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COMMENTS ON SPARK CHAMBERS FOR THE NEUTRINO EXPERIMENT

by
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I. INTRODUCTION

As far as mass of the detector is concerned, the advantage of a spark chamber as a great mass neutrino detector is obvious. However, the conditions of measurements of the quantities involved in the neutrino reactions vary much according to the material, thickness and area of the plates. This report presents an attempt to relate those three characteristics of the plates to the quantities to be measured, in order to optimize a spark chamber for this specific experiment.

If the intermediate boson does not exist, and if there is only one kind of neutrino, the simplest neutrino reactions to be considered are

$$\nu + n \rightarrow p + \mu^- \quad (1)$$
$$\rightarrow p + e^- \quad (2)$$
$$\bar{\nu} + p \rightarrow n + \mu^+ \quad (3)$$
$$\rightarrow n + e^+ \, . \quad (4)$$

To those we should add pion-producing reactions which, according to recent estimates[1,2]) have cross-sections of about 20% of those of reactions (1) to (4).

Most of the people involved in the neutrino experiment are inclined to believe that the first and easiest part of neutrino physics will be to determine whether there is only one kind or two kinds of neutrino. It is very likely that this problem is settled by the experiment at Brookhaven. We have to ask then what will have to be done next.

The obvious problem which we can think of is the measurements of cross-sections as a function of energy, which is related to the existence of the intermediate boson. If the intermediate boson exists, its mass, spin, magnetic moment have to be measured. All those processes require the identification of the secondaries of neutrino reactions and the measurement of their energies and angles between lines of flight.

In this respect it is worth while emphasizing that there are good reasons for us to take seriously the possibility of existence of two kinds of neutrino. If this is true, reactions (2) and (4) cannot occur with neutrinos coming from pion decay.

The report will be presented in the following order: 1) a study of the kinematics of the simplest neutrino reactions; 2) the range-momentum of protons and muons in three materials (Al, Fe and Pb); 3) a study of the integral momentum spectrum of protons produced in the simplest neutrino reactions; 4) the measurement of momentum of proton, muon and electron in the three materials, as functions of plate thickness and neutrino energy; and 5) proposition for a type of spark chamber.

II. KINEMATICS

Let us consider the reactions

$$\nu + n \rightarrow p + \mu^- \qquad (1)$$

$$\rightarrow p + e^- \qquad (2)$$

and call:

φ_p^* = angle of emission of the proton in the centre-of-mass system (c.m.s.);

φ_p = angle of emission of the proton in the laboratory system (ℓ.s.);

$\varphi_\mu(\varphi_e)$ = angle of emission of the muon (electron) in the ℓ.s.;

P_p = momentum of the proton in the ℓ.s.;

$P_\mu(P_e)$ = momentum of the muon (electron) in the ℓ.s.;

E_ν = energy of the neutrino.

The kinematics of the two reactions have been computed in three different cases:

case a) in which the Fermi energy of the target neutron was assumed equal to zero;

case b) in which a head-on collision of the neutrino and a neutron with Fermi energy equal to 25 MeV was assumed;

case c) in which a collision between a neutrino and a neutron with Fermi energy of 25 MeV moving in the same direction was assumed.

The results are presented in Figures 1 to 8. In all diagrams the full lines are curves of constant neutrino energy and the dotted lines are curves of constant angle of emission of the proton in the c.m. system. Figures 1 and 2 show the relationship between φ_p and P_p, and between φ_μ and P_μ respectively, for case a) of reaction (1). The similar relations for cases a), b) and c) of reaction (2) are represented in Figs. 3 and 4, 5 and 6, and 7 and 8 respectively.

The diagrams corresponding to cases b) and c) for the muon production are not reproduced here because the results are nearly the same as those for the electron production.

III. RANGE-MOMENTUM RELATIONS

Three materials have been considered: aluminium, iron, and lead (we should, in fact, consider lead reinforced with antimony, which is a hard material). The curves of range (in millimetres)-momentum (in MeV/c) of muons and protons in those metals are represented in Fig. 9. Note that when range is measured in unit of length (not in g cm^{-2}) there is practically no difference between range in iron and in lead for the same momentum.

IV. INTEGRAL SPECTRUM OF MOMENTUM OF THE PROTONS

Let us consider the neutrino energy interval in which neutrino beams produced with the CERN PS are efficient-- ~ 200 MeV to ~ 1.5 GeV, with a maximum between ~ 500 and ~ 700 MeV, depending on the position of the detector. Figures 2, 4, 6 and 8 show that we shall have to measure muons and electrons with momenta greater than 100 MeV/c, possibly greater than 150 MeV/c, up to 1.5 GeV/c, with most of the cases below 1 GeV/c. It is very unlikely that the plates of the spark chamber will be thicker than 35 mm of Al or 20 mm of Fe. Then Fig. 9 shows us that we shall have no problem in seeing the muon or the electron (or the cascade) coming out of the plate where the reaction occurs.

Figures 1, 3, 5 and 7 show that the situation is different for the proton. Since they can be produced very slowly and be emitted at large angles, many protons will not leave the plate where they originated. In order to know how many will leave a plate of given thickness and given material we must know the momentum integral spectrum of the protons as a function of neutrino energy. This spectrum was computed for reaction (2), in two conditions:

i) without taking into account the Pauli principle and using the differential cross-sections computed by Lee and Yang[3], and by Yamaguchi[4]. The result is given in Fig. 10.

ii) Taking into account the effect of the Pauli principle and using the differential cross-sections computed by Berman[5]. The results for lead and for a conjugate nucleus are represented in Figs. 11 and 12 respectively.

Note that there is little difference on the integral spectrum if the Pauli principle is considered or not.

The kinematics relations necessary for this computation were extracted from Figs. 3 and 4.

V. MEASUREMENT OF MOMENTUM (OR ENERGY)

1. Protons

We must know the probability for a proton to leave the plate where it was produced and, when it leaves, how many plates it goes through.

The average place of interaction is the median plane of the plate. The diagrams of kinematics and the integral spectrum of the proton show that in most of the cases the proton will be emitted at an angle less than 45°. Take pessimistically 45° as the average φ_p. If t is the plate thickness, the average distance travelled by a proton before leaving the plate where it was produced is then 0.7 t.

The value of 0.7 t, taken to Fig. 9 gives the minimum momentum, p_{min}, for a proton to leave the plate. The value of p_{min} taken to the integral spectrum gives directly the probability, α, for a proton to leave the plate of thickness t, for a given enutrino energy. This procedure allows for comparison of the different thickness of the same material.

In order to compare different thicknesses of different materials we must take into account the difference in number of interactions which occur in different materials. Being ρ the density, the number of neutrino interactions is proportional to $t\rho$, and the number of protons that come out of the plate is proportional to $\alpha t \rho$. This quantity is plotted in Fig. 13 as a function of t for different neutrino energies for aluminium, iron, and lead.

Diagram 13 alone compares the efficiency of having one proton coming out of the plate where it was produced. By combining the information contained in diagrams 9, 10 and 13, we can compare the number of protons which pass through two plates, etc. We see that in a very wide range of t (from 3 to ~ 30 mm), 2.5 times more protons will come out of iron than out of aluminium with the same thickness, and about twice as many protons will go through two plates. Table I gives an average (relative to neutrino energy) probability for a proton to pass a certain number of gaps, assuming that the proton travels at 45° relative to the plates.

Table I

	1 gap	2 gaps	3 gaps
5 mm Al	0.85	0.70	0.65
10 mm Al	0.80	0.65	0.55
20 mm Al	0.70	0.55	0.40
5 mm Fe	0.75	0.65	0.55
10 mm Fe	0.70	0.50	0.35
20 mm Fe	0.55	0.35	0.20

In order to compare total numbers, the figures of Table I must be multiplied by the densities.

Lead gives better yield than iron, as far as the proton is concerned. We are neglecting lead in this discussion because the negative muons would be nearly all captured without decaying.

We conclude that as far as the measurement of the proton energy is concerned, iron plates of thickness from ~ 5 to ~ 10 mm are advantageous.

2. Muons

A fraction of muons is lost when they are emitted around 90°, but certainly less than protons. For comparison, Table II gives some ranges of high-energy muons in aluminium and iron. As far as range of muons is concerned, iron allows a more compact chamber.

Table II

Muon momentum (MeV/c)	Range in centimetres	
	Al	Fe
500	82	32
700	125	47
1000	184	73

However, the aluminium has the advantage that about five times more negative muons decay in aluminium than in iron. Apart from eventual technical difficulties in construction, lead has the great disadvantage that it absorbs practically all negative muons.

3. Electrons

In the absence of a magnetic field the energy of an electron must be measured from the cascade that it produces. The cascade theory does not help in making this estimate. As far as the author knows there are two experiments in which the energy of cascades was measured from the number of electrons produced in a multiplate cloud chamber. Hazen[6], by counting the cascade electrons produced in 1 cm thick copper plate, measured the energy of the primary electrons, in the range from ~ 200 MeV to ~ 1 GeV, within about 30%. Burmeister[7] measured in the range of a few MeV within about 25%. If no thick plate is used iron is better than aluminium for this measurement.

It can be said conservatively that the electron would be identified from the cascade and its energy measured within about 40%.

4. Influence of the intermediate boson

So far we have not considered the intermediate boson. If the intermediate boson exists, in the coherent process, for instance,

$$\nu + p \rightarrow p + W^{+} + \mu^{-},$$

both the proton and the μ^- will be slower than in reaction (1). This is an argument for not using very thick plates. The μ^+ which comes from the decay of the W^+ will be fast, and so the spark chamber should have a large number of thin plates.

VI. A POSSIBLE SPARK CHAMBER

From what was exposed above, a spark chamber made of iron plates 0.5 to 1.0 cm thick seems to be a reasonable neutrino detector. The possibility of existence of the intermediate boson is a further argument for not using thicker plates. Let us consider plates of 1 cm.

In order to use as anticoincidence shielding the counters that have already been made for the neutrino experiment a suggestion was made to construct plates of area 1 m × 1.6 m. However, an alternative solution can be plates of 1.5 m × 1.5 m, which have the following advantages:

a) the mass is 40% greater without any serious complication in geometry or in construction;

b) such a chamber could be photographed from two orthogonal directions, this being an advantage for the analysis and measurement of the events;

c) the efficiency in detection of secondaries emitted at large angles is greater.

The mass of each plate would be 175 kg. With 100 plates the total mass would be 17.5 tons. Taking into account events that cannot be measured because some tracks are not seen or leave the chamber, the effective mass of such a chamber should be about 10 to 12 tons.

As the last plates of chamber can only be used for analysis of particles produced in the precluding plates, the efficiency of the chamber will increase if the last plates are thick. The chamber could contain, for instance, 90 iron plates 1 cm thick, totalizing 15.8 tons, and 10 iron plates 3 cm thick which would make a compact 5.3 tons of material used mainly for measurement. The chamber would be about 2.5 m long.

1. Triggering

The construction of the chamber would be much simpler and cheaper if, instead of triggering by scintillators, a collection of plates of the chamber itself is used as spark counters. For instance, the voltage on these counters could be applied during the machine pulse and the spark chamber be triggered only if two or more counters work in a convenient coincidence arrangement.

If such triggering is used the iron plates should not be more than 1 cm thick. A test on this type of triggering will start within a few weeks.

2. Optics

The optics of such a chamber is being treated in a separate report.

VII. ACKNOWLEDGEMENTS

The author is grateful to Professors S.M. Berman, M. Deutschman, T.D. Lee and Dr. H. Burmeister for a series of very profitable discussions.

* * *

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1) S.M. Berman, private communication.

2) L.L.L. Vick, unpublished. Result presented at CERN in a seminar by Dr. E. Leader.

3) The author is grateful to Professor T.D. Lee for a very valuable discussion on this point and for having lent his unpublished notes on the differential cross-section.

4) Y. Yamaguchi, CERN Report 61-2.

5) The author is grateful to Professor S.M. Berman for having lent his results on differential cross-sections under the effect of the Pauli principle, prior to publication.

6) W. Hazen, Phys.Rev. **99**, 911 (1955).

7) H. Burmeister, Thesis, Technischen Hochschule, Aachen. The author is grateful to Drs. Burmeister and M. Deutschman for a discussion on this point.

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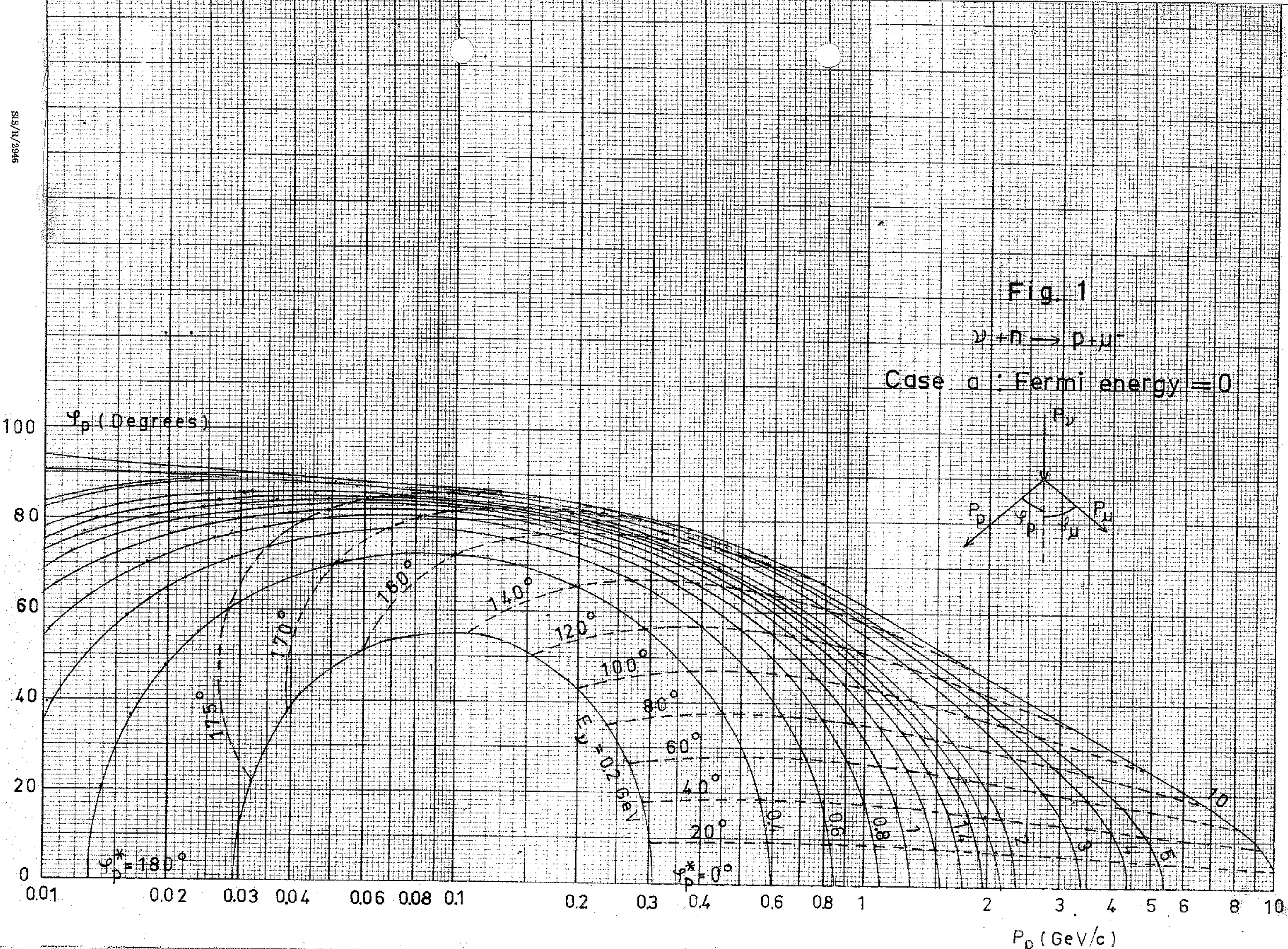

Fig. 1
ν + n ⟶ p + μ⁻
Case a : Fermi energy = 0
φp (Degrees)
Pp (GeV/c)
Pν
Pp
Pμ
φp
ψμ
Eν = 0.2 GeV
0.4
0.6
0.8
1
1.4
2
3
4
5
10
φp* = 180°
175°
170°
160°
140°
120°
100°
80°
60°
40°
20°
φp* = 0°
100
80
60
40
20
0
0.01
0.02
0.03
0.04
0.06
0.08
0.1
0.2
0.3
0.4
0.6
0.8
1
2
3
4
5
6
8
10

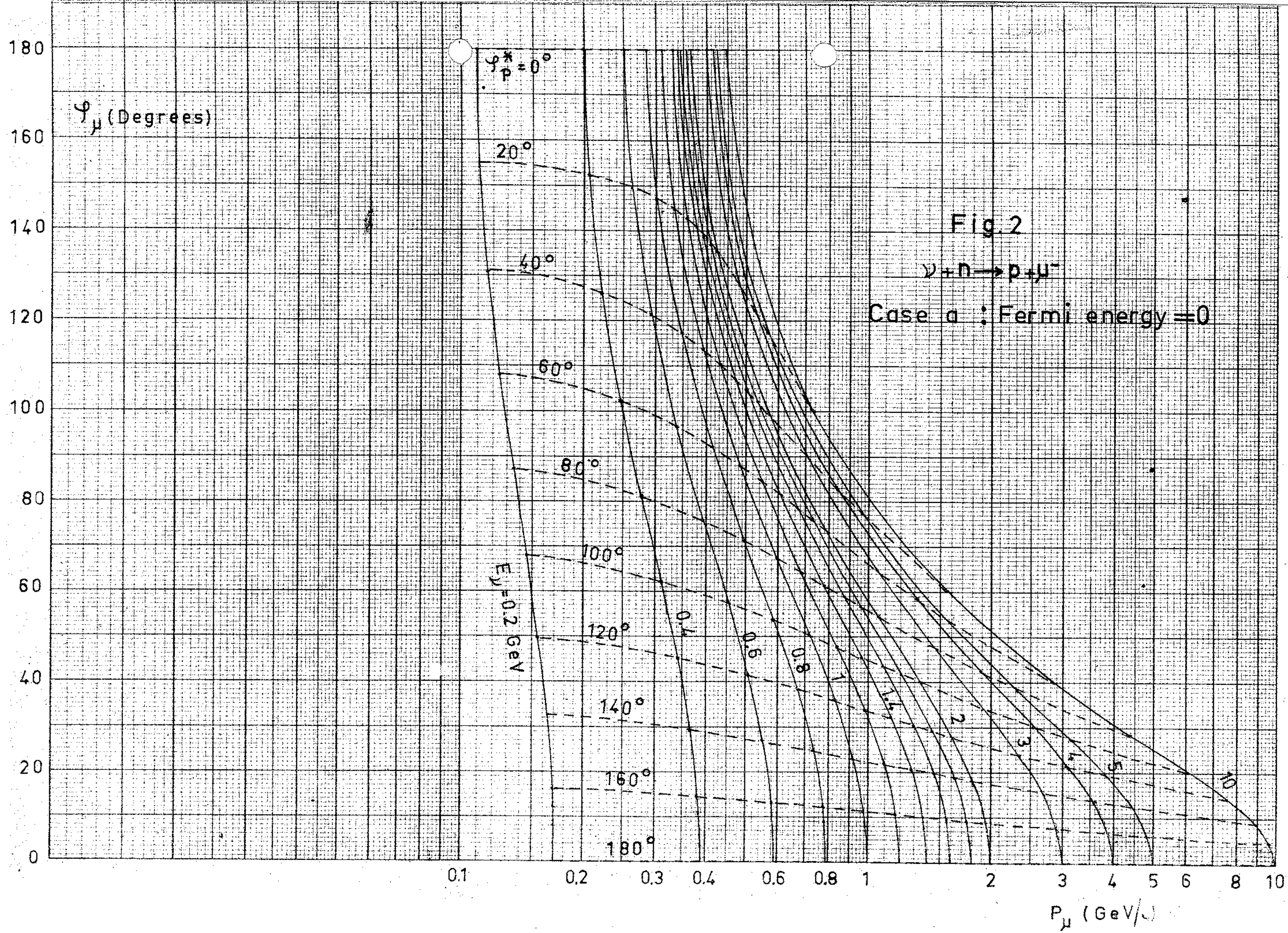

Fig. 2

$\nu + n \rightarrow p + \mu^-$

Case a : Fermi energy = 0

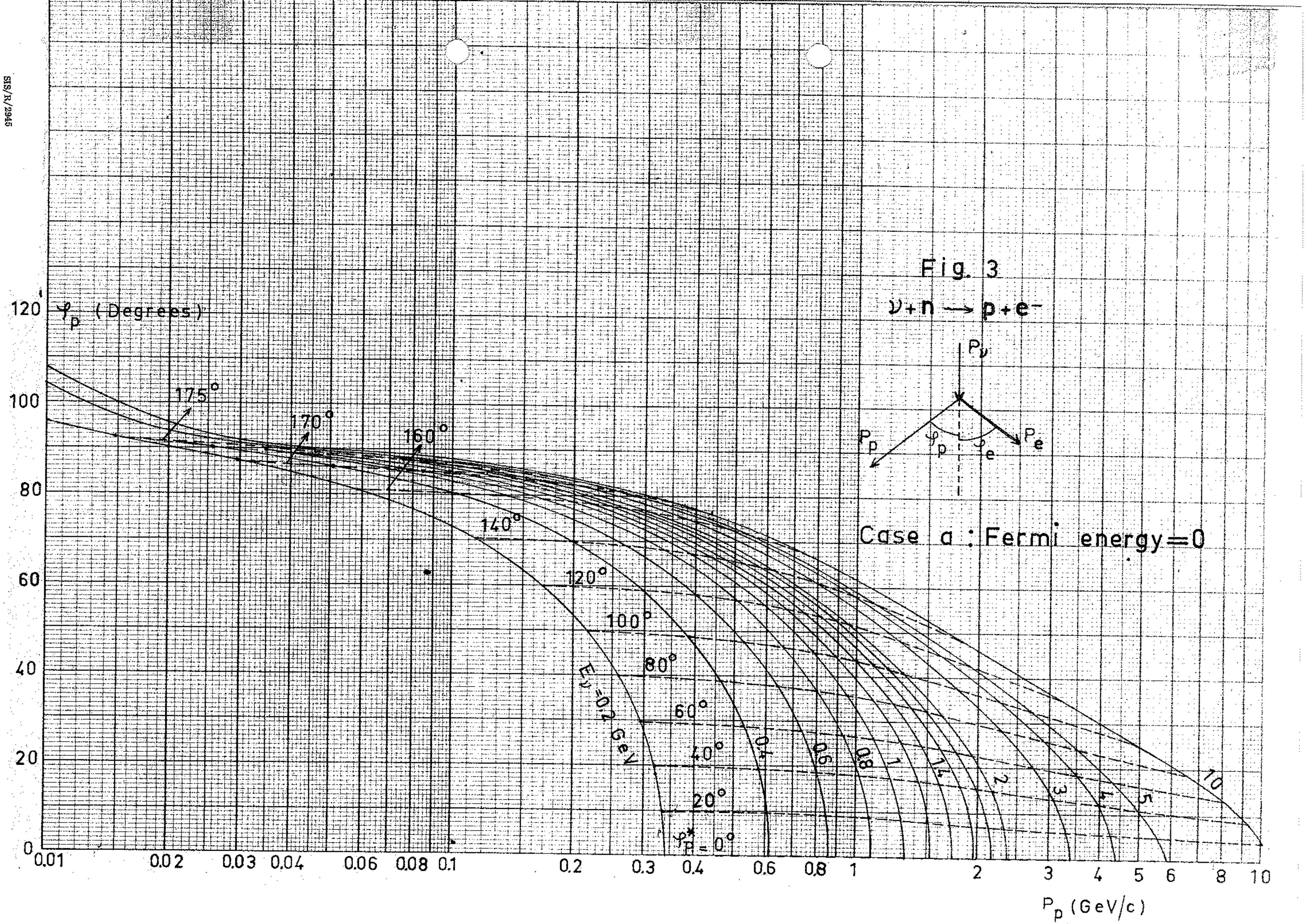

Fig. 3
$\nu + n \longrightarrow p + e^-$
Case a : Fermi energy = 0
φ_p (Degrees)
P_p (GeV/c)
P_ν
P_p
P_e
φ_p
φ_e
175°
170°
160°
140°
120°
100°
80°
60°
40°
20°
$\varphi_p^* = 0°$
$E_\nu = 0.2$ GeV
0.4
0.6
0.8
1
1.4
2
3
4
5
10

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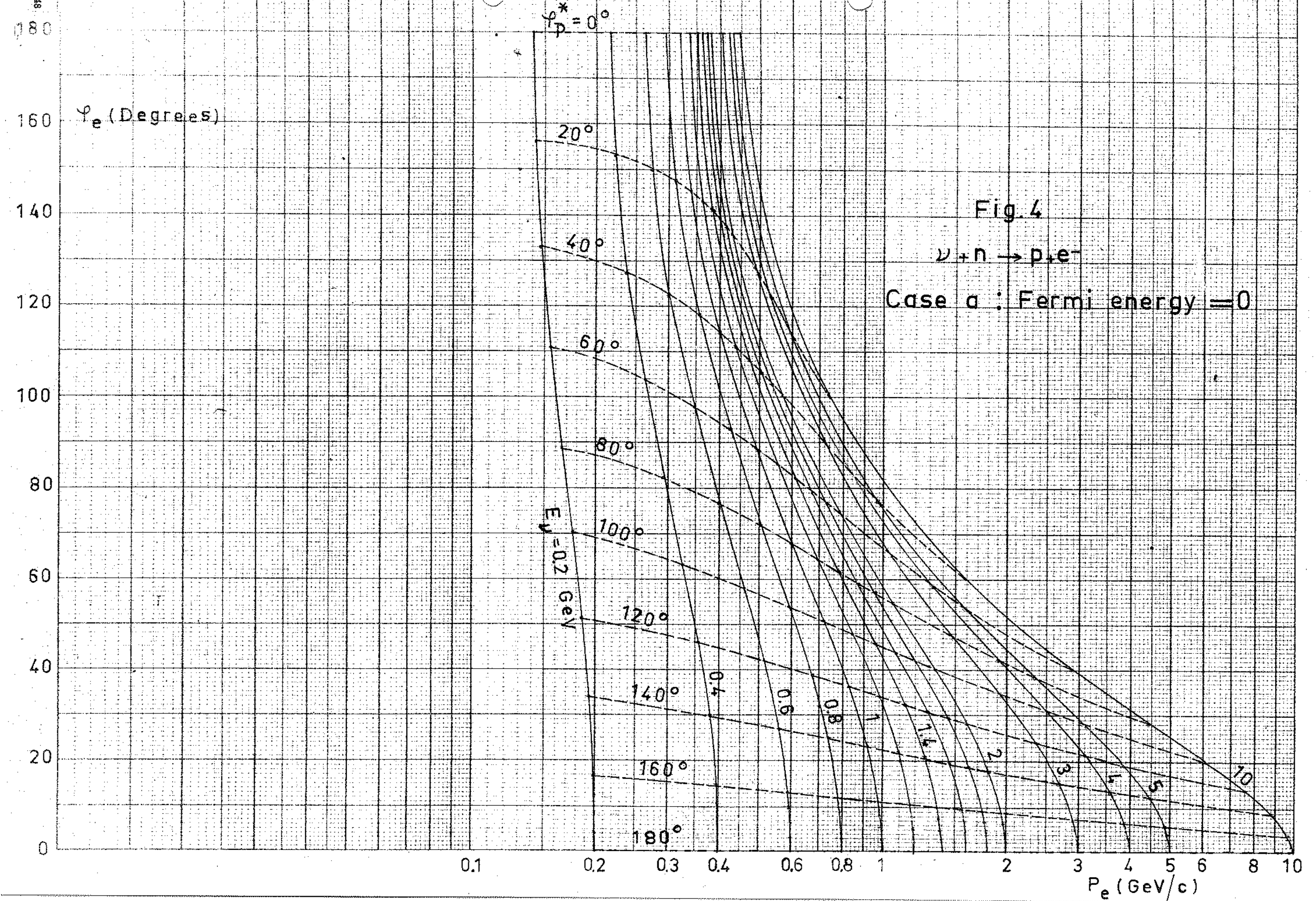

Fig. 4

$\nu + n \to p + e^-$

Case a : Fermi energy = 0

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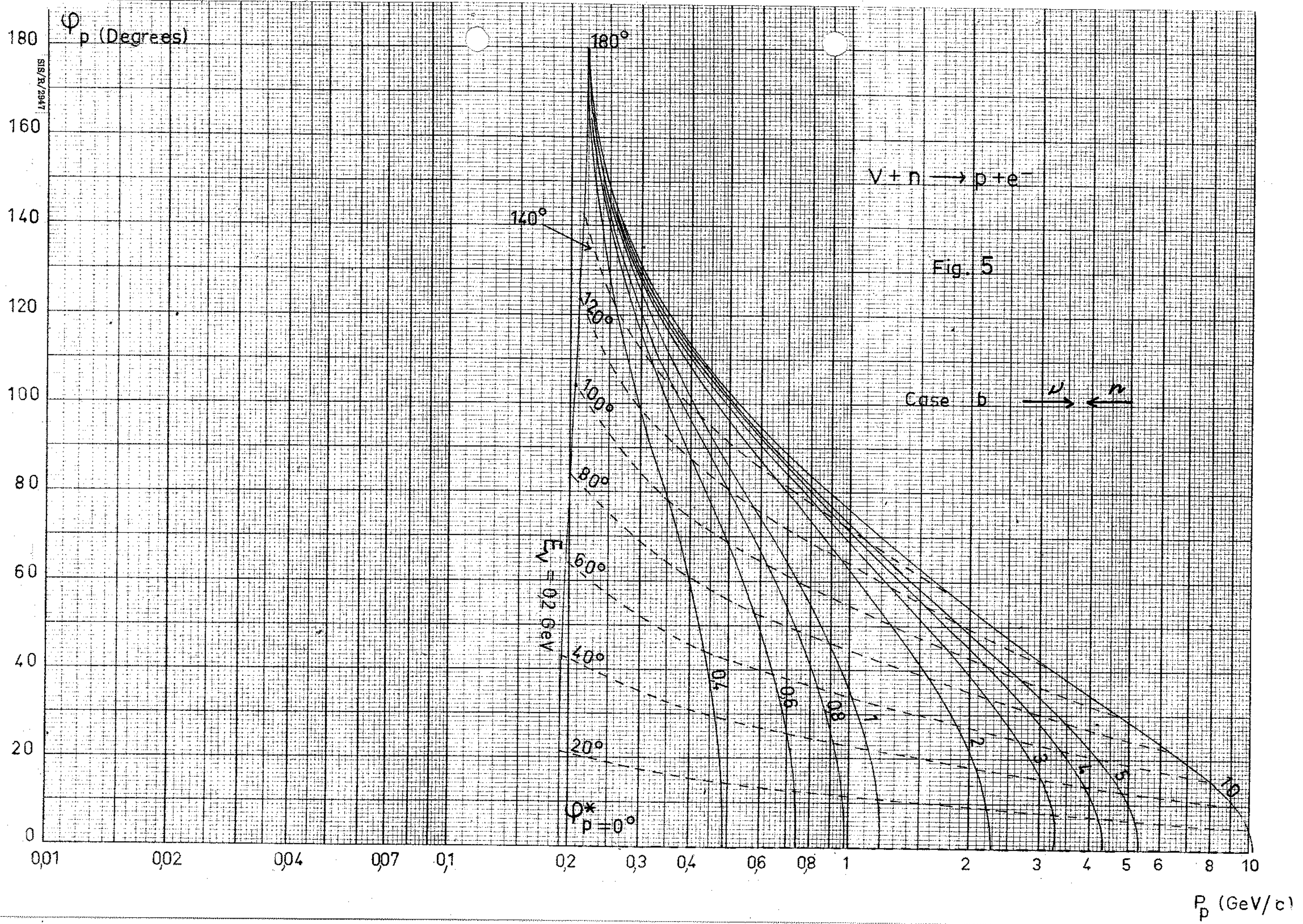
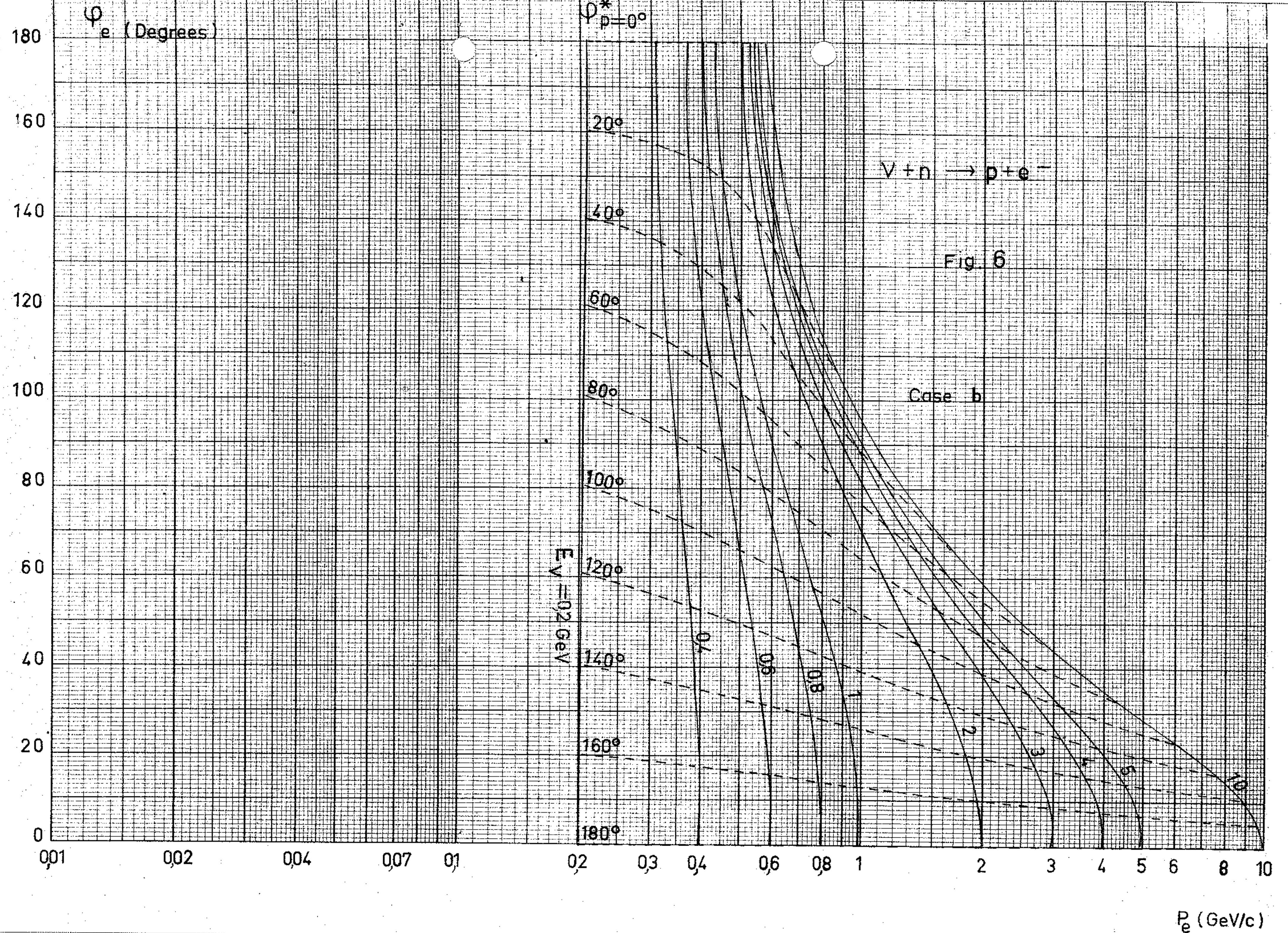


φp (Degrees)
SIS/R/2947
180°
140°
120°
100°
80°
60°
40°
20°
φ*p = 0°
Eν = 0,2 GeV
0,4
0,6
0,8
1
2
3
4
5
10
ν + n ⟶ p + e⁻
Fig. 5
Case b
ν
n
180
160
140
120
100
80
60
40
20
0
0,01
0,02
0,04
0,07
0,1
0,2
0,3
0,4
0,6
0,8
1
2
3
4
5
6
8
10
Pp (GeV/c)



φe (Degrees)
φ*p=0°
ν + n → p + e⁻
Fig. 6
Case b
Eν = 0,2 GeV
20°
40°
60°
80°
100°
120°
140°
160°
180°
0,4
0,6
0,8
1
2
3
4
5
10
180
160
140
120
100
80
60
40
20
0
0,01
0,02
0,04
0,07
0,1
0,2
0,3
0,4
0,6
0,8
1
2
3
4
5
6
8
10
Pe (GeV/c)

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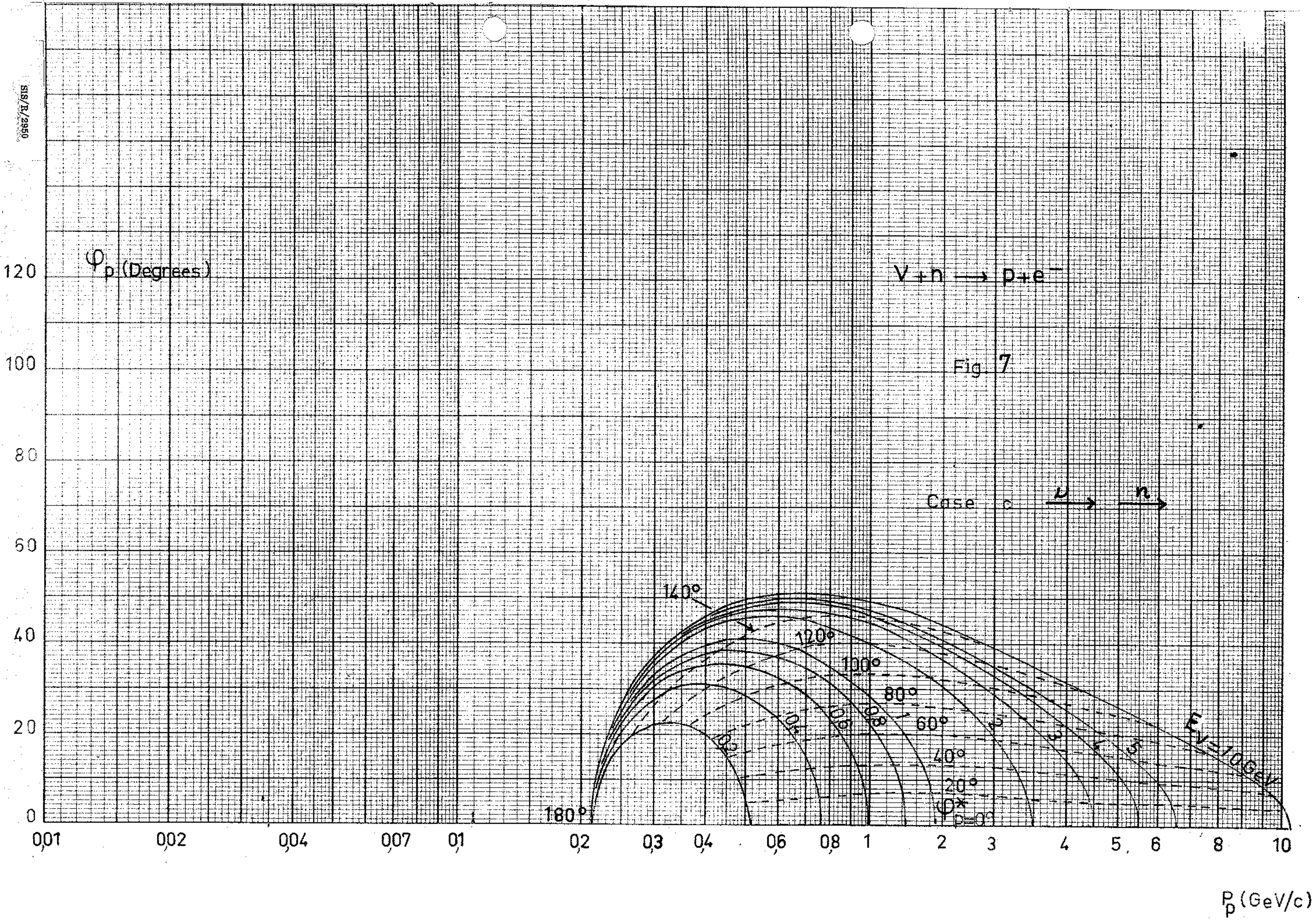
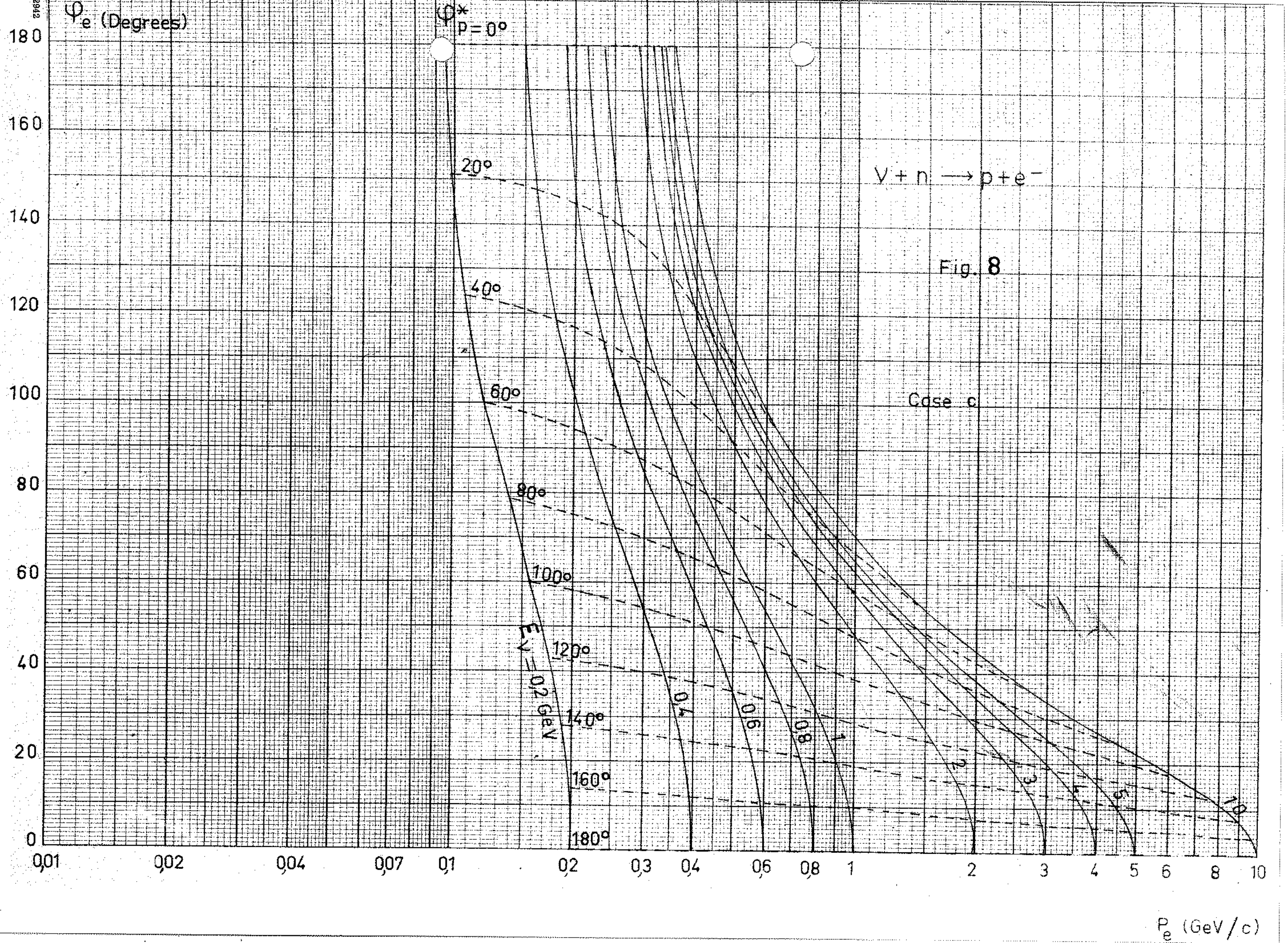
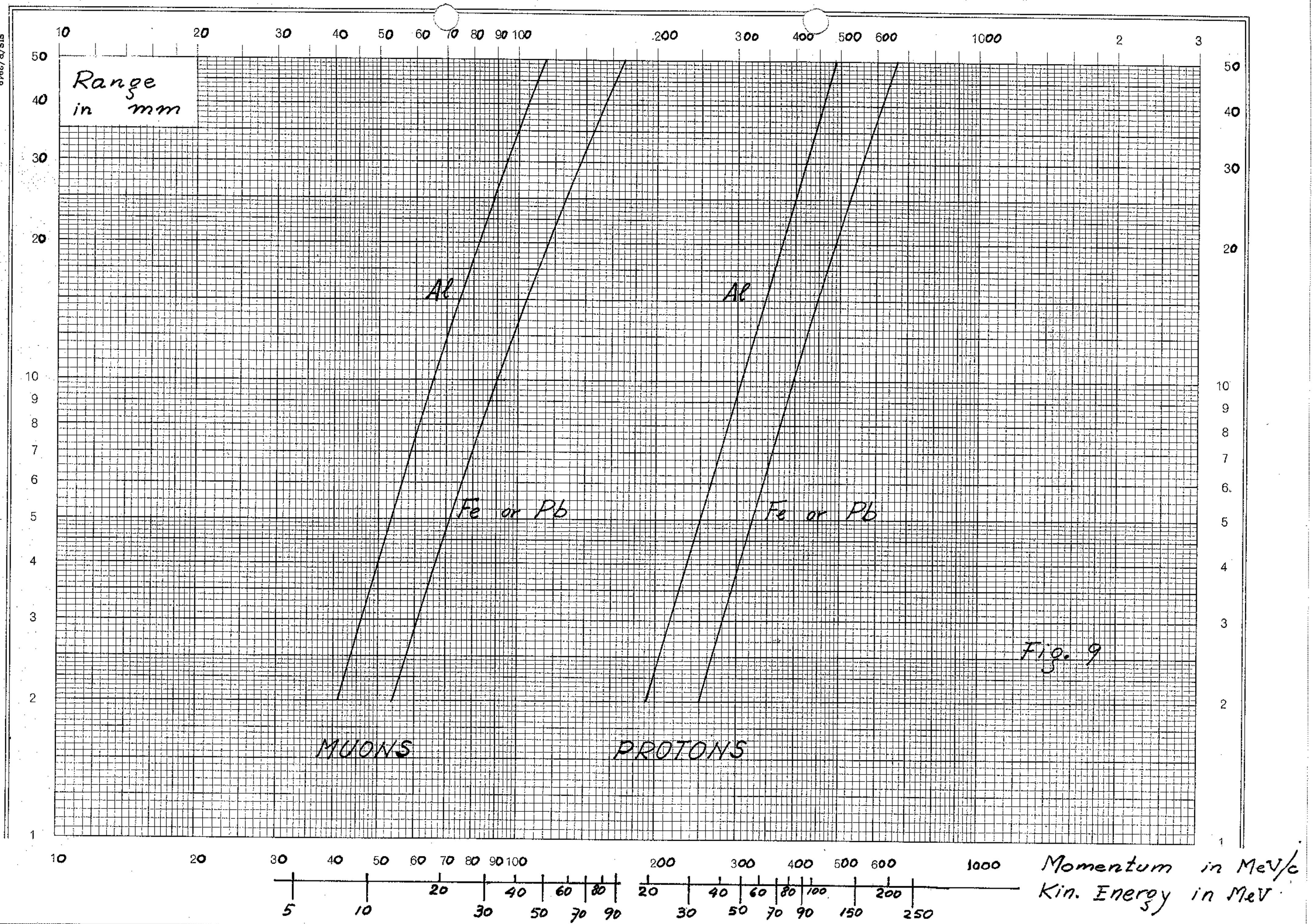

φp (Degrees)
120
100
80
60
40
20
0
ν + n ⟶ p + e⁻
Case c
ν
n
140°
120°
100°
80°
60°
40°
20°
180°
φ*p = 0°
0,2
0,4
0,6
0,8
1
2
3
4
5
Eν = 10 GeV
0,01
0,02
0,04
0,07
0,1
0,2
0,3
0,4
0,6
0,8
1
2
3
4
5
6
8
10
Pp (GeV/c)

Fig. 7



φe (Degrees)
φ*p = 0°
20°
40°
60°
80°
100°
120°
140°
160°
180°
Eν = 0,2 GeV
0,4
0,6
0,8
1
2
3
4
5
10
ν + n ⟶ p + e⁻
Case c
180
160
140
120
100
80
60
40
20
0
0,01
0,02
0,04
0,07
0,1
0,2
0,3
0,4
0,6
0,8
1
2
3
4
5
6
8
10
Pe (GeV/c)

Fig. 8


Range in mm
Al
Fe or Pb
Al
Fe or Pb
MUONS
PROTONS
Fig. 9
Momentum in MeV/c
Kin. Energy in MeV

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INTEGRAL SPECTRUM OF MOMENTUM OF PROTONS

FROM THE REACTION $\nu + n \rightarrow p + e^-$

The curves give percentage of protons with momentum greater than p for constant neutrino energy E_ν.

Fermi energy of neutron assumed equal to zero.

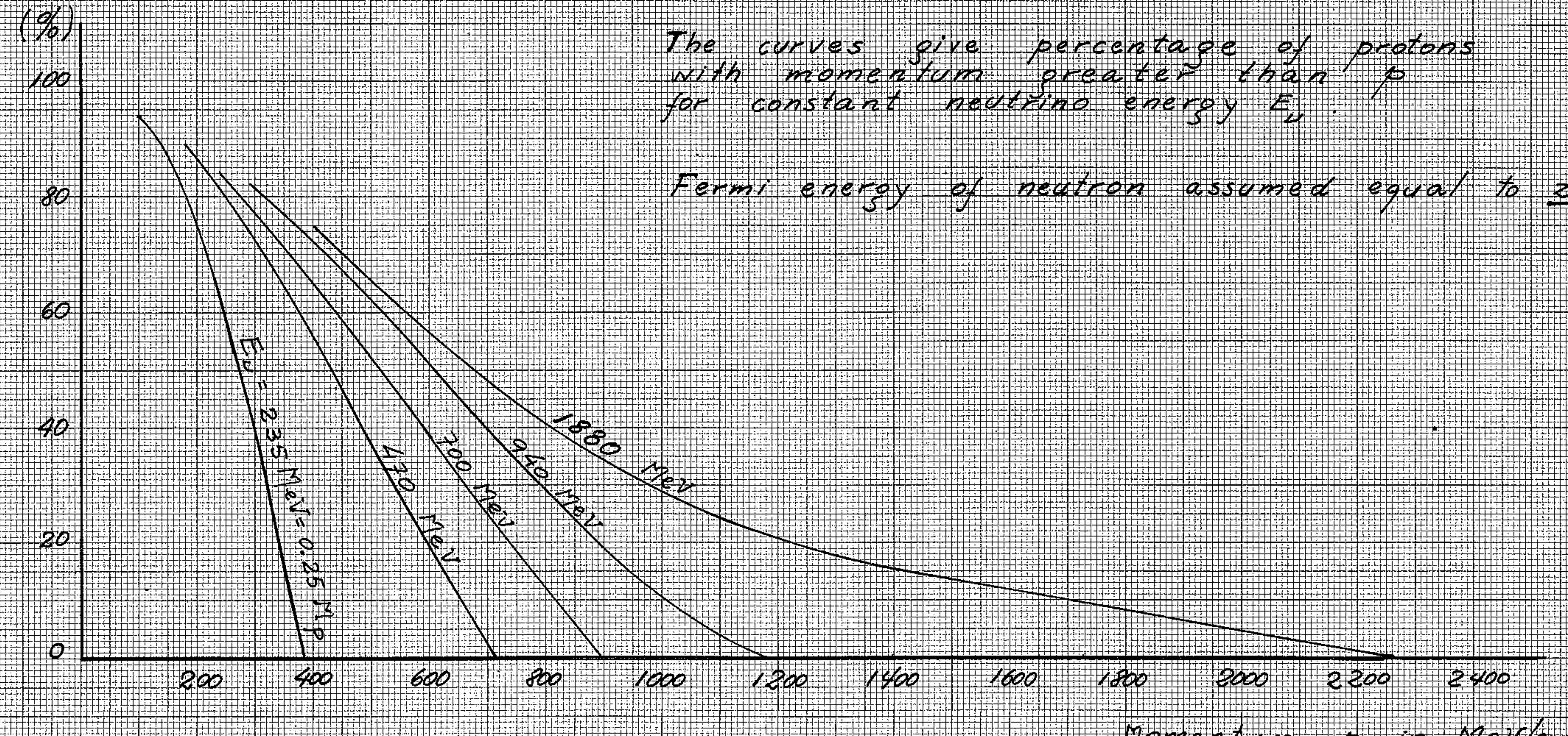


Fig. 10

INTEGRAL SPECTRUM OF MOMENTUM OF PROTONS FROM THE REACTION $\nu + n \rightarrow p + e^-$

The curves give percentage of protons with momentum greater than p for constant neutrino energy E_ν.

Fermi energy of neutron assumed equal to zero.

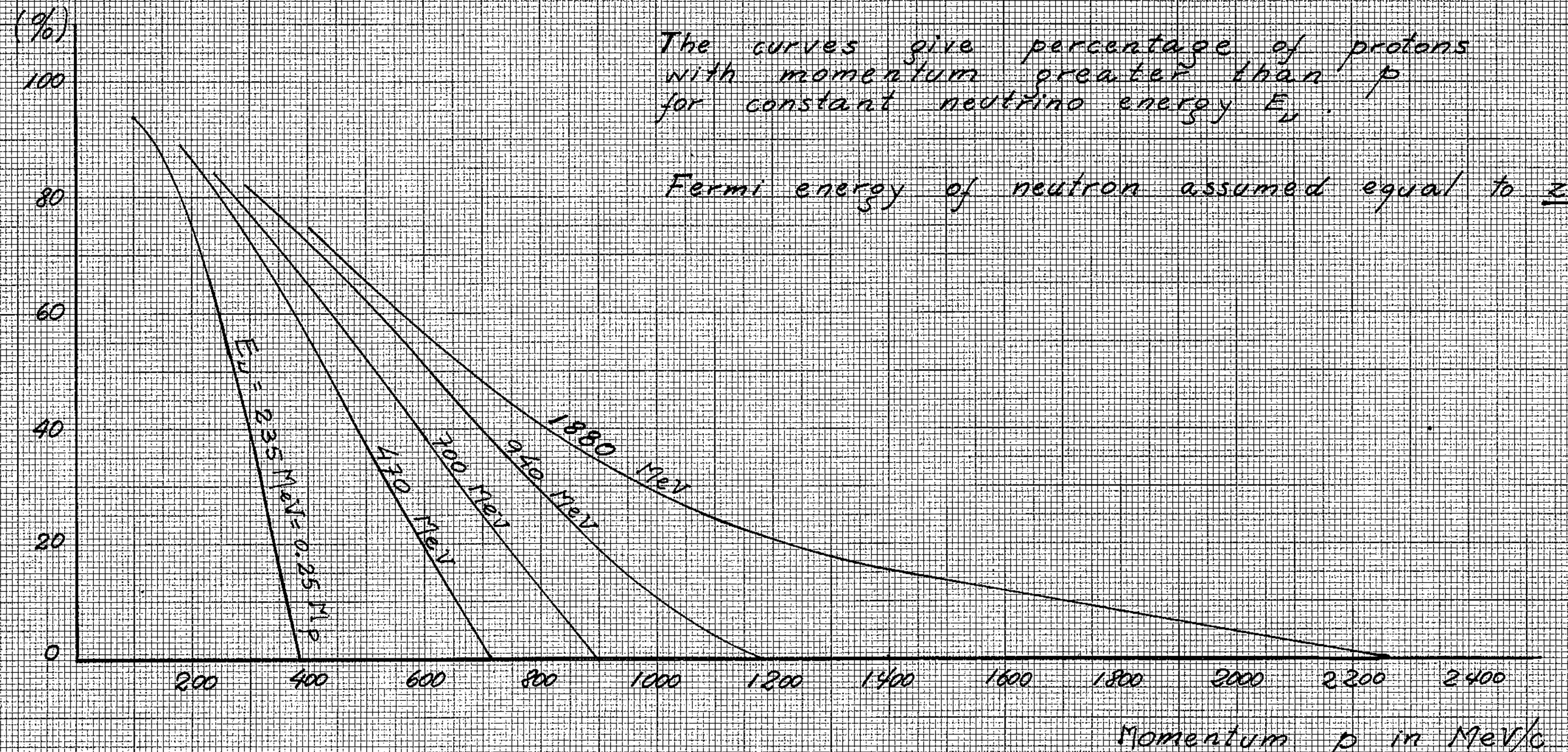


Fig. 10

<u>INTEGRAL SPECTRUM OF MOMENTUM OF PROTONS</u>

<u>FROM THE REACTION $\nu + n \rightarrow p + e^-$</u>

The curves give percentage of protons with momentum greater than p for constant neutrino energy E_ν

Reaction in <u>lead</u>

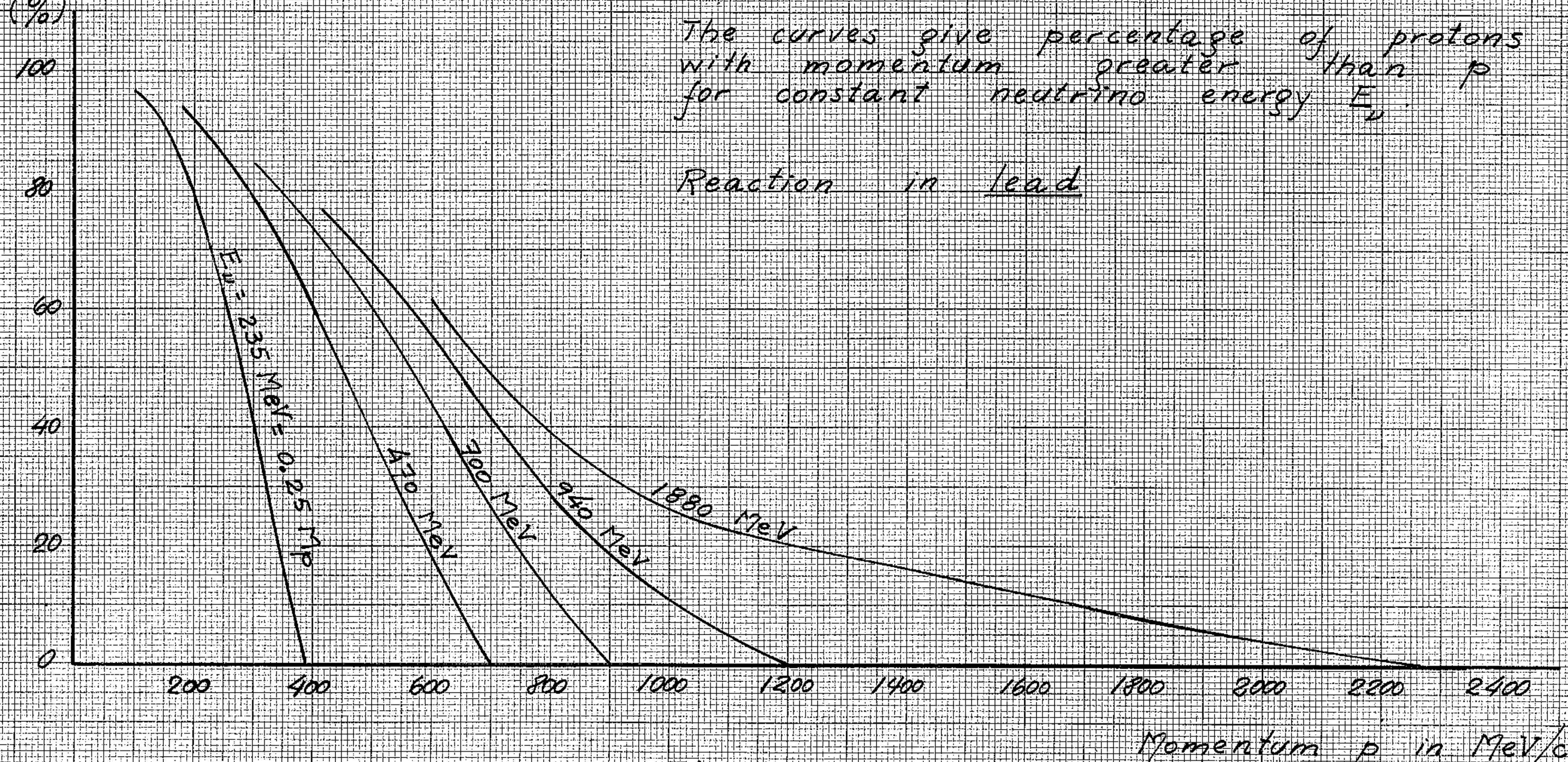


Fig. 11

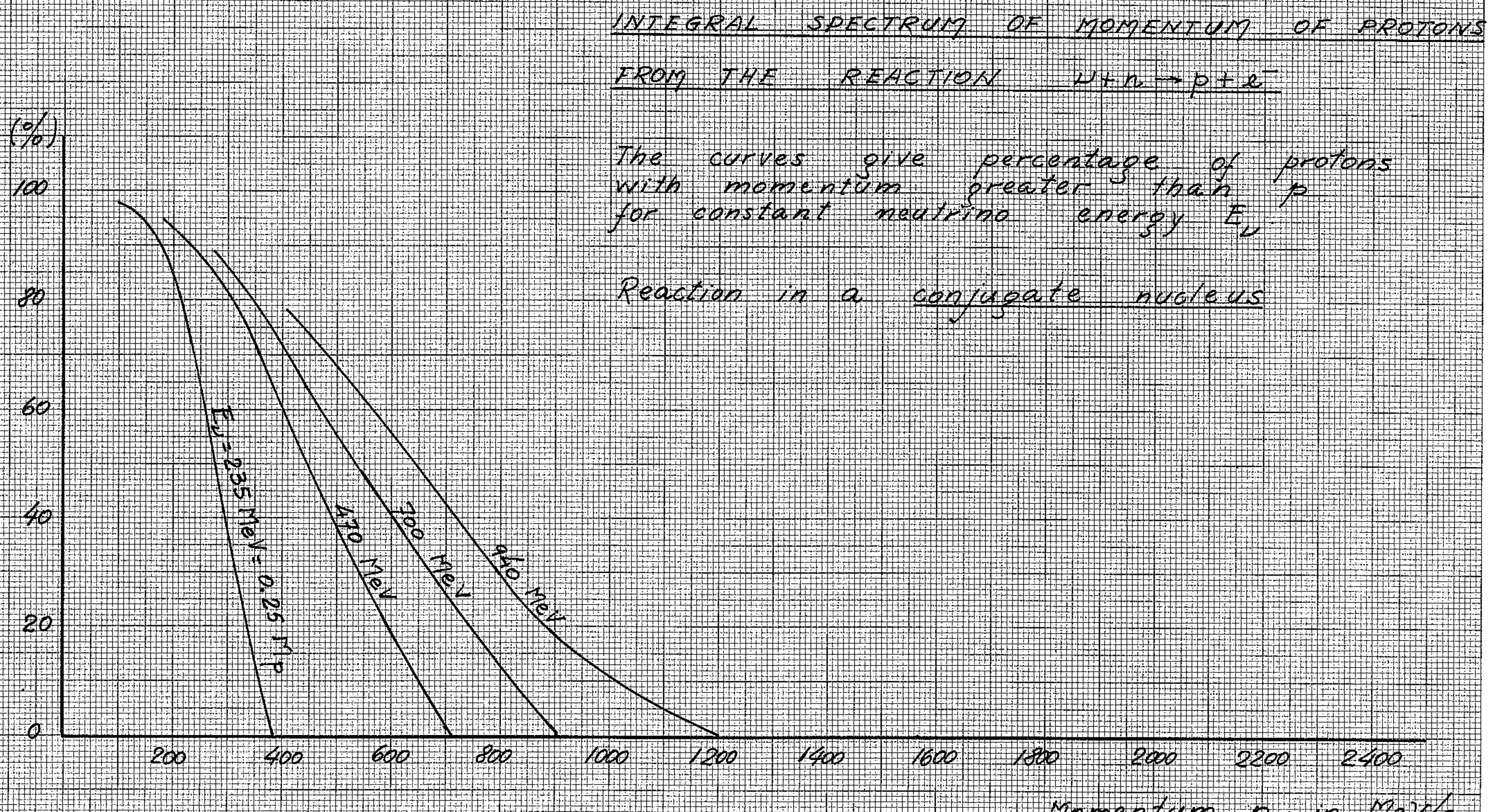
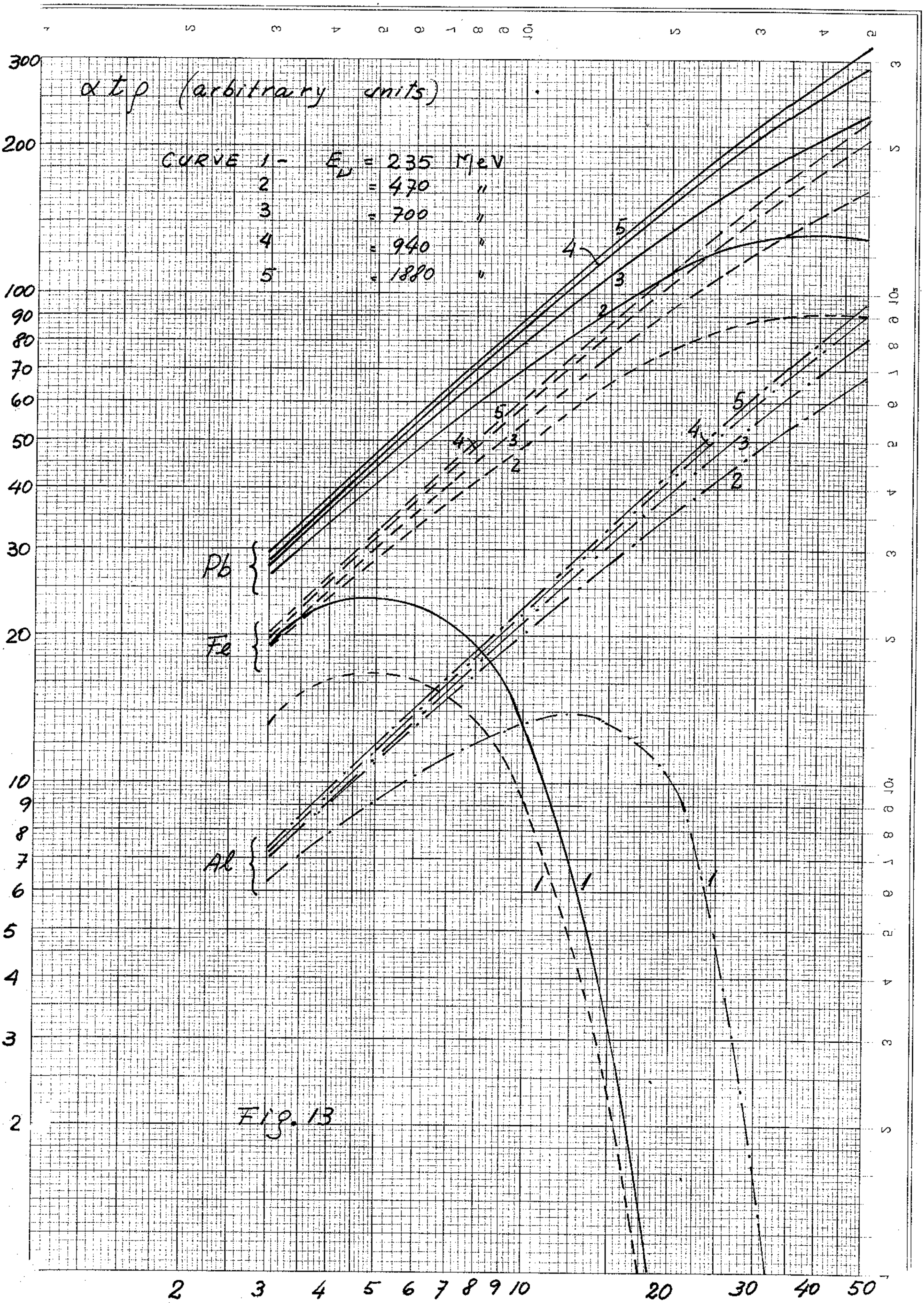

INTEGRAL SPECTRUM OF MOMENTUM OF PROTONS
FROM THE REACTION $\nu + n \rightarrow p + e^-$
The curves give percentage of protons with momentum greater than p for constant neutrino energy E_ν
Reaction in a conjugate nucleus
(%)
100
80
60
40
20
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
E_ν = 235 MeV = 0.25 M_p
470 MeV
700 MeV
940 MeV
Momentum p in MeV/c

Fig. 12



αtρ (arbitrary units)
CURVE 1 - Eν = 235 MeV
2 = 470 "
3 = 700 "
4 = 940 "
5 = 1880 "
Pb
Fe
Al
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
2
3
4
5
6
7
8
9
10
20
30
40
50
t (mm)

Fig. 13