Precision radiation detectors for cutting edge research projects developed at the MPS Semiconductor Lab (MPG HLL)

Jelena Ninkovic for the MPG HLL team

- MPS Semiconductor Lab
- Devices & Selected Applications

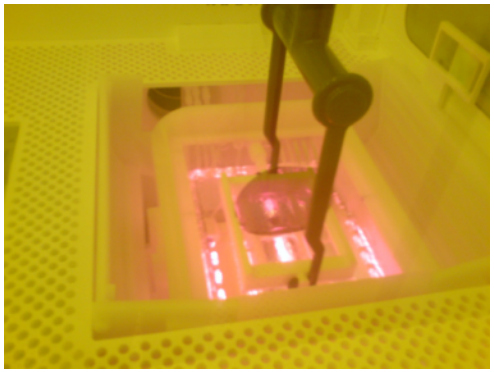
Inside MPG HLL

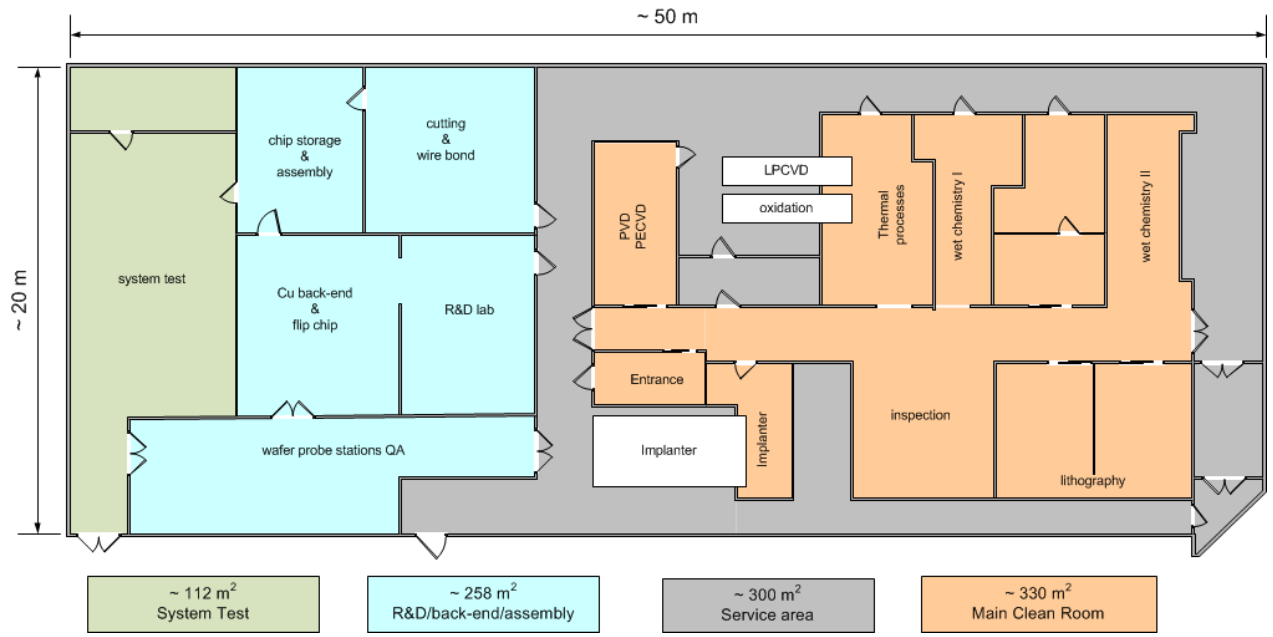
assembly and test

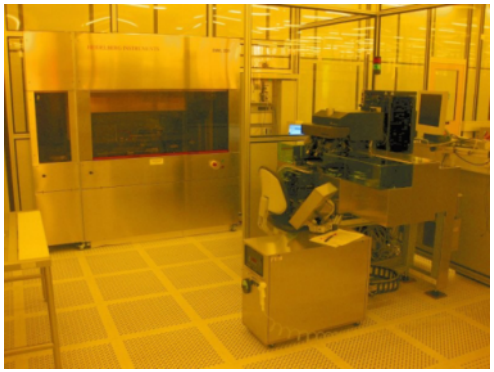
flip chip

Cu line

complete 6″ processing line



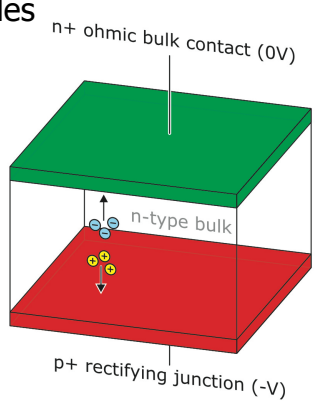




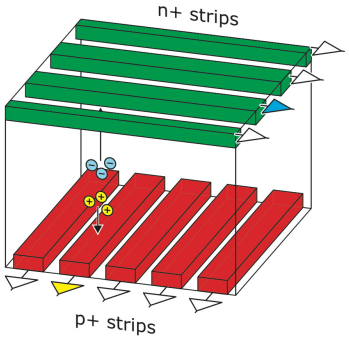
Devices @ MPG HLL

- **Building blocks**

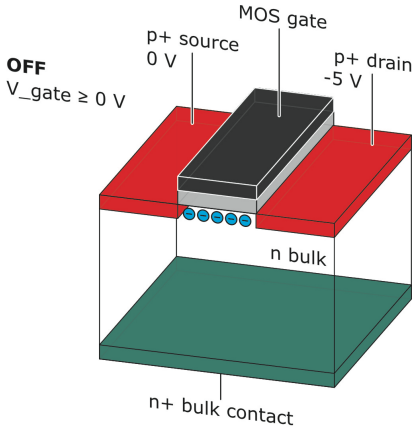
Diodes



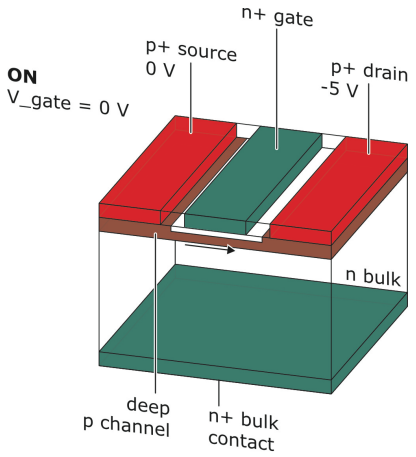
Strip detectors



MOSFETs

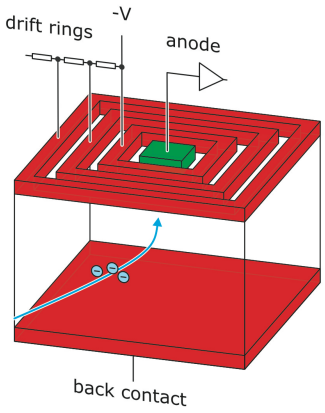


JFETs

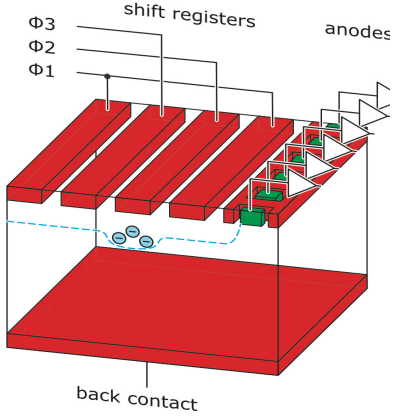


- **Devices**

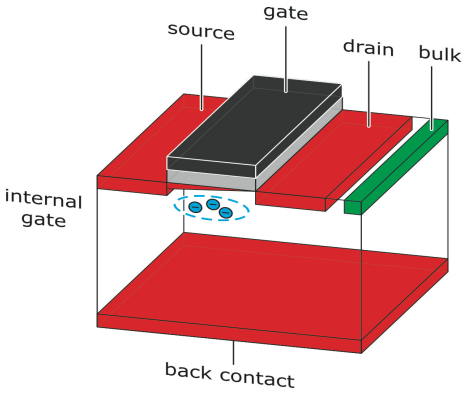
Silicon drift detectors (SDD)



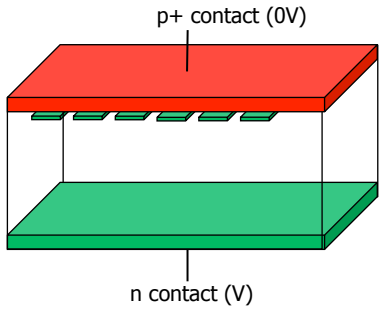
pnCCDs



DEPFETs



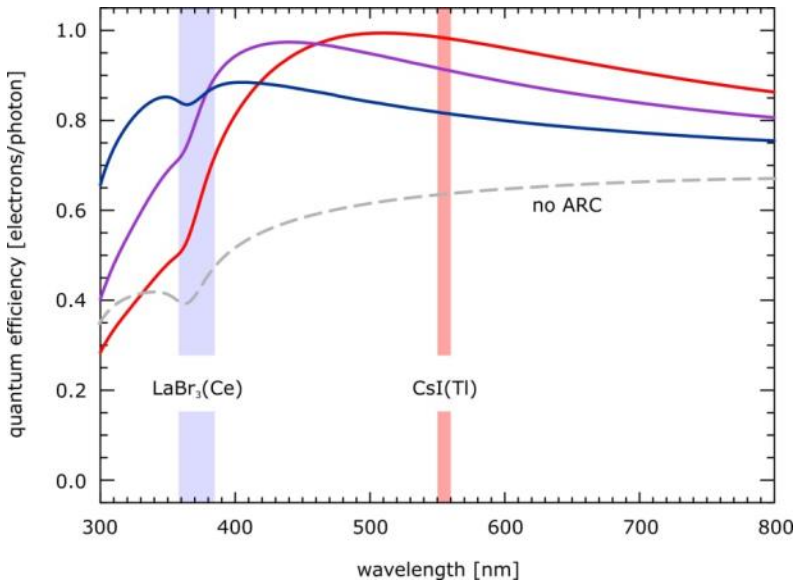
SiMPl

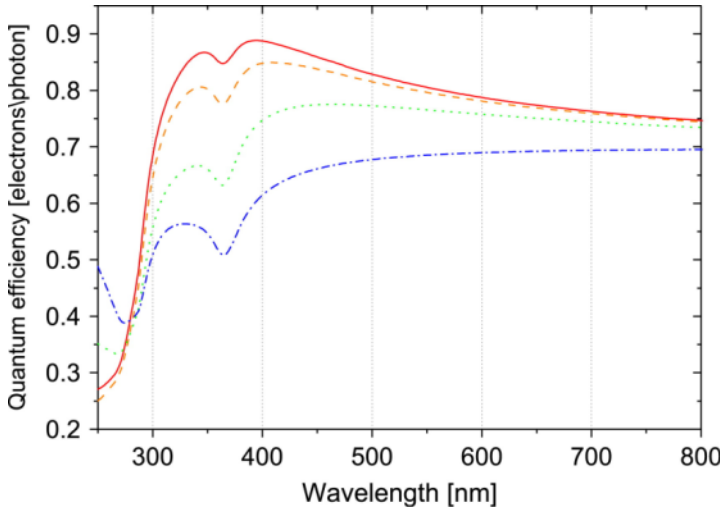


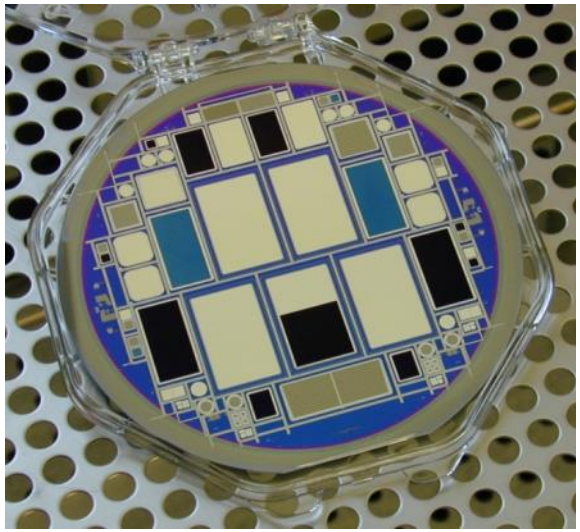
Entrance window engineering – application optimization

- anti-reflective coating (ARC)
  - ▷ sequence of dielectric layers deposited on the entrance window
  - ▷ variation of material and thickness
  - ▷ transmittance tuning to application needs

- polymer passivation
  - ▷ mechanical protection
  - ▷ optical coupling



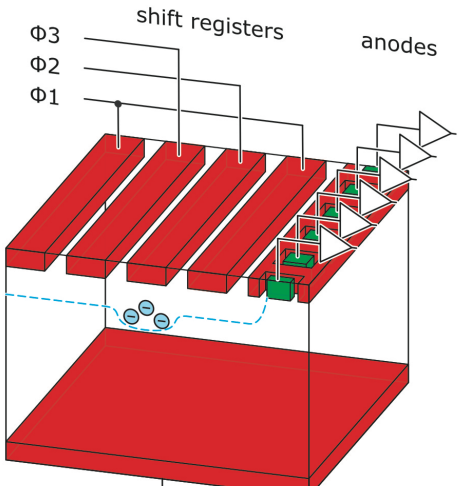




pnCCDs

Proposed by Lothar Strüder et al., 1987

- ▷ definition of potential pockets by differently reverse-biased diodes
- ▷ charge transport by periodic clocking of shift registers
- ▷ **column-parallel readout** → high frame rate (5 msec @ 200 pixel)
- ▷ integrated 1st FET (1 / column) → **low noise** (**3el. ENC**)
- ▷ backside illuminated, **fully depleted** → **high quantum efficiency**



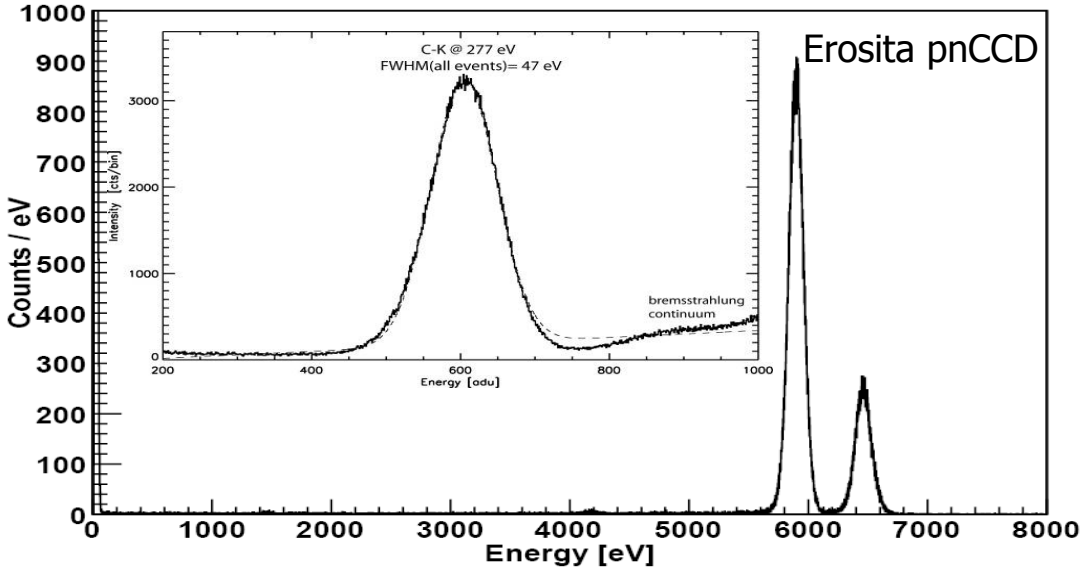
- format ~ cm² … **wafer scale**
- thickness 450 µm
- **pixel size 36 … 150 µm**

Applications
- X-ray imaging & spectroscopy
- optical light imaging

XMM Newton Mission (1999 -)

EROSITA (2017 -)

ATHENA (2028 -)

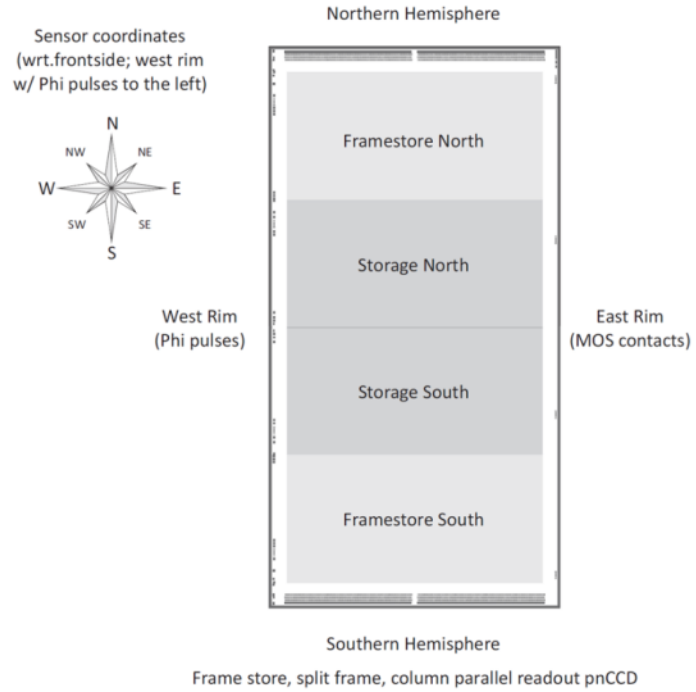


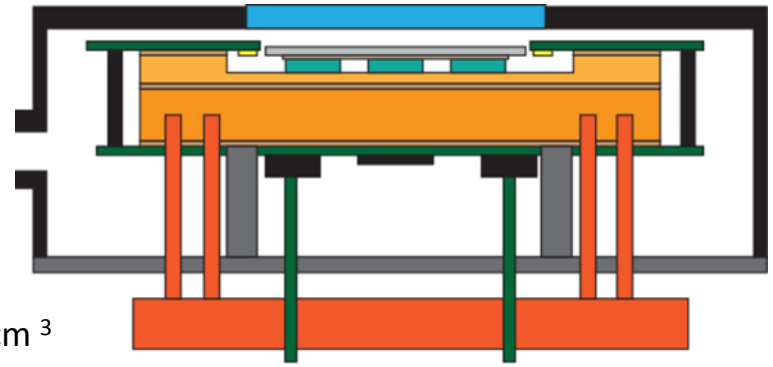
Small pixel pnCCDs @ HLL

Motivation: development of a sensor for Fast Solar polarimetry
(collaboration partner MP Solar System Research)

Device characteristics:

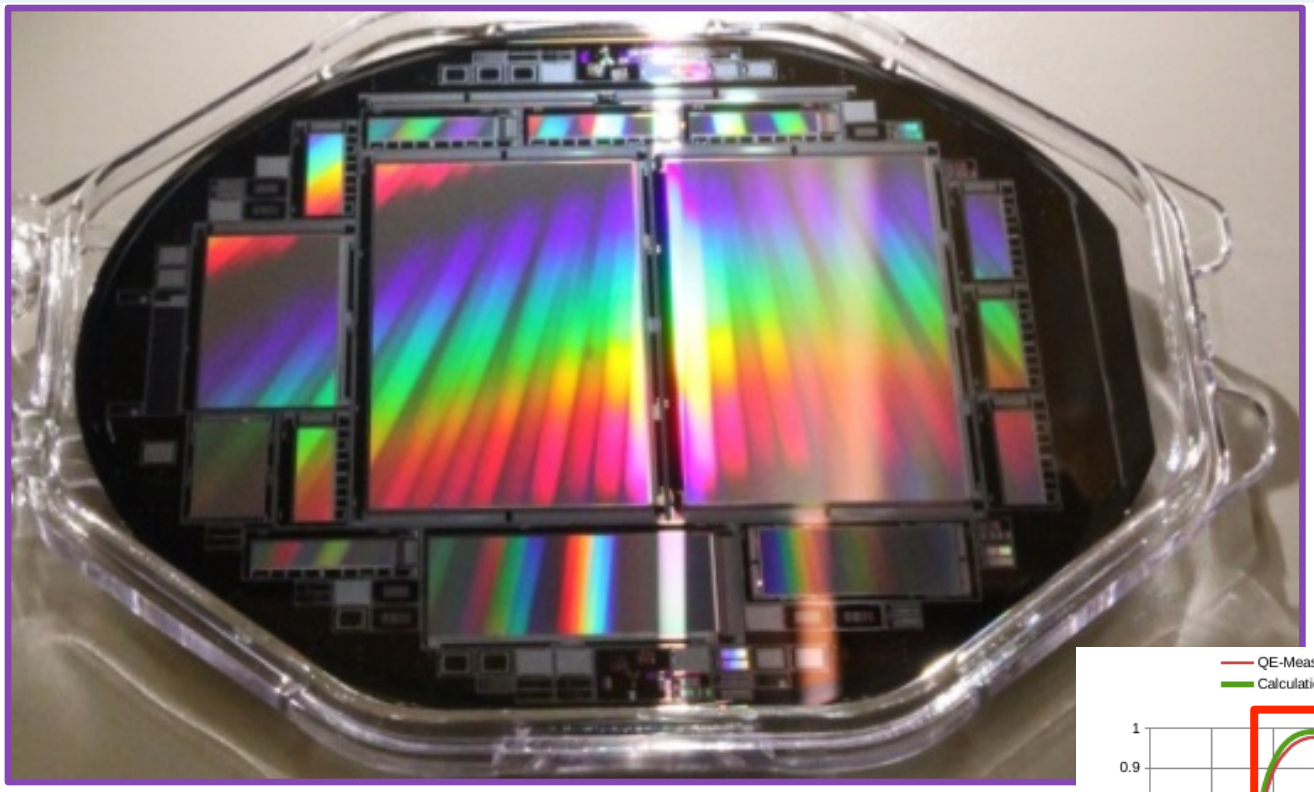
- pnCCD concept:
  - Backside illuminated,
  - frame store,
  - split frame,
  - column-parallel readout
- Format: **1k x 1k** storage, 2 x 1 k x 0.5 k framestore
- Pixel size: **36 x 36** μm^2
- Total sensitive area: 36.8 x 73.3 mm^2
- Total chip size: 4.2 x 8.1 cm^2
- Optimized for **optical wavelength** using ARC
- Operating temperature: -35°C (target)
- Target operating frame rate: **400 Hz** (~4 μs /row)
- Data rate: 840 Mbyte / s (16 bit)

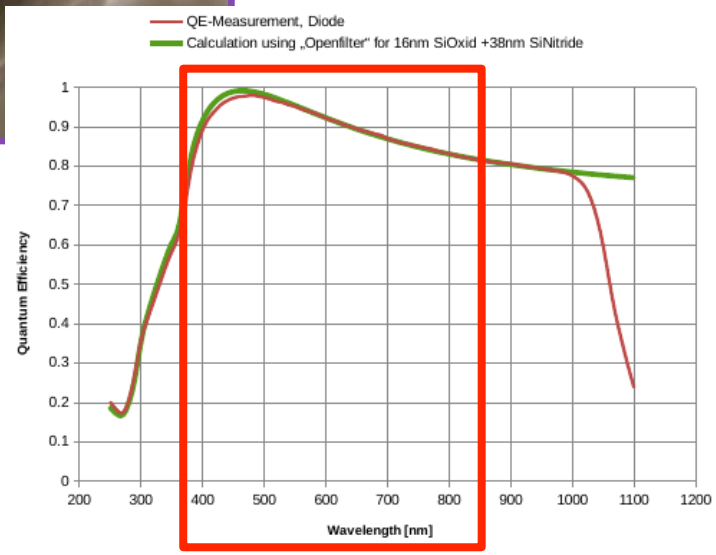




Compact vacuum-tight camera housing ~ 18 x 25 x 10cm ^{3}

FSP pnCCDs



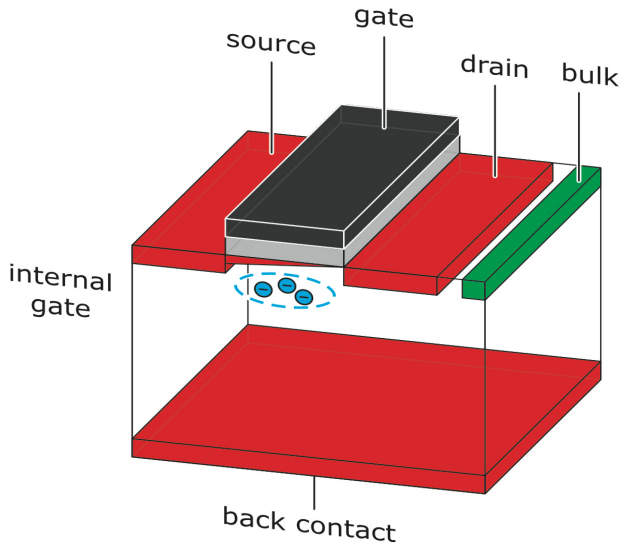

QE-Measurement, Diode
Calculation using „Openfilter" for 16nm SiOxid +38nm SiNitride
Quantum Efficiency
Wavelength [nm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
200
300
400
500
600
700
800
900
1000
1100
1200

DEPFETs

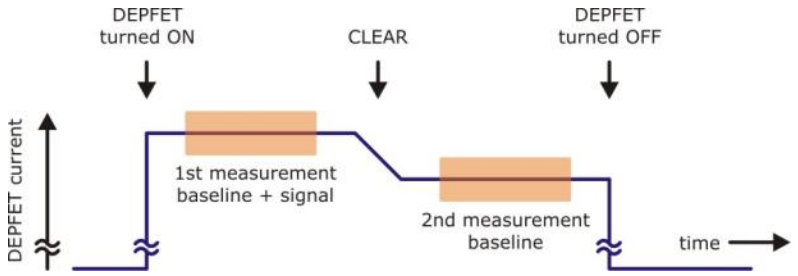
p-MOSFET on fully depleted n-substrate

- **fully depleted** sensitive volume
  - fast signal rise time (~ns), small cluster size
  - no stitching, 100% fill factor
- **Charge collection in "off" state**, read out on demand
  - potentially low power device
  - Non destructive readout
- **internal amplification**
  - charge-to-current conversion (300 pA/el.)
  - large signal, even for thin devices
  - r/o cap. independent of sensor thickness (20 fF)
- Usually read out in rolling shutter mode, but hybrid devices also available

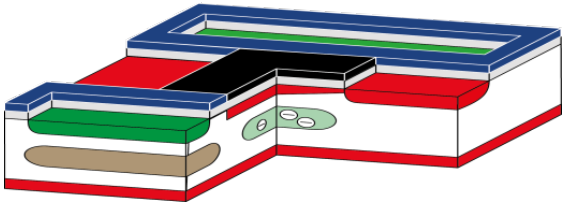
Proposed by
Josef Kemmer &
Gerhard Lutz, 1987

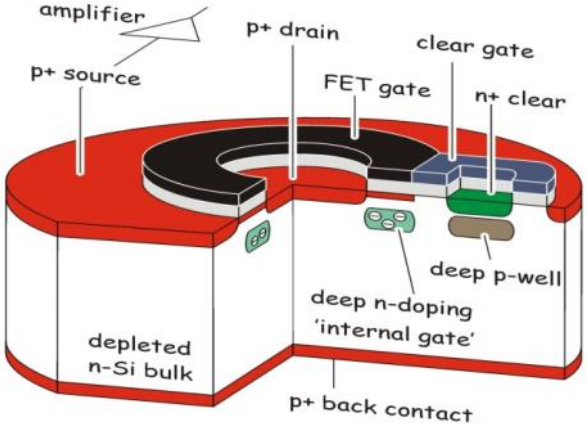


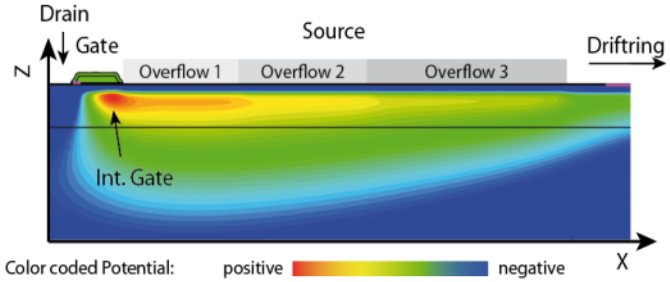
Applications:
- unit cell of active pixel sensor
- integrated readout device of SDD, pnCCD, …



DEPFET classes







Thin & small pixel: vertex, low E electron detectors (TEM)

pixel size: 20µm…75µm
read out time per row: 25ns-100ns
Noise: ≈100 el ENC
thin detectors: 50µm…75µm → still large signal: 40nA/µm for MIP

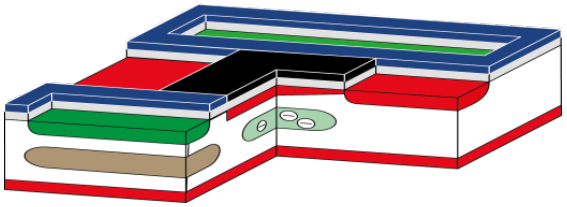
Low noise: Spectroscopic X-Ray imaging

pixel size: 100µm, with drift rings several 100s of µm
read out time per row: few µs
Noise: ≈4 el ENC
fully depleted, the thicker the better → large QE for higher E

High Dynamic range

DEPFET **S**ensor with **S**ignal **C**ompression
Sensitivity to single photons and high dynamic range
pixel size: 60 -200 µm

DEPFETs for **Vertex detectors: BELLE II**



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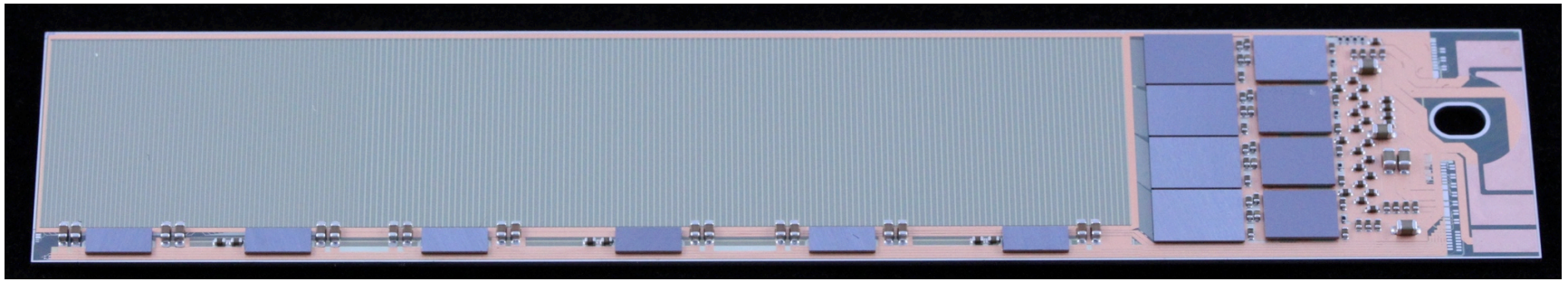
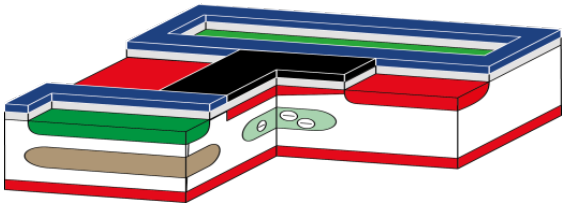
Poster by
L. Andricek

Characterization of the first full-sized DEPFET PXD Module for the Belle II Pixel Detector
8 Aug 2016, 18:30
Riverwalk A/B

Low mass vertex detectors with at present highest possible integration!



DEPFETs for **Vertex detectors: BELLE II**



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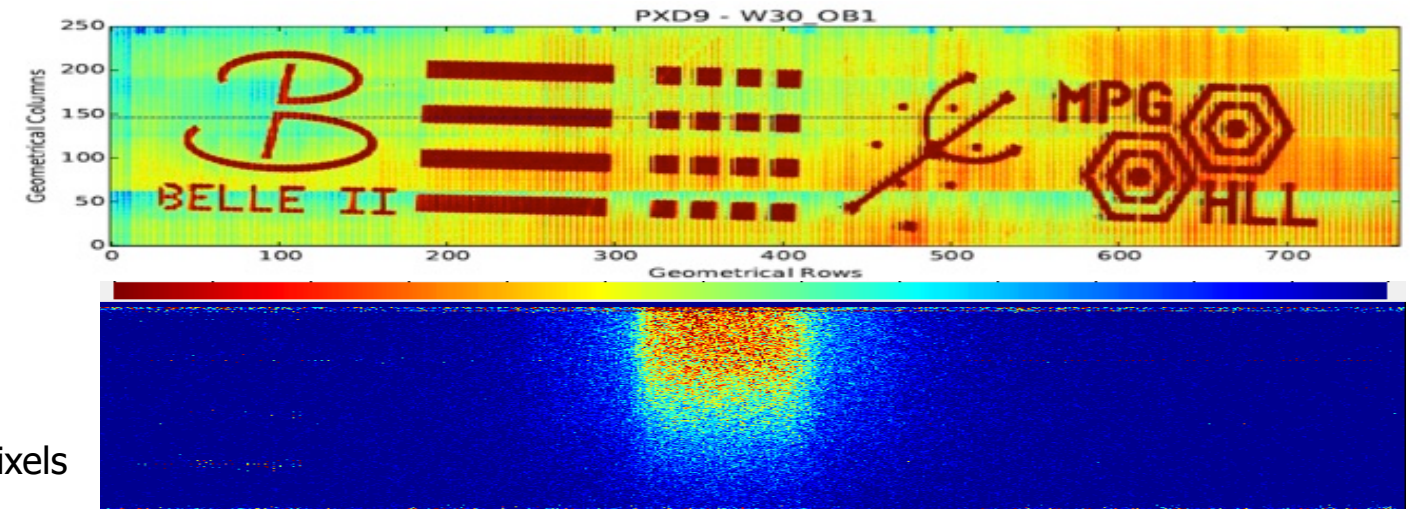
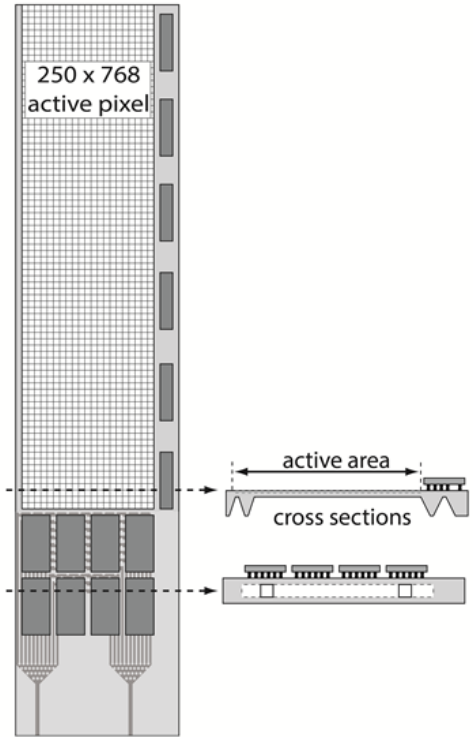
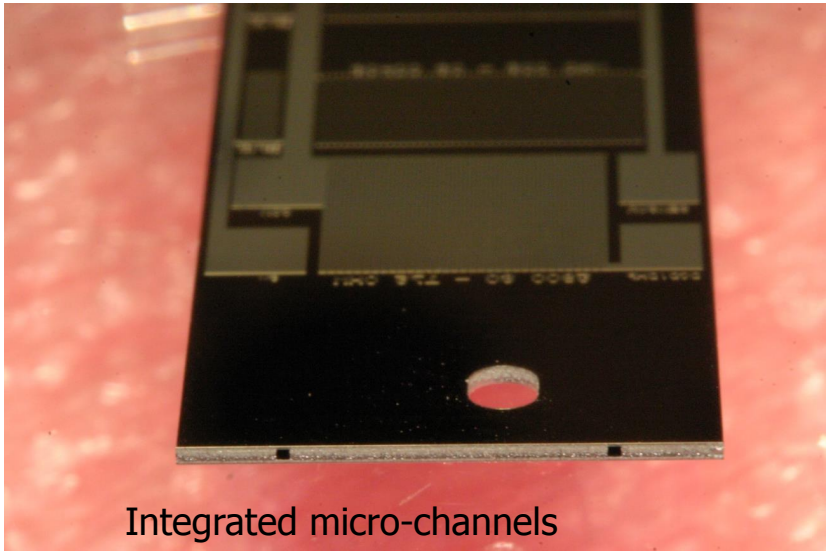


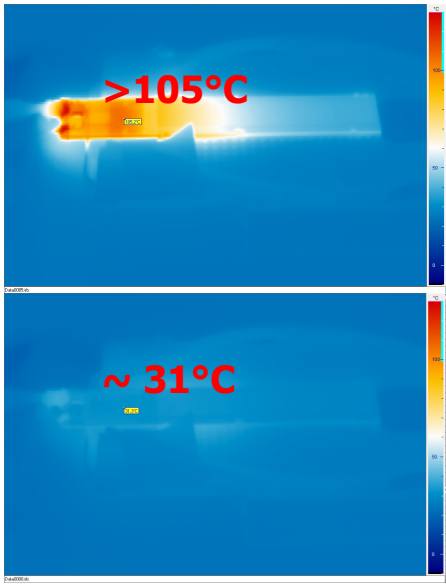
~ 0.1 ‰ masked pixels

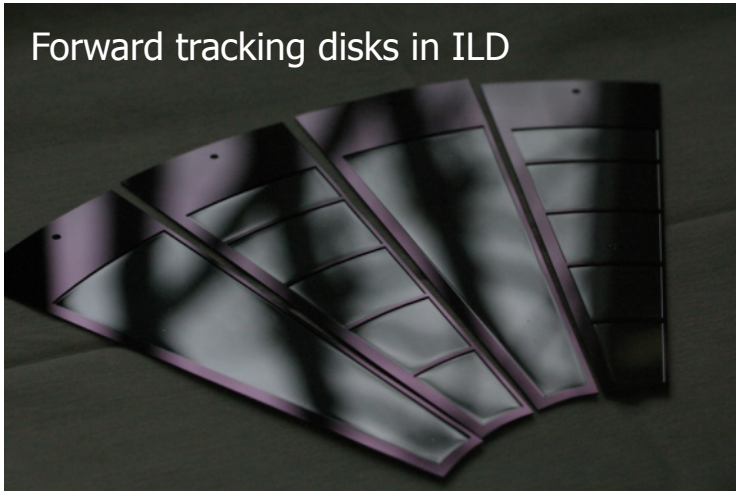
outer backward module, 200k pixel, 7.7cm²

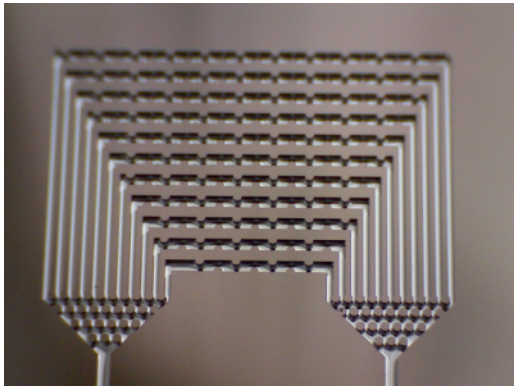
Future all silicon modules – going towards ILC





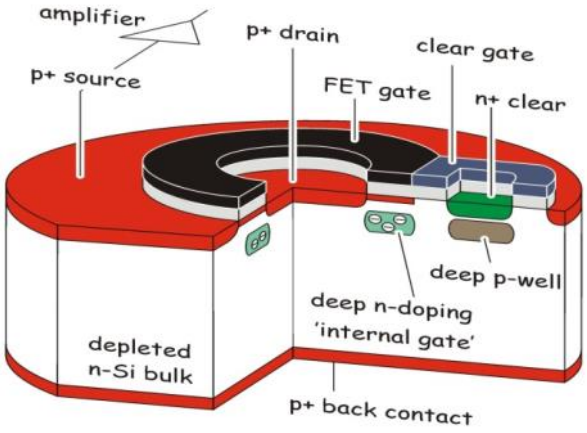






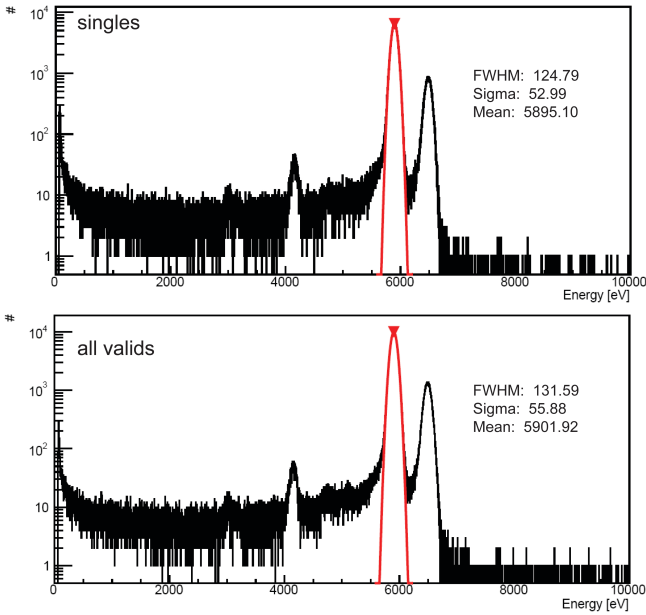
Collaborative work with: University of Bonn and IFIC Valencia

DEPFETs for **Spectroscopic X-Ray imaging**

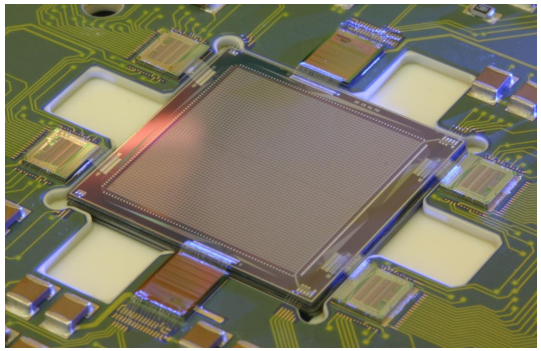


Low noise: Spectroscopic X-Ray imaging

pixel size: 100µm, with drift rings several 100s of µm
read out time per row: few µs
Noise: ≈4 el ENC
fully depleted, the thicker the better → large QE for higher E



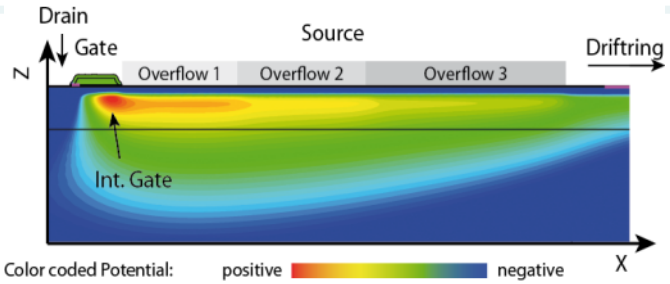
MIXS – Ready for launch
First Imaging X-ray spectrometer for planetary X-ray fluorescence



- Format
  - **1.92 x 1.92** cm²
  - **64 x 64** pixels
  - **300 x 300 µm²** pixel size
- Energy resolution
  - **200 eV FWHM @ 1 keV**
  - QE > of 80 % @ 500 eV
- Time resolution
  - **< 1 ms** due to dynamics
- Radiation hardness
  - ~ 20 krad ionizing
  - 3 x 10^{10} 10 MeV p/cm²
  - **equivalent to** 1.11 x 10^{11} 1 MeV n/cm²

next large X-ray observatory ATHENA

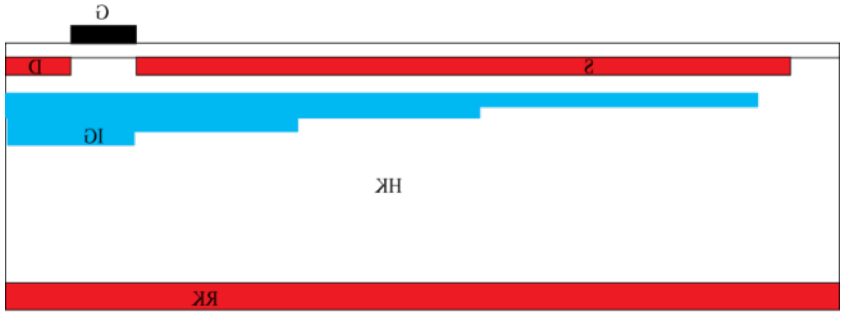
DEPFETs with **high dynamic range**



High Dynamic range

DEPFET **S**ensor with **S**ignal **C**ompression
Sensitivity to single photons and high dynamic range
pixel size: 60 -200 µm

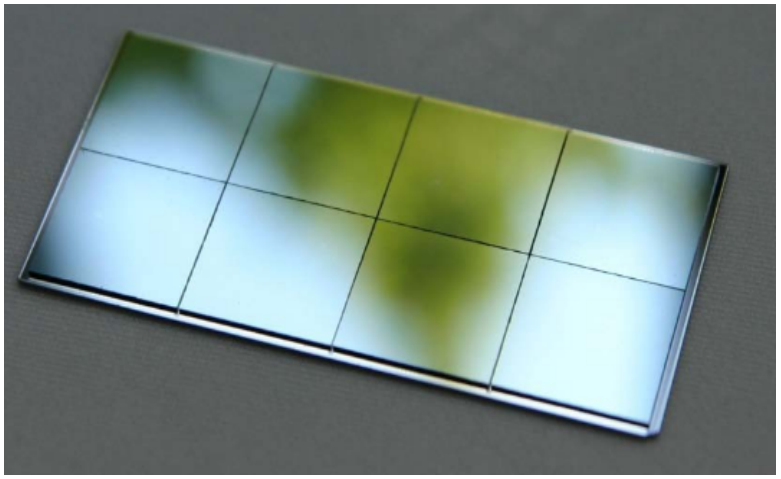
DSSC - **D**EPFET **S**ensor with **S**ignal **C**ompression



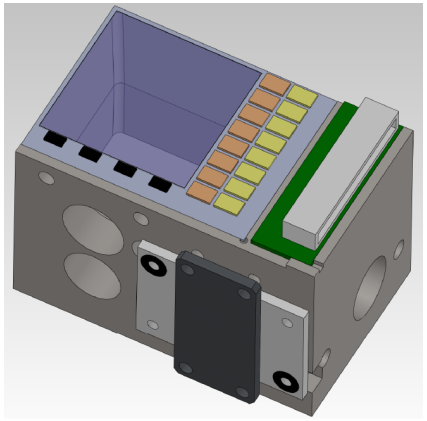
- The internal gate extends into the region below the source
- Small signals assemble below the channel, being fully effective in steering the transistor current
- Large signals spill over into the region below the source. They are less effective in steering the transistor current.
- 200 x 200 µm pixel has been designed and produced
- 60 x60 µm pixel has been designed and is being produced now

DEPFETS with signal compression

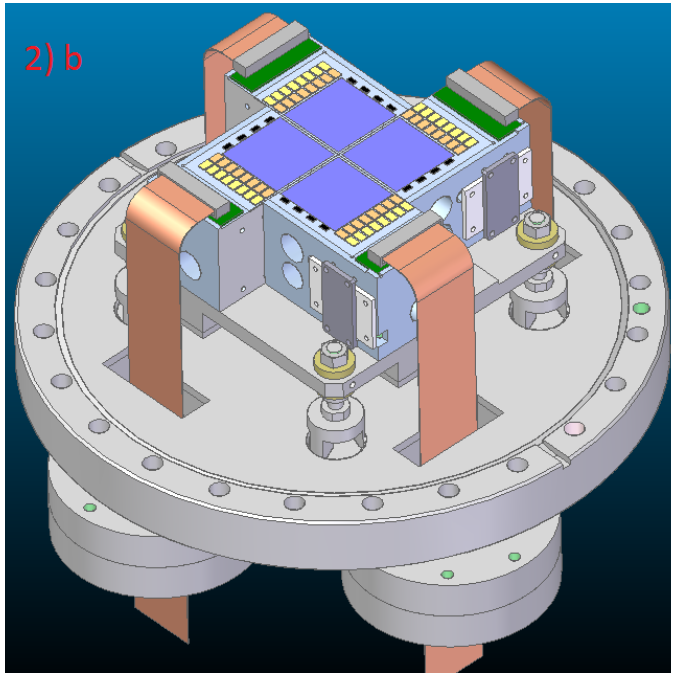
DSSC for EuXFEL: hybrid detectors



DEPFETs for low Energy Electron detection (TEM)



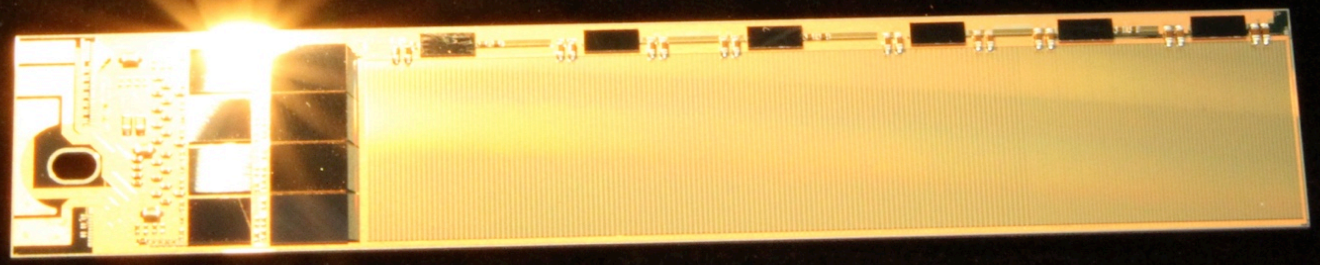
	DSSC	**Edet**
size	1Mpixel	1MPixel
Pixel size	200 µm	60 µm
Thickness	450 µm	30 and 50 µm
Total area	21x21cm²	6x6 cm²
Frame rate	4.5MHz	80kHz



Summary

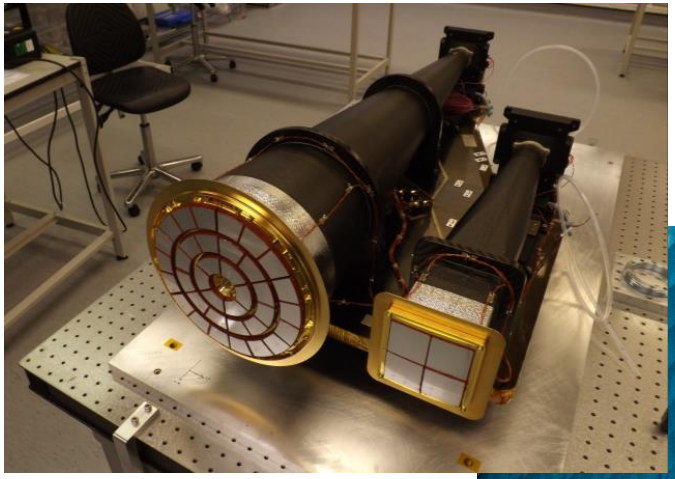
I showed :

- Some very attractive devices developed and produced at MPS Semiconductor Laboratory
- Some of the potentials of those devices are used in current projects
- Still space to explore much more …



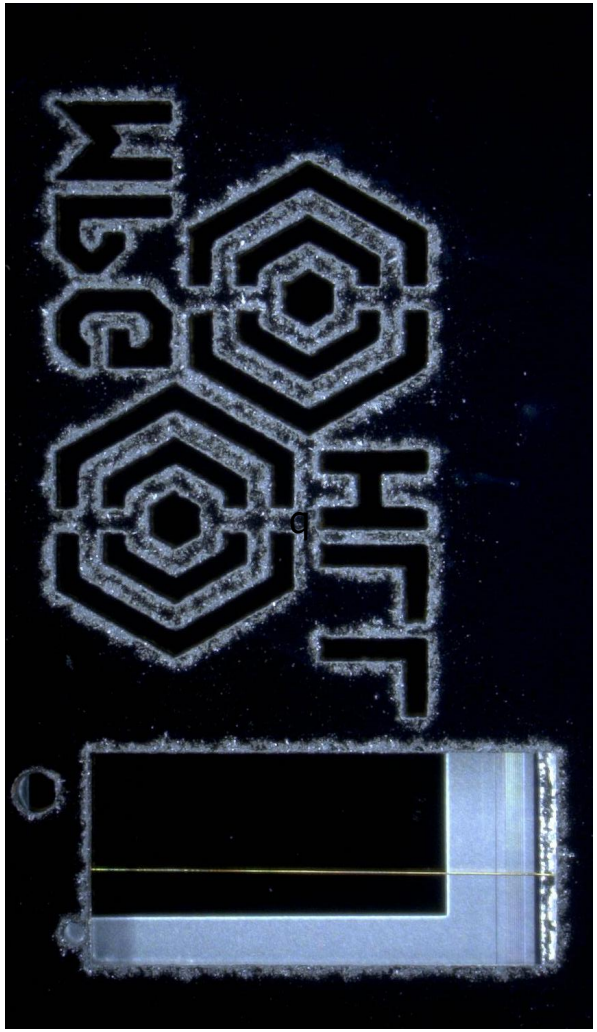
Thank you for your attention!

Fully assembled MIXS module

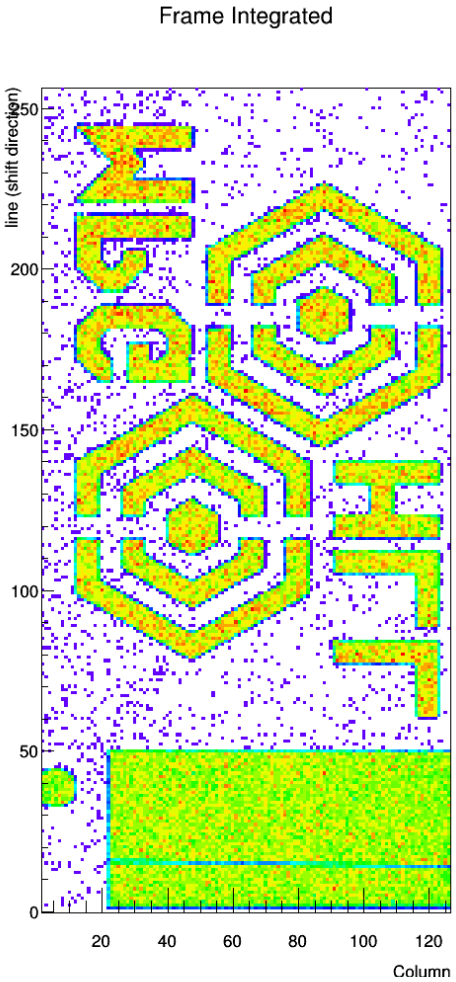


X ray imaging using small pixel pnCCDs

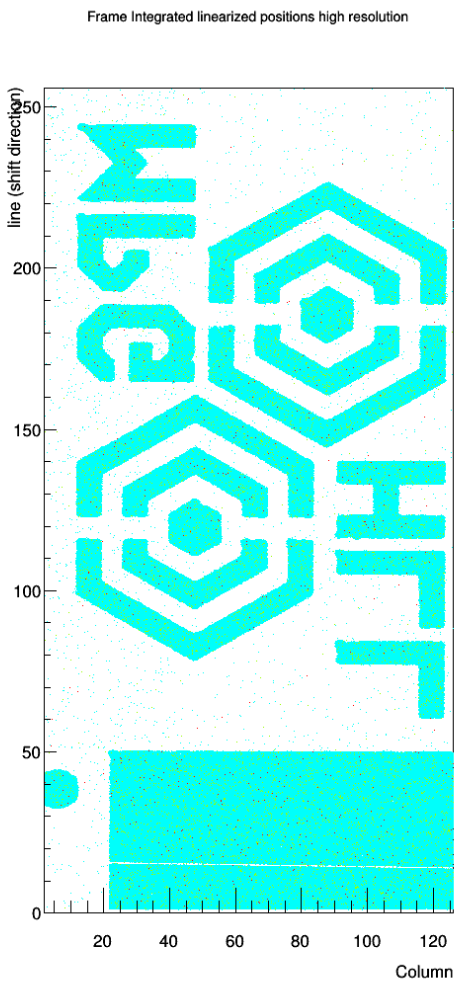
Imaging of a collimated Fe^{55} Source through a mask + goldwire



Mikroscope Image of mask and wire in front of the pnCCD.



Frame as obtained by integrating Photons per pixel



Frame as obtained by cluster reconstruction and integration per subpixel (32x32 subgrid)

Image Resolution for Cluster Imaging @ 5.9 keV