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EFFECT OF CALORIMETER RESOLUTION AND PILE-UP ON TRIGGER RATES*

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INFORMAL REPORT

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Effect of Calorimeter Resolution and Pile-up on Trigger Rates*

W. Carithers

In the high rate Isabelle environment it has long been recognized that fast time resolution and short memory times are highly desirable. Unfortunately, calorimeters have been inherently slow devices on the time scales of interest. The bunched beam scheme of Isabelle, Phase I, offers some temporary respite as suggested in Figure 1 where the time structure of the luminosity is displayed. The instantaneous luminosity is quite high and leads to an interaction probability of .2 per crossing. However, there is no hope of tagging multiple interactions within a bunch using time resolution alone. In that sense a time resolution of 200 ns is as good as 5 ns, and "conventional" calorimeter technologies (including gas multiplication readout) can be used.

Even for Phase I the problem of pile-up, while independent of detector, is a real one. For an unbiased trigger every event has a 20% probability of containing an extraneous interaction, 4% probability of 2, etc. For a $p_\perp$ trigger, the event sample can be heavily biased toward multiple events. To illustrate this point, the transverse energy spectrum for multiple minimum bias events is shown in Figure 2. While most events are quite soft, a p_T threshold of 5 GeV preferentially selects multiple events.

*Work performed under the auspices of the U.S. Department of Energy.

For Phase II, the problem appears worse. For the full luminosity of $10^{33}cm^{-2}sec^{-1}$, the probability for multiple interactions within ΔT is given by:

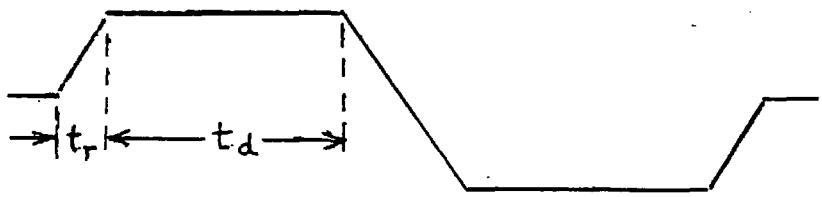
$$P = 1 - e^{-(.05/ns)\Delta T}$$
$$= (.05/ns)\Delta T \quad \text{for} \quad \Delta T \quad \text{small} .$$

This would seem to require ΔT ~ few nanoseconds to control the pile-up.

It is probably worth noting that there is an intrinsic "pile-up" for every event due to the spectator constituents. A useful trigger will pick out events with a hard scattering of two constituents, but all the other constituents will distribute 3-4 particles per unit rapidity over the detector and will confuse the analysis of the hard scattering. This pile-up is independent of detector resolution so the base-line for pile-up is .7-1 event rather than zero. Fortunately, most of these particles are quite soft and may not interfere with the calorimetric measurement of high $p_\perp$ events.

For a calorimeter time resolution of 200 ns, we expect an average of 10 events in the pile-up. With bipolar, equal-area shaping, there will be no net base-line shift due to pile-up, but the fluctuations will smear the energy measurements. We investigate those conditions where the pile-up fluctuations are comparable to or smaller than the sampling fluctuations in the calorimeter itself. For this purpose, we choose a calorimeter with sampling fluctuations, $\sigma \approx .8\sqrt{E(GeV)}$, as might be obtained with 5 cm Fe sampling.

We consider a proportional chamber or tube read-out with an 80 ns maximum drift time. We take a shaping function given by:



rise time, t_r = 20 ns

dwell time, t_d = 80 ns

The mean square energy deviation is given by

$$\overline{\Delta E}^2 = nE_0^2 + n\sigma_E^2$$

where $n = L\sigma_{TOT} \int_{-\infty}^{\infty} W(t)^2 dt$

$\simeq 10$

E_0 = average energy deposited by a pile-up event

σ_E = RMS of energy deposition by a pile-up event

The first term in $\overline{\Delta E}^2$ takes into account the fluctuations in the number of pile-up events and would obtain even if every event deposited an exactly fixed amount of energy. The second term accounts for the fluctuations in the energy deposited by each pile-up event and would be present even if the pile-up were not random in time.

As a numerical exercise, we consider a "trigger element" of one unit of rapidity ($0 \leq y \leq 1$) and half of the azimuthal coverage (i.e., roughly 1/16 of the full coverage). From examining minimum bias events from the ISAJET Monte

Carlo, we find that the average E_T per pile-up event into this element is about .55 GeV and coincidentally the RMS is also roughly .55 GeV. The RMS fluctuation in the total pile-up given by the above formulas is 2.58 GeV.

In Figure 3, we show separately the effect of smearing on the differential $P_\perp$ spectrum due to sampling fluctuations above and in quadrature with the pile-up term. Above 40 GeV, the pile-up has almost no effect.

For triggering purposes, the integral spectrum is relevant since we accept all events above a threshold. Figure 4 shows this spectrum where the cross section has been converted into trigger rate using $L = 10^{33} cm^{-2} sec^{-1}$ and the solid angle of the "trigger element" described above. Data handling requirements will limit the trigger rate to 10-20 Hz or less, and the threshold must be set in the 40-50 GeV range. As noted before, the effect of pile-up is negligible. If lower thresholds are required, the luminosity must be reduced and the pile-up correspondingly diminishes. Note that even the sampling fluctuations have a surprisingly small effect in this regime. (We have also studied another model calorimeter that is close to the state-of-the-art, namely $\sigma_E = .4\sqrt{E}$, $\Delta T = 50$ ns. The performance obviously falls between Detectors 1 and 3 of Figure 4.)

If one insists on high efficiency for a particular $p_\perp$, the effects of sampling fluctuations and pile-up are more severe. Here the resolution enters twice: once because the threshold must be lowered to maintain the efficiency and a

second time since events with a lower true $p_\perp$ may fluctuate up to cross threshold. For example, a perfect detector would have a rate of 7 Hz at $p_\perp \geqslant 50$ GeV. For detector 3, the threshold must be set at 42 GeV to be 90% efficient at 50 GeV. The trigger rate rises to 23 Hz -- a factor of three higher.

Another caveat is in order. If one uses MWPC readout some care must be taken to control the contribution of electronic noise to the trigger signal. Williams and Radeka have studied this effect (see their contribution to this workshop) and concluded that the RMS is approximately 5 GeV equivalent for a gas gain of 10^3. This is even larger than the pile-up term. If the gas gain is increased to 10^4, the equivalent noise drops to a negligible 0.5 GeV, but then one must be careful about chamber lifetime effects.

We conclude that calorimeters, even slow ones, are relatively insensitive to pile-up and may be useful for many studies even at the full luminosity. Since the costs of the hadron calorimetry may dominate the total for a general purpose detector, one should not reject a less expensive technology out of hand just because the memory time allows several events to pile up.

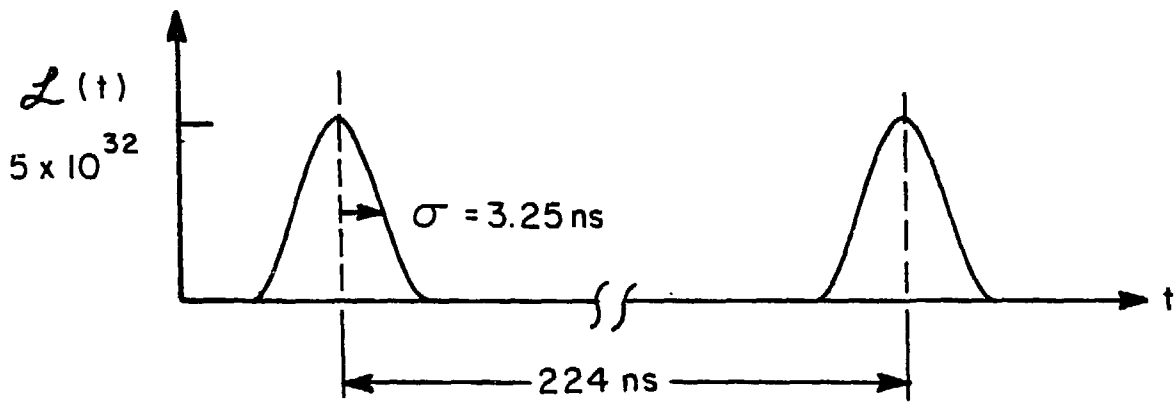


FIG. 1 BUNCHED BEAM TIME STRUCTURE

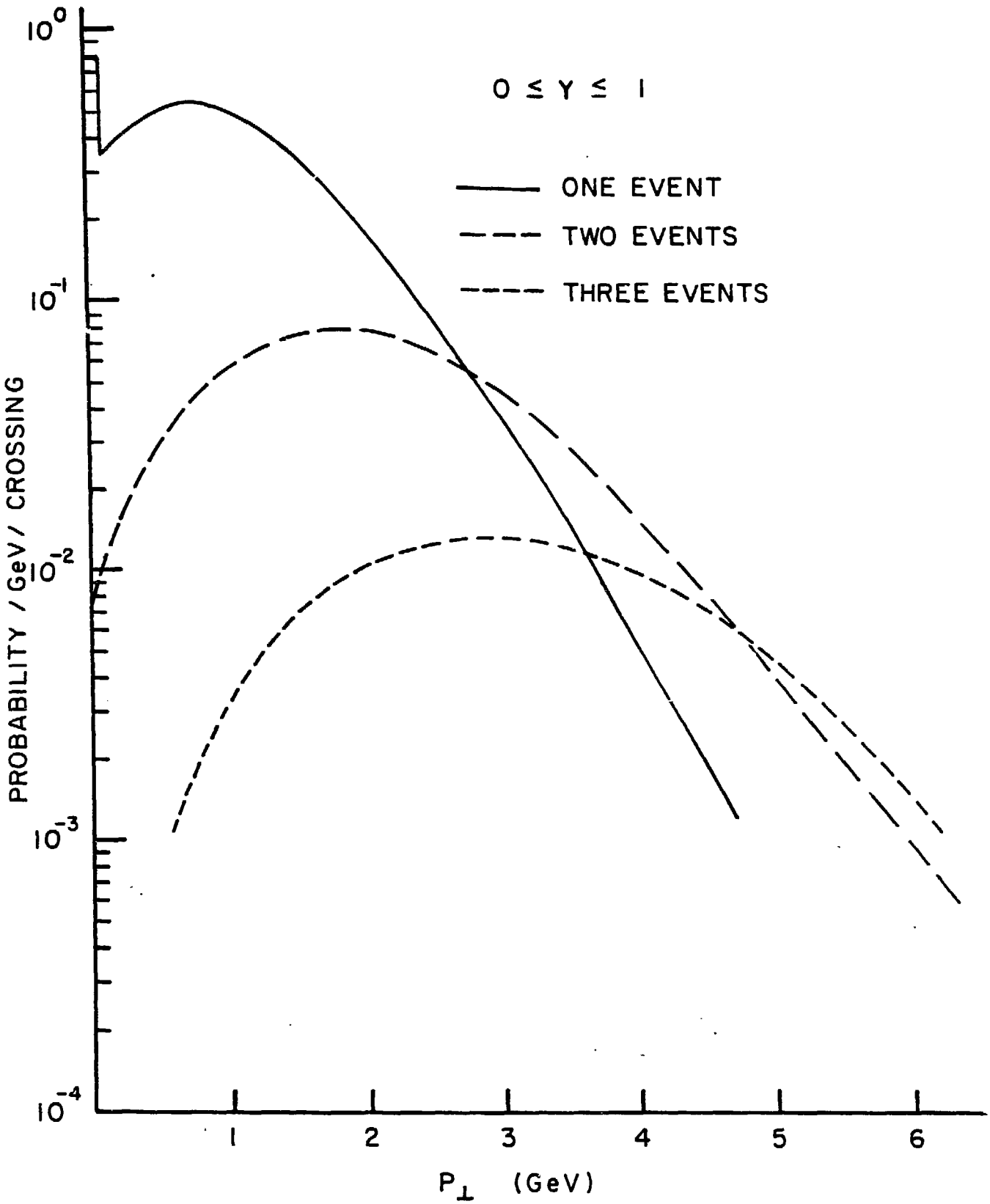

10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
PROBABILITY / GeV / CROSSING
$0 \leq Y \leq 1$
ONE EVENT
TWO EVENTS
THREE EVENTS
1
2
3
4
5
6
$P_\perp$ (GeV)

FIG. 2

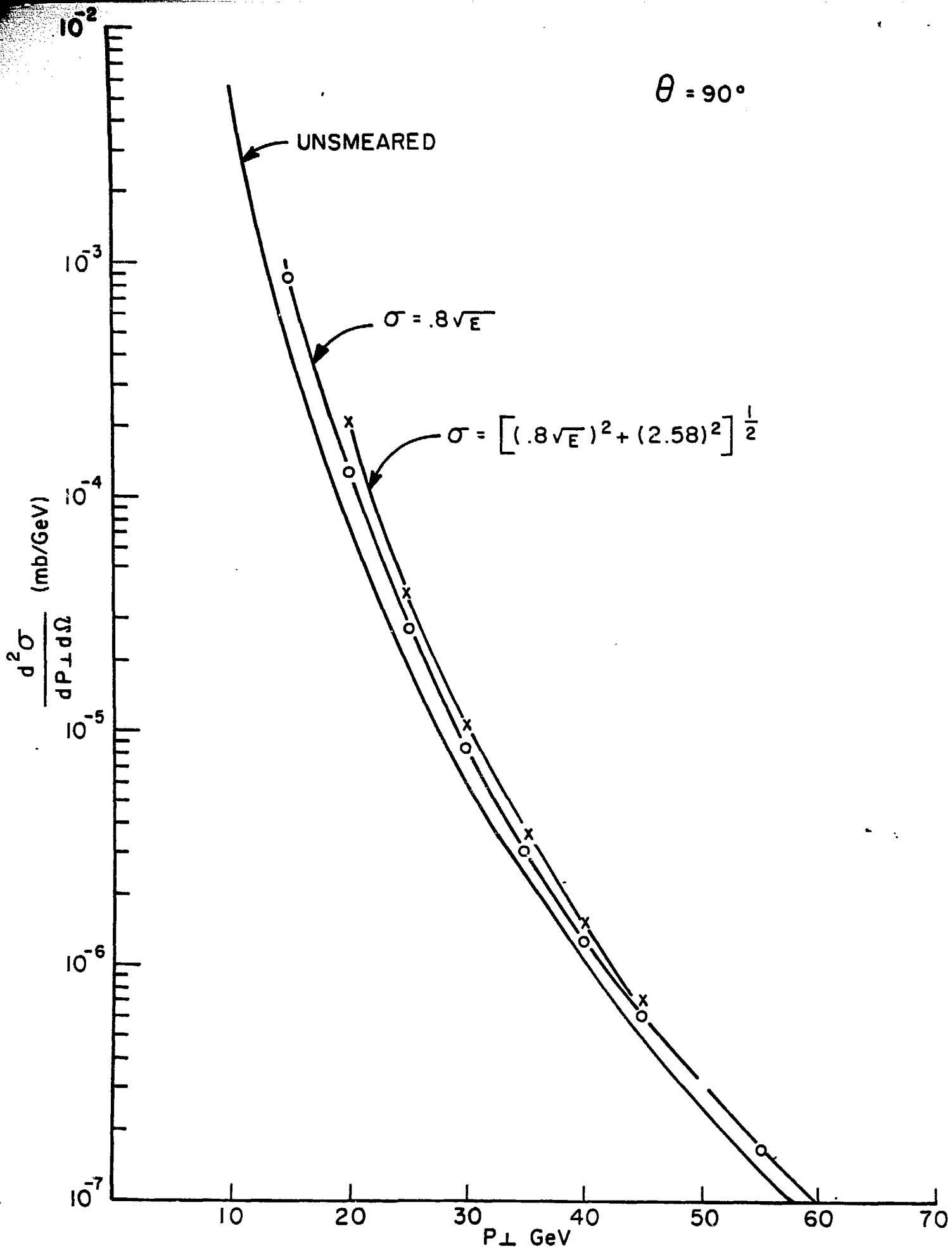

$\theta = 90°$
UNSMEARED
$\sigma = .8\sqrt{E}$
$\sigma = \left[(.8\sqrt{E})^2 + (2.58)^2\right]^{\frac{1}{2}}$
$\frac{d^2\sigma}{dP_\perp d\Omega}$ (mb/GeV)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10
20
30
40
50
60
70
$P_\perp$ GeV

FIG. 3

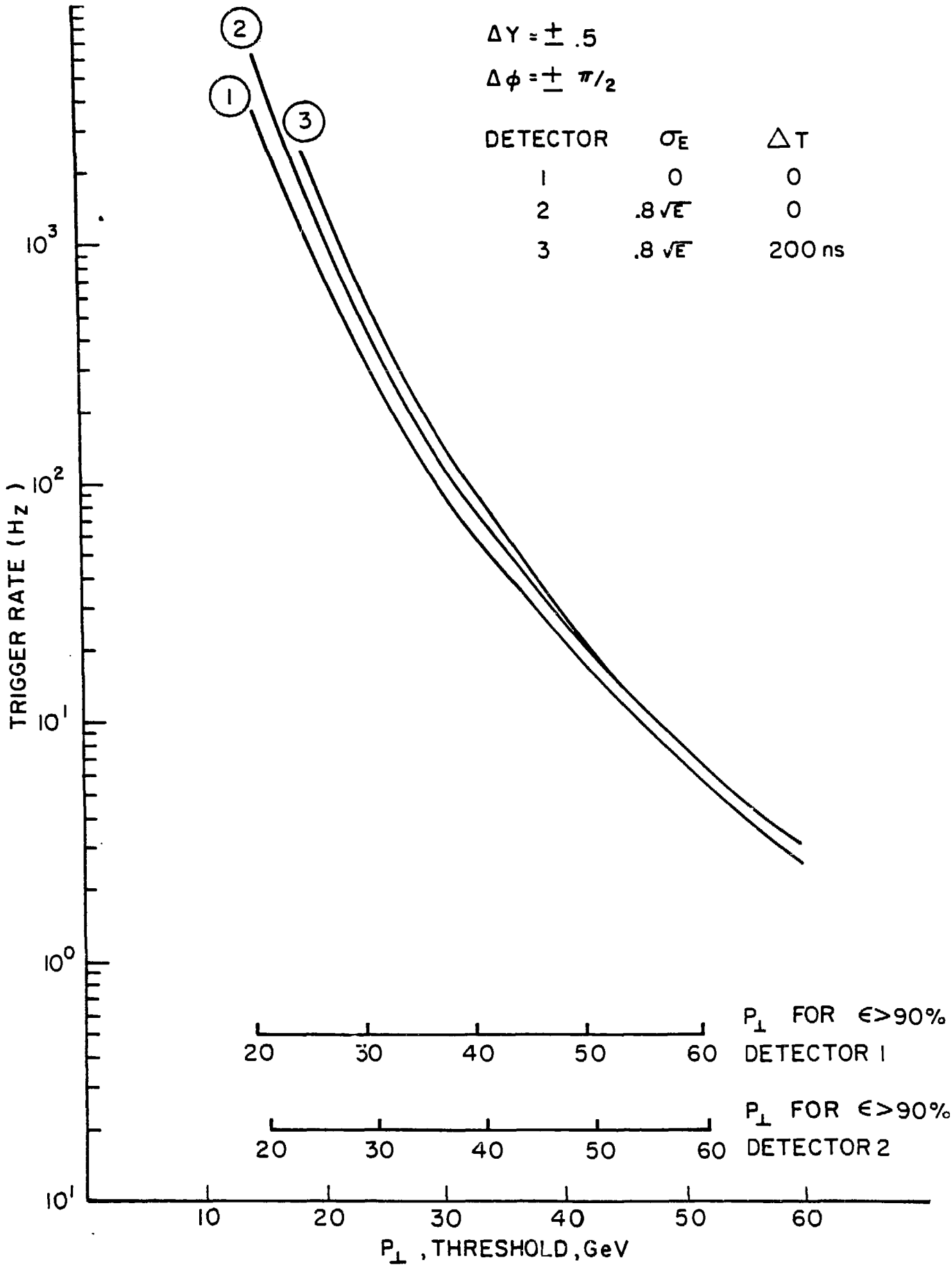



FIG. 4 TRIGGER RATE VS. $P_\perp$ THRESHOLD