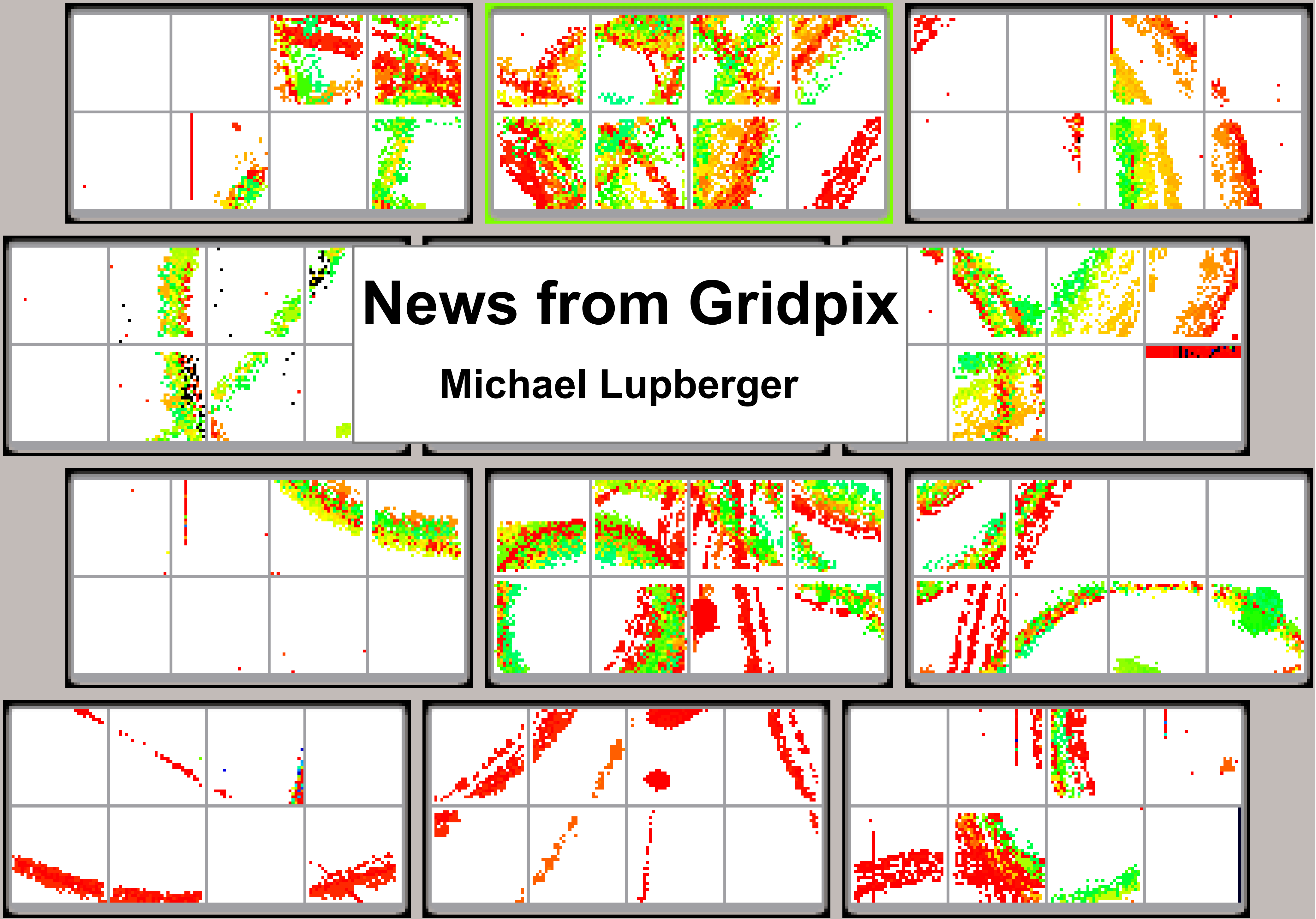


News from Gridpix

Michael Lupberger

Outline

New Structures and Technologies

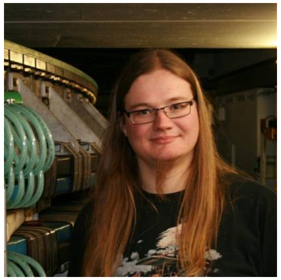
- GridPix
- The large area GridPix readout and the Pixel-TPC
- CAST GridPix detector upgrade
- IZM-7
- Summery and outlook

The Bonn detector development group



- Prof. Klaus Desch
- Dr. Jochen Kaminski
- GridPix production: Dr. Yevgen Bilevych

- Pixel-TPC: Daniel Danilov, Alexander Hamann
  Michael Lupberger
- CAST: Christoph Krieger, Tobias Schiffer
  Sebastian Schmidt



- IZM-7 tests: Lucian Scharenberg

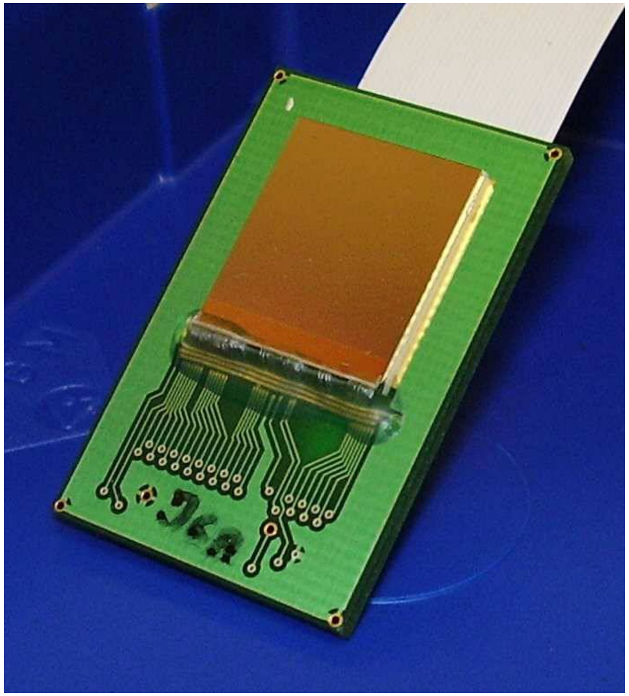
The Timepix ASIC

Charge sensitive digital readout chip

Properties

- 1.4 x 1.4 cm^2 active surface
- 256 x 256 pixel matrix
- 55 x 55 μm^2 per pixel
- Amplifier, discriminator in each pixel
- 14 bits count clock cycles

  → TOT(charge) or TOA(arrival time)
- Clock up to 100 MHz in every pixel
- Threshold level ~ 500 e^- (90 e^- ENC)

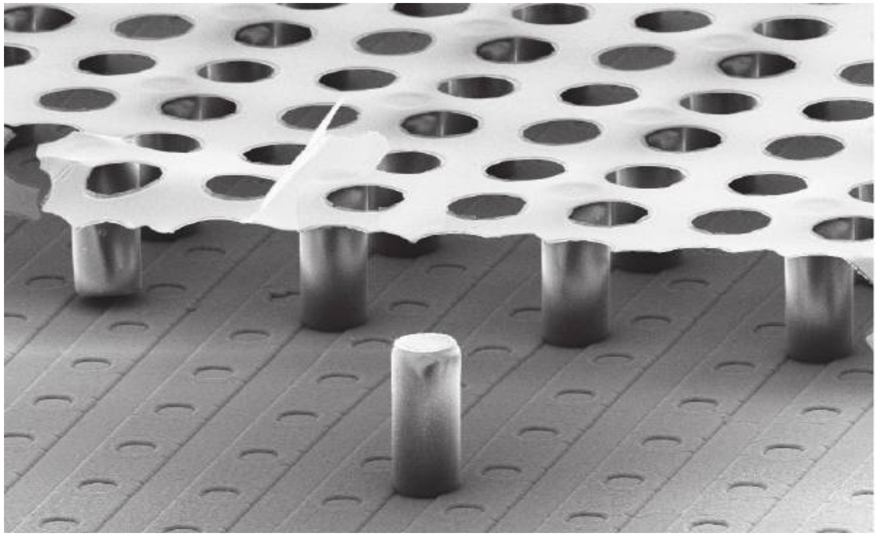


Use bump bond pads as charge collecting anode in gaseous detectors

Timepix+Micromegas = GridPix

Aluminium mesh on chip

- Hole to pixel alignment
- Pillar height uniformity



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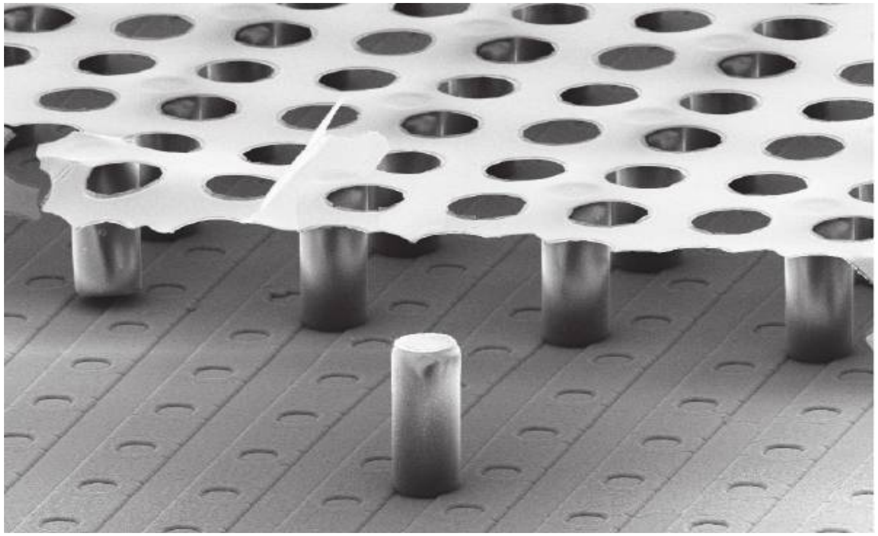

Use photolithographic process

- Pioneered and optimised by
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- Production on single chip basis

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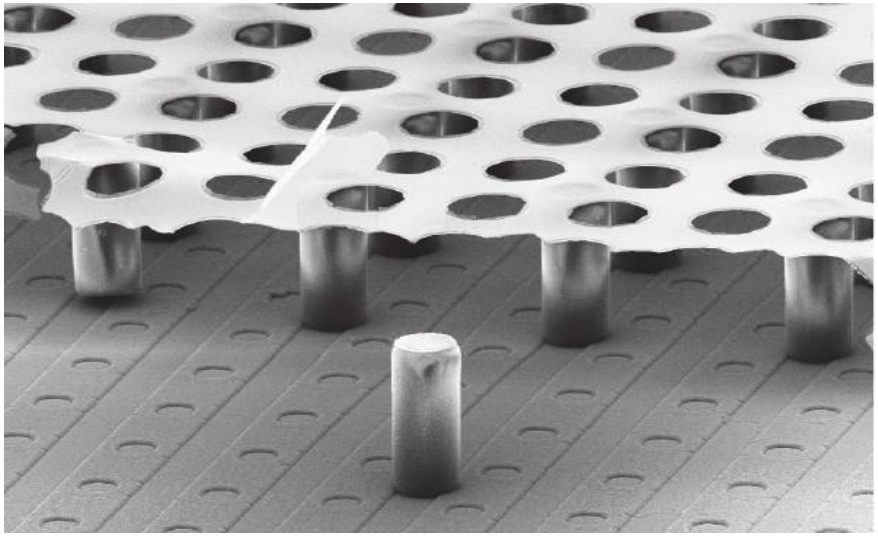


Use photolithographic process

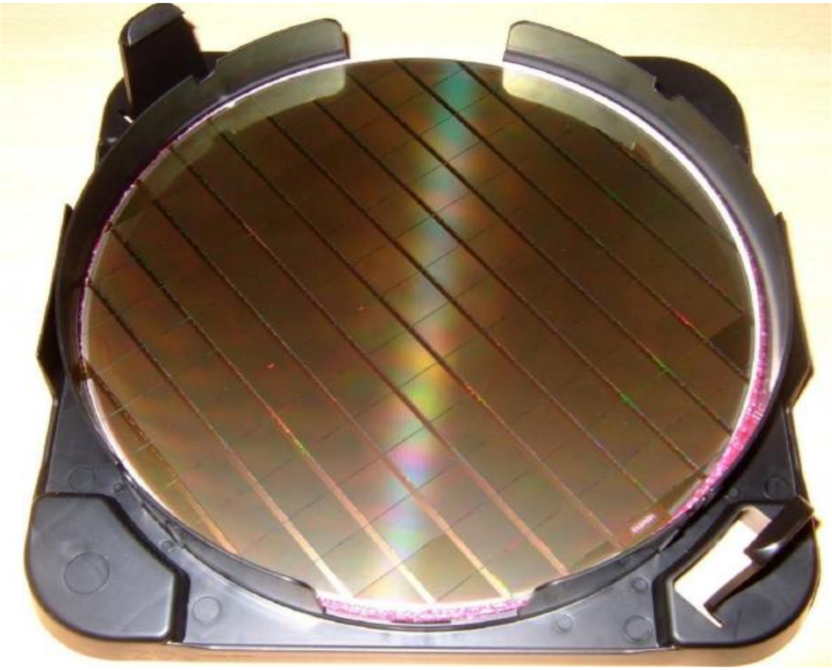
- Pioneered and optimised by Nikhef and University of Twente
- Production on single chip basis

High demand for GridPix:

- R&D groups
- Equipment of larger surfaces

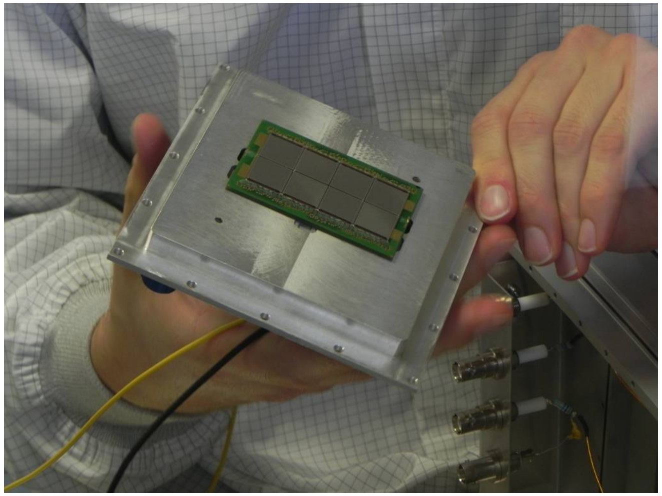
→ Production on wafer scale

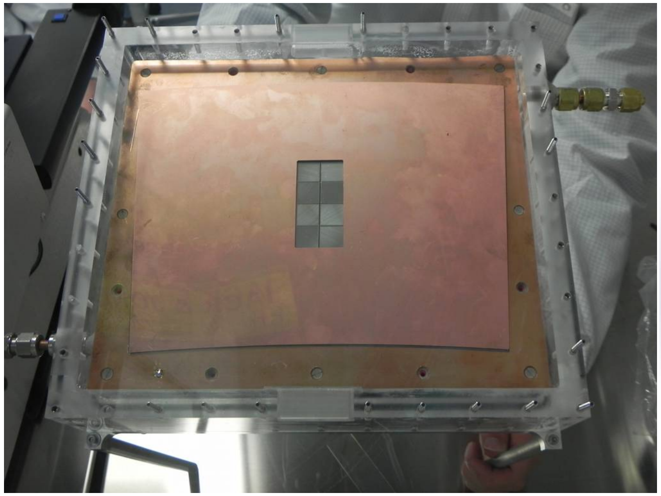
Wafer processing at IZM Berlin

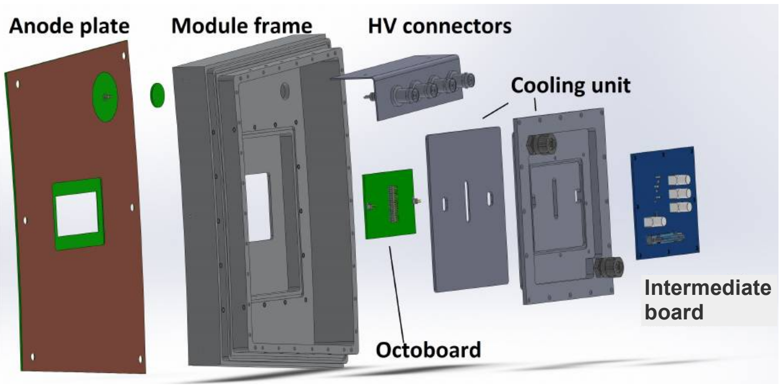


Large area GridPix module

- Octoboard as basic unit: eight ASICs in a chain







CAD design by Robert Menzen

- Successful test as readout of LCTPC prototype TPC at DESY (2013)

Large area GridPix module

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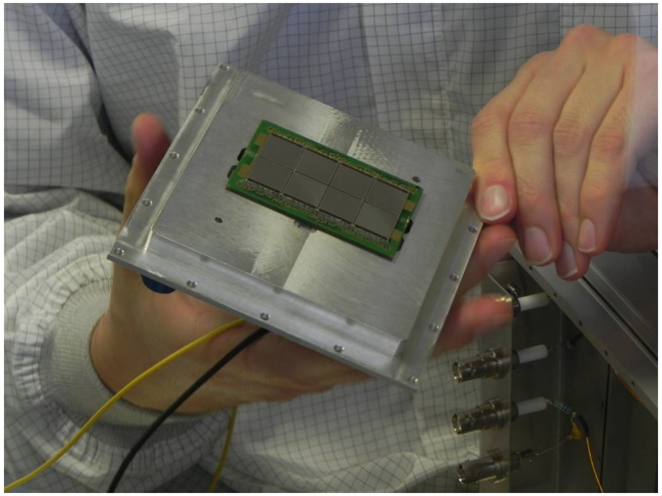

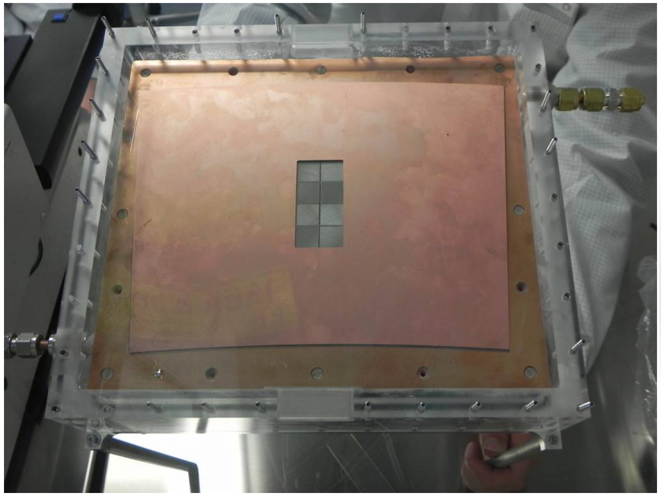

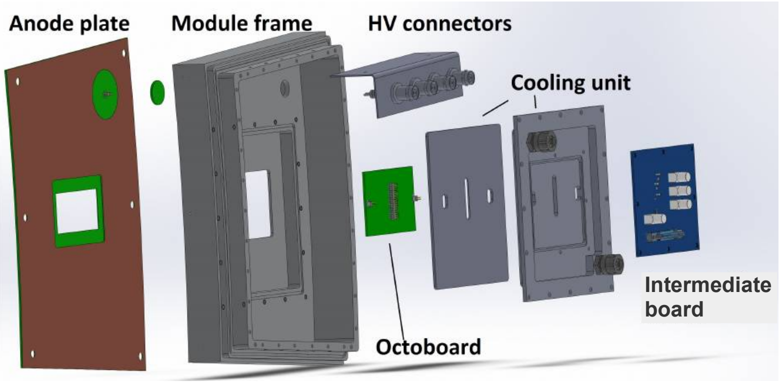

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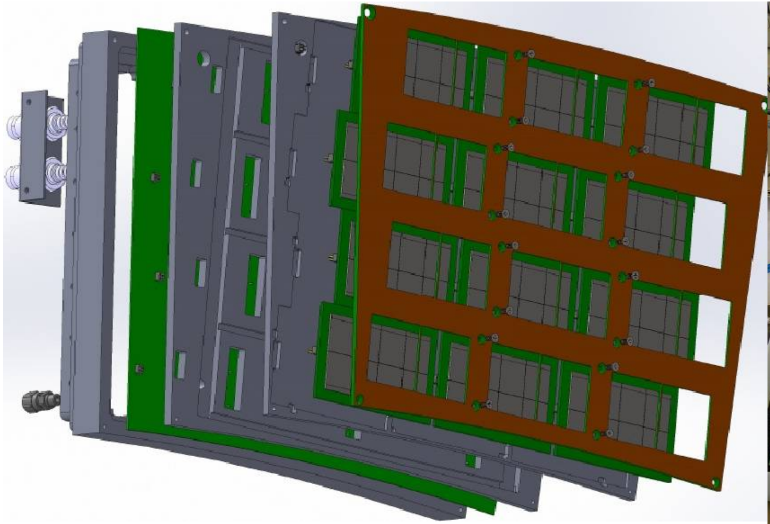
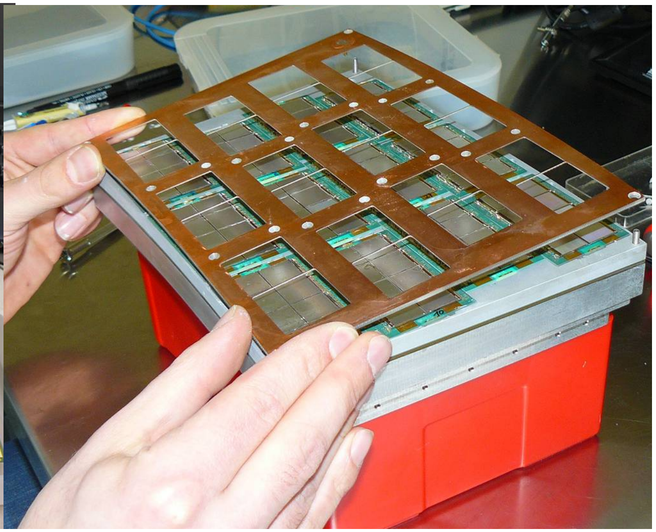
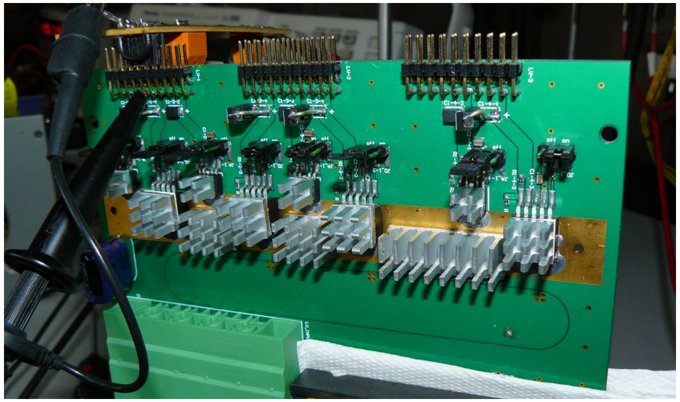

CAD design by Johann Tomtschak



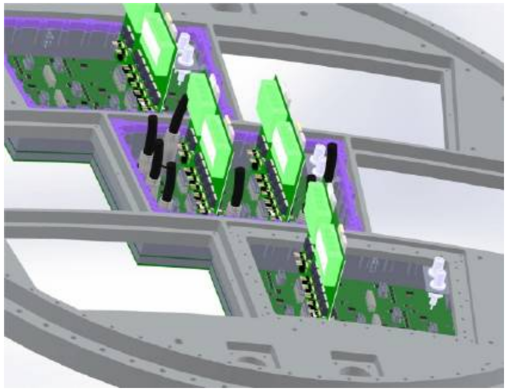
- 96 GridPix module: 12 Octoboards

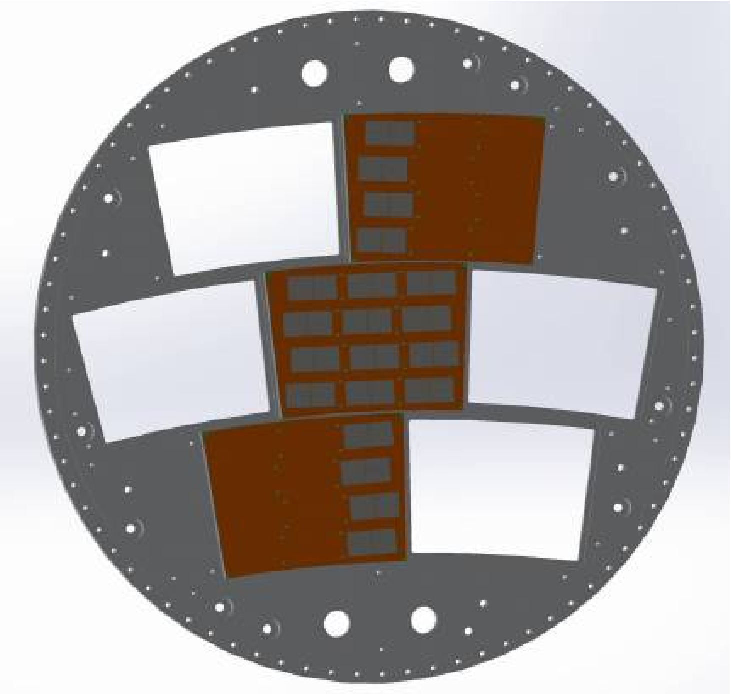
Test beam with the large area module

- Finally achieved: 3 modules (1x96 GridPix, 2x32 GridPix)
- Readout by 5 SRS FECs via HDMI cables
- Low voltage by ATX power supplies
  and dedicated electronics



Developed by Alexander Hamann





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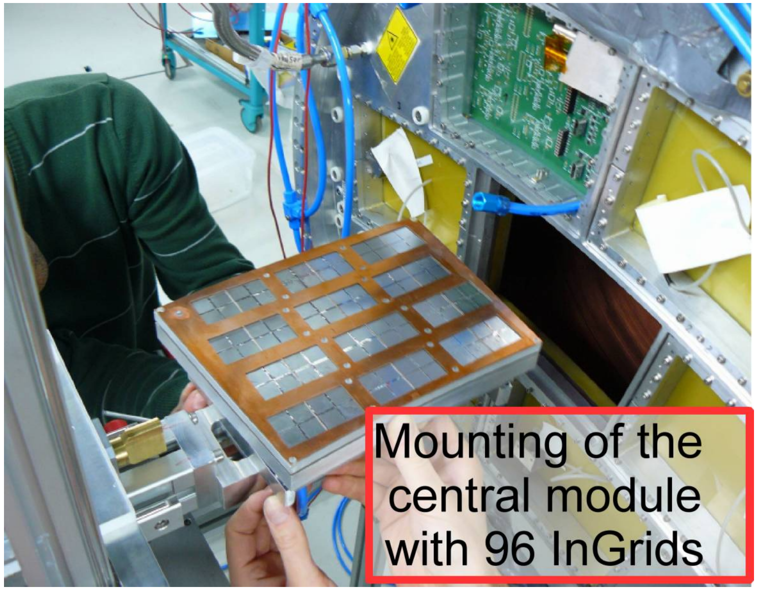

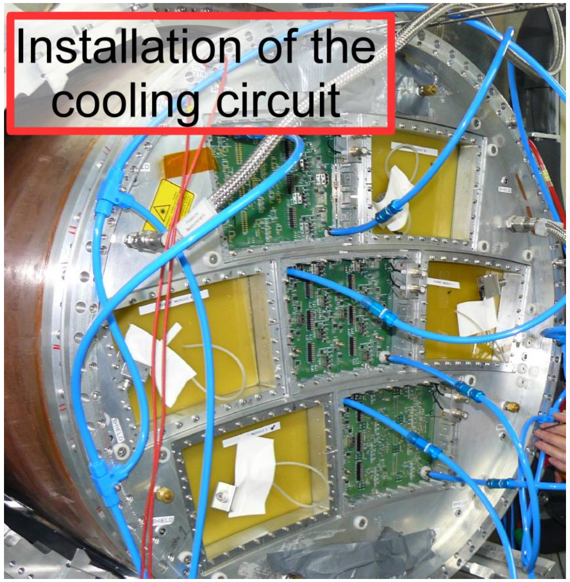

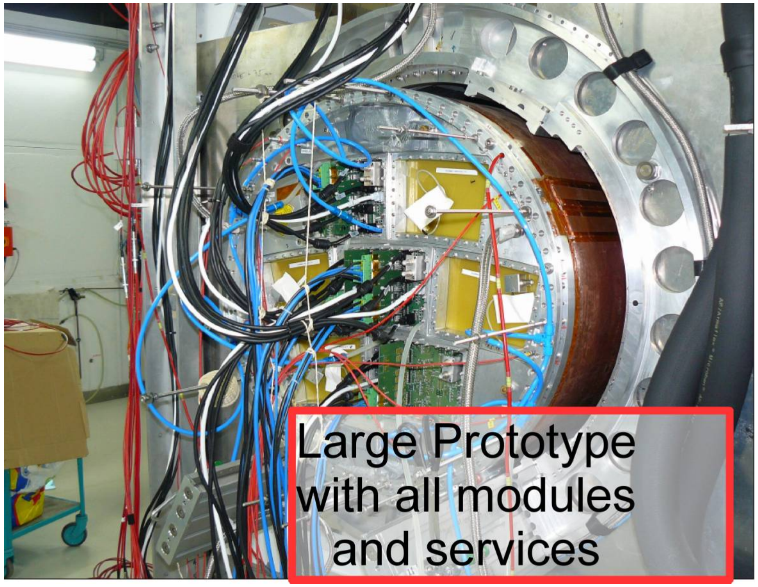

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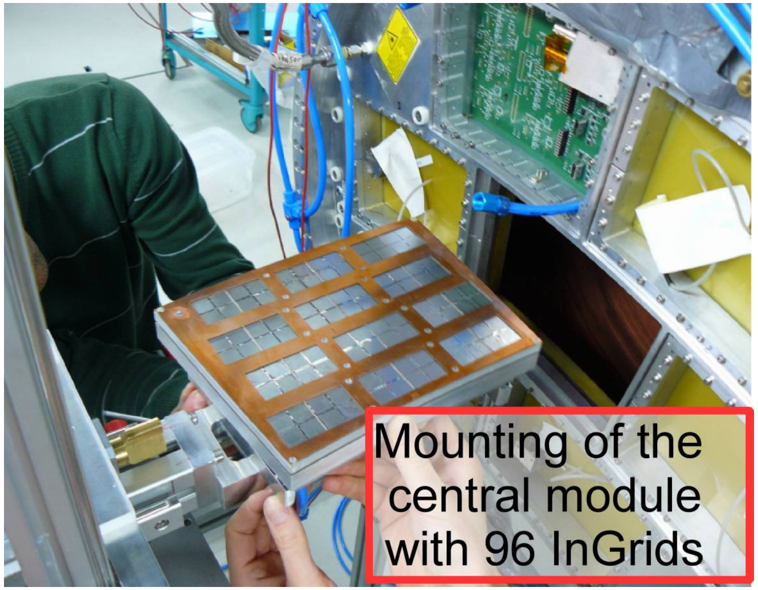
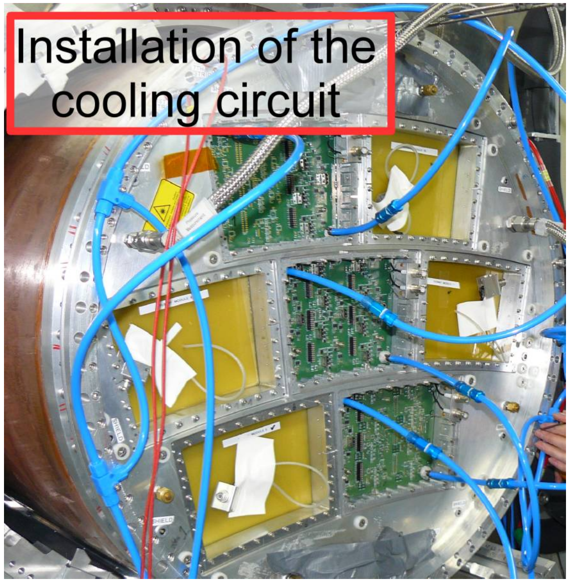
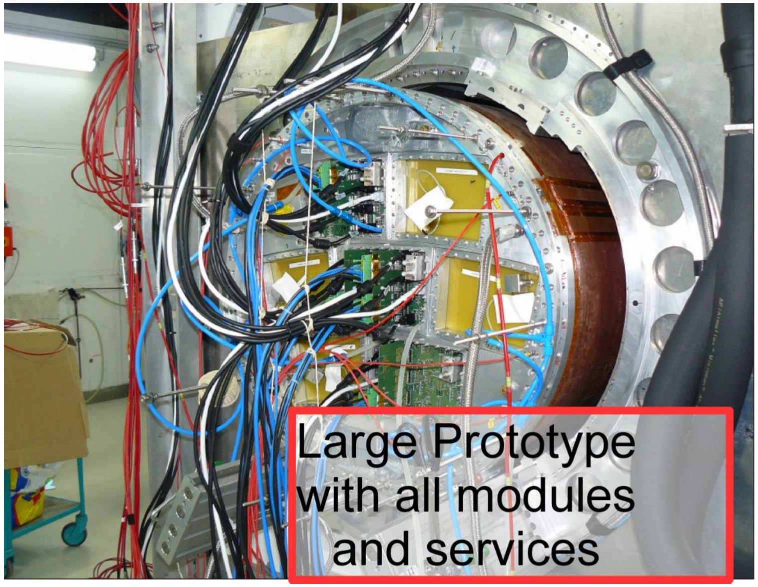
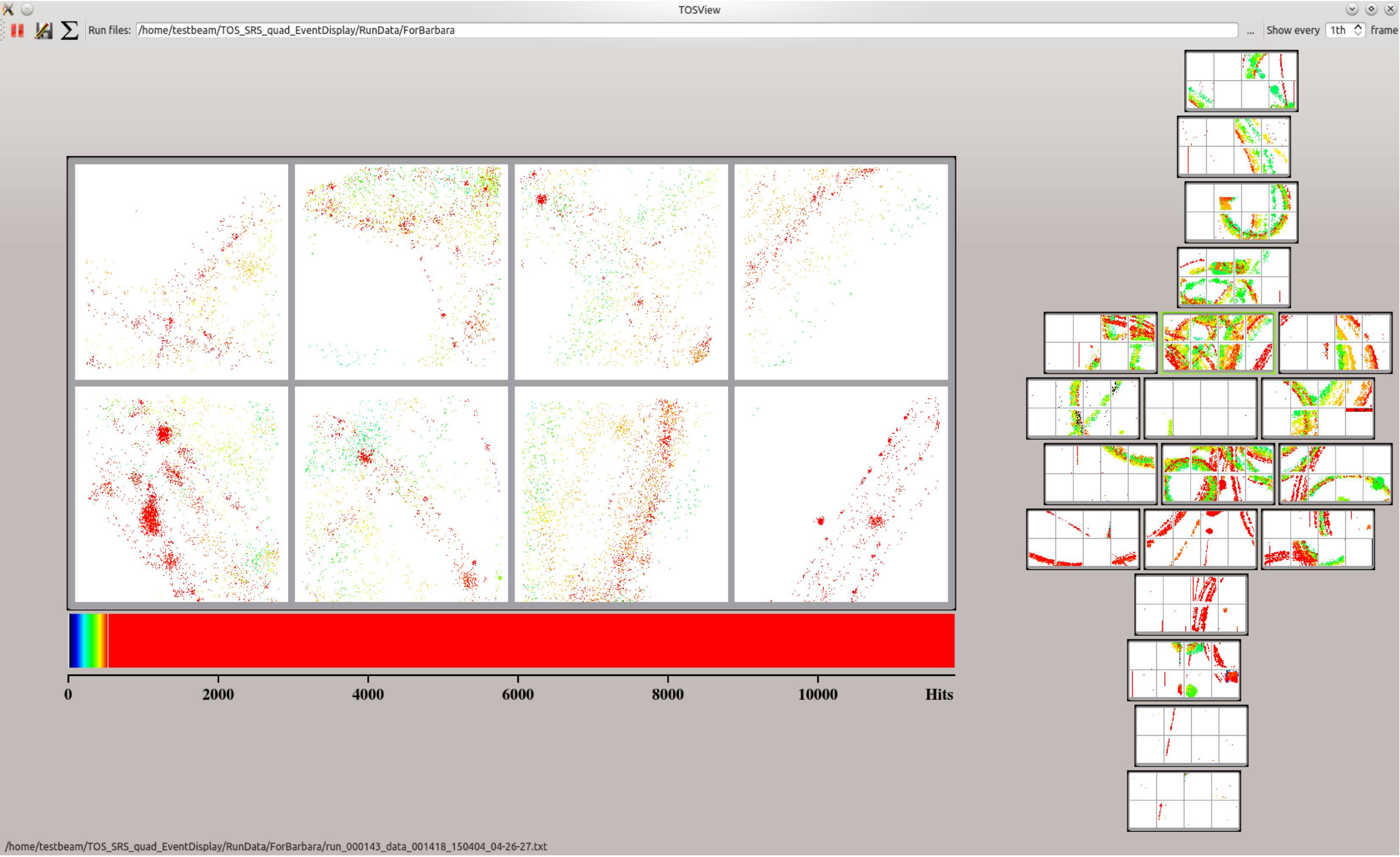






- Electrons up to 6 GeV, readout triggered by scintillator in beam
- 1.5 million events
- Different configurations: drift field, magnetic field, beam position...

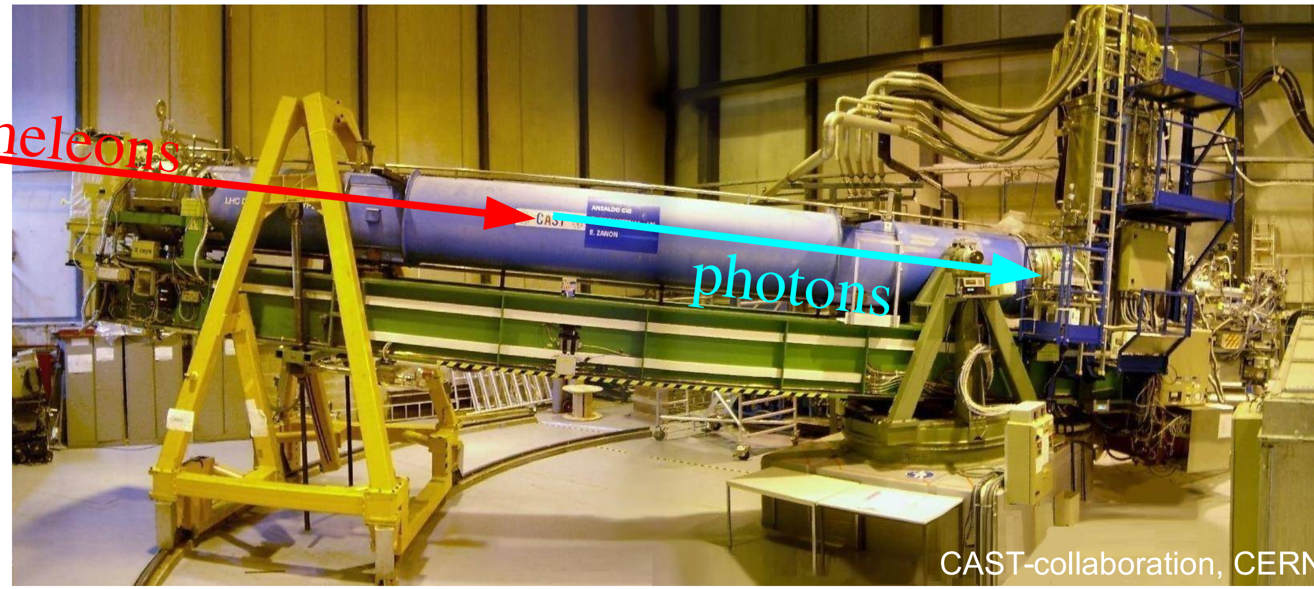
Event display

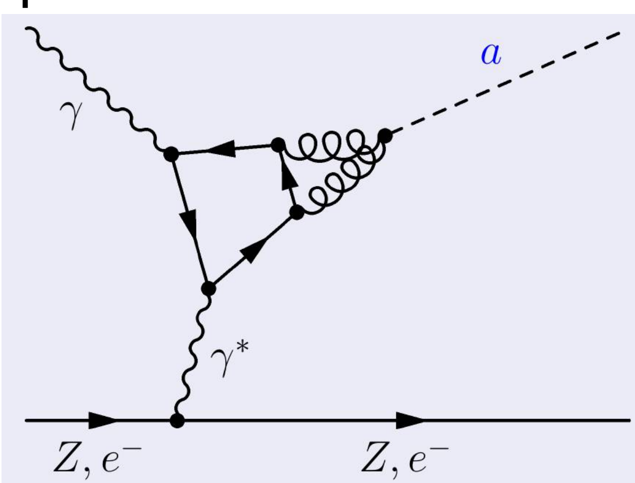


Developed by Daniel Danilov

CAST GridPix detector upgrade

Decommissioned LHC-magnet is pointed to the sun. Axions and chameleons produced in the Sun convert into X-ray photons.





<u>The magnet</u> is 10 m long and is cooled down to 1.8 K.

In the aperture a magnetic flux of B = 9 T is reached by a current of 13 kA.

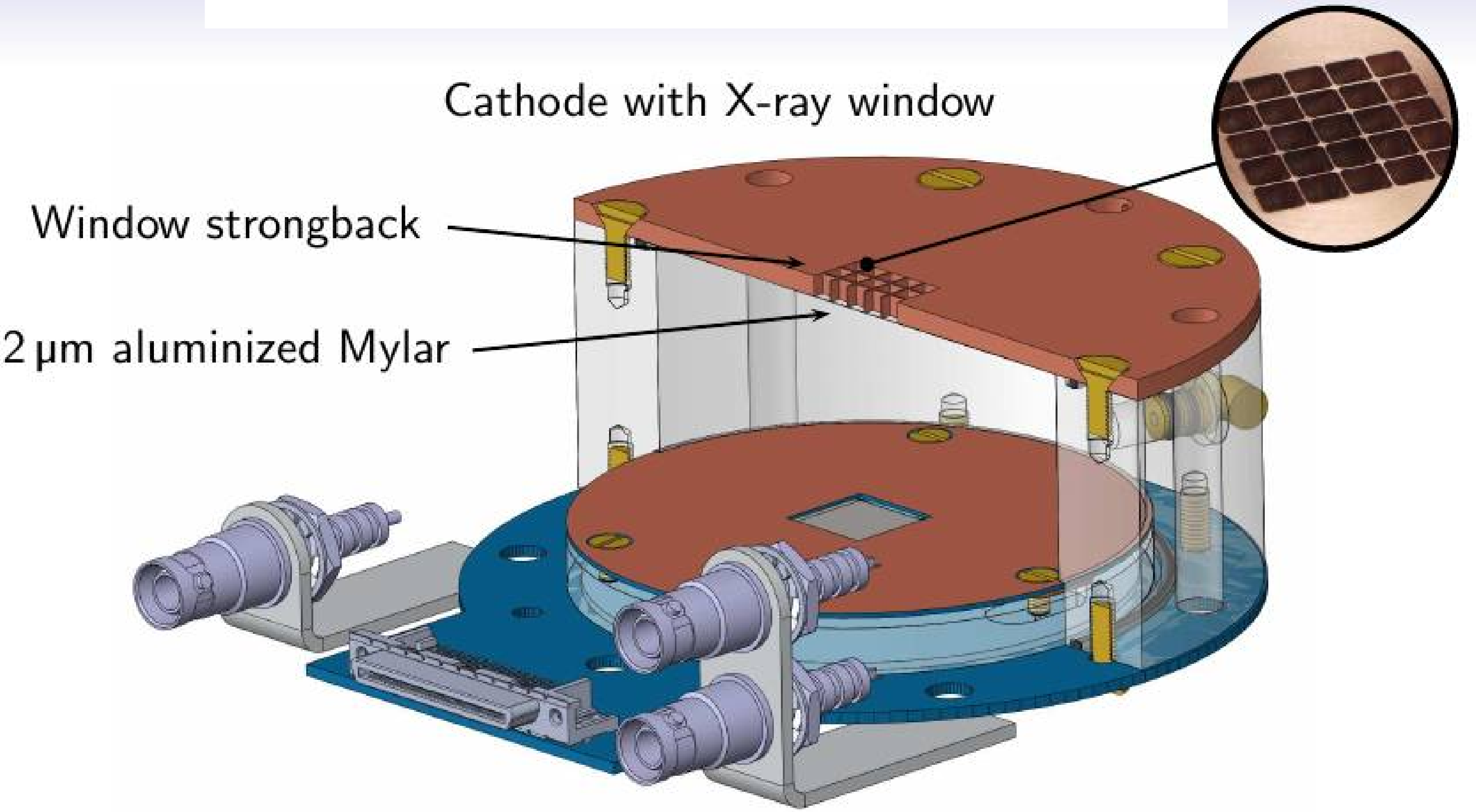
<u>The support structure</u> can be turned vertically ~±8° and horizontally ~±40°.

<u>Sun tracking</u> lasts 2×1.5 h/d (Sunrise & Sunset).

https://www.facebook.com/CASTexperiment/videos?ref=page_internal

CAST GridPix detector upgrade

Detector of 2014/15 run period



Drift volume flushed with Ar/iC_4H_{10} 97.7/2.3

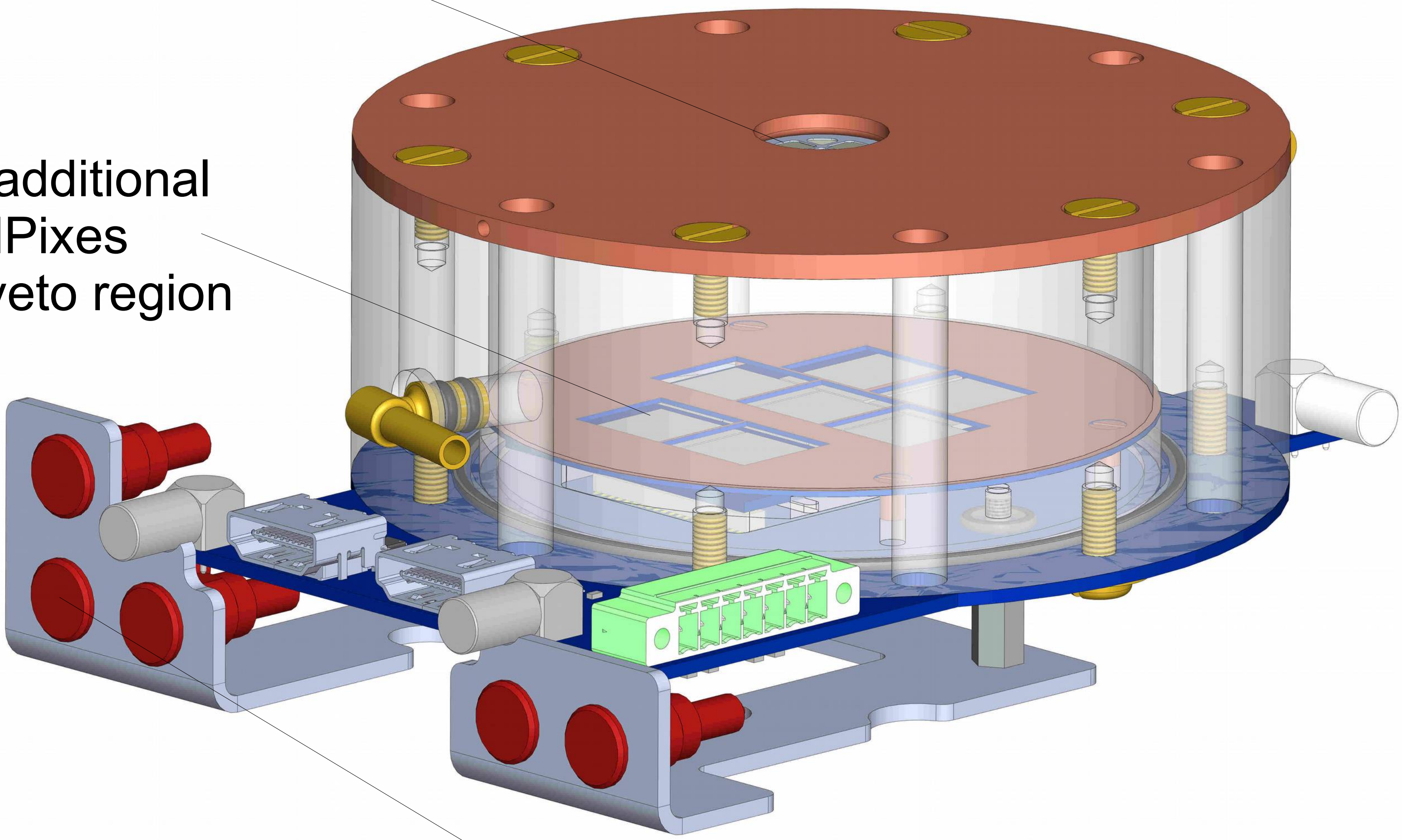
CAST GridPix detector upgrade

Detector of 2016/17 run period

Muon veto by scintillators (not shown)

New silicon nitride window (200 nm) with strongback

Six additional GridPixes for veto region



Grid readout by FADC for background reduction

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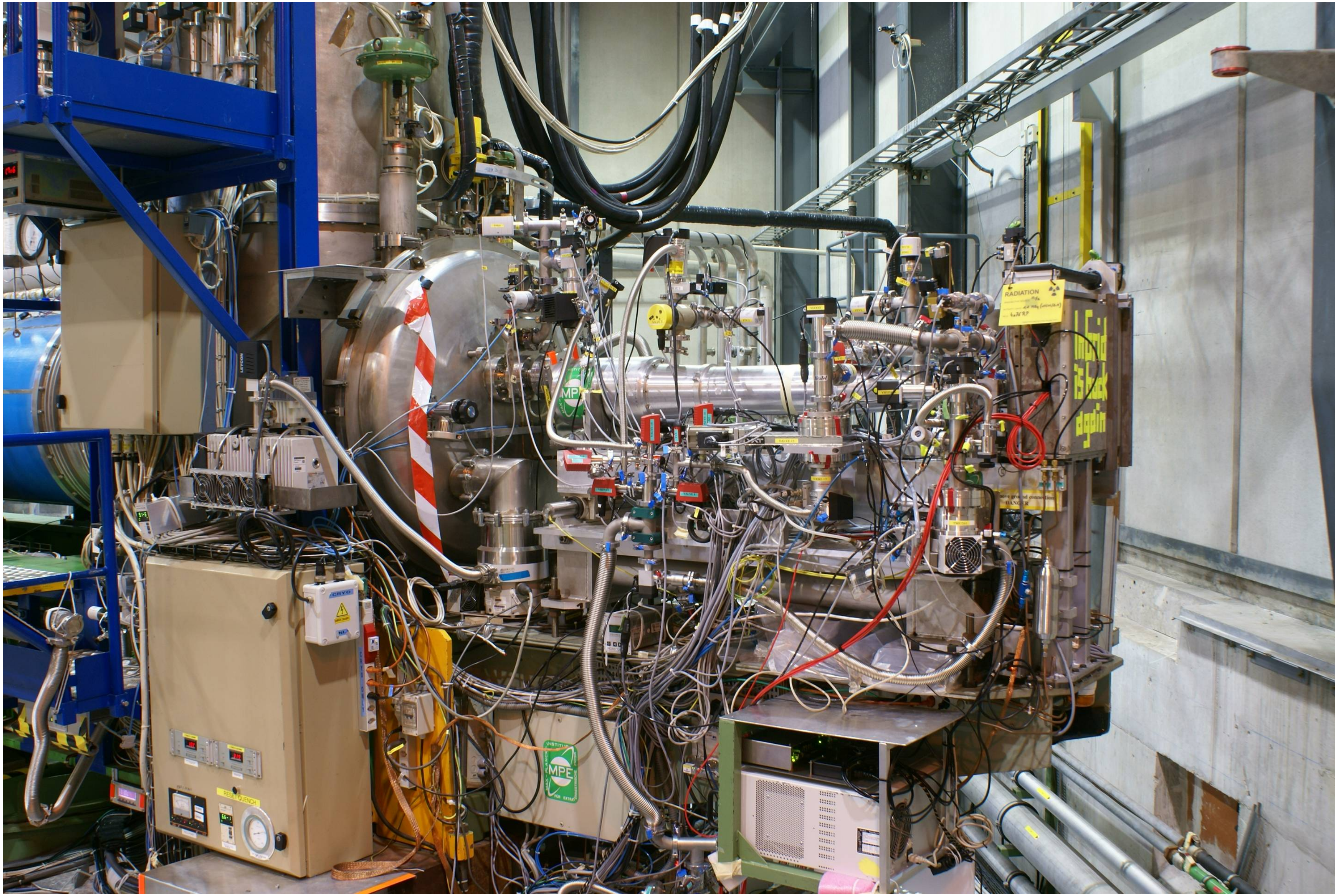
Detector of 2016/17 run period: installed in last week of August



CAST GridPix detector upgrade

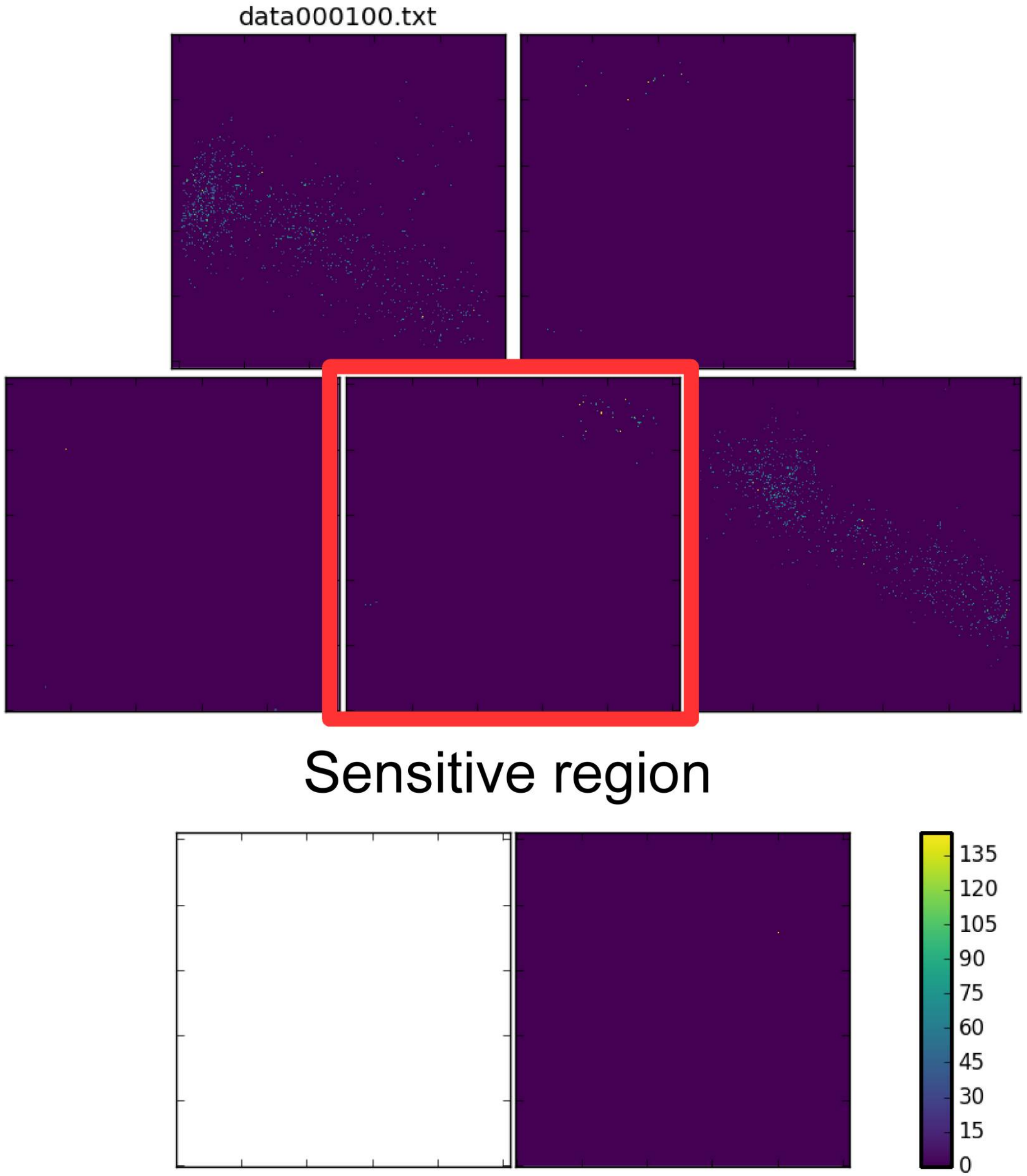
Detector of 2016/17 run period: data taking ongoing

Looking for X-rays converted in detector volume → small spot of ionisation

→ electrons have almost circular shape in x-y plane

Background: cosmics

→ ionisation along a track



GridPix reliability

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Goal: make the GridPix more robust to sparks → SiProt layer

Improvement during the different production runs at IZM-Berlin

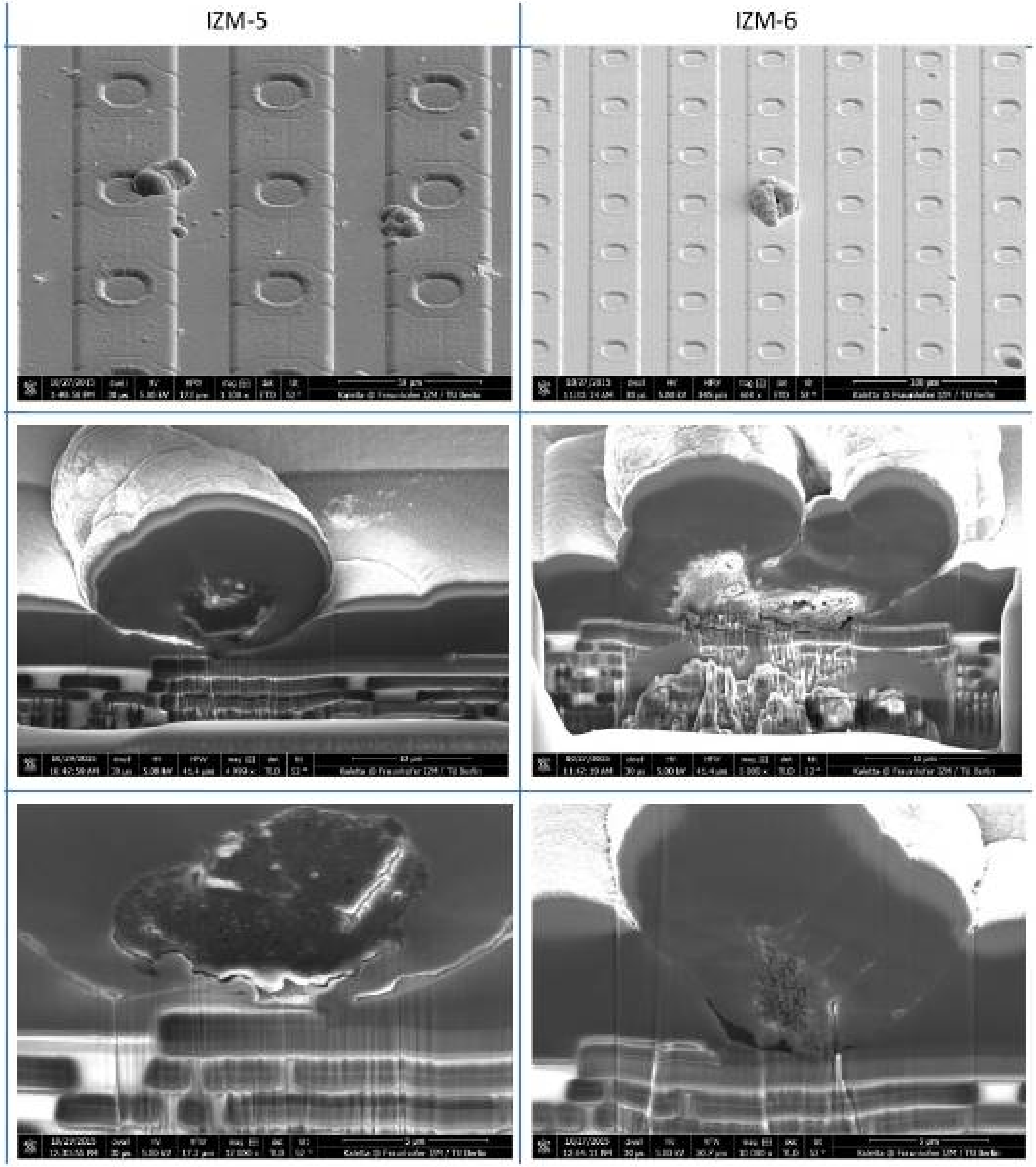
Experiences with large area GridPix module: IZM-5 better than IZM-6

Reasons:

- Timepix wafers not clean
- Impurities in SiNi sputtering machine

Results: cracks in SiProt

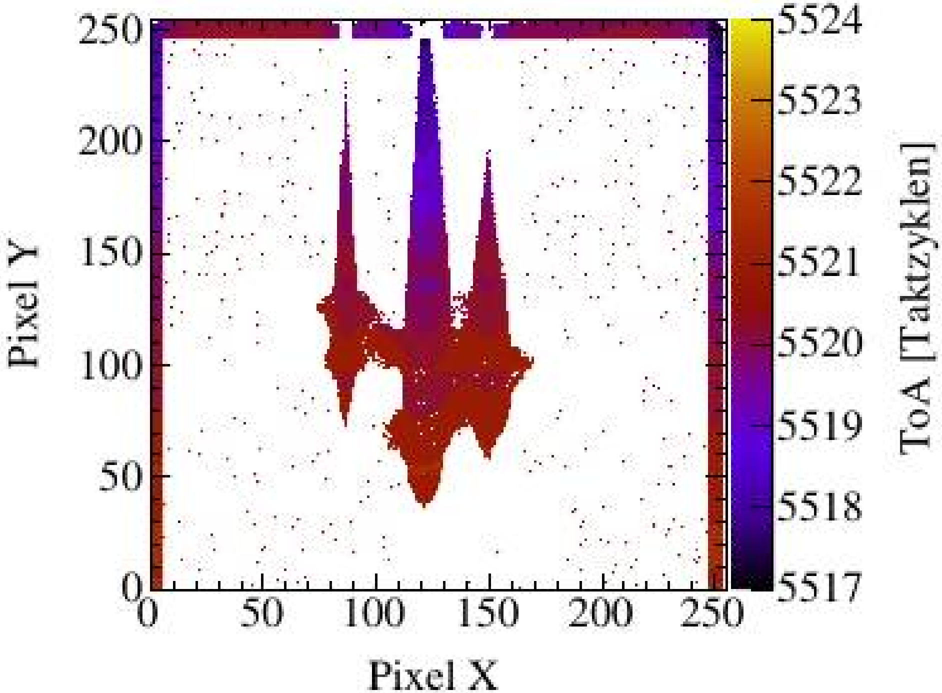
=> New IZM-7 production



GridPix reliability: IZM-7

Systematic investigation of different productions

- Increase grid voltage and measure energy resolution (Ar/Iso 97,7/2,3)
- IZM-5, 6, 7
- IZM-5/6 break down at 350 – 380 V (G~<1-5x10^5, SiProt charges up) Timepix electronically defect
- IZM-7 holds 500V for several hours, constantly sparking, 70% spontaneous sparks, no breakdown
- For all series: energy resolution becomes works → grid suffers



Summary and Outlook

GridPix is advancing very well!

- Large area GridPix detector with ~100 chips

→ data of DESY test beam partly analysed

→ upcoming: LAL test beam with ~MeV electrons (dE/dx measurements)

- Upgraded GridPix at CAST

→ installed and taking data

- IZM-7

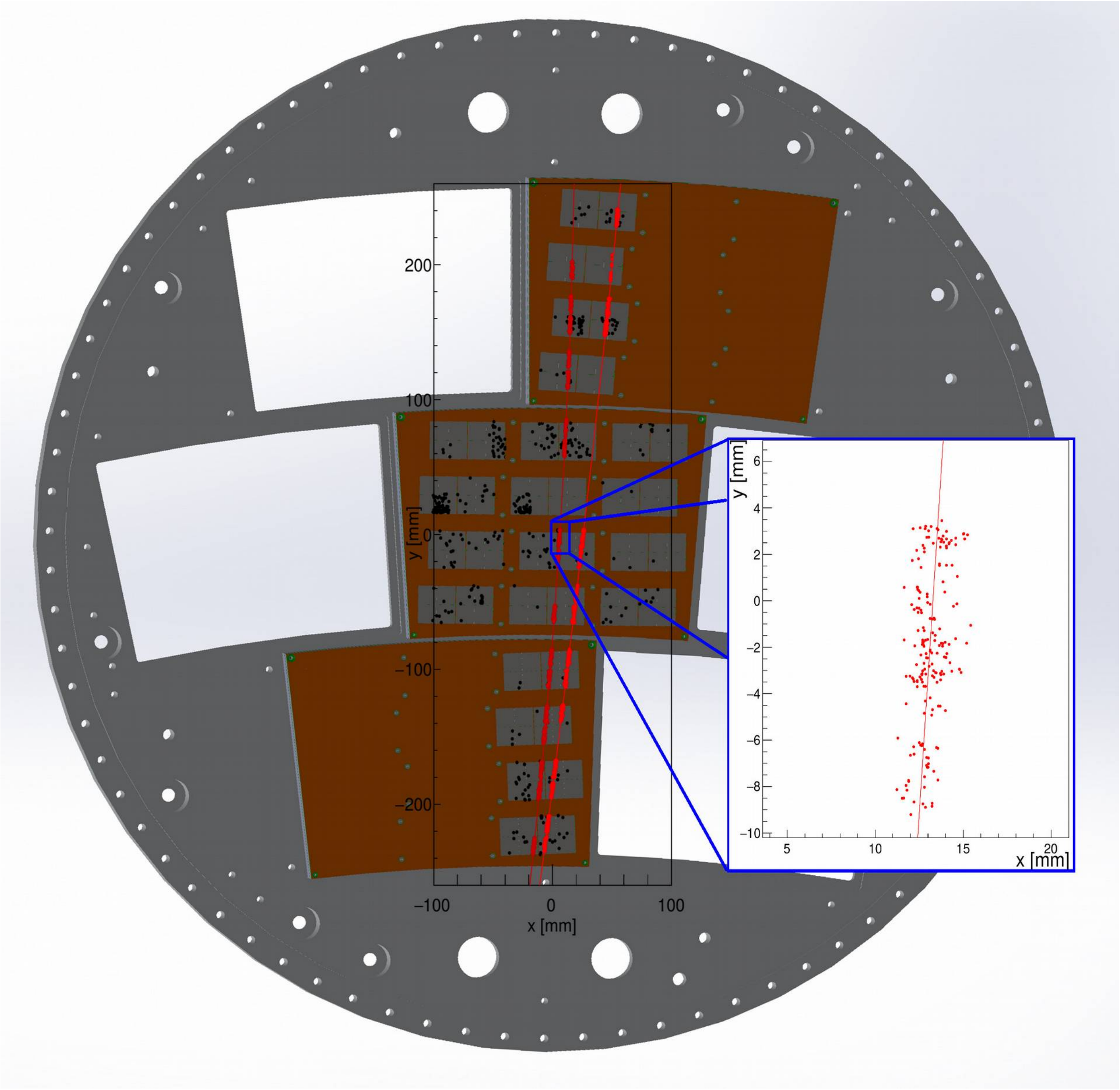
→ by far more spark-proof than previous generations of GridPixes

→ will improve reliability and lifetime of GridPix detectors

BACKUP
SLIDES

Test beam results

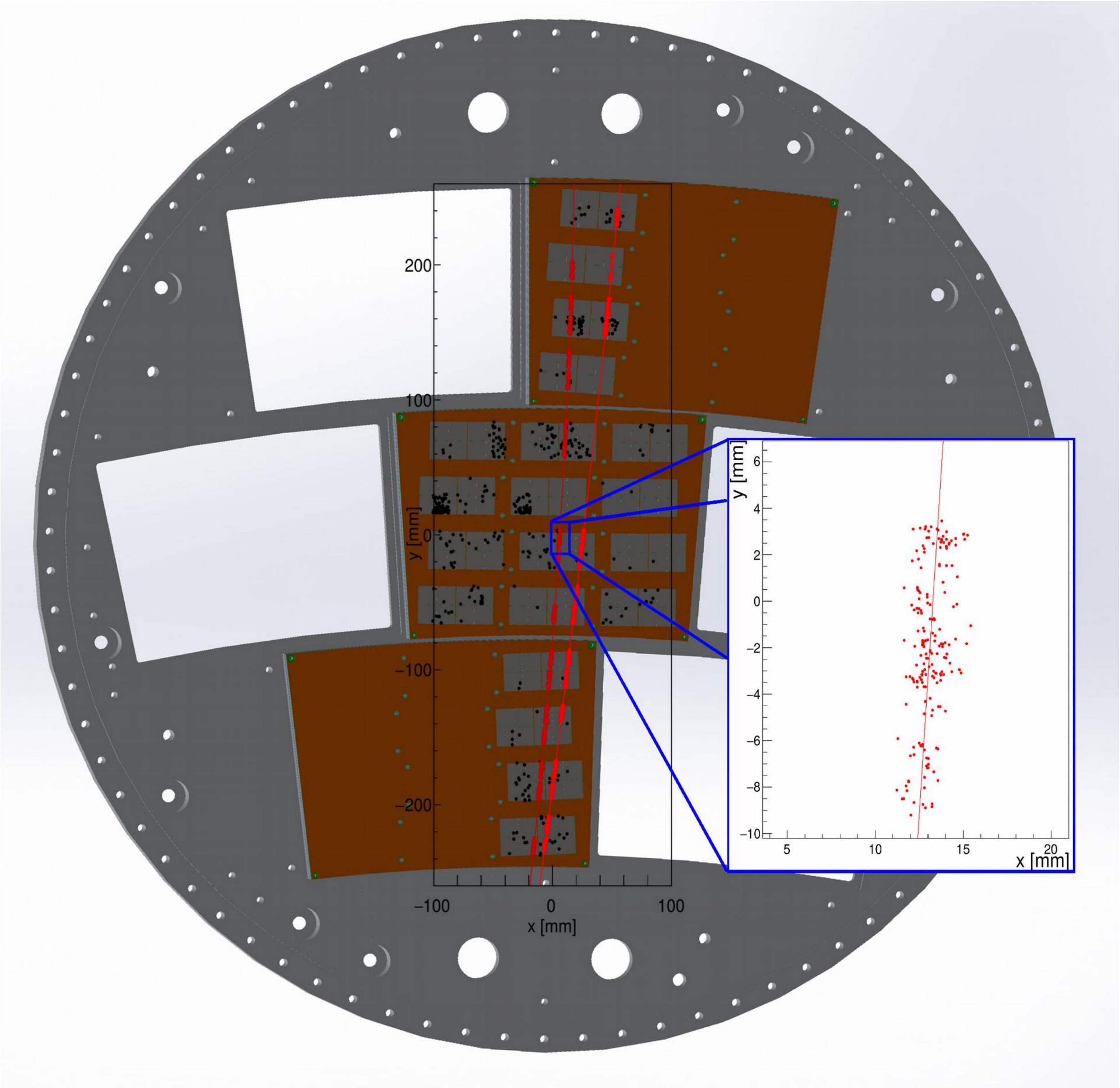
CAD drawing of endplate with reconstructed double track event



50 cm track length with about 3000 hits, each representing an electron from the primary ionisation.

Test beam results

CAD drawing of endplate with reconstructed double track event



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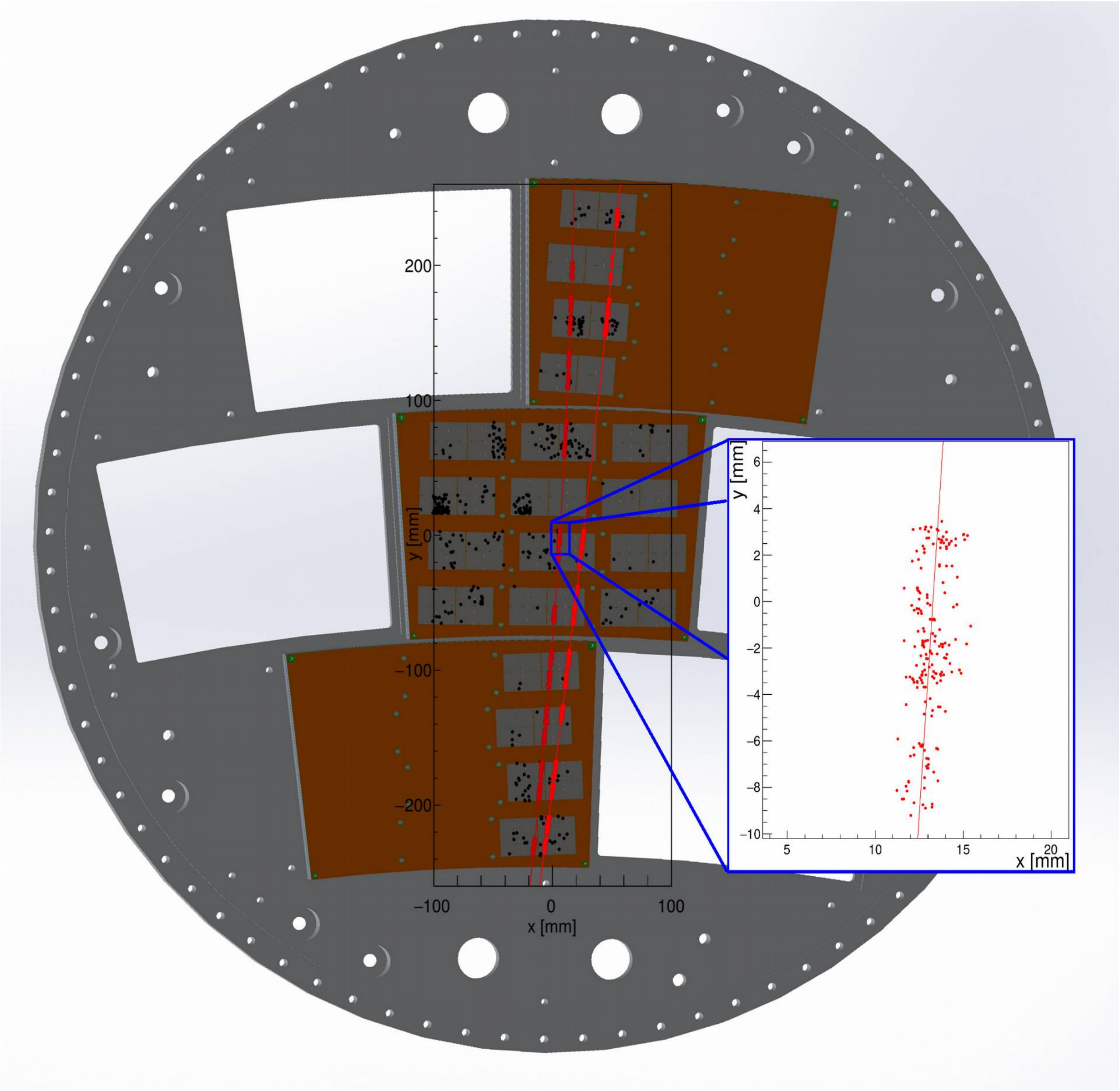
→ demanding for track reco, especially in case of curved tracks

CAD drawing of endplate with reconstructed double track event



50 cm track length with about 3000 hits, each representing an electron from the primary ionisation.

→ demanding for track reco, especially in case of curved tracks

→ preliminary analysis:

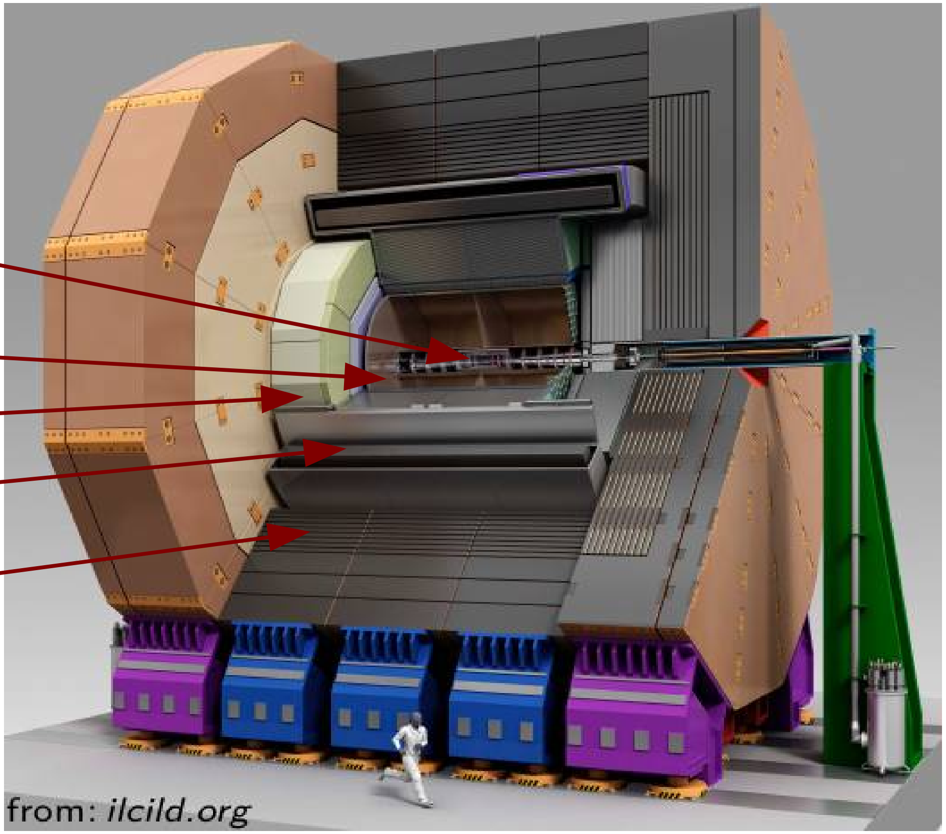
- Drift velocity
- Field distortions
- dE/dx resolution
- Single point resolution
- Track angular effect

Looking into the future

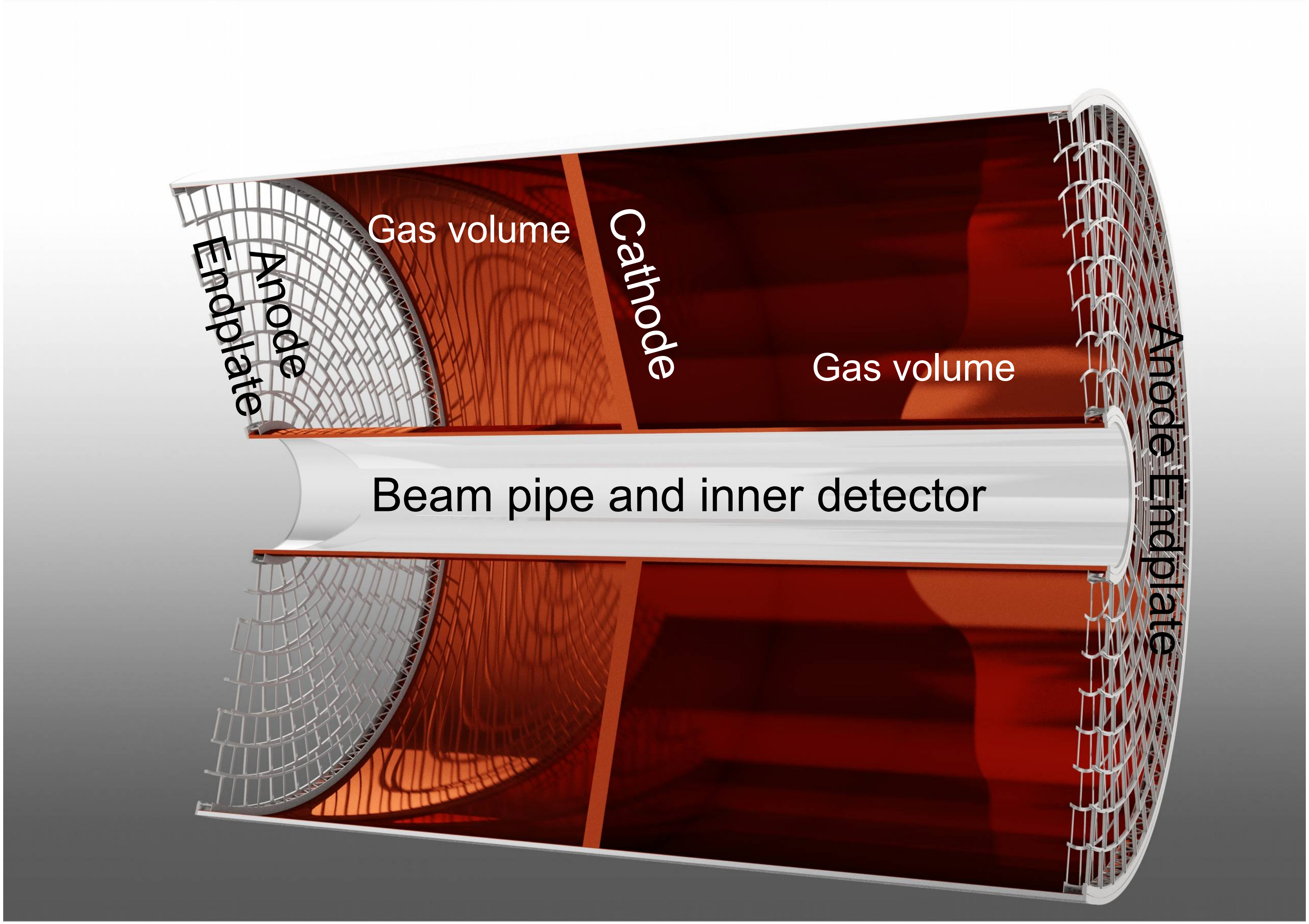
The International Linear Collider (ILC)

- High precision physics requires high precision detectors
  - Silicon Detector (SID)
  - International Large Detector (ILD)

- ILD: A general purpose 4π detector
  - Vertex detector
  - Tracking detector: Time Projection Chamber (TPC)
  - Calorimeter
  - Magnet system
  - Muon detector



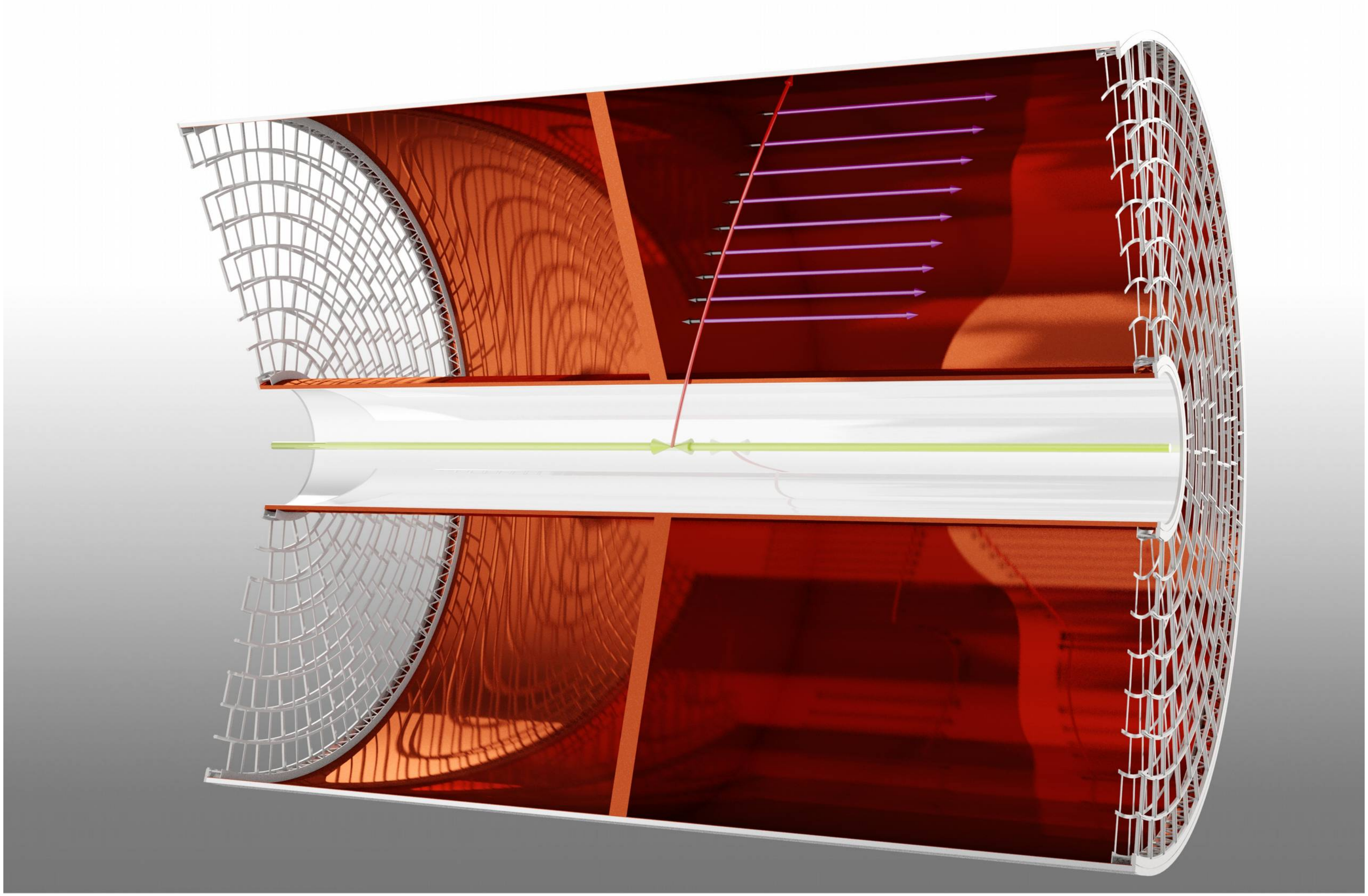
Gas filled cylinder with central cathode and two anode endplates



CAD design by Tobias Schiffer

Following the tracks: What is a TPC

Charged particle ionises gas atoms along its track→electrons drift to anode



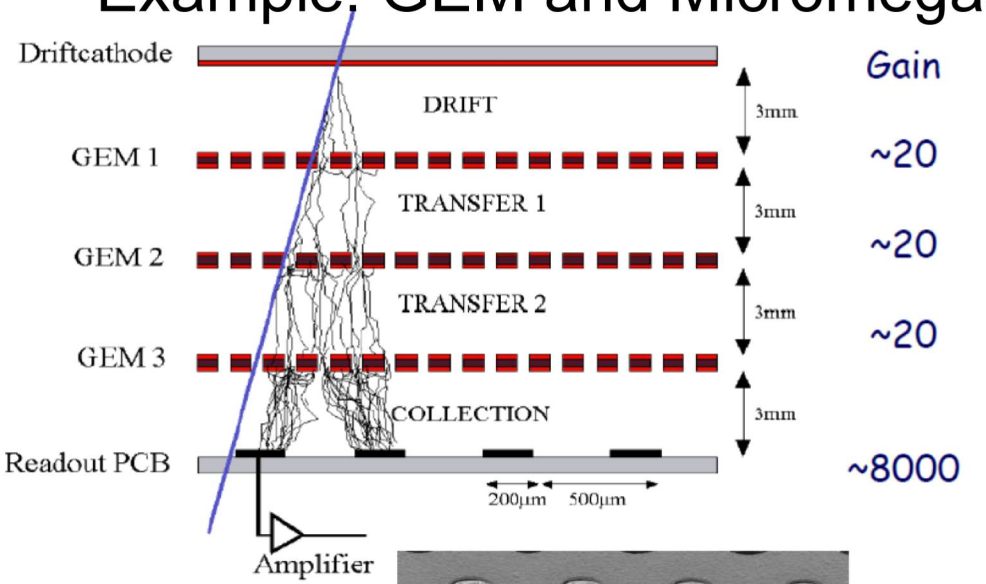
Advantages: low material, continuous tracking, particle identification

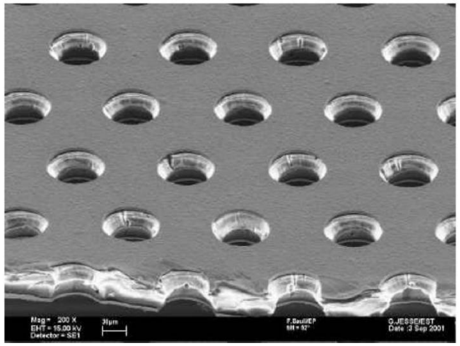
TPC readout

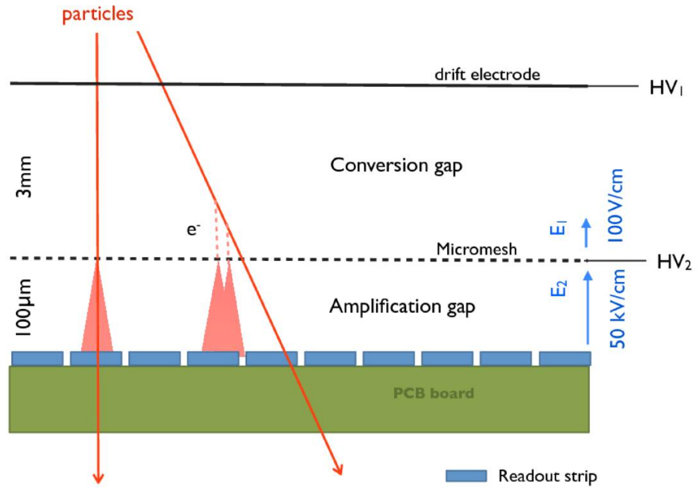
Primary electrons form track projection at the endplates

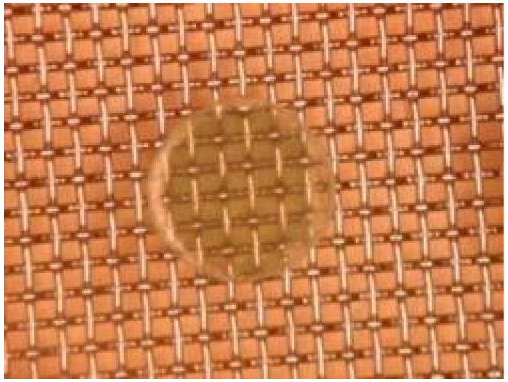
→ measure their (x,y)-position and arrival time t

- Signal from single electrons too weak for electronics
- Gas amplification: Micro-pattern gaseous detectors (MPGD)
- Example: GEM and Micromegas









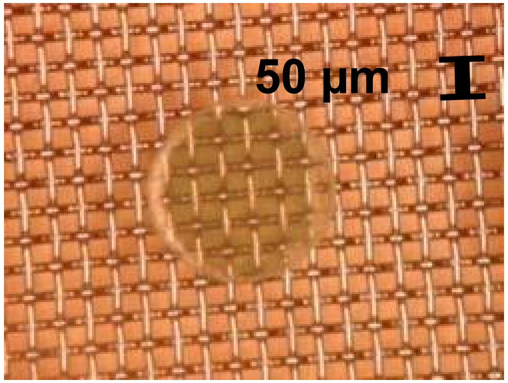
TPC readout

MPGDs: very fine grained gas amplification structures

→ High intrinsic resolution, resolves single e⁻ from primary ionisations

→ Anode segmentation should not spoil this resolution

Traditional readout: pads with rectangular shape



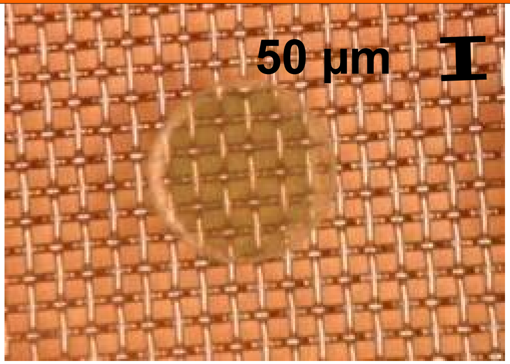
MPGDs: very fine grained gas amplification structures

→ High intrinsic resolution, resolves single e^- from primary ionisations

→ Anode segmentation should not spoil this resolution

Traditional readout: pads with rectangular shape

Pad 1x3 mm² to scale of mesh



TPC readout

MPGDs: very fine grained gas amplification structures

→ High intrinsic resolution, resolves single e^- from primary ionisations

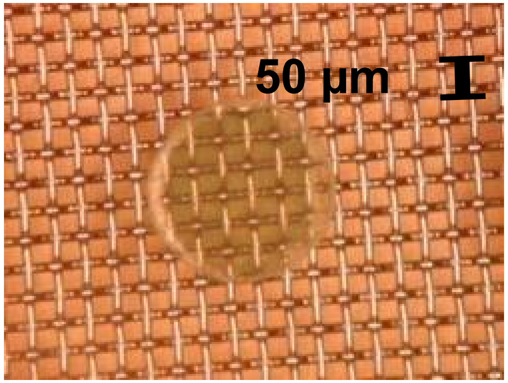
→ Anode segmentation should not spoil this resolution

Traditional readout: pads with rectangular shape

New approach: match readout segmentation to MPGD cell size

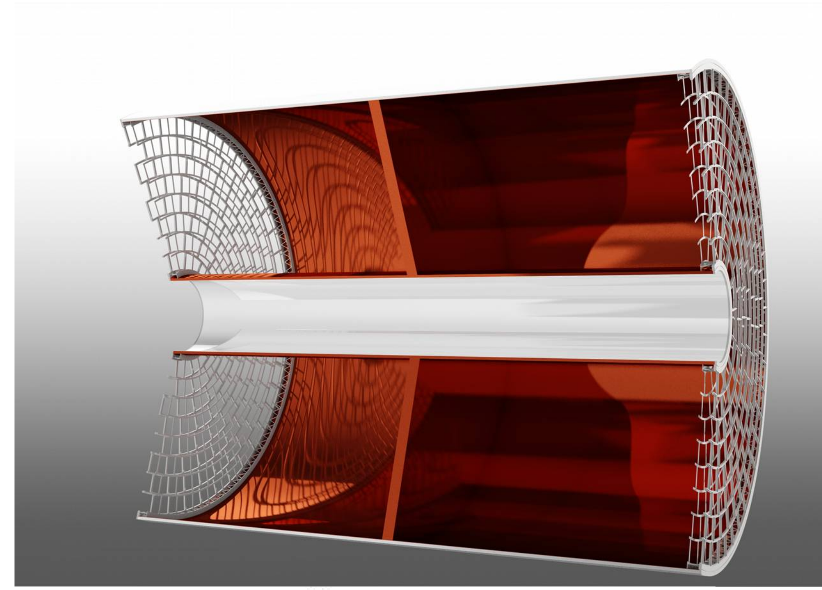
Use ASIC with charge sensitive pixels

- Charge treated in analogue section
- Digital output
- High density electronics
- Include gas amplification stage

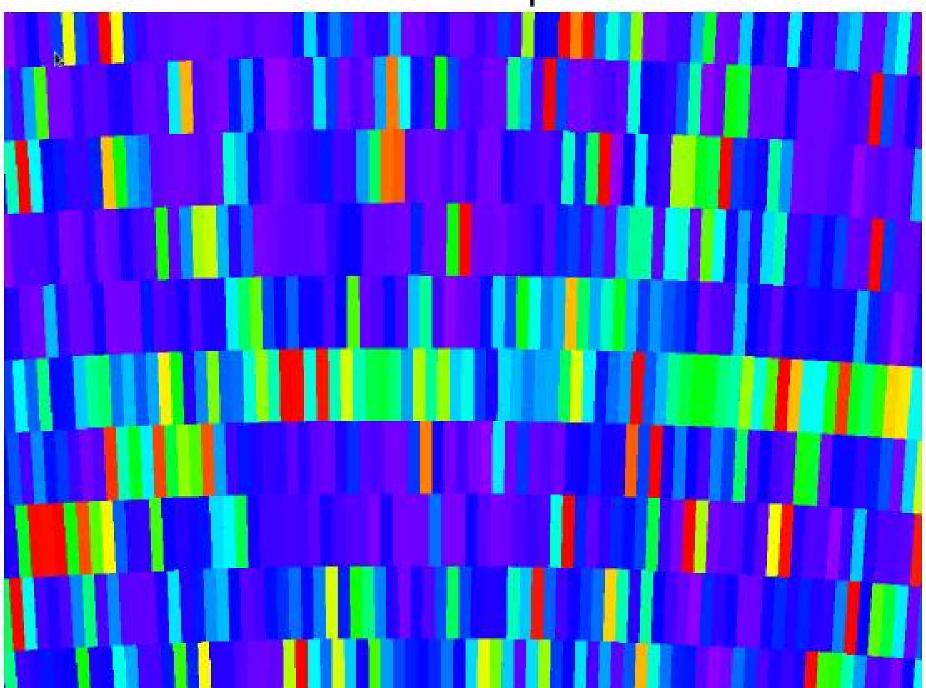


The Pixel-TPC concept

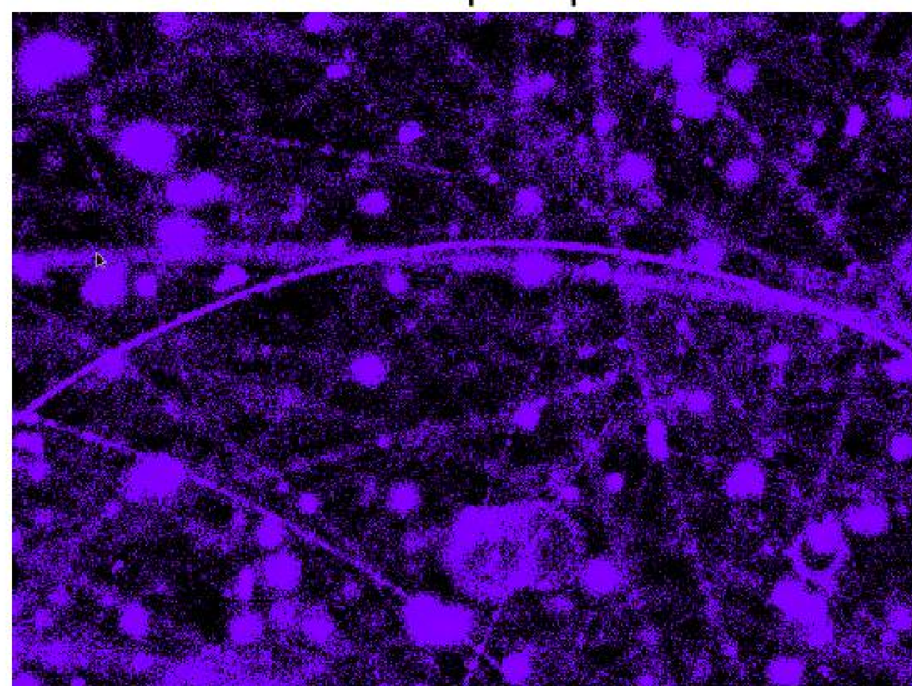
Idea: Equip endplate of TPC with GridPixes



$1\times6\ \mathrm{mm}^2$ pads



$100\times100\ \mu\mathrm{m}^2$ pixels



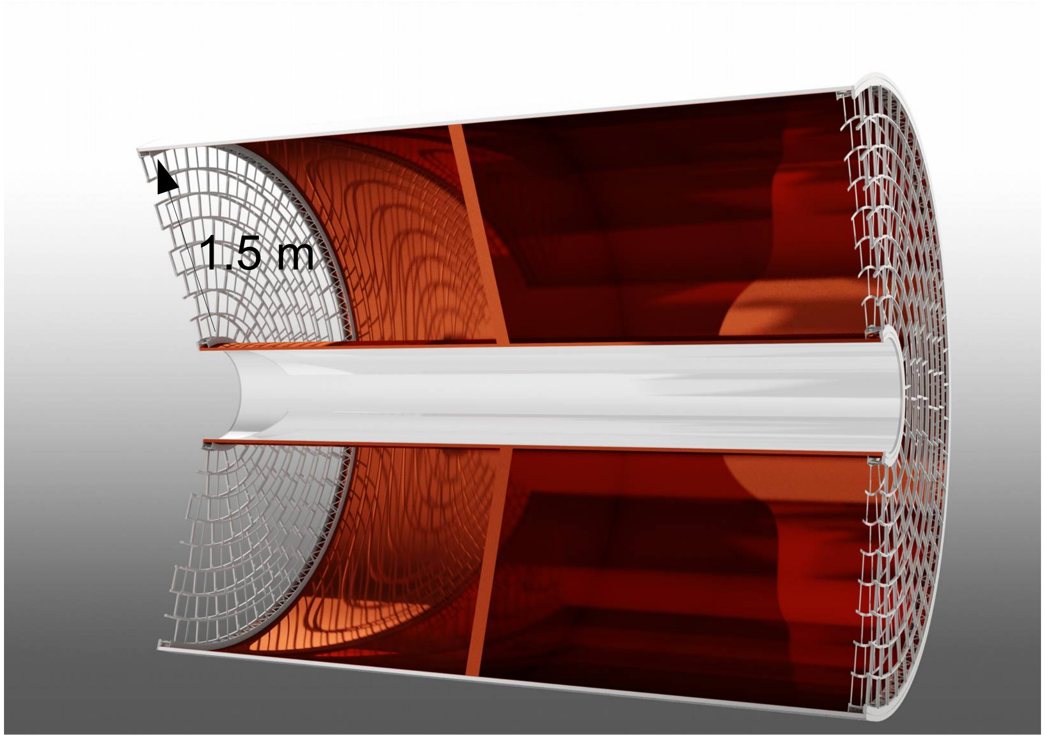
M. Killenberg: simulations of a Pixel-TPC at CLIC

The Pixel-TPC challenge

Idea: Equip endplate of TPC with GridPixes

- Problem: GridPix 2 cm², TPC endplate 10 m²

  → Need many GridPixes



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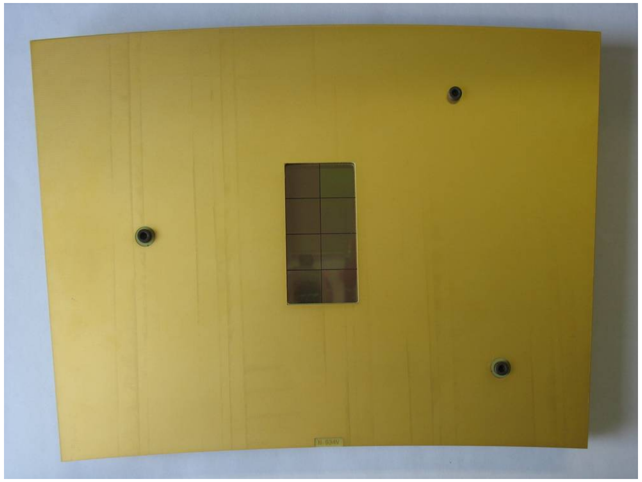
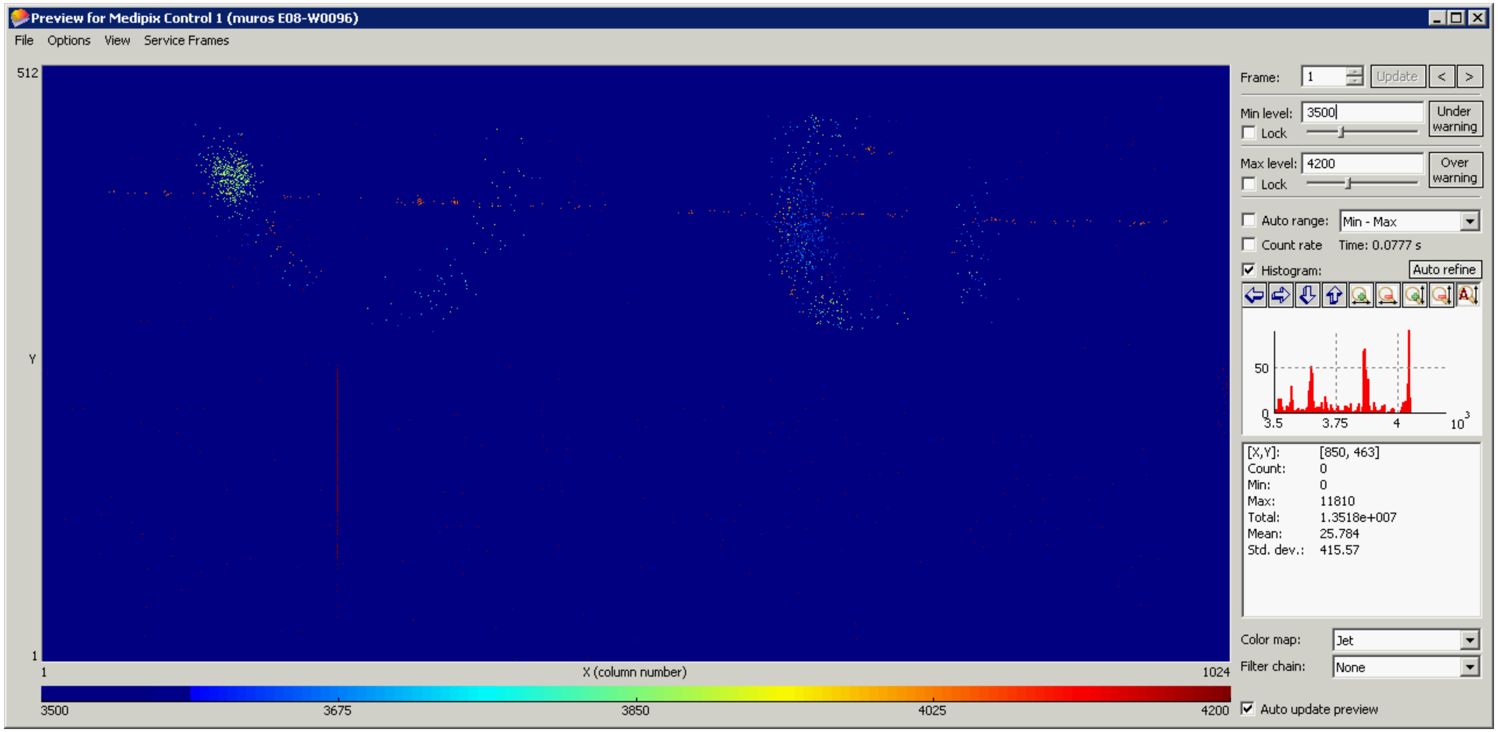
Idea: Equip endplate of TPC with GridPixes

- Problem: GridPix 2 cm², TPC endplate 10 m²

  → Need many GridPixes

- CEA Octopuce 2010: number of chips limited to 8 by readout system





The Pixel-TPC challenge

Idea: Equip endplate of TPC with GridPixes

- Problem: GridPix 2 cm^2, TPC endplate 10 m^2

  → Need many GridPixes
- CEA Octopuce 2010: maximum for available readout system

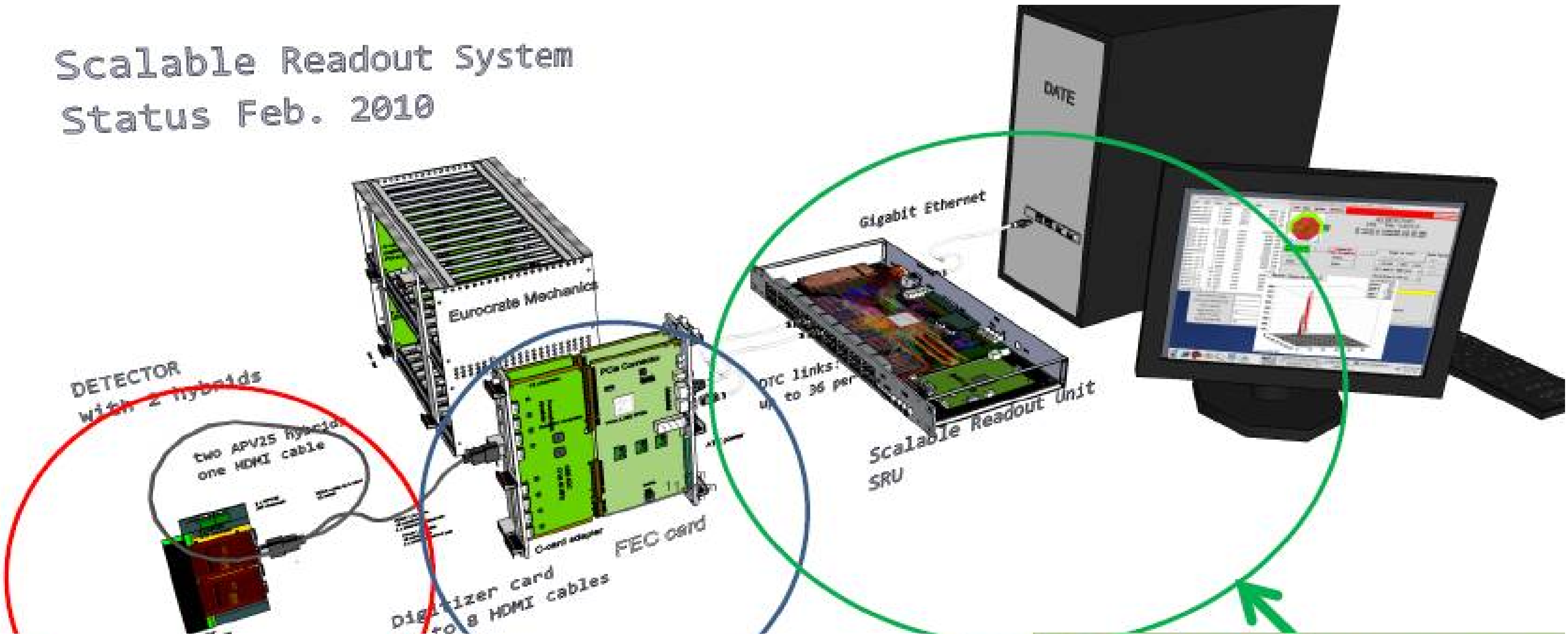
- ILD TPC endplate is modular

  → Demonstrator: one module (100 GridPixes)
  - New, large scale readout system
  - Data acquisition software and online event display
  - New module design including cooling, low voltage power supply, high voltage for GridPixes

The Scalable Readout System (SRS)

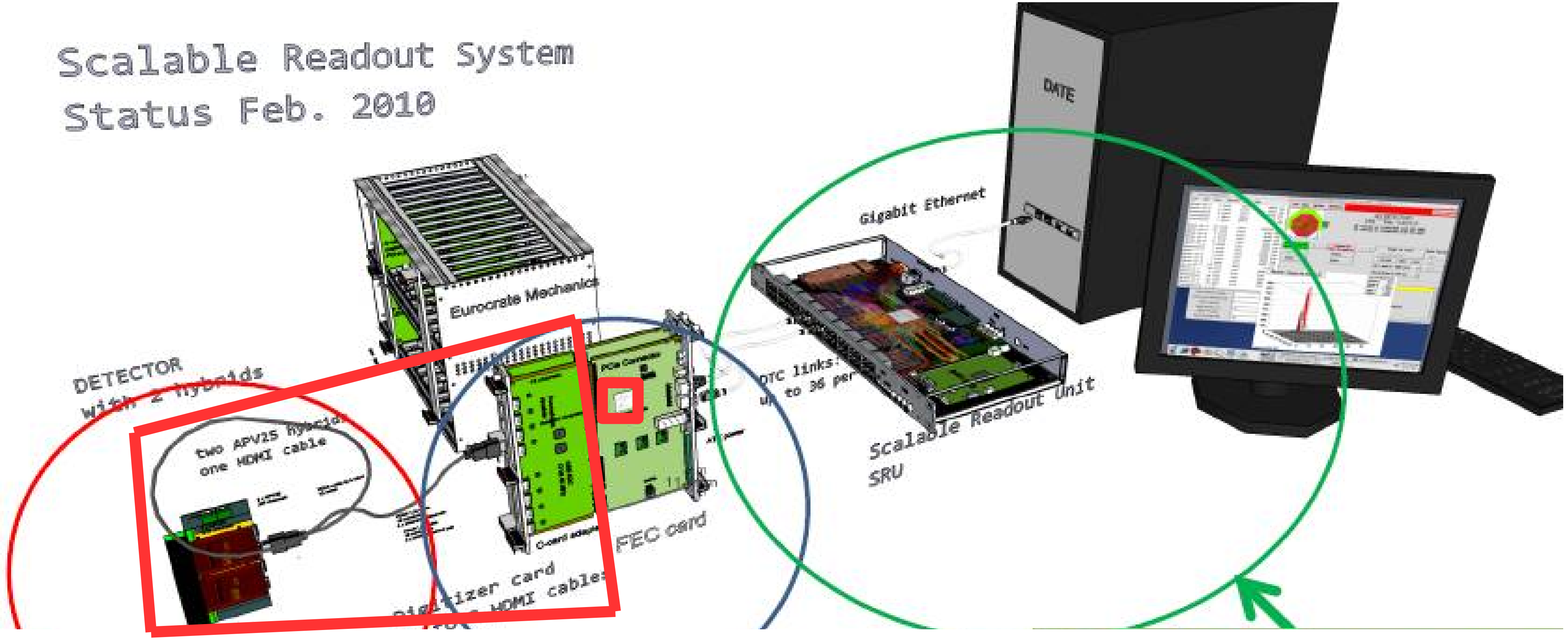
Implementation of the Timepix ASIC in SRS

- SRS: multi-purpose system from RD51 at CERN



Implementation of the Timepix ASIC in SRS

- SRS: multi-purpose system from RD51 at CERN
- Development of new FPGA firmware and hardware components



The Scalable Readout System (SRS)

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Implementation of the Timepix ASIC in SRS

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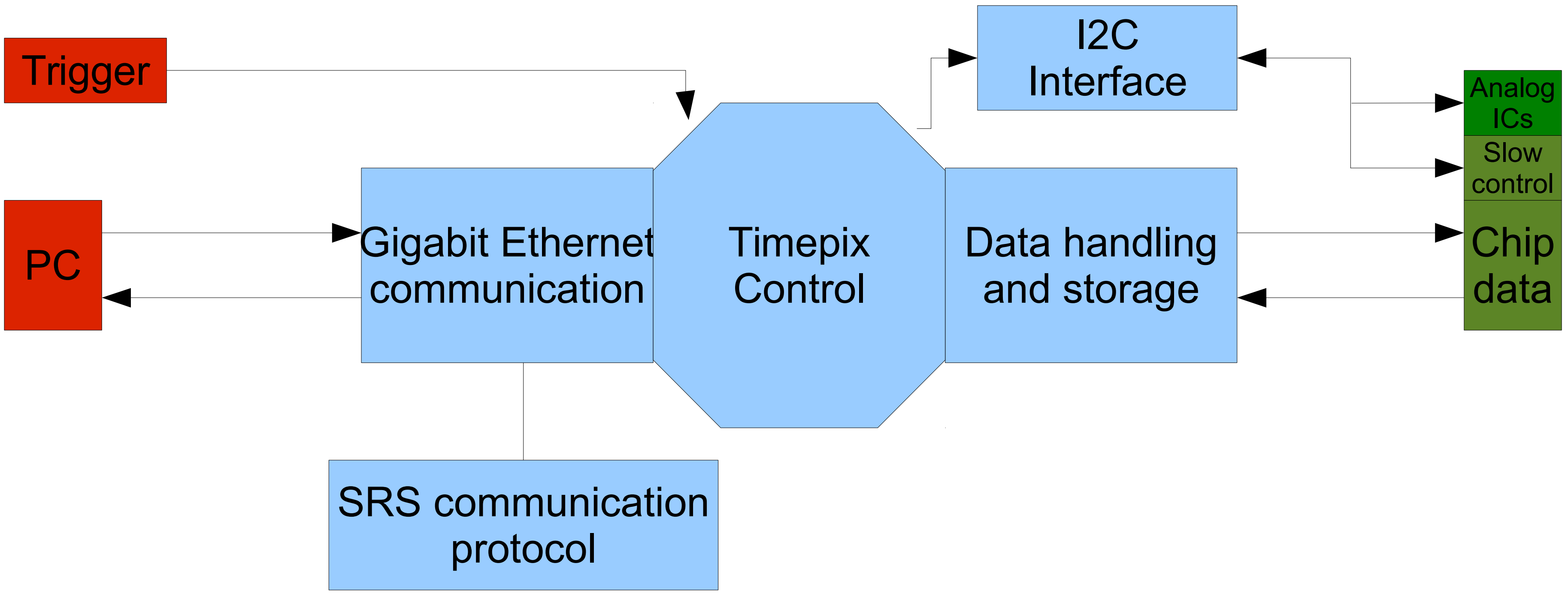

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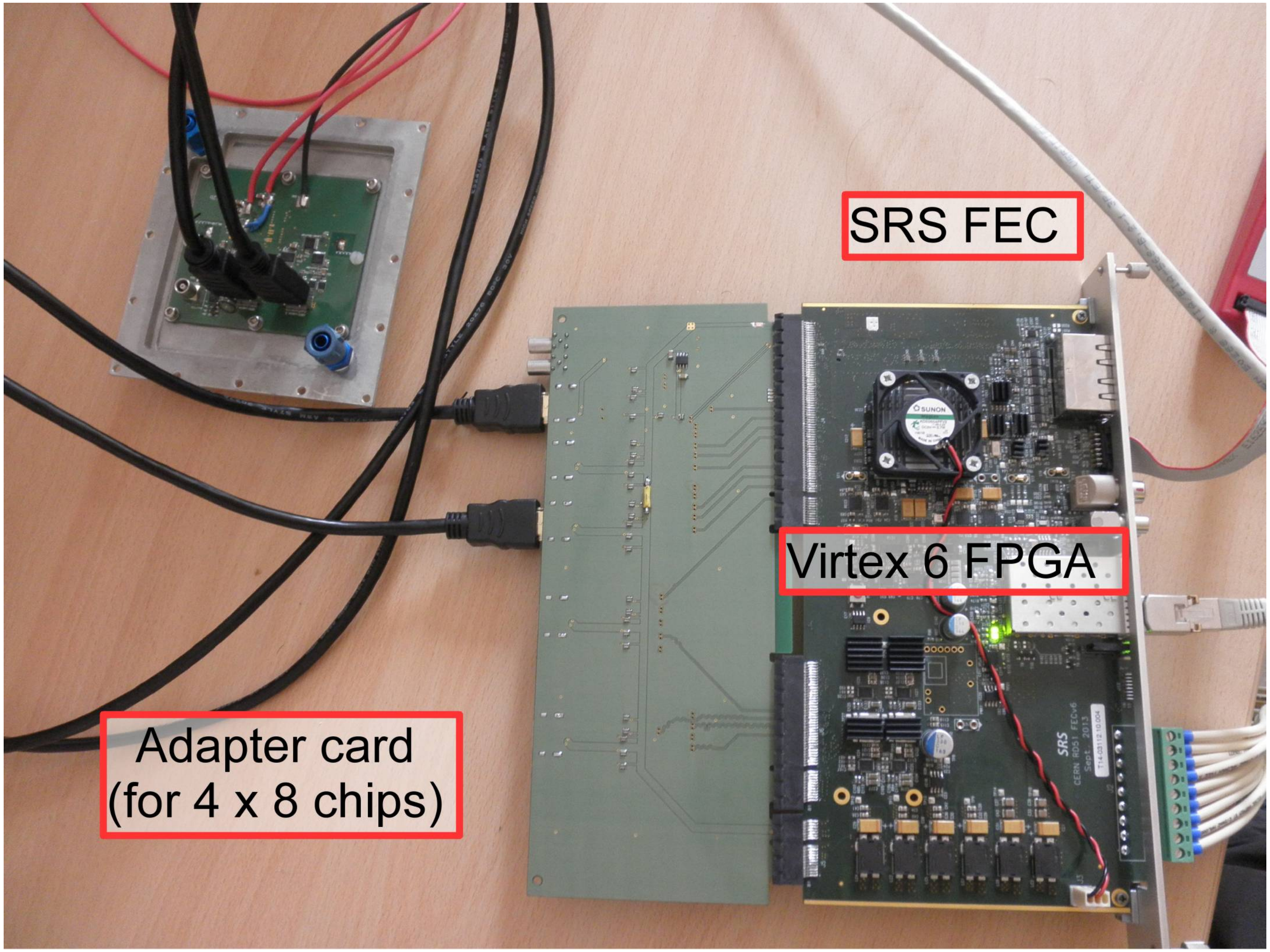

The Scalable Readout System (SRS)

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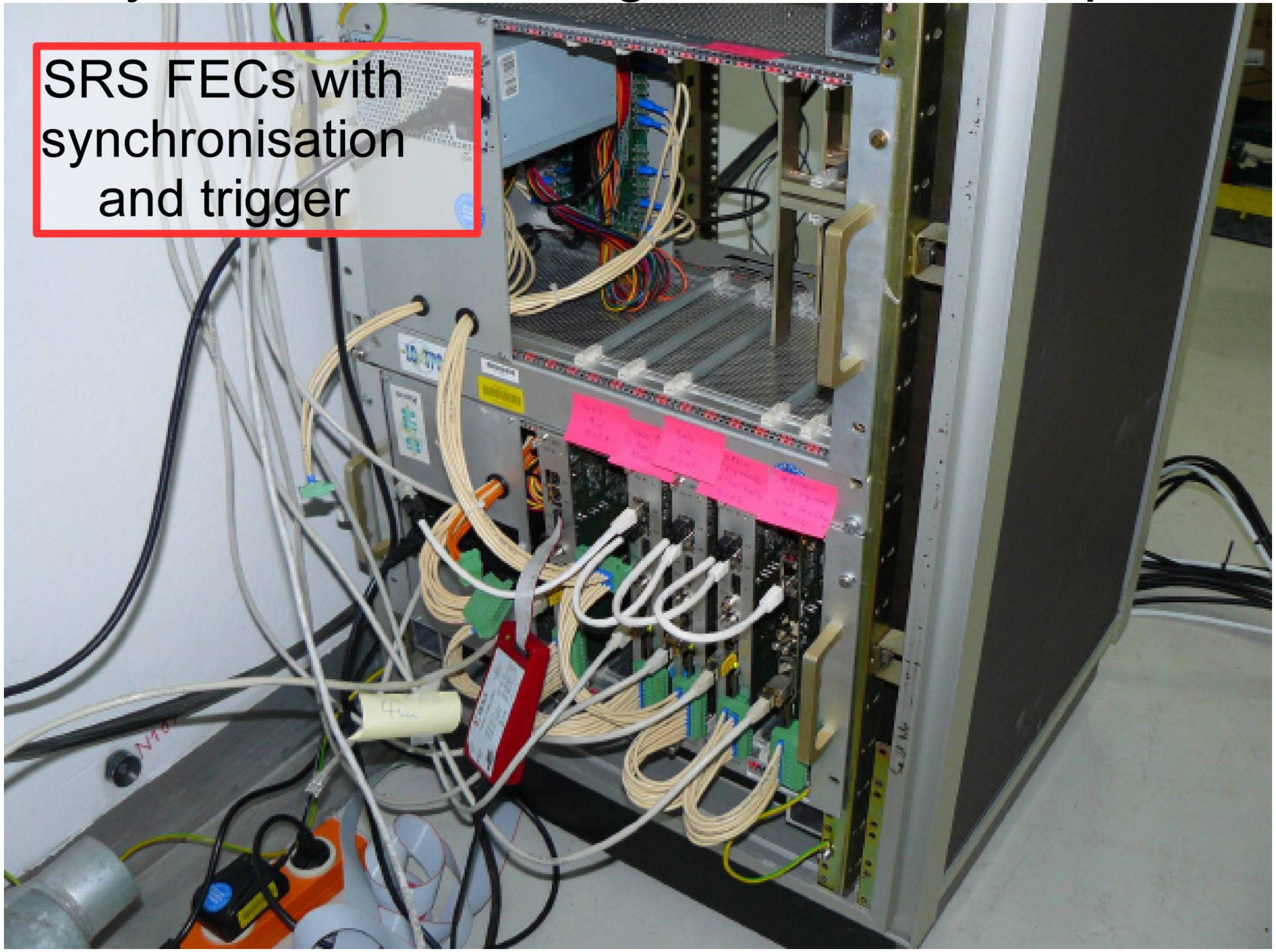
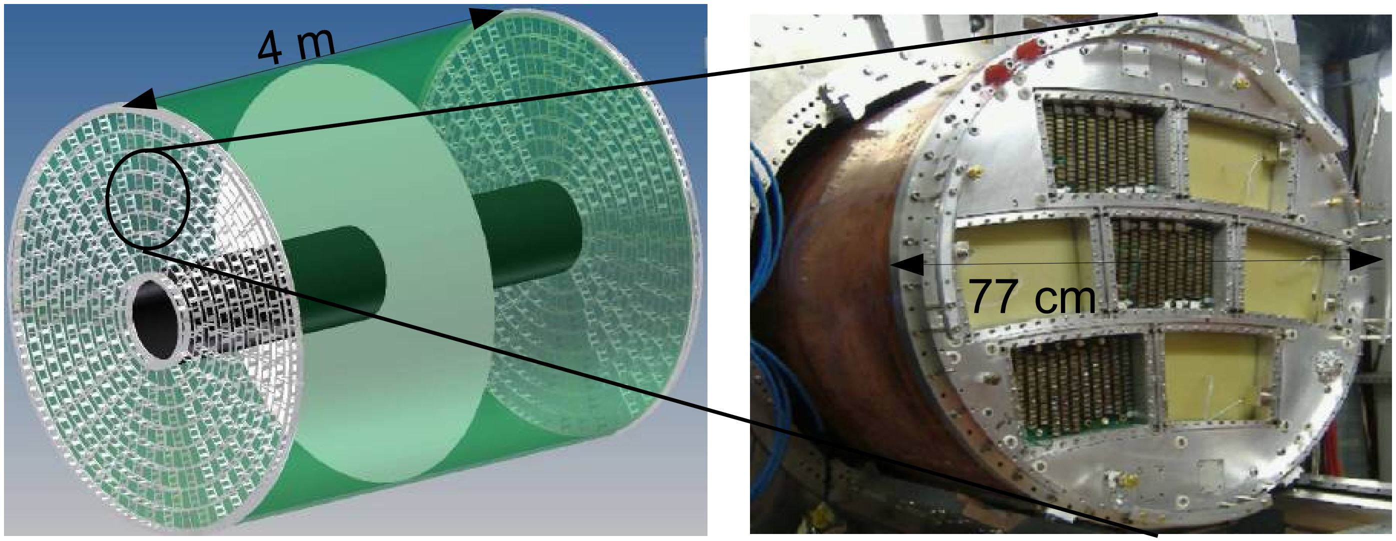
Implementation of the Timepix ASIC in SRS

- SRS: multi-purpose system from RD51 at CERN
- Development of new FPGA firmware and hardware components
- Use scalability to read out a large number of chips



Test setup

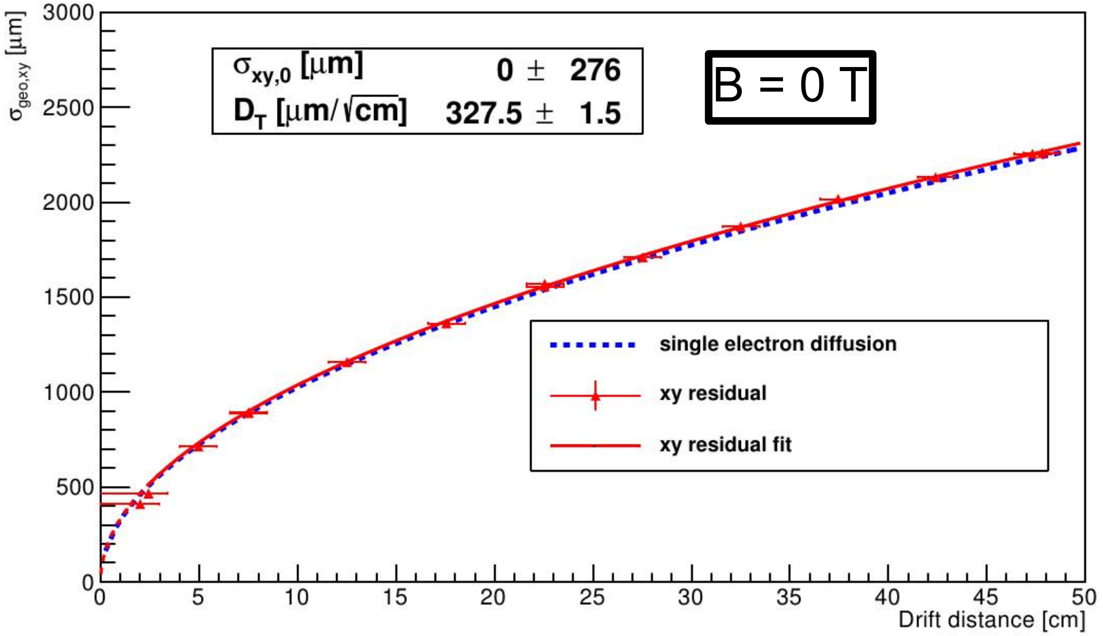
- LCTPC collaboration studies different concepts for ILD TPC
- Large Prototype of a TPC in a magnet at DESY

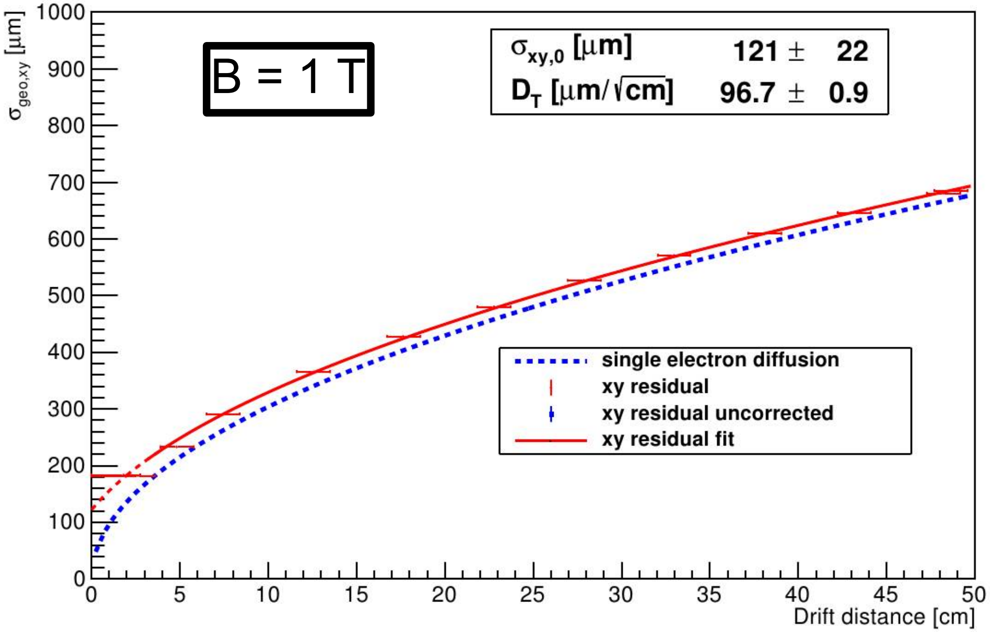


  - Drift length: 56 cm
  - Magnetic field: up to 1.25 T
  - Endplate for up to seven ILD TPC modules
  - Setup on a movable stage (lift, rotate, shift)
  - Electrons with up to 6 GeV from DESY II synchrotron

Spatial resolution:

In x-y plane, from residuals

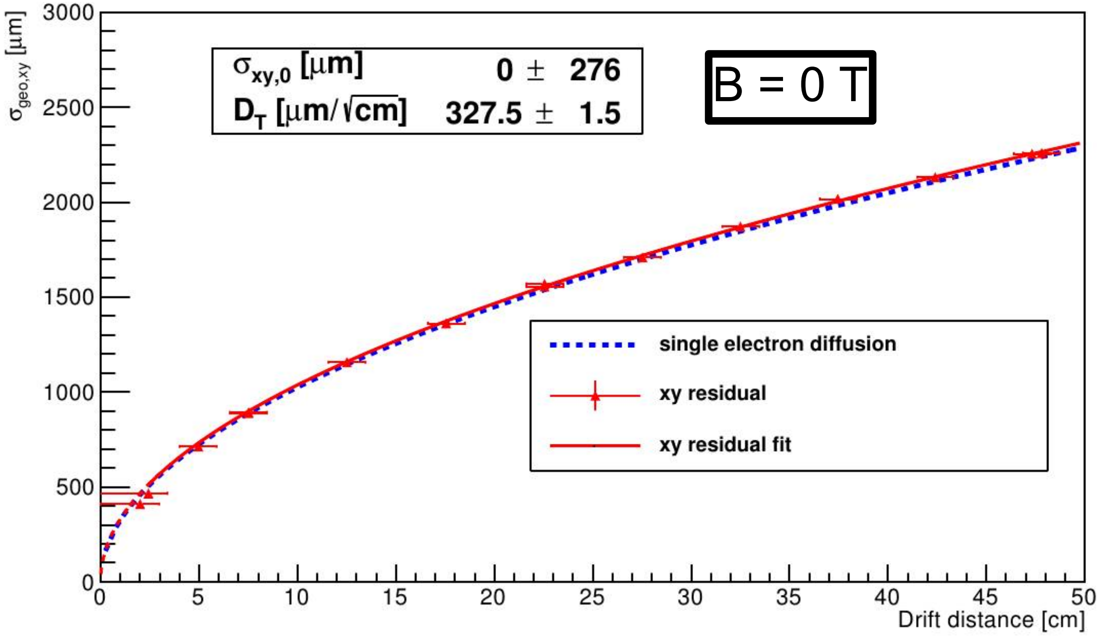


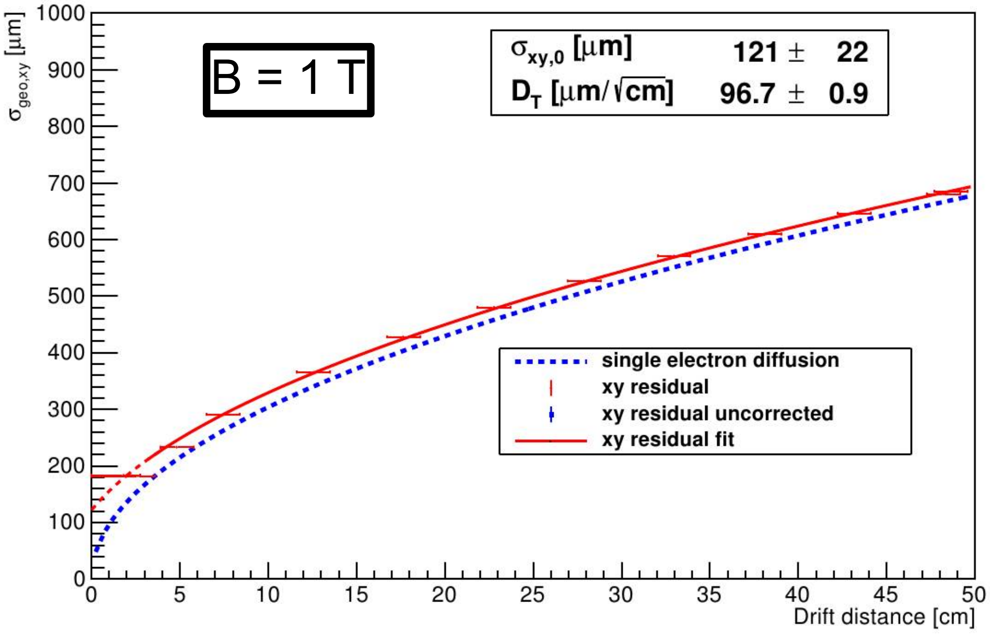


Test beam results

Spatial resolution:

In x-y plane, from residuals



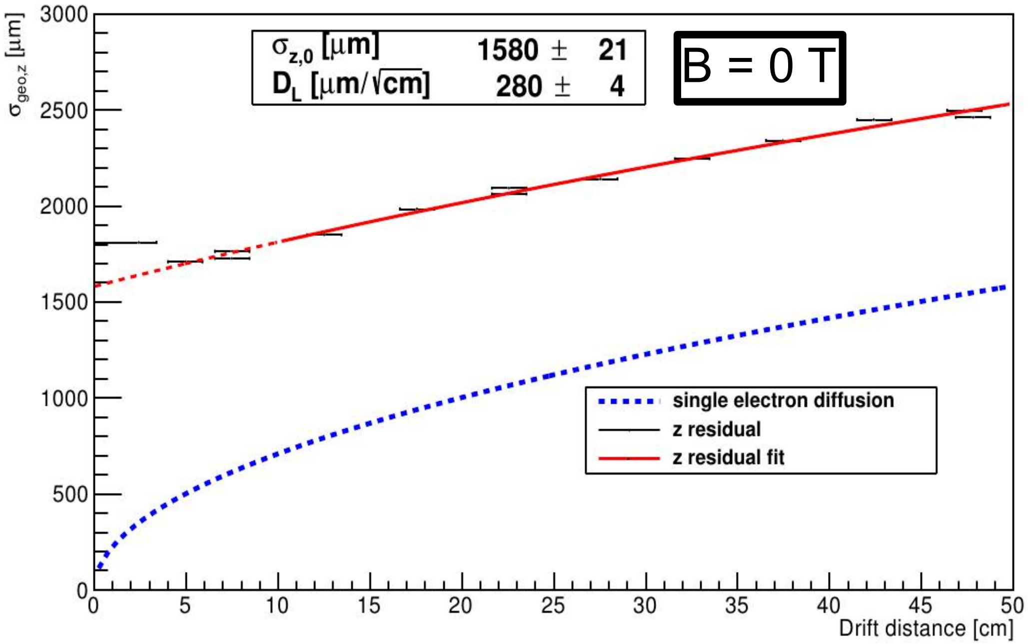


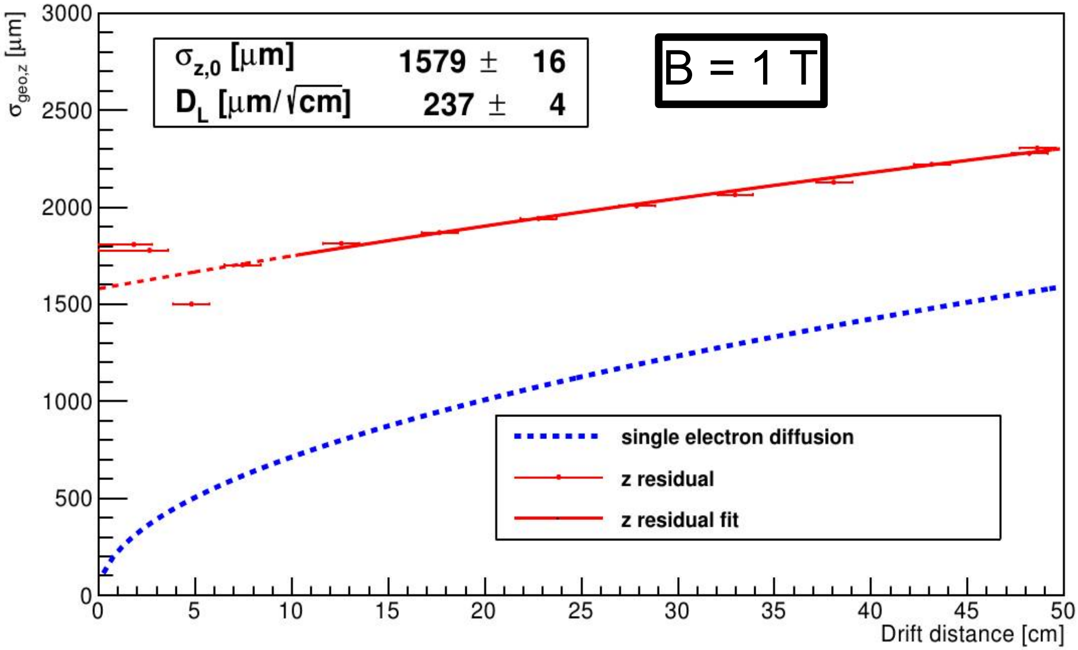
Transverse spatial resolution follows diffusion of single electrons.

Reconstructed diffusion constants in agreement with simulations.

Spatial resolution:

In z-direction, from residuals

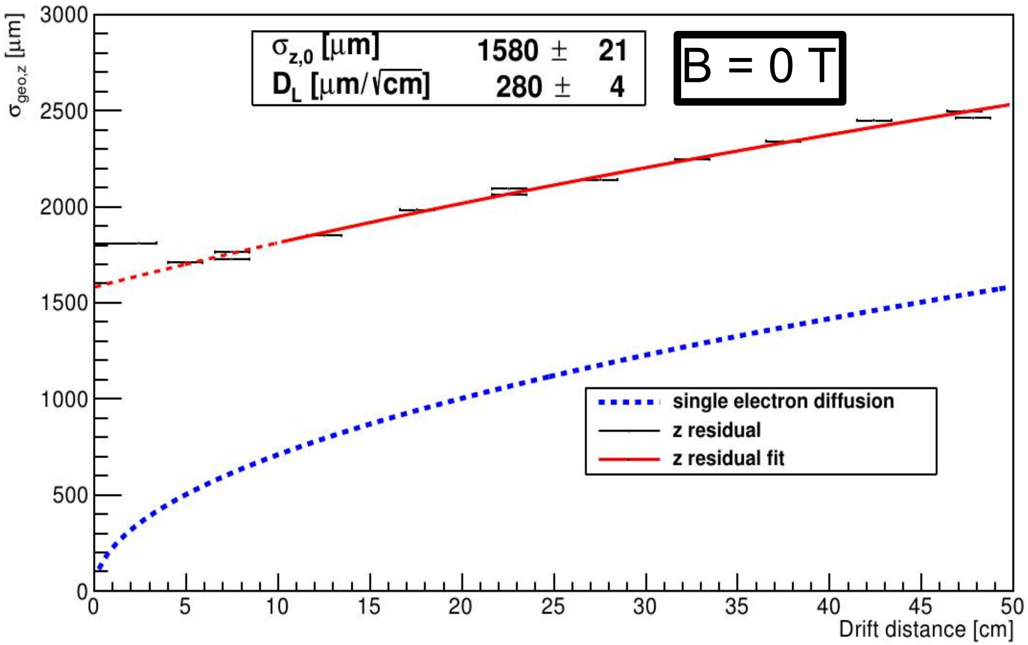


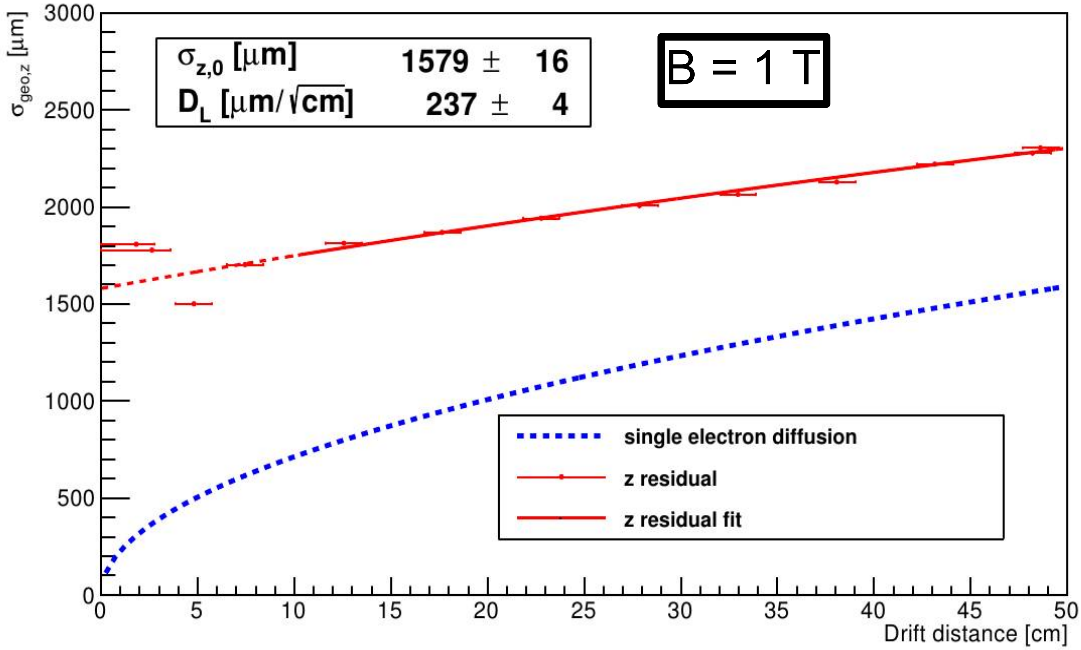


Test beam results

Spatial resolution:

In z-direction, from residuals





Longitudinal spatial resolution differs from diffusion of single electrons.

Reconstructed diffusion constants not in agreement with simulations.

Many degrading effects: Time walk, low time resolution, field distortions

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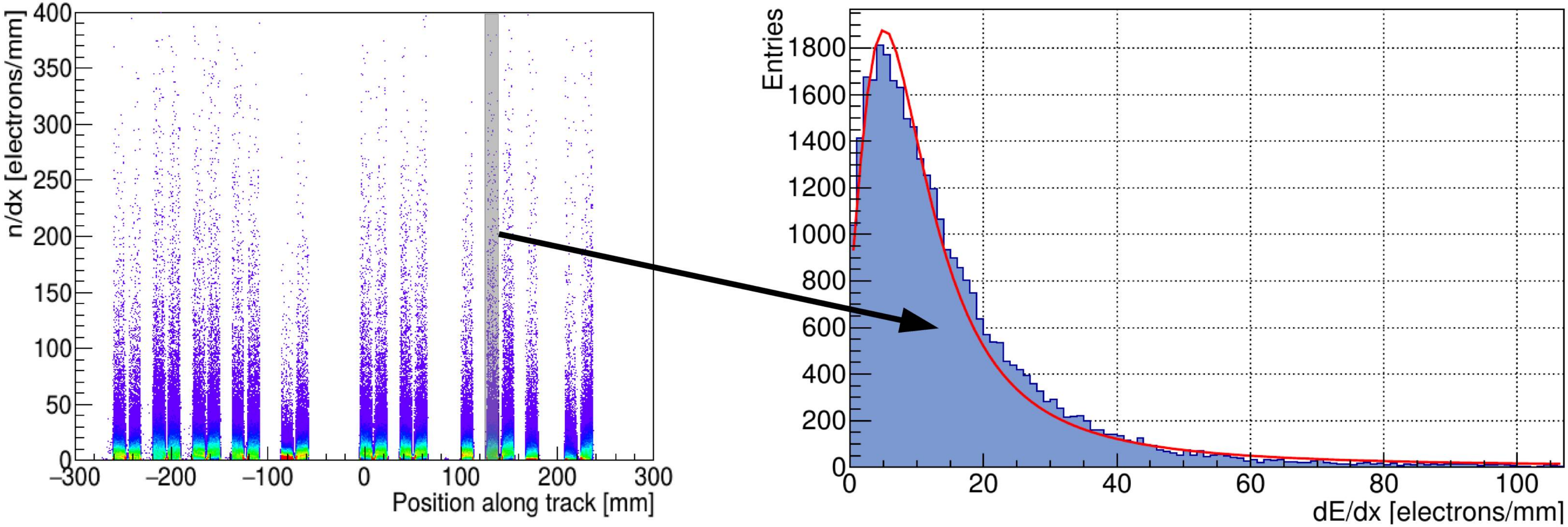
Energy loss resolution:

Thin slices of 1 mm track length, count number of hits (primary electrons)

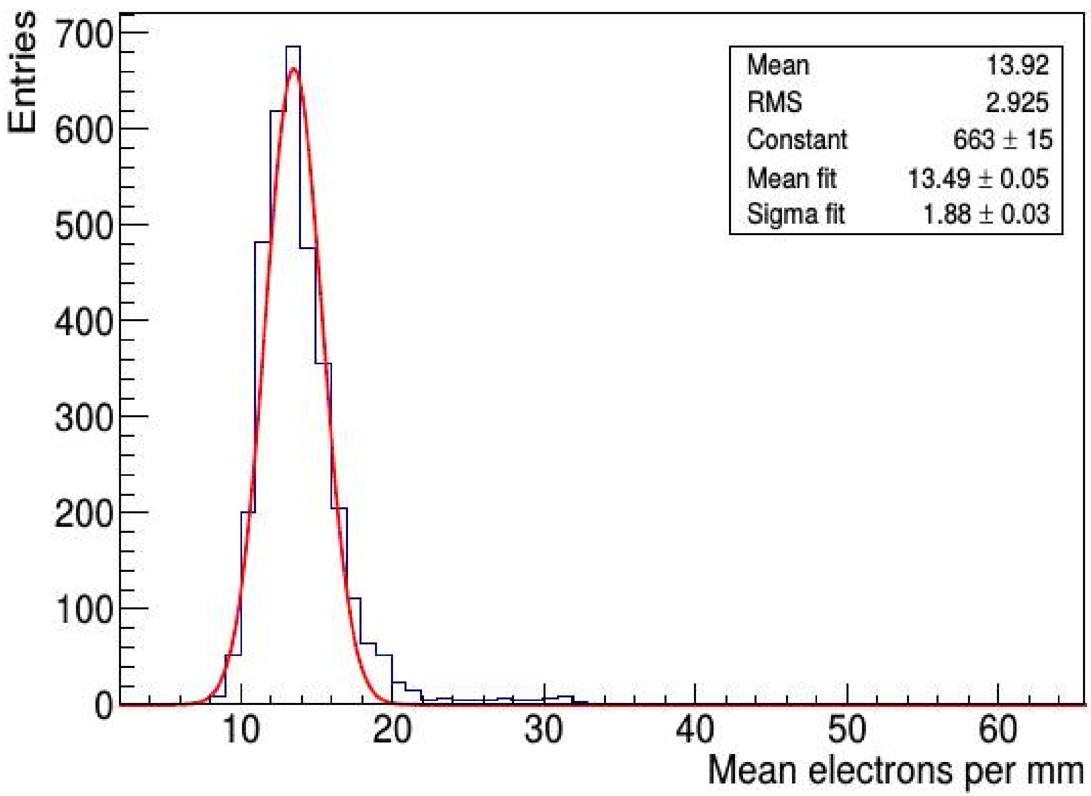


Landau like distribution when hits in a 10 mm interval of chip centre is projected

Test beam results

Energy loss resolution:

Thin slices of 1 mm track length, count number of hits (primary electrons)

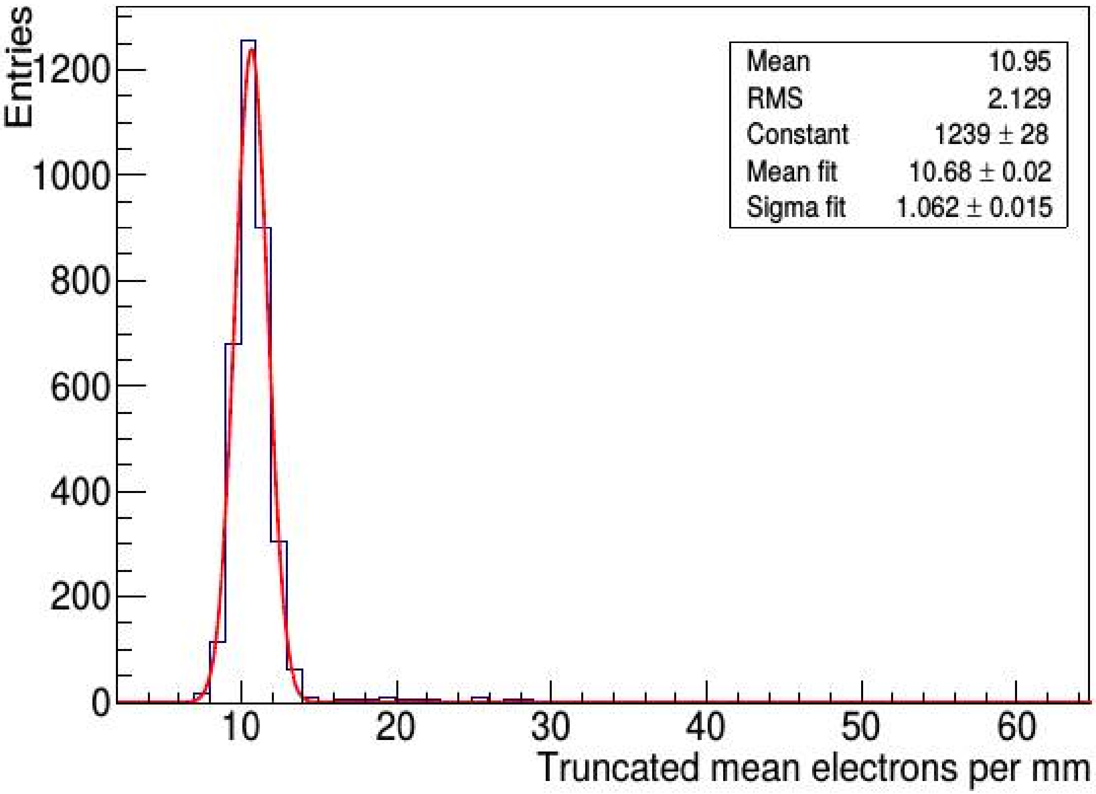


Mean number of hits in intervals of 1 mm along the track with a resolution of (14.0 ± 0.3) % in the peak fitted by a Gaussian distribution.

Test beam results

Energy loss resolution:

Thin slices of 1 mm track length, count number of hits (primary electrons)

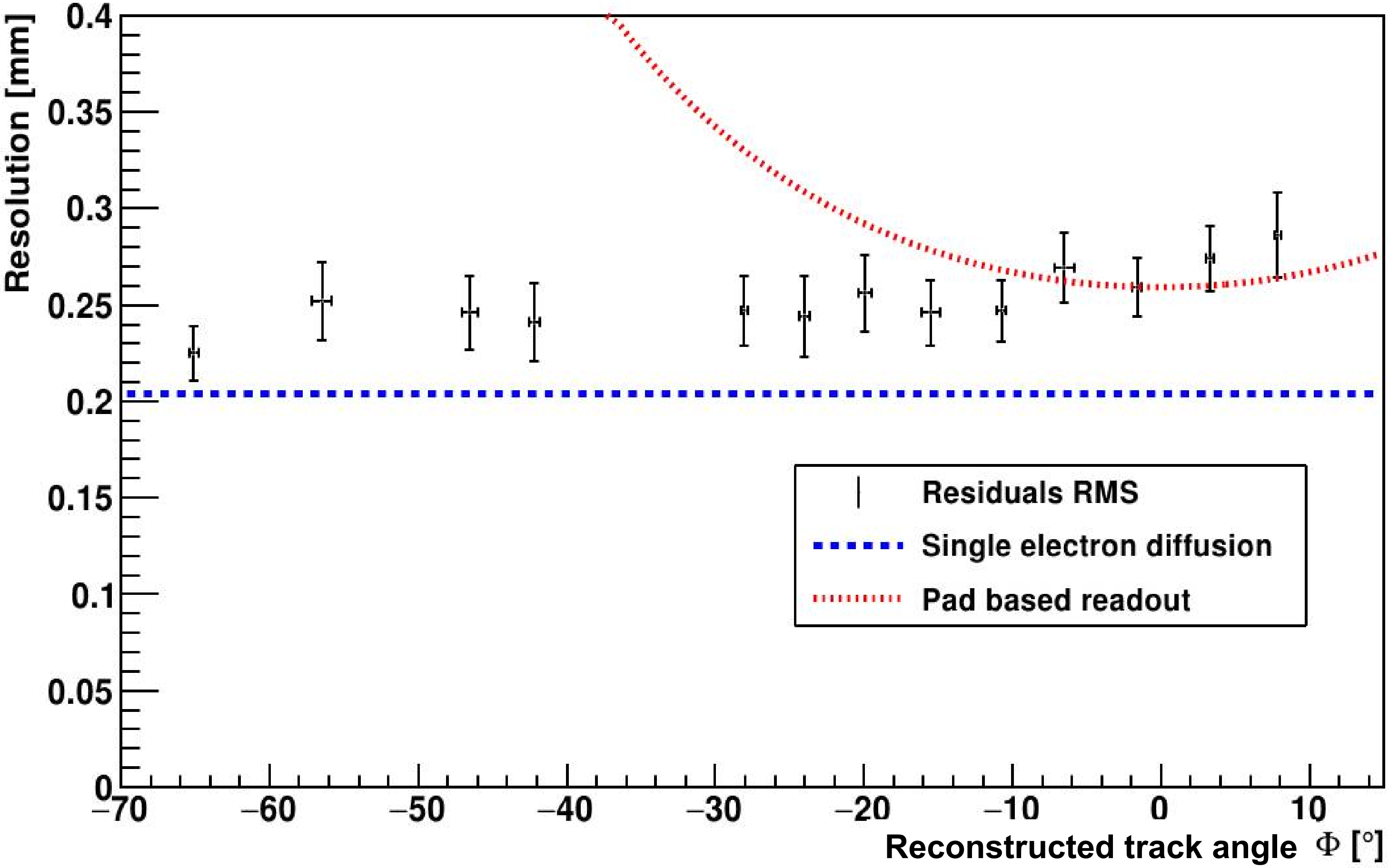


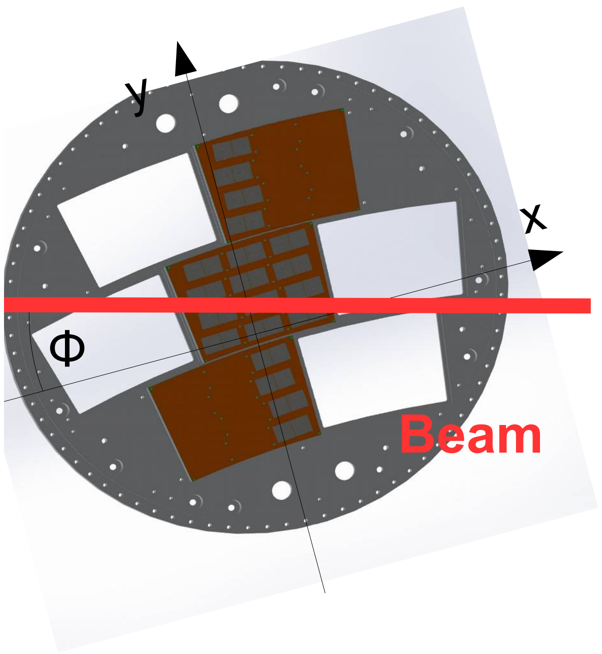
Truncated mean (reject 5 % highest, 5 % lowest means) number of hits in intervals of 1 mm along the track with a resolution of (9.9 ± 0.5) % in the peak fitted by a Gaussian distribution.

When extrapolated to full ILD TPC 5.7 % could be achieved.

Test beam results

Single point resolution of the detector for different track angles with respect to the y-axis
(= rotation of the endplate with respect to the beam-axis)





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Single point resolution of the detector for different track angles with respect to the y-axis
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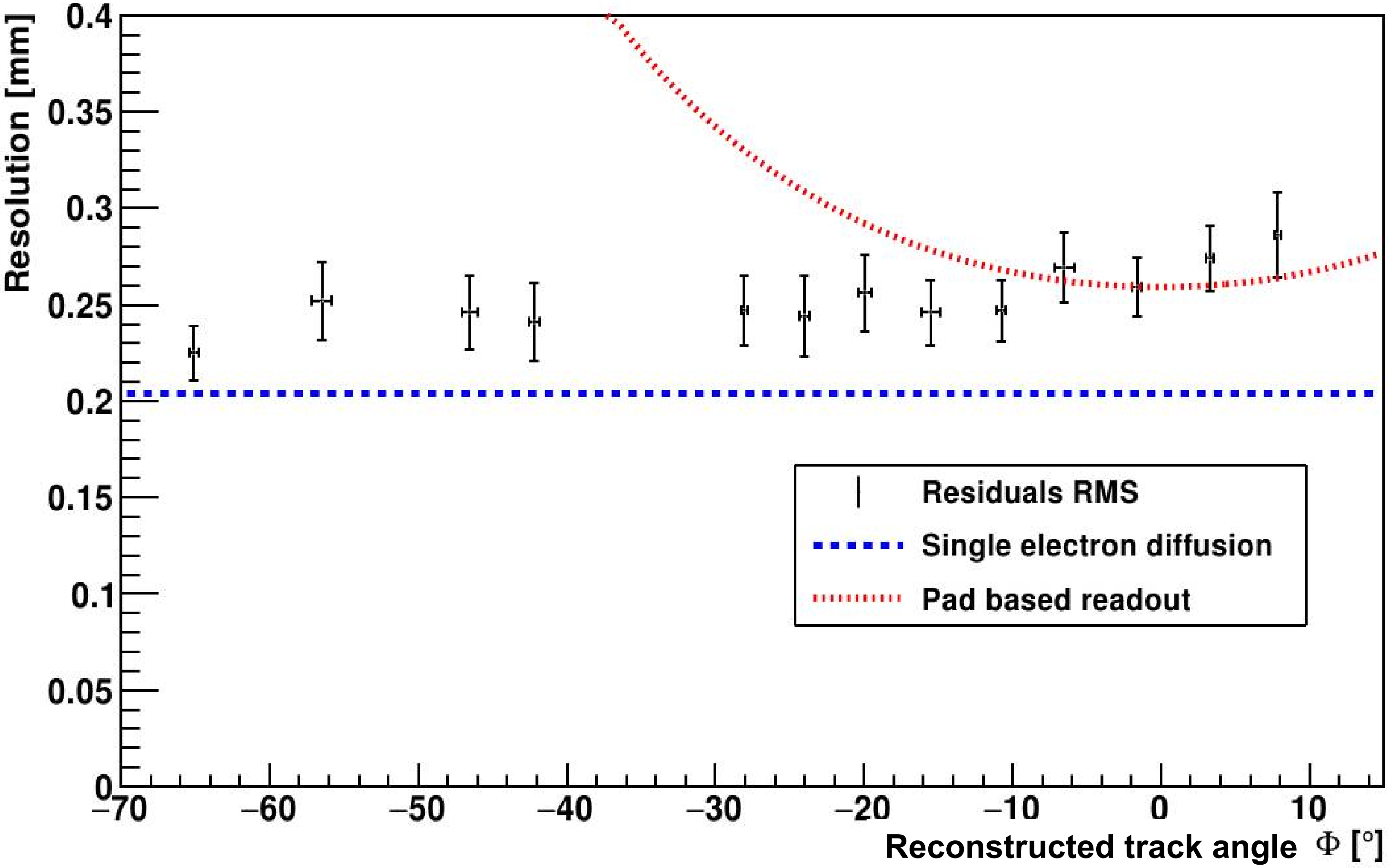

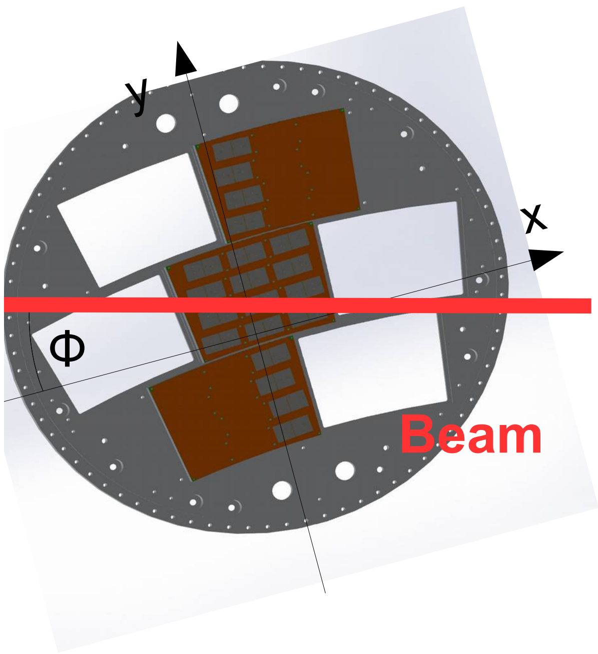

As expected for a Pixel-TPC, the resolution does not strongly depend on the track angle.

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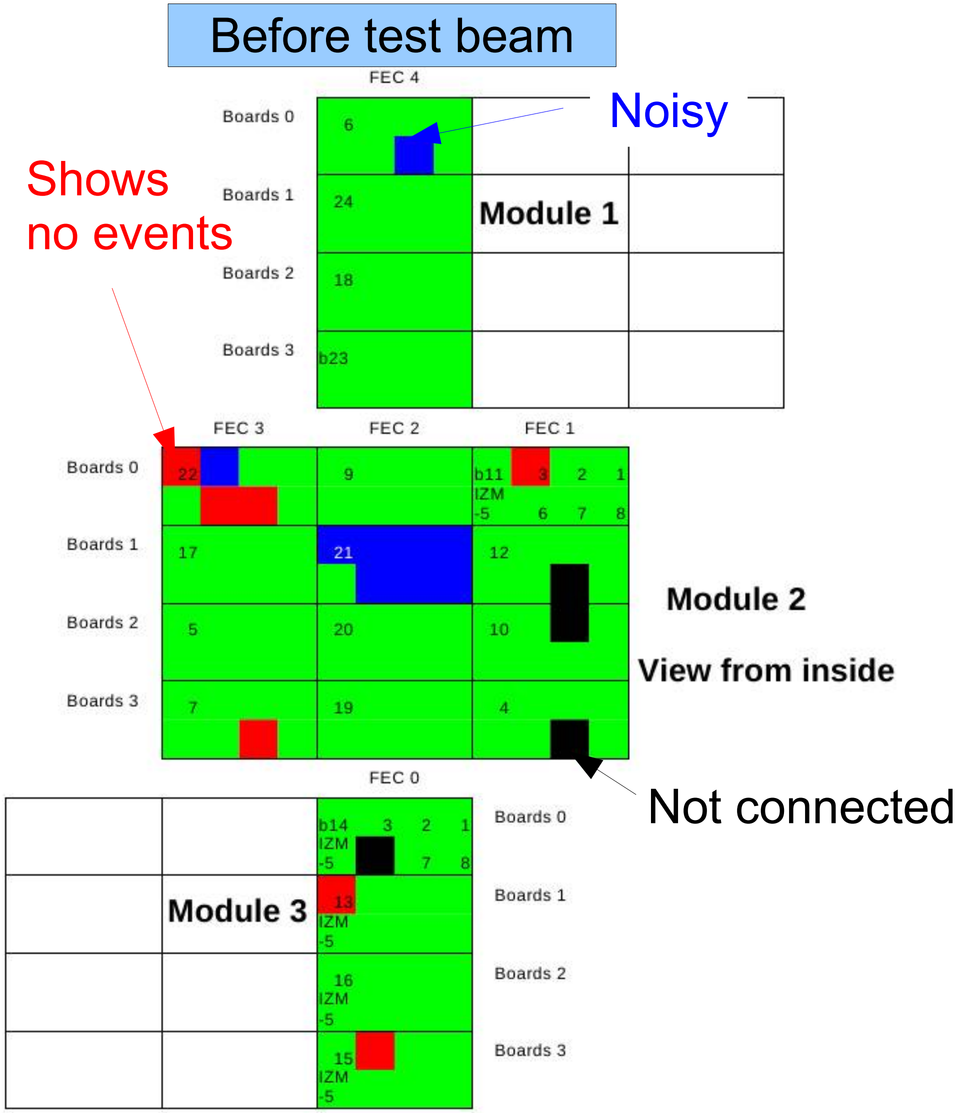
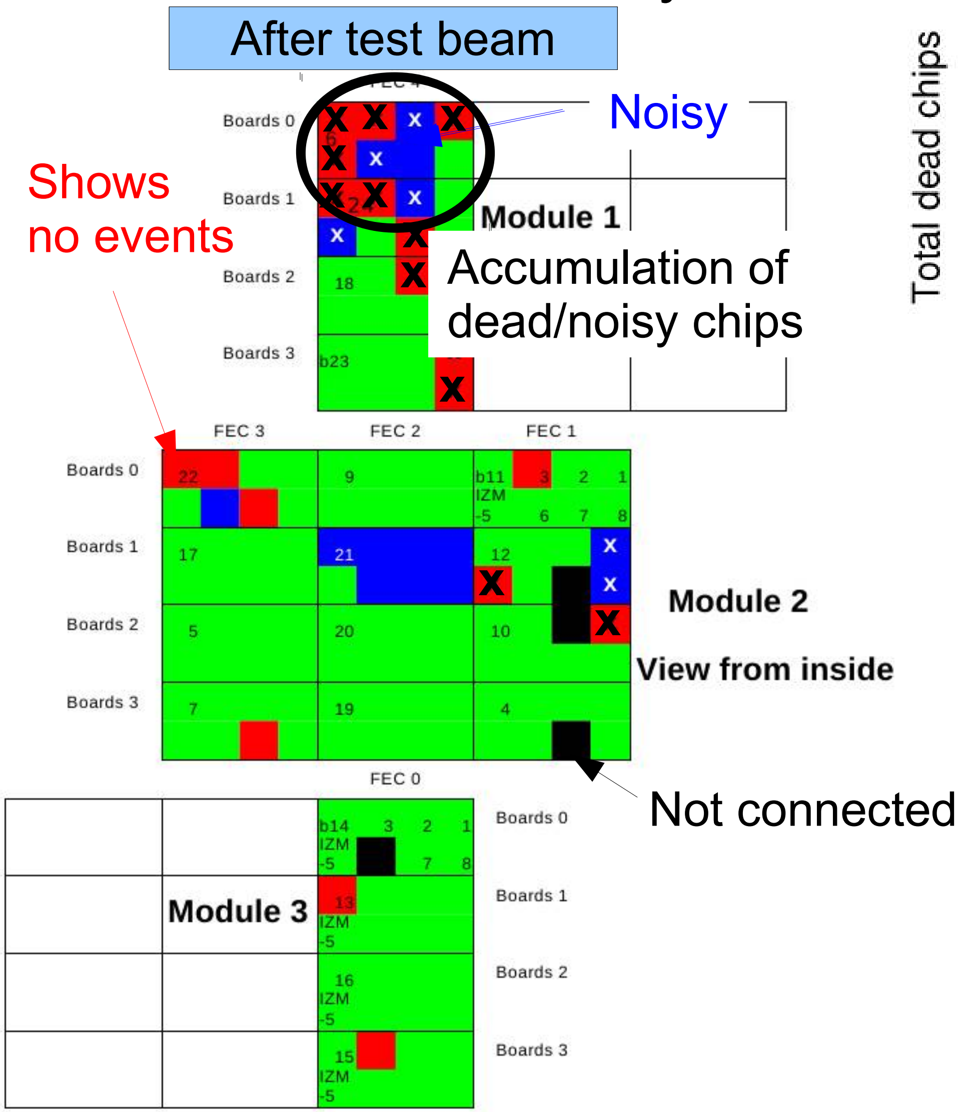
Not functioning chips

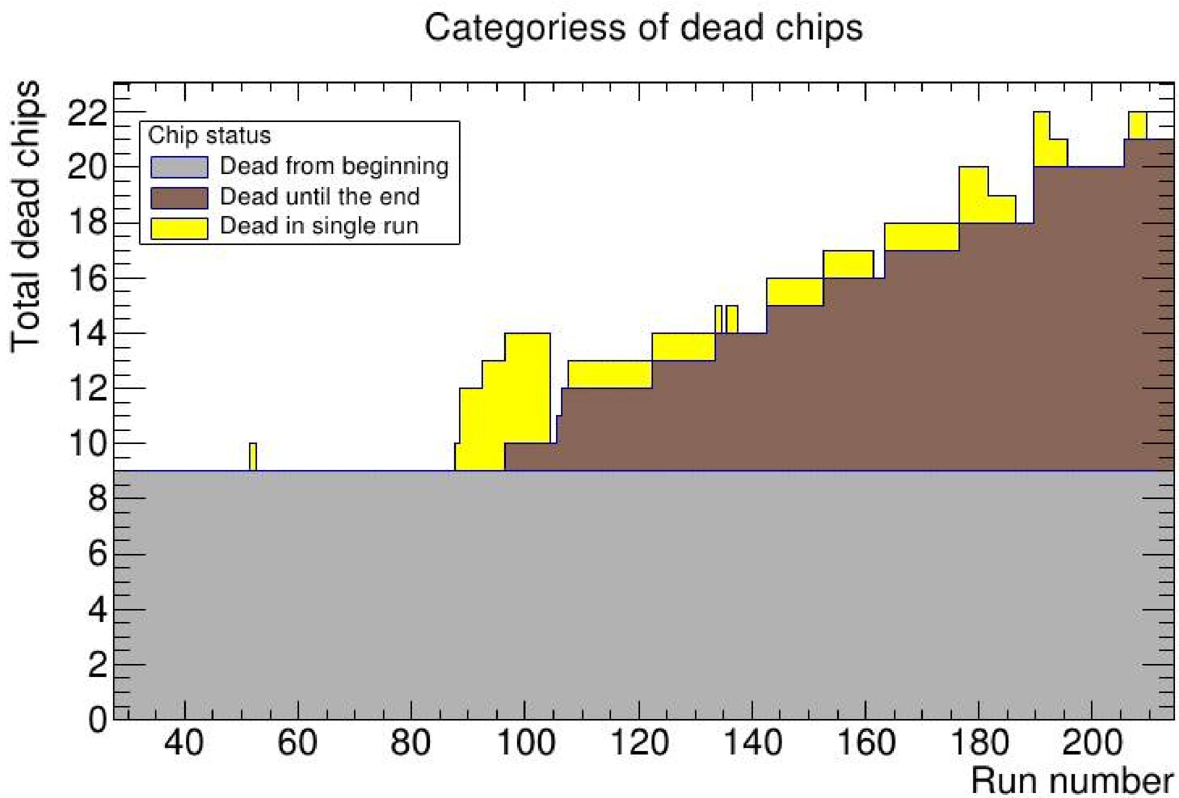


Reliability of chips

Not functioning chips

X: additional dead/noisy





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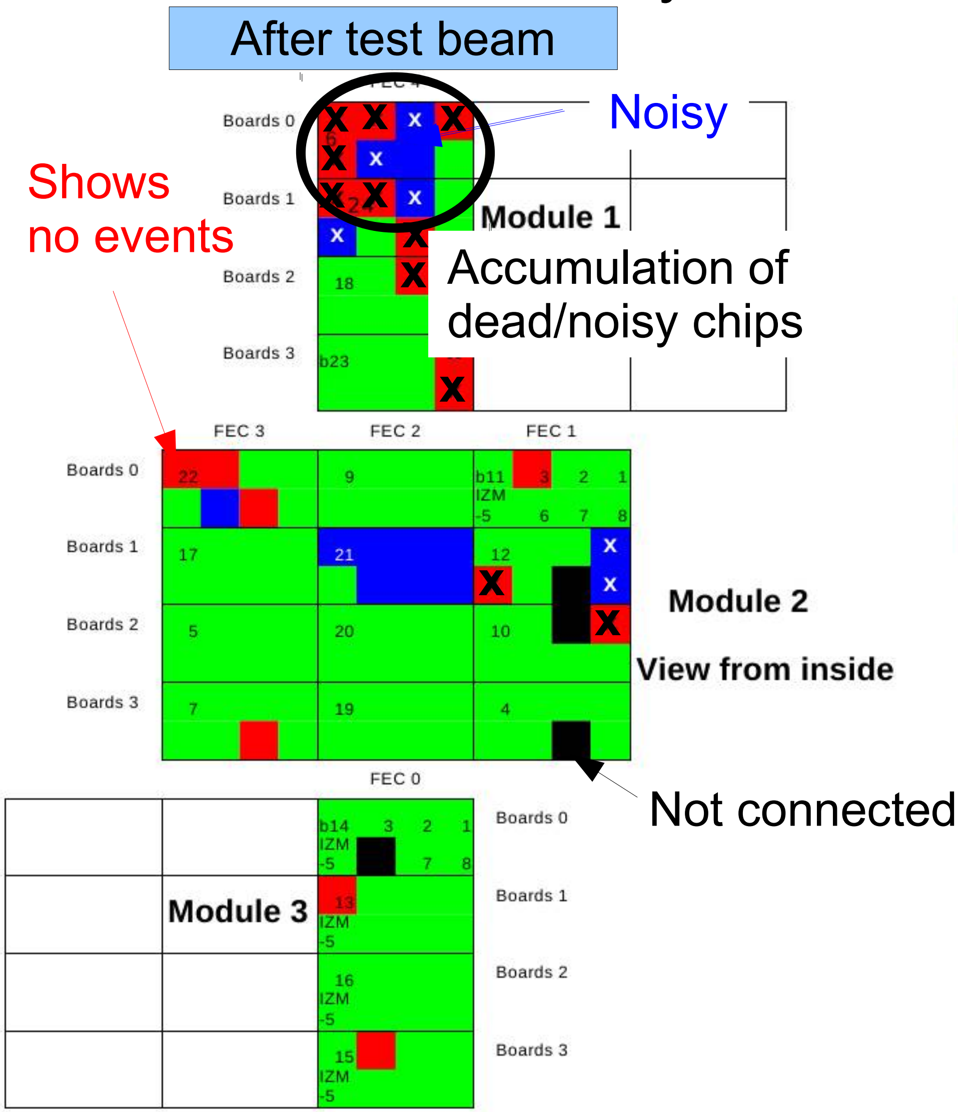
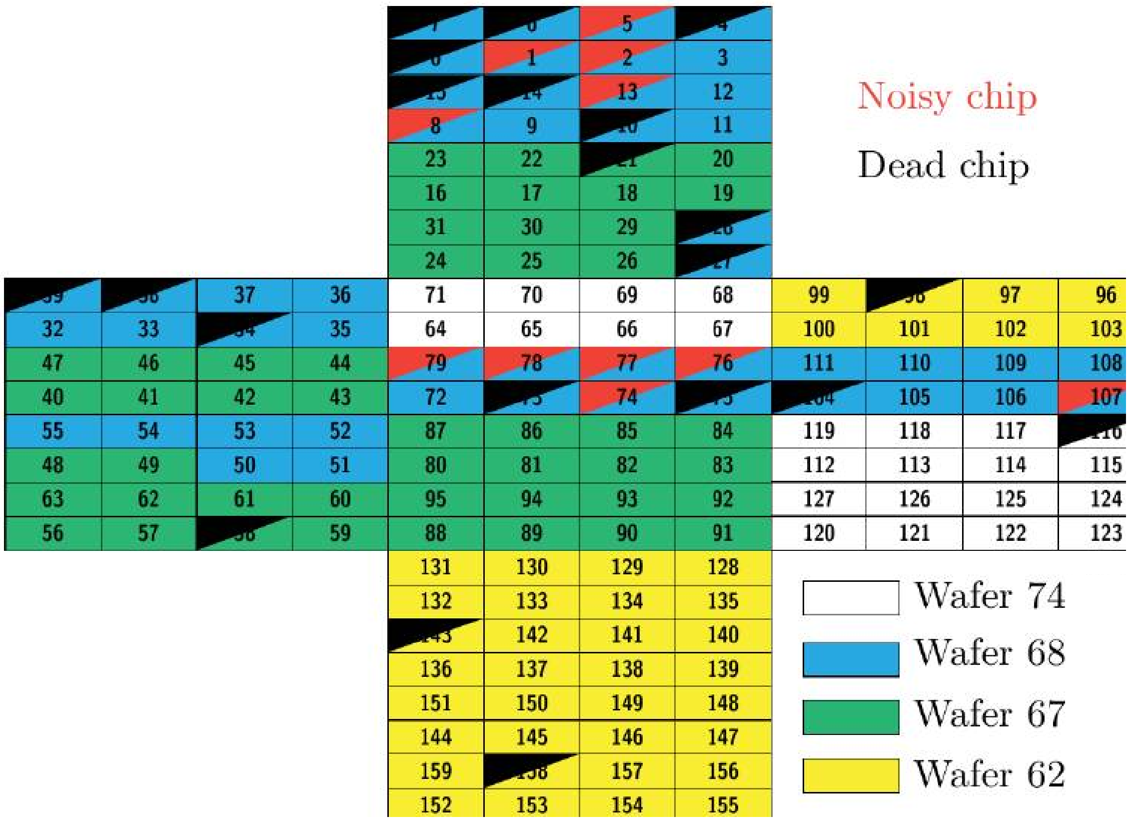


Correlation with wafer number



Taking into account chips which have to be replaced during production
W62: 12% bad, W67: 30% bad,
W68: 60% bad, W74: 35% bad

Summary

- MPGDs with pixelised readout can improve detector performance
- Pixel-TPC concept: Endplate consists out of many GridPixes
- R&D for a demonstrator module: successful test beams 2013 and 2015
- Test beam 2015: Demonstrator with 160 GridPixes on 3 modules
  - Results from analysis: excellent single point resolution (independent of track angle), excellent dE/dx resolution
  - Uncorrected field distortions degrade some results

→ Feasibility of Pixel-TPC has been proven!

The concept could improve the precision of the ILD TPC.

Outlook

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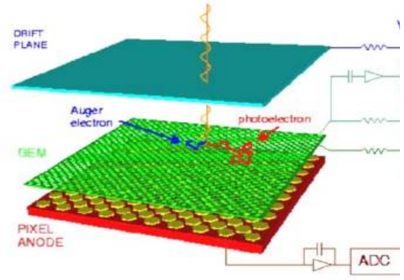
- Improve and extend data analysis
- Field distortions and alignment need further investigations
- New algorithm for track finding in a Pixel-TPC required

- Timepix3 offers new possibilities
- Further R&D especially for reliability of GridPixes needed

Backup slides

Timepix+GEM or Micromegas / GridPix History

- 2003: MicroPattern Gas Detectors with pixel read-out
  R. Bellanzini, G. Spandre, Nucl. Instrum. Methods Phys. Res., Sect. A 513 (2003) 231



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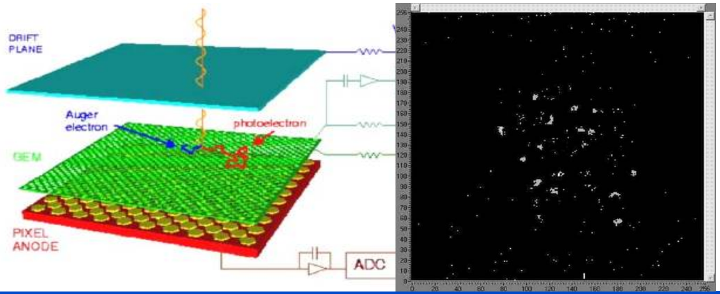

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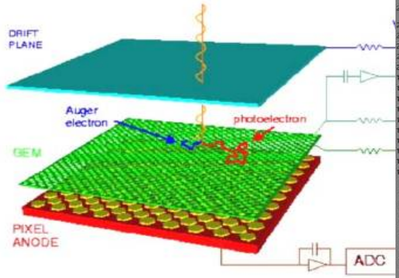

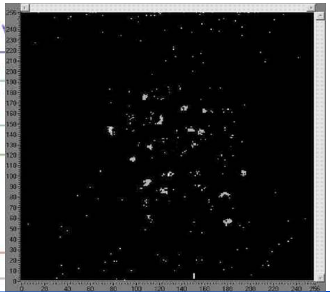

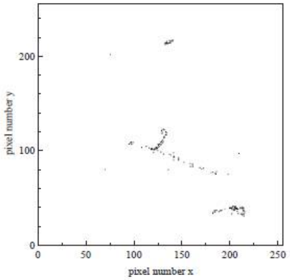

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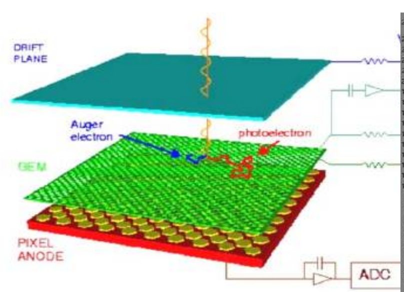

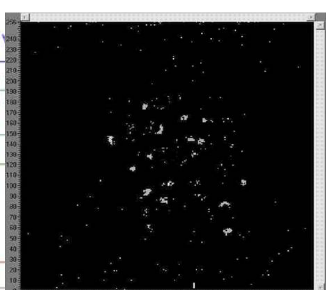

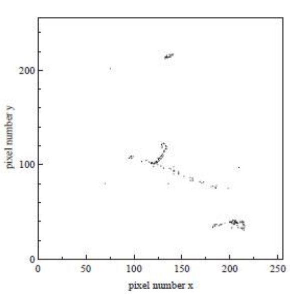

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- 2007: Resolution studies on 5 GeV electron tracks observed with triple-GEM and MediPix2/TimePix-readout
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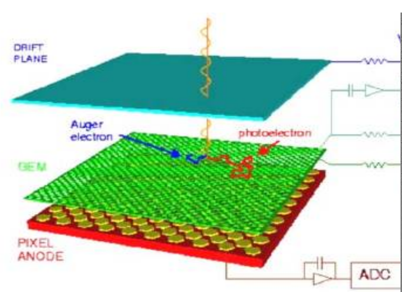

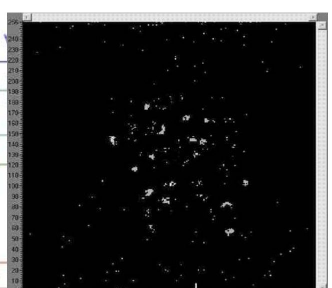

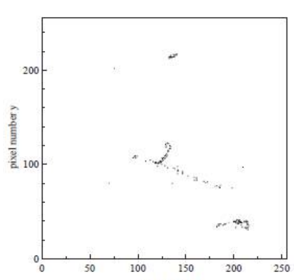

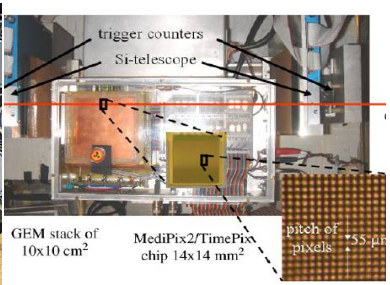

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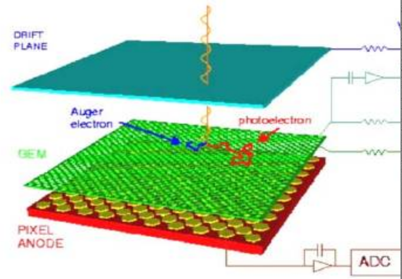
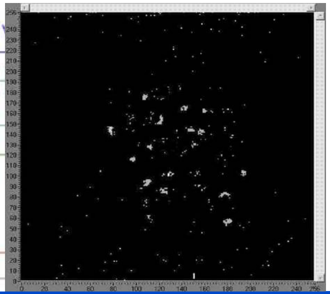
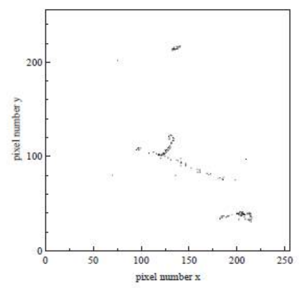
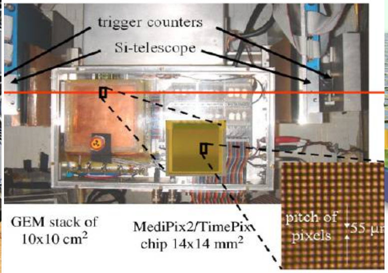
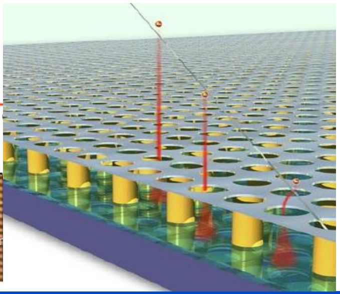
- **2009: Performance and prospects of GridPix and Gossip detectors**
  H. van der Graaf, F. Hartjes, A. Romaniouk, ATLAS note ATL-P-MN-0016

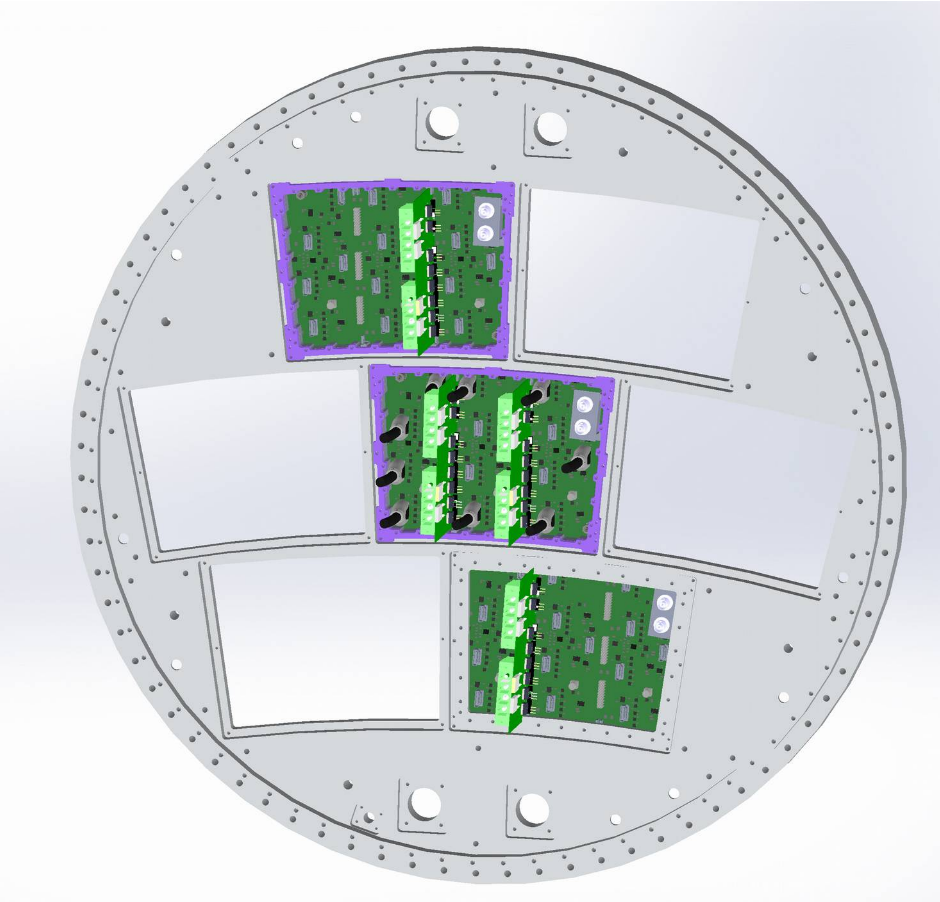


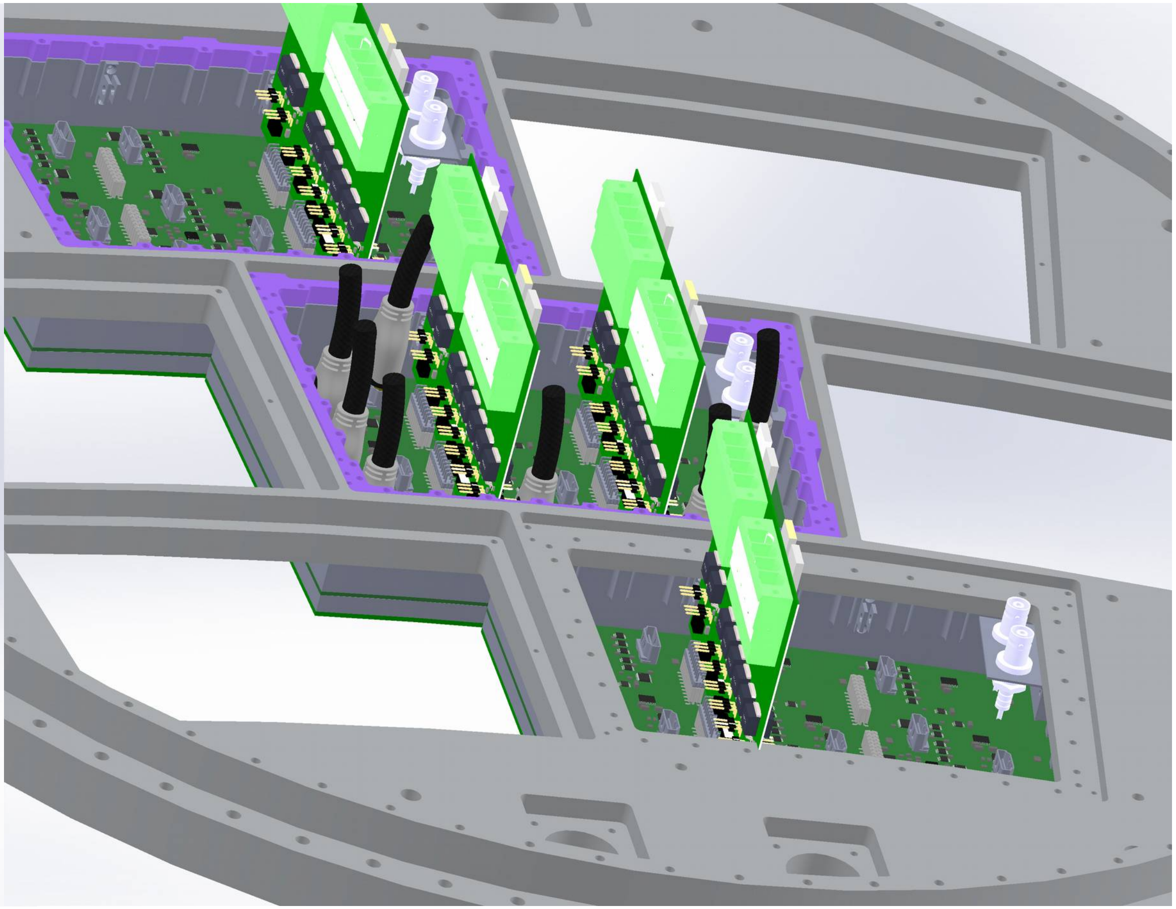



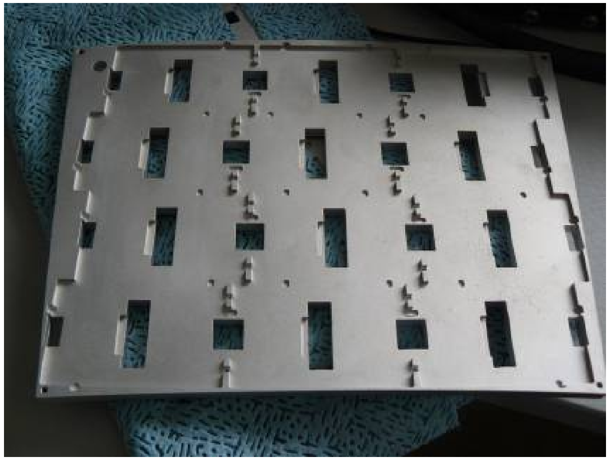


Endplate CAD

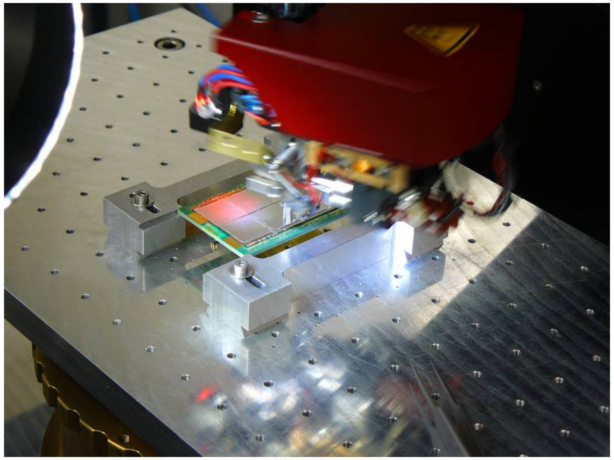




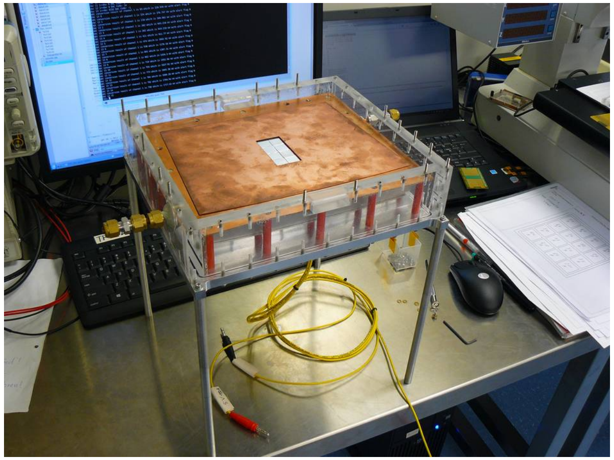
Module assembly



Carrier plate with cooling

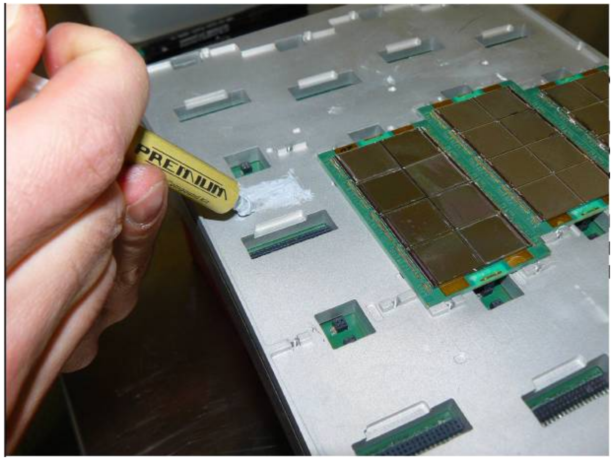


Wire bonding of an octoboard

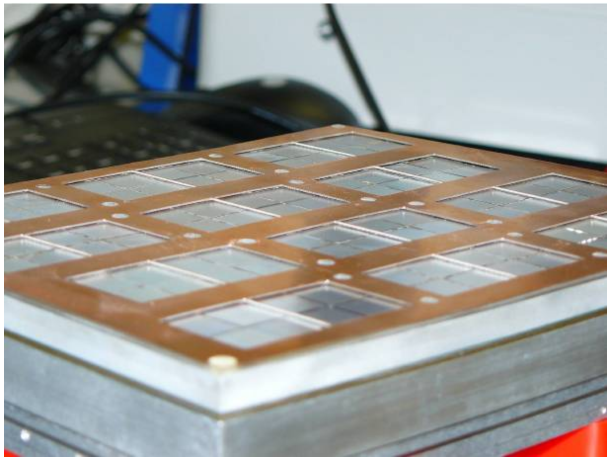


Single octoboard testing

Collection of octoboards



Placement of boards



Completed module

Powering

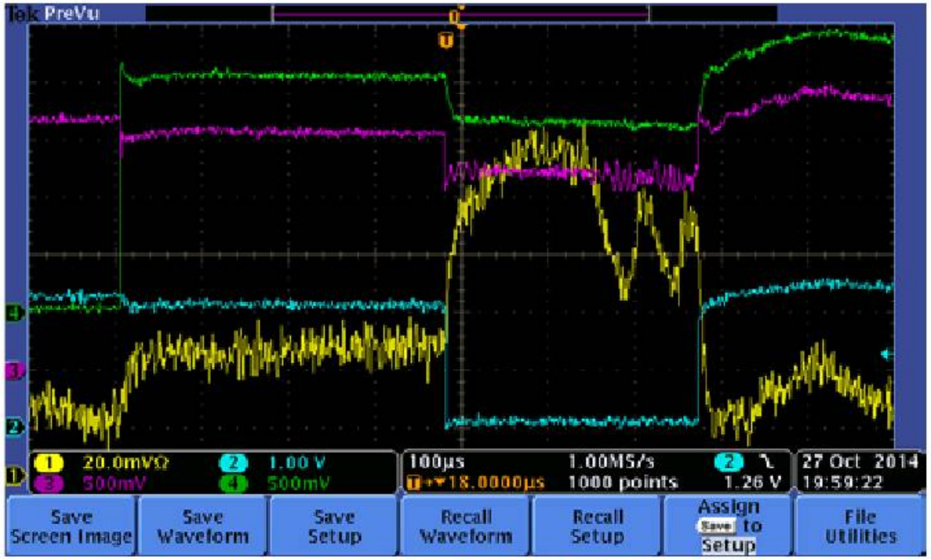
Timepix chip: power consumption not constant

Example: Octoboard

in counting mode (blue signal low)

→ supply voltage (magenta) breaks

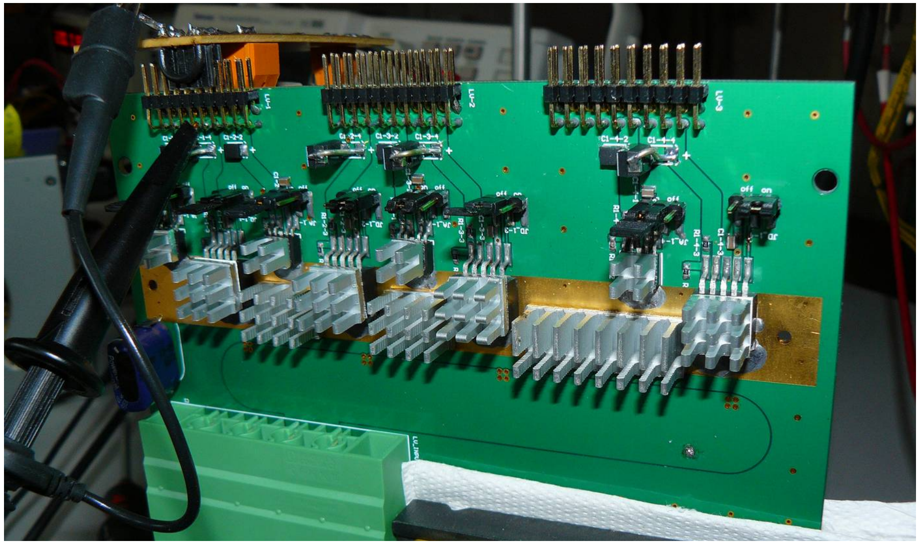
down, supply current (yellow) fluctuates



Solution: Low voltage power board

with LDOs, capacitors and supercaps

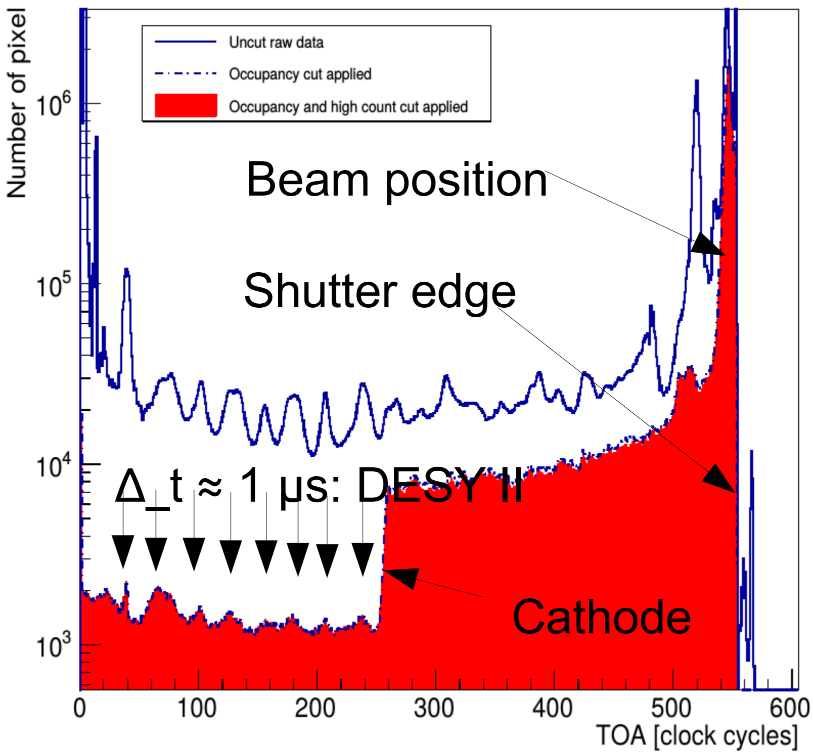
+ thick long cables

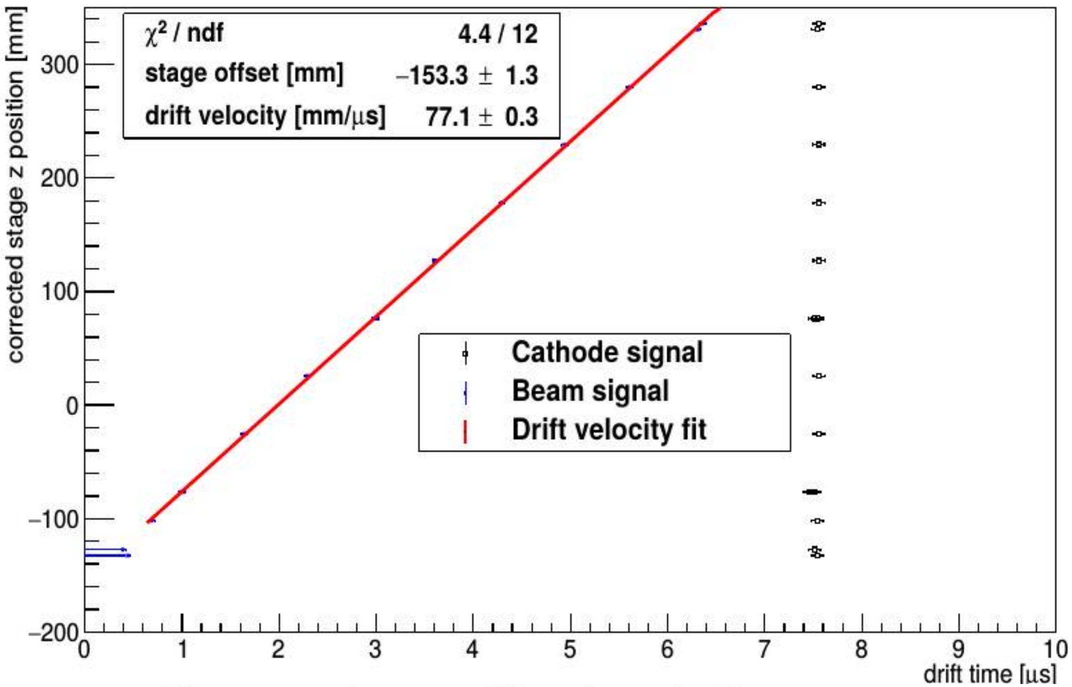


Drift velocity

1. Data cleaning (noisy chips, not properly functioning chips)

2. Drift time spectrum analysis → drift velocity

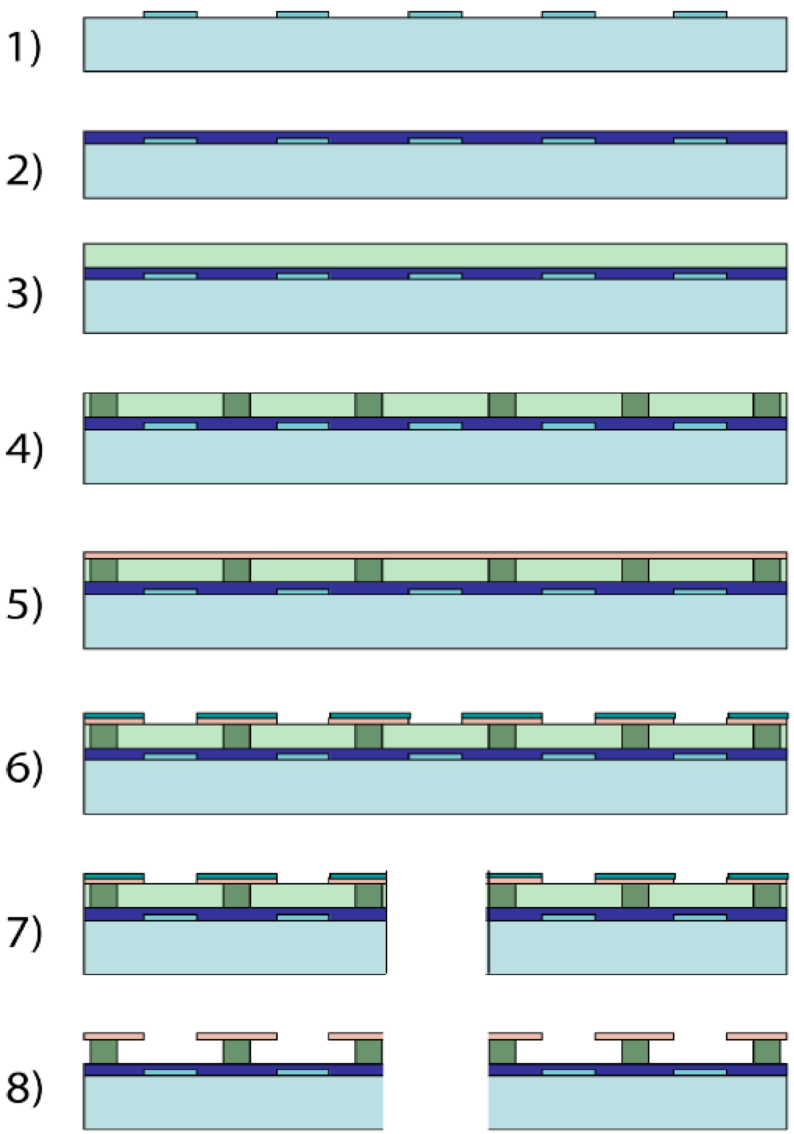




Comparison with simulation:

Condition	Simulation	Measurement
E=130 V/cm, B= 0T	5.64±0.01 cm/µs	5.50 ±0.08 cm/µs
E=230 V/cm, B= 0T	7.64±0.01 cm/µs	7.56 ±0.1 cm/µs
E=230 V/cm, B= 1T	7.64±0.01 cm/µs	7.55 ±0.09 cm/µs

InGrid production on wafer scale



Probing and cleaning of the wafer

Adding Si_x N_y protection layer

Application of the SU-8

UV-Exposure of the SU-8

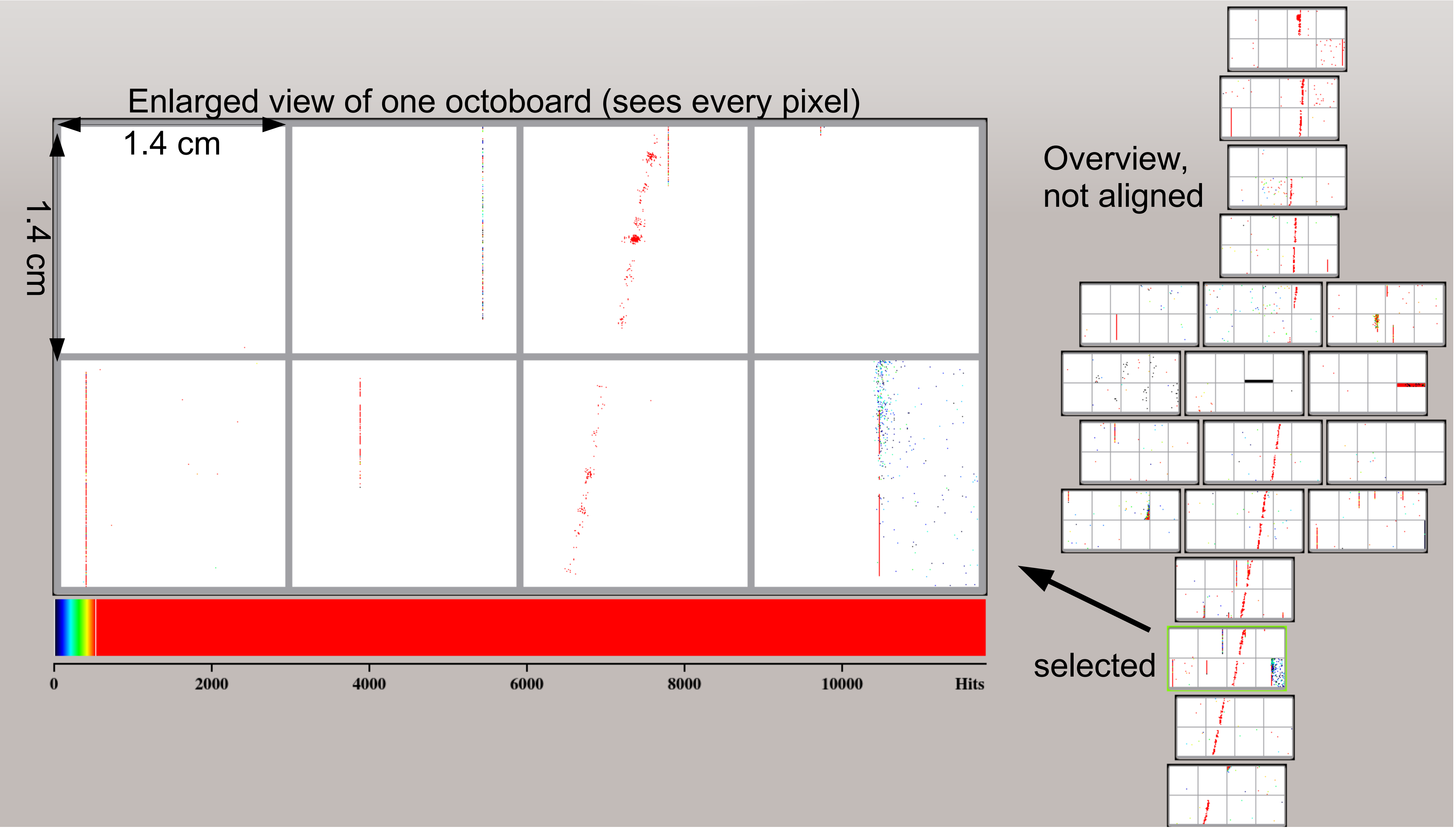
Application of the grid

Patterning of the grid

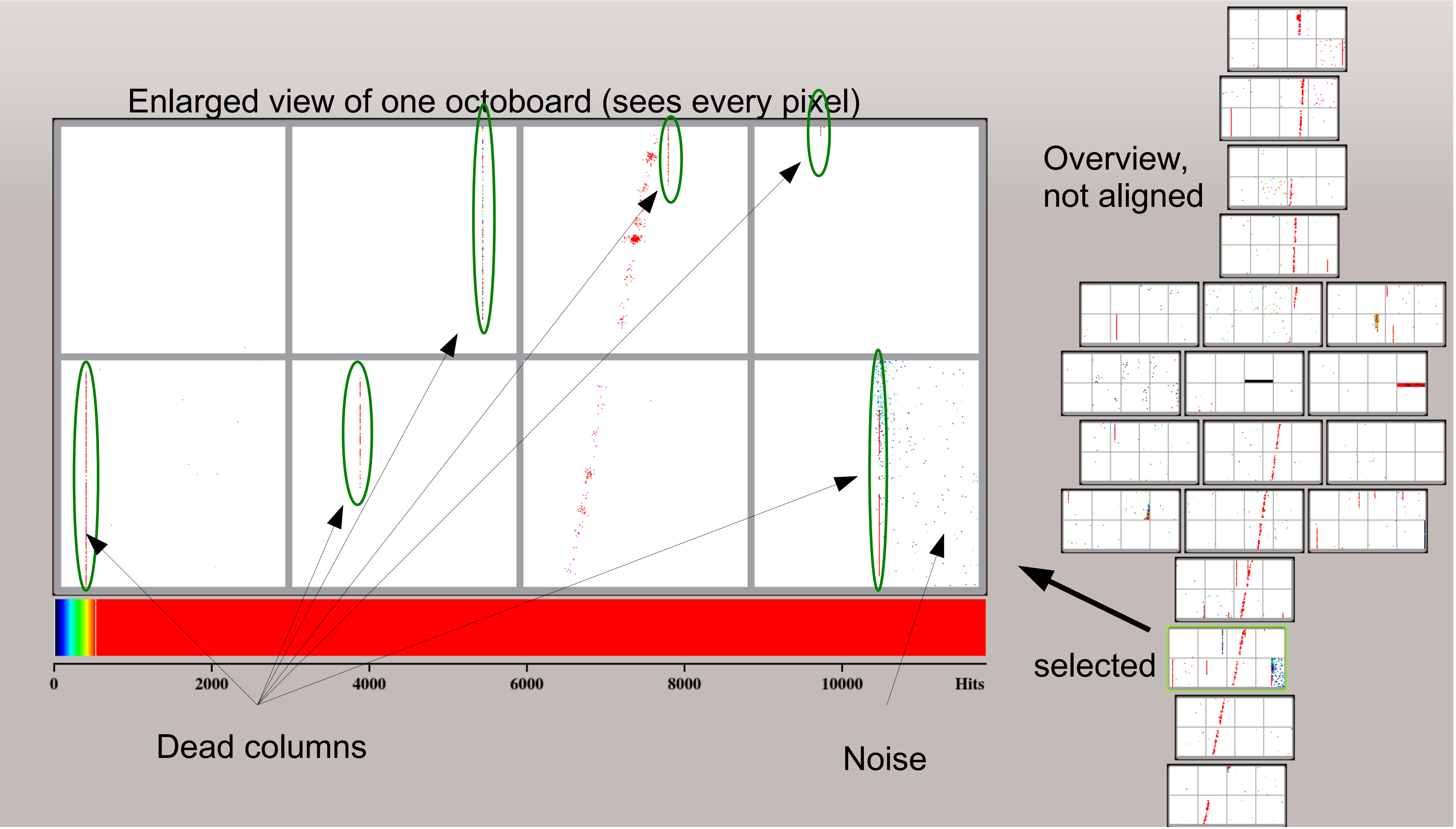
Dicing of the wafer

Development of the SU-8

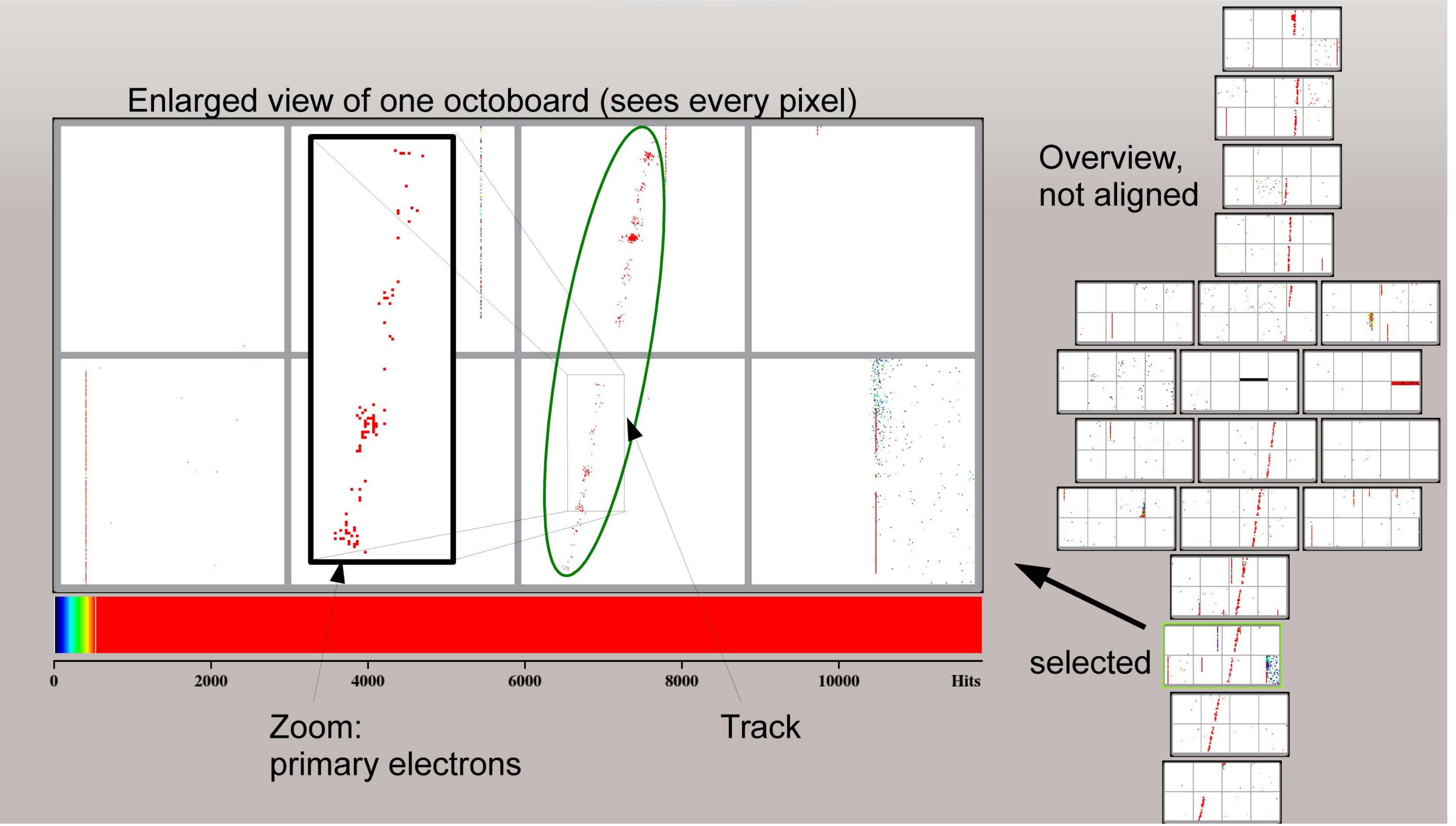
Event 1: Typical track



Event 1: with explanations

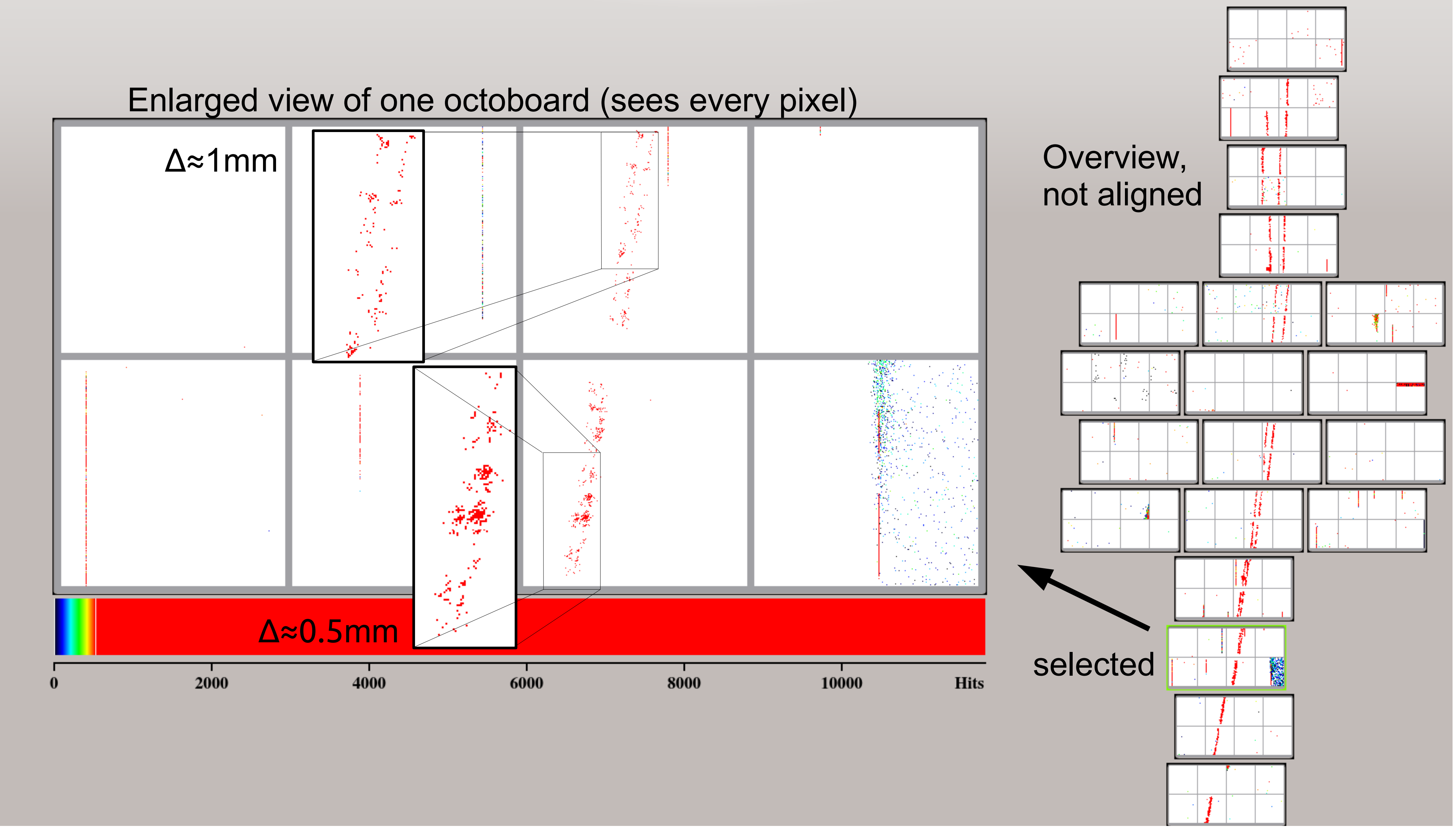


Event 1: Zoom



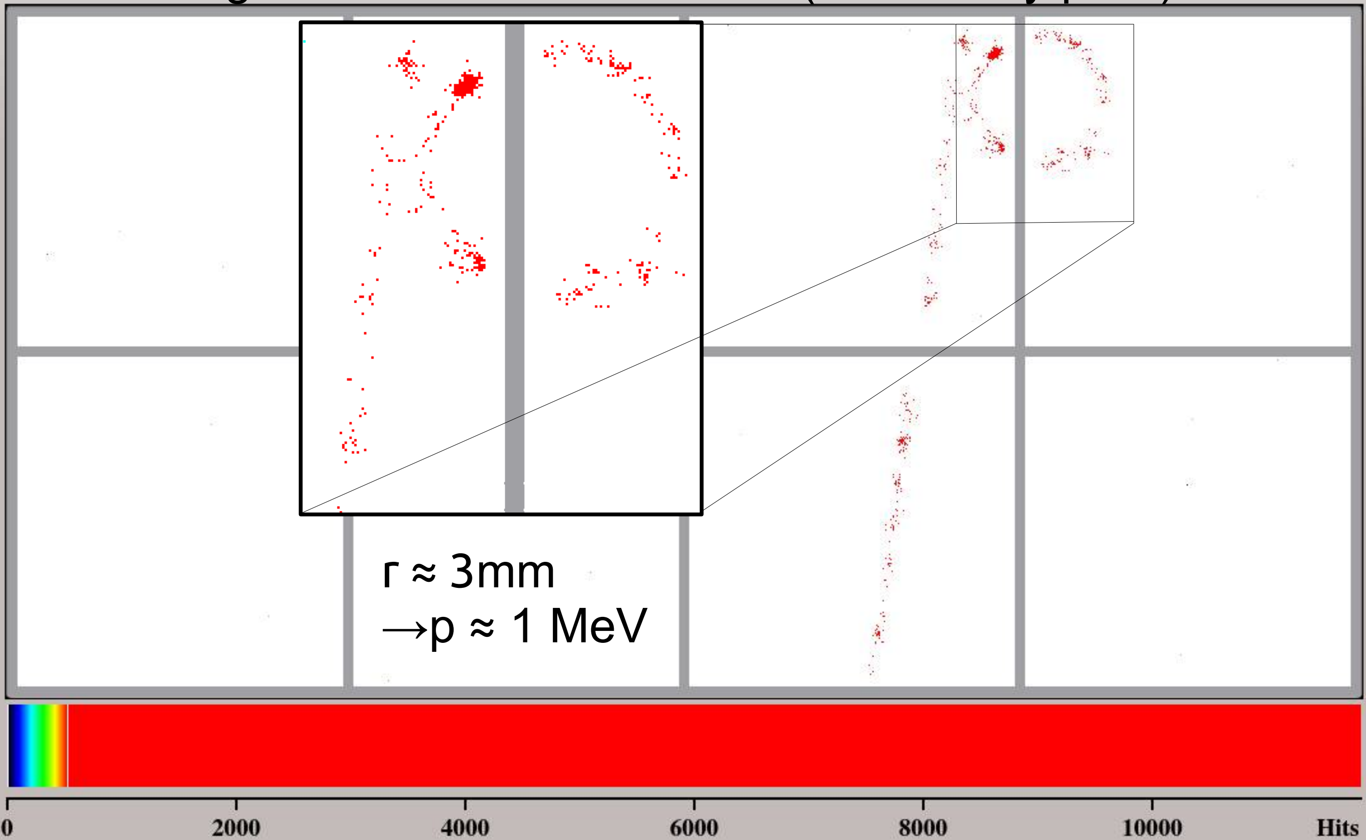
Enlarged view of one octoboard (sees every pixel)
0
2000
4000
6000
8000
10000
Hits
Zoom:
primary electrons
Track
Overview,
not aligned
selected

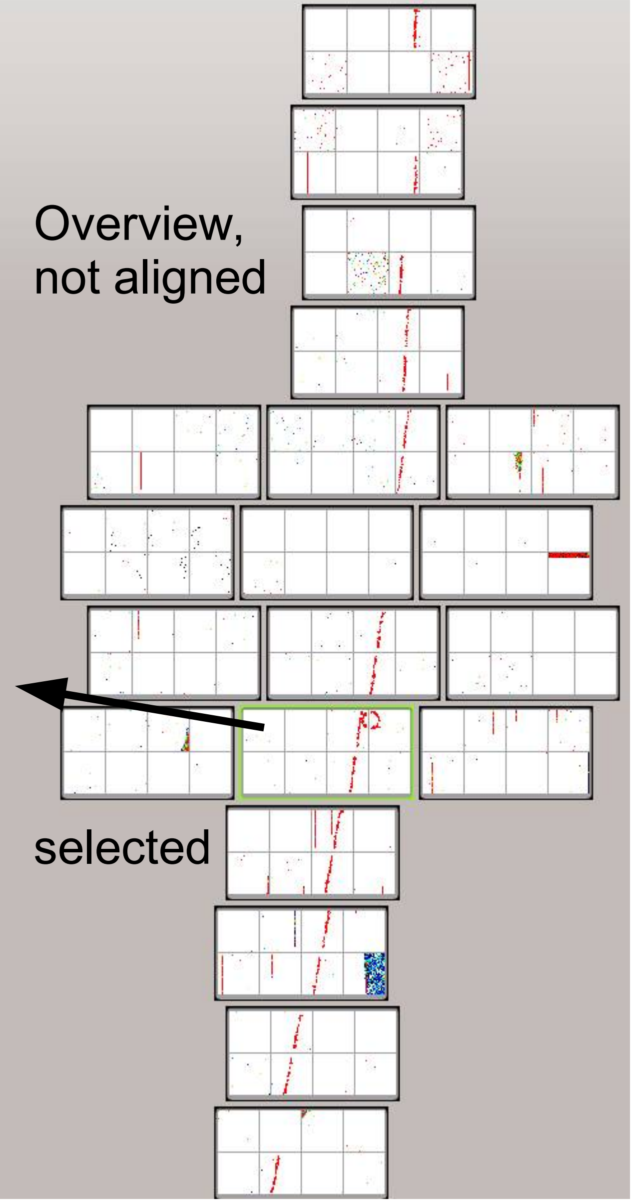
Event 2: Double Track



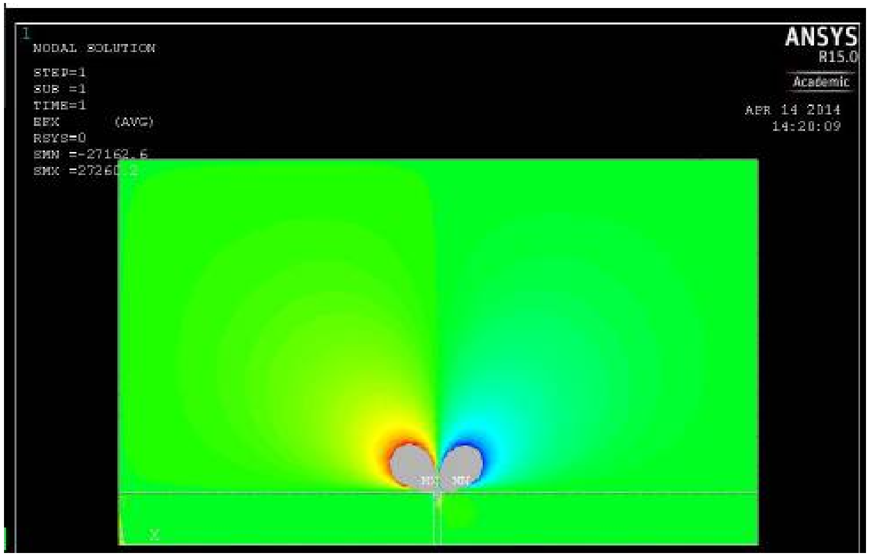
Event 3: Delta electron on track

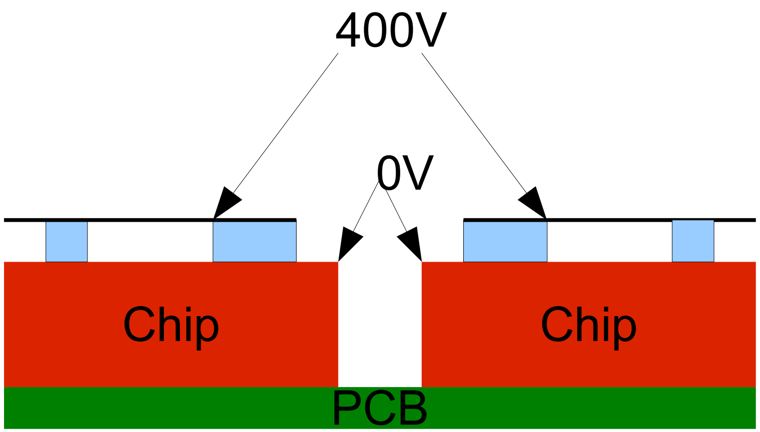
Enlarged view of one octoboard (sees every pixel)



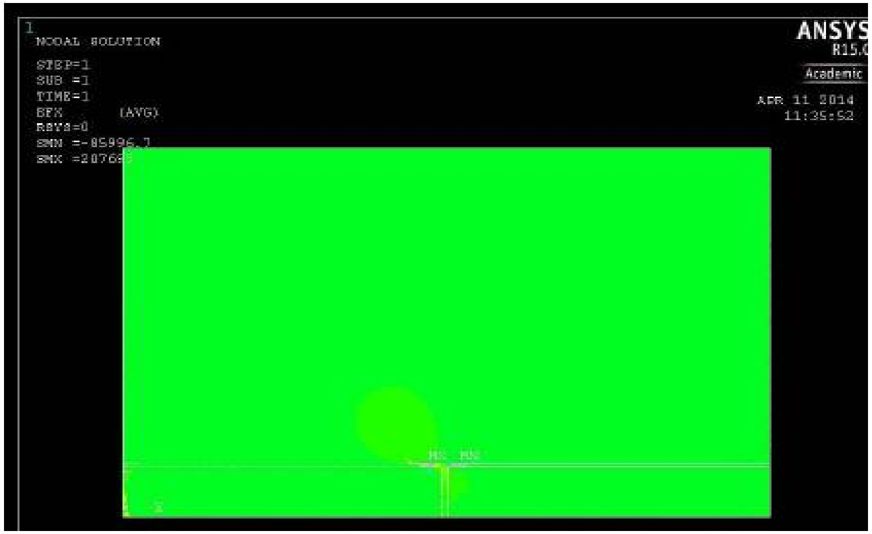


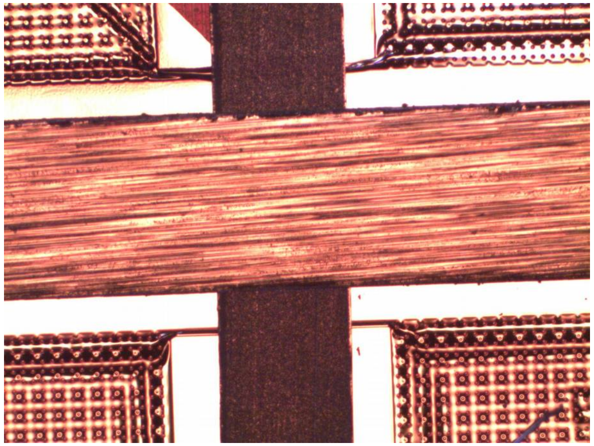
Field distortions



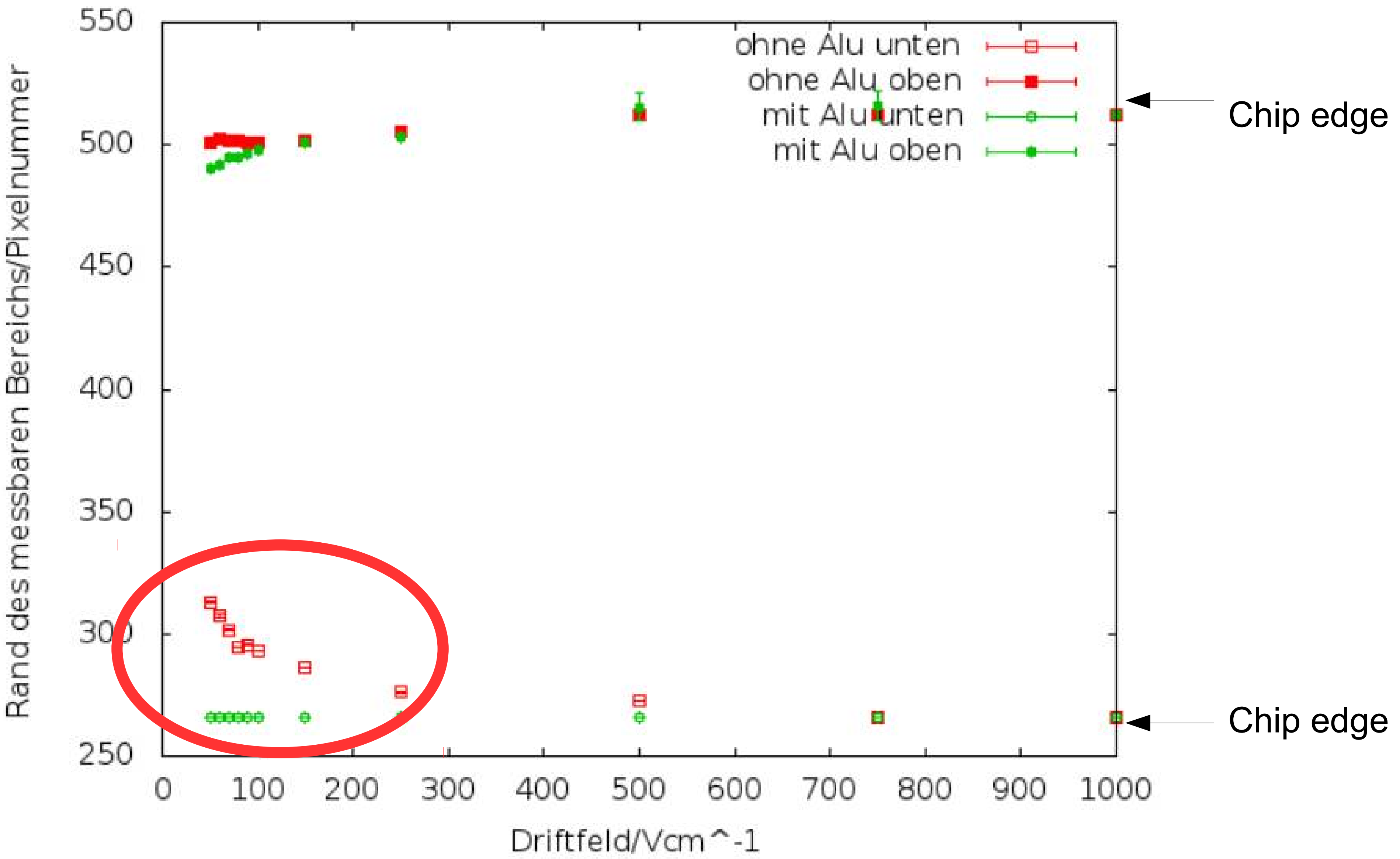


Simulations by Katrin Kohl

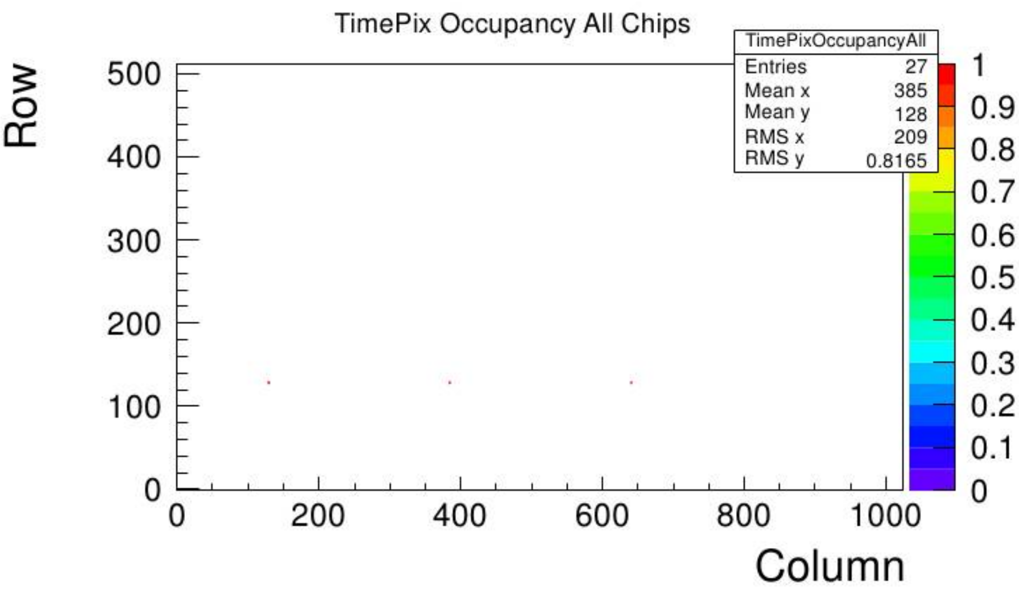


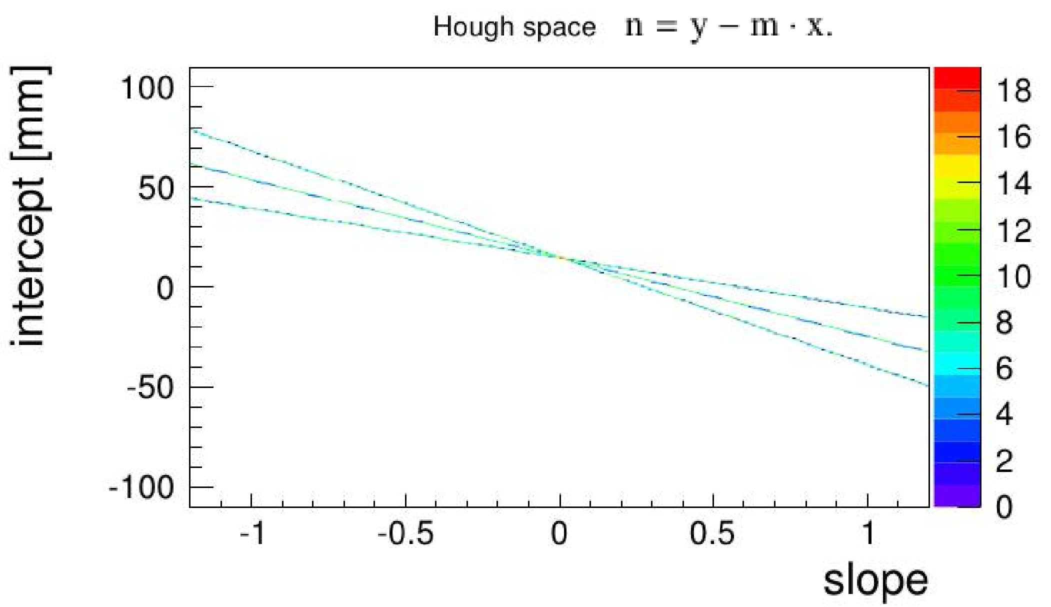


Field distortions and aluminium strips



Hough transformation

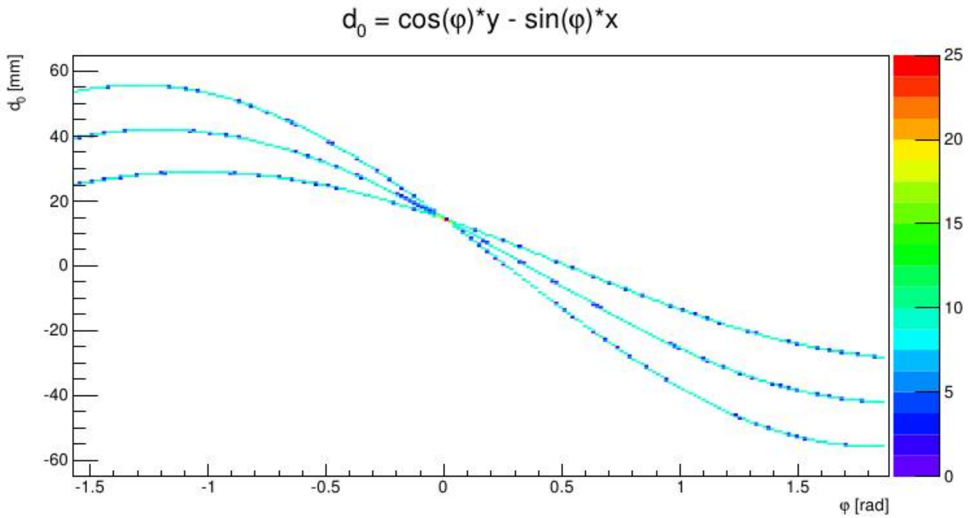




Line parametrisation

$$y_i = m \cdot x_i + n$$

$$y = x \cdot \tan(\varphi) + \frac{d_0}{\cos(\varphi)},$$



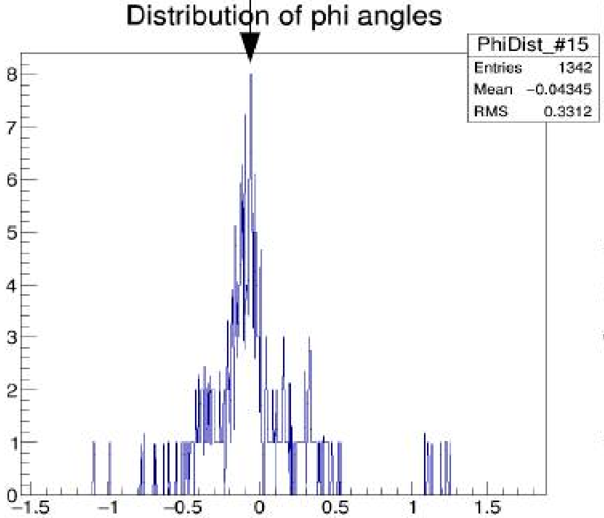
From Martin Rogowski, Master thesis

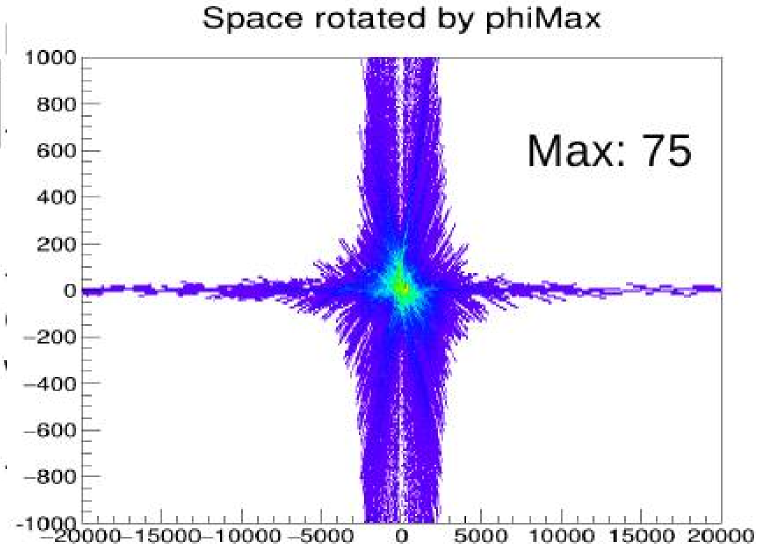
Circle Finder

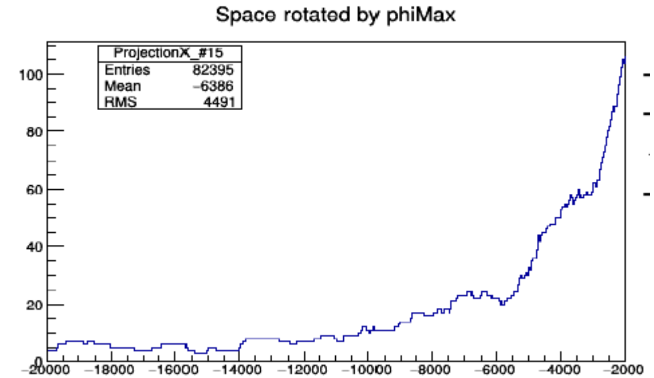
universitätbonn

Noise event

Take maximum

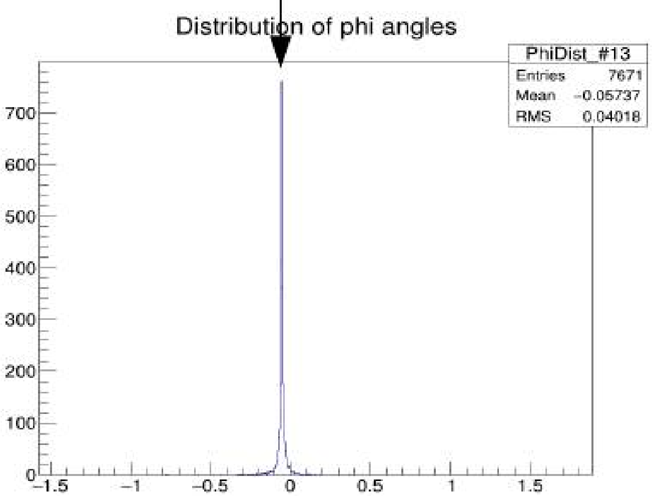


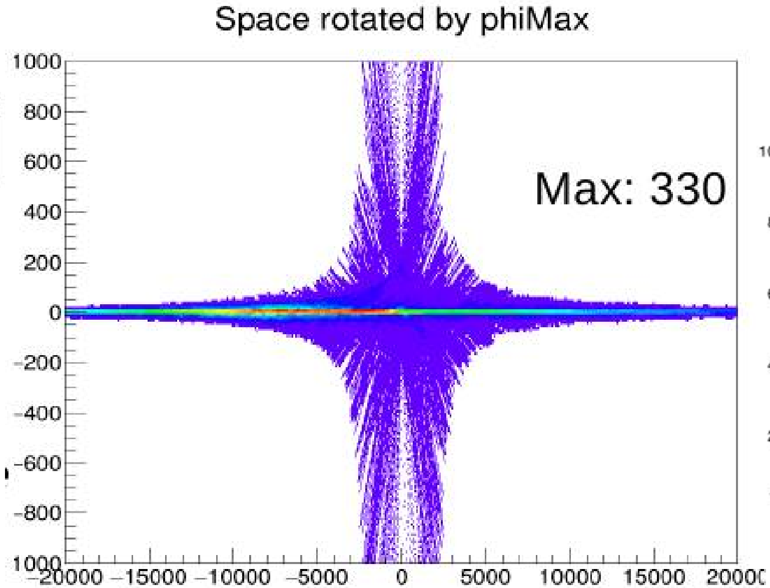


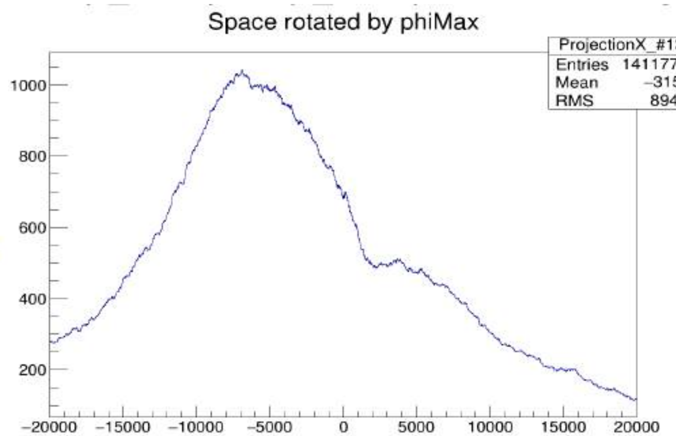


Track event

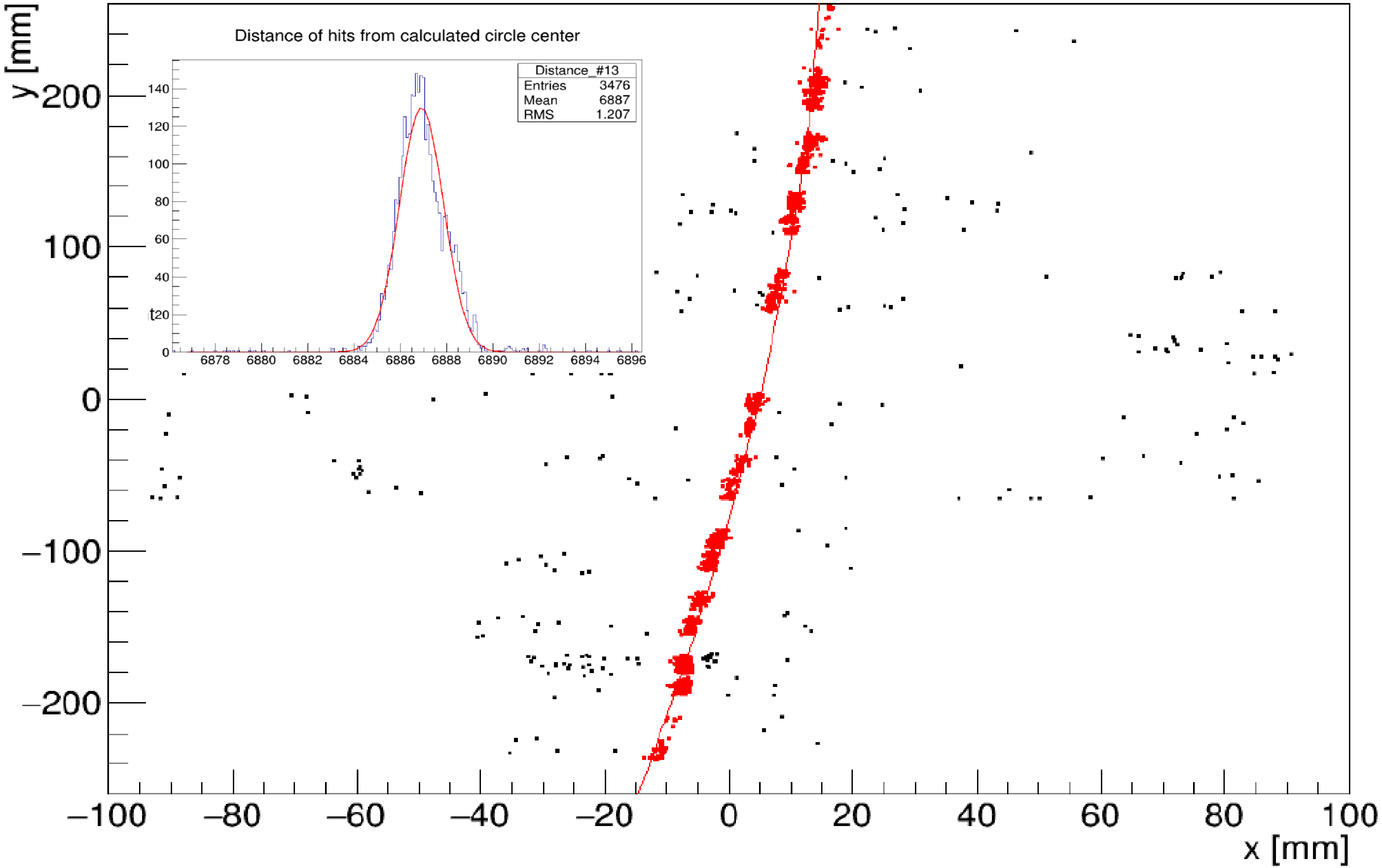
Take maximum





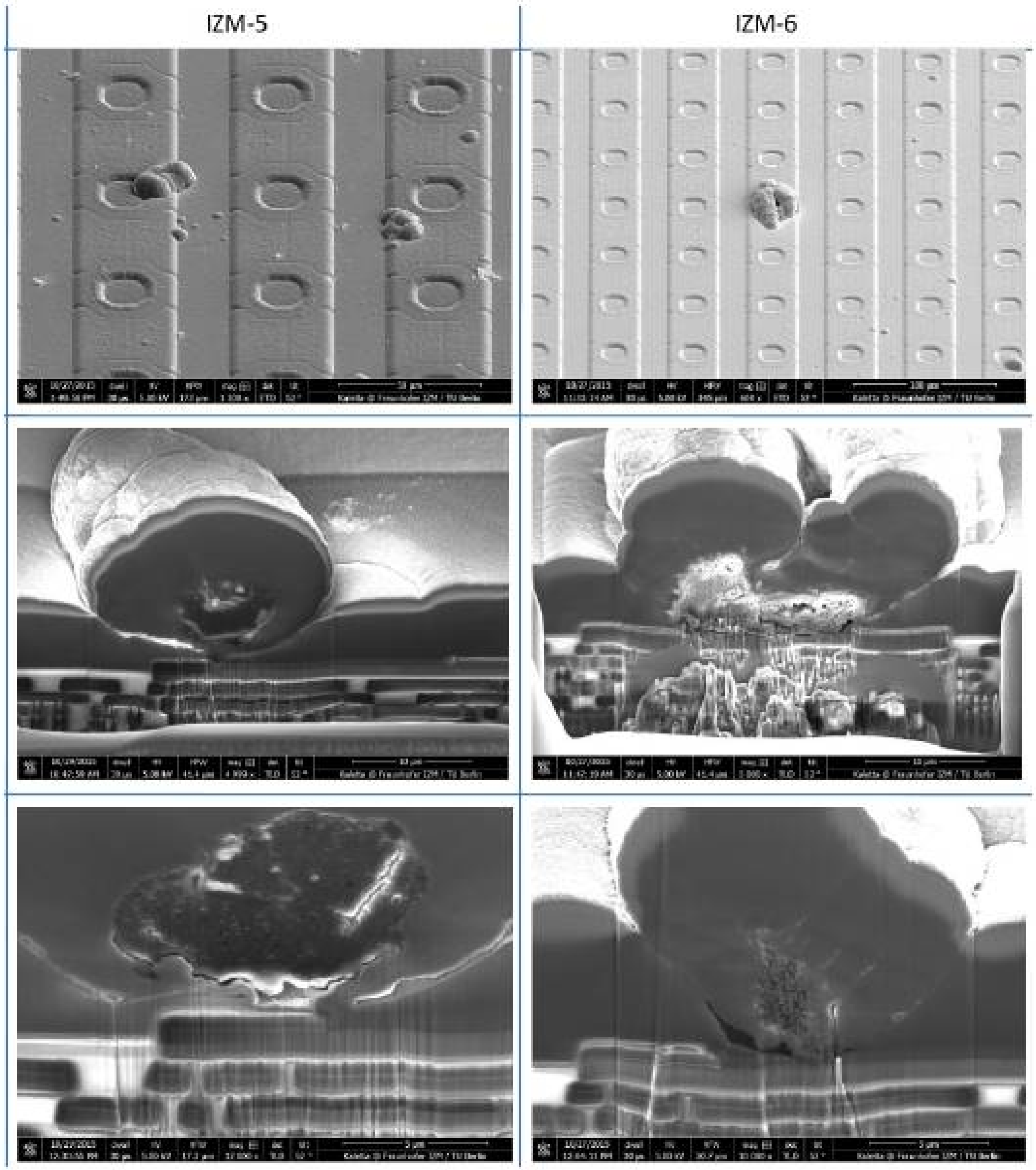


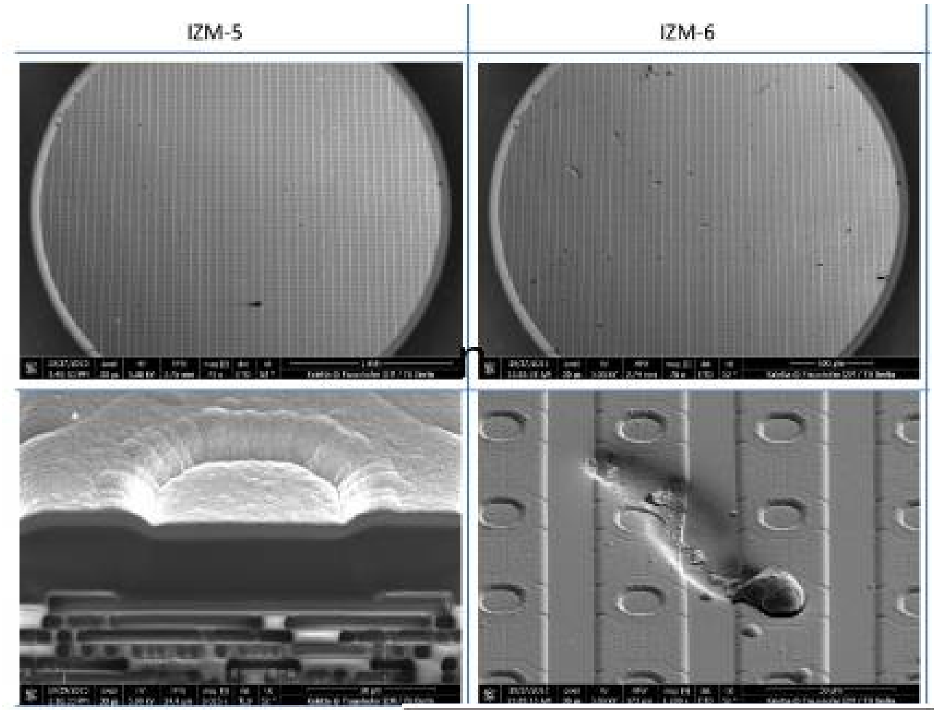
Circle Finder



Investigation on dead chips

- Protective layer Si_xN_y on top of Timepix ASIC
- SEM images show low quality of protection layer in IZM-6 prodution





IZM-7: new machine
For Si_xN_y deposition