Fermilab

TM-1275
2060.000

PROMPT LEPTON PRODUCTION FROM HIGH ENERGY BEAM DUMPS
I. PROMPT NEUTRINO EVENT RATES WITH 1 TeV PROTONS

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August 1984

As a consequence of work begun at the SSC Fixed Target Workshop, it appears[1] that a whole array of extremely interesting leptonic physics would be possible at an SSC Fixed Target Facility (FTF). One of the major concerns with the FTF is the expense in both money and land that conventionally designed lepton beams would require. In reference 1 it was proposed that a beam dump type facility, which relied mainly on prompt lepton production, could eliminate the costly decay space needed by conventional beams. Such a facility could provide all types of ν and μ beams except a narrow band ν beam which is, at best, a quite complicated beam at SSC energies due to the miniscule beam divergence required to maintain the E_ν vs R_ν(radius) correlation.

In contemplating how this facility could be practically realized, it became apparent that, even at Tevatron energies, no contemporary[2] study had been performed which took into account the many recent advances from charm experiments and theory. This report is therefore intended to give updated results for neutrino production from a beam dump facility at the <u>Tevatron</u> i.e. 1000 GeV protons on target.

INPUT

There is still considerable controversy concerning the inclusive D and F cross sections as well as their x_F and P_t distributions. Measurements of $\sigma(D)$ are further complicated by ignorance of the correct A^α scaling law when comparing experiments using nuclear targets with hydrogen results. Therefore in this report all quoted event rates will be calculated with the F cross section per nucleon (i.e. an H_2 Dump). When the correct A^α scaling law is finally determined, the corresponding multiplicative factor can then be applied to our results. Excluding experiments using nuclear targets, one can compare pp and πp experiments at FNAL-SPS energies ($\sqrt{s} \approx 27$GeV) with CERN-ISR results at $\sqrt{s} = 52$ and 62 GeV. These results tend to indicate a total D cross section rising from $\approx$20μb at 27 GeV to $\approx$ 200-300μb at 62 GeV. Fitting a "standard" excitation curve through these points would imply a D cross section of $\approx$ 100-200 μb at Tevatron energies ($\sqrt{s} = 43$ GeV). Based upon this still quite crude data and rough extrapolation, a D cross section of 150μb will be assumed for the present calculations. The knowledge of F production is even more limited than D production. The CERN experiment NA16 using 360 GeV p and π in LEBC found[7] the ratio

$$\frac{\sigma(F)}{\sigma(D)} = (11^{+11}_{-6})\%$$

However the experiment had no particle identification. An improved LEBC experiment (NA27), including particle identification, has found[7] (preliminarily) not a single F in a sample corresponding to 80-90 charged D's. This would indicate that the 11% figure of NA16 could be quite high. Taking into account that F/D could rise with $\sqrt{s}$ as K/π does, a value of $\sigma(F) = 15$ μb per nucleon will be assumed in these calculations. It should be emphasized that this value of $\sigma(F) = 15$μb represents an "average" value reflecting the ranges $100 < \sigma(D) < 200$μb and $.05 < \sigma(F)/\sigma(D) < .10$ which could be expected at Tevatron energies.

For pp charm production, the only truly "diffractive" process is expected to be Λ_c^+ production, and leading D production should follow a $(1-x_F)^3$ distribution. Central production should contribute D's and F's with a $(1-x_F)^5$. Rescattered pions, on the other hand, would have leading production of the form $(1-x_F)^{.5-1.5}$ and central production of the form $(1-x_F)^5$. Event rates are therefore calculated for two extreme x_F distributions; - $(1-x_F)^4$ and $(1-x_F)^{0.8}$ - where the contribution from the diffractive x_F dependence should be greatly reduced with respect to central production. In both cases, the P_t distribution is described by $\exp(-1.1\ P_t^2)$.

The other pertinent input is as follows:

$$BR(D^{\pm}\to K\mu\nu_\mu) = .16$$

$$BR(D^{\pm}\to Ke\nu_e) = .19$$

The $D^o\bar{D}^o$ semi-leptonic branching ratios are taken to be 0.5 times the above charged $D^{\pm}$ ratios and $D^o\bar{D}^o$ production is assumed to be equal to D^+D^- production. The relevant F and τ branching ratios are

$$BR(F\to\nu_\tau\tau) = .02 \text{ (reflecting recent F mass measurements)}$$

$$\tau\to e\nu_e\nu_\tau = .18$$

$$\to\mu\nu_\mu\nu_\tau = .18$$

$$\to\rho\nu_\tau = .22$$

$$\to\pi\nu_\tau = .10$$

The results are obviously, <u>extremely</u> sensitive to the $F\to\nu_\tau\tau$ branching ratio.

The program NUADA[8] was used to determine the various ν spectra. The dump consists of seven interaction lengths of Cu(=1.5m) or W(=1.0m) and fluxes/event rates are given for i) a detector situated 160m from the dump with radius 1.4m and mass 10 tons; ii) a detector at 58m with r=0.5m and 0.5 tons. Absorption of D's, F's and τ's has been taken into account with the following values of $c\tau/M$ (m/GeV) used in the calculation; D, 1.80×10^{-4}; F, 3.0×10^{-5}; and τ, 5.57×10^{-5}; For the contribution from $\pi_{\mu 2}$ and $K_{\mu 2}$ decay, the parameterization of FN-341 has been used.

RESULTS

Fig. 1 and Fig. 2 show the expected ν spectra at the 58m and 160m location respectively. The shape is that coming from a copper dump and assuming that D's as well as F's are produced with a $(1-x_F)^4$ dependence. The ν_τ spectra is broken down into the $F\to\nu_\tau\tau$ contribution and the sum of all τ decay modes ($\tau\to\nu_\tau\mu\nu_\mu$, $\nu_\tau e\nu_e$, $\nu_\tau\pi$ and $\nu_\tau\rho$). The $\Sigma\nu_\ell$ spectra contains the $D\to K\mu\nu_\nu$ + $D\to Ke\nu_e$ and the $\pi_{\mu 2}$ + $K_{\mu 2}$ contributions. Except at very low energies, the ν_e, ν_μ flux and event rate is dominated by D decay. If the suppression of $\pi_{\mu 2}$ and $K_{\mu 2}$ induced ν_μ is the main motivation for targetting at 20mr or even 40mr with respect to the detectors, the proton transport could be reconsidered. Particularly in light of the rapid loss of event rate as the targetting angle is increased. As Figure 3 shows, the ν_τ and ν_μ + ν_e event rates fall roughly an order of magnitude for every 15-20mr increase in scattering angle. At 20mr, the ν_τ event rates are down by a factor of 5.5×10^{-2} and at 40mr by a factor 6×10^{-3}. Note that since both detectors subtend the same angle with respect to the dump, the shapes of the spectra are the same at the two locations with magnitude differing only by a simple constant. A detailed breakdown of the ν_τ spectra is shown in Fig. 4. The

ν_τ and ν_e event energy distributions are shown in Fig. 5 for the two extreme x_F distributions.

Expected event rates are given in Table I. For 0° (20mr) targetting angle, one could expect ≈ 45(2.5) and 116(6.4) ν_τ events per 10^{18} protons-15μb F cross section at the 58m and 160m position respectively.

UNCERTAINTIES

Beside the obvious uncertainties regarding the D and F cross sections and F branching ratio which we estimate to be ≈(30-50)%, there are several other factors which would effect event rates. We have considered the consequences of a hard-$(1-x_F)^{.8}$-F production spectra which would increase event rates by ≈50%. On the other hand a softer F spectra, arising from a central F production proportional to $(1-x_F)^5$, is perhaps more probable and would result in a decrease of event rates by ≈ 20% with respect to $(1-x_F)^4$. It seems likely that a further (15-20)% loss of events will occur since the primary proton energy may be 900 GeV instead of 1000 GeV. This lower proton energy would reduce the muon background in the bubble chambers to an acceptable level. The overall consequence of these two modifications would be an ≈ 30% decrease in ν_τ event rates.

COMPARISON WITH PREVIOUS RESULTS

In TM-848 Mori gives ν_τ event rates /10^{18} protons in a 100 ton detector located 250m from the dump for an F cross section of 10μb/nucleon. A comparison of events / F or τ decay shows that the present rate is approximately 2/3 that of Mori. This reflects the more precise x_F distribution and consideration of absorption effects which are included in the present calculation. If we now include the changes in cross sections and branching ratios we find

			present/Mori
events per F or τ decay			2/3
$\sigma(F)$	15μb/10μb		3/2
$F \rightarrow \tau + \nu_\tau$	2%/3%		2/3
Dump→Detector(250m→160m, including ν_τ radial fall off)			1.6
Net Increase			1.07

On the other hand the event rates of the other flavors of prompt neutrinos-$\overset{(-)}{\nu}_\mu$ and $\overset{(-)}{\nu}_e$-show an increase of ≈ 3.

A similar comparison with event rates from the bubble chamber proposal E646 shows that the various enhancing and depleting factors tend to cancel. The expected number of ν_τ interactions should be the same within 10% as estimated by E646 in their 1980 proposal.

REFERENCES:

1) Morfín, J. G., "Leptoproduction at an SSC Fixed Target Facility", Submitted to Proceedings of the SSC Fixed Target Workshop and Fermilab physics note FN-440.

2) The most recent beam dump calculations are Mori, S.; TM-848 and Mori, S. and Walker, J.K., TM-953.

3) Duffy, M.E. et. al. University of Wisconsin preprint WISC-EX-84-235.

4) Halzen, F. "Production of Heavy Quarks" in Proceedings of Paris High Energy Physics Conference, pg. C3-381.

5) Nash, T. "Recent Results on D decays and Lepton, Photon, (and Hadron) Production of Charm" in Proceedings of 1983 Lepton Photon Conference, pg. 329.

6) Fisher,C. M., ibid.,pg C3-146.

7) S. Reucroft, private communication.

8) Carey, D. C. and White, V. A. NUADA, Fermilab Publication.

Table I Event Rates for 10^{18}p with

σ_D = 150μb and σ_F = 15μb

	$\overset{(-)}{\nu}_\mu + \overset{(-)}{\nu}_e$	$\overset{(-)}{\nu}_\tau$		
	0^o	0^o	20mr	40mr
<u>Copper</u> <u>Dump</u>				
ℓ = 58m; 0.5 ton				
$d\sigma/dx \propto (1-x)^4$	4320	45	2.5	.26
$\propto (1-x)^{.8}$	6350	69	3.8	.40
ℓ = 160m; 10 tons				
$d\sigma/dx \propto (1-x)^4$	11100	116	6.4	.67
$\propto (1-x)^{.8}$	16700	176	9.7	1.02
<u>Tungsten</u> <u>Dump</u>				
ℓ = 58m				
$d\sigma/dx \propto (1-x)^4$	3700	42	2.3	.24
$(1-x)^{.8}$	5410	65	3.6	.38
ℓ = 160m				
$(1-x)^4$	9600	110	6.1	.64
$(1-x)^{.8}$	14100	165	9.1	.96

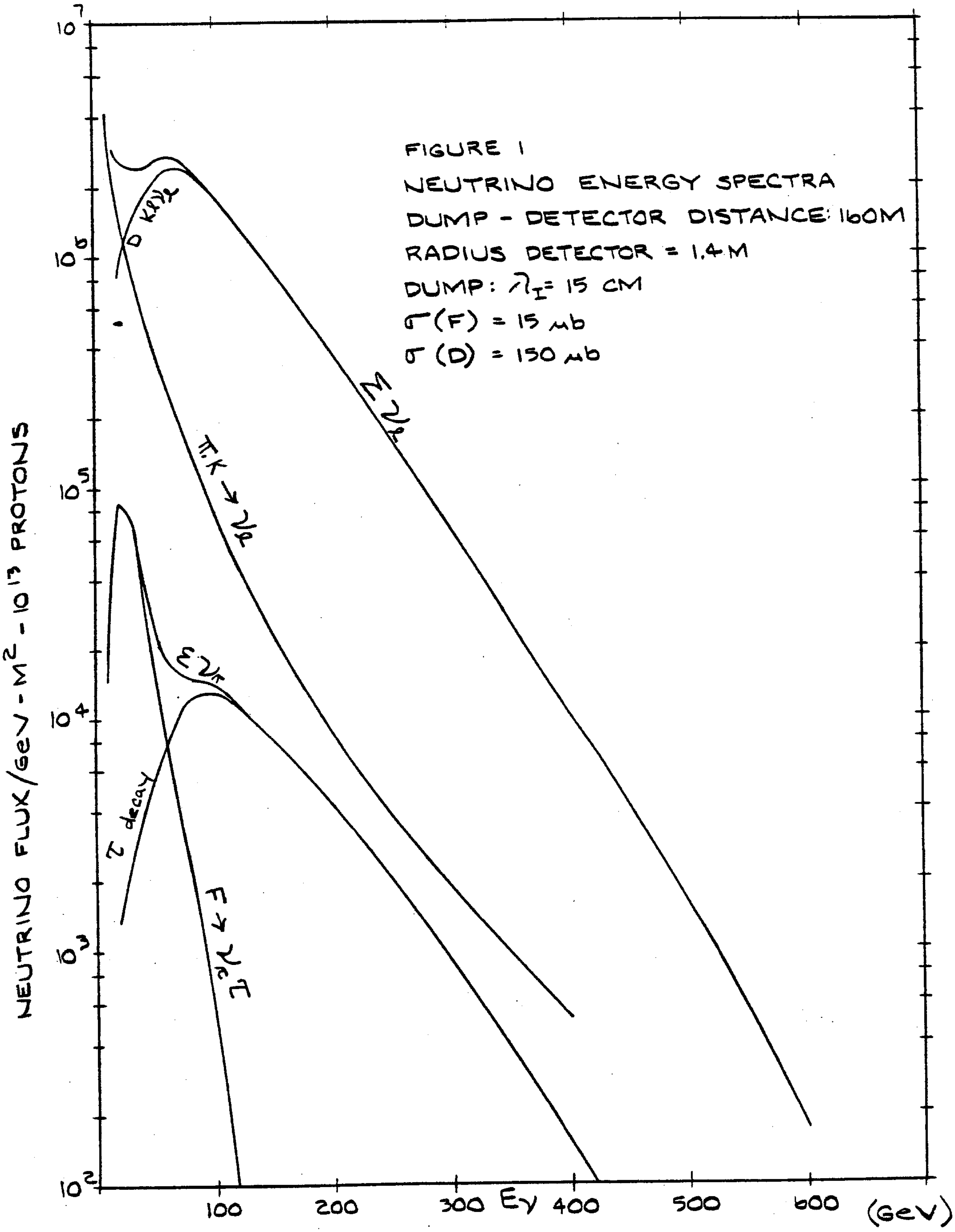
FIGURE 1
NEUTRINO ENERGY SPECTRA
DUMP - DETECTOR DISTANCE: 160M
RADIUS DETECTOR = 1.4 M
DUMP: λ_I = 15 CM
σ(F) = 15 μb
σ(D) = 150 μb
NEUTRINO FLUX/GeV - M² - 10¹³ PROTONS
10⁷
10⁶
10⁵
10⁴
10³
10²
100
200
300
400
500
600
E_ν
(GeV)
D K ℓ ν_ℓ
Σ ν_ℓ
π, K → ν_ℓ
Σ ν_τ
τ decay
F → ν_τ τ

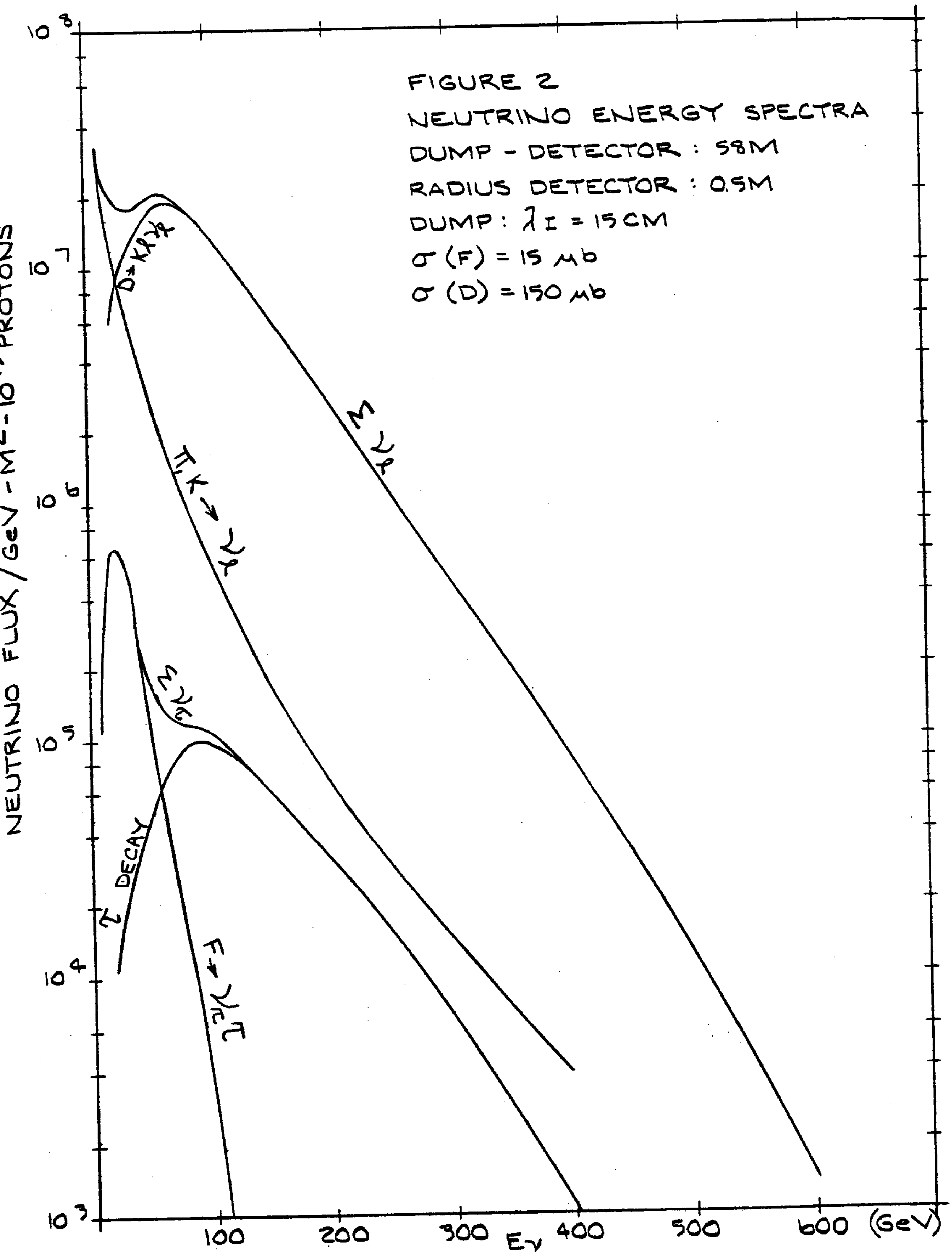
FIGURE 2
NEUTRINO ENERGY SPECTRA
DUMP - DETECTOR : 58M
RADIUS DETECTOR : 0.5M
DUMP : λI = 15CM
σ (F) = 15 μb
σ (D) = 150 μb
NEUTRINO FLUX / GeV - M2 - 10^13 PROTONS
10^8
10^7
10^6
10^5
10^4
10^3
100
200
300
400
500
600 (GeV)
Eν
D→ Kℓνℓ
π, K → νℓ
τ DECAY
F → ντ

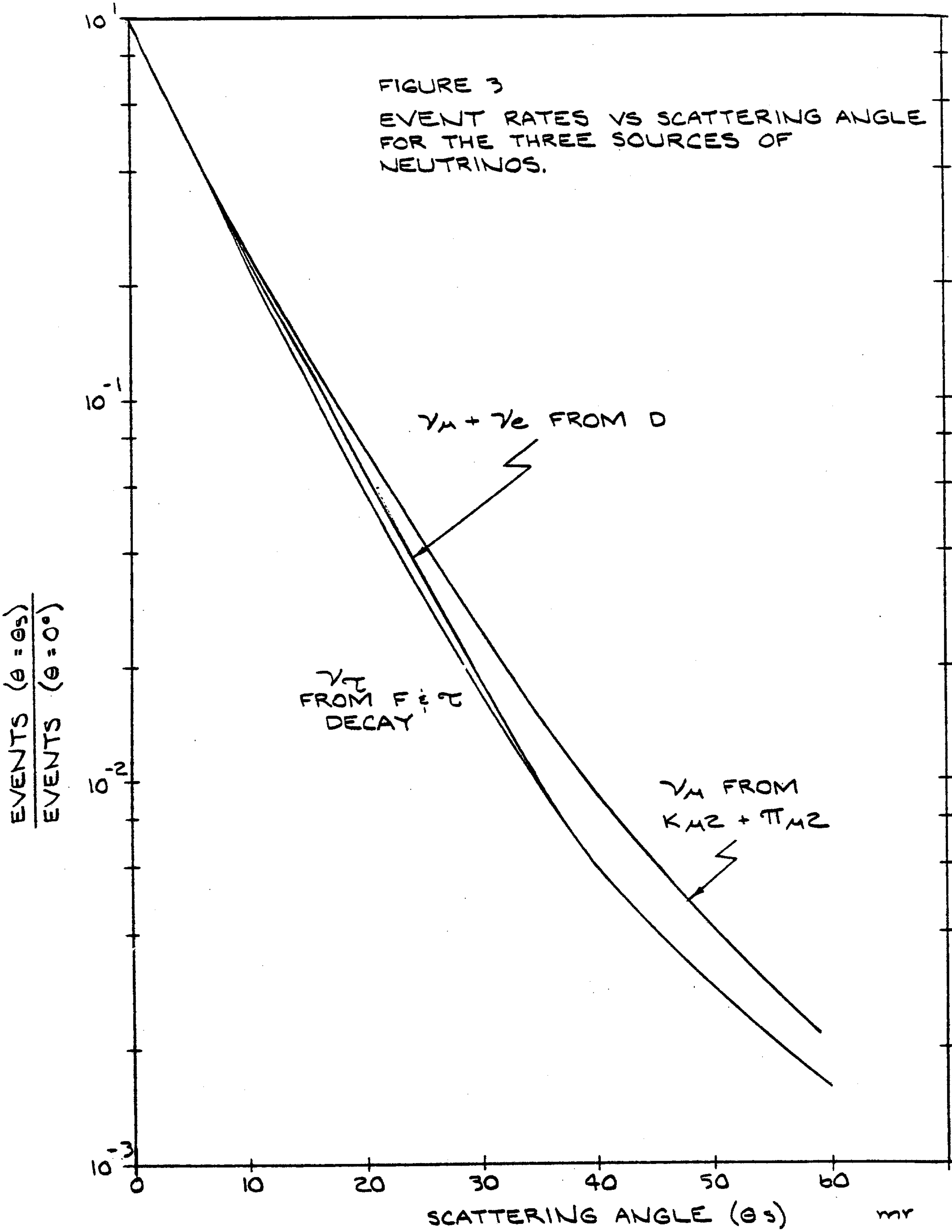
FIGURE 3
EVENT RATES VS SCATTERING ANGLE FOR THE THREE SOURCES OF NEUTRINOS.
$\nu_\mu + \nu_e$ FROM D
ν_τ FROM F & τ DECAY
ν_μ FROM $K_{\mu 2} + \pi_{\mu 2}$
10^{1}
10^{-1}
10^{-2}
10^{-3}
EVENTS ($\theta = \theta_s$) / EVENTS ($\theta = 0°$)
0
10
20
30
40
50
60
SCATTERING ANGLE (θ_s) mr

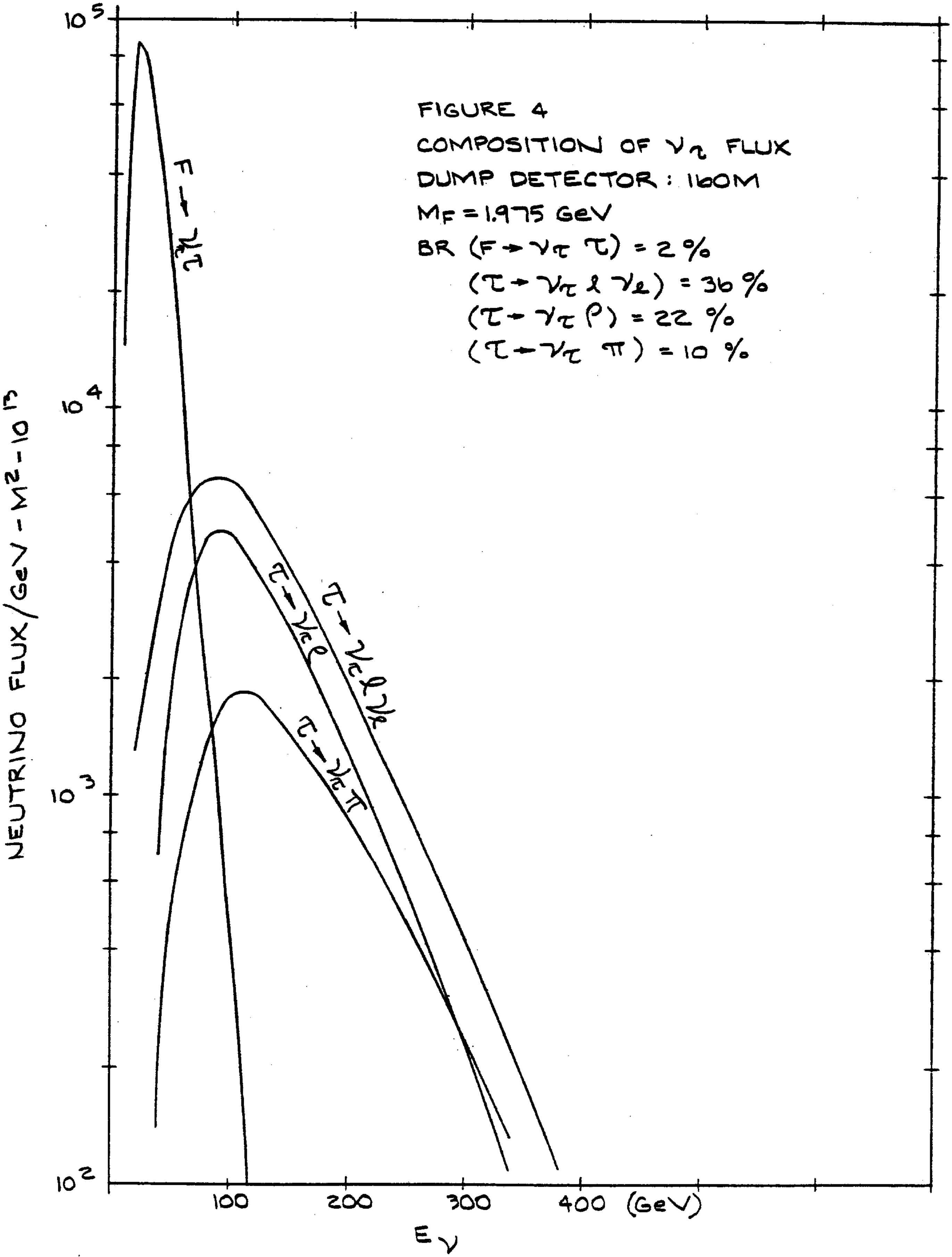
FIGURE 4
COMPOSITION OF ν_τ FLUX
DUMP DETECTOR : 160M
$M_F = 1.975$ GeV
BR $(F \to \nu_\tau \tau) = 2\%$
$(\tau \to \nu_\tau \ell \nu_\ell) = 36\%$
$(\tau \to \nu_\tau \rho) = 22\%$
$(\tau \to \nu_\tau \pi) = 10\%$
$F \to \nu_\tau$
$\tau \to \nu_\tau \ell \nu_\ell$
$\tau \to \nu_\tau \rho$
$\tau \to \nu_\tau \pi$
10^5
10^4
10^3
10^2
NEUTRINO FLUX/GeV - M^2 - 10^{13}
100
200
300
400 (GeV)
E_ν

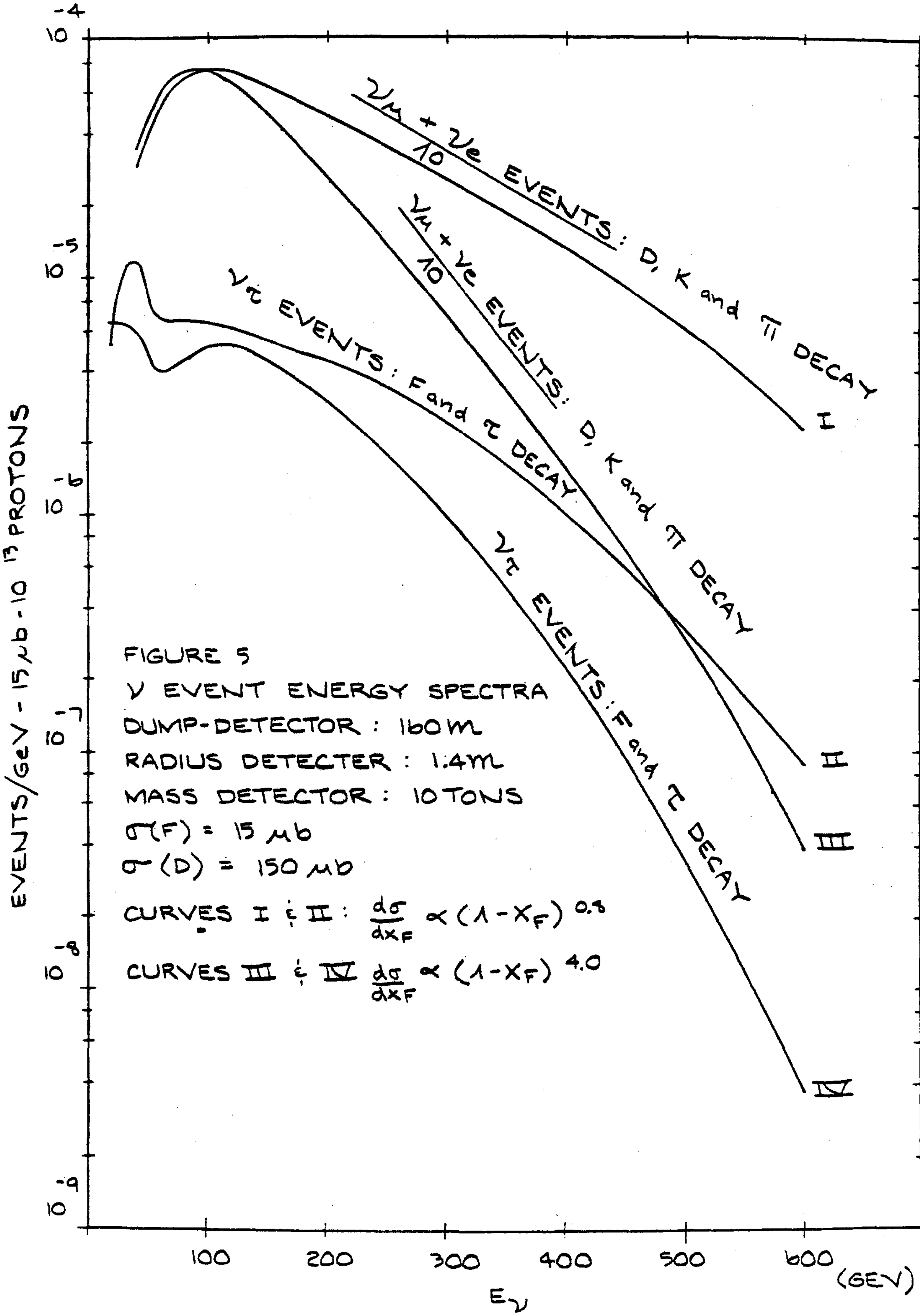

FIGURE 5
ν EVENT ENERGY SPECTRA
DUMP-DETECTOR : 160 m
RADIUS DETECTER : 1.4 m
MASS DETECTOR : 10 TONS
σ(F) = 15 μb
σ(D) = 150 μb
CURVES I & II : $\frac{d\sigma}{dx_F} \propto (1-X_F)^{0.8}$
CURVES III & IV $\frac{d\sigma}{dx_F} \propto (1-X_F)^{4.0}$
$\frac{\nu_\mu + \nu_e}{10}$ EVENTS : D, K and π DECAY
$\frac{\nu_\mu + \nu_e}{10}$ EVENTS : D, K and π DECAY
ν_τ EVENTS : F and τ DECAY
ν_τ EVENTS : F and τ DECAY
I
II
III
IV
EVENTS/GeV - 15 μb - 10^{13} PROTONS
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
100
200
300
400
500
600
(GEV)
E_ν