NAL PROPOSAL No. 111

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PROPOSAL TO STUDY $\pi^- p \to \pi^\circ n$ and $\pi^- p \to \eta n$ AT HIGH ENERGY

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FOR NAL.
Written in real ink!

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PROPOSAL TO STUDY $\pi^- p \to \pi^o n$ and $\pi^- p \to \eta n$ AT HIGH ENERGY*

The asymptotic behavior of hadronic cross sections is one of the important questions that NAL may be able to answer. We propose here a simple experiment to measure the $\pi^- p$ charge exchange cross section up to the highest energies available at NAL. This cross section is sensitive to small differences between the total cross section for $\pi^- p$ and $\pi^+ p$. If these cross sections persist in staying apart as is perhaps indicated by the Serpukhov data, then the charge exchange cross section will stay large.

In addition, a measurement of $\pi^- p \to \eta^o n$ will be made. The π^o reaction is a classic example in Regge theory of essentially pure ρ exchange and the η^o reaction of pure A_2 exchange. Thus this experiment will also test the predictions of this theory at high energies. Two π^o production will also be measured.

The experiment utilizes very simple equipment, but uses a new scheme to accurately determine the π^o or η^o direction. This detector is composed of 140 narrow "finger counters" that locate the shower position and integrate its total energy loss. This knowledge allows one to uniquely solve for the direction of the π^o or η^o. Tests have been made at SLAC to verify that the detector will operate as described.

The experiment is planned to run at eight different energies between 20 and 200 GeV. The lower end will tie in to existing measurements. The time required is 450 hours, including data taking and test time, in a π^- beam with $\Delta p/p < \pm 0.5\%$, with intensity between 10^6 and 2×10^6 π^-/pulse and with energy adjustable over the aforementioned range.

All of the necessary equipment, excluding the beam, but including the target, Cerenkov counters, shower counter, and fast electronics can be supplied by Caltech and LRL.

The physics of this experiment is so exciting, and the demands on NAL to stage it so modest that we feel that NAL will be eager to schedule it to run as soon as protons are available in the meson area.

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I. PHYSICS JUSTIFICATION

We propose to measure the two reactions: 1) $\pi^- p \to \pi^o n$ and 2) $\pi^- p \to \eta^o n$ in the energy region between 20 GeV and 200 GeV and for momentum transfers between 0 and 1.5 GeV/c^2. The physics to be studied includes:

(A) Asymptotics

The recent results on meson-nucleon total cross sections at high energies[1] show the measured $\pi^\pm$ cross sections constant above 30 GeV. The implications of these results are among the most exciting initial physics problems to pursue at NAL energies. A closely related experiment is the charge exchange reaction $\pi^- p \to \pi^o n$ which can be used to shed more light on the asymptotic behavior of the cross sections. We can write through the use of the optical theorem and charge independence the following equation:

$$\frac{d\sigma_{CEX}}{dt}\Bigg|_{t=0} = \frac{\pi}{k^2}\left[(\mathrm{Re}\ A_{CEX})^2 + (\mathrm{Im}\ A_{CEX})^2\right]_{t=0} =$$

$$= \frac{1}{32\pi}\left|\sigma_t^+ - \sigma_t^-\right|^2 + \frac{\pi}{k^2}\left|\mathrm{Re}\ A_{CEX}\right|^2_{t=0} \qquad (1)$$

where σ_{CEX} is the charge exchange cross section, $\sigma_t^\pm$ is the total $\pi^\pm$ cross section on protons, and A_{CEX} is the amplitude of the charge exchange reaction and is related to the charged scattering amplitudes by

$$A_{CEX} = \frac{1}{\sqrt{2}}\,(A^+ - A^-) \qquad (2)$$

Our first observation is that the charge exchange cross section provides an upper limit on the value of $\left|\sigma_+ - \sigma_-\right|^2$ as can be seen from Equation (1). For instance, if the observed $\left.\frac{d\sigma_{CEX}}{dt}\right|_{t=0}$ is of the order of 25 $\mu b/GeV^2$ (as appears plausible by extrapolating present data), then $\left|\sigma_+ - \sigma_-\right|^2 \leq 1$ mb .

The above numbers are only meant to give a feeling for the sizes of the cross section involved and the relation of this experiment to the total cross section experiments. If both **experiments** are done carefully, then at t=0 it will be possible to separate the amplitudes into real and imaginary parts by combining the data.

The behavior of the CEX cross section has been investigated in detail in a paper(2) by D. Horn and A. Yahil who use dispersion relations to predict what would happen if the π^- and π^+ cross sections asymptotically approach a constant difference at high energies. It is seen from their Figure 4, which is reproduced on the next page, that the charge exchange cross section deviates from its 1/p low energy dependence, intially flattening-off and subsequently actually increasing with rising energy.

(B) Reggeizm

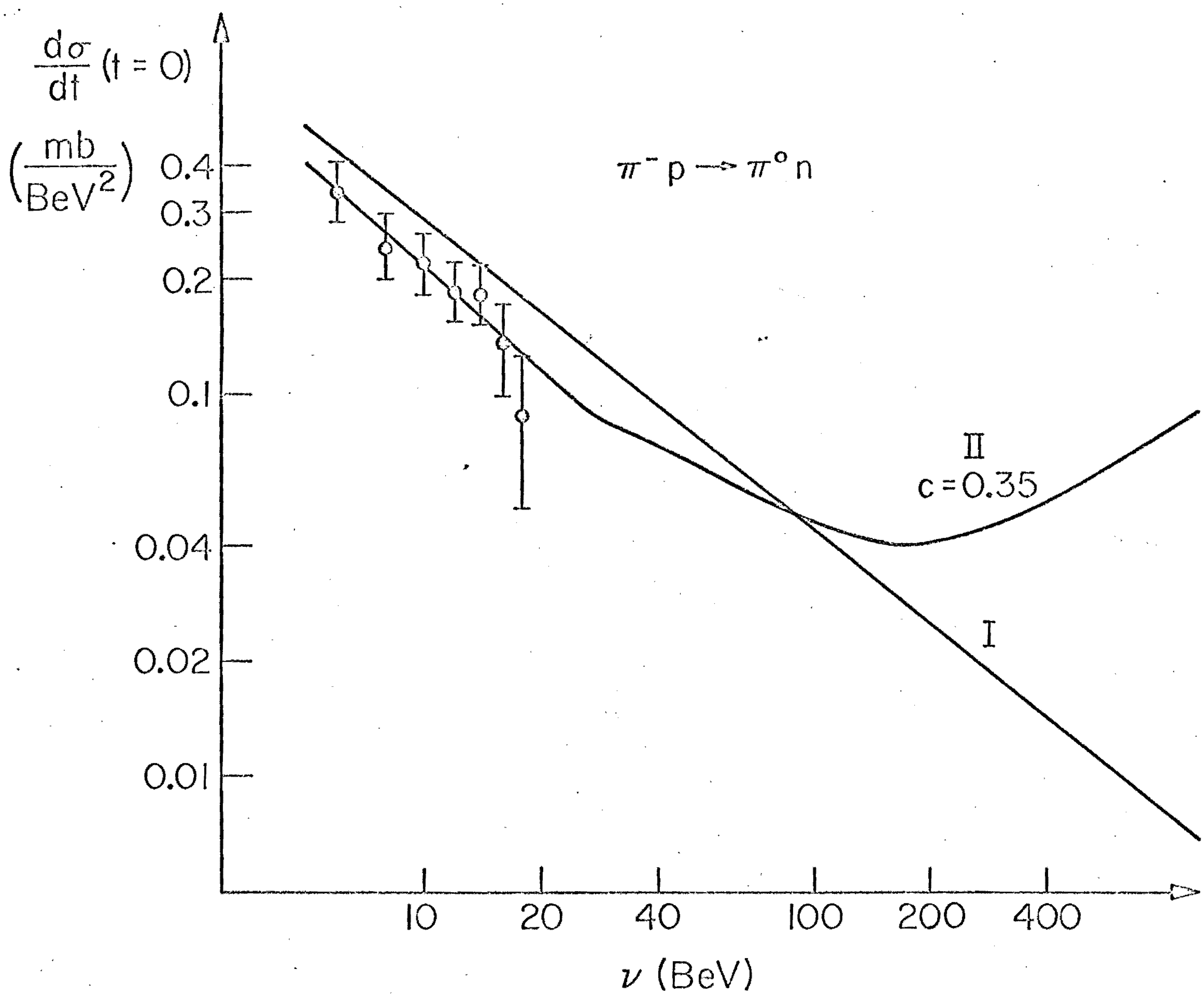
The reactions to be measured in this experiment are dominated by a single exchange.

$$\pi^- p \rightarrow \pi^o n \qquad (\rho \text{ exchange})$$

$$\pi^- p \rightarrow \eta^o n \qquad (A_2 \text{ exchange})$$

They therefore represent an excellent place to study Regge theory as the energy of the process is increased. The highest energy measurements at present have only been made at 18 GeV(3,5). The qualitative features of the data are a relatively sharp forward peak and a dip at $|t| \sim 0.6\ (GeV/c)^2$ for $\pi^- p \rightarrow \pi^o n$.

Figure 1



From: D. Horn
A. Yahil

Will this behavior continue at higher energies? The dip is interpreted as resulting from the Regge trajectory $\alpha_\rho(t)$ going through zero near $-t \approx .6$. The $\pi^- p \to \pi^o n$ cross section has been the classic example for Regge theory. Excellent fits have been obtained from 2 GeV to 18 GeV. Originally pure ρ exchange was tried and the complications of cuts in the angular momentum plane were ignored. However, the appearance of a small amount of polarization requires the presence of some other trajectory or cuts. Nevertheless, the fit to this reaction over such a wide energy range suggests this reaction as one to test the predictions of the Regge pole model as the energy is increased. Similar remarks can be made about the $\pi^- p \to \eta n$ cross section. Here the data have been fit by means of pure A_2 exchange. Again, the comparison of these fits at higher energy to actual measurements will provide an interesting test of Regge theory.

These two reactions in combination with other experiments can be used to test certain predictions of exchange degeneracy. $K^o p \to K^+ n$, which is a combination of ρ and A_2 exchange, must be exchange degenerate since it is an exotic channel and resonances are absent. The amplitude for this reaction, up to a phase, is identical to the line reversed reaction $K^- p \to \bar{K}^o n$.

The assumptions of exact SU(3) vertices plus exchange degeneracy leads to the sum rule

$$\frac{d\sigma}{dt}(K^- p \to \bar{K}^o n) = \frac{1}{2}\frac{d\sigma}{dt}(\pi^- p \to \pi^o n) + \frac{3}{2}\frac{d\sigma}{dt}(\pi^- p \to \eta^o n) \quad .$$

At 5.9 GeV/c, the data are consistent[6] with this sum rule for $\alpha(t) = 0.55 \pm 0.95t$. This experiment will yield some information on this sum rule at very different energies.

We also intend to study the production of I=0 and I=2 neutral final state bosons which decay into more than two γ's. This study will include mass distributions of $\pi^o\pi^o$ and $\pi^o\gamma$ final states as well as production and decay angular distributions for the various mass regions. Among the interesting physics to come out of these data will be a search for high mass neutral resonances, and the high energy angular distributions of known resonances, such as the f^o meson.

Of these later reactions, the $\pi^o\pi^o$ state is unique among so-called "$\pi\pi$ scattering" experiments in that it is the channel that can be most cleanly analyzed on the basis of this model.

II. EXPERIMENTAL METHOD

The charge exchange reactions,

$$\pi^- p \to \pi^o n \quad \text{and} \quad \pi^- p \to \eta n$$

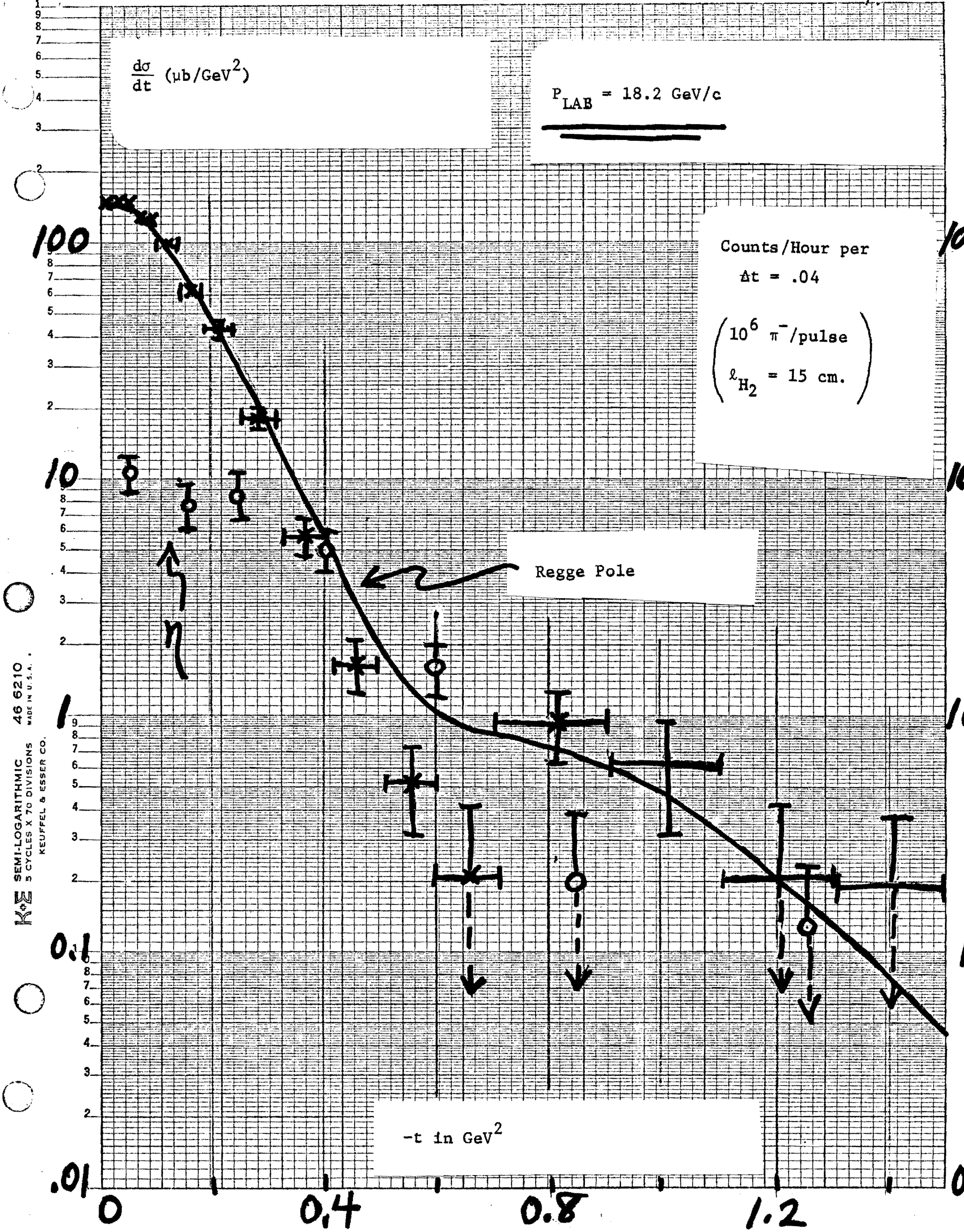
are to be studied by observing the two gamma decay modes of the π^o and the η mesons. At high energies and small angles, $-t \leq 2$ GeV^2, most of the decay photons are emitted at very small angles in the laboratory so that in a large fraction of the decays both gamma rays can be observed in a single relatively small detector.

The apparatus must be designed to satisfy two basic requirements. One is to be able to identify the desired charge exchange reactions in the presence of background arising from all the other possible reactions which occur and the second is to provide good resolution in the momentum transfer t. These requirements can be met by suitable measurements of the positions and energies of the two decay gamma rays, together with a carefully designed veto system capable of vetoing not only charged particles which may be emitted from the target but also gamma rays from the π^o's produced in other reactions than the one of interest. The manner in which these objectives are to be accomplished will be described in more detail in this report.

(A) Desired Range in t and t-Resolution

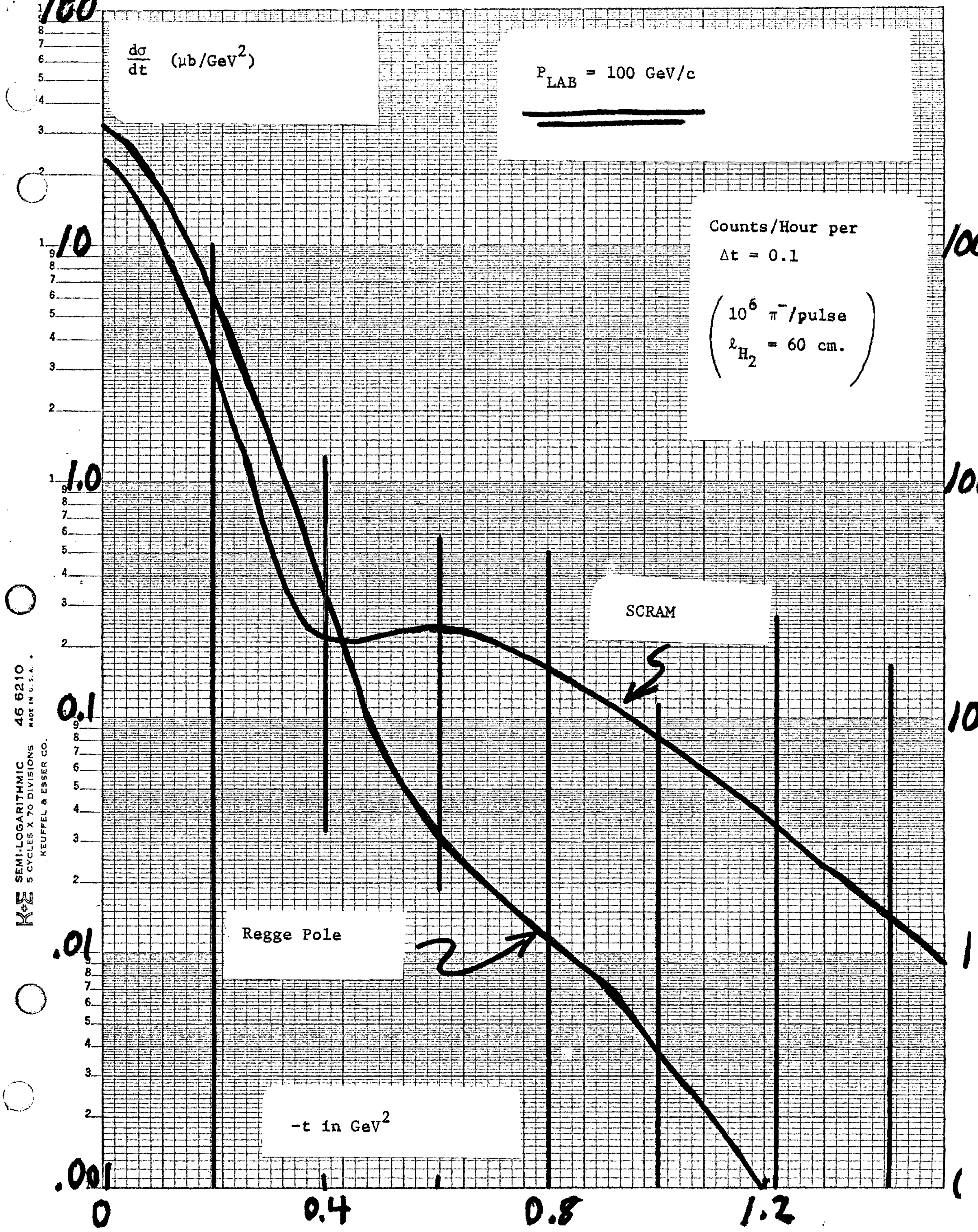
In Figure 2 are shown the existing data at 18.2 GeV for both the π^o and η reactions. Cross sections for π^o's at 100 GeV as predicted by two different phenomenological models are shown on Figure 3 . Objectives of this experiment are to measure the cross section accurately over the forward

Figure 2



dσ/dt (μb/GeV²)
P_LAB = 18.2 GeV/c
Counts/Hour per
Δt = .04
10⁶ π⁻/pulse
ℓ_H2 = 15 cm.
Regge Pole
η
-t in GeV²
100
10
1
0.1
.01
0
0.4
0.8
1.2
SEMI-LOGARITHMIC
5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6210
MADE IN U.S.A.

Figure 3



$\frac{d\sigma}{dt}$ (μb/GeV^2)
P_{LAB} = 100 GeV/c
Counts/Hour per
Δt = 0.1
10^6 π^-/pulse
ℓ_{H_2} = 60 cm.
SCRAM
Regge Pole
-t in GeV^2
100
10
1.0
0.1
.01
.001
0
0.4
0.8
1.2
SEMI-LOGARITHMIC
5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6210

peak, to extrapolate the cross section to zero degrees, and to investigate the behavior of the dip and, if possible, the secondary maximum at higher energies. For these purposes we propose to make measurements over a range of $-t$ extending from 0 to 1.5 GeV^2 with the following resolution in t:

$-t =$	0.005	0.03	0.10	0.60	1.50	GeV^2
$\Delta t =$	0.0025	0.005	0.01	0.05	0.10	GeV^2

(B) Kinematic Relations

Some useful kinematic relations are given here. The sign $\approx$ indicates approximate relations which are valid for high energies and small angles,-- conditions which obtain in this experiment.

$$s \approx 2m_N E_o \tag{1}$$

$$-t \approx E_o^2 \theta^2 \tag{2}$$

where E_o is the total energy of the incident π^- and θ is the angle of the outgoing π^o or η, both in the lab. system. We may also express t in terms of the kinetic energy, T_N, or the momentum, p_N, of the recoil nucleon:

$$-t \approx 2m_N T_N \approx p_N^2 \quad \text{(if non-relativistic)} \tag{3}$$

The kinematics of π^o or η decay into two photons are especially important for this experiment. In the π^o rest frame the decay is isotropic and each photon has energy $k' = \frac{1}{2} m_{\pi^o}$. Let subscripts 1 and 2 refer to the two photons, γ_1 and γ_2, γ_1 being the one with higher energy in the lab. Let primed quantities refer to the π^o rest system, and unprimed ones refer to the lab.

Let θ_s be the lab. angle of either photon for the symmetric decay,-- $\theta_1' = \theta_2' = 90^\circ$.

$$\theta_s \approx m_{\pi^o}/p_{\pi^o} \approx m_{\pi^o}/E_o \tag{4}$$

Useful relations at other angles are:

$$k_1 + k_2 = E_{\pi^o} \approx E_o \tag{5}$$

$$k \sin\theta = \tfrac{1}{2}\, m_{\pi^o} \sin\theta' \quad \text{(subscripts 1 or 2)} \tag{6}$$

$$\theta_1\theta_2 \approx \theta_s^2 \tag{7}$$

Define $$X_1 \equiv \cos\theta_1' \,. \tag{8}$$

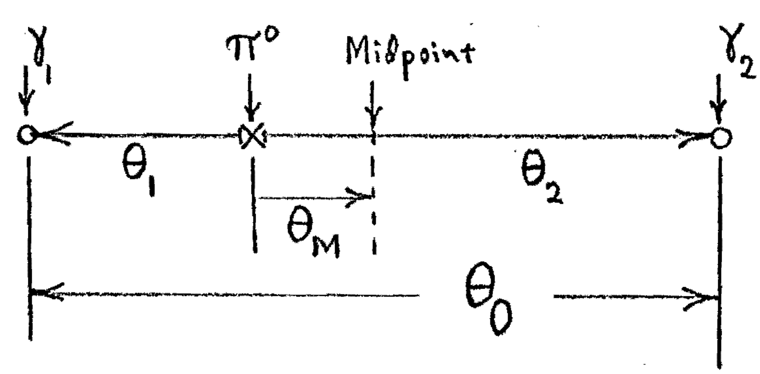
The parameter X_1 is useful in various ways. For example, the number of decays is uniformly distributed in X_1:

$$\text{Fraction of decays in } \Delta X_1 = \Delta X_1 \tag{9}$$

The photon energies are linear in X_1:

$$k_1 \approx \frac{E_o}{2}(1 + X_1) \quad ; \quad k_2 \approx \frac{E_o}{2}(1 - X_1) \tag{10}$$

For observational reasons, the opening angle, θ_0, between the two photons, and the angle θ_M of the midpoint between the two photons are useful. They are related to θ_1 and θ_2 as indicated in the diagram below:



$$\theta_0 = \theta_1 + \theta_2 = \theta_s \frac{2}{\sqrt{1 - X_1^2}} \tag{11}$$

$$\theta_M = \tfrac{1}{2}(\theta_2 - \theta_1) = \theta_s \frac{X_1}{\sqrt{1 - X_1^2}} = \theta_0 \left(\frac{X_1}{2}\right) \tag{12}$$

One further relation can be very useful in this experiment. If we note that in the π^o rest frame $\sin\theta_1' = \sin\theta_2'$, we see from Equation (6) that

$$k_1 \sin\theta_1 = k_2 \sin\theta_2 \qquad \text{or} \qquad k_1\theta_1 \approx k_2\theta_2 \tag{13}$$

That is, the π^o direction is the weighted average direction of the two γ-rays, each weighted by the γ-ray energy. This result is simply a special case of the general statement that the total transverse momentum (vector sum) in any decay is zero. If the two γ-rays are detected by showers produced in a detector, each shower will spread symmetrically about the γ-ray direction, so that the π^o direction is given simply by the average position of the total energy in both showers.

(C) Dimensions of the Apparatus

The π^o or η angle corresponding to a given t, and the angles θ_s, θ_0, and θ_M in the 2γ decay all scale with energy by a factor $1/E_o$. Therefore it is planned to increase the distance from target to detector as the incident energy increases, making this distance L proportional to E_o.

$$L = L_o \cdot \frac{E_o \text{ in GeV}}{100} \tag{14}$$

The scale distance L_o is chosen with the following considerations:

(a) The two γ-rays from the decay must be sufficiently separated at the detector to be clearly resolved.

(b) The expected spatial resolution in determining the position of the γ-rays must provide the desired resolution in t and the required resolution in opening angle θ_0.

(c) It is desirable to keep the overall dimensions of the detector as small as possible, consistent with requirements (a) and (b).

With our detector design, we believe point (a) can be satisfied if the minimum opening angle, $2\theta_s$, gives a spatial separation of 4 cm. at the detector. For $E_o = 100$ GeV , $\theta_s = 1.35$ mrad. Therefore we choose

$$L_o = 15 \text{ meters} \quad . \tag{15}$$

The transverse dimensions of the detector must be sufficient to give good efficiency for detecting events corresponding to the maximum t values. At $E_o = 100$ GeV,

$$\theta_s \text{ (100 GeV } \eta) = 5.5 \text{ mrad.} \qquad \text{and}$$

$$-t = 1.5 \text{ GeV}^2 \text{ for } \theta_{\pi^o} = 12.3 \text{ mrad.}$$

Thus the detector should have a sensitive area of radius larger than (18 mrad.) $\cdot$ L_o = 27 cm.

A schematic layout of the apparatus and an indication of how the gamma rays will be distributed over the face of the detector are shown in Figures 4,5. In this figure a magnet is indicated between the target and the detector. Its purpose is to sweep the incident π^- beam away from the exact center of the detector which is the most critical region for measurements at small t. The detector can be desensitized in the spot where the deflected incident beam strikes it.

Figure 4

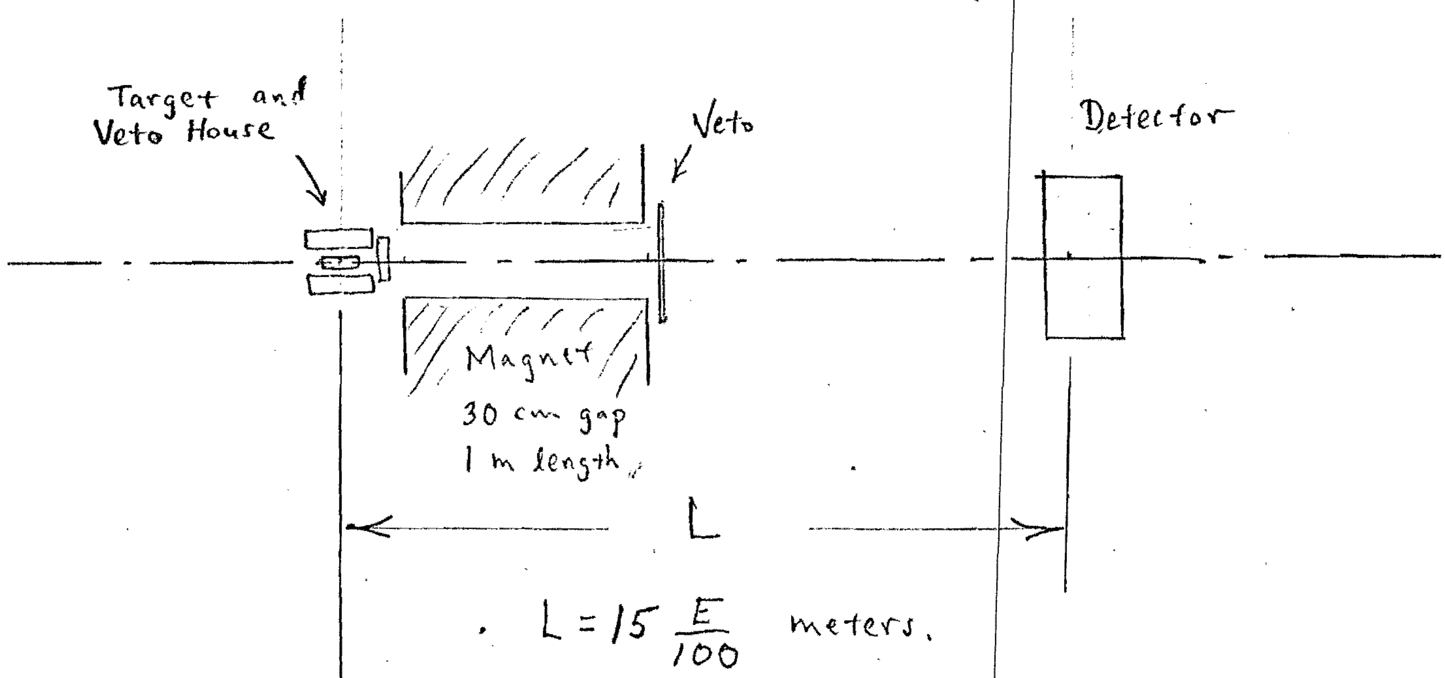
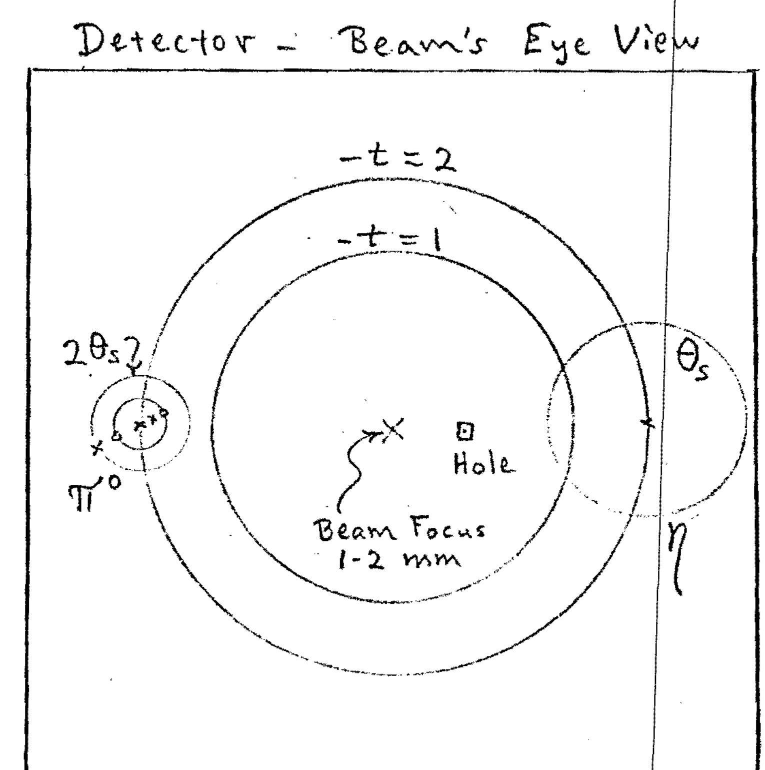


Figure 5



The target is to be surrounded by a system of veto counters, indicated schematically in Figure 4 , which must be designed so as to eliminate a very large fraction of gamma rays from π^{o}'s produced in background reactions as well as any charged particles which may be emitted from the target.

(D) t-Resolution

In order to obtain the desired resolution in t, it is necessary to measure accurately the scattering angle of the π^{o} (or η). It is planned to focus the incident π^{-} beam on a small spot at the detector position. If this is successful the scattering angle will be given directly by the direction of the π^{o} or η. If the beam halo is too large it may be necessary to define the incident π^{-} direction by means of a beam hodoscope.

The π^{o} direction may be obtained from observations of the two decay gamma rays in a number of ways:

(a) The average position of the total energy of the two showers gives directly the π^{o} direction as pointed out in the discussion following Equation (13).

(b) A measurement of the opening angle θ_0 determines the parameter X_1 through Equation (11). If one also determines which gamma ray has the larger energy, the position of the π^{o} can be found from the positions of the two gamma rays. If X_1 is small, this is not a very sensitive way to determine it because of the slow square root dependence in Equation (11). For larger values of X_1 and θ_0, it is a good method.

(c) Measurements of the individual gamma ray energies k_1 and k_2 may also be used to determine the parameter X_1 through Equation (10). The π^{o} direction would then be obtained from the positions of the two gamma rays as in (b).

It may be useful to employ more than one of the above methods for finding the π^o scattering angle in order to obtain a consistency check and thereby help eliminate certain backgrounds.

We think that we can achieve a resolution in the π^o scattering angle corresponding to an effective uncertainty of 2.5 mm. in the position of the π^o as extrapolated to the detector. This corresponds to an uncertainty in the π^o scattering angle of $\Delta\theta = (.12)\ \theta_s$. The resulting effect on the t resolution is shown by the solid line in Figure 6.

For the η reaction the larger angles of the decay photons will lead to a somewhat poorer resolution in t. However, the desired requirements on resolution for the η reaction can be correspondingly relaxed.

Another factor contributing to the uncertainty in scattering angle is the finite length, ℓ, of the hydrogen target. This is one effect which does not scale with incident energy as do all of the other angles so that it will be advisable to change the length of the hydrogen target in two or three steps as the incident energy increases. The effect on the resolution of the finite length of the hydrogen target is also shown in Figure 6.

The net t resolution shown in Figure 6 is approximately equal to the desired resolution as given in Section (A).

(E) Identification of the Charge Exchange Reactions and Discrimination Against Background

The following conditions and requirements will be used to distinguish charge exchange events from the background.

1) Two gamma rays and not more should be observed by the detector.

2) The total energy of the two gamma rays should equal the incident π^- energy, $k_1 + k_2 = E_o$.

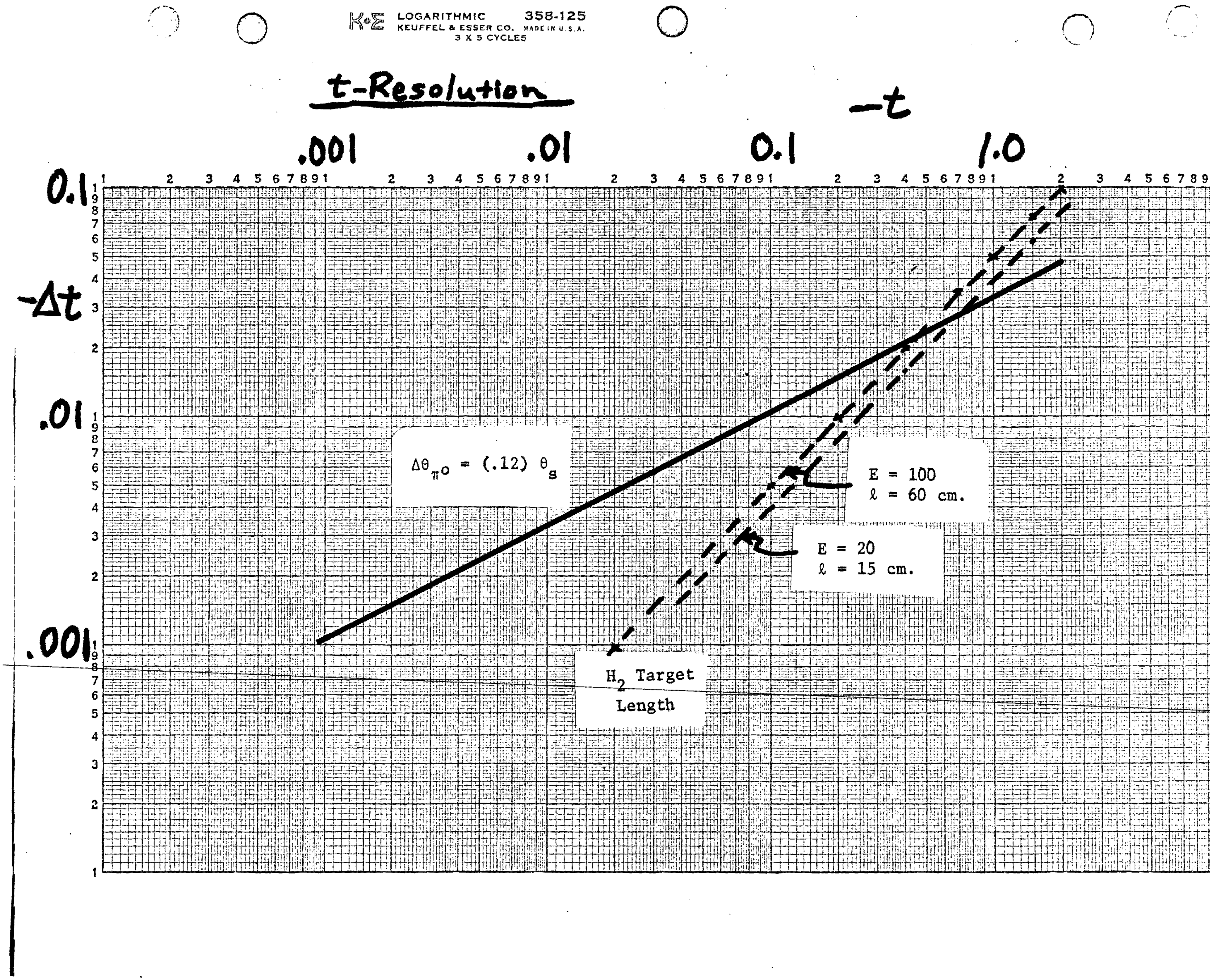

K+E LOGARITHMIC 358-125
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 X 5 CYCLES
t-Resolution
-t
.001
.01
0.1
1.0
0.1
-Δt
.01
.001
Δθ_πo = (.12) θ_s
E = 100
ℓ = 60 cm.
E = 20
ℓ = 15 cm.
H2 Target
Length

Figure 6

3) The distribution in opening angle θ_0 of the two gamma rays is very characteristic of π^o or η decay. The distribution has a sharp peak at the minimum opening angle, $2\theta_s$, and a fall-off of known shape toward larger angles.

4) The distribution in the parameter X_1 should be uniform.

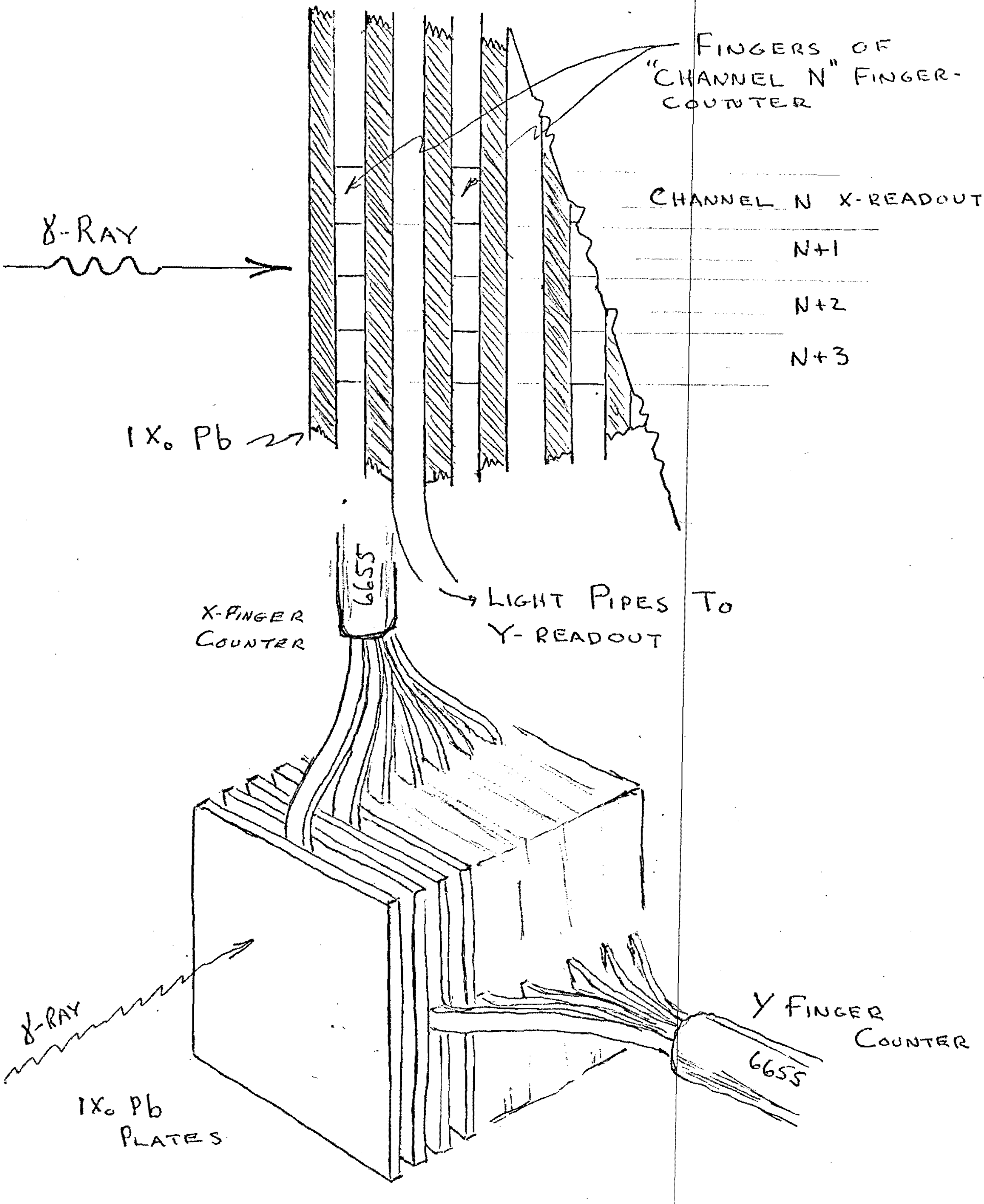
5) The individual gamma ray energies k_1 and k_2 are correlated with the opening angle θ_0. This correlation can be used to provide a consistency check.

6) Most important of all, the veto system must be designed to veto background reactions,--if possible with known efficiency. It will be relatively easy to veto reactions with a charged particle emerging from the target. However, it is also necessary to veto gamma rays from the decay of low energy π^o's coming from low mass N*'s produced in association with a high energy π^o, which by itself cannot be distinguished from a π^o resulting from charge exchange scattering. The most troublesome background reactions and the problems in vetoing them will be discussed in detail later in this report.

III. DETECTOR DESCRIPTION

As discussed above in Section II, the detector must measure the simultaneous energy and position of the two gamma ray showers from the π^o decay. We have proposed the arrangement of counters shown in Figure 7 to accomplish this job. As indicated there is a stack of 20 lead sheets, one radiation length thick and about 70 cm square, which is used to contain the shower. In order to measure the energy and position of the individual gamma rays we have arranged the counters so that they integrate in depth the total energy lost by each gamma ray of the shower. In order to measure the position we have segmented the integration counters so that 70 samples horizontally and 70 samples vertically are made of the shower. As can be seen in the figure, the counters are made of plastic that has been cut into strips 1 cm wide and 1/4 in. thick by 70 cm long. Now, if we concentrate our attention on the counters that are running vertically, we see that there are 8 layers of these of 70 counters each. In order to integrate the shower in depth all of the counters that lie the same distance in from the edge of the stack go to one photomultiplier tube by means of bent-light pipes. Thus, there are 70 different phototubes, each phototube tied on to 8 vertical slats of scintillator material located within the lead absorber. We see that we have a hodoscope arrangement with 70 channels giving the X projection of the energy loss of the showers within the absorber. The alternate 8 layers go off in a horizontal direction and tie on to a similar bank of 70 photomultipliers that allow us to read out the projection of the energy lost in the absorber along the vertical axis. Now that the detector has been described we can go back and answer in detail the questions that may be raised regarding it.

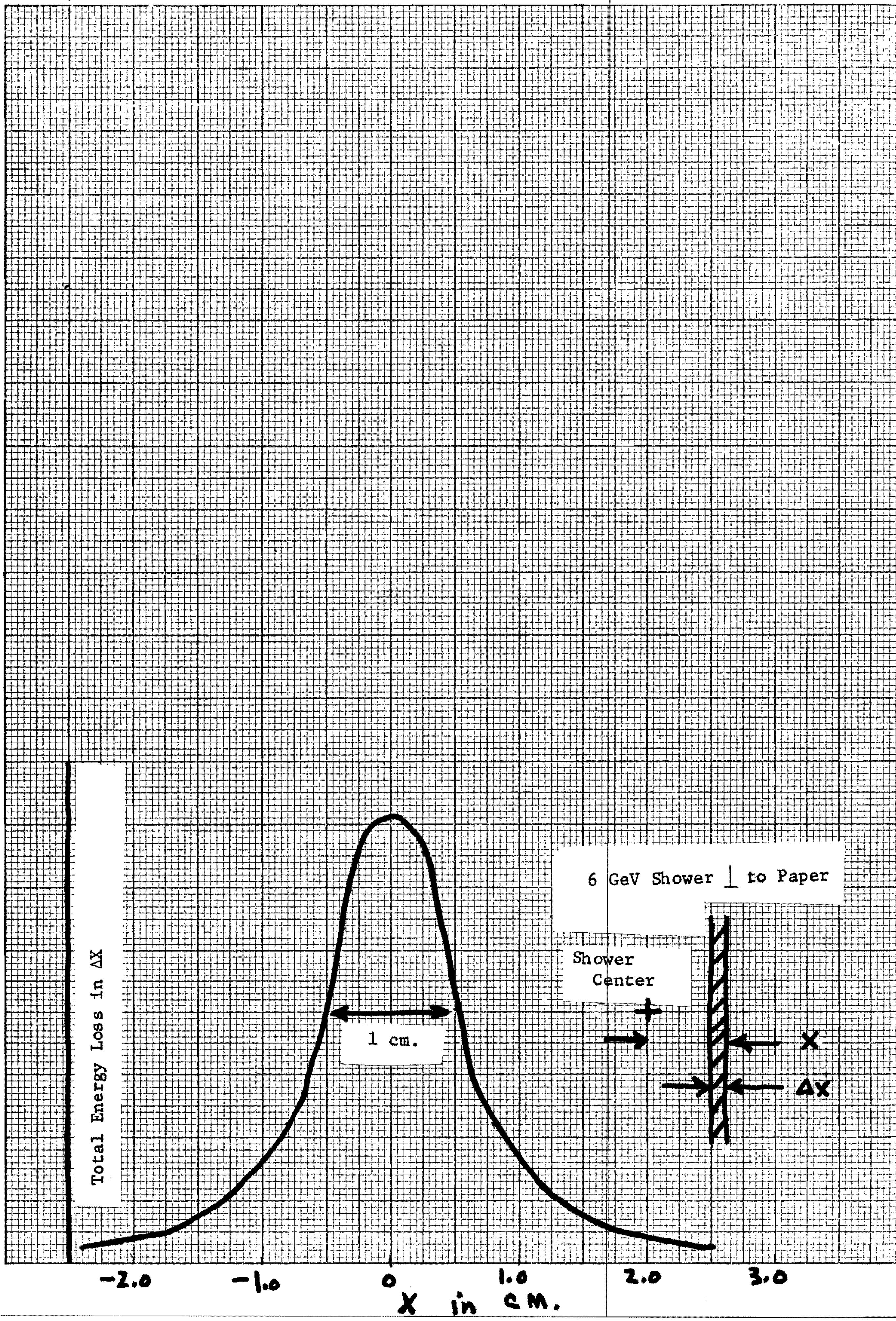
Figure 7


FINGERS OF "CHANNEL N" FINGER-COUNTER
CHANNEL N X-READOUT
N+1
N+2
N+3
γ-RAY
$1X_0$ Pb
6655
X-FINGER COUNTER
LIGHT PIPES TO Y-READOUT
γ-RAY
$1X_0$ Pb PLATES
Y FINGER COUNTER
6655

The first question that comes to mind concerns the scale of the apparatus and that has already been discussed in the previous section.

Next we consider the number and width of channels necessary. The first observation that we make is that the radial size of a shower is nearly independent of the energy of a shower. The relative intensity of a 6 GeV shower in a longitudinal plane slab a distance X from the core center is shown in Figure 8. As can be seen, the half-width of this peak is a little over a centimeter wide in lead. We expect the shower curve may be a little broader than this due to the fact that the lead has openings in it for the plastic counters. The detector must resolve two gamma rays whose energy, in general, will not be equal. In analyzing the data we will put a cut on the opening angle of the gamma rays. For instance, we will have a 70% efficiency if the opening angle cut is taken to be equal to $2.8\ \theta_s$, which is 3.8 mrad. for a 100 GeV π^o . The energies at this limiting opening angle correspond to one gamma ray at 15 BeV and a second gamma ray of 85 BeV. Thus a 6 to 1 ratio of energies is the maximum that we need to handle. We judge from examination of the curve in Figure 8 that if the two showers were separated by 4 cm we would adequately resolve the 85 GeV shower from the 15 GeV shower. Now, we have to also remember that the π^o can decay with its two gamma rays uniformly distributed in azimuth about the π^o direction. Hence, the worst projected opening angle that we have is $0.7 \times 2.8\ \theta_s$ is equal to 2.7 mrad. for the case where the plane of the π^o is at 45^o to the direction of the slats. We have used these two numbers to determine the distance of the detector from the target by the equation that $d = X_{min}/\theta_{min} = 4/2.7 \times 10^{-3} = 15$ meters for a π^o energy of 100 GeV. Since the shower is of the order of 1 cm wide, we have also picked the width of the finger counters to be 1 cm. If we add

Figure 8


Total Energy Loss in ΔX
1 cm.
6 GeV Shower ⊥ to Paper
Shower Center
X
ΔX
-2.0
-1.0
0
1.0
2.0
3.0
X in cm.

10 cm around the edges of the counter for edge effects, we arrive at a counter composed of 70 channels in X and Y, which makes the detector 70 cm square.

Each of the photomultipliers will be interfaced to the computer by means of a pulse-height analyzer. This will probably be accomplished through stretch and hold circuits that are then digitized in sequence. The computer thus has access to the shower distribution in the X and Y directions and, as discussed in Section II, can readily calculate the weighted X position and the weighted Y position in order to determine the π^o direction. Notice that the smearing introduced by the counter does not change the fact that the π^o direction is given by the weighted average of the two shower energy distribution. Thus the individual position measurements and energy measurements on the shower are mainly used to verify that the event was caused by a single π^o. Another important feature of the hodoscope nature of the shower detector is that it allows us to throw out background events that have more than 2 gamma rays within the detector area. This feature is important in getting rid of some of the backgrounds that will be discussed later.

An additional problem with this type of detector is involved in keeping the gain of the system constant as well as equalizing the gains of the individual channels. The phototube gains can be kept constant by placing a small radioactive source on a piece of scintillator that the phototube can see. A few hundred counts per minute is enough to monitor the gain to the individual channels and this can be done automatically by the computer between pulses. These monitors will have to be calibrated, preferably with high energy electrons or γ-rays produced by the π^- beam. To facilitate this calibration and the equalization of the counters, the detector support will be constructed in a way which will make it easy to move the detector in X and Y so as to center the beam on any individual finger counter.

In principle, there is no reason why the beam should not be allowed to go through the center of this apparatus. Since the gamma rays that we are interested in detecting are highly concentrated in a very small space about the beam direction we have considered placing a magnet downstream of the target which would move the beam away from the position in the detector that corresponds to t=0. Rather than allowing the beam particles to interact in the lead, a small series of holes would be drilled through the plates so that the beam would only be exposed to the plastic scintillator. This would mean that one or two channels of the apparatus would have a fairly high counting rate due to the beam particles passing through them but as there is a minimum of material in the beam the total energy which these particles would lose should be small. Alternatively we have considered constructing a veto system that guarantees that there are no other particles in the beam for a period of $\pm \Delta t$ around any possible candidate event. The period of $\pm \Delta t$ would be long enough to insure that the detector had recovered from any previous event and that there was no interference from a following beam particle. As this system does not involve any magnets and associated power supplies it simplifies the region downstream from the target. At present we favor this solution.

In short, we feel that this detector is an elegant solution to the problem of measuring the position and energy of individual gamma ray showers as well as an advancement in the techniques of determining the direction of π^0's from a high energy reaction. The next section describes tests made at SLAC to verify the general feasibility of the detector.

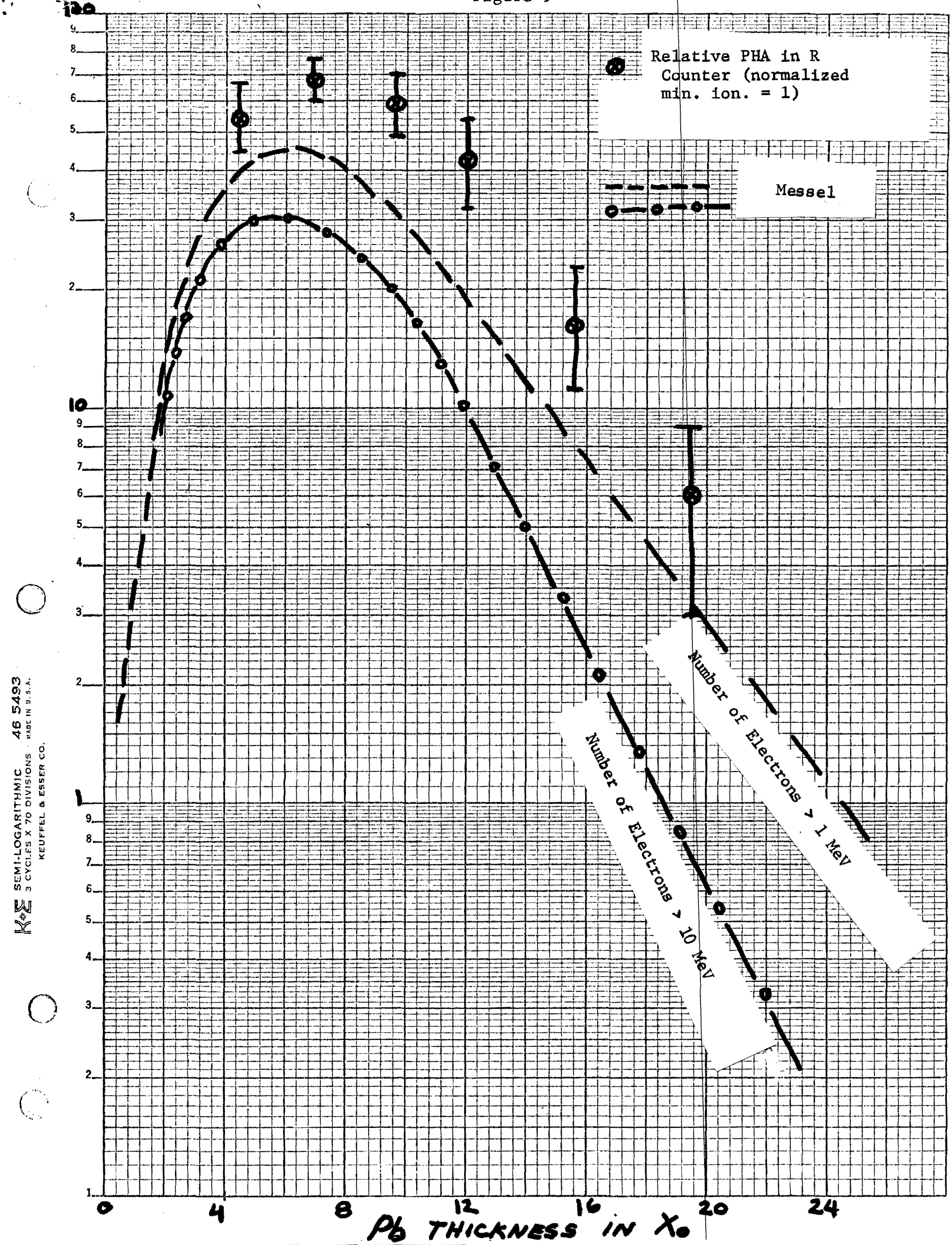
IV. DETECTOR TESTS AT SLAC

In order to verify that the detector described above would work in the proposed manner, at the end of January 1971 we set up tests at SLAC that were carried out in an electron beam. A short description of this test follows, and although at this stage there is more work that we would like to do, we feel that the results show clearly that the detector will work in the manner proposed. In order to work with the limited facilities that were available, we constructed only two channels of finger counters of six fingers each. These counters were constructed of one cm wide plastic into which a shifter had been added for shifting the Cerenkov light into the visible part of the spectrum. This plastic is available from Pilot Chemical and is designated as Pilot Plastic-Type 425. These fingers were 70 cm long and were 1/4 in. thick. All six fingers went to a single 6655-type phototube. The support stand was arranged so that various amounts of lead could be inserted between the fingers of the counters. Finally, the light pipes were arranged so that the two counters could be mounted side by side or spaced multiples of 1 cm apart. By placing two radiation lengths of lead between the fingers, we were thus able to essentially model two typical channels of either the X readout or the Y readout system described in the detector section. To the rear of these finger counters, we had an additional counter that was constructed of 4 sheets of plastic, all leading to one 6655. These sheets of plastic were 8 in. wide by 12 in. long and were such that we could put one radiation length of lead in between the sheets. This counter, which was mounted behind the finger counters and served to integrate the energy in the tail end of the shower.

The 82 in. bubble chamber was broken and we were able to make measurements in the beam that normally goes to this chamber. For this purpose we used a system of scintillation counters and lead collimators to produce a beam of electrons that was less than 3 mm wide. We made measurements at 4.5 GeV, 9.1 GeV, and 15 GeV. The first set of measurements made after ascertaining that the beam was aligned and was at least as small as we have indicated above consisted of measuring the pulse-height in the R counter as it was moved deeper into the stack of lead. The results of this measurement are shown in Figure 9. The bars associated with each point do not reflect errors, but rather the width of the pulse-height distribution observed at each of the points measured. For comparison, the calculations of Messel for the number of electrons greater than 1 and 10 MeV, respectively, are also shown in this figure. Later measurements indicated that the peak ionization loss was about 67 times greater at shower maximum than would be made by a single electron traversing a counter located at this point in the lead. The curve indicates that the response of the plastic counters corresponds roughly to the number of 1 MeV electrons found in the shower. This number is useful for estimating the energy resolution achievable in such a detector, as will be described later.

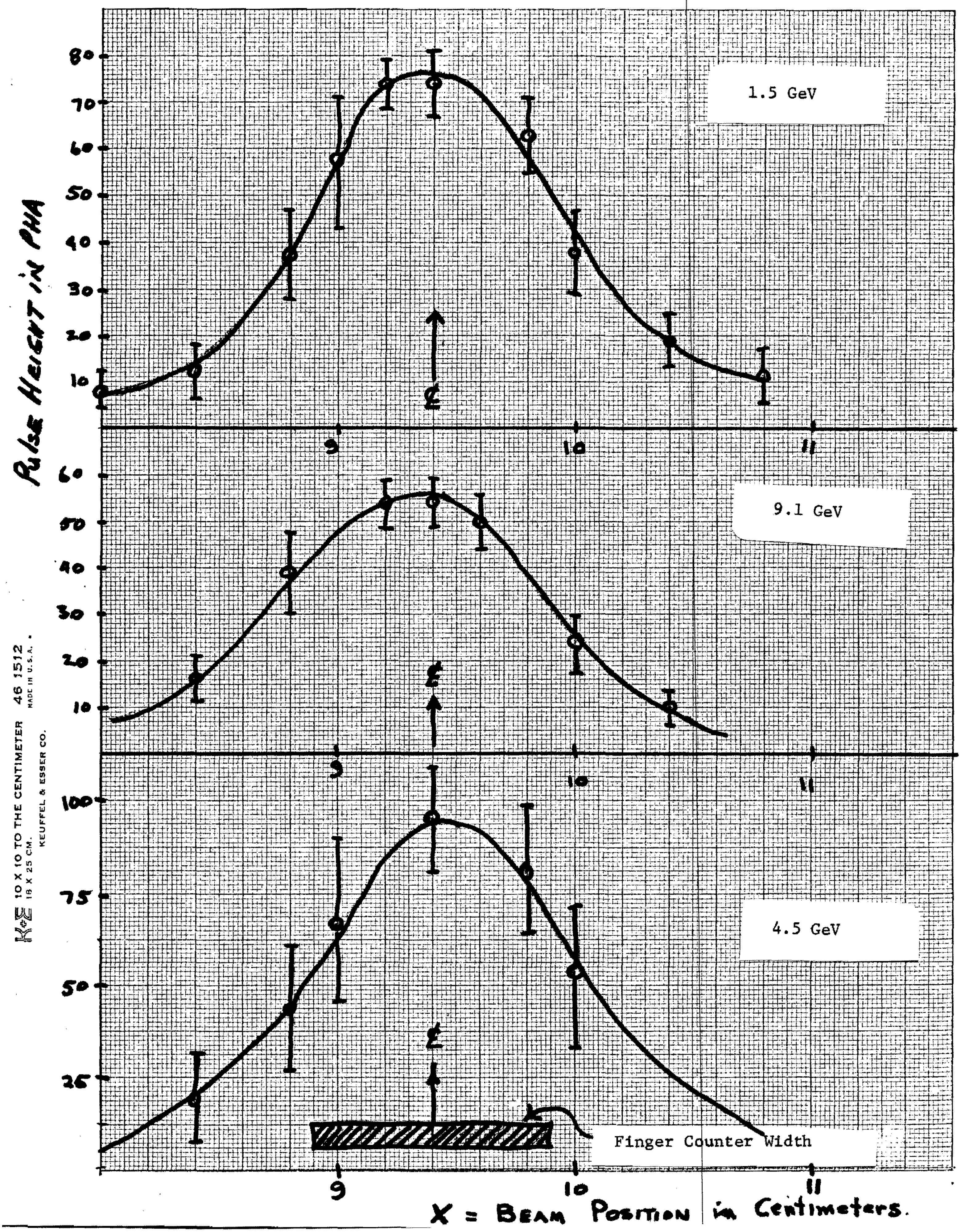
We were interested in verifying that the width of the showers was indeed as narrow as predicted from the calculations of Messel. For this purpose we used one finger counter connected to the pulse-height analyzer and moved the beam across this counter in small steps. At each point we recorded the pulse-height distribution from the counter. The results of these measurements are shown in Figure 10 . Again, the flags on each point indicate the width of the pulse-height distribution that was observed, not the errors. It should be remembered that the finger counters were 1 cm. wide perpendicular to the beam and that the beam was 3 mm or less in width; it is seen from the curves that the

Figure 9



Relative PHA in R Counter (normalized min. ion. = 1)
Messel
Number of Electrons > 1 MeV
Number of Electrons > 10 MeV
Pb THICKNESS IN X_0
0
4
8
12
16
20
24
100
10
1
KE SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS · MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 10


1.5 GeV
9.1 GeV
4.5 GeV
Finger Counter Width
PULSE HEIGHT IN PHA
X = BEAM POSITION in Centimeters
80
70
60
50
40
30
20
10
100
75
50
25
9
10
11
10 X 10 TO THE CENTIMETER 46 1512
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

shower is certainly as narrow as predicted. We feel that from this curve alone it is obvious that the detector will work and has enough spatial and energy resolution to separately measure the energy of the two gamma rays from π^0 decay as has been proposed in the above detector description.

We also carried out a limited experiment with the 2-dimensional pulse-height analyzer to investigate the correlation of pulse-heights observed in the two adjacent finger counters, as beam position was moved from the center of one counter to the center of the next counter in small steps. Another set of runs was taken where a 1 cm dummy counter was placed between the two finger counters and the correlations between the two counters recorded as the beam was shot into the middle of the space in between. From these measurements it is possible to estimate what the spatial resolution will be, although more complete measurements on this point are clearly desirable. The algorithm for locating a gamma ray in the detector is that

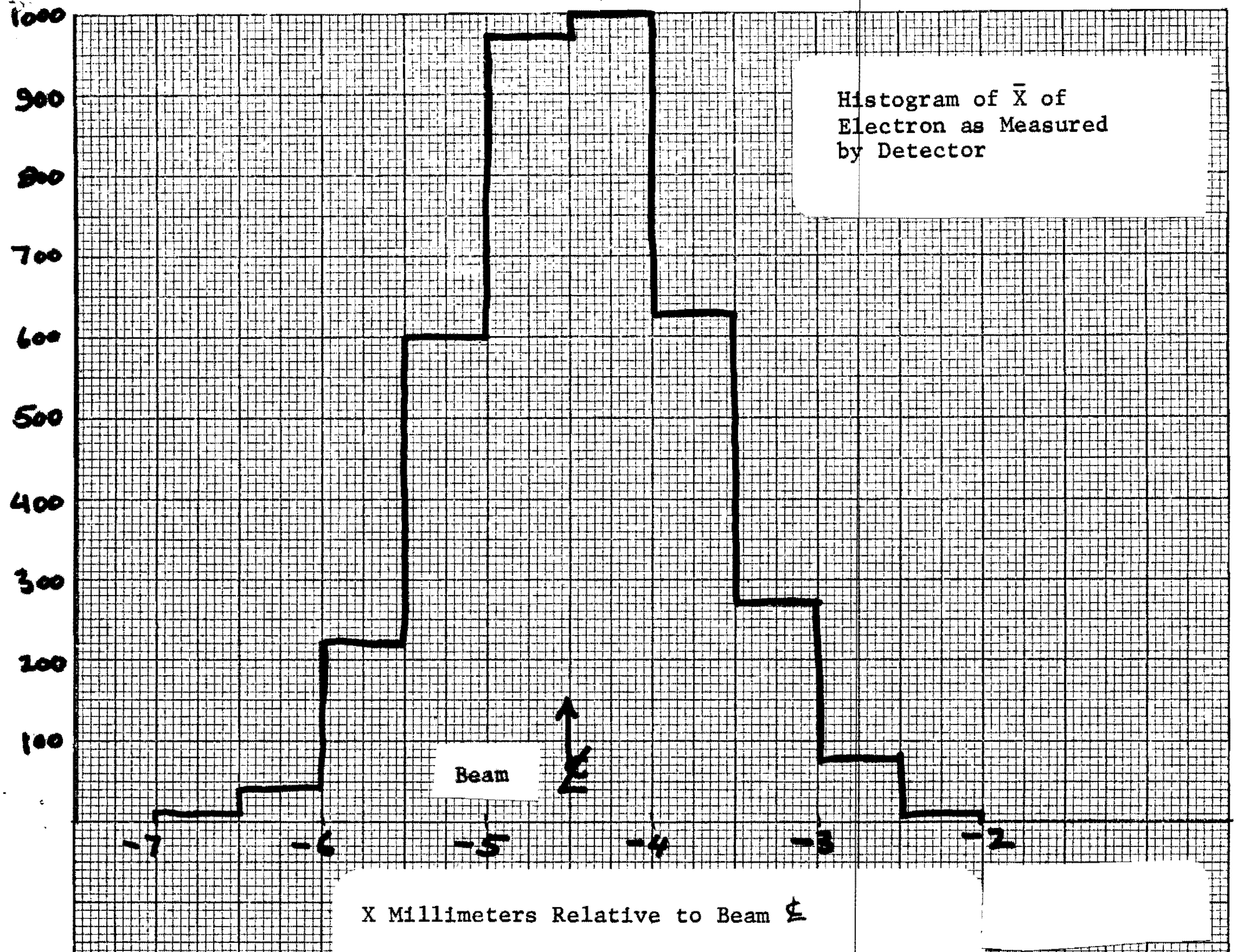
$$\bar{x} = \Sigma x_i k_i / \Sigma k_i$$

where x_i is the center of each finger counter channel and k_i is the energy measured in that channel. As we had only two channels of pulse-height analysis available, we were only able to simultaneously measure two of the k_i's in the above expression. However, consider the situation with the beam centered on one channel located at $x=0$. Since the k in this channel is multiplied by xero, it is only necessary to know the pulse-height in this channel in order to complete the sum in the denominator of the above equation. Thus, we could effectively model a 3-channel detector by spacing our two finger counters with a 1 cm wide dummy plastic strip between them and shooting the beam into the center of this plastic strip. The 2-dimensional analyzer then recorded the pulse-height in the two finger counters located at each side of the central dummy strip. Using this information, we could calculate the sum in the numerator of the above equation as though we had a 3-channel detector. Since the pulse-height fluctuation in the central channel is rather small, the fact that we were not able to measure this simultaneously in order to evaluate the denominator of the above equation was not a serious handicap. A histogram of impinging electron position as calculated by this algorithm is shown in Figure 11. Similar measurements were made with the beam centered between two counters and at a point midway between these two positions. We feel that these measurements demonstrate that this system has a remarkable position resolution for high energy gamma rays and represents an exciting new way to measure their position and energy.

In the last figure (12) we show the ability of this detector to measure the energy of the gamma ray shower. The measurements show the result of varying the incident energy of the electron when the beam was arranged to impinge on the center of the finger counter. Notice that there is some saturation effect showing up. At the present time, we do not know whether this is caused by leakage of the shower out of the rear of the finger counter array or whether there was some kind of electronic saturation.

Further measurements are planned at SLAC to investigate the question of how many fingers should be on a typical finger counter. The presents ones had only 6 and there were two radiation lengths of lead in between each. Two radiation lengths of lead were also placed in front of this array. Thus the finger counter sampled the shower at depths between 2 radiation lengths to 12 radiation lengths. At 9 GeV about 10% of the shower is leaking out of the back end of the finger counter and at 15 GeV the effect should be worse. The answer

Figure 11



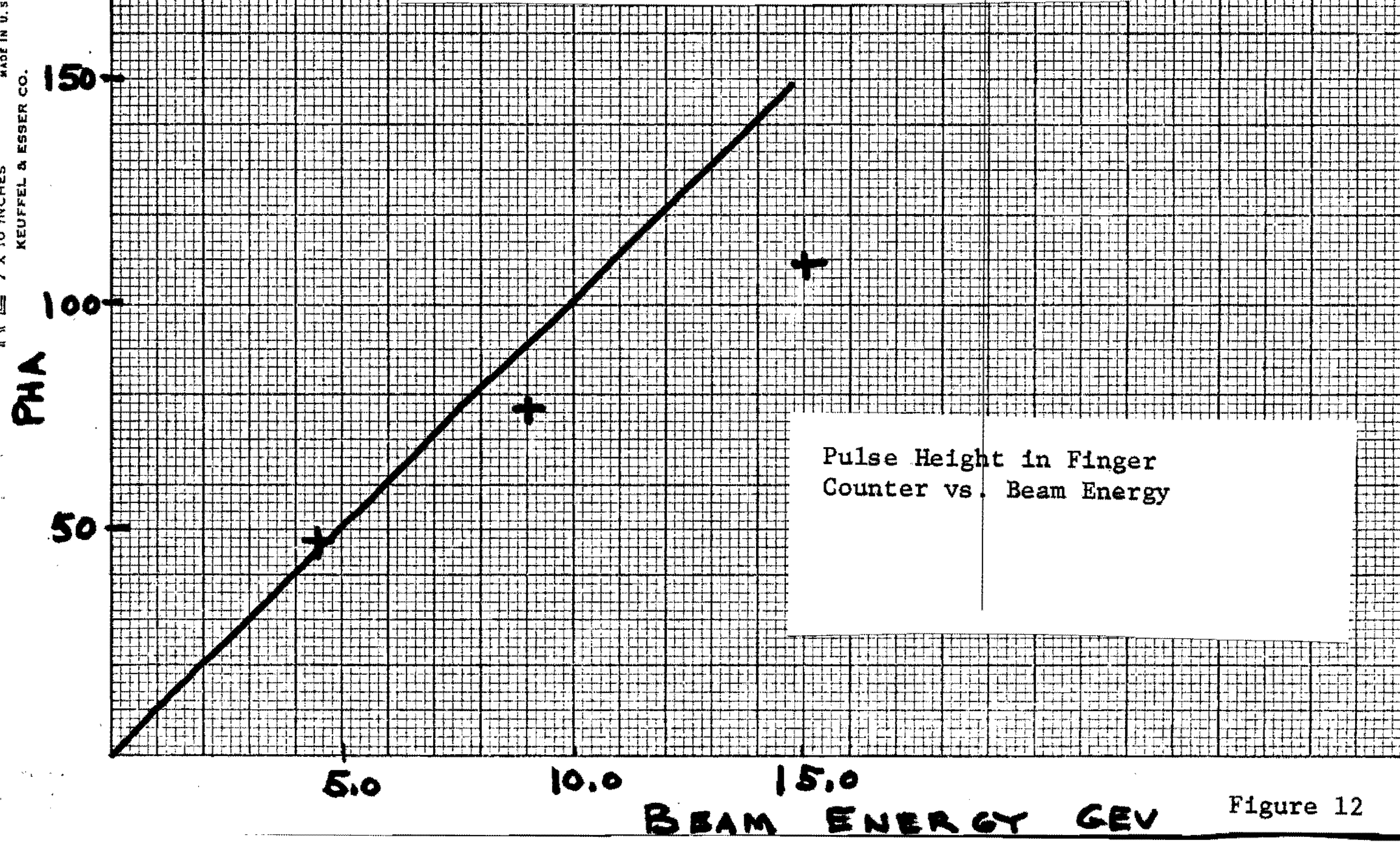


Figure 12

to this problem will have to await further tests.

In order to investigate whether or not the plastic with shifter in it is worthwhile, we made two additional tests. First of all, we compared at shower maximum the light output from lucite that with that from Pilot 425. Small test counters that were 6 in. long, 1/4-in. thick, and 1-1/2-in. wide were used and the ratio of the light output was measured at 15 GeV back of 10 radiation lengths of lead. The ratio of the light output was found to be 1.64. However, a subsequent measurement of the attenuation of light in the finger counters showed that the Pilot 425 has an attenuation length of between 40 and 50 inches. This length is rather short and would make the energy response of the detector over its face rather non-uniform. This is not crucial in that it can be compensated for in the computer that reads out the detector. However, such non-uniformity is undesirable and we intend to make further measurements to ascertain whether or not UVT lucite exhibits similar attenuation lengths. For use at high energies, the increase in the amount of light available from the Pilot plastic is probably not sufficient to make this a major consideration in the design of the detector.

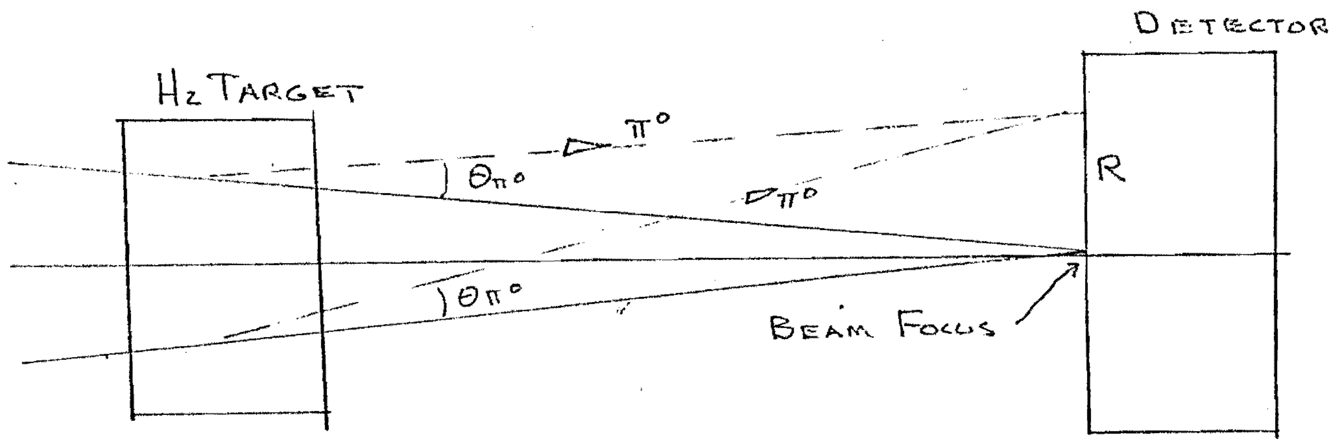
A simple-minded model of the detector enables us to understand the above measurement and also extrapolate what we have found to higher energy. To this end, we propose that the distribution in X and Y directions of the shower be approximated by a Gaussian. This distribution is then sampled by the finger counters at a number of points across it. Now each point will have a certain fluctuation associated with it--either due to the fluctuation in the light collected or due to the intrinsic shower process causing fluctuations in that channel. These fluctuations arise either from the number of photoelectrons collected or from the finite number of electrons that traverse each finger of the counter. To this end, we have attempted to estimate the energy resolution that we should see when the beam strikes the center of one of the finger counters. From Messel's calculations at 10 GeV, we find that for our configuration about 210 electrons are traversing the fingers of the counter for a 10 GeV shower. From this we would expect a $\Delta E/E$ of 7% due to the fluctuations in this number. In actual fact, of course, we would expect the resolution to be worse than this due to fluctuations in the leakage out the back and sides of the finger counter. The measured width at 9 GeV has a sigma of about 8.4%--very roughly the width was found to vary inversely with the square root of the energy. The extrapolation of these widths to 100 GeV according to this law would indicate energy resolutions with sigma of the order of 3% for either the X or the Y measurements. This is probably indicative of the energy resolution that can be obtained with this counter and is limited somewhat by the rather coarse sampling that is being applied. Finally, a simple calculation can be made of the expected position resolution on the basis of the above simple theory. One uses Equation (1) above to calculate the RMS spread expected in $\bar{x}$ due to these fluctuations in energy measurements. If one assumes that the energy measurements across the shower projection fluctuate with a width inversely proportional to the square root of the energy loss in that channel, then we find the following result for the error on the position measurement:

$$\langle \delta x \rangle = \sigma \cdot \frac{\alpha}{\sqrt{E}}$$

The term $\alpha/\sqrt{E}$ represents the fluctuation on any given gamma ray energy measurement and the term σ_s is the RMS width of the shower distribution as projected out in either the X or the Y direction. Thus, for an RMS width of the shower of 1 cm and an energy measurement of 10%, we should be able to make the position measurement with a sigma of 1 mm. Thus for both the energy resolution and the positional accuracy measurement, this rough theory agrees with the measurements that were made at SLAC.

V. BEAM

The beam arrangement is shown in the following figure on a much exaggerated scale.



As can be seen, the beam is focussed at the shower detector. If we assume that the beam spot is well-defined and that there is not a halo around it, then the angle that the π^0 makes with the beam in the target is measured by the distance R shown in the figure and this angle is independent of the position where the interaction took place within the target. Thus, if this scheme works it is not necessary to measure the angle of the particles in the incoming beam nor the position in the target where the interaction took place. Also, focussing the beam at the detector makes it possible to drill a small hole through the detector to keep the major portion of the beam from interacting within the detector volume. The parameters of the beam have been assumed to be those detailed by Reeder and McLachlin(4). The momentum resolution is not important and can be 1% or less. We have assumed the beam emittance to be 2 mrad. x mm. An intensity of about 10^6 particles per pulse is envisioned. As discussed in the section on the detector, if it is necessary to move the beam spot away from dead center on the detector a magnet placed as shown after the target is capable of doing this. A 1 meter magnet of 10 kg will move the beam 5 cm off from the center of the target. We do not at present favor this solution.

A hodoscope consisting of a set of wire planes to measure the incoming beam angle may be used initially to explore the properties of the beam. If there is a halo around the beam, or if we are not able to set up the experiment in a beam that can be focussed in the manner shown, then it will be necessary to use a hodoscope in order to measure the incoming angle. A small amount of halo around the beam could give very serious errors to the cross section measurement at large t value, where the counting rates will be as small as 1/1,000 of that found for lower t values. If it can be verified that the halo is not a serious effect, then the hodoscope will be dispensed with during the data taking phase of the experiment.

A threshold gas Cerenkov counter in front of the target will be used to identify the incoming particle as a pion. If the K^- yield in the beam is as much as 1% of the π yield then it will also be useful to tag the K's and keep track of the charge exchange cross section for K's on hydrogen. This Cerenkov counter would have to go between the two hodoscopes or, perhaps in front of them. Again, it is certainly not necessary for measurements of the cross sections at small t values, but, again, at large t values where the cross section has become very small, other competing reactions from other particles in the beam may give serious errors if they decrease with t at a slower rate than the CEX cross section does. Inasmuch as both the hodoscope and the Cerenkov counter are dependent upon the beam, we would envision that this part of the experiment will be designed after the appropriate location has been found for the experiment.

VI. TARGET AND VETO HOUSE

The target is a conventional hydrogen target of length variable from 6 inches to 2 feet and with a cell about 2 inches in diameter. The vacuum jacket of the target should be kept as small as possible for it is necessary to build a veto house around the target. This veto house is a sandwich of lead and scintillator plastic and must be built carefully in order that the veto efficiency for multiparticle reactions that occur within the target will be high. This veto house will be integrated with the target and hence we do not show any detailed design at present. There is a more complete discussion of the background caused by the lack of veto efficiency in the section on backgrounds.

VII. BACKGROUNDS

The possible backgrounds for this experiment have been intensively investigated. The handles one has to eliminate backgrounds are the following: First, the shower detector, downstream, should detect only 2 gamma rays and the energy and position of these gamma rays should be correlated in such a fashion that only a single π^o is involved in making the showers. This has been discussed under the section on experimental method. The second handle is that there should be no particles detected back at the hydrogen target, since the π^o charge exchange reaction leaves only a low energy neutron there. Hence, the backgrounds will all come from failure of either the veto house around the target to detect multiparticle events or a lack of discrimination in the shower detector that allows events of more than 2 gamma rays to be counted. The target veto must not veto slow neutrons.

Figures 13 and 14 show the various cross sections that have a bearing on the background processes for the charge exchange. These cross sections have all been fit by eye on log-log paper in order to extrapolate their t-dependence to the energies that we are interested in. The background processes can be divided into two types. (1) Diffractive processes such as $\pi^- p \to A^- p$. These cross sections do not fall with energy and hence must be vetoed with high efficiency. Typically we expect a cross section of the order of one mb., compared to 3 μb. for the CEX at 100 GeV. Thus, rejections of the order of 1,000/1 are necessary. This particular process is dangerous when the A^- decays into a ρ^- and a π^o with the ρ^- decaying into a forward-going π^o. Thus one is left in the target with a proton, a low energy π^- and a low energy π^o. A Monte Carlo study has been made of the diffractive processes involving an A^- production.

Figure 13

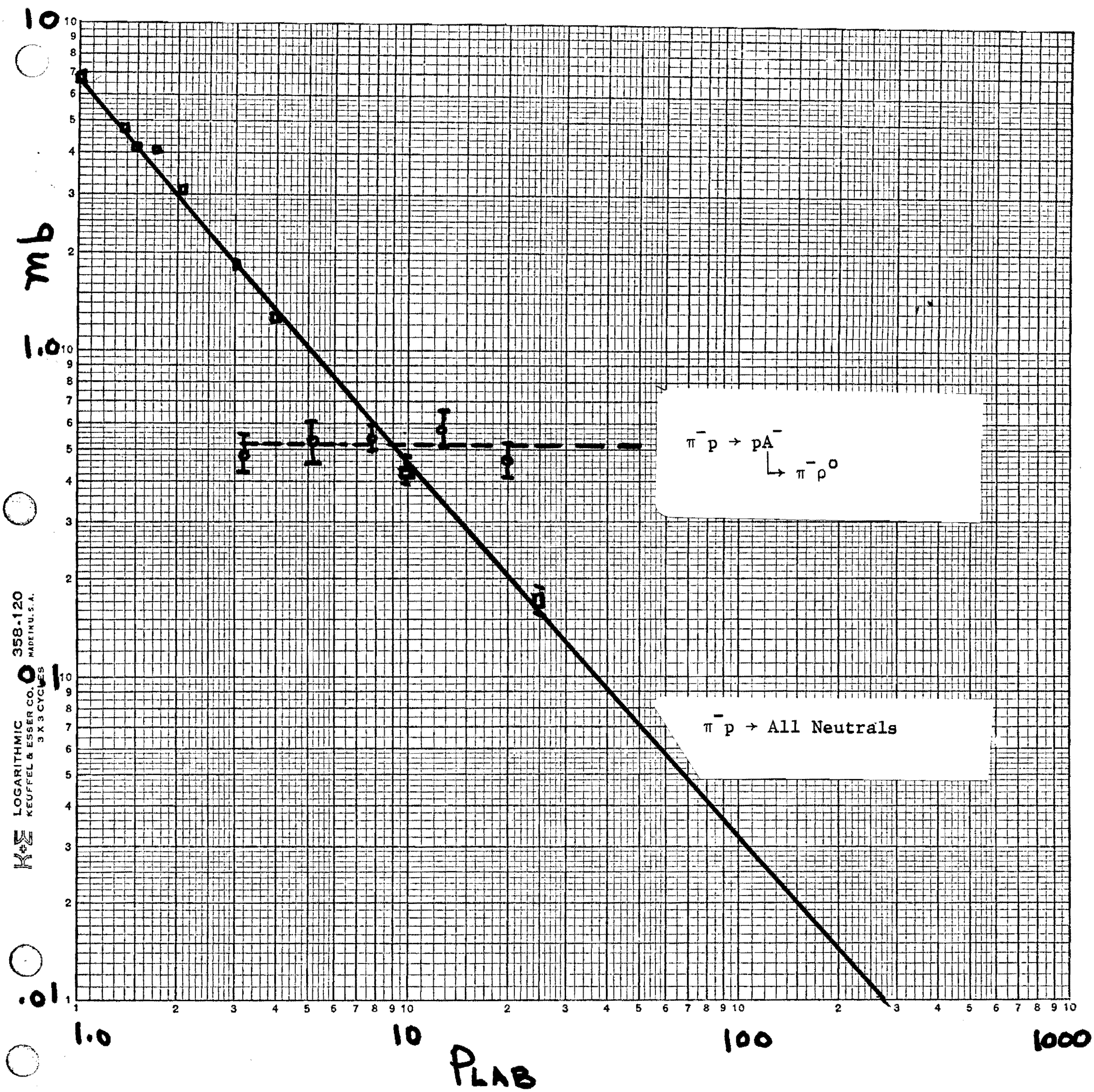
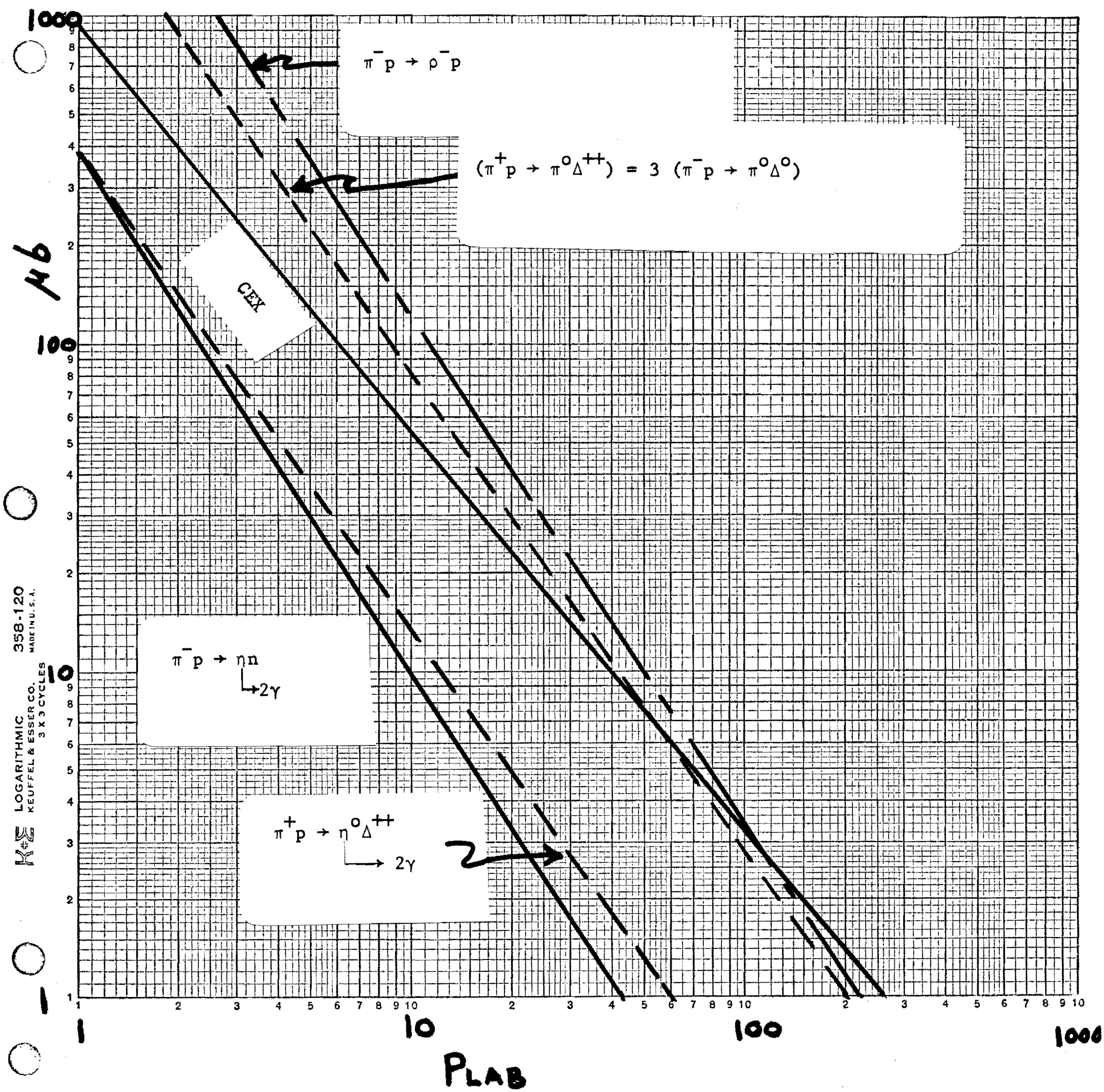

10
mb
1.0
.1
.01
1.0
10
100
1000
PLAB
$\pi^- p \to pA^-$
$\hookrightarrow \pi^- \rho^0$
$\pi^- p \to$ All Neutrals
LOGARITHMIC 358-120
KEUFFEL & ESSER CO.
3 X 3 CYCLES
MADE IN U.S.A.

Figure 14


$\pi^- p \to \rho^- p$
$(\pi^+ p \to \pi^0 \Delta^{++}) = 3\ (\pi^- p \to \pi^0 \Delta^0)$
CEX
$\pi^- p \to \eta n$, $\eta \to 2\gamma$
$\pi^+ p \to \eta^0 \Delta^{++}$, $\eta^0 \to 2\gamma$
μb
1000
100
10
1
10
100
1000
PLAB
LOGARITHMIC 358-120
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 X 3 CYCLES

We have been able to compare these results with a 16 GeV $\pi^- p$ exposure in a hydrogen bubble chamber to verify that our Monte Carlo assumptions are roughly correct at the energies that are presently accessible. First of all, about 2/3 of the events can be rejected by means of protons having sufficient energy to escape from the hydrogen target and strike the veto counters. Kinematics alone on the π^- interaction would give a rejection of 1 in 10^4. However, a number of the π^-'s that would normally escape from the hydrogen target and strike the veto counters, instead interact within the hydrogen. The secondary products may then either veto the event or they may be neutral and escape vetoing. If we assume that the shower detector can measure the energy of the shower to 5% then we can place a cut on the events such that the shower energy is greater than 90 GeV which means that the π^- energy cannot be greater than 10 GeV. The average cross section for $\pi^- p$ going to all neutrals below 10 GeV can be seen in the graphs. Let's assume this number for the moment is 7 mb. and that the average length of target that the π^-'s have to interact in is 1 foot. Then 6% of the π^-'s will interact for those events that cannot be rejected on the basis of the energy of the shower. Thus, the total rejection is equal to the product of the proton rejection, the π^- rejection, and the shower criterion. This gives an overall rejection for this process of $1/3 \times 1/10 \times 1/160 = 1/5{,}000$. There is an additional rejection that has not yet been used and that involves vetoing the γ-rays of the low energy π^0. The accompanying table shows the cross section of the offending reaction, the rejection, and the partial cross section that will appear in the final results due to this background.

(2) Non-diffractive processes. The rest of the backgrounds can be characterized as non-diffractive in that they all involve the exchange of some

particle. Since the charge exchange involves the ρ trajectory and its p dependence is lower than any of the rest of the trajectories all of these background processes will fall with energy at least as fast as the charge exchange cross section does. Hence, a rough statement is that if these processes do not cause trouble at one energy they will not cause trouble at a higher energy. Let's investigate these processes in detail.

(a) $\pi^- p \to \rho^- p$. This process is characterized by forward ρ^- production with the subsequent decay of the ρ, according to the following process:

$$\pi^- p \to \rho^- p$$
$$\qquad \rho^- \to \pi^- \pi^0$$

This process will trigger the shower detector when the ρ^- decays with the π^0 going in the forward direction and leaving a low energy π^- and a proton within the target. We can reject this reaction by vetoing on the proton and the π^-. A Monte Carlo study of this reaction shows that over 99% of the protons recoil with an angular range of 60-90°. Thus, the amount of hydrogen and target walls that must be penetrated is rather small and we assume that we can veto whenever the momentum of the proton is greater than 250 MeV/c. This corresponds to a range of 10 cm in hydrogen. A third of the protons have a momentum less than this cut-off momentum. The second rejection we have on this process is provided by the total energy measurement of the shower in the π^0 detector. If we assume that this energy spectrum of the π^0 is essentially flat, then the rejection of the shower detector obtained by making an energy cut at 90 GeV is 1/10. Finally, we have the rejection provided by vetoing the π^-. Again, the π^- spectrum goes from essentially zero to the full energy of the beam. However, since we have cut the π^o energy to be greater than 90 GeV, the π^- energy will be confined to the region between zero and 10 GeV. We can veto these π^-'s with 100% efficiency except for those π^-'s that interact in the target. Assuming an interaction cross section of 60 mb., and an average length of the target of 1 foot, we find that 6% of these pions interact. This is a very pessimistic estimate in that many of the interactions will produce charged prongs which will activate the veto counter. However, this cross section gives an upper limit for the veto inefficiency of the π^- and corresponds to missing less than 6%. The product of these rejections times the cross section gives a background of less than .06 μb.

(b) $\pi^- p \to \Delta^o \pi^o$. This reaction can be broken into two categories as is indicated in the following equation:

$$\pi^- p \to \pi^o \Delta^o$$

$$\Delta^o \to n^o \pi^o \qquad \sigma \sim 0.6\ \mu b$$

$$\Delta^o \to p\pi^- \qquad \sigma \sim 0.3\ \mu b$$

The most serious background here is the decay of the Δ^o into $n\pi^o$ and the only effective handle one has for rejecting this reaction is through the π^o decay. A Monte Carlo study of this process with a realistic veto house, shows that 93.7% of the gamma rays from the π^o are vetoed. The other decay process of the Δ^o may be vetoed by means of either the π^- or the proton. The Δ^o is mostly produced in directions making large angles to the beam. However, when it decays the proton can be moving in almost any direction. We find that 3/4 of the protons have momentum greater than 450 MeV/c which corresponds to 30 cm of hydrogen, hence we assume that we miss 1/4 of the protons. The π^-

veto is ineffective 7% of the time because of the π's going out through the backward end of the veto house, and 5% of the time they have an energy less than 140 MeV, which again corresponds to about 1 foot of hydrogen. Interactions of the pions in the target with the subsequent neutral products being missed by the veto house is about 1% of the time. This gives a total inefficiency for this reaction of 3%. Adding the above two numbers together with the proper weights for the partial cross section gives a background of .05 μb and a veto inefficiency of 5%.

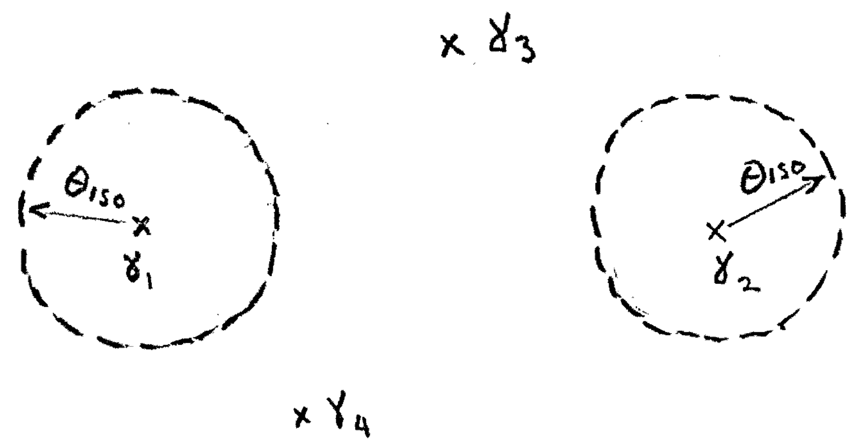
(c) $\pi^- p$ to all neutrals. As can be seen from the figure, the cross section for $\pi^- p$ to go to all neutrals is about 30 μb. Thus it is 10 times bigger than the process that we want to measure. On the other hand, we have very little information about composition of all neutral products. Some of them, of course, have already been considered above. There are two limiting cases that we have studied in an attempt to evaluate the seriousness of this process. For the first limit we have used the results of a study by J.W. Elbert, et al.[7] who observed neutral and charged pion multiplicities in 25 GeV/c $\pi^- p$ collisions. They find that the average number of π^o's per event for $\pi^- p$ to all neutrals is given by about 2. Clearly, as the number of high energy forward-going π^o's increases the discrimination afforded by the downstream shower detector will also increase due to the fact that a larger number of gamma ray showers will be found in the shower detector. Thus, the first limit we have assumed is that the whole 30 μb of cross section goes in the process:

$$\pi^- p \rightarrow \pi^o \pi^o n$$

Thus we have the problem of discriminating two π^o's from one π^o by means of the veto house and the downstream shower detector.

We have constructed a model for this process that involves the peripheral production of the two π^0's. The mass of this state was assumed to be rather broad, as lower energy measurements have shown it to be. The decay of the two π^0 system was assumed isotropic in its own center of mass, and the π^0's were assumed to decay in a state described by Breit-Wigner with a mass of 500 MeV and a width of 500 MeV. This curve was cut off at the mass of two π^0's.

The events can be divided into two classes: those in which all four gamma rays hit the shower detector and those with less than four γ's in the shower detector. If a gamma ray falls outside of the shower detector it is a candidate for being vetoed by the veto house. Let's consider first the category in which all four gamma rays hit the shower detector. This comprises 62% of the cases. Here our rejection must be completely provided by the shower detector in that it must correctly identify that there are more than two gamma rays present and that their energies and angles do not correspond to a single π^0 decay. Now, from our discussion of the π^0 identification it will be remembered that we accept events that have an opening angle between $2\ \theta_s$ and $3.3\ \theta_s$. Furthermore, the energies of the individual showers must correlate with the π^0 decay. Our Monte Carlo study first of all investigated the angle between all pairs of gamma rays and selected those events for which 2 of the gamma rays had an opening angle of less than $3.3\ \theta_s$. Now, as shown in the figure below, we define an angle called θ_{iso} which is an isolation angle.

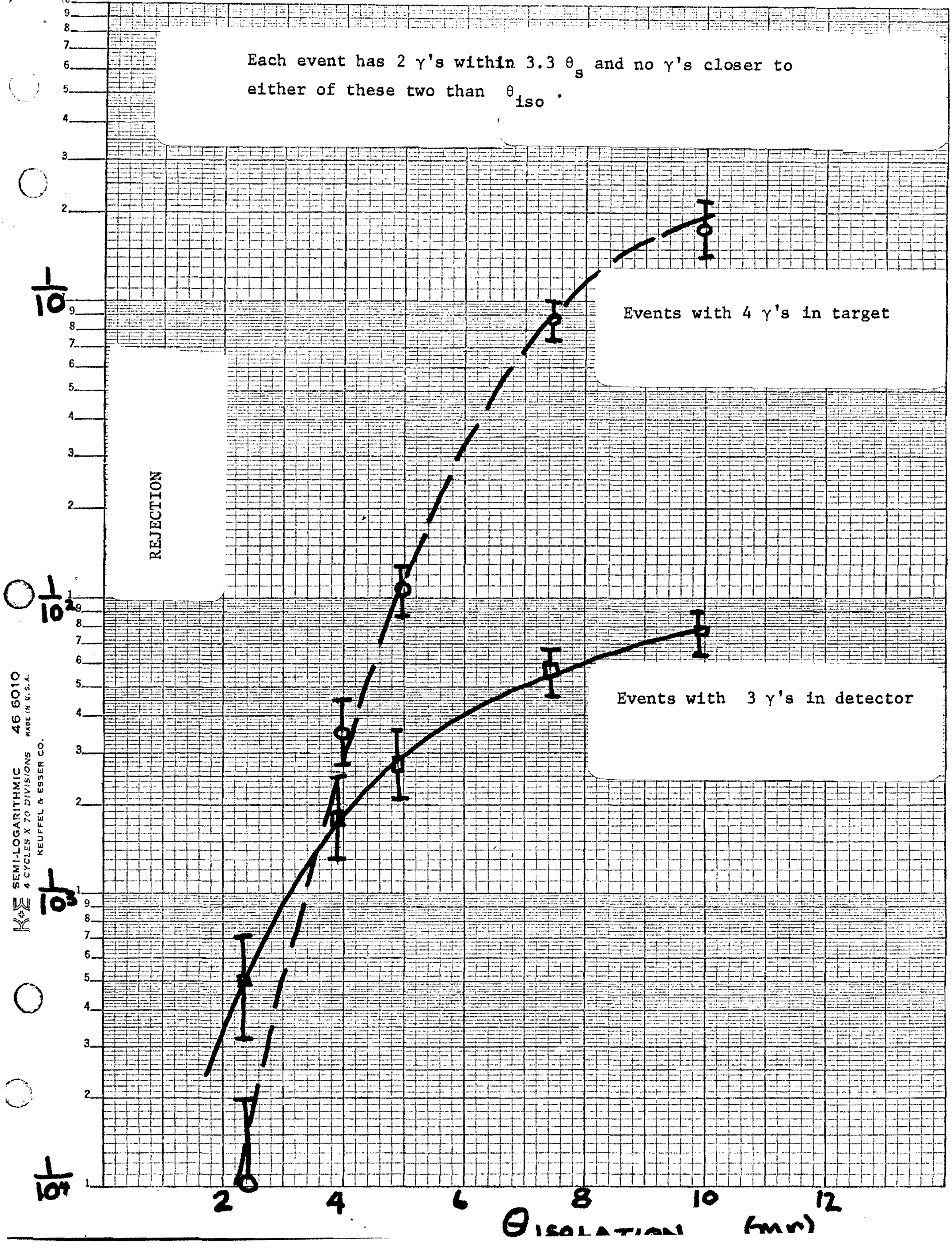


γ_1, γ_2 Candidates for $\pi^0 \to \gamma_1 + \gamma_2$

If either of the other two gamma rays has an energy greater than 1 GeV and is at an angle greater than θ_{iso}, then we assume that the event can be rejected. The graph on the next page shows this rejection as a function of θ_{iso}, Fig. 15. If we pick θ_{iso} equal to 3 mrad, the separations of the showers in the shower detector would be at least 5 cm. Inspection of the shower curve, Figure 8, shows that with this separation we ought to be able to easily find a gamma ray of 1 GeV. Hence, we can assume a rejection of one in 1,000. This leads then to a partial cross section for this background of .018 μb. We find that 26.3% of our events have only three gamma rays in the shower detector, with one escaping gamma, and 3% of these escaping gammas are missed by the veto house. Hence, if we again pick $\theta_{iso} = 3$ mrad. we see that we get a rejection for these events of roughly 10^{-3} in the shower detector. A total rejection leads to a partial background cross section of $.23 \times 10^{-3}$ μb. The case of two gamma rays in the shower detector and two escaping leaves an even smaller background than this. Hence, the total background from this process is around .018 μb.

The second limit to this background reaction can be assumed to take place by the following process: $\pi^- p \rightarrow \pi^o N^*$. Here the N* is assumed to decay in an all neutral mode and represents the mass spectrum of N*'s such as the Δ^o, the N*(1400), etc. We have already considered one channel of this reaction, i.e., that for the N* equal to the Δ^o. The problem here is that we do not have a good estimation of the mass spectrum of the N*'s excited. What little bubble chamber data that does exist indicates this contamination will be small. Previous measurements also have not been troubled by reactions of this type. It is important to note that events vetoed on low energy γ's at the target can be separately recorded and analyzed. Thus, we will directly measure during the

Figure 15



Each event has 2 γ's within 3.3 θs and no γ's closer to either of these two than θiso .
Events with 4 γ's in target
Events with 3 γ's in detector
REJECTION
1/10
1/10²
1/10³
1/10⁴
2
4
6
8
10
12
θ ISOLATION (mr)
K&E SEMI-LOGARITHMIC 46 6010
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

experiment the amount of contamination from this type of reaction. If the veto inefficiency were about 5% then the 30 μb would give a background of 1.5 μ or 50%. However, this represents a rather gross upper limit for several reasons: (a) None of the measurements at lower energy indicate such strong isobar production. In general, about 10% of the all neutral channel is due to isobars. (b) As the isobar energy increases, the efficiency of the veto house rapidly increases. Thus we expect our study of the efficiency of the veto house for eliminating Δ^{o} represents a pessimistic view of the problem posed by higher mass isobars. We expect to study this problem more, and hope to experimentally study the design of the veto system at the Lawrence Radiation Laboratory.

VII. RUNNING TIME ESTIMATES

The counting rates for the experiment are shown in the accompanying table. We have used the following two equations, which fit the low energy data, to extrapolate to high energies.

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

$$\sigma_{t<0.5} = \frac{720}{(p_{gev})^{1.17}} \quad \mu b$$

$$\sigma_{t=0} = \frac{2300}{p_{gev}} \quad \mu b$$

$\pi^- p \to \eta^o n$

$\qquad\qquad 2\gamma$

$$\sigma_{t=0} = \frac{630}{(p_{gev})^{1.4}} \quad \mu b$$

$$\sigma_{TOTAL} = \frac{286}{(p_{gev})^{1.46}} \quad \mu b$$

We have assumed a beam of 10^6 π^-/pulse and 700 pulses/hour. The momentum spread of the beam is not critical and $\Delta p/p = \pm 1/2\%$ would be satisfactory. The target length must be variable with energy as discussed in Section II. Its length is also shown in the table. We have assumed cuts on the opening angle and corrections for dead time will combine to give an overall efficiency of 0.5.

Using these assumptions, the time required to obtain 50,000 counts for $t < 0.1$ in the CEX reaction is listed and also the counts that will be obtained in this time for the $\pi^- p \to \eta^o n$ reaction. In addition to these runs, we estimate an equal amount of time will be necessary for background runs, veto counter efficiency tests, and detector calibration. Hence we request a running time of 450 hours.

COUNTING RATE TABLE

$\pi^- p \rightarrow \pi^o n$

E	Target Length cm.	$\sigma_{t<0.5}$	$d\sigma/dt\|_{t=0}$	Counts/hr. t<0.5	Counts/hr. t<0.1	Time for 5×10^4 Counts for t<0.1
20	15	21	110	4700	2500	20
40	30	9.6	60	4300	2700	20
60	45	6	38	4100	2600	20
80	60	4.2	30	3800	2700	20
100	60	3.3	23	3000	2100	25
120	60	2.7	20	2400	1800	25
140	60	2.2	16	2000	1400	35
200	60	1.4	12	1260	1080	50
					TOTAL	215 hours

$\pi^- p \rightarrow \eta^o n$ $\eta^o \rightarrow 2\gamma$

E	Target Length cm.	σ_{TOTAL}	$d\sigma/dt\|_{t=0}$	Counts/hr. all t	Counts/hr. t<0.1	Total Counts for Time Equal to 5×10^4 in $\pi^o n$ Channel
20	15	3.3	10	740	225	4500
40	30	1.3	4	590	180	3600
60	45	0.7	2.2	470	150	3000
80	60	0.5	1.5	450	135	2700
100	60	.35	1.1	315	100	2500
120	60	.27	0.9	240	80	2000
140	60	.22	0.67	200	60	2100
200	60	.13	0.42	120	38	1900

IX. EQUIPMENT AND PERSONNEL

The following persons are the experimenters:

CIT: R. Gomez
A.V. Tollestrup, Correspondent
R.L. Walker

NAL: D. Eartley

LRL: O. Dahl
R. Kenney
M. Pripstein
M. Wahlig

The following equipment is necessary:

Beam: 20-200 GeV/c π^-, $\Delta p/p = \pm \frac{1}{2}\%$ or less, 10^6 π^-/pulse. Detector - target space clear 2 meters each side of beam. The detector moves so that distance from target is $L = 15$ meters x (p_{gev}/100).

Beam Optics: Phase space 2 mr. x mm. Focus at detector.

Beam Hodoscope: Initially a hodoscope is planned for aid in tuning and investigating optical properties of beam. If the beam halo is not bad, the hodoscope will not be used during running.

Beam Cerenkov Counter: A threshold counter for identifying pions is planned.

Target and Veto House: The target length must be variable from 15 cm → 60 cm and be somewhat larger in diameter than the beam. Veto counters must be integrated into the H_2 appendix design.

Downstream Detector: Lead lucite finger-counter assembly ∿ 140 phototubes.

Electronics: (1) Readout shower detector.

(2) Σ-2 computer.

(3) Interface to Σ-2.

(4) Fast beam and veto house electronics.

(5) Beam hodoscope readout.

(6) Beam Cerenkov counter electronics.

The above hardware, except for the beam, can be supplied in its entirety by Caltech and LRL. Thus, a minimum commitment from NAL is required.

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