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Dr. Norman M. GELFAND
FERMILAB
P.O. Box 500
Batavia

USA-ILLINOIS 60510

Geneva, 22 February 1982

Dear Dr. Gelfand,

Please find enclosed an addendum to our proposal P632 requesting

"An exposure of the 15-foot bubble chamber with a Neon-Hydrogen mixture to a wideband neutrino beam from the Tevatron".

Essentially the addendum emphasises that good physics can be done even with short low-intensity runs when the Tevatron first starts and also the importance of using holography - we are busy preparing a holography system for BEBC. There are also some changes in the membership of the Collaboration and in particular we are pleased to be joined by a Fermilab group.

Best wishes,

Douglas R.O. Morrison

Douglas R.O. Morrison
EP - Division

36 pgs.

FERMILAB-Proposal-0632

6 May 1980 *Revised*

Tevatron Proposal No. 632

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

by the American-European 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 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 $\tau$ 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 $\tau^{+}$ 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, $\nu_e$ 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

Spokesman: D.R.O. Morrison Contactman: W.F. Fry

## 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, $\tau$, 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, $\tau$ 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.

(c) Measurement of inelastic structure functions.

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 $F \rightarrow \tau \nu_\tau$ has a 3% branching fraction then approximately 40 $\tau$ leptons should be produced in this exposure. These would be characteristic double decay events. The $\tau$ lifetime is predicted to be $3 \times 10^{-13}$ s, which is in our range of sensitivity.

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

Table 1

| Reaction | Number of events |
|---|---|
| $\nu + N \rightarrow \mu^- + X$ | 70 000 |
| $\nu + N \rightarrow \mu^- D^+(D^o) + X$ | 5800 |
| $\nu + N \rightarrow \mu^- + F^+ + X$ | 1200 |
| $\quad \hookrightarrow \tau^+ + \nu_\tau$ | 40 |
| $\nu + N \rightarrow \mu^- + \bar{b}$ | 20 |
| $\bar{\nu} + N \rightarrow \mu^+ + X$ | 9000 |
| $\bar{\nu} + N \rightarrow \mu^+ + b$ | 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 $W^2 < 16$ 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 $W^2 > 16$ 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

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

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 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 $\Lambda$ 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 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 $K^o$, $\rho$, $\omega$ 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 $\nu$ ($<$ 1 GeV) and therefore the complete $\nu$ 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 $\nu$ 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 $\nu_e$ 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 $\nu_e$ events, of $\nu_\tau$ 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.

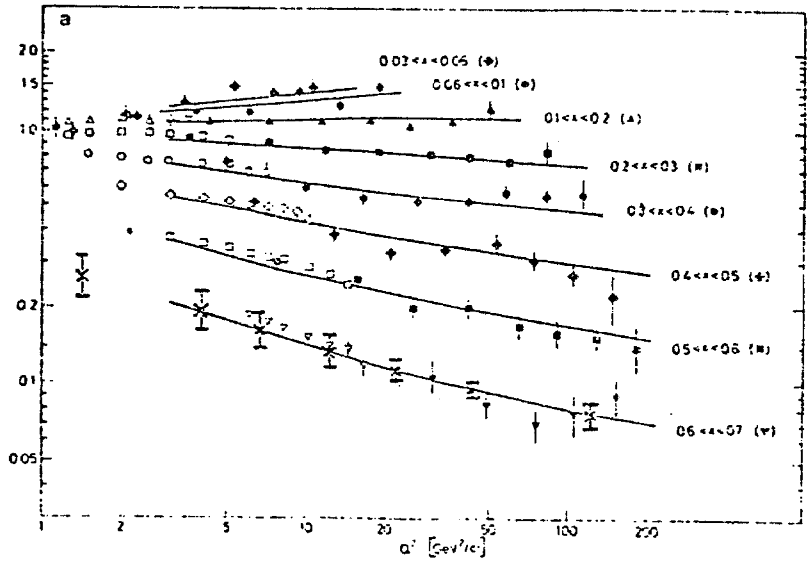
We request the quad-triplet beam tuned to 400 GeV/c and using the highest proton energy available. If a 64 mole per cent Ne-$H_2$ mixture is used then $2.5 \times 10^{13}$ protons on target will correspond to $\sim$ 1 event per photograph ($\nu + \bar{\nu}$, CC + NC). We believe therefore that we can tolerate the highest proton intensity on target. At an intensity of $1 \times 10^{13}$ 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.

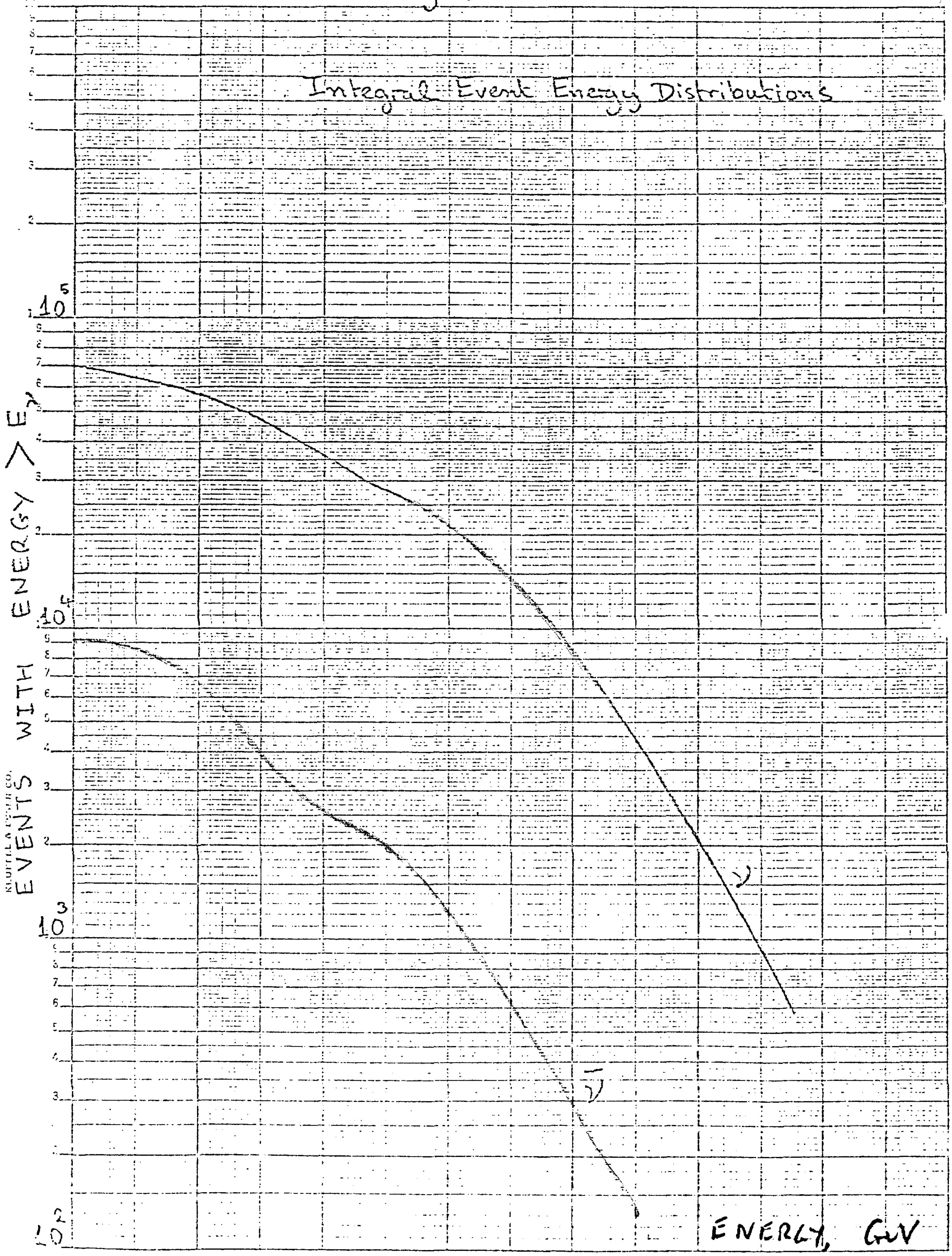
# Fig 5




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

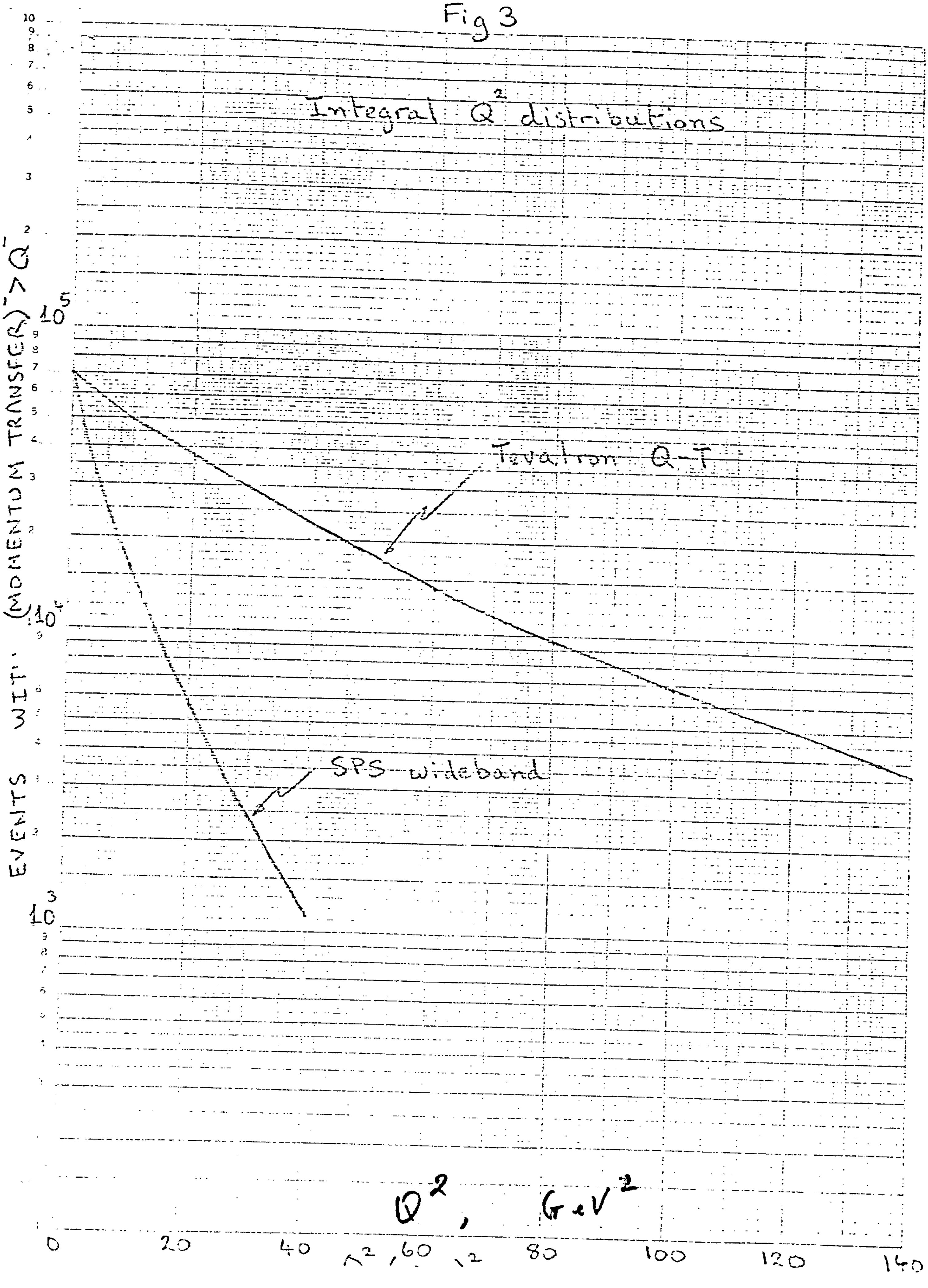
The solid points are neutrino data from de Groot et al. (Phys. Letters 82B (1979) 456) and the open points are derived from eD scattering.

Fig 6

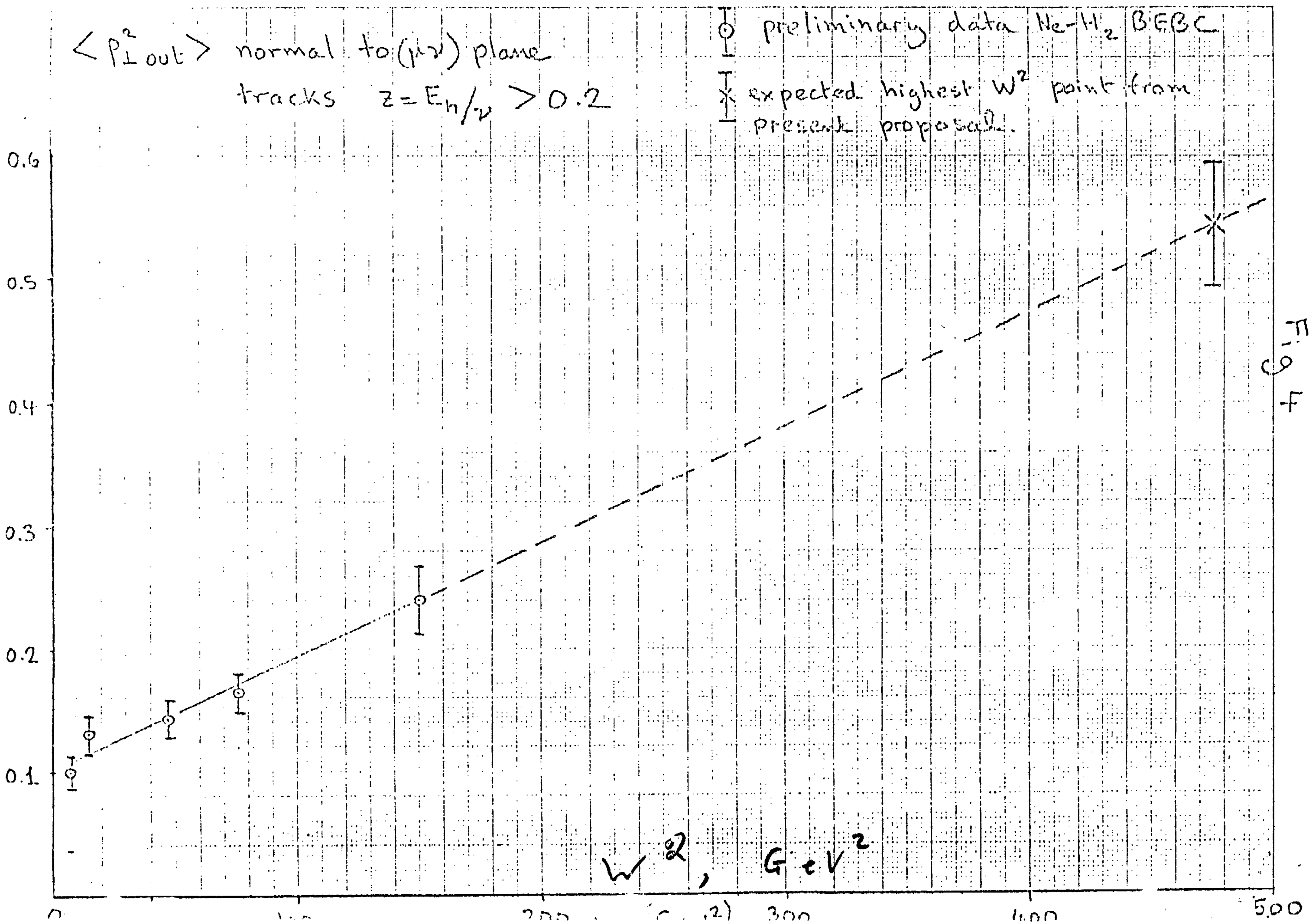


Integral Event Energy Distributions
EVENTS WITH ENERGY > $E_\nu$
$10^5$
$10^4$
$10^3$
$10^2$
ν
ν̄
ENERGY, GeV

Fig 3



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



$\langle p^2_{\perp out} \rangle$ 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
300
400
500
$W^2$, $GeV^2$


Fig 4

Fig 1

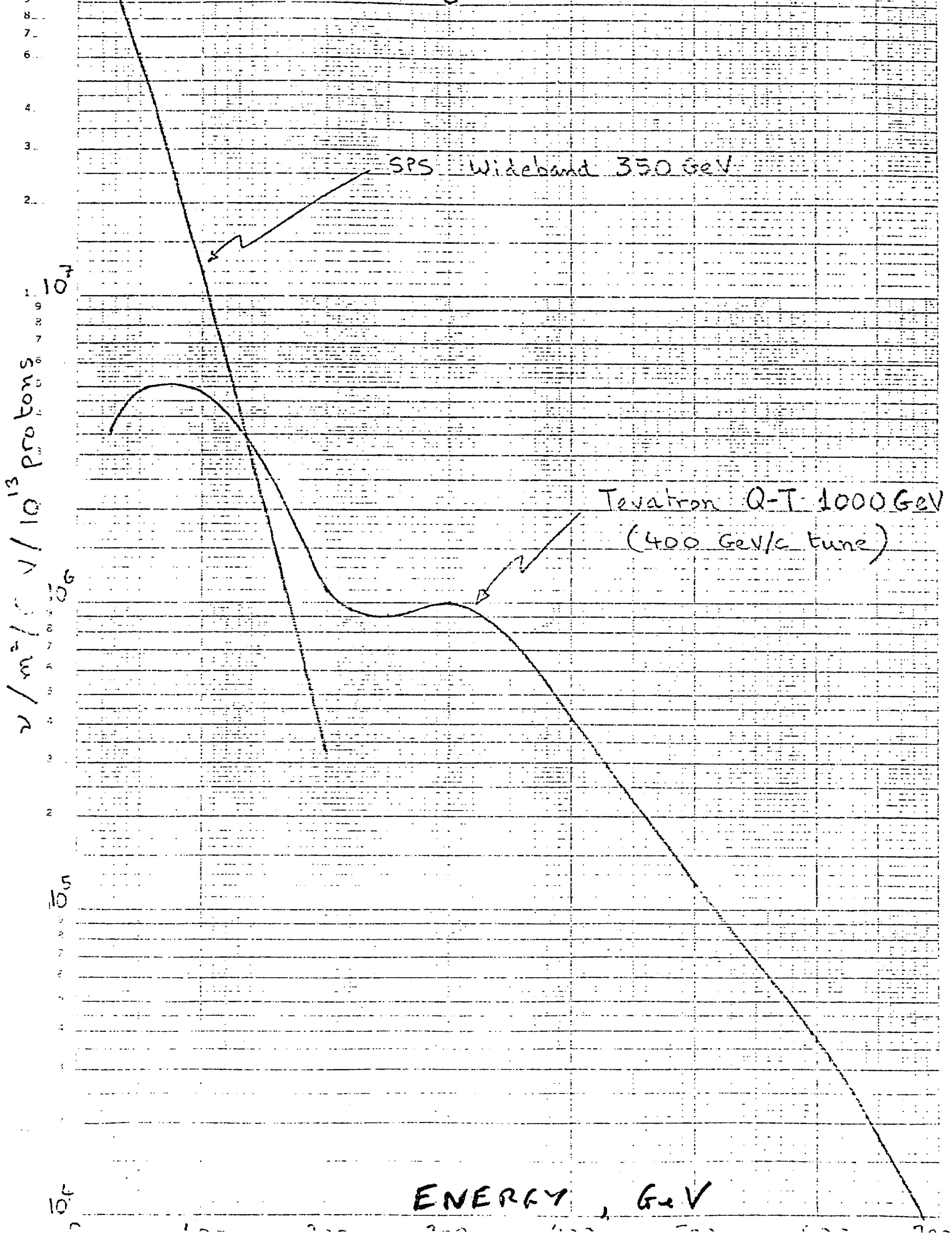
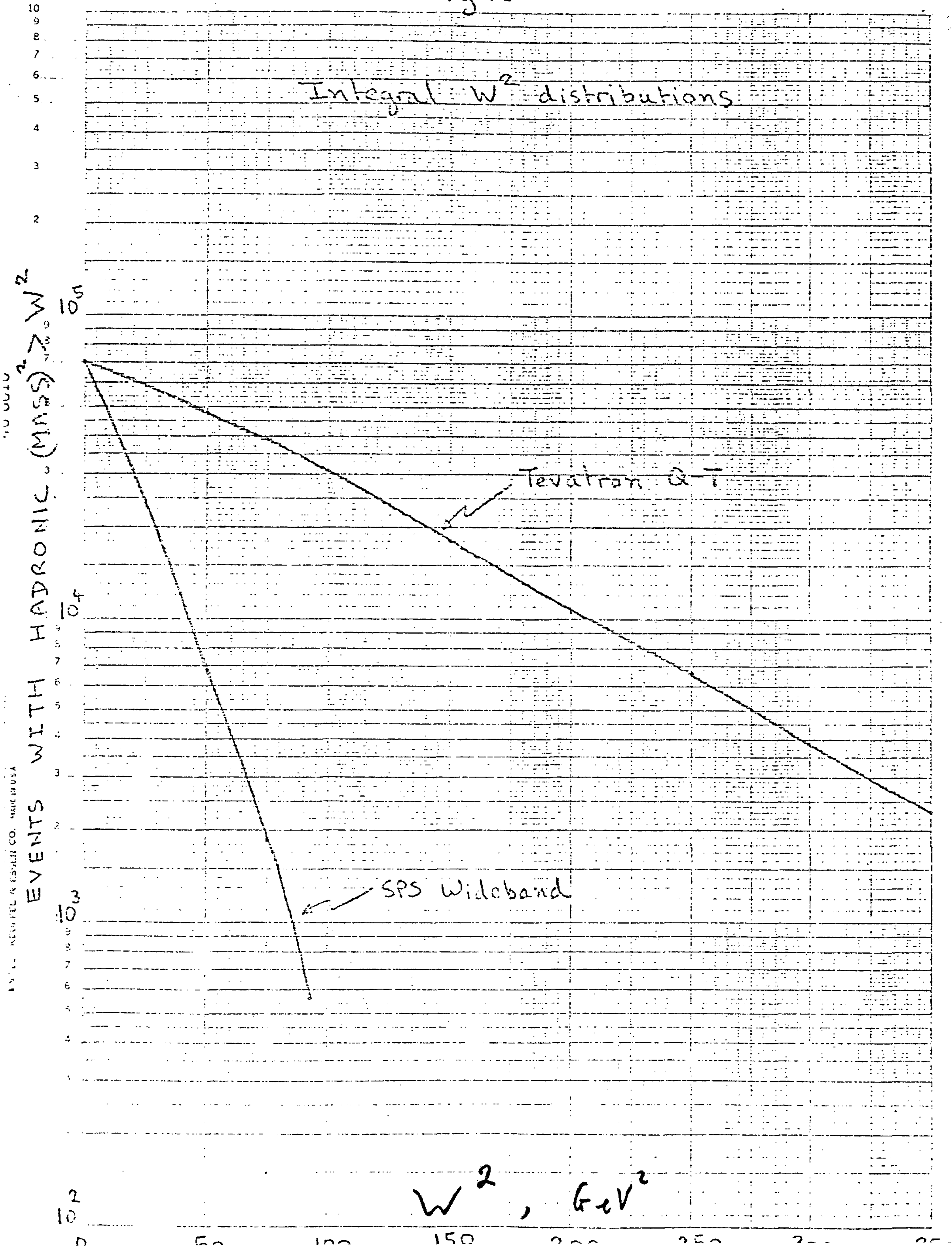

SPS Wideband 350 GeV
Tevatron Q-T 1000 GeV
(400 GeV/c tune)
ENERGY, GeV
$10^8$
$10^7$
$10^6$
$10^5$
$10^4$

Fig 2



Integral W² distributions
EVENTS WITH HADRONIC (MASS)² ≥ W²
10⁵
10⁴
10³
10²
Tevatron Q-T
SPS Wideband
W², GeV²

# Addendum to Tevatron Proposal No. 632

Spokesman: D.R.O. Morrison, CERN, EP-Division,
1211 Geneva 23, Switzerland, Tel. 83-61-11

Local contact: W.F. Fry, Department of Physics, University of Wisconsin, Madision,
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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

February 12, 1982

by the

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

## INTRODUCTION

Since our proposal, P632, was submitted in April 1980, many things have changed. We present in this addendum the most important of them, namely that we believe that we can do good and possibly exciting physics with $\sim 1.10^{18}$ protons from the Tevatron. The development of holographic optics means that high resolution of 30 to 50 $\mu$m should be obtainable over a volume of one to 4 $m^3$.

## 1. Laboratories and Participants

The Collaboration is pleased to be joined by groups from

Fermilab (R. Hanft, W. Smart, M. Sokoloff, E. Treadwell and L. Voyvodic).

Brussels (Inter-university Institute for High Energy — E.A. de Wolf, P. Marage, J. Moreels, J. Sacton and P. Vilain).

The group from Aachen has had, with regret, to withdraw.

## 2. High Resolution Optics

A first improvement in resolution has been obtained in BEBC where by using a specially designed high resolution camera with conventional optics a resolution of 200 $\mu$m was obtained over a volume of $\sim 3$ $m^3$ to be compared with the 600 $\mu$m resolution of the standard cameras.

Holographic optics was first tried in the small BIBC chamber at CERN where a resolution of $\sim 8$ $\mu$m was obtained in the first test. A first experiment has now begun with the HOBC chamber (also a heavy liquid one) and a resolution $\sim 8$ $\mu$m was obtained. Using the on-line scanning and measuring machine HOLMES, it has been found to be easy to scan, to track-follow and to measure events with short-lived decays on holographic film.

A vigorous programme is underway to install holographic optics in BEBC and the first series of tests are very encouraging. At the same time close contact has been maintained with the Fermilab 15-foot group and with the Colombia group of C. Baltay who are also making tests of holographic optics for the 15-foot chamber.

For an experiment with $\sim 1.10^{18}$ protons we would expect about 28,000 charged current events of which $\sim$ 2800 would contain a charmed particle. Correcting for the probability of observing the decay ($\sim$ 30%) and for the reduced fiducial volume, about 10% of the charmed particles decays would be observable, about 280 events.

High resolution optics should also allow us to search also for other new short-lived particles apart from charm.

(a) There is some small probability of producing beauty particles and discussions at the Moriond Workshop on New Flavòrs, January 1982, showed that there is no reliable lifetime estimate (the values proposed range from $10^{-15}$ to $10^{-13}$ sec). The possible signals of beauty decay would be (i) multi decays (ii) large transverse momentum (iii) unusually high charged multiplicity (average expected $\sim$ 6 compared with $\sim$ 2.5 for D-mesons).

(b) The observation of tau-leptons would be interpreted as evidence for incoming tau-neutrinos — a particle for which there is no direct experimental evidence. Sources of tau-neutrinos could be from the production of F mesons in the target giving ($\nu_\tau$ $\tau$) decays, or possibly neutrino oscillations. However the background of charmed particle decays will make the identification of tau-decays difficult until reasonable statistics are accumulated.

(c) Charmed baryons are produced infrequently in $e^+e^-$ interactions and in photoproduction, but with reasonable frequency in neutrino interactions.

(d) There is some evidence for long-lived particles, in particular E531 has a candidate for a long-lived neutral baryon. Such particles should be observable.

(e) Any other new short-lived particle. Since the 15-foot chamber is sensitive to all known weakly decaying particles there is an excellent chance it would be sensitive to some unknown decay.

It should be emphasised that we intend to measure all events conventionally on the film from three cameras, while studying the vertex region in more detail with high resolution optics.

### 3. Like-Sign Dileptons

Results from counter experiments have given cross sections for like sign dimuons which are more than an order of magnitude higher than predictions from QCD. These results have been summarised by the CHARM Collaboration [P.L. 107B (1981) 241] and are shown in fig. 1. Added to this figure are the latest cross-sections from the CDHS Collaboration which are lower than those previously published but which are still significantly above the theoretical prediction. This discrepancy is not understood theoretically.

The basic process assumed is that in a charged current interaction, a $c\bar{c}$ pair is produced in the sea by a gluon. If this is correct then the strange particle content of like-sign dileptons should be about twice that for opposite sign dileptons. Strange particles can be identified in bubble chambers. For an experiment with $2.5 \cdot 10^{18}$ protons, the 70000 charged current events maybe expected to give $\sim$ 50 events of like-sign $\mu\mu$ and $\sim 50\,\mu e$ events if the CHARM Collaboration is correct, less if CDHS is correct, and $\sim$ 2 events according to theory, this with the muon momentum cut at 10 GeV/c.

Because of the large background of $\pi$ and K decays, it is unlikely that meaningful results can be obtained for $\mu\mu$ events. But with $\mu e$ events the background is very low. Further electrons can be identified down to 0.3 GeV/c instead of the cut-off at 4 to 10 GeV/c for like-sign dimuons in counter experiments and this will increase the number of events by a factor of $\simeq$ 3.

Thus strange particle production in association with like-sign dileptons can be studied and this could provide an important new piece of evidence in the question of the unexpectedly high cross-sections. However, for good statistics $\sim 2.5 \cdot 10^{18}$ protons are required.

## 4. Results Obtainable from Early Tevatron Runs

After the Tevatron first accelerates particles, it is reasonable to expect that, like all previous accelerators, it will have low beam intensity. The question is then whether good, useful physics can be done with short runs of low intensity.

To have the highest possible number of events one should use (a) the quad triplet beam and (b) a neon-hydrogen mix in the 15-foot chamber.

In section 2 above it has been shown that charm production can be studied and new exotic particles searched for with small numbers of protons — numbers for $10^{18}$ protons have been given but first results could be obtained with less.

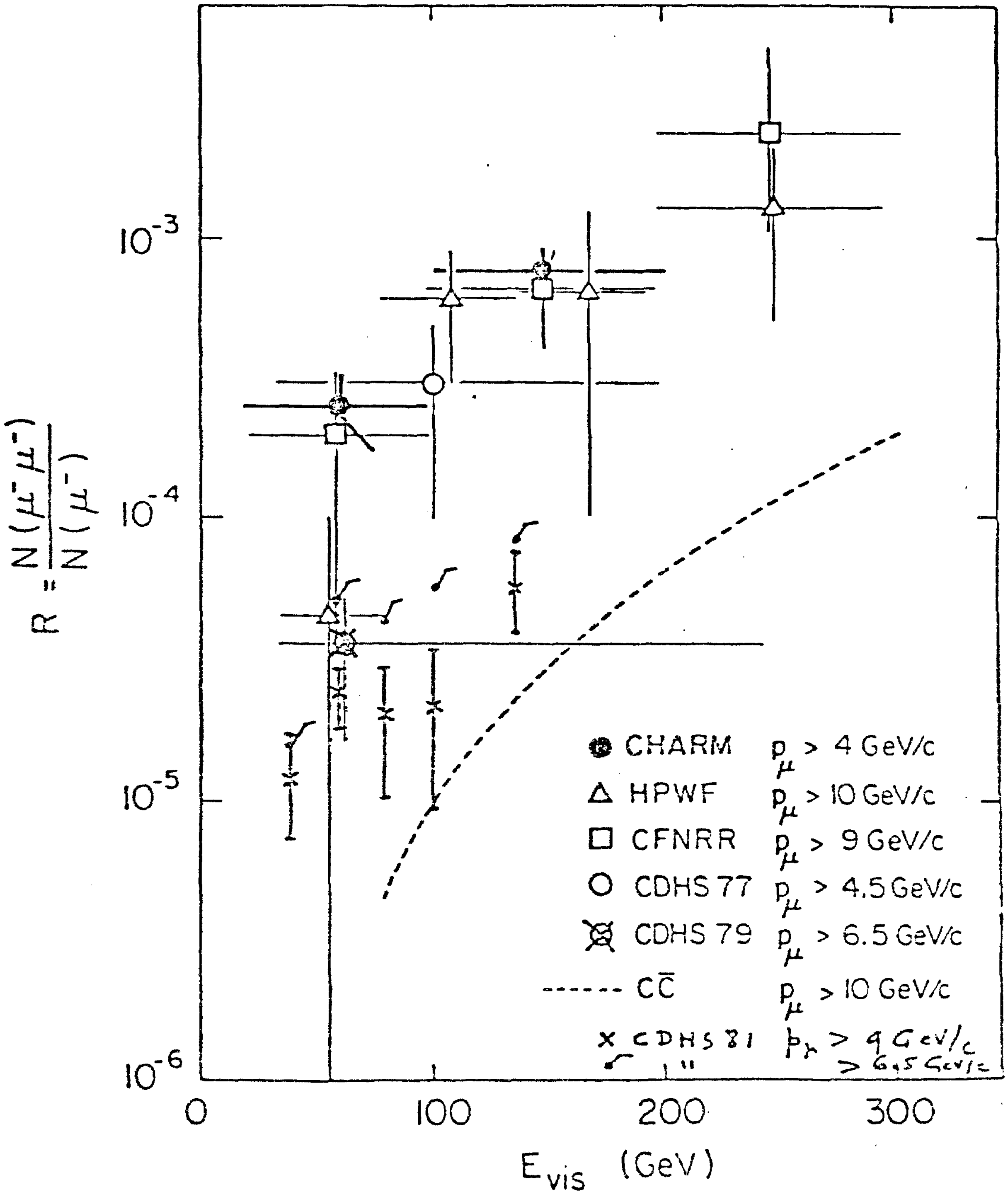
Studies of fragmentation functions have been made with only several thousand events whereas $1 \cdot 10^{18}$ protons would give 28000 CC events of which $\sim$ 200 would have $W^2 \sim 450\ \text{GeV}^2$ so that the $W^2$ range studied would be greatly extended compared with previous neutrino experiments. Similiarly the range of $Q^2$ would be much greater so that moments of fragmentation functions can be measured to these higher values.

Low intensity runs allow studies of a number of other subjects e.g. separation of forward (current) and backward (diquark) fragments, strange particles, resonances etc. However some subjects do require high statistics e.g. like-sign dileptons, structure functions.

## 5. Conclusions

In conclusion, we believe that good and exciting physics can be done with a small exposure of the 15-foot chamber to the neutrino quad triplet beam, in particular by the use of high resolution optics-holography. With the full exposure requested much more can be done, e.g. a study of strange particle production in association with dileptons which may help to explain the unexpectedly high cross-section observed.

It would be a great help to the members of the Collaboration if this experiment could be approved soon as this would allow budget applications for equipment, measuring apparatus etc. to be accepted.



R = N(μ⁻μ⁻) / N(μ⁻)
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
0
100
200
300
E_vis (GeV)
CHARM p_μ > 4 GeV/c
HPWF p_μ > 10 GeV/c
CFNRR p_μ > 9 GeV/c
CDHS 77 p_μ > 4.5 GeV/c
CDHS 79 p_μ > 6.5 GeV/c
CC̄ p_μ > 10 GeV/c


- Fig. 1

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April 17, 1980

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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 $\tau$-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, $\nu_e$ 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.

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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, $\tau$ 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, $\tau$-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. Rec tly 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 ($\mu e$) events. The dimuon events will be identified using the well-proven EMI and the ($\mu e$) 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:

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

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

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

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 $\bar{c} \rightarrow \bar{e} + \bar{s}$ 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 $\tau$-leptons should be produced in this exposure. There would be characteristic double decay events. The $\tau$ lifetime is predicted to be $3 \times 10^{-13}$ 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 |
| $\quad \hookrightarrow \tau + \nu_\tau$ | 40 |
| $\nu + N \rightarrow \mu^- + b$ | 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 $\Lambda$ 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 $\rho$, $\omega$ 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 $\nu$ (<1 GeV) and therefore the complete $\nu$ 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 $\nu$ 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 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 $\nu_e$ 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.

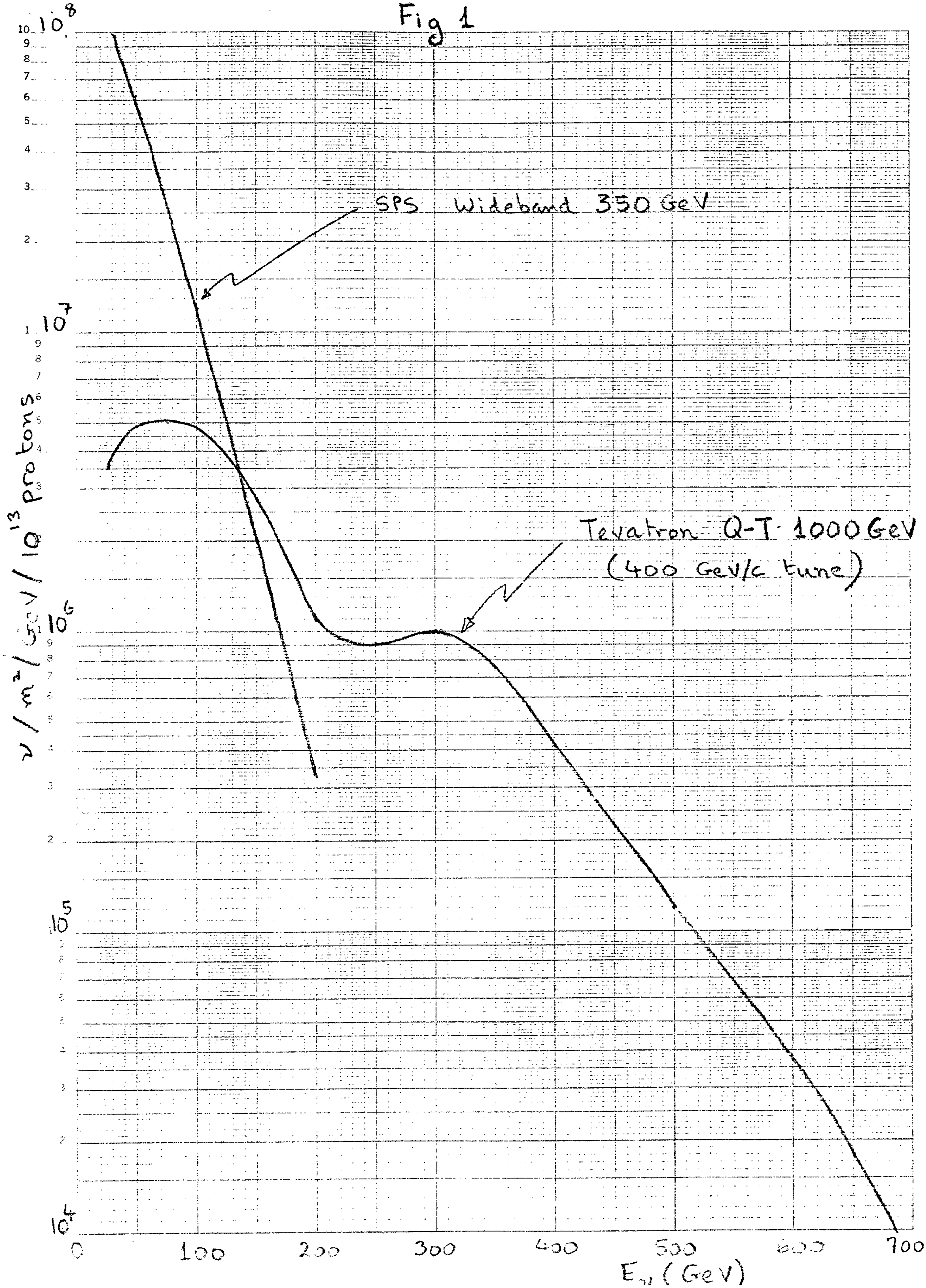
We request the quad triplet beam tuned to 400 GeV/c and using the highest proton energy available. If a 64% (mole) Ne-$H^2$ mixture is used then 2.5 x $10^{13}$ protons on target will correspond to ~ 1 event per photograph ($\nu + \bar{\nu}$ + NC). We believe therefore that we can tolerate the highest 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
$E_\nu$ ( GeV)
10⁸
10⁷
10⁶
10⁵
10⁴
0
100
200
300
400
500
600
700

Fig 2

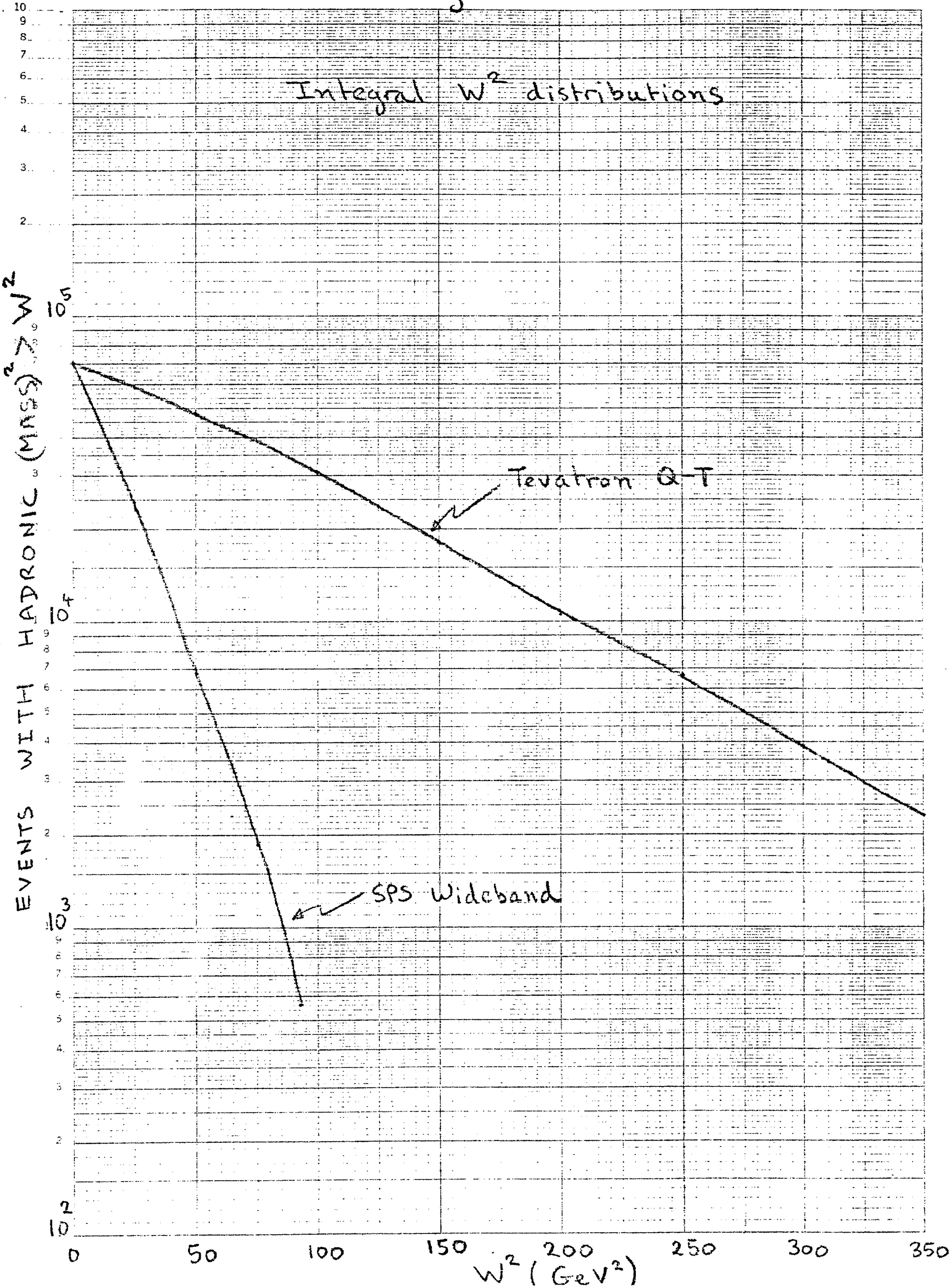
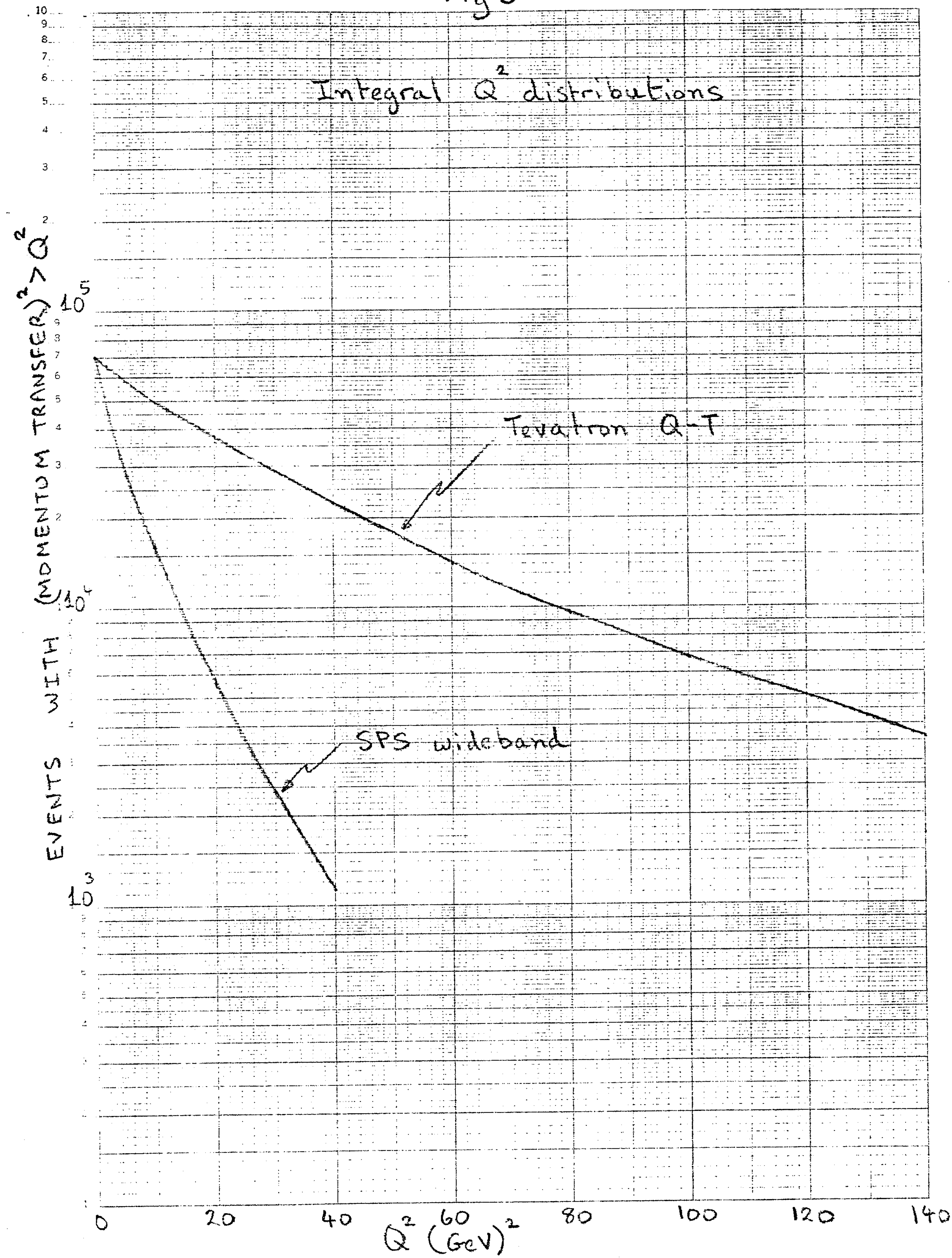
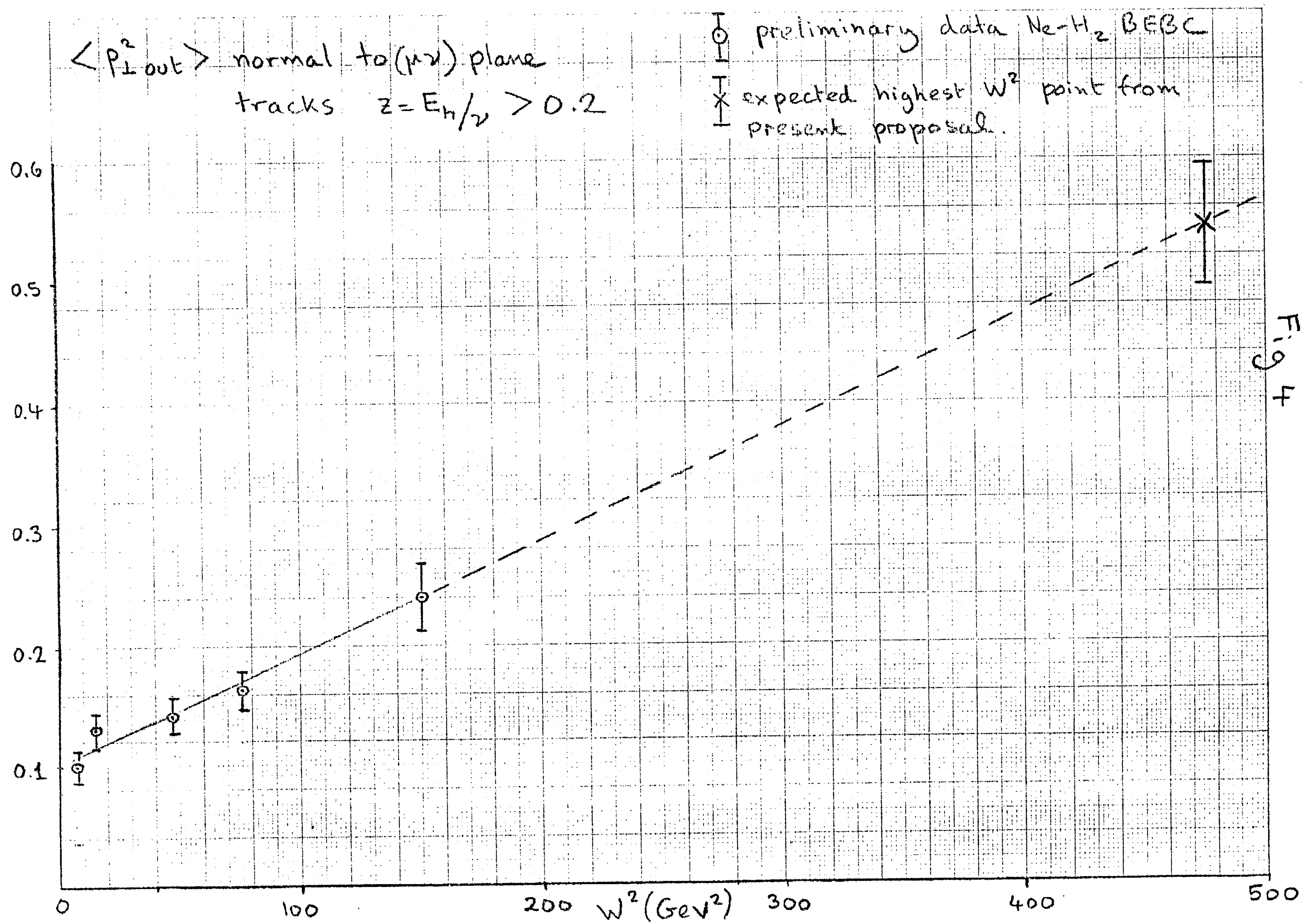

Integral $W^2$ distributions
Tevatron Q-T
SPS Wideband
EVENTS WITH HADRONIC $(MASS)^2 > W^2$
$10^5$
$10^4$
$10^3$
$10^2$
0
50
100
150
200
250
300
350
$W^2$ ($GeV^2$)

Fig 3



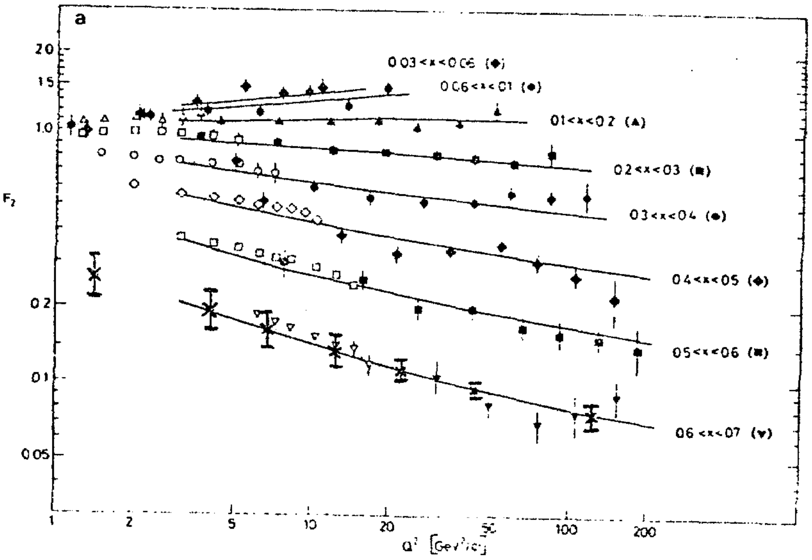
Integral $Q^2$ distributions
Tevatron Q-T
SPS wideband
EVENTS WITH (MOMENTUM TRANSFER)$^2$ > $Q^2$
$10^5$
$10^4$
$10^3$
0
20
40
60
80
100
120
140
$Q^2$ $(GeV)^2$



$\langle p^2_{\perp out} \rangle$ 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 4

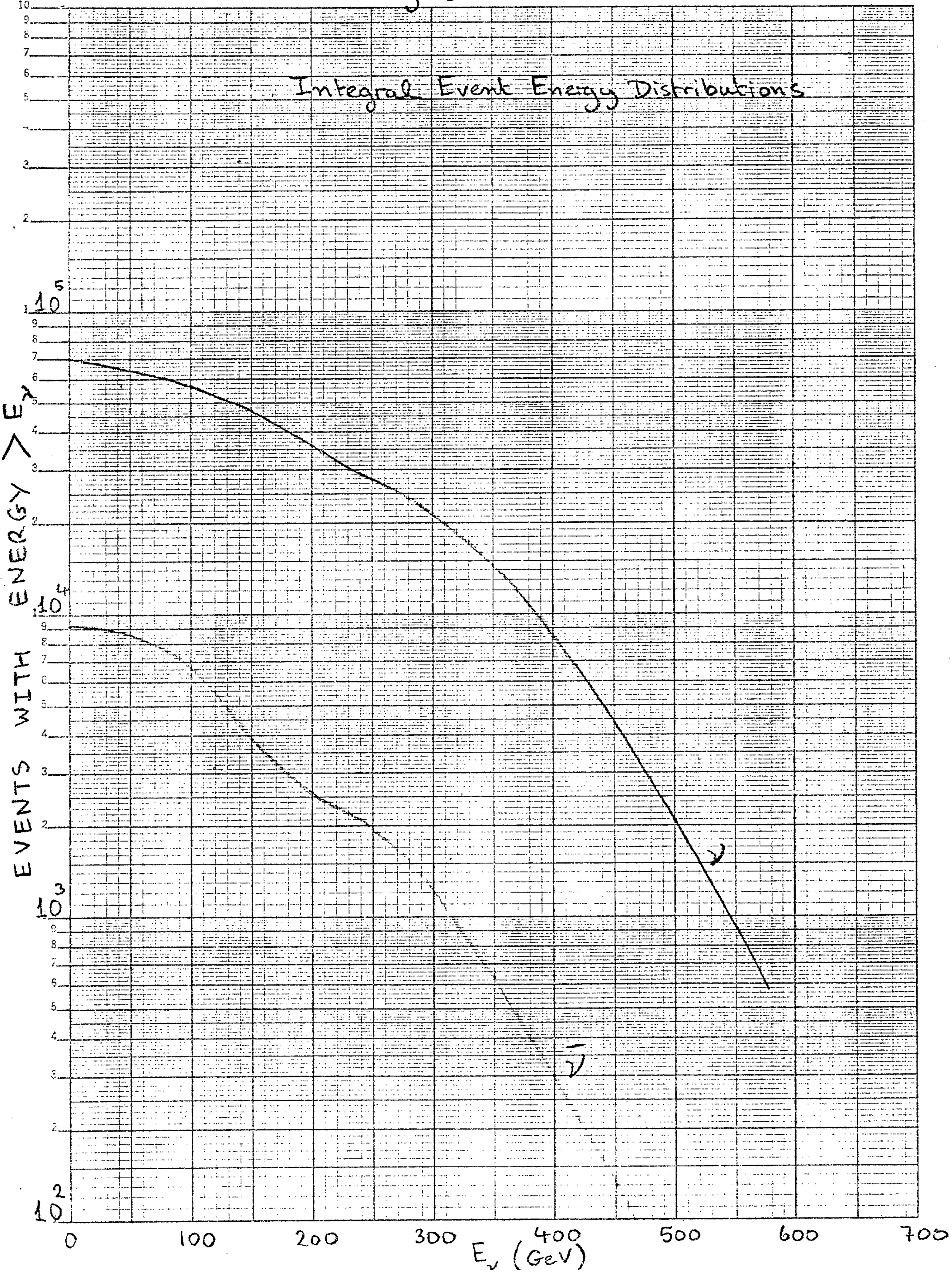
# Fig 5




Ӿ 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 <u>82B</u> (1979) 456) and the open points are derived from eD scattering.

Fig 6



Integral Event Energy Distributions
EVENTS WITH ENERGY > $E_\nu$
$10^5$
$10^4$
$10^3$
$10^2$
$\nu$
$\bar{\nu}$
0
100
200
300
400
500
600
700
$E_\nu$ (GeV)