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RESEARCH PROGRESS MEETING

February 19, 1948

R. K. Wakerling

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Physics-General

RESEARCH PROGRESS MEETING

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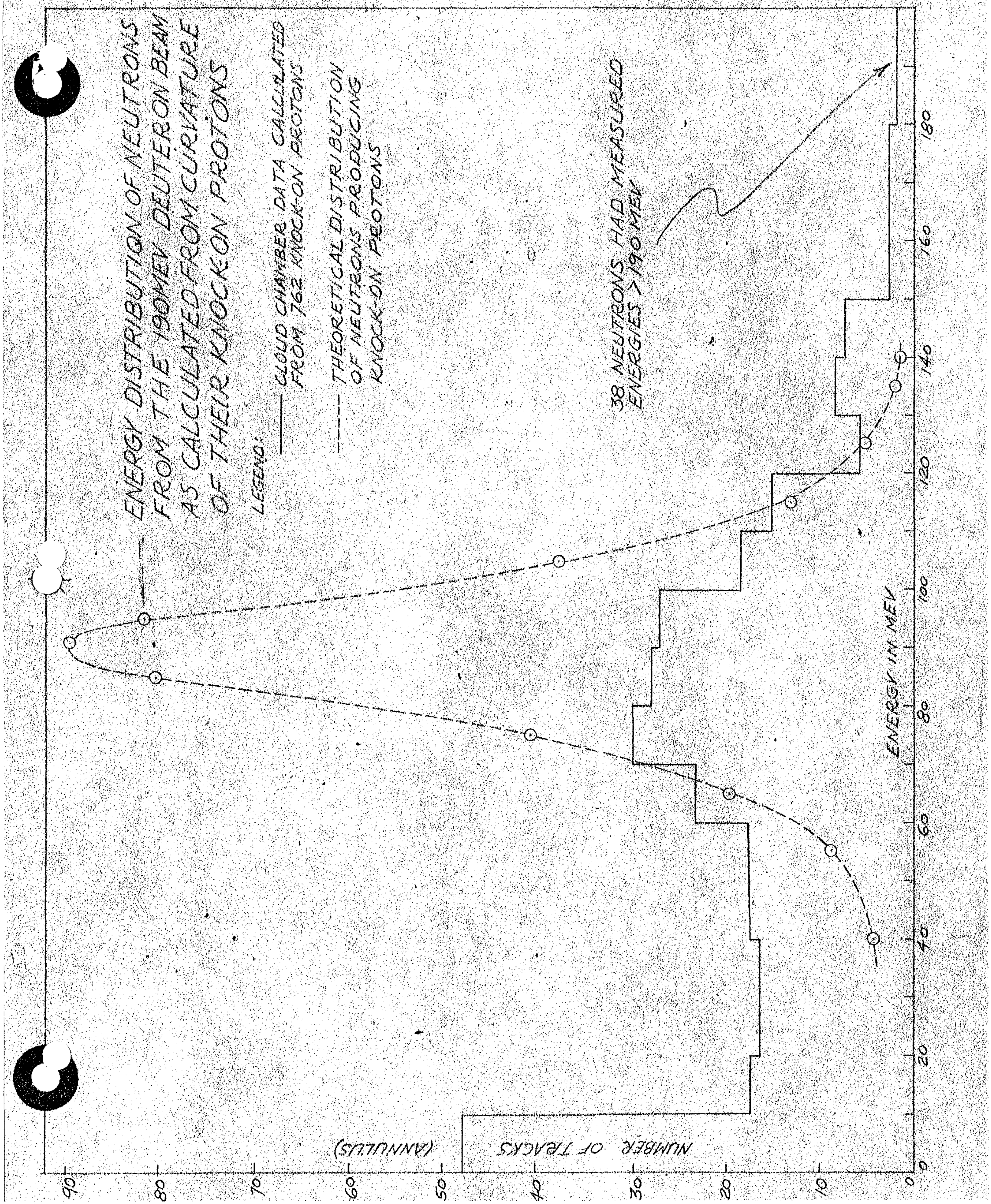
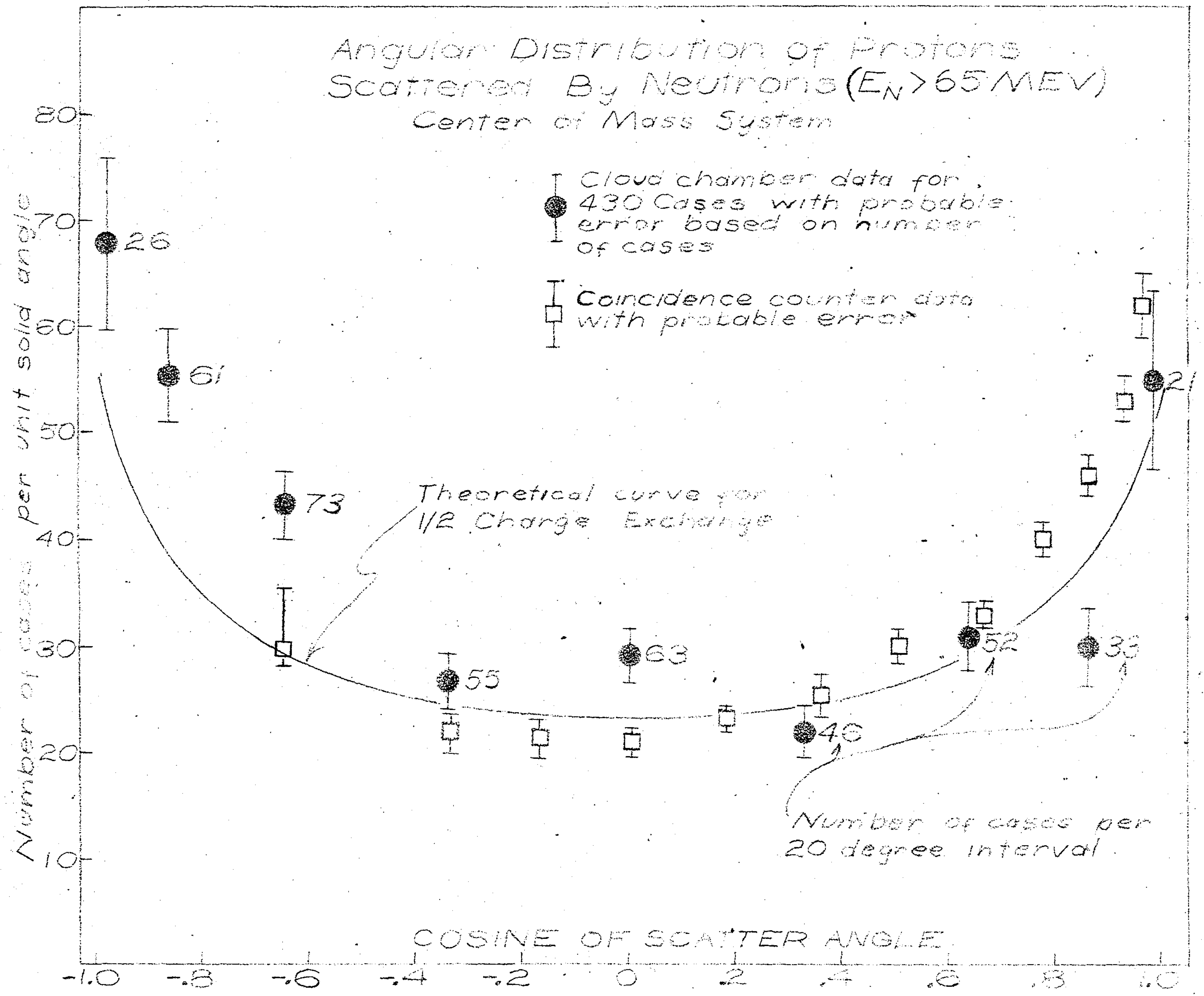
Deuteron-Protron Scattering. By K. Bruekner Much of the cloud chamber work has been directed toward obtaining the angular distribution of protons bombarded by deuterons from the 184-inch cyclotron. The observations have been restricted to those protons arising from neutrons of energy greater than 65 Mev. The cloud chamber used for this work is of 16-inch diameter and employs a magnetic field of 14000 gauss. The chamber is filled with hydrogen at a pressure of 1/2 atmosphere; the vapor used is water and alchohol.

Nearly 800 proton tracks were measured and calculated before analysis of the data indicated that the measuring procedure should be revised. They gave the angular and energy distributions shown in Figures 1 and 2. The discrepencies between the theoretical and experimental energy distribution of the neutrons shows that serious errors were being made. As a first check of possible sources of error, random parts of the data were remeasured. They indicated that errors in the measurements of the angles were being made that gave a mean deviation of about $\pm$ 2° in the beam angle and $\pm$ 4° in the dip angle. These errors were largest at large scatter angles. In addition, a more serious error occured in the measurements of the curvature. The mean deviation was as large as 15 percent, with many tracks having errors of 50 to 100 percent in the measured curvature. These errors were due to the fact that an adequate measuring technique had not been developed, that the original measuring apparatus and projector


ENERGY DISTRIBUTION OF NEUTRONS FROM THE 190 MEV DEUTERON BEAM AS CALCULATED FROM CURVATURE OF THEIR KNOCK-ON PROTONS
LEGEND:
CLOUD CHAMBER DATA CALCULATED FROM 762 KNOCK-ON PROTONS
THEORETICAL DISTRIBUTION OF NEUTRONS PRODUCING KNOCK-ON PROTONS
38 NEUTRONS HAD MEASURED ENERGIES > 190 MEV
NUMBER OF TRACKS (ANNULUS)
ENERGY IN MEV
0
20
40
60
80
100
120
140
160
180
10
20
30
40
50
60
70
80
90



Angular Distribution of Protons
Scattered By Neutrons (E_N > 65 MEV)
Center of Mass System
Cloud chamber data for 430 Cases with probable error based on number of cases
Coincidence counter data with probable error
Theoretical curve for 1/2 Charge Exchange
Number of cases per 20 degree interval
Number of cases per unit solid angle
COSINE OF SCATTER ANGLE
26
61
73
55
63
46
52
33
21
80
70
60
50
40
30
20
10
-1.0
-.8
-.6
-.4
-.2
0
.2
.4
.6
.8
1.0

FIGURE 2

were difficult to operate, and that the cloud chamber technique had not been perfected. A systematic analysis of the errors and difficulties involved in the experiment made it evident that revisions in the technique were necessary.

In view of the inaccuracy of the original measurements it is not possible to make more than a qualitative analysis of the first 800 tracks. The data showed definitely the existence of exchange forces and point to the conclusion that classical forces are slightly dominate in the proton-neutron reaction at these energies. This is indicated by the excess of high angle scattering, with 246 protons scattered at angles greater than 45^{o} and 183 scattered at angles less than 45^{o}. It is to be noted that this excess existed despite a selective tendency for the increased errors at large scatter angles to exclude the data from the group having energy greater than 65 Mev.

The data taken under revised and improved procedure shows good agreement with theoretical energy distribution as may be seen from Figure 3. The angular distribution given in Table I now shows more definately the asymmetry of the scattering, with 59 protons scattered at angles greater than 45^{o} and 38 at angles less than 45^{o}. However, the probable statistical errors are still relatively large, and there is still a possibility that errors are introduced from high energy protons knocked on in the forward direction which may not ionize heavily enough to be observed. This effect is small since the protons now being observed are knocked on in hydrogen at one and one half atmospheres pressure with the resulting much greater ionization.

E. Segre. The angular distribution of n-p scattering with 90 Mev

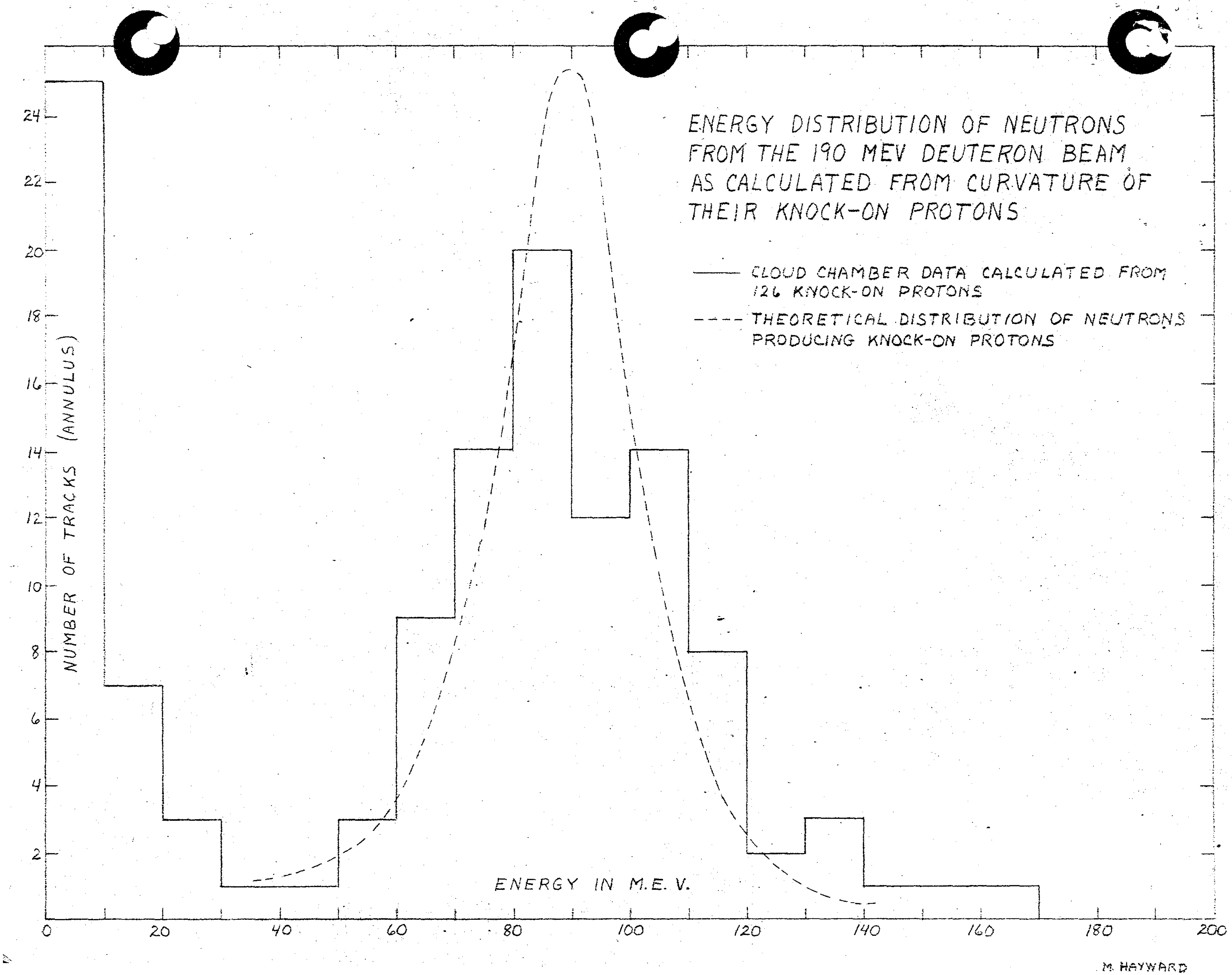

ENERGY DISTRIBUTION OF NEUTRONS FROM THE 190 MEV DEUTERON BEAM AS CALCULATED FROM CURVATURE OF THEIR KNOCK-ON PROTONS
CLOUD CHAMBER DATA CALCULATED FROM 126 KNOCK-ON PROTONS
THEORETICAL DISTRIBUTION OF NEUTRONS PRODUCING KNOCK-ON PROTONS
NUMBER OF TRACKS (ANNULUS)
ENERGY IN M.E.V.
0
20
40
60
80
100
120
140
160
180
200
2
4
6
8
10
12
14
16
18
20
22
24
M. HAYWARD

FIGURE 3

TABLE I

Number per annulus in laboratory system

Lab angle	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89
	3	8	10	12	12	16.8	23.4	11.9	3.6

Distribution per equal cosine interval in the center of mass system

C.M. Angle	0-52	53-78	79-100	101-126	127-180
	19	14	13	23.7	27.7

neutrons has been measured in the center of mass system between the angles of 70^{o} and 170^{o}. Figure 4 shows the schematic layout of the apparatus. The neutron beam produced by stripping 180 Mev neutrons in a beryllium target was collimated to a diameter of about 2.5 centimeters and scattered by paraffin or polyethylene targets which were larger in diameter than the neutron beam. The recoil protons used for the measurement were detected by a set of three proportional counters in coincidence and placed in a line pointing towards the scatterer. The primary neutron beam was monitored either by the protons scattered by an auxiliary hydrogenous target or by a bismuth fission chamber. The set of three coincidence counters was made insensitive to protons with an energy below a certain minimum by means of an absorber of aluminum placed between the second and third counters. The thickness of absorber was so adjusted that the protons of energy less than 66 $\cos^2 \frac{\pi - \theta}{2}$ Mev could not enter the third counter.

Table II gives the cross section as a function of angle. The data are also plotted in Figure 5 with the relativity correction. Smaller and larger angles are being investigated at the present time.

These experiments were performed independently with two separate sets of equipment which were similar in principal but different in many details. This procedure helped considerably in revealing unsuspected causes of trouble. A very careful study was made of the sources of systematic error and it is felt that these preliminary results may be viewed with some confidence.

TABLE II

DIFFERENTIAL CROSS SECTION IN 10^{-28} cm^2
(normalization hypothetical)

The errors listed are based only on statistical standard deviations.

Scattering Angle Θ	(1)	(2)	(3)	(4)
70	43.7 ± 4.0	35.3 ± 2.8	39.0 ± 3.7	40.8 ± 3.1
80	42.6 ± 3.5	32.5 ± 4.9	40.4 ± 3.7	40.2 ± 2.5
90	42.0 ± 2.4	44.0 ± 4.2	45.1 ± 4.9	43.5 ± 2.4
100	47.0 ± 3.0	42.4 ± 6.1	48.0 ± 3.7	46.7 ± 2.7
110	50.2 ± 3.4	51.8 ± 6.1	53.0 ± 3.5	51.4 ± 2.5
120	59.0 ± 2.7	59.7 ± 6.3	63.2 ± 4.5	60.4 ± 2.4
130	66.8 ± 3.1	70.0 ± 7.0	61.5 ± 3.8	65.6 ± 2.7
140	79.5 ± 3.1	78.5 ± 7.8	84.7 ± 5.6	81.2 ± 2.8
150	92.5 ± 4.4	99.0 ± 7.0	94.0 ± 5.4	94.1 ± 4.1
160	105.5 ± 3.8	127.0 ± 10.6	107.5 ± 7.9	107.7 ± 3.8
170	126.0 ± 5.8	127.5 ± 14.0	123.2 ± 9.4	125.7 ± 5.0

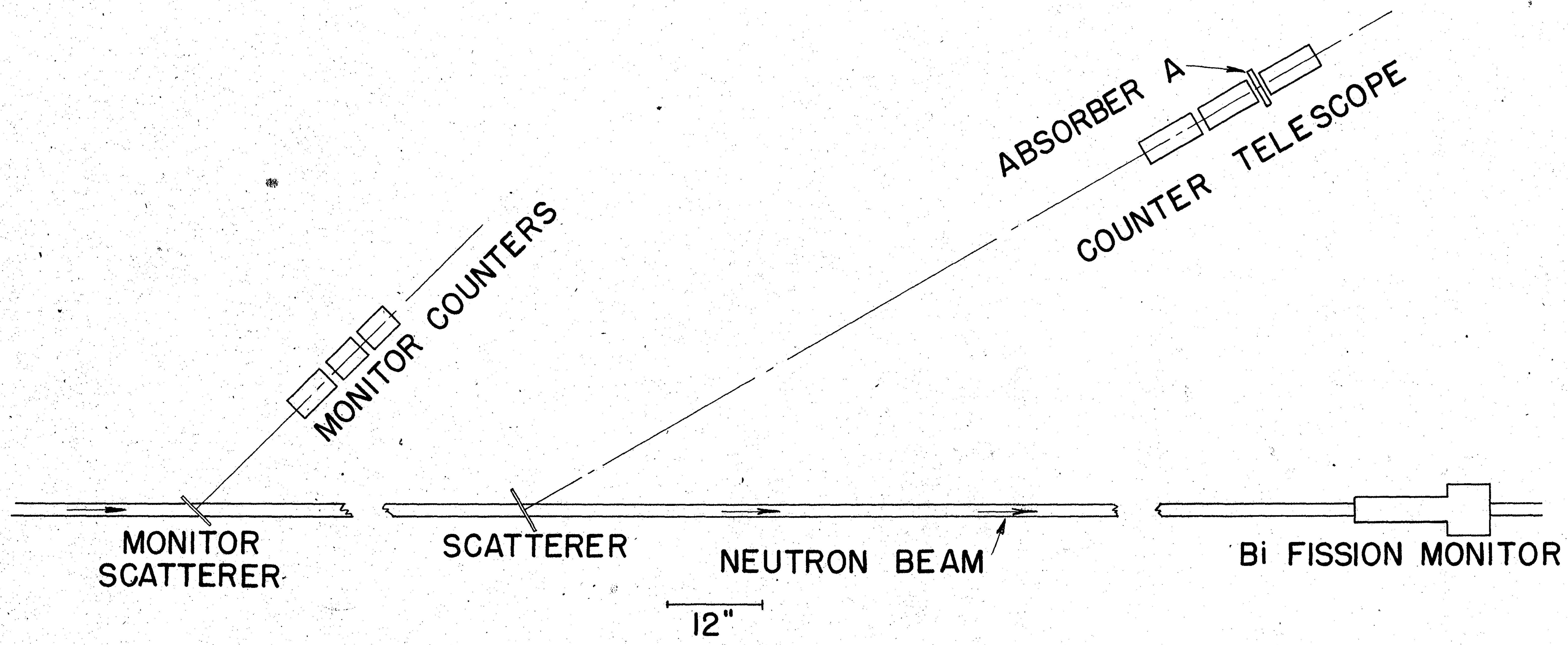
Θ Neutron scattering angle in the center of mass system.

(1) Composite of runs on apparatus 1.

(2) Run on apparatus 2, scatterer 150 mg/cm^2 $(CH_2)n$

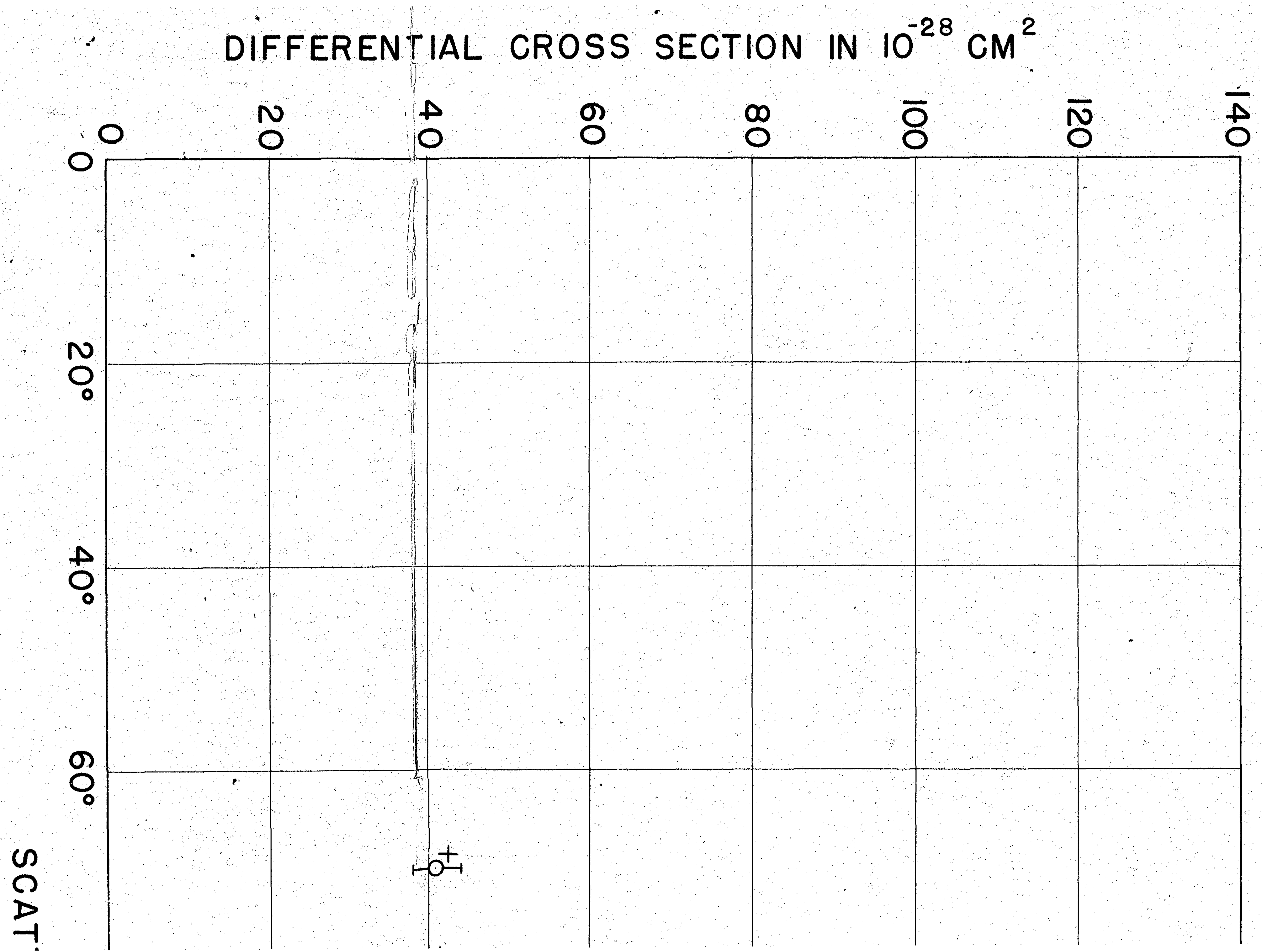
(3) Run on apparatus 2, scatterer 283 mg/cm^2 $(CH_2)n$

(4) Weighted average of all runs with estimated error.



PLAN VIEW OF EXPERIMENTAL ARRANGEMENT

FIG. 4


DIFFERENTIAL CROSS SECTION IN 10^{-28} CM^2
0
20
40
60
80
100
120
140
0
20°
40°
60°
SCAT

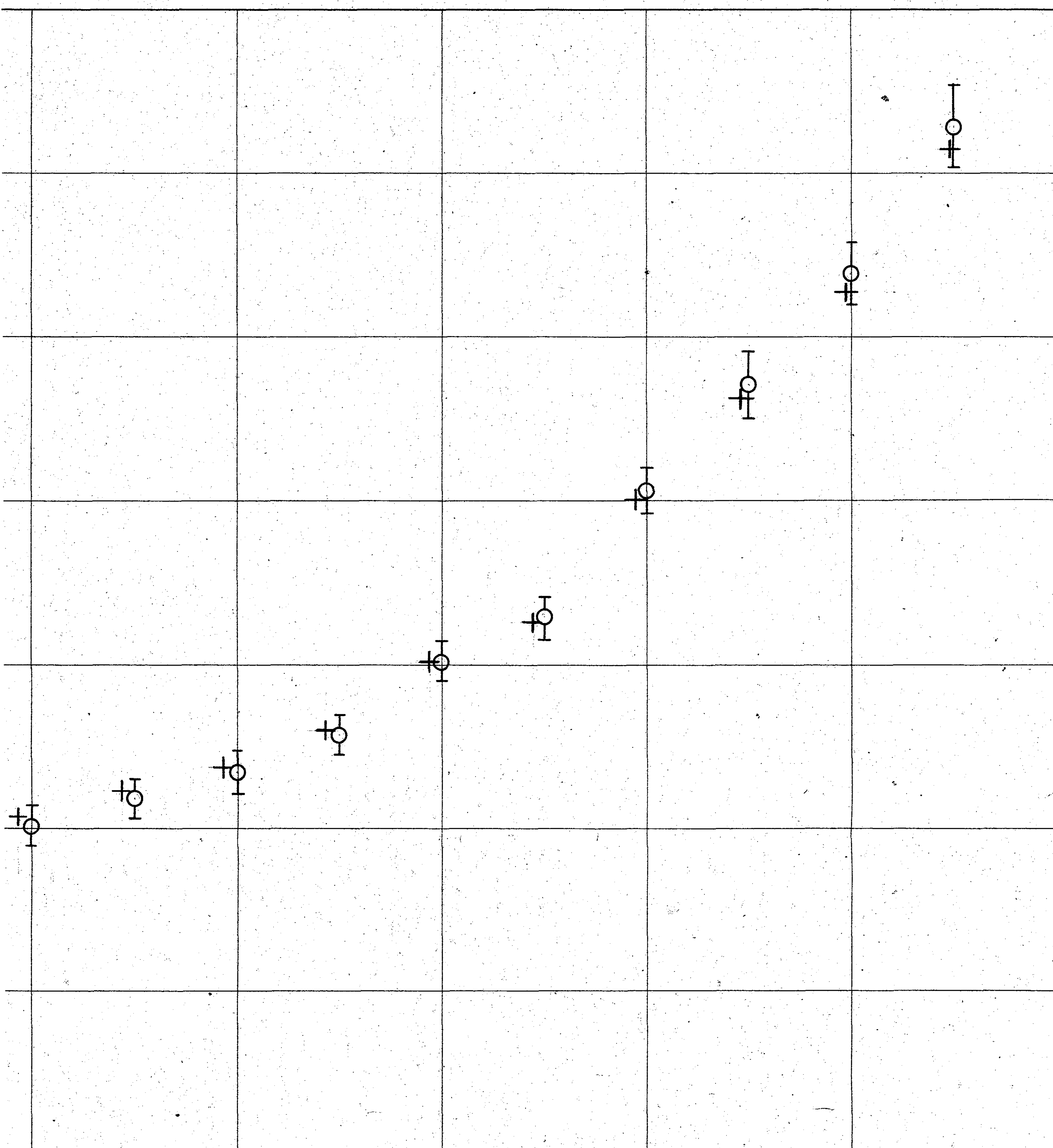


FIG. 5

The peak of protons in the forward direction is a clear indication of the existence of the exchange forces between neutron and proton. A more detailed analysis that takes into account the total scattering cross section and the angular distribution indicates that there might be comparable amounts of ordinary forces.

R. Serber. Calculations are being made to account for the scattering results found. To start with, the potential

$$V = C \frac{e^{-r/1.z \times 10^{-13}}}{r}$$

has been used, which had previously been found to work at low energy. In these calculations one half exchange and one half ordinary force was assumed. On this basis variations of scatterings with angle of the type shown in Fig. 6 (curve 1) was discovered. A total cross

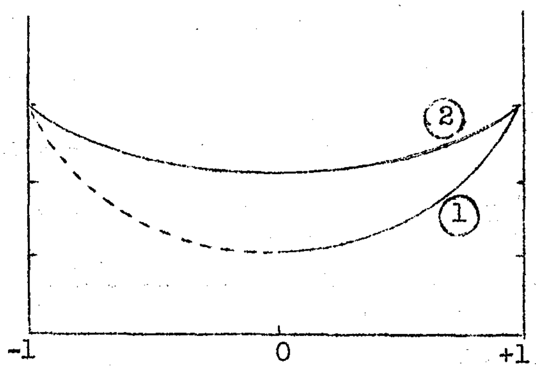


Figure 6

section of .087b was thus found which compares favorably with McMillan's measured value of .083 ± .004b. However, if the tensor forces are introduced into the calculation the curve number 2 is obtained, which gives totally different result. This means of course that the potential is not correct. Unfortunately if the range is increased the cross section found to increase. Relativistic corrections should also be made but these are difficult.

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