NPA/Int. 63-7
Meyrin, 19th February 1963

AN ESTIMATE OF THE AMOUNT OF ADDITIONAL INFORMATION WHICH WOULD BE FURNISHED BY AN AUXILIARY SPARK CHAMBER USED WITH THE CERN H.L.B.C. DURING THE NEUTRINO EXPERIMENT

1. Introduction

One of the objects of the neutrino experiment is to study the reaction

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

To do this it is important to be able to distinguish the muon from a pion which could be produced by a neutrino or by a neutron entering the chamber. If the particle is of low momentum and is seen to stop in the chamber then the distinction can be made since a negative pion will almost always be absorbed by a nucleus whereas a negative muon will in half the cases decay, yielding a visible electron. However, when the particle has sufficient momentum to leave the chamber it can only show itself to be a pion if it interacts, and since the dimension of the chamber is of the order of one interaction length, it is by no means certain to do so. Thus it will happen that interactions are observed which yield a negative secondary that leaves the chamber, and it will not be possible to decide if it is a pion or a muon.

It has been suggested that if a large spark chamber were placed in the neutrino beam downstream of the H.L.B.C. then a particle which left the chamber and gave a corresponding spark in the spark chamber, would be certainly a muon, since a pion would have a negligible probability of penetrating the large amount of material in the coils and yoke of the magnet. However, only the highest energy muons would be able to penetrate to the spark chamber and it was the object of the present work to estimate in what proportion of cases of the above reaction the proposed spark chamber would give useful information.

2. Data and principal approximations

The geometry of the chamber, coils and yoke was assumed to be that shown in Fig. 1. Fig. 1 a is a vertical section through the centre of the chamber perpendicular to its axis and Fig. 1 b is a horizontal section passing through the axis of the chamber. The axial magnetic field was taken to be 27 kGauss at the centre of the chamber; the radial variation across the chamber and the coils was then found from the measurements of S. Pichler and G. Pluym [1]. The field was assumed to be zero between the coils and the yoke, and the return flux density in the yoke was taken to be uniform and equal to 16 kGauss.

All muons were assumed to be produced at the centre of the chamber. The energy loss by muons crossing the chamber, coils and yoke was taken into account by assuming a constant rate of loss of momentum, $\left(\frac{dp}{dt}\right)$, of 1.7 MeV/c per gm/cm^2, irrespective of the medium. This is a good approximation at relativistic energies. To allow for the fact that the copper conductors of the coils contain channels for the cooling water, the density of the copper was taken to be 0.7 times the normal density.

The calculation was performed for a spark chamber covering the entire vertical face of the yoke; this corresponds to an area of 2.8 sq. metres.

3. The method

The trajectories of muons emitted at the centre of the chamber and in a plane perpendicular to its axis (the "median plane"), were found graphically for momenta of 1.27, 1.37, 1.5, 1.6, 1.9 and 3.0 GeV/c. The initial direction of a muon was described by its angle α to the horizontal plane. Using a transparent template consisting of a scale drawing of a vertical section of the yoke, the maximum values of α within which the muon would enter the spark chamber were determined for each muon momentum. At the lower muon momenta the limits were determined by the ranges of the particles since the thickness of iron to be penetrated increased with increasing values of α. At the higher momenta the limits of α tended to be those determined by the restriction that the emerging muon should pass through the area supposed to be covered by the spark chamber. The results of this computation are shown in Fig. 2.

When the muon was not emitted in the median plane, its direction was defined by the angle α of its initial direction projected on to the median plane, and by the angle ψ between the direction of the muon and the medium plane. To the accuracy of the approximations already introduced the projection on to the median plane of a particle of momentum p is the same as the path of a particle of momentum p cos ψ moving in the median plane. Thus the range of permissible values of α could be found from the curve shown in Fig. 2. However, for large values of ψ there is an additional restriction that the displacement of the muon in the axial direction must be less than the axial extension of the spark chamber. This introduces a further coupling between the value of ψ and the range of α in addition to the kinematical one. However, since the former coupling only arises at the extreme values of ψ and since it would lengthen the calculation considerably to take it into account fully, it has been considered approximately by cutting off the permissible area in the (α, ψ) plane squarely at values of ψ corresponding to the actual dimensions of the yoke and an average value of the projected path length of an emerging muon. The error introduced by this approximation is considered to be less than 10 o/o.

It was desired to find the limits of muon emission angle α corresponding to an incident neutrino of a given momentum. In this case the muon momentum is a function of the angle of emission. This function is plotted in Fig. 2 for a neutrino momentum of 1.5 GeV/c. The limits of α were then found from the intersection points A and B in Fig. 2. Thus, using the results obtained so far, it was possible to construct, for each neutrino momentum, a contour in the (α, ψ) plane within which the muon would enter the spark chamber. These contours were then transformed into contours in a (θ, φ) plane, where O and φ are the polar and azimuthal angles of the muon relative to the neutrino direction and the horizontal plane respectively. The contour for neutrino momentum 1.5 GeV/c is shown in Fig. 3.

In order to calculate the relative numbers of muons entering the spark chamber it was necessary to make some assumption about the unknown angular distribution of muons. The simplest assumption is that they are emitted isotropically in the centre-of-momentum system of the neutron and neutrino. On this basis circles were drawn on the (θ, φ) diagrams such that 10 o/o of the muons were emitted in the anuli between the circles. The fraction of muons entering the spark chamber was found for each neutrino momentum by measuring the area of that part of each anulus whic' was enclosed by the contour. The measurements of area were made with a planimeter. The calculation was performed for five different neutrino energies and the results for the fraction of muons which would enter the spark chamber are shown in Fig. 4. The end point at low neutrino momentum was estimated from the momentum below which a muon would be unable to emerge from the yoke.

The distribution in energy of neutrino interactions to be expected in the bubble chamber can be found from the predicted neutrino interaction cross section of T.D. Lee and C.N. Yang [2)], and the incident neutrino spectrum calculated by S. van der Meer [3)] from the characteristics of the magnetic horn. This distribution is shown in Fig. 5. The relative number of muons which enter the spark chamber was then found by multiplying the ordinates of the curves in Figs 4 and 5 and integrating numerically over neutrino momentum. The integral was then compared to the total number of neutrino produced muons, which is proportional to the area under the curve of Fig. 5.

4. The result

The result of the calculation was that 4.9 o/o of all muons would pass through a spark chamber placed against the yoke of the bubble chamber magnet. For comparison, the figure for muons which would stop in the chamber, assuming a magnetic field of 27 kGauss, has been estimated to be 3.5 o/o.

The energy spectrum of neutrino interactions which would be characterised by a muon stopping in the bubble chamber, and also the spectrum of interactions which would result in a muon entering the spark chamber are both shown in Fig. 5.

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References

1) S. Pichler, G. Pluym - Measurement of the magnetic field of the heavy liquid bubble chamber magnet, NPA/Int. 62-2

2) T.D. Lee, and C.N. Yang - Theoretical discussion on possible high energy neutrino experiments, Phys. Rev. Letters. 4, 307 (1960)

3) S. van der Meer - A directive device for charged particles and its use in an enhanced neutrino beam

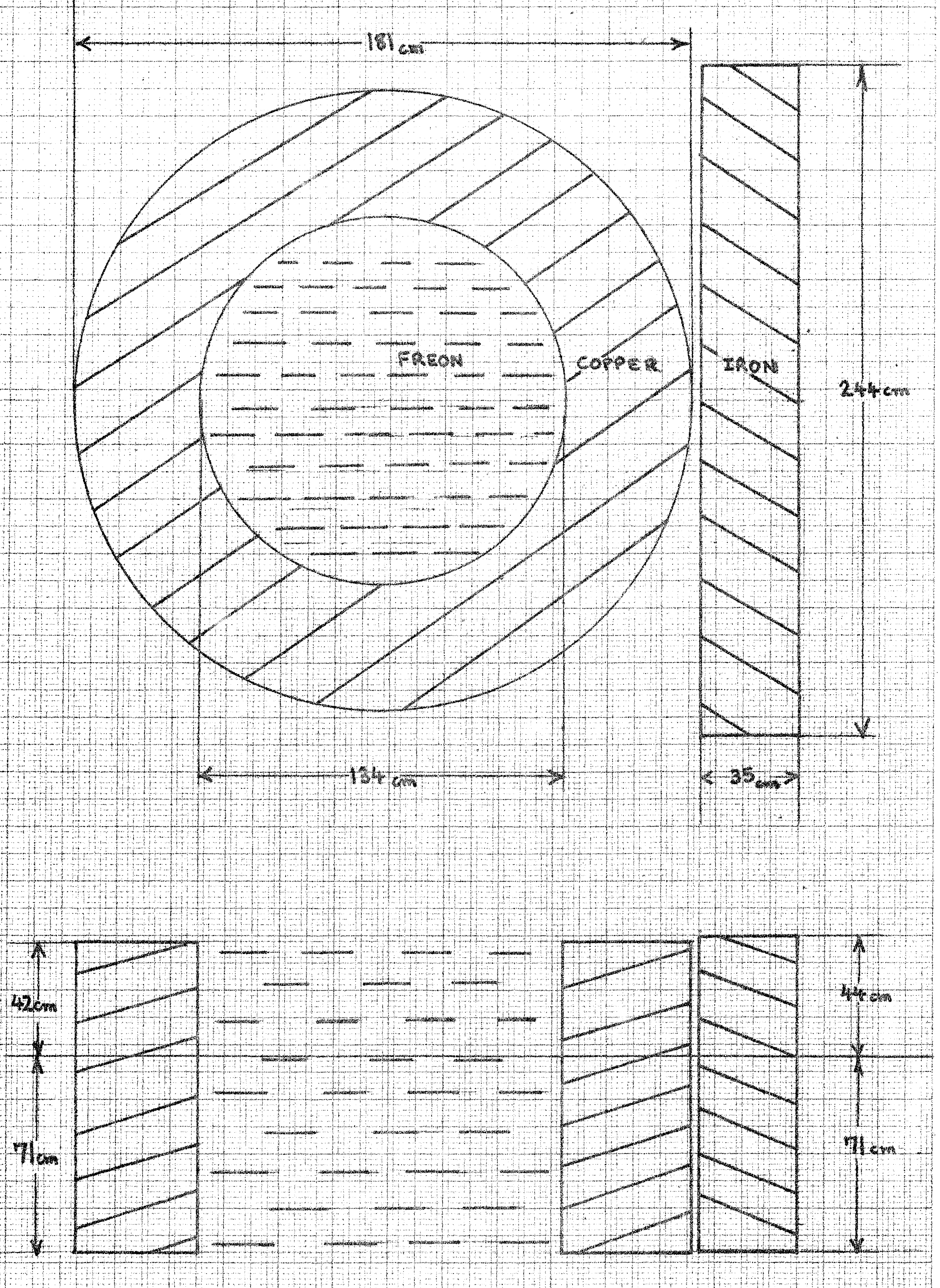
181 cm
FREON
COPPER
IRON
244 cm
134 cm
35 cm
42 cm
71 cm
44 cm
71 cm

Fig. 1.

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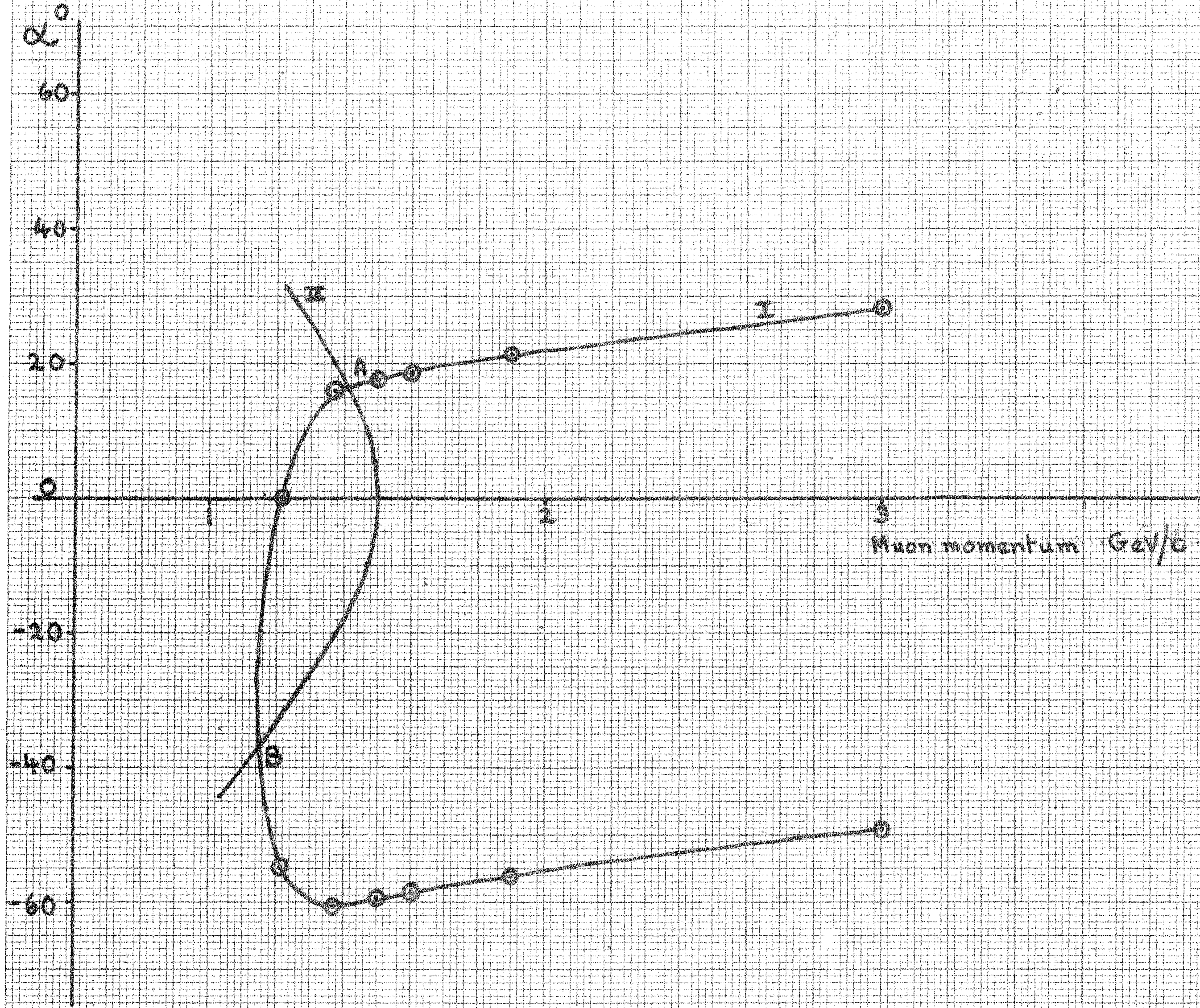

I Limits of angle α versus muon momentum

II Variation of muon momentum with emission angle α for fixed neutrino momentum (1·5 GeV/c)

Fig. 2.

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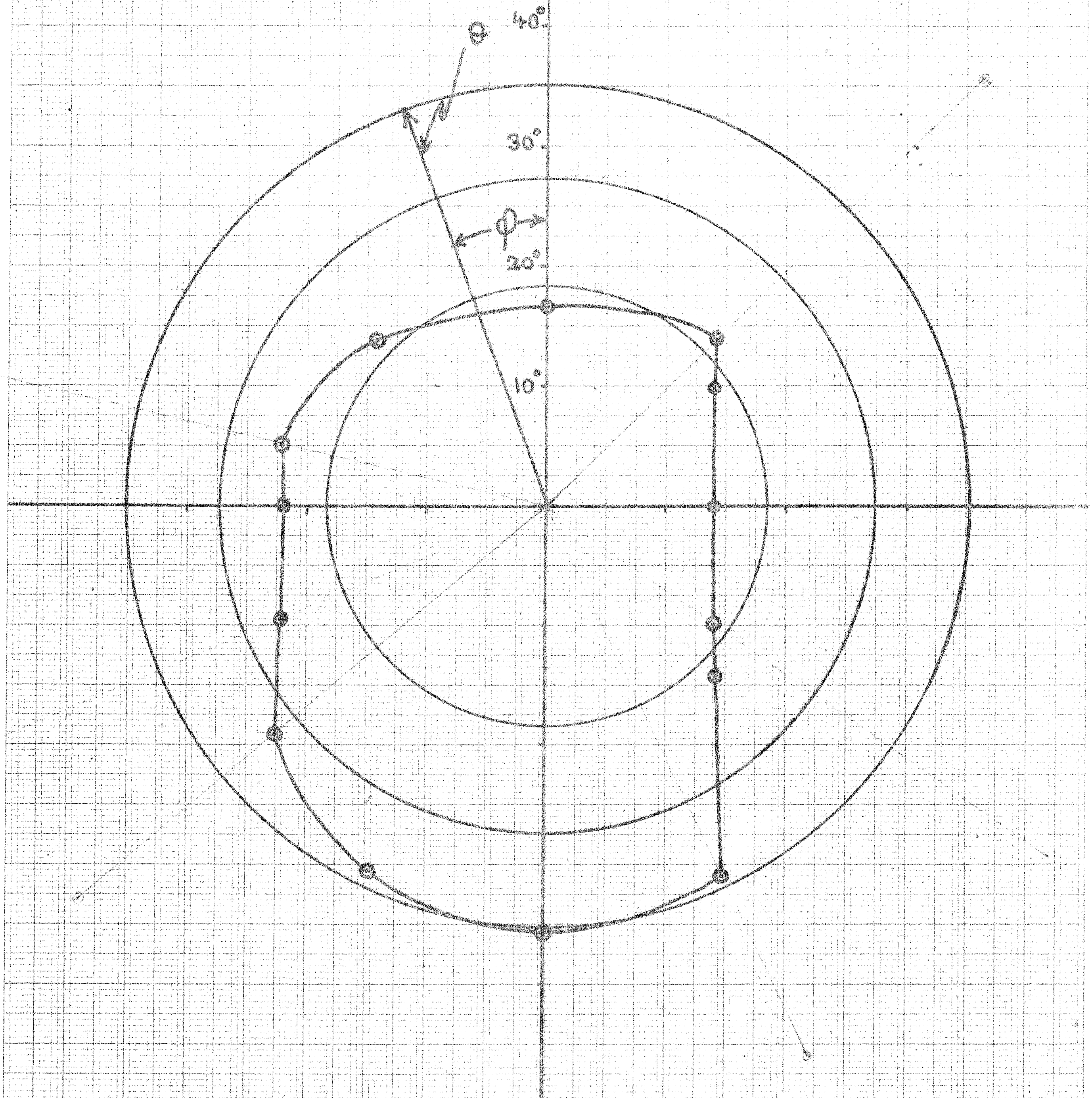

Contour in (θ, φ) plane and the angular distribution of muons for neutrino momentum 1·5 GeV/c

Fig. 3.

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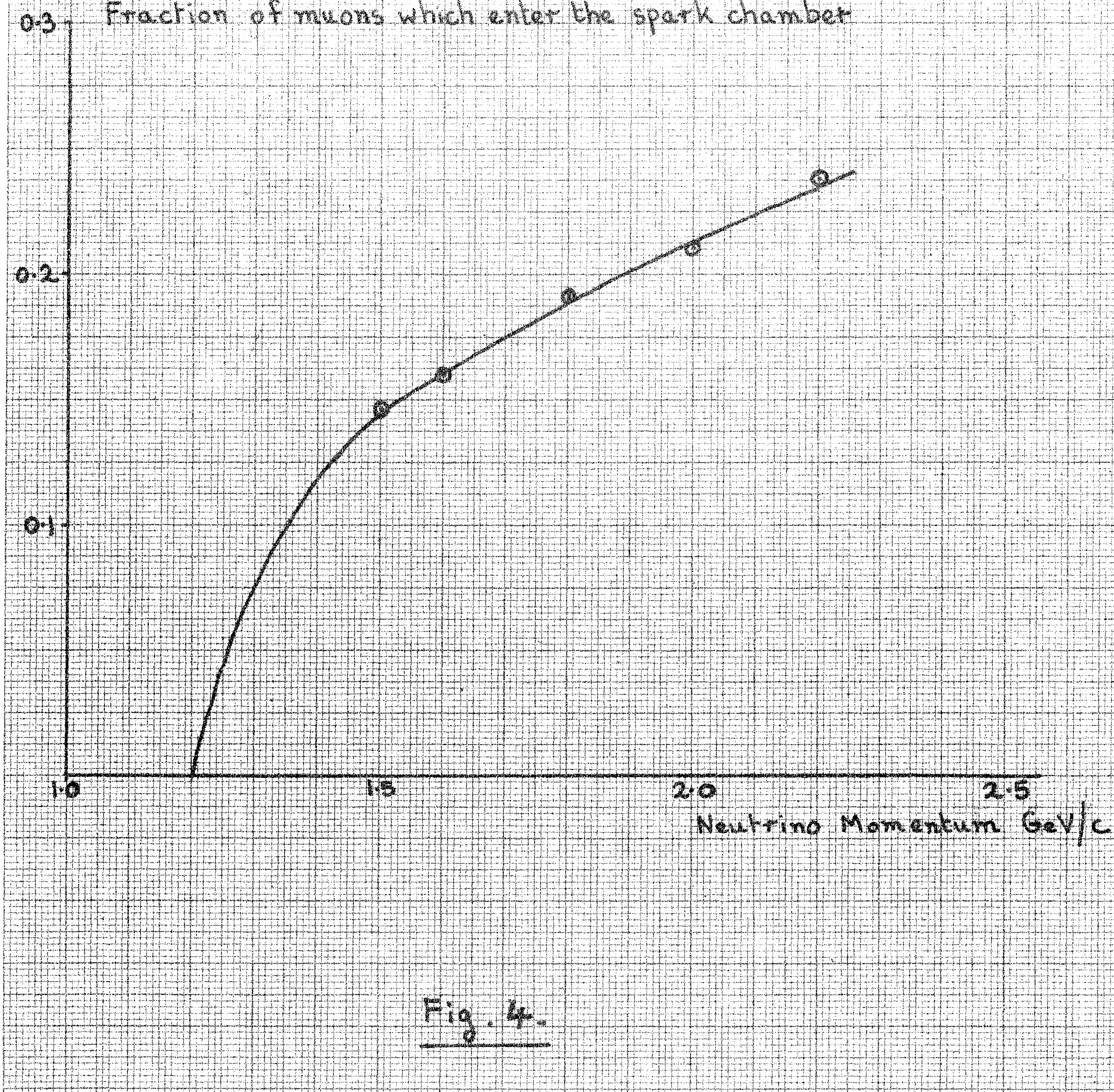

Fraction of muons which enter the spark chamber
0·3
0·2
0·1
1·0
1·5
2·0
2·5
Neutrino Momentum GeV/c

Fig. 4.

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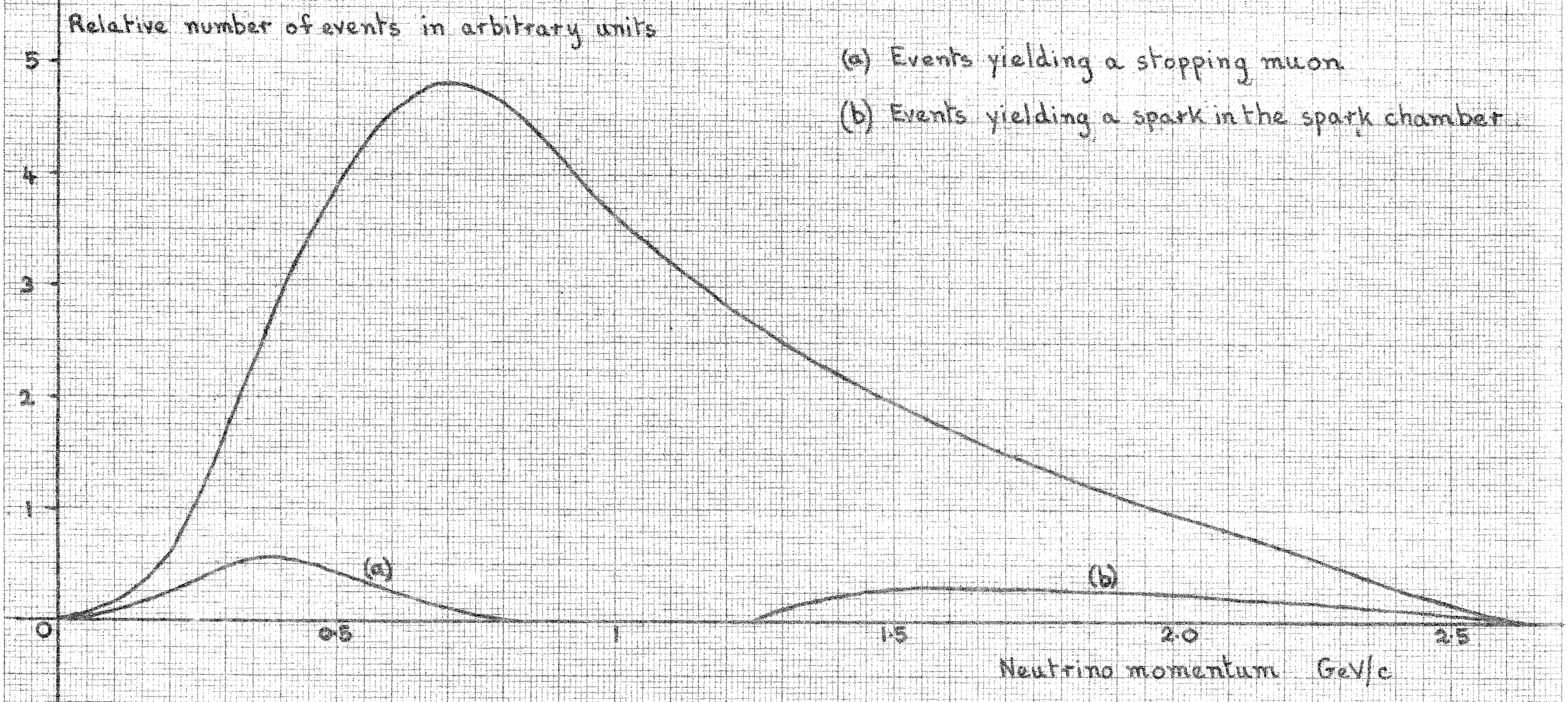
Relative number of events in arbitrary units
(a) Events yielding a stopping muon
(b) Events yielding a spark in the spark chamber
5
4
3
2
1
0
0.5
1
1.5
2.0
2.5
(a)
(b)
Neutrino momentum GeV/c

Fig. 5.

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