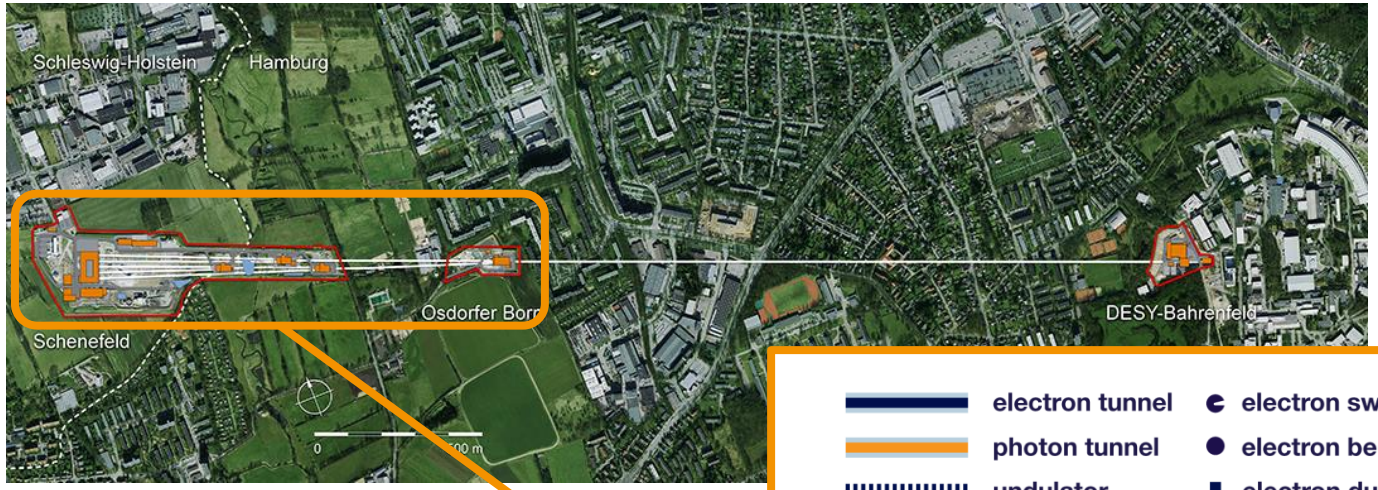
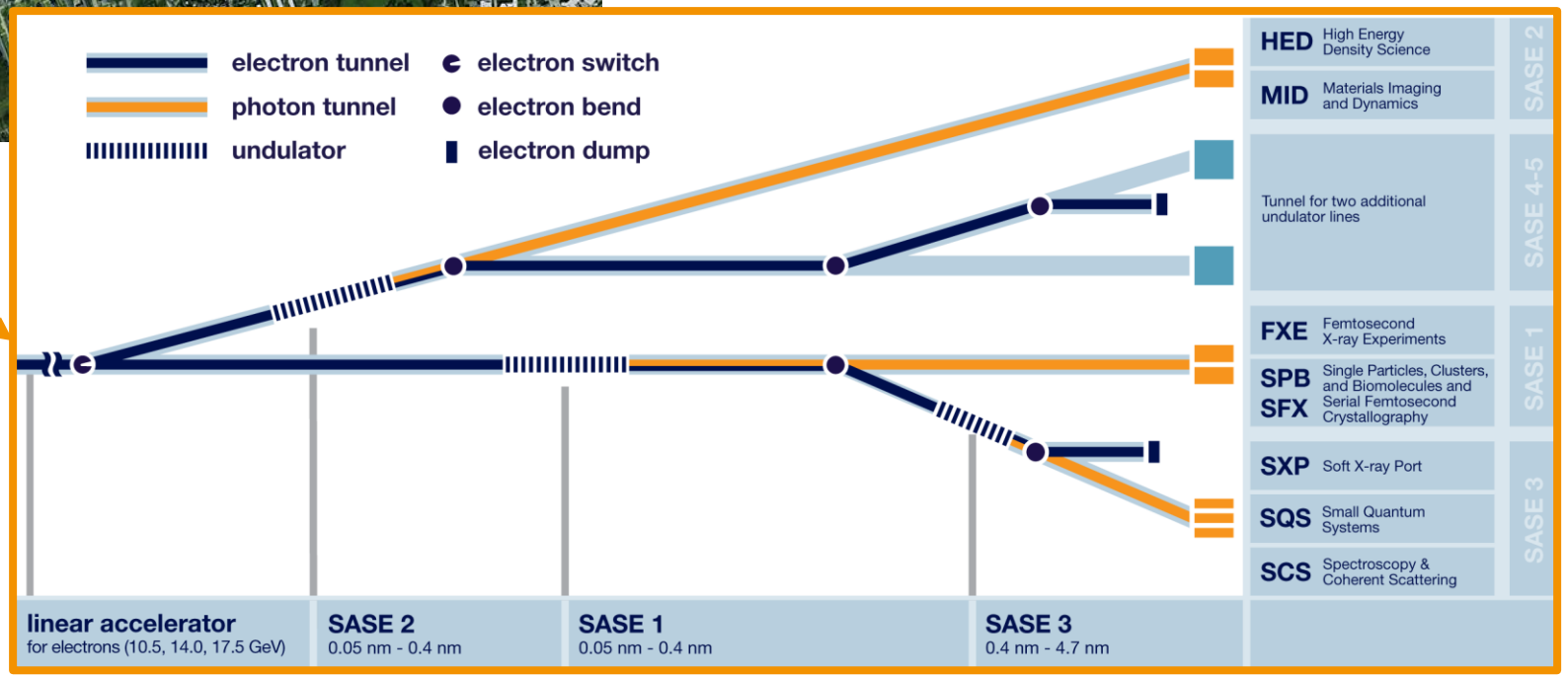
High Pulse Rate Experiments at the European X-ray Free-electron Laser

Romain Letrun
On behalf of the EuXFEL instrument groups

Luzern, 30.08.2023
67th ICFA Advanced Beam Dynamics Workshop on Future Light Sources: FLS 2023

EuXFEL instruments overview





Motivations for higher pulse rate

- Reduction of data acquisition time
  - Quickly reach sufficient signal-to-noise ratio
  - Evolution of existing techniques and development of new methods
  - Enlarge the scientific community
- Collection of very large datasets
  - Required for experiments with low hit rate
  - Classification into data subsets
  - Advanced data analysis methods
- Systematic studies
  - Lacking due to scarcity of beamtime

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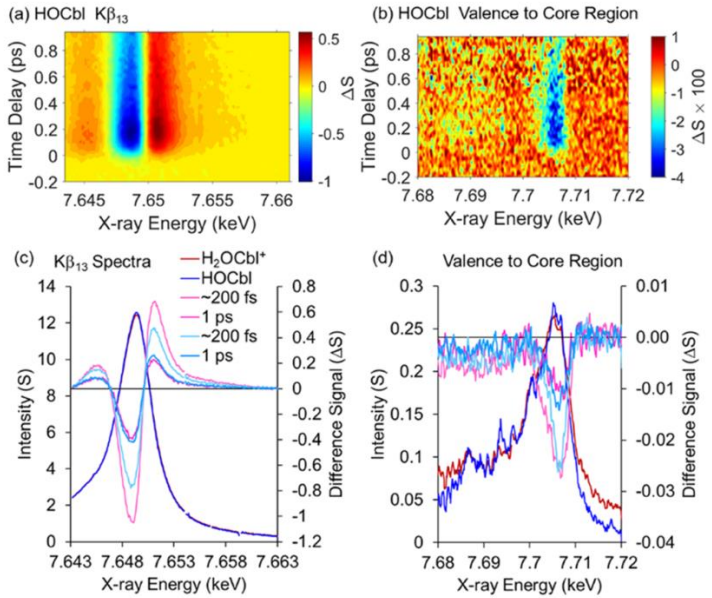

Sension *et al.*, *JACS* **145** 14070–14086 (2023)

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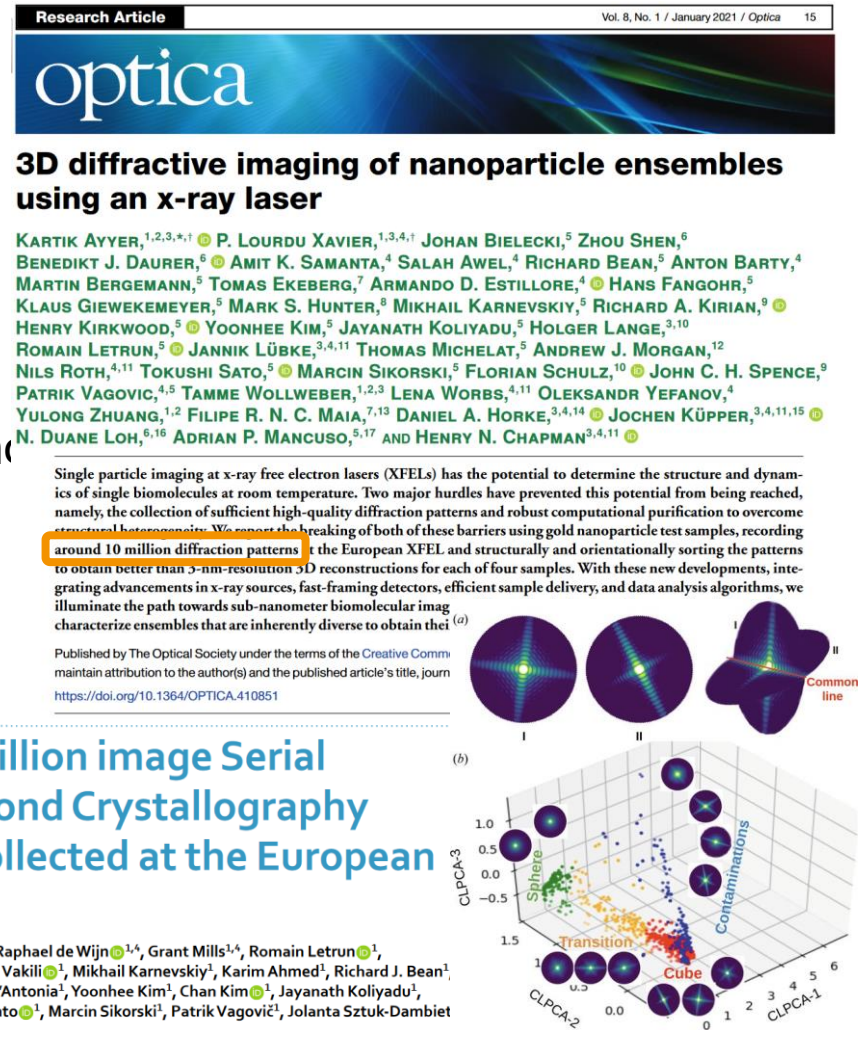
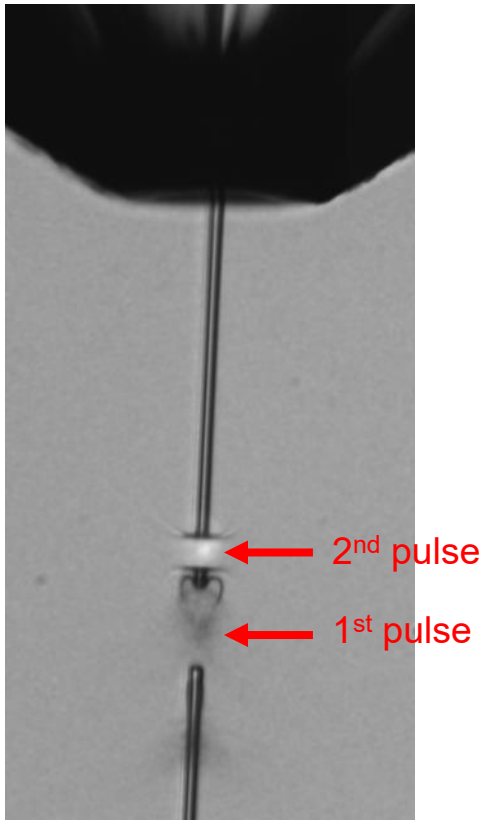


Ayyer *et al.*, *Optica* **8**, 15–23 (2021)
Zhuang *et al.*, *IUCrJ* **9** 204–214 (2022)
Kirkwood *et al.*, *Sci. Data* **9** 161 (2022)

Sample delivery for high repetition rate XFELs



Liquid/aerosol/gas phase samples

- High jet velocity (≥50 m/s for 1.1 MHz)
  - very high sample consumption
  - velocity limited for thick or viscous jets

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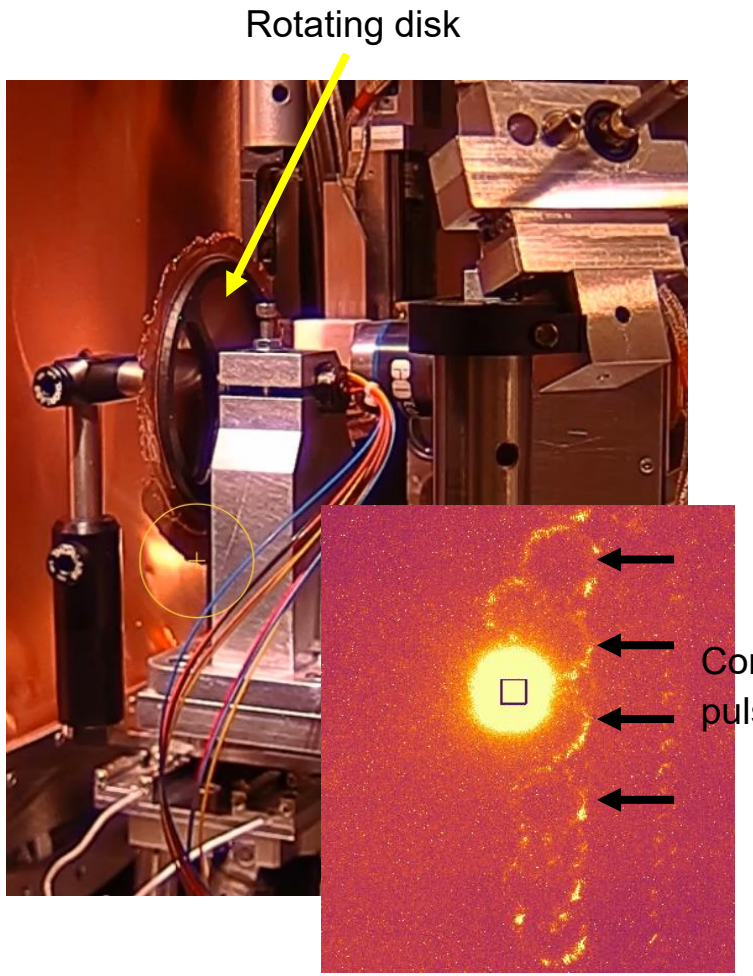

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Solid state samples

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  - not applicable to all samples

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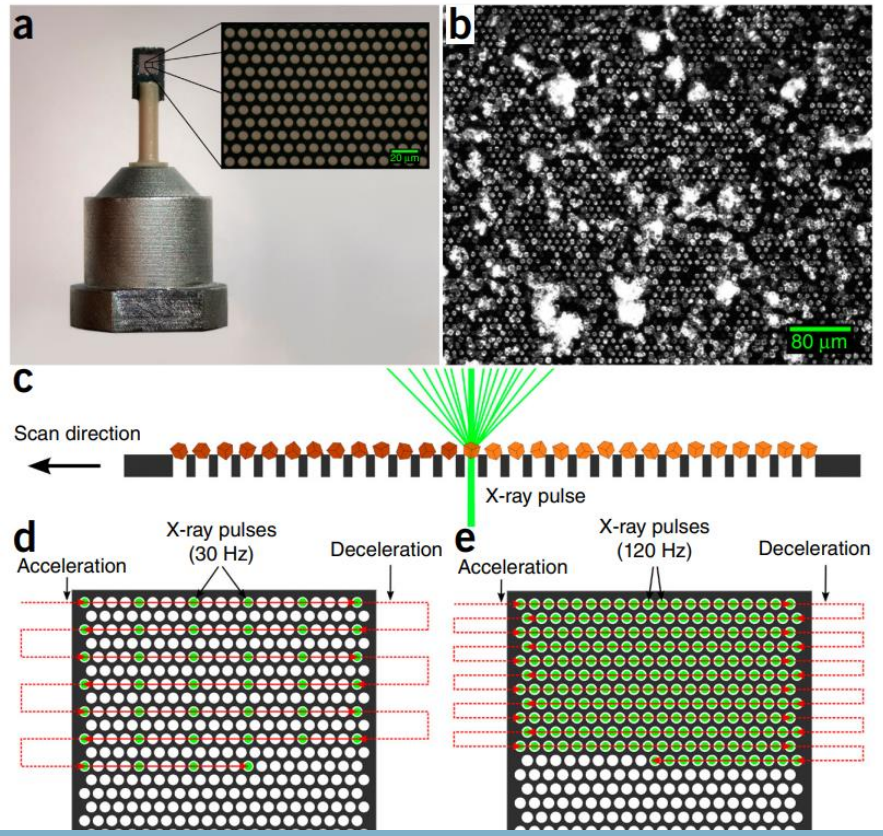

Already complex at low repetition rate

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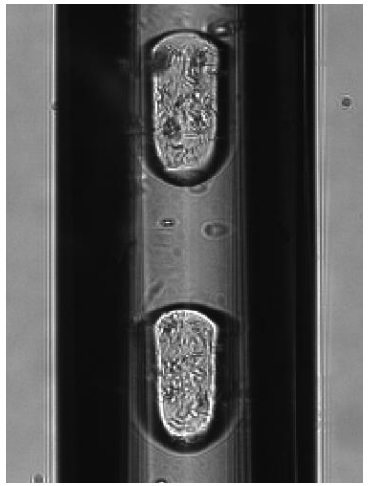
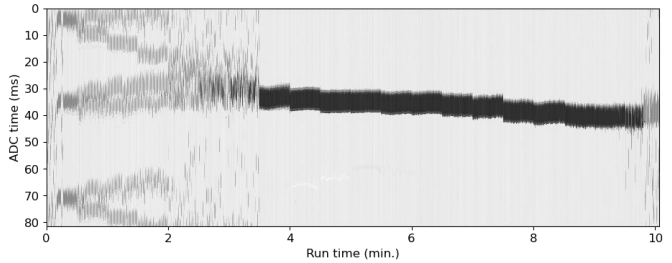
Roedig *et al., Nat. Methods* **14**, 805–810 (2017)

MHz burst mode operation at EuXFEL – A blessing and a curse

- High sample wastage (>99.4% at EuXFEL) for liquid/aerosol jet experiments where sample cannot be recirculated. Those experiments also have an inherently low hit rate (0.1% - ~10%)
  - New sample delivery methods under development, but not yet routine
- Undesirable effects with solid state samples, e.g., heating/cooling strain
- Present 2D area detector technology is trade-off between on-chip memory and pixel size
  - Development ongoing along with better use of existing detectors, e.g. event vetoing
- User data storage
  - Data reduction effort in progress, need to change mindset of users

Aqueous sample droplets in oil at 10Hz





Courtesy of A. Ros, ASU

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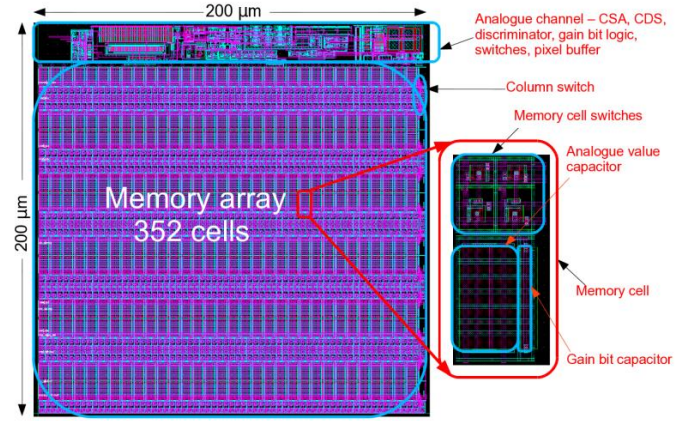
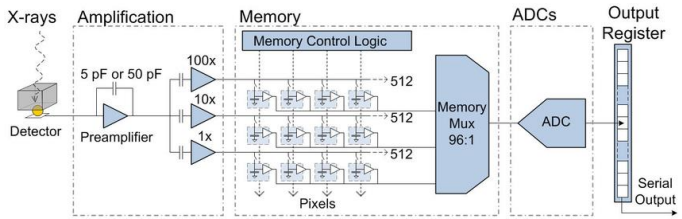
AGIPD detector, 200 µm pixels
352 memory cells up to 4.5 MHz



LPD detector, 500 µm pixels
512 memory cells up to 4.5 MHz



Allahgholi *et al., JINST* **10** C01023 (2015)
Koch *et al., JINST* **8** C11001 (2013)

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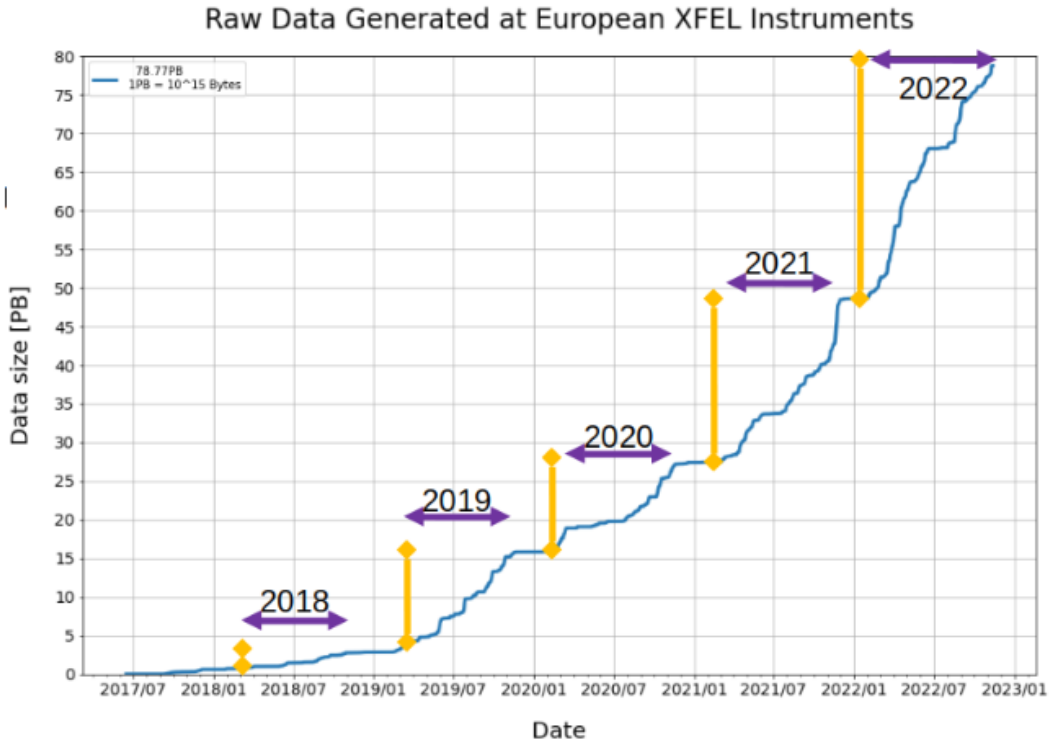
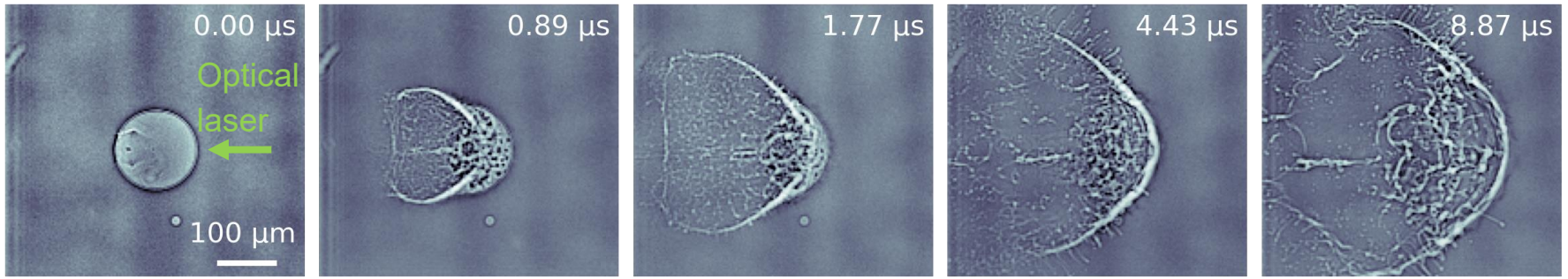
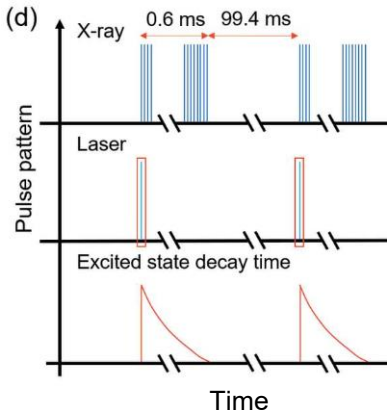


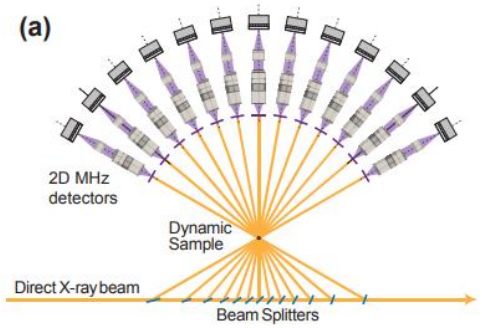
MHz burst mode applications

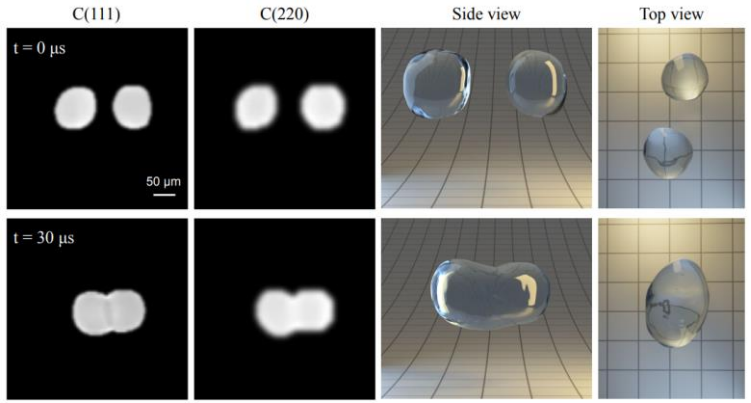
Dynamics on microsecond timescale - Time grid defined by pulse period

Time-resolved X-ray microscopy







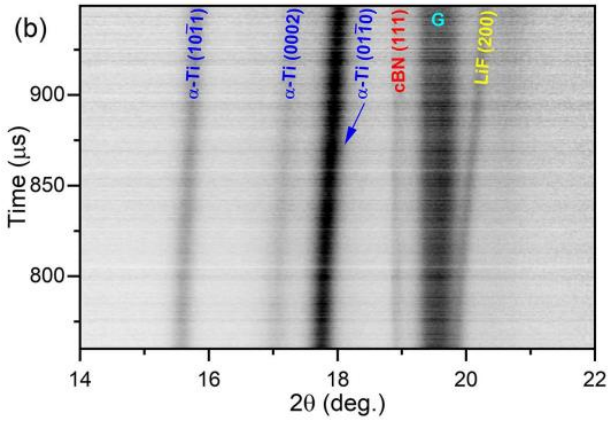


Reuter *et al.*, under review
Villanueva-Perez *et al.*, under review

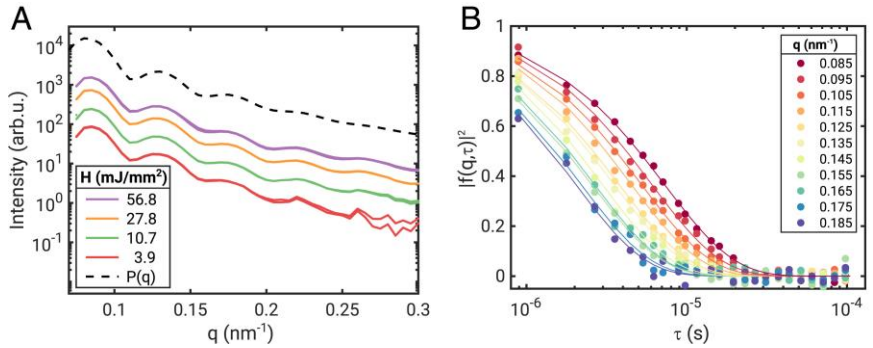
MHz burst mode applications

Dynamics on microsecond timescale, but also femtosecond timescale

Dynamic compression



X-ray photon correlation spectroscopy



Husband *et al., J. Synchrotron Rad.* **30** 671-685 (2023)
Lehmkühler *et al.,* PNAS **117** 24110-24116 (2020)

Towards higher duty cycle operation

10s to 100s kHz CW or long burst operation

- Would support many classes of experiment
  - Relaxed sample delivery requirements, reduction of sample wastage
- Longer burst: easier to accommodate independent RF regions for each beamline → increased flexibility

MHz CW or burst operation

- Leveraged by a limited number of experimental techniques at the moment, but has opened up new opportunities
- Applications specific to MHz burst mode

Not a one-size-fits-all!

Acknowledgements

DESY accelerator team

EuXFEL instruments and technical groups

EuXFEL users community