national accelerator laboratory

TM - 535

THE ELECTRON BEAM TEST OF OCTOBER - NOVEMBER, 1974

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December 6, 1974

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Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

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Introduction

This note describes briefly some of the results obtained during the first test run of the electron beam. Numbers quoted here regarding fluxes, backgrounds, sizes, etc. should be considered extremely preliminary and used with caution. They are not to be quoted formally without permission. The main focus of the test was to turn on the vast array of complex equipment that make up the beam, and the measurements were often made under trying conditions. In particular, the last quadrupole doublet and bending string were not operational making a fine tune at the dispersed first focus of the beam difficult.

Targeting Studies

We steered 300 GeV/c protons across our target in order to maximize the secondary ionization as measured by a loss monitor located on the first dumping magnet near the target. We normalized to the SEM measurement of incident protons. Horizontal and vertical proton beam scans using BH403 and BH404 on the 14" Be target are shown in Figures 1 and 2. The target sits inside the ½" gap of the first dumping magnet. This aperture is clear in the loss monitor scan in Figure 1. Also plotted are electrons counted at the first focus. The magnet aperture barely shows up there because the beam acceptance (as expected) falls off for large source sizes. The same effect appears in the vertical scan (Figure 2). The loss monitor scan shows no fall off when the protons strikes the base of the target (see sketch, Figure 1) while the beam scan falls off at ∿ .060" from the center. This corresponds reasonably to the magnification of the source by ∿ 2.1 at the ± .2" counters and some loss of acceptance for large sources at the first collimator. No effort was spent to improve the targeting efficiency of approximately 95% measured in these scans.

Front End Studies

Thanks to much effort spent checking the beam alignment optically, we were fairly confident of the beam alignment. The alignment was verified by looking at the beam profile with hi gain SWICs at ∿ 65 feet downstream of the target and at the first bend point. These SWICs were preceded by ½" Pb sheets to convert photons. The SWIC downstream of the target indicated a misalignment of ∿ .060" in agreement with a known horizontal error in the alignment of the target box drawers. At the first bend no difference was observed with the bending magnet on or off indicating that we were only observing neutrals. The SWIC appears ∿ .060" low relative to BH415-1 and CV409. Horizontal alignment in this region appears good to ± .1".

Tuning of First Two Thirds of Beam

To study the beam we assembled two crossed finger counters (∿ .4" x .4") with X and Y motor drives in front of one of the tagging system Pb glass blocks (2½" x 2½" x 23") viewed by a photomultiplier tube from the rear. The beam was first tuned to 115 GeV/c electrons. With the counters first in EE-4 ∿ 60' downstream of the design first focus, we minimized the FWHM of the pulse height distribution by varying the horizontal and vertical quads upstream of the first bend point in EE-1. This tune also corresponded to a minimum vertical size and was close to values given by the beam transport program, TRANSPORT, and a standard set of excitation curves.[1] The vertical size of the electron beam was inferred from a vertical scan of the counters at the first focus by unfolding the 0.2" vertical counter size. With a 1/8" Pb converter, the full width was found to be .2" assuming a square beam and .11" assuming a gaussian beam envelope. No significant reduction in size was observed with a 1/32" Pb converter. Based on a TRANSPORT magnification of 2.1, a measured proton beam vertical size of .040", and a calculation of the expected multiple scattering of the electrons in the converter, one would expect a full width of .15" for 1/8" converter and .11" for 1/32". These predictions are fully consistent with the measurement. The vertical distribution of the pion component of the beam was spread over the full aperture of the nearest beam element, also as expected.

A direct measurement of the beam acceptance was made. With the quadrupoles turned off, the flux was counted in a known small area at the first focus. This is a very simple geometry for which the acceptance window can readily and accurately be calculated. With the quads turned on, another flux count was taken. The ratio of flux with quads on and off times the simple quads off acceptance is a good measure of the beam acceptance. The measured acceptance is 5.3 μsr% compared to 5.14 μsr% predicted. The good agreement indicates no serious loss of acceptance in the first stage. An early and crude scan at the focus in the plane of dispersion, shows a loss of about 11% of the horizontal acceptance in roll off at the edges. (This early scan was used in scaling the quads on flux to full beam width in the acceptance measurement and could be a source of error as its reliability is not the best).

Beam was successfully transported to the entrance of the Tagged Photon Lab (see Figure 3) about 700 feet from the target. (The tagging radiator is at 870 feet.) Horizontal and vertical scans were made, and the beam size was measured to be .8" horizontal and .5" vertical (FWHM). Calculations similar to those described above give predictions of 1.0" horizontal and 0.94" vertical. The vertical discrepency is not easily explainable at this time. It is hard to believe it is due to vertical clipping downstream of the focus since the beam was very clean (See Figures 7 and 8). On the other hand, the beam was known to be very close to the top of temporary flanges at both ends of the pipe between EE-4 and TPL and scraping cannot be ruled out.

Yields, π/e Ratios, Halo Studies and all that

Yields of electrons were measured both at the focus in EE-4 and at the Tagged Photon Lab. Backgrounds were studied at the Tagged Photon Lab.

Figure 4 shows a summary of e^- yield measurements made using various techniques. Absolute measurements at the first focus were within ∿ 12% of predicted yields.[2] Another cruder set of measurements at the focus showed correct energy dependence. Measurements were made at the entrance of the TPL both by scanning the counters across the beam and integrating the resulting distributions and by counting Pb glass singles in the electron peak, the beam being small enough to fit in the glass block. The yields tend to be about 15% lower than at the first focus and about 25% below predictions. This and the small vertical size noted earlier may indicate we had a transmission problem into the TPL, which should be rectified by an optical survey and alignment of the vacuum pipe.

A rough check of the dependence of e^- yields on the lead converter thickness is shown in Figure 5. There is reasonably good agreement with predictions.[3]

An upper limit on the pion contamination was measured at the entrance to the TPL using the lead glass block. Figure 6 shows pulse height spectra from this counter. When plotted on a linear scale, nothing but the electron peak is visible. In a log plot, some off energy electrons are seen (at the 0.1% level), and there is a peak that we attribute to pions. This peak is at the channel for $\sim$ 1 - 2 GeV energy deposition in the glass which is about right for minimally ionizing particles. Muons that come through when all beam collimators are closed also give a peak at this channel. By setting a threshold above this peak, we could discriminate between e^- and π^- and scale the respective yields. At 115 GeV, we found $\pi/e \sim .3 - .4\%$ compared to predictions of $\sim .15\%$.

We also measured the off angle beam halo. Vertical and horizontal scans are shown in Figures 7 and 8. This halo also seems to be at the 10^{-3} level at the edges of the future quadrupoles. Calculations[3] predict that another factor 1000 cleanup will occur in the last bends to bring the halo down to the 10^{-6} level necessary to insure clean tagging. One would expect these backgrounds (including the pions) to improve as known misalignments are corrected. Halos will be the subject of high priority in the next test.

Shower Counter Tests

During the run, numerous strange phenomena were observed with the Pb glass counters (2½" x 2½" x 23" SF2) being tested for the tagging system and Experiment 25. Some of the peculiarities were eventually understood as beam effects. Some problems remain. This test represented the first time phototubes used in analogue applications were subjected to light levels from 10^5 100 GeV showers per second. It is thus not surprising that problems turned up.

Resolution

It is not clear what the counter resolution really is due to beam effects and rate effects. Pulse height spectra were taken triggered on a double coincidence between two (.4" x .4") square scintillation counters positioned upstream and centered on the Pb glass counter. At the first focus with the 115 GeV beam focused to give the smallest FWHM pulse height spread, spectra of width 4.5% were observed. One very low statistics run with quads off and collimators nearly closed, gives a FWHM of 3.7%. Most spectra show wider distributions presumably due to rate effects or beam momentum spread.

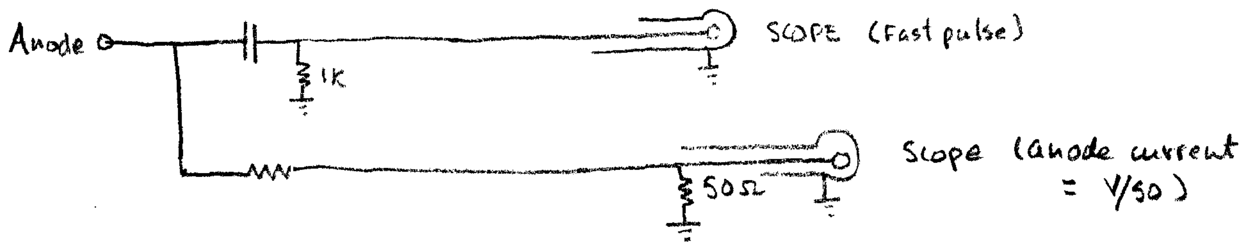
Rate Effects

The first evidence of rate effects occurred during an attempt to measure the beam acceptance with the quads off and collimators closed. At low rate, 115 GeV corresponded to 187 channels; at rates a factor of 250 higher, 115 GeV corresponded to 204 channels or $\sim$ 10% higher. The low rate run was repeated and the pulse height shifted back down. The actual rates in the Pb glass counter were not recorded. At the high rate, we had 700 triples/pulse. This corresponds to $\sim$ 5,000/pulse in the counter.

After moving to the TPL, we started to notice a change in gain during the beam spill, the gain increasing $\sim$ 20% shortly after the spill began. This problem led to a series of tests and attempts to isolate the problem. Here is a list of observations.

1. The voltage sag at the last dynode (EMI 9815 tube) was measured to be $\sim$ .1 volt.
2. Boosting the base with an external supply did not improve the situation.
3. Increasing the base current by a factor of 2 did not improve the situation.
4. Replacing the EMI tube with a 56AVP and the standard Fermilab base did not improve things.
5. Boosting the AVP did not make any difference.
6. We turned the gain down so that 115 GeV gave a 15 millivolt Anode pulse rather than 1.5 volts. This reduced the size of the effect by about a factor of 2, and also increased somewhat the rate at which the effect is clearly observable. The anode current was presumably reduced by a factor of 100 to achieve $\sim$ x 2 improvement.
7. The light was attenuated with apertures and alternatively with neutral density filters. Again there may have been some improvement but not much.
8. Later in the run, the time dependent effect went away. Both the 56 AVP, EMI 9815, and a 6810 showed no time dependence during the pulse even at $\sim 10^5$ e^-/pulse. This may have had something to do with the spill which was not carefully monitored.

After the run, tests of the tube and base were made by Cordon Kearns. In a light tight box, he pulsed a DC light source onto the tube for 1 sec. and at a rep rate similar to the synchrotron cycle. The tube response to pulses from a fast light pulser were than measured as a function of the anode current (due to the DC light level) using the following circuit.



The behavior of the pulse size as a function of the time after the onset of the DC light pulse looked exactly like the behavior during the electron beam test. The size of the increase in gain was measured as a function of anode current. (figure 9). With the 56 AVP at the same high voltage as used during the experiment, a 23% increase was observed with only a 10 μ amp anode current. An 83% increase in gain was observed at an anode current of .1 milliamp. We can estimate the average anode current for a 3 volt pulse at 10^5/pulse as:

$$i = \frac{3}{50} \times 10^5 \times 20\ 10^{-9} = 1.2\ 10^{-4} \text{ amps.}$$

At 10^5/pulse we should have seen an effect, but we also saw an effect with the tube putting out 30 millivolts (measured at the tube) and 10,000/pulse. This gives $i = 1.2\ 10^{-7}$ amps. This current did not give an effect in the Laboratory.

The stage voltages were monitored with the anode current in the region of .1 milliamps. The voltages were seen to droop by only .1 volt, so it appears the problem is not primarily in the base. It is speculated that the problem is a dynode fatigue effect, and that the source of the anode current is not all from Cerenkov light. Further studies of this problem are being persued.

Muon Measurements in the Tagged Photon Lab

During the November test of the electron beam in Proton East, we measured muon fluxes in the Tagged Photon Lab. We describe here the measurements and our resulting tentative conclusion as to the source of the muons. Finally, we suggest some possible modifications to reduce the worst components of the muon background.

Apparatus

Measurements were made with 3 scintillators each ¼" thick; A and B are 7.5" x 7.5" and C is 5.3" x 5.3" in area. A and B were mounted parallel, 5" apart and with the centers of their large faces on a common normal to that face. C was either mounted on the same axis 5" downstream of B or on a separate frame 30' or 60' downstream for making angle scans.

Measurements

1. Flux

The flux of μs was measured at 3 heights above the floor .5 feet, 5.5 feet, and 8.5 feet for various positions along and "E-W" line across the Tagged Photon Lab. The fluxes are not very different at the three heights as shown in Figure 10. The flux is about $3.5 \times 10^5\ \mu/m^2$ (10^{13}, 300 GeV protons on target) at the planned positions of the γ beam and rises as one moves East. The slight decrease between 17 and 20 feet East of the West wall probably results from the shielding of the extra earth when one moves out of the line of TP1. The further rise is due to the continued approach towards the 0^o line defined by the incoming proton beam.

2. Angles

Two horizontal angle scans were made with a 60 foot lever arm and with AB at 14' and 17.5' from the West wall of TP3. These each show a divergence of the muons of 13 mr FWHM corrected for the finite size of the counters. The centers of the peaks for these scans define two lines which, to the accuracy of our surveying, intersect 625' ± 80' upstream in the vicinity of the intersection of our beam pipe with EE-3. (See Figure 11).

This suggests that a fairly large component of our μ flux comes through the beam pipe joining EE-1 to EE-4 thus avoiding attenuation in the 90' of steel between those two pits.

Further support for this hypothesis comes from the effect of BH415, the two bending magnets immediately upstream of this pipe. Since the axis of the pipe does not intersect the proton target, the flux of muons through the pipe can be increased by bending in the iron yokes of these two magnets, and indeed the flux rises by 20% when they are powered.

We also made two vertical angle scans. During the first of these, BH415 was on and the measured divergence of 12 mr is very close to that obtained for the horizontal scan. With BH415 off, however, a vertical divergence of 22 mr was observed, suggesting that the muons are less collimated.

If one assumes that a fairly well collimated beam from the EE-1 - EE-4 beam pipe is incident on the downstream end of EE-4 and that the observed divergence of the muons in TP3 is mainly due to the multiple scattering in the 120 feet of earth between EE-4 and TP1, then the mean μ energy would be about 20 GeV. This length of earth ranges out 15 GeV μs, so we are concerned primarily with attenuating muons in the energy range 15 - 40 GeV. This is a significant number in the design of a spoiler suggested below.

3. Effects of Beam Components

In an attempt to identify the sources of muons, we measured the flux at 14 feet from the West wall for most of the possible combinations of target in/out; converter in/out; EE-1 collimator open/closed; BH415 on/off. The most interesting observations were the following:

a. $\frac{\text{Proton Target out}}{\text{Proton Target in}} = .46$ suggests that almost ½ of the muons come from the proton dump or sources upstream of the proton target.

b. With Proton Target in $\frac{\text{BH415 off}}{\text{BH415 on}} = .77$ but with

Proton Target out $\frac{\text{BH415 off}}{\text{BH415 on}} = .88$

Thus, BH415 increases the flux due to the target related component by about 43% but only increases the flux due to the dump and upstream related component by about 13%. This is consistent with our conclusion that the beam pipe acts as a collimator and that BH415 steers muons into it since the dump and upstream component will be at a lower height than the target component and thus less affected by BH415.

c. With Proton Target in $\frac{\text{Converter out}}{\text{Converter in}} = .76$

Thus, a significant fraction of the μs appear to be produced in the converter by the neutral beam. A modest improvement should be obtained by using a 1" diameter converter which is matched to our electron acceptance rather than the 2" diameter one used in the last run. These μ's will also travel along the vacuum system.

4. Spoiler Immediately Downstream of Target Box

An Experiment 87 spoiler 10 feet long was placed in our beam, with its aperture below and to the West of our beam. When switched on with the polarity to bend μ^+ West towards our experimental line, it increased the flux by a factor of 2 to 3. When powered with the opposite polarity, it increased the flux by about 20%. We conclude that immediately after the target box, the μ^+ and μ^- are in a narrow cone and any horizontal bending may increase the μ flux at the Tagged Photon Lab.

However, with the power off, the spoiler decreased the μ flux to 0.59 (spoiler in flux) with the target in, and to 0.66 (spoiler out flux) with the target out. These two measurements may be used to make a crude estimate of the relative contributions of the dump ($\equiv$ d) and the upstream sources ($\equiv$ u) to the target out flux. Assuming that the dump component is affected as much as the target generated μs and that the μs from the upstream sources are only attenuated ½ as much, we have $0.59d + 0.80u = 0.66\ (u + d)$ which gives $\frac{u}{d} \approx .5$. We, therefore, estimate that (33 ± 30)% of the target out component comes from upstream sources and (67 ± 30)% comes from the dump.

The effect of the spoiler is somewhat irrelevant since it intercepted the whole beam but does suggest that additional unmagnetized iron shielding below the beam where the dump component is concentrated and on the West side of the beam pipe where wide angle μs heading directly for TP3 are to be found, will help.

5. Recommendations

We recommend that:

a. A spoiler with a 3" diameter beam pipe be placed in EE-3. It should have at least 33 kg. m integrated field in the iron surrounding the pipe and 45 kg. m would be preferable. The field is calculated by requiring 45 GeV μs be swept ± 6" transversely soon enough to see 50 feet of iron before entering EE-4, thus reducing all 45 GeV μs to below 15 GeV, the energy needed to penetrate the earth between EE-4 and TP1. A simple design for this spoiler is being studied.

b. That iron shielding at least 4" thick be placed adjacent to our beam pipe below it and on the West side immediately downstream of the converter in EE-1 for a thickness of 20 feet.

These measures should reduce the μ flux to tolerable levels (as discussed in the July 24 memo to J. Sanford following the earlier μ tests) for 300 GeV proton running, but further measures may be necessary for 400 GeV protons since our previous run showed about 2.5 times more μs at the higher proton energy. If further improvement is needed, we shall probably recommend a second spoiler at the upstream end of EE-4 and possibly iron shielding between EE-4 and TP1 or in TP1 alongside our beam line.

Summary

1. The muon flux is 3.5 10^5 μ/m^2 which is somewhat too high for comfortable 300 GeV running with 10^{13} protons on target. Our previous report (July 24 memo to J. R. Sanford) shows that the flux will be 2 to 4 times larger for 400 GeV protons incident on our target, and this will be intolerably high.

2. The main sources of muons are:

a.	the proton target	$\sim (50 \pm 20)\%$
b.	the proton dump	$\sim (25 \pm 20)\%$
c.	sources upstream of the proton target	$\sim (13 {}^{+20}_{-13})\%$
d.	converter	$\sim (12 \pm 12)\%$

3. The beam pipe between EE-1 and EE-4 forms a vertical source of muons and that a spoiler in EE-3 will help significantly.

4. Unmagnetized iron shielding west of and below the beam downstream of the target box will reduce the direct and dump components.

Further improvements may still be required, but experience shows that the weaker sources of muons can only be successfully identified after the strongest ones have been attenuated.

Shielding Problems in EE-1

One clear problem pointed out in these tests is the need for very heavy shielding in EE-1 around the neutral dump and plugging the post target area. With 24" of concrete on the sides of BH415-2 (which acted as neutral dump) and about 60" on top, the following averaged dose rates were measured with 10^{11} protons on target:

Roof of EE-1	100 mrem
West window EE-1	30 mrem
Road	10 mrem
Field Office	1 mrem

Some of this radiation was coming from a 2½ foot hole in the cave plug near the West wall, and some was penetrating the side shielding of BH415-2. At both places, R. Sorber measured 1 Rem about 5 times higher than elsewhere on the shield.

A factor of 100 improvement is required for operation near 10^{13} protons with personnel working in the field office. Plugging of the hole and 2 feet of steel around a proper neutral dump in front of BH415-2 should give a factor 10 improvement. The possibility of extending the cave to the end of EE-1 is being discussed. This would allow more shielding to be installed on the side of the neutral dump but would require a prolonged (2 weeks) shutdown of P-East.

Instrumentation

High gain SWICs worked well in the neutral beam as they have for Experiment 87, but because of a series of problems, no electron profile was ever observed. This should be easy to cure for the next test.

Conclusion

These tests were a success in proving our ability to produce a clean electron beam of the promised intensity. No fundamental problems were turned up in the beam despite two weeks of looking for trouble. Beyond the success, the tests proved the need for more shielding of μ backgrounds to make the TPL a clean place to do physics as well as the need for more shielding in EE-1 (as expected).

FOOTNOTES

1. Excitation curves for the quadrupoles and bending magnets were obtained from the following reports:

   a. F. Mallie, "3Q120 Quadrupole Magnet Beam Transfer - 10' Quad. Data Sheet - D.C. Operation", Fermilab Engineering Note, section Exper. Facil, project Standard Magnets, February 5, 1971 (Rev. March 29, 1971).

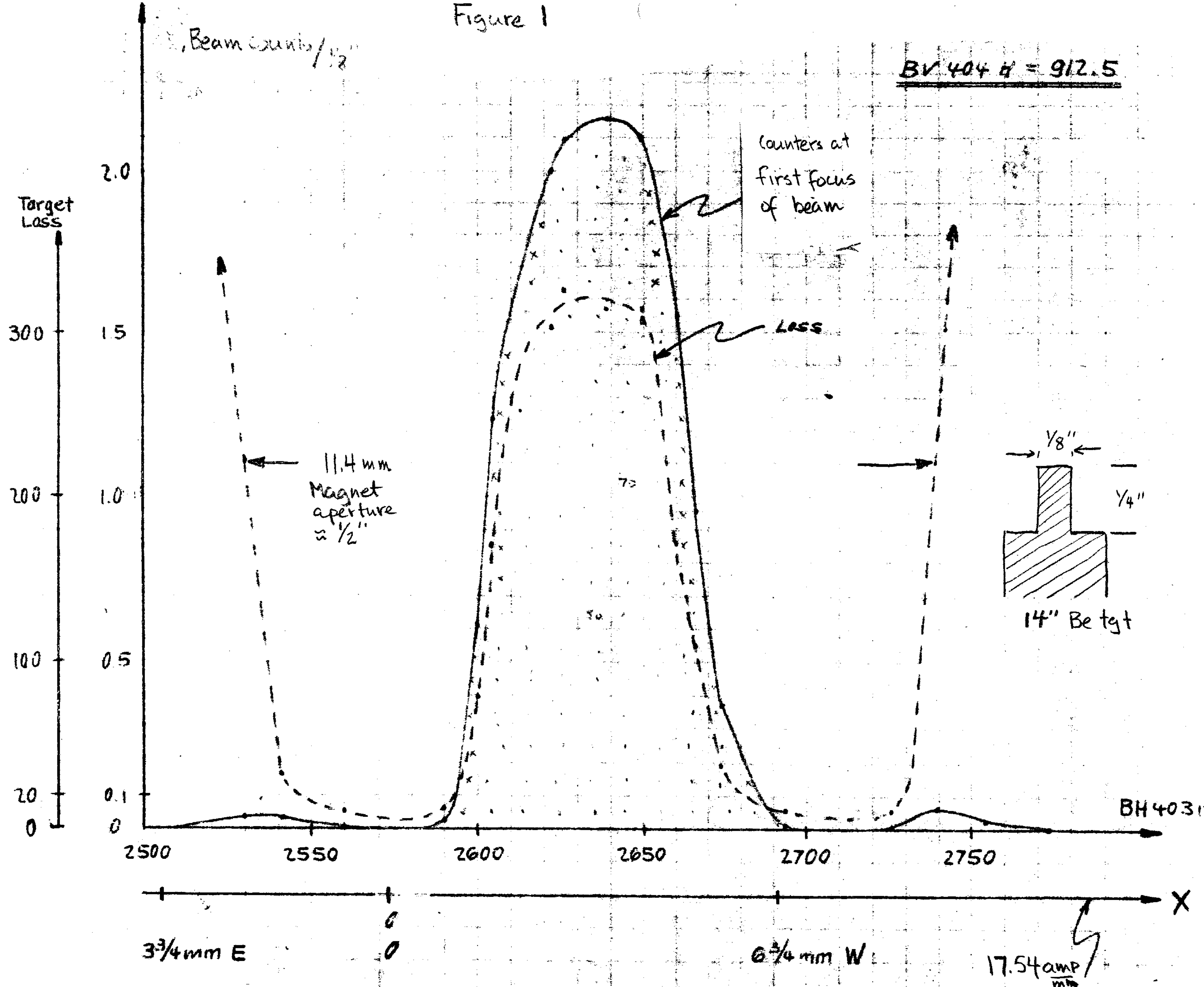
   b. W. Nestander, "4-2-240 Bending Magnet Data Sheet - D.C. Operation", Fermilab Engineering Note, Neutrino Laboratory Section, Standard Magnets Project, serial - category EN-7027.

   c. R. Juhala, "EPB Dipole Magnetic Field Measurements", Fermilab Note, TM-434 0621.05, July 26, 1973.

2. Thomas Nash, Status Report on the 300 GeV Electron-Tagged Photon Facility at Fermi National Accelerator Laboratory, Paper submitted to The International Symposium on Electron and Photon Interactions at High Energies, Bonn, Germany, August 1973.

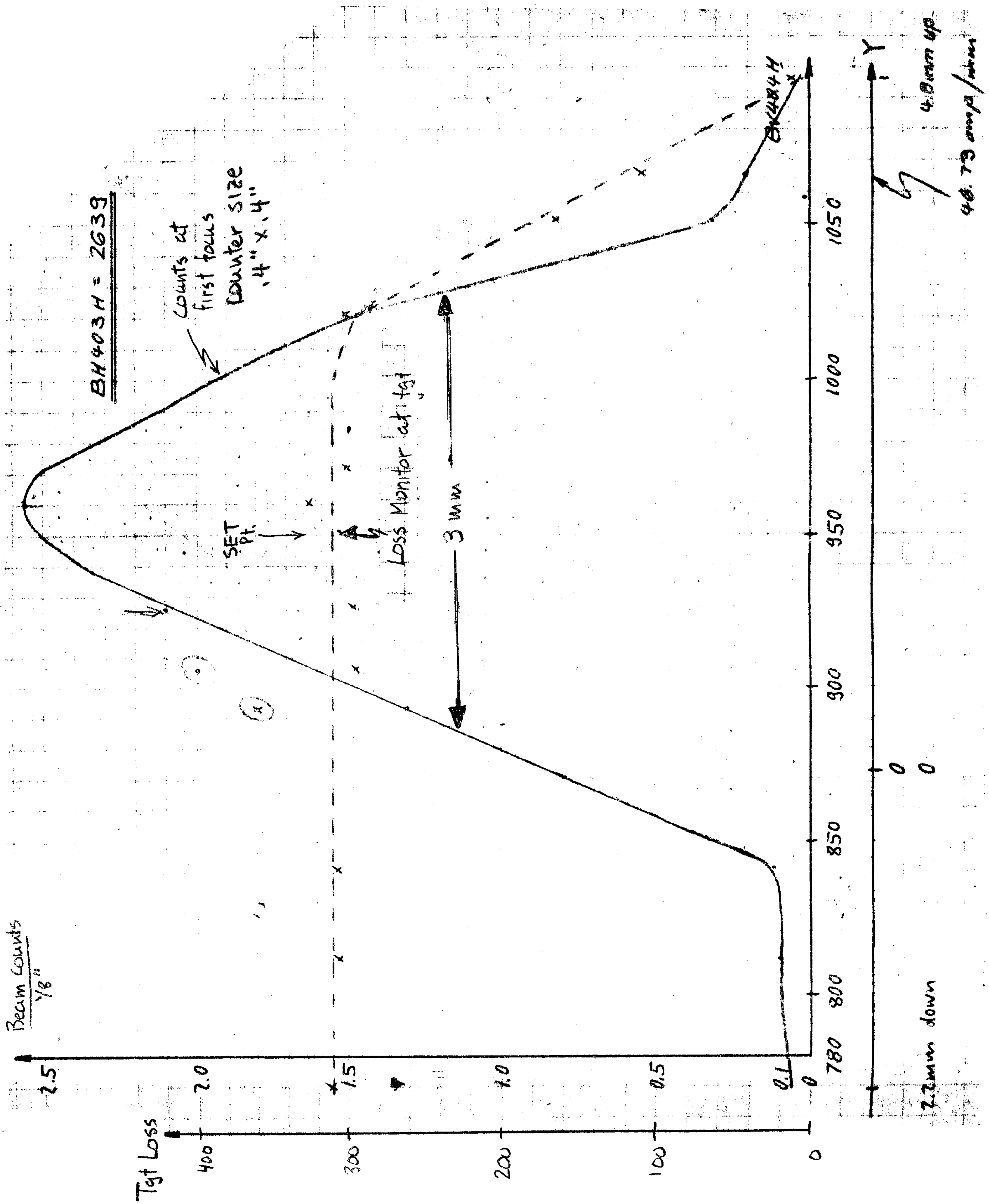
3. C. Halliwell, P. J. Biggs, W. Busza, M. Chen, T. Nash, F. Murphy, G. Luxton, and J. D. Prentice, Design of a Tagged Photon-Electron Beam Facility for Fermi National Accelerator Laboratory, FNAL FN-241 (1972).

Figure 1



Beam counts/1/2
BV 404 # = 912.5
Target Loss
Counters at first focus of beam
Loss
11.4 mm
Magnet aperture ≈ 1/2"
1/8"
1/4"
14" Be tgt
BH 403
2500
2550
2600
2650
2700
2750
2.0
1.5
1.0
0.5
0.1
0
300
200
100
20
0
X
3 3/4 mm E
0
6 3/4 mm W
17.54 amp/mm

Figure 2



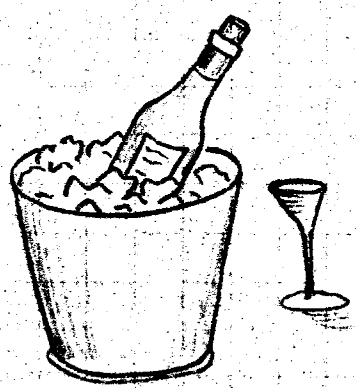
BH403H = 2639
Counts at first focus Counter size .4" x .4"
Beam Counts /⅛"
Tgt Loss
SET Pt.
Loss Monitor at tgt
3 mm
BH404H
2.5
2.0
1.5
1.0
0.5
0.1
0
400
300
200
100
0
780
800
850
900
950
1000
1050
2.2mm down
4.8mm up
40.79 amp/mm
Y

-14 -16 -18 -20 -22 -24

ED AT TPI

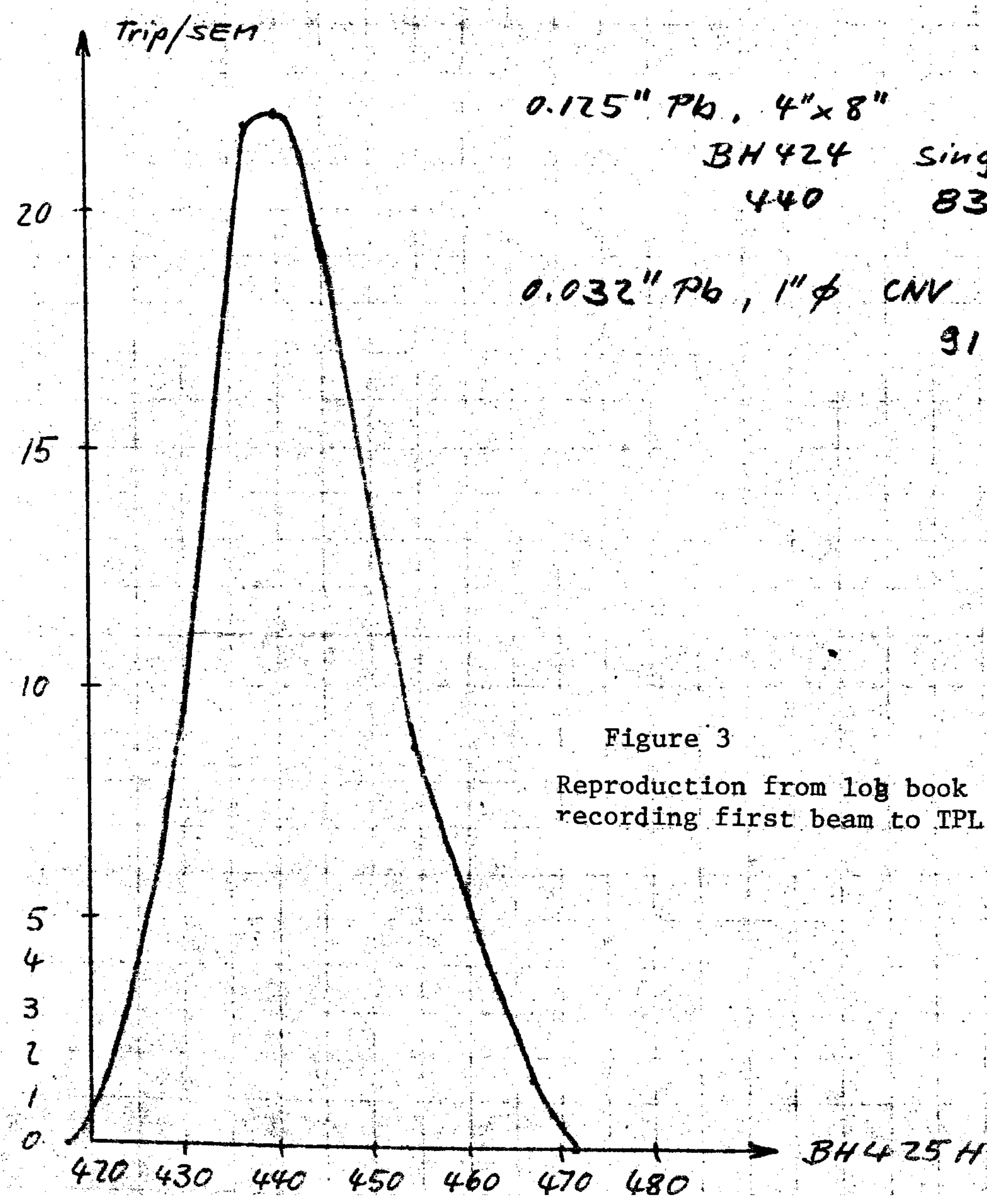
FOCUSING !!)

Singles / SEM
31.2
29.6
32.3
32.6
34.1
32.2
59.7



Singles / SEM
72.65

464	1041	1025	672	1.523
45[illegible]	6281	6248	715	8.7[illegible]3
440	16992	16973	770	22.043 ←
430	8277	8241	865	9.527
414	101	77	847	0.091
445	17939	17907	935	19.152
437	17610	17587	805	21.847



0.125" Pb, 4"x8"
BH424 Singles(Dy)
440 83227

0.032" Pb, 1"φ CNV
9100

Figure 3

Reproduction from log book recording first beam to TPL

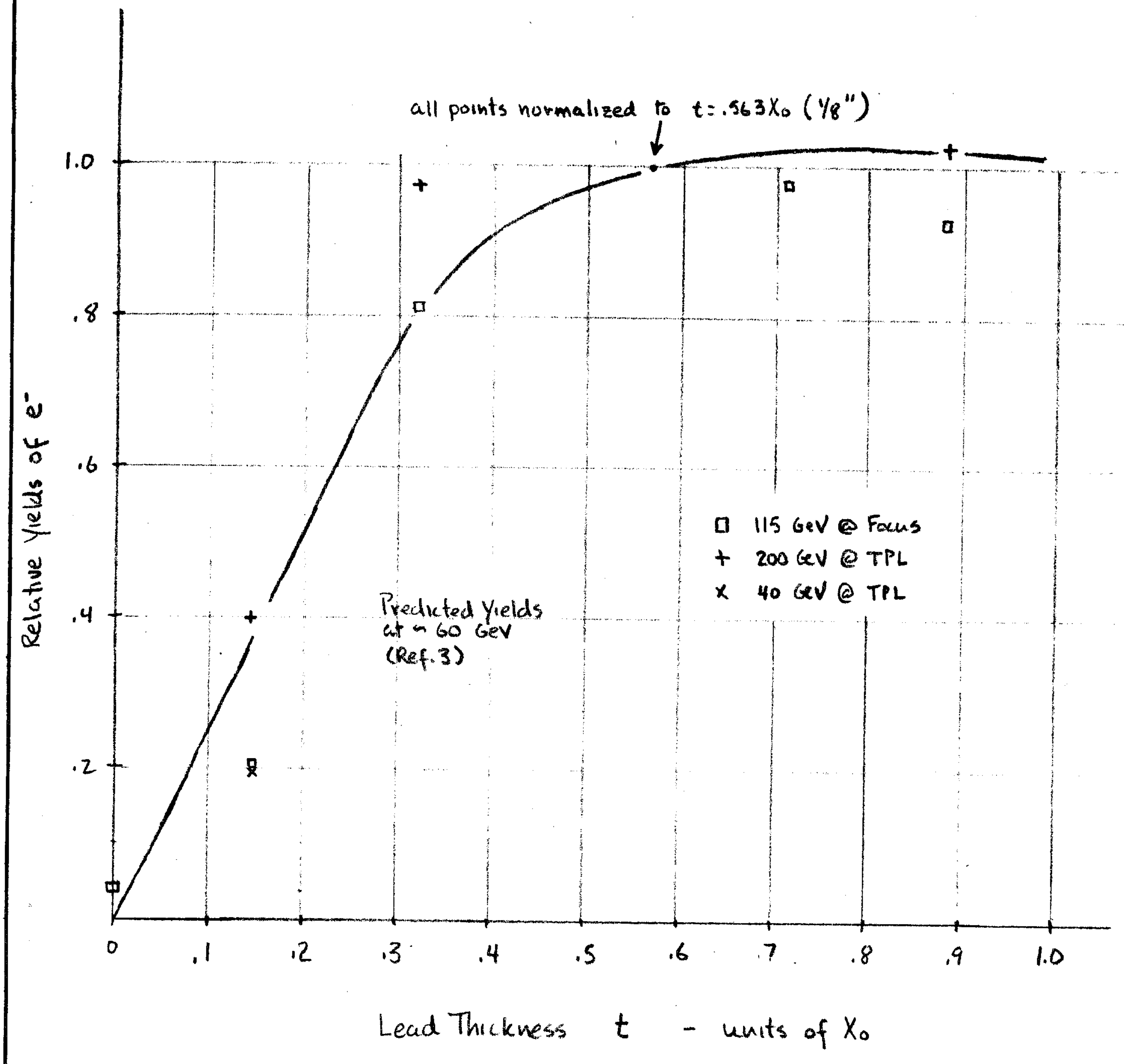
SUBJECT Figure 5

e^- Yields vs Convertor Thickness

NAME T.N.

DATE Dec 6, 1974

REVISION DATE

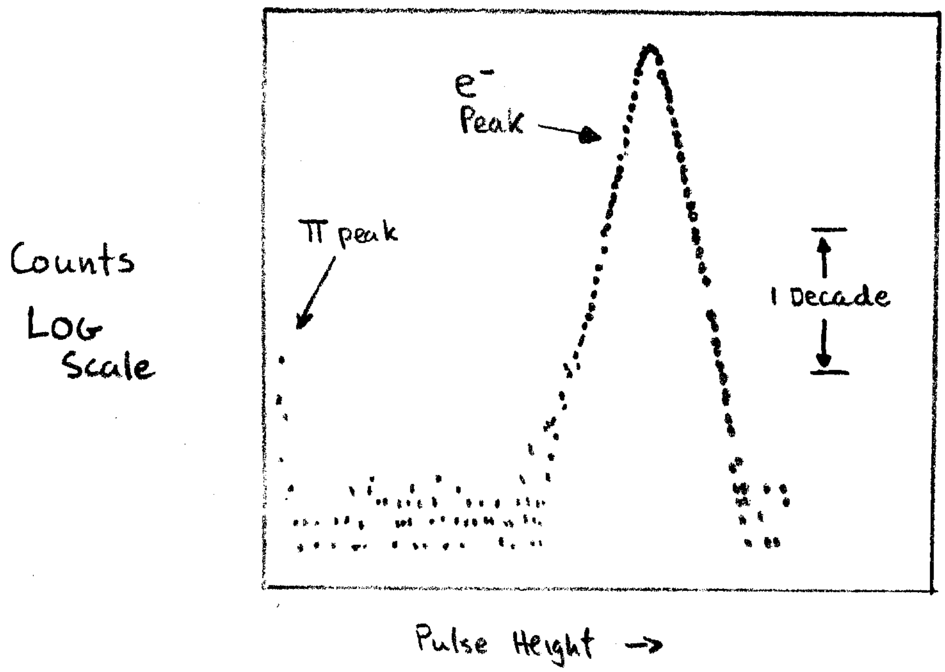


NATIONAL ACCELERATOR LABORATORY
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
			25

SUBJECT: Figure 6
Lead Glass Pulse Height Spectra at 115 GeV

NAME	
DATE	REVISION DATE



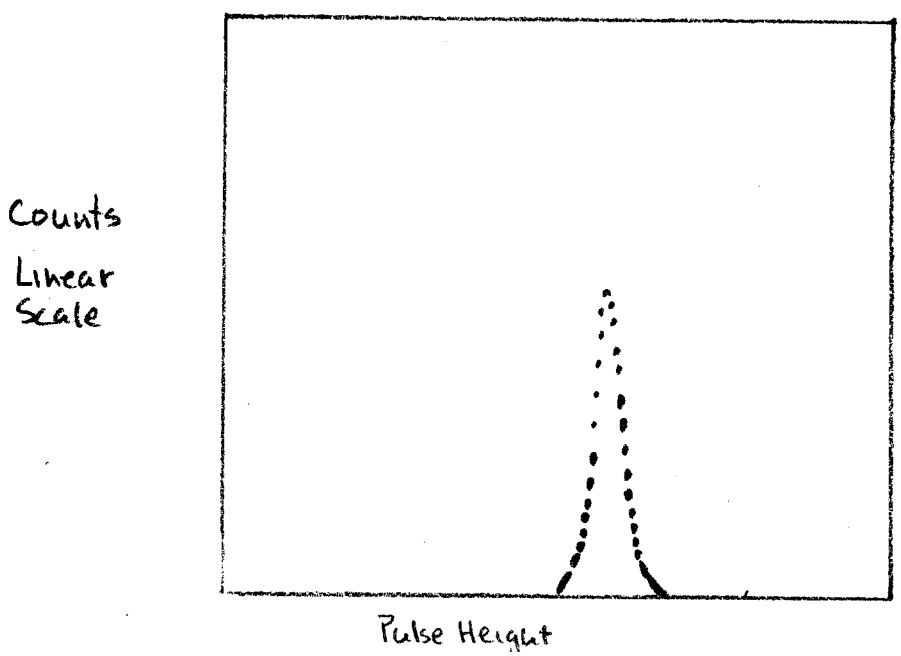


Fig 1 Horizontal Scan at Tagged Photon

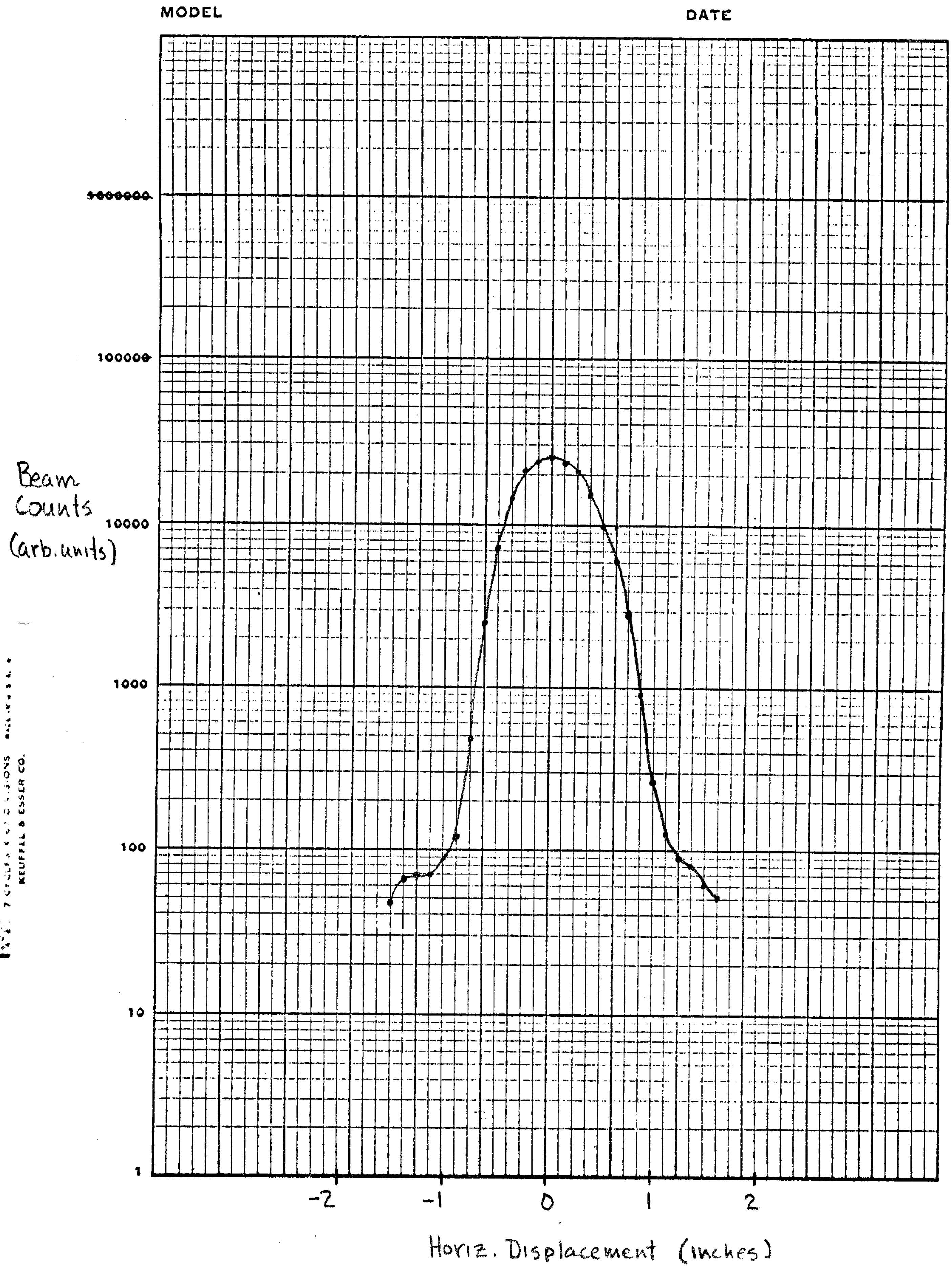
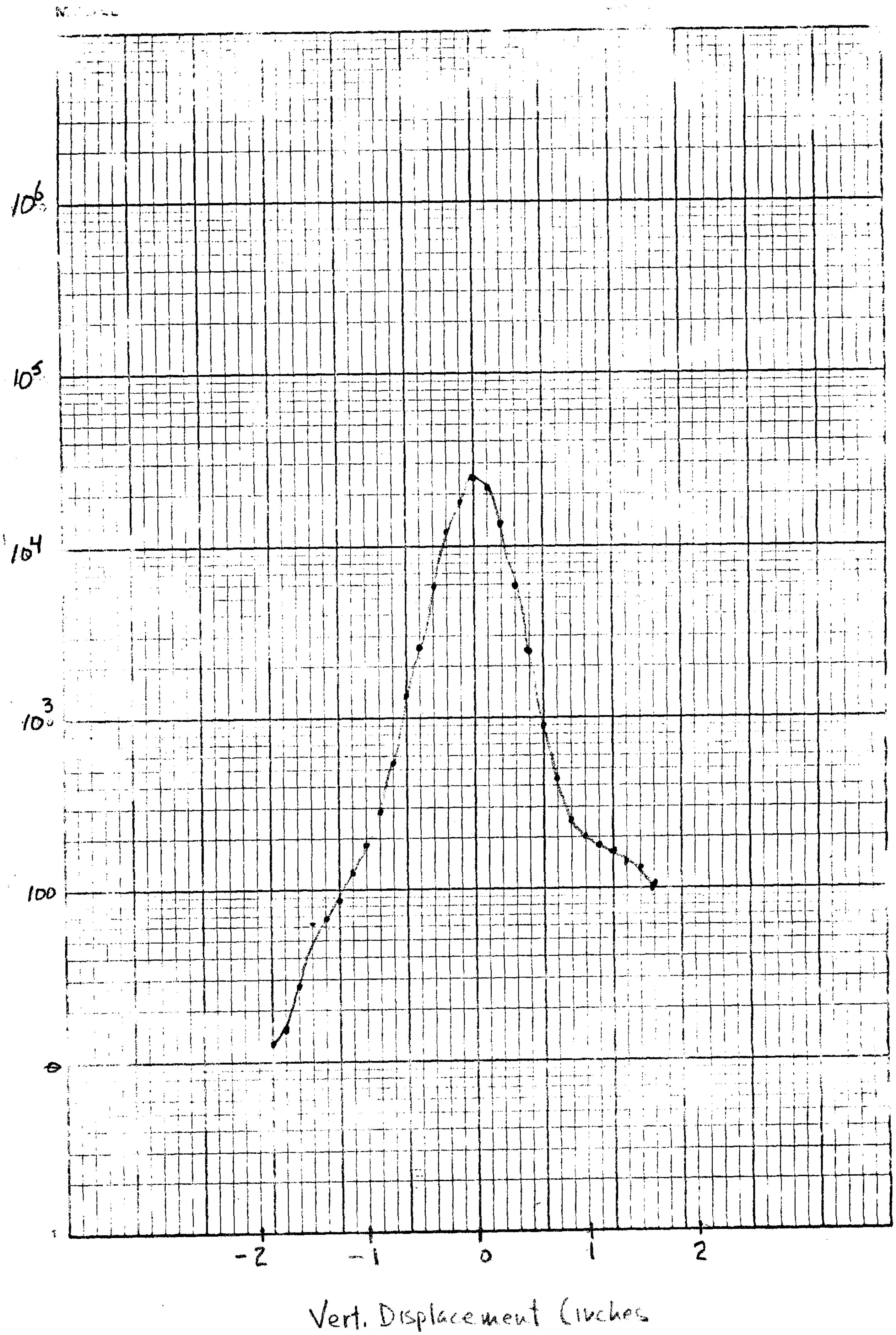


Fig 0 - Vertical scan at Tagged Photon Lab



SUBJECT: Figure 9
Lab measurement of Gain Sag vs Anode Current

NAME

DATE | REVISION DATE

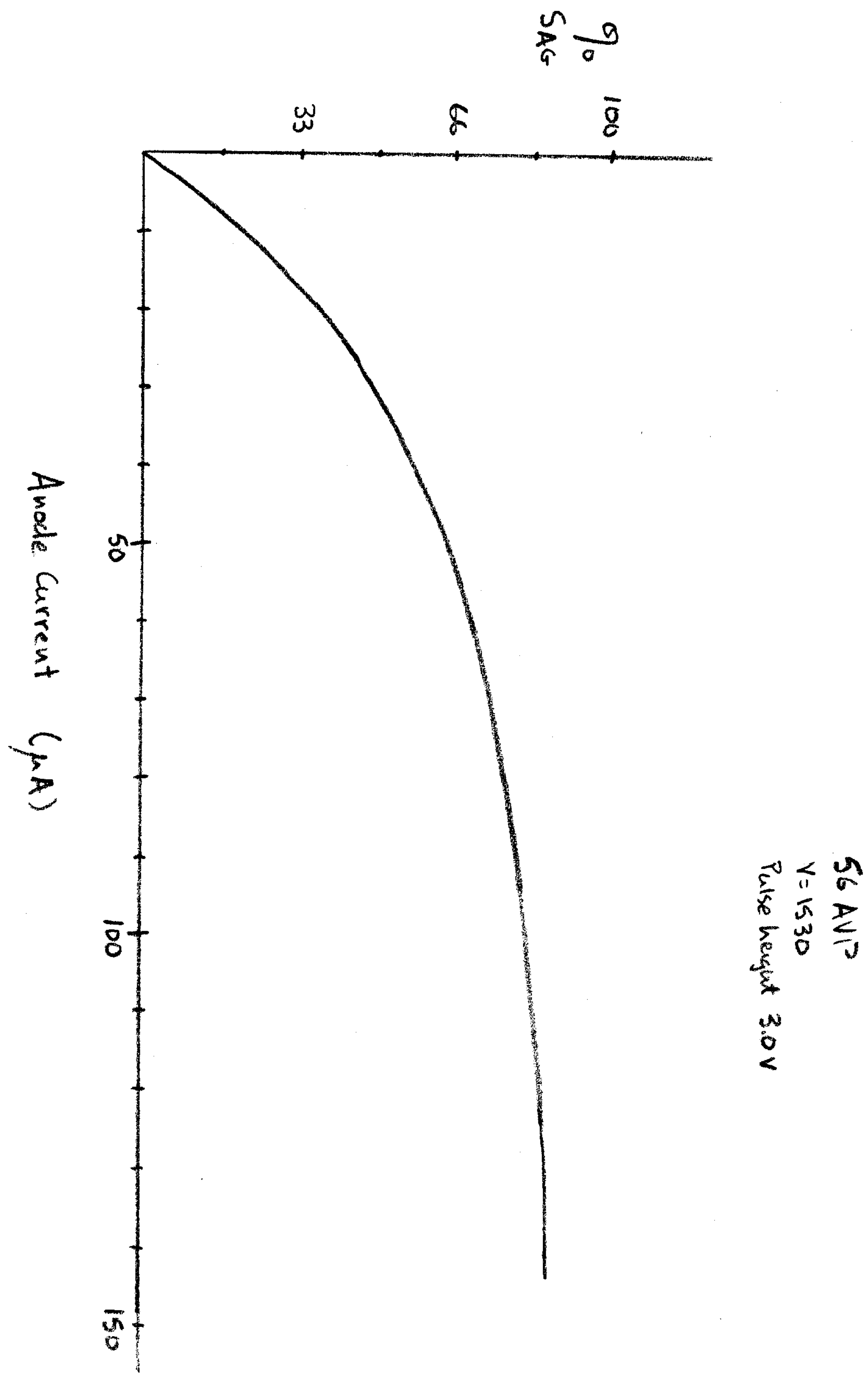


Figure 10

HORIZONTAL VARIATION OF MUON FLUX AT VARIOUS HEIGHTS IN TP3

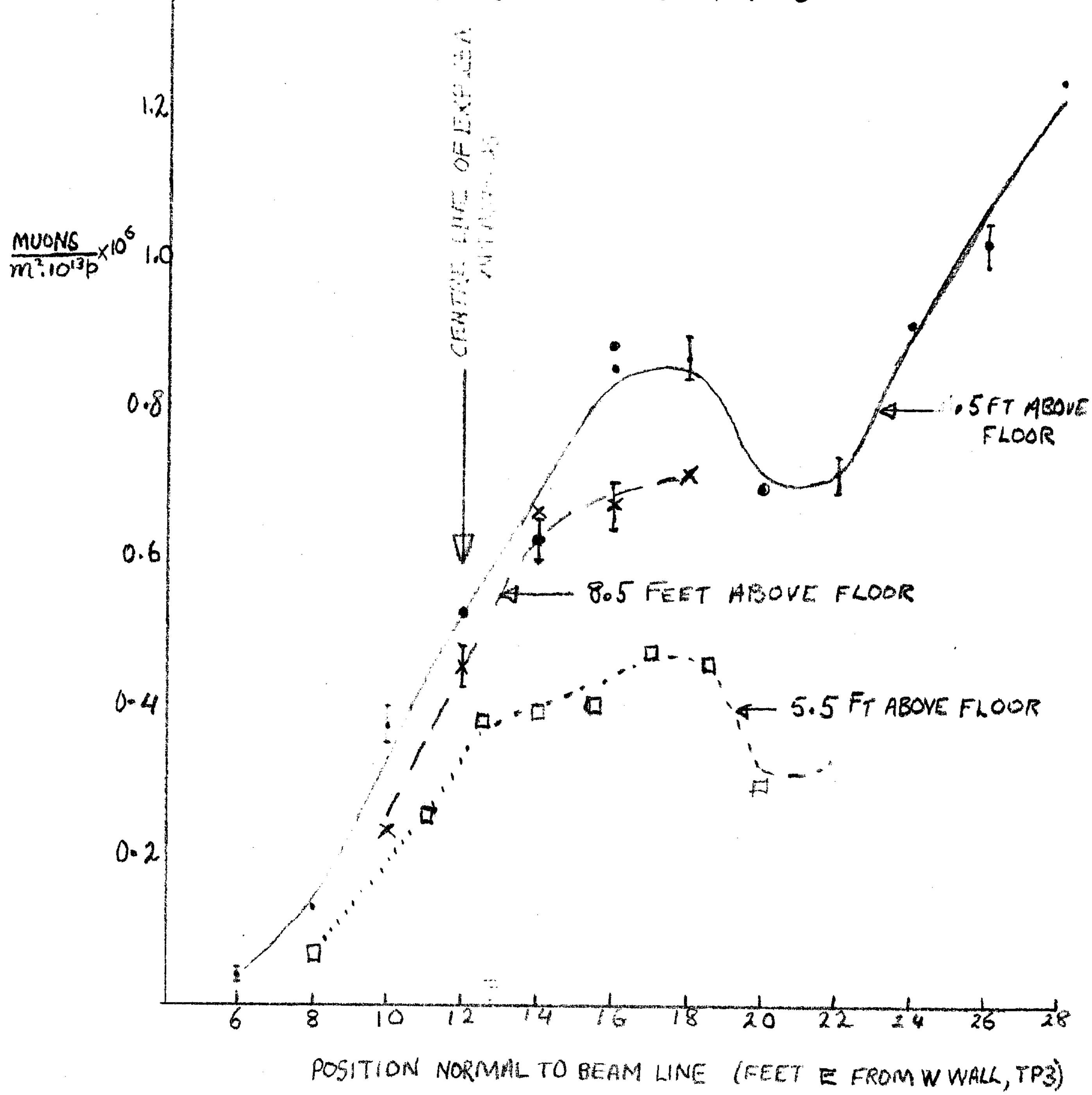
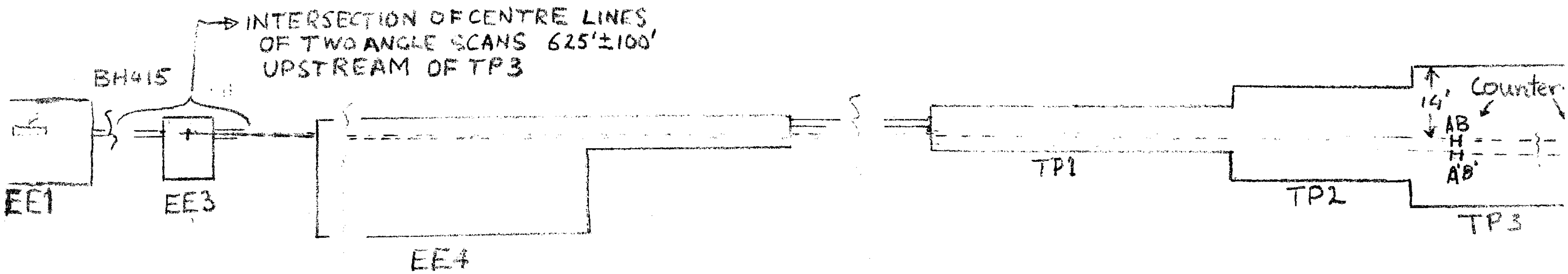


FIG. 11

LOCATION OF VIRTUAL MUON SOURCE



FOR DETAILED SCALE DRAWING OF BEAM SEE DRAWING NO. 6001 LE-43920