PAUL SCHERRER INSTITUT

Anna Bergamaschi :: SLS Detector Group :: Paul Scherrer Institut

Position sensitive LGADs with single photon counting readout for X-ray detection

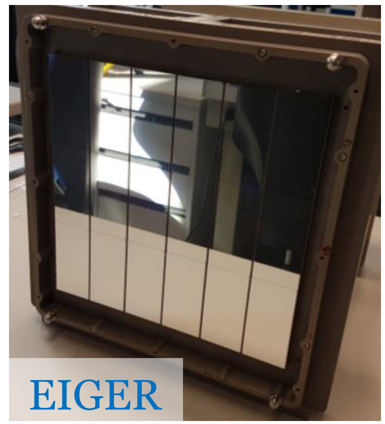
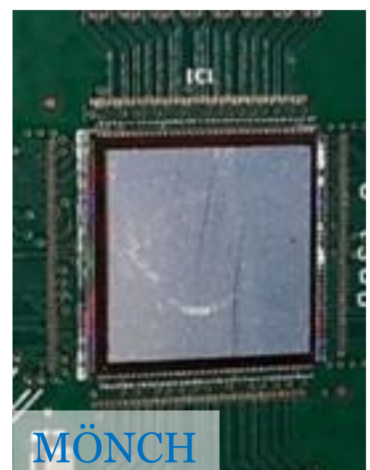
14th "Trento" Workshop on Advanced Silicon Radiation Detectors

27th February 2019

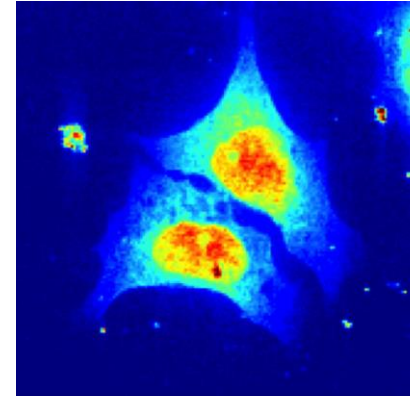
Outline

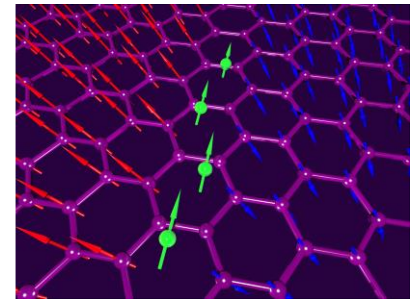
- Motivation
- Single photon counting
- LGAD characterization
- Perspectives

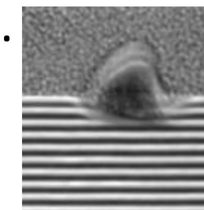
Hybrid SLS Detectors

	Microstrips	Pixels		
	50 um	75 um	25 um	200 um
Single Photon Counting				
Charge Integrating				

Soft X-rays (250-2 keV)







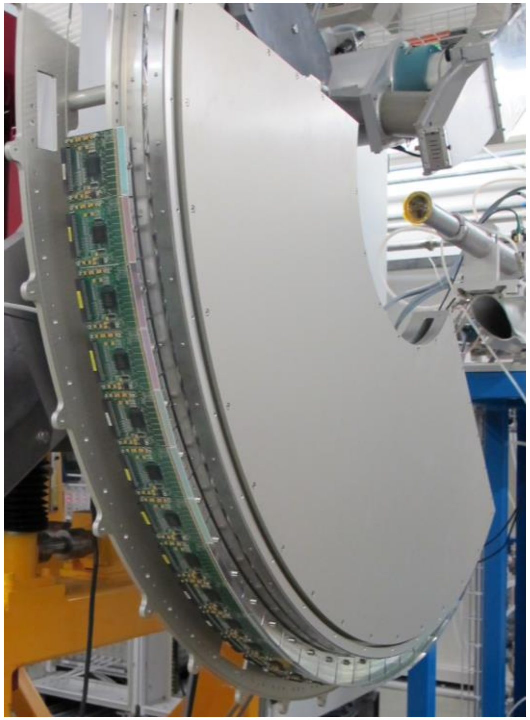
- High absorption coefficient
  - Thin samples
  - Light elements
- K-edges of bio-elements (e.g. C, O, N, S, P)
  - pharmaceuticals, cell imaging
- L-edges of 3d-transition metals
  - magnets, superconductors, batteries, quantum materials, catalysts…
- EUV: lithography and mask inspection
- **1 keV photon generates less than 280 e-h pairs in silicon**
  - Photodiodes, APDs
    - Unsegmented
  - CCDs thanks to their low noise
    - Slow frame rate
    - Radiation damage
    - No electronic shutter

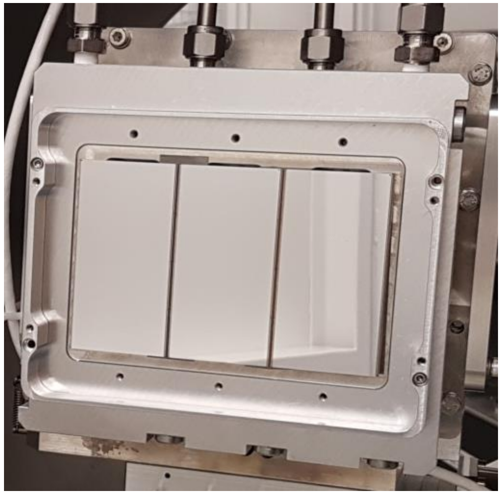
Same as hard X-ray applications 15 years ago

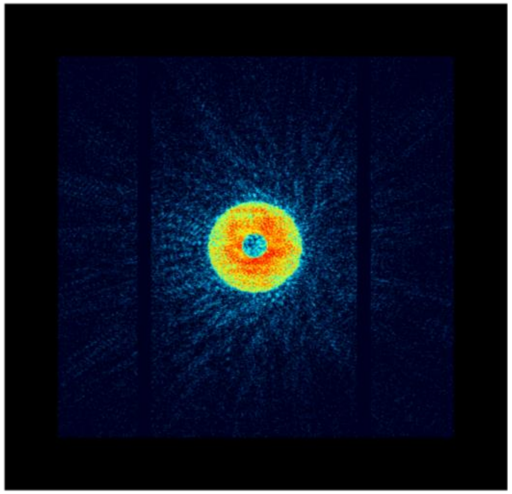
Photon Counting detectors for photon science

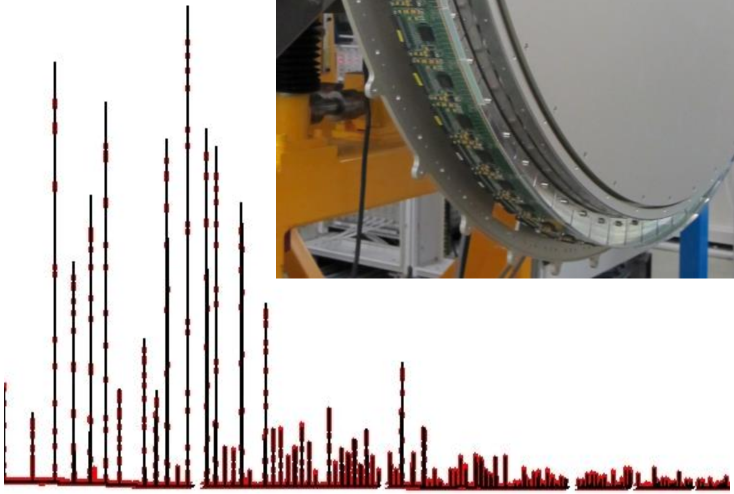
Pixel and strip single photon counters have been a game changer for hard X-rays synchrotron applications 5-20 keV

- Poisson-limited statistics
- Noise free
- Large dynamic range
- Fast readout
- Almost insensitive to sensor leakage current
- Stable and user friendly

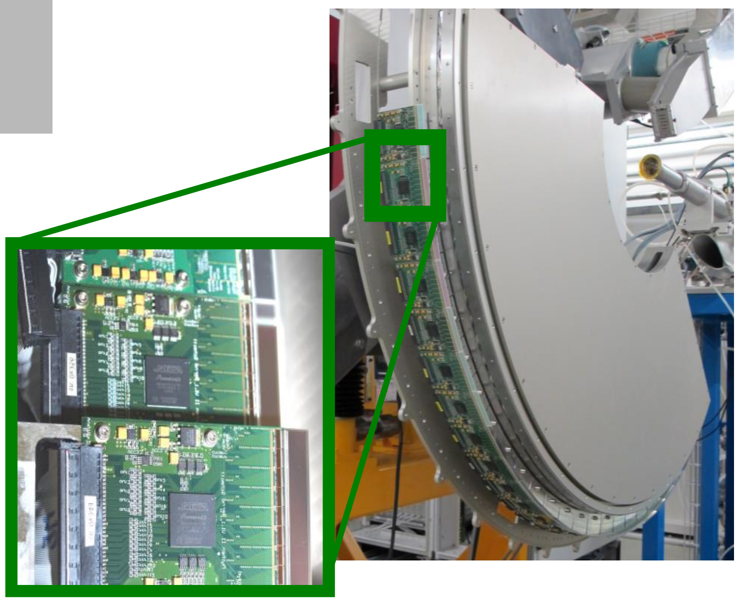


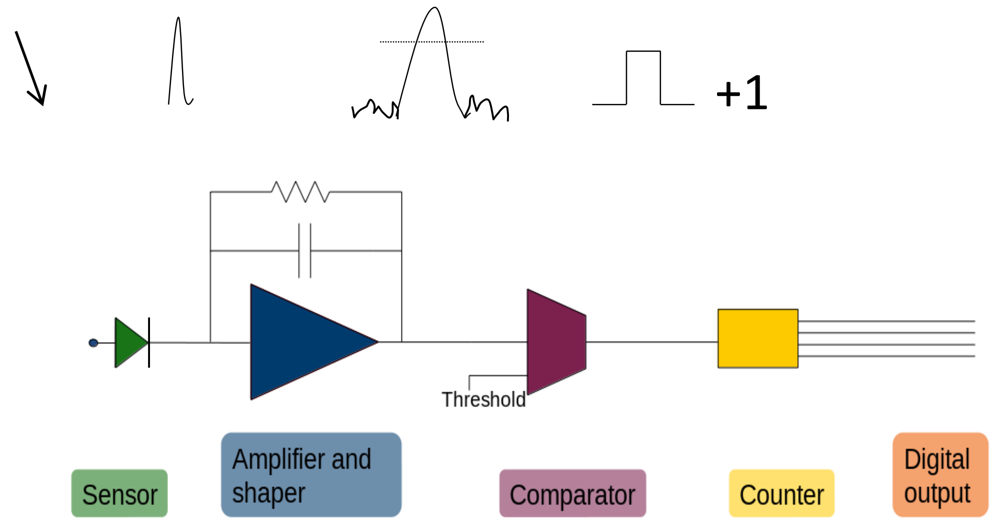






The MYTHEN detector





The ENC limits the minimum detectable energy

ENC > 250 e- rms ≈ 1000 eV

Min Threshold = 5·ENC = 5keV

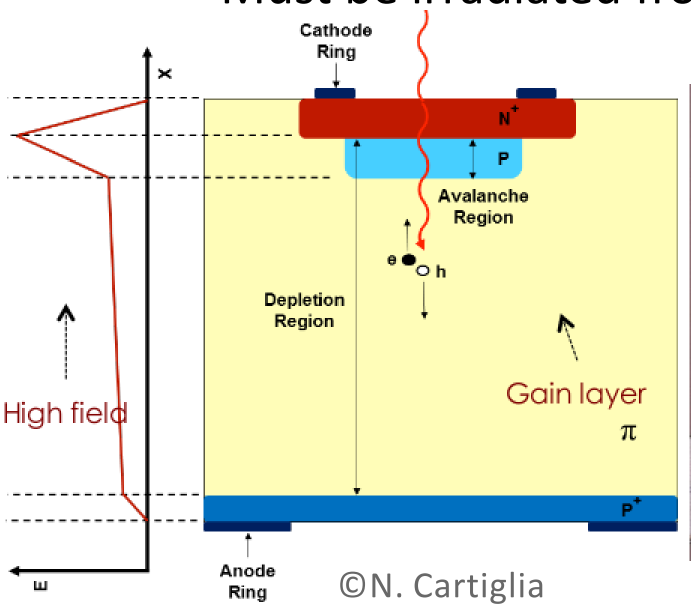
Min Energy=2·threshold = 10 keV

Standard MYTHEN microstrip sensors	
Strip pitch	50 µm
Strip length	8 mm
Sensor thickness	300-450 µm
ENC (rms)	250 e-

A. Bergamaschi, et al., Journal of Synchrotron Radiation 17 (5) (2010) 653–668.

LGAD strips

- Microstrip sensors 150 µm pitch, 50 µm thick, 5 mm long
  - Junction Termination Extension around the strips
  - Input capacitance 2.57 pF:
    - Higher noise than 1.52 pF standard MYTHEN sensors
  - Electron collection
    - MYTHEN is optimized for holes
  - Fabricated on a substrate
    - Must be irradiated from the strip side



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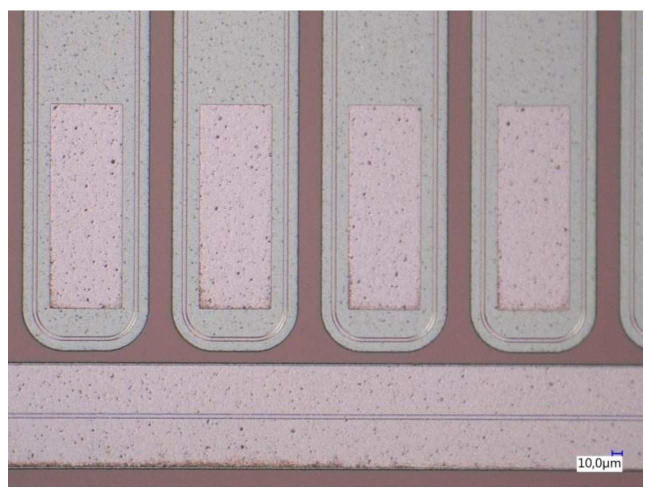
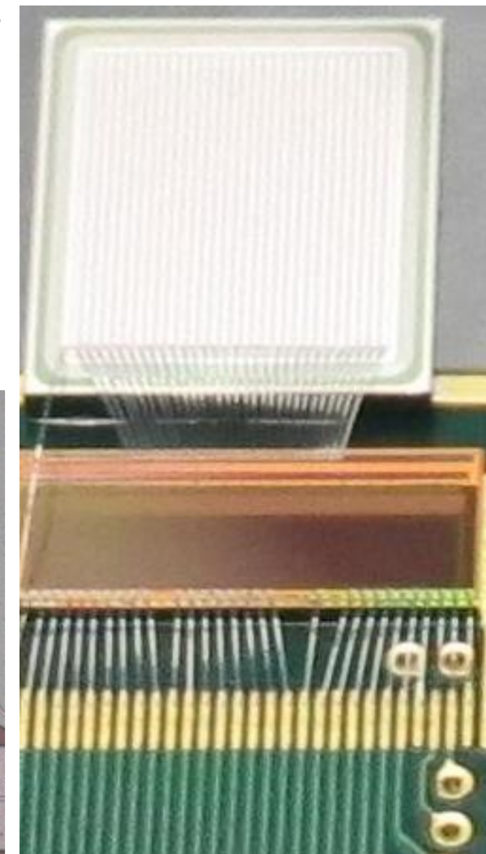
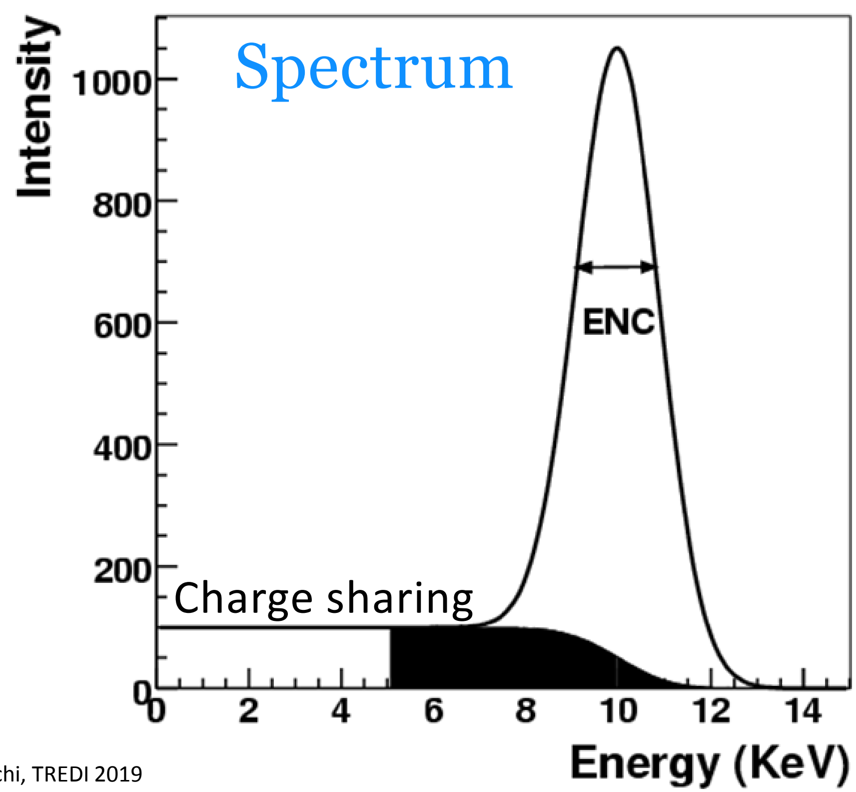


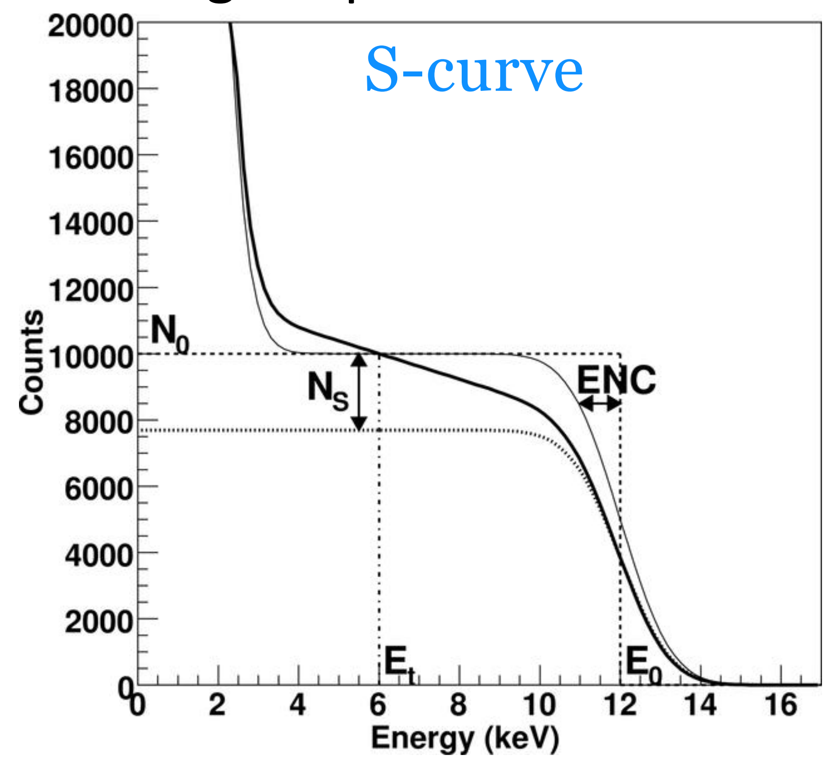


Characterization of photon counters

- X-rays interact by photoelectric effect
  - Point-like interaction
- Can be monochromatic
  - Use fluorescence emission
- Can be focused



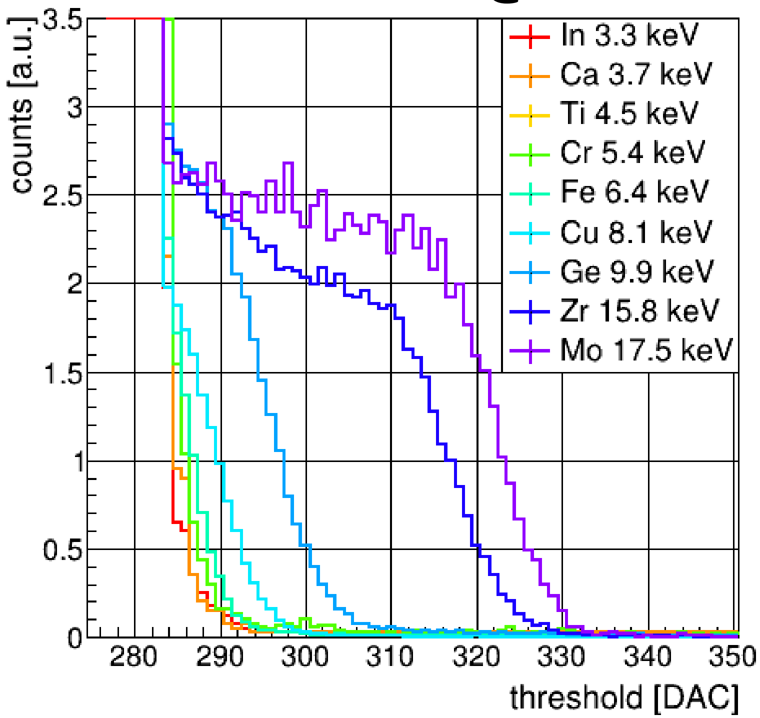
- S-curve obtained by scanning the threshold
  - Is the integral of the pulse-height spectrum



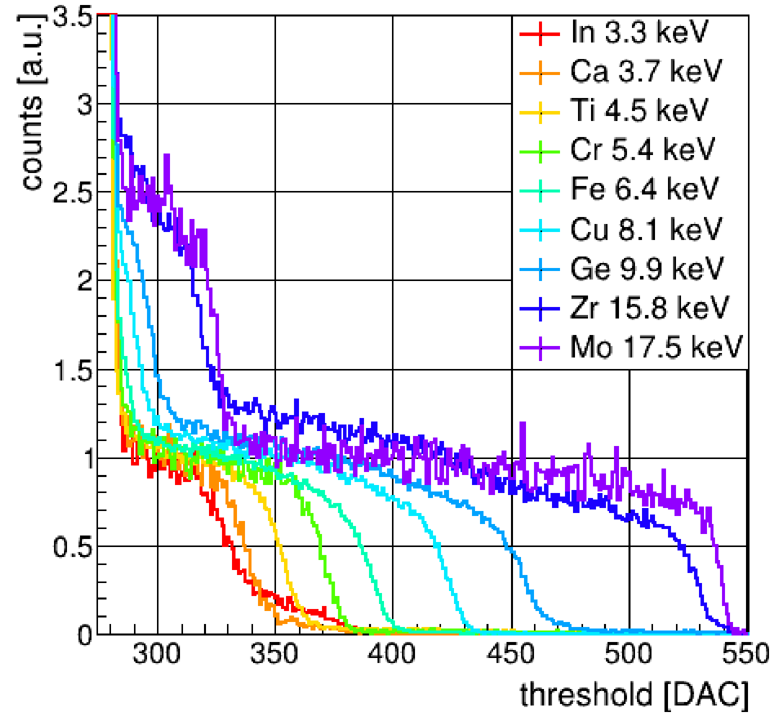
S-curves: LGADs vs planar Si sensor

©M. Andrae

Planar sensor @150V



LGAD @ 150 V



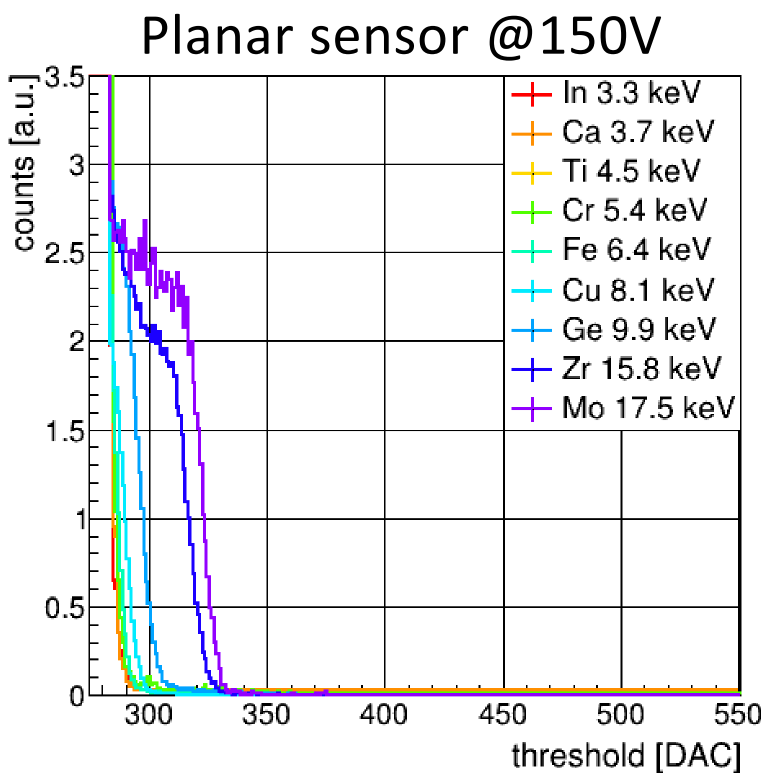
- Only high energies > 8 keV clearly detectable

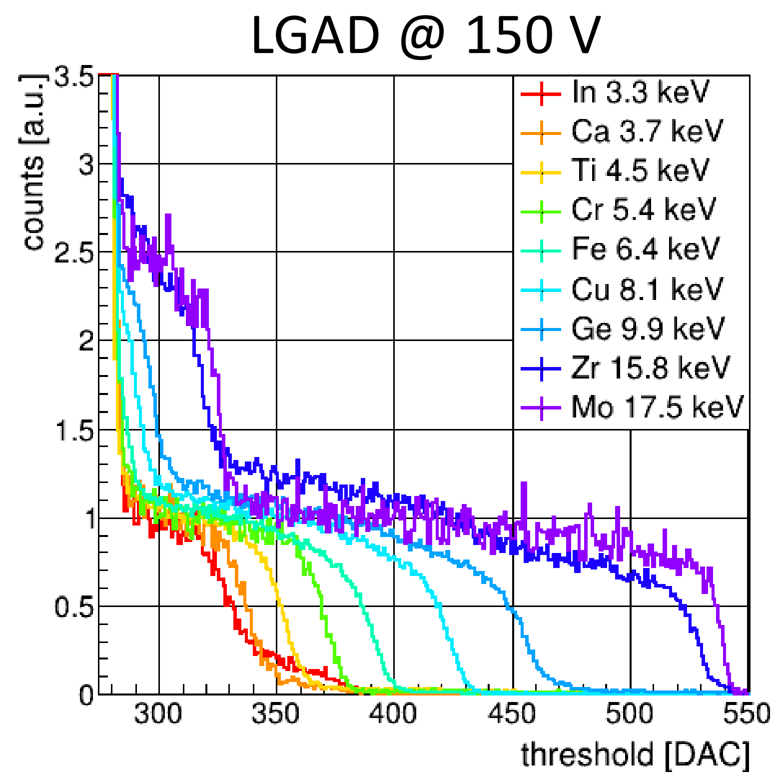
- Low energies < 3.3 keV visible
- No charge sharing, but gain-spread tail

M. Andrae et al., submitted to Journal of Synchrotron Radiation

S-curves: LGADs vs planar Si sensor

©M. Andrae





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Energy calibration using S-curve scans

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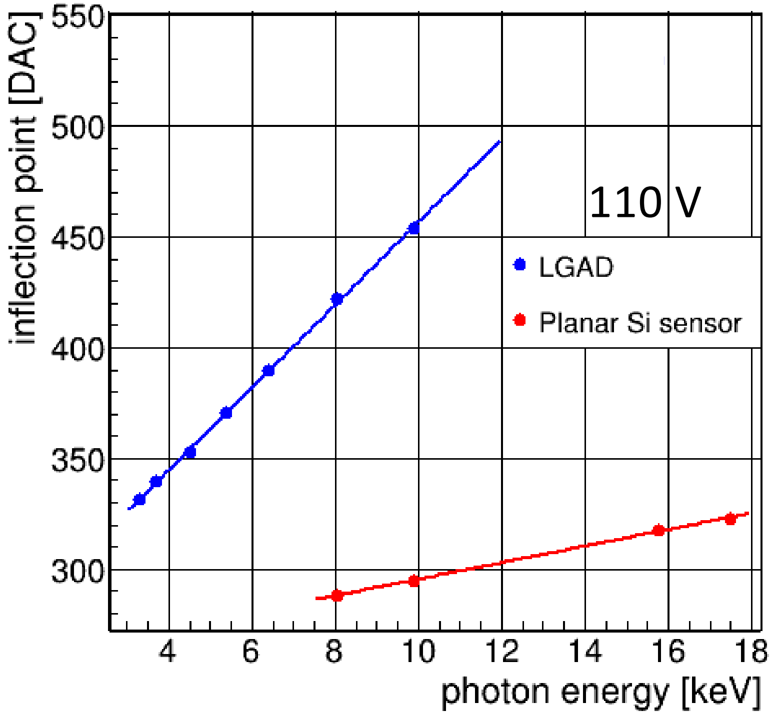

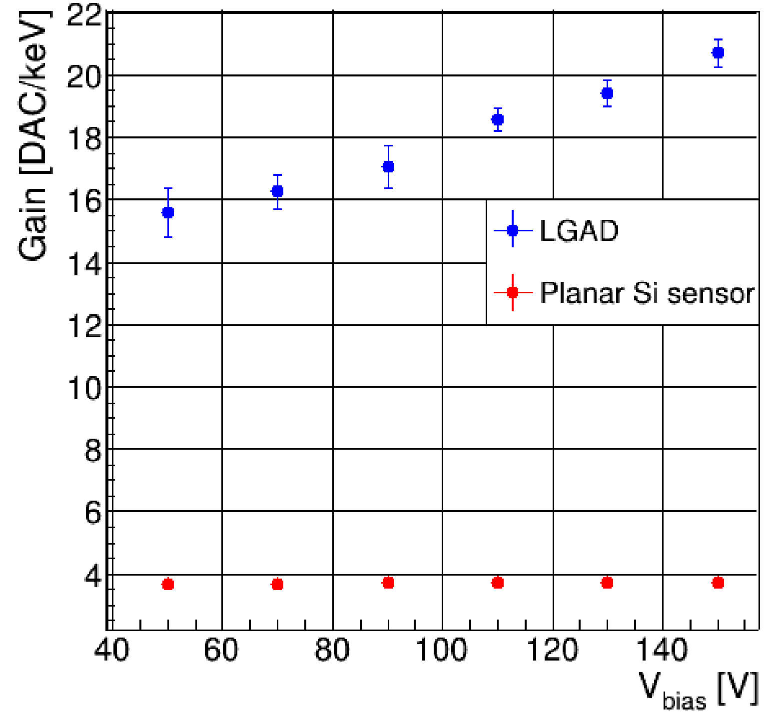

- Conversion gain from linear fit between X-ray energy and inflection point of S-curves
  - LGADs: 15.6-20.7 DAC/keV for 50-150 V
    →Depends on bias voltage
  - Planar Si sensor: 3.7 DAC/keV

LGAD Multiplication factor is the ratio of the gains

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Multiplication and energy resolution

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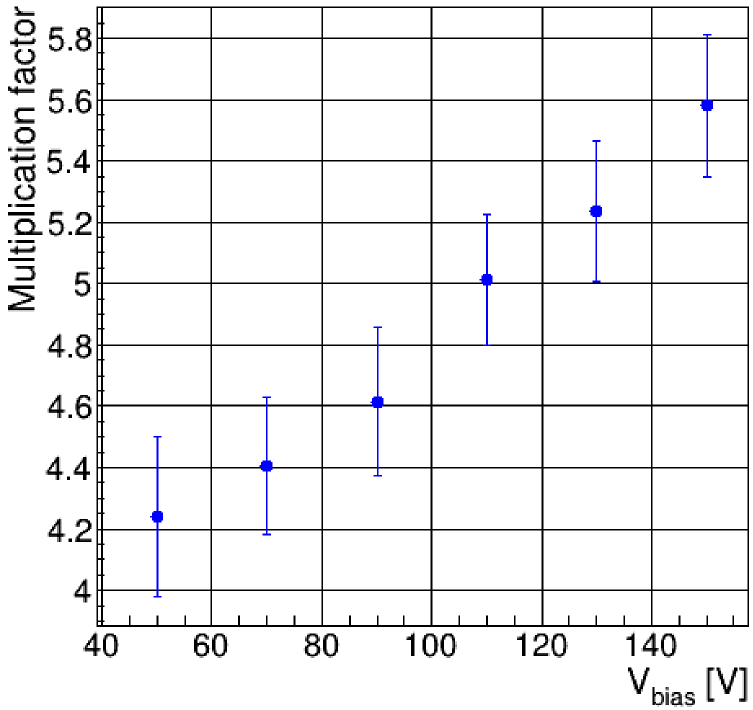

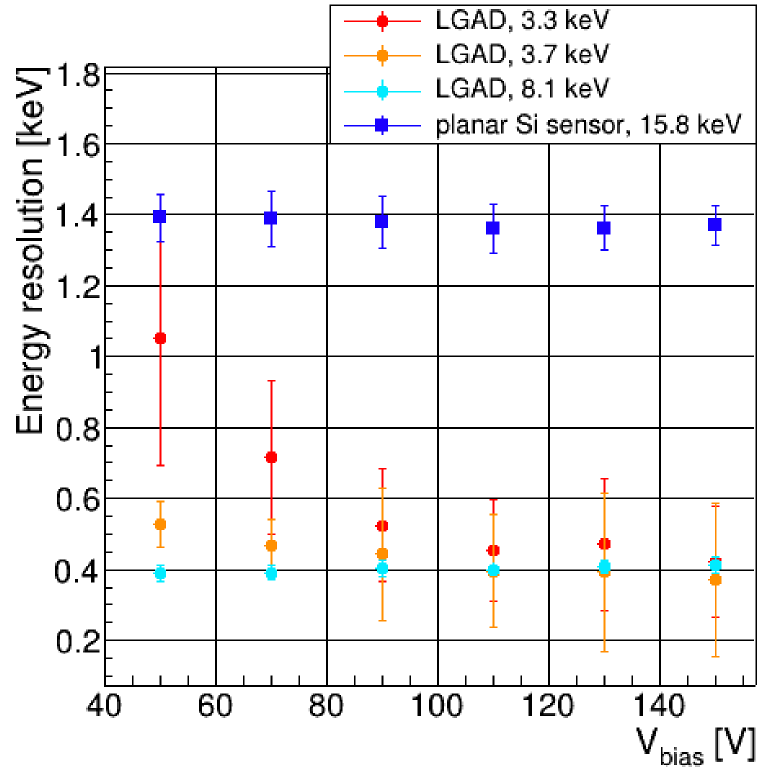

- LGAD multiplication factor increases with bias voltage
  – 4.2-5.6 @ 50-150 V
- Noise decreases with increasing bias voltage
  → improved energy resolution at high voltage

M. Andrae et al., submitted to Journal of Synchrotron Radiation

Fill factor

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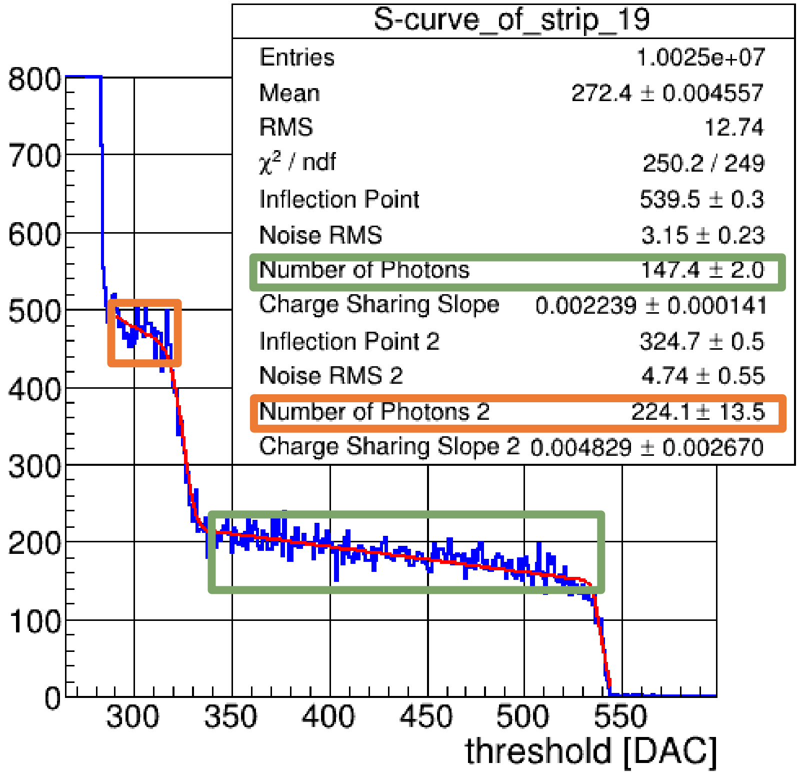
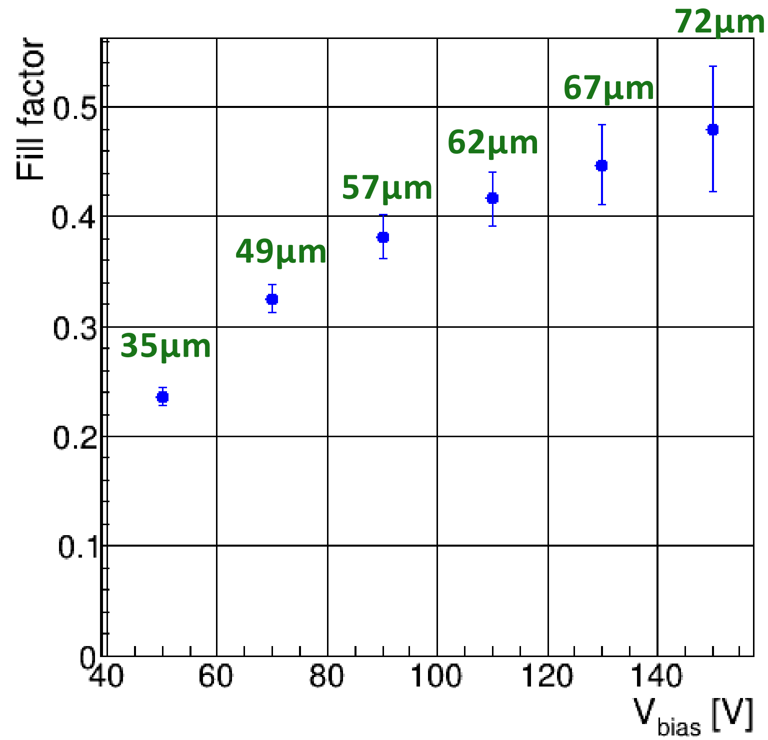




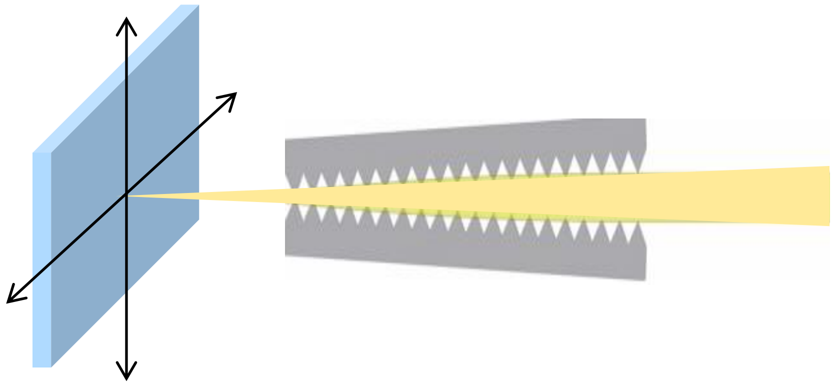
$$\text{Fill factor} = \frac{\text{multiplied } \gamma}{\text{total } \gamma}$$

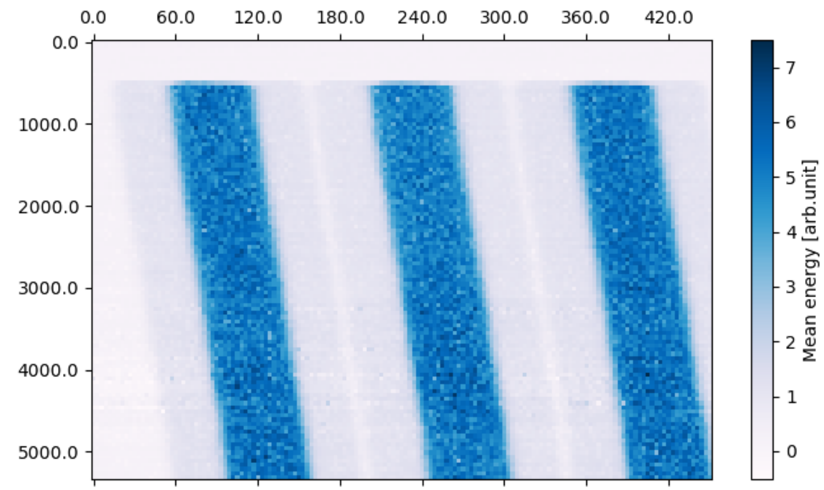
- The fill factor increases with bias voltage
  →Change of electric field distribution inside sensor

M. Andrae et al., submitted to Journal of Synchrotron Radiation

Fill factor compared to layout

- Pencil beam scan with the charge integrating GOTTHARD readout chip at 20 keV, 120 V_{bias} at the ESRF
- The measured fill factor agrees very well with the simulations, the S-curves and the sensor layout





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Synchrotron radiation on LGADs

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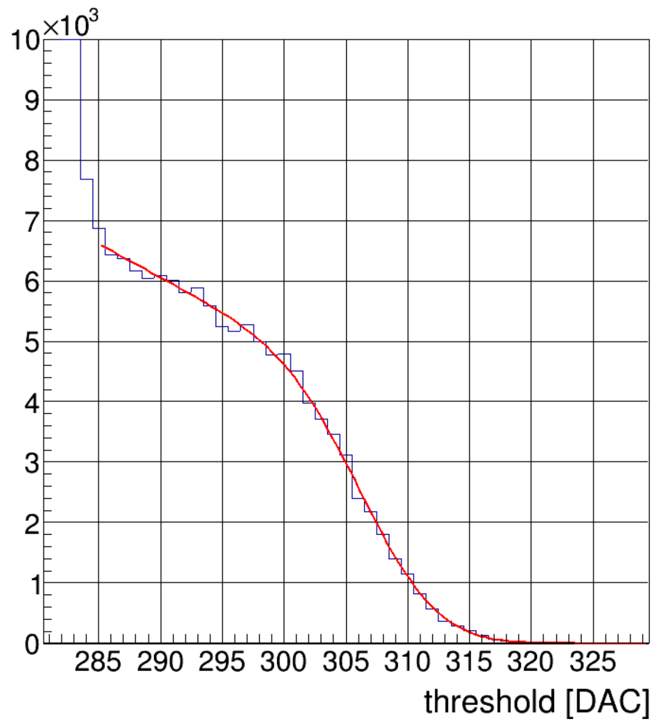
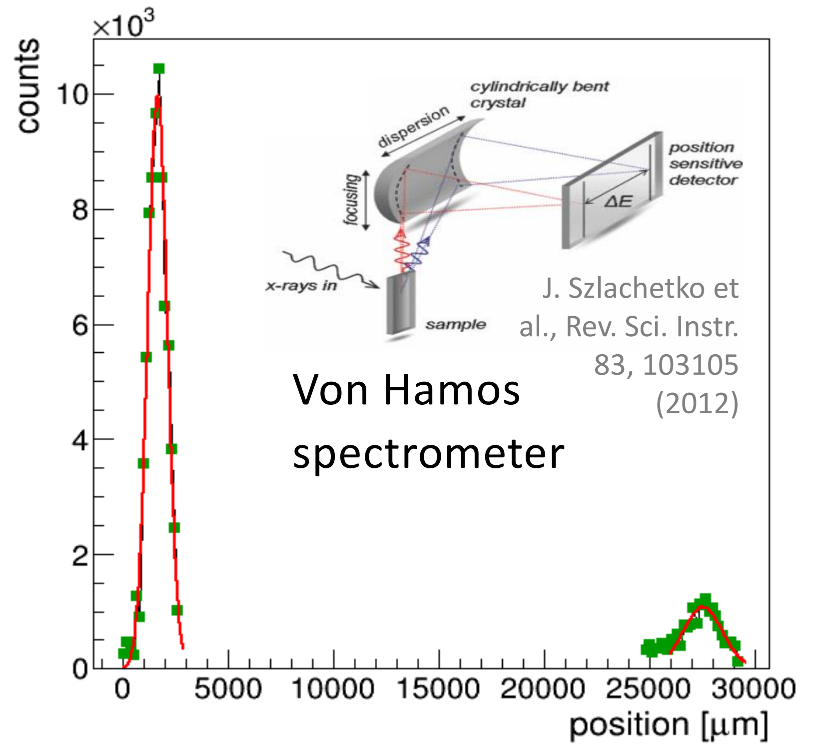




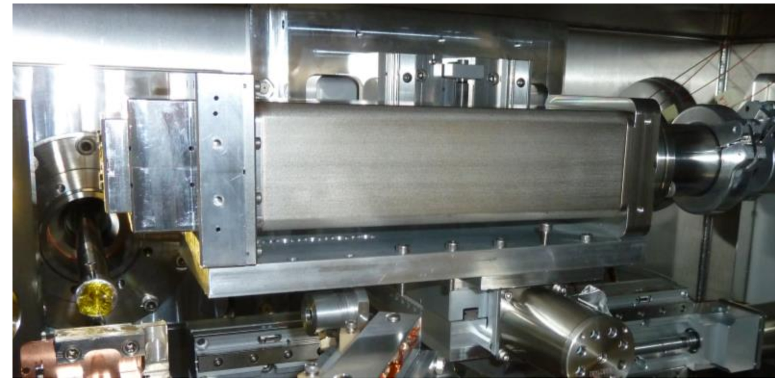
Threshold scan at 2.1 keV in direct beam at the Phoenix beamline of SLS
Energy resolution ≈ 300 eV

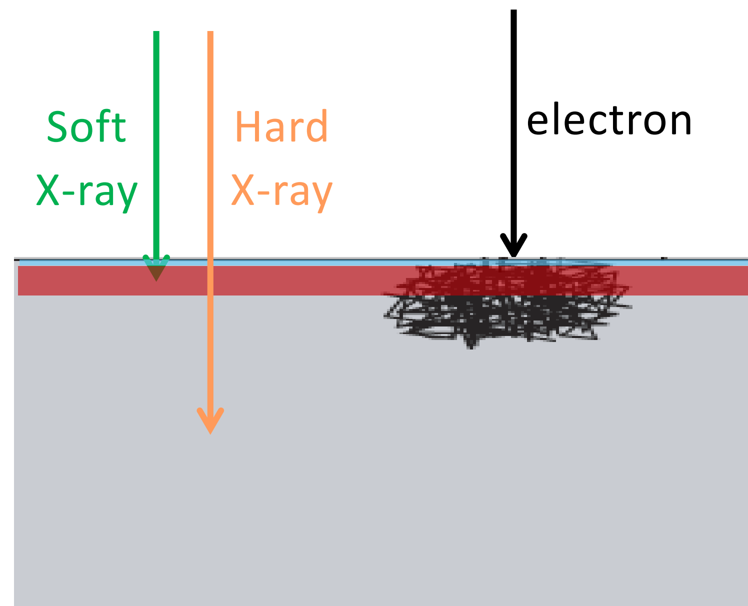
Fluorescence emission spectrum of Sulphur (K_α=2.31 keV, K_β=2.46 keV)
Unfocused 3 keV beam, 150 V_{bias}

M. Andrae et al., submitted to Journal of Synchrotron Radiation

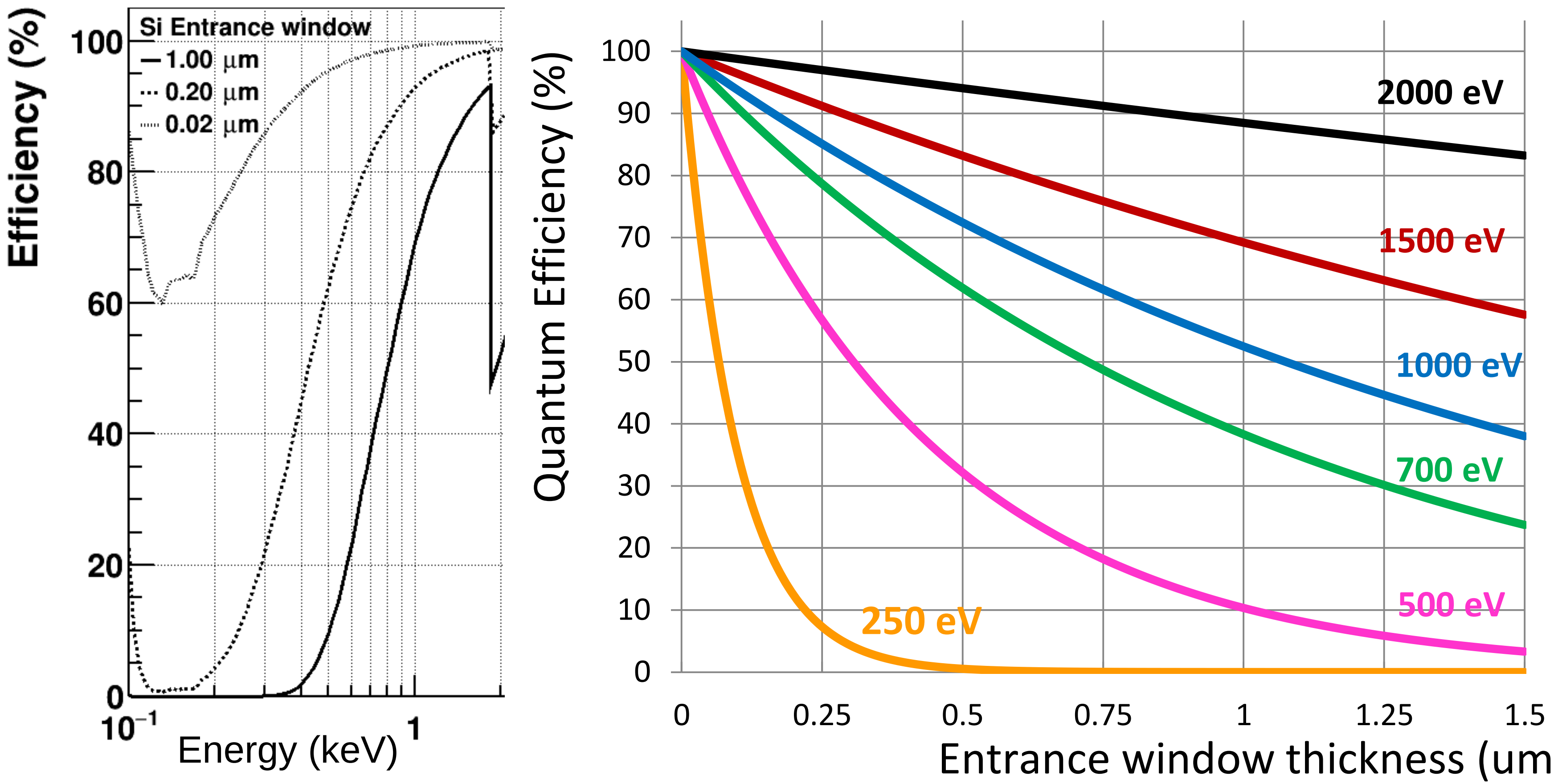
Soft X-rays challenges

- Single photon resolution
- Vacuum operation and cooling
  - Vacuum barrier between the detector and the readout board
- Quantum efficiency
  - Shallow implant required to avoid absorption in the entrance window
  - Useful also for electron detection
  - Aluminum can be etched away





Soft X-rays quantum efficiency



Entrance window shallower than 100 nm necessary to detect 250 eV X-rays with more than 50% efficiency

Charge collection efficiency is more important than implant thickness and requires optimization

Summary and perspectives

- LGADs work well with single photon counting detectors
  - Minimum detectable energy with MYTHEN lower than 2.1 keV compared to 8 keV with planar sensors (with multiplication factor 5.6 at 150 V)
  - No additional dark counts
- Improvements still needed for soft X-ray detection
  - Shallow entrance window
  - Thicker sensors with no substrate
  - Higher segmentation (50 µm strips, 25-75 µm pixel) with close to 100% fill factor

The goal is a photon counting detector below 1 keV

Should work with low noise state-of-the-art pixel detectors (ENC<100e-) and higher multiplication factors

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