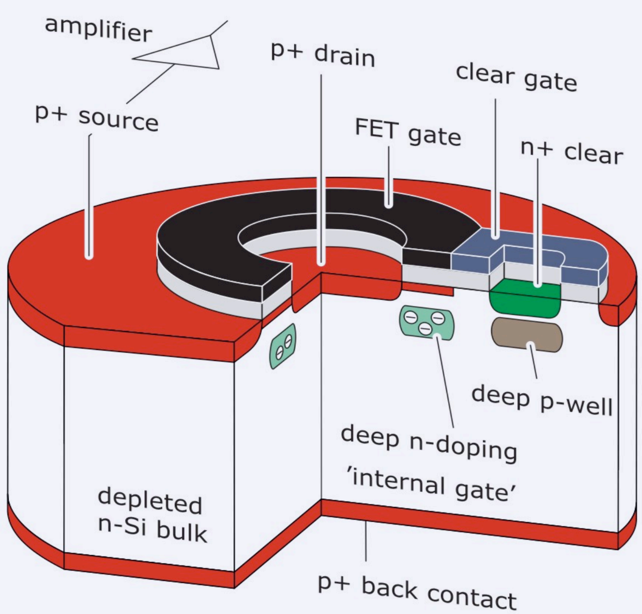
The Wide Field Imager for IXO

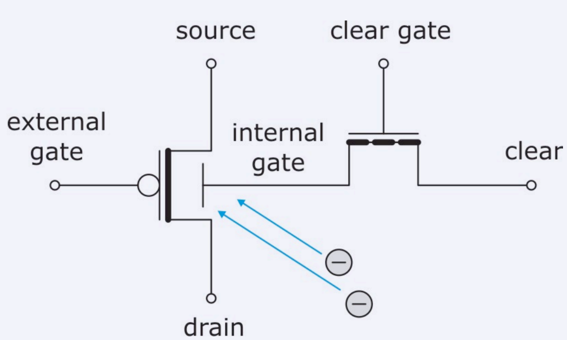
Outline:

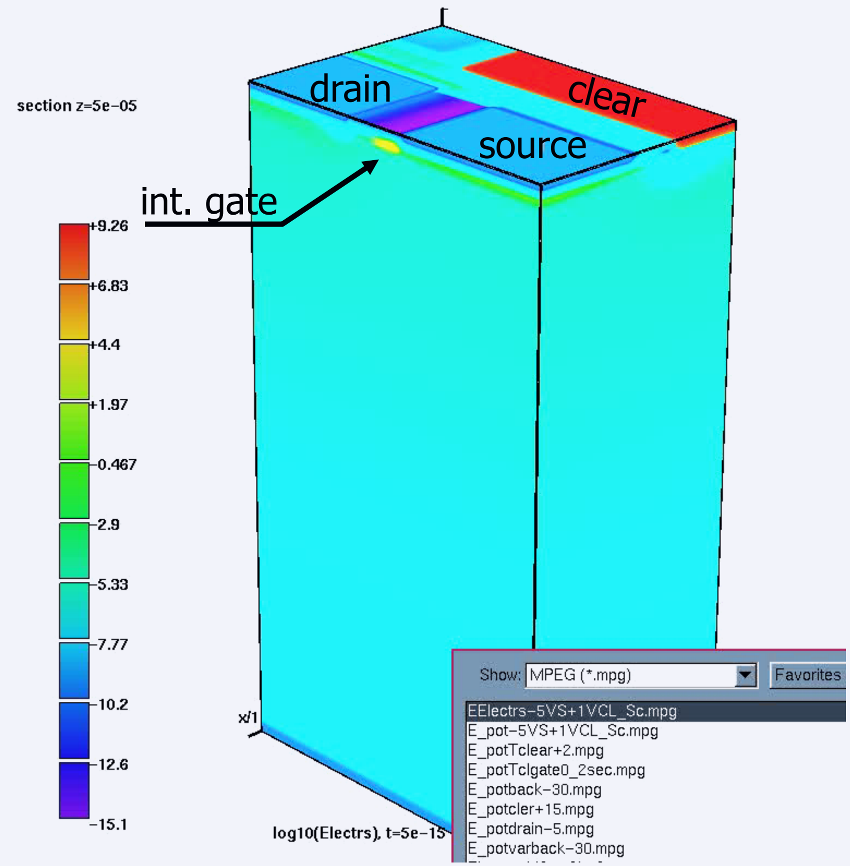
1. DePFET basics – a novel active pixel sensor
2. WFI layout
3. Science specs and achievements
4. Status
5. Future activities , collaborations, etc. . . .

Lothar Strüder

3-dim simulation of the DEPFET

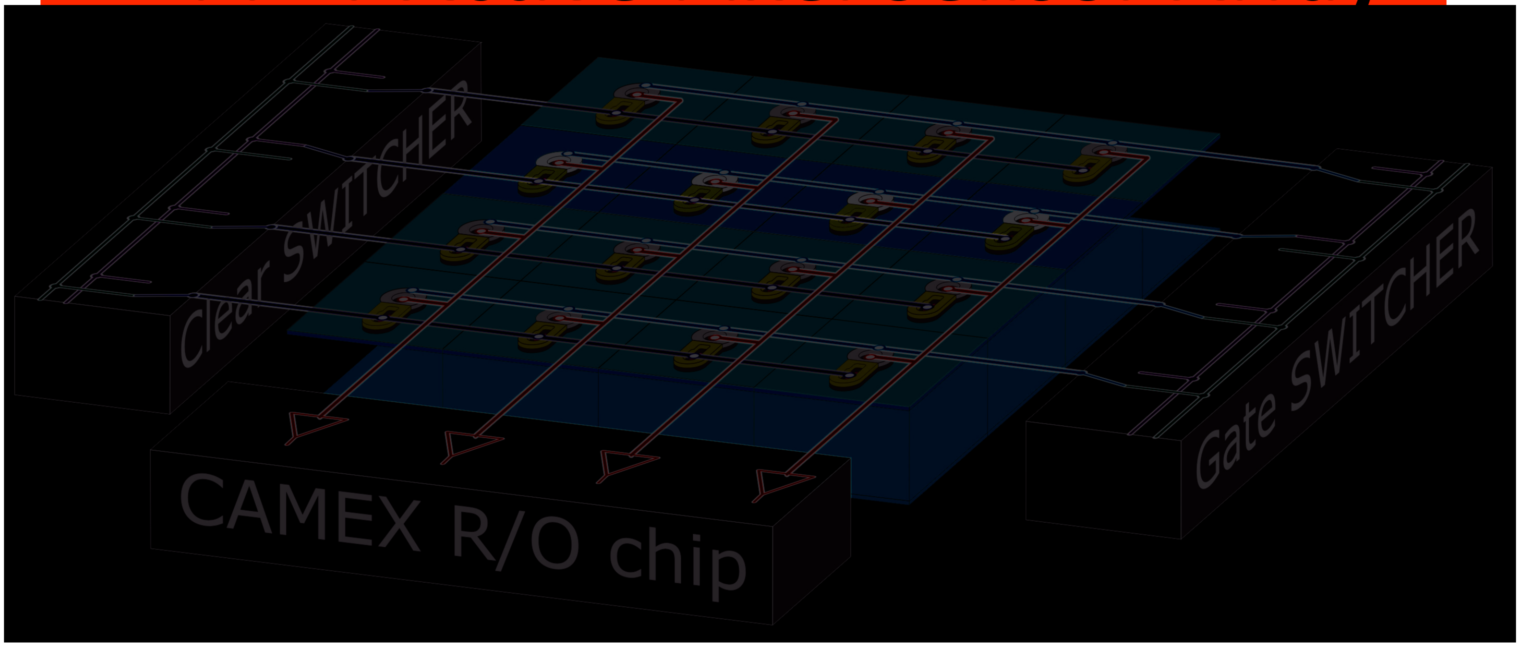






TeSCA 3D Simulation by K.Gärtner, WIAS, Berlin

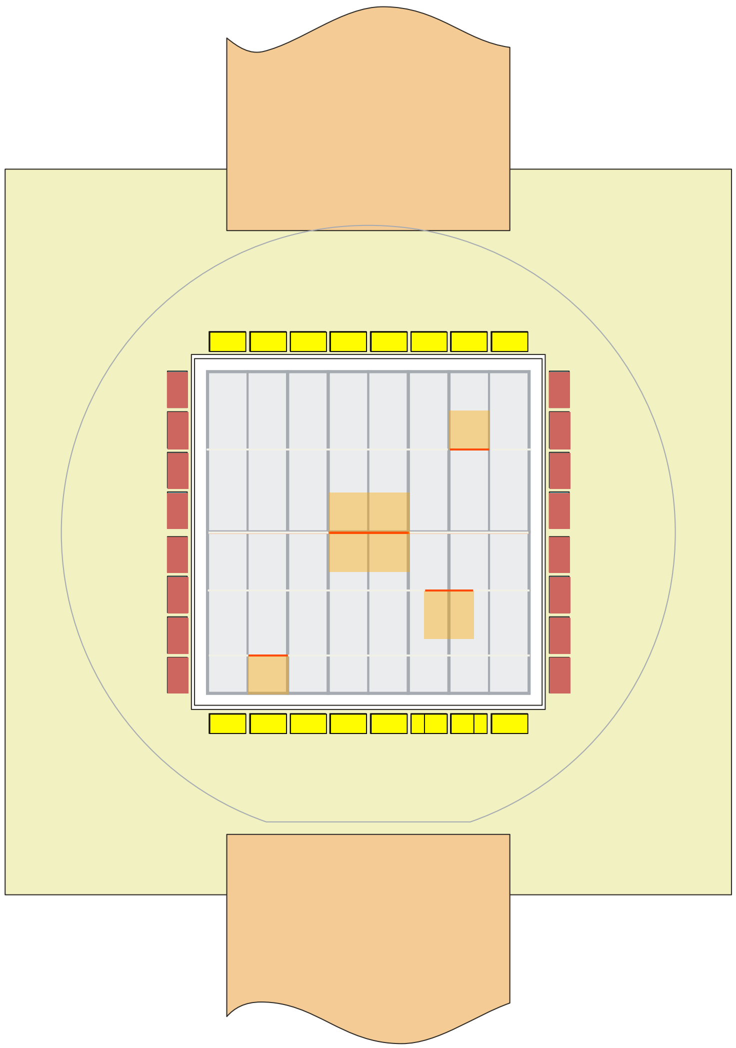
DEPFET Active Pixel Sensor Array



- **matrix organisation**
  - common back contact
    - » **thin, homogeneous entrance window**
    - » **fill factor 100 %**
  - row-wise connection of gate, clear, clear gate
  - column-wise connection of source / drain
    - » **individually addressable pixels**
    - » **windowing option**

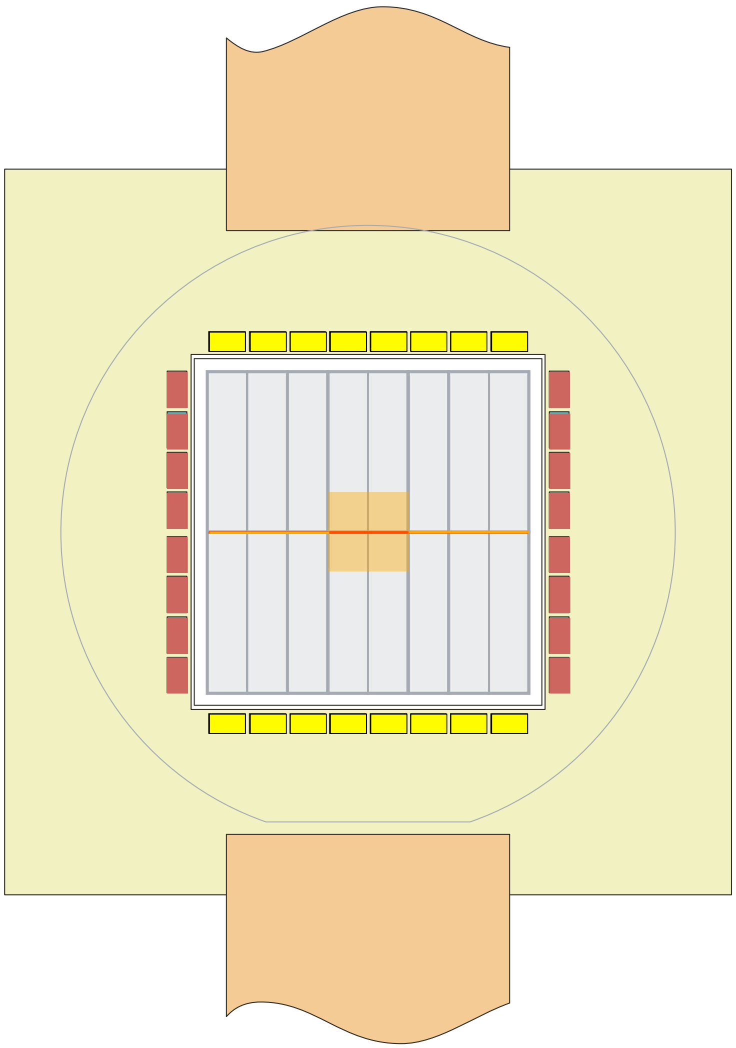
- **operation philosophy**
  - one active row
  - all other pixels turned off
    - » **low power consumption**
  - all operations in a row in parallel
    - » **fast processing**

WFI readout concept



- *Readout modes:*
  - **Full frame mode**: Parallel readout of both hemispheres on full width
  - **ROI mode**: Define ROI, read out repetitively with high framelet rate
  - Information of entire row is acquired, but information from outside ROI is discarded in preprocessing
  - Arbitrary position anywhere on the sensor
  - Simultaneous readout of disjunkt ROIs on different hemispheres
  - With next generation of ICs:
  - On-the-fly selection of ROIs / switch between ROIs
  - ROIs exceeding sector borders

WFI readout concept



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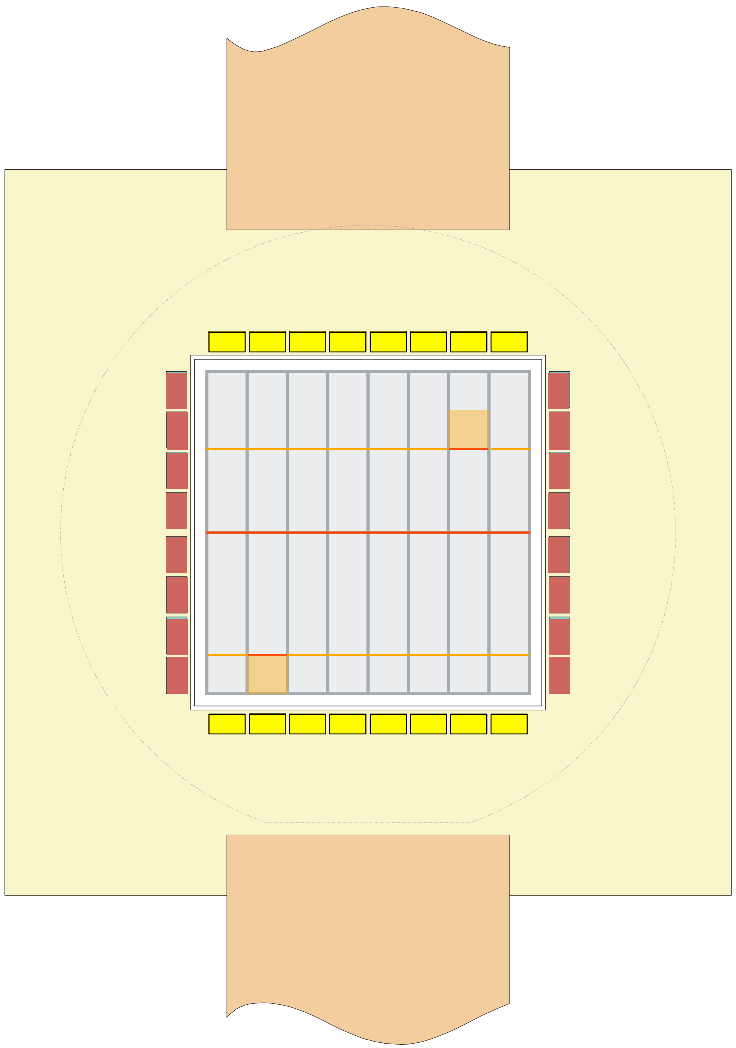
  - Read rest of frame with reduced framerate

WFI readout concept



- *Readout modes:*
  - **Window mode:** Acquire fully sized window strip (anywhere on FPA) repetitively
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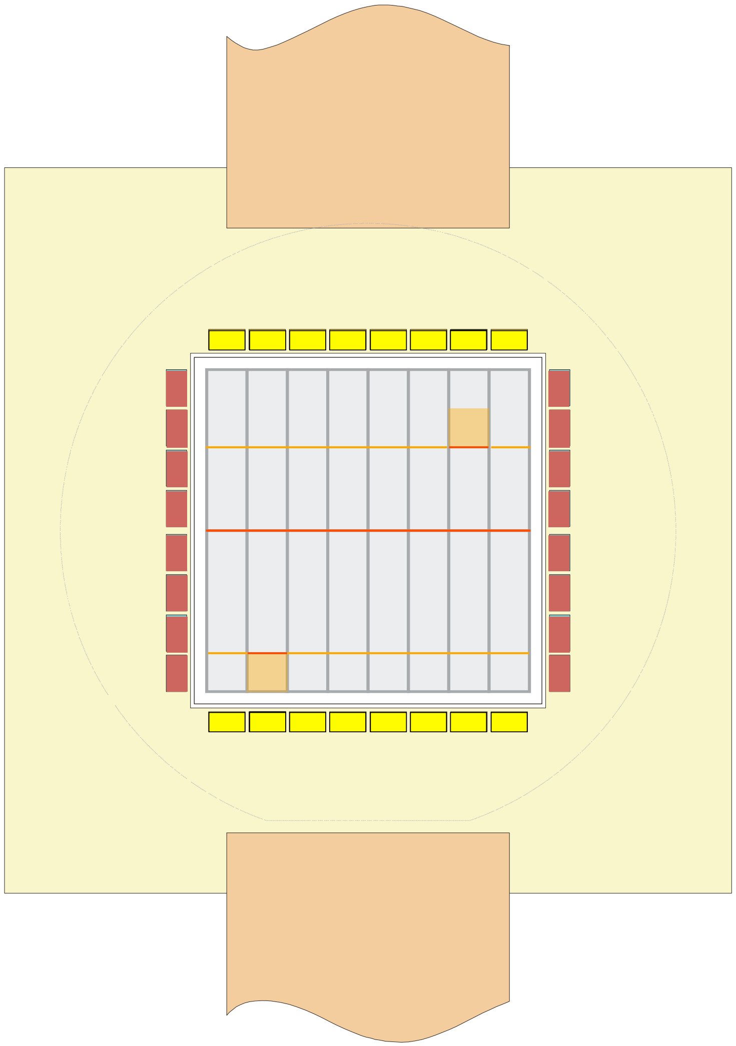
  - Different ROIs on arbitrary positions on FPA

WFI readout concept



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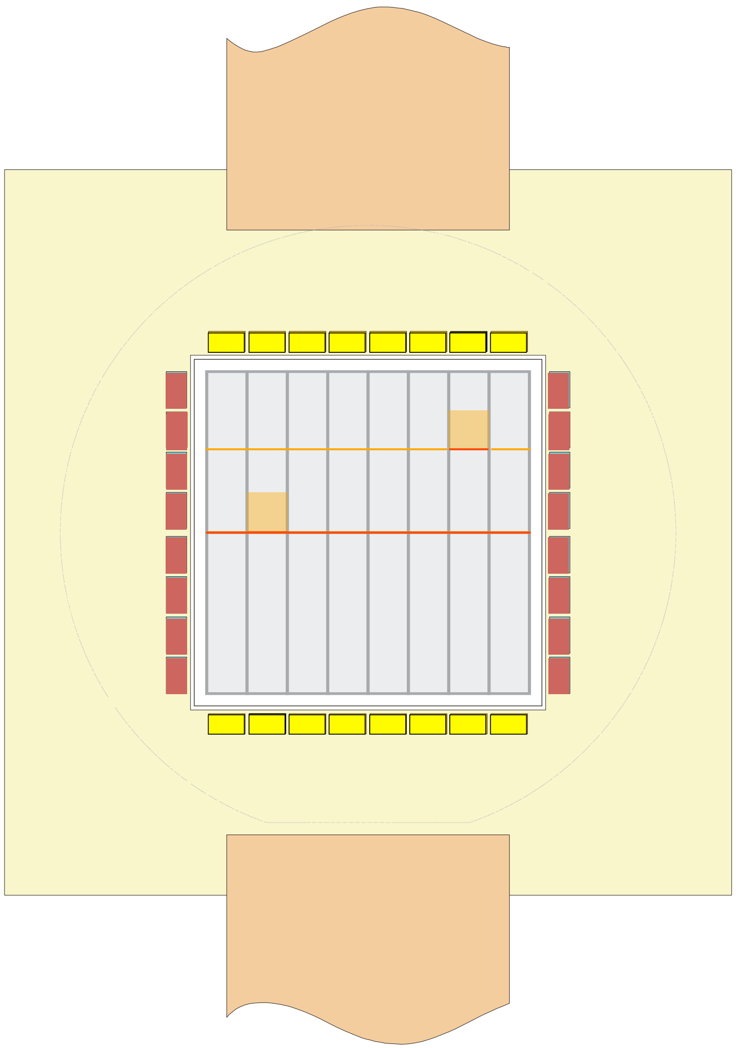

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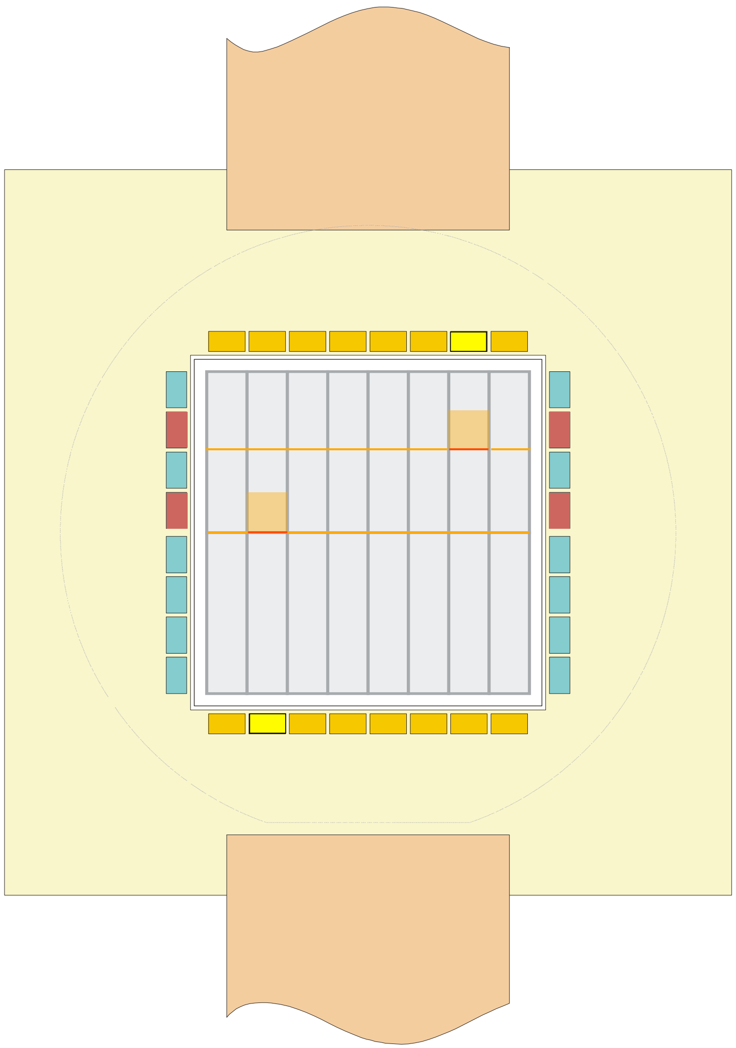
  - Even different non-overlapping ROIs on same Hemisphere possible (subsequent readout)

WFI readout concept



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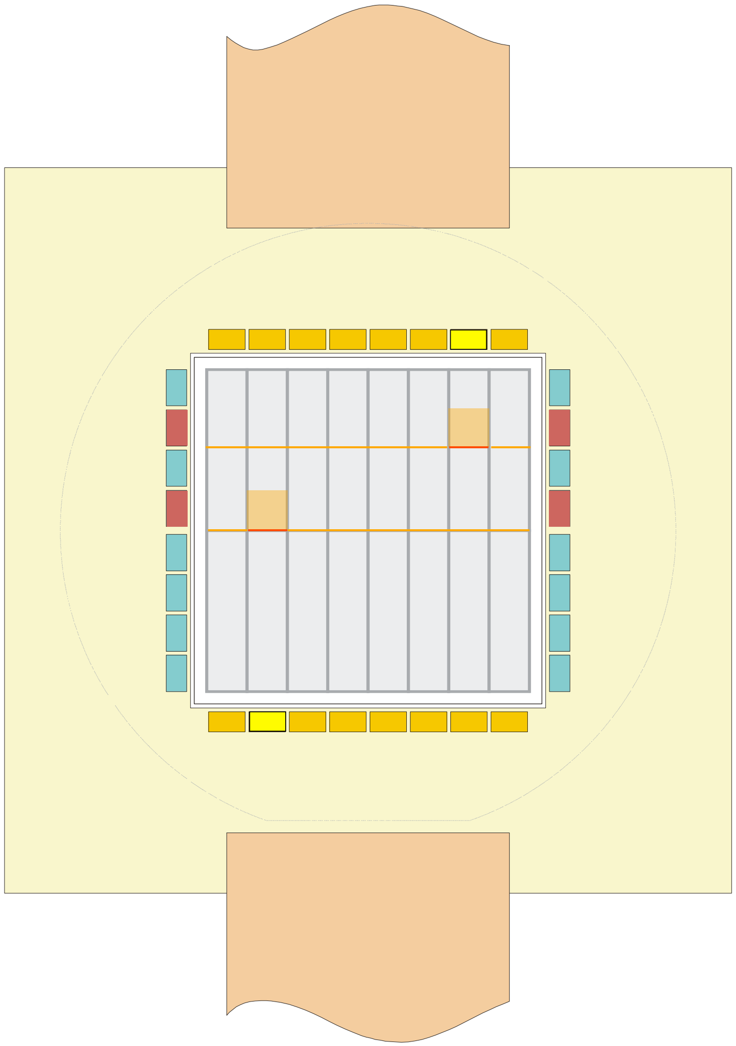

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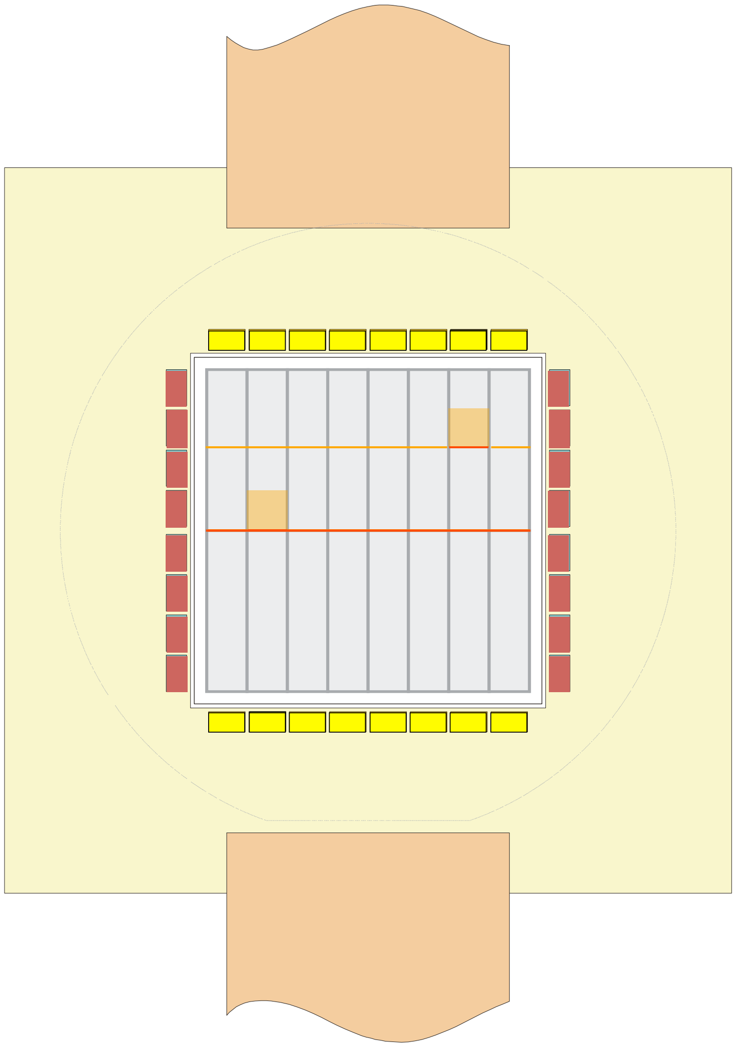
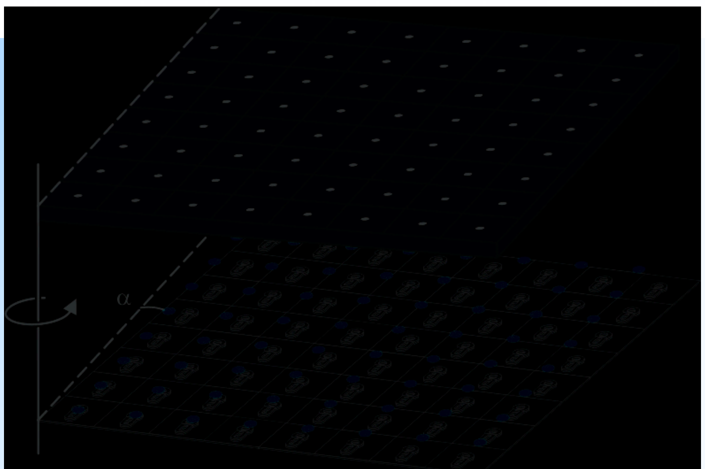
WFI readout concept



- *Readout modes:*
  - **Window mode (cont.):** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate
  - Different ROIs on arbitrary positions on FPA
  - Even different non-overlapping ROIs on same Hemisphere possible (subsequent readout)

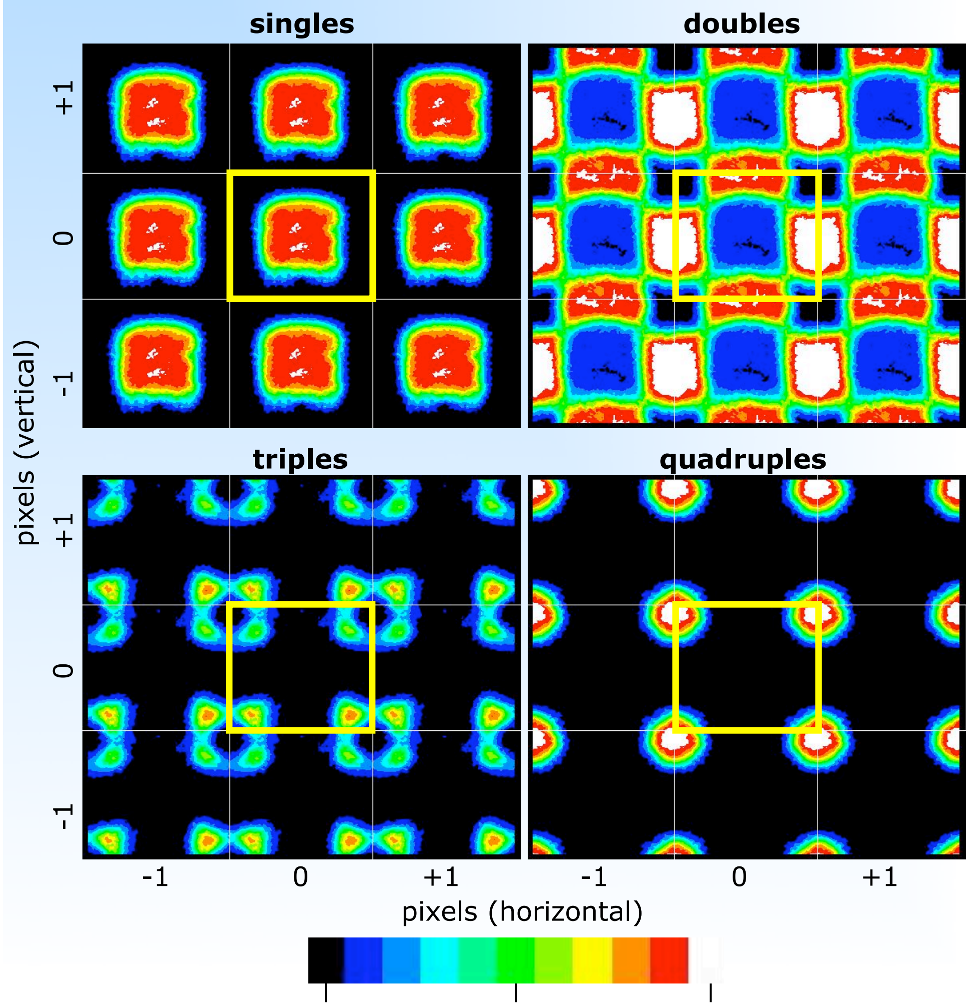
DEPFET APS – mesh experiment

- **method**
  - irradiation through tilted periodic mesh
  - Moire pattern
  - X-ray interaction position with subpixel resolution
-



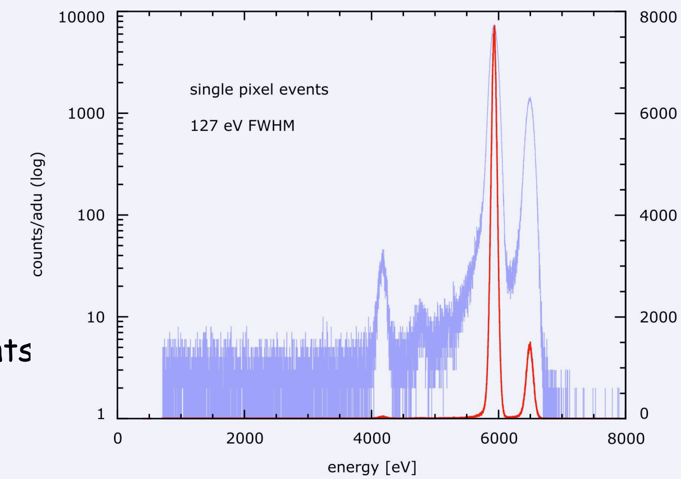
- mesh 10 µm gold
  5 µm holes
  150 µm pitch
- X-rays Cr-K_α (5.4 keV)

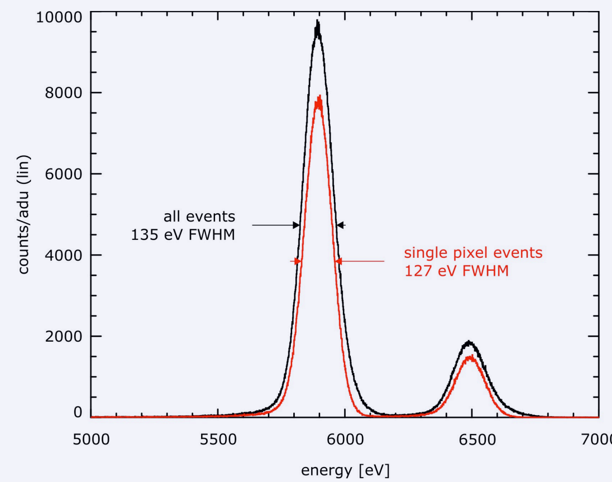
- **example**
  - variation of multiple pixel hit patterns with back contact voltage
  - V_back = -400 V

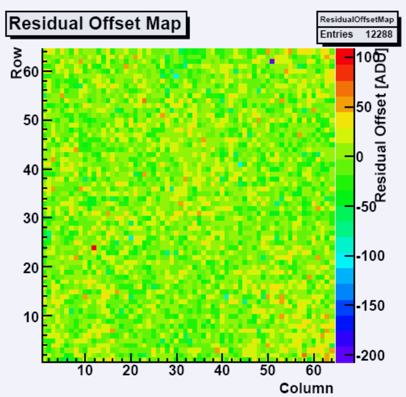


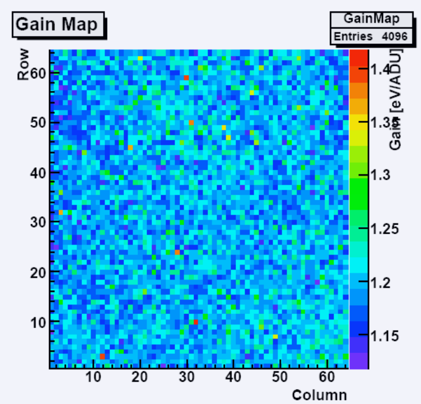
DePFET - status

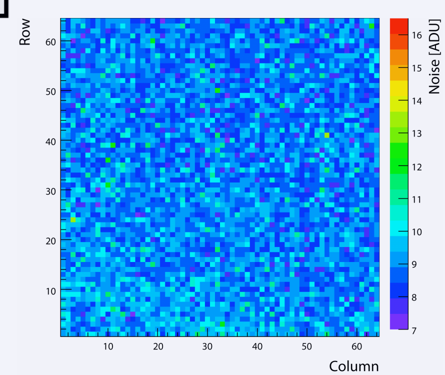
- **spectroscopy**
  - flat field illumination
  - energy resolution (FWHM @ 5.9 keV)
    - **127 eV** (singles)
    - **135 eV** (all events
  - peak/background ratio
    - **6.000:1**
  - pattern statistics
    - 60 %singles
    - 30 %doubles
  - (in)homogeneity
    - 0.3 %offset
    - 2.3 % gain
    - 9.0 %noise



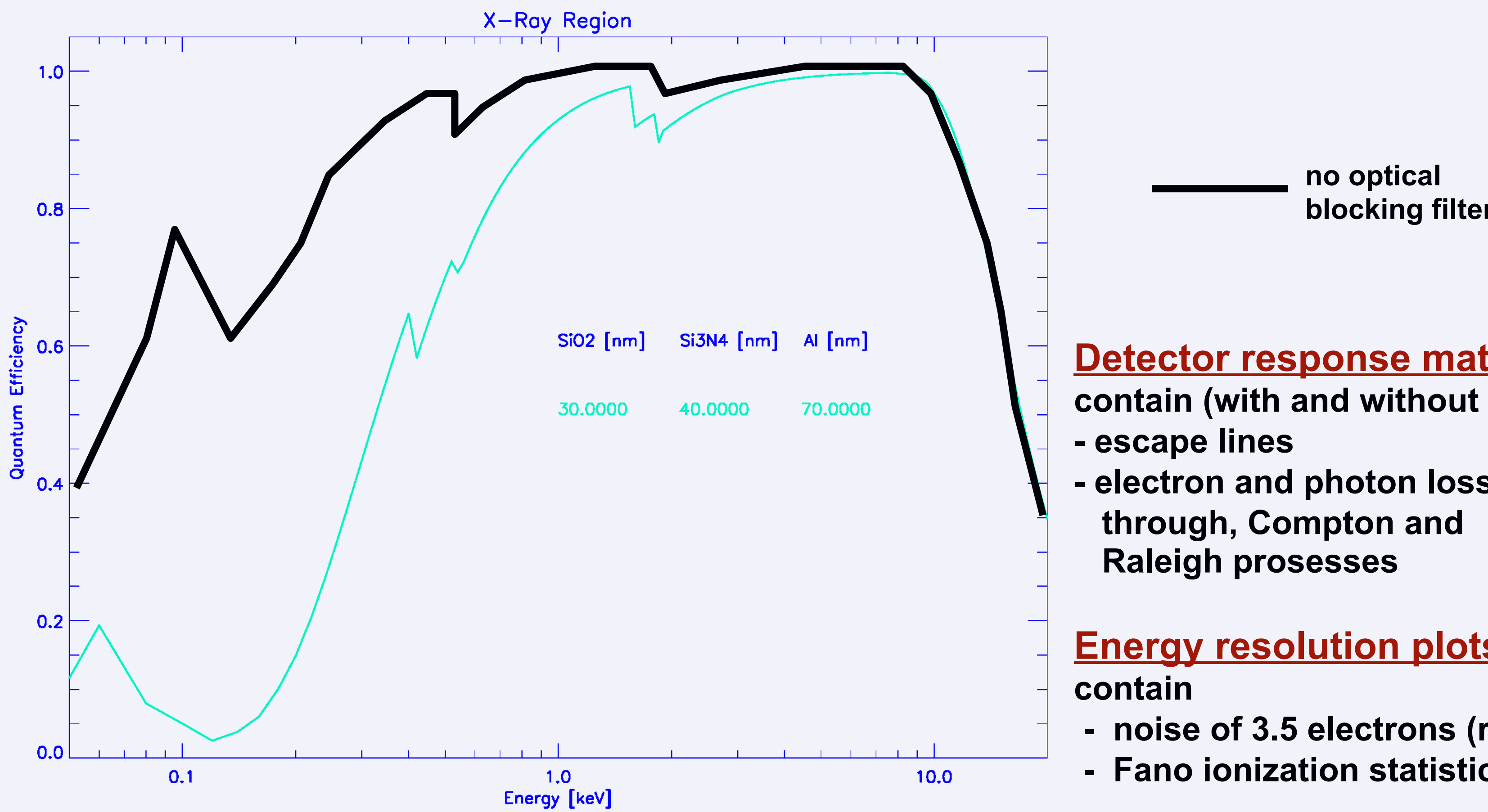








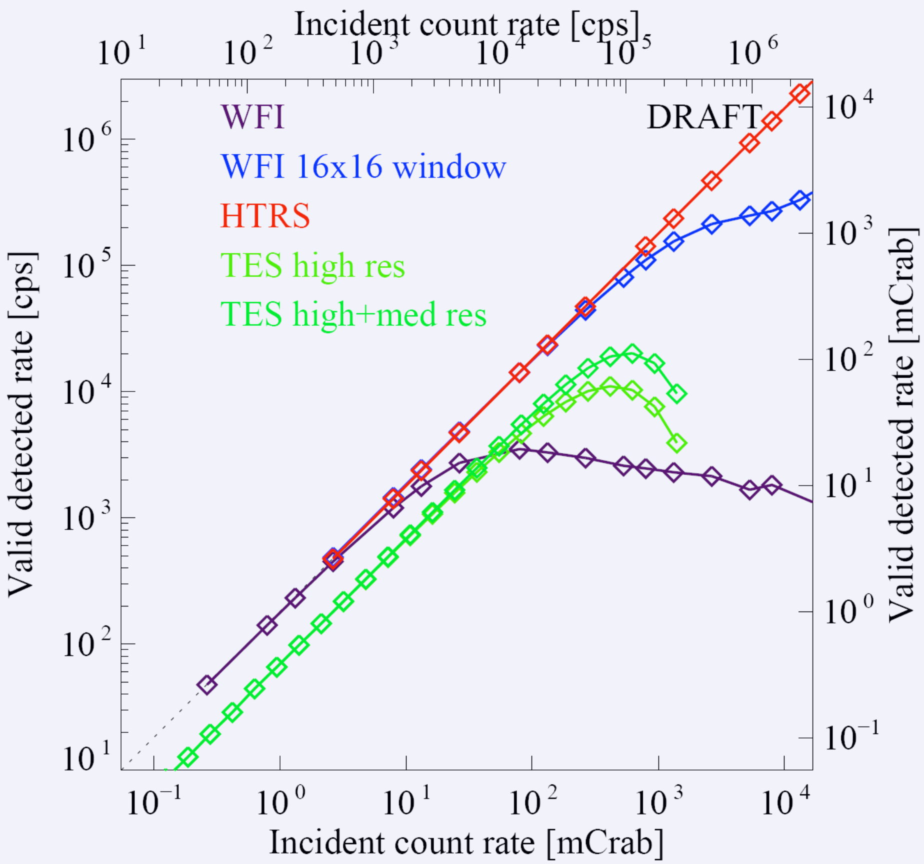
X-ray response with(out) optical blocking filter

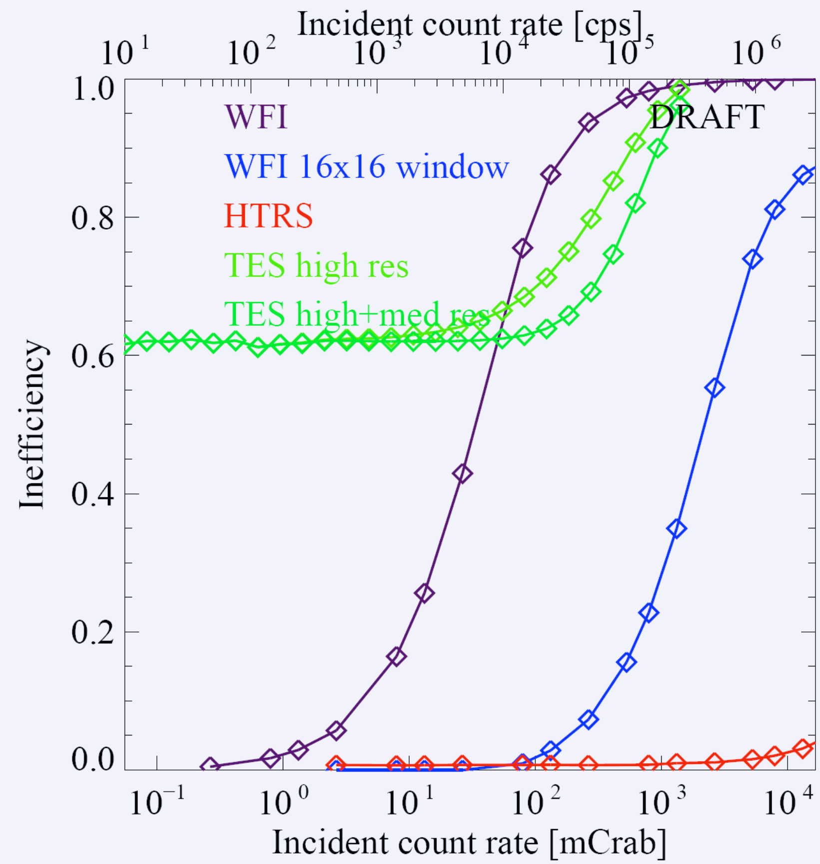


Detector response matrices
contain (with and without filter)
- **escape lines**
- **electron and photon losses through, Compton and Raleigh prosesses**

Energy resolution plots
contain
- **noise of 3.5 electrons (rms)**
- **Fano ionization statistics**

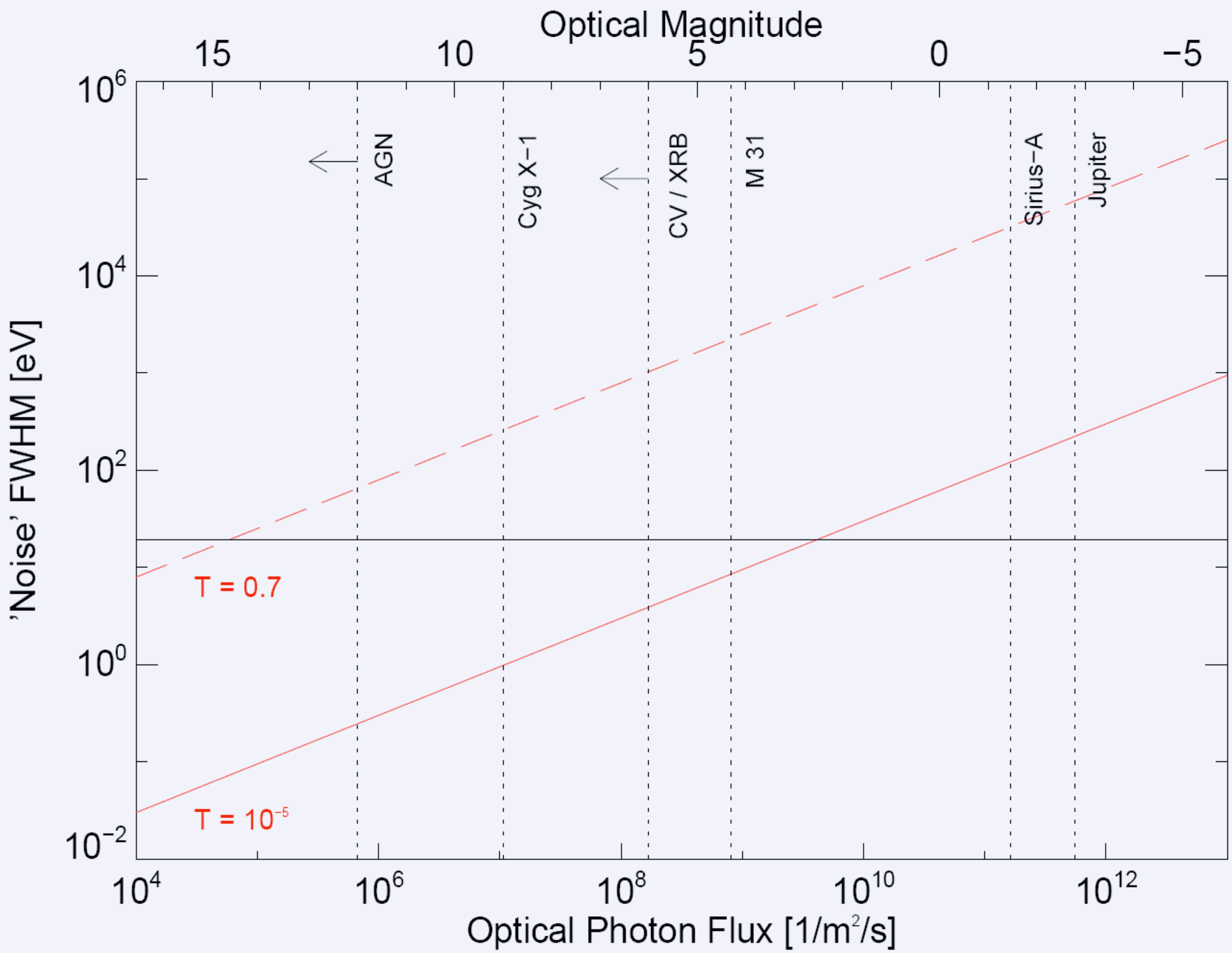
Count rate capability





Calculations performed by Jörn Wilms et al.

Implementation of an integrated optical blocking filter



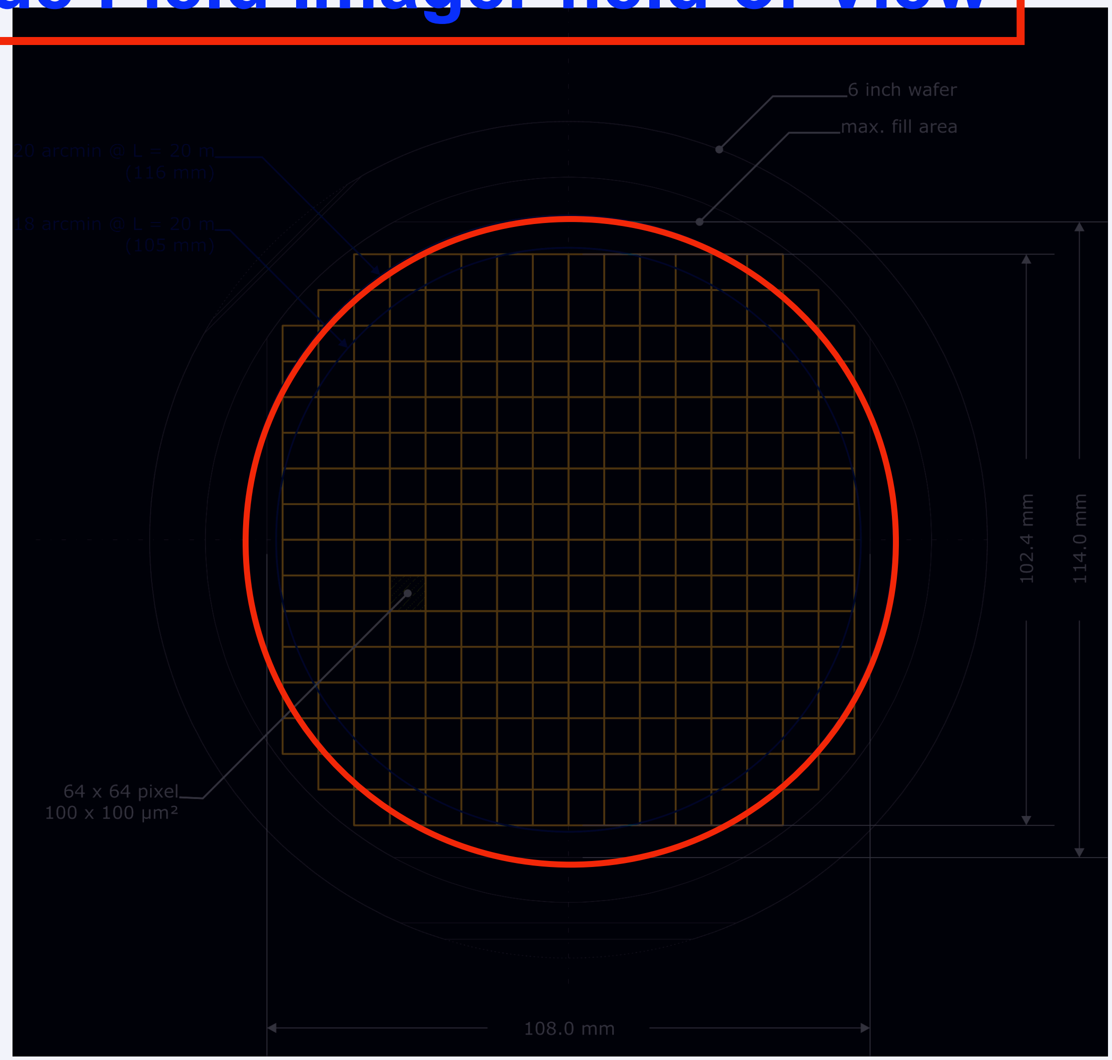
Noise contribution (FWHM) for the IXO filter system as a function of optical photons in front of the IXO mirror

This line indicates a noise contribution of 20 eV (FWHM) to be quadratically added to the electronic noise and the ionization statistics noise (Fano)

C_K: 45 eV → 49 eV
^{55}Fe: 130 eV → 131 eV

Wide Field Imager field of View

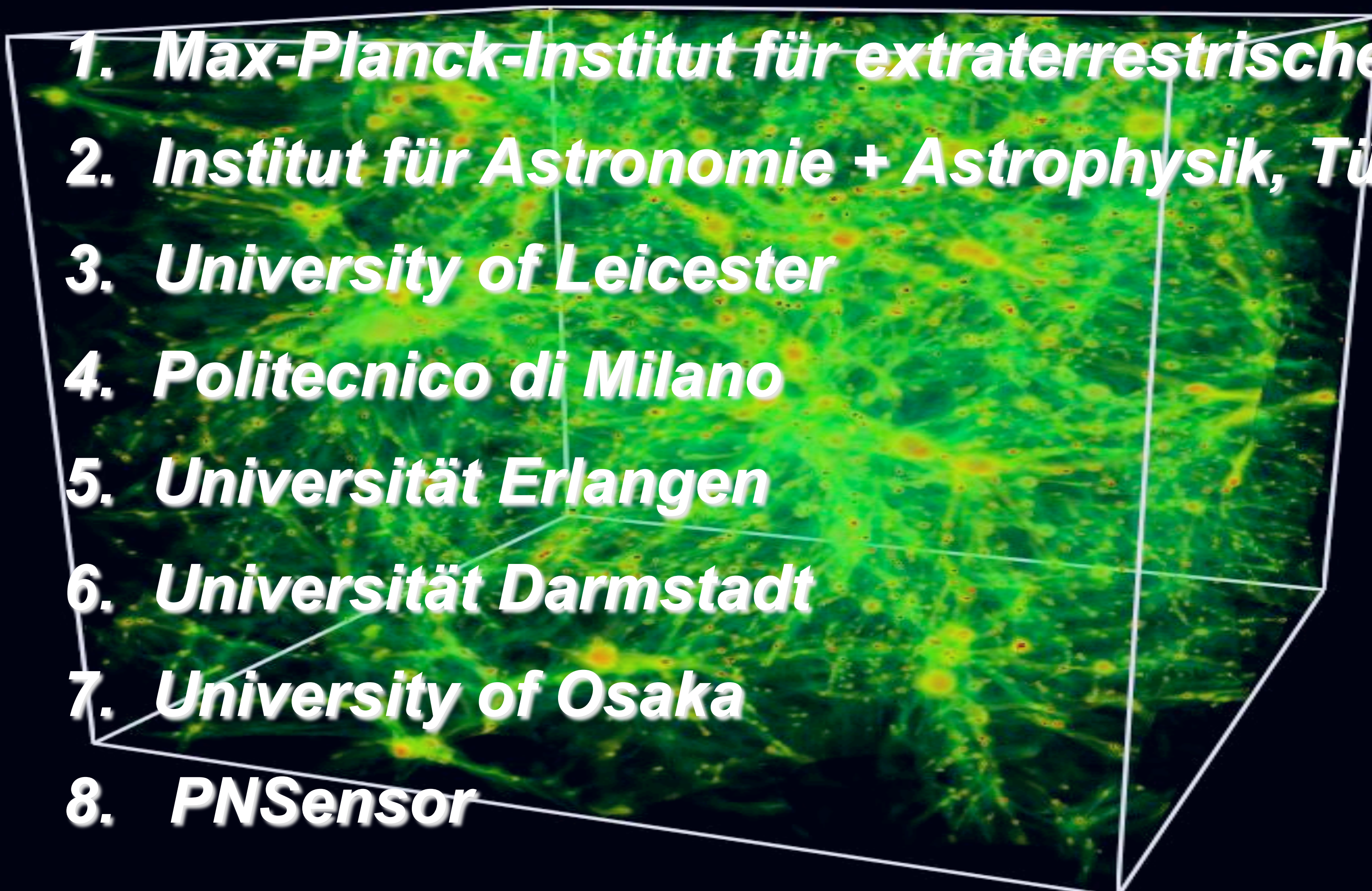
- **tentative wafer layout**
  - **pixel size** 100 µm ☐
    1 arcsec ≈ 97 µm @ 20 m
    ≈ 1/5 of PSF (5 arcsec)
  - **format**
    102.4 x 102.4 mm²
    1024 x 1024 pixels
    with 'rounded' corners
  - **field of view**
    18 arcmin ≈ 105 mm @ 20 m
    20 arcmin ≈ 116 mm @ 20 m
  - no. of pixels 999.414
  - FOV fraction outside sensor area
    1.6 ‰ @ 18 arcmin
    9 % @ 20 arcmin (can be improved)



Expected and experimentally verified WFI pr

1. **Energy bandwidth:** 0.1 keV up to 20 keV
2. **Electronic noise:** 3 electrons (rms)
3. **Energy resolution:** 130 eV (FWHM) @ 6 keV
   45 eV (FWHM) @ 0.2 keV
4. **Format:** 1024 x 1024 pixels
5. **Pixel (FP) size:** 100 x 100 µm² (11 x 11 cm²)
6. **Position resolution:** $\sigma_{x,y} \leq 40$ µm
7. **Readout speed** 2 µs/pix , 2048 pix. in parallel
8. **Time resolution:** 1 ms in FF, down to 16 µs in WM
9. **Integrated optical filter:** 10^5 optical light reduction
10. **Windowing modes:** adjustable according to target
11. **Depleted thickness:** 480 µm
12. **Radiation hardness:** > 100 krad for p, n, e and γ
13. **Operating temperature** typ. – 60 °C
14. **´´Dead´´ area in FP** no

``Committed´´ Institutions for the WFI:



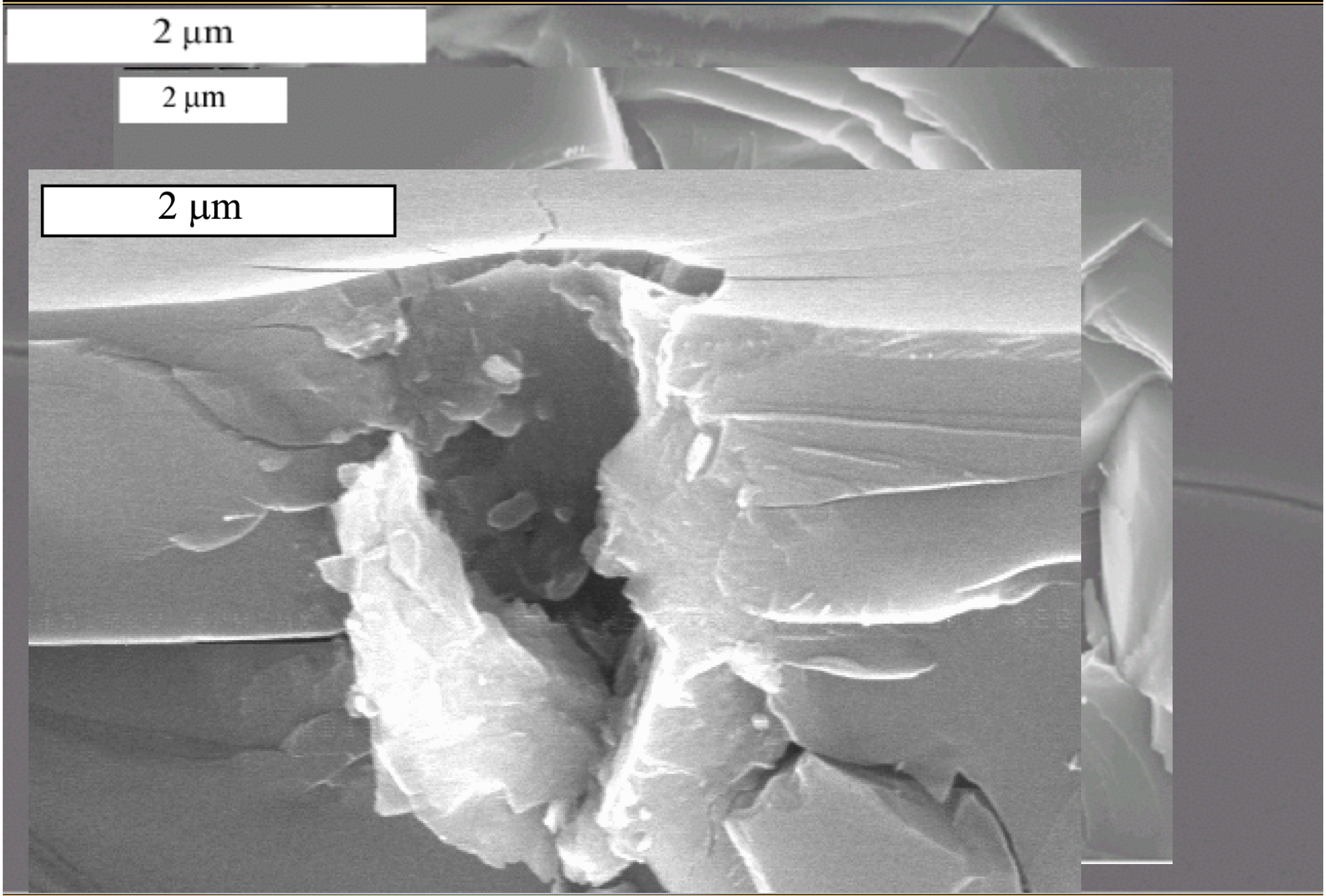
1. Max-Planck-Institut für extraterrestrische Physik
2. Institut für Astronomie + Astrophysik, Tübingen
3. University of Leicester
4. Politecnico di Milano
5. Universität Erlangen
6. Universität Darmstadt
7. University of Osaka
8. PNSensor

Conclusions

DePFET is ready for

- fast and slow readout
- thick and thin depletion layers
- for large and small pixels
- for small and large monolithic fields of view

radiation hard and defect free


2 µm
2 µm
2 µm

CaseC.gif

Al particles, 1 µm diameter, velocity: 20 km/s, incident angle: 2 deg

caseB.gif

Fe particles, 1 µm diameter, velocity: 5 km/s, incident angle: 5 deg

caseA.gif

Fe particles, 1 µm diameter, velocity: 5 km/s, incident angle: 1 deg

[redacted]

Optical Light contamination

$$\Delta E = \frac{N_{op}}{N_{pix} \cdot N_{fr}} \cdot QE \cdot w$$

Shift of the pixel charge level (equivalent to energy) by optical photons

ΔE	**- energy shift**	**e.g.**	**in eV**	
N_{op}	**- number of optical photons/s**	**e.g.**	**10^6**	
N_{pix}	**- number of pixel in the HEW**	**e.g.**	**25**	
N_{fr}	**- number of frames per second**	**e.g.**	**1.000**	
QE	**- quantum efficiency in the optical**	**e.g.**	**0.7**	
w	**- pair creation energy for X-rays**		**e.g.**	**3.68 eV**

The shift in energy will be ΔE = 104 eV for 10^6 optical photons

Optical Light contamination

The "noise" associated with the statistical (Poisson distributed) variations of the incoming photons is:

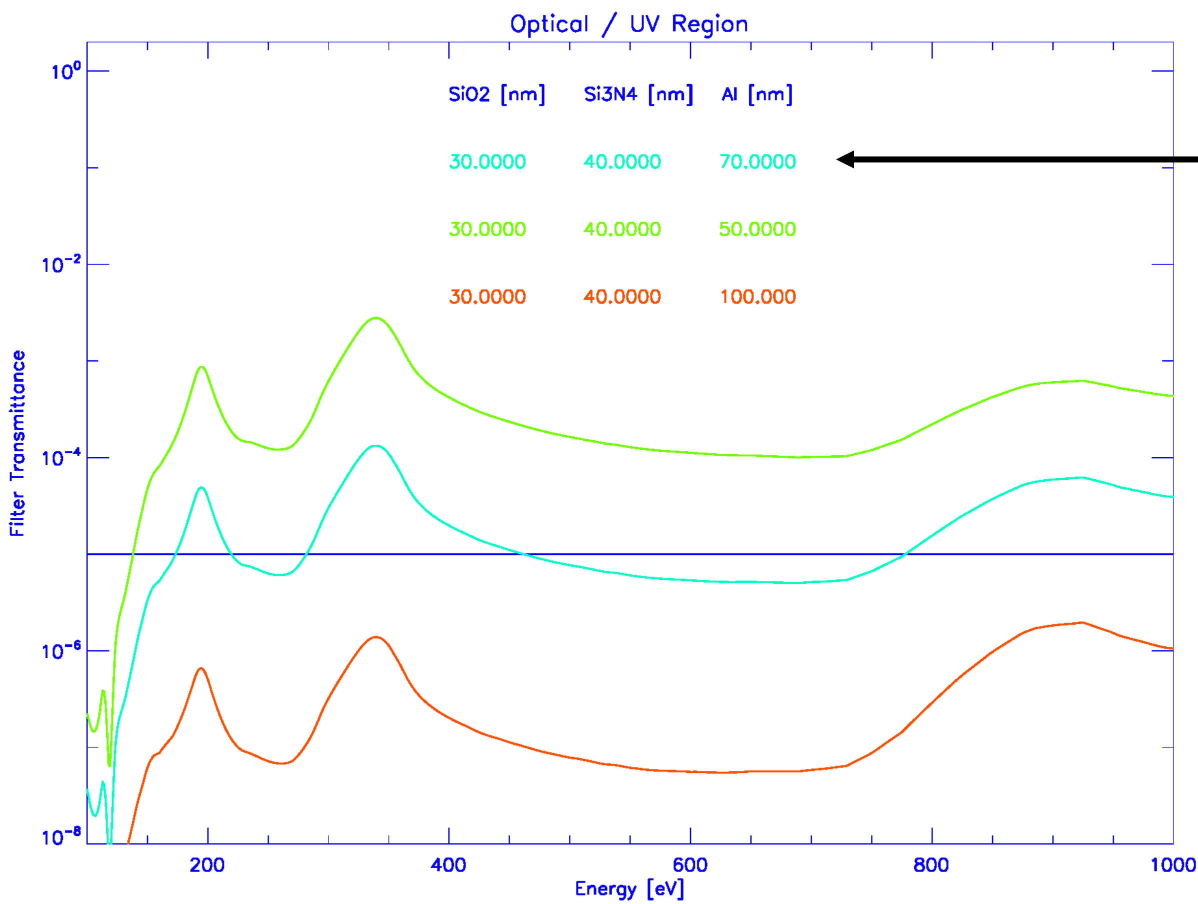
$$\Delta E_{rms} = \sqrt{\frac{N_{op} \cdot QE}{N_{pix} \cdot N_{fr}}} \cdot w$$

with ΔE_{rms} - the amplitude fluctuation (rms)

- **N_{op} - number of optical photons/s e.g. 10^6**
- **N_{pix} - number of pixel in the HEW e.g. 25**
- **N_{fr} - number of frames per second e.g. 1.000**
- **QE - quantum efficiency in the optical e.g. 0.7**
- **w - pair creation energy for X-rays e.g. 3.68 eV**

This yields a photon induced noise on top of the energy shift of ΔE_{rms} = 19.6 eV, i.e. 45.8 eV (FWHM)

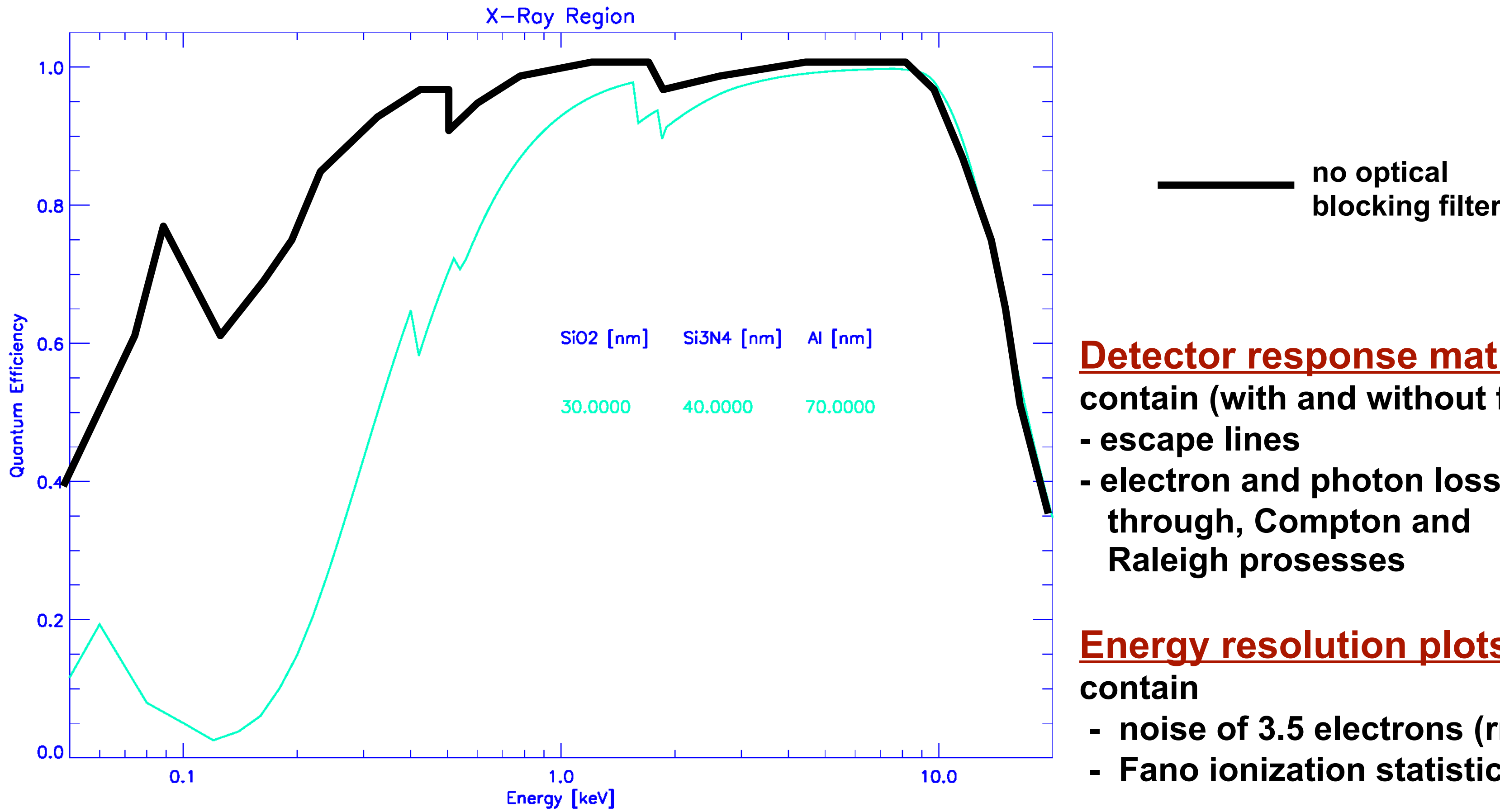
Optical light attenuation



selected filter

selected filter attenuation: 10^5

X-ray response with(out) optical blocking filter



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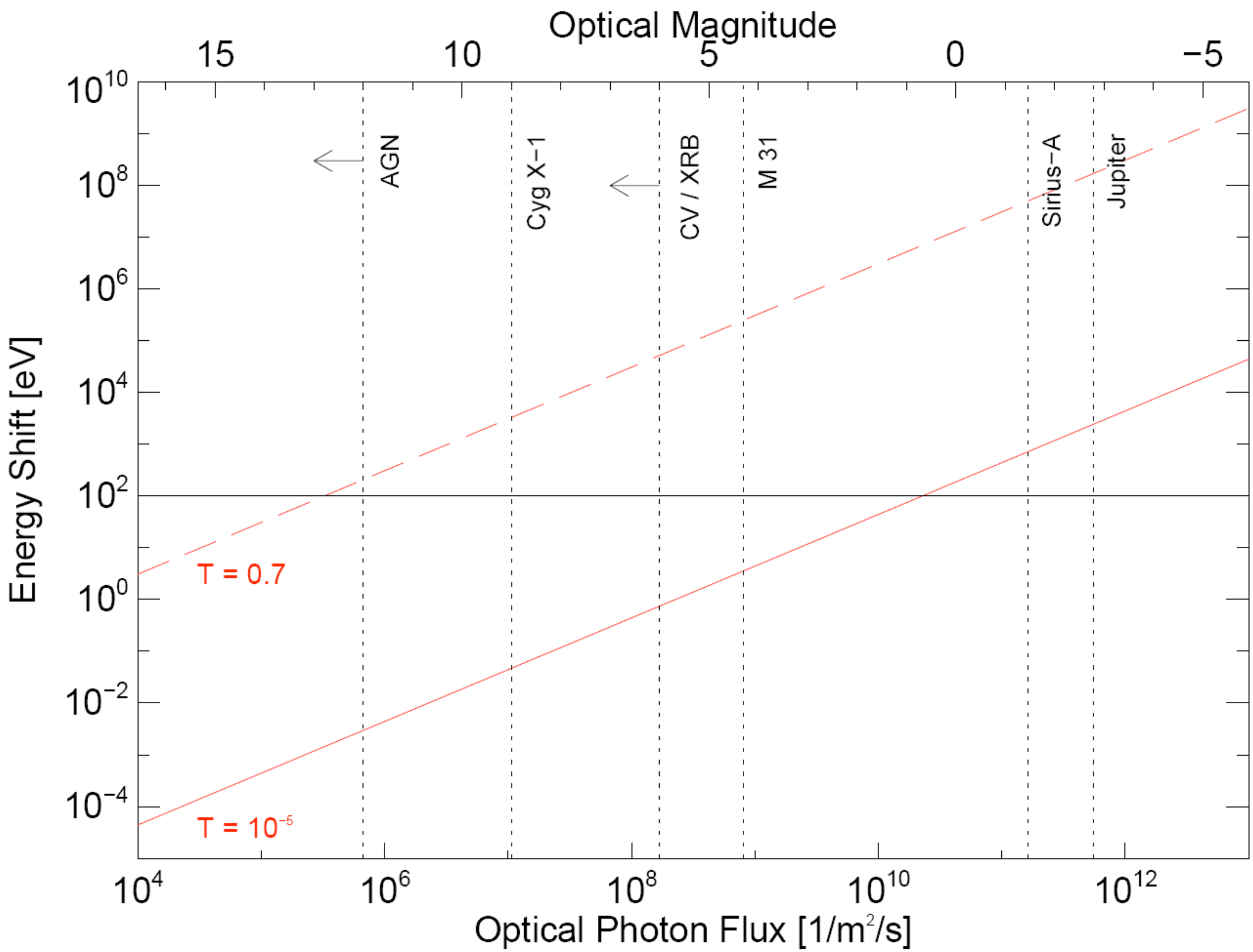
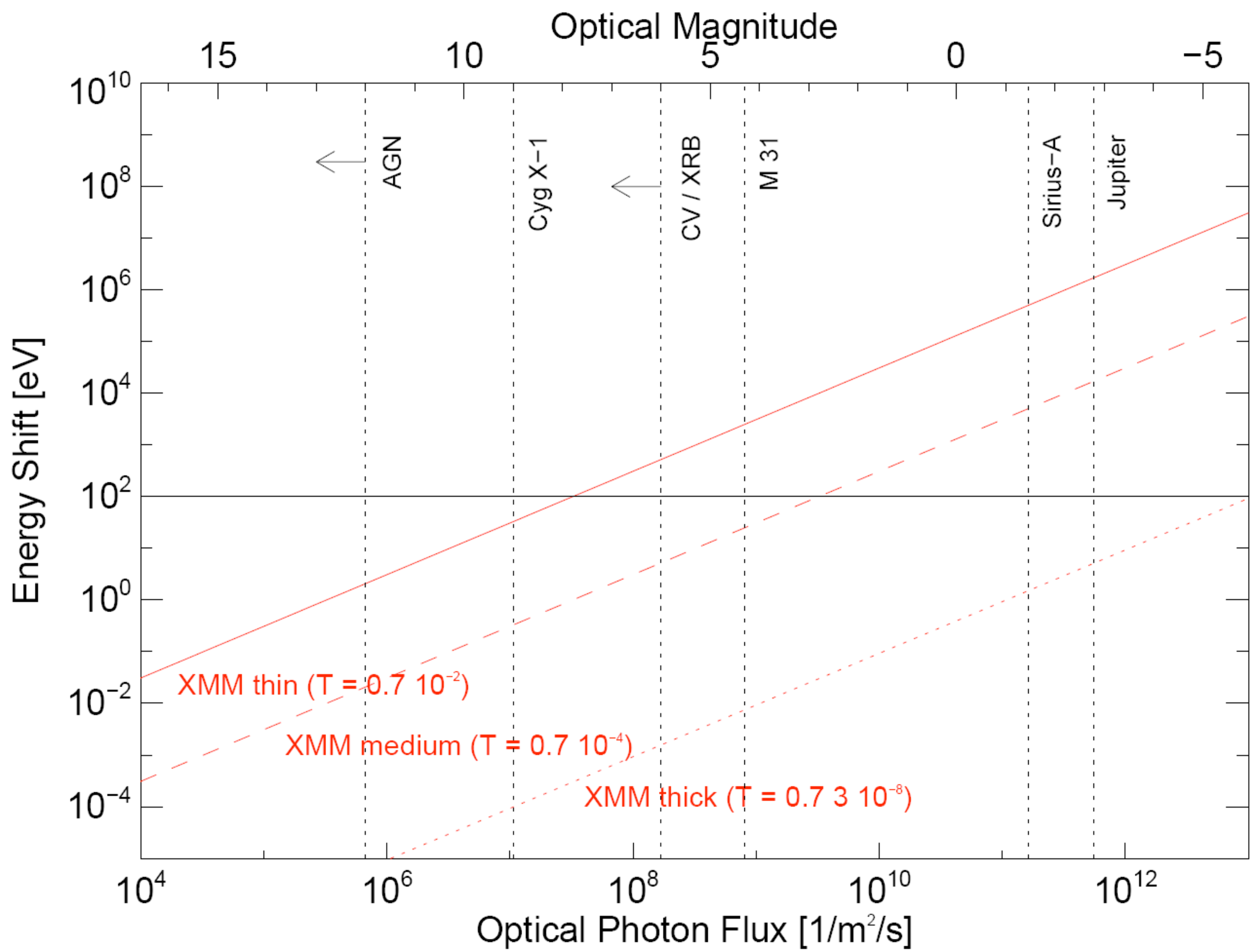


Assumptions:

A = 3 m^2
pixel in PSF: 25
frame rate: 1.000 fps



IXO equipped with XMM filter

(WFI) Calibration Issues

We plan to use the following calibration facilities:

PANTER
PUMA
BESSY (PTB)
SPRING 8

Topics for the calibration on ground:
- fill detector response matrix with
    - position response (with mirrors, with pinholes, with slits)
    - timing response with pulsed monochromatic X-rays
    - energy response with monochromatic X-rays
    - homogeneity of all the above parameters

Calibration in space:
- ask XMM and Chandra scientists !

Possible WFI collaborations (LTS)

1. ***Calibration of the WFI***, e.g.
   - Charge splitting, invalid pattern recognition and suppression
   - Position resolution as a function of X-ray energy, mesh experiments
   - in flight calibration strategies
   - absolute quantum efficiency measurements, spatial homogeneity
2. ***Digital data processing and reduction***
   - development of fast algorithms for zero suppression
   - algorithms for common mode reduction
   - gain, offset and non-linearity corrections
   - conversion from pixel events into incident photons
   - Implementation of the algorithms in hardware
3. ***Data analysis and simulation***
   - development of a WFI system simulator, comprising the timing, event pattern, system efficiency as a function of the incoming X-ray photon bandwidth, intensity and spatial distribution of the photons
   - check of the models with experiments
   - study of dedicated (known) objects within the IXO set of parameters
   - sensitivity study of all relevant parameters
4. ***Implementation and test of different operation modes***, e.g.
   - windowing modes
   - counting modes
   - health check modes

Possible WFI collaborations (LTS), continued

5. ***Background simulations***
   - **DePFET internal "background", particle recognition and suppression**
   - **total instrument background with experimental exitation data**
   - **"X-ray and optical photon background" imaged through the telescope**
   - **experimental verification of simulations**

6. ***Development of ceramic detector boards*** **(detector housing boards)**
   - ***development of the schematics***
   - ***layout***
   - ***simulation, mechanical, electrical and thermal***
   - ***quality assurance and control***
   - ***qualification, tests***

DEPFET - simulation

3D Poisson solver POSEIDON