Correspondent
Uriel Nauenberg
University of Colorado
FTS 323-3151
Commercial (303)492-0111
x. 7715, 7901

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Proposal to

Study the Interactions of K_L^o Mesons in the Momentum Region Above 50 GeV/c Using a Pion Induced K_L^o Beam

David Bartlett, William Ford, Uriel Nauenberg,
Gary Schultz, Jim Smith, Kelly Wild

University of Colorado
Boulder, Colorado 80309

Table of Contents

I. Abstract - 1

II. Introduction - - - - - - - - - - - - - - - - - - 2

III. Fluxes of Particles at the Target - - - - - - 6

IV. Targets - 7

V. Expected Fluxes at the Detector - - - - - - - 8

VI. Measurement of the Total Cross Section - - - 8

VII. Measurement of the Dilution Factor - - - - - - 12

VIII. Measurement of the Elastic Processes - - - - 14

IX. The Detector - - - - - - - - - - - - - - - - - 22

X. Requests from Fermilab - - - - - - - - - - - - 25

XI. Cost Estimate - - - - - - - - - - - - - - - - - 26

I. Abstract

We propose here to study the strong interactions of K_L^o mesons in hydrogen, deuterium and other targets for K_L momenta above 50 GeV/c. The kaon beam is to be produced by the high intensity pion beam colliding with a solid target. This latter beam is being constructed in the P-West area and, therefore, we propose to have the neutral beam further downstream from the pion experimental hall. Although at present FNAL energies, this beam will not go above 350 GeV/c, with the future existence of the doubler both the beam momentum and intensity will increase substantially. We propose to design the experiment and present the parameters with these higher energies in mind.

The major characteristic of this neutral beam is its small neutron flux (about 1/3 to 1/10 of the K_L flux). This is to be contrasted with a proton induced K_L beam which has a much larger neutron background (about 100 to 1000 neutrons per K_L). Our immediate goal is as follows: 1) To measure the inclusive spectra of K^o, $\bar{K}^o$, Λ^o, $\bar{\Lambda}^o$, γ and neutrons in the forward direction and if possible at larger angles, and 2) To measure the total cross sections of $K_S(K_L)$ in hydrogen and deuterium and simultaneously, that of Λ^o and $\bar{\Lambda}^o$. Our longer range plan is to study the elastic scattering $K_S p \to K_S p$, $K_L p \to K_S p$ to make detail tests of Regge predictions and where possible the $\Lambda^o p \to \Lambda^o p$ and $\bar{\Lambda}^o p \to \bar{\Lambda}^o p$ elastic scattering.

We request initially a 400 hour running period for equipment testing, measurement of inclusive spectra and measurement of total cross sections. Although at this time we do not request time to carry out the study of elastic processes we will describe fully the method of measurement.

II. Introduction

The interactions of neutral kaons with matter is poorly known. The reason for this is mainly the fact that K_L beams have been produced with an incident proton beam striking the target. This leads to a very large neutron flux superimposed on the much smaller K_L flux which makes the study of K_L interactions difficult. Experimenters have resorted to various techniques to reduce the neutron flux but all these methods either degrade the K_L flux or reduce its maximum energy. Hence, except for regeneration in the forward direction below 100 GeV/c incident momenta very little work on K_L interactions has been carried out.(6)

We propose to develop a K_L beam with low neutron contamination. By producing kaons with pions we expect 3-10 K_L per neutron.(8) This beam is to be constructed downstream of the intense pion beam in the P-West area and hence should share this area's ability to take beams up to 1 TeV once the energy doubler becomes operational. In addition, charged K beams at these high energies cannot be physically separated from its other components resulting in a large pion (10 to 100 π per K) intensity also striking the target. This property of charged beams makes experiments with high energy kaons difficult.

From preliminary measurements carried out (to be discussed later on) we observe a Λ° and $\bar{\Lambda}^\circ$ flux which is large enough to carry out some strong interaction studies with these particles as projectiles.

We present now an experimental program that can be carried

out with such a beam. The purpose of these experiments are mainly to study Regge Predictions on particle production, the effect of strangeness on direct lepton production and search for new states of matter like charm. As we will show in this proposal neutral kaon interactions seem to be the only way to measure the phase, by interference techniques, of two strong interaction amplitudes, namely $K_S p \rightarrow K_S p$ and $K_L p \rightarrow K_S p$. This will lead to very definite tests of Regge Theory, both in its prediction of the amplitude and phase of these processes. The list of experiments that can be carried out in this beam include

1) K_L, K_S p total cross section
   K_L, K_S d total cross section
   K_L, K_S A total cross section
   Λp total cross section
   $\bar{\Lambda} p$ total cross section
   Λd total cross section
   $\bar{\Lambda} d$ total cross section
2) $K_S p \rightarrow K_S p$
   $K_L p \rightarrow K_S p$
   $K_S d \rightarrow K_S d$
   $K_L d \rightarrow K_S d$
   $\Lambda p \rightarrow \Lambda p$
   $\bar{\Lambda} p \rightarrow \bar{\Lambda} p$
   $\Lambda d \rightarrow \Lambda d$
   $\bar{\Lambda} d \rightarrow \bar{\Lambda} d$

3) $K_L + N \rightarrow \psi + A$

$\hookrightarrow \mu^+\mu^-$

$K_L + N \rightarrow$ di-leptons

4) $K_L + N \rightarrow$ Multiple Particle States (Charm, etc.)

5) $K_L p \rightarrow K^* p \quad K^* \rightarrow K\pi$

$K_L d \rightarrow K^* d$

6) $K_L p \rightarrow Qp \quad Q \rightarrow K\pi\pi$

$K_L d \rightarrow Qd$

7) $K_L p \rightarrow \Lambda^\circ \pi^+ \quad \Lambda^\circ$ polarization

8) Single particle inclusive distribution near x=1

9) High P_T single particle spectra

10) Accurate measurement of rare decay modes of the K_S, K_L

$K_S \rightarrow \pi^+\pi^-\pi^\circ$

$K_S, K_L \rightarrow 2\gamma$

$K_S, K_L \rightarrow \mu^+\mu^-$

$K_L \rightarrow K^\pm + e + \nu(\bar{\nu})$

Although, as can be seen from the list, there is a large variety of measurements that can be carried out with this beam, our proposal, at this time, will only concentrate on the simpler and more direct measurements that can be carried out simultaneously with a measurement of inclusive spectra. Our present proposal is addressed to experiments indicated in groups 1 and 2.

We propose to carry out a program defined as steps A, B, and C. We discuss here the calculations and the detector physical requirements of programs A and B. We are only requesting, at this time, definite approval for the measurements

in program A. We propose, as program A, to measure the inclusive production of K°, $\bar{K}^\circ$, Λ°, $\bar{\Lambda}^\circ$, neutrons and gammas in the forward direction and if possible at larger angles. The K° and $\bar{K}^\circ$ production spectrum can be determined by measuring the number of leptonic decays and determining the charge sign of the lepton. This flux must be measured at moderate distances from the target, namely 10 to 40 meters. The interpretation of this measurement to determine the K° and $\bar{K}^\circ$ flux separately requires the assumption of the $\Delta S = \Delta Q$ rule. This particular measurement is necessary for measurements to be carried out later on. We propose to measure also the $K_S(K_L)$ total cross section in hydrogen and deuterium and simultaneously that of Λ° and $\bar{\Lambda}^\circ$. As program B we propose to measure the elastic scatterings $K_S p \rightarrow K_S p$, $K_L p \rightarrow K_S p$, and simultaneously $\Lambda p \rightarrow \Lambda p$ and $\bar{\Lambda} p \rightarrow \bar{\Lambda} p$. The regeneration type scattering is to be carried out at various distances from the target, namely 60 to 180 meters and above. The interference between the amplitudes for $K_S p \rightarrow K_S p$ and $K_L p \rightarrow K_S p$ leads to scattering rates which are sensitive to the Regge parameters. All of these processes we propose to measure up to transverse momenta of 1 GeV/c and above and in the momentum region above 50 GeV/c. We request, at this time, conditional approval, upon completion of program A, for these measurements also. Nevertheless, no allotted beam time is requested. Program C consists of measuring various types of production mechanisms by constructing a many particle spectrometer. We would measure anomalous lepton production, high P_T inclusive particle production and search for new massive states of matter. This program has not been studied in detail as yet and will not be discussed any further in this proposal.

III. Fluxes of Particles

The fluxes of K_L, n, γ and Λ were calculated from lower energy inclusive data and were presented in proposal #360.[8] Because of the difficulty of calculating the neutron flux and of extrapolating from 10 to 200 GeV we carried out a short run to measure these fluxes in collaboration with the Wisconsin, Michigan, Rutgers group. We present in fig. 1 and 2 some of the very preliminary results. These should be considered only to be approximately the fluxes we can expect. These results may well change by ~10% when the analysis is completed. The results essentially support the calculations made for proposal #360.

The essential results are presented in Table 1.

Table 1

10^{10} interacting 300 GeV/c pions on Beryllium into a μ sterad. solid angle give

5×10^6 K_L

5×10^5 Λ

5×10^5 $\bar{\Lambda}$

The neutron flux below 100 GeV/c is about the same as the K_L flux. Between 100 and 150 GeV/c it is anywhere between 1/2 and 1/3 of the K_L flux and above 150 GeV/c it is much smaller. In addition there is a very intense photon flux associated with this beam which we also measured. This flux

is likely an order of magnitude larger than the K_L flux. The photon momentum spectrum is fairly flat up to the maximum energy. This beam could be very useful for photoproduction experiments but will not be discussed any further here.

IV. Targets

In a series of these proposed experiments the cross section is expected to change rapidly as a function of transverse momentum and hence as a function of the momentum of the recoiling target. To be able to observe the recoil we require a target thin enough so that the recoil is not stopped by the liquid in the target. Hence we propose to use targets 1 cm. and 10 cm. in diameter. The 10 cm. target would be used in the measurement of the large q^2 region ($q^2 > .1(\mathrm{GeV}/c)^2$) of elastic scattering processes where the cross section is small and hence large beam fluxes are necessary. The 1 cm. target would be used in the measurement of the low q^2 region. For program A we request a 1 cm. diameter 1 meter long target. For program B we will request a 2 meter long both 1 cm. and 10 cm. diameter target. We request that these targets be supplied by FNAL.

V. Expected Fluxes at the Detector

For the initial phase we propose to carry out these measurements at ~10 meters from the primary target. The intervening space is to have a sweeping magnet to remove the charged component of the beam.

Using the 1 cm. diameter target we expect a solid angle $d\Omega = \pi x 1/4 x 10^{-6} \simeq .7 x 10^{-6}$ and hence fluxes comparable to those presented in figures 1 and 2. The expected fluxes at this secondary target are $3x10^6 K_L$, $10^6 K_S$, $10^5 \Lambda$ and $10^5 \bar{\Lambda}$ per pulse.

For future work when we propose to measure the incoherent regeneration $K_L p \rightarrow K_S p$ at distances of 100 meters from the target the fluxes of K_L will be $3x10^4 K_L$/pulse with the 1 cm. diameter target and $3x10^6 K_L$ with the 10 cm. target.

VI. Measurement of the Total Cross Section

We propose to measure the $K_S p$ and $K_S d$ total cross section during the beam survey. Present charged total cross sections are known to about 280 GeV/c.[1] It is worthwhile to carry out these measurements up to much higher energies namely ~400 GeV/c and higher. As the beams increase to higher and higher energies the separation of the charged kaons from the much larger pion intensity in the same beam becomes nearly impossible with Cerenkov counters and one may have to use transition radiation. Even here this separation is not very clean and can give a pion contamination of ~50 to 100%[2]. With the K_L beam proposed here there is no such contamination.

Measurements of the total cross sections may answer a few interesting questions. Do the Kp and pp cross sections rise at the same rate? Is the rate of increase such that the Kp and pp cross sections will have a constant difference, tend towards equality or towards two-thirds, the ratio of the number of valence quarks in the incident beams.

In fig. 3 we present what is known about the total cross section of protons on protons and kaons on protons. Measurements up to 400 GeV/c would allow us to make a good determination of the rise of the total cross section beyond 100 GeV. When 1 TeV energies become available this beam would be able to measure the total cross section up to this energy.

Expected Rates - To calculate the expected rates we consider a 1 meter long 1 cm. diameter target illuminated by $10^4 K_S$, $10^3 \Lambda$, $10^3 \bar{\Lambda}$ and $3 \times 10^4 K_L$/100 GeV/c momentum interval. Hence we require only about 10^8 interacting pions for these series of experiments. We present, for simplicity, only the numbers expected for K^o's. We assume a constant 20 mb. cross section for the calculation. Hence the fraction of K_S interactions in our 1 meter hydrogen target is 1m x 20/240 = .083 where 240 is the mean free path (in meters) per mb. In table 2 we show the number of charged K_S decays per pulse both with target full and target empty. We assume the target is followed by a 10 meter decay region.

Table 2

P(GeV/c)	Fraction of Charged K_S decays $.687(1-e^{-10/.0268P/m})$	Charged Decays/Pulse T.E.*	T.F.*
50-150	.58	$.58\times10^4$	$.53\times10^4$
150-250	.42	$.42\times10^4$	$.38\times10^4$
250-350	.32	$.32\times10^4$	$.29\times10^4$
350-450	.25	$.25\times10^4$	$.23\times10^4$

*T.E. = target empty

*T.F. = target full

At this rate we are limited by the computer read in capacity which we expect to be 300 events/sec. Hence we assume a reduction by a factor of 100 in the number of events recorded.

Assuming 5×10^3 pulses/day in each mode T.F., T.E. we can calculate the number of decays observed and hence calculate the accuracy of our measurement. We use the formula

$$\frac{\Delta\sigma}{\sigma} = \frac{1}{\ln N'/N}\sqrt{\frac{N'+N}{N'N}} = 11.6\sqrt{\frac{N'+N}{N'N}}$$

$$\frac{N'}{N} = \frac{1}{1-.083} = 1.09$$

where N' = number of decays with target empty

N = number of decays with target full.

In table 3 we show the accuracy obtained in a 1 day run.

Table 3

P(GeV/c)	N'/day	N/day	(N'+N)/NN'	$\Delta\sigma/\sigma$
50-150	$.29\times10^6$	$.26\times10^6$	7.2×10^{-6}	3.1×10^{-2}
150-250	$.21\times10^6$	$.19\times10^6$	10.0×10^{-6}	3.7×10^{-2}
250-350	$.16\times10^6$	$.15\times10^6$	13.0×10^{-6}	4.2×10^{-2}
350-450	$.12\times10^6$	$.11\times10^6$	17.0×10^{-6}	4.7×10^{-2}

Hence as this table shows a run of one week (~100 hours) will allow us to measure the total cross section of K_S, Λ and $\bar{\Lambda}$ to an accuracy of about 2%.

In a similar manner we can measure the Λ, $\bar{\Lambda}$ - p cross section and the K_S, Λ, $\bar{\Lambda}$-n cross section using a deuterium target and making the usual correction for the proton shadowing effect.

Systematics - Various systematic effects can be neglected in the measurement of the total cross section. Systematic effects due to lack of knowledge of lifetime, decay branching ratios, and detection efficiency do not affect the results since the cross section is related to the ratio of the number of decays with the target full and empty and hence these factors drop out.

We must make sure that the beam shape and intensity does not vary between target full and target empty runs. Hence we plan to include into our detector a V monitor to detect these changes and normalize the data. This will be discussed in more detail in the section discussing the detector.

One troublesome aspect in the determination of the total cross section is the extrapolation of the elastic scattering $K_S p \rightarrow K_S p$, $\Lambda p \rightarrow \Lambda p$ or $\bar{\Lambda} p \rightarrow \bar{\Lambda} p$ to $q^2 < .04\ (\mathrm{GeV/c})^2$. (See next page, 2nd paragraph). For such low transverse momenta, the recoil nucleon does not come out of the target. This correction will be carried out by demanding that the K_S point back to the primary target 10 meters away. Assuming a spot size of ~4 mm. diameter the maximum undetectable P_T becomes
400 GeV/c x .2/1000 = .08 GeV/c or $q^2 \simeq .0064\ (\mathrm{GeV/c})^2$. This correction can be carried out from a measurement of the elastic scattering.

The Detector - The detector will consist of a V spectrometer in the forward direction. The details of it will be discussed later on since all the experiments proposed here require the same spectrometer.

The target will consist of a 1 meter long 1 cm. diameter, 5 mil jacket surrounded by 10 layers of 1/4 mil insulation. The vacuum jacket will be 1/2" of foam which is equivalent to 20 mils of Mylar. Hence on the average protons with momenta <.19 GeV/c will be stopped in the target leading to a limiting q^2 of .04 $(GeV/c)^2$.

The target will be surrounded by an anti-counter lead sandwich array of 4 radiation lengths to detect charged particles or gammas coming out of the target. In addition, in the forward direction, right after the target we will have a similar anti-counter with a 1 cm. hole in the lead to allow the beam to go through. The hole will be covered by a MWPC to detect charged particles going through. In this manner and by demanding that the K_S point back to the target we will insure that the observed K_s decay was not a by product of an interaction.

VII. Measurement of the Dilution Factor

The dilution factor indicates the number of K^o and $\bar{K}^o$ produced at the target namely

$$\alpha = \frac{N(K^o) - N(\bar{K}^o)}{N(K^o) + N(\bar{K}^o)}$$

This quantity needs to be determined as a function of the K^o, $\bar{K}^o$ momentum for a proper measurement of the process $K_L p \to K_S p$ as we will see later on.

We propose to determine α by measuring the number of leptonic decays of each sign at a distance of 10 meters from the target.

Using a branching ratio

$$\frac{K^o,\ \bar{K}^o \to \pi e \nu}{K^o,\ \bar{K}^o \to \pi^+ \pi^-} \approx 10^{-3}$$

and using the results from table 2 we determine that we can observe about 30 leptonic decays per pulse. In figures 4 and 5 we show the K^o, $\bar{K}^o$ amplitude at various distances from the target assuming various values of α. Hence we can measure α above 100 GeV/c. For example at 200 GeV/c, for $\alpha = 0.5$, we expect twice as many K^o as $\bar{K}^o$ leptonic decays or twice as many positive leptons as negative leptons in our decay region.

Since we must determine the momentum of the K^o that decayed not all observed decays are useful. When the missing neutrino's momentum direction is perpendicular to the K_L direction then the K_L momentum is determined uniquely. We have determined the fraction of decays where the two momentum solutions are within 10% of each other and hence the average within at least 5% of the true value. In table 4 we show the fraction of decays with this particular configuration.

Table 4

P(GeV/c)	Fraction of Decays
50-150	.46
150-250	.47
250-350	.50
350-450	.63

Hence a good rule of thumb is 50% of all leptonic decays are useful in determining the K°, $\bar{K}^\circ$ momentum.

In table 5 we show the number of useful leptonic decays of each charge seen for $\alpha = 0.5$ in a 100 hour (7 days) run assuming 10^4 pulses/day.

Table 5

P(GeV/c)	N(+ lepton)	N(- lepton)	$\frac{\Delta\alpha}{\alpha}$
50-150	1.0×10^5	$.9 \times 10^5$	~6%
150-250	$.92 \times 10^5$	$.46 \times 10^5$	~2%
250-350	$.80 \times 10^5$	$.30 \times 10^5$	~2%
350-450	$.83 \times 10^5$	$.21 \times 10^5$	~2%

VIII. Measurement of the Elastic Processes

$$K_L p \rightarrow K_S p$$

$$K_S p \rightarrow K_S p$$

One of the interesting studies in the strong interactions of elementary particles is the concepts generated by Regge in the theory of Regge Poles[3]. Experimentally it soon became evident that tests of the theory were most successful when dealing with reactions where only 1 or 2 Regge trajectories

could be exchanged in the collision. A clear example of this is the good agreement between theory and experiment in pion-nucleon charge exchange

$$\pi^- p \to \pi^0 n$$

where the Reggeized exchange explains many features of the data[5]. Another reaction where only a few Reggeized exchanges can take place is in the reaction

$$(1) \quad K_L p \to K_S p$$

where only a ρ, ω, and ϕ can be exchanged. The Regge theory description of this reaction is clearly discussed in the work of Gilman[4]. Experimentally the ϕ does not seem to couple strongly to nuclei and hence its exchange contribution to this process can be neglected and only ρ and ω exchange need to be considered. Similarly the elastic scattering

$$(2) \quad K_S p \to K_S p$$

is supposed to be completely determined by the Pomeron trajectory.

The Regge theory states that the scattering amplitude due to a Regge trajectory being exchanged is given by[7]

$$F(s, q^2) = f'(q^2) \frac{1 + \tau e^{-i\pi\alpha(q^2)}}{\sin\pi\alpha(q^2)} \left(\frac{s - u}{2s_o}\right)^{\alpha(q^2)} \qquad (1)$$

where

$\tau = -1$ for process 1 (odd signature)

$= +1$ for process 2 (even signature)

$f'(q^2)$ is supposedly an unknown slowly varying function of the momentum transfer squared q^2; s is the center of mass energy

squared; u is the Mandelstam variable defined by $s + q^2 + u = 2 M_p^2 + 2M_K^2$; $\alpha(q^2)$ describes the Regge trajectory of the particle being exchanged; and s_o is an energy scale which we set to 1 GeV.

The totality of data about reaction (1) in the $q^2 > 0$ region (non coherent regeneration) is thoroughly described in the work of Brandenburg et. al.[6] Most of the data is for energies below 10 GeV/c and consists of only ~2000 events. Whether the Regge theory already applies at these low energies is a matter of conjecture. Nevertheless they observe that ω exchange seems to dominate. Hence in our presentation here we will assume that only one Regge trajectory, namely the ω, is important in the description of reaction (1).

We propose to measure the s and q^2 dependence of the differential cross section for both reactions (1) and (2). Because at the primary target we have the production of an incoherent K^o, $\bar{K}^o$ mixture we must consider the time development of this mixture to determine the amplitude at the secondary target where the K_L and K_S components of the beam will collide with the protons to produce K_S. If the production of K^o and $\bar{K}^o$ at the primary target in the forward direction is not equal then this beam can, while colliding in a hydrogen target, produce interference effects between reaction 1 and 2 which are sensitive to the dynamics of the collision. Although at first glance one feels this interference problem "muddies the water", we will show that, in fact, it leads to very exciting effects which are sensitive to the Regge parameters and "clears the water".

If we write

$$\sigma_2 = \frac{1}{2}[\sigma_T(K^+n)+\sigma_T(K^-n)] \qquad (2)$$

$$\sigma_1 = \frac{1}{2}[\sigma_T(K^+n) - \sigma_T(K^-n)] \qquad (3)$$

then the scattering amplitude for reaction (1) and (2) can be written as

$$F_1(s, q^2) = -s\sigma_1 \Big/ \left(\frac{s-u}{2s_o}\right)^{\alpha_1(0)}_{q^2=0} f_1(q^2) \frac{e^{i\frac{\pi}{2}(\alpha_1(q^2)-1)}}{\cos\frac{\pi}{2}\alpha_1(q^2)} \left(\frac{s-u}{2s_o}\right)^{\alpha_1(q^2)} \qquad (4)$$

$$F_2(s, q^2) = -s\sigma_2 \Big/ \left(\frac{s-u}{2s_o}\right)^{\alpha_2(0)}_{q^2=0} f_2(q^2) \frac{e^{i\pi/2\alpha_2(q^2)}}{\sin\frac{\pi}{2}\alpha_2(q^2)} \left(\frac{s-u}{2s_o}\right)^{\alpha_2(q^2)} \qquad (5)$$

where we used eq. 1, 2, 3, the optical theorem, and where now $f_1(q^2)$ and $f_2(q^2)$ are normalized to 1 at $q^2 = 0$.

If we use these amplitudes we can determine the "effective" scattering amplitude of the incoherent K^o, $\bar{K}^o$ beam at time t defined by the distance between the primary and secondary target. Because of CP violation we must also include the process $K_L p \to K_L p \to \pi^+\pi^- p$. Hence we obtain

$$F_{tot}(s,q^2,t) = A_1(s,q^2,t) + A_2(s,q^2,t)$$

$$A_1(s,q^2,t) = \sqrt{\frac{N(K^o)}{2}} \left\{ e^{-t/2\tau_S + i M_S t} F_2(s,q^2) + e^{-t/2\tau_L + i M_L t}(F_1(s,q^2)+\eta_{+-}F_2(s,q^2)) \right\}$$

$$A_2(s,q^2,t) = \sqrt{\frac{N(K^o)}{2}} \left\{ e^{-t/2\tau_S + i M_S t} F_2(s,q^2) - e^{-t/2\tau_L + i M_L t}(F_1(s,q^2)+\eta_{+-}F_2(s,q^2)) \right\}$$

where we have neglected the process $K_S p \to K_L p \to \pi^+\pi^- p$. The "effective" differential cross section can then be determined using the relation

$$\frac{d\sigma}{dq^2} = \frac{1}{16\pi s^2}\left\{|A_1(s,q^2,t)|^2 + |A_2(s,q^2,t)|^2\right\}$$

where $[N(K^o) + N(\bar{K}^o)]/2$ is set to 1.

We have plotted this differential cross section for the following parametrization of the data

$\alpha_2(q^2) = \alpha_2(0) + \alpha_2'(0)q^2 \qquad .8 \le \alpha_2(0) \le 1.;\ .8 \le \alpha_2'(0) \le 1.$

$\alpha_1(q^2) = \alpha_1(0) + \alpha_1'(0)q^2 \qquad .3 \le \alpha_1(0) \le .5;\ .8 \le \alpha_1'(0) \le 1.$

σ_1 = 20 mb and is const. with energy.

σ_2 = 130/s mb s in GeV^2. Fit to ref. (1)

$f_2(q^2) = |1 + q^2|^{1/2}$ slowly varying in q^2 with a 0 at $q^2 = -1$ to cancel pole due to $\frac{1}{\sin^2\pi/2\alpha_2(q^2)}$

$f_1(q^2) = 1.$

$S_o = 1.$ GeV

$\alpha(K^o, \bar{K}^o) = \frac{N(K^o)-N(\bar{K}^o)}{N(K^o)+N(\bar{K}^o)} = .15 + .85\,\frac{P_K}{180.}$ Assumed

$= 1$ for $P_K > 180.$

$\eta_{+-} = 2.272\times10^{-3}e^{i45.0^o}$

The data is plotted as a function of the K^o, $\bar{K}^o$ momentum for fixed q^2 and fixed distance from the primary target. Since σ_2 is about 100 times larger than σ_1 we expect the maximum of the interference to occur where the K_S amplitude has been reduced by a similar factor. This occurs around 10 K_S mean lifes. The results are shown in figs. 6,7,8,9,10,11,12 where in each case we have varied various parameters as described in the figs. As can be seen the interference effects are quite strong and can be measured in our beam. Hence we can expect to measure

the parameters $\alpha_2(0)$, $\alpha_2'(0)$, $\alpha_1(0)$, $\alpha_1'(0)$, $\sigma_1(s)$ by measuring the differential cross section between 50 and 300 GeV/c at 60, 120, and 180 meters from the target.

Expected Rates - We consider a 2 meter long hydrogen target 1 cm. in diameter at 120 meters from the target. The detector will consist of a V spectrometer 20 meters from the target to allow the $K_S \rightarrow \pi^+\pi^-$ decay to occur. In addition we have a recoil spectrometer that only covers 1/2 of the available solid angle. We assume in formula (7) that $N(K^o) + N(\bar{K}^o)/2$ into the target = 10^4/100 GeV independent of momentum.

An effective cross section for a given momentum is obtained as the integral of our expression for $d\sigma/dq^2$. The results are shown in table 6.

Table 6

P(GeV/c)	σ(μb)(based on $\alpha_2(q^2)=1+q^2$ $\alpha_1(q^2)=.5+q^2$)
100	1.02
200	.41
300	.83
400	6.4

The interaction mean free path in liquid hydrogen for a 1 μb. cross section is 2.4×10^5 meters. The number of interactions per incident particle, the detection efficiency, and the number of detected interactions/pulse are given by the expressions

$$\#\text{ of interactions/particle} = \frac{2}{2.4\times10^{5}}\,\sigma(\mu b) = .84\times10^{-5}\sigma(\mu b)$$

Detection Efficiency $\equiv \varepsilon = 1/2 \times B.R.(K_S \to \pi^+\pi^-) \times$ (Fraction of K_S decays in 20 meters) where 1/2 refers to the solid angle covered by the recoil spectrometer.

$$\text{Number of Detected Interactions/pulse} = 10^{4} \times .84\times10^{-5} \times \sigma(\mu b) \times \varepsilon$$
$$= .084 \times \sigma(\mu b) \times \varepsilon$$

In table 7 we calculate the efficiency ε and in table 8 the number of interactions/pulse

Table 7

P(GeV/c)	Fraction of K_S Decays in 20 meters	ε
100	.98	.33
200	.85	.29
300	.71	.24
400	.61	.20

Table 8

P(GeV/c)	# of Detected Int./pulse	Detected Int./200 hours*
100	.027	3.8×10^{3}
200	.010	1.4×10^{3}
300	.017	2.0×10^{3}
400	.11	1.5×10^{4}

*based on 1.4×10^{5} pulses

The incident number of effective particles was based on a 1 cm. diameter target. We expect to use such a target only for the very low q^2 ($q^2 < .10 (GeV/c)^2$) region in order to observe the recoiling proton. For the higher q^2 region we propose to use a 10 cm. diameter target implying a factor of 100 increase in the number of interacting kaons. We calculate the number of high q^2 events expected in 200 hours of running. The results are presented in table 9.

Table 9

P(GeV/c)	$\sigma(q^2 > .1)\mu b$	Detected Int/200 hours
100	.29	1.1×10^5
200	.10	3.4×10^4
300	.18	4.3×10^4
400	2.36	5.5×10^5

Since the differential cross section is expected to have a dip at $q^2 \simeq .15\ (GeV/c)^2$ and the cross section only varies slowly with q^2 after that we expect these events to populate uniformly the region up to $q^2 \approx 1 (GeV/c)^2$.

We would like to point out here that this is the only process we know of where we can produce an interference between two strong interaction processes and hence obtain detailed information on the structure of their scattering amplitudes. It is also a sensitive way to determine the cross section difference $\sigma(K^\circ p) - \sigma(\bar{K}^\circ p)$.

IX. The Detector

The detector consists of a forward V spectrometer and a recoil detector. The recoil detector is only necessary for program B. A schematic diagram is shown in fig. 13.

The V Spectrometer - The V spectrometer is placed 20 meters after the target, the intervening space being used as a decay region. The front V detector consists of a .7mx.7m. MWPC used for triggering on 2 or more hits. This is followed by 2X and 2Y drift chambers of the same size just after the MWPC and a similar set of drift chambers 5 meters further downstream. In between these is U-V MWPC to separate the ambiguity between the two tracks of the V. The spatial resolution of these chambers is expected to be 150μ and hence we get an angular resolution on each track $\Delta\theta = \sqrt{2}\times150\times10^{-6}/5 \simeq 4\times10^{-5}$ radians.

In order to measure the full range in q^2 for which this beam is capable ($q^2 \simeq 1.5(\mathrm{GeV}/c)^2$) we need a magnet with a $.7\times.7\mathrm{m}^2$ gap and a magnetic field integral of ~20 Kg meters. Hence a magnet with a 1-2 meter depth is adequate. We propose that Fermilab supply this magnet. This magnet will also be useful in the study of multiparticle final states in this beam.

The chambers behind the magnet will be 1.4 m. in the bend plane and 1m. in the other. After this we have an electron and gamma detector made up of a MWPC and lead sandwich and a muon detector. This back array is used to trigger either on a leptonic decay mode or $K_L\pi_3$ by using the lepton detector in coincidence or a purely $\pi^+\pi^-$ decay mode by using it in anti-coincidence.

This arrangement will allow us to measure the momentum of 300 GeV/c track with a $\sigma \simeq 3\%$ and the V momentum with a $\sigma \simeq 5\%$. The direction of the V is known with a $\sigma \approx 6 \times 10^{-5}$ radians leading to a σ in $q \approx .02$ GeV/c. Finally this leads to an error in the mass of the V $\sigma \simeq 3\%$.

<u>The Recoil Spectrometer</u> - There are 2 arms in the recoil detector as shown in fig. 14. Each arm consists of 2 sets of XY MWPC chambers separated by 20 cms. They are used to measure the direction of the recoiling proton. Most of the error in direction is due to multiple scattering in the recoiling proton and varies from 1.6º at 200 MeV/c to .13º at 800 MeV/c.

At a distance of 50 cms. from the target we have a liquid array scintillator bank to be used to measure the momentum of the recoil by timing and for higher momenta by energy deposition. Using a timing error of .4nsec we have a momentum error $\Delta P/P = 11\%$ at 400 MeV/c, or $\Delta P \approx 0.044$ GeV/c comparable to the error in the V spectrometer. As the momentum of the recoiling proton increases the timing becomes less useful but the error in the direction of the recoil decreases. In this kinematic region a measurement of the energy deposited in the liquid scintillator gives similar errors. Both of these measurements can be used as a constraint to tell we have an elastic scatter.

In fig. 15 we present a plot of the recoiling arm kinematics and in fig. 16 the resolution we expect as a function of the transverse momentum squared.

The Beam Line - In fig. 17 we show an experimentalist view of an area in which one could carry out an experimental program up to 1 TeV in the future. We need a hall with maximum dimensions 500 meters long and 7 meters wide to accommodate large transverse momentum experiments. We require a series of sweeping magnets. One after the primary target to bend out the charged beam, and two others to allow for removal of the photon component of the beam with a series of radiators about 10 radiation lengths total. For future experiments doing photoproduction experiments or where the neutron component of the beam needs to be reduced further one may need a liquid deuterium filter to remove the hadronic component of the beam.

For the present proposed series of experiment we require a target station, at ~10 meters from the detector.

To carry out the series of regeneration experiments from $t = 0$ to $t = 1(\mathrm{GeV}/c)^2$ we need a hall that starts 60 meters from the target with regions of access in between for sweeping magnets. The hall needs to be 140 meters long in order to carry out measurements of at least 3 positions namely 60m., 120m., and 180m. The width of the hall should be 7m. to accommodate large P_T experiments. We propose that the detector be mounted on rails so that it can be moved back and forth to various positions.

An experimental hall that would accommodate all these experiments up to 1 TeV should be ~500 meters long.

X. Requests from Fermilab

For program A -

1) A sweeping magnet right after the target to sweep out all charged particles associated with the beam.

2) An analyzing magnet with a $.7x.7m^2$ gap and a field length integral of 20 Kg. meters. Although this large a magnet is not essential for the measurements in program A it becomes important for programs B and C and we request its construction at this time.

3) An amount of iron for a muon identifier. It should cover an area of $2.0x1.5m^2$ and at least 3 meters deep.

4) Sufficient PREP equipment in the form of coincidence units, discriminators, scalars and CAMAC equipment to allow us to carry out these measurements. We expect half of our needs to be supplied by us.

5) We request an initial running period of only 400 hours of beam time at a pion beam energy of about 300 GeV/c (200 GeV/c is also acceptable at the start) with an intensity of $\sim 10^8$ pions/pulse for the initial beam survey and for the leptonic decay measurements.

For program B -

1) Construction of an experimental hall that will allow us to carry out regeneration type measurements. This area is to be 140 meters long and about 7 meters wide and can start about 60 meters from the K generating target. If future experiments up to 1 TeV are considered the hall should be 400 meters long which together with the presently proposed pion hall would add to 500 meters.

XI. Cost Estimate

4 (.2x.2 m^2)MWPC	\$ 4 K
400 wires \$10/wire	
2 (.7x.7 m^2)MWPC	\$ 7 K
700 wires \$10/wire	
2 (1.4x.1 m^2)MWPC	\$ 14 K
1400 wires \$10/wire	
8 (.7x.7 m^2) Drift Chambers	\$ 14 K
280 wires \$50/wire	
8 (1.4x1 m^2) Drift Chambers	\$ 28 K
560 wires \$50/wire	
Wire Chamber Construction Cost	~ \$ 10 K
Lepton Detector	~ \$ 40 K
Anticounter array	~ \$ 5 K
Analyzing magnet	~ \$300 K
.7x.7 m^2 aperture 20 Kgm.	
Electronics for Logic	~ \$ 30 K

<u>For program B</u>

The estimate for the experimental ball (long range)~\$1000 K

7 m. wide x 400 m long

8 recoil (2mx.5 m^2)MWPC	\$ 50 K
5000 wires \$10/wire	
2 Scintillator Tanks (2x1x.3 m^3)	\$ 6 K
26 Phototubes \$400/(tube + bases)	\$10.4 K

Acknowledgment

We would like to thank Brad Cox and Sam Aronson for many helpful comments.

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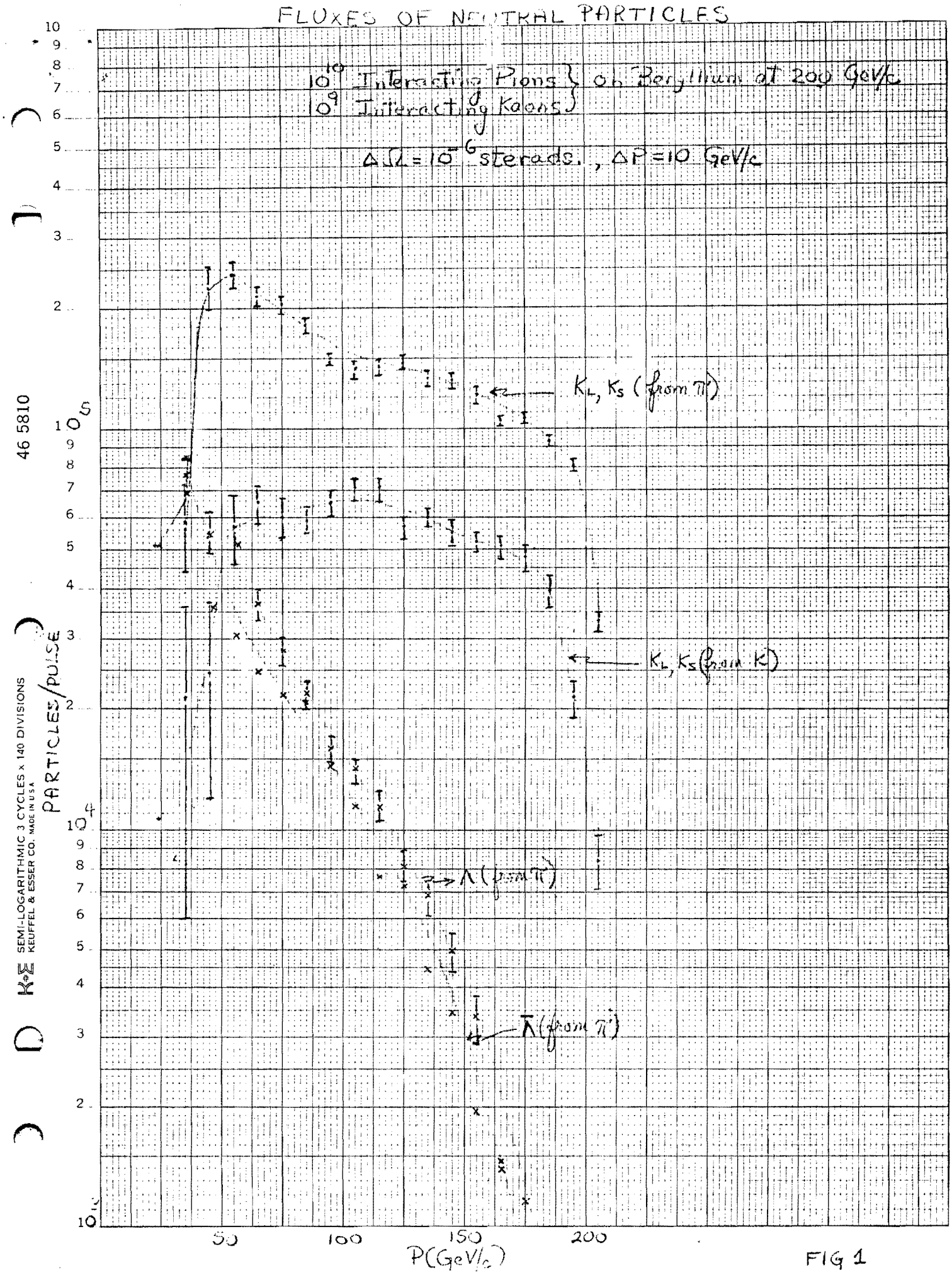

FLUXES OF NEUTRAL PARTICLES
10^{10} Interacting Pions } on Beryllium at 200 GeV/c
10^{9} Interacting Kaons }
$\Delta\Omega = 10^{-6}$ sterads. , $\Delta P = 10$ GeV/c
K_L, K_S (from π)
K_L, K_S (from K)
Λ (from π)
$\bar{\Lambda}$ (from π)
PARTICLES/PULSE
P(GeV/c)
50
100
150
200
46 5810
K&E SEMI-LOGARITHMIC 3 CYCLES x 140 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG 1

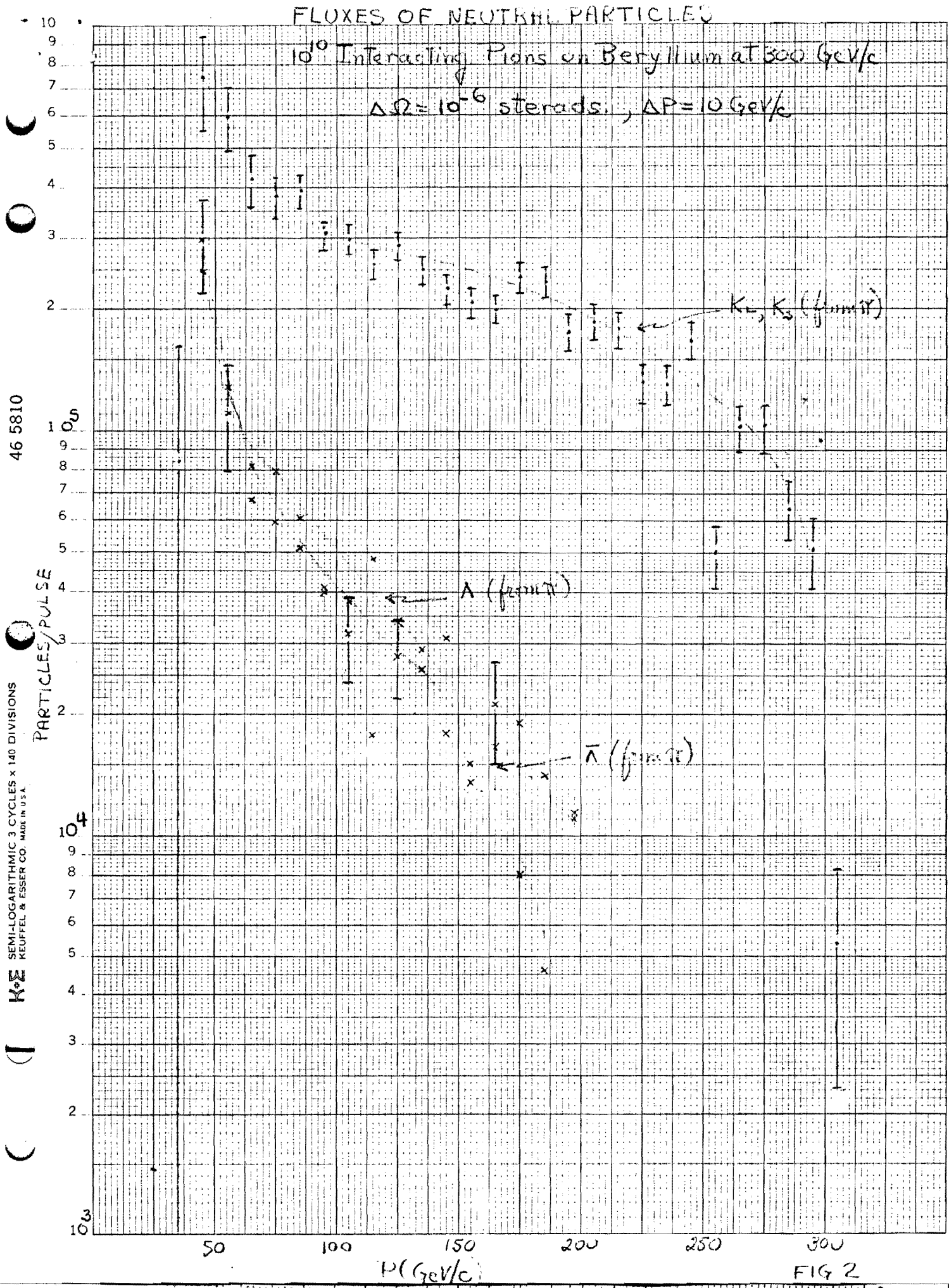

FLUXES OF NEUTRAL PARTICLES
10^{10} Interacting Pions on Beryllium at 300 GeV/c
$\Delta\Omega = 10^{-6}$ sterads., $\Delta P = 10$ GeV/c
K_L, K_S (from π)
Λ (from π)
$\bar{\Lambda}$ (from π)
PARTICLES/PULSE
P (GeV/c)
50
100
150
200
250
300
46 5810
K+E SEMI-LOGARITHMIC 3 CYCLES x 140 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG 2

Spatial Oscillations of a K^0, $\bar{K}^0$ System for Various Dilution Factors

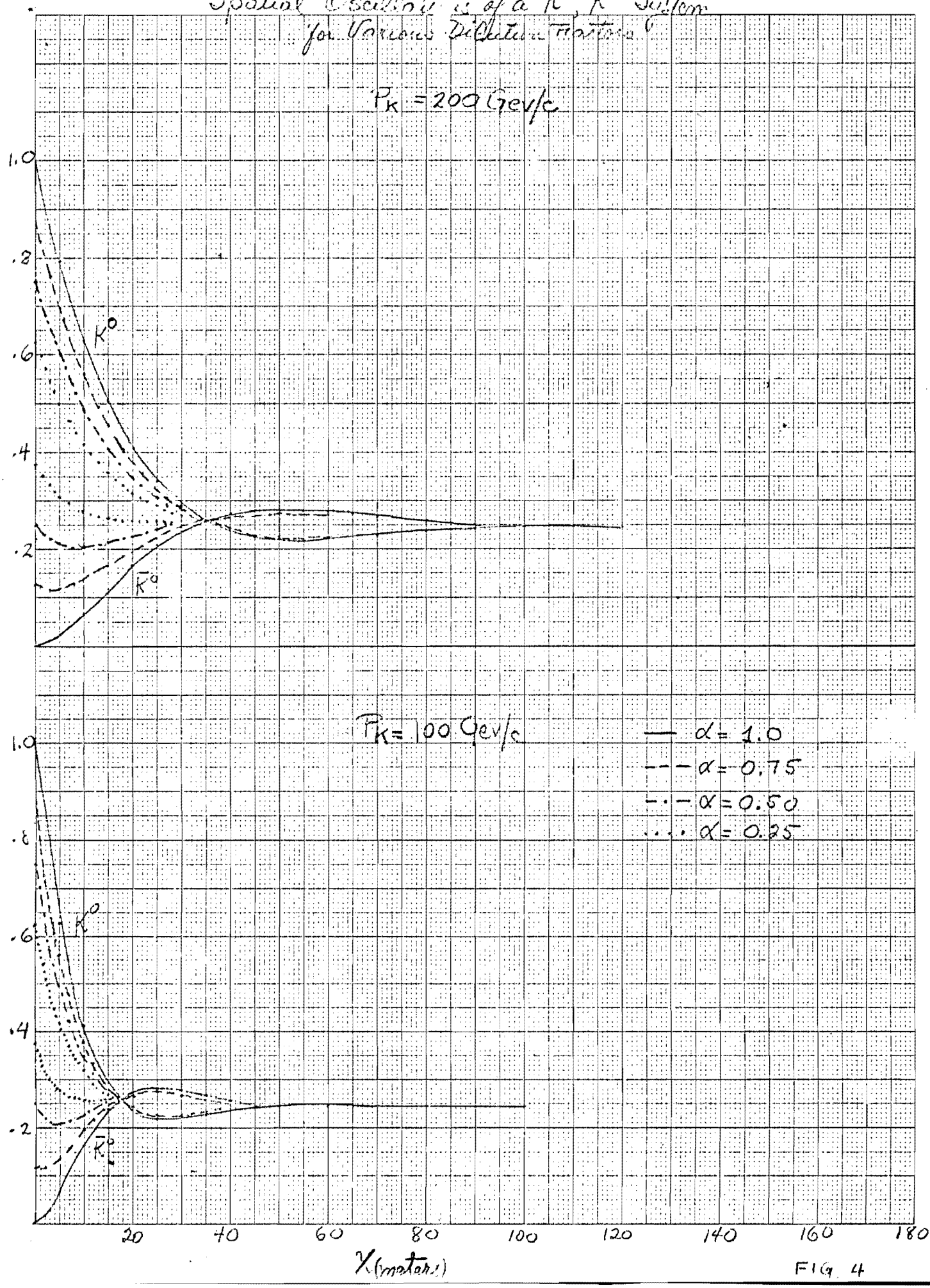


FIG. 4

461510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

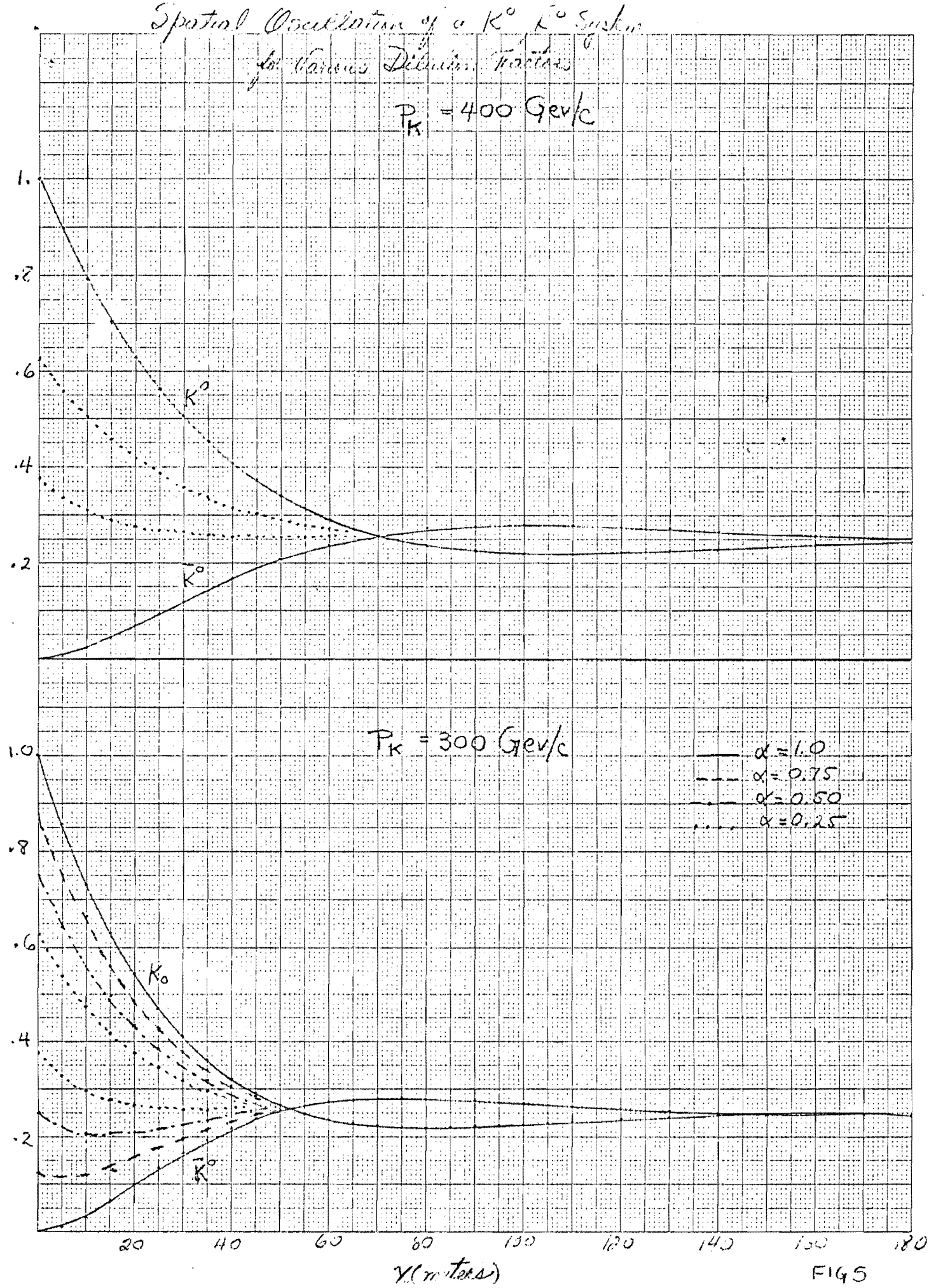
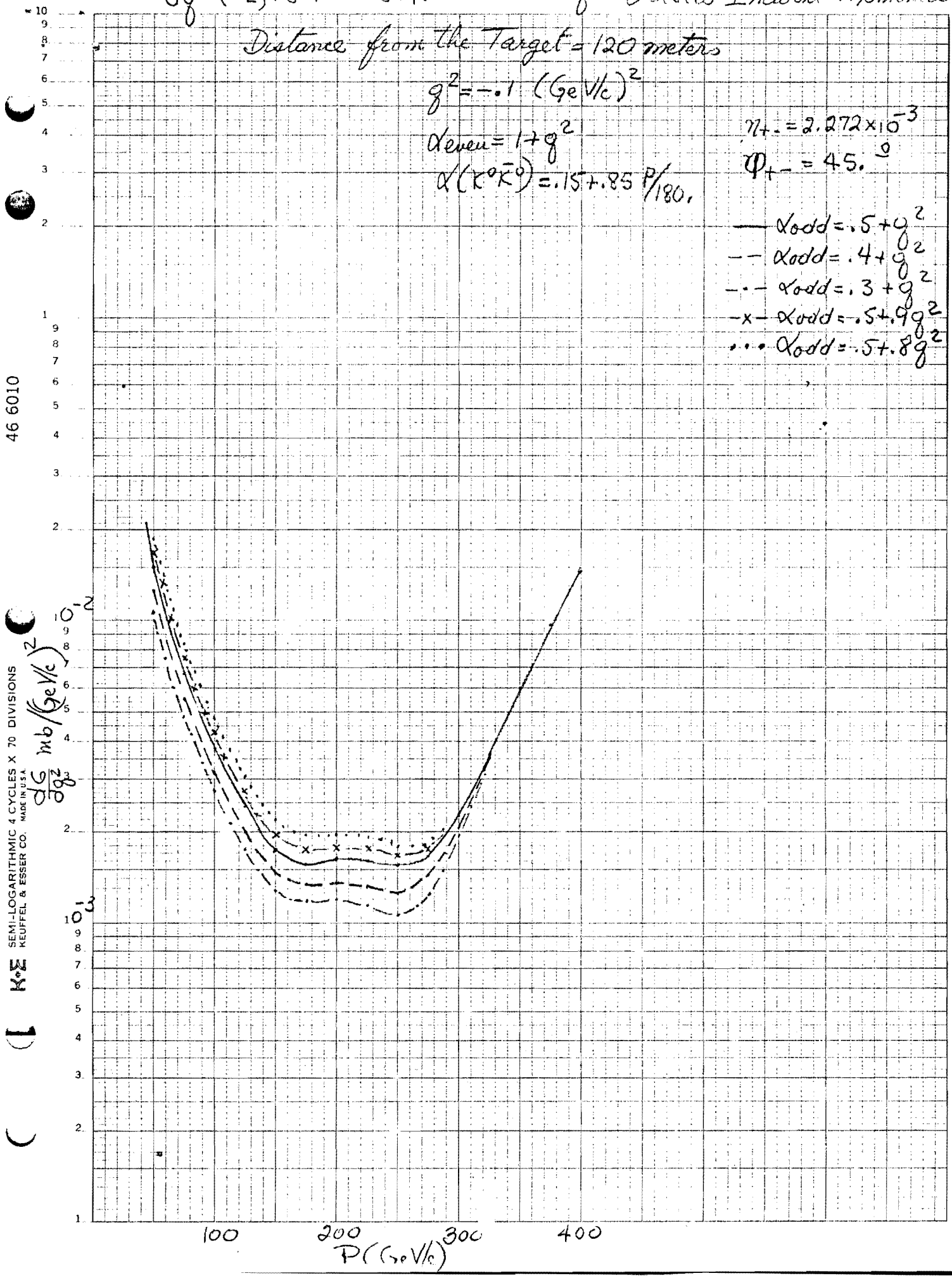


FIG 5

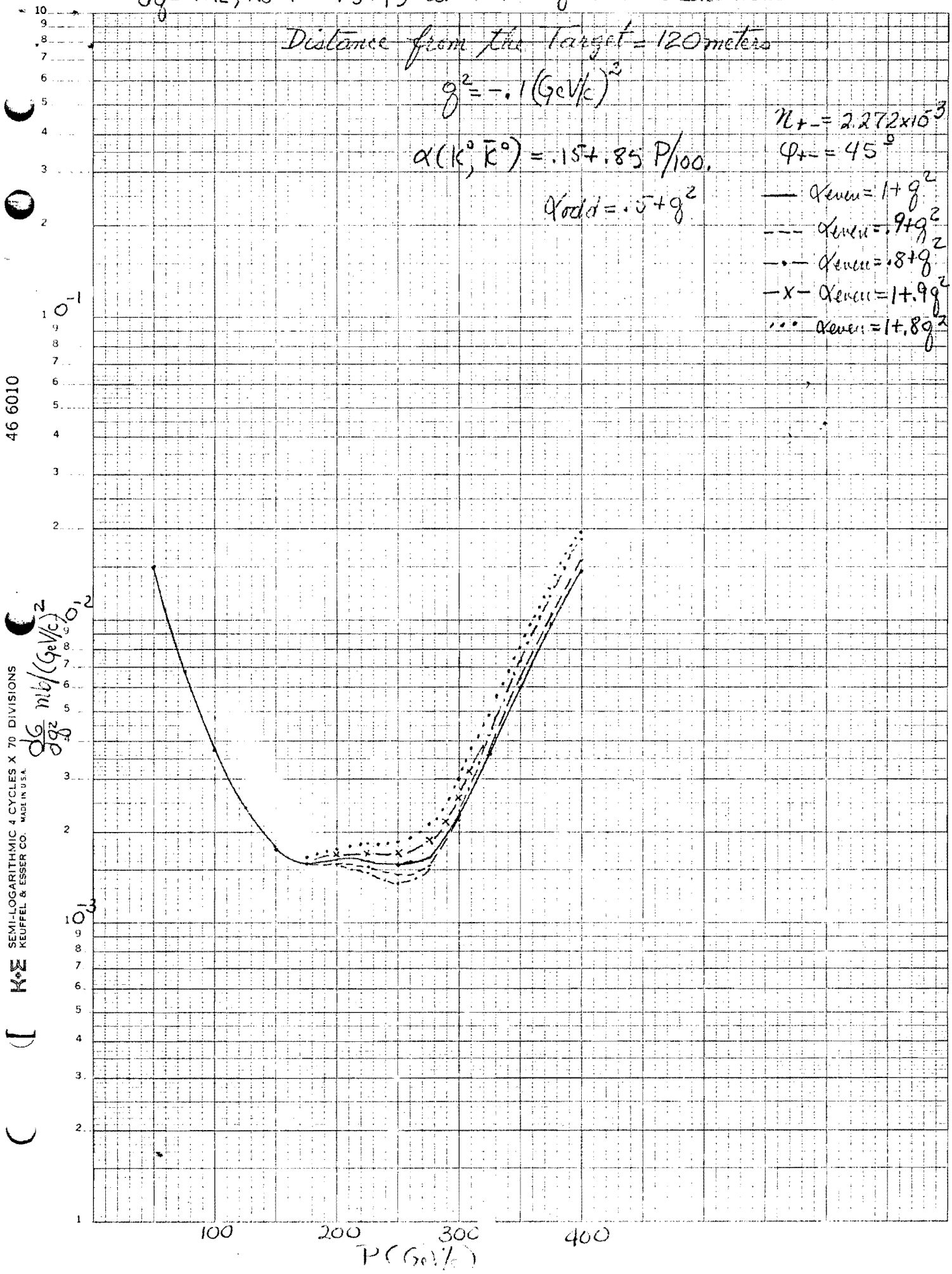
461510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

$\frac{d\sigma}{dq^2}(K_L, K_S+p \to K_S+p)$ at Fixed q^2 Various Incident Momenta



46 6010
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

$\frac{d\sigma}{dq^2}(K_L, K_S+p \to K_S+p)$ at Fixed q^2 Versus Incident Momenta



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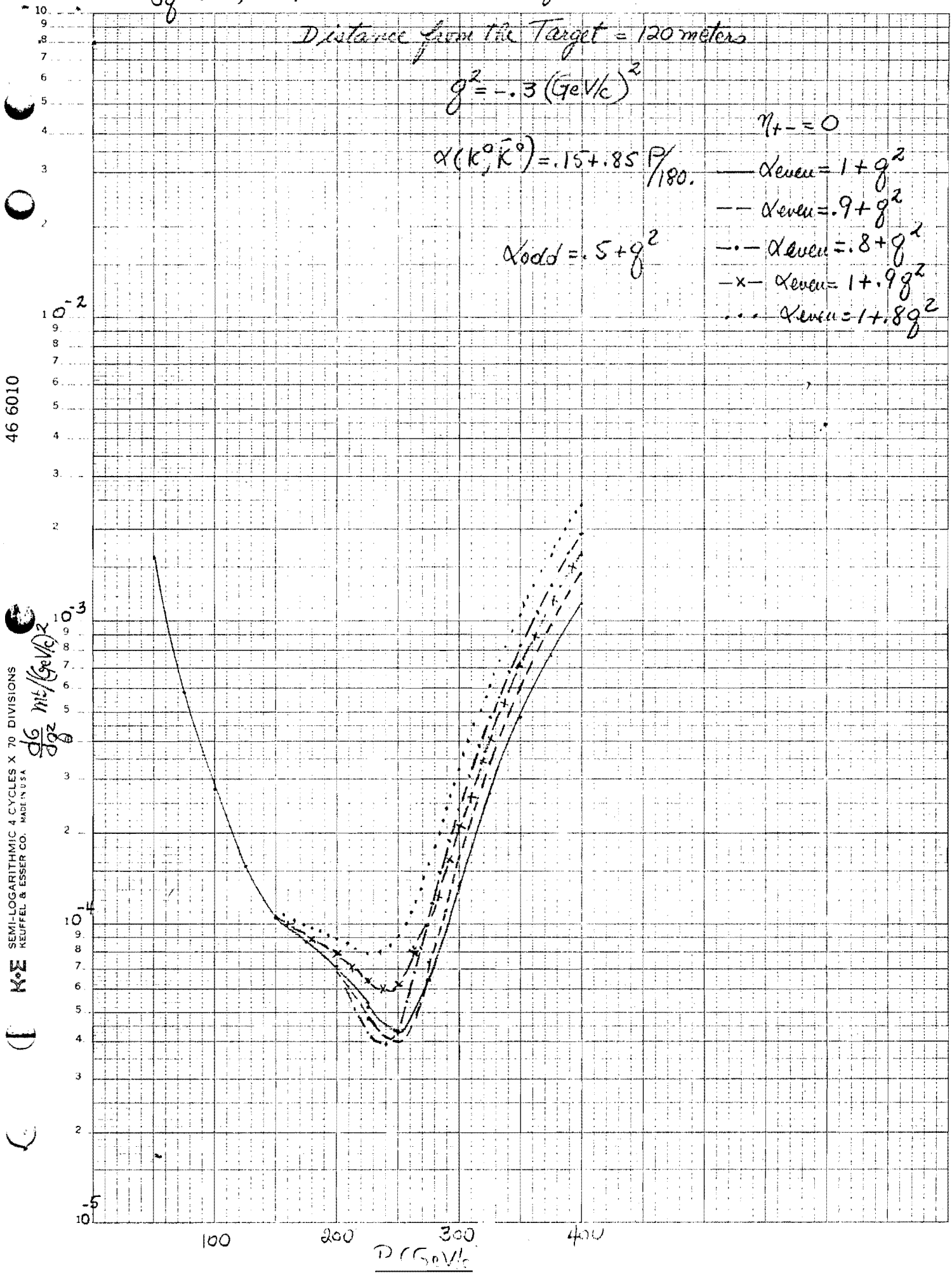
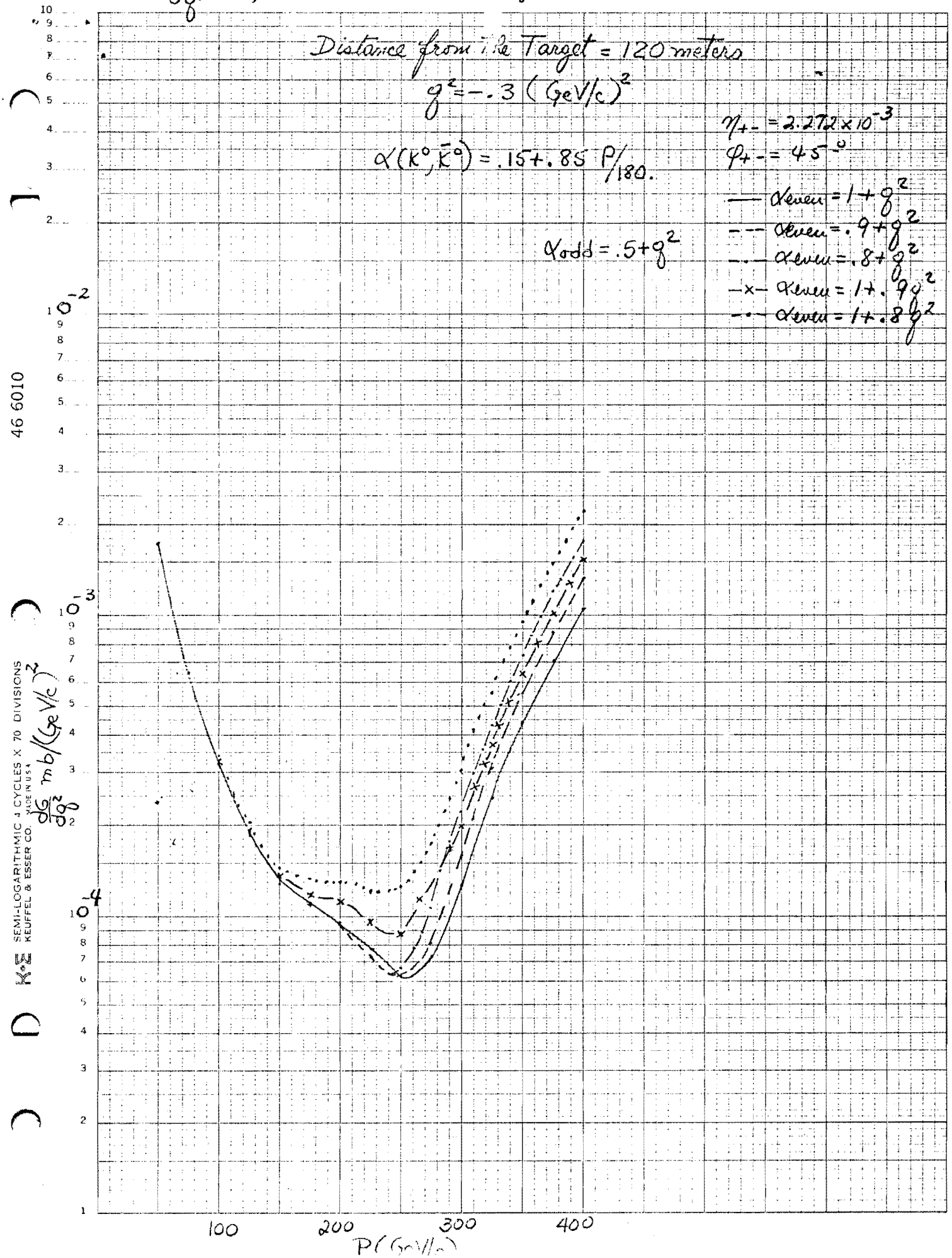
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

$\frac{d\sigma}{dq^2}(K_L, K_S+p \to K_S+p)$ at Fixed q^2 Versus Incident Momenta



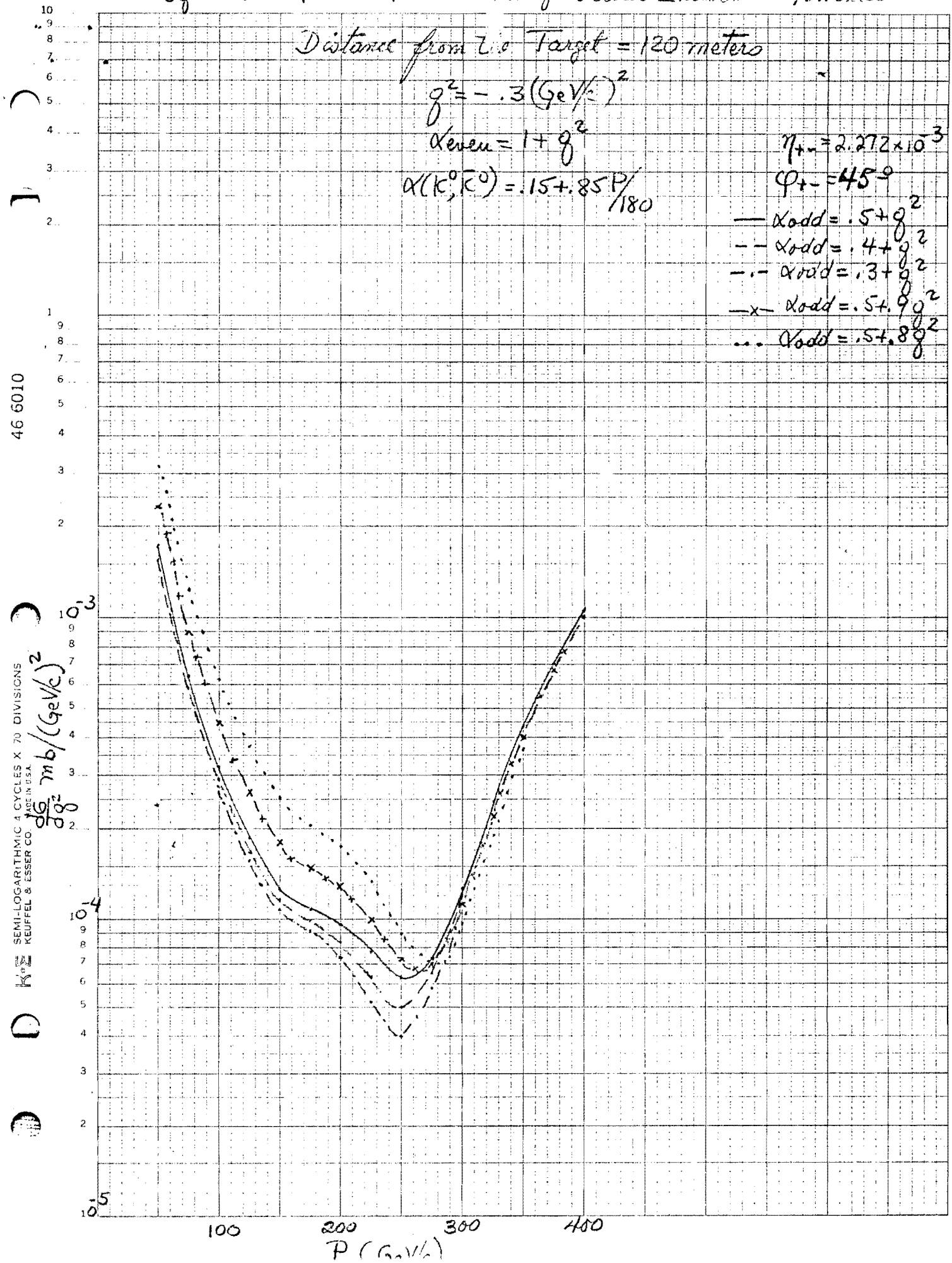
46 6010
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

$\frac{d\sigma}{dq^2}(K_L, K_{S+P} \to K_{S+P})$ at Fixed q^2 Versus Incident Momenta

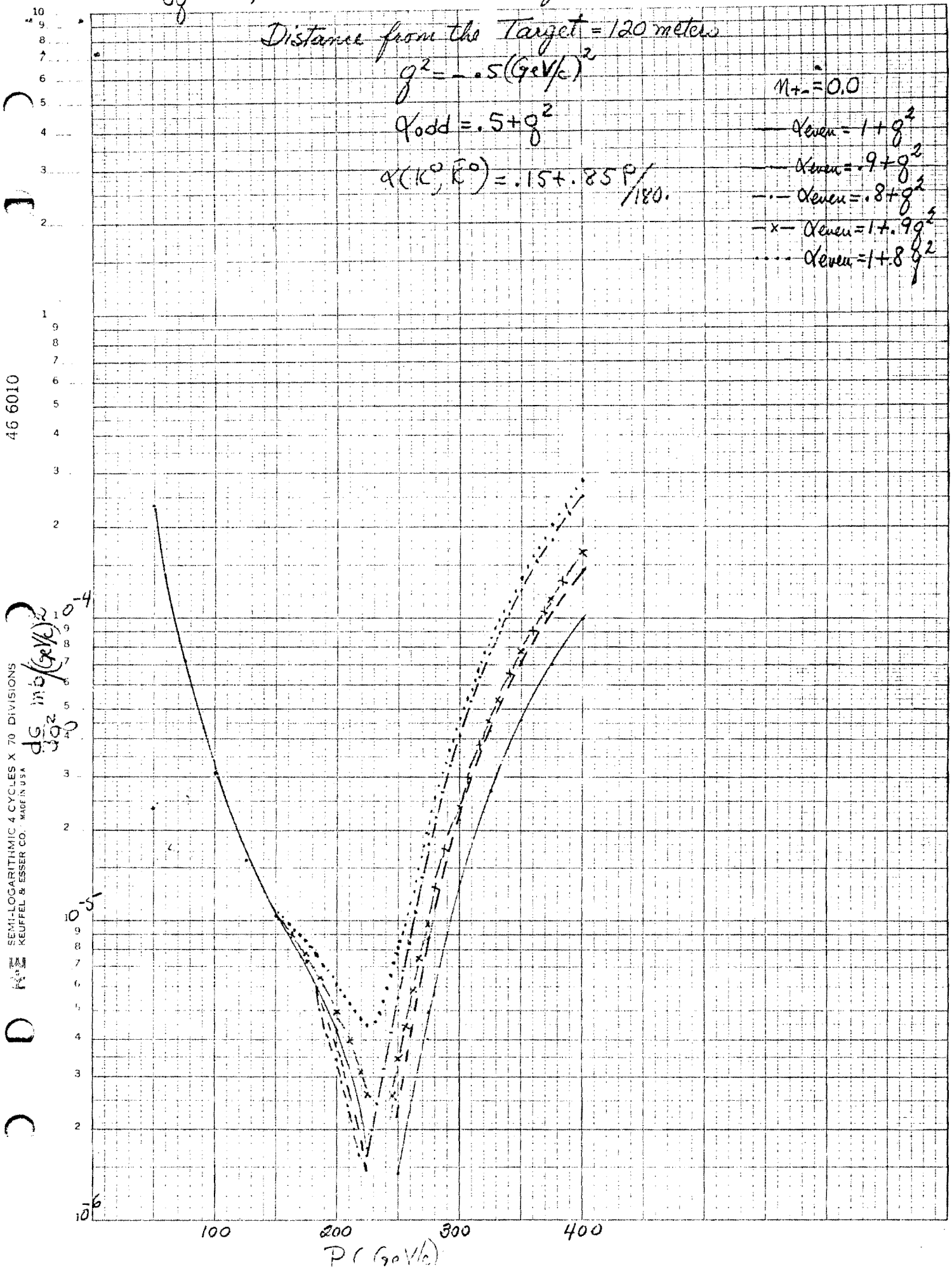


46 6010
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

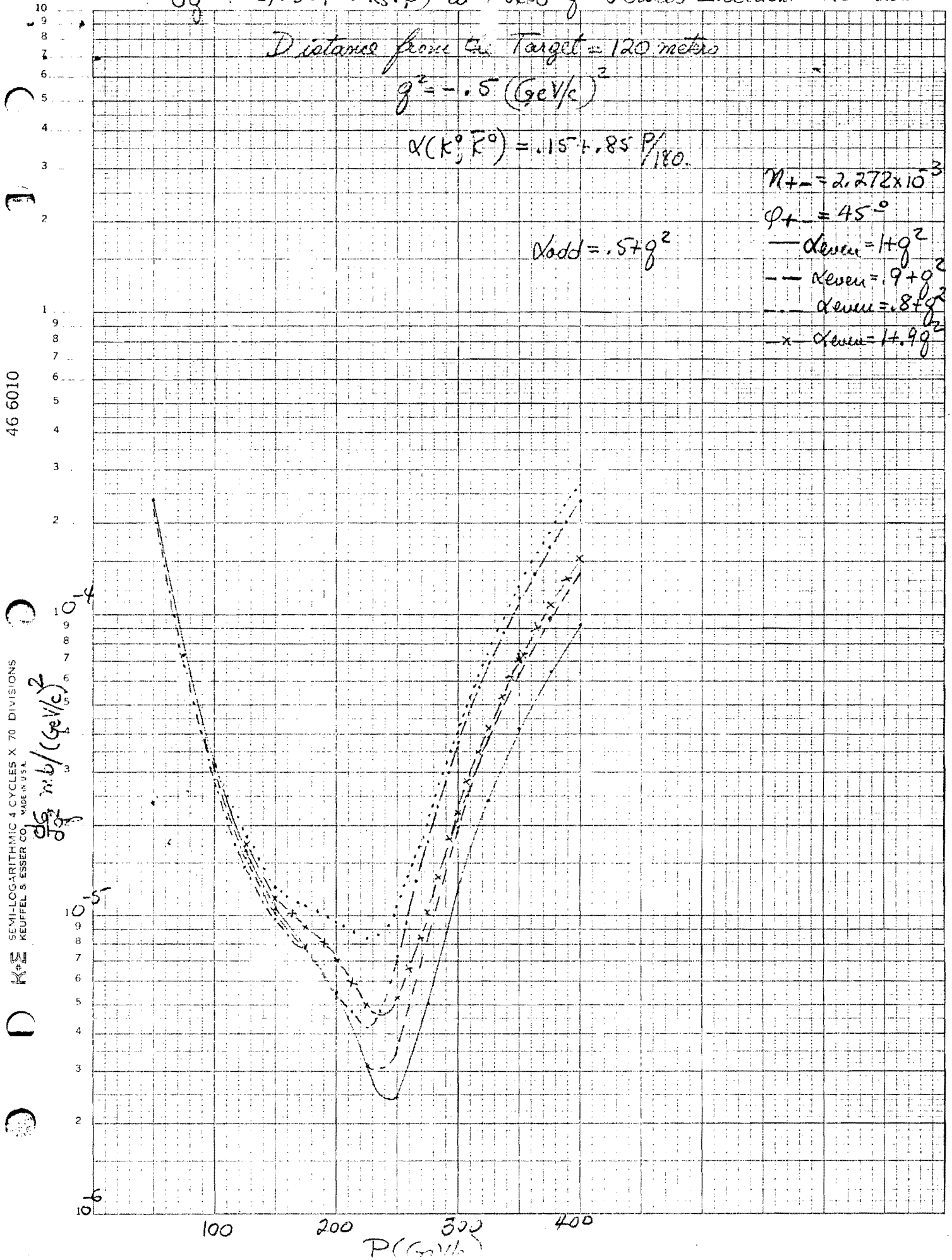
$\frac{d\sigma}{dq^2}(K_L, K_S + p \to K_S + p)$ at Fixed q^2 Versus Incident Momentum



$\frac{d\sigma}{dq^2}$ (K_L, $K_S+p \to K_S+p$) at Fixed q^2 Versus Incident Momenta



$\frac{d\sigma}{dq^2}(K_L, K_S + p \to K_S + p)$ at Fixed q^2 Versus Incident Momenta.



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K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

DETECTOR

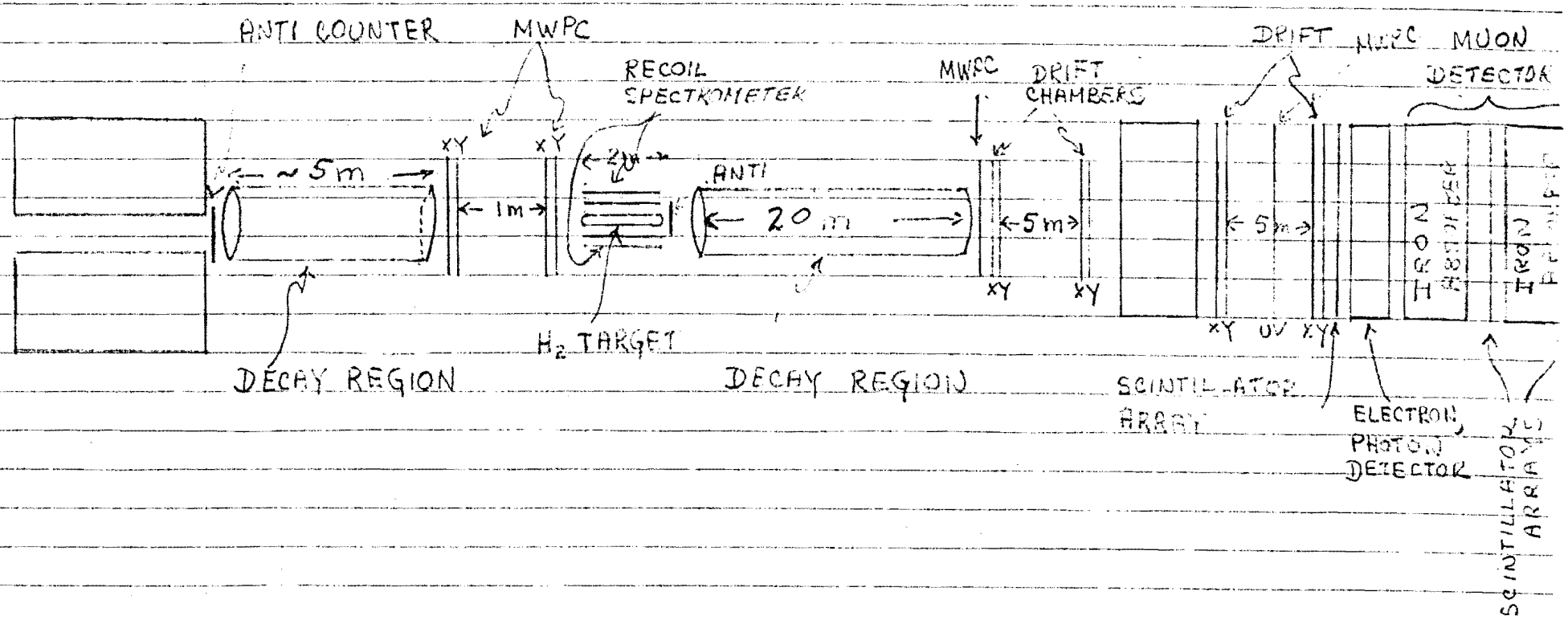
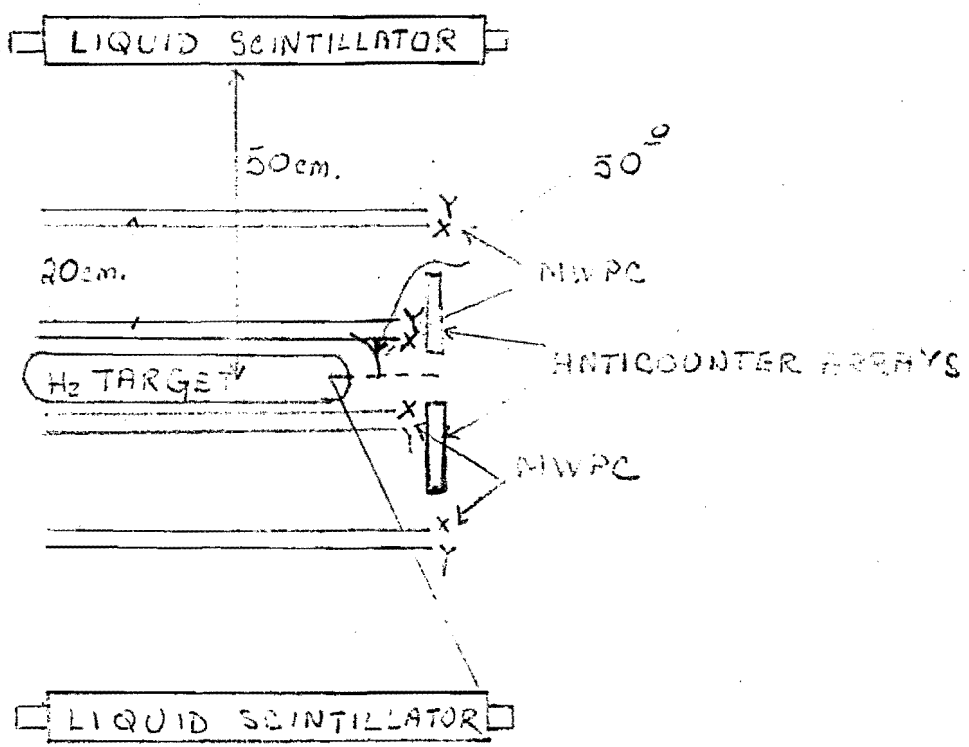


FIG. 13.

RECOIL SPECTROMETER
PROGRAM B
TOP VIEW



THERE ARE ANTI COUNTER ARRAYS ABOVE AND BELOW THE TARGET

FIG 14

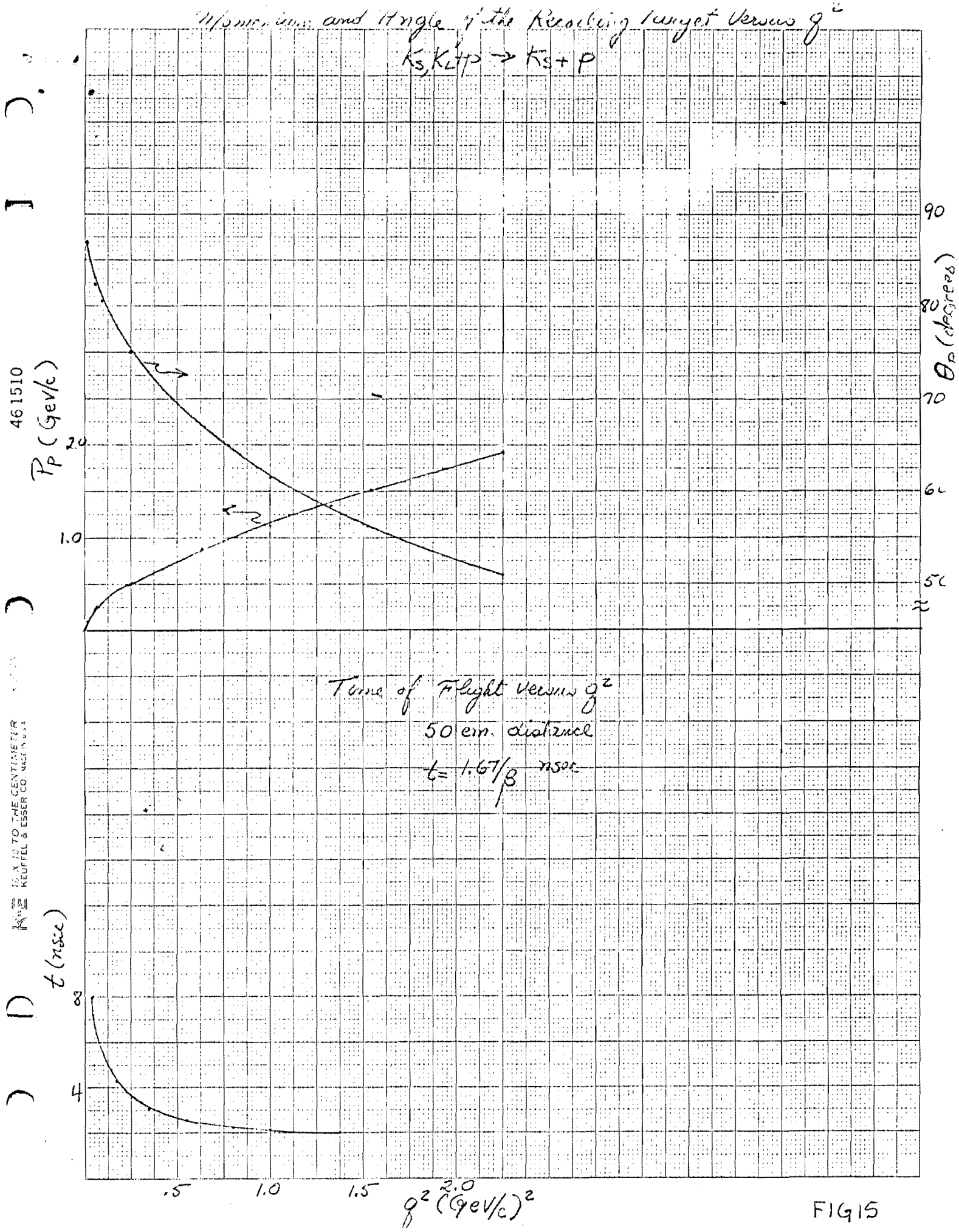

Momentum and Angle of the Recoiling Target Versus q^2
$K_S, K_L + p \rightarrow K_S + p$
P_p (Gev/c)
2.0
1.0
θ_p (degrees)
90
80
70
60
50
Time of Flight Versus q^2
50 cm. distance
$t = 1.67/\beta$ nsec.
t (nsec)
8
4
.5
1.0
1.5
2.0
q^2 $(Gev/c)^2$
461510
K+E 10 X 10 TO THE CENTIMETER
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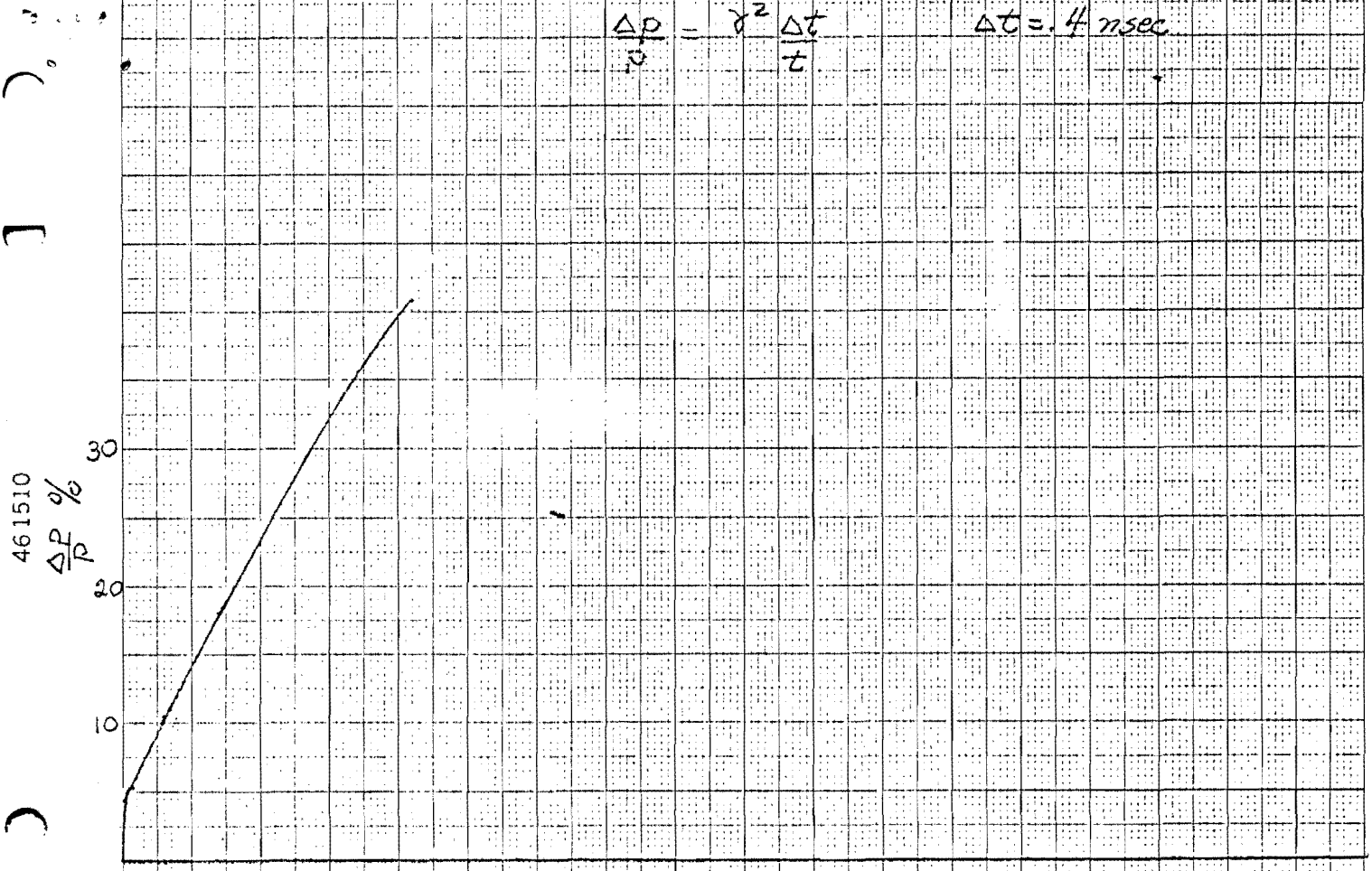
FIG 15

Resolution of the Recoil Spectrometer in Momentum

$$\frac{\Delta p}{p} = \gamma^2 \frac{\Delta t}{t} \qquad \Delta t = .4 \text{ nsec}$$



Resolution of the Recoil Spectrometer in Angle

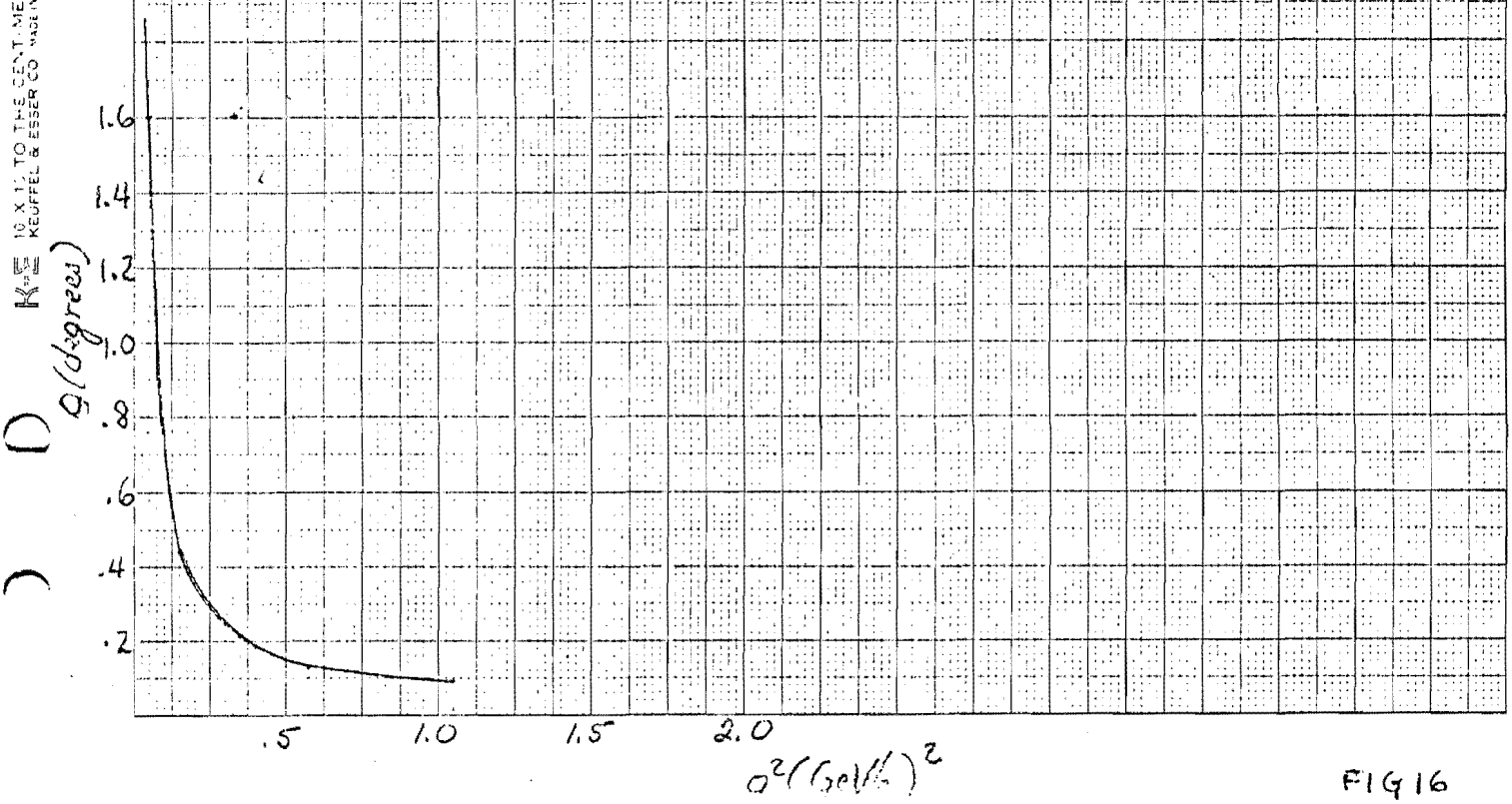


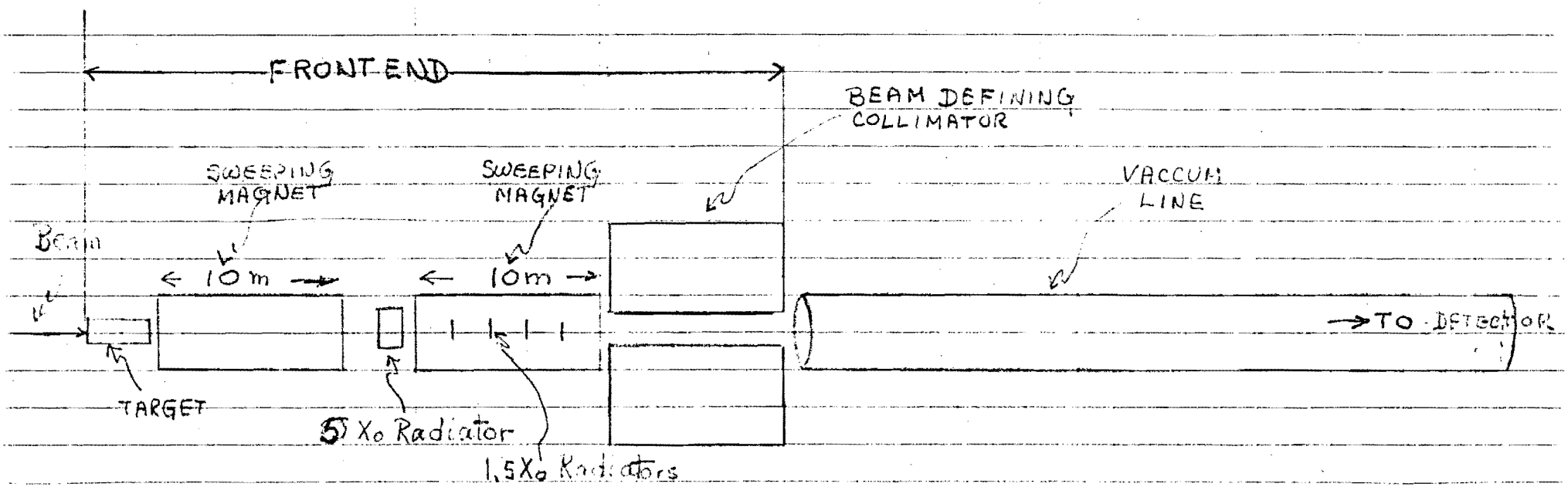
FIG 16

461510
K&E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.

POSSIBLE BEAM LINE FOR PROGRAM B

THE DETECTOR IS MOVABLE TO THREE POSSIBLE LOCATIONS

180 m., 120 m., 60 m. DOWNSTREAM FROM THE TARGET



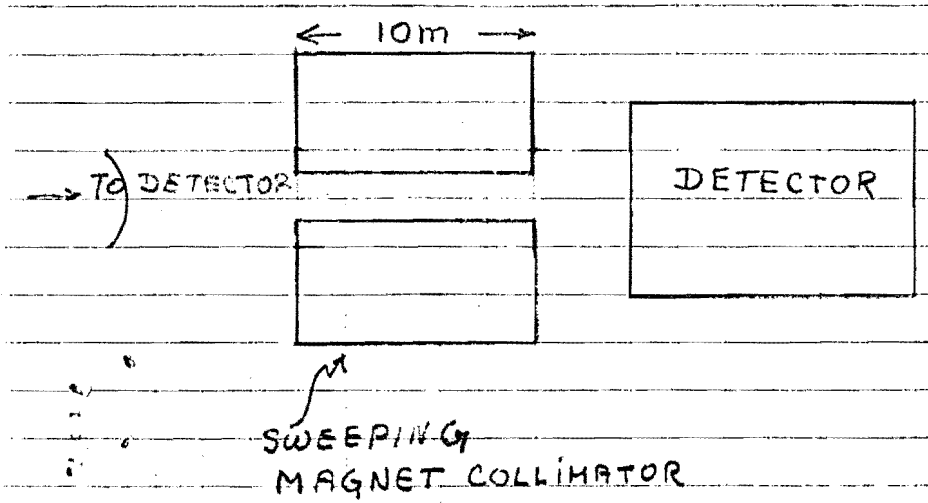


FIG 17