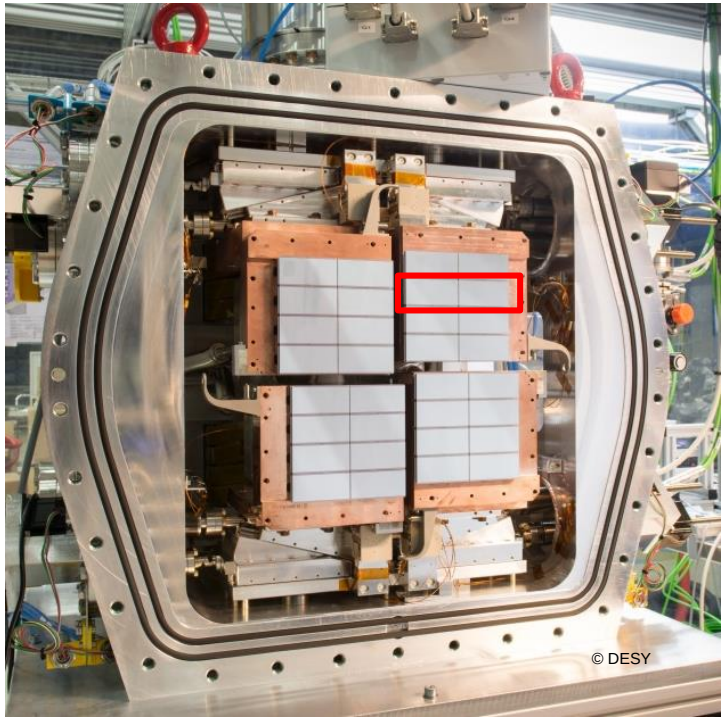
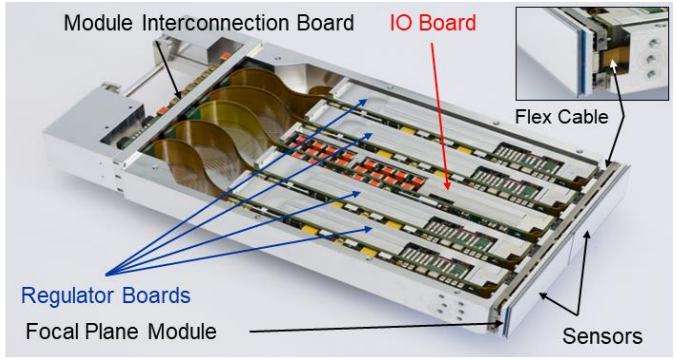
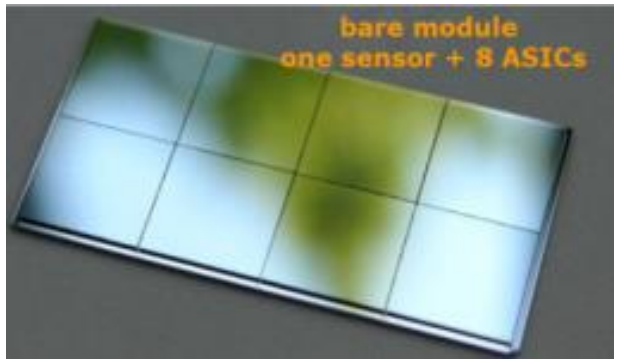
The DSSC soft X-ray camera with Mega-frame readout capability for the European XFEL

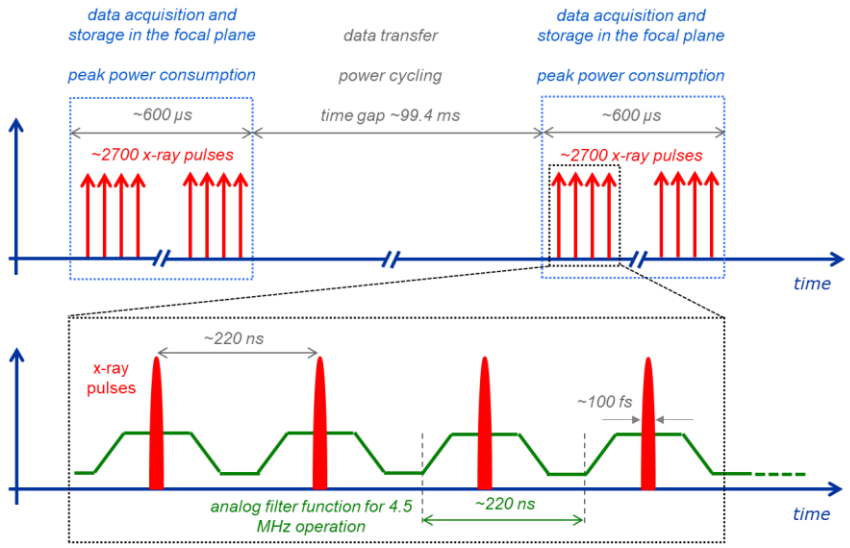
M. Porro
on the behalf of the DSSC Collaboration
(XFEL.EU, DESY, University of Heidelberg, Politecnico di Milano, University of Bergamo, PNSensor, MPG-HLL)



- DSSC is one of the three large Detectors for the XFEL.EU (LPD, AGIPD)
- Target Energy Range: **0.25 – 6 keV**
- First DSSC installed at the Spectroscopy and Coherent Scattering (SCS) Instrument at XFEL.EU in May 2019
- Megapixel camera **4.5 MHz peak frame rate (burst mode)**
  - Active area ~ 505 cm2
  - 4 quadrants (512 x 512)
  - **16 ladders (512 x 128)**
  - 32 monolithic sensors 128x256
  - 256 Readout ASICs 64 x64 – Globalfoundries CMOS 130nm







Parameter		Value
Target energy range		0.25 keV – 6 keV
Pixel count		1024 × 1024
Pixel shape		hexagonal
Sensor pixel pitch		~204 µm × 236 µm
Active area		~ 505 cm^2
Input photon range / pixel / pulse (*)	MiniSDD	2^n × N -1
	DEPFET	*$>10^4$*
Achievable noise	MiniSDD	~ 60 e- r.m.s.
	DEPFET	*~30 e- r.m.s.*
Peak frame rate		4.5 MHz
Stored frames per X-ray train		800
Average / peak data rate		134/ 144 Gbit / s
Average power consumption		~ 260 W
Operating temperature		-20º C optimum, room T possible

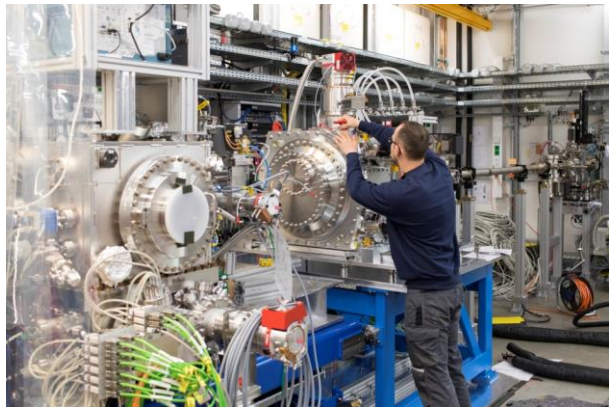
- Si-Sensors:
  - **MiniSDD arrays 1st camera (produced by MPG-HLL)**
  - DEPFET arrays 2nd camera (managed by PNSensor)
- Readout concept
  - **Full parallel readout**
  - **Each ASIC readout channel provides:**
    - **Optimum analog filter (trapezoidal Weighting function)**
    - **One Wilkinson type ADC (8 bit @ 4.5 MHz, 9 bit @ f≤2.2 MHz)**
    - **SRAM (800 frames)** with the possibility to overwrite non-valid frames (VETO)
    - Pixel-wise gain and offset trimming
  - Output average **data rate for 1-Megapixel: 134.4 Gbit/s**
- **Power cycling**
  - The camera is fully powered only during the arrival of the X-ray pulses
  - total Power Dissipation 263 W (250 µW per Pixel)
  - Coolant Load in Vacuum 149 W (142 µW per Pixel)

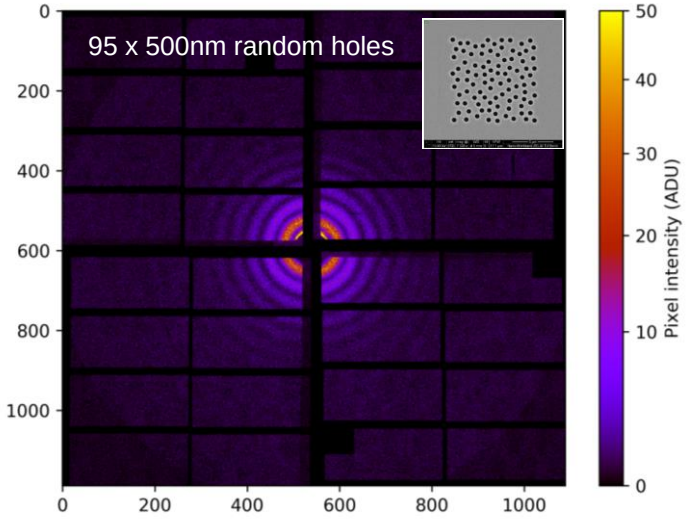
Porro, M. et al. " The MiniSDD-based 1-Megapixel Camera of the DSSC Project for the European XFEL", submitted to IEEE Transactions on Nuclear Science, Feb. 2021.

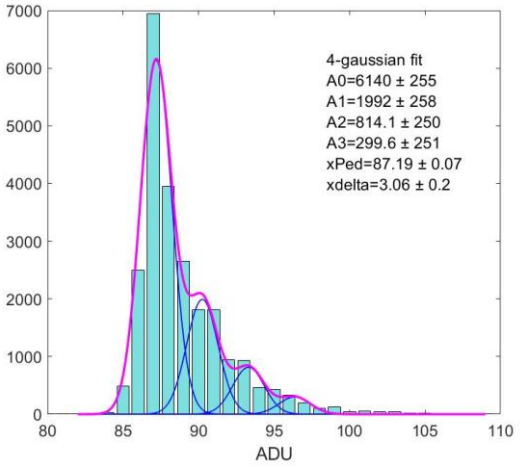
K. Hansen et al., "Qualification and Integration Aspects of the DSSC Mega-Pixel X-Ray Imager," in IEEE Transactions on Nuclear Science, vol. 66, no. 8, pp. 1966-1975, Aug. 2019. doi: 10.1109/TNS.2019.2927421

M. Porro et al., "Development of the DEPFET Sensor With Signal Compression: A Large Format X-Ray Imager With Mega-Frame Readout Capability for the European XFEL," in IEEE Transactions on Nuclear Science, vol. 59, no. 6, pp. 3339-3351, Dec. 2012. doi: 10.1109/TNS.2012.2217755

In May 2019, the MiniSDD-DSSC has been installed and commissioned at the Spectroscopy and Coherent Scattering (SCS) Instrument



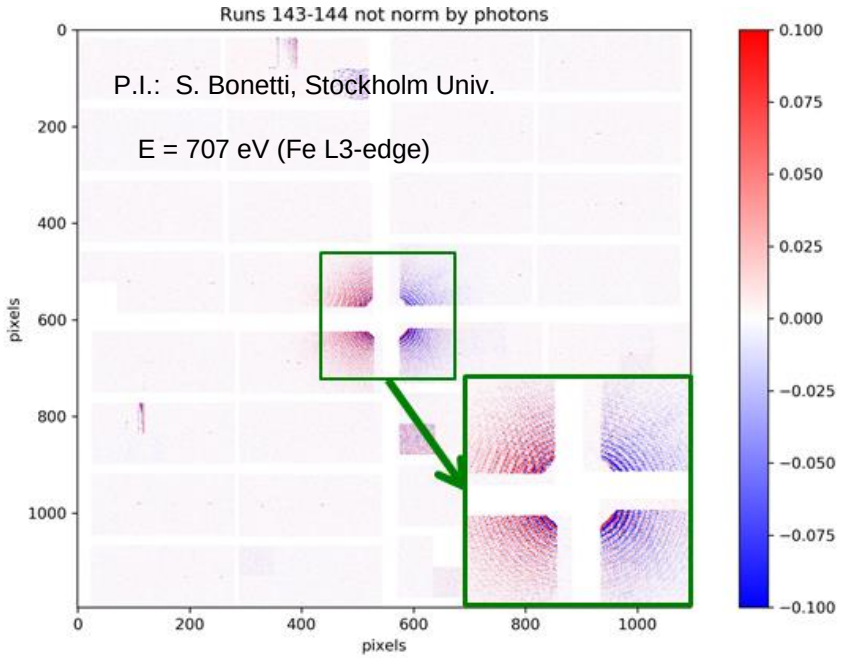




Spectrum of one pixel - 24000 frames

- low photon multiplicity on DSSC, acquisitions done at high gain 3 bin/ph (i.e. 0.236 keV/ADU)
- 4-gaussian fit with free amplitudes (all sigma's fixed at Pedestal sigma)
- delta between centroids 3.11± 0.25 ADU, compatible with calibration (3 ADU)
- amplitudes nicely follow Poisson (λ=0.38)

- 1-Megapixel single-shot diffraction image of pinholes with **707 eV photons**
- DSSC readout **speed 4.5 MHz**
- Measured average **noise ~ 60 el. rms**
- First users' experiment May 28, 2019
  - X-ray holography of ultrafast magnetism: femtosecond movies at the nanoscale
  - P.I. S. Bonetti, Stockholm University, Sweden
  - More than 400 TB of data successfully taken



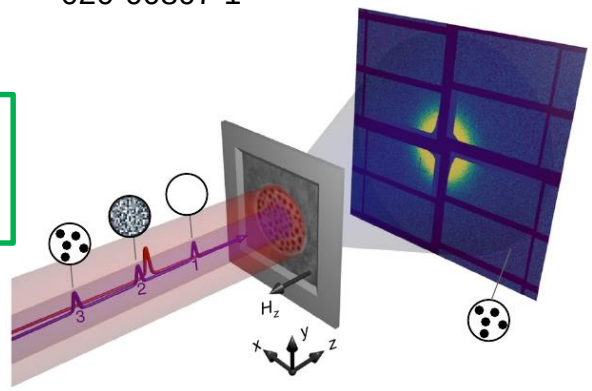
So far 11 user experiments have been successfully performed at SCS. Among them:

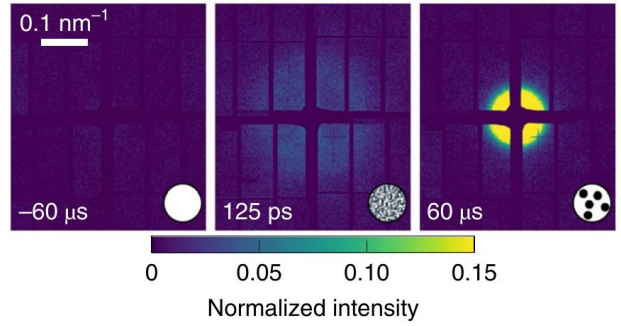
- **X-ray holography of ultrafast magnetism: femtosecond movies at the nanoscale**, S. Bonetti, Stockholm University, Sweden, **E = 707 eV (Fe L3-edge)**
- **Single shot time-resolved imaging of ultrafast thermal skyrmion, nucleation and annihilation in a ferromagnet**, F. Büttner / G. Beach, Massachusetts Institute of Technology, United States, **E = 778 eV (Co L3-edge)**
- **Time resolved magnetic Small Angle X-ray Scattering to follow the multi-pulse helicity dependent switching in CoTb thin films**, E. Jal, Sorbonne Univ., France, **E = 778 eV (Co L3-edge), 853 eV (Ni L-edge)**
- **Ultrafast element selective electronic structure dynamics in photo-excited phase change material,** L. Le Guyader, XFEL.EU**, E = 1219 eV (Ge L3)**
- **State-resolved electron and spin dynamics in laser-driven first-order phase transition FeRh,** A. Scherz, R. Carley, XFEL.EU, **E = 707 eV, (Fe L3-edge) E = 3004 eV (Rh L3-edge)**
- **Microscopic insight into ultrafast electronic and lattice excitations in a correlated oxide,** PI: Andrea Eschenlohr, University of Duisburg, **E=853 eV (Ni L-edge)**

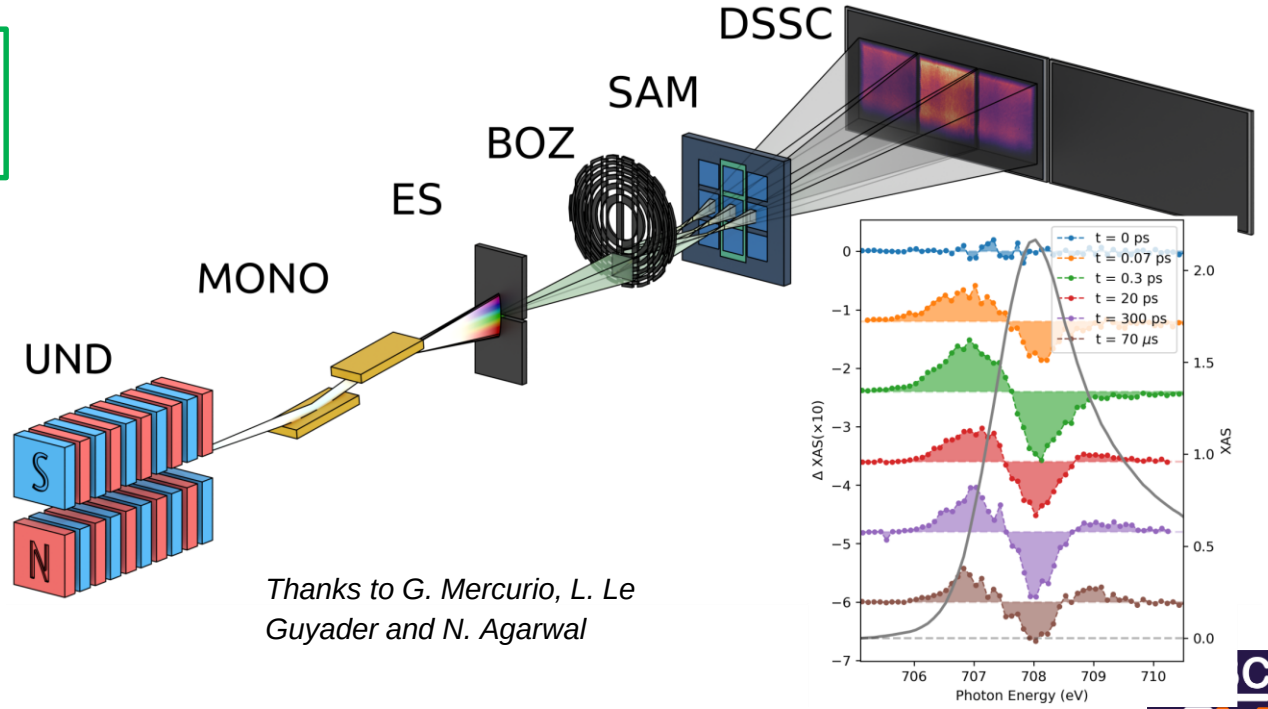
Very positive feedback by the users on DSSC data quality and calibration: "This is synchrotron-like XAS quality but providing femtosecond time resolution"

In 2021 the DSSC camera will be used also at the Small Quantum System (SQS) instrument

Büttner, F., et al., *Observation of fluctuation-mediated picosecond nucleation of a topological phase*. Nat. Mater. 20, 30–37 (2021). https://doi.org/10.1038/s41563-020-00807-1







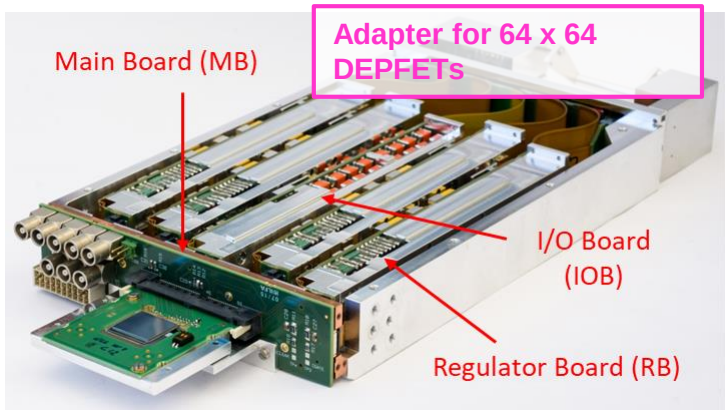
Thanks to G. Mercurio, L. Le Guyader and N. Agarwal

DEPFET-based DSSC Camera

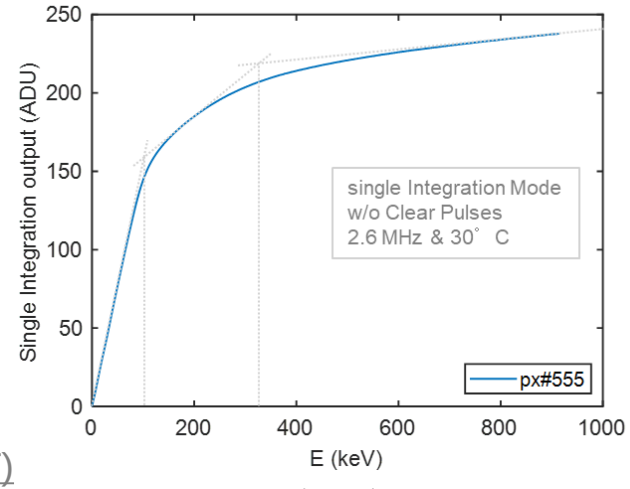
- In the second DSSC camera the MiniSDD sensors will be replaced by **DEPFET arrays**
- DEPFETs are **active pixels** that provide a **non linear response**
  - **Low noise** for single photon detection
  - **High dynamic range**
- The DEPFET arrays are compatible with the existing DSSC system
- A maximum signal **> 10^4 ph / pixel is achievable for E ≥ 800 eV**, assuming an 8-bit ADC and single photon detection capability
- Noise **~30 el rms** has been measured with 64 x 64 prototypes @ 4.5 MHz
- Large format sensors are available and are being assembled

Lechner, P. et al. " DEPFET active pixel sensor with non-linear amplification" (2012) art. no. 6154112, pp. 563-568.

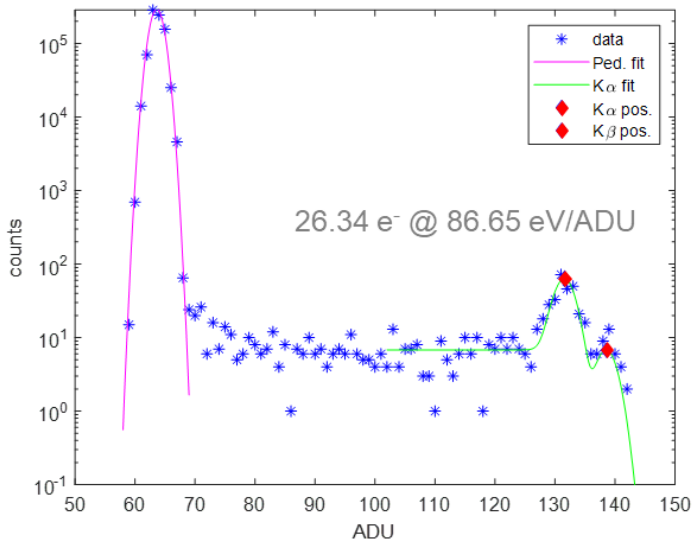
S. Aschauer, et al, „First results on DEPFET Active Pixel Sensors fabricated in a CMOS foundry - A promising approach for new detector development and scientific instrumentation", (2017) Journal of Instrumentation, 12 (11), art. no. P11013.

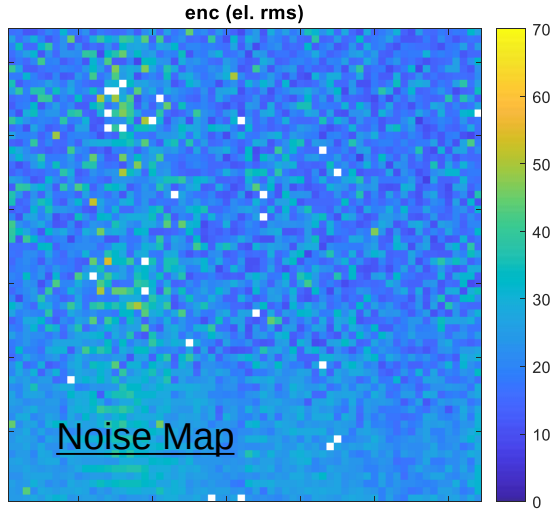


Transfer Characteristic



Histogram (px#555 @ highest Gain & RT)





Mean: 23.12 e⁻
Std. Dev.: 32.41 %

Thank you for your attention