New Generation Detectors: Requirements, Strategy and First Steps

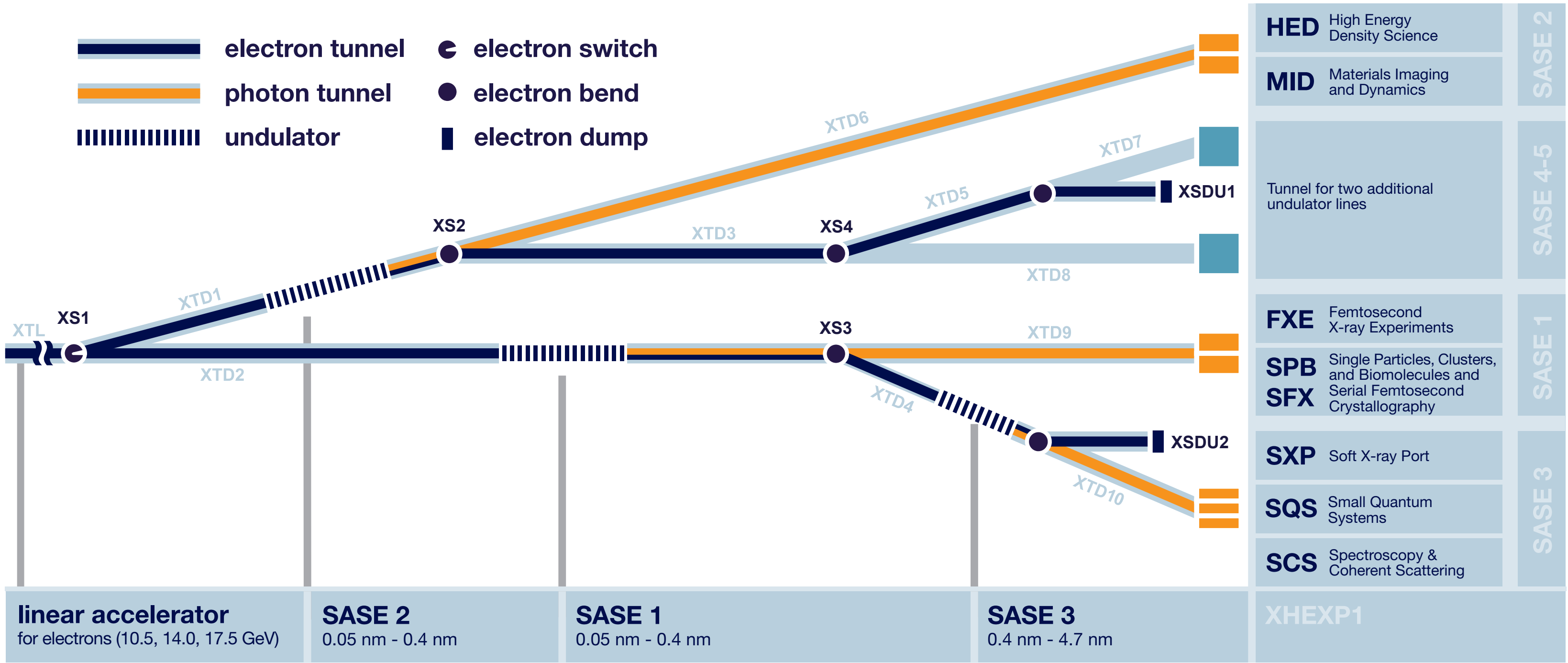
Monica Turcato
European XFEL

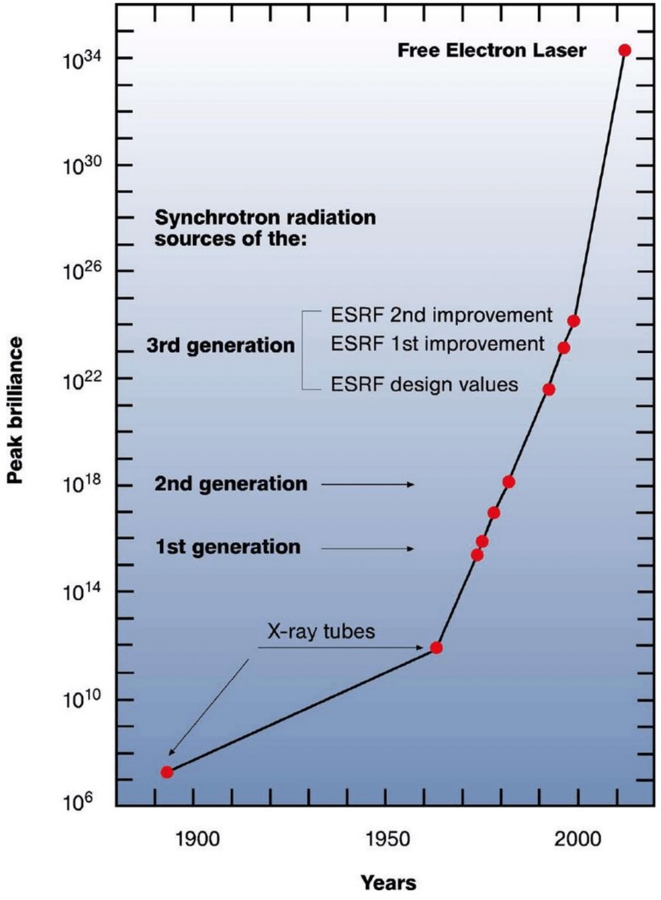
Future Detectors for the European XFEL
Schenefeld, September 18, 2023

Outline

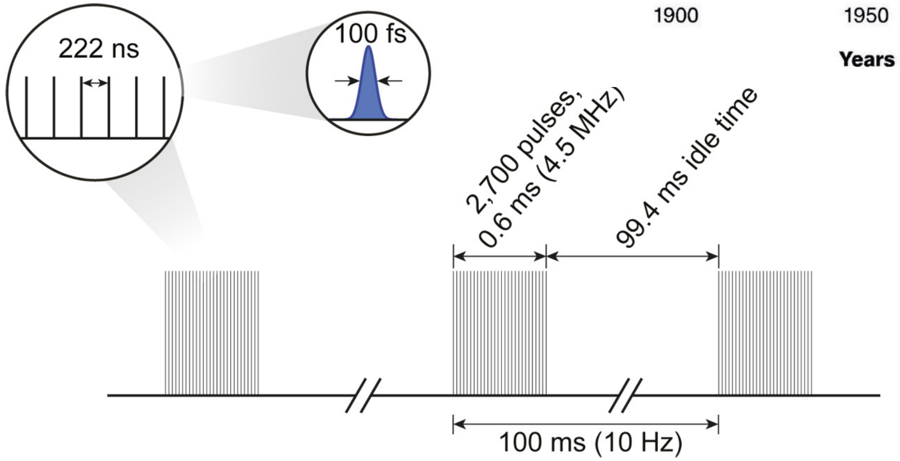
- EuXFEL and its need for custom detectors
  - Detectors presently installed
- What do we need for future detectors
  - Facility updates
  - Science needs
- EuXFEL involvement in the new developments
  - DET group structure and expertise, synergy with other groups
- Detector specifications
  - Move away from ‚swiss army knife' detector?

The European XFEL beamlines



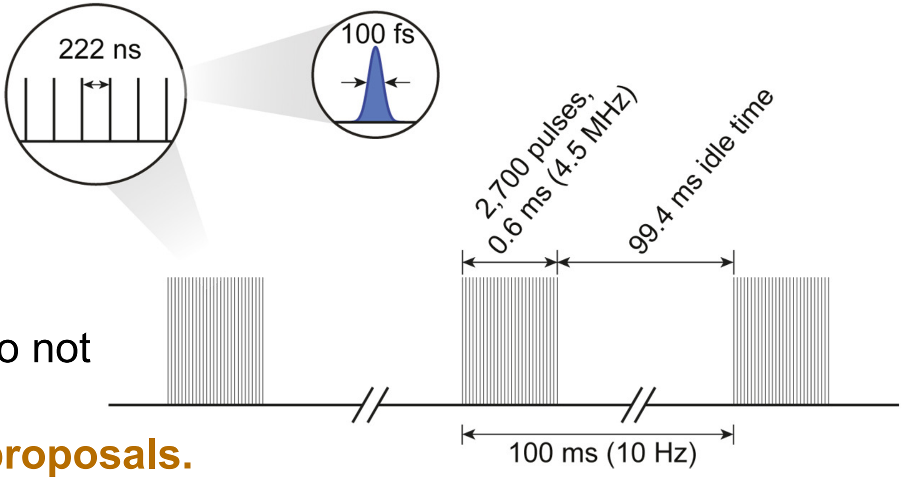


The specific time structure of the EuXFEL challenges detector design!



What are the challenges for the detectors?

- The time structure of the machine is unique:
  - burst mode operation, with pulses arriving at max 4.5 MHz frame rate, typical experiment rates 0.5-1.1-2.2 MHz
  - 99.4 ms interval between the 0.6 ms pulses, 10 times per second
- High dynamic range: up to 10^5 photons / pixel / pulse, with the capability at the same time to detect also single photons
- Radiation resistance
- Large active area
- Suitable for very different scientific applications
- Commercial detectors with these capabilities did not exist and still do not

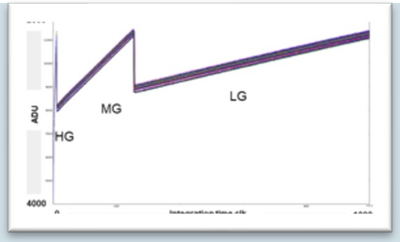
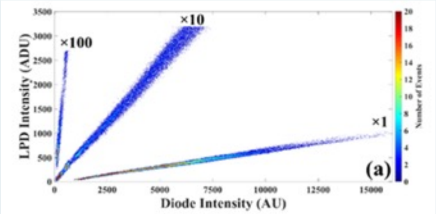
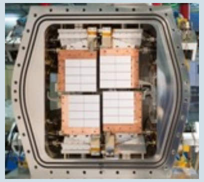
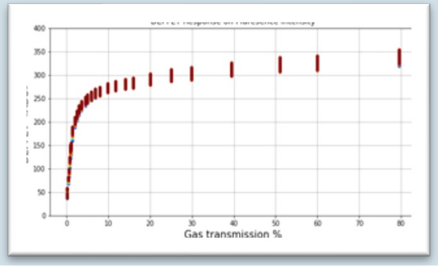


For the first generation detectors we went for a dedicated call for proposals.

The first detector generation at the EuXFEL

For the first generation detectors we went for a dedicated call for proposals.

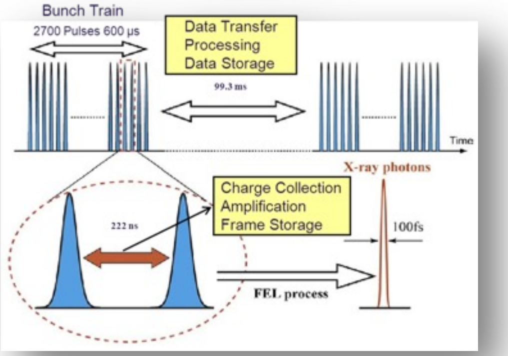
- Development time for the first detectors ca 2009-2023
  - AGIPD (SPB/SFX): 2017
  - LPD (FXE): 2017
  - AGIPD (MID): 2018
  - DSSC (SCS): 2019
  - DSSC DEPFET: 2024
- New AGIPD generation
  - AGIPD500k (HED): 2020
  - AGIPD4M (SFX): 2024
  - AGIPD1M (HED): 2024
- Three different projects adopting different solutions to solve the challenges
- Other detectors for specific applications or as backup

Detector	Specs	Gain Mechanism	Gain
AGIPD 	352 memory cells (analog) 200µm x 200µm sq. pixels 1-10^4 12 keV ph 3-20 keV Modular: 16 (1MPix) or 8 (0.5MPix) modules	3 gains with automatic switching	
LPD 	(3x)512 memory cells (analog) 500µm x 500µm sq. pixels 1-10^5 12 keV ph 7- 20 keV Modular: 16 (1MPix) modules	3 parallel gain stages with on front-end selection	
DSSC 	800 memory cells (digital) 204µm x 236µm hex. pixels N x 256 ph @ 4.5 Mhz N x 512 @ f≤2.2 MHz N ≤ 1 for single ph sensitivity 0.5 – 6 keV Modular: 16 (1MPix) modules	Linear response (miniSDD), non-linear signal compression in sensor (DEPFET)	

Where do we want to go next with EuXFEL detectors?

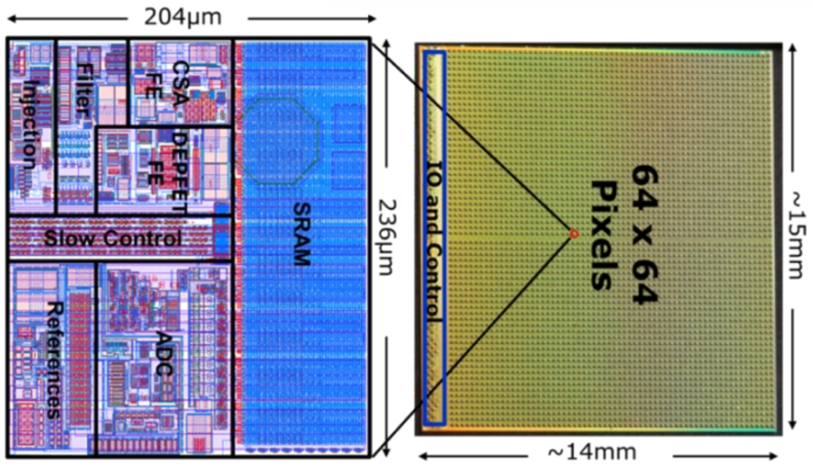
- The first generation detectors were excellent for the start of the EuXFEL program, but to keep EuXFEL as world leading facility and allow producing excellent science we need to provide new possibility also in terms of detectors

- The technology of the 1st detector generation is now old and difficult to reproduce or to update
  - Transferring the same concept and specs to another technology is long and expensive
  - We need to exploit the characteristics of new technologies also for new features



- What are the main **facility upgrades** we are facing, and when will they take place?
  - ► **high energy (> 20 keV) operation already started**
  - ► change of pulse rate, at present under discussion → **not before 2030++**

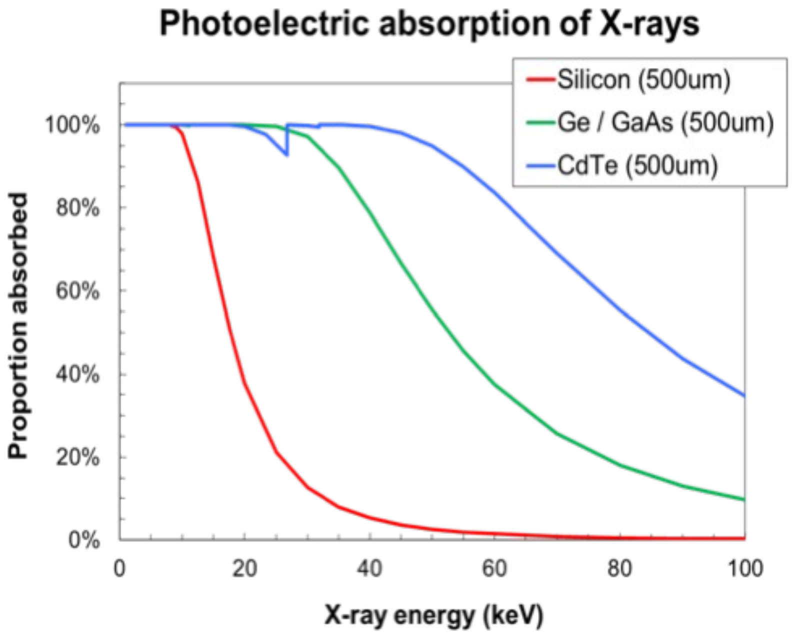
- Which are the main upgrades the instruments are asking for?
  - Main request from **all** instruments, since 2017:
    - ► **smaller pixels**
  - Present detectors have 200-500 μm pixel pitch
    - ► major upgrade needed, floor space already small
    - ► memory dominates the area occupancy in the pixel but relaxes the peak data rate

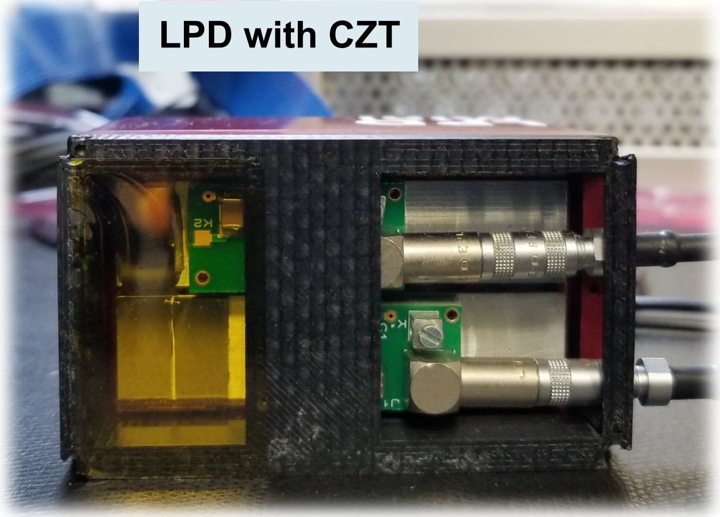


DSSC pixel and ASIC

Running the EuXFEL with harder X-rays: now!

- First 23 keV photons operation at EuXFEL made clear the limitations of silicon:
  - only ca 20% of the radiation is absorbed by the sensor
  - electronics damage on the ASIC becomes likely
    - ► need materials able to absorbe these photons: GaAs, Cd(Zn)Te
    - ► the worldwide community is looking for a solution to this problem
    - ► EuXFEL to provide beam and joining sensor qualification activities

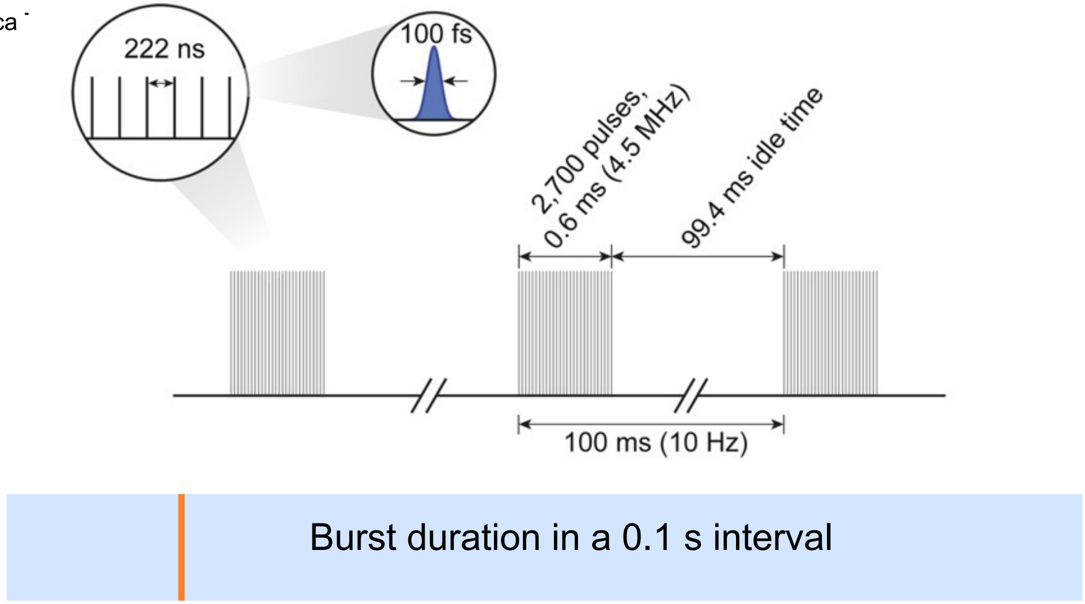


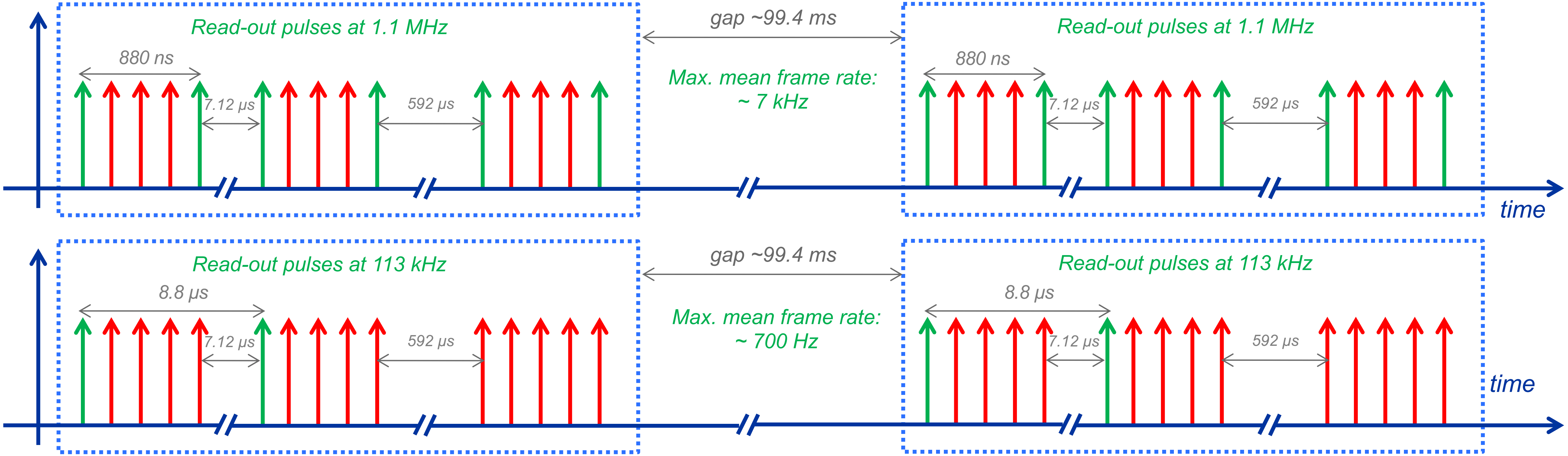


EuXFEL is joining the community of scientists active in this topic

Burst mode operation

- **Burst mode will still be our operation mode until ~2035**
  - this has no equal in the world
  - even a very fast (100 kHz) continuous readout detector will not help
    - per 0.6 ms burst, we could only read out max 60-70 frames, at present we read out 350-800 per burst
    - EuXFEL is bound to MHz repetition rate





What is the goal of the next detector development program?

- If you ask users: provide excellent data quality and easiness of analysis
- If you ask Instrument Scientists: they would add ease of operation and maintenance
- If you ask Detector Scientists at XFEL: emphasis move on ease of operation, maintenance and calibration
- If you ask Detector Developers: the project must also be innovative and at the same time feasible from the technology point of view.

At the end of the day, the common goal is excellent data quality, the point of view slightly different → we should combine the views and expertise since the beginning!

Detector development

2023 Phase I – R&D 2026

Phase II – Development and Production 2030

Goal: 2nd generation of Large Area Pixel Detectors 2028-2030, matching expected lifetime

Phase I 2023 – 2025 (1 MEUR per year budget established to cover four areas of investigation)

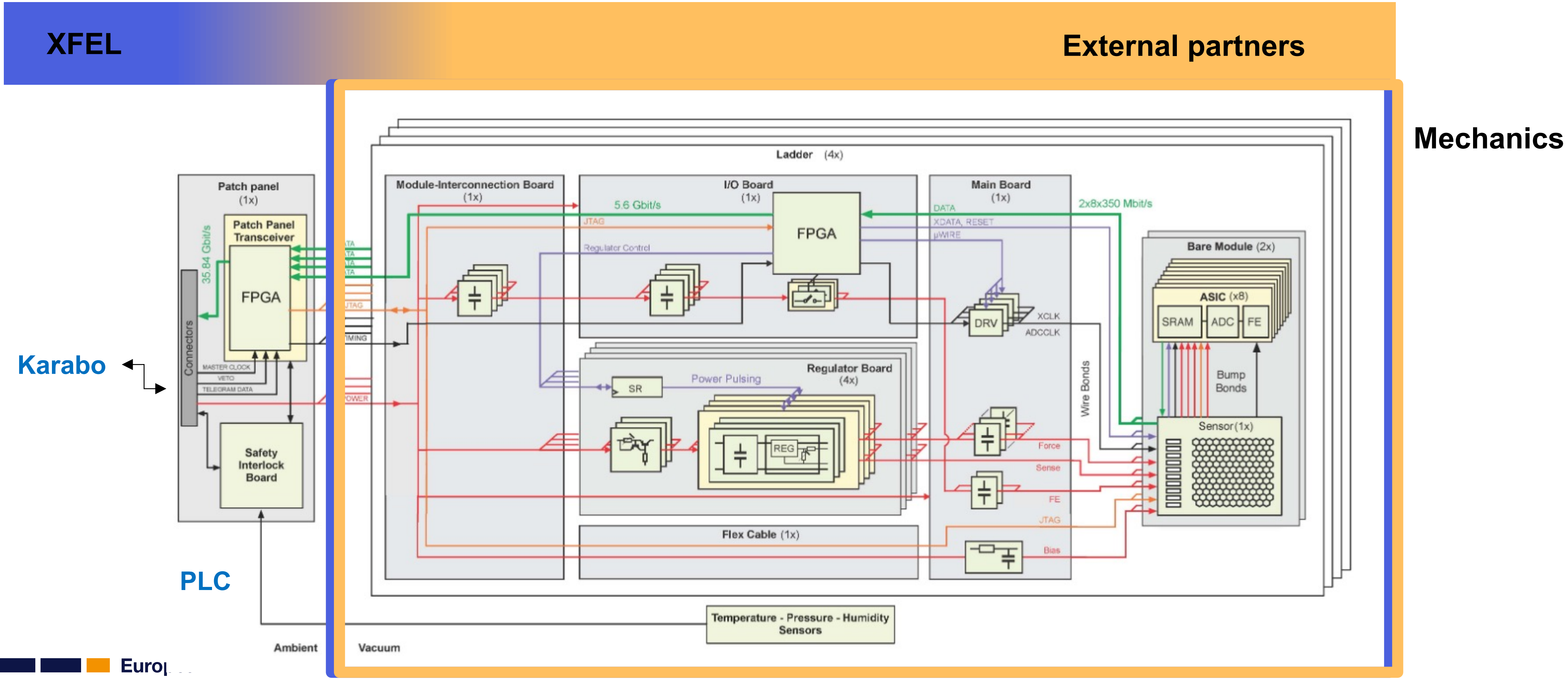
- Areas of investigation:
  - System integration, backend electronics
  - System integration, mechanics and cooling
  - High-Z materials
  - Sensor and ASIC
- Main goals:
  - **increase our expertise in key areas**
  - **identify a feasible project fitting with the timeline, possibly in the direction we want to go in the far future**

Phase II 2025 – 2030

- Establish concrete projects to build detectors to be ready for 2030
- Prototyping of selected technologies
- Final designs
- Construction and commissioning at Scientific Instruments

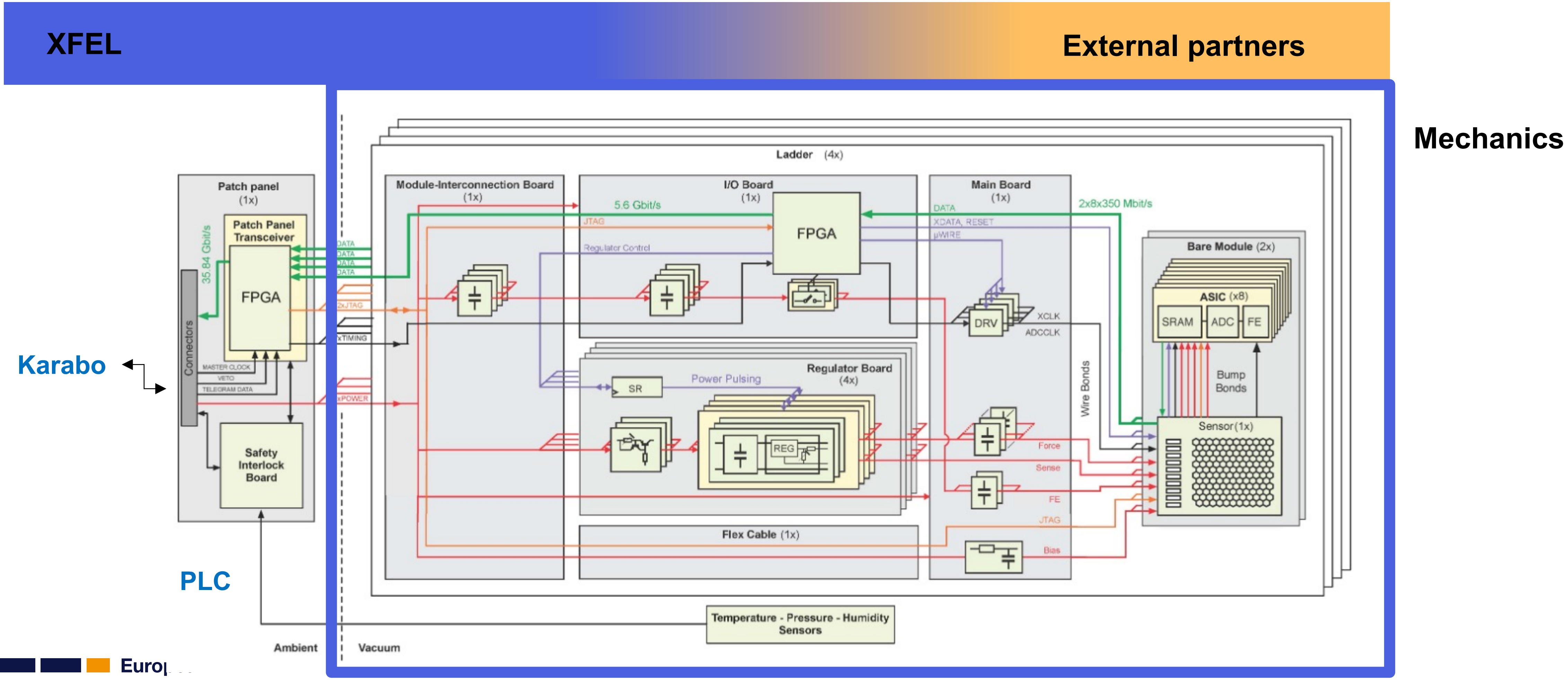
Where is our main expertise right now?

- Our main expertise is integration together with calibration, and some part of mechanics including assembly



Where do we want to go? Take over system assembly and integration

- How we plan to be involved: significant engineering resources needed



Composition and expertise of the DET group

- Main group expertise
  - Detector integration, testing commissioning, calibration
  - Detector mechanics (integration) and installation
  - Control and calibration software

- New composition since start of the development phase:
  - Detector scientists and postdocs, 9 people, 1 postdoc hired on high-Z sensors
  - Detector instrument scientists, 6 people: contact with the instrument, main detector experts at the instrument → seconded to DET from the instruments
  - Software engineers, 3 people
  - Mechanics engineers+technicians, 3 people, 1 new mechanics engineer, one will join in Feb 2024
  - Electronics engineers, 2 people
  - 2 student assistants
  - In the hiring phase: 1 ASIC designer

- We are consolidating personnel power in mechanics/cooling and building up new expertise in electronics

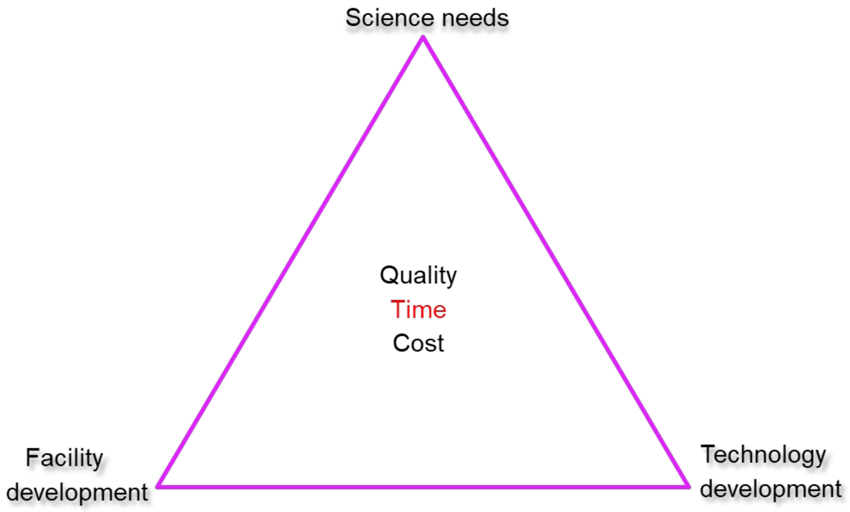
Still available funding for positions from the present R&D budget

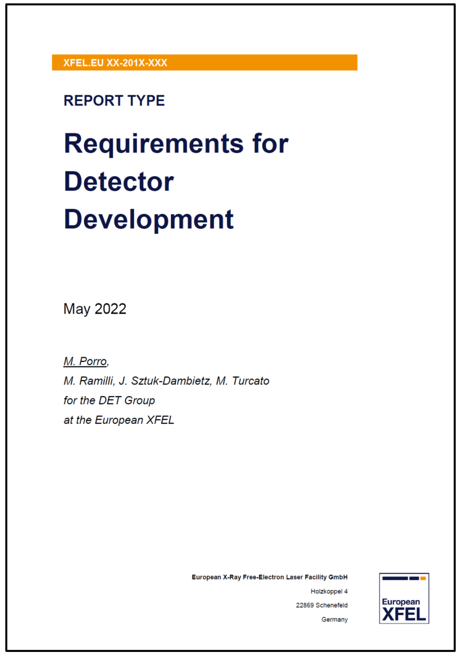
- Additional funding is available for other positions at the EuXFEL or outside
  - The idea is to use it for the coming collaborations with external partners (3-years positions)
    - ► 1 position in electronics (FPGA f/w design)
    - ► 4-5 positions for ASIC development
    - ► 1 PhD position for new materials

- EuXFEL has significant expertise also on
  - Detector control
  - DAQ
  - Interlocks, electronics, cabling, timing
  - Synergy / interaction with instruments
  - **Early synergy with the other groups of the Data Department and of the EuXFEL has proven to be beneficial in facilitating the integration process and to establish ergonomic operation routines**

How to get to the final requirements?

- **Burst mode will still be our operation mode**
  - this has no equal in the world
  - even a very fast (100 kHz) continuous readout detector will not help
  - a continous readout MHz detector is far away in the future
- For 2030+ we still need detectors able to cope with our burst mode!
  - **Focus on burst mode for next detector round**
- Can we upgrade our detectors so that we get closer to what we could need in 2035?
  - **Consider facility upgrades, science needs and technology developments all together, keep communication open**




XFEL.EU XX-201X-XXX

REPORT TYPE

Requirements for Detector Development

May 2022

M. Porro,
M. Ramilli, J. Sztuk-Dambietz, M. Turcato
for the DET Group
at the European XFEL

European X-Ray Free-Electron Laser Facility GmbH
Holzkoppel 4
22869 Schenefeld
Germany

Our preliminary requirements

Not all parameters to be reached at the same time!

Hard X-ray detector

	Target values	Possible variant
Sensitive Energy Range	5-13 keV[1] with Si 13-50 keV with high-Z	3-13 keV[1] with Si
Dynamic range in photons	> 5 x 10^3 12 keV ph./px	500 - 1000 12 keV ph./px, one gain
Noise (ENC)	< 300 el. rms. ~1keV photon in Silicon	
Frame rate	Burst mode, 1.1 MHz	Burst mode, 1.1 - 4.5 MHz
Sensor type	2D pixelated	
Pixel size	80 - 100 µm pitch	
Pixel count	Move away from fixed large detectors, modular approach, max 4 Mpix	
Operating pressure range	Both ambient and vacuum (below 10^{-3} mbar) versions needed	

Soft X-ray detector

	Target values	Possible variant
Sensitive Energy Range	0.4 - 3 keV, possibly higher	
Dynamic range in photons	> 5 x 10^3 1 keV ph./px	500 - 1000 1 keV ph./px, one gain
Noise (ENC)	< 30 el. rms ~0.125 keV photon in Silicon	
Frame rate	Burst mode, 1.1 MHz	Burst mode, 1.1 - 4.5 MHz
Sensor type	2D pixelated	
Pixel size	80 - 100 µm pitch	
Pixel count	Move away from fixed large detectors, modular approach, max 4 Mpix	
Operating pressure range	< 10^{-6} mbar	

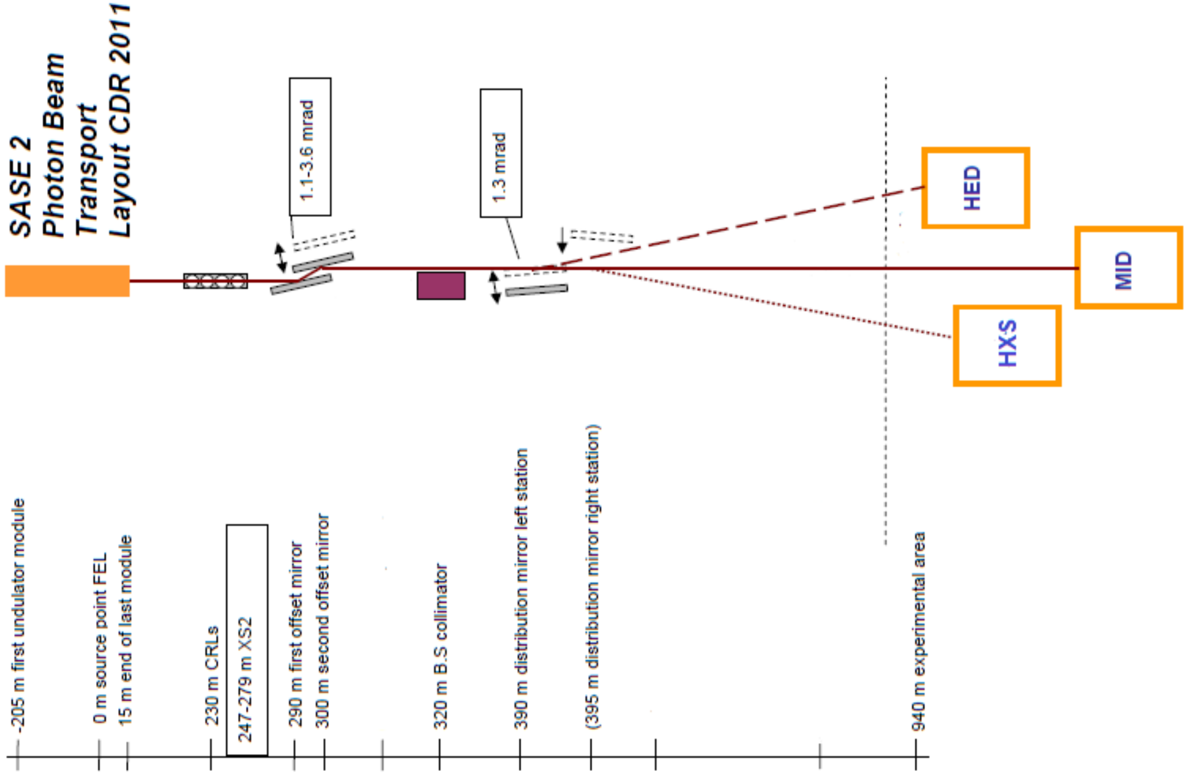
[1] *Defined by QE of the sensor. Operation above/below is possible with reduced performance.*

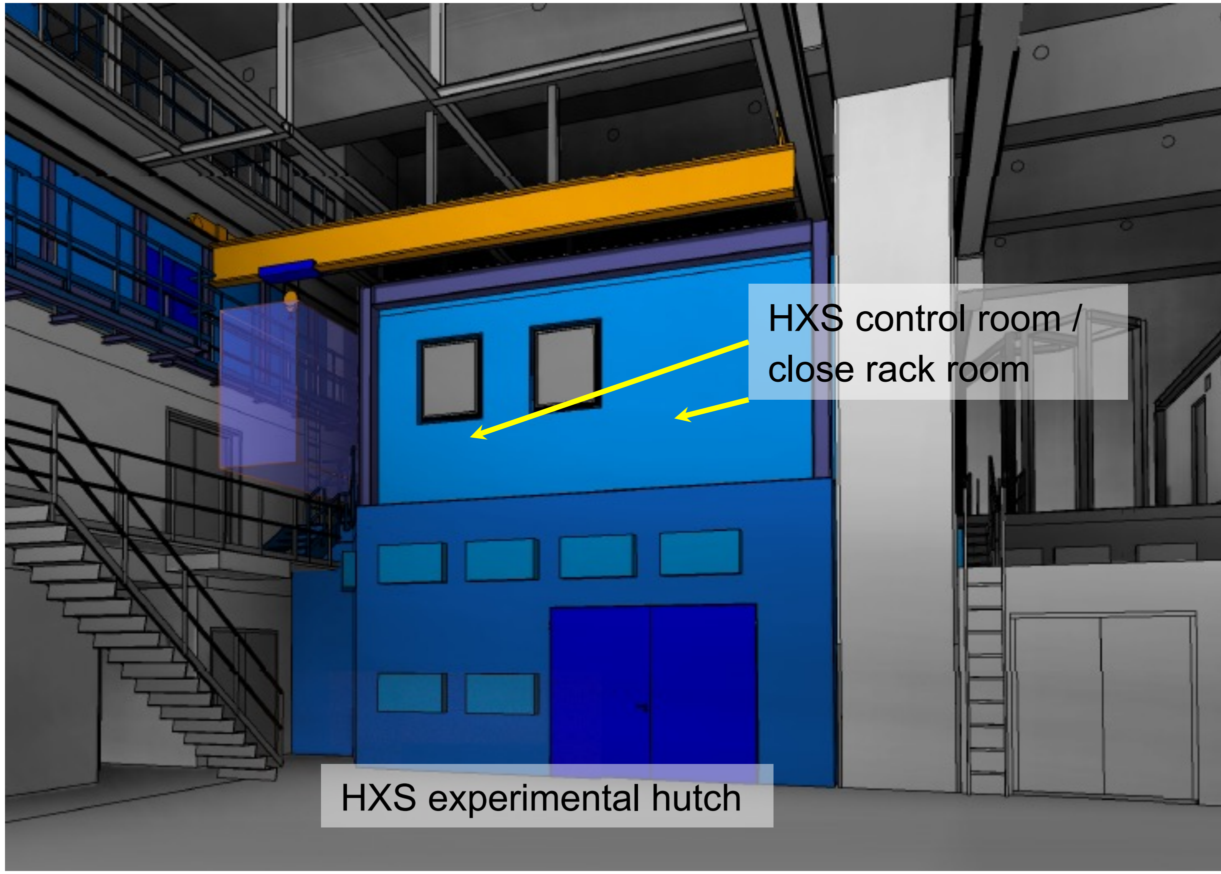
Move away from swiss army knife detector concept

- Work towards standardisation of infrastructure
- Phase I of development: where can we compromise? Which range of parameters can be supported by a single front-end development?
- Where do we need dedicated developments? What are the flagship science case we must cover at best?

Third port of SASE2 approved for construction in 2025

- Hutch and beam transport tunnel approved, installation in the 2025 long shutdown until early 2027





- ***Can offer extra possibilities for detector testing***

Conclusions

- Detector development funding has been established at the EuXFEL and first steps have been done to allocate it.
- Phase 1 of the development will serve to increase EuXFEL expertise in certain fields and to define collaboration with external partners in specific topics (ASICs, sensors…)
- Phase 1 is also aimed to define what is possible in terms of detector development and on which time scale
- Real development on few selected options will start in Phase 2

Thank you!