Towards MPGDs with embedded pixel ASICs

Lucian Scharenberg *on behalf of the CERN EP-DT-DD GDD team*

8th International Conference on Micro-Pattern Gaseous Detectors, USTC
14 October 2024

Outline

Motivation:
Why high-granularity readout of MPGDs? Why Timepix4?

1. **Embedding into the amplification stage:**
   Simple PCB manufacturing techniques and intrinsic discharge protection.

2. **First steps, triple-GEM:**
   Before embedding, explore GEMPix with Timepix4. Testing of TSV-Timepix4.

3. **Large-area ASICs:**
   Long-term perspective and ideas for ambiguity-free readout

Summary

Motivation

High-granularity readout of gaseous detectors

Possibilities offered by high-granularity readout of gaseous detectors:

➔ Low-material budget tracking with high spatial accuracy

➔ Event-selection based on geometrical signature

➔ Sensitivity to low-energetic photon interactions (E_{gamma} < 2 keV)

Example applications:

➔ X-ray polarimetry (e.g. IXPE @ NASA)

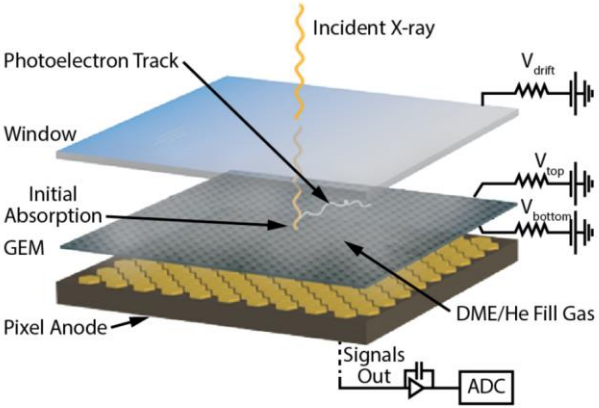
➔ Nuclear recoil events (e.g. MIGDAL, CYGNO)

➔ Material science (e.g. MIXE @ PSI)

➔ Axion helioscopes (e.g. IAXO)

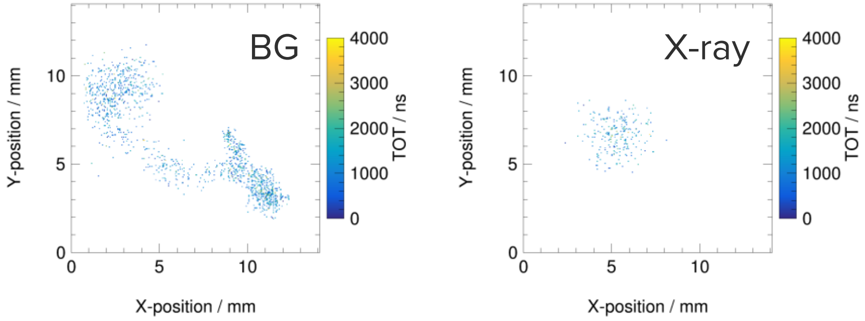
➔ Micro dosimetry (e.g. GEMPix)

Illustration for X-ray polarimetry @ IXPE



https://ixpe.msfc.nasa.gov/for_scientists/papers/2017spie_0829_sgro.pdf

Geometry selection with GridPix data



Hybrid pixel ASICs

The Timepix4

Most commonly used ASIC for this purpose: **Timepix family**

➔ Use **bump-bond pads** for semiconductor sensor **as charge collection pads**

Timepix4: latest version of the Timepix

➔ 2.5 x 3.0 ≈ **7 cm^2** active area with **448 x 512 pixels** (55 µm square pitch)

➔ **700 electrons energy resolution**

➔ Up to **60 ps front-end time resolution**

➔ Up to **3 MHz/mm^2 hit rate (data-driven)** and up to 5 GHz/mm^2 (frame-based)

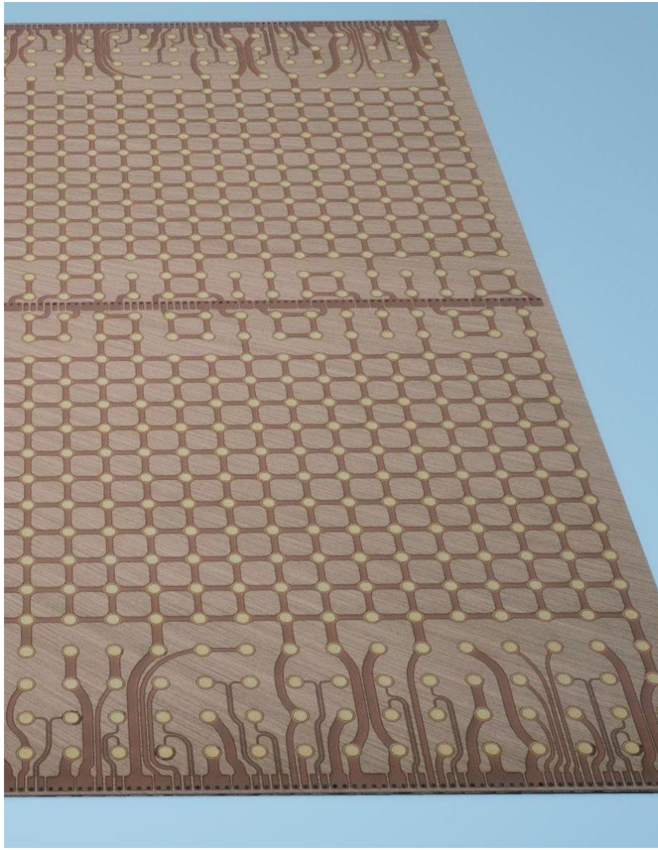
Most interesting feature for us: 4-side tileable

➔ Connect from the back-side, using **Through Silicon Vias (TSVs)** with Redistribution Layer (RDL)

➔ No dead area, **no wire bonds!** Required for embedding process

Backside of a TSV-Timepix4

Courtesy of Jerome Alozy



Part 1: embedding concept and status

Embedding approach

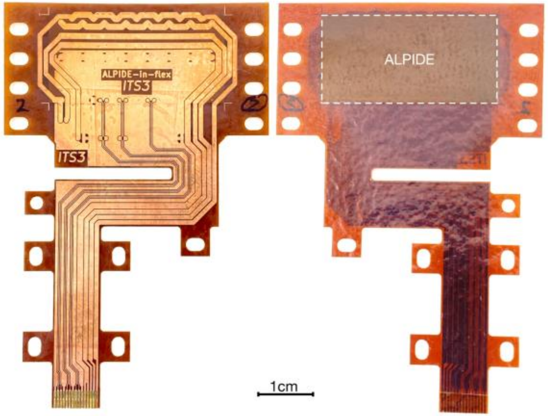
New research line with CERN EP R&D Work Package 2

Embedding of front-end ASICs in flexible PCB, i.e. micro-pattern amplification structures

➔ Possible with **Micro-Resistive Well (µRWELL)** structure, **using standard PCB technologies**

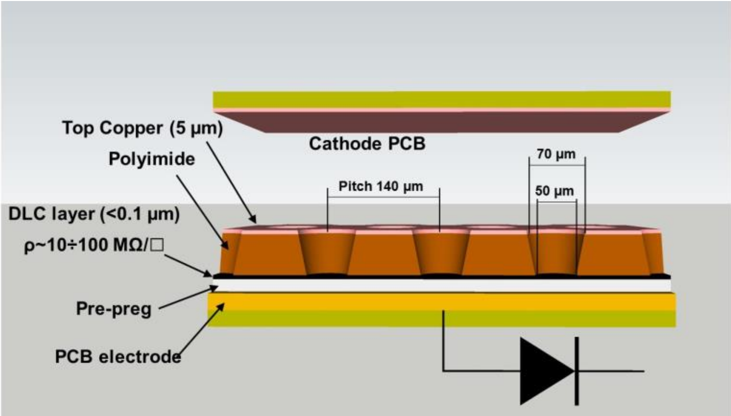
➔ Conceptually inspired by **“MAPS foil”** (Magnus Mager and Rui de Oliveira): MPGD 2022

MAPS foil



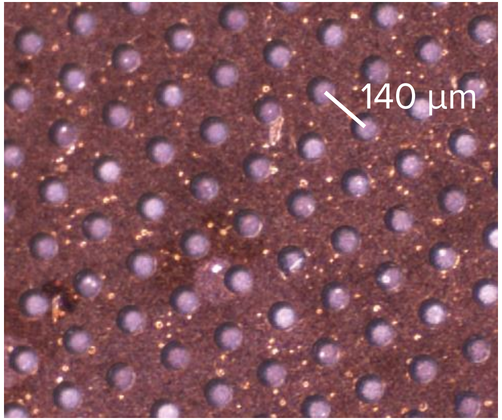
https://doi.org/10.1016/j.nima.2022.167673

µRWELL concept



https://doi.org/10.1088/1748-0221/14/05/P05014

µRWELL microscope



http://doi.org/10.1088/1748-0221/10/02/P02008

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Not drawn to scale!

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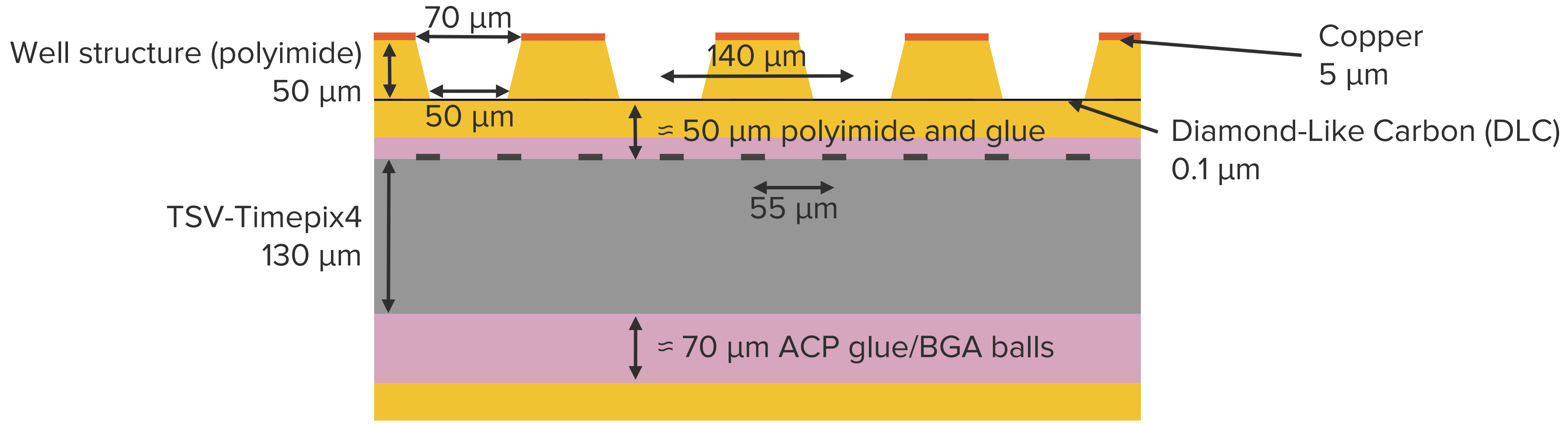
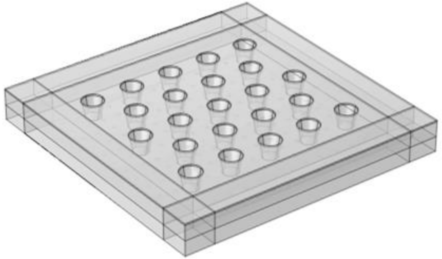
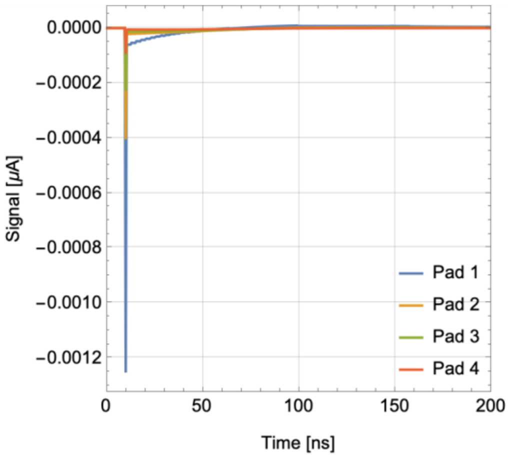


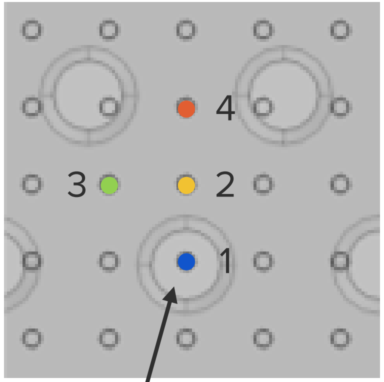
Signal induction simulation



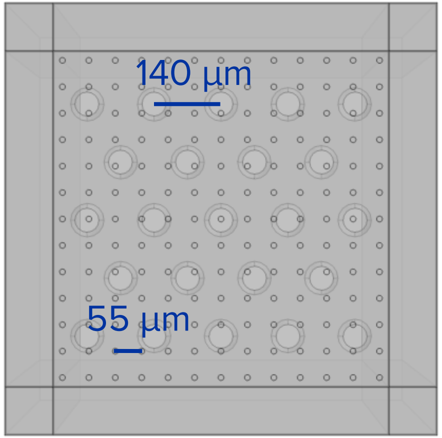
How is the charge measurement affected?
➔ Distance (up to 50 µm) between DLC and charge collection pads
➔ Different geometry between Timepix4 pixels and µRWELL holes

Simulation of signal induction using **COMSOL** and **Garfield++** (Djunes Janssens)





Avalanche in single hole



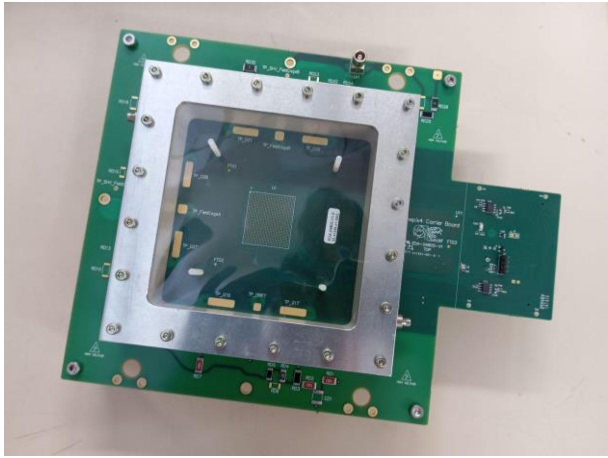
Next step: include front-end response, i.e. Timepix4 transfer function

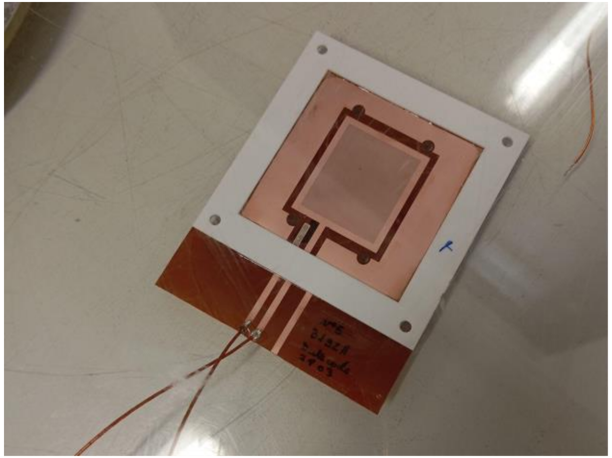
Next steps and production status

Designed and produced custom detector PCB (William Billereau)
➔ Based on Nikhef carrier
➔ Support typical MPGD R&D detector housing

Allows **µRWELL test without embedding** and various GEM configurations
➔ Electrostatic coupling between µRWELL foil and TSV-Timepix4
➔ After low yield in first production, **new production ongoing**

Received electrically broken TSV-Timepix4v0
➔ At CERN MPT workshop for **mechanical tests of embedding**





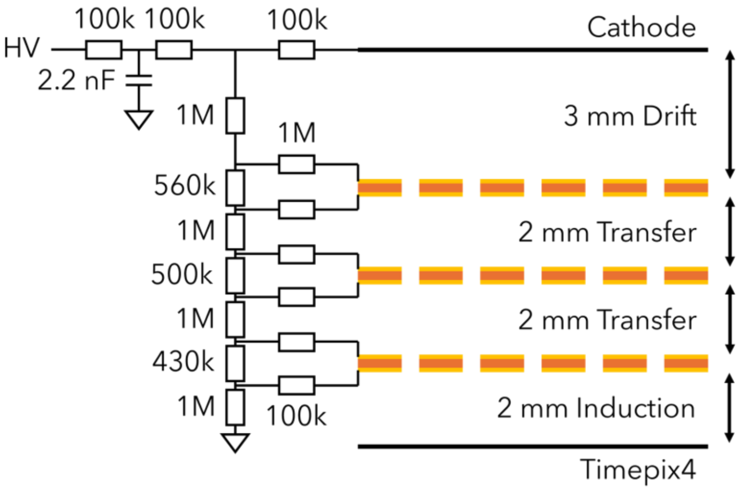
Part 2: performance evaluation with GEM

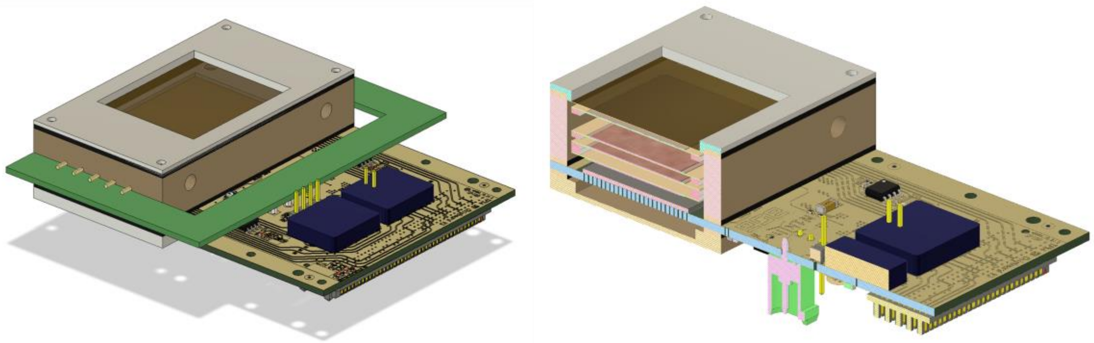
Well-known technology (GEMPix) to understand gaseous detector properties and software optimisation

Triple-GEM detector for TSV-Timepix4v1

Detector design

Small gas volume with **3 mm drift/interaction region**, filled with **Ar/CO_2 (70/30)**
➔ **Triple-GEM** well established with Timepix (GEMPix)
➔ **Reach sufficient gain while maintaining low discharge probability** (bare, unprotected Timepix)



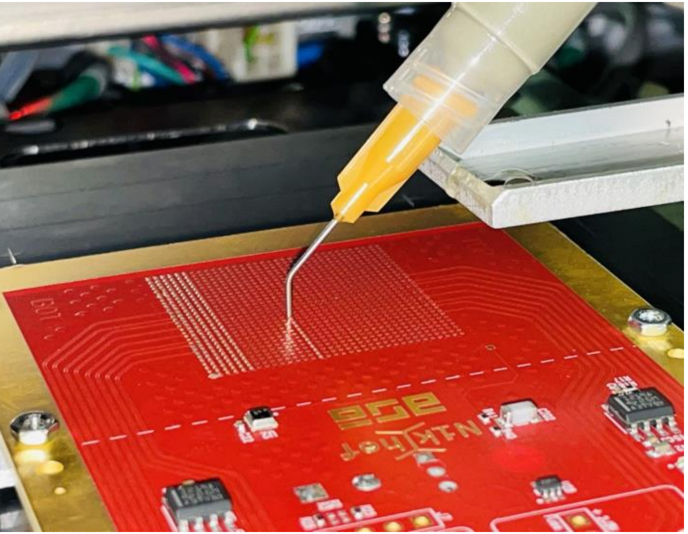


Fit on **default carrier board** of reference readout system:
SPIDR4 from Nikhef

Triple-GEM detector for TSV-Timepix4v1

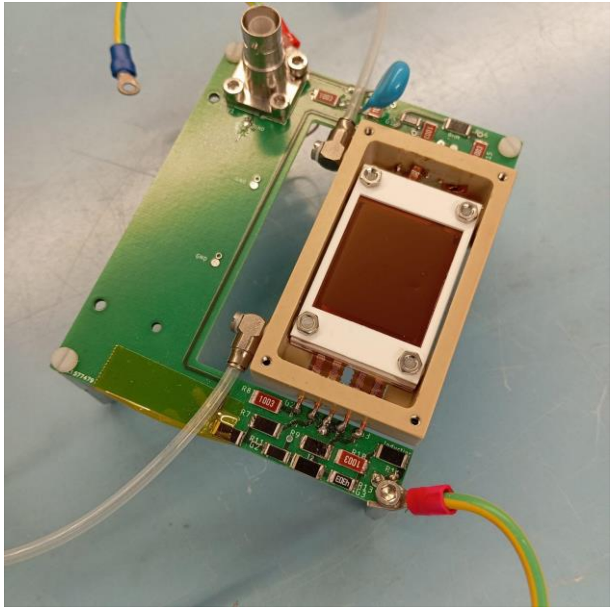
Assembly of TSV chips

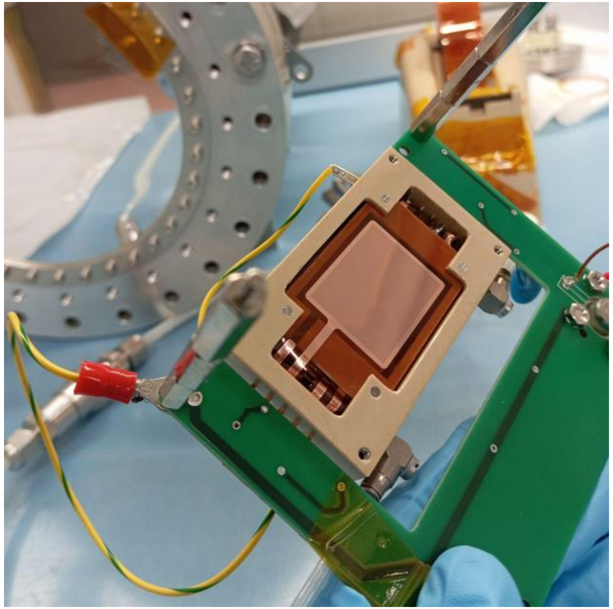
Chip assembly through **ACP** (Anisotropic Conductive Paste) on Nikhef carrier at University of Geneva (Mateus Vicente):

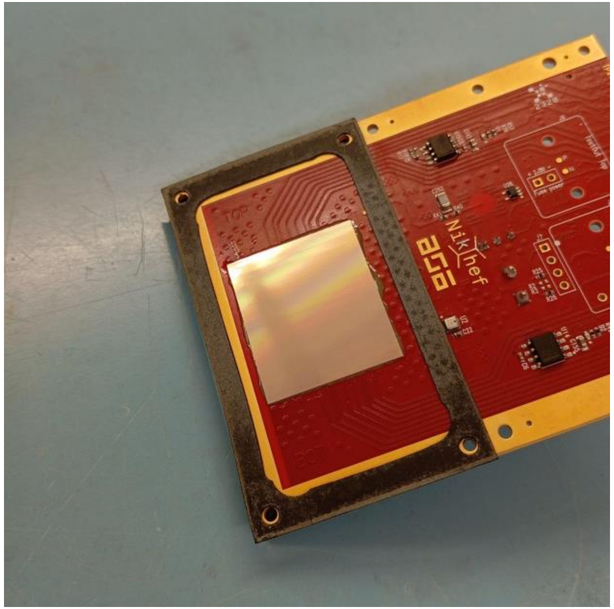


Triple-GEM detector for TSV-Timepix4v1

Detector assembly (GEMPix4)



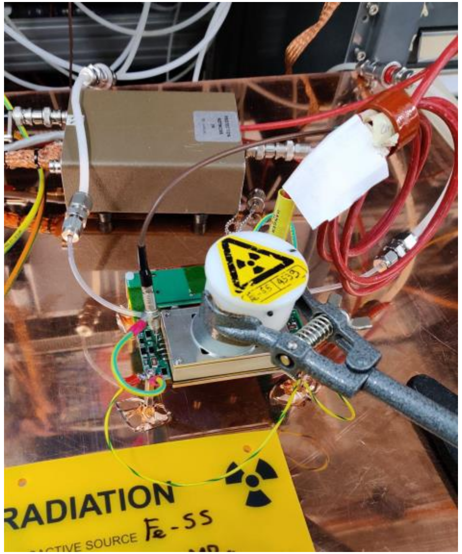


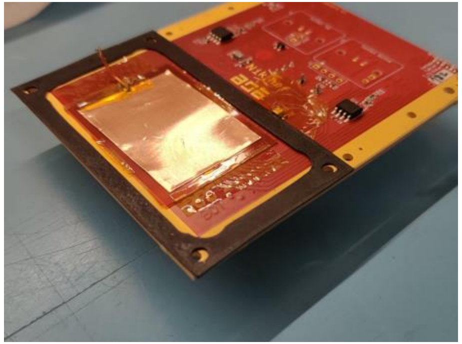


Detector with 2.5 x 3.0 cm^2 active area surprisingly complicated in handling and operation.

Triple-GEM detector for TSV-Timepix4v1

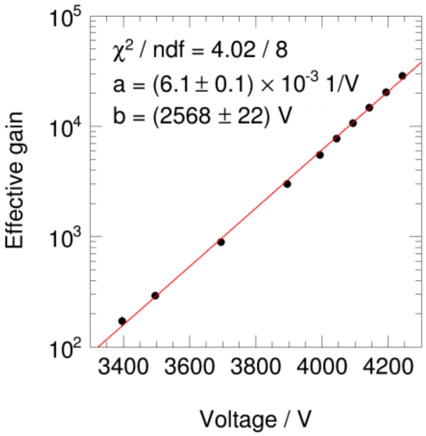
Single-channel characterisation



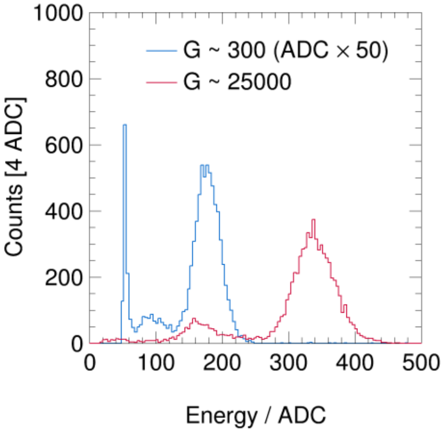


Single-channel copper electrode, read out with NIM electronics (pre-amp, shaper, MCA + picoammeter for anode current)

Gain curve



^{55}Fe spectra at different gains



→ **Gains > 25k** without discharges

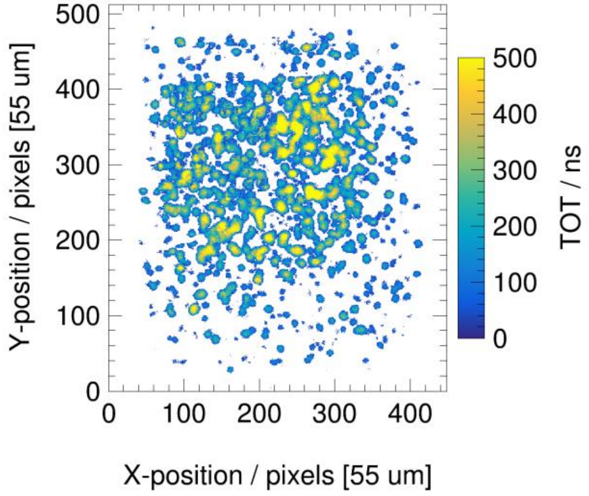
→ **Good energy resolution at low gains**

First results

Individual interactions

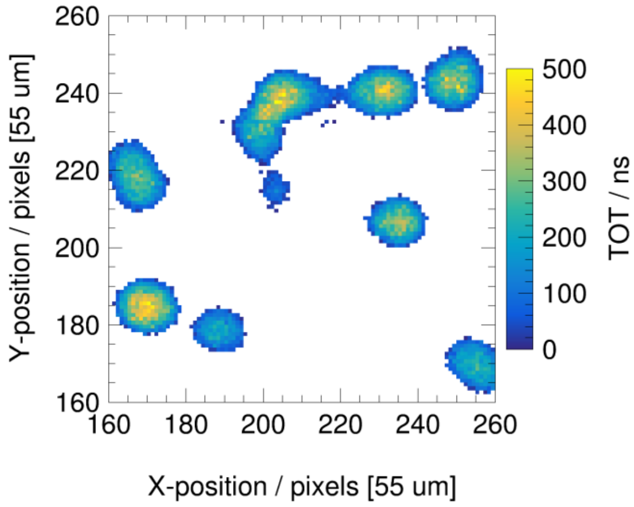
Measurements with ^{90}Sr at G ≈ 5000

TSV v1: 100 ms
3 mm Ar/CO_2 (70/30)



3 mm drift is too thin for full absorption

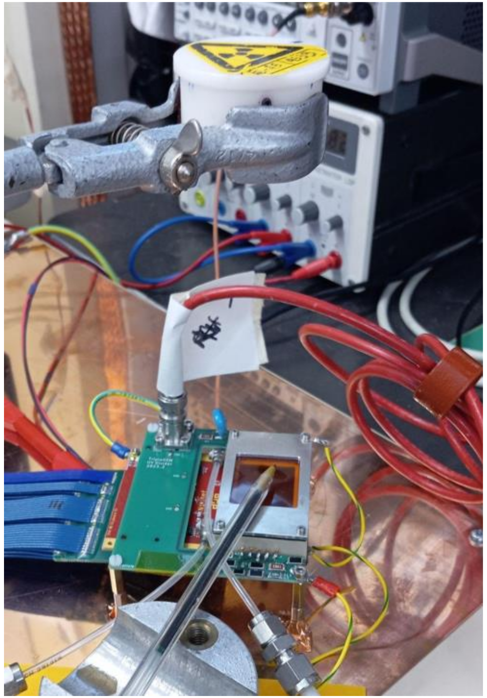
Zoom and 10 ms slice



≈ 10^2 pixels per interaction

First results

Imaging

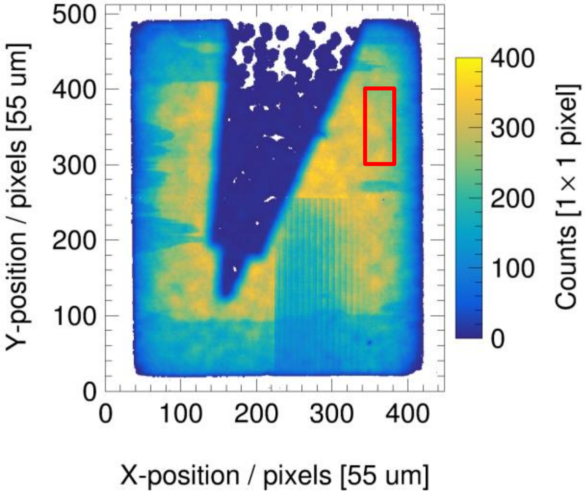


First X-ray image recorded with TSV-Timepix4

Hits only

Image of pen, low interaction rate

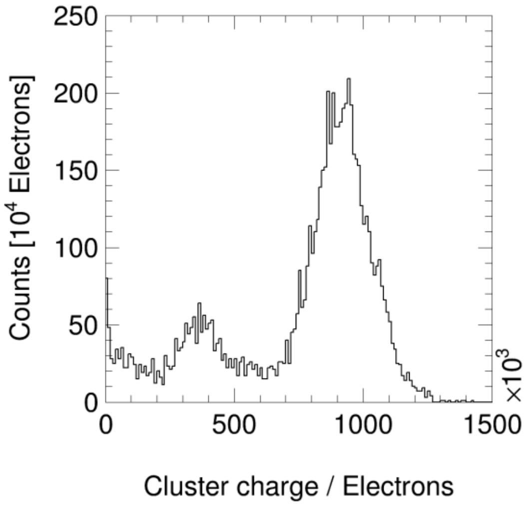
2000 s acquisition time



Clusters

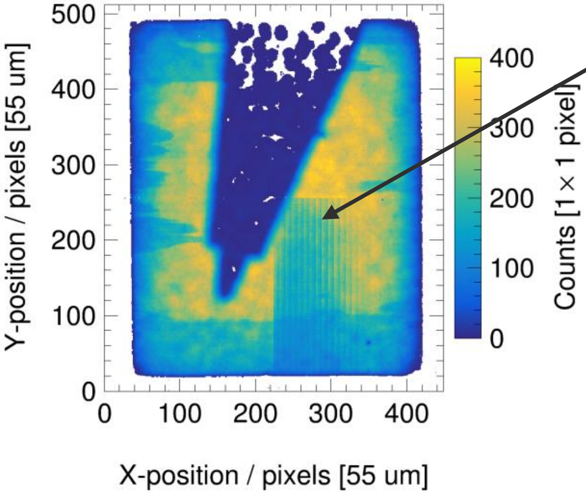
Rudimentary clustering

Only within selected region



Detector gain ≈ 5000

Next steps with GEMPix4



Redo measurements with **Timepix4v2** (Fast-links work correctly)
➔ 10 Gbps instead of 40 Mbps over slow control links

Flat-field corrected image and understanding of origin of image features

Explore the possibility of a **2 x 2 chip matrix and larger area** readout

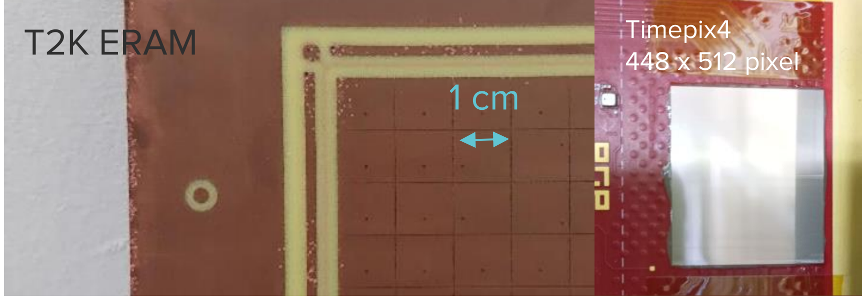
Continue the work of Fabrizio Murtas with his colleagues from the **CERN RP Dosimetry team** (Pierre Carbonez, Tristan Genetay and Andrea Garcia-Tejedor)
➔ Optimisation of the detector
➔ Applications (e.g. micro dosimetry or part of CT in hospitals)

Part 3: future perspective and dreams

Other front-end ASICs and readout boards in silicon

Large area coverage

Typical gaseous detector applications



https://indico.cern.ch/event/973503/contributions/4099220/

Pixel/pad readout = **ambiguity free**

Examples of pad readout:

➔ ALICE Time Projection Chamber:	4 x 7 mm^2, 6 x 10 mm^2, 6 x 12 mm^2 and 6 x 15 mm^2
➔ T2K Time Projection Chambers:	10 x 11 mm^2
➔ RHUM project:	1 x 3 mm^2, 1 x 8 mm^2 and 10 x 10 mm^2
➔ MPGD-based DHCAL:	10 x 10 mm^2
➔ Picosec MicroMegas:	10 x 10 mm^2

Compare with typical pixel ASICS: 0.055 x 0.055 mm^2

Large area gaseous detector applications do not require this fine granularity

➔ Find a solution with e.g. **1 x 1 mm^2 or 3 x 3 mm^2 pads**

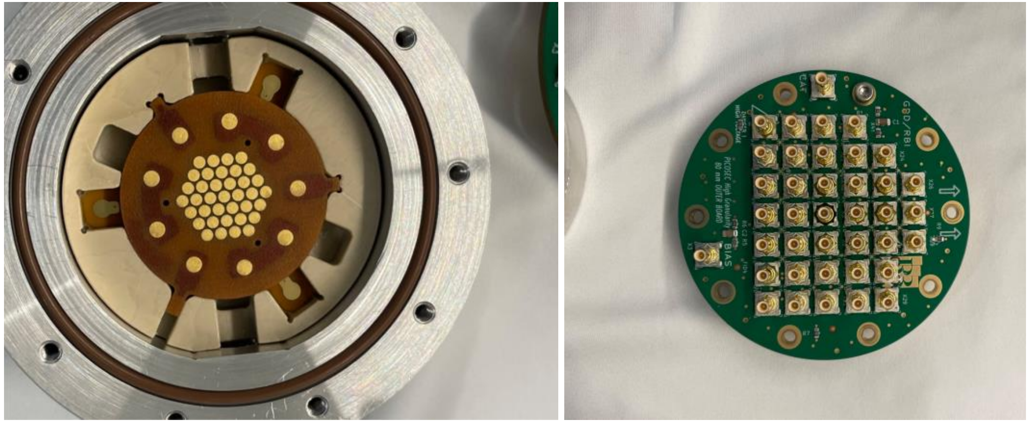
Other front-end ASICs

Establish a manufacturing technique that can be applied to other ASICs

➔ Use ASICs with larger pixel pitch, e.g. **ALTIROC** or **ETROC** (both 1.3 mm pitch)

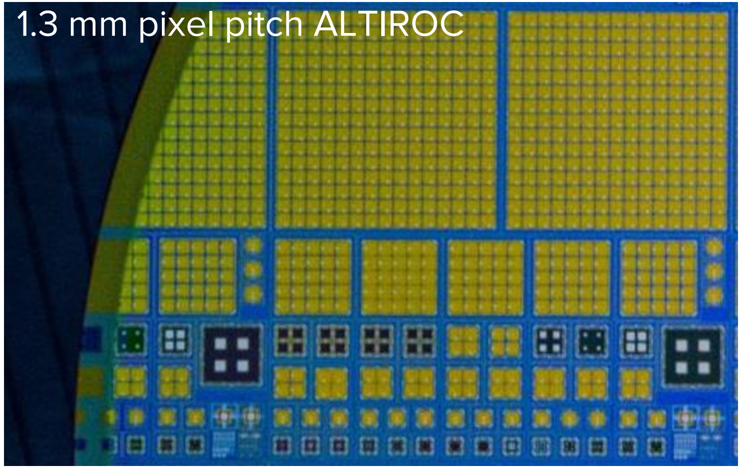
➔ Could enable **high-granularity Picosec** MicroMegas/µRWELL with **integrated front-end electronics**

High-granularity Picosec MM (2 mm pads, discrete electronics)



Courtesy of Florian Brunbauer

1.3 mm pixel pitch ALTIROC



https://indico.cern.ch/event/1323113/contributions/5823798/

Dreaming a bit – the silicon readout board

General idea

Go beyond the "classical" front-end ASIC

➔ Timepix4 and ALTIROC < 10 cm^2

➔ Gaseous detectors > 100 cm^2

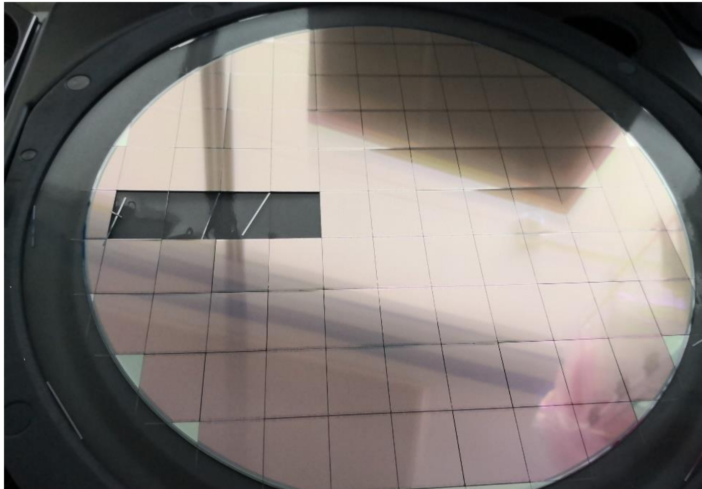
Go beyond the "classical" PCB

➔ PCB with 30 x 30 pads of 3 x 3 mm^2 size very expensive (several kCHF)

➔ Does not include front-end electronics (900 channels = e.g. 8 VMM3a hybrids = several kCHF on top)

Typical wafer costs (does not include the mask): 1 to 4 kCHF

➔ **Why not make a readout board from a wafer?**
The silicon readout board for gaseous detectors!



300 mm Timepix4 wafer (diced)

https://indico.cern.ch/event/1413681/contributions/5998158/

Dreaming a bit – the silicon readout board

Advantages

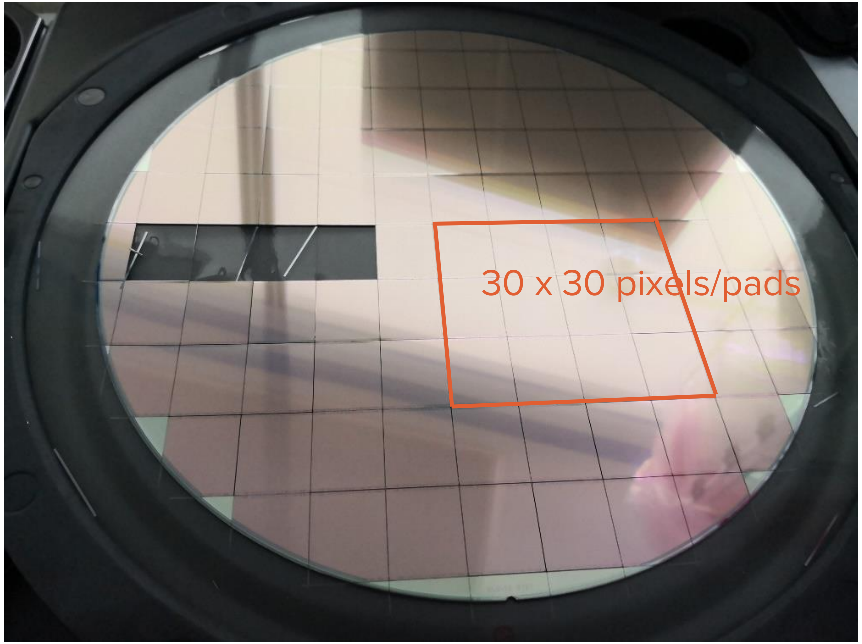
Why not make a readout board from a wafer?

The silicon readout board for gaseous detectors!

Example: 100 x 100 mm^2 ASIC with 3 x 3 mm^2 pixels
➔ Ambiguity free, large-area readout

Cheap process possible (e.g. 130 nm instead of 28 nm)

With 3 x 3 mm^2 pads
➔ Sufficient space for redundancy and discharge protection
➔ Increase reliability of electronics



Summary and next steps

Summary and next steps

New research line on **embedding of high-granularity readout ASICs in micro-pattern amplification stage**

➔ Profit from the capabilities of **TSV-Timepix4**

➔ **First promising results obtained with GEMPix4**, allows to study signal induction and electronics understanding and optimisation

Next steps with Timepix4

➔ Perform **tests with µRWELL**, first without embedding

➔ Mechanical embedding tests at CERN MPT workshop

➔ Target construction of **multi-chip PCB** with e.g. 2 x 2 chip matrix

Future goals and dreams

➔ Test different front-end ASICs, e.g. **ALTIROC** or **ETROC**

➔ Start development of **silicon readout board**

Acknowledgements

This project is only possible, because of the help and support from many people.
Many thanks to all of them!

CERN:
Jerome Alozy, William Billereau, Florian Brunbauer, Michael Campbell, Pierre Carbonez, Tristan Genetay, Djunes Janssens, Xavi Llopart, Magnus Mager, Rui de Oliveira, Eraldo Oliveri, Francisco Piernas Diaz, Miranda van Stenis

University of Geneva:
Mateus Vicente

Nikhef:
Martin Fransen, Kevin Heijhoff, Martin van Beuzekom, Bas van der Heijden

Thanks for your attention :-)

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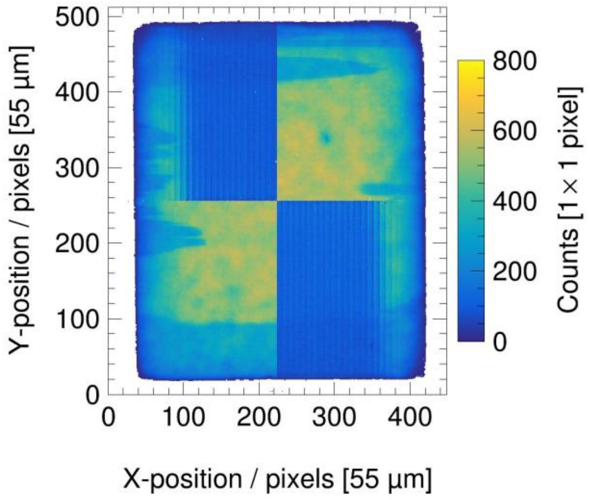
Back-up slides

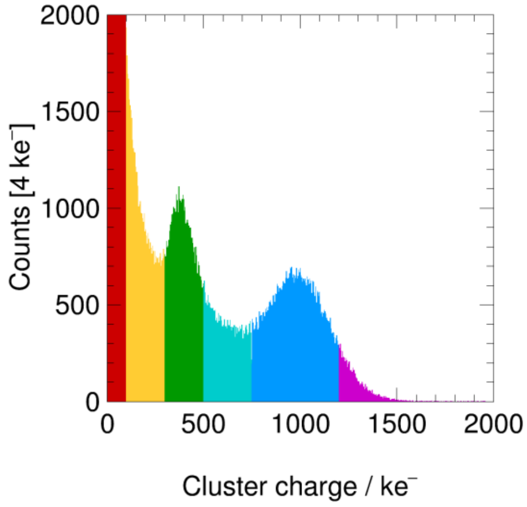
First results

Spectroscopy

X-ray **image has some structures**. Affects the quality of the ^{55}Fe spectrum.

Use the cluster information to **select the energy** and the plot the **hit positions** for each energy slice.





First results

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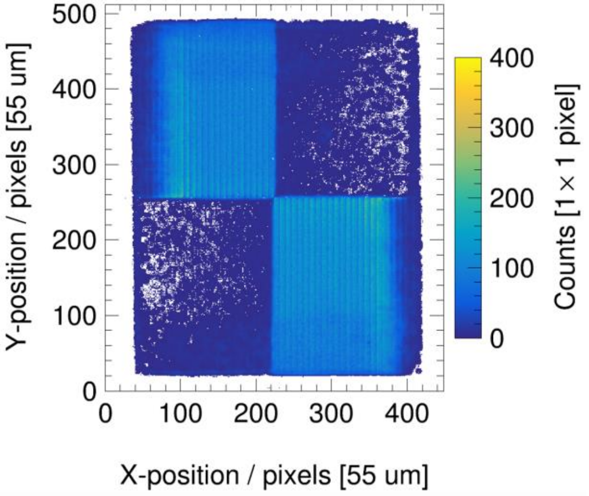
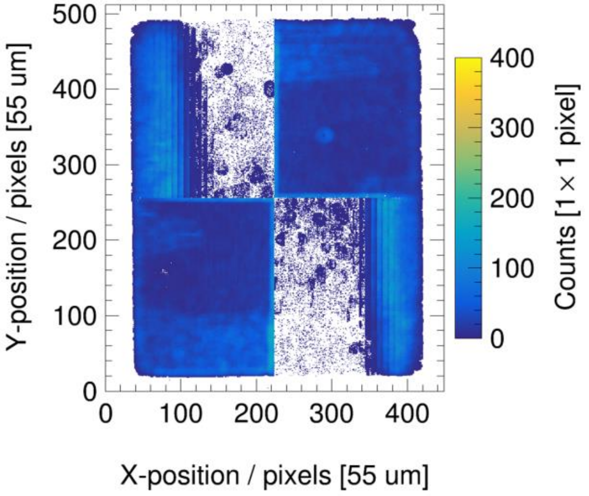
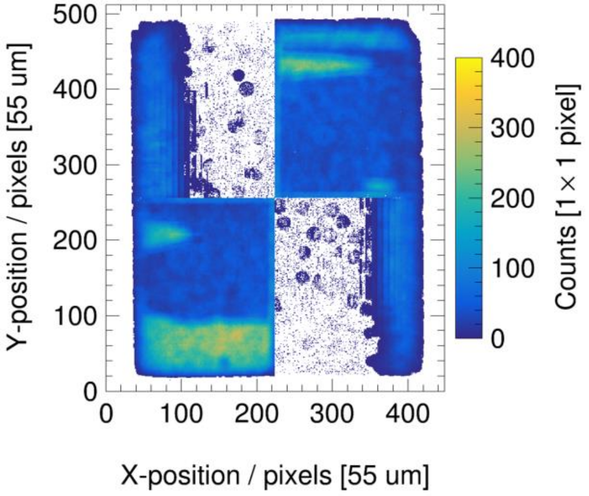


0 to 100 ke



100 to 300 ke



300 to 500 ke

First results

Spectroscopy

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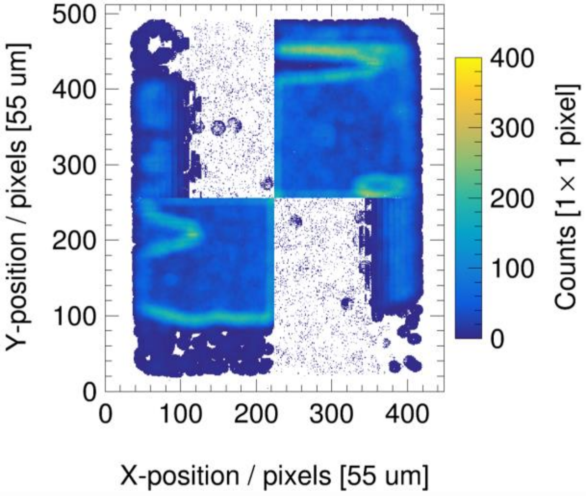
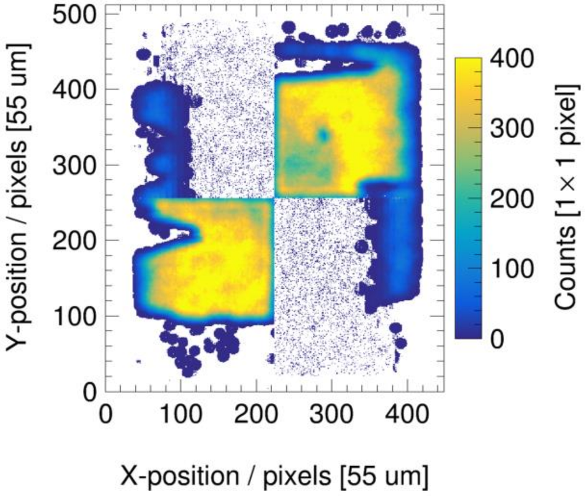
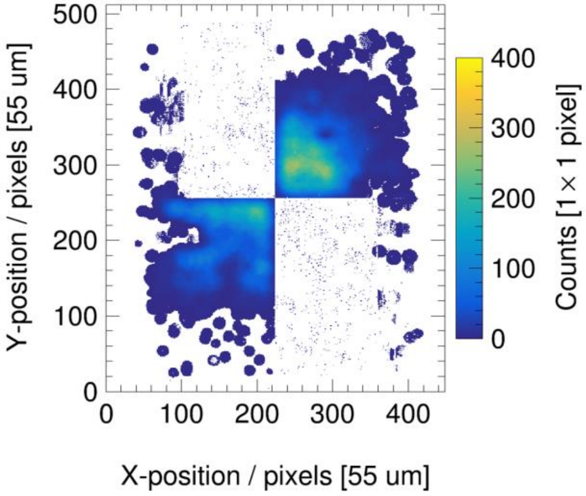


500 to 750 ke



750 to 1200 ke



> 1200 ke