Laser Pulse Arrival Time Measurements for User Experiments at FLASH and EuXFEL

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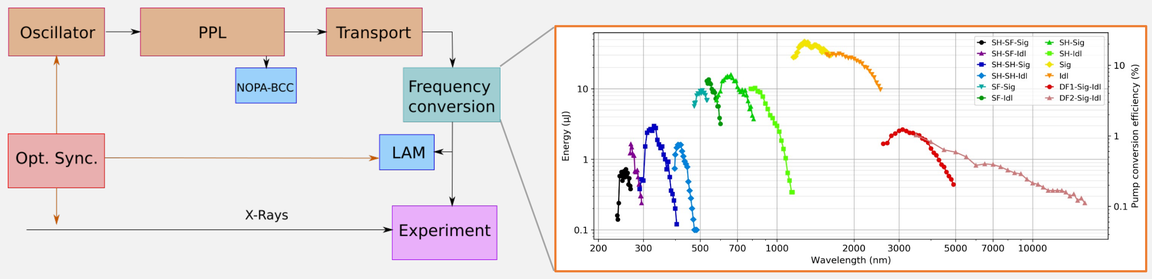
Goal

- improving the status quo: optical laser against photon (X-ray) arrival stability:
  - sub-15 fs rms (uncorrected, short-term)
  - sub-10 fs rms (corrected, very short-term)
  - with ~5 fs electron arrival time stability
- **laser arrival pulse time in the same range!**

Requirements and Challenges

- sub-500 as LAM sensitivity
- intra-burst single-pulse resolution
- burst–to-burst drift compensation
- full integration into control system



End-Stations

- peculiarities of each end-station
  - use of PP or instrument-specific laser
  - location of LAM w.r.t. interaction point
- wavelength and pulse energy changes

Optical Design

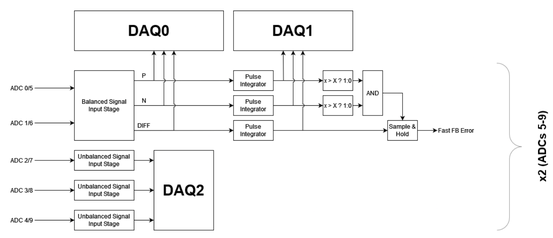
- **broad wavelength coverage**
- ultra-short pulse duration (15 fs - 50 fs)
- pulse-on-demand pattern
- large pulse energy variation within a run

Detectors

- high sensitivity, low-noise
- high bandwidth to resolve 4.5 MHz pulses
- large wavelength coverage
- small analog signal from LAM to ADCs

Firmware Specification

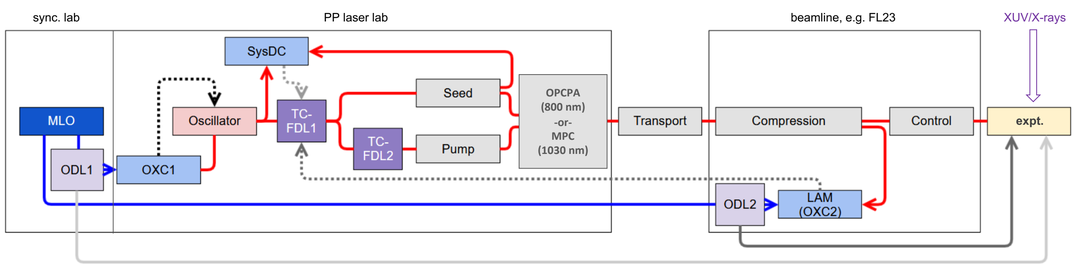
- SIS8300KU + SIS8900 combo for digitisation



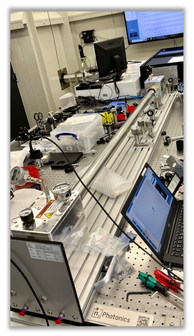
- tests at FLASH using SW-based implementation, TAMC532 digitiser

Measurement Campaign at FLASH FL23 with MPC-based Laser Delivery

- follow up on study using 800 nm OPCPA at FLASH [1]

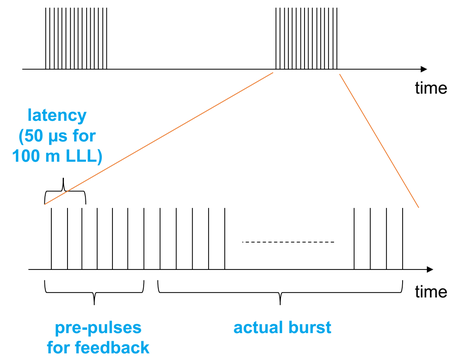


MPC	1030 nm
"n_2 photonics"	
repetition rate	100 kHz
burst rate	10 Hz
no. of pulses	82
pulse energy	few mJ
pulse duration	70 fs – 1 ps
external compressor	**gratings** (installed in MOD2.3)
FEL	**no FEL**



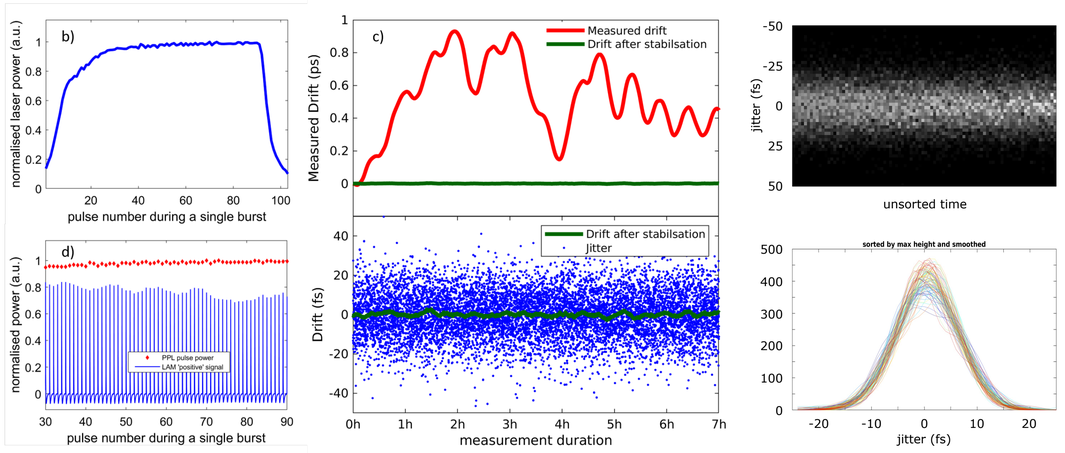
Burst-mode and Feedbacks

- burst-to-burst rate 10 Hz, up to 800 µs duration (FLASH)
- intra-burst from single pulse on demand to 2700 pulses at max. 4.5 MHz (EuXFEL)



Preliminary Results

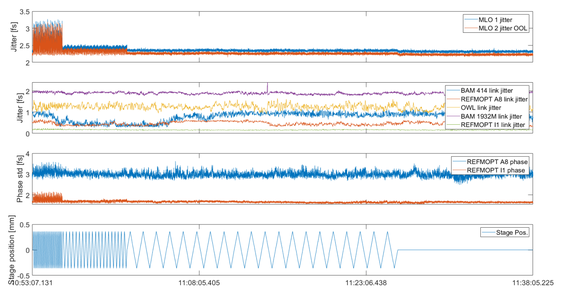
- few-ps drift over few hours
- compensated with slow feedback
- sub-30 fs laser pulse arrival time jitter
  - improvement over previous results [2]
- LAM inevitable for future user experiments



Under Investigation

- correlations of arrival time to environmental and laser parameters, e.g. τ and λ_0, $\Delta\lambda$
  - single pulse-resolved
- influence on LAM sensitivity, e.g. pointing

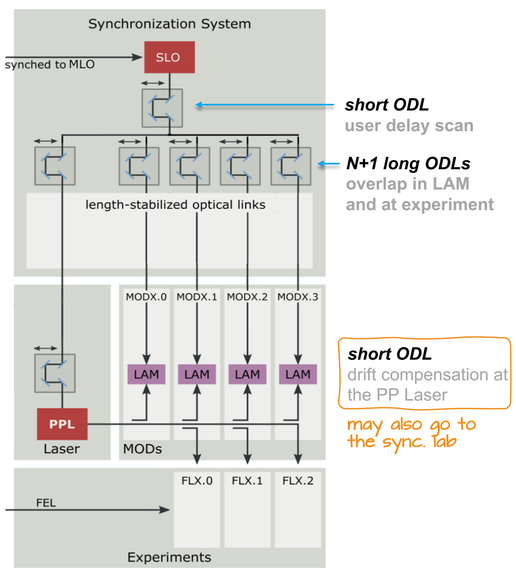
- pulse-resolved arrival time data for *a posteriori* data sorting
- slow and fast feedbacks
- **actuator choice!**
  - **piezo inertia drive**
  - air bearing
  - piezo crawler



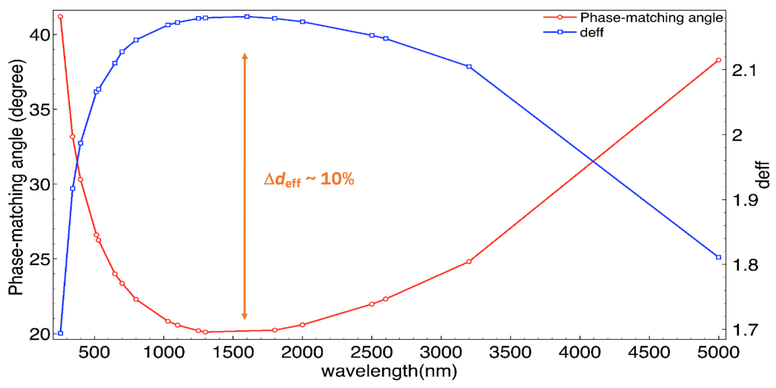
- **minimising influence on all sub-systems**
  - reasonably slow movement required

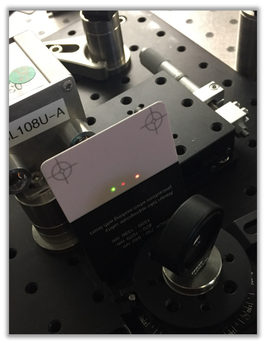
User Delay Scans

- maintaining overlap in experiment and LAM
- scan ranges
  - **few 10s of ps**
  - single data points at 100s of ps, ns
- no influence on other beamlines
- slightly different concept FLASH vs. EuXFEL
- **actuator choice?**

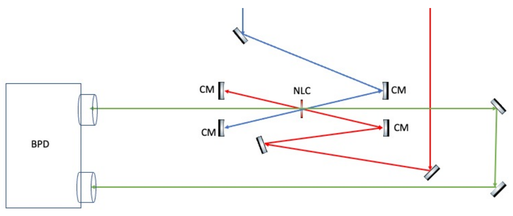


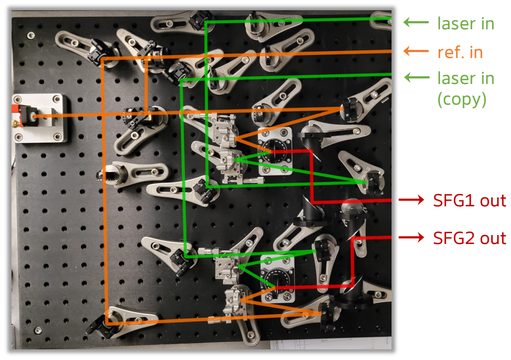
Non-collinear Cross-Correlator Geometry





- large phase-matching possible by tilting the crystal
- investigations on-going
  - 1030 nm, 515 nm and 343 nm
  - one vs. **two-crystal implementation**
  - **more robust setup and automation**





Wrap-up

- successful **measurement campaigns at FLASH (OPCPA + MPC)**
- user delay actuator defined
- progress in **FW and SW specification**
- progress **towards wavelength-tuneable balanced cross-correlators**

[1] Atia-tul-noor et al., "Sub-50 fs temporal resolution in an FEL-optical laser pump-probe experiment at FLASH2." Opt. Express 32(4), 6597-6608 (2024).
[2] A.-L. Viotti *et al.*, "60 fs, 1030 nm FEL pump- probe laser based on a multi-pass post-compressed Yb:YAG source." J. Synchrotron Rad. 28, 36-43 (2021).