Study of the Z resolution with Fit Method for Micromegas TPC

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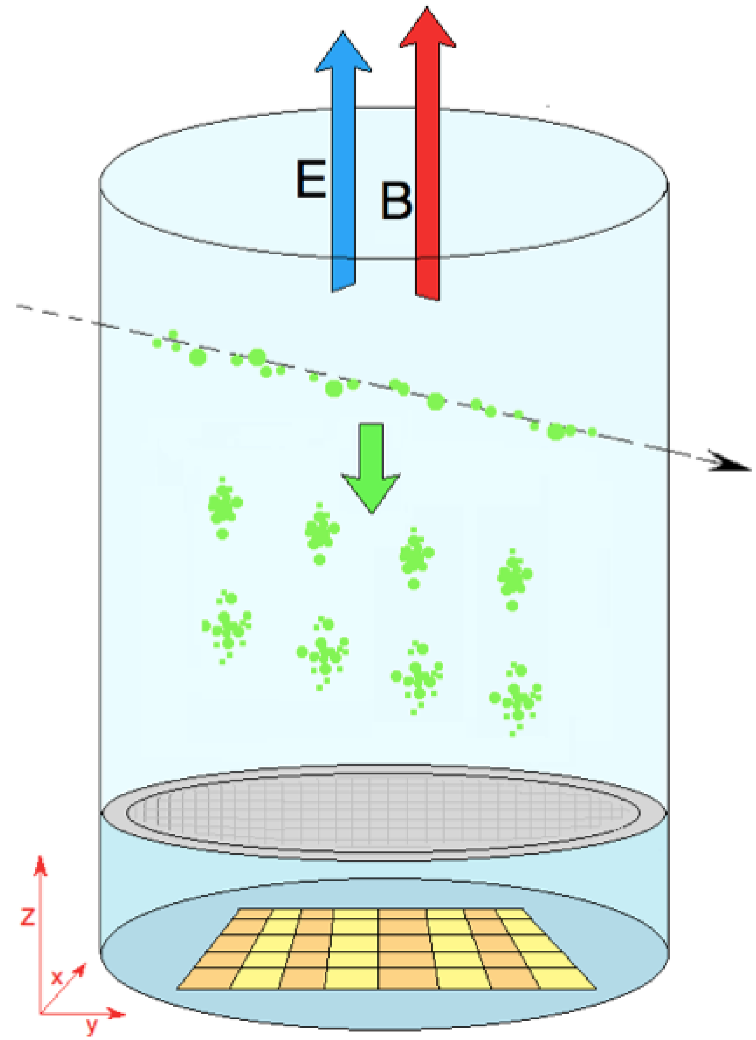
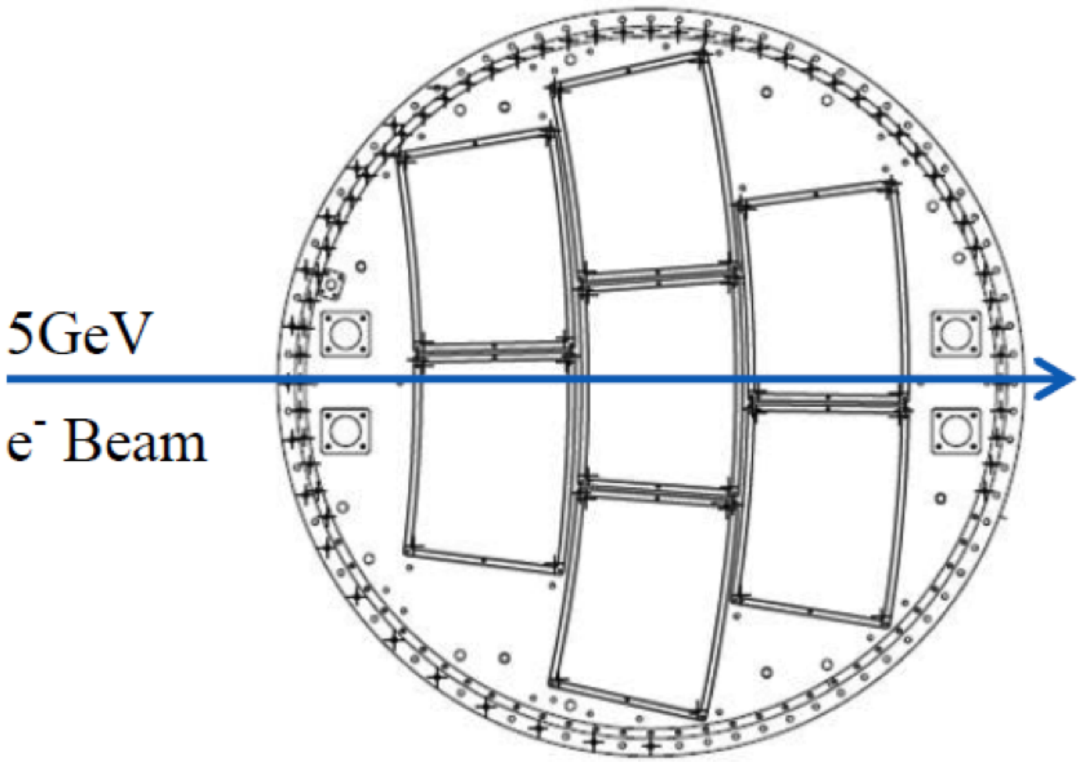
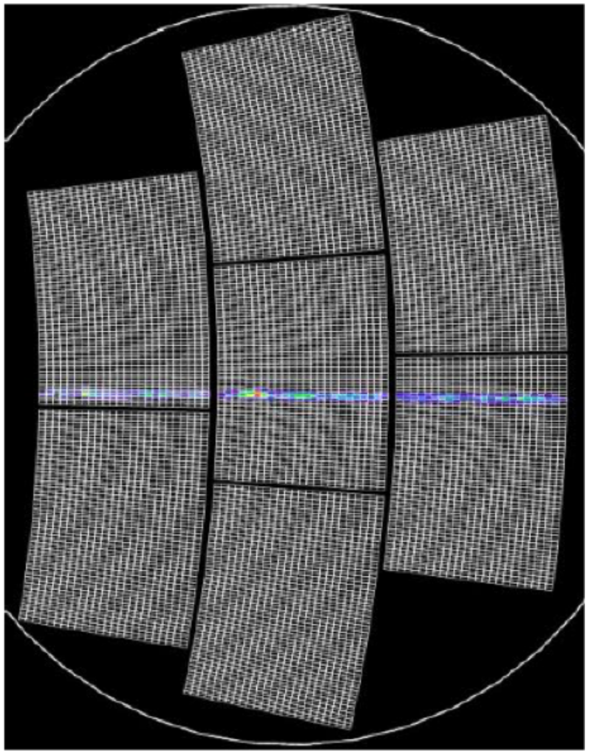
- **Transverse and Longitudinal** resolutions are major characteristics of the TPC
  - this talk focuses on Z resolution
  - measure time between ionization and detection multiply by drift velocity
  - ILD TPC requirements: $\sigma_z \sim 400\mu m$
  - critical for recoil mass resolution $\mathrm{ZH} \rightarrow (\mathrm{ll})\mathrm{X}$
  - details are in **A. Bellerive AWLC14 talk**
- Each pad readout provide charge (ADC) as a function of time with 40 ns intervals
- It is possible to determine **arrival time ($\mathbf{T_{max}}$)** and **amplitude (A)** for each pad
  - best estimation if **pulse shape** is known
  - build one hit per row by grouping pulses
  - fit Pad Response Function (PRF) to the pulse amplitude **A** to find **XY position** of the hit

The TPC acts as a 3D camera taking a snapshot of the passing particle







Study was done with a multi-module setup of the LP Micromegas TPC detector using beam test data at DESY facility (Feb. 17– Mar. 2, 2014)

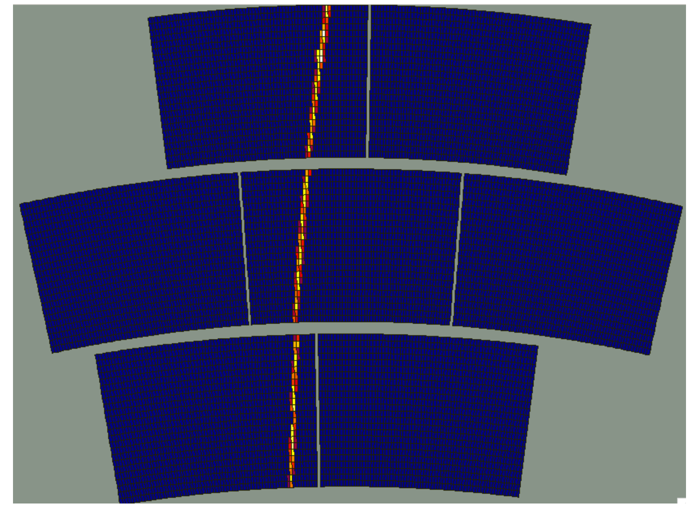
Data with B=0, 1 T, E=140, 230 V/cm were taken for $\Delta z = 5\,\mathrm{cm}$

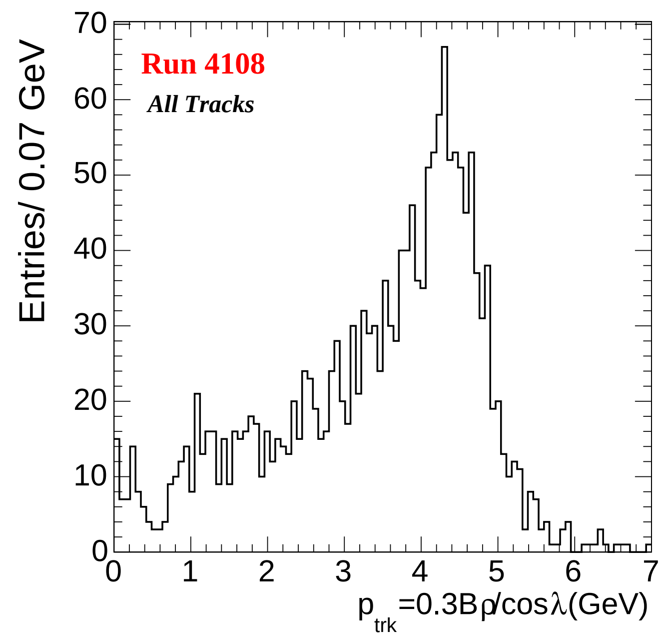
Analysis Dataflow

Dataflow for the beam test:
DAQ and analysis

- ☞ DAQ software store data in **raw format** (calib. view, event dispay, etc)
  - ➠ calibration (pedestal)
  - ➠ data taking (beam, cosmic, laser)
  - ➠ slow control (temperature)
- ☞ High level analysis with **MarlinTPC** framework
  - ➠ subtract pedestals
  - ➠ build hits from pulses
  - ➠ reconstruct tracks (KalmanFit)
  - ➠ analysis (resolution, distortion, etc)

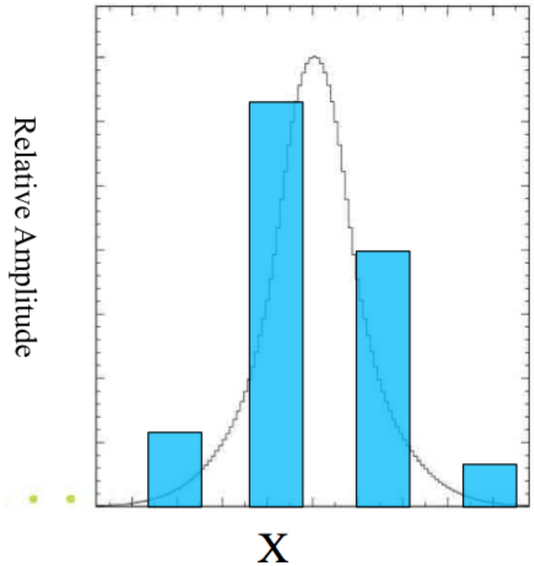
Determine resolution from residuals of the whole 3D track fit, e.g. Kalman algorithm

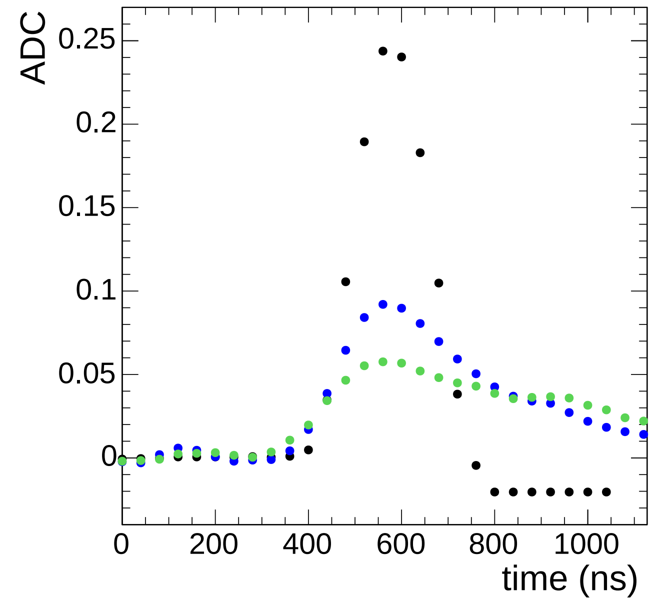




☞ **Possible pulse shape variations:**

- ➠ channel-by-channel (electronics, shaping)
- ➠ leading and subleading pulses (charge)
- ➠ rise-time and tails (shape)



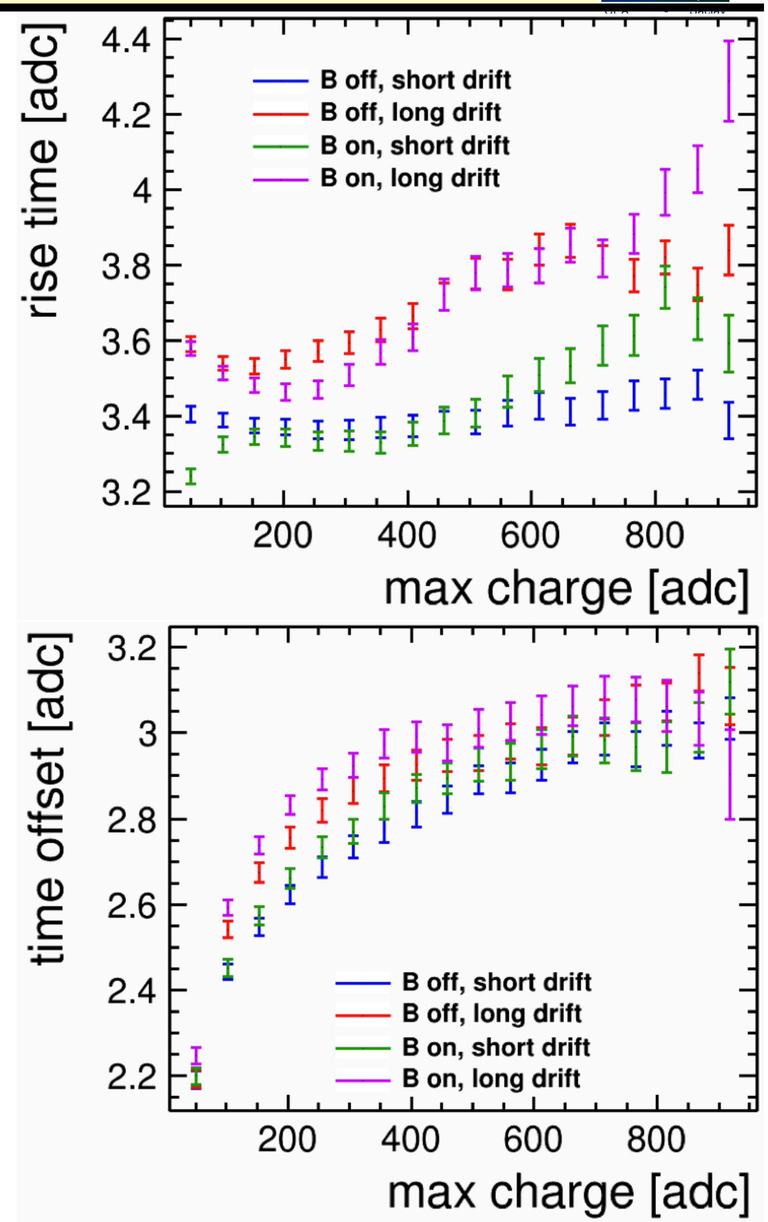


☞ Improved estimtion of amplitude **A** of the group of adjacend pulses can go beyond the current **precision for XY position**

- ➠ deserves special study (foreseen to be implemented in the future)
  - ➔ subleading pulses have quite different shape
  - ➔ implementation has to be at `MMHitFinderProcessor` level as it is done for GEM

Current study focuses on the leading pulse time reconstruciton only and implemented at MMHitTimeCorrectionProcessor

Previous Study for GEM



Study of time reconstruction with pulse shape method for GEM was reported by F. Müller

☞ The following analytic function was proposed:

$$\mathbf{f(t) = A \cdot e^{\alpha} \cdot \left(\frac{t - T_0}{T_{rise}}\right)^{\alpha} e^{-\alpha \frac{t-T_0}{T_{rise}}} \theta(t - T_0)}$$

$\mathbf{A}$ - amplitude $\mathbf{T_0}$ - offset, $\mathbf{T_{rise}}$ - risetime, $\boldsymbol{\alpha}$ - pulse width,

☞ Two major obeservations with simulation study:

- ➠ dependency of T_{rise} and T_0 on the pulse charge
- ➠ inconsistency with drift distances and B-field

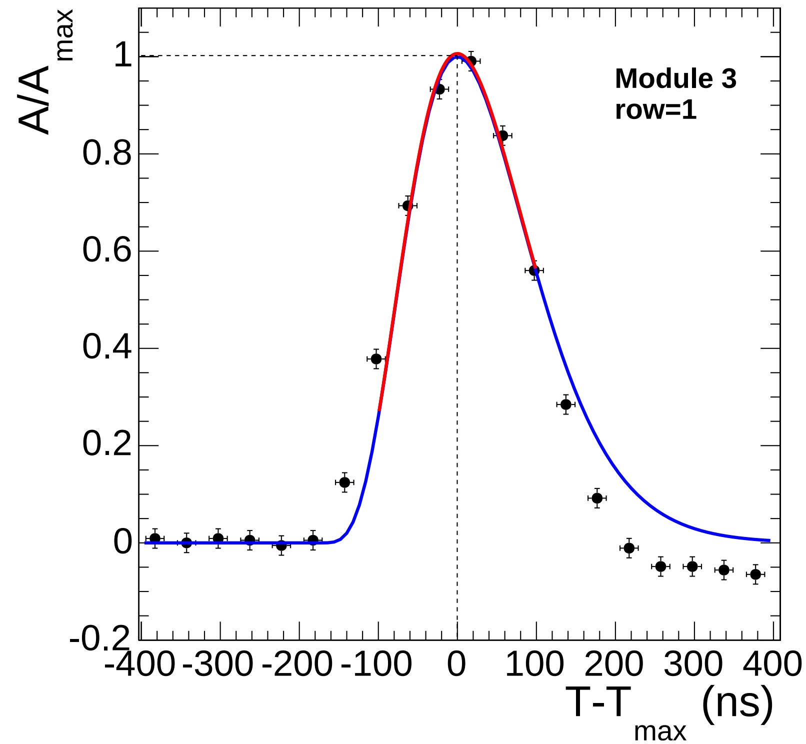
Due to such an instability of the fit parameters steek to barycenter and inflection point methods

https://agenda.linearcollider.org/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=6375

- We determine arrival time $\mathbf{T_{max}}$ as

$$\mathbf{T_{max} = T_0 + T_{rise}}$$

  - there is strong correlation between $\mathbf{T_0}$ and $\mathbf{T_{rise}}$ (limited fit range)
  - the stability of the fitted $\mathbf{T_{max}}$ is what we have to worry



- Modify function in such a way that both $\mathbf{A}$ and $\mathbf{T_{max}}$ are direct fit parameters

$$\mathbf{f(t) = A \cdot \left[\frac{t-(T_{max}-T_{rise})}{T_{rise}}\right]^{\alpha} e^{-\alpha\frac{t-T_{max}}{T_{rise}}} \boldsymbol{\theta}(t - T_{max} - T_{rise})}$$

- Modify parametric form according to transfromation $\mathrm{T_{rise}} = \alpha\beta$ so that $\beta \simeq 1$ at $\alpha = 5$ and define $\Delta\mathrm{t} = \mathrm{t} - \mathrm{T_{max}}$

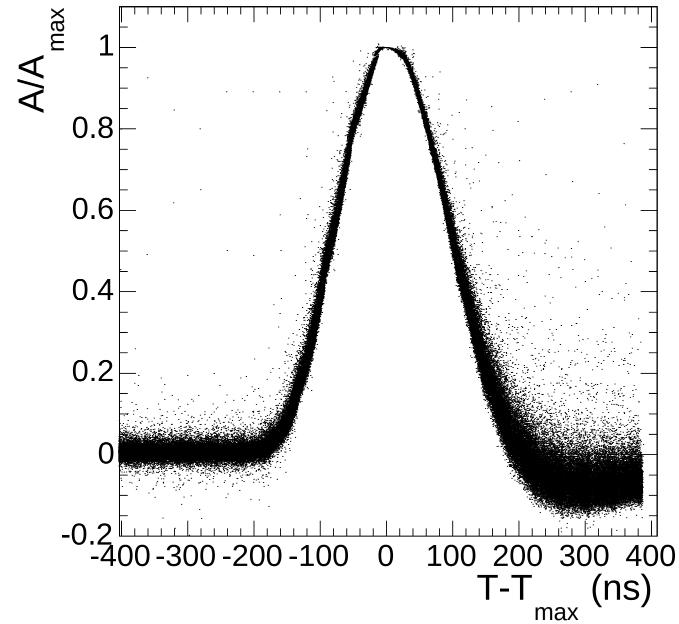
$$\mathbf{f(t) = A \cdot \left(1 + \frac{\Delta t}{\alpha\beta}\right)^{\alpha} e^{-\frac{\Delta t}{\beta}} \cdot \boldsymbol{\theta}(\Delta t + \alpha\beta)}$$

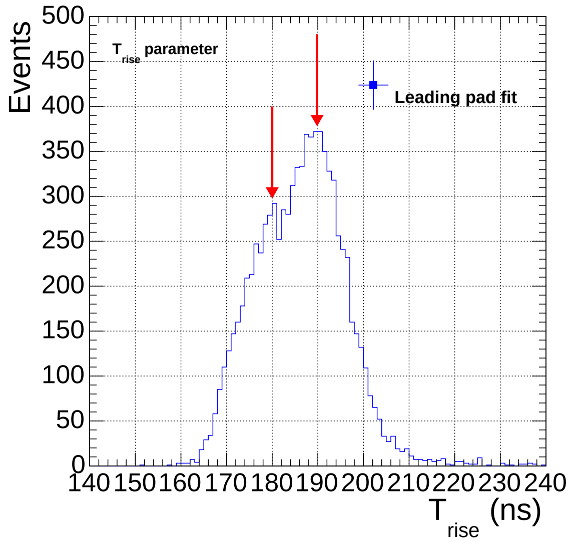
Single pulse fit with 3 floated parameters ($\alpha = 5$): restricted the fit range to +3 and -2 time samples around the maximum bin

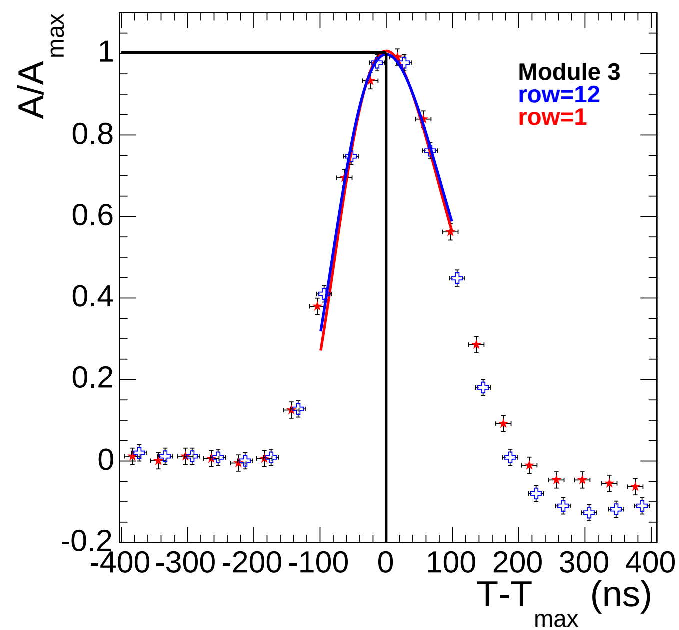
Fit Procedure

☞ Fit each individual (leading) pulse with f(t)

- normalize amplitude to A_{max} pulse-by-pulse
- force pulse maximum at zero
- reasonable stability of the pulse shape
  - → difference is minimal around the peak
  - → sizable uncertainty around T_0
  - → large variation in tails (can be negative)





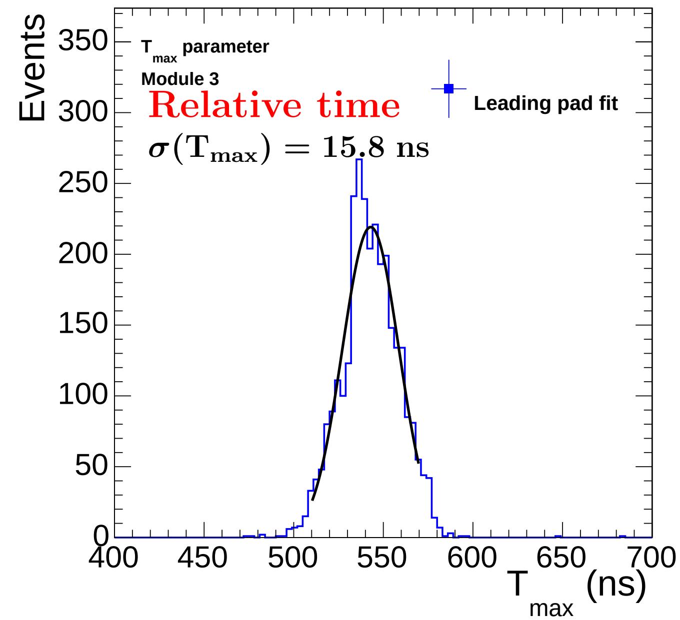


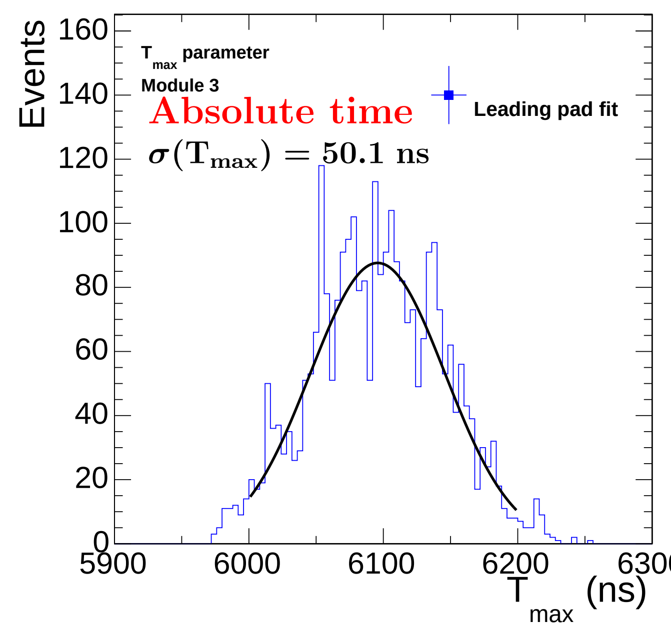
Sholder structure indicates T_{rise} *variation from channel-by-channel (event-by-event)*

Direct study of arrival time stability is troublesome with current setup

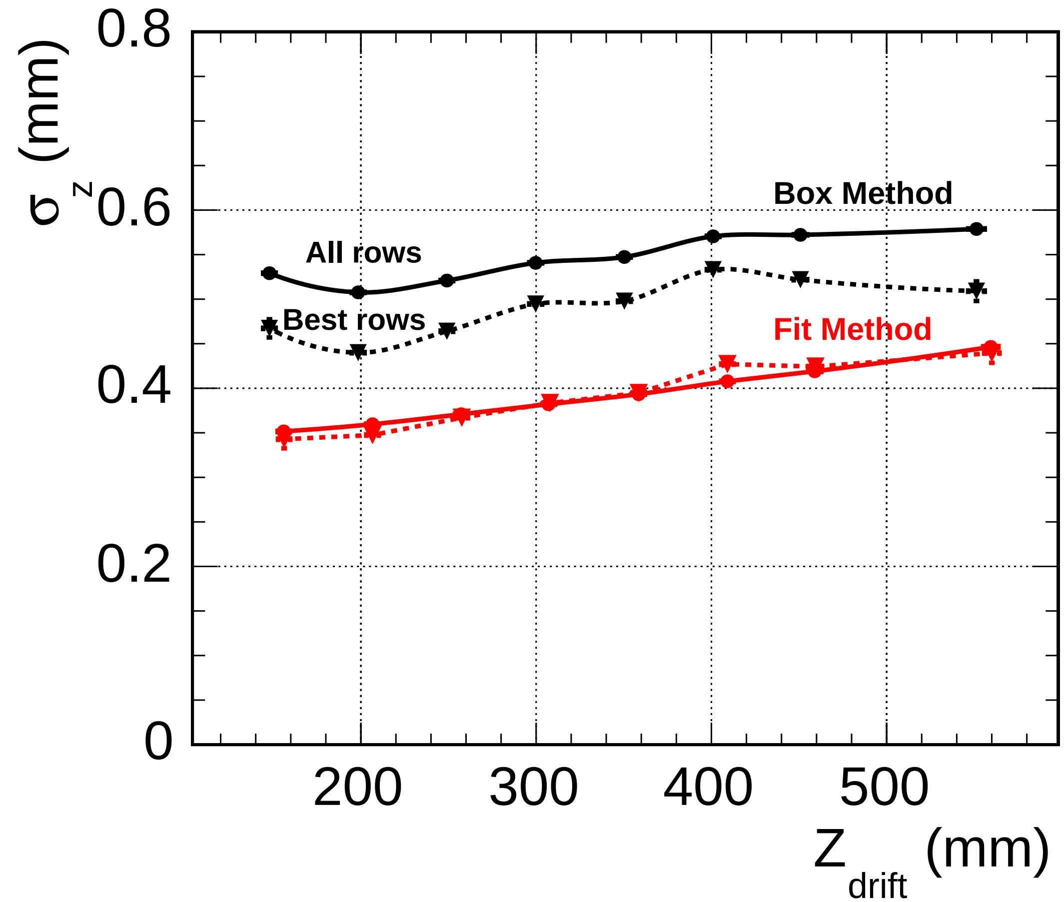
- Jitter of T_{max} takes place due to
  - absolute variation of the start bin
  - finit size of the beam (absolute time)
- Direct stability test is feasible with facility upgrade
  - includes a few silicon layers for precision beam position determination

However, it is not a problem for the resolution, which can be determined from residuals of the Kalman track fit





- Z resolution study with the Kalman fitter has been performed
  - improvement of **about 25%** is achived at short drift distance tracks
  - slightly reduces the improvement at long distance due to diffusion contribution
  - current method accounts channel-by-channel/event-by-event pulse shape variation and **offers homogenious resolution accross the module**



- **Longitudinal resolution of Micromegas TPC has been studied using the pulse shape fit method**
  - analytic function for pulse shape parameterization has been proposed
  - fit to leading pulse with 3 floated parameters
  - reach reasonable stability of the fit in the restricted time range
- Z resolution study with the Kalman fitter has been performed
  - improvement of **about 25%** is achived at short drift distance tracks
  - slightly reduces the improvement at long distance due to diffusion contribution
  - current method accounts channel-by-channel/event-by-event pulse shape variation and **offers homogenious resolution accross the module**
- Further study foreseen
  - extend the pulse shape fit for the subleading pads
  - study of impact on $\sigma_{r\phi}$ resolution
  - code implementation at `MMHitFinderProcessor`

Worth a combination of efforts between MM and GEM groups for further study

Backup