Front-end ASICs for Micro Pattern Gas Detectors

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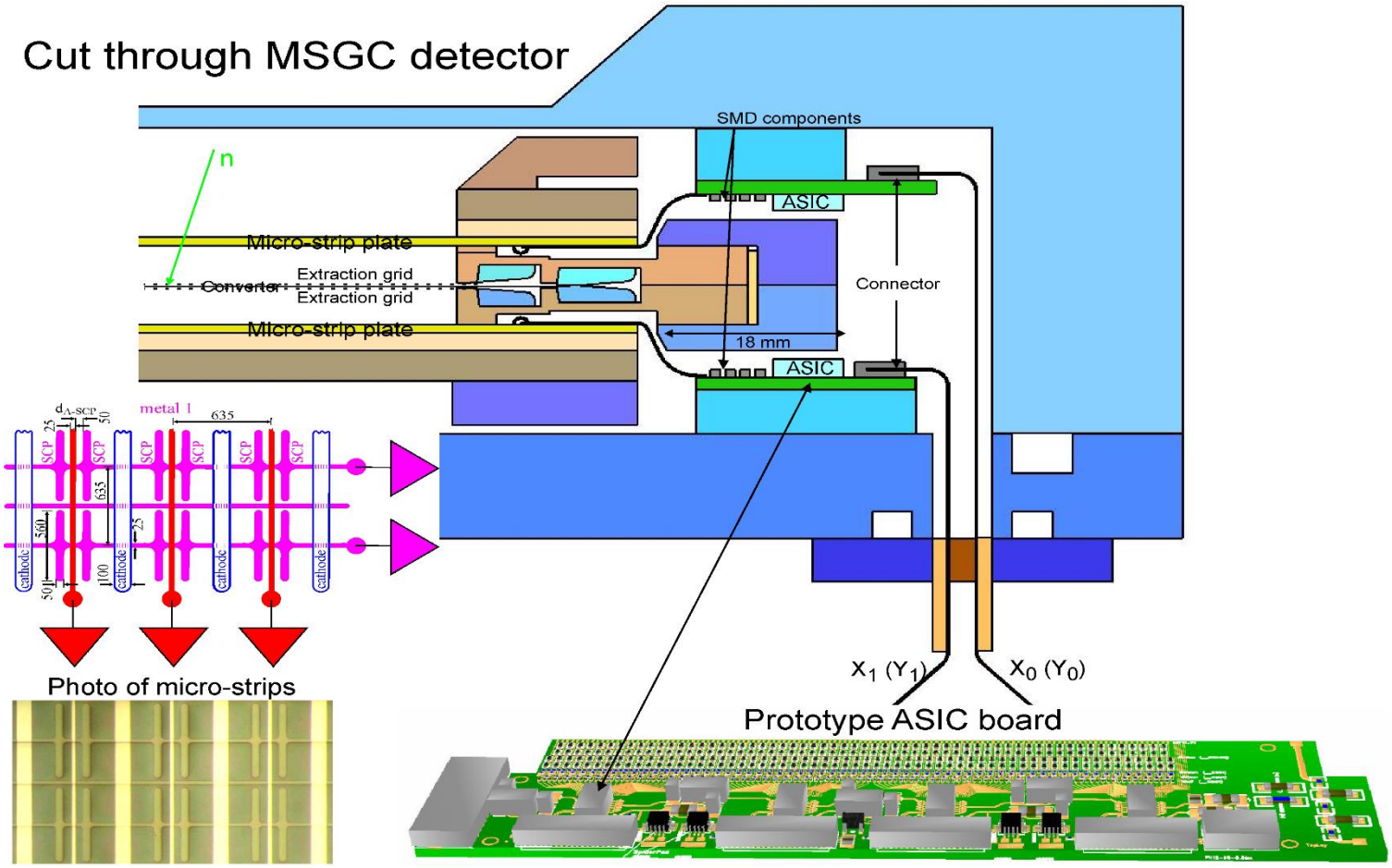
Outline

- Introduction
- MSGCROC
- GEMROC
- ARTROC/GEMROC2
- Summary

^{157}Gd/CsI MSGC neutron detector

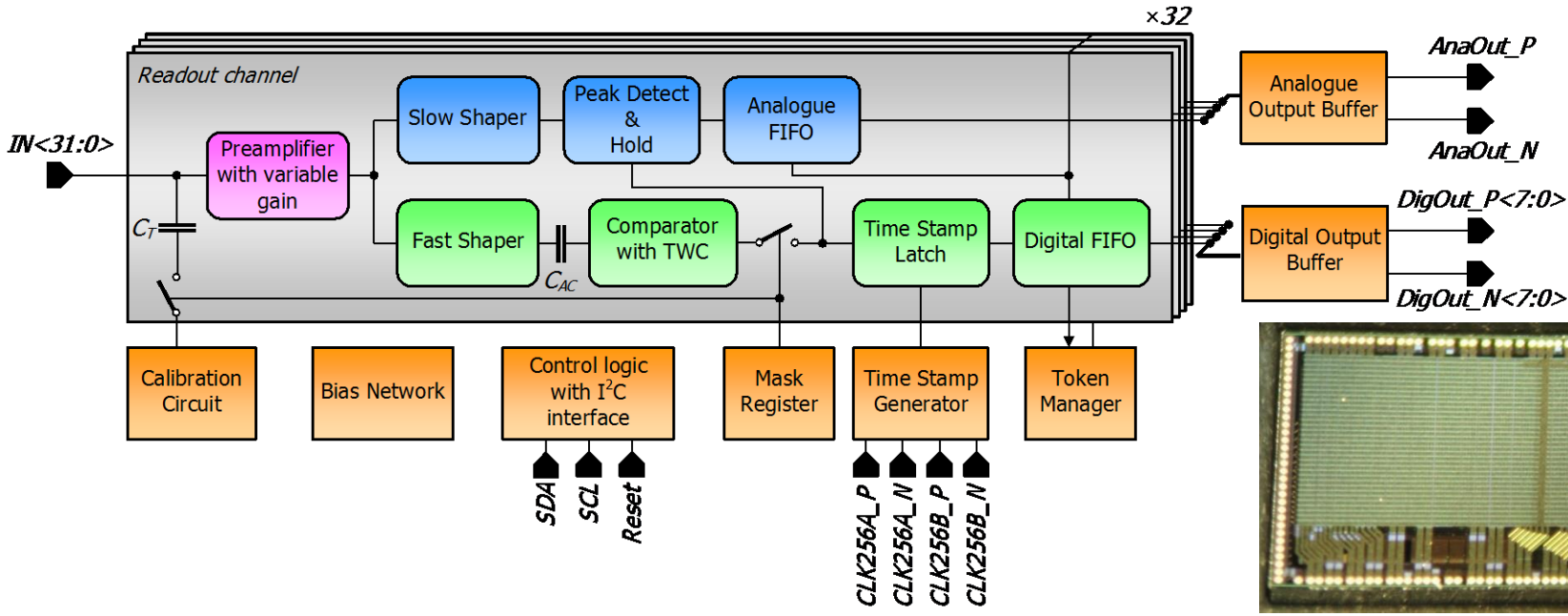


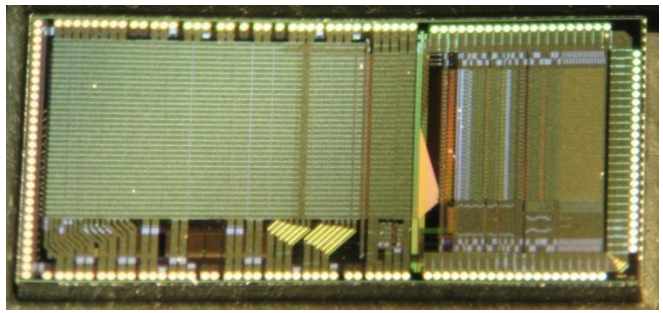
- Composite ^{157}Gd/CsI neutron converter foil, on negative electrical potential with extraction grids on either side, located in the central detector plane
- Two adjacent low-pressure (p~20mbar) preamplification gas gaps on either side of the converter followed by amplification at constant reduced field strength E/p.
- Two micro-strip gas detector planes, which function as third amplification and readout elements (400 stripes per detector module).

MSGCROC ASIC

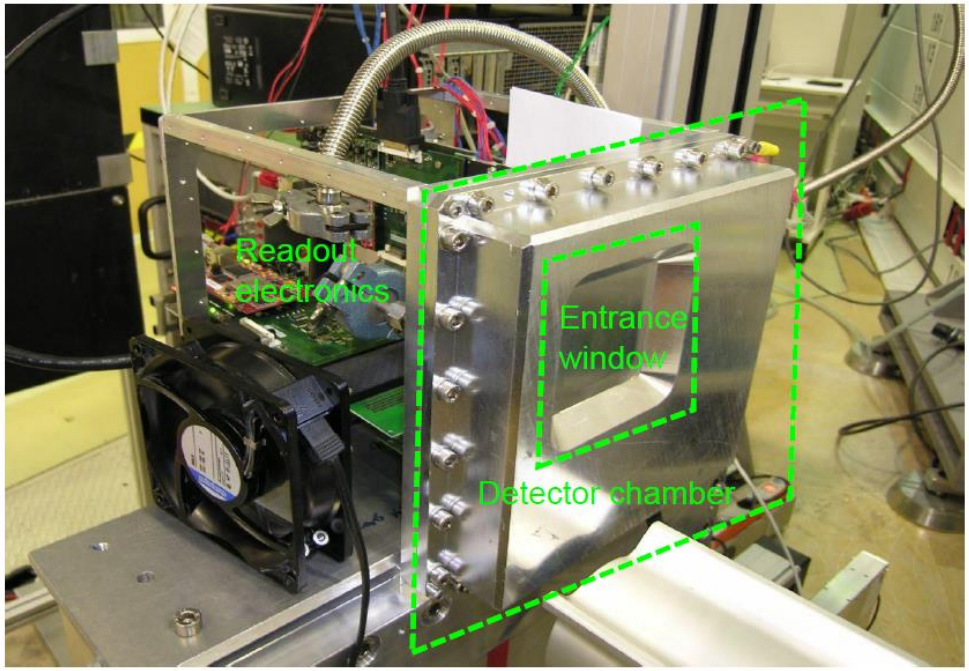
- Parameters to be measured: X/Y,T, E_X/E_Y
- Detector strip capacitance: ~ 23 pF
- Strip multiplicity per event: ~ 3.5 (c.o.g.)
- Hit rate per strip: ~ $9 \cdot 10^5$ /s
- Input signal charge: $2 \cdot 10^5$ e^- - $5 \cdot 10^6$ e^- (depending on gas gain)
- ENC required for E (5σ threshold): ~ 2000 e^- rms

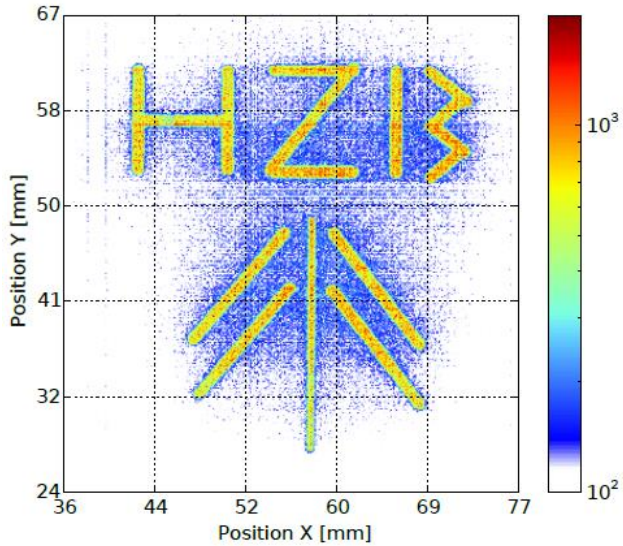
- X/Y coincidence window 2 ns + ($E_X = E_Y$)
- Discriminator: time walk < 2 ns, jitter < 1 ns FWHM.
- The preamp-shaper circuits must handle both polarities of the input signal and deliver signals of one polarity to the discriminator and peak detector circuit.
- Variable gain to cope with different detector gas gains





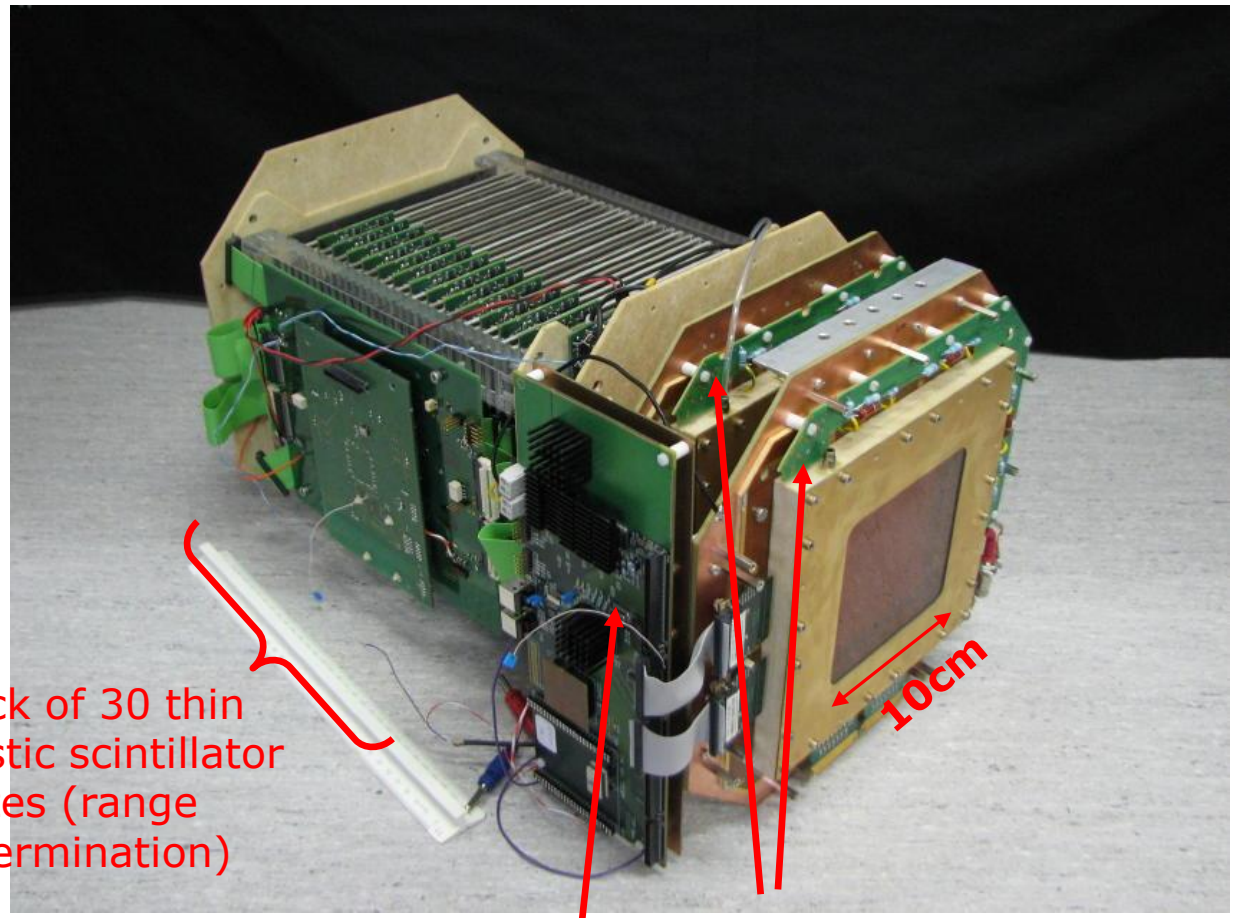
2-D imaging with neutrons





B. Mindur et al., *Performance of a Micro-Strip Gas Chamber for event wise, high rate thermal neutron detection with accurate 2D position determination*. JINST 9 P12004 (2014)

The Proton Range Radiography system



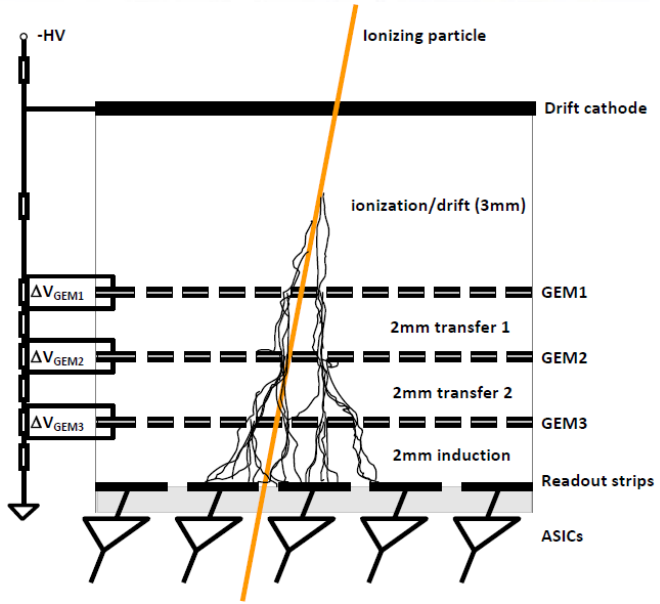
- diagnostic tool for proton radiotherapy
- to monitor position of irradiated organs in real time
- to measure residual proton energy (range) after crossing a target

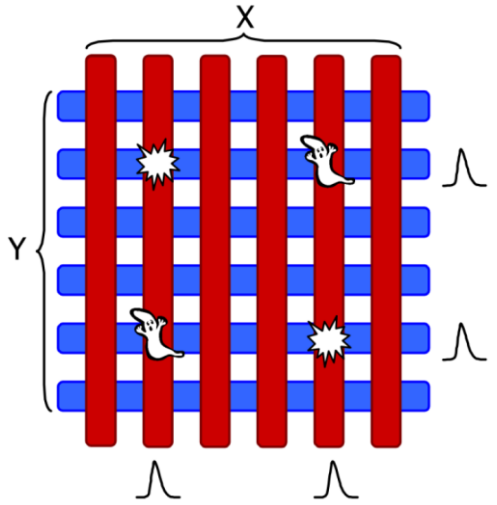
http://project-aqua.web.cern.ch/project-aqua/

Specification for the readout electronics

Determined by readout of large area 30x30 cm^2 2-D GEM detector in the PRR system

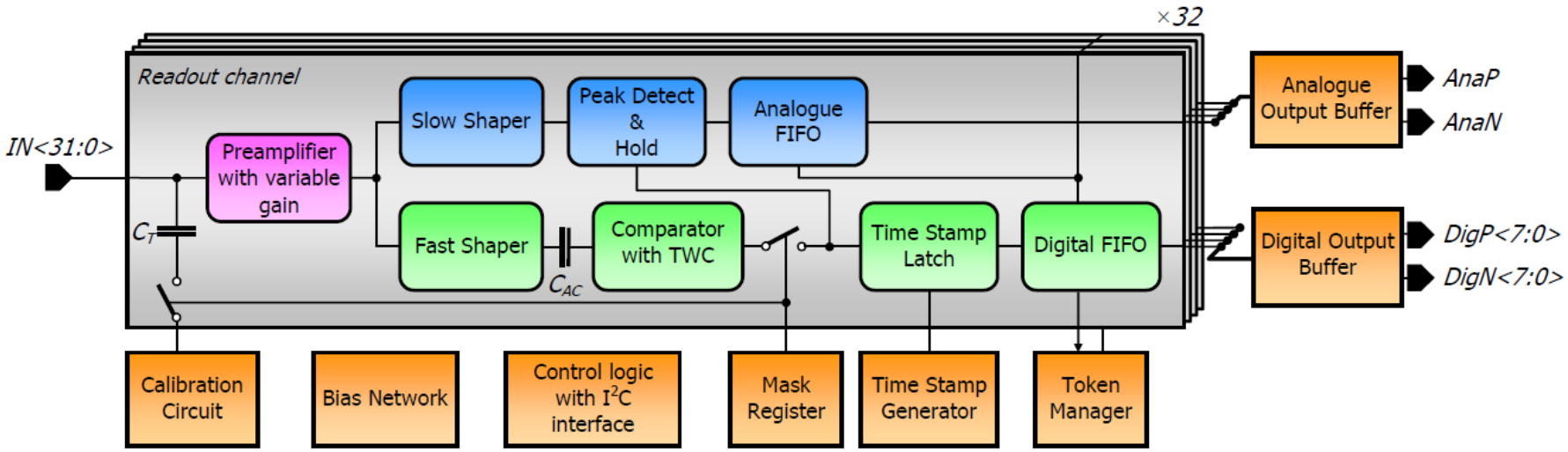
- input signals – short current pulses with the duration of 30ns
- input charge range from 2 to 500fC with the most probable value of 50fC
- noise defined as the Equivalent Noise Charge (ENC) below 0.5fC for the timing sub-channel and 0.43fC for the energy sub-channel (strip capacitance of 60pF)
- discrimination threshold 6fC input equivalent
- self-triggering
- expected particle flux ~10^6 $cm^{-2}s^{-1}$ ($3 \cdot 10^5$ pulses/s per readout channel appearing randomly in time)
- the maximum rate is limited by the time resolution of signals recorded from X and Y strips → required time resolution < 100ns peak-to-peak
- to be implemented as a multichannel Application Specific Integrated Circuit (ASIC)





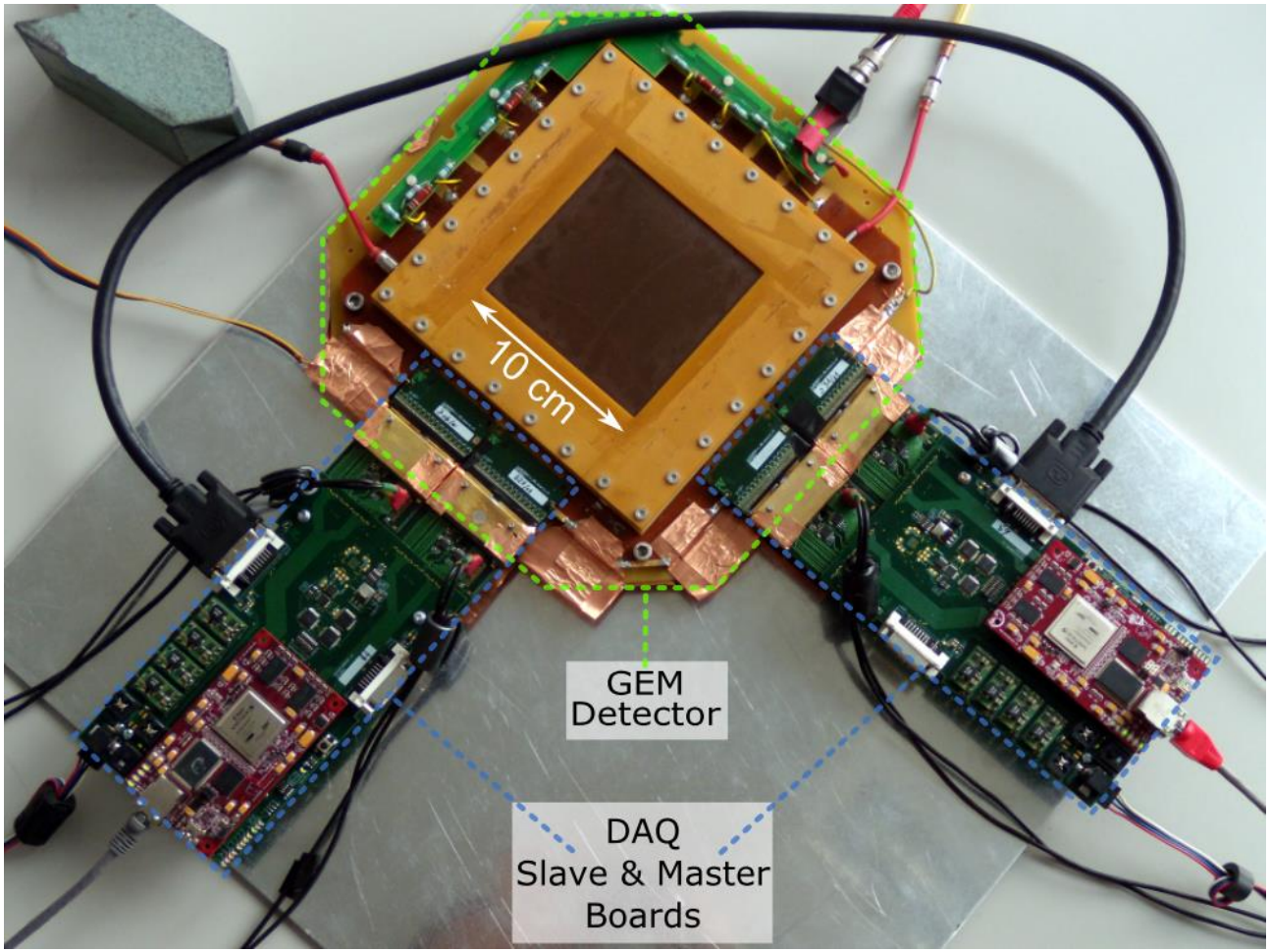
Position is derived from coincidences of X and Y signals

GEMROC architecture



- each channel is split into: slow (energy) and fast (timing) sub-channels
- switchable gain (2 modes) and signal polarity selection
- derandomization of data and zero suppression in the token-based readout
- self triggering mode – readout initiated by the input signal
- internal testability functions
- 32 channels per ASIC
- 0.35μm CMOS process

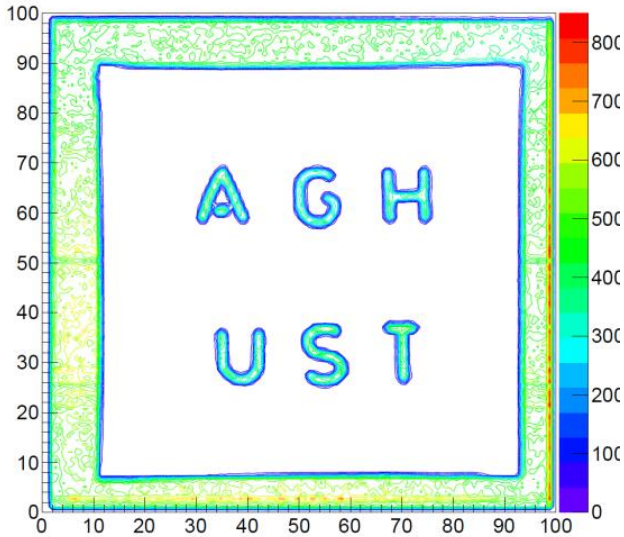
Detection system with triple-GEM (GEMROC ASIC)

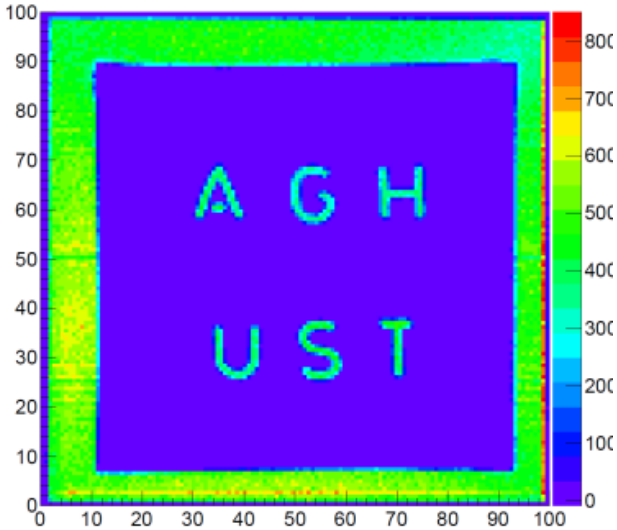


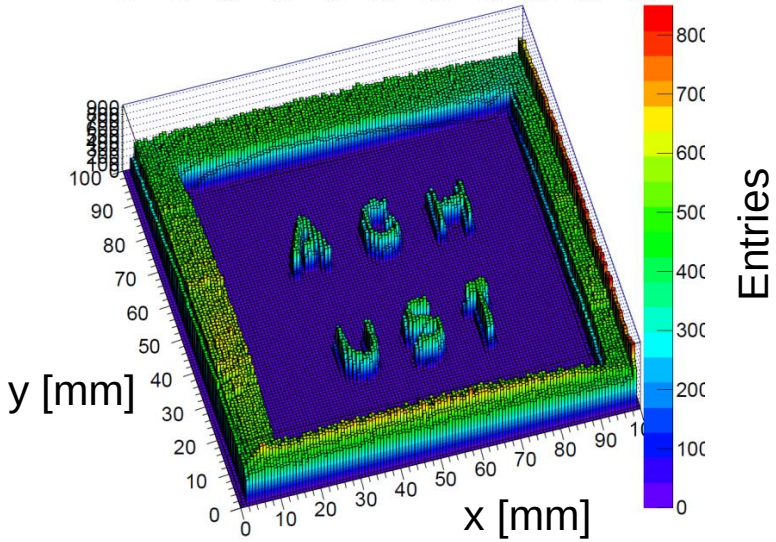
- Custom designed DAQ board with Ethernet based communication protocol
- Four 32-channel GEMROCs for each coordinate (one channel per two readout strips)
- Triple-GEM with 256 × 256 readout strips (pitch of readout strips is 800 μm)

T. Fiutowski et al., *Design and performance of the GEMROC ASIC for 2-D readout of gas electron multiplier detectors*, 2011 IEEE Nucl. Sci. Symp. Conf. Rec., (2011)
B. Mindur et al., *A compact system for two-dimensional readout of Gas Electron Multiplier detectors,* JINST 8 T01005 (2013)

2-D imaging with X-rays



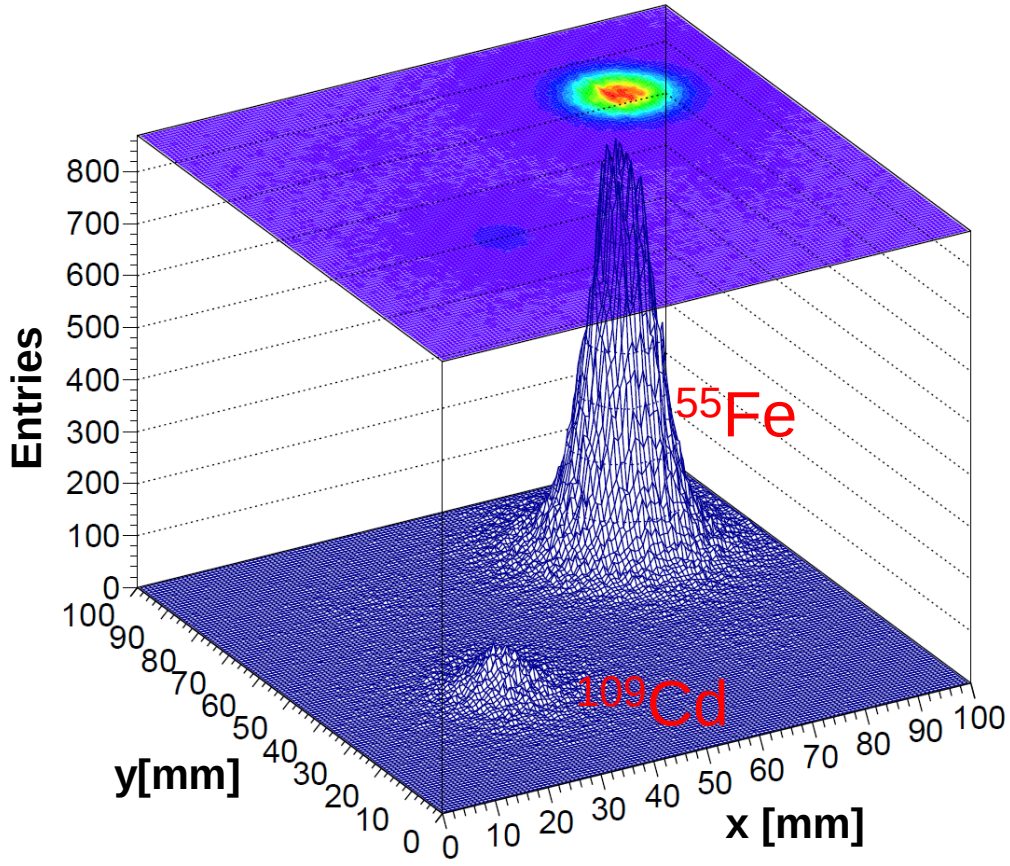




Reconstructed events count rate ~ 26 ke/s

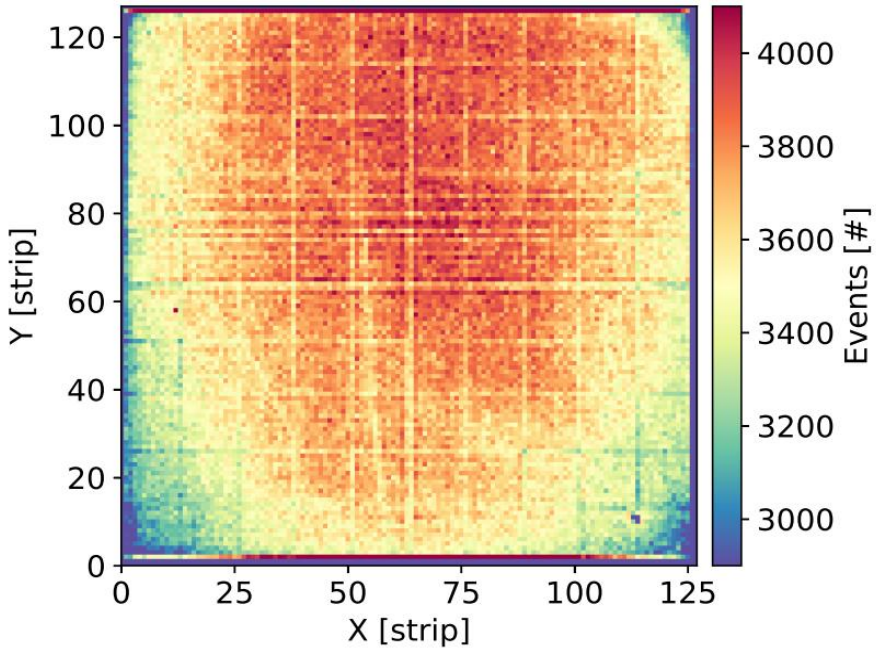
Count rate measurements

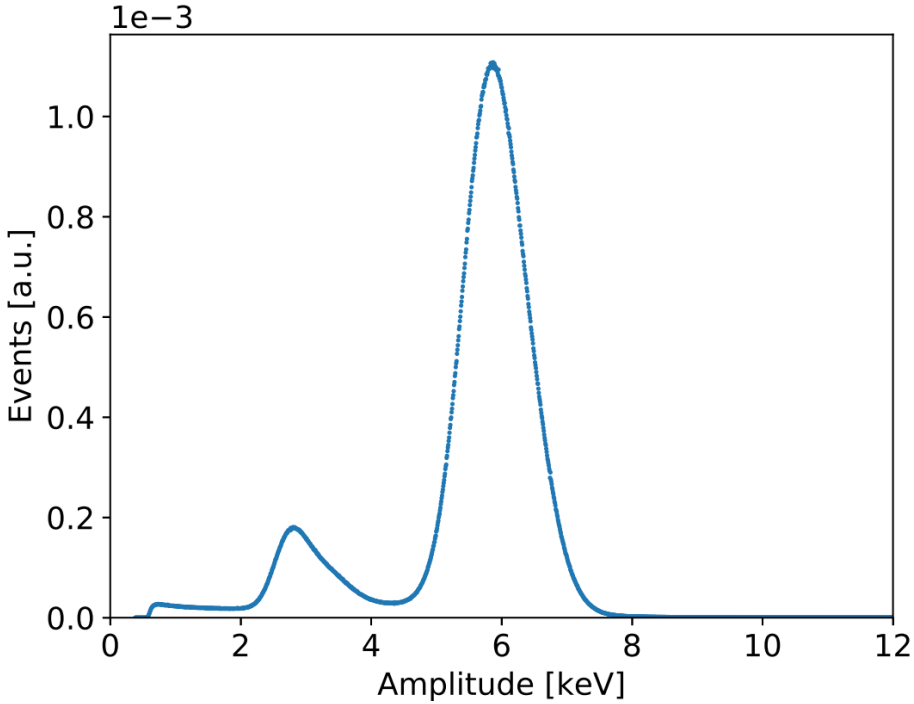
Simultaneous measurement with two X-ray sources Fe-55 and Cd-109



Reconstructed events count rate ~ 1.5 Me/s (Hits count rate ~ 5.6 Mh/s)

Energy resolution





Energy resolution Fe-55 (FWHM) - **19.8%** @ 3860V Ar/CO_2 (70/30)

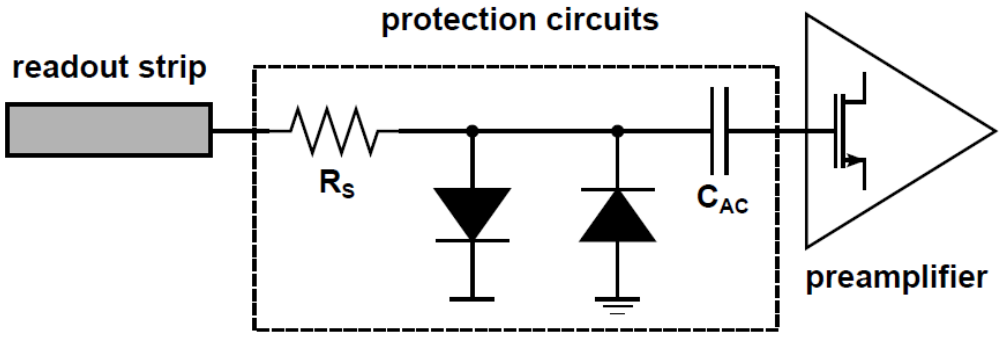
GEMROC upgrade motivation

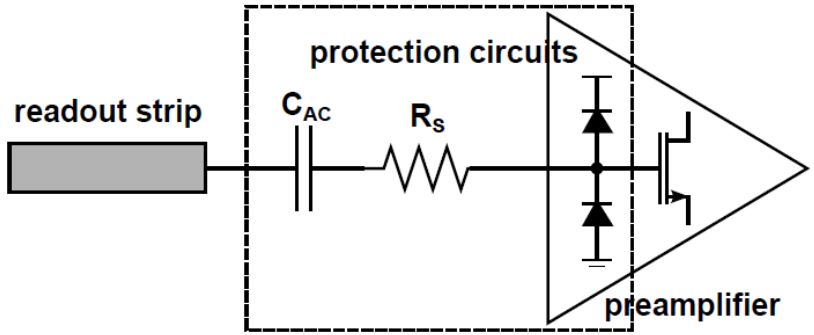
- Much simpler assembling
  - Higher number of channels in one ASIC
    - one plane read out by two ASICs (800 μm readout pitch)
    - one plane read out by four ASICs (400 μm readout pitch)
  - Integrated input protection against discharges

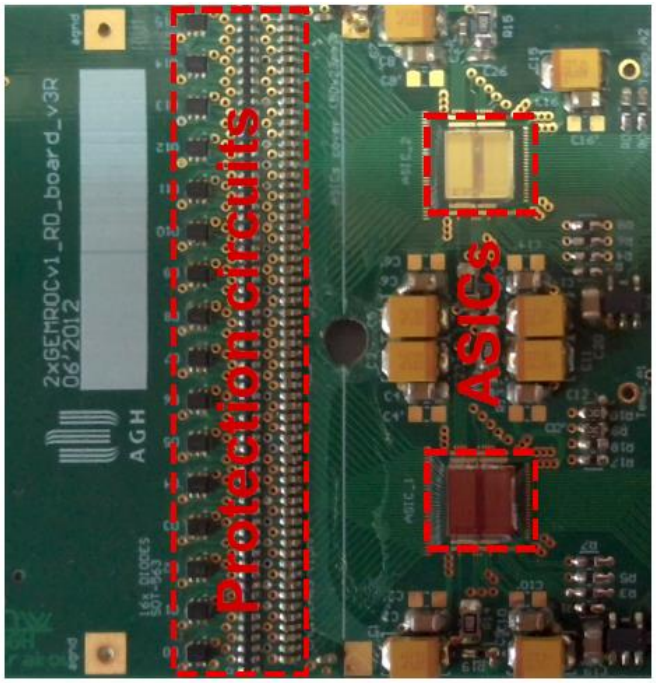
- Optimization of the system energy resolution
  - Higher dynamic range
  - Lower electronic noise level (slower readout)
  - Higher front-end gain (lower gas gain)

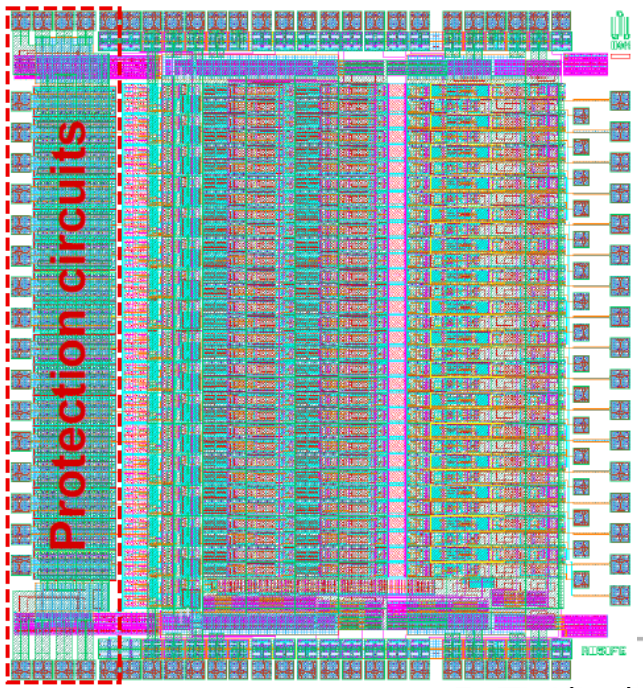
Protection against discharges

External SMD components vs. integrated structures



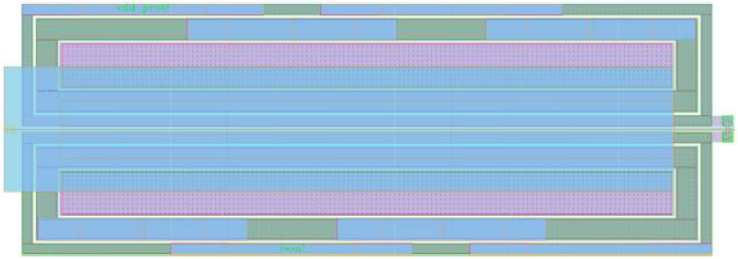




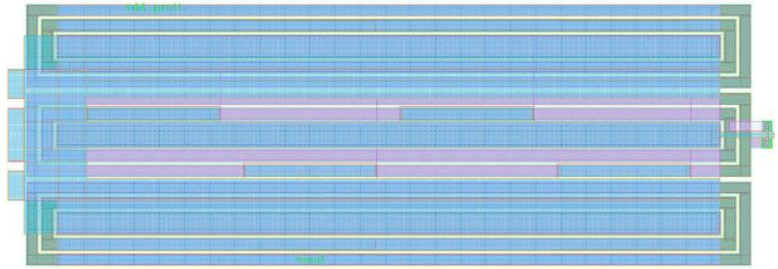


Protection against discharges

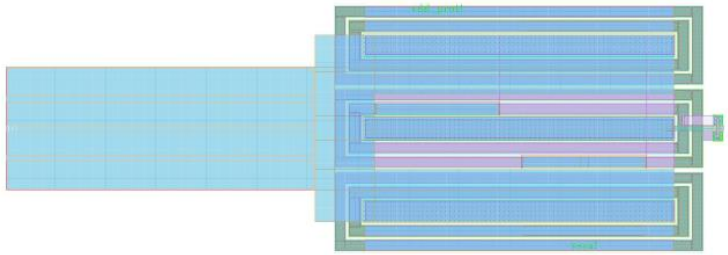
Designed integrated structures



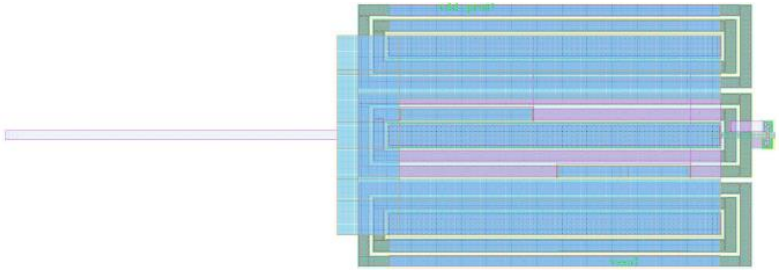
A: P-type & N-type diode, 2×9500 μm^2



B: P-type & 2×N-type diode, 3×5000 μm^2



C: P-type & 2×N-type diode, 3×2500 μm^2



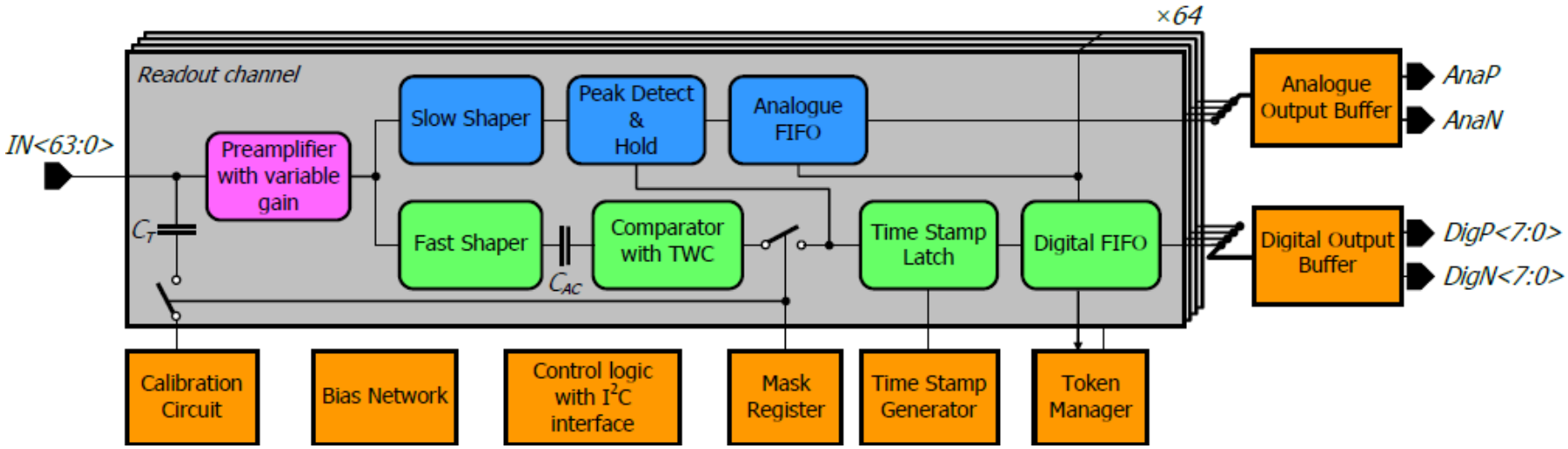
D: P-type & 2×N-type diode + 4Ω metal resistor

During destructive tests failure observed only for structure D

T. Fiutowski et al., *Front-end electronics for Micro Pattern Gas Detectors with integrated input protection against discharges*, JINST 11 C01036 (2016)

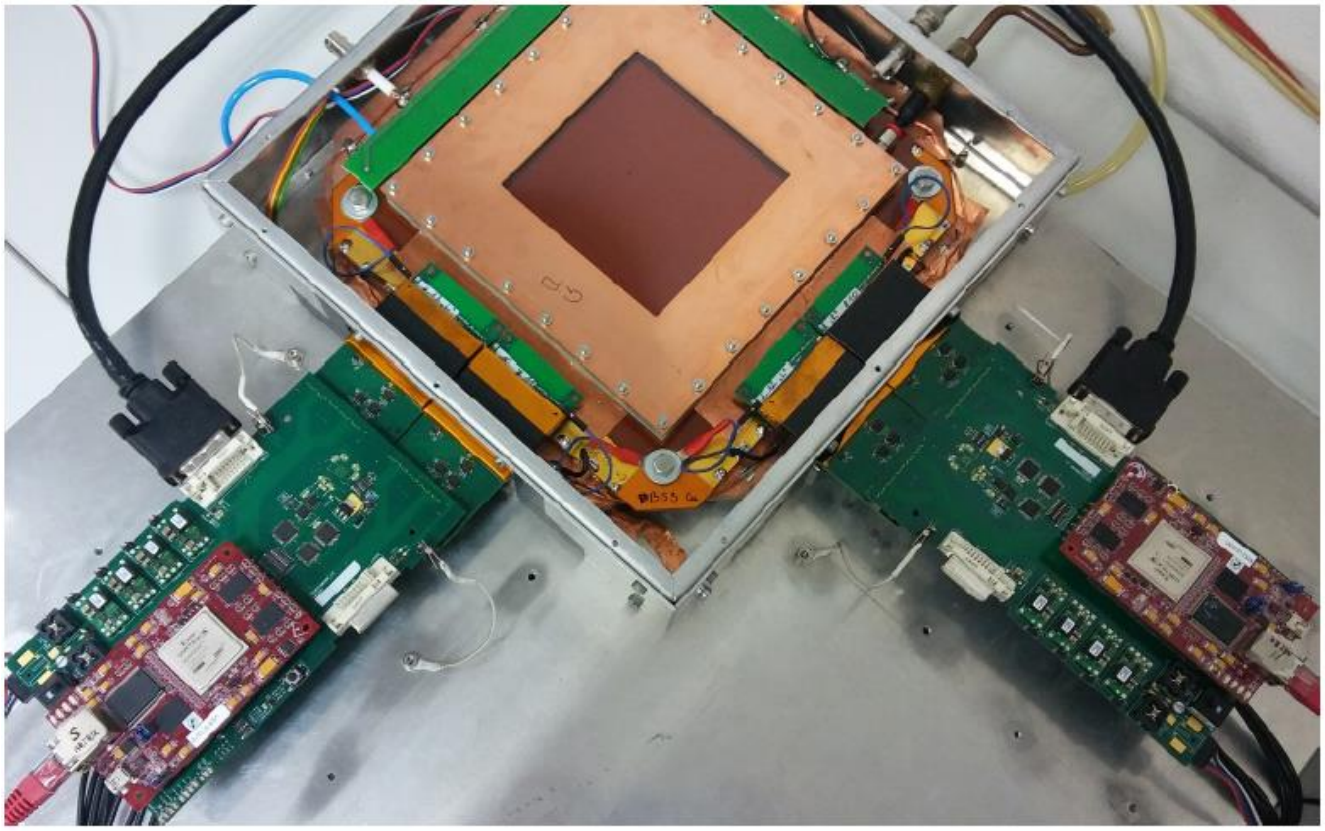
T. Fiutowski et al., I*ntegrated input protection against discharges for Micro Pattern Gas Detectors readout ASICs*, JINST 12 C02021 (2017)

ARTROC/GEMROC2 architecture



- each channel is split into: slow (energy) and fast (timing) sub-channels
- switchable gain (6 modes) and signal polarity selection
- derandomization of data and zero suppression in the token-based readout
- self triggering mode – readout initiated by the input signal
- internal testability functions
- 64 channels per ASIC
- integratedd input protection against discharges
- 0.35µm CMOS process

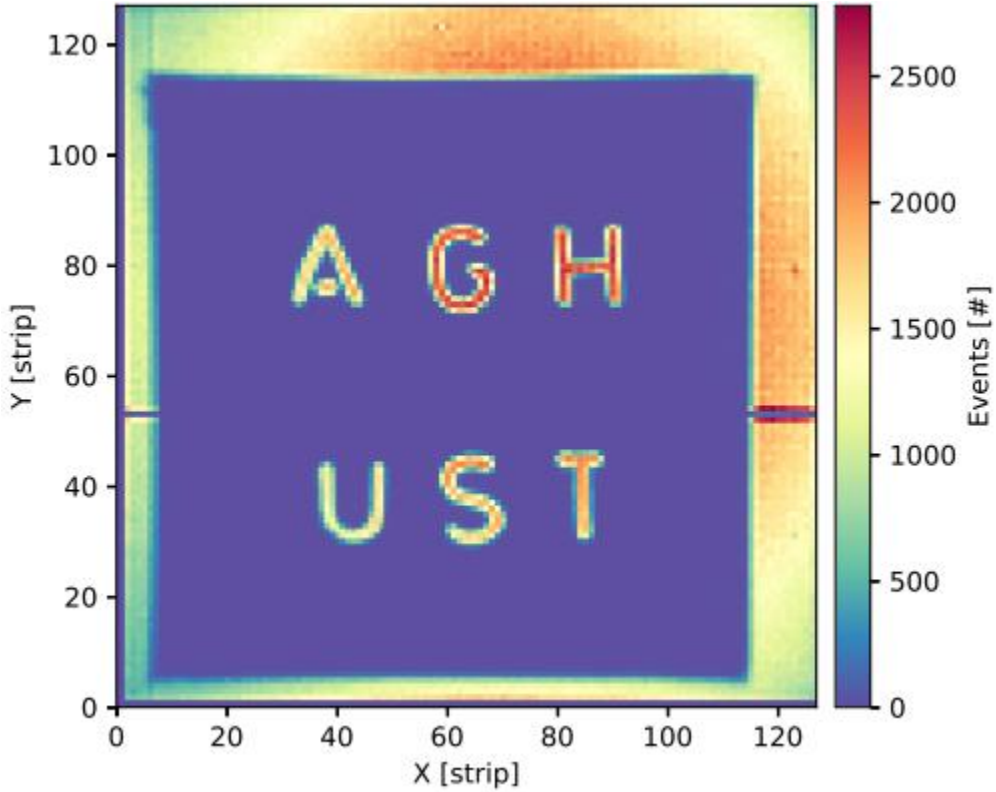
Detection system with triple-GEM (ARTROC/GEMROC2 ASIC)



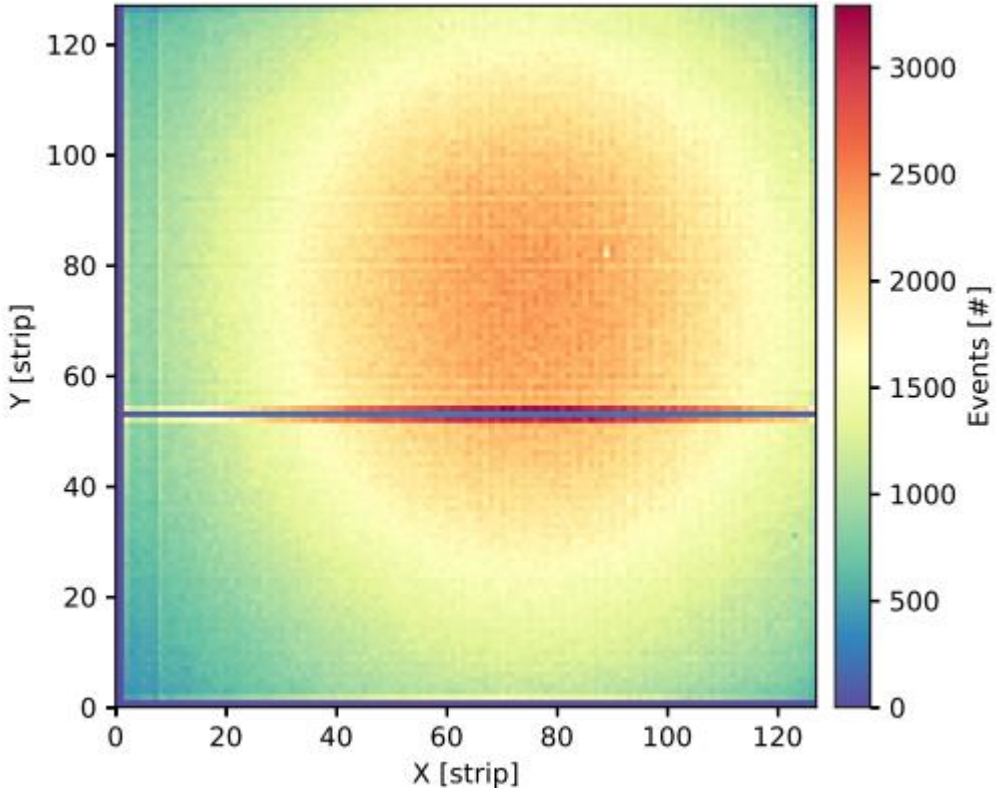
- Custom designed DAQ board with Ethernet based communication protocol
- Two (four) 64-channel GEMROC2 for each coordinate (one channel per two (one) readout strips)
- Triple-GEM with 256 × 256 readout strips (pitch of readout strips is 800 (400) μm)

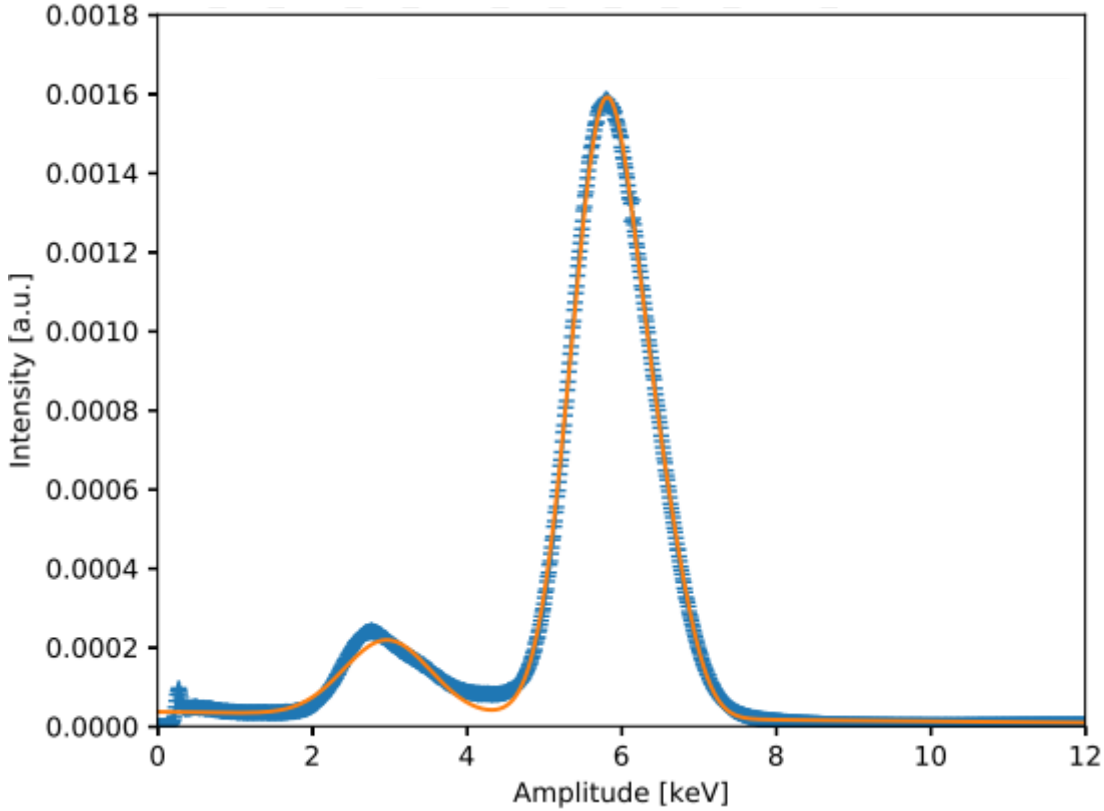
T. Fiutowski et al., ART*ROC – a readout ASIC for GEM-based full-field XRF imaging system,* JINST 12 C12016 (2017)

2-D imaging
(800 μm readout pitch)



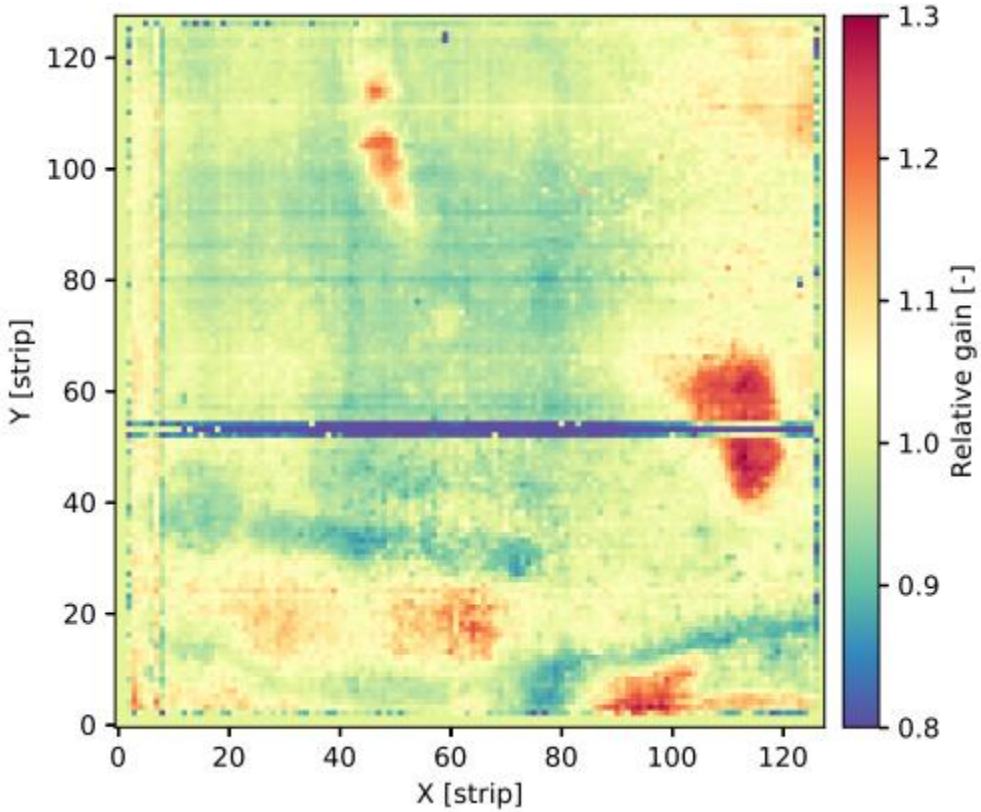
2-D imaging
(800 µm readout pitch)

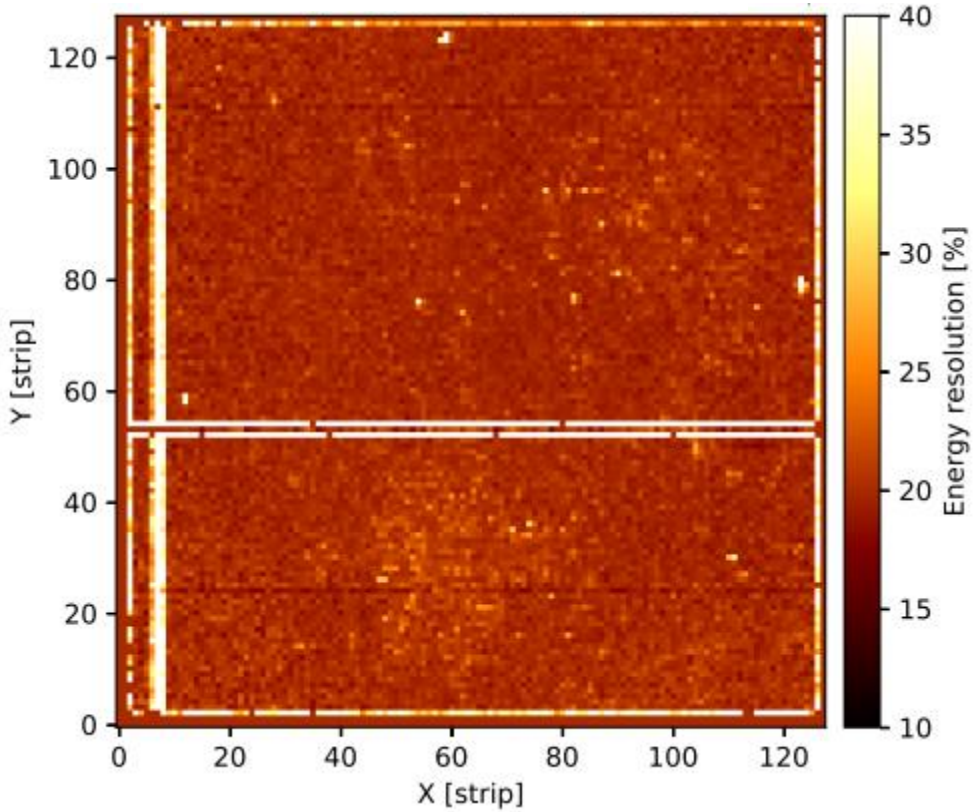




Energy resolution Fe-55 (FWHM) - **17.6%** @ 3470V Ar/CO_2 (80/20)

Gas-gain variations and local energy resolution

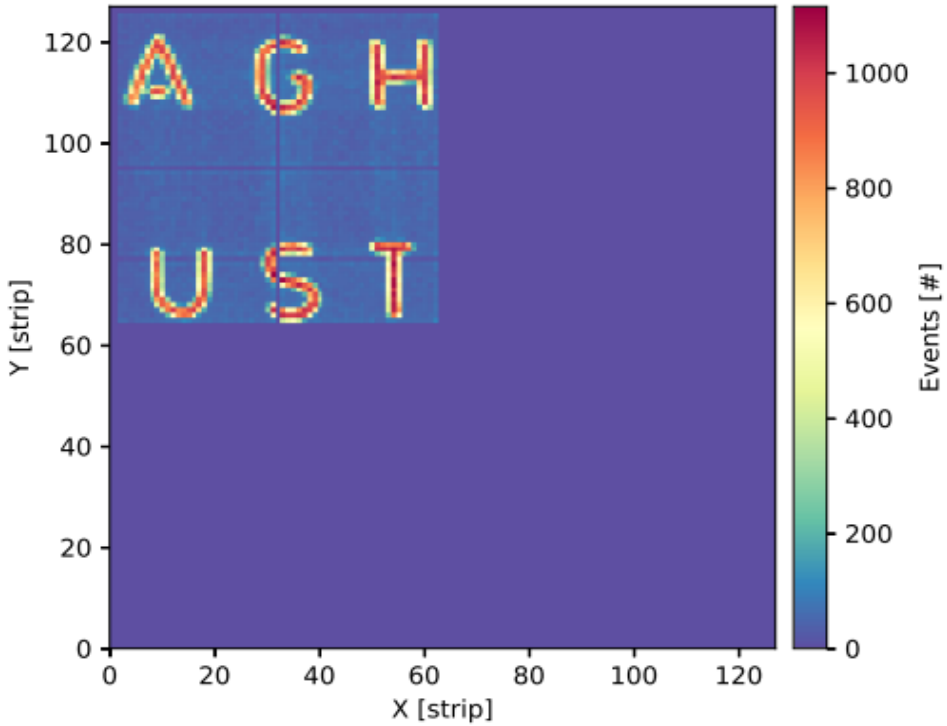


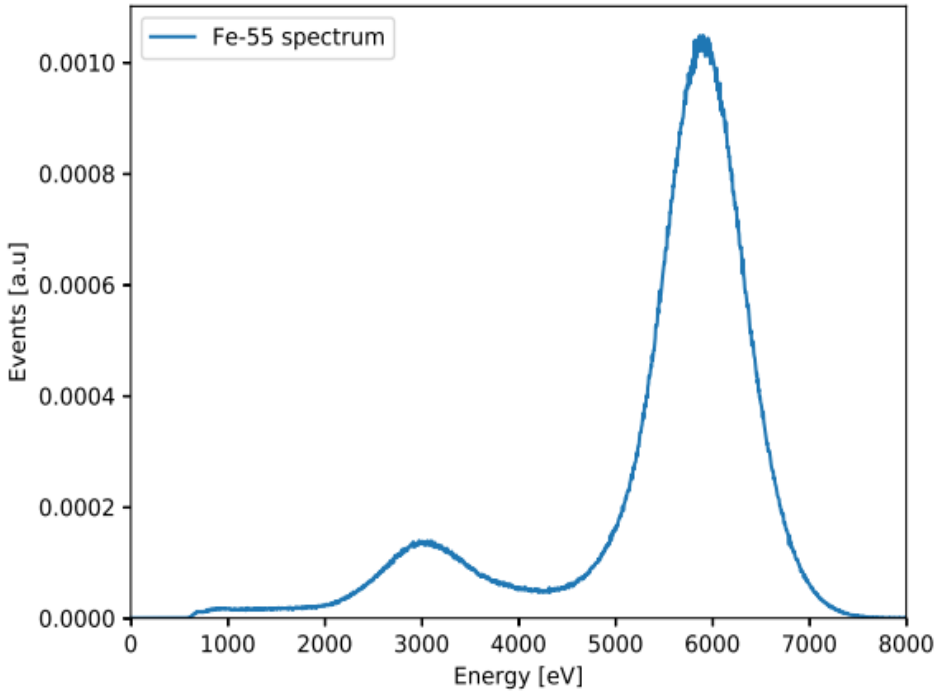


Energy resolution Fe-55 (FWHM) - 17.6% @ 3470V Ar/CO_2 (80/20)

2-D imaging
(800 µm readout pitch)

One ASIC board per plane is used (one forth of the detector is read out)

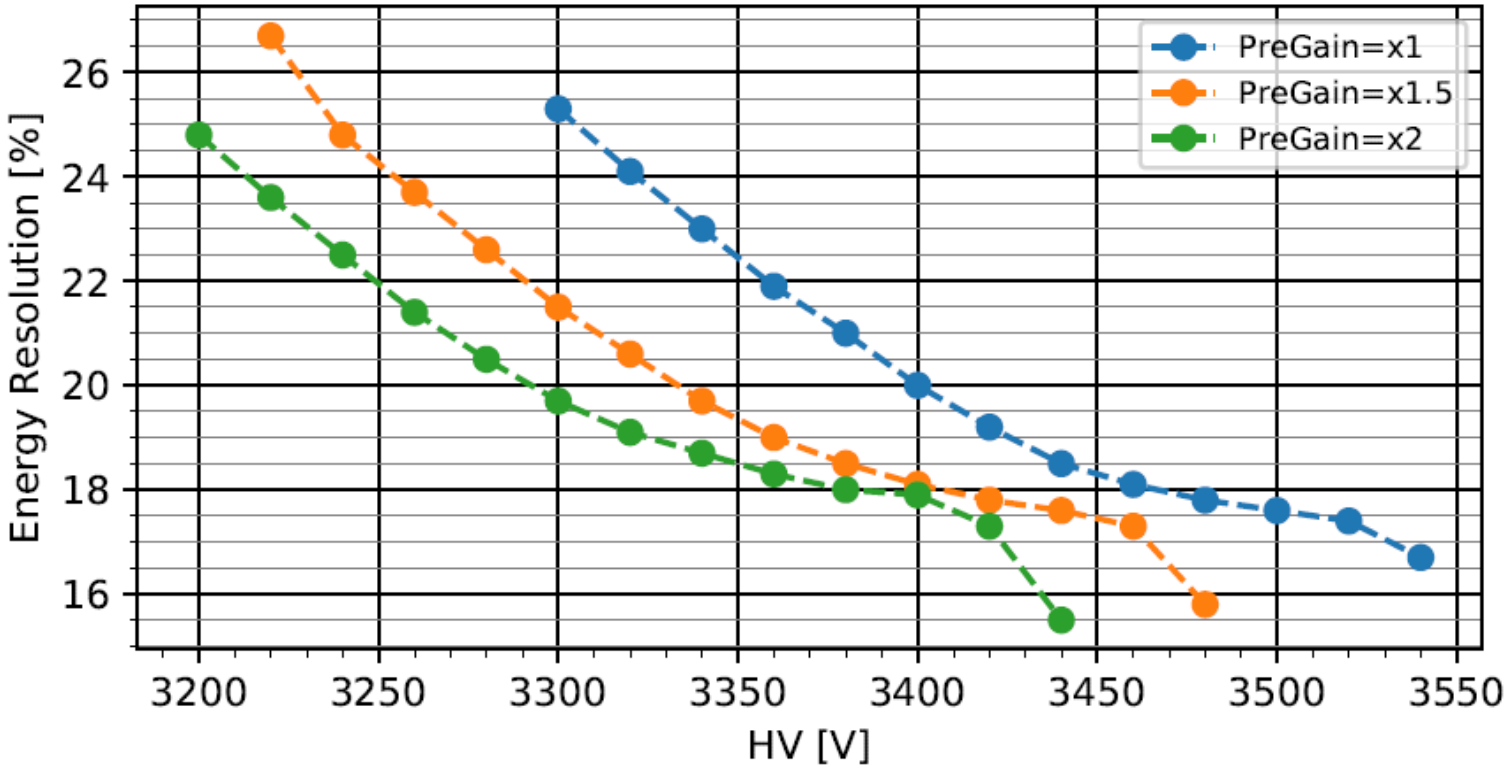




Energy resolution Fe-55 (FWHM) - **15.7%** @ 3600V Ar/CO_2 (80/20)

Energy resolution vs. system gain

Energy resolution Fe-55 (FWHM) for Ar/CO_2 (80/20)



Theoretical intrinsic energy resolution of the GEM detector ~17%

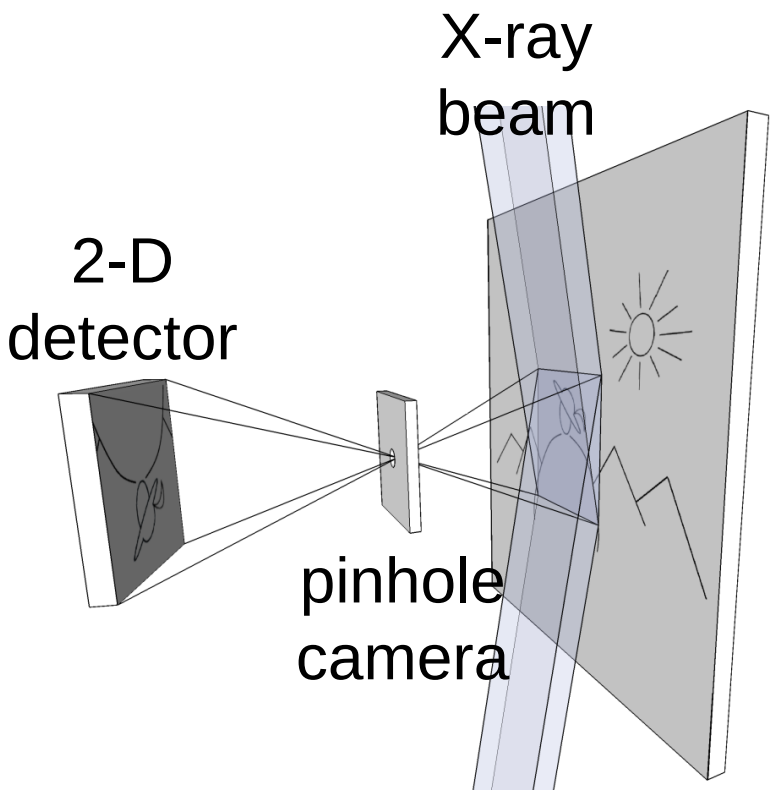
$$R_{FWHM} = \sqrt{8ln\,(2)\,\frac{1}{n_0}\left(F + \frac{\bar{A}-1}{\bar{A}}\right)}$$

Motivation – system perspective

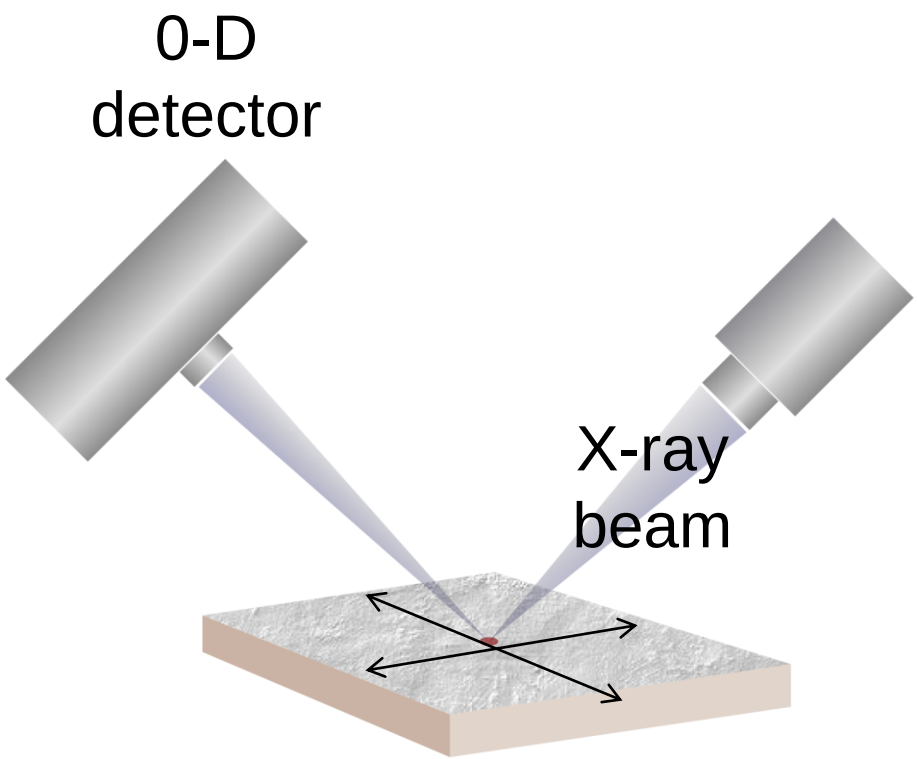
- Great interest in non-destructive techniques for investigation of large area historical art objects, mainly paintings
- Mapping of elemental distribution in non-visible layers, e.g. underpaintings using the X-ray fluorescence (XRF) technique
- Fast screening of large area objects with dimensions up to 1 m or more
- Investigation of large area non-flat objects

Full-field vs macro-XRF imaging

Full-field imaging



Macro-XRF imaging



Full-field vs macro-XRF imaging

Full-field imaging

- Spatial resolution determined by the diameter of the pinhole camera and detector spatial resolution
- Simultaneus imaging of large area
- 2-D position sensitive and energy dispersive detector needed
- Custom-designed systems under developement

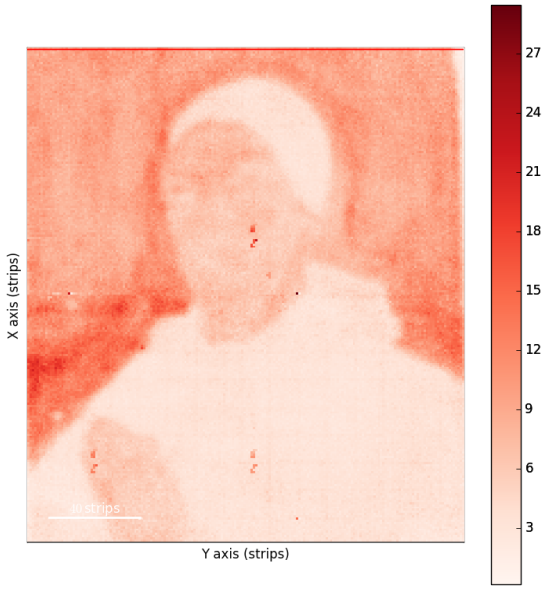
Macro-XRF scanning

- Spatial resolution determined by the diameter of exciting beam
- Time consuming scanning of large areas
- Possibility of employing high energy resolution 0-D detectors
- Commercial and custom developed system exist

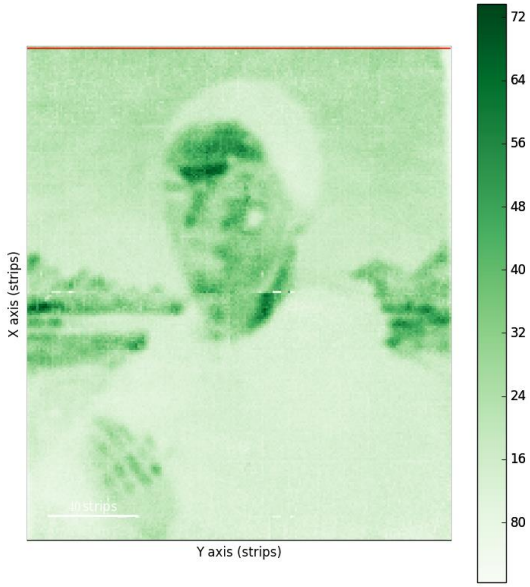
Commonly used historical pigments

Pigment	X-ray characteristic lines
Umber	Mn-Kα – 5.90 keV, Fe-Kα – 6.40 keV
Carbon black	Fe-Kα – 6.40 keV
Cobalt blue	Co-Kα – 6.93 keV, Co-Kβ – 7.65 keV
Azurite	Cu-Kα – 8.05 keV, Cu-Kβ – 8.90 keV
Zinc white	Zn-Kα – 8.64 keV, Zn-Kβ – 9.57keV
Vermilion	Hg-Lα – 9.99 keV, Hg-Lβ – 11.92 keV
Lead-tin yellow	Pb-Lα – 10.55 keV, Pb-Lβ – 12.62 keV
Lead white	Pb-Lα – 10.55 keV, Pb-Lβ – 12.62 keV

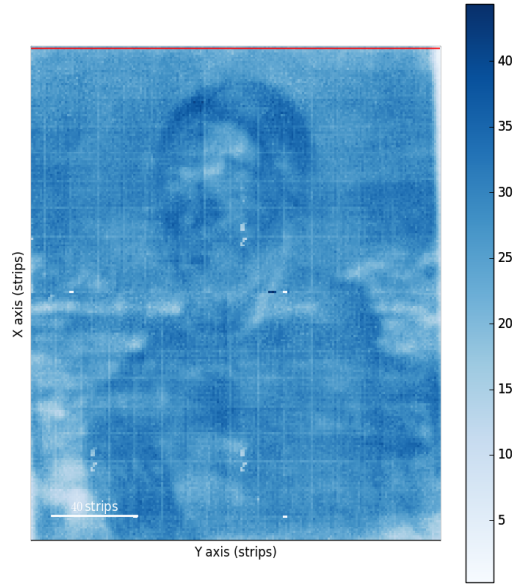
Results
Hidden layers



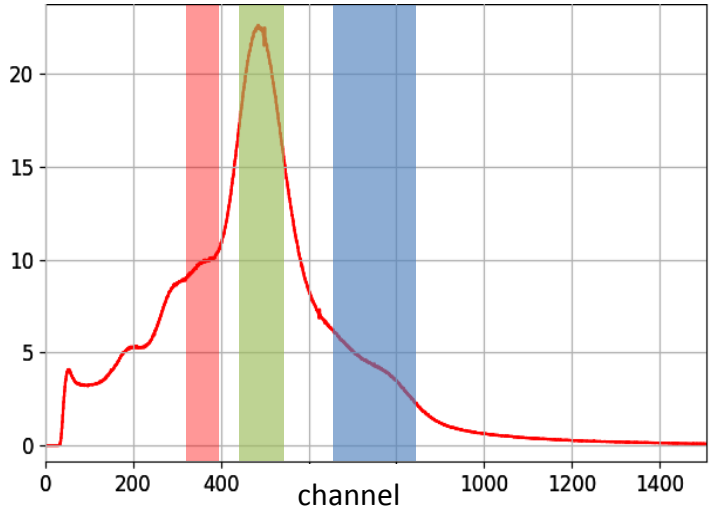
Fe and Mn map (5.8-6.8 keV)



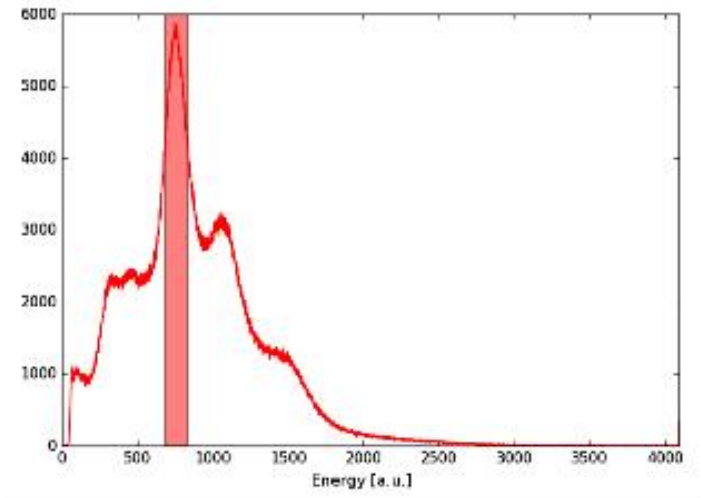
Cu Map (7.6-8.4 keV)

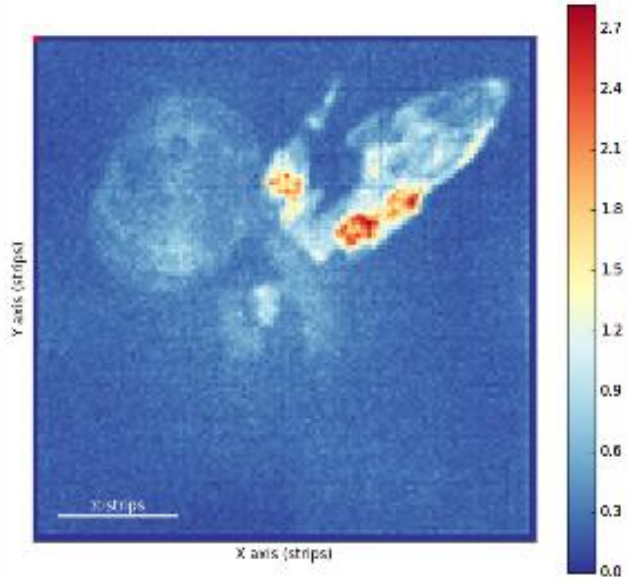


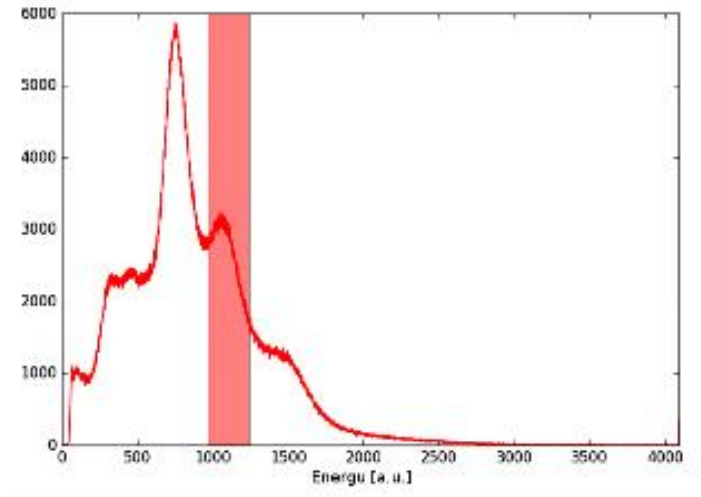
Pb and Hg map (9.6-13 keV)

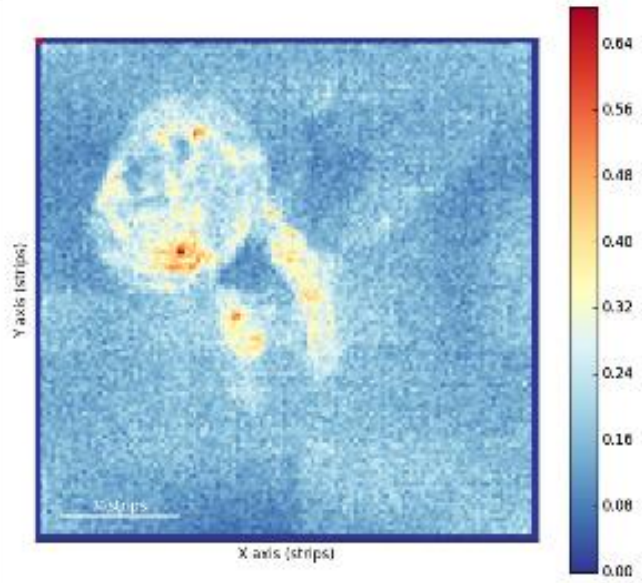


Results
Curved surfaces









Summary

- Long experience in designing ASICs and building readout setups for MPGD
- The best ever published energy resolutions for 10cm×10cm GEM detector and Ar/CO_2 mixture
  - at the level of 15.7% for the selected area.
  - at the level of 17.6% for the whole detector area.
- Plans for near future
  - measurements with 400 μm readout pitch
  - measurements with Kr based gas mixtures