PAUL SCHERRER INSTITUT

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WIR SCHAFFEN WISSEN - HEUTE FÜR MORGEN

JUNGFRAU: first full dynamic range calibration

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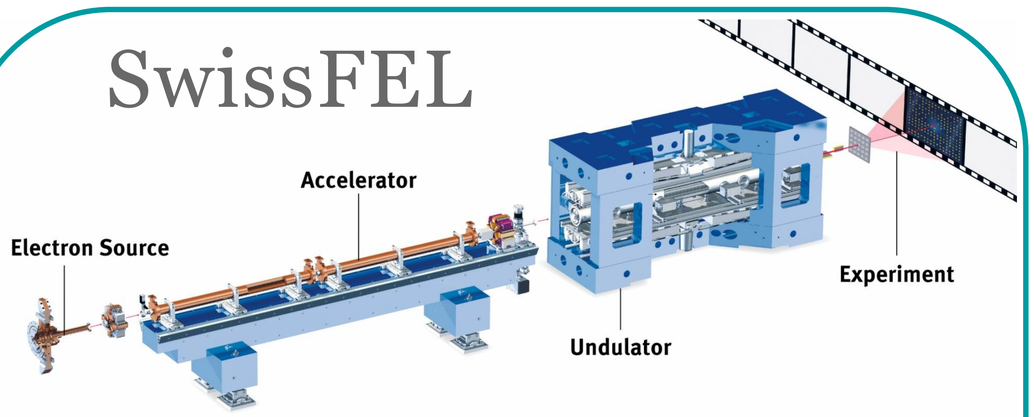
SwissFEL



(Illustration not to scale)

Free electron laser:

electrons + undulators → short pulses of intense, coherent X-ray light

Key numbers

- **Repetition rate:** 100 Hz
- **Electrons per pulse:** 2 x 1.24 x 10^9
- **Undulators:** 12 x 1060 alternating neodynium magnets
- **Photon energy:** 0.25 - 12 keV
- **Duration of light pulse:** 1 - 60 fs
- **Brilliance:** 1.3 x 10^{33} γ / (s x 0.1% b.w. x mm^2 x $mrad^2$)
- **Compared to the SLS:** 10^{10} times more brilliant

Science case: what could you study with a 10 fs image?

- Catalytic reactions
- Ultrafast magnetism
- Protein behaviour
- Correlated electrons

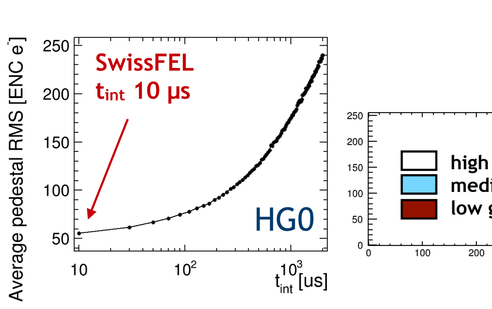
Detector challenge:
how to measure 10^4 photons all arriving within 10 fs?

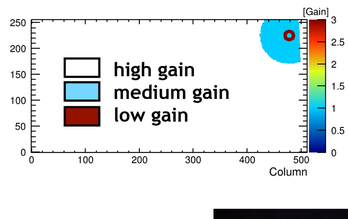
The JUNGFRAU detector

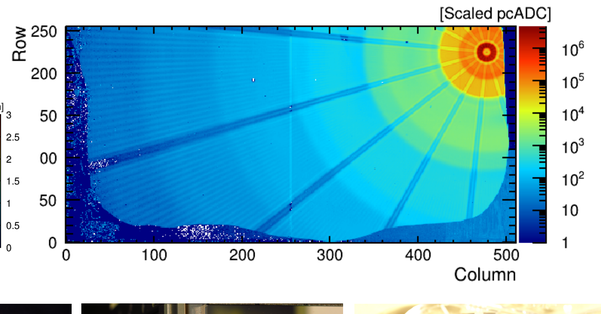
Sensitive from 1 - 10^4 photons per pixel per frame
no matter when the photons arrive

How is it possible?

- **charge integrating:** collect charge throughout the integration window
- **low noise:** ensures single photon sensitivity
- **high dynamic range:** three dynamically switching gain stages per pixel

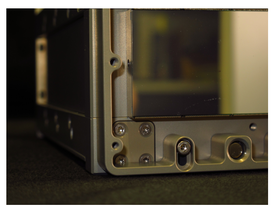


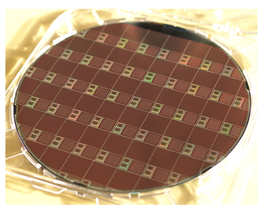




JUNGFRAU chip:

- 256 x 256 pixels of 75 µm x 75 µm
- dead time free readout up to 2.4 kHz
- 16 bits per pixel: 2 gain + 14 ADC





JUNGFRAU module:

- 320 µm thick silicon sensor
- bump-bonded to 2 x 4 chips
- sensing area ~ 4 cm x 8 cm
- 0.5 Mpixels

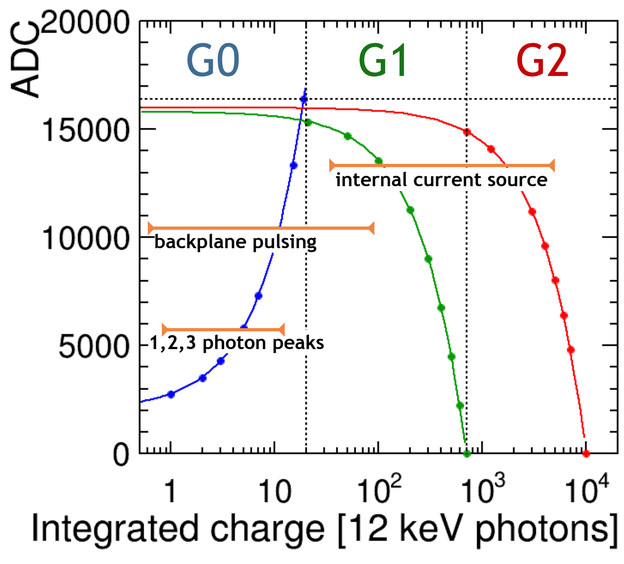
But how to convert from ADC to number of photons?

Detector calibration

Parametrise the energy-response of the detector using a variety of input charge sources

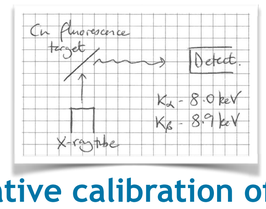
Challenges:

- **1 - 10^4**
  input charge range
- **0.5 million**
  pixels per module
- **3**
  gains per pixel
- Non-linearities
- Switching points
- Double size pixels



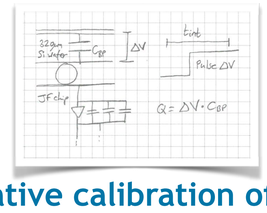
Absolute calibration of G0:

- Fluorescence photons



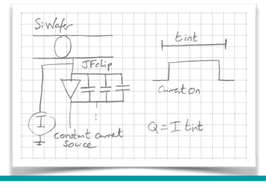
Relative calibration of G1/G0:

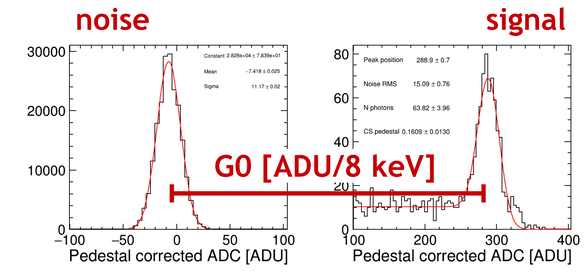
- Backplane pulsing

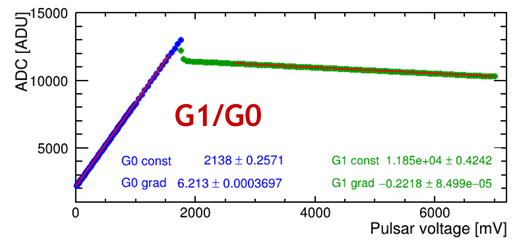


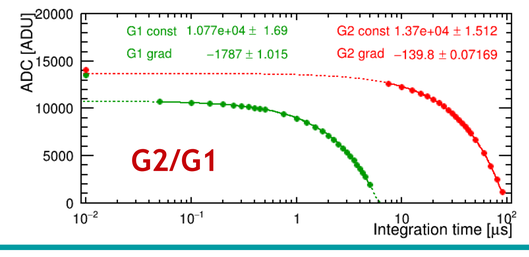
Relative calibration of G2/G1:

- Internal current source









3 gains:

G0:
40 ADU / keV

G1:
-1.4 ADU / keV

G2:
-0.1 ADU / keV

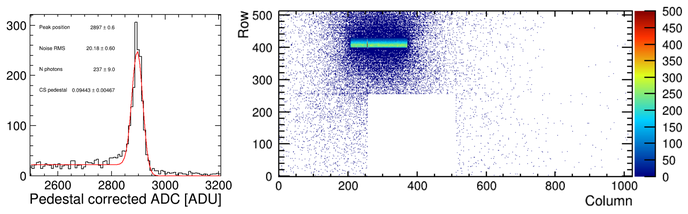
depending on pixel charge

Calibration validation

Testing the lab-based calibration with data recorded at ESRF BM05

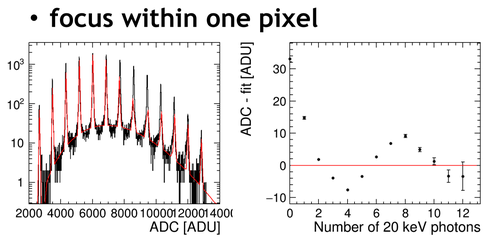
Direct diffuse beam:

- at 70 keV, 85 keV



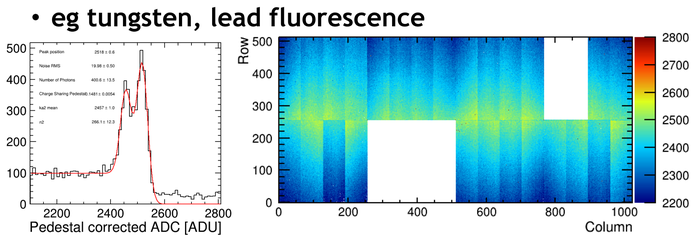
Direct focused beam:

- focus within one pixel



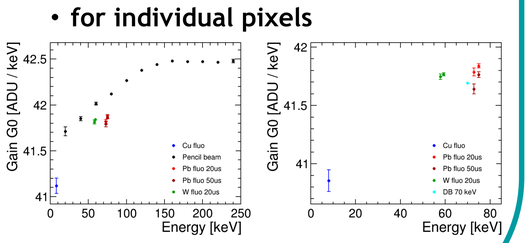
High energy fluorescence:

- eg tungsten, lead fluorescence

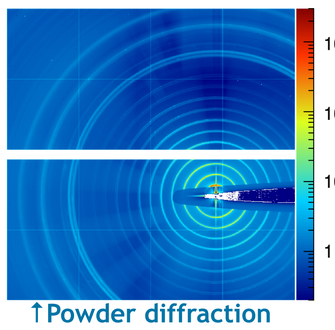


Comparison of all methods:

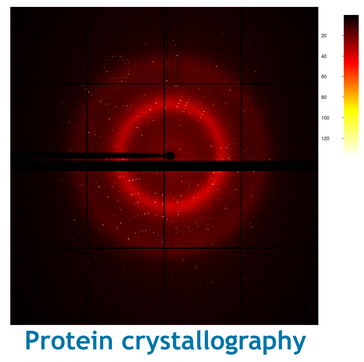
- for individual pixels



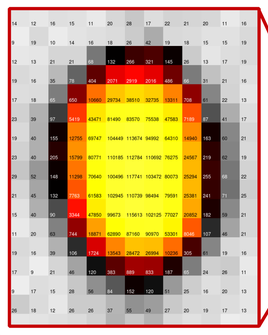
Calibrated images

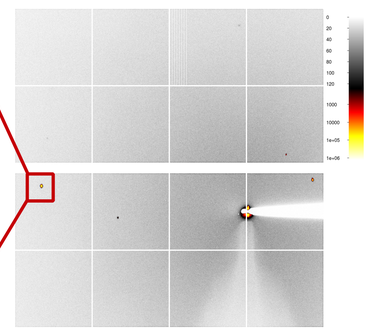


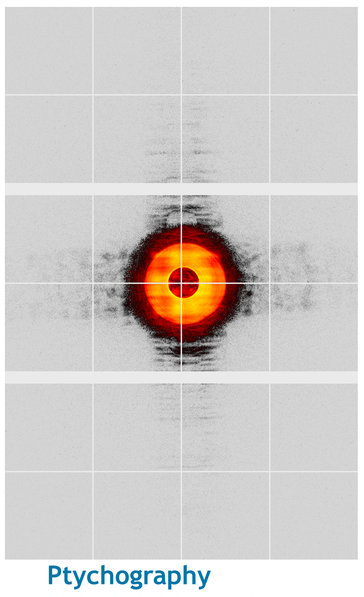
↑Powder diffraction
↓crystal diffraction
LCLS XCS beamline



Protein crystallography
SLS PX beamline







Ptychography
SLS cSAXS beamline

1.A. Mozzanica et al., Characterization results of the JUNGFRAU full scale readout ASIC, JINST, vol. 11, C02047.
2.S. Redford et al., Calibration status and plans for the charge integrating JUNGFRAU pixel detector for SwissFEL, JINST, vol. 11, C11013.
3.D. Mezza et al, New calibration circuitry and concept for AGIPD, JINST, vol. 11, C11019.