Performance of the GridPix detector quad

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Outline

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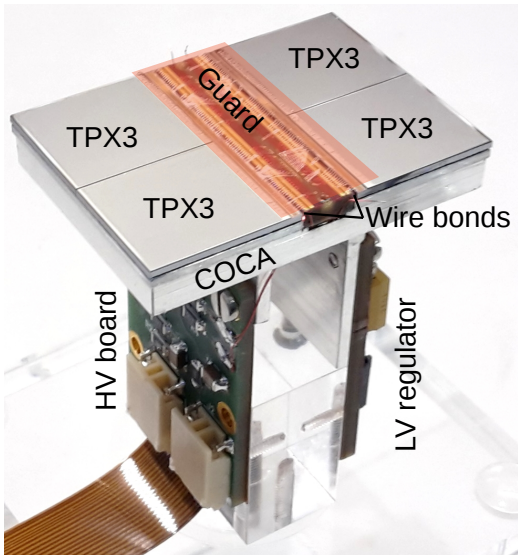
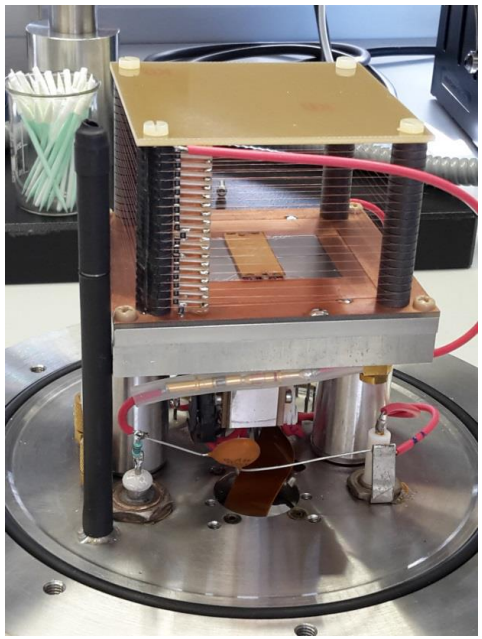
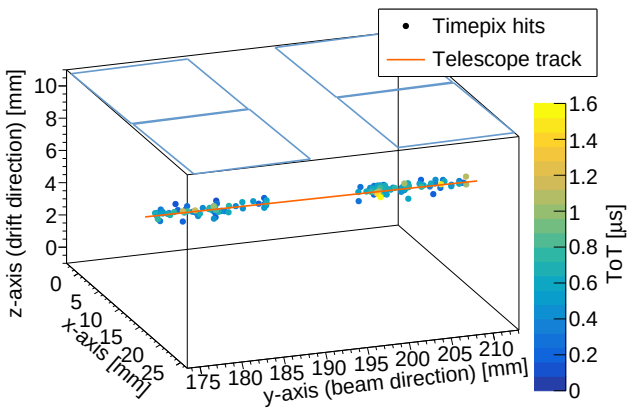
Introduction

- Quad is a module consisting of 4 Timepix3 GridPix chips, with all services under the active area
- Quad detector is put inside a test box with guards and field shaping, filled with T2K gas





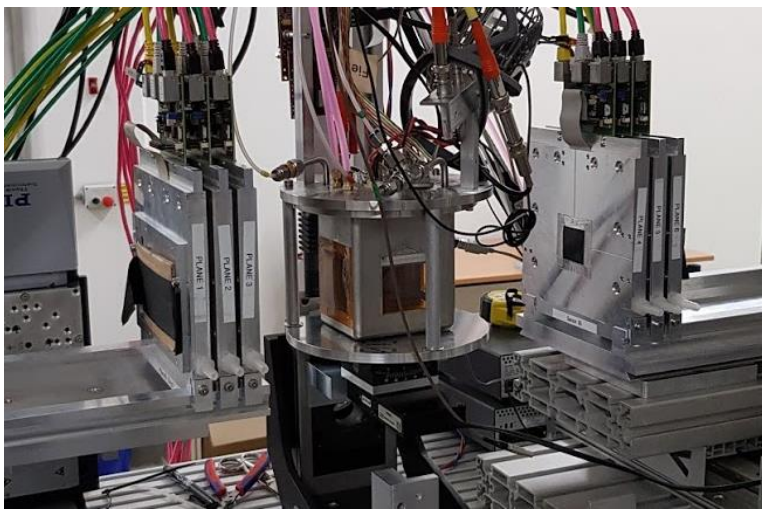


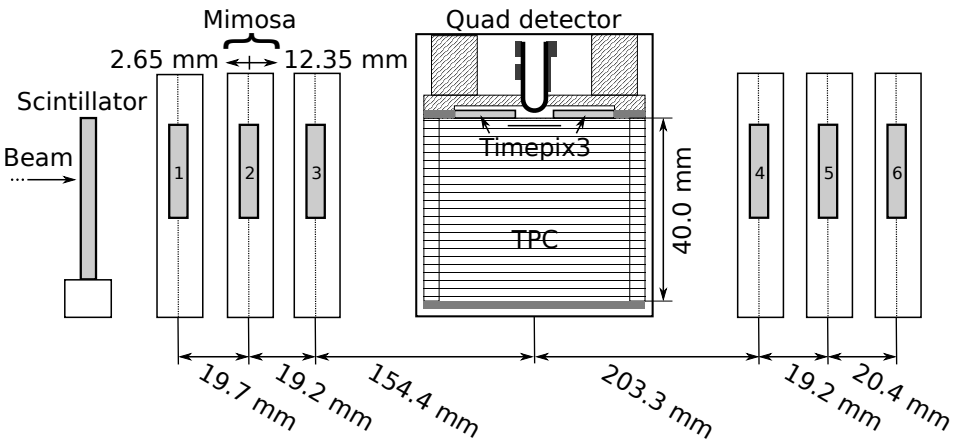
Example event with 148 hits

See also talk by Fred Hartjes

Detector setup at Bonn test beam

- 2.5 GeV electrons provided by the ELSA facility (Bonn) at a 10 kHz rate
- Events are triggered by a scintillating plane and numbered by the Trigger Logic Unit with a trigger rate of about 4 kHz
- The telescope consist of 6 mimosa planes with 18.4 µm × 18.4 µm sized pixels





Results published in NIM-A: doi:10.1016/j.nima.2019.163331

Run parameters and selection

- The grid voltage was set to 330 V and the drift voltage was set to 400 V/cm to compensate for water vapor contamination.
- The measured drift velocity of 54.6 µm/ns is slightly lower than the expected value of 59 µm/ns
- Selection cuts were impossed to acquire a clean set of tracks

Run parameters	
Runs duration	10 minutes
Triggers per run	2.2×10^6 triggers
V_{grid}	330 V
E_{drift}	400 V/cm
Threshold	550 e^-
Temperature	(300.5 $\pm$ 0.13) K
Pressure	(1011 $\pm$ 0.16) mbar
Oxygen concentration	814 ppm
Water vapor concentration	6000 ppm

Selection cuts
Telescope
Number of planes hits ≥ 5 Reject outliers ($r_{x,z} < 50\,\mu$m) Slope difference between sets of planes < 1 mrad
GridPix hit selection
$-500\text{ ns} < t_{\text{hit}} - t_{\text{trigger}} < 500\text{ ns}$ Hit ToT $> 0.15\,\mu$s Reject outliers ($r_x < 1.5\text{ mm}, r_z < 2\text{ mm}$) Reject outliers ($r_x < 2\sigma_x, r_z < 3\sigma_z$)
Event Selection
$N_{\text{hits}} \geq 20$ $(N_{r_x<1.5\text{mm}} \,/\, N_{r_x<5\text{mm}}) > 0.8$ $\lvert x_{\text{Timepix}} - x_{\text{telescope}} \rvert < 0.3\text{ mm}$ $\lvert z_{\text{Timepix}} - z_{\text{telescope}} \rvert < 0.3\text{ mm}$

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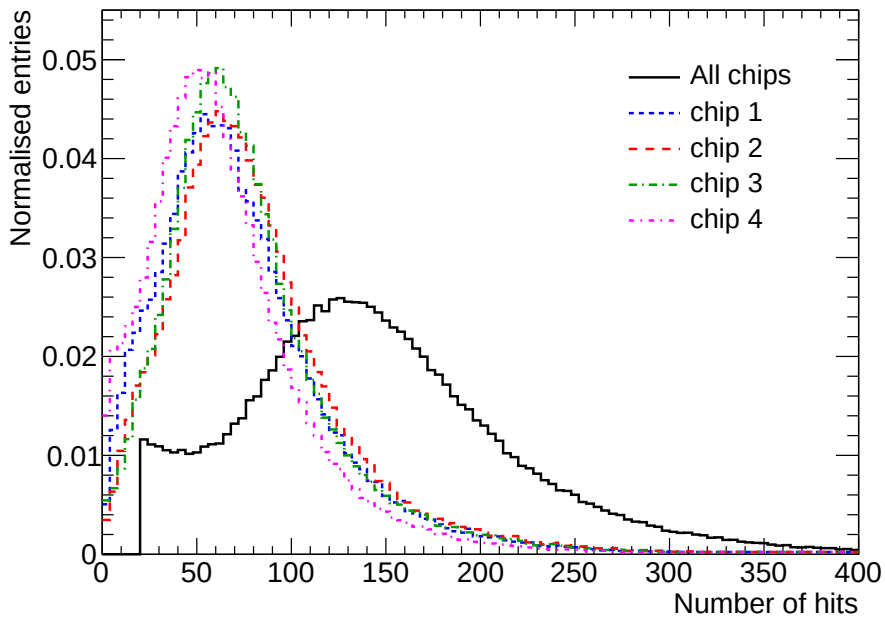
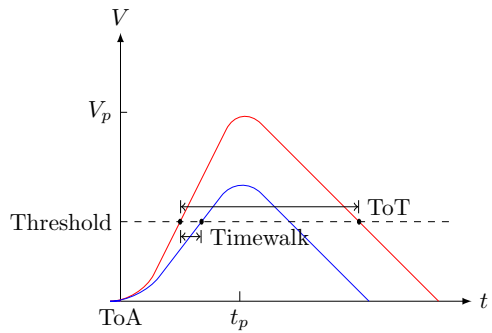
Number of hits

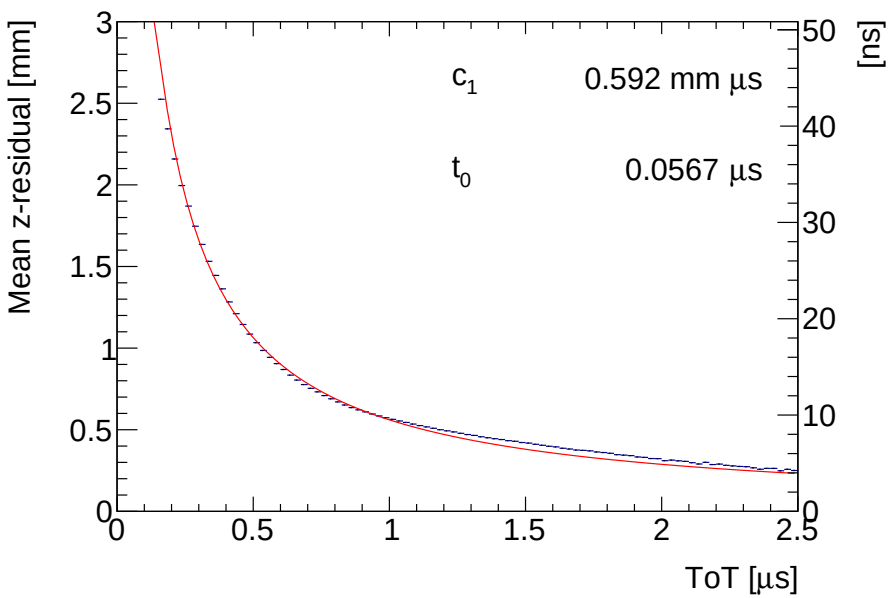
- The most probable number of hits of 131 is below the calculated most probable value of 225 electron-ions pairs
- This is due to the too low effective grid voltage, because of charging up effects and possibly also due to read-out problems

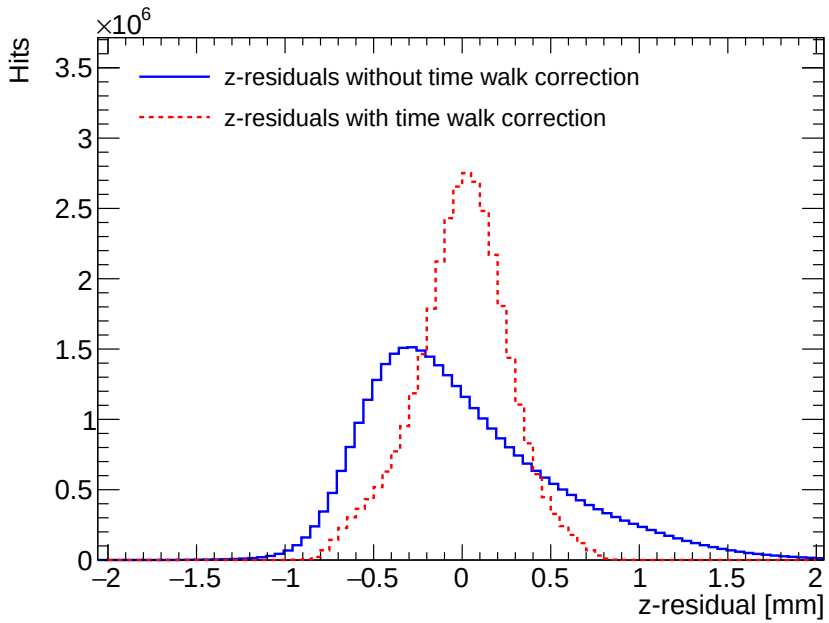


Time corrections

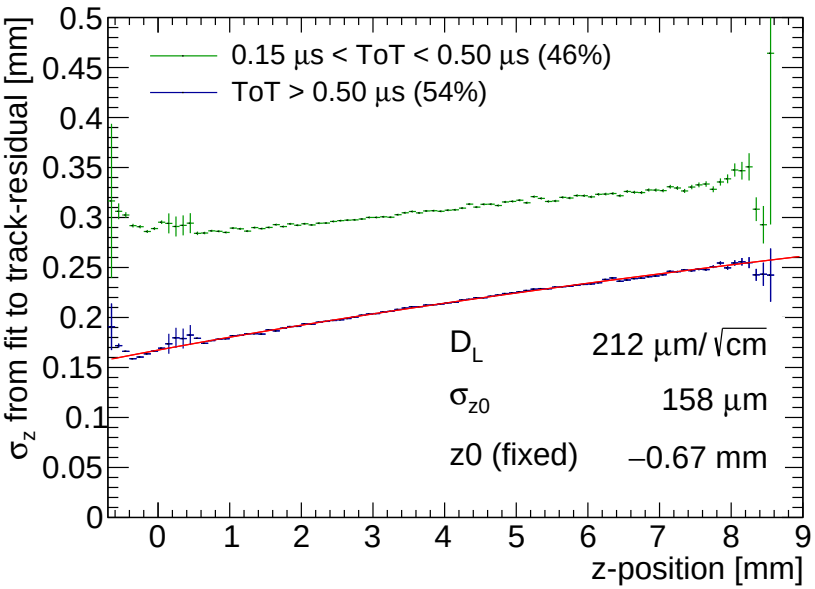
- Time walk occurs when the apparent time of arrival depends on the signal amplitude
- The time walk can be corrected using the Time over Threshold (ToT) as measure of signal strength:
  $\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$







Hit resolution in drift direction



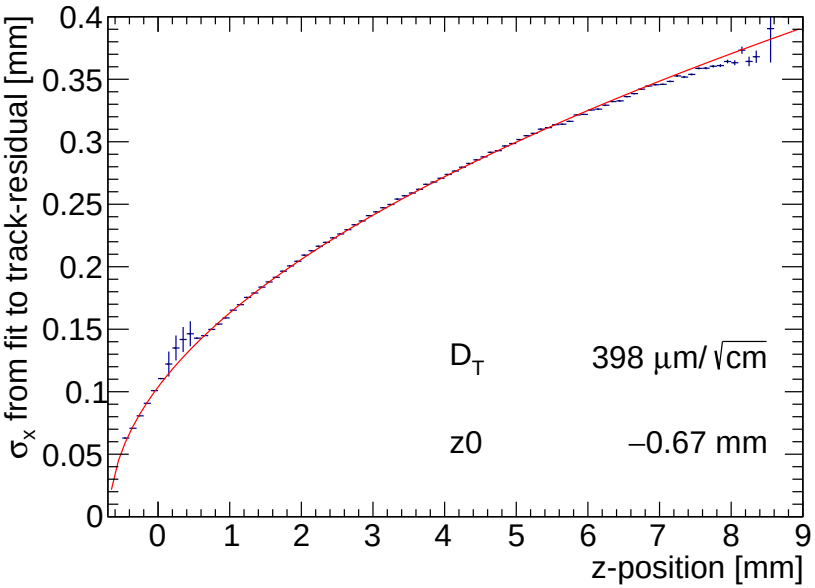
Single hit resolution in drift direction $\sigma_z^2 = \sigma_{z0}^2 + D_L^2(z - z_0)$, depends on

- σ_{z0} from fit
- Diffusion D_L from fit

Because of a large time walk error in hits with a low signal strength, an additional ToT cut ($> 0.60\,\mu s$) was imposed

The longitudinal diffusion coefficient at $B = 0$ agrees with the Magboltz value of $212\,\mu m/\sqrt{cm}$.

Hit resolution in pixel (precision) plane



Single hit resolution in drift direction $\sigma_x^2 = \sigma_{x0}^2 + D_T^2(z - z_0)$, depends on

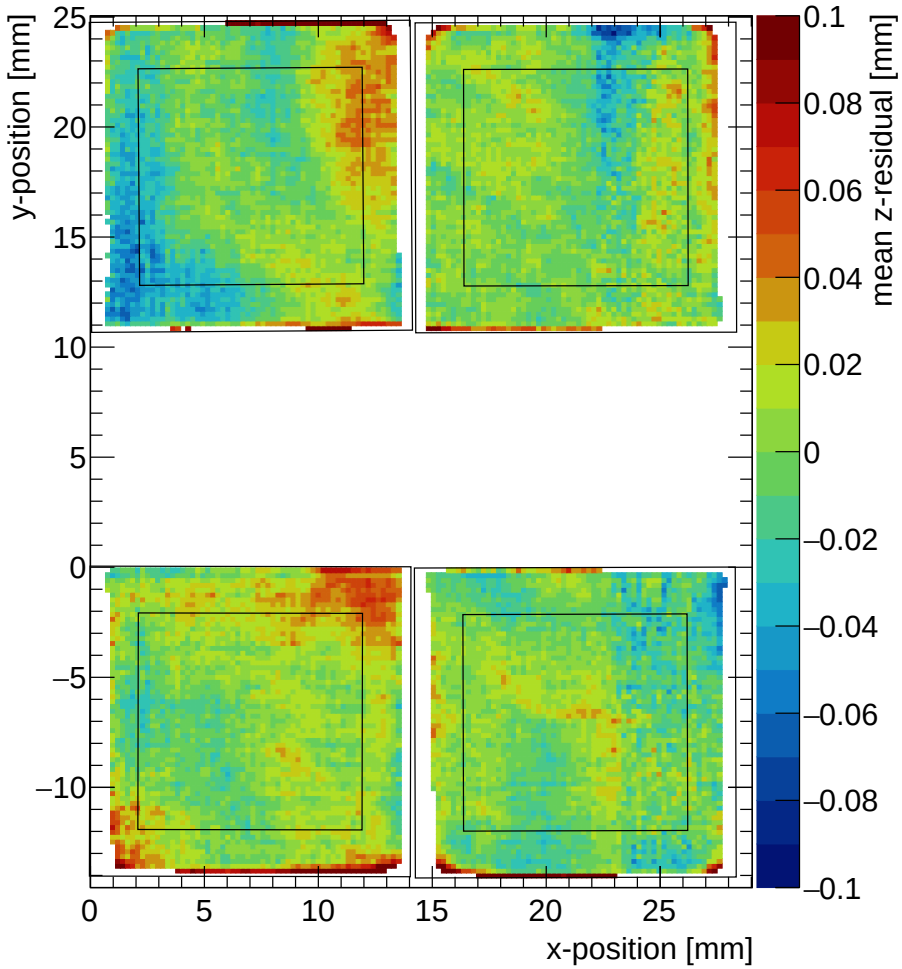
- σ_{x0} set to pixel size $55\,\mu m/\sqrt{12}$
- Diffusion D_T from fit

The transverse diffusion coefficient at $B = 0$ is larger than the Magboltz value of $270\,\mu m/\sqrt{cm}$, due to an error in the mixing of the CF_4 gas.

A single hit resolution of 250 µm corresponds to a resolution of 44 µm for a 6 mm track with 32 electrons.

Deformations in the drift direction

- Investigation of systematic deviations over the pixel plane
- Each bin displays mean of residuals from 4 $\times$ 4 pixels
- Primarily due to electric field distortions



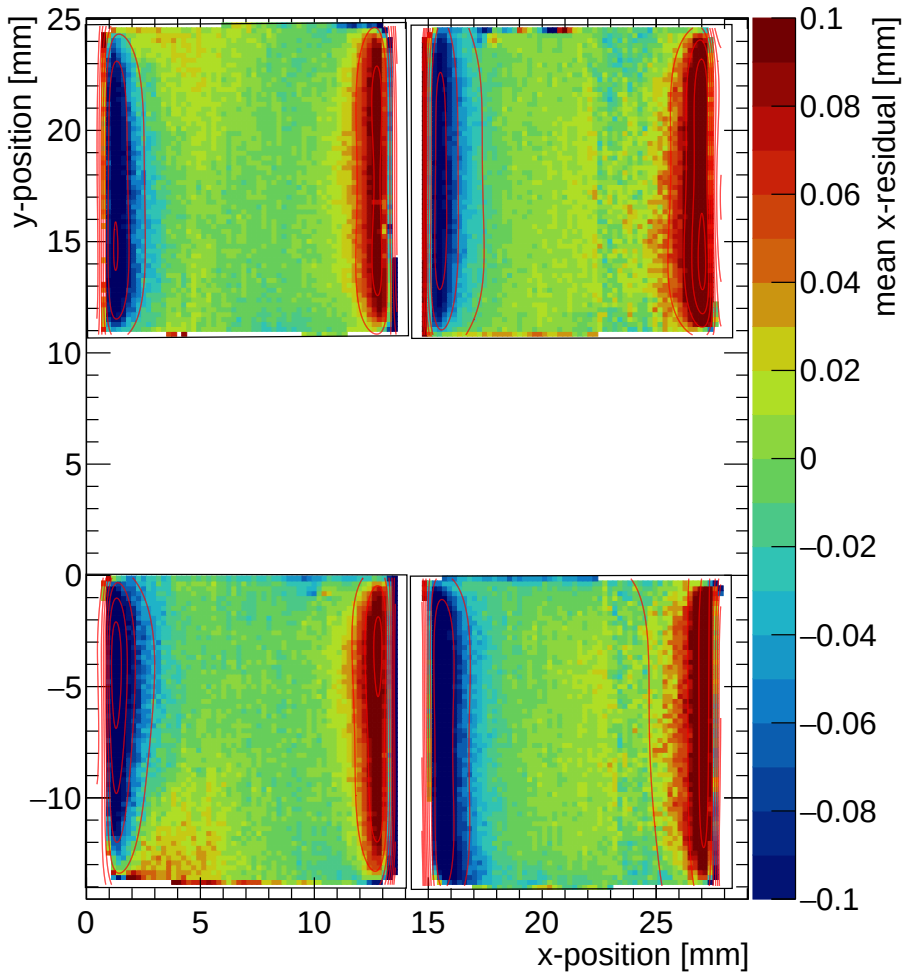
Deformations in the pixel plane

before corrections

- Investigation of systematic deviations over the pixel plane
- Each bin displays mean of residuals from 4×4 pixels
- Primarily due to electric field distortions

- Correction of deformations with 4 fitted Cauchy functions per chip:

$$\delta x_{\text{deform}} = \sum_{j=0}^{4} \left(\frac{1}{\pi} \frac{\gamma_j}{(x - d_j)^2 + \gamma_j^2} \sum_{i=0}^{4} \left(c_{ij} y^i \right) \right).$$



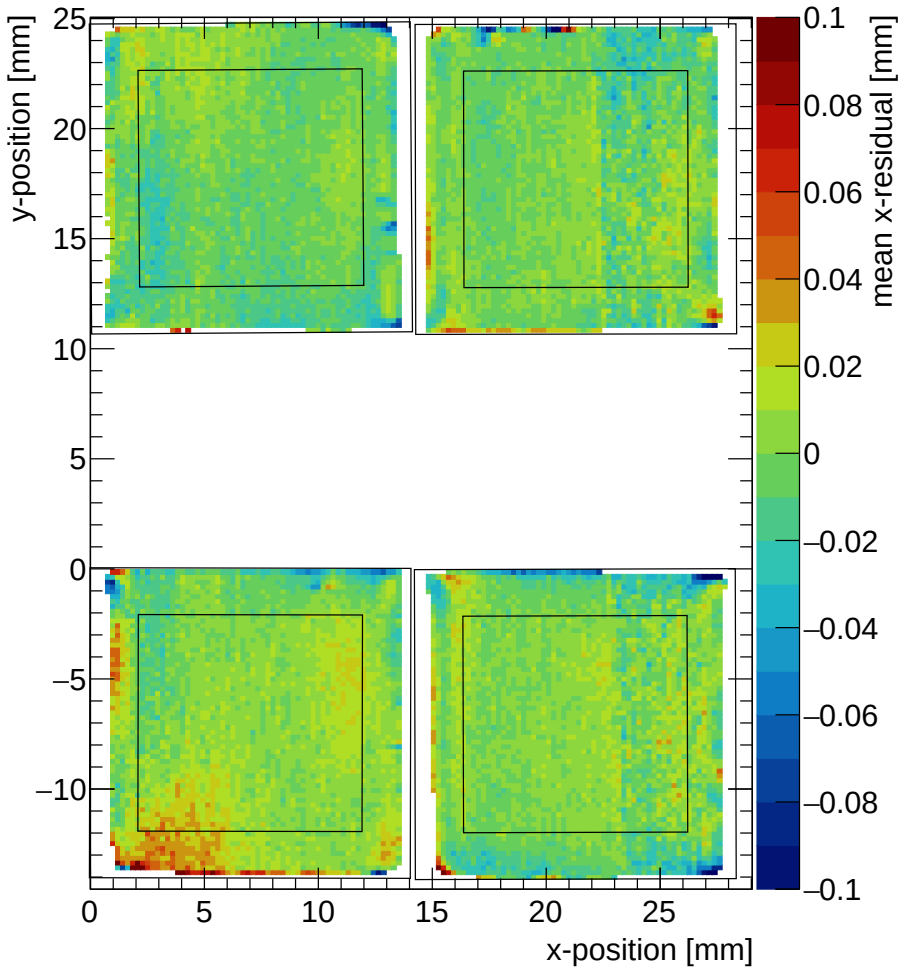
Deformations in the pixel plane

after corrections

- Investigation of systematic deviations over the pixel plane
- Each bin displays mean of residuals from 4×4 pixels
- Primarily due to electric field distortions

- Correction of deformations with 4 fitted Cauchy functions per chip:

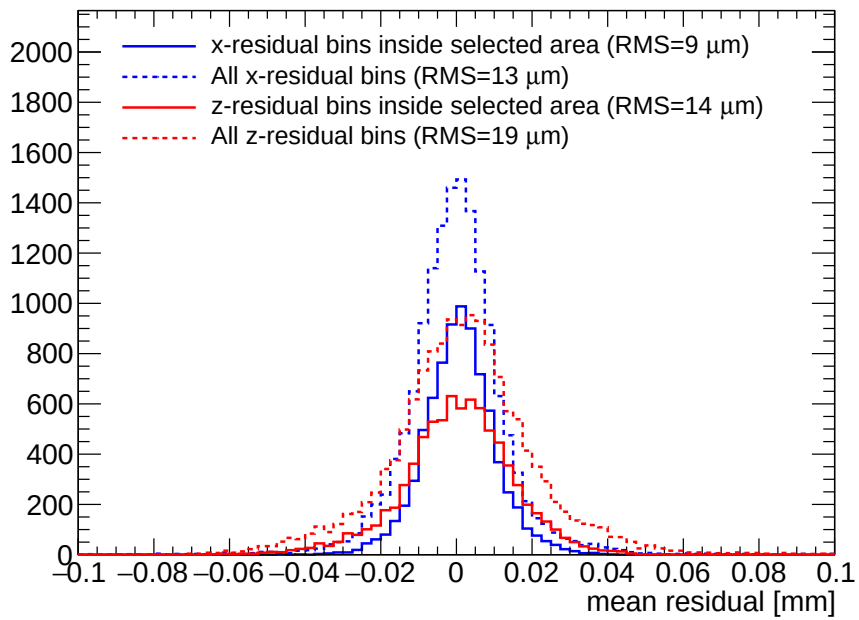
$$\delta x_{\text{deform}} = \sum_{j=0}^{4} \left(\frac{1}{\pi} \frac{\gamma_j}{(x - d_j)^2 + \gamma_j^2} \sum_{i=0}^{4} \left(c_{ij} y^i \right) \right).$$



Deformations r.m.s.

The r.m.s. is a quantitative measure of the deformation or the systematic error

- In the drift direction the r.m.s. of the distortion is 19 µm (0.35 ns) and 14 µm (0.26 ns) in the black outlined central area 2 mm from the edges
- In the precision plane the r.m.s is 31 µm before corrections, and 13 µm (9 µm in the central region) after corrections

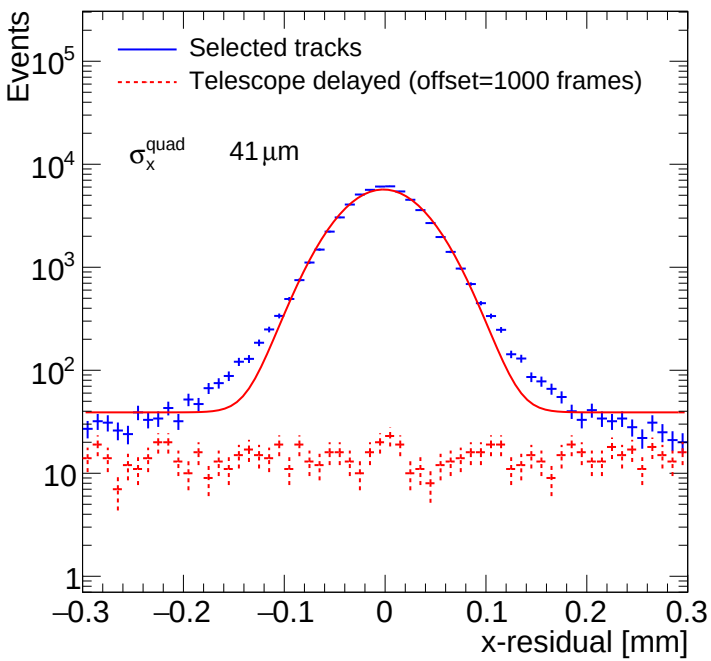


Quad detector resolution

Determine overall accuracy of a track position measurement
Subtract a background of unrelated tracks, estimated by shifting the telescope
Error contributions:

- Statistical error using hit resolution
- Systematic errors from r.m.s. in pixel plane and drift direction
- Multiple scattering contribution from simple Monte Carlo simulation

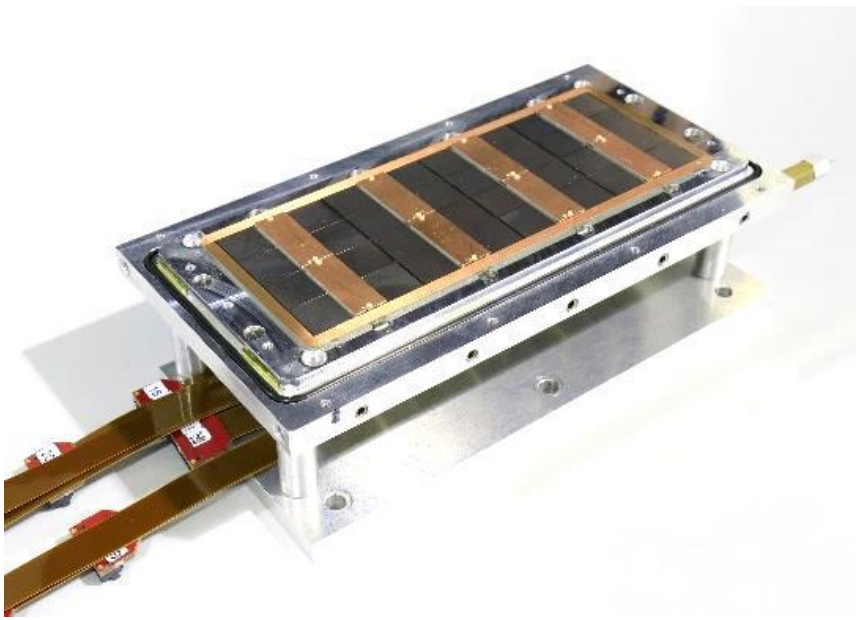
In the end, an unidentified contribution remains



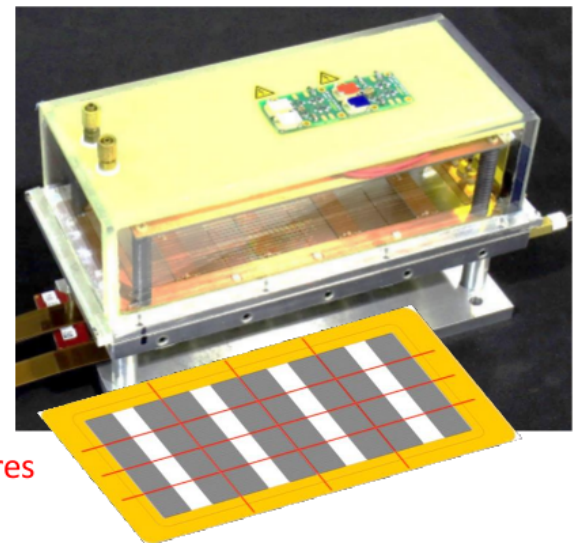
Observed standard deviation σ_x^{quad}	41 µm
Statistical quad detector error	25 µm
Statistical telescope error	2 µm
Systematics over the pixel plane (corrected)	9 µm
Systematics along the drift direction	17 µm
Multiple scattering contribution	22 µm
Remaining systematic error	14 µm

The 8 quad module

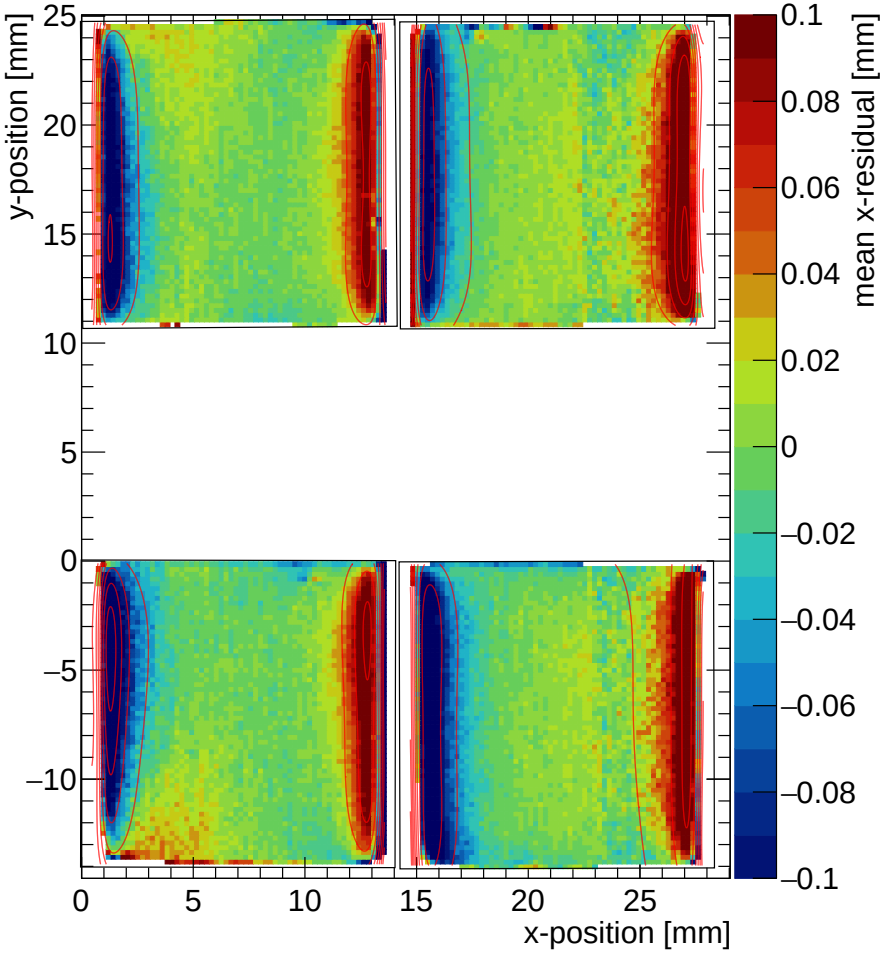
- 8 quad test box with (32 chips)
- Simultaneous read out through one SPIDR board using a data concentrator
- Field wires added to improve electric field, and reduce deformations



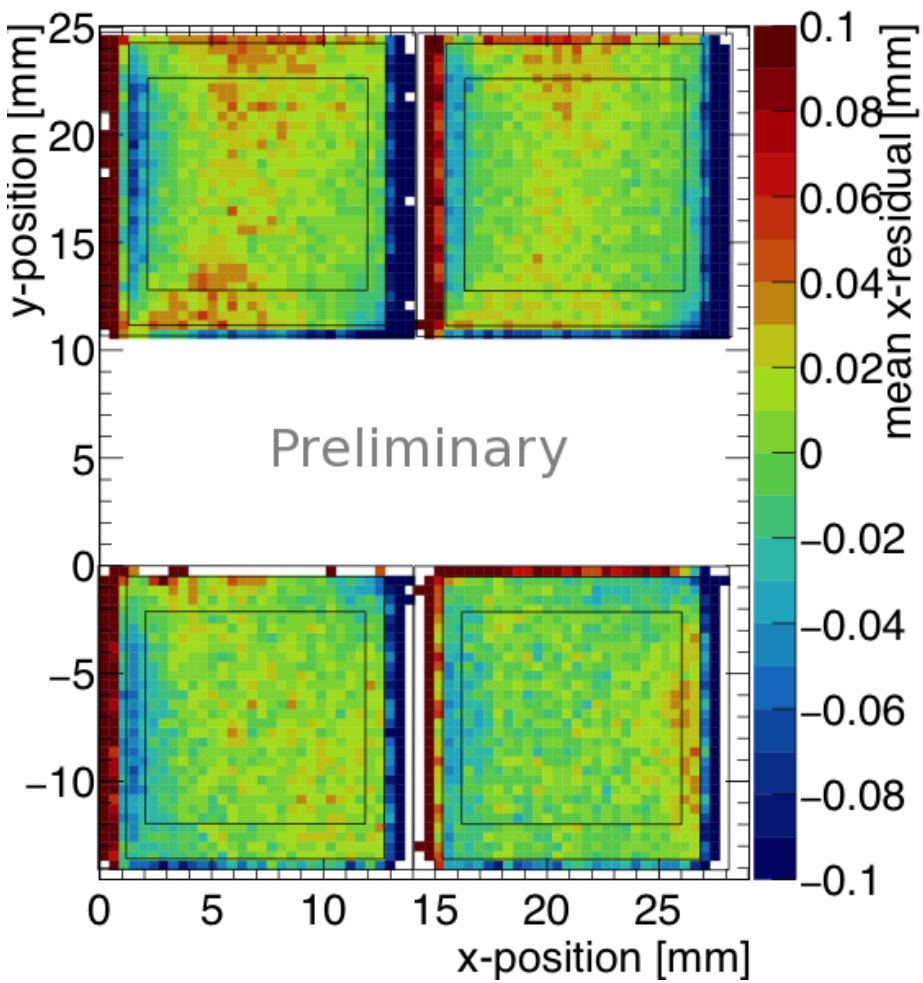
New field wires



Distortion in the 8 quad module



Uncorrected residuals from quad test beam



Uncorrected residuals from laser test with field wires

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Conclusions

- The quad detector was successfully operated at the the ELSA test beam facility
- The resolution in the transverse and longitudinal directions are primarily limited by diffusion
- A systematic error from the quad detector for the distortions over the pixel plane of 13 µm (9 µm in the central region) has been achieved
- The demonstrated resolution of the setup is 41 µm
- An improved detector with 8 quad modules (32 chips) will be tested soon

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