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STUDY OF THE PROPERTIES OF WEAK NEUTRAL CURRENTS IN THE INTERACTIONS OF A NARROW BAND NEUTRINO BEAM IN LIQUID NEON

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Study of the Properties of Weak Neutral Currents in the Interactions of a Narrow Band Neutrino Beam in Liquid Neon

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Summary of Proposal

The purpose of this experiment is to study the nature of the weak neutral currents in neutrino interactions. We propose a 200,000 picture exposure of the FNAL 15 ft bubble chamber filled with a heavy neon-hydrogen mixture (preferably pure neon) to a narrow band neutrino beam. With 5 x 10^{12} protons per pulse at 300 BeV, we estimate an event rate between 1 event/20 pictures and 1 event/40 pictures, depending on detailed beam conditions.

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Physics Motivation

Evidence indicating the existence of weak neutral currents has been found in a number of neutrino experiments. The main purpose of the experiment proposed here is to study the detailed properties of these neutral currents, about which very little is known at this time. The main features of this experiment are:

1. The knowledge of the energy E_ν (and direction) of the incident neutrino by using a narrow band neutrino beam.

2. Detection and identification of the individual hadrons produced in these reactions,

$$\nu + N \rightarrow \nu + \text{hadrons}$$

and a measurement of their total momentum and energy $\bar{P}_{had}$, $\bar{E}_{had}$, by using the 15 ft FNAL bubble chamber filled with liquid neon as a detector.

An estimate of the energy and direction of the outgoing neutrino can thus be obtained by using energy and momentum conservation, and the values of the inelastic variables q^2, ν can be calculated for each event. (q^2, ν are the four momentum squared and the energy, respectively, transferred to the hadrons.) In this way, the distribution of the neutral currents in E_ν, as well as the variables $x = q^2/2m\nu$, and $y = \nu/E_\nu$, can be obtained. Some examples of the physics questions that we can address ourselves to are:

a. Do the neutral currents have a vector-axial vector (V,A) structure or a scalar-pseudoscalar (S,P) structure? As shown in Fig. 1, a V,A interaction would have a y distribution flat in y or like $(1-y)^2$ (or somewhere in between) while an S,P interaction is expected to have a y^2 dependence. These two shapes should be easily distinguishable with the numbers of events expected in this experiment.

b. The total cross section for the neutral current events at several values of E_ν. This information until now has been available from the neutral current to charged current ratio integrated over E_ν. It has however been pointed out that in the experiments done so far this ratio has not been too reliable due to the fact that the detection efficiency of the neutral current (NC) events (relative to the charged current (CC) events) depends sensitively on the y distributions, which are so far unmeasured and could be quite different for NC and CC events. In the experiment proposed here, the y distributions will be measured and the detection efficiency corrections can be made more reliably.

c. From the x and y distributions, a crude estimate of the structure functions in the inelastic neutral current interactions can be obtained.

d. Due to the hadron detection capabilities of the neon bubble chamber, we can learn something about the nature of the hadrons produced in the neutral current events. Nuclear reabsorption will certainly be a problem here; however, some corrections for nuclear effects are possible.

In addition to the neutral current events, the narrow band exposure will contain a large sample of charged current events. Although the statistics will not be as good as in the wideband neutrino runs, the knowledge of the neutrino energy will be a big advantage in some cases, as for example in the measurement of the total cross section as a function of E_ν. In a very real sense, the narrow band and the wideband runs in the same detector, but with very different beam conditions, will provide many valuable cross checks and calibrations that will make the interpretation of the large statistic wideband runs more reliable.

One problem connected with the neutrino energy information provided by the narrow band beams is that these beams have actually two distinct energy components, due to π and K decays, respectively. If in any given interaction, the total visible energy is larger than the energy of the π decay neutrinos, we know that it was induced by a K decay neutrino. Thus, the K decay neutrinos can be used to study the upper half of the y distribution (large visible hadronic energy means large y) in an unambiguous way. Since the flux of K decay neutrinos is smaller than that from π decays by more than an order of magnitude, the small y events from

K decay neutrinos will be a small (less than 10%) background in the larger sample of events from π decay neutrinos. This background can be estimated and subtracted out by using the unambiguous large y events from K decay neutrinos.

II. Detection Capabilities of the Neon Chamber

We believe that the 15 ft bubble chamber filled with liquid neon or a heavy neon-hydrogen mixture has unique advantages as a neutrino detector. We therefore feel that narrow band neutrino runs in the neon chamber will in a very important way complement the narrow band experiments in other detectors.

Liquid neon has the following properties:

atomic number	$Z = 10$
atomic weight	$A = 20$
isotopic spin	$I = 0$
density	$\rho = 1.2$ g/cm^3 (or tons/m^3)
radiation length	$x = 25$ cm
interaction length	$L = 60$ cm
effective interaction length	$= 75$ cm .

(The effective interaction length is our estimate of the length if only those interactions are counted which are detectable in the chamber.)

For a neon-hydrogen mixture, these numbers have to be adjusted, depending on the fraction of neon in the mixture.

Some of the advantages of the neon chamber are as follows:

a. High event rates. The event rates in neon are 20 or 10 times those in hydrogen or deuterium, respectively. The total mass of liquid in the chamber is around 40 tons, of which 20 tons are in the usable fiducial volume. This compares favorably even with presently existing large spark chamber detectors. This feature is especially important with narrow band beams where the neutrino flux is relatively low.

b. Identification of e, μ and hadrons. Because of the short radiation length in neon, electrons can be identified as such due to their characteristic appearance in the chamber. Muons can be distinguished from hadrons by the fact that muons will leave the chamber without interacting, while hadrons, due to their short interaction lengths, are likely to interact in the chamber. For events in which muon-hadron distinction is important, a fiducial volume can be chosen such that the outgoing tracks traverse on the average four effective interaction lengths of liquid, and thus 98% of these should have a detectable interaction. Thus 2% or less of the hadrons could be confused with muons.

c. Detection of neutral particles. K^o and Λ^o decays can be detected from their charged decay products, as usual in bubble chambers. Photons will convert into e^+e^- pairs, and thus they can be detected and their energy measured with average efficiencies better than 98% since there are many radiation lengths from the center of the chamber to the edge. π^0's can thus be detected and reconstructed with detection efficiencies ~ 96%. Neutrons will interact in the chamber most of the time. Even though only some fraction of the energy of the neutron is given to charged particles, this information can be used in a statistical way to estimate the average amount of energy going into neutrons.

d. Momentum measurement from curvature in the 30 kG magnetic field of the chamber, over the entire volume of the detector.

e. Measurement of the total hadronic energy is possible since the chamber is sensitive to both charged and neutral hadrons, as discussed above. This feature is especially important in this experiment since it provides, when combined with the knowledge of the incident neutrino energy and direction, an estimate of the internal variables of the neutral current interactions where the final state neutrino is undetected.

f. The usual feature of bubble chambers, 4π solid angle geometry, will be also useful in neutrino physics. The large transverse dimensions of the visible liquid in the 15 ft chamber allows good muon and electron identification at all angles. The fine grain, i.e., the ability to see tracks down to a few millimeters in length, will be important to detect short muons or other stopping hadrons.

III. Narrow Band Beams

We have considered three different narrow band (dichromatic) trains. We feel that this experiment will be worthwhile with any of these three alternatives:

1. The existing narrow band train used by the Cal Tech-FNAL Group. As presently operating, this beam has a 11.6 μsr solid angle acceptance and $\sim \pm$ 20% momentum spread. The ν energy spectrum is shown in Fig. 2 (B. Barish, private communication). Because of the coupling between the momentum bite and the solid angle accepted by this beam, it is hard to improve the energy resolution of this beam without an intolerable reduction in flux. For a bubble chamber run, this beam could be operated with a 1 ms beam spill. The counter experiments could also run usefully with such a spilltime, although it may not be optimum for some of their purposes. We would like to use this beam if the logistics of an early run can be worked out.

2. The new dipole-quadrupole narrow band beam now being designed by FNAL and the Cal Tech Group. The ν flux anticipated in a preliminary version of this beam, with a solid angle acceptance of 20 μsr and a momentum bite of $\pm$ 5% is shown in Fig. 2 (from an informal report by L. Stutte) for a meson momentum of P_o = 140 BeV/c. This beam has far superior energy resolution and a reduced wideband ν and $\bar{\nu}$ background compared with the existing beam. The integrated

ν flux is about 1/2 of that of the existing beam. This flux can be increased by a factor of 2 or 3 for this experiment in the following way. The beam with a 20 μsr solid angle has been designed to run at meson momenta up to 300 BeV/c. In our experiment, we would run in the vicinity of $P_o \sim$ 100 BeV/c. At this lower momentum, the front end quadrupoles could be run differently (without any physical rearrangement) to increase the solid angle acceptance to the vicinity of 50 μsr. In this way, the flux in the new beam would be comparable or somewhat higher than in the existing beam (however, with a much improved energy resolution and wide band background).

3. A new two horn narrow band beam using no magnets but two pulsed magnetic horns which, with appropriate collimators, do both the focusing and the momentum selection of the meson beam. Such a beam would not require the construction of a new train, but would involve only a minor modification of the existing horn focusing wideband train. The existing horns would remain as mounted in their present location. The inner conductors, which are removable, would be replaced by differently shaped conductors designed to produce a narrow band beam. The current requirement ($\sim$ 140 kA) of this beam would be identical to that of the wide band horns, so that the power supplies, feeding connections, etc. would remain as they are now. Such a beam could operate in

the vicinity of $P_o \approx 100$ BeV/c with a solid angle acceptance of ~ 150 μsr, which is considerably larger than is possible with quadrupole focusing. A momentum bite approaching ± 5% seems possible. The larger solid angle represents a gain in flux at lower momenta (below ~ 150 BeV/c) over the new dichromatic beam being designed with quadrupoles and dipoles; thus, the flux is somewhat higher than the magnet beam below $P_o \sim 150$ BeV/c, but somewhat lower above $P_o \sim 150$ BeV/c, with a comparable momentum bite.

A preliminary design of such a beam has been carried out and is described in a separate note. The neutrino flux for $P_o = 100$ BeV/c, with a ± 5% momentum bite, is shown in Fig. 3. After some discussion with FNAL Staff (both physicists and engineers), it appears that the cost of constructing the new narrow band inner conductors is relatively small (of the order of $50,000 including the collimators), and the problems involved in changing inner conductors and mounting the collimators on the wideband train (including problems due to high radioactivity) seem manageable.

The two horn beam would have to be pulsed (the existing power supply puts out a ~ 100 μs pulse). This makes the flux calibration measurements difficult compared to the magnet beam which can operate DC (extending the pulse length of the supply to 1 ms, which seems possible, would alleviate this problem considerably). Another advantage of the magnet beam is that it can go to the highest energies with good flux. However, the two horn beam is probably an order of magnitude cheaper. Should the time table of the new magnet beam get stretched out for any reason, the two horn beam might become an attractive interim solution to run this (and probably other counter-spark chamber) experiment .

For any of the three alternatives discussed above, we propose to run in the vicinity of P_o = 100 BeV/c, where the neutrino event rates are the highest. However, we would run at somewhat lower or higher energies if compatibility with other experiments required it. At P_o = 100 BeV/c, the neutrinos from π decay are around 35 BeV, and those from K decay around 95 BeV. The energy resolution for neutrinos from K decay should be similar to $\Delta P/P$ of the meson beam. The resolution for those from π decay are broader; Fig. 3 shows the resolution integrated over the entire fiducial volume of the chamber. The position of the event in the chamber can be used to improve the resolution considerably. Near the center of the chamber the neutrino energy resolution is similar to that of the π beam, while near the edge it is about a factor of two to three worse (see curves on Fig. 3).

The neutrino fluxes in the existing beam (with a $\Delta P/P \simeq \pm 20\%$) is roughly comparable with the new quadrupole-dipole beam (with $\Delta P/P \simeq \pm 5\%$) with the solid angle opened up to 50 μsr. The two horn beam (also with $\Delta P/P = \pm 5\%$) should be at least as good, possibly somewhat better at low momenta.

IV. Event Rates

We calculate the number of events we expect in this experiment using the following parameters:

200,000 photographs
5×10^{12} protons/pulse on target
20 m^3 fiducial volume (24 tons of neon)
300 BeV protons
100 BeV/c meson beam (P_o) .

We start from the actually observed number of good charged current events detected by the Cal Tech-FNAL Group in the existing narrow band beam. They see (B. Barish, private communication) 14,000 events/10^{18} protons at P_o = 140 BeV/c in a fiducial volume of 100 tons, with a ~ 50% muon detection efficiency. This corresponds to 28,000 events correcting for their muon detection efficiency. We then apply the following factors:

1/2 for the loss of solid angle between the Wonder Building and the 15 ft chamber;
1/4 for the ratio of the fiducial masses;
1 1/2 for the increase in event rates for P_o = 100 BeV/c instead of 140 BeV/c.

We thus expect

$$28{,}000 \times 1/2 \times 1/4 \times 1\ 1/2 = 5250 \text{ events}/10^{18} \text{ protons.}$$

Or, in 200,000 pictures, using a neutral current to charged current ratio of 1/4,

5200 charged current events

1300 neutral current events .

This corresponds to a rate of

1 event/40 pictures.

These numbers can be expected to be roughly the same for the three different beams considered in the previous section, however with a ± 20% spread for the existing beam and ± 5% for the new beam. If this experiment were to run with either of the new narrow band beams, one would consider running with a ± 10% spread, in which case, the numbers of events would be

10,000 charged current events

2,500 neutral current events

corresponding to

1 event/20 pictures.

NEUTRAL CURRENT INELASTICS, y DIST ($y = \nu/E_\nu \cong E_{\text{hadron}}/E$

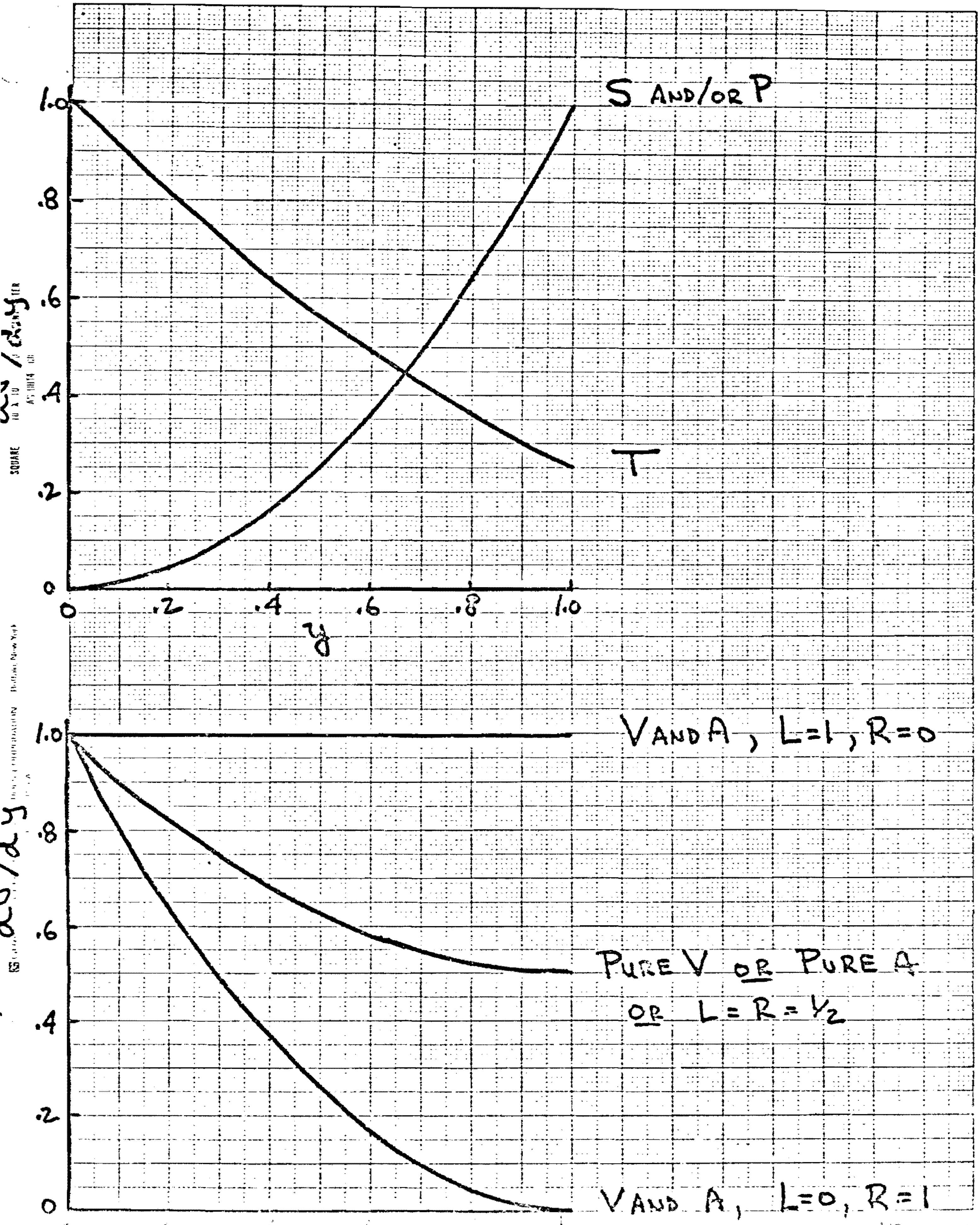


Fig. 1

NARROW BAND NEUTRINO SPECTRA

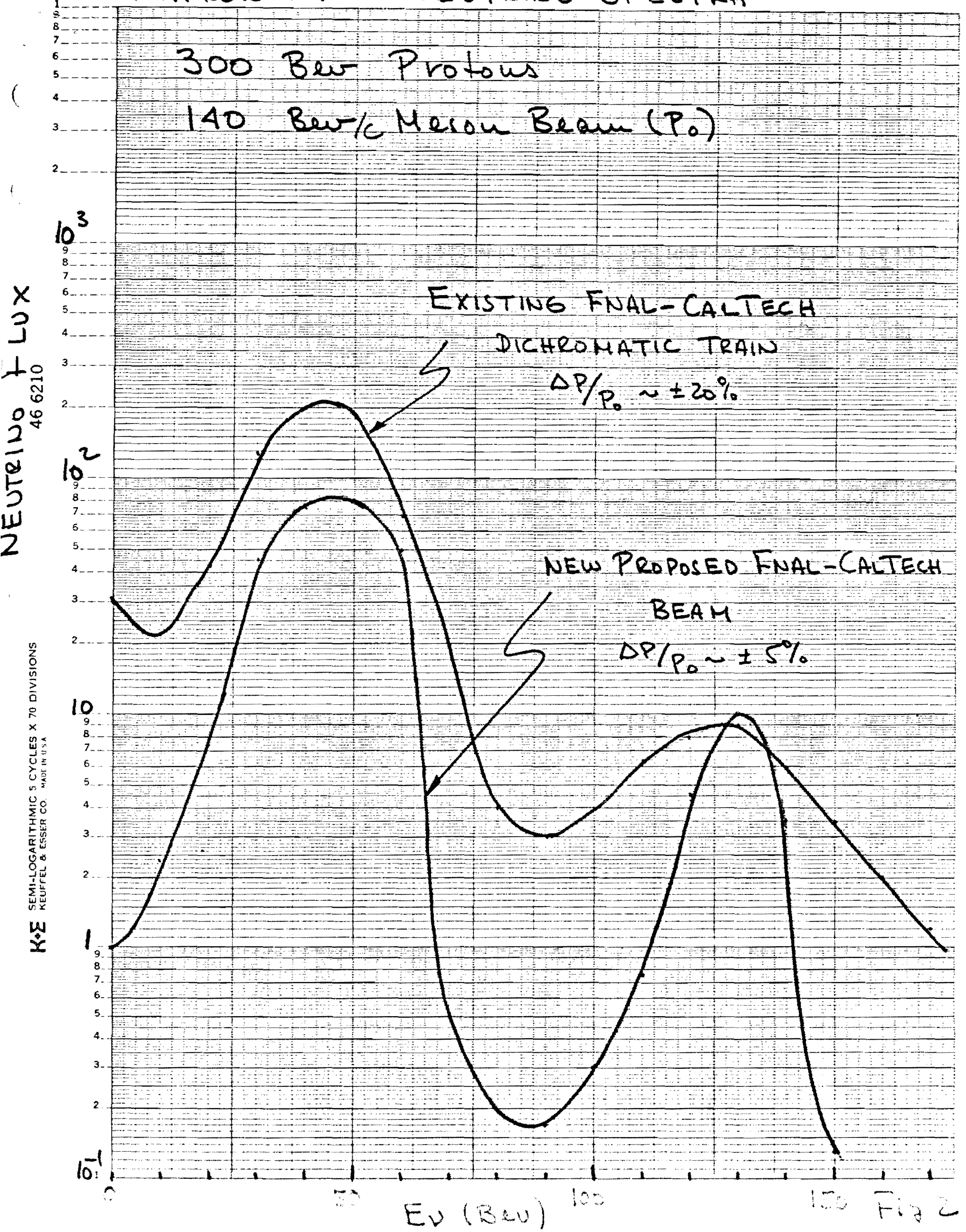
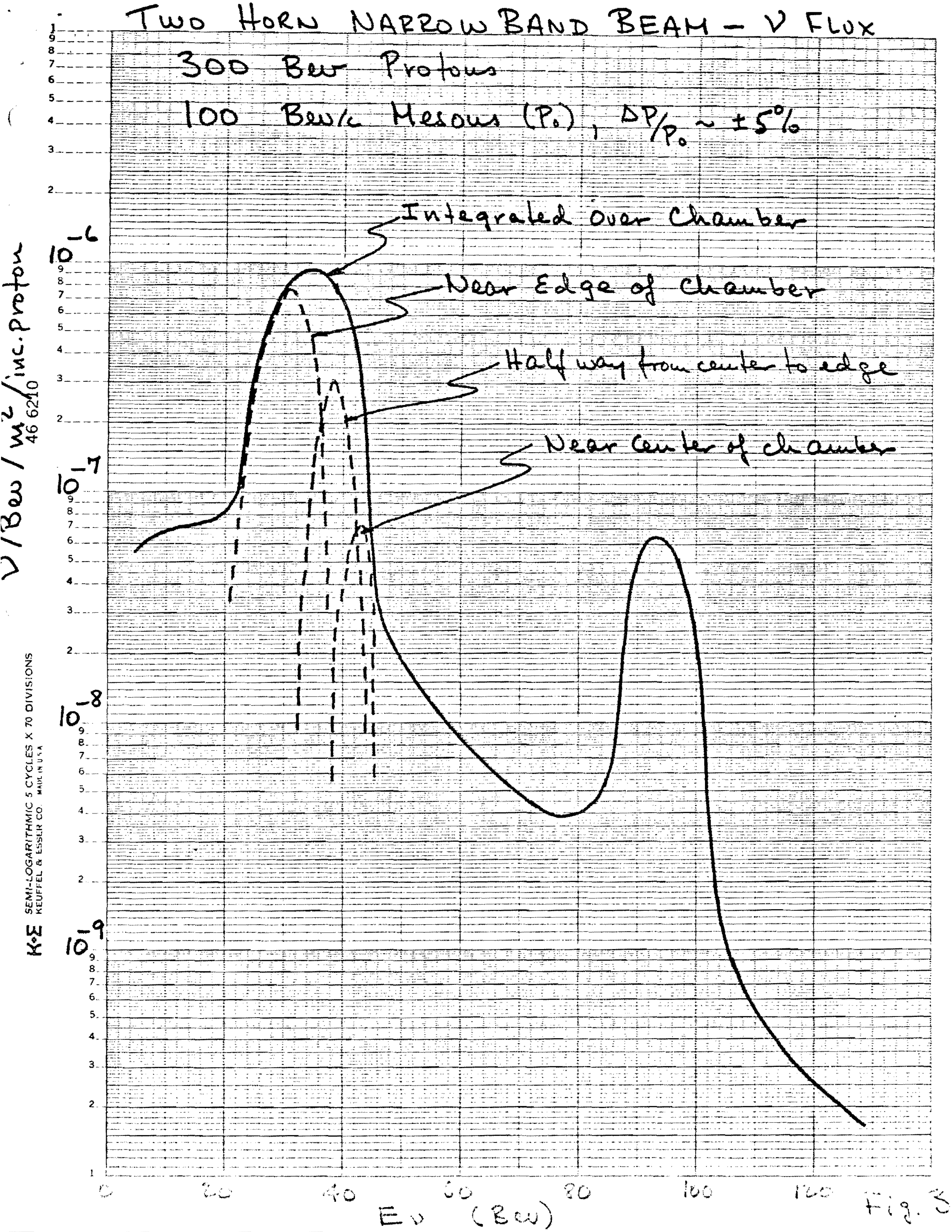


Fig 2



Addendum #380

Two Horn Narrow Band Neutrino Beams

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I. Introduction

In the 1974 neutrino summer study, we started some calculations on narrow band neutrino beams which use two pulsed magnetic horns, to do both the focusing and the momentum selection.[1] Since then we have carried out a detailed design of an actual set of horns that satisfy the requirements of such a beam, will fit interchangeably into the existing horn outer jackets, and can be powered by the existing power supplies and feeding cables. The wideband ν and $\bar{\nu}$ backgrounds have been calculated and seem quite tolerable. The resolution of the beam can be chosen to be ± 5% or ± 10%. Event rates between 1 event/20 pictures and 1 event/40 pictures, depending on the resolution chosen, seem feasible in the 15-ft chamber filled with neon.

II. Principle of Operation of the Beam

The main idea of the narrow band beam is the same as has been used previously.[2,3,4] A momentum selected beam of π and K mesons (with momentum P_o) is directed toward the detector. The neutrinos originate in the decays, $\pi, K \rightarrow \mu + \nu$. Because of the two body kinematics of these decays, there will be a correlation between the lab energy E and the lab angle θ of the neutrinos. In particular, near very forward angles, the neutrino flux peaks near 0.4 P_o from π decays and near 0.95 P_o from K decays (see Fig. 8). Because of the large diameter of the bubble chamber, the peak from π decays is not very narrow. However, if the position of the neutrino interaction in the chamber is used, the neutrino energy resolution $\Delta E/E$ approaches the resolution $\Delta P_o/P_o$ of the meson beam near the center of the chamber, and is roughly twice $\Delta P_o/P_o$ near the edge of the chamber (see Fig. 9). Thus, with a meson beam of $\Delta P_o/P_o = \pm 5\%$, a neutrino energy resolution varying from ± 5% to ± 10% can be achieved.

The intensity of such a beam with a given momentum resolution (say $\Delta P_o/P_o = \pm 5\%$) depends to a large extent on the solid angle accepted at the target. In the existing narrow band beam at FNAL, quadrupoles are used to focus the meson beam, and a solid angle of ~ 12 μster is achieved.[2] In the present design, the first element of the beam is a magnetic focusing horn that can collect a solid angle of 150 μster. The gain in flux due to the larger solid angle depends on the meson momentum P_o selected. At the highest momenta, the gain is not so large because the mesons are produced at very small angles. However at lower momenta, the gain becomes substantial, approaching an order of magnitude near 50 BeV.

The focusing and momentum analysis of the meson beam can be accomplished by two pulsed magnetic focusing horns without any conventional magnets. The principle of operation of such a beam is shown schematically in Fig. 1. Both horns consist of thin rotationally symmetric conductors carrying currents in a direction roughly parallel to the beam direction (the currents return in an outer conducting jacket). Thus, the magnetic field has the shape of circles in planes perpendicular to the beam axis, deflecting beam particles radially toward the axis. The length, shape, and current of the first horn is arranged in such a way that mesons originating from the target with production angles between 1 and 7 mrad are focused into a 6 cm radius ring at a focal plane 37.5 m downstream from the target. The beam crosses the axis at roughly 10 m from the target. The momentum analysis is performed by collimator 2, located in the focal plane, with a ring shaped aperture of inner radius 5 cm and outer radius 7 cm. With this aperture a momentum bite of $\Delta P_o/P_o = \pm 5\%$ results. The momentum bite can be varied by changing the radii of the opening of this collimator (see Fig. 6). A central plug located in or near the first horn serves to stop mesons within the central 1 mrad cone which cannot be focused (and therefore momentum analyzed) by the horn. Collimator 1, a 1-cm radius hole at the crossover point 10 m from the target, serves to eliminate high momentum mesons which could otherwise go from the horn 1 through collimator 2 without crossing the axis.

Finally, the second horn forms a parallel beam out of the momentum analyzed mesons, aimed down the decay pipe toward the detectors. The angular divergence of the momentum analyzed beam in the decay pipe is about 1/3 mrad, as shown in Fig. 7.

The existing geometry of the neutrino area, like 400 m decay path and the 1000 m shield, have been used in this design. The position of the two horns are the same as their positions in the existing wide band beam. A new target train will thus not be necessary for this beam. The existing wide-band train can be used, with the inner conductors of the two horns, which are removable, replaced by the narrow band inner conductors, which can be made to fit into the existing horn outer jackets.

III. Design of the Narrow Band Horns

The design of the first horn depends sensitively on the energy range of interest, since the meson production angles vary rapidly with momentum, as shown in Fig. 2. For P_o between 50 and 150 BeV/c, which is an interesting region for running with the bubble chamber because of the high event rates, a horn that accepts mesons produced between 1 and 7 mrad ($\sim$ 150 μster solid angle) seems like a good compromise. The length of the horn was taken to be 4 m, which is the length of the existing wide band horn 1. The target is placed 3.5 m upstream of the first horn. The shape of the horn, which focuses particles from the target into a 6 cm radius ring 37.5 m downstream of the target, is shown in Fig. 3. This optimum shape was calculated by a computer program written for this purpose. Ray traces through the horn for particles produced between 1 and 7 mr are also shown on this figure. The diameter of the horn varies from a maximum of 5.0 cm down to a minimum of 1.4 cm. Particles produced within the central 1 mr are not focused by the horn; they are stopped by a plug located within the first horn. This plug also serves as the dump for the protons that do not interact in the target. Aluminum oxide, with water cooling, seems like a suitable material for a plug of this geometry (4 m long, with a diameter increasing from 0.7 cm to ~ 1.4 cm). The horn has a relatively simple shape and has been designed to fit into the outer jacket of the existing wide band horn. It is shown to scale on Fig. 4 for comparison with the wideband horn.

The second horn has been designed to fit inside the outer jacket of wide band horn 2 and to run at the same current as horn 1. (The wideband horns are also run in series, so the existing transmission lines feeding the horns can remain unchanged.) Horn 2 is shown to scale with the wideband horn 2 on Fig. 5. Its effective length is 2.7 m, with a diameter varying from 6 cm to 20 cm.

The inductance of the narrow band horn system is within 20% of the inductance of the wide band horn system.

The narrow band horns were designed to operate at a current of 140 kA at $P_o = 100$ BeV/c. This is the same as the current used for the existing wide band horns. The same narrow band horn configuration can be used for different P_o by varying the current. (P_o is linear in the current, keeping the geometry of the beam unchanged.) Thus, the existing power supplies and transmission lines can be used without modification to operate the narrow band beam up to $P_o = 100$ BeV/c with ease, and can probably be pushed to go up to $\sim$ 150 BeV/c.

We have had some discussions with the physicists and engineers in charge of the wideband train load, and some of the mechanical parameters of this horn design are the results of these discussions. They foresaw no great difficulty in manufacturing the two horns and the required collimators, and gave a rough, preliminary cost and time estimate $\sim$ \$50,000 and $\sim$ 4 months. We also discussed how the narrow band inner conductors can be inserted in place of the wide band inner conductors, considering the mechanical assembly, insulators, high radiation levels, etc. The neutrino target lab is now equipped to remove, service, and reinsert the wideband inner conductors between runs. Installing the narrow band horns should be quite similar to these procedures, and no real problems were foreseen.

IV. Neutrino Fluxes

We have used a Monte Carlo program written at Columbia to study the detailed properties and fluxes in the two-horn beam. The program traces the particles through the horns and collimators, taking finite target length and chromatic effects into account.

The momentum resolution of the beam can be chosen by adjusting the aperture of collimator 2. Since this collimator is at a focus, this will not alter the angular acceptance of the beam. The momentum spectrum of the meson beam entering the decay tunnel is shown in Fig. 6, for collimator 2 opening (radius) at 5 to 7 cm and 4 to 8 cm. The momentum resolution is roughly ± 5% and ± 10% for these settings respectively.

The angular spread of the meson beam in the decay tunnel is about 1/3 mrad, as shown in Fig. 7. This is sufficiently small, since the fiducial volume of the chamber subtends about 1 mrad at the upstream end of the decay pipe.

The momentum of the meson beam, P_o, can be varied by changing the current in the horns without changing the geometry of the beam. The neutrino fluxes, averaged over a 1.35 m radius fiducial area, are shown in Fig. 8 for $P_o = 50$, 100, and 150 BeV/c. The energy resolution of the neutrinos from K decay is approximately equal to the resolution of the meson beam. The resolution for neutrinos from π decay is worse since the large volume of the chamber subtends a large range of π decay angles. However, if the knowledge of the position of the event in the chamber is used, the π decay angle is better known, and a better neutrino energy resolution is possible. Figure 9 shows the energy resolution for neutrinos from π decay at various points inside the chamber. It approaches the meson beam momentum resolution at the center of the chamber, and is about twice that at the edge of the fiducial volume. Thus, an energy resolution ranging from ± 5% to ± 10% is possible for a meson beam with $\Delta P/P = \pm 5\%$.

The major component of the beam can be chosen to be ν_μ or $\bar{\nu}_\mu$ by focusing positive or negative mesons, respectively. The neutrino spectra for positive and negative focus, with $\Delta P/P = \pm 5\%$ and $\pm 10\%$, for $P_o = 100$ BeV/c are shown in Figs. 10, 11, 12 and 13.

The "wideband backgrounds" of ν and $\bar{\nu}$ from positive and negative π and K decays between the target and horn 2 (i.e., before the beam is momentum analyzed) have been calculated and are shown in Figs. 10-13. As can be seen from these figures, these backgrounds at the peaks are typically at the few percent level.

We have also considered the background neutrino flux due to the plug (beam dump) inside the first horn. We have written a Monte Carlo program following the development of the hadronic cascade in the plug, including effects due to finite proton beam size and angular divergence, energy loss, and multiple scattering, etc. The background from meson decays inside the plug was calculated. Because of the small transverse dimensions of the plug (0.7 to 1.4 cm diameter), a substantial number of π's and K's leak out the side of the plug. These mesons were traced through the horns and collimators, and the background from their decays was calculated (most of these mesons have a relatively low energy and are thus swept out by horn 1 and thus do not get past the first collimator). The neutrino backgrounds due to the plug are also shown in Figs. 10 and 11. They do not appear to be a serious problem.

There are other backgrounds due to three body K decays, decays of pions from K_S^o and Λ decays, muon decays, etc. A careful calculation of these backgrounds is in progress. A rough estimate indicates that these backgrounds are not serious; i.e. they are smaller than the wideband backgrounds.

The neutrino flux curves of Figs. 8-13 are for 300 BeV incident protons. They all include a factor of 1/2 loss due to absorption in crossing the horn surfaces and another factor of 1/2 loss due to thick target effects.

To illustrate the usefulness of the event rates from such a narrow band beam in the bubble chamber, we have calculated the numbers of events per picture for the following conditions:

300 BeV protons

5×10^{12} protons per pulse on target

$20\ m^3$ fiducial volume of liquid neon (24 tons)

$\Delta P/P = \pm\ 5\%$ and $\pm\ 10\%$

$P_o = 50,\ 100,\ 150$ BeV/c

$\sigma_{tot} = 0.8 \times 10^{-38}\ cm^2$/nucleon .

The results are summarized in Fig. 14. At $P_o = 100$ BeV/c, we can expect between 1 event/20 pictures and 1 event/40 pictures depending on the resolution used.

V. Comparison with Other Narrow Band Beams

The existing narrow band beam at Fermilab has an aperture of 11.6 μster with the collimators wide open. At this setting, the momentum resolution is $\Delta P/P \sim \pm\ 20\%$. It would be desirable to have a better resolution in the next generation of experiments. If the collimators were closed down to give a $\Delta P/P \sim \pm\ 10\%$, the acceptance of the beam falls to ~ 3 1/2 μster, since the angular acceptance and the momentum bite are very strongly correlated in this beam. The increase in flux due to the 150 μster acceptance of the two horn beam depends on the meson momentum P_o, since the relevant production angles decrease with increasing P_o. The fraction of the mesons captured by the acceptance of the two beams at $\Delta P/P = \pm\ 10\%$ is shown in Fig. 15. The curve corresponding to the two horn beam has been reduced by a factor of two to allow for losses due to absorption in the horns. Other losses, such as thick target effects, etc., should be similar in the two beams; thus, the ratio of these curves should be a fair estimate of the relative fluxes of the beams at the same $\Delta P/P$. The gain in flux below $P_o = 150$

BeV/c in the two horn beam is substantial.

The new improved dichromatic beam using dipole and quadrupole magnets now being designed by the Cal-Tech-FNAL group will have a solid angle of ~ 20 μster at either a $\Delta P/P$ of ± 5% or ± 10%. This beam is intended to run up to ~ 300 BeV/c or so. For lower momenta, the front end quadrupoles can be run differently to increase the solid angle without physically moving the magnets. A very similar beam designed at CERN can accept 34 μster at P_o = 100 BeV/c and 64 μster at P_o = 50 BeV/c. We use these CERN beam acceptances to estimate the relative fractions of the mesons accepted by the new Cal-Tech beam and the two horn beam which are also shown in Fig. 15. Below P_o = 150 BeV/c, the two horn beam has the advantage. Above 150 BeV/c, the two horn beam starts to fall off because the central 1 mrad removed by the beam dump plug contains a significant part of the flux. The energy resolution of the two beams should be comparable. The wideband backgrounds should be lower in the new dipole beam, although they should be quite acceptable in the two horn beam.

Another consideration is the spill time of the beams. The horn beam is limited to ~ 100 μs by the pulse length of the horn power supplies. This would make the monitoring of the fluxes in the beam harder than in the long spilltime dipole beam. However, the pulse length of the supplies could be extended to ~ 1 ms, which would alleviate this problem considerably.

We thus feel that the new dipole beam is better because of the longer spill time and the capability to go to the highest energies. For this reason, the two horn beam is not intended to compete for the best beam at Fermilab in the long run. However, the two horn beam may be as much as an order of magnitude cheaper, and much quicker to implement, and may therefore be attractive in the near future, especially if the time scale of the dipole beam were to slide.

References

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[4] R.B. Palmer, Brookhaven National Laboratory Preprint, 4/22/71.

Schematic of Two Horn Beam

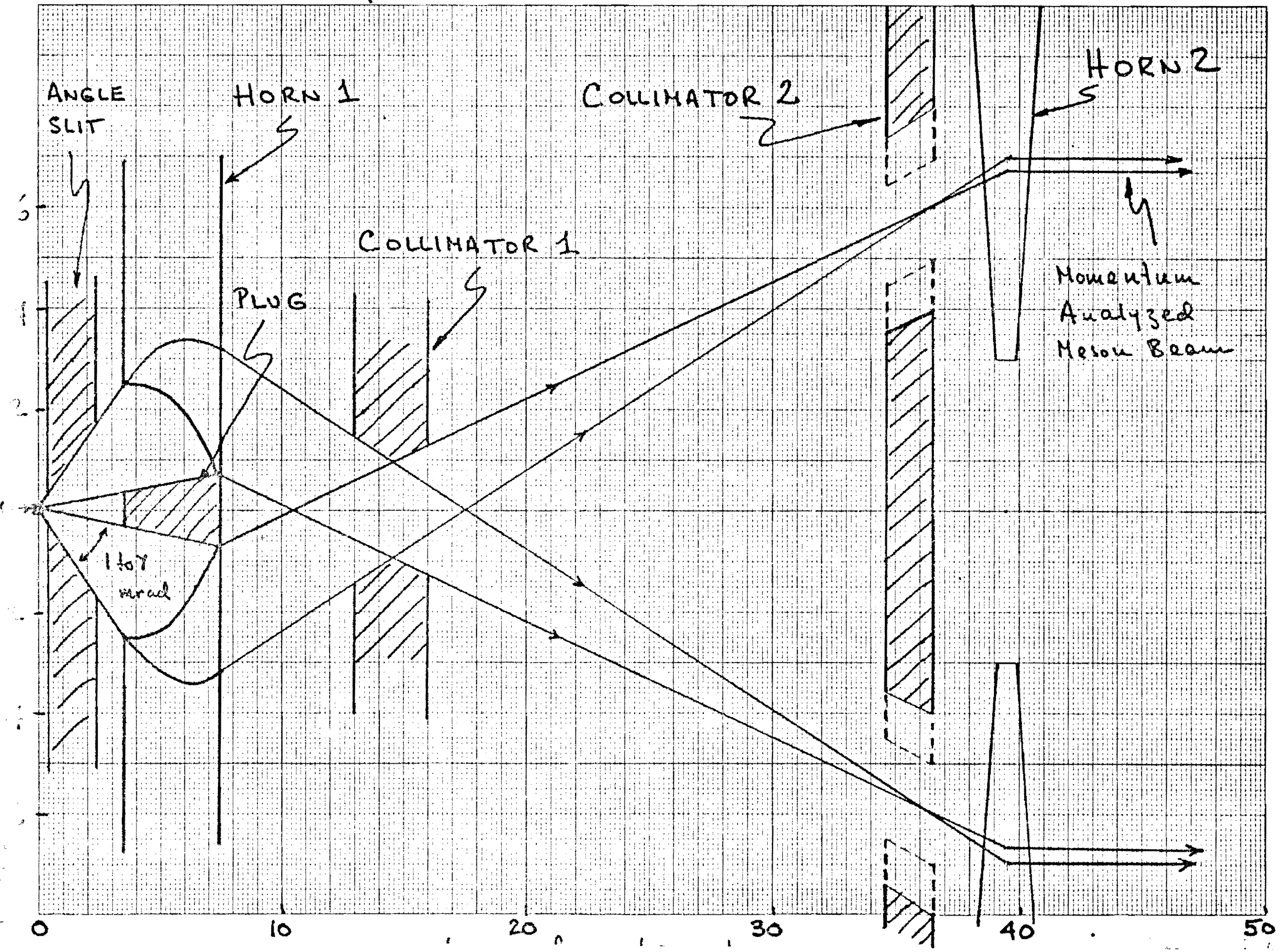
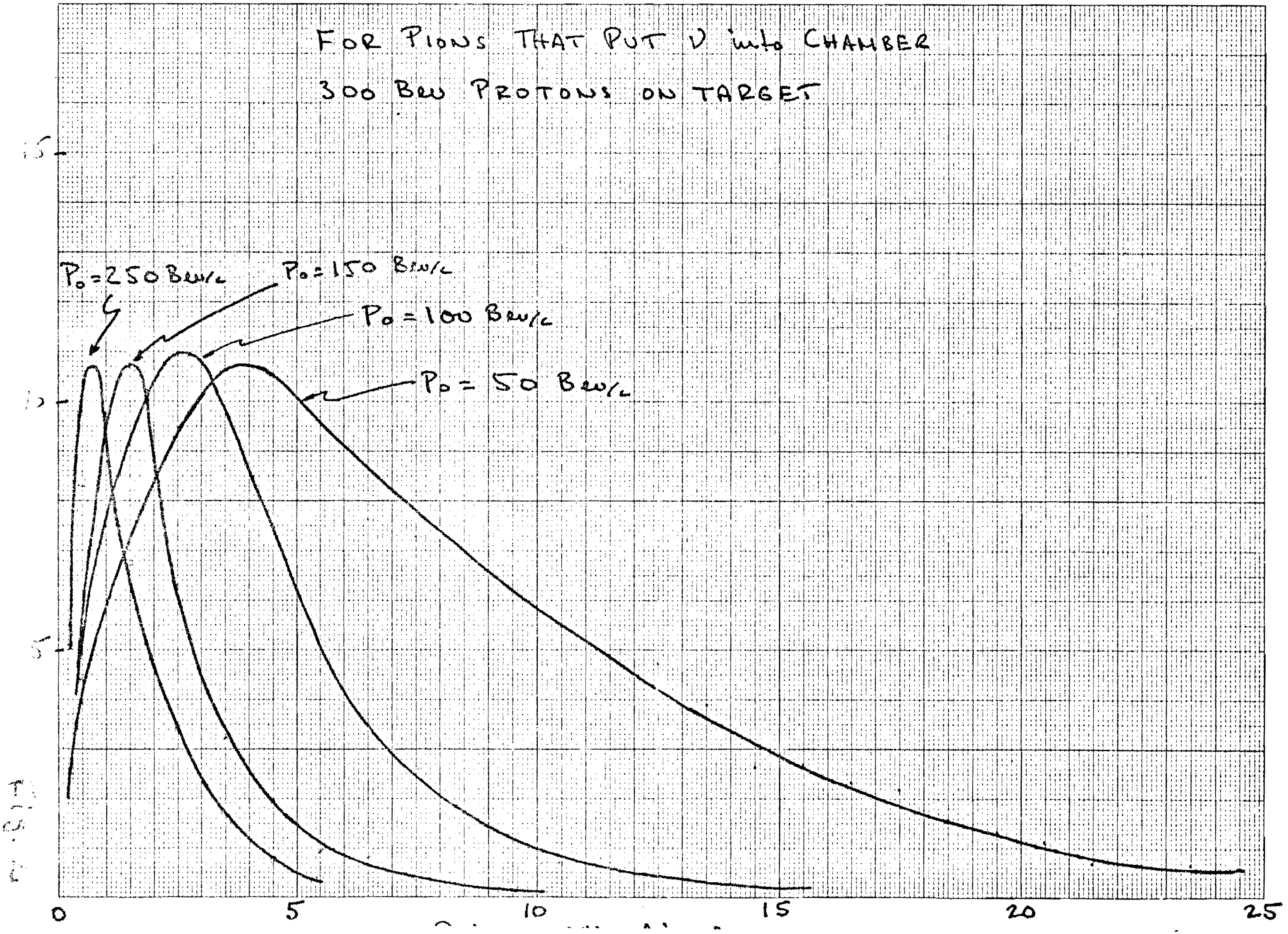


Fig. 1

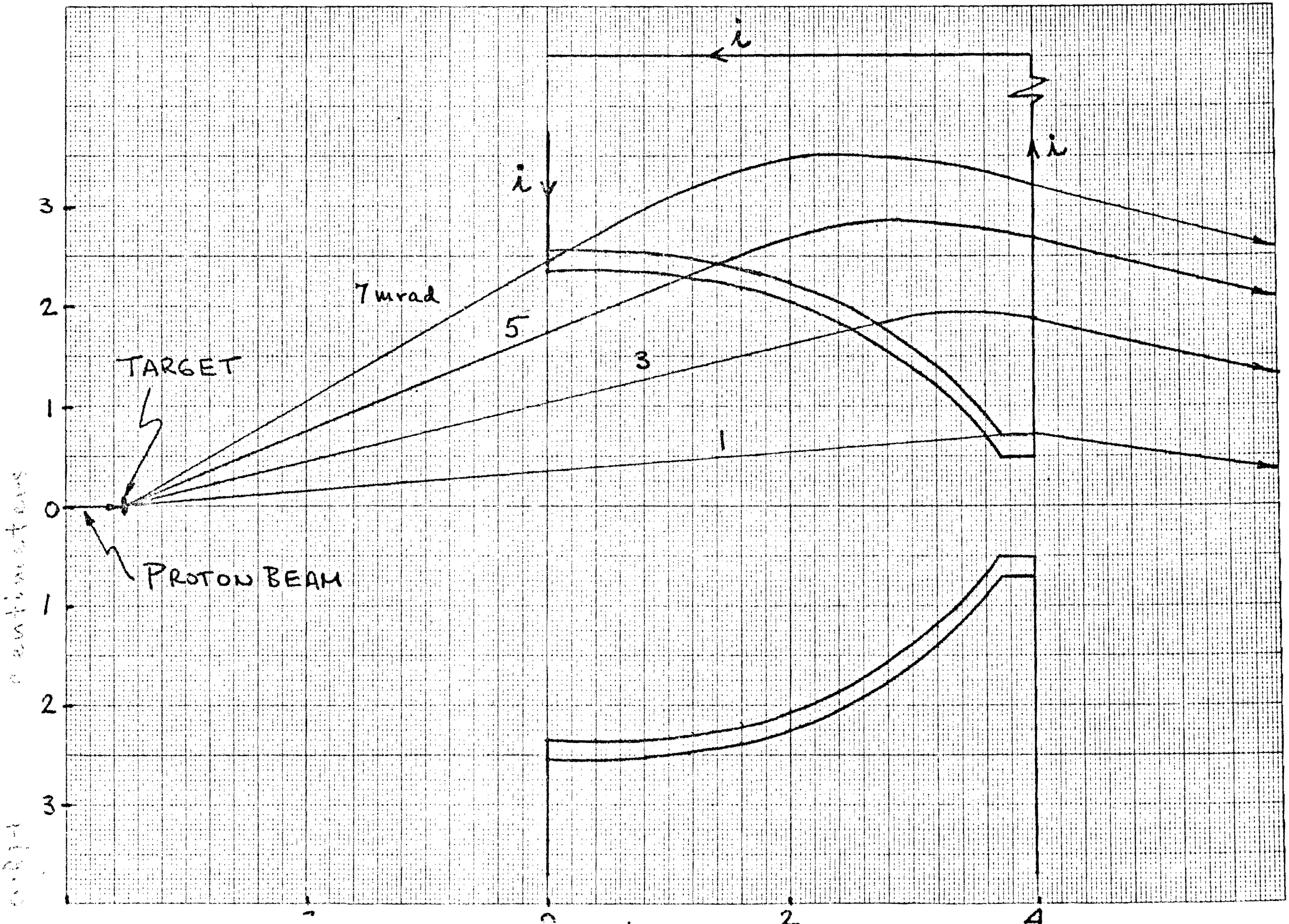
DISTRIBUTION IN PRODUCTION ANGLE Θ AT TARGET VS. PION MOMENTUM P_0

FOR PIONS THAT PUT ν into CHAMBER

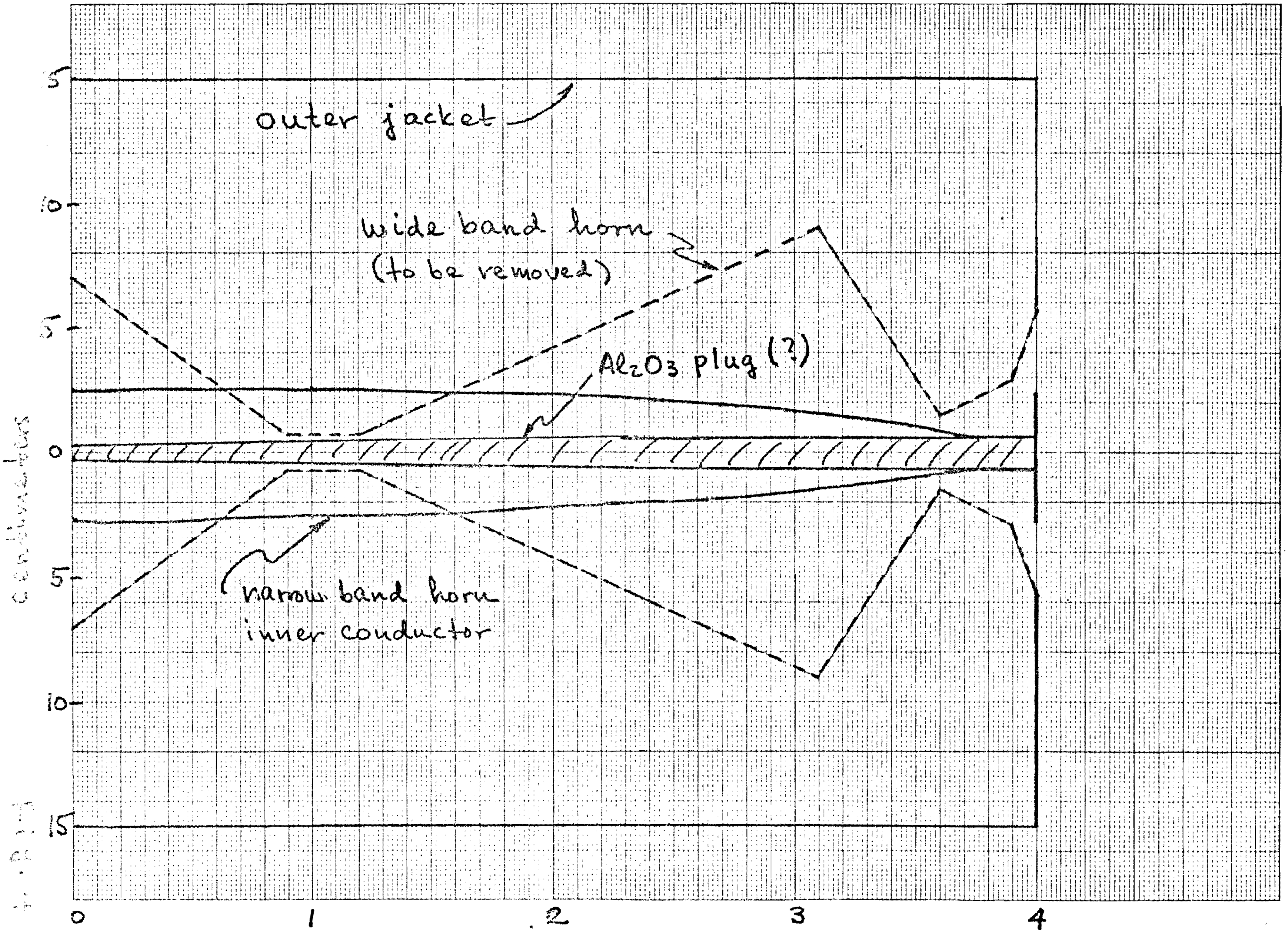
300 Bev PROTONS ON TARGET



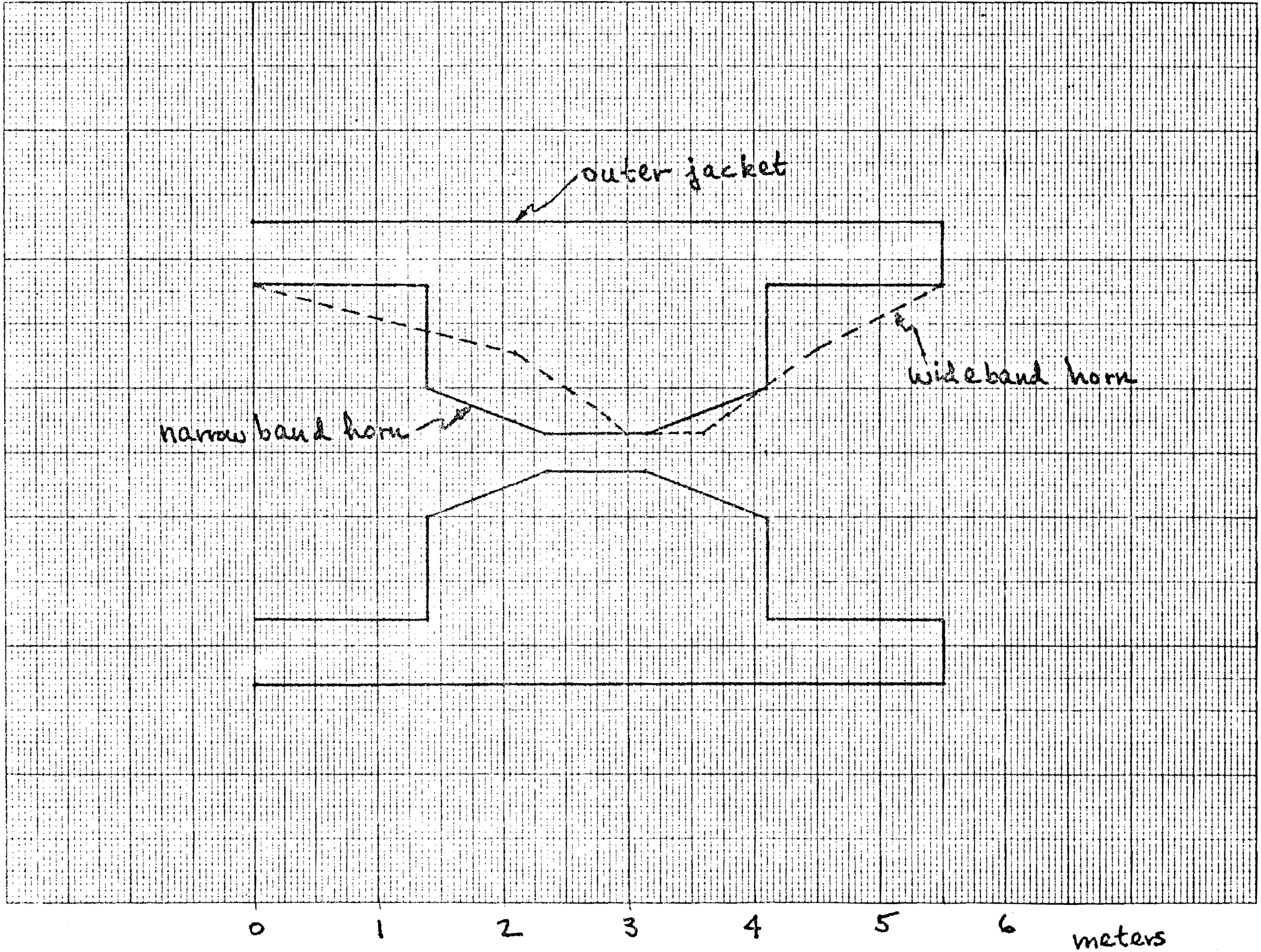
HORN 1 FOR FNAL TWO HORN NARROW BAND BEAM 1-7 mrad



Horn 1   1-7 milliradians



HORN 2


outer jacket
wideband horn
narrow band horn
0
1
2
3
4
5
6
meters

Two Horn Beam   Momentum Resolution

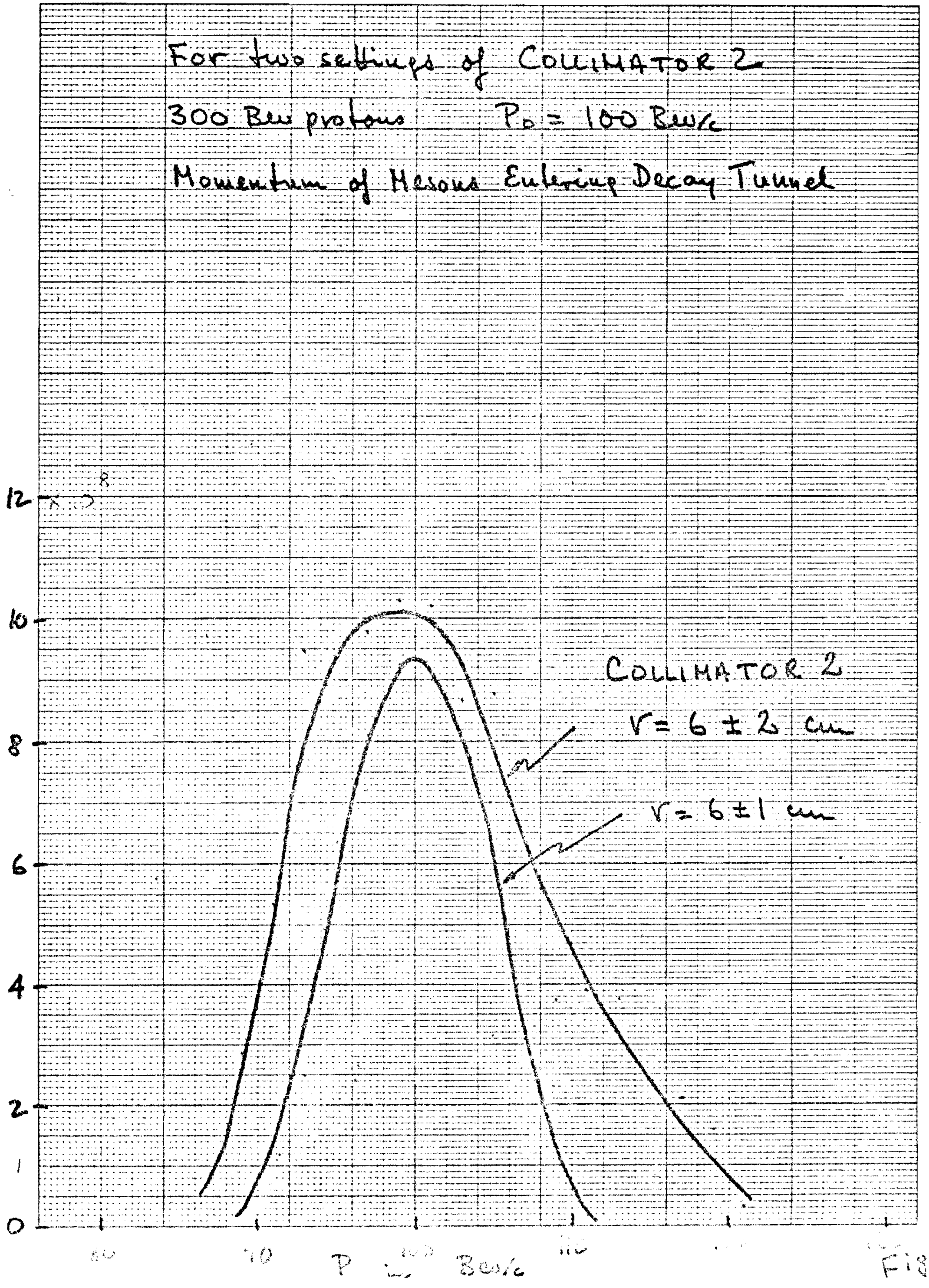


Fig. 6

Two Horn Narrow Band Beam Rec'd Feb 14. 75

300 Bev Protons, $P_0 = 100$ Bev/c
1-7 mr horn

Divergence of Beam in decay tunnel

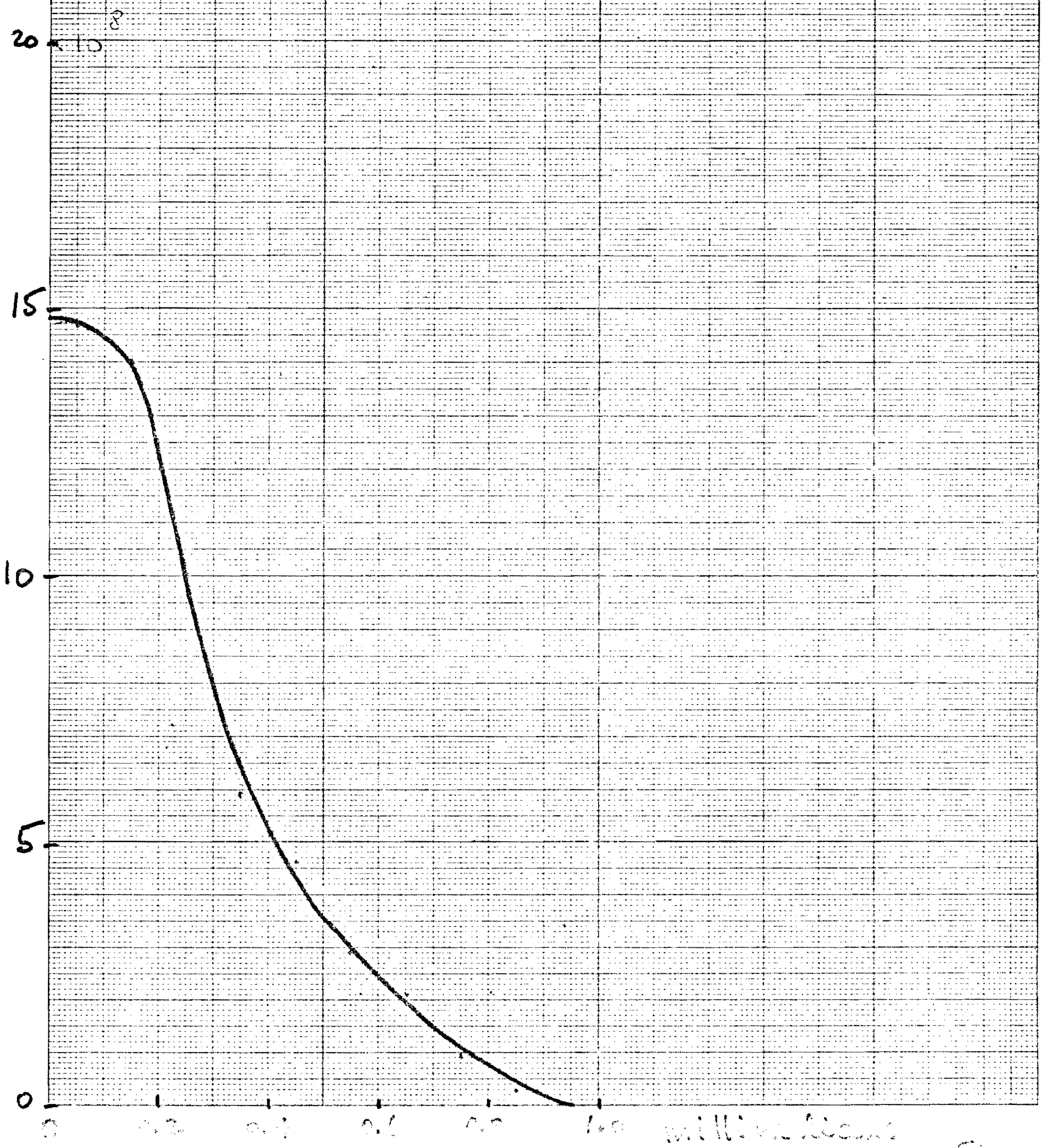
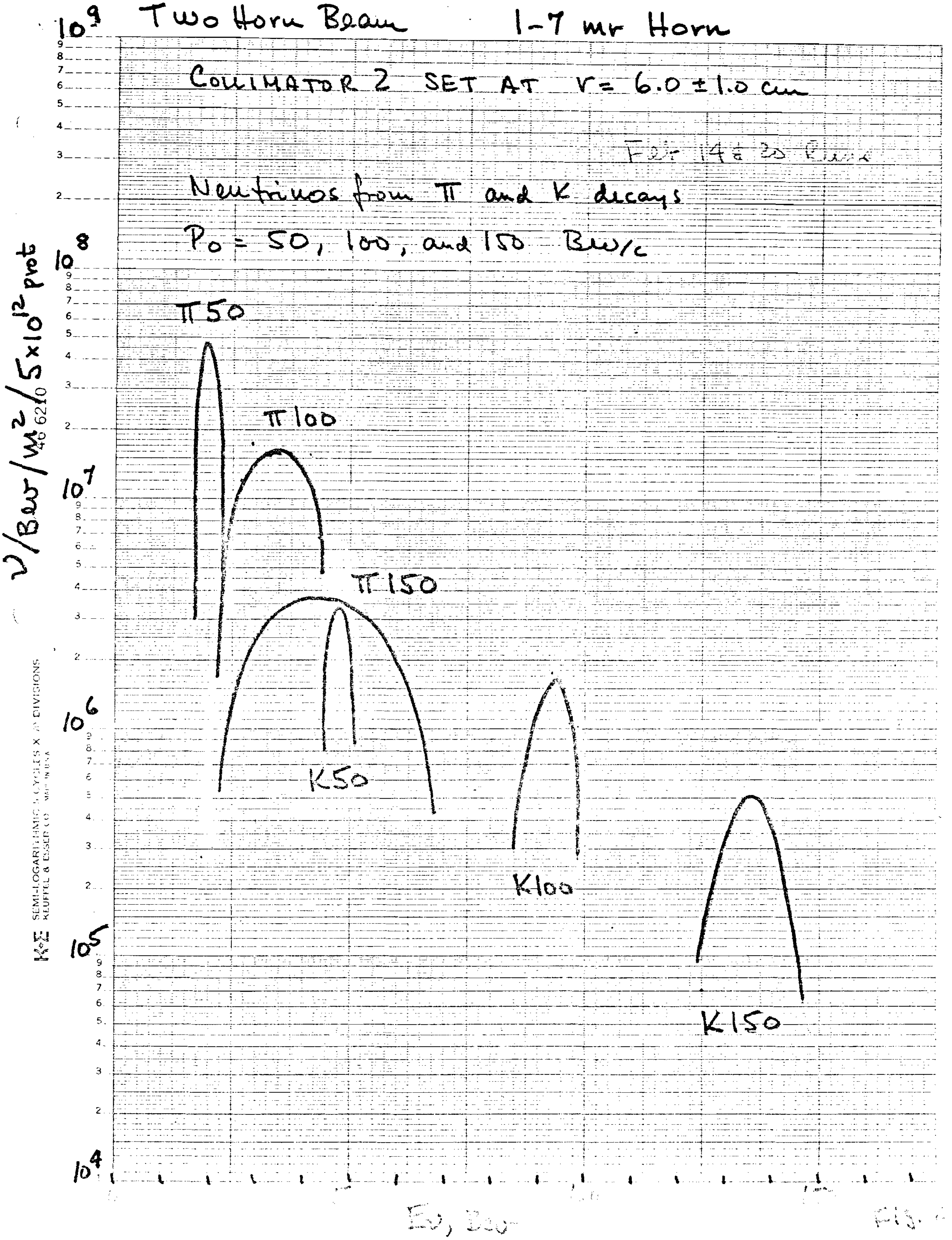


Fig. 7



Two Horn Beam 1-7 mr Horn

COLLIMATOR 2 SET AT r = 6.0 ± 1.0 cm

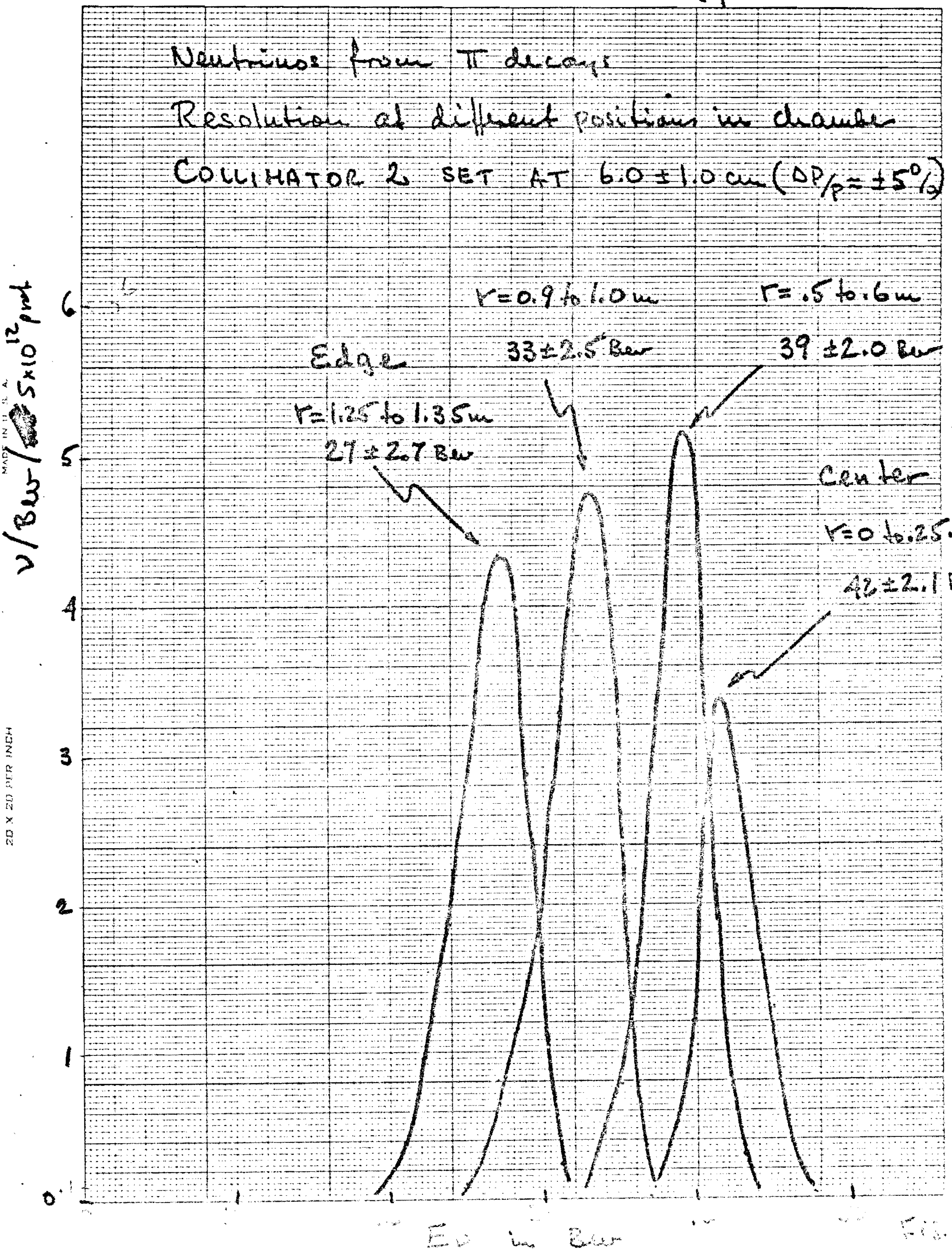
Feb 14 & 20 Runs

Neutrinos from π and K decays

P_0 = 50, 100, and 150 Bev/c

FIG.

Two Horn Beam Neutrino Energy Resolution



Neutrinos from π decays

Resolution at different positions in chamber

COLLIMATOR 2 SET AT 6.0 ± 1.0 cm ($\Delta P/p = \pm 5\%$)

FIG. 9

Two Horn Beam ν_μ SPECTRUM

$P_0 = 100$ BeV/c   POSITIVE MESONS FOCUSED

COLLIMATOR 2 SET AT 6 ± 1 cm $\Delta P/p \approx \pm 5\%$

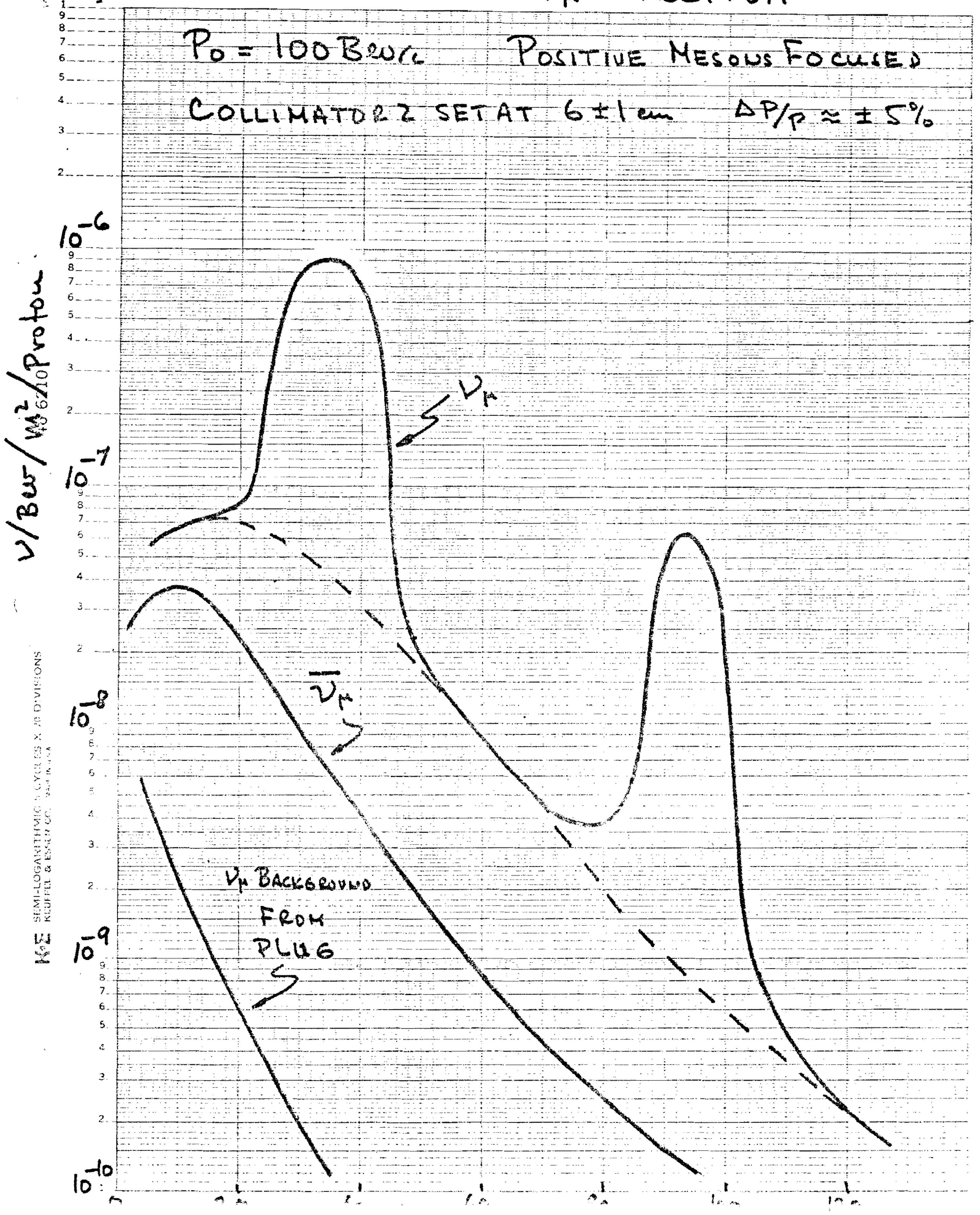


FIG. 10

TWO HORN BEAM ν_μ SPECTRUM

$P_0 = 100$ BeV/c POSITIVE MESONS FOCUSED

COLLIMATOR 2 SET AT 6 ± 2 cm $\Delta P/P = \pm 10\%$

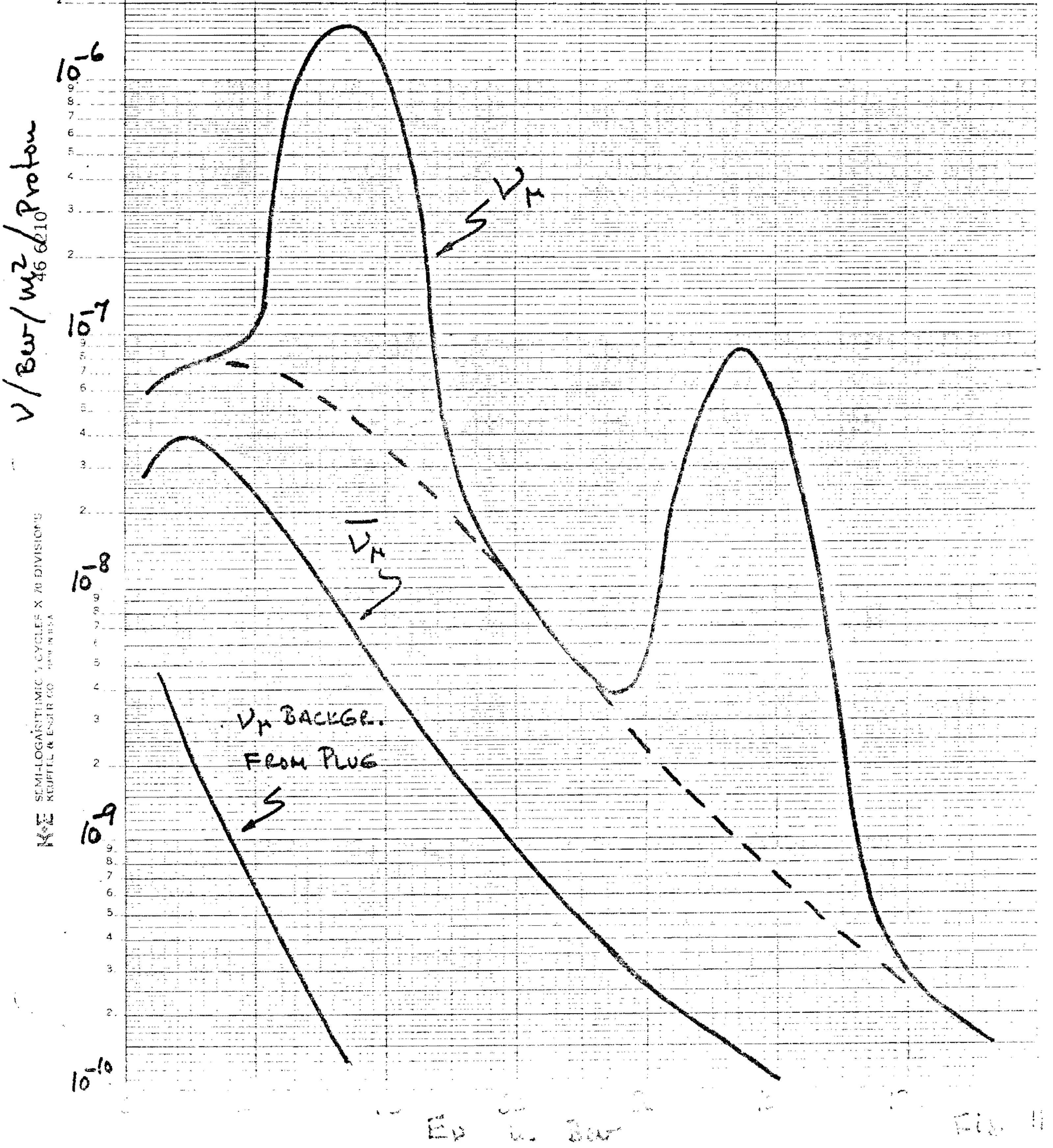
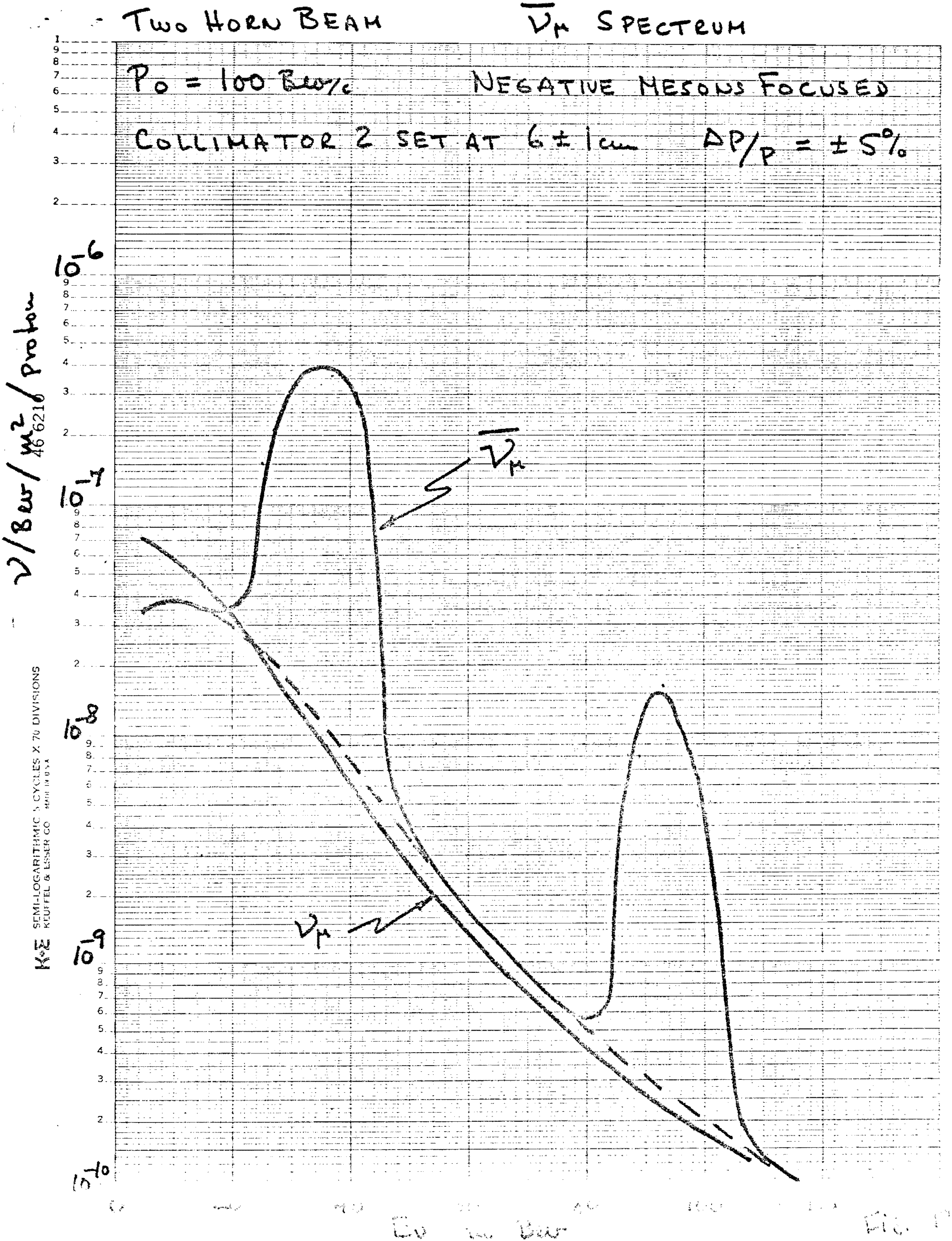


FIG. 11



TWO HORN BEAM $\overline{\nu}_\mu$ SPECTRUM

$P_0 = 100$ Bev/c NEGATIVE MESONS FOCUSED

COLLIMATOR 2 SET AT 6 ± 1 cm $\Delta P/P = \pm 5\%$

FIG.

TWO HORN BEAM ν_μ SPECTRUM

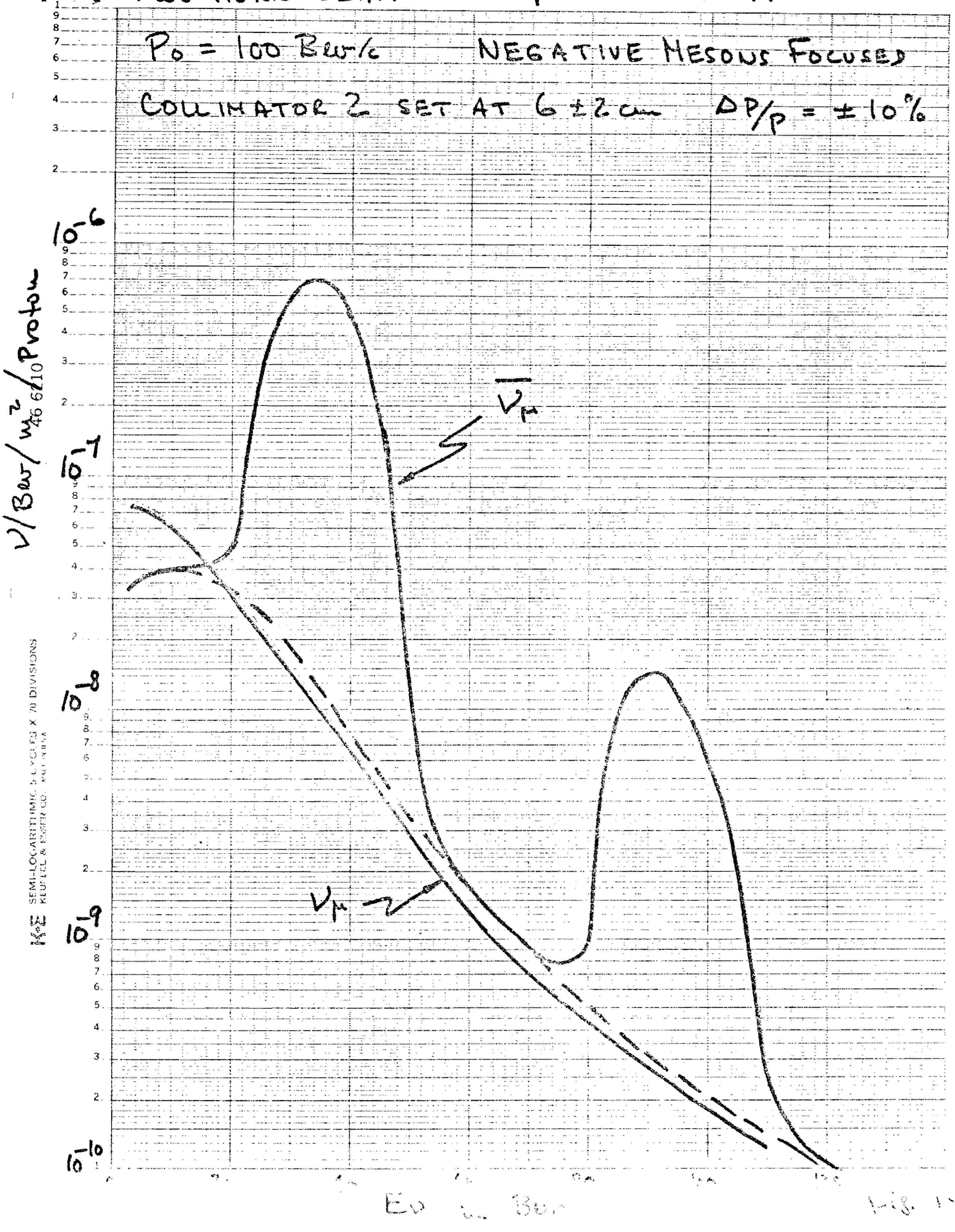


Fig. 1

TWO HORN BEAM EVENTS/PICTURE vs. Po

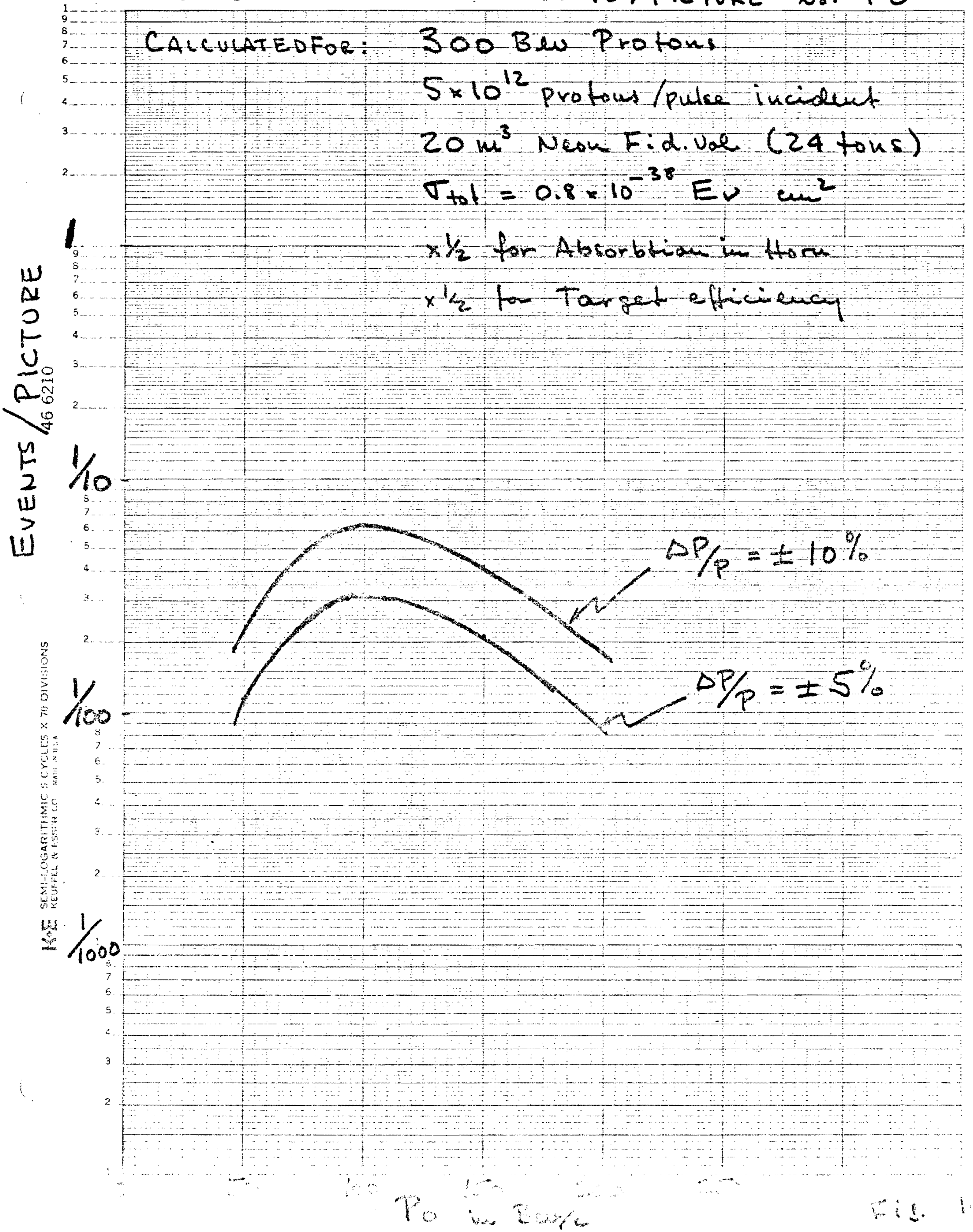


Fig. 1

COMPARISON OF VARIOUS NARROW BAND BEAMS