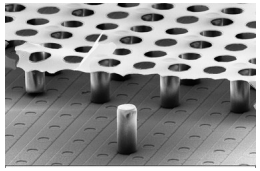
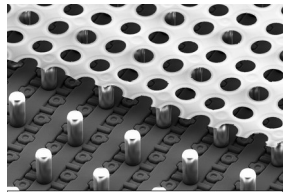




New Results from GridPixes

Yevgen Bilevych, Klaus Desch, Markus Gruber,
Jochen Kaminski, Tobias Schiffer, Sebastian Schmidt
University of Bonn

Jean-Paul Fransen, Fred Hartjes, Bas van der Heijden,
Kevin Heijhof, Charles Ietswaard, Dimitri John, Peter Kluit,
Naomi van der Kolk, Auke Korporaal, Cornelis Ligtenberg,
Oscar van Petten, Gerhard Raven, Joop Rövekamp,
Jan Timmermans, Harry van der Graaf
Nikhef, Amsterdam

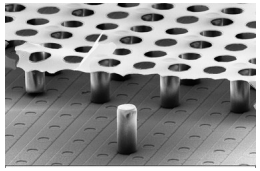
GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

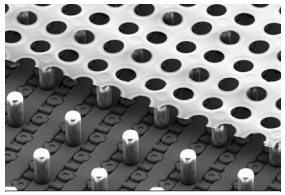
MPGD2019
La Rochelle
10.5.2019

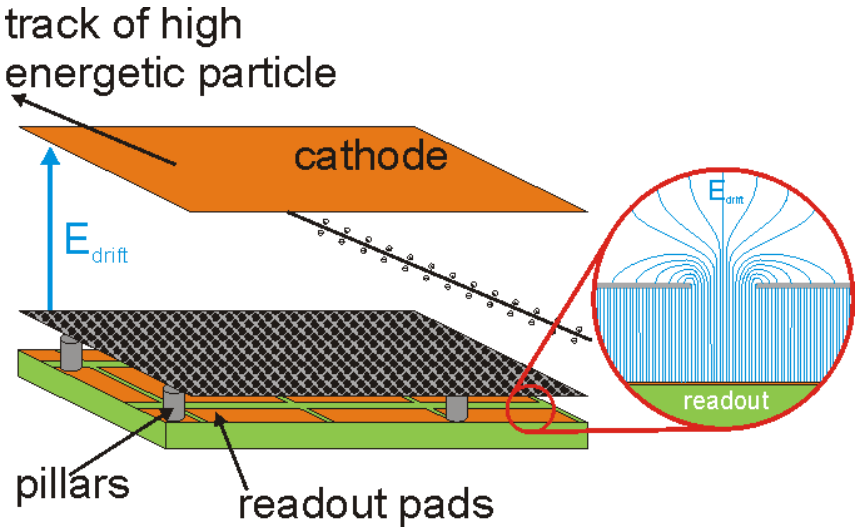
UNIVERSITÄT BONN

Nikhef



Improving Micromegas: GridPix





Standard charge collection:

- Pads of several mm²
- Long strips (l~10 cm, pitch ~200 µm)

Instead: Bump bond pads are used as charge collection pads.

Could the spatial resolution of single electrons be improved?

$Ar:CH_4$ 90:10 → $D_T = 208\ \mu m/\sqrt{cm}$

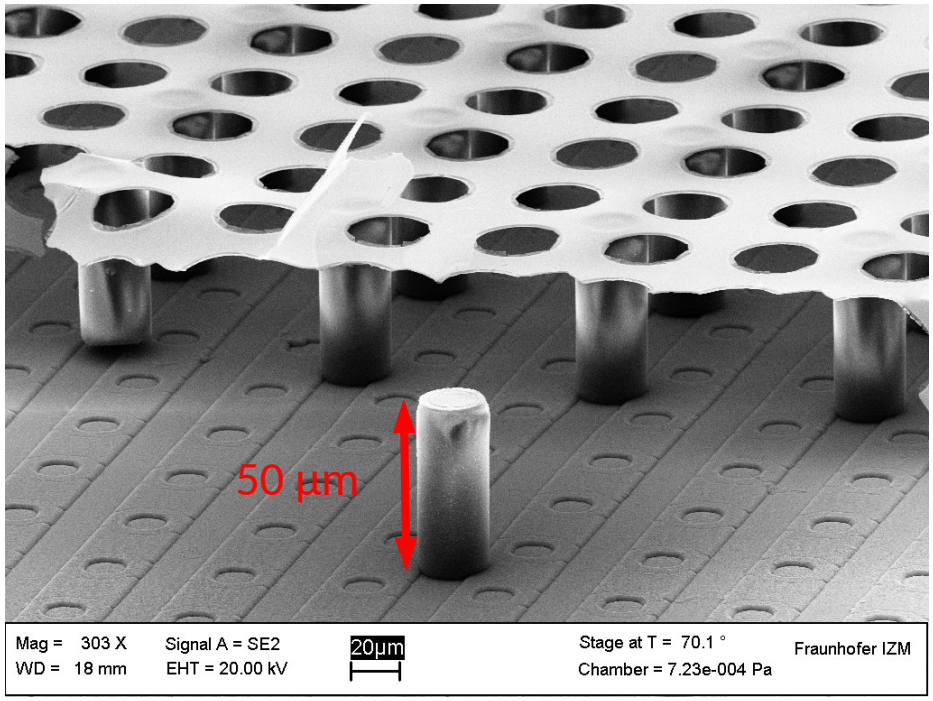
→ $\sigma = 24\ \mu m$

Ar:iButane 95:5 → $D_T = 211\ \mu m/\sqrt{cm}$

→ $\sigma = 24\ \mu m$

Smaller pads/pixels could result in better resolution!

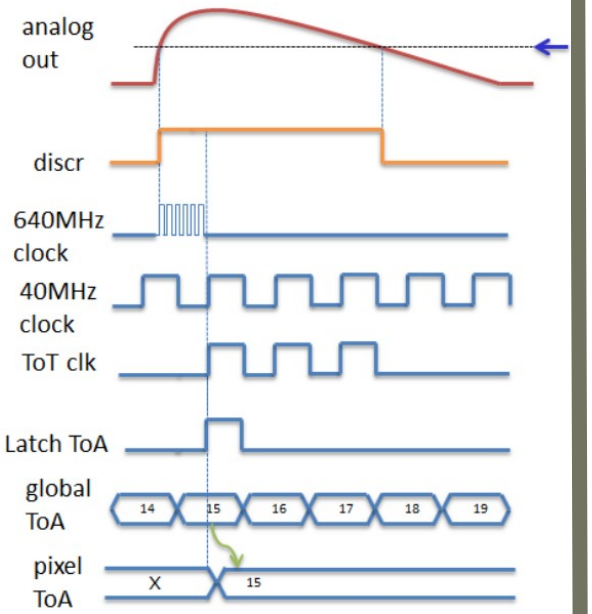
At Nikhef the GridPix was invented.

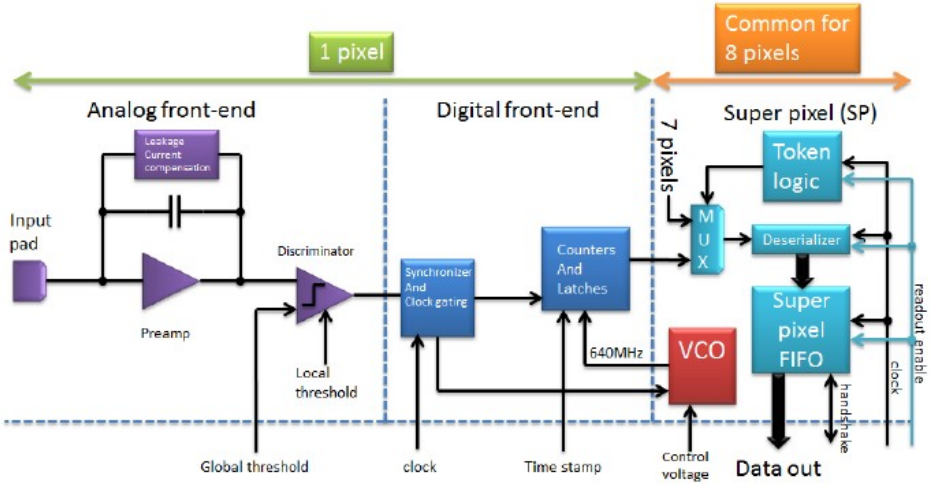


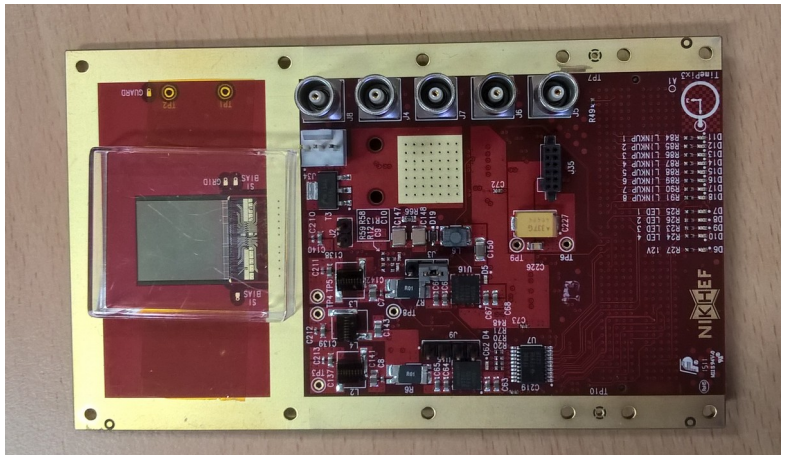
Timepix3

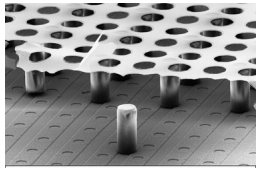
- Number of pixels: 256 × 256 pixels
- Pixel pitch: 55 × 55 µm²
- ENC: ~ 60 e^-
- Charge (ToT) and time (ToA) available for each hit
- Timing resolution: 1.56 ns for duration of ~410 µs
- Zero suppression on chip (sparse readout)
- Multi-hit capable (pixels sensitive after t_{ToT}+475 ns)

  Super-pixels store hits for some time
- Output rate up to 5.12 Gbps
- Power pulsing possible (800 ns for start up)

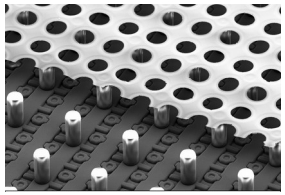




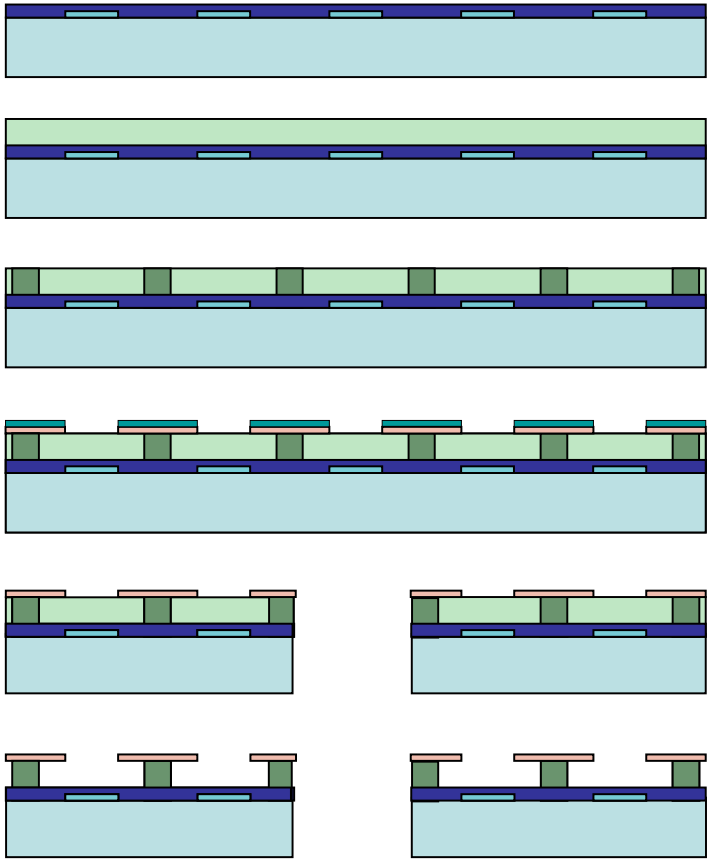




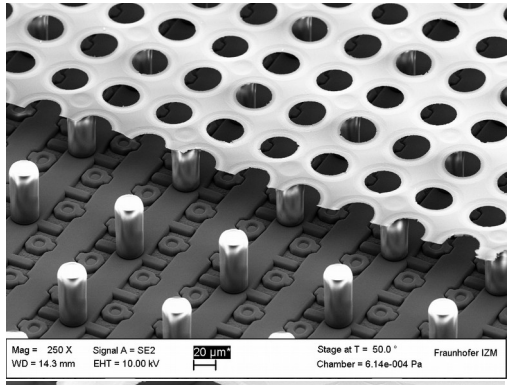
Production at IZM

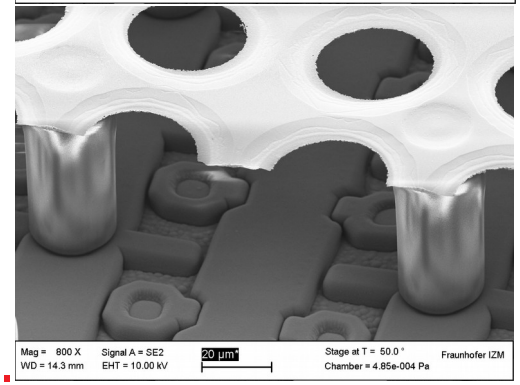


Production was set up at the Fraunhofer Institut IZM at Berlin.
This process is wafer-based → batches of up to 4 wafers (105 chips each) at a time.



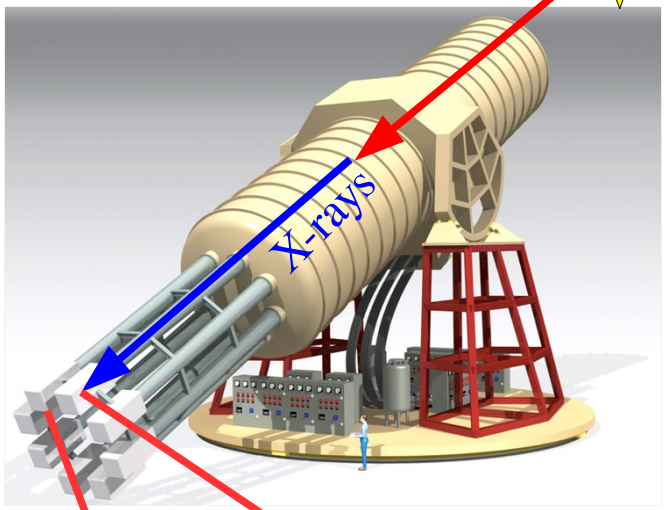
1. Formation of Si_xN_y protection layer (to protect chip from discharges)
2. Deposition of SU-8
3. Pillar structure formation
4. Formation of Al grid
5. Dicing of wafer
6. Development of SU-8

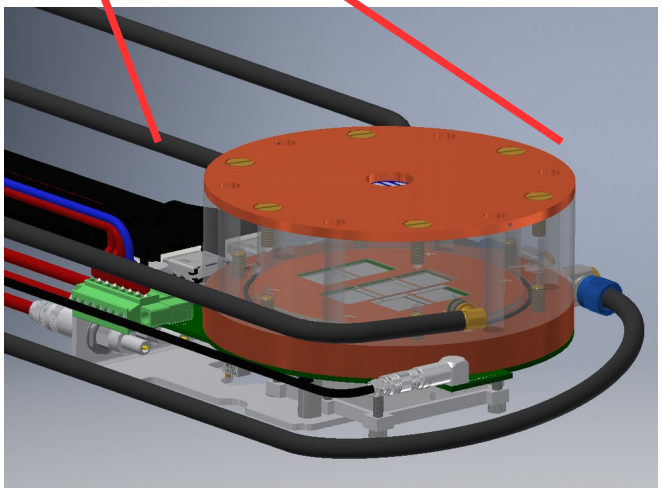




The process will be transferred to the FTD at Bonn in 2020.

Application IAXO/CAST





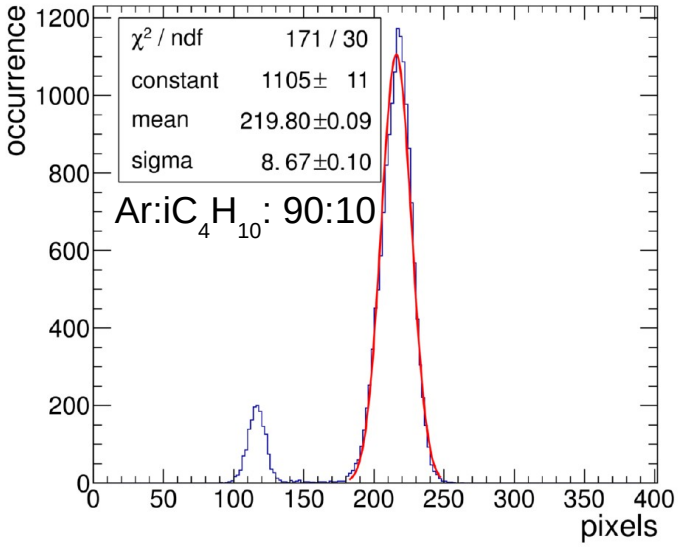
Magnet is pointed to the Sun. Axions and chameleons produced in the Sun convert into X-ray photons.

Detector requirements:

- Radiopure materials
- Good background separation (distinguish round X-rays and longer tracks)
- Good energy resolution
- Very low dead time

=> Detector optimized for spatial and energy resolution:

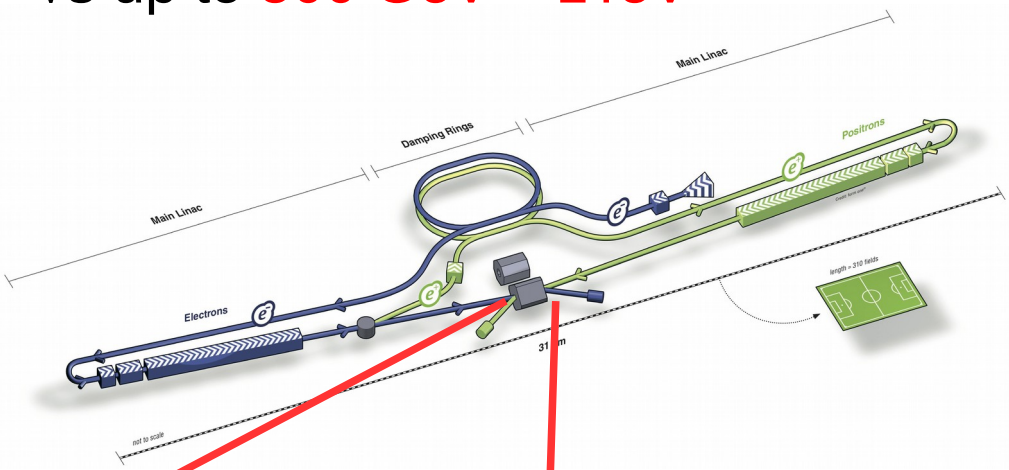
- Gas mixture ($Ar:iC_4H_{10}$: 97.7:2.3)
- Electric fields (E_{drift} = 500 V/cm)
- Gas gain (G~ 2500) and
- Analysis (pixel counting).

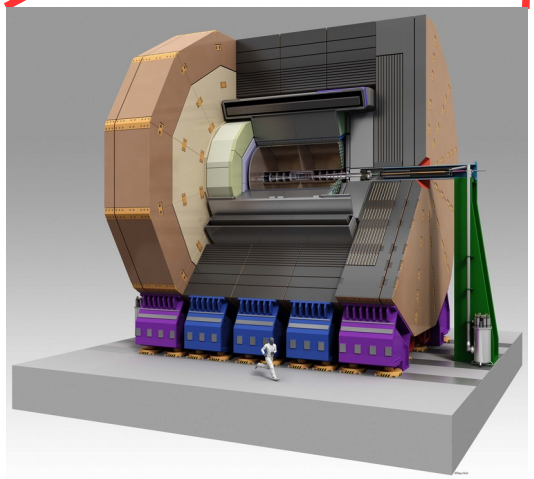


During the study energy resolutions of σ_E/E=3.95% for the photopeak of ^{55}Fe could be reached.

Application ILC

International Linear Collider (ILC)
is a linear e^+e^- collider with
$\sqrt{s}$ up to 500 GeV – 1TeV





International Large Detector
- Standard HEP detector
- TPC as main tracker

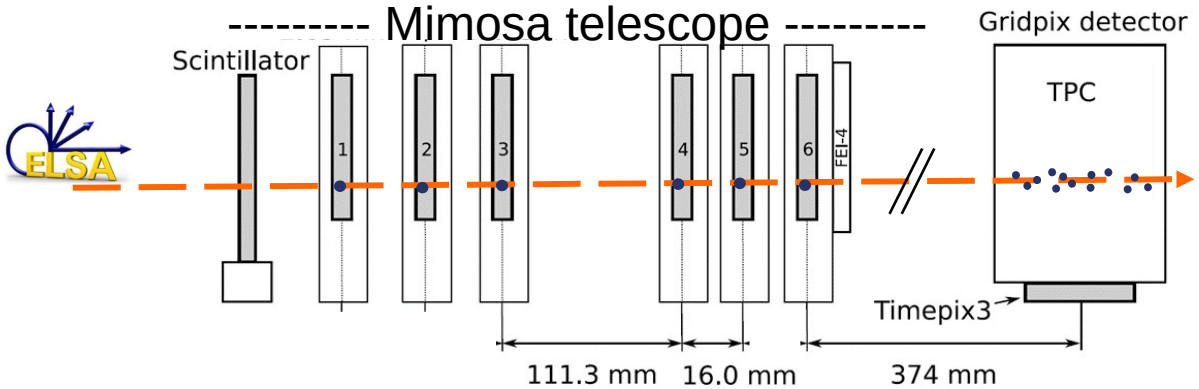
TPC Requirements :

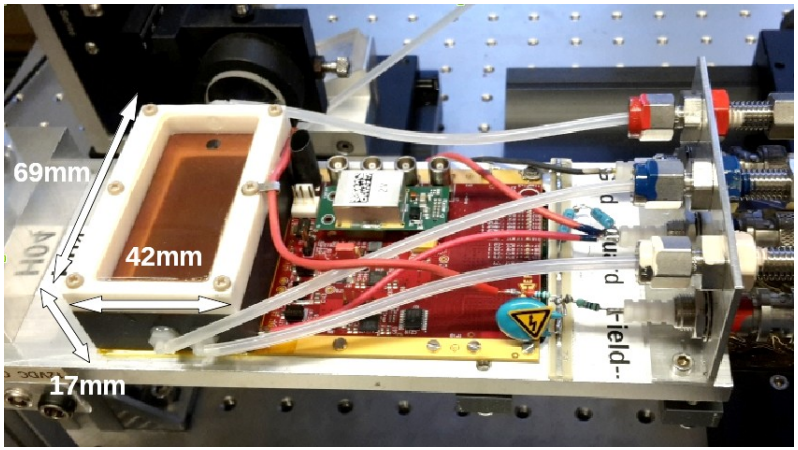
Parameter	
Geometrical parameters	r_{in} 329 mm, r_{out} 1808 mm, z ± 2350 mm
Solid angle coverage	up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05\ X_0$ including outer fieldcage in r
	$< 0.25\ X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq$ 1-2 $\times 10^6$/1000 per endcap
Pad pitch/ no.padrows	$\simeq 1\times 6$ mm^2 for 220 padrows
σ_{point} in $r\phi$	$\simeq 60\ \mu$m for zero drift, $< 100\ \mu$m overall
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq 2$ mm
2-hit resolution in rz	$\simeq 6$ mm
dE/dx resolution	$\simeq 5$ %
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)

Benefits of GridPix readout:
- Lower occupancy → better track finding
- Identification/removal of δ-rays/kinks
- Improved dE/dx → primary e^- counting

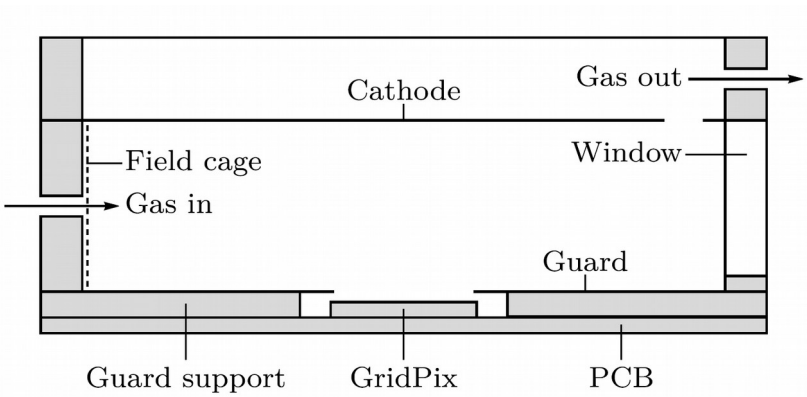
But to readout the TPC with GridPixes:
~100-120 chips/module 240 module/endcap (10 m²)
→ 50k-60k GridPixes

Test Beam with Single GridPix



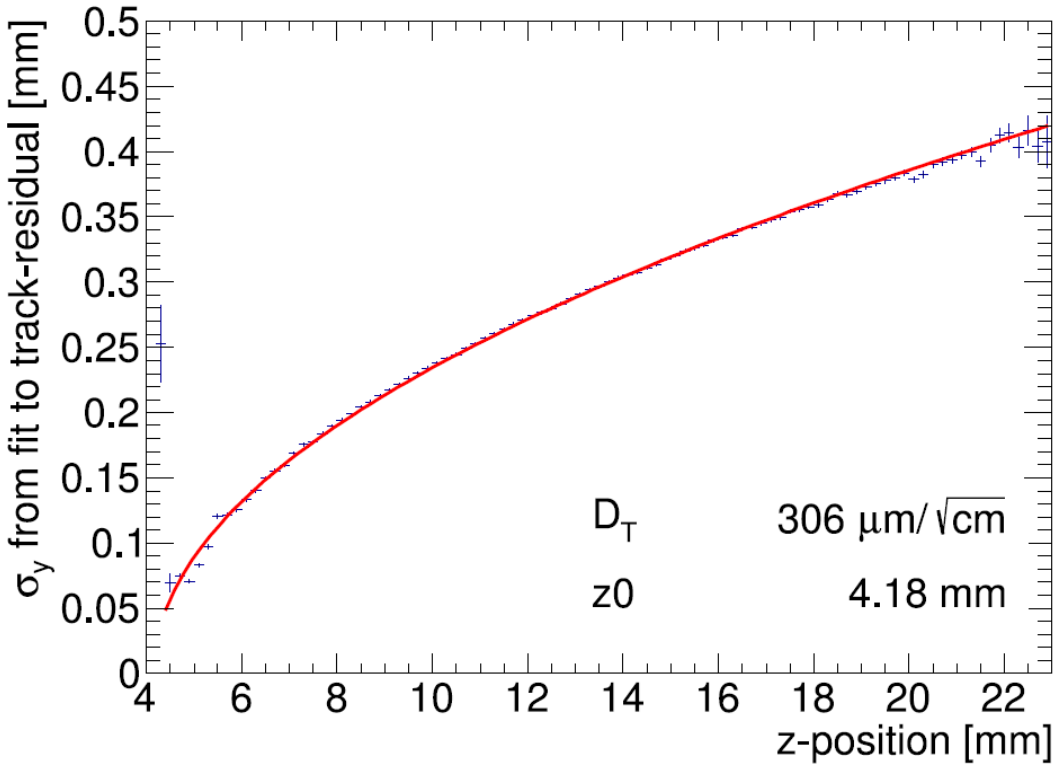


- Test beam in July 2017 at ELSA, Bonn
- 2.5 GeV electrons at up to 10 kHz
- Tracks referenced by 6 layers of Mimosa telescope in front of detector
- Gas: $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)
- Electrons: ~100 e/cm
- E_d = 280 V/cm, V_{grid} = -350 V



Results published in: Nuclear Inst. and Methods in Physics Research, A 908 (2018) 18–23

Transverse Spatial Resolution



Single hit resolution in pixel plane:

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

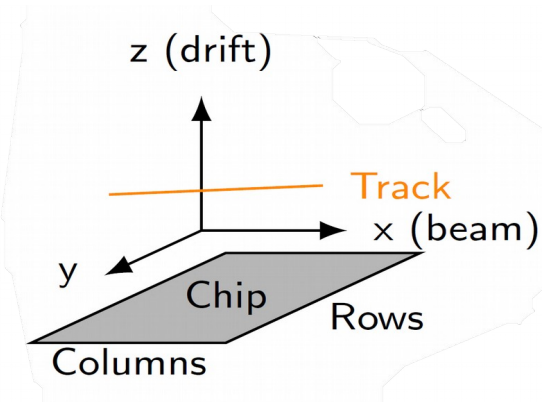
Depends on:

pixel size → σ_{y0} = pixel size/$\sqrt{12}$

diffusion coefficient D_T from fit

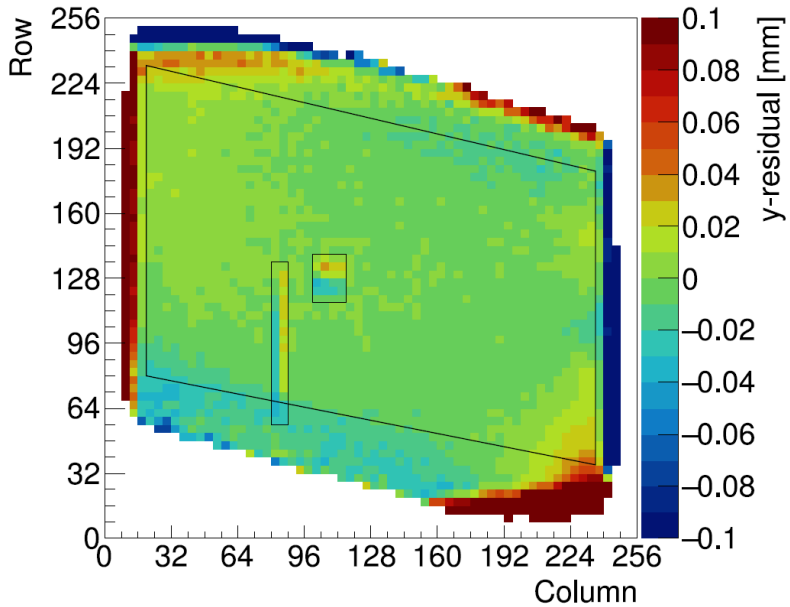
Deformations in pixel plane:

7 μm (RMS) in selected area

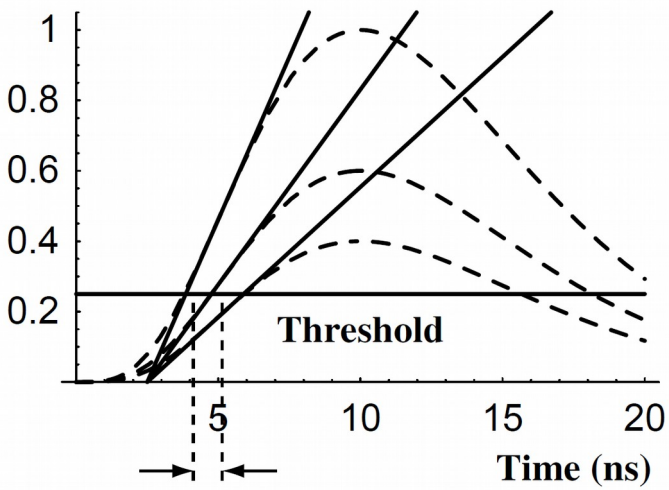


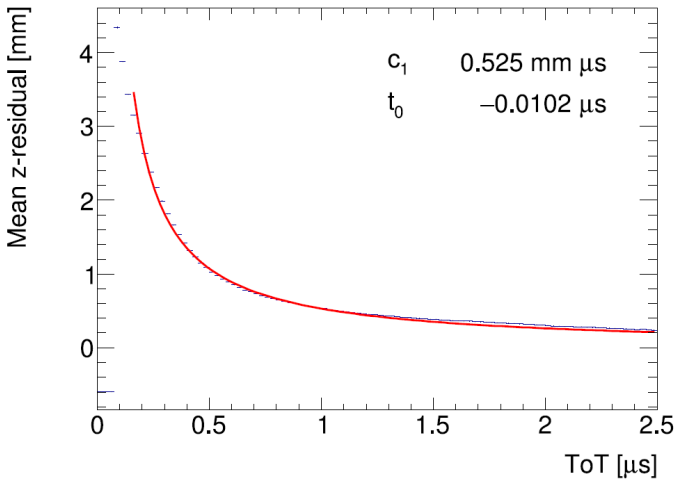
$$D_T = 306\ \mu\mathrm{m}/\sqrt{\mathrm{cm}}$$

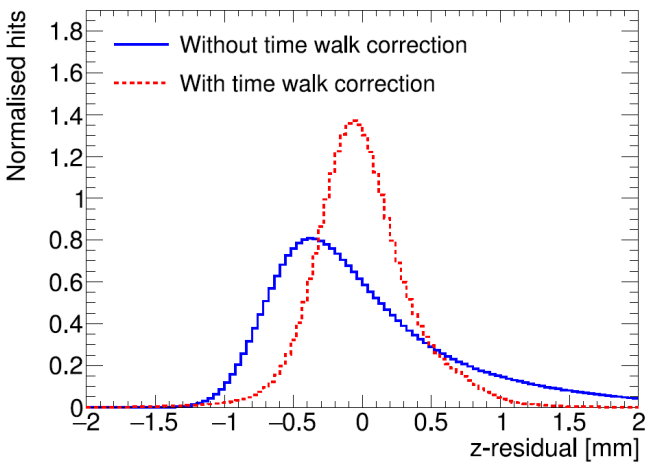
$$(318 \pm 7\ \mu\mathrm{m}/\sqrt{\mathrm{cm}}\ \text{expected})$$



Time Walk Correction







Time walk error: time of arrival depends on signal amplitude

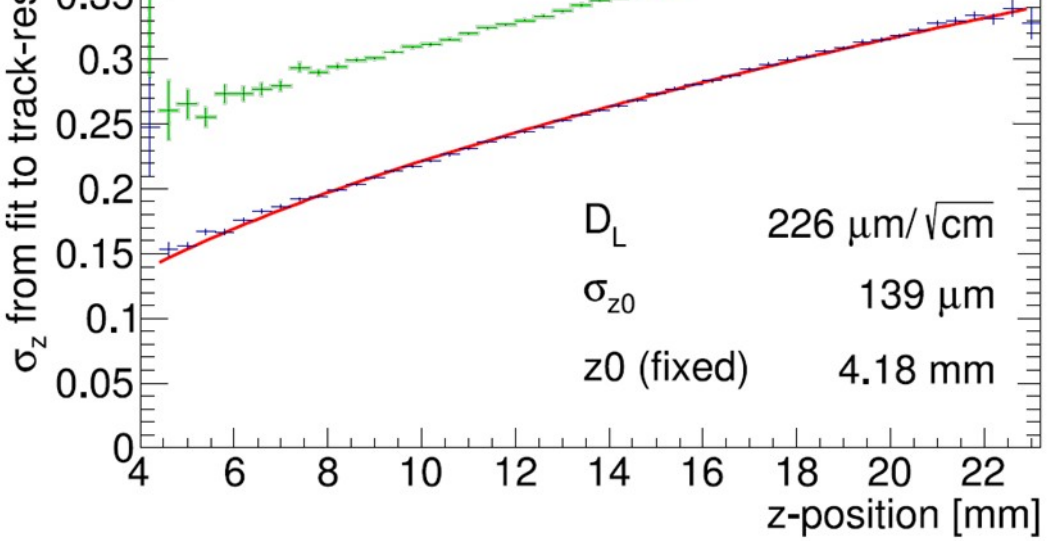
Correction using Time over Threshold (ToT) as a measure of signal strength

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

Residual distribution improved

Higher order corrections did not yield further improvements

Longitudinal Spatial Resolution

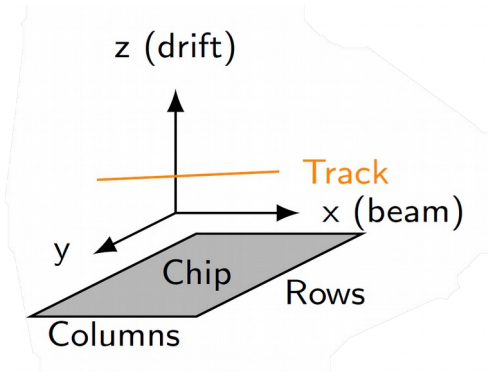


Single hit resolution in pixel plane:

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

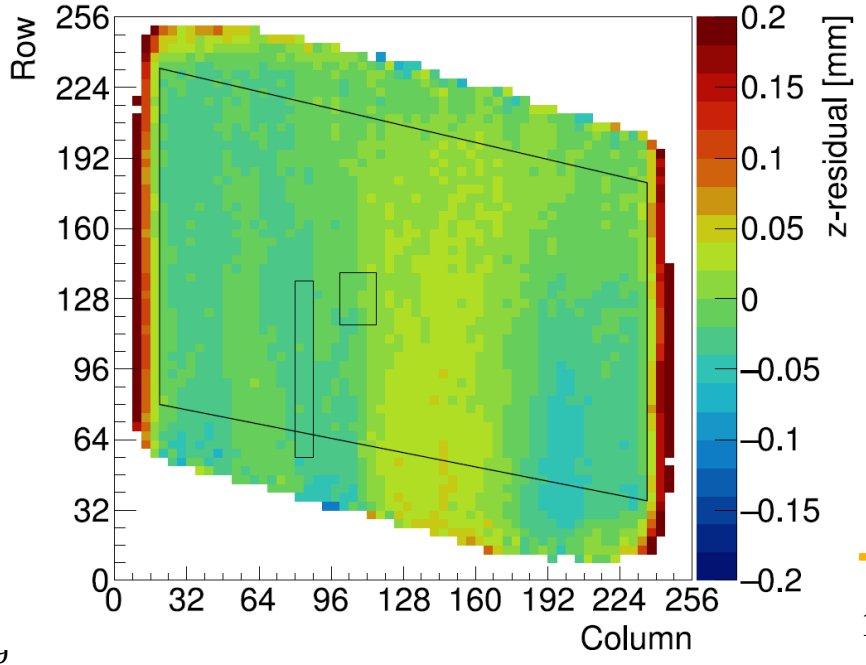
Additional selection cuts:
ToT cut (>0.60 µs) was applied to avoid large time walk errors

Deformations in z-direction: 21µm (RMS) in selected area



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

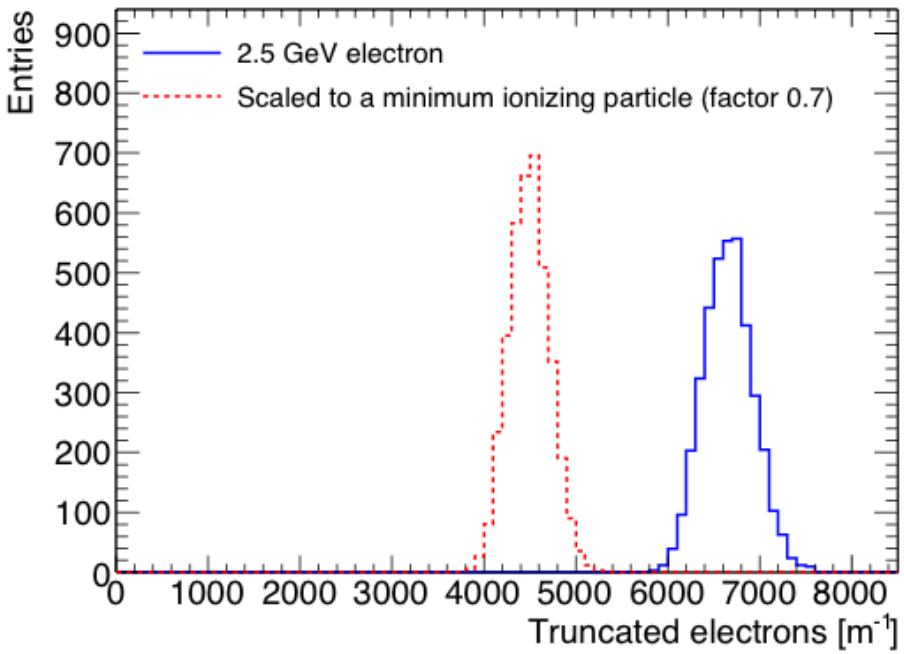
$$(201 \pm 5\ \mu\text{m}/\sqrt{\text{cm}}\ \text{expected})$$



dE/dx Measurements

- dE/dx resolution with truncated mean
  - From the single chip tracks 1 m long tracks are made;
  - n_r 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 1m track

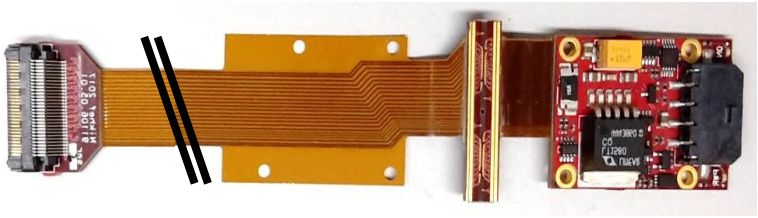
A pixel readout can in principle within the resolution (diffusion) separate primary from secondary clusters. dE/dx can be measured by cluster counting and performance separation enhanced.

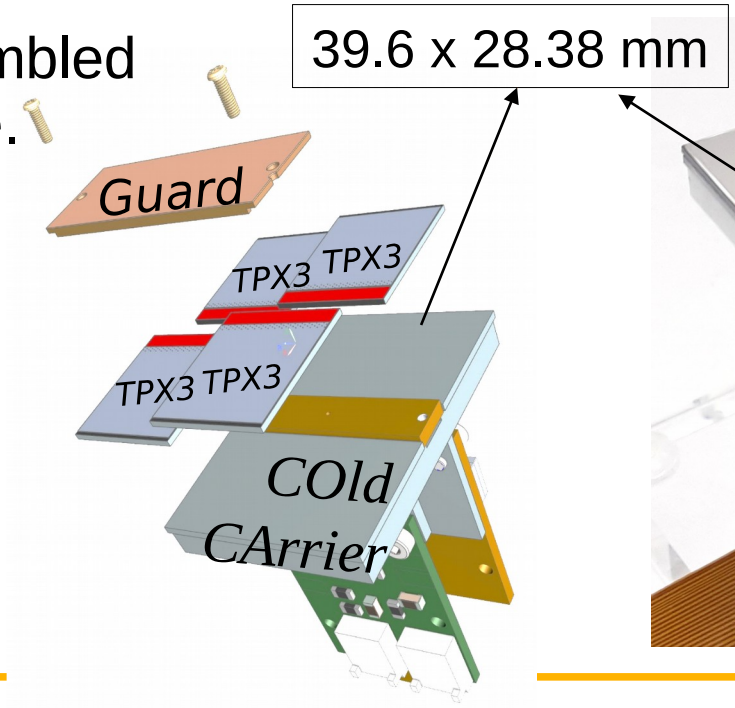


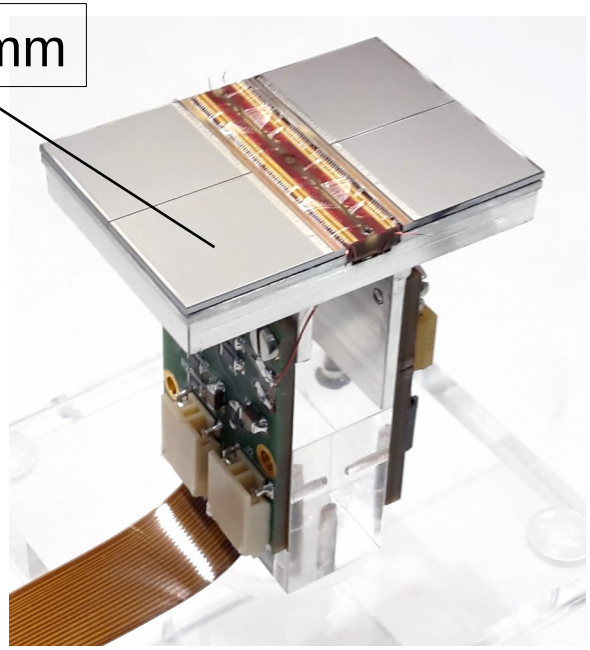
Construction of a QUAD

- Four-Timepix3 chips
- All services (signal IO, LV power) are located under the detection surface
- The area for connections was squeezed to the minimum → QUAD has an sensitive area of 68.9%
- Very high precision 10 µm mounting of the chips and guard
- 14 QUADs have been assembled of these 12 are working fine.
- DAQ by SPIDR

series of QUADs

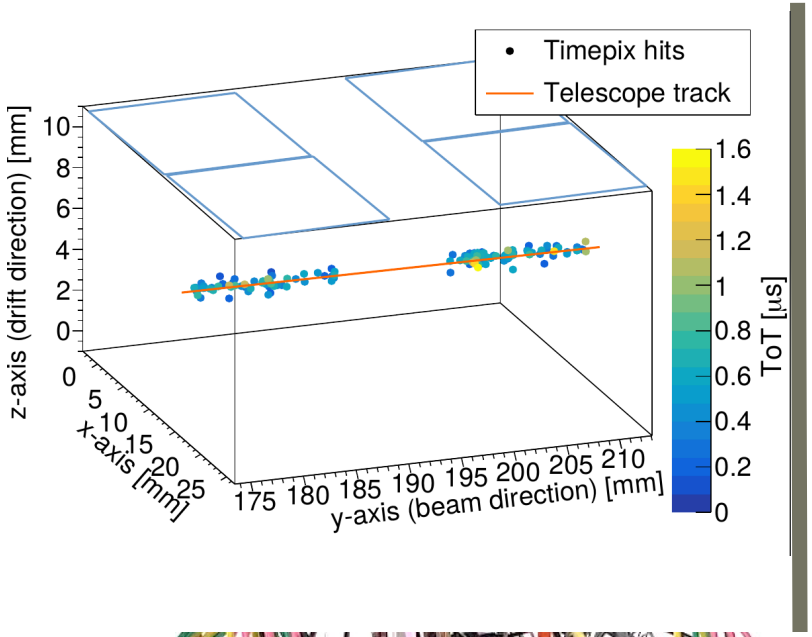


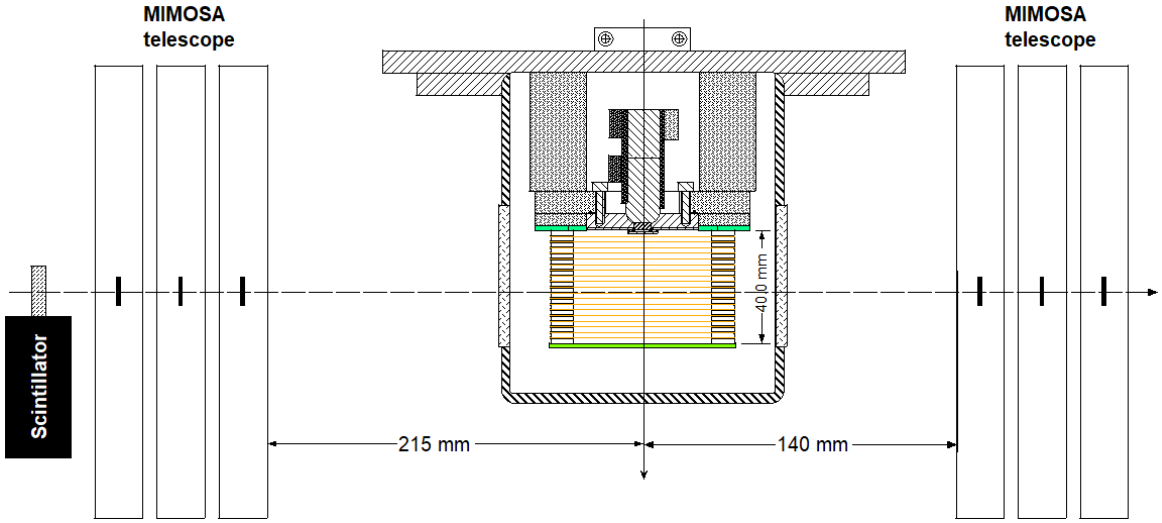




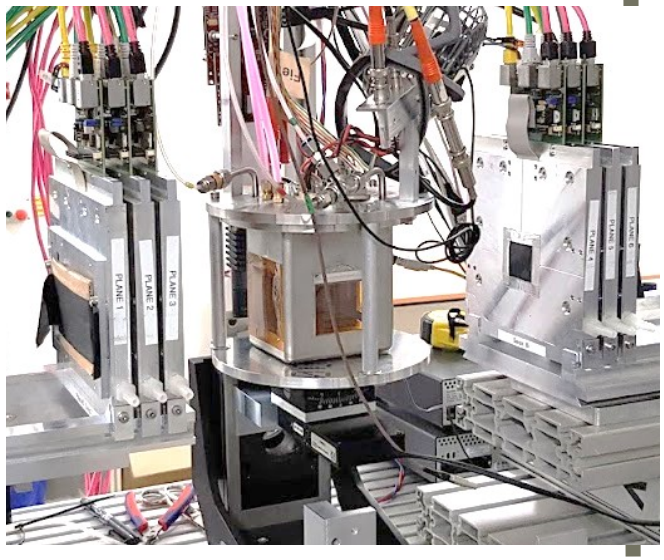
Test Beam with QUAD

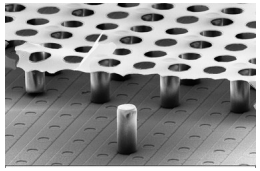
- Test beam in October 2018 at ELSA, Bonn
- 2.5 GeV electrons at up to 10 kHz
- Typical beam height above the grid: ~1cm
- Tracks referenced by 6 layers of Mimosa telescope with DUT in the middle
- Gas: $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)
- E_d = 280 V/cm, V_{grid} = -330 V
- Longer drift distance (4 cm) with field cage



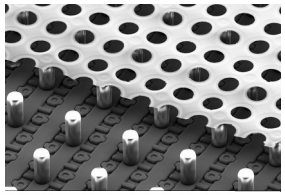


@Bonn

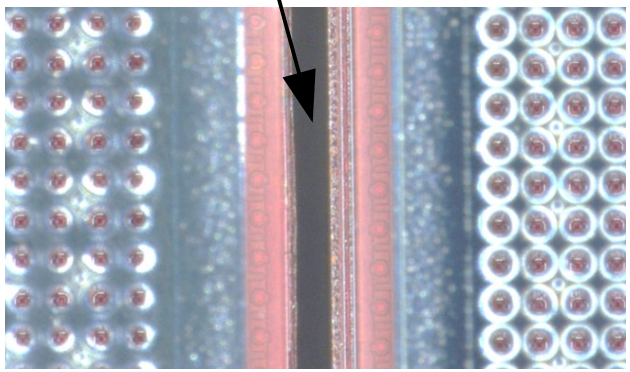


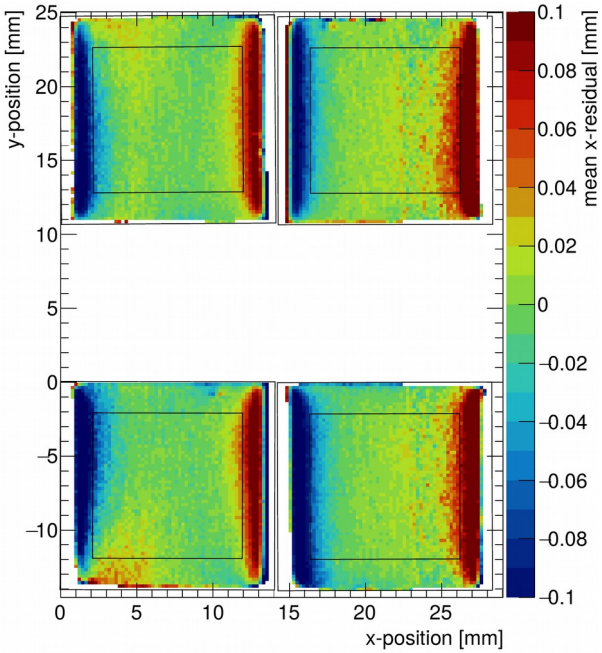


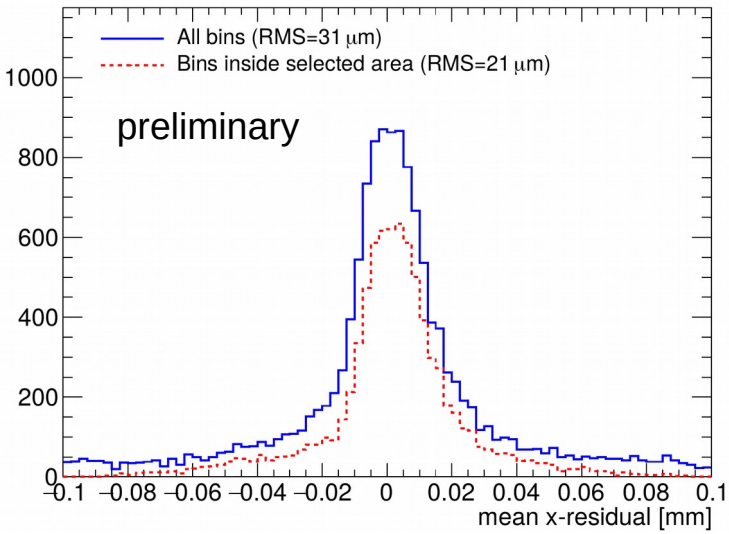
Global Distortion Correction



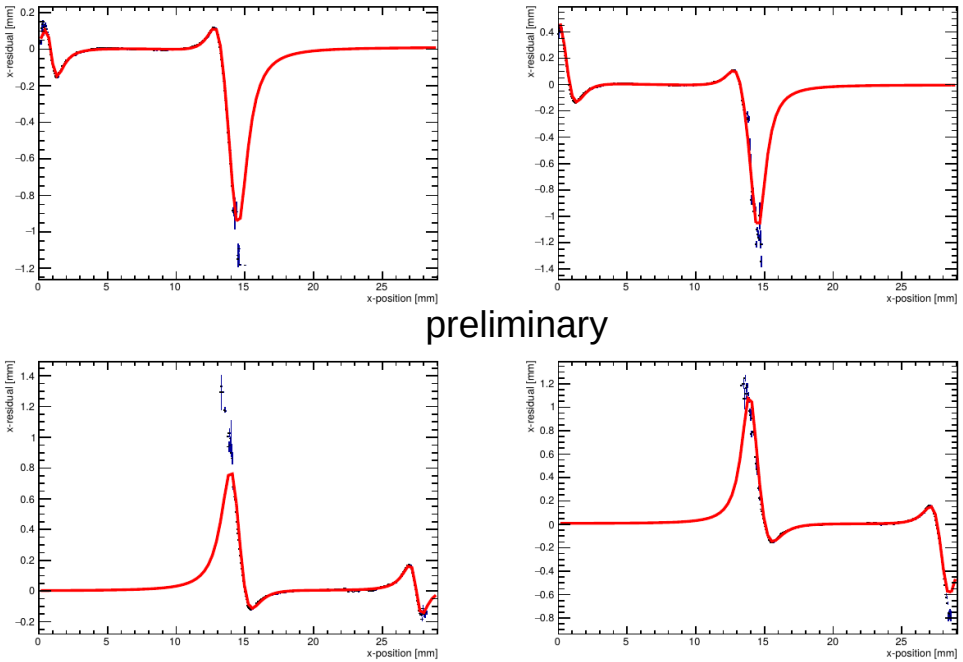
Gap between GridPixes is grounded. This leads to field distortions.





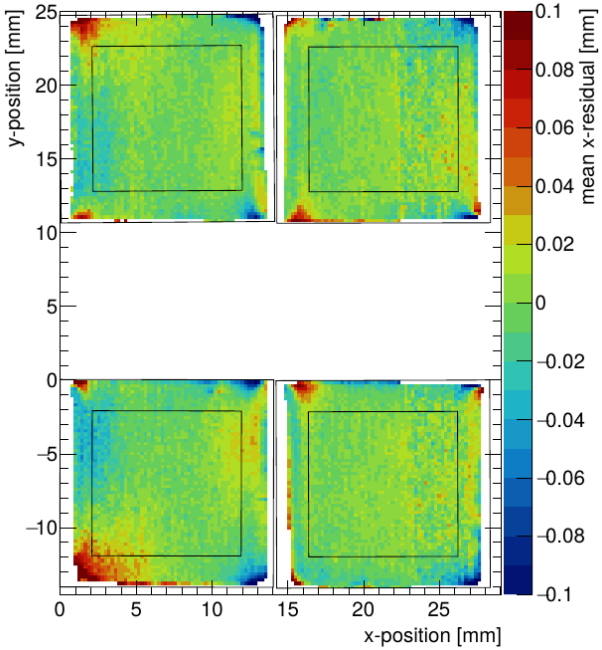


At boarders larger residuals.
→ 1.) reduce fiducial volume

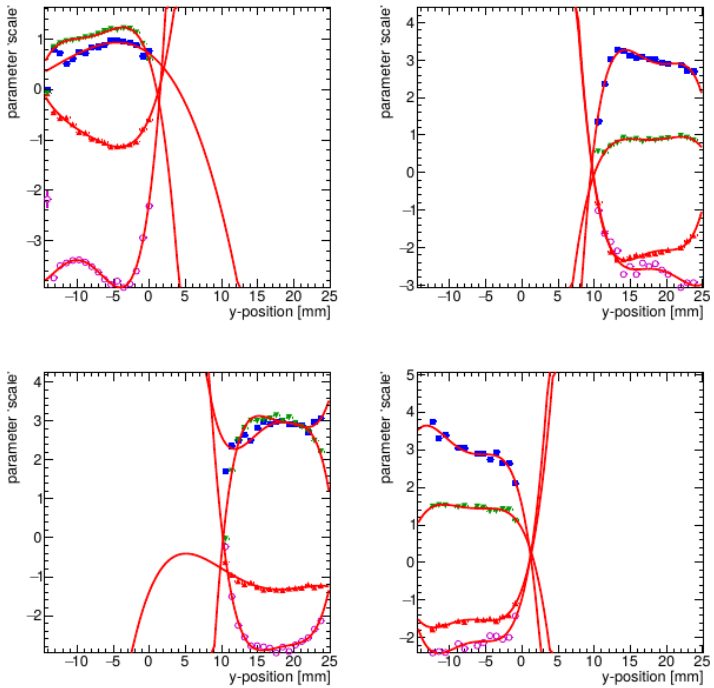


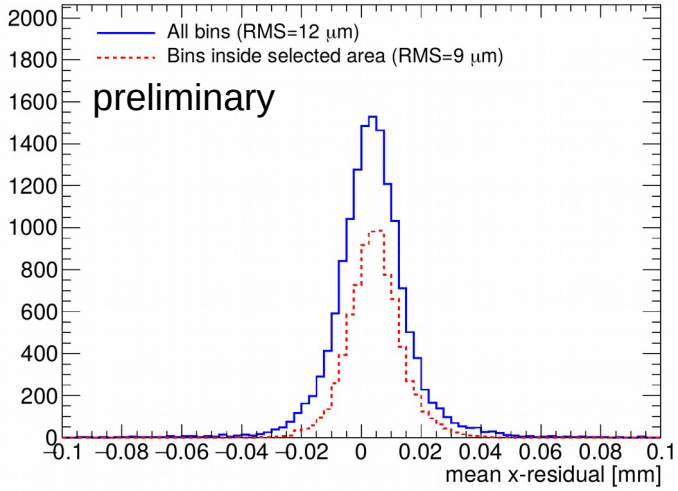
preliminary

2.) - project residuals on x-axis
- fit analytic function
- correct for deviations
→ RMS 16/9 μm

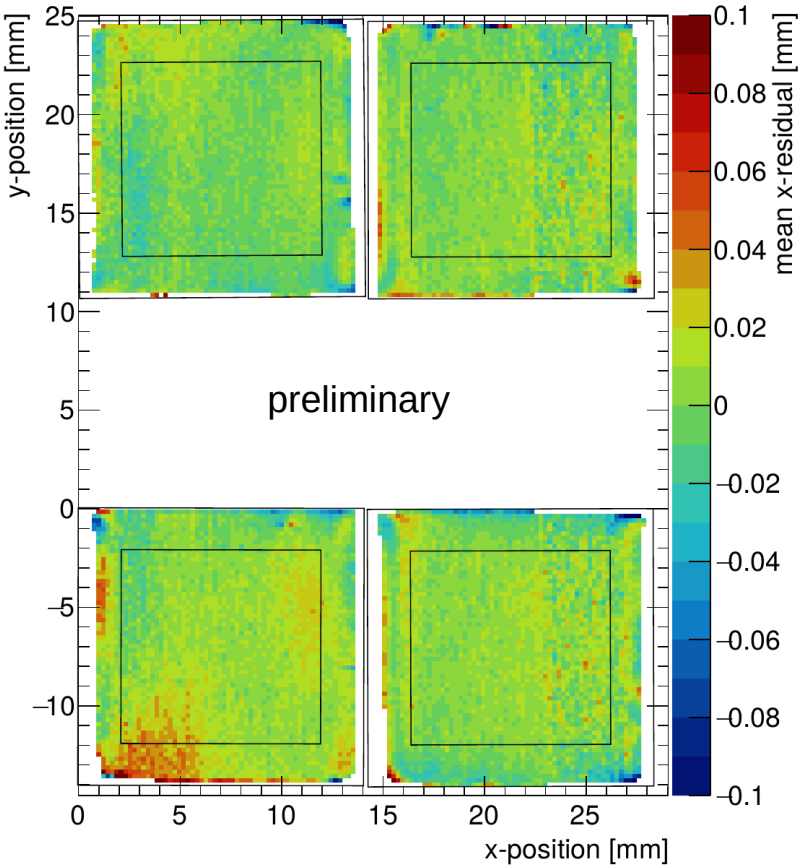


Local Distortion Correction

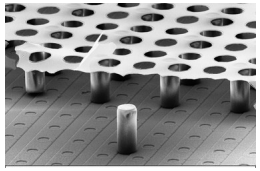




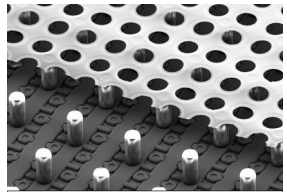
3.) - Split data in slices along the y-axis
- fit analytical function to distribution
- correct slicewise



Correction improves corners but not the central regions. → RMS 12/9 µm



Spatial Resolutions



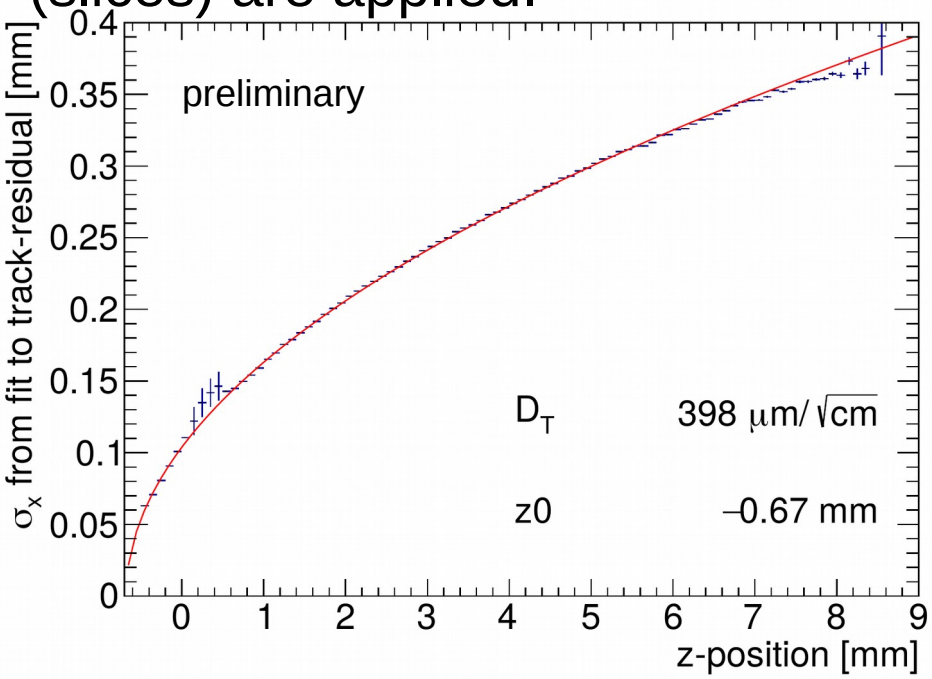
Both distributions show small bumps at the beginning from tracks scattered of the guard.

Transverse spatial resolution

Fit gives D_T = 398 µm/√cm

Magboltz: D_T = (273±3) µm/√cm

Corrections with y-dependence (slices) are applied.

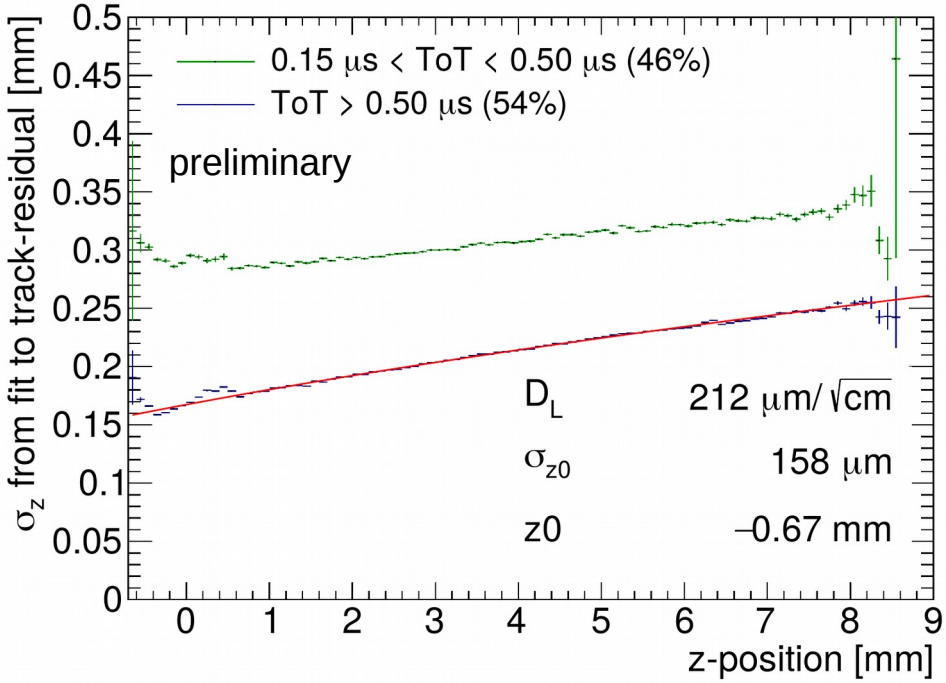


Longitudinal spatial resolution

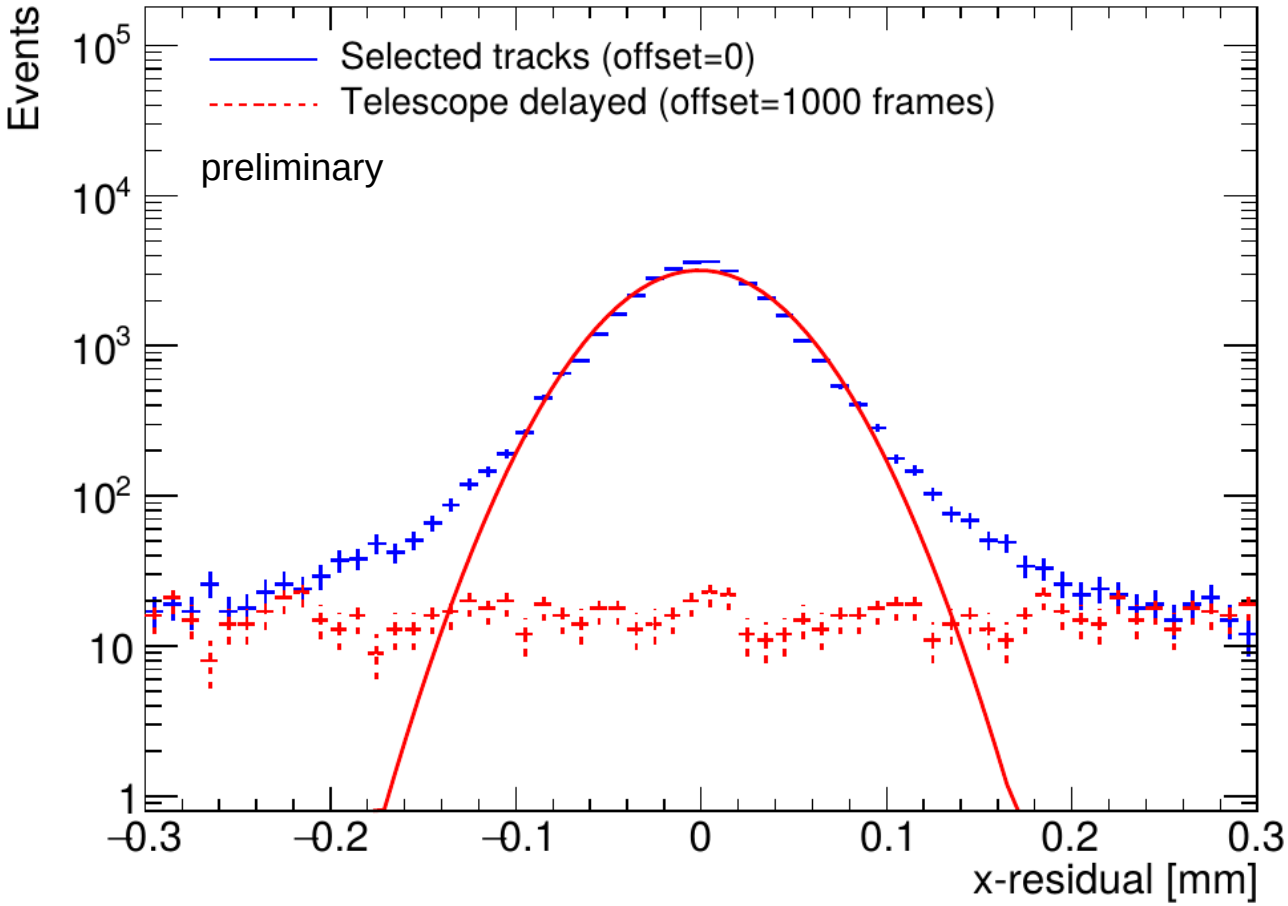
Fit gives D_L = 212 µm/√cm

Magboltz: D_L = (201±3) µm/√cm

Same corrections are applied in drift direction.



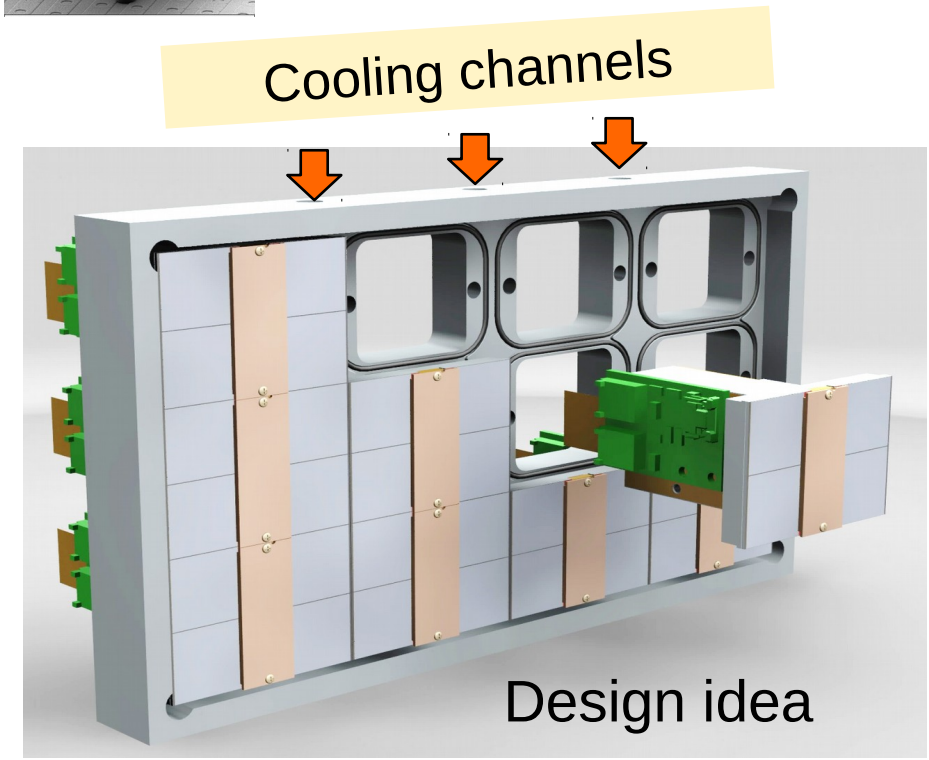
Distance of all QUAD hits to Telescope Track

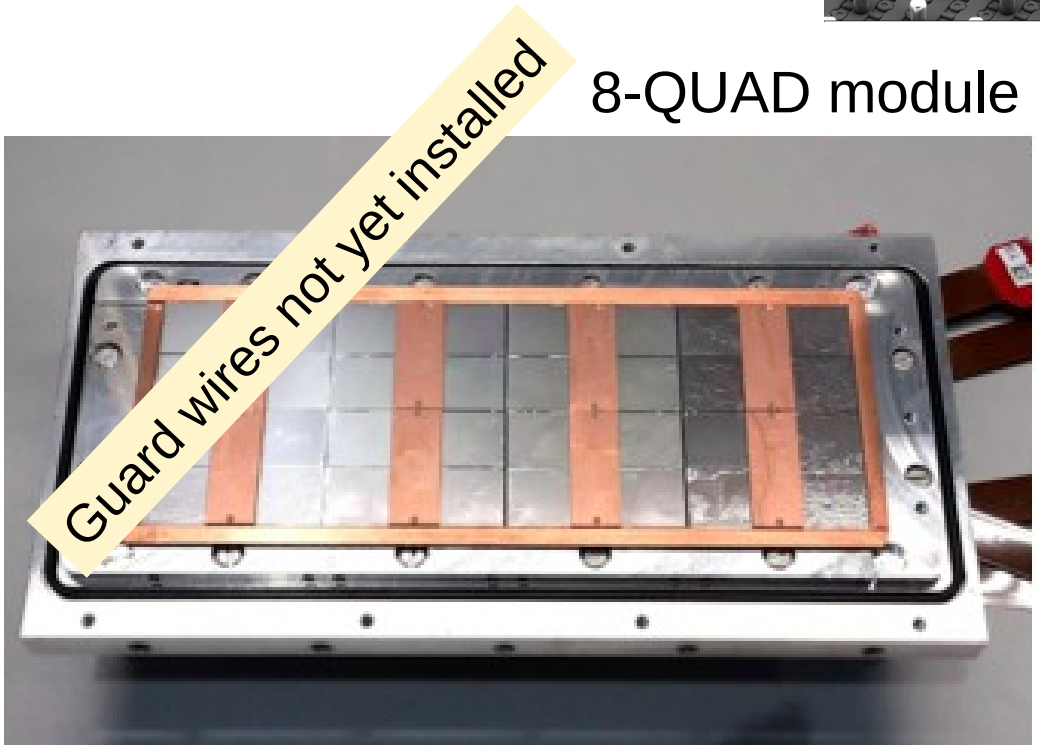


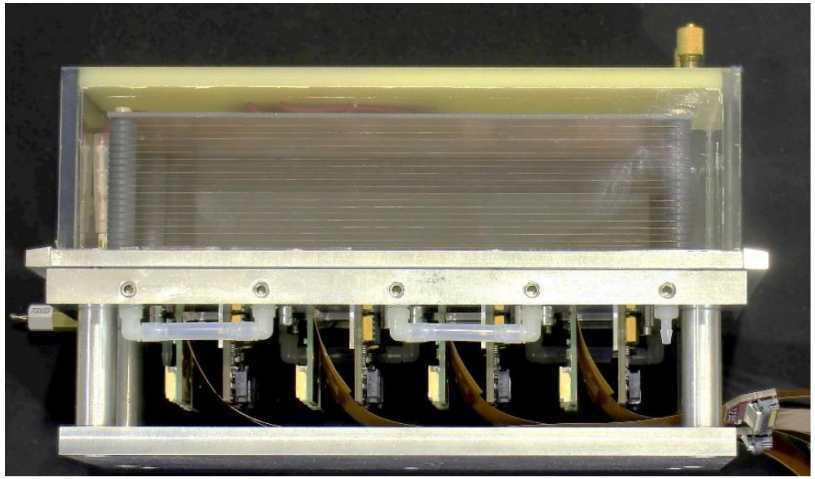
Gauß fit yields a width of σ = 42 µm

Background of coincidental tracks estimated to 3 % by introducing a time delay of 115 ms.

Module made of QUADs





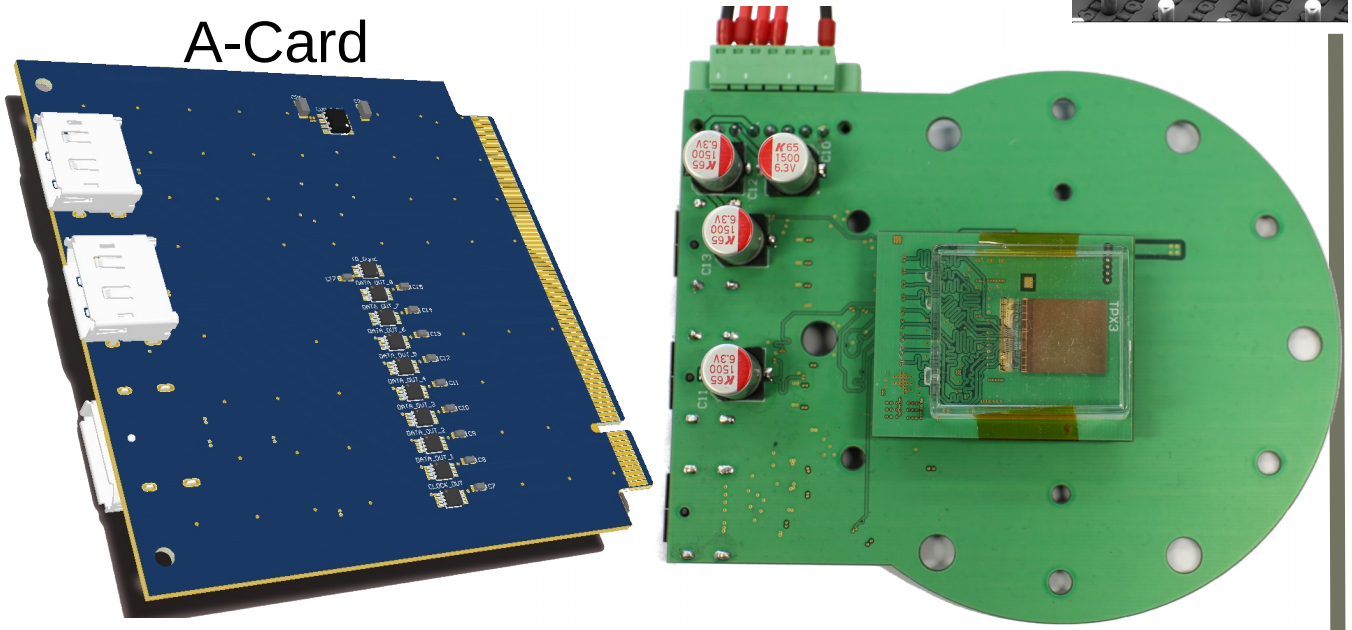


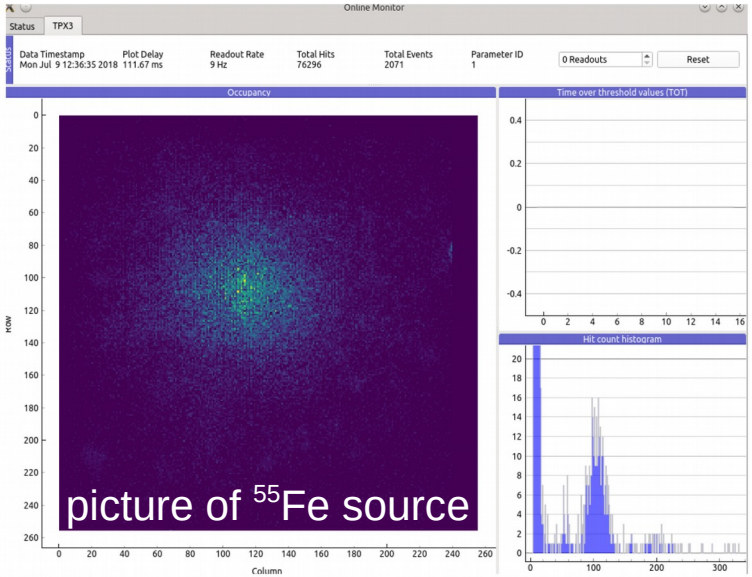
- Module with 8 functional QUADs is finished.
- Test detector with field cage assembled and tested (gas tight, stands HV, low gas contamination)
- Quads are individually tested
- Firmware to readout complete module with one SPIDR is being developed.
- Adding a guard electrode (wire) set on correct voltage to reduce field distortions between GridPixes.

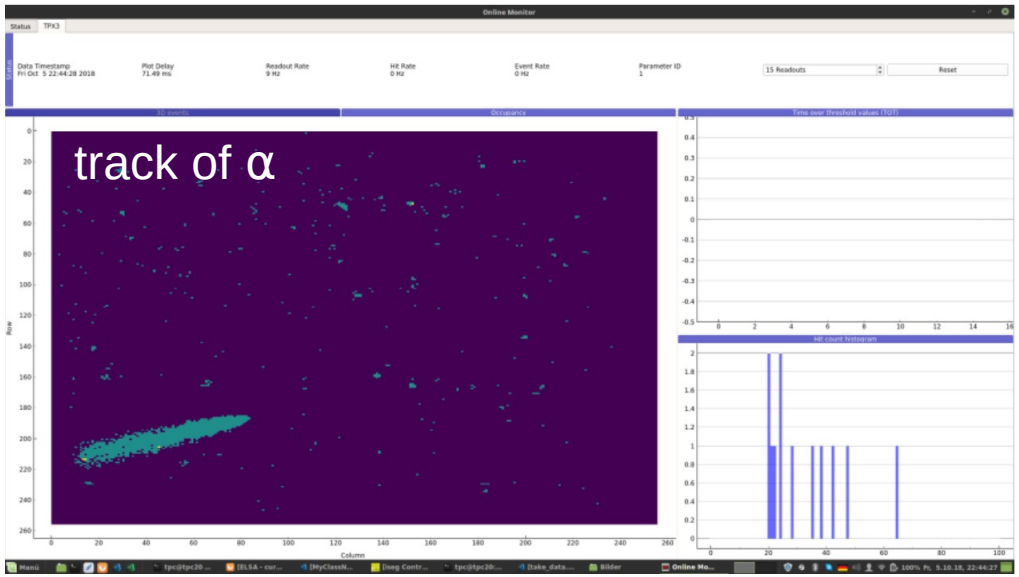
Timepix3 Readout for SRS

- Firmware had been developed on ML650 Xylinx development board
- Important functions are available
- Hardware for SRS is available now
- Firmware has been transported on FECv6
- Tests and detailed studies are ongoing

A-Card

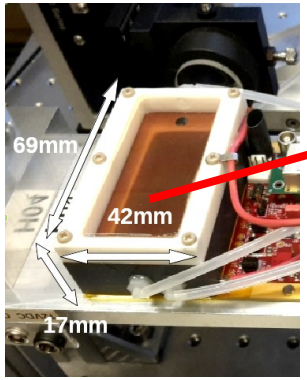




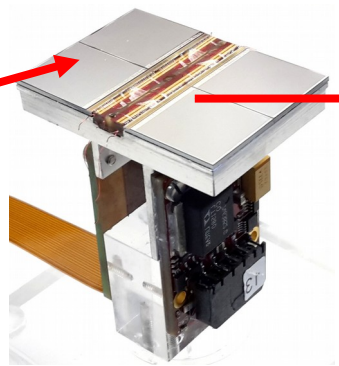


Summary

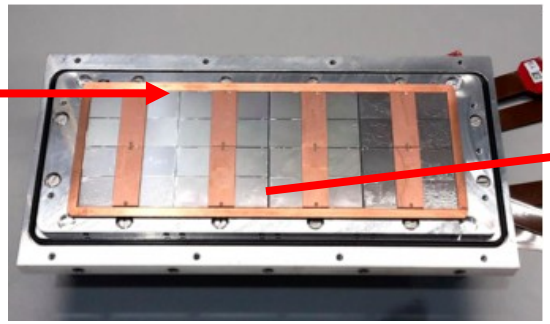
- GridPixes based on Timepix3 are available since ~3 years
- Intense program to go to larger areas
  - Single chip detectors tested in 2017
  - QUAD detector constructed and tested in 2018
  - 8 QUAD modules constructed, tests ongoing, test beam scheduled for September
- 2 Test beams have been performed showing excellent performance
- Observed field distortions currently mitigated during analysis, a hardware remedy is tested.
- Additional applications (e.g. IAXO) are planned and new designs will be implemented soon.



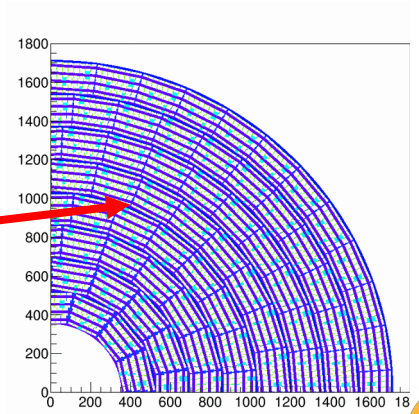
Single chip 2017



Quad 2018



Module 2019



TPC plane 2030