Laser-to-RF Synchronization with Femtosecond Precision.

... How to Provide Femtosecond Stability in Free-Electron Lasers ...

Thorsten Lamb
on behalf of the
Laser-Based Synchronization Team

August, 23rd 2017

FEL 2017, Santa Fe, NM, USA

European XFEL

DESY

fs LbSync

Outline

Motivation

The European XFEL

- FEL pulse length: 10 fs to 100 fs
- RF field stability requirements:
  - amplitude stability of 1×10^{-5}
  - phase stability of 0.01 ° or about 20 fs
- RF reference stability requirement: 10 fs
- facility length: 3.4 km
- additional stabilization required
- optical synchronization provides femtosecond stability
- optical reference module (REFM-OPT)

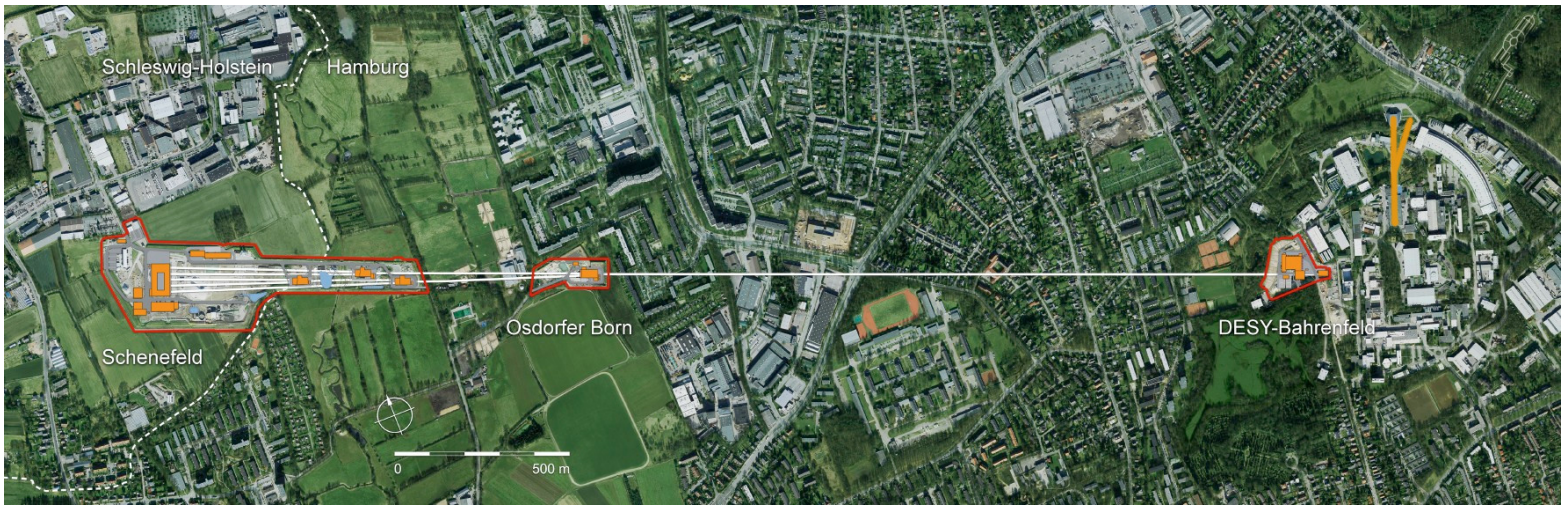
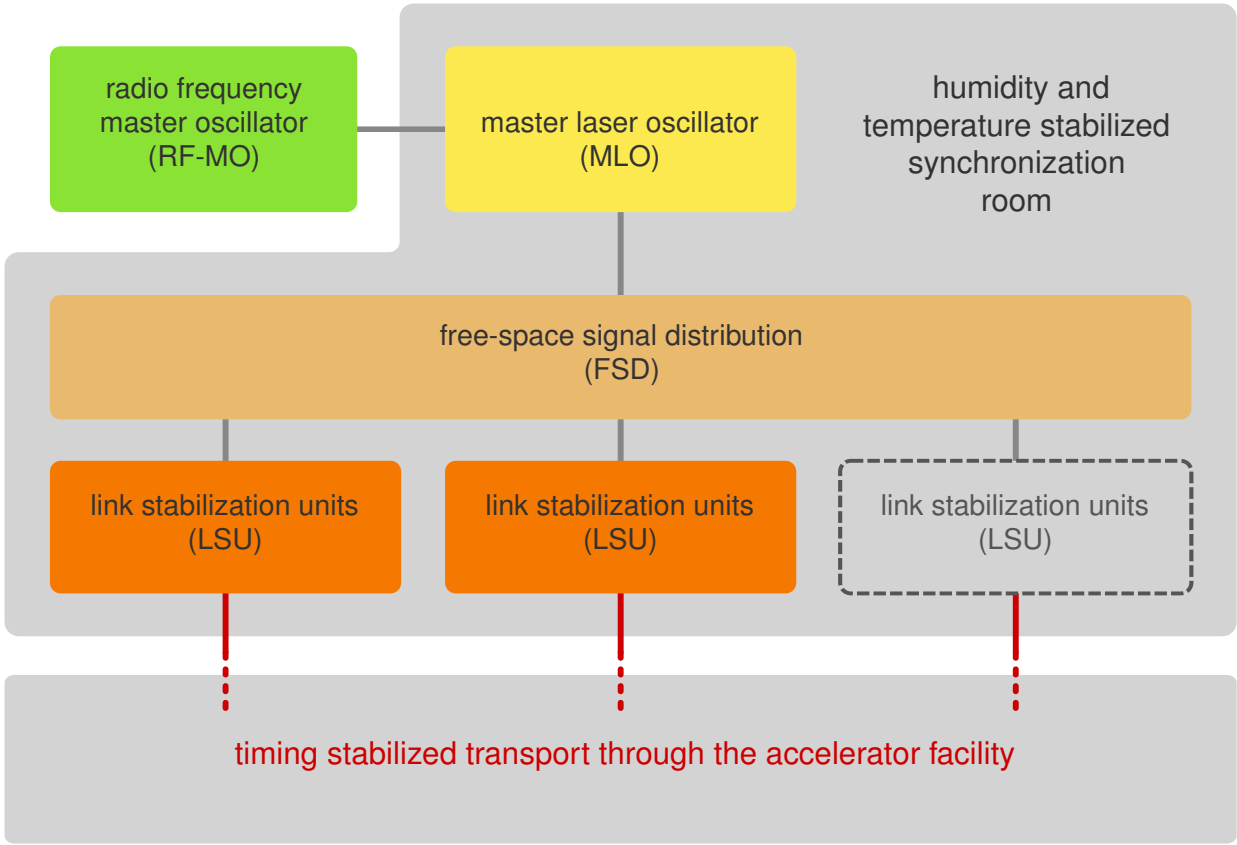


photo: courtesy of the European XFEL GmbH

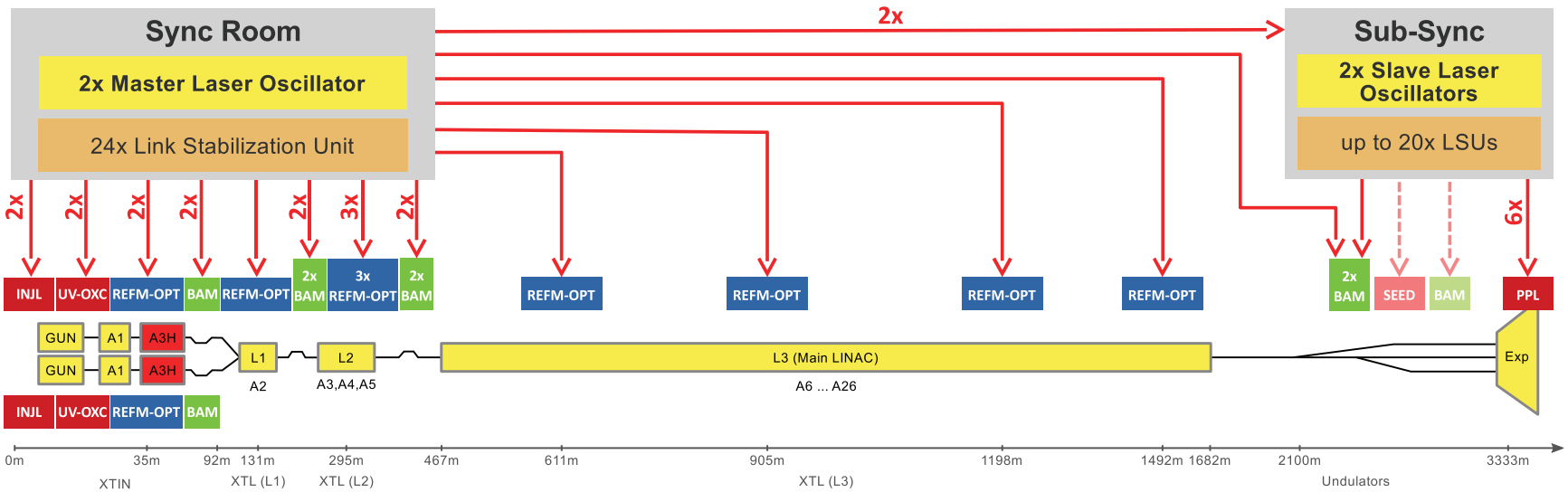
The Pulsed Optical Synchronization System



Installation

photo: courtesy of Cezary Sydlo

The Optical Synchronization System at the European XFEL



Laser-to-Laser Synchronization (L2L)

- balanced, two-color optical cross-correlation
- synchronize different laser systems with femtosecond precision

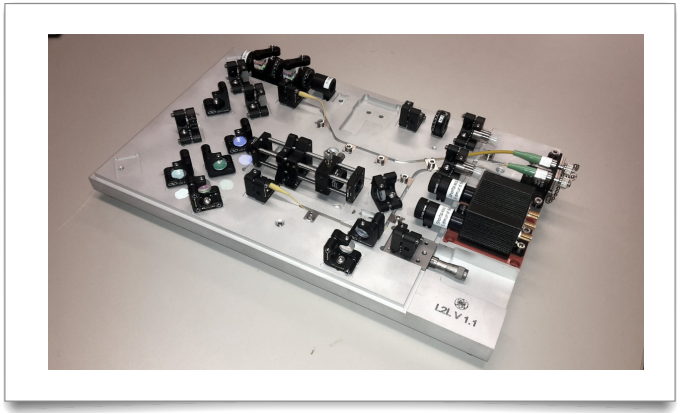
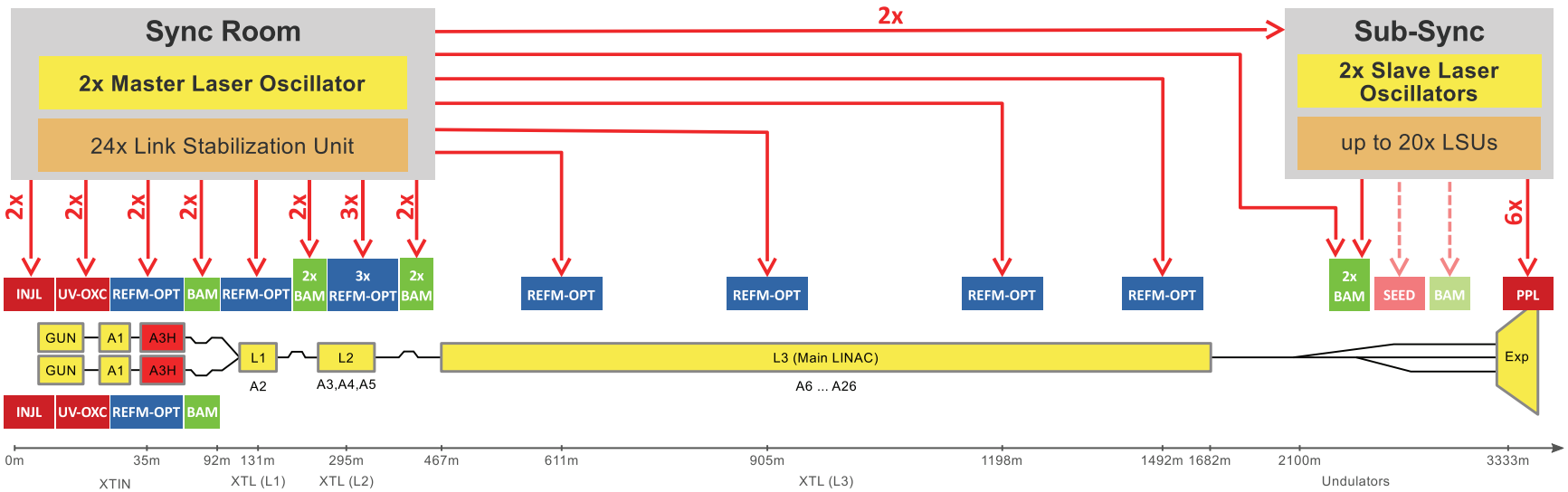


photo: courtesy of Jost Müller

The Optical Synchronization System at the European XFEL

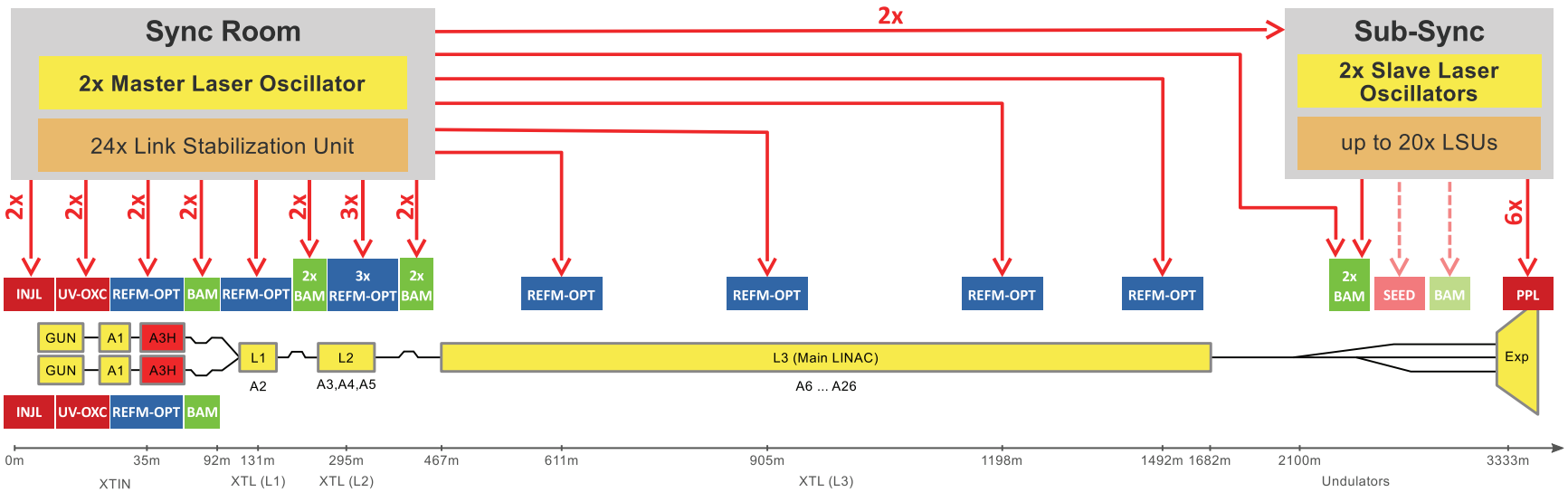


Bunch Arrival-Time Monitor (BAM)

- measurement of the electron bunch arrival time with femtosecond precision
- arrival time feedback to the LLRF system

photo: courtesy of Marie Kristin Czwalinna

The Optical Synchronization System at the European XFEL

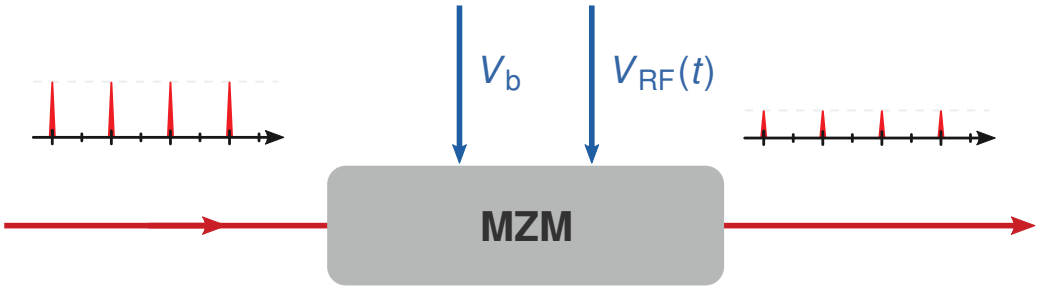


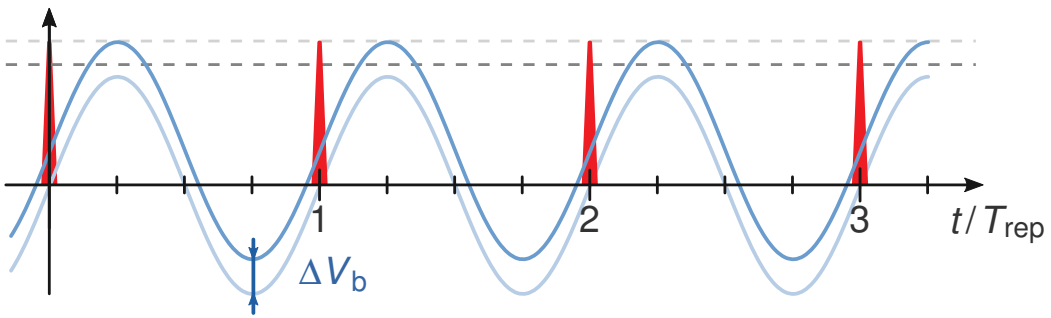
Provide RF Reference Signals with Femtosecond Stability

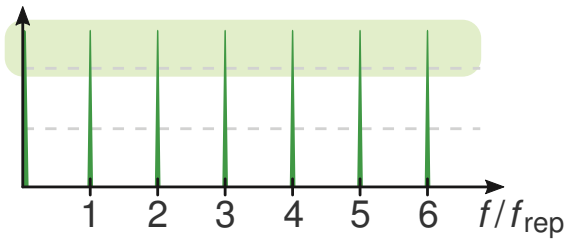
- engineered optical reference module (REFM-OPT)
- use the optical synchronization system as reference
- employ Laser-to-RF phase detection
- phase stability better than 10 fs

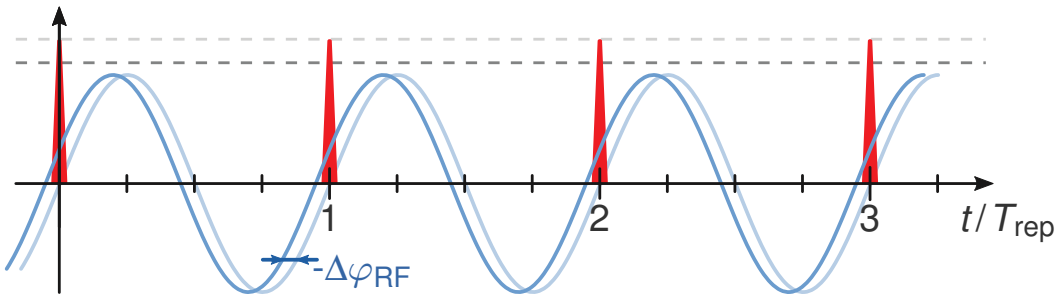
for more information on the optical synchronization system see **WEP032**, this afternoon

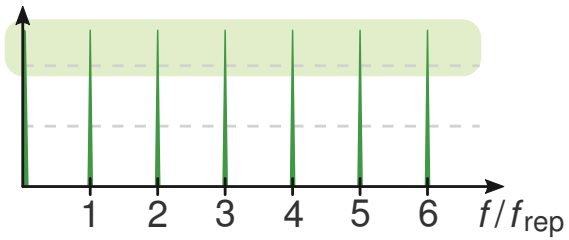
Laser-to-RF Phase Detection (1/2)



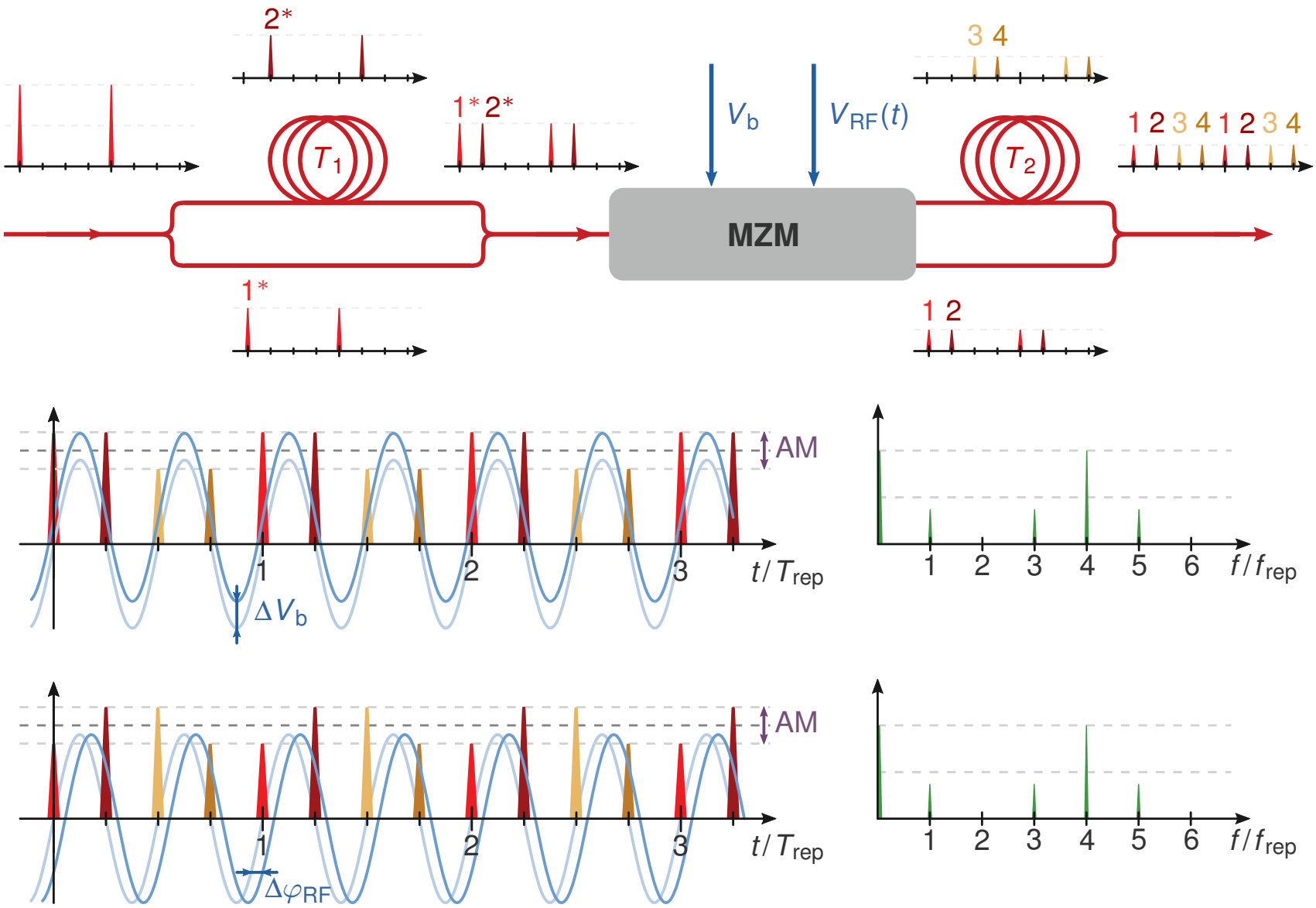




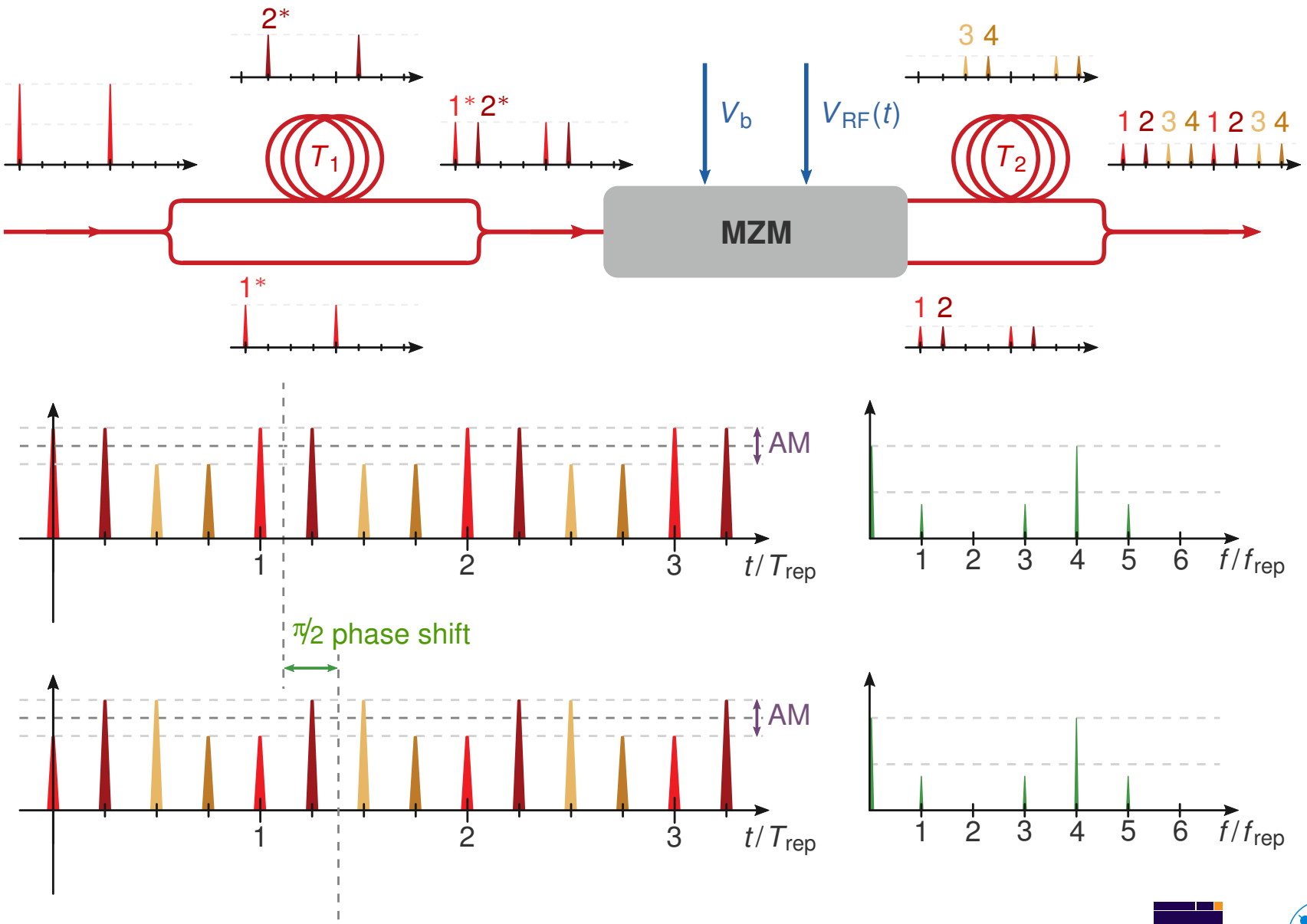




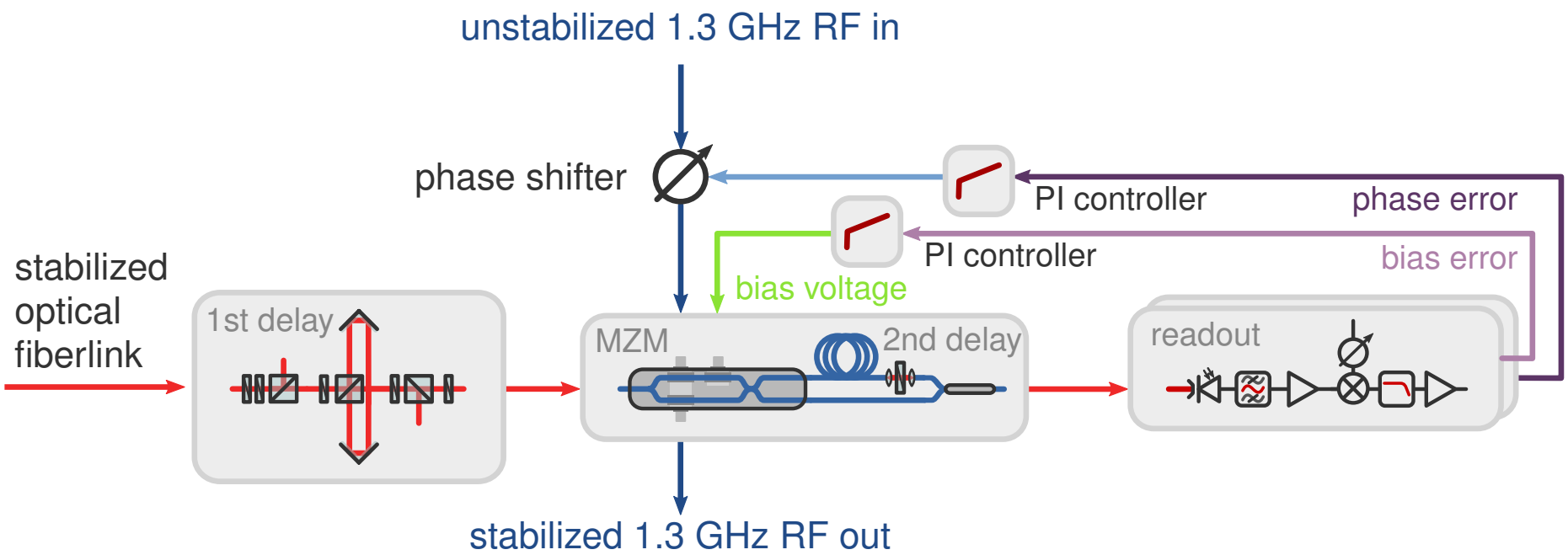
Laser-to-RF Phase Detection (2/2)



Laser-to-RF Phase Detection (2/2)

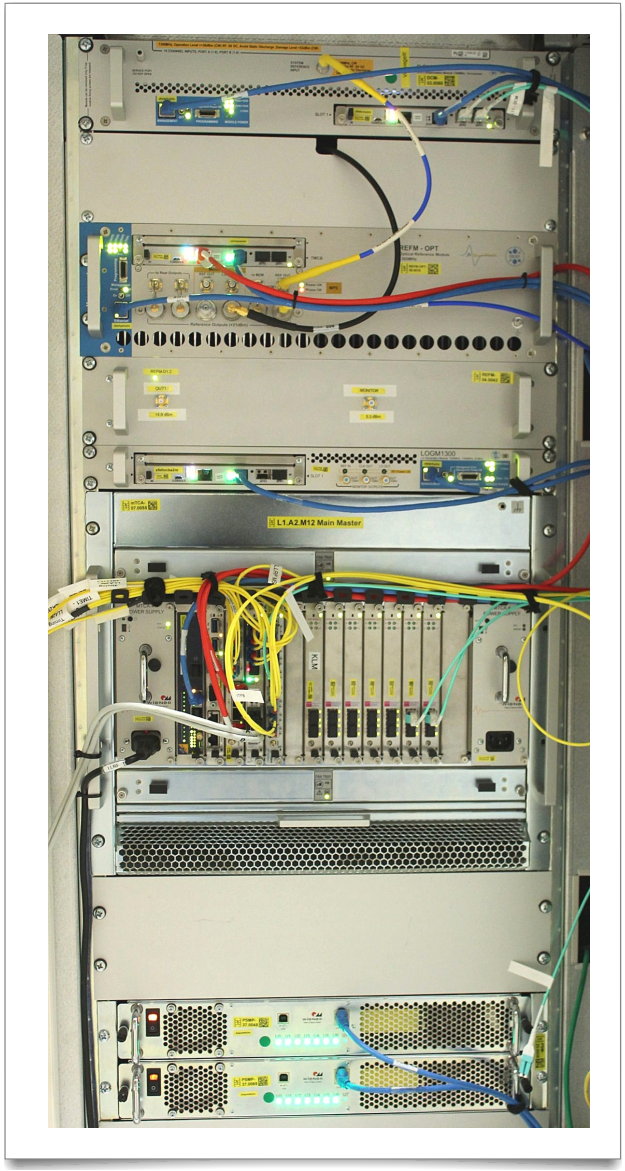


The Optical Reference Module (REFM-OPT) (1/2)



The Optical Reference Module (REFM-OPT) (2/2)

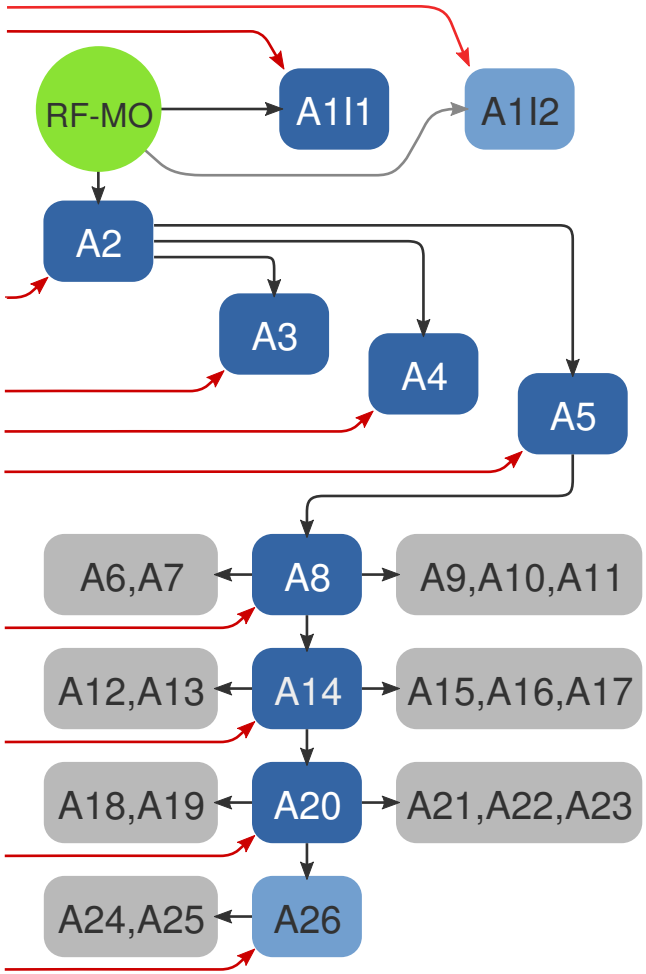
RF Reference Distribution at the European XFEL (1/2)



LLRF Rack Installations at A2

- drift calibration module (DCM)
- optical reference module (REFM-OPT)
- RF reference module (REFM)
- LO generation module (LOGM)
- MicroTCA.4 crate
- power supply module (PSM)

RF Reference Distribution at the European XFEL (2/2)

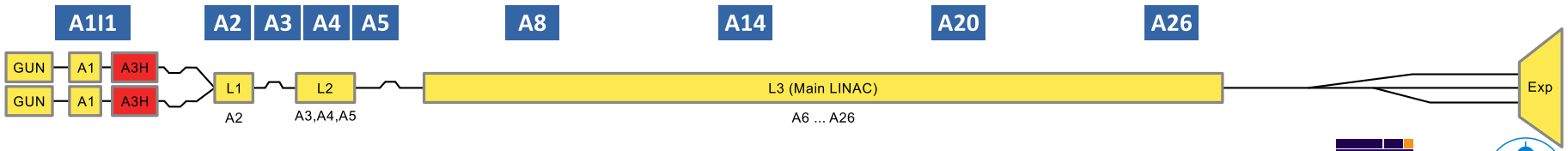


RF Subdistribution

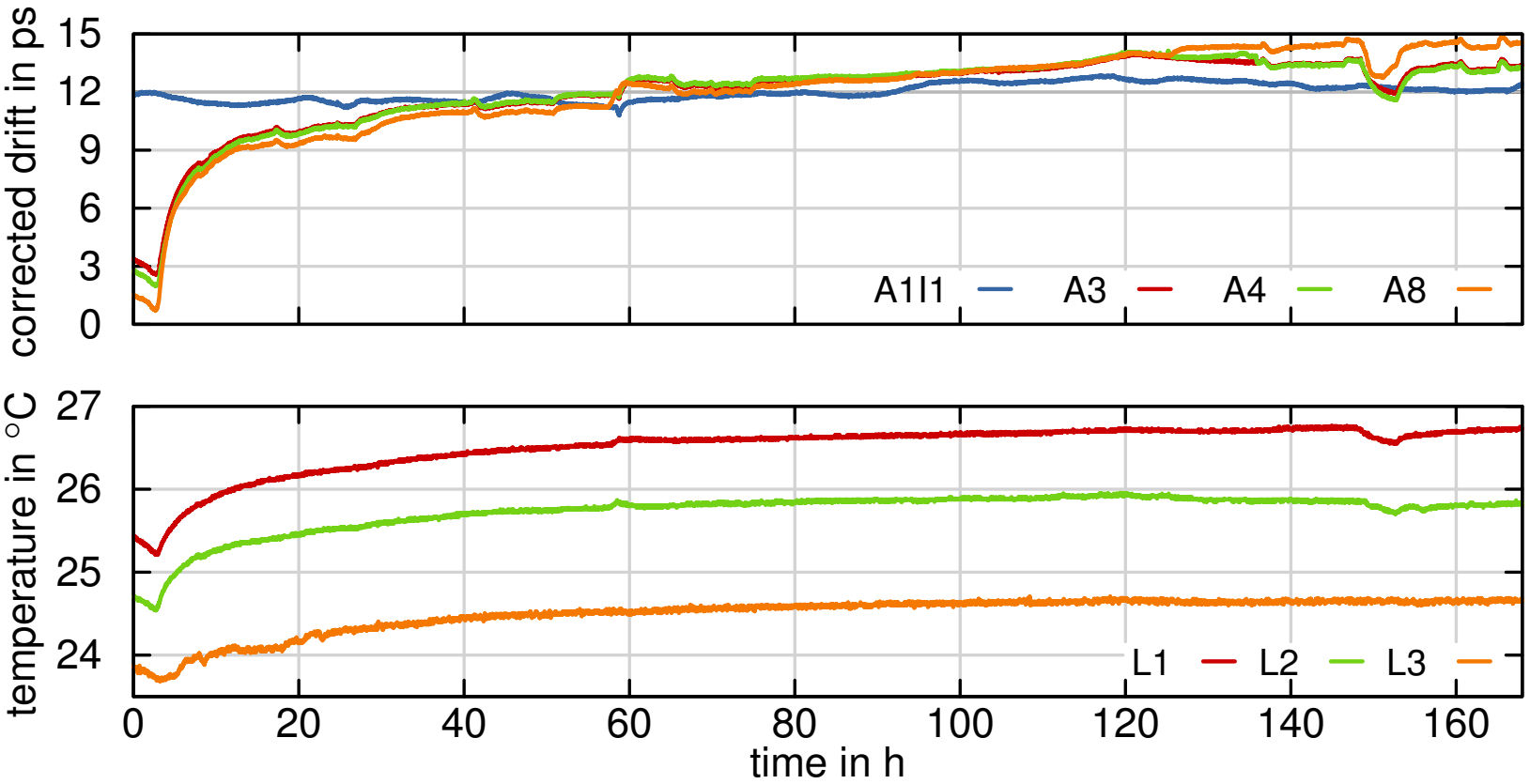
- currently passive system
- interferometric stabilization foreseen (upgrade)

LLRF Stations Used for Long-Term Measurements

- A1I1
- A3 (located at 247 m)
- A4 (located at 295 m)
- A8 (located at 611 m)

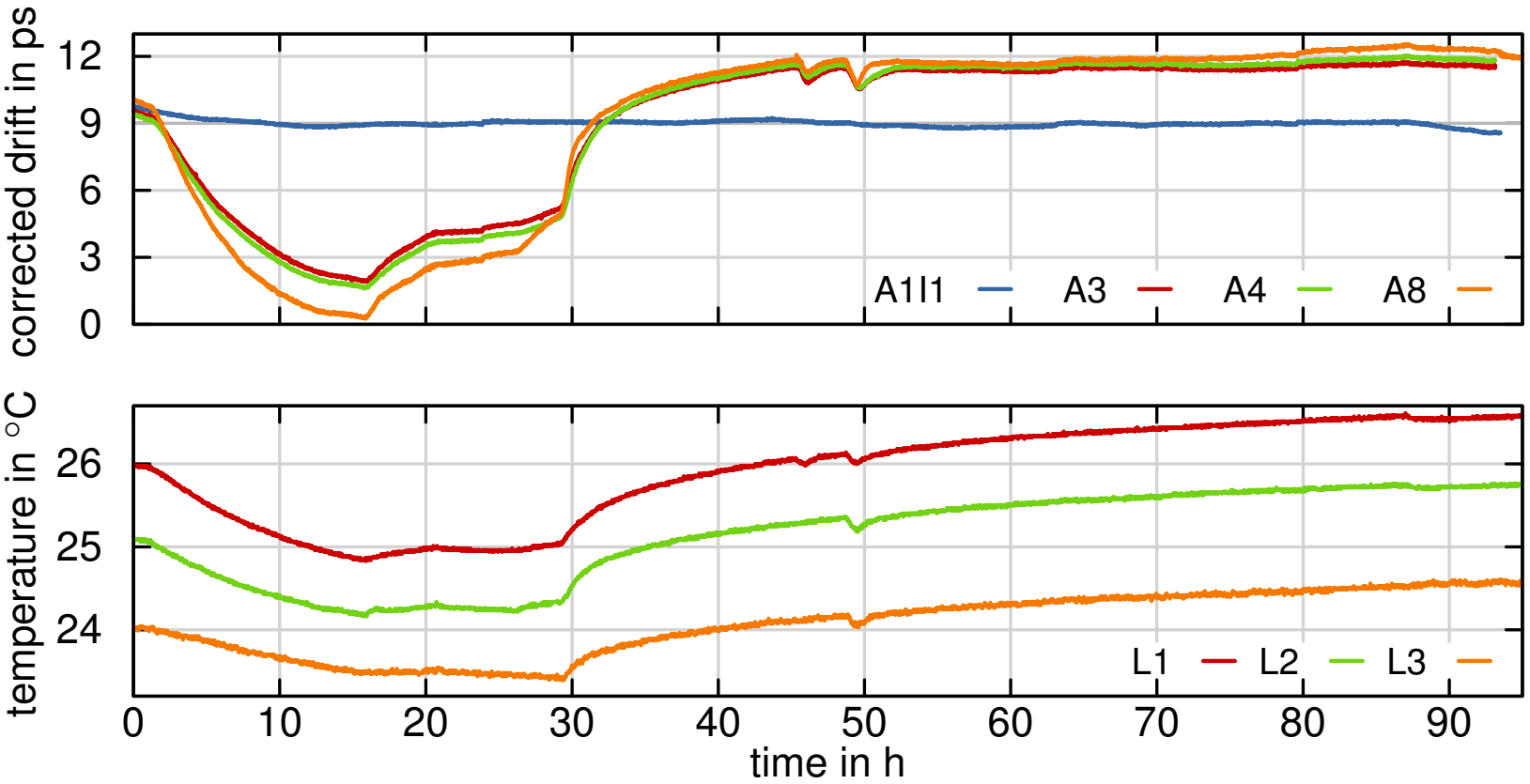


Long-Term Measurements (1/2)



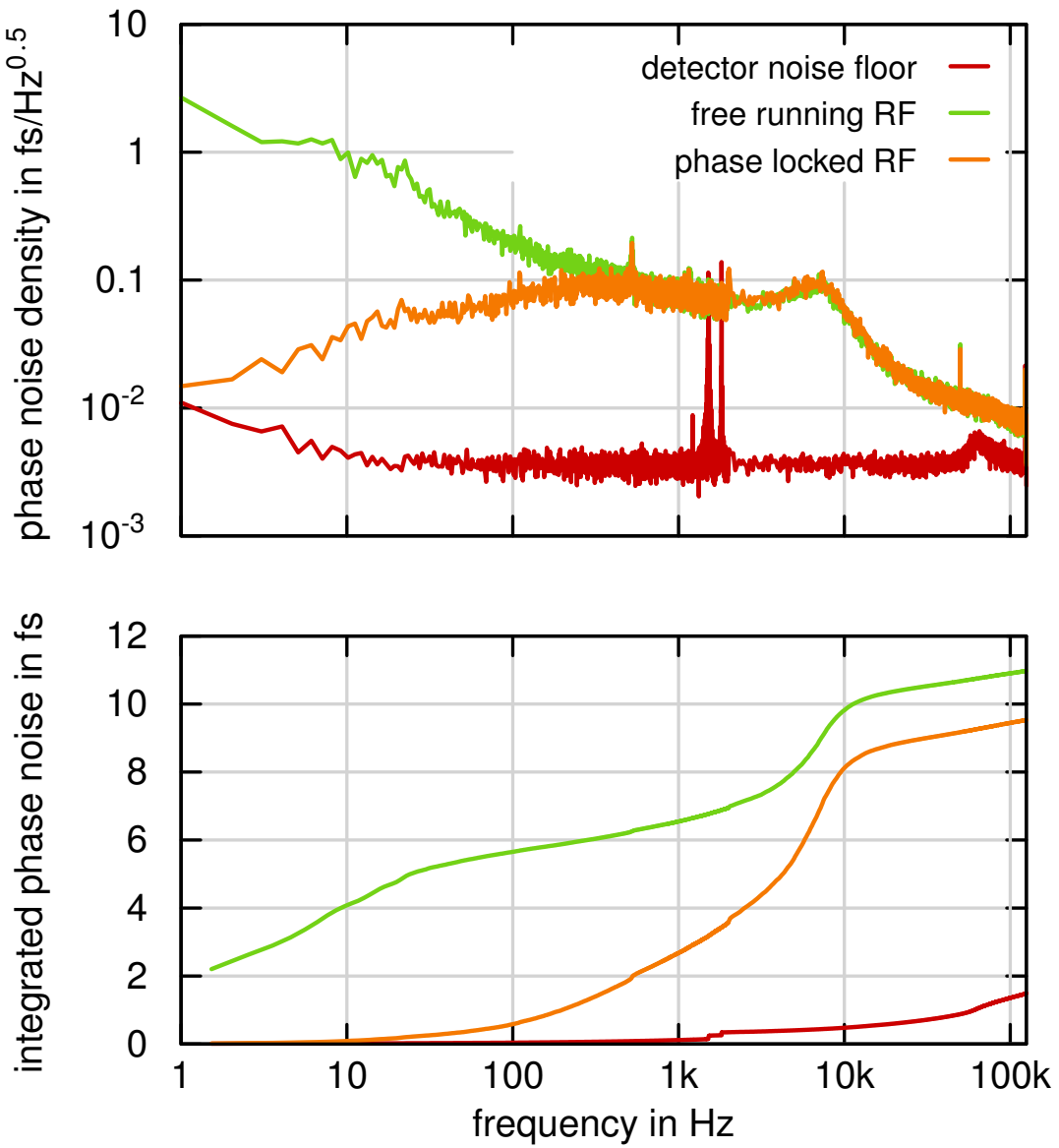
- measurement started after a regular maintenance day
- in-loop jitter 9.5 fs (1 Hz to 125 kHz bandwidth)
- 14.2 ps (peak-to-peak) total corrected phase drift at A8 (orange)
- 2.9 ps (peak-to-peak) corrected phase drift during the last 72 h at A8 (orange)
- 2.1 ps (peak-to-peak) total corrected phase drift at A1I1 (blue)

Long-Term Measurements (2/2)



- measurement started after two days of downtime
- 12.3 ps (peak-to-peak) total corrected phase drift at A8 (orange)
- 1.3 ps (peak-to-peak) total corrected phase drift at A1I1 (blue)

Short-Term Measurement (from A3)



Measurement Bandwidth 1 Hz to 125 kHz

- K_φ of 1.8 V ps^{-1}
- integrated detector noise floor of 1.5 fs (red)
- unlocked RF integrated jitter 11 fs (green)
- locked RF integrated jitter 9.5 fs (orange)
- noise bump at 7 kHz originates from the power amplifier in the RF-MO

Locking Bandwidth of 200 Hz

- integrated detector noise floor amounts to 55 as
- in-loop jitter is 1 fs

Conclusion

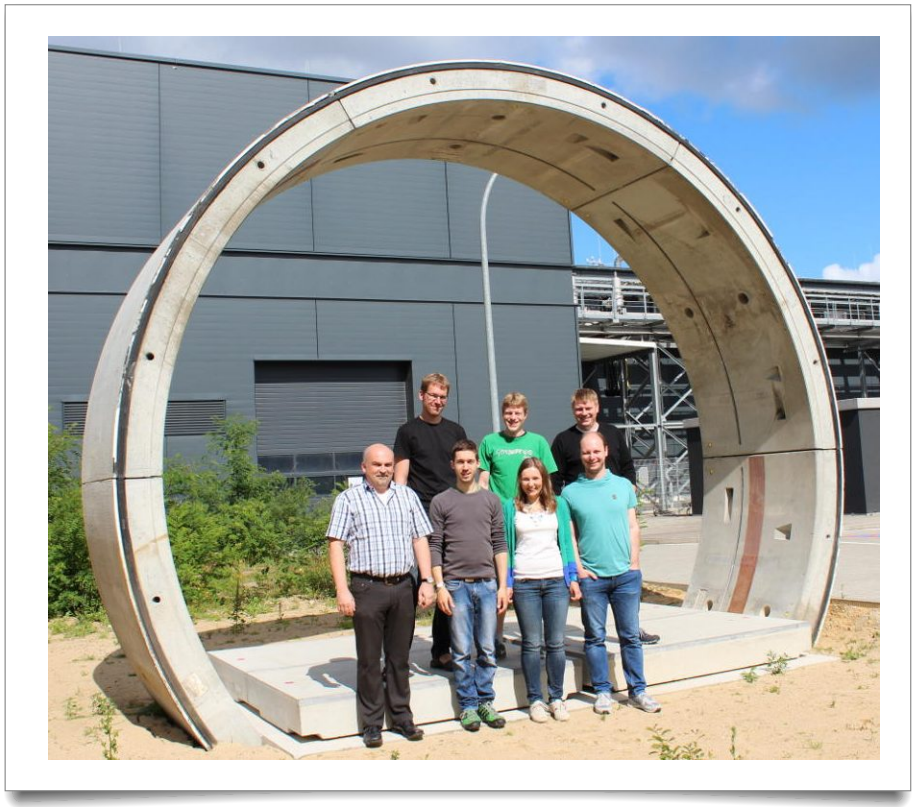
Installation Status

- eight REFM-OPTs are currently installed
- four of them are already in permanent operation
- the next and crucial station to be permanently operated is A2 in order to cover the whole L1 and L2 sections

Performance

- the in-loop jitter amounts to 9.5 fs so the 10 fs requirement is well met
- average corrected drifts are in the range of about 2 ps peak-to-peak over a few days during regular operation
- the REFM-OPT has to correct much higher drifts after maintenance periods (usually more than 10 ps)

Thank you for your attention.



Group Leader Holger Schlarb

Sync Team

Team Leader	Cezary Sydlo
L2L/OXC	Jost Müller
REFM-OPT	Thorsten Lamb
Electronics	Matthias Felber
L2L (Phd)	Ewa Felber
Fiberlinks	Falco Zummack
Laser Sync	Mikheil Titberidze
BAM	Marie Kristin Czwalinna
Software	Tomasz Kozak