GEM TN-93-449
PITT/GEM 93-4

Timing Performance of the GEM Calorimeter Trigger for Large Signals

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In order to achieve the required dynamic range compression for the calorimeter, it has been proposed to utilize a preamplifier with a nonlinear response curve. One consequence of such a response curve is that the waveform of the output signal becomes a function of its amplitude. A concern is that the calorimeter level 1 trigger may not properly identify the bunch crossing for signals of very large amplitude. Two solutions to this problem are available, and they are evaluated in a simple bilinear model of the preamplifier response curve.

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1 Introduction

For the GEM calorimeter, in order to accomodate the full dynamic range with adequate precision, it will be necessary to introduce a roll-off in the gain of the preamplifiers. A nonlinear (or bilinear) gain of the calorimeter preamplifier will cause a shift in the peaking time of up to 20 ns in the output signal of the shaper[1], as one passes from the linear region (~200 GeV) to the highest energy signal. In what follows, we refer to the signal above the transition region with shorter rise time as "distorted". We consider two solutions to this problem, and they are evaluated by modelling the response curve of the preamplifier in a simple way. We assume that the output waveform has a peaking time of 75 ns up to the amplitude corresponding to 200 GeV, which is set to be half of the output voltage scale. From this point to full scale, the preamplifier gain changes to accomodate signals up to the maximum (~6 TeV or so), with a peaking time of 50 ns.

The level 1 trigger system can easily identify that a signal beyond the transition region may have occurred, as the highest threshold will be set just below this region (since we deal with trigger sums, it is also possible that a signal above the transition region is undistorted). The important question is whether the trigger system can identify correctly the bunch crossing when the signal is distorted.

In the calorimeter level 1 trigger, the bunch crossing is identified in two different ways, using either the timing of the timing discriminator[2] output or from the zero-crossing of the timing signal generated in the digital filter on the jet sums. Without precaution, both can identify the wrong crossing in the case of a distorted signal. There is a solution to each problem. A suggestion[3] has been made that for large signals, the discriminator can be switched to leading-edge timing, and thus becomes much less sensitive to the exact shape of the signal. In Fig. 1 we show an example of a 200 GeV signal of peaking time 75 ns and amplitude 2 Volts at the discriminator input. A 2 GeV threshold corresponds to 20 mV on this scale, which is indicated as the horizontal line in the figure. We also show a full-scale (4 Volt) signal with a peaking time of 50 ns, representing the most extreme case of signal distortion. We see that the discriminator fires 7.6 ns earlier for this signal. Thus, if we set the leading edge nominal timing to the middle of this range as indicated, the output will lie within ±3.8 ns, adequate for proper bunch identification.

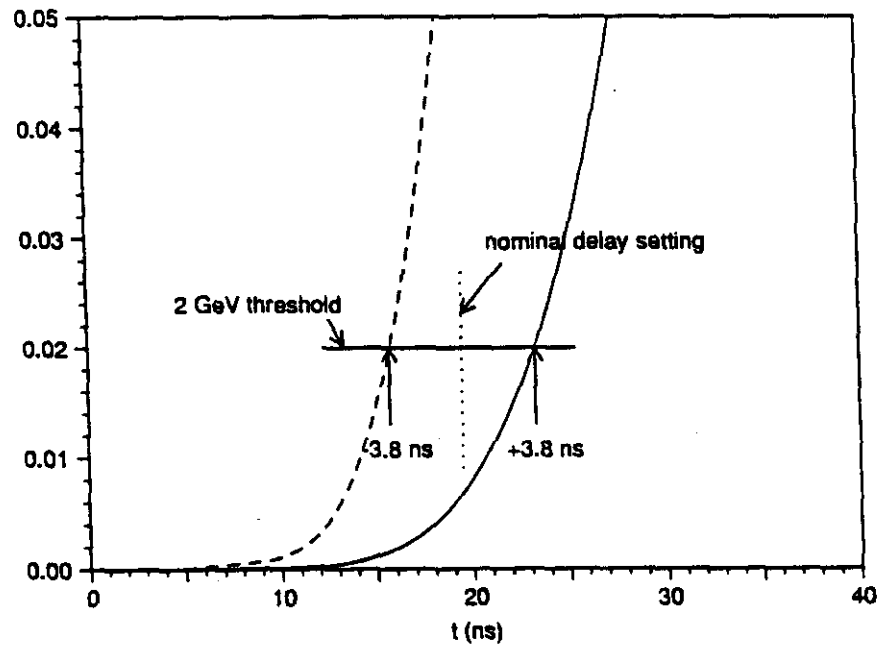

Figure 1: Leading edge discriminator timing for large signals. The solid curve is the normal signal with energy up to the preamplifier break point, with a peaking time of 75 ns. The amplitude corresponds to 2 V, which will be half scale at the discriminator input. The dashed line is the leading edge of a 4 V signal with a peaking time of 50 ns, corresponding to the most extreme case of distortion. A low level threshold is used to determine the timing in each case, the example shown here corresponding to an energy of 2 GeV. The difference in the times of crossing the threshold for the two cases is 7.6 ns. Thus, if the nominal delay for the leading edge timing, relative to the normal timing output, is set at the indicated point, the the maximum timing error incurred is 3.8 ns.

The digital filter which operates on the jet sum can also be programmed to handle a

distorted signal. If we model the distortion as a linear sum of two signals with different shaping time

$$g(t) = \alpha f_1(t) + (1-\alpha) f_2(t)$$

and introduce the fraction α as a parameter in the fit, the result is that the amplitude and timing parameters are, to first order, independent of α. Of course, there is a price to pay in fitting one additional parameter; the values of σ_A and σ_τ are increased. However, if this is done only for large ($\geq$200 GeV) signals, the increased error is acceptable. The solution for the coefficients is a straightforward extension of the optimal filter formalism[4]. We define three linear sums over the samples S_i as follows:

$$u = \sum a_i S_i$$
$$v = \sum b_i S_i$$
$$w = \sum c_i S_i$$

and demand that u, v, and w evaluate to A, $A\tau$, and $A\alpha$, respectively. We then solve for the coefficients a_i and b_i (we could also solve for the c_i, but that is unnecessary) by minimizing the variances of u, v, and w. The solution can be written as a linear sum of four vectors $\mathbf{V}\vec{U}_i$ with coefficients A_i and B_i, as follows:

$$\vec{a} = \sum_{i=1}^{4} A_i \mathbf{V}\vec{U}_i$$
$$\vec{b} = \sum_{i=1}^{4} B_i \mathbf{V}\vec{U}_i$$

The vectors $\vec{U}_i$ are given by

$$\vec{U}_1 = \vec{f}_1$$
$$\vec{U}_2 = \vec{f}_2$$
$$\vec{U}_3 = \frac{d\vec{f}_1}{dt}$$
$$\vec{U}_4 = \frac{d\vec{f}_2}{dt},$$

and $\mathbf{V}$ is the weight matrix (the inverse of the covariance matrix $\mathbf{R}$) for the samples. The values of the coefficients A_i and B_i are found from the elements of the matrix $\mathbf{Q}$, the inverse of the matrix $\vec{U}_i \mathbf{V} \vec{U}_j$, as follows:

$$A_i = Q_{1i} + Q_{2i}$$
$$B_i = -(Q_{3i} + Q_{4i}).$$

The errors of the parameters are found from the coefficients and the covariance matrix:

$$\sigma_A^2 = \sum_{ij} a_i a_j R_{ij}$$
$$A^2 \sigma_\tau^2 = \sum_{ij} b_i b_j R_{ij}.$$

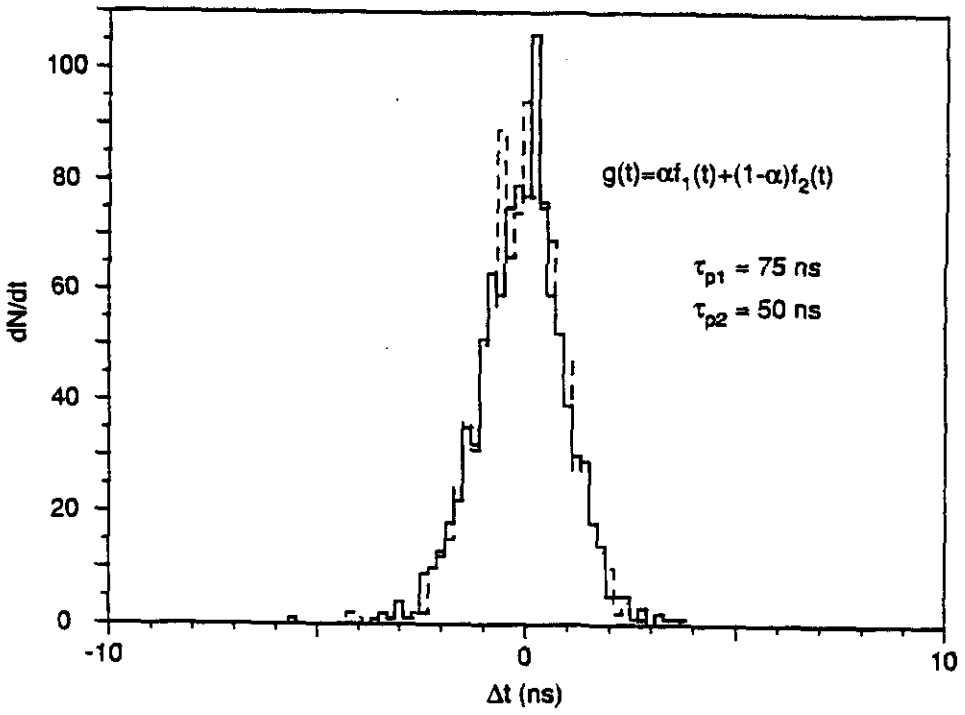

Figure 2: Histogram of the fitted value of timing to a composite waveform. Two cases are shown The solid curve is for α=0.1 and the dotted curve is for α=0.9. The two functions $f_1(t)$ and $f_2(t)$ are the same functions illustrated in Fig. 1.

Table 1: Errors on the parameters for fits to single and composite waveforms. The case chosen is a 6×6 EM sum in the barrel calorimeter operating at a luminosity of $10^{33}\text{cm}^{-2}\text{sec}^{-1}$. In the composite case (α free), the energy is split (with a fraction α) between two waveforms with peaking times of 75 ns and 50 ns.

Case	σ_A	$A\sigma_\tau$
	(GeV)	(Gev-ns)
$\alpha = 1$	0.37	9.3
α free	3.0	206

We demonstrate this technique by using the two waveforms shown in Fig. 1. In Table 1 we show the values for σ_A and $A\sigma_\tau$, both for the case where α is fixed at unity (*i.e.* the normal case) and for α free. One sees that the errors are an order of magnitude larger for the latter case, but for large amplitude signals, they are acceptable.

A Monte Carlo calculation has been done to verify this result. In Fig. 2 we show the timing error distribution for a 200 GeV signal at a luminosity of $10^{33}\text{cm}^{-2}\text{sec}^{-1}$ for the cases α=0.1 and α=0.9. Such a wide range of values of α could not really occur near the preamplifier break point, but we wish to demonstrate the most unfavorable case of low energy and a wide range of α. One sees that there is no discernable dependence on α, and that the value of σ_τ is close to 1 ns, as expected. Note that in reality there will be a continuum of rise times between the two gain regions of the preamp, which may widen this distribution for certain energies, but it is unlikely that this will be a significant effect.

In summary, there are two solutions to the problem of timing shifts introduced by the distortion of the waveform at high signal amplitudes. Either is sufficiently accurate to permit unambiguous identification of the bunch crossing.

References

[1] S. Rescia, private communication.

[2] O. Benary, et al, Nucl. Inst. and Methods in Phys. Research A332 (1993) 78.

[3] R. Chase, private communication.

[4] W. E. Cleland and E. G. Stern, "Signal Processing Considerations for Liquid Ionization Calorimeters in a High Rate Environment" submitted to Nucl. Inst. and Methods in Phys. Research, July, 1993.