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STUDY OF INTERACTIONS IN WHICH GAMMA RAYS AND ELECTRONS WITH LARGE TRANSVERSE MOMENTUM ARE EMITTED

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CONTENTS

I - INTRODUCTION

The aim of this experiment is to measure :

a) the single electron $e^{\pm}$ momentum distribution in reactions such as : $pp \rightarrow (e^{\pm}) + \text{anything}$ (1)

b) the mass spectra of electrons pairs (e^+e^-) :

$$pp \rightarrow (e^+e^-) + \text{anything} \qquad (2)$$

The production cross section for these reactions could be explored down to a limit $\sigma = 10^{-34} cm^2$ in a relatively short period of machine time $\tau \sim 100$ hours [1].

The experimental resolution would be of the order $(\Delta p/p)_{e^{\pm}} \sim 5\ \%$ for momenta in the range $1.5 \leqslant p \leqslant 4.0$ GeV/c which would permit to obtain the electron pair mass with a resolution $(\Delta m/m)_{e^+e^-} \sim 3.5\ \%$ in a considerable mass interval.

The measurement of the $e^{\pm}$ momentum spectrum - reaction (1) - will provide an upper limit on the production rate of electrons with large transverse momentum, in other words a very useful information on the hypothetic production of heavy vector mesons : $W^{\pm} \rightarrow e^{\pm} + \nu_e$ [2].

The measurement of the (e^+e^-) mass spectrum - reaction (2) - with a resolution $\Delta m/m \sim 3.5\ \%$ will provide interesting information on possibly existing heavy vector mesons $(W^{\circ} \rightarrow e^+e^-)$, strong production of (W^+W^-) pairs, etc... and a very useful information in order to correct the single electron spectrum from contributions in which one electron escapes [2].

Furthermore a detailed study of these production spectra will have a great theoretical interest [3].

The information which will be obtained from a precise measurement of the momentum of particles emitted in the large solid angle of the detector will provide a detailed study of what we have called anything in reactions (1) and (2), a more precise energy balance of these reactions.

The other by-products of this preliminary experiment are the following :

a) a measurement of the production spectra of γ rays which will give information on the spectra of π°, η°, K° decaying into γ's

b) a measurement of all the events of the type π° + anything in particular $\pi^\pm\pi^\circ$ events

c) more generally the multiple production of pions in the large solid angle of the detector.

II - APPARATUS

1) Preliminary remarks

One of the most important criteria for the success of such an experiment is the possibility to identify the decay products of reactions (1)-(2) (electrons or electrons pairs) in a large background.

Most of this background will originate from π^0 and K^0 decays and subsequent γ ray internal and external conversion. In other words production of electron pairs (e^+e^-).

As soon as one can separate each of the two electrons: e^+ and e^- from a pair, one obtains a very efficient handle on the background : an extra factor 10^{-3} in the rejection of single electron events from γ conversion [4].

This is the basic motivation for the introduction of a small magnetic field in the apparatus [8].

~ [The use of this magnetic field is of course subject to the condition that it will not introduce any perturbation on the ISR proton beam. This very stringent condition is analyzed in Ch.II paragraph 5, and the necessary shielding is defined.] ~

Furthermore the introduction of a small magnetic field will help :

a) to improve considerably the momentum resolution $\frac{\Delta p}{p} \approx 5\%$ (see paragraph 6 below);

b) to reject the spurious unassociated electron pairs in the study of reaction (2) as the sign of the particles will be known;

c) to improve the rejection of the $\pi^{\pm}$ contamination [4] :

- firstly by a better knowledge of the momentum of each track ($\frac{\Delta p}{p} \sim 5\%$) which will be compared with the momentum derived from the analysis of the shower development in the last large spark chamber (see Appendix I),

- secondly, by the possible use of a strict momentum definition and cutoff with counter arrays before and after the spectrometer which will improve the triggering system.

The proposed apparatus is entirely compatible with the introduction of two extra magnets, so that one keeps essentially the same useful solid angle $\Delta\Omega = \pi$ as shown on the layout of the set-up figures (1 - 2).

2) Wire chambers

These chambers - represented on figure 1 - will provide an accurate location of the begining of tracks coming from the interaction region.

These wire chambers will operate in the proportional mode [5]

Number of gaps	~ 3
dimensions	~ 80 × 30 cm
total thickness	~ 0.05 g/cm^2
spatial resolution	~ ± 1 mm
time resolution	~ 20 ns
dead time	~ 250 ns
wire spacing	~ 3 mm.

When measuring the γ ray spectra (see experimental program Ch.III) these two gaps will be followed by 4 × thicker plate wire chambers (with 4 × 0.1 radiation length lead plates) in order to improve the γ detection efficiency ($\mathcal{E} \simeq$ 30 %). The two front thin gaps will ensure that the γ rays have been materialized in the following thick plate gaps.

3) Cerenkov counter

The Cerenkov counter 60 cm long - see figure 1 - will be filled with N_2 at a pressure $p \simeq 1$ atmosphere. The threshold for detecting electrons is $\sim$ 20 MeV/c and for pions $\sim$ 5 GeV/c.

This large solid angle counter will be subdivided into 8 cells - see figure 1 and 2 - in order to minimize multiple track counting. The total thickness of the counter will be $\sim$ 0.1 g/cm^2.

The rejection ratio of charged particles other than electrons obtained with this Cerenkov counter has been discussed in reference [4] and a résumé of the total discrimination of the apparatus against $\pi^{\pm}$ is given below Ch.III.

4) Shower spark chamber

As explained in more detail in Appendix I it is necessary to have a total plate thickness of $\sim$ 20 radiation lengths in order to get the most precise information on the energy of the electrons from the analysis of the shower development. The momentum resolution obtained with this method will be extremely useful in the first part of the experiment when the magnetic field will not be available and also in the rejection of the contamination from $\pi^{\pm}$ tracks.

These gaps will be distributed into two groups of approximately $\sim$ 40 and 30 units. The overall dimensions of the chambers are illustrated in figure 1. The average plate thickness will be $\sim$ 0.2 radiation lengths.

These chambers will provide a permenent record of actual events , i.e. : a visualisation of all the problems one will meet at first while working near ISR interaction region. In our view the drawback of picture processing and analysis will be largely offset by the more complete information on background and also on accompanying hadron states called "anything" in reactions (1) and (2).

Furthermore the analysis of the shower development will provide a powerful discrimination on charged $\pi^{\pm}$ tracks as the energy of each track will be known from the magnetic analysis with a good resolution $\frac{\Delta p}{p} \sim 5\,\%$ (see Appendix I).

In the first period of ISR operation when we will probably not be using any magnetic field, the momentum definition of each track in the large spark chamber assembly can be considerably improved by using an assembly of scintillation counters such as described in reference [9] - (see also paragraph 6). Also, from the pulse height analysis from these counters one obtains a better handle on the $\pi^{\pm}/e^{\pm}$ discrimination.

5) Magnets

We propose to use two existing magnets with an aperture $\sim$ 180 cm along the beams, $\sim$ 80 cm high, and 40 cm deep. In order to maximize the solid angle about the interaction region the vertical sides of the aperture could be shaped as shown on figure 1.

The magnetic field distribution is illustrated on figure 3. The central field in each magnet is equal to 3 200 gauss, with a tota field strength $\int B dl \sim 3 \times 10^5$ gauss. cm. With the two magnetic fields in opposite directions the field in a central region $\pm$ 20 cm about the interaction zone varies between $\pm$ 600 gauss.

The conditions for minimum perturbation of the ISR beams i.e. : $\pm$ 1 mm displacement at the end of the straight section correspond to the following limits [10] :

- maximum uniform field B $\sim$ 25 gauss/1 m (6 gauss/4 m)
- maximum gradient $\frac{\partial B}{\partial x} \sim$ 20 gauss/cm over 1 m

The proposed shielding consists of an iron tube $\emptyset$ - 40 cm of thickness e = 15 m plus a permalloy (μ-metal) layer of $\sim$ 0.5 mm. The shielding of each separate beam in a region where the field is less than B $<$ 150 gauss would need on iron tube $\emptyset \sim$ 20 cm and thickness e $\sim$ 5 mm.

An aperture $\pm$ 6 cm high and 100 cm long would let particles come out of the interaction region in the large solid angle of the detector (figure 2).

The background introduced by γ - ray conversion and particle interaction in the 15 mm iron shield has been calculated and is considered in more detail in the next chapter.

Finally, we remark that our proposed arrangement with a small field near the interaction region is favourable to let very low momentum particles with a small curvature radius come out and be detected. This momentum limit is as low as $p \sim 20$ MeV/c and is particularly useful in the rejection of the γ - ray converted electron pairs background. This is to be compared with a momentum threshold for detection $p \sim 150$ MeV/c in the case of a large central field magnet with $B \sim 15\,000$ gauss.

6) Momentum resolution

There will probably be no magnetic field in the first part of the experiment and the momentum measurement will be obtained by analysing the electron shower development in the large spark chamber. The momentum resolution will be limited by track counting bias, saturation effects of individual gaps and the energy threshold for spark formation. The average momentum resolution obtained by this method is equal to $\frac{\Delta p}{p} \sim 20$ % for momenta in the interval : $1.5 \leq p \leq 3.0$ GeV/c.

A definite improvement has been obtained by using the technique described in reference [9] with scintillation counters in the spark chamber assembly. According to these results the energy resolution varies from 15 % to 10 % in the momentum range between 1.0 GeV and 2.5 GeV/c.

A momentum resolution $\frac{\Delta p}{p} \sim 15$ % is therefore a safe and conservative estimate in the range $1.5 \leq P \leq 4.0$ GeV/c with this technique.

Such a resolution is large enough during all the preliminary tests before one can introduce the magnetic field.

In the second part of the experiment where we will be using the two magnets with a field strength $\int Bdl \sim 3 \times 10^5$ gauss.cm we expect to obtain a momentum resolution varying between 4 to 6 % in the momentum range $1.5 \leq p \leq 4.0$ GeV/c, taking into account the errors on the track position and multiple scattering in spectrometer detector and chambers [14].

III - BACKGROUND

1) Charged particle contamination $\pi^{\pm}$, $K^{\pm}$ ...

The total number of $\pi^{\pm}$ going through the apparatus solid angle $\Delta\Omega \sim \frac{\pi}{2}$ in an average data taking period $\tau \sim 50$ hours and the expected δ ray contamination in the Cerenkov counter are reproduced in the following table [4]. These numbers correspond to the nominal ISR luminosity $L \sim 4\times10^{30}$ cm^{-2} s^{-1}. [A cross section $\sigma \sim 10^{-34}$ cm^{2} would correspond to approximately 10 events in the detector solid angle $\Delta\Omega$ in the same period $\tau \sim 50$ hours.]

Momentum interval GeV/c	Total number $\pi^{\pm}$ in $\Delta\Omega \sim \frac{\pi}{2}$ and	δ-ray contamination $\tau \sim 50$ hours
1.5 - 2.5	$\sim 10^{8}$	2×10^{3}
$P_{\pi} \gtrsim 2.5$	$\sim 10^{6}$	~ 50

The further $\pi^{\pm}$, $K^{\pm}$ discrimination obtained from the spark chamber assembly has been discussed at length in a preceding addendum [4]. It has been shown that $\pi^{\pm}$ rejection ratio of the electron shower detector is equal to $\sim 10^{-3}$ so that the total $\pi^{\pm}$ contamination in the electron spectrum will be reduced to an <u>extremely low level</u> for momenta above $P \geq 2.0$ GeV/c.

Furthermore the accurate magnetic momentum measurement ($\frac{\Delta p}{p} \sim 5\ \%$) will considerably increase the $\pi^{\pm}$ discrimination from the analysis of the shower spark chamber pictures, as explained in more detail in Appendix I.

Lastly, the correction from the few remaining and possibly missidentified $\pi^{\pm}$ events in the single electron spectra will be carefully calculated from the calibration tests of the detectors.

to eliminate most of the electron background from γ-ray conversion for momenta $P \geq 2.0$ GeV/c.

Furthermore the residual electron background will be very precisely calculated from the measured γ-ray spectra with the same apparatus - see Ch.IV . In other words, this contamination will have been accurately measured.

In the case of the mass spectrum of e^+e^- pairs, the background will first be very much reduced and the magnetic field will help to rejet uncorrelated pairs.

3) Background introduced by the magnetic shielding

This electron background will come from γ- ray conversion and particle interactions in the 15 mm iron shield. These electrons will have to be scattered through an angle larger than $\theta \geq 20°$ to get into the detector solid angle and also have a minimum momentum $p \geq 1.5$ GeV/c.

The anticoincidence counters C_1C_2 will eliminate most of the electrons originating from the top of the vacuum chamber wall and also from the magnetic field shield. The background from γ- ray conversion in the 3 mm counters $[6\times10^{-3}]$ will be less abundant than the $\sim[2\times10^{-2}]$ γ conversion in the 0.2 mm vacuum chamber wall and Dalitz pair production.

Furthermore the track reconstruction will reject all the events where the electron track origin is not located in the $\pm$ 5 mm high interaction region.

IV - EXPERIMENTAL PROGRAM

1) Starting period of ISR operation

We propose to measure the electron and γ- ray spectra in the momentum range $1.5 \leqslant P \leqslant 3.0$ GeV/c with essentially the same apparatus.

The " γ-ray events" will be obtained by asking the γ-ray conversion in the $\sim$ 0.4 R.L. thin plate chamber (WC), a signal in the Cerenkov counter (C), and a shower in the last spark chamber (SC), so as to reject showers not originating from the interaction region (figure 1).

The "electron events" will be obtained by simply removing the $\sim$ 0.4 RL thin plate chamber (WC).

As we will probably not be using the magnets in these preliminary measurements one should note the following :

a) the momentum resolution $\frac{\Delta p}{p} \sim 15\ \%$ is largely sufficient for a preliminary survey of low momentum electron and γ-ray spectra,

b) as the expected initial intensity of the ISR proton beam will be low, the signal/background ratio for the measurement of the γ-ray spectra will be large [4]. So that the contamination problems will be limited.

The general motivation for these preliminary measurements are the following :

- they do not depend on the intensity of the circulating proton beam,
- the data taking time will be short ($\tau \sim 50$ hours),
- at first only one half of the equipment will be used with a solid angle : $\Delta \Omega = \frac{\pi}{2}$. The magnetic field will not be used in this preliminary run, so that the experimental assembly will

not be heavy and could be rapidly dismantled,

- the requirements from ISR would be reduced to a minimum. The vacuum chamber design is compatible with ISR standards [6];
- this experimental arrangement would be compatible with many other experiments;
- the initial ISR starting period of operation would be the most favorable period for experimental set-up and optimization of experimental conditions , i.e. : The study of ISR background [7] has already produced encouraging results as to the possibility of reducing the general environment background near the interaction regions. The starting period of ISR operation is certainly the best time to optimize this shielding in connection with the first experimental measurements;
- Furthermore these preliminary measurements will provide invaluable information on all unexpected difficulties which are apt to occur at first while working near ISR;
- Lastly, the simplicity of our proposed experimental arrangement will certainly be an asset in the starting period.

2) Second period of ISR operation

The intensity of the circulating proton beam will then have approximately reached its nominal value $\sim 10^{14}$ protons which corresponds to a luminosity $\sim 10^{30}$ cm^{-2} s^{-1}.

We propose to measure :

1) the momentum distribution of the electron spectrum produced in reaction of the type

$$pp \rightarrow e^{\pm} + \text{anything} \qquad (1)$$

in the momentum range $1.5 \leq P \leq 5.0$ GeV/c with the increased momentum resolution $\frac{\Delta p}{p} \sim 5\ \%$ provided by the magnetic field.

2) the mass spectra of electron pairs (e^+e^-) from reactions such as

$$pp \to (e^+e^-) + \text{anything} \qquad (2)$$

with a mass resolution $\frac{\Delta m}{m} \sim 3.5\ \%$.

The production cross section for these reactions would be explored down to a cross section as low as $\sigma : 10^{-34}\ cm^2$ in several data taking runs of a duration $\tau \sim 50 - 100$ hours.

The experimental arrangement will be essentially the same as in the previous measurements but for the following improvements :

a) we propose to use the two magnets after a careful check on the proposed shielding;

b) the apparatus will be symetrical with respect to the interaction region in order to provide a useful solid angle $\Delta\Omega = 2 \times (\frac{\pi}{2}) \sim \pi$ steradians.

The preliminary measurements of the electron and γ-ray spectra carried out in the starting period of ISR operation (paragraphe 1) will have provided invaluable information on the residual "electron" background as it will have been measured.

As it has already been explained the introduction of the "small" magnetic field will increase the momentum resolution but will mostly provide a very powerful handle on the background.

The proposed experimental arrangement will also provide a <u>record</u> of extra data on π^0, K^0 ... $\pi^{\pm}$, $K^{\pm}$ ... production which could well be extremely interesting from the point of view of multiple particle production and should not be forgotten as an extra secondary by-product.

3) <u>Further outlook</u>

a) extension of these measurements to the momentum range <u>$p \geq 4$ GeV/c</u> where the gas Cerenkov counter will no more be efficient to reject pions and where the momentum resolution obtained from the magnetic field will no more be competitive with other possible techniques :

- large solid angle Charpak shower detector (see Appendix I)
- lead glass Cerenkov counters [13]

b) identification of the complete reaction (1) or (2) with the measurement of the forward scattered nucleons.

V - CONCLUSION

The proposed apparatus which is essentially based on well defined and already tested techniques will provide useful preliminary information on the electron momentum distribution and electron pair mass spectrum in reactions (1) and (2), down to a cross section $\sigma \sim 10^{-34}$ cm^2 in reasonable data taking periods $\tau \sim$ 100 hours.

The same apparatus will also provide on the same pictures a record of very interesting data for the study of multiple pion production as a secondary by-product.

APPENDIX I

STUDY OF CASCADE SHOWER DEVELOPMENT IN LEAD PLATES DUE TO PRIMARY ELECTRONS AND PHOTONS IN THE MOMENTUM INTERVAL $0.250 \leq P \leq 4.0$ GeV/c

We present here a short résumé of the study of cascade shower development in array of lead plates due to primary electron and γ - rays in the momentum interval $0.250 \leq P \leq 4.0$ GeV/c. These results were obtained with a Monte Carlo program written by H.ZACCONE [11] . The purpose of this investigation was to put a reasonable limit on the accuracy one could expect to obtain on the energy measurement of the primary electrons and γ - rays, from a fairly extensive study of the shower development, i.e. : the spatial distributions of the secondary electrons.

A preliminary search which will be discribed elsewhere has indicated that by far the most precise criteria for energy determination was the total number N of secondary electrons in the complete array of lead plates. The difficulty to find a criteria such as the position of the maximum, the center of gravity, the width or even a parametrized function which could be applied to the secondary electron distribution as a function of depth ε in the array of plates can be traced back to the large statistical fluctuations from one individual shower to another. These fluctuations arise from the strong correlations in the number of secondary electrons in nearby gaps. This can be easily understood as each individual electron shower extends over several contiguous gaps, and the origin of these elementary cascade not continuously distributed. None of the smoothing methods which we have used has given a result more precise than the total number N of secondary electrons which we will now briefly consider. (Some results on the study of the lateral structure of electromagnetic showers are given in reference [12] .)

We have studied with this Monte Carlo program the variation of the total number N of secondary electrons as a function of depth ε (in radiation length : r.l.) in an array of 100 plates of thickness $e \sim 0.2$ r.l. a minimum cut off in the energy of the secondary electrons $E_{min} \sim 1.0$ MeV. (These results correspond to an average $\sim$ 100 showers at each energy). The variation of N against ε (r.l.) is plotted on figure 4 . The total number of electrons N in 100 plates corresponding to $\varepsilon \sim 20$ r.l. against momentum is illustrated on figure 5 . The ratio $\alpha = \frac{\sigma}{N}$ where σ is the standard deviation about N is plotted against the depth ε (r.l.) on figure 6 . The variation of the same ratio α for $\varepsilon \sim 20$ r.l. is represented against momentum on figure 7 , and can be fitted by the curve $\alpha \sim \frac{4.5}{\sqrt{P}}$ (P in GeV/c).

The influence on the total number of electrons N of the energy threshold E_{min}, the plate thickness ε and the minimum distinguishable distance λ between two adjacent tracks due to the finite space resolution of the detector have also been studied. Similarly energy distributions of secondary electrons as a function of depth ε have been obtained.

From this preliminary study of the shower development in a lead plate detector one can draw the following conclusion : the total number of electrons N can provide a useful criteria on the energy of the primary electron/γ-ray if :

a) the total depth ε (r.l.) of the lead plates array is at least equal to $\varepsilon \sim 20$ r.l., in the momentum range $0.5 \leq p \leq 4.0$ GeV/c. This limit is illustrated on figures 4 and 6 .

b) the optimum number of lead plates is $\sim$ 80 with plate thickness $\varepsilon \sim 0.2$ r.l.

Applications of these calculations to spark chamber [11] detectors and also ionization measurements [15] have already been considered.

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Figure 1

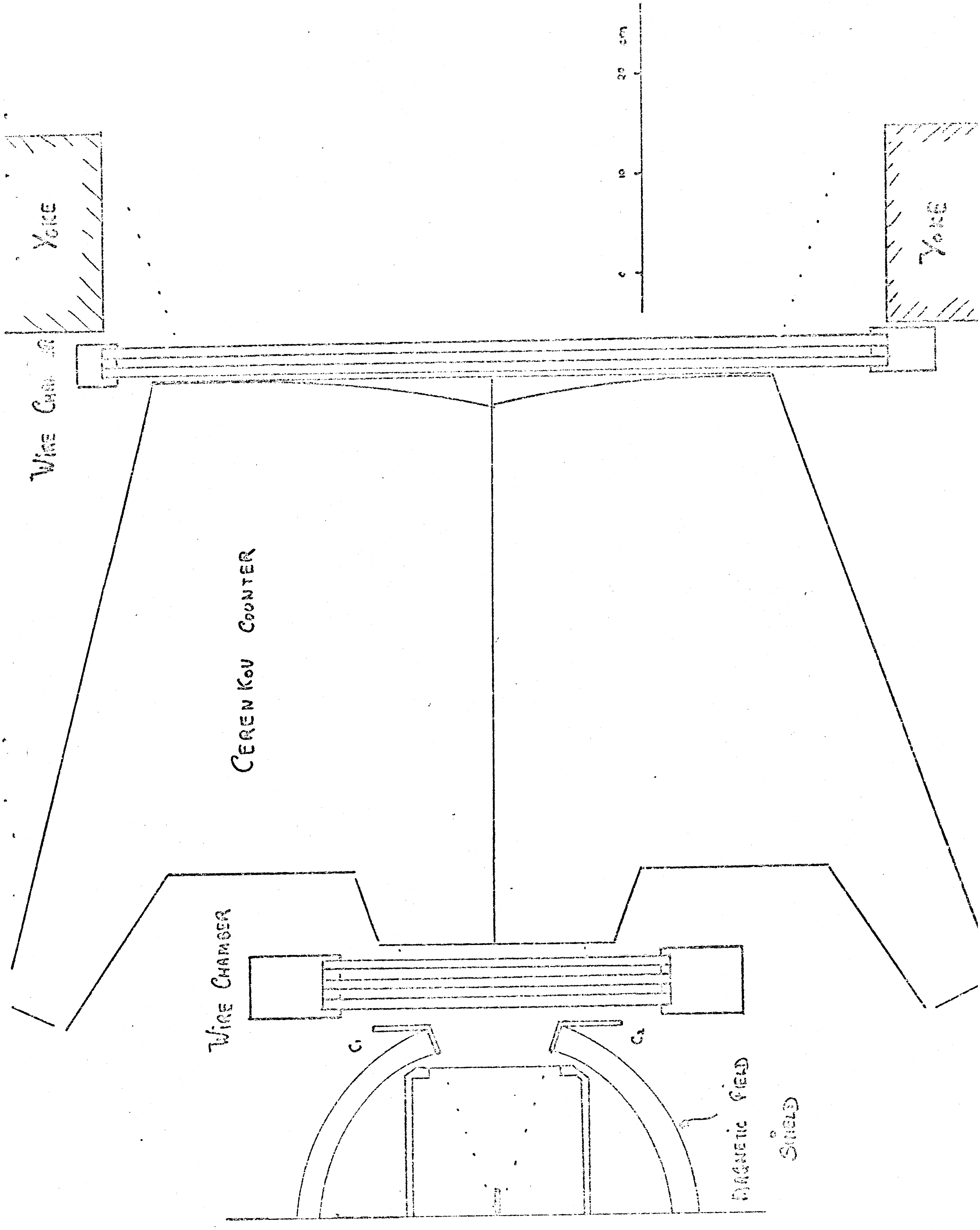
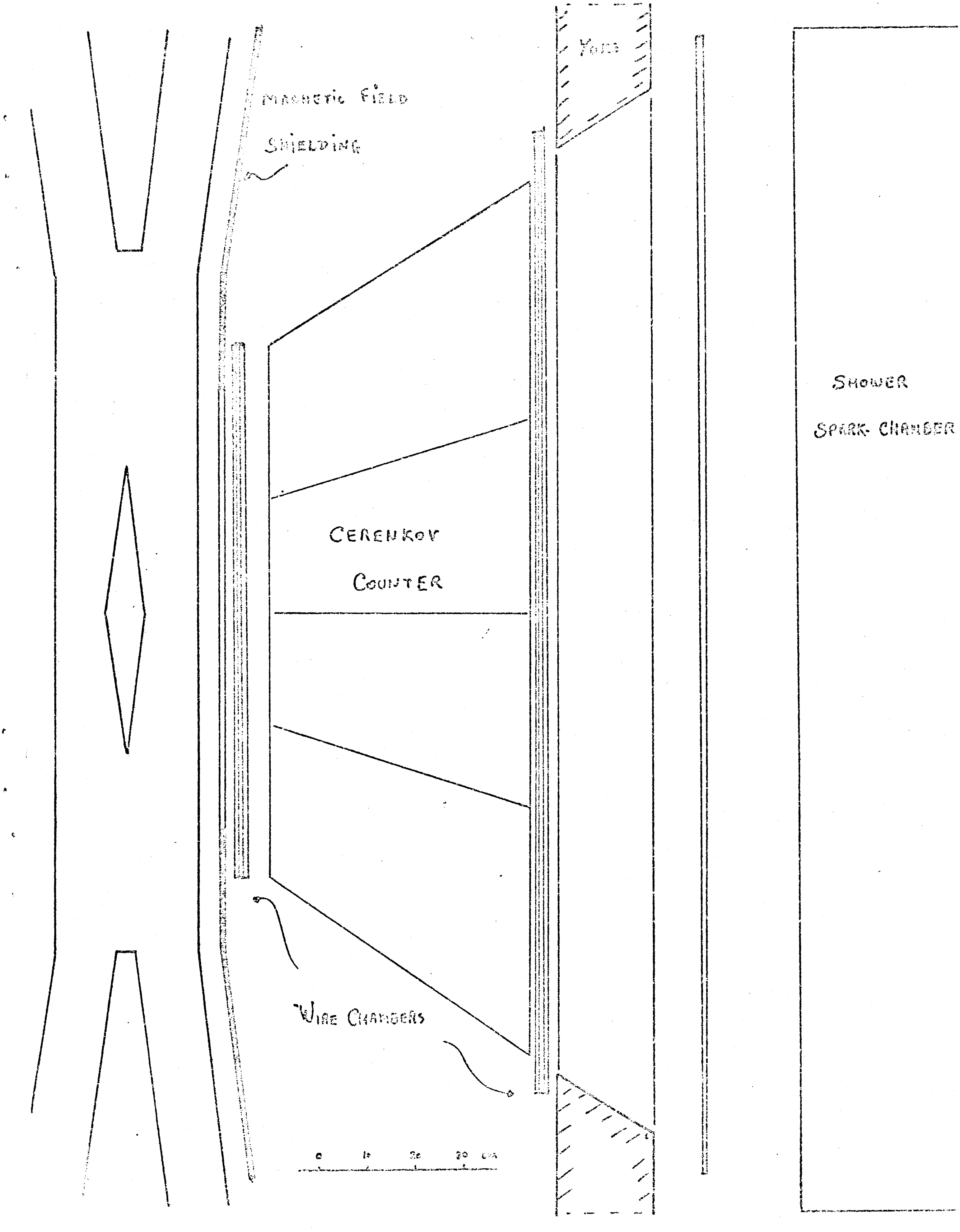
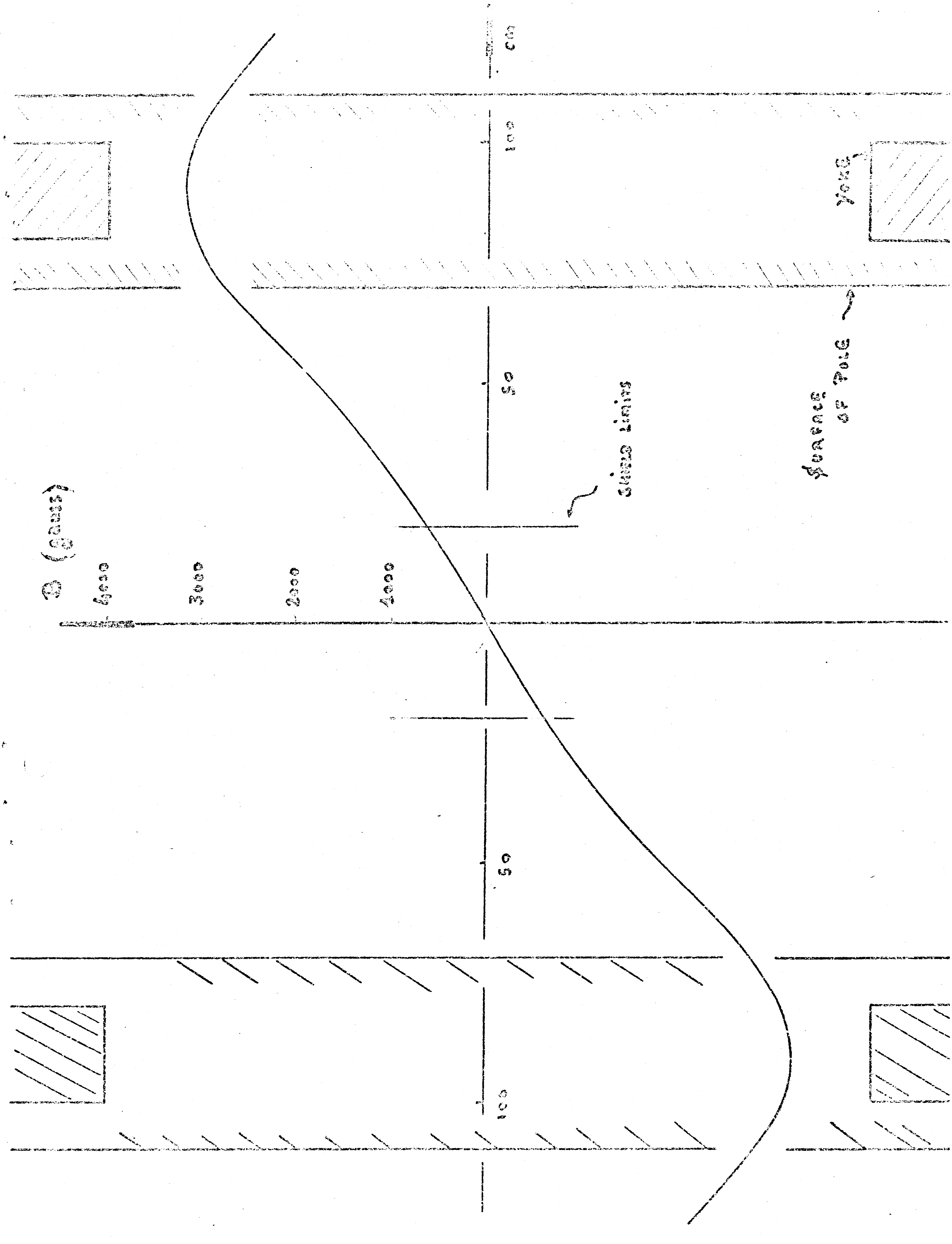

Yoke
Yoke
Wire Chamber
Cerenkov Counter
Wire Chamber
Magnetic Field Shield
0
10
20 cm

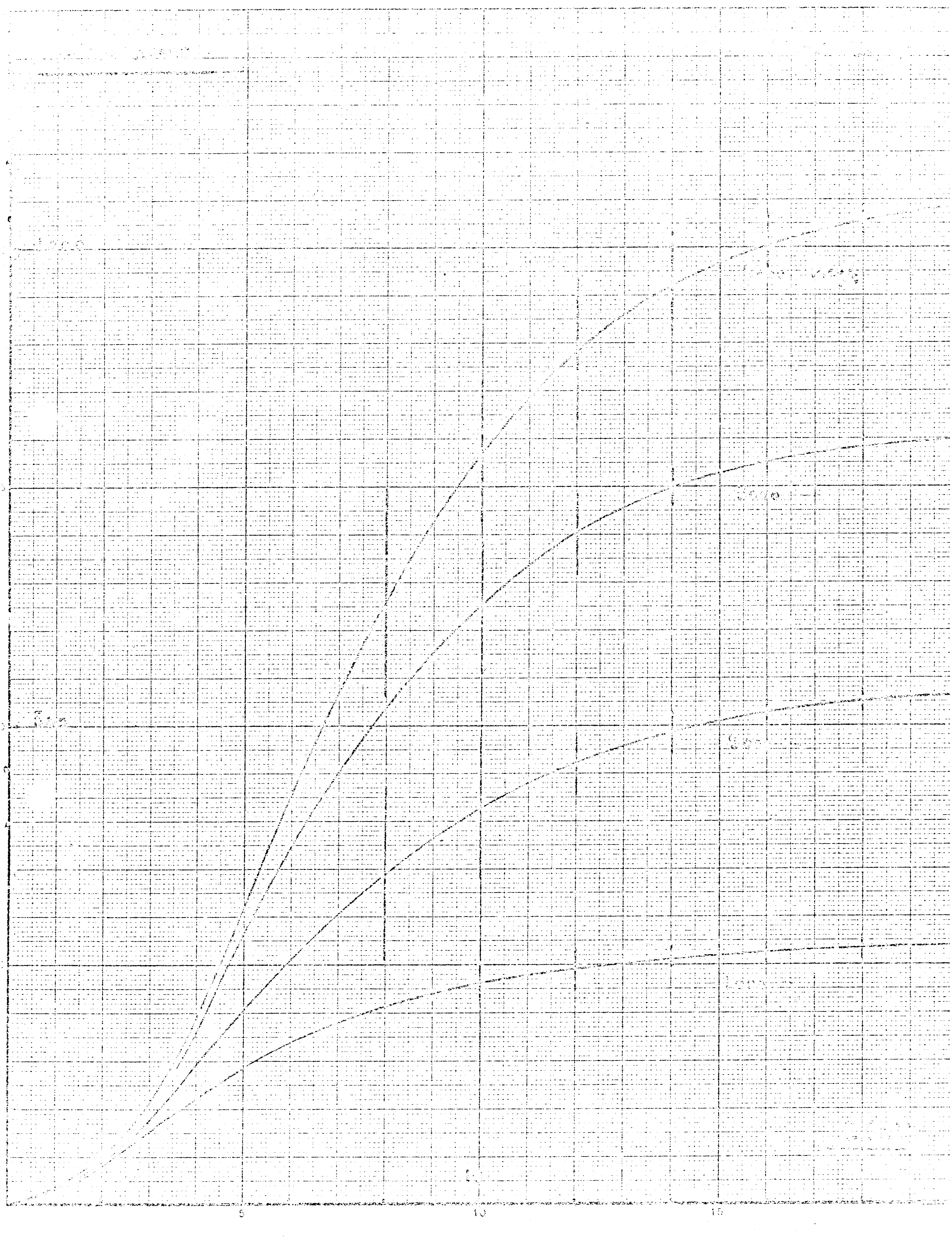
Figure 2



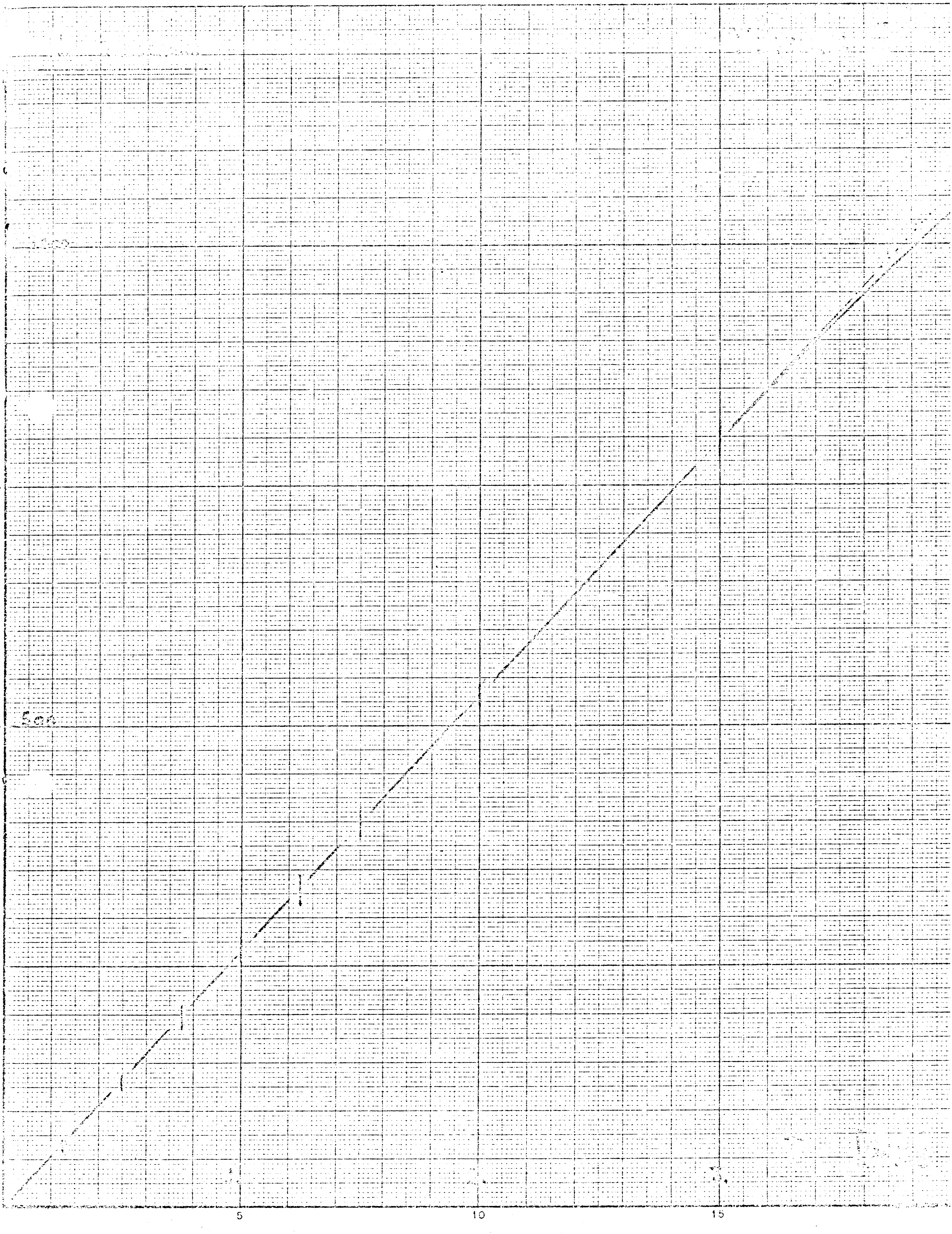
YOKE
MAGNETIC FIELD
SHIELDING
SHOWER
SPARK CHAMBER
CERENKOV
COUNTER
WIRE CHAMBERS
0 10 20 30 cm

Figure 3


cm
100
50
50
100
B (gauss)
4000
3000
2000
1000
Shim limits
Yoke
Surface of Pole



5
10
15



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5
10
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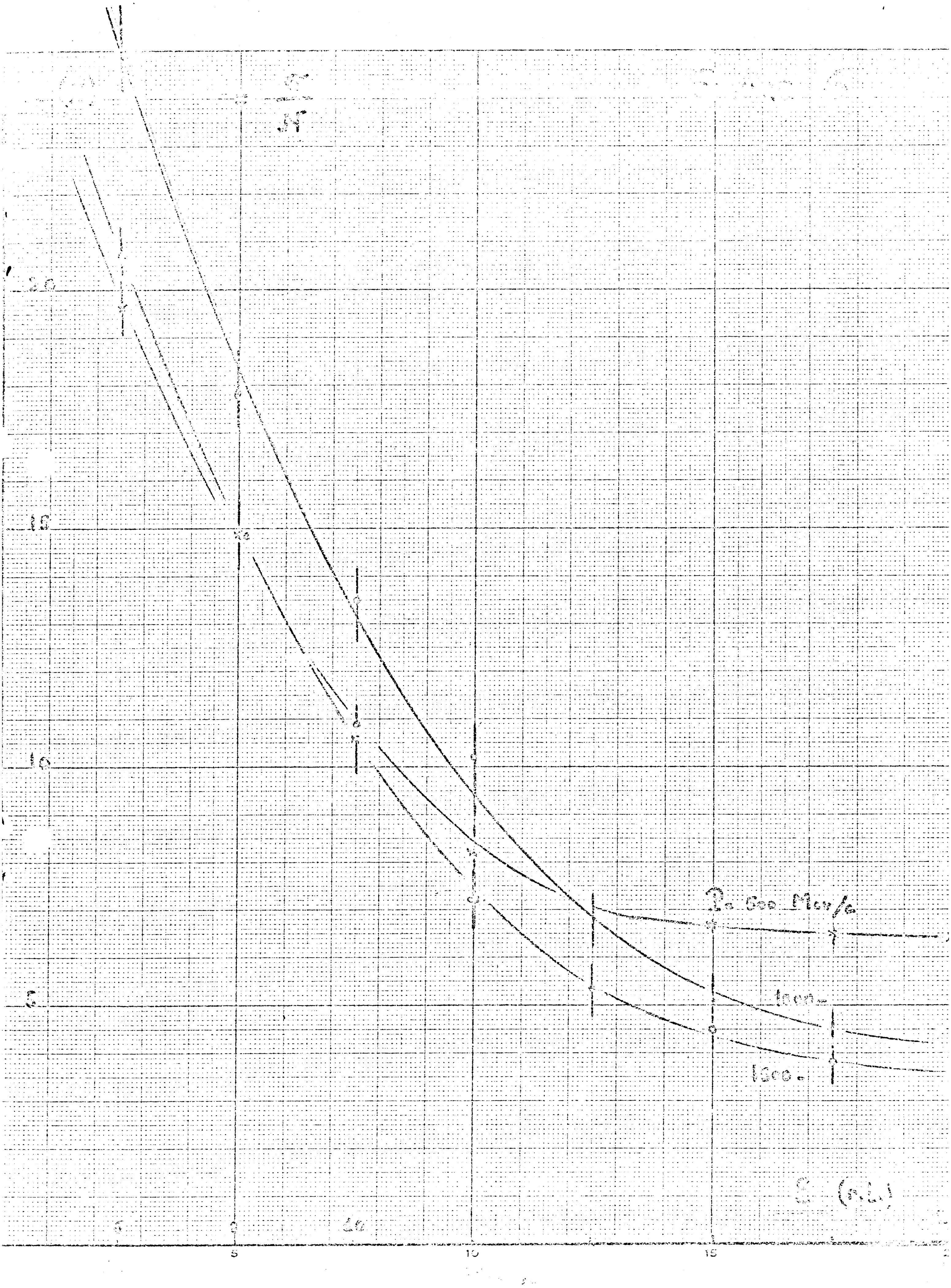

20
15
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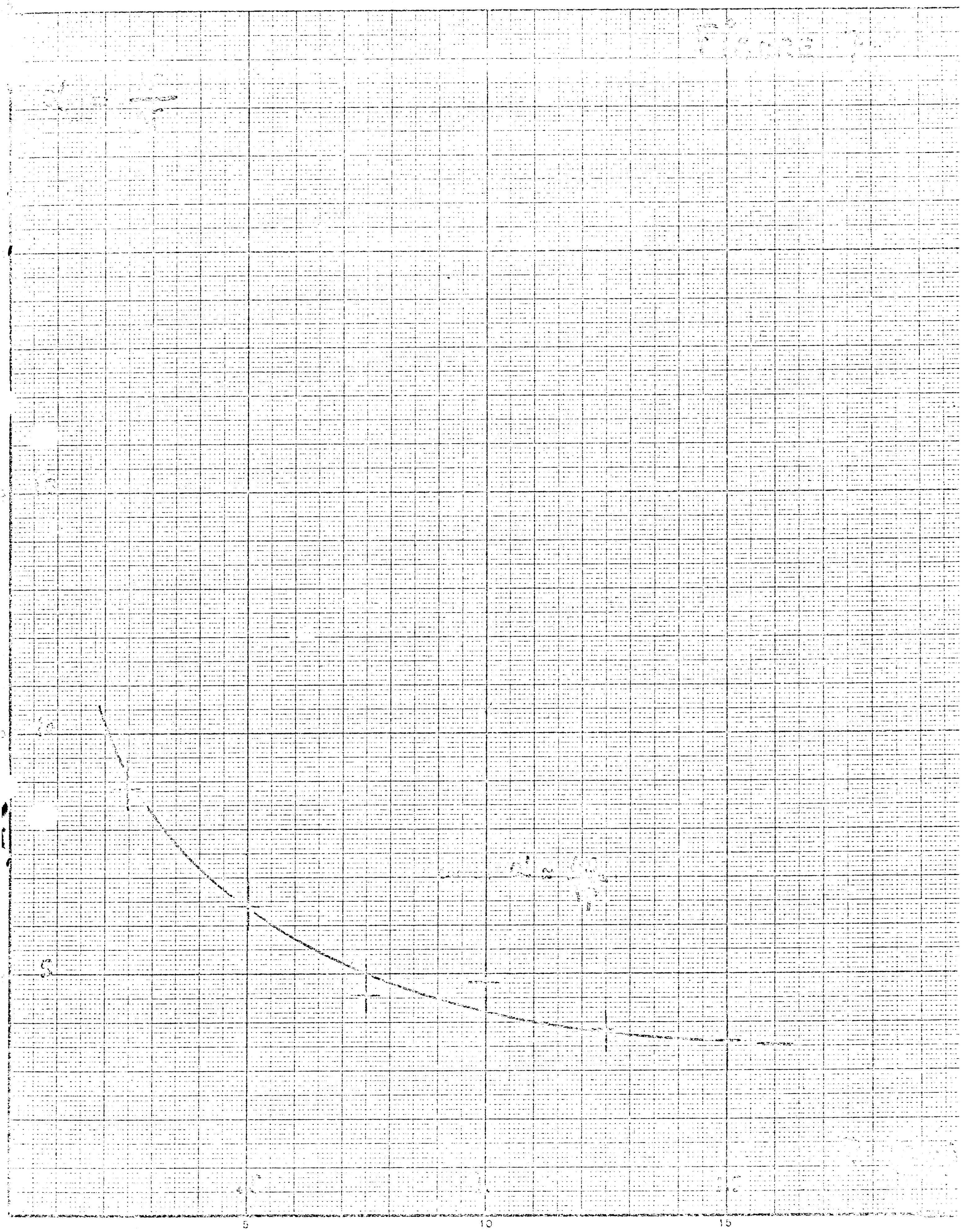
15
P = 600 Mev/c
1000
1500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