NAL PROPOSAL No. 262

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NEUTRAL CURRENT INVESTIGATIONS AT NAL

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Dr. E.L. Goldwasser
National Accelerator Laboratory
Batavia, Illinois

Dear Ned:

We would like to officially propose a run for our experiment on the neutral current question. This is in response to your letter of September 10, 1973.

As you know, the Gargamelle group at CERN claims to have strong evidence (Physics Letters 46B,138,1973), with a signal/noise ratio of about 5, for the existence of the processes

$$\nu_\mu + N \rightarrow \nu_\mu + \text{hadrons}$$
$$\bar{\nu}_\mu + N \rightarrow \bar{\nu}_\mu + \text{hadrons}$$

In addition, the Harvard-Penn-Wisconsin Group at NAL has also claimed evidence (signal/noise ~ 1) for the effect at high energies (Rubbia at Bonn and Aix-en-Provence). They are presently scheduled for a new run to further pursue their investigation.

Neutral currents, if real, will have a profound influence on both future experiments and theories. The most important task now, is to obtain an independent measurement capable of convincingly confirming or "killing" the effect. We feel that our experiment and beam conditions are uniquely suited for this job. We discussed with you in early August some of the detailed technical reasons for this; let us reiterate them here.

The effect, as described by Gargamelle, is quoted as a ratio charged to neutral currents; i.e

$$R = \frac{\sigma(\nu_\mu + N \rightarrow \nu_\mu + \text{hadrons})}{\sigma(\nu_\mu + N \rightarrow \mu^- + \text{hadrons})}$$

$$\bar{R} = \frac{\sigma(\bar{\nu}_\mu + N \rightarrow \bar{\nu}_\mu + \text{hadrons})}{\sigma(\bar{\nu}_\mu + N \rightarrow \mu^+ + \text{hadrons})}$$

Their results are

$$R = 0.2 \pm 0.03$$

$$\bar{R} = 0.45 \pm 0.09$$

The E1A results, as reported by Rubbia at Bonn and Aix-en-Provence, agree with these numbers, although they do not measure them separately.

The major background expected by Gargamelle comes from neutron interactions, though they feel they have dealt with this. This is because the amount of surrounding material (shield, bubble chamber housing, etc) is large compared to target material, and the typical neutrino interaction is of low energy. At NAL, this should not be a significant effect because neither of these conditions is present.

At NAL, the most important source of background is from the ordinary processes

$$\nu_\mu + N \rightarrow \mu^- + \text{hadrons} \qquad (1)$$

$$\bar{\nu}_\mu + N \rightarrow \mu^+ + \text{hadrons} \qquad (2)$$

where the charged muon carries a small energy and, therefore, can go off at a large laboratory angle.

It is evident, therefore, that a clear determination can only be made in an experiment that has large solid angle for muon determination and minimizes the number of events of type (1) or (2) where the muon is missed. Figure 1 shows a typical "hadron trigger" event in our apparatus. Since the apparatus contains steel plates, we are sensitive to muons very quickly -- as soon as the hadron shower is killed. At a typical hadron energy (say 50 Gev) this is after about 10 collision lengths, or 40 inches of steel. The muon penetration is observable in two ways: (1) spark chambers located every 16" of iron; (2) scintillation counters located every 4" of iron. The picture shows the muon observed in both ways. We believe that the apparatus is sensitive to all muon contained inside the apparatus for a longitudinal distance of between 60" and 120", depending upon the hadron energy. This gives a solid angle acceptance between 0.25

and 1 steradian. Very definitely, the high density target with the built-in capability for killing the hadron shower very close to the vertex provides a very effective solid angle for muon acceptance.

But the large solid angle is not enough. There are, in principle, neutrinos that can produce background of types (1) and (2), even with very good acceptance. Consider, for example, an experiment run with a trigger threshold, for the hadron energy deposition, set at 8 Gev (a typical value in our experiment). Then neutrinos of 10 Gev energy will produce muons in the trigger of 2 Gev energy or less. It is precisely these low energy muons that tend to emerge at large laboratory angles.

Figure 2 shows as a function of incident neutrino energy, the fraction of events (requiring $E_h > 10$ Gev) of type (1) or (2) where the muons leave the apparatus before they are visible. Comparing figures (2a) and (2b), we see immediately that the anti-neutrino case has substantially less contamination than the neutrino case. This is due to the fact that the fraction of the neutrino energy that goes to the muon is substantially greater for anti-neutrino's than for neutrinos. Figure (3a) shows the inelasticity distribution for neutrino events from our experiment. Figure (3b) shows the preliminary distribution for anti-neutrinos. About 50% more energy, on the average, goes to the muon. This is reflected in the more advantageous situation shown in figure 2. The narrow-band beam, with almost complete sign-selection, particularly at high energies, allows the investigation of anti-neutrinos alone.

But even an anti-neutrino beam with substantial contamination of either neutrinos or anti-neutrino's at low energy will not be adequate. Figure 2 shows that at 15 Gev, neutrinos will look like neutral currents about 20% of the time (for an E_h threshold of 10 Gev). Figure 4 shows the energy distribution for neutrinos in the sign-selected beam. Shown separately are the contributions from the decay pipe and from the region of the beam-forming elements. This latter, so-called "wide-band background", contains neutrinos of an energy that might produce background events at about the five-percent level in a neutral current experiment, and is the major limitation in our sensitivity. The number of neutrinos in this backgroundproducing energy is orders-of-magnitude smaller than in an ordinary wide-band beam. Of course, the statement that it produces background at the five-percent level is the result of a calculation--assuming beam fluxes, etc. An extremely important point is that it can be independently measured. A slit located at the very end of the beam-forming elements, after the dumping of the incident proton beam, allows the contribution of high-energy neutrinos from the decay pipe be removed, and the wide-band contamination separately measured.

Taken together, we feel that we are ready now to verify the neutral current effect on anti-neutrinos. If the process is really there, there are many questions to pursue:

(1) Neutrinos vs. anti-neutrinos;

(2) Energy distribution of hadrons from the high energy kaon neutrino in a narrow-band beam of better energy resolution;

(3) Energy dependence of the effect.

The narrow-band beam is highly appropriate to pursue all these questions. But the burning question now is: Is the effect real? We are prepared to answer that question in a single, definitive run.

We propose then to embark on a run on anti-neutrinos as soon as possible after completing the total cross-section run in November. The experiment does not require the toroidal magnet in our building, so that work could proceed in parallel, if necessary. We will require a total of $3\ 10^{17}$ protons on target at an average intensity of $> 2\ 10^{12}$ protons/pulse with fast spill.

We are sure you are as eager as we are to obtain more information that will help resolve this most interesting physics question.

Sincerely,

Barry Frank

Barry C. Barish, Frank Sciulli

BB/FS:nms

$\nu_\mu + N \rightarrow \mu^- +$ Hadrons.

Typical wide angle muon Identified in Caltech Apparatus

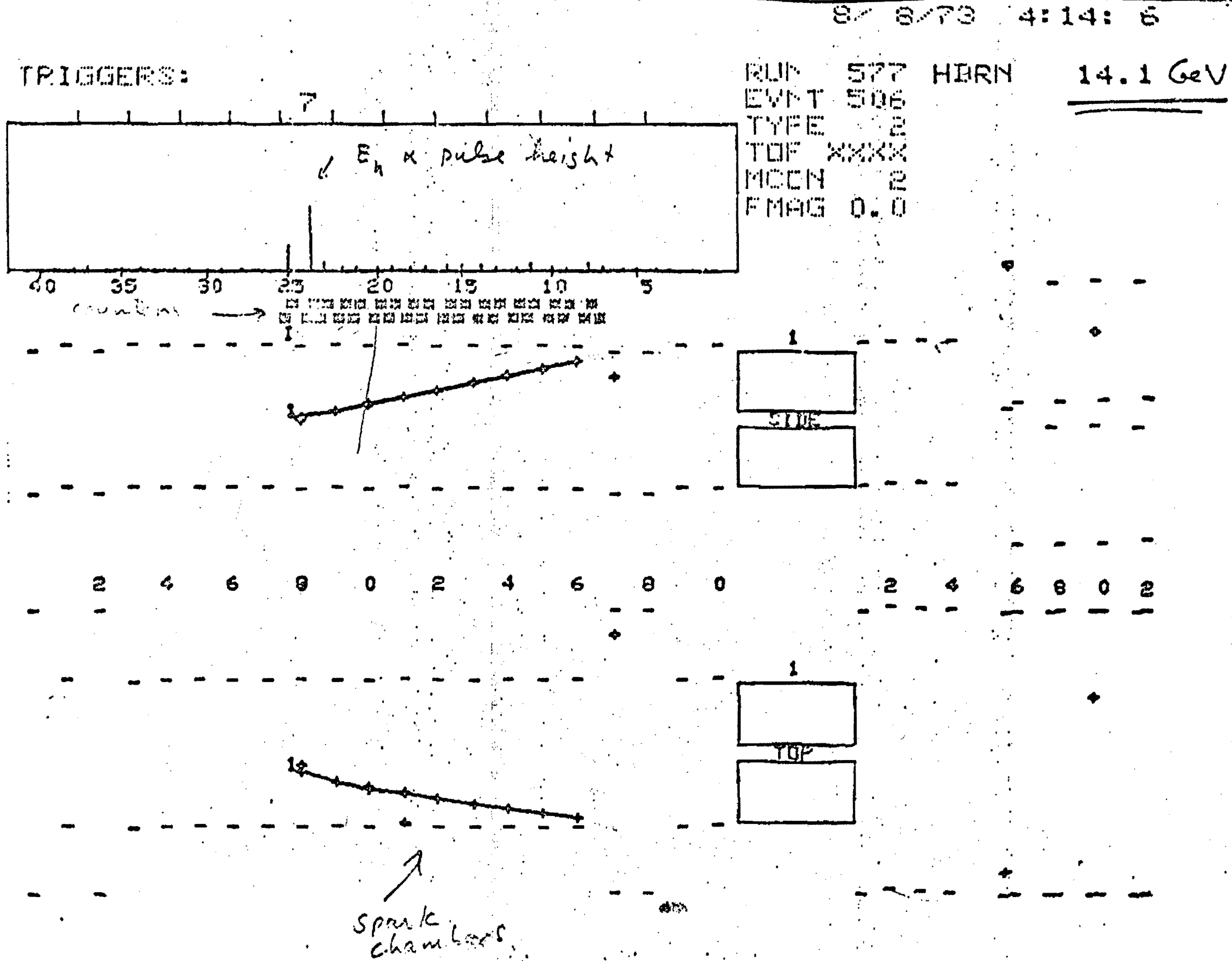
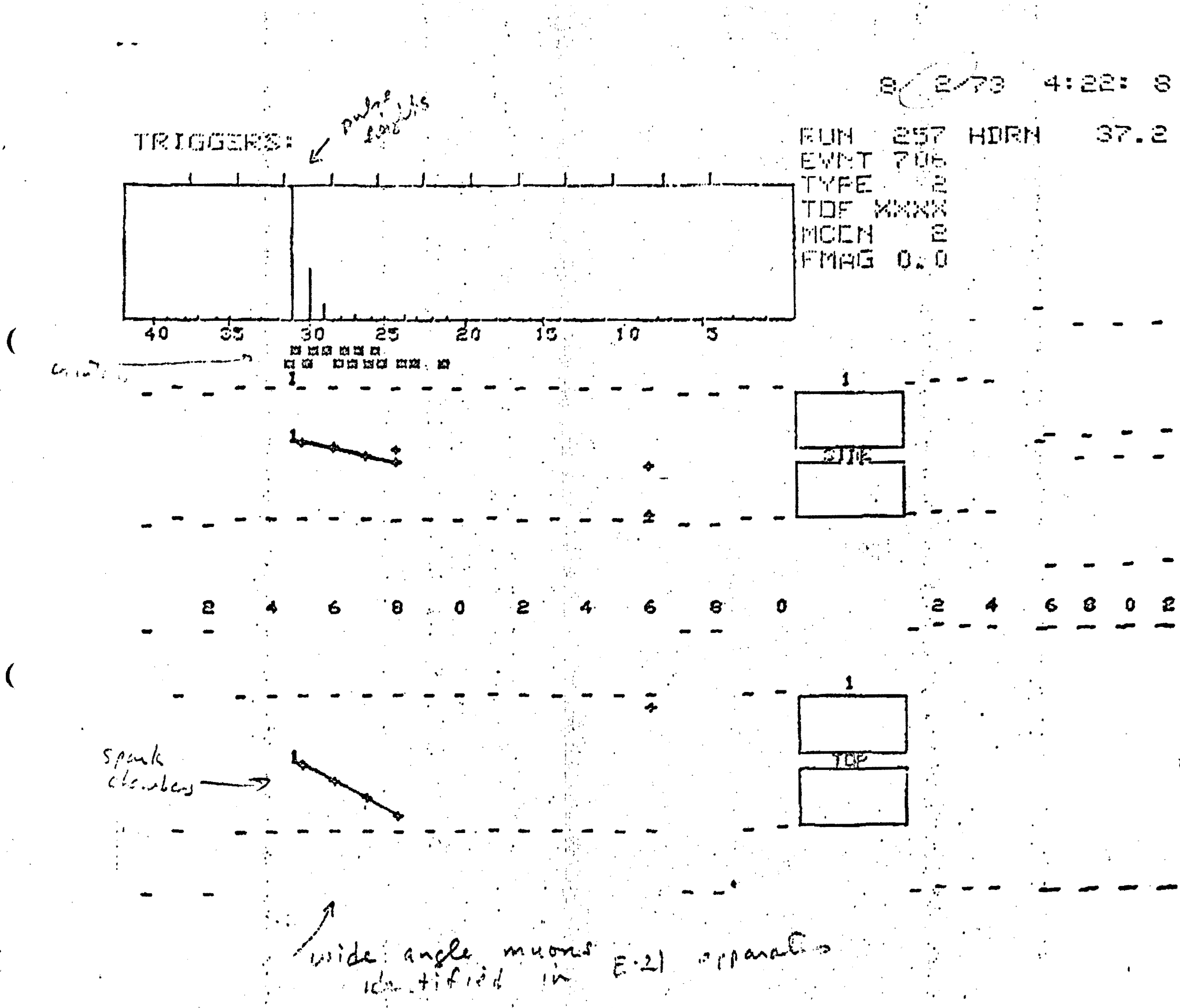


Fig. 1A.


8/ 2/73 4:22: 8
TRIGGERS:
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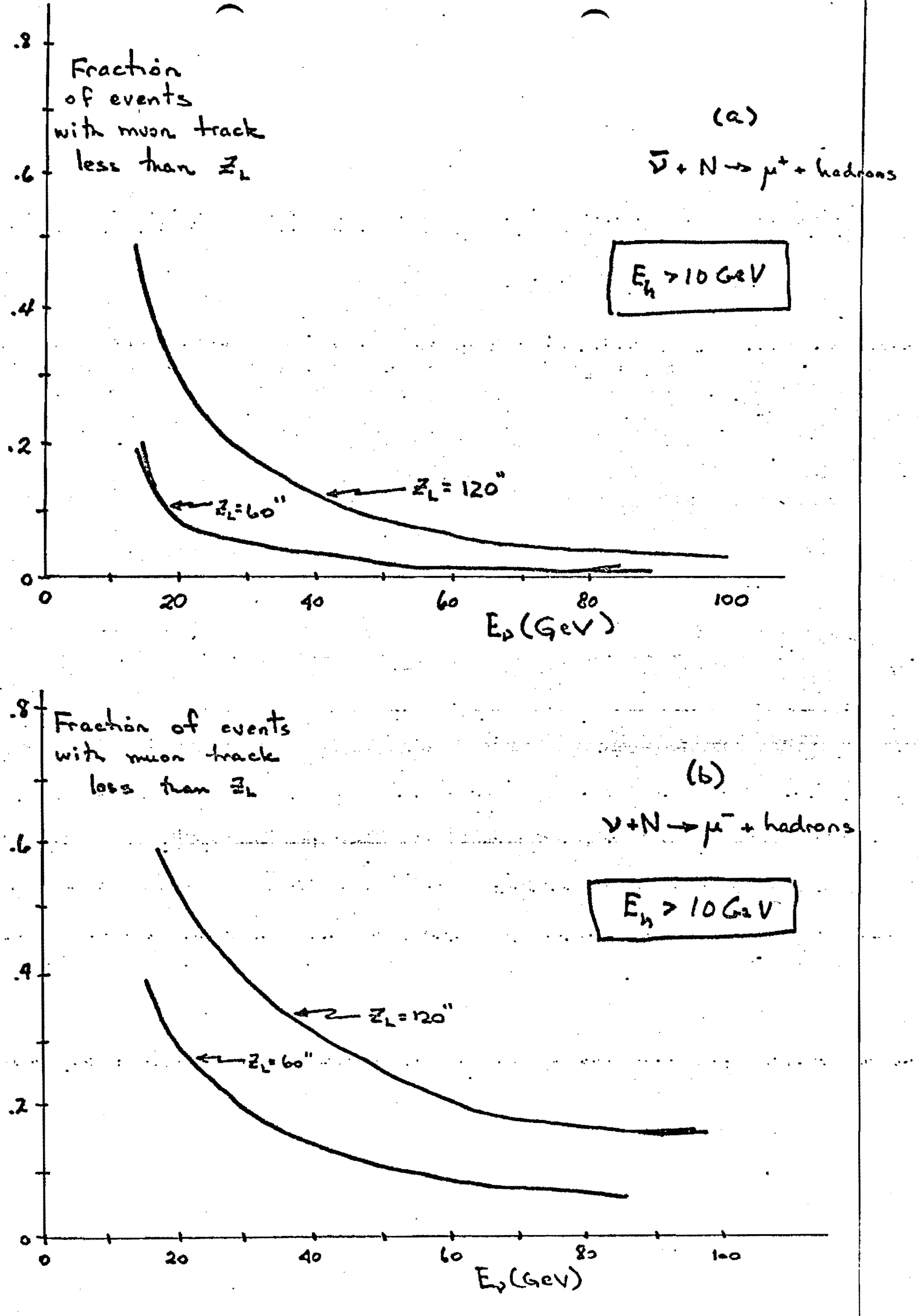
EVNT 706
TYPE 2
TOF XXXX
FMAG 0.0
40 35 30 25 20 15 10 5
SIDE
2 4 6 8 0 2 4 6 8 0 2 4 6 8 0 2
TOP
spark chambers
wide angle muons identified in E-21 apparatus

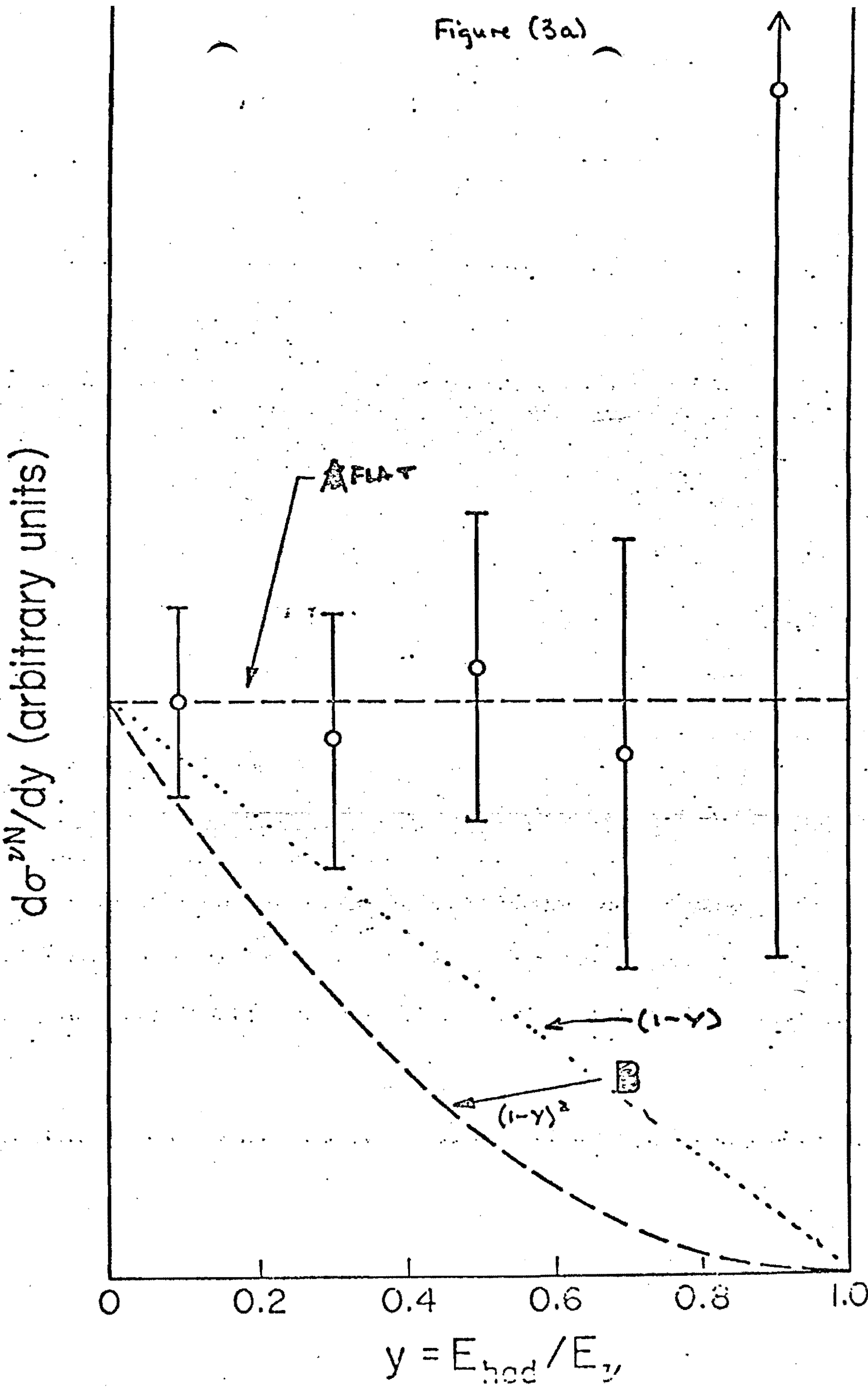
Figure 1B

FIGURE 2



Fraction of events with muon track less than Z_L
(a)
ν̄ + N → μ⁺ + hadrons
E_h > 10 GeV
Z_L = 120"
Z_L = 60"
0
.2
.4
.6
.8
0
20
40
60
80
100
E_ν (GeV)
Fraction of events with muon track less than Z_L
(b)
ν + N → μ⁻ + hadrons
E_h > 10 GeV
Z_L = 120"
Z_L = 60"
0
.2
.4
.6
.8
0
20
40
60
80
100
E_ν (GeV)

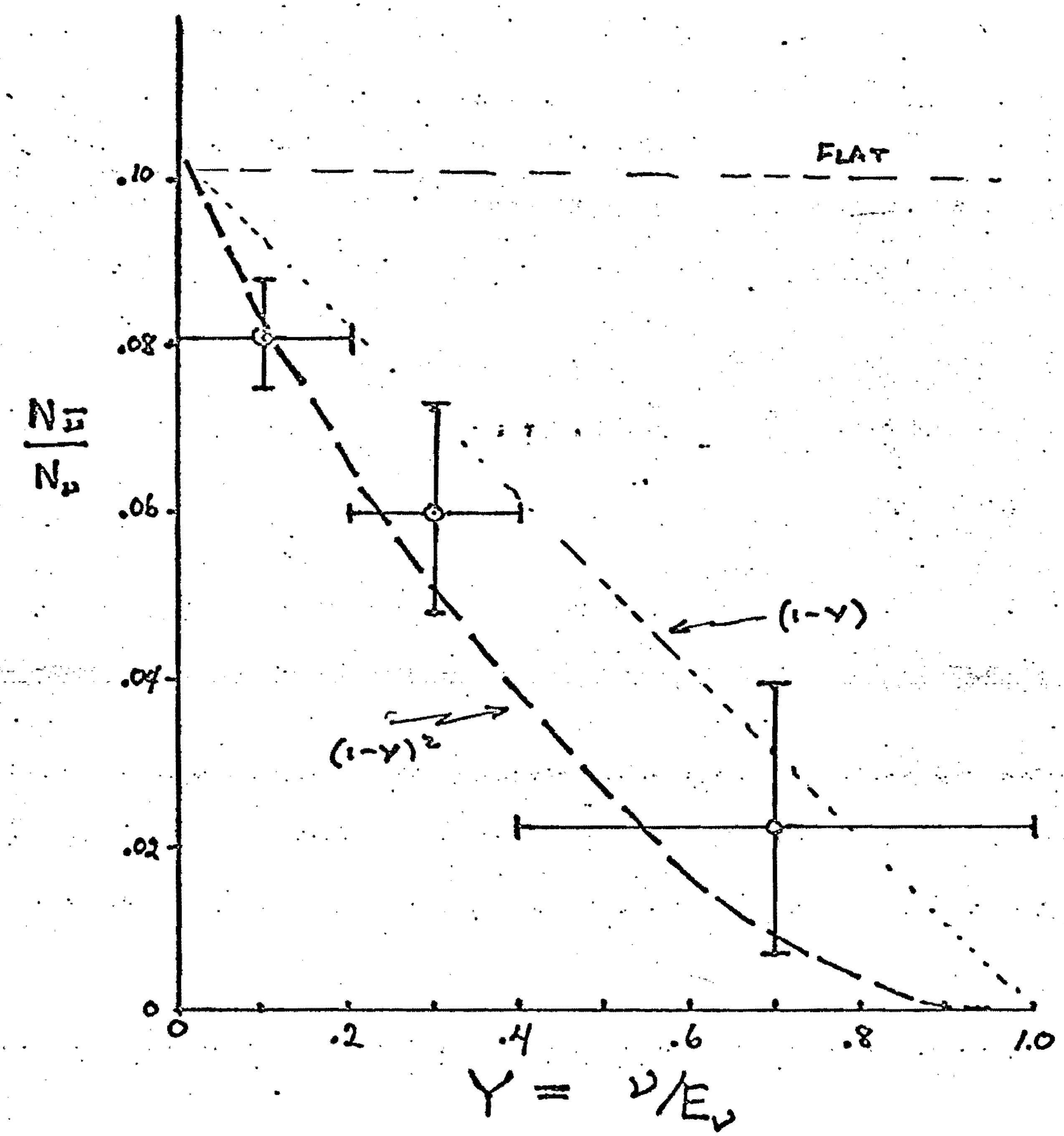
Figure (3a)

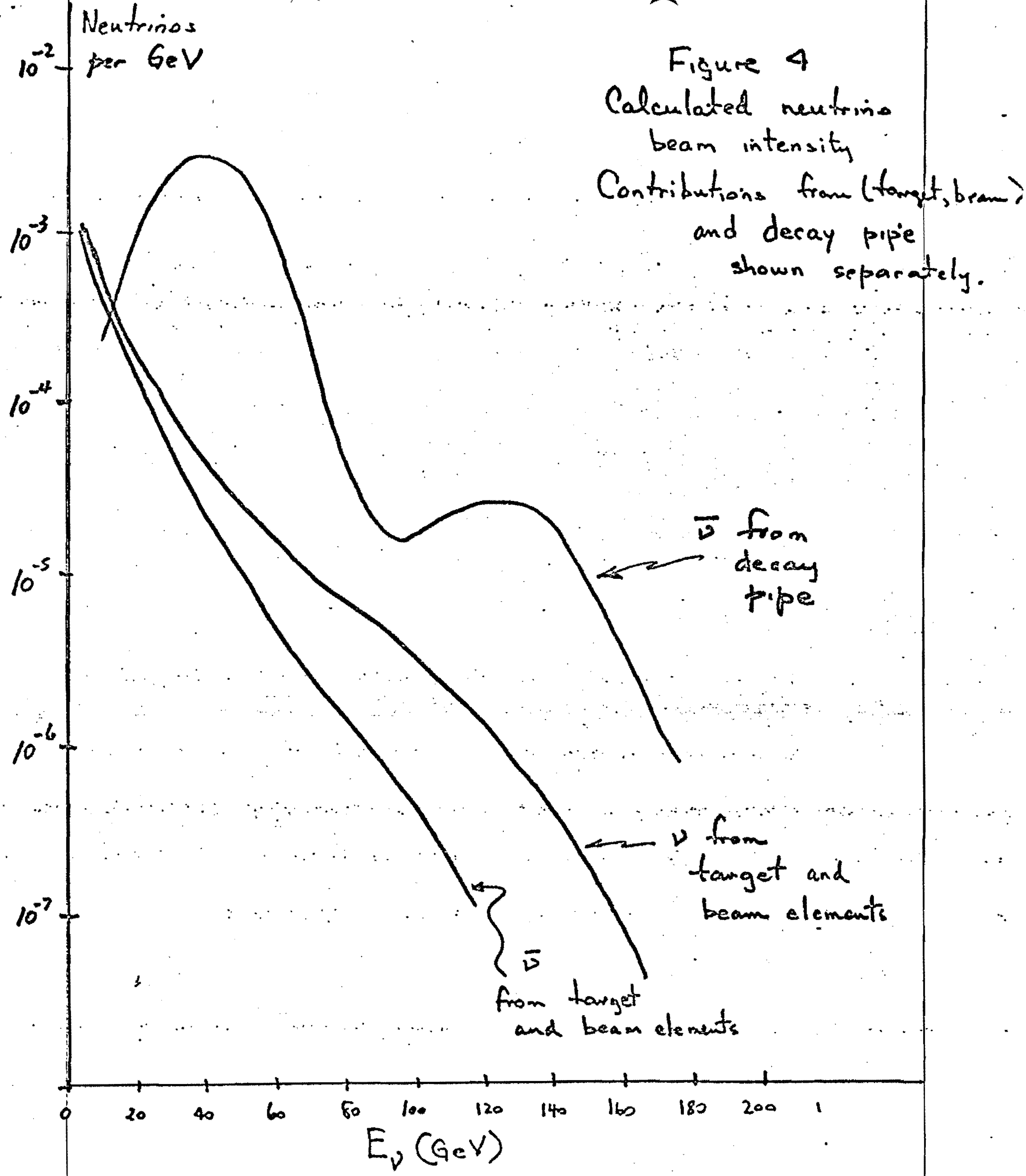


- PRELIMINARY -

8/10/73

Ratio of $\bar{\nu}$ to ν events vs Y





Neutrinos per GeV
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Figure 4
Calculated neutrino beam intensity
Contributions from (target, beam) and decay pipe shown separately.
$\bar{\nu}$ from decay pipe
ν from target and beam elements
$\bar{\nu}$ from target and beam elements
0
20
40
60
80
100
120
140
160
180
200
E_ν (GeV)