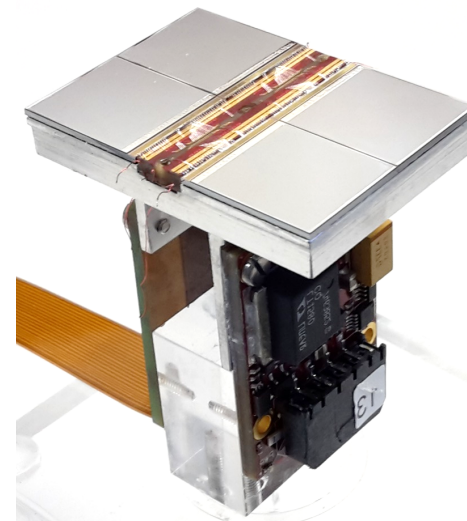




The gaseous QUAD pixel detector



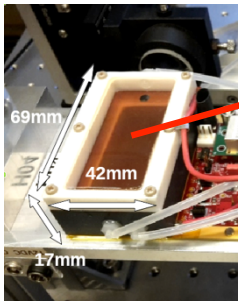
Yevgen Bilevych, Klaus Desch, Jean
-Paul Fransen, Harry van der Graaf,
Markus Gruber, Fred Hartjes, Bas van
der Heijden, Kevin Heijhof, Charles
Ietswaard, Dimitri John, Jochen
Kaminski, Peter Kluit, Naomi van der
Kolk, Auke Korporaal, Cornelis
Ligtenberg, Oscar van Petten, Gerhard
Raven, Joop Rövekamp, Lucian
Scharenberg, Tobias Schiffer,
Sebastian Schmidt and Jan
Timmermans



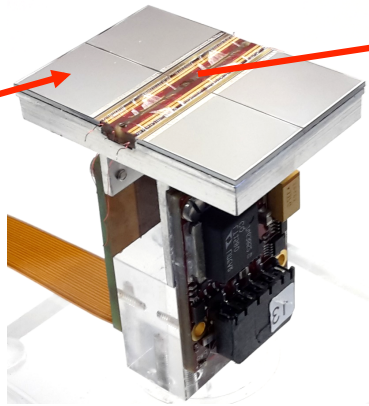
VCI2019 - 15th Vienna Conference on Instrumentation



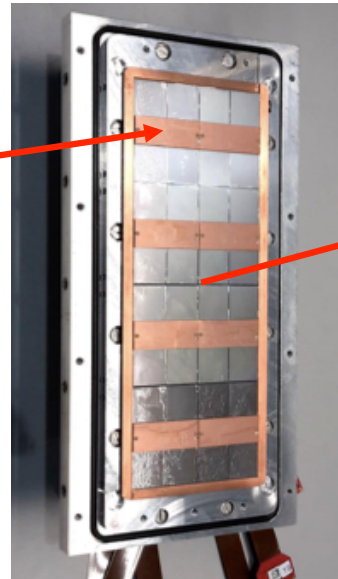
Pixel TPC



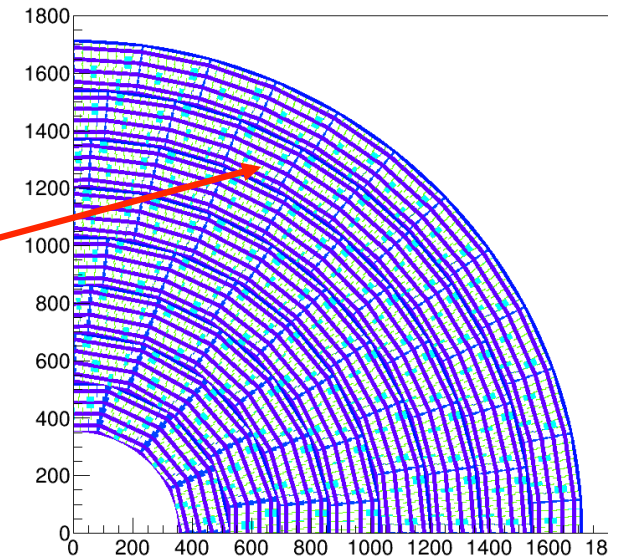
Single chip
2017



Quad
2018



Module
2019



TPC plane

LEPCOL: van quad naar 8 quads

- Single chip geanalyseerd, begrepen en NIM gepubliceerd
- Quad testbeam data zijn geanalyseerd, gepresenteerd in Vienna VCI (Peter) en La Rochelle MPGD (Jochen)
- Kees werkt aan de publicatie NIM
- 8 quad status
 - Laser test opstelling werkt zonder multiplexer
 - ET werk (< september)
 - stabilisatie van voeding (Bas);
 - multiplexer (Sander/Bas) voor 8 quad uitlezing.
- Wie gebruikt er quads:
 - Lab Master UvA/VU (LCB post doc)
 - Lab Master Nijmegen (Frank Filthaut)
 - Bonn CAST en follow-up IAXO experiment;
 - mogelijkheden bij een van de vele TPC experimenten.

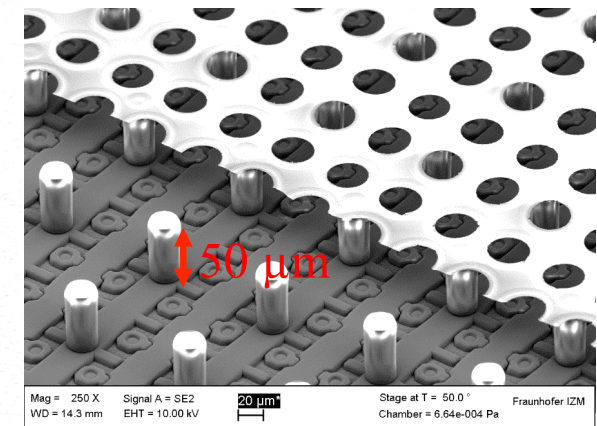
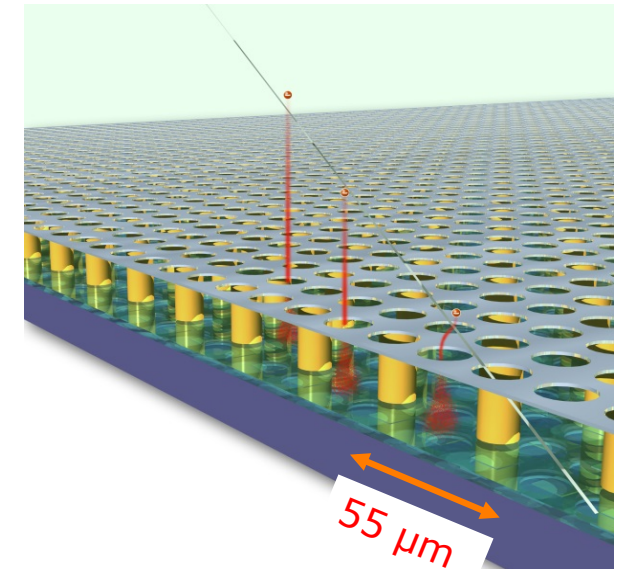
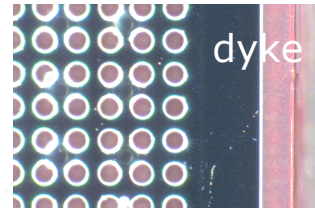
LEPCOL: van quad naar 8 quads

- plannen komende jaar:
 - publicatie quad
 - september test beam data in Bonn met 8 quads
 - eind 2019 LCTPC vergadering
 - begin 2020 test beam DESY
 - presentatie resultaten bij conferenties
- Dit doen we met onze crew: Kees, Fred, Jan, Naomi, Gerhard, Peter (& Bonn collega's)
- Toestemming voor reizen om de test beam voor te bereiden en uit te voeren en resultaten te presenteren.

GridPix technology

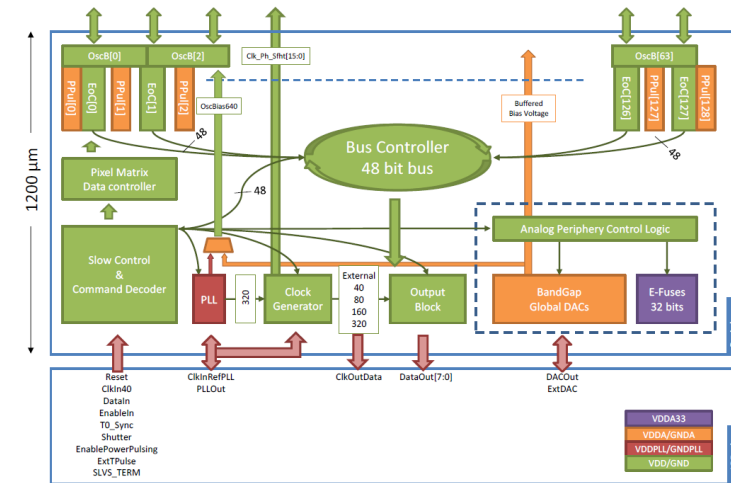
- Pixel chip with integrated Grid (Micromegas-like)
- InGrid post-processed @ IZM
- Grid set at negative voltage (300 – 600 V) to provide gas amplification
- Very small pixel size (55 μm)
- detecting individual electrons

- 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



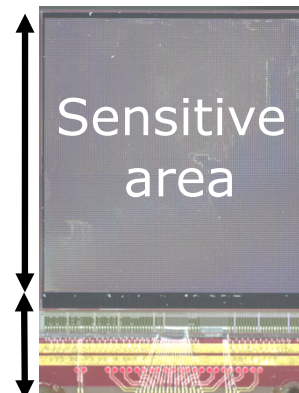
Pixel chip: TimePix3

- 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
 - $\sim 1\text{ A}$ @ 2 V (2W) depending on hit rate
 - good cooling is important



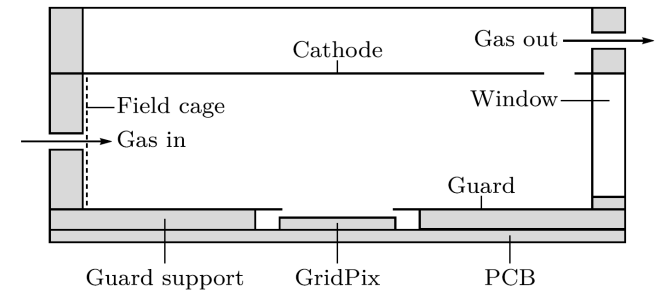
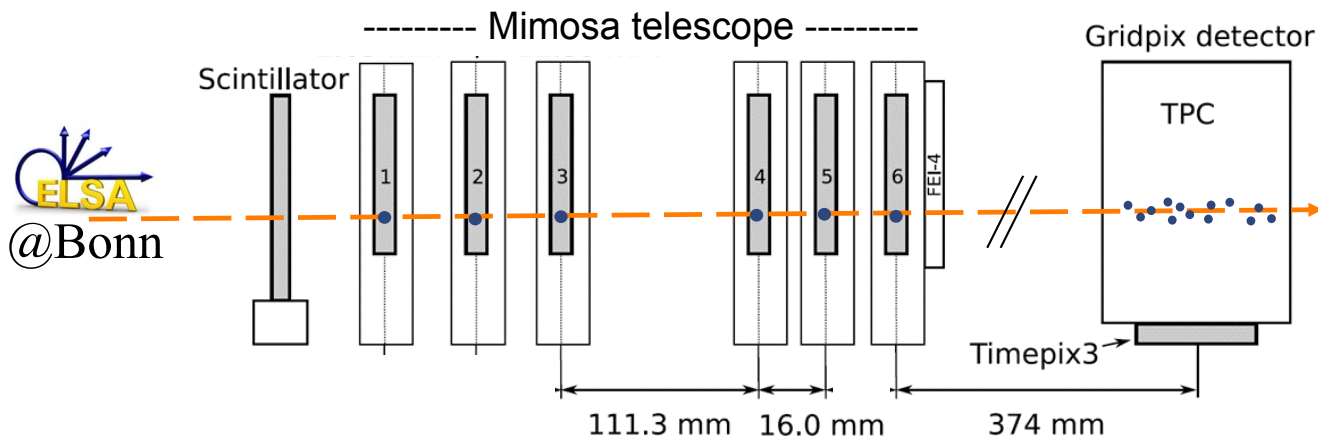
14.1 mm

2+3 mm

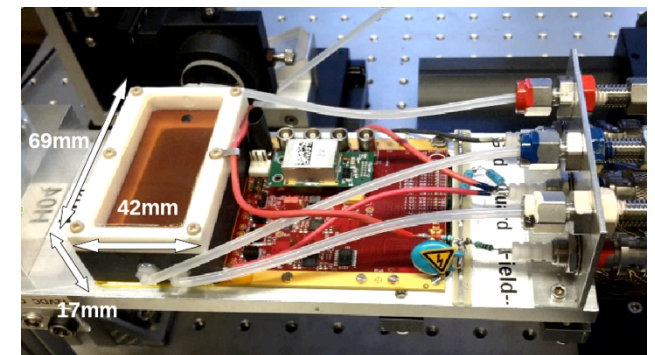


Single chip test in test beam Bonn (June 2017)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- Gas: Ar/CF₄/iC₄H₁₀ 95/3/2 (T2K)
- Electrons: ~100 e/cm
- $E_d = 280 \text{ V/cm}$, $V_{\text{grid}} = -350 \text{ V}$

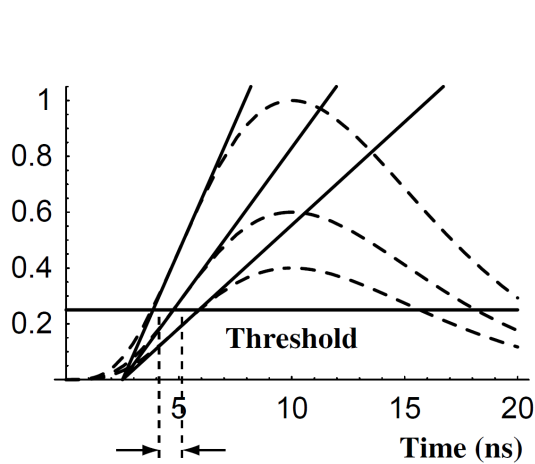


Detector with guard and field shaper



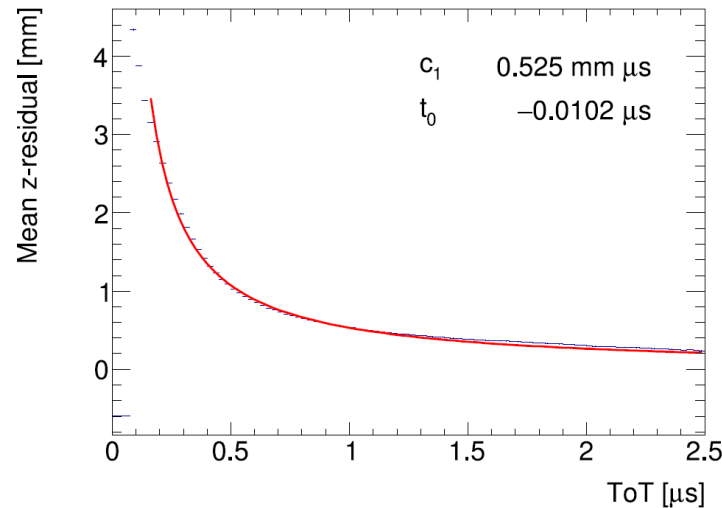
Published paper on 2017 testbeam: <https://doi.org/10.1016/j.nima.2018.08.012>

TimePix3 time walk correction



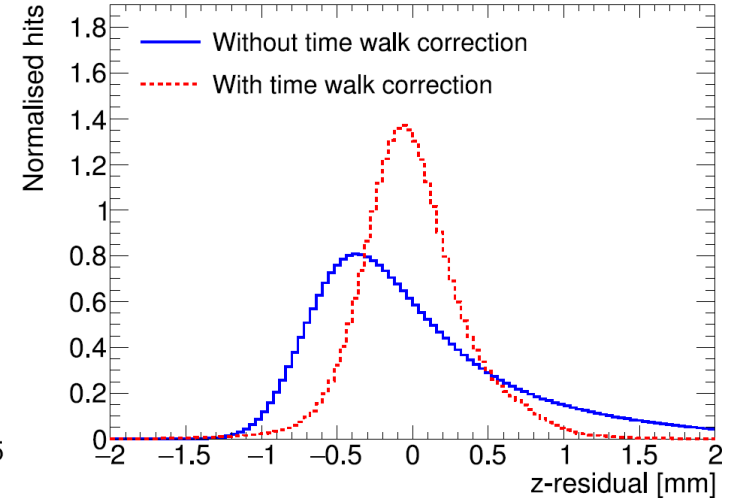
Time walk error: time of arrival depends on signal amplitude

(Blum, Particle detection 2008)



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

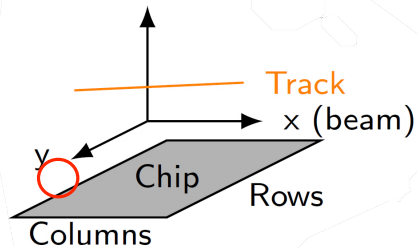
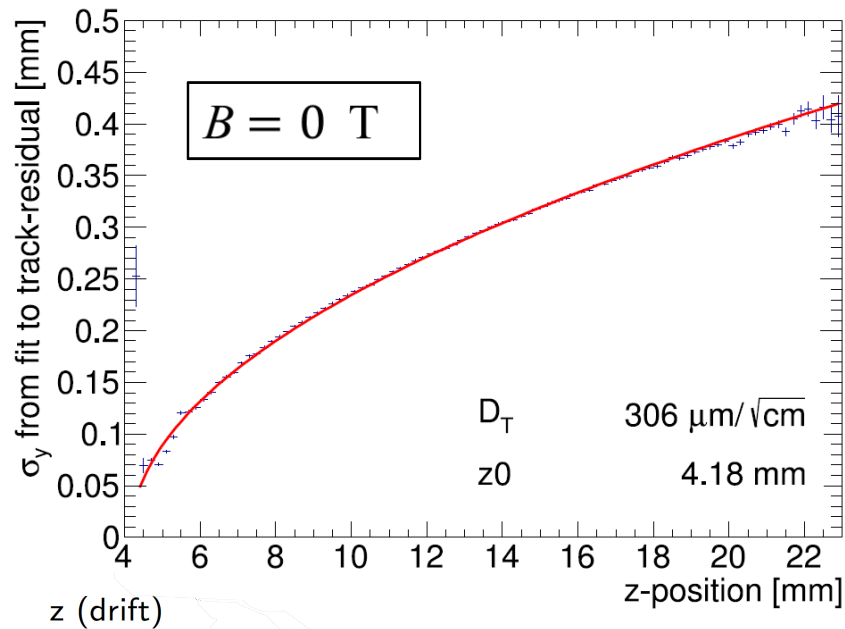
$$\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$$



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:

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

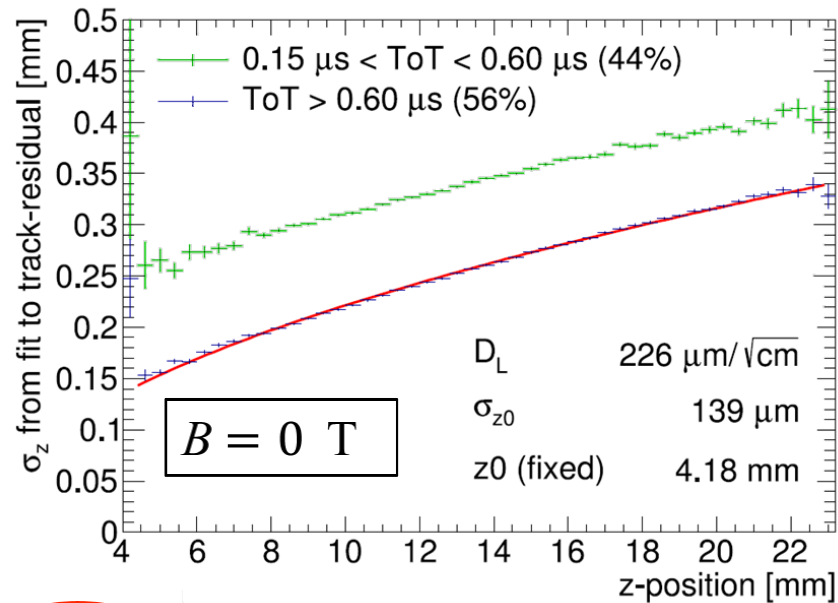
Depends on:

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

Note that:

- ☐ A hit resolution of $\sim 250 \mu\text{m}$ is $\sim 25 \mu\text{m}$ 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



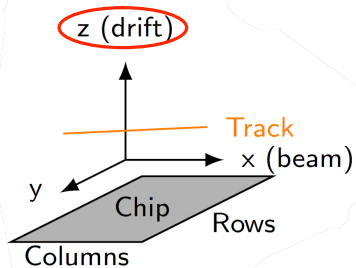
Single hit resolution in drift direction

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

Depends on

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

The additional ToT cut ($>0.60 \mu\text{s}$) was applied to avoid large time walk errors

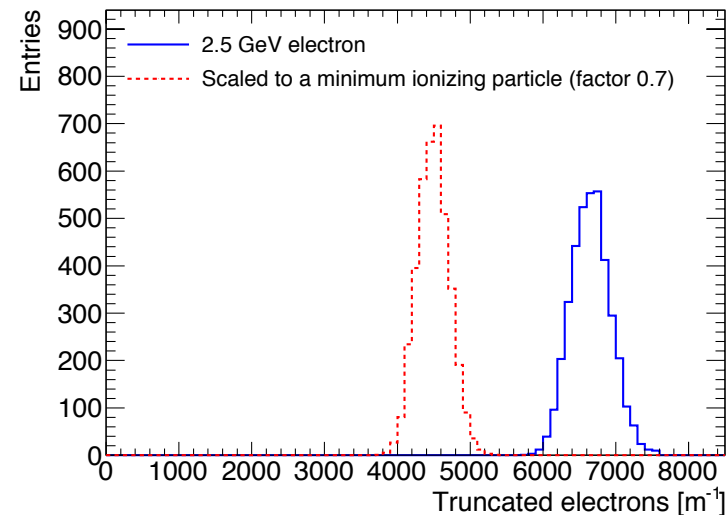


$$D_L = 226 \mu\text{m}/\sqrt{\text{cm}}$$

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

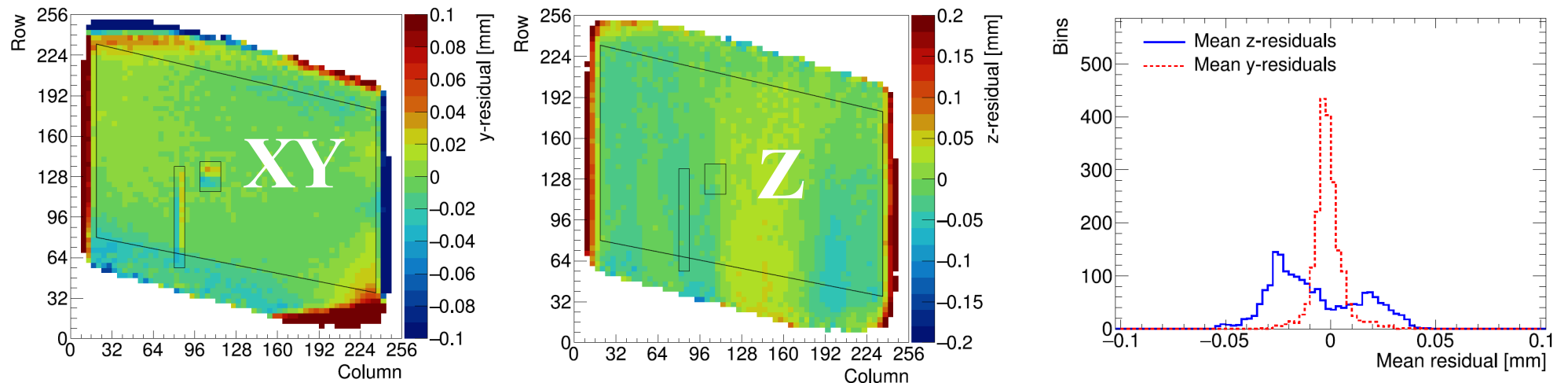
Pixel dE/dx performance

- 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 $S = (N_e - N_{\text{MIP}})/\sigma_e$
- 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)

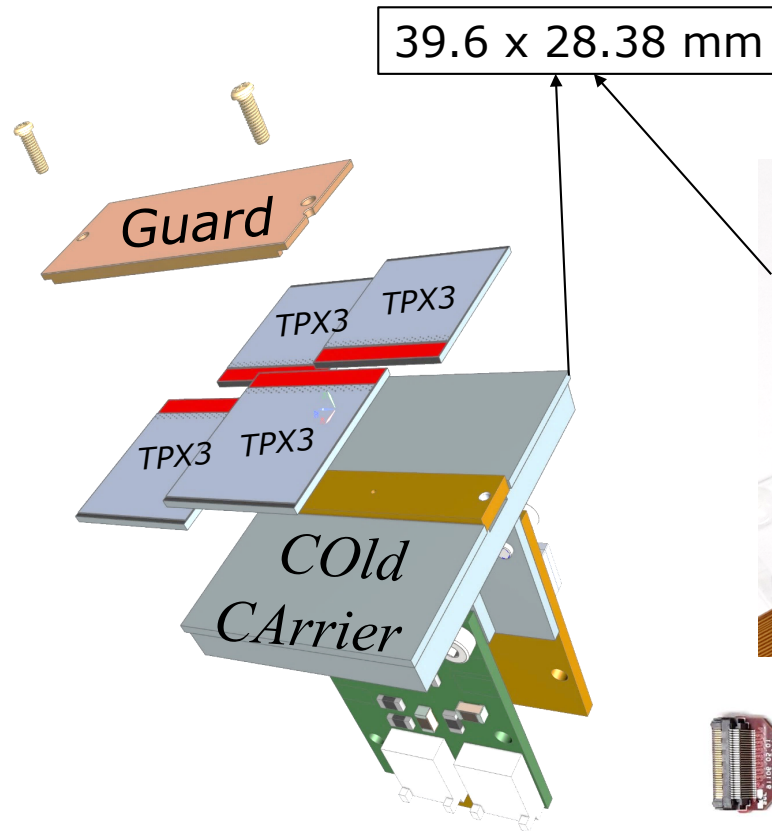
- The RMS of the mean residuals is $7\text{ }\mu\text{m}$ in the pixel plane and $21\text{ }\mu\text{m}$ (0.3 ns) in the drift direction in the selected region



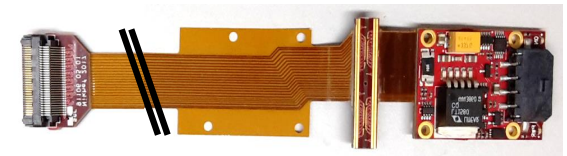
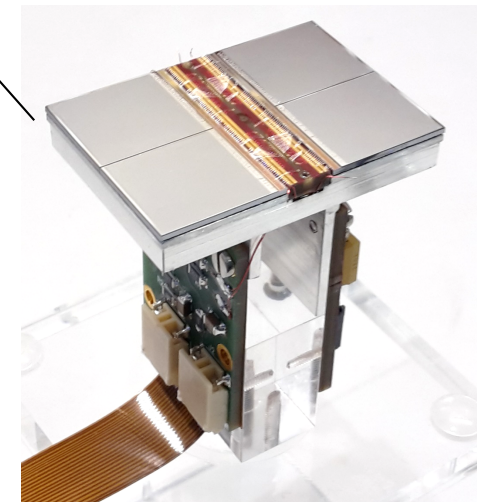
- How can we make an even better detector?
 - Improve the quality (homogeneity) of the InGrid; redesign the dike and edges
 - Go to a large areas keeping the field distortions (at edges) minimal -> QUAD

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



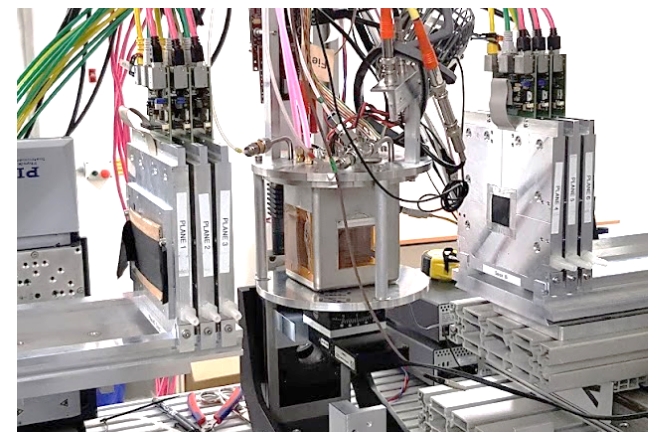
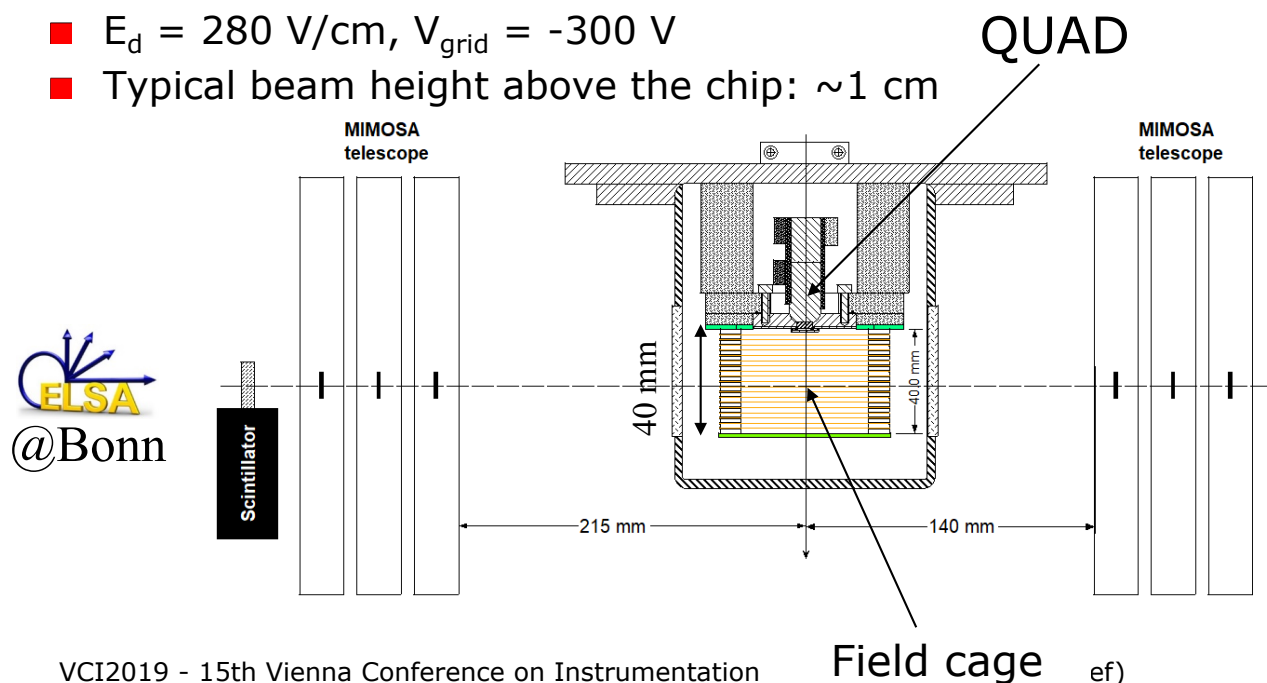
series of QUADs



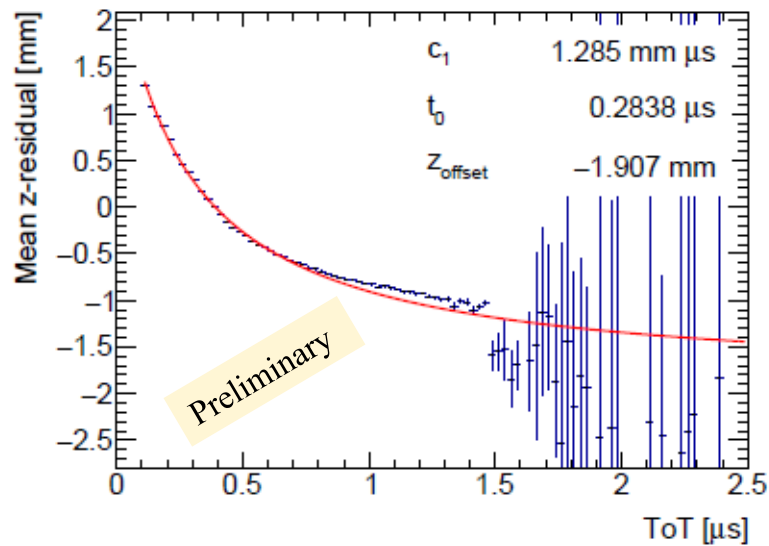
QUAD test beam in Bonn (October 2018)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- QUAD sandwiched between Mimosa planes
 - Largely improved track definition
- Gas: Ar/CF₄/iC₄H₁₀ 95/3/2 (T2K)
- $E_d = 280 \text{ V/cm}$, $V_{\text{grid}} = -300 \text{ V}$
- Typical beam height above the chip: $\sim 1 \text{ cm}$

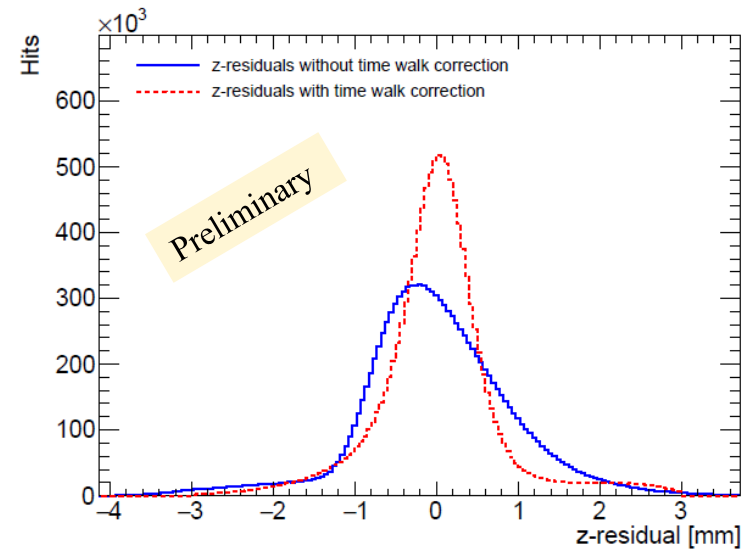
Preliminary results will be presented here



QUAD time walk results



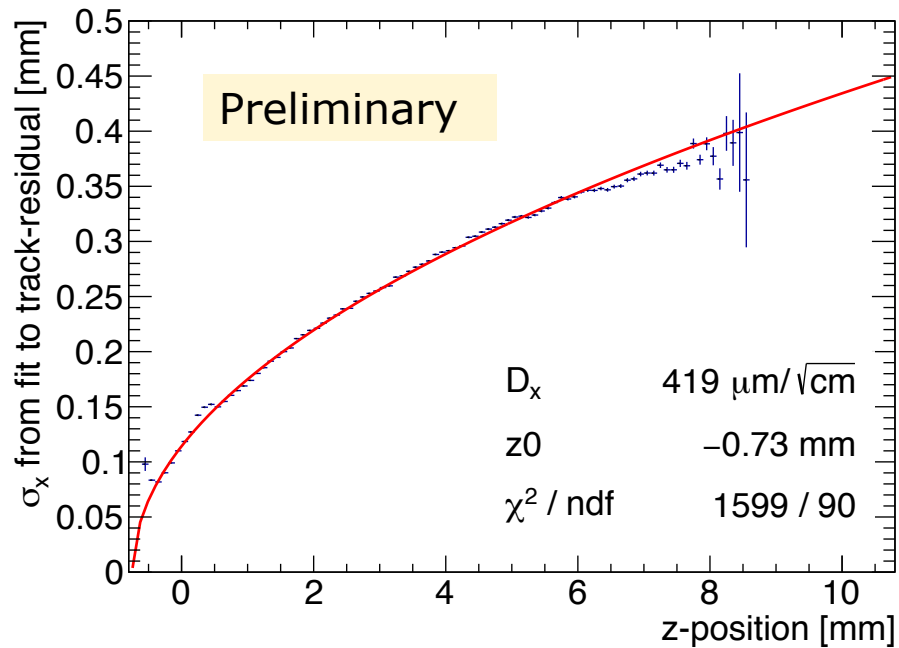
$$\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$$



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

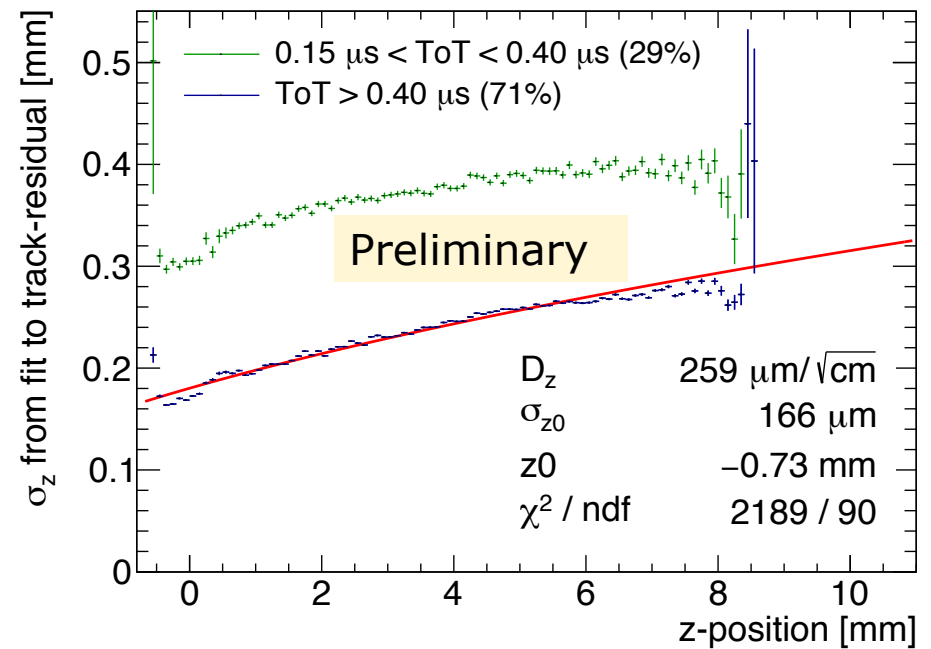
QUAD single hit resolution

Transverse



$$D_T = 419 \mu\text{m}/\sqrt{\text{cm}}$$

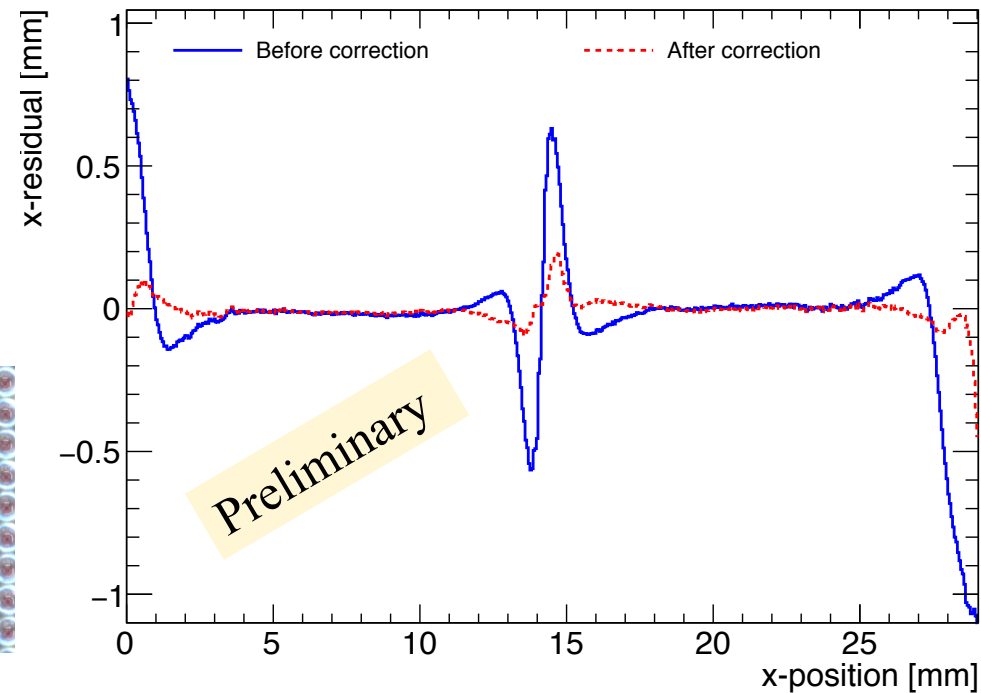
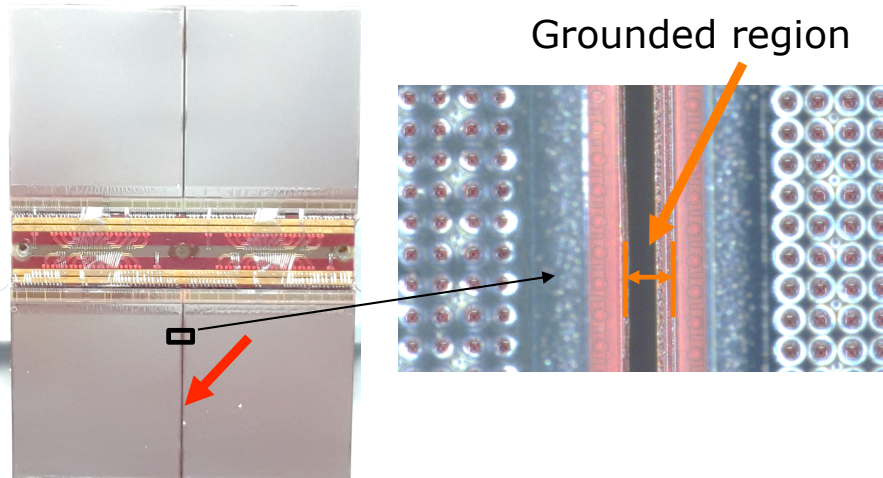
Longitudinal



$$D_L = 259 \mu\text{m}/\sqrt{\text{cm}}$$

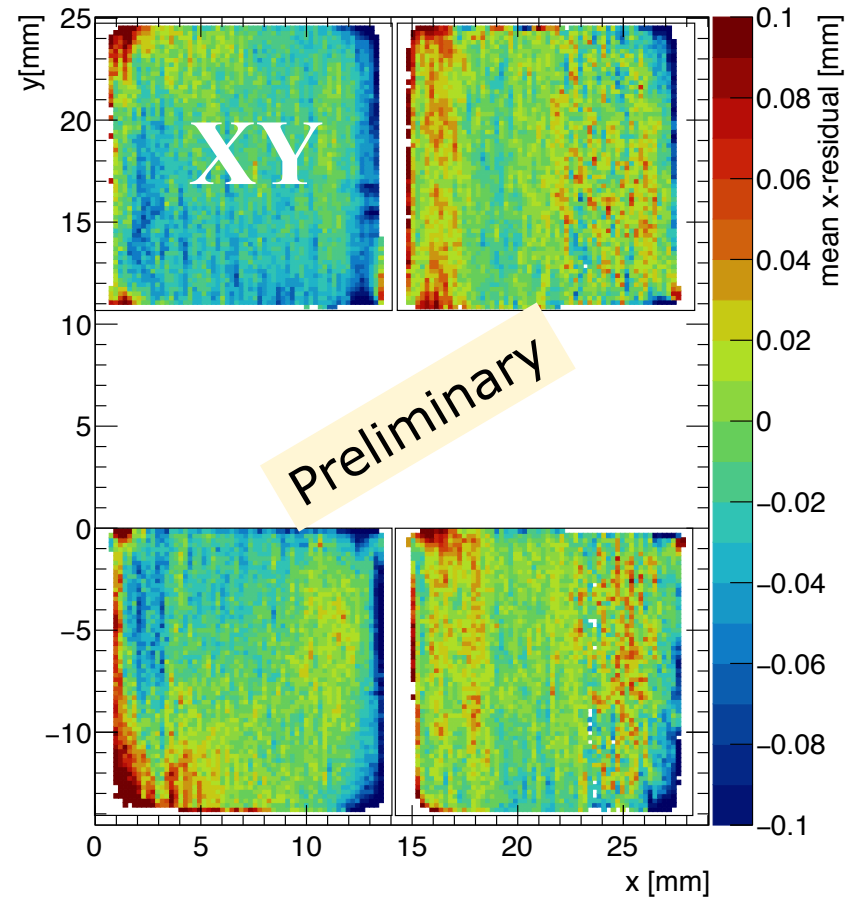
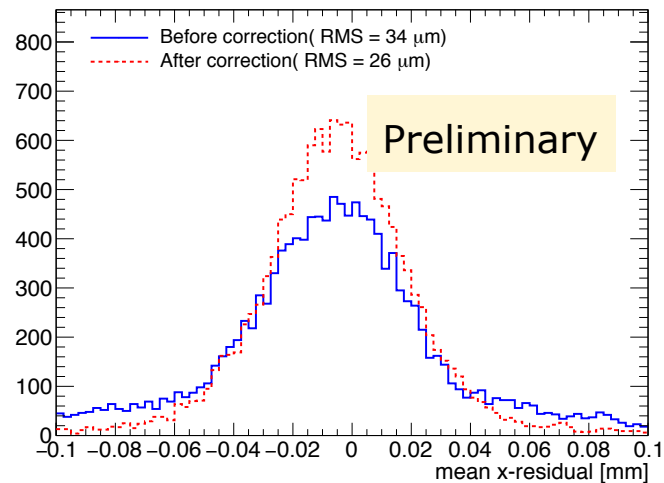
QUAD edge deformations

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

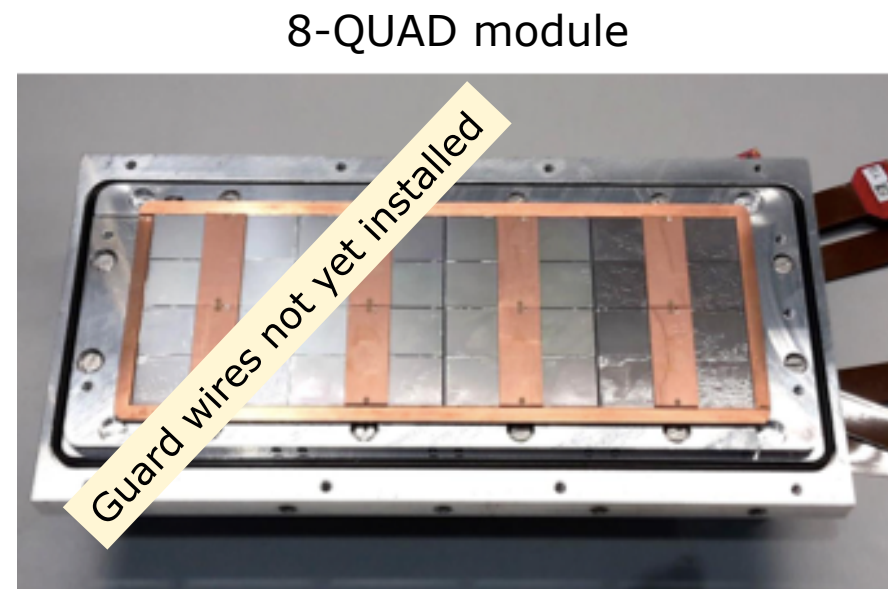
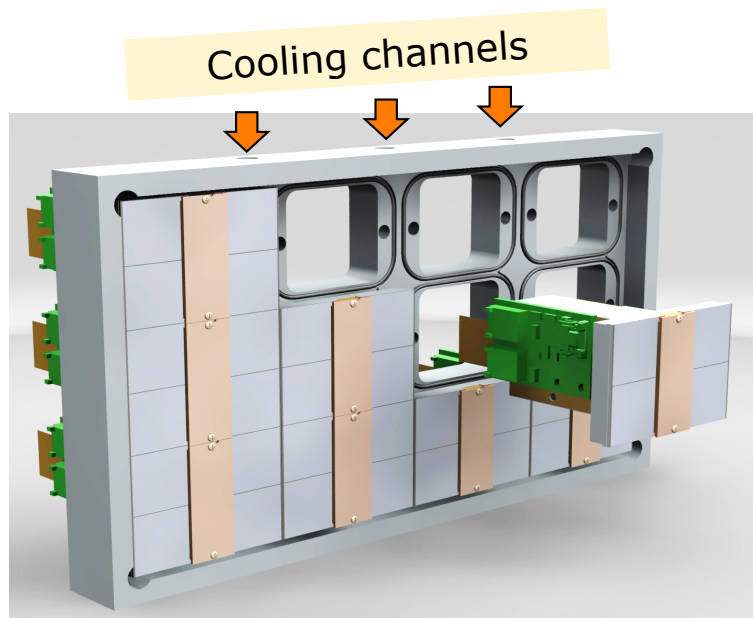


QUAD deformations in transverse plane (XY)

- After applying fitted edge corrections
- RMS of the mean residuals are $26\text{ }\mu\text{m}$ over the whole QUAD

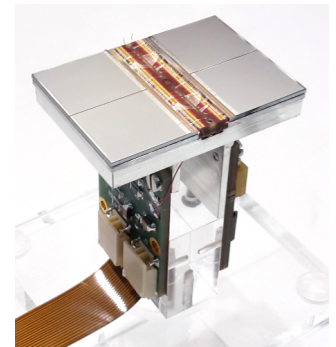


Next: QUAD as a building block



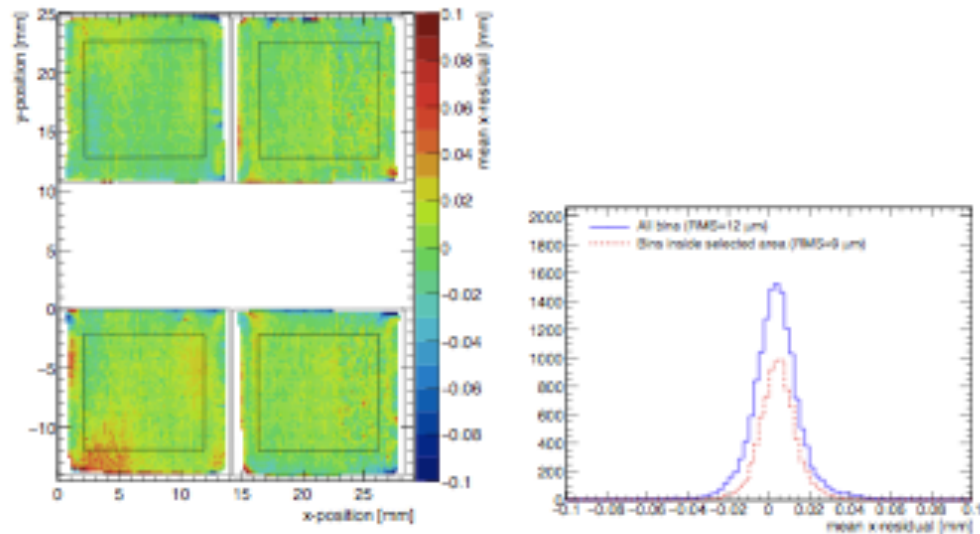
Conclusions

- 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: $< 10 \mu\text{m}$ 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



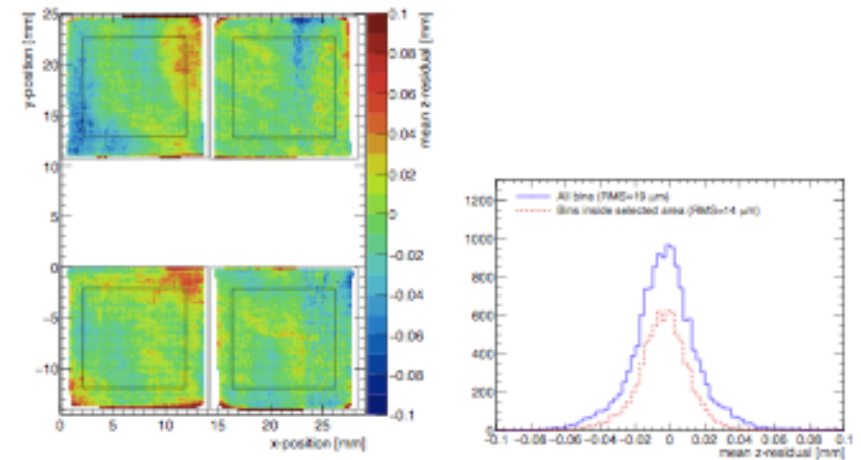
Understanding the quad

Deformation in pixel plane



Introducing a y-coordinate dependence improves corners, but there is no difference for the central region

Deformation in drift direction



Nikhef