Performance of a DTBX Prototytpe

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(Presented by P. Zotto)

Abstract

A novel muon detector concept for LHC was studied in a test beam. The application of mean-timer technique to arrays of drift tubes provides the space and time resolution needed for first level trigger and track reconstruction using only the drift time information. A complete study of the performance of this new concept was done.

Introduction

The forthcoming LHC machine puts severe constraints on the performance of a muon detector. In particular the first level muon trigger must have a time resolution of about 2-3 ns to be able to recognize the interaction that generated the muon traversing the detector, a decision time of ~ 1 μs and a spatial granularity of few centimeters. The standard choice proposed to meet this requirements is the use of fast response dedicated trigger devices like RPCs or PPCs with strips or pads readout [1]. The main drawback to this choice is the need to complement the trigger device with a drift chamber to get the spatial resolution needed for track reconstruction. The DTBX (Drift Tubes with Bunch X-ing identification capability) concept was developed provide the same results using only the drift times information.

Drift Cell Mechanics and Electrostatics

The drift cell geometric and electrostatic layout was developed performing several simulation studies with the GARFIELD [2] and ANSYS programs. The aim of the design was to get a linear space-time relationship and insensitivity of the drift time to the track's angle. These targets were achieved with the layout of Figure 1 [3]. The prototype is made of PVC: two profiles of 16 x 50 cm^2 were 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 1. Nine layers of tubes were staggered by half a tube separated by an aluminised mylar foil kept at ground potential. The deformation of the more external drift lines caused by the shaped electrode assures longer drift paths for primary electrons produced outside the central zone, thus highly reducing the dependence of the drift time on track's angle. The finite elements ANSYS simulation shows that the high dielectric constant of the plastic produces a regularization of the electric field lines, implying a constant drift velocity using saturated gases. 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 each tube independently using a cosmic ray scintillator telescope. The data, reported in Figure 2, 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 [4]. The amplified signal was shaped using ECL discriminators (with 30 mV threshold) developed by INFN Padova for the APPLE experiment at LEAR [5]. The prototype was equipped whith 42 mean-timer channels using analogical mean-timers developed by INFN Padova for the $N\overline{N}$ experiment [6]. We will show that the mean-timer operation applied to the drift times is providing the requested time resolution. 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.

The Mean-Timer Method

The most important feature of the readout is the application of the mean-timer technique to arrays of drift tubes. Let's consider a three layers array of drift tubes and assume a linear space-time relationship, accurate wire positioning and accurate layers staggering. The drift times in consecutive cells originated from a particle crossing at normal incidence, as in Figure 3a, satisfies the relation $t_{MAX} = t_A + t_B$ and $t_{MAX} = t_B + t_C$ where t_{MAX} is the maximum possible drift time. If the track is inclined the relations are $t_{MAX} = t_D + t_E + \Delta t(\theta)$ and $t_{MAX} = t_E + t_F - \Delta t(\theta)$ as can be argued from figure 3b. A mean-timer conceptual design is sketched in Figure 4: the signals from two wires are sent into two delay lines and propagates in opposite directions. The two signals will meet after the fixed time t_{MAX} inside the mean-timer. If the mean-timer is made of a chain of logical gates, the location where the AND occurred gives also the drift time measurement, so that the mean-timer itself acts as a TDC. In case of an inclined track, the mean-timing operation will happen too late (D+E) or too early (E+F), depending on the track inclination. This problem can be solved making a second mean-timer operation on the two available mean-timers outputs, just adding an additional short fixed delay to the bunch crossing absolute time. Then applying the mean-timer technique we get signals at a fixed time after the muon traversed the detector and the time resolution is then given from the dispersion of this fixed time. 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.

Results on Space and Time Resolution

The prototype was exposed to the CERN H_2 muon beam in August 1992 and in November 1992 in the RD5 set-up. The prototype was positioned just after an iron block, that could simulate the calorimeter or the iron yoke of an LHC detector and generated the expected background accompayning the muon. 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.

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 5 and is always in the range 150-200 μm, showing that the required figure was achieved. No χ^2 cut was applied to the track interpolation and a constant drift velocity of 52 μm/ns was used to get the points in space.

The time distribution of a typical mean-timer channel at normal beam incidence is shown in Figure 6. 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 can have several causes that are discussed below. The prototype was exposed to different beam incident angles from $\theta=0^0$ to $\theta=20^0$, with θ defined in Figure 3b, 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 7a-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.

Study of the Backgrounds to the Method

From the time distributions shown it is clear that there is a sizeable fraction of background events. The long tail towards negative values may have several causes:

- noise
- electric field shaping
- cross-talk
- double tracks
- δ-rays production
- muon bremmstrahlung

Noise and cross -talk were verified using a cosmic ray telescope and found to be negligible.

The uniformity of the mean-timer output 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. Then we can conclude that there is no evidence of a bad field shaping.

There is always soft δ-ray production inside the detector and bremmstrahlung happens 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 ≥ 7.5 ns (equivalent to ~800 μm two track separation) off the peak centre. Only a small fraction (~20 %) 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 multitrack events interesting several mean-timer channels 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 positive shoulder in Figure 7 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 wire of the central layer. This problem can be solved using four layers of drift tubes and a more careful mean-timer design.

Application of DTBX in CMS

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 the events they become negligible only if enough redundancy is available in the muon detector.

The DTBX chambers were developed for the proposed CMS [7] experiment. In this case four muon stations inserted in the iron yoke are proposed for the muon measurement. The proposed mechanics for each station using DTBX is shown in Figure 9. Two modules composed of four layers of tubes to measure the coordinate in the bending plane and two orthogonal layers are separated by a 12" aluminium honeycomb assuring the stability and the planarity of the chambers. This layout will give up to sixteen determinations of the crossing absolute time, allowing the possibility of a bunch crossing identification based on a simple majority logic.

A VLSI logical mean-timer was fully designed using the SOLO 1400 ES program for this type of modules. The simulated integrated circuit performance was verified on the data recorded at normal incidence. The efficiency for bunch crossing identification of the mean-timers on the δ-ray sample is in the range 97 to 99 % per muon station, depending on alternative mean-timer designs. A full simulation of the CMS detector was also done using GEANT [8]. The result of the performance of is reported in Figure 10 and looks quite impressive: the good timing signals cumulates on one bunch crossing , while the background ones are dispersed in a large bunch crossing window, leaving no space for a wrong bunch crossing identification.

Conclusions

The DTBX concept is well suited for its use in the LHC environment. The chamber efficiency is close to the geometrical one (97.5 %), single cell spatial resolution is very good (150-200 μm) and he mean-timer technique provides an excellent time resolution (2ns). A careful design of the mean-timer circuit can solve all seen problems, giving a 99 % efficiency as tested on data for a CMS muon station.

New studies and developments will soon be done in the RD5 muon beam. In particular test with non flammable gases, larger wires diameter and non flammable plastic will be done. In parallel the mechanics and electronics of the DTBX in CMS are under study.

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p(Gev)	δ-rays (%)	Bremsstrahlung(%)	Total(%)
100 200 300	17.0 ± 0.7 % 16.4 ± 0.6 % 17.6 ± 0.6%	3.9 ± 0.3 % 5.5 ± 0.4 % 6.4 ± 0.3 %	$20.9 \pm 0.8 \pm 0.5$% $21.9 \pm 0.8 \pm 0.5$% $24.0 \pm 0.8 \pm 0.5$%

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

Figure Captions

Figure 1 - 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 2 - 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 3 - The principle of mean-timing for (a) normal tracks and (b) inclined tracks

Figure 4 - Conceptual design of a mean-timer module

Figure 5 - Residuals to the straight line fit. No cut on χ^2 was applied.

Figure 6 - Mean-timer time distribution for normal track incidence

Figure 7 - Mean-timer time distribution for different tracks inclination

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

Figure 9 - Proposed layout for a muon station in CMS using DTBX tubes

Figure 10 - Performance of a mean-timer based majority trigger in CMS: on x-axis is plotted the bunch crossing number in 15 ns steps, on the y-axis is plotted the number of mean-timer signals per event per bunch crossing and on the z-axis the number of events.

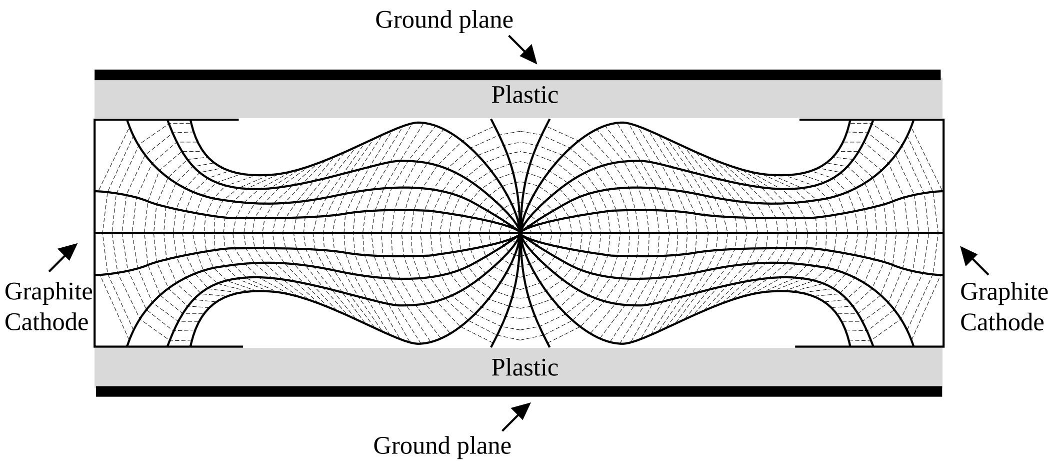


Figure 1

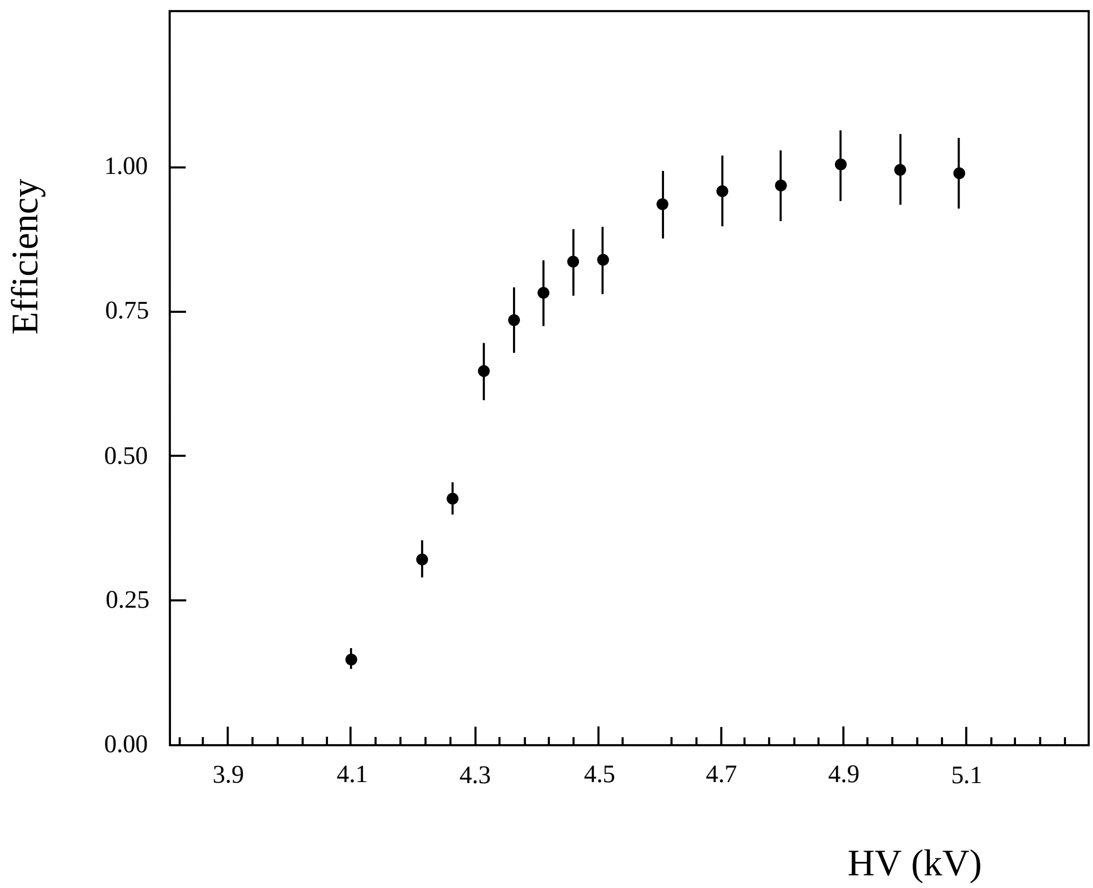


Figure 2

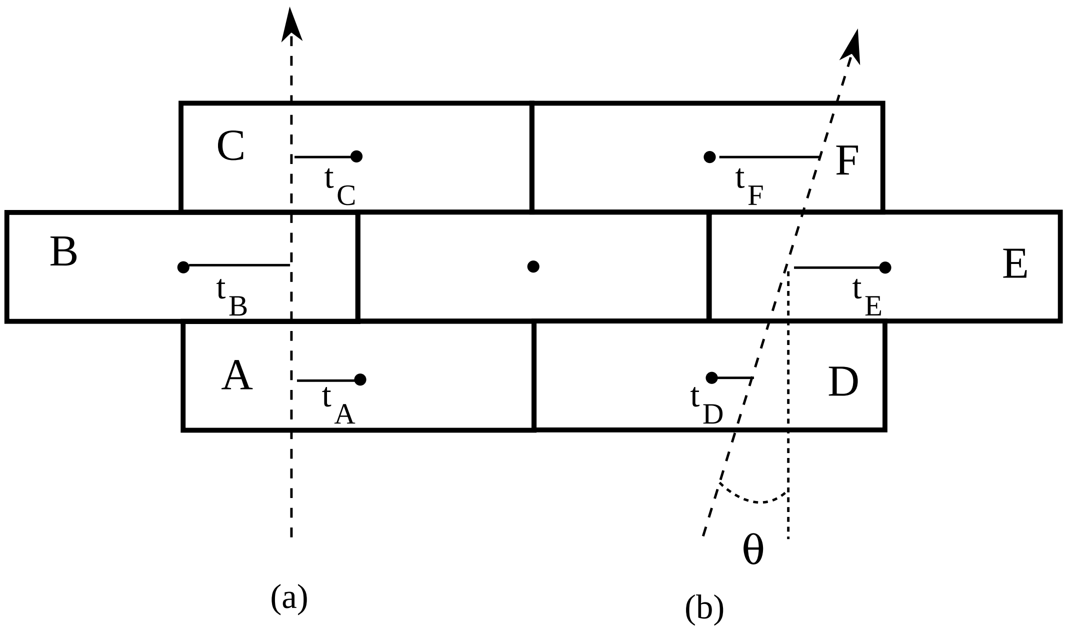


Figure 3

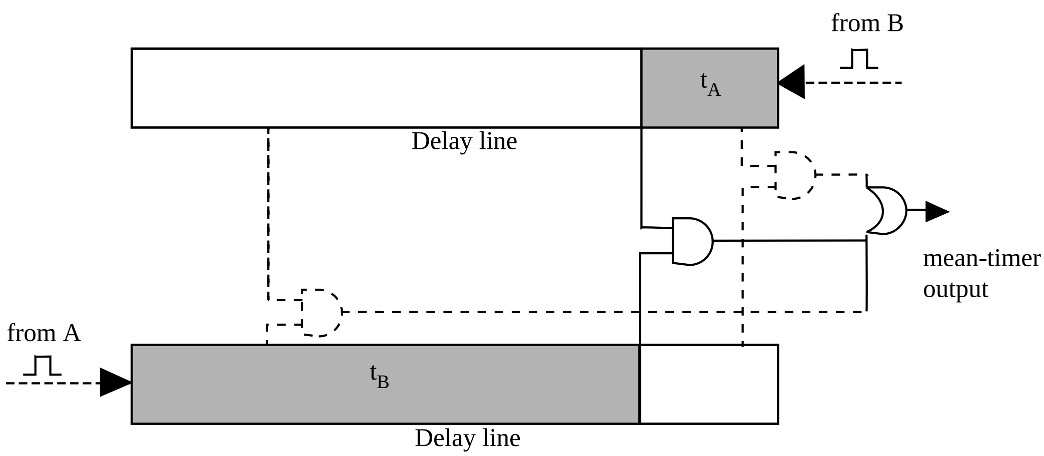


Figure 4

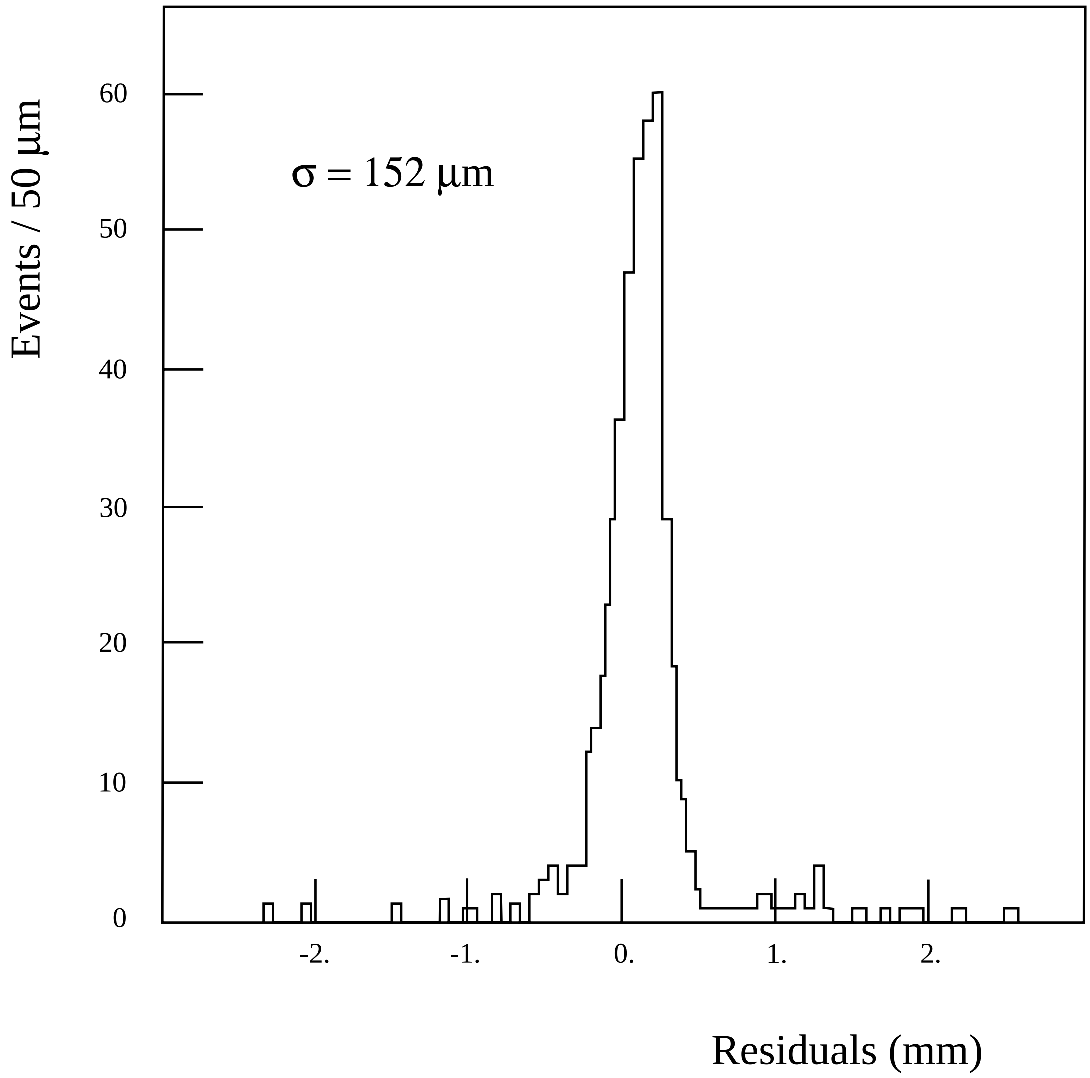
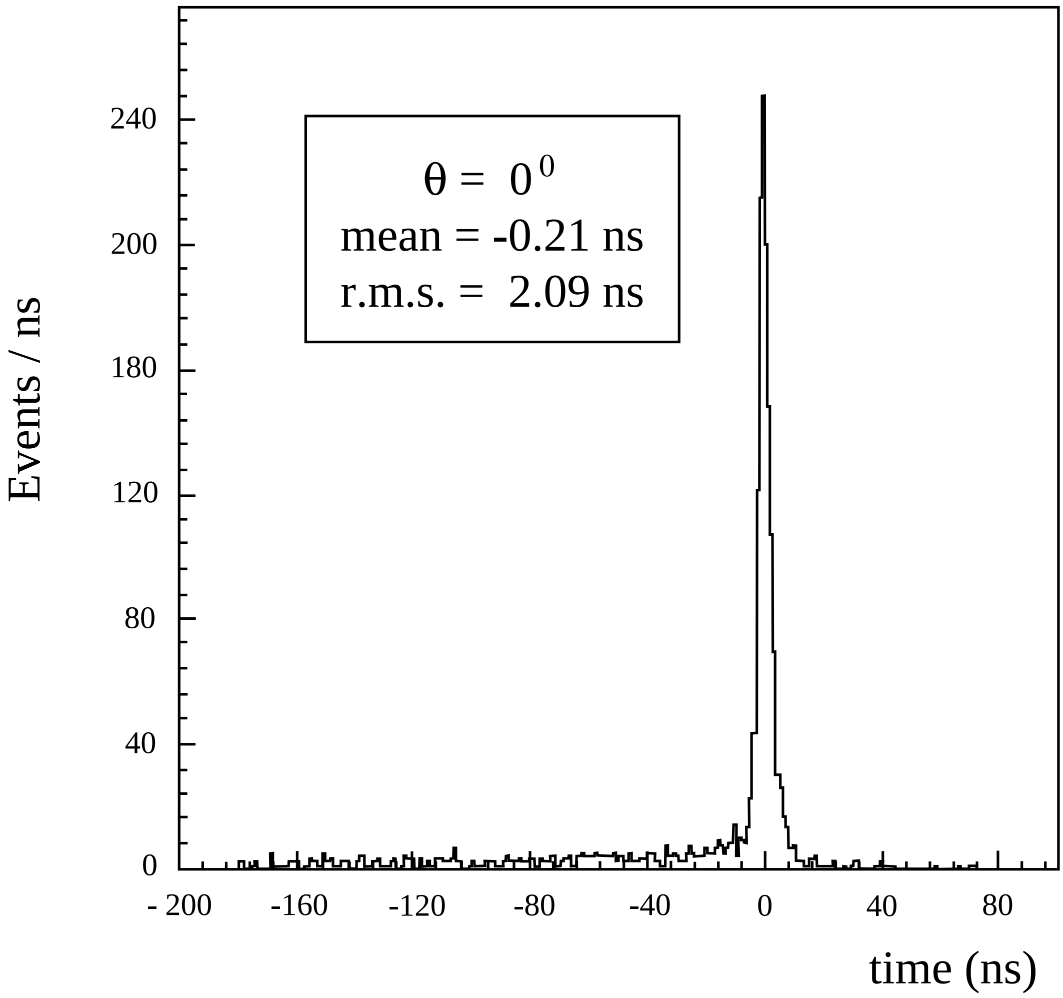
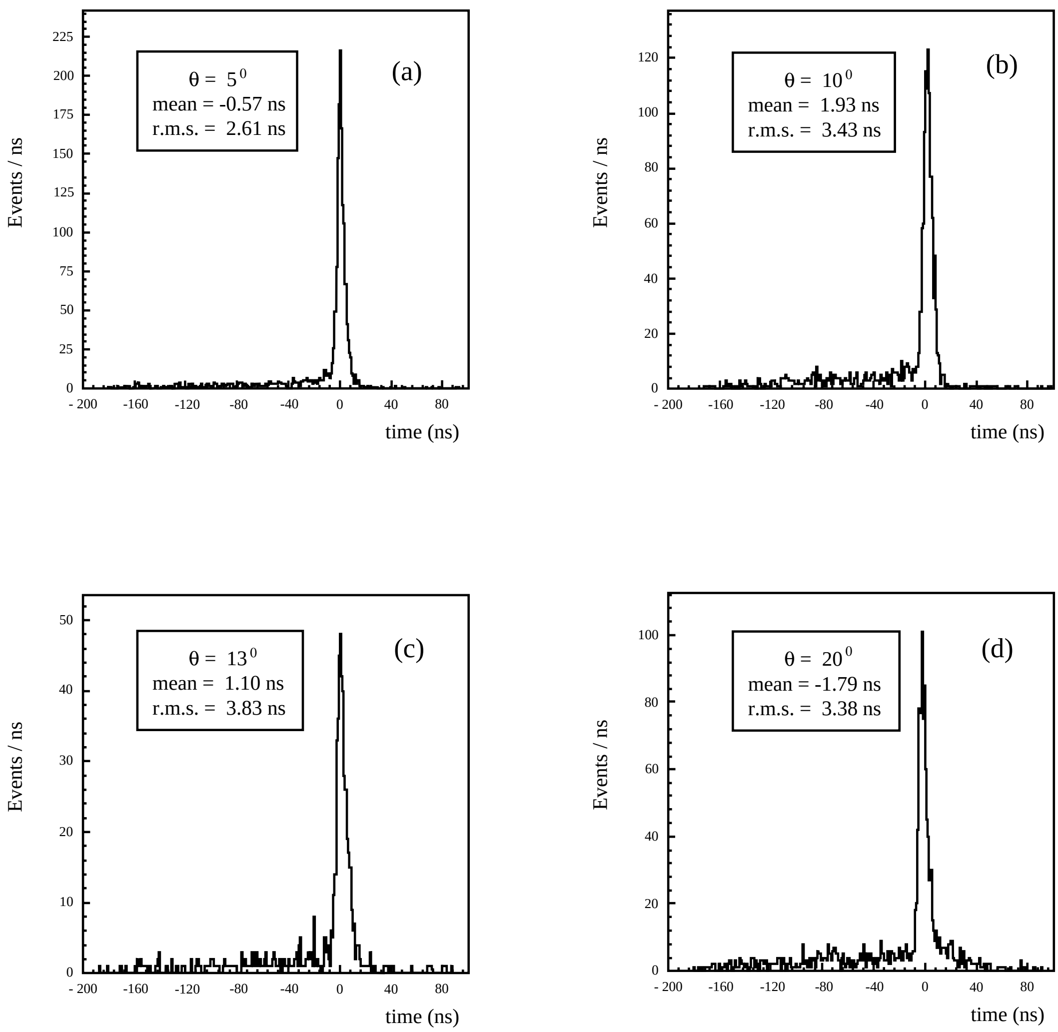


Figure 5



θ = 0^0
mean = -0.21 ns
r.m.s. = 2.09 ns
Events / ns
240
200
180
120
80
40
0
- 200
-160
-120
-80
-40
0
40
80
time (ns)

Figure 6



(a)
θ = 5⁰
mean = -0.57 ns
r.m.s. = 2.61 ns
Events / ns
time (ns)
(b)
θ = 10⁰
mean = 1.93 ns
r.m.s. = 3.43 ns
Events / ns
time (ns)
(c)
θ = 13⁰
mean = 1.10 ns
r.m.s. = 3.83 ns
Events / ns
time (ns)
(d)
θ = 20⁰
mean = -1.79 ns
r.m.s. = 3.38 ns
Events / ns
time (ns)

Figure 7

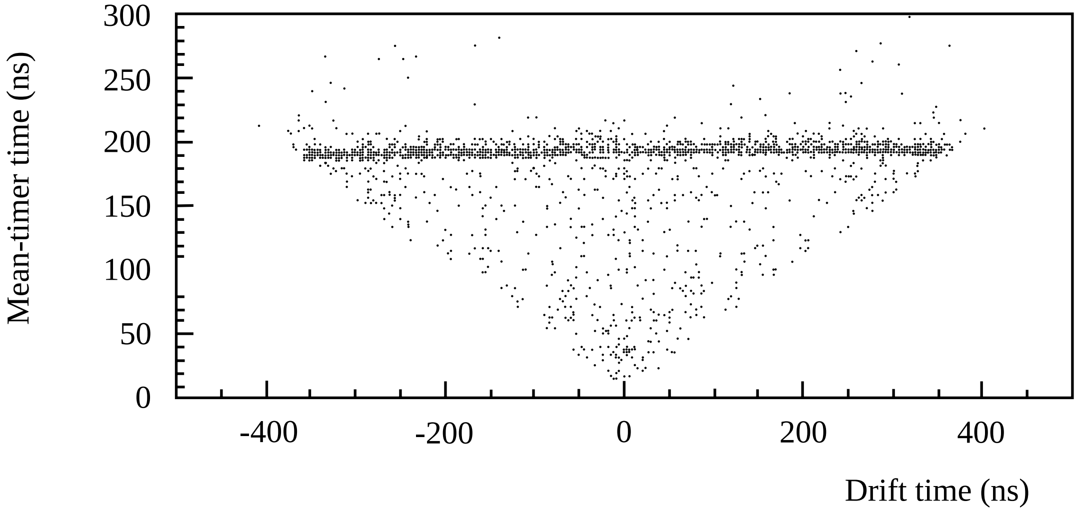


Figure 8

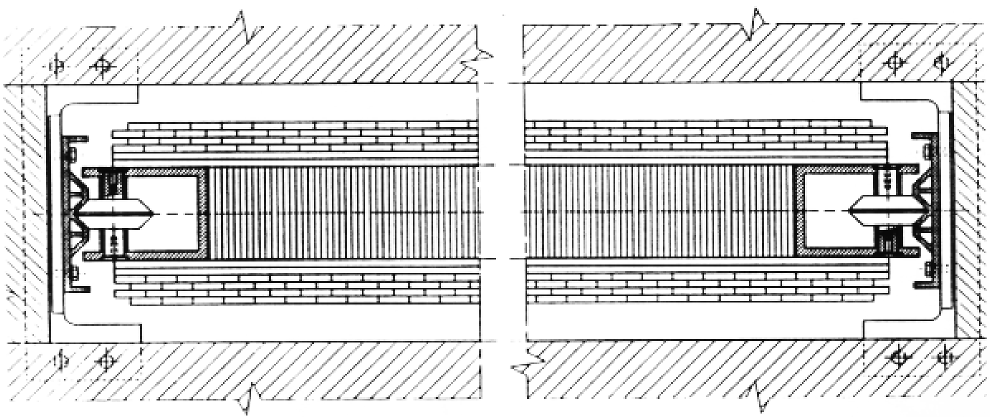


Figure 9

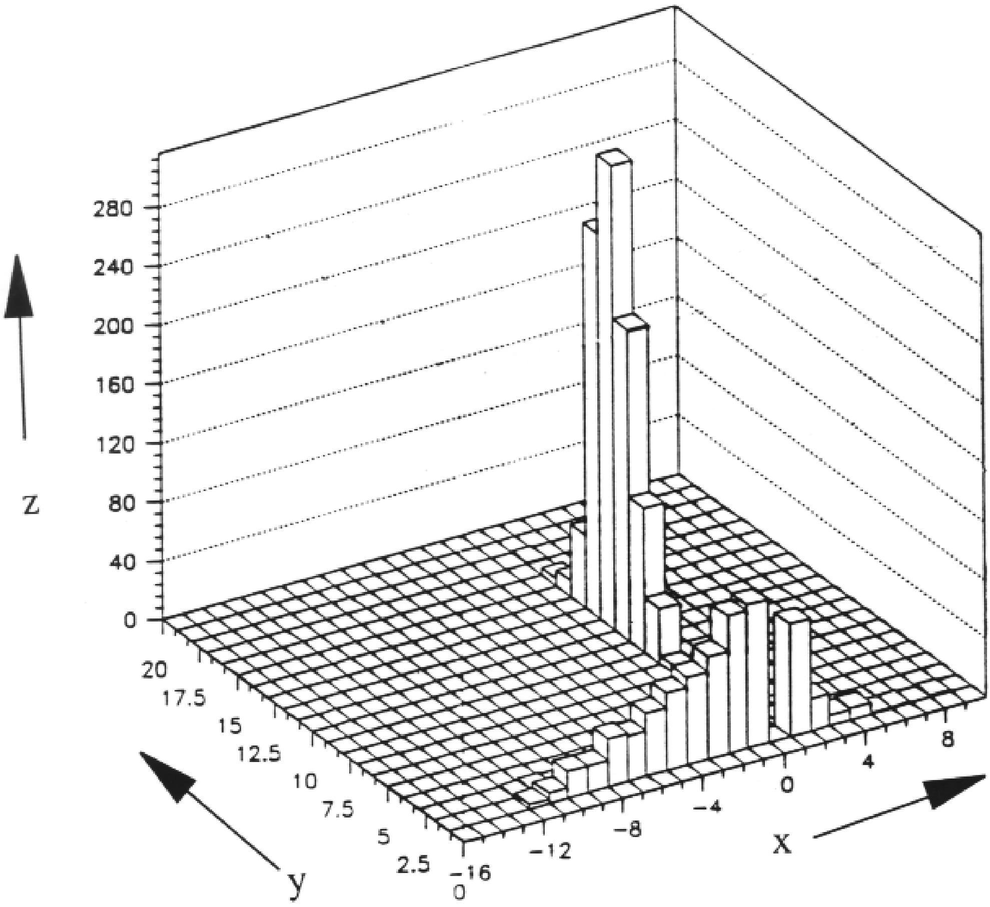

z
280
240
200
160
120
80
40
0
20
17.5
15
12.5
10
7.5
5
2.5
0
y
-16
-12
-8
-4
0
4
8
x

Figure 10