FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

FasXcam:
a monolithic active pixel sensor for fast, energy-resolved soft X-ray imaging

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Marek Tunkl

on behalf of CAPADS team:

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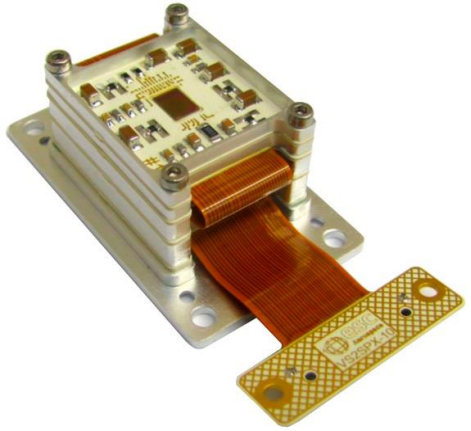
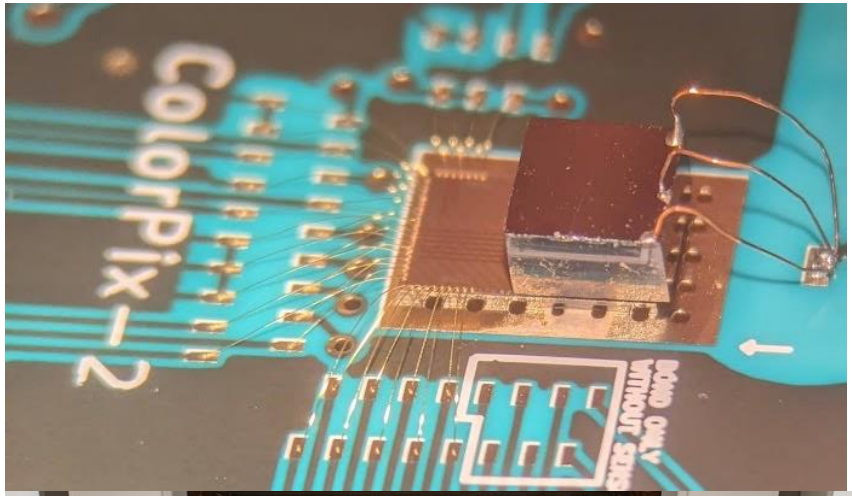
CAPADS Group

https://capads.fjfi.cvut.cz

- Center of Applied Physics and Advanced Detection Systems (CAPADS) is research group at the Czech Technical University in Prague
- Current projects:
  - SiC sensors development with onsemi
    - (T. Vasiljev's talk)
  - Quantum astrometry
  - Chip design of monolithic and hybrid detectors
    - ColorPix – SXR hybrid detector for medical imaging
      - (J. Broulim's poster)
    - SpacePix – space weather monitoring
    - FasXcam – MAPS for fusion reactors monitoring





1. Motivation and Design

2. Testing and characterization

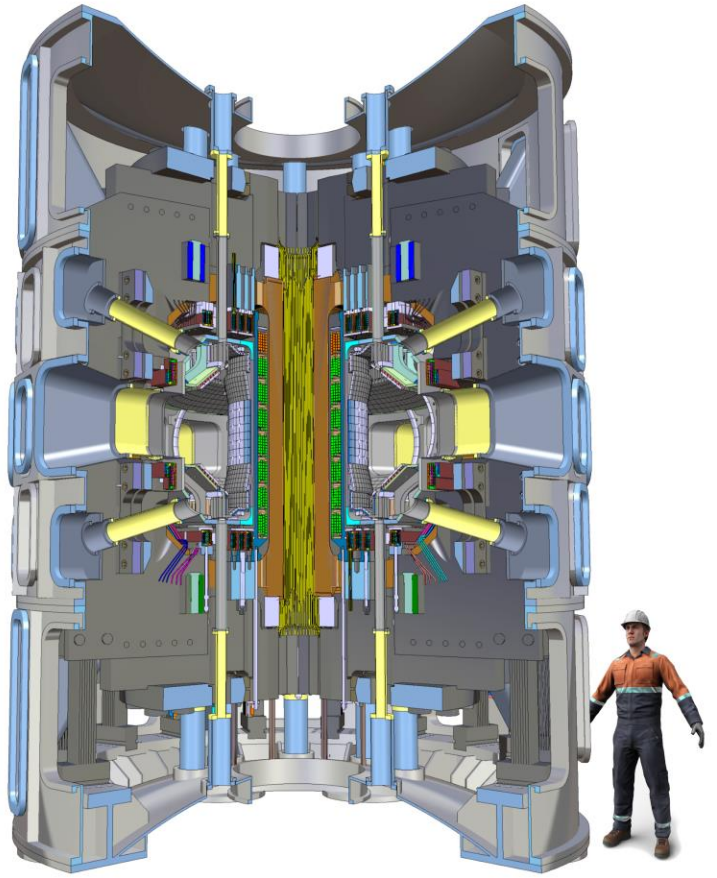
Motivation: SXR In Plasma

- Development of **FAS**t**X**ray**CAM**era
  - Collaboration with IPP CAS
  - Evolution of previous SpacePix / SmartPix designs

- Soft X-ray in fusion plasma indicate the presence of
  - Impurities (C, O, Fe, W, etc.)
    - Degrades performance
  - Suprathermal electrons
  - Magnetohydrodynamic (MHD) instabilities

- High-speed spectral monitoring of X-ray events in plasma of COMPASS-U
- Operating conditions:
  - High Vacuum
  - Intense magnetic fields
  - Significant electromagnetic interference (EMI)
  - High radiation environment (neutrons, gammas)

COMPASS-U	
R	0.9 m
a	0.27 m
B_T	≤ 5 T
T_e	≤ 6 keV



COMPASS-U tokamak

IPP INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

Intended camera setup

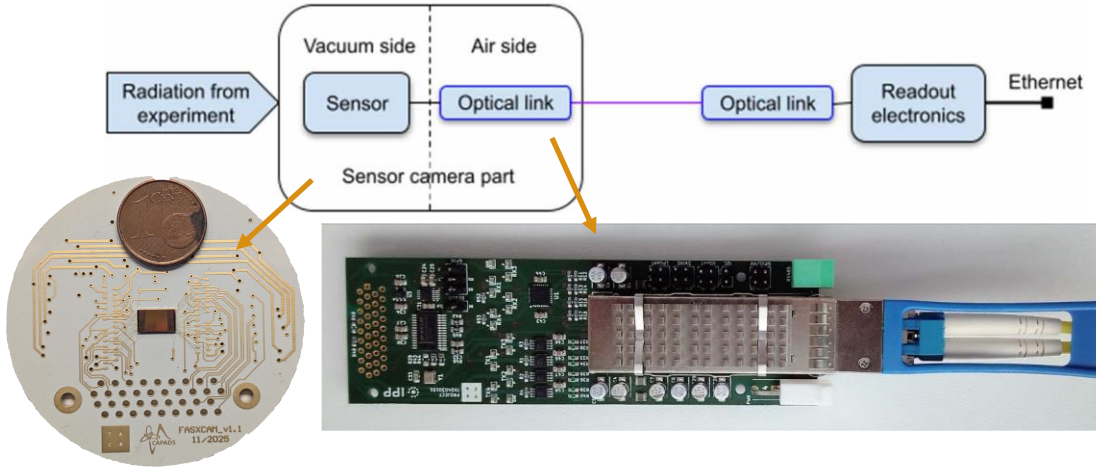
[Havranek, A., 2026, 10.1088/1361-6587/ae4144]

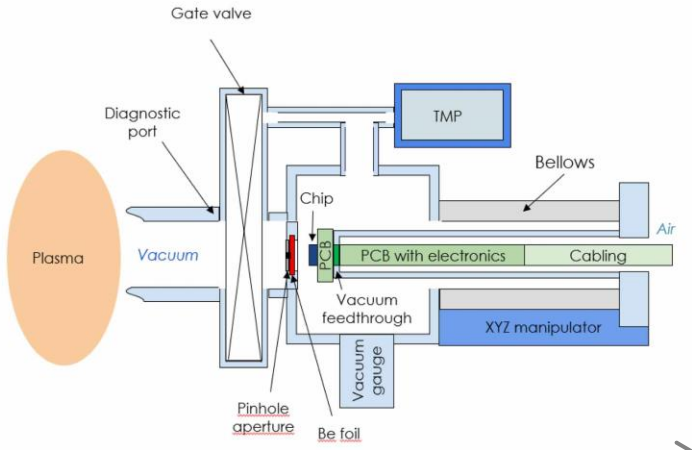
- Tokamak plasma
- Be filter + pinhole
- FasXcam sensor
- Vacuum feedthrough
- Air-side interface board
  - Provides BIAS, Power supply
  - Translates communication
- Optical link to readout board
- Readout board
  - Based on AMD ZynqTM 7000 SoCs
- Ethernet
- Control system

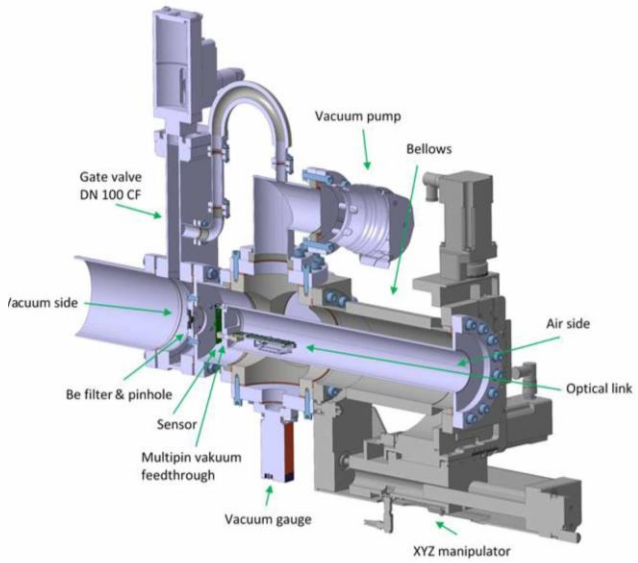
Vacuum side

Air side

Tokamak hall

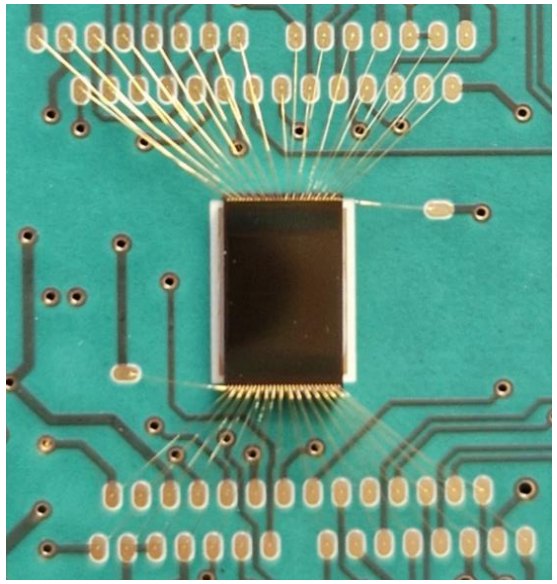


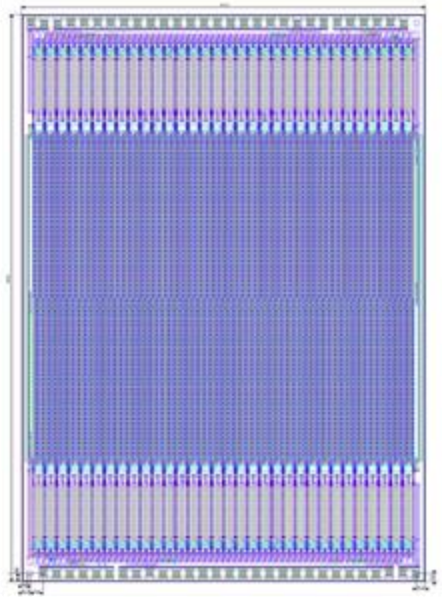


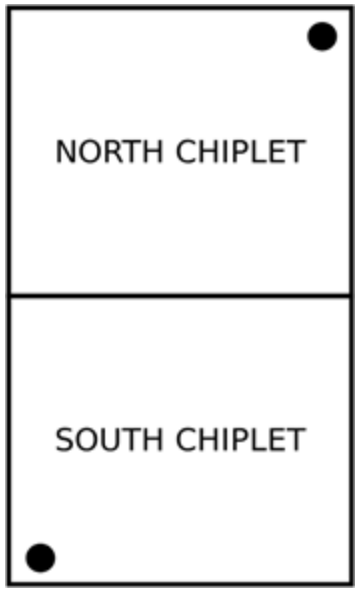


Specifications

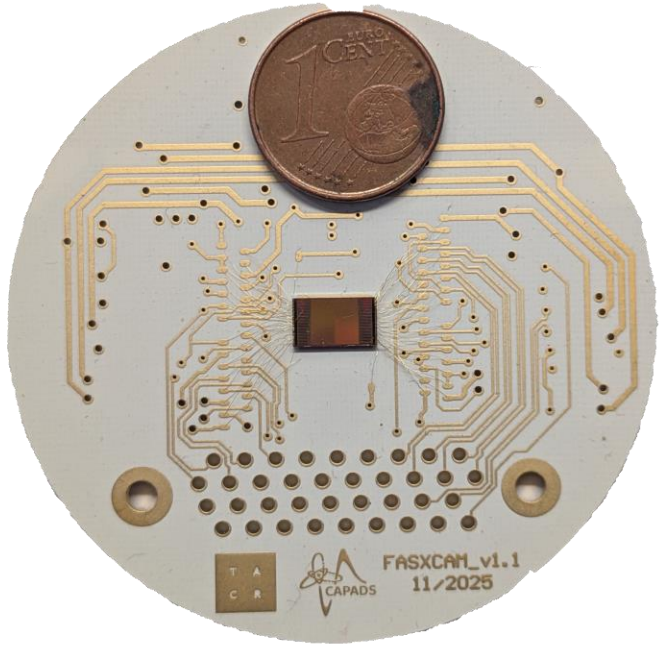
- MAPS chip fabricated by X-FAB 180 nm SOI
- Two 32x64 pixel chiplets → faster data transfer
- Pixel area ~ 60µm x 60µm
- Sensitive matrix area 3840 µm × 3840 µm
- Energy range 2.9 keV to 21.6 keV
  (0.8ke to 6ke in Si)
- SAR ADC with 8-bit resolution
- Shutter mode: frame and rolling
- BIAS –150V
- External charge injection (0.6fF cap.) for a calibration/test
- Global HIT signal
- Analog output
- ADC/DAC input/output for calibration





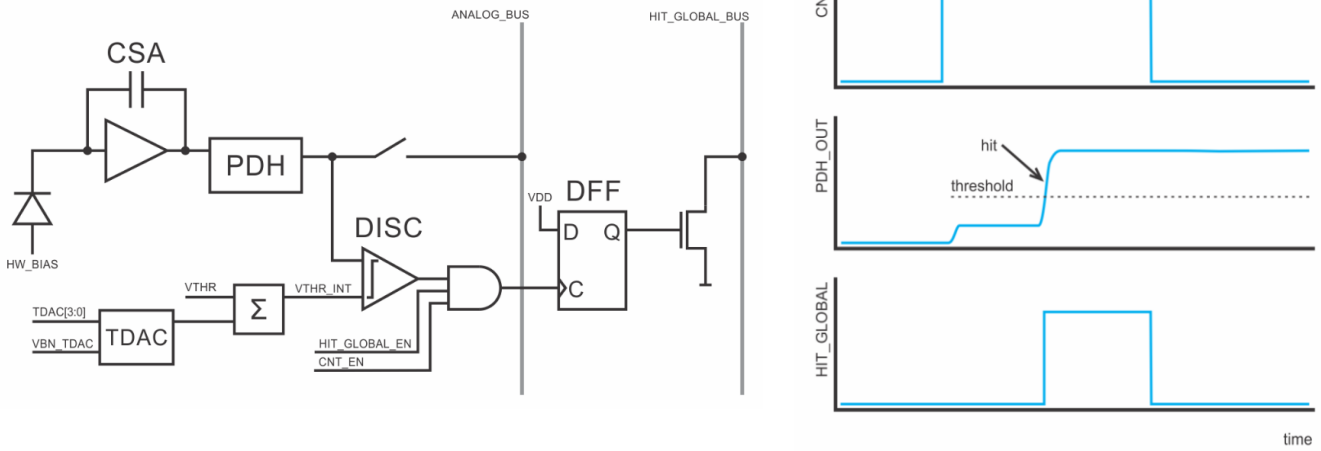


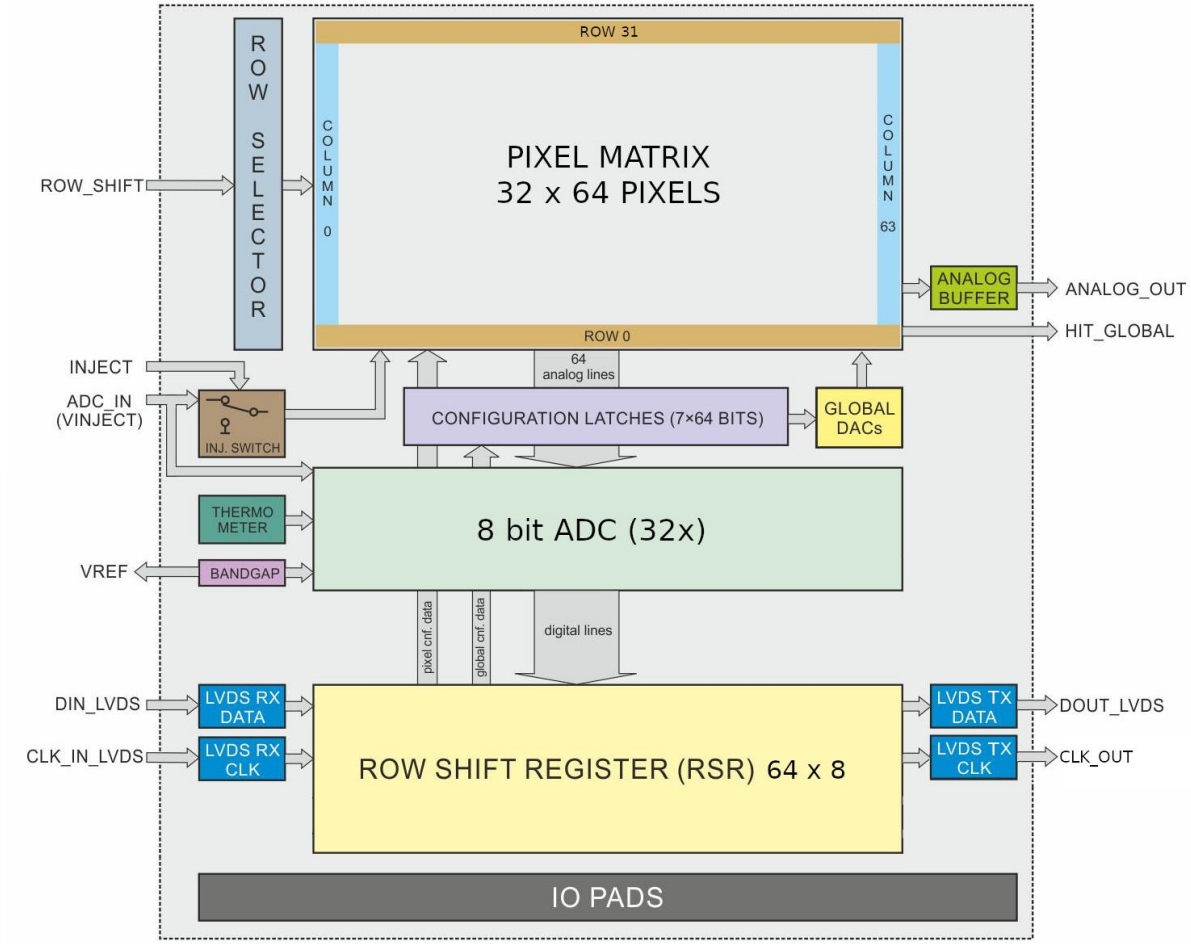
- 400 MHz LVDS bus
- Max. ~15000 FPS @ 400 MHz
- On-die thermometer
- Power supply 1.8V,
  max. 45mA / chiplet



Operation principle

- Analog pixel frontend:
  - CSA
  - Peak Detector Hold (PDH)
  - Discriminator (DISC)
    - Configurable local + global threshold
  - HIT event generator

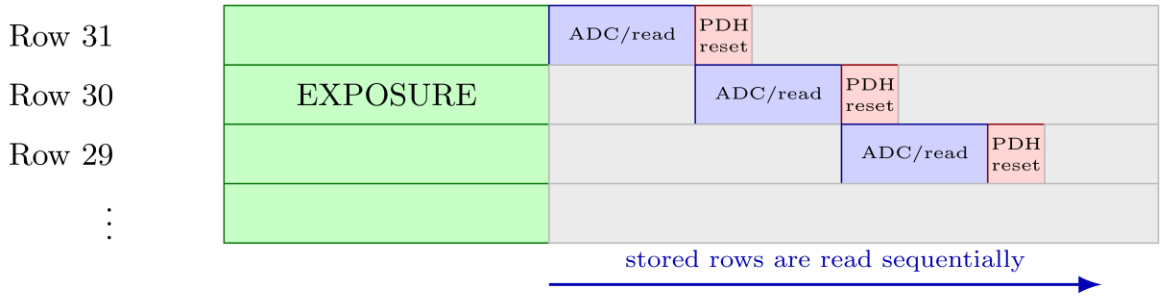




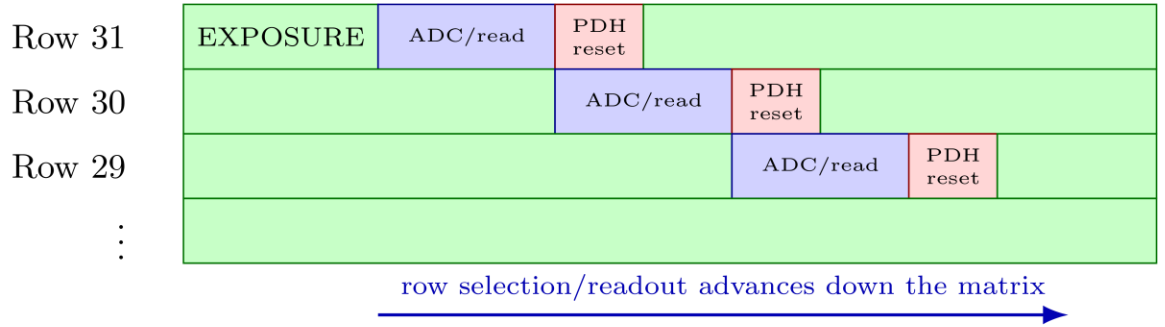
- Conversion via 8-bit SAR ADCs
- Configuration and communication via shift register up to 400MHz

Sampling modes

- Frame shutter mode
  - Exposure is separate from data readout
  - Exact exposure time
  - Minimal analog–digital cross-talk during exposure



- Rolling shutter mode
  - Exposure is active during data readout
  - Minimal dead time
  - Worse position and timing resolution
  - Analog–digital cross-talk during exposure

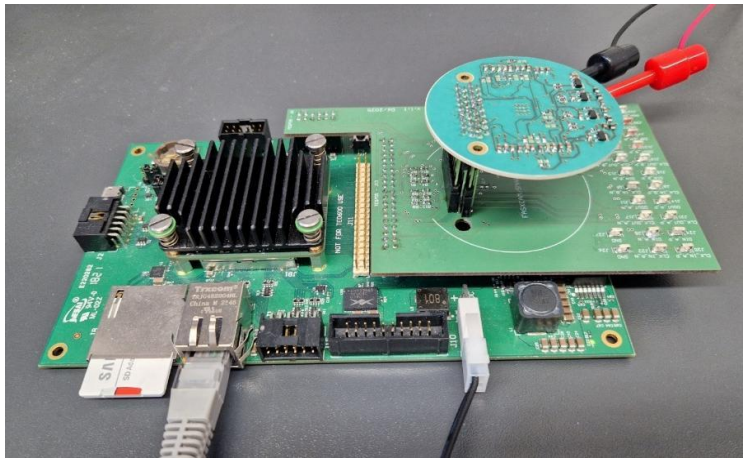


1. Motivation and Design

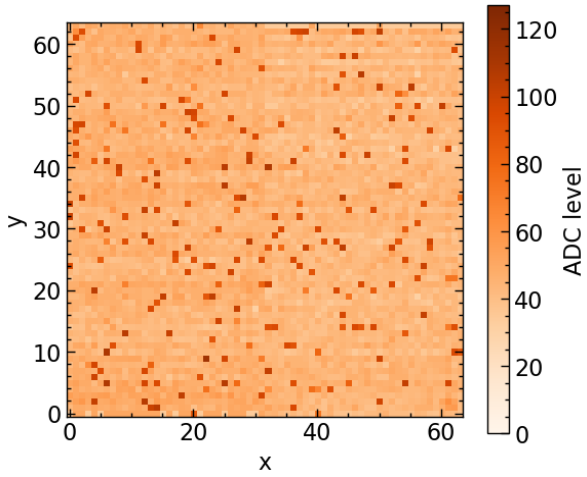
2. Testing and characterization

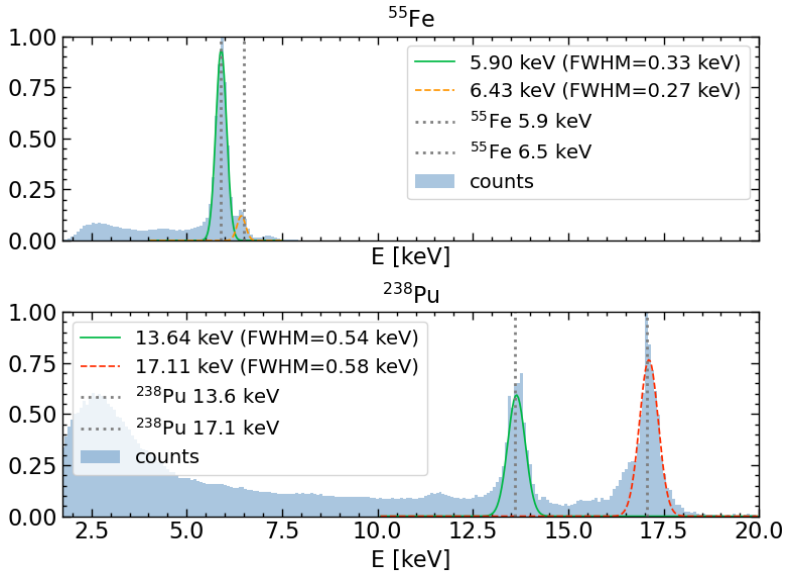
Calibration & characterization

- Tests with prototype of a readout setup
- Radiation sources:
  - ^{55}Fe
  - ^{238}Pu



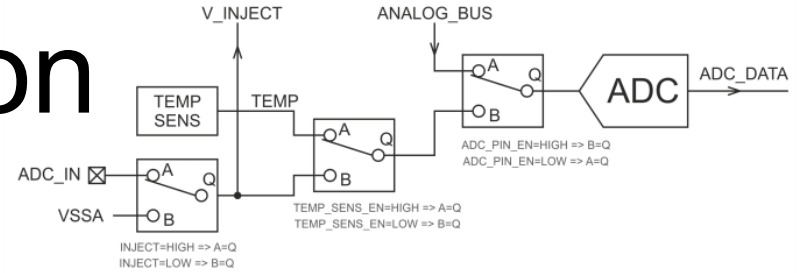
- Verification of the readout chain
- FWHM ≈ 0.33 keV at 5.9 keV

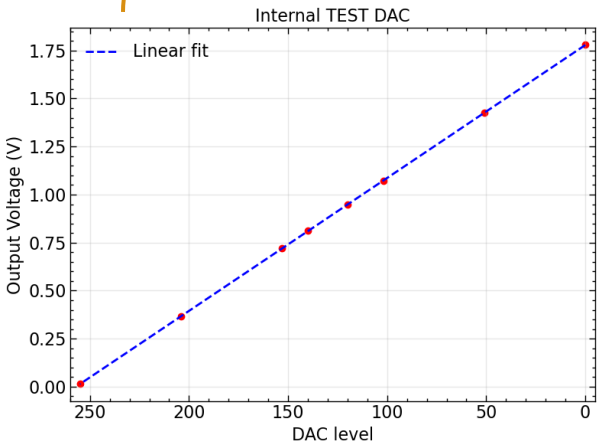


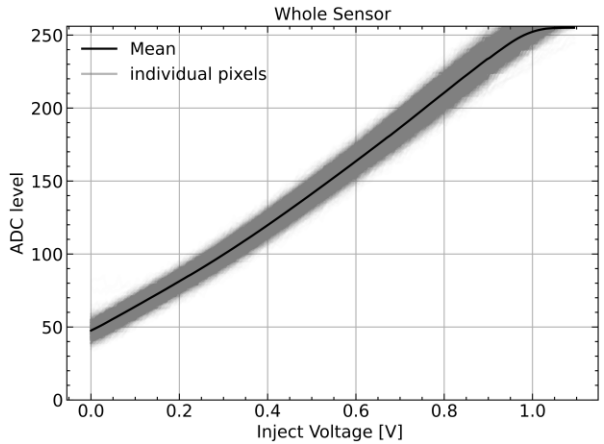


Charge-Injection Calibration

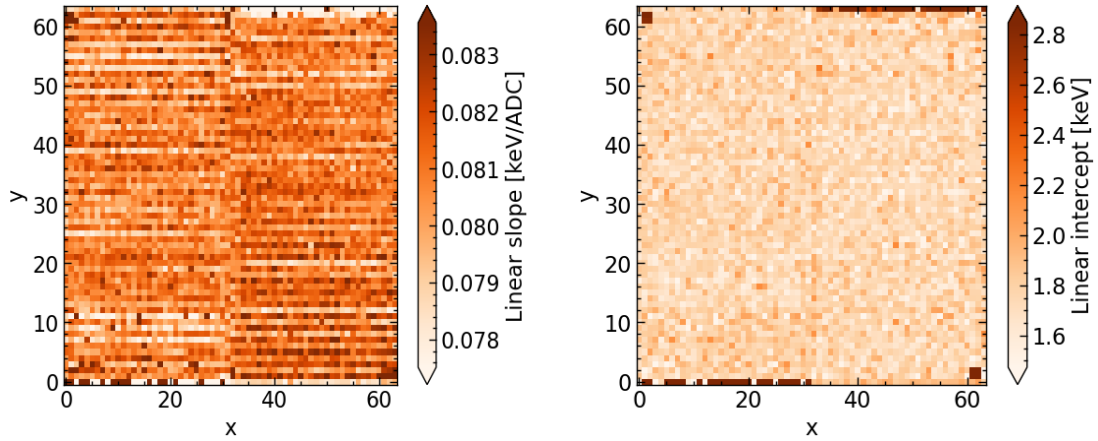
- Internal DAC can be used for charge inject calibration and self-tests
- Non-linearity confirmed by calibration with rad. sources & X-ray fluorescence

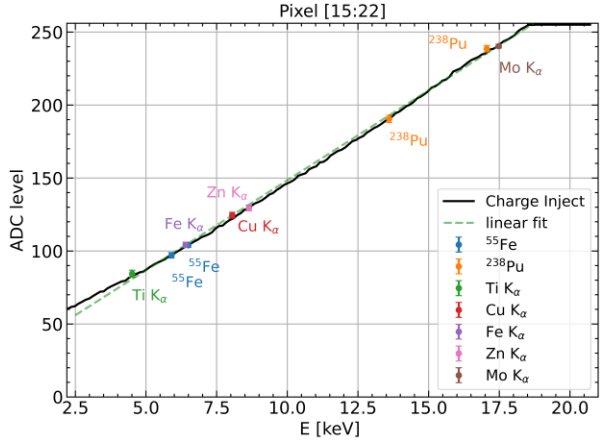






E = a x + b

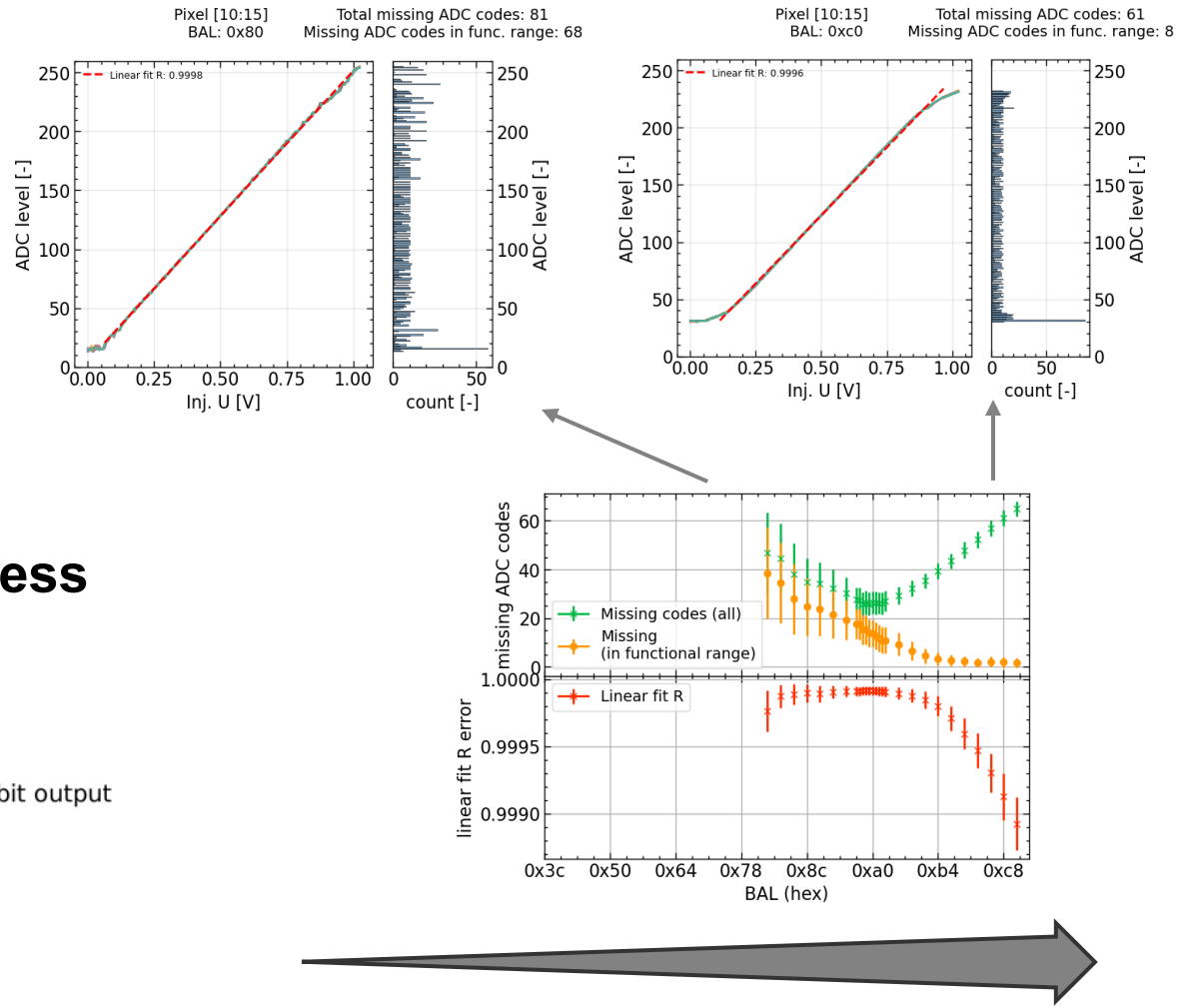




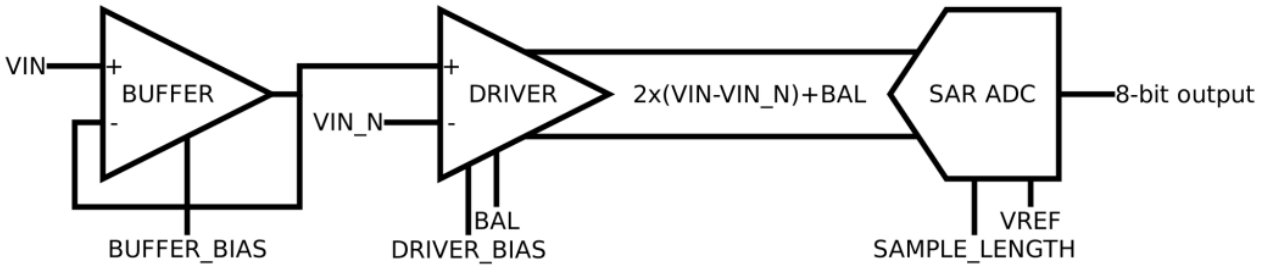
Charge injection + X-ray sources

ADC Characterization

- ADCs and front-end electronics need to be properly adjusted
- Trade-off between
  - Accuracy
  - Non-linearity
  - Conversion Time



- Full characterization is currently **work in progress**

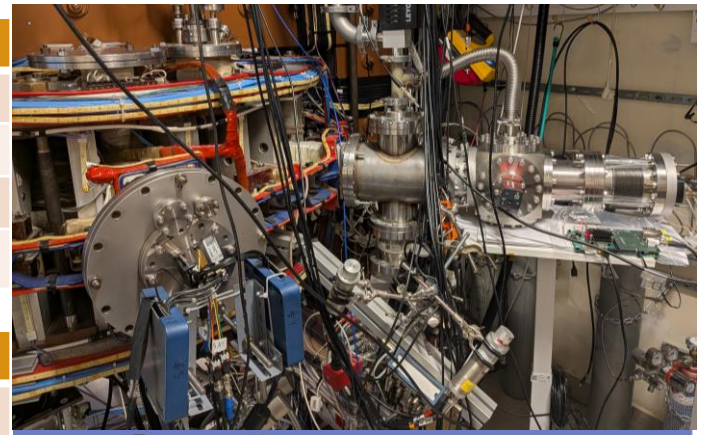


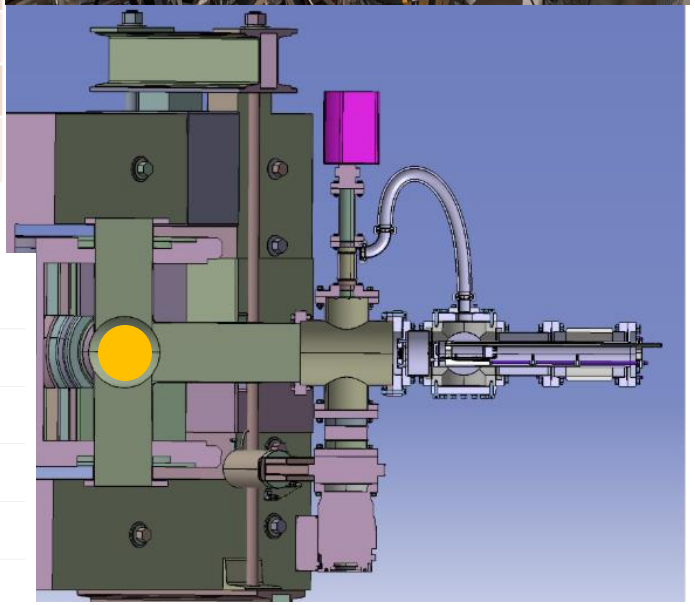
Testing in a Tokamak Environment

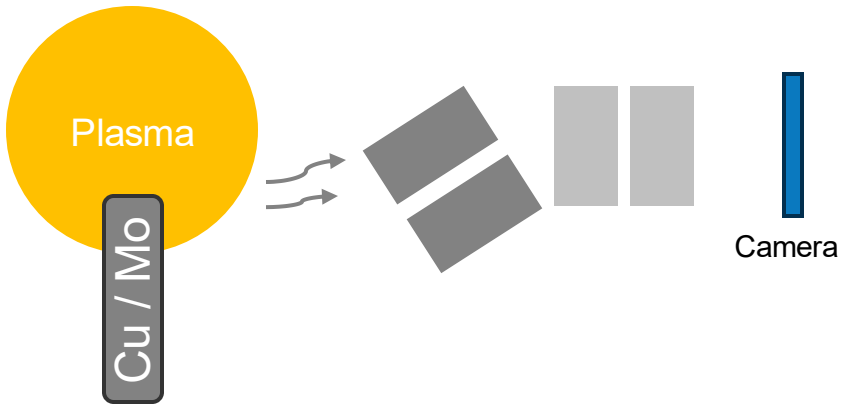
- Camera setup tested in tokamak environment
  - GOLEM at CTU
- Simple optics – two plates forming X-like aperture
- Runaway electrons (~ 500 keV) interacting with different materials → SXR
- Tests underway

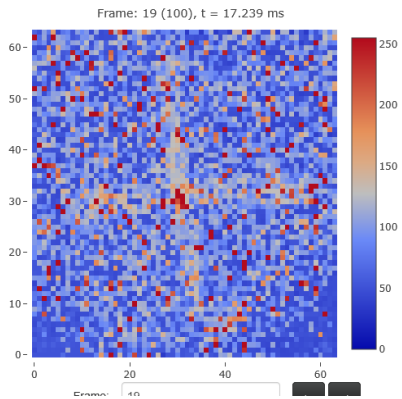
COMPASS-U	
R	0.9 m
a	0.27 m
B_T	≤ 5 T
T_e	≤ 6 keV

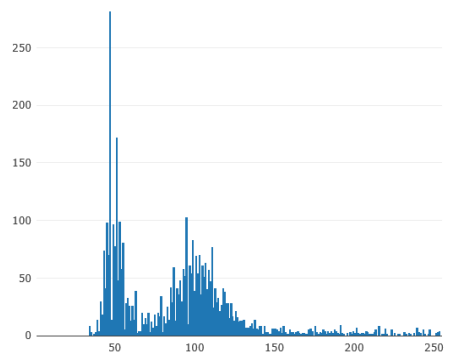
GOLEM	
R	0.4 m
a	0.09 m
B_T	≤ 0.8 T
T_e	≤ 0.1 keV











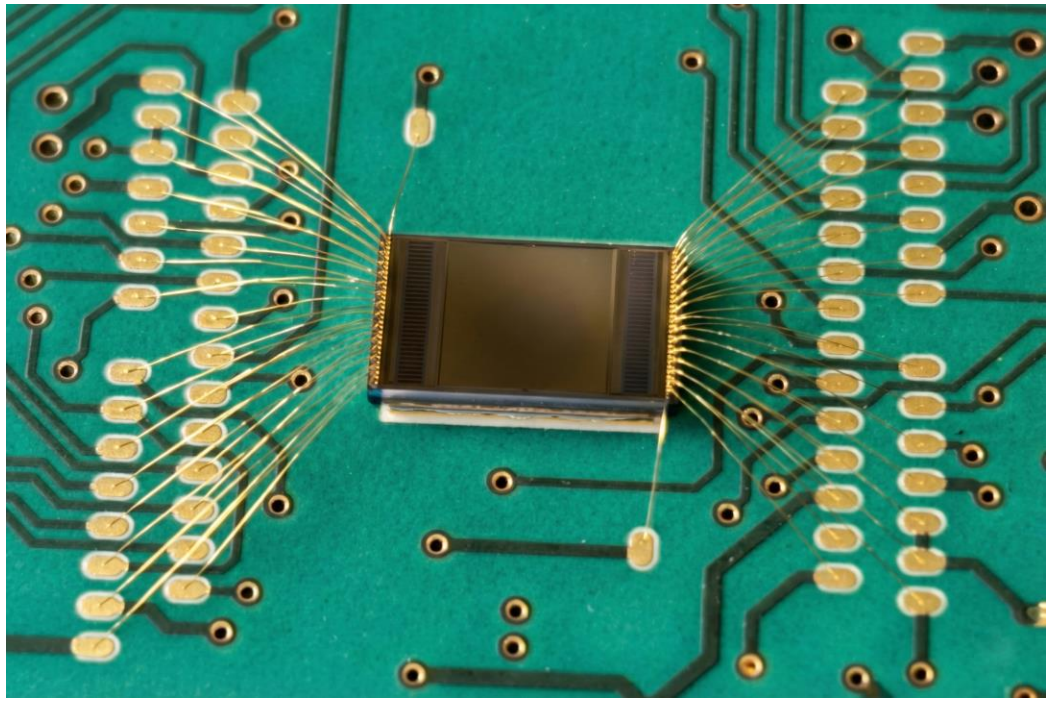
Conclusion and outlook

- First functional verification of the FasXcam detector
- Homogeneous pixel response with no structural defects observed
- Charge-injection calibration established the nonlinear ADC-to-charge transfer function
- Characteristic X-ray lines from ^{55}Fe and ^{238}Pu successfully resolved
- Energy resolution of ≈0.33 keV FWHM at 5.9 keV
- Near-linear response demonstrated up to ≈20 keV

- Initial tests in tokamak plasma-relevant environment underway

Future work

- Optimization of ADC operating parameters
- Evaluation of rolling-shutter crosstalk
- Quantum-efficiency measurements



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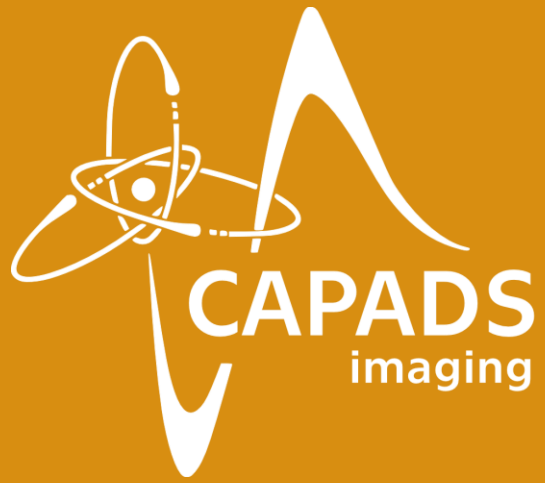

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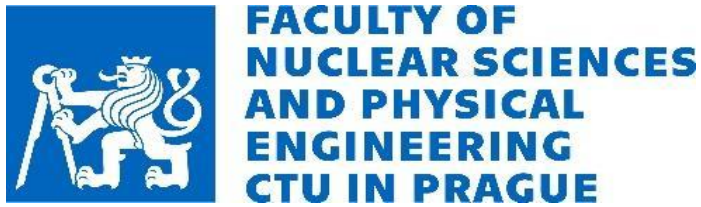
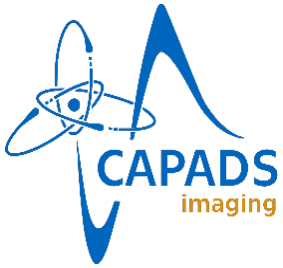
Acknowledgements





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the European Union

Backup

From SpacePix to FasXcam

SpacePix3

- Monolithic sensor designed for space dosimetry measurements
- 64×64 pixel matrix
- 60 µm pixel pitch
- 10-bit asynchronous differential SAR ADC
- Input range up to 80 ke^-
- SPI + LVDS readout

FasXcam

- High-speed monitoring of X-ray events in plasma

- Two independent chiplets **32×64** pixels each
- 60 µm pixel pitch
- **8-bit** asynchronous differential SAR ADC
- Input range 0.8 ke^- to 6 ke^-
- ~~SPI +~~ LVDS readout with CLK_OUT for phase alignment
- Improved internal reference stability for ADCs
- Optional external voltage reference
- Added rolling shutter mode

Process of data acquisition

- Row-by-row digitization
  - Pixel values are digitized one row at a time
  - Same mechanism used in frame and rolling shutter modes.
- Column conversion
  - Two columns share one ADC
    32 ADCs for 64 pixels
  - Enables high throughput without global analog bottleneck
- Frame formation
  - Digitized rows are stored in a shift register
  - Complete frame is streamed via LVDS interface.