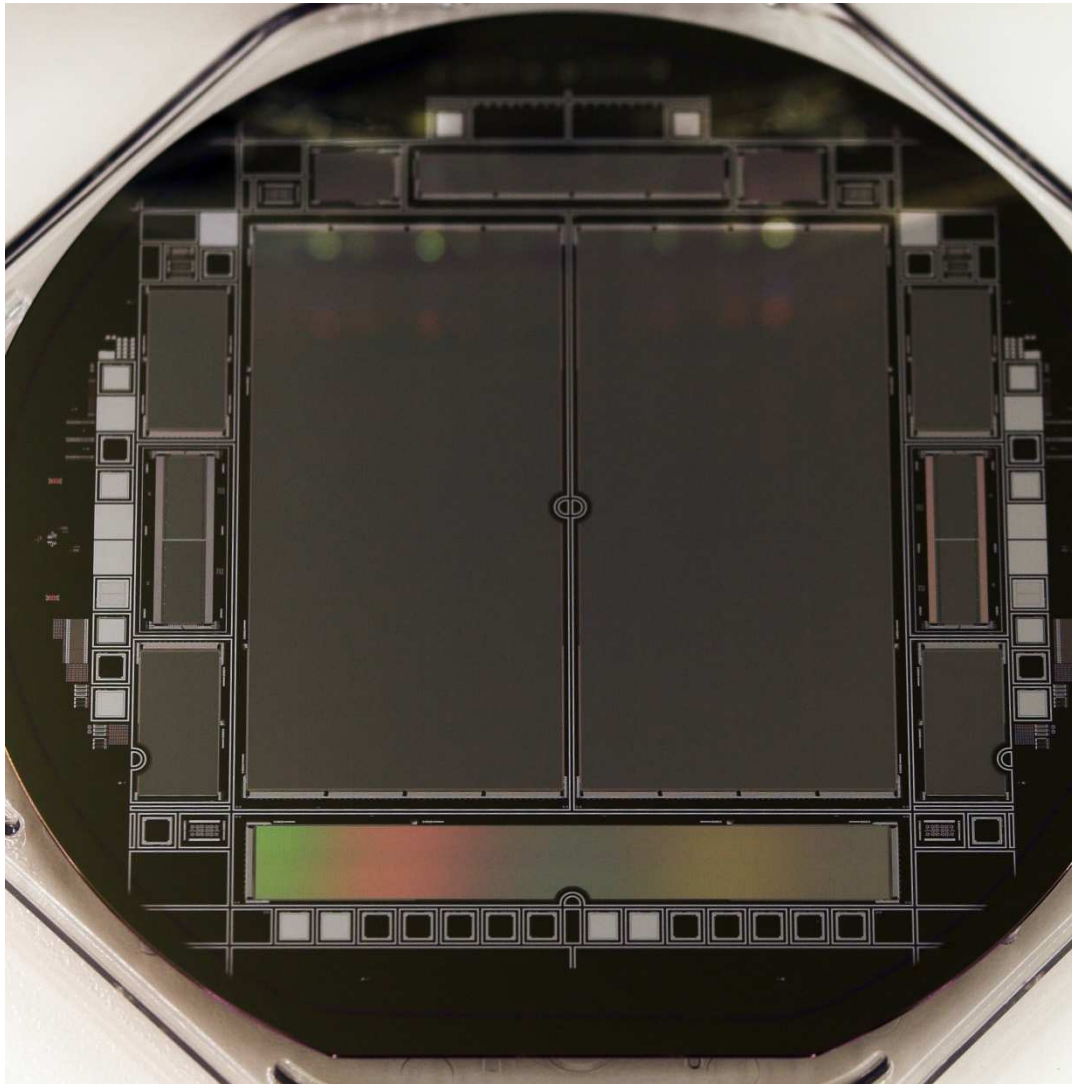
High Speed Imaging and Spectroscopy with X - rays



Lothar Strüder

ESRF Spectroscopy Meeting, Paris
16.3.2015

PNSensor

Outlook

- Photon counting, integrating and spectroscopy detectors
- Experiments with pnCCDs at synchrotrons
  - ESRF
  - BESSY
  - ANKA
- Experiments at X-ray Free electron Lasers
  - LCLS, all end stations
  - FLASH
  - SACLA
- Performance figures: pnCCDs
- DePFET active pixel sensors
  - X-ray calibration at the PTB end stations at BESSY
  - Performance figures
- The new Fab of PNDetector and PNSensor

PNSensor

2 – dim X-ray Imaging Detection

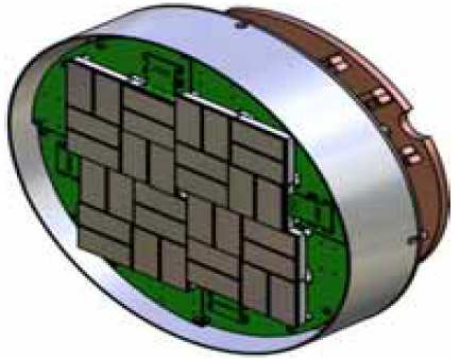
I. Photon counting systems

Every single photon is counted individually
Up to 10^7 individual X-rays can be recorded per pixel,
Two X-rays arriving simultaneously are counted as 1 photon
(PILATUS, XPAD, . . .)


SLS PILATUS

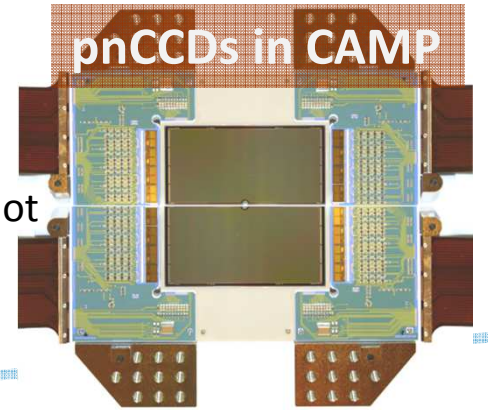
II. Integrating pixel array detectors (PAD)

The number of created electron-hole pairs is proportional to the deposited energy of the incident X-rays.
The amplitude of all incident photons is measured, the amplitude is proportional the number of X-rays, if the energy of the incident X-rays is known. Up to10^4 X-rays per pixel, per shot can be recorded. (CSPAD, LPD, AGIPD, DSSC. . .)


Cornell-SLAC LCLS

III. Spectroscopic imaging detectors

The number of created electron-hole pairs is proportional to the deposited energy of the incident X-rays. **Very low readout noise** allows to measure the energy of individual photons (single photon mode), dynamic range at 2 keV typ. 2.000 X-rays per pixel and per shot (pnCCDs in CAMP, LAMP) 10^4 photons of 10 keV (DePFETS in DSSC) in integration mode. Energy resolution typ. 30 eV (FWHM) to 150 eV (FWHM) from 50 eV to 10 keV X-rays



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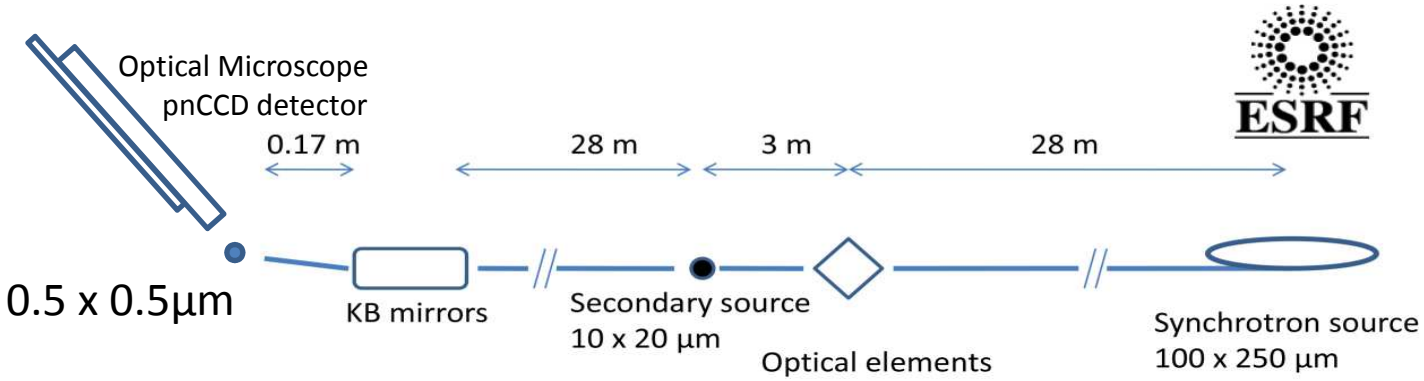
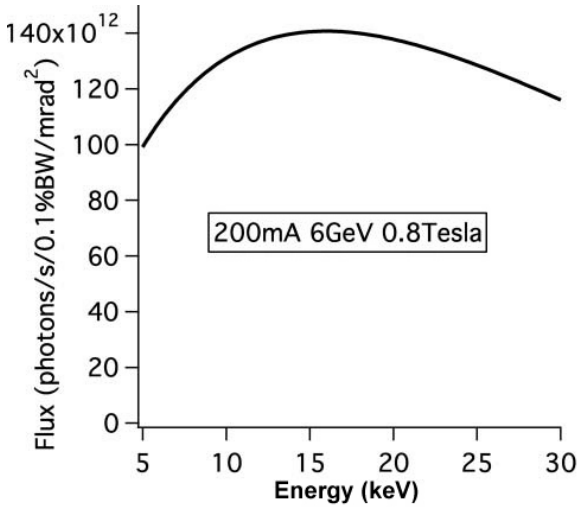
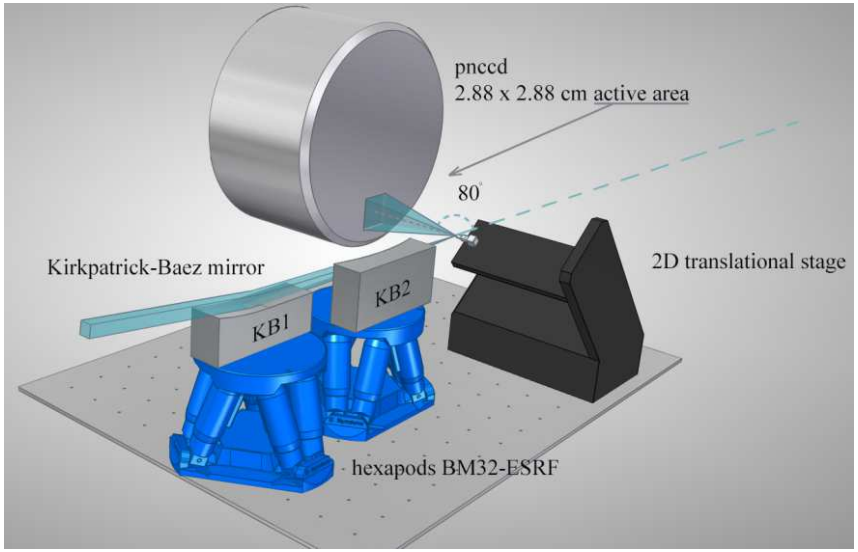
Laue X-ray µDiffraction

- Sample, Laue Setup and Measurement





Beam line energy spectrum



Kirkpatrick-Baez-mirror

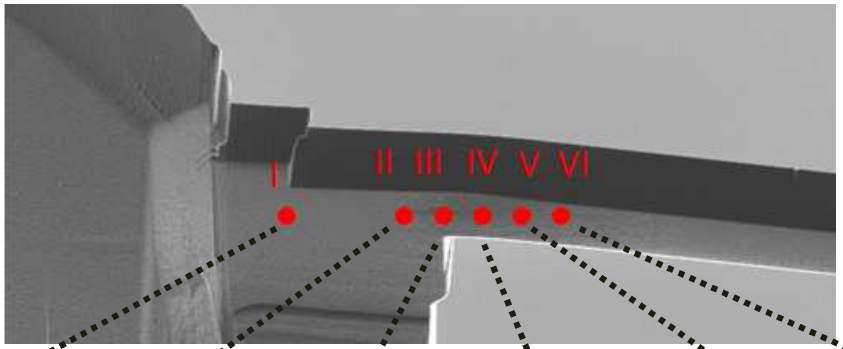
PNSensor

Laue X-ray µDiffraction

- Results: Laue spots in 3 dimensions

position I

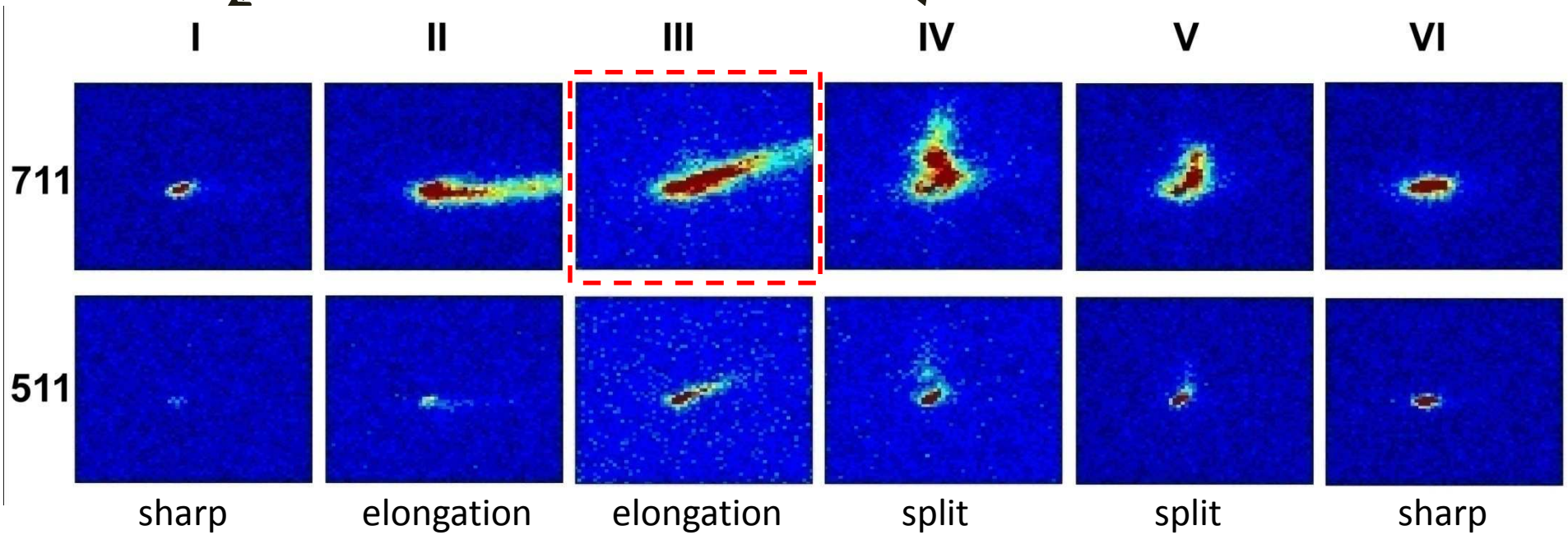
$\sigma_x \approx \sigma_y \approx 1\ pixel$



position III

$\sigma_x \approx 5.6\ pixels$

$\sigma_y \approx 1\ pixel$



Laue X-ray µDiffraction

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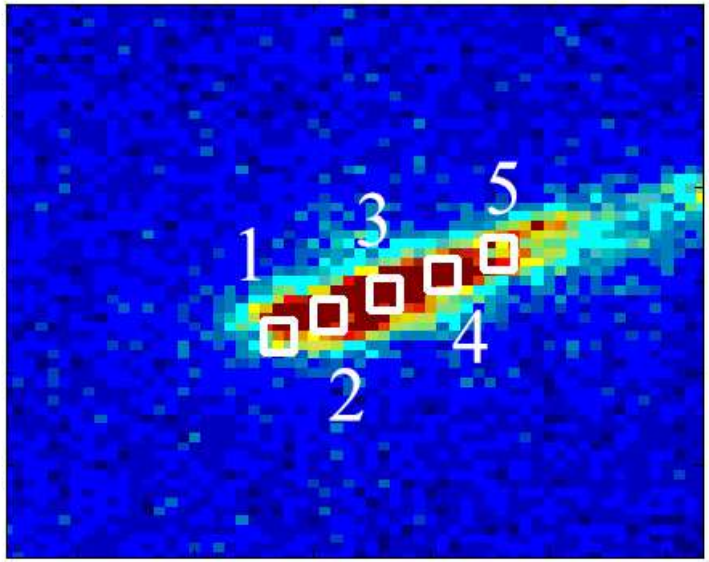

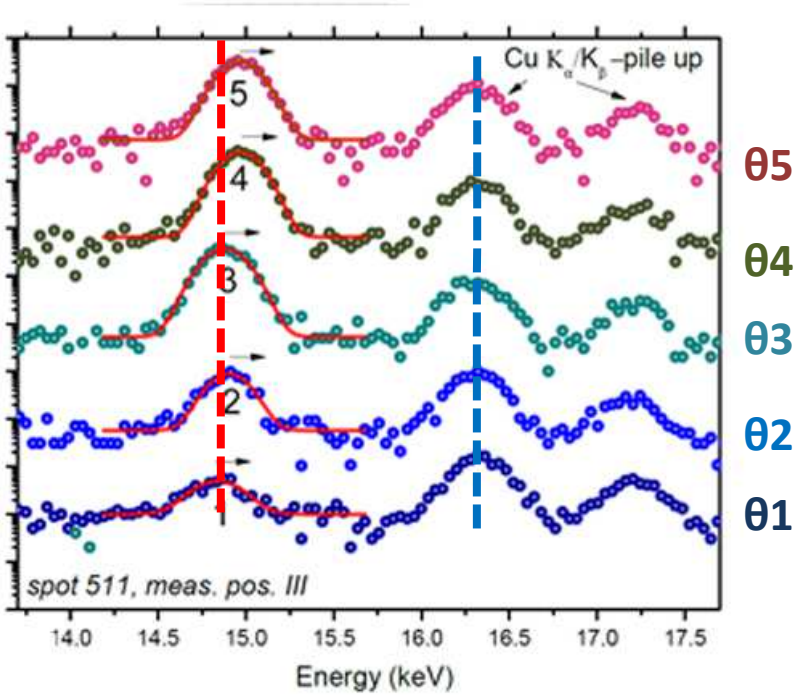

•Systematic increase in the energy along the streak $E \equiv f(\theta)$

•High sensitivity: Relative change in energy (50eV)

PNSensor

pnCCDs and DePFET formats

1. pnCCD-0
   - 64 x 200 pixel, 150µm x 150µm, 0.96cm x 3.0 cm
   - Active area: 2.88 cm^2 , no optical blocking filter

2. pnCCD-10
   - 256 x 256 x 2 pixel, 75µm x 75µm
   - OBF optional, area 7.4 cm^2

3. pnCCD-11
   - 384 x 384 pixel, 75 µm x 75µm
   - OBF optional, area 15 cm^2

4. pnCCD-12
   - 512 x 1024 pixel, 75 µm x 75µm
   - OBF, area 29.5 cm^2

5. pnCCD-20
   - 264 x 264 x 2 pixel, 48µm x 48µm
   - OBF optional, area 3.3 cm^2

6. pnCCD-30 test
   - 128 x 128 x 2 pixel, 36µm x 36µm
   - OBF optional, area 0.5 cm^2

7. DePFET – 10
   - 64 x 64 pixel, 300µm x 300µm
   - 256 x 256 pixel, 75µm x 75µm
   - 512 x 512 pixel, 75µm x 75µm

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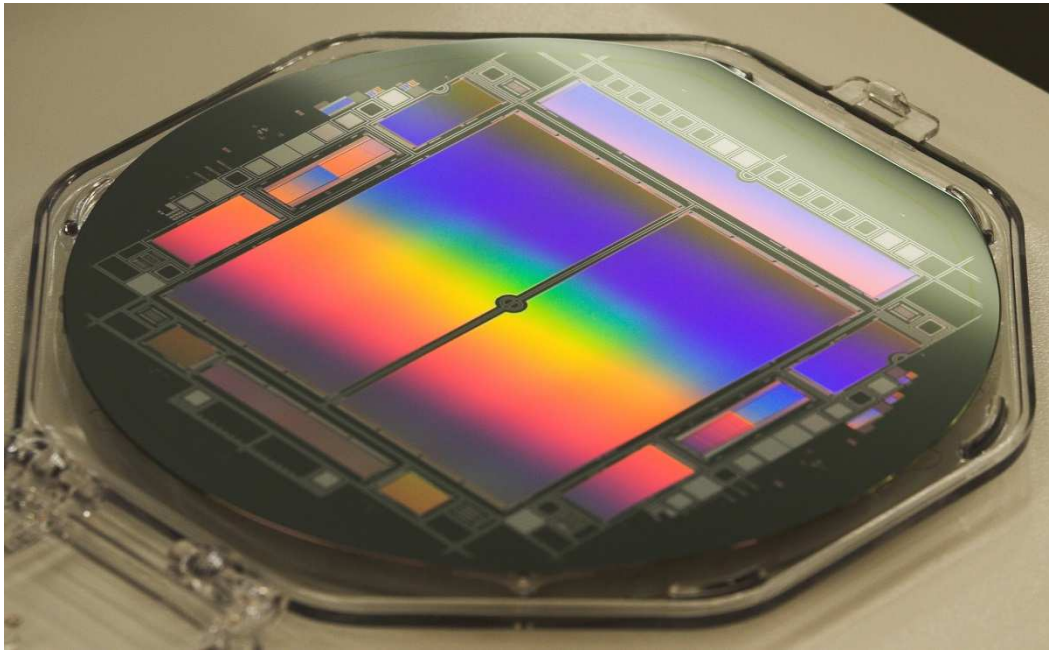

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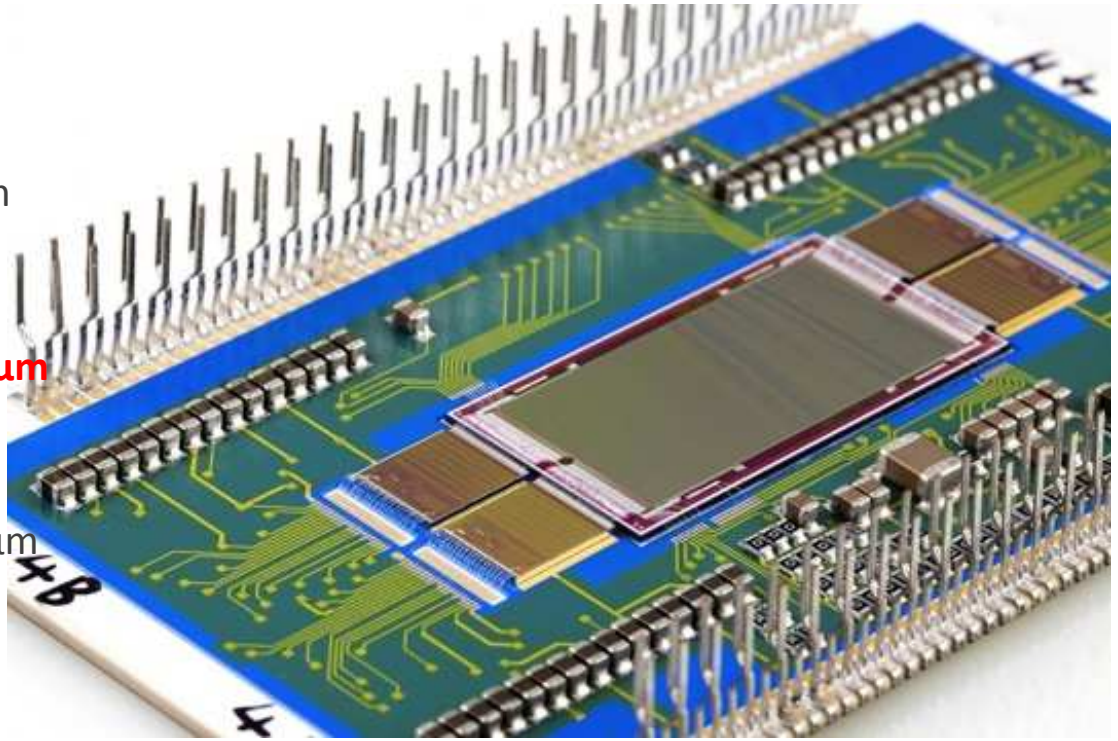

PNSensor

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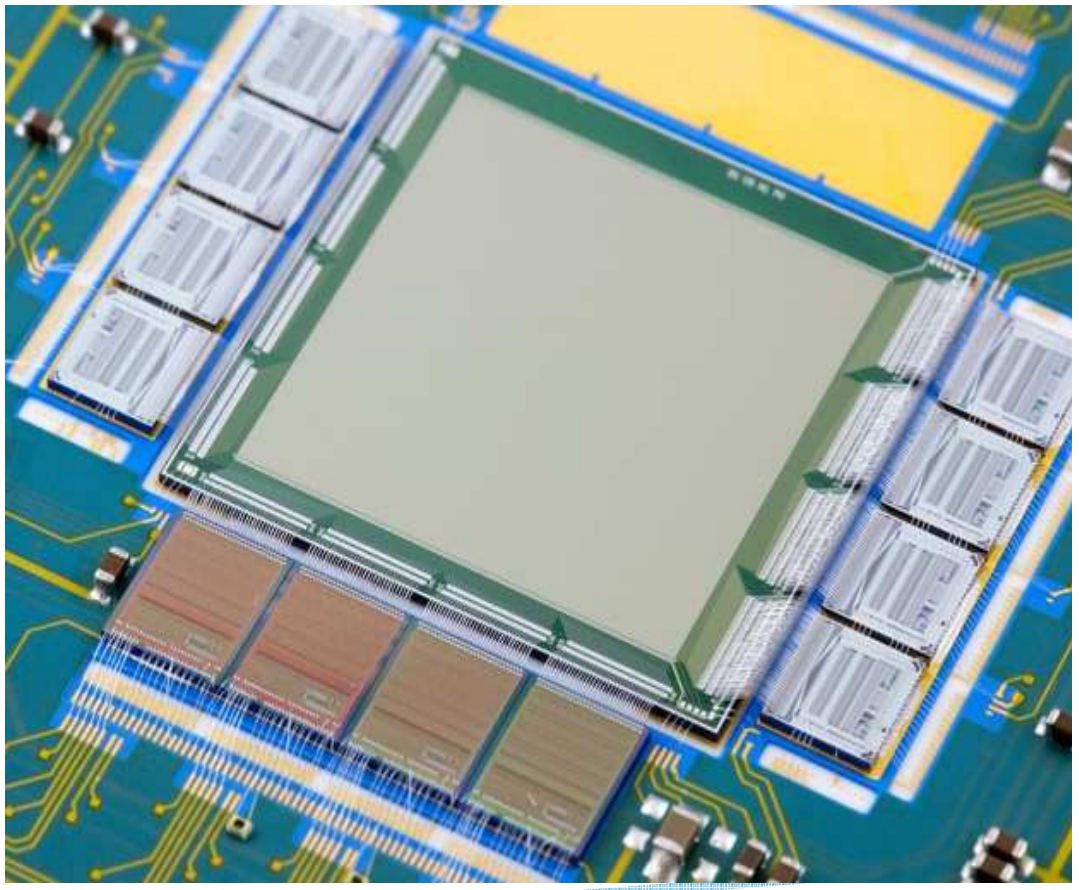

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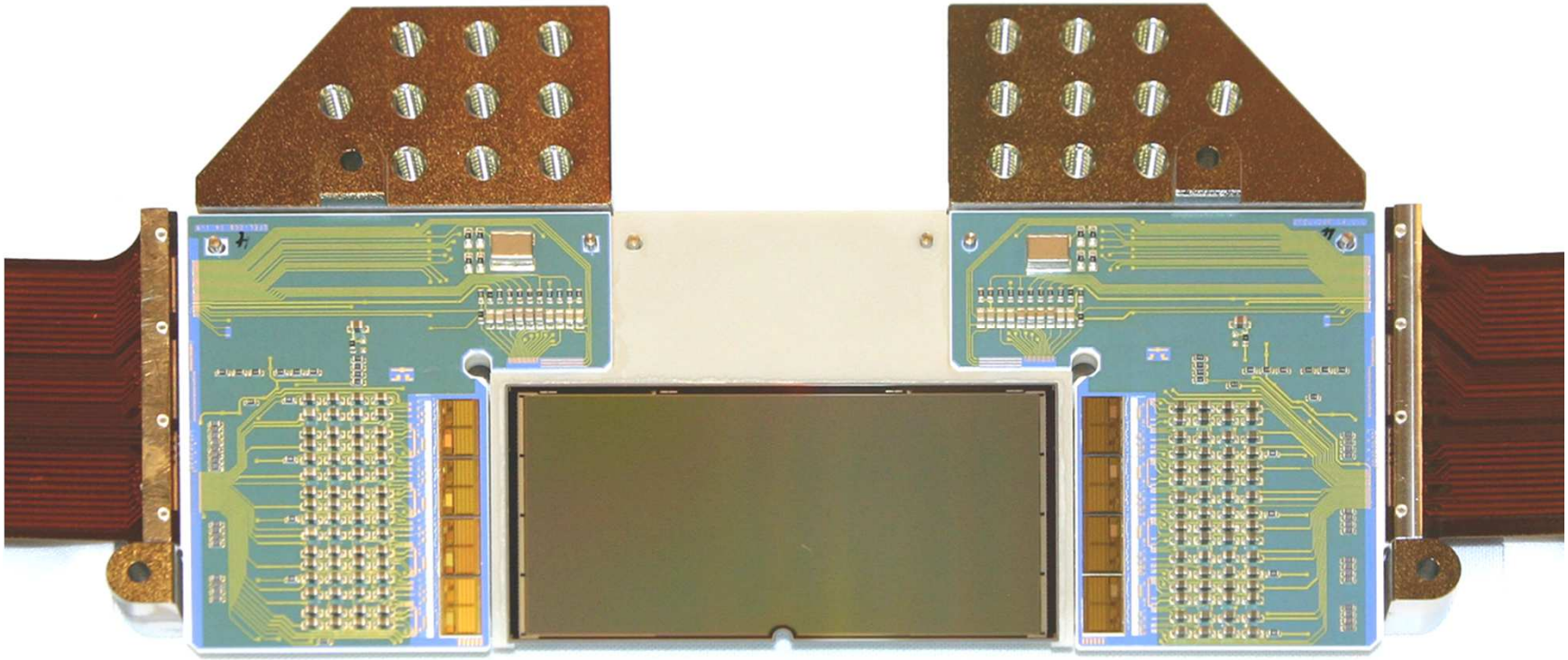
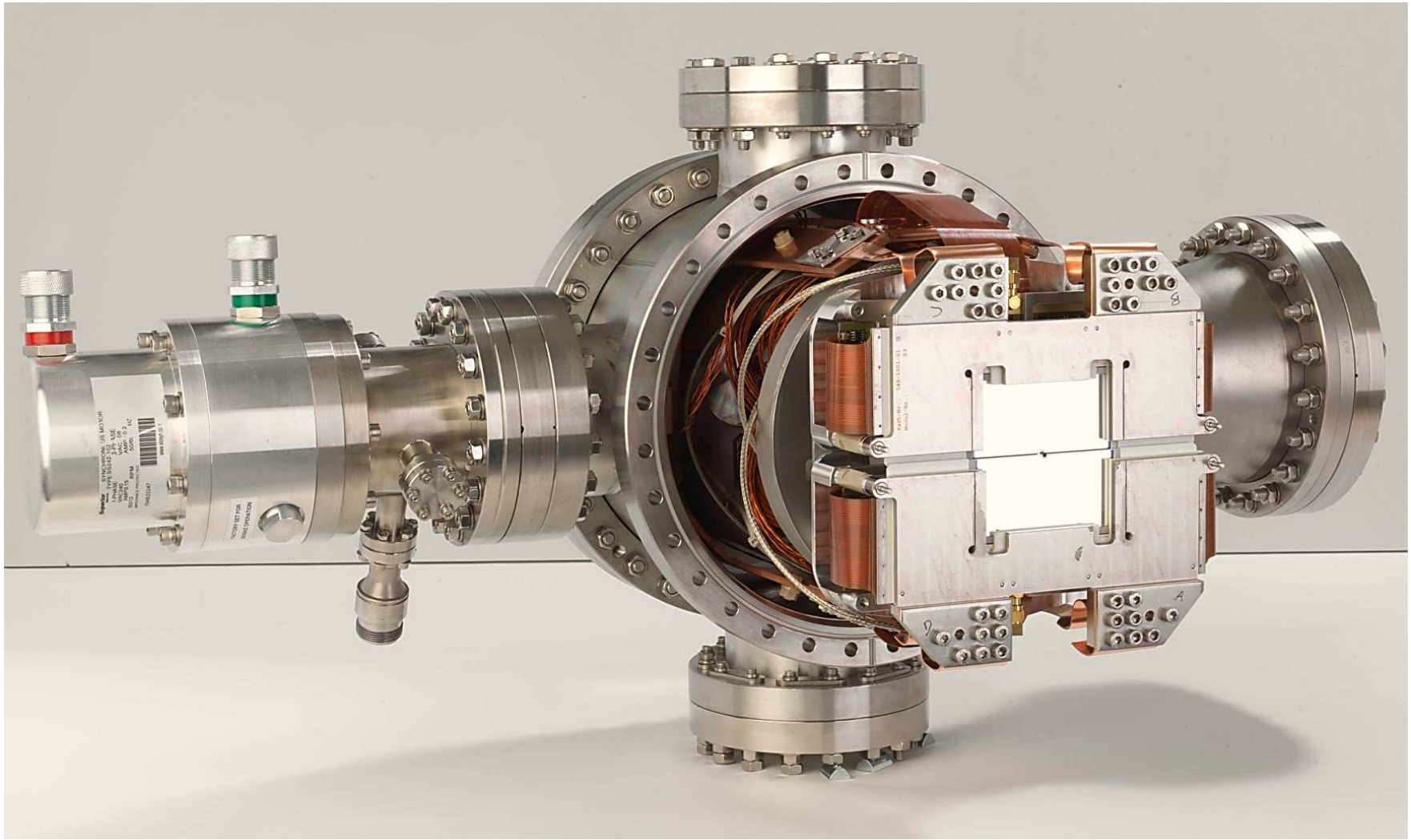
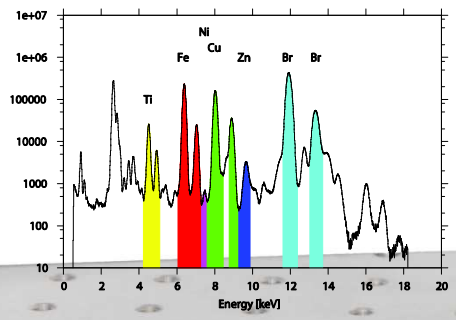


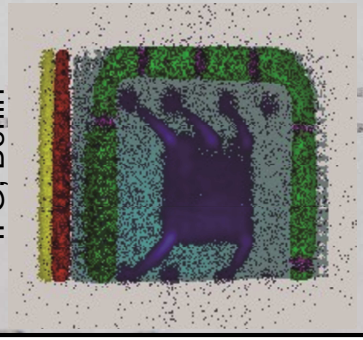


PNSensor

Compact X-ray Camera

Polycapillary optics from IFG, Berlin

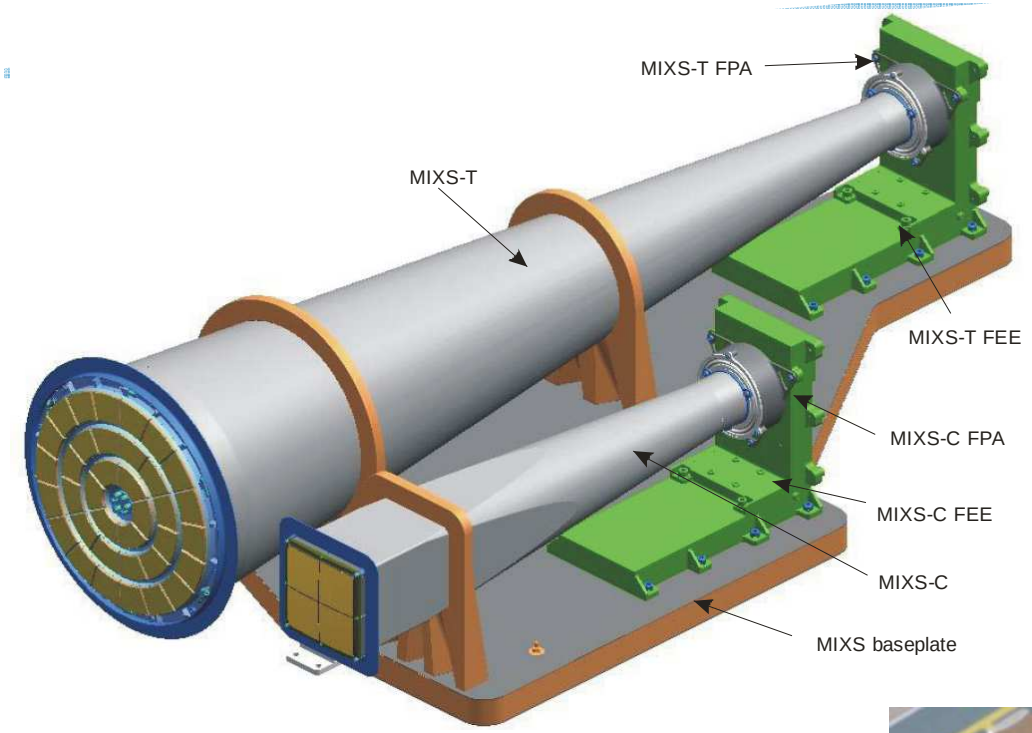


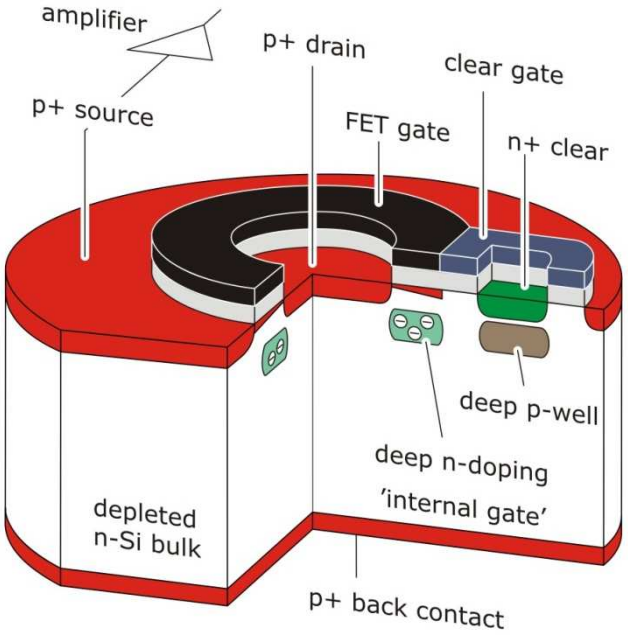


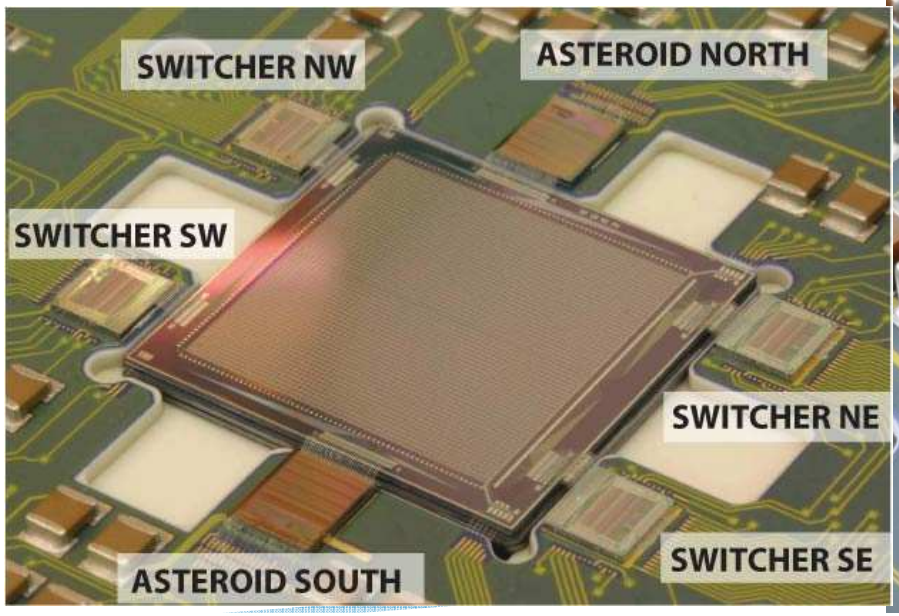
IFG, Berlin

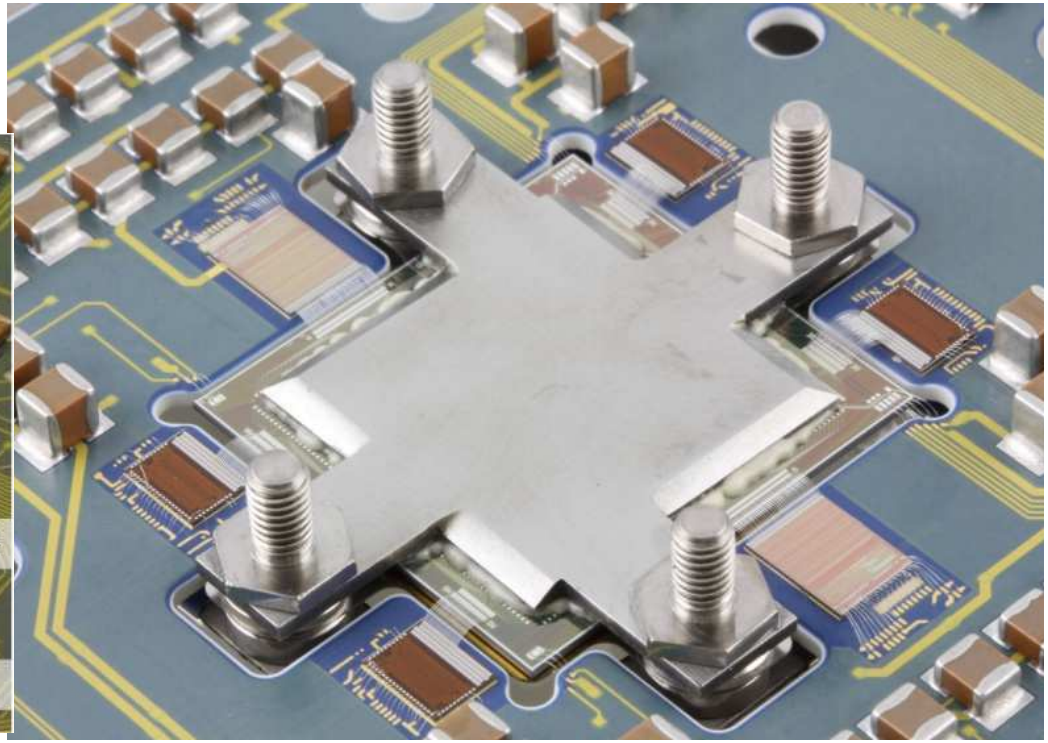
Stand alone x-ray camera with 264 x 528 pixel, 48µm x 48 µm, Fano limited energy resolution at 1.000 frames per second

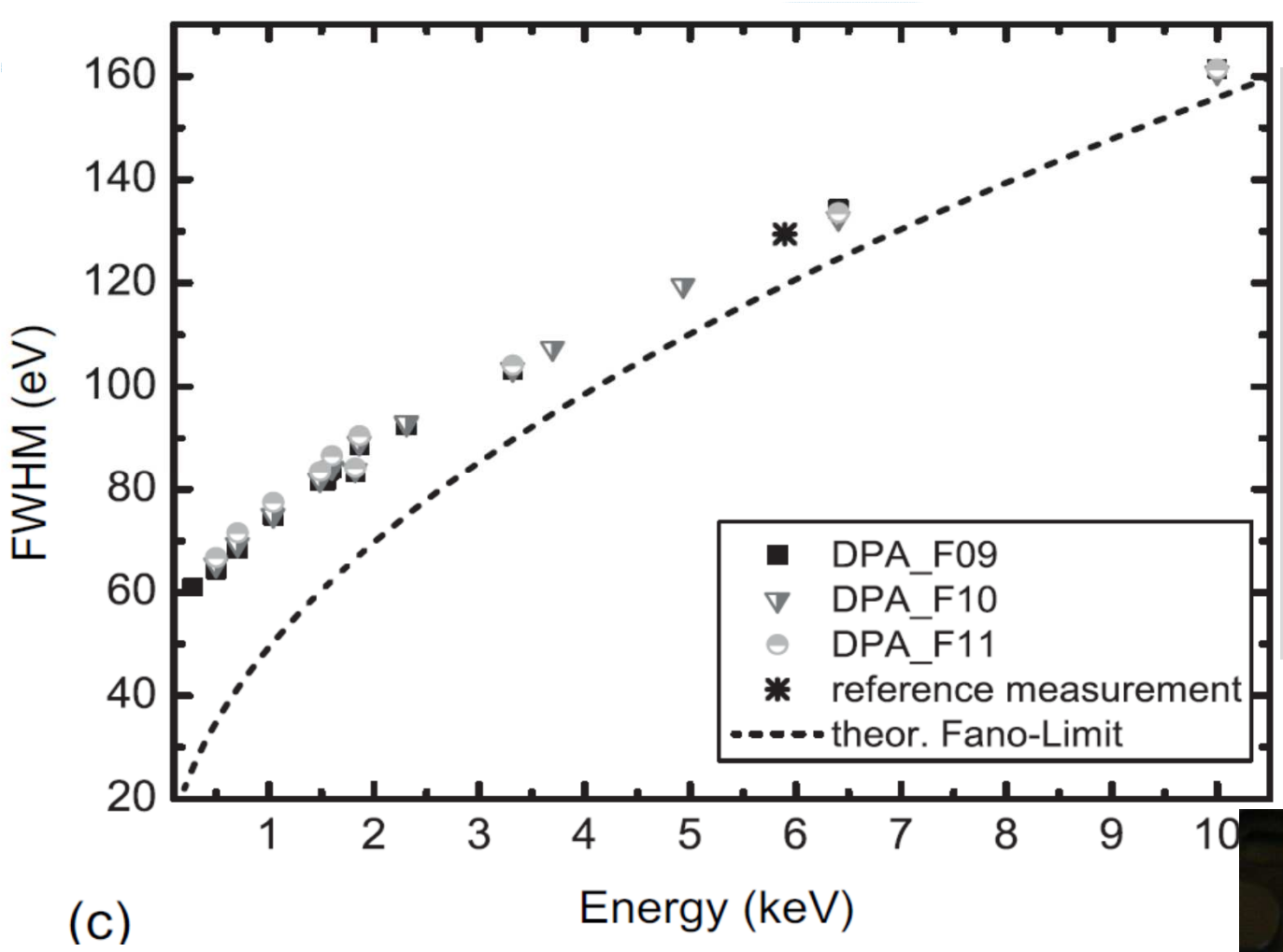
Parameter	pnCCD properties
single photon resolution	yes
energy range	0.03 keV to 30 keV
number of X-rays/pixel/readout frame	2×10^3 at 2 keV
frame rate repetition rate	continuous up to 1 000 Hz, with binning: 20.000 Hz
charge handling capacity	approx. 2.8×10^6 electrons per pixel (max.) for 75 µm × 75 µm pixel size
quantum efficiency in the NIR and visible	> 0.8 from 0.3 to 12 keV, no filter > 0.8 from 250 nm to 1100 nm
number of pixels, format	from 128 × 256 to 1 024 × 1 024
pixel size	from 36 µm to 150 µm
charge transfer efficiency	< 0.99999
externally triggerable	yes
integrated center hole	if needed Ø > 2.0 mm
integrated optical blocking filter	if desired, yes
readout noise	20 e^- (lower gain), down to 2 e^- (high gain)
energy resolution	Fano limited in the high gain mode
spatial precision	< 3 µm for 75 µm pixel size @ 17.5 keV
operation temperature	from room temperature to – 90°C
UHV compatibility	yes


MIXS-T FPA
MIXS-T
MIXS-T FEE
MIXS-C FPA
MIXS-C FEE
MIXS-C
MIXS baseplate


amplifier
p+ drain
clear gate
p+ source
FET gate
n+ clear
deep p-well
deep n-doping
'internal gate'
depleted
n-Si bulk
p+ back contact


SWITCHER NW
ASTEROID NORTH
SWITCHER SW
SWITCHER NE
ASTEROID SOUTH
SWITCHER SE





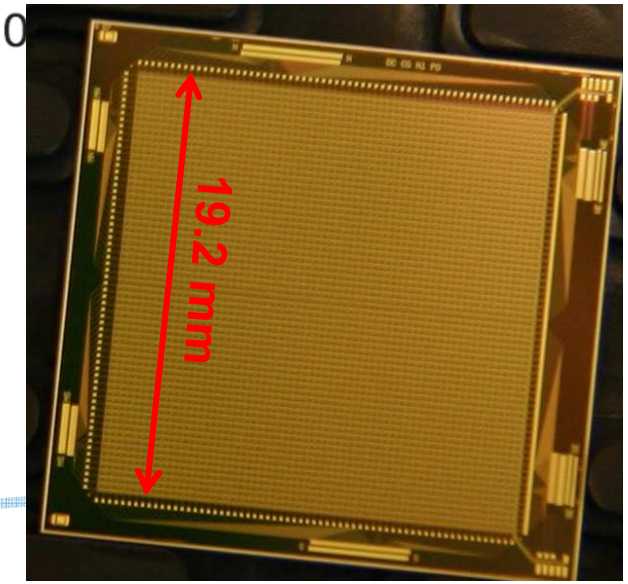
Pixel size: 300x300µm^2
Format: 64 x 64
ENC: 3 el. (rms)
Op. temp.: - 40^o C
FPS (typ.): 7.000 Hz
Area: 3.7 cm^2
Dyn.range: 10.000 @ 2keV

With analog , nonlinear

signal compression: 10^5 @ 2 keV

DePFET based detector system
aboard ESAs BepiColombo mission

Final pre-launch calibration measurements



PNSensor

Summary

I. PNSensor supplies the largest, fastest, 450 µm fully sensitive back-illuminated CCDs

II. Pixel sizes and formats are matched to the experimental set-up

III. The pnCCDs are extremely radiation hard: Below 8 keV no damage;
at 22 keV energy resolution starts to degrade from 230 eV (FWHM) to 235 eV after 5 x 10^{15} X-rays

IV. The dynamic range is presently limited to 3x10^{6} el. per pixel, i.e. 11 MeV of X-ray energy per pixel and per Millisecond.

V. DePFET active pixel sensors will finally win in the future as X-ray imager with spectroscopic capabilities:

- They overcome the dynamic range problem, analogue non-linear compression
- They can operated in a gated mode on a 10 ns time scale
- They owe a repetitive non-destructive readout: 0.18 el. (rms) was measured
- Pixel sizes can vary between 20 µm x 20 µm and 1 cm x 1 cm