Characterization of Edgeless Sensors

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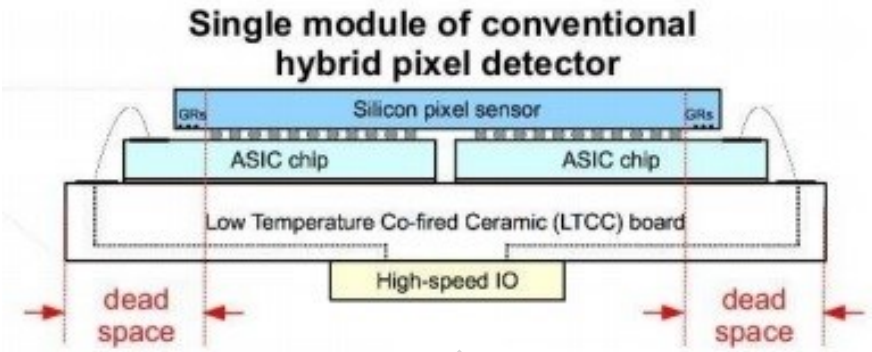
Outline

- Motivation of edgeless detectors
- Introduction to edgeless sensors and Medipix chips
- Sensors under investigation
- Measurement results:
    - I – V characteristics
    - Dark field and flat field images
    - Object Images
    - Energy Calibration
- Summary

Edgeless Detectors - Motivation

- Drawback of conventional detectors against edgeless detectors

  Miss of information in dead region ⇨ problems for image reconstruction



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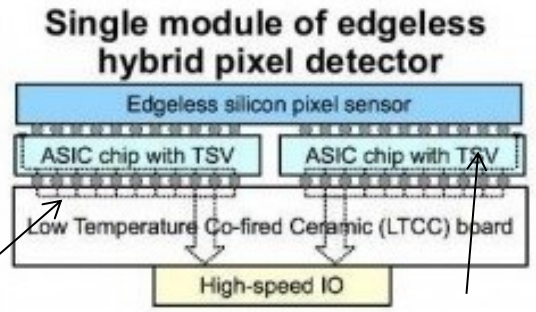
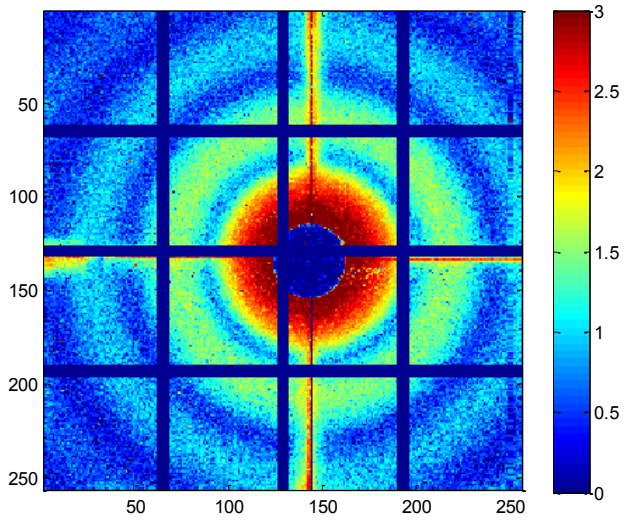
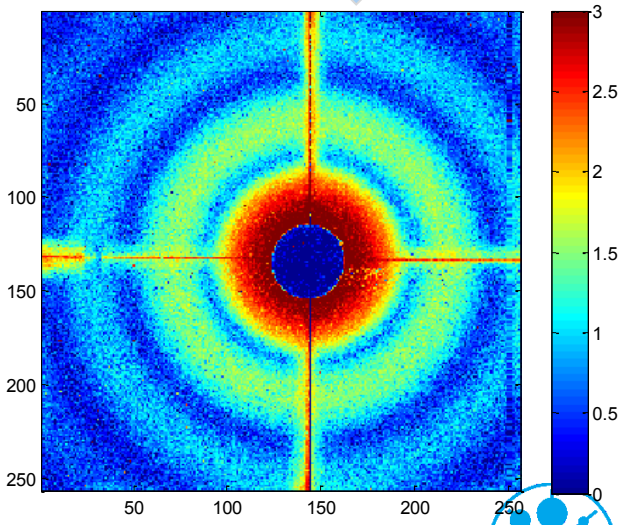




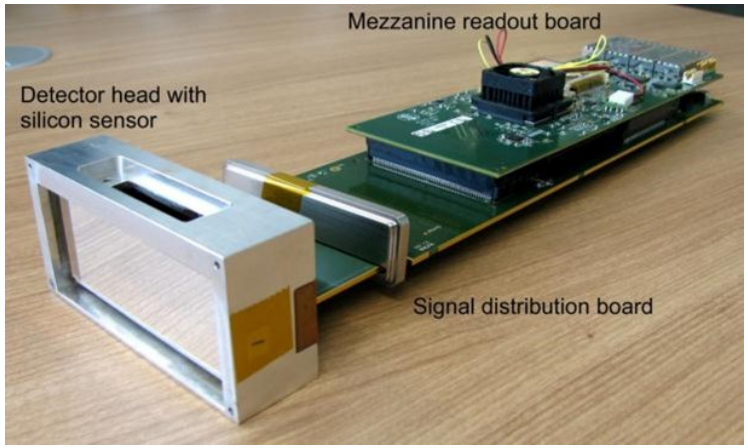


Edgeless Sensors and Medipix chips

- Conventional sensors : Current Collection Ring (CCR) and Guard Rings (GR) in conventional sensors
- Edgeless sensors : Deep Reactive Ion Etching (DRIE), side implantation with Phosphorous or Borons, Aluminum Metallization, Passivation on top etc.
- Ideal Edgeless Sensor:
  - Good Quantum efficiency
  - Low noise ⇨ low leakage current and interpixel capacitance
  - High breakdown voltage
  - Small last pixel-to-edge distance
  - Good sensitivity to low energy photons for edge pixels
- Medipix family chips : Medipix1, Medipix2, Medipix3 and Medipix3RX

From LAMBDA to Edgeless LAMBDA

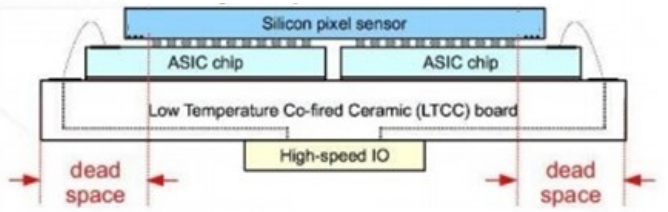
- Edgeless detectors as part of LAMBDA ongoing FS-DS project



LAMBDA: Large Area Medipix Based Array

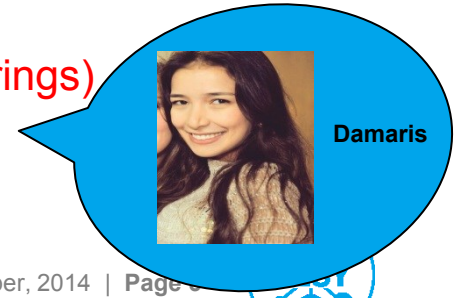
- Si sensor with 512 x 1536 (28 mm x 85 mm)
- 2 x 6 Medipix chips
- High-frame-rate readout system (2000 fps)

- New future Developments: edgeless LAMBDA

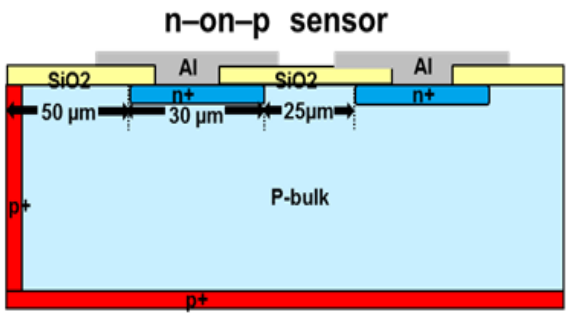


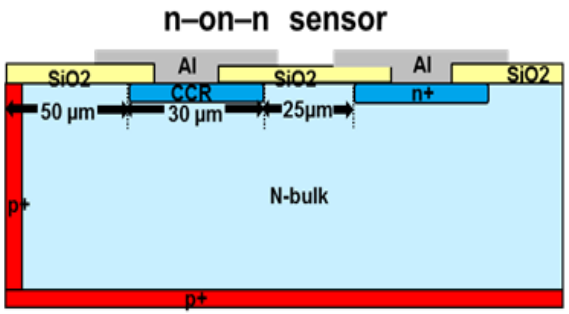
  - Edgeless sensor compatible with Medipix chips
  - Medipix chips with TSV+RDL implemented
  - Ball Grid Array to board

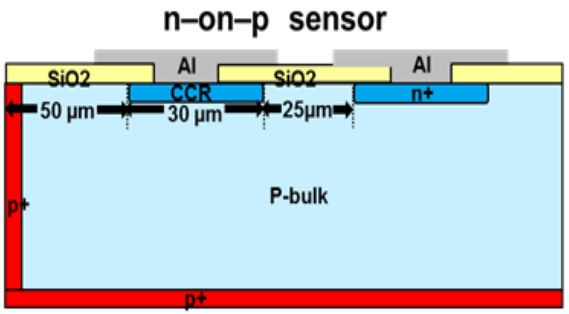
  - **My task:** Characterization of edgeless sensors (without gard rings) coupled to conventional Medipix3 chips (without TSV + RDL)



Measured three different test structures







No Current Collection Ring

Polarity	**n-on-p**
Thickness	500 µm
Doping	$1.1\times10^{12}cm^{-3}$
V_{dep}	208.9 V
$V_{breakdown}$	22 V
$V_{operation}$	20 V
W_{dep}	154,7 µm

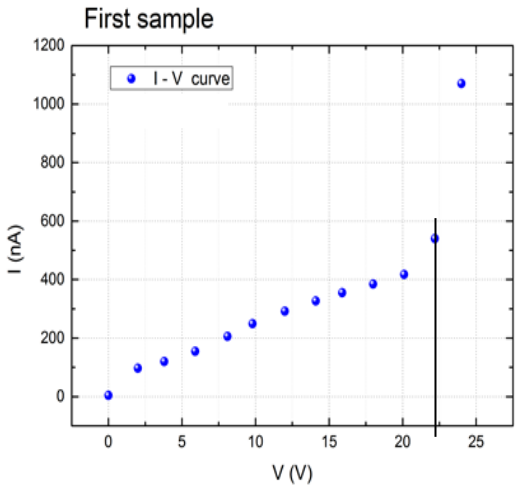
Current Collection Ring

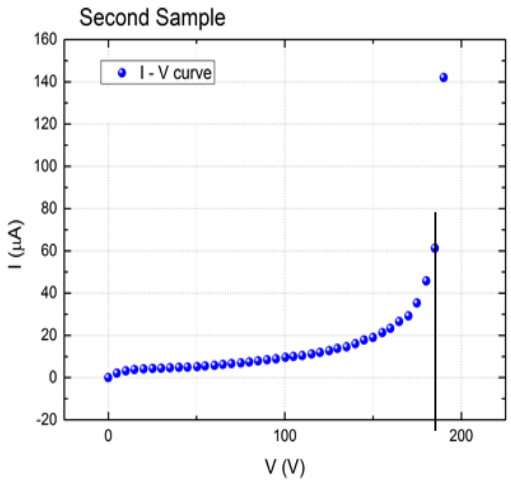
Polarity	**n-on-n**
Thickness	500 µm
Doping	$7\times10^{11}cm^{-3}$
V_{dep}	132.9 V
$V_{breakdown}$	190 V
$V_{operation}$	160 V, 170 V, 180 V, 190 V
W_{dep}	500 µm

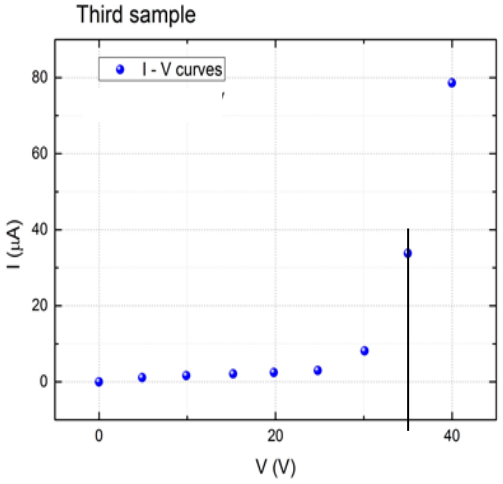
Current Collection Ring

Polarity	**n-on-p**
Thickness	500 µm
Doping	$1.1\times10^{12}cm^{-3}$
V_{dep}	208.9 V
$V_{breakdown}$	35 V
$V_{operation}$	20 V
W_{dep}	154,7 µm

I-V curves, Equalization







$V_{breakdown}$	22 V
$V_{depletion}$	208.9 V

$V_{breakdown}$	190 V
$V_{depletion}$	132.9 V

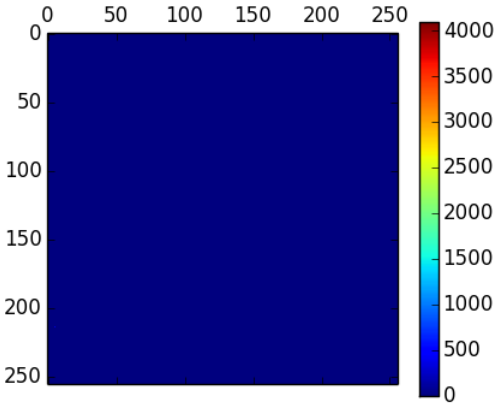
$V_{breakdown}$	35 V
$V_{depletion}$	208.9 V

First and third sensor cannot depleted fully!

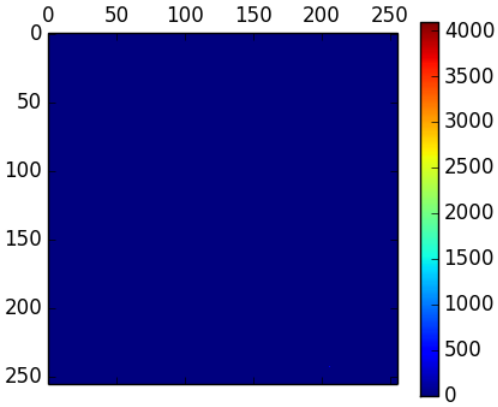
Dark and Flat Field Images for the three samples

Dark Field Image

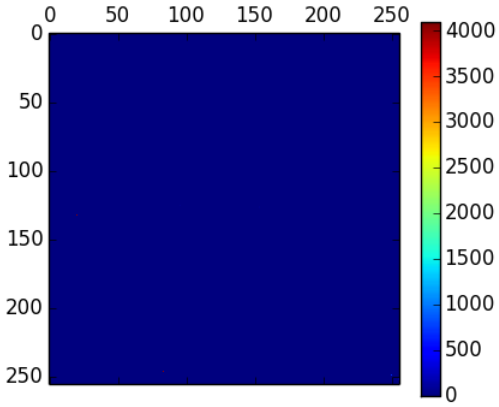
1st sample



2nd sample

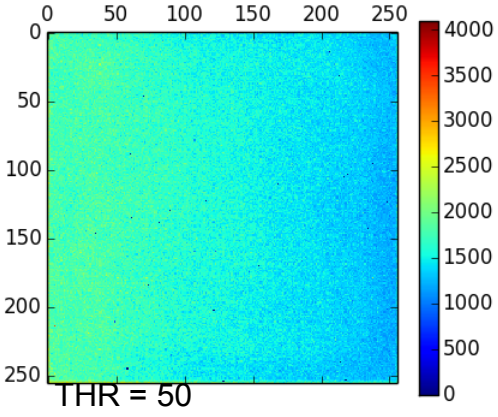


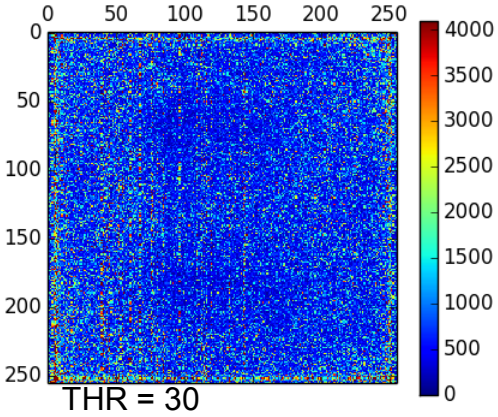
3rd sample

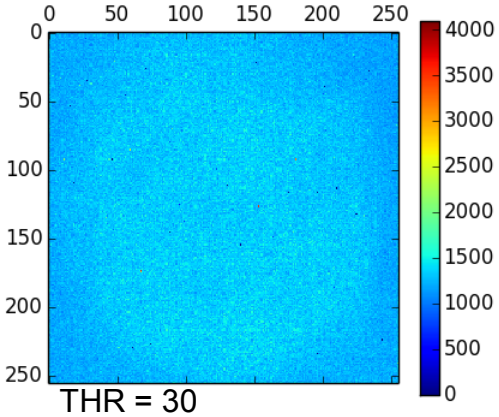


Flat Field Image

V = 50kV
I = 40mA



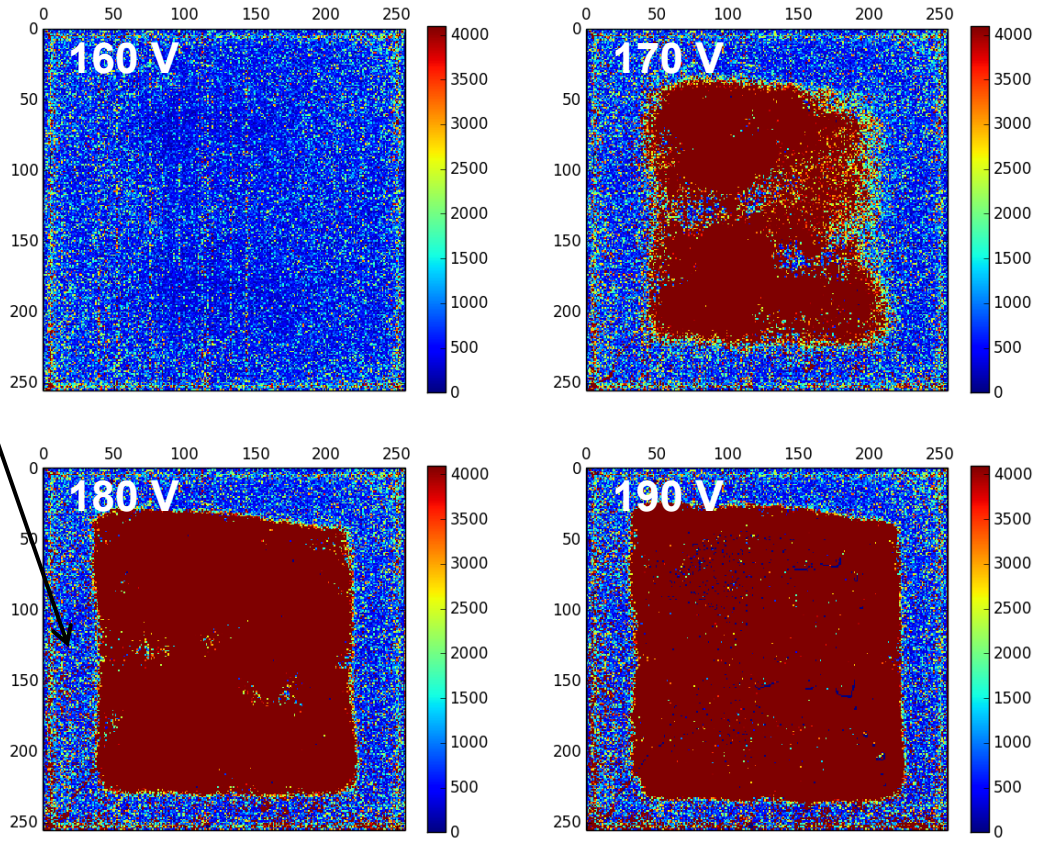




2nd sample shows good depletion conditions but does not show any counts. Why?

Second Sample

On increasing the applied voltage, the photons appear, but not all the pixels respond

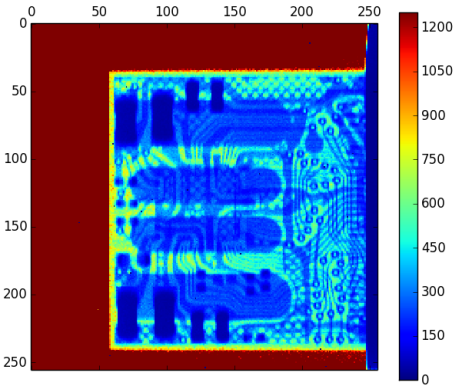


Problem during production?
vendor (Advacam) confirmed: due to backside oxide layer not completely removed!!

Object Image and Flat Field Corrected Image

Raw Image of an Object (USB drive)

1st sample



3rd sample

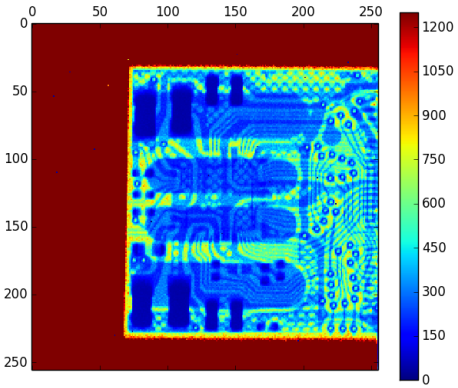
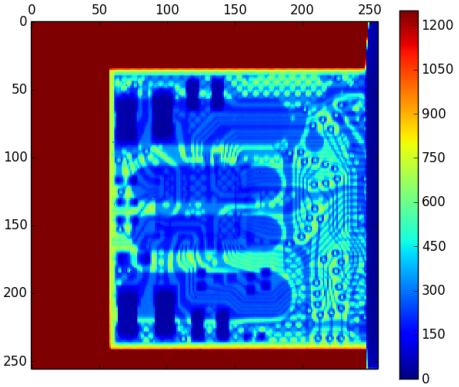
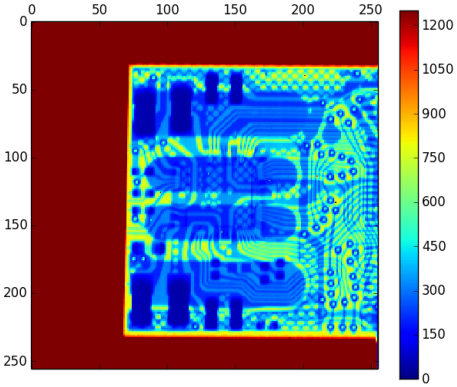


Image of an Object after flat field correction





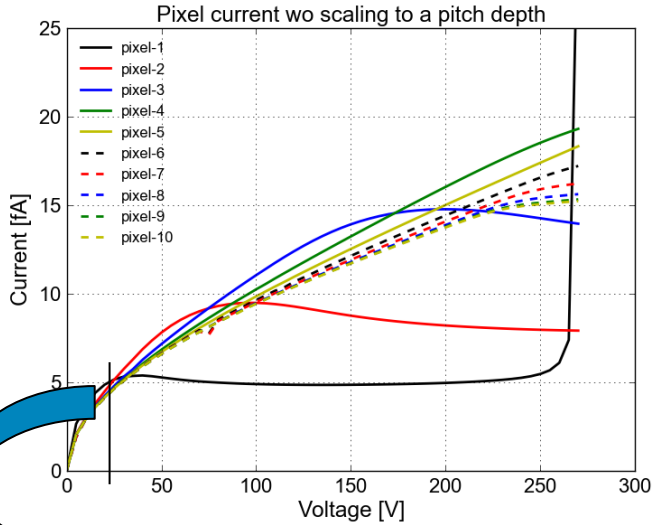
Flat field correction:

$$C = \frac{(O - D)m}{(F - D)}$$

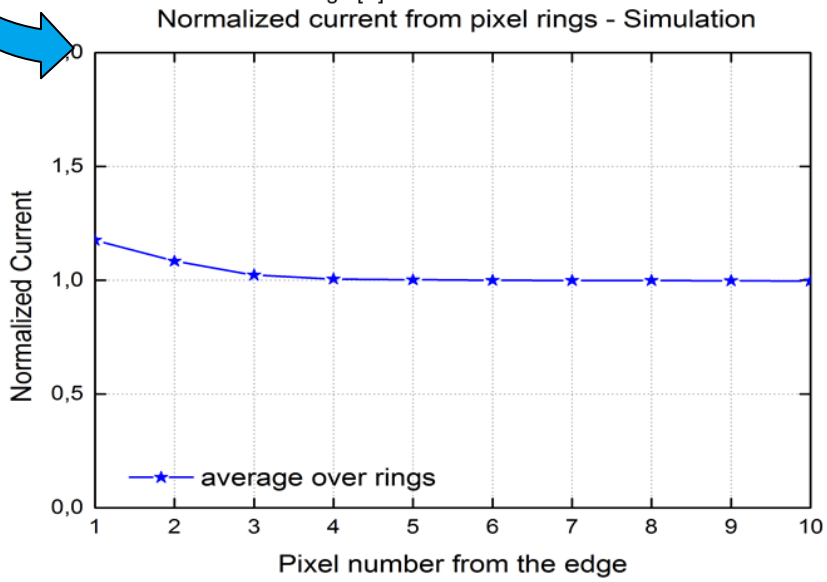
Where:
C – corrected image
O – object raw image
D – dark field image
F – flat field image
m – mean value of (F-D)

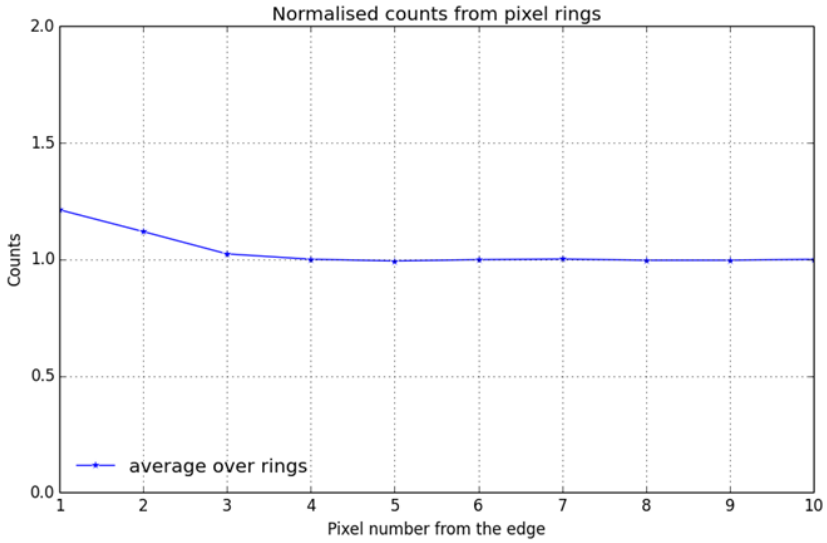
- Although the sensors are not fully depleted they can still work for imaging experiments
- Quality of the image after flat field correction gets better

Comparison Simulation and Experiment for first sample

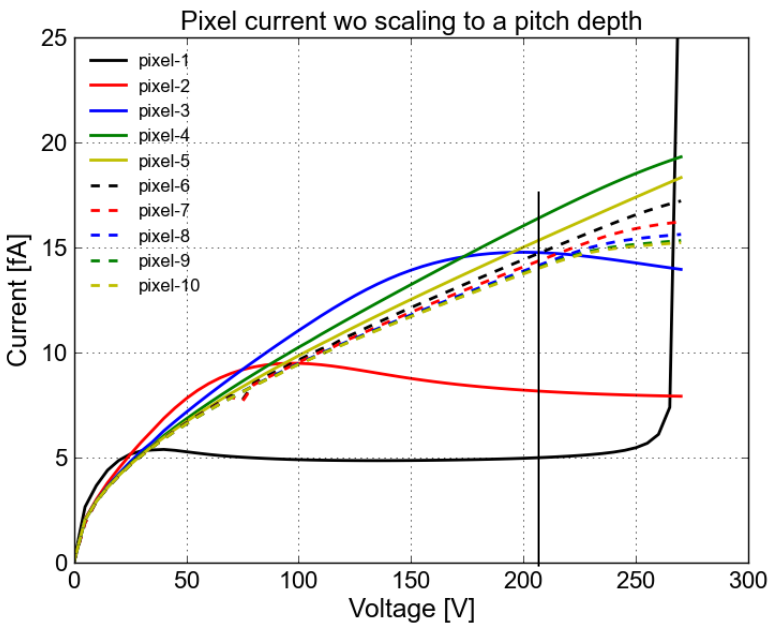


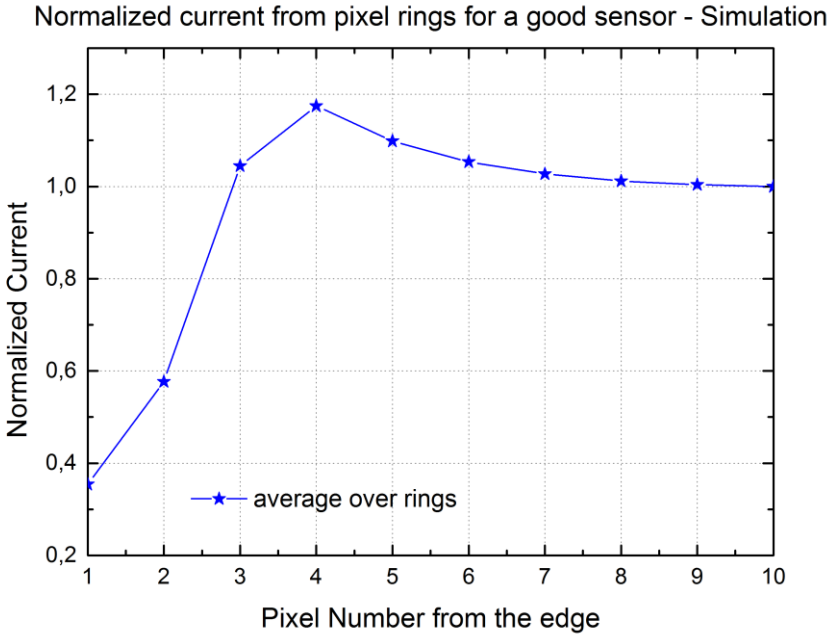
- Edge pixels count differently from central pixels
- The results from the simulated normalized current reproduces the measurement results





Comparison Simulation and Experiment for first sample

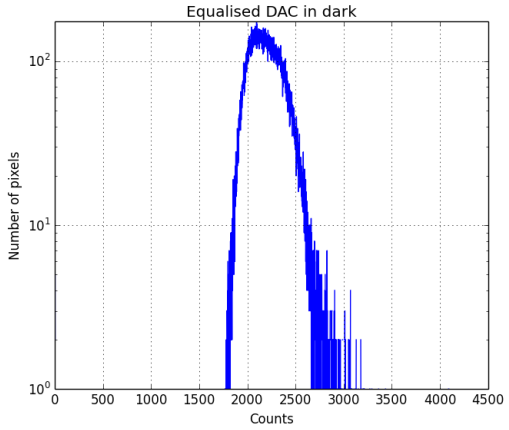


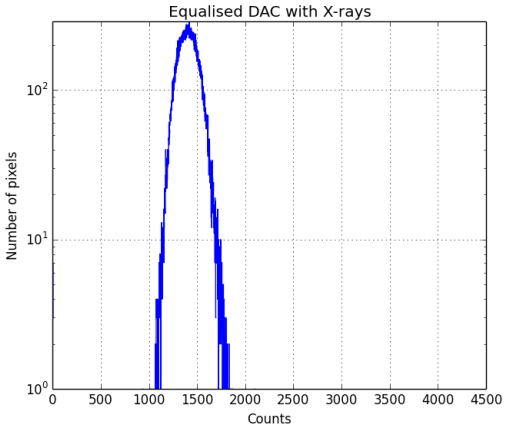


- Prediction for a good sensor (full depletion) shows that the last few pixels counts much less than central pixels

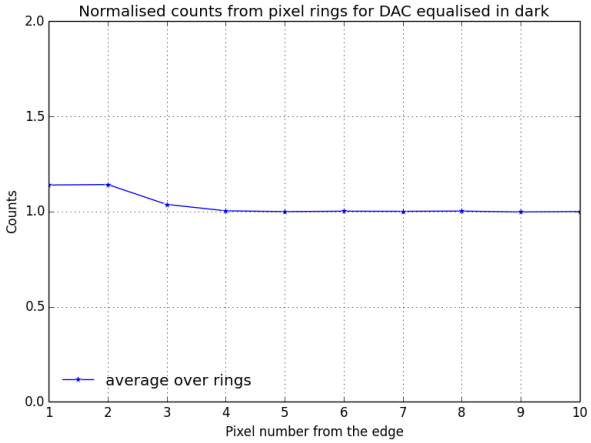
Performance of Different Equalization Procedures

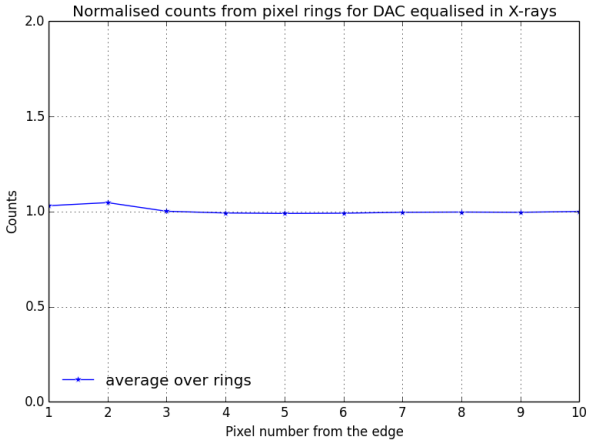
Equalized with X-rays shows a better performance





Full Width at Half Maximum (FWHM) for an equalization with X-rays is smaller than the FWHM for equalization in dark.





Normalized counts from pixel rings for the two equalization procedures show a difference of ~5%.

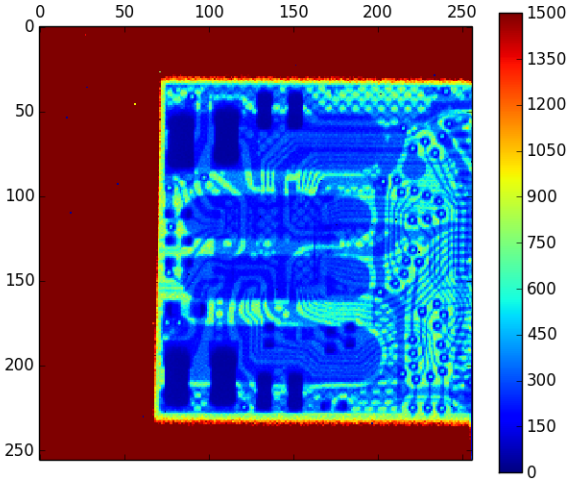
Results derived from the flat field image

Performance of Different Equalization Procedures

Equalized dark

Equalized x-rays

Image of an USB drive



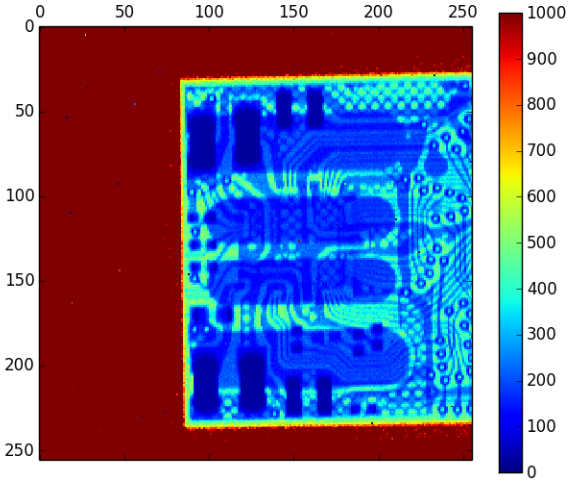
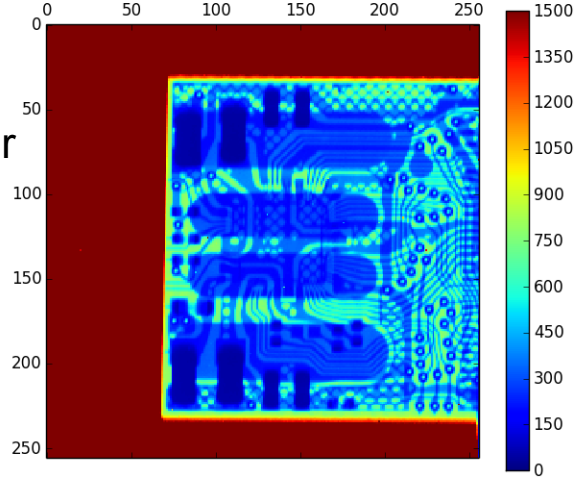
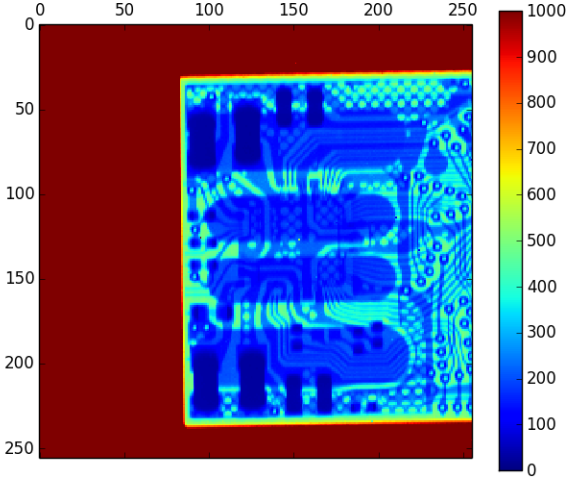


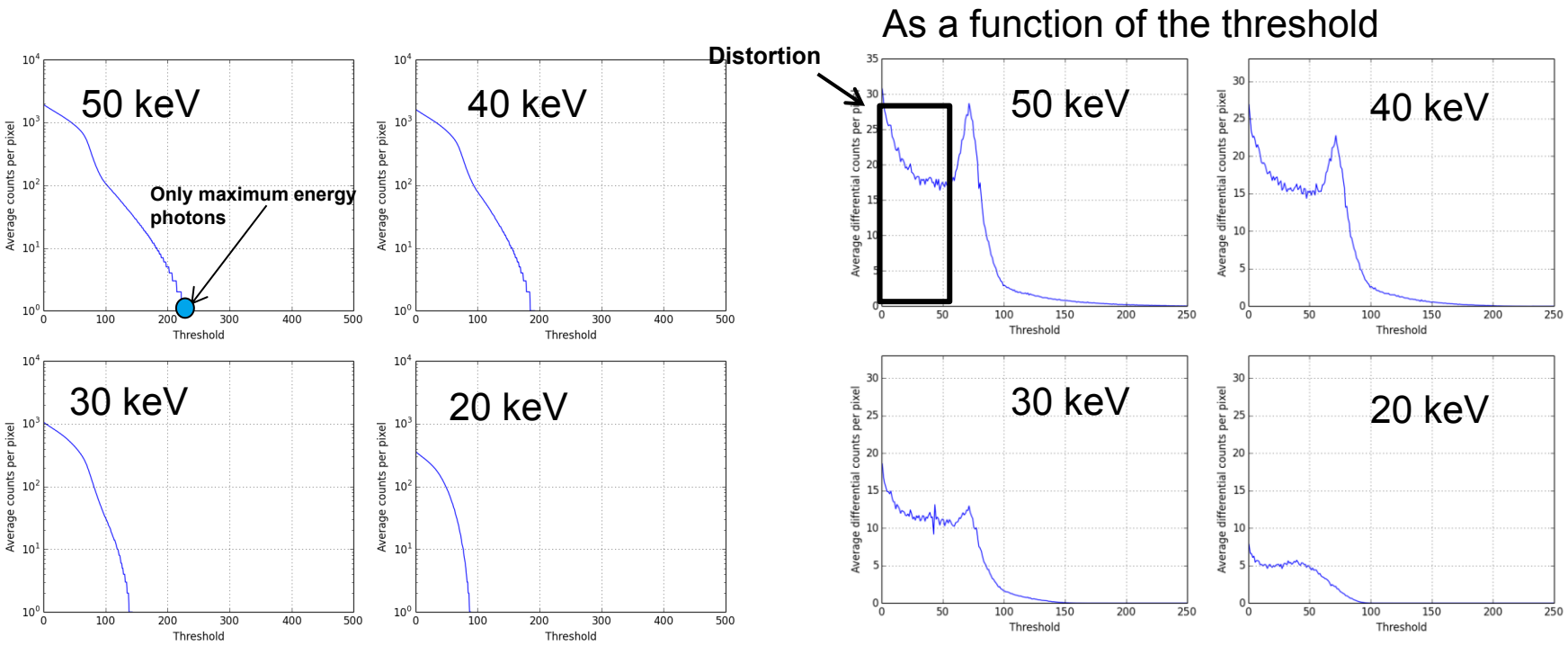
Image of an USB drive after flat field correction





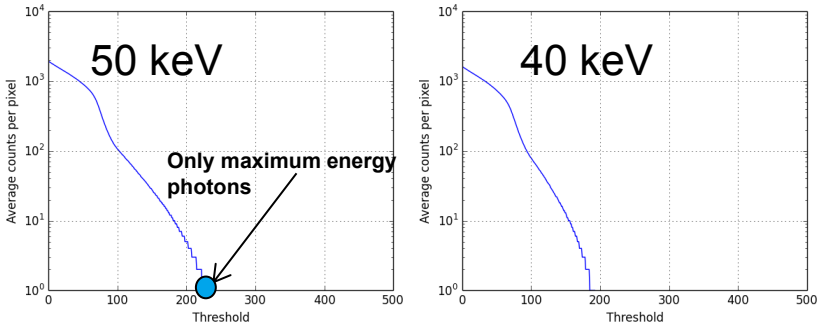
Object Image for Equalized DAC with X-rays is slightly better than object image for Equalized dark

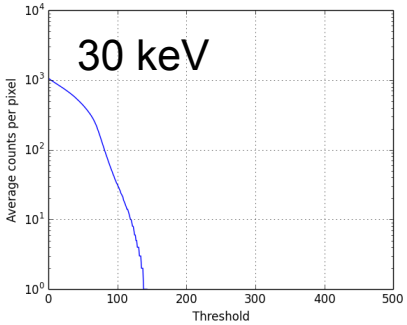
Energy Spectrum

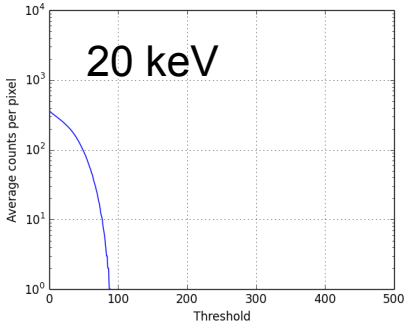


- **Distortion in the energy spectrum due to charge summing**

Energy Calibration

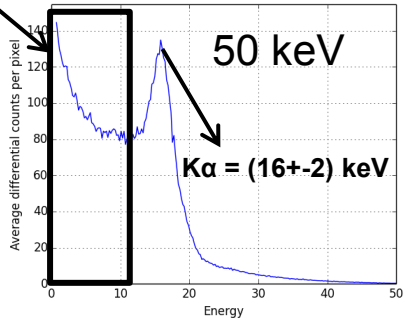


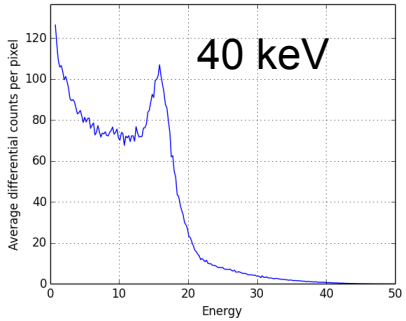


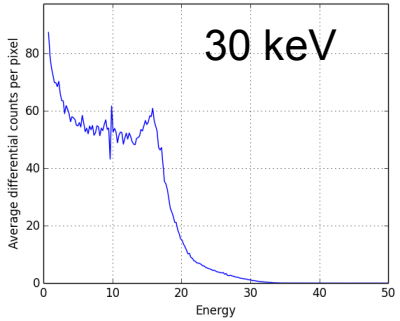


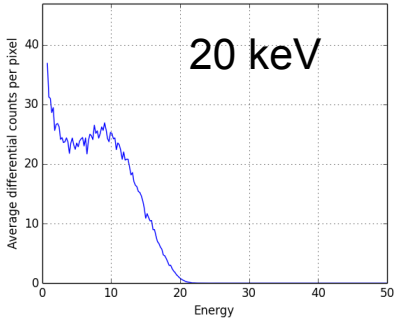
Distortion

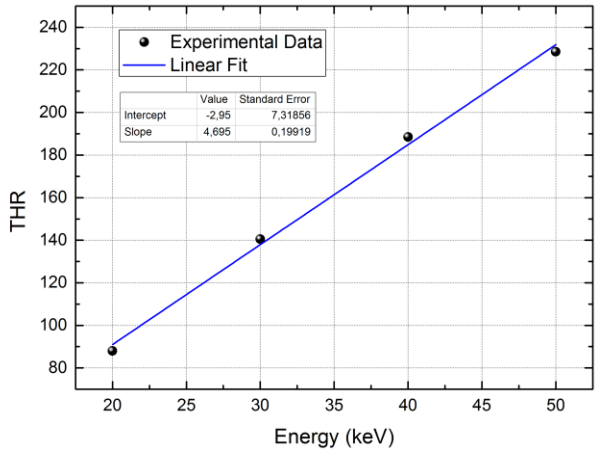
As a function of the energy











- Energy calibration based on the end-point energy of the X-ray tube operated with different tube voltage
- Distortion in the energy spectrum due to charge summing

Summary

- Three edgeless samples were tested:
  - I-V measurement: the first and the third sample cannot be fully depleted!
  - Flat field images with X-ray tube: Problem found for n^+n sensor (production problem?)
  - Object (USB drive) images taken: Both n^+p sensors work, but it is a pity that 350 µm thick Si cannot be depleted! ☹
- Normalized counts (charge-collection) from edge pixels understood and compared to I-V simulation results:
  - Simulation shows good agreement to measurement
  - Prediction done for good sensors which can be fully depleted
- Different Equalization Procedures
  - Equalization performed with X-rays shows a slightly better performance
- Energy Spectrum
  - Distortion caused by charge summing

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Thanks for your attention!