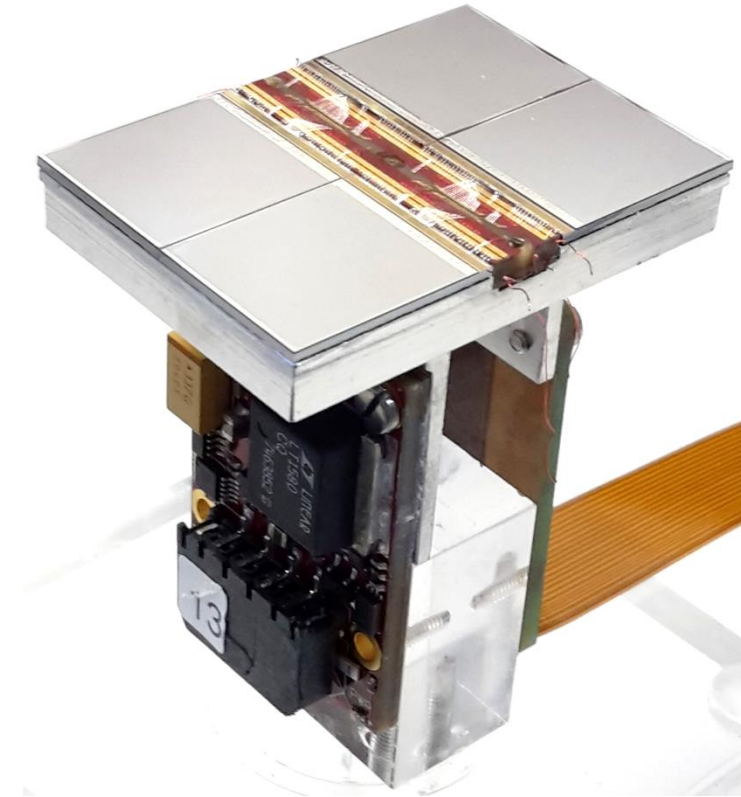


Fred Hartjes

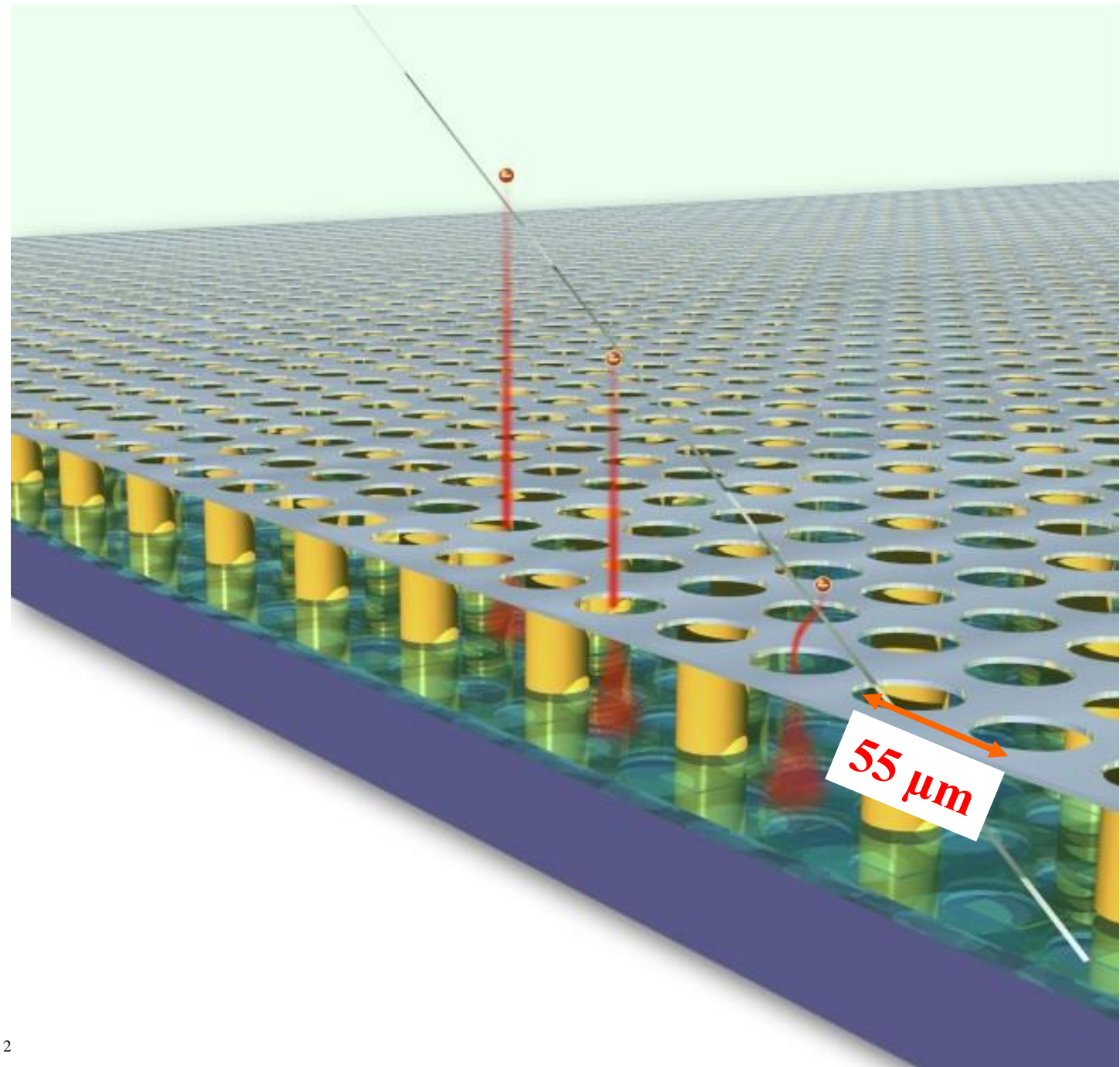
On behalf of  
Nikhef  
and  
Physikalisches Institut  
Universität Bonn



# GridPix technology

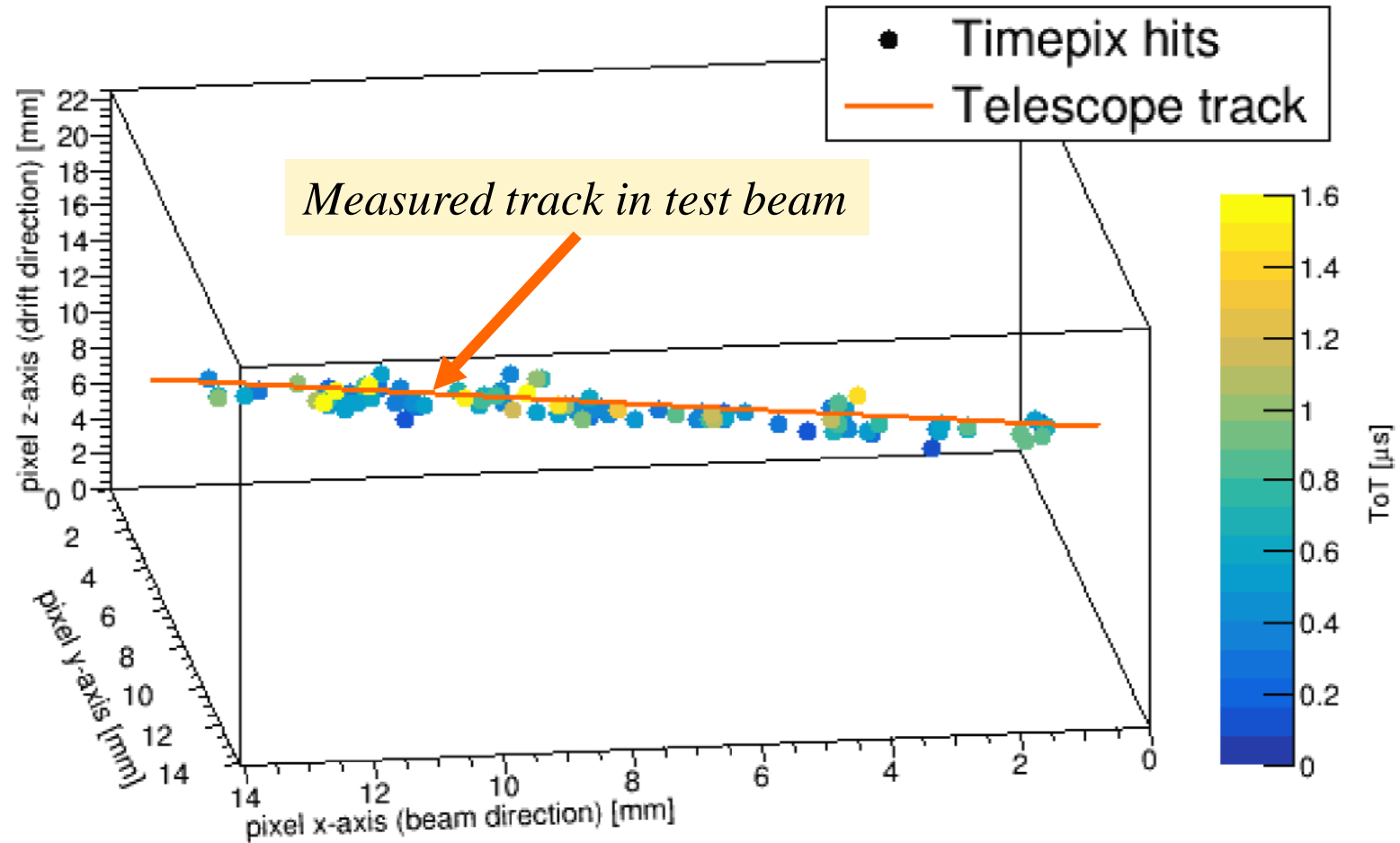
- Pixel chip with integrated Micromegas
- => **InGrid**
- Grid set at negative voltage (300 – 600 V) to provide gas amplification
- Very small pixel size (55  $\mu\text{m}$ )
- => mostly detecting **individual electrons**

*GridPix chip*



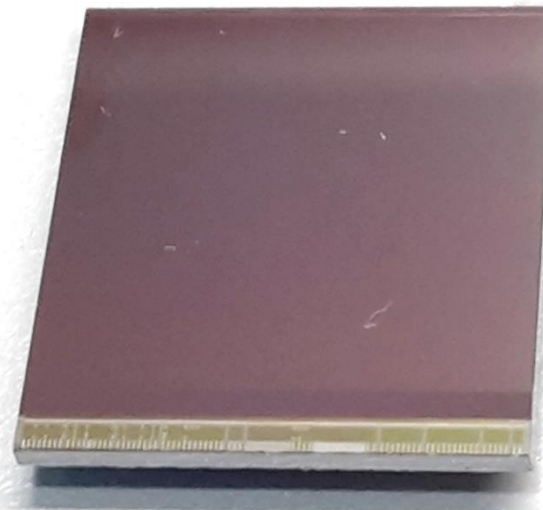
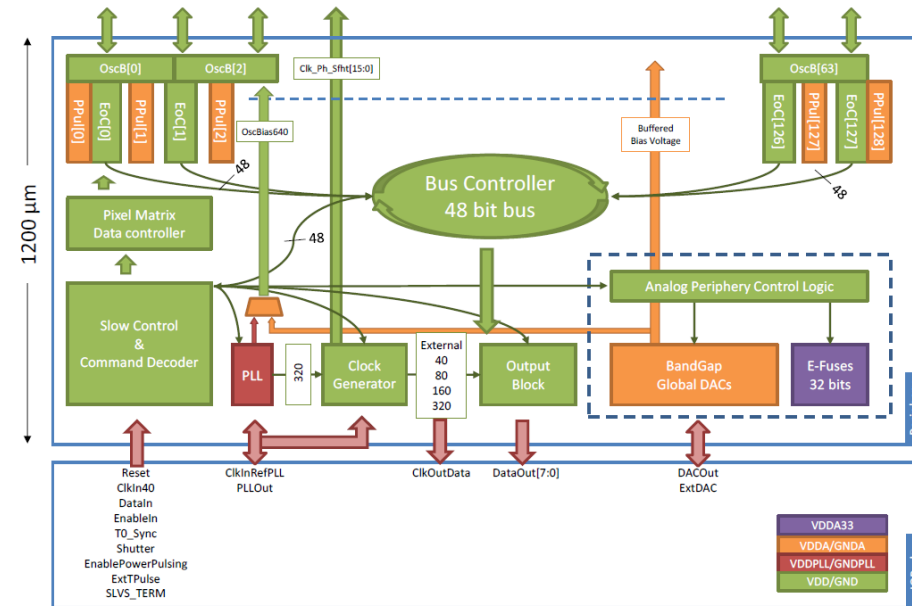
# GridPix: detecting individual electrons

- Uses the **complete information** of the ionization profile
- The **best resolution** that can be obtained with a gaseous detector
  - dE/dx by single electron counting
- **Fine granularity** enables **rejecting background tracks** and **deltas** in offline analysis



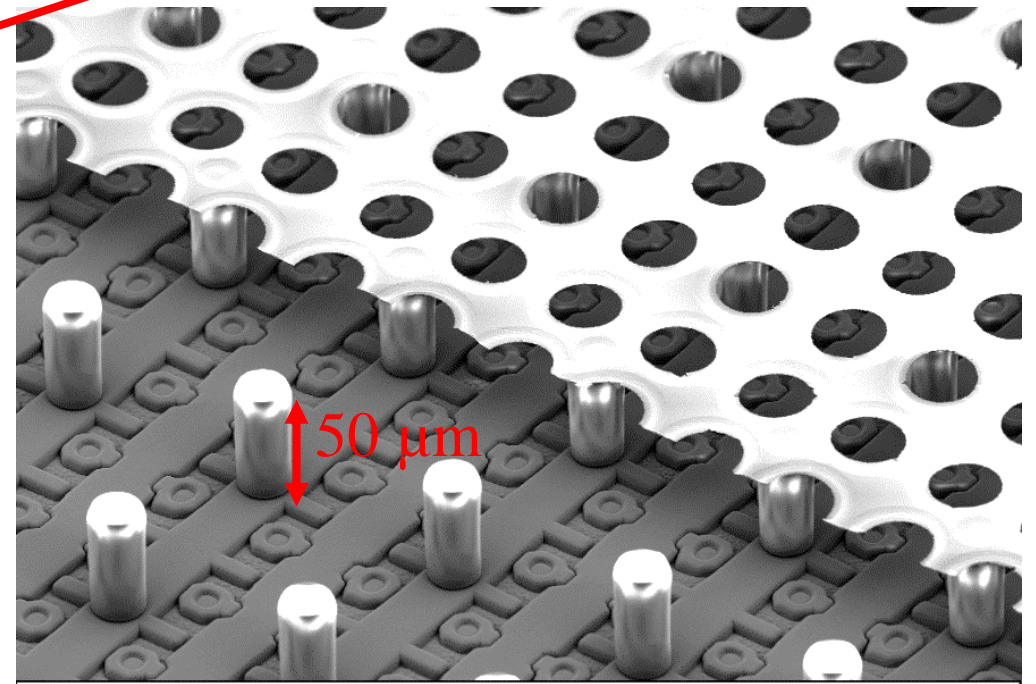
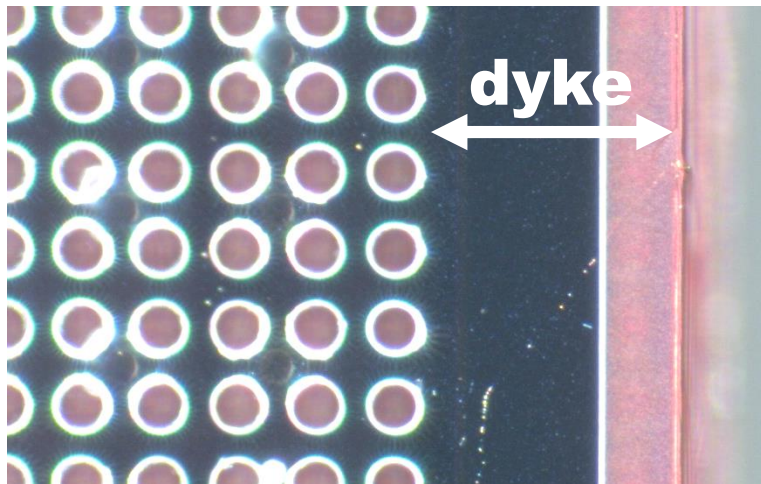
# Pixel chip: TimePix3

- 256 x 256 pixels
- 55 x 55  $\mu\text{m}$  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
- High power consumption
  - ~ 1 A @ 2 V (2W), depending on hit rate
  - => good cooling is important



# TimePix3 equipped with InGrid

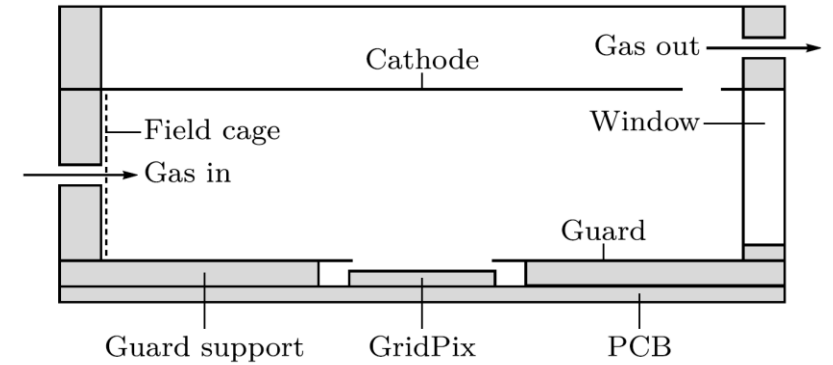
- Wafer post-processing at IZM Berlin
- Aluminium grid (1  $\mu\text{m}$  thick)
- 35  $\mu\text{m}$  wide holes, 55  $\mu\text{m}$  pitch
- Supported by SU8 pillars 50  $\mu\text{m}$  high
- Grid surrounded by SU8 dyke (150  $\mu\text{m}$  wide solid strip) for mechanical and HV stability



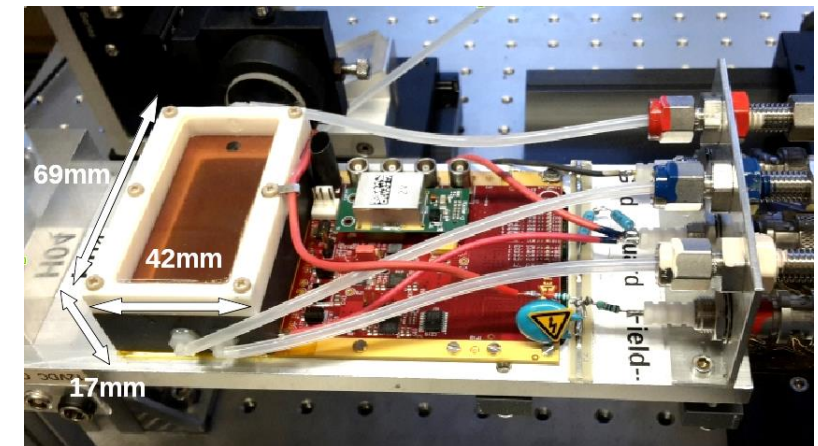
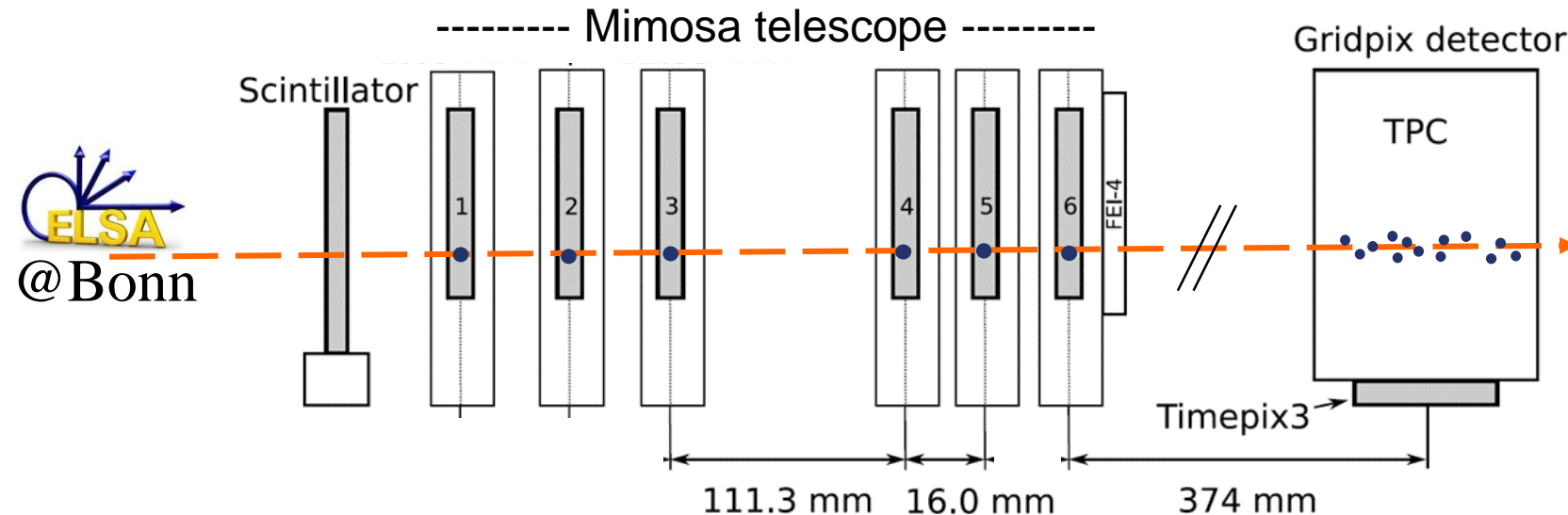
Mag = 250 X Signal A = SE2  
WD = 14.3 mm EHT = 10.00 kV  
20  $\mu\text{m}$   
Stage at T = 50.0 °  
Chamber = 6.64e-004 Pa  
Fraunhofer IZM

# Single chip test at Bonn (June 2017)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- Gas: Ar/CF<sub>4</sub>/iC<sub>4</sub>H<sub>10</sub> 95/3/2 (T2K)
- $E_d = 280 \text{ V/cm}$ ,  $V_{\text{grid}} = -350 \text{ V}$

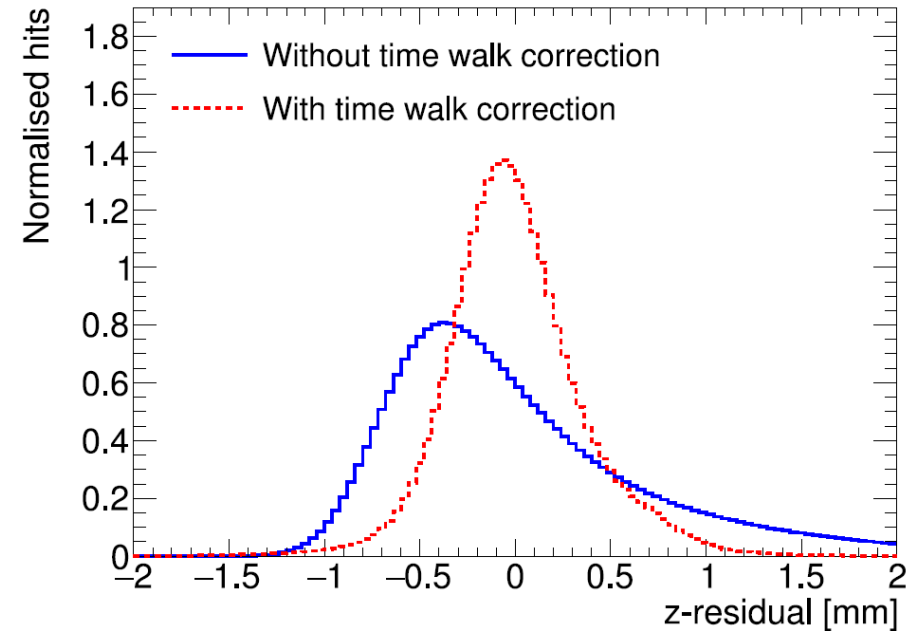
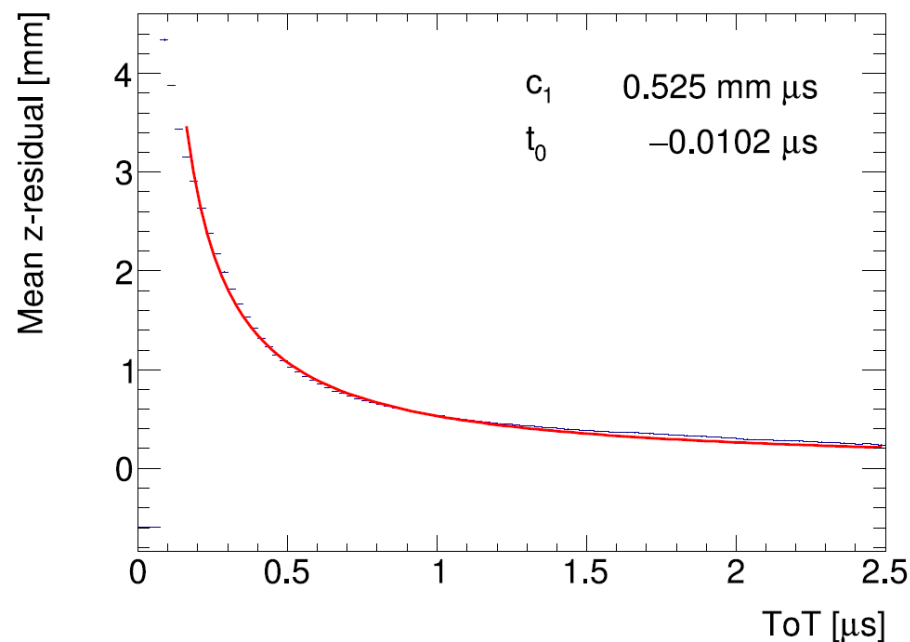
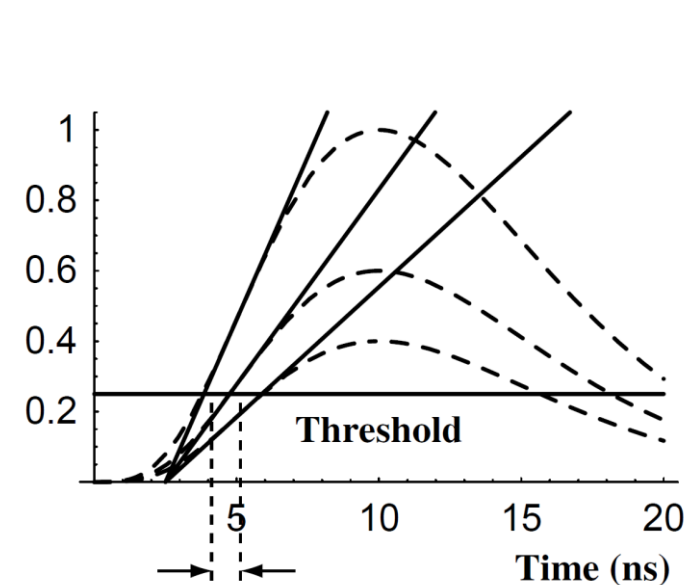


Detector with guard and field shaper



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

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

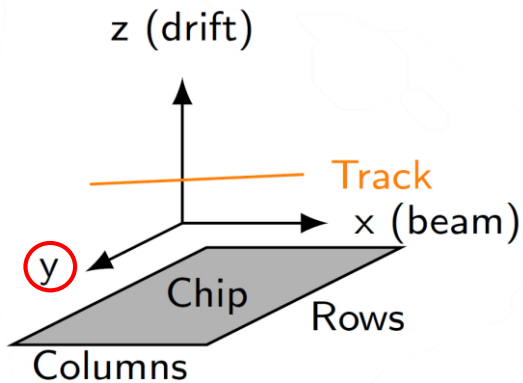
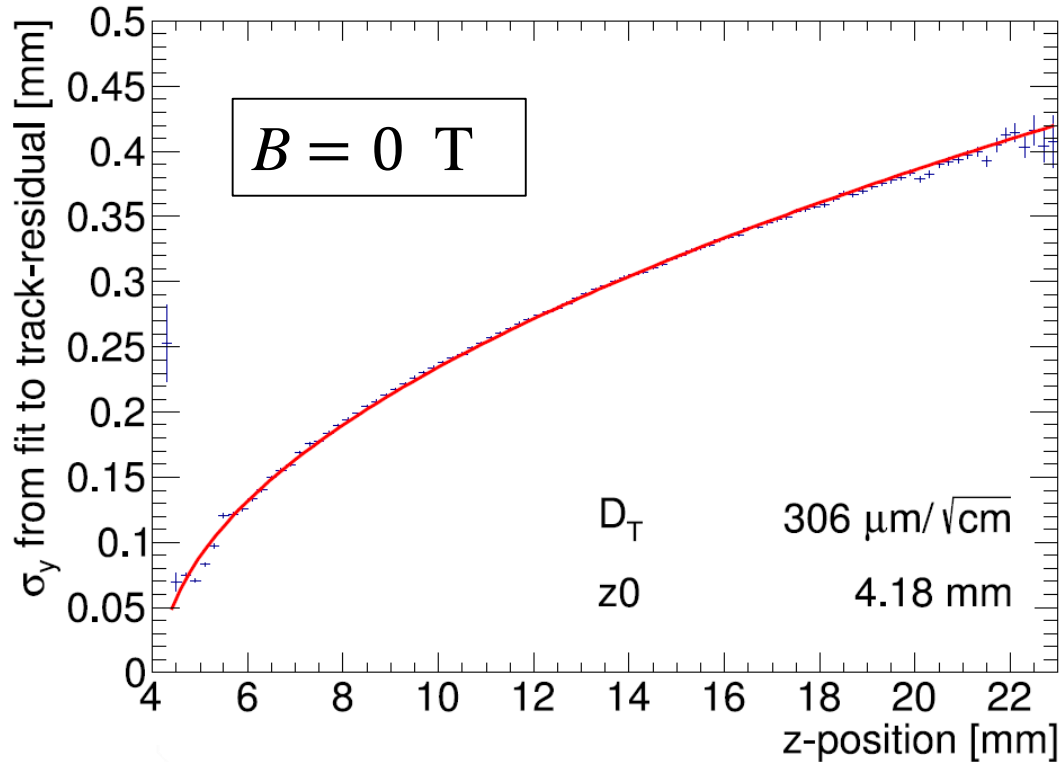
Residual distribution improved

(Blum, Particle detection 2008)

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

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:

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

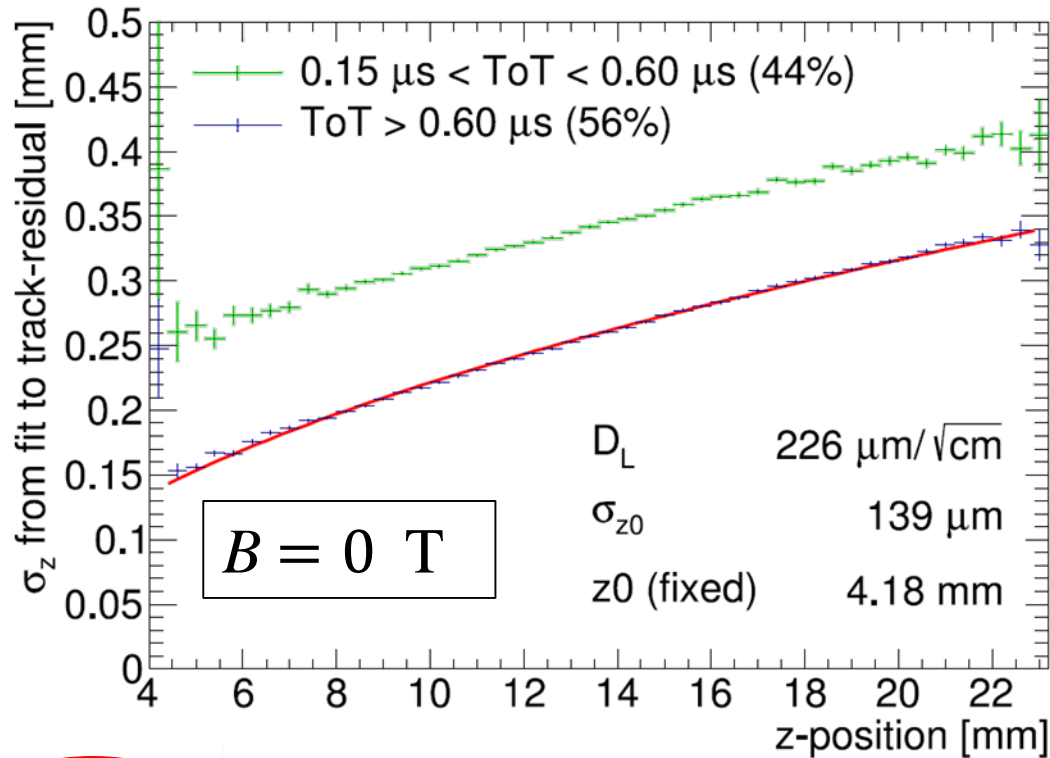
Depends on:

- $\sigma_{y0} = \text{pixel size} / \sqrt{12}$
- 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 ( $\sim 1 \text{ cm}$  track length)
- At  $B = 4 \text{ T}$ ,  $D_T = 25 \mu\text{m}/\sqrt{\text{cm}}$

# Single hit resolution in longitudinal direction



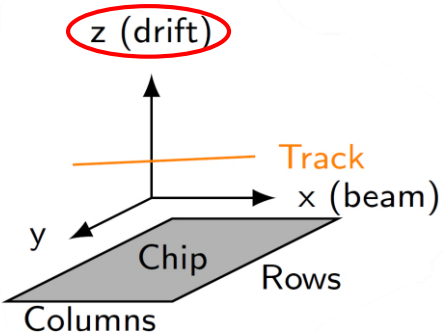
Single hit resolution in drift direction

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

Depends on

- $\sigma_{z0}$  from fit
- Diffusion  $D_L$  from fit

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

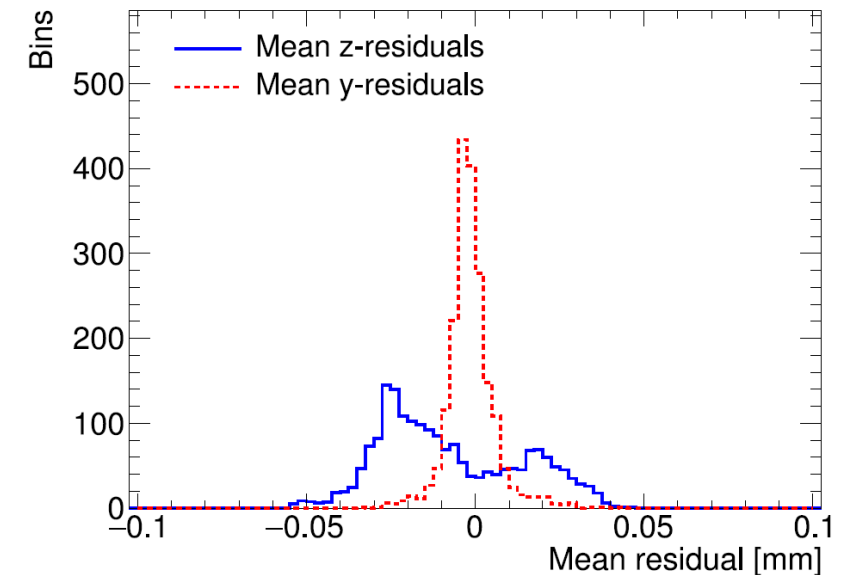
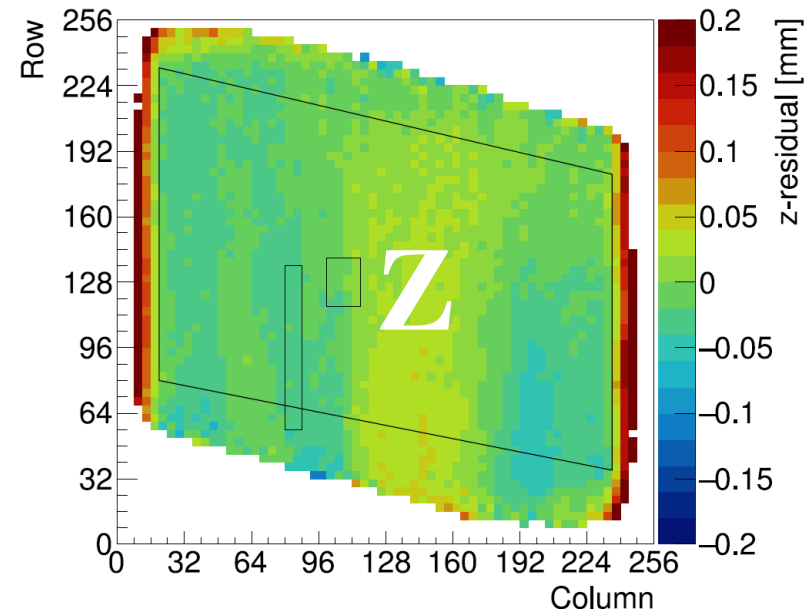
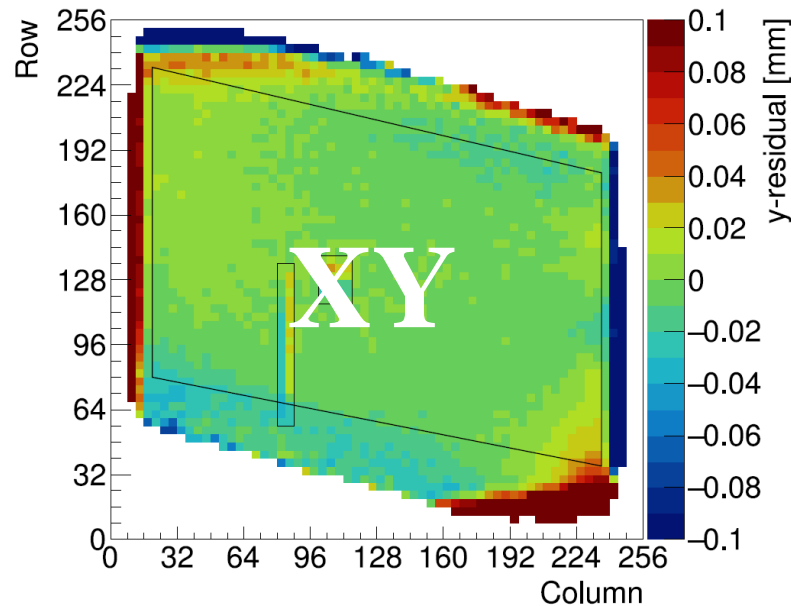


$$D_L = 226 \mu\text{m}/\sqrt{\text{cm}}$$

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

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

- The RMS of the mean residuals is 7  $\mu\text{m}$  in the pixel plane, and 21  $\mu\text{m}$  (0.3 ns) in the drift direction  $\Rightarrow$  Overall grid quality is very good
- Simulations show an improvement in momentum resolution of a pixel TPC readout over a pad readout\*
- Energy loss resolution (dE/dx) by truncated sum is 4.1% per meter\*



- Report about Gridpix for the TPC of the ILD experiment at the ILC can be found in: C. Ligtenberg et al., "Performance of a GridPix TPC readout based on the Timepix3 chip", Proceedings of the International Workshop on Future Linear Colliders (LCWS2018), Arlington, Texas, 22-26 October 2018. C18-10-22. <https://agenda.linearcollider.org/event/7889/contributions/42682>

# Covering large detection areas: QUAD

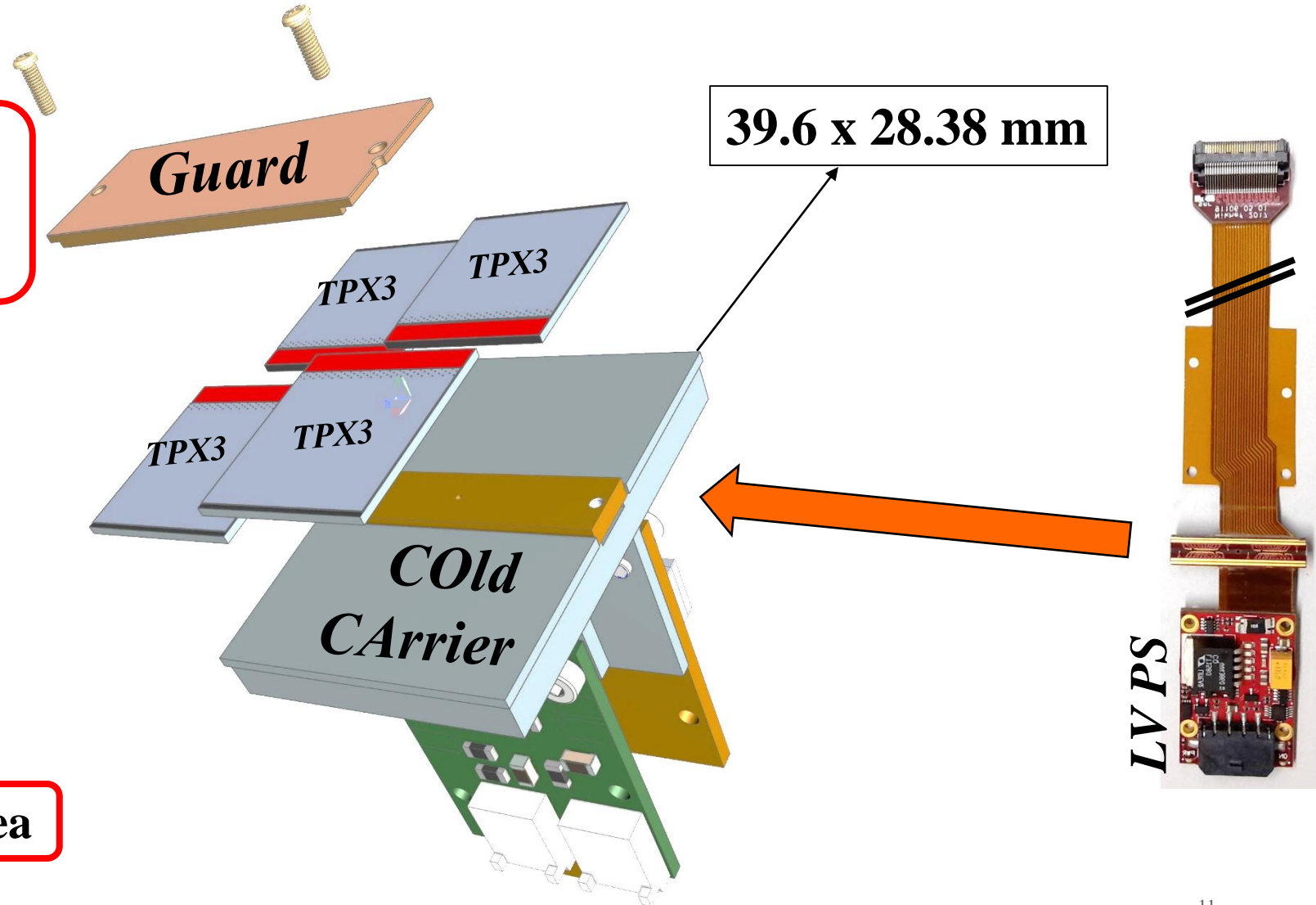
- Four-TimePix3 chips

■ All services (signal IO, LV power) are located **under** the detection surface

- The area for connections was squeezed to the minimum

- Detection surface can be extended by adding other QUADs at all 4 sides

■ => **no limit on detection area**



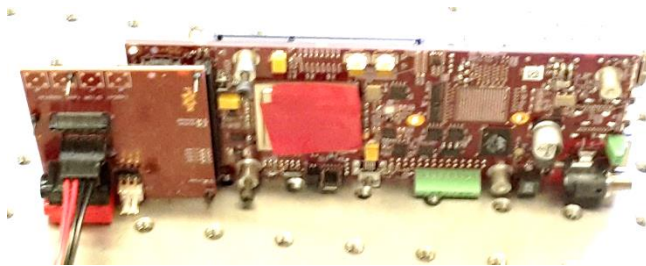
# Assembled QUAD

Cold Carrier  
(COCA)

- QUAD has a sensitive area of 68.9%

- DAQ by SPIDR

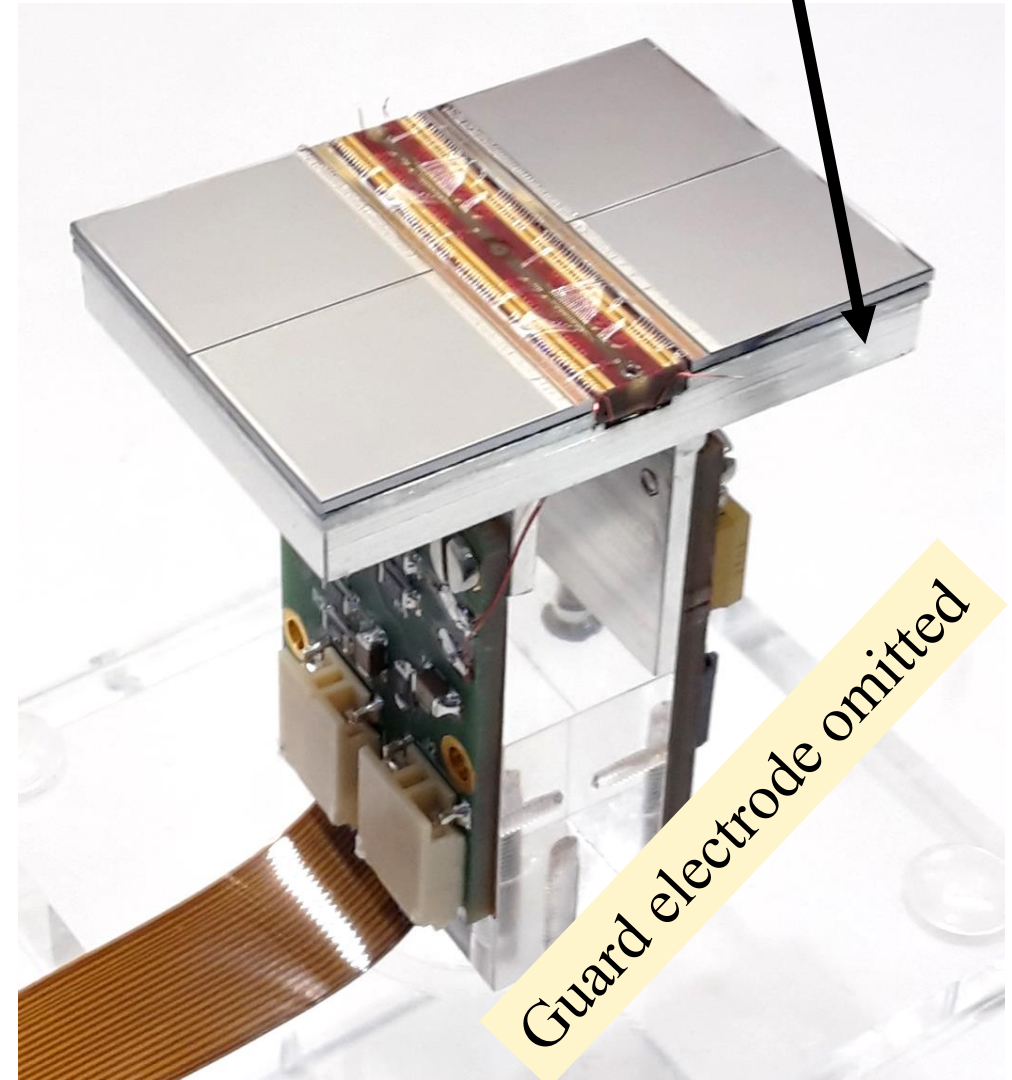
- Optical link



QUADs being produced in series  
(14 QUADs)



**Commercialization under study**

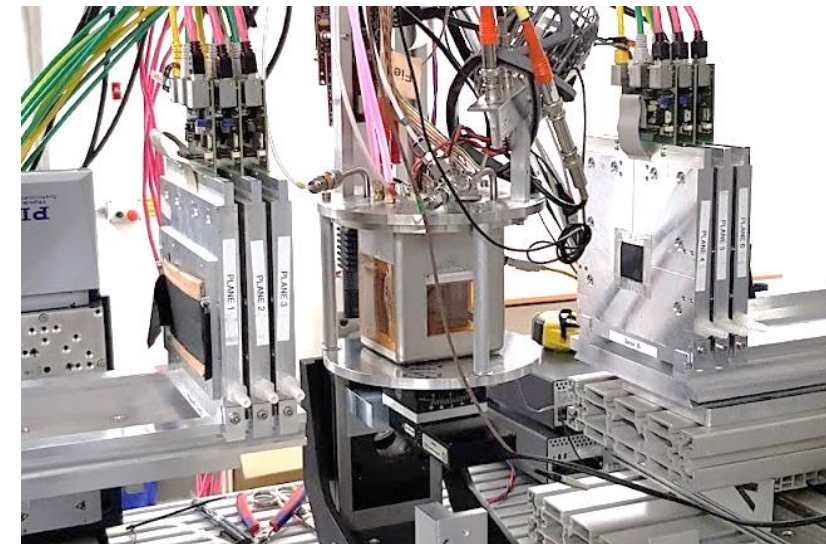
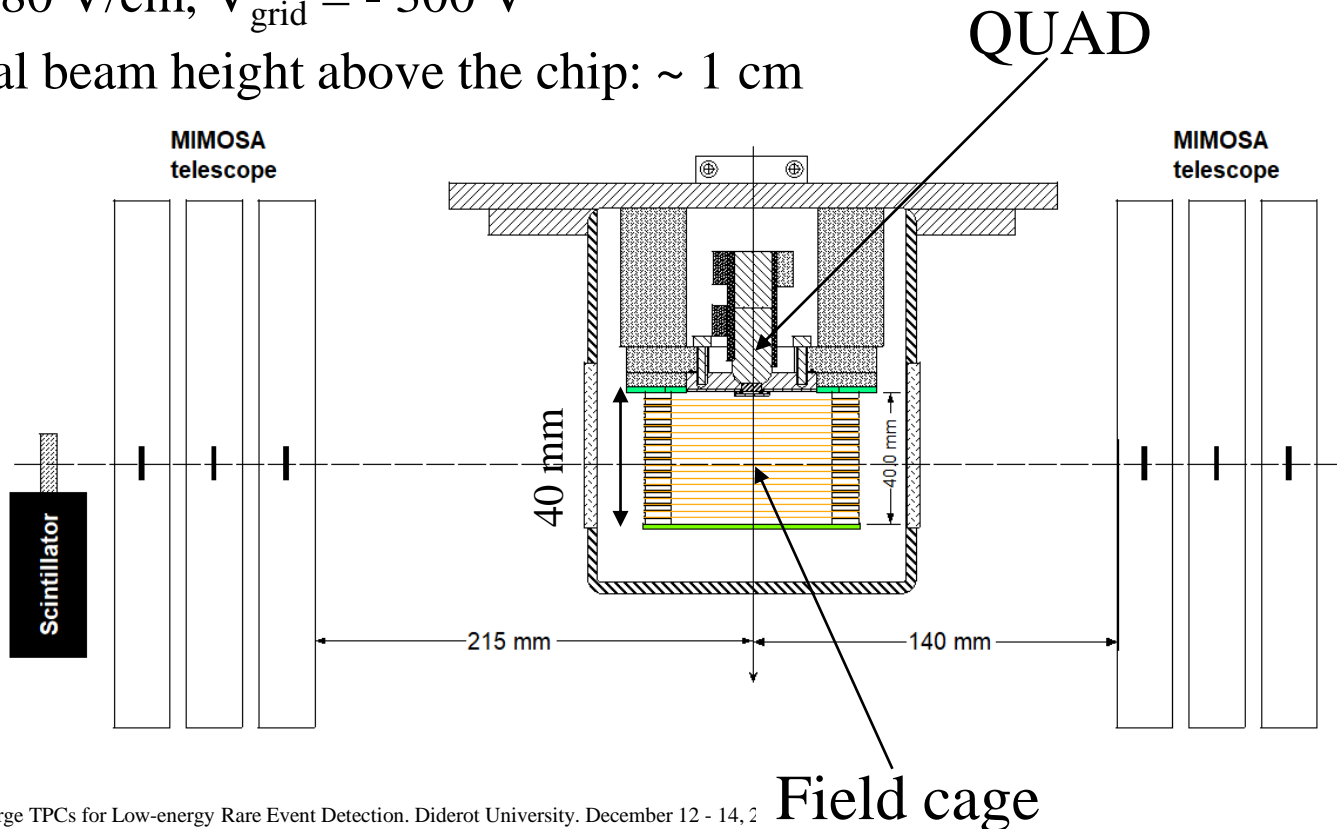


Contact us if you are interested

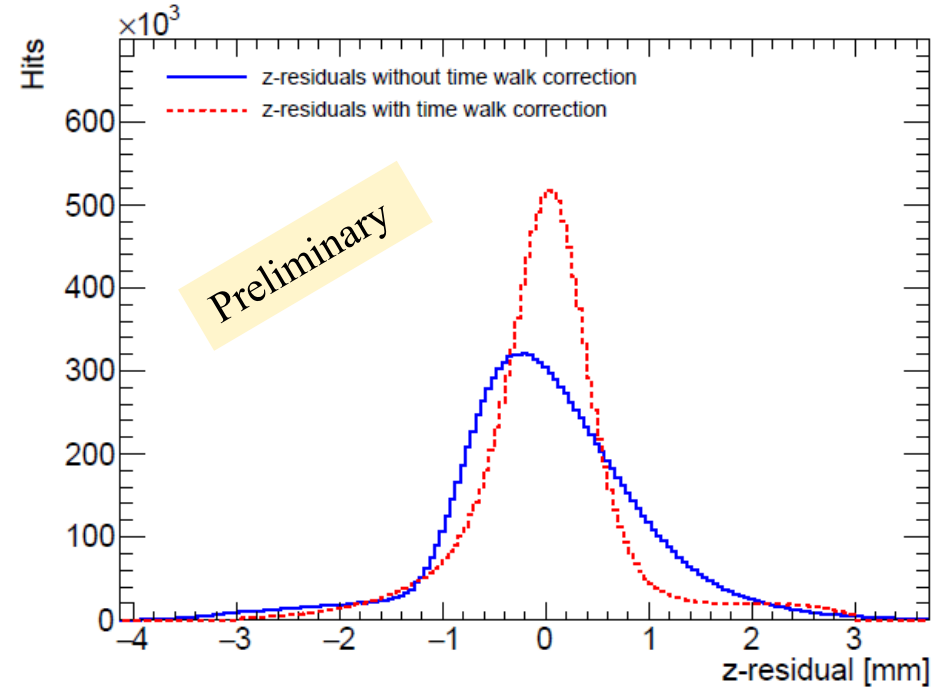
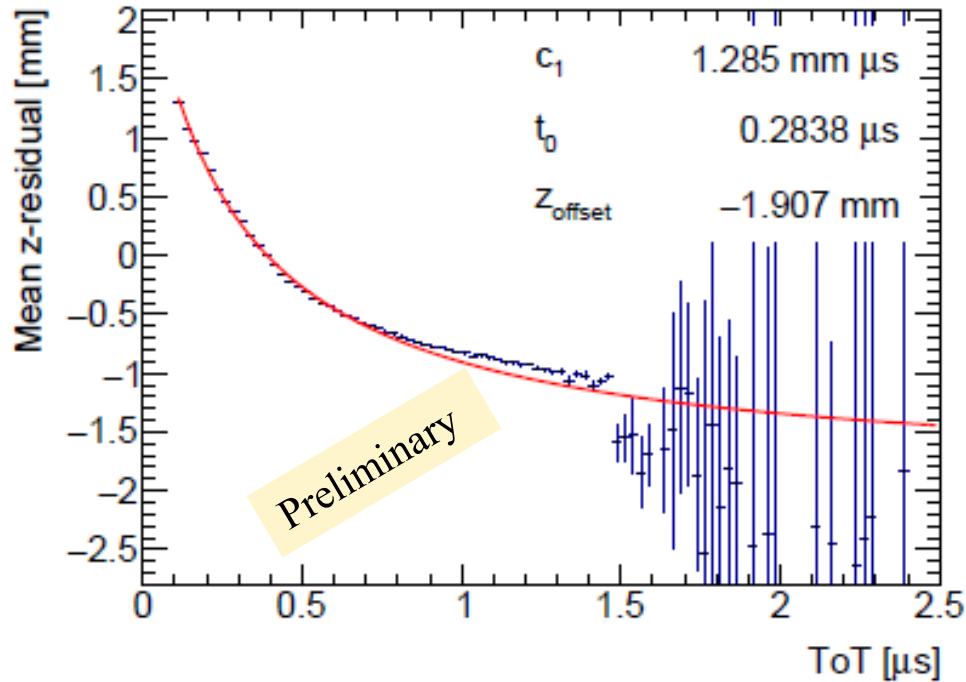
# QUAD test in Bonn (October 2018)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- QUAD sandwiched between Mimosa halves
  - Largely improved track definition
- Gas: Ar/CF<sub>4</sub>/iC<sub>4</sub>H<sub>10</sub> 95/3/2 (T2K)
- E<sub>d</sub> = 280 V/cm, V<sub>grid</sub> = - 300 V
- Typical beam height above the chip: ~ 1 cm

Only preliminary results  
Analysis in progress



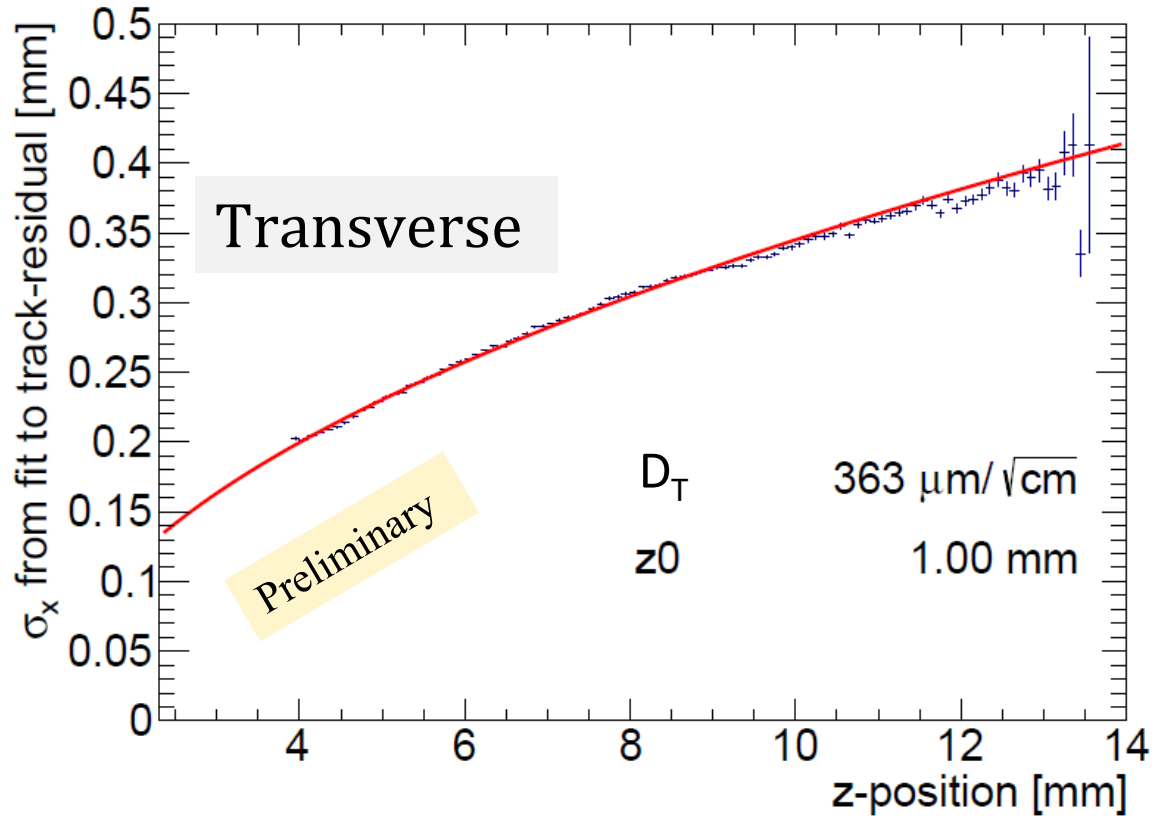
# QUAD time walk results



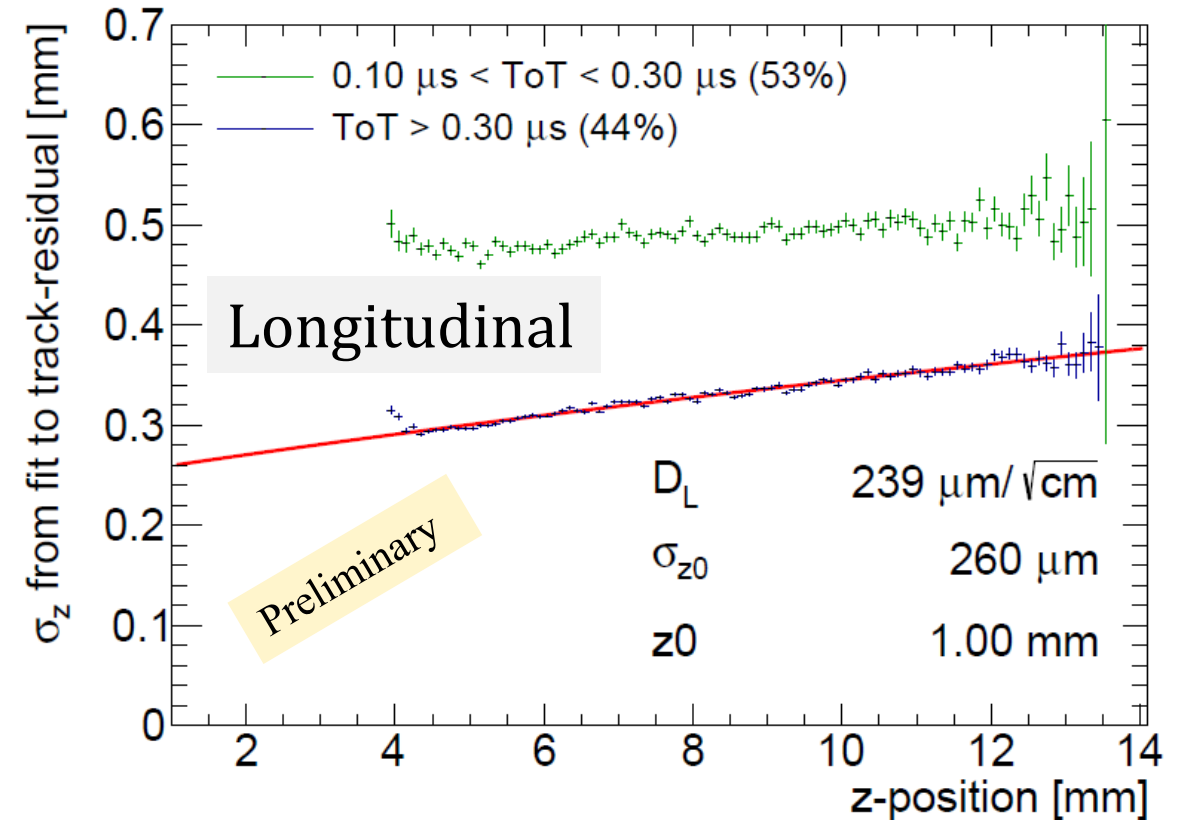
$$\delta Z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + Z_0$$

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

# QUAD diffusion measurements



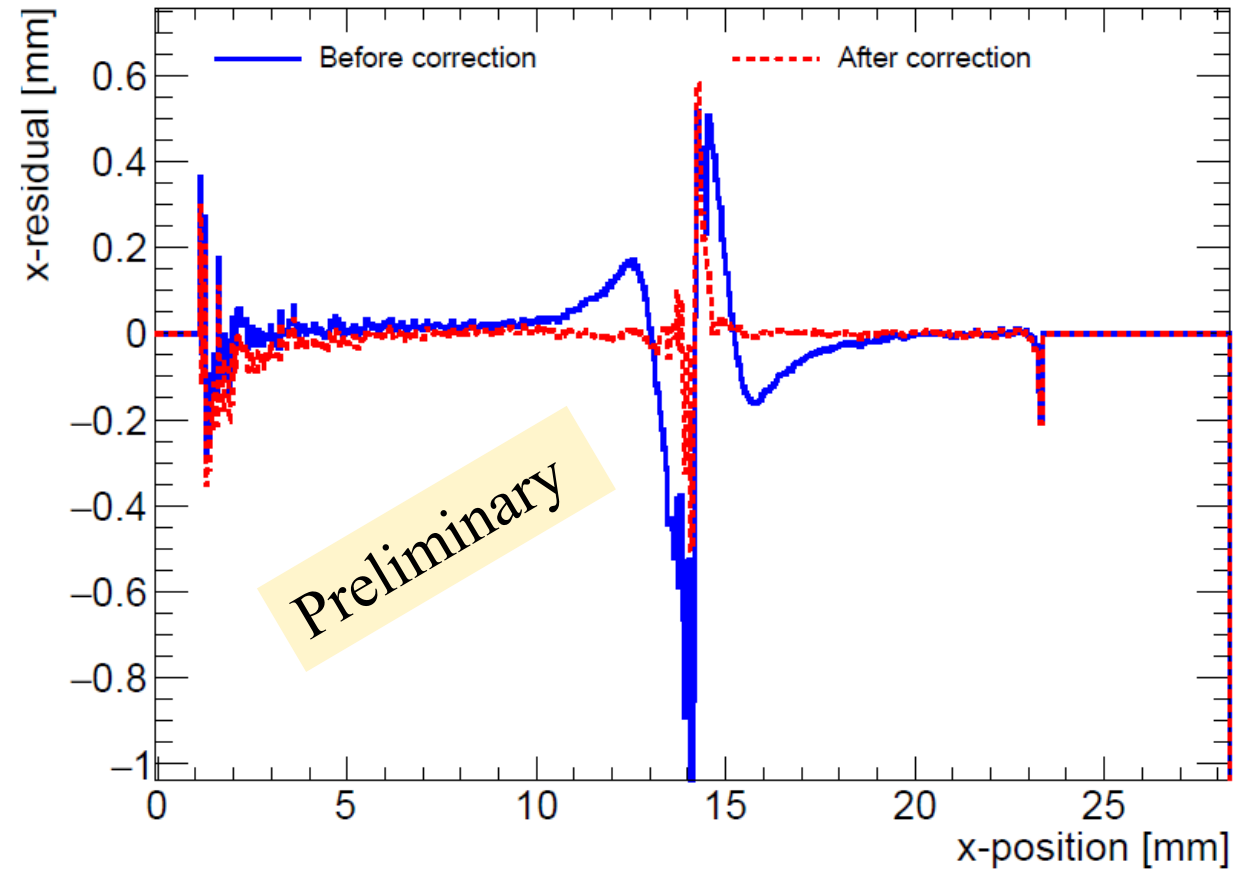
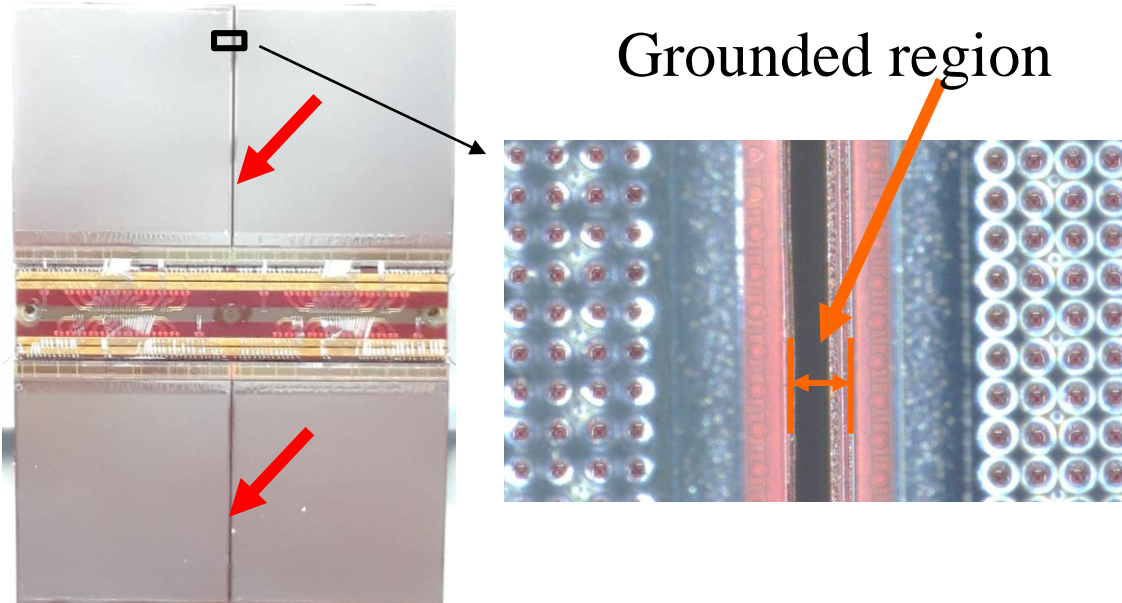
$$D_T = 363 \mu\text{m}/\sqrt{\text{cm}}$$



$$D_L = 239 \mu\text{m}/\sqrt{\text{cm}}$$

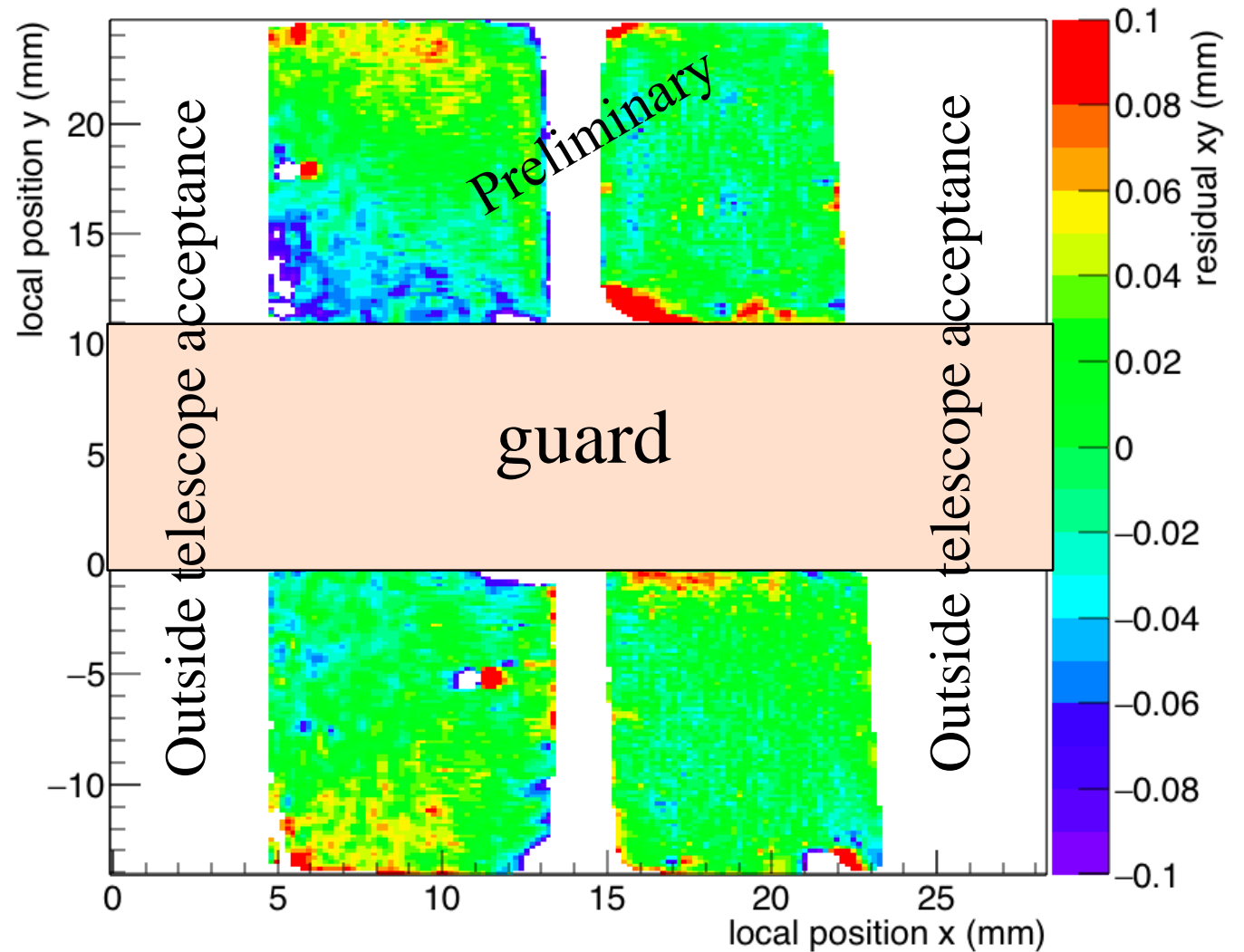
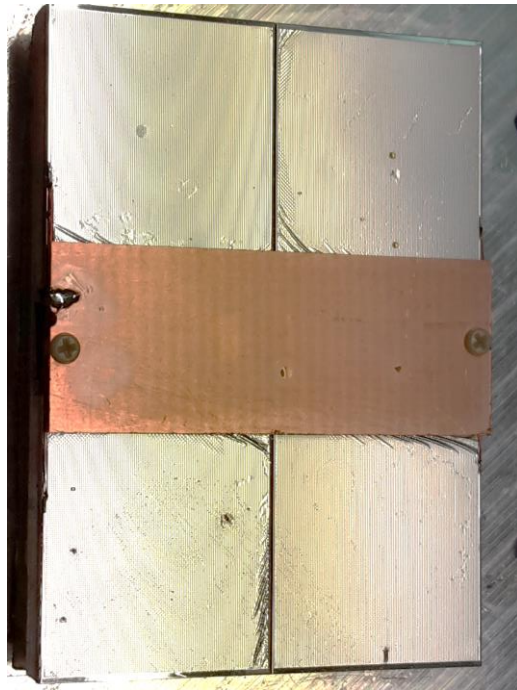
# QUAD edge deformations

- Small deformations due to
  - Dead zone between chips
  - Grounded region between chips
- May be corrected by fitted correction function or adding proper guard electrode



# QUAD deformations in pixel plane (XY)

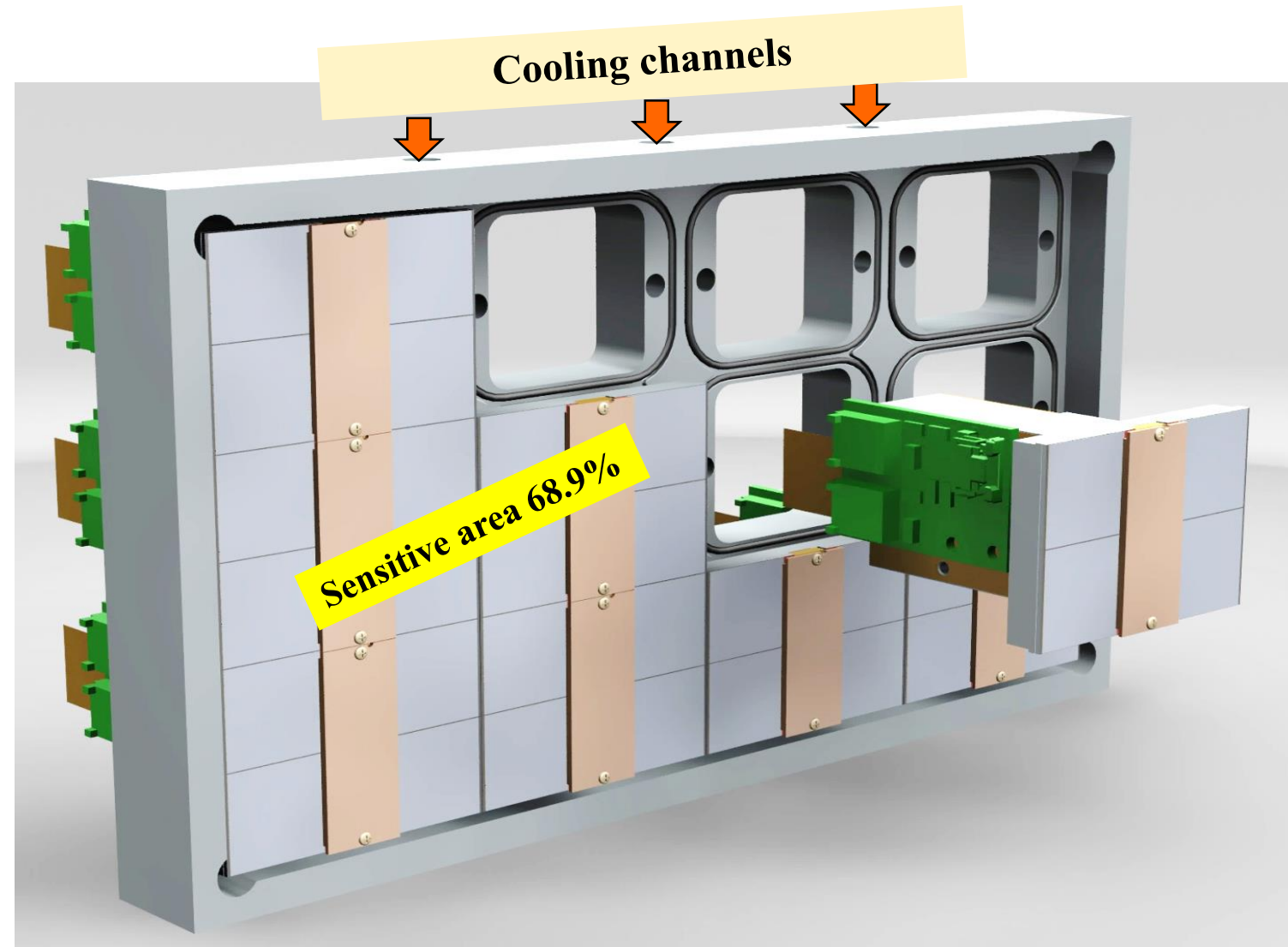
- After applying fitted edge corrections
- The cut offs at left and right side are due to the telescope acceptance and beam coverage



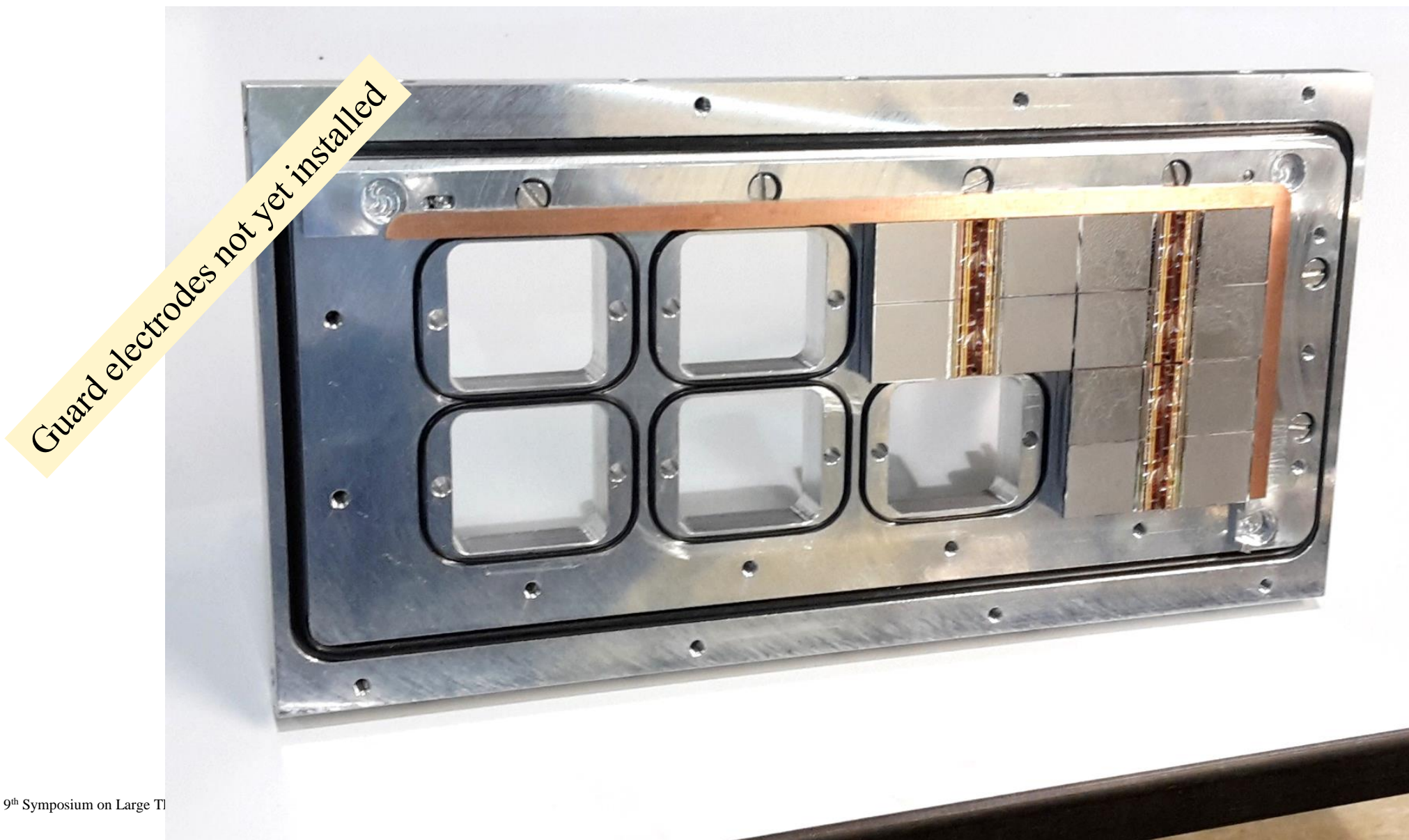
Residuals well below 100  $\mu\text{m}$

# QUAD as a building block

- Building blocks of **39.6 x 28.38 mm**
- Unlimited surface may be covered
- Plug in QUADs into a cooled gastight mounting plate
- Push them from two sides to a mechanical reference
- Concentrator board to connect 4 QUADs to a single SPIDR board in progress

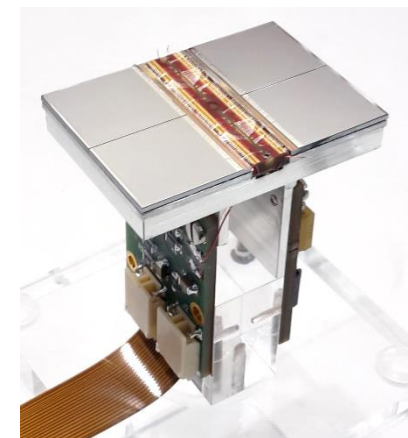


# Mounting plate for 8 QUADs being assembled



# 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
- Preliminary data from a recent 2018 **QUAD** test beam has been 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 can correct them but also study solutions with guard electrodes to reduce them
- A production of 14 **QUAD** modules is almost finished
  - **QUADs** are being installed in an 8-**QUAD** mounting plate



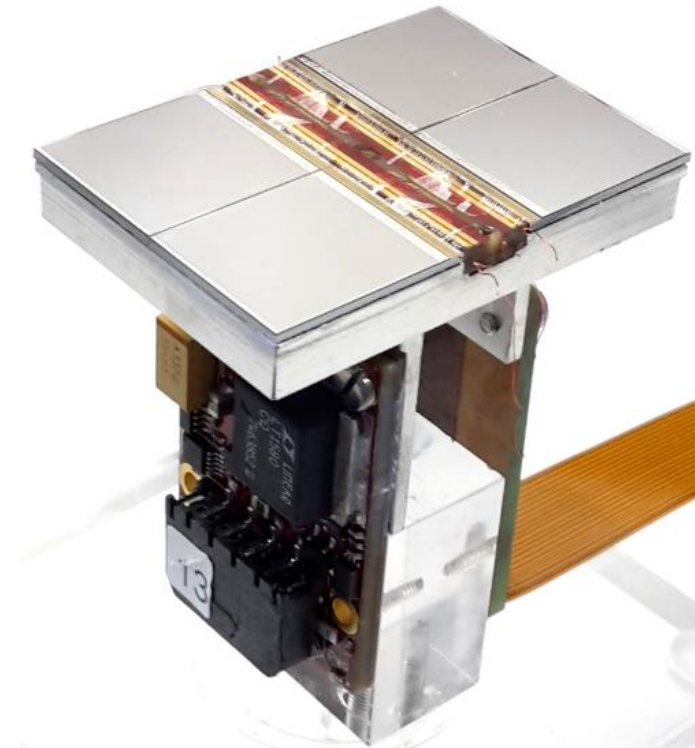
This work is done by the effort of:

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

**Nikhef**

and

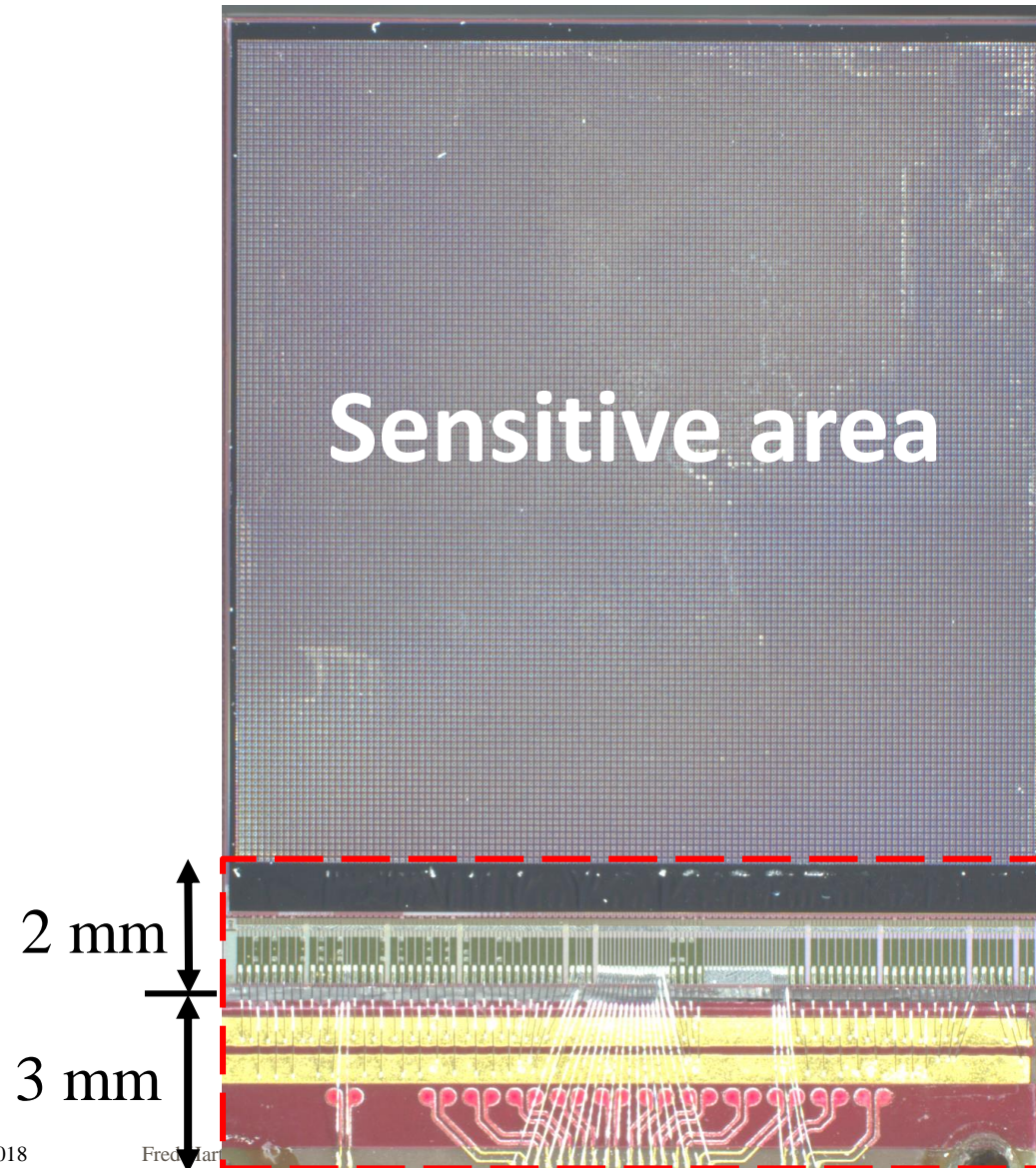
**Physikalisches Institut Universität Bonn**



# BACKUP

# Maximizing QUAD active area

- Using TimePix3 chip
- Wirebond board squeezed to smallest width possible => **3 mm**
- Inactive zone (wirebond pads + electronics) => **2 mm**
- => **we have to reserve a 5 mm wide zone for connection + chip electronics**
  
- By using a possible future through via option, the active area can be increased from 68.9% to 86.4%



# QUAD's active area

- Each chip has 256 x 250 active pixels of 55 x 55  $\mu\text{m}$ 
  - 4 columns of pixels used for dykes
  - $\Rightarrow 4 \times 193.6 = 774.4 \text{ mm}^2$  in a QUAD
- QUAD's outer dimensions
  - $39.60 \times 28.38 = 1123.8 \text{ mm}^2$
- **$\Rightarrow$  QUAD has an active area of 68.9%**
- By using a possible future through via option, the active area can be increased to 86.4%



# 2018 Testbeam track and hit selection

$$-500 \text{ ns} < t_{\text{hit}} - t_{\text{trigger}} < 500 \text{ ns}$$

$$\text{Hit ToT} > 0.10 \mu\text{s}$$

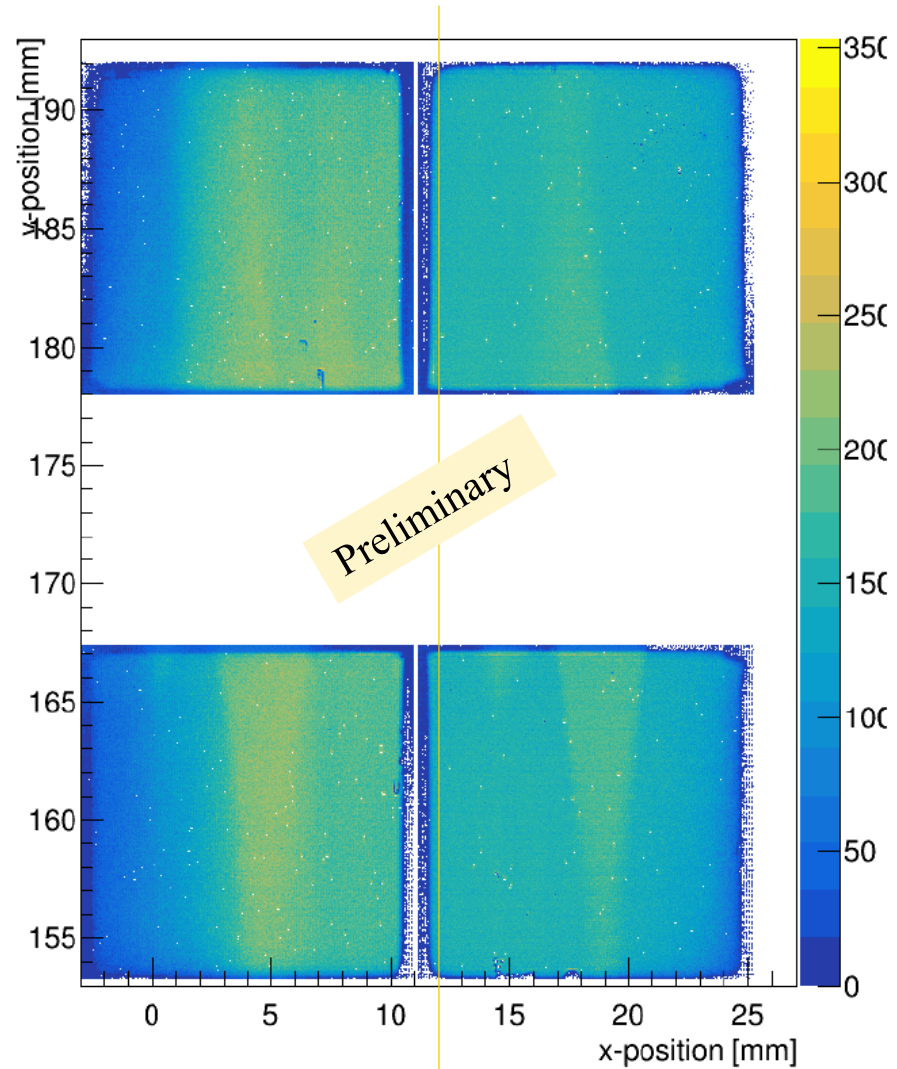
Reject outliers (  $r_x < 1.5 \text{ mm}, r_z < 3 \text{ mm}$  )

$$N_{\text{hits}} > 20$$

$$(N_{r_x < 1.5 \text{ mm}} / N_{r_x < 5 \text{ mm}}) > 0.8$$

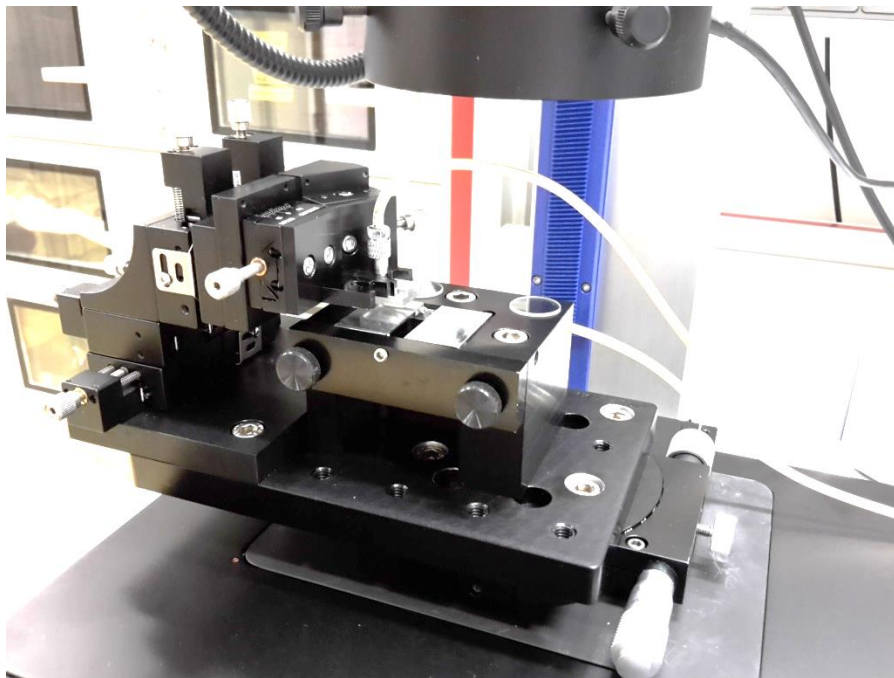
$$\overline{x_{\text{hit}}} - x_{\text{track}} < 0.3 \text{ mm}$$

# QUAD raw hit map

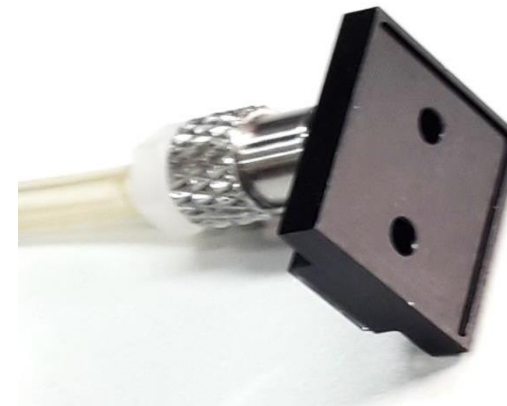
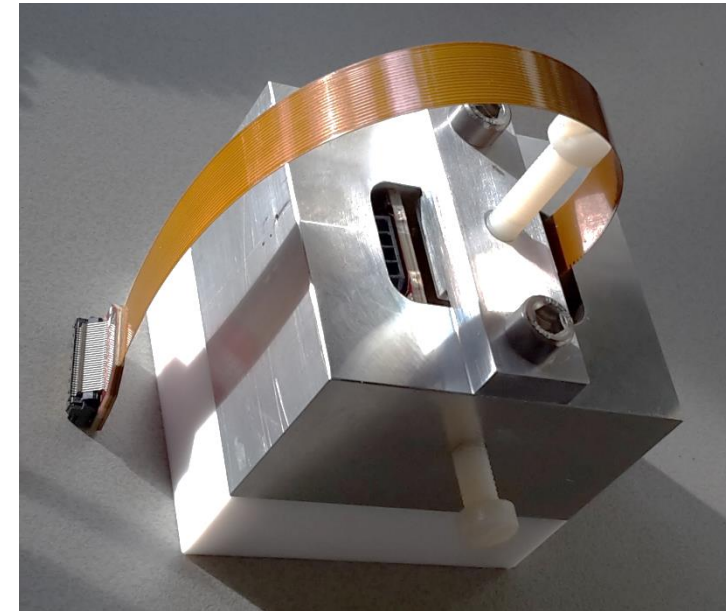


# QUAD's tooling

Chip alignment jig



Assembly tool



Pickup tool for chip with InGrid

# QUAD chip alignment

- Semi automatic under LabVIEW
- Referring the bonding pads of the chips to the precise edges of the COCA
- Aimed accuracy 20  $\mu\text{m}$  in X,Y and Z

