ARTROC – a readout ASIC for GEM-based full-field XRF imaging system

T. Fiutowski, W. Dąbrowski, S. Koperny, B. Łach, B. Mindur, K. Świentek and P. Wiącek

AGH University of Science and Technology

Faculty of Physics and Applied Computer Science

Work supported by the **Polish National Centre for Research and Development**

Grant no. **PBS3/A9/29/2015**

Outline

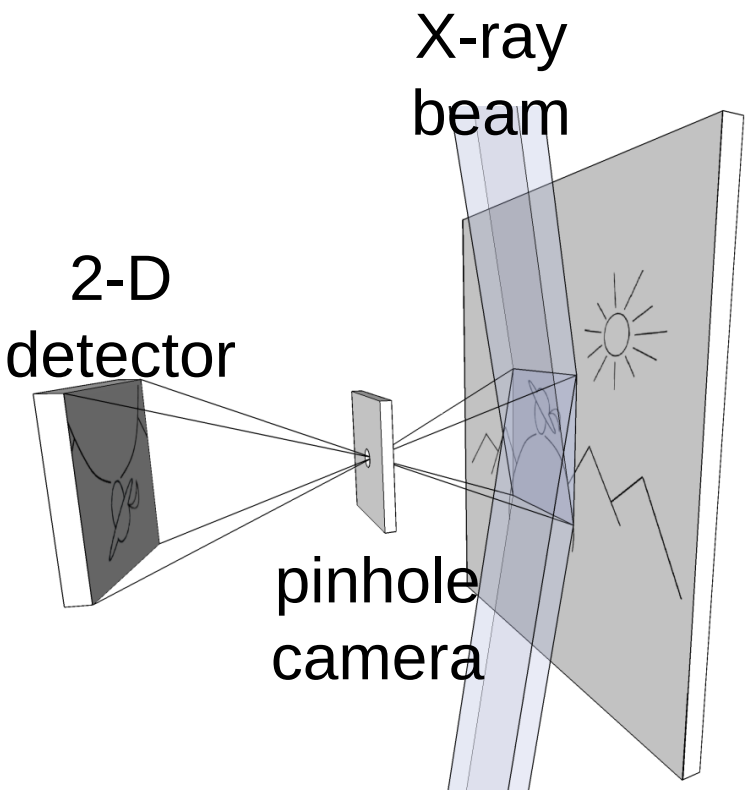
- Motivation – system perspective
  - full-flield vs. Macro-XRF imaging
- Motivation – ASIC perspective
  - limitations of the pliot proof-of-principle set-up
- Measurement results
  - physical tests (Readout System)
  - electronic tests (ASICs)
- Conclusions

Motivation – system perspective

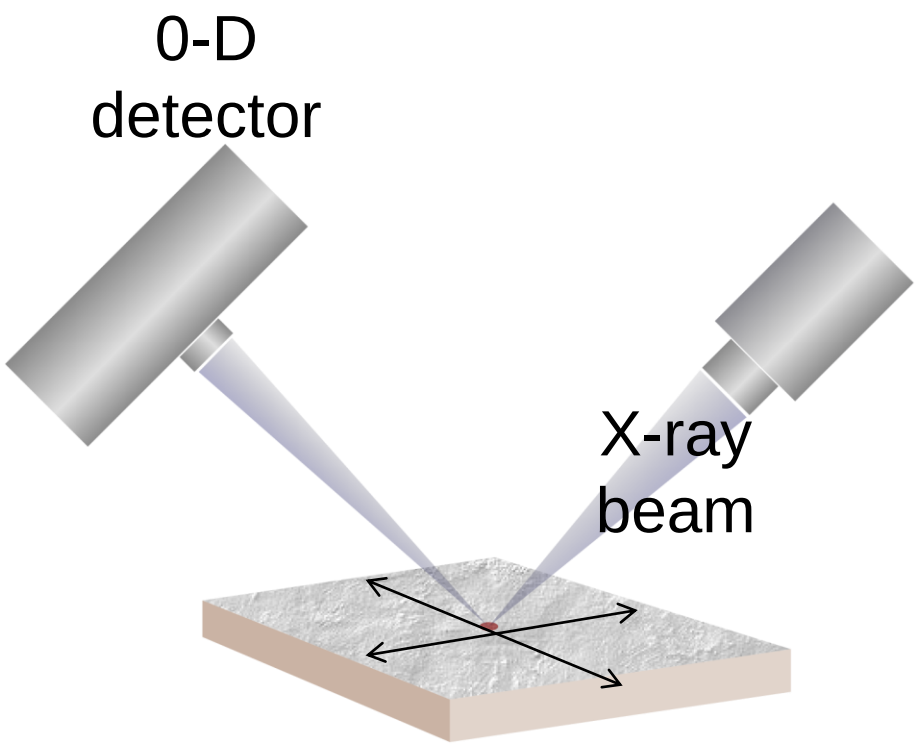
- Great interest in non-destructive techniques for investigation of large area historical art objects, mainly paintings
- Mapping of elemental distribution in non-visible layers, e.g. underpaintings using the X-ray fluorescence (XRF) technique
- Fast screening of large area objects with dimensions up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

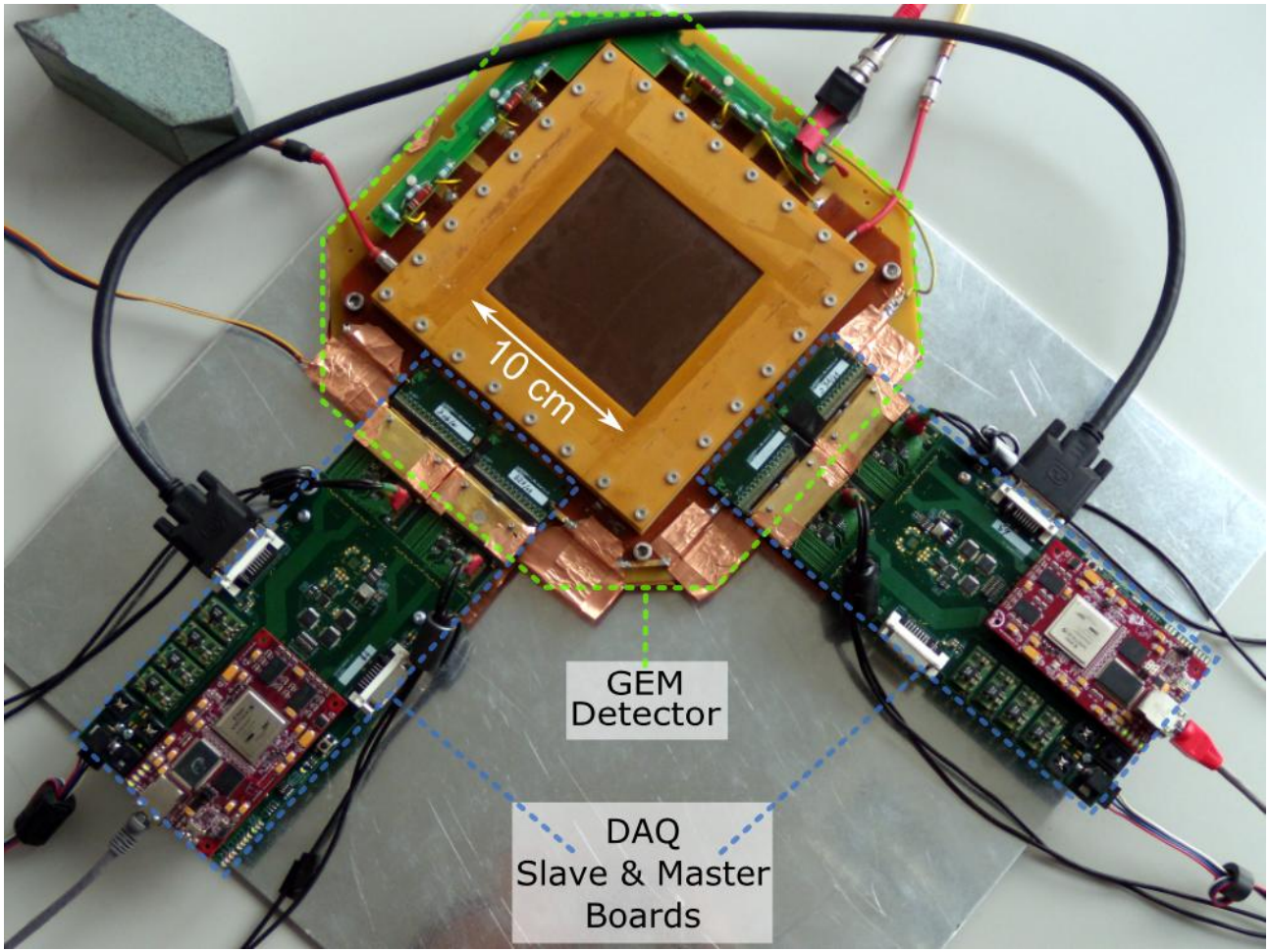
Full-field imaging

- 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 development

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

Detection system with triple-GEM (GEMROC ASIC)

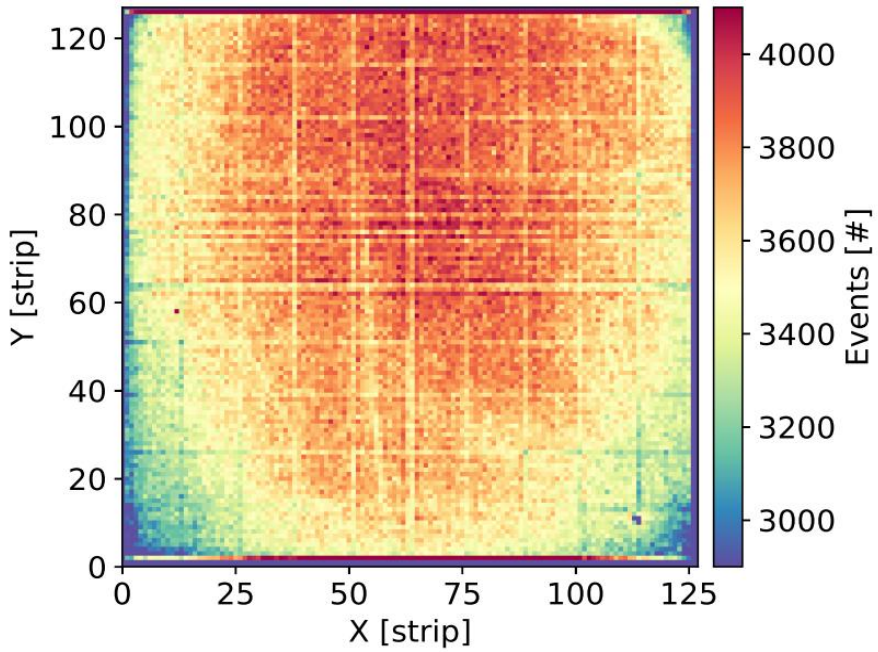


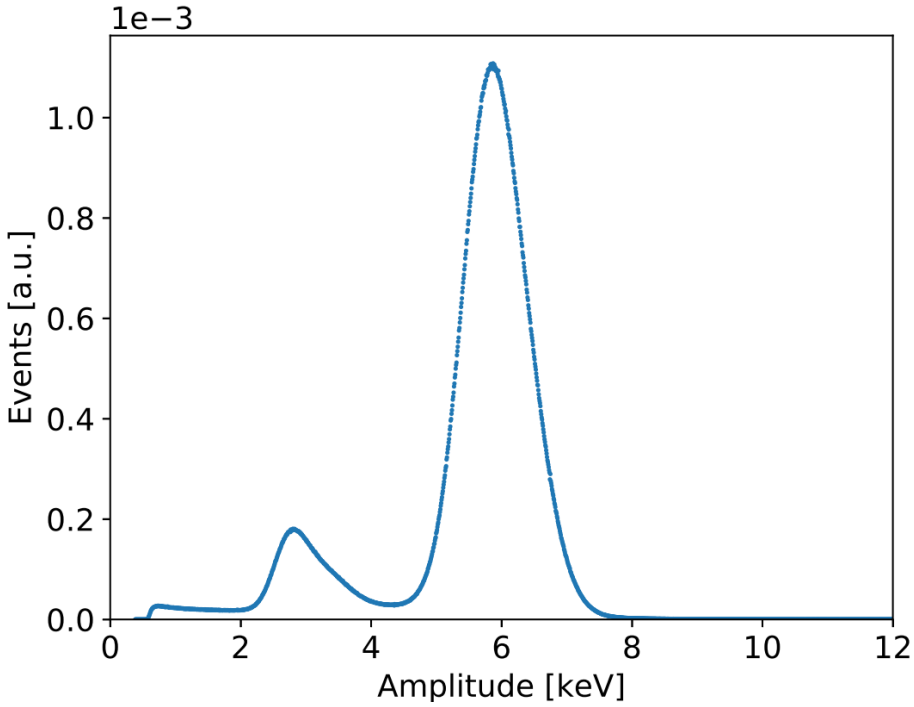
- custom designed DAQ board with Ethernet based communication protocol
- four 32-channel GEMROCs for each coordinate (one channel per two readout strips)
- triple-GEM with 256 × 256 readout strips (pitch of readout strips is 800 μm)

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)

Energy resolution (GEMROC set-up)





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

Commonly used historical pigments

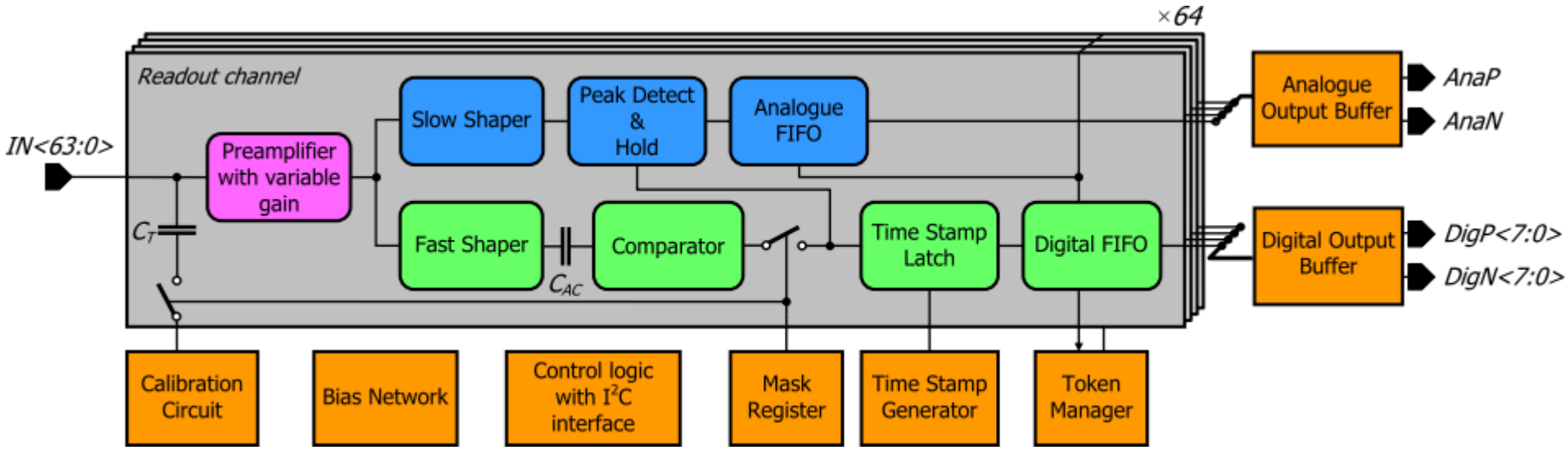
Pigment	X-ray characteristic lines
Umber	Mn-Kα – 5.90 keV, Fe-Kα – 6.40 keV
Carbon black	Fe-Kα – 6.40 keV
Cobalt blue	Co-Kα – 6.93 keV, Co-Kβ – 7.65 keV
Azurite	Cu-Kα – 8.05 keV, Cu-Kβ – 8.90 keV
Zinc white	Zn-Kα – 8.64 keV, Zn-Kβ – 9.57keV
Vermilion	Hg-Lα – 9.99 keV, Hg-Lβ – 11.92 keV
Lead-tin yellow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

Motivation – ASIC perspective

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

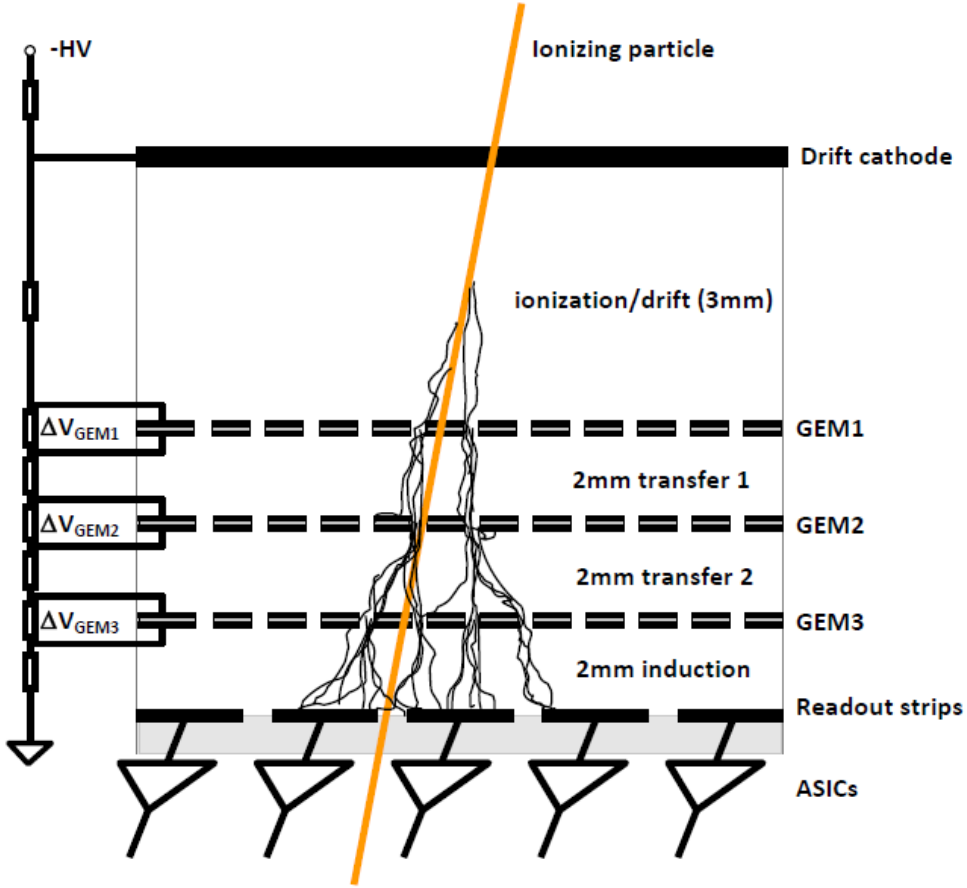
- Much simpler assembling
  - Higher number of channels in one ASIC
    - one plane read out by two ASICs (800 μm readout pitch)
    - one plane read out by four ASICs (400 μm readout pitch)
  - Integrated input protection against discharges

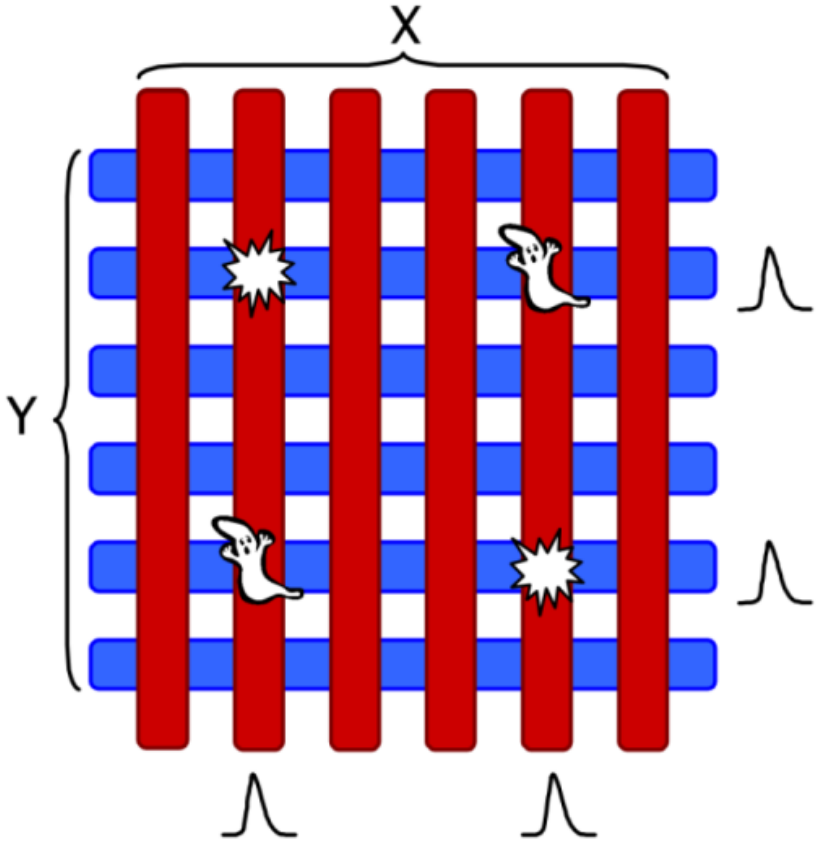
ARTROC architecture



- each channel is split into: slow (energy) and fast (timing) sub-channels
- switchable gain (8 modes)
- 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

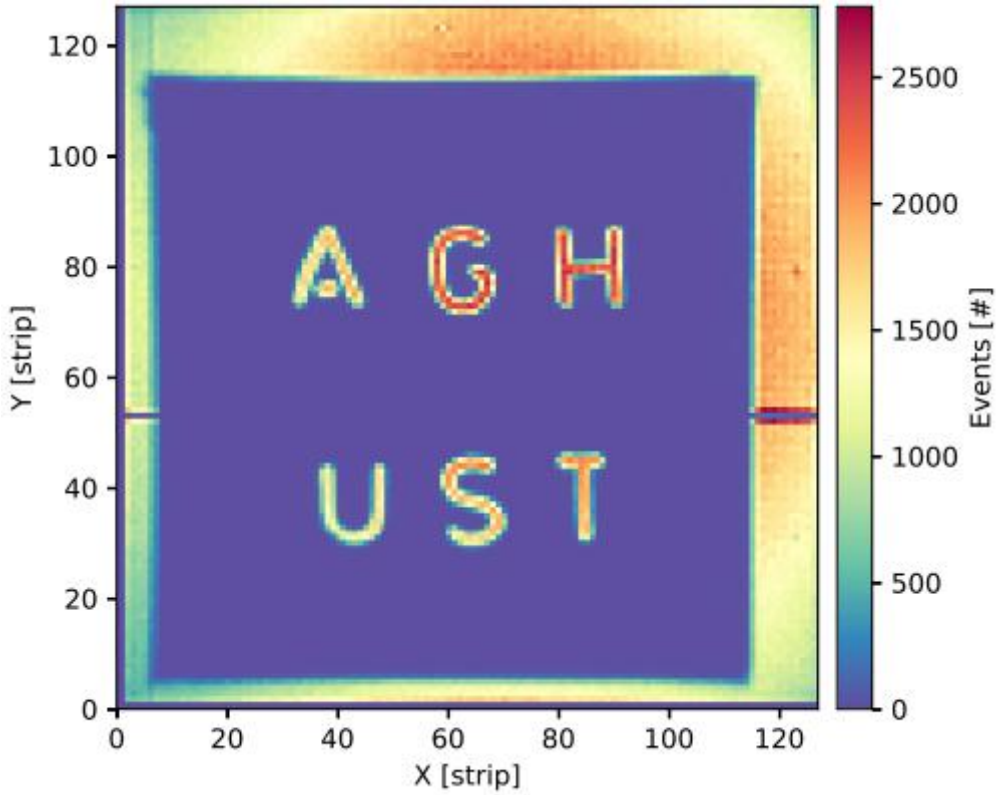
2-D strip-like readout



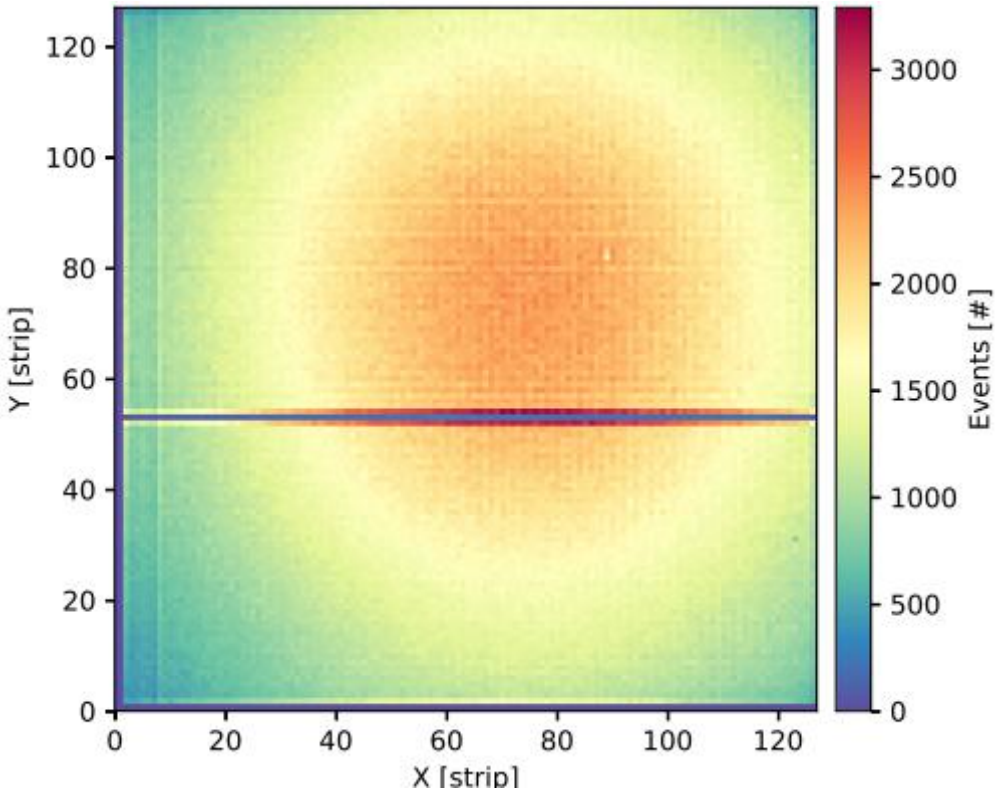


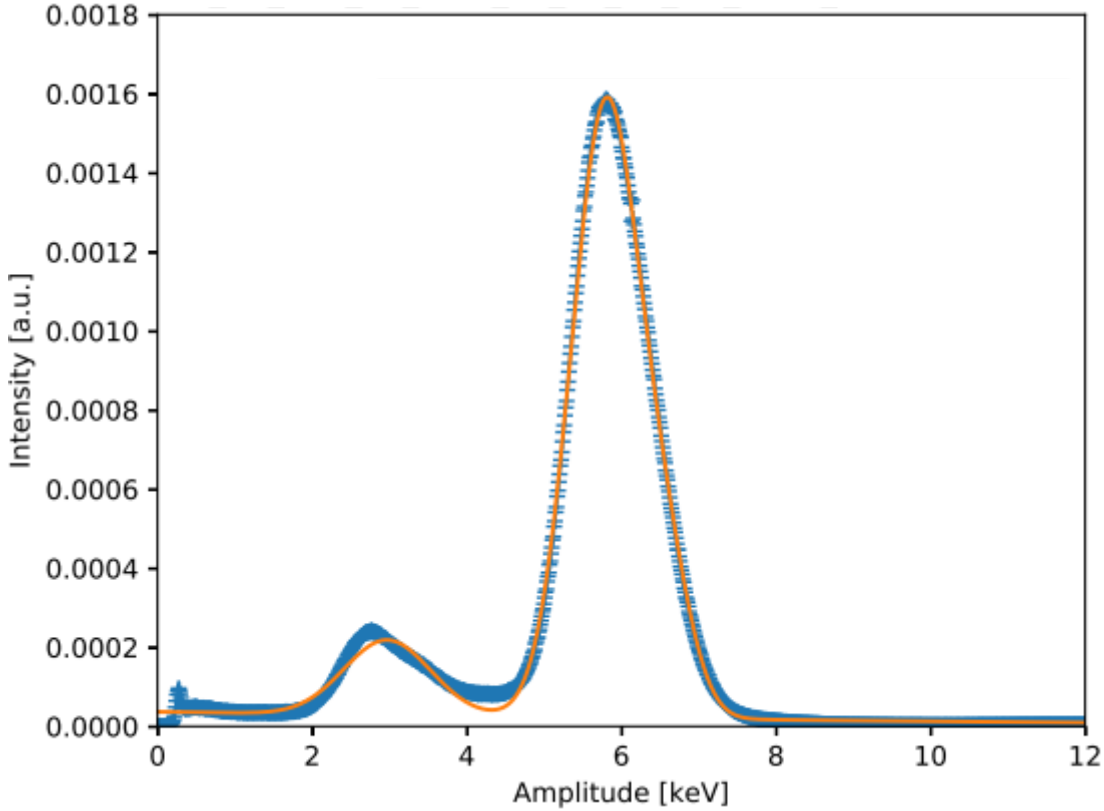
Position is derived from time stamp coincidences of X and Y clustered signals

2-D imaging
(800 µm readout pitch)



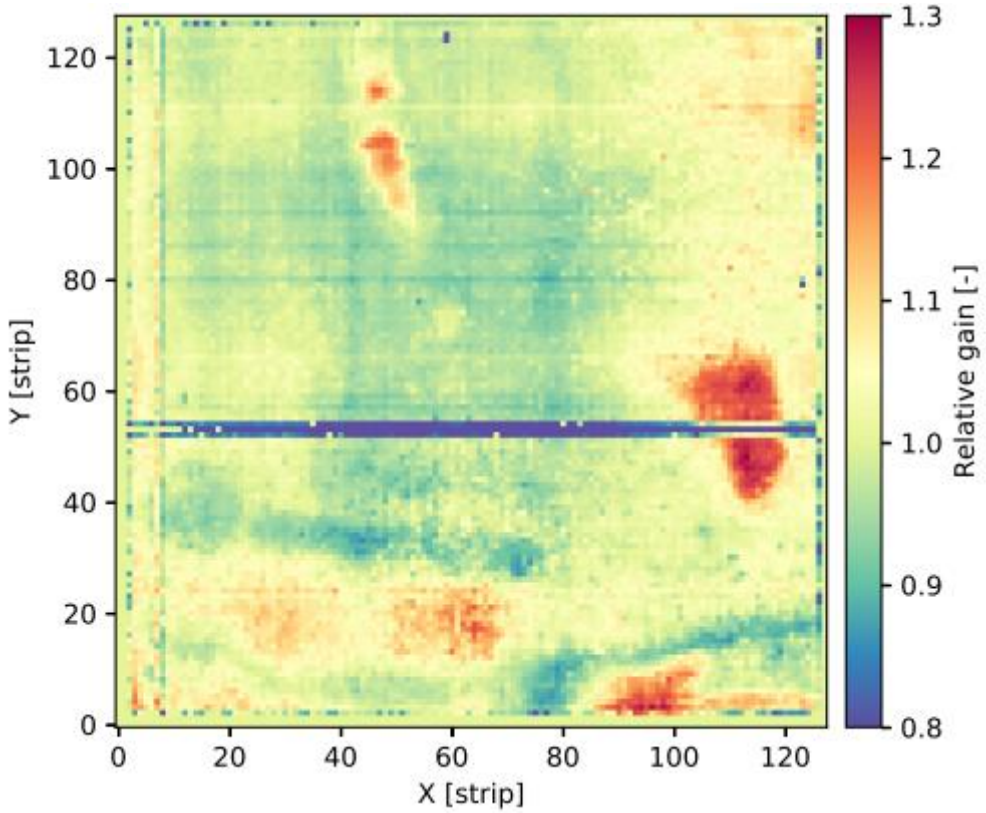
2-D imaging
(800 µm readout pitch)

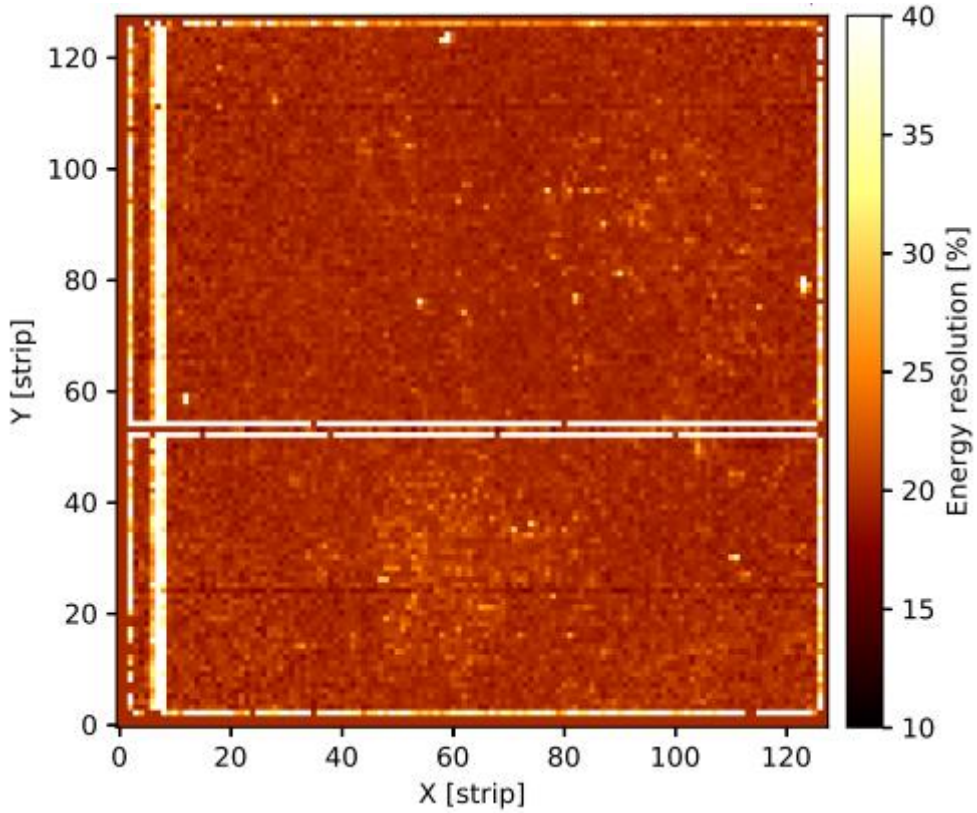




Energy resolution Fe-55 (FWHM) - 17.6% @ 3470V Ar/CO_2 (80/20)

Gas-gain variations and local energy resolution

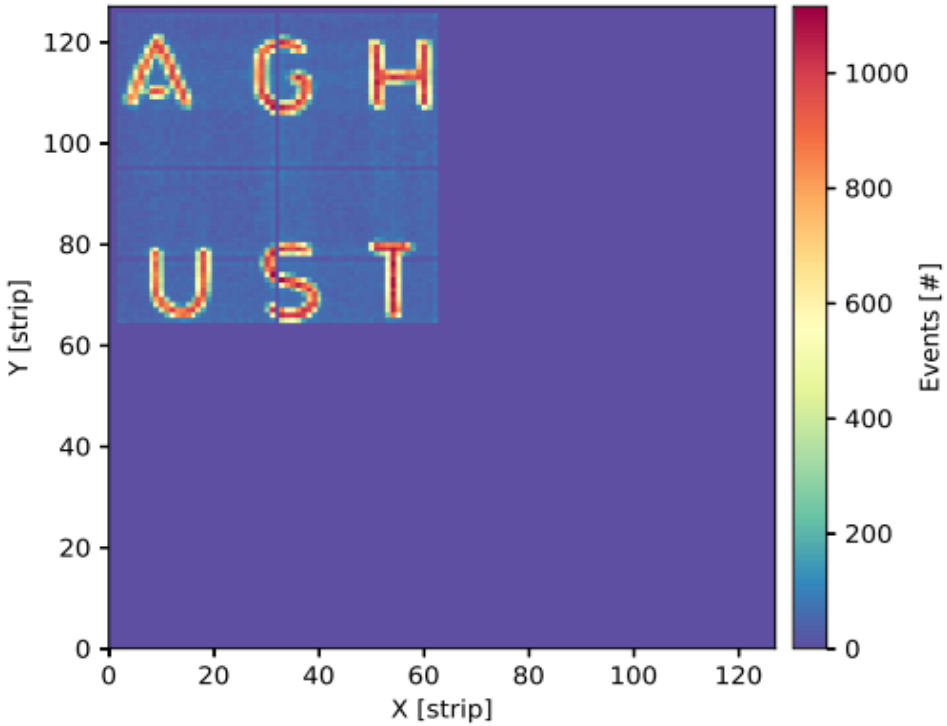


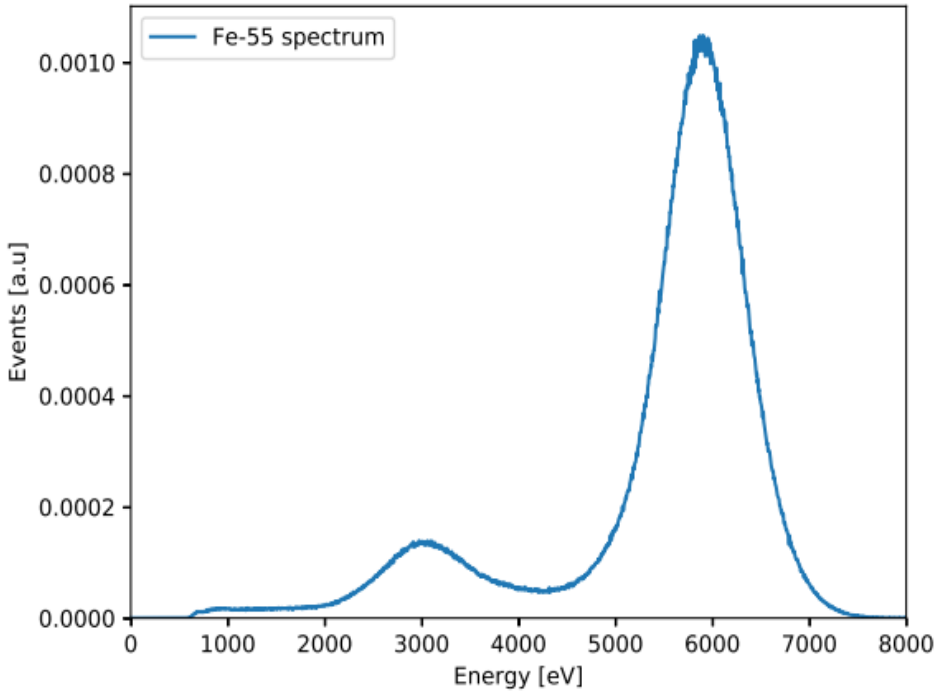


Energy resolution Fe-55 (FWHM) - 17.6% @ 3470V Ar/CO_2 (80/20)

2-D imaging
(800 µm readout pitch)

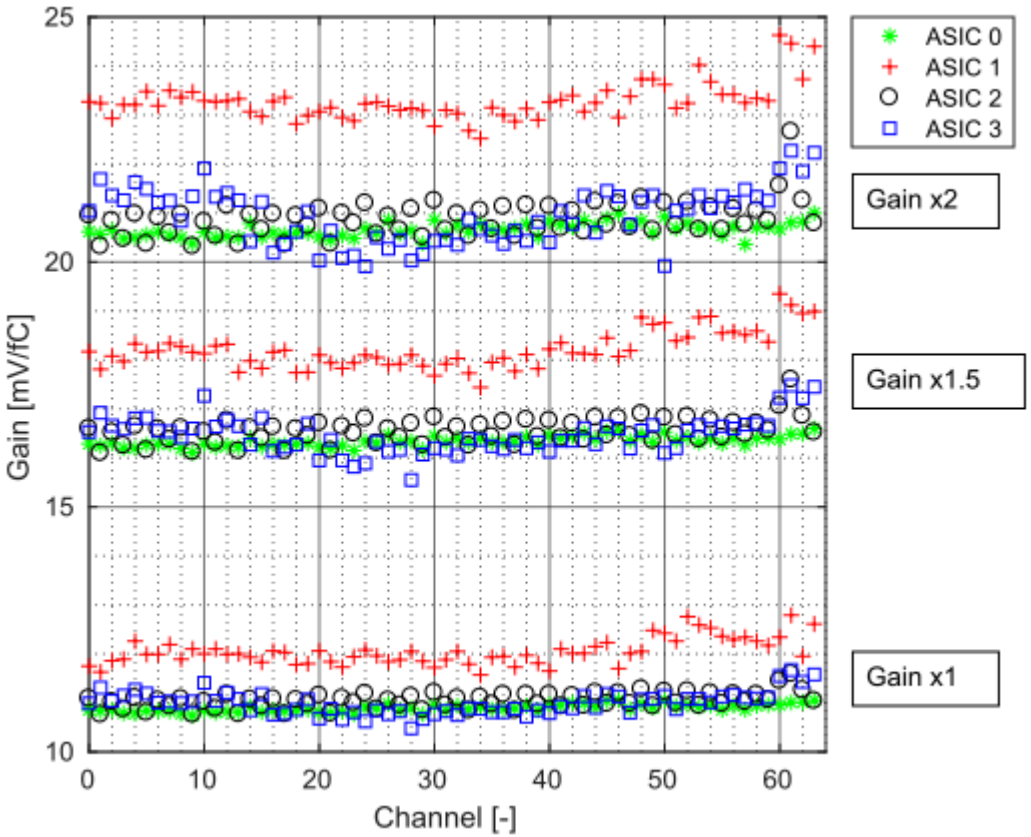
One ASIC board per plane is used (one forth of the detector is read out)



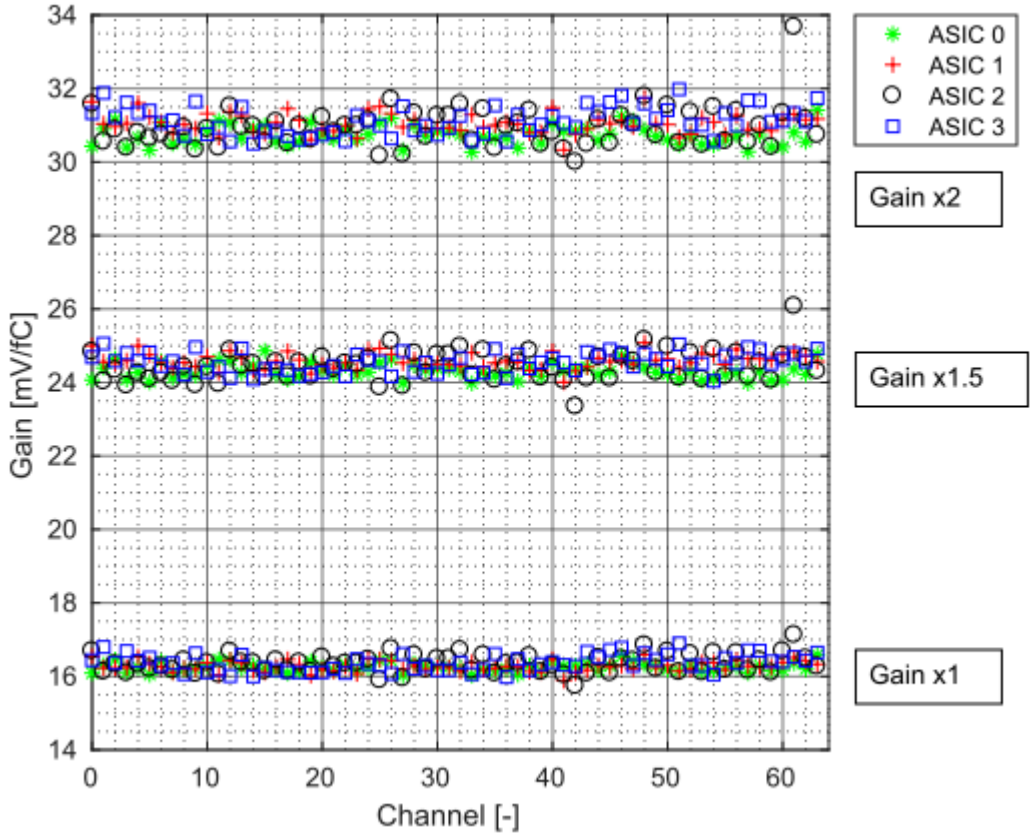


Energy resolution Fe-55 (FWHM) - 15.7% @ 3600V Ar/CO_2 (80/20)

Energy and timing sub-channels test results



ENC ≈ 1400e$^-$



ENC ≈ 1500e$^-$

Conclusions

- The ARTROC ASIC has been designed and manufactured successfully
- The electrical tests have confirmed correct functionality of all building blocks
- Analogue parameters: gain, noise and offset spread are as expected
- System level measurements results have shown very good performance:
  - energy resolution at the level of 15% for the selected area
  - energy resolution at the level of 18% for the whole detector area
- Plans for near future
  - further optimization of the system operation conditions
  - measurements with 400 μm readout pitch

References

- Front-end
  - 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)
  - T. Fiutowski et al., *Integrated input protection against discharges for Micro Pattern Gas Detectors readout ASICs*. JINST 12 C02021 (2017)
- DAQ hardware and software
  - B. Mindur et al., *A compact system for two-dimensional readout of Gas Electron Multiplier detectors,* JINST 8 T01005 (2013)
- Application
  - A. Zielińska et al., *X-ray fluorescence imaging system for fast mapping of pigment distributions in cultural heritage paintings.* JINST 8 P10011 (2013)
  - W. Dąbrowski et al. *Application of GEM-based detectors in full-field XRF imaging*, JINST 11 C12025 (2016)