Bunch Crossing Identification at LHC Using a Mean-timer Technique

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Abstract

A novel method of bunch crossing identification in muon detectors at LHC was tested in a muon beam. A very good time resolution of ~2 ns was obtained. Some other topics related to muon detection were investigated.

Introduction

The forthcoming LHC machine makes severe demands on the performance of a muon detector. In particular the muon trigger must have a time resolution better than 15 ns if it is to be able to determine the bunch crossing in which a muon originated. Fast response dedicated trigger devices like RPCs or PPCs have been proposed to meet this requirement [1]. We will discuss in the following note an alternative in which a bunch crossing identification is obtained directly from proportional drift tubes at the first trigger level. We present the results of a test of this method using the RD5 experimental set-up [2].

Method Description

The method is based on the mean-timer technique applied to arrays of drift tubes. Particles crossing an array of staggered drift tubes at normal incidence hit two cells as shown in Figure 1a. The mean-timer conceptual design is sketched in Figure 2: the signals from the two wires will meet in the delay lines of the mean-timer at fixed time $t_k = t_A + t_B$ after the particle passage through the drift cells. The location of the coincidence gives a measure of the drift time. The delay lines can be realized as logical gates (as the VLSI developed for the ZEUS muon detector [3]): the cell where the AND occurred gives also the drift time measurement, so that the mean-timer itself acts as a TDC.

This simple system needs to be made more sophisticated in case of an inclined track since the coincidence will occur too early or too late depending on the track inclination. Looking at Figure 1b we see that this problem can be solved considering a triplet of planes and taking the mean time of the two available mean-timers. We will show that this method provides a bunch crossing identification delayed by the maximum drift time in a cell, i.e. well within the one microsecond allowed for the first level trigger decision, without the help of a dedicated trigger detector. Furthermore the drift times measured using the mean-timer are already t_0 corrected and the left-right ambiguity common to all drift chambers is elegantly solved.

Cell Mechanics and Electrostatics

The performance of the method depends the linearity of the space-time relationship and therefore upon the choice of the geometric and electrostatic layout of the drift cell. Several simulation studies done with the GARFIELD [4] and ANSYS programs indicated the use of plastic tubes with the layout of Figure 3 as the most suitable one[5]. The prototype is made of PVC: two profiles of 16 x 50 cm^2 are faced to form four drift cells of section 38 x 10 mm^2 cross section. In each cell the anode was a 20 μm gold plated tungsten wire kept at positive HV, while the cathodes at negative HV were obtained by coating the sides of the profiles with graphite paint to form the C-shaped electrodes shown in Figure 3. Nine layers of tubes were staggered by half a tube width and separated by an aluminized mylar foil kept at ground potential. The prototype was operated in proportional mode using Ar/iso-C_4H_{10} (70/30) and Ar/C_2H_6 (40/60) mixtures. The efficiency in Ar/iso-C_4H_{10} (70/30) was measured for all the tubes independently using a cosmic ray scintillator telescope. The data, reported in Figure 4, shows that the geometrical efficiency of 97.5% can be reached and a rather long plateau is available for HV setting and therefore field tuning.

Electronics and Readout

Readout of the wires was made using available electronics from different experiments. The front end transresistance amplifiers (13 ns rise time and a 12.5 mV/μA gain) were those from the UA1 Central Detector Drift-Chamber [6]. The amplified signal was shaped using ECL discriminators (with 30 mV threshold) developed by INFN Padova for the APPLE experiment at LEAR [7], while the 42 mean-timer channels were made using analogic mean-timers developed by INFN Padova for the $N\overline{N}$ experiment [8]. The output signals from the mean-timers were sent together with the shaped wire signals to one nanosecond resolution 2277 Lecroy multi-hit TDC's, started from the trigger signal generated from the RD5 beam telescope. Only the first hit inside any cell was recorded.

Results on the Drift Tubes

The prototype was exposed to the CERN H_2 muon beam in August 1992 and in November 1992 in the RD5 set-up. Data were taken at different high voltage settings and at different beam energies using the Ar/C_2H_6 (40/60) mixture. The bulk of data was taken at +2350 V on the anode and -2500 V on the cathodes and using a 100 GeV/c muon beam. During this test the efficiency was ~90%, mainly due to bad gas flow conditions. Unless stated otherwise we will refer to these data. The drift time spectrum is shown in Figure 5. The spectrum can be tuned to get a very good linear space-time relationship by the different field shaping which can be obtained changing the HV on the electrodes. The tubes spatial resolution was measured by computing the residuals of a straight line fit through the layers. The distribution of the residuals for a typical channel is shown in Figure 6 and is always in the range 150-200 μm.

Results on the mean-timers

The time distribution of a typical mean-timer channel at normal beam incidence is shown in Figure 7. It can immediately be seen that the method performs very well, since the r.m.s. of the peak is ~2 ns. The time origin is set to the absolute time of crossing of the muon through the cell. The tail towards negative values is due to δ-ray production inside the detector and particles generated from the radiative processes in the shielding block installed just in front of the chamber. If an extra-particle crosses the same drift cell as the muon the mean-timer gives a signal too early with respect to the muon crossing time. Data were taken at different beam energies and, owing to the very good time resolution, we could get a measurement of the fraction of δ-ray production in the detector and radiative processes. The data are summarized in Table 1. Corrections for detection efficiency and double beam tracks (~2%) in coincidence in the same events, identified as parallel tracks, were applied to get the right estimation of the fraction of background processes.

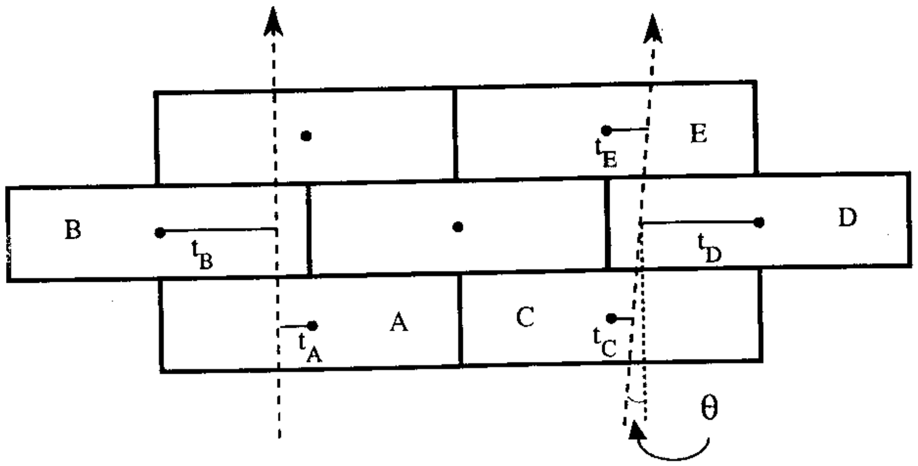
In our sample out of time hits were classified as δ-rays if there was only one mean-timer channel in a layer out of time by ≥ 7.5 ns (equivalent to ~800 μm two track separation). A large fraction of such hits (>65 % at all energies) were contained in a single drift cell, supporting the hypothesis of soft δ-ray production. Muon bremsstrahlung events were identified as having more than mean-timer hit per layer. In this case a shower interpretation was supported by the fact that all subsequent layers contained several hits. It is important to note that, while showers obviously give more mean-timer signals, in ~50% of cases at least one of the signals comes at the right absolute time thus adding information to the trigger logic.

The uniformity of the result using the mean-timer method inside the cell is shown in Figure 8, where the mean-timer output time is shown versus the drift time to the wire of the central cell. The mean-timer absolute time is extremely constant along the whole cell.

The prototype was exposed at inclinations from $\theta=0^0$ to $\theta=20^0$, with θ defined in figure 1b, to verify the resolution achievable at these angles. The typical mean-timers distributions for $\theta=0^0,5^0,10^0,13^0,20^0$ are shown in Figures 9a-d. The mean of the peak remains unchanged confirming the validity of the algorithm for inclined tracks. The width of the peak varies slowly up to ~4 ns, but the distribution also shows a shoulder towards positive values. This effect is easily explained by geometrical considerations: the sum of the two drift time exceeds the expected constant value when the track is crossing the region close to the cathodes of the central layer. The inefficient zone is equal to $d \tan\theta$ where d is the transverse distance between two wires of two consecutive layers. In addition the information is lost in the region close to the central layer.

p(Gev)	δ-rays	bremsstrahlung	total
100	17.0 ± 0.7 %	3.9 ± 0.3 %	20.9 ± 0.8 ± 0.5 %
200	16.4 ± 0.6 %	5.5 ± 0.4 %	21.9 ± 0.8 ± 0.5 %
300	17.6 ± 0.6 %	6.4 ± 0.3 %	24.0 ± 0.8 ± 0.5 %

Table 1 - Fraction of background events.
In the table first error is statistical and second error is systematic



(a) (b)

Figure 1

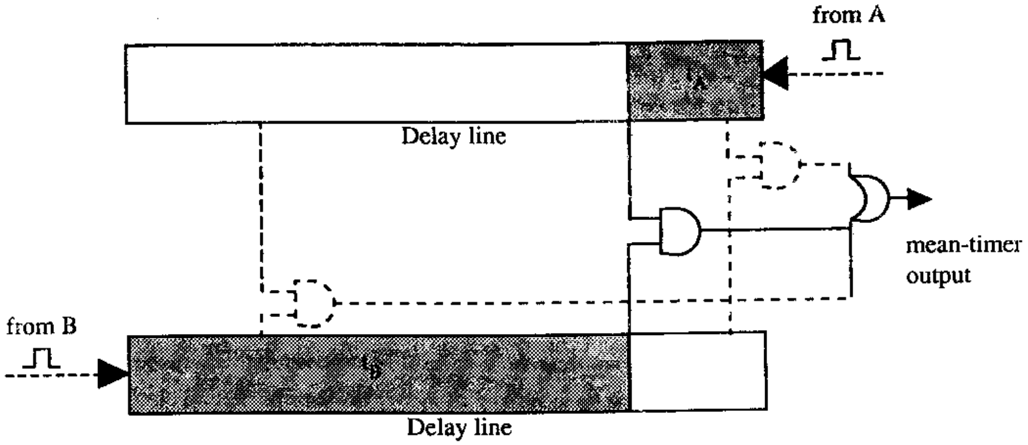


Figure 2

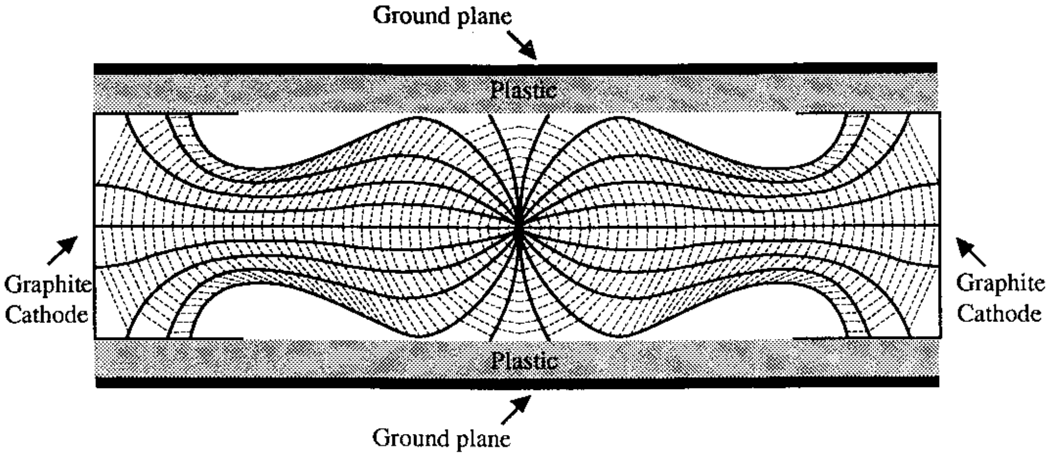


Figure 3

The overall impact of these problems on a LHC detector cannot be quantified unless a concrete example is considered. Since these effects are present in a sizable fraction of the events they become negligible only if enough redundancy is available in the muon detector. A suitable environment to apply these techniques can be found in the proposed CMS [9] experiment. In this case four muon stations inserted in the iron yoke are proposed for the muon measurement. Each station is built of a superlayer in which three triplets of tubes can be installed. This layout will give up to twelve determinations of the crossing absolute time, allowing the possibility of a bunch crossing identification based on a simple majority logic.

Conclusions

The mean-timer technique can be successfully applied for the purpose of bunch crossing identification at a first level trigger at LHC. The space resolution obtained with the proposed chamber mechanics satisfies the physics requirements on the detector. Potentially dangerous problems are related to background processes and inclined tracks. Both these problems can probably be reduced to a negligible level with the help of redundancy alone, but we are also investigating several possible methods to improve the performance of the single layer.

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Figure Captions

Figure 1 - The principle of mean-timing for (a) normal tracks and (b) inclined tracks

Figure 2 - Conceptual design of a mean-timer module

Figure 3 - Drift cell layout as simulated from GARFIELD: solid lines are drift paths to the anode and dashed lines are equal drift time contours in steps of 10 ns

Figure 4 - Efficiency vs HV between anode and cathode in Ar(70)/Isobutane(30). In this measurement the cathode HV was kept fixed at -2300 V on the cathode. No effect was seen on efficiency changing cathode voltage setting.

Figure 5 - Drift time distribution in Ar(40)/Ethane(60)

Figure 6 - Residuals to the straight line fit. No cut on χ^2 was applied.

Figure 7 - Mean-timer time distribution for normal track incidence

Figure 8 - Mean-timer uniformity response across the drift cell

Figure 9 - Mean-timer time distribution for different tracks inclination

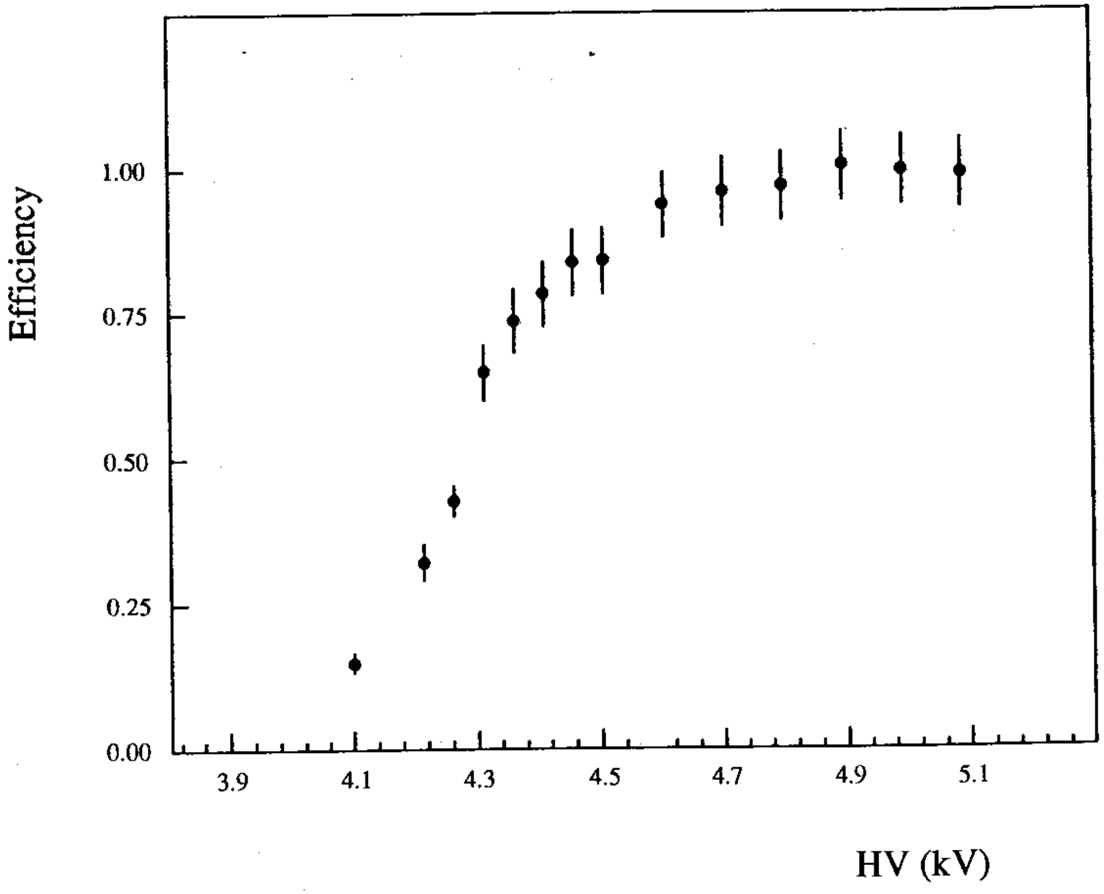
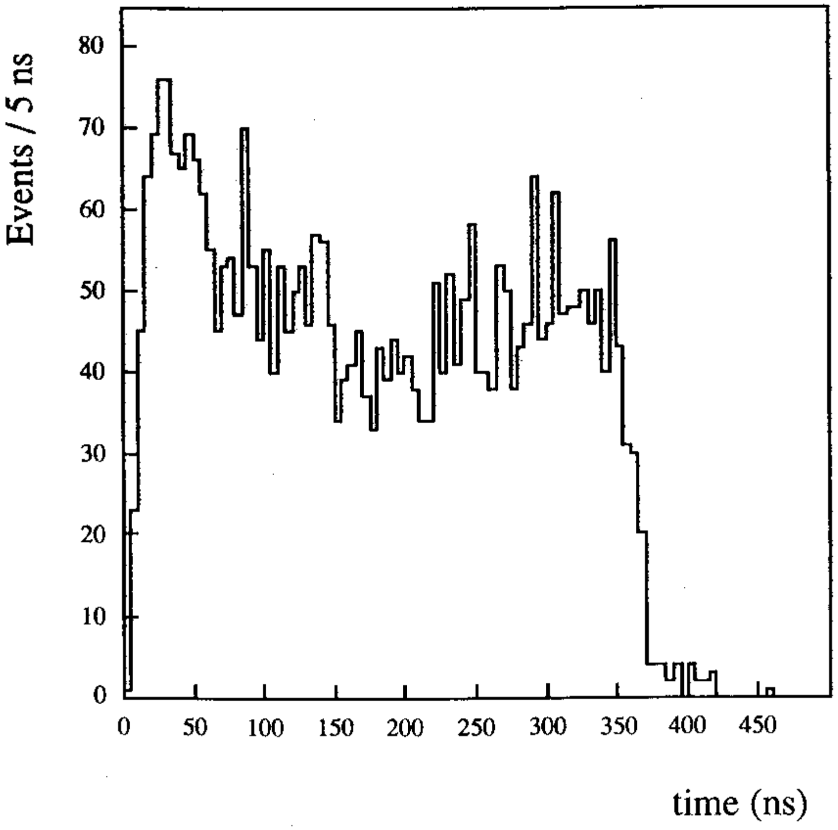


Figure 4



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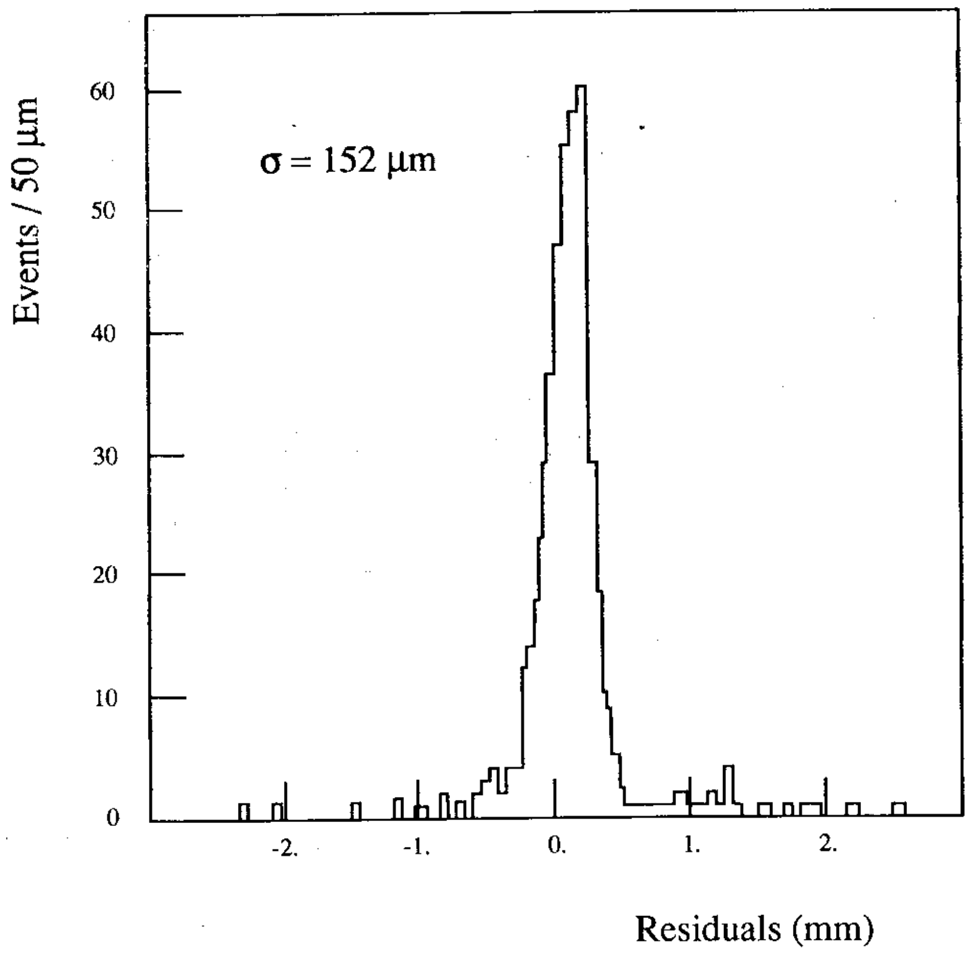

Figure 6

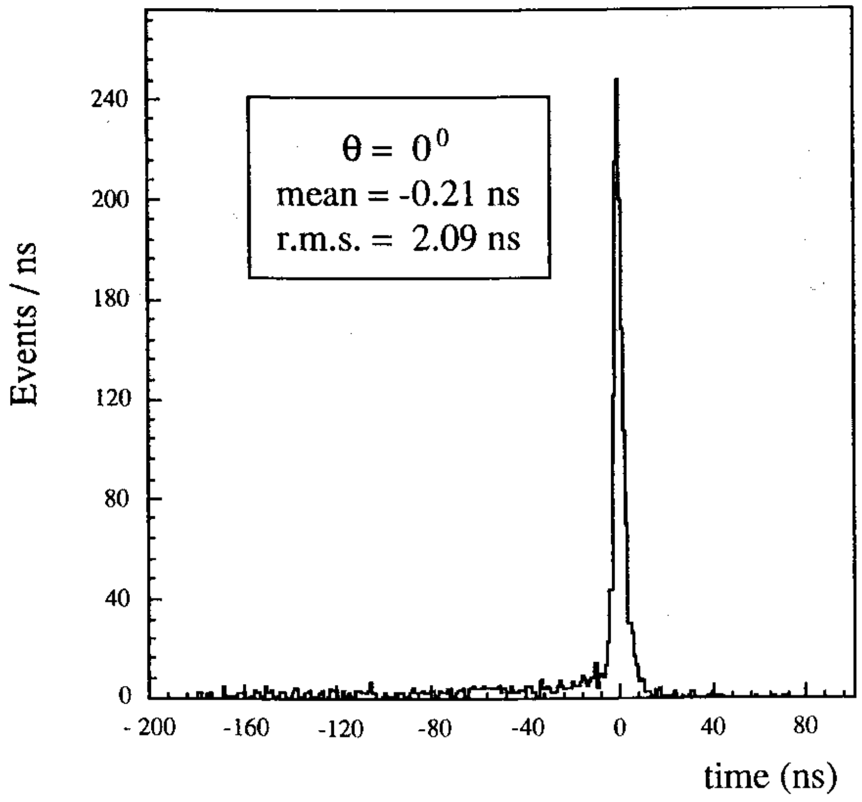

Figure 7

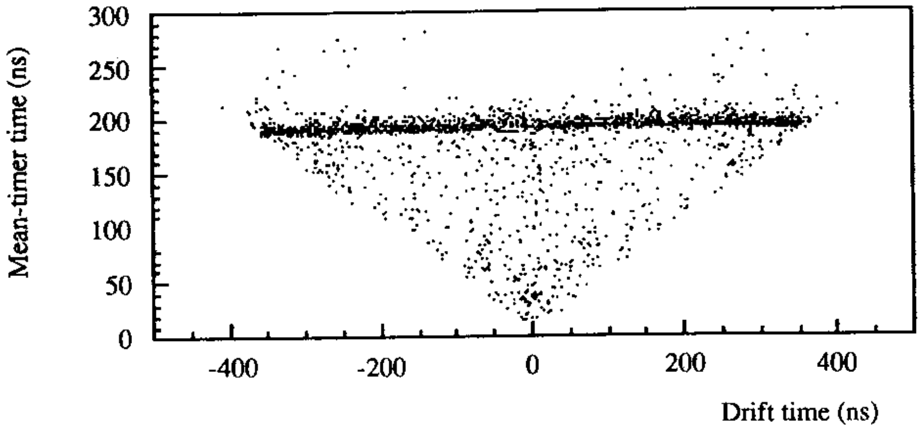

Figure 8

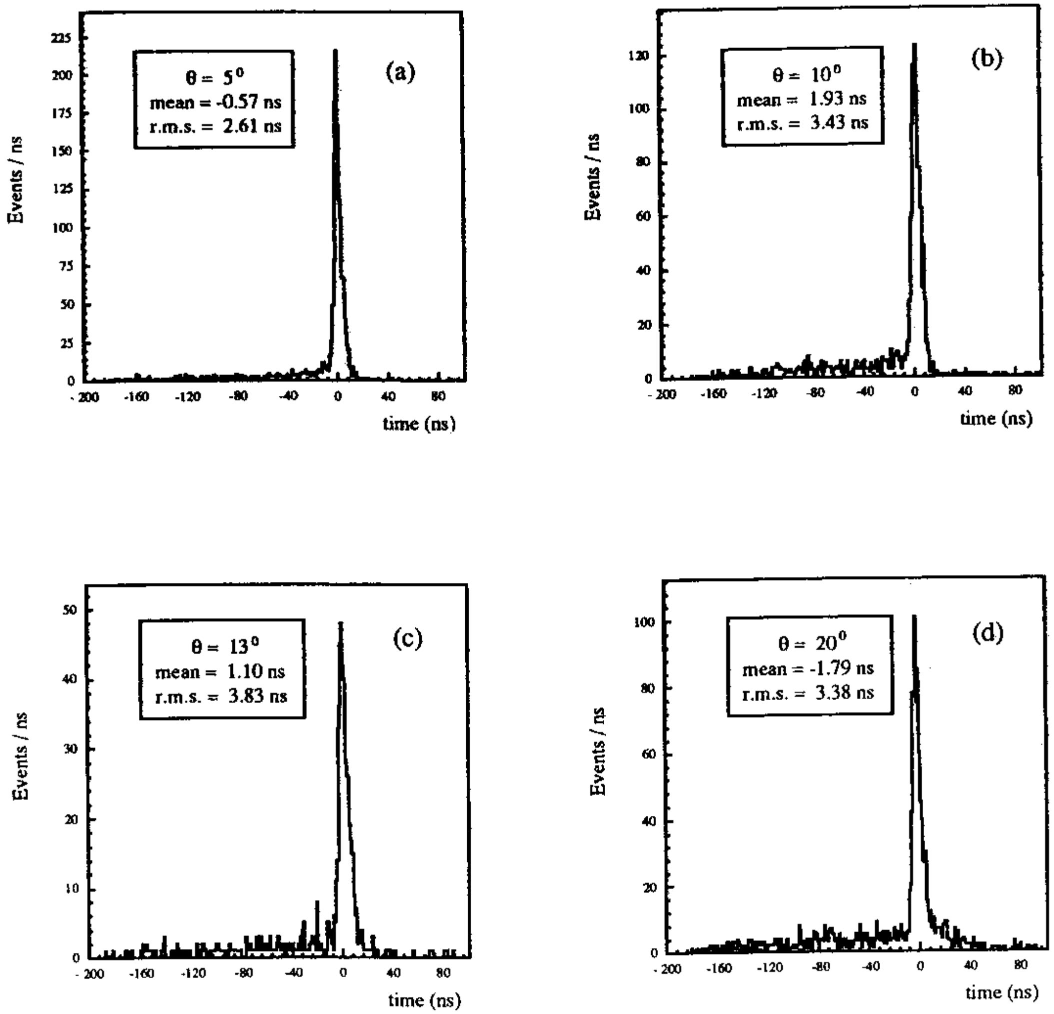

Figure 9