# Detectors for the European XFEL

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for the Detector Group

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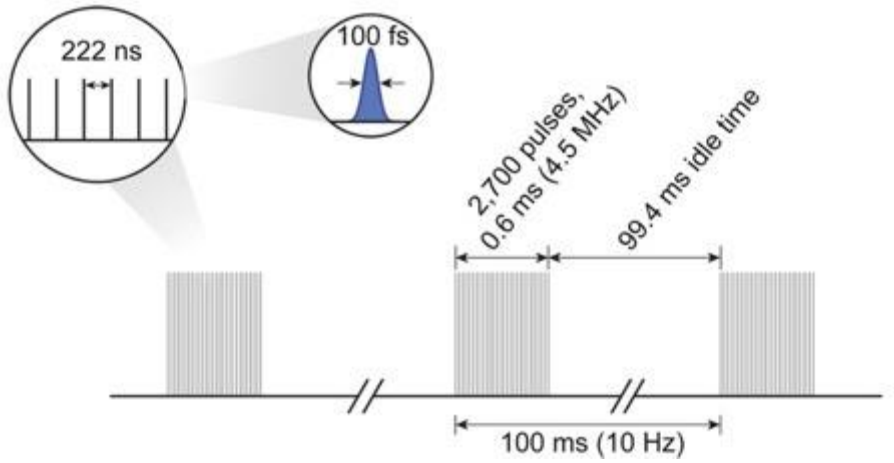
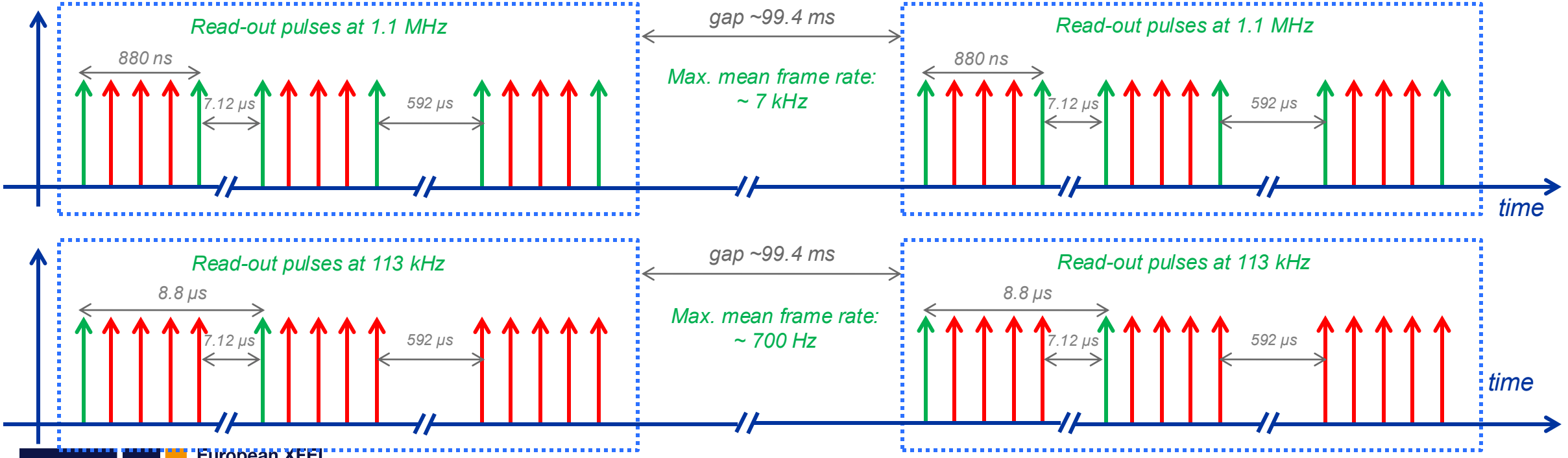
# Detector challenges at the EuXFEL

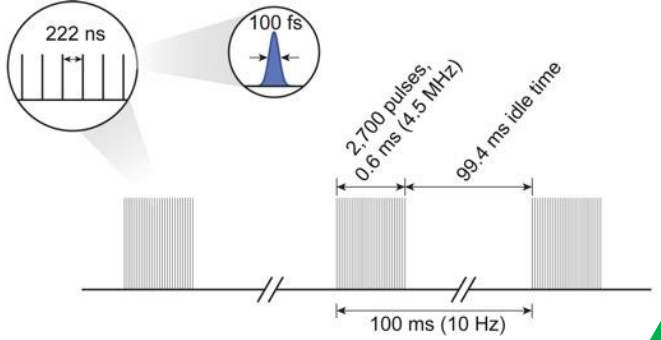
- High dynamic range, low noise, radiation resistance, reliability
  - Same as for other FELs
- The time structure of the machine is unique:
  - burst mode operation, with pulses arriving at max 4.5 MHz frame rate
  - 99.4 ms interval between the 0.6 ms bursts, 10 times per second
  - typical experiment rates 0.5-1.1-2.2 MHz




Burst duration in a 0.1 s interval



# Detectors for EuXFEL




*X-ray energy*

Hard X-rays 6-25 keV

Soft X-rays 0.5-3 keV

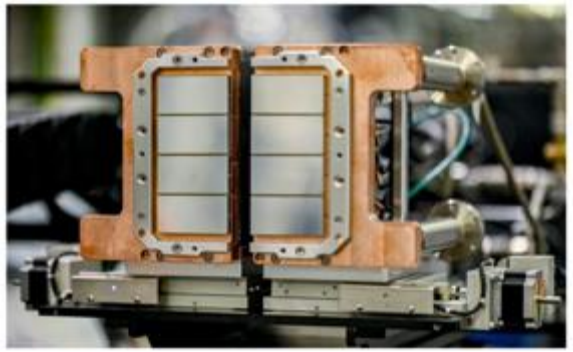
10 Hz

*Rate*

4.5 MHz

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

**ePix100 (2 instruments)**

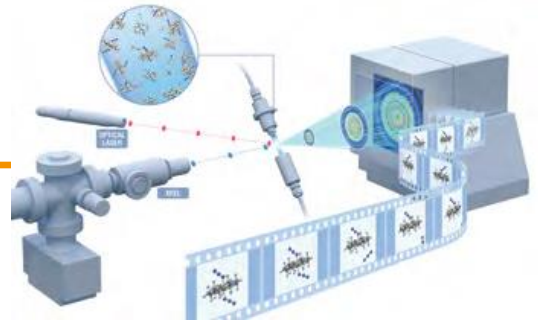


**Jungfrau x 18 (all hard X-ray inst.)**
Noise: 80 e- (HG)
Dyn range: $10^4$ 12 keV ph

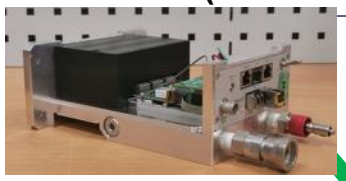
**pnCCD (1 instrument)**

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

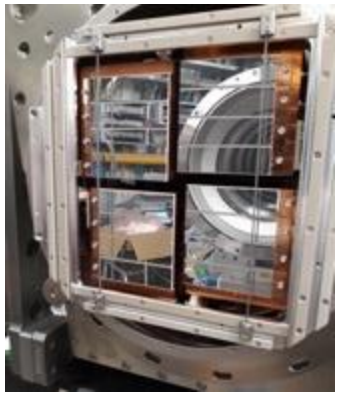
Low noise to see low energy photons
High dynamic range to see many photons in the same pixel



**Gotthard-II (all instr.)**

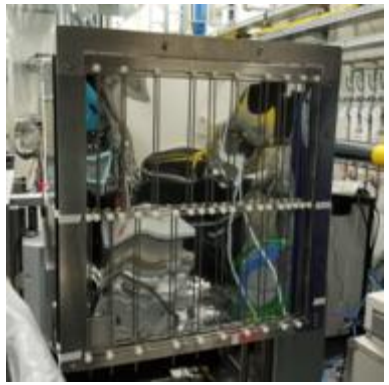


**AGIPD (3 instruments)**



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

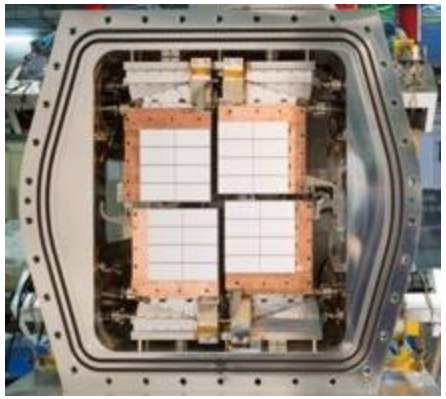
**LPD (1 instrument)**



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

***EuXFEL specific!***

**DSSC (2 instruments)**



Noise: 40/60 e-
Dyn range:
N x 256 ph @ 4.5 Mhz –
N x 512 @ f≤2.2 MHz
N ≤ 1 for single ph sens.

# Detectors at the EuXFEL

- European XFEL started operation in 2017
  - Pixelated MHz cameras developed specifically for the facility are in use until then
  - Deployed for many different scientific applications
  - Damages mainly due to radiation damage
  - Aging effects start to become apparent

# Status of the detector development programme at the EuXFEL

- Goal: develop the next generation of detectors for the European XFEL
  - Requirements and specs have been defined according to indications from the instruments
  - Main differences wrt the present generation:
    - ► smaller pixels, ca 100 um pitch
    - ► need to detect harder X-rays: high-Z material sensors
- The detector development program (Phase I) was approved and funded at the end of 2022
  - Dedicated personnel started mid of 2023
- The European XFEL DET group is going on with the plans of
  - increasing expertise in specific areas (sensors, ASIC, electronics, mechanics)
- Phase II is meant to design, produce and test the building blocks of the next generation detector
  - budget defined, submitted for approval these days

# Pixel size and new materials are the main cha(lle)nge

## Our existing detectors largely achieve the specs we set also for next generation

Hard X-ray detector

| | Target values | Possible variant |
|---|---|---|
| **Sensitive Energy Range** | 5-13 keV[1] with Si<br>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.<br>~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 | |

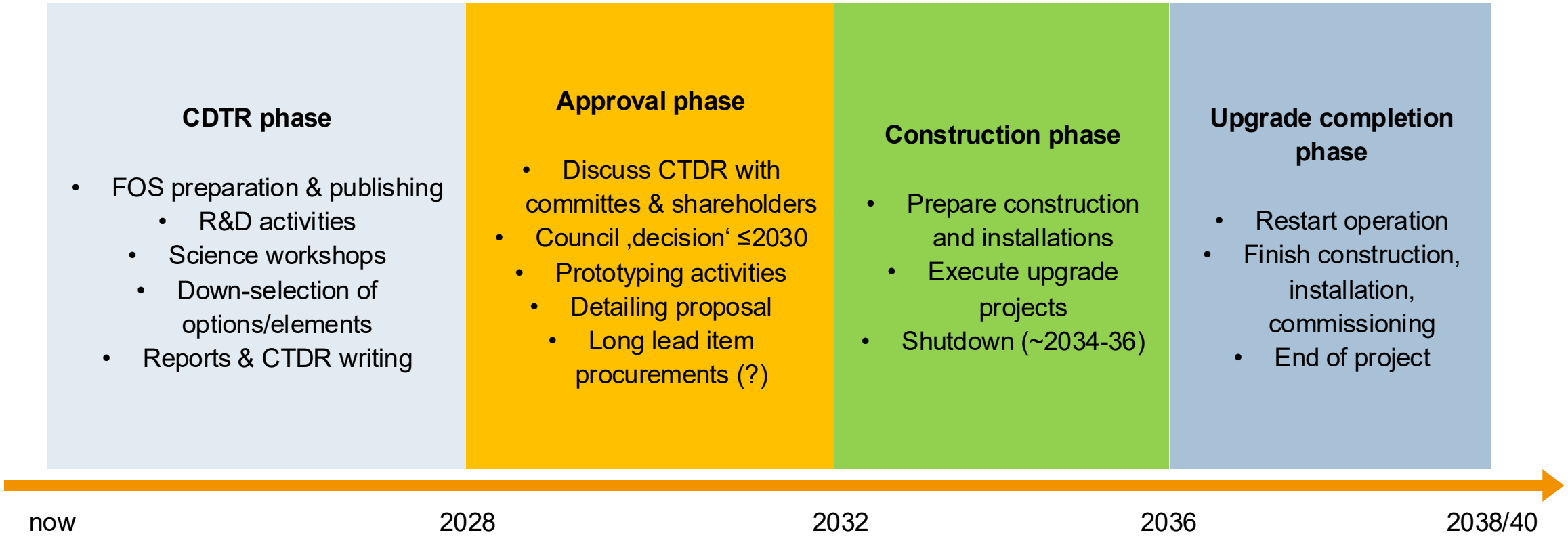
Soft X-ray detector

| | 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<br>~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.*

# Time line European XFEL upgrade



# Time line European XFEL upgrade

## Focus on burst mode until 2036-40

**CDTR phase**

- FOS preparation & publishing
- R&D activities
- Science workshops
- Down-selection of options/elements
- Reports & CTDR writing

**Approval phase**

- Discuss CTDR with committes & shareholders
- Council ‚decision' ≤2030
- Prototyping activities
- Detailing proposal
- Long lead item procurements (?)

**Construction phase**

- Prepare construction and installations
- Execute upgrade projects
- Shutdown (~2034-36)

**Upgrade completion phase**

- Restart operation
- Finish construction, installation, commissioning
- End of project

now 2028 2032 2036 2038/40

# European XFEL detector platform

## XAPPHIRE: Detector platform sharing the same data format, DAQ, control, interlock, mechanics as much as possible, and part of the front end

- **Start from baseline versions for soft and hard+very hard X-rays applications**
  - soft X-rays: sensor needs different, lower capacity for the same dynamic range, maybe more memory?
  - hard X-rays: radiation hardness critical (for Si sensor), high capacitance for signal storage, maybe less memory cells
    - ► for very hard: likely e-collection needed
- **Define how to deal with soft, hard and very hard X-rays, keeping as much as possible in common**
  - develop as many common ASIC blocks as possible (common design starting from ADC?)
  - backend electronics in common
  - mechanics allowing easy exchange of modules is a must
- **Focus on burst mode given the timeline**
  - Prepare also development for HDC with lower priority

# European XFEL detector platform: XAPPHIRE specs

| | Soft / Tender X-rays | Hard X-rays |
|---|---|---|
| ***Photon Energy*** | 250 eV - 6 keV | 6 keV- 20 keV |

| ***Readout*** | |
|---|---|
| pulse structure | burst |
| train duration | ~ 1ms |
| max rate | 2.2 MHz |
| min rate | 200 kHz |

| ***Pixel size*** | 100 µm x 100 µm |
|---|---|

| ***Input dynamic range*** | |
|---|---|
| with single ph res (5 LSB / ph) | ~200 |
| max dynamic range (0.2 LSB / ph) | ~5000 |

| ***Target noise*** | 40 el. rms | 330 el. rms |
|---|---|---|

| ***Sensor*** | | |
|---|---|---|
| Full size format | 256 x 512 | |
| type | MiniSDD / Si diodes | Thick Si diodes |

| ***ASIC*** | | |
|---|---|---|
| **Technology** | under investigation: 28 nm or 22 nm | |
| **Full size format** | 128 x 128 | |
| **Analog Channel** | | |
| Preamplifier | CSA | |
| Filter | Trapezoidal | |
| gain settings | position dependend selectable gains | |
| dynamic gain switching | to be investigated | |
| **ADC** | | |
| number of bits | 10 | |
| architecture | under investigation | |
| **Memory size** | >800 | >512 |
| **Serializer** | ~2 GBit/sec | |

# And what is the goal?

- EuXFEL has the best idea of what is needed for operation and performance
  - Operation must be easy and handy
  - Access to new operation modes must be easy
  - Calibration must be redone fast
  - Repairs must be fast
  - Robust safety mechanisms must be put in place

- This affects essentially all aspects of detector design
  - Operation must be easy and handy
  - Access to new operation modes must be easy
  - Calibration must be redone fast
    - ► ASIC, f/w...
  - Repairs must be fast
    - ► Mechanics
  - Robust safety mechanisms must be put in place
    - ► Backend electronics, power system, mechanics, cooling…

***EuXFEL to take full responsibility and coordination of the EuXFEL tailored detector development project***

***EuXFEL to take full ownership of mechanics and cooling***

***EuXFEL to play a significant role also in***
***- electronics and f/w design***
***- ASIC design***
***with fruitful collaborations with partners***

***Goal is to have variants of detectors covering different applications within the same platform***
***→ need to clearly define interfaces***

# And what is the goal?

- As in the past, the new EuXFEL detector development program would greatly gain from collaboration with DESY, leveraging synergies to enhance our collective efforts.

- The fields were we would mostly benefit from a collaboration with DESY are the following:
  - ASIC design
  - electronics design
  - hard X-ray sensors

# *Thank you!*