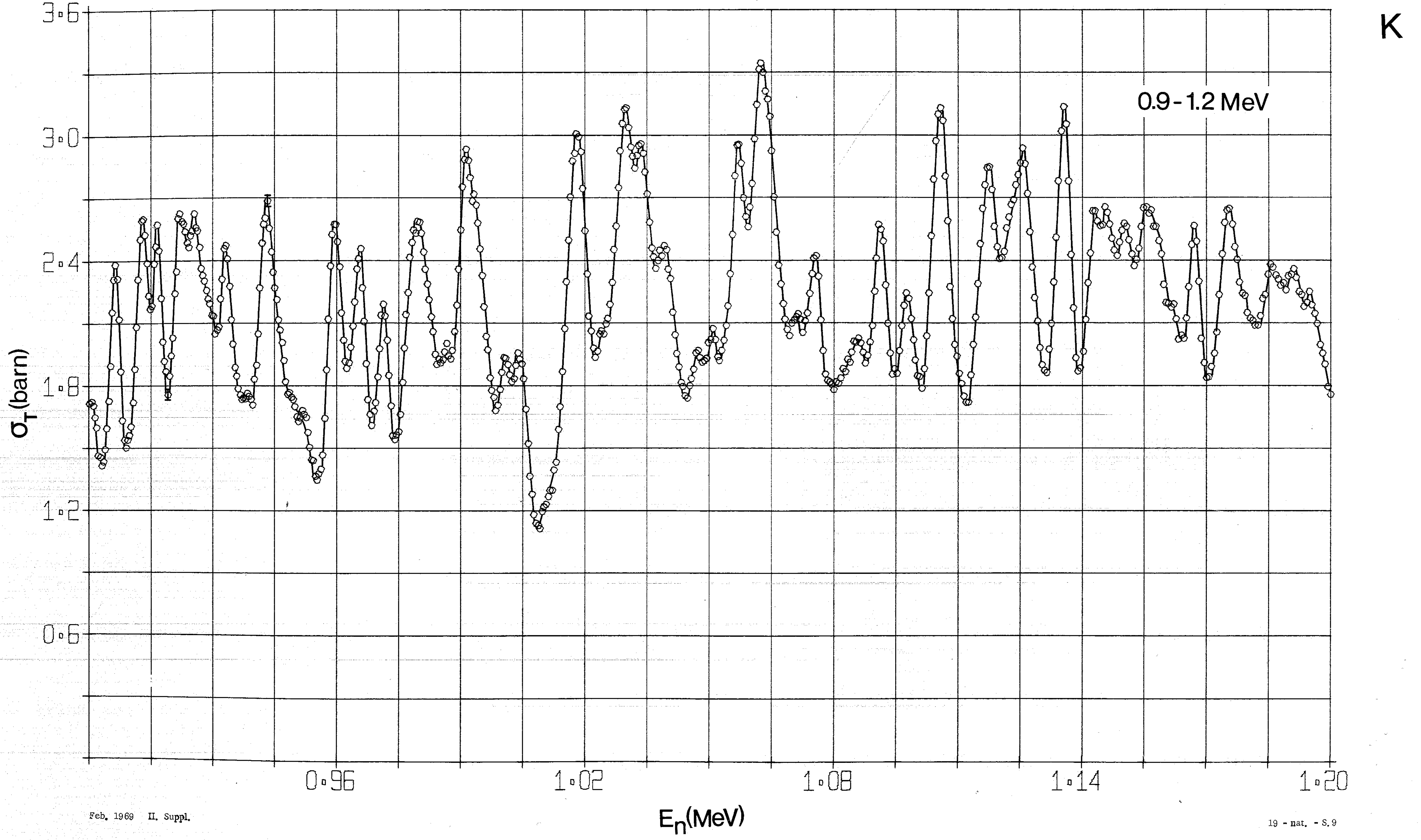
K
0.42 - 0.5 MeV
6.0
5.0
4.0
3.0
2.0
1.0
σT (barn)
0.44
0.46
0.48
0.50
En(MeV)


K
6·0
5·0
4·0
3·0
2·0
1·0
0.5 - 0.6 MeV
σT (barn)
0·52
0·54
0·56
0·58
0·60
En(MeV)

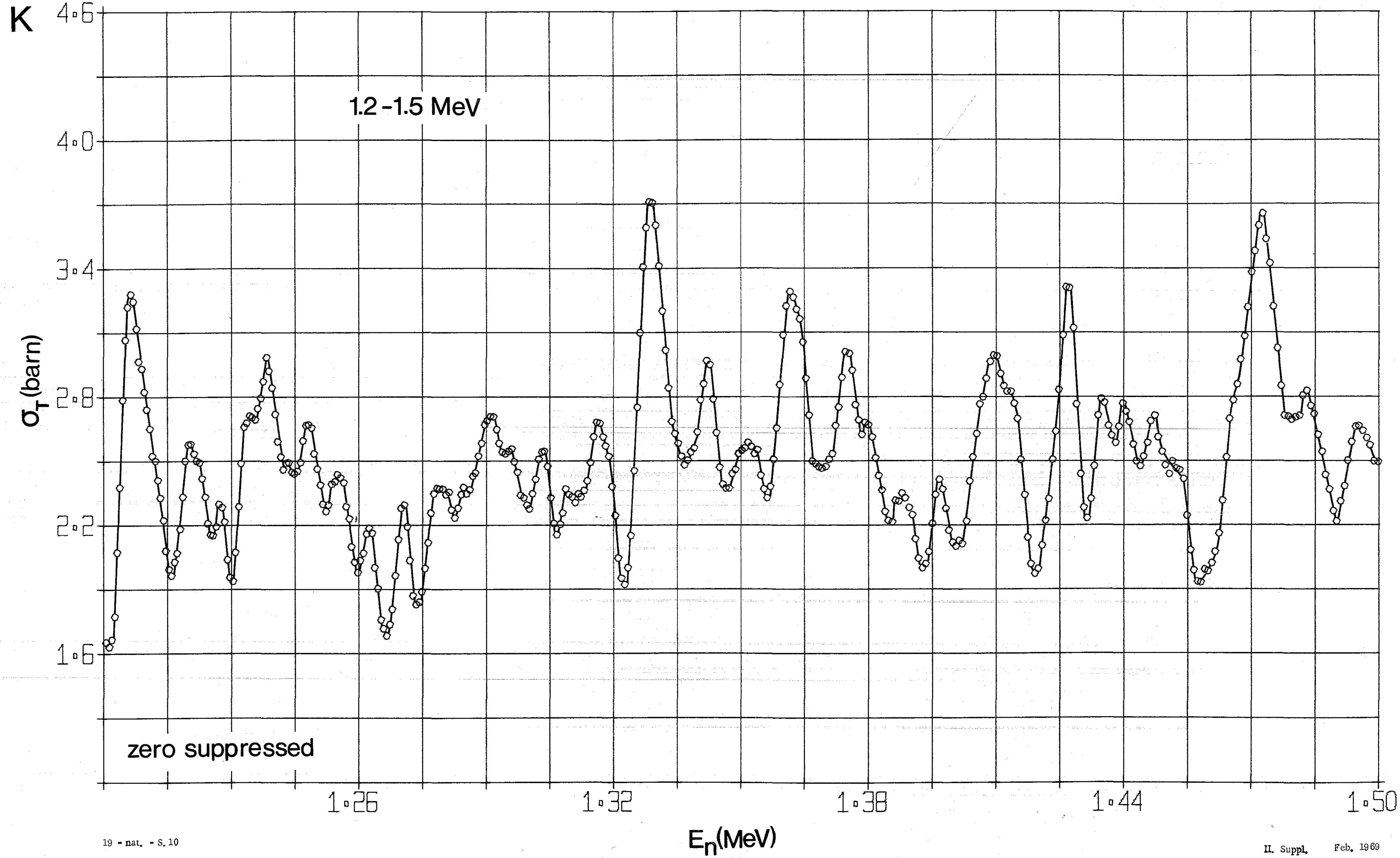
K

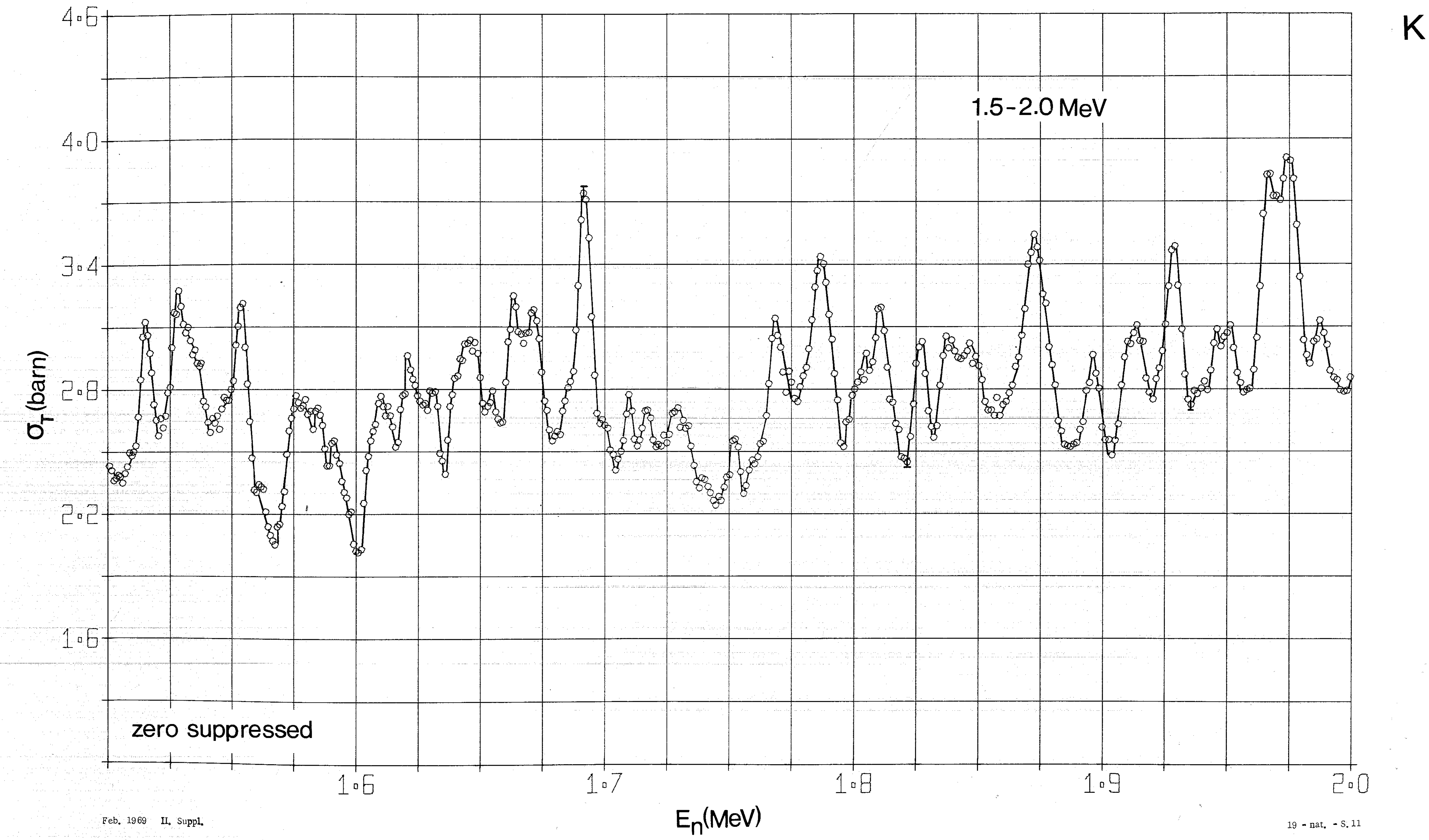


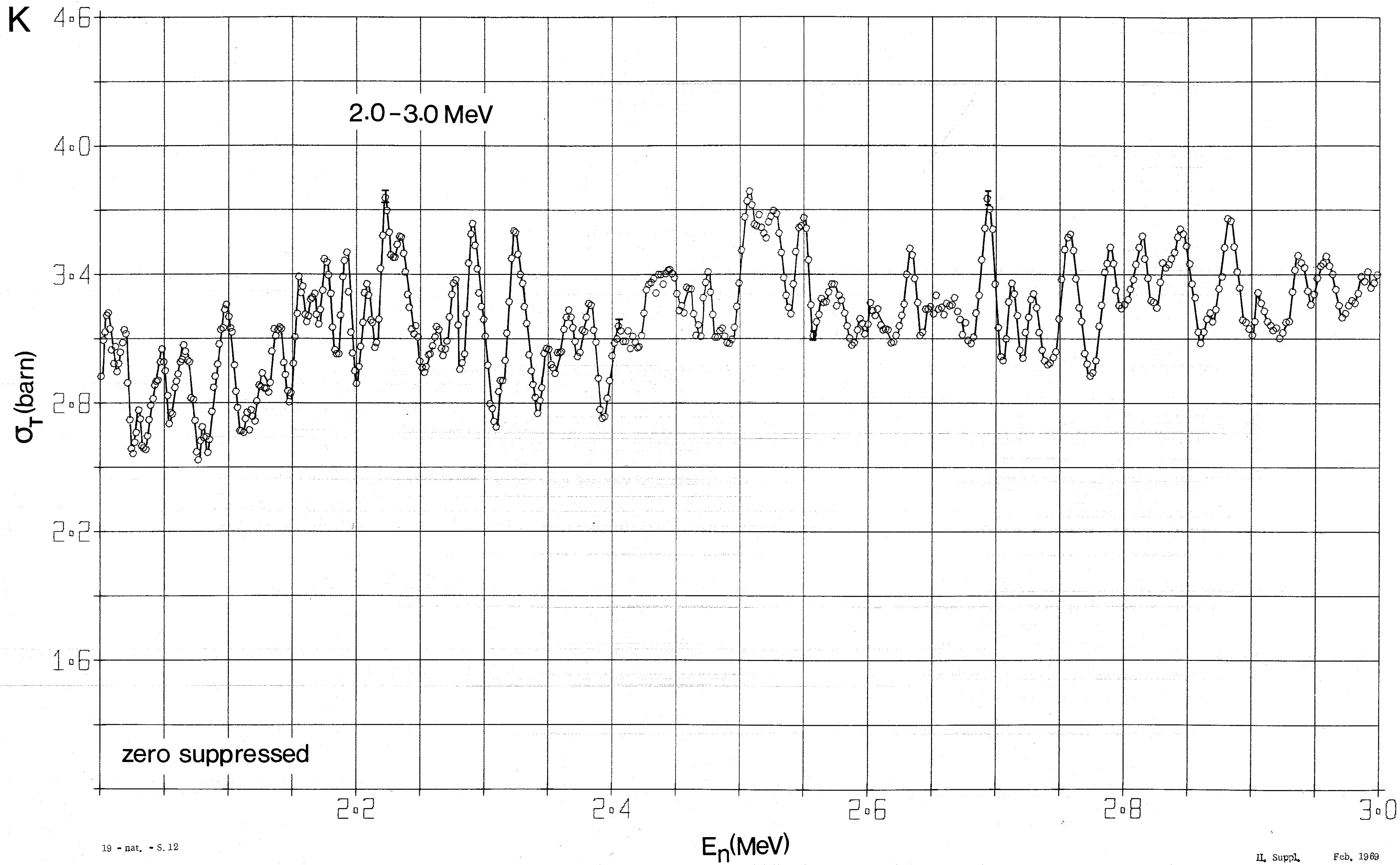

K
0.7 – 0.9 MeV
4·8
4·0
3·2
2·4
1·6
0·8
σT (barn)
0·74
0·78
0·82
0·86
0·90
En(MeV)



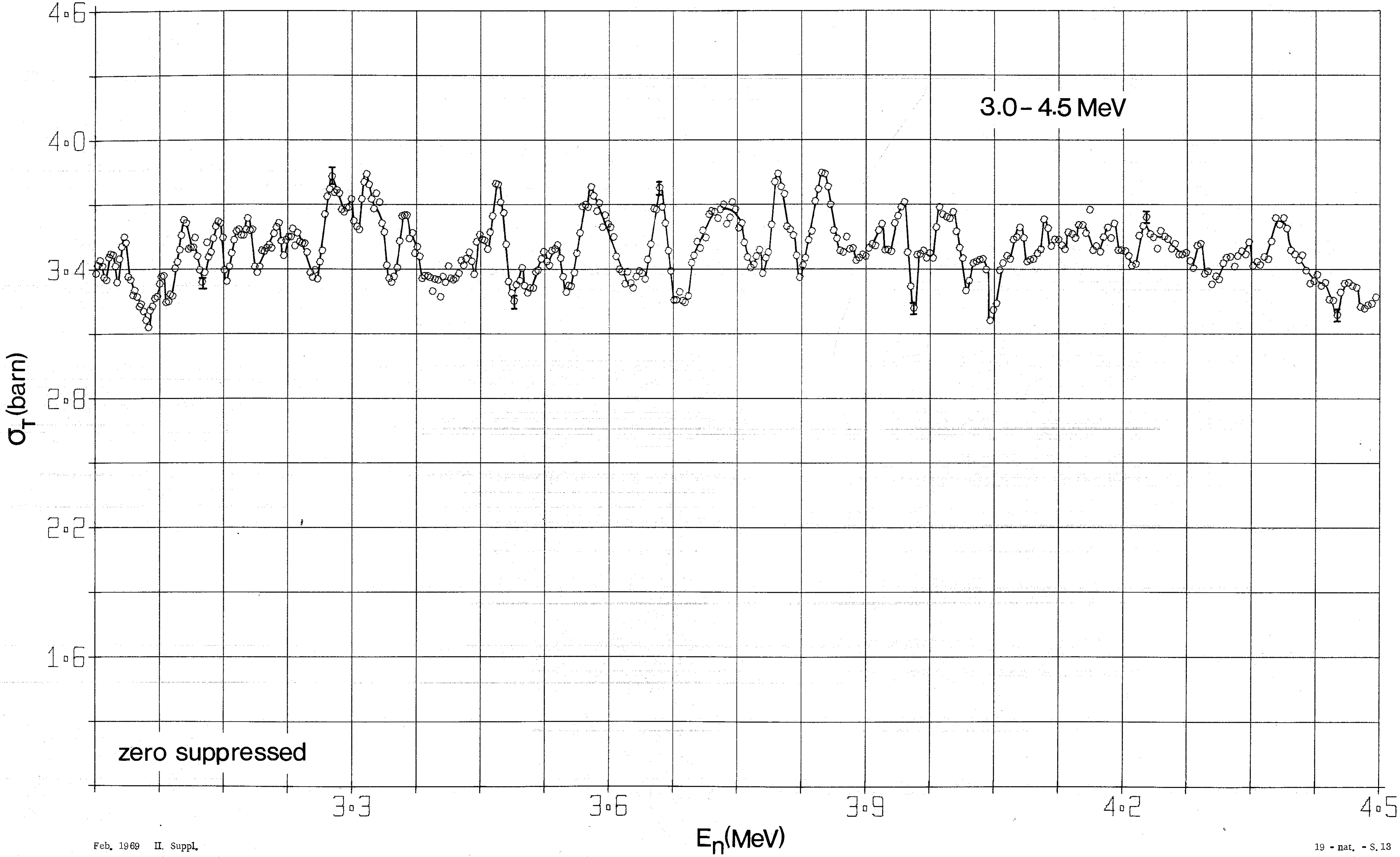
K
0.9 - 1.2 MeV
3·6
3·0
2·4
1·8
1·2
0·6
σT (barn)
0·96
1·02
1·08
1·14
1·20
En(MeV)

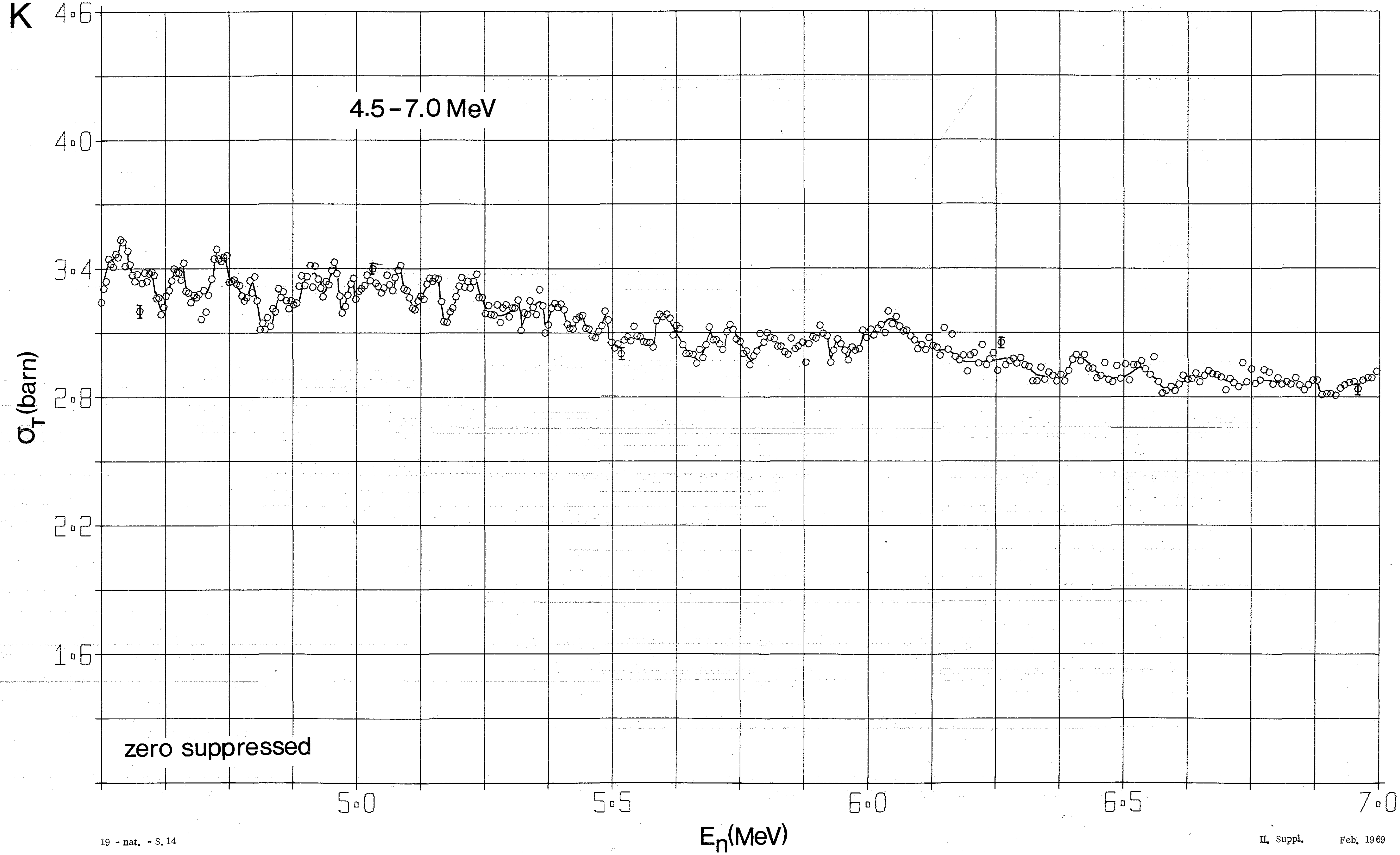

K
1.2 -1.5 MeV
σ_T(barn)
4·6
4·0
3·4
2·8
2·2
1·6
zero suppressed
1·26
1·32
1·38
1·44
1·50
E_n(MeV)


K
1.5-2.0 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T(barn)
zero suppressed
1·6
1·7
1·8
1·9
2·0
E_n(MeV)

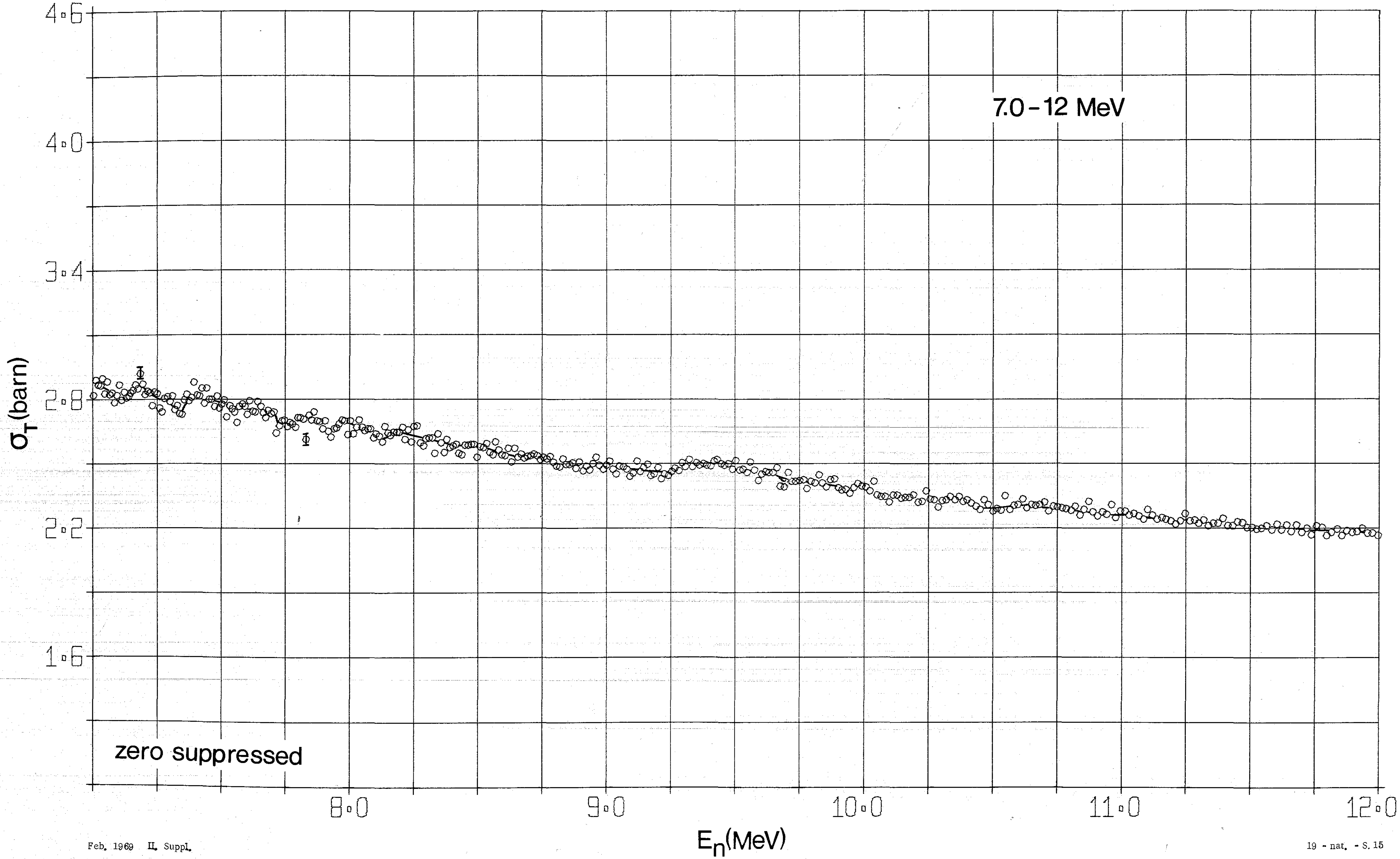

K
2.0-3.0 MeV
σT(barn)
4·6
4·0
3·4
2·8
2·2
1·6
zero suppressed
2·2
2·4
2·6
2·8
3·0
En(MeV)

K

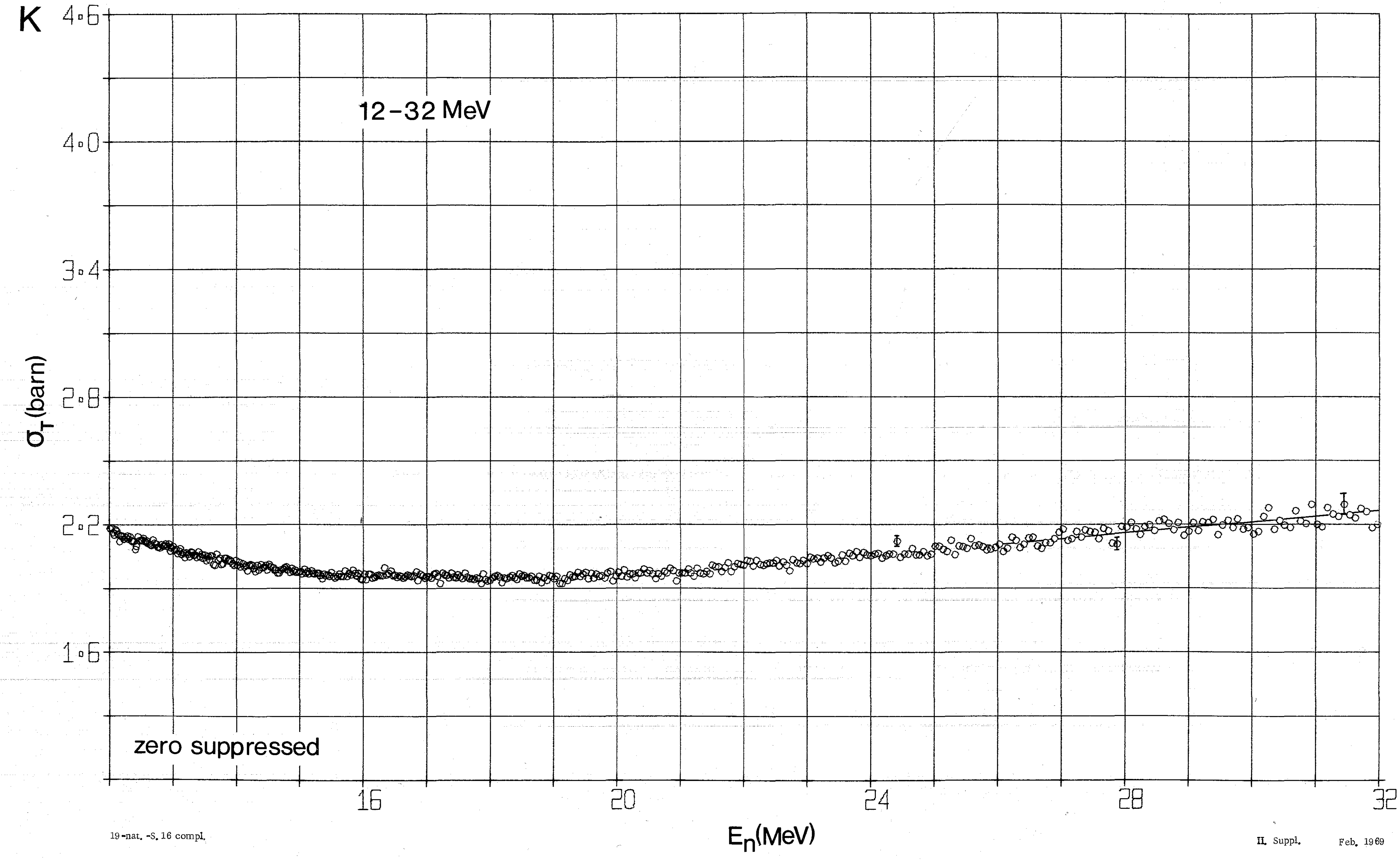

3.0 - 4.5 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
E_n(MeV)


K
4·6
4·0
3·4
2·8
2·2
1·6
4.5-7.0 MeV
σ_T(barn)
zero suppressed
5·0
5·5
6·0
6·5
7·0
E_n(MeV)

K



4.6
4.0
3.4
2.8
2.2
1.6
7.0-12 MeV
σ_T(barn)
zero suppressed
8.0
9.0
10.0
11.0
12.0
E_n(MeV)


K
4·6
12-32 MeV
4·0
3·4
2·8
σT (barn)
2·2
1·6
zero suppressed
16
20
24
28
32
En(MeV)

Ca

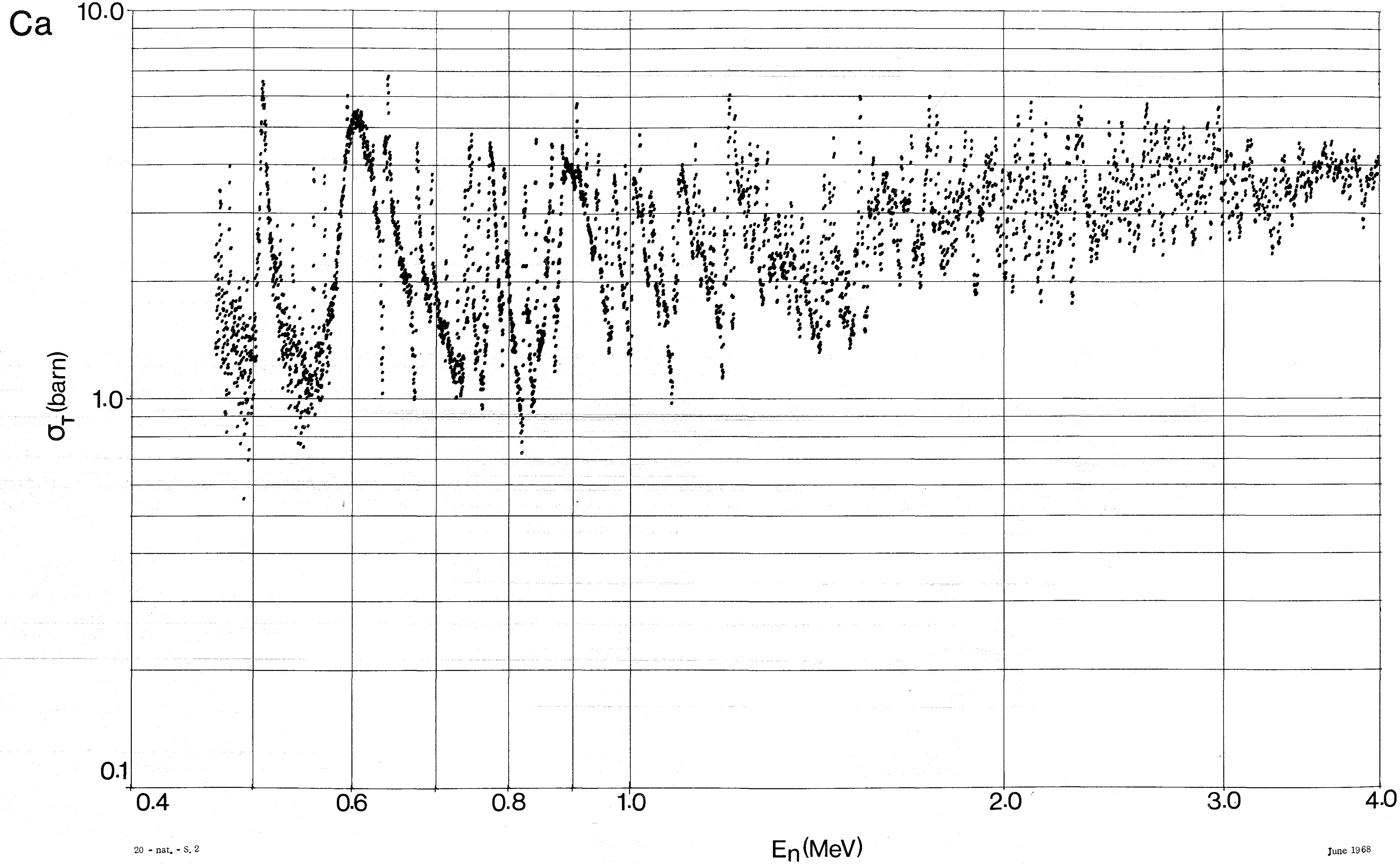
n = 0.21326 at/barn

p = 98.5 %

l = 57.398 m

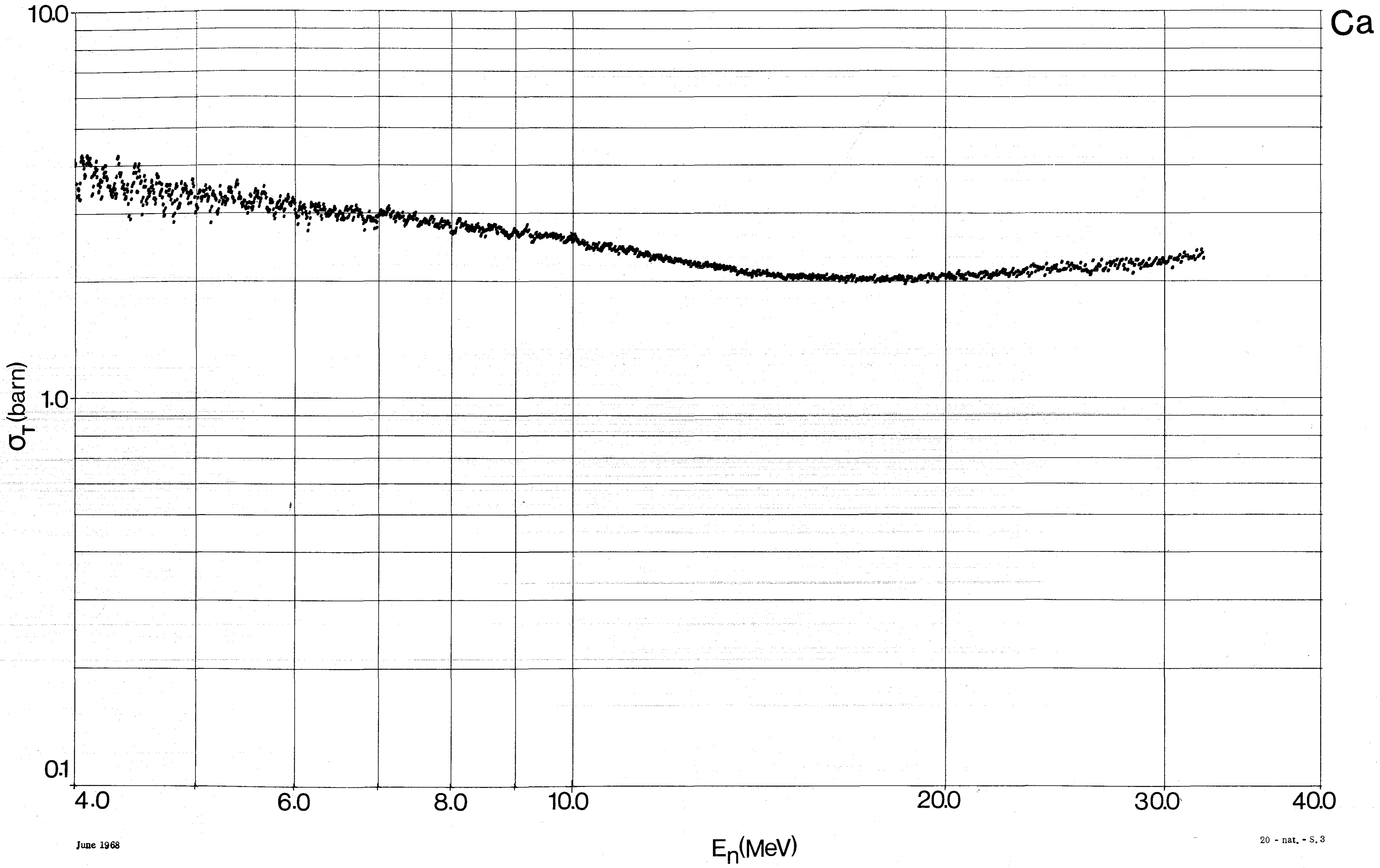
Δt = 2.5 nsec

i : natural



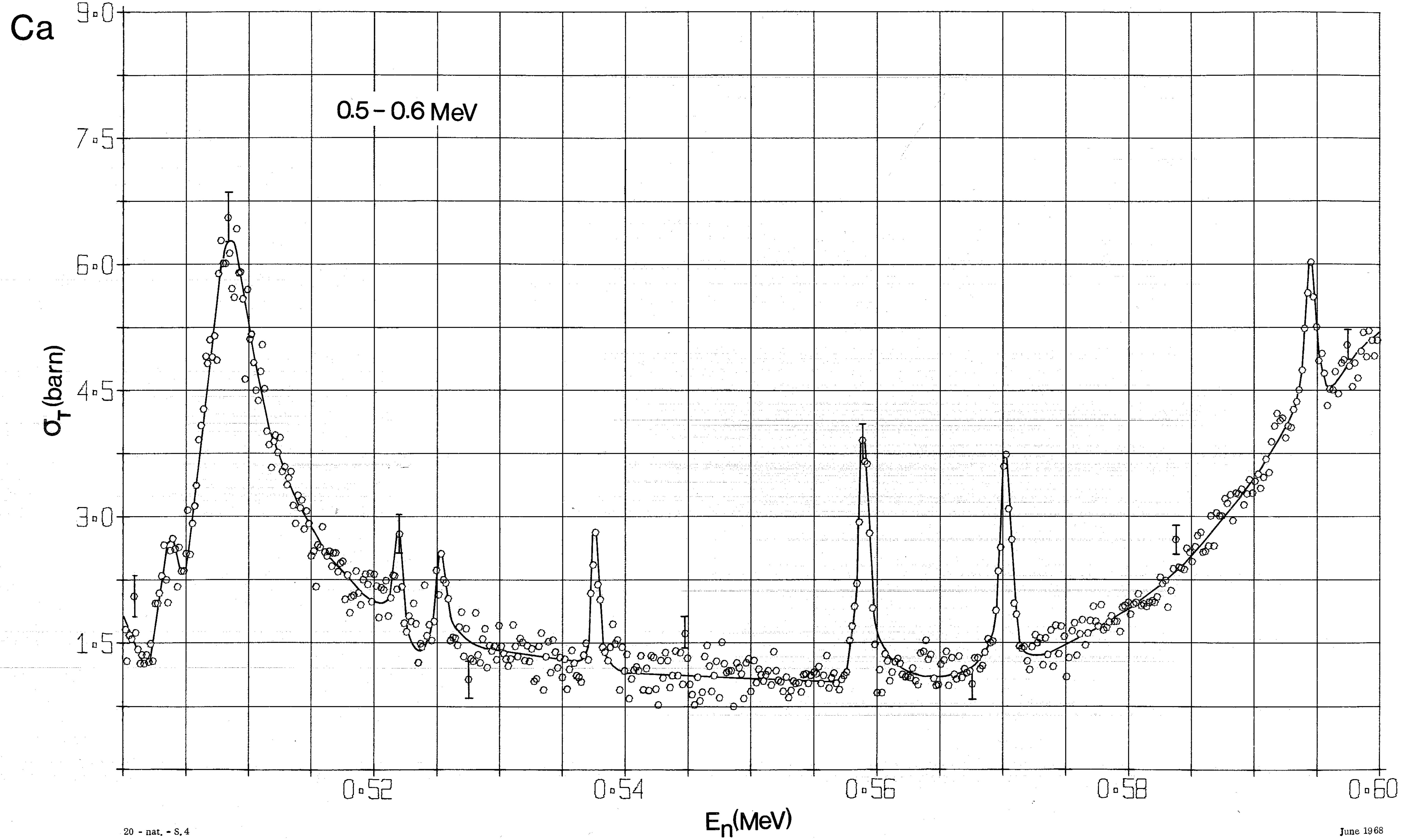
20 - nat. - S. 2

June 1968



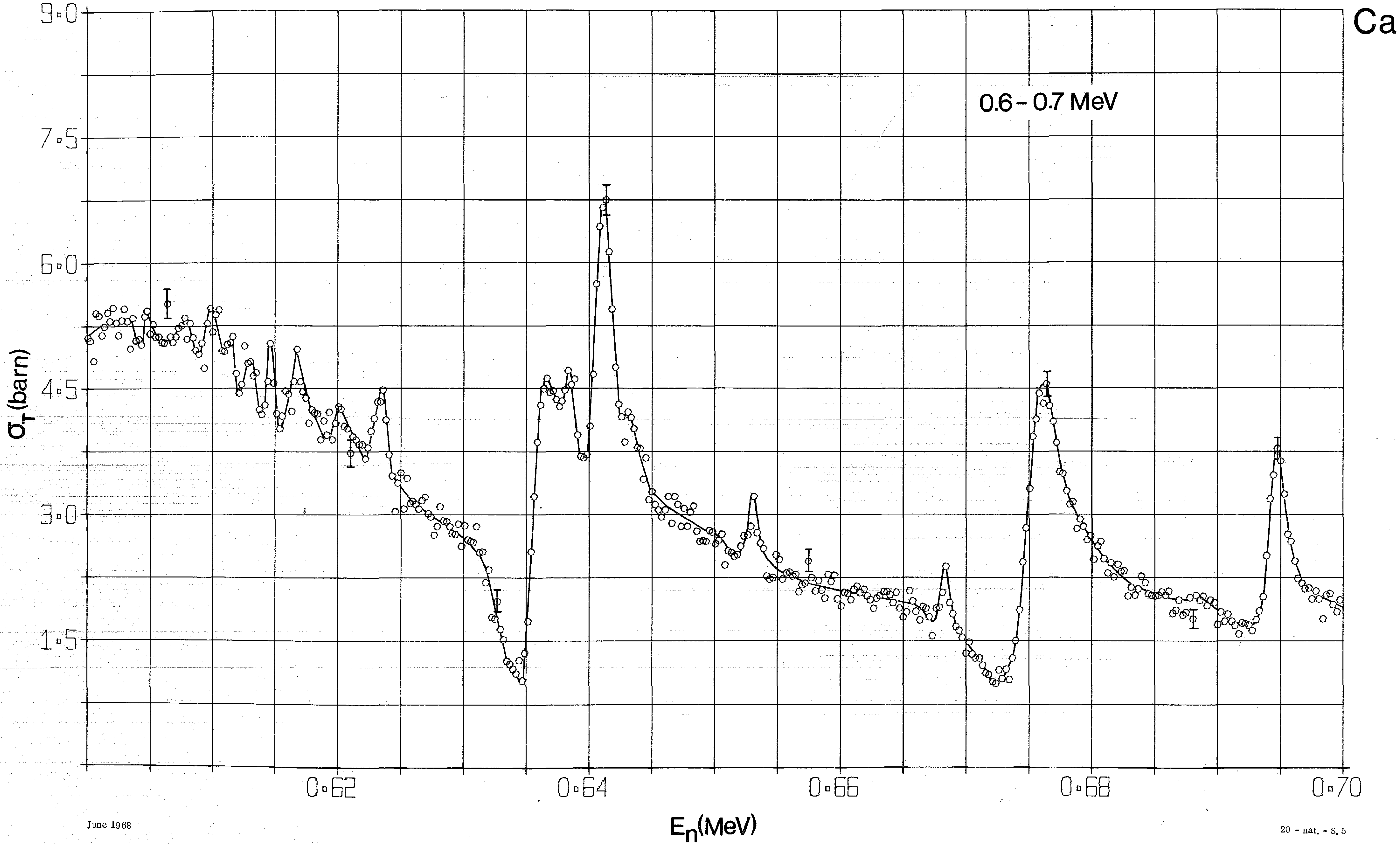
June 1968

20 - nat. - S. 3

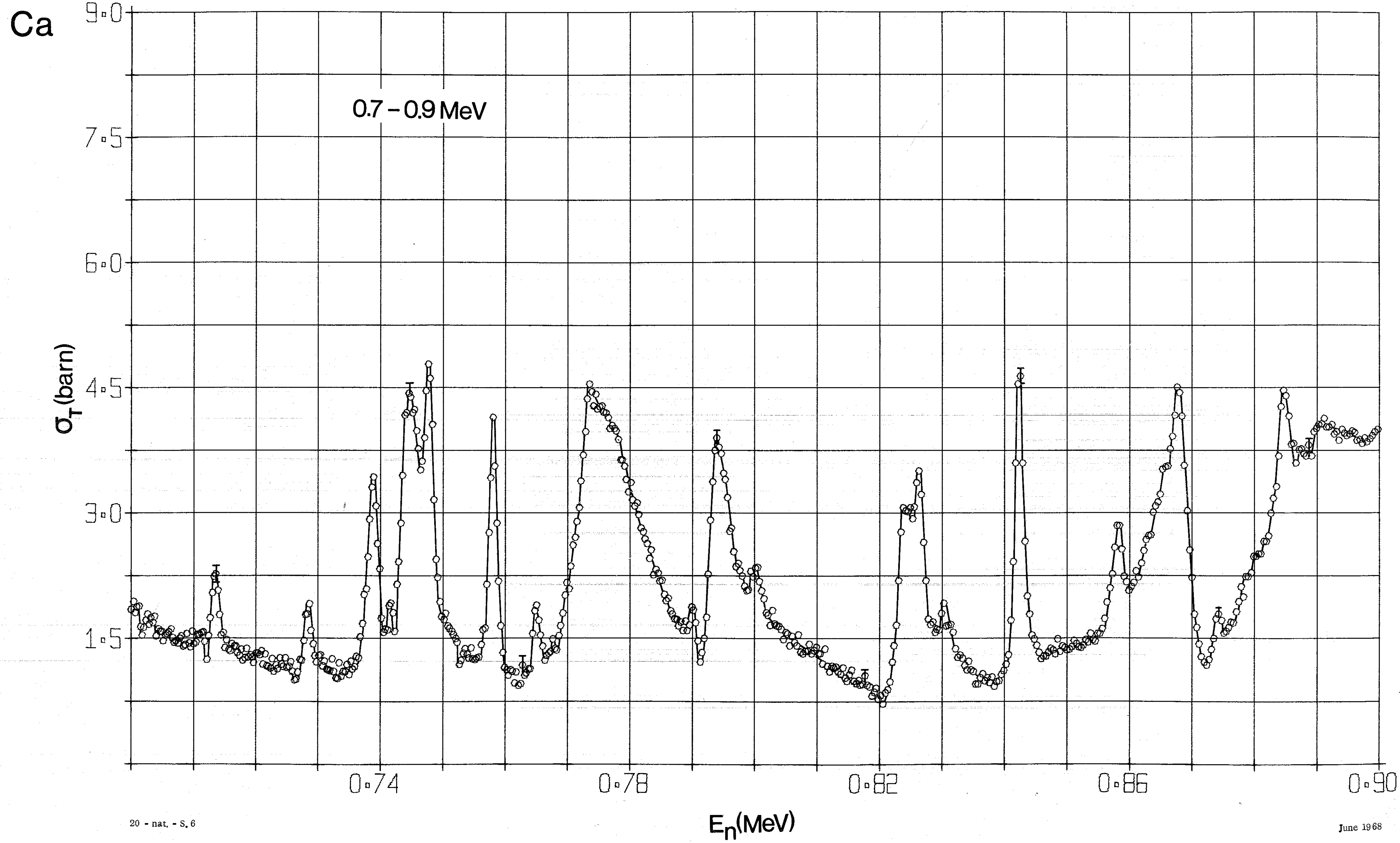


20 - nat. - S.4

June 1968

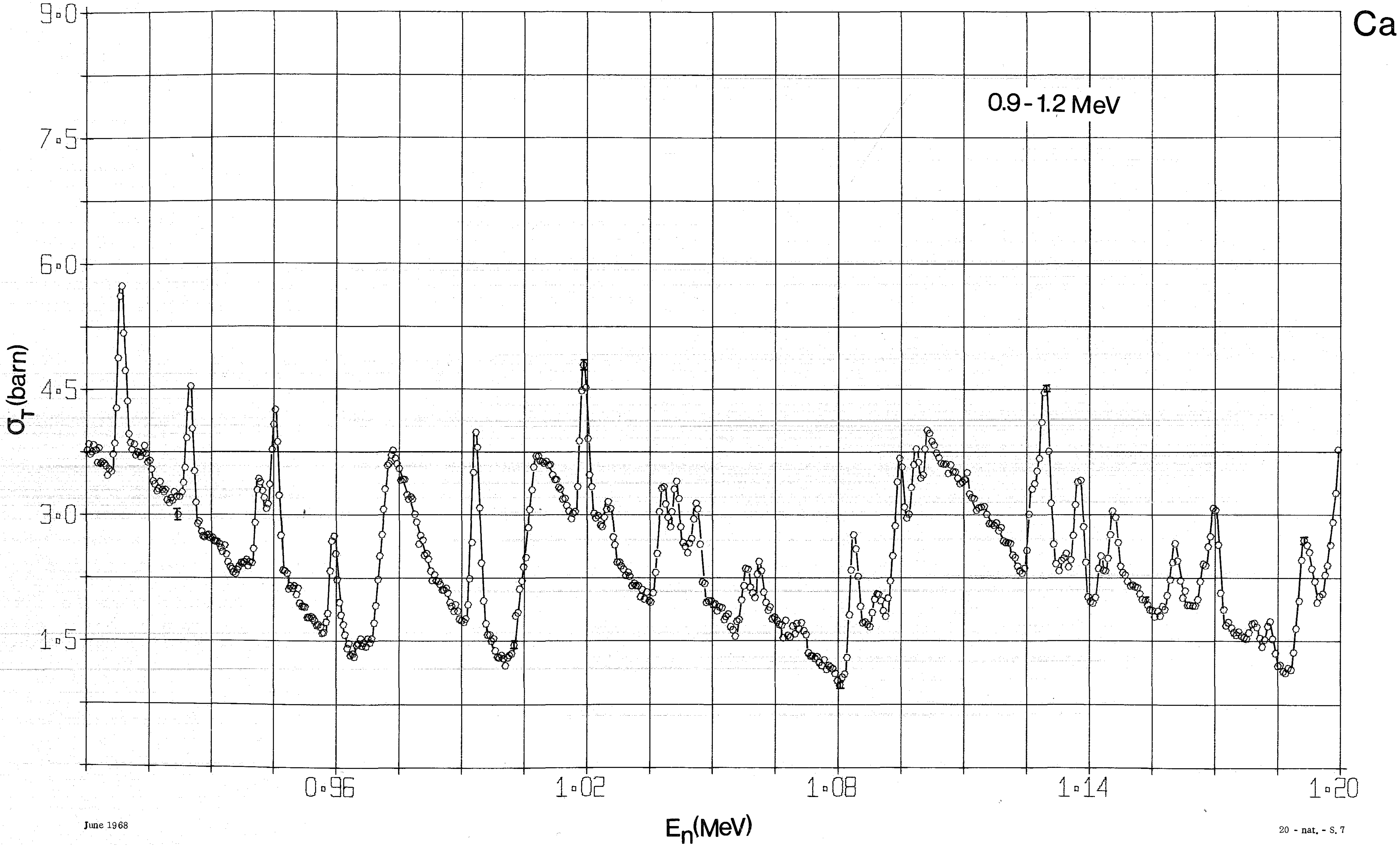

Ca
0.6 - 0.7 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σ_T (barn)
0·62
0·64
0·66
0·68
0·70
E_n(MeV)

June 1968



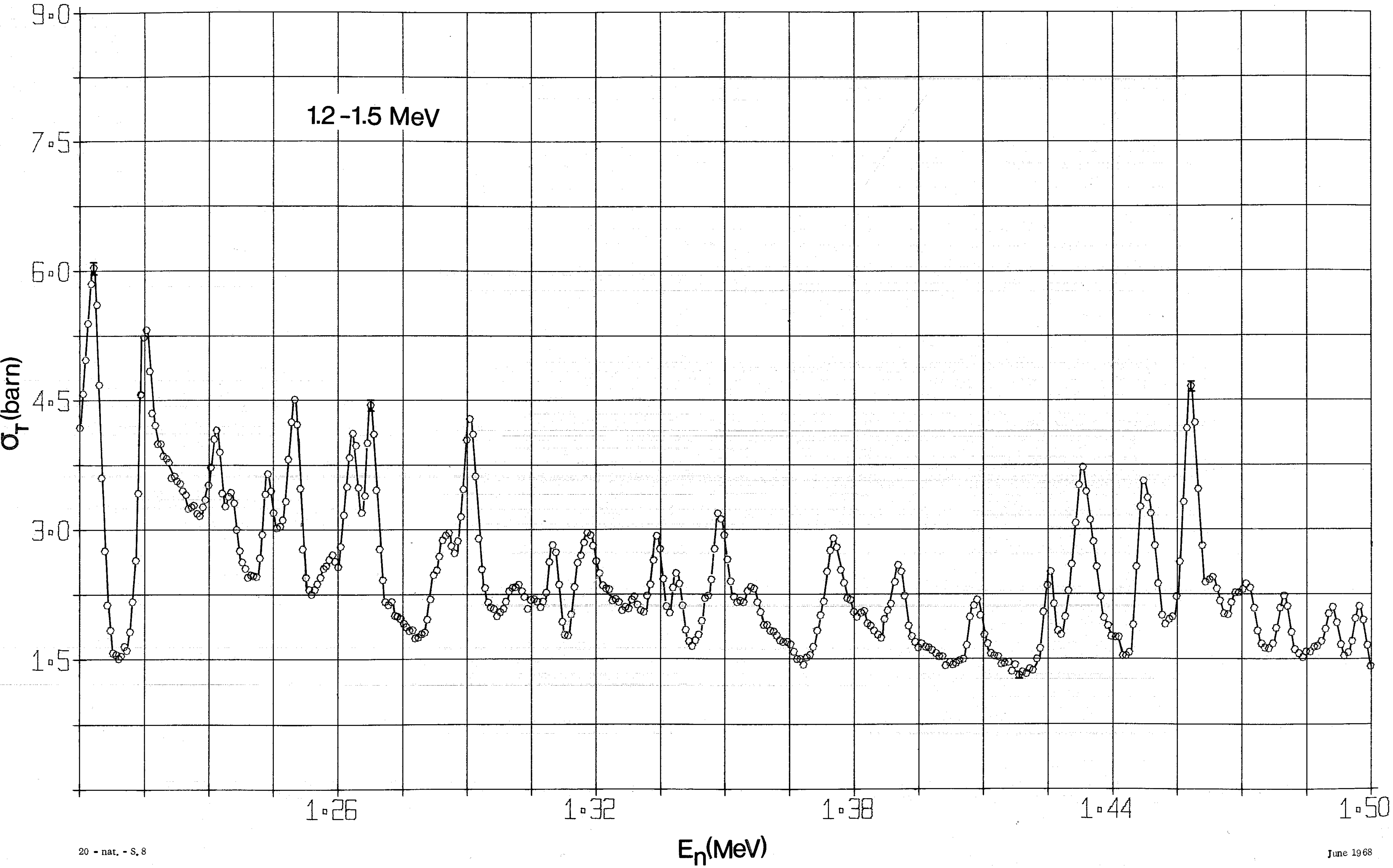
20 - nat. - S. 6

June 1968



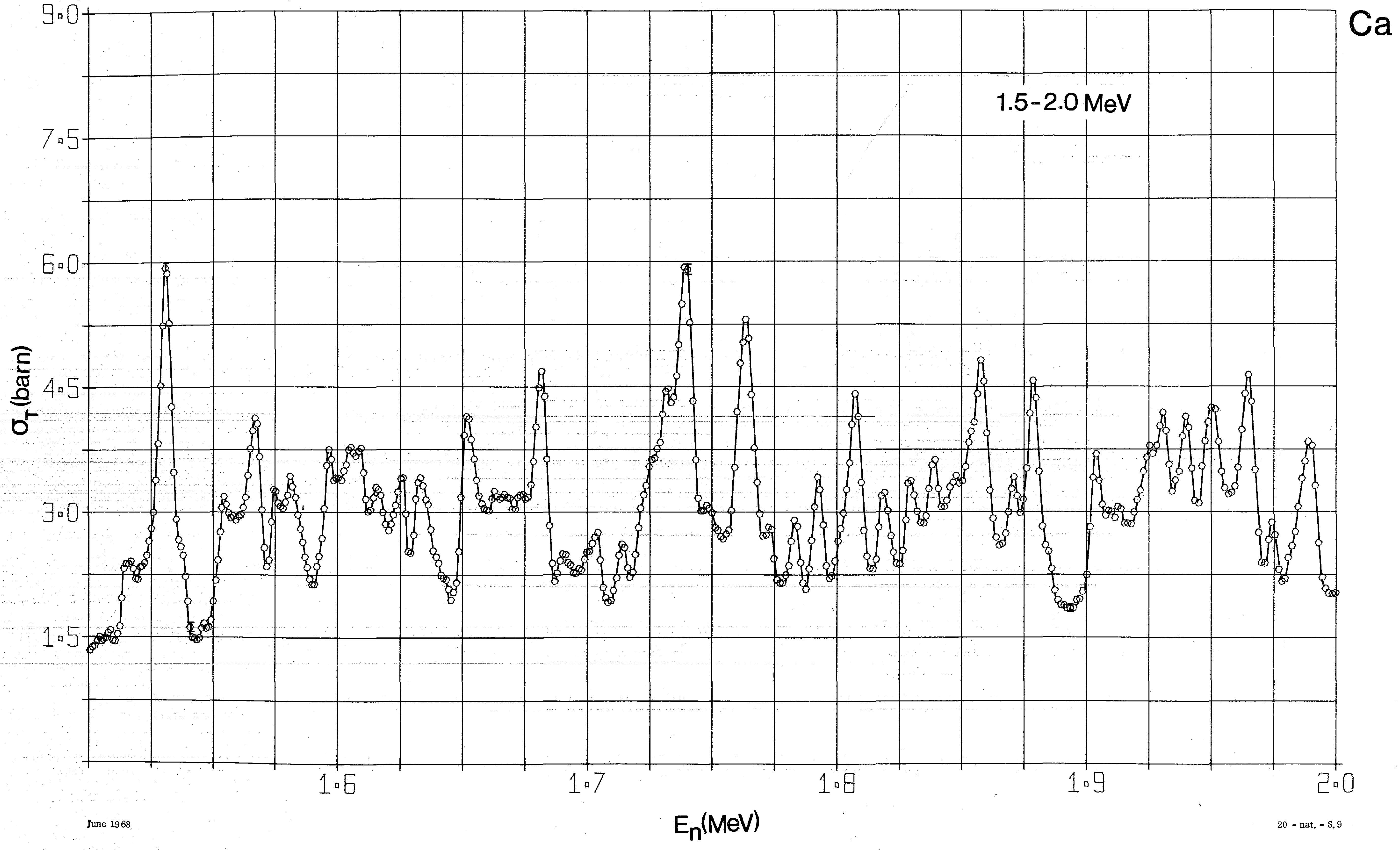
Ca
0.9 - 1.2 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σT (barn)
0·96
1·02
1·08
1·14
1·20
En(MeV)

Ca



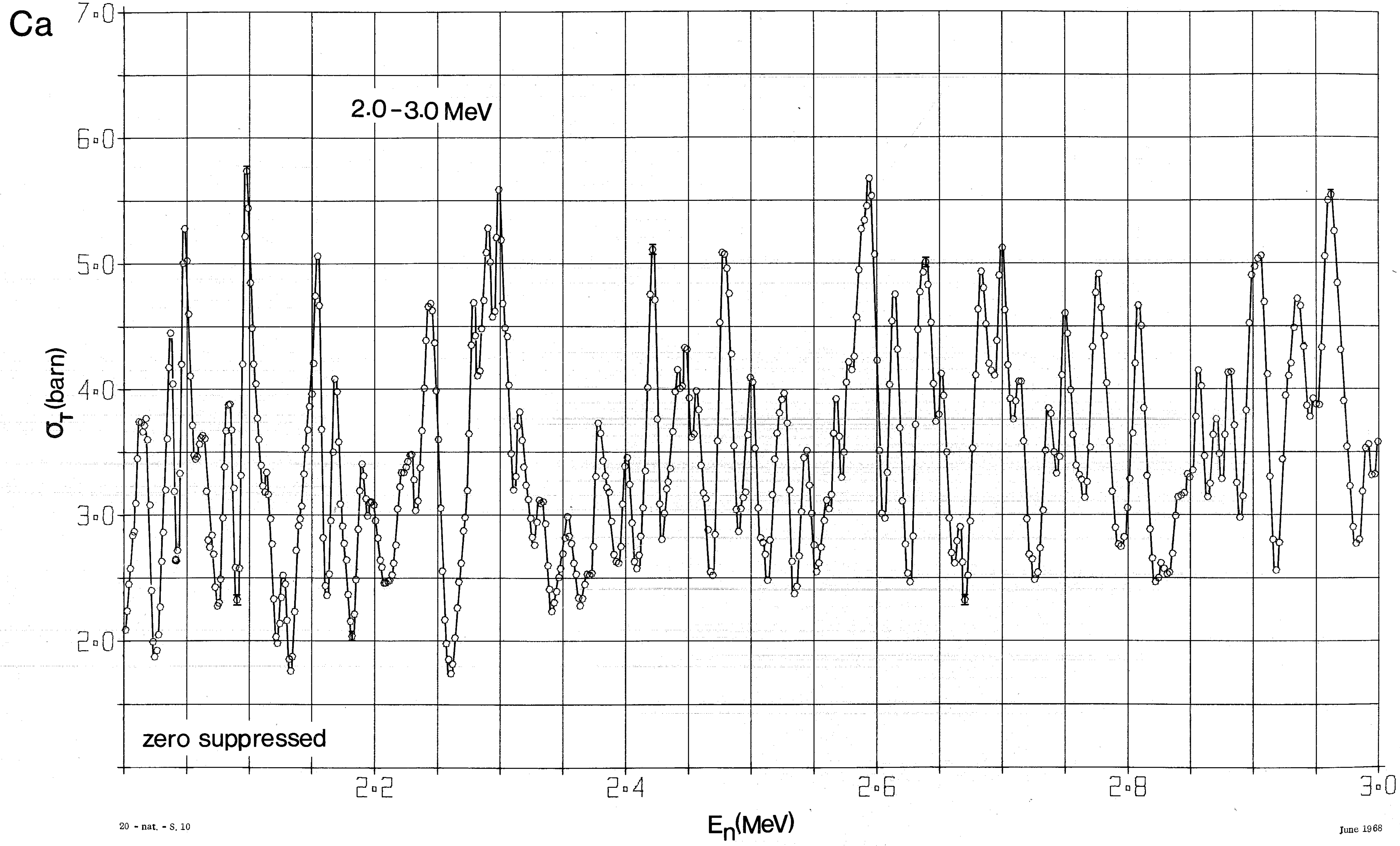
20 - nat. - S. 8

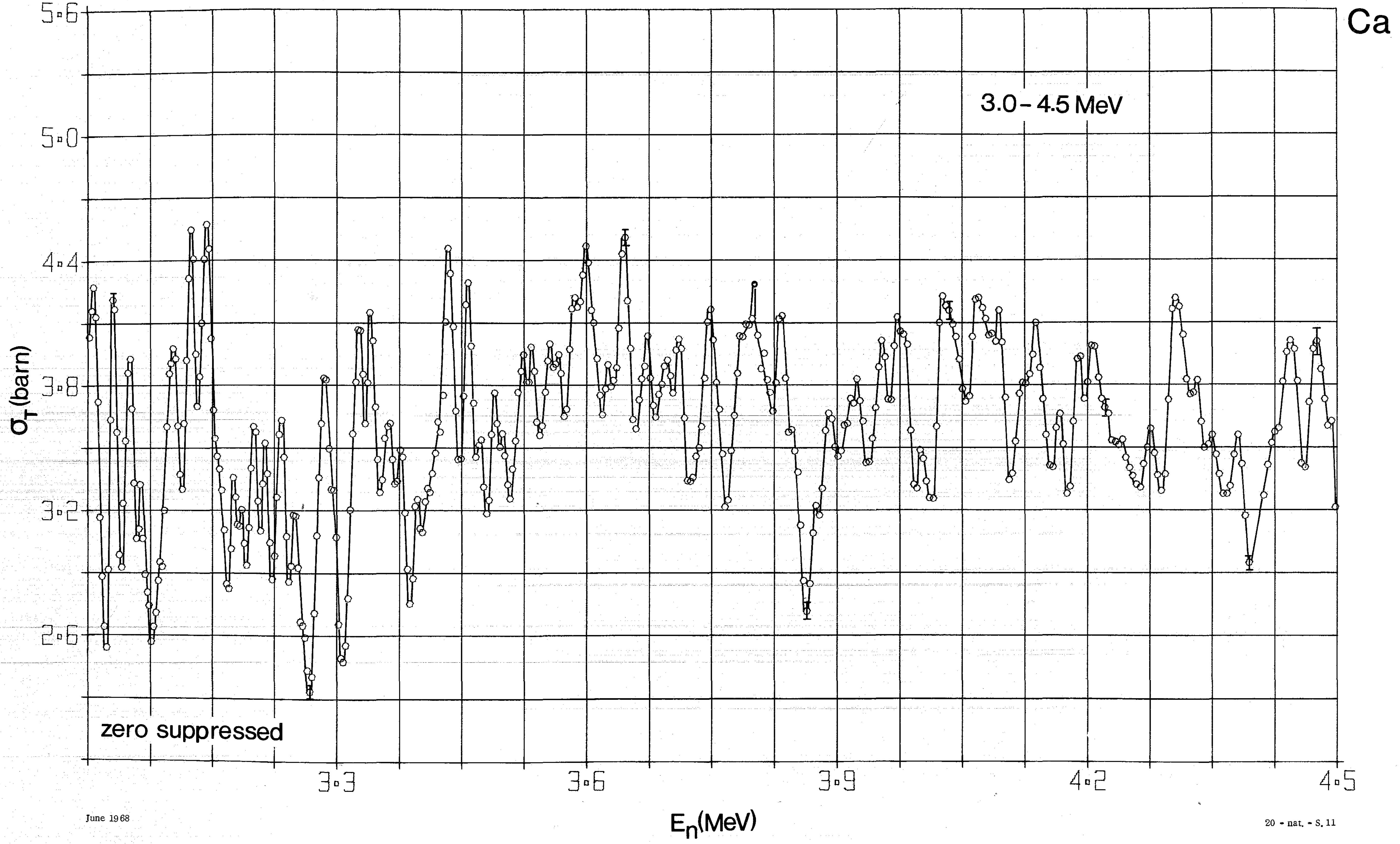
June 1968



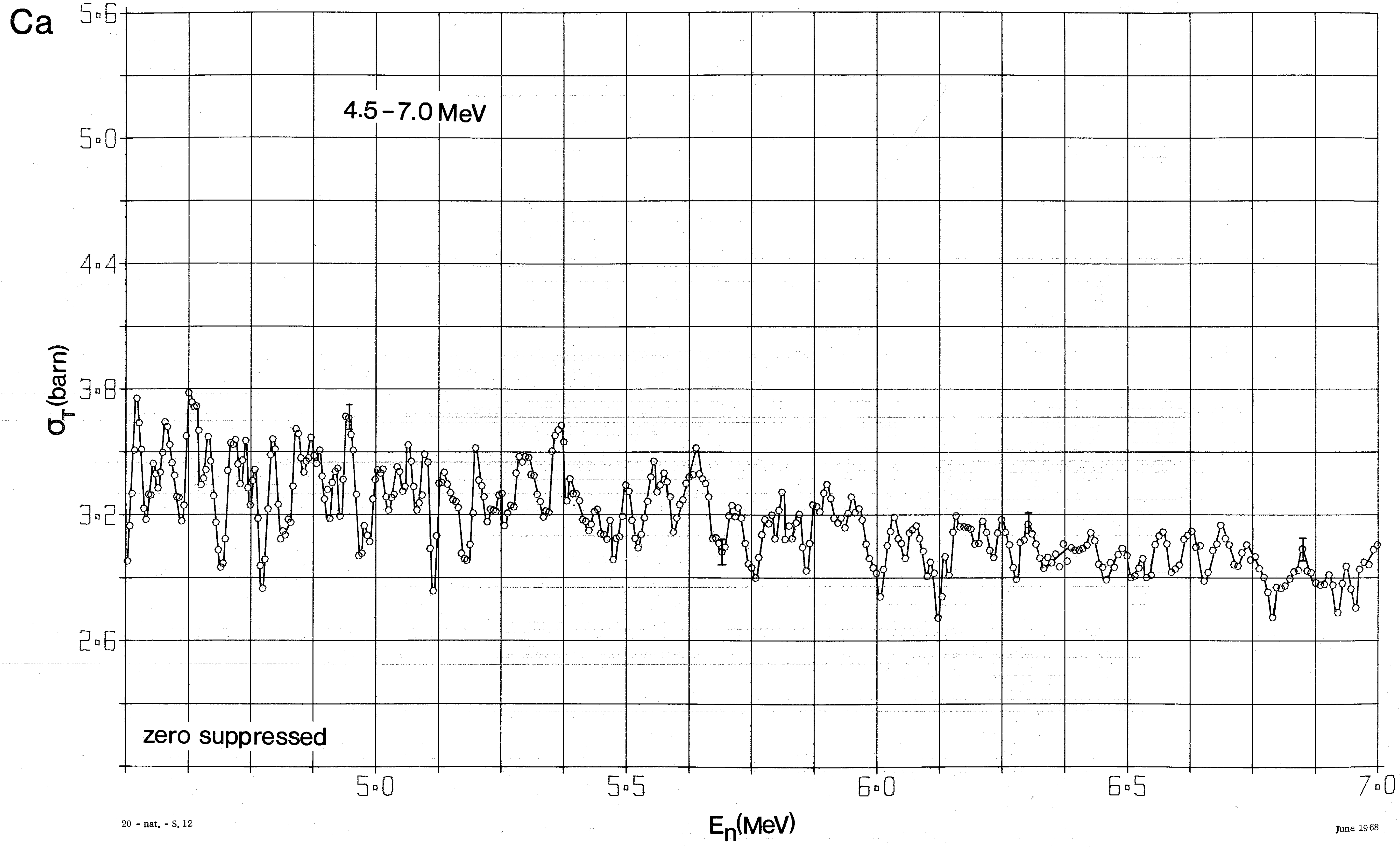
June 1968

20 - nat. - S.9


Ca
2.0-3.0 MeV
zero suppressed
σ_T(barn)
7.0
6.0
5.0
4.0
3.0
2.0
2.2
2.4
2.6
2.8
3.0
E_n(MeV)

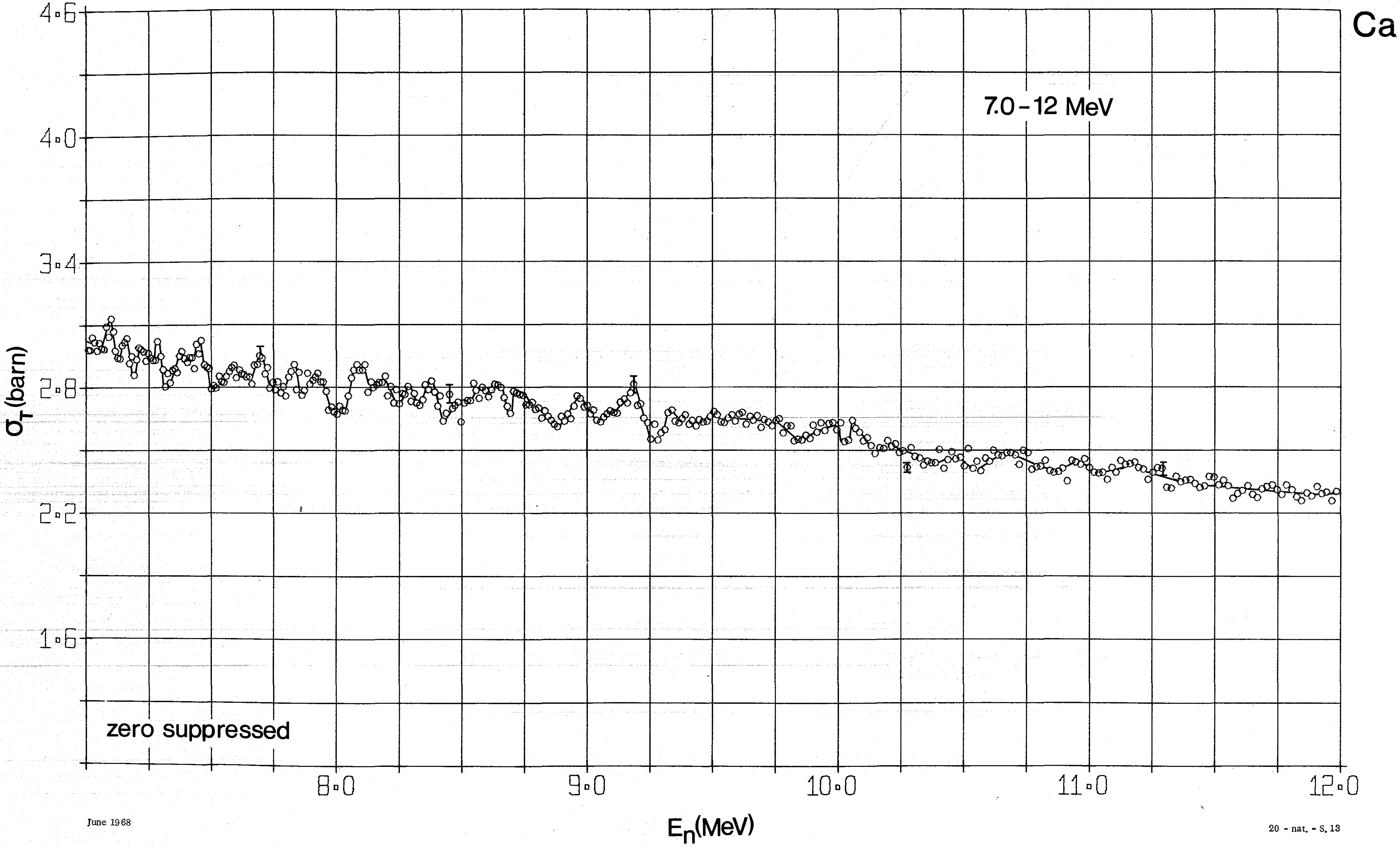

Ca
3.0 - 4.5 MeV
5·6
5·0
4·4
3·8
3·2
2·6
σT (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
En(MeV)

June 1968



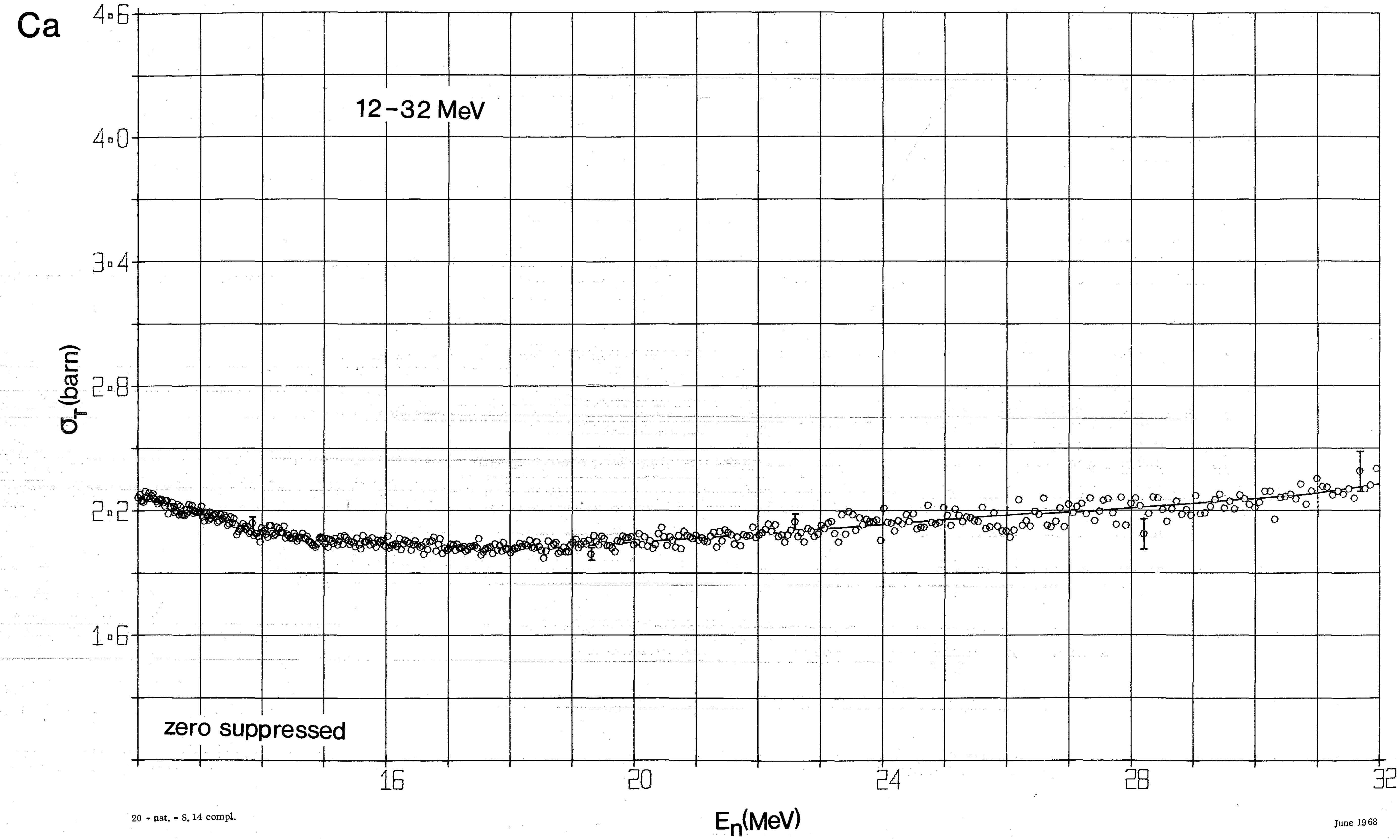
Ca
4.5-7.0 MeV
zero suppressed
5·6
5·0
4·4
3·8
3·2
2·6
σT (barn)
5·0
5·5
6·0
6·5
7·0
En(MeV)

June 1968



June 1968

20 - nat. - S. 13

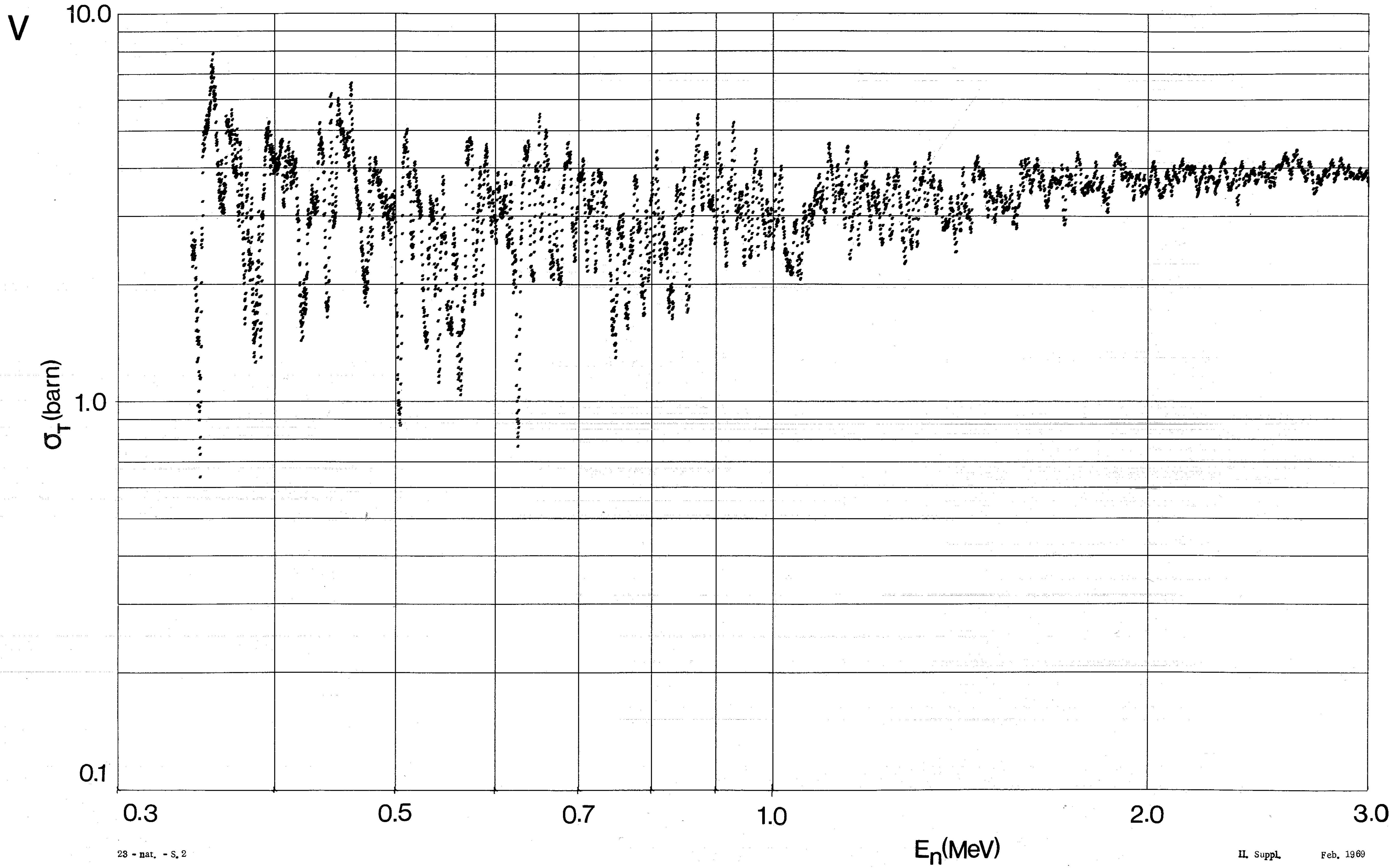


20 - nat. - S. 14 compl.

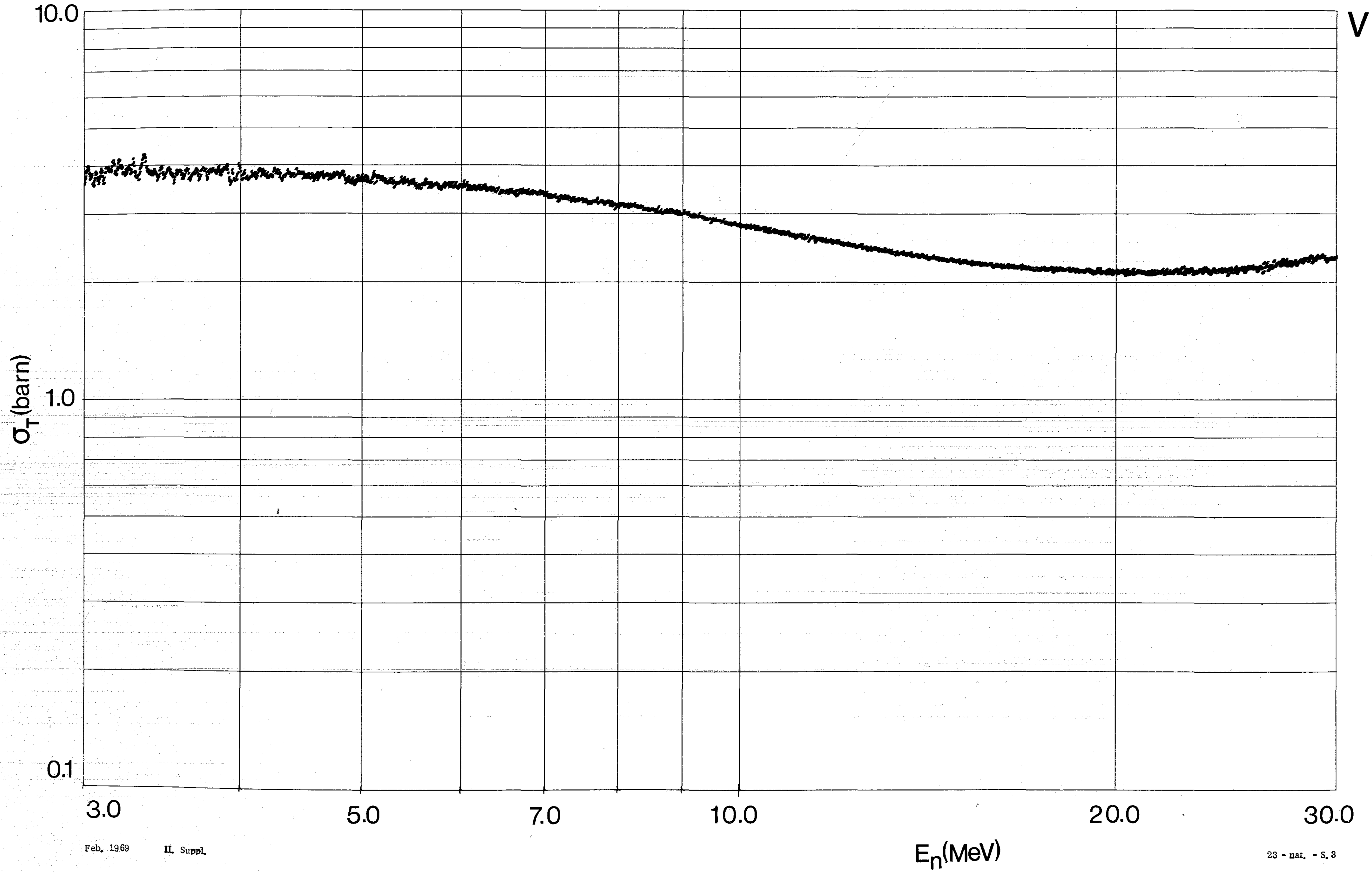
June 1968

V

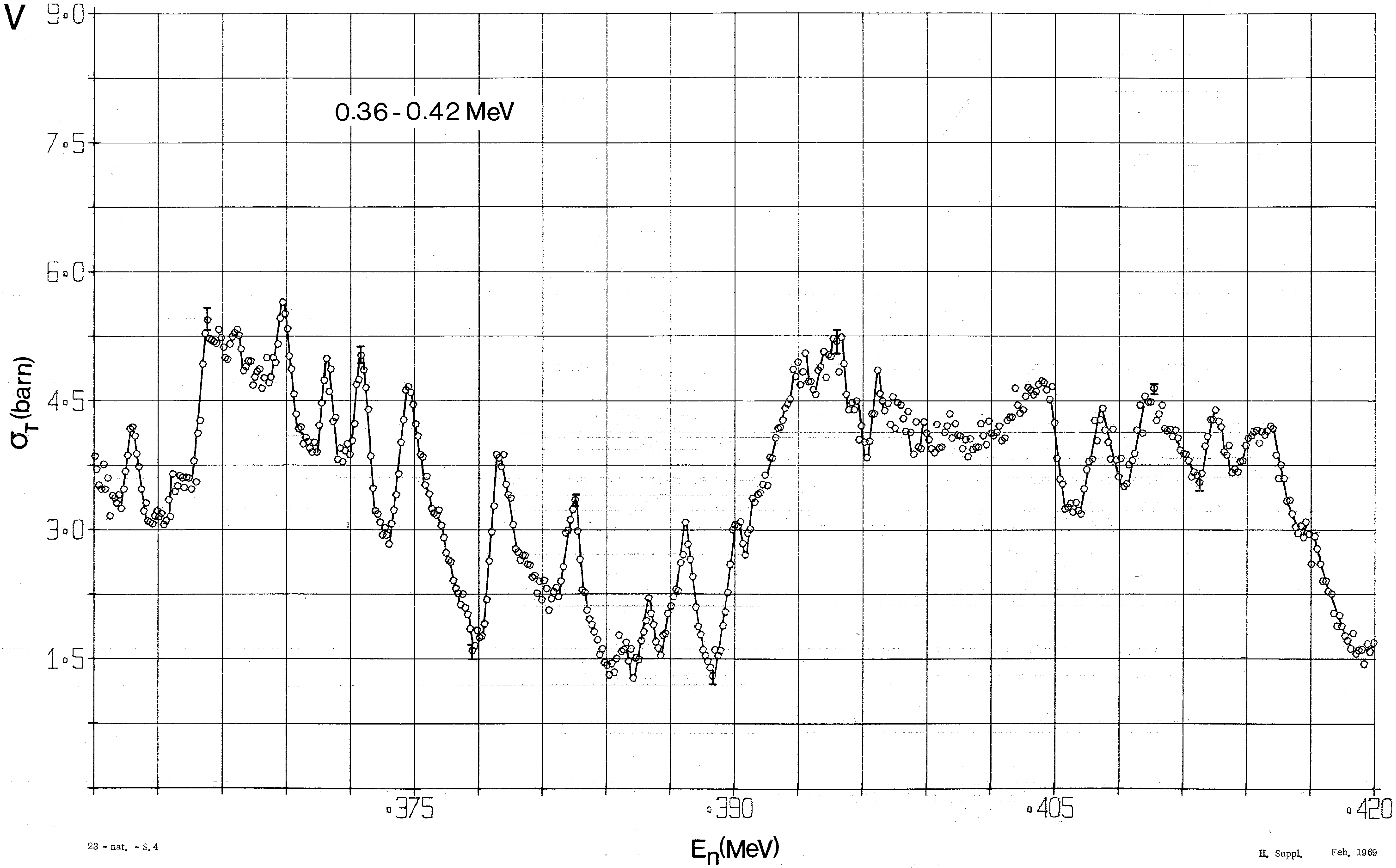
n	=	0.2523	At/barn
p	=	99.7	%
l	=	57.540	m
Δt	=	3.9	nsec
i	:	natural	

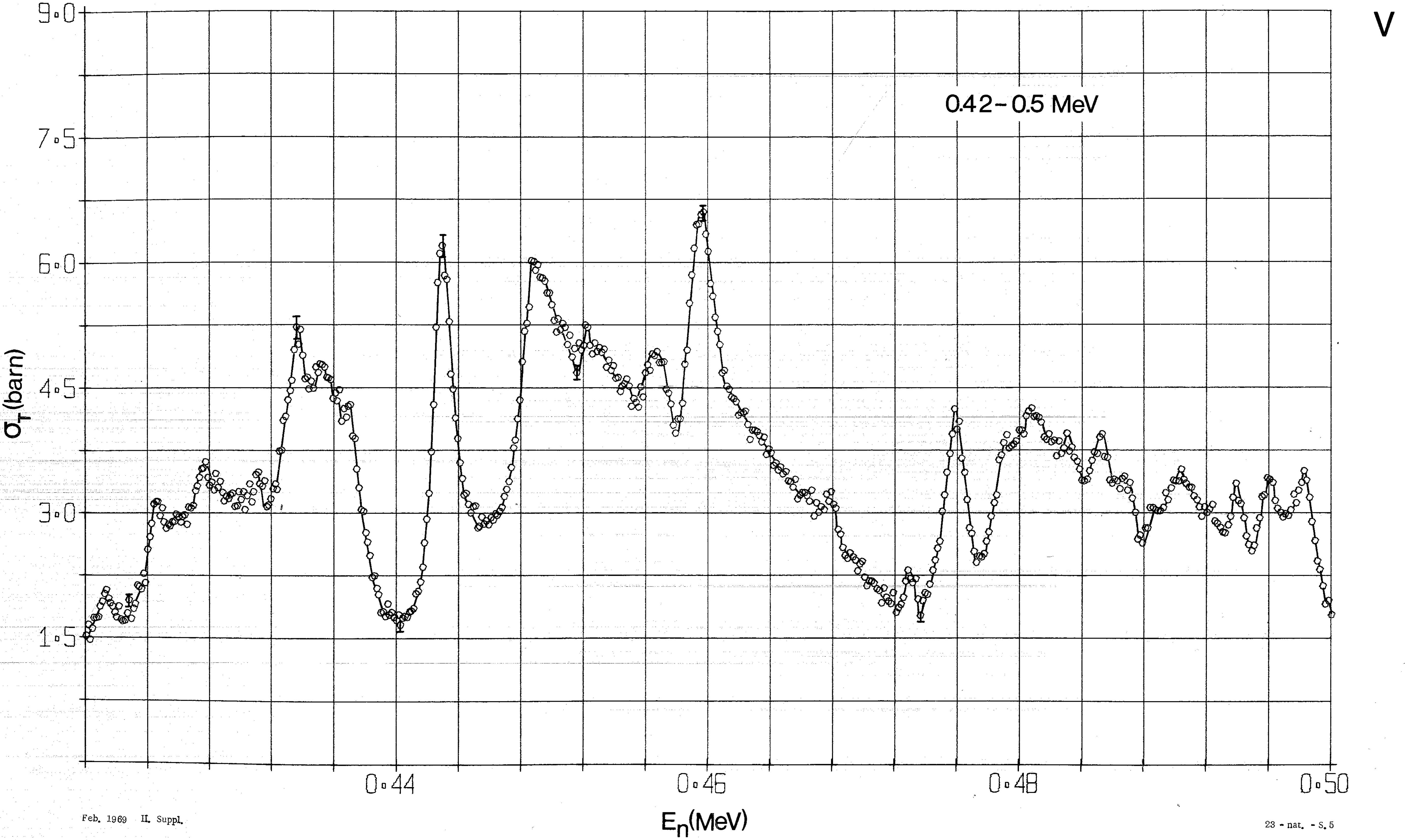


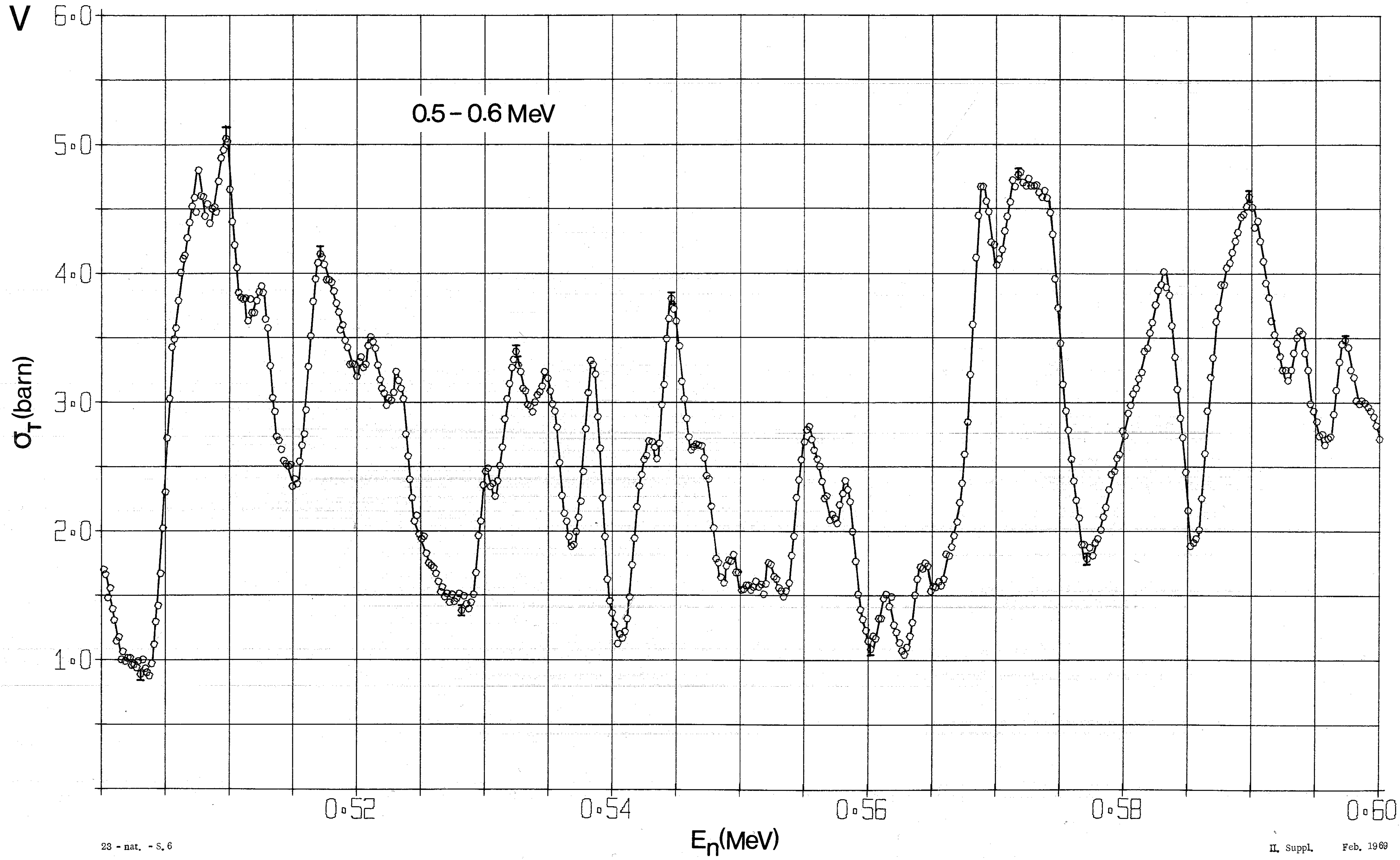
V
10.0
1.0
0.1
σT(barn)
0.3
0.5
0.7
1.0
2.0
3.0
En(MeV)

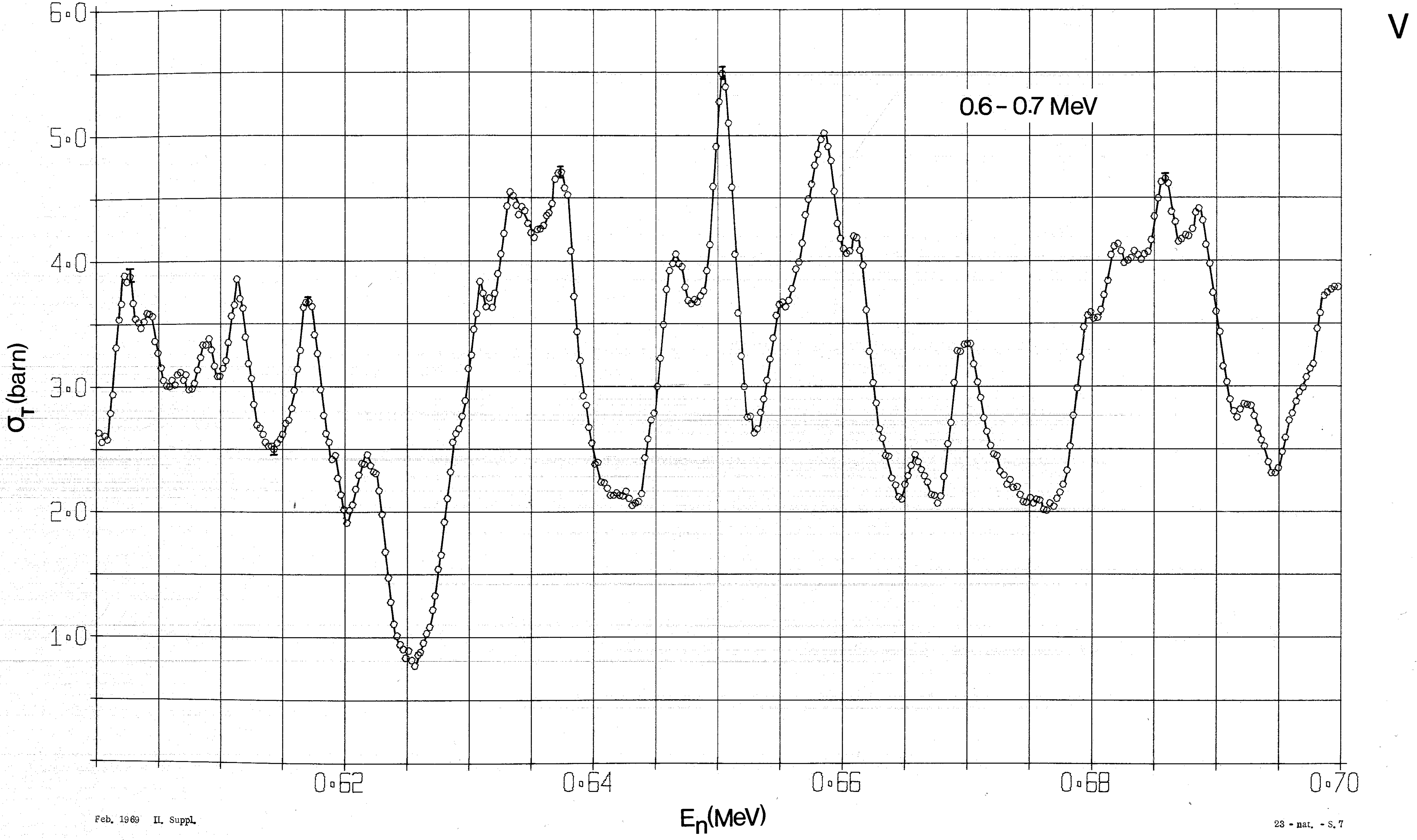


V
10.0
1.0
0.1
σT (barn)
3.0
5.0
7.0
10.0
20.0
30.0
En(MeV)

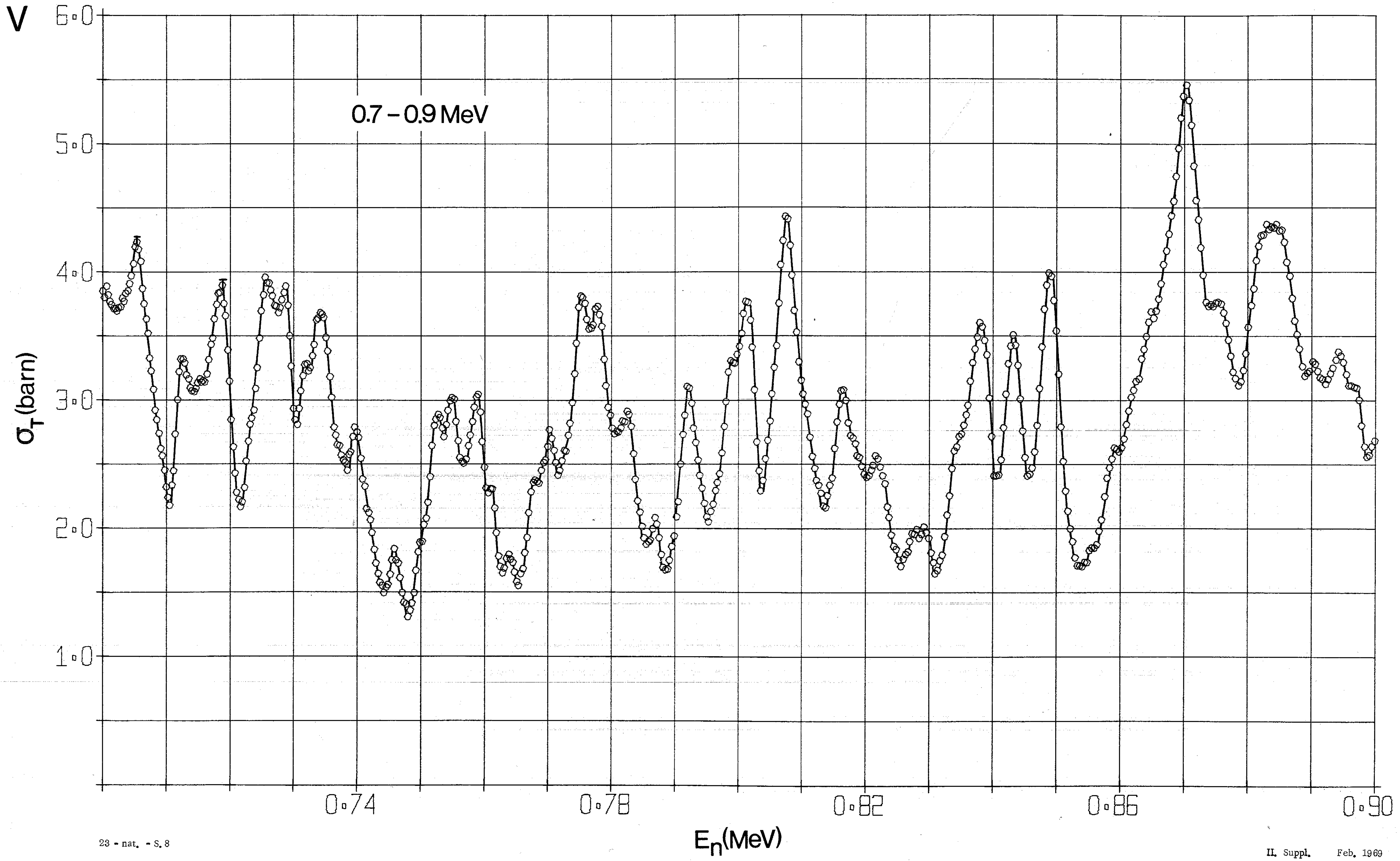

V
9·0
7·5
6·0
4·5
3·0
1·5
0.36 - 0.42 MeV
σT (barn)
·375
·390
·405
·420
En(MeV)

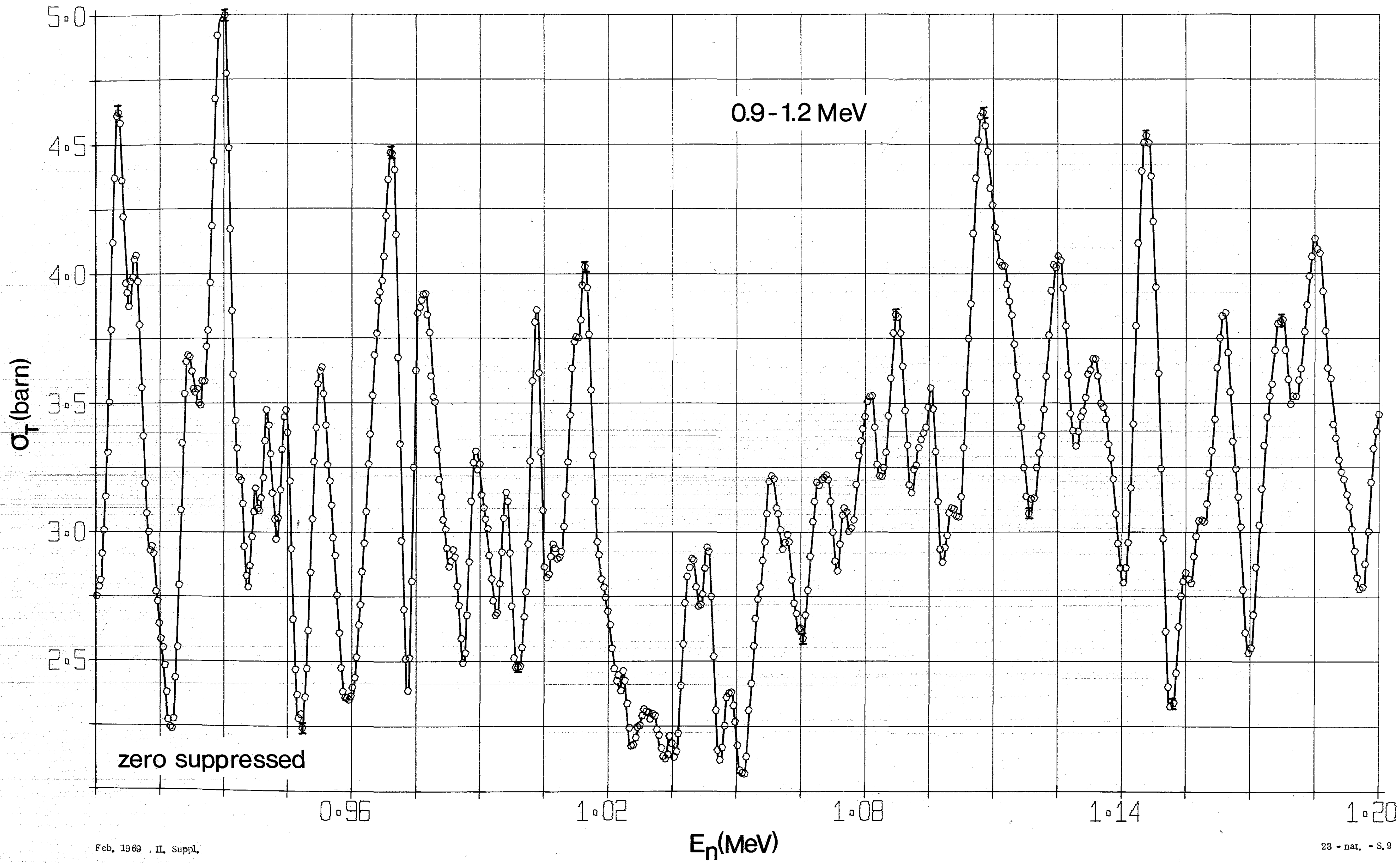

V
0.42 - 0.5 MeV
9.0
7.5
6.0
4.5
3.0
1.5
σT (barn)
0.44
0.46
0.48
0.50
En(MeV)


V
6·0
5·0
4·0
3·0
2·0
1·0
0.5 - 0.6 MeV
σ_T (barn)
0·52
0·54
0·56
0·58
0·60
E_n(MeV)



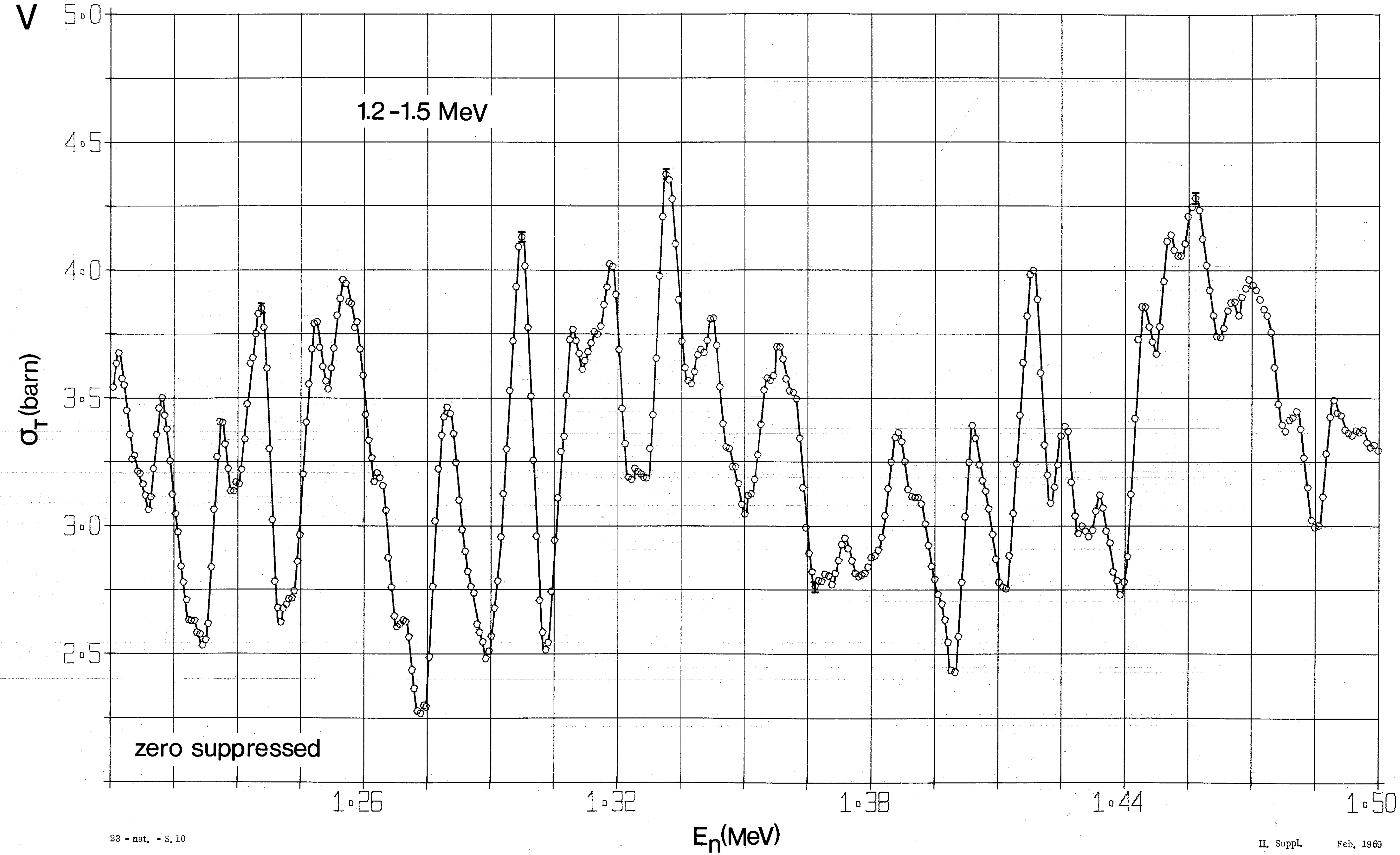
6·0
5·0
4·0
3·0
2·0
1·0
σ_T (barn)
0.6 - 0.7 MeV
0·62
0·64
0·66
0·68
0·70
E_n(MeV)


V
0.7 – 0.9 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σ_T (barn)
0·74
0·78
0·82
0·86
0·90
E_n(MeV)

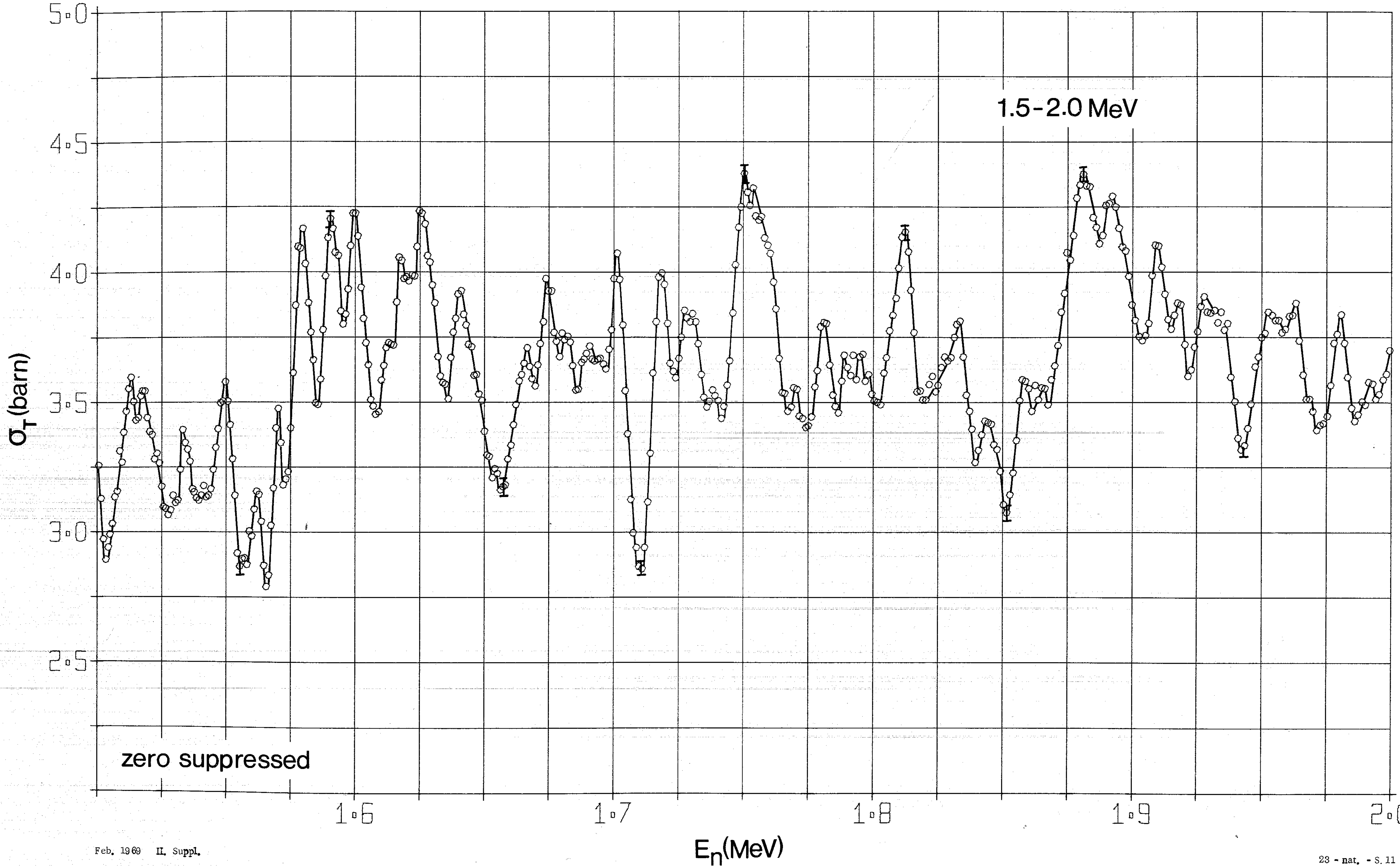


5·0
4·5
4·0
3·5
3·0
2·5
σT (barn)
0.9 - 1.2 MeV
zero suppressed
0·96
1·02
1·08
1·14
1·20
En(MeV)

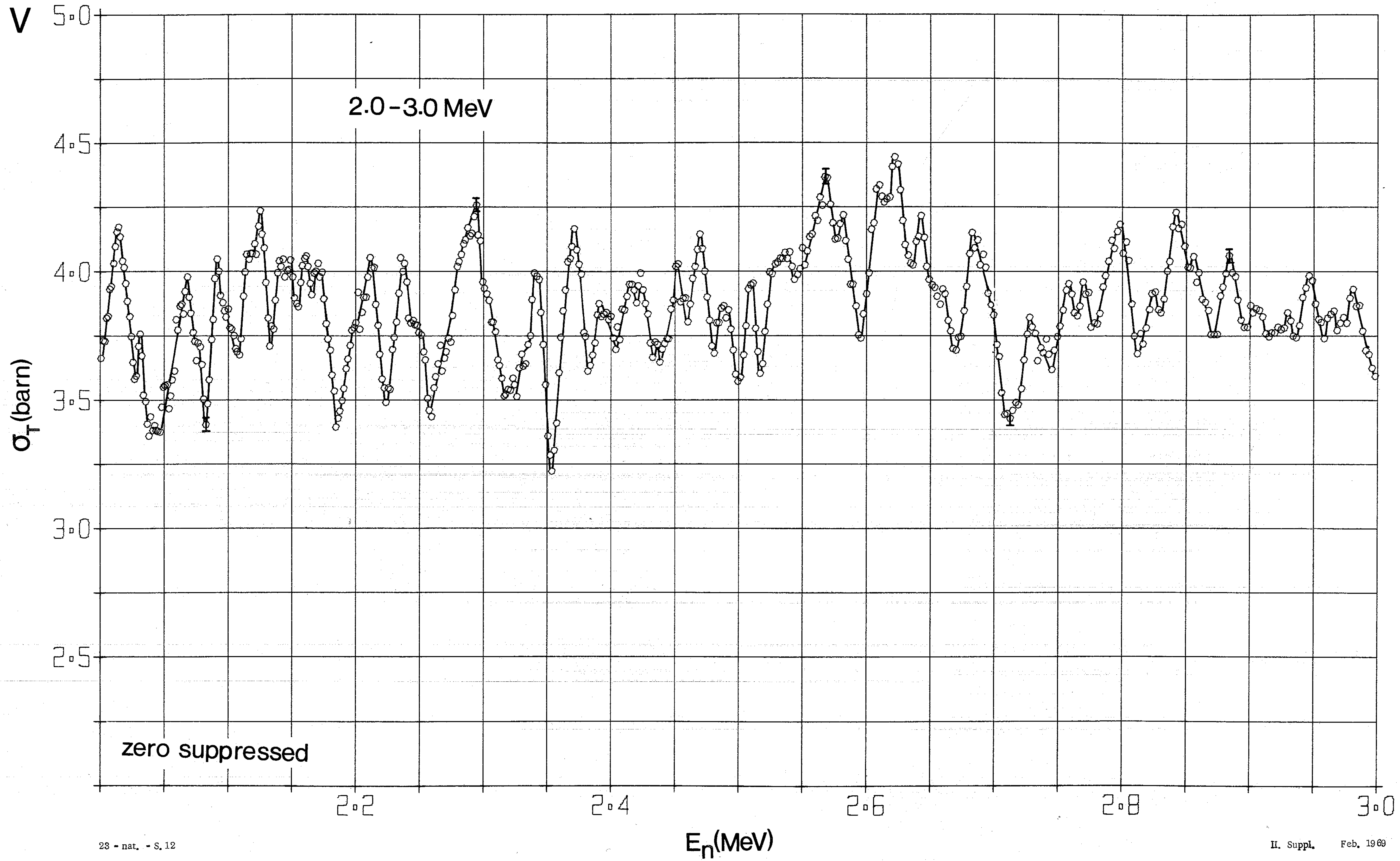
V


V
1.2 -1.5 MeV
zero suppressed
σT (barn)
5·0
4·5
4·0
3·5
3·0
2·5
1·26
1·32
1·38
1·44
1·50
En(MeV)

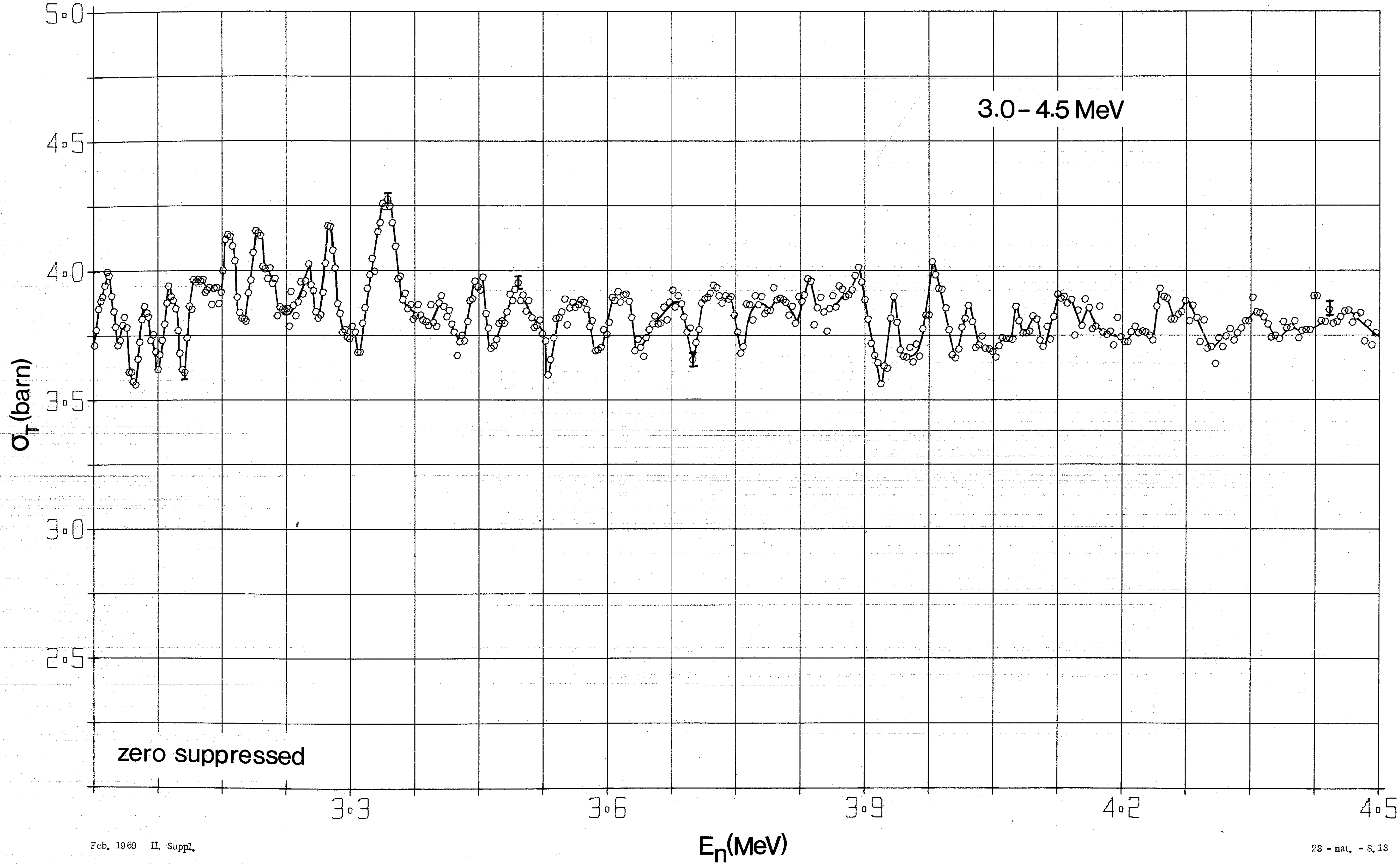
V



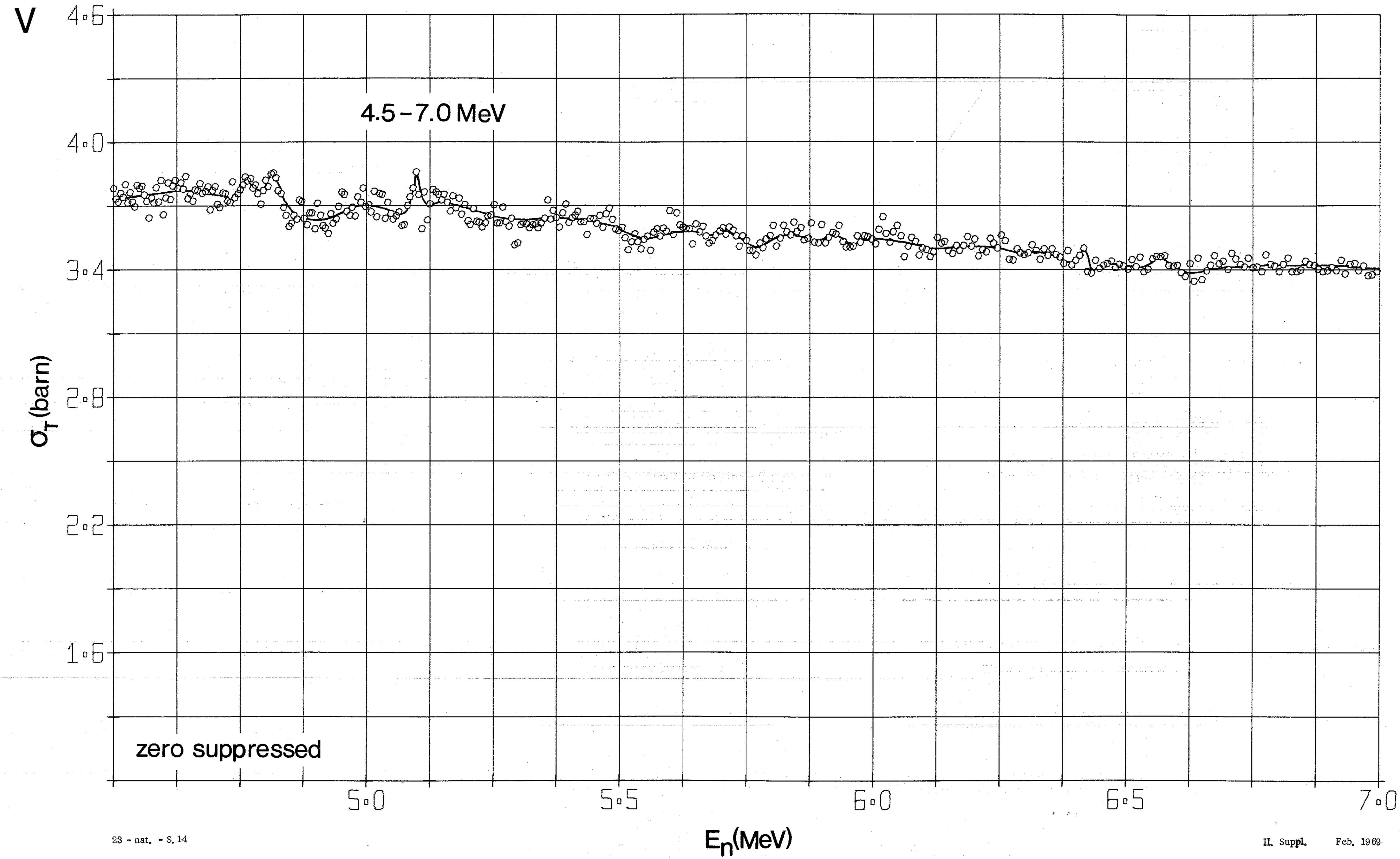
5.0
4.5
4.0
3.5
3.0
2.5
σT (barn)
1.5-2.0 MeV
zero suppressed
1.6
1.7
1.8
1.9
2.0
En(MeV)


V
2.0 - 3.0 MeV
zero suppressed
5·0
4·5
4·0
3·5
3·0
2·5
σ_T (barn)
2·2
2·4
2·6
2·8
3·0
E_n(MeV)

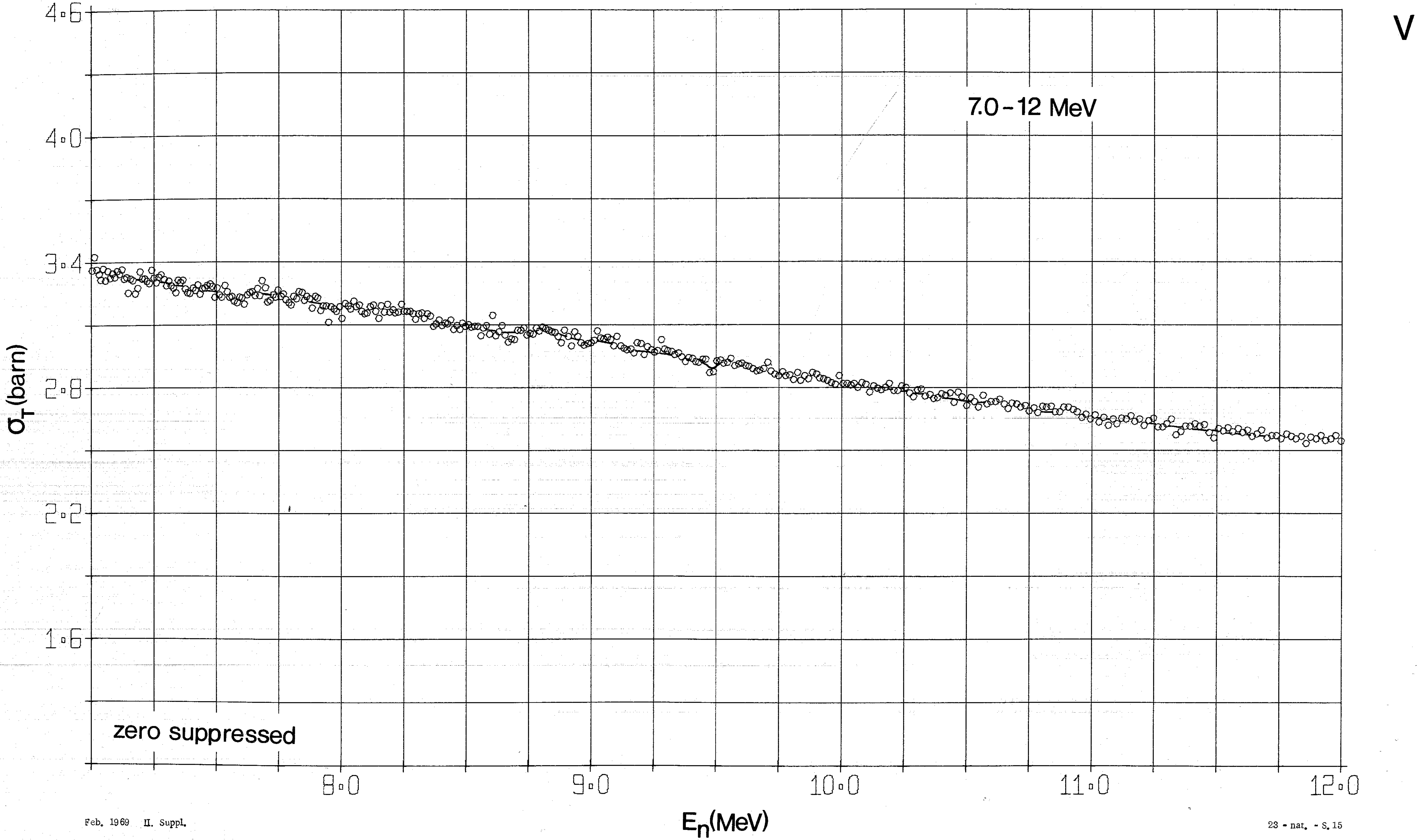
V



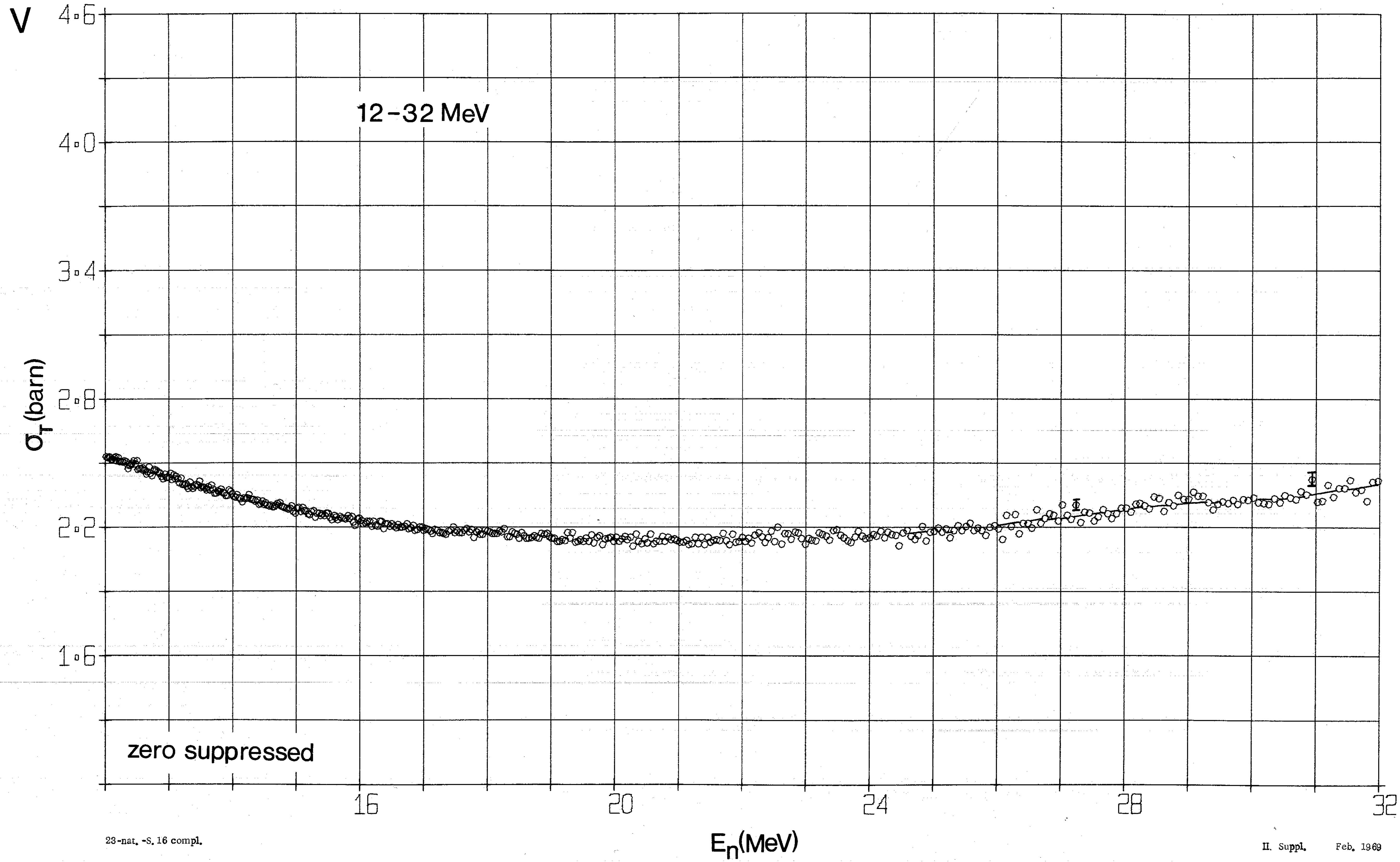
3.0 - 4.5 MeV
5·0
4·5
4·0
3·5
3·0
2·5
σT (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
En(MeV)



V
4.5 - 7.0 MeV
σT (barn)
4·6
4·0
3·4
2·8
2·2
1·6
zero suppressed
5·0
5·5
6·0
6·5
7·0
En(MeV)



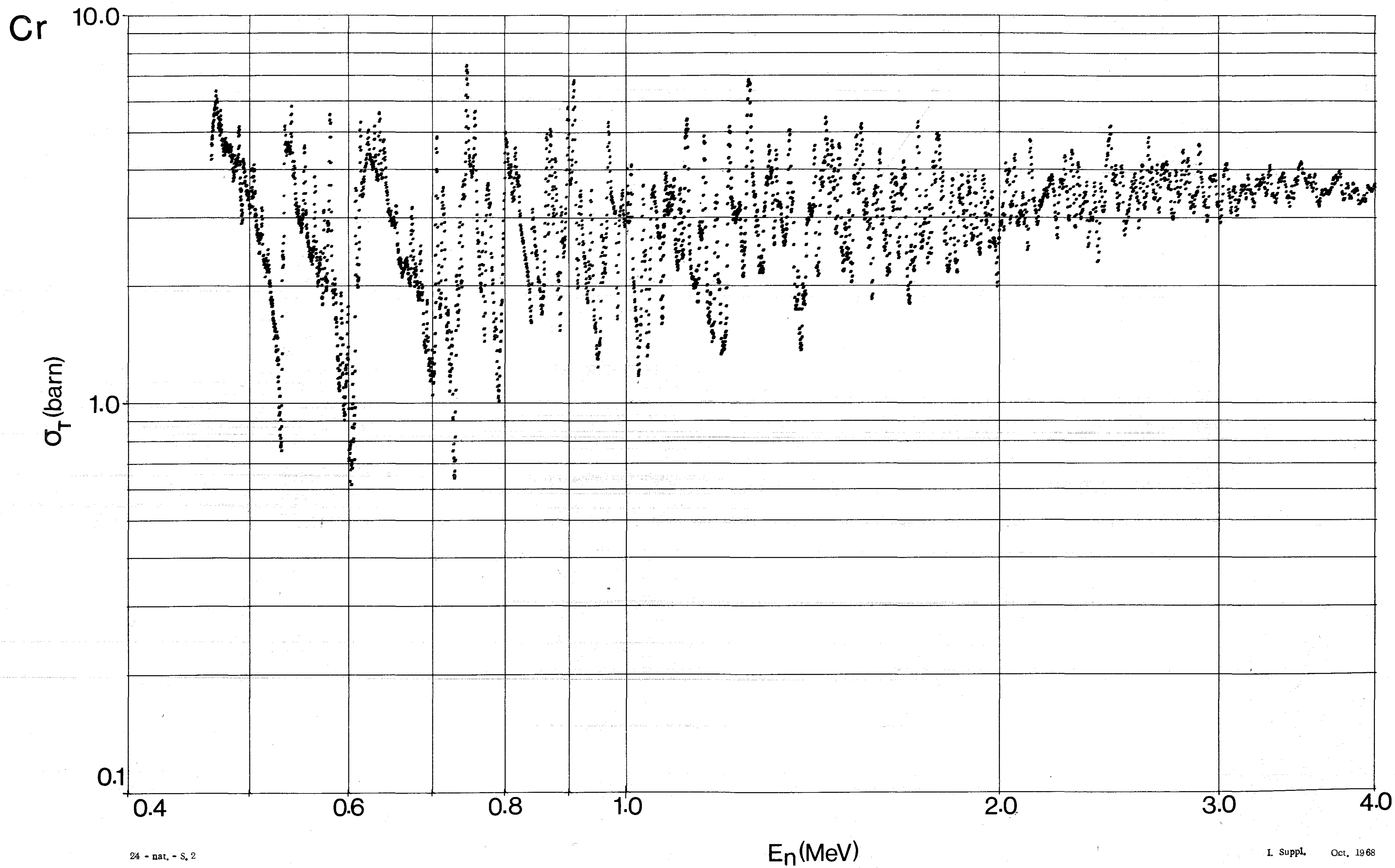
V
7.0 - 12 MeV
zero suppressed
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
8·0
9·0
10·0
11·0
12·0
E_n(MeV)



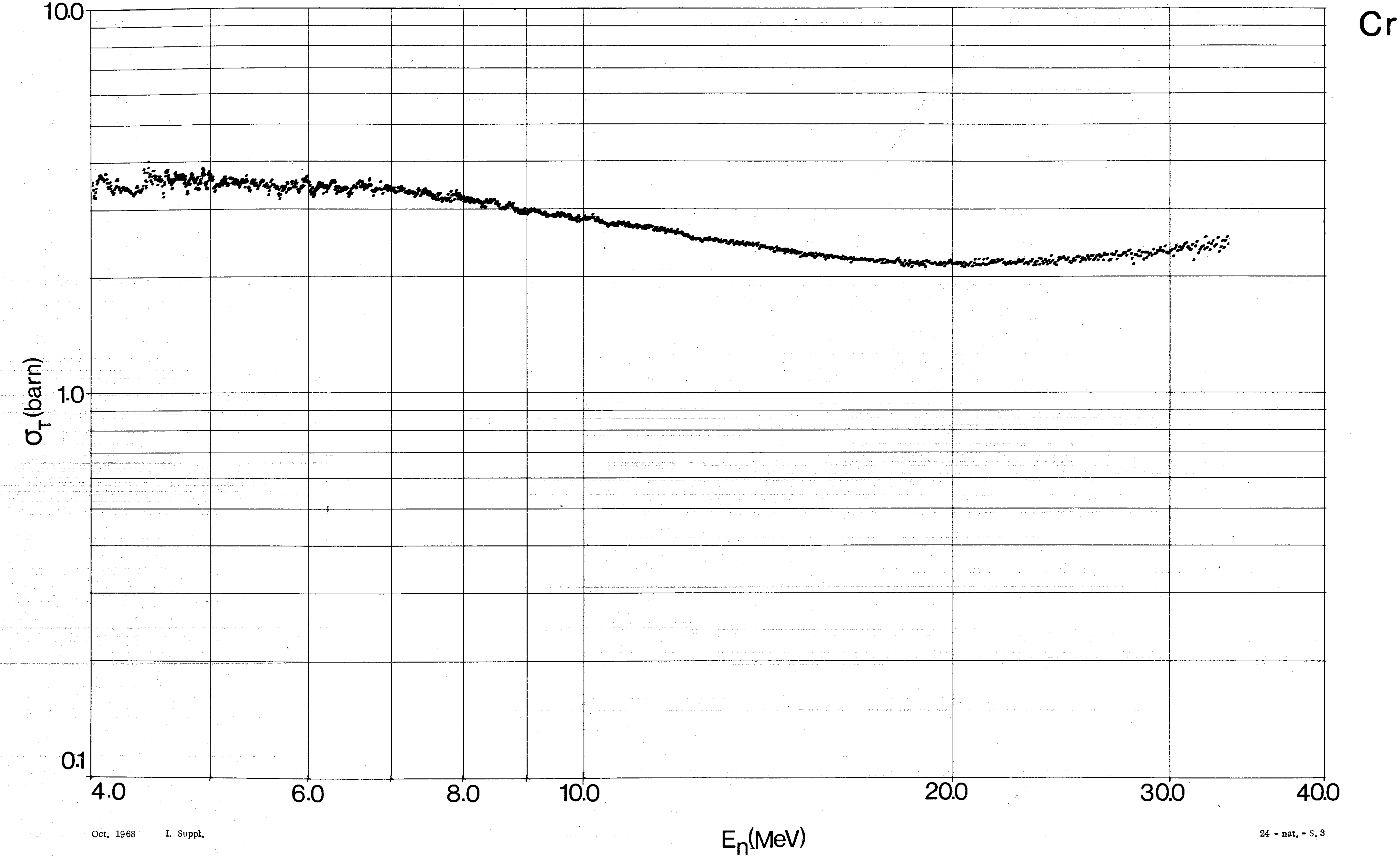
V
12-32 MeV
zero suppressed
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
16
20
24
28
32
E_n(MeV)

Cr

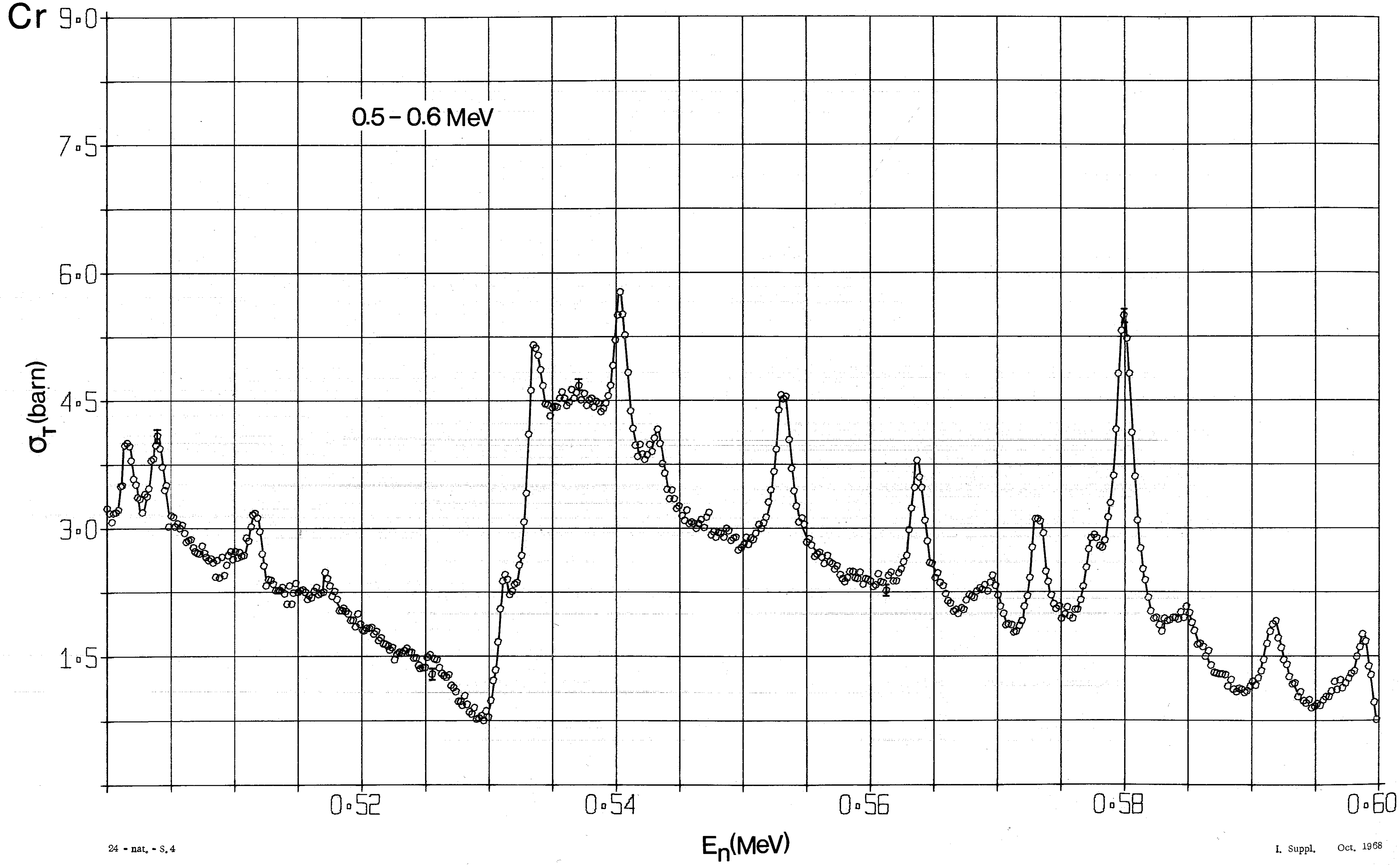
n	=	0.2836	At/barn	(0.5 - 4.403 MeV)
n	=	0.3686	At/barn	(4.403 - 32.0 MeV)
p	=	99.0	%	
l	=	57.394	m	
Δt	=	3.1	nsec	(0.5 - 4.403 MeV)
t	=	2.6	nsec	(4.403 - 32.0 MeV)
i	:	natural		

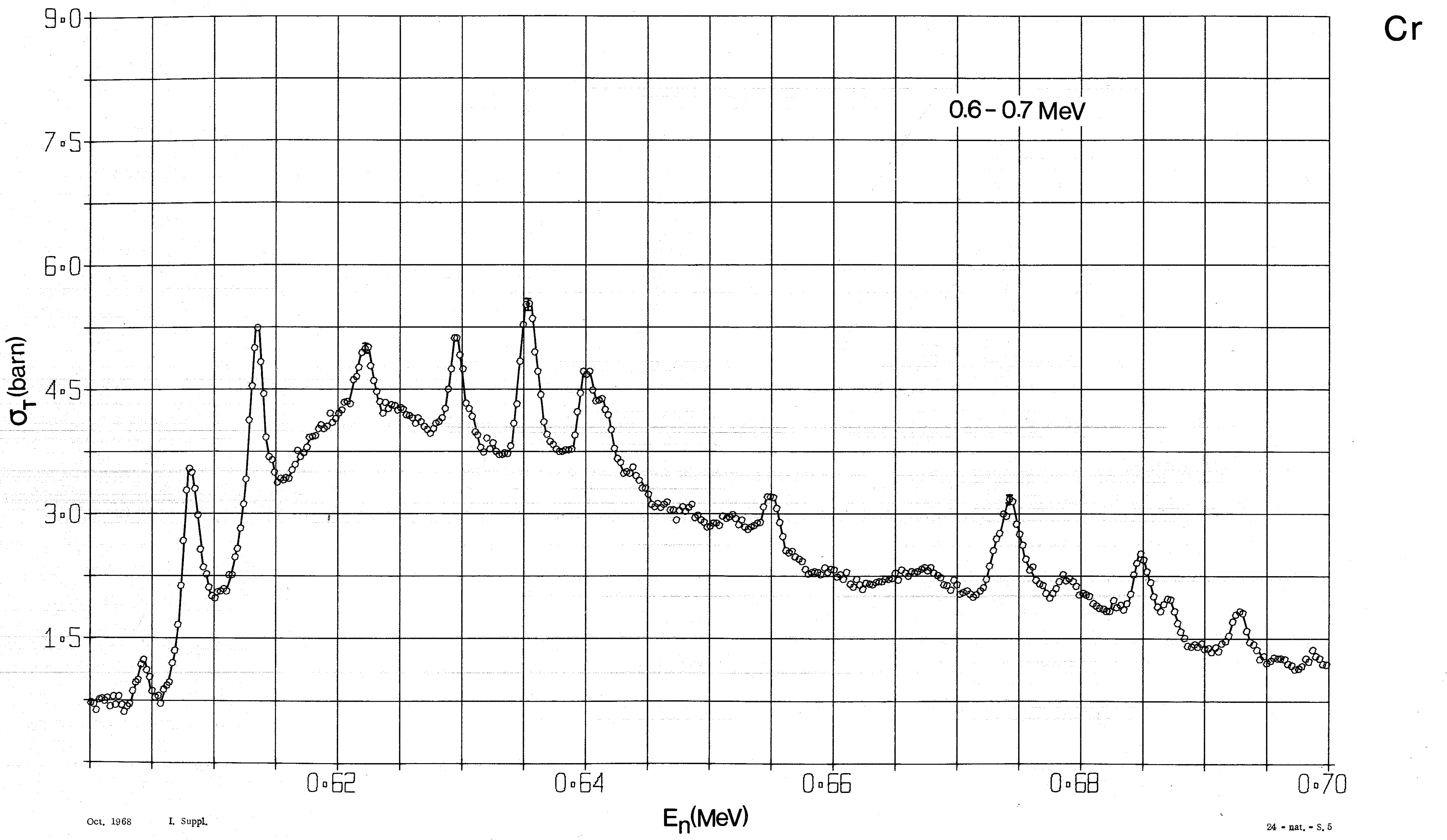


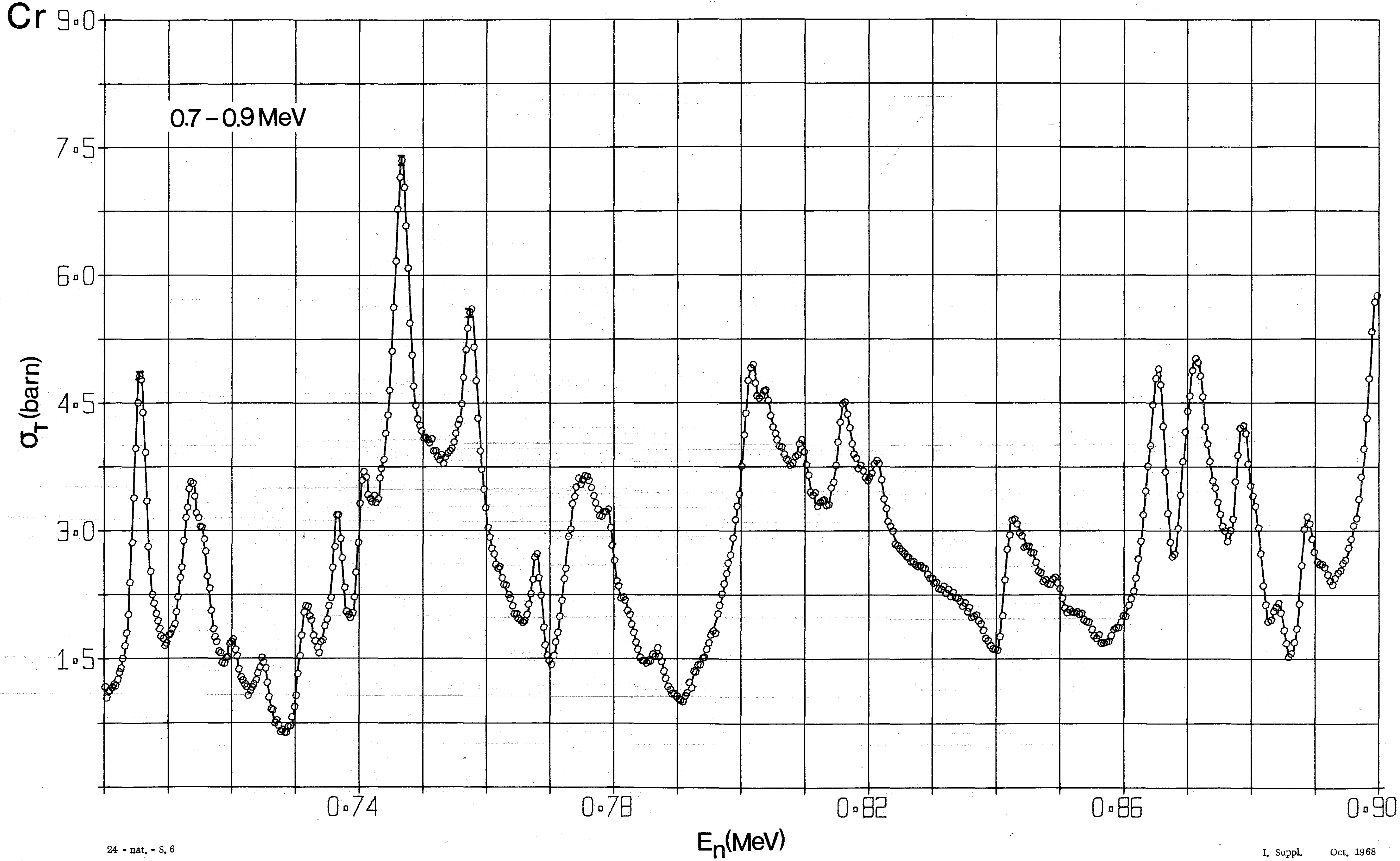
I. Suppl. Oct. 1968



Cr
10.0
1.0
0.1
σ_T (barn)
4.0
6.0
8.0
10.0
20.0
30.0
40.0
E_n(MeV)

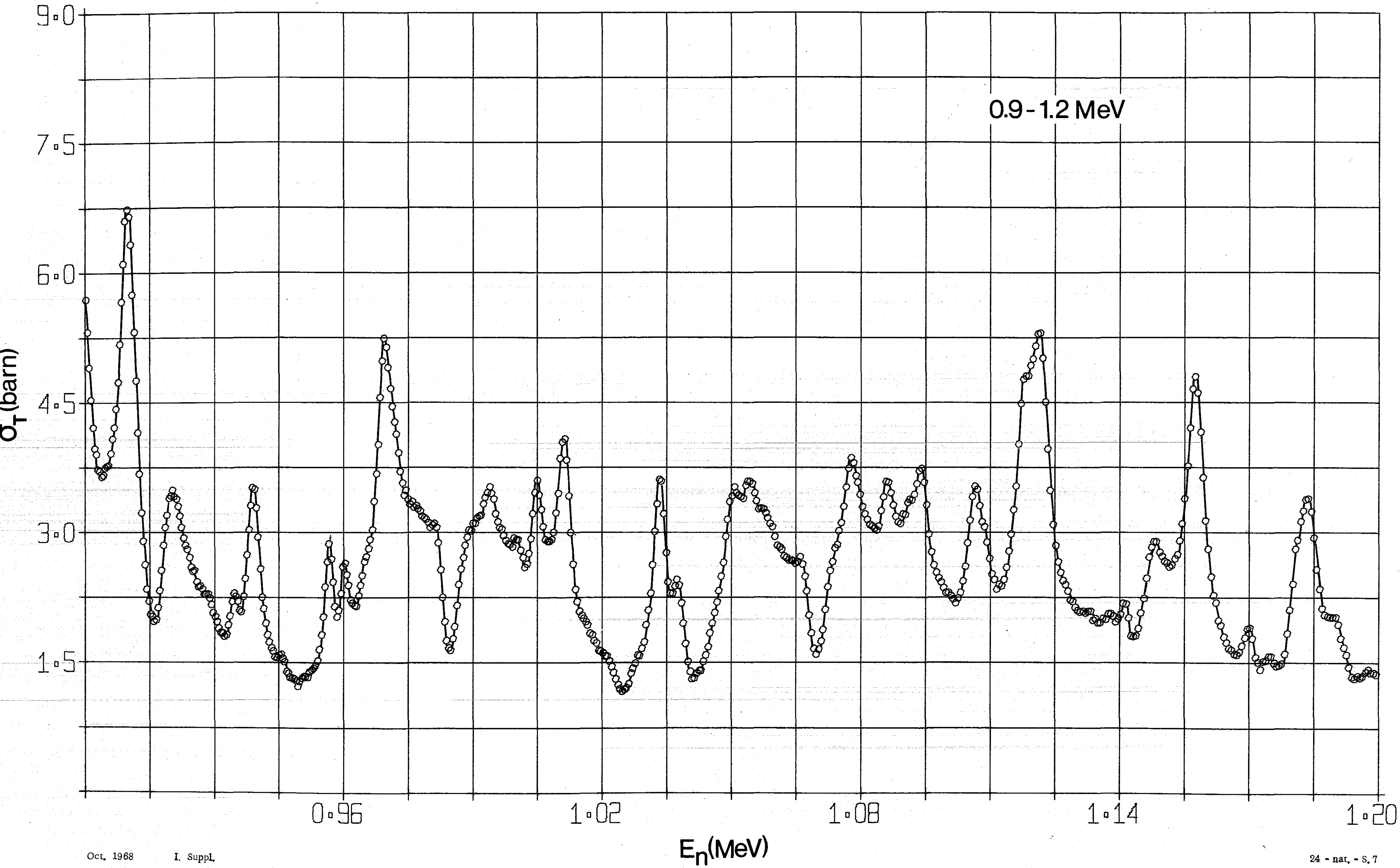

Cr
9·0
7·5
6·0
4·5
3·0
1·5
0.5 - 0.6 MeV
σT (barn)
0·52
0·54
0·56
0·58
0·60
En(MeV)

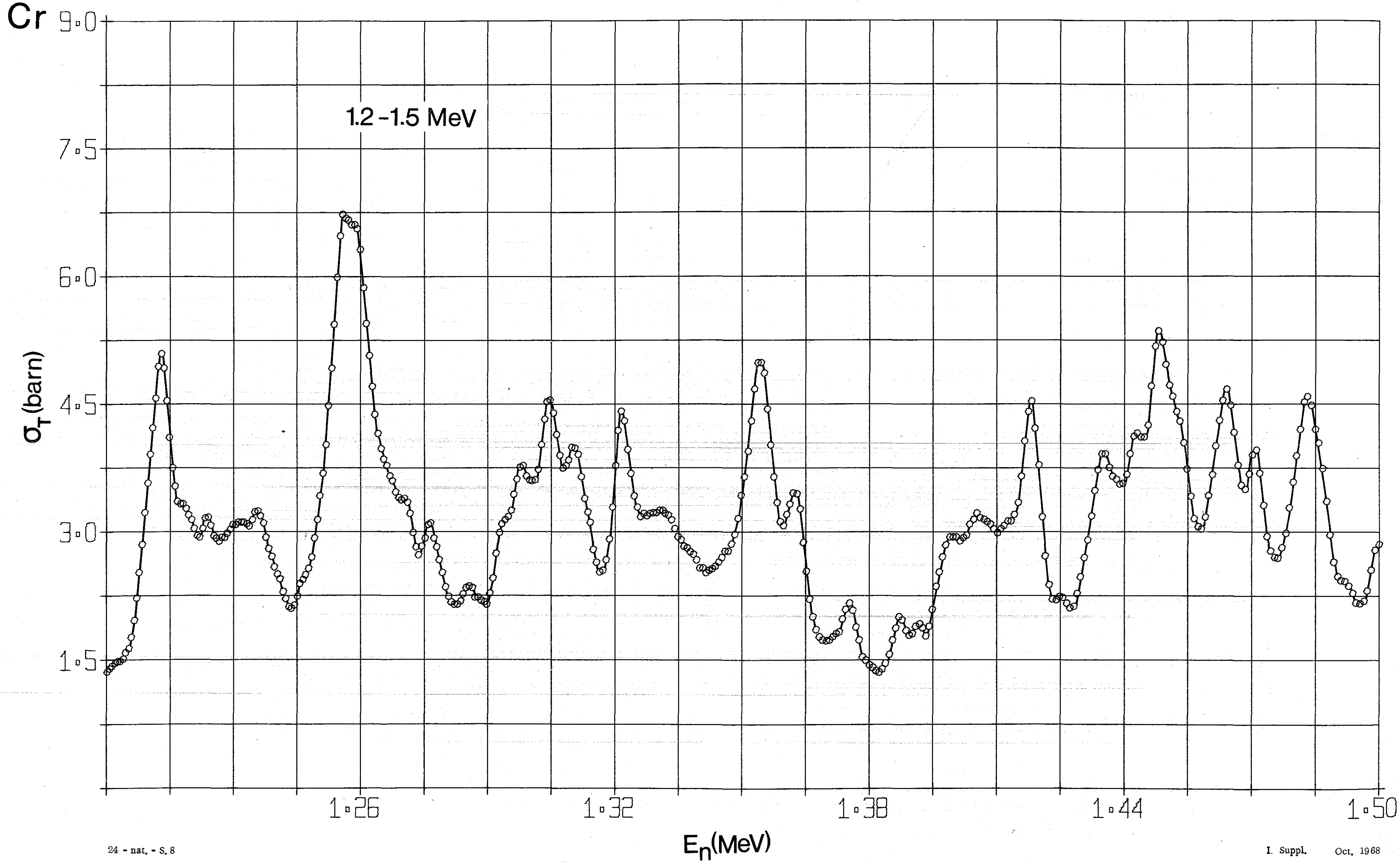

Cr
0.6 - 0.7 MeV
σT (barn)
9.0
7.5
6.0
4.5
3.0
1.5
0.62
0.64
0.66
0.68
0.70
En(MeV)



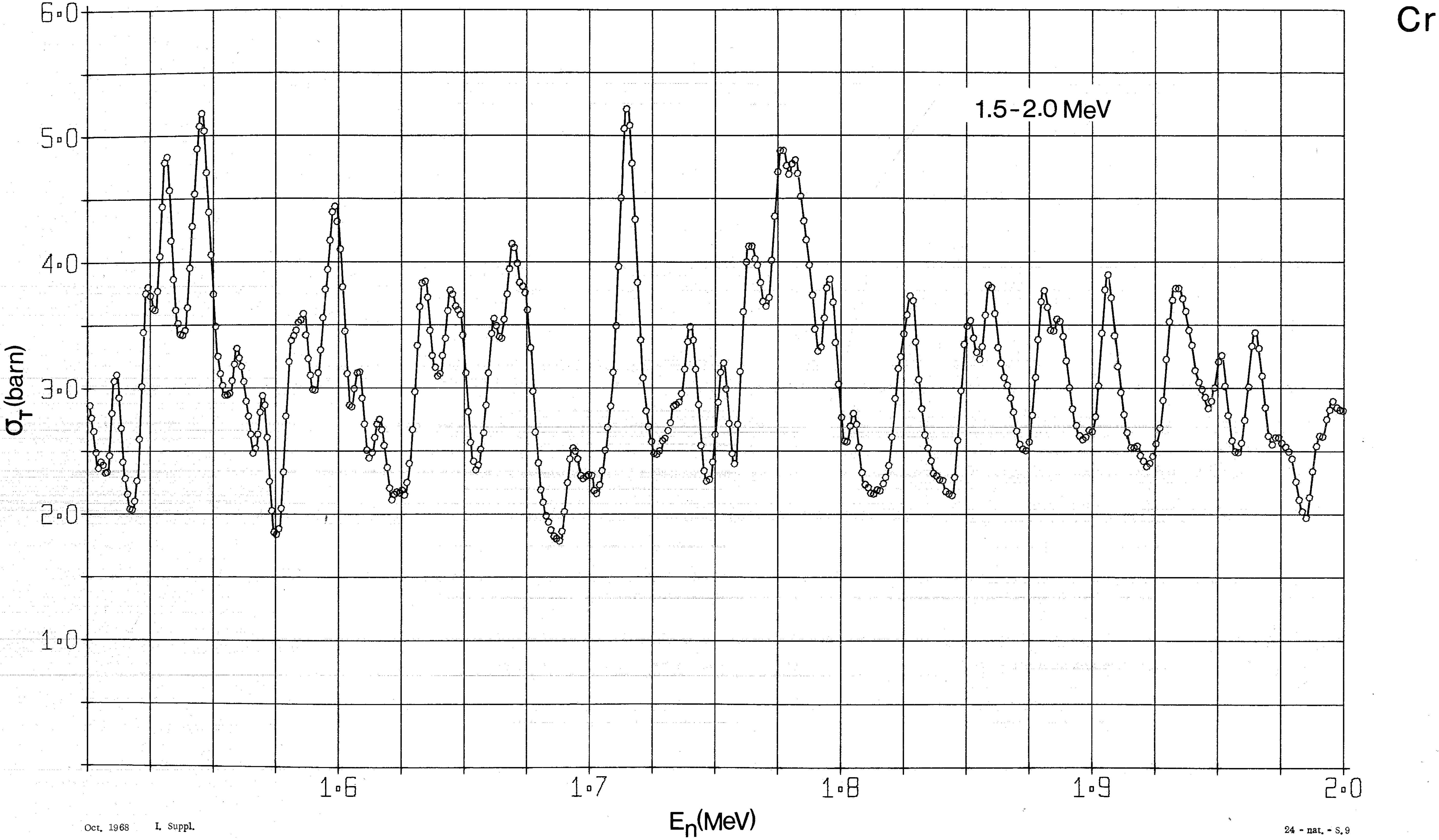
Cr
9·0
7·5
6·0
4·5
3·0
1·5
0.7 - 0.9 MeV
σT (barn)
0·74
0·78
0·82
0·86
0·90
En(MeV)

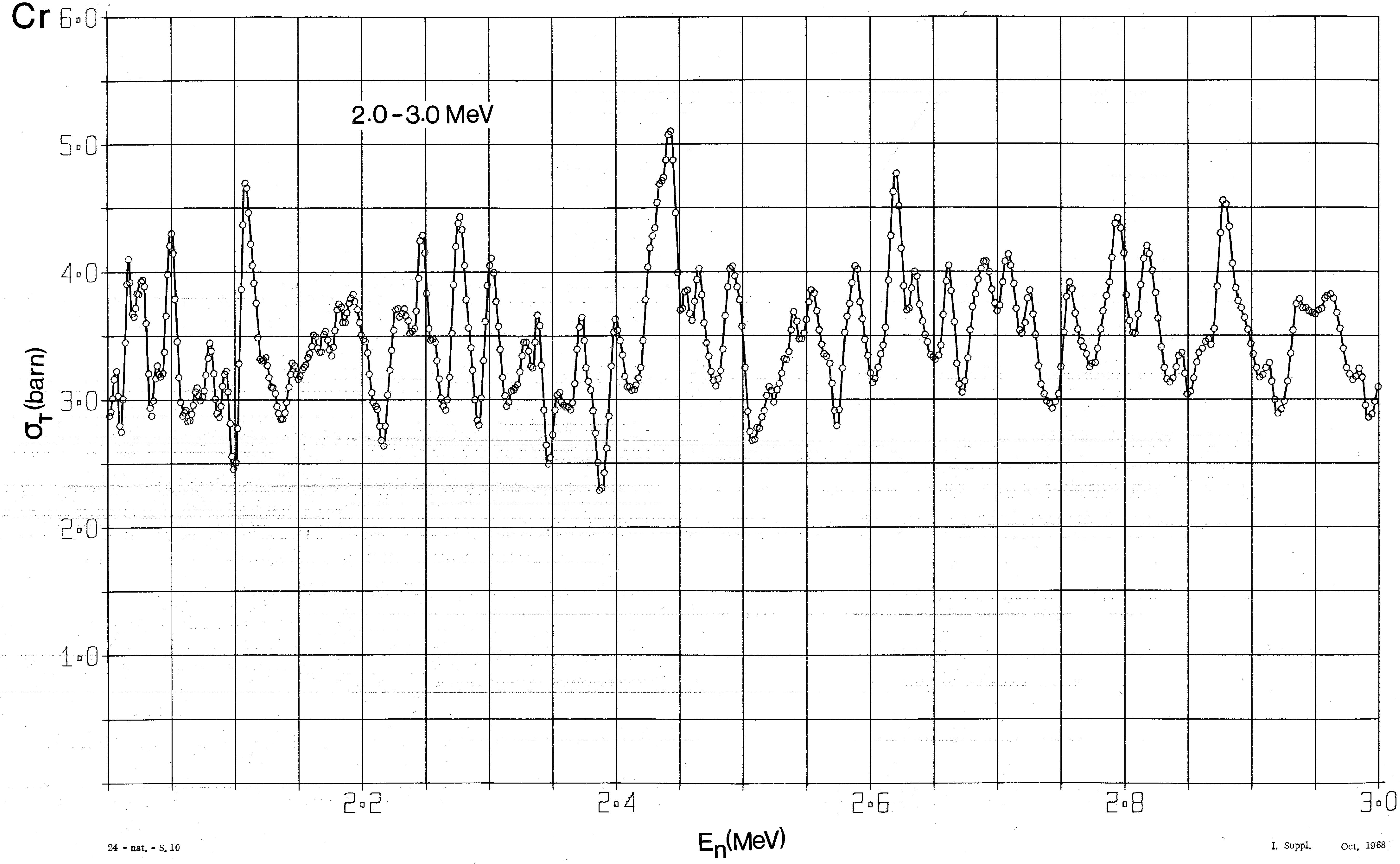
Cr

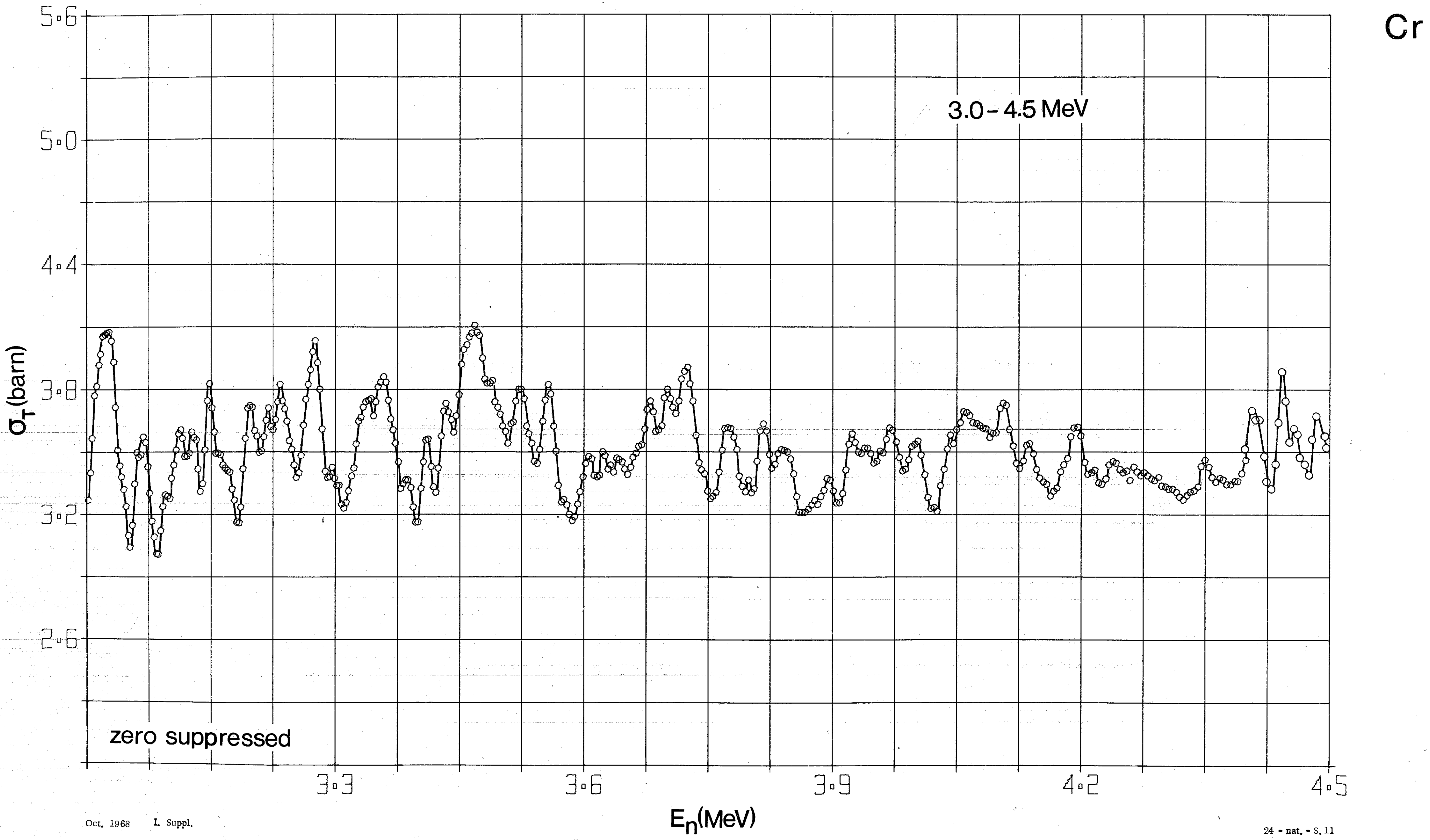


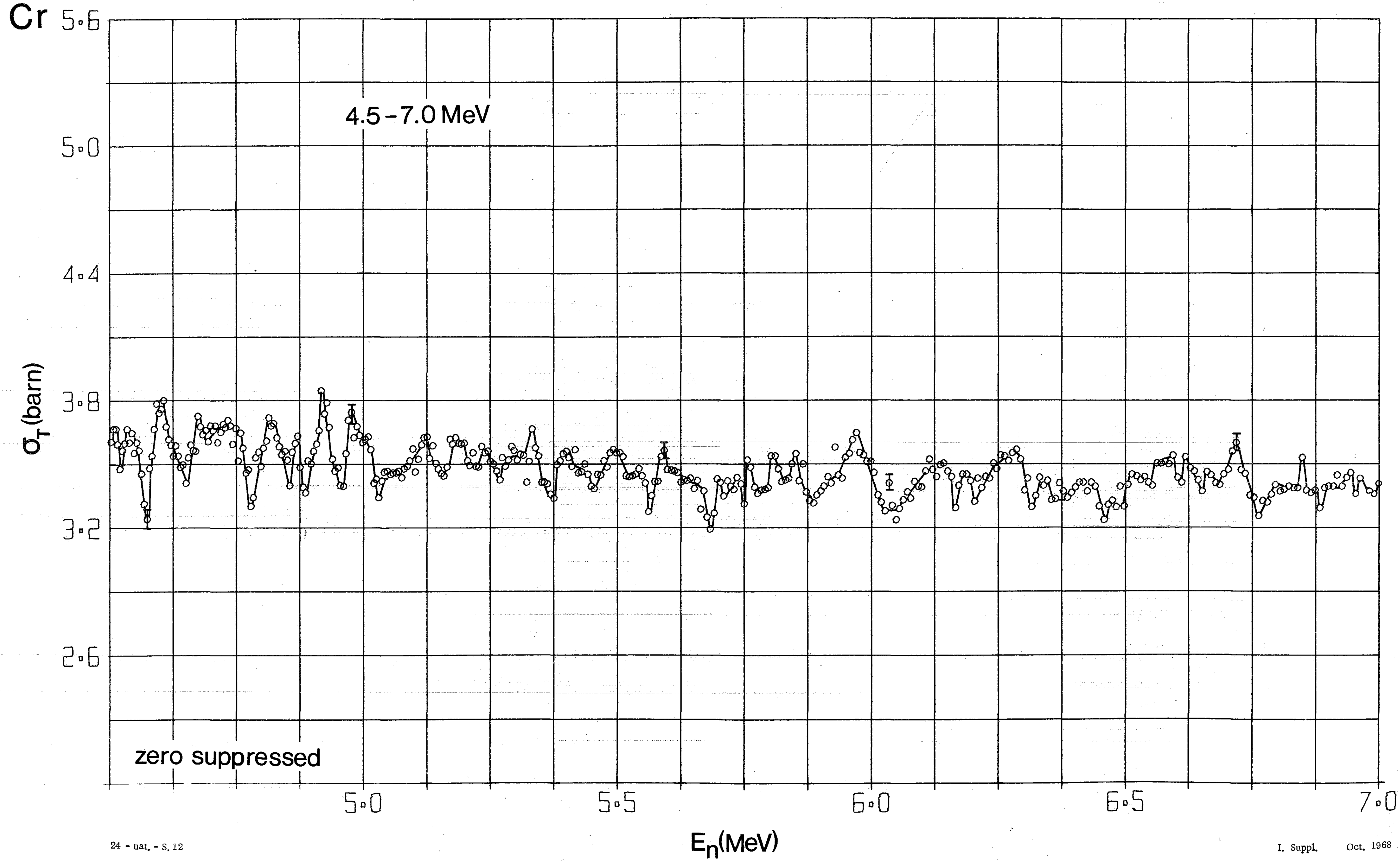


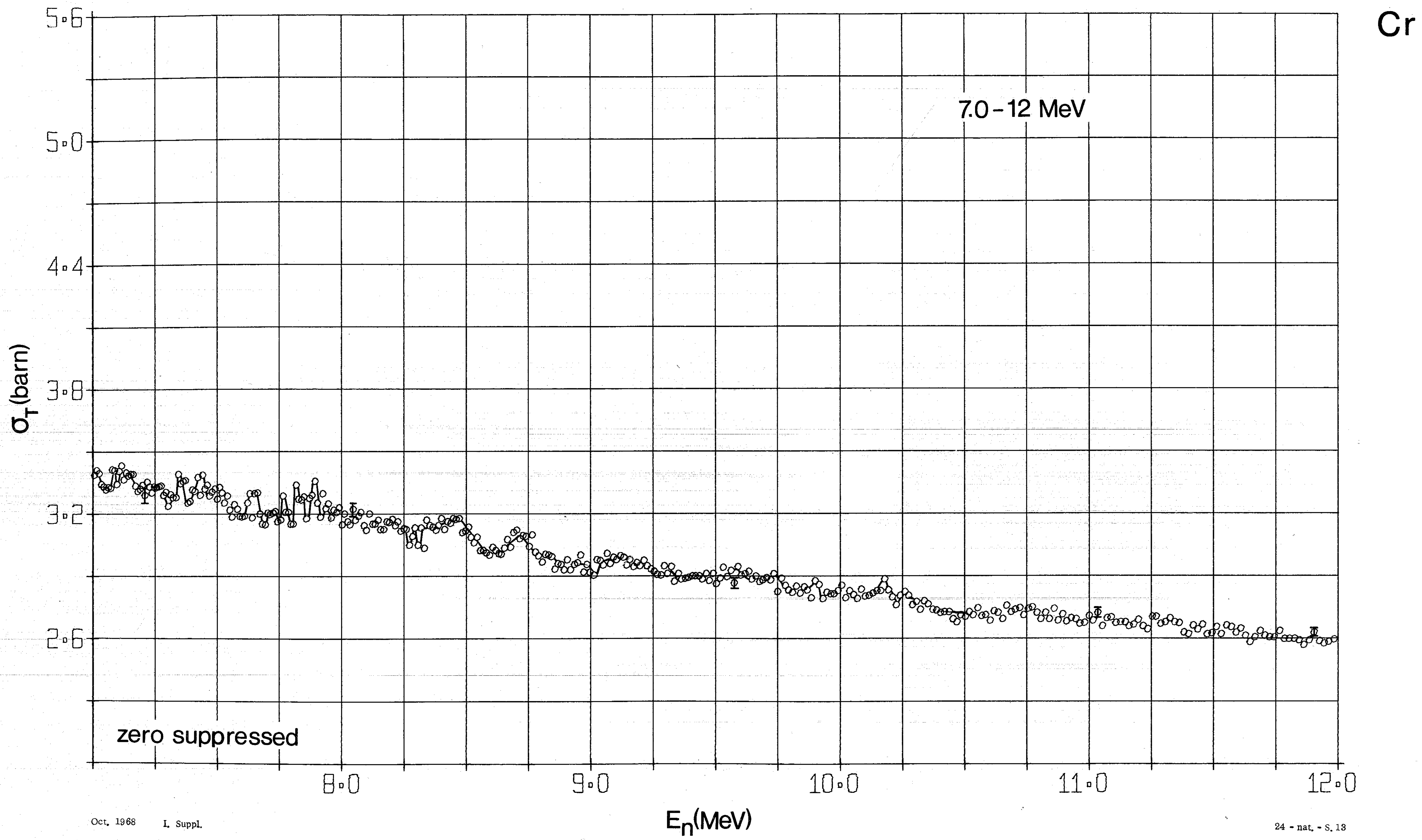
I. Suppl. Oct. 1968


Cr
1.5-2.0 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σT (barn)
1·6
1·7
1·8
1·9
2·0
En(MeV)

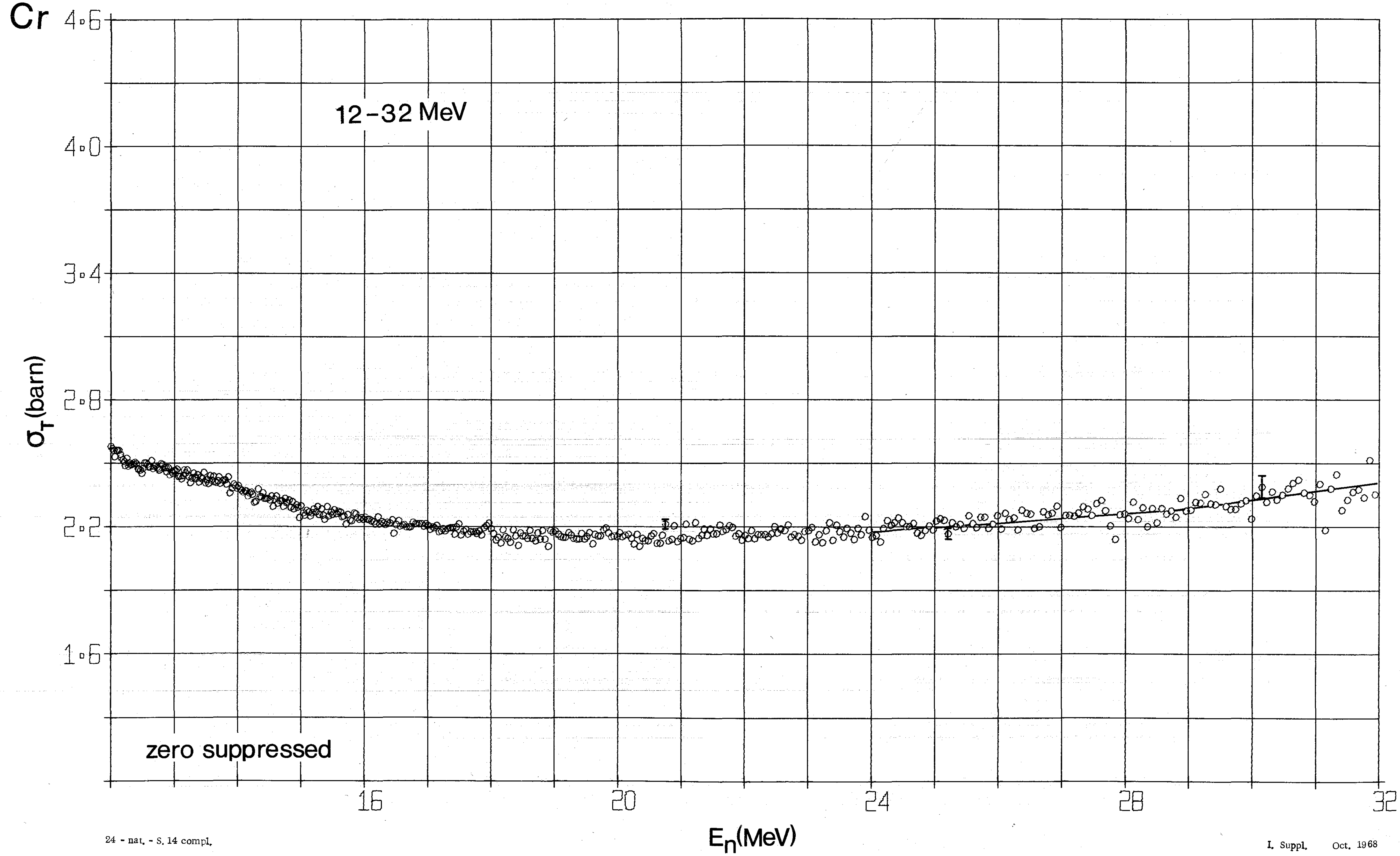

Cr
2.0 - 3.0 MeV
σT (barn)
6·0
5·0
4·0
3·0
2·0
1·0
2·2
2·4
2·6
2·8
3·0
En(MeV)


Cr
3.0 - 4.5 MeV
5·6
5·0
4·4
3·8
3·2
2·6
σT (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
En(MeV)


Cr
5·6
5·0
4·4
3·8
3·2
2·6
4.5-7.0 MeV
σ_T (barn)
zero suppressed
5·0
5·5
6·0
6·5
7·0
E_n(MeV)



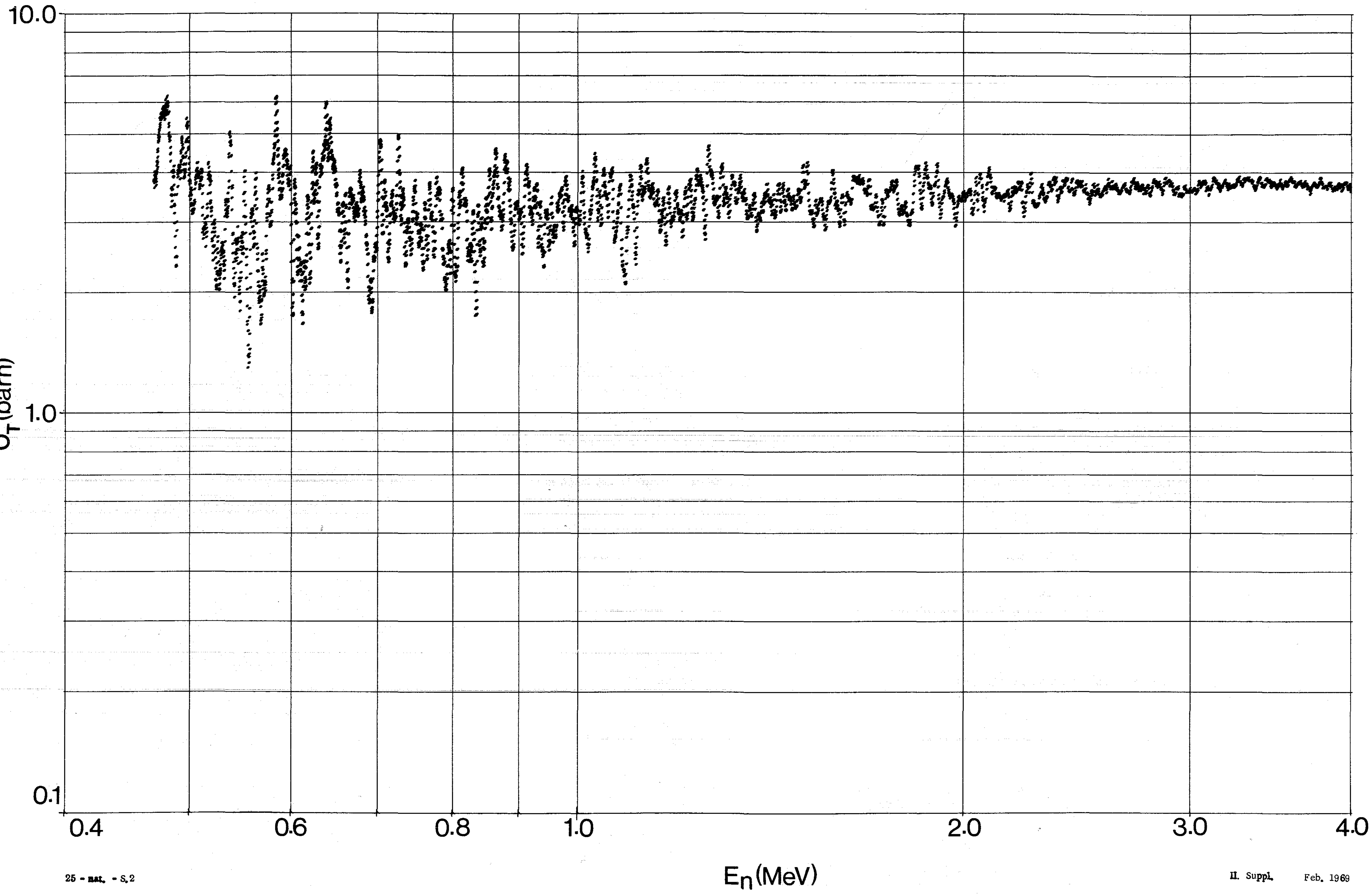
Cr
7.0 - 12 MeV
5.6
5.0
4.4
3.8
3.2
2.6
σ_T(barn)
zero suppressed
8.0
9.0
10.0
11.0
12.0
E_n(MeV)

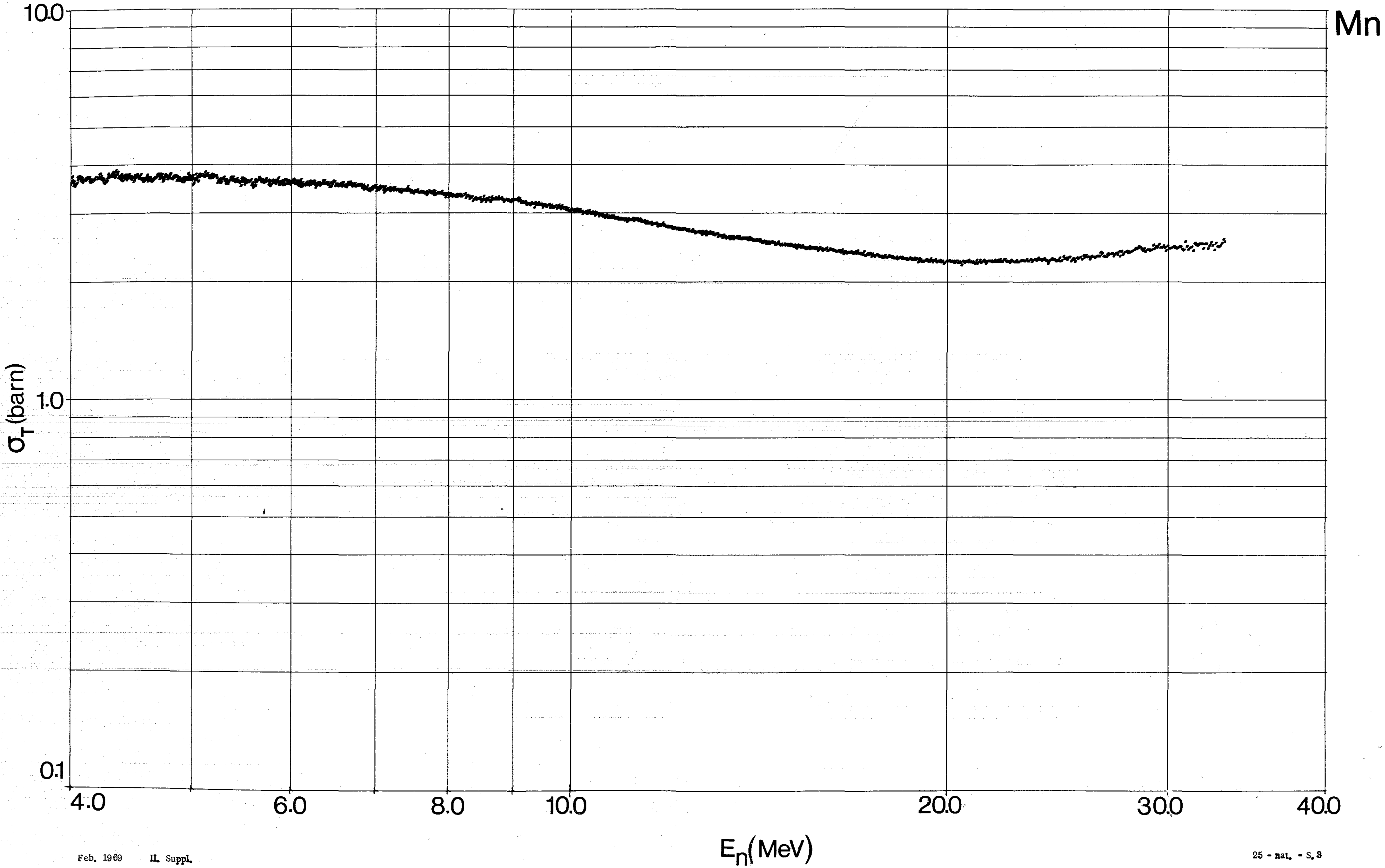

Cr
4·6
4·0
3·4
2·8
2·2
1·6
σ_T(barn)
12-32 MeV
zero suppressed
16
20
24
28
32
E_n(MeV)

Mn

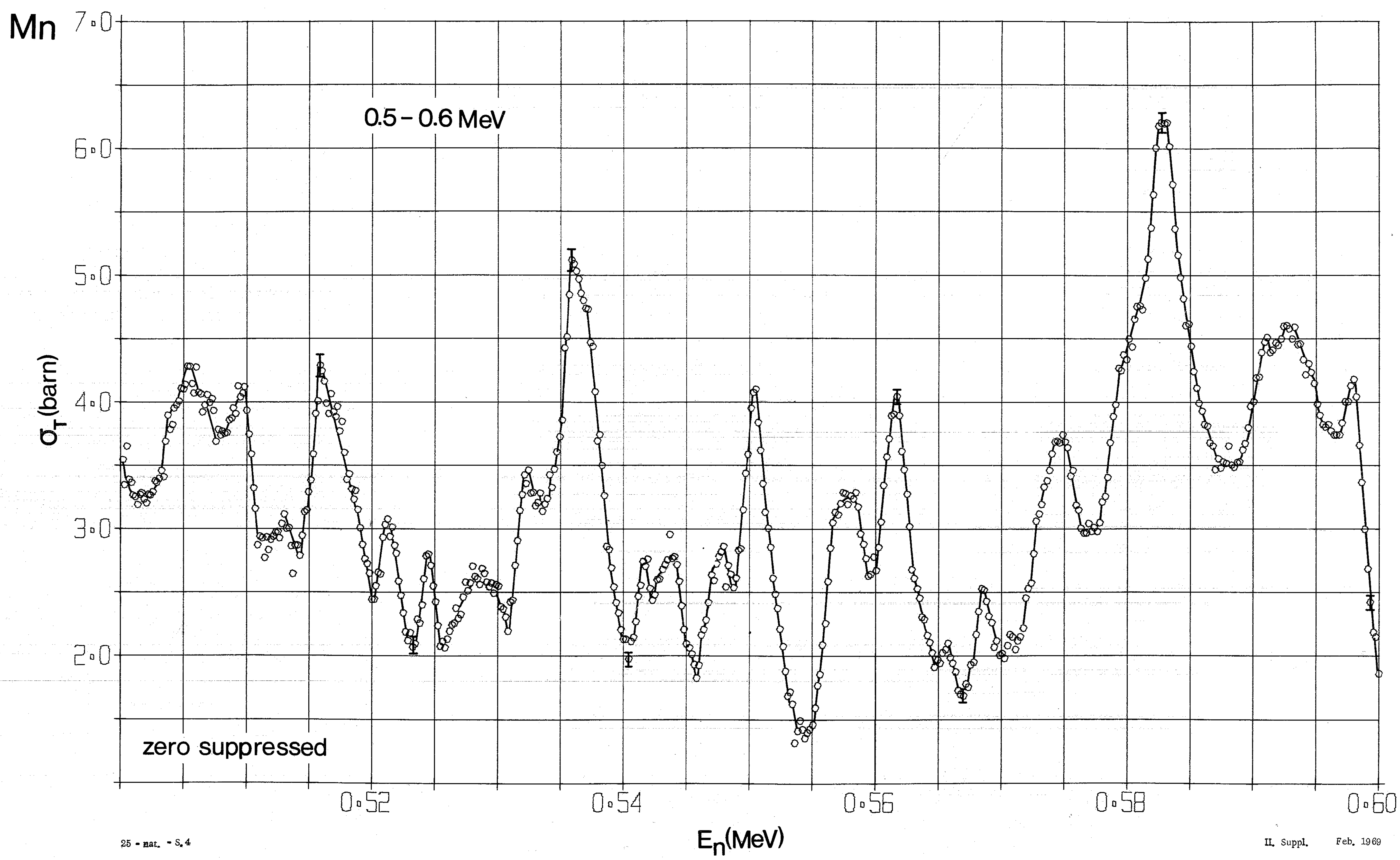
n	=	0.2464	At/barn
p	=	99.5	%
l	=	57.540	m
Δt	=	3.3	nsec
i	:	natural	

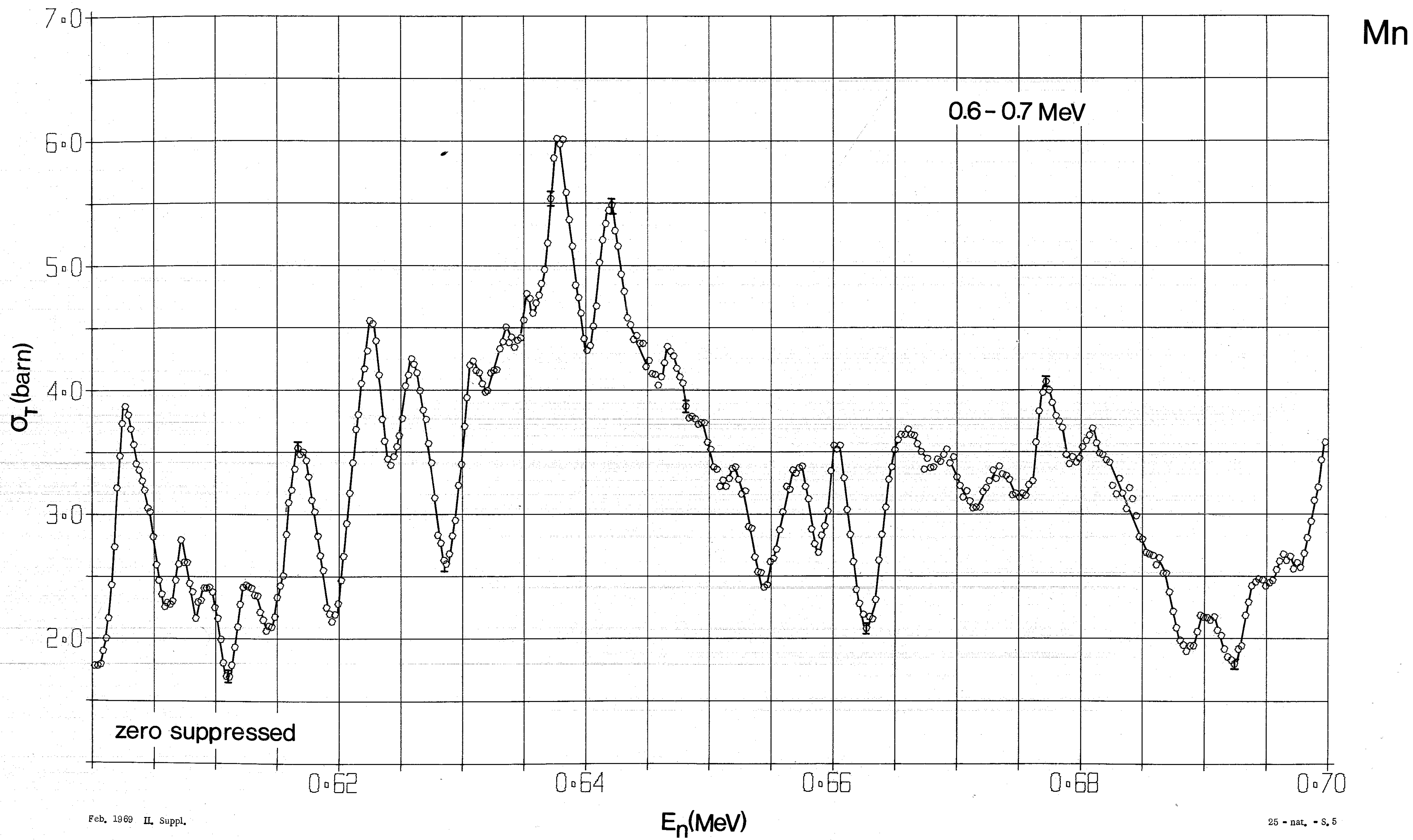
Mn

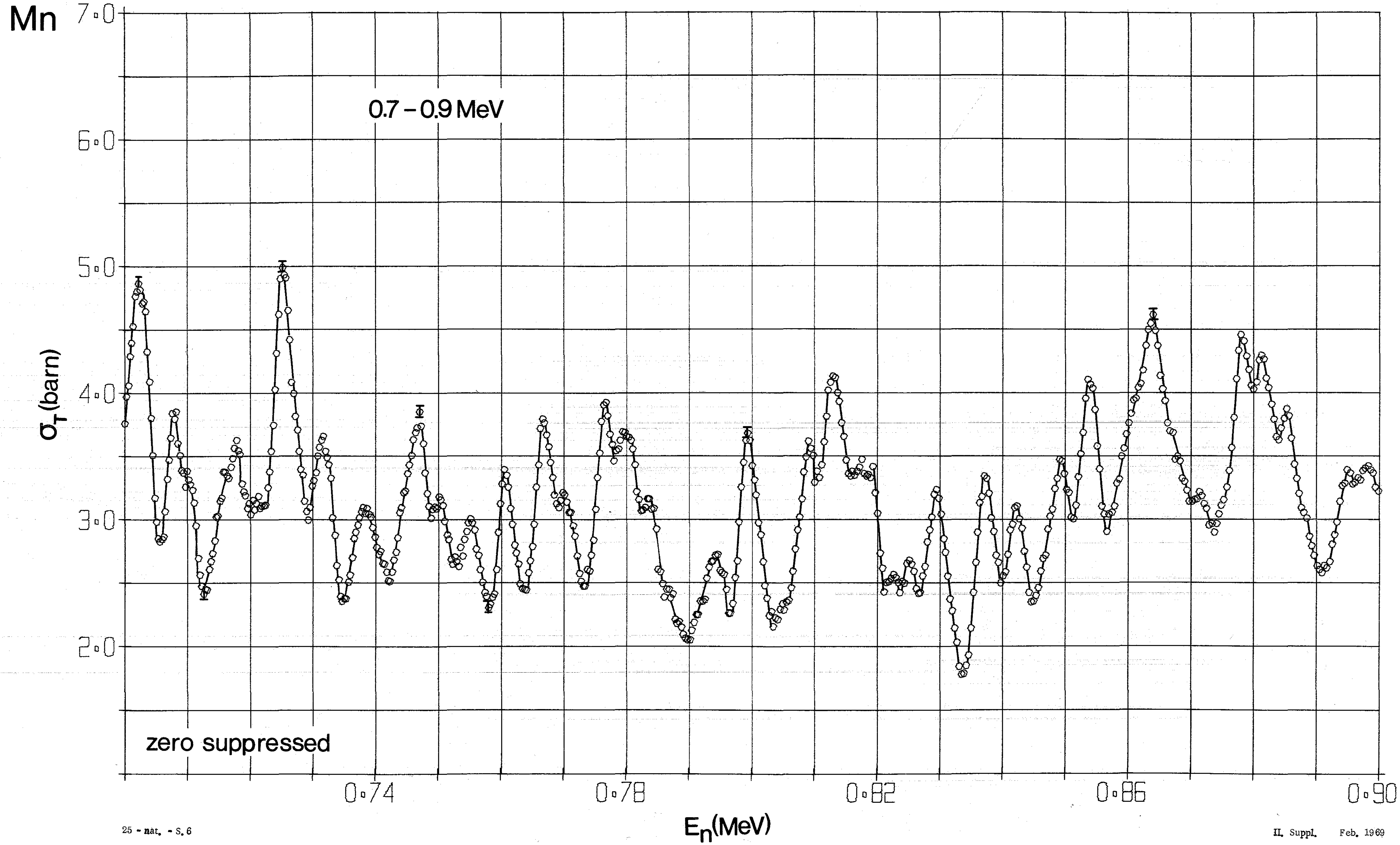




Mn
10.0
1.0
0.1
σT (barn)
4.0
6.0
8.0
10.0
20.0
30.0
40.0
En(MeV)

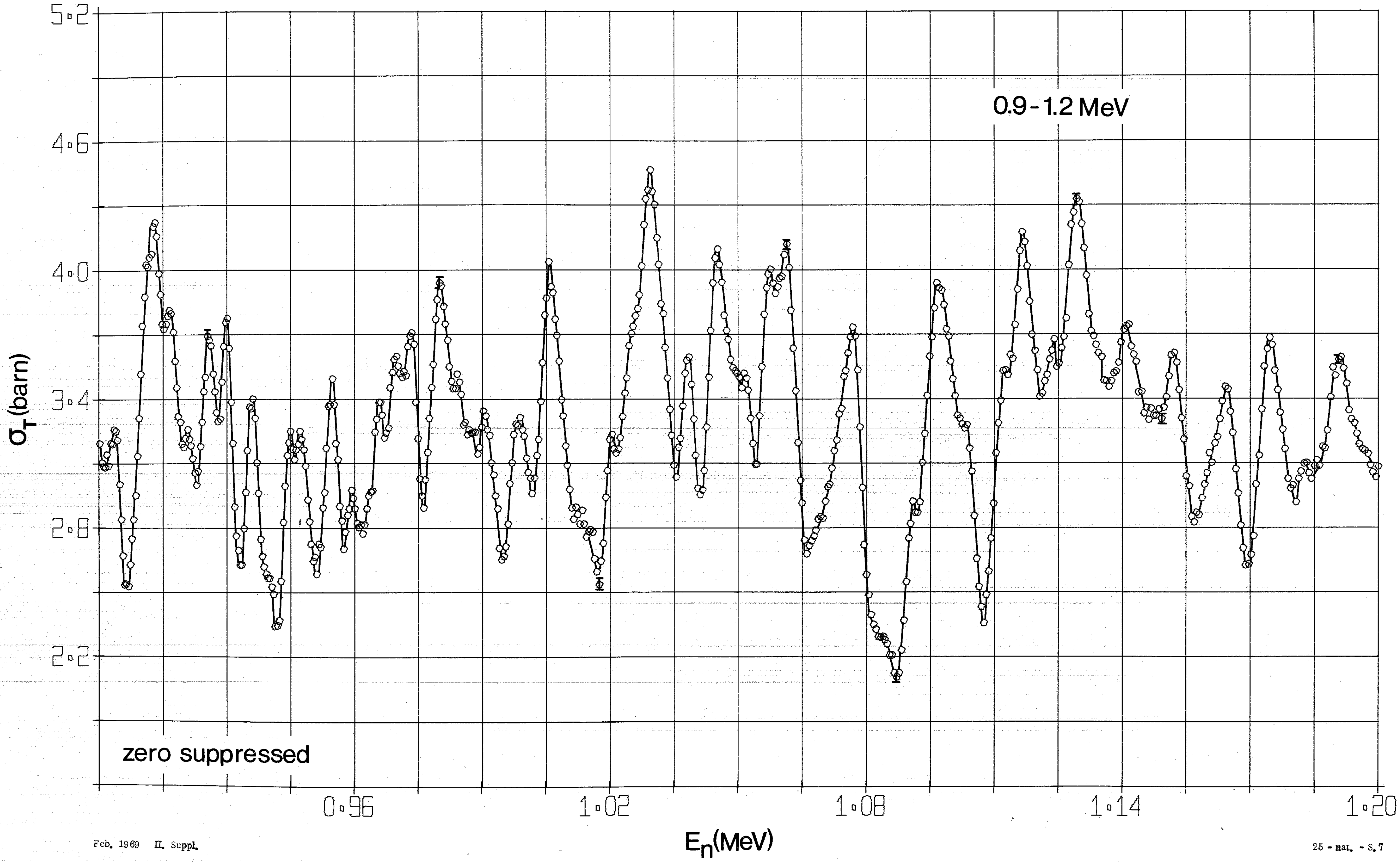

Mn
0.5 - 0.6 MeV
zero suppressed
σ_T (barn)
7·0
6·0
5·0
4·0
3·0
2·0
0·52
0·54
0·56
0·58
0·60
E_n(MeV)

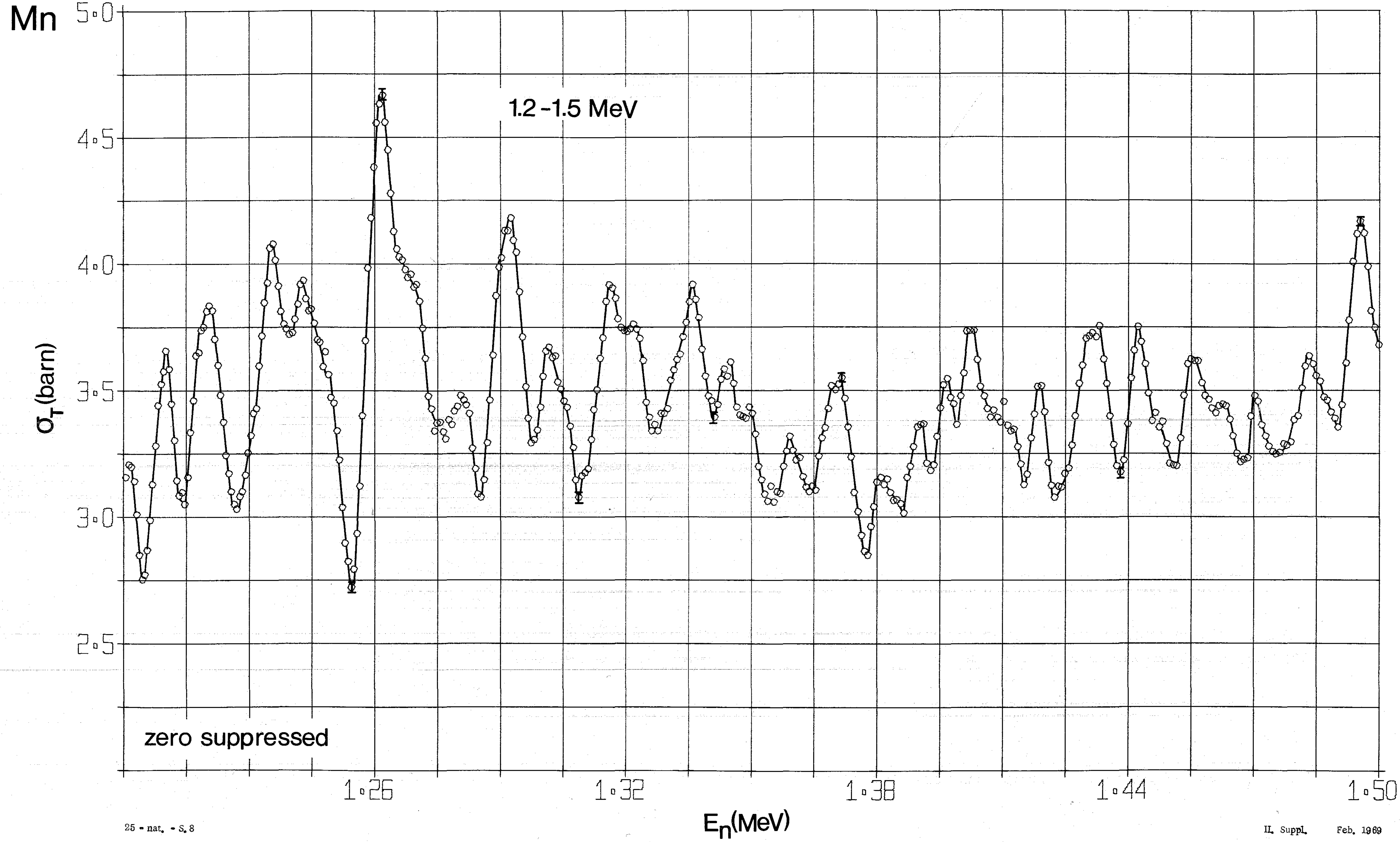

Mn
0.6 - 0.7 MeV
7·0
6·0
5·0
4·0
3·0
2·0
σ_T (barn)
zero suppressed
0·62
0·64
0·66
0·68
0·70
E_n(MeV)



Mn
0.7 – 0.9 MeV
7·0
6·0
5·0
4·0
3·0
2·0
σ_T (barn)
zero suppressed
0·74
0·78
0·82
0·86
0·90
E_n(MeV)

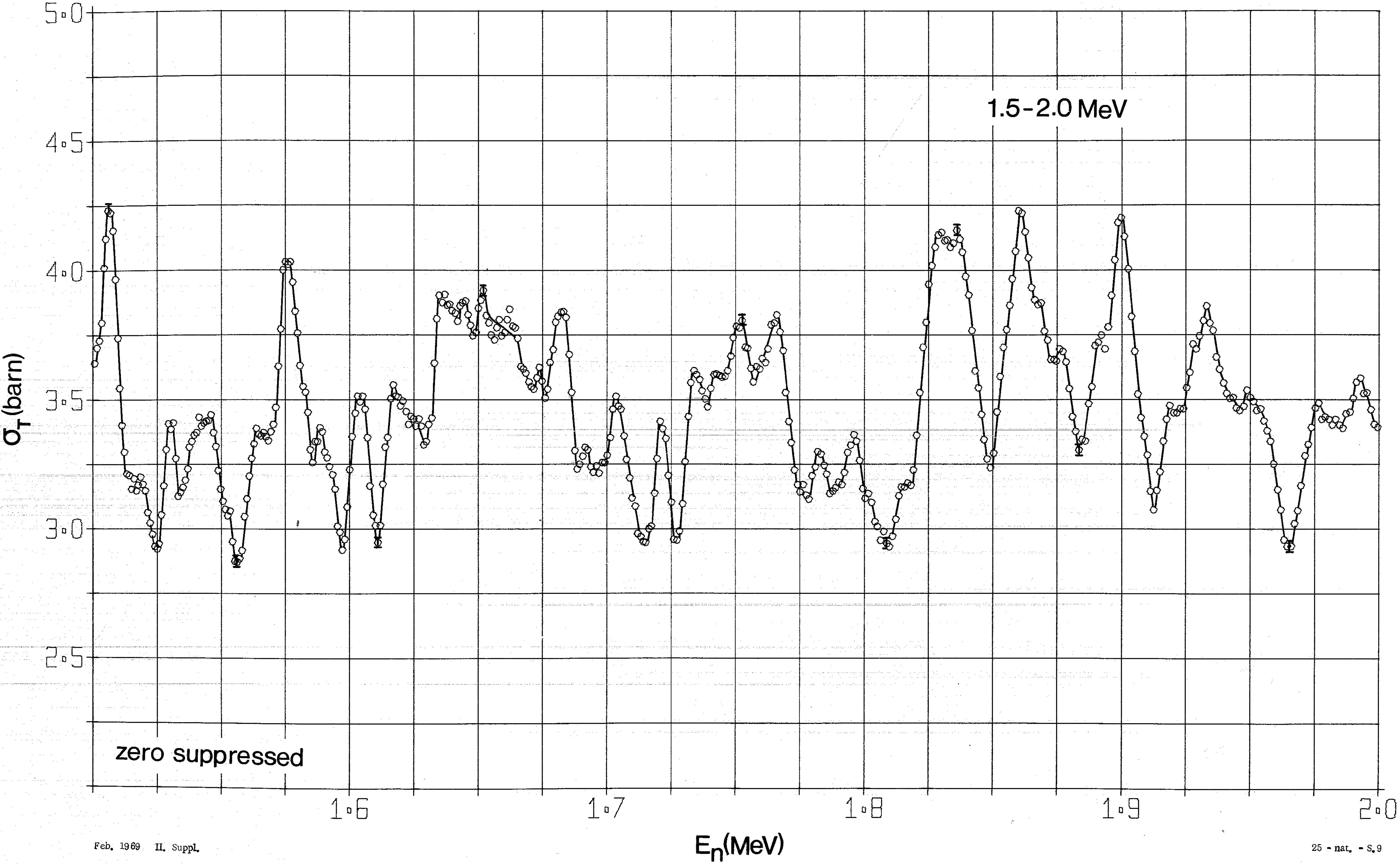
Mn


0.9 - 1.2 MeV
5·2
4·6
4·0
3·4
2·8
2·2
σT (barn)
zero suppressed
0·96
1·02
1·08
1·14
1·20
En(MeV)

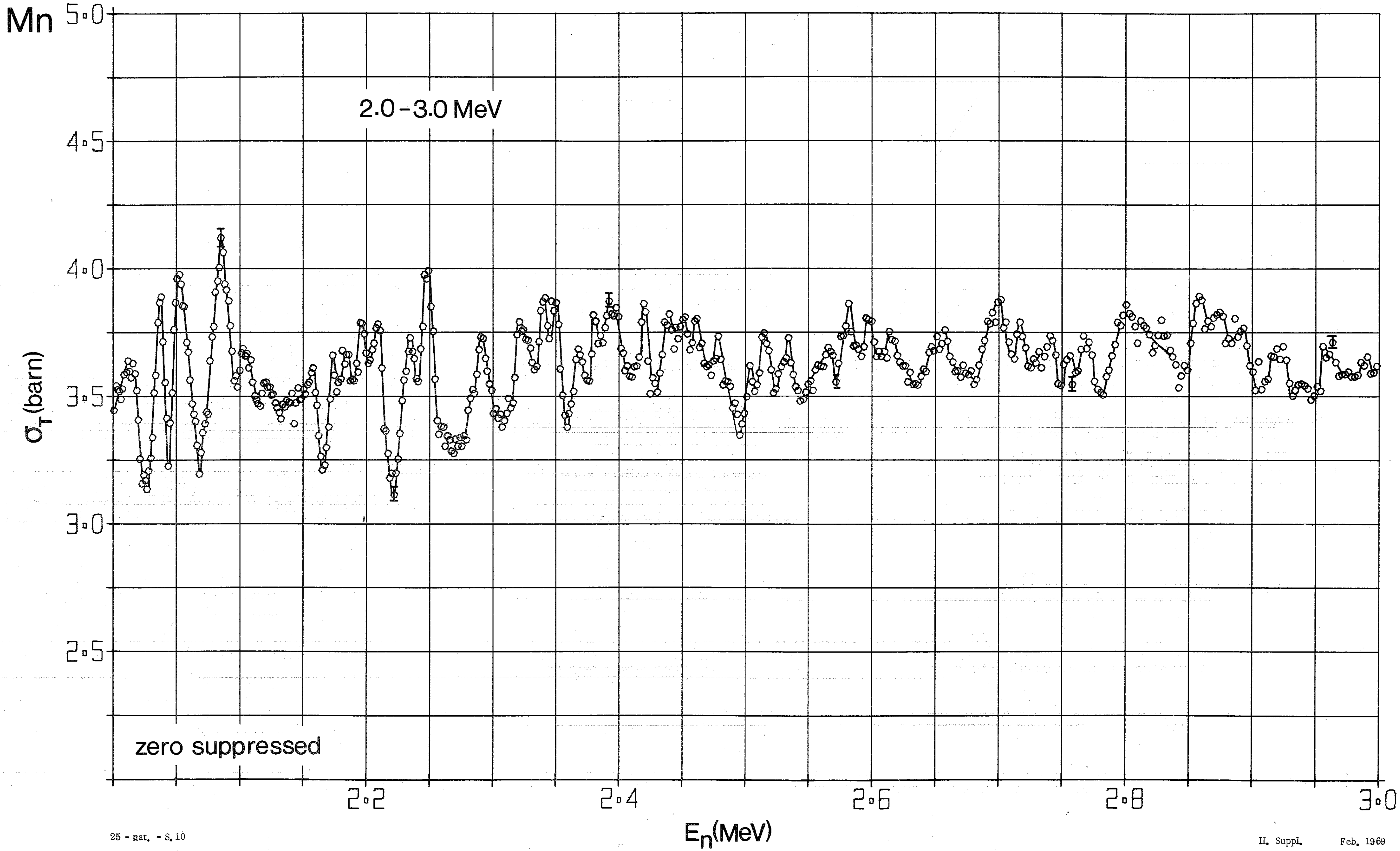


Mn
1.2 -1.5 MeV
zero suppressed
5·0
4·5
4·0
3·5
3·0
2·5
σ_T (barn)
1·26
1·32
1·38
1·44
1·50
E_n(MeV)

Mn

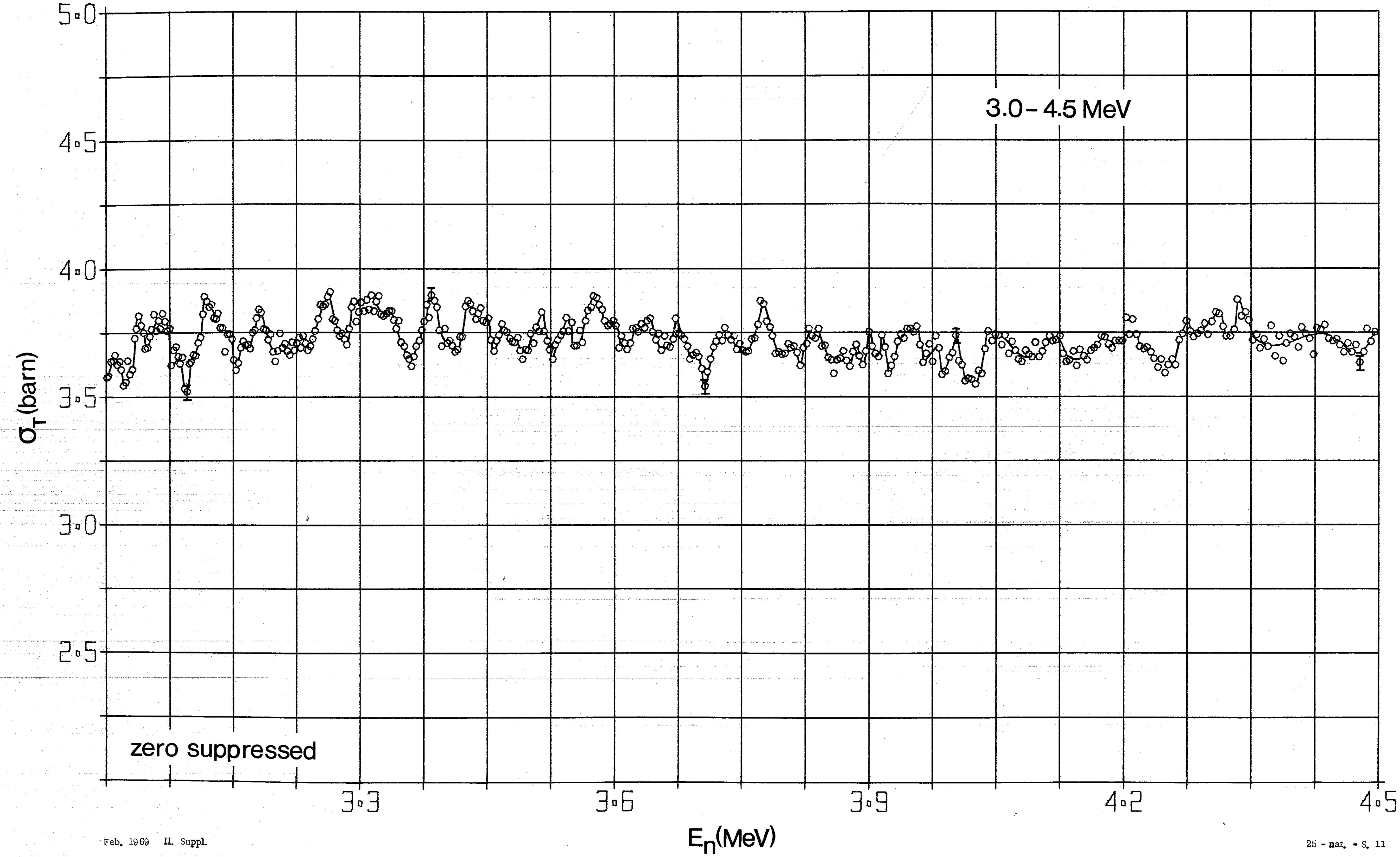


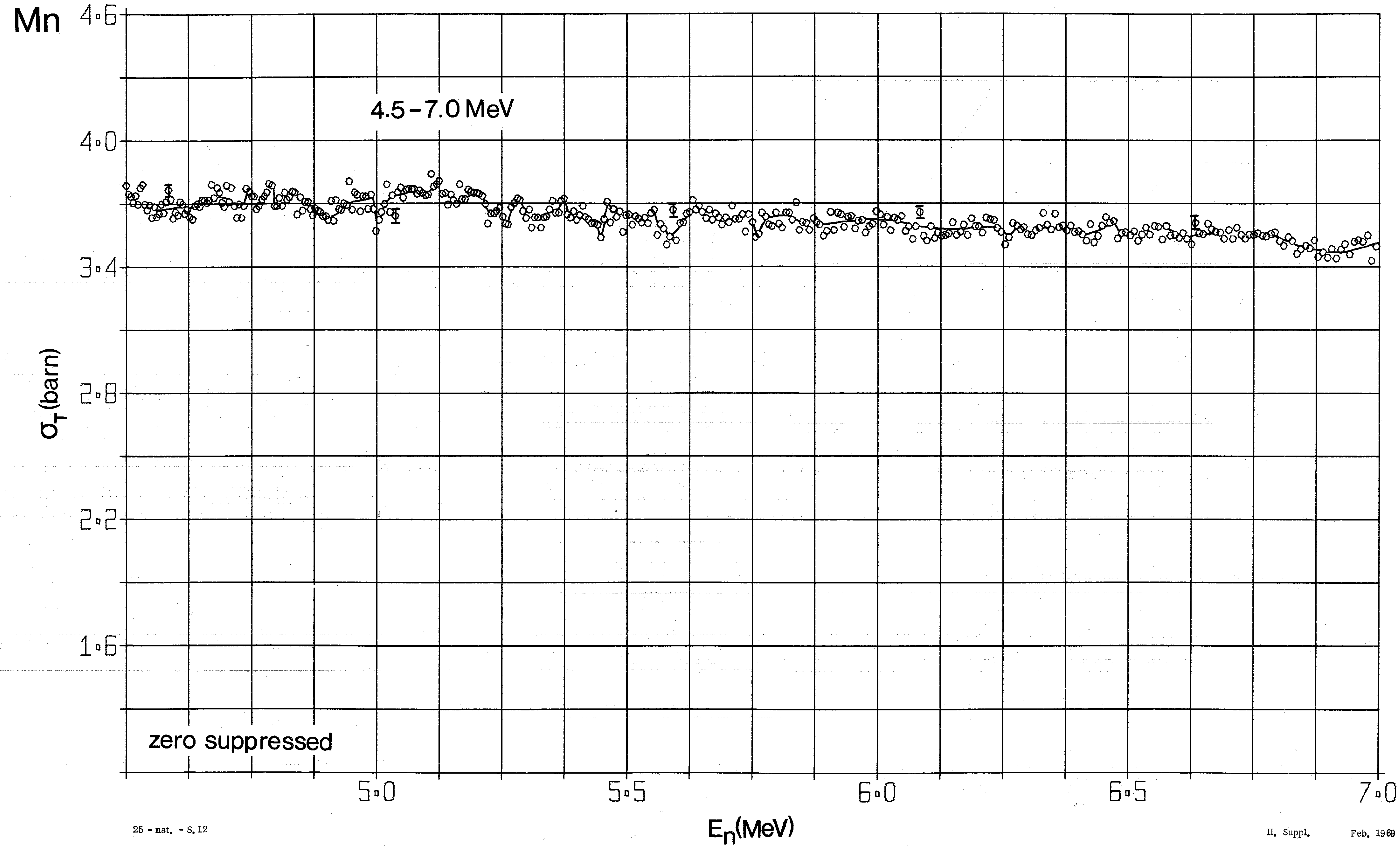
1.5-2.0 MeV
5·0
4·5
4·0
3·5
3·0
2·5
σ_T (barn)
zero suppressed
1·6
1·7
1·8
1·9
2·0
E_n(MeV)



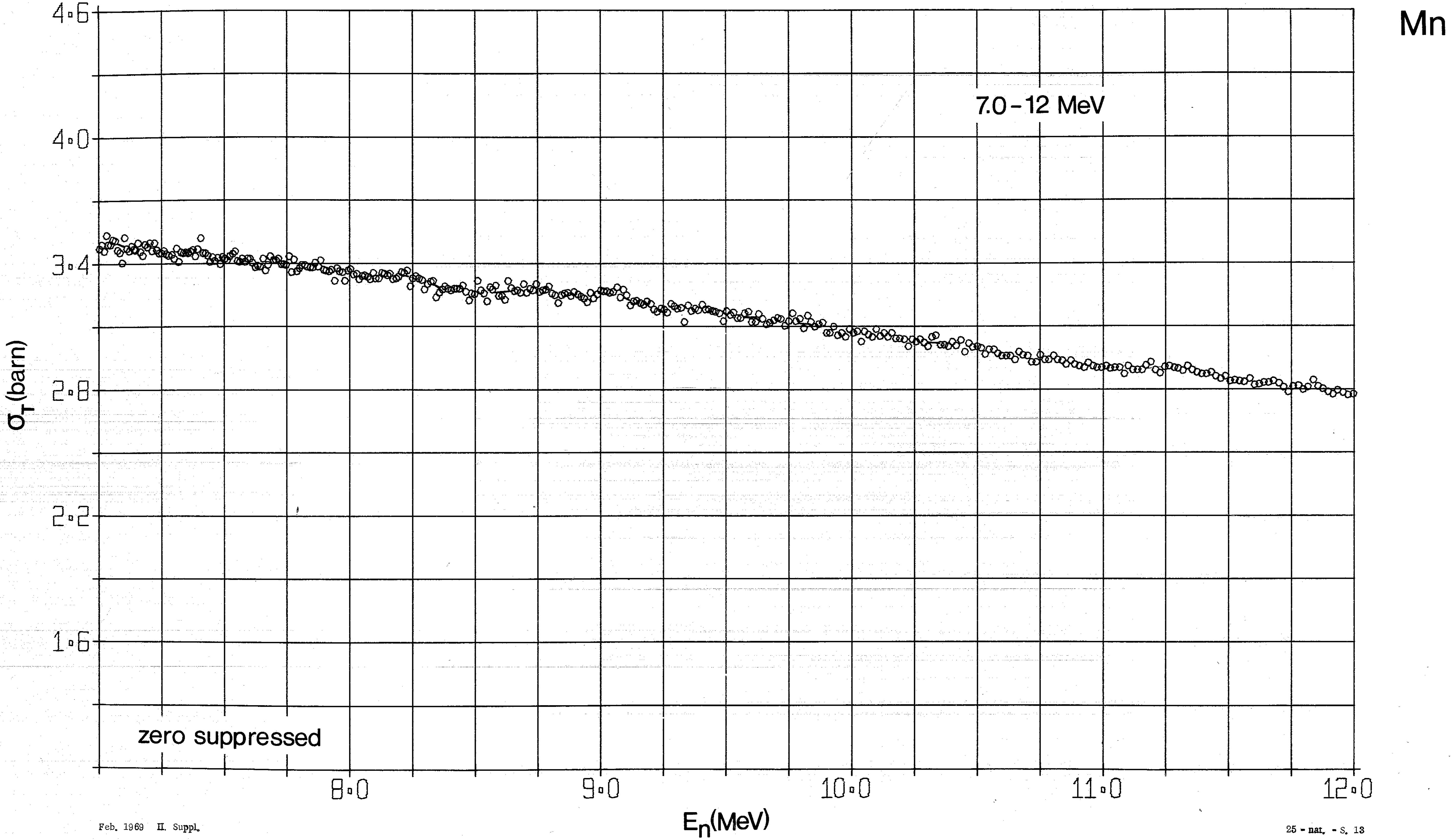
Mn
5·0
4·5
4·0
3·5
3·0
2·5
2.0 - 3.0 MeV
zero suppressed
σT (barn)
2·2
2·4
2·6
2·8
3·0
En(MeV)

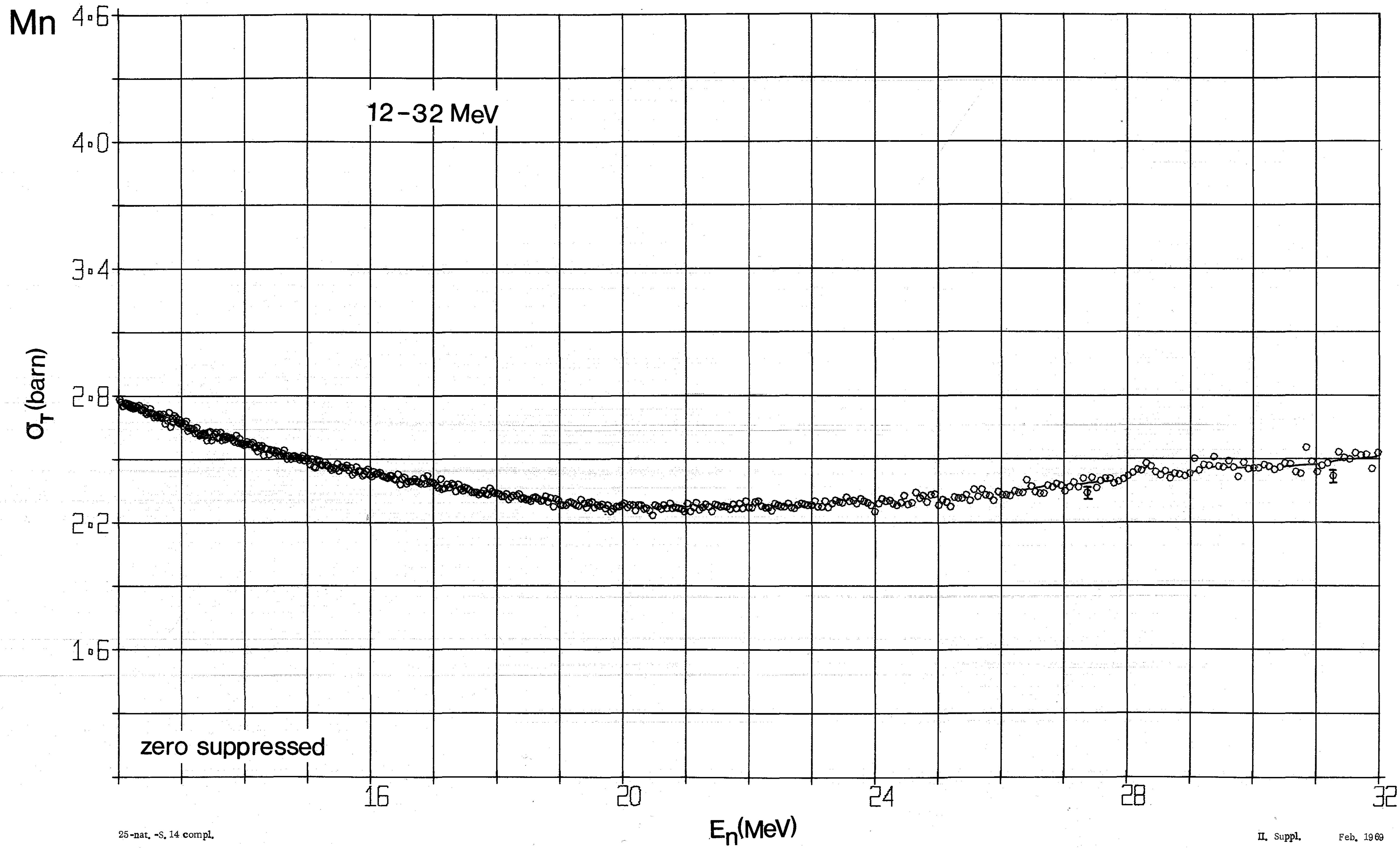
Mn


5·0
4·5
4·0
3·5
3·0
2·5
σ_T(barn)
3.0 - 4.5 MeV
zero suppressed
3·3
3·6
3·9
4·2
4·5
E_n(MeV)



Mn
4·6
4.5-7.0 MeV
4·0
3·4
σT (barn)
2·8
2·2
1·6
zero suppressed
5·0
5·5
6·0
6·5
7·0
En(MeV)


Mn
7.0 - 12 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
zero suppressed
8·0
9·0
10·0
11·0
12·0
E_n(MeV)



25-nat. -S. 14 compl.

II. Suppl. Feb. 1969

Fe

n = 0.3175 at/barn (0.5 - 1.06 MeV)

n = 0.1587 at/barn (1.06 - 32.0 MeV)

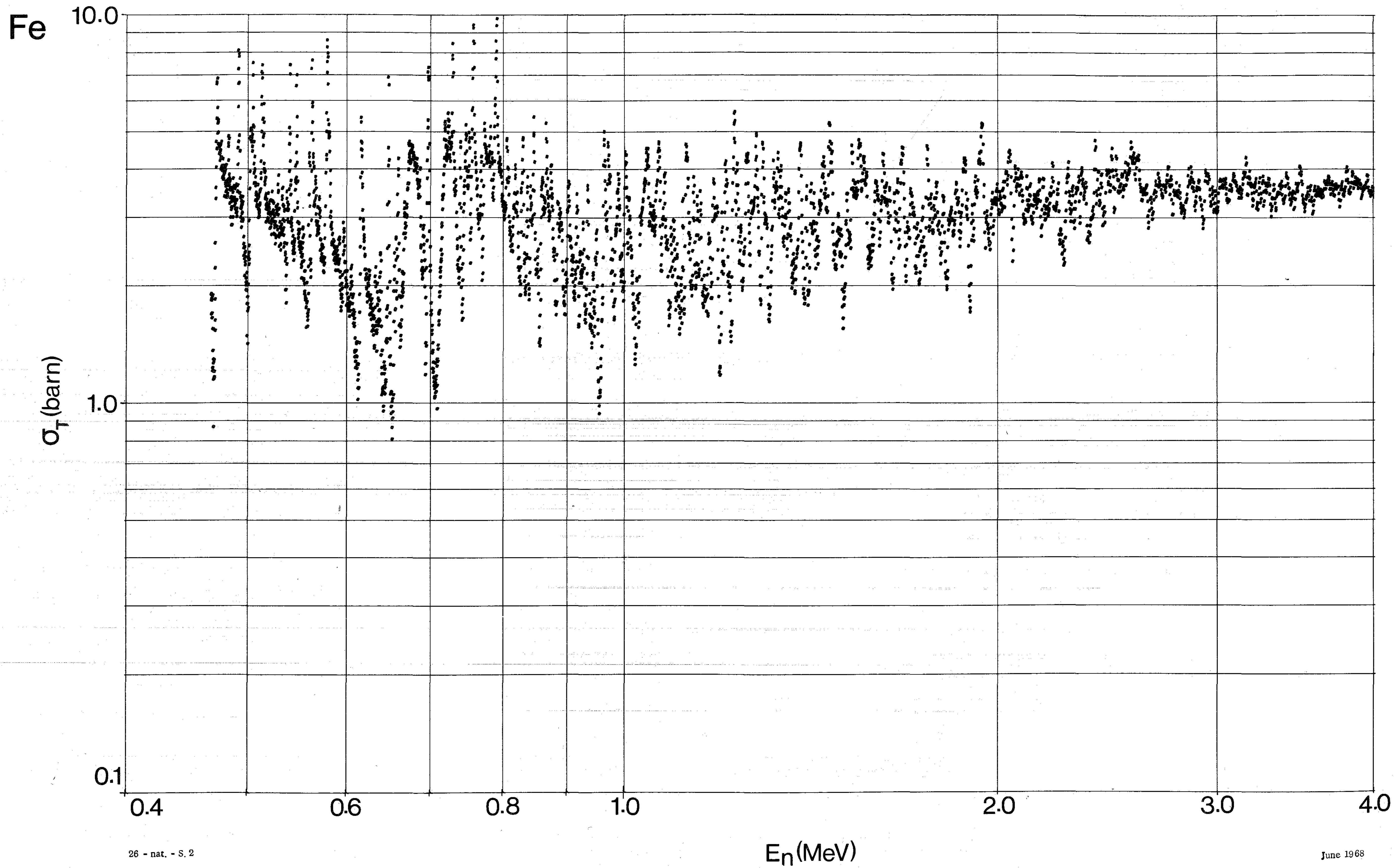
p = 99.85 %

l = 57.393 m

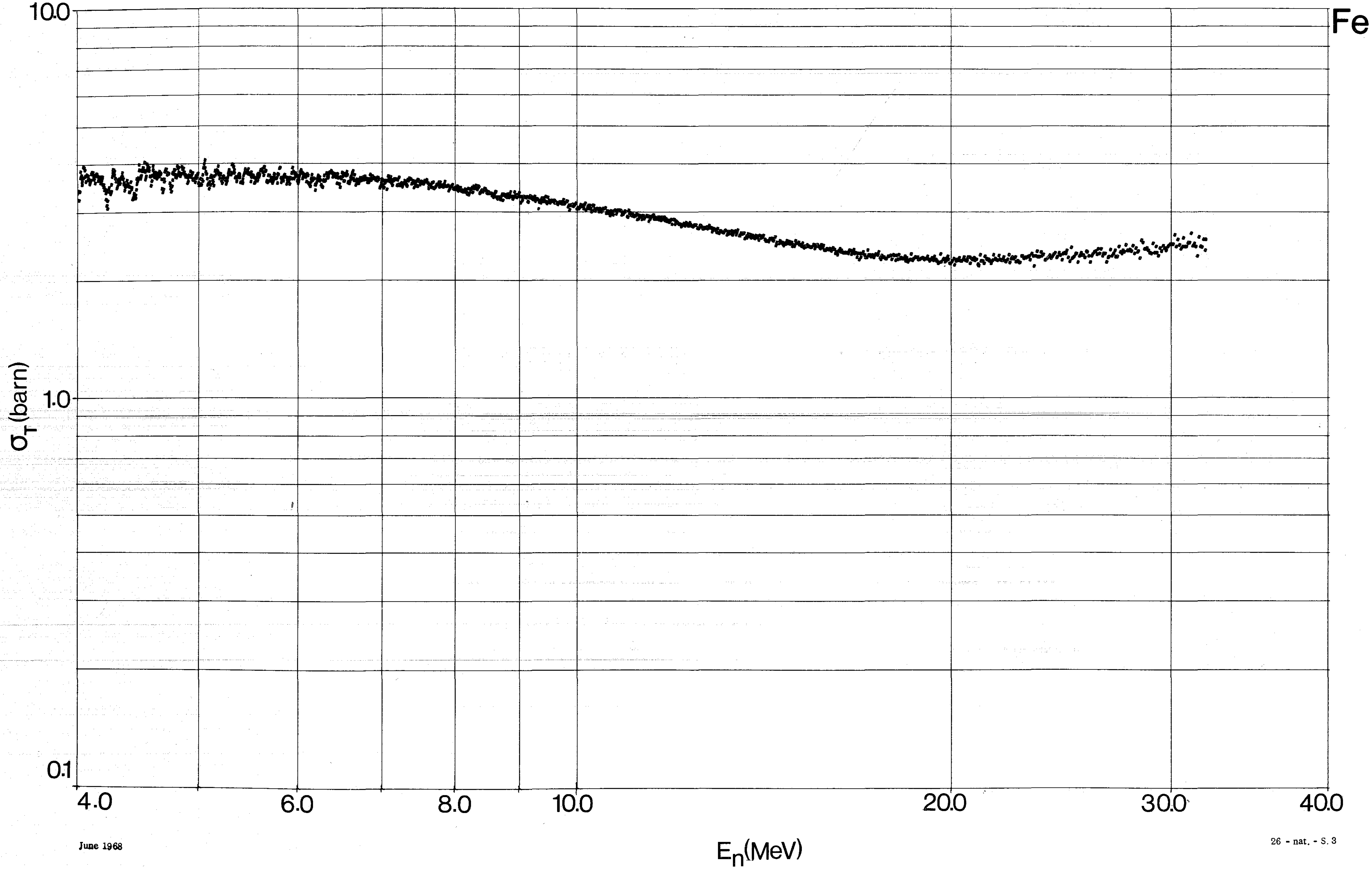
Δt = 2.5 nsec

i : natural

The data points sybolized by + represent additional results with $\Delta t = 1.0 \pm 0.3$ nsec

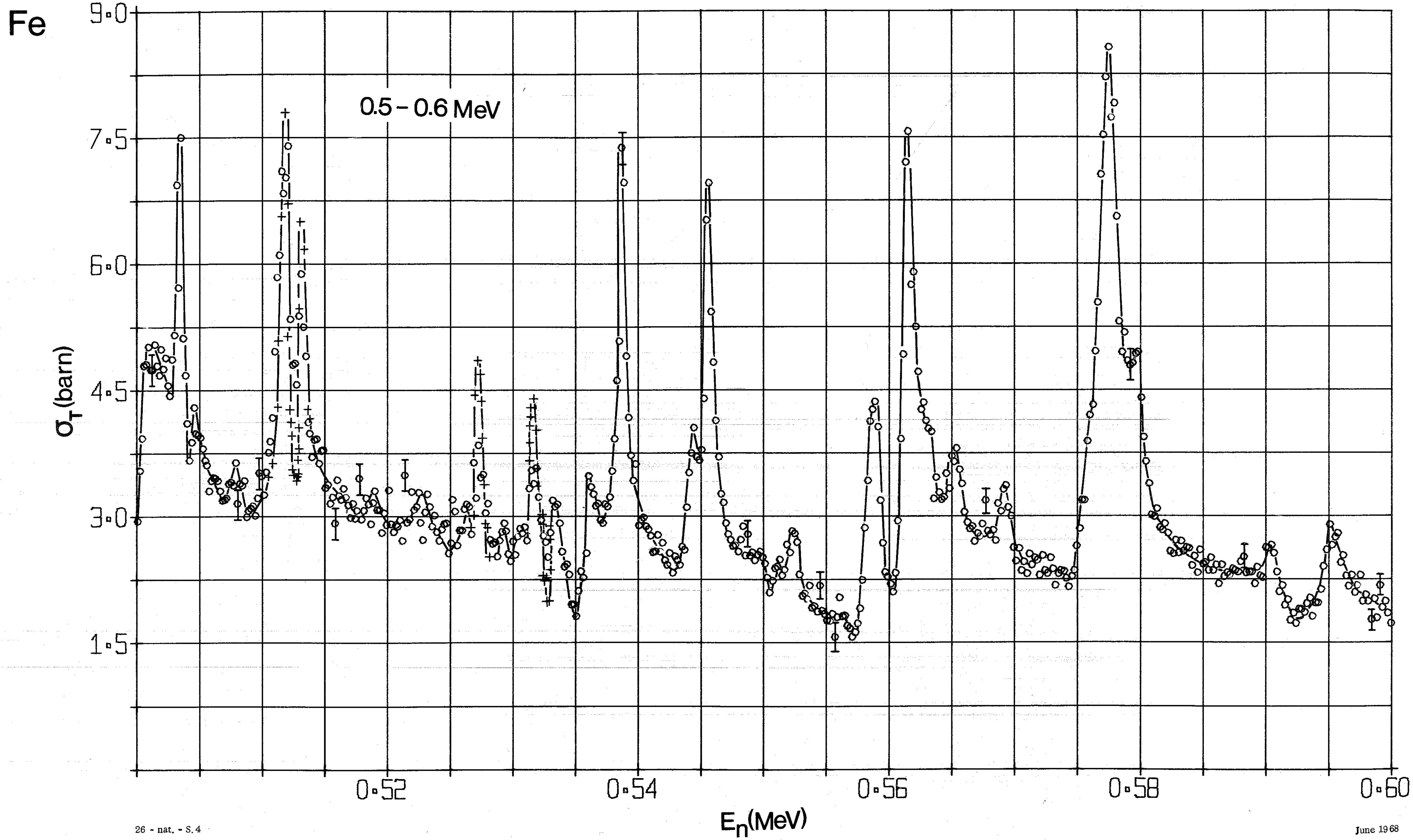


June 1968



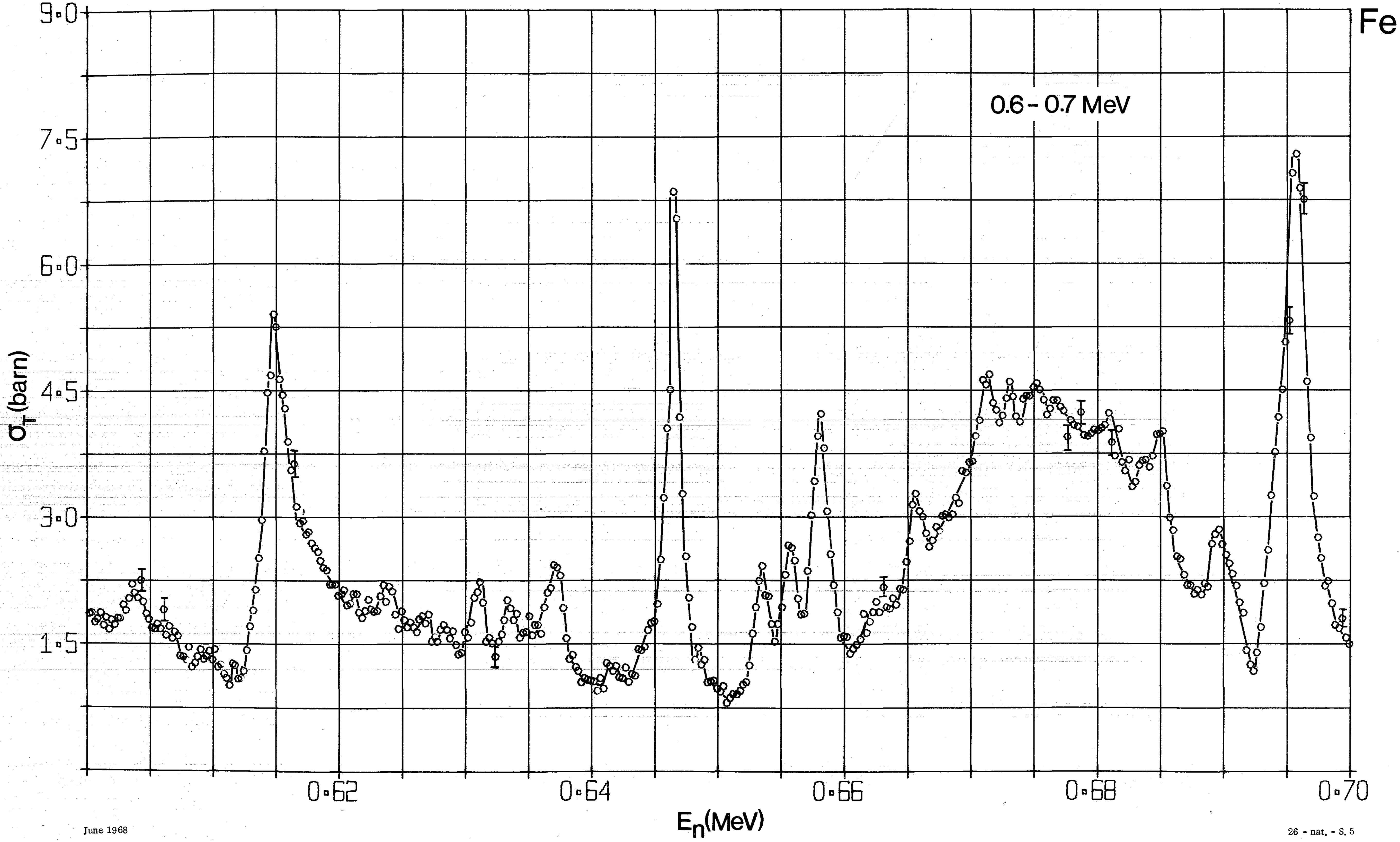
June 1968

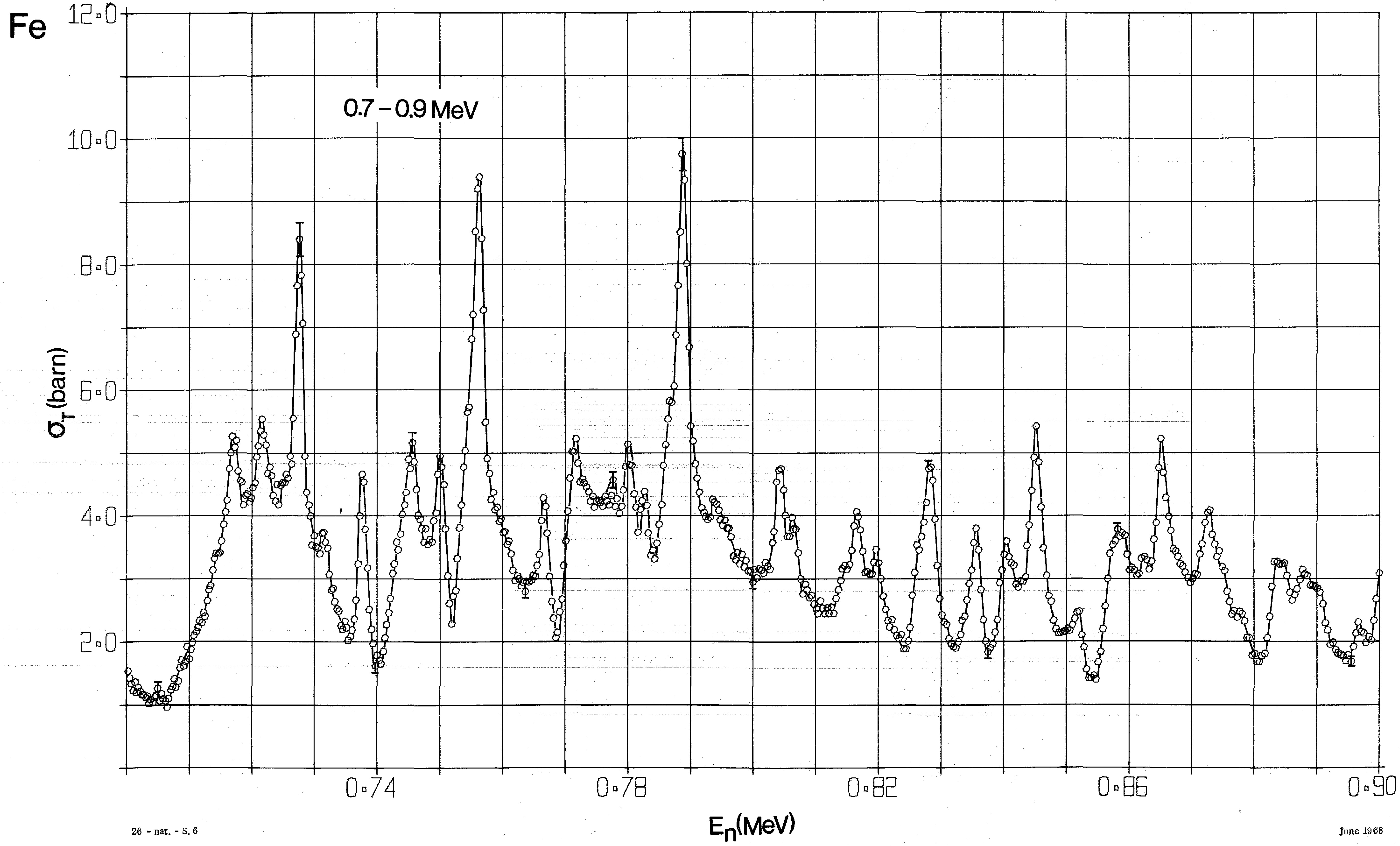
26 - nat. - S. 3



26 - nat. - S.4

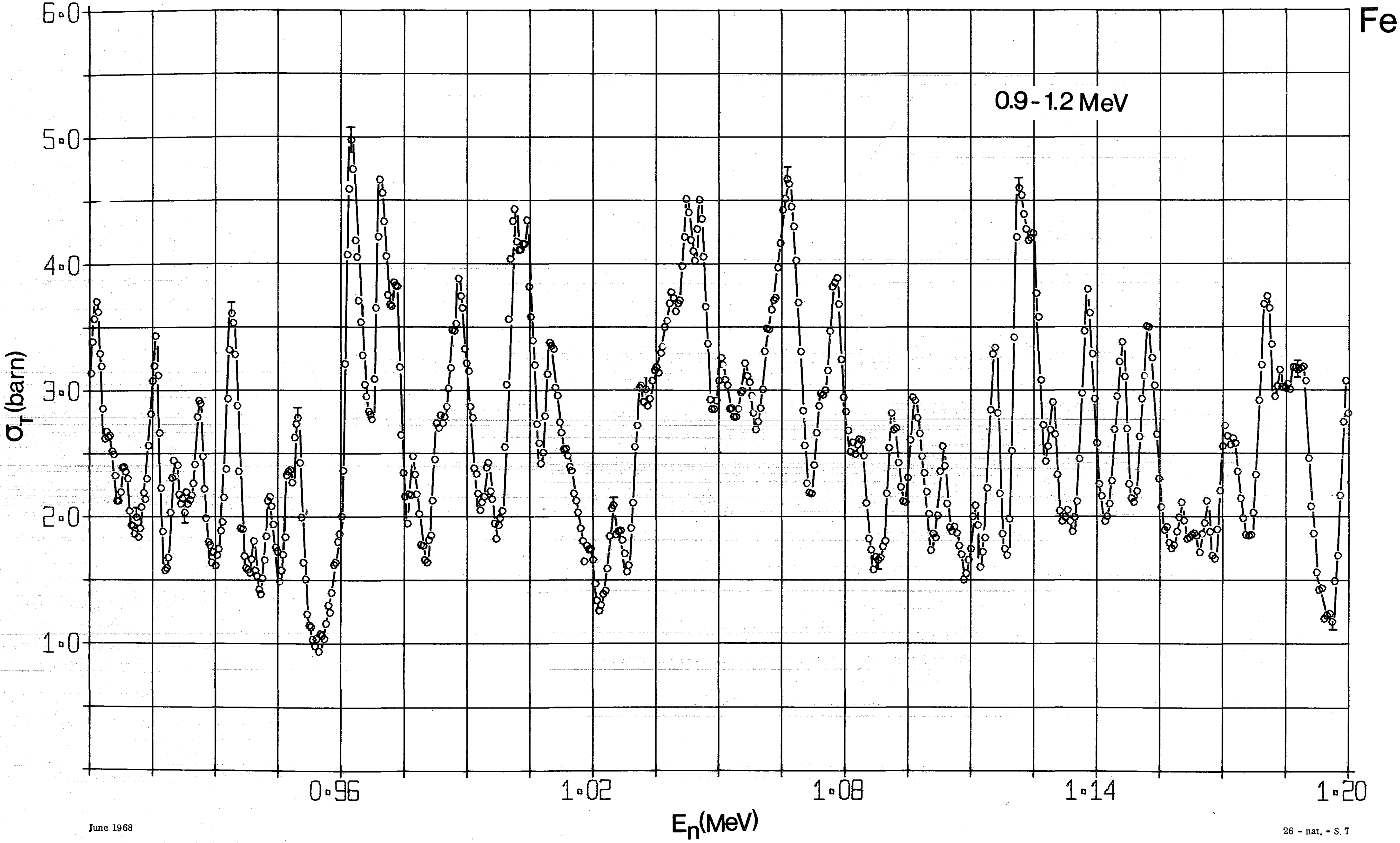
June 1968


Fe
0.6 - 0.7 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σT (barn)
0·62
0·64
0·66
0·68
0·70
En(MeV)

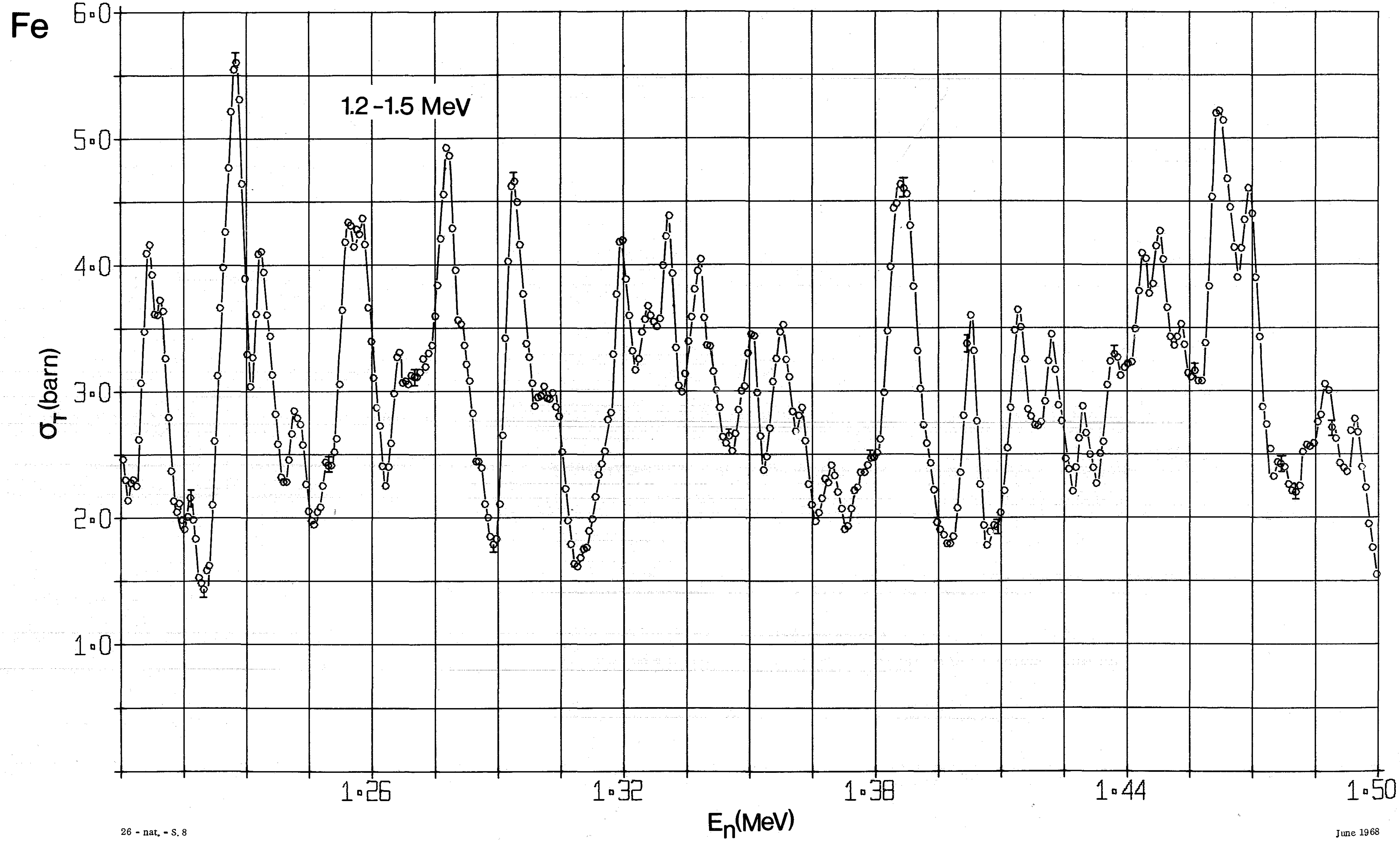


26 - nat. - S. 6

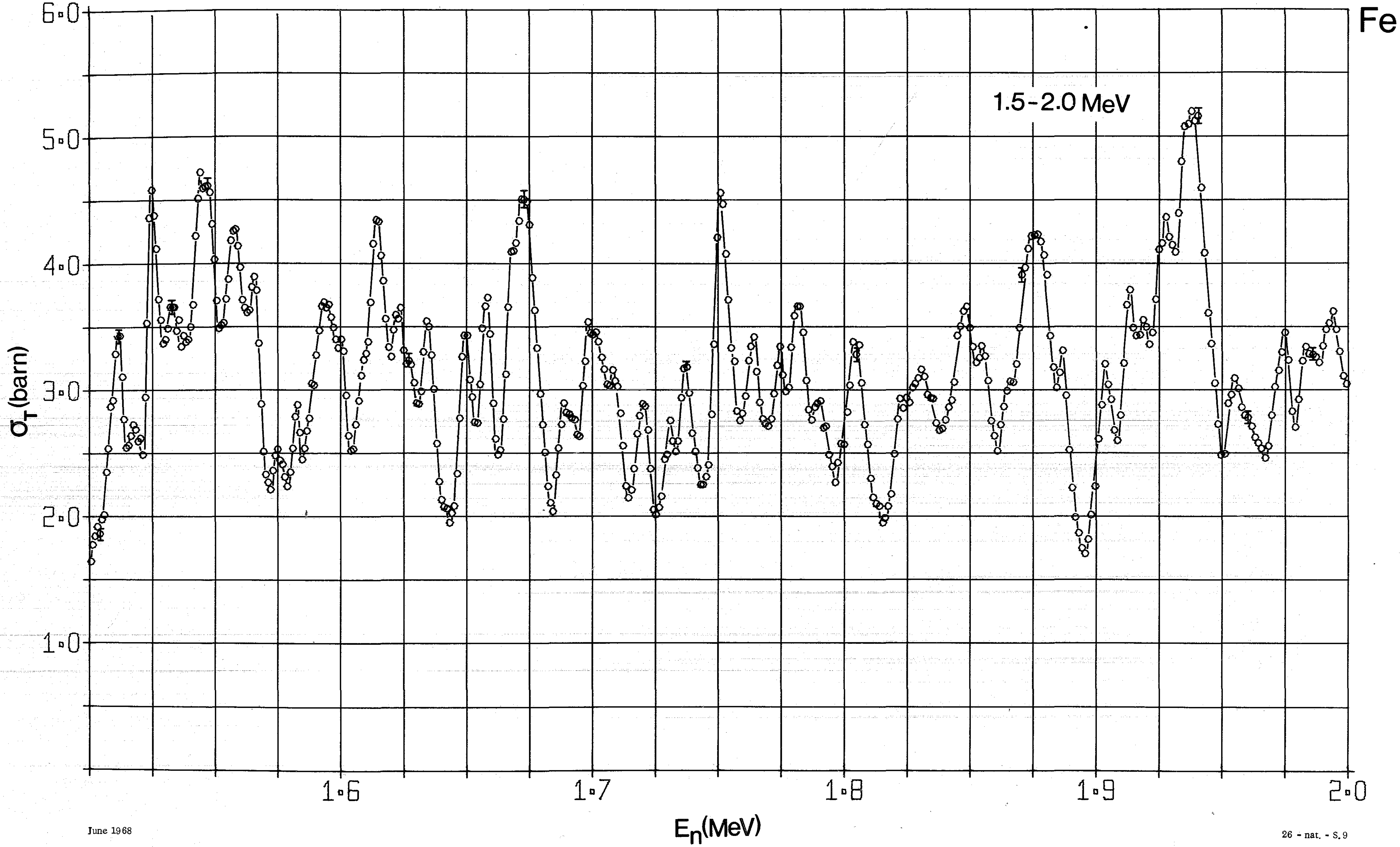
June 1968



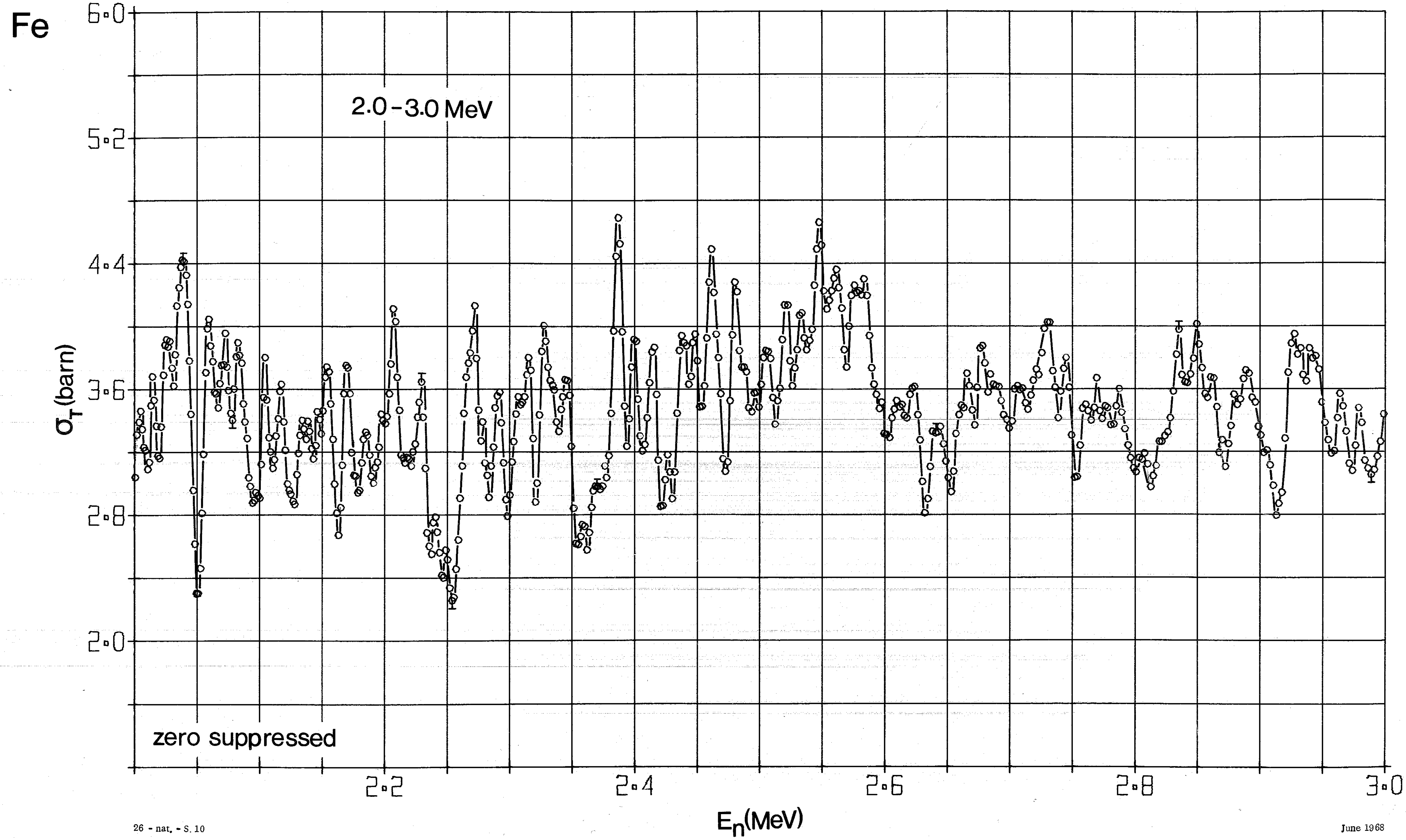
June 1968



Fe
1.2 - 1.5 MeV
σT (barn)
6·0
5·0
4·0
3·0
2·0
1·0
1·26
1·32
1·38
1·44
1·50
En(MeV)

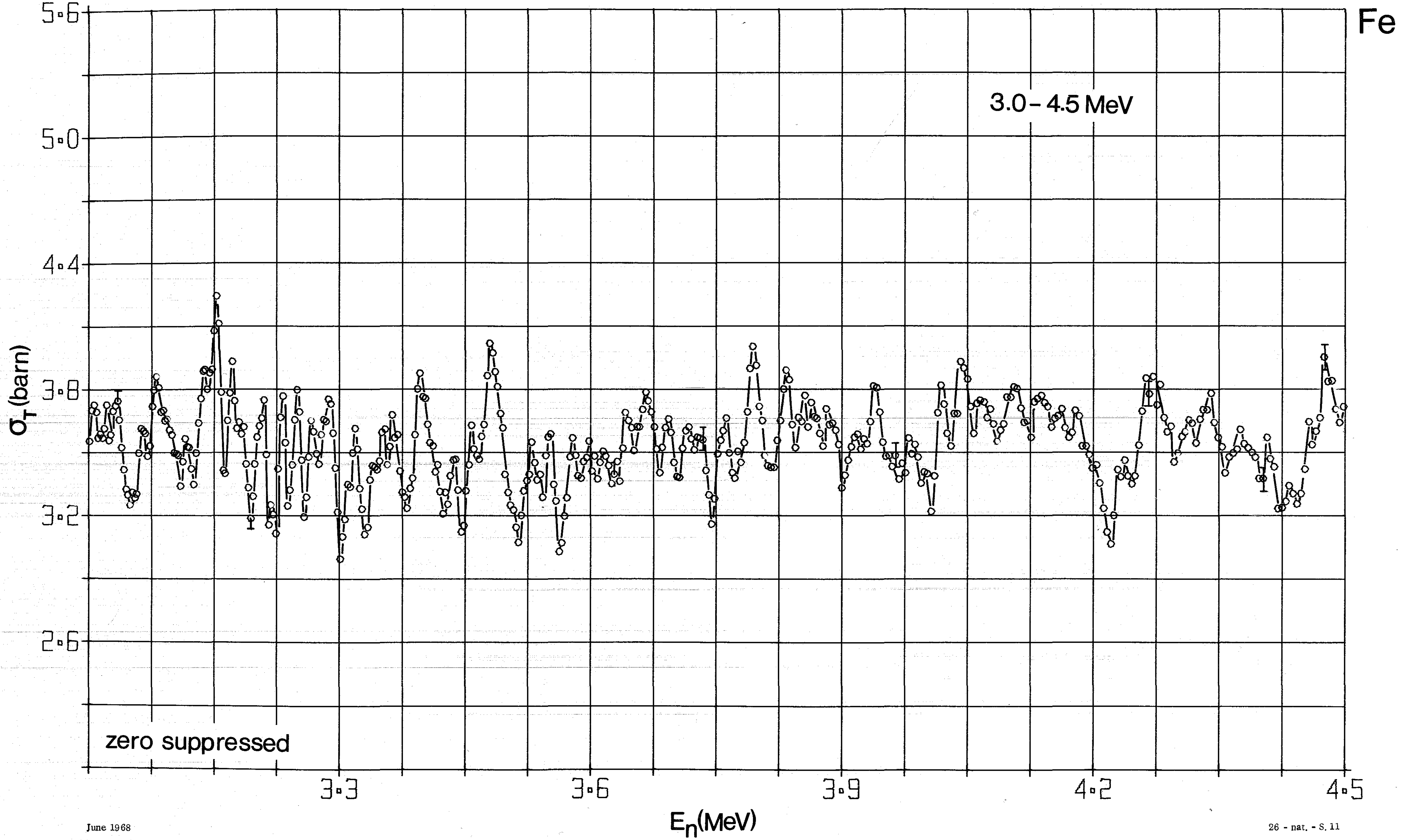


Fe
1.5-2.0 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σT (barn)
1·6
1·7
1·8
1·9
2·0
En(MeV)



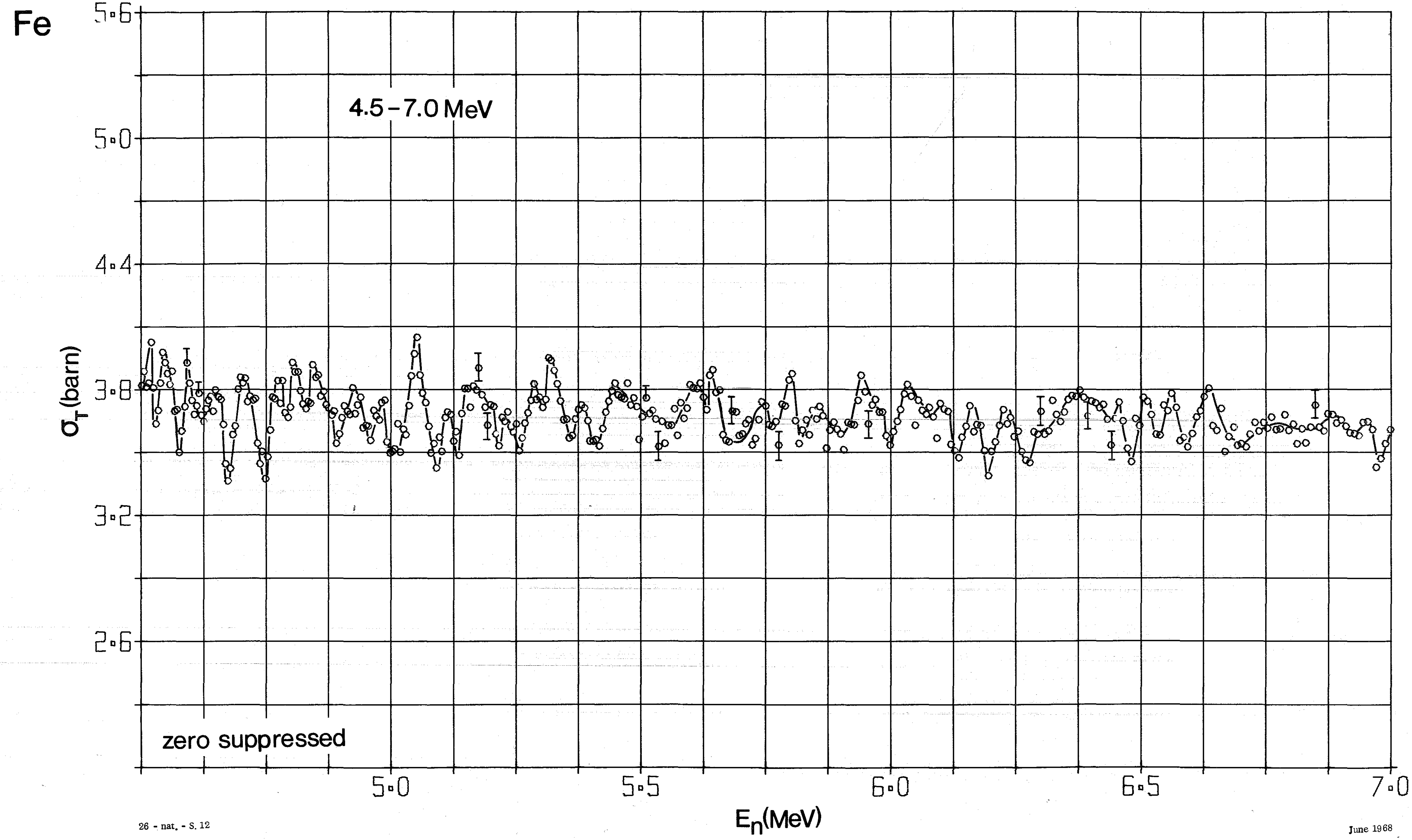
26 - nat. - S. 10

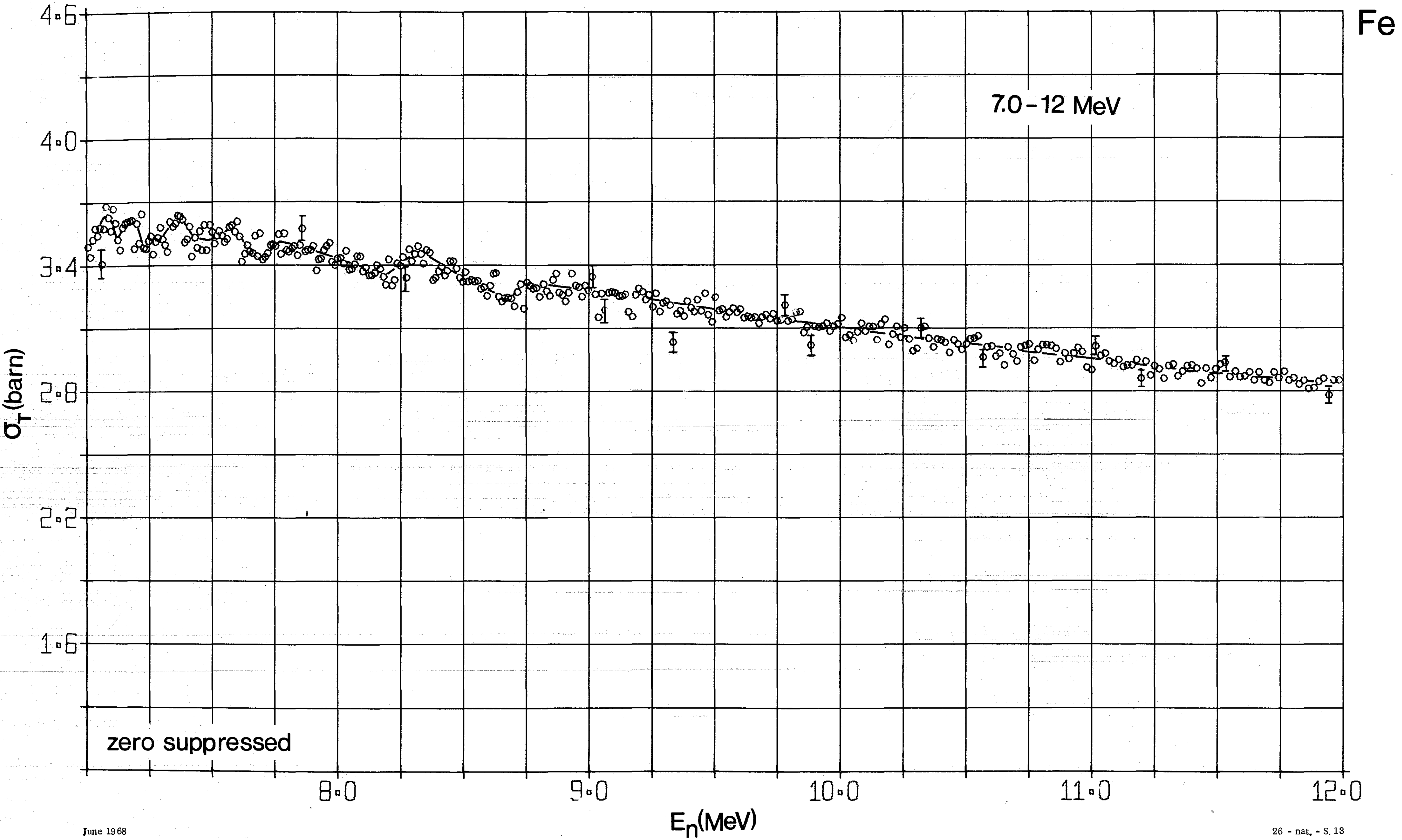
June 1968



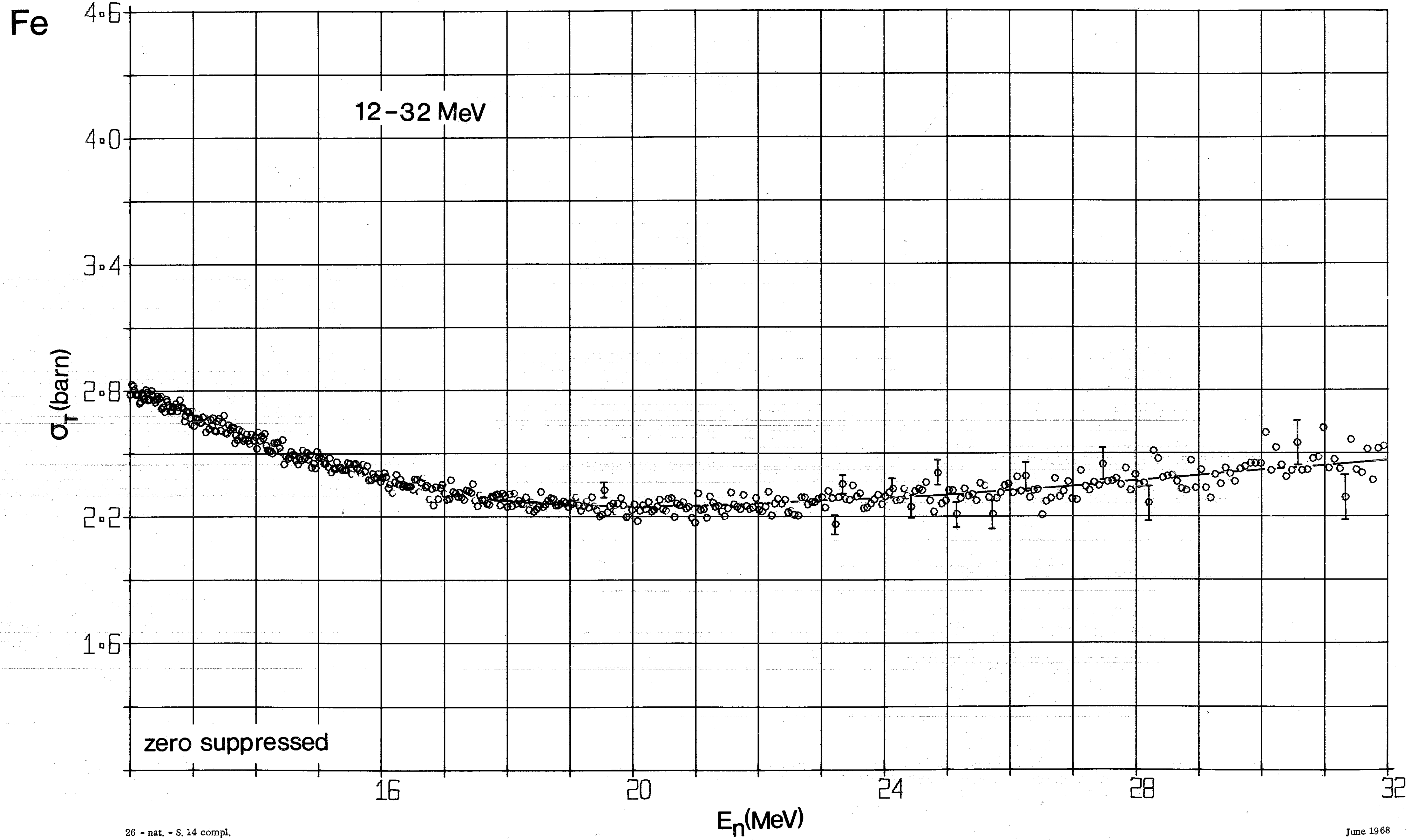
June 1968

26 - nat. - S. 11


Fe
4.5 - 7.0 MeV
5·6
5·0
4·4
3·8
3·2
2·6
σ_T (barn)
zero suppressed
5·0
5·5
6·0
6·5
7·0
E_n(MeV)



Fe
7.0 - 12 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σT (barn)
zero suppressed
8·0
9·0
10·0
11·0
12·0
En(MeV)

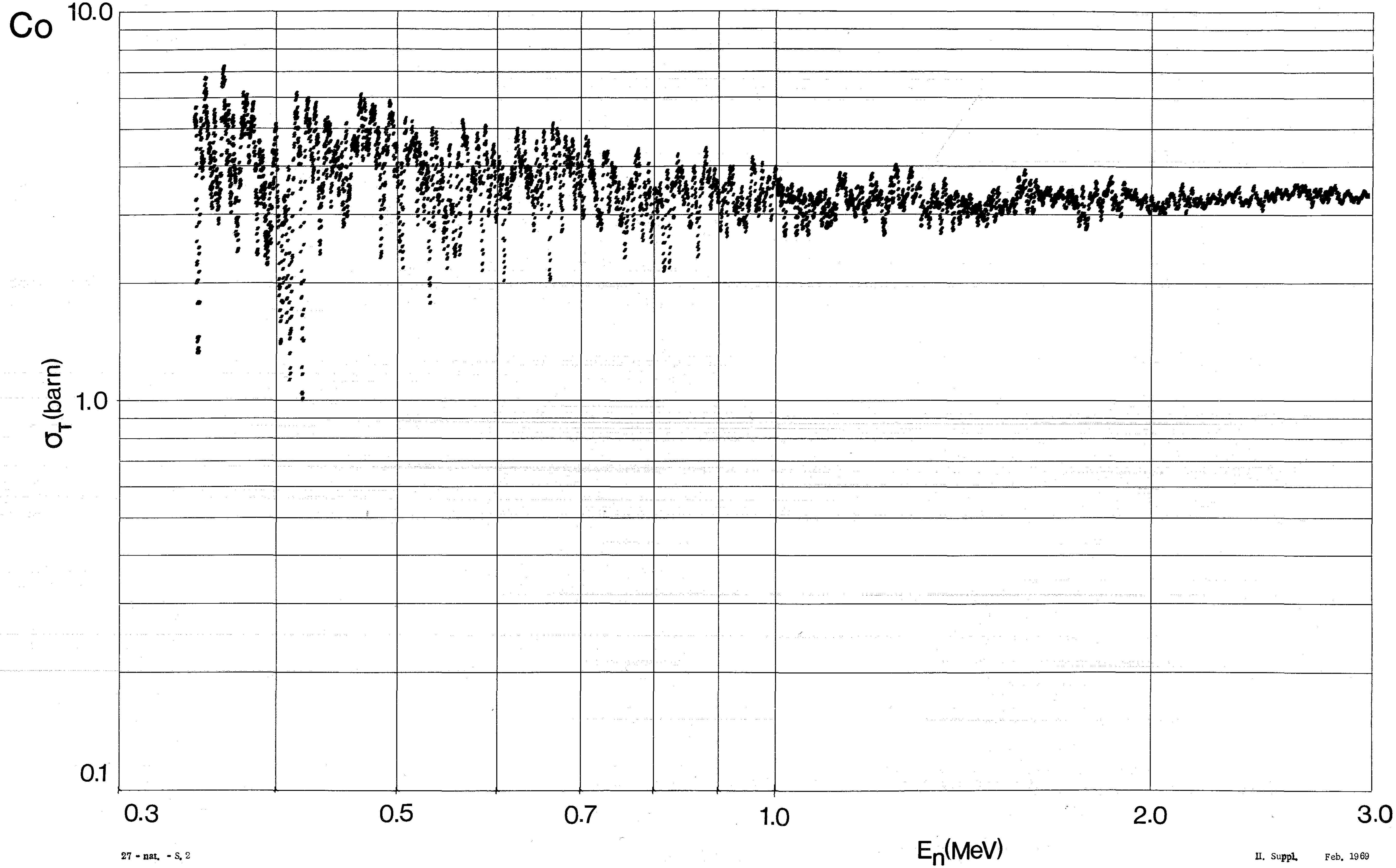


26 - nat. - S. 14 compl.

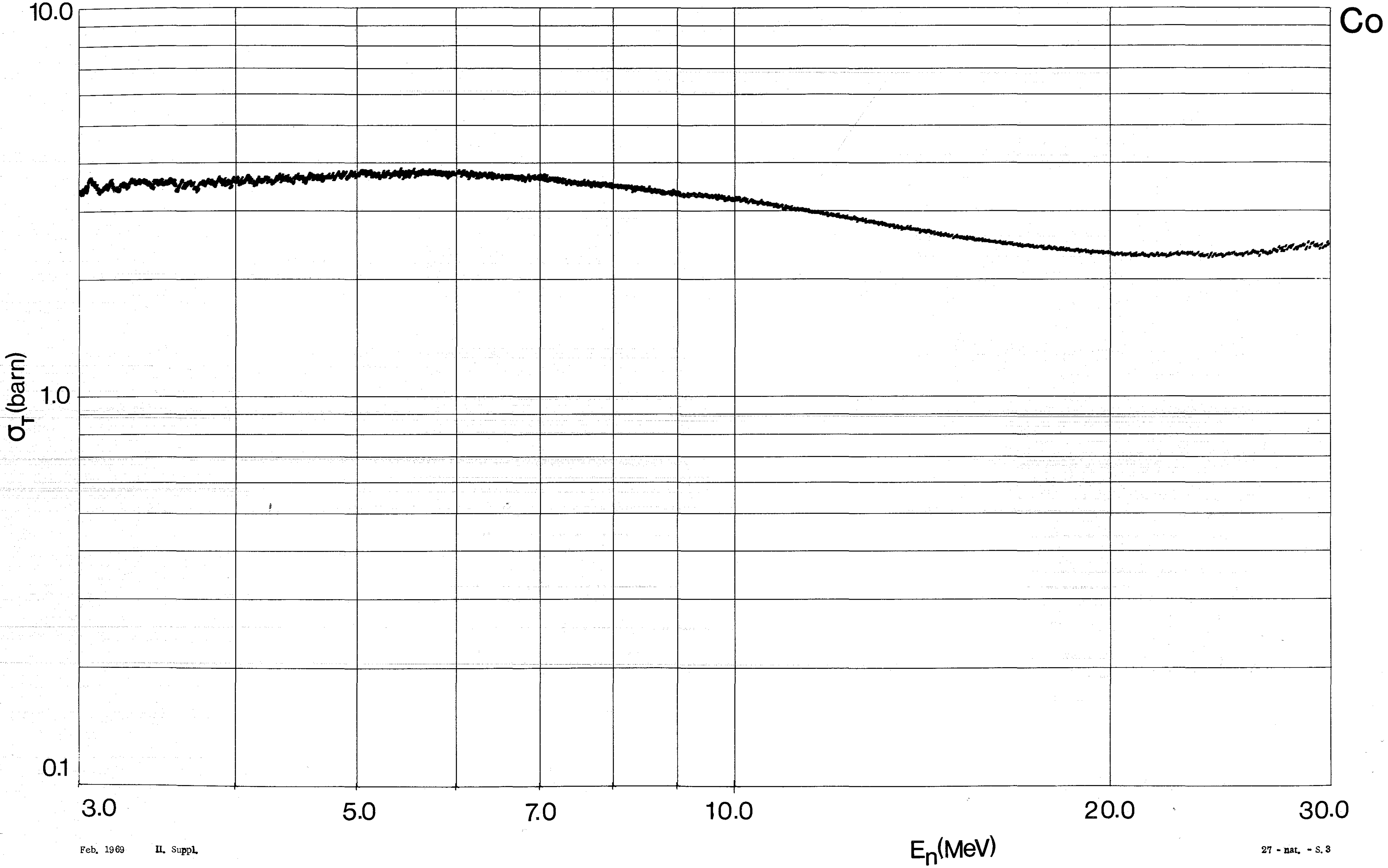
June 1968

Co

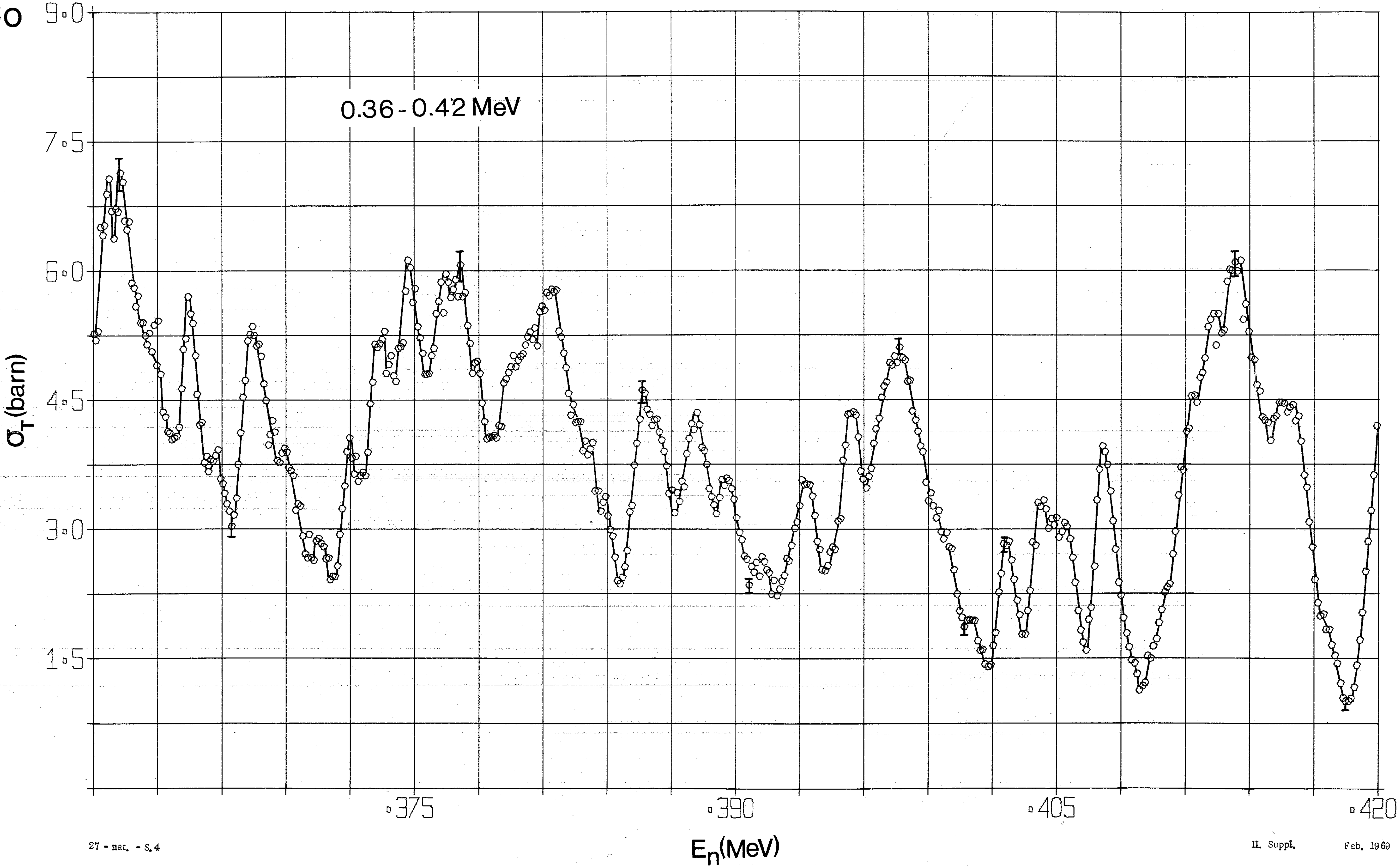
n	=	0.3069	At/barn
p	=	99.9	%
l	=	57.540	m
Δt	=	4.0	nsec
i	:	natural	



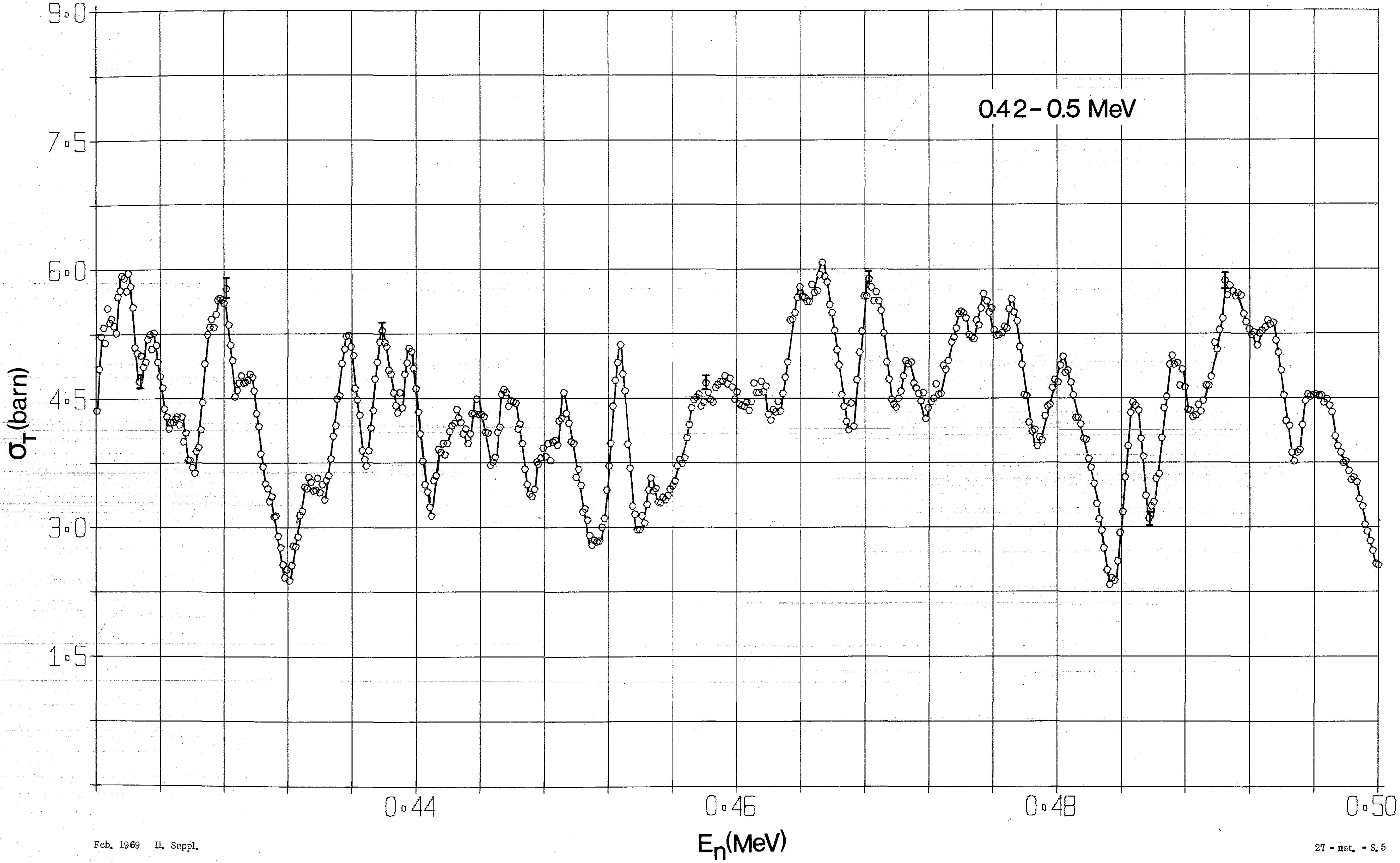
Co
10.0
1.0
0.1
σT(barn)
0.3
0.5
0.7
1.0
2.0
3.0
En(MeV)

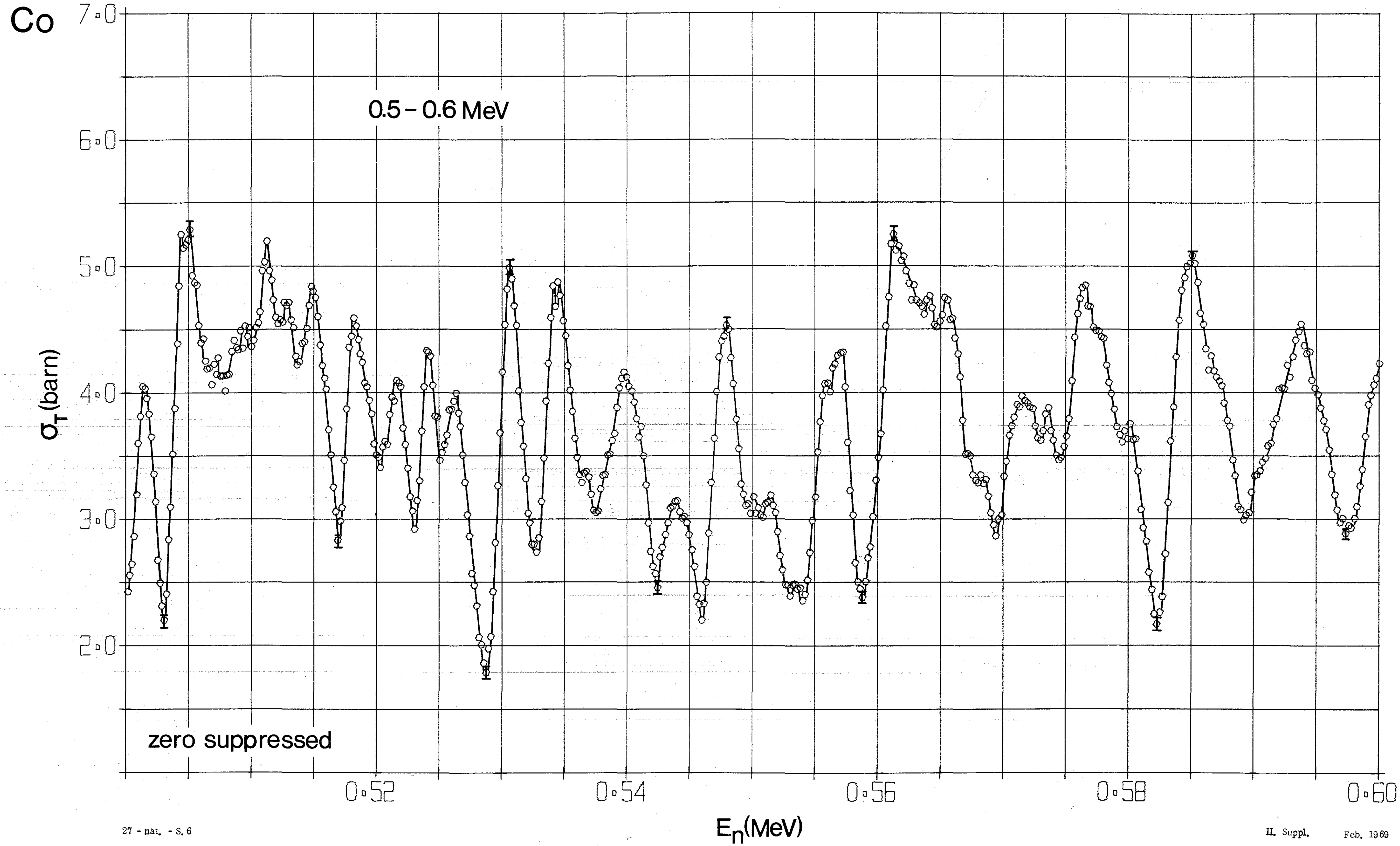

Co
10.0
1.0
0.1
σ_T(barn)
3.0
5.0
7.0
10.0
20.0
30.0
E_n(MeV)

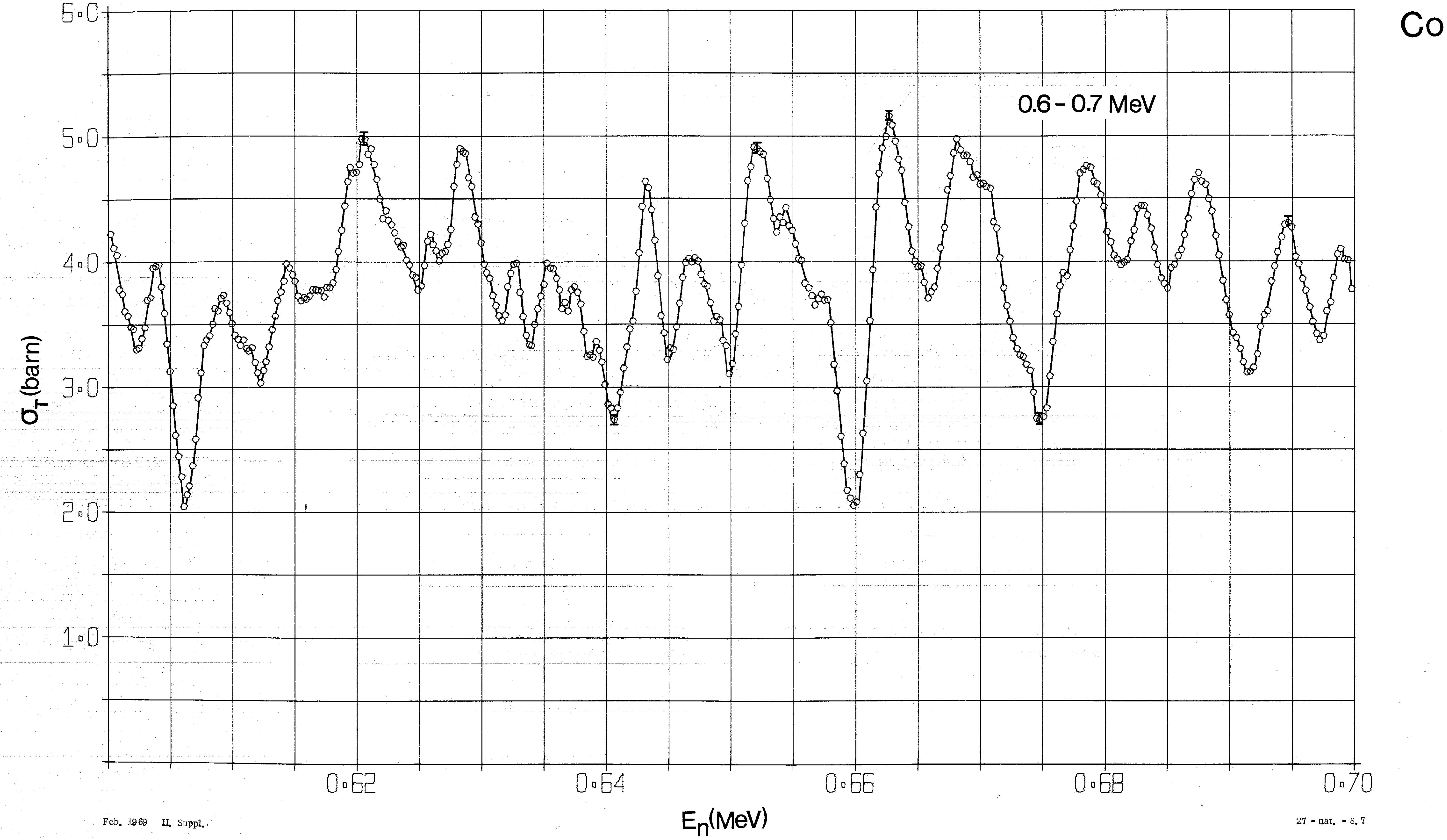
Co

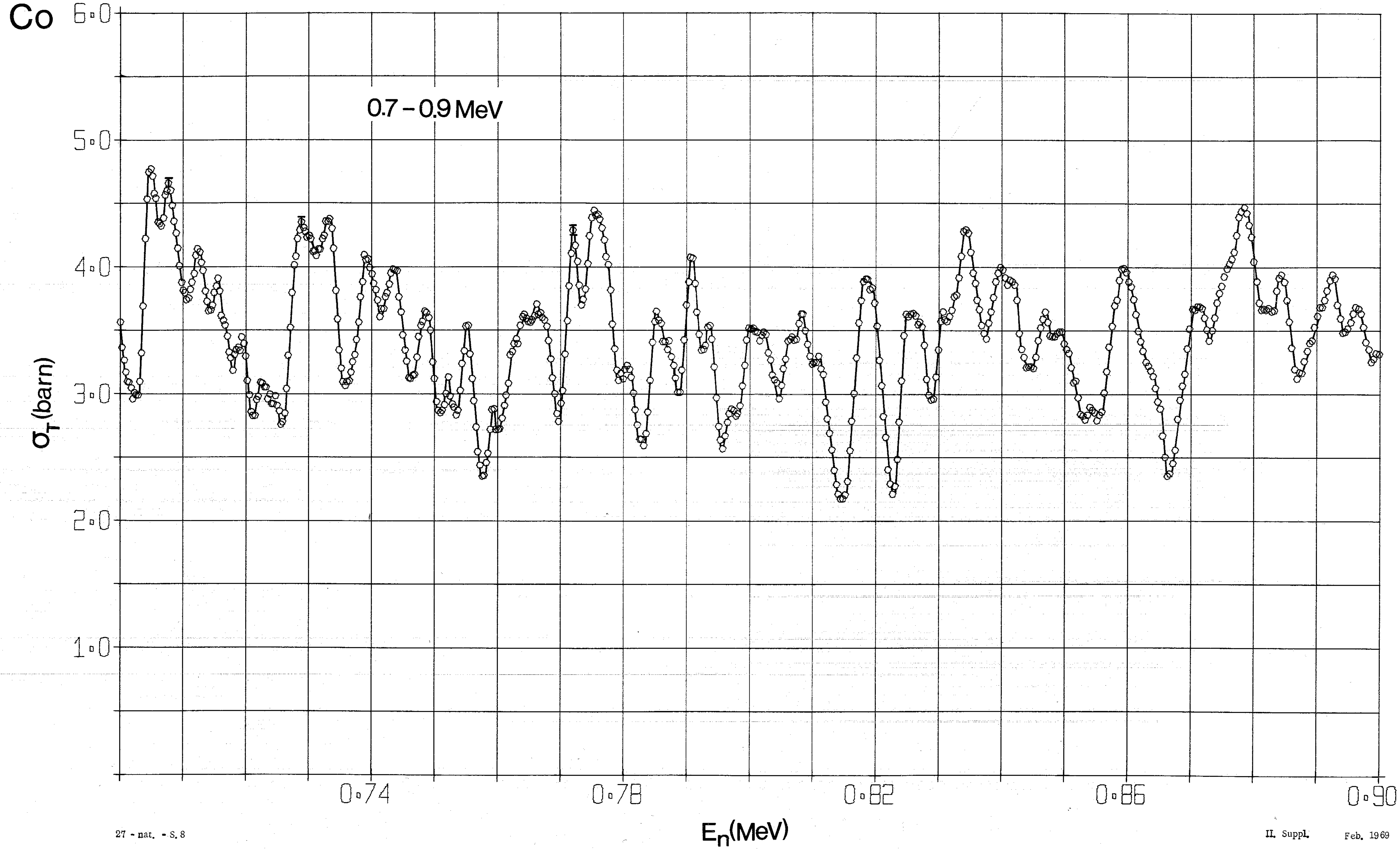


Co



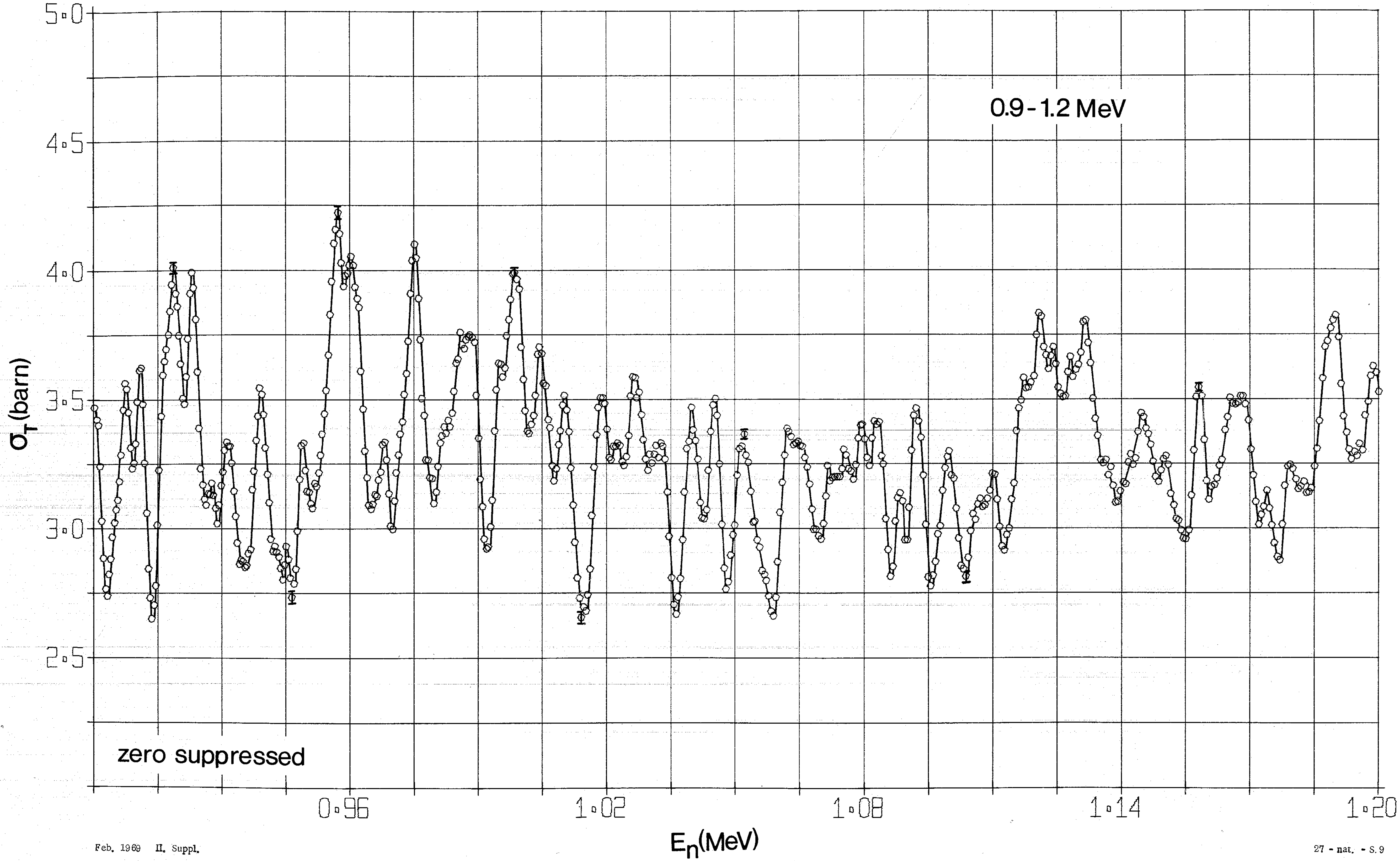

Co
7·0
6·0
5·0
4·0
3·0
2·0
0.5 - 0.6 MeV
σT (barn)
zero suppressed
0·52
0·54
0·56
0·58
0·60
En(MeV)

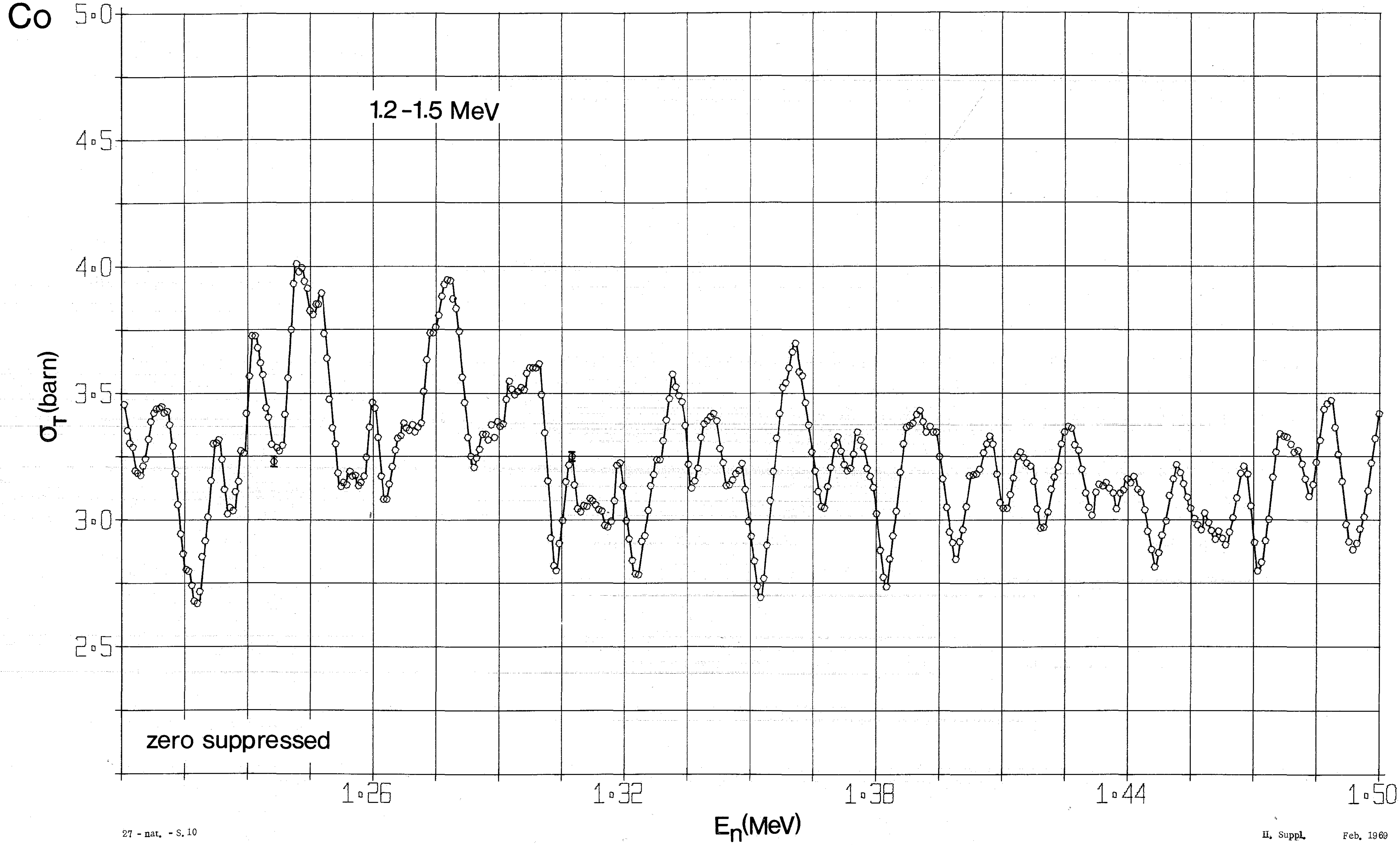

Co
0.6 - 0.7 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σ_T (barn)
0·62
0·64
0·66
0·68
0·70
E_n(MeV)

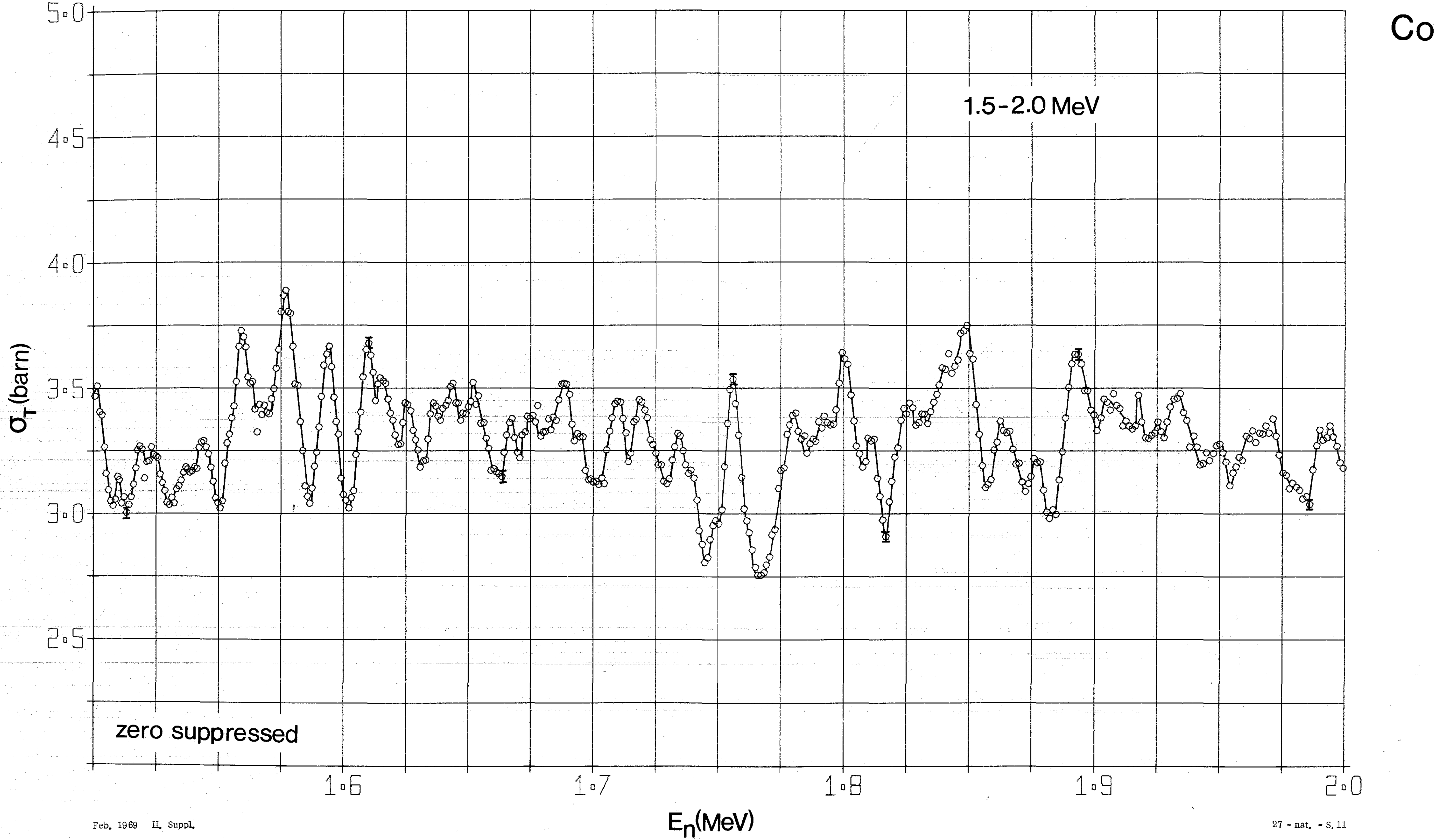


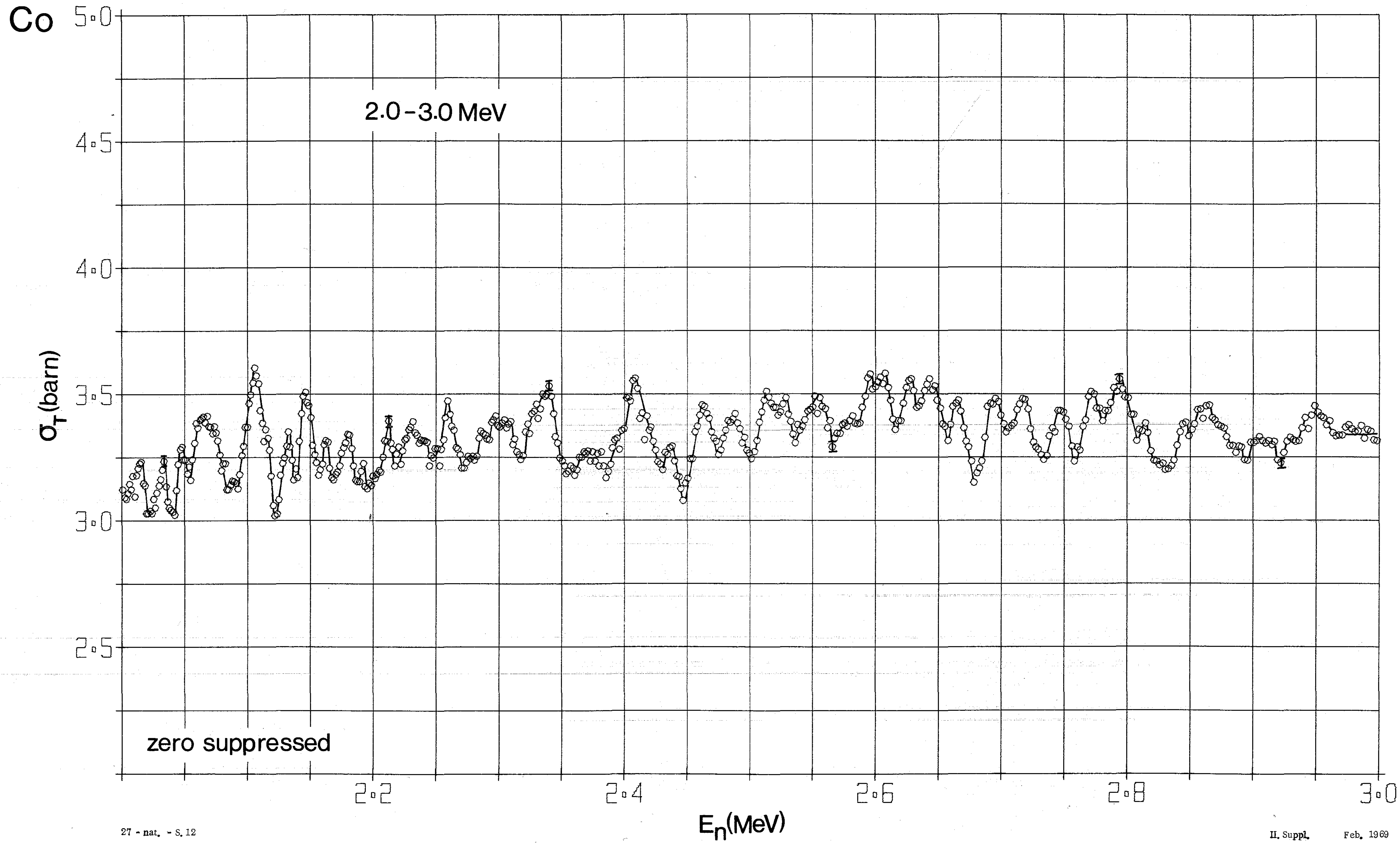
Co
0.7 – 0.9 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σT (barn)
0·74
0·78
0·82
0·86
0·90
En(MeV)

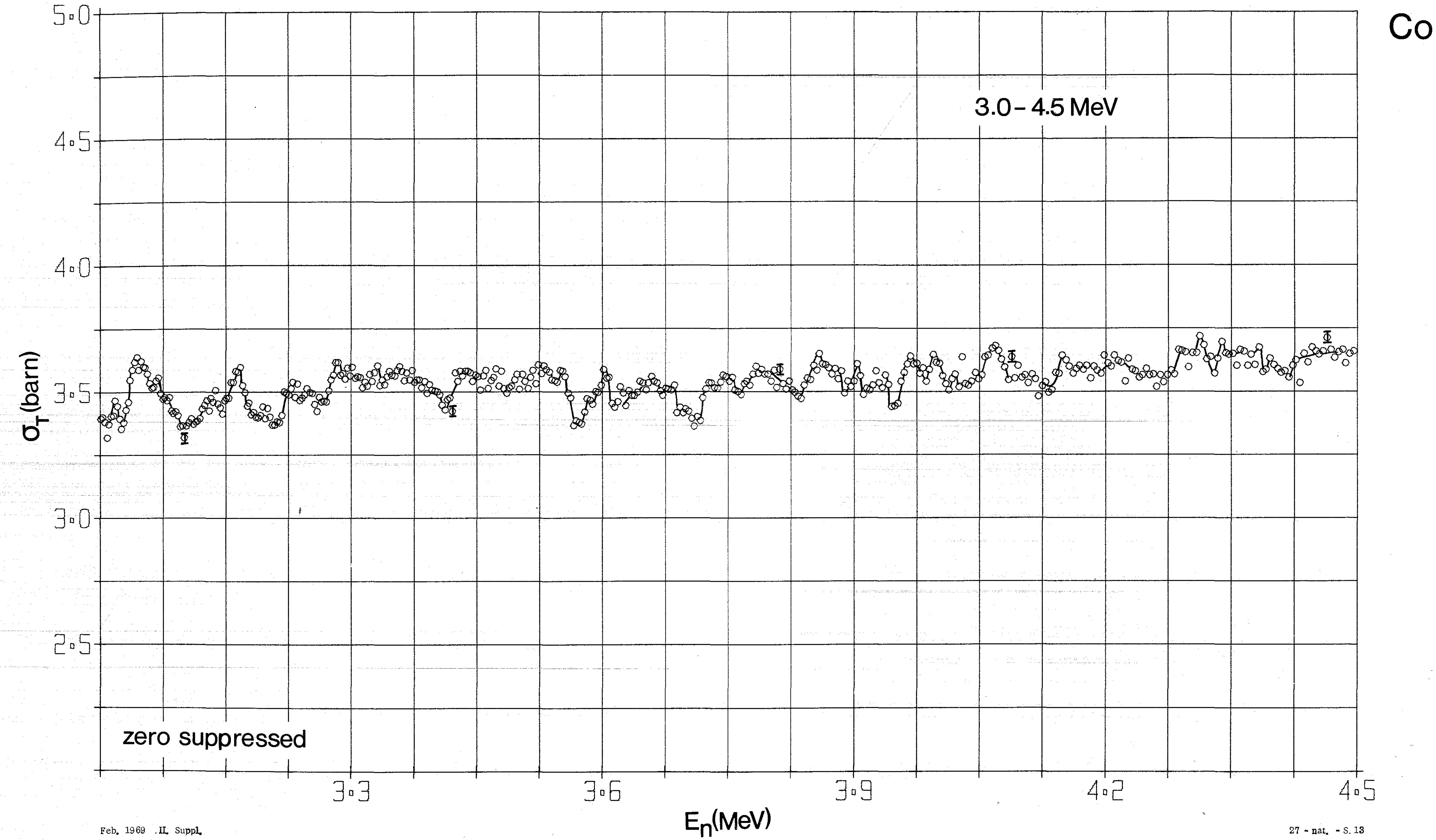
Co

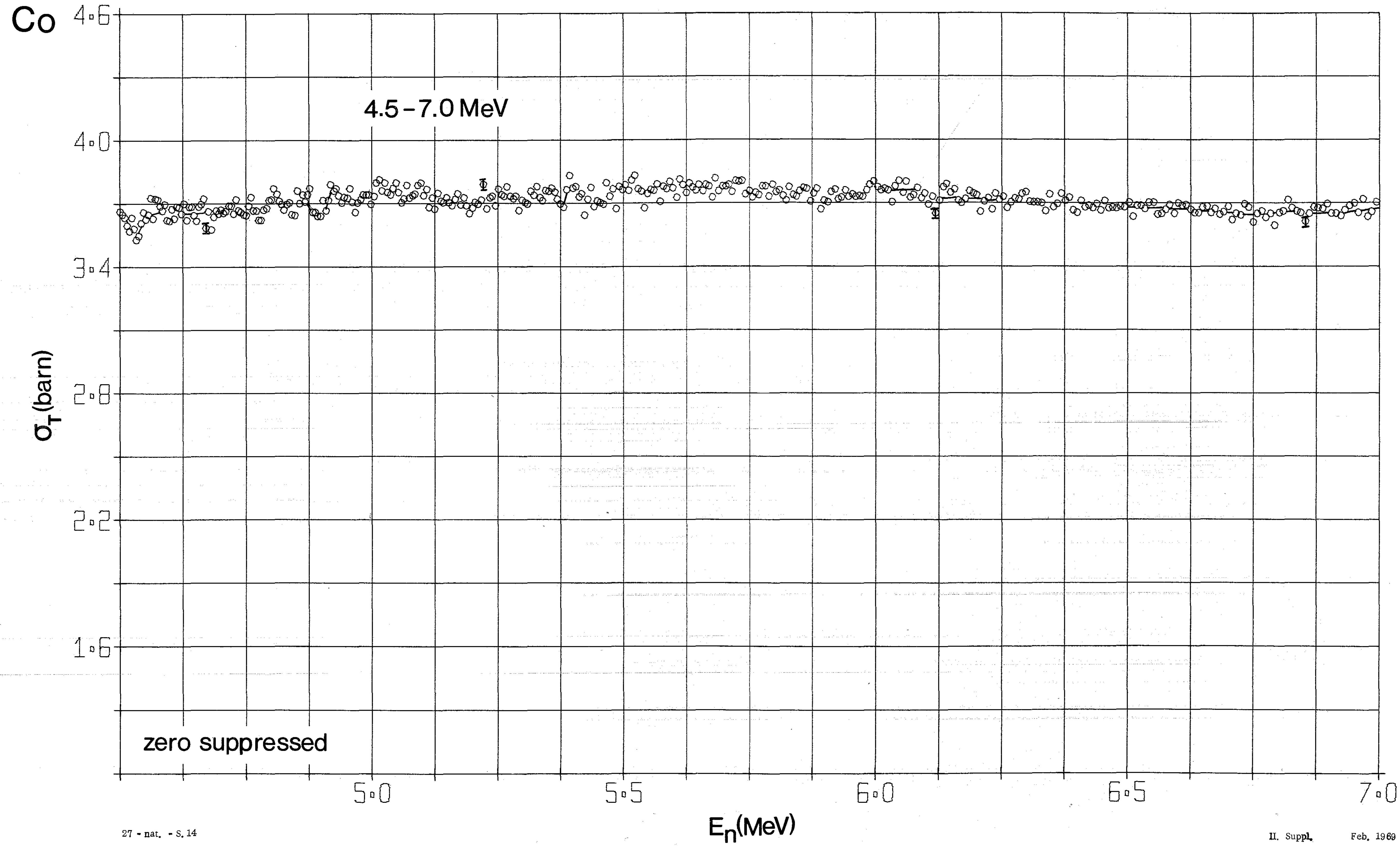

0.9 - 1.2 MeV
σT (barn)
5·0
4·5
4·0
3·5
3·0
2·5
zero suppressed
0·96
1·02
1·08
1·14
1·20
En(MeV)

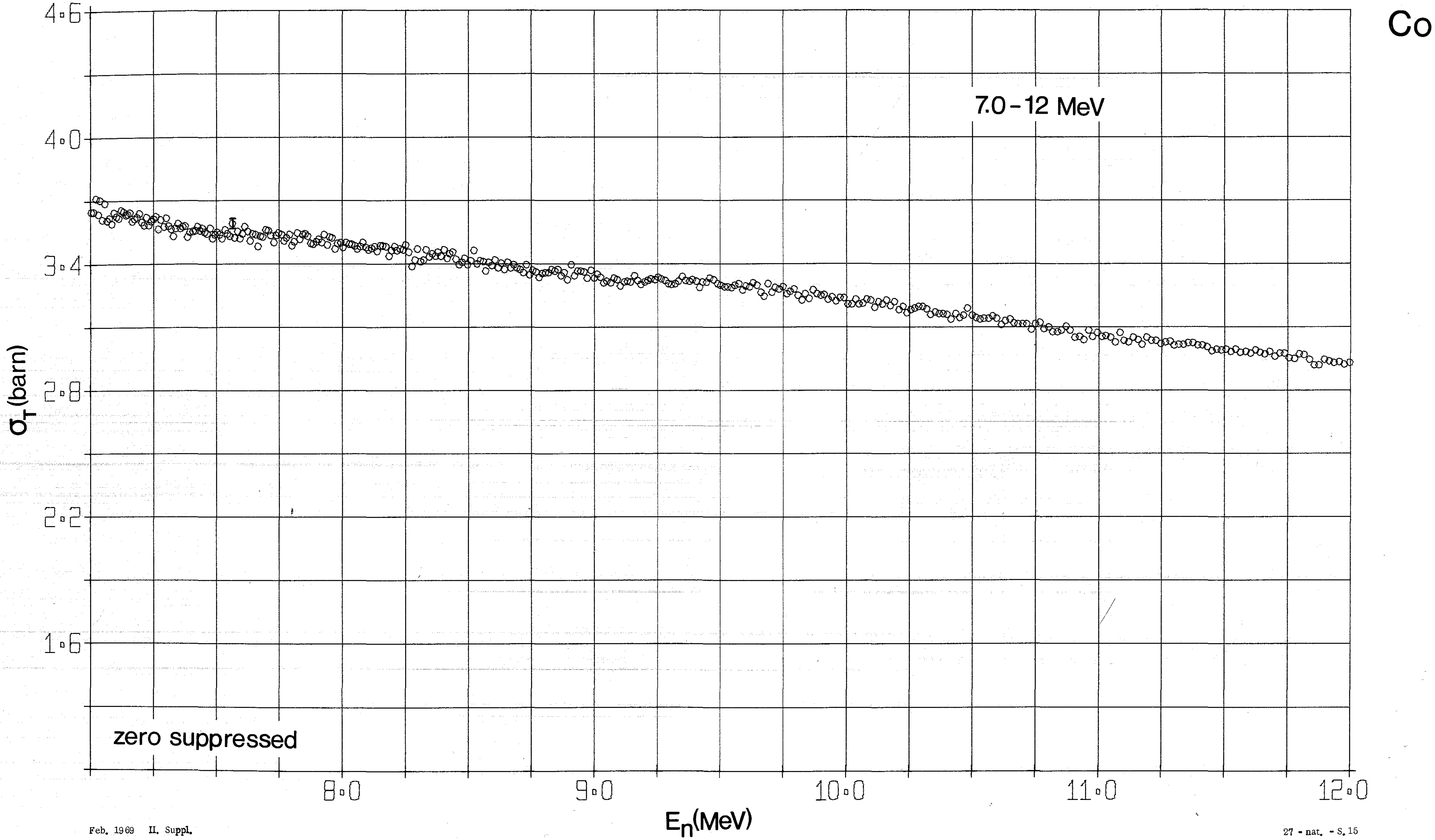

Co
1.2 -1.5 MeV
σT (barn)
5·0
4·5
4·0
3·5
3·0
2·5
zero suppressed
1·26
1·32
1·38
1·44
1·50
En(MeV)


Co
1.5-2.0 MeV
5.0
4.5
4.0
3.5
3.0
2.5
σT (barn)
zero suppressed
1.6
1.7
1.8
1.9
2.0
En(MeV)

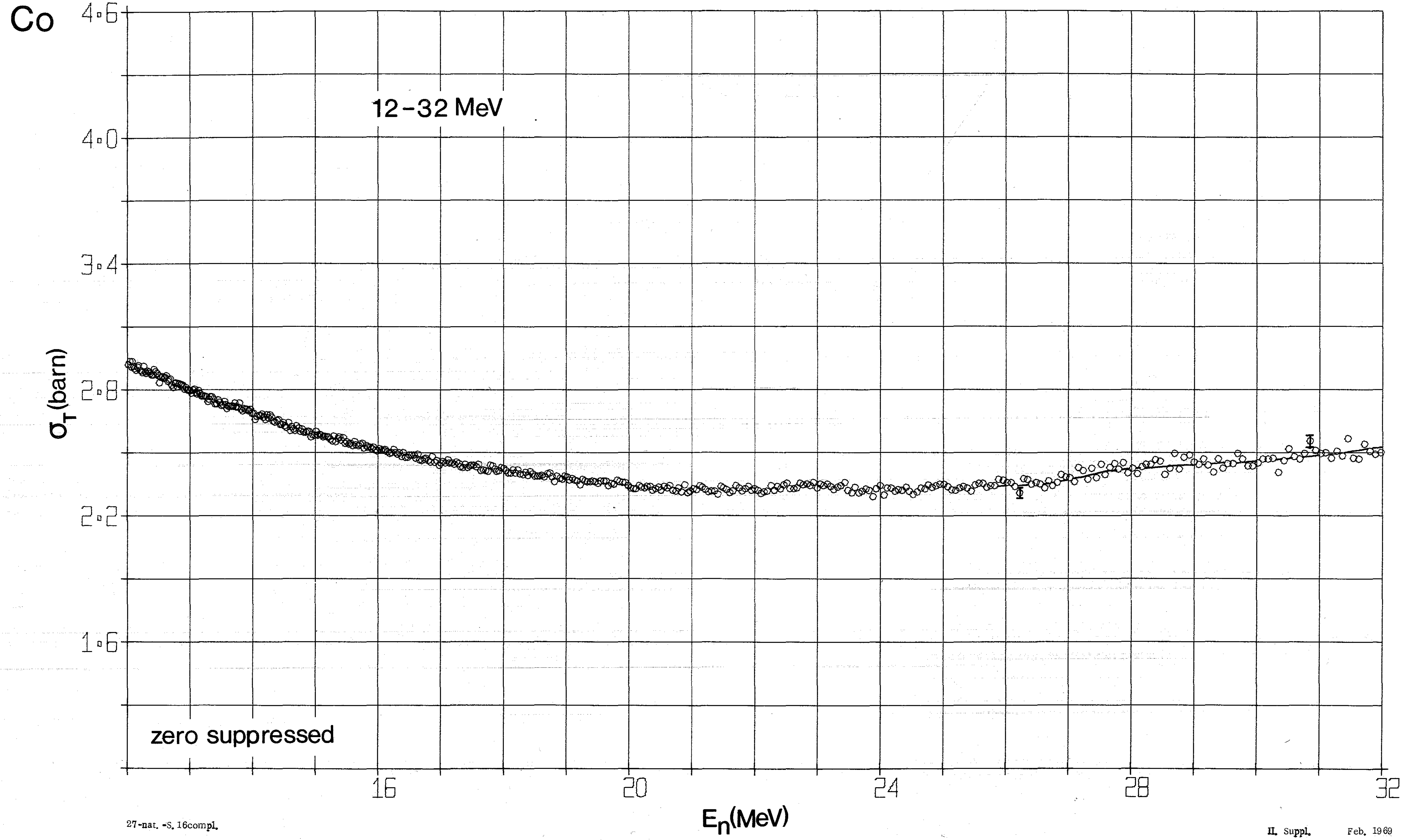

Co
5·0
4·5
4·0
3·5
3·0
2·5
2.0-3.0 MeV
σT (barn)
zero suppressed
2·2
2·4
2·6
2·8
3·0
En(MeV)


Co
3.0 - 4.5 MeV
zero suppressed
σ_T(barn)
5·0
4·5
4·0
3·5
3·0
2·5
3·3
3·6
3·9
4·2
4·5
E_n(MeV)


Co
4·6
4·0
3·4
2·8
2·2
1·6
4.5 - 7.0 MeV
σT (barn)
zero suppressed
5·0
5·5
6·0
6·5
7·0
En(MeV)



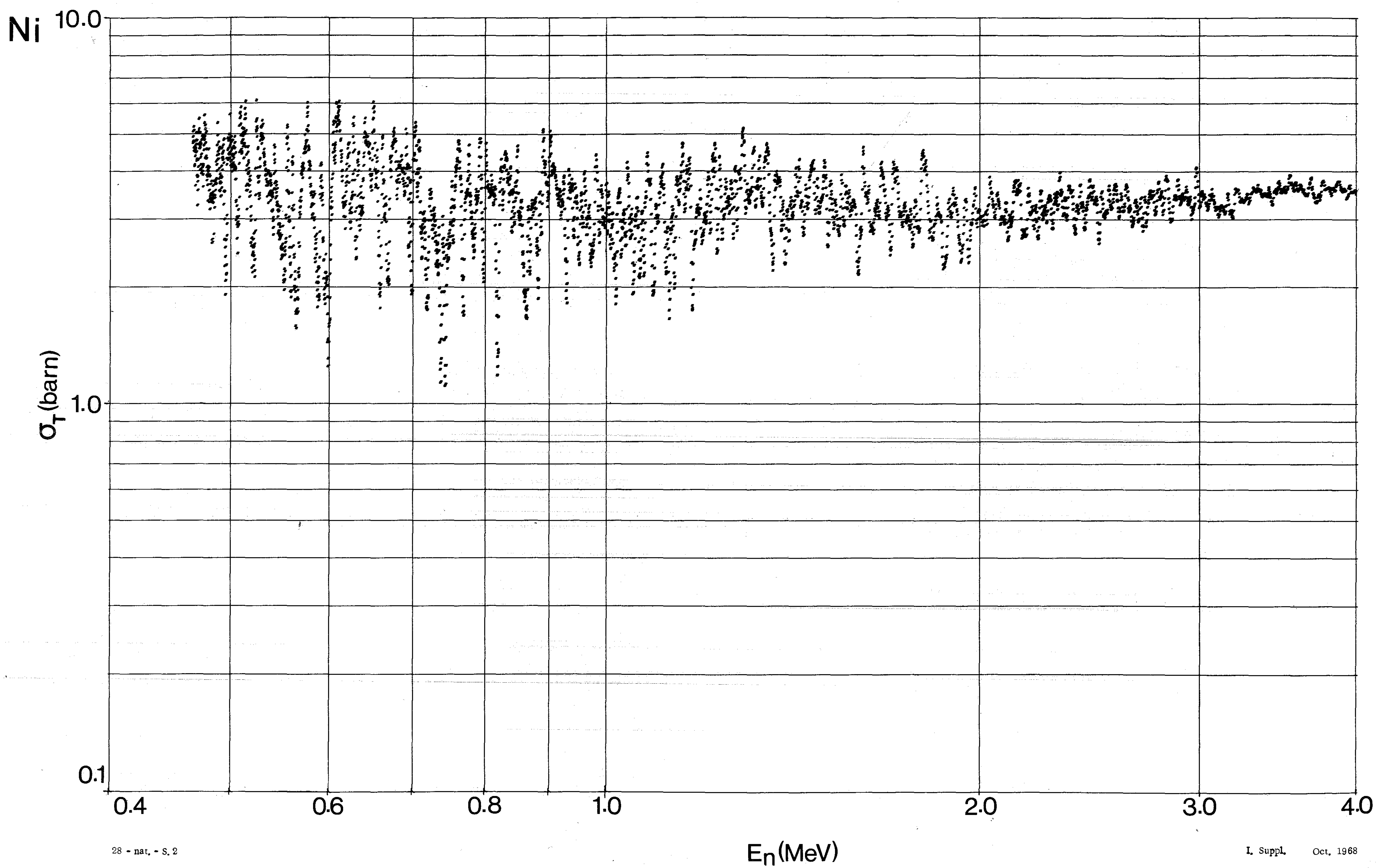
Co
7.0 - 12 MeV
σ_T (barn)
4.6
4.0
3.4
2.8
2.2
1.6
zero suppressed
8.0
9.0
10.0
11.0
12.0
E_n(MeV)

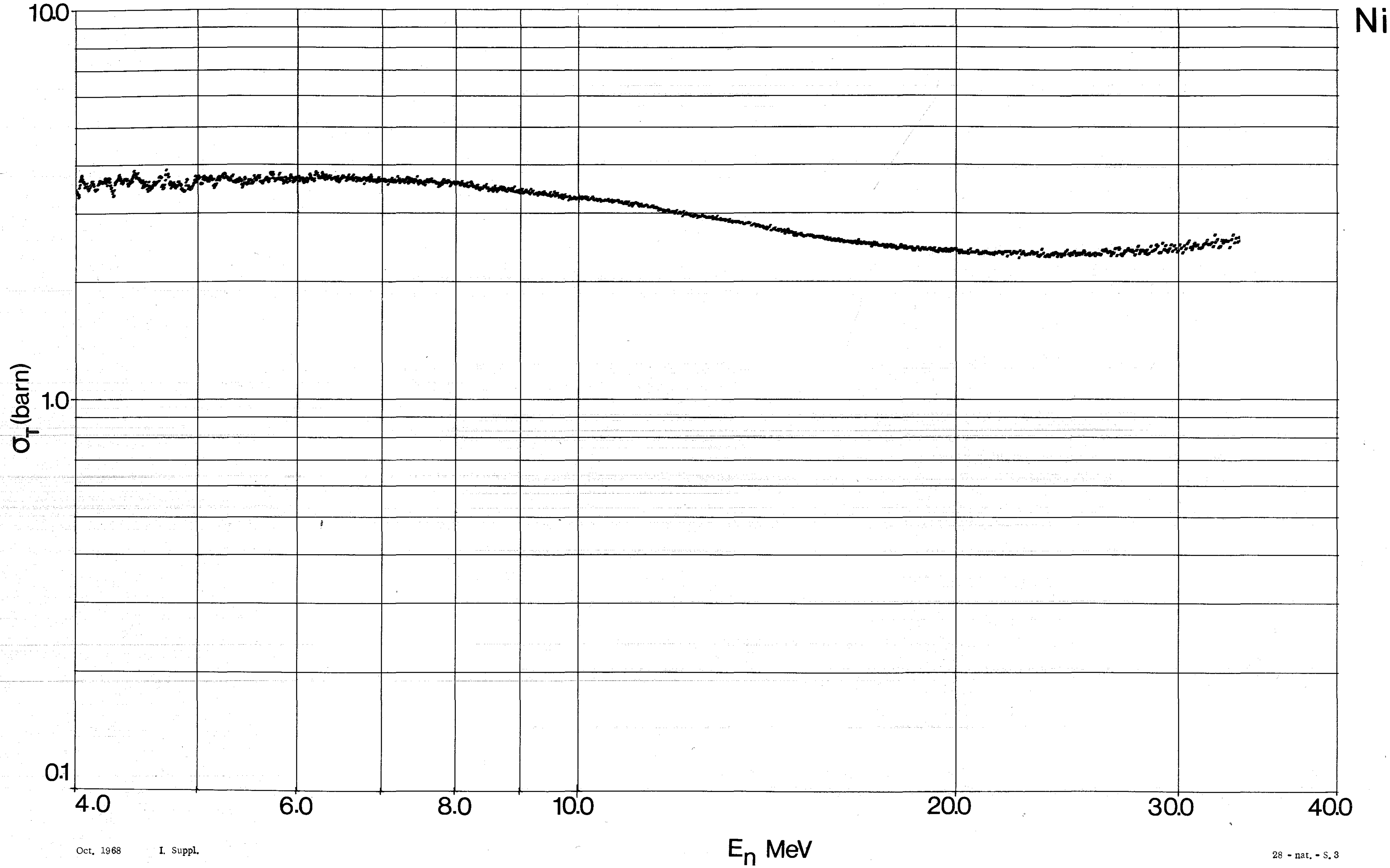


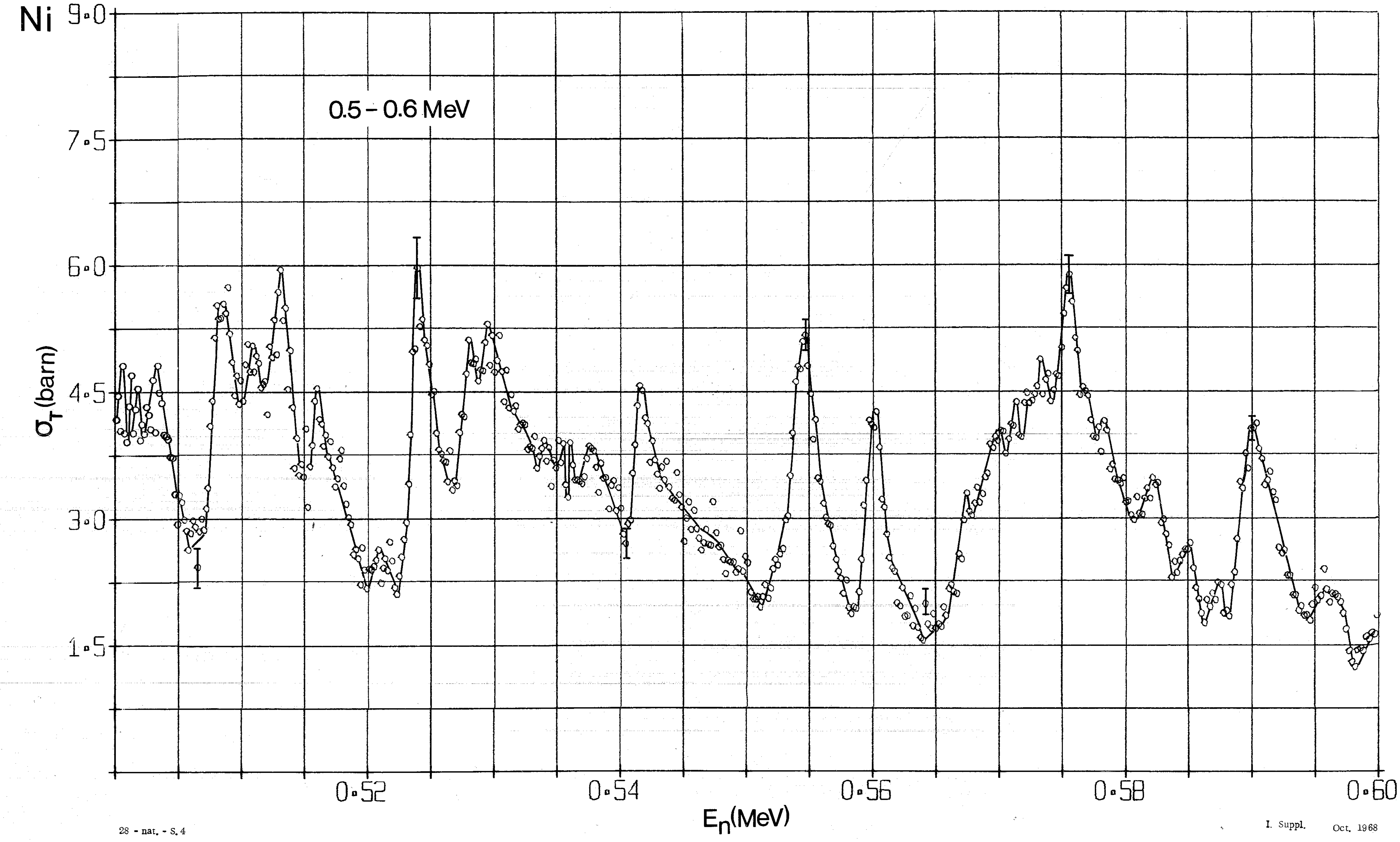
27-nat. -S. 16compl.

Ni

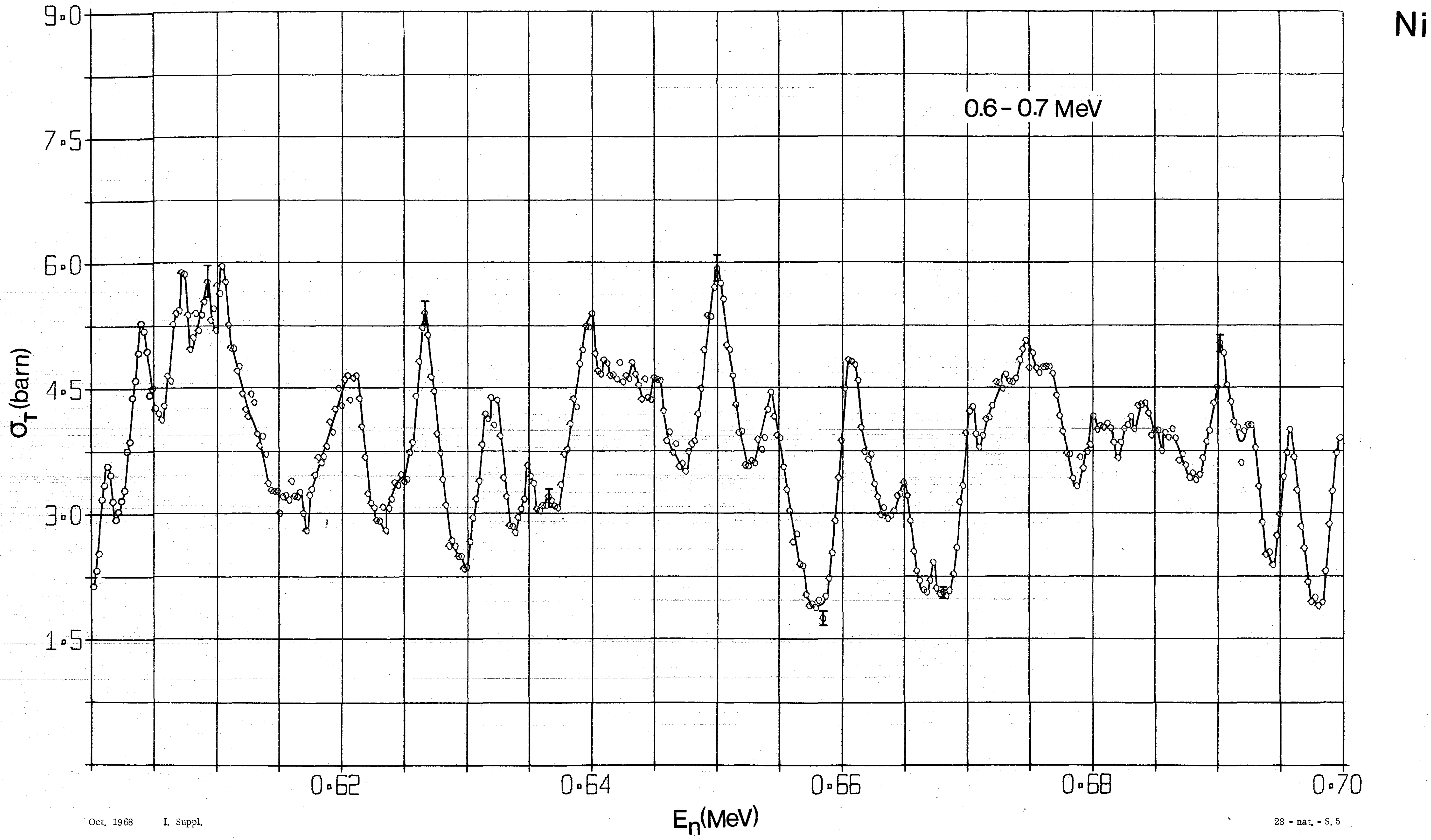
n	=	0.3110	At/barn
p	=	99.0	%
l	=	57.394	m
Δt	=	2.7	nsec
i	:	natural	


Ni
10.0
1.0
0.1
σ_T (barn)
0.4
0.6
0.8
1.0
2.0
3.0
4.0
E_n (MeV)

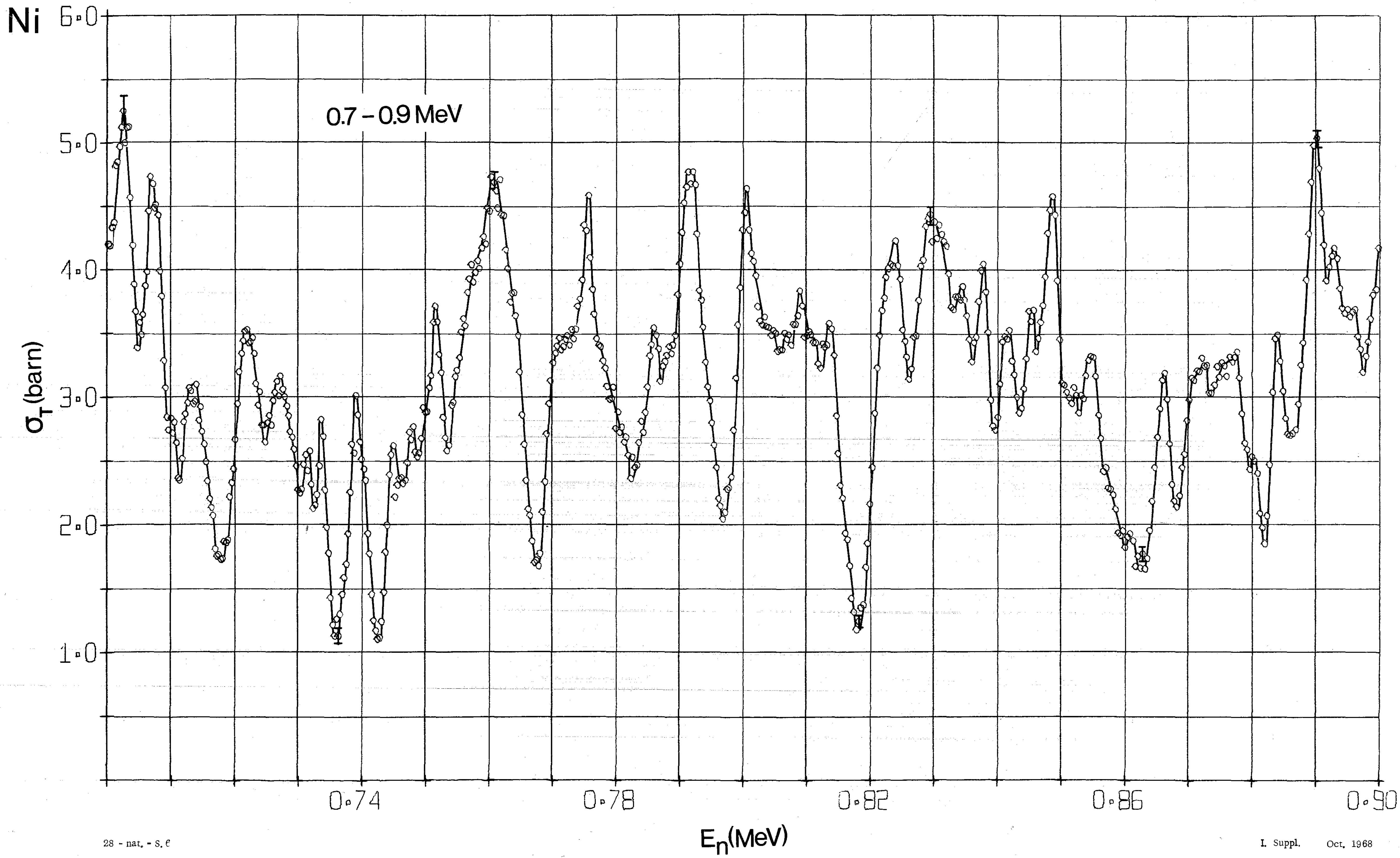

Ni
10.0
1.0
0.1
σT (barn)
4.0
6.0
8.0
10.0
20.0
30.0
40.0
En MeV

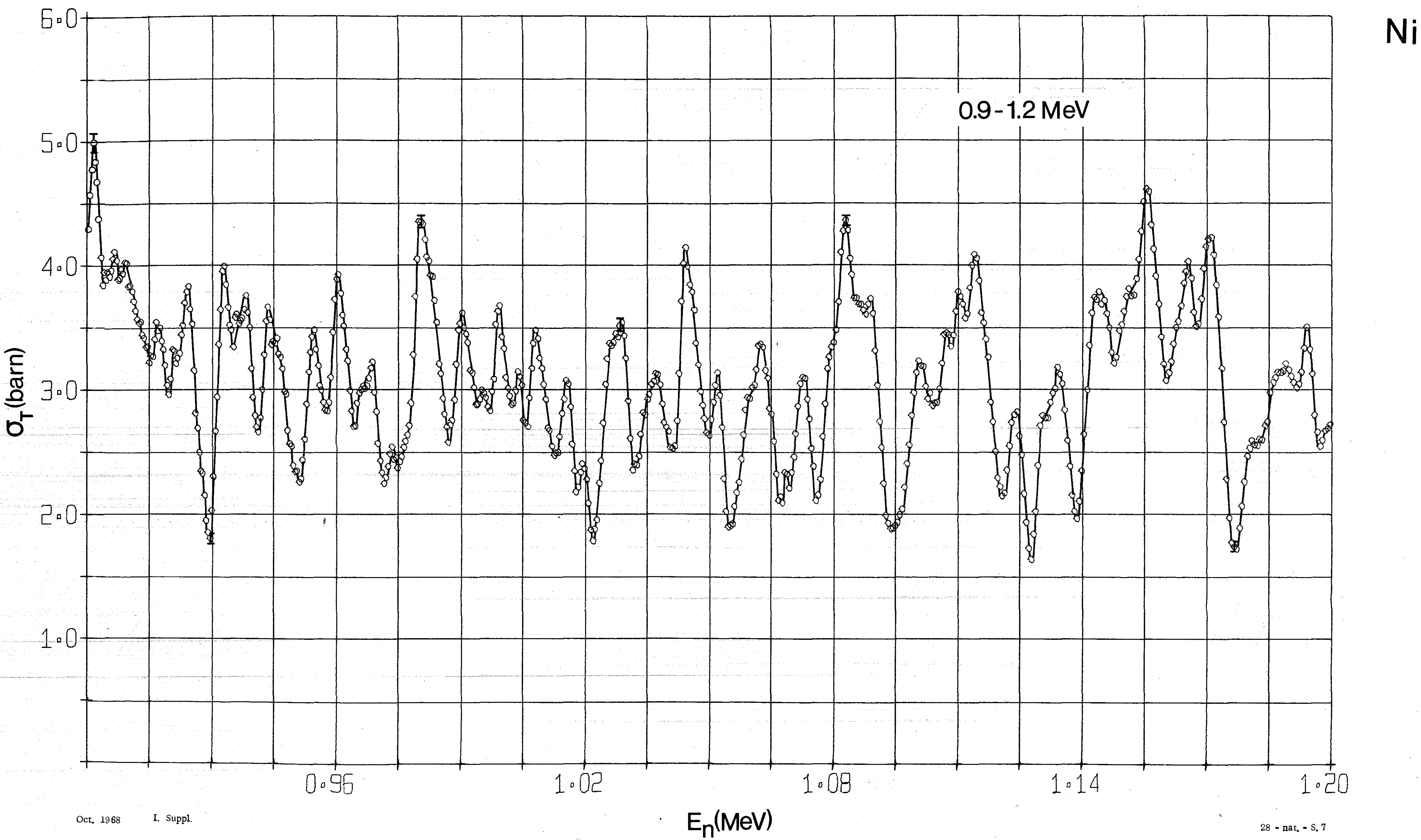


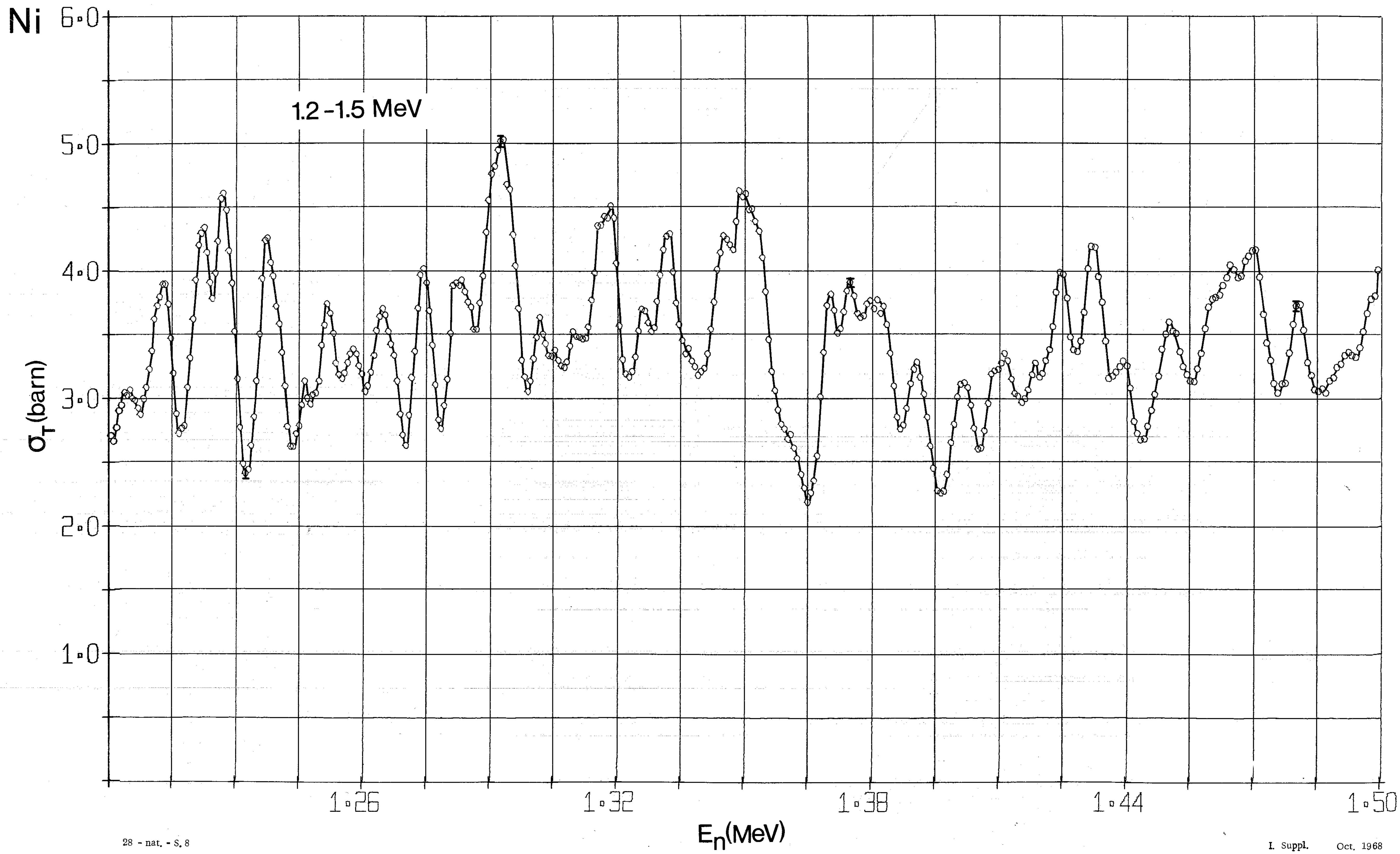
Ni
0.5 - 0.6 MeV
9.0
7.5
6.0
4.5
3.0
1.5
σ_T (barn)
0.52
0.54
0.56
0.58
0.60
E_n(MeV)

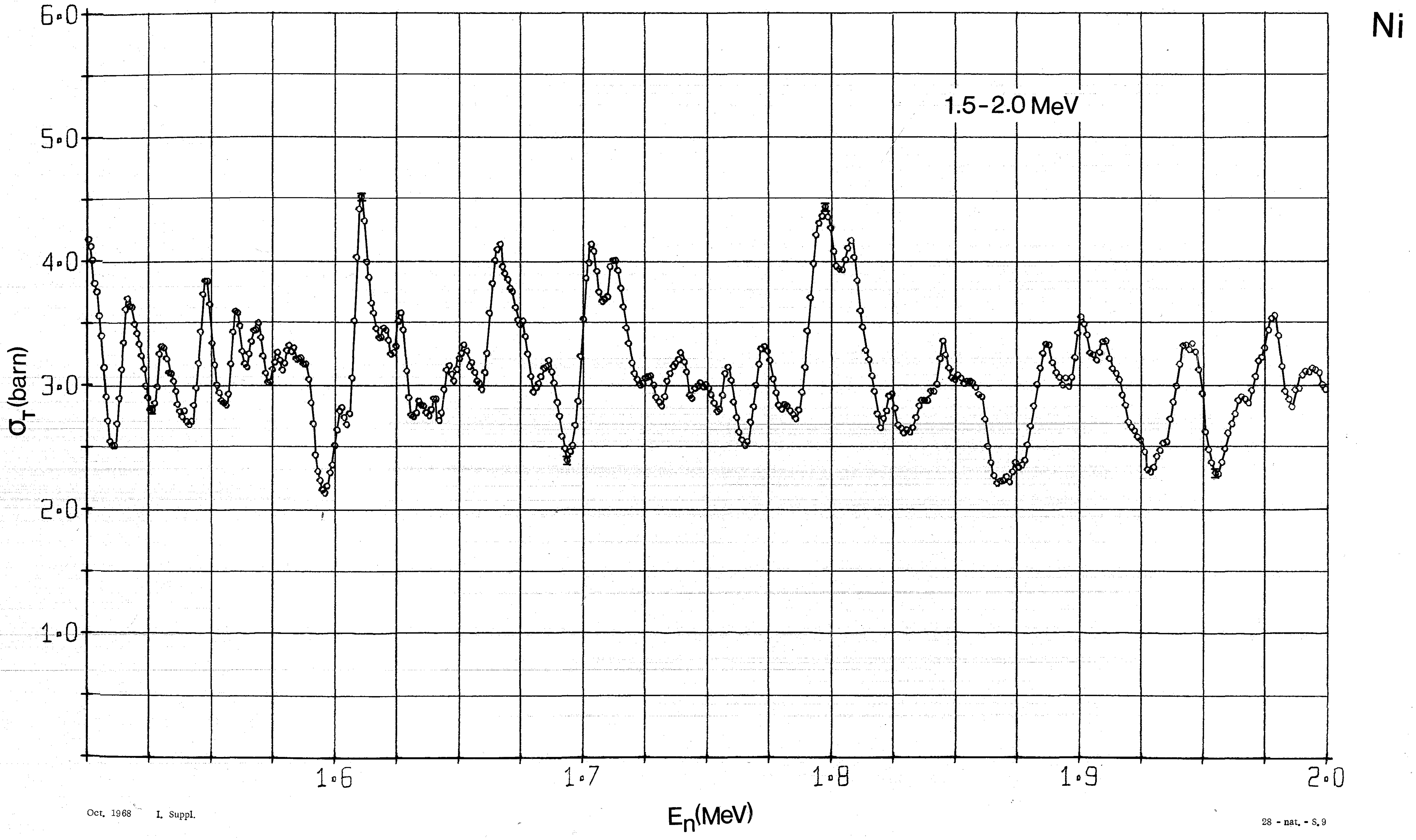


Ni
0.6 - 0.7 MeV
9·0
7·5
6·0
4·5
3·0
1·5
σ_T (barn)
0·62
0·64
0·66
0·68
0·70
E_n(MeV)

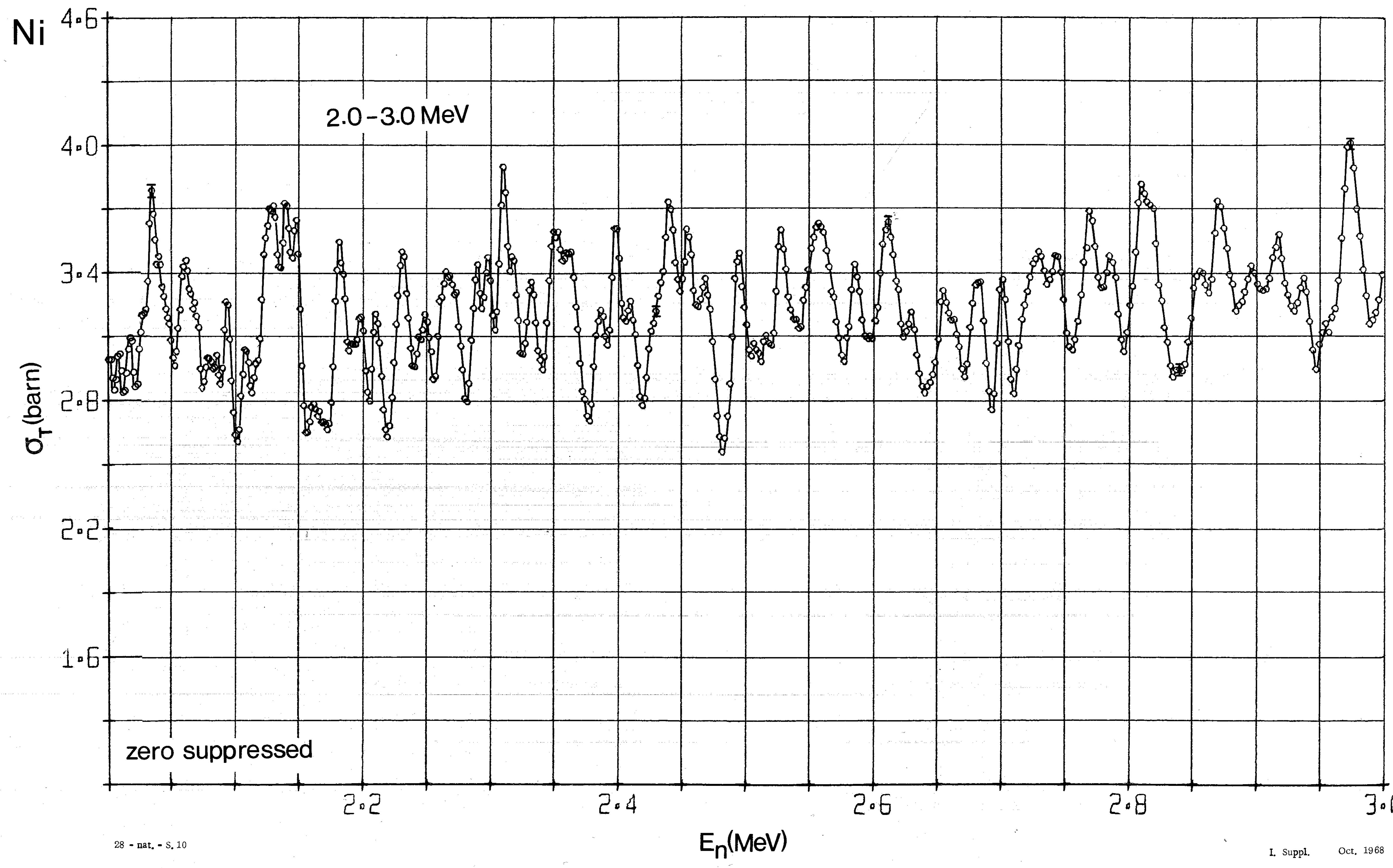

Ni
0.7 – 0.9 MeV
σT (barn)
6.0
5.0
4.0
3.0
2.0
1.0
0.74
0.78
0.82
0.86
0.90
En(MeV)

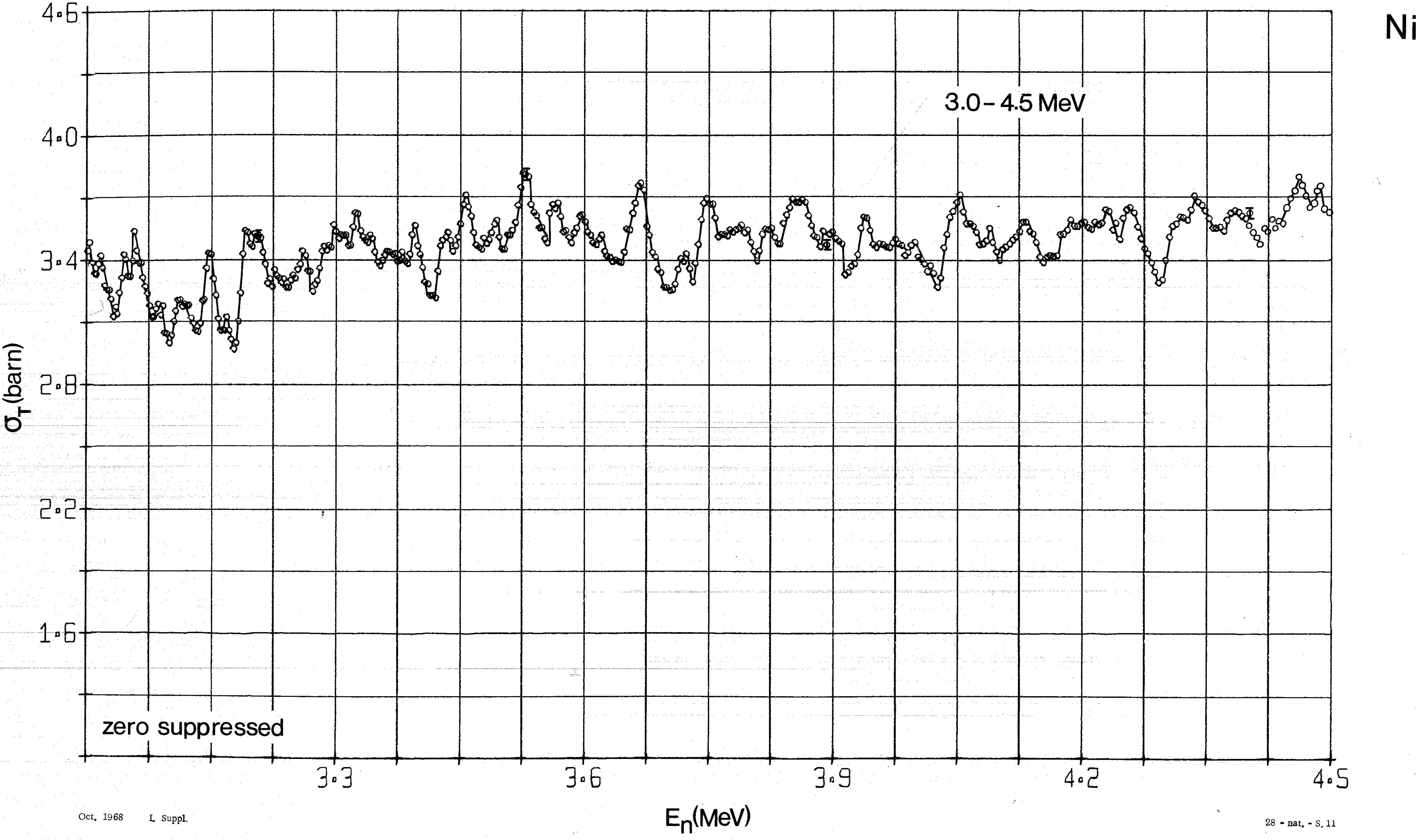

Ni
0.9 - 1.2 MeV
6.0
5.0
4.0
3.0
2.0
1.0
σ_T (barn)
0.96
1.02
1.08
1.14
1.20
E_n(MeV)


Ni
1.2 -1.5 MeV
σT (barn)
6.0
5.0
4.0
3.0
2.0
1.0
1.26
1.32
1.38
1.44
1.50
En(MeV)

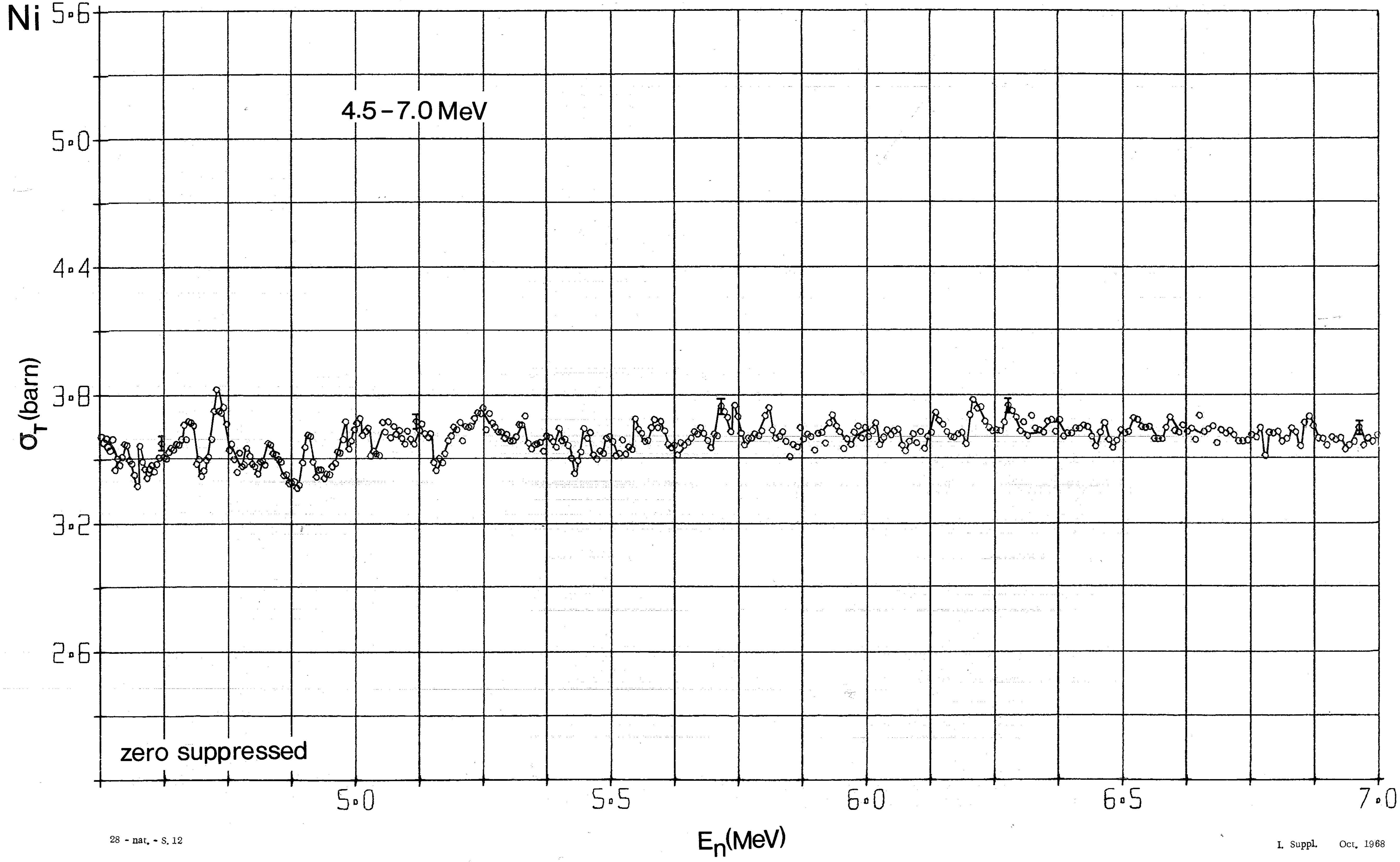


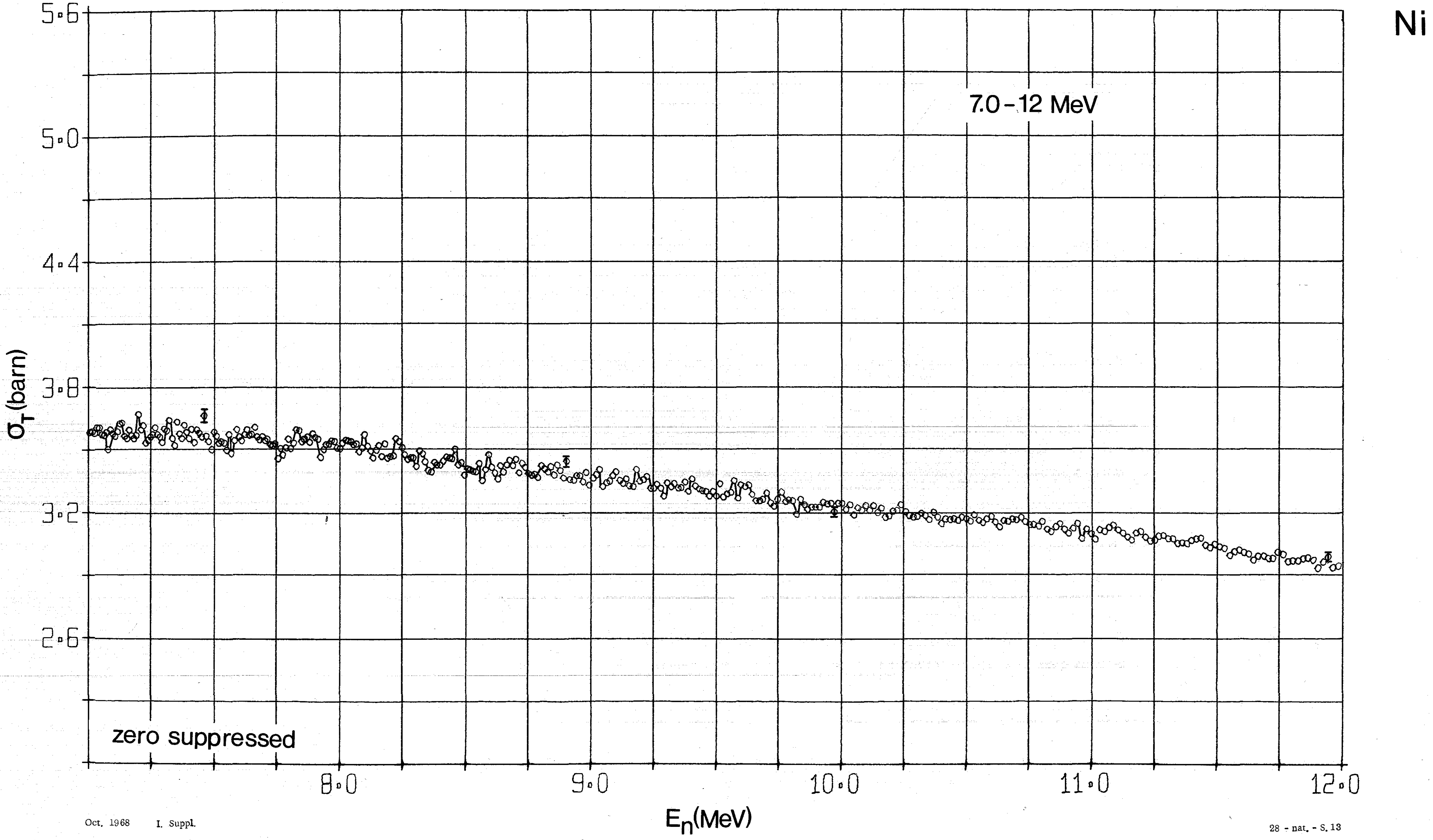
Ni
1.5-2.0 MeV
6·0
5·0
4·0
3·0
2·0
1·0
σT (barn)
1·6
1·7
1·8
1·9
2·0
En(MeV)

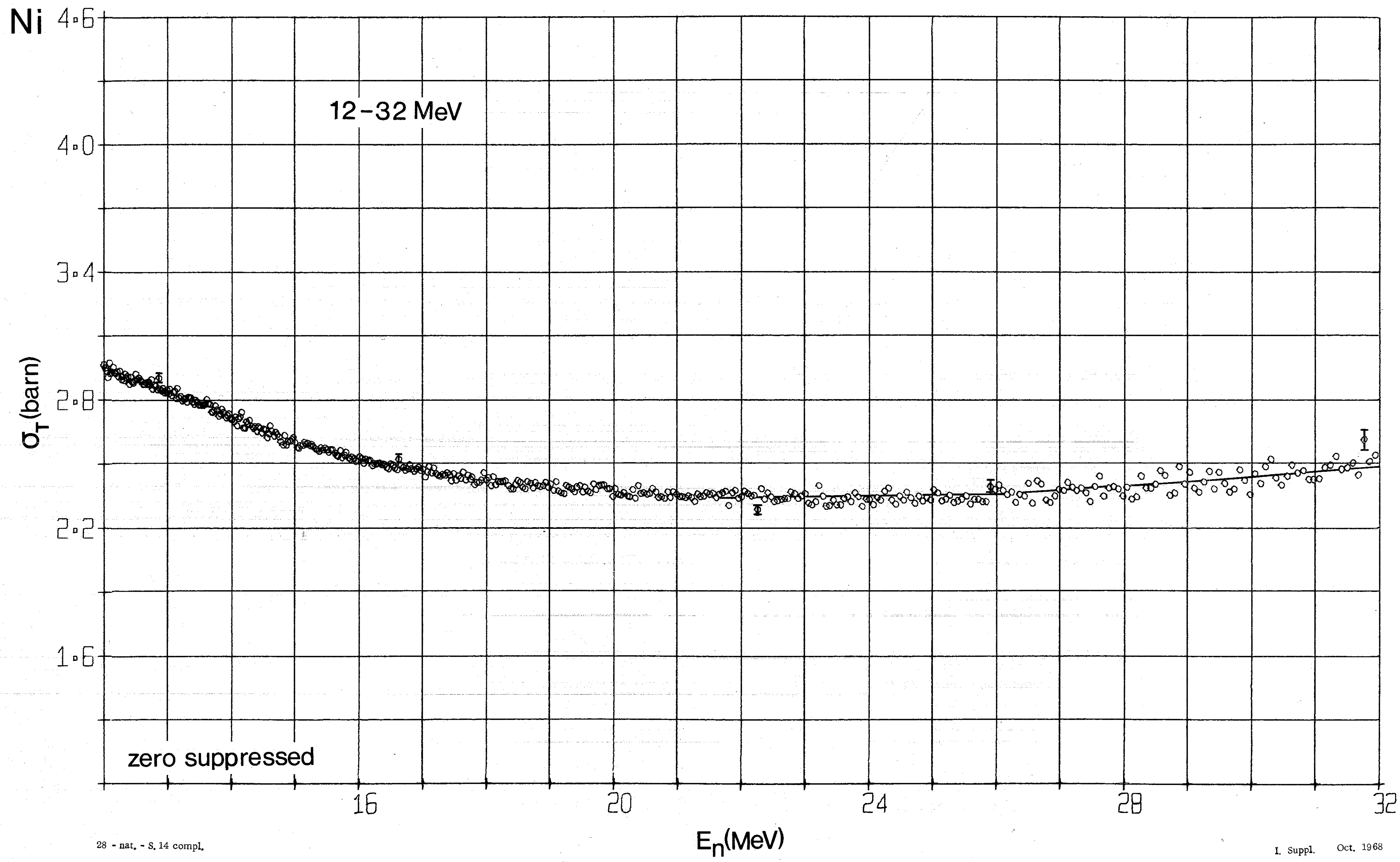

Ni
2.0-3.0 MeV
zero suppressed
σT(barn)
4·6
4·0
3·4
2·8
2·2
1·6
2·2
2·4
2·6
2·8
3·0
En(MeV)



Ni
3.0 - 4.5 MeV
4·6
4·0
3·4
2·8
2·2
1·6
σ_T (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
E_n(MeV)


Ni
4.5 - 7.0 MeV
zero suppressed
σT (barn)
En(MeV)
5·6
5·0
4·4
3·8
3·2
2·6
5·0
5·5
6·0
6·5
7·0


Ni
7.0 - 12 MeV
5·6
5·0
4·4
3·8
3·2
2·6
σT (barn)
zero suppressed
8·0
9·0
10·0
11·0
12·0
En(MeV)



Ni
4·6
4·0
3·4
2·8
2·2
1·6
12-32 MeV
σ_T(barn)
zero suppressed
16
20
24
28
32
E_n(MeV)

Tl

n = 0.1515 at/barn

p = 99.99 %

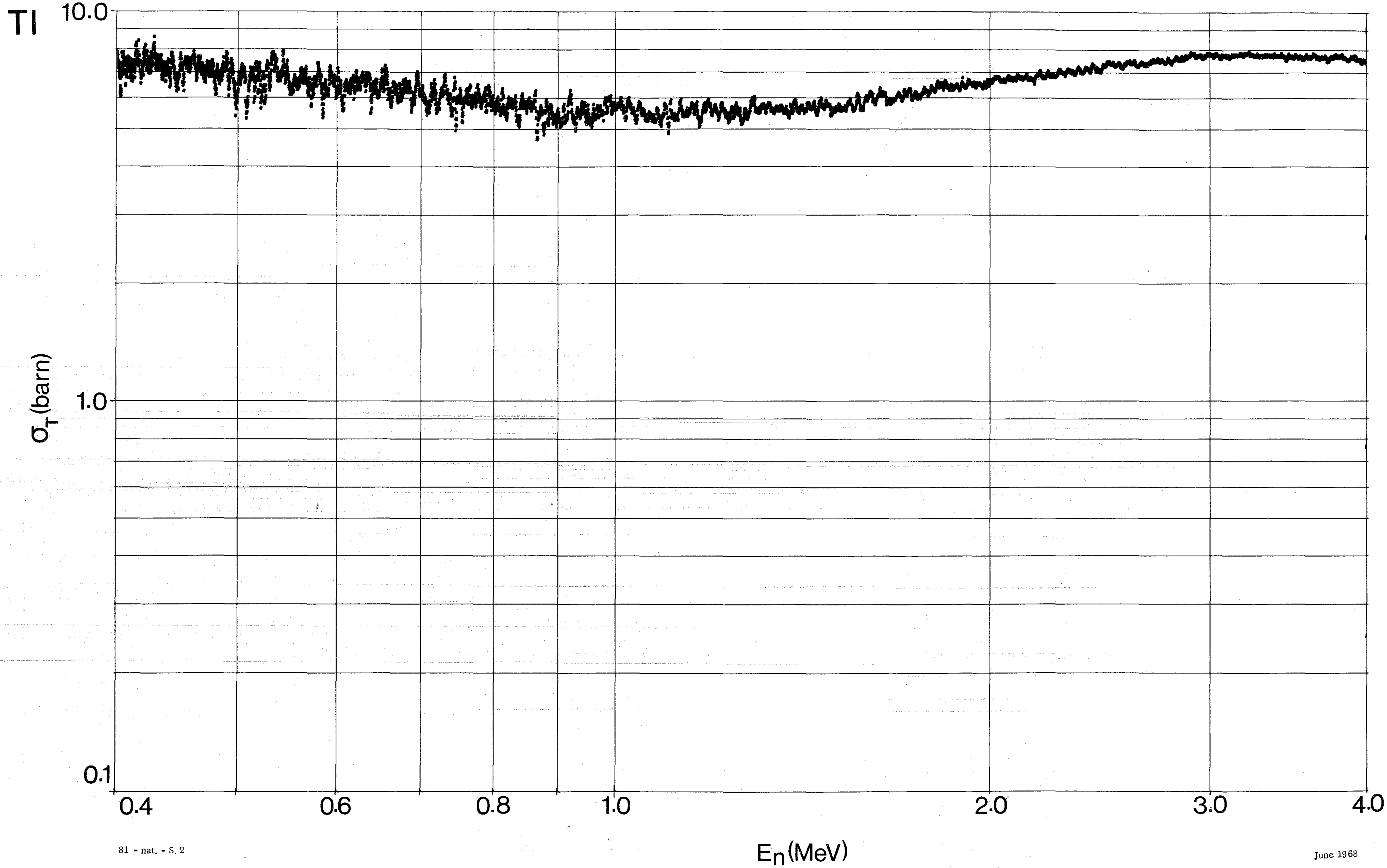
l = 57.228 m

Δt = 3.8 nsec

i : natural

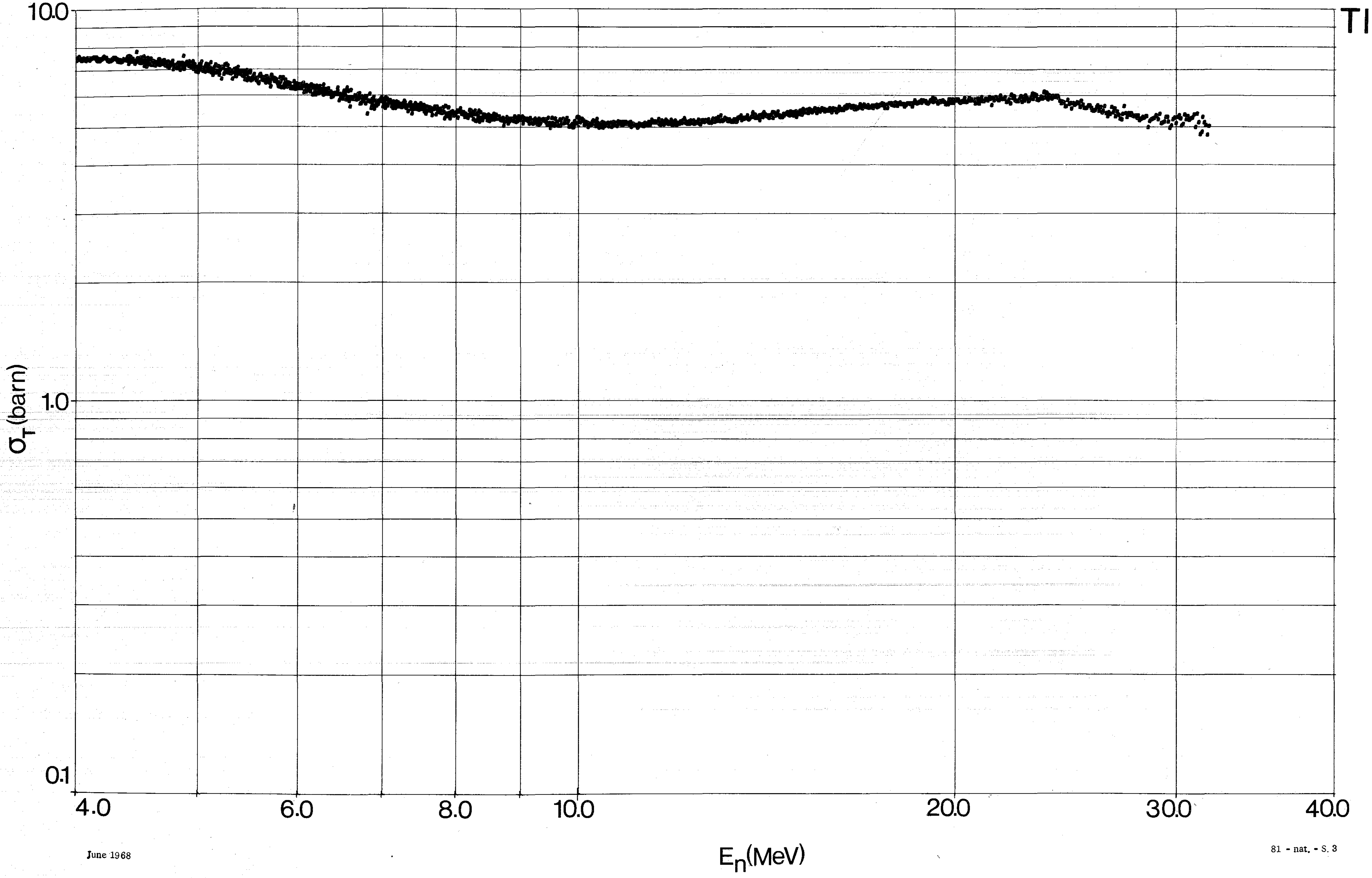
Mathematically smoothed from 1.125 - 4.5 MeV

(see introduction)

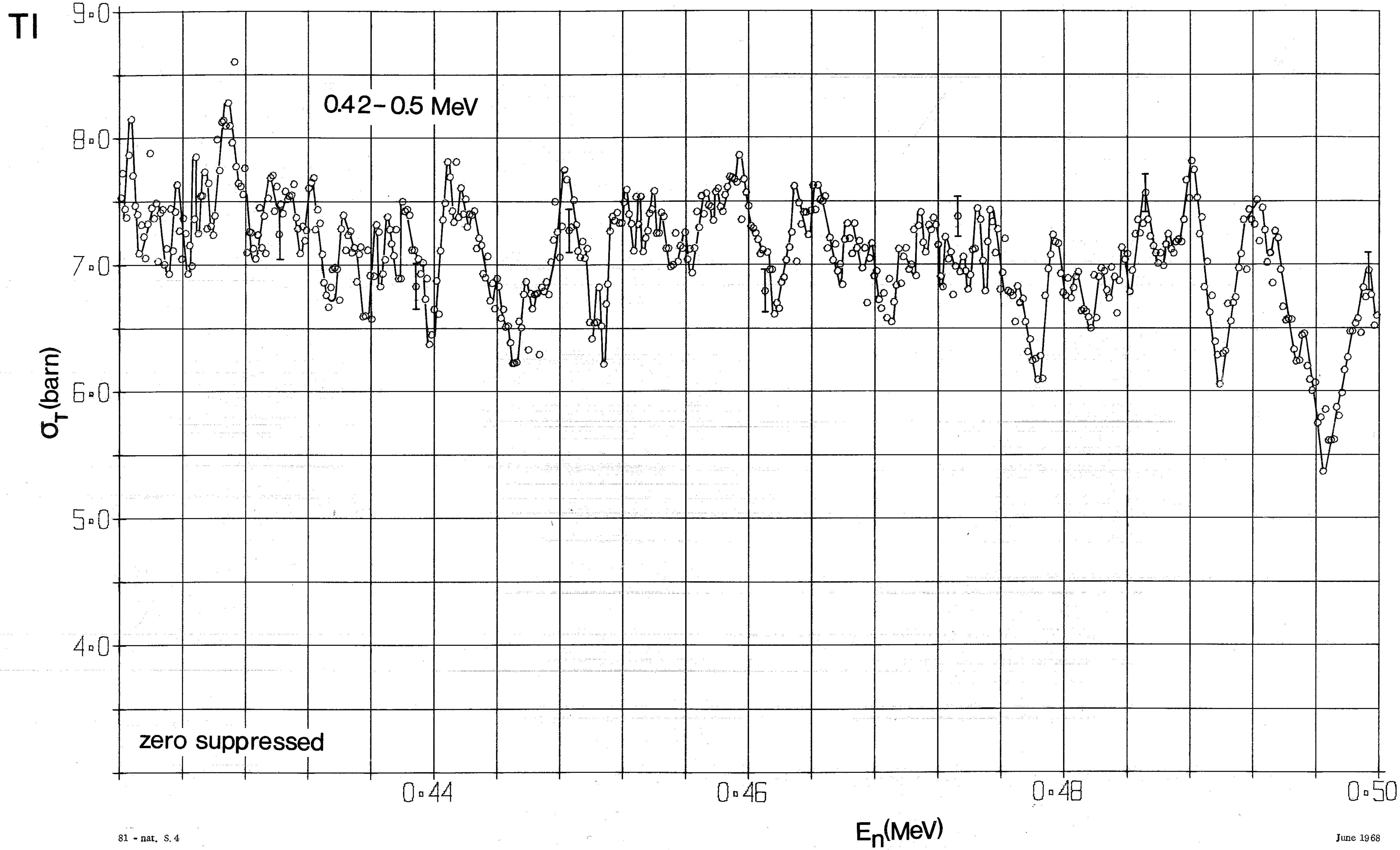


81 - nat. - S. 2

June 1968

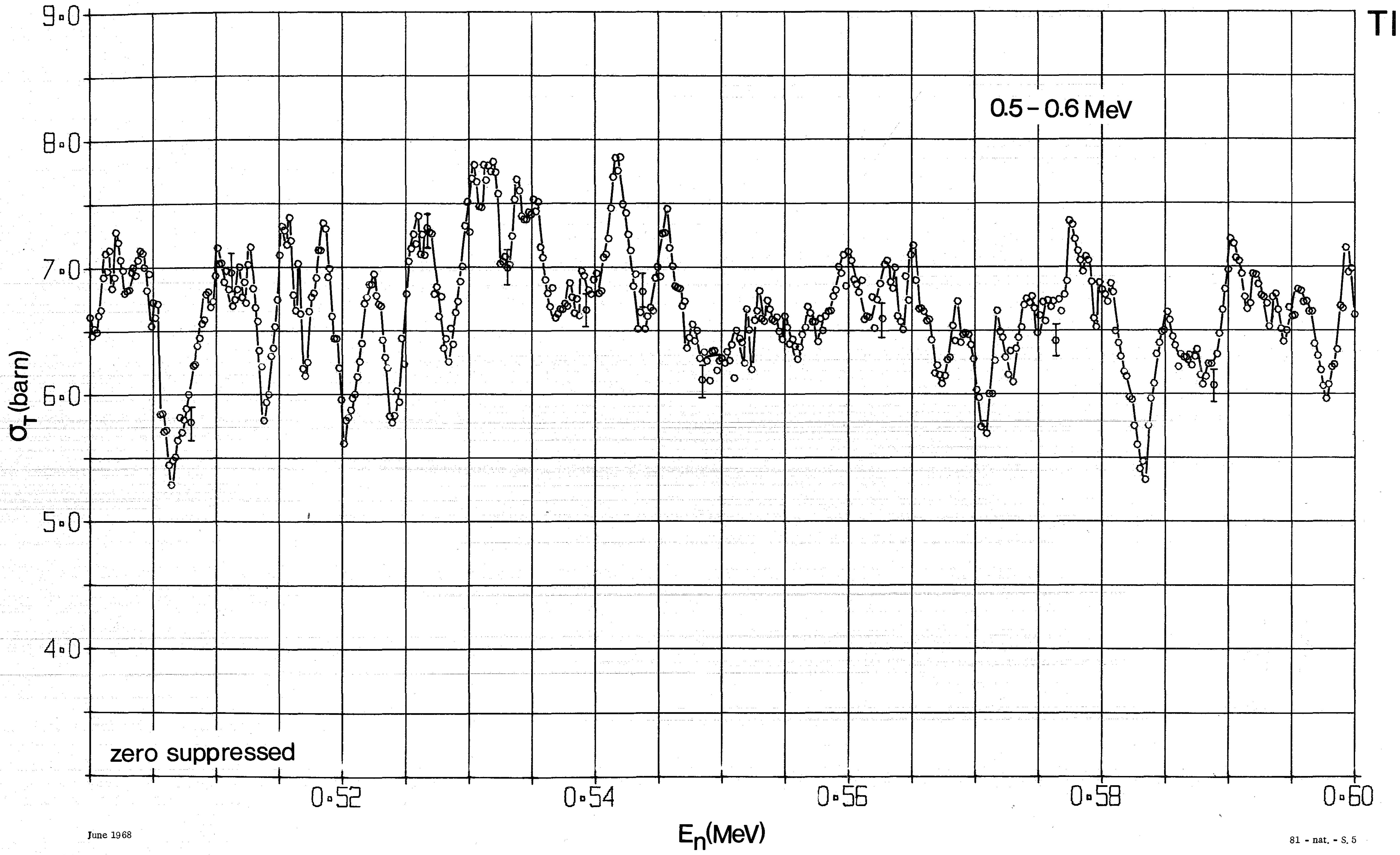


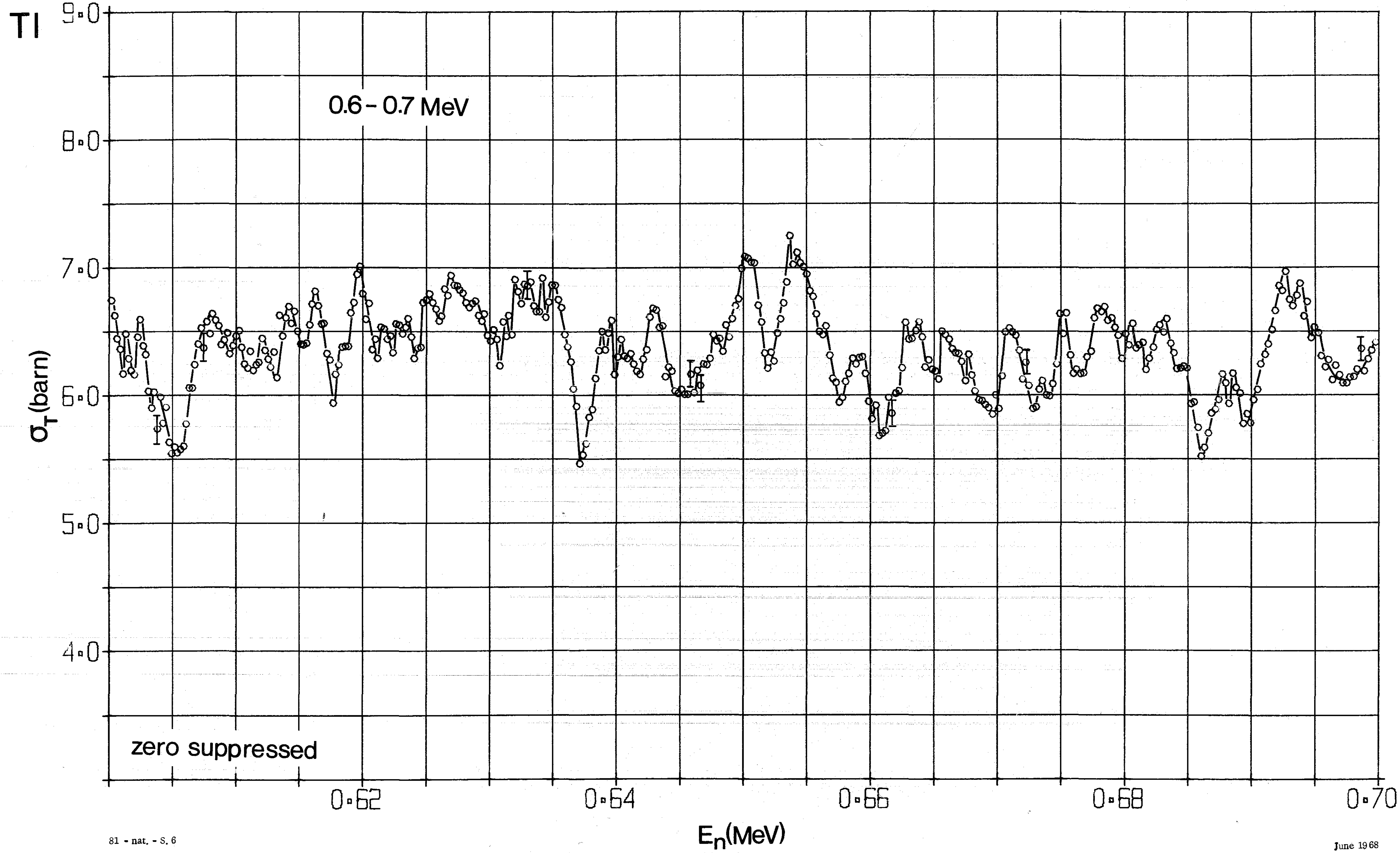
June 1968



81 - nat. S. 4

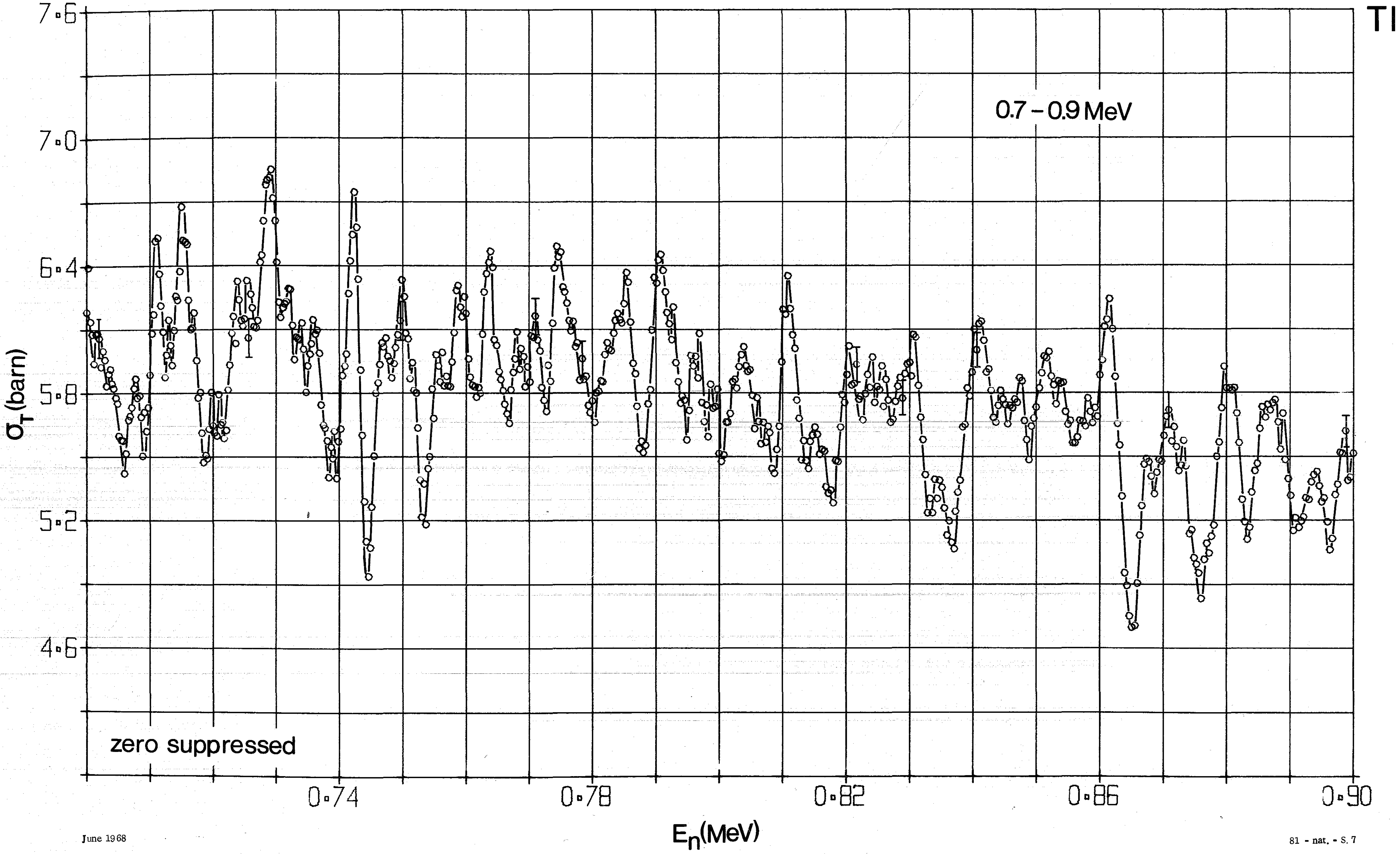
June 1968


Tl
0.5 - 0.6 MeV
9.0
8.0
7.0
6.0
5.0
4.0
σT (barn)
zero suppressed
0.52
0.54
0.56
0.58
0.60
En(MeV)

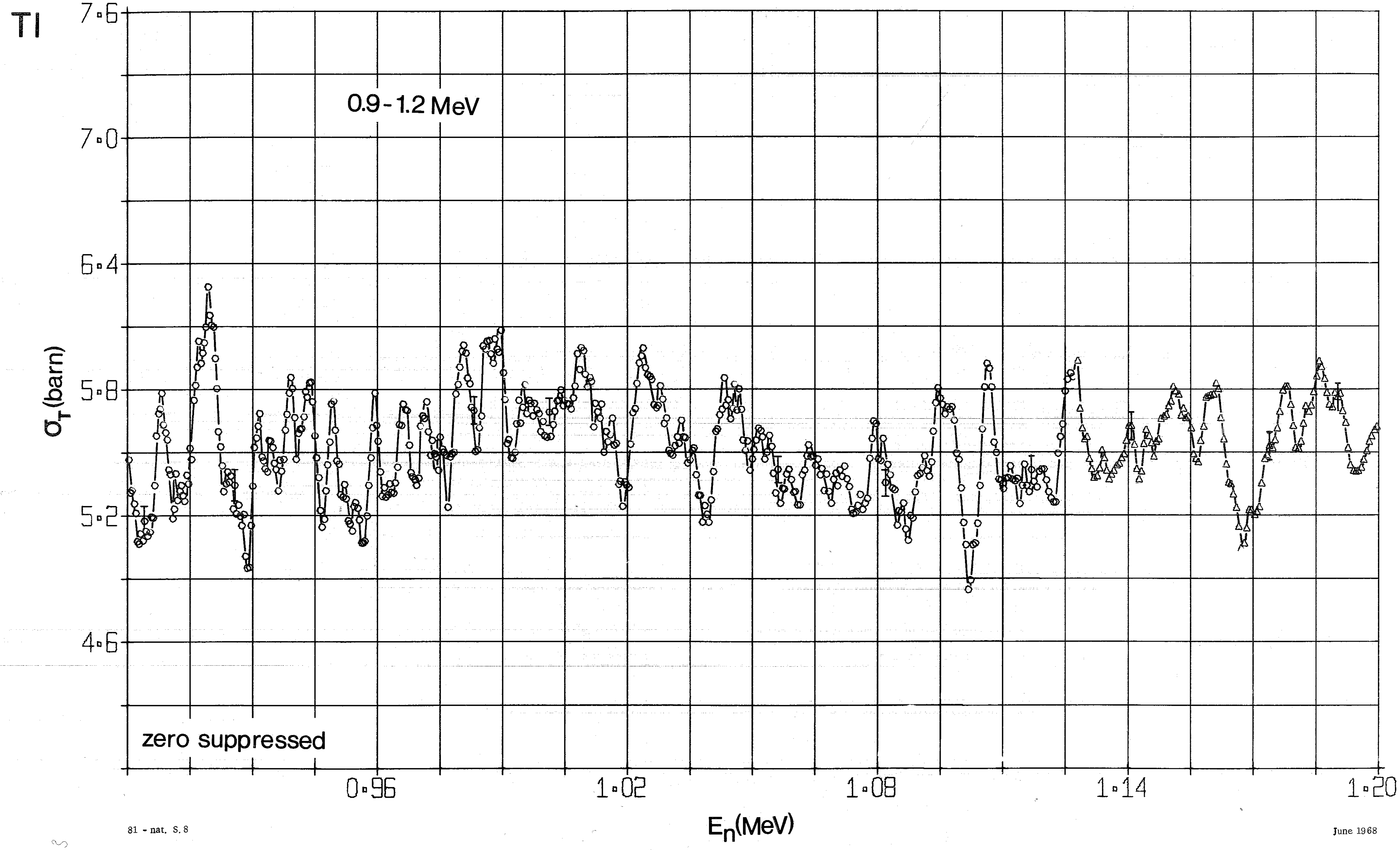


81 - nat. - S. 6

June 1968

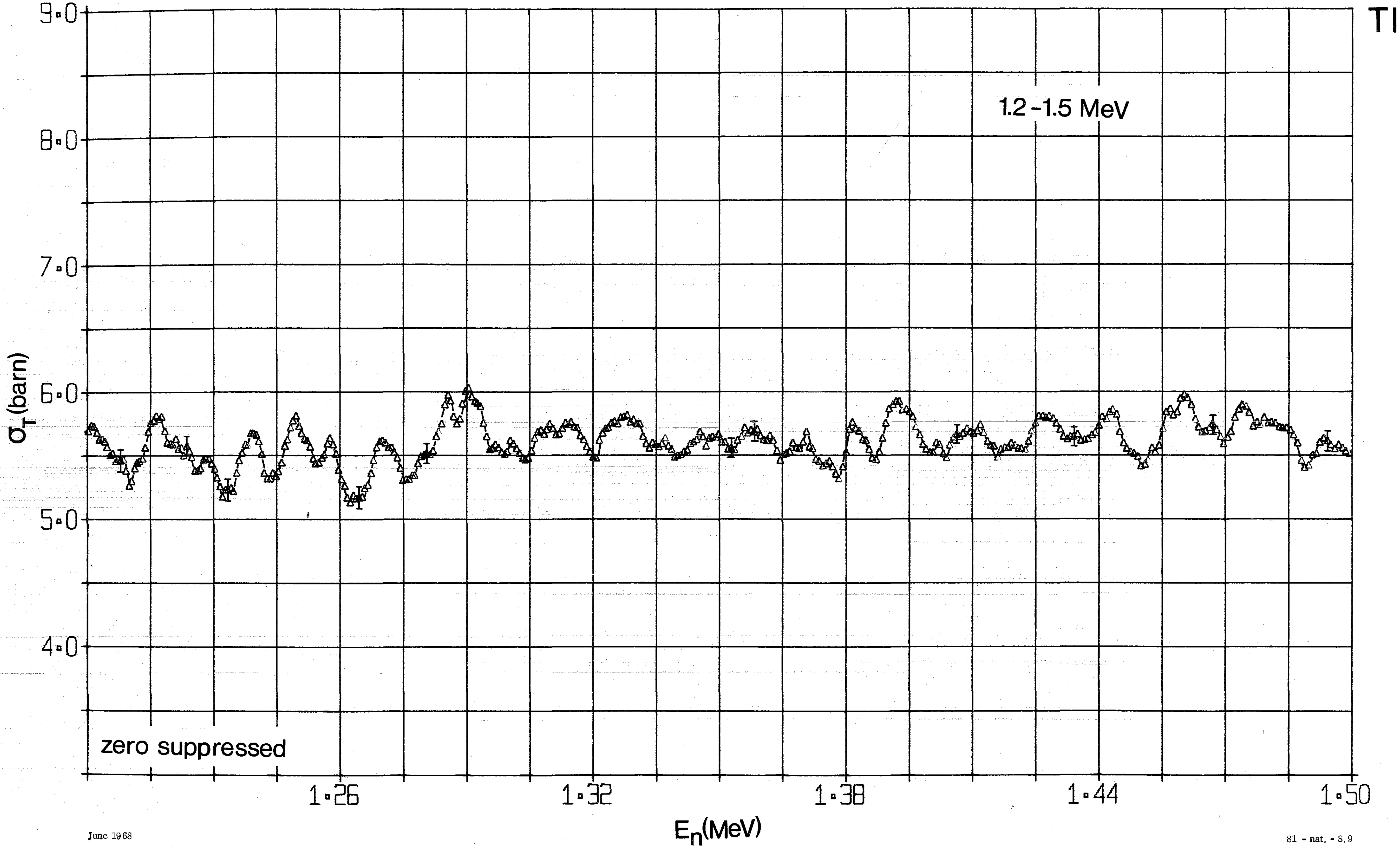


Tl
0.7 - 0.9 MeV
7·6
7·0
6·4
5·8
5·2
4·6
σ_T (barn)
zero suppressed
0·74
0·78
0·82
0·86
0·90
E_n(MeV)



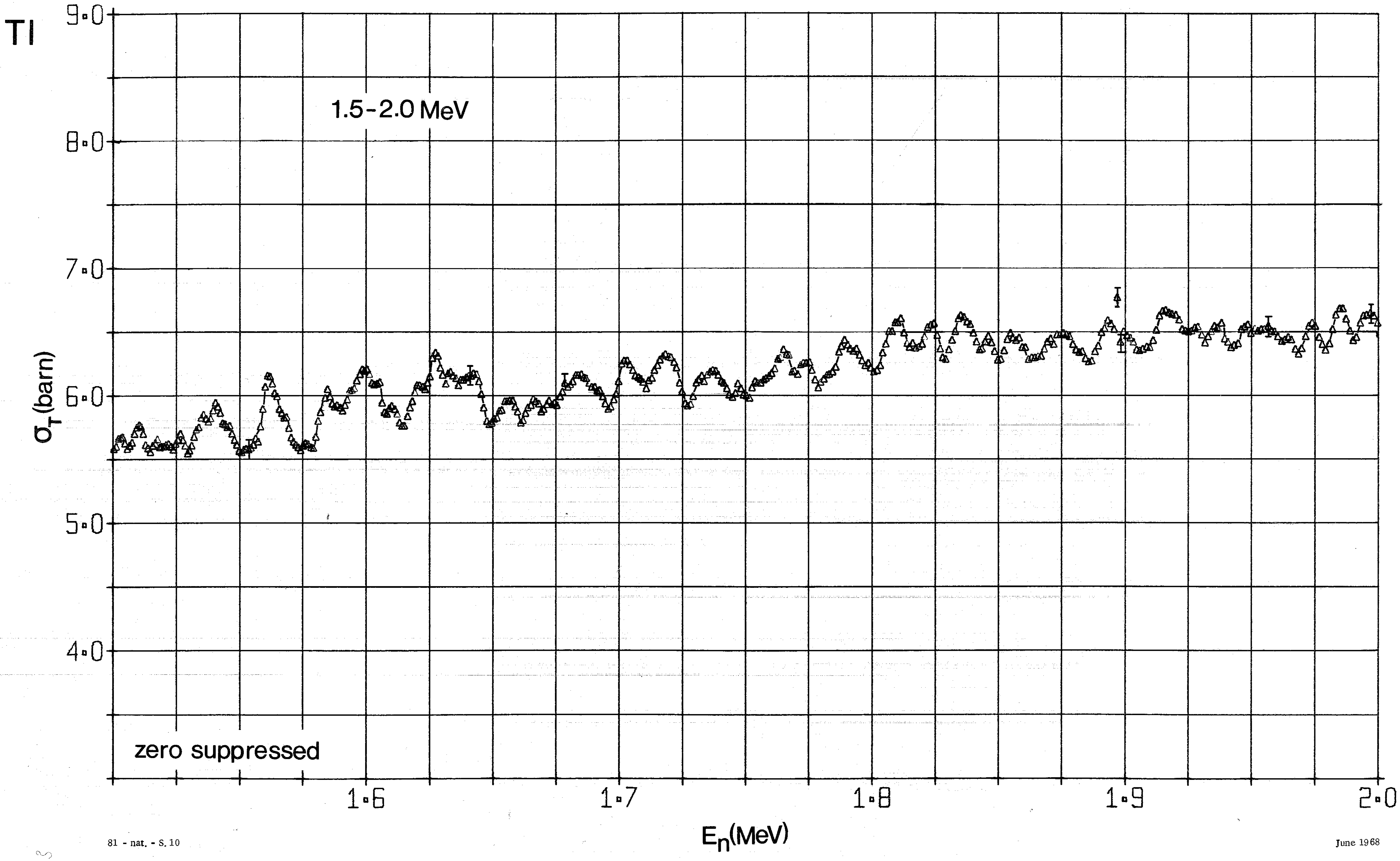
81 - nat. S. 8

June 1968



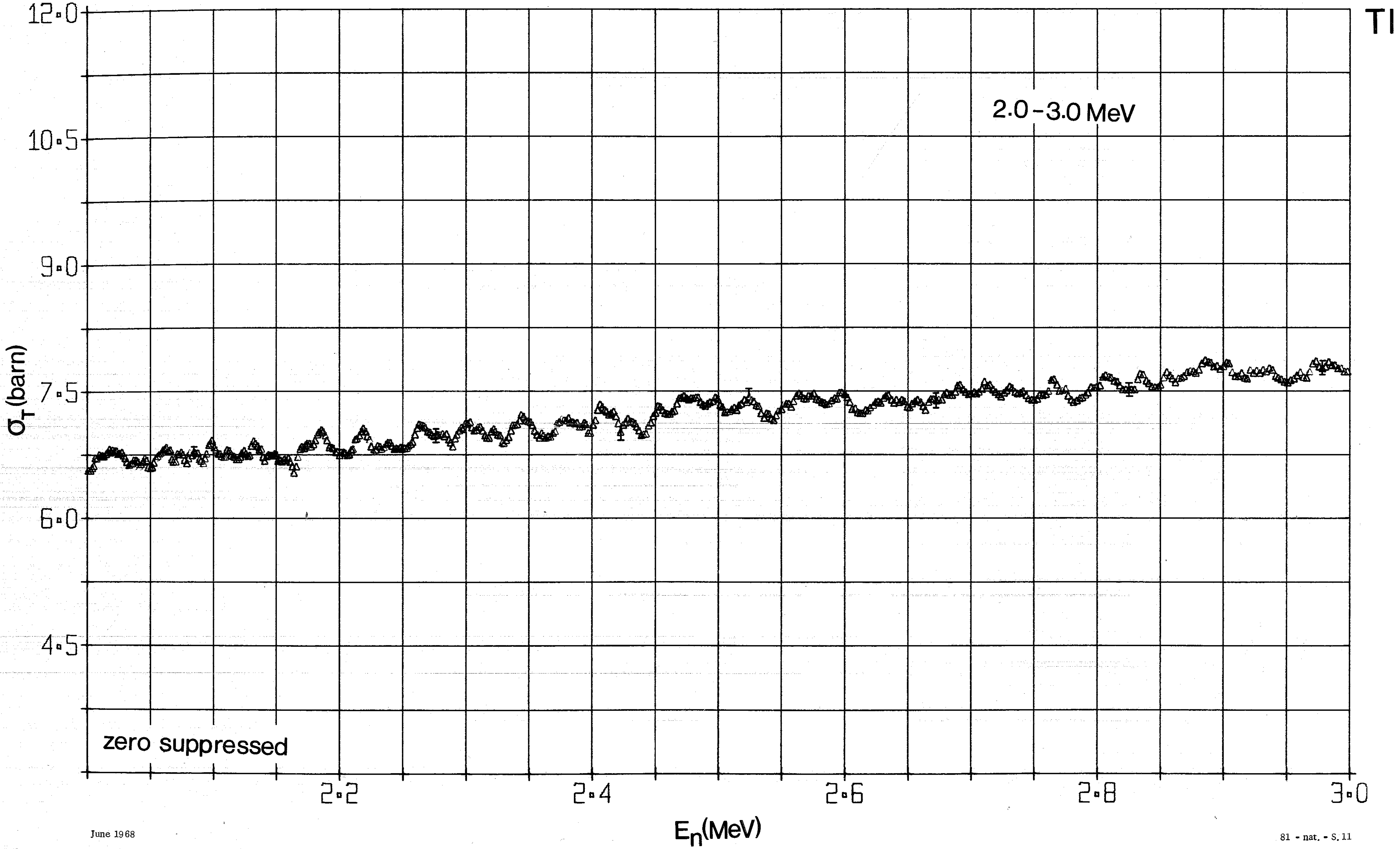
9·0
8·0
7·0
6·0
5·0
4·0
σ_T(barn)
Tl
1.2 - 1.5 MeV
zero suppressed
1·26
1·32
1·38
1·44
1·50
E_n(MeV)

June 1968

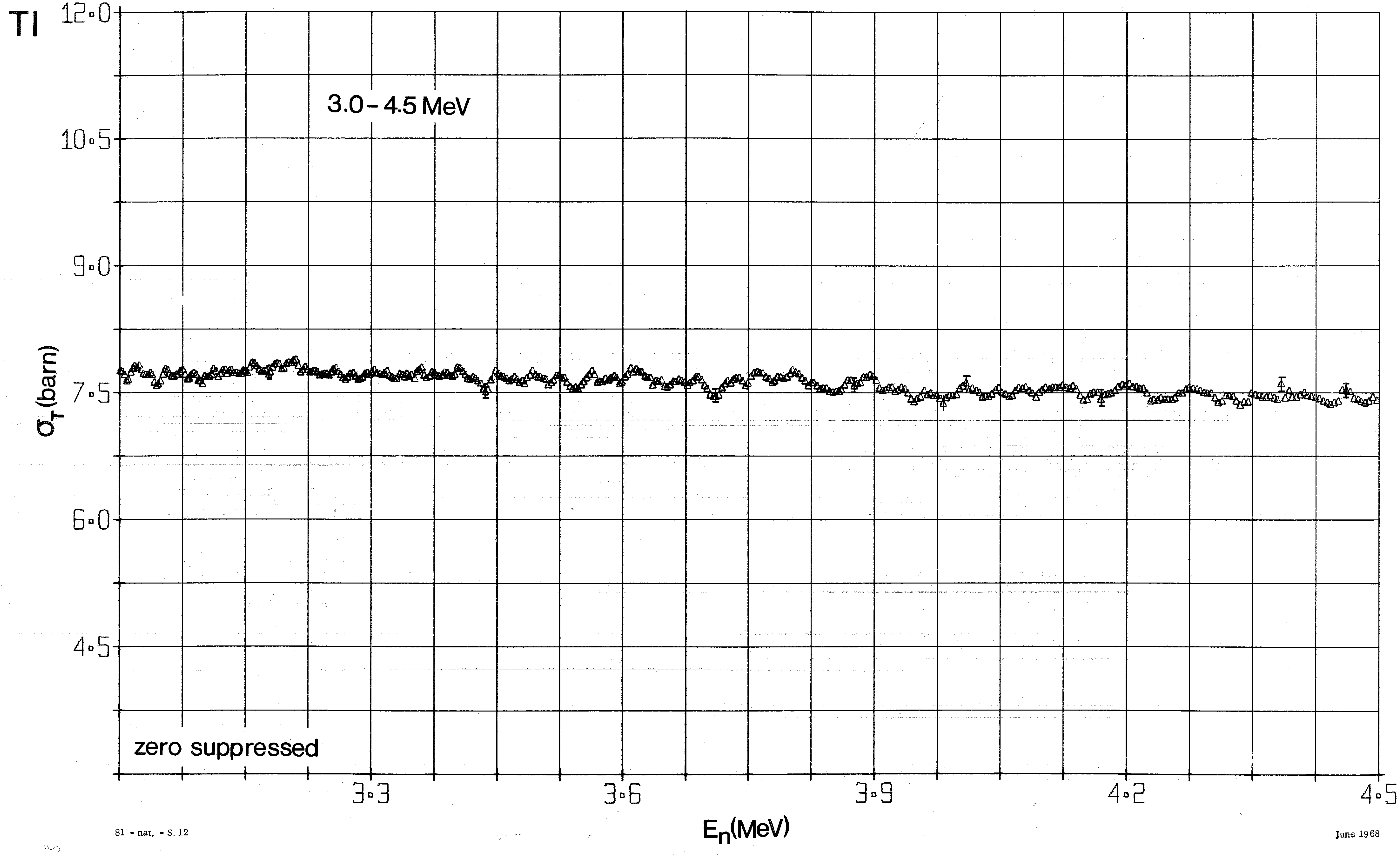


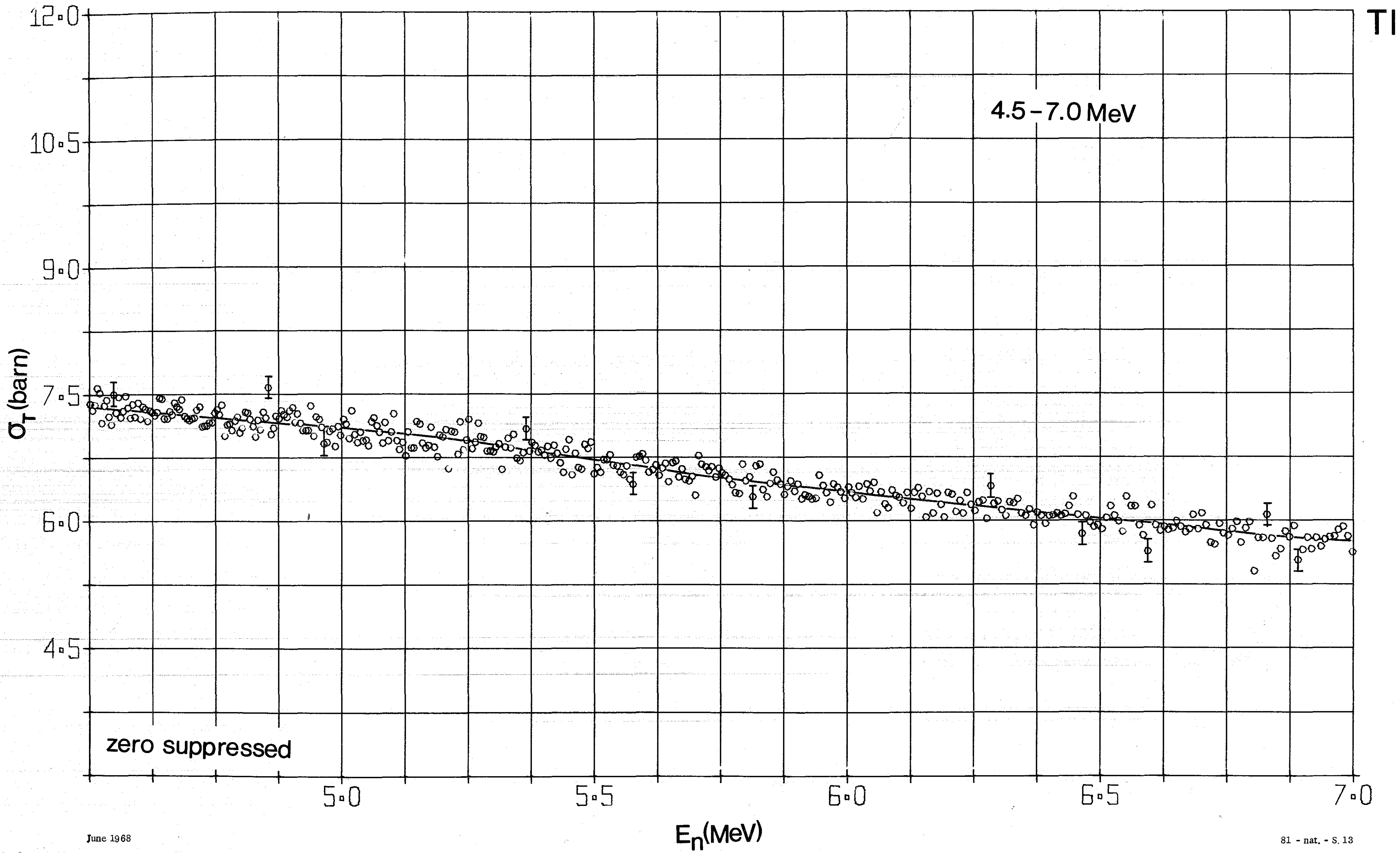
Tl
1.5-2.0 MeV
9·0
8·0
7·0
6·0
5·0
4·0
σT(barn)
zero suppressed
1·6
1·7
1·8
1·9
2·0
En(MeV)

June 1968

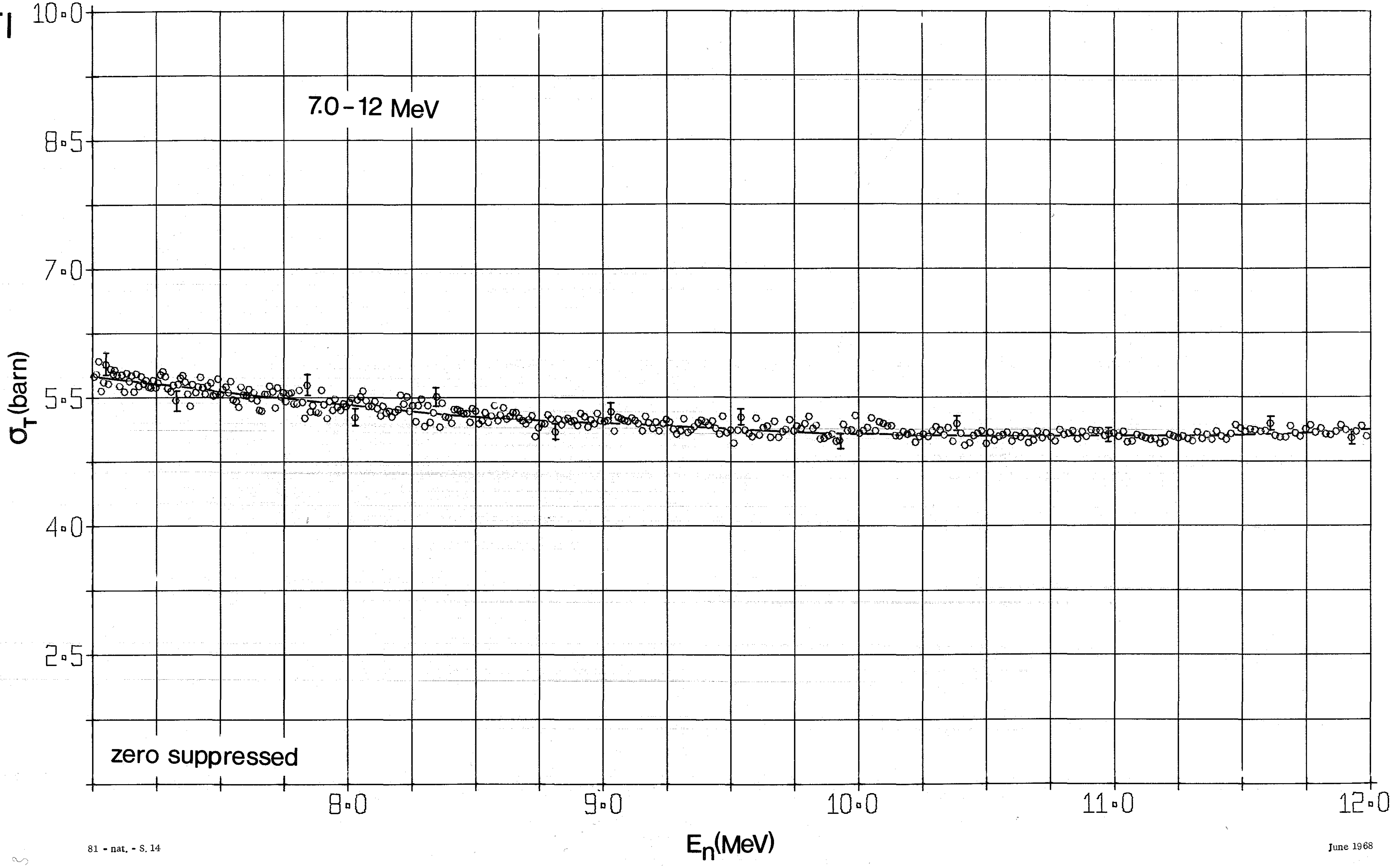


Tl
2.0-3.0 MeV
12.0
10.5
9.0
7.5
6.0
4.5
σT (barn)
zero suppressed
2.2
2.4
2.6
2.8
3.0
En(MeV)

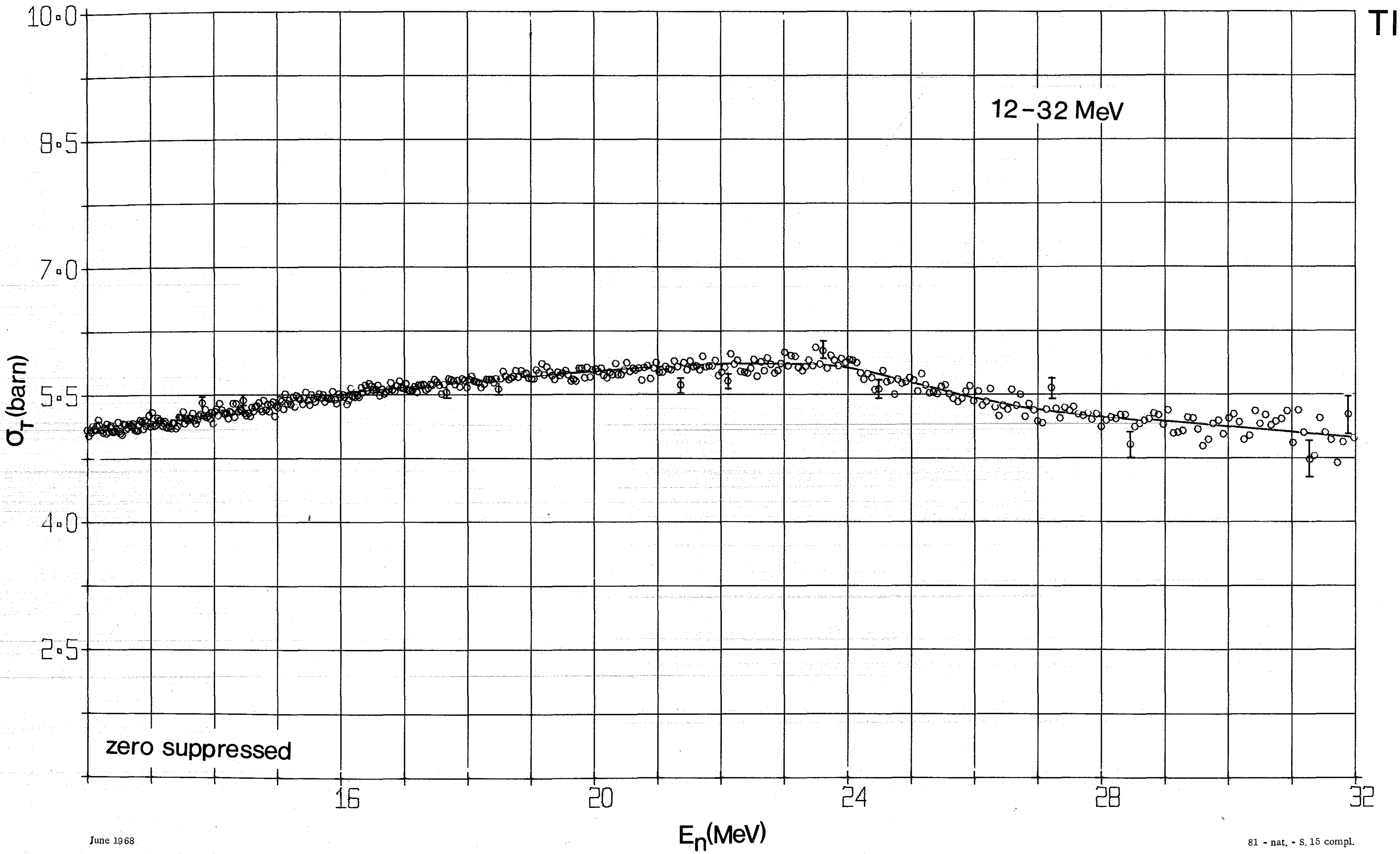

Tl
3.0 - 4.5 MeV
12·0
10·5
9·0
7·5
6·0
4·5
σT (barn)
zero suppressed
3·3
3·6
3·9
4·2
4·5
En(MeV)


Tl
4.5 - 7.0 MeV
12·0
10·5
9·0
7·5
6·0
4·5
σ_T (barn)
zero suppressed
5·0
5·5
6·0
6·5
7·0
E_n(MeV)

Tl


10.0
8.5
7.0
5.5
4.0
2.5
7.0 - 12 MeV
σ_T(barn)
zero suppressed
8.0
9.0
10.0
11.0
12.0
E_n(MeV)

June 1968



June 1968

81 - nat. - S. 15 compl.

Bi

n = 0.1493 at/barn

p = 99.9995 %

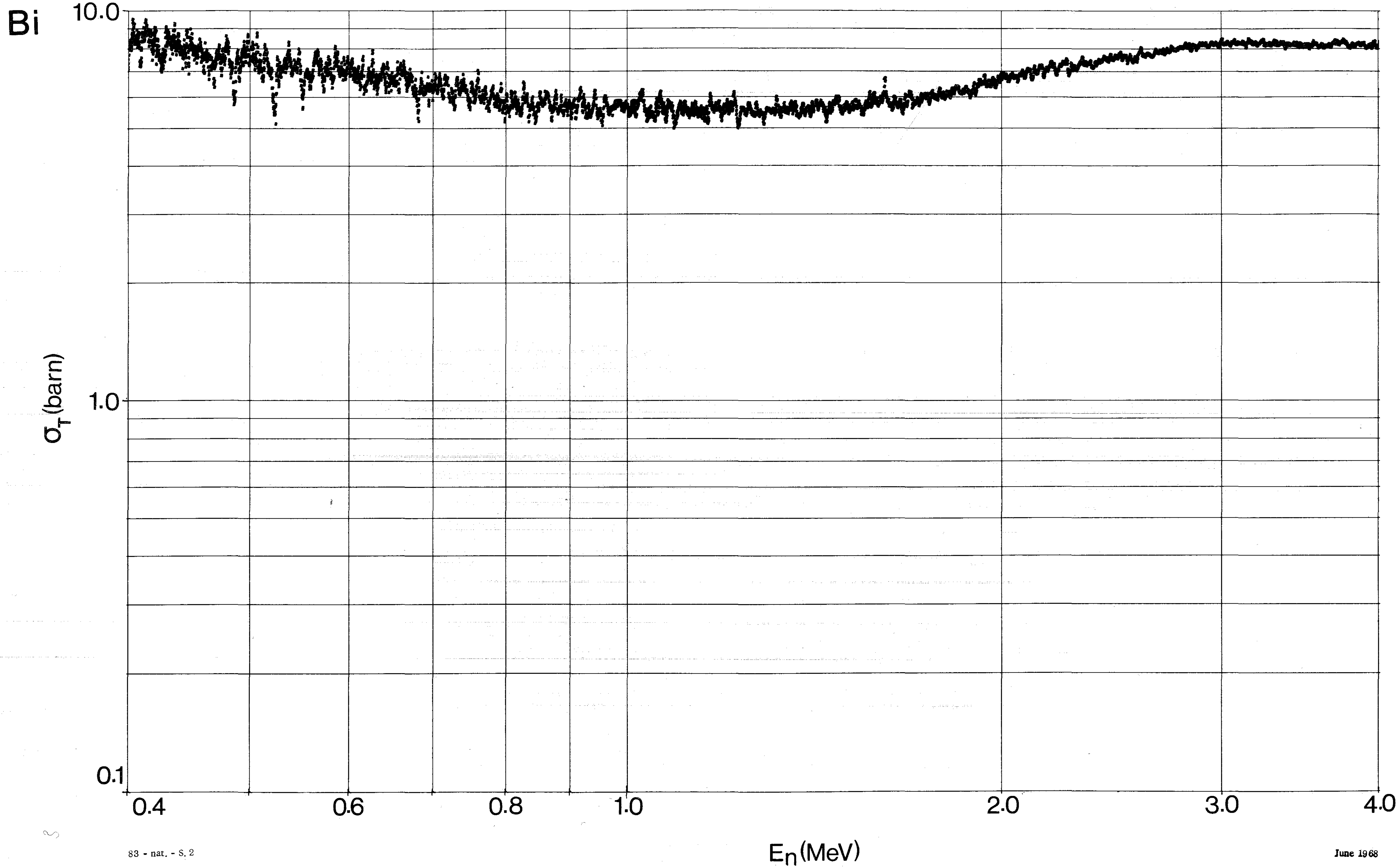
l = 57.228 m

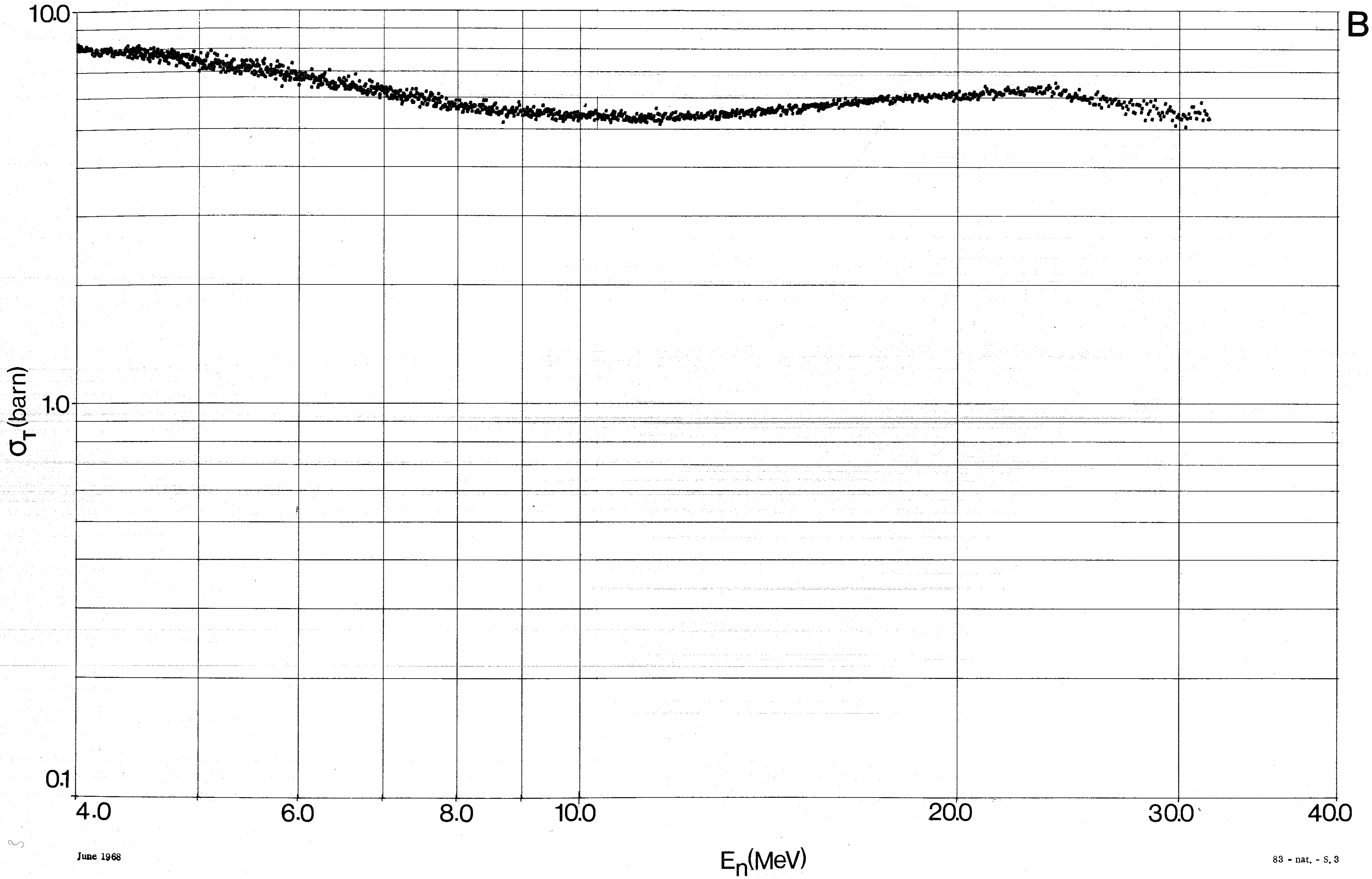
Δt = 3.5 nsec

i : natural

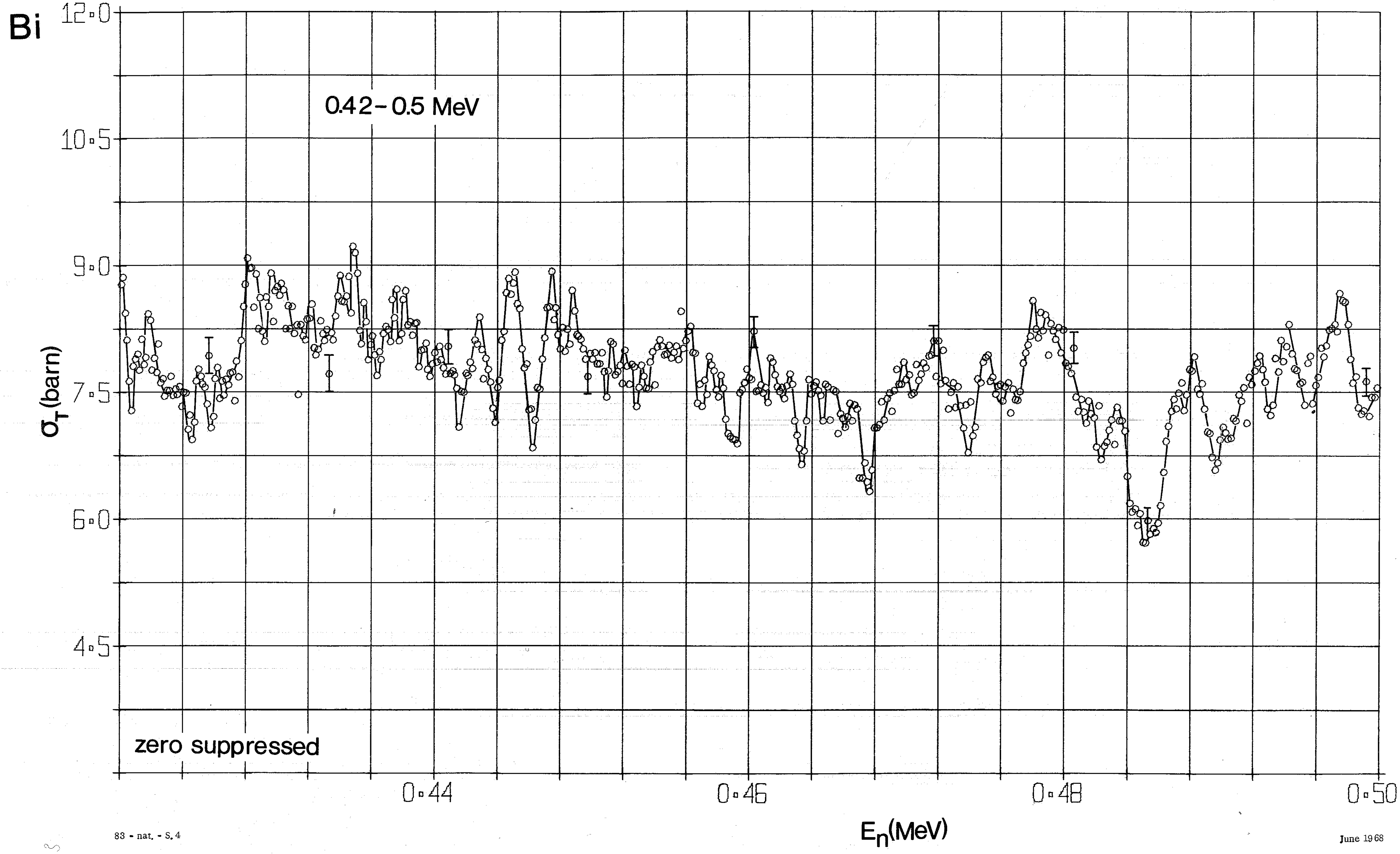
Mathematically smoothed from 1.9 - 4.5 MeV

(see introduction)


Bi
10.0
1.0
0.1
σ_T (barn)
0.4
0.6
0.8
1.0
2.0
3.0
4.0
E_n (MeV)

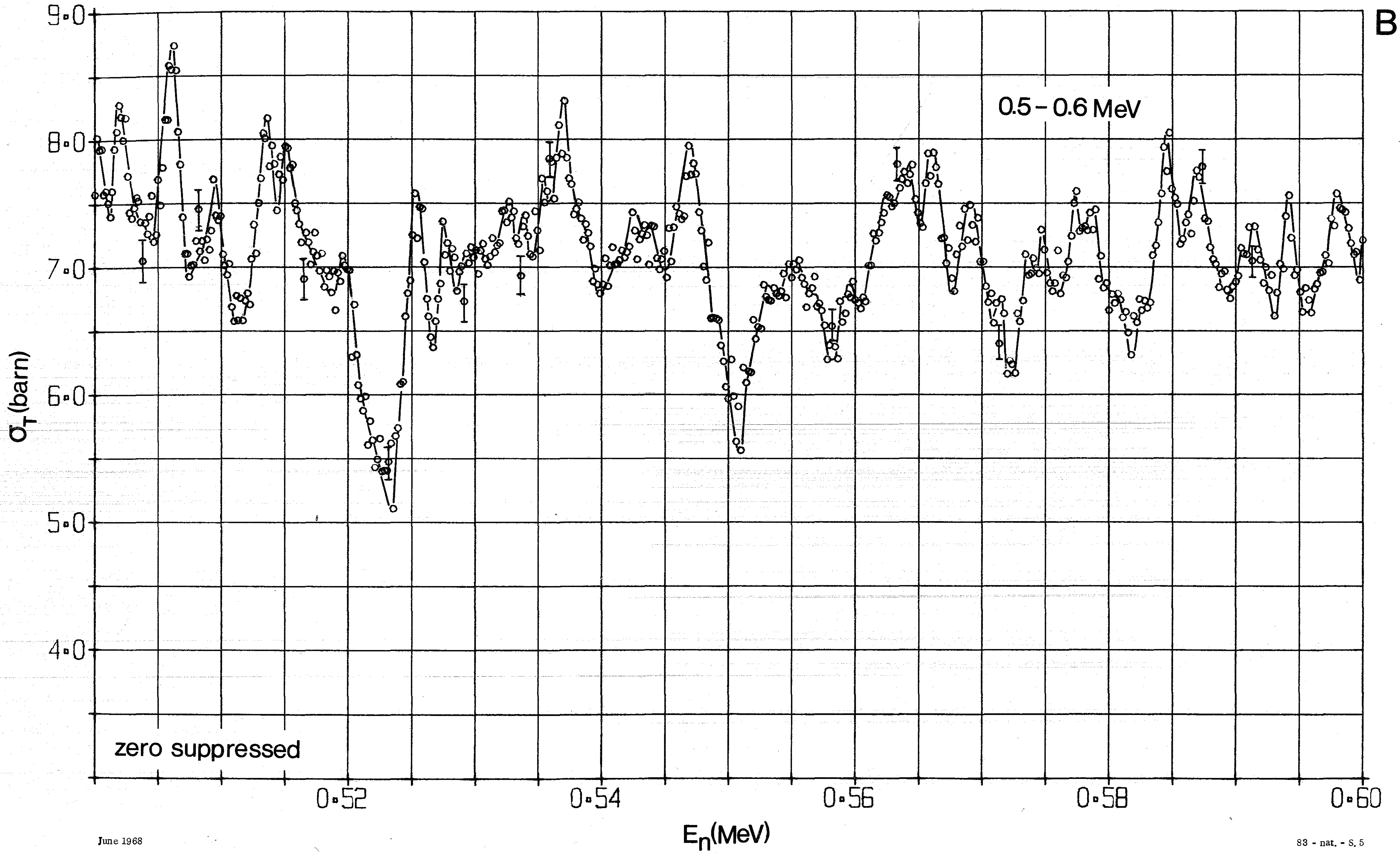


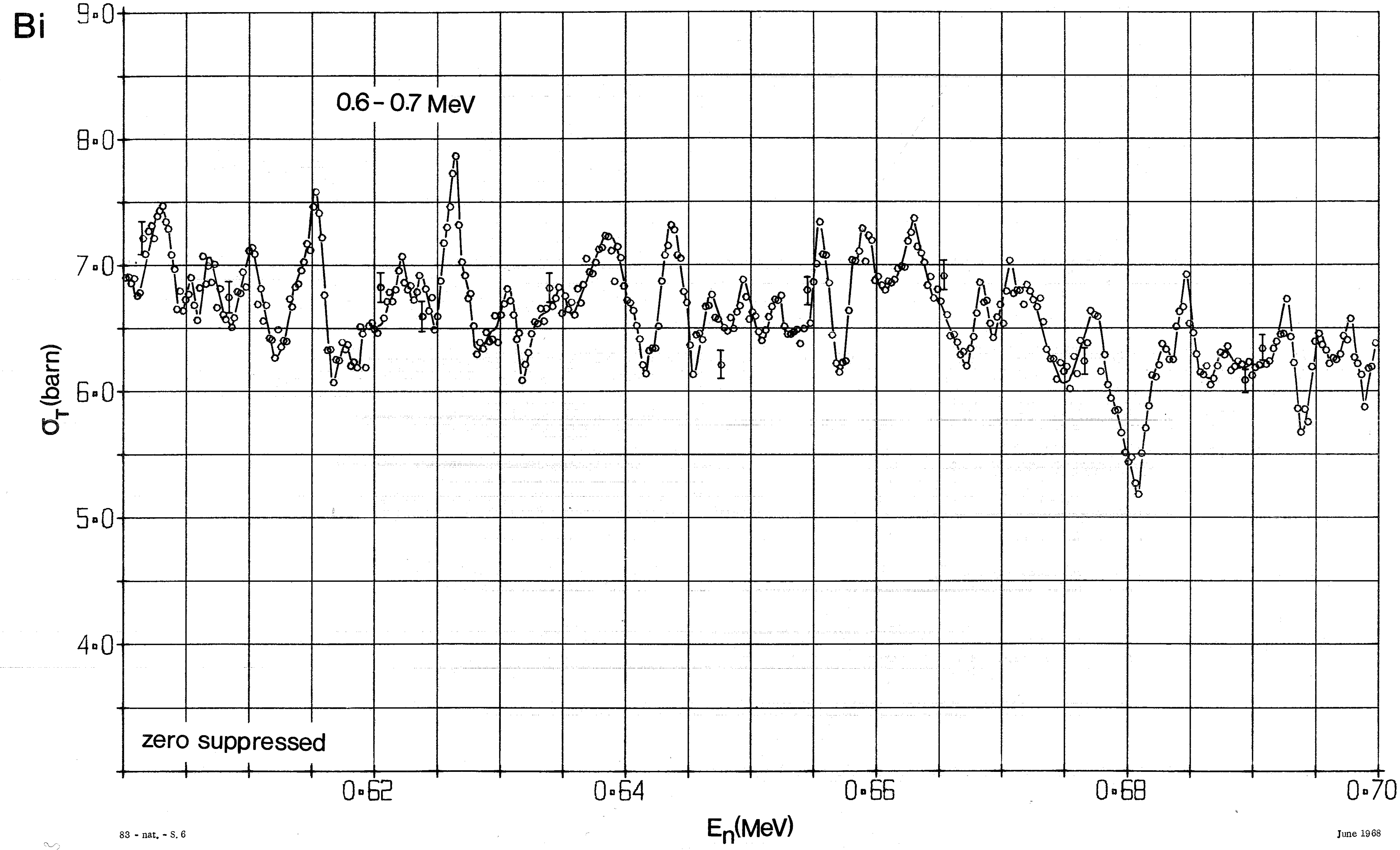
June 1968



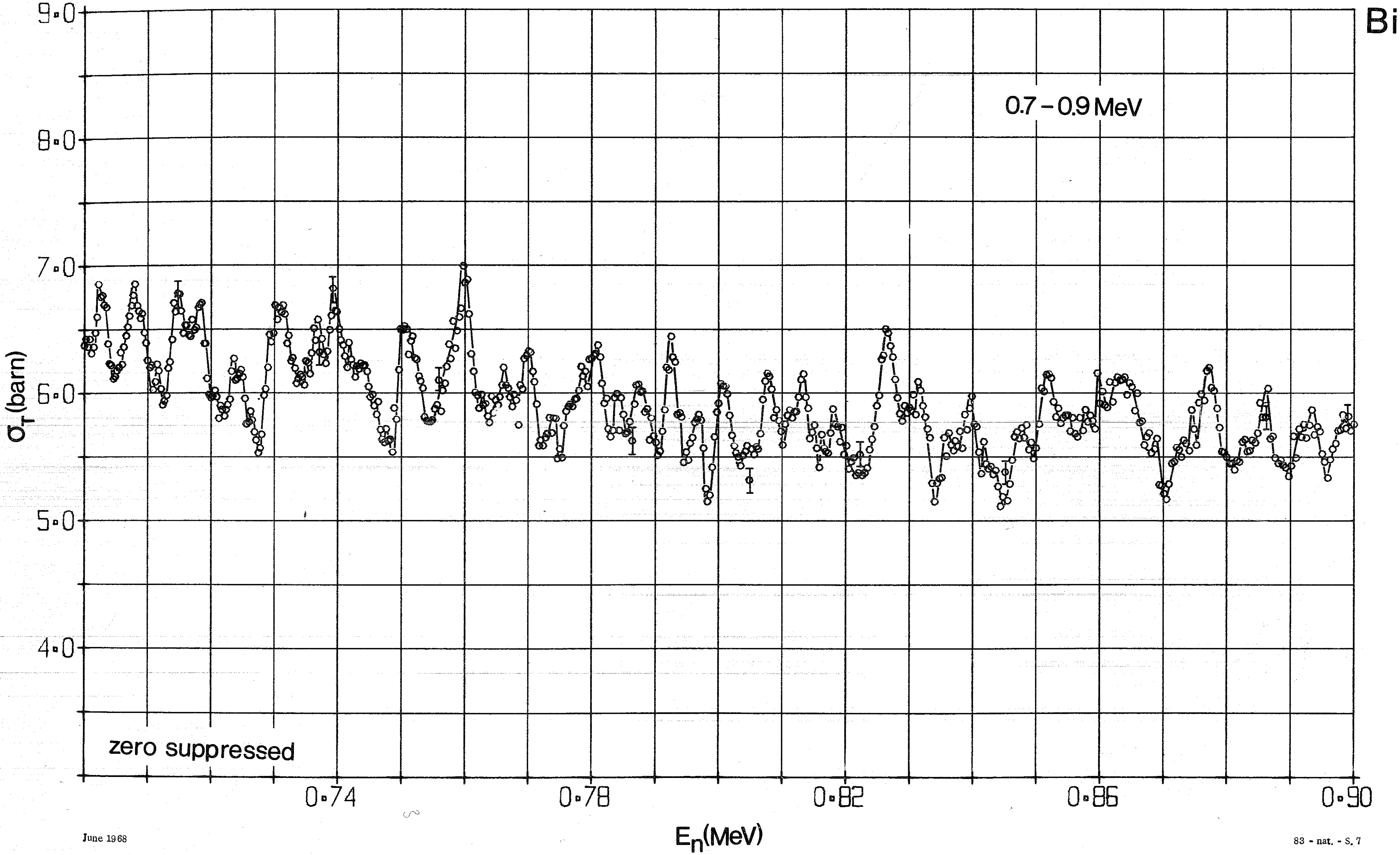
83 - nat. - S. 4

June 1968

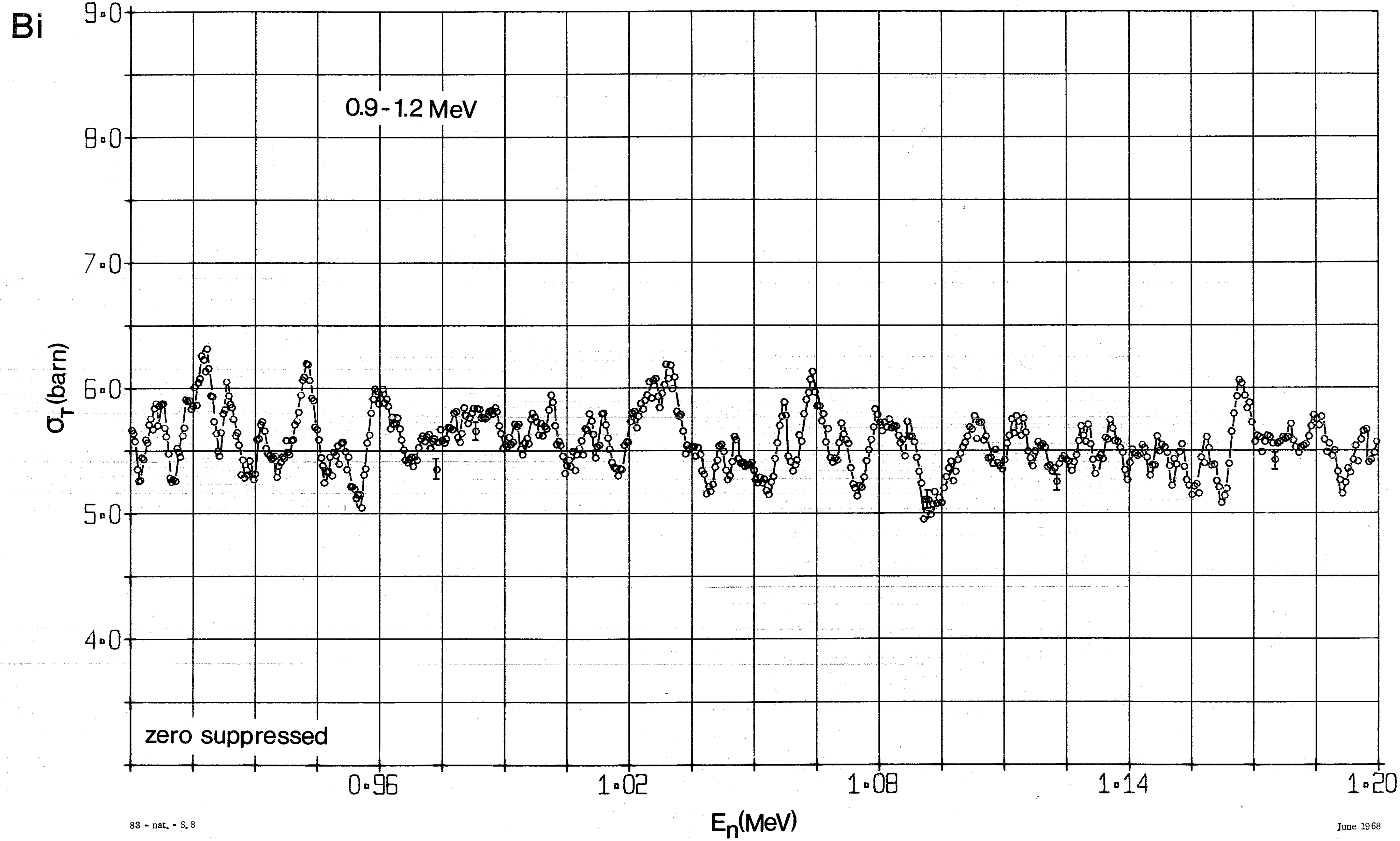

Bi
0.5 - 0.6 MeV
9·0
8·0
7·0
6·0
5·0
4·0
σT (barn)
zero suppressed
0·52
0·54
0·56
0·58
0·60
En(MeV)



Bi
0.6 - 0.7 MeV
9.0
8.0
7.0
6.0
5.0
4.0
σ_T(barn)
zero suppressed
0.62
0.64
0.66
0.68
0.70
E_n(MeV)

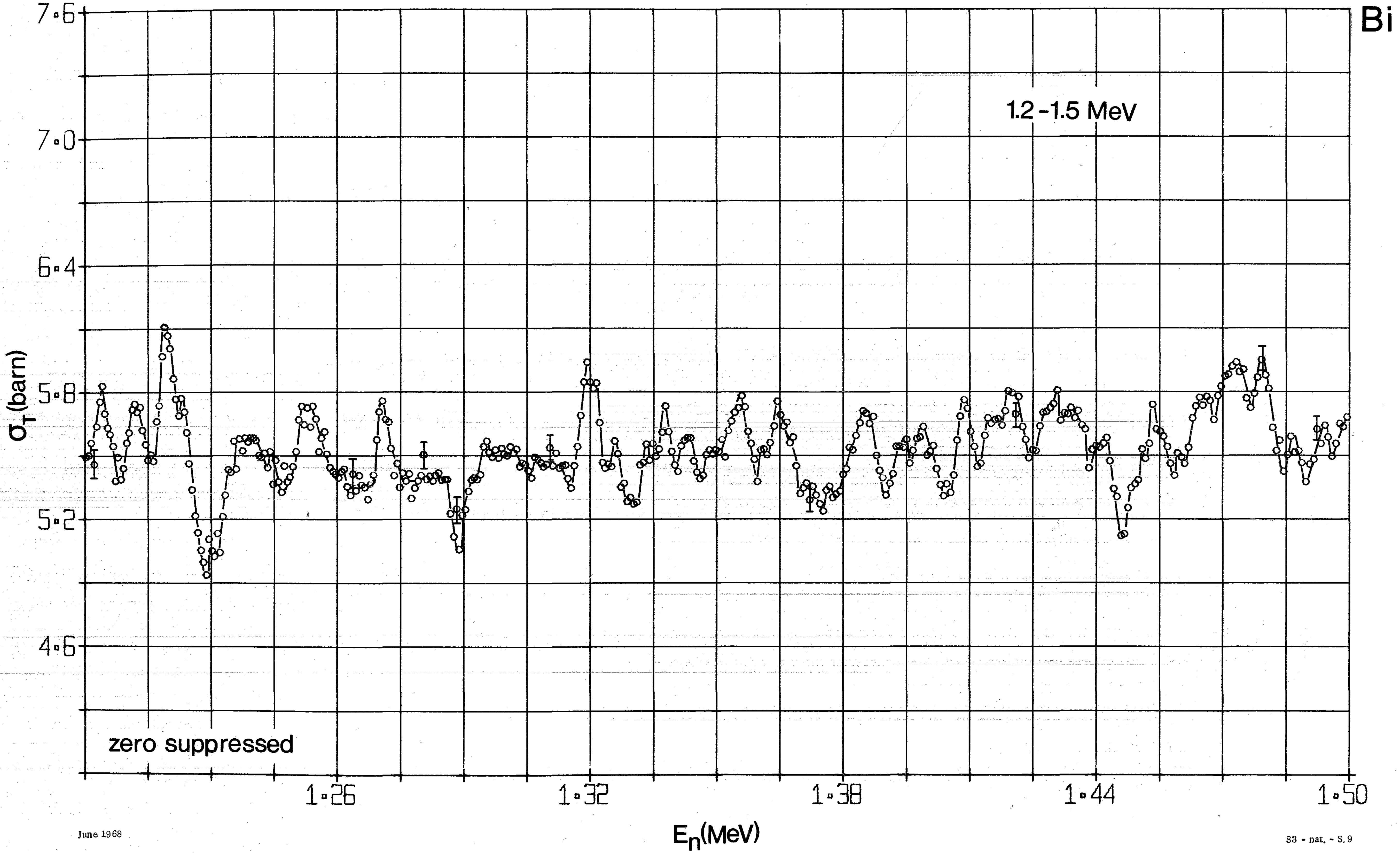


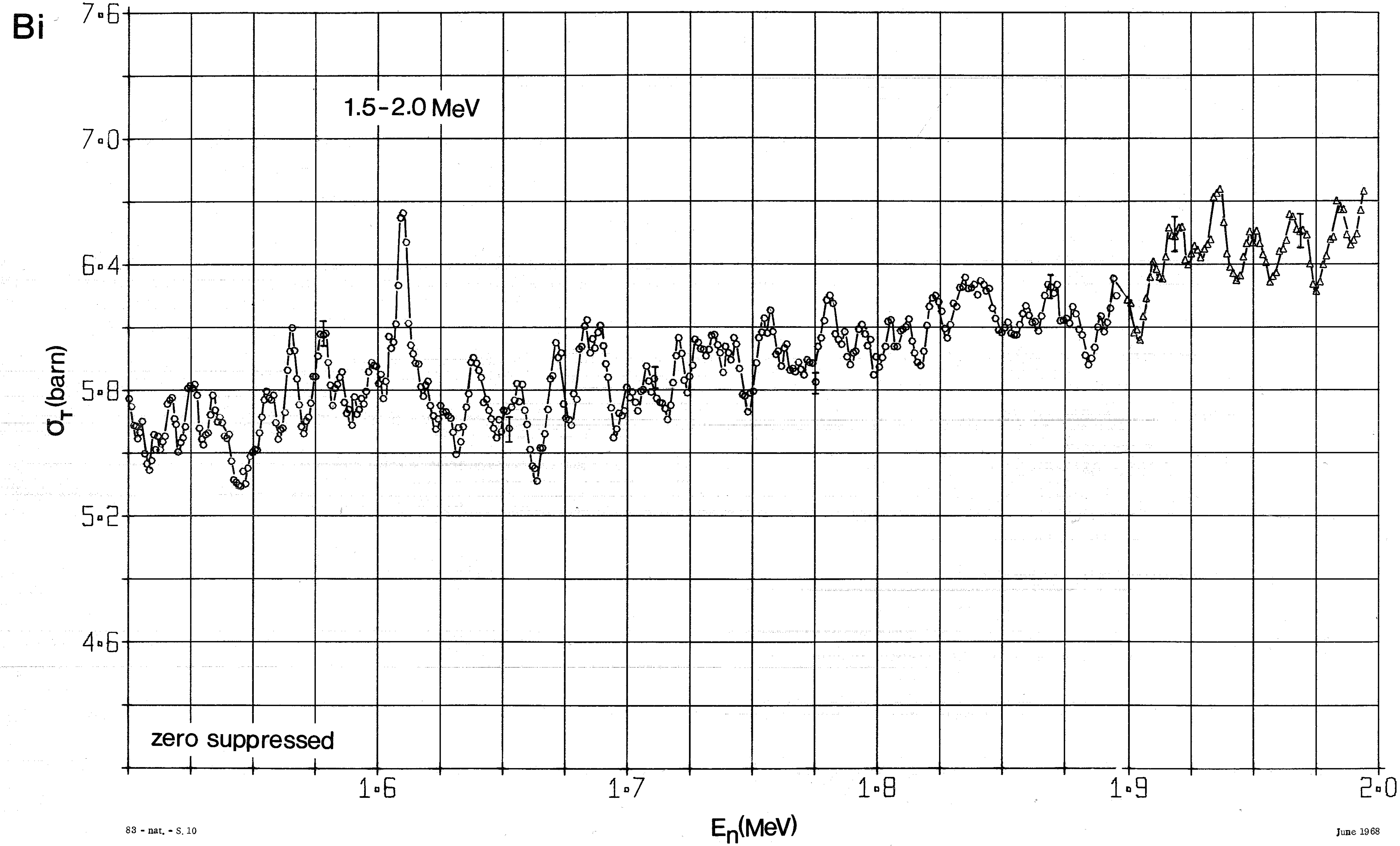
Bi
0.7 – 0.9 MeV
9·0
8·0
7·0
6·0
5·0
4·0
σT (barn)
zero suppressed
0·74
0·78
0·82
0·86
0·90
En(MeV)



83 - nat. - S. 8

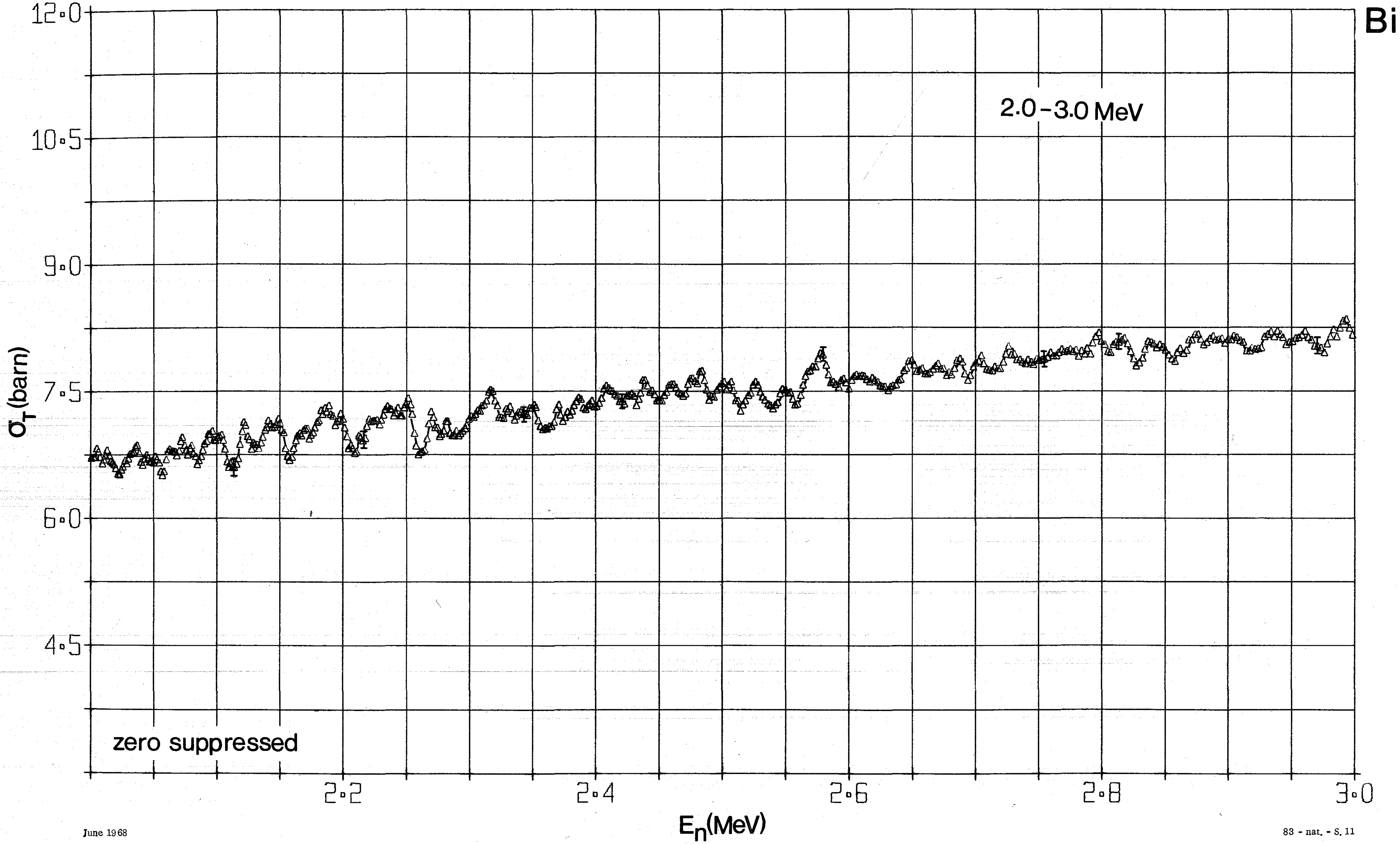
June 1968


Bi
1.2 - 1.5 MeV
7·6
7·0
6·4
5·8
5·2
4·6
σ_T (barn)
zero suppressed
1·26
1·32
1·38
1·44
1·50
En(MeV)

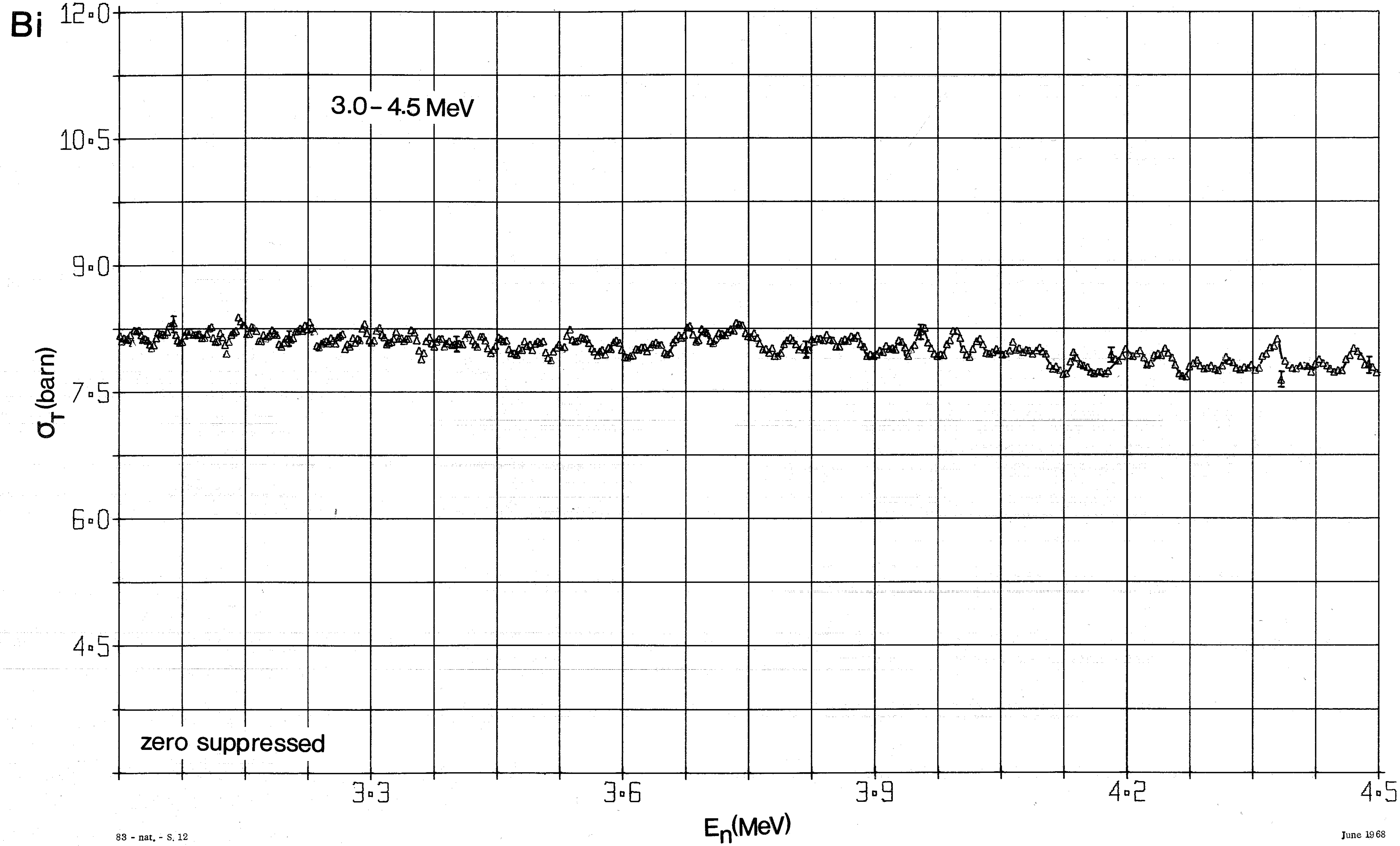


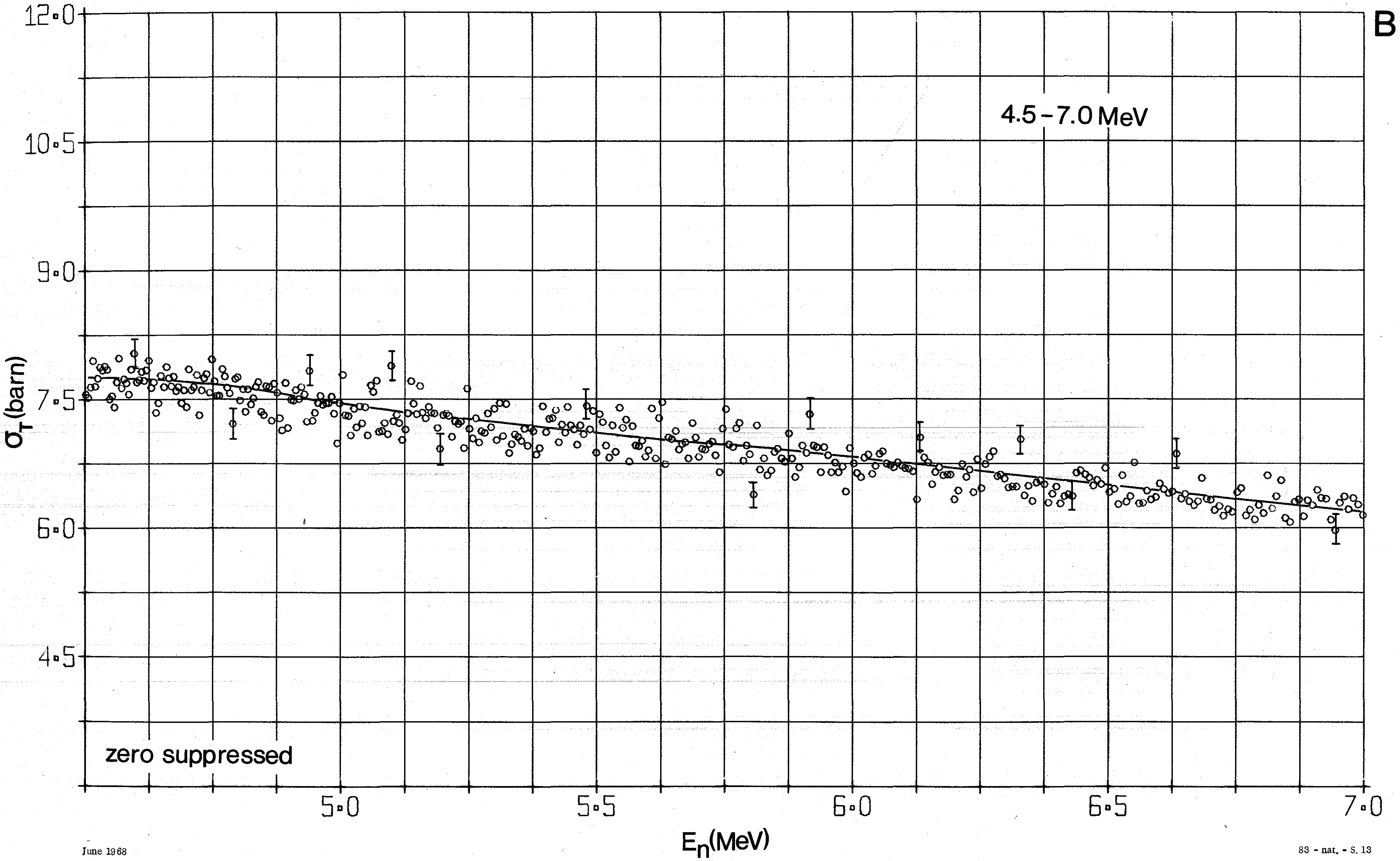
83 - nat. - S. 10

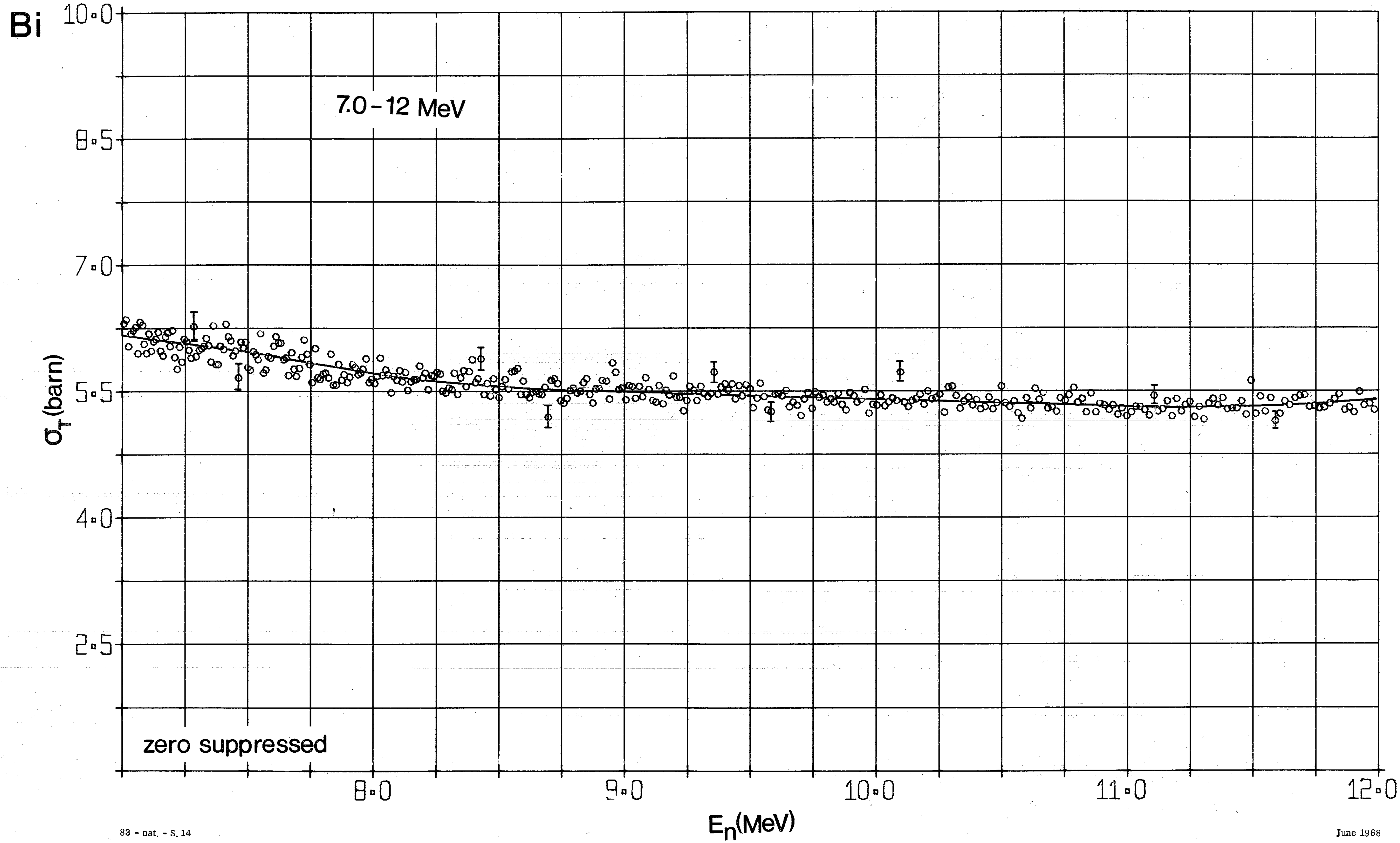
June 1968



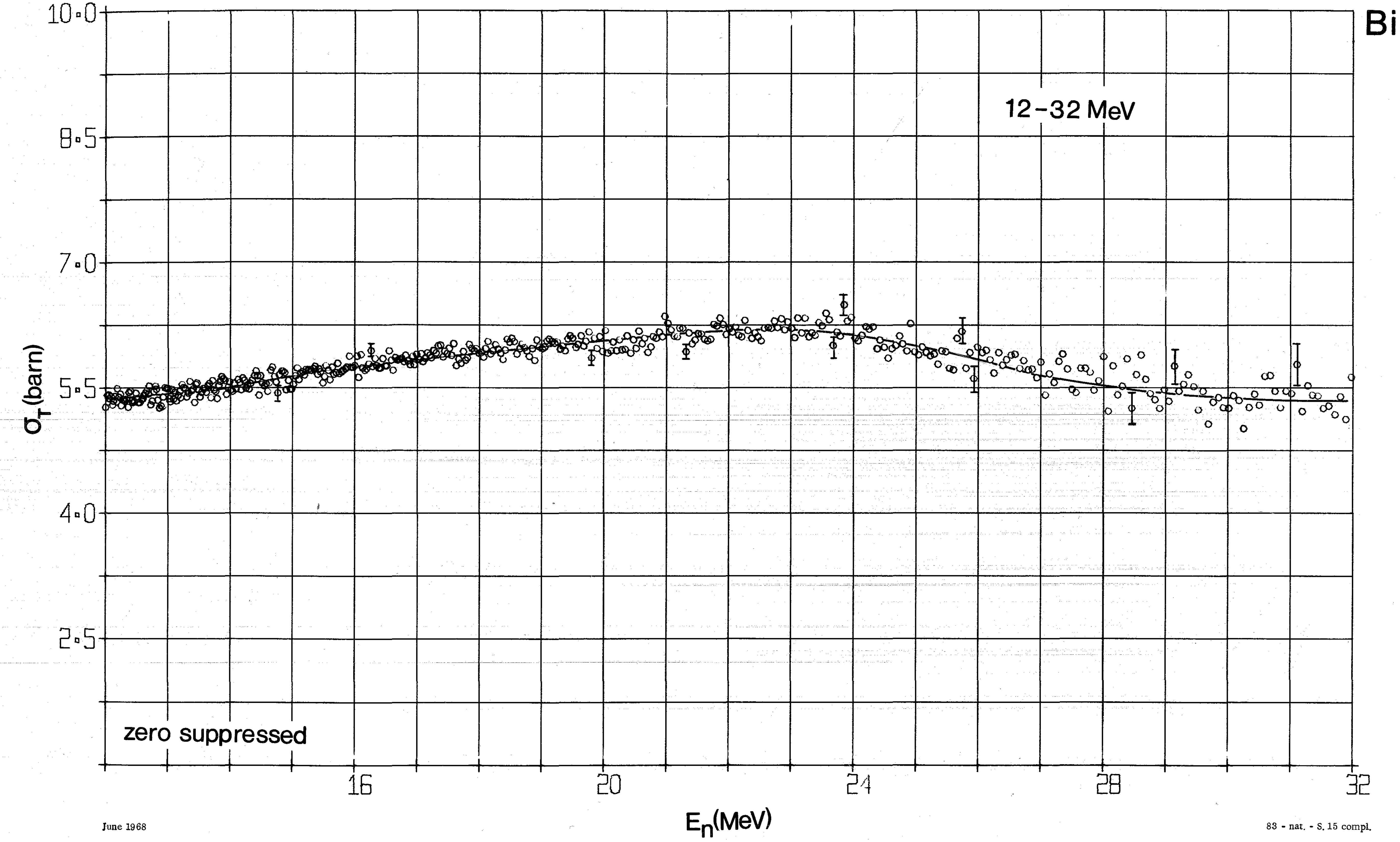
Bi
2.0 - 3.0 MeV
12·0
10·5
9·0
7·5
6·0
4·5
σ_T (barn)
zero suppressed
2·2
2·4
2·6
2·8
3·0
E_n(MeV)


Bi
3.0 - 4.5 MeV
zero suppressed
σT (barn)
12·0
10·5
9·0
7·5
6·0
4·5
3·3
3·6
3·9
4·2
4·5
En(MeV)


Bi
4.5-7.0 MeV
zero suppressed
12·0
10·5
9·0
7·5
6·0
4·5
σ_T (barn)
5·0
5·5
6·0
6·5
7·0
E_n(MeV)


Bi
7.0 - 12 MeV
zero suppressed
σT (barn)
10.0
8.5
7.0
5.5
4.0
2.5
8.0
9.0
10.0
11.0
12.0
En(MeV)

June 1968



June 1968

83 - nat. - S. 15 compl.