Zero dead-time charge sensitive shaper for calorimeter signal processing

LHCb Technical Note

Issue: 1
Revision: 1.0

Reference: LHCb CALO 2000-041
Created: 21th Mar 2000
Last modified: 12th Jun 2000

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Abstract

The main goal of the hadron calorimeter (HCAL) of the LHCb experiment is to provide data for the L0 trigger. Due to the high L0 trigger rate up to 1 MHz [1] and high occupancy of the calorimeter cells, a zero dead time is required for an operation in the LHC conditions with 25 nsec bunch crossing. The aim of the note is to describe the zero dead-time charge sensitive shaper for calorimeter signal processing offered in TP [1] and analyse the parameters of the analogue front-end electronics components for the best performance of this method.

Document Status Sheet

Table 1 Document Status Sheet

1. Document Title: [Project Name Qualification] User Requirements Document			
2. Document Reference Number: [Document Reference Number]			
3. Issue	**4. Revision**	**5. Date**	**6. Reason for change**
Draft	1	15 April 00	First version
1	1	12 June 00	

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1. Introduction

The main goal of the hadron calorimeter (HCAL) of the LHCb experiment is to provide data for the L0 trigger. Due to the high L0 trigger rate up to 1 MHz [1] and high occupancy of the calorimeter cells, the requirements to a front-end signal processing is quite hard. First of all a zero dead time is required for an operation in the LHC conditions with 25 nsec bunch crossing. In the same time other requirements to the front-end electronics are not hard. The main requirements are the following:

- 12-bit dynamic range,
- 9-bit resolution,
- An 8-bit transverse-energy measurement must be supplied to L0 trigger logic.

The zero dead time method of the calorimeter signal processing has been proposed in the LHCb technical proposal [1],[2]. An input signal shape and a time uncertainty of the calorimeter signals with the LHC clock define an efficiency of this method. The HCAL is scintillating tile hadron calorimeter. The WLS fibres transfer scintillation light to the rear of the calorimeter where it is detected by photo-multipliers. The characteristics of the WLS fibres and photo-multipliers mainly define the signal shape as shown in notes [3], [4].

The aim of this note is to describe the signal processing method and optimise parameters of the analogue front-end electronics components for the best performance of the method. This note is based on the reports presented on LHCb workshop and CALO meetings since 1997.

2. Main Idea and Optimization of the Shaper Output Width

2.1. Method of the Zero Dead-time Charge Sensitive Shaping

Figure 1 shows the simplified circuit diagram of the charge sensitive shaper and the timing diagrams clarified an operational principle. The shaper consists of a linear adder, integrator and 25 nsec delay line. The linear adder sums a direct input signal and an inverted delayed signal. The shaper is operated with the input signals that have a pulse width less than 25 nsec. The integrator is charged in time when a direct signal is existed. Then, till a delayed signal comes, the shaper output voltage is stable. This stable voltage (flat top) is proportional an input charge. The inverted delayed signal discharges the integrator up to a base level. The signal digitising by ADC is occurred on the flat top of the shaper output signal.

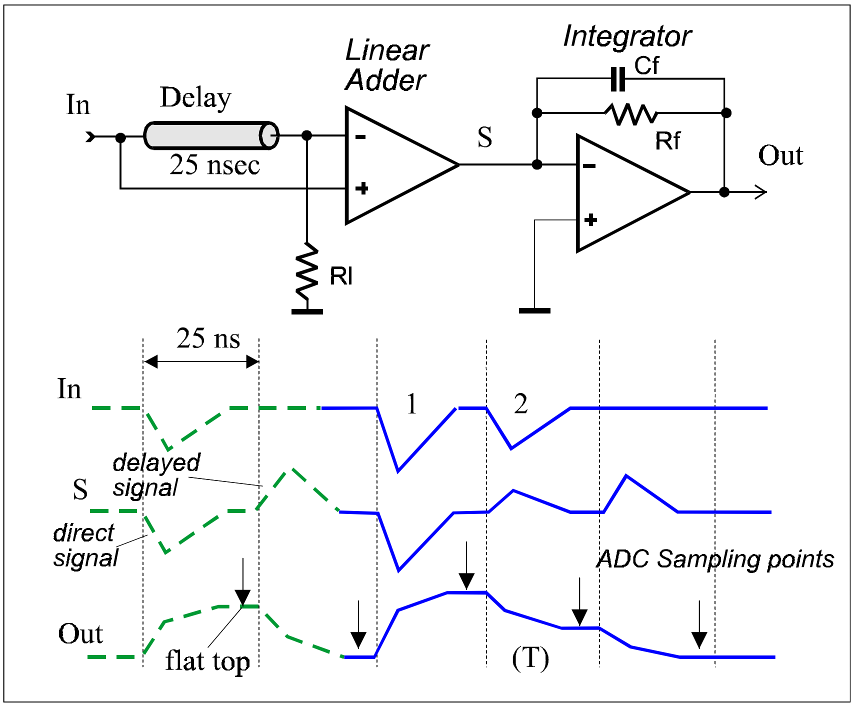

Figure 1 Charge Sensitive Shaper and Timing Diagrams

The flat top on the shaper output allows avoid a measurement error due to a time uncertainty of the calorimeter signals. The time constant of the integrator RC feedback chain is chosen for getting a minimal slope of the flat top. The same time this feedback chain allows completely discharge the integrator up to a base level.

The simplified timing diagrams when three signals come into a time interval 100 nsec is shown on Figure 1. For a case the two consecutive signals come, a solid line on diagram, in time (T) when an integrator discharge from a signal 1 is occurred the integrator is charged from second signal. Due to the shaper is linear for a charging and discharging, the shaper output voltage is corresponded to second signal at the moment of an ADC sampling.

2.2. Optimisation of the Shaper Output Width

The charge sensitive shaper operates with a zero dead time when a shaper output signal width is less than 50 nsec. The HCAL signal arriving time has a variation due to following factors:

- The time of flight of the particles according to their bending radius in the magnetic field is +-0.5 nsec
- The transit time shift of the light along WLS fiber (HCAL depth 1.2 m) is +-0.8 nsec
- The location of the interaction point within the crossing particle bunches is about +-0.3 nsec
- The PMT transit time spread is +-0.15 nsec

Total uncertainty time (Tuncert.) with a safety margin is about +-1.5 nsec. Therefore the flat top of the shaper output signal must be more than 3 nsec.

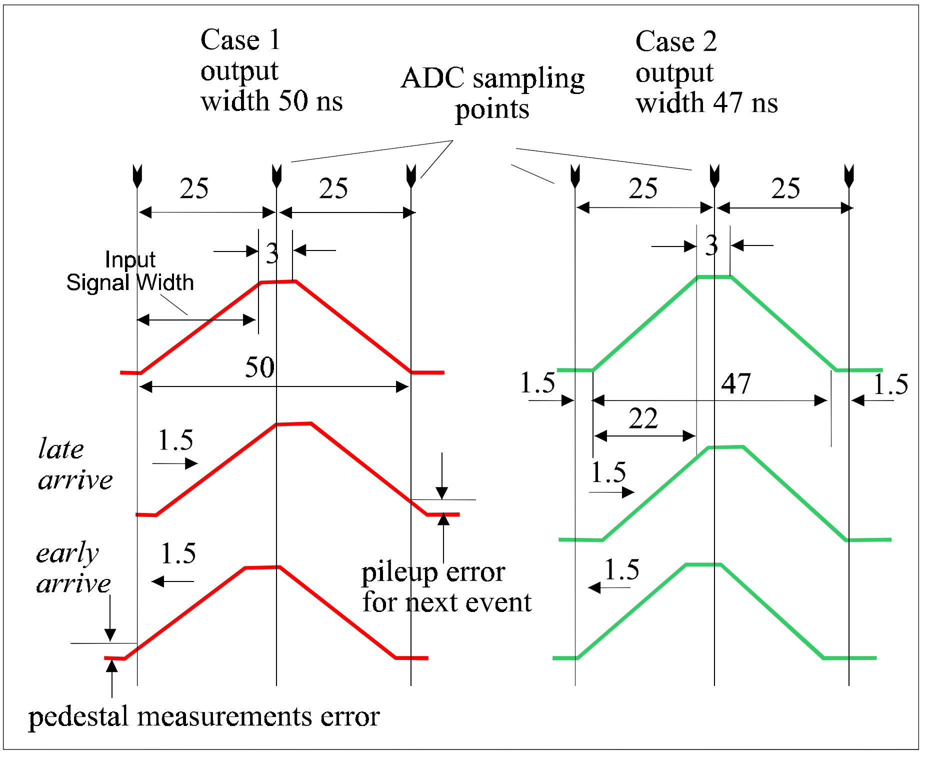

Figure 2 Timing Diagrams of the Output Signal Shape

Figure 2 illustrates the possible errors for two cases of the shaper output width. In the first case the shaper output width is 50 nsec. There is a pileup error for a late arrived signal and a pedestal measurement error for an early arrived signal. For a second case the shaper output width is 47 nsec and there are no any errors. This figure shows that an input signal width, calculated by formula (50 nsec – 2 * Tuncert.) / 2, must be less than 22 nsec.

3. Optimization of the Calorimeter Signal Shape

3.1. HCAL Signal Shape Properties

As was mentioned above, the performance of the zero-dead time shaping method strongly depends of an input pulse width. The calorimeter signal shape is mainly defined by the following:

- The type of a scintillating plastic is used. In HCAL the plastic tiles, made of PSM115 with 1.5% PTP and 0.015% POPOP are used. An emission time for this plastic is less than 2.5 nsec.

- The WLS fiber is more important component. The study of five different fibers has been done [3]. Figure 3 shows the signal shapes for five types of the fibers. As any one can see the signal width (on 10% level) is changed from 21 nsec for a fiber Bicron BCF92 to 43 nsec for Bicron BCF91A.

- The photo-multiplier must be fast enough. The photo-multipliers FEU115m [4] with a signal rise time less than 5 nsec were used in the HCAL tests.

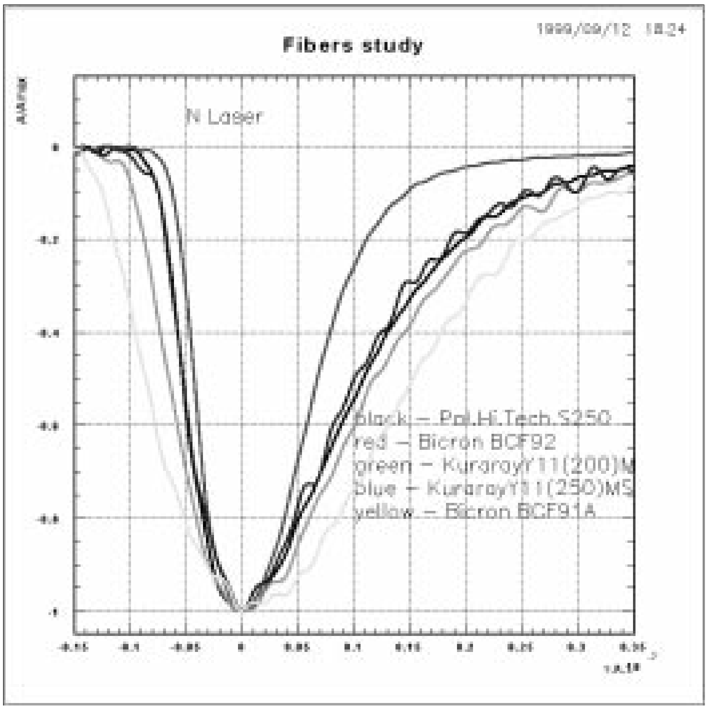

Figure 3 Signal Shapes for five WLS Fibers

Conclusion based on these measurements is the following. There is no a fiber option satisfied a required pulse width less than 22 nsec on level 1%. Therefore an additional clipping circuitry must be used for the calorimeter signal processing.

Another important fiber characteristic is radiation hardness. As was shown in note [5], the fastest BCF92 fiber has a less radiation hardness. A Y11 fiber could be used in a central region of the HCAL, due to its radiation hardness satisfied the needed requirements. In the other hand a BCF92 could be used in an outer region of HCAL.

3.2. Signal Clipping

Clipping a photo-multiplier pulse can solve the problem. There are some methods of the pulse clipping.

- Clipping with passive pole zero RC chain – T-filter
- Clipping on a short 1.1 m coax cable terminated at the end by a RC chain. Delay time in cable defines a clipping time Tclip

Figure 4 shows three circuit diagrams: a) without clipping, b) clipping on T-filter and c) clipping on coax cable.

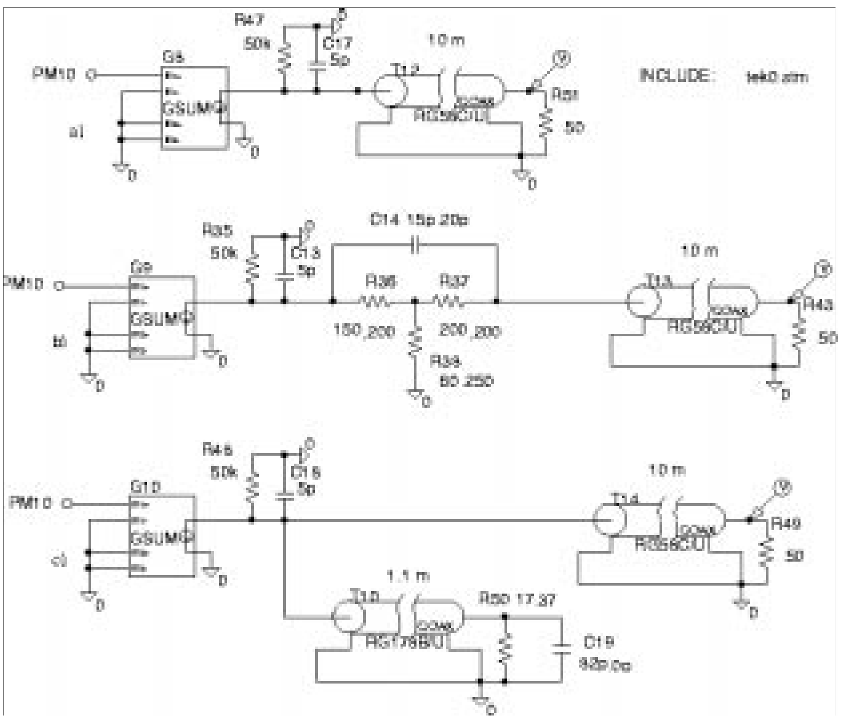

Figure 4 Simulated Circuit Diagrams for two Methods of the Signal Clipping

An efficiency of these clipping chains has been simulated by PSPICE software for two types of the calorimeters. One is equipped with fiber Y11 and other with BCF92. As the input data the digitized calorimeter signals are used. Realistic models of coax cable are used for the delay line simulation. The component values of the clipping chains have been chosen for getting an output pulse width less than 22 nsec.

The output signals without clipping and for two clipping chains in case of calorimeter with Y11 fibers are shown on Figure 5 (A). Same signals in case of calorimeter with BCF92 fibers are shown on Figure 5(B). Comparison of these methods shows that signal attenuation in case of the cable clipping is always about

50% (when leading edge of signal less 2*Tclip). The signal clipping with T-filter gives a different attenuation for an input signal with different width. The clipped signal height for slow input signal (A) is about 30% and for fast signal (B) is 70% of the non-clipped signal.

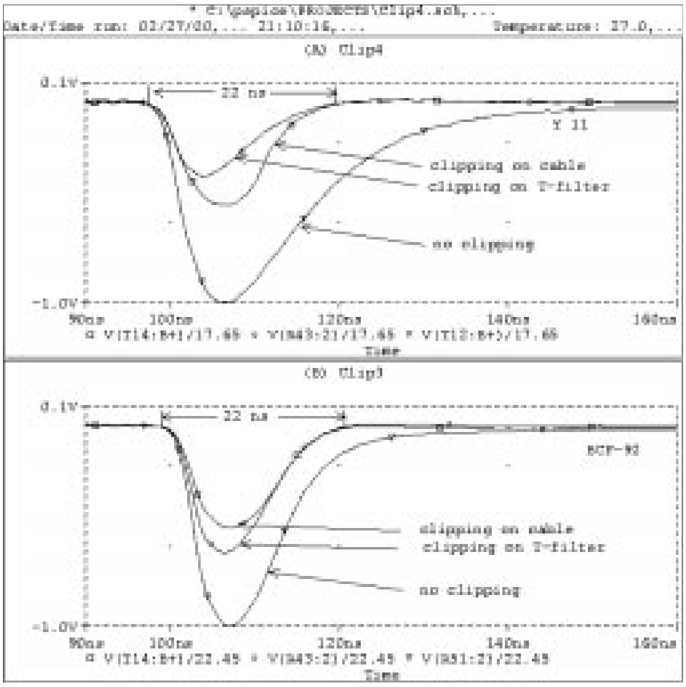

Figure 5 Signal Shapes for Two Fiber Types and Two Methods of the Signal Clipping

A price of technical implementation of these clipping chains is quite different. The component price estimation shows that T-filter implementation cost of about 0.6 SFr and the cable implementation is about 9 SFr (included a connector price). Practically T-filter could be made on the SMD components and placed on a PMT base printed board.

4. PSPICE Simulation of the Two Shaper Samples

PSPISE simulation of the various implementation of the shaper has been done. The circuit diagrams for two of them are shown on Figure 6. The simulated chain includes a photo-multiplier, transmission line and shaper that implemented on the commercial available components.

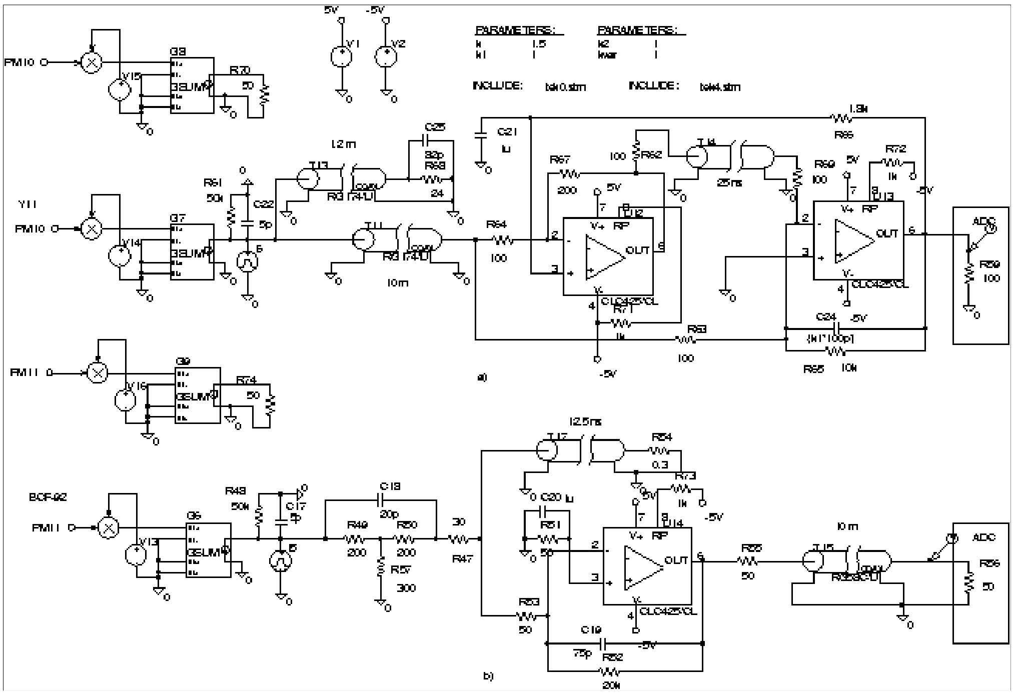

Figure 6 Simulated Circuit Diagram for Two Shapers

The shaper a) with a cable clipping chain could be placed at 10 m far from PMT on a printed board with an ADC and digital front-end electronics. The component values of this shaper are optimized for a signal from calorimeter equipped with Pol.Hi.Tech.S250 fibers (with the same timing characteristics as Y11 fiber).

The shaper b) with T-filter clipping chain is placed on the detector and a shaped signal comes to a digital front-electronics through coax cable. A delay line of 12.5 nsec is used for getting a delayed and inverted signal for an integrator discharge. This shaper was simulated for calorimeter with BCF92 fibers.

Table 2 Simulation Results

Shaper	Gain	Non Linearity	On top Error	Pileup Error	RMS Noise
a)	0.6 mV/pQ	< 0.1 %	< 0.2 %	< 1 %	190 uV
b)	0.4 mV/pQ	< 0.1 %	<0.2 %	< 1%	125 uV

Simulation results are shown in Table 2 and Figure 7.

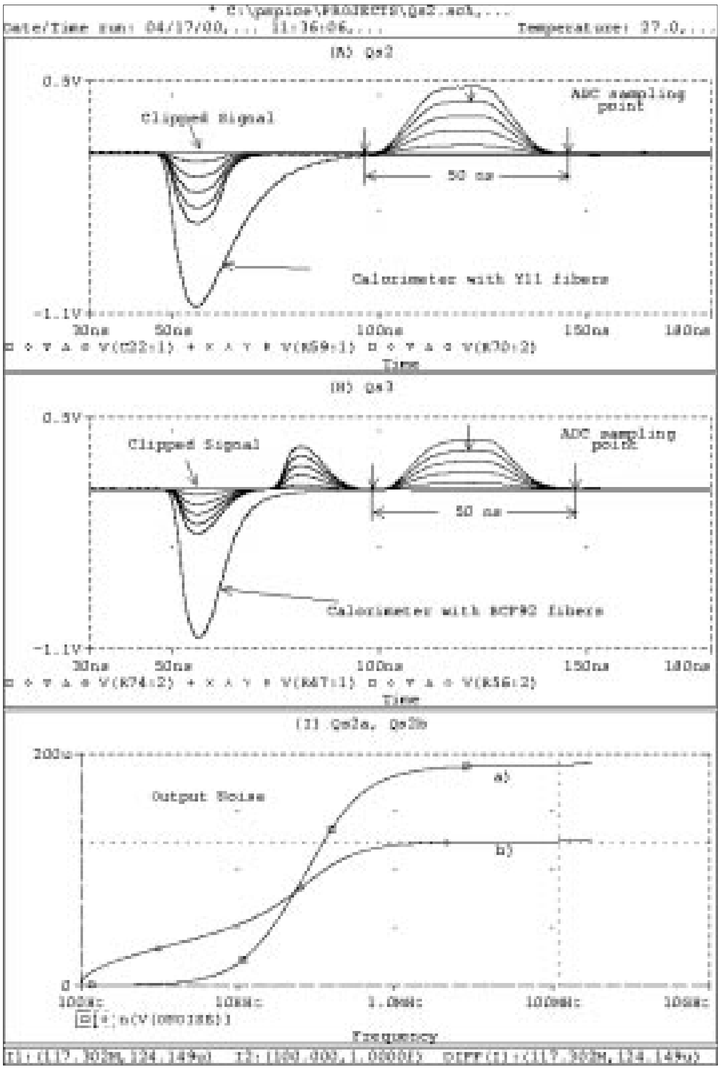

Figure 7 PSPICE Simulation Results

These results show that both implementations of the shapers satisfy the requirements of the LHCb experiment.

5. Beam Test Results

The prototype of the zero dead-time charge sensitive shaper (shown on Figure 6a) and different type of clipping circuitry have been tested at CERN on X7 test beam with the LHCb HCAL prototype [6]. The HCAL prototype has been equipped with Pol.Hi.Tech.S250 and BCF92 fibers and photo-multiplier FEU115m. A signal pulse shape is measured by a LeCroy LC564A scope.

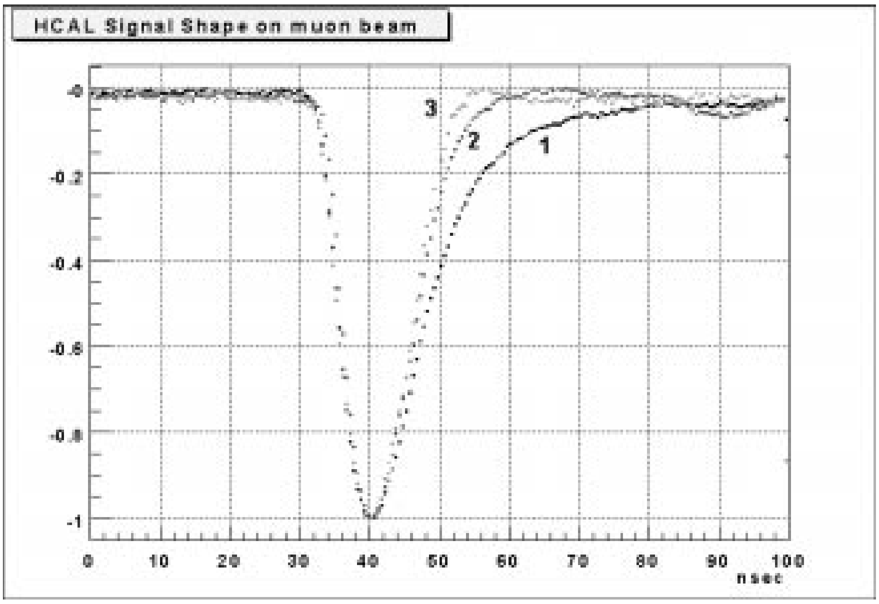

Figure 8 HCAL (with BCF92 fibers) Signal Shapes

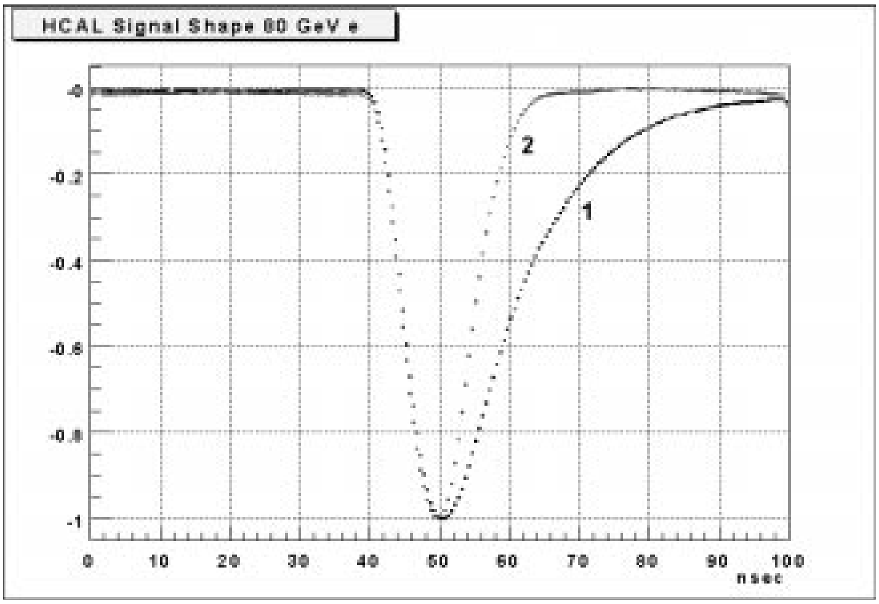

Figure 9 HCAL (with Pol.Hi.Tech.S250 fibers) Signal Shapes

Figures 8 and 9 show the clipped and non-clipped signals for two types of the HCAL cells (with BCF92 or Pol.Hi.Tech.S250 fibers). The curves 2 and 3 on Figure 8 illustrate a signal shape for two clipping chains. Curve 2 is for T-filter clipping with parameters as shown on Figure 5B. Curve 3 is for clipping on cable with 12 nsec clipping time and 35 ohms terminator resistor. Curve 2 on Figure 9 shows the clipped on cable signal with 10 nsec clipping time 18.5 ohms || 82 pF terminator chain.

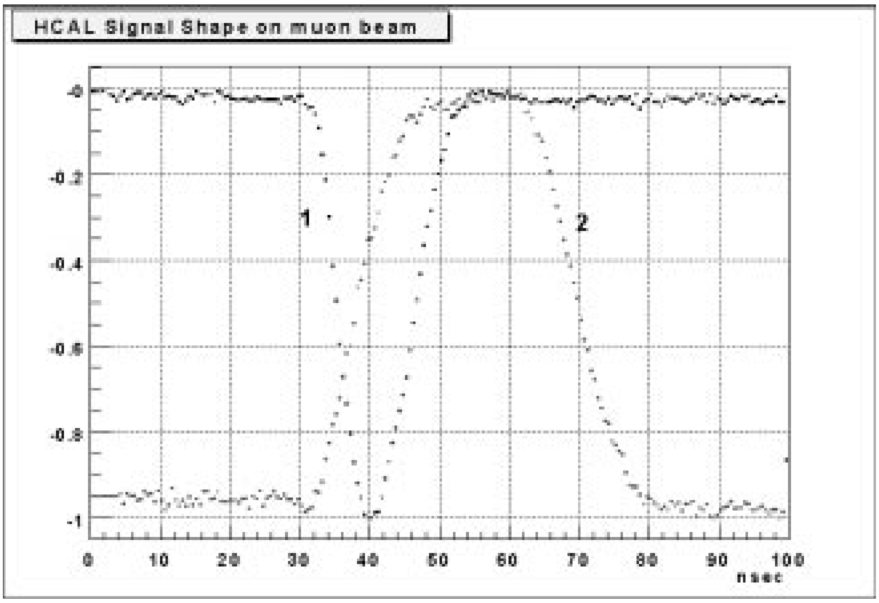

Figure 10 Charge Sensitive Shaper Output Signal Shape

The charge sensitive shaper output signal shape (2) with the input signal (1) are shown on Figure 10. The shaper output pulse width is less then 50 nsec and a flat top time is about 5 nsec.

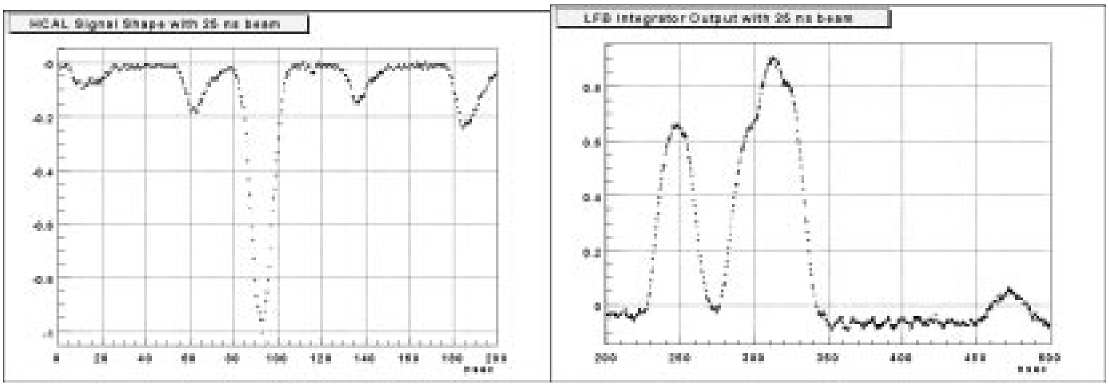

Figure 11 HCAL Signal and LFB Integrator Output Shapes with 25 nsec Beam

Figure 11 illustrates the HCAL clipped signals and the signals on the integrator output of the LFB module [7] that were obtained on a test beam with 25 nsec bunch structure of SPS machine.

6. Conclusion

The offered method of the analog signal processing of the HCAL signals allows to operate with zero dead-time in the LHC conditions with 25 nsec bunch crossing. Two realizations of the charge sensitive shapers have been simulated by PSPICE and prototype one of them has been build and tested on the beam.

The analysis, that has been done, shows that for the best performance of this method the calorimeter signals must be clipped up to 22 nsec and the shaper output pulse width must be about 47 nsec. The clipping circuitry can be realized by the coax cable with RC termination or by the pool-zero chain (T-filter).

The experimental study of the clipping circuitry and the charge sensitive shaper prototype on a test beam with the HCAL prototype shows a good matching with the simulation data.

7. References

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