# Bunch Crossing Identification at LHC Using a Mean-timer Technique

RD5 Collaboration, CERN, Geneva, Switzerland

F. Gasparini, R. Giantin, R. Martinelli, A. Meneguzzo, G. Pitacco, P. Sartori,
R. Soggia
*Dip.di Fisica dell'Univ. di Padova and Sezione dell'INFN di Padova, Italy*
P. Zotto
*Dip. di Fisica del Politecnico di Milano and Sezione dell'INFN di Padova, Italy*
M. Andlinger, F. Szoncso , G. Walzel, C.-E. Wulz
*Institut für Hochenergiephysik der Öst. Akad. d. Wissenschaften,Vienna, Austria*
Gy. L. Bencze[1], M. Della Negra, D. Peach, E. Radermacher, C. Seez[2],
G. Wrochna[3]
*European Center for Nuclear Research (CERN), Geneva, Switzerland*

(1) Visitor from Central Research Inst. for Physics, KFKI, Budapest, Hungary
(2) Visitor from Imperial College, London, U.K.
(3) Visitor from Institute of Experimental Physics,Warsaw University, Poland

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# Abstract

The test of a bunch crossing identification method in the muon detector at LHC was performed in a muon beam. A very good time resolution of ~2 ns was obtained and some topics related to the muon detection were investigated.

## Introduction

The forthcoming LHC machine puts severe constraints on the performance of a muon detector. In particular the muon trigger must have a time resolution better than 15 ns to be able to recognize the interaction that generated the muon traversing the detector. Fast response dedicated trigger devices like RPCs or PPCs are until now proposed methods which meet this requirement [1]. We will discuss in the following note an alternative way to obtain at the first trigger level a bunch crossing identification directly from proportional drift tubes, presenting the results of a test using the RD5 experimental set-up.

## Method Description

The method we developed is based on the mean-timer technique applied to arrays of drift tubes. Particles crossing at normal incidence an array of staggered drift tubes 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. If the mean-timer is made of a chain of logical gates (as the VLSI developed for the ZEUS muon detector [2]), the cell where the AND occurred gives also the drift time measurement, so that the mean-timer itself acts as a TDC. This simple argument needs to be modified in case of an inclined track, since the mean-timing operation will happen 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, just adding an additional short fixed delay to the bunch crossing absolute time. We will show that this method provides the high spatial resolution needed at LHC, together with a bunch crossing identification delayed by the maximum drift time in a cell, well within the one microsecond allowed for the first level trigger decision and without the help of a dedicated trigger device. 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 naturally solved.

## Cell Mechanics and Electrostatics

The performance of the method is tightly related to the linearity of the space-time relationship and therefore highly depends on the choice of the drift cell geometric and electrostatic layout. Several simulation studies done with the GARFIELD [3] and ANSYS programs indicated the use of plastic tubes with the layout of Figure 3 as the most suitable one[4]. 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 coating the sides of the profiles with graphite paint to have the C-shaped electrodes shown in Figure 3. Nine layers of tubes were staggered by half a tube separated by an aluminised 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

The wires' readout was done using available electronics from different experiments. The front end transresistance amplifiers featuring 13 ns of risetime and a 12.5 mV/µA gain were the ones used for the UA1 Central Detector Drift-Chamber [5]. The amplified signal was shaped using ECL discriminators (with 30 mV threshold) developed by INFN Padova for the APPLE experiment at LEAR [6], while the 42 mean-timer channels were made using analogic mean-timers developed by INFN Padova for the $N\overline{N}$ experiment [7]. The output signals from the mean-timers were sent together with the shaped wire signals to one nanosecond resolution 2277 Lecroy multihit TDC's, started from the trigger signal generated from the RD5 beam telescope. Only the first hit inside the interested 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 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 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, showing that the required figure has been achieved.

## Results on the mean-timers

The time distribution of a typical mean-timer channel at normal beam incidence is shown in Figure 7. We can immediately see that the method is very well performing, 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. In fact in presence of an extra-particle crossing the same drift cell as the muon the mean-timer gives a signal too early w.r.t. 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. In our sample events were classified as δ-rays if there was only one hit mean-timer channel per layer at $\geq 7.5$ ns (equivalent to ~800 μm two track separation) off the peak centre. Only a small fraction (~15 %) of these type of events was also seen in next layers following the one already affected from this phenomenon, supporting the hypothesis of soft δ-ray production. Muon bremsstrahlung events were identified as events having more than one mean-timer channel per layer. In this case the shower interpretation was supported from the fact that all subsequent layers were hit. 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. It is important to note that showers give obviously more mean-timer signals and in ~50% of cases at least one of the signals come at the right absolute time adding some important 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 to different beam incident angles 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.

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 sizeable fraction of theevents they become negligible only if enough redundancy is available in the muon detector.

The good environment to apply these technique can be found in the proposed CMS [8] 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 due to the very high time resolution obtainable with this method. The space resolution obtained with the proposed chamber mechanics is satisfying the physics requests on the detector. Potentially dangerous problems are related to background processes and inclined tracks. Even if both the problems can be reduced to a negligible level just with the help of redundancy, we are investigating several possible methods to improve the performance of the single layer.

## Acknowledgements

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## References

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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 $\chi^2$ 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

| 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 the first error is statistical and the second error is systematic

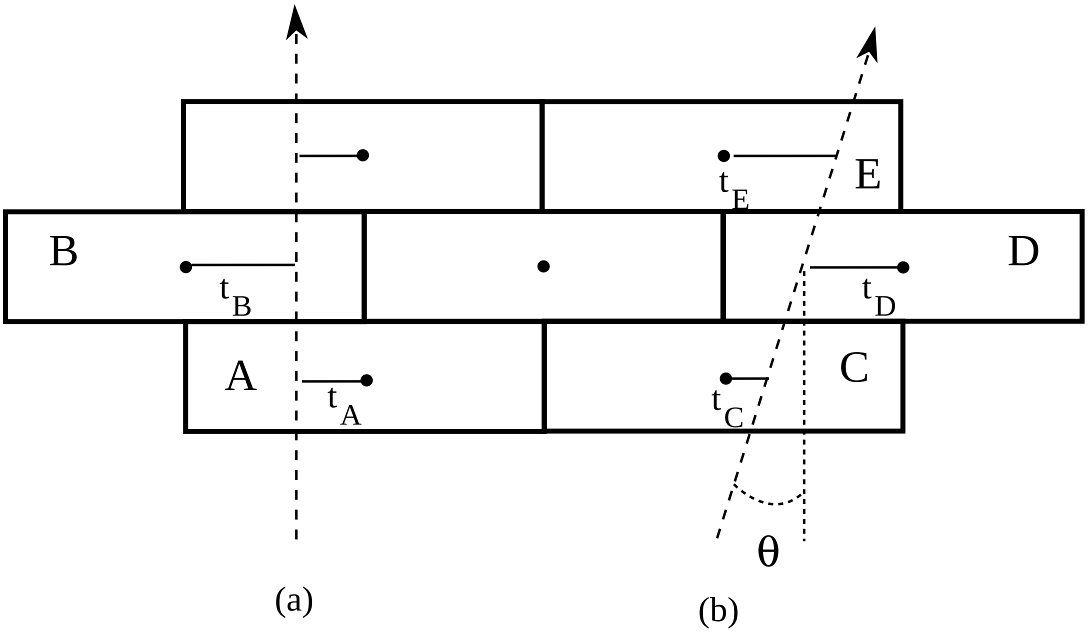

Figure 1

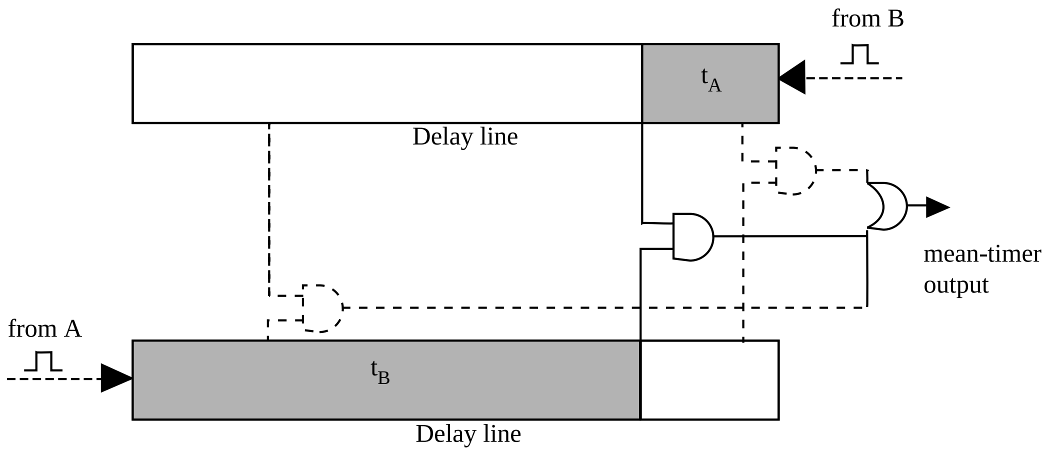

Figure 2

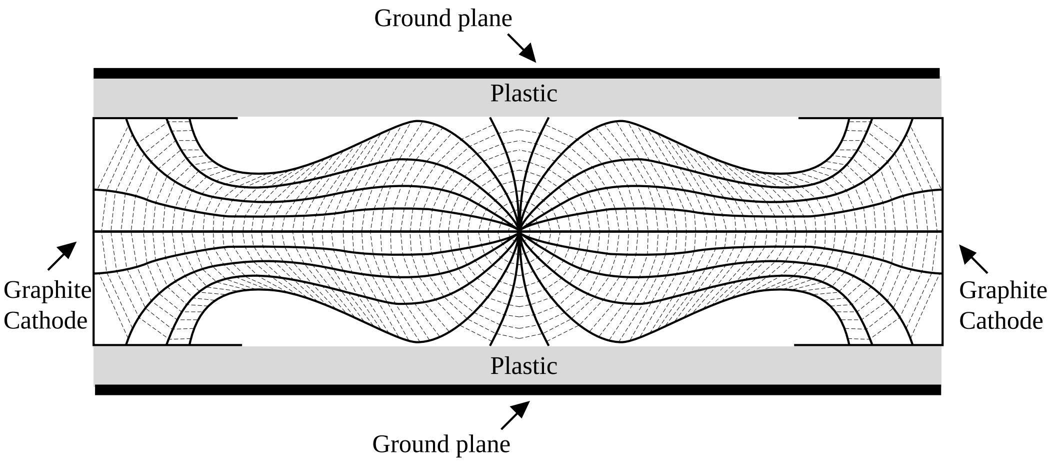

Figure 3

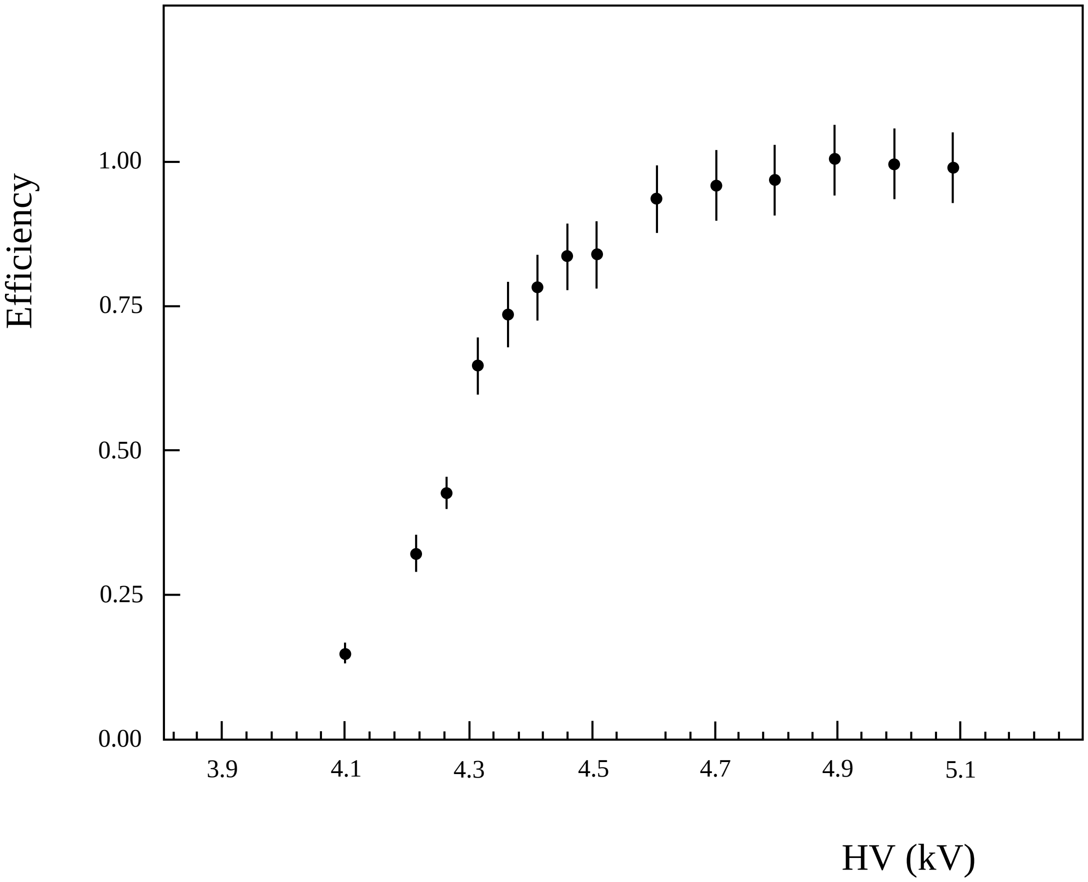

Figure 4

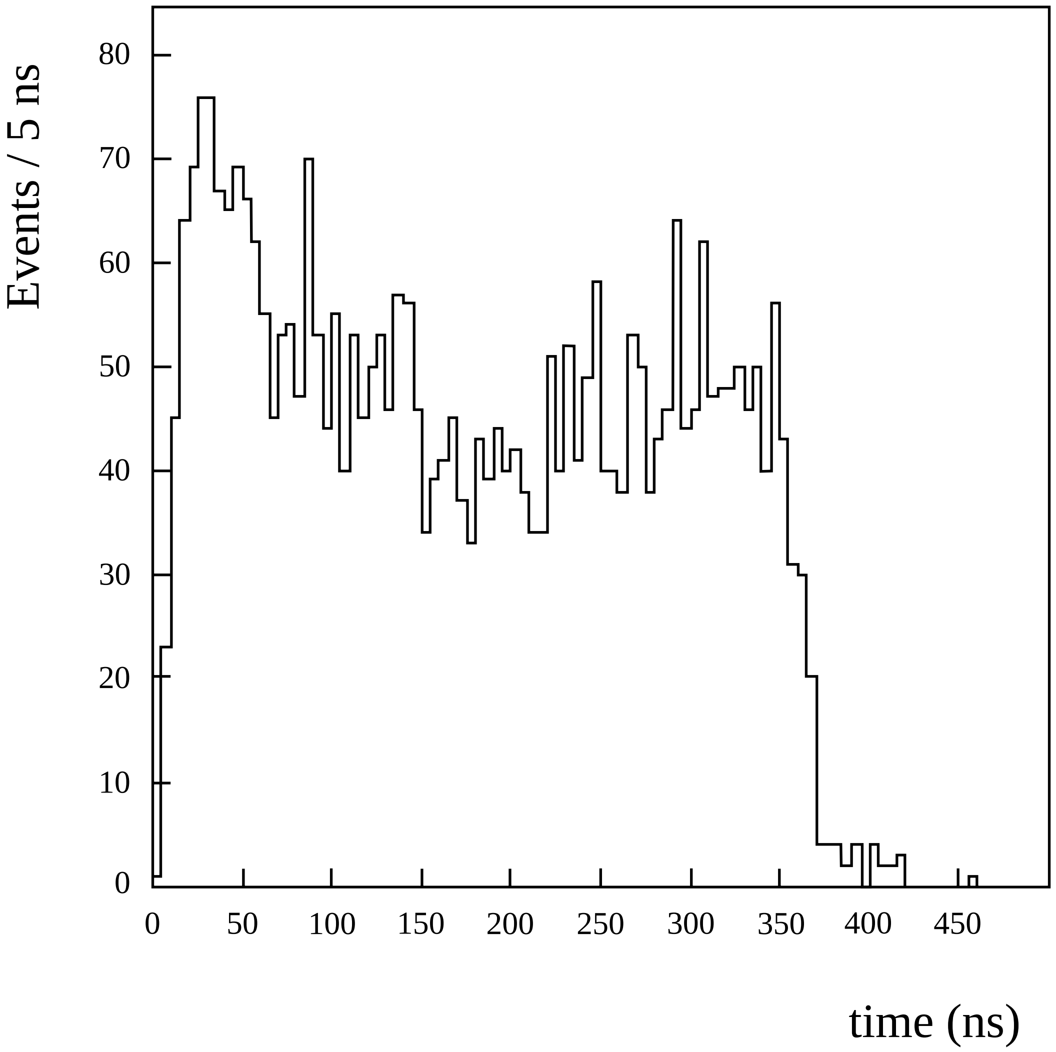
Events / 5 ns
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
time (ns)

Figure 5

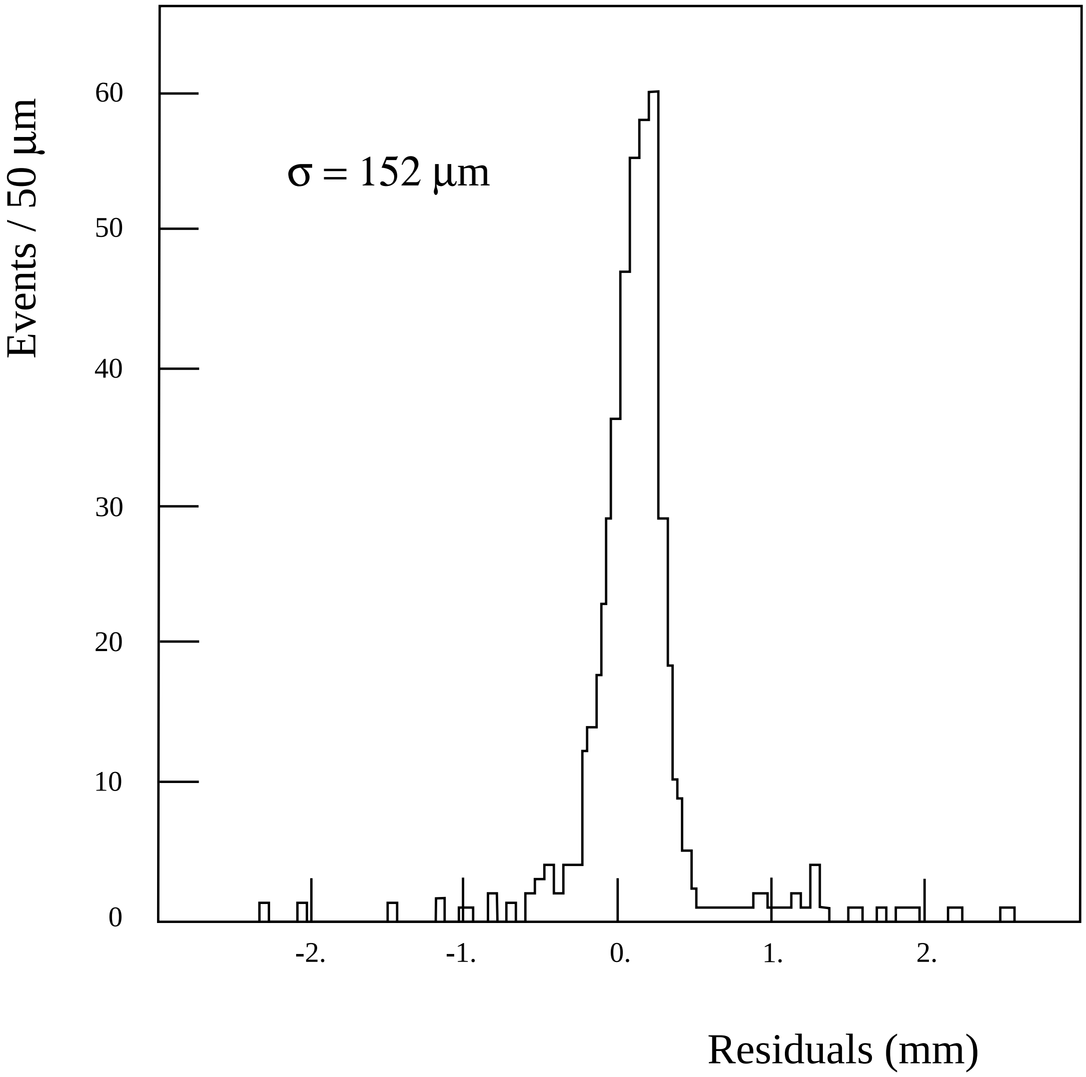

Figure 6

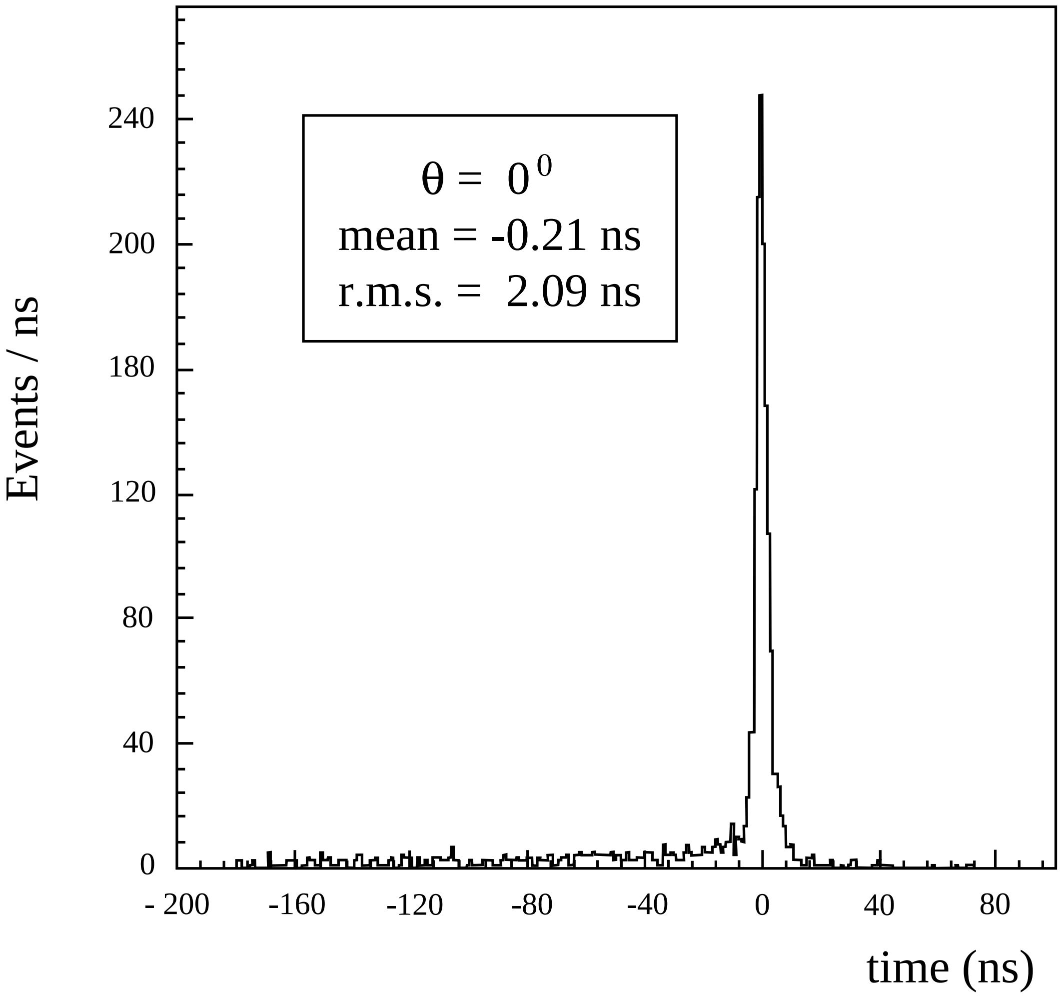

Figure 7

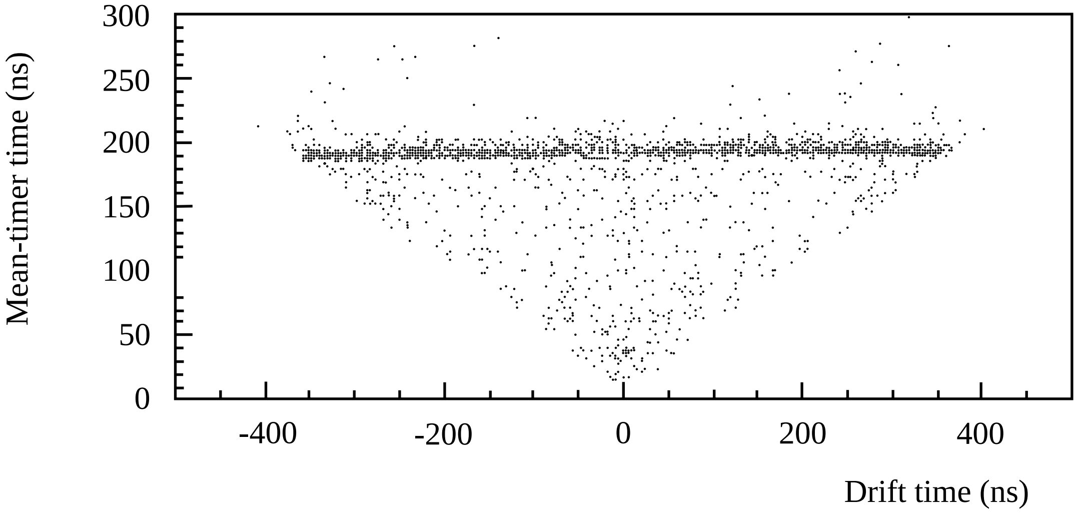

Figure 8

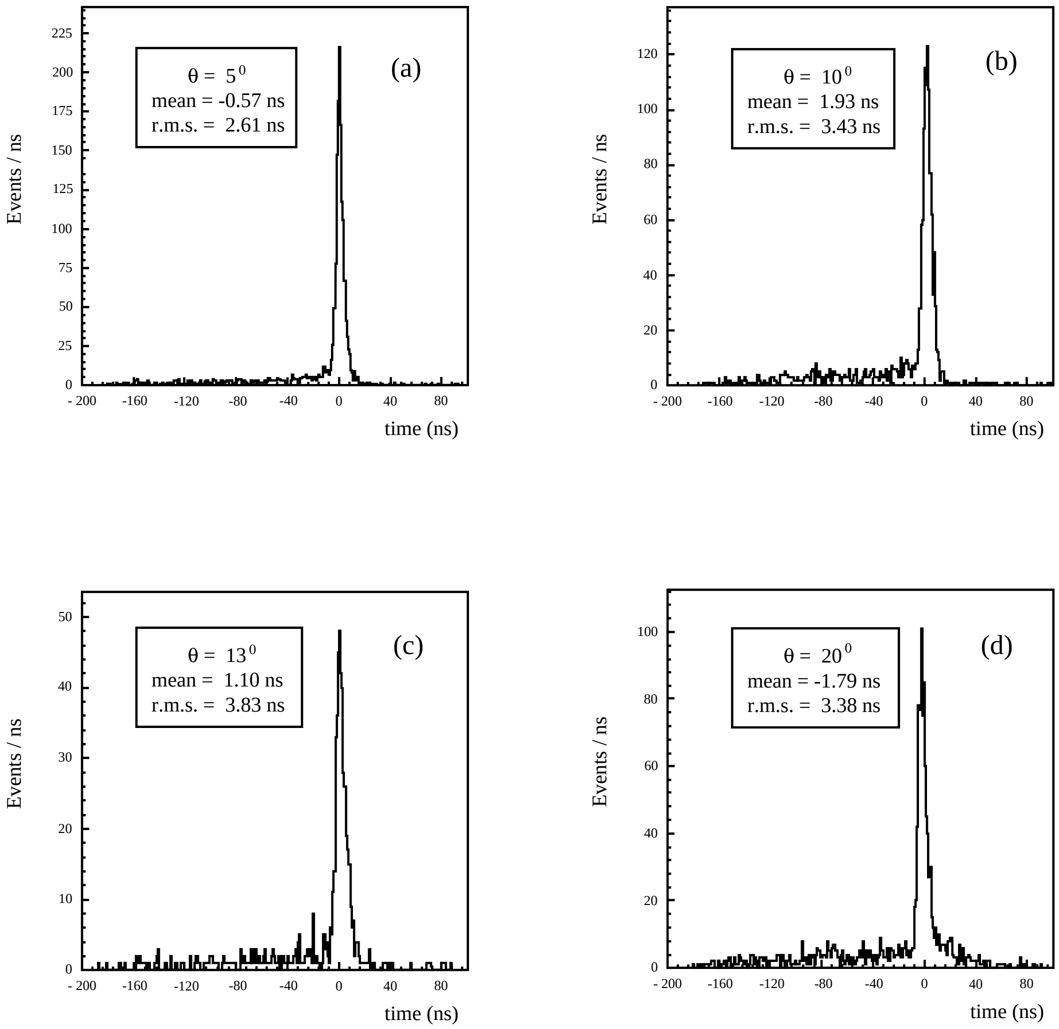
(a)
θ = 5°
mean = -0.57 ns
r.m.s. = 2.61 ns
Events / ns
0
25
50
75
100
125
150
175
200
225
- 200
-160
-120
-80
-40
0
40
80
time (ns)
(b)
θ = 10°
mean = 1.93 ns
r.m.s. = 3.43 ns
Events / ns
0
20
40
60
80
100
120
time (ns)
(c)
θ = 13°
mean = 1.10 ns
r.m.s. = 3.83 ns
Events / ns
0
10
20
30
40
50
time (ns)
(d)
θ = 20°
mean = -1.79 ns
r.m.s. = 3.38 ns
Events / ns
0
20
40
60
80
100
time (ns)

Figure 9