Comparison of different pulse time estimators

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September 4, 2013

Abstract

In this report different pulse time estimators for the Time Projection Chamber of the International Linear Collider are compared. This time information is used to reconstruct the z component of a transversing charged particle. Thus the time estimators are mainly compared in their effects on the z component, while comparison in xy is performed to show, that the estimators do not effect xy reconstruction. Additionally a new Pulse GUI is presented, which can be used to look directly into the pulse spectra.

Important results are that the timewalk effect for all time estimators is similar and that the default time estimator provides the best resolution.

Contents

1 Introduction

The aim of this project is to study the different time estimators used for reconstruction of charged tracks in a Time Projection Chamber (TPC). This TPC is designed for the future International Linear Collider (ILC). The following sections may give a short introduction into the working principle of a TPC and the reconstruction steps.

1.1 TPC

In a Time Projection Chamber tracks of charged particles can be detected via ionization of the gas in the chamber. A magnetic field can be applied along the beam axis to measure the momentum. The electrons produced during ionization processes are accelerated towards the anode by an electric field. There the charge has to be amplified. One possible way would be to use small wires that produce locally a strong electrical field, if a voltage is applied. Because the size of the wires and therefore the resolution is limited, here another method is used: Gas Electron Multiplier (GEM). Small holes in a capacitor foil produce the required electrical field to amplify the signal (if a voltage is applied to the capacitor). Three such amplifying structures are stacked and followed by a padplane which is connected to the readout electronics.
The chamber has a cylindrical form and the electronics is placed at one endcap. Thus one needs the drift time of the electrons to determine the z component (direction of the beam axis) of a charge packet.
The electronics is divided into several modules and the readout channels are arranged in circular rows.

1.2 Reconstruction

The amplified signal is digitized with an Analog Digital Converter (ADC) operating at 20 MHz. For each channel the result is pedestal corrected and zero suppressed.
In this raw data one searches for pulses (charge packets). These pulses have a quality byte which contains information about the pulse shape, the overflow status of the ADC, etc. The time of the pulse is reconstructed via different time estimators, explained in section 3.1.
In each row the pulses are combined into a hit and the hits are used to construct a track via track fitting algorithms.
The data used was produced with a testbeam parallel to the x-axis. So all z components should be around the z position, at which the beam is injected. The distance of this position to the anode is the drift distance.

2 Pulse GUI

First I have programmed a pulse GUI to visualize pulses and their reconstructed time. This GUI is based on ROOT GUI and a screenshot is shown in figure 1. On the right side the pulse spectrum is shown with the reconstructed time (red line) and some information about the current pulse. The left part of the GUI contains three sections:

- top section: Load input file, event and pulse.
- middle section: Select filter criteria such as quality or charge of the pulse.
- bottom section: Save pulse spectra to a pdf file.

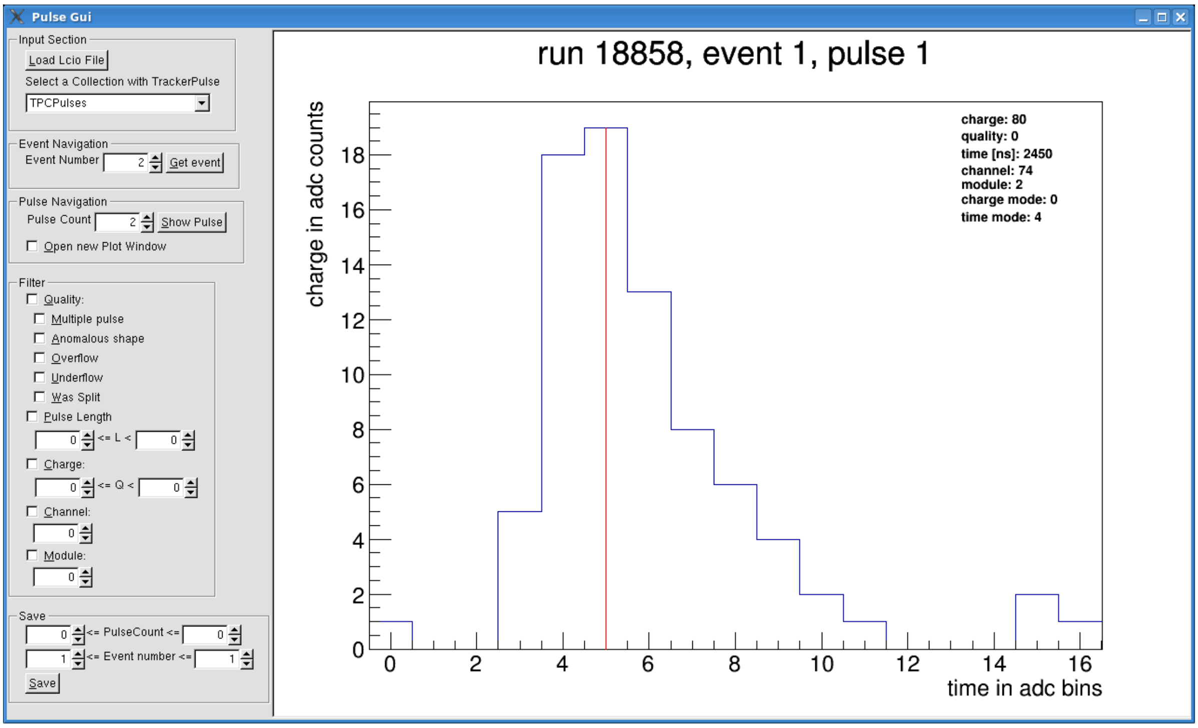

Figure 1: Screenshot of the pulse GUI

One purpose of this GUI is to see, if the time calculation works as expected.

3 Time estimator comparison

3.1 Different time estimators

The following list shows the different time estimators, that are currently used. The colored numbers indicate the colors used in plots. The missing methods are those which produces unstable results on real data:

- **Method 0:** Calculates inflexion point by finding the mean of the rising "edge": $t = \frac{\sum_{bins} t_i D_i}{\sum_{bins} D_i}$ with the time t_i, the derivative $D_i = q_i - q_{i-1}$ and the charge q_i (in ADC counts) of the i-th (ADC) bin.

- **Method 2:** The time is calculated as the center of gravity of the full pulse: $t = \frac{\sum_{bins} t_i q_i}{\sum_{bins} q_i}$
- **Method 3:** Time of the first bin above threshold.
- **Method 4:** Time of maximum bin.
- **Method 5:** Calculates when 90% of the maximum height is reached (constant fraction).
- **Method 7:** Center of gravity of the maximum bin and the 2 neighboring bins on both sides.

Figure 2 shows the time spectra of the different methods for run 18863 (drift distance $z = 20\,\mathrm{mm}$, no magnetic field). Especially for those methods, which use a single bin for time calculation, a discrete spectrum is observed because the bins of the histogram are smaller than an ADC bin. For the methods 0, 5 and 7 these binning effects are also observed, but the pure delta function is smeared because more bins are used in the time calculation. For method 2, which uses the most bins, no binning effects can be observed.

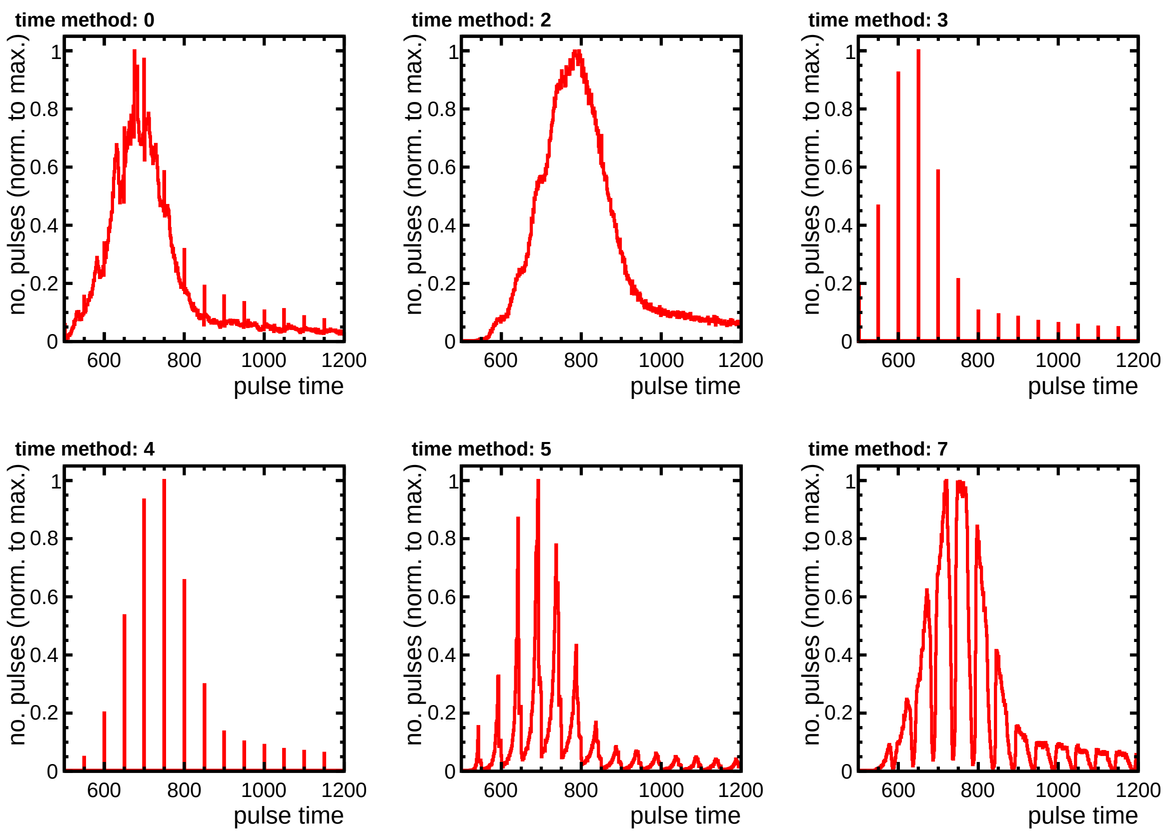

Figure 2: Time spectra for the different time methods (run 18863)

In figure 3 the charge dependence of the hit time (time of the largest pulse) is shown for run 18863 (drift distance $z = 20\,\mathrm{mm}$, no magnetic field). Therefore mean and RMS_{90} of the time distribution is determined for every charge bin. RMS_{90} is a RMS (Root Mean Square) taking into account only 90% of total area of a distribution. Because there are many possibilities to build this 90% area, RMS_{90} is the minimum of all the possible results.

For all time methods the mean is decreasing in $\log Q$. This looks like a classical time walk due to a threshold, that is passed earlier for higher pulses. As expected the different time methods have different offsets (e. g. first bin above threshold should be earlier than maximum bin).

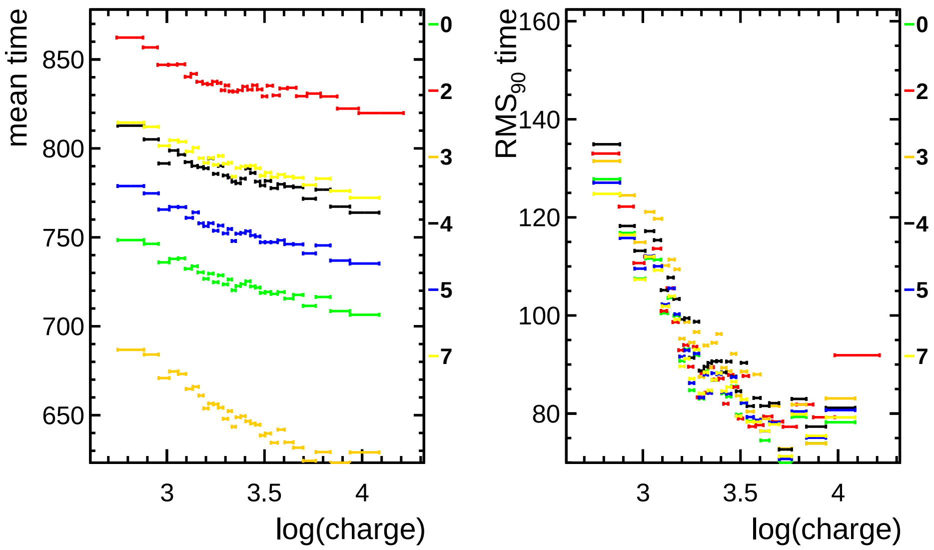

Figure 3: Charge dependence of hit time (run 18863)

Figure 4 is the same plot for run 18849 (drift distance $z = 500\,\mathrm{mm}$, no magnetic field). If the plots are compared, one can see an interesting behavior: For a long drift distance the mean decreases much slower than for short distances except for time method 3. The most likely reason for this is, that for longer drift distance the diffusion is higher and thus the pulses are longer. Therefore the rising edge is less steep. Because the slope of the rising edge is thought to be charge dependent, the smaller steepness causes the charge dependence to reduce.

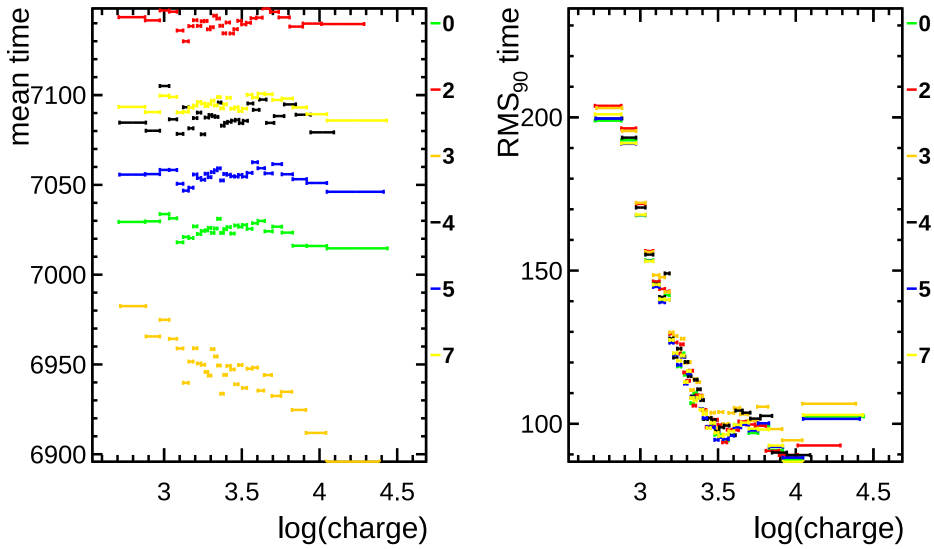

Figure 4: Charge dependence of hit time (run 18849)

3.2 Distances based on tracks and triplets

If one wants to determine a resolution of the hit reconstruction, a distance from a reference object has to be measured. Resolutions can then be calculated as the σ value (from Gaussian fits) of the resulting distance distribution.

For every hit the reference object can either be the reconstructed track (true track is unavailable) or the two neighboring hits (the 3 hits are called triplet).

Because distinguishing x and y distances would not be reasonable, one uses one distance in the xy plane. If the reference object is a track, the distance from the track in xy plane is the radial distance from the circle that describes the track in this projection. This distance has a conventional sign depending on the side of the track the current hit is located on. In z direction the normal distance is used. The current hit can be used in the track fit or not. In the first case the distance is called "distance" in the second case "residual". The (point) resolution is then given by [1]: $\sigma_{point} = \sqrt{\sigma_{dist}\sigma_{res}}$.

For triplets the distance in xy is the arc distance (along the row) of the current hit from the line defined by the neighboring hits (visualized in figure 5). In z direction again the normal distance is used.

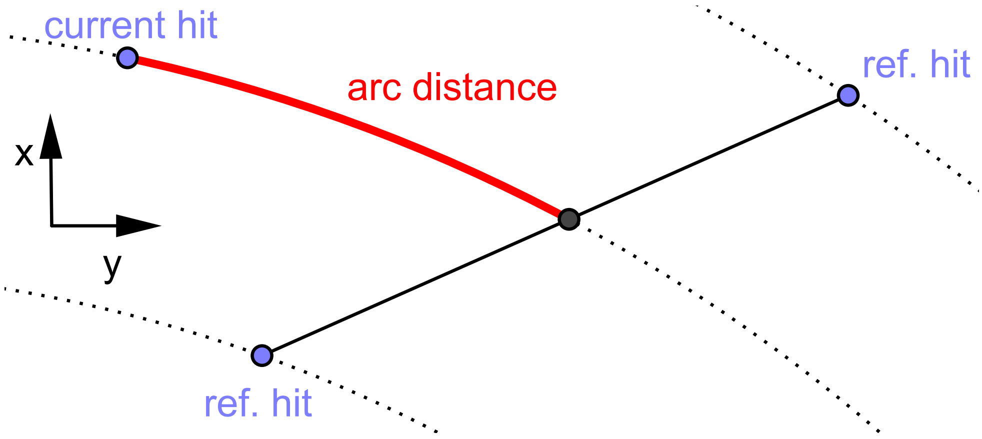

Figure 5: Distance for triplets in xy plane

Due to non Gaussian distance distributions σ is replaced by RMS_{90}.

3.3 Resolution

Now the resolution in z for the different time estimators can be compared. Figures 6 and 7 show the z resolution for different drift distances (without magnetic field). The first observation is, that time method 0 (inflexion point) provides the best resolution. Furthermore the resolution for all methods is almost constant in the drift distance. Comparing the resolutions for tracks and triplets one observes, that the triplet resolution is better than the track-based. This has been expected because the track depends on all hits not only on the neighboring ones and is therefore more sensitive towards global systematic effects.

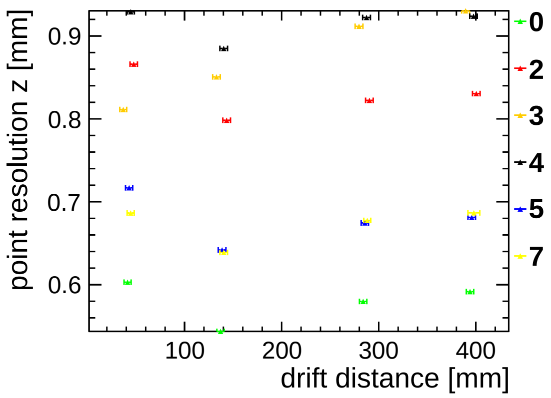

Figure 6: track-based z resolution (0 T)

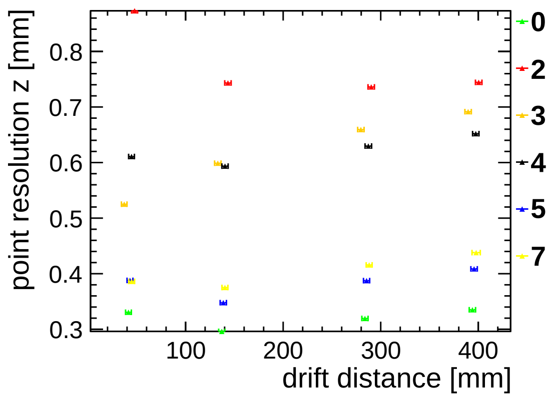

Figure 7: triplet-based z resolution (0 T)

The same plots (figures 8 and 9) for runs with magnetic field (1 T) look very similar, what has been expected, because the longitudinal diffusion is independent of the magnetic field.

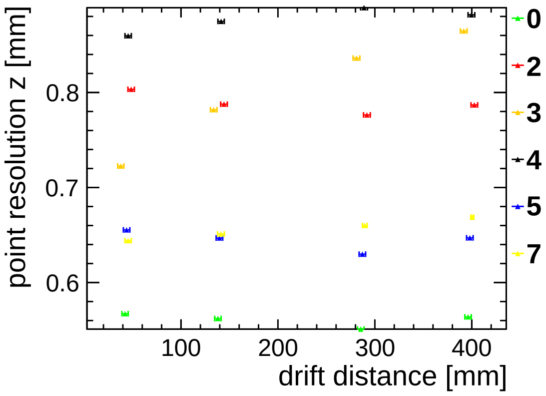

Figure 8: track-based z resolution (1 T)

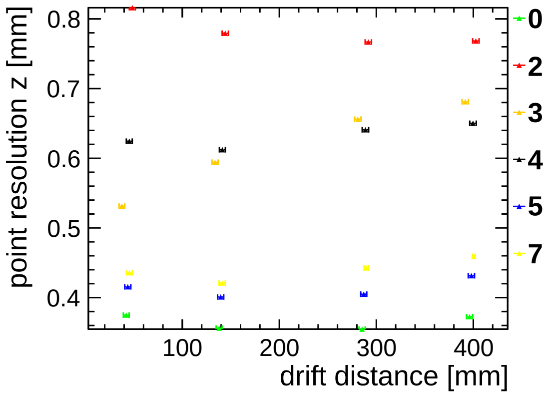

Figure 9: triplet-based z resolution (1 T)

3.4 Charge dependence of z component

For futher comparison of the time estimators the charge dependence of the distance distributions can examined. Figures 10 and 11 show the charge dependence of track-based and triplet-based distance distributions for run 18863. In the plots the charge dependence of the distributions mean and RMS_{90} is shown for xy and z.
For xy the mean is not charge dependent and mean and RMS_{90} do not depend on the time method. This was expected because the time measurement should only effect the z component.
The track-based mean rises in $\log Q$ and looks very similar for the different time methods. RMS_{90} has a minimum at medium charges and again time method 0 provide the best resolution.
For triplets the mean in z decreases with rising charge except for time method 3. RMS_{90} for triplets is again lower than the track-based one and has smaller variations in $\log Q$. The different sign of the slope seen in the mean values is still unexplained, but probably caused by different conventions.

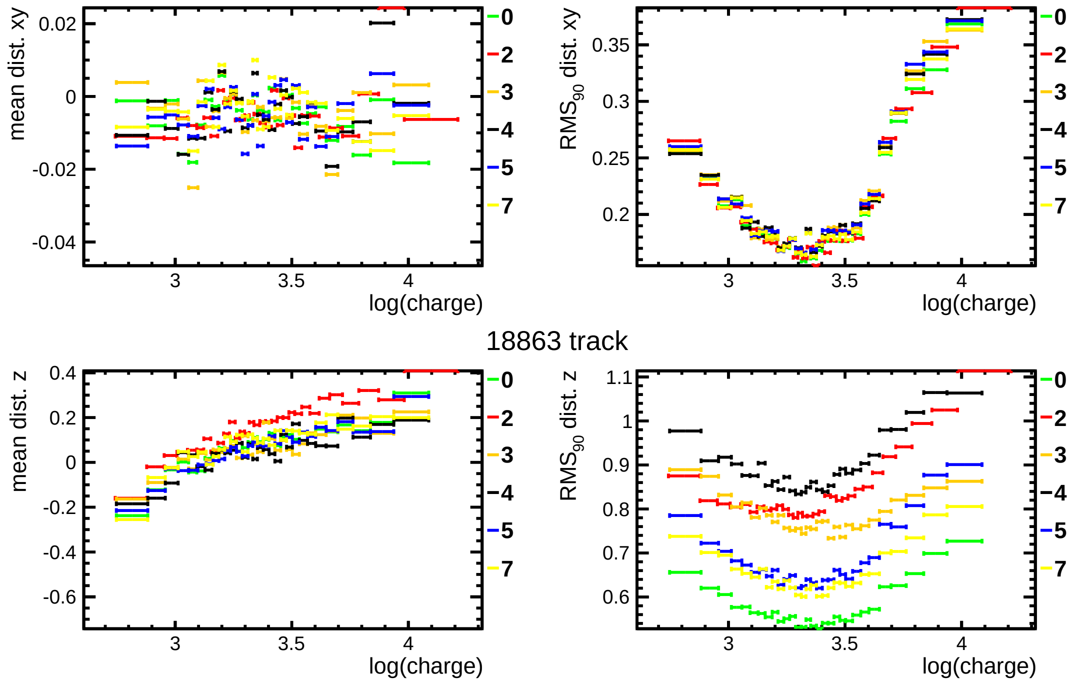

Figure 10: Charge dependence of the track-based distance distribution (run 18863)

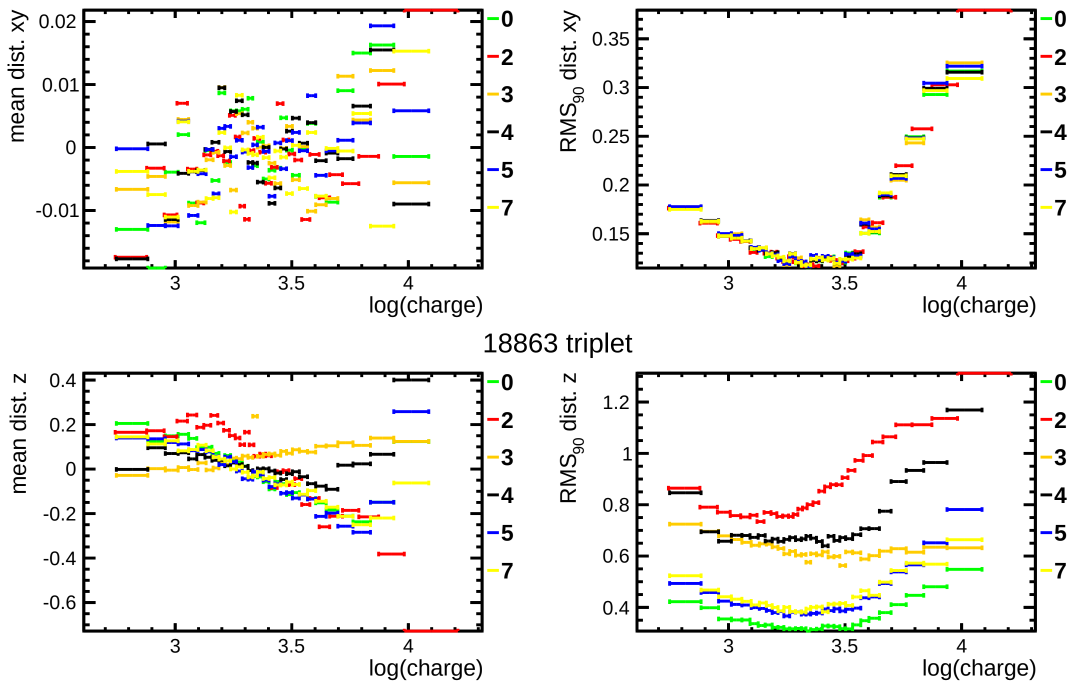

Figure 11: Charge dependence of the triplet-based distance distribution (run 18863)

3.5 Distortions

The gaps between modules produce field distortions (mainly electrical) and so the electrons are attracted by these gaps. This causes row dependent distortions in z and xy. The influence of the time method on these distortions is shown in figure 12. Compared to the z distortions the distortions in xy are small. The xy distortions are independent of the time method, while the z distortions are slightly dependent on the time method.

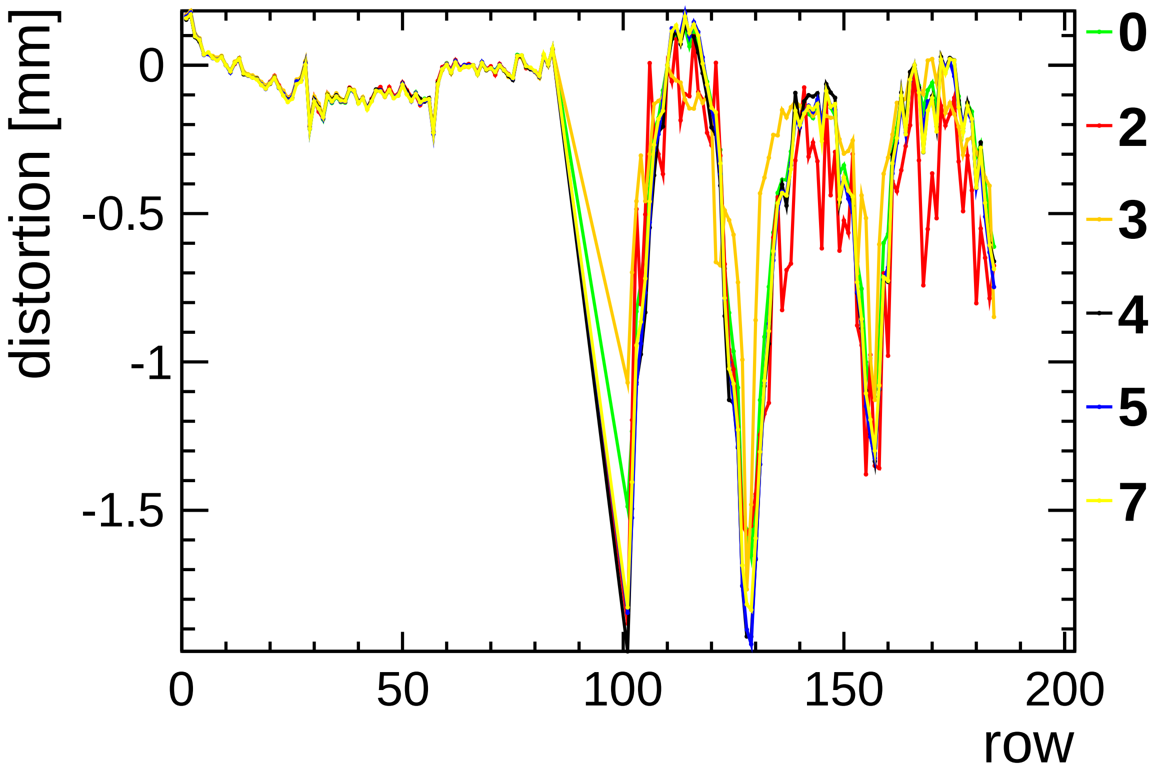

Figure 12: Distortions (run 18863); row number 0-84: xy distortions, row number 100-184: z distortions

4 Conclusion and Outlook

An interesting result from comparing the time methods is, that the mean hit time decreases faster in the charge for small drift distances. The explanation via diffusion has to be verified.
As expected the resolution derived from the triplets is better than the track-based one. Another important (but expected) result is the small influence of the magnetic field on z resolution. The comparison shows also that the inflexion point time method provides the best resolution.

The mean distance in xy is charge and time method independent (as expected), the xy resolution however is charge but not time method dependent. The mean distance in z is clearly charge dependent and one still has to explain the different signs of the slopes for track-based and triplet-based mean. Because of the monotonic behavior of the mean the charge dependence can be corrected. Since the charge dependence of the mean distance in z does not depend on the time method, the time method can be chosen based on the provided resolution. So the default method should be used.
It is important to know, that the (row dependent) xy distortions are not and the z distortions are barely influenced by the time method. This shows, that all differences between the time method seen for the mean distance in z are really global effects and not influenced by the row dependent distortions.
Another time method has been tested. It calculates the inflexion point via convolution and can apply several filters to smear the result. Some effects are not understood well enough to present the results here, but the method seems not to yield a better z resolution or smaller charge dependence.

References

[1] Ralf Diener: *Study of Reconstruction Methods for a Time Projection Chamber with GEM Gas Amplification System.* Univ. Hamburg.