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PROPOSAL TO CONTINUE THE STUDY OF NEUTRINO AND ANTINEUTRINO INTERACTIONS IN THE 15′ BUBBLE CHAMBER USING A HEAVY MIX OF NEON AND HYDROGEN AND A DICHROMATIC NEUTRINO BEAM

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We request a 15′ bubble chamber run in a dichromatic neutrino-antineutrino beam to take place simultaneously with E-594 which could be as early as October 1981. The bubble chamber would be filled with a heavy mix of Neon and Hydrogen. In this 22 week period we would hope to get approximately 0.6×10^{19} protons on target, split equally between neutrinos and antineutrinos. If all went well, we would have the worlds largest sample of ν and $\bar{\nu}$ events in a bubble chamber taken with a dichromatic beam. The exposure would amount to as much as 600k pictures. We assume that the distribution of energies at which the dichromatic beam will be tuned will be about the same as in the letter of March 2, 1979 from J.K. Walker and F.E. Taylor to T. Groves. In our previous antineutrino dichromatic run, E-388 , we obtained only a disappointing 0.23×10^{19} protons on target.

NEUTRAL CURRENTS

The run proposed here would more than double the amount of data we have with antineutrinos. Our antineutrino neutral current sample would go from the 240 events we now have to about 550 events. A CERN experiment in BEBC has reported 140 antineutrino neutral current events in a dichromatic beam. This same experiment has another 240 unpublished events.

For neutrino neutral current events in a dichromatic beam the world sample of bubble chamber events consists of about 400 events (not yet published) from E-380 and 900 events (600 not yet published) from a CERN BEBC experiment. With 0.3×10^{19} protons on target in a dichromatic beam tuned for neutrinos we would expect to get about 1500 neutral current events.

The physics of neutrino induced neutral current events was discussed in detail in our original proposal for E-388 and reiterated in a letter to the Fermilab director dated February 15, 1979. We list here briefly the physics objectives described in that letter:

1. Neutral current structure functions,
2. Ratios of various charge pion states (π^+/π^-, $\pi^0/\pi^\pm$) for both charged currents and neutral currents and for neutrinos and antineutrinos,
3. Measurment of yields of strange particles for neutral current as well as charged current events,
4. Search for single charmed particles in the neutral current sample, forbidden by the standard model,
5. Fragmentation functions of π's, K's and Λ's in neutral current events,
6. QCD effects in neutral current events.

We emphasize again that to perform kinematic analysis on neutral current events it is necessary to have good information on the neutrino energy. Only in a dichromatic neutrino beam is this possible.

CHARGED CURRENTS

This proposed run would result in 4900 neutrino and 820 antineutrino charged current events. When combined with the data from E-388, we would have a total of about 1440 antineutrino charged current events. The antineutrino charged current events are especially interesting because of the apparent anomaly in the W-distribution (invariant mass of the hadron system) in dilepton events reported by the BEBC "TST" Collaboration.[1] There appears to be a excess of events near 5 GeV. Fig. 1 shows the same W-distribution (unpublished) for dilepton events corresponding to 1500 antineutrino charged current events from

E-546 (Berkeley-Fermilab-Hawaii-Seattle-Wisconsin collaboration). If the charm model used to calculate the curve on the Fig. is, in fact, correct, there is only a 1% probability of obtaining the observed distribution of events. In agreement with BEBC there appears to be an anomalously large number of events in the region of 5 GeV. This excess is not understood. With the data from the run proposed here we would be able to nearly double the number of events shown in Fig. 1.

NEUTRINO OSCILLATIONS

A new and exciting possibility is that this experiment can set a significant limit on neutrino oscillations. At first glance it might seem surprising that an experiment using a dichromatic neutrino beam could compete with one using a broadband beam due to the much larger event rate in the latter. However, the main uncertainty that determines the limit that can be set in a neutrino experiment is not due to the statistical error on the number of events. Rather it is determined by the uncertainty in the background ν_e flux due to K decays. This background is typically 1-1/2% with an uncertainty of 1/2% in a broadband neutrino beam. One way to reduce this uncertainty with confidence is to measure the K flux emerging from the beam train. For the broadband beam at Fermilab this has proved to be impossible. However, the K flux emerging from the dichromatic train was measured by the CFRR collaboration during our E-388 run. Preliminary results for the K/π ratio are shown below:

TUNE ENERGY (GeV)	120	140	169	200	250
K^+/π^+	9.1%	11.3%	12.2%	13.0%	16.1%
K^-/π^-	6.6%	6.0%	5.5%	4.7%	4.1%

The fractional errors on the above numbers are estimated at ±5%. Final results are expected to have an error of about ±3%. From the above table we see that the background is expected to be lower in an antineutrino beam. For our E-388 antineutrino run we calculate 3.4 background events out of a total of 620 expected charged current events. Without any energy cuts this is about three times smaller than for a broadband neutrino beam. As we will see below, energy cuts will reduce this by another factor of about 20. Because the proton is targeted at a large angle relative to the antineutrino beam direction the broadband background is only 0.30 events for the whole of for E-388 and was measured by taking data with the beam defining slits closed. The broadband background appears to have no energy dependence. The main background comes from charged K decays. Even here discrimination is possible due to the fact that the neutrino energy spectrum from charged K decays is quite different from that due to π decays. This is shown in Fig. 2 which shows the spectra for a 120 GeV tune at a transverse radius of 1.5 meters in the bubble chamber. A cut at 40 GeV would eliminate 95% of the background due to K^- decays but would keep 98% of the neutrinos due to π decay. At higher energies the separation is about the same as shown in Figs. 3 and 4. The limit set by this experiment would be determined by the statistical uncertainty in the number of events. The requested 0.3×10^{19} protons on target tuned to antineutrinos plus the data from E-388 would give us a total of about 1500 charged current events. After energy cuts as described above the total background including wideband background will amount to about 1 event. Thus, we could set an upper limit of ~ 0.1% for antineutrino oscillations. For maximum mixing . : this would give the limits,

$$\Delta m^2_{\mu e} < 1 \text{ ev}^2, \ \Delta m^2_{\mu\tau} < 3 \text{ ev}^2.$$

For neutrino oscillations the mass limits would be about the same.

The above limits on Δm^2 are similar to those published by other antineutrino experiments at larger L/E. This includes an experiment at LAMPF which has reported a limit,[2]

$$\Delta m^2_{\mu e} < 0.64 \text{ eV}^2,$$

and a result reported by the Gargamelle collaboration,[3]

$$\Delta m^2_{\mu e} < 1 \text{ eV}^2.$$

There is some doubt about this last result because the errors appear to have been underestimated.[4] A BNL-Columbia experiment has reported an upper limit of 2-1/2% for the oscillation of μ neutrinos into τ neutrinos in a high energy broadband <u>neutrino</u> beam.[5] If neutrino oscillations actually occur at this limit, the experiment proposed here would see a signal of about 20 events in the dichromatic neutrino beam with a total background of about 6 events. An emulsion experiment, again using neutrinos, has reported a limit,[6]

$$\Delta m^2_{\mu\tau} < 3 \text{ eV}^2.$$

It has been pointed out that if neutrino oscillations do not conserve CP, then neutrino and antineutrino oscillations will be different.[7] Furthermore, CP violation is a function of L/E. This means that neutrino oscillations need to be examined with both neutrinos and antineutrinos at many different values of L/E. To date only the Gargamelle Collaboration has reported a result using both neutrinos and antineutrinos and there is some doubt about it as mentioned above.

For that experiment L/E was about 0.04 m/MeV. The experiment proposed here would examine oscillations with both neutrinos and antineutrinos at $L/E \sim 0.02$ m/MeV.

Finally, and with some hesitation, we mention that we do in fact have one intriguing event in E-388. The only lepton is an e^+ with a measured energy of 5 GeV with a large error. The reconstructed $\bar{\nu}_e$ energy is 10 to 20 GeV. The tune and radius correspond to the parameters in Fig. 2. As can be seen from Fig. 2 it is very unlikely that this event comes from a $\bar{\nu}_e$ from K^- decay. However, its energy is consistent with the event coming from a $\bar{\nu}_\mu$ from π decay. Since this event was found in the first 1/3 of our film, it corresponds to a total of 200 antineutrino events. The broadband background and the background from K^- decays added together amount to 0.15 events for this sample. Here then is a candidate for a neutrino oscillation! If real the rate implied by this event gives,

$$\Delta m^2_{\mu e} = 0.5 - 1.0 \text{ eV}^2,$$

for maximum mixing.

REFERENCES

1. BEBC "TST" Collaboration, Phys. Lett. 94B, 527 (1980).

2. LAMPF, S.E. Willis et al., Phys. Rev. Lett. 44B, 522 (1980).

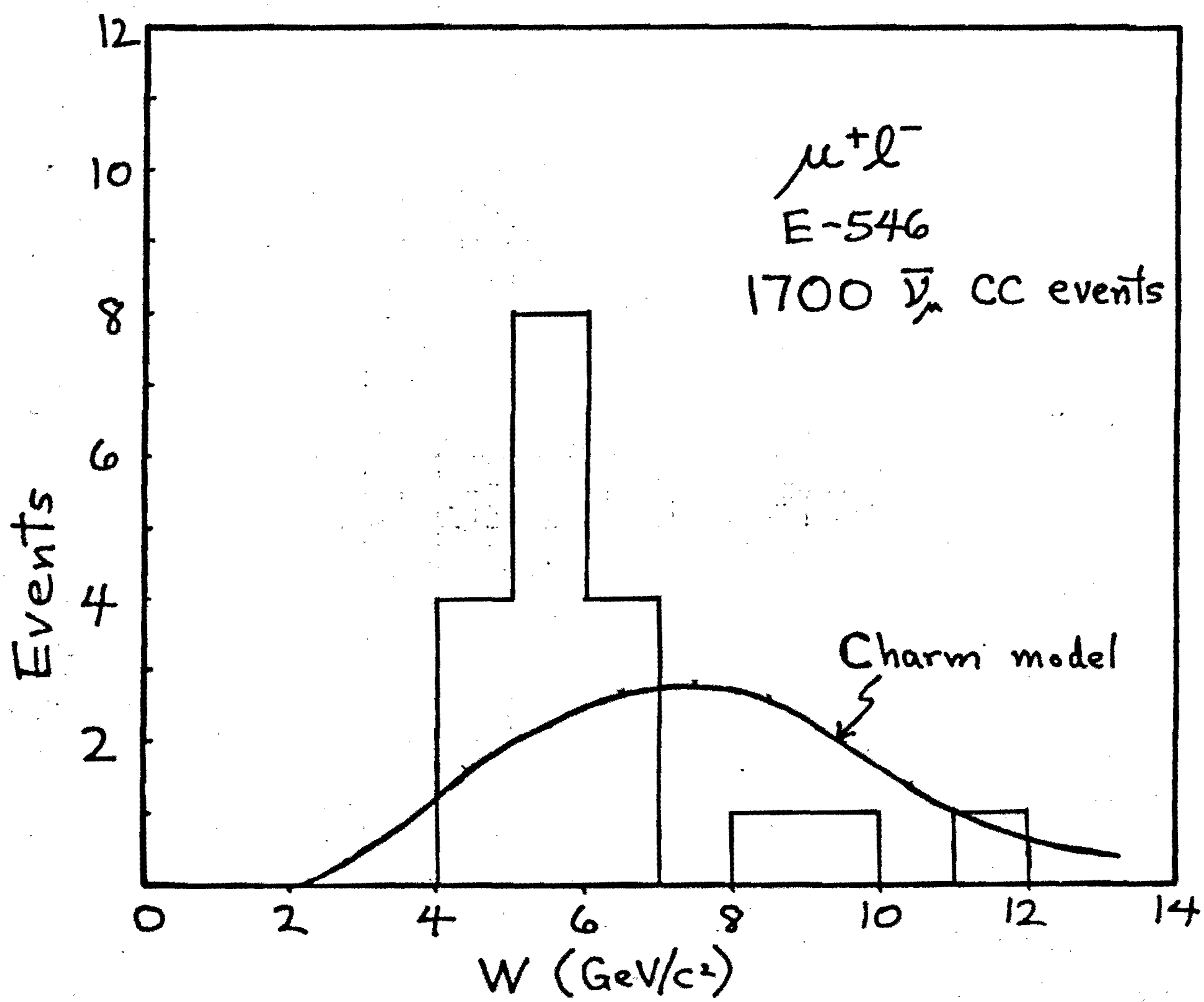
3. Gargamelle Collaboration, J. Blietschau et al., Nucl. Phys. B133, 205 (1978).

4. D.O. Morrison, CERN/EP 80-190, Oct. (1980)

5. BNL-Columbia Collaboration, A.M. Cnops et al., Phys. Rev. Lett. 40, 144 (1980).

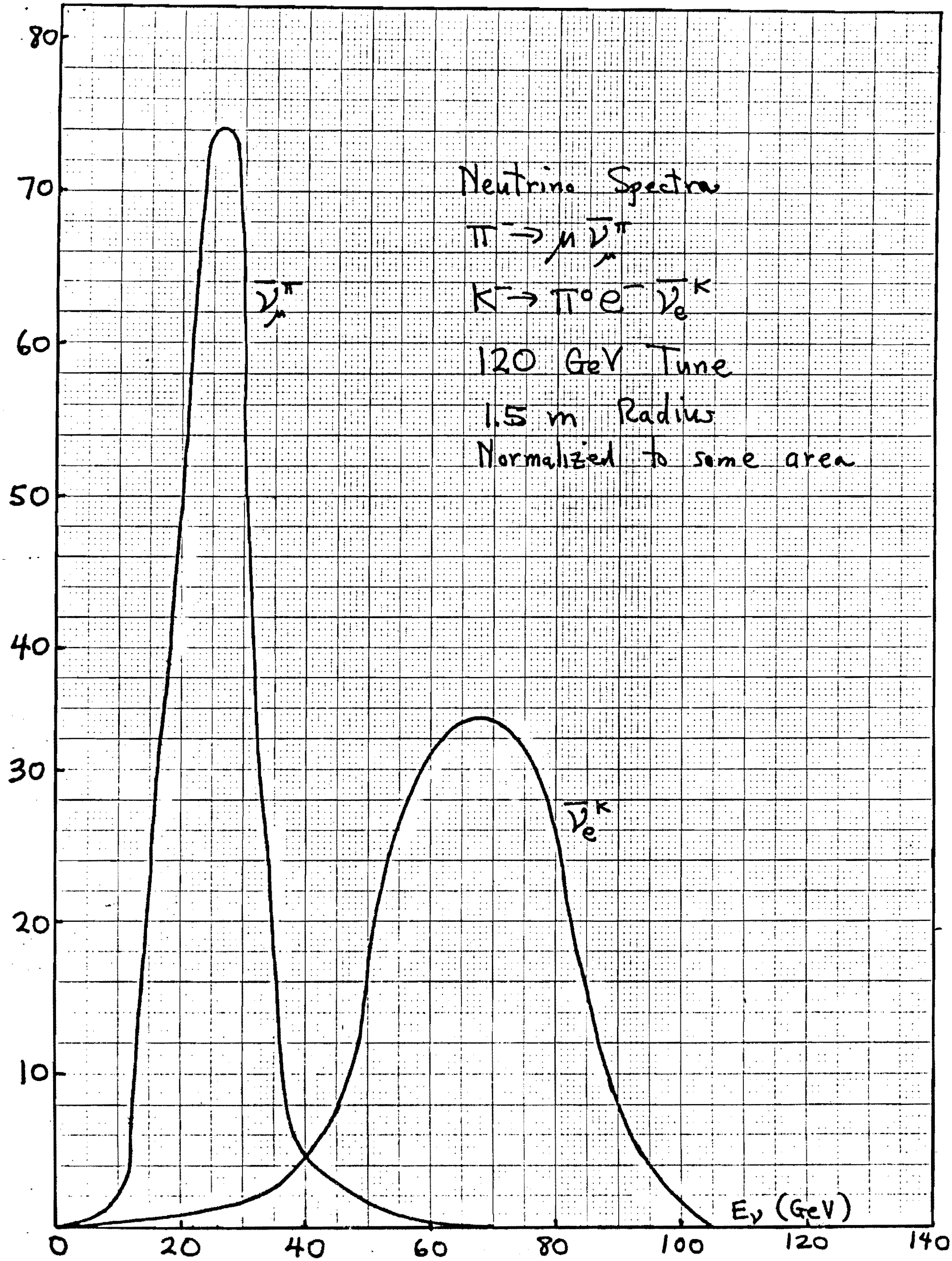
6. United States-Canada-Korea-Japan Collaboration, K. Niu, Nagoya Report DPNU 28-80, and T. Kondo, Madison Conf. (1980).

7. Barger, Whisnant, and Phillips, Phys. Rev. Lett. 45, 2084 (1980).



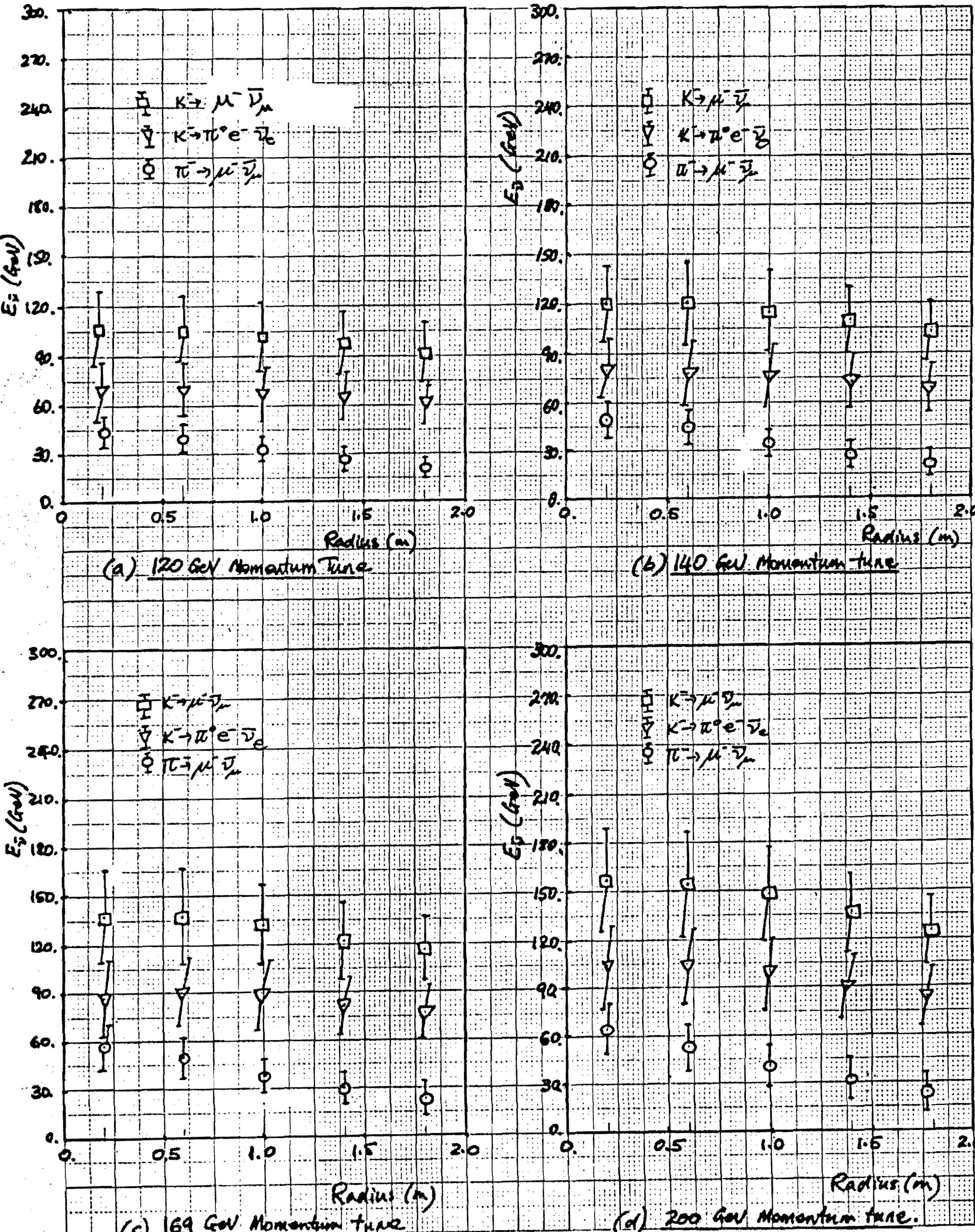
μ⁺ℓ⁻
E-546
1700 $\bar{\nu}_\mu$ CC events
Charm model
Events
0
2
4
6
8
10
12
14
W (GeV/c²)

Fig 1



Neutrino Spectra
$\pi^- \to \mu \bar{\nu}_\mu^\pi$
$K^- \to \pi^0 e^- \bar{\nu}_e^K$
120 GeV Tune
1.5 m Radius
Normalized to same area
$\bar{\nu}_\mu^\pi$
$\bar{\nu}_e^K$
E_ν (GeV)
0
10
20
30
40
50
60
70
80
100
120
140

Fig 2



K⁻→ μ⁻ ν̄μ
K⁻→ π° e⁻ ν̄e
π⁻→ μ⁻ ν̄μ
Eν (GeV)
Radius (m)
(a) 120 GeV Momentum Tune
(b) 140 GeV Momentum tune
(c) 169 GeV Momentum tune
(d) 200 GeV Momentum tune.

Fig 3

Distributions of Antineutrinos in the Radius – Energy Plane from three sources:

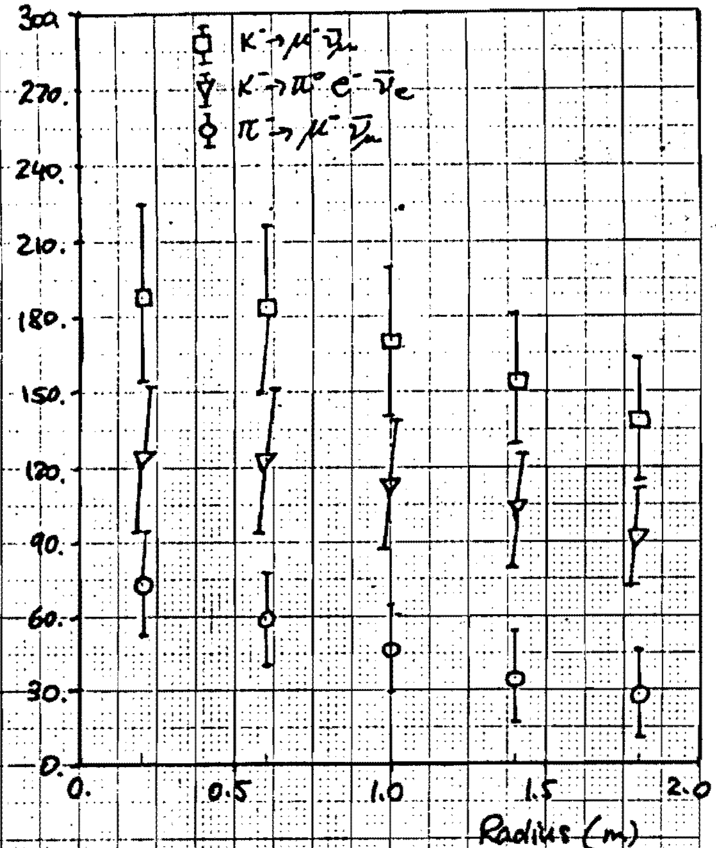
(a) $\pi^- \to \mu^- \bar{\nu}_\mu$

(b) $K^- \to \pi^0 e^- \bar{\nu}_e$

(c) $K^- \to \mu^- \bar{\nu}_\mu$

Errors are R.M.S. deviations.

Results from DECAY TURTLE.



(e) 250 GeV Momentum tune.

Fig. 4