Detector Development for the future European XFEL

Marco Ramilli
for the EuXFEL Detector Group

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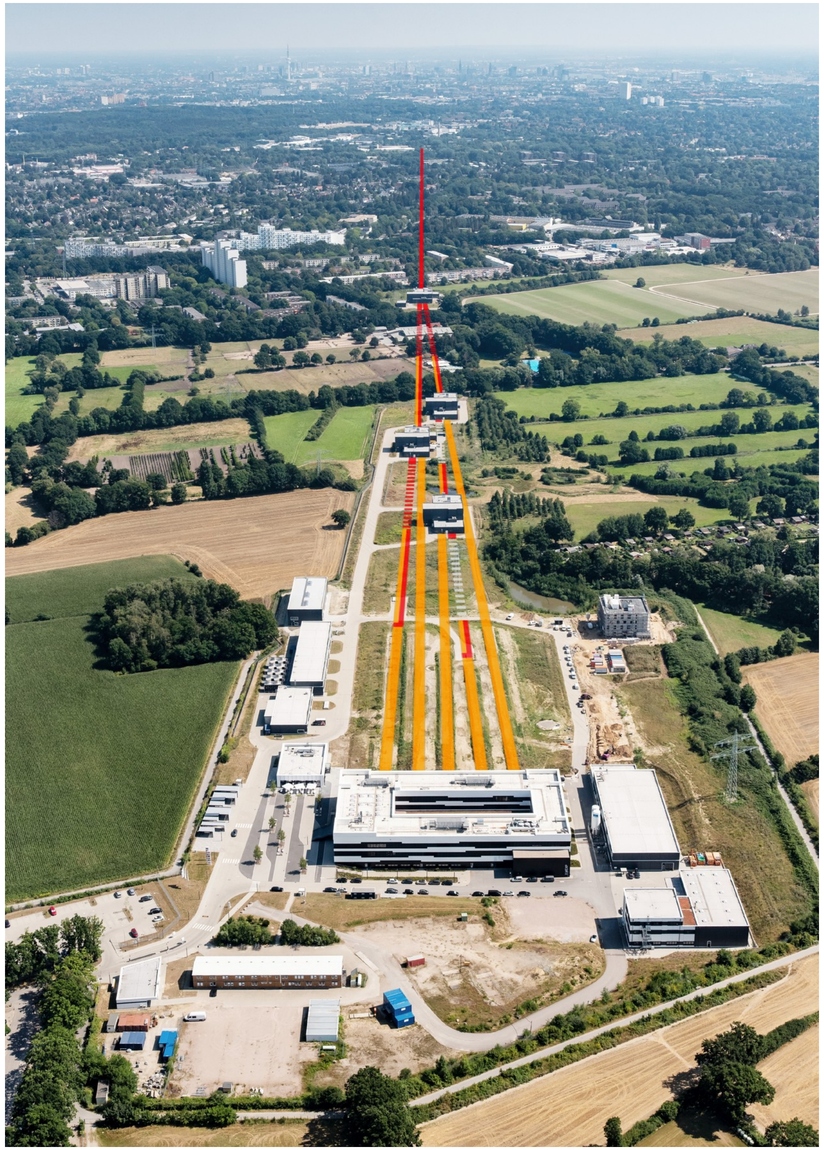
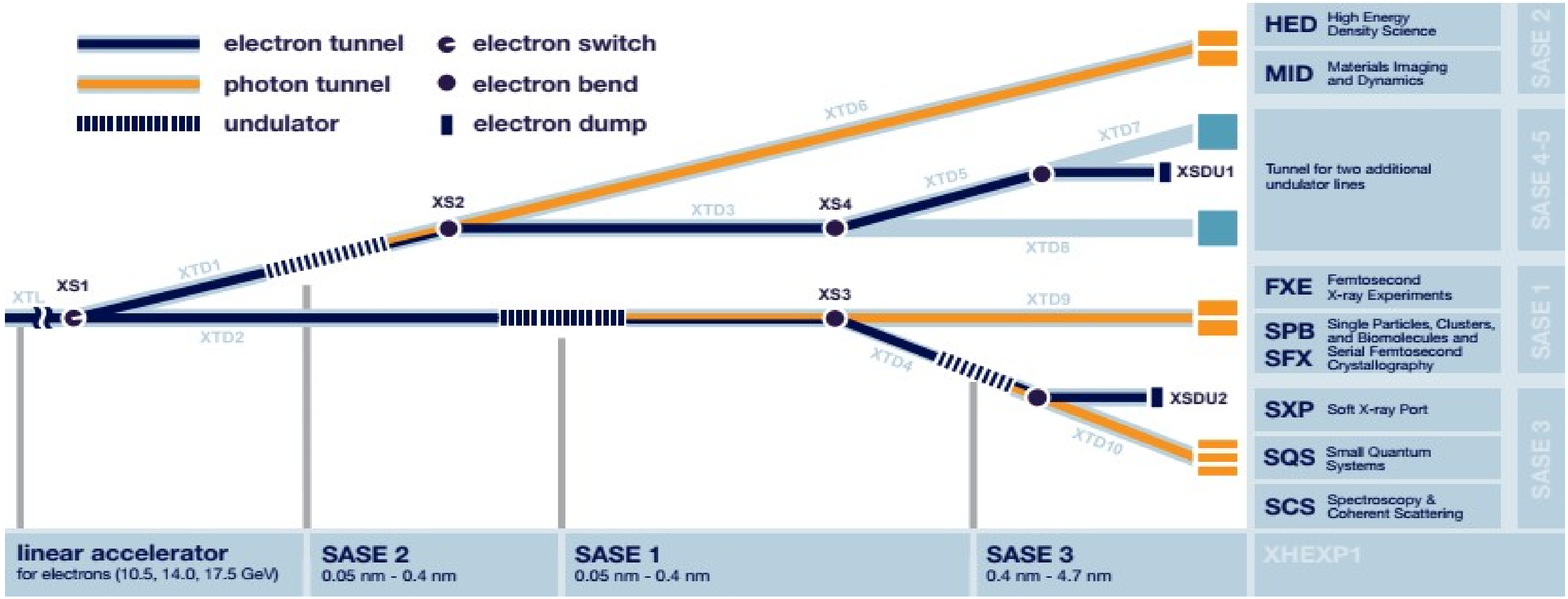
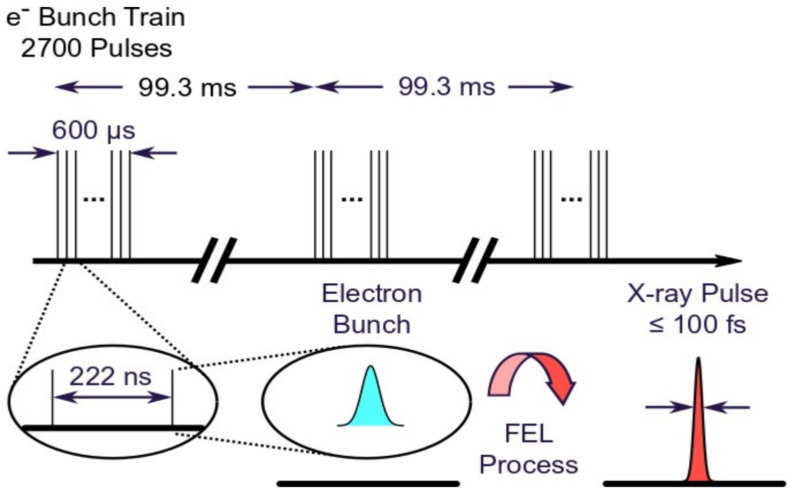
Outline

- Introduction
- Future detectors requirements
- How we plan to be involved
- Conclusions



Introduction: European XFEL





- Three main undulator systems (SASE 1, 2, 3)
  - Supply seven scientific instruments
  - SPB/SFX, FXE, MID, HED (‘hard X-ray’)
    - 6 keV < E < 25 keV
  - SCS, SQS, SXP (‘soft X-ray’)
    - 0.25 keV < E < 3 keV

- 10 Hz train rate
- Bunch train internal structure
  - **2700 pulses** for 600 µs
  - **4.5 MHz pulse rate** (~222 ns spaced)
  - Lasing pulses < 100 fs width
- Pulses of ~ 10^{14} photons
  - Most experiments are pulse-resolved
  - Detectors need to cope with bunch train structure

Detectors for EuXFEL

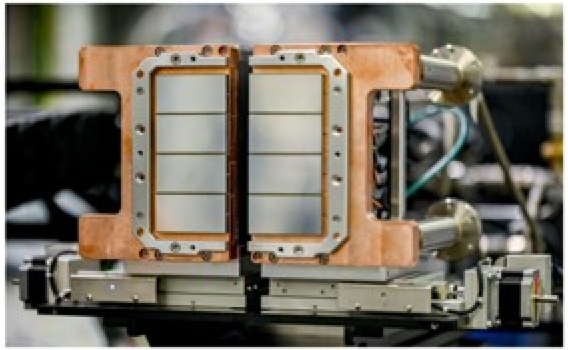
Hard
X-rays
6-25 keV

X-ray energy

Soft
X-rays
0.5-3 keV

Noise: 50 e- (HG)
Dyn range: 100 8 keV ph

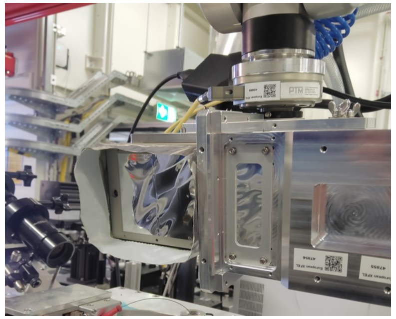
ePix100 (MID, HED)



JUNGFRAU x 18lrth (all hard X-ray inst.)

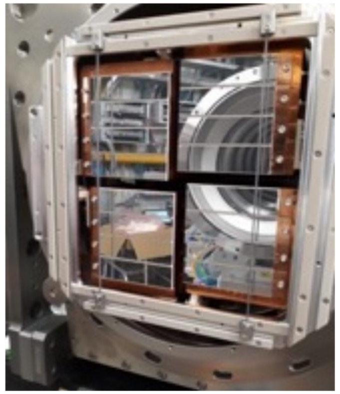
Noise: 80 e- (HG)
Dyn range: 10^4 12 keV ph

GOTTHARD-II (all instr.)



Strip detector
Noise: 280 e- (HG)
Dyn range: 10^4 12 keV ph
Up to 2700 images/train

AGIPD (SPB/SFX, MID)

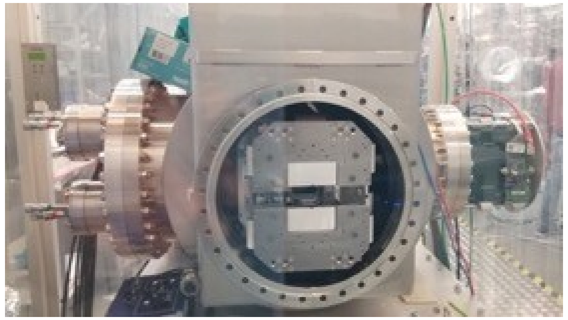


Noise: 350 e- (HG)
Dyn range: 10^4 12 keV ph

LPD (FXE)

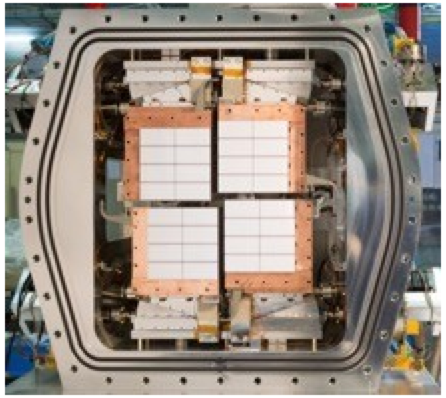
Noise: 2010 e- (HG)
Dyn range: 10^5 12 keV ph

pnCCD (SQS)



Noise: 3 e-
Dyn range: 1500-3000 1 keV ph

DSSC (SCS, SQS)



Noise: 60 e-
Dyn range:
N x 256 ph @ 4.5 Mhz –
N x 512 @ f≤2.2 MHz
N ≤ 1 for single ph sens.

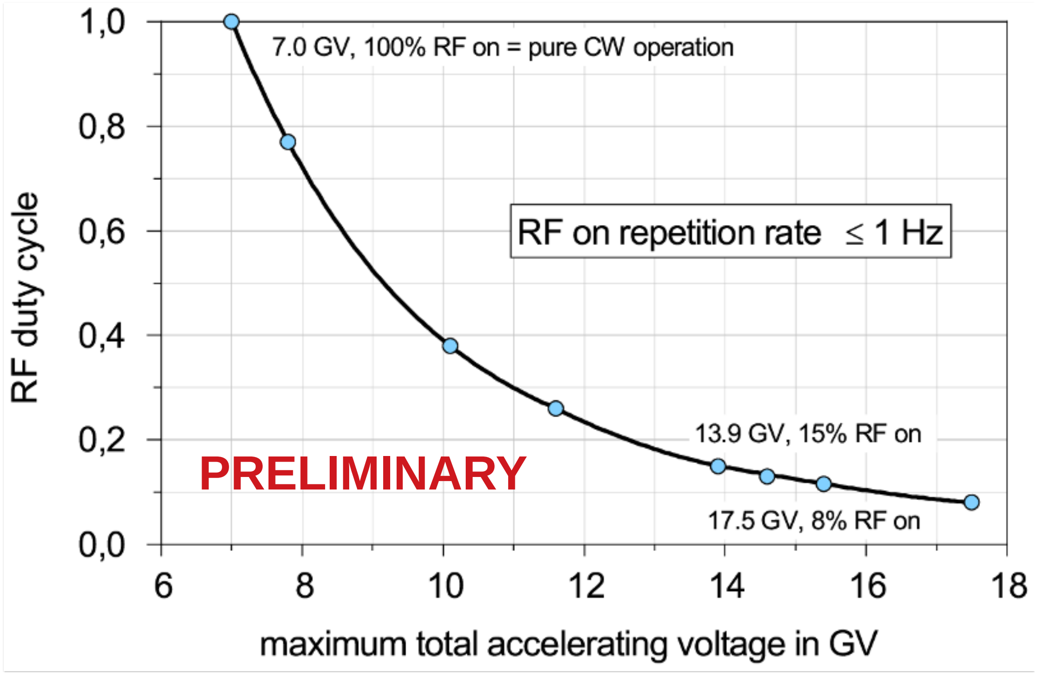
10 Hz

4.5 MHz

Rate

Facility developments: new time structure and photon energy

Time structure not yet defined, some options under consideration

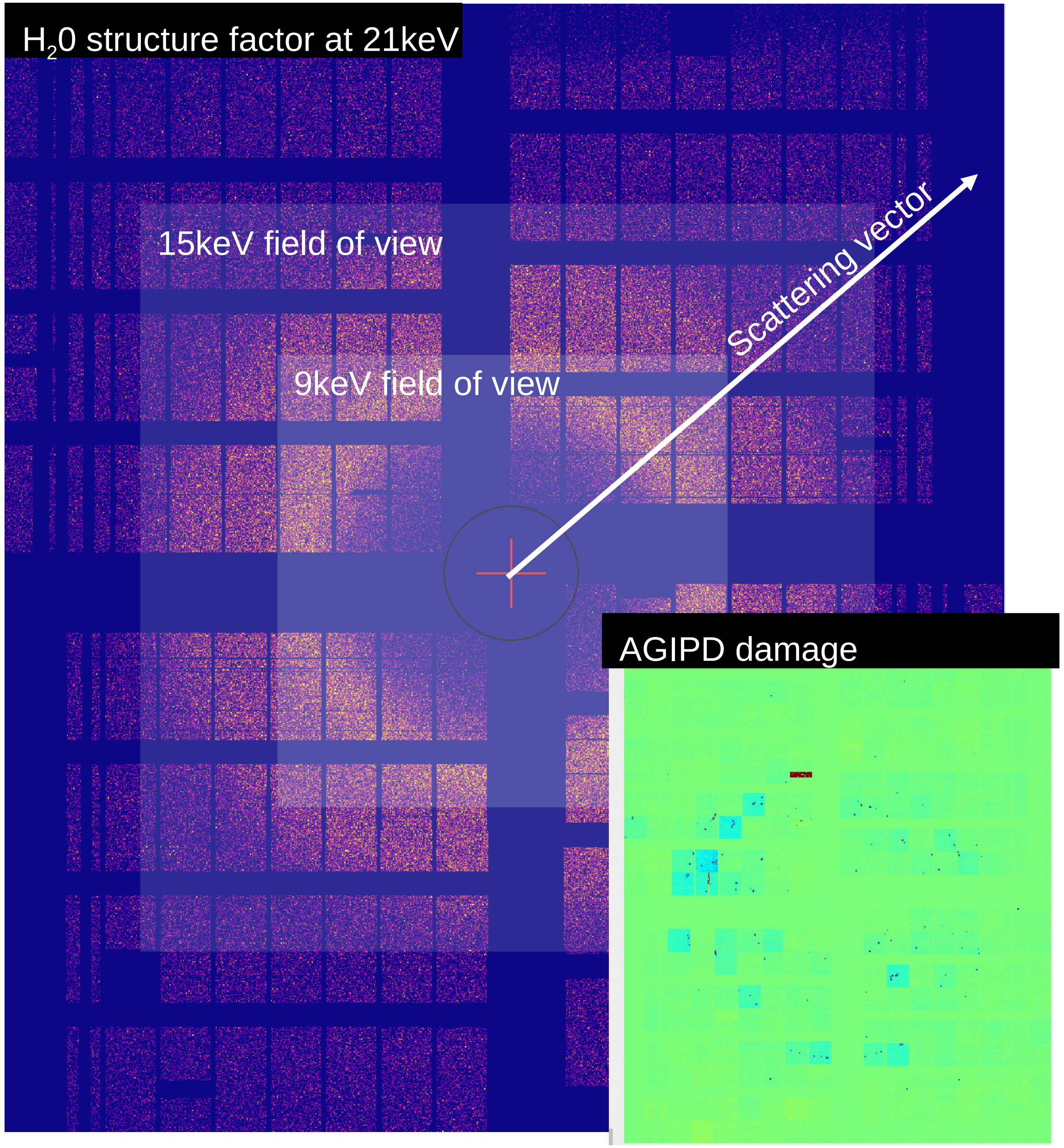


- Without major accelerator modifications
  - CW mode implies a max electron energy of 7 GeV (with respect to the 17.5 GeV of now)
  - energy can be gained by running in high duty-cycle mode, when RF is on for a fraction of time (the present burst mode corresponds to a duty cycle of 0.006)
- Optimizing the usage of higher harmonics
  - Increase photon energy to ~ 30 keV
  - photons/pulse ~ factor 10 lower at E ~ 30 keV

Slide courtesy of the accelerator team, in particular J. Sekutowicz and E. Vogel

Water experiments at MID

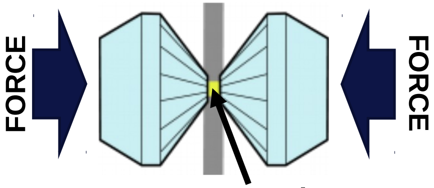
- Scattering experiment to measure properties of water
  - Performed with AGIPD 1M at MID
  - Scattering vectors scientifically interesting:
    - Photons @ 21 keV
    - Detector closer to increase field of view
    - Very dangerous for current detector
- Increased photon energy would allow access to larger scattering vectors
  - High Z sensor would allow better ASIC safety
- **Detector requirements**
  - Good QE E > 20 keV
  - Single photon sensitivity
  - Smaller pixel for increased angular resolution



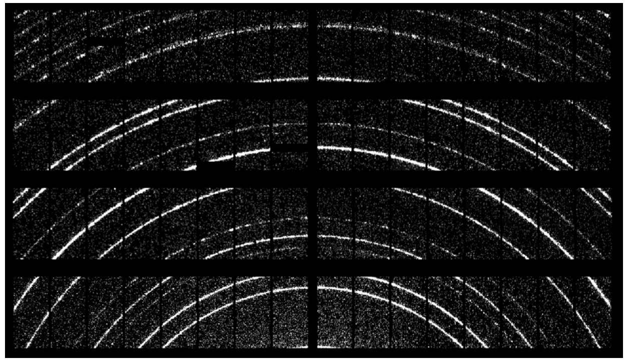
slide courtesy of Roman Shayduk

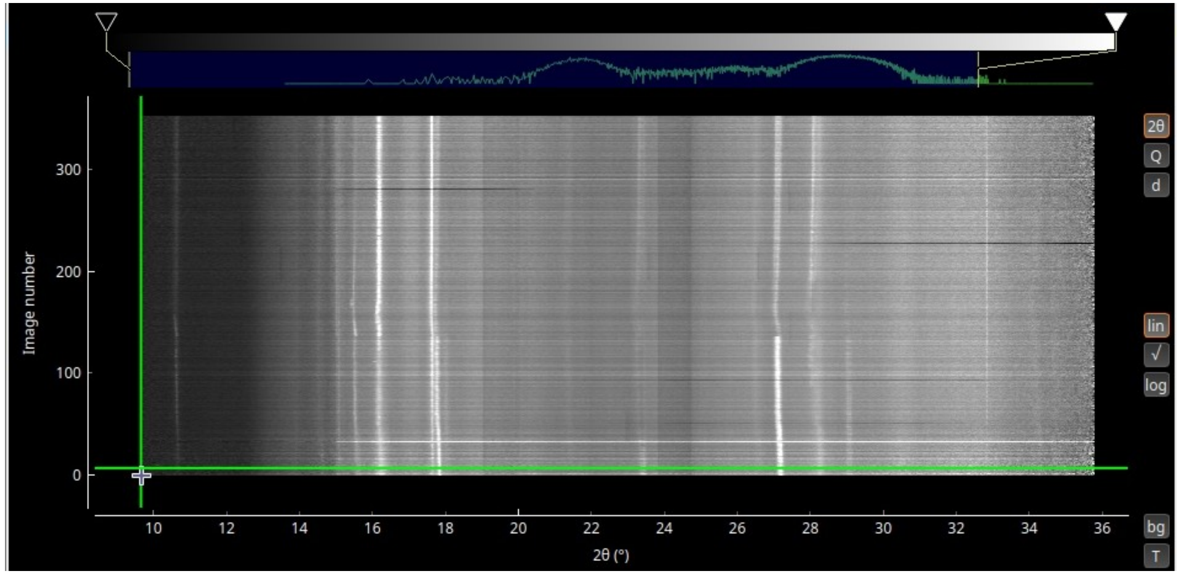
Determination of phase diagram of low Z materials

- Exploring the phase diagrams at high P-T conditions
  - Conditions found in interior of planets
- Performed at scientific instrument HED
  - High pressure achieved with diamond anvil cells
  - Heating with X-rays or laser
  - Diffraction acquired with AGIPD 500k
    - ► 4.5 MHz frame rate allows tracking of material dynamics
- Higher photon energies:
  - More information on a smaller detector
  - Reach higher q
  - Penetrate the diamond more easily
  - Investigate lower Z materials
- **Detector requirements**
  - Good QE E > 20 keV
  - MHz-level frame rate to track dynamics



0.5 Mpx AGIPD mini-half prototype with Ce_2O_3 diffraction standard at 20keV

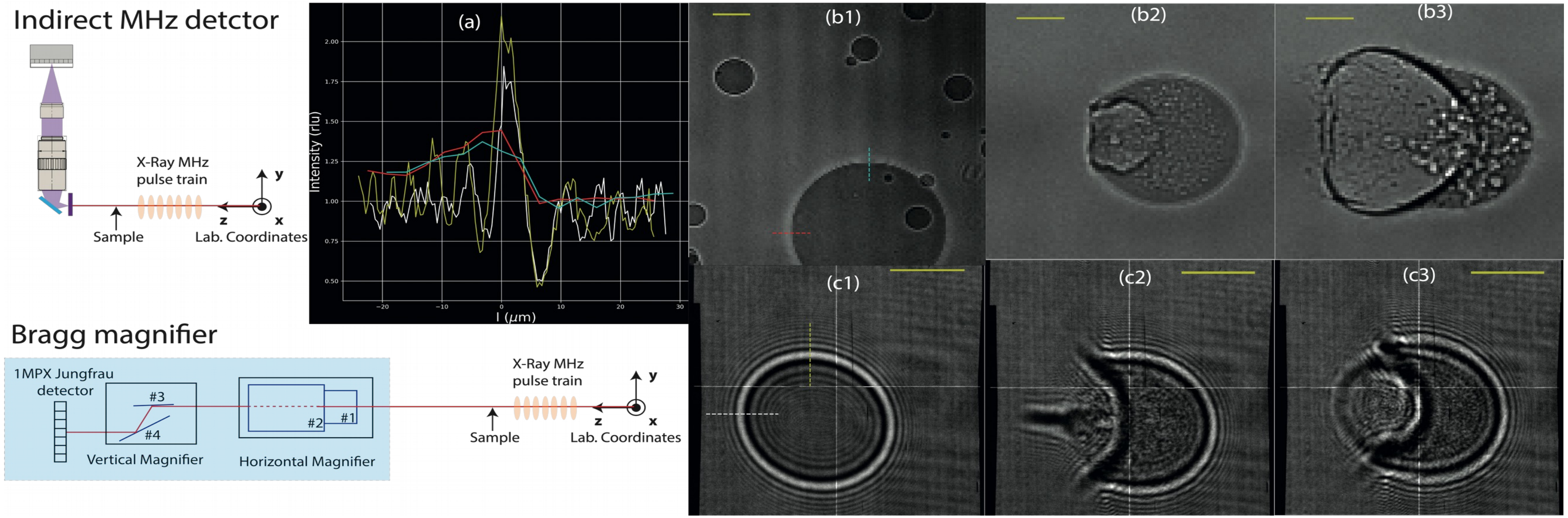




slide courtesy of Thomas Preston

Courtesy of proposal #3406: Determination of the carbon phase diagram using single pulsed laser heating in a diamond anvil cell in combination with MHz X-ray diffraction

MHz X-ray microscopy



Indirect detection
- Scintillator
- Visible light detector

Direct detection
- JUNGFRAU 1M + Si
- Bragg magnifier

- Material imaging
  - Obtain structural and temporal information
- Proof of principle performed at SPB/SFX
  - JUNGFRAU in ‘burst’ mode (~100 kHz, 75 μm pixel)
  - Photon energy at 10.8 keV
  - Very high contrast and resolution reached
- Increasing energy to 30 -35 keV
  - Penetrate deeper into material
- **Detector requirements**
  - Good QE ~ 30 keV range
  - Maintain pixel pitch ~75 μm
  - MHz frame rate capability

slide courtesy of Patrik Vagovic

Preliminary requirements from Scientific Instruments

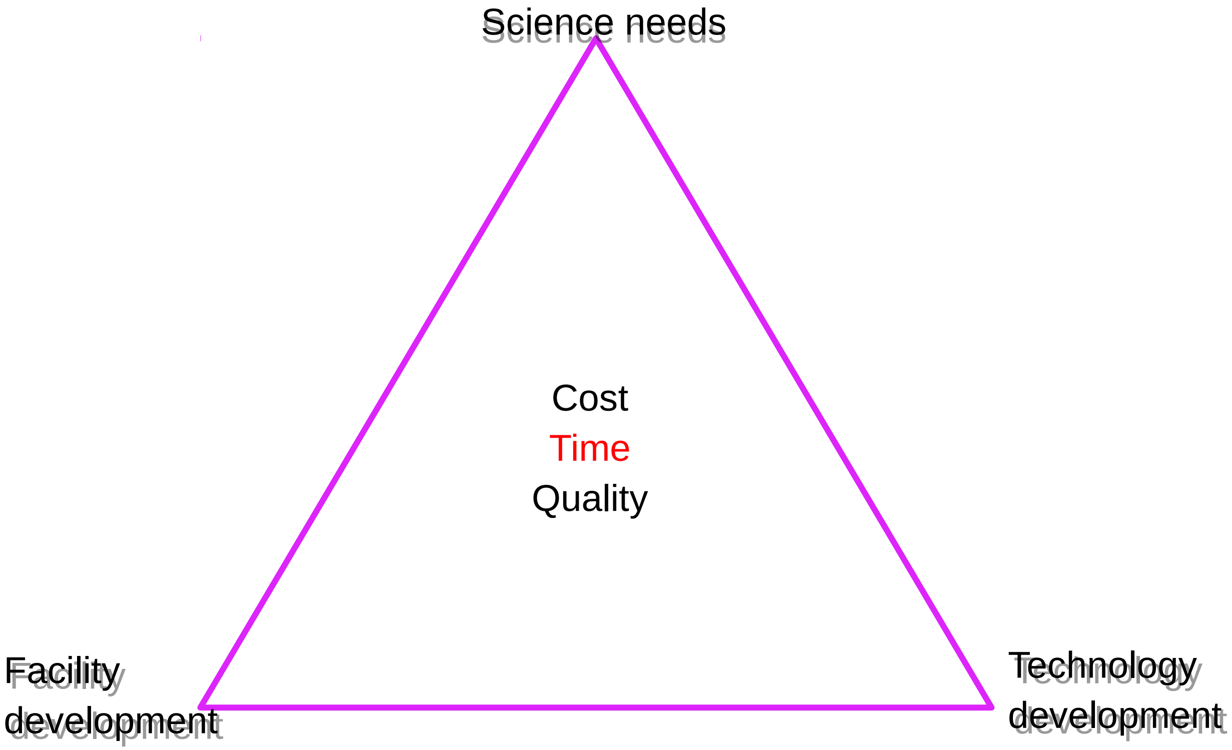
Hard X-ray detector

Parameter	Target values	Possible variants
Sensitive Energy Range	3-13 keV with Si 13-50 keV with high-Z materials	
Dynamic range in photons	5 x 10^3 12 keV ph./pixel	500 – 1000 12 keV ph./pixel fixed gain
Noise (ENC)	< 300 el. rms.	
Frame rate	1.1 MHz burst/long burst	4.5 - 1.1 MHz burst/long burst
Sensor type	2D pixelated	
Pixel size	80 -100 µm pixel pitch	
Pixel count	Modular detector, min. module size tbd. Able to build up several Mpixel full-size detector	
Number of modules	Tbd, depending on module size	
Operating pressure range	Ambient or below 10^{-3} mbar	

How to get to the final requirements?

How do we get to the h/w definition and final requirements?

- Continue to evaluate scientific requirements
  - e.g. dyn. range at high energies
- Max repetition rate:
  - MHz rate is a must, continuous operation is not
  - duty cycle will be a machine parameter
- Fully integrate lessons learned from first systems in the new developments
  - Avoid multiple standards
  - Modular detectors
  - ...



Detector development

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

Phase I 2023 – 2025

- 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 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

How we plan to be involved

- Our main expertise are in calibration, system integration and some part of mechanics
- Take a leading role concerning mechanics and backend
- Take a more active role for the front-end development (ASIC and sensor)
  - Need to retain know-how in house
    - ► Small team of experts with overview of the systems developed

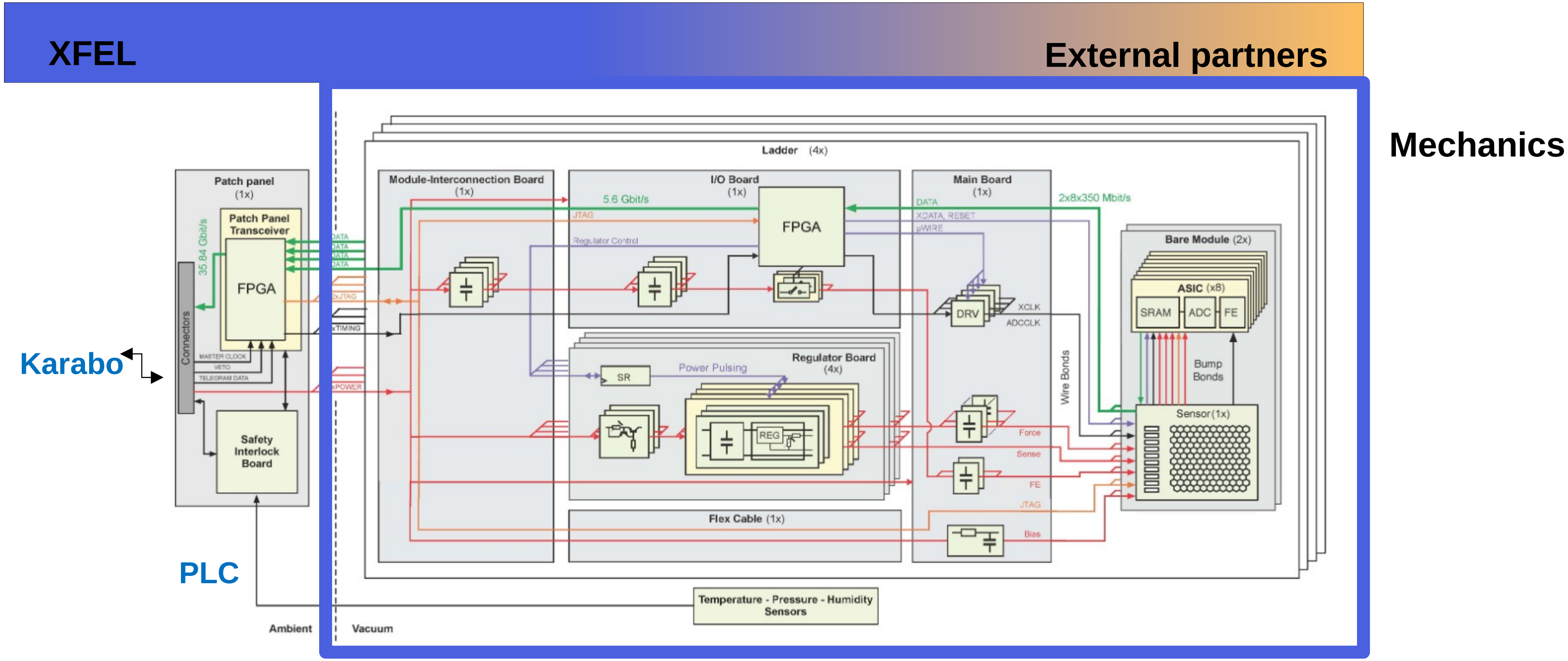


Figure from M. Porro *et al*., "*IEEE Transactions on Nuclear Science*, vol. 68, no. 6, pp. 1334-

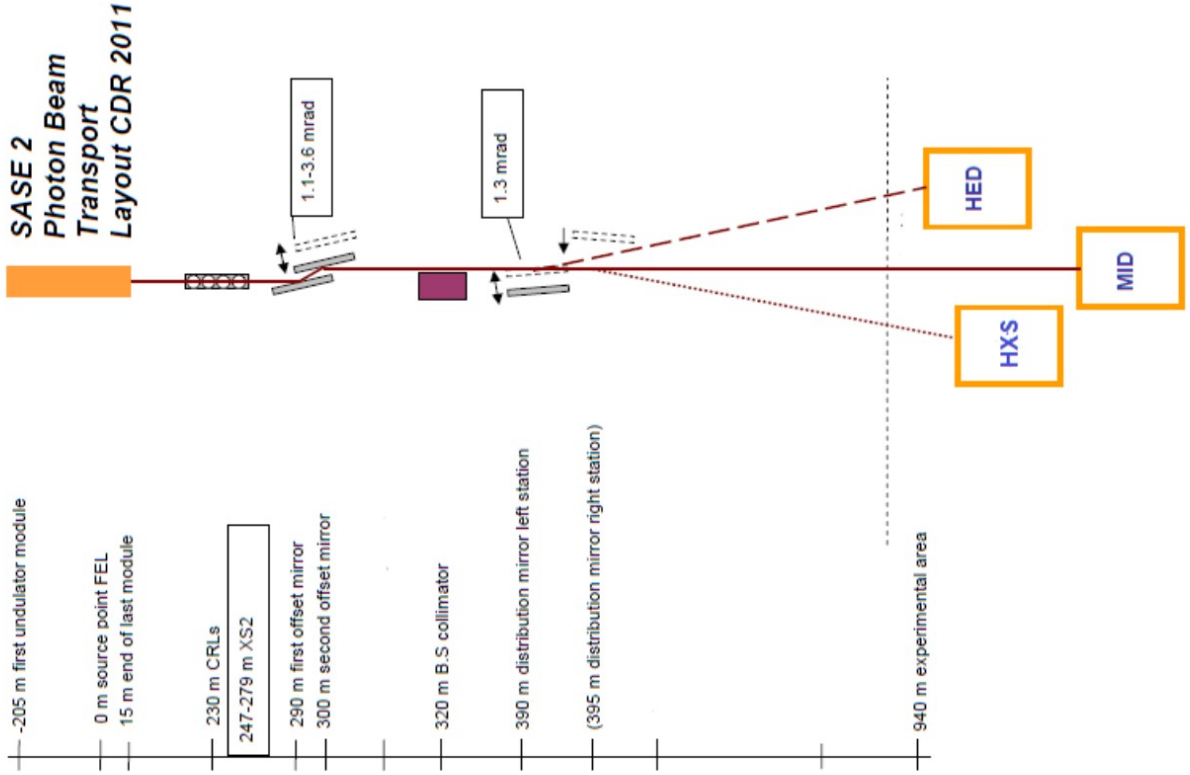
… next steps

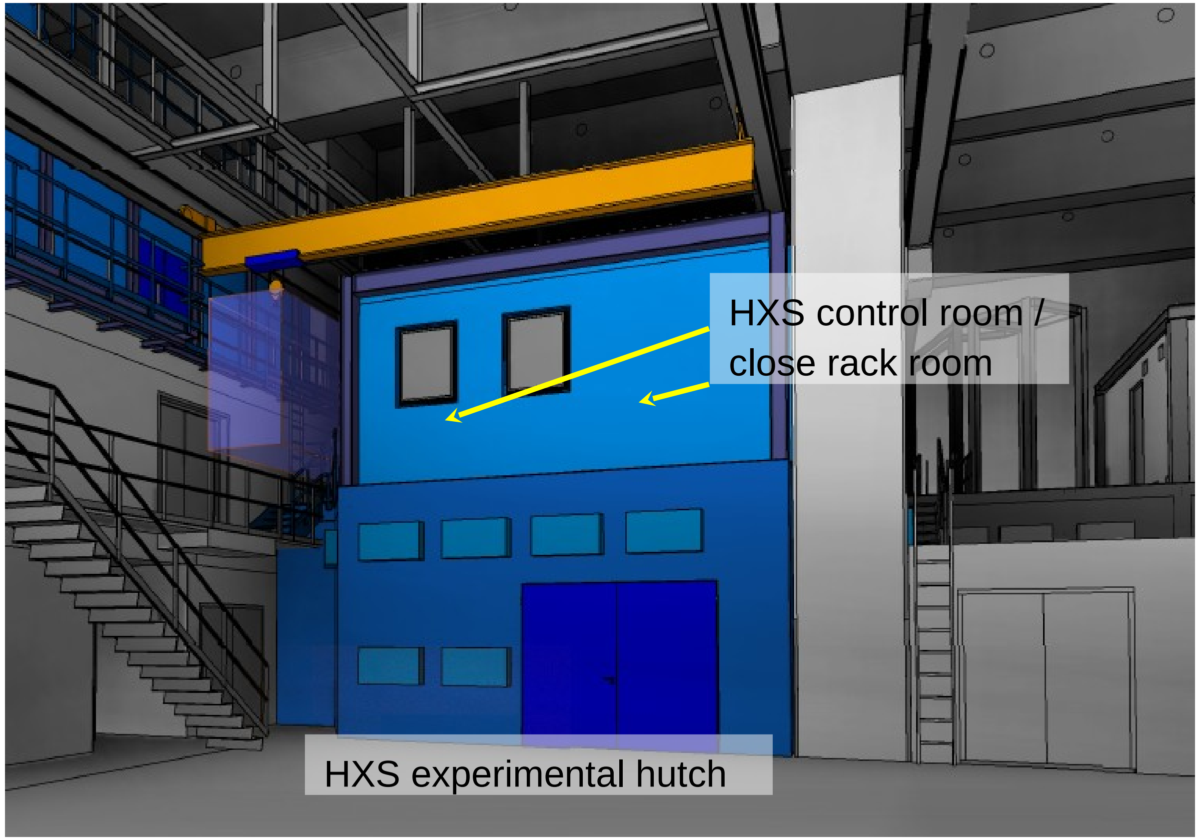
- Our main expertise are in calibration, system integration and some part of mechanics
- Take a leading role concerning mechanics and backend
- Take a more active role for the front-end development (ASIC and sensor)
  - Need to retain know-how in house
    - ► Small number of people with overview of the systems developed

- Put in place collaborations with high Z experts
  - Strengthen collaboration with more experienced groups
  - Allow us to build experience
    - ► First hand experience in testing, data analysis
    - ► Understand usability
    - ► Perform first applications
- Offer the possibility to test sensors and assemblies in EuXFEL beam
  - Dedicated limited amount of hours allocated by scientific instruments for Detector Development
    - ► Need to prioritize in agreement with the scientific instruments
    - ► Contact us (but 9 to 12 months in advance)!
    - ► No more time available for Feb-June 2024

Third port of SASE2 approved for construction in 2025

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

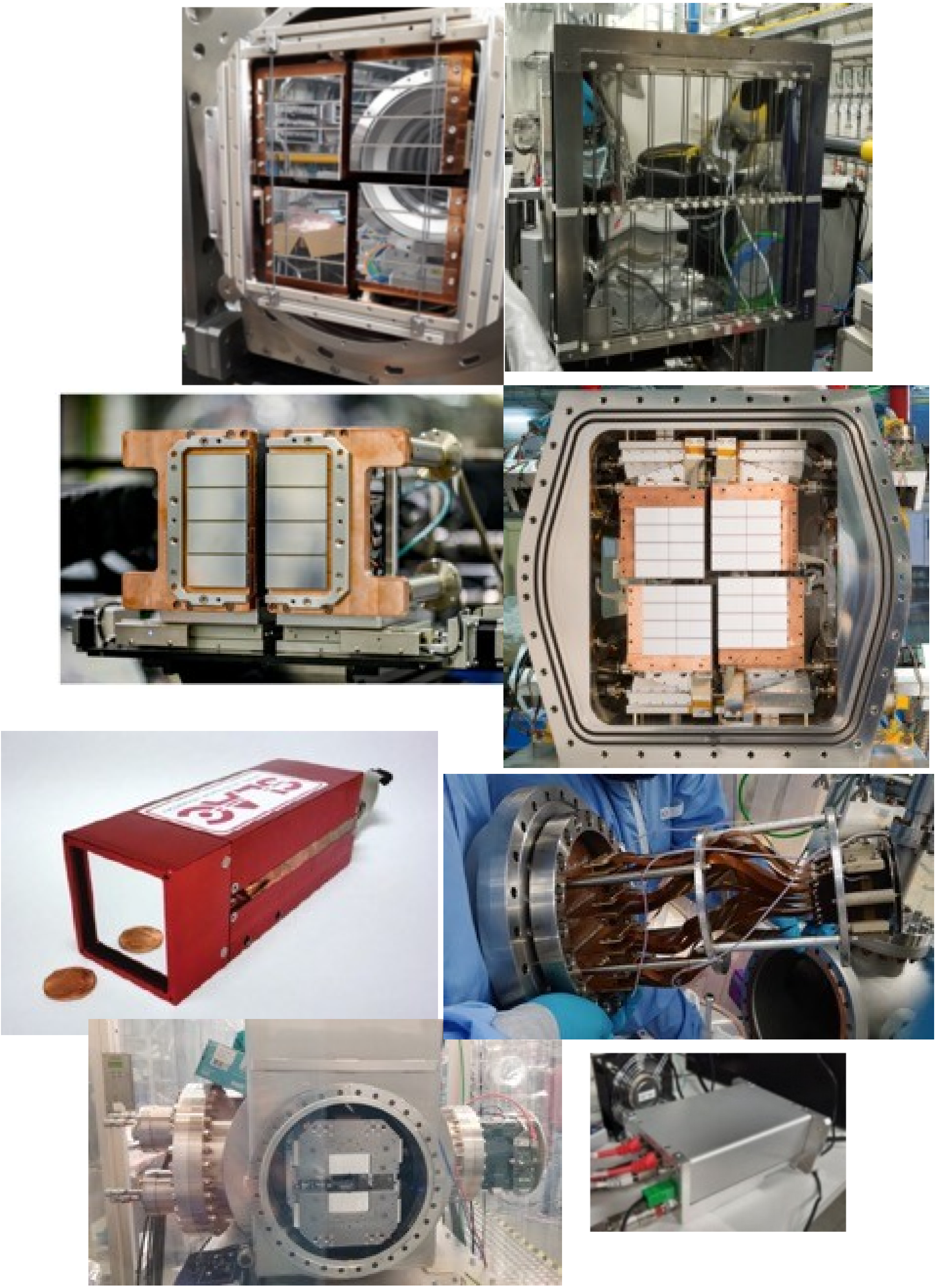




- ***Can offer extra possibilities for detector testing***

Conclusions

- European XFEL is starting its detector development
- Requirements are being defined
  - Photon energy up to 30 keV
  - ~ 5 × 10^3 photons/pixels dynamic range
  - MHz-level burst frame rate
  - Pixel size ~100 µm
- Put in place collaborations with high Z experts
  - Strengthen collaboration with more experienced groups
  - Allow us to build experience
- We offer to collaborate on beam time
  - Limited amount of hours for now
  - Possibly more in the future



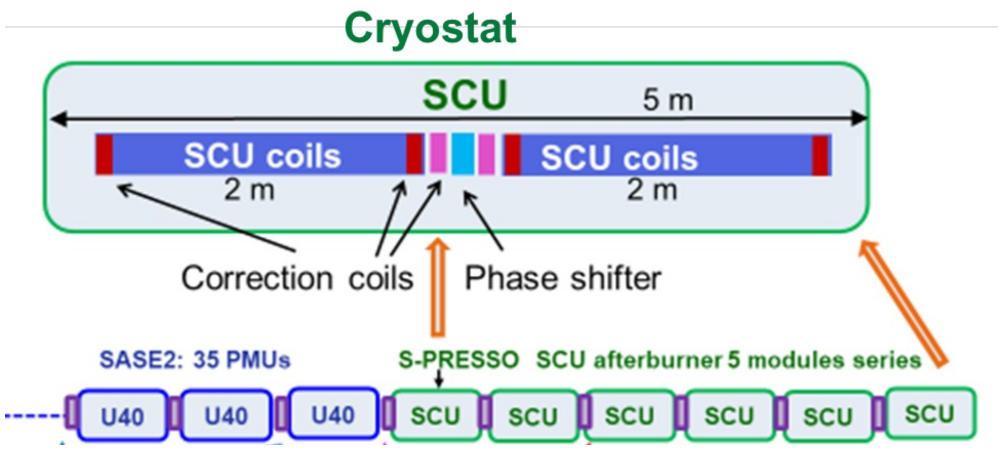
Backup

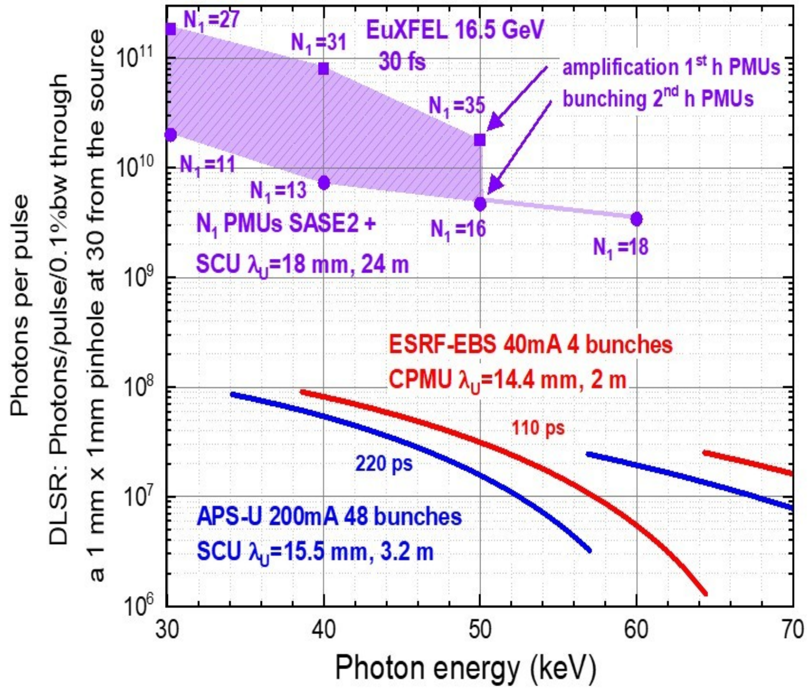
Facility developments: SCU system

- Electron beam energy > 16.5 GeV
- Estimated range of photons per pulse achievable by tuning the SCU afterburner to amplify
  - the output of the fundamental of the PMUs
  - the bunching of the second harmonic of the PMUs
- Peak flux ~100 x higher than HE diffraction-limited SR sources
- Large dynamic range detectors needed!

Normalized emittance	0.4 mm mrad
Initial energy spread	3 MeV
Current	5 kA

The simulations do not consider wake fields and tapering. A flat top 3 fs bunch is considered





Slide courtesy of Sara Casalbuoni and UND group of EuXFEL