Tevatron Proposal No. 632

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AN EXPOSURE OF THE 15-Foot BUBBLE-CHAMBER WITH A NEON-HYDROGEN MIXTURE TO A WIDEBAND NEUTRINO BEAM FROM THE TEVATRON

April 17, 1980

by the

European-American collaboration composed of physicists from Aachen-Bonn-CERN-London-Munich-Oxford-Saclay and Berkeley-Hawaii-Seattle-Wisconsin.

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ABSTRACT

It is proposed to study interactions of wideband neutrino beam in the 15-foot bubble chamber filled with a neon-hydrogen mixture. Using a total sample of 70,000 charged current neutrino events the main physics aims are (a) searches for production of heavy quarks and τ-leptons or other unexpected phenomena - the production mechanisms of these and of charmed mesons and baryons will be studied. The event sample is expected to include decays of 7000 charmed particles (including 1200 $F+$) and 40 $\tau+$ particles (b) the study of quark and gluon fragmentation functions, jets, high P_T phenomena (c) the measurement of inelastic structure functions. Many other physics topics (resonance and strange particle production, neutral current, ν_e interactions etc) will be studied. Three high resolution cameras will be used to study the decays of short-lived particles. It is requested that a first sample of 20,000 charged current events be obtained as soon as possible after the Tevatron begins operation to search for new phenomena.

Proposal for an exposure of the 15-foot Bubble Chamber with a neon-hydrogen mixture to a wideband neutrino beam from the Tevatron.

Berkeley, Hawaii, Seattle, Wisconsin, Aachen, Bonn,
CERN, Imperial College, Munich, Oxford, Saclay
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Introduction

For several years the above groups have been studying various aspects of neutrino physics at the FNAL accelerator and the CERN-SPS. The aim of this proposal is to extend these studies to Tevatron energies. In figure 1 we show the neutrino spectra as they have been used at the CERN-SPS and what can be expected from a wideband beam at the Tevatron. It can be seen that the proposed beam has a much greater coverage in energy and that for energies above 150 GeV the yield of neutrinos per proton is an order of magnitude greater at the Tevatron.

A new feature will be the use of high resolution cameras to search for new particles (e.g. top, bottom, τ etc). We expect to observe several hundred examples of charmed particle decays.

Physics Aims and Proposed Exposure

The main aims of the experiment are threefold;

a) Study of charm and heavy quark production, τ-lepton production and search for unexpected phenomena.

b) Study of quark and gluon fragmentation functions, the transverse momentum behavior of hadrons and other aspects of the hadron system.

c) Measurement of inelastic structure functions.

In order to carry out these aims we propose an exposure to yield 70,000 charged current neutrino events. The beam we propose to use is the quad-triplet train set to a 400 GeV/c tune. The advantage of this beam is that for energies greater than ~ 100 GeV the neutrino flux is greater than that of a horn powered beam and the large flux of neutrinos of lower energies is suppressed. This allows the use of greater proton intensities on target and consequently a move rapid accumulation of high energy events.

We propose to use a moderately dense neon-hydrogen mixture. The use of neon is essential for electron identification and total energy measurement, however, too dense a mixture can lead to measurement problems. The groups working at CERN have carried out an exposure at 275 GeV/c in the narrowband beam. It was found that using a 75% (mole) Ne-H_2 mixture ~ 20% of the events were unmeasurable. Recently on exposure at 300 GeV/c has been carried out using a 33% Ne-H mixture and the rate of unmeasurable events is very low. The groups working at FNAL have used a 64% Ne-H^2 mixture in the present quad triplet beam and have been able to measure all events with some difficulty. The optimum mixture will be decided after a detailed comparison of the above exposures,

Search for Heavy Quark and Lepton Production

In an exposure of 70,000 charged current events we expect to obtain approximately 7,000 examples of charm production. These will lead to approximately 500 dimuon events and a larger number of (μe) events. The dimuon events will be identified using the well-proven EMI and the (μe) events will make use of the good electron identification of the heavy liquid. The bubble chamber is unique in that it allows the observation of the accompanying strange particles and therefore charmed baryon production can be distinguished from charmed meson production. Hadronic decay modes of charmed particles can also be studied making use of the detection efficiency of the heavy liquid.

In recent exposures of BEBC at CERN a high resolution camera has been installed as a test in addition to the usual camers. This camera works satisfactorily and using a short flash delay a resolution of ~200 in space is obtained on axis CERN is currently developing optimized cameras for BEBC. We propose to use three specially designed cameras in the hadron parts of the 15-foot bubble chamber giving an approximately 30% coverage of the visible volume including 60% of the events. Decay lengths of a few mm should be clearly visible 2mm corresponds to a D+ meson of 12 GeV/c if the lifetime is 10^{-12} seconds. We therefore expect to see many charmed particle decays using these cameras. To facilitate the observation of short decays the bubble chamber should be operated to obtain little distortion and good uniform contrast.

Production of the heavier quarks b and t has been estimated using excitation functions given by Baltay* and the Schrock and Wang estimates of the Vobayaski-Maskawa missing angles. Using these numbers we expect:

$$\nu + \begin{Bmatrix} \bar{u} \\ \bar{c} \end{Bmatrix} \rightarrow \mu^- + \bar{b} \quad 20 \text{ events}$$

$$\bar{\nu} + \begin{Bmatrix} u \\ c \end{Bmatrix} \rightarrow \mu^+ + b \quad 6 \text{ events}$$

$$\nu + \begin{Bmatrix} d \\ s \\ b \end{Bmatrix} \rightarrow \mu^- + t \quad 25 \text{ events } (M_t = 18 \text{ GeV})$$

There events should be characterized by cascade decays

$$(t \rightarrow) \rightarrow b \rightarrow c \rightarrow s \rightarrow u \quad \text{etc.}$$

or

$$\bar{b} \rightarrow \bar{c} \rightarrow \bar{s} \rightarrow \bar{u}$$

In the latter case leptonic decay of the $\bar{c} \rightarrow e^- + \bar{s}$ would lead to characteristics $\mu^- e^-$, $\mu^- \mu^-$ events. Current upper limits to these processes at neutrino energies of ~ 100 GeV and below are a few percent of the opposite-sign dileptons, corresponding a few dozen events in our experiment. Some of the multiple decays should be visible using the high resolution cameras if some of the b or t states have lifetimes of the same order (a few times 10^{-13} seconds) of the lowest charmed states.

* C. Baltay, meeting on Bubble Chamber Neutrino Physics at the Tevatron, Argonne October 1979.

If the F production is 20% of the charmed particle production and if $F \rightarrow \tau\nu_\tau$ has a 3% branching fraction then approximately 40 τ-leptons should be produced in this exposure. There would be characteristic double decay events. The τ lifetime is predicted to be 3×10^{-13} seconds, which is in our range of sensitivity.

The yields of events are summarized in the following table:

Table 1

Reaction	Events
$\nu + N \rightarrow \mu^- + x$	70,000
$\nu + N \rightarrow \mu^+ + x$	9,000
$\nu + N \rightarrow \mu^- + D^+(D^o) + X$	5,800
$\nu + N \rightarrow \mu^- + F^+ + X$	1,200
$\hookrightarrow \tau + \nu_\tau$	40
$\nu + N \rightarrow \mu^- + \bar{b}$	20
$\nu + N \rightarrow \mu^- + b$	6
$\nu + N \rightarrow \mu^- + t$	25

Study of Quark and Gluon Fragmentation Functions and Final State Hadron Properties

There properties have been extensively studied in wideband and narrowband experiments at CERN and FNAL. The interest of a Tevatron exposure is in the much greater range of hadronic mass W and Q^2 which are of interest for the following reasons;

I. For $W^2 < 16$ GeV^2 the separation of current and target fragments is ambiguous. In the SPS exposures a large proportion of events are in or near this region. In the proposed Tevatron exposure only a small proportion of events have $W^2 < 16$ GeV^2~

II. In the SPS wideband and narrowband experiments an increase in the average transverse momenta of hadrons relative to the current direction has been observed as the hadronic mass increases. This can be approximately described by:

$$\langle P_T^2 \rangle = 0.15 + 4 \times 10^{-4}\, W^2 \ (\text{GeV}^2)$$

The CERN measurements extend out to $W^2 = 200$ GeV^2. An exposure of 70,000 events in the quad triplet-beam would allow measurements out to $W^2 = 450$ GeV^2 (500 events) where the $\langle P_T^2 \rangle$ should be more than twice its value at low W^2 if the above behavior persists. This highest W point is shown together with the existing BEBC data in Figure 4. The value of $\langle P_T^2 \rangle$ is greater for larger values of $Z = E_h/\nu$ for hadrons emitted forward with respect to the current, whereas hadrons emitted backward show no increase in $\langle P_T^2 \rangle$ as expected from hard gluon emission and the data are in quantitative agreement with QCD predictions.

III. The range of Q^2 used for the determination of fragmentation function moments and the QCD parameter Λ can be greatly extended. Present data extend to $Q^2 = 64$ GeV^2. The higher energy and greater statistics of the proposed experiment would allow this range to be increased to > 400 GeV^2 with similar statistics.

We are currently studying other ways to reveal gluon jets in neutrino interactions (angular energy flow, azimuthal asymmetries etc). Our Monte Carlo studies predict greatly enhanced sensitivity in gluon effects at the larger W and Q^2 accessible to this experiment. In addition to fragmentation into pions we will also study fragmentation into K^0 and ρ, ω and other resonances.

Measurement of Inelastic Structure Functions

Although the measurement of inclusive structure functions can be carried out with a variety of techniques, the bubble chamber has advantages, in spite of lower statistics, than electronic detectors. The principle of this is the measurements can be made down to low hadron energy ν (<1 GeV) and therefore the complete ν and Q^2 range accessible to the beam can be used. This is particularly important in the evaluation of moments, which is the most direct way to compare with QCD predictions. Figure 6 shows the cummulative energy distribtion of ν and $\bar{\nu}$ events in the proposed exposure. It can be seen that 1000 neutrino events will be obtained at energies greater than 600 GeV and 300 antineutrino events will be obtained above 400 GeV. There numbers of events are similar to those used in the BEBC structure function work at 200 GeV at the SPS.

In order to carry out measurements of structure functions it is necessary to know the neutrino flux. Since we will be using an almost isoscalar target we can determine the neutrino flux using the energy distribution of the events themselves and normalizing to the measured cross sections in iron. These measurements are being made out to 300 GeV at CERN and will no doubt be made to 600 GeV using narrowband beams at the Tevatron. Nevertheless it is important to have a monitoring of the muon flux in the shield for the purposes of setting up and monitoring of the stability of the beam. If our proposal is approved we will request that CERN supply flux monitoring equipment for the beam.

A study of inelastic interactions requires good measureability of both hadrons and the final state muon. At the very high energies involved the deflection of muons in the bubble chamber field will be small and may reach the limits of resolution. We have studied this effect in detail and find that it can be overcome by requiring a certain potential length for high energy muons in the bubble chamber. If at 600 GeV neutrino energy we restrict the fiducial region such that all muons are measured with momentum error less than 25% then we nevertheless accept 60% of all neutrino interactions in the bubble chamber. We therfore feel that the provision of an external muon measuring device is not essential.

Other Physics Topics

In addition to the major topics discussed above the proposed exposure will also allow us to study many other topics including strange particles production, resonance production, neutral currents and ν_e interactions.

Summary of Experimental Conditions

We request that the bubble chamber be filled with a moderate density neon-hydrogen mixture and equipped with the EMI and internal picket fence. We also request that photos be taken with high resolution cameras in the three hadron ports.

We request the quad triplet beam tuned to 400 GeV/c and using the highest proton energy available. If a 64% (mole) Ne-H^2 mixture is used then 2.5 x 10^{13} protons on target will correspond to ~ 1 event per photograph ($\nu + \bar{\nu}$ + NC). We believe therefore that we can tolerate the highest proton intensity on target. An intensity of 1 x 10^{13} protons per pulse 250,000 pulses would be required to yield 70,000 charged current neutrino events. At the same time we would acquire 9,000 charged current antineutrino events. These event numbers are our long term aim. We would like to have a first sample of ~ 20,000 charged current events as soon as possible after the Tevatron begins operation in order to search for new phenomena.

We will request that CERN provides some flux measuring equipment to be installed in the new FNAL iron shield.

Measurement Capacity of the Collaboration

An important feature of this proposal is that we intend to measure completely all events. All the laboratories have considerable experience in measuring neutrino events in heavy liquid. We estimate our combined measurement capacity at 40,000 events per year. The proposed experiment results on rare events or partial samples will be available beforehand.

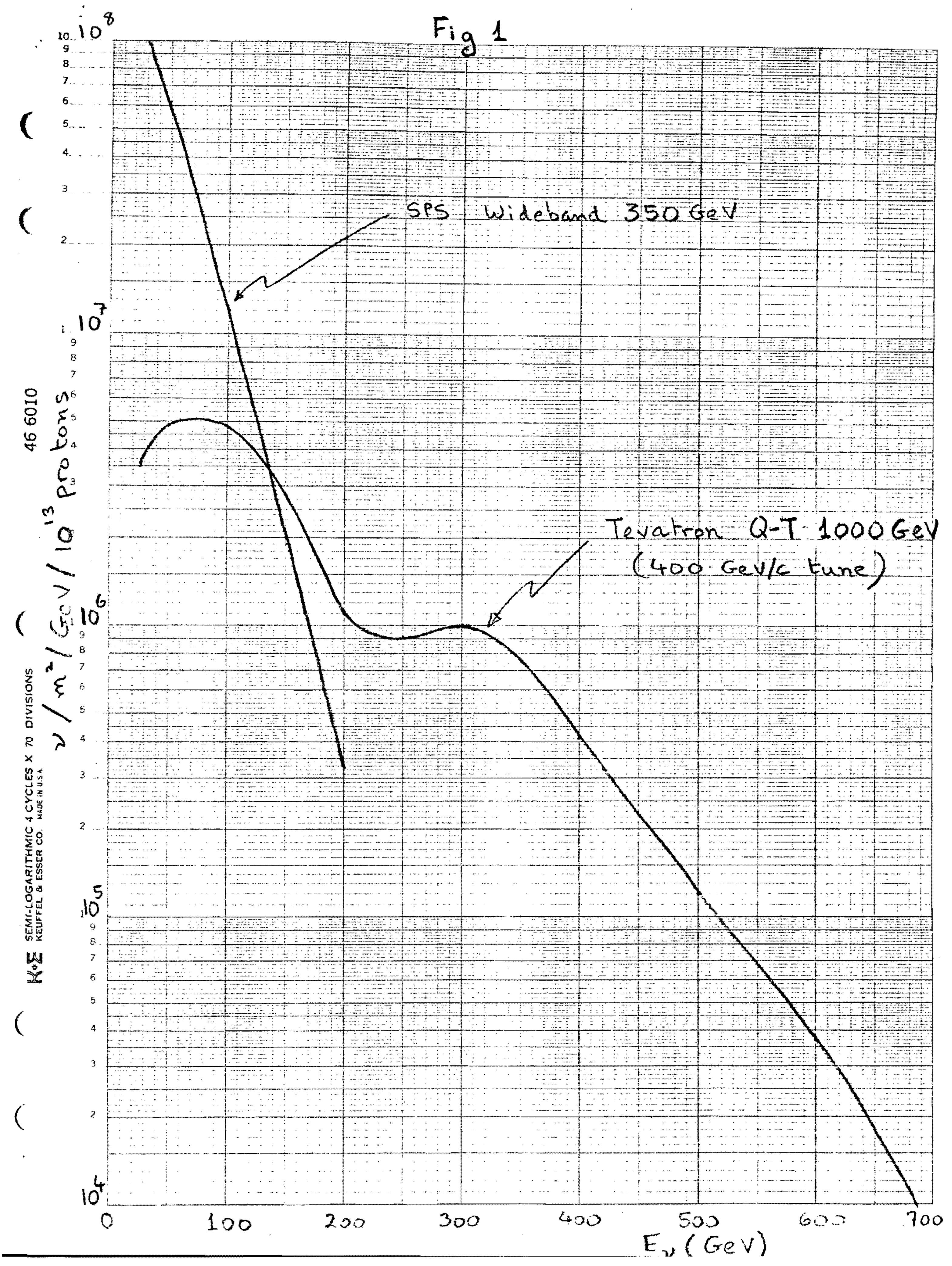


Fig 1
SPS Wideband 350 GeV
Tevatron Q-T 1000 GeV
(400 GeV/c tune)
ν / m² / GeV / 10¹³ protons
E_ν (GeV)
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6010

Fig 2

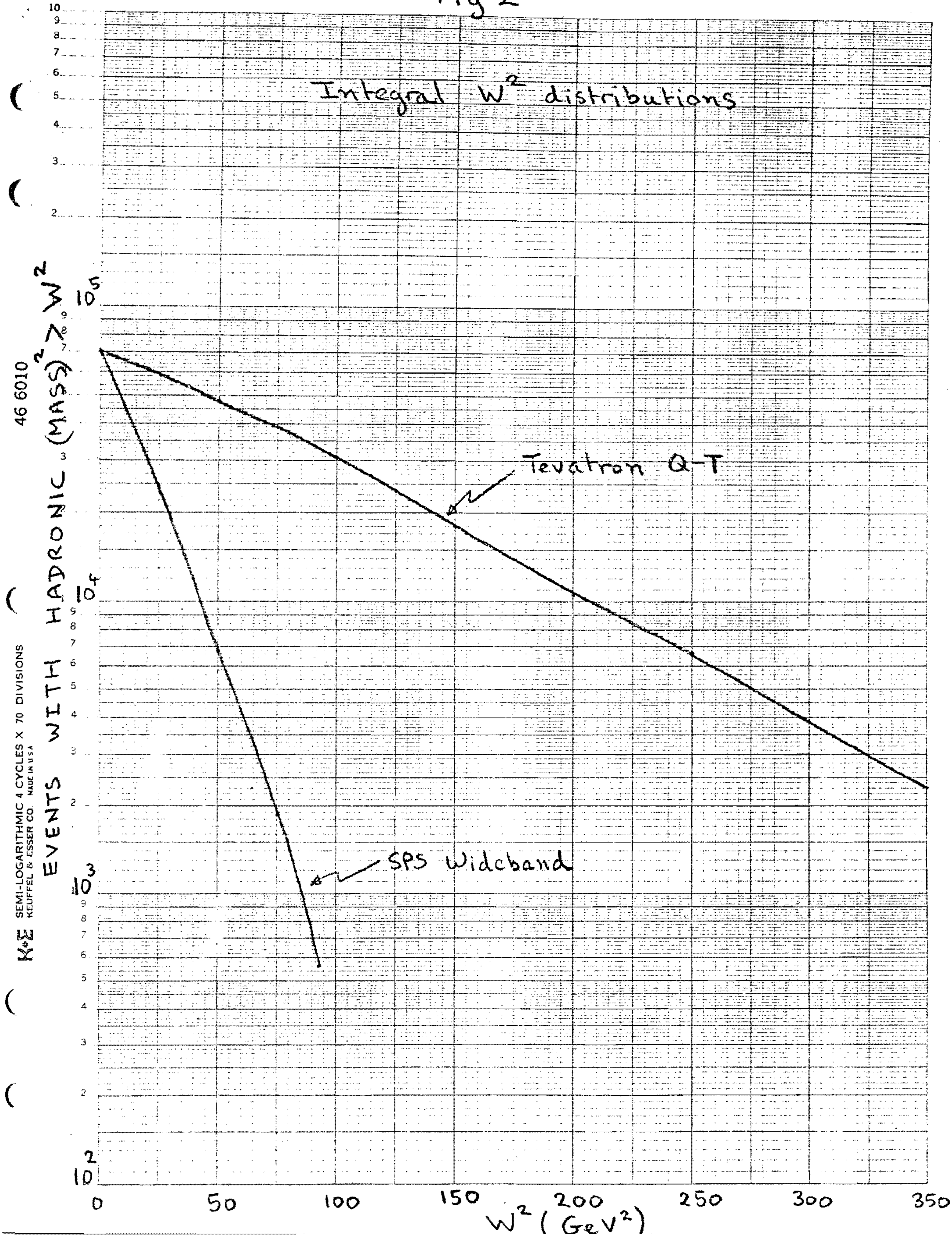
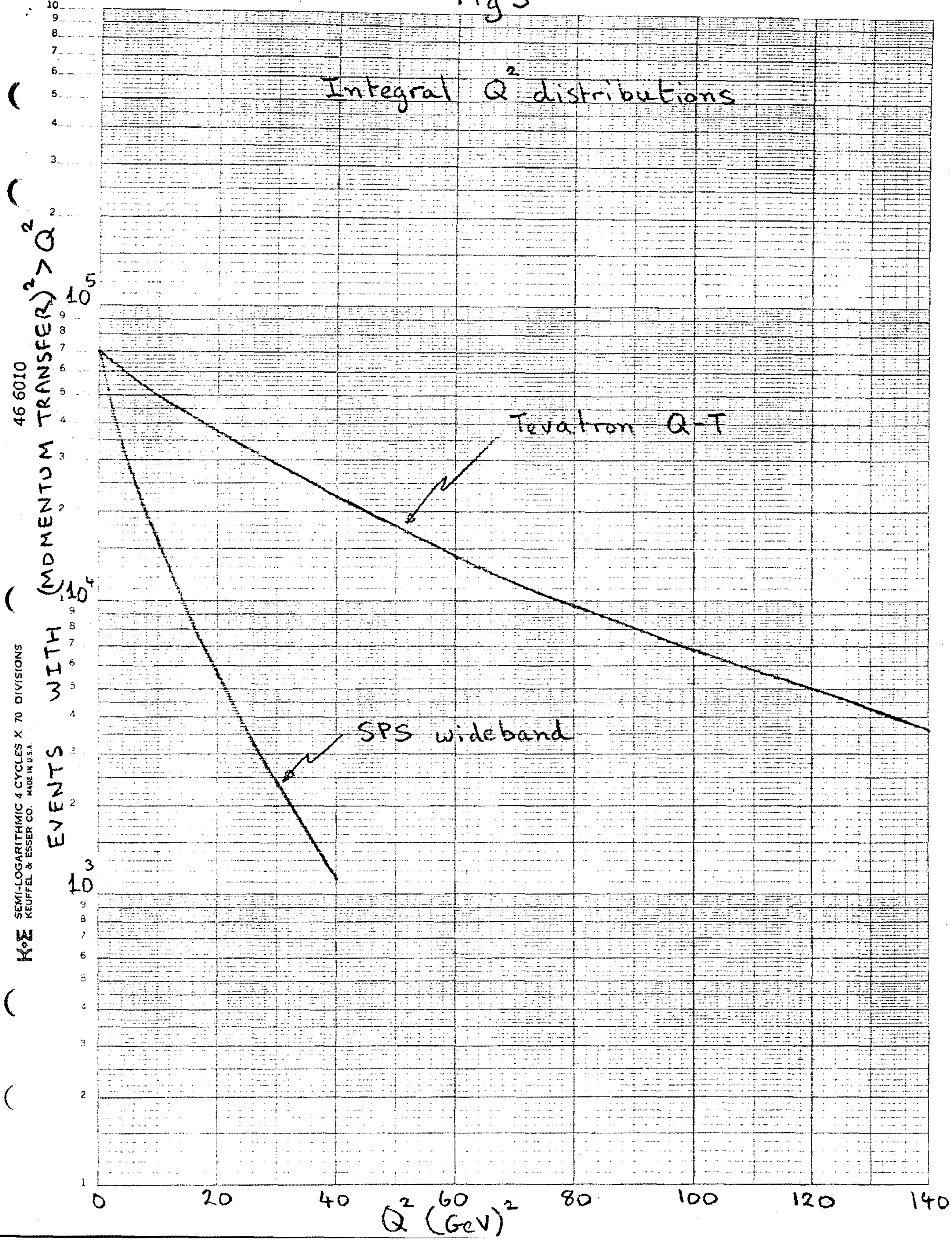

Integral W2 distributions
Tevatron Q-T
SPS Widcband
EVENTS WITH HADRONIC (MASS)2 > W2
W2 (GeV2)
0
50
100
150
200
250
300
350
10 2
10 3
10 4
10 5
46 6010
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

Fig 3



Integral Q^2 distributions
Tevatron Q-T
SPS wideband
EVENTS WITH (MOMENTUM TRANSFER)^2 > Q^2
10^5
10^4
10^3
0
20
40
60
80
100
120
140
Q^2 (GeV)^2
46 6010
K&E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
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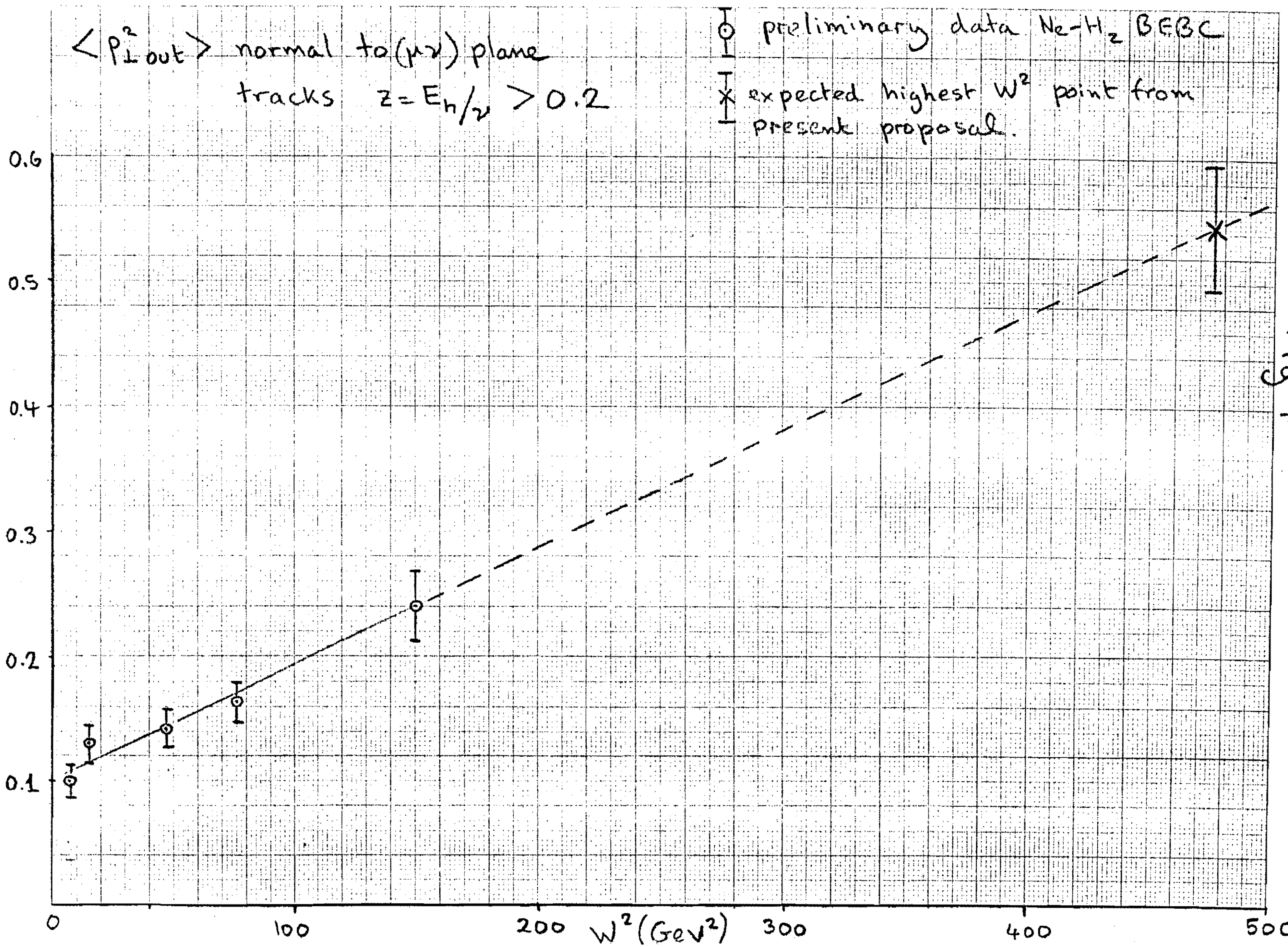
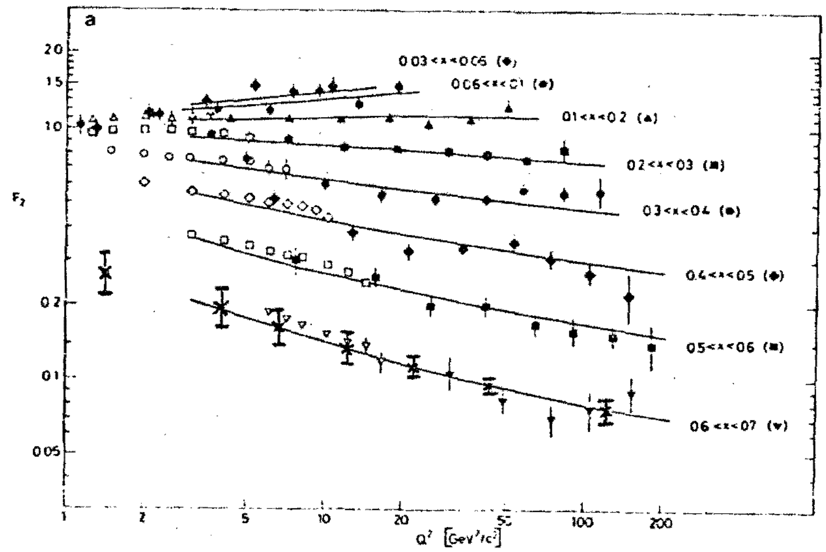

$\langle p^2_{\perp out} \rangle$ normal to ($\mu\nu$) plane
tracks $z = E_h/\nu > 0.2$
preliminary data Ne-H$_2$ BEBC
expected highest W^2 point from present proposal.
0.6
0.5
0.4
0.3
0.2
0.1
0
100
200
300
400
500
W^2 (GeV^2)

Fig. 11

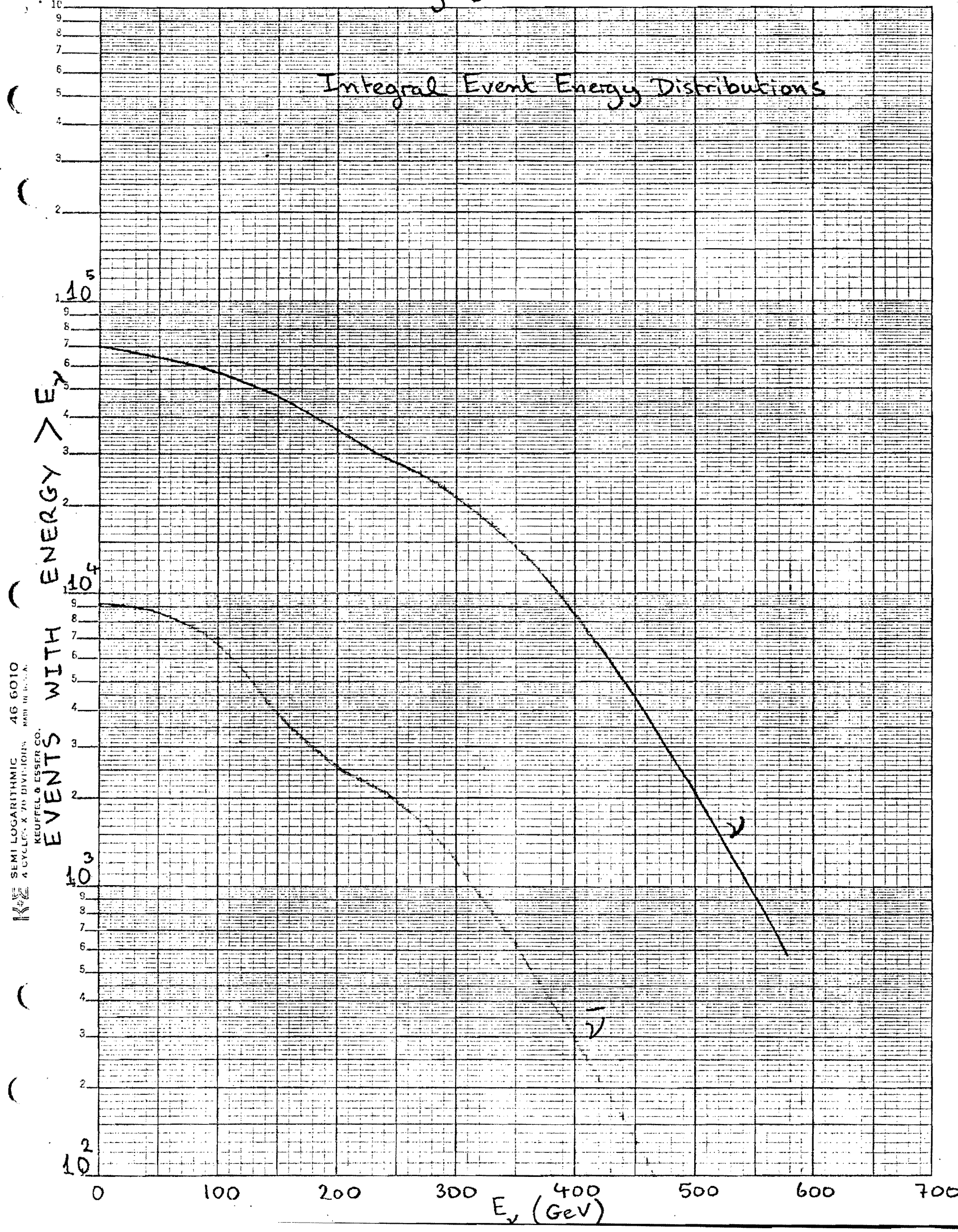
Fig 5



expected results on $F_2(x, Q^2)$ at large x from the proposed experiment

The solid points are neutrino data from de Groot et al. (Phys. Letters 82B (1979) 456) and the open points are derived from eD scattering.

Fig 6


Integral Event Energy Distributions
EVENTS WITH ENERGY > E_ν
10^5
10^4
10^3
10^2
ν
$\bar{\nu}$
0
100
200
300
400
500
600
700
E_ν (GeV)
SEMI LOGARITHMIC 46 6010
4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
MADE IN U.S.A.

6 May 1980 *Revised*

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ABSTRACT

It is proposed to study interactions of the wideband neutrino beam of the Tevatron in the 15' bubble chamber filled with a neon-hydrogen mixture. Using a total sample of 70 000 Charged Current (CC) neutrino events the main physics aims are: (a) searches for production of heavy quarks and τ leptons or other unexpected phenomena - the production mechanisms of these and of charmed mesons and baryons will be studied. The event sample is expected to include decays of 7000 charmed particles (including 1200 F^+) and τ^+ particles; (b) the study of quark and gluon fragmentation functions, jets, high p_T phenomena and (c) the measurement of inelastic structure functions. Many other physics topics (resonance and strange particle production, neutral currents, ν_e interactions, etc.) will be studied. Three high resolution cameras will be used to observe the decays of short-lived particles. It is requested that a first sample of 20 000 CC events be obtained as soon as possible after the Tevatron begins operation to search for new phenomena.

PROPOSAL

FOR AN EXPOSURE OF THE 15' BUBBLE CHAMBER FILLED WITH A NEON-HYDROGEN MIXTURE TO A WIDEBAND NEUTRINO BEAM FROM THE TEVATRON

Berkeley-Hawaii-Seattle-Wisconsin-Aachen-Bonn-CERN-Imperial College-Munich-Oxford-Saclay Collaboration

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1. INTRODUCTION

For several years the above groups have been studying various aspects of neutrino physics at the FNAL accelerator and the CERN-SPS. The aim of this proposal is to extend these studies to Tevatron energies. In fig. 1 we show the neutrino spectra as they have been used at the CERN-SPS and what can be expected from a wideband beam at the Tevatron. It can be seen that the proposed beam has a much greater coverage in energy and that for energies above 150 GeV the yield of neutrinos per proton is an order of magnitude greater at the Tevatron.

A new feature will be the use of high resolution cameras to search for new particles (e.g. top, bottom, τ, etc.). We expect to observe several hundred examples of charmed particle decays.

2. PHYSICS AIMS AND PROPOSED EXPOSURE

The main aims of the experiment are three:

(a) Study of charm and heavy quark production, τ lepton production and search for unexpected phenomena.

(b) Study of quark and gluon fragmentation functions, the transverse momentum behaviour of hadrons and other aspects of the hadron system.

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In order to carry out these aims we propose an exposure of the 15' bubble chamber to yield 70 000 CC neutrino events. The beam we propose to use is the quad-triplet train set to a 400 GeV/c tune. The advantage of this beam is that for energies greater than ∿ 100 GeV the neutrino flux is greater than that of a horn powered beam and the large flux of neutrinos of lower energies is suppressed. This allows the use of greater proton intensities on the target and consequently a more rapid accumulation of high energy events as shown in fig. 1.

We propose to use a moderately dense neon-hydrogen mixture. The use of neon is essential for electron identification and total energy measurement. However, too dense a mixture can lead to measurement problems. The groups working at CERN have carried out an exposure at 275 GeV/c in the narrowband beam, and have found that using a 75 mole per cent Ne-H_2 mixture ∿ 20% of the events were unmeasurable. Recently, an exposure at 300 GeV/c has been carried out using a 33% Ne-H_2 mixture and the rate of unmeasurable events is very low. The groups working at FNAL have used a 64% Ne-H_2 mixture in the present quad-triplet beam and have been able to measure all events though with some difficulty. The optimum mixture will be decided after a detailed comparison of the above exposures.

3. SEARCH FOR HEAVY QUARK AND LEPTON PRODUCTION

In 70 000 CC events we expect to obtain approximately 7000 examples of charm production. These will lead to approximately 500 dimuon events and a larger number of (μe) events. The dimuon events will be identified using the well-proven EMI and the (μe) events will make use of the good electron identification of the heavy liquid. The bubble chamber is unique in that it allows the observation of the accompanying strange particles and therefore charmed baryon production can be distinguished from charmed meson production. Hadronic decay modes of charmed particles can also be studied making use of the detection efficiency of the heavy liquid.

In recent exposures of BEBC at CERN a high resolution camera has been installed as a test, in addition to the usual cameras. This camera works satisfactorily and using a short flash delay a resolution of ∿ 200 μ in space is obtained on axis. CERN is currently developing optimized cameras for BEBC. We propose to use three specially designed cameras in the hadron ports of the 15' bubble chamber giving approximately a 30% coverage of the visible volume including 60% of the events. Decay lengths of a few millimetres should be clearly visible (2 mm corresponds to a D^+ meson of 12 GeV/c if the lifetime is 10^{-12} s). We therefore expect to see many charmed particle decays using these cameras. To facilitate the observation of short decays the bubble chamber should be operated so as to obtain little distortion and good uniform contrast.

Production of the heavier quarks b and t has been estimated using excitation functions given by Baltay(*) and the Schrock and Wang estimates of the Kobayashi-Maskawa mixing angles. Using these numbers we expect:

$$\nu + \left\{ \begin{matrix} \bar{u} \\ \bar{c} \end{matrix} \right. \rightarrow \mu^- + \bar{b} \qquad \text{20 events}$$

$$\bar{\nu} + \left\{ \begin{matrix} u \\ \bar{c} \end{matrix} \right. \rightarrow \mu^+ + b \qquad \text{6 events}$$

$$\nu + \left\{ \begin{matrix} d \\ s \\ b \end{matrix} \right. \rightarrow \mu^- + t \qquad \text{25 events } (M_t = 18 \text{ GeV}) .$$

These events should be characterized by cascade decays

$t \rightarrow b \rightarrow c \rightarrow s \rightarrow u$ etc., or

$\bar{b} \rightarrow \bar{c} \rightarrow \bar{s} \rightarrow \bar{u}$

In the latter case leptonic decay of the $\bar{c} \rightarrow e^- + \bar{s}$ would lead to characteristic $\mu^- e^-$ events. Current upper limits to these processes at neutrino energies of $\sim$ 100 GeV and below are a few per cent of the opposite sign dileptons, corresponding to a few dozen events in our experiment. Some of the cascade decays should be visible using the high resolution cameras if some of the b or t states have lifetimes of the same order (a few times 10^{-13} s) as the lowest charmed states.

(*) C. Baltay, meeting on Bubble Chamber Neutrino Physics at the Tevatron, Argonne, October 1979.

If the F production is 20% of the charmed particle production and if $F \to \tau\ \nu_\tau$ has a 3% branching fraction then approximately 40 τ leptons should be produced in this exposure. These would be characteristic double decay events. The τ lifetime is predicted to be 3×10^{-13} s, which is in our range of sensitivity.

The quad-triplet beam contains some antineutrinos as well as neutrinos. The yields of events for 2.5×10^{18} protons are summarized in the following table:

Table 1

Reaction	Number of events
$\nu + N \to \mu^- + X$	70 000
$\nu + N \to \mu^-\ D^+(D^o) + X$	5800
$\nu + N \to \mu^- + F^+ + X$	1200
$\quad\quad\quad\quad\quad \hookrightarrow \tau^+ + \nu_\tau$	40
$\nu + N \to \mu^- + \bar{b}$	20
$\bar{\nu} + N \to \mu^+ + X$	9000
$\bar{\nu} + N \to \mu^+ + b$	6

4. STUDY OF QUARK AND GLUON FRAGMENTATION FUNCTIONS AND FINAL STATE HADRON PROPERTIES

These properties have been extensively studied in wideband and narrowband experiments at CERN and FNAL. The interest of a Tevatron exposure is in the much greater range of hadronic mass W and of Q^2 as shown in figs 2 and 3, which are important for the following reasons:

(a) For $W^2 < 16\ \mathrm{GeV}^2$ the separation of current and target fragments is ambiguous. In the SPS exposures a large proportion of events are in or near this region. In the proposed Tevatron exposure almost all events have $W^2 > 16\ \mathrm{GeV}^2$.

(b) In the SPS wideband and narrowband experiments an increase in the average transverse momentum of hadrons relative to the current direction has been observed as the hadronic mass increases. This can be approximately described by

$$\langle p_T^2 \rangle = 0.15 + 4 \times 10^{-4}\ W^2\ (\mathrm{GeV}^2)\ .$$

The CERN measurements extend out to $W^2 = 200\ \mathrm{GeV}^2$. An exposure of 70 000 events in the quad-triplet beam would allow measurements out to $W^2 = 450\ \mathrm{GeV}^2$ (500 events) where the $\langle p_T^2 \rangle$ should be more than twice its value at low W^2 if the above behaviour persists. This highest W point is shown together with the existing BEBC data in fig. 4. It has been found [1,2] that the value of $\langle p_T^2 \rangle$ is greater for hadrons emitted energetically forward in the hadron c.m.s. than for those emitted energetically backwards. This is in agreement with QCD predictions that hard gluons should be emitted forwards.

(c) The range of Q^2 used for the determination of fragmentation function moments and the QCD parameter Λ can be greatly extended. Present data extend to $Q^2 = 64\ \mathrm{GeV}^2$. The higher energy and greater statistics of the proposed experiment would allow this range to be increased to $> 400\ \mathrm{GeV}^2$ with similar statistics.

We are currently studing other ways to reveal gluon jets in neutrino interactions (angular energy flow, azimuthal asymmetries etc.). Our Monte-Carlo studies predict greatly enhanced sensitivity in gluon effects at the larger W and Q^2 accessible to this experiment. In addition to fragmentation into pions we will also study fragmentation into K^o, ρ, ω and other resonances.

5. MEASUREMENT OF INELASTIC STRUCTURE FUNCTIONS

Although the measurement of inclusive structure functions can be carried out with a variety of techniques, the bubble chamber has advantages in spite of lower statistics, over electronic detectors. The basis of this is that measurements can be made down to low hadron energy ν (< 1 GeV) and therefore the complete ν and Q^2 range accessible to the beam can be used. This is particularly important in the evaluation of moments, which is the most direct way to compare with QCD predictions. Fig. 6 shows the cumulative energy distribution of ν and $\bar{\nu}$ events in the proposed exposure. It can be seen that 1000 neutrino events will be obtained at energies greater than 600 GeV and 300 antineutrino events will be obtained above 400 GeV. These numbers of events are similar to those used in the BEBC structure function work at 200 GeV at the SPS.

In order to carry out measurements of structure functions it is necessary to know the neutrino flux. Since we will be using an almost isoscalar target we can determine the neutrino flux using the energy distribution of the events themselves and normalizing to the measured cross sections in iron. These measurements are being made out to 300 GeV at CERN and will no doubt be made to 600 GeV using narrowband beams at the Tevatron. Nevertheless, it is important to have a monitoring of the muon flux in the shield for the purposes of setting up the beam and monitoring its stability.

A study of inelastic interactions requires good measureability of both hadrons and the final state muon. At the very high energies involved, the deflection of muons in the bubble chamber field will be small and may reach the limits of resolution. We have studied this effect in detail and find that it can be overcome by requiring a certain potential length for high energy muons in the bubble chamber. If at 600 GeV neutrino energy we restrict the fiducial region such that all muons are measured with momentum error less than 25%, then we nevertheless accept 60% of all neutrino interactions in the bubble chamber. We therefore feel that the provision of an external measuring device for the muon momentum is not essential.

6. OTHER PHYSICS TOPICS

In addition to the major topics discussed above, the proposed exposure will also allow us to study many other topics including strange particle production, resonance production, neutral currents and ν_e interactions.

An example of a topic that could be of special interest when the Tevatron first operates is neutrino oscillations. In the bubble chamber filled with a neon-hydrogen mixture, they could be studied in three ways simultaneously, from the numbers of ν_e events, of ν_τ events and from the NC/CC ratio.

7. MEASUREMENT CAPACITY OF THE COLLABORATION

An important feature of this proposal is that we intend to measure completely all events. All the laboratories have considerable experience in measuring neutrino events in heavy liquid. We estimate our combined measurement capacity at 40 000 events per year. In the proposed experiment, results on rare events from the entire sample and results of measurements of all events on a partial sample of the film, will be produced quickly.

8. SUMMARY OF EXPERIMENTAL CONDITIONS

We request that the 15' bubble chamber be filled with a moderate density neon-hydrogen mixture and equipped with the EMI and Internal Picket Fence. We also request that photos be taken with high resolution cameras in the three hadron ports.

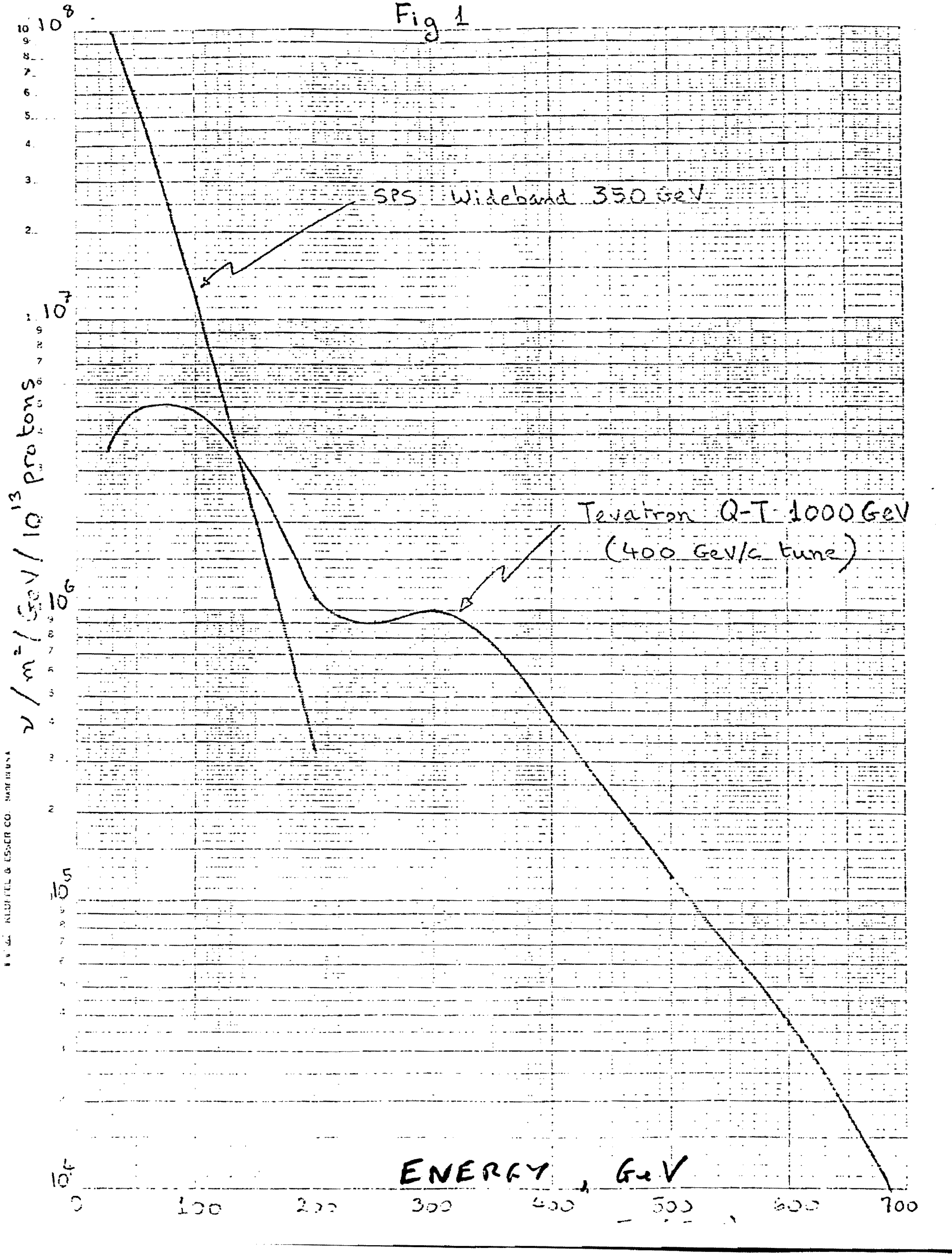
We request the quad-triplet beam tuned to 400 GeV/c and using the highest proton energy available. If a 64 mole per cent Ne-H_2 mixture is used then 2.5×10^{13} protons on target will correspond to $\sim$ 1 event per photograph ($\nu + \bar{\nu}$, CC + NC). We believe therefore that we can tolerate the highest proton intensity on target. At an intensity of 1×10^{13} protons per pulse, 250 000 pulses would be required to yield 70 000 CC neutrino events. At the same time we would acquire 9000 CC antineutrino events. These event numbers are our long-term aim. We would like to have a first sample of $\sim$ 20 000 CC events as soon as possible after the Tevatron begins operation in order to search for new phenomena.

REFERENCES

[1] Aachen-Bonn-CERN-Munich-Oxford Collaboration, G. Saitta et al., XVth Rencontre de Moriond (1980) and to be published.

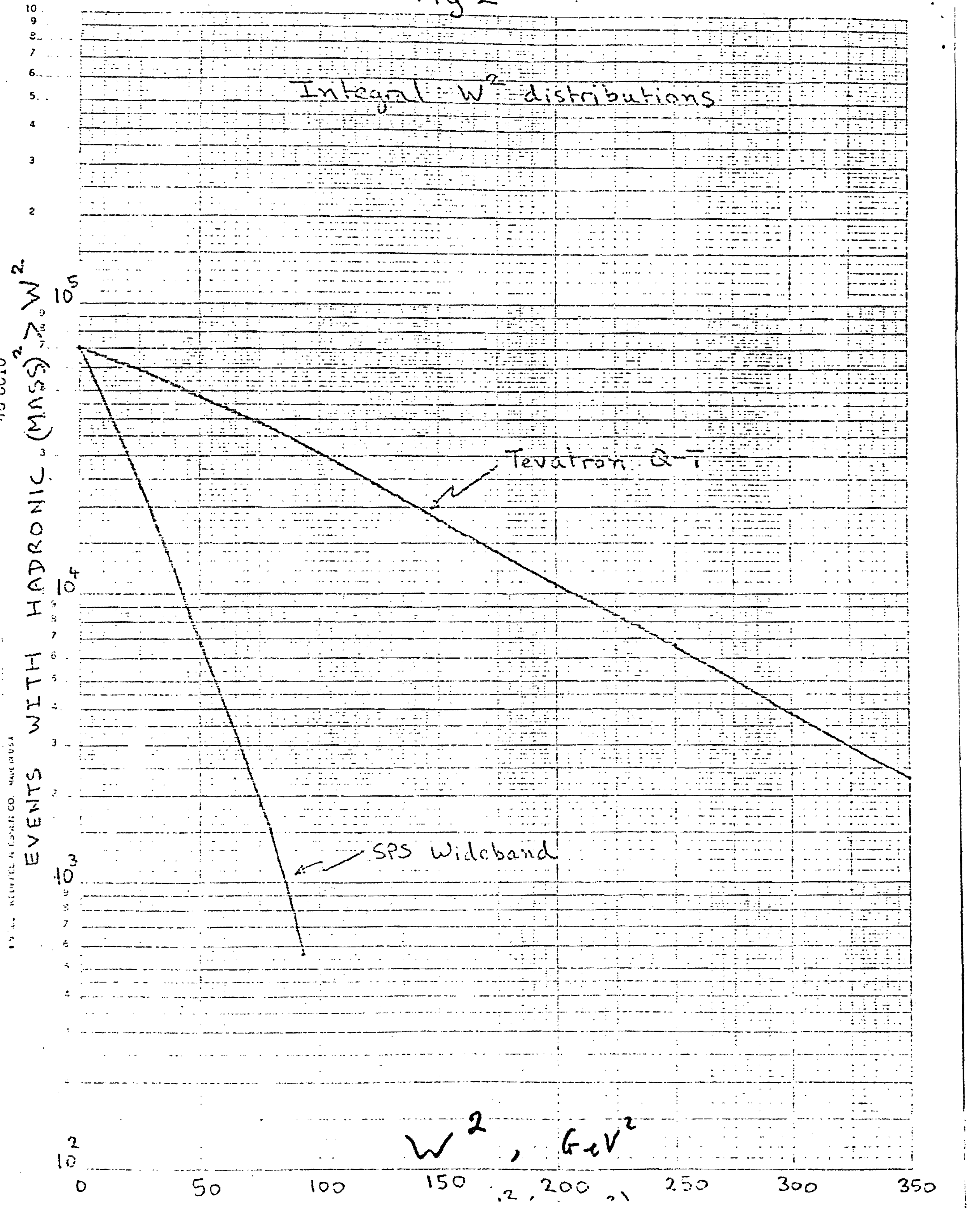
[2] Aachen-Bonn-CERN-Demokritos Athens-London-Oxford-Saclay Collaboration, L. Pape et al., XVth Rencontre de Moriond (1980) and to be published.

Fig 1



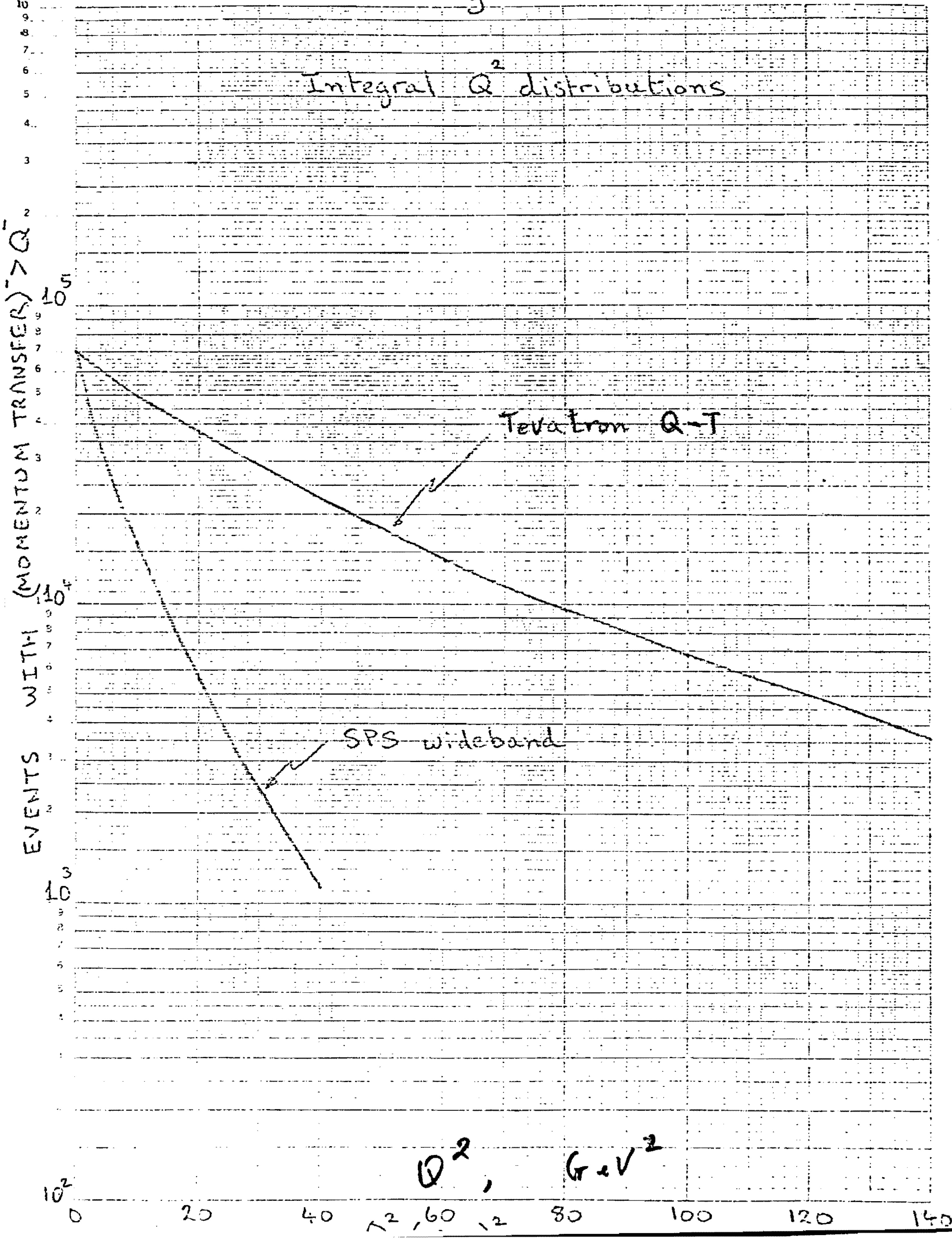
SPS Wideband 350 GeV
Tevatron Q-T 1000 GeV
(400 GeV/c tune)
ν / m² / GeV / 10¹³ protons
ENERGY, GeV
10⁸
10⁷
10⁶
10⁵
10⁴
0
100
200
300
400
500
600
700

Fig 2

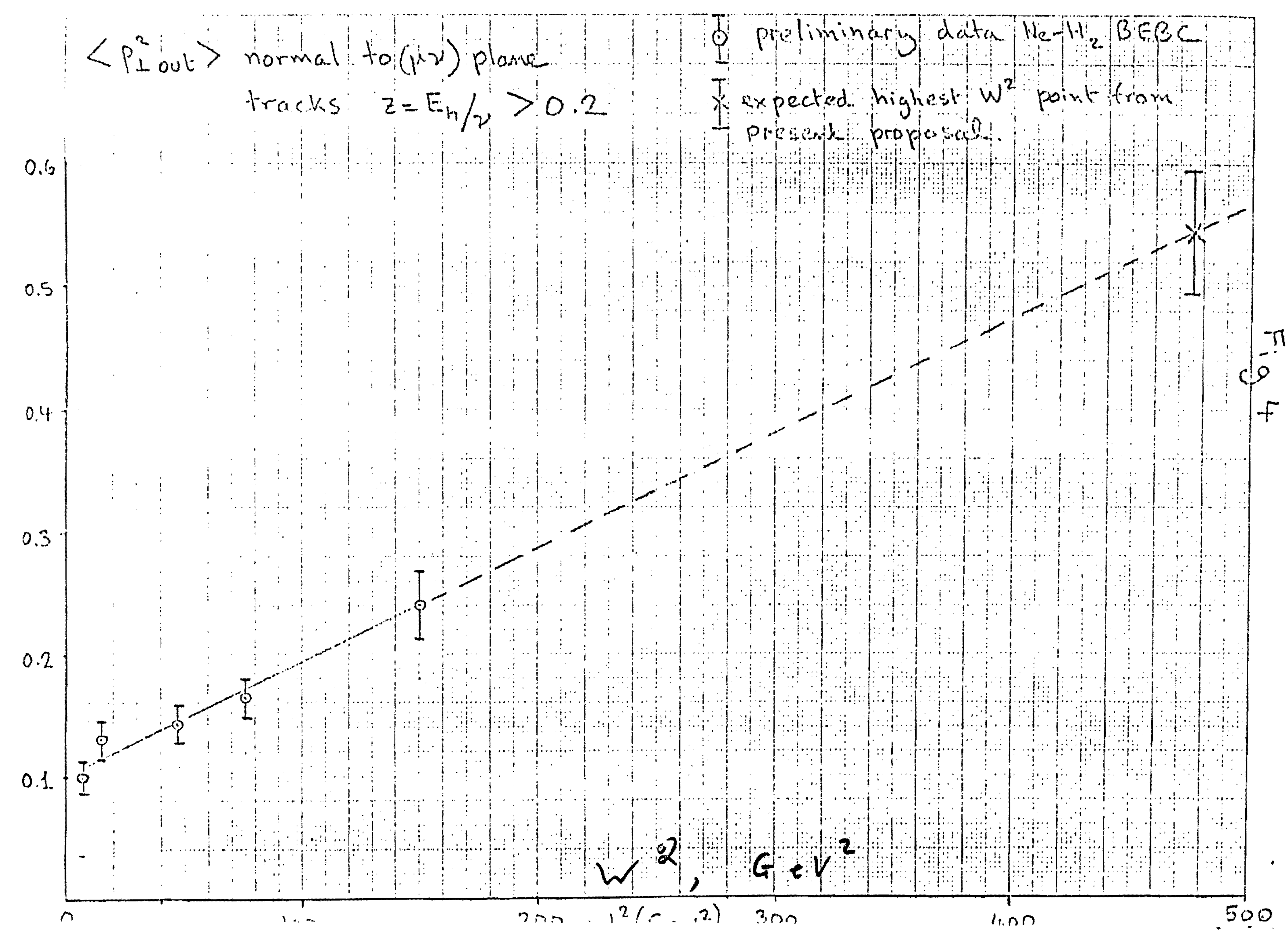


Integral W^2 distributions
Tevatron Q-T
SPS Wideband
EVENTS WITH HADRONIC (MASS)^2 > W^2
10^5
10^4
10^3
10^2
W^2, GeV^2
0
50
100
150
200
250
300
350

Fig 3

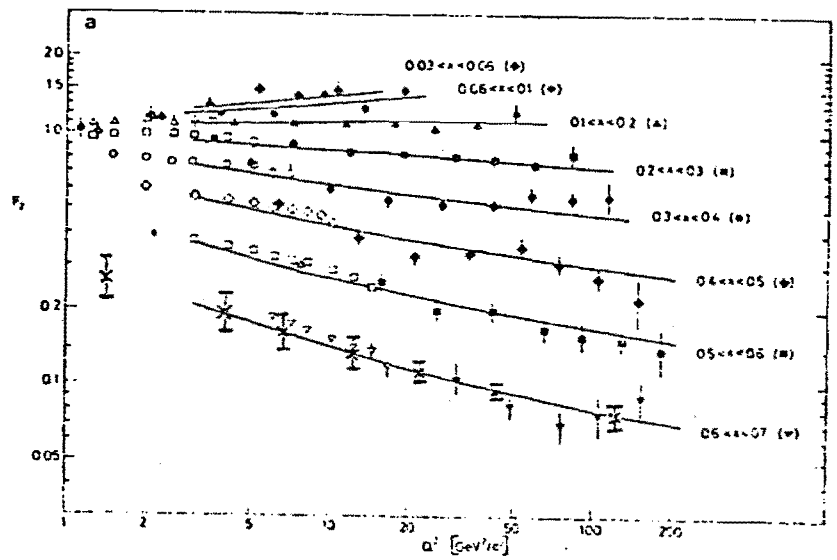


Integral Q^2 distributions
Tevatron Q-T
SPS wideband
EVENTS WITH (MOMENTUM TRANSFER)^2 > Q^2
10^5
10^4
10^3
10^2
0
20
40
60
80
100
120
140
Q^2, GeV^2



<p²⊥ out> normal to (μν) plane
tracks z = E_h/ν > 0.2
preliminary data Ne-H₂ BEBC
expected highest W² point from present proposal.
0.6
0.5
0.4
0.3
0.2
0.1
W², GeV²
0
300
500

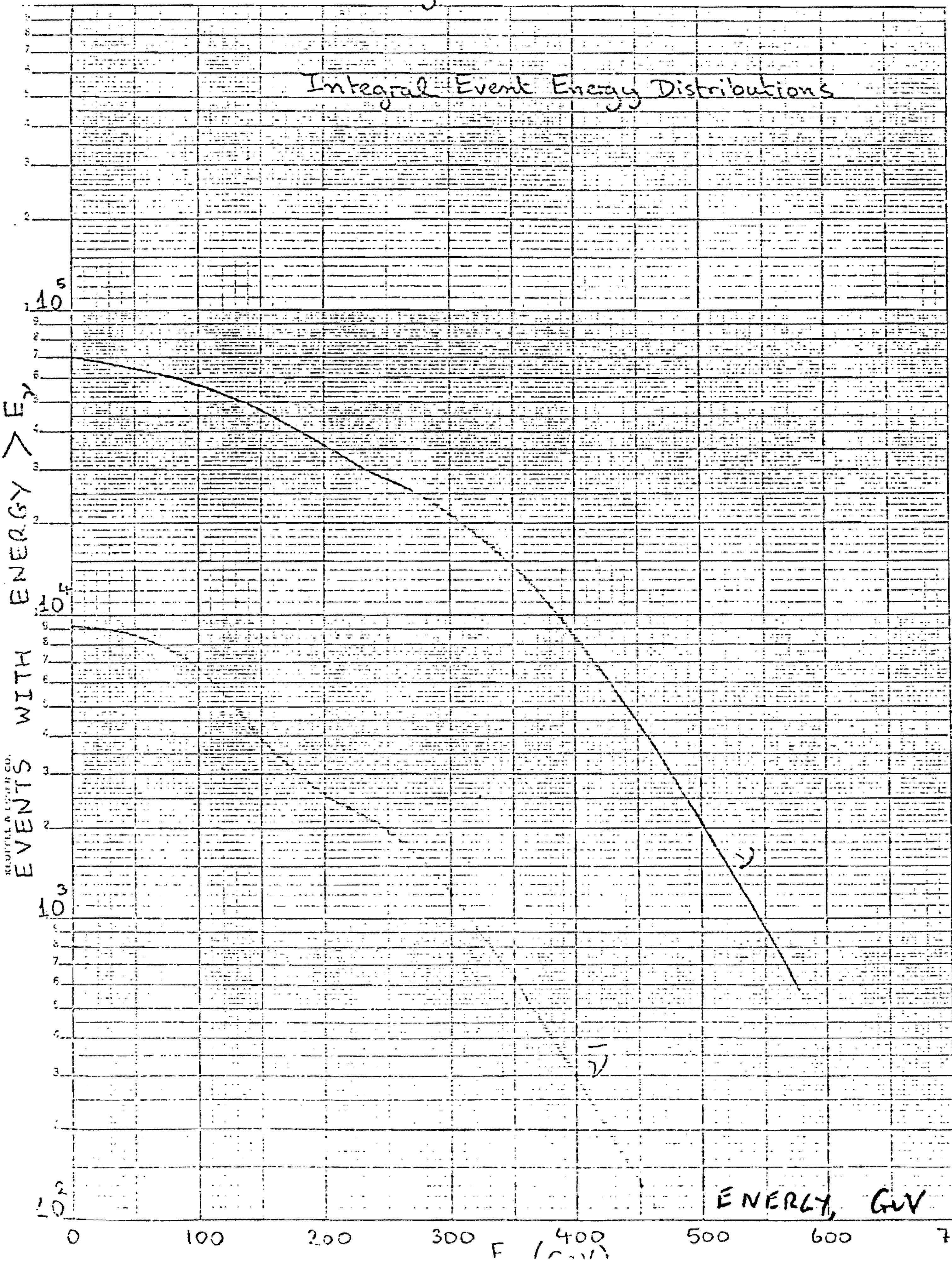
Fig 5



I̽ expected results on $F_2(x, Q^2)$ at large x from the proposed experiment

The solid points are neutrino data from de Groot et al. (Phys. Letters 82B (1979) 456) and the open points are derived from eD scattering.

Fig 6



Integral Event Energy Distributions
EVENTS WITH ENERGY > Eν
ENERGY, GeV
10^5
10^4
10^3
10^2
0
100
200
300
400
500
600
700
ν
ν̄

DIRECTOR'S REVIEW OF E632

COMMITIUM 21 OCTOBER 1986 at 13.30

1. Introduction, beam, shielding	Douglas Morrison	15 min.
2. Physics and Analysis	Pierre Marage	45 min
3. Bubble Chamber	Wes Smart	30 min
4. EMI/IPF and Dimuons	Fred Harris	15 min
5. Holography	Michael Peters	45 min
6. Summary	Douglas Morrison	15 min.

E 632

DIRECTOR'S REVIEW

INTRODUCTION } D. R. O. MORRISON
SUMMARY

21 OCT 1986

E 632

EXPERIMENT IS:

WIDE BAND NEUTRINO BEAM IN
HYBRID BUBBLE CHAMBER.

15 FOOT BUBBLE CHAMBER
WITH 4 CONVENTIONAL CAMERAS
+ HIGH RESOLUTION OPTICS — HOLOGRAPHY

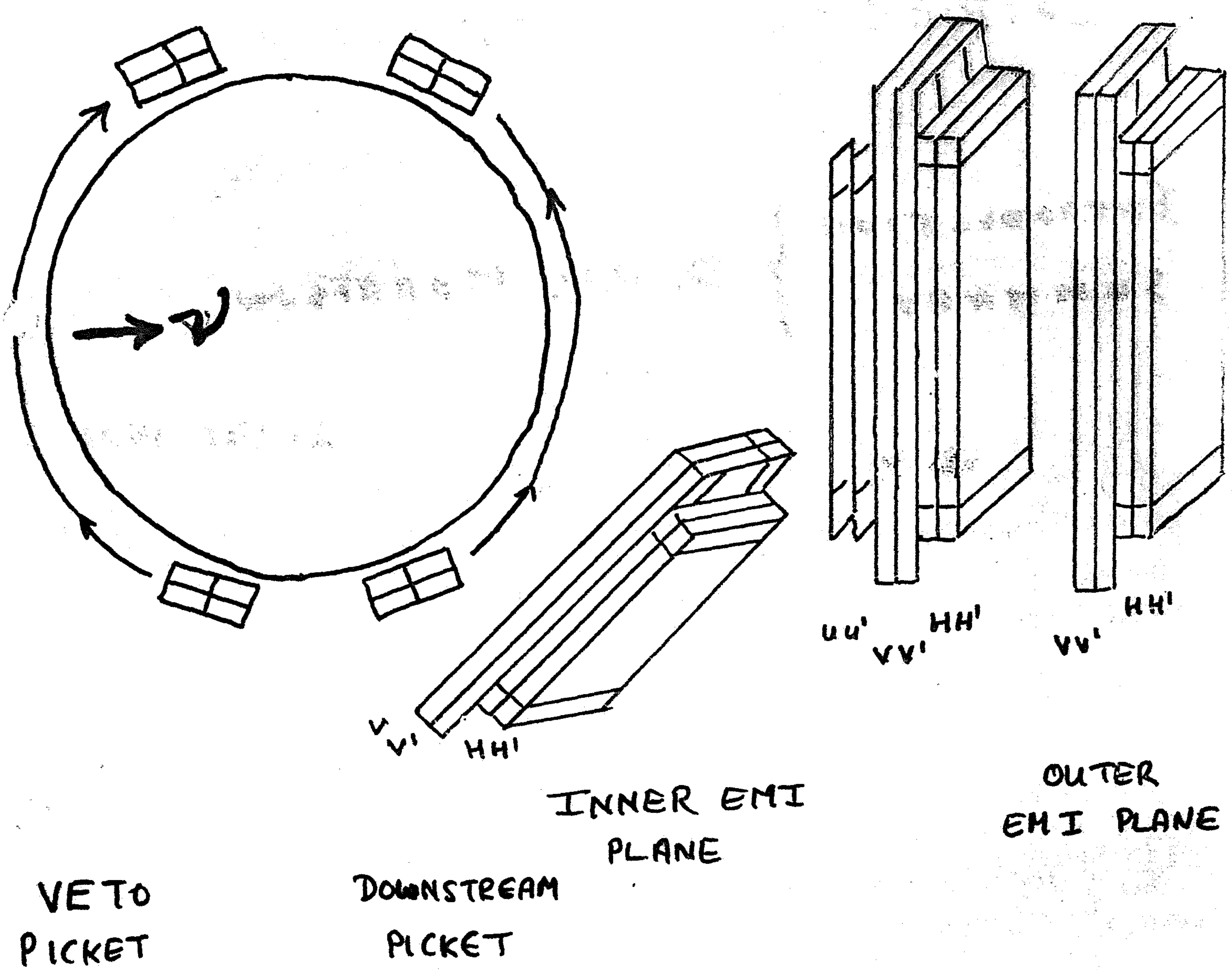
COUNTERS { EMI — TO IDENTIFY MUONS
COUNTERS { IPF < TIME LINKAGE TRACKS ↔ COUNTER
COUNTERS { IPF < UPSTREAM VETO COUNTER

HAD FIRST RUN 1985,

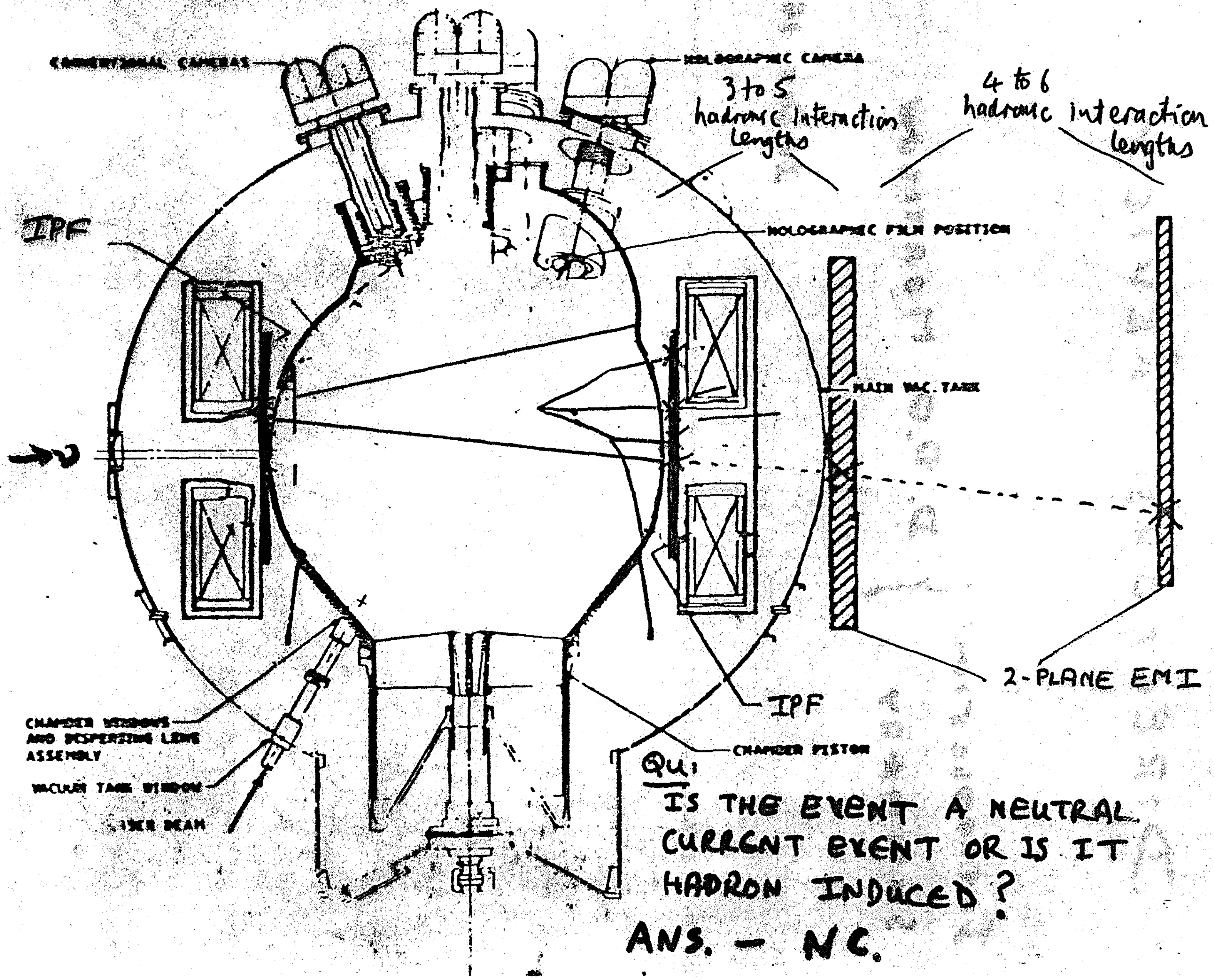
0.25×10^{18} PROTONS OF 800 GeV.

LAYOUT OF EMI AND IPF

Proportional tubes : 500 nsec timeslots



Spatial resolution of EMI = $\frac{1}{2}$ inch



<u>Qu:</u> IS THE EVENT A NEUTRAL CURRENT EVENT OR IS IT HADRON INDUCED?

ANS. — NC.

New Phenomena

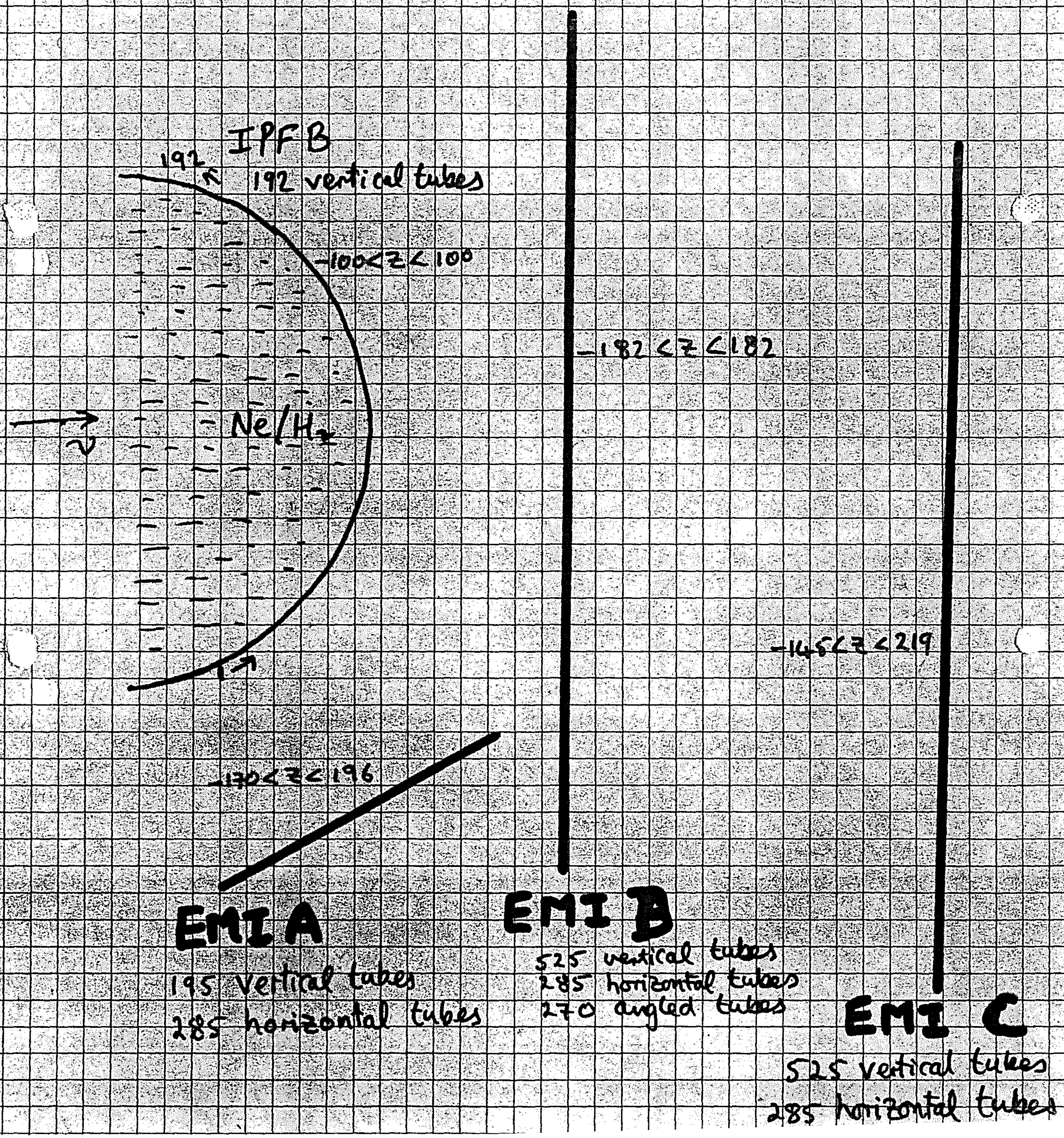
Multi-purpose hybrid detector:

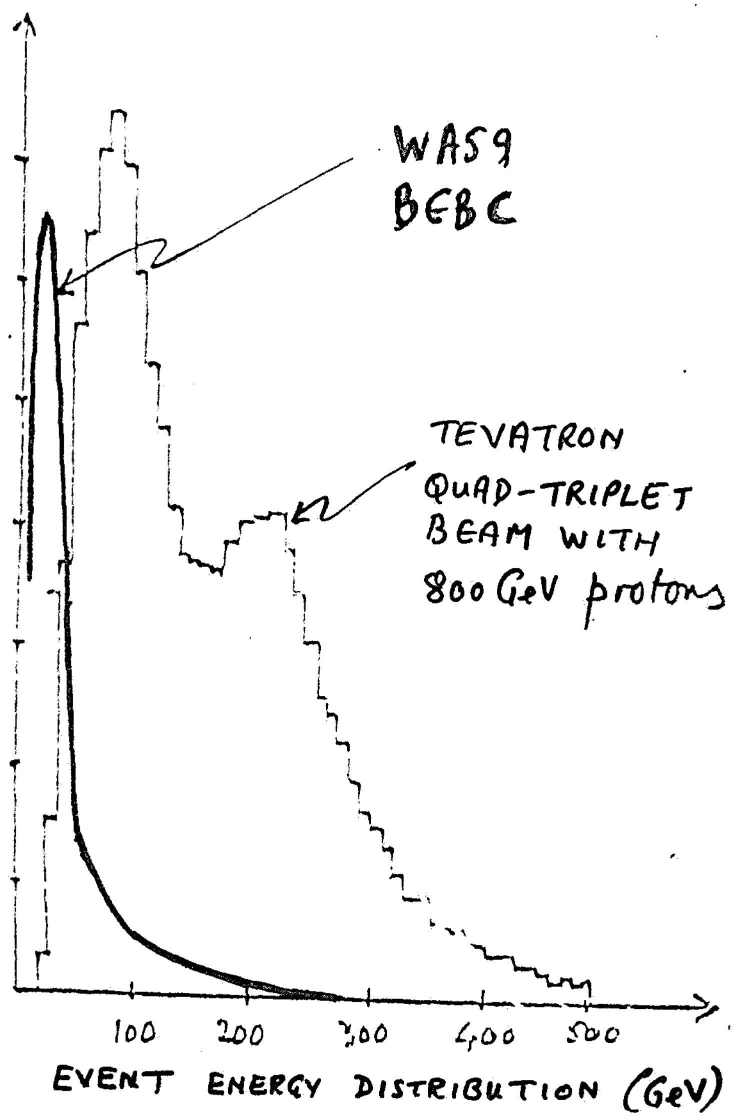
① μ's	EMI
② association of events in time	IPF
③ e's and photons	Ne/H_2
④ neutral strange ptles, V^0	15'
⑤ low energy protons	STOP
⑥ short lifetimes	Holography / HRC

coupled to highest energy neutrino beam from TEVATRON

LAY-OUT OF IPF AND EMI

(500 nsec time slots)





$\langle E \rangle \sim 150$ GeV

LAB	1985 RUN	1987 RUN.
BERKELEY	✓	✓
* BIRMINGHAM	✓	✓
BRUSSELS	✓	✓
CERN	✓	PEOPLE + SCANNING.
FERMILAB	✓	✓
I.I.T.	✓	✓
HAWAII	✓	✓
I.C. LONDON	✓	✗
MUNICH	✓	✓
OXFORD	✓	✗
RUTGERS/STEVENS.	✓	✓
* RUTHERFORD	✓	✗, BUT HOLRED WILL OPERATE.
* SACLAY	✓	✓
TUFTS	✓	✓
CHANDIGAHR	✓	✓
JAMMU	✓	✓

FOR LABS IN 1987 RUN:-

SCANNING + MEASURING/LAB AS BEFORE
NUMBER OF PEOPLE/LAB AS BEFORE

SOFTWARE ETC. NOW WELL ESTABLISHED.

* IF START-UP NOT DELAYED.

CHOICE OF BEAM ENERGY 800 → ?

PROBABLY SAFE FOR 850 GeV
SOME DOUBTS FOR 900 GeV.

BACKGROUNDS

A. HIGH ENERGY MUONS PUNCH-THROUGH

B. REGENERATION + FOCUSSING LAB.E.

C. SINGLE RANDOM HITS.

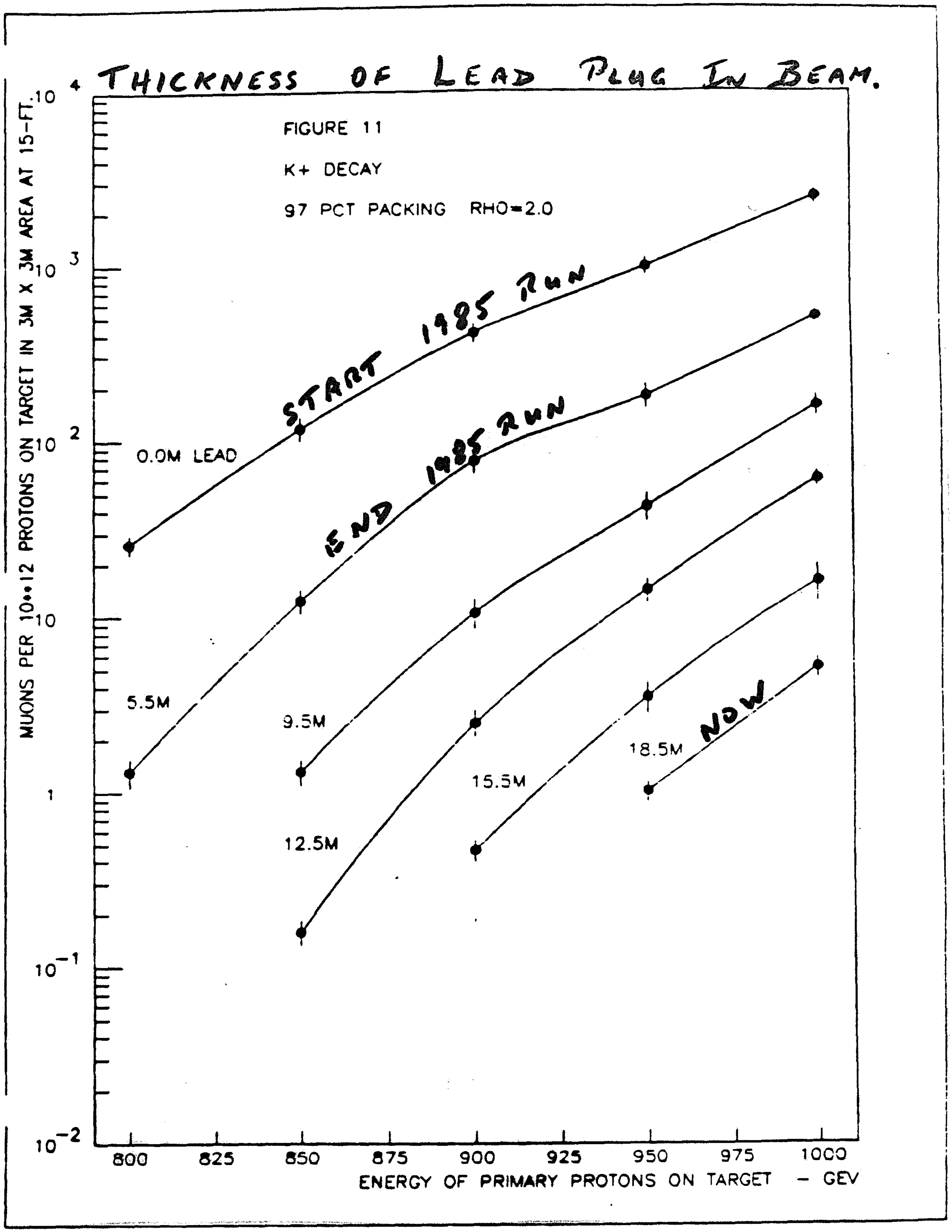
A, DURING FIRST RUN, BACKGROUND TOO HIGH
ADDED 158 TONS Pb (5.5m THICK, 1.8 m Ø
– BLOCKED LEAK NWEST TEST LINE

LINDA et al. HAVE ADDED MORE LEAD
5.5 → 18.3 m THICK.

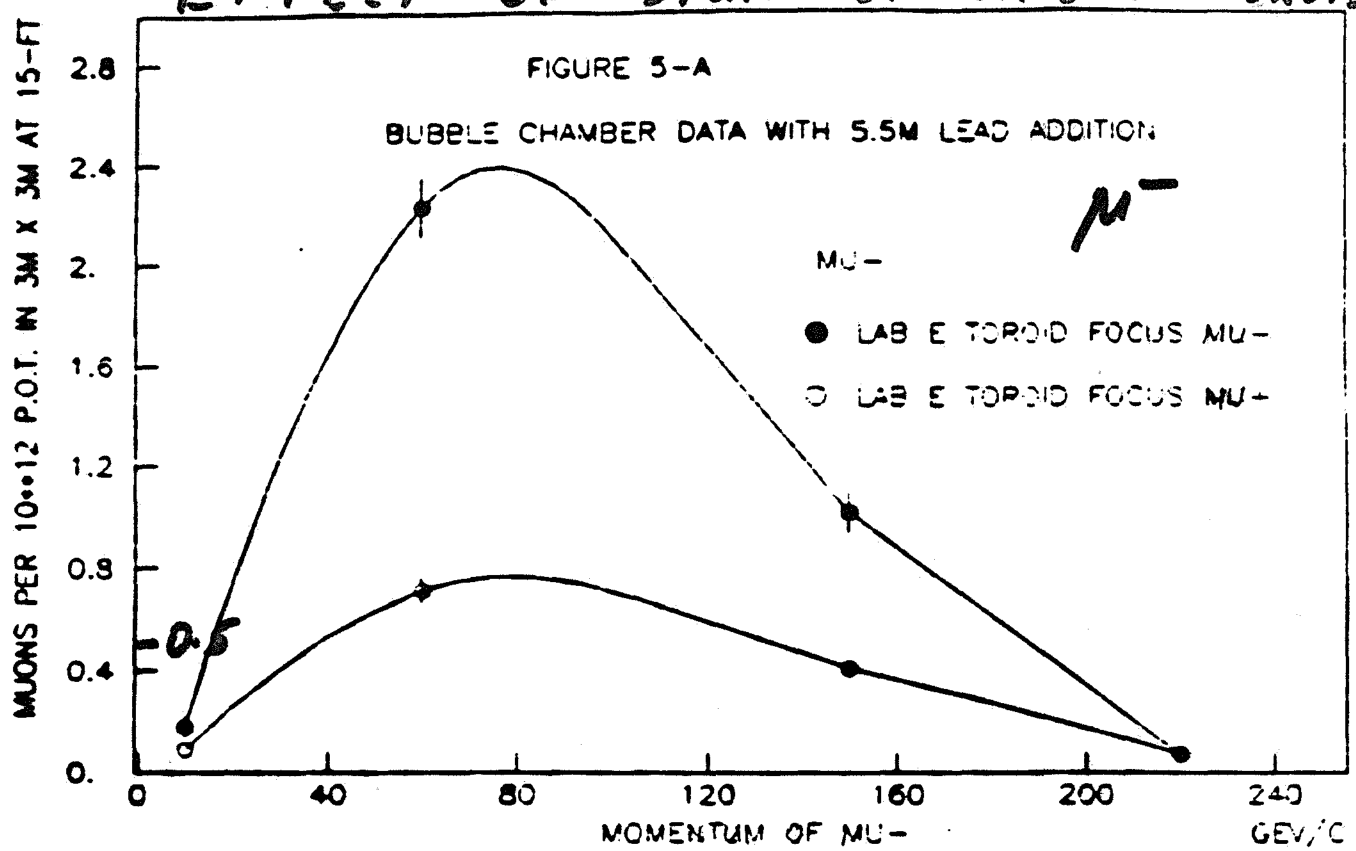
SEEMS O.K. FOR 900 GeV.

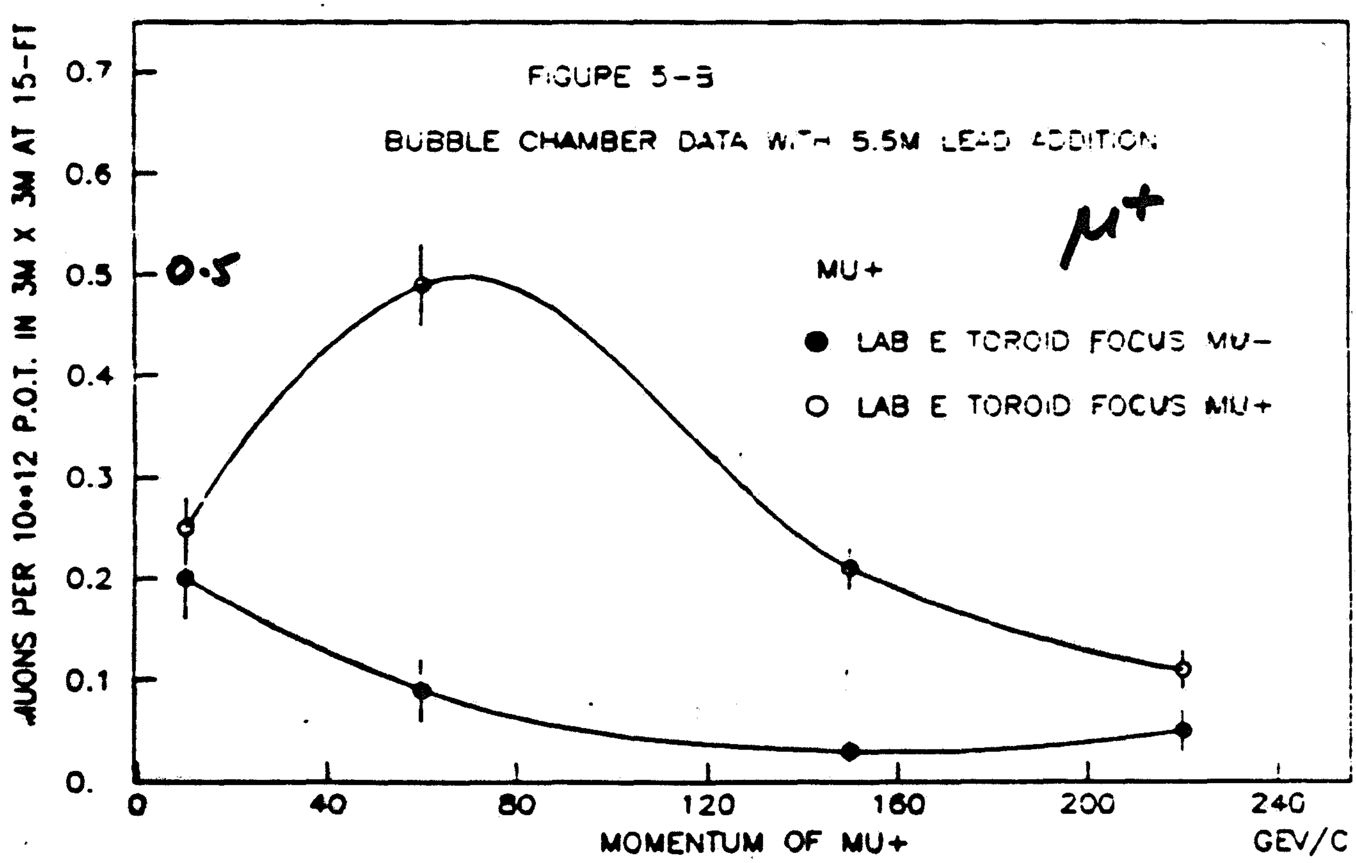
B. REGENERATION IN 400 TONS OF LAB E
DETECTOR + FOCUSSING – UNAVOIDABLE

~30 MUONS > 20 GeV IN EMI, ~10 IN CHAMBER
IF 800 → 900 GeV, 30% INCREASE.
PLUS LOWER ENERGY TRACKS.
TOLERABLE.

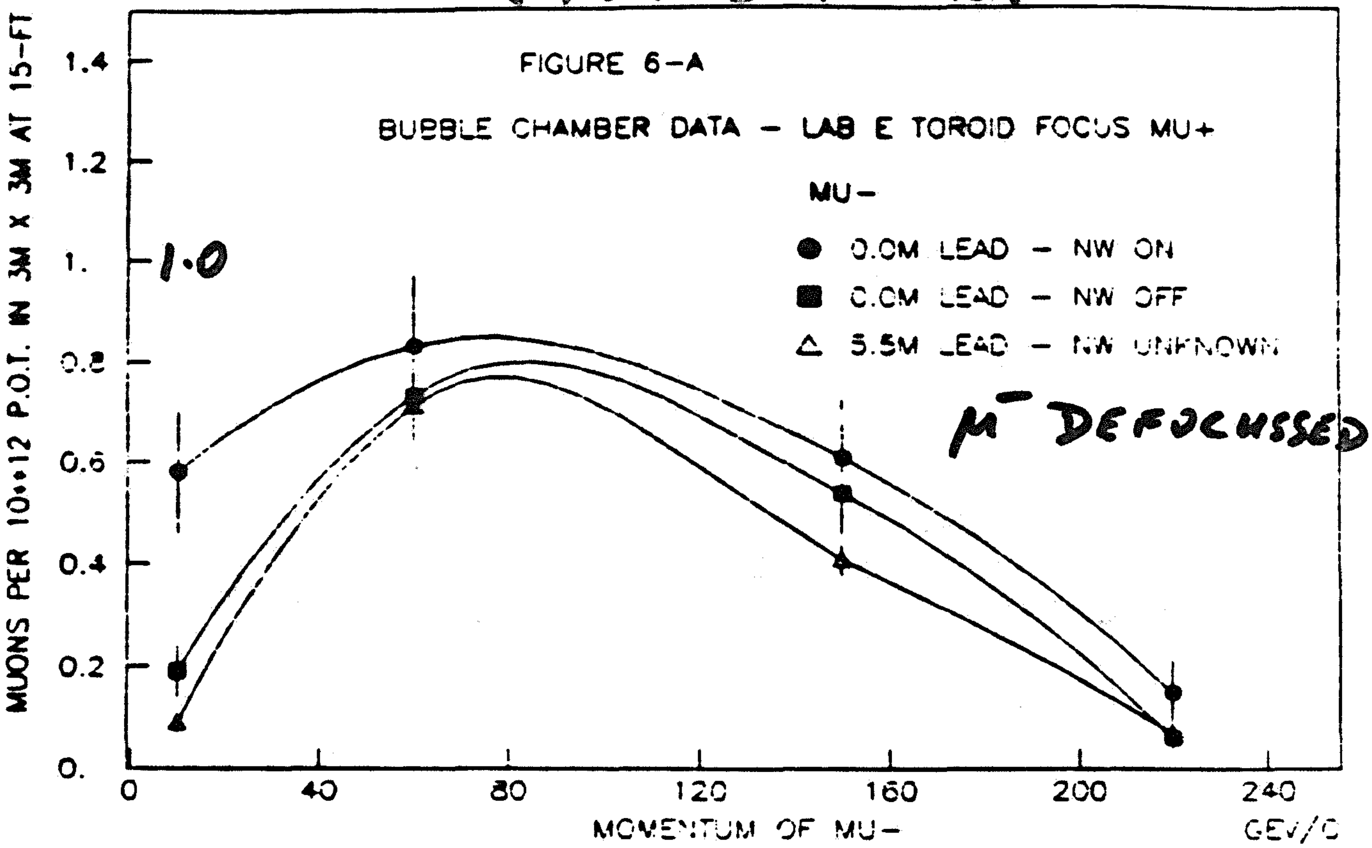

THICKNESS OF LEAD PLUG IN BEAM.
FIGURE 11
K+ DECAY
97 PCT PACKING RHO=2.0
MUONS PER 10**12 PROTONS ON TARGET IN 3M X 3M AREA AT 15-FT.
ENERGY OF PRIMARY PROTONS ON TARGET - GEV
0.0M LEAD
5.5M
9.5M
12.5M
15.5M
18.5M
START 1985 RUN
END 1985 RUN
NOW
800
825
850
875
900
925
950
975
1000

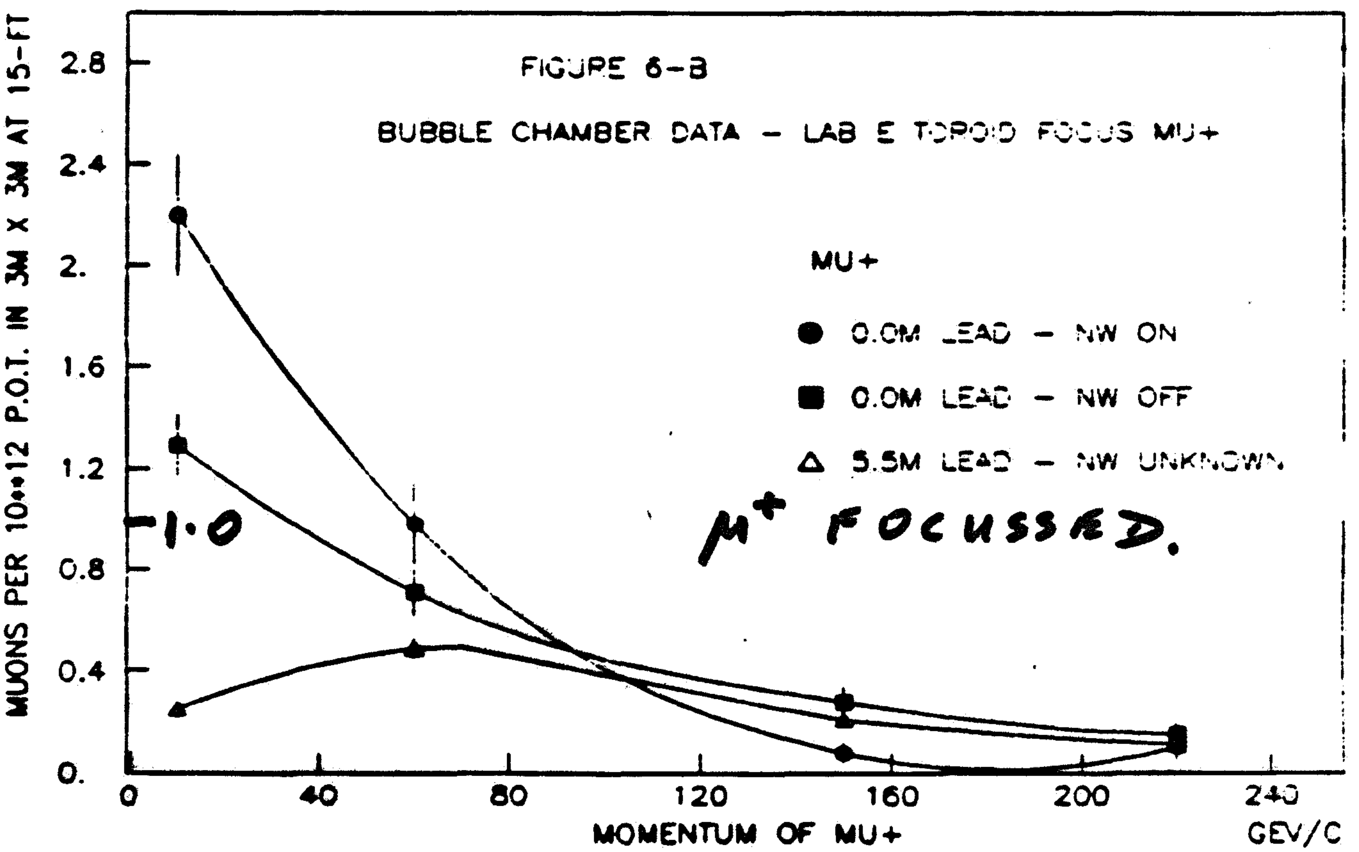
EFFECT OF SIGN OF LAB E TOROID





EFFECT OF { 5.5 m Pb
NW TEST LINE ON/OFF.
TOROID FOCUS.





C. SINGLE RANDOM HITS.

TROUBLE SOME AS WANT EMI C PLANE
TO BE CLEAN.

NOT FULLY UNDERSTOOD.
— BEST GUESS — MAINLY LOW ENERGY GAMMAS FROM SKYSHINE, THEY CURL UP IN MAGNETIC FIELD.
+ POSSIBLY SOME LOW ENERGY NEUTRONS ALSO SEEN AS SINGLE BUBBLES.

HAVE SATURATED EMI — BUFFER OVERFLOWS

CURE? WALL v. BIG.

O.K. FOR 850 GeV.
NEED TO CHECK 900 GeV.

CONCLUSION

HIGHER ENERGY IS WELCOME

- FOR MODERATE INCREASE IN EVENT NUMBERS
- FOR HIGH ENERGY TAIL.

BUT NOT IF APPRECIABLE DOWN TIME AND LOWER INTENSITY IS CAUSED.

2. PHYSICS AND ANALYSIS.

PHYSICS AIMS BASICALLY THE SAME. THOUGH MORE INTEREST IN COHERENT PRODUCTION (→ PCAC, EMC EFFECT, ...)

∴ MEASURED 2 AND 4 PRONGS.

→ FIRST PAPER SENDAI AND BERKELEY CONF.

— PIERRE MARAGE.

3 BUBBLE CHAMBER

MANY IMPROVEMENTS.

WES, JIM AND CREW HAVE WORKED HARD AND WELL

WITH SO MUCH WORK BEING DONE NEED TO TEST BY COOLING TO CHECK IF LEAKS OR OTHER PROBLEMS.

i.e. NEED COOL-DOWN A.S.A.P.

— WES SMART.

MANY EMI HARDWARE PROBLEMS

DURING FIRST HALF OF RUN

GREAT NEED FOR DE-HUMIDIFIER

BACKGROUND HIGHER THAN EXPECTED.

ANALYSIS SHOWED WHEN SYSTEM OPERATIONAL IT AND TRIGGERING WORK EFFICIENTLY.

STEPHEN AND TEAM AND COLLABORATION MAKING IMPROVEMENTS.

TO GIVE STABLE SYSTEM FOR CHECKING BEFORE HYDROGEN SAFETY ZONE DECLARED,

ESSENTIAL MAJOR CHANGES FINISHED BEFORE END OF DECEMBER '86.

5. HOLOGRAPHY.

THE PROJECT OF TAKING ~10^5 HOLOGRAMS OF A LARGE VOLUME WITH HIGH RESOLUTION RELIABLY IS AT THE FRONTIER OF TECHNOLOGY AND PHYSICS.

THE FIRST RUN OF 1985 REVEALED A NUMBER OF PROBLEMS. MAJOR CHANGES HAVE BEEN MADE WITH A LARGE NEW DISPERSING LENS AND BAFFLES IN THE CHAMBER.

NEED TIME TO CHECK NO MAJOR PROBLEMS AND TO FIND OPTIMUM CONDITIONS.

— MICHAEL PETERS

LASER PULSE STRETCHING NOT YET RELIABLE.

NEED JON HAWKINS et al (+ GERT HARIGEL) TO FINISH. (NOV. + DEC.).

FIBRE REFERENCE BEAM IN HOLOGRAPHIC CAMERA – NEED KARL LINDENMEYER FOR DESIGN.

– MICHAEL PETERS

E 632 SUMMARY

1. WELCOME INCREASE IN BEAM ENERGY.

   IF NOT TOO MUCH TIME TO SETUP

   PRUDENT TO HAVE EXTRA SHIELDING AVAILABLE.

2. PROMPT OR EARLY START-UP NECESSARY FOR SOME LABS

3. EARLY COOL-DOWN OF BUBBLE CHAMBER IMPORTANT TO CHECK MANY CHANGES MADE.

4. MAJOR CHANGES TO EMI SHOULD BE FINISHED BY END OF DECEMBER.

5. NEED COOL-DOWN TO CHECK AND OPTIMIZE HOLOGRAPHY UNDER OPERATIONAL CONDITIONS.

6 NEED JON HAVKINS FOR RELIABLE PULSE STRETCHING.

7. NEED KARL LINDENMEYER TO DESIGN FIBRE HOLOGRAPHIC CAMERA.

21/10/86
P. MARAGE

PHYSICS AIMS AND ANALYSIS.

1. NEW, UNEXPECTED PHENOMENA.
2. COHERENT F, F^*, F_A^* ($c\bar{s}$) PRODUCTION.
3. LIKE-SIGN DILEPTONS ($\mu e, \mu\mu$)
4. DIRECT OBSERVATION OF CHARM DECAYS (F, Λ_c)

RARE EVENTS
- FOR WHICH BUBBLE CHAMBER IS A POWERFUL TOOL
- HOLOGRAPHY.

+ FILM IMAGE DIGITIZING (cf E743)

SEVERAL DIFFERENT SCANNING/MEASUREMENT PROCEDURES (AND MUCH PHYSICIST TIME...).

1. NEW PHENOMENA

PHYSICIST "ZOO" SCAN

"CIA" (CLOSE-IN ACTIVITY) SCAN

→ HOLOGRAPHY.

SLOWLY ACCUMULATING;
NEED CAREFUL BG. CALCULATIONS.

2. COHERENT PRODUCTION

CLEAN, LOW TOPOLOGY EVENTS

2 AND 4 PRONG MEASUREMENT

3. DILEPTONS

$\mu\mu$ SEE F. HARRIS

μe e SEARCH AMONG CIA

4. CHARM : CIA.

NORMAL SCAN

VERTEX MEASUREMENT → HOLOG., $\mu\mu$

2 & 4 PRONG MEASUREMENT

LEAVERS MEASUREMENT FOR $\mu\mu$

CIA SCAN

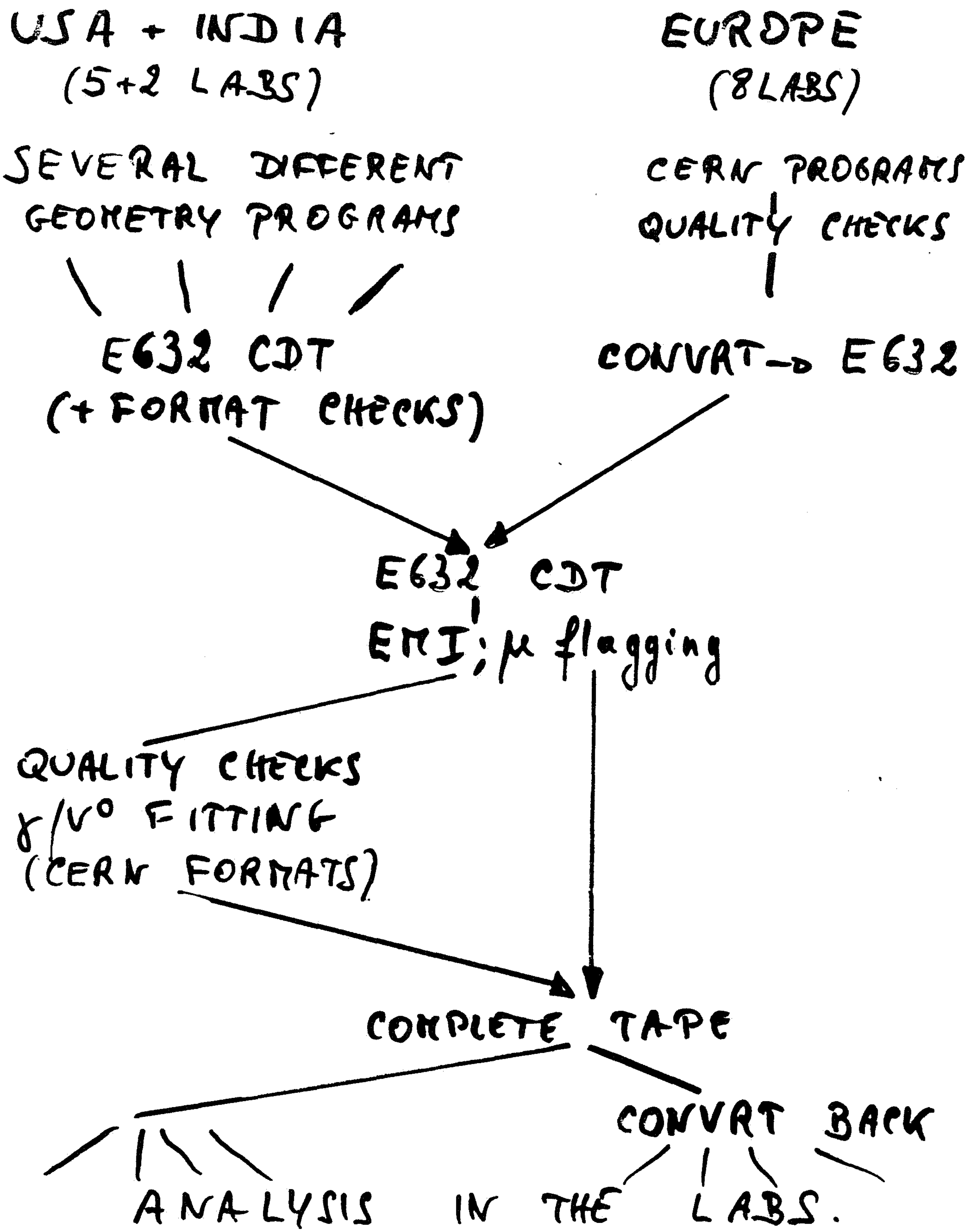
ZOO SCAN

$\mu\mu$, CIA, ZOO MEASUREMENTS

UNBIASED SAMPLE MEASUREMENT

SOFTWARE

(AND COORDINATION ...)



F, F* COHERENT PRODUCTION ON NEON NUCLEI.

1 - PRESENTATION

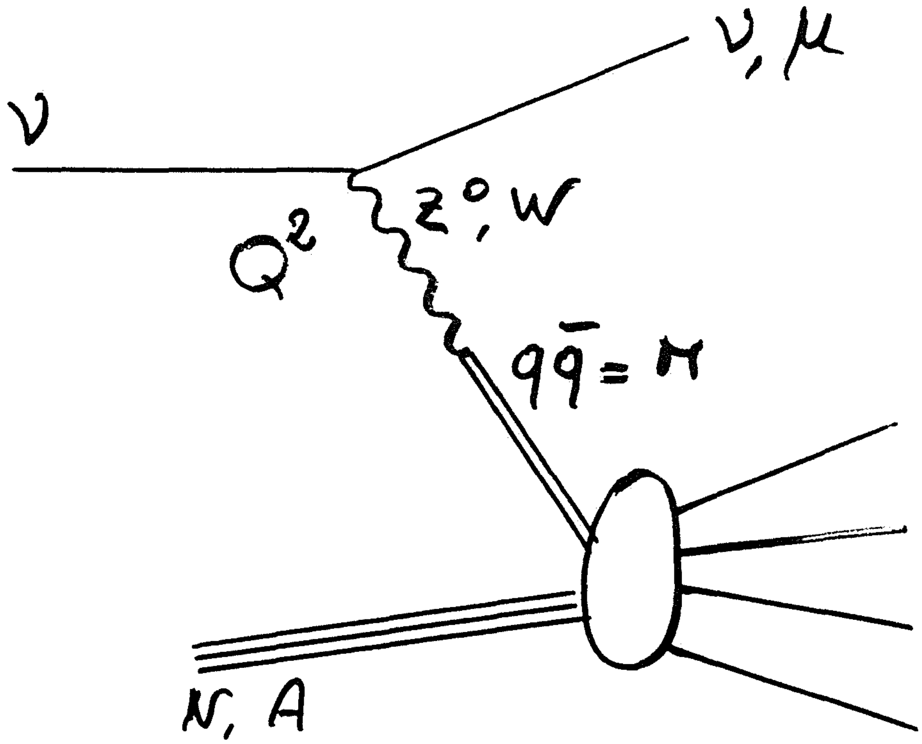
- INCLUSIVE SIGNAL (E632 ~ 1.5 10^{17} p)

2 - EXCLUSIVE CHANNELS
- SINGLE PION
- ρ MESON } BEBC $\bar{\nu}$

↳ TEST THEORY, FIX PARAMETERS

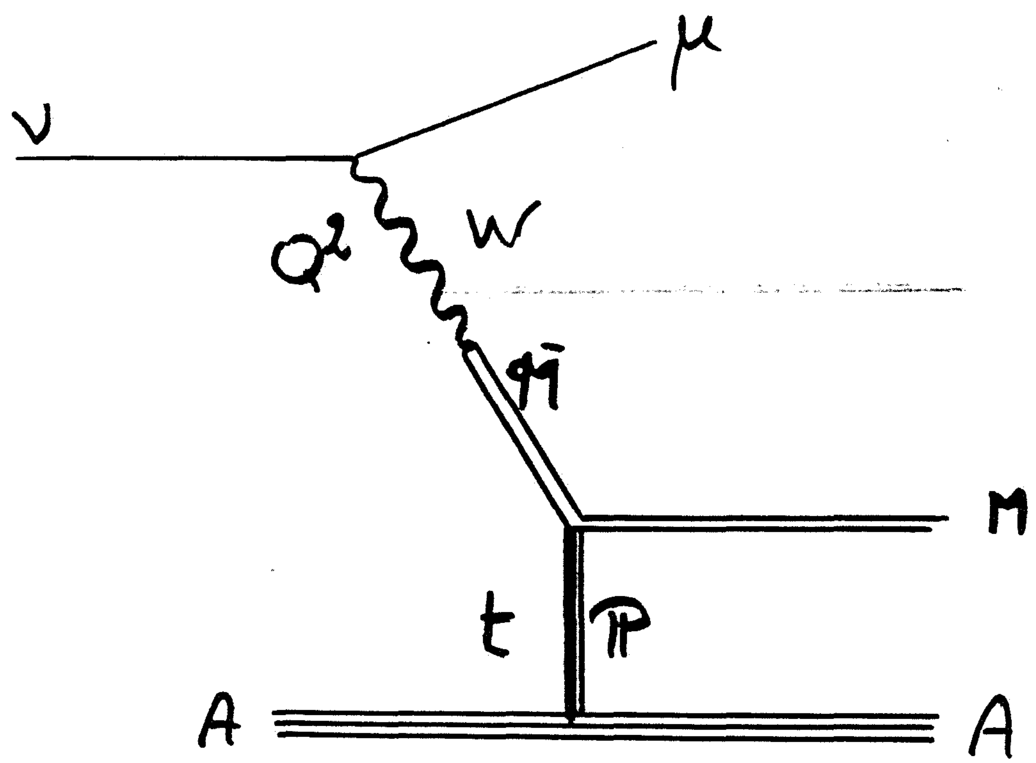
3. PREDICTIONS FOR F, F* IN NEW RUN

MESON DOMINANCE cf γ: VMD.



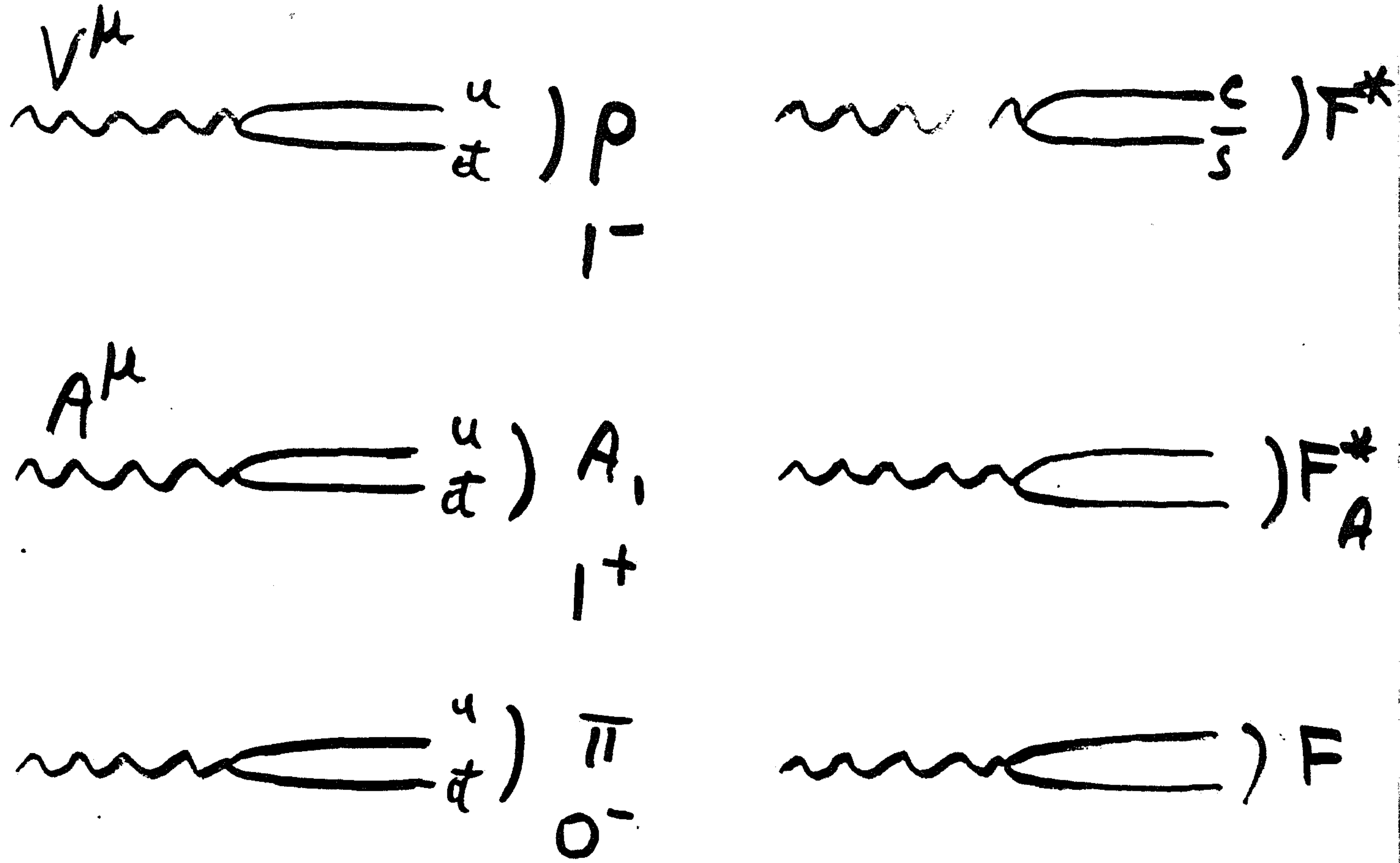
- TOTAL σ
- SHADOWING
- ?

COHERENT INTERACTIONS



WHICH $q\bar{q}$ STATES?

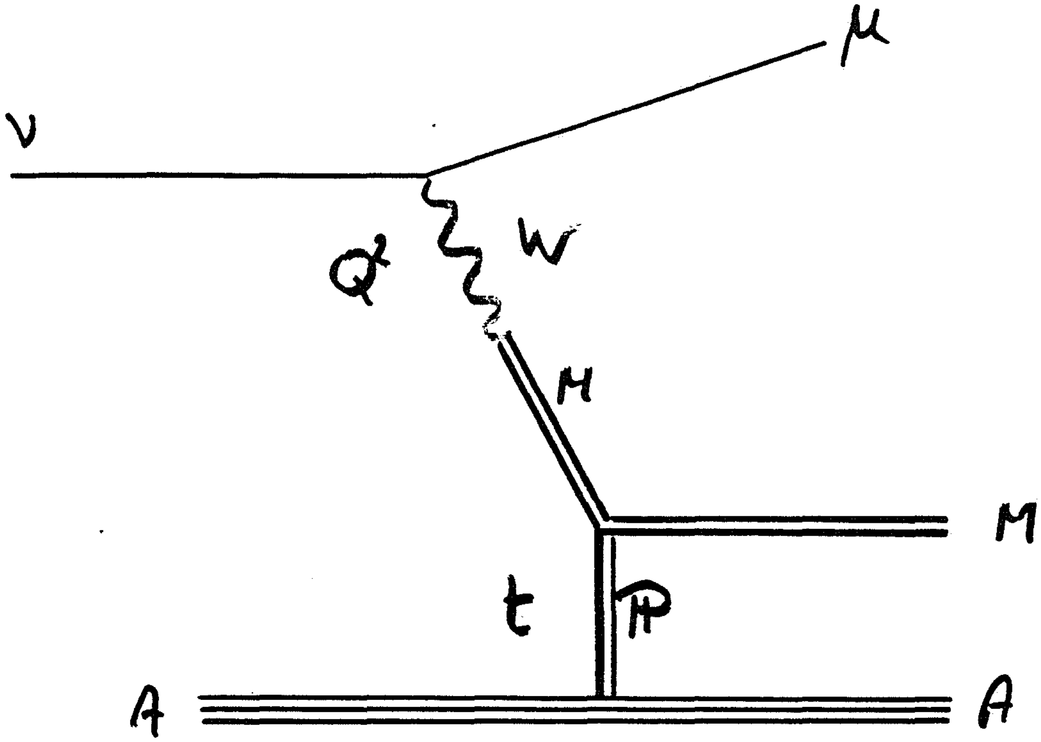
$$W^\mu = V^\mu + A^\mu$$



PCAC: $A^\mu \sim \partial^\mu \phi$

↑ STUDIED/ SEEN IN BEBC

↑ TO BE FOUND IN 15'



CHARACTERISTICS

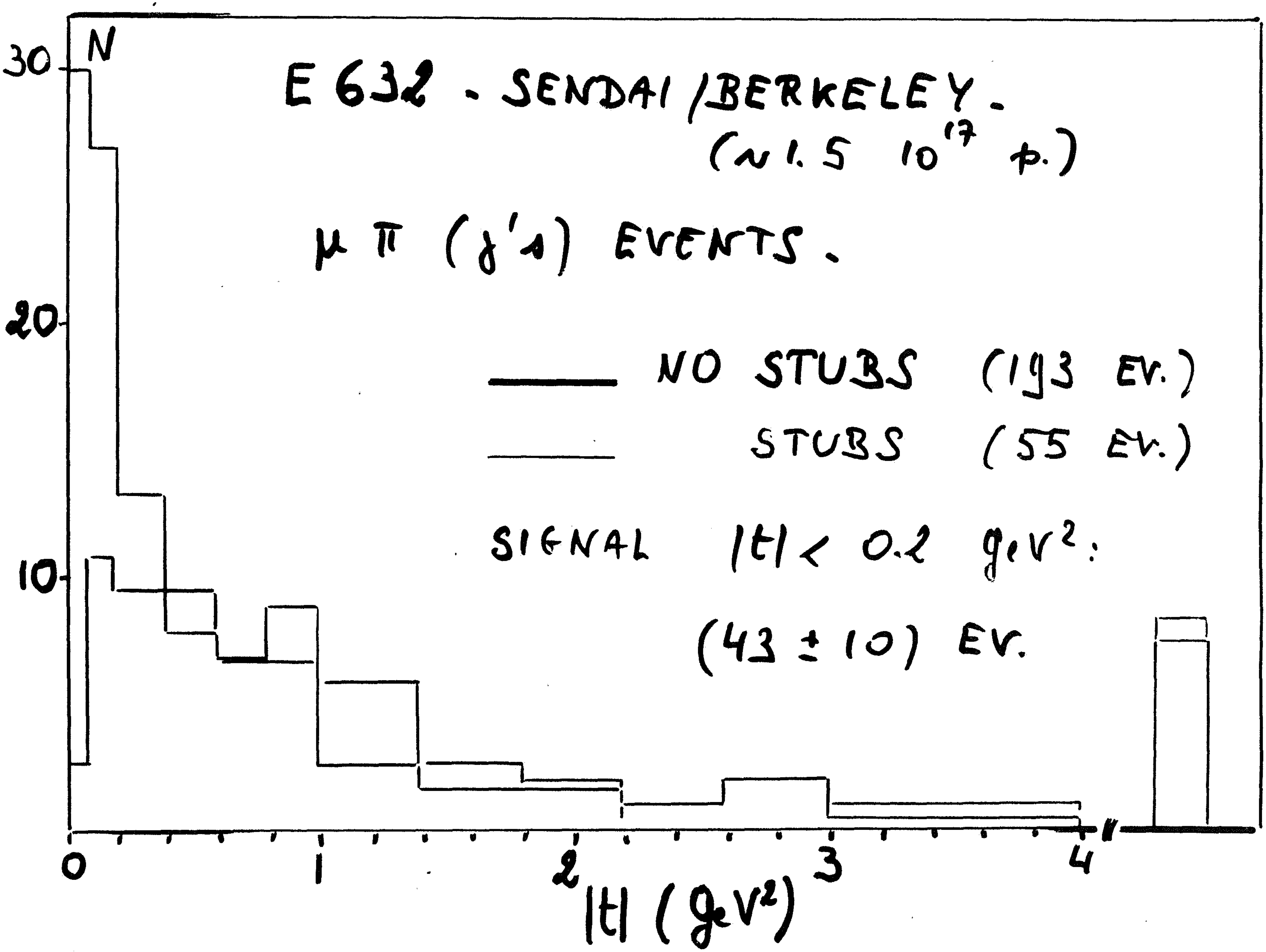
1. NUCLEUS UNDETECTED

$Q_F = 0$, n_c EVEN

2. NO NUCLEONS EMITTED,
NO STUBS.

3. LOW $|t|$:

$$\frac{d\sigma}{dt} \sim e^{-b|t|}, \quad b \sim R^2$$

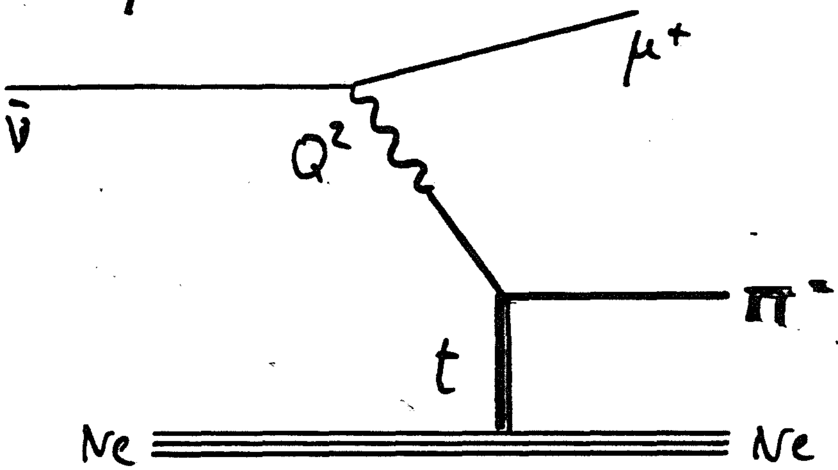


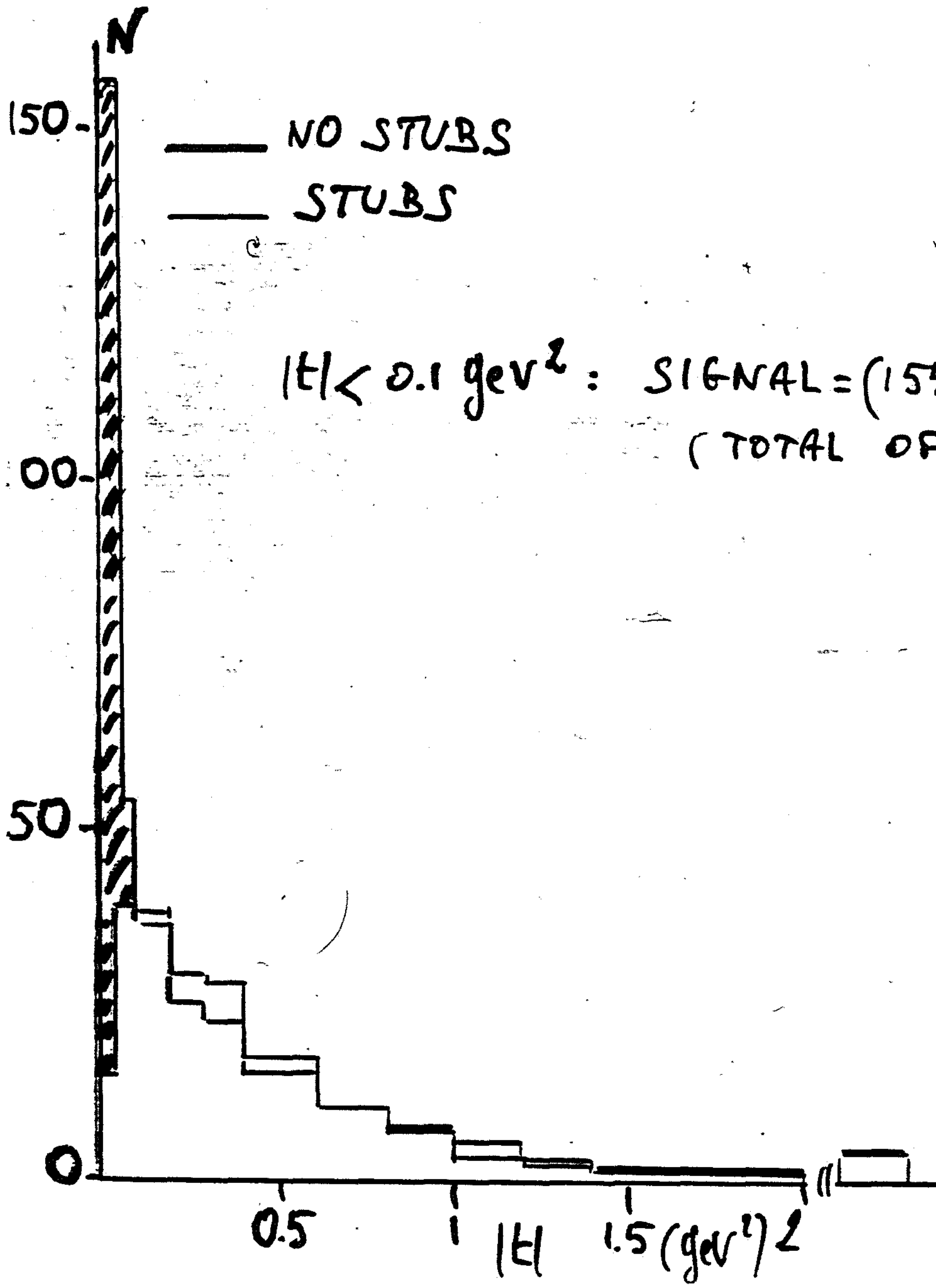
N
E 632 - SENDAI / BERKELEY -
(~1.5 10^17 p.)
μ π (γ's) EVENTS.
NO STUBS (193 EV.)
STUBS (55 EV.)
SIGNAL |t| < 0.2 GeV²:
(43 ± 10) EV.
30
20
10
0
1
2
3
4
|t| (GeV²)

EXCLUSIVE CHANNELS (BEBC $\bar{\nu}$)

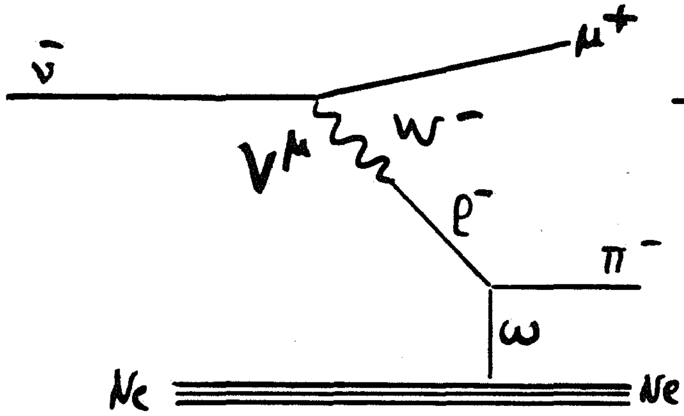
1. SINGLE PION COH. PROD.

$\mu^+\pi^-$ EVENTS, NO STUBS



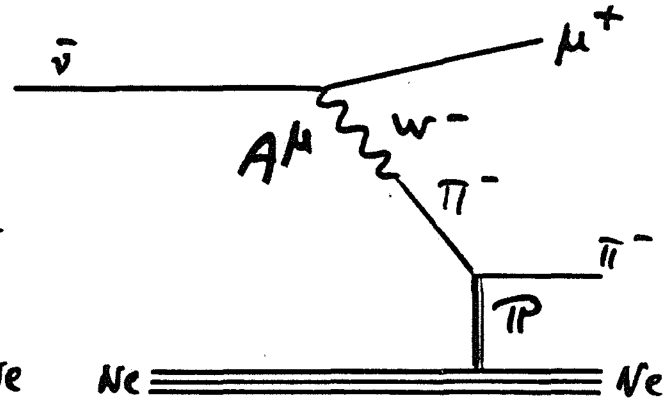


PRODUCTION MECHANISMS.



SUPRESSED:

- $= 0$ AT $Q^2 = 0$ (CVC)
- AT $Q^2 \neq 0$: ω-EXCHANGE
  $\Downarrow$ AT LOW $|t|$

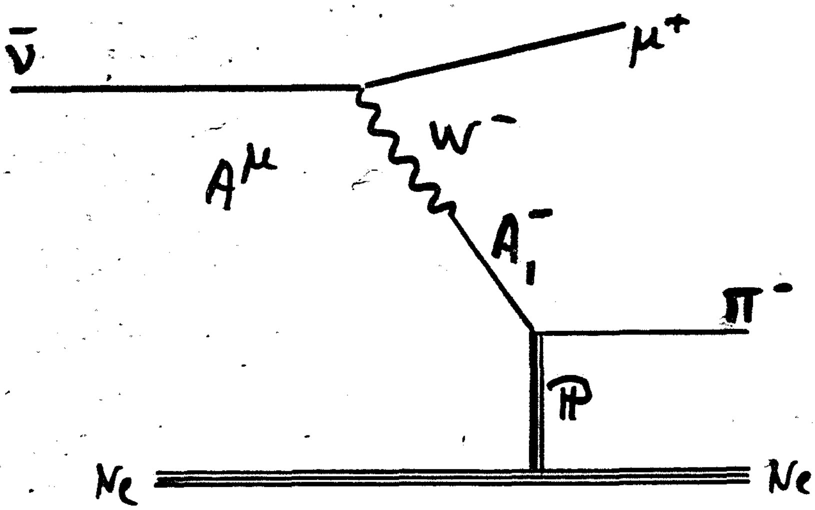


SUPRESSED:

$J^\mu \sim \partial^\mu \phi$

$T \sim J^\mu J^\nu \mathcal{L}_{\mu\nu}$

m_μ^2 (DIRAC)



AT $Q^2 = 0$:

- HELICITY CONSERVATION . A_{1L} ——— π ———
- ADLER'S THEOREM (PCAC):

$$T(\nu N \to \mu X) \sim T(\pi N \to X)$$

$$f_{W - A_{1L}}^{Q^2 = 0} \simeq f_\pi$$

AT $Q^2 \neq 0$: $\sigma \sim f_\pi^2 \left(\frac{m^2_{A_1}}{m^2_{A_1} + Q^2} \right)^2$ TEST $\begin{cases} Q^2 \text{ DEPENDANCE} \\ \text{ABSOLUTE } \sigma (\sim f_\pi) \end{cases}$

CROSS SECTION :

$$\frac{d^3\sigma}{dQ^2\, d\nu\, dt} = \frac{G^2}{2\pi^2} f_\pi^2 \frac{1-y}{\nu} \left(\frac{m_A^2}{m_A^2+Q^2}\right)^2 \times$$

$$\frac{d\sigma(\pi Ne \to \pi Ne)}{dt}$$

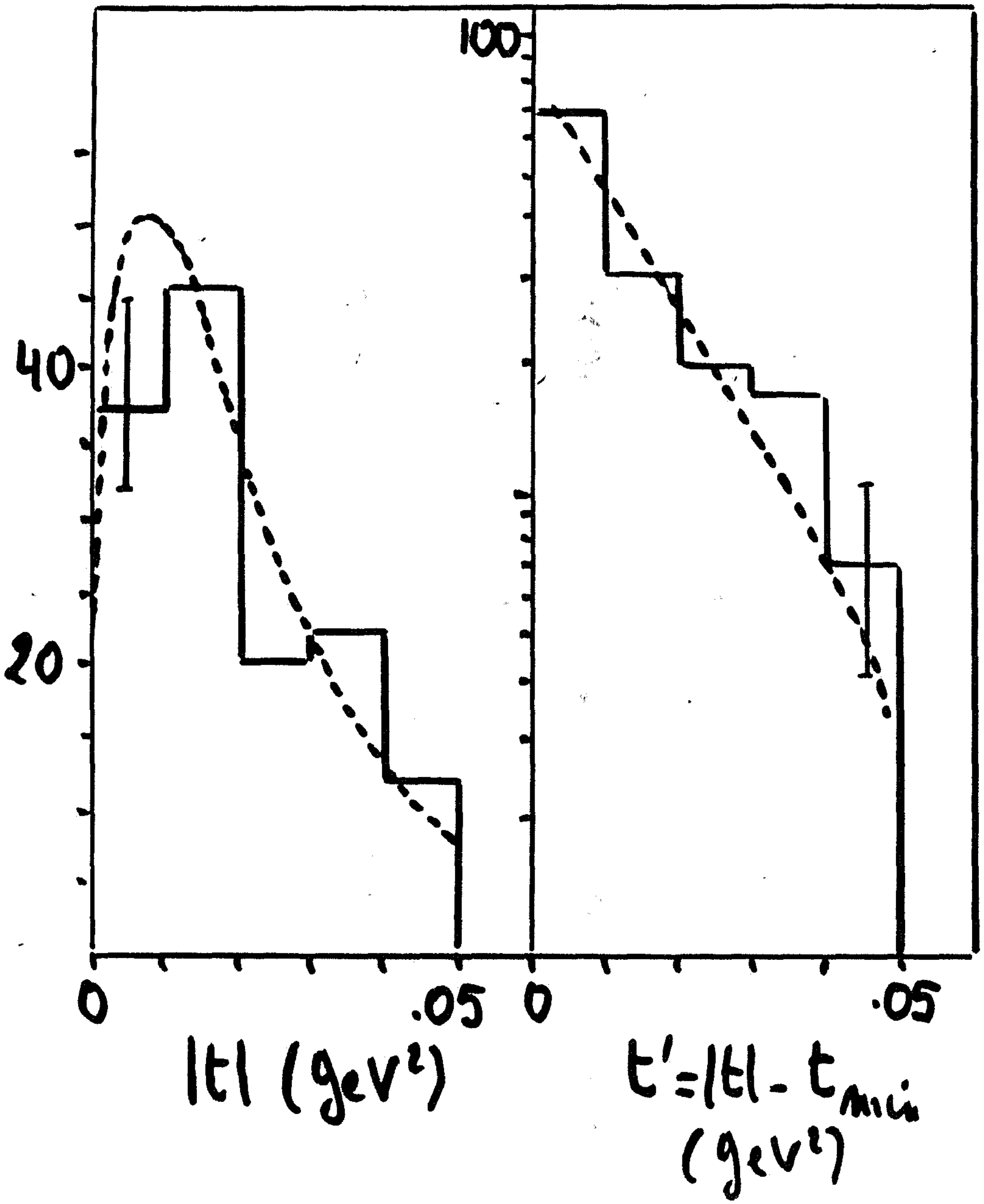
WHERE

$$\frac{d\sigma(\pi Ne \to \pi Ne)}{dt} = \frac{A^2}{16\pi} \sigma_{tot}^2(\pi N)\, e^{-b|t|} F_{abs}$$

$$b = \frac{1}{3} R^2 \quad \longleftarrow$$

$$F_{abs} \quad \longleftarrow$$

AND NB $t_{min} \sim \left(\frac{Q^2+m^2}{2\nu}\right)^2$



π^- COHERENT PROD. (BEBC)

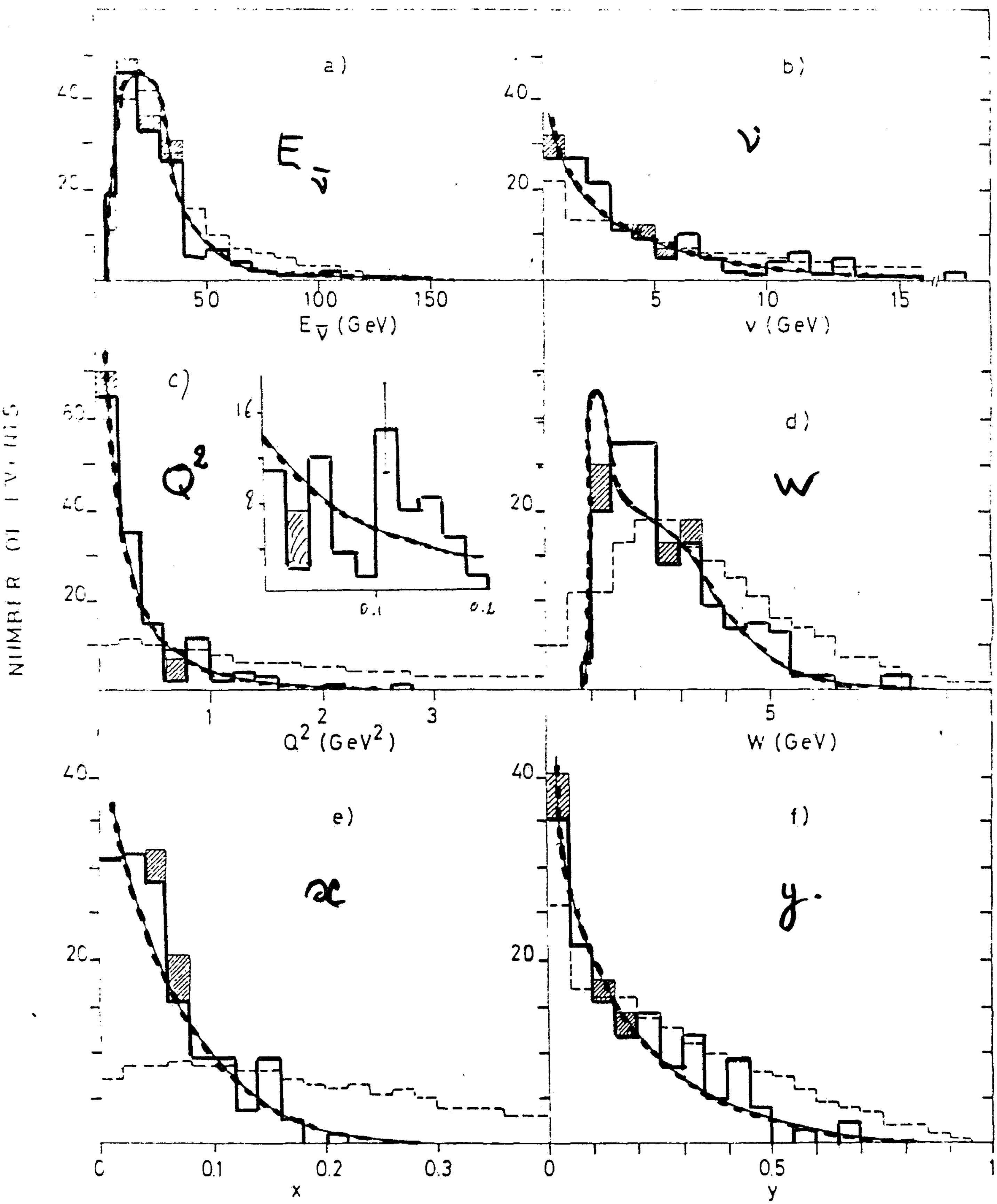
--- MODEL PREDICTIONS

EXP. : $R = (2.8 \pm 0.3)$ fm

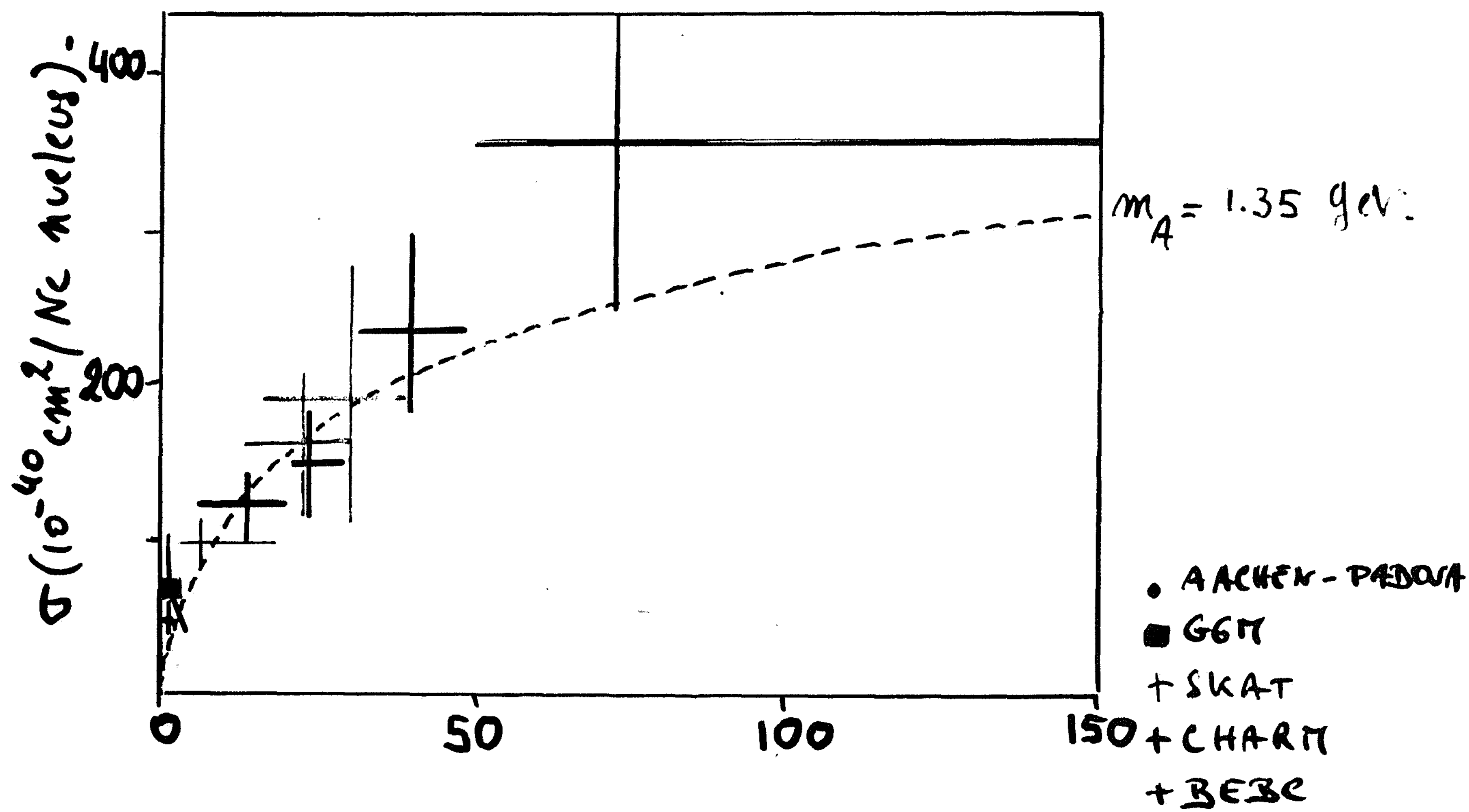
MEASURED (e scatt.): $R = 3$ fm.

SINGLE π⁻ COHERENT PRODUCTION

--- THEORETICAL PREDICTIONS -

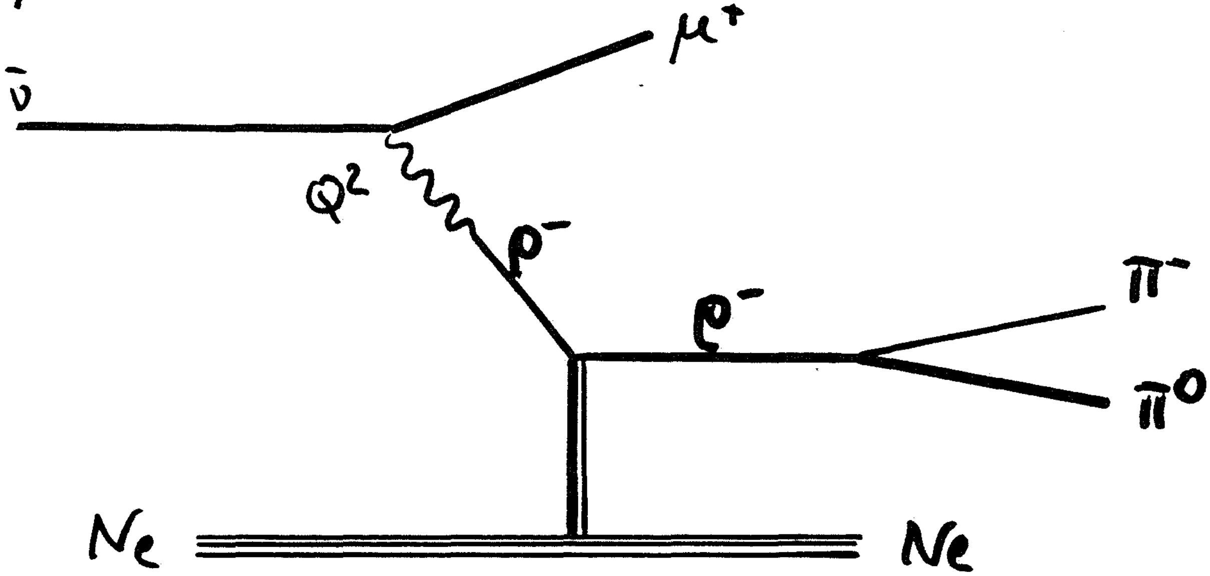


SINGLE π COHERENT PRODUCTION

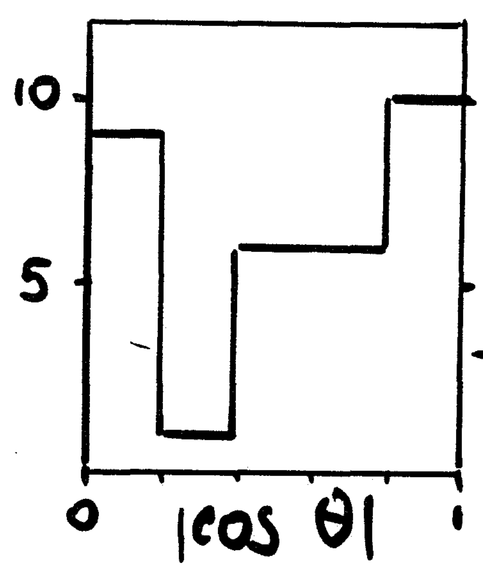


2. ρ^- MESON COHERENT PRODUCTION

$\mu^+ \pi^- \pi^0$ EVENTS - NO STUBS -



BEBC : (28 ± 8) EV. OBSERVED.



$f(\theta) \sim \sin^2\theta$: PURE T

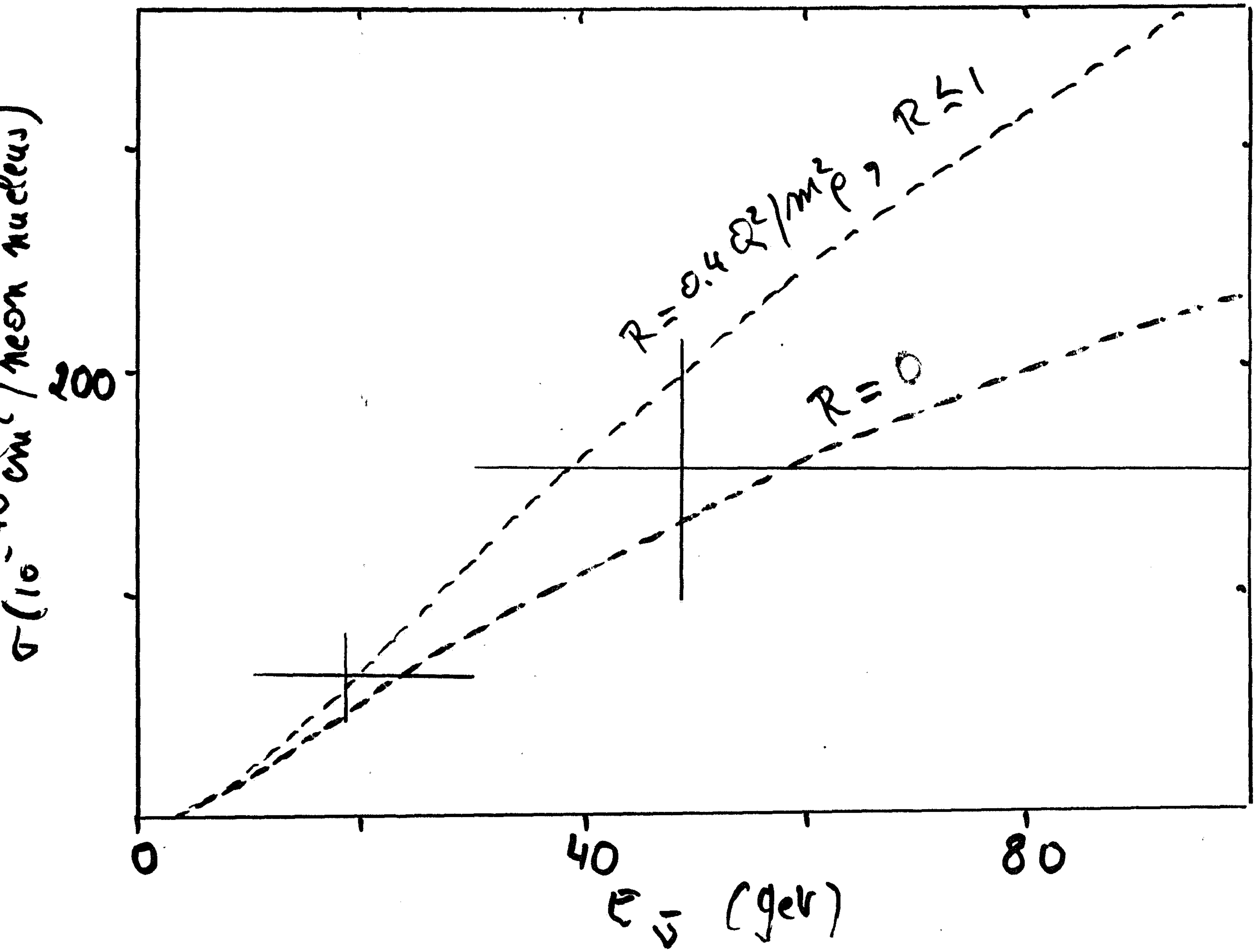
$\sim \cos^2\theta$: PURE L

→ SIZEABLE LONG. ρ PRODUCTION :

$$\sigma^{COH} \sim {\sigma^T_{tot}}^2 \, (1 + R)$$

$$R = \frac{\sigma_L}{\sigma_T}$$

ρ⁻ COHERENT PRODUCTION (BEBC).



IN SUMMARY:

$$\sigma^{COH} = C \cdot F(E_\nu, \nu, Q^2) \cdot \frac{d\sigma^{EL.}}{dt}$$

DIFFERENT TH. FIXED

$$\frac{d\sigma^{EL}}{dt} = \frac{A^2}{16\pi} \sigma^2_{tot} \; e^{-b|t|} \; F_{abs}$$

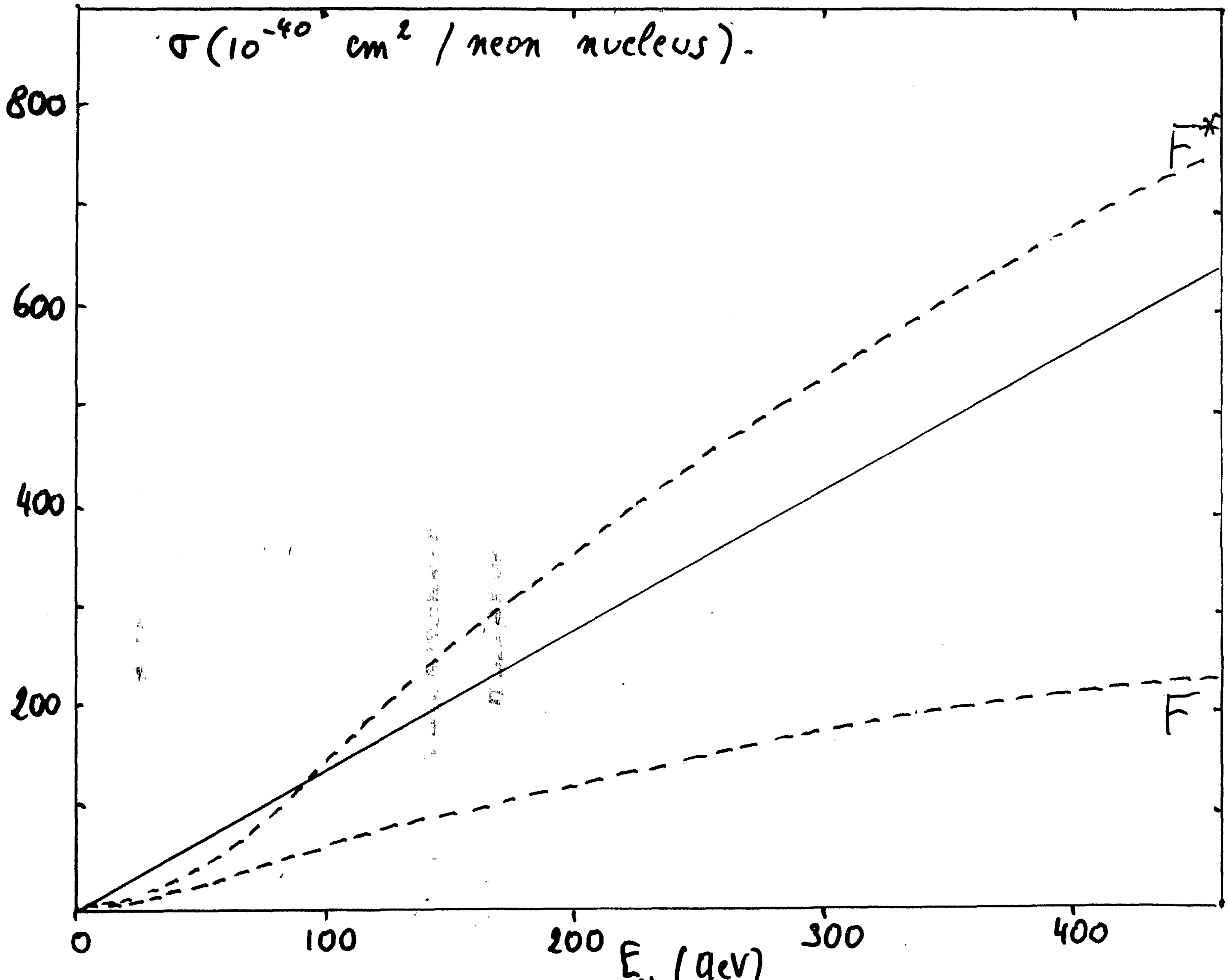
TESTED / FIXED

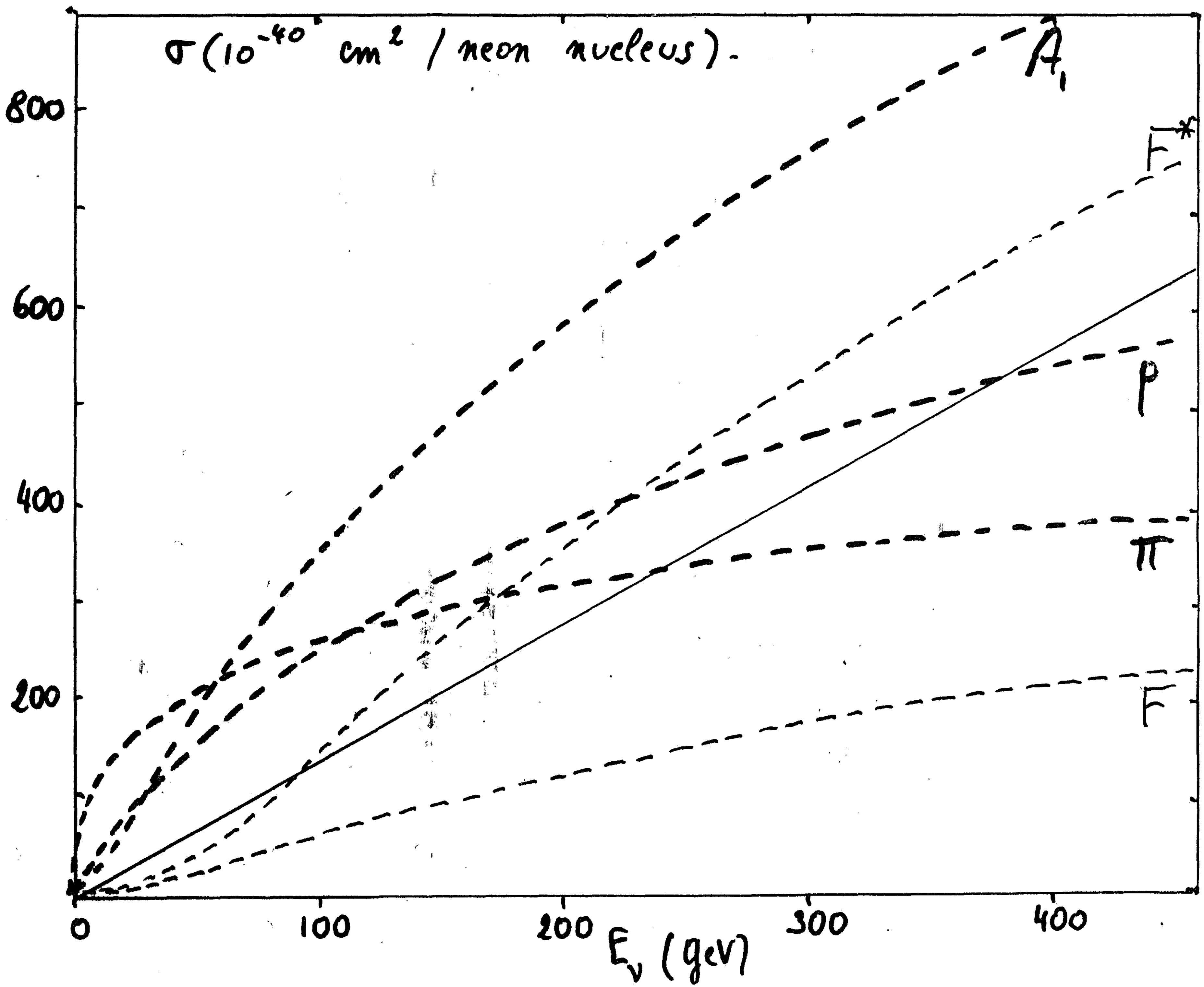
→ - CLEAN LOW MULTIPLICITY EVENTS

- CONTROL OF THE BACKGROUND (EVENTS WITH STUBS)

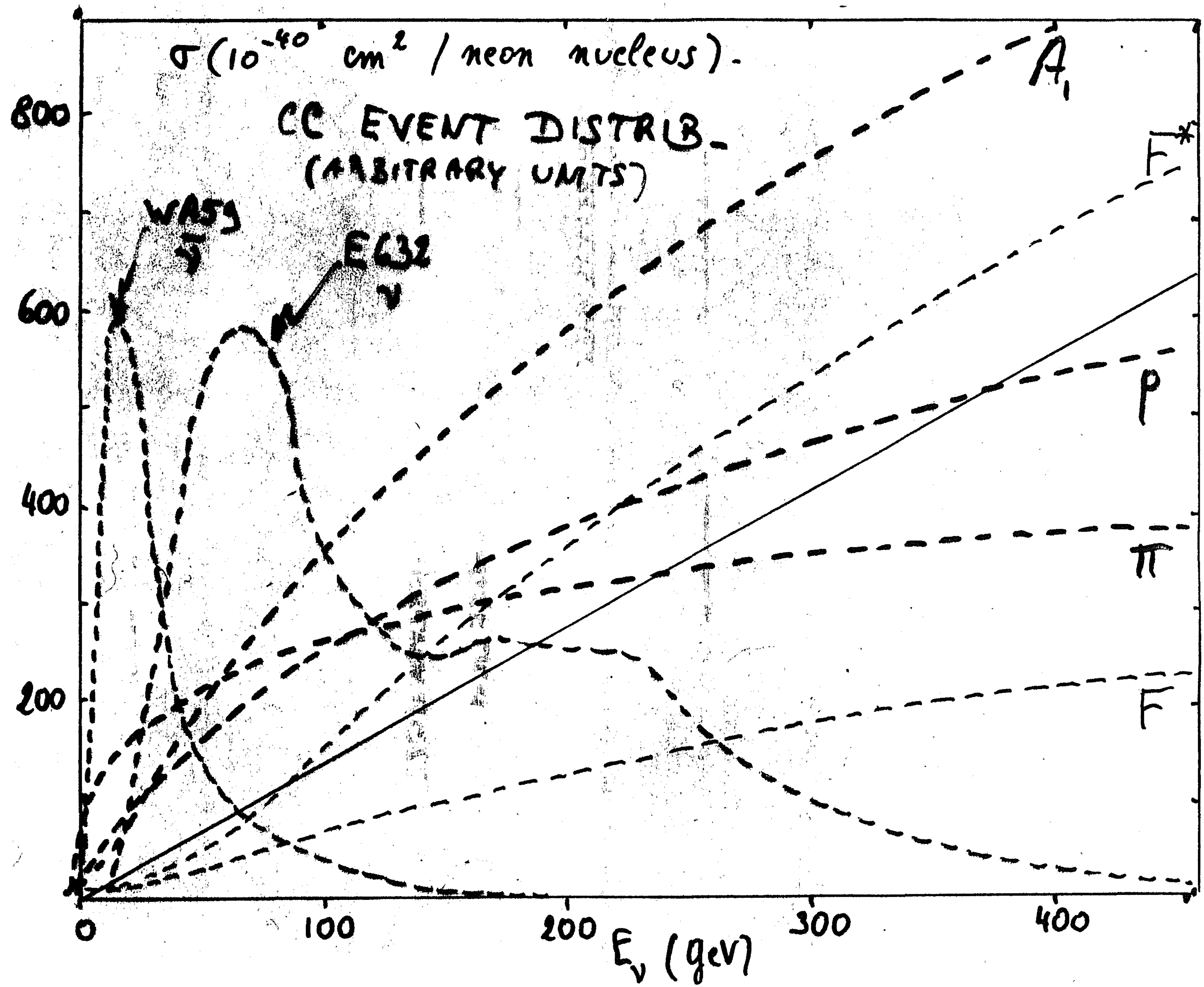
- TESTED / FIXED THEORETICAL PREDICTIONS

∴ CONFIDENT FOR F, F^*, F^*_A


σ (10^-40 cm^2 / neon nucleus).
800
600
400
200
0
100
200
300
400
E_ν (geV)
F*
F



σ(10⁻⁴⁰ cm² / neon nucleus).
800
600
400
200
0
100
200
300
400
E_ν (geV)
A₁
F*
ρ
π
F


σ (10^-40 cm^2 / neon nucleus).
CC EVENT DISTRIB.
(ARBITRARY UNITS)
WA59
E632
A1
F*
P
π
F
800
600
400
200
0
100
200
300
400
Eν (GeV)

EXPECTED F, F*

COHERENT PRODUCTION

PER $\left\{ \begin{array}{l} 5\ 10^{17}\ p \\ 800\ \text{GeV} \end{array} \right.$, i.e. 25000 C.C. ($\bar{\nu}/\nu = 14\%$)

$\sigma(F, F^* \cdot N) = 10$ mb.

$f_F = 2 f_\pi$

$\sigma_L(F^*) = 0$

⟶

30	F*
6	F

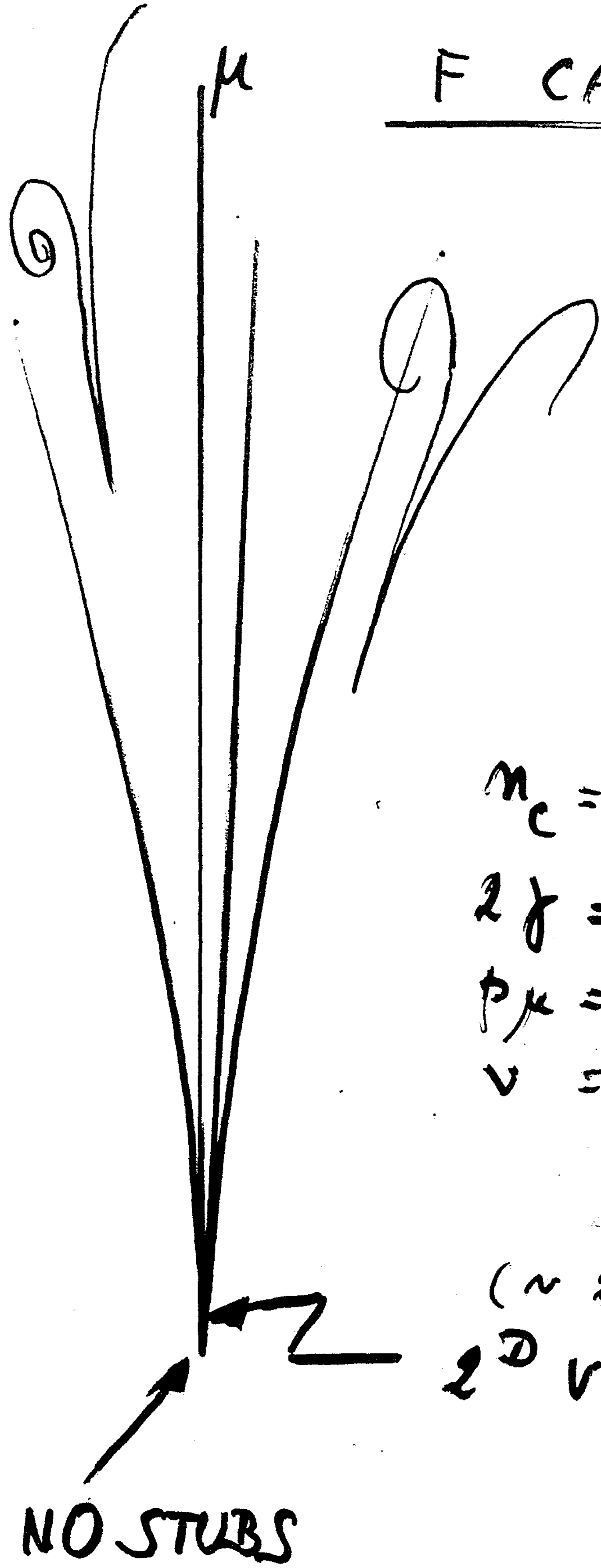
N.B. 48 π, 48 ρ, 64 A_1

RANGE: 50% HAVE RANGE > 3 mm

25% > 6 mm.

($\tau = 3.5\ 10^{-13}$ sec.)

F CANDIDATE



$n_c = 4$

$2\gamma = \pi^0$

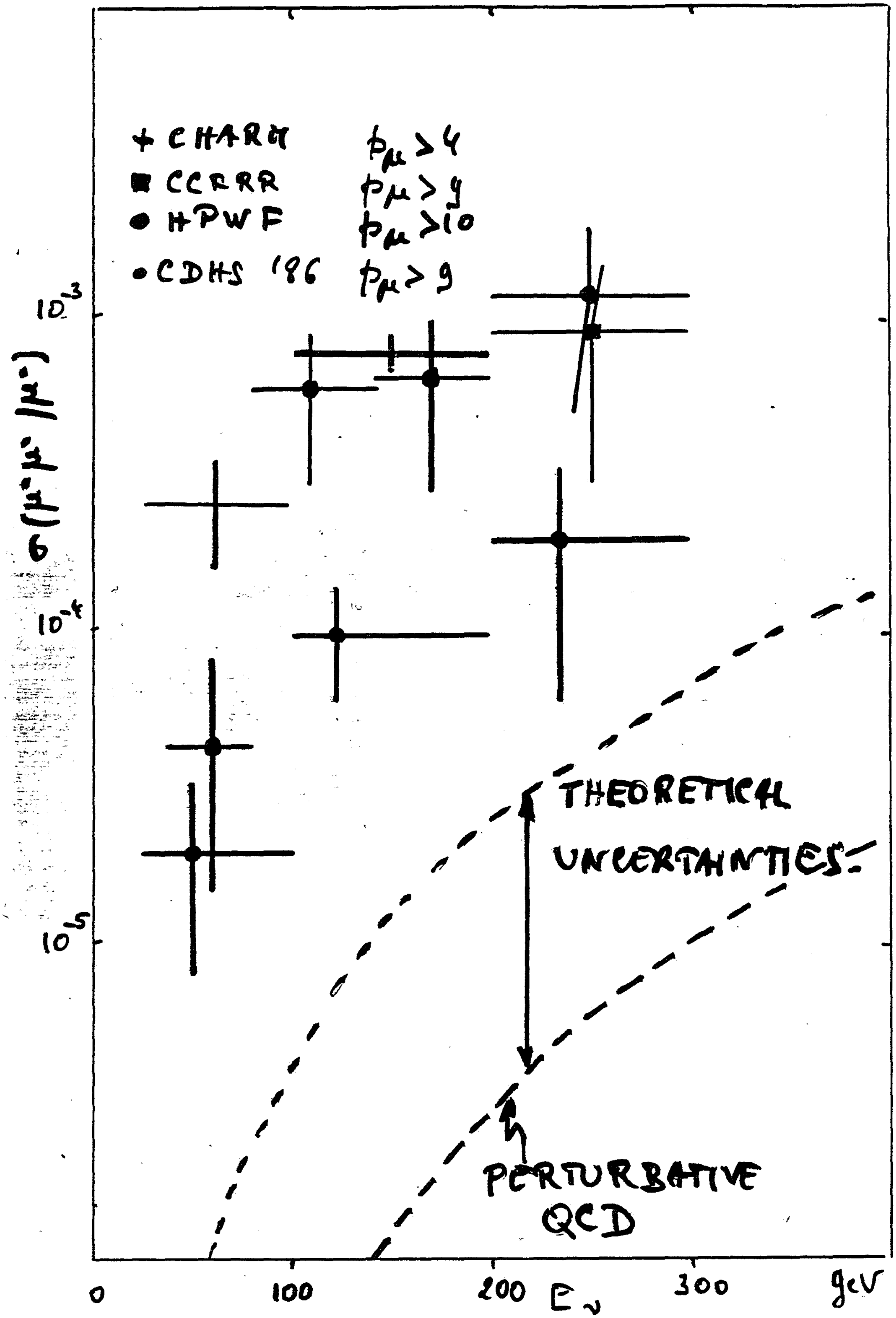
$p_\mu = 175$ GeV

$\nu = 35$ GeV

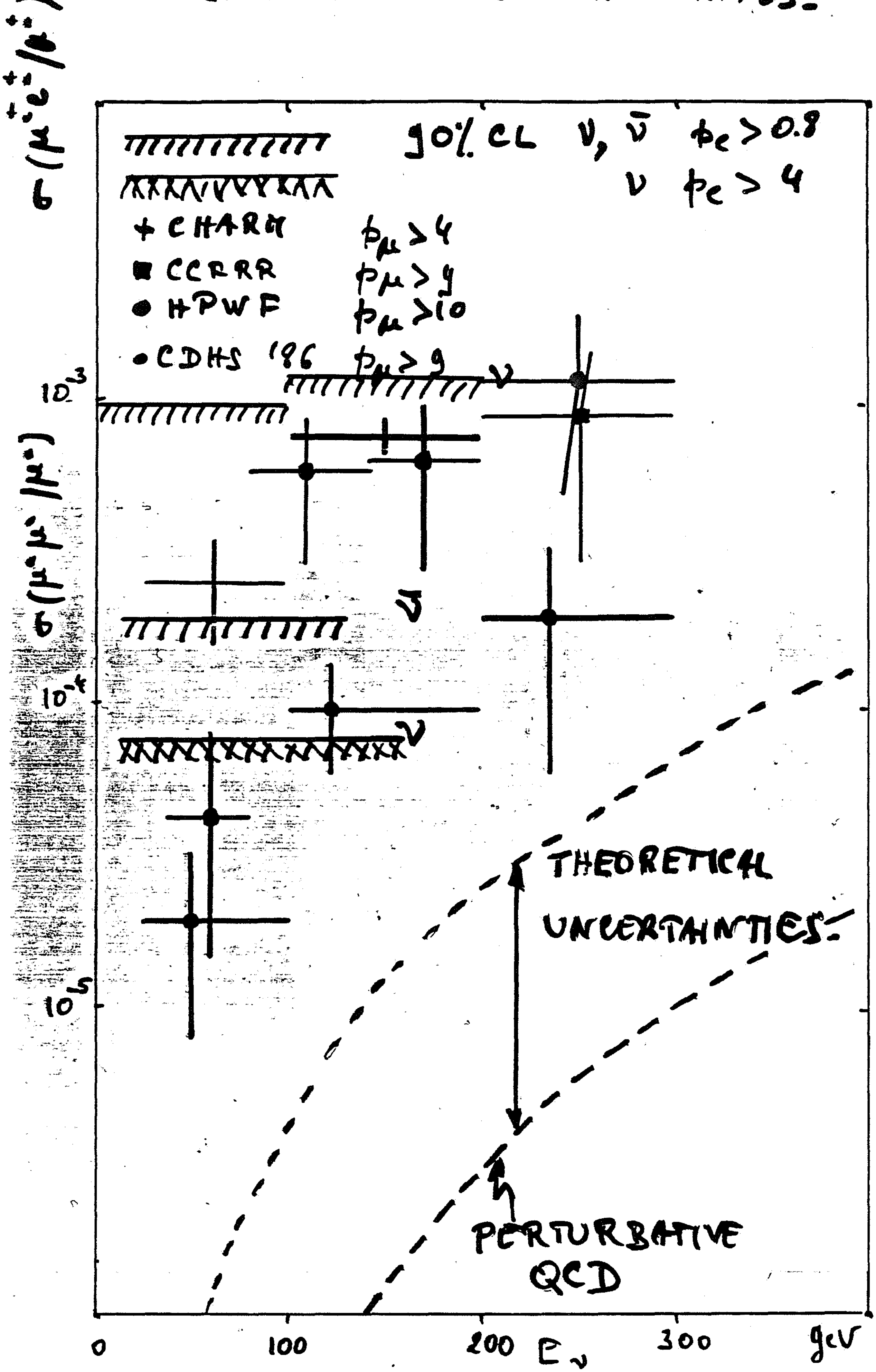
$|t| = 0.09$ GeV^2

$m(\pi^+ K^+ K^- \pi^0) = 1.957 \pm 0.057$ GeV

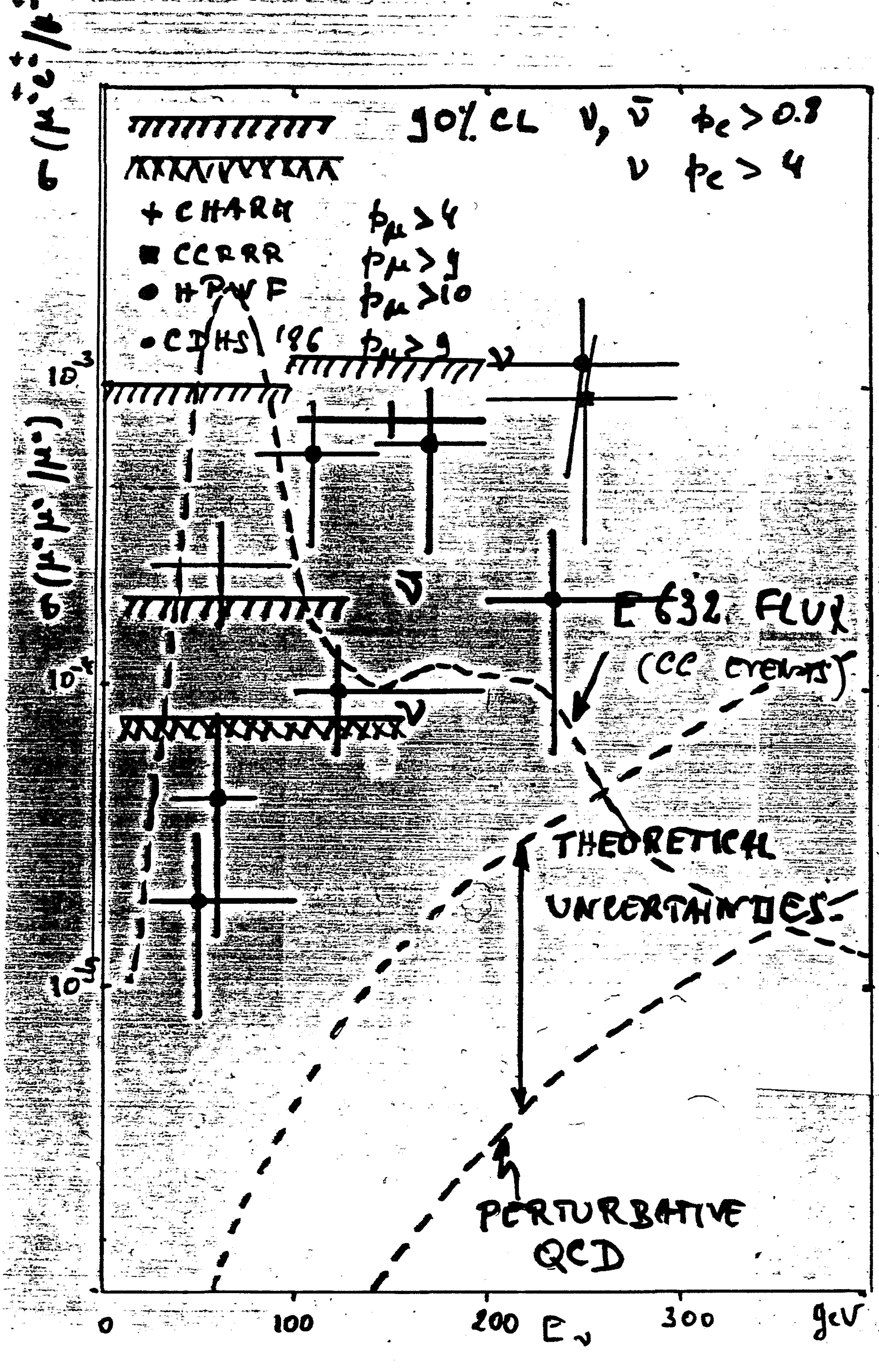
LIKE-SIGN DILEPTON RATES.



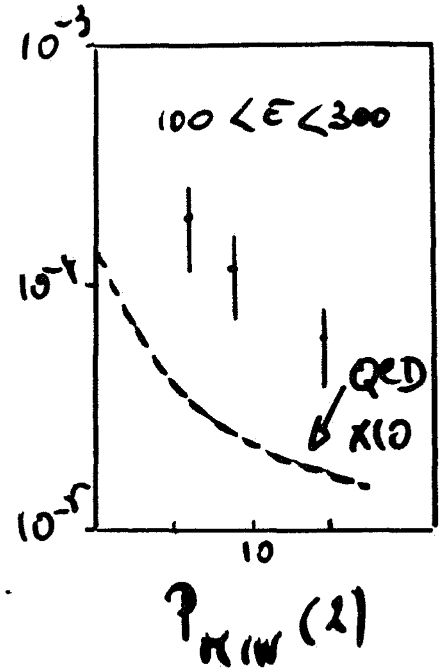
LIKE-SIGN DILEPTON RATES.



LIKE-SIGN DILEPTON RATES.



STRONG EFFECT OF SECOND LEPTON MOMENTUM CUT :



CDHS - $100 < E_\nu < 300$:

$$\sigma\Big|_{P_{MIN}=1} = \sigma\Big|_{P_{MIN}=9} \times 4$$

NEW RUN

∴ NUMBER $\mu^- e^-$, $P_{e^-} > 1$ GeV, for $5\ 10^{17}$ p: (800 GeV)

- CDHS - 10-12 EVENTS

- HPWF/CCFRR (SLIGHTLY LESS STEEP P_{MIN} EFFECT):

20-40 EVENTS

BACKGROUND ESTIMATED ~20 EV. (MAINLY COMPTON)

∴ 15'
- 10-30 / 20 BG   CDHS: 60 EV. / 200 BG !
- DETAILED KINEMATIC STUDIES
- V^0 RATES
- SECONDARY VERTICES ← (HCL)

IN SUMMARY:

FOR $\begin{cases} 5\ 10^{17} \text{ PROTONS} \\ 800 \text{ GeV} \end{cases}$

($\times$ 1.3 IF $\rightarrow$ 900 GeV) :

- COHERENT F, F^* PRODUCTION:

  6 F

  30 F^* 30 F_A^*

  [$f_F = 2 f_\pi$; $\sigma(F, F^* - N) = 10\ \mu b$; $\sigma_L = 0$]

- LIKE-SIGN μe :

  10 - 30 $\mu^- e^- + \mu^+ e^+$ $p_e > 1$ GeV

  BACKGROUND = 20 CONV. OPTICS

  $\downarrow$

  OBSERVE DECAYS : HOLOGRAPHY.

15 ft Bubble Chamber

Work done since last run, which finished in Sept 1985

Descale Compressor Heat Exchangers
Rebuild Compressors
Rework Z-Section Flex Lines (vacuum leak)
Helium Liquefier
- redesign gas engine warm end
- repair tubine vacuum leak
- test run - observed new leak to vacuum
- found and repaired leak

Commission new Neon Hydrogen Dewar (E tank)
Dewar Refrigerator Repair (vac leak) + operation
Removed entire Expansion System from pit (needed to repair chamber leg foundation)
Replaced grout under Chamber legs
9" expansion valve inspection
Rebuilt and tested expansion system pilot values (Ross valves)
Progress on electronics work list
Holography
- designed and tested optical relay for laser beam
- installed ~70% of baffles inside B.C.

15' B.C. work done (Con't)

Repaired N_2 to H_2 leak in main Hydrogen Refrigerator (cooling loop plugs)

Gas analysis improvements

Repaired Nitrogen Dewar (leak to vacuum)

Crew manpower - very good.

We were allowed to hire people for all vacant positions - including a replacement for someone who will retire in Dec 86 - before the Fermilab hiring freeze started on Sept 1, 1986

Major Jobs to do before Run

done ~~Chamber leg foundation - pour new grout this week~~
Replace "permanent" part of expansion system in pit
Test run hydrogen refrigerator (after heatexchanger repair
done ~~Locate and repair leak in Helium Cold Box~~
(~~found after 1st Test run~~)
Install 2nd Mycom Helium Compressor (for muon lab)
Install high pressure Helium recovery compressor
Build + install bayonet box for Helium liquid engine
Test run Helium Liquefier (again)
Clean, reassemble + install chamber optics windows
Finish baffles
Fiber optics holographic camera
Hydrogen fill for windows on cooldown (was N_2)
Clean optics vacuum hoses + manifolds
Mount for combined laser window/dispersing lens
Recoat laser windows
Replace "Tee" with new laser beam monitoring system
Instrument repair/calibration
Electronics worklist
re-scotchlite entire chamber
survey fiducials
assemble chamber and expansion system

W. M. Smart Oct 20, 86

Summary of technician work needed on 15 ft. Bubble Chamber before starting shifts for E632 physics run.

As of Sept 22, 1986:

Mechanical work	Manweeks	
Hydrogen System	17.5	
Helium System	68.0	
Expansion System	27.2	
Optics / Holography	73.0	
Cooling Water System	7.5	
Vacuum System	7.0	
General	87.0	
Total Mechanical	287.2	manweeks
Electronics work	96.8	manweeks

Have 15 Mech Techs $\frac{287.2}{15}$ = 19.15 weeks work

Have 6 Elect Techs $\frac{96.8}{6}$ = 16.1 weeks work

	Calendar weeks	Holidays	Work weeks
Sept 22, 86 to Jan 12, 87	16	-1.5	14.5
Sept 22, 86 to Feb 2, 87	19	-1.5	17.5

Mech Tech work on E706 Argon Calorimeter since Sept 22 will add about 15 mw or about 1 Calender week to schedule.

W. H. Smart Oct 20, 86

Comments on Specific Items

Chamber legs

Bubble Chamber vessel is supported independently from vacuum tank (and magnet). B.C. legs have ~1 inch of grout between steel base plate and concrete floor. This grout contained iron particles which had rusted, causing the grout to crack. Measurement of the fiducials in July 84 and Dec 85 indicate:

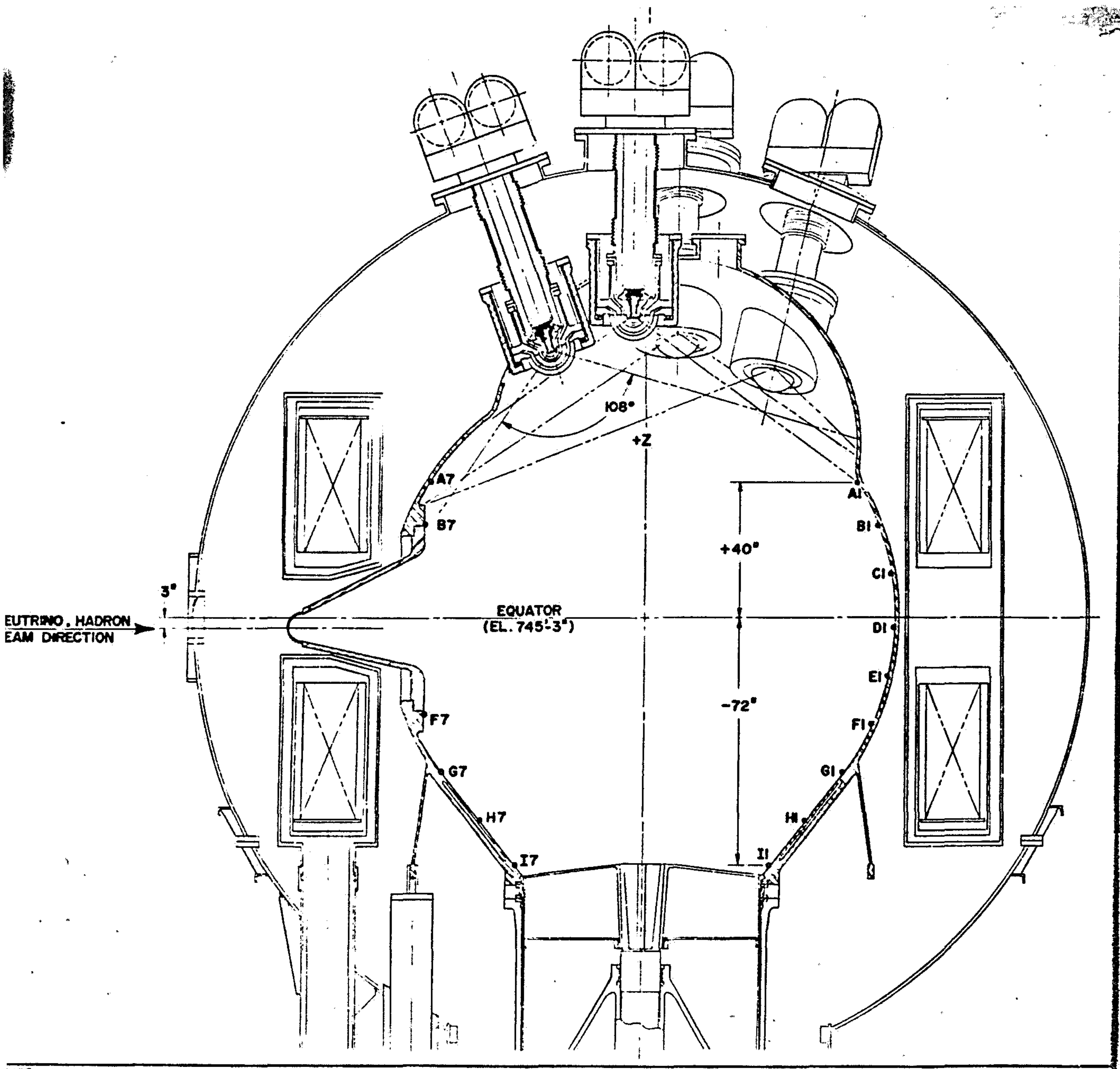
East leg - assume fixed
NW leg down 0.060 inch
SW leg down 0.143 inch

causing a movement projected to the top of the vacuum tank of 0.567 inch.

Chamber legs were supported on jacks, the old grout removed, and new (improved) grout poured between the leg base plates and the concrete.

Baffles

Needed to catch the ruby laser light after it has gone across the chamber once. Basically they are sets of black anodized Al venetian blinds. Those which cover scotchlited areas are backed up by black anodized Al


108°
+Z
A7
B7
A1
B1
C1
D1
E1
F1
G1
H1
I1
+40°
-72°
3°
EUTRINO, HADRON
EAM DIRECTION
EQUATOR
(EL. 745'-3")
F7
G7
H7
I7

cylindrical plates. These have scotchlite on their upper surfaces, so the conventional cameras see only scotchlite. The ruby laser beam, which comes from below, hits the black surfaces first. Blades are attached to the frame by welding completely around the contact area (to prevent boiling).

→

Dispersing lens

New design combines the dispersing lens and laser chamber window in one piece of fused quartz. Two pairs of split mounting rings are now required to hold the quartz in place.

→

FERMILAB
ENGINEERING NOTE

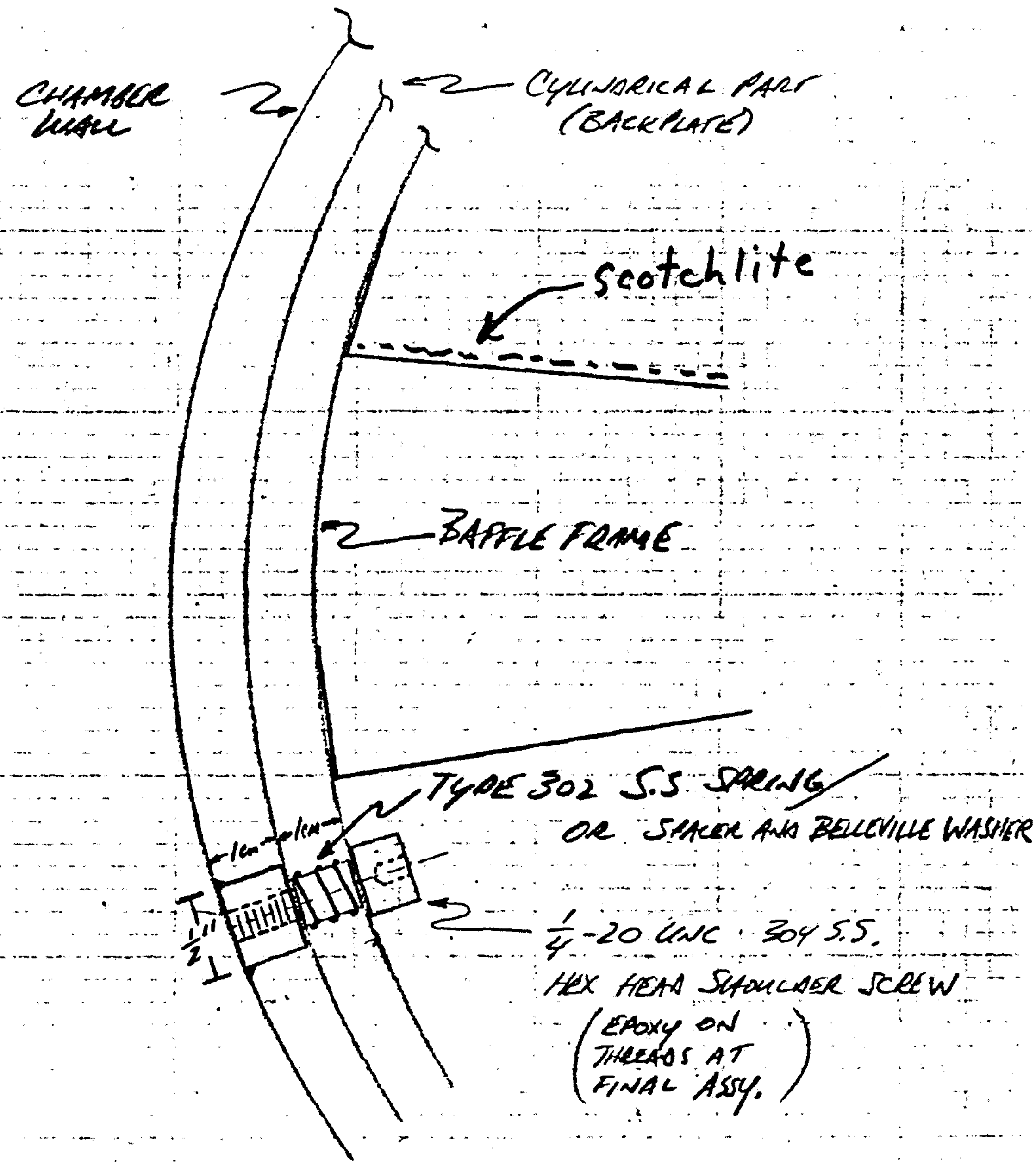
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	15' HOLOGRAPHY		

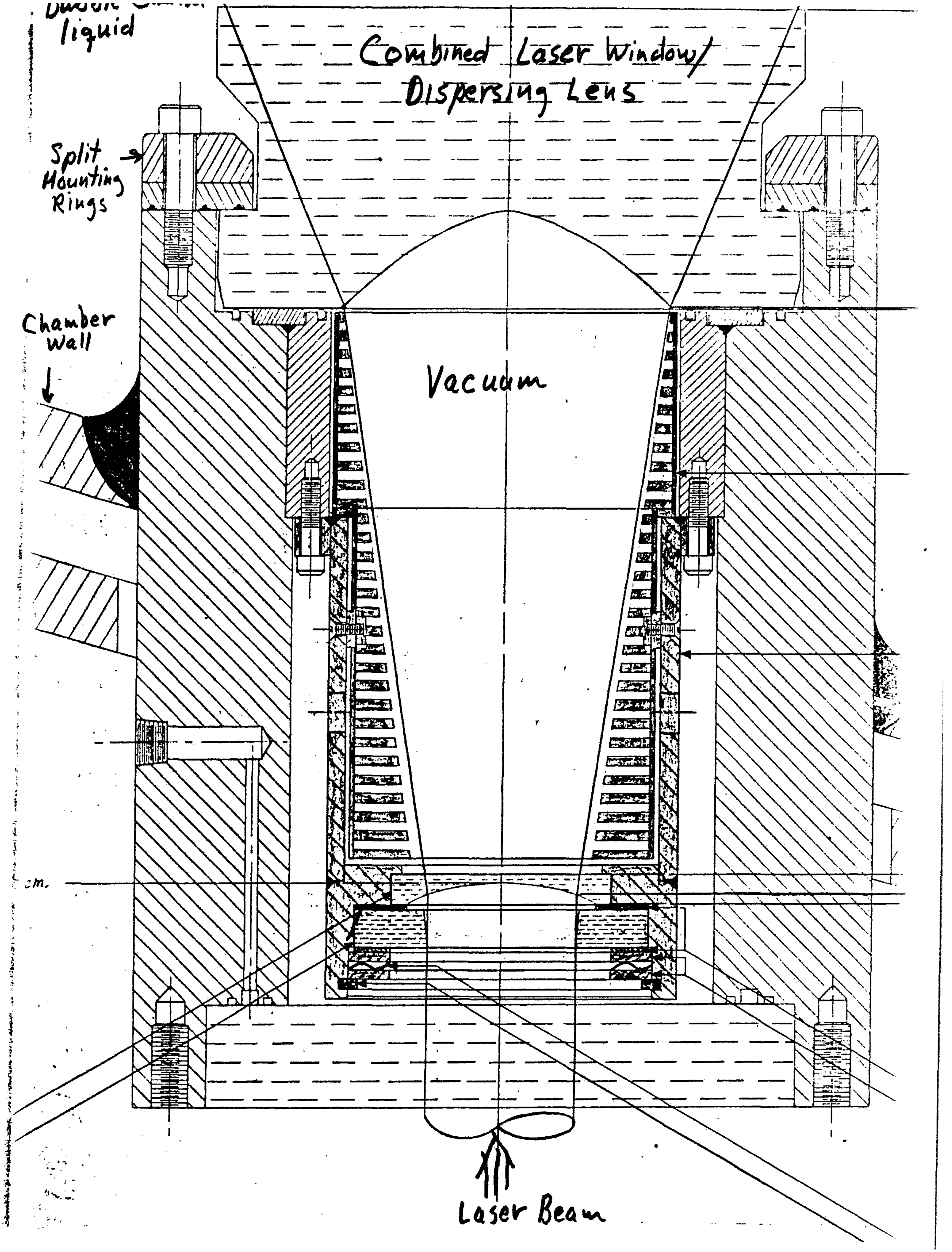
SUBJECT: MOUNTING STUD FOR CHAMBER BAFFLES

NAME: J. URBIN

DATE: 3 JUN 86

REVISION DATE:




liquid
Combined Laser Window/
Dispersing Lens
Split
Mounting
Rings
Chamber
Wall
Vacuum
cm.
Laser Beam

Test run

With the new baffles and dispersing lens mount, plus other changes to holography, it is very desirable to do a cold test before the physics run.

A full engineering run, ie.

- cool down
- test with track sensitive chamber
- warm up
- repair period

would take about 6 months (did in Oct 84 - Mar 85)

The present fixed target schedule does not allow for this, but if the schedule is delayed, a full engineering run should be carefully considered.

Since time for a full engineering run appears unlikely, I believe an early cooldown would be helpful. Even if the schedule slips for a month or two, the chamber would start cooling down as soon as all necessary work has been completed. The hope here is to uncover problems early, so they can be fixed with a smaller lose of physics time. However, the chamber should not be cooled down so early that it will be track sensitive more than 6 weeks before beam is scheduled, or we greatly increase the risk of breakdown before the 5 month physics run is over.

Present estimated startup schedule

Feb 2, 87	Start shifts
~ Feb 16	start cooldown
~ Mar 2	Track sensitive, start holographic tune up
Mar 15, 87	Start of physics run.

E632

F. A. Harris

Talk

EMI / IPF

15' Hybrid Bubble Chamber

External Muon Identifier } New ones for Tevatron era.
Internal Picket Fence }

IPF - determines time of event. Veto.

Prop. tubes ; BEBC design
Built at CERN & paid for by European Groups
Installed by Bubble Chamber Crew and Facilities Support Group.
Inside vacuum tank ; hostile environment.

EMI - muon identification.

Prop. tubes behind absorber. 4
Built and installed by Facilities Support Group with much manpower from E632.

TDS - Time Digitizing System.
Designed by Dan Green - built by Nanometric Systems.
1 CAMAC Crate reads out ~3000 tubes.
All hits in >1 msec. spill read out.

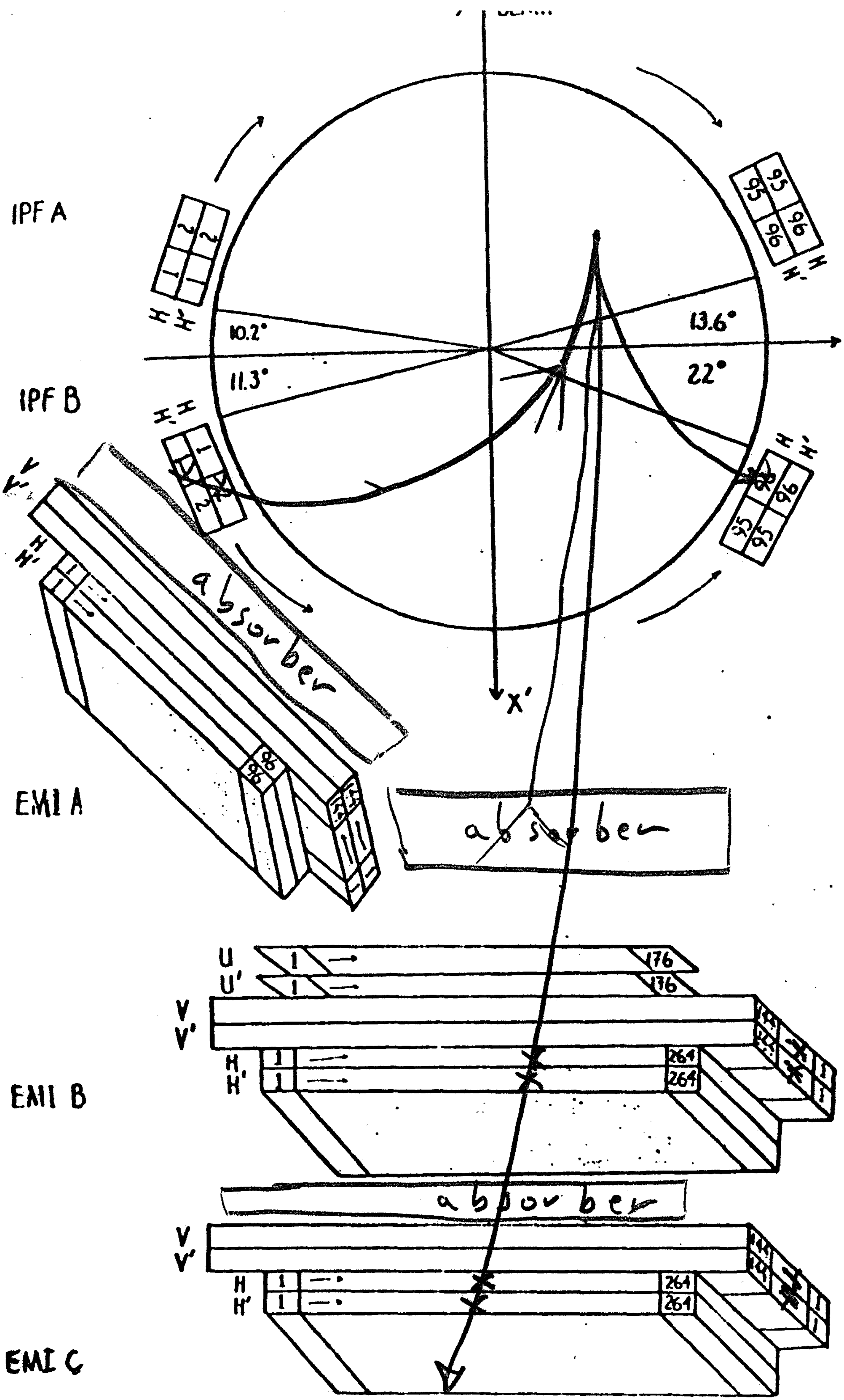

IPF A
IPF B
EMI A
EMI B
EMI C
Y'
X'
10.2°
11.3°
13.6°
22°
absorber
absorber
absorber
U
U'
V
V'
H
H'
1
176
264
95
96

FIG. 5.4-1μ

Online System - responsibility of E632.

- used MULTI
- got help from Computing Department on changes to D.A. part.
- unique feature: use cosmics between beam spills to check system "efficiency".
- online important in debugging system initially.

Holography trigger - needed so laser can be fired while bubbles small. Trigger formed using EMI/IPF hits.

How did it work?

Had startup problems but system began to operate reasonably well sometime after beginning of run.

Overall we are quite pleased with the new system.

1) Geometric Acceptance (2 plane - thru EMIC)
Using an unbiased sample of ν charged current events, we obtained an acceptance for $P_\mu > 4$ GeV/c of 92%.

2.) Instrumental Efficiency of EMI.

Using through muons, we obtained an instrumental efficiency (2 plane) of 94%. Can improve by requiring fewer matches but background increases. Redundancy important.

System could be improved:

Problems:

- 6% dead wires
- IPF electronic noise ⇒ high thresholds & low efficiency
- Bent tubes EMIC. Top and bottom extrusions dead.
- Some bad read out cards.

Operational Problems:

- Humidity / HV (Humidity up; HV down)
- Difficult to fix timing problems (clock).
- Access poor for repairs.

EMI / IPF Improvements (Hardware) 4

by Facilities Support Group

1.) **General Reorganization.**

cabling, HV & LV power distribution – organize / segment.

Improves: Timing adjustment problems, HV difficulties

Status: Nearly Complete.

2.) **Dehumidifier – dehumidified air for electronics on EMI prop. tubes.**

can remove 2 gallons of water per hour.

Improves (cures?): HV problem.

Status: Designed and tested. Installation taking longer than expected.
Estimate mid November for completion.

3.) **Better Covers for EMI.** More substantial.

Improves access.

Status: Design complete.
Complete EMIC ~ mid November
Others thereafter.

4.) **EMI C – remount properly.**

Take out, place on new mounting, repair dead wires. No Design yet!

or

Try to straighten in place, difficult for horizontal tubes.

Note: Any major change should be completed by about the end of December so there is time to fix any problems created before the beginning of the run.

5.) IPF Noise – from IPF heater?

Dan Chapman (Berkeley) to be out in November to help on this.

Layer efficiency : IPF A ~70%
IPF B ~80%

Hopefully the above will improve the system efficiency and solve many of the operational problems.

Software Changes

With increased proton energy and intensity, our data buffer <u>may</u> overflow.

Solution: break events up into multiple buffers.

E632 responsible for changes with help from Computing Department on D.A. part.

Dimuon Search

Good sample to examine for
NEW PHYSICS.

To reduce measuring, dimuon candidates are selected using raw EMI tapes plus measured vertex positions.

Candidates must give two or more "tracks" in the top and side view. *

Status:

80% of event vertices have been measured and processed through the search program.

30% of events found by search program (passing cuts) have been measured and analyzed.

Hope to finish most of film by December. Thesis project for Vivek Jain.

At present: 11 opposite sign dimuons

DIMUON SELECTION

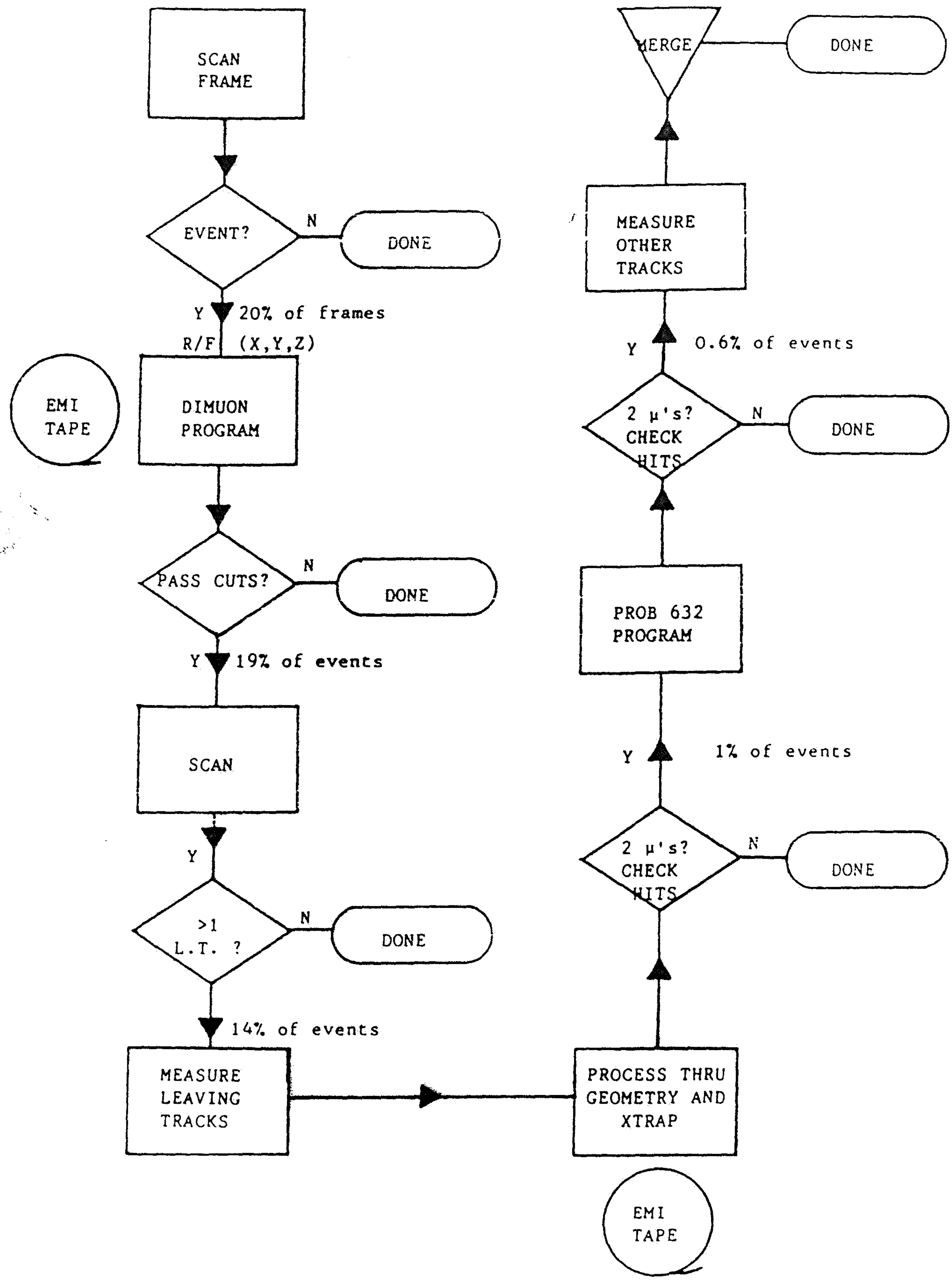
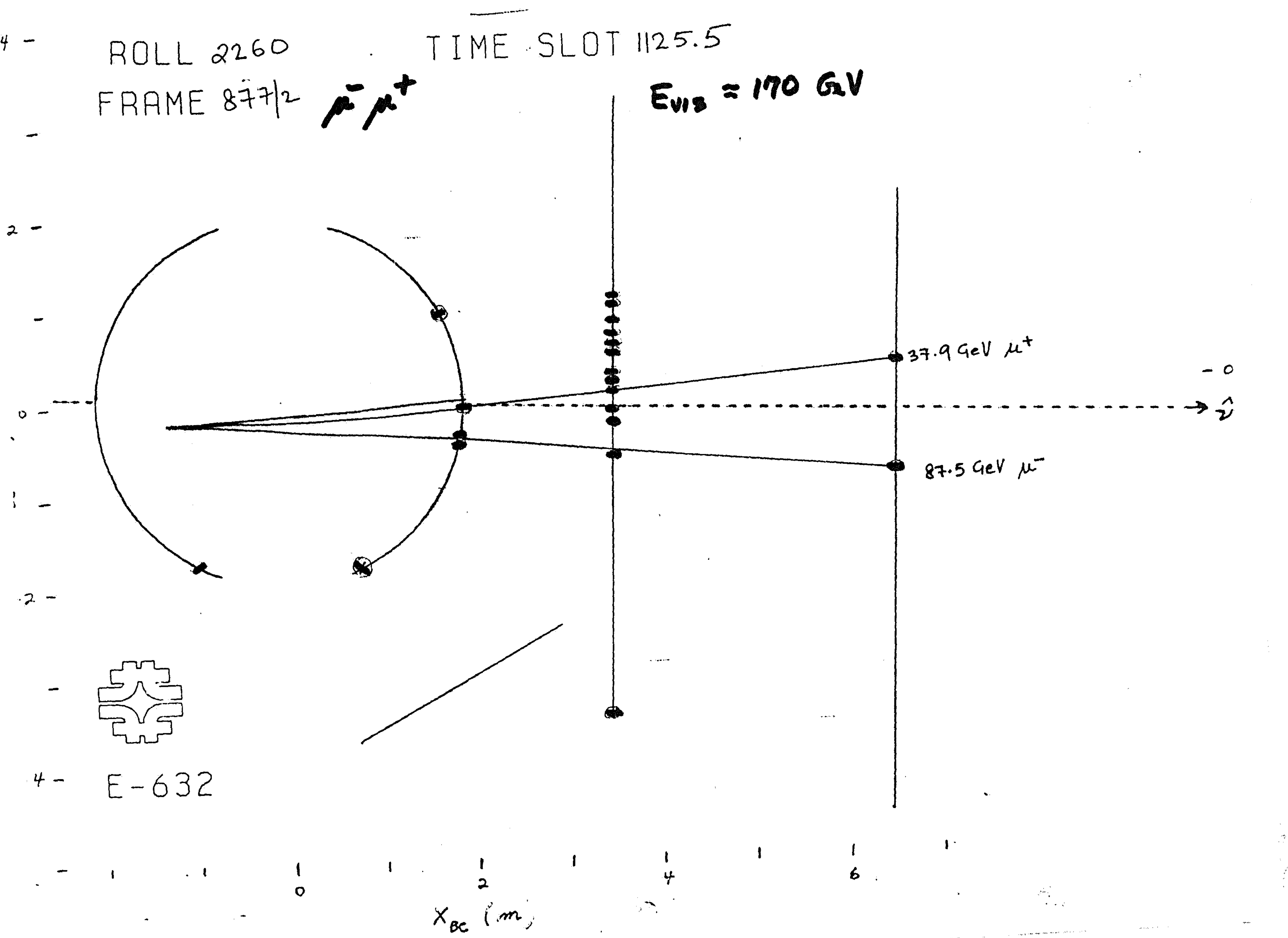


Fig. 2.1.7-1



ROLL 2260
TIME SLOT 1125.5
FRAME 877/2
μ⁻ μ⁺
E_VIS ≈ 170 GeV
37.9 GeV μ+
87.5 GeV μ-
E-632
0
2
4
6
X_BC (m)

Like Sign Dileptons ($\mu\mu$)

Statistics worse than μe.

$P_\mu > 4$ GeV/c

detection efficiency for 2nd muon low: ~80%

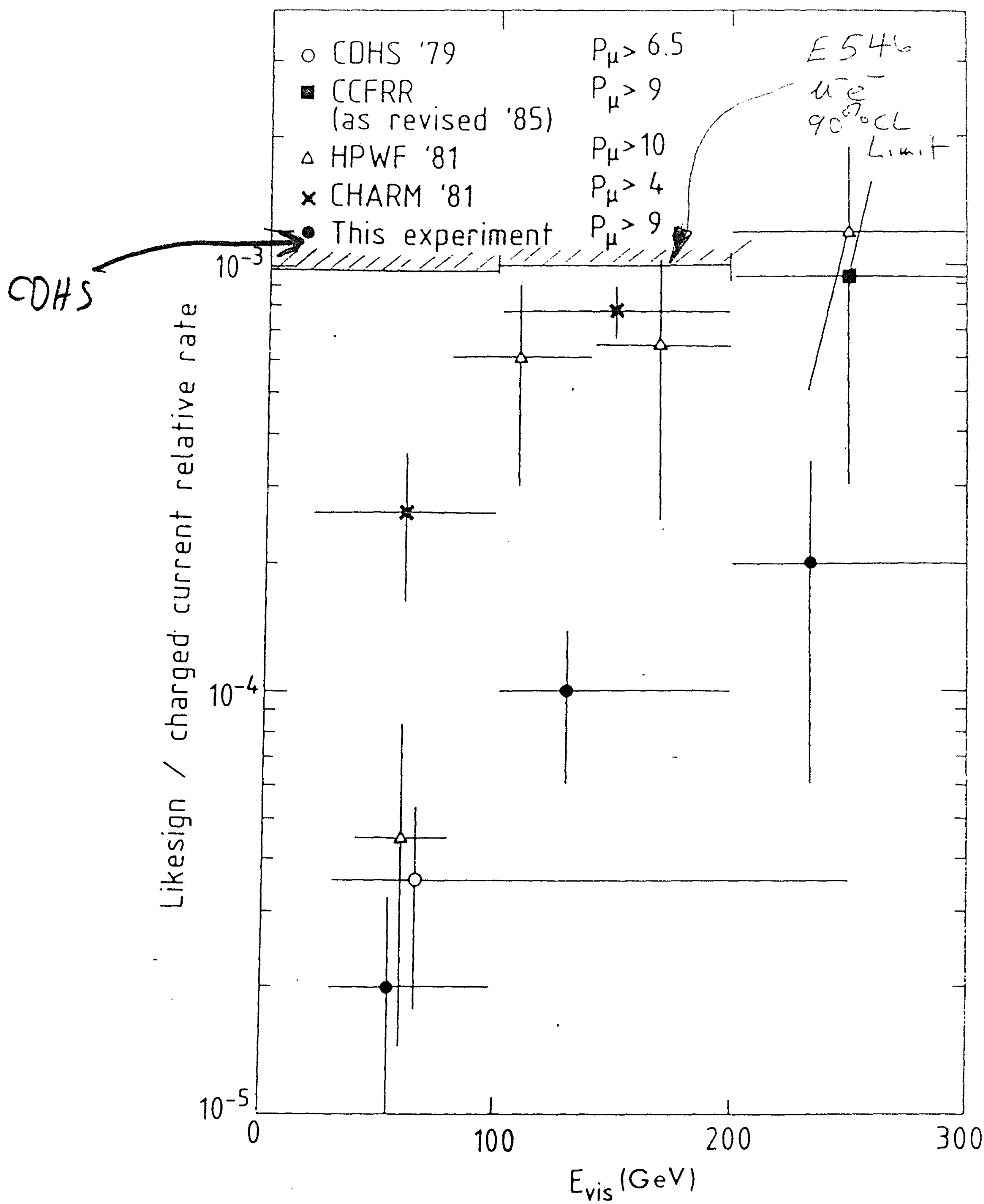
For 5×10^{17} protons @ 900 GeV/c;

expect 45K CC events.

		signal	background (E546)
bound CDHS & CCFRR/HPWF	@ 10^{-3}	36	32
	@ 10^{-4}	4	32

Need holography to find close decays.

Should be able to see likesign signal if CCFRR rate correct.



CDHS '79
CCFRR (as revised '85)
HPWF '81
CHARM '81
This experiment
$P_\mu > 6.5$
$P_\mu > 9$
$P_\mu > 10$
$P_\mu > 4$
$P_\mu > 9$
E546
$\mu^- e^-$
90% CL
Limit
CDHS
10^{-3}
10^{-4}
10^{-5}
Likesign / charged current relative rate
0
100
200
300
E_{vis} (GeV)

Fig. 14

M. PETERS

TALK

HOLOGRAPHY IN THE 15' BC

Developed over period of years by
people from Columbia, CERN, Fermilab

Tested in cold 15' BC just prior to
first E632 run

Took 90K holograms in run (150K pix)

Few, low quality events found

Many problems are now understood and
solutions have been found

Expect to record events over 4.7
cubic meters with 100 micron resol'n

FERMILAB 15' BUBBLE CHAMBER

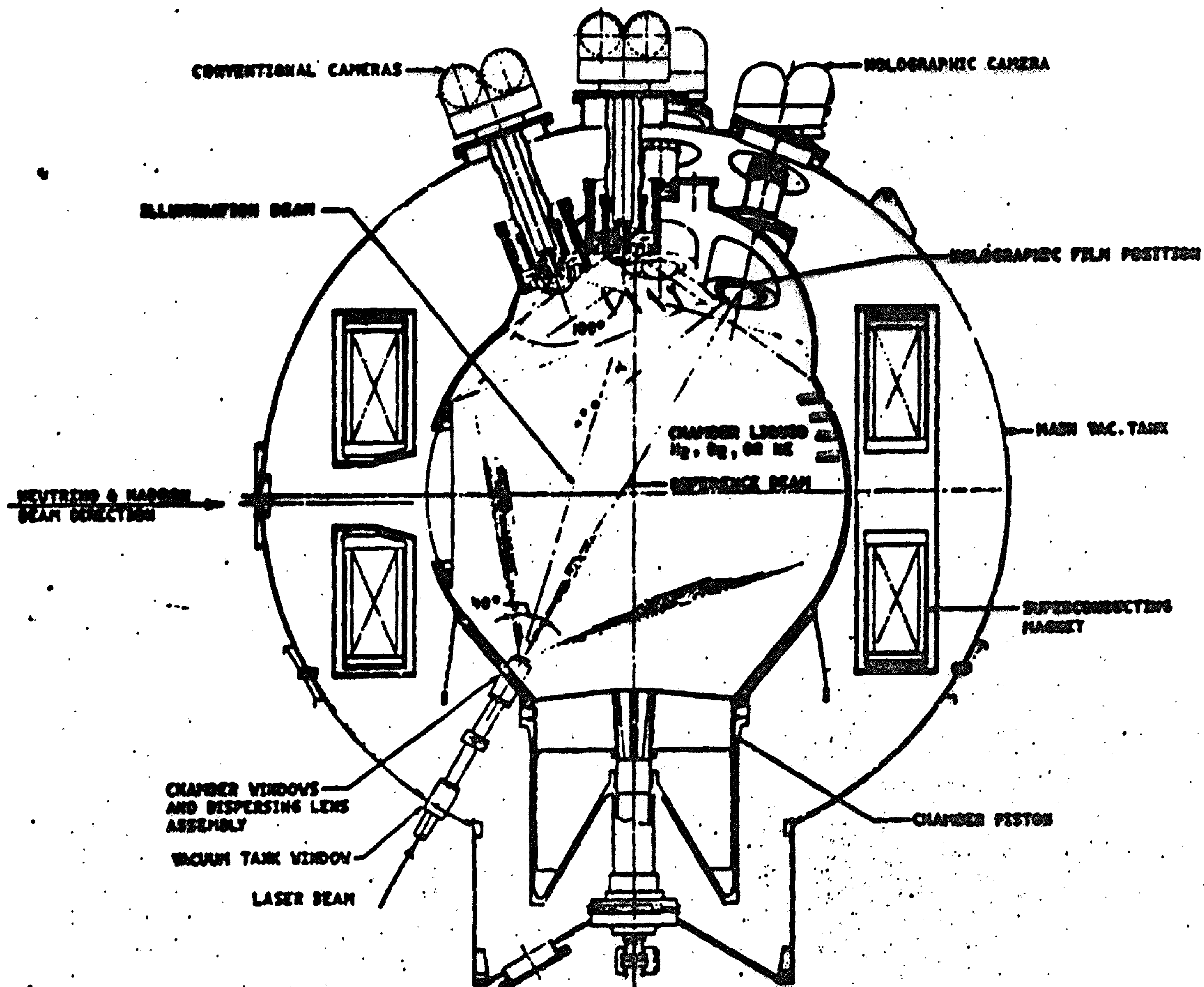


FIGURE 1.

HOLOGRAPHY PROBLEMS

1. Volume limited by fringe motion during long pulse

2. Wrong light distribution at BC

3. Lack of monitoring

4. Volume limited by boiling

5. Volume limited by stray light

6. Quality possibly limited by
   a) Reference beam change in liq
   b) Microboiling

HOLOGRAPHY SOLUTIONS

1. Laser improvements
   - Pulse Stretching: Works usually
   - Simmering : In progress

2. Laser beam transport
   - Works

3. Laser beam monitoring
   - Designed, parts ordered

4. Dispersing lens/window
   - Designed, ordered, partially ground

5. Light baffles
   - Installed on wall
   - Partially installed in beanie
   - Tested in warm BC

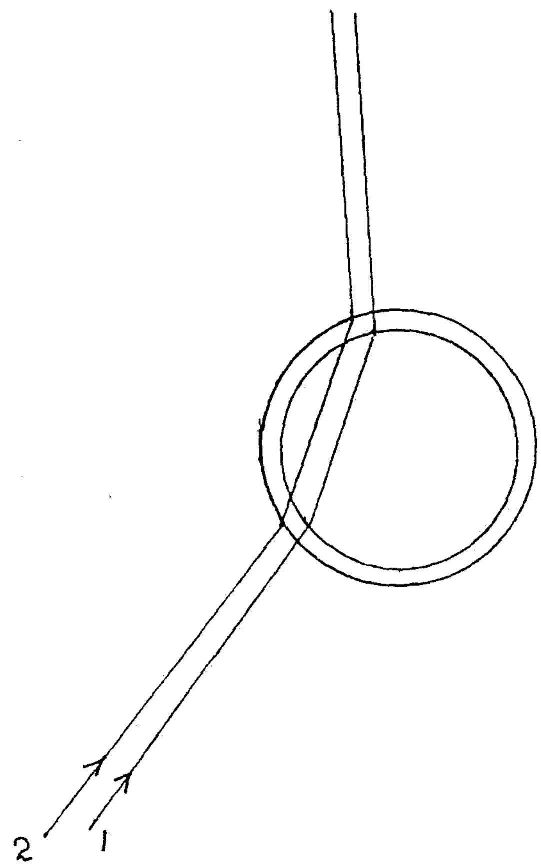
6. Fiber optic camera
   - Being tested at CERN

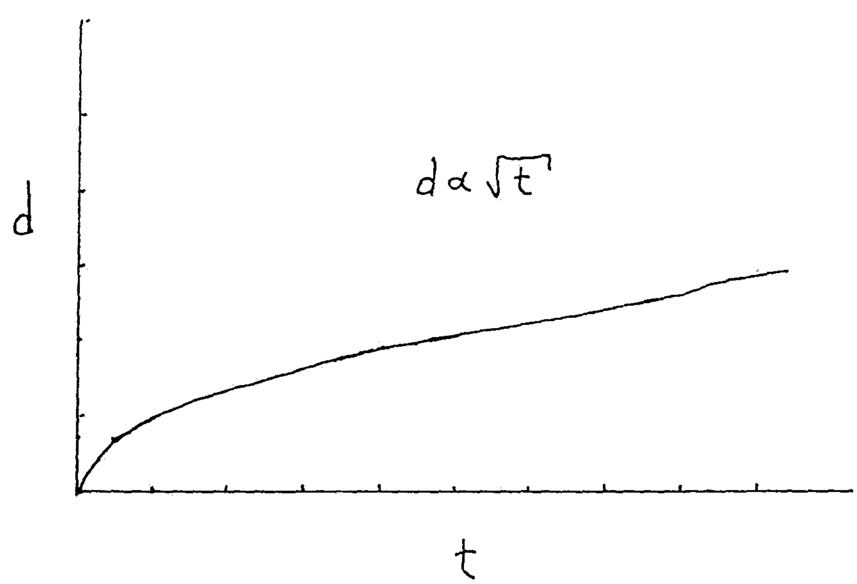
LASER IMPROVEMENTS

1. Pulse Stretching
   - Want 3-10 microsec pulse
   - Opto-electronic feedback
   - Now get 70% good pulses
   - Need Jon Hawkins et al again

2. Simmering
   - Want 400 microsec delay from trig
   - Establish low current arc
     then trigger big capacitor
   - Tufts design
   - Tom Kovarik building & testing

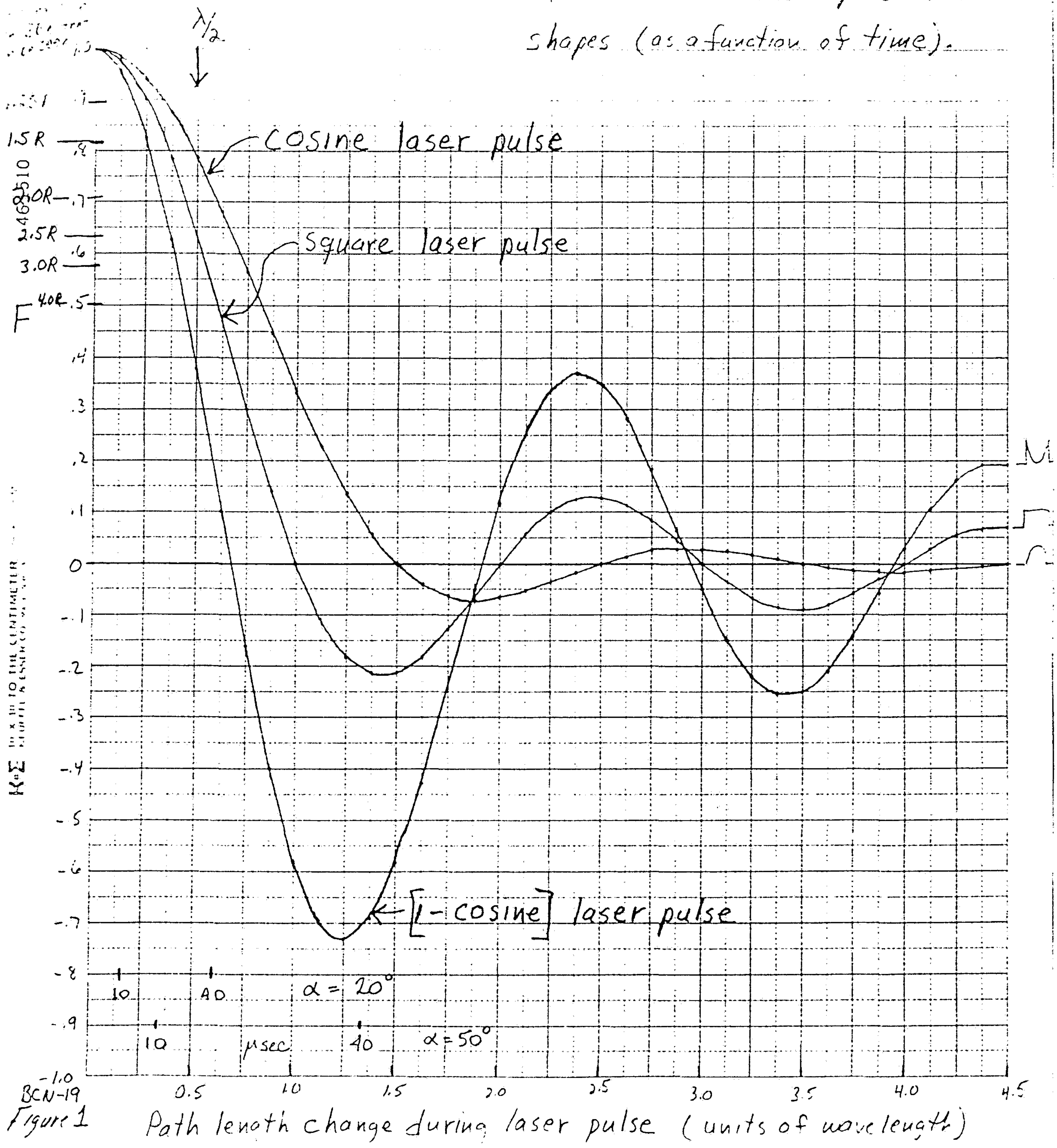
Optical Path Length Change





[redacted]

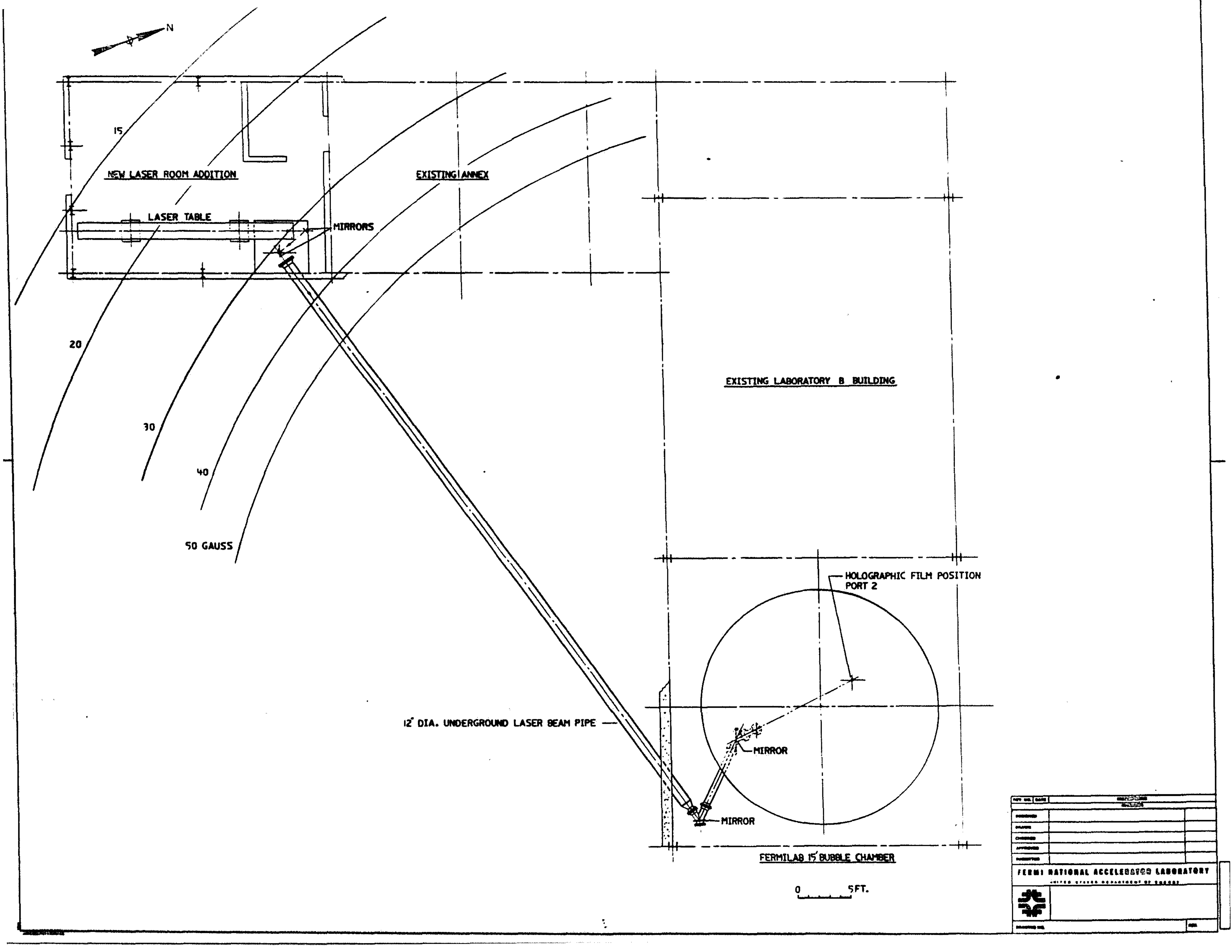
Fraction of (zero path length change) interferrence pattern intensity modulation as a function of total path length change during laser pulse. Curves for different laser pulse shapes (as a function of time).



BCN-19
Figure 1

LASER BEAM TRANSPORT

Raw beam gives donut at disp lens
Two stage optical relay designed by
  Wes Smart
Built with uncoated lenses
Tested sucessfully-uniform light dist
Lenses have been bought-to be coated



N
15
20
30
40
50 GAUSS
NEW LASER ROOM ADDITION
EXISTING ANNEX
LASER TABLE
MIRRORS
EXISTING LABORATORY B BUILDING
HOLOGRAPHIC FILM POSITION
PORT 2
12" DIA. UNDERGROUND LASER BEAM PIPE
MIRROR
MIRROR
FERMILAB 15' BUBBLE CHAMBER
0
5FT.
FERMI NATIONAL ACCELERATOR LABORATORY

LASER BEAM MONITORING

Want to monitor beam position, shape
and energy while running

System designed by Wes Smart &
Ludo Verluyten (Brussels)

Electronics development by
Herm Haggerty

Lenses ordered

Electronics being ordered

Apertures ??

FERMILAB ENGINEERING NOTE

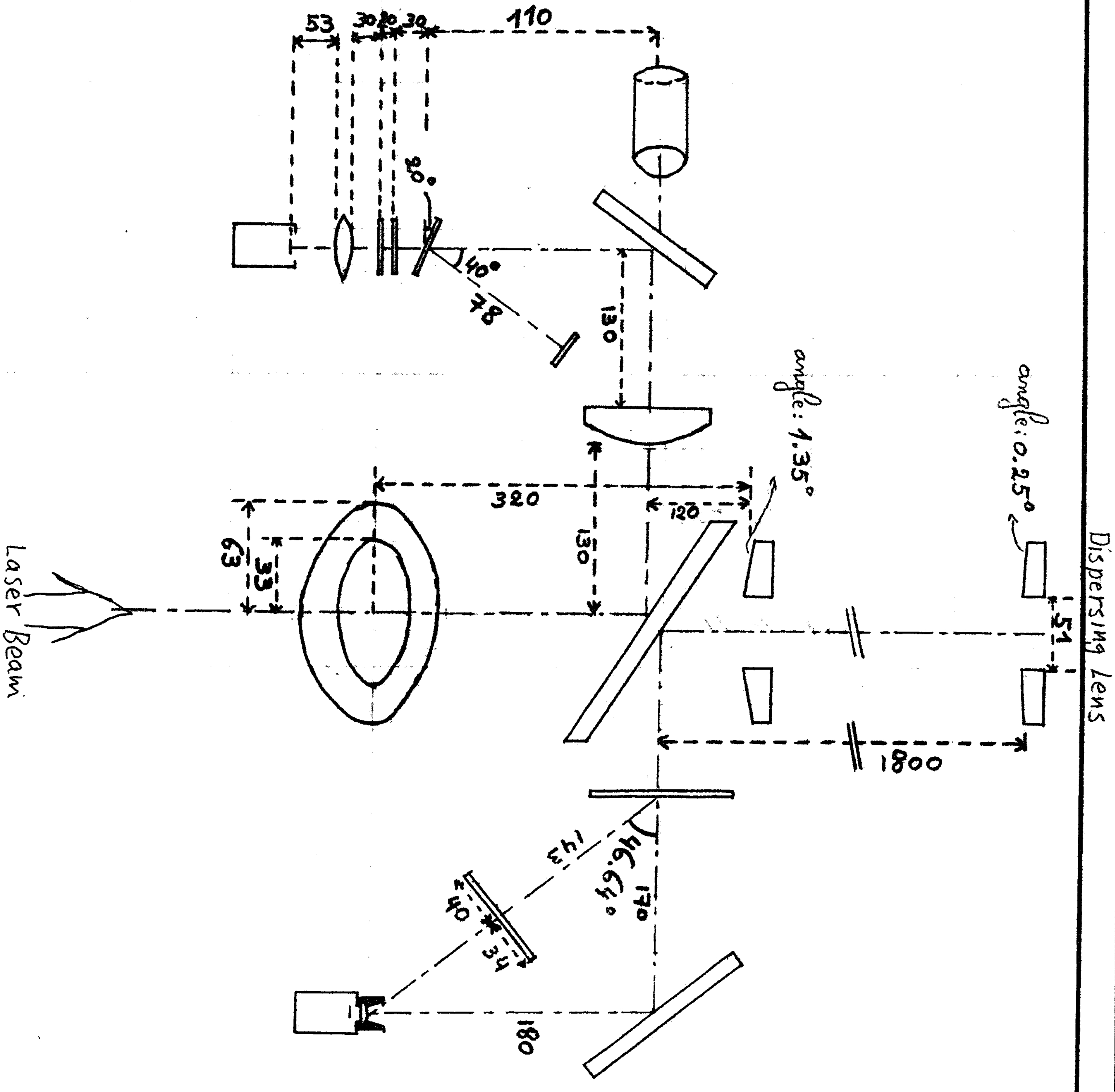
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
39	HOLOGRAPHY		1

SUBJECT: LASER BEAM MONITORING

NAME: LUDO VERLUYTEN

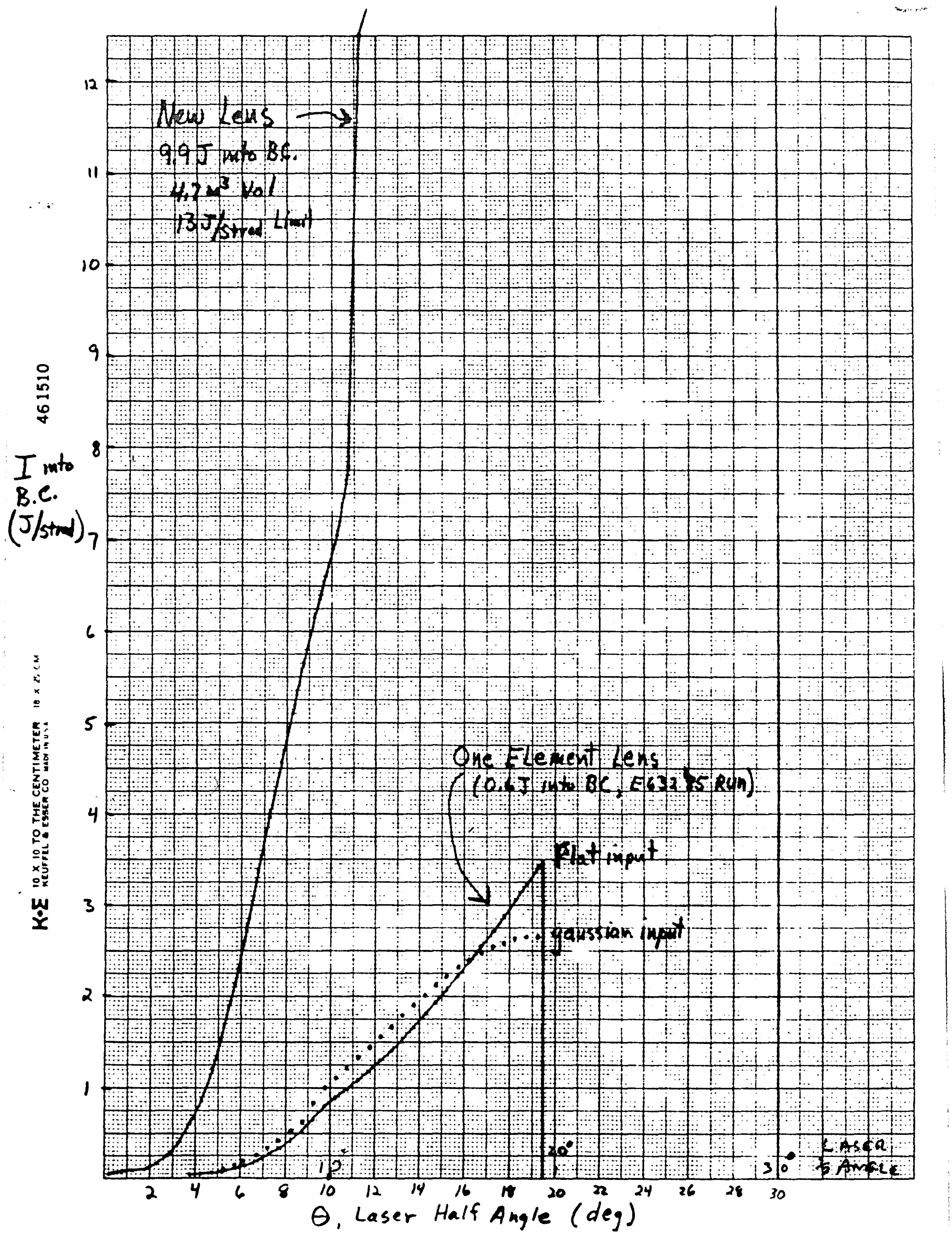
DATE: 9/27/1986

REVISION DATE:

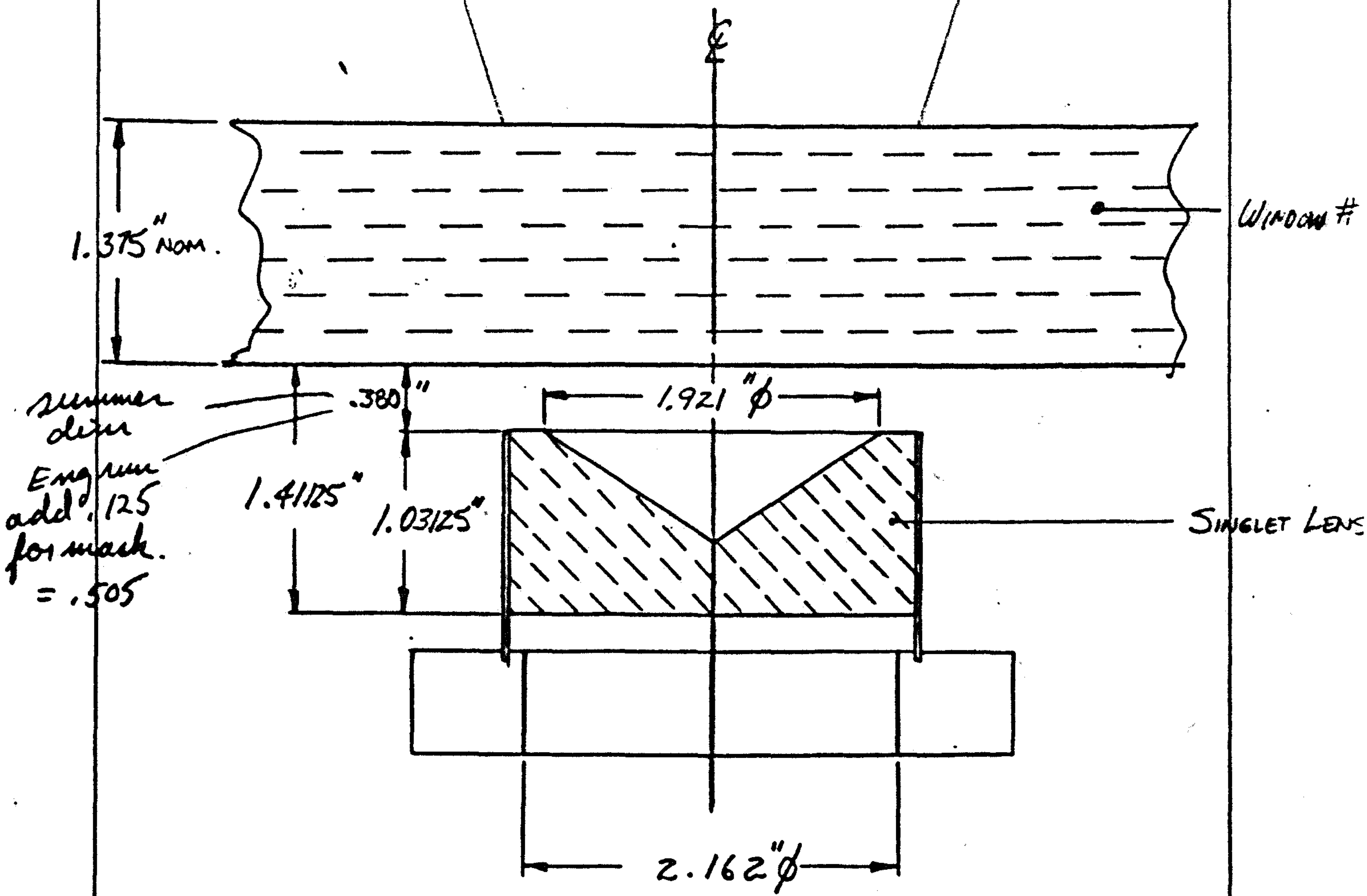


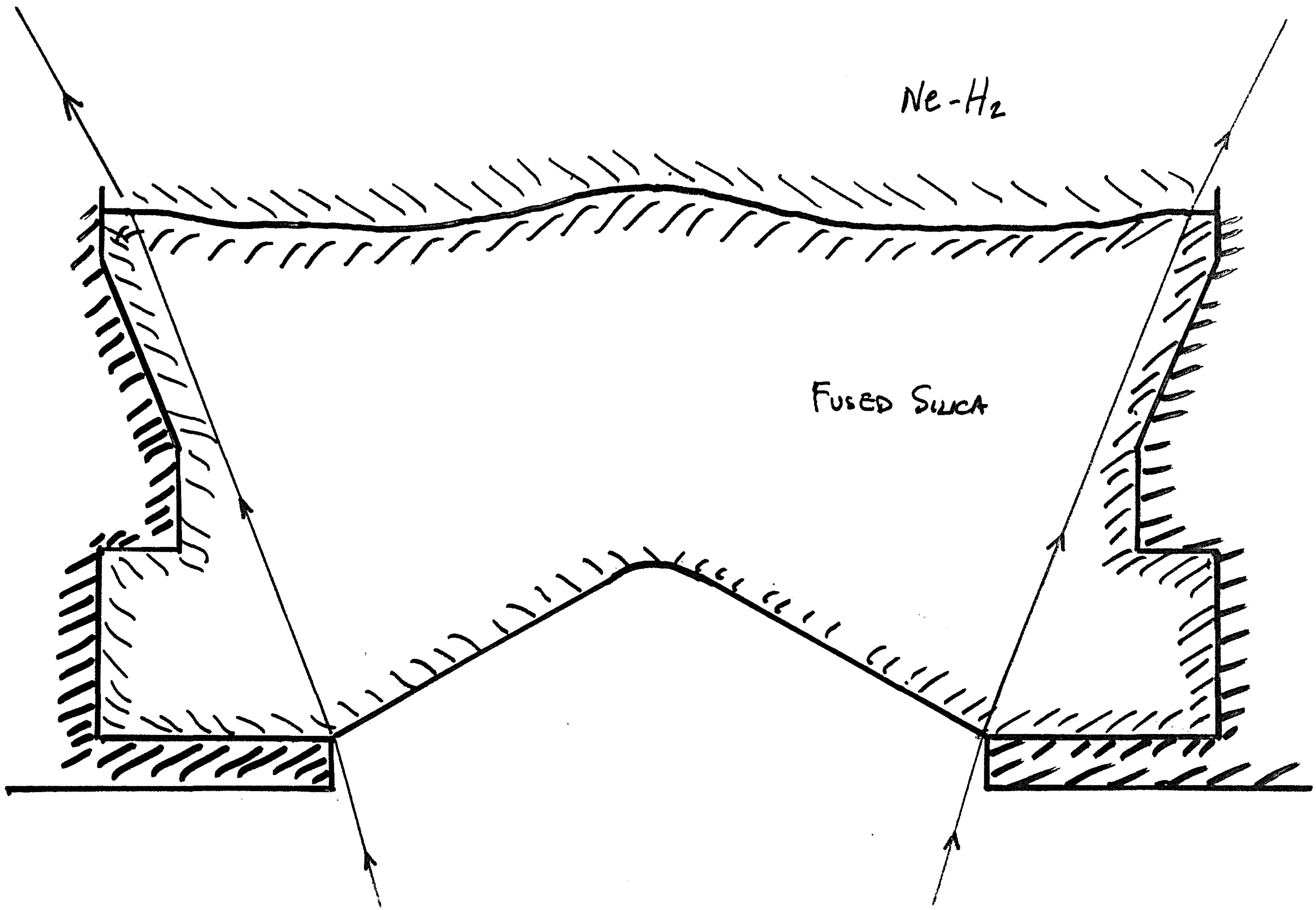
DISPERSING LENS/WINDOW

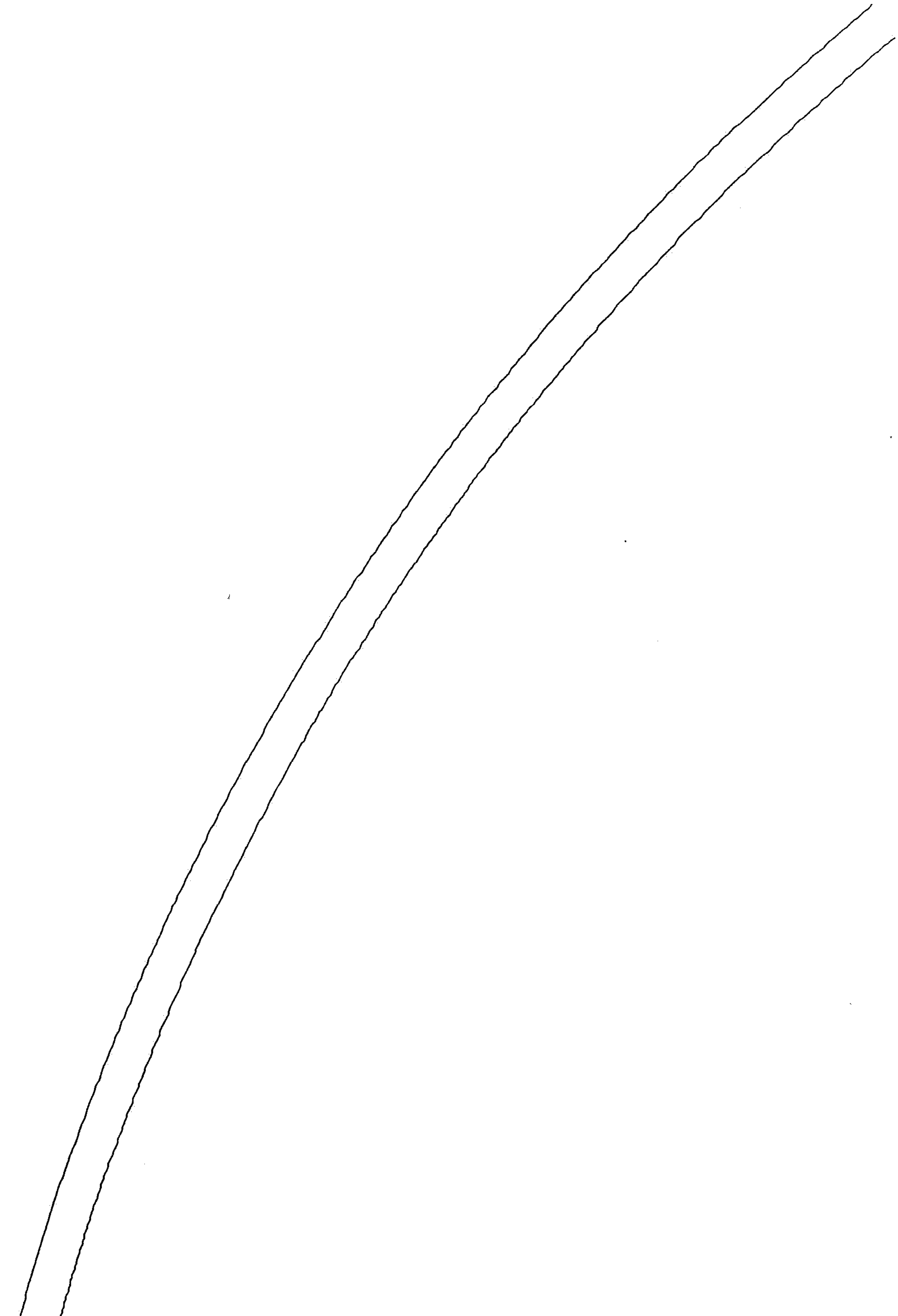
Design with limit on power density
  to limit boiling
Maximize area to limit boiling (8x)
Two-lens system to spread light
Light angular dist designed by W. Smart
Lens optical surface designed by
  M. Peters
Reflection analysis & edge design by
  W. Smart
Order placed
Lens partially ground
Grinding to be done Nov 14-28
Coating to be done Dec 5-19

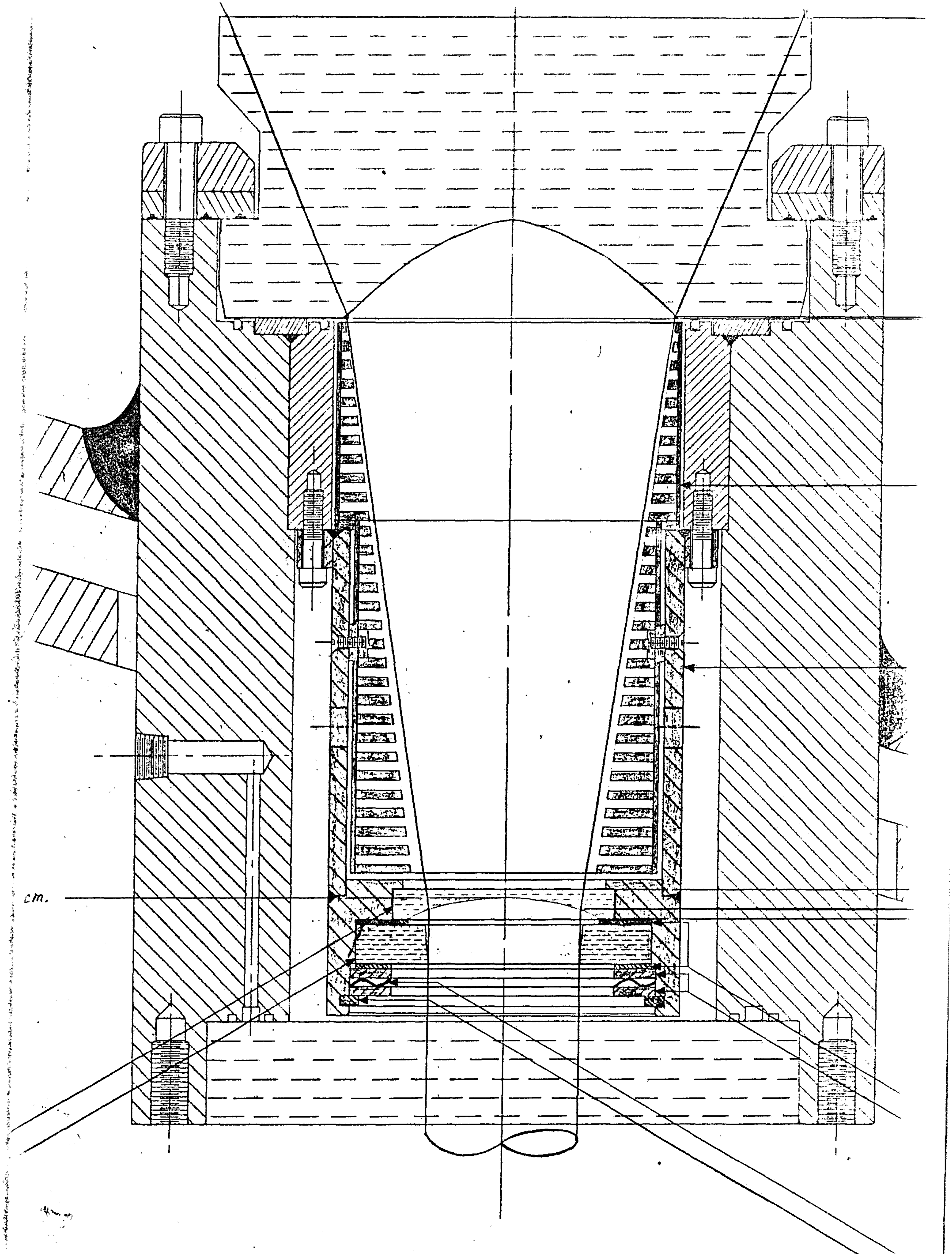

New Lens
9.9 J into B.C.
4.7 m³ Vol
13 J/Strad Limit
One Element Lens
(0.6 J into BC, E632 85 Run)
Flat input
gaussian input
20°
LASER ½ ANGLE
I into B.C. (J/strad)
θ, Laser Half Angle (deg)
1
2
3
4
5
6
7
8
9
10
11
12
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
461510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

ALL DIMENSIONS ±.002"



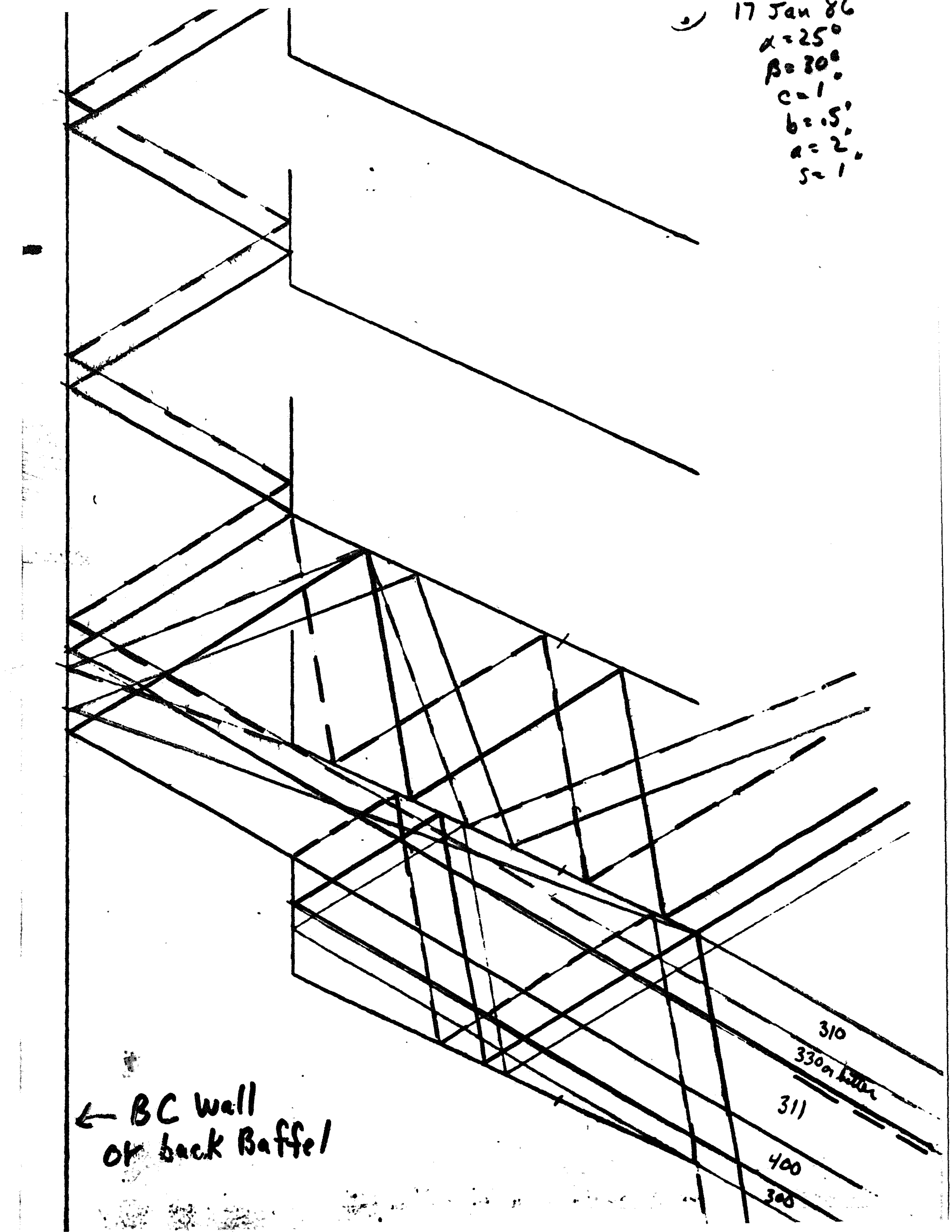

Ne-H2
Fused Silica

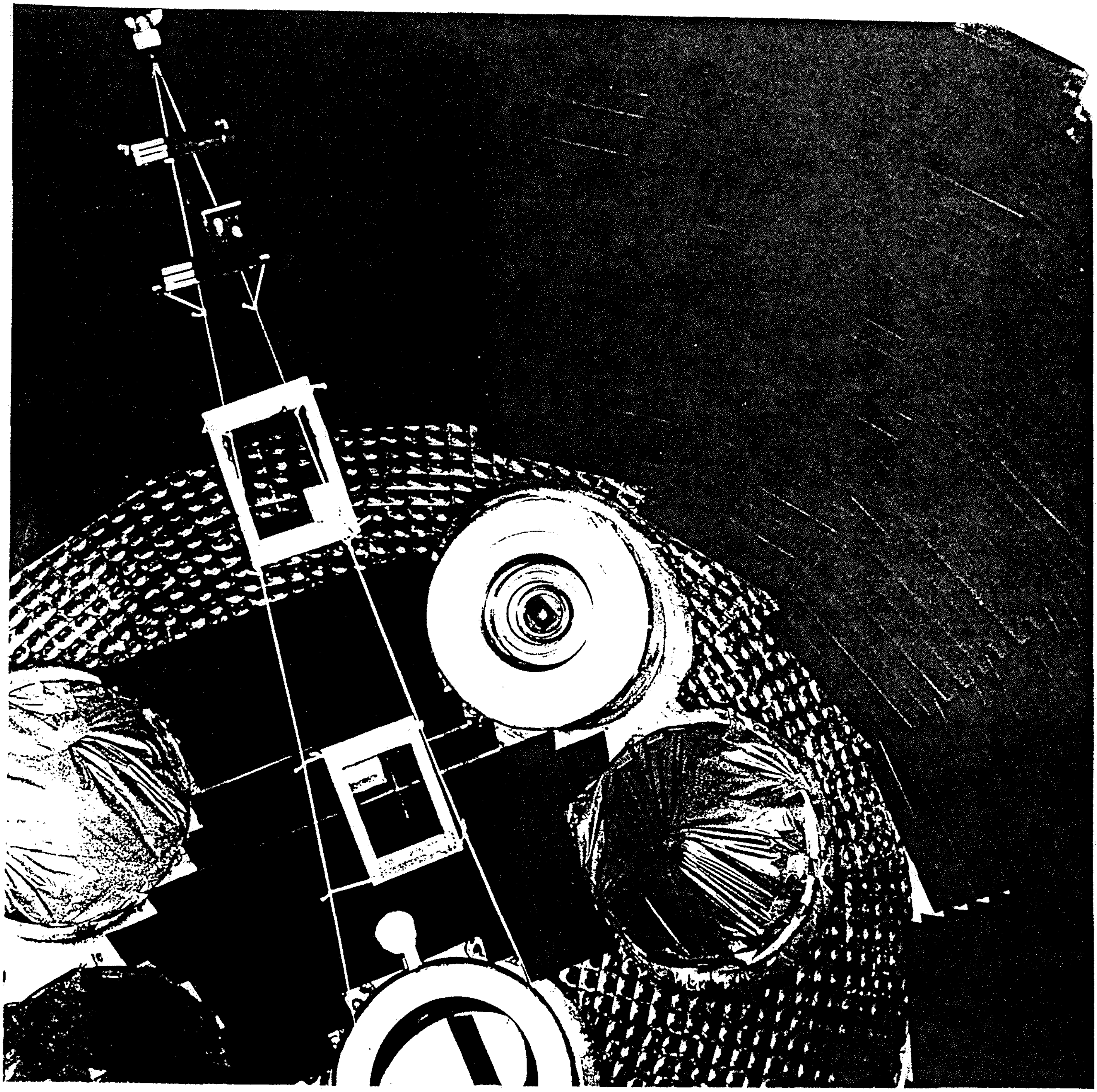



cm.

LIGHT BAFFLES

Prevent illumination light from
  reaching film by scattering off wall
Anodized aluminum only safe material
Venetian blinds black on bottom
                Scotchlite on top
Designed for max absorption by
  Jeremy Lys (Berkeley)
Built and installed by BC crew
  (Partial coverage)
Tested by team from Fermilab & E632
Background now about = ref beam
Must cover rest of area
Test with new dispersing lens Jan 87


17 Jan 86
α = 25°
β = 30°
c = 1
b = .5'
a = 2'
s = 1
← BC Wall
or back Baffel
310
330
311
400
300



FIBER OPTIC CAMERA

Want to have backup in case of
- a) Wrong reference intensity
- b) Change of ref beam by liquid
- c) Microboiling

Need to couple and transmit
- 25-30 microjoules in fiber

Tried by H. Bjelkhagen
- Fails in monomode fiber due to stimulated Brillouin scattering
- Works in 50 micron multimode fiber

Remaining problems
- Speckle due to fiber size
- Resolution due to fiber size
- Test of design
- Engineering design & construction

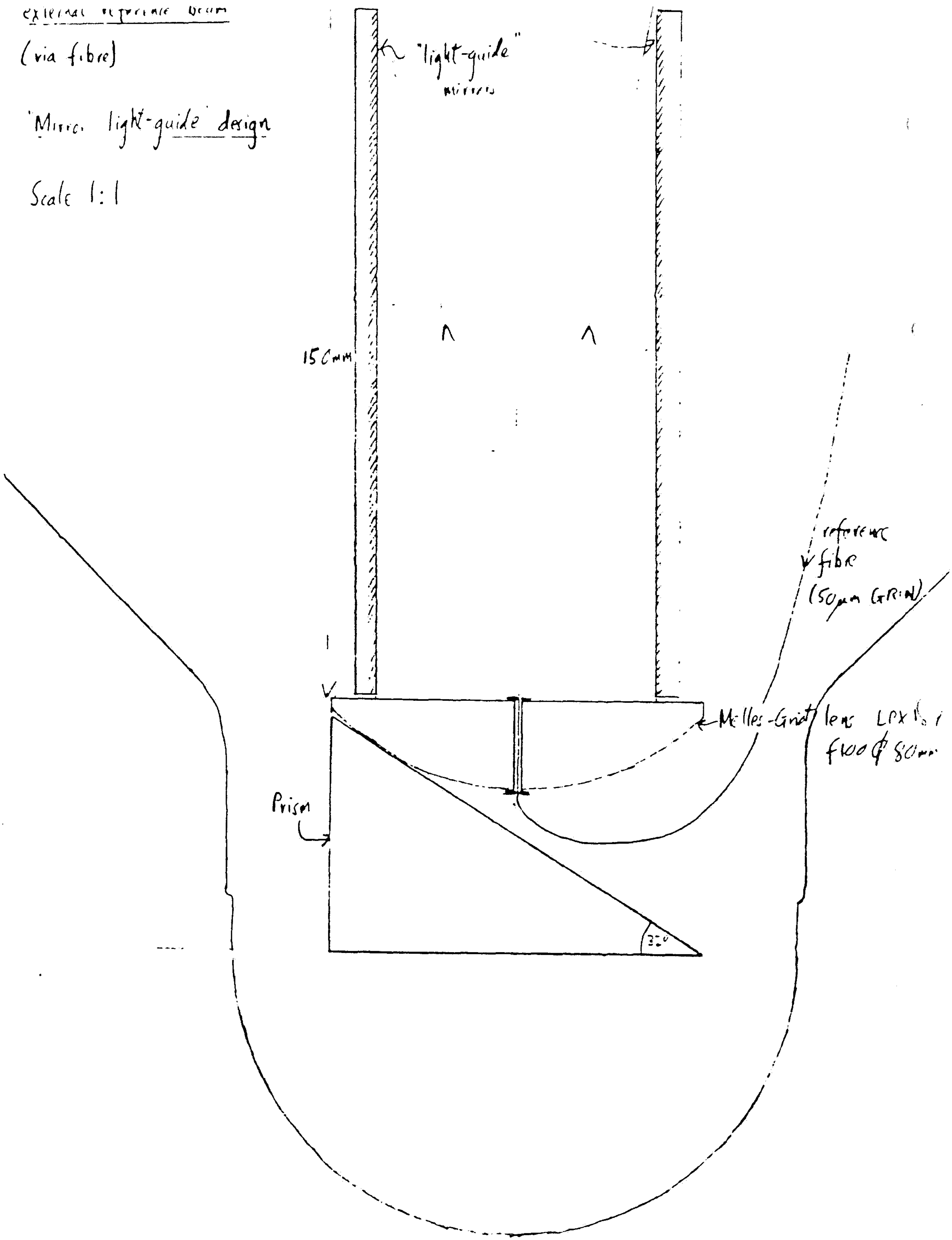

(via fibre)
'Mirror light-guide' design
Scale 1:1
"light-guide" mirrors
150mm
reference fibre (50μm GRIN)
Melles-Griot lens
f100 ⌀ 80mm
Prism
30°

Figure 3

MONOMODE FIBRE.

[from H [illegible] & [illegible] May 86]

(PULSE LENGTH 8–10 μs)

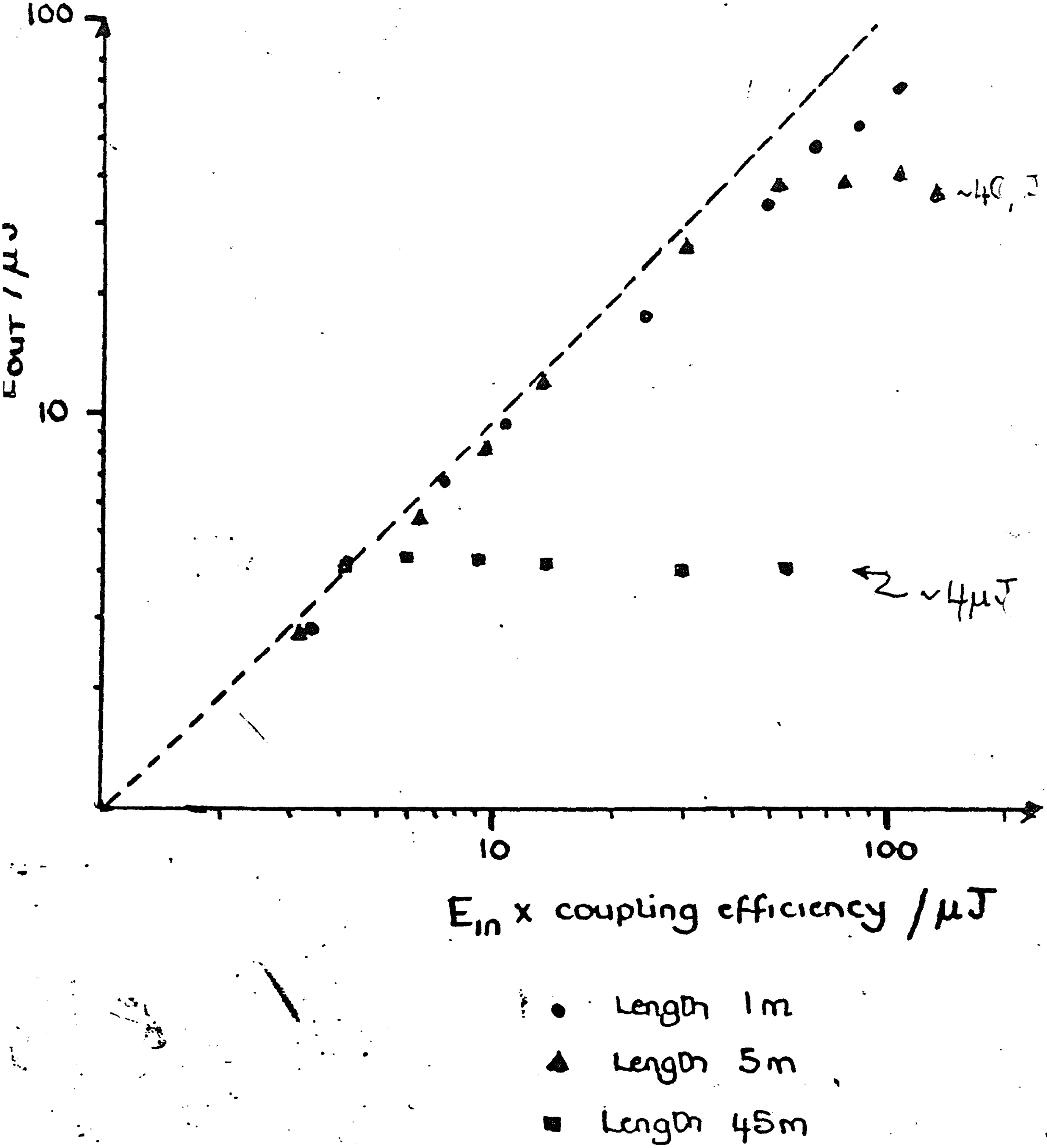


Figure 1