First FLASH2 FEL-pplaser experiment

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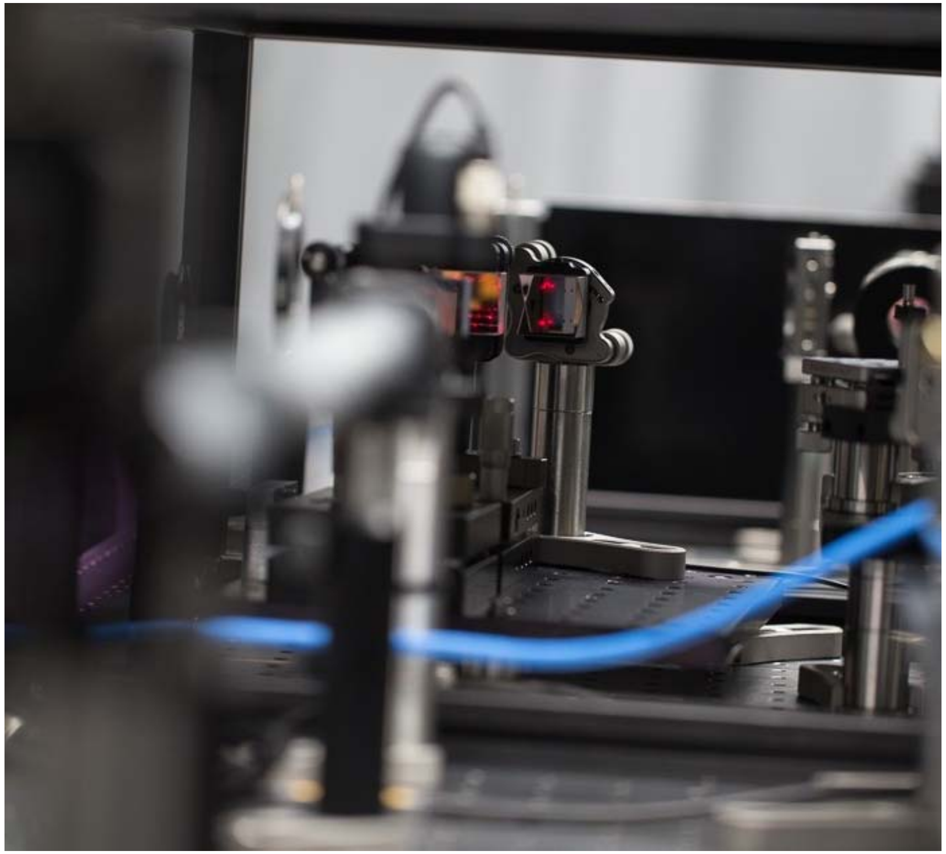
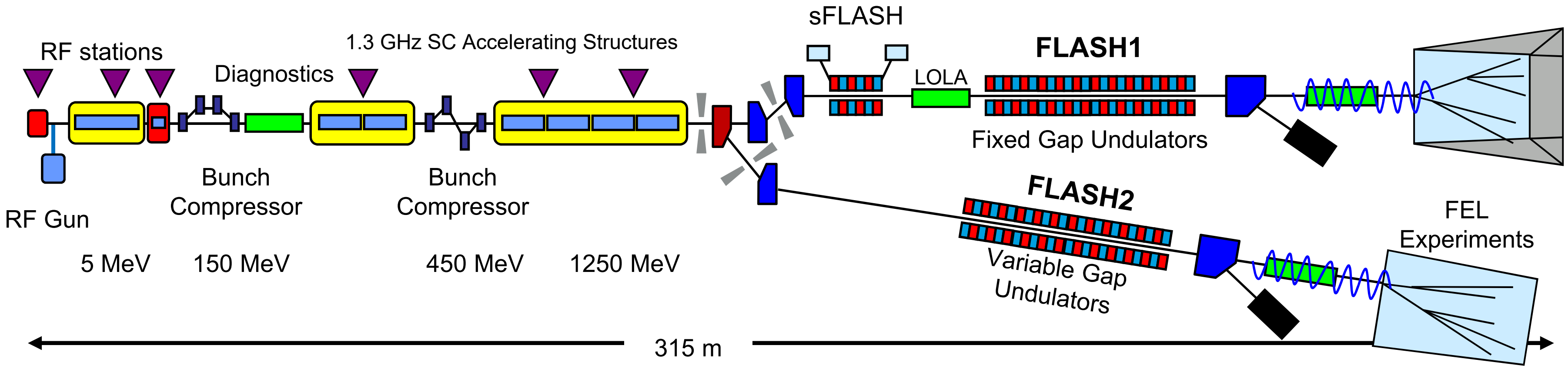
FEL Seminar
2-Apr-2019
DESY

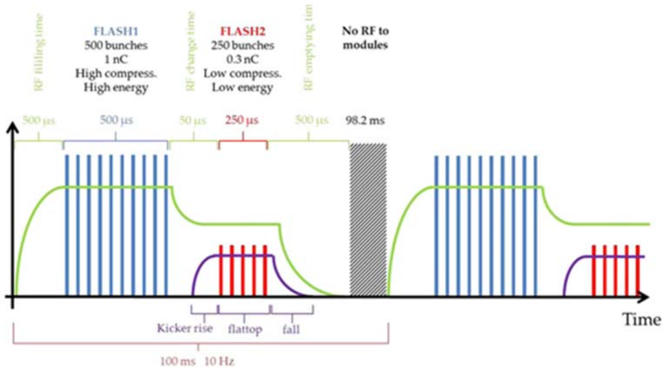
Outline

- Motivation
  - Pump probe experiments at FLASH
  - FLASH2 pump probe laser
  - Arrival time and synchronization
- Experiment
  - Xe photoionization
  - Results
  - Interpretation
- Summary + Outlook
  - Recent user experiments
  - Upcoming timing experiments
  - Improvements



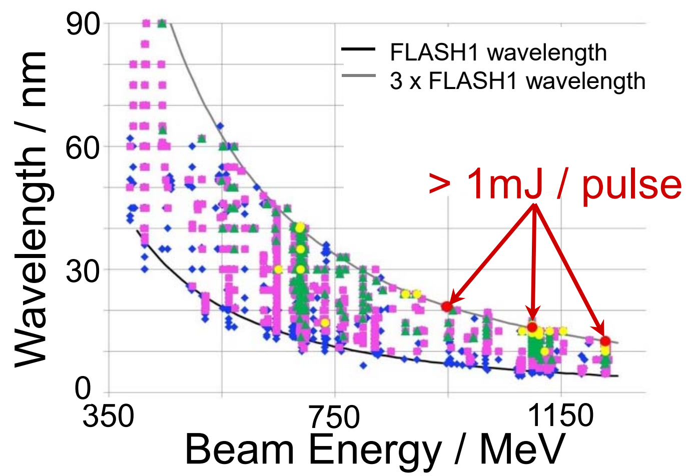
Soft X-ray FEL in Hamburg - FLASH





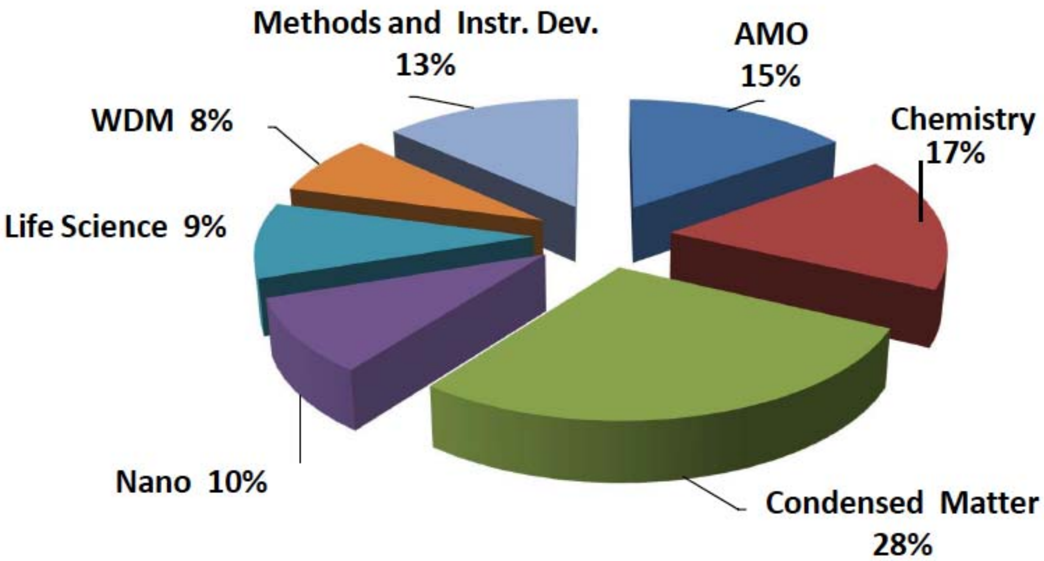
FLASH2

- Photon pulse duration 10-200 fs
- 10 Hz bursts (≤ 800 intra burst pulses)
- Fundamental photon energy 14 - 310 eV
- Beamlines 2 (up to 7)



Science at FLASH

Average over last calls



~80 % time-resolved (pump-probe) experiments

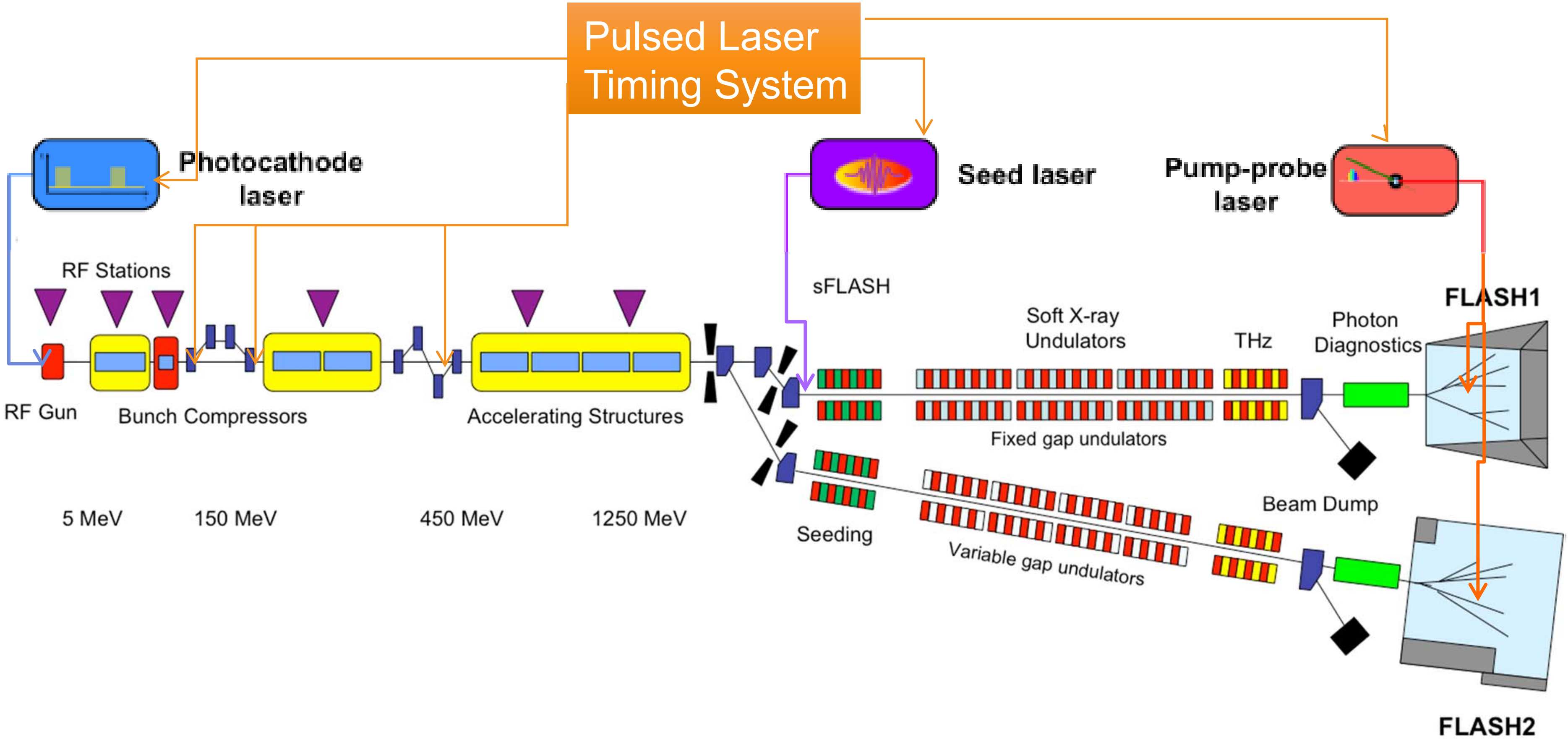
- ~ 50% Optical Laser/FEL (fully synchronised – jitter at exp. below 30fs)
- FEL/FEL (with split & delay units)
- THz/FEL

The performance of FEL and optical laser is crucial for the success of a pump probe experiment

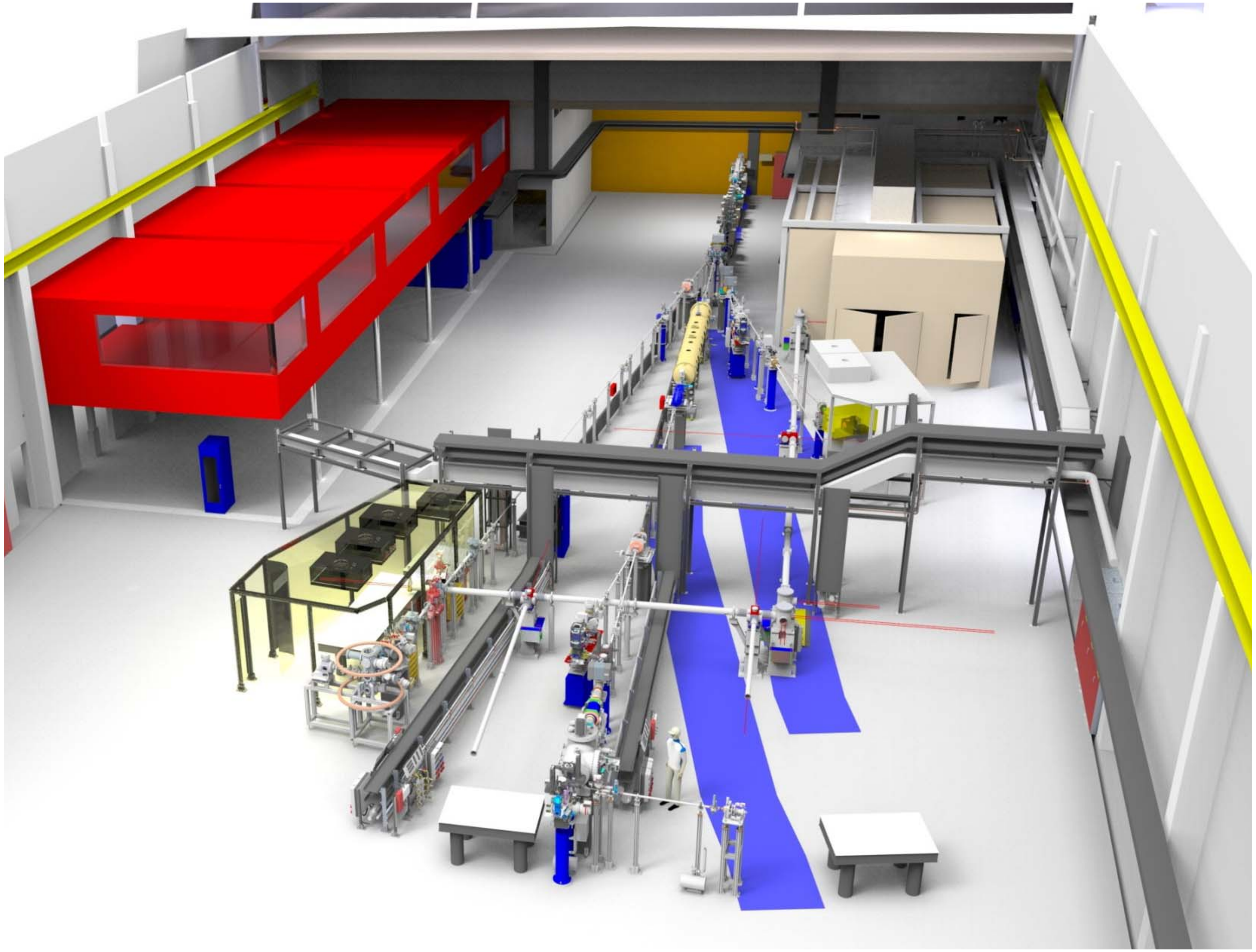
Control of:

- Wavelength
- Pulse energy
- Pulse duration
- Arrival time
- Spatial overlap

Optical lasers for FLASH

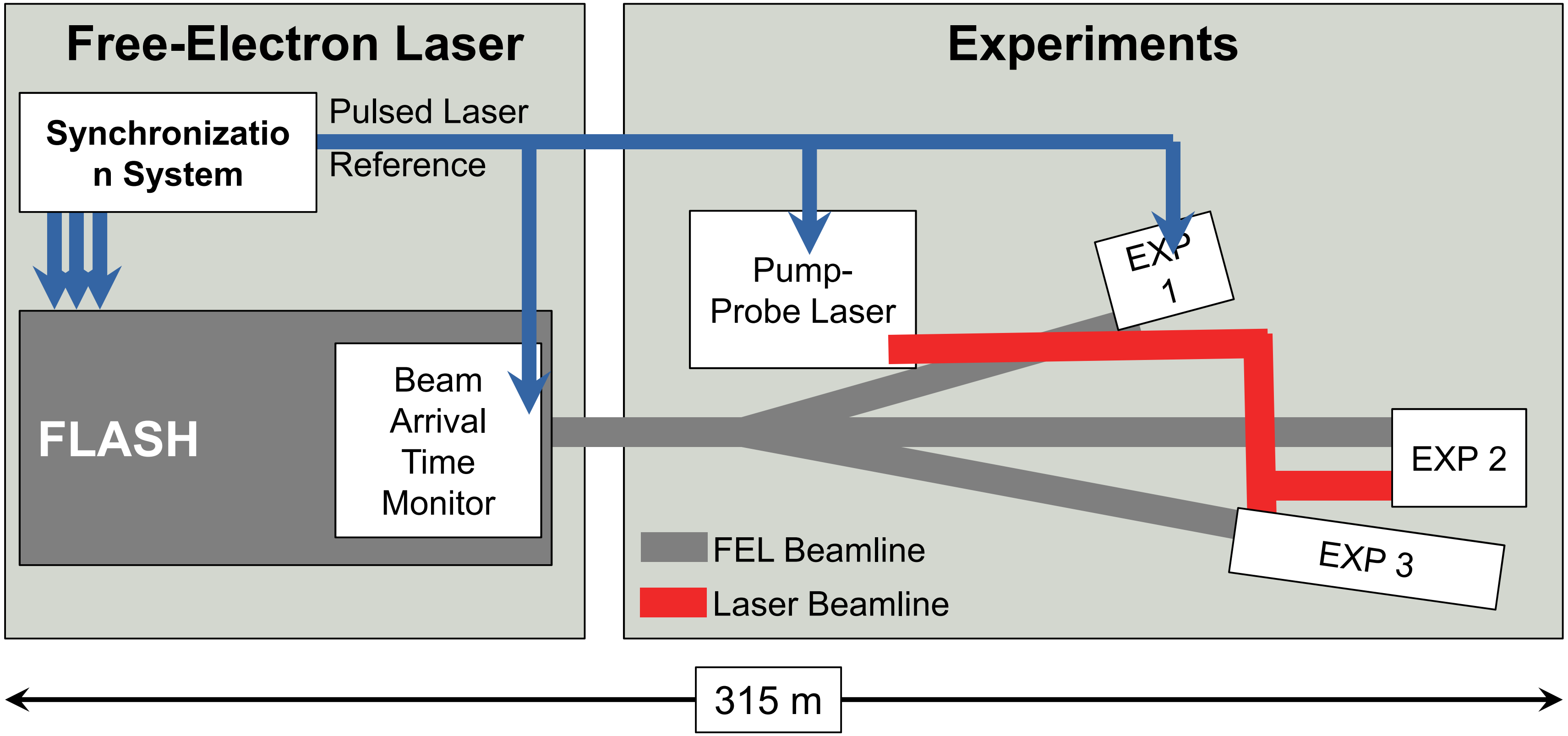


Looking into the FLASH2 hall “Kai Siegbahn”



Pump-probe Experiment @ FLASH2

Pulse arrival time stability



Required arrival time stability:
< 30 fs or 9 µm rms

~80 m Laser system + 40 m Laser Beamline

Optical path length stability: $<3 \times 10^{-8}$

Arrival time stability

Main effects

Free electron laser

- RF phases
- Beam energy
- Thermal expansion
- SASE process

Optical laser

- Refractive index of optical fibers
- Thermal expansion
- Refractive index of air
- Vibrations

Golden Rules

- Passive stability
- Measure arrival time
- Feedback loops
- Minimize uncontrolled path

Electron Bunch Arrival Monitors (BAMs)

New Pickups, Electronics and Synchronization

RF Pickup

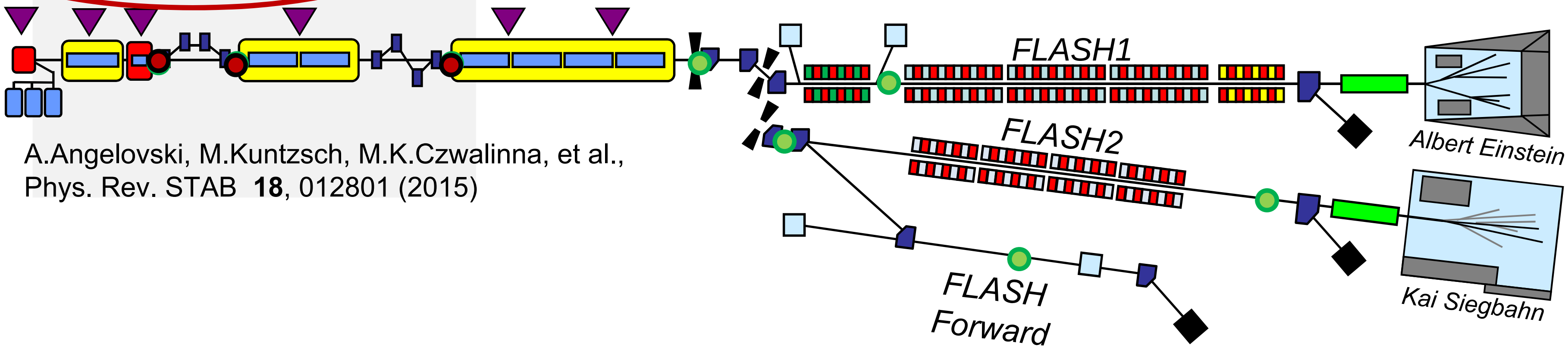
TECHNISCHE UNIVERSITÄT DARMSTADT

4 pickups in one vacuum-tight body

- **Temporal resolution: < 10fs**
- Even very low electron bunch charges used in short-pulse operation
- All individual BAMs will be put into operation one by one 2018/2019

40GHz pickups (•) installed for all BAM locations at FLASH (07/2018)

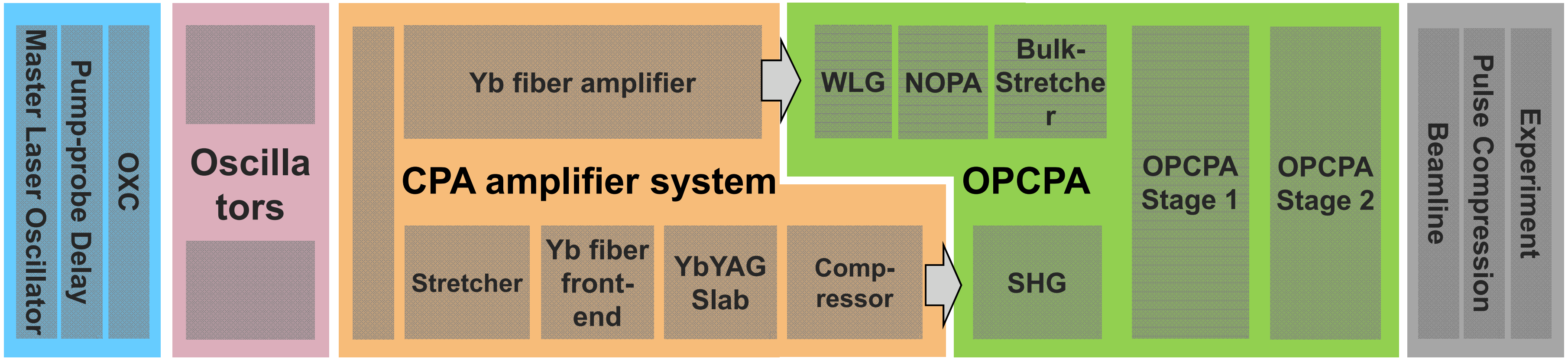
1UBC2	3DBC2	4DBC3	15ACC7	(FL2EXTR)	1SFELC	8FL2BURN	7FLFMAFF
22m	27m	85m	138m		185m	243m	203m



A.Angelovski, M.Kuntzsch, M.K.Czwalinna, et al., Phys. Rev. STAB **18**, 012801 (2015)

OPCPA Laser System

System Overview



Laser parameters

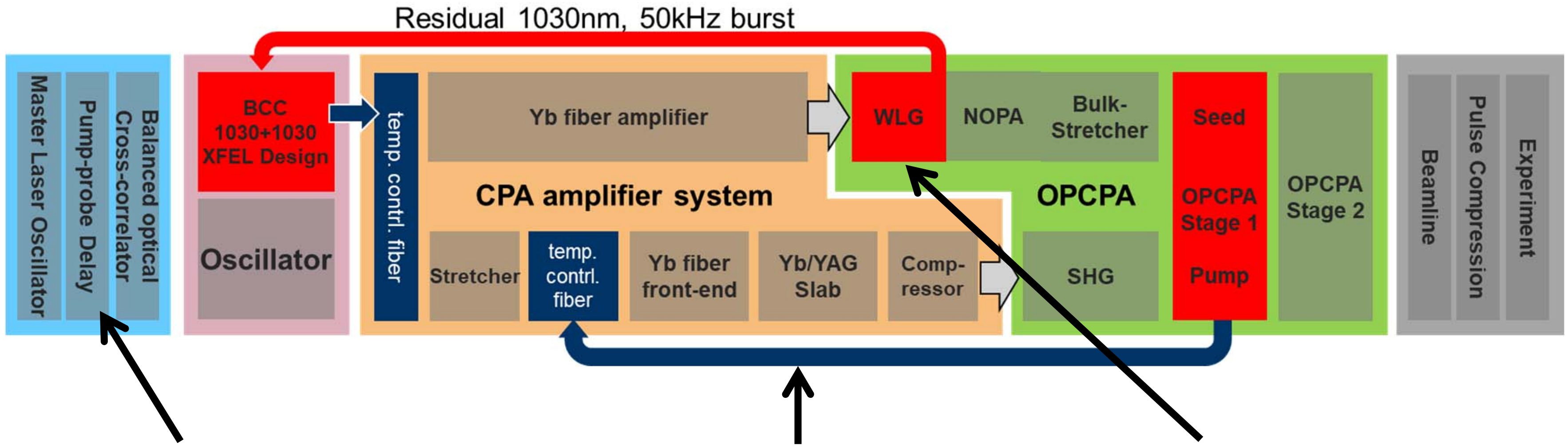
Rep.-Rate: 100 kHz in 800μs burst @ 10Hz

Pulse energy: 400 μJ (before transport)

Pulse duration: 15 fs - 50 fs

Wavelength: 700nm – 900 nm

Drift compensation system laser system



Pump probe delay

- Shifts complete system
- No influence on triggers or drifts

Wavelength

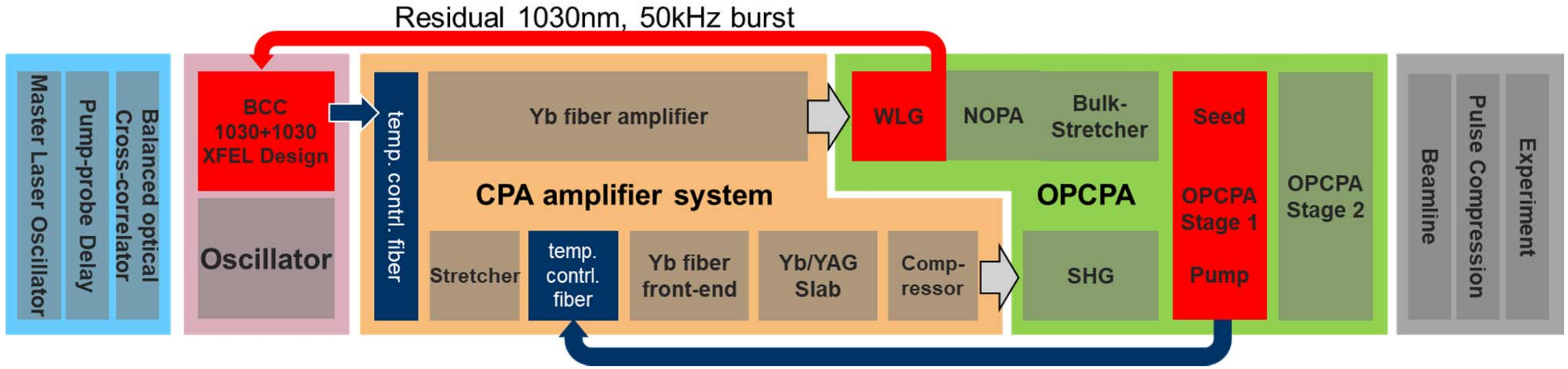
- Relative seed/pump timing in OPCPA
- Slow control with spectral encoded drift correlator feedback

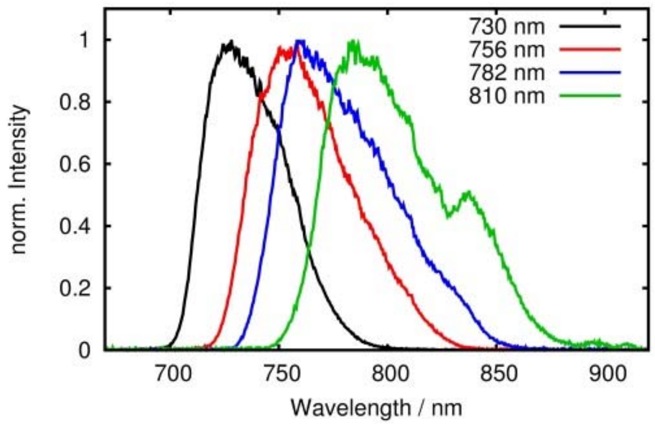
Timing at experiment

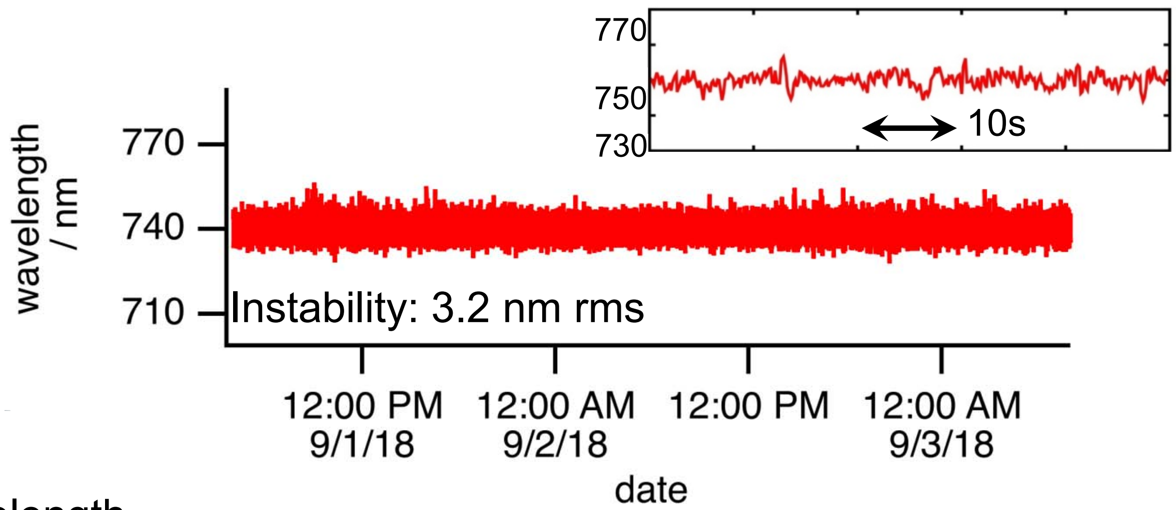
- Correlates with seed timing in OPCPA
- Slow control with balanced optical cross correlator (BCC)

OPCPA - Pump vs. Seed

Wavelength Stabilization



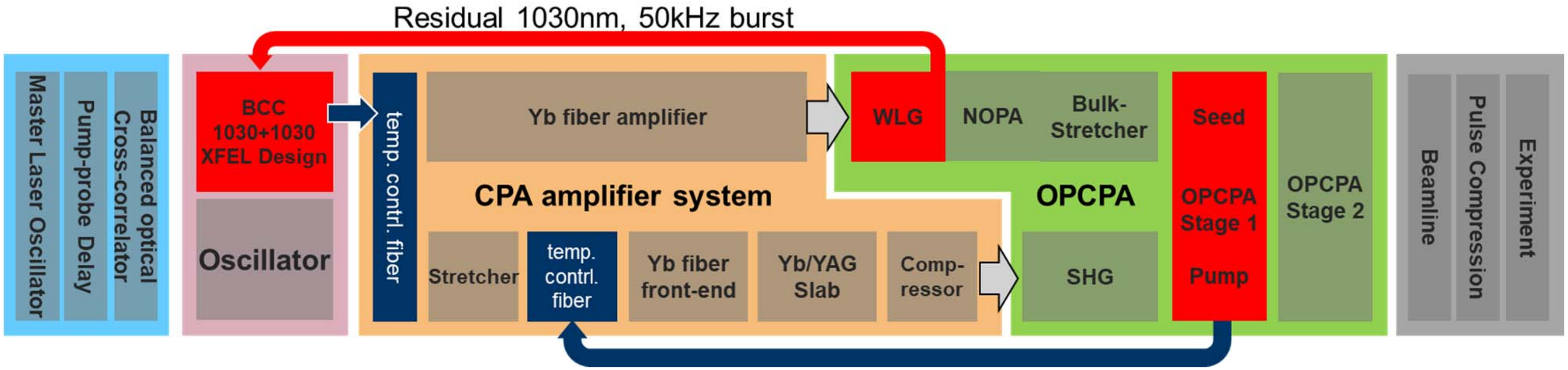




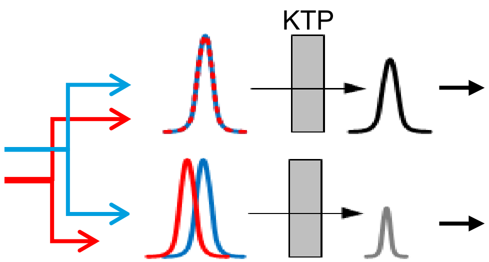
- Fast change of central wavelength
- drift control with temperature controlled fiber delay line

Timing drift stabilization

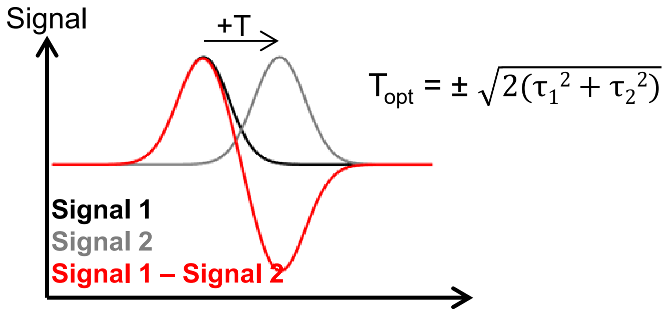
Balanced cross correlator



- Crosscorrelation of oscillator pulse and amplifier pulse
- two cross correlations with small time delay



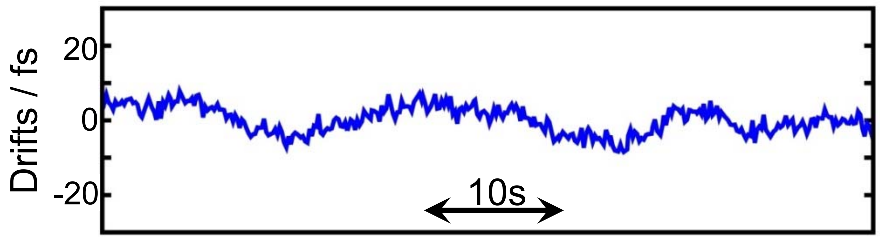
Schibli et al. Opt. Lett. 28, 947-949 (2003).

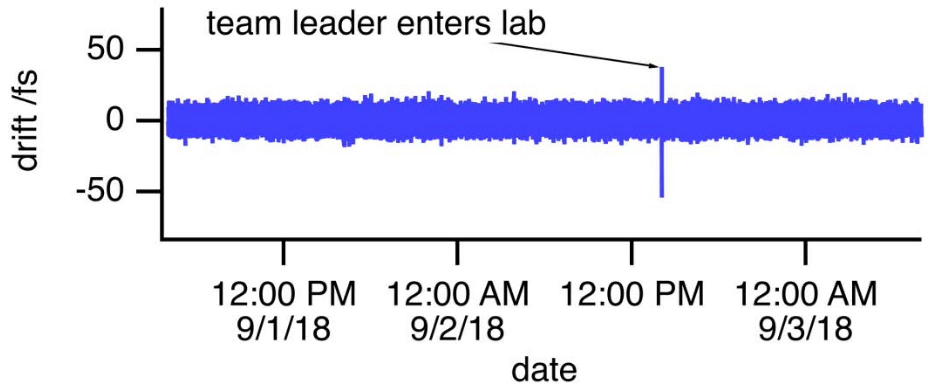


Timing drift stabilization

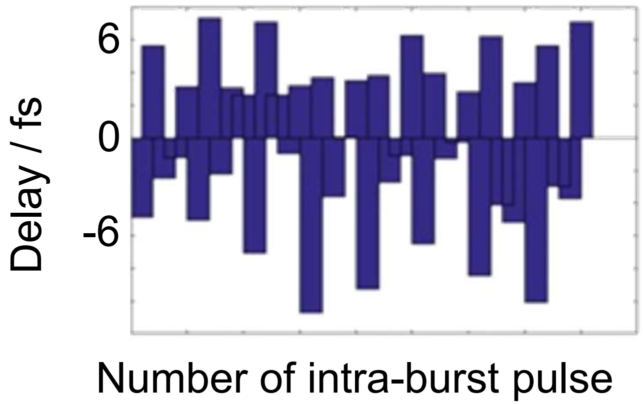
Performance

- Full fiber amplifier is in feedback loop
- OPCPA amplifier, beamtransport and pulse compresson is not controlled
  - 50 m out of loop beam path
- **Standard drift deviation: 5.7 fs rms**
- Oscillations of 30 s period

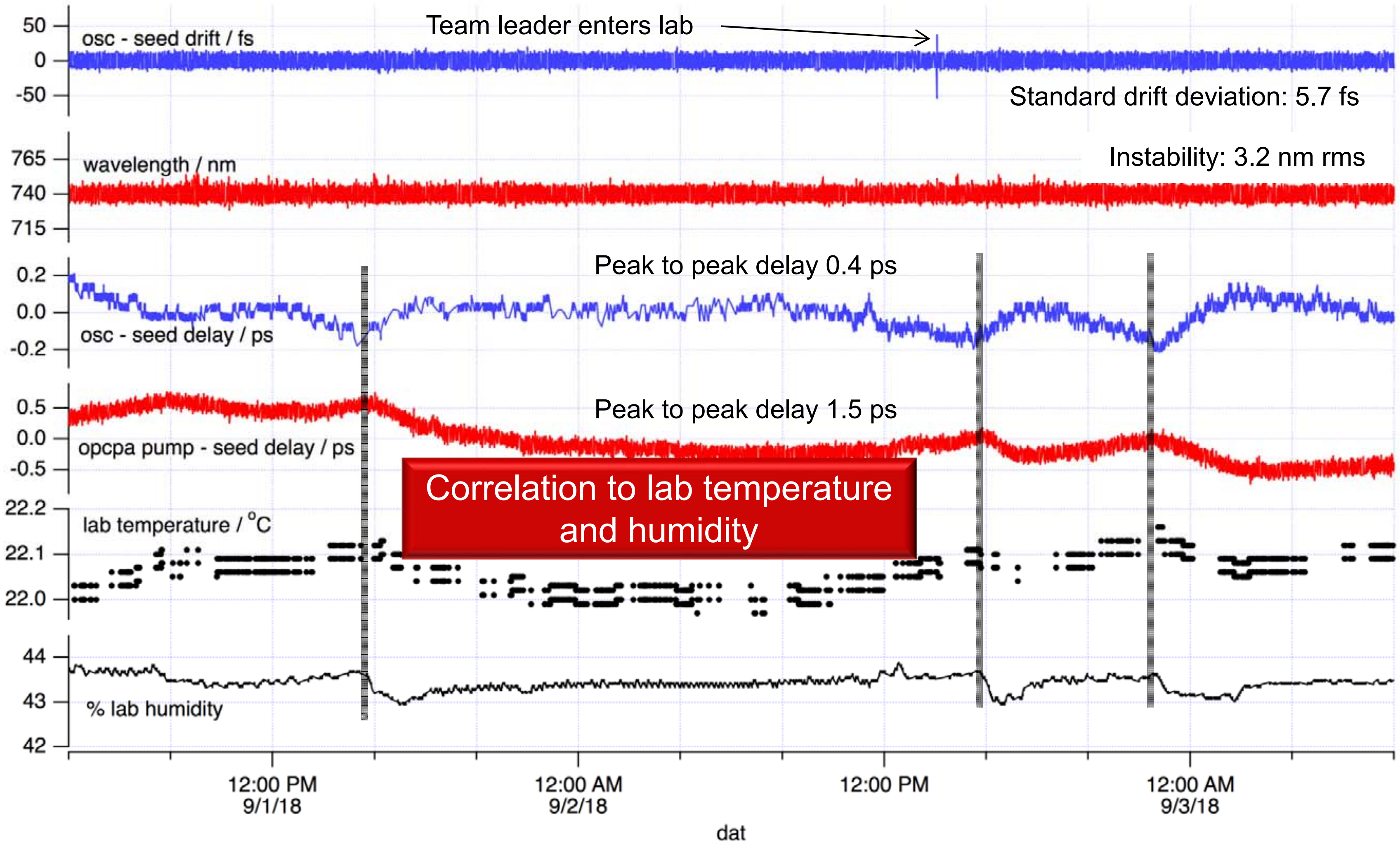




- Single shot measurement in burst
  - No slope over the pulse train visible
  - But high noise



Wavelength and timing drift stability



FLASH2 FEL-pump optical-probe experiment

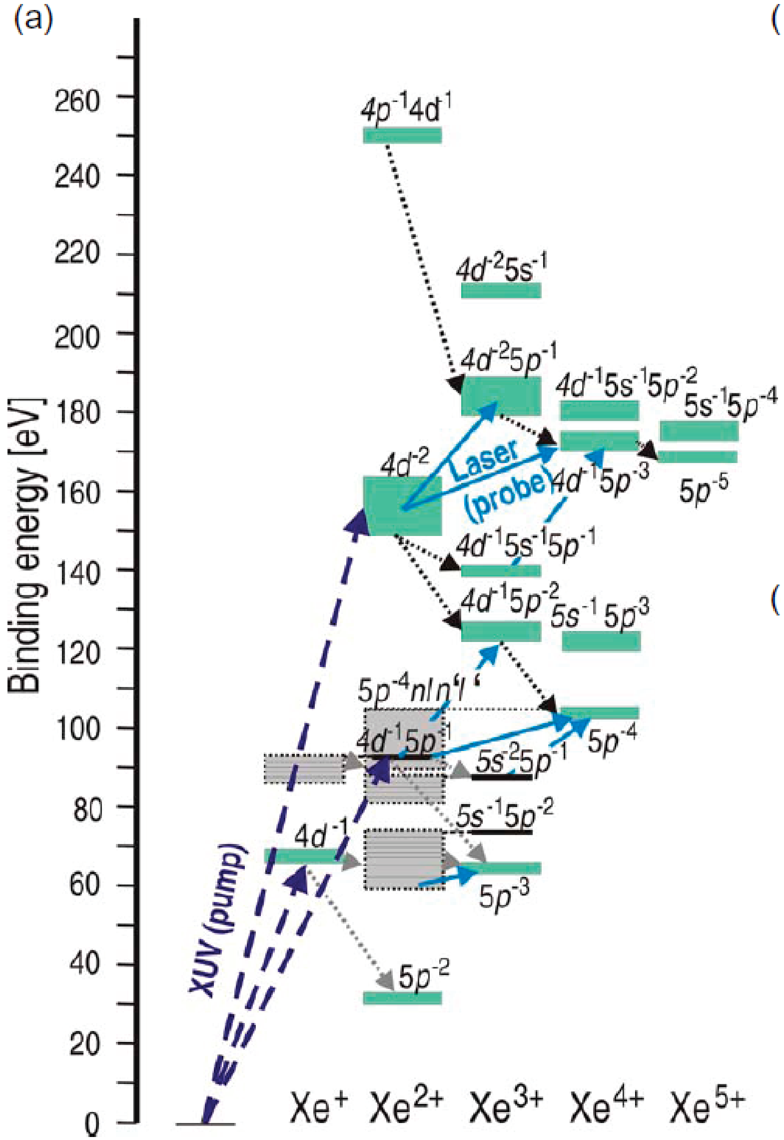
- Test the performance of the new FLASH2 pump probe laser and the FLASH2 FEL by performing a standard timing experiment

- Xenon(4d) ionization
  [Krikunova et al 2009 *New J Phys.* **11** 123019]

  Pathway

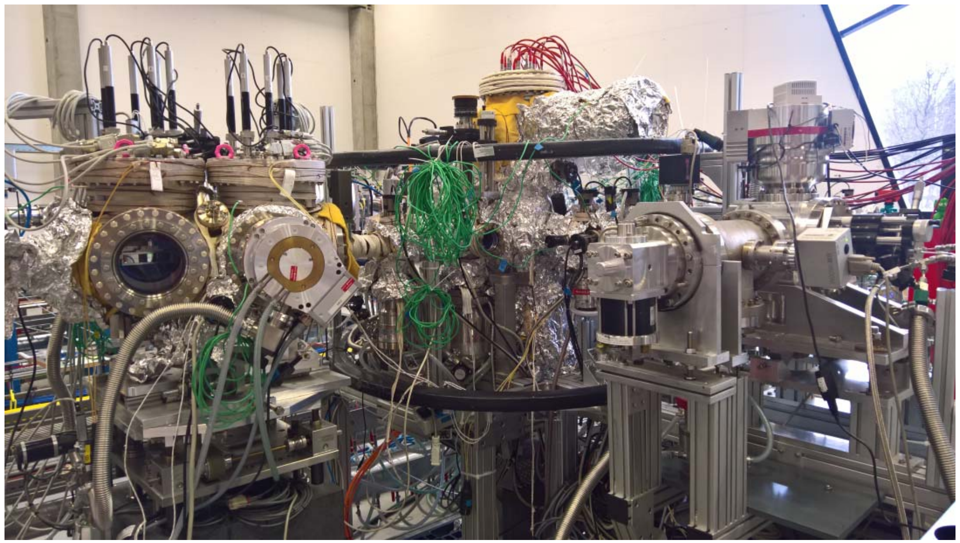
  1. $\mathrm{Xe} + h\nu_{XUV} \rightarrow \mathrm{Xe}(4d^{-1}) + e^-$
  2. $\mathrm{Xe}(4d^{-1}) \xrightarrow[\text{Auger decay} <5\text{fs}]{} \mathrm{Xe}(5p^{-2})^* + e^-$
  3. $\mathrm{Xe}(5p^{-2})^* + h\nu_{IR} \rightarrow \mathrm{Xe}(5p^{-3}) + e^-$

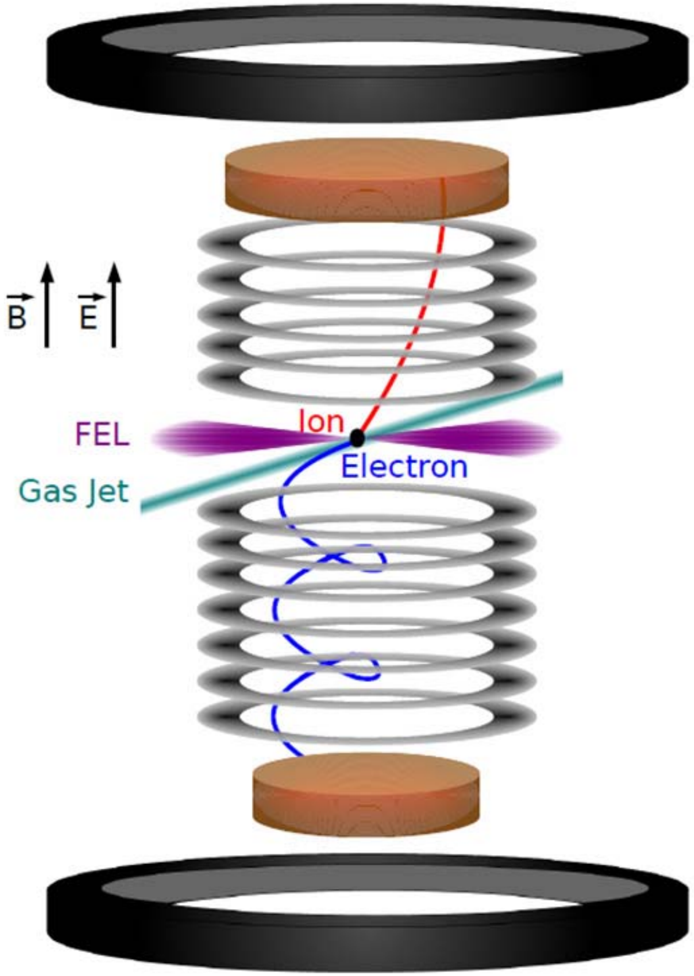
- **Xe^{3+} ion yield is increased when IR pulse arrives after XUV pulse**



Experimental apparatus REMI@FL26

- Reaction microscope
  - Ions and electrons detectors
  - coincidence detection
- Added incoupling optics for the optical laser
- Only ion TOF measurement required

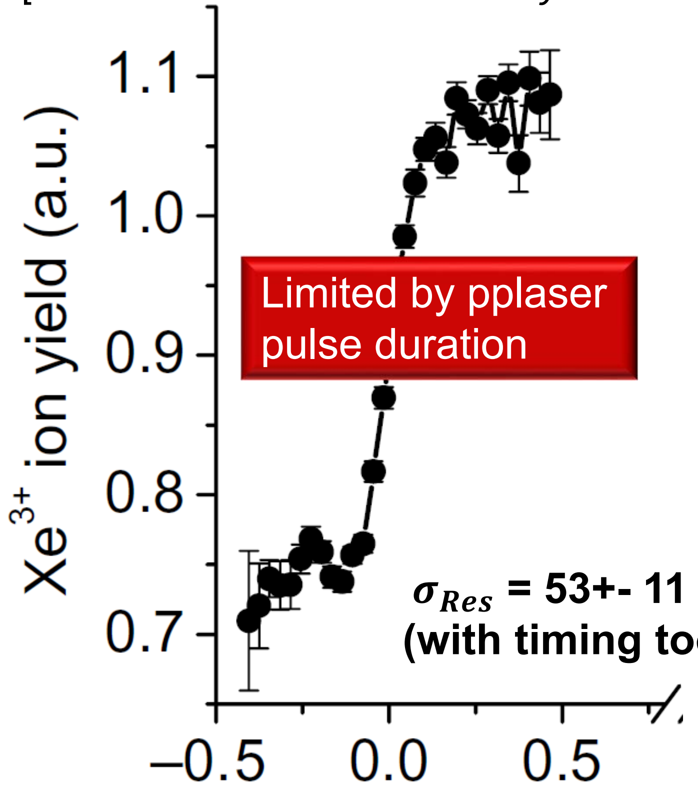




Experimental results

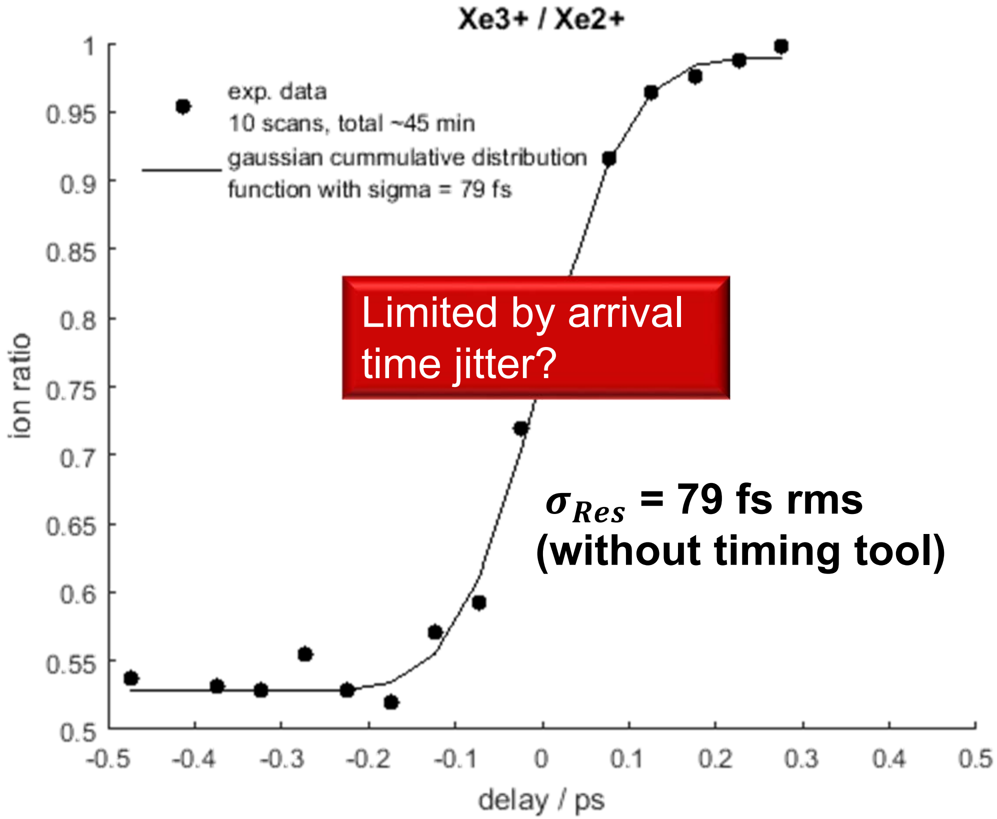
FLASH1

FEL: λ=13.4 nm/92 eV; T_{FWHM} = 35 fs
Laser: λ=400 nm/3.1 eV; T_{FWHM} = 120 fs
[Krikunova et al 2009 *New J Phys.* **11** 123019]



FLASH2

FEL: λ=12.7 nm/150 eV; T_{FWHM} = < 50 fs?
Laser: λ=800 nm/1.55 eV; T_{FWHM} = 26 fs?



$$\sigma_{Res} = \sqrt{\sigma_{Laser}^2 + \sigma_{FEL}^2 + \sigma_{Jitter}^2}$$

Discussion: many open questions

- **Time resolution in this experiment: 79 fs rms**
  why are we not better?
- correction of electron arrival time 4DBC3 BAM jitter $\sigma_{jitter} \approx 70 \text{ fs rms}$
  - No significant improvement, BunchID mismatch?
  - Influence of FLASH2 extraction?
- Laser pulse duration on target?
  - FL26 laser incoupling not optimized for ultrashort pulses
  - No influence on signal when changing laser pulse duration between 20 and 80 fs (FWHM)
- FEL pulse duration on target?
  - Settings similar to experiment 1 week earlier
  - No pulse duration measurement during beamtime?
- OPCPA amplifier and laser transport not drift controlled
  - Jitter/drifts?

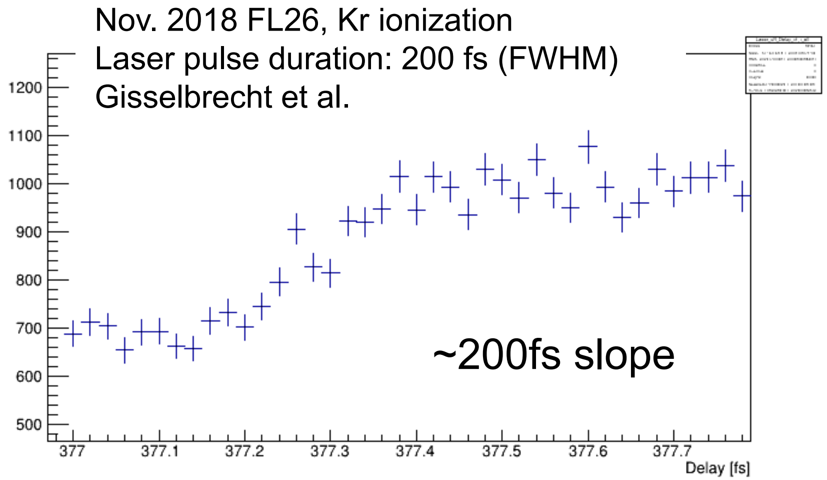
Summary

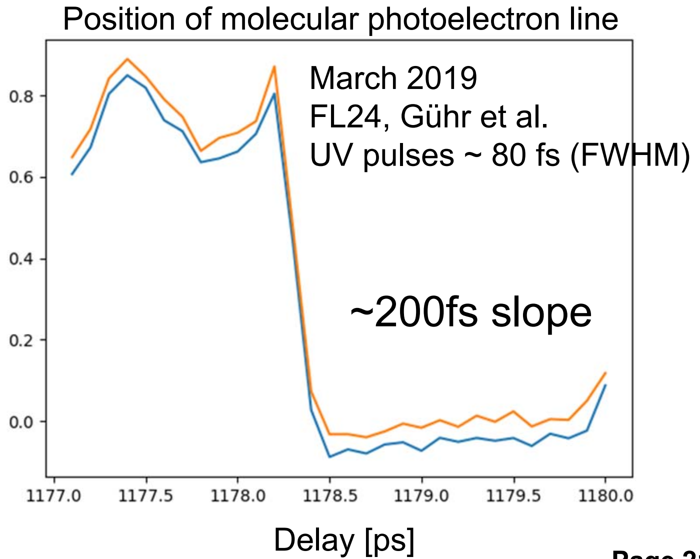
- Importance of arrival time for pump probe experiments
- Measured arrival time performance using Xe photoionization
  - Achieved resolution 79fs rms/186 fs FWHM without BAM correction

- Drift stabilization systems at FLASH
  - Beam arrival monitors at FLASH
    - Arrival time jitter 70fs rms / Resolution < 10fs (4DBC3)
  - Drift stabilization of FLASH2 pump probe laser
    - Wavelength stabilized with 3.2 nm instability for 80 nm FWHM
    - Temporal drift stabilized to 5.7 fs rms

Outlook

- So far two user beamtimes with FLASH2 pump probe laser
  - Spatial and temporal overlap stable over several days without issues
  - But no experiments with ultrashort pulses again, limited by laser pulse duration
- Next dedicated beamtime April 2019
  - Toleikis et al. using a timing tool
- Influence of length drift in laser beam transport and at the endstation
  - Is a free space length stabilization possible and practical?
  - Measurement of laser arrival time at endstation with respect to MLO link
- E-beam arrival feed back with new BAM





Acknowledgements

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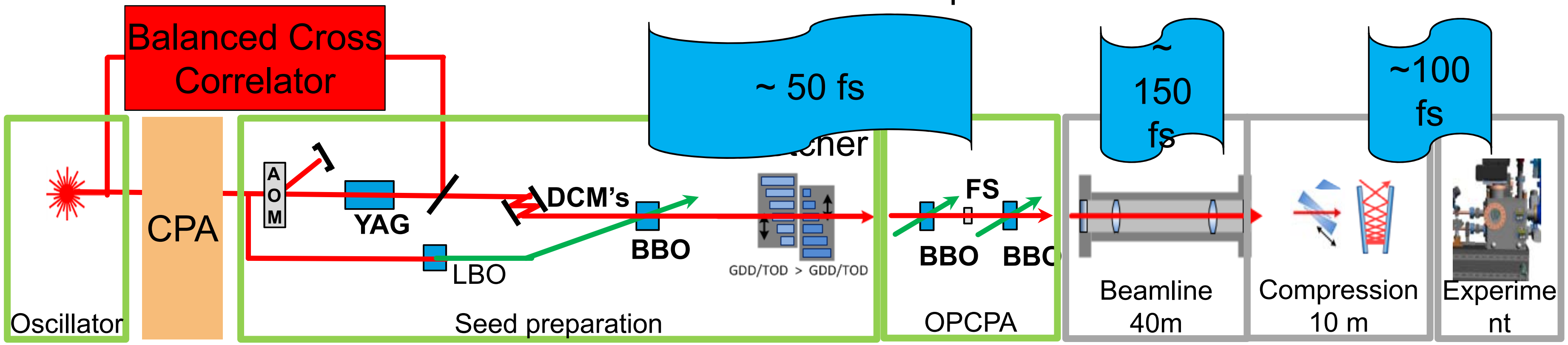
Robert Moshammer, Kirsten Schnorr

FS-FLASH, DESY
Markus Braune

Thank you for your attention

Expected drifts and their origins in the laser



Fiber drifts

Temperature	**4 fs / (m * 0.1 K)**
Humidity	**5 fs / (%hum * m)**
50 m fiber	Oscillator to CPA
70 m fiber	in CPA for pump

→ **All fibers are compensated**

Free space beam path drifts

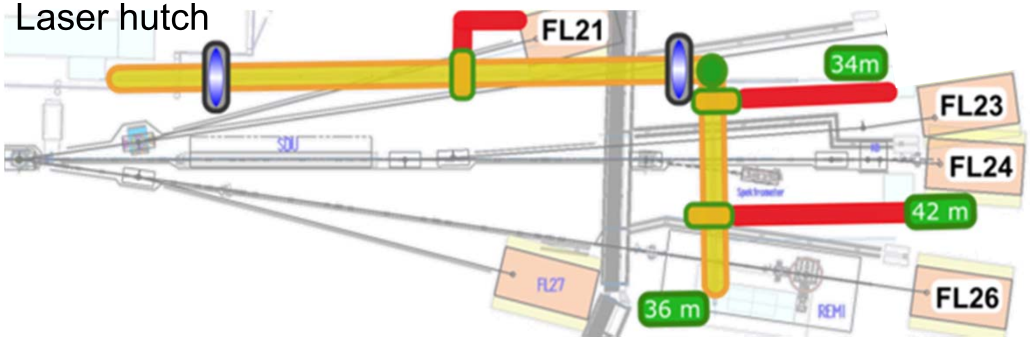
Aluminum Breadboard	**7.7 fs / (m * 0.1 K)**
Steel Table	**3.7 fs / (m * 0.1 K)**
Concrete Floor	**4.0 fs / (m * 0.1 K)**
Invar pump-probe Delay Line	**0.7 fs / (m * 0.1 K)**

Refraction index changes of air by changes in humidity, temperature and pressure

Typical lab conditions: ± 0.2 K / h, ± 5 %hum / h

FLASH2 pump-probe laser

… available since second half of 2018



Beamline layout in FLASH2 hall

„Panorama view“ into the ~80 m² laser hutch

Initial laser parame	
Technology	Optical para (OPCPA)
Wavelength	700 nm – 90
Repetition rate	**50 kHz** (1 -
Pulse duration	**< 20 fs** (fwh
Pulse energy	**> 250 µJ**
Beam transport	Relay Imagi 2 Experimer

Optical laser synchronization

During September 2018

- balanced optical cross-correlation with MLO
- optical delay line for user delays scans (4 ns, resolution 1 fs)
- **rms jitter < 10 fs**