Development of the DSSC Single Module (DSSCsm) Detector for EuXFEL High-Rate Soft X-ray Applications

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Introduction

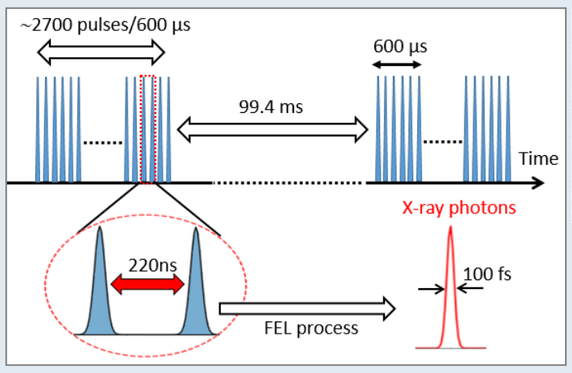
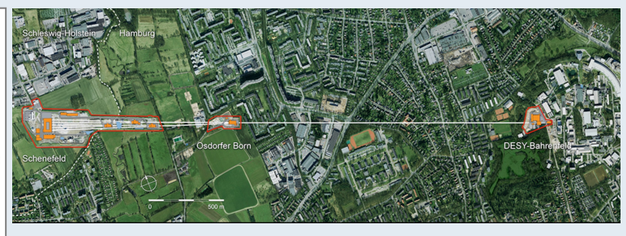


Fig 1. EuXFEL bunch structure (left) illustrates one of X-ray timing scenario.



The EuXFEL specs:

Burst mode operation:	10 Hz
Flashes per second:	27000
Wavelength:	0.05 - 4.7 nm
Duration:	< 100 fs
Peak brilliance:	$5 \cdot 10^{33*}$

(* photons/s/mm²/mrad²/0.1% bandwidth)

The European XFEL is an X-ray Free Electron Laser source. Up to 2700 extremely brilliant X-ray pulses are delivered in a single bunch train at 4.5 MHz, repeated every 100 ms [1]. This unique bunch scheme poses significant design challenges, demanding high-performance imaging detectors to fully exploit the facility's capabilities.

The DSSC Detector

The DEPFET Sensor with Signal Compression (DSSC) is a 1-Mpixel camera operating at up to 4.5-MHz frame rate, developed for photon science in the 0.25-6 keV range at the European XFEL. Each of its 16 modules carries 128 × 512 hexagonal pixels – equipped with either miniSDD or DEPFET sensors and provides in-pixel signal shaping, digitization, and storage in 800-cell-deep SRAM [2].

The DEPFET device is a field effect transistor with an additional internal gate beneath the external gate. To enhance charge collection, it is encircled by several drift rings. Figure 2 shows a schematic drawing, 3D model of a DEPFET pixel sensor and of the signal compression principle of a DSSC pixel. A deep n-doping beneath the external gate creates a potential minimum for electrons, attracting negative charge carriers. This altered potential draws positive charge carriers below the external gate, forming a conducting channel. Thus, the deep n-doping acts as an internal gate. The clear contact removes trapped charge carriers from this internal gate.

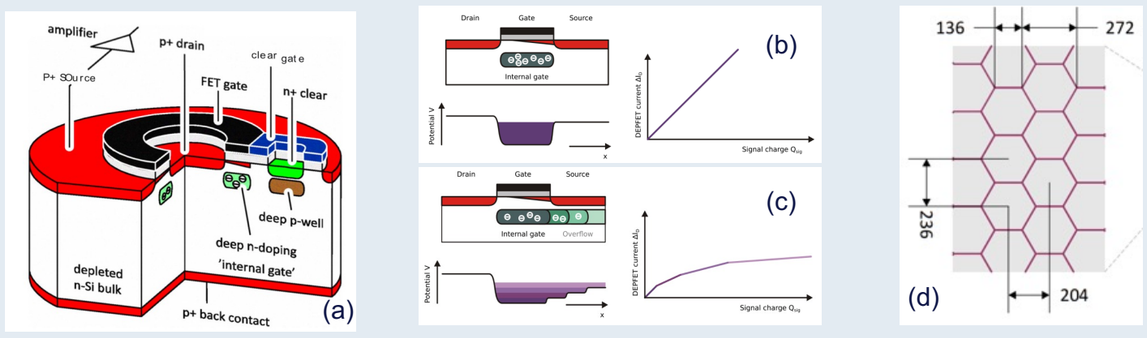
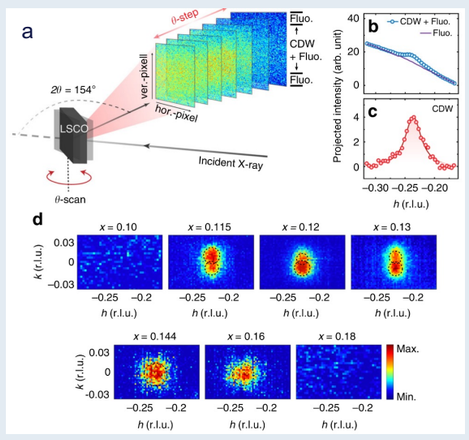


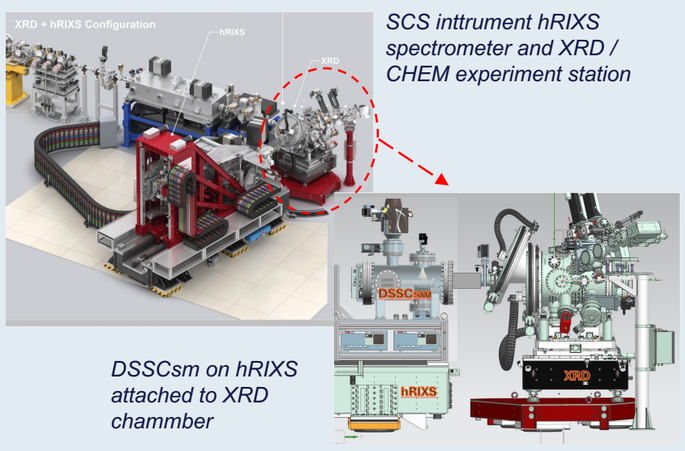
Fig 2. (a) – 3D illustration of a DEPFET pixel. The deep n-doping is a potential minimum for signal electrons. The second n-doped area, the clear contact, is shielded from the bulk by an additional p doping. (b) – DEPFET linear response. (c) – DEPFET with signal compression feature. (d) – Depicts DSSC pixel shape and sizes.

The DEPFET-based camera offers an order-of-magnitude larger dynamic range and lower noise (ENC < 10 e^- rms) than any comparable detector operating at MHz frame rates, opening new opportunities in X-ray imaging.

DSSC Single Module (DSSCsm) Detector

The DSSCsm is a compact, single-module standalone DSSC detector system developed as a flexible platform. This implementation prioritizes portability and simplified integration without sacrificing key detector performance. Ultimately, the deployment of the DSSCsm enables and enhances a diverse range of photon science applications:





SCS inttrument hRIXS spectrometer and XRD / CHEM experiment station

DSSCsm on hRIXS attached to XRD chammber

Fig 2. RSXS measurements on LSCO [3] a) Schematic of the RSXS setup; the top and bottom regions of each CCD image are taken as the fluorescence background. b) Intensity profiles projected along the h-direction at the CDW (k ≈ 0 r.l.u.) and fluorescence (k ≈ ±0.04 r.l.u.) regions. c) CDW profile after fluorescence-background subtraction. Data in (b, c) are from the x = 0.13 sample at 23 K. d) Background-subtracted scattering patterns for various LSCO samples, each measured at its respective T_C; dashed circles outline the intensity contour.

Optimizing Transient X-ray Absorption Spectroscopy (tr-XAS)

- Validated Established tr-XAS setup at SCS uses a standard single DSSC ladder with a beam-splitting off-axis zone plate (BOZ), to date run with the full MiniSDD camera reading a single sensor.

Advancing Time-Resolved Resonant Soft X-Ray Scattering (tr-RSXS)

- Probing Complex Spatial Modulations: Resonant Elastic X-ray Scattering (REXS/RSXS) uniquely pairs the electronic structure sensitivity of X-ray absorption with the spatial modulation sensitivity of diffraction.
- Overcoming Long-Wavelength Limitations: Soft X-rays excel at probing multi-unit-cell long-range order, making them ideal for mapping complex magnetic phenomena (e.g., spin spirals, skyrmions) and charge density waves in high-T_C cuprates.
- Picosecond Dynamics: Time-resolved RSXS allows researchers to shift from the energy domain to the time domain, mapping sub-meV low-energy CDW excitations on the picosecond timescale.

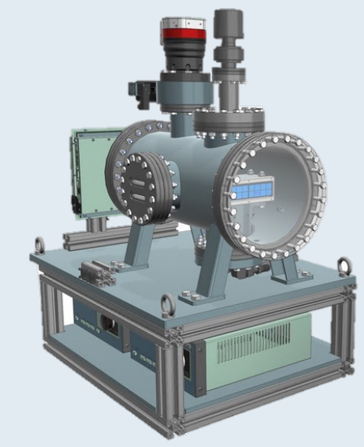


Fig 4. DSSCsm camera 3D model

DSSCsm Detector Key Parameters:

Energy Range:	0.25 keV ≤ E ≤ 6 keV
Pixel number:	128 x 512
Active area:	120 x 30 mm²
Sensor Pixel Shape:	Hexagonal
Sensor Pixel Pitch:	≈ 204 × 236 µm²
Dynamic range (pix):	> 10^4 photons for E ≥ 1keV
Resolution:	Single photon detection @ 0.5 keV
ENC:	<10e (RMS)
Frame rate:	1.1 – 4.5 MHz
Stored frames per pulse train:	800
Mean power consumption:	≈ 18 W in vacuum
Operating temperature:	15°C (-20°C miniSDD)
Average data rate:	1050 MB/s

Full R&D Cycle for Mechanics and Cooling

- Concept and 3D CAD design through to 2D production drawings
- Mechanical and thermal FEA plus CFD studies of the cooling configuration
- Bench testing of all subsystems
- Solid-state cooling modes optimised; mechanical refinements derived from real operation

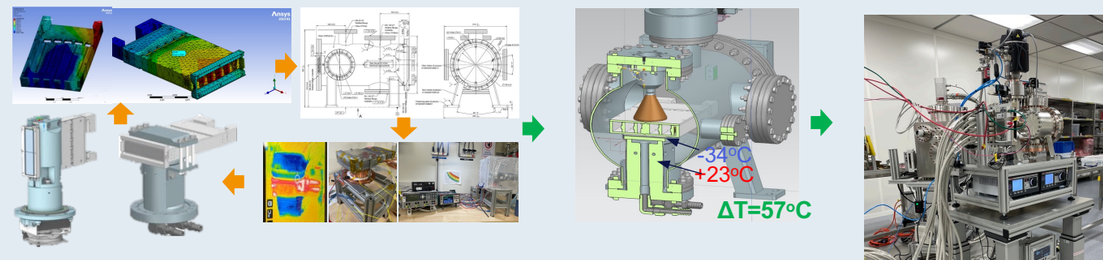


Fig 4. DSSCsm cooling and mechanics R&D cycle and the final system

Final Qualification — All Technical Parameters Met

- Validated with a real detector under realistic thermal load (18W) in vacuum
- FPM thermal stabilisation at **−19.25 °C**, regulation envelope **±0.01 °C**
- Vacuum quality 1 × 10^{-7} mbar in fully equipped configuration

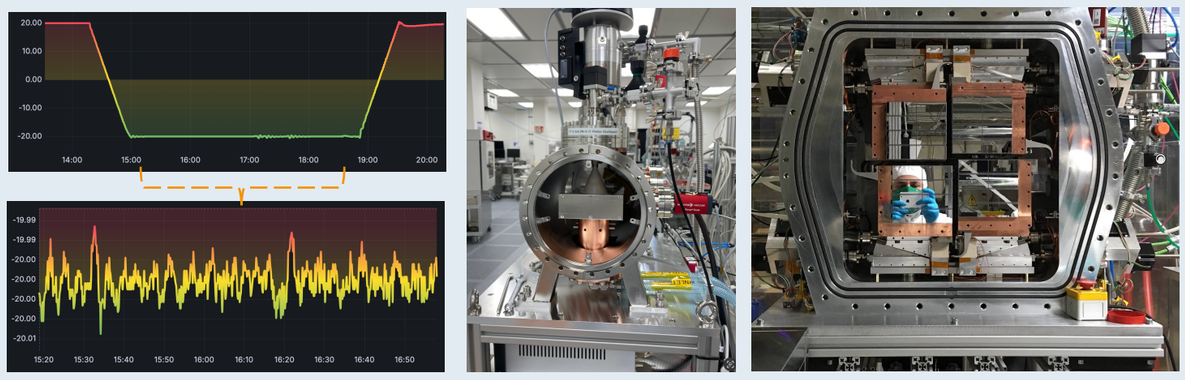
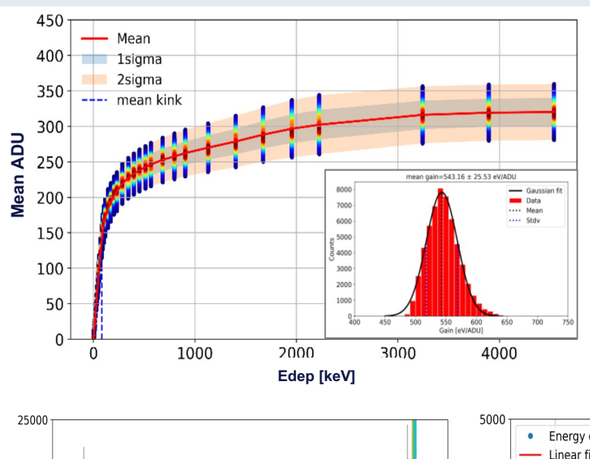
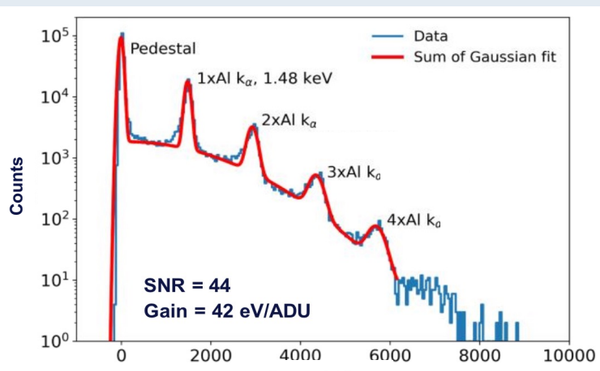
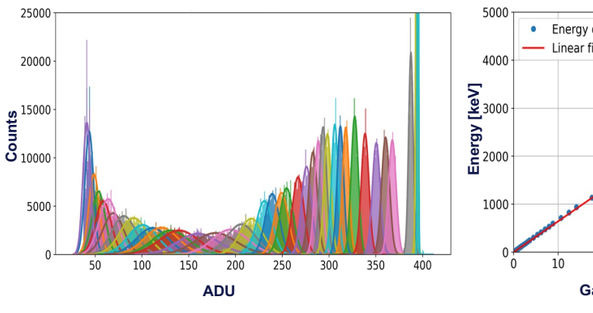


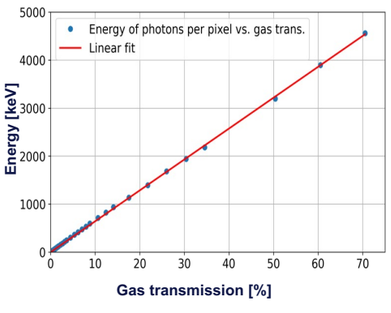
Fig 5. Final DSSCsm detector system (middle), its cooling performance (left), and comparison to the 1-Mpixel DSSC detector (right). **The DSSCsm detector is fully integrated into the EuXFEL infrastructure, with user beamtimes scheduled for autumn 2026**

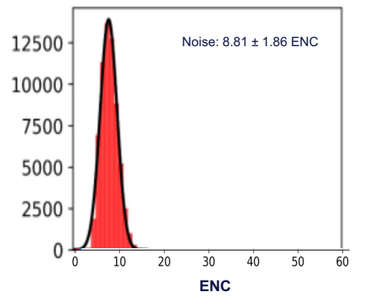
Calibration and Characterization on DEPFET DSSCsm











The DSSCsm detector NLR calibration, using Al fluorescence photons from FEL at varying intensities, was validated at SQS with a single DEPET DSSC module, demonstrating excellent noise performance and single photon detection capability: **ENC: ~9e (RMS)** **SNR: 44**

Reference

1. M. Porro et al. (2021) IEEE Transactions on Nuclear Science, vol. 68, no. 6, pp. 1334-1350
2. Maffessanti, S. et al. Sci Rep 13, 11799 (2023). https://doi.org/10.1038/s41598-023-38508-9
3. J.-J. Wen, H. Huang, S.-J. Lee, et al Nature Communications 10 (2019) doi:10.1038/s41467-019-11167-z

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