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# Triggering at High Luminosity: Fake Triggers from Pile-up

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# TRIGGERING AT HIGH LUMINOSITY: FAKE TRIGGERS FROM PILE-UP

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Triggers based on a cut in transverse momentum ($p_t$) have proved to be useful in high energy physics both because they indicate that a hard constituent scattering has occurred and because they can be made quickly enough to gate electronics. These triggers will continue to be useful at high luminosities if overlapping events do not cause an excessive number of fake triggers. In this paper, I will determine if this is indeed a problem at high luminosity machines.

The trigger probability for high $p_t$ processes with n additional overlapping events can be calculated as follows. Let $P_n(E_{min})$ be the probability that n overlapping events give an energy $E \geq E_{min}$ with $P_n(0) = 1$. (E can be total energy, transverse momentum along an axis in a hemisphere, or any other continuous parameter of an event which is positive and additive among overlapping events.) $P'_n(E) = dP_n/dE$ = the differential probability for getting n overlapping events between E and E + dE.

$$P'_0 = \frac{1}{\sigma_{TOT}} = d\sigma/dE$$

and

$$P_0 = \frac{1}{\sigma_{TOT}} \int_{E_{min}}^{\infty} d\sigma/dE \, dE$$

= trigger probability of an individual event.

Then

$$P_n(E_{min}) = \int_{E_{min}}^{\infty} dE \int_0^E d\varepsilon \, P'_1(\varepsilon) \, P'_{n-1}(E - \varepsilon).$$

Changing the order of integration gives

$$P_n(E_{min}) = P_1(E_{min}) + \int_0^{E_{min}} d\varepsilon \, P'_1(\varepsilon) \, P_{n-1}(E_{min} - \varepsilon).$$

The probability that n interactions give a trigger is the probability one interaction triggered the system plus the convolution integral for the probability that one interaction combined with the group of (n - 1) interactions to give a trigger. With this formula, the probability for n interactions can be calculated by successive convolutions of the single interaction probability distribution.

Convolutions of exponential distributions get equal contributions from all portions of the integration interval; convolutions of distributions which fall less steeply will tend to get the most weight from the limits of the integration. Therefore, it is not surprising that the most probable high $p_t$ trigger from n overlapping events will come from one moderately high $p_t$ event plus (n - 1) low $p_t$ events.

For triggering purposes, the mean number of interactions during the integration time of the analog sum is the appropriate measure of the luminosity. High luminosity at the ISR has meant .2 to .4 interactions per trigger integration time. At a luminosity of $10^{33}/cm^2/sec$ the mean number of interactions might be between 1 and 5. The trigger probability for an average multiplicity of $\bar{n}$ and trigger threshold of $E_{min}$ is the sum of $P_n(E_{min})$ weighted by the Poisson statistic for n with a mean of $\bar{n}$.

Before moving on to some examples, let me make a disclaimer. I am not trying to predict rates for any specific experiment in a high rate environment with these examples, although they are taken from ISR experiments and the ISAJET Monte Carlo calculations.[1] Instead, I will show what generic types of cross sections can and cannot be measured, and what can be done at the trigger level to reduce the pile-up trigger rate.

The first example is a pure exponential: $P_1(E_t) = .84\, e^{-.84 E_t}$ (shown in Figure 1). As can be seen in Figure 1, any amount of pile-up during the measurment is disastrous. Increasing the trigger threshold reduces the fraction of interesting triggers (triggers from single events with $E_t > E_{min}$).

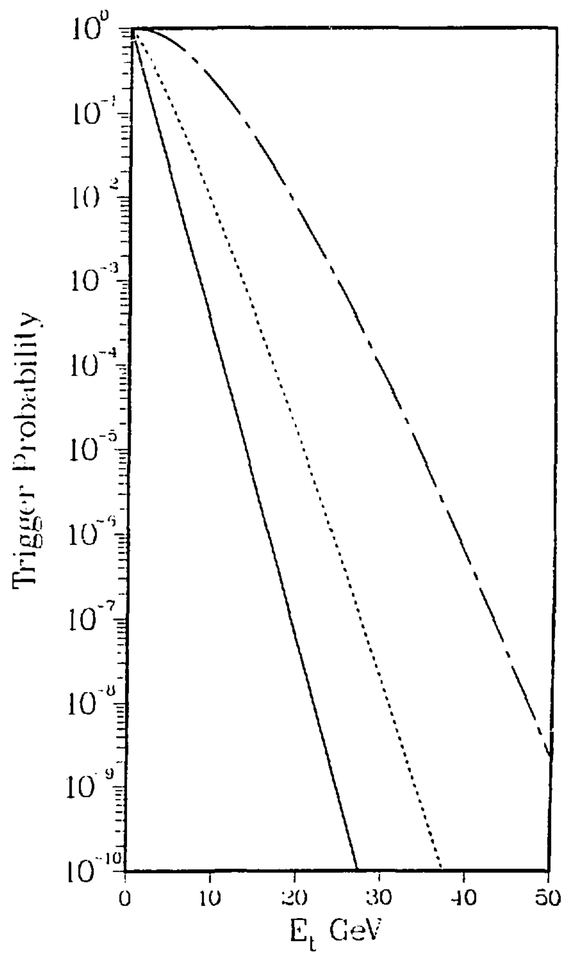


Figure 1. Trigger probability per interaction for the cross section $P'_0(E) = .84\, e^{-.84E}$. Solid line is the integral production cross section (n = 0). Dashed line is for n = 1 and dashed-dotted line for n = 5.

A parton picture of the nucleons implies that the high $p_t$ scattering cross section eventually deviates from a pure exponential. As the second example, let the cross section follow the exponential to $E_t = 10$ GeV/c and then fall like $E_t^{-8}$ beyond that. The *triggering probability distributions for this cross* section are shown in Figure 2. The low $E_t$ portion is still dominated by pile-up from multiple events from the exponential region, but, as $E_t$ goes up, the trigger rate eventually deviates from this exponential pile-up and stays at approximately a constant factor above the true cross section. In the high $E_t$ region, the pile-up just lowers the effective threshold from $E_t$ to $E_t - \bar{n}\, E_t^{average}$.

These first two examples are consistent with the $E_t$ cross section measured by R807 at the ISR.[2] They observed an increase in the trigger rate of about 5 when going from a mean multiplicity of 0 to .2 with an $E_t$ threshold of 10 GeV/c. The exponential *distribution of example 1 gives a factor of* 3.3 increase for these parameters.

At higher energy storage rings, the flattening of the $E_t$ cross section is expected to begin sooner. The $E_t$ cross section predicted by ISAJET for $E_{cm}$ = 800 GeV is shown in Figure 3 along with the trigger rates for n = 1 and n = 5. Because the cross section is flatter, the deviation from exponential pile-up occurs at a lower $E_t$. The $E_t^{average}$ per event has not changed, however, and the shift in the effective trigger level is about the same as in Figure 2.

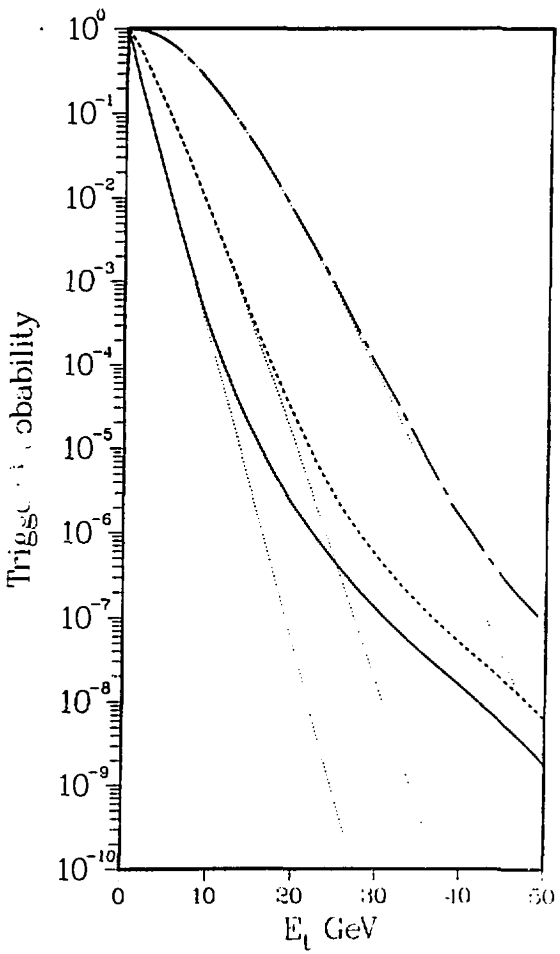


Figure 2. Trigger probability per interaction for the cross section $P'_0(E) = .84\ e^{-.64E}$ for $E \leq 10$ GeV and $P'_0(E) = 1.8 \times 10^4 \cdot E^{-8}$ for $E > 10$ GeV. Solid line is the integral production cross section, dashed line for n = 1 and dashed-dotted line for n = 5. The dotted lines are the curves from Figure 1 for the pure exponential distribution.

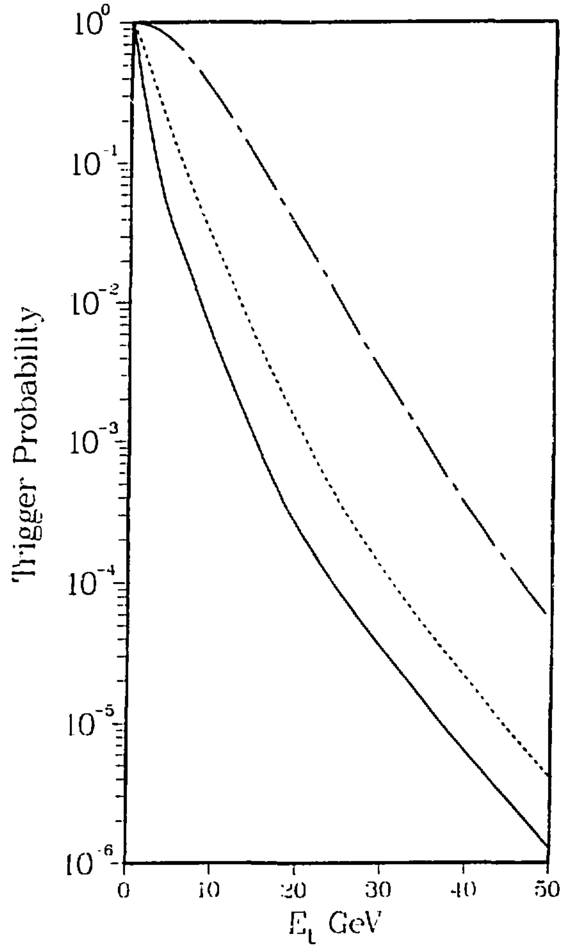


Figure 3. Trigger probabilities per interaction for the ISAJET production cross sections at $E_{cm}$ = 800 GeV/c. Solid curve is for the integral production cross section, dashed curve for n = 1 and dashed-dotted curve for n = 5.

The way to reduce the number of pile-up triggers is to reduce either $\bar{n}$ or $E_t^{average}$. Obviously, better time resolution and smaller integration times will reduce $\bar{n}$. $E_t^{average}$ can be reduced in a number of ways. Rather than summing the $E_t$ over the entire solid angle, just the $E_t$ in the small area around the jet need be summed. Then the $E_t$ from the jet would be unaffected, but the ambient $E_t$ would be reduced (Figure 4). The probability distribution for one jet is the same as in the previous example, but the probability distributions for all subsequent events are reduced. By reducing the integration area from $\Delta y = 4$, $\Delta\phi = \pi$ (as in Figure 3) to $\Delta y = 1$, $\Delta\phi = \pi/2$ the average $E_t$ for an accidental coincidence is reduced from 3 GeV/c to .7 GeV/c. With this technique, the accidental to actual rate is 1:1 down

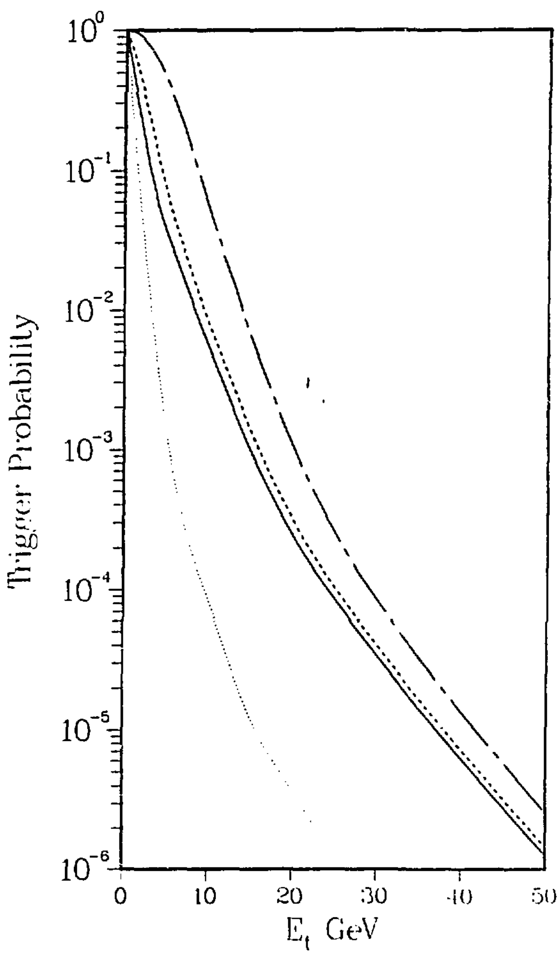


Figure 4. Trigger probabilities per interaction for the reduced solid angle trigger described in the text. The solid line is the integral production cross section used for $P_0(E)$; the dotted line is the random jet probability distribution used for the convolution integrals. The dashed curve is for n = 1 and the dashed-dotted curve for n = 5.

technique, the accidental to actual rate is 1:1 down to 30 GeV/c for 5 overlapping events. Placing a threshold requirement on the subelements of the detector reduces the average $E_t$ even further. Although this technique cannot be calculated analytically as the previous examples have, Howard Gordon and Dennis Weygand have written a Monte Carlo program using ISAJET to simulate this process.[3] They find that with a minimum cut of 1 GeV/c the high luminosity trigger rate ($\bar{n} = 10$) is only 30% more than the low luminosity rate down to $E_t = 10$ GeV.

What do these examples teach us? First, the amount of pile-up is dependent on the cross section to be measured. Exponential cross sections are very difficult to measure at anything but extremely low luminosities; cross sections which flatten out at high $p_t$ are easier. For those flatter cross sections, the ambient background from multiple events tends to shift the energy scale of the trigger. A trigger set for 50 GeV/c will trigger, on events produced at $p_t = 50 - \bar{n}\, p_t^{average}$. $\bar{n}$ can be reduced by reducing the resolving time of the apparatus. $p_t^{average}$ can be reduced by reducing the area covered by the trigger, or by summing only the showers generated by particles coming from a given vertex region. If these techniques are used, triggering on high $p_t$ events can be quite efficient even at high luminosities.

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