A new monolithic proportional gas detector with a micro-gap electron multiplier structure directly integrated on top of a finely pixelated readout ASIC

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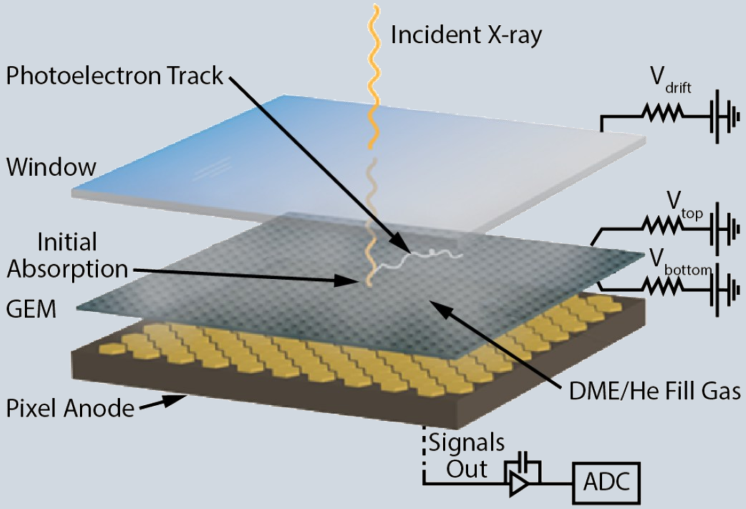
The goal of this project

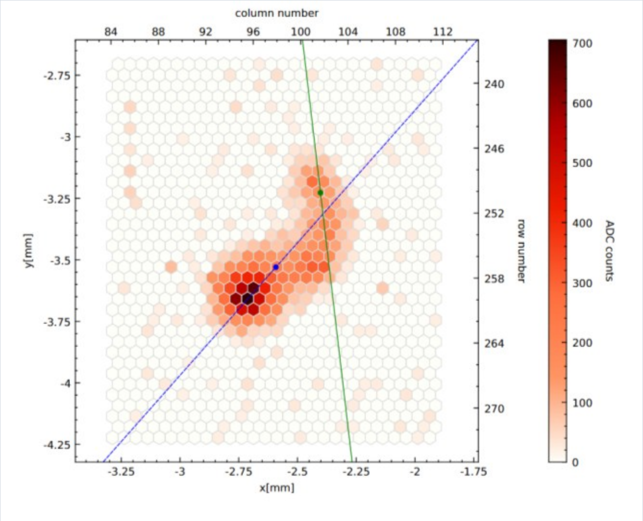
- A gas detector with readout, collecting pads and charge multiplication structures monolithically integrated on a single ASIC
- Pixel readout with hexagonal pattern
- Micro-gap amplification scheme
    - Optimal option for our purpose

- Incremental steps:
    1. Testing the principle (working with an existing hardware)
    2. Develop a dedicated ASIC
    3. Build a complete detector

- We will see the motivation and the current status

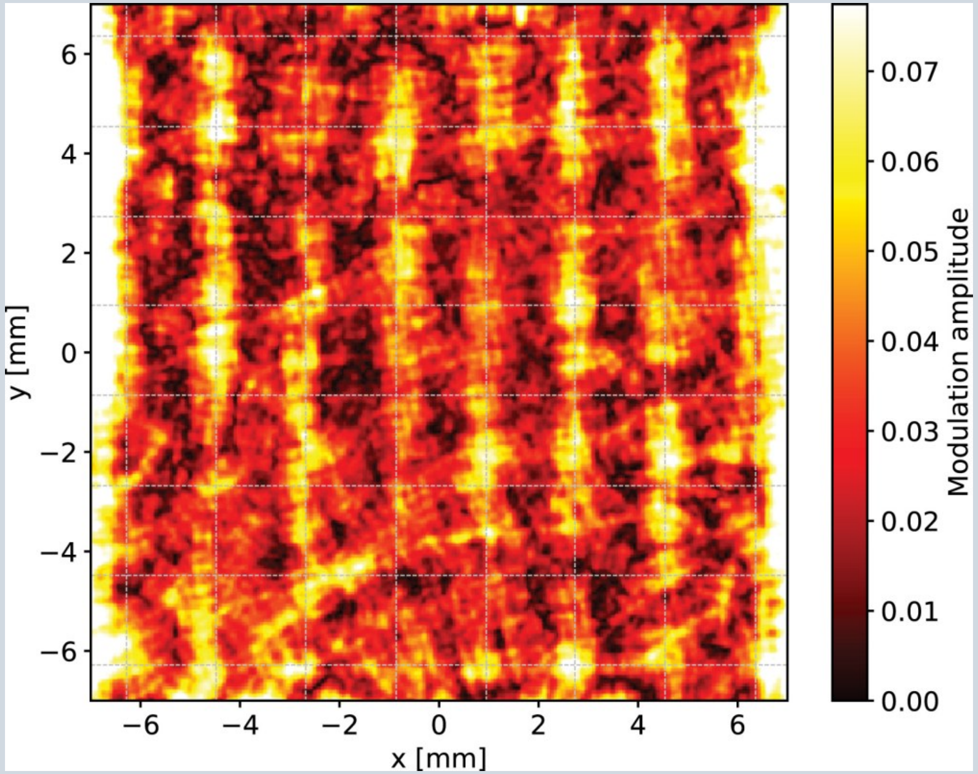
The Gas Pixel Detector





- Developed specifically for X-ray polarimetry based on photoelectric effect
  - Photoelectron emission direction modulated according to the beam polarization
  - High-resolution imaging of photoelectron track
- The IXPE mission is based on the GPD
  - In science operation since January 2022
- The Gas Pixel Detector concept
  - A gas as absorption medium to increase the electron range
  - A Gas Electron Multiplier as multiplication stage
  - A custom pixelated ASIC as charge collection and event readout
- First use of an ASIC as both charge collection and front-end electronics
  - One of the building block of this project

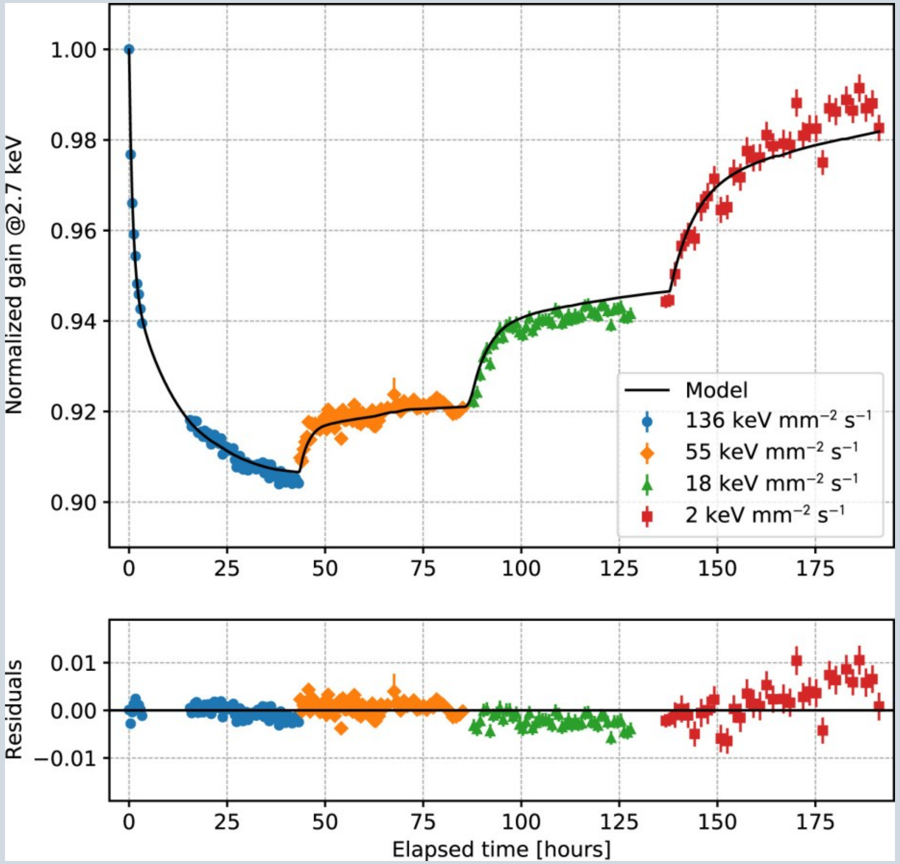
GPD improvement: residual modulation



Modulation amplitude map
from an un-polarized X-ray source at 2.7 keV

- “Preferred direction” for non polarized beam
  - Ideally isotropic distributed
- Position (and energy) dependent effect
- Follows the patterns of the laser swipes on the GEM
  - Mostly related to the GEM itself
  - Limited precision in hole drilling
- Need to be calibrated
  - Complex and lengthy procedure

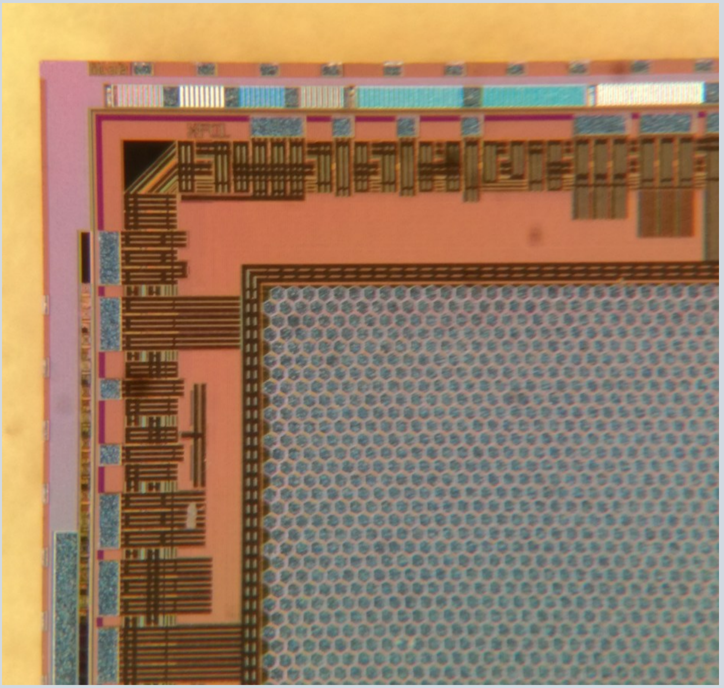
GPD improvement: charging



Relative gain as a function of time,
while the detector is being irradiated with
a monochromatic X-ray beam at different rates

- Rate-dependent gain variations
- Well-known effect due to charge accumulation in the dielectric of the GEM
- Can be modeled as a function of energy flux
  - Position dependent
- Calibration can be quite complex procedure
  - Need the history of the flux for a proper correction
- Can be important for future high-throughput telescopes

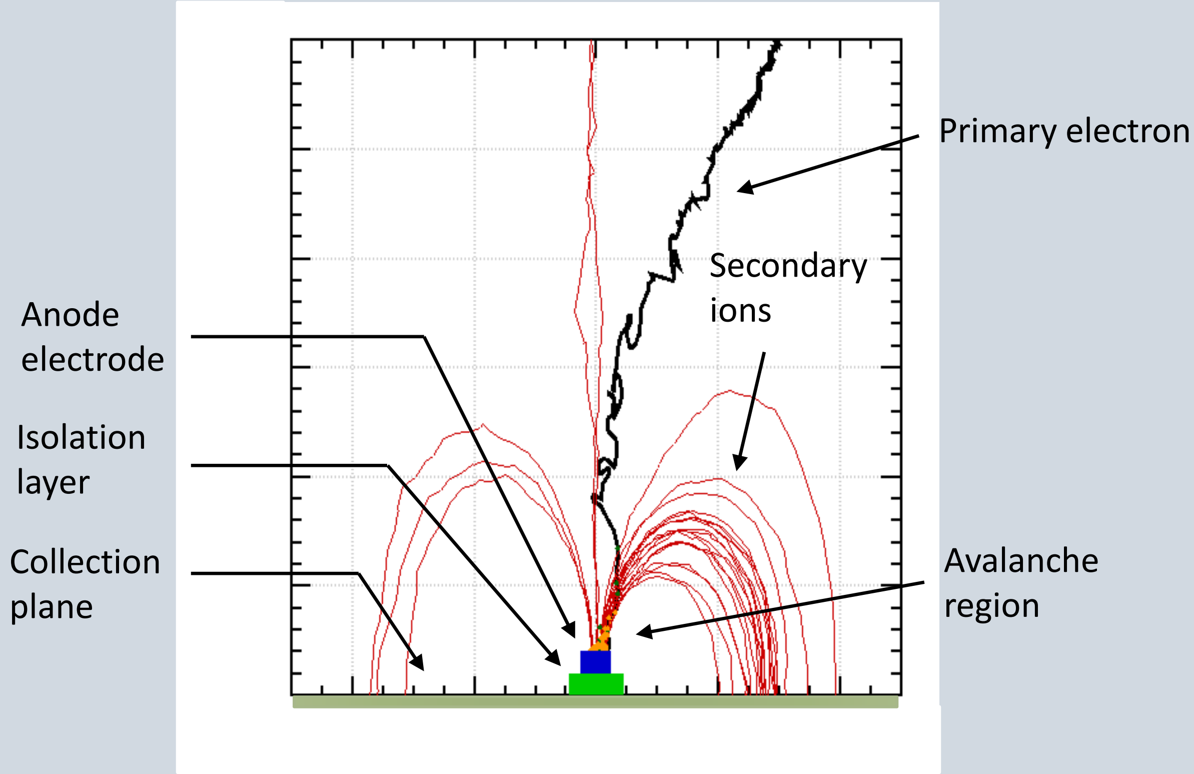
XPOL ASIC family



Top-left corner of the XPOL chip

- Developed specifically for a gas detectors
  - Top metal layer as collection plane
  - Hex matrix to minimize distortion
- Active area ~15x15 mm2
  - 300x352 pixels with hex patterns
  - 50 µm pitch
- Self-trigger with Region-Of-Interest definition around the event
- Very low pixel noise ~20-30 e- ENC
- 180nm CMOS technology
  - XPOL flying in the IXPE mission
  - A newer XPOL-III for higher rate (smaller dead time)

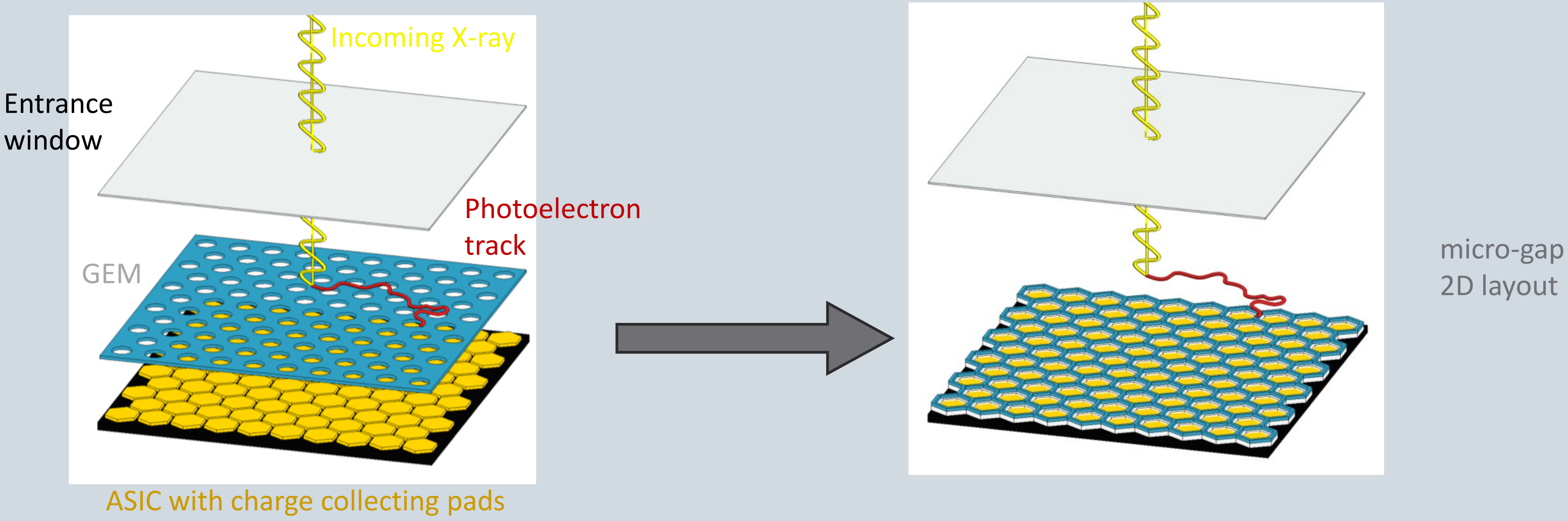
The micro-gap concept



- Radical change in the multiplication mechanism: the micro-gap concept
  - Developed in the ’90s for high-flux applications
- Need only 1 insulation and 1 metal layer on top of the existing chip
  - Electron amplification in a small region close to the top electrode
  - Collecting ions on the chip pads
- Size and materials compatible with microelectronic fabrication technology (e. g. CMOS)
- Sub-micron precision
  - Solve local distortions
- Small exposed dielectric
  - Minimize charge accumulation

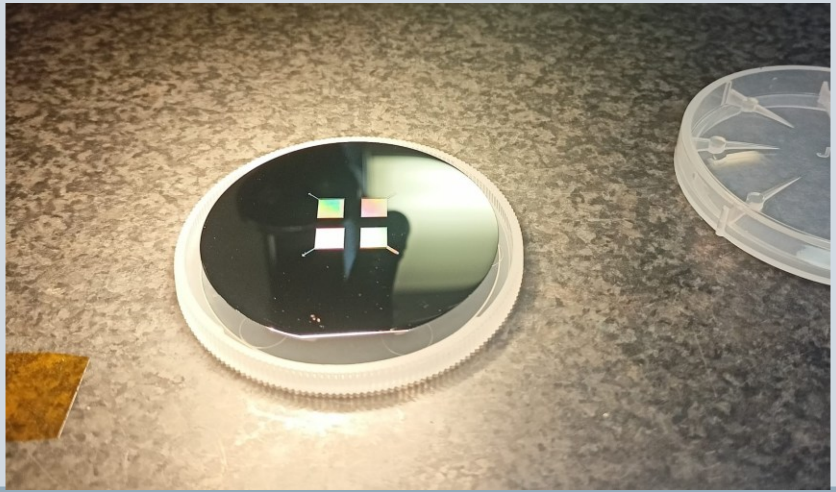
Monolithically integrated on the ASIC

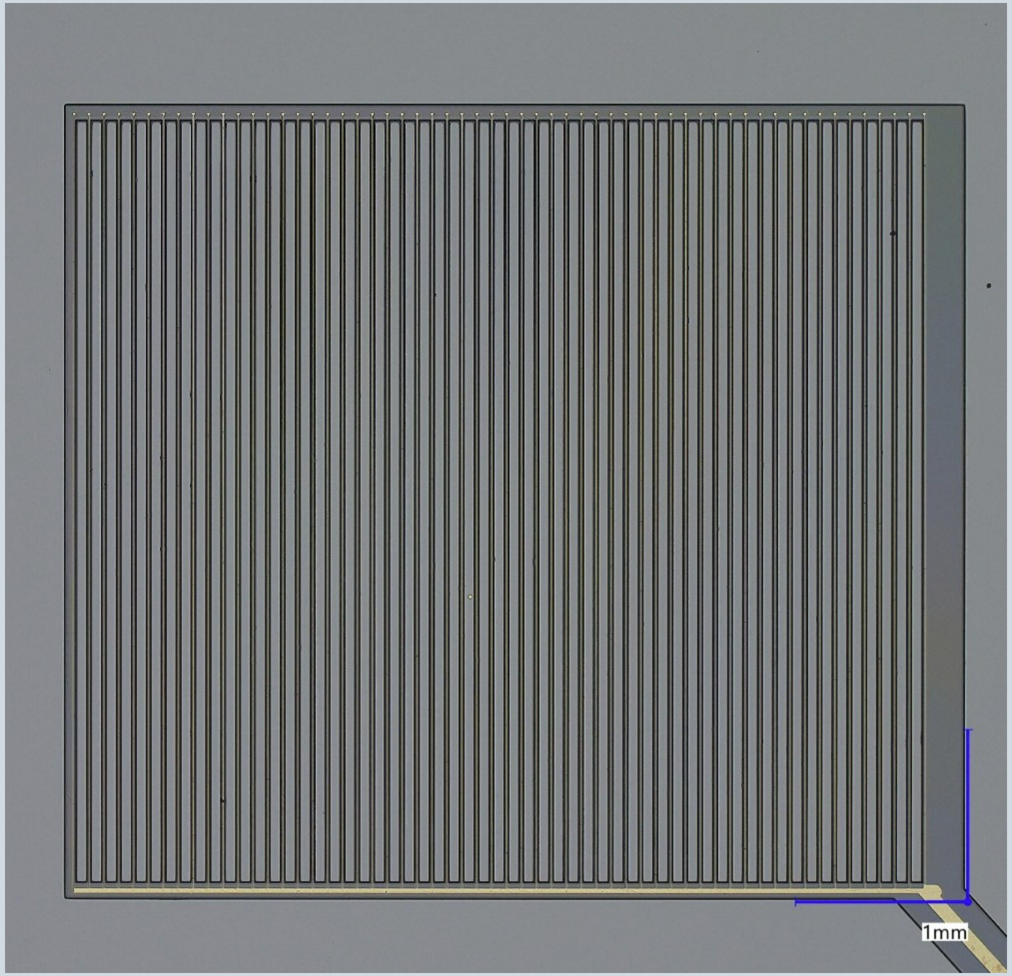
- Building the micro-gap structure directly on the ASIC
  - A detector-on-chip ready to go in a gas cell
  - Ideally it can be done directly at a modern foundry
- Several geometries for multiplication structures both 1D (“original” concept) and 2D
  - The pixel pitch of 50 µm set the scale



Multiplication structures on silicon wafer

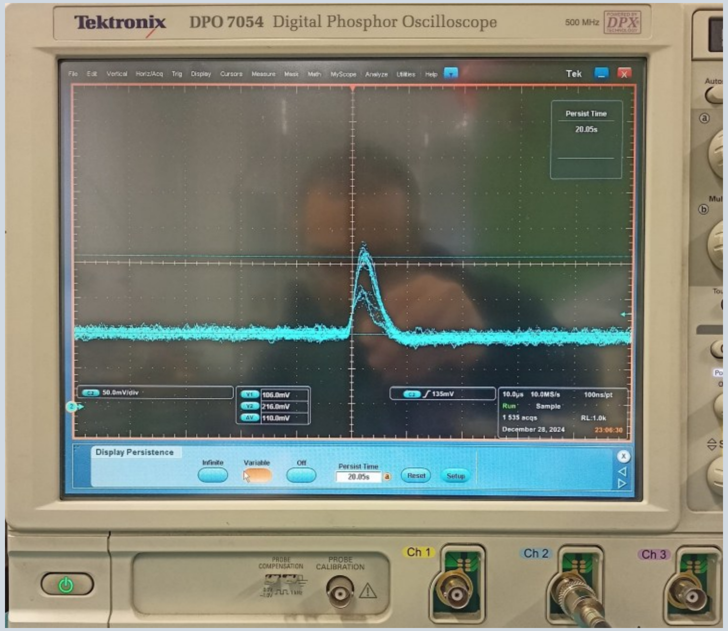
- First test of small-pitch micro-gap detector
  - Proof of principle: sustain high voltage and test gain characteristics
  - Refine production steps in preparation of chip processing
- Four 5x5mm structures ready for XPOL layout
- Testing 1D geometries
  - Two pitch options: <u>43.3 µm and 86.6 µm</u>
  - Insulation: polyimide 2 µm thick and 13 µm wide
    Metal: aluminum 2 µm thick and 5 µm wide



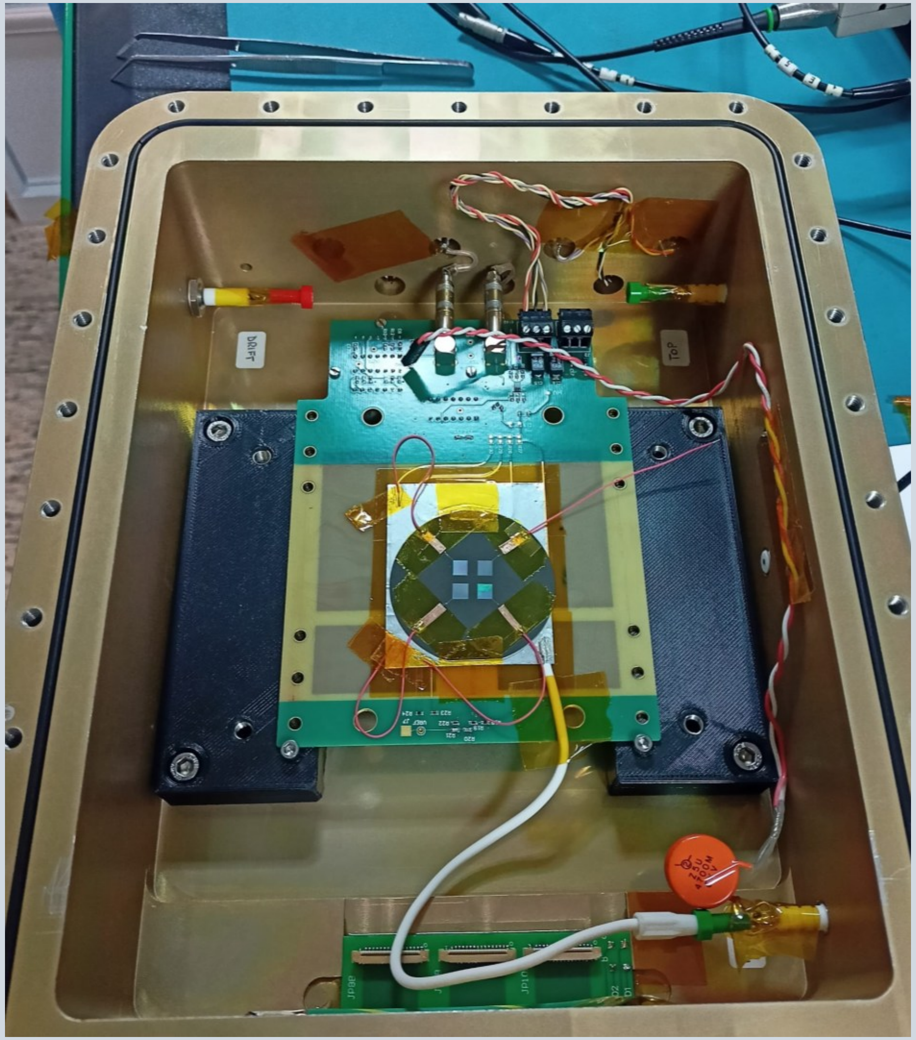


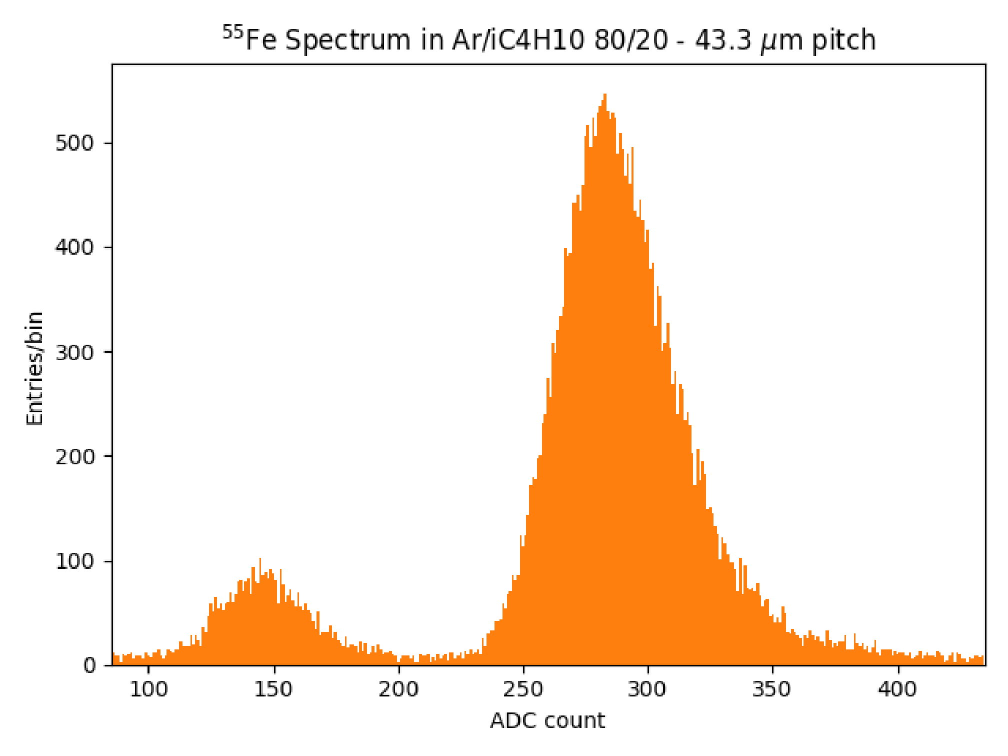
Functional test of small-pitch micro-gap

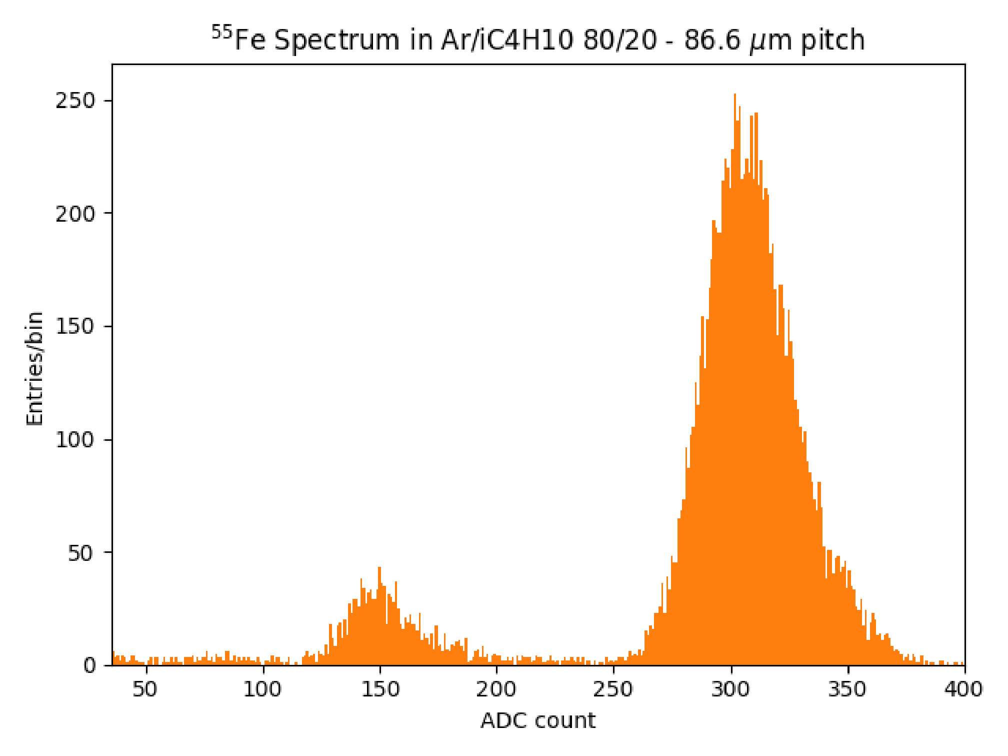
- Wafer placed on a custom PCB inside a gas cell
- Anode strips connected to a single channel amplification chain
- Back side of Si wafer for high voltage bias
- Gas cell fluxed with a mixture of Ar/iH4C10
- X-ray source: ^{55}Fe
- Readout with a commercial MCA and oscilloscope



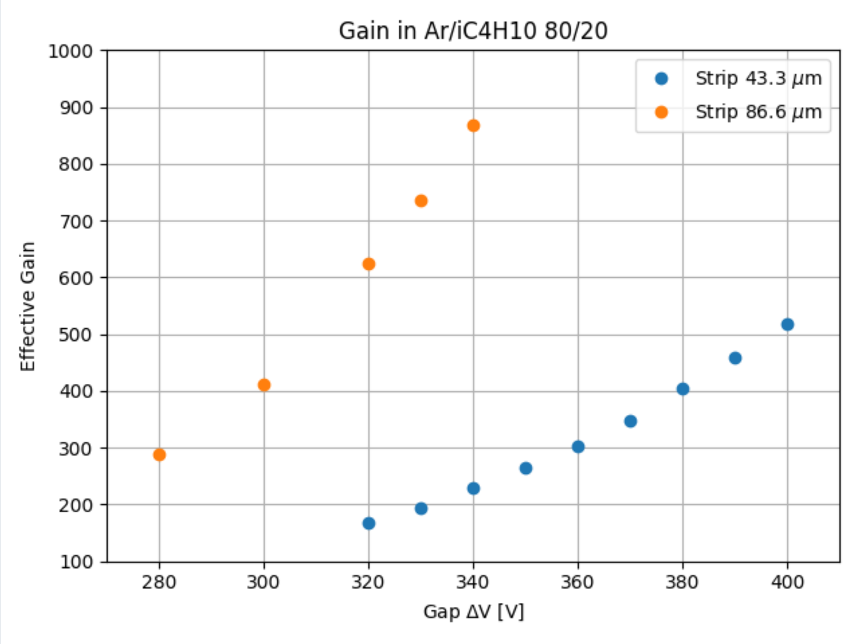
First light of the small-pitch micro-gap

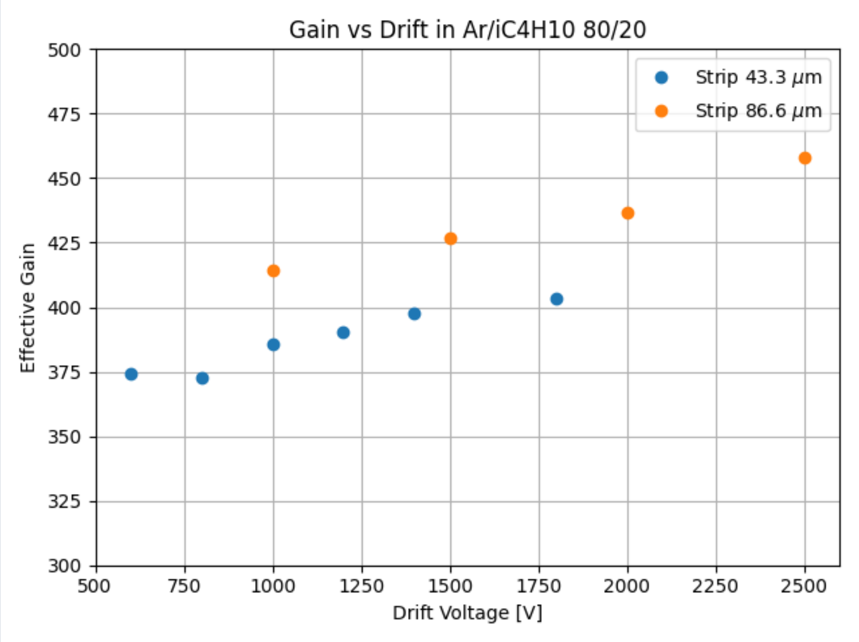






Response to ^{55}Fe X-rays



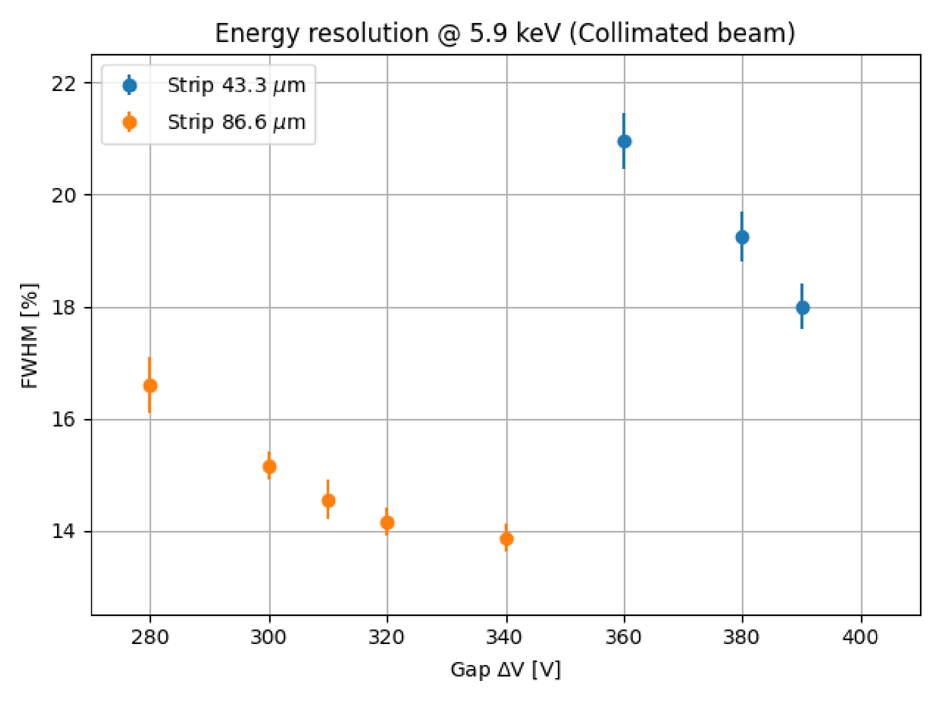


Effective Gain

- Effective gain of a few hundreds can be reached with ΔV <400V
- GPD operates with effective gain ~300
  - Low noise of the single pixel
- Smaller pitch has smaller gain
  - Expected from simulation
- No breakdown or high current observed in this voltage range
- Small linear increase in gain with drift voltage

Energy resolution

- Collimated beam to remove boundary effects
- Resolution improves with gain
  in this ΔV range
- Can reach value comparable with expectation from GPD experience
  - Just a qualitative comparison due to difference in gas and readout
- We can reach 18% even with 43.3 µm pitch
  - The finest pitch in class

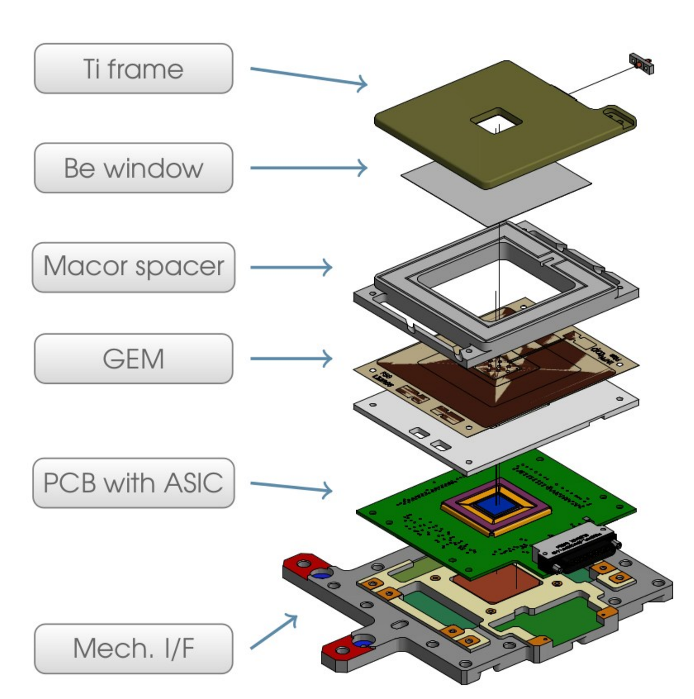


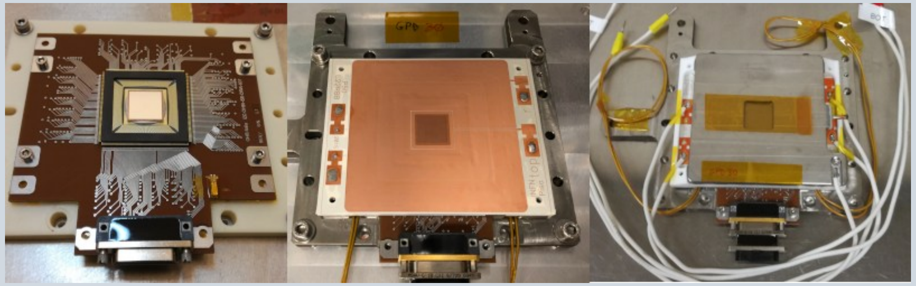
Conclusions

- We are aiming at an ASIC with gas amplification, collection and readout capability
  - With micro-gap concept as a multiplication stage
- First proof of operation of small-pitch micro-gap gas detector
  - Geometry compatible current XPOL chip design
  - Only 2 µm tick isolation layer
- Required gain can be reached at relatively small voltages
  - No sign of leakage current or destructive sparks
  - Good performance in current test setup
- First verification of the production process
  - Previous batch (directly on chip) had a too low anode-cathode resistance
  - 2D geometry will be tested in next production batch
  - Next step is building the micro-gap on the current XPOL chip
- A dedicated ASIC is the final goal

EXTRA

The GPD in more details





- Sealed detector with 1 cm thick absorption gap
  - Filled with DME 600-800 mbar
  - Low outgassing materials
- Readout ASIC 300x352 pixels with hex pattern 50 µm pitch
- GEM with 50 µm pitch on LCP substrate
  - Laser etching technique
  - Developed by RIKEN
- Energy resolution ~17.5% FWHM at 5.9 keV
- Gas gain ~ a few hundred
- Position resolution <100 µm
- Modulation factor ~28-55% at 2.7-6.4 keV