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SOLENOIDAL DETECTOR NOTES

FAKE MISSING E_T ($\not{E}_T$) TRIGGER RATES DUE TO NON-HERMETICITY, FINITE ENERGY RESOLUTION, AND FINITE DEPTH (USING CCFR DATA)

M. Pang, J. Hauptman

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Myungyun Pang
John Hauptman
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Fake Missing E_T ($\not{E}_T$) Trigger Rates Due to Non-hermeticity, Finite Energy Resolution, and Finite Depth (using CCFR data)

Abstract

We calculate expected fake missing E_T ($\not{E}_T$) trigger rates for single QCD jets due to calorimeter imperfections. Curves of fake $\not{E}_T$ trigger rates are displayed *versus* energy threshold, total calorimeter depth, and both the amount and the location of dead material.

1. Method Used in This Note

The fake trigger rate *versus* triggering threshold, E_{thr}, resulting from mismeasurement of calorimeter energy in the barrel region ($-1< \eta <+1$) can be calculated as

$$\not{E}_T \text{ Rate} = \int_{-1}^{+1} dy \int_{E_{thr}}^{\infty} dp_T \frac{d\sigma}{dp_T dy} \times \mathcal{L} \times f. \tag{1.1}$$

where $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1} = 1 event/nanobarn/second is the luminosity, $d\sigma/dp_T dy$ is the differential cross section for jet+X at y=0 from EHLQ, and f is the fraction of jets at momentum p_T which loose more than E_{thr} of energy, either due to dead spaces, leakage out the back, or energy resolution fluctuations. These are absolute calculations based on EHLQ and parameterized data.

Displaying explicity the variables describing the calorimeter properties which determine the triggering fraction "f", the trigger rate can be written as

$$\not{E}_T \text{ Rate}(E_{thr}, \lambda_0, \lambda, \lambda_T, k_0) =$$

$$\int_{-1}^{+1} dy \int_{E_{thr}}^{\infty} dp_T \frac{d\sigma}{dp_T dy}(p_T, y=0)\ \mathcal{L}\ f(p_T, E_{thr}, \lambda_0, \lambda, \lambda_T, k_0)$$

Dead spaces are characterized by the starting position of the dead space (λ_0) and its extent (λ), both in units of proton absorption lengths (λ_p). Leakage is characterized by λ_T, the total depth of the calorimeter mass in proton absorption lengths, and resolution is characterized by k_0, where the resolution is $k_0/\sqrt{E}$.

The function f is determined from CCFR data. By selectively removing measurement gaps in the CCFR calorimeter, we can estimate the fraction of jets of energy E_{jet} which loose more energy in a dead space than a specified triggering threshold, E_{thr}. Also, by examining the depth distribution of energy deposit out to 19 absorption lengths in Fe, we can estimate the fraction of jets which leak more energy than E_{thr} out the back of a calorimeter.

Since the shower population is sampled every $0.67\lambda_p$ in CCFR data, we construct an interpolation formula for the triggering fraction, f(p_T,E_{thr},λ_0,λ,λ_T,k_0), for p_T(GeV/c) "jets" (described below) exceeding a triggering threshold E_{thr}(GeV) due to dead space (λ_0, λ), finite depth (λ_T), or resolution (k_0). The CCFR data give measurements of f at the following points:

$$\lambda_0 = 0., \ .37, \ 1.04, \ 1.71\lambda_p, \tag{1.2}$$

and

$$\lambda = 0., \ .67, \ 1.34, \ 2.01, \ 2.68, \ 3.35\lambda_p, \tag{1.3}$$

for "jet" energies of

$$p_T = 250, \ 500, \ 750, \ 1000, \ 2000, \ \text{and } 10000 \text{ GeV}. \tag{1.4}$$

The fraction f is evaluated for E_{thr} values of

$$E_{thr} = 50, \ 100, \ 150, \ \text{and } 200 \text{ GeV}. \tag{1.5}$$

This interpolation formula for "f" (the "fraction–to–trigger") is concocted to have the proper limiting values for extrema in p_T , λ, λ_0, and E_{thr}, and also to pass through the discrete points measured by CCFR data. Thus, f is just an interpolation formula, and we expect that is is accurate over its region of use in this problem to a factor of three.

In this note, we only solve this problem near y=0 for now, so p_T=E_{total} and we integrate the differential cross section over just 2 units in rapidity. Hence, these rates are just for a barrel calorimeter. The problem for end caps, and the cracks between barrel and end caps, will be solved later.[1]

2. The Data Sample Used

The CCFR data [2] consist of measurements of pulse height in each of the 28 depth samples in a calorimeter exposed to a π^- beam at energies of 25, 50, 90, 140 and 250 GeV. Each of the 28 modules is an Fe-scintillator-Fe sandwich, and both the Fe plates and the liquid scintillator volume are 2-inches thick. This sums to about 19 λ_p, and is therefore very deep on the scale of any SSC calorimeter. Each liquid scintillator samples the debris from 4 inches of upstream Fe and 2 inches of scintillator, which is 0.669 λ_p or 5.90 X_0. This is uniform throughout the calorimeter except for the first scintillator layer, which samples the debris from only 2 inches of upstream Fe and 2 inches of scintillator. There is no transverse shower information, and essentially no transverse shower leakage in these 3 meter wide modules.

[1] This code was employed for a comparision of the long and short coils under consideration by the SDC Collaboration, "Coil Effects on the Calorimeter," *Int'l Workshop on Solenoidal Detectors for the SSC*, KEK, Tsukuba, Japan, 23-25 April 1990. Only the effects of dead material were calculated in this note.

[2] F.S. Merritt, et al., NIM **A245** (1986)27. David Bintinger obtained these data from John Yoh, measured the pedestal levels, established the energy scale, and gave a reading program and data files to us.

"Jet" Event Samples Used

Again we have used Dave Bintinger's idea of constructing "jets" by adding up individual pions from the several data sets. We have made samples of 250, 500, 750, 1000, 2000, and 10000 GeV "jets" by randomly selecting single pions from the CCFR data sets at 25, 50, 90, 140, and 250 GeV according to a Peterson-like fragmentation function.

3. Finite Depth: Energy Leakage out the Back

An examination of the CCFR event samples at 140 and 250 GeV revealed several events per thousand in which more than half the energy deposit was beyond a depth of $10\lambda_p$. This will clearly lead to a fake $\not{E}_T$ trigger rate at some level (if some intelligent "catcher" is not used.) Due to cost considerations, the absorption length depth of an SSC calorimeter made of either depleted uranium or lead cannot be much greater than about $10\lambda_p$, and probably smaller as some have argued.

We have found that the fraction of CCFR "jets" which deposit more than E_{thr} of energy beyond λ_T can be written as

$$\text{fraction--to--trigger} = e^{-(z/z_0)^p} + ae^{-z/.08}, \tag{3.6}$$

where $z = E_{thr}/E_{jet}$, $z_0(\lambda_T)$ is a monotonically decreasing function of λ_T, "a" is a few percent, and the power $p(\lambda_T)$ varies from about 2.0 (Gaussian-like in z) down through 1.0 (exponential in z) and below (concave shape in z) as a function of increasing λ_T. The parameters of this function are only weakly dependent on E_{jet}. Examples of this function compared to CCFR data are shown in Figures 1(a-b) at two energies.

The motivation for studying the fake $\not{E}_T$ trigger rate problem in the first place arose for our analysis of CCFR data on other problems. We noticed that about 0.5% of the events had more that half the energy of the incident hadron deposited beyond 10 λ_p. This is a rather large "non-hermeticity", especially since the production rate of QCD jets is enormous in the hundreds of GeV region, only falling to 1 Hz at 1 TeV. The problem is not so severe for jets, since a large ensemble of hardons, most of low energy, will comprise a jet. Just four examples of such events from just one run, 250 GeV, are shown in Figures 2(a-d), although all energies from 25 through 250 GeV have such events. The total energy distribution of the 16 events at 250 GeV satisfying this condition is shown in Figure 2e. Clearly, they are beam particles. Hans Trost has suggested they are μ DIS interactions; maybe they are, or some fraction of them are, but the μ must give up all its energy, and there isn't a tail in Figure 2e. We have not looked at the drift chamber information in CCFR data, nor do we know this experiment well, so there is a chance we are making some mistake here.

4. Hermeticity: Energy Lost in Dead Spaces

Missing energy in a coil, cryostat, or support structure can also lead to a fake $\not{E}_T$ trigger. We have used the functions characterizing the mean energy lost due to dead space in a calorimeter done earlier[3] as a starting point.

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[3] "Hermeticity Study using CCFR Data", M.Pang, J.Hauptman, SDE-11, Sept. 15,1989

The fraction of jets of energy E_{jet} which loose more than E_{thr} in a dead space characterized by λ_0 and λ is parameterized by

$$\text{fraction-to-trigger} = \frac{1}{\sqrt{2\pi}\sigma}\int_{E_{thr}}^{\infty} e^{-\frac{1}{2}((t-\mu_{lost})/\sigma_{lost})^2}\,dt \tag{4.7}$$

where the mean energy lost in dead space, μ_{lost}, and its rms variation, σ_{lost}, are written as

$$\mu_{lost} = c_1 E_{lost} \tag{4.8}$$

$$\sigma_{lost} = c_2\sqrt{E_{lost}}. \tag{4.9}$$

The assumption (not always a good one) is that the distribution of missing energy is Gaussian, and we just integrate this distribution from E_{thr} up to infinity. If E_{thr} is just equal to μ_{lost}, then the fraction is 1/2. The mean expected loss, μ_{lost}, is scaled by c_1, and its rms spread, σ_{lost}, is multiplied by c_2 to allow this function some minimal flexibility in fitting the discrete data points from CCFR data. We fit c_1 and c_2 at all energies and all (λ,λ_0, E_{thr}) values. We expect that $c_1 \approx 1$, and $c_2 \approx$ 2-5, which turns out to be the case.

Yasuo Fukui has pointed out that the above is an overestimate of f, since one can correct for the mean energy lost, μ_{lost}, in a higher-level trigger processor. For the moment, we will use this overestimate, although Yasuo is quite right, and we will update this calculation later.

This integral is calculated as

$$\text{fraction-to-trigger} = \frac{1}{2}[1 - \text{erf}(\frac{E_{thr} - c_1 E_{lost}}{c_2\sqrt{2E_{lost}}})] \tag{4.10}$$

The fits are generally good, and this function represents CCFR data to about a factor of 3 (we hope). Some examples of this function are shown in Figures 3(a-b).

5. Resolution Fluctuations

Michael Barnett, et al., [4] considered the effects of fluctuations in the energy deposit, and the probability (derived from a Gaussian line shape) that a fluctuation will yield a fake $\not{E}_T$ trigger. They considered two hadronic resolution constants, and also added a Gaussian with wide tails to simulate the response of a non-compensating calorimeter. They concluded that the resolution contribution is negligible. We agree.

For CCFR data, with a resolution constant of about $k_0 = 0.90$, the fraction of events with satisfy a trigger threshold of E_{thr} is

$$\text{fraction-to-trigger} = \frac{2}{\sqrt{2\pi}\sigma}\int_{-\infty}^{-E_{thr}} e^{-(E-E_{jet})^2/2\sigma^2}\,dE, \tag{5.11}$$

where $\sigma = k_0\sqrt{E_{jet}}$. That is, you can get a trigger if the fluctuation from the mean is larger than E_{thr}. Now, in this Fe–scintillator device the resolution constant is

[4] "The Impact of Resolution, Cracks and Beam Holes on Detection of Processes with Missing Energy", M. Barnett, et al., SDE-10, Sept. 1989

large, $k_0 = .90$, while for SDC we are in the 0.50–0.70 range, so the rates shown in the fits to CCFR data are too large, especially for very high energy jets. We use a value of $k_0 = 0.50$ for all trigger rate estimates pertaining to the SDC calorimeter.

This fraction is calculated as

$$\text{fraction-to-trigger} = [1 + \text{erf}(\frac{-E_{thr}}{k_0\sqrt{2E_{jet}}})] \tag{5.12}$$

This fraction is generally quite small. A 3-σ fluctuation is $\Delta E = 3 \times k_0\sqrt{E} \approx 1.5\sqrt{E} \approx 45$ GeV at E = 1 TeV. So a threshold of 50 GeV is already at the 10^{-3} level for a 1 TeV jet, whose production rate is only 1 Hz. Of course, if the line shape is not Gaussian this fraction can become much larger. We have not studied this question.

6. Fake $\not{E}_T$ Trigger Rates

The fake $\not{E}_T$ trigger rate *versus* E_{thr} is displayed in Figure 4, for four values of λ_{dead} and for $\lambda_T = \infty$ and for a fixed $\lambda_0 = 0$, that is, for dead material in front of an infinitely deep calorimeter. The λ's are in units of proton absorption lengths in Fe. We choose the criterion that the trigger rate should be less than 0.1 Hz, on the grounds that this would result in a 10% readout dead-time at a trigger rate of 1 Hz. In this case, for example, if a coil is 0.2 λ_p, then the lowest energy threshold the calorimeter could sustain is about 80 GeV, by interpolation in Figure 4.

If the dead material begins at a depth of one absorption length, $\lambda_0 = 1\ \lambda_p$, the corresponding trigger rates are shown in Figure 5. The trigger rate at E_{thr}= 80 GeV seems to be increased by only a factor of 2.

The fake $\not{E}_T$ trigger rate *versus* calorimeter depth in proton absorption lengths due only to calorimeter leakage is shown in Figure 6, for four different triggering thresholds, E_{thr}= 50, 100, 150, and 200 GeV. Again, for a criterion of 0.1 Hz and at a threshold of 100 GeV, a total depth of 14 λ_p is required, although at the higher threshold of 150 GeV only 9 λ_p are required. The number of 14 λ_p is so large, and carries such large fiscal implications, if for physics reason one insists on a 100 GeV triggering threshold, that it must be checked carefully. We will address this issue with the PYTHIA code to accurately calculate the ν $\not{E}_T$, and GEANT to calculate the punch-through rate. (The point of using CCFR data in the first place was to avoid such work, but CCFR data are imprecise at the 10^{-3} level, as is evident from Figures 1(a,b).) This will become an addendum to this note.

Resolution fluctuations (the simple Gaussian ones considered here) make a negligible contribution to the fake $\not{E}_T$ trigger rate.

Finally, for a nominal case with $\lambda_0 = 0$, $\lambda = 0.20$, and $\lambda_T = 10\ \lambda_p$, the three fractions which contribute to the trigger rate, f_{dead}, $f_{resolution}$, and f_{depth} are shown in Figures 7(a-c) for jet energies of 100, 500, and 1000 GeV. At the higher triggering thresholds, 100-150 GeV, which this experiment is likely to use, the trigger rate is dominated by leakage out the back at about 0.1 Hz (from Figure 6), but this rate seems tolerable.

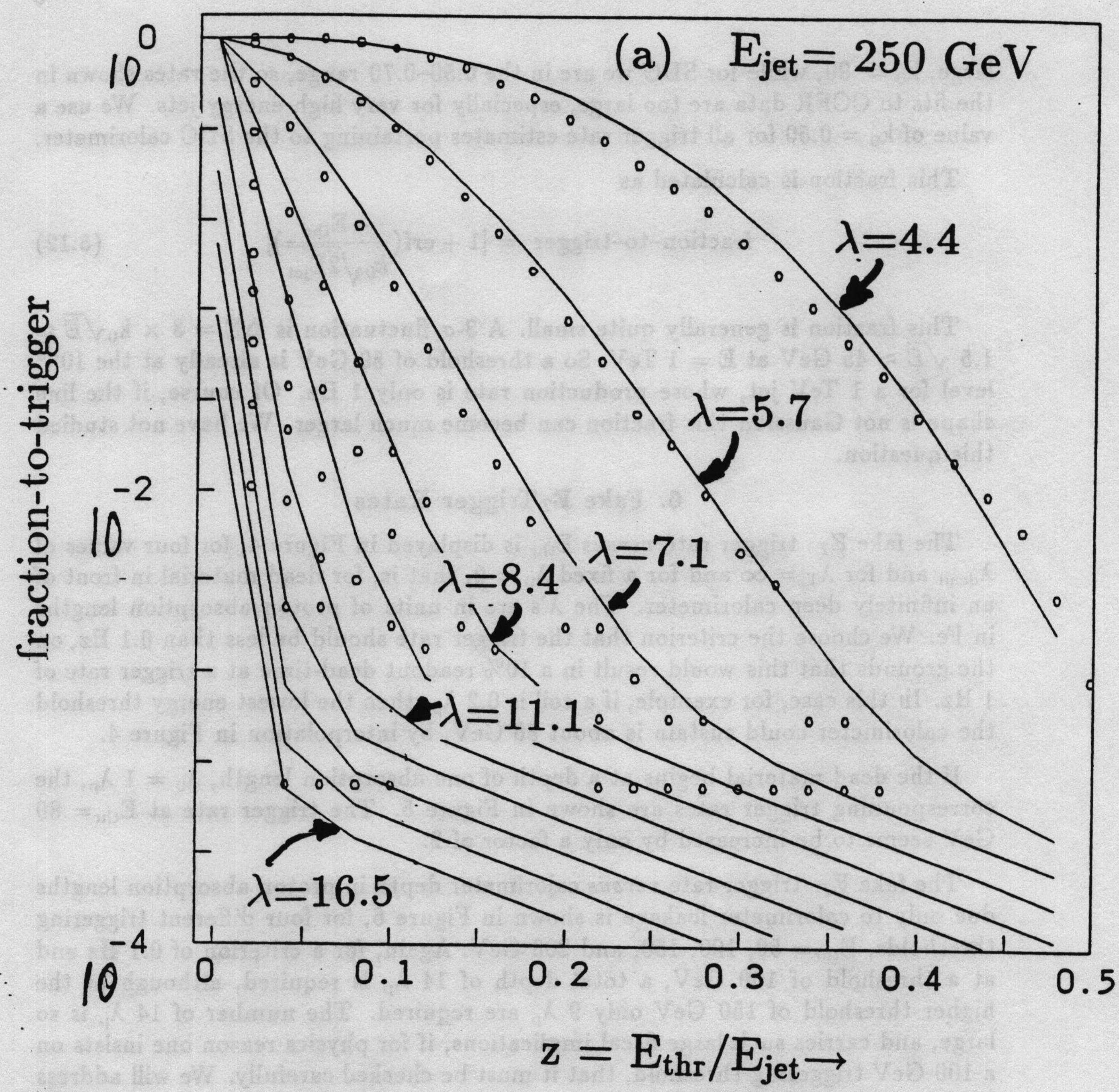
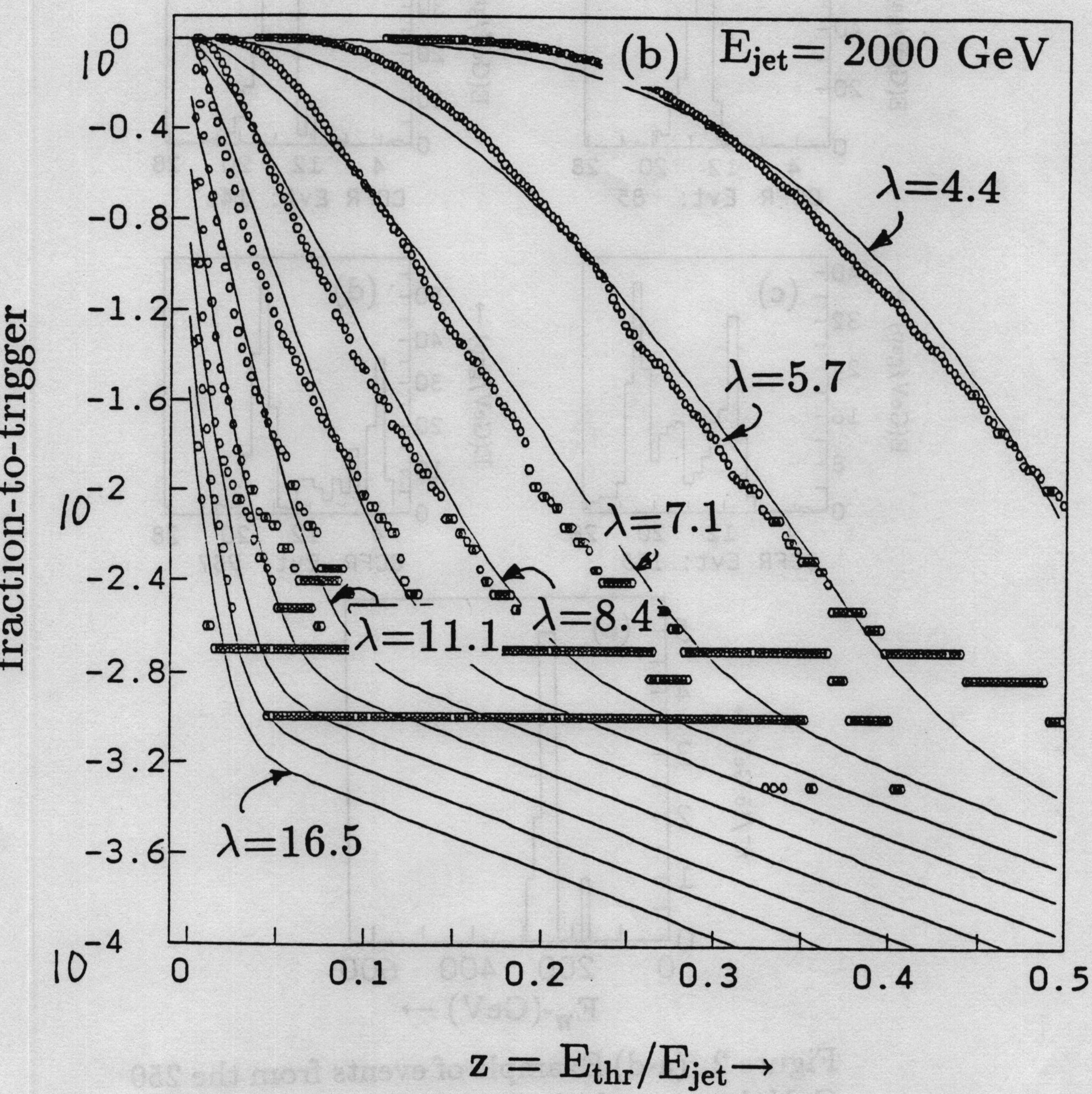


Figure 1. The fraction "f" used to parameterize the trigger fraction due to leakage out the back, compared to CCFR data. The x-axis is the E_{thr}/E_{jet}, and the vertical axis is the fraction of events to satisfy the trigger threshold. A family of curves from $\lambda_T = 4.4\ \lambda_p$ through $16.5\ \lambda_p$ are shown. (a) E_{jet}= 250 GeV, and (b) E_{jet}= 2000 GeV.



(b) E_{jet}= 2000 GeV
λ=4.4
λ=5.7
λ=7.1
λ=8.4
λ=11.1
λ=16.5
fraction-to-trigger
10^0
-0.4
-0.8
-1.2
-1.6
10^{-2}
-2.4
-2.8
-3.2
-3.6
10^{-4}
0
0.1
0.2
0.3
0.4
0.5
z = E_{thr}/E_{jet}→

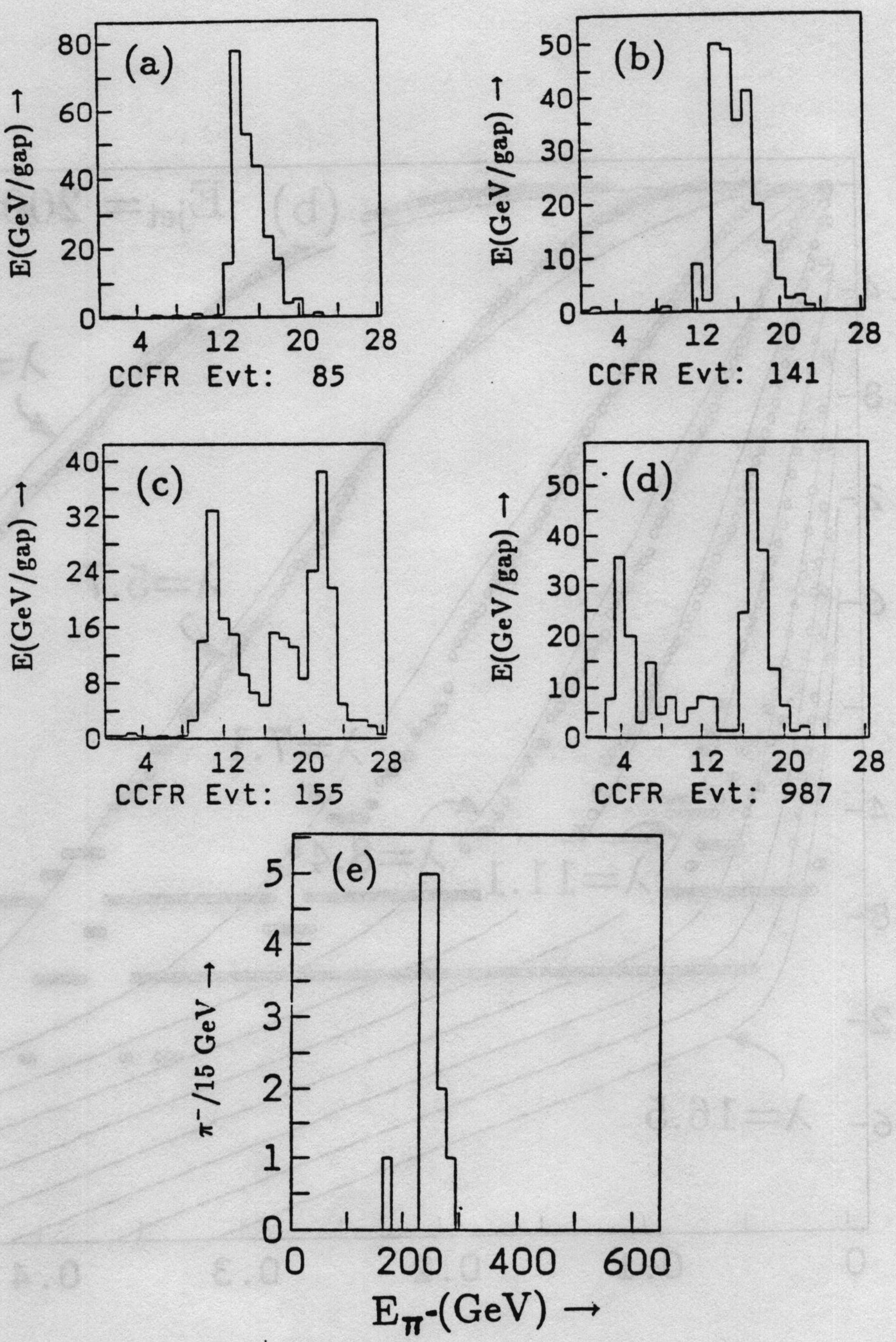


Figure 2. (a-d) Example of events from the 250 GeV data set which deposit more than half the beam energy beyond 10 λ_p. The x-axis is the CCFR gap number, where gap 15 is at a depth of about 10 λ_p. (e) The total energy distribution of all 16 events satisfying this condition. One event has only about 180 GeV of energy within the calorimeter.

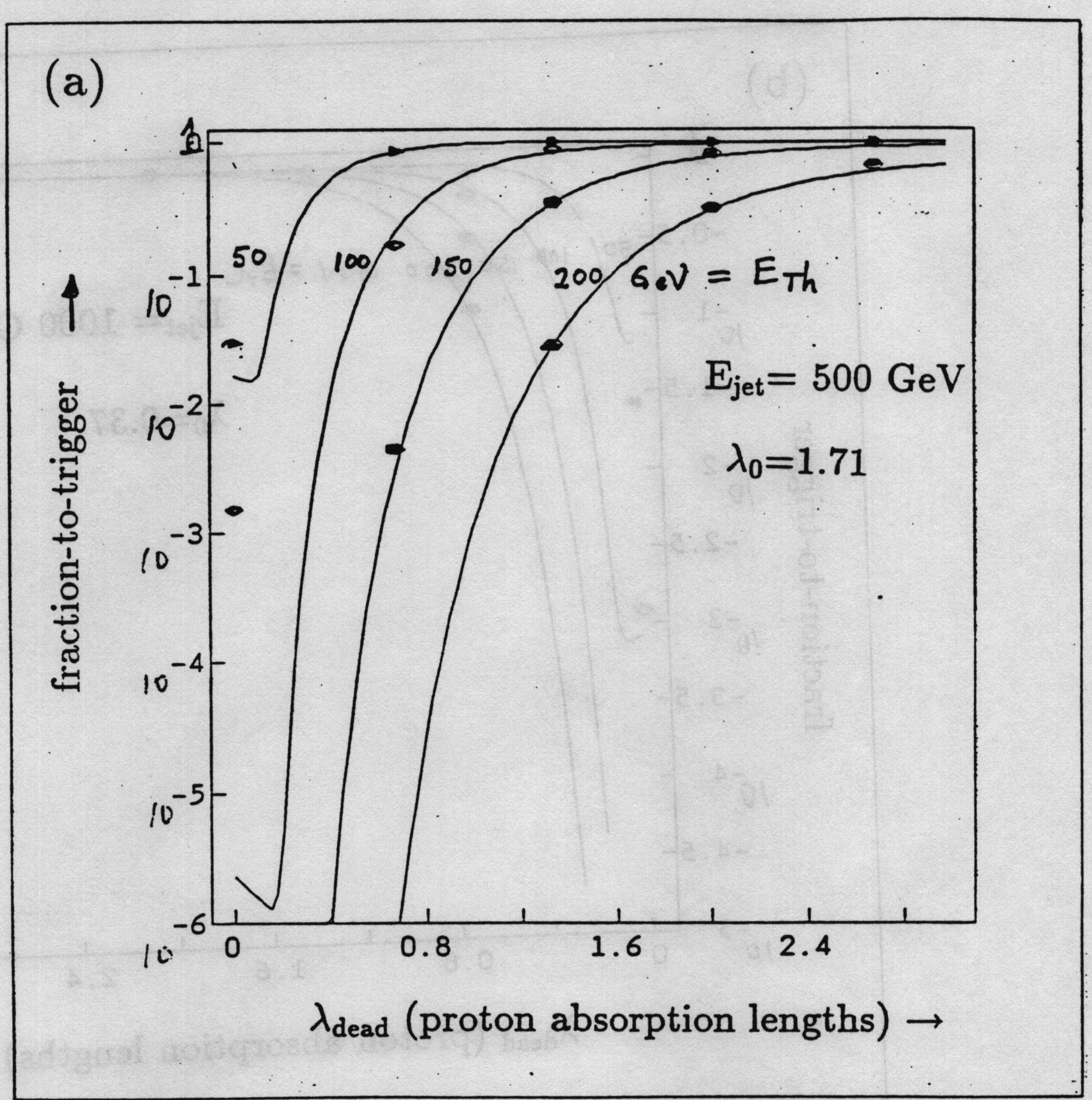
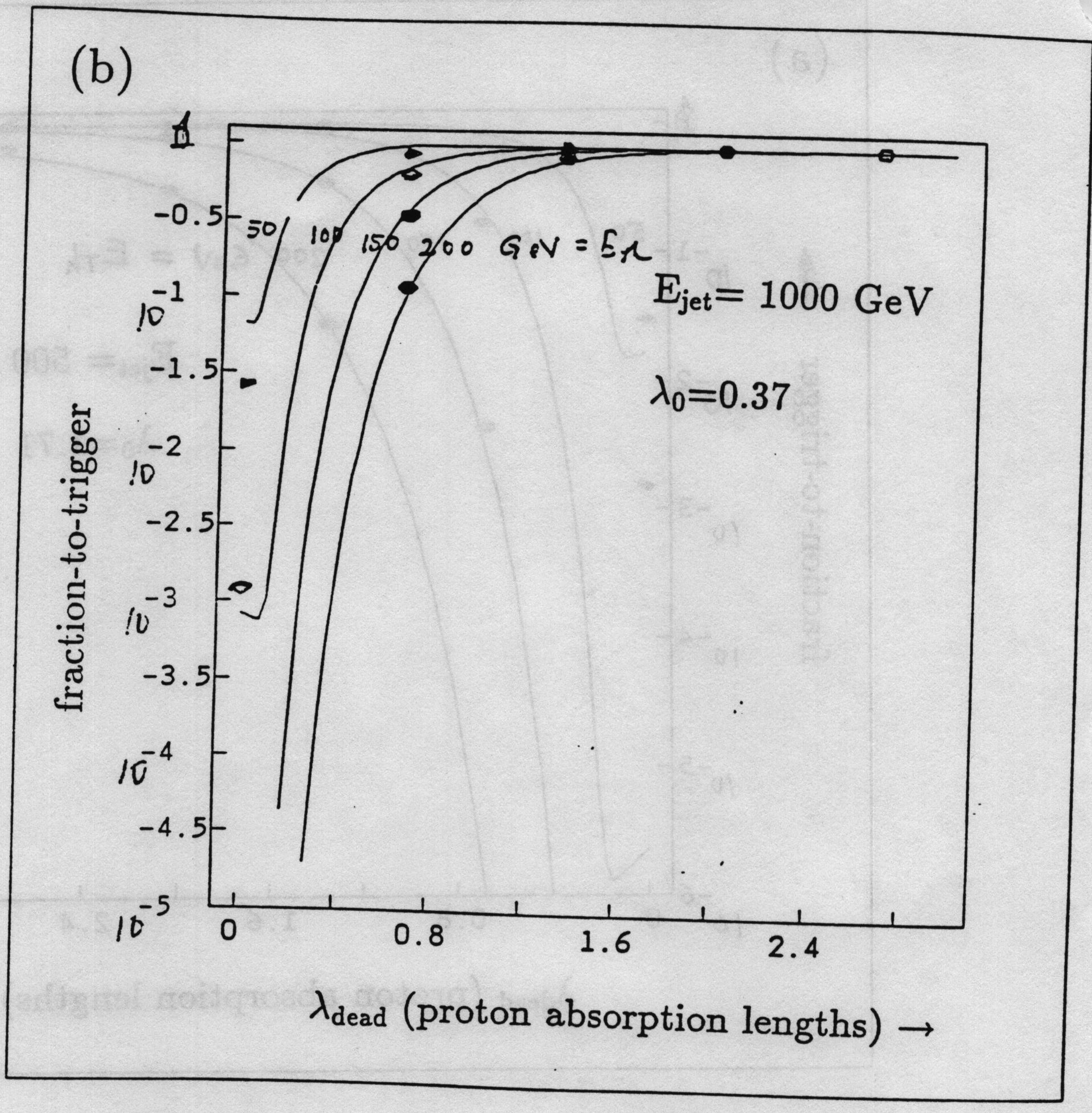


Figure 3. The fraction "f" used to parameterize the trigger fraction due to energy lost in dead spaces situated at two depths (λ_0=0.37λ_p and λ_0=1.71λ_p) within the calorimeter mass, and for two energies E_{jet}=500 GeV and 1000 GeV. (a) E_{jet}=500 GeV, λ_0=1.71λ_p , and (b) E_{jet}=1000 GeV, λ_0=0.37λ_p.



(b)
fraction-to-trigger
-0.5
-1.5
-2
-2.5
-3.5
-4.5
10^-1
10^-2
10^-3
10^-4
10^-5
50 100 150 200 GeV = E_h
E_jet= 1000 GeV
λ0=0.37
0
0.8
1.6
2.4
λdead (proton absorption lengths) →

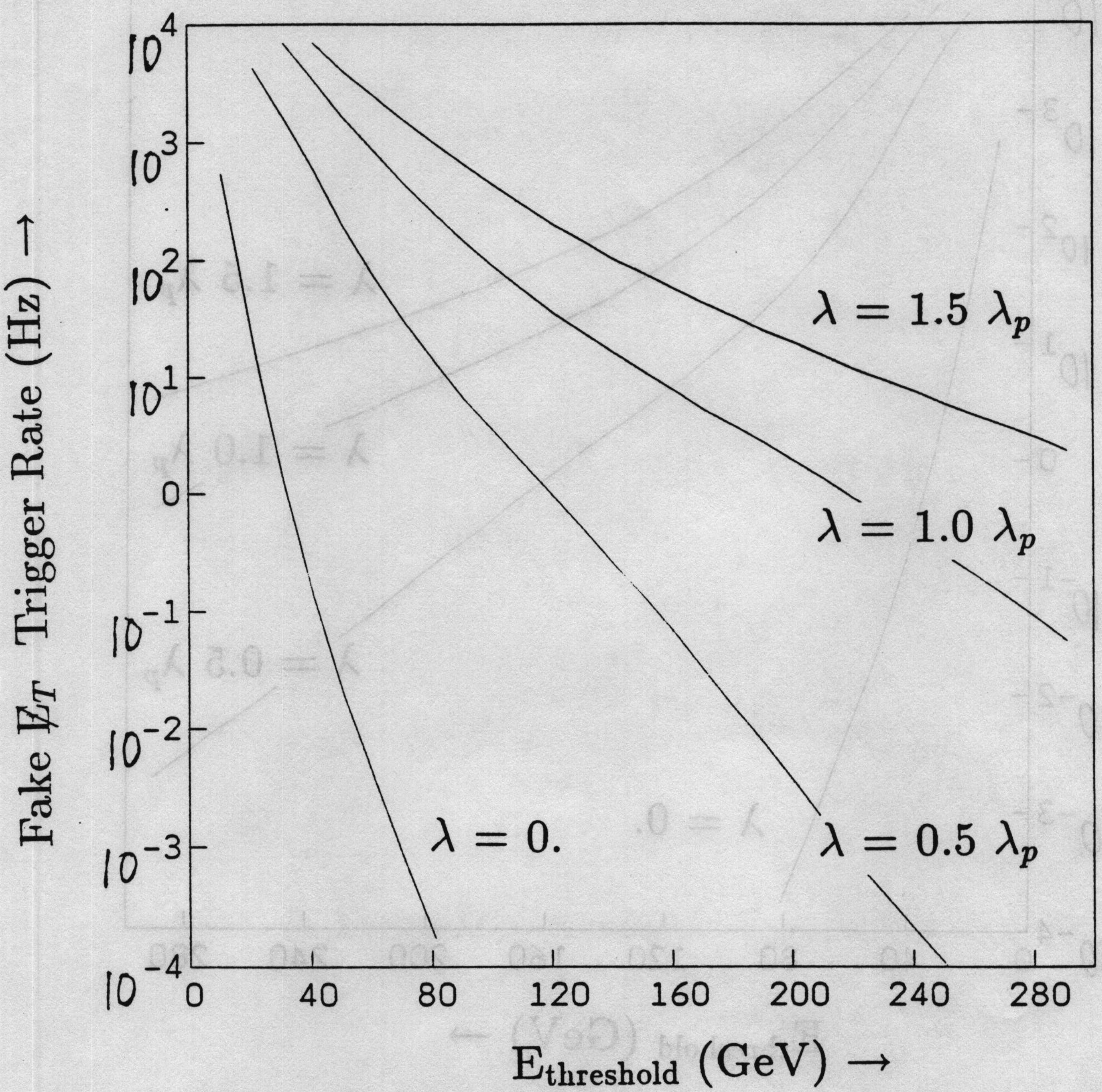


Figure 4. Fake $\not{E}_T$ trigger rate due only to dead space in front (λ_0=0) of the calorimeter, for $\lambda = 0$, .5, 1., and 1.5 λ_p. For these curves, $\lambda_T = \infty$.

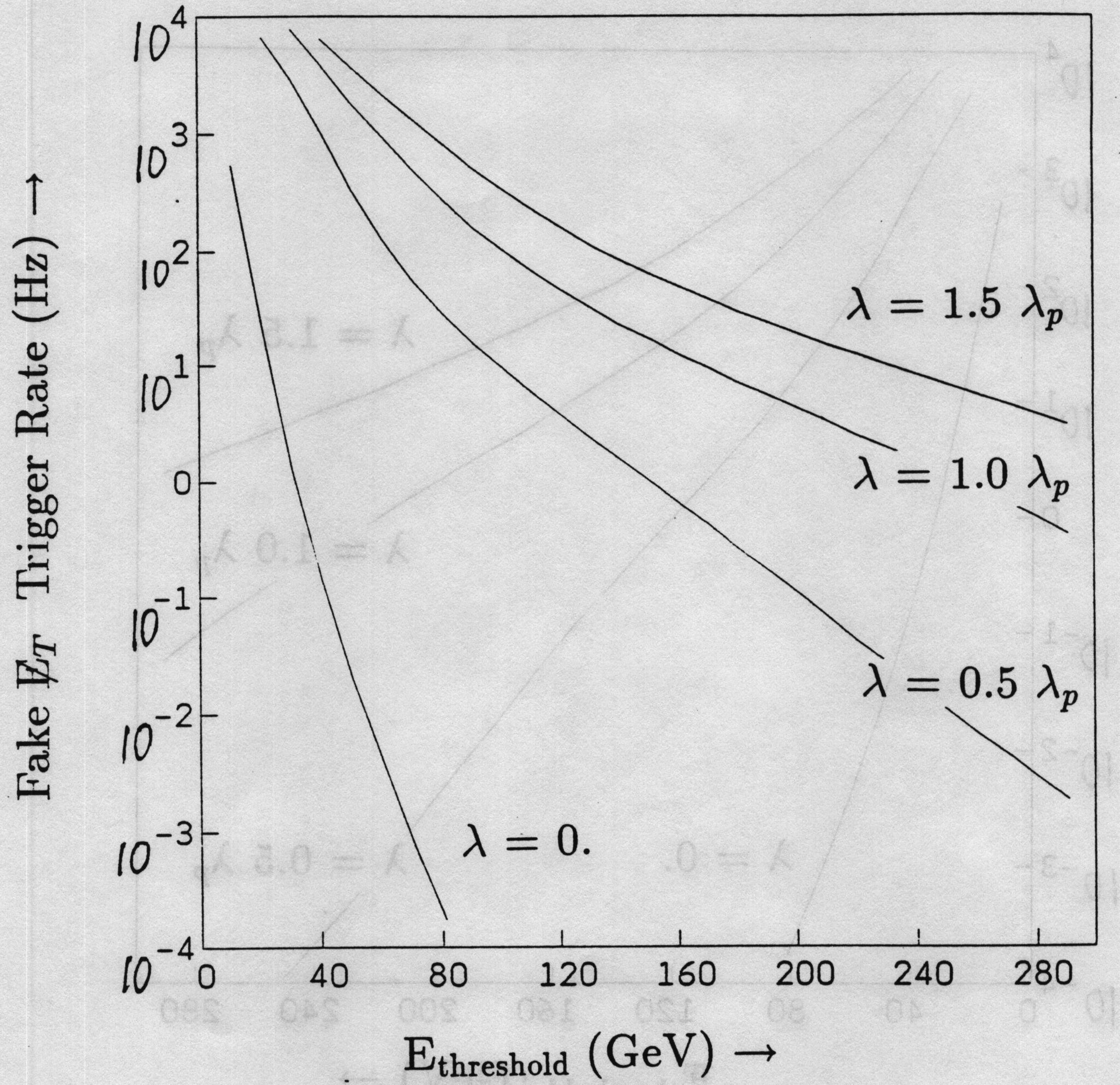


Figure 5. Same as Figure 4, but with $\lambda_0 = 1.0\lambda_p$.

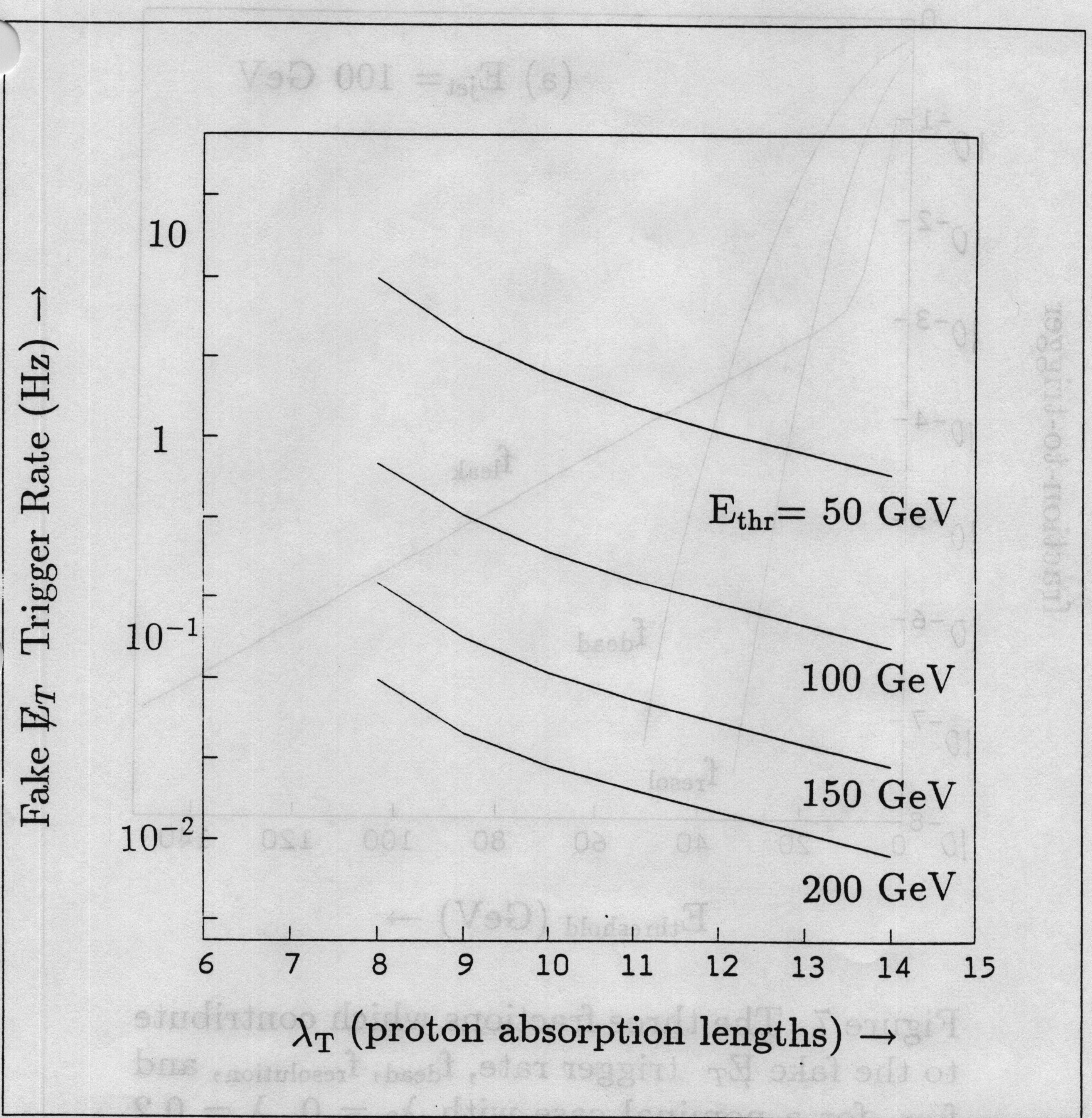


Figure 6. The fake $\not\!\!E_T$ trigger rate *versus* calorimeter depth in proton absorption lengths due only to calorimeter leakage, for four different triggering thresholds, E_{thr}= 50, 100, 150, and 200 GeV.

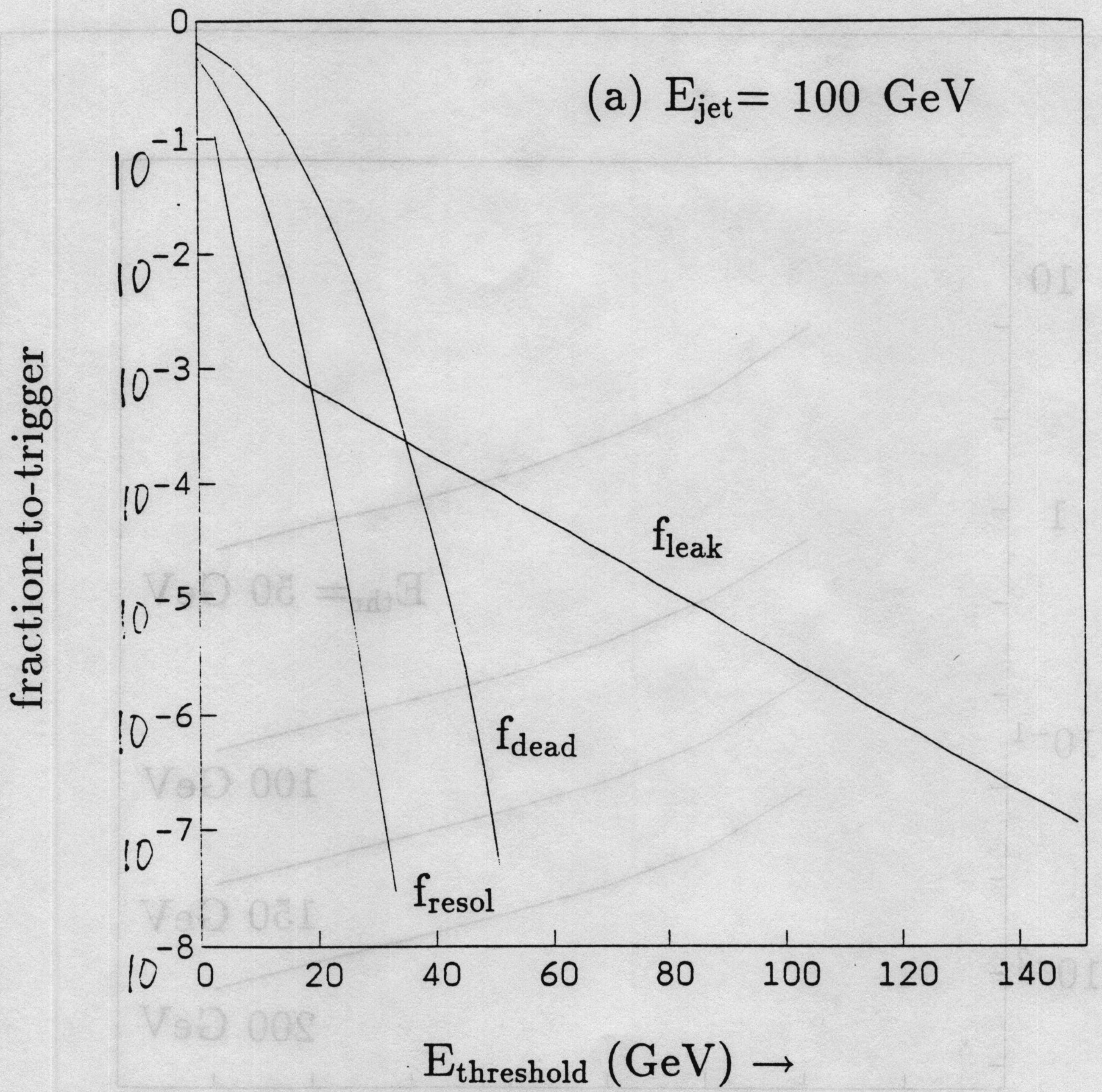
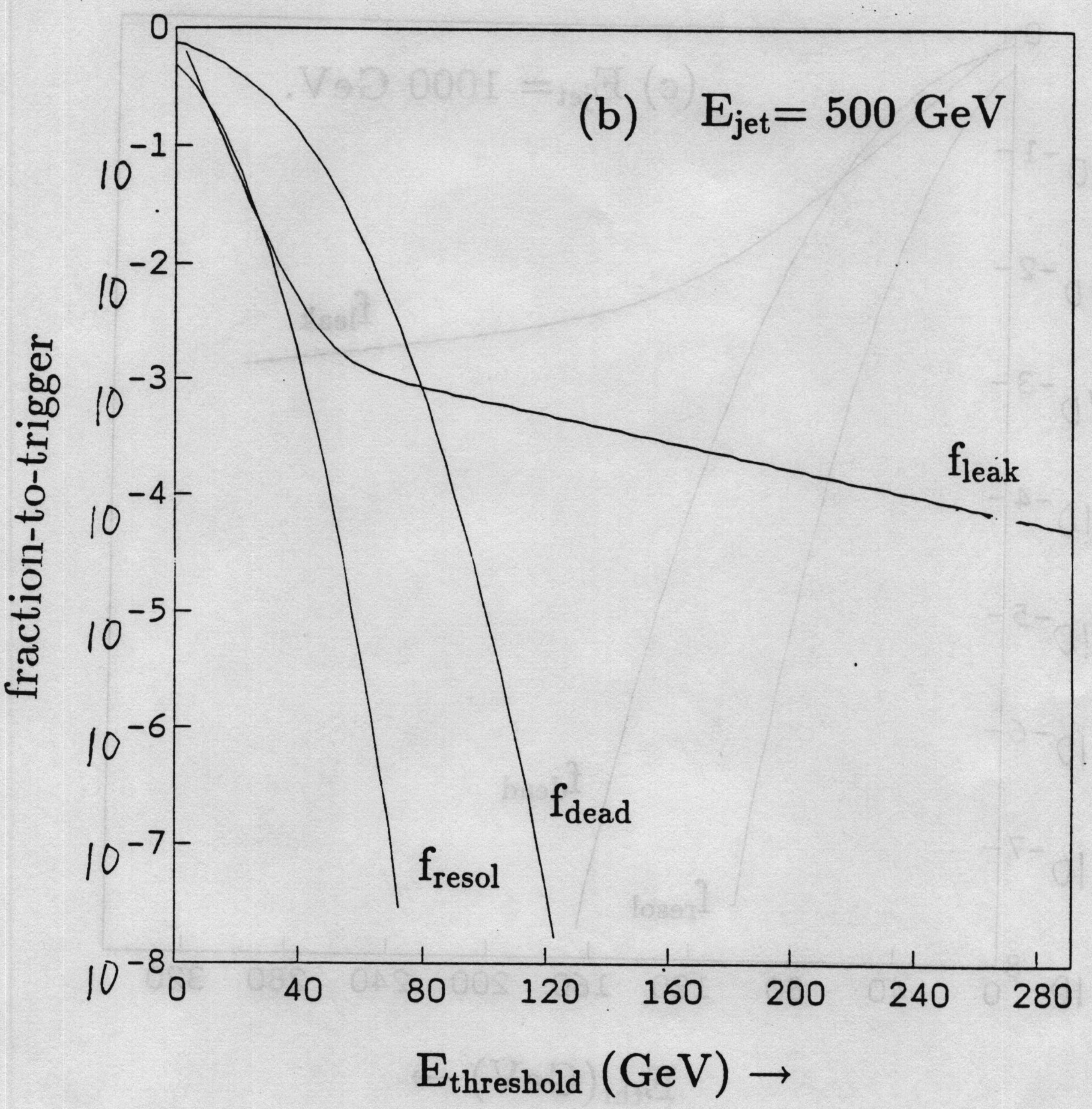
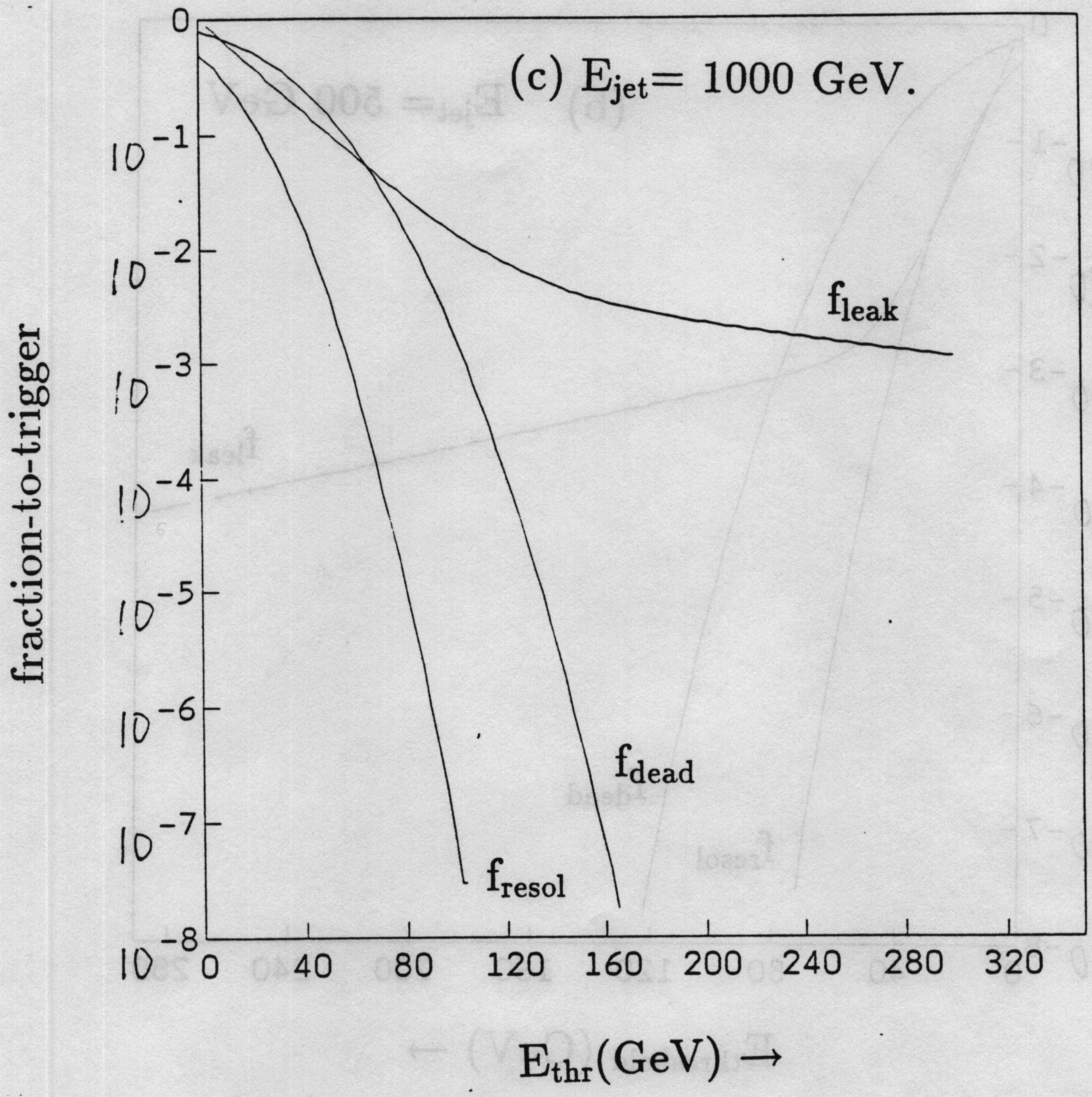


Figure 7. The three fractions which contribute to the fake $\not{E}_T$ trigger rate, f_{dead}, $f_{resolution}$, and f_{leak}, for a nominal case with $\lambda_0 = 0$, $\lambda = 0.2\ \lambda_p$, and $\lambda_T = 10\ \lambda_p$. (a) E_{jet}= 100 GeV, (b) E_{jet}= 500 GeV, and (c) E_{jet}= 1000 GeV.


(b) E_{jet}= 500 GeV
fraction-to-trigger
$E_{threshold}$ (GeV) →
f_{leak}
f_{dead}
f_{resol}
0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
40
80
120
160
200
240
280


(c) E_{jet}= 1000 GeV.
f_{leak}
f_{dead}
f_{resol}
fraction-to-trigger
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
40
80
120
160
200
240
280
320
E_{thr}(GeV) →