The gaseous QUAD pixel detector

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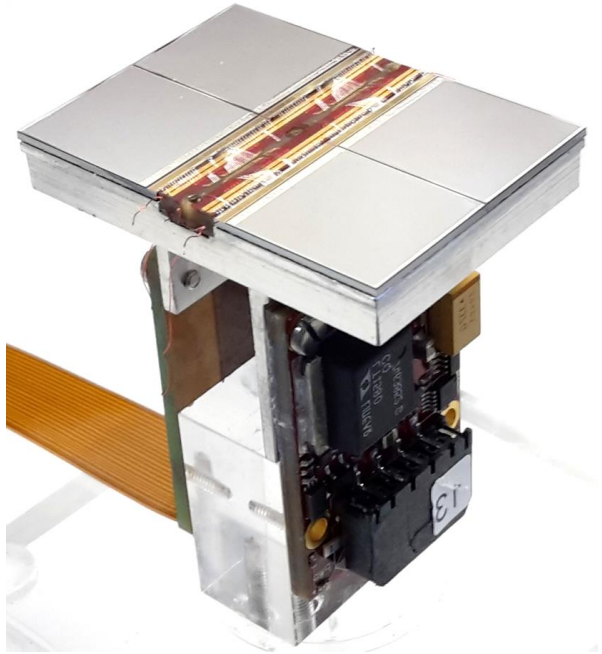
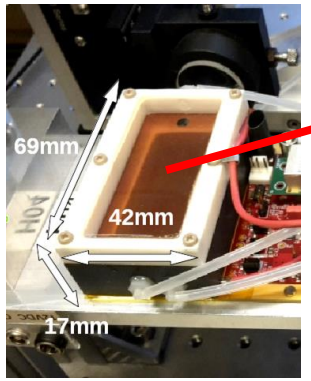
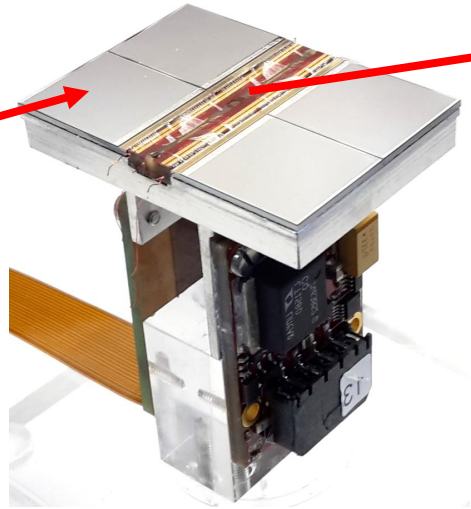
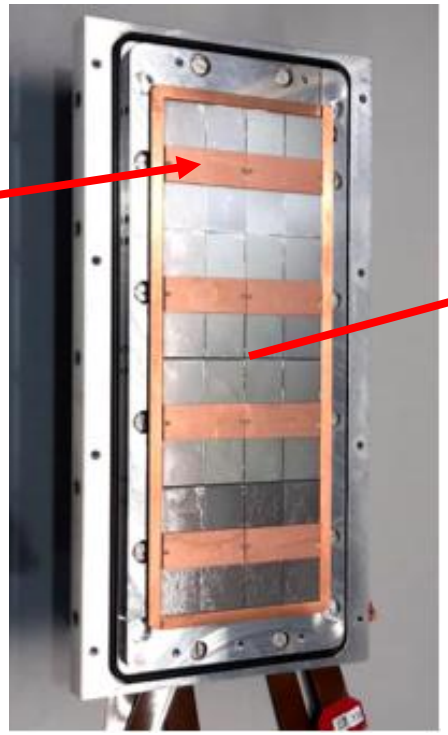


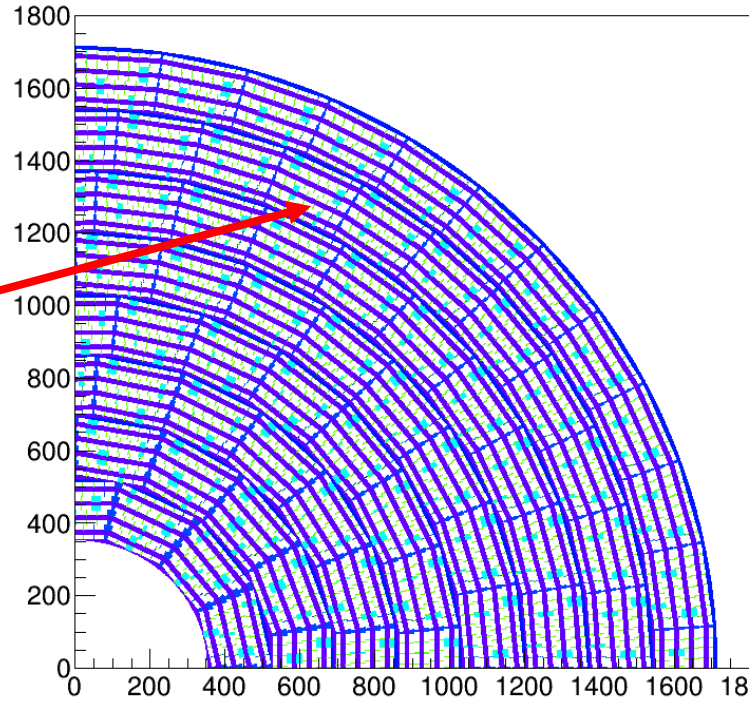
VCI2019 - 15th Vienna Conference on Instrumentation

Pixel TPC









Single chip 2017

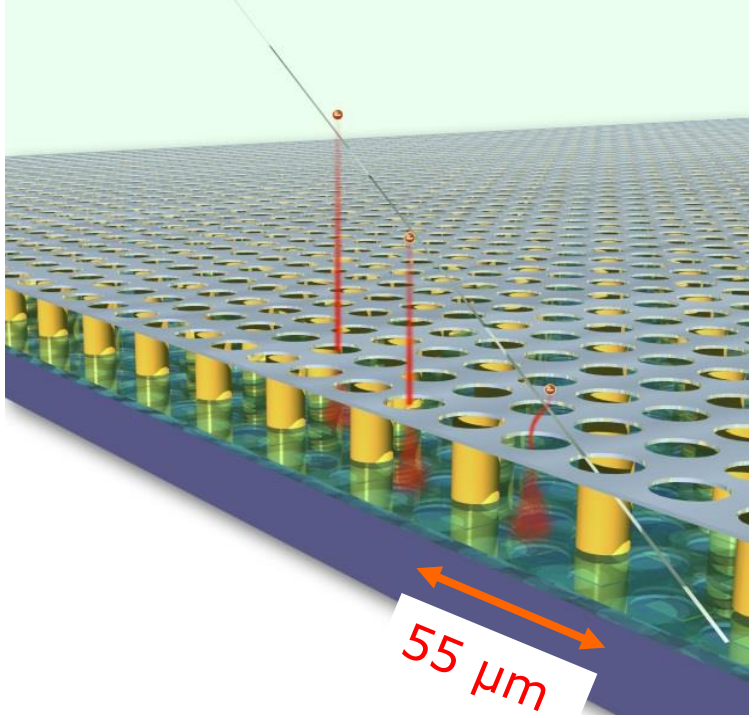
Quad 2018

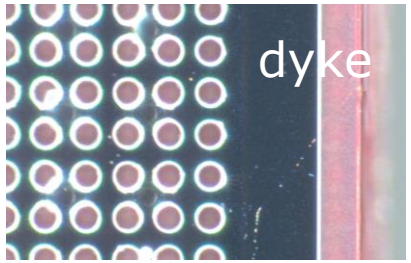
Module 2019

TPC plane

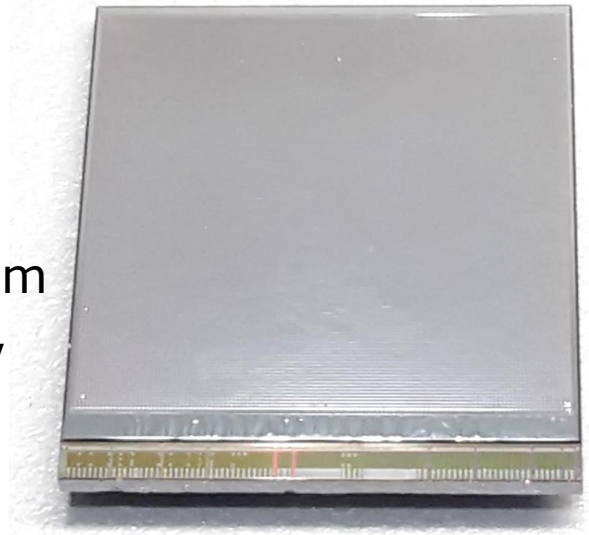
GridPix technology

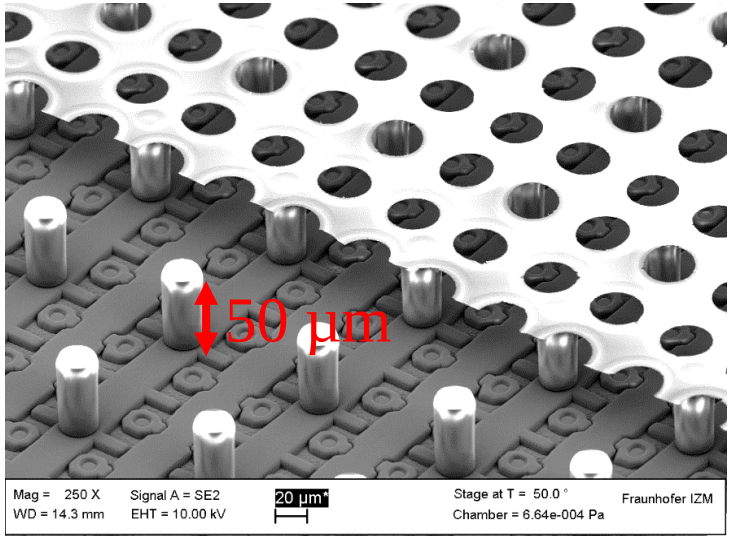
- Pixel chip with integrated Grid (Micromegas-like)
- InGrid post-processed @ IZM
- Grid set at negative voltage (300 – 600 V) to provide gas amplification
- Very small pixel size (55 μm)
- detecting individual electrons





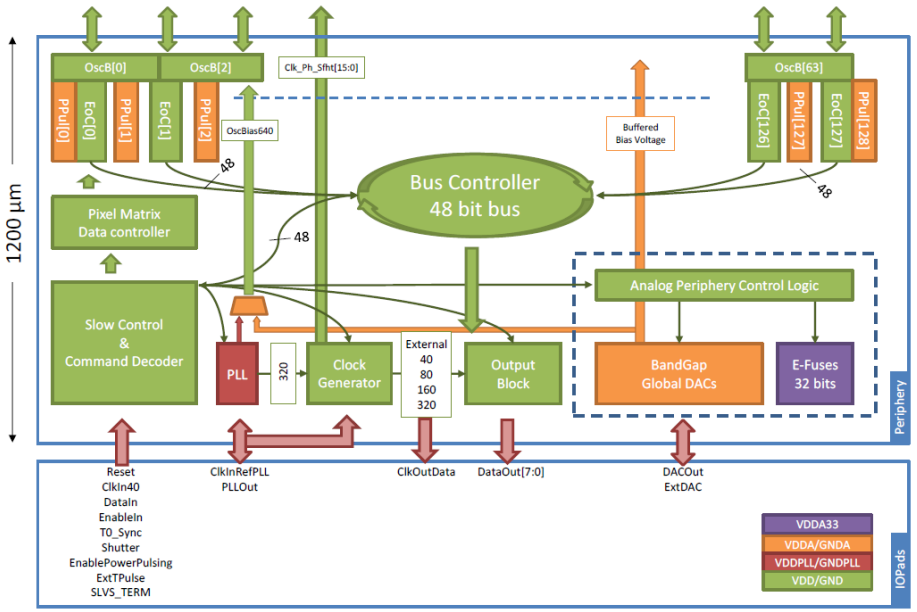
- Aluminium grid (1 μm thick)
- 35 μm wide holes, 55 μm pitch
- Supported by SU8 pillars 50 μm high
- Grid surrounded by SU8 dyke (150 μm wide solid strip) for mechanical and HV stability

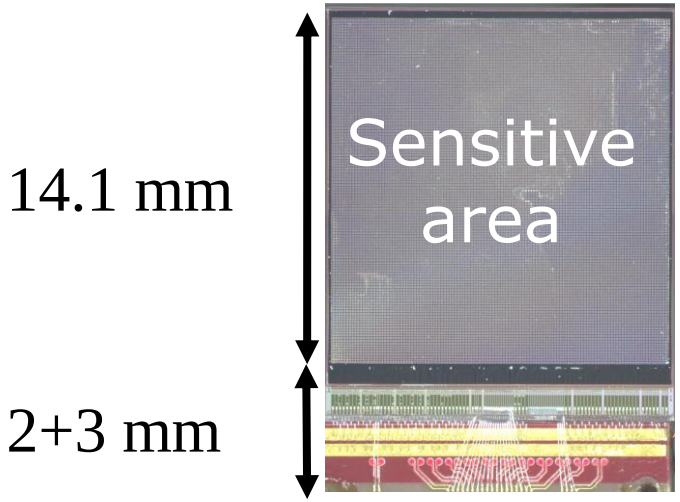




Pixel chip: TimePix3

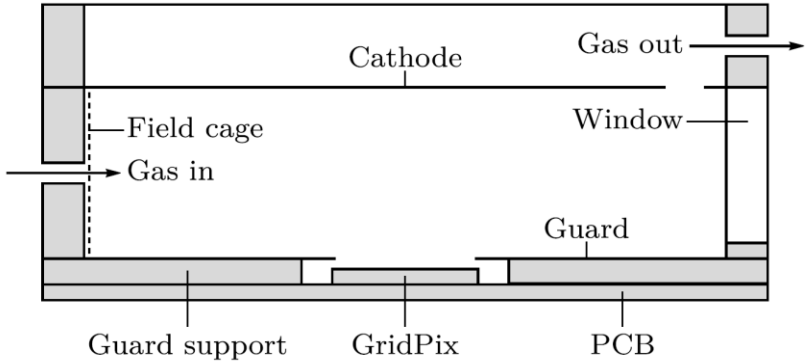
- 256 x 256 pixels
- 55 x 55 μm pitch
- 14.1 x 14.1 mm sensitive area
- TDC with **610 MHz clock** (1.64 ns)
- Used in the data driven mode
  - Each hit consists of the **pixel address** and **time stamp** of arrival time (ToA)
  - Time over threshold (ToT) is added to register the signal amplitude
  - compensation for time walk
  - **Trigger** (for t_0) added to the data stream as an additional time stamp
- Power consumption
  - ~1 A @ 2 V (2W) depending on hit rate
  - good cooling is important

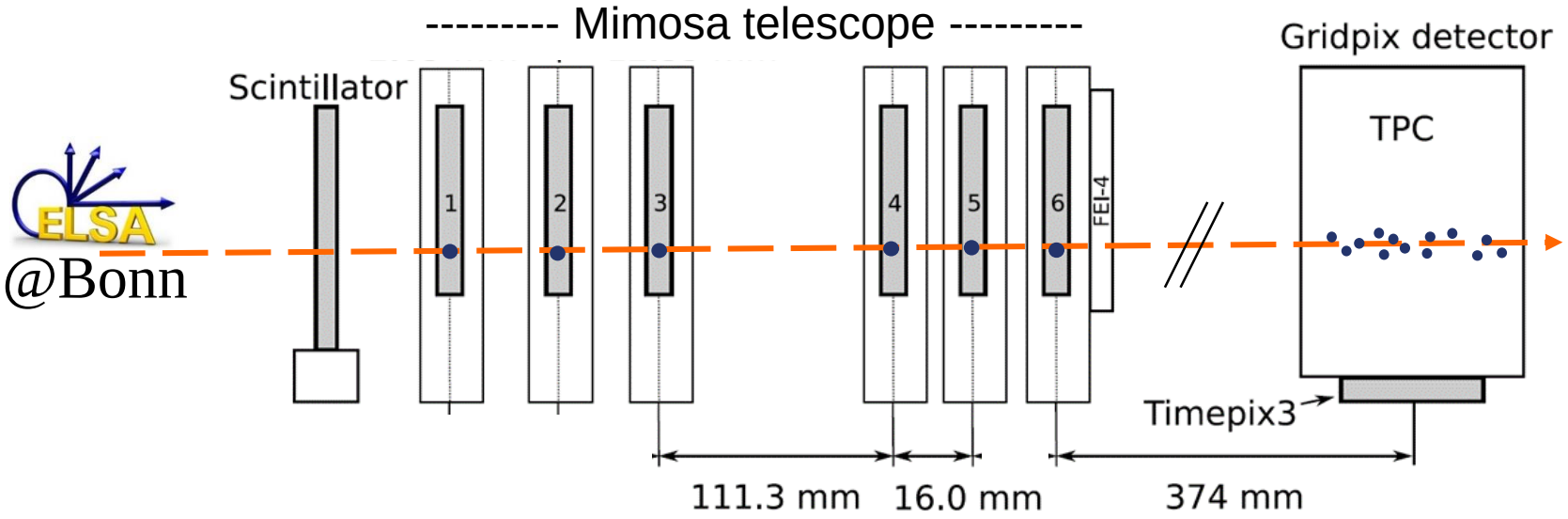




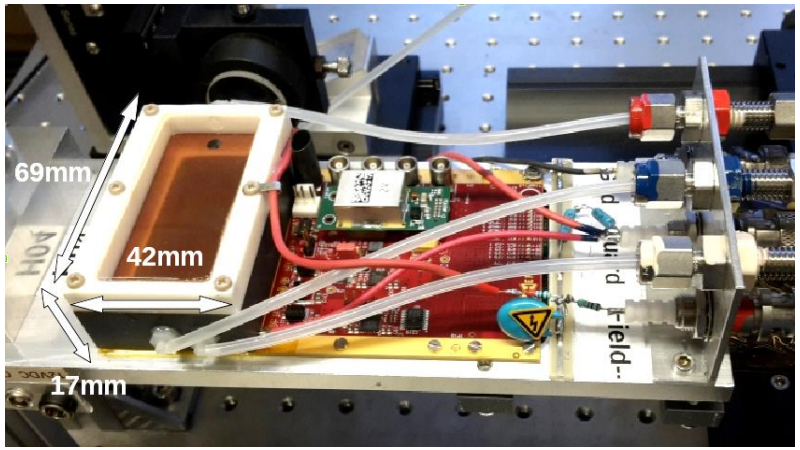
Single chip test in test beam Bonn (June 2017)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- Gas: $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)
- Electrons: ~100 e/cm
- E_d = 280 V/cm, V_{grid} = -350 V



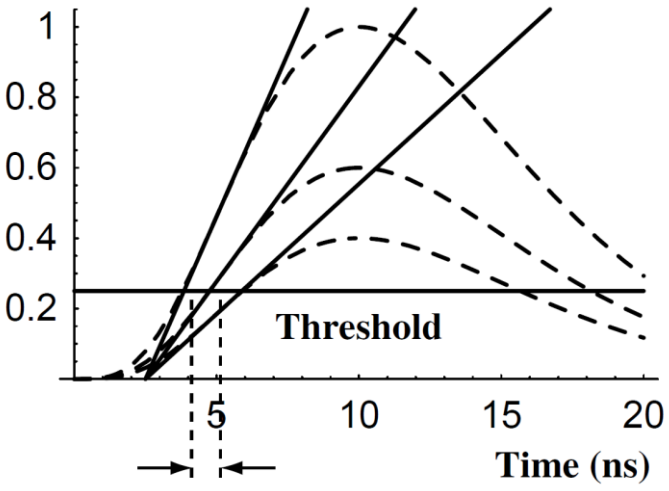


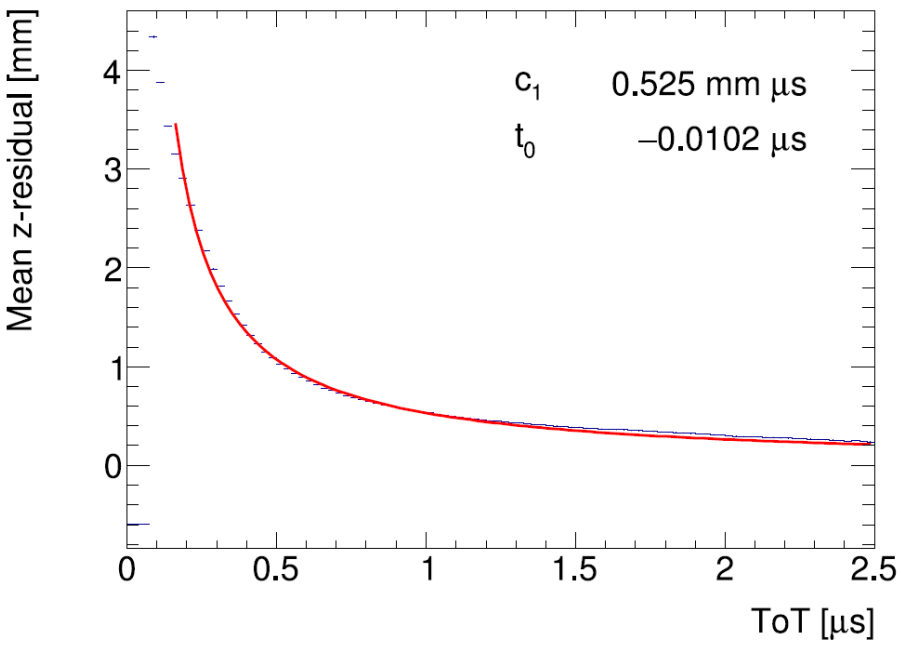
Detector with guard and field shaper

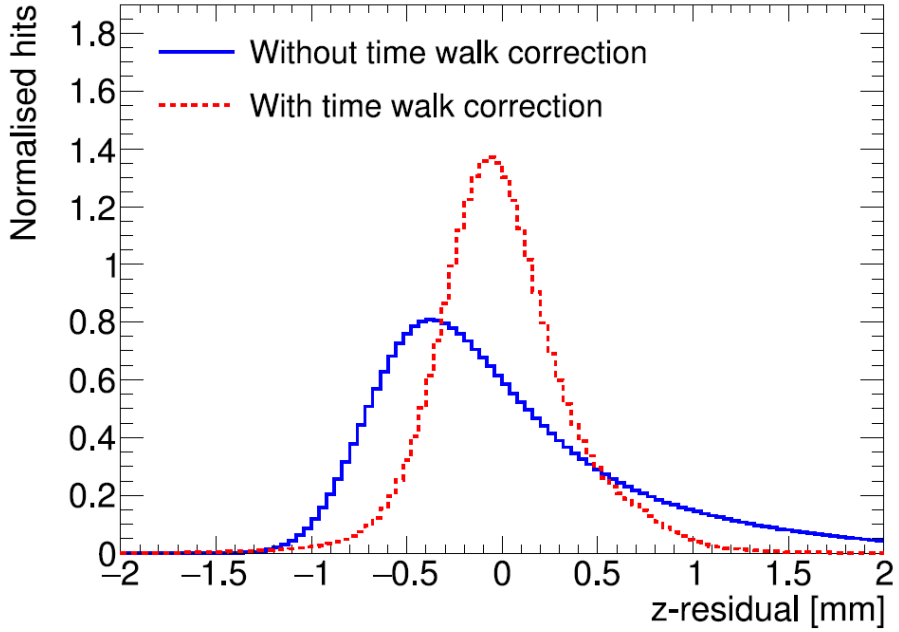


Published paper on 2017 testbeam: https://doi.org/10.1016/j.nima.2018.08.012

TimePix3 time walk correction







Time walk error: time of arrival depends on signal amplitude

(Blum, Particle detection 2008)

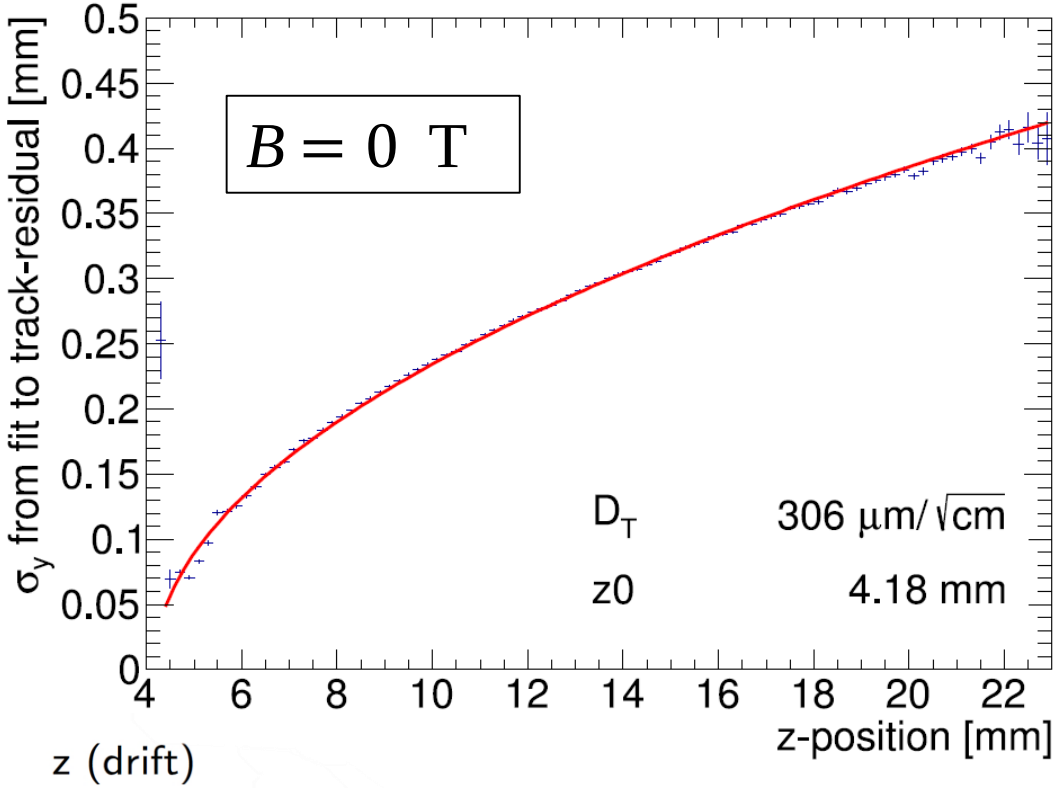
Correction using Time over Threshold (ToT) as a measure of signal strength

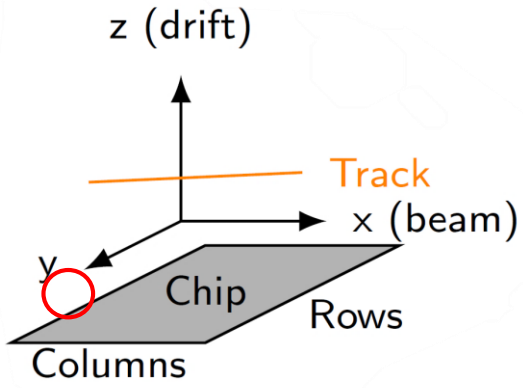
$$\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$$

Residual distribution improved

Higher order corrections did not yield further improvements

Single hit resolution in transverse direction





$$D_T = 306\ \mu\text{m}/\sqrt{\text{cm}}$$

($318 \pm 7\ \mu\text{m}/\sqrt{\text{cm}}$ expected)

Single hit resolution in pixel plane:

$$\sigma_y^2 = \sigma_{y0}^2 + D_T^2(z - z_0)$$

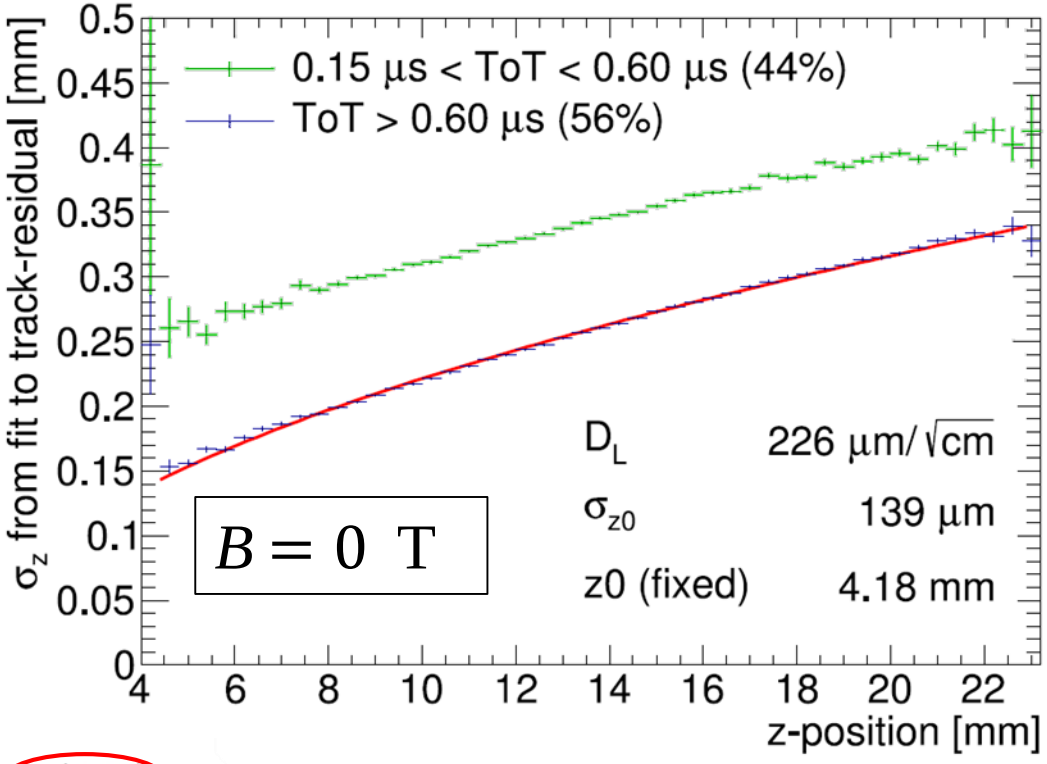
Depends on:

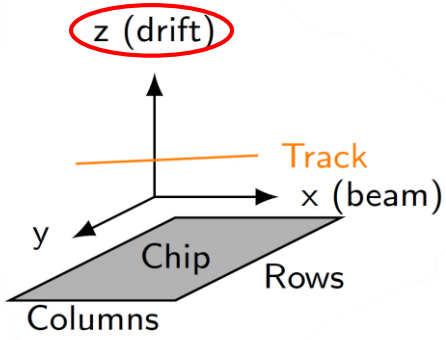
- σ_{y0} = pixel size $/\sqrt{12}$
- Diffusion D_T from fit

Note that:

- A hit resolution of ~250 μm is ~25 μm for a 100-hit track (~ 1 cm track length)
- At $B = 4$ T , $D_T = 25\ \mu\text{m}/\sqrt{\text{cm}}$

Single hit resolution in longitudinal direction





$$D_L = 226\ \mu\text{m}/\sqrt{\text{cm}}$$

$(201 \pm 5\ \mu\text{m}/\sqrt{\text{cm}}$ expected)

Single hit resolution in drift direction

$$\sigma_z^2 = \sigma_{z0}^2 + D_L^2(z - z_0)$$

Depends on

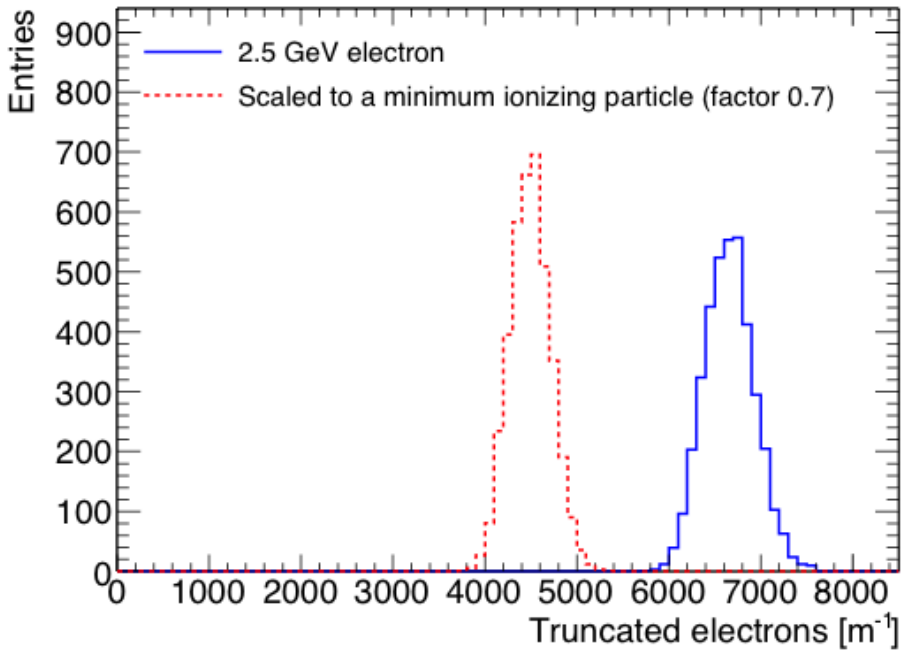
- σ_{z0} from fit
- Diffusion D_L from fit

The additional ToT cut (>0.60 μs) was applied to avoid large time walk errors

Pixel dE/dx performance

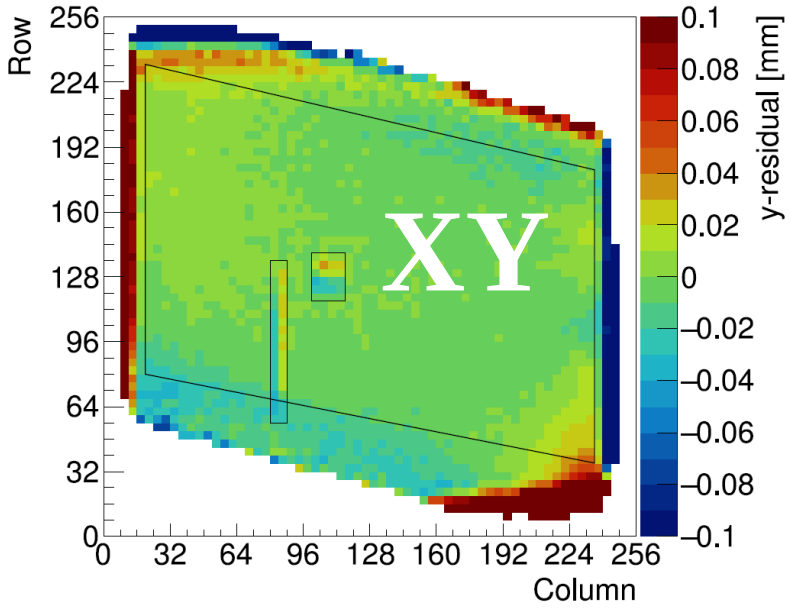
- dE/dx resolution with truncated mean
  - From the single chip tracks; 1 m long tracks are made;
  - nr of electrons counted in slices of 20 pixel and reject 10% highest slices
  - Distances along track are scaled by 1/0.7 to get an estimation for the dE/dx of a MIP
  - Resolution is 4.1% for a 2.5 GeV electron and 4.9% for a MIP
- Separation $S = (N_e - N_{MIP})/\sigma_e$
- 8σ MIP-e separation for a 1 meter track

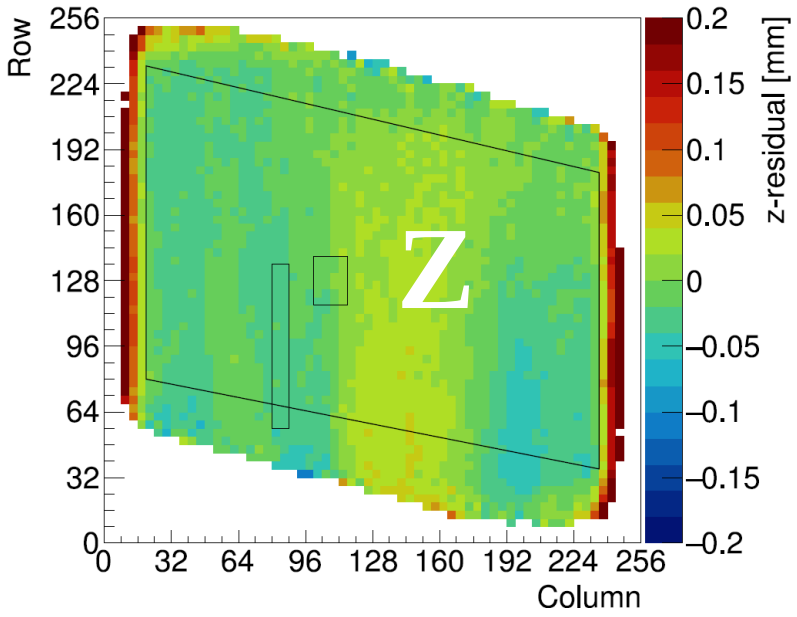
- A pixel readout can in principle within the resolution (diffusion) separate primary from secondary clusters. dE/dx can be measured by cluster counting and performance separation enhanced.

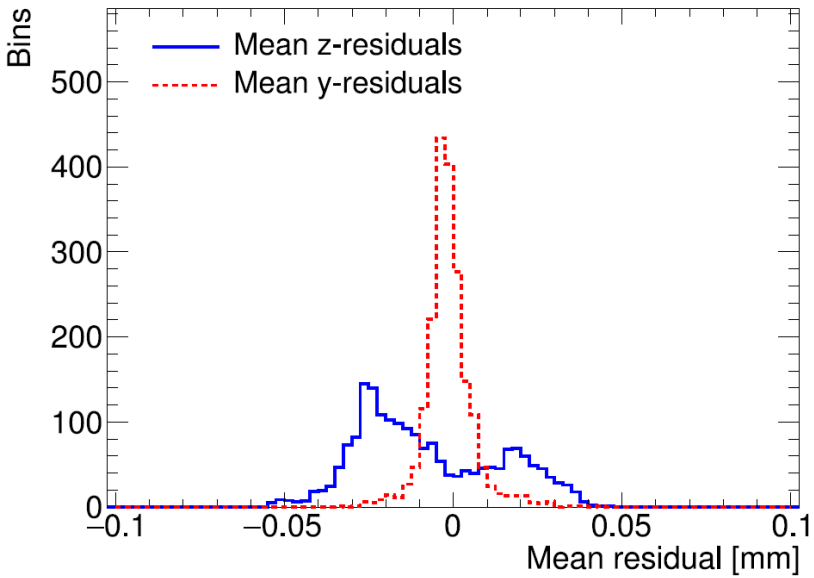


Deformations in pixel plane (XY) and drift direction (Z)

- The RMS of the mean residuals is 7 μm in the pixel plane and 21 μm (0.3 ns) in the drift direction in the selected region



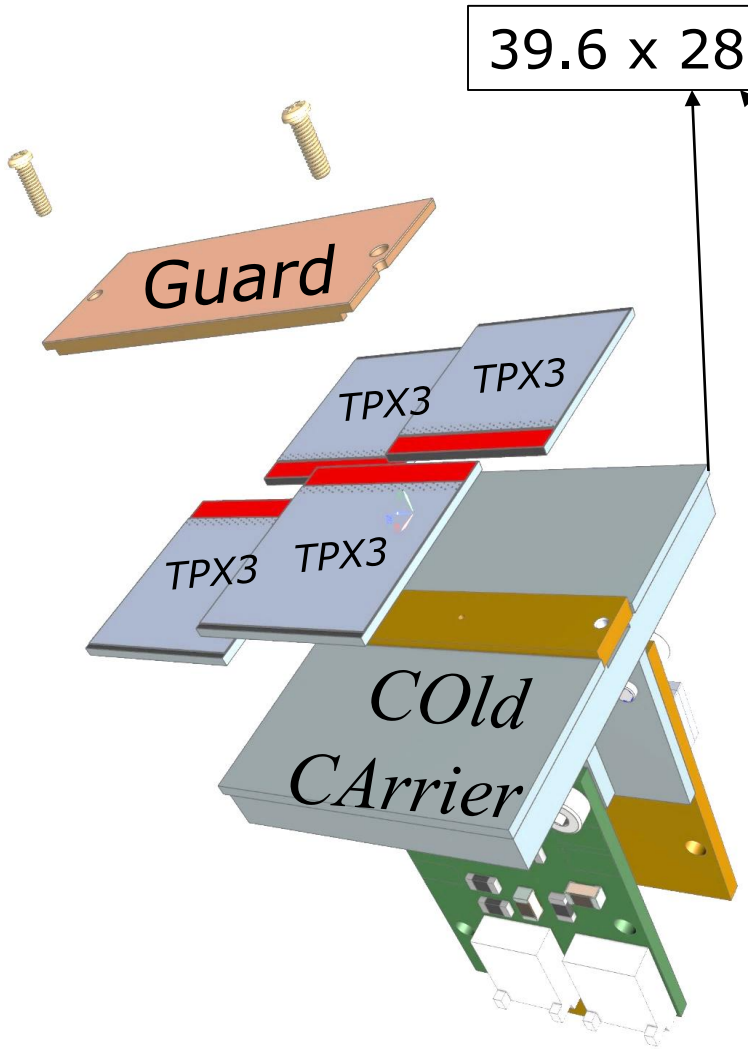




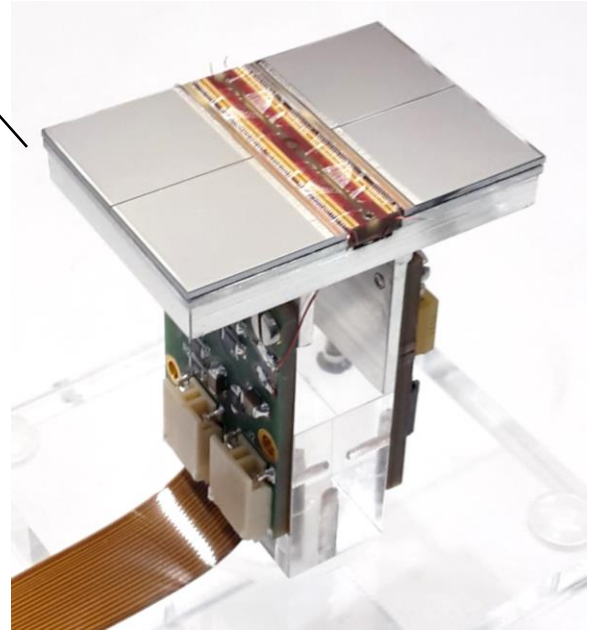
- How can we make an even better detector?
  - Improve the quality (homogenity) of the InGrid; redesign the dike and edges
  - Go to a large areas keeping the field distortions (at edges) minimal -> QUAD

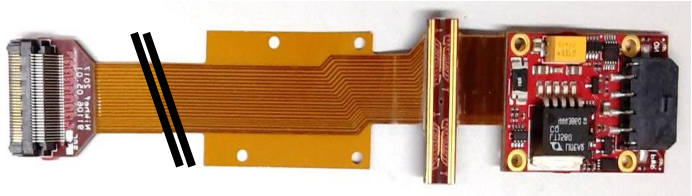
QUAD design and realization

- Four-TimePix3 chips
- All services (signal IO, LV power) are located under the detection surface
- The area for connections was squeezed to the minimum
- Very high precision 10 μm mounting of the chips and guard
- QUAD has an sensitive area of 68.9%
- DAQ by SPIDR



series of QUADs

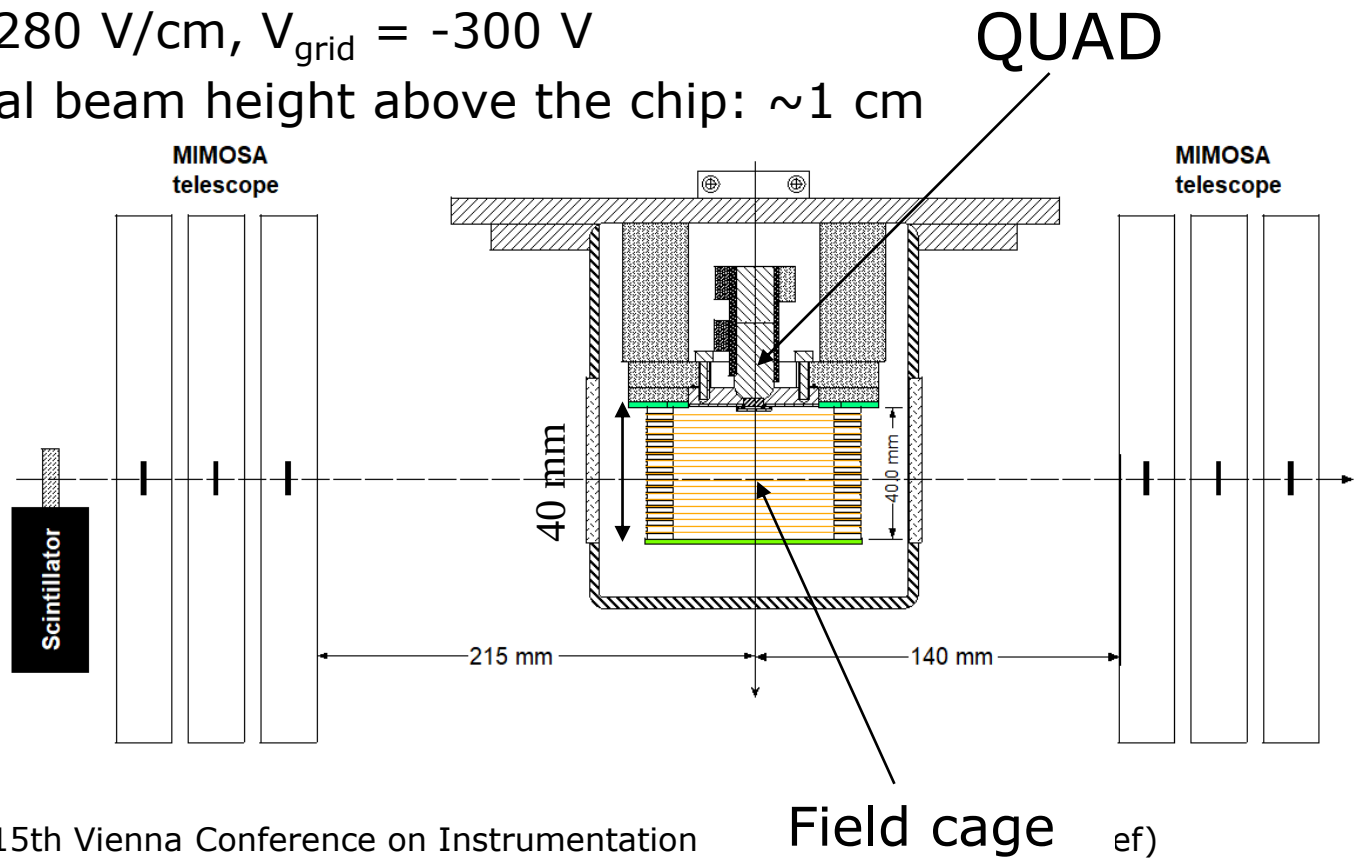




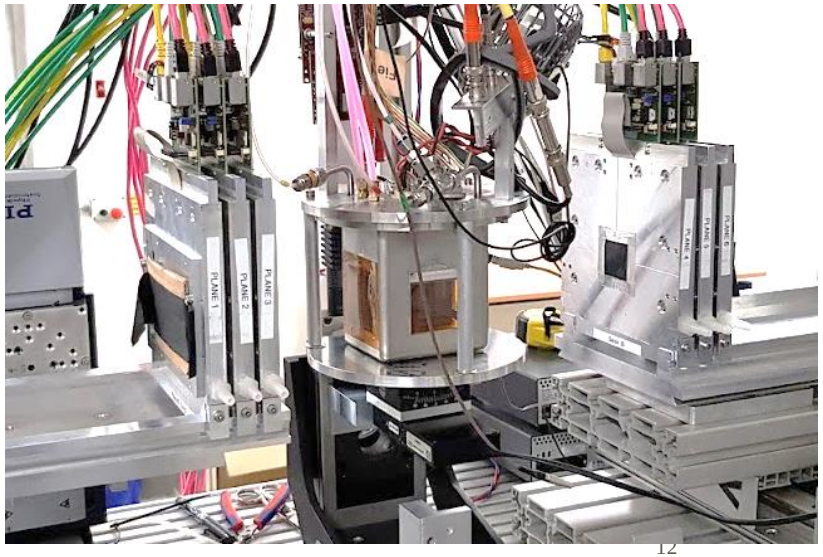
QUAD test beam in Bonn (October 2018)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- QUAD sandwiched between Mimosa planes
  - Largely improved track definition
- Gas: $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)
- E_d = 280 V/cm, V_{grid} = -300 V
- Typical beam height above the chip: ~1 cm

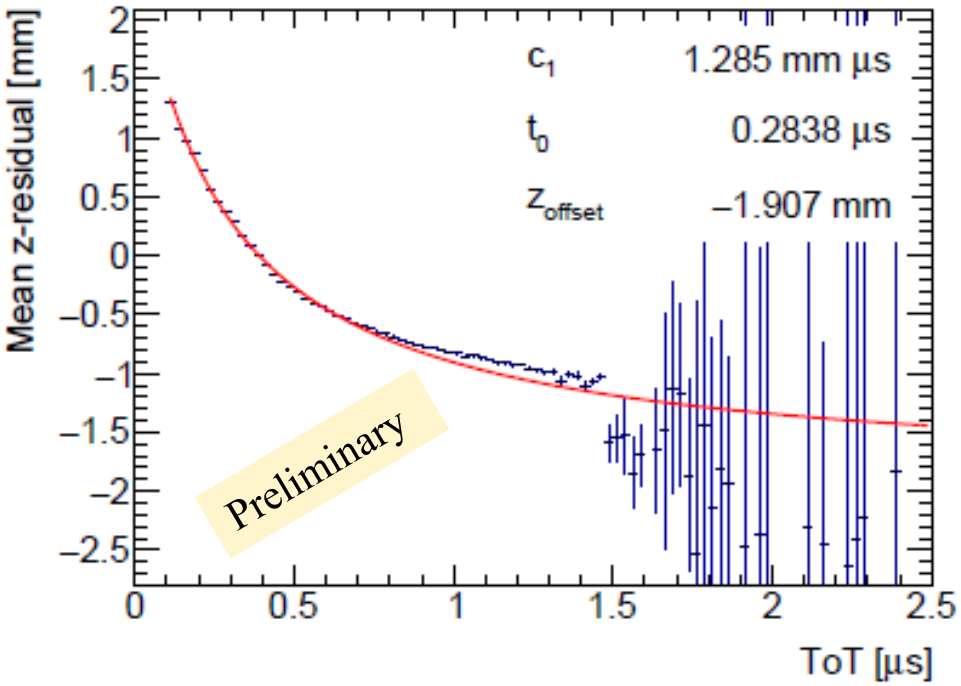
Preliminary results will be presented here

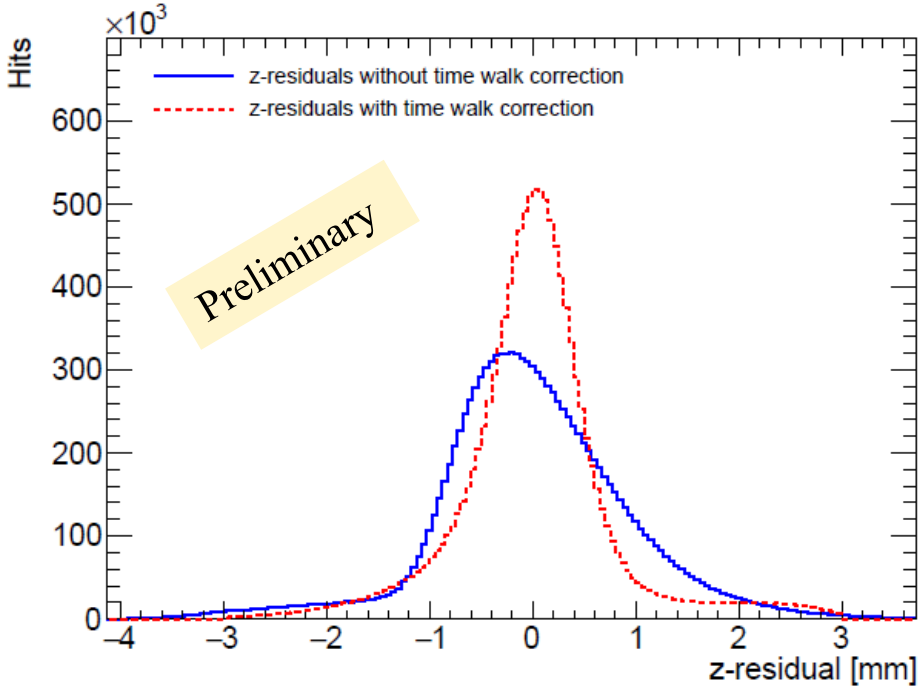


@Bonn



QUAD time walk results



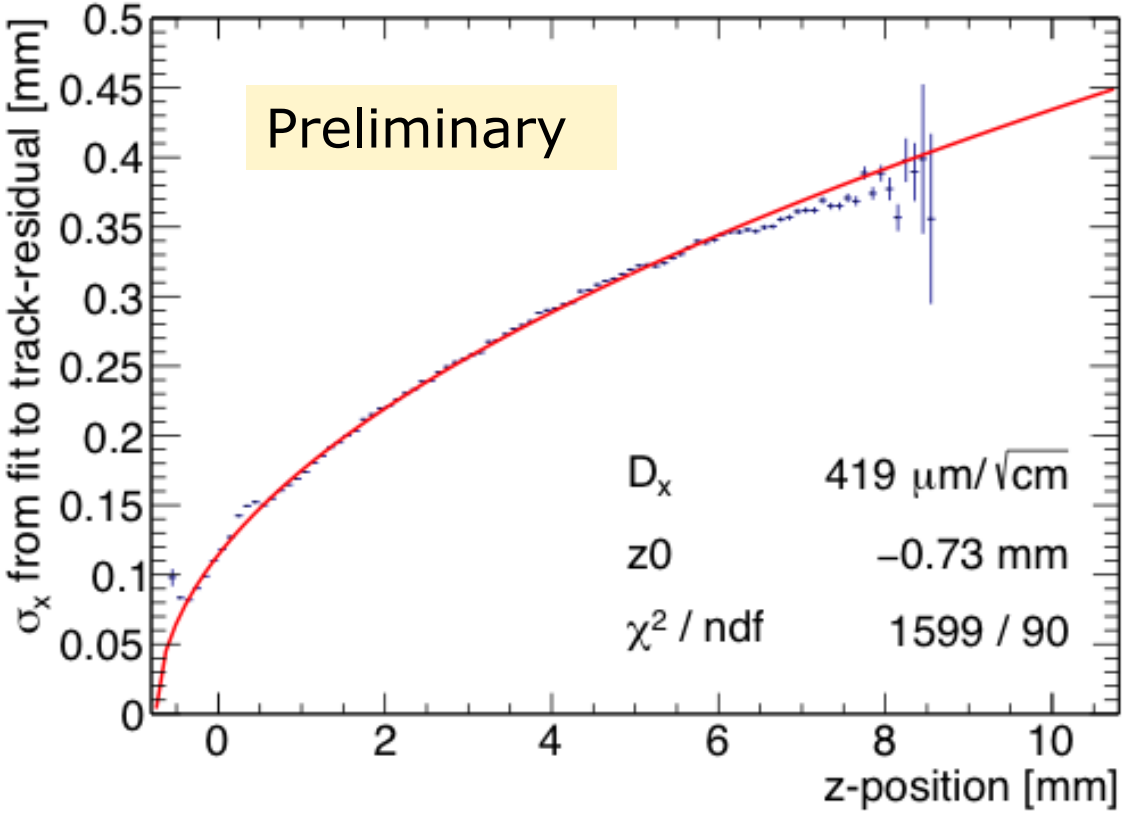


$$\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$$

- Time walk correction works well
- Applied for all analysis results

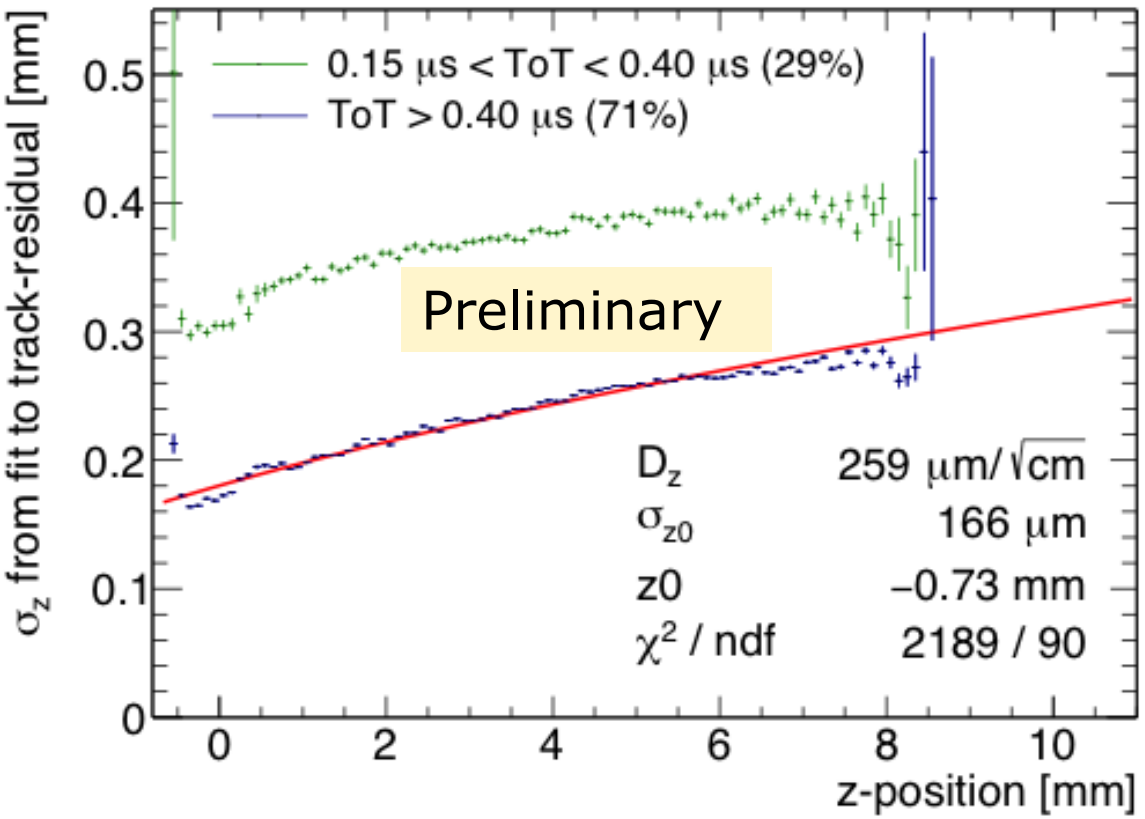
QUAD single hit resolution

Transverse



D_T = 419 μm/√cm

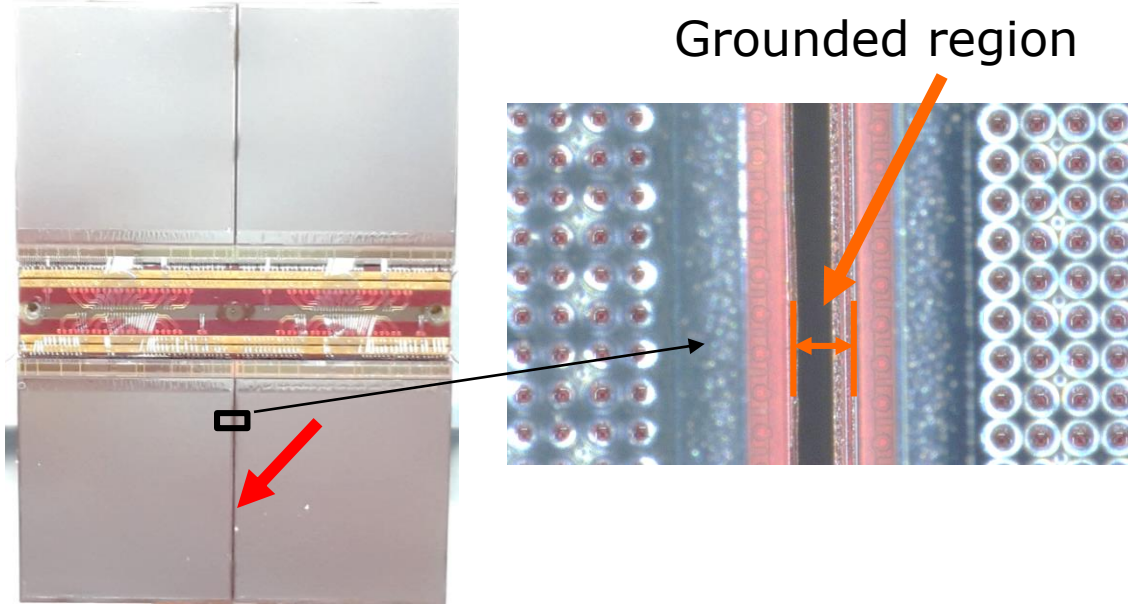
Longitudinal

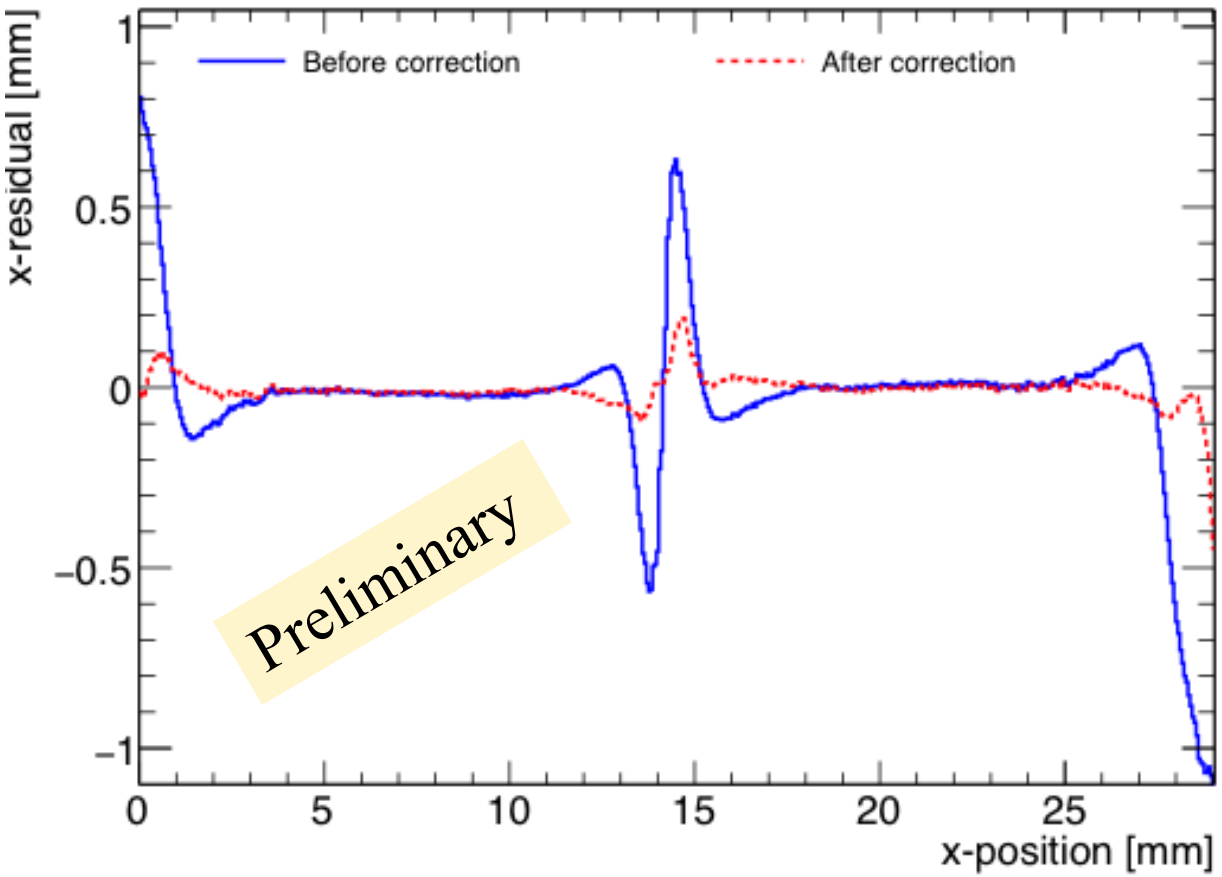


D_L = 259 μm/√cm

QUAD edge deformations

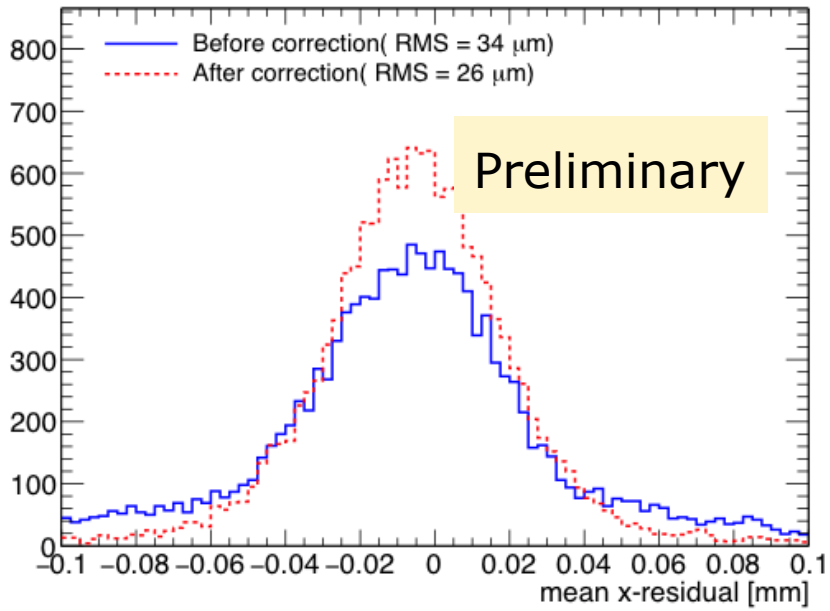
- Small deformations due to
  - Dead zone between chips
  - Grounded region between chips
- Are corrected by:
  - fitted correction function
  - adding proper guard wire electrode

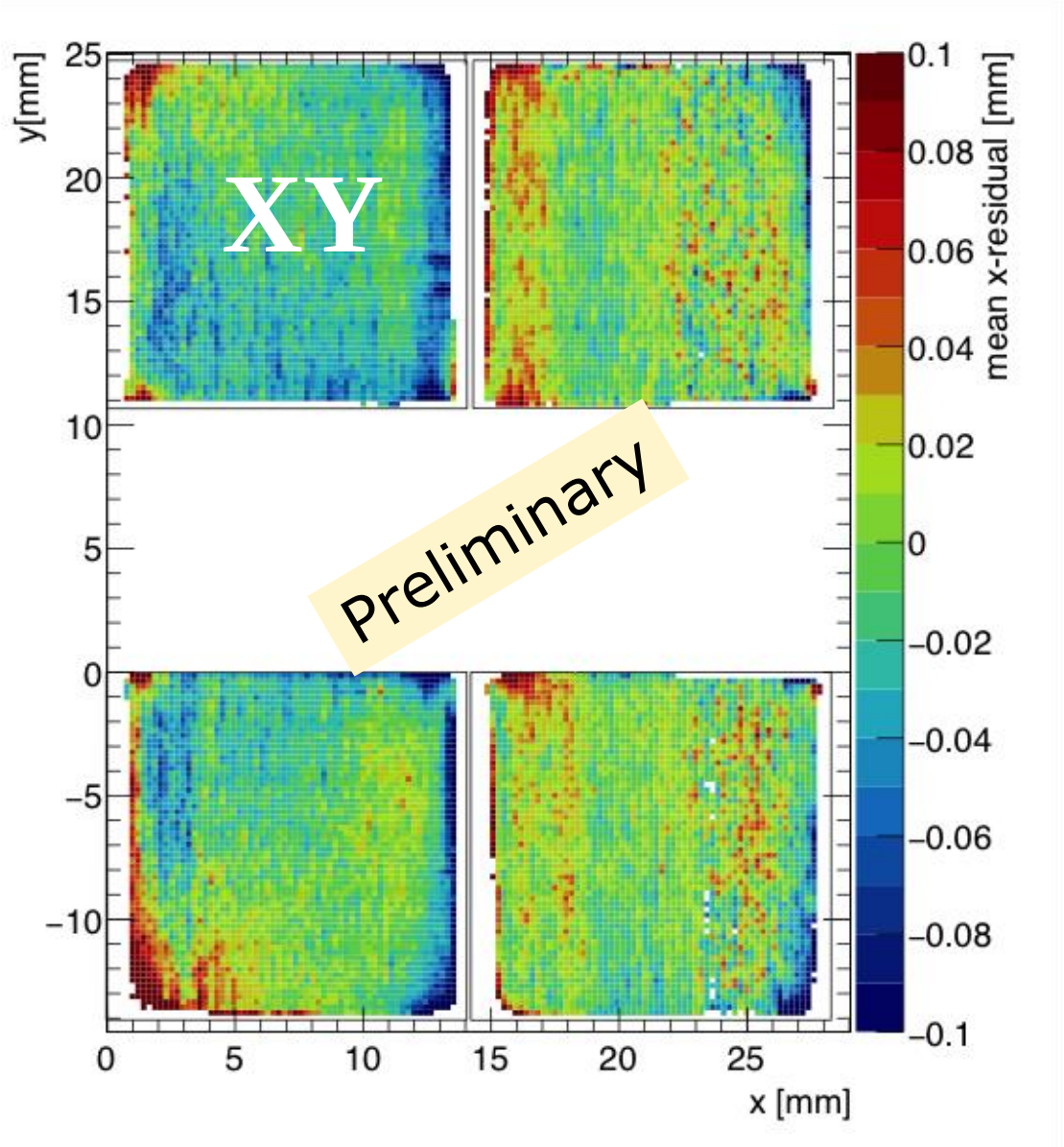




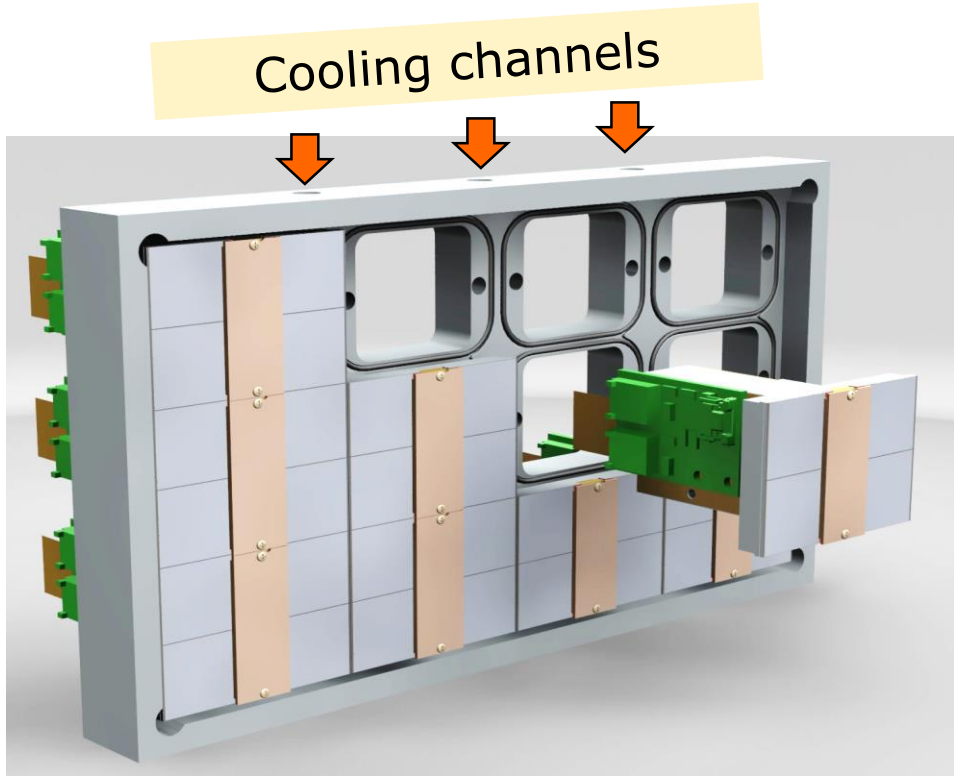
QUAD deformations in transverse plane (XY)

- After applying fitted edge corrections
- RMS of the mean residuals are 26 μm over the whole QUAD

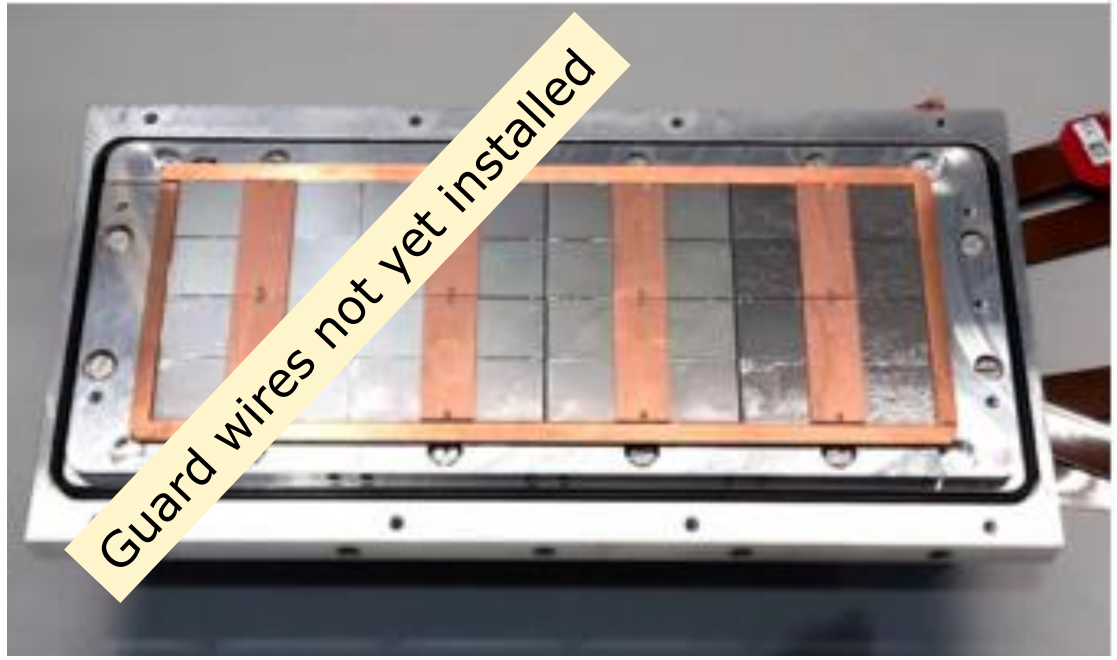




Next: QUAD as a building block



8-QUAD module



Conclusions

- Since 2017 three TimePix3 wafers were successfully equipped with an InGrid
- A single chip GridPix detector from this production was reliably operated in a test beam in 2017
  - Single electron detection => the resolution is primarily limited by diffusion
  - Systematic uncertainties are low: < 10 μm in the pixel plane
  - dE/dx resolution for a 1 m track is 4.1%

- Preliminary results from a recent 2018 QUAD test beam were presented
- Data quality and resolutions are similar to the single chip test beam results
- Small edge deformations at the boundary between two chips are observed
  - We will add guard wires to the module
- A production of 14 QUADs is finished
  - QUADs are installed in an 8-QUAD module