PSI Center for Photon Science

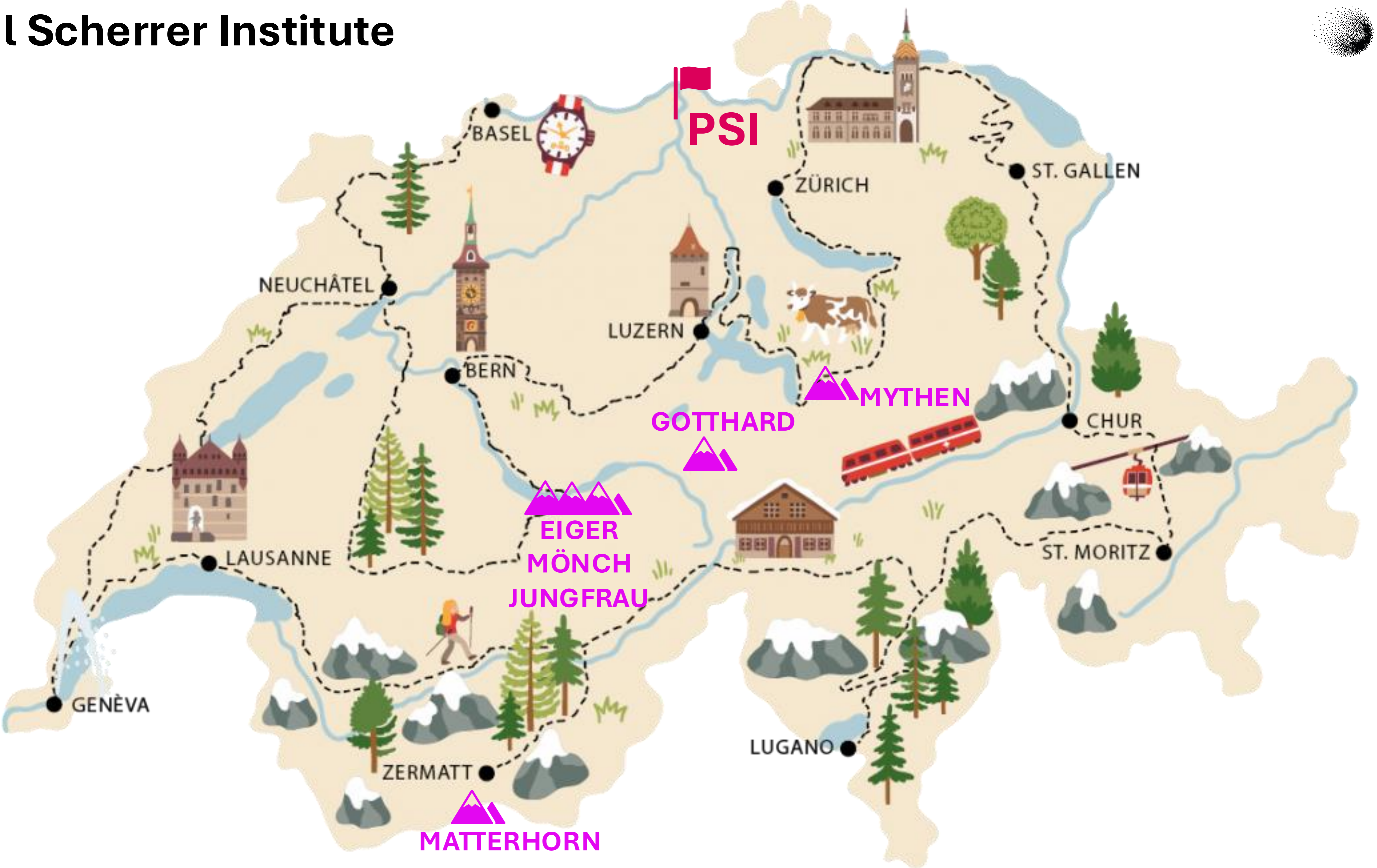
Detector Development for Photon Science

A very brief introduction

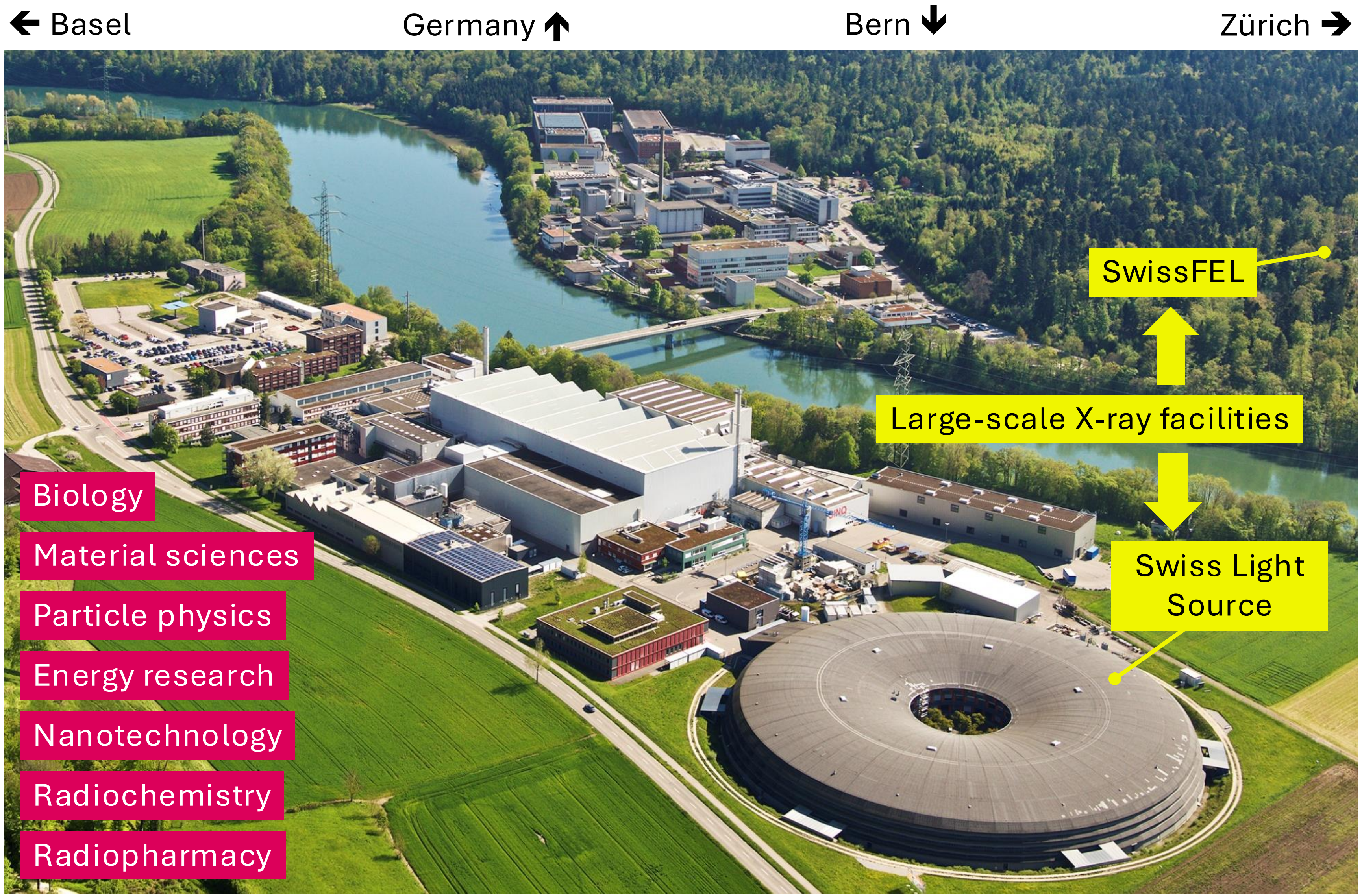
Many slides are with courtesy from Viktoria Hinger

Saverio Silletta, 2026

Paul Scherrer Institute



Paul Scherrer Institute



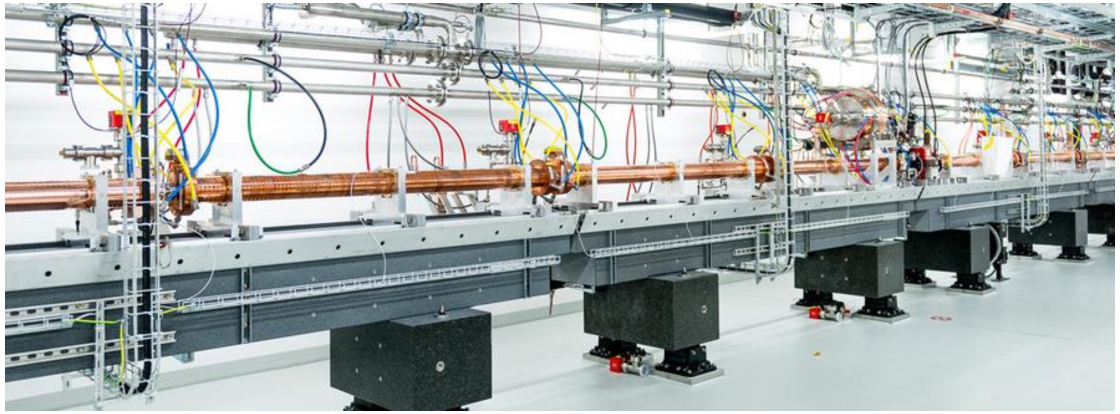
Main areas of research

- Future Technologies
- Energy and Climate
- Health Innovation
- Fundamentals of Nature

2,300 employees,
~ 400 PhDs and postdocs

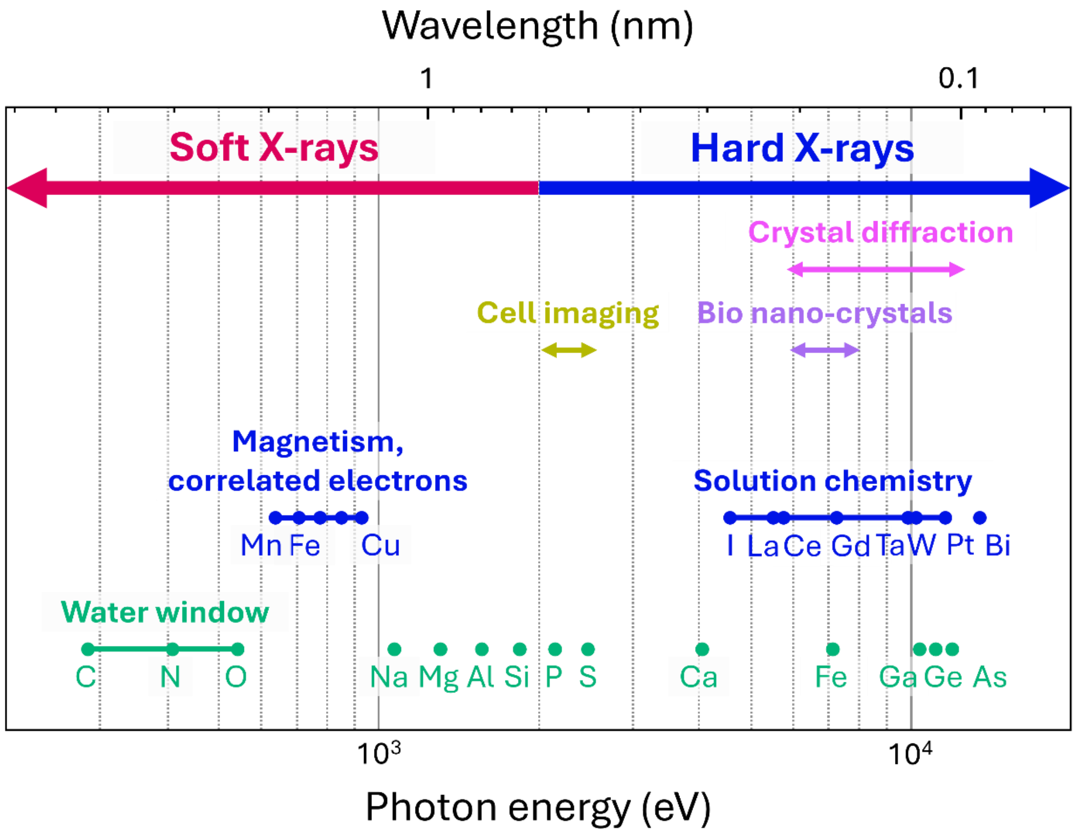
3,500 visiting scientists

Photon Science at PSI



Swiss Free Electron Laser (SwissFEL)

Swiss Light Source (SLS)



Role of Detectors

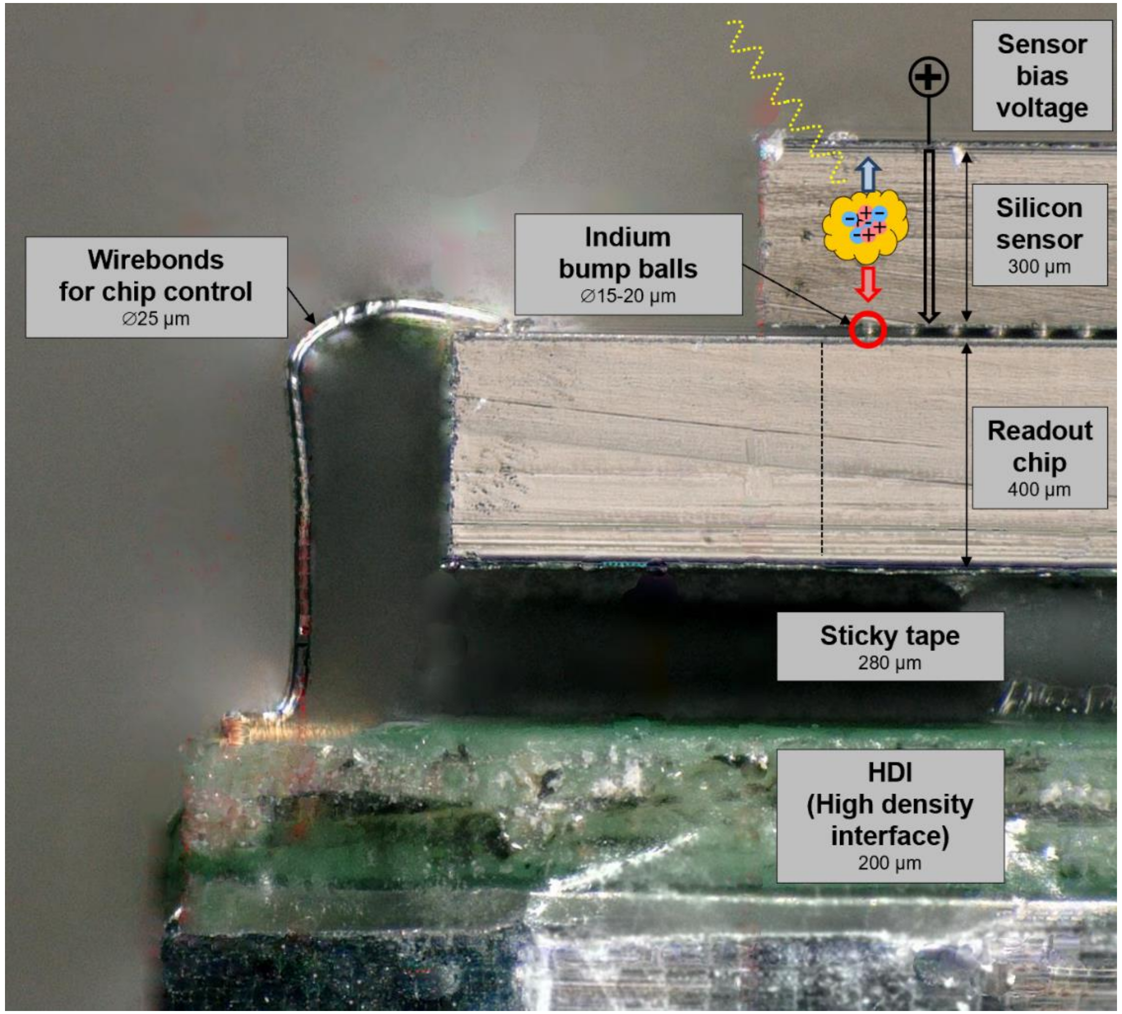
X-rays → Sample → Detector → Data

- ❑ Synchrotron
- ❑ FEL
- ❑ Tubes
- ❑ Radiation Sources

- ❑ Capture all photons
  - ➢ Be fast
  - ➢ Be sensitive
  - ➢ Cover necessary area
  - ➢ Don't overload
- ❑ Get a smooth signal
  - ➢ Not limited by noise
  - ➢ No artefacts
  - ➢ Sample speed
  - ➢ Spatial resolution
- ❑ Be reliable
  - ➢ Environment
  - ➢ Time
  - ➢ Radiation

No detector is good in all categories, so one needs to compromise and choose

Hybrid Pixel Detectors



Semiconductor Sensor

Thickness, material, and technology can be **optimized for X-ray energy**

Versatile CMOS Readout Chip

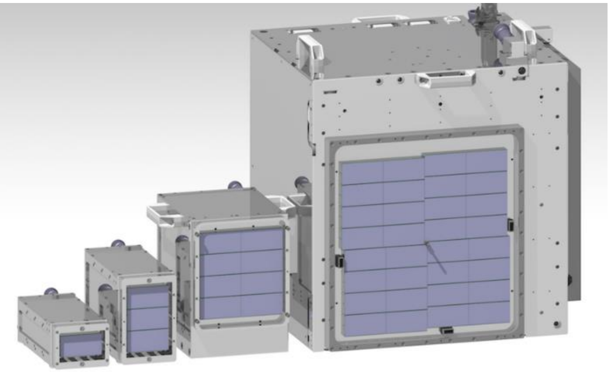
Fast readout (multi-kHz)

Bump Bonding

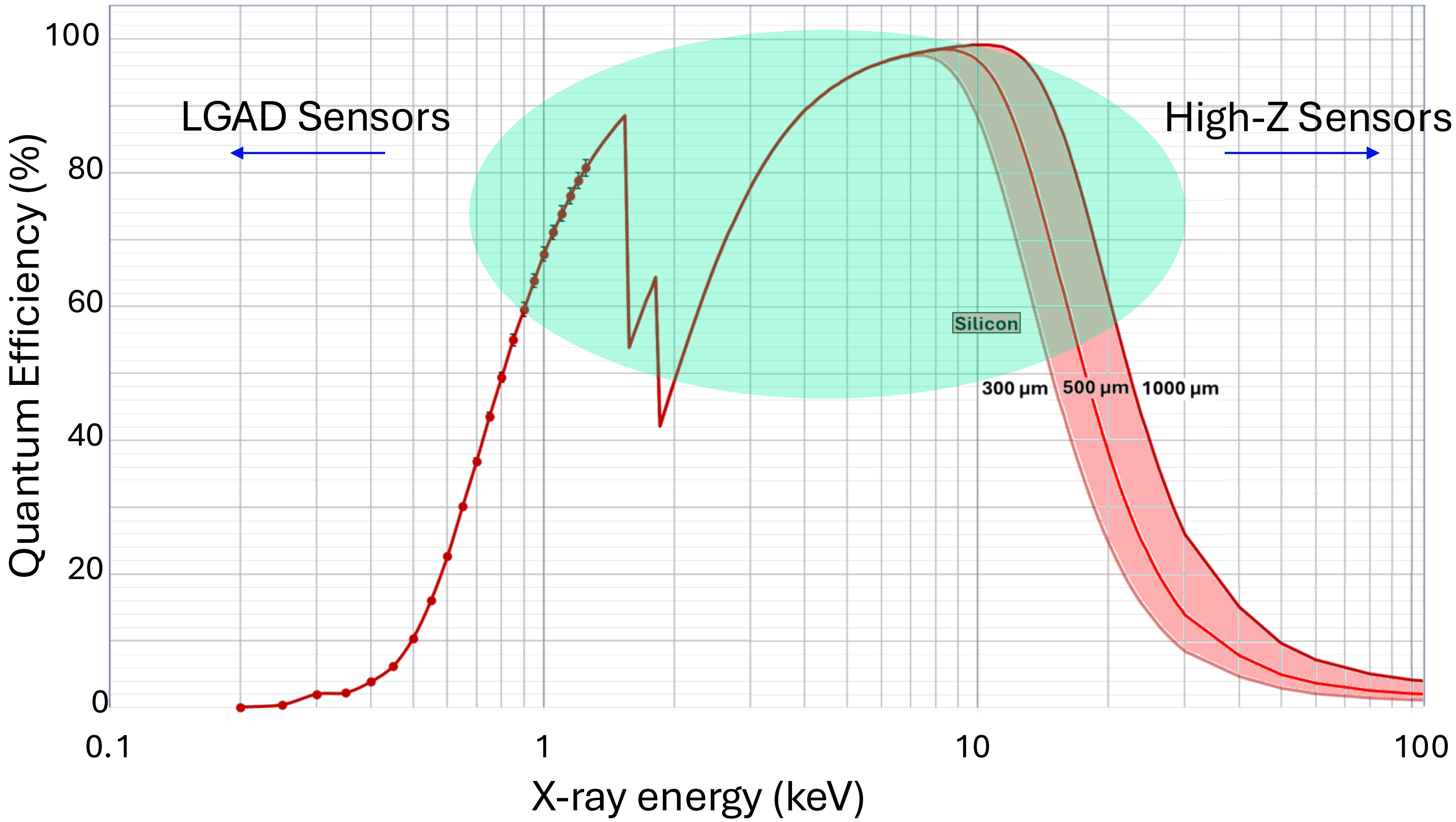
Minimum pixel pitch ~ 20 µm

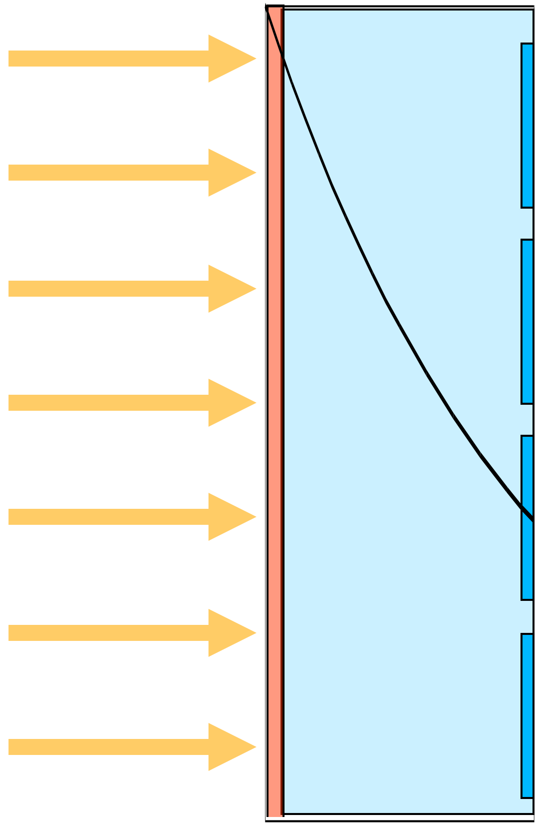
Noise due to input capacitance

Large Area by Tiling



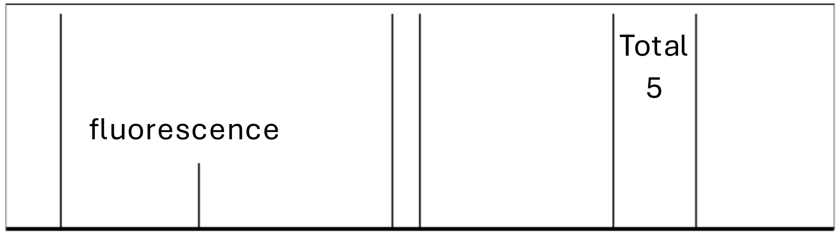
Silicon as a sensor material

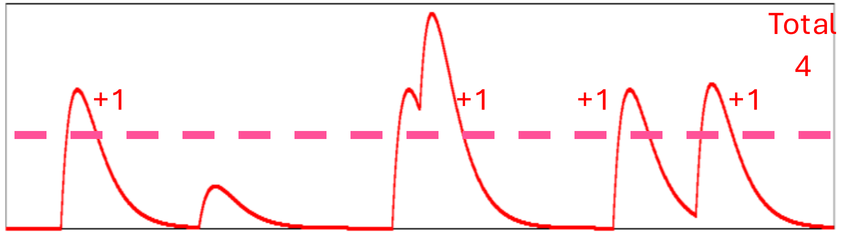




Readout modes

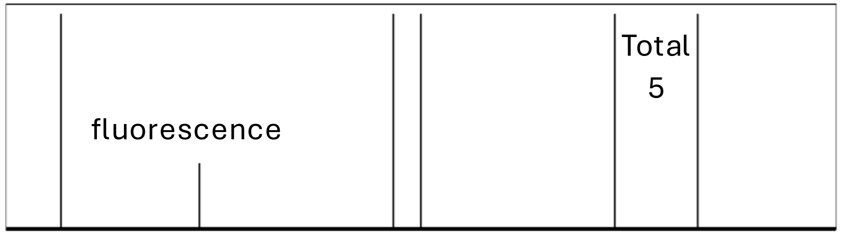
Photon counting

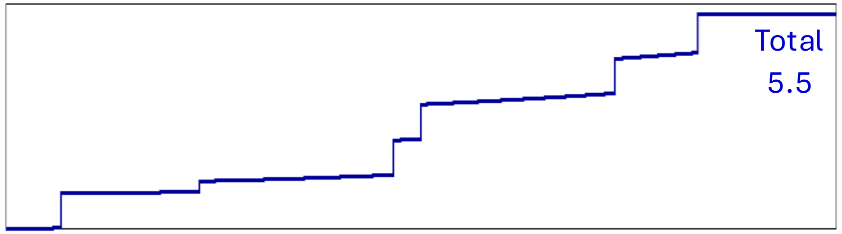




- ✓ Noiseless, very large dynamic range
- ✓ Stable operation, well established calibration
- ✓ Fluorescence suppression
- ✓ Frame rate scales with counter depth
- ✘ Pile-up ≳1MHz/pixel
- ✘ Soft X-ray detection prevented by noise

Charge integrating





- ✓ Compromise between noise and dynamic range
- ✓ Works at pulsed sources
- ✓ Detection of multiple soft X-rays
- ✘ Long integration times
- ✘ No fluorescence suppression

Our Detectors – Named After Swiss Mountains

PSI

Single-photon counting

Mythen

Strip detector

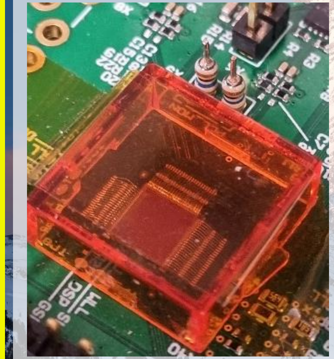
50 µm × 8 mm
Max size: 120°
20 MHz/pixel count rate
100 kHz/module frame rate

Eiger

Pixel detector

75 µm × 75 µm
Max size: 9 Mpixel
0.2-0.7 MHz/pixel count rate
24 kHz/module frame rate (4 bit)

Matterhorn



Pixel detector

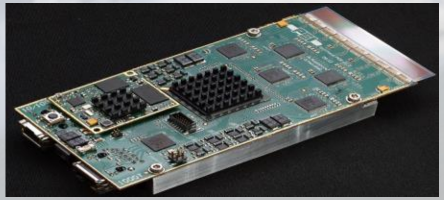
(prototyping)
75 µm × 75 µm
20 MHz/pixel count rate
20 kHz/module frame rate

Charge-integrating

Gotthard

Strip detector

50 µm pitch
Max size: single module



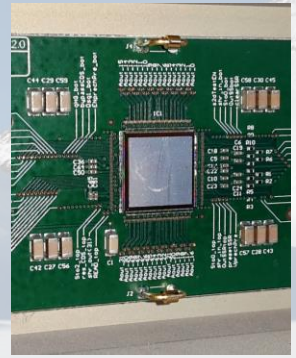
Noise: < 300 e^-
Dynamic range: 10^4 photons @ 12 keV per chan.
400 kHz (4.5 MHz burst) frame rate

Jungfrau

Pixel detector

75 µm × 75 µm
Max size: 16 M
Noise: < 35 e^-
10^4 ph @ 12 keV
2.2 kHz (250 kHz burst) frame rate

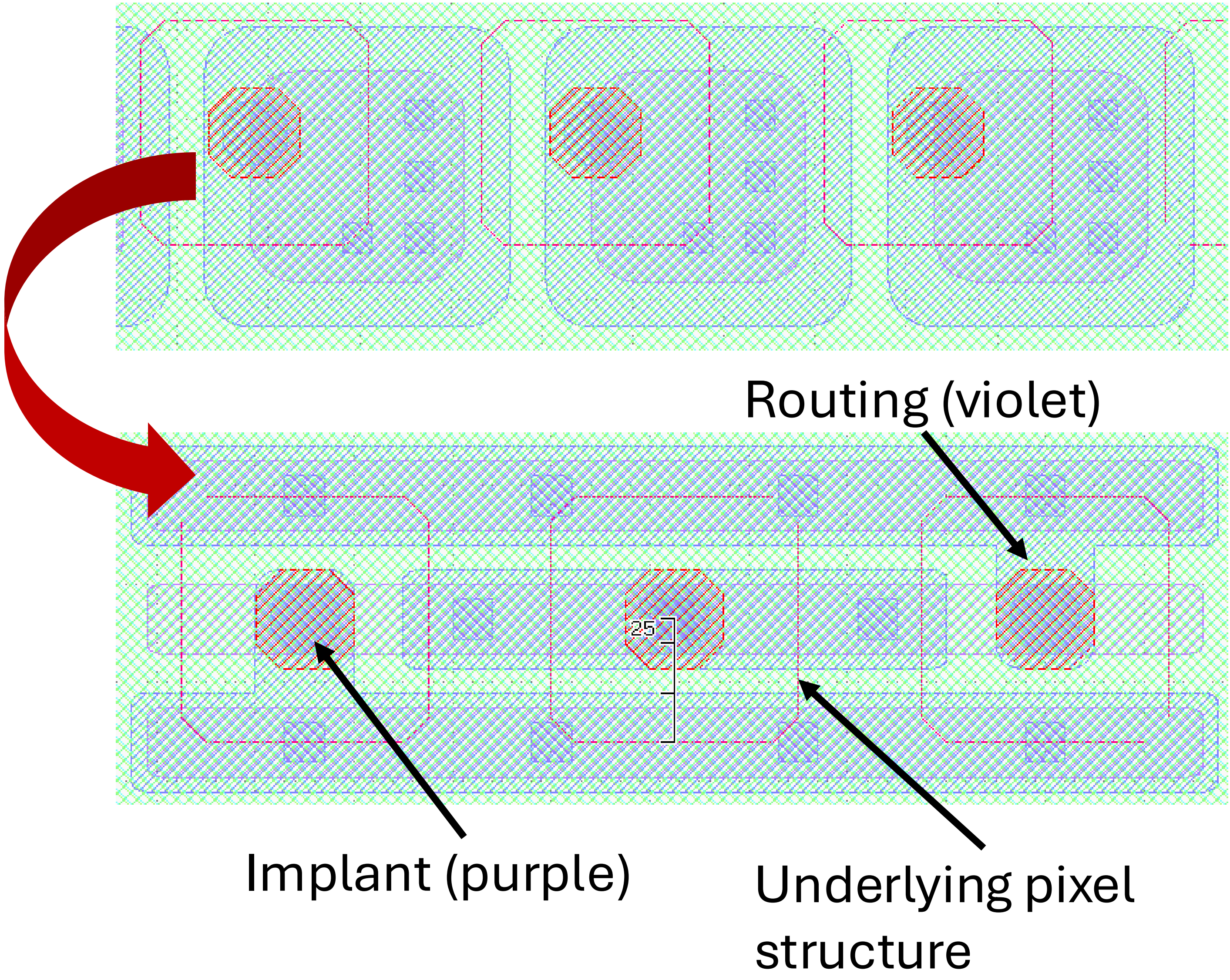
Mönch



Pixel detector

25 µm × 25 µm
Max size: single chip (2 × 3 cm^2)
Noise: < 20 e^-
500 ph @ 12 keV
6-8 kHz frame rate

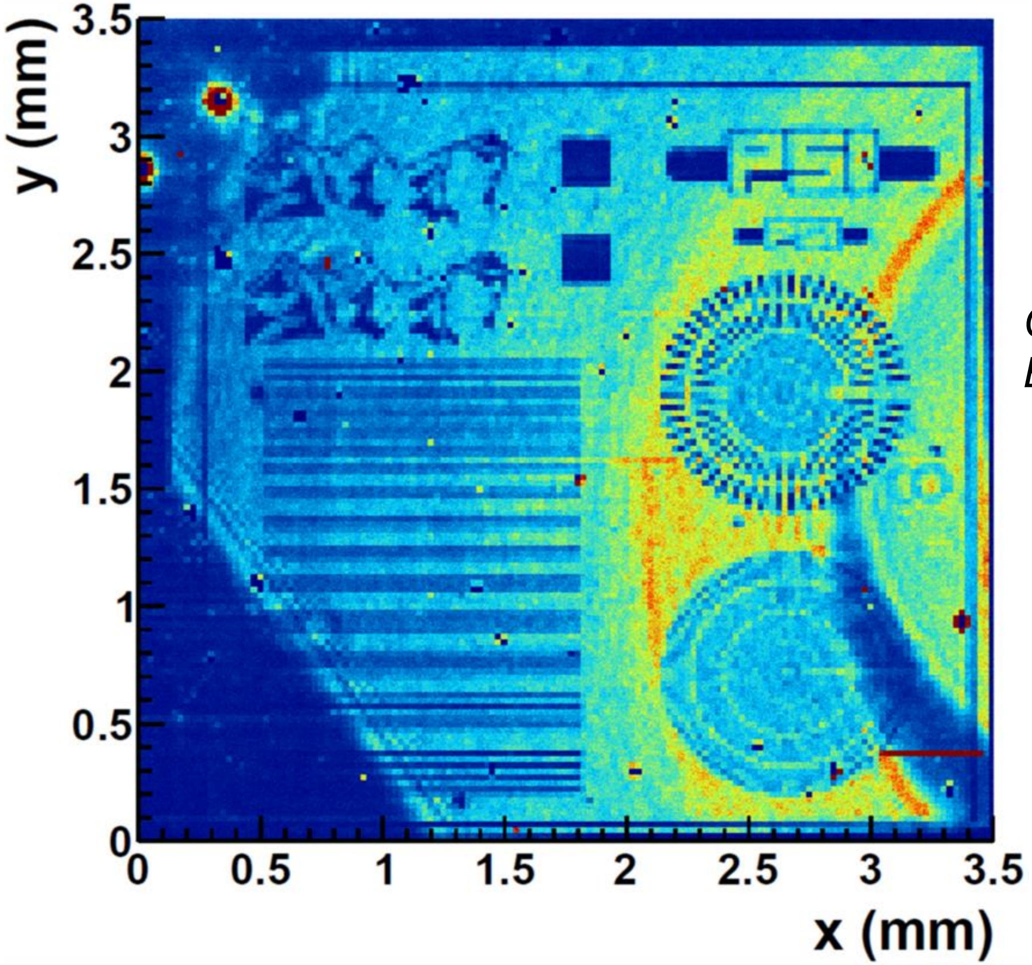
Strixel Design



- Instead of square pixels we work with rectangle pixels, called **strixels**
- 15-25 µm pitch along vertical direction
- Bump-Bonded to a JUNGFRAU ASIC (large area possible today)
- Use **inverse low gain avalanche diode** sensor (soft X-ray detection)

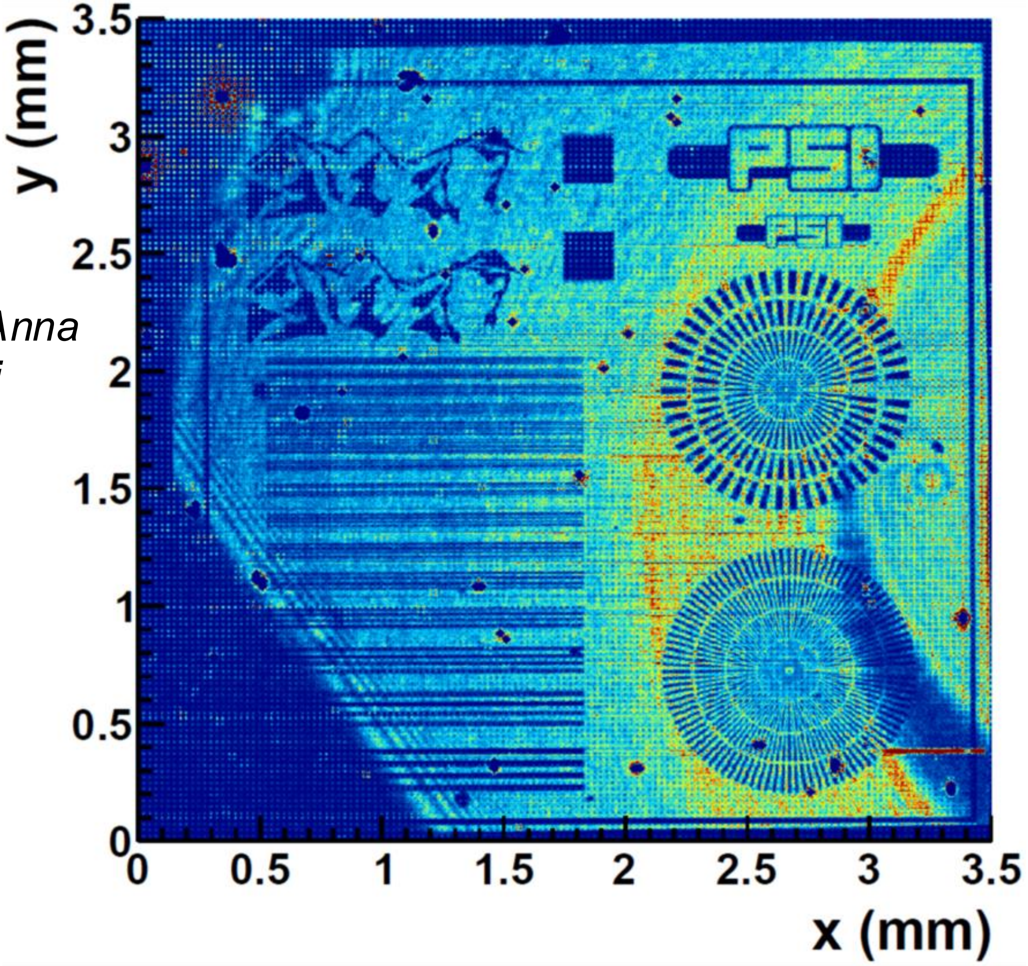
Interpolation

Raw Image



Courtesy of Anna Bergamaschi

Interpolated Image



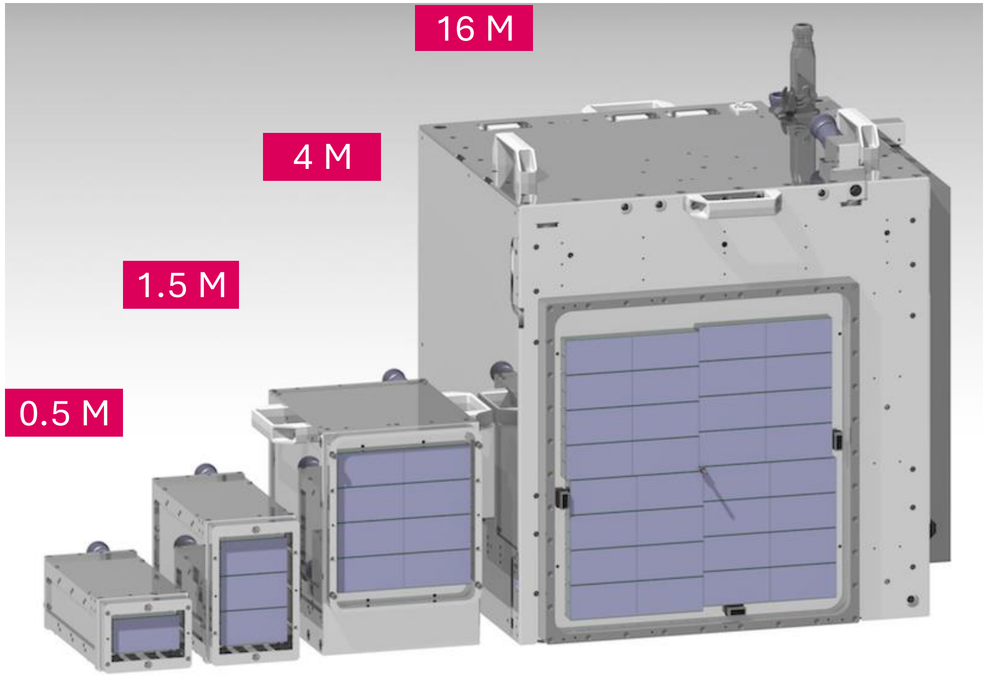
Möench Detector 25 µm pixel pitch, 500 eV. **Spatial Resolution (3-5µm)**

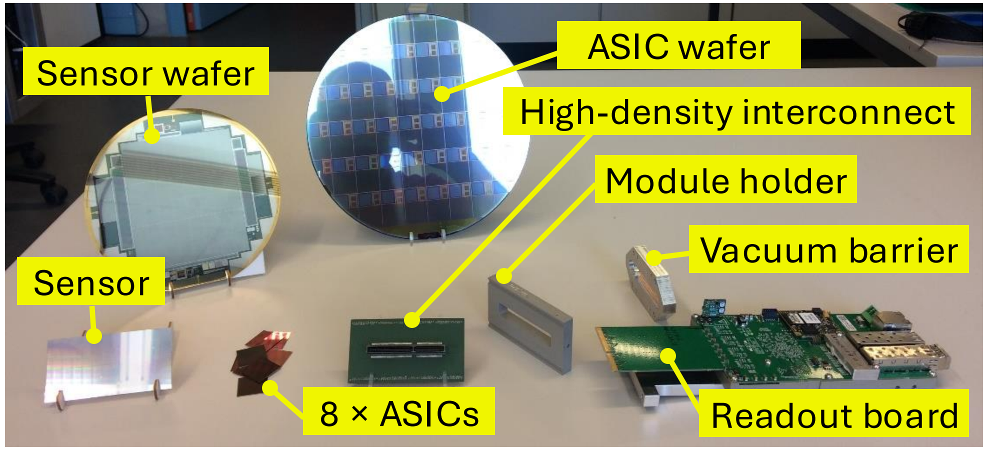
The Photon Science detector group

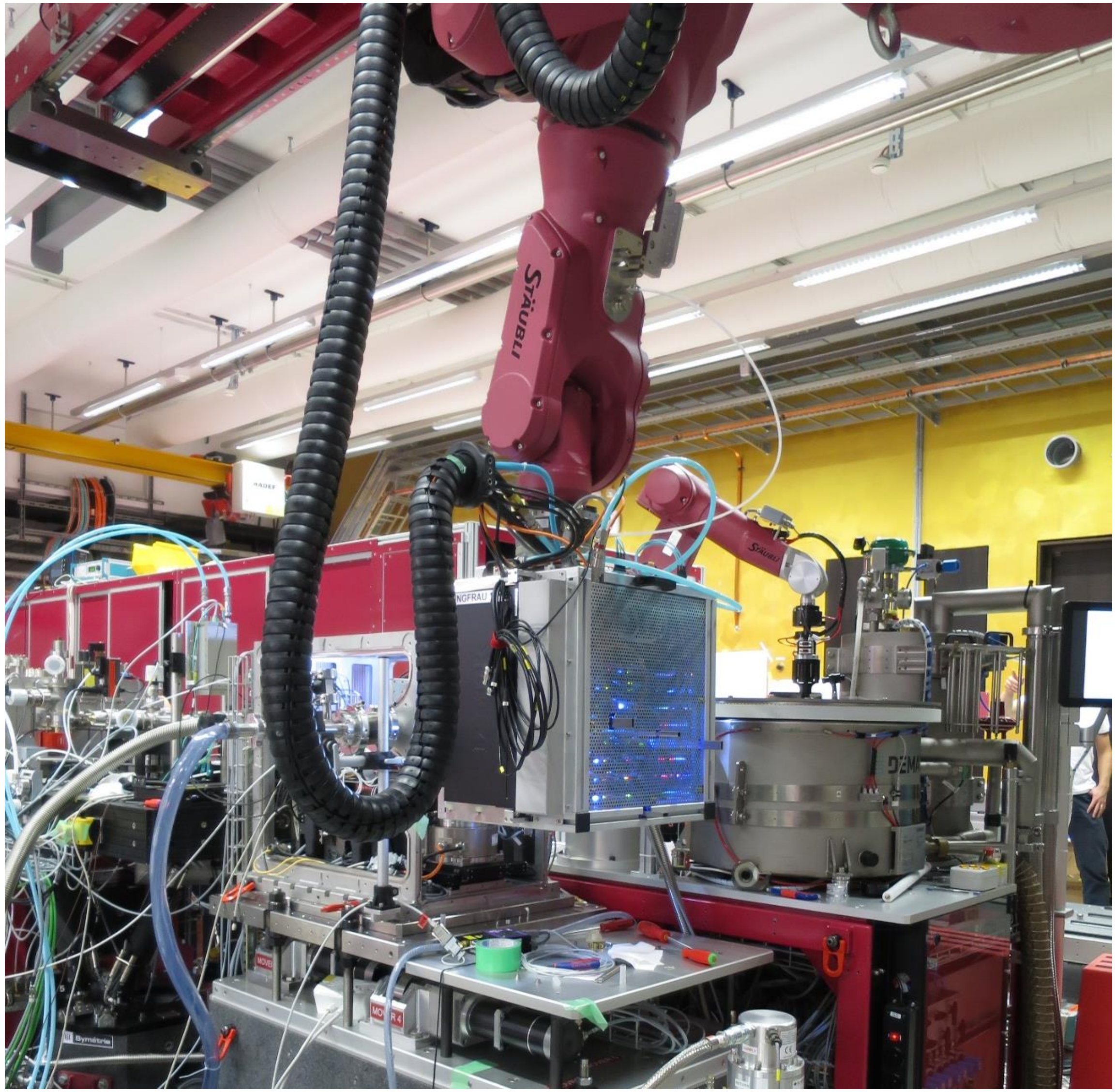
Anna Bergamaschi, Martin Brückner, Maria Carulla, Roberto Dinapoli, Simon Ebner, Simone Emiliani, Khalil Ferjaoui, Erik Fröjdh, Viveka Gautam, Dominic Greiffenberg, Shqipe Hasanaj, Viktoria Hinger, Marius Hürst, Vadym Kedych, Thomas King, Shuqi Li, Carlos Lopez-Cuenca, Leonid Lunin, Alice Mazzoleni, Davide Mezza, Konstantinos Moustakas, Aldo Mozzanica, Martin Müller, Jonathan F. Mulvey, Christian Ruder, Bernd Schmitt, Saverio Silletta, Dhanya Thattil, Xiangyu Xie, Jiaguo Zhang

Backup

Modular Systems for Large-Area Detectors



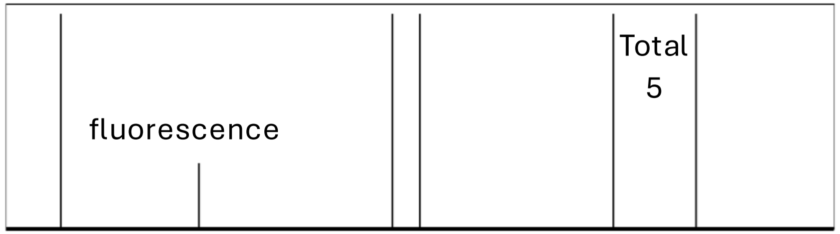


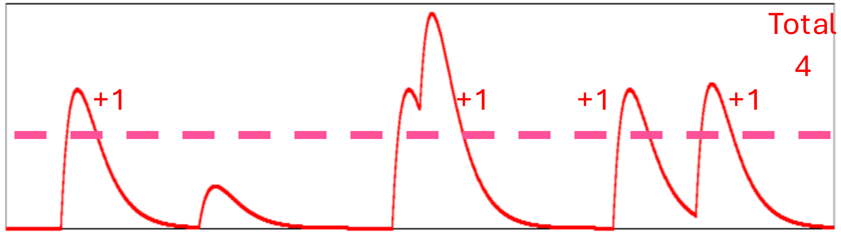


16 Mpixel JUNGFRAU at SwissFEL Bernina

State of the art

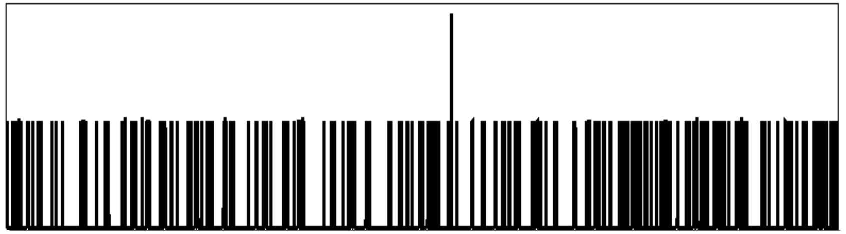
Photon counting

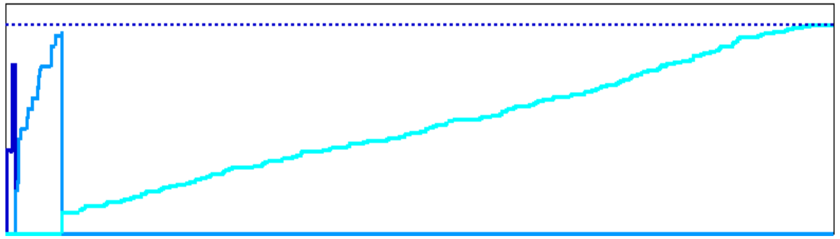




- ✓ Noiseless, very large dynamic range
- ✓ Stable operation, well established calibration
- ✓ Fluorescence suppression
- ✓ Frame rate scales with counter depth
- ✗ Pile-up ≳1MHz/pixel
- ✗ Soft X-ray detection prevented by noise

Charge integrating with adaptive gain

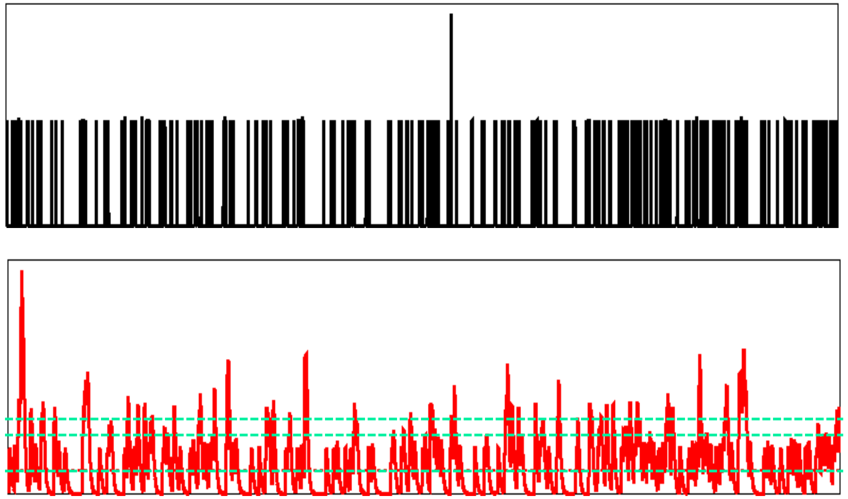




- ✓ **Single photon resolution for hard/tender X-rays**
  - ✓ Detection of multiple soft X-rays
- ✓ **Dynamic range up to 10^4 photons/pixel/s**
- ✗ Long integration times
- ✗ No fluorescence suppression
- ✗ **Challenging calibration and cumbersome data processing**

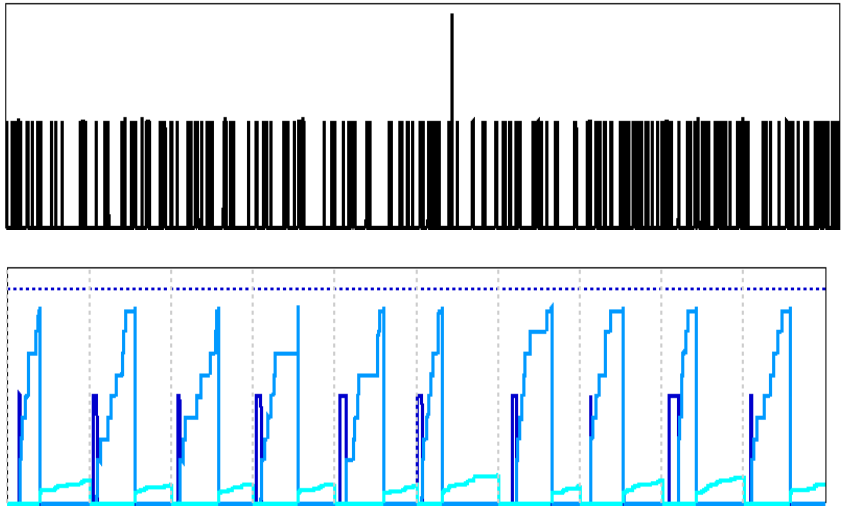
Upgraded light sources: many more photons!

Photon counting



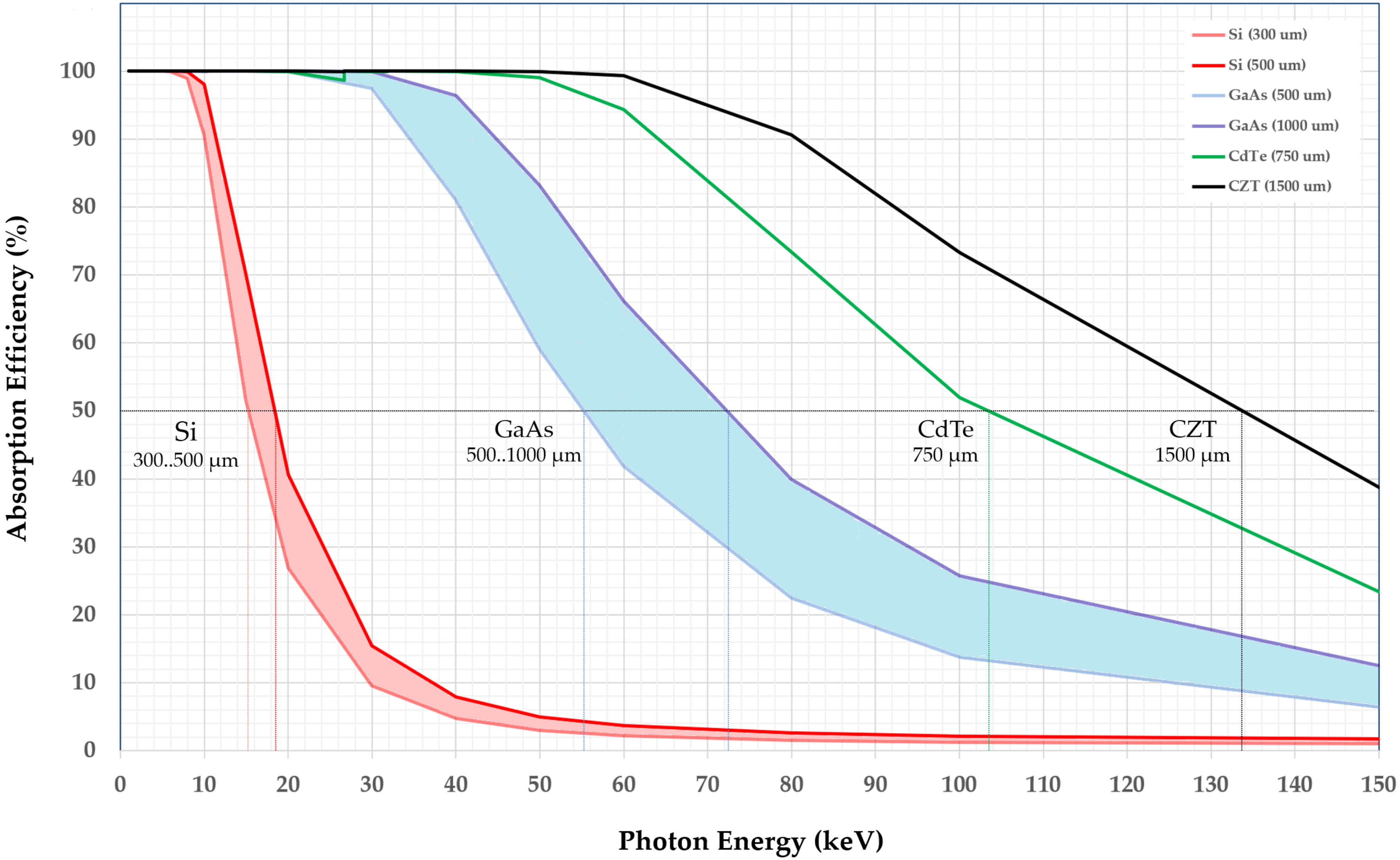
- ✓ Noiseless, very large dynamic range
- ✓ Stable operation, well established calibration
- ✓ Fluorescence suppression
- ✓ Frame rate scales with counter depth
- ✓ **Faster shaping, pile-up tracking**
- × Pile-up $\gtrsim$1MHz/pixel
- × Soft X-ray detection prevented by noise

Charge integrating with adaptive gain

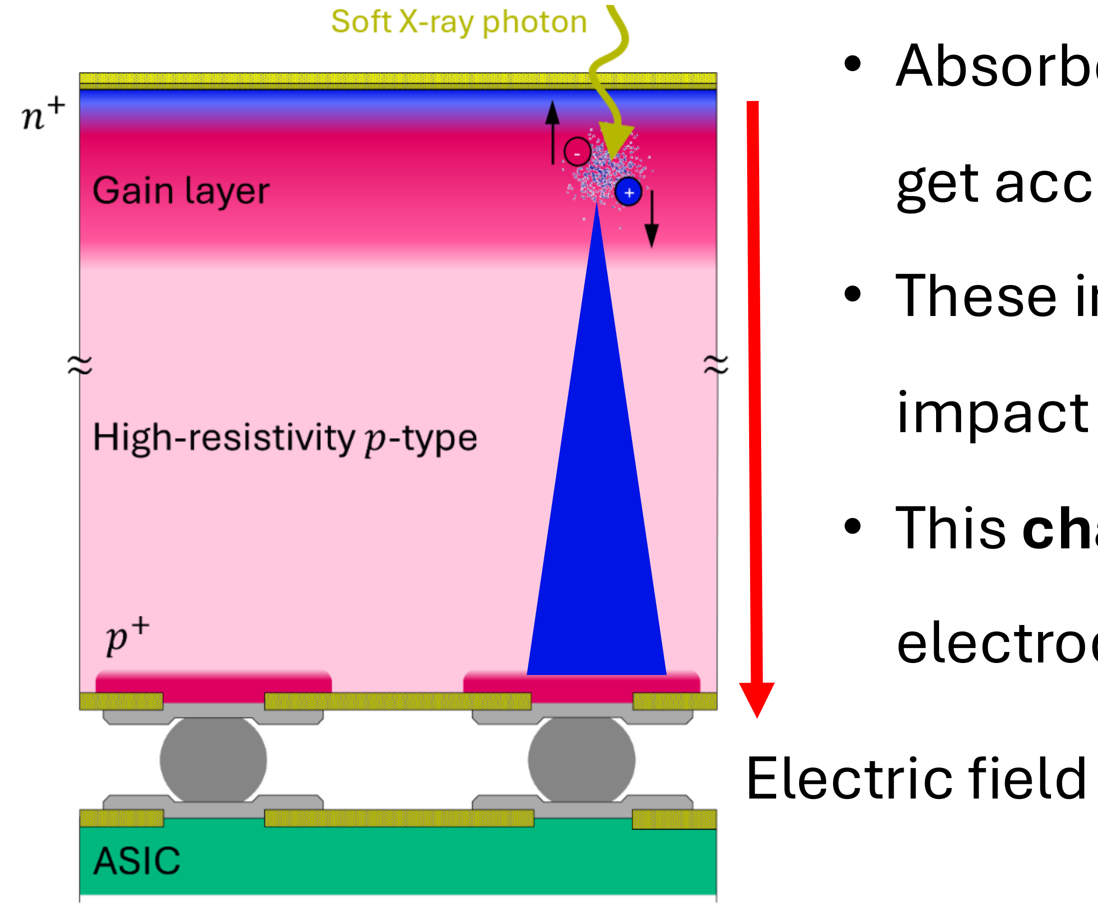


- ✓ Single photon resolution for hard/tender X-rays
  - ✓ Detection of multiple soft X-ray
- ✓ Works at pulsed sources
- ✓ Dynamic range up to ~10^4 photons/pixel/s
- ✓ **Supported flux scales with frame rate**
- × Long integration times
- × No fluorescence suppression
- × **Challenging calibration and cumbersome data processing needs high throughput!**

High-Z sensors for hard X-rays



Charge Collection



Courtesy of Viktoria Hinger

- Absorbed photon creates electron-hole pair, which get accelerated due to the electric field (bias voltage)
- These initial charges will create more charges due to impact ionization, eventually forming a charge cloud
- This **charge cloud** can reach multiple readout electrodes depending on absorption position

1 keV X-ray ~ 10 μm