GridPix Detectors – Developments and Applications

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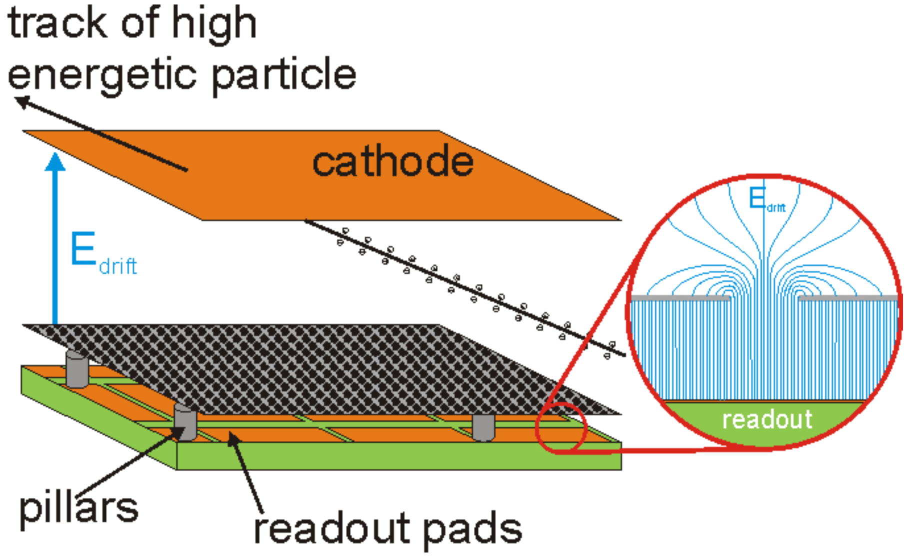
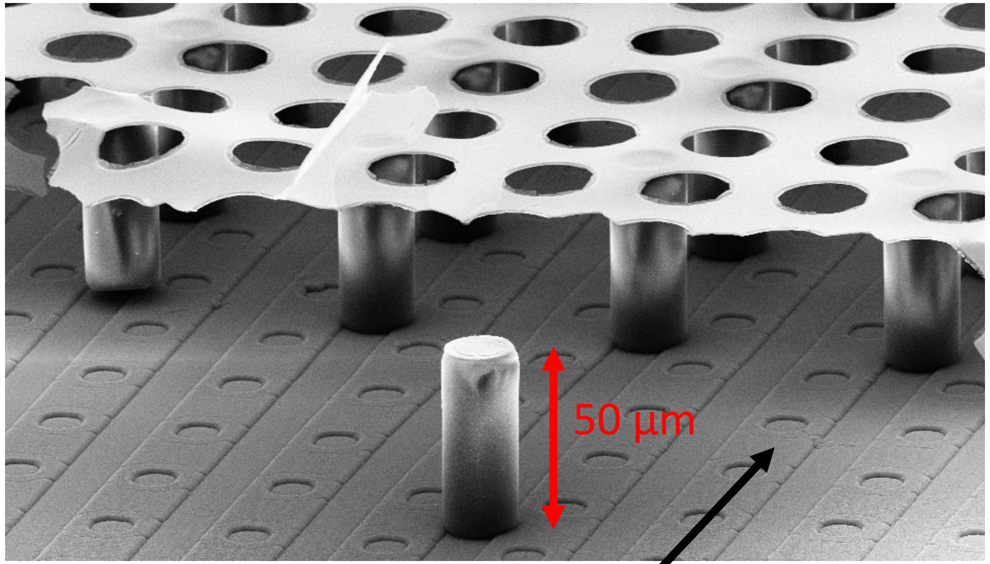
From Micromegas to GridPix Detectors

Micromegas



GridPix



Standard charge collection:
- Pads of several mm²
- Long strips
  (~10 cm length, ~200 µm pitch)

Diffusion within gas amplification region:
- Ar:CH_4 90:10 → σ ≈ 25 µm
- Ar:iC_4H_{10} 95:5 → σ ≈ 25 µm

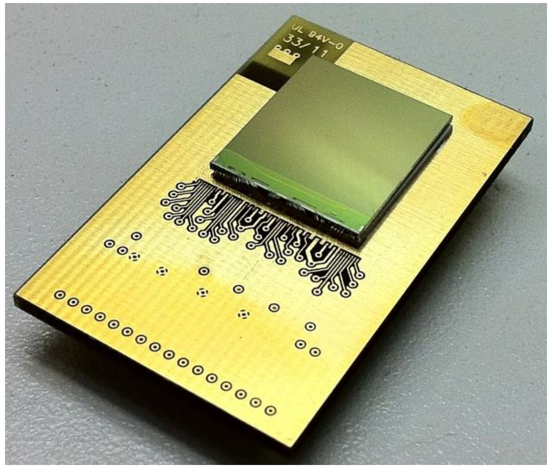
Smaller pads/pixels should improve spatial resolution
Invention of the GridPix in 2006 at Nikhef

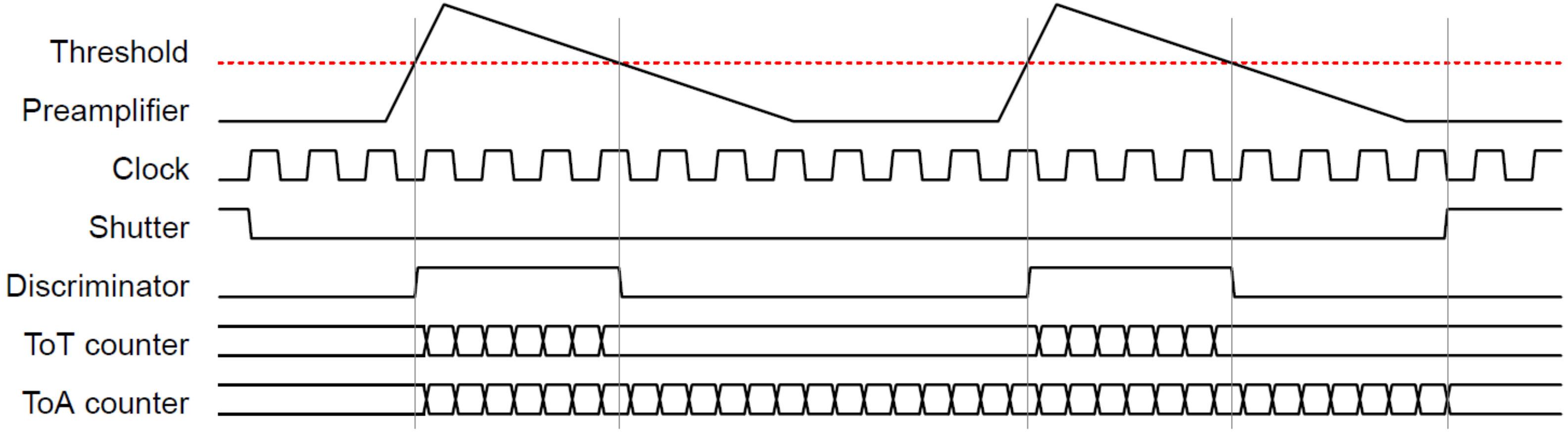
Use **bump bond pads** of a readout ASIC as charge collecting anodes

Production of Micromegas structure directly on top of pixelized readout ASIC through photolithographic postprocessing

The Timepix ASIC

- Pixelized readout ASIC
- Derived from Medipix2 ASIC (medical imaging)
- 256 x 256 pixels with 55 µm pitch
- 1.4 x 1.4 cm² active area
- Each pixel can be individually configured to measure either charge (ToT) **OR** time (ToA)
- Limitations: No multi-hit capability, no simultaneous charge and time measurement





Timepix3 ASIC

- Available since short time
- Successor to Timepix ASIC to overcome limitations
- Simultaneous charge **and** time measurement in each pixel
- Multi-hit capability
- Data-driven readout with high bandwidth (5.12 Gbps)

Wafer-based GridPix Production

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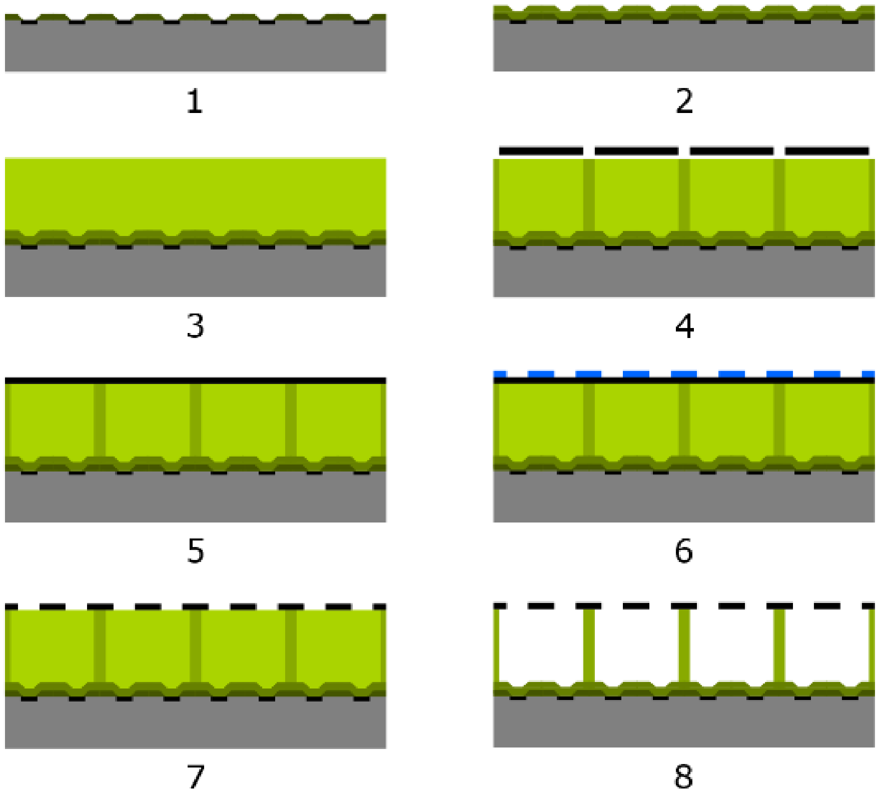
- Production at University of Twente was based on a single to few chip process
  → Could not satisfy the increasing demand
- Wafer-based process was established together with the Fraunhofer IZM at Berlin
  → Batches of up to three 8” Timepix wafers can be produced at a time (107 chips per wafer)

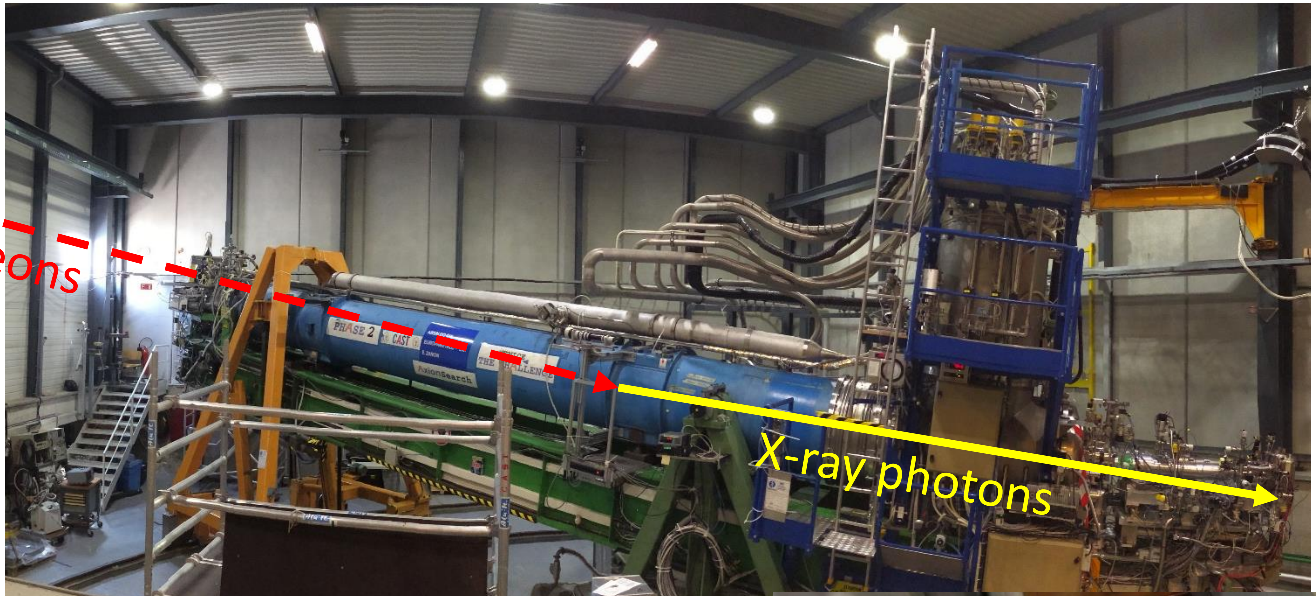


1. Start with bare Timepix wafer
2. Formation of Si_xN_y protection layer (4 or 8 µm) (protects chip in case of discharges)
3. Deposition of SU-8 (spin coating)
4. Create pillar structures by exposition of SU-8
5. Sputter Al layer (typically 1 µm)
6. Create mask on top of Al layer
7. Open grid holes by wet etching
   Dice wafer into individual chips
8. Remove unexposed SU-8

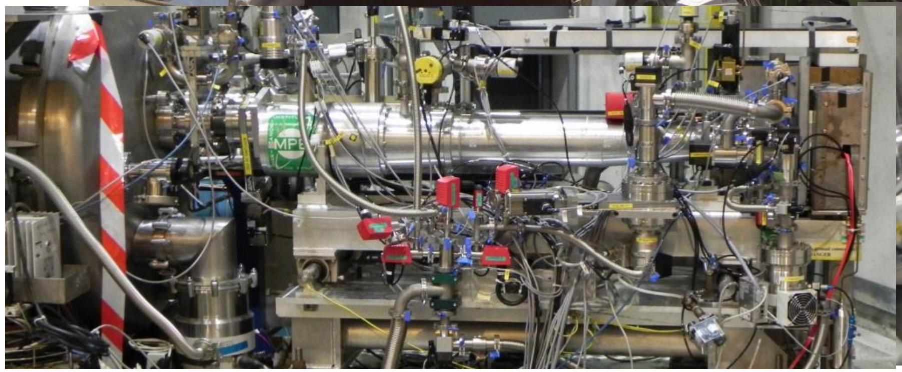
Fraunhofer IZM

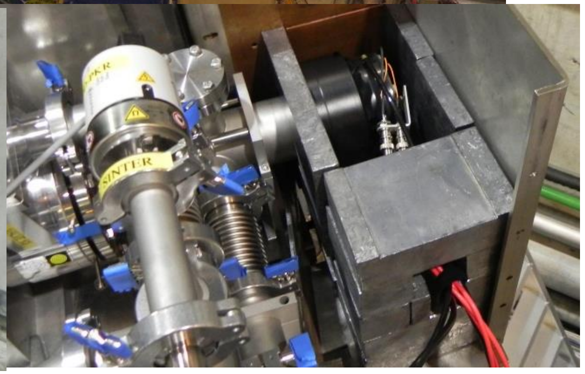
Applications I – GridPix at CAST since 2014

CERN **A**xion **S**olar **T**elescope



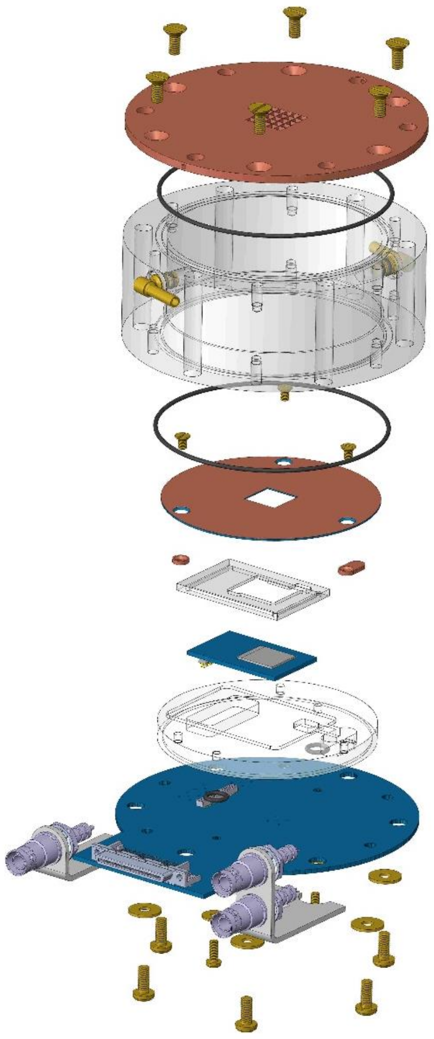
- Axions/chameleons produced in the Sun
- Reconversion to X-ray photons in strong magnetic field (Primakoff effect)





At CAST:
- Decommissioned LHC prototype dipole magnet (10 m long, 9 T, 1.8 K)
- Movable structure:
  Vertical ~±8°
  Horizontal ~±40°
- Sun can be tracked during sunrise & sunset (2 x 1.5h per day)

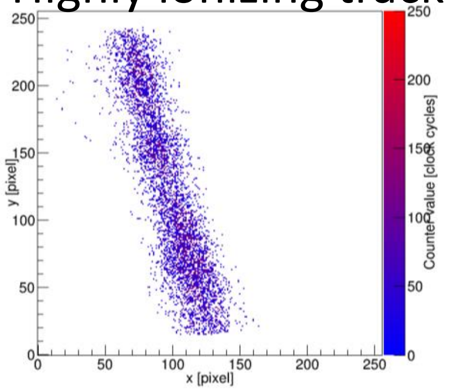
Applications I –
GridPix at CAST since 2014



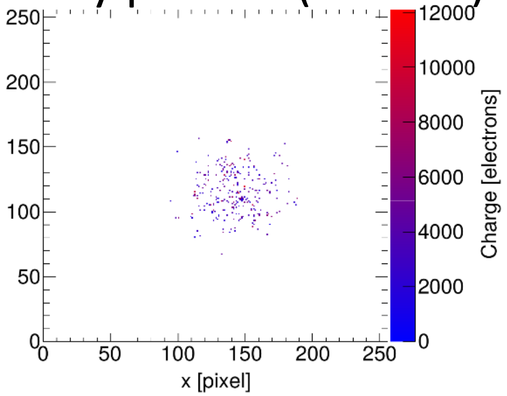
Requirements for an X-ray detector at CAST:

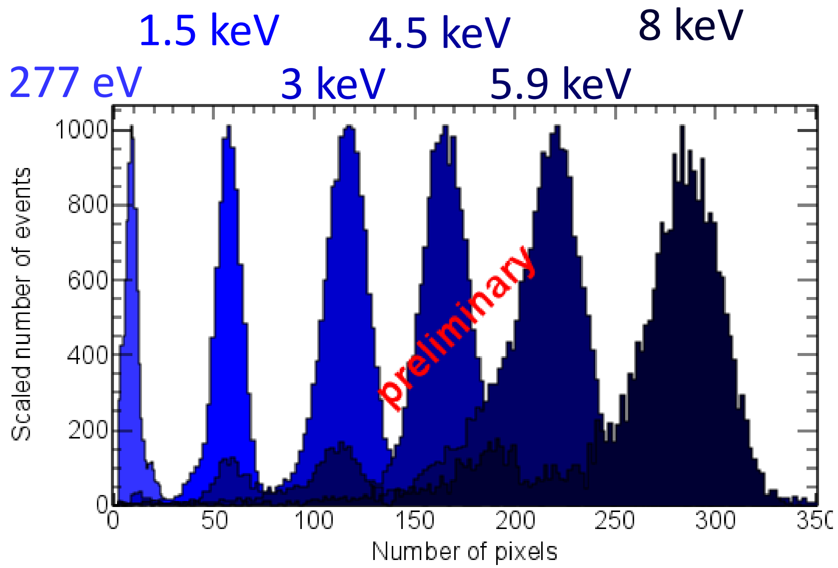
- High detection efficiency → $Ar{:}iC_4H_{10}$ mixture @ 1 bar
- Background rate as low as possible
  → Radiopure materials, lead shielding, focusing by X-ray telescope
  → Event shape based background discrimination
- Entrance window transparent for low energy X-rays (< 1 keV) → thin window
- Vacuum tightness (in the detector: 1 bar; in the beam pipe: 10^{-6} mbar) → tight window
  → Compromise: 2 µm Mylar with 40 nm Al (300 nm SiN windows under development)
- Sensitivity for X-ray photons < 1 keV shown at an variable X-ray generator

Highly ionizing track



X-ray photon (5.9 keV)

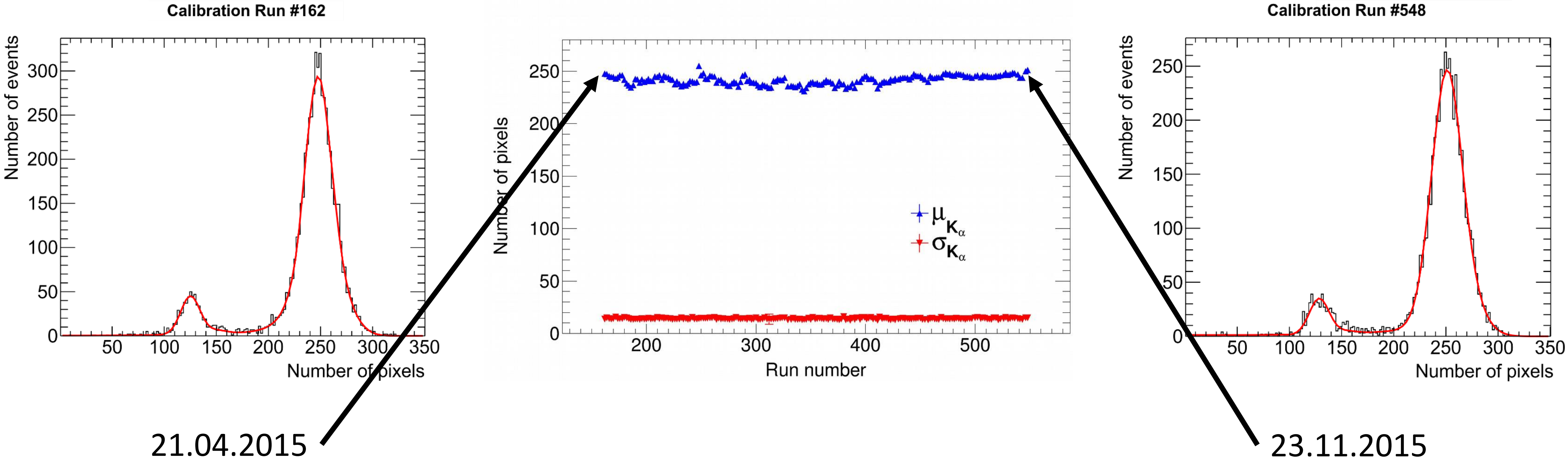




Applications I – GridPix at CAST since 2014

Long term operation:

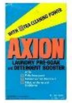
- Data taking 24 h per day: 1.5 h tracking the Sun, 1 h calibration with ^{55}Fe source and 21.5 h background data
- GridPix based detector installed in October 2014, 30 days of data taking, then remained at CAST for 6 months
- 200 days of data taking in 2015 before dismantling
- No detector related stops or interruptions during both periods

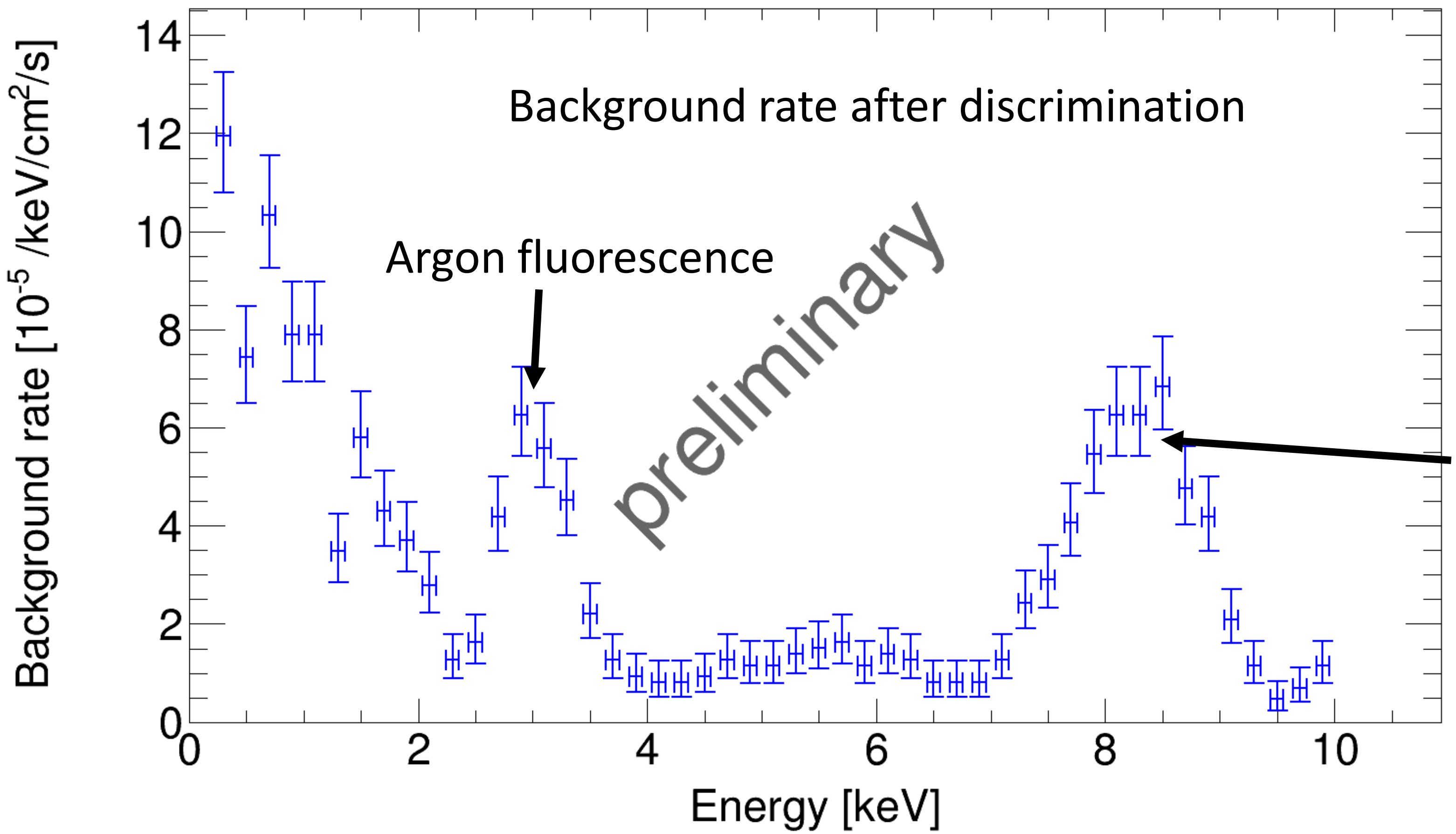


Applications I – GridPix at CAST since 2014

Interesting for chameleon search

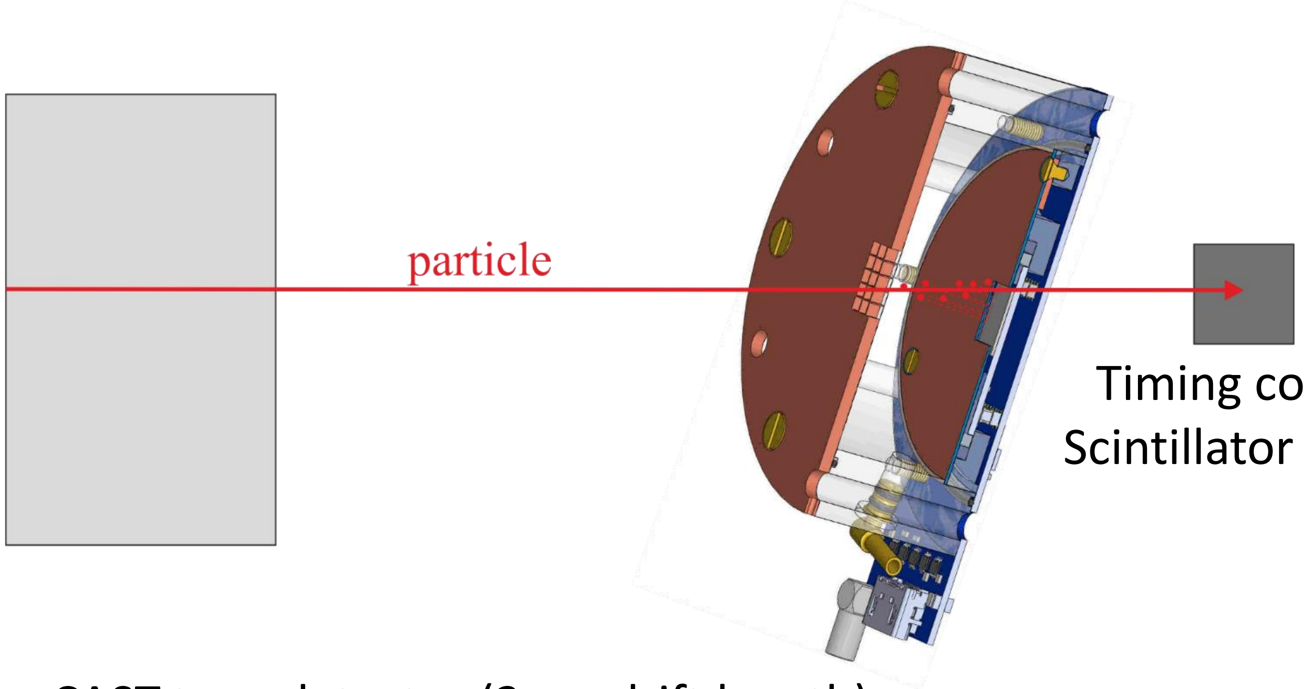
Interesting for axion search

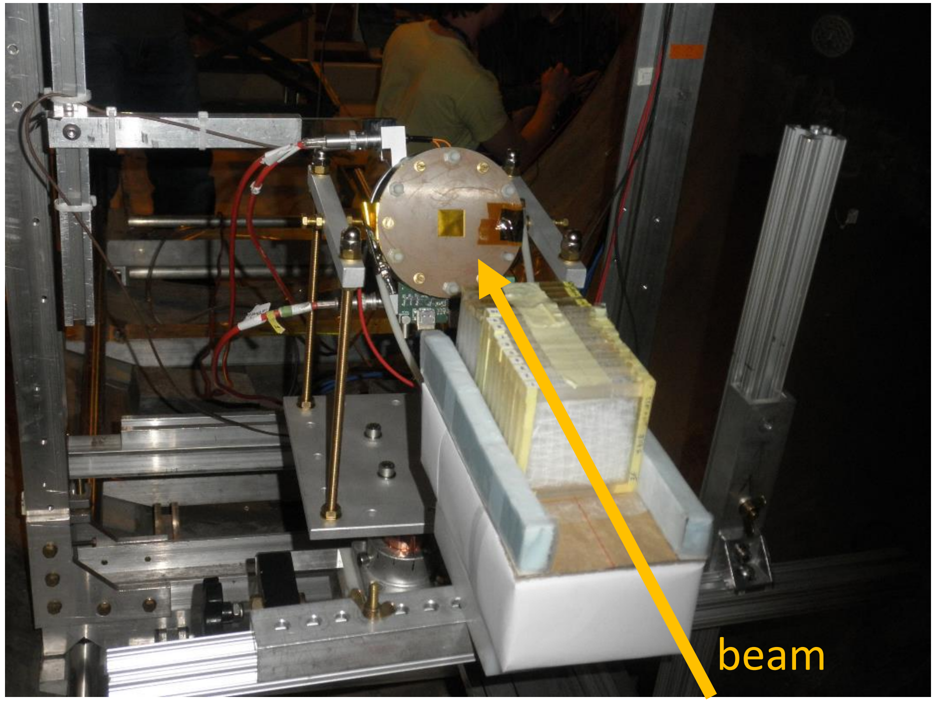




Cosmic rays and copper fluorescence

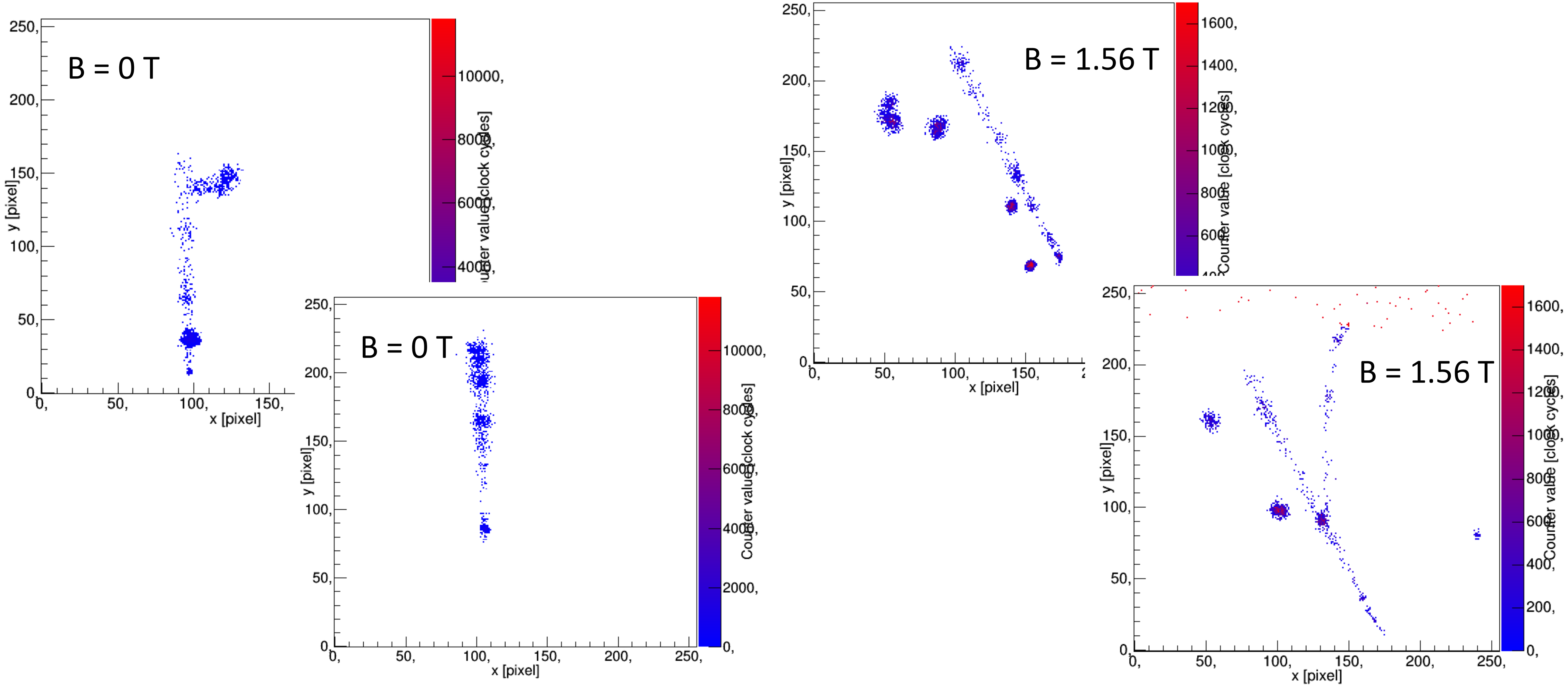
Applications II – Transition Radiation Detector



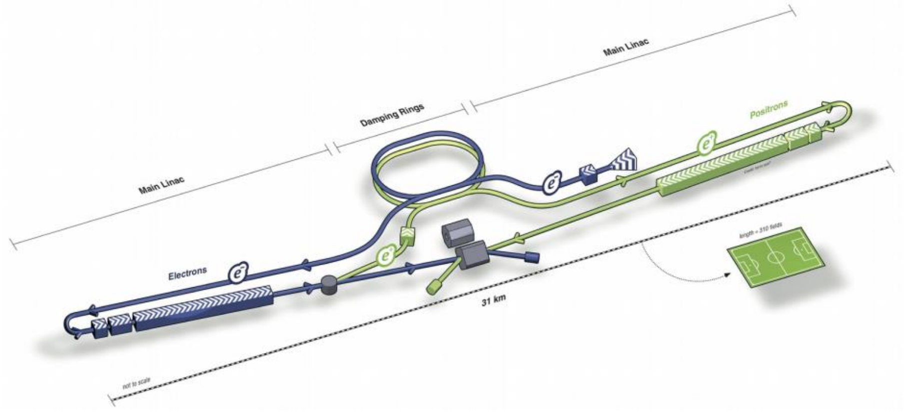


- CAST type detector (2 cm drift length)
- Gas mixtures: $Xe:CO_2:CF_4$ 80:10:10 and $Kr:iC_4H_{10}$ 80:20
- Tests at CERN in North Area using e^-- and p-beam of SPS
- Various radiators were used
- With and without magnetic field of 1.56 T
  → bends the track about 1 mm away from TR photons
- In total 43 runs with ~185,000 events.

Applications II – Transition Radiation Detector



Applications III – Large Area GridPix Detector

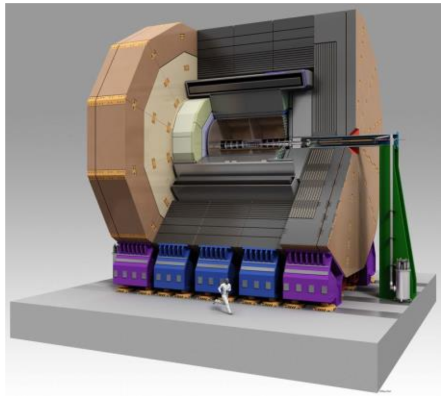


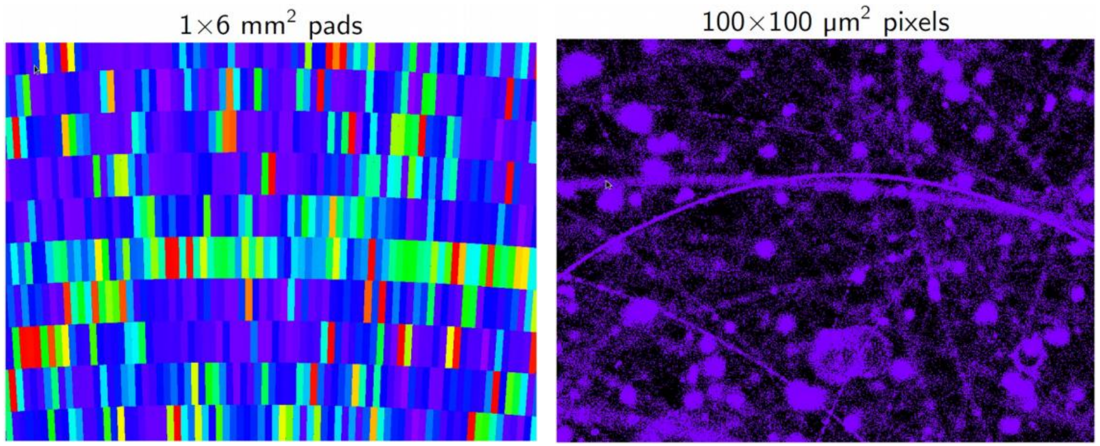
International **L**inear **C**ollider:

- Linear e^+e^- collider with $\sqrt{s}$ = 500 GeV – 1 TeV

International **L**arge **D**etector:

- One of two ILC general purpose detectors
- Foresees a central TPC as main tracker





Simulation for the CLIC detector, M. Killenberg, LCD-Note-2013-005

- High occupancy through background processes ($\gamma\gamma \rightarrow$ hadrons, $e^+e^- \rightarrow$ pairs/beam halo)
- Use of GridPixes would minimize the occupancy
  → better track finding, δ-ray removal
  → improved dE/dx by primary e^- counting
  →pad plane and readout electronics fully integrated
- For full readout of ILD-TPC about 50,000 to 60,000 GridPixes are needed (2 endcaps with 10 m² each)
  → need to prove large area coverage and scalability

Applications III – Large Area GridPix Detector

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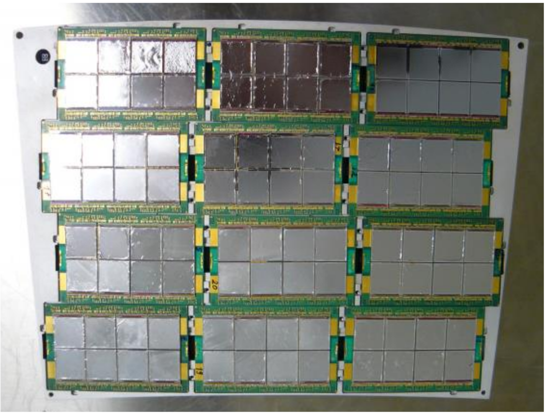
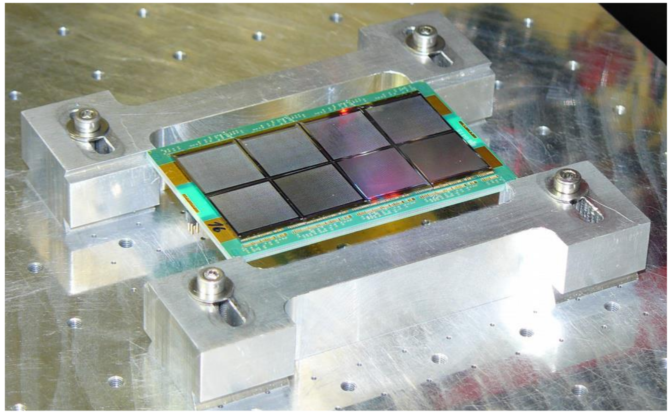
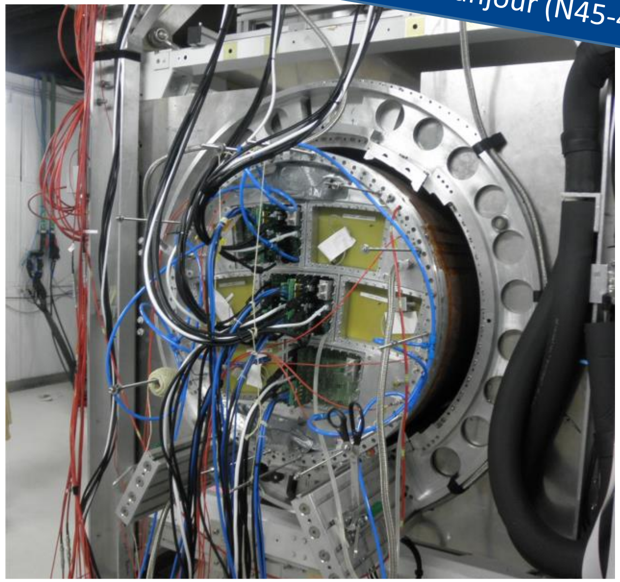
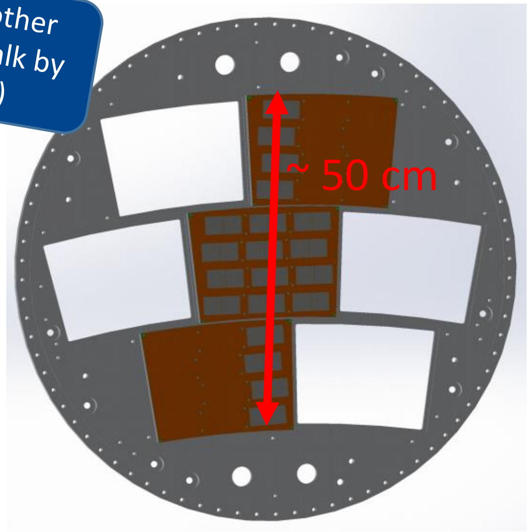
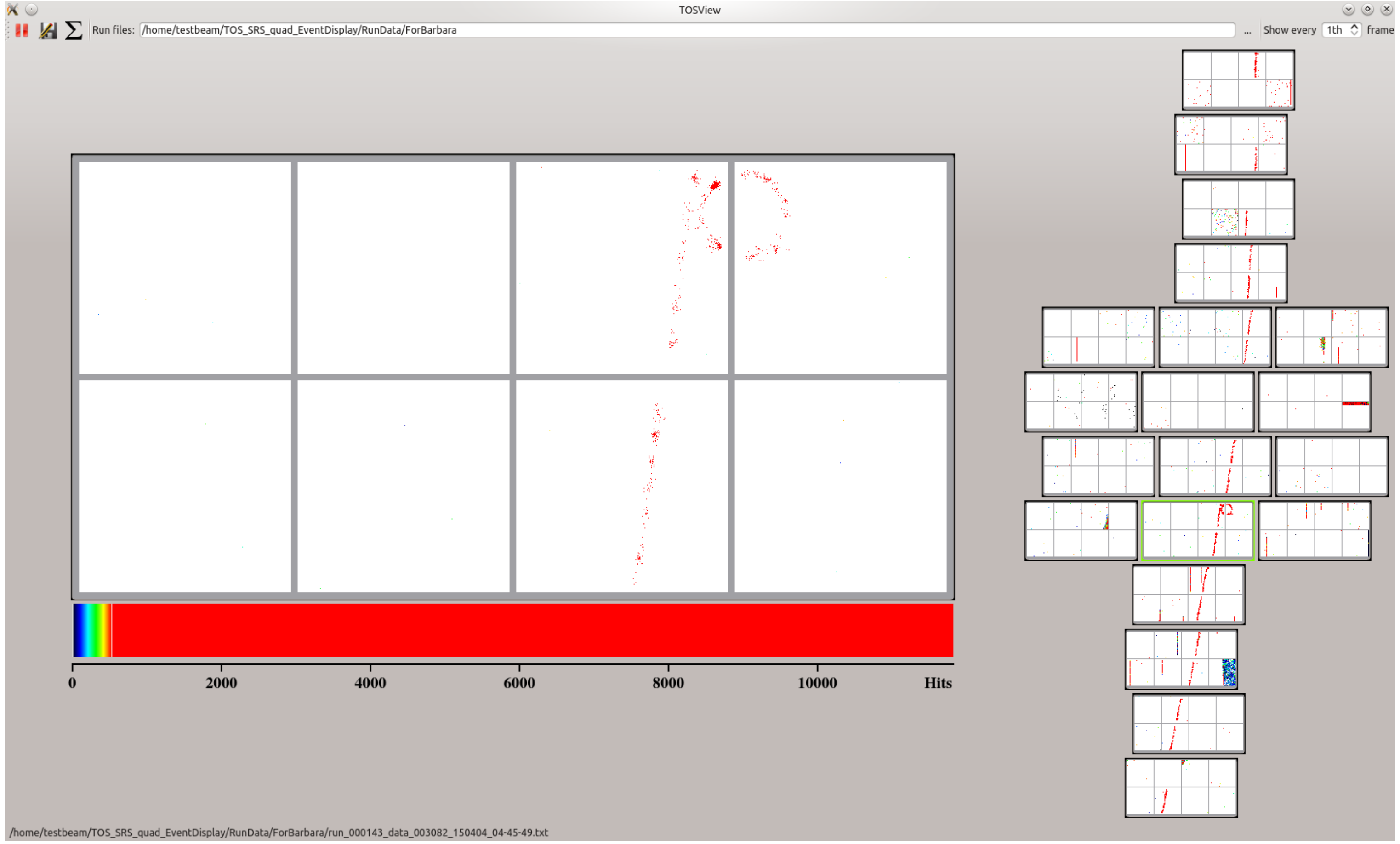
- GridPix modules for the dedicated ILD-TPC test infrastructure at DESY
- One central module with 96 GridPixes (~ 50 % coverage)
- Two partially equipped modules with 32 GridPixes each
- In total: 160 GridPixes covering 320 cm² active area

For more details & other modules tested see talk by S. Ganjour (N45-4)

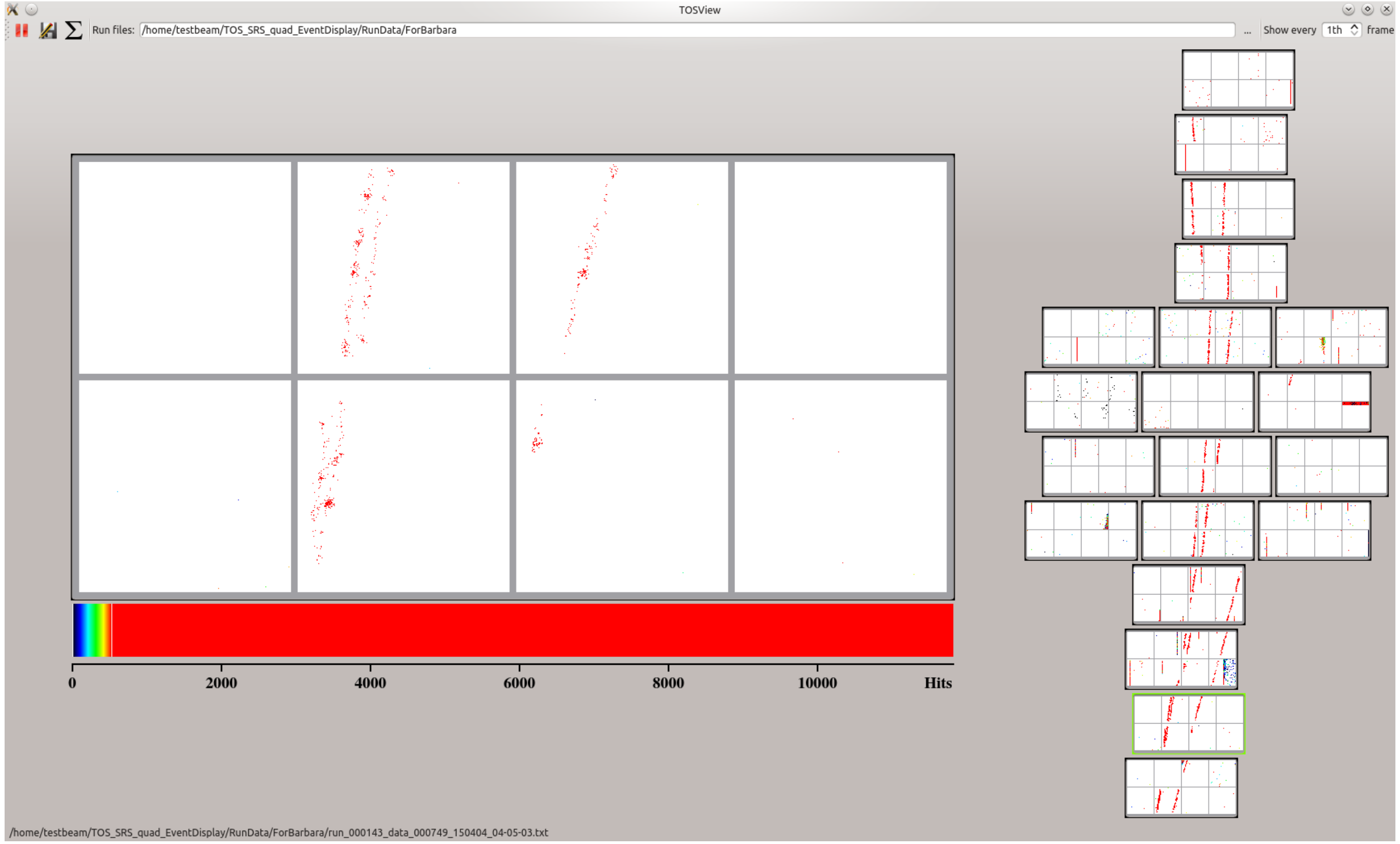





- Test beam campaign at DESY in April 2015 was a huge success
  → The Pixel-TPC is not a crazy idea anymore but a realistic concept
- Full test beam program: voltage scan, z-scan, momentum scan, different angles, with and without magnetic field, etc.
- About 10^6 frames at a rate of 4.3 to 5.1 Hz recorded, analysis of data is in progress

Applications III –
Large Area GridPix Detector



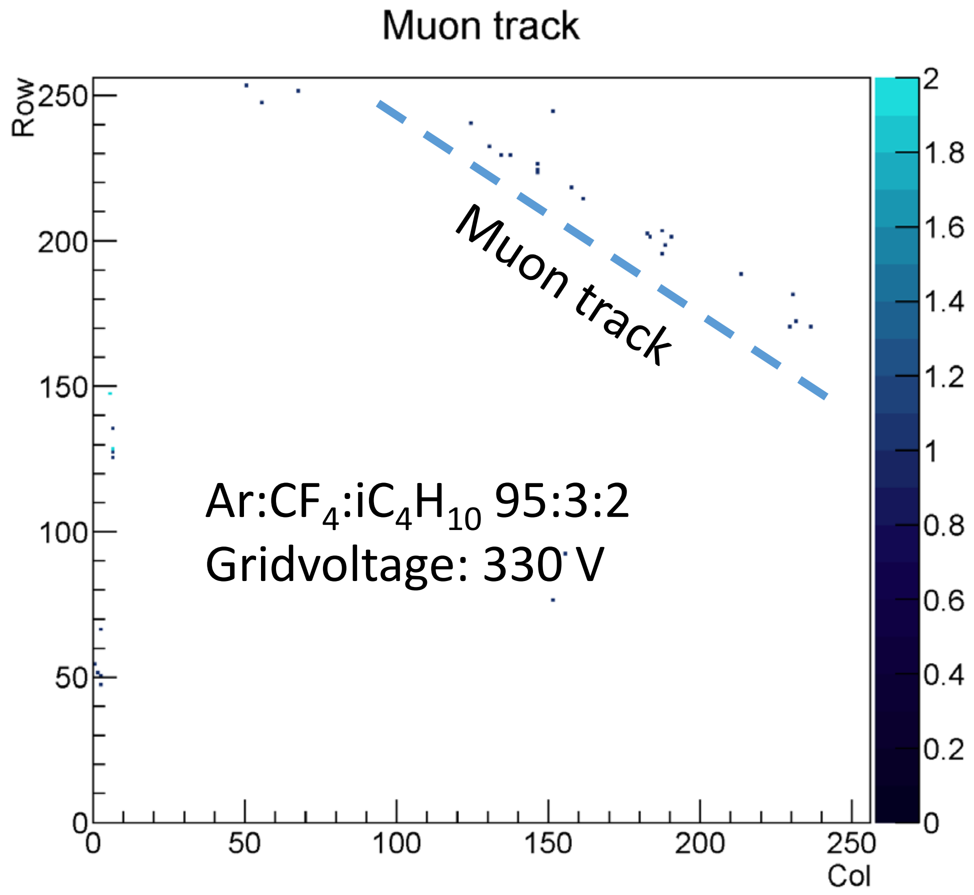
Applications III – Large Area GridPix Detector

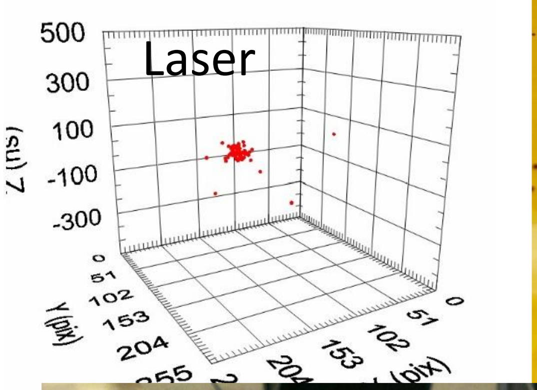


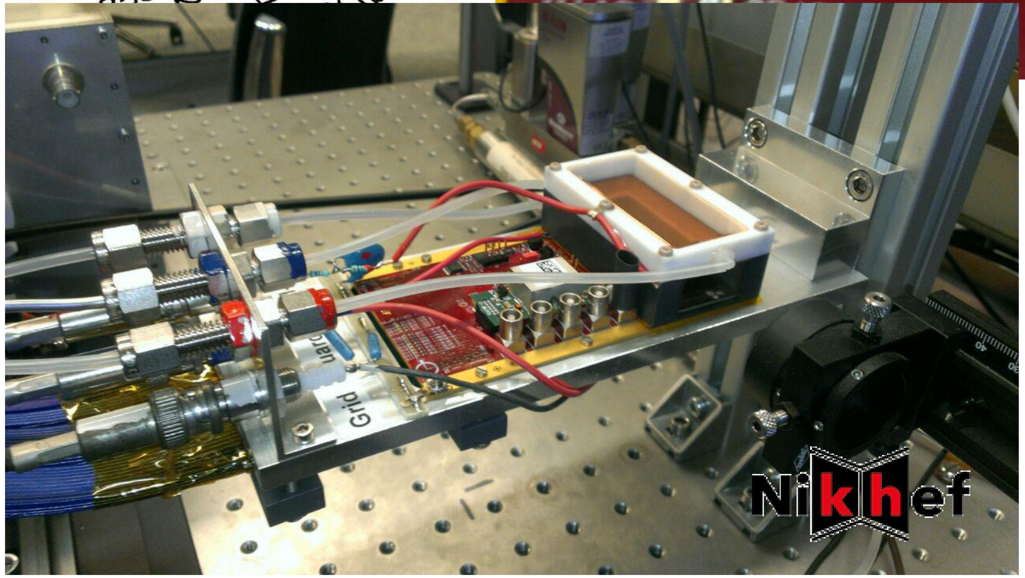
First Timepix3 GridPix

In collaboration with Nikhef LEPCOL group:
F. Hartjes, K. Heijhof, P. Kluit, G. Raven,
J. Timmermans, S. Tsigaridas, H. van der Graaf

- First Timepix3 wafer has been successfully processed at IZM Berlin
- First tests with Timepix3 GridPix were performed at Nikhef some days ago







Summary and Outlook

- Wafer-based production process for GridPix devices has been established at IZM Berlin
- GridPix technology shows excellent performance in already many different applications
- Large area coverage and scalability have been demonstrated with the operation of 160 GridPixes in a testbeam campaign at DESY
  → Important step towards Pixel-TPC
- Long term operation has been shown at the CAST experiment
- First Timepix3 GridPixes are available and appear to work
- Outlook:
  Further improvement of GridPix production, e.g. different materials
  Applications of Timepix3 GridPixes, e.g. a new detector for CAST