FEL 2014
August 28, 2014
THB03

Femtosecond-stability delivery of synchronized RF-signals to the klystron gallery over 1-km optical fibers

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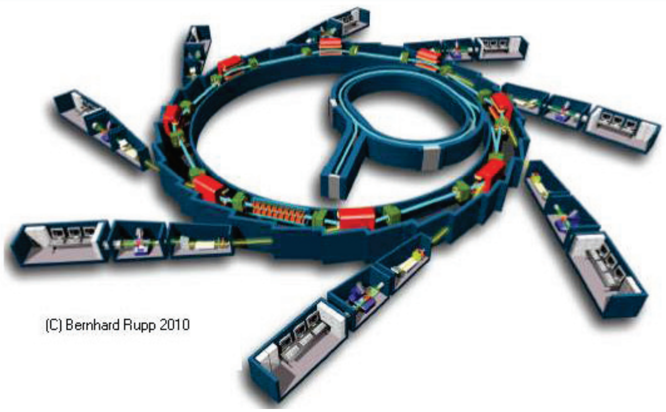
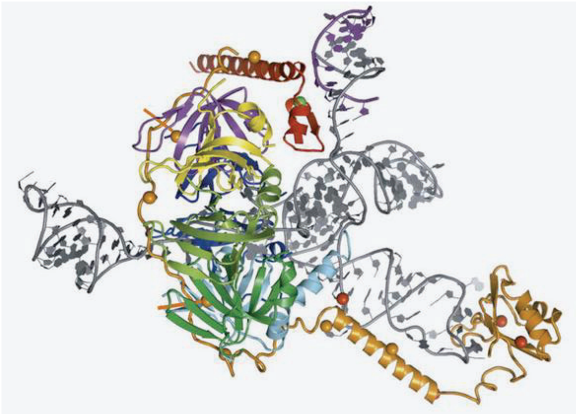
Why do we need XFEL?

Synchrotron (3rd generation)

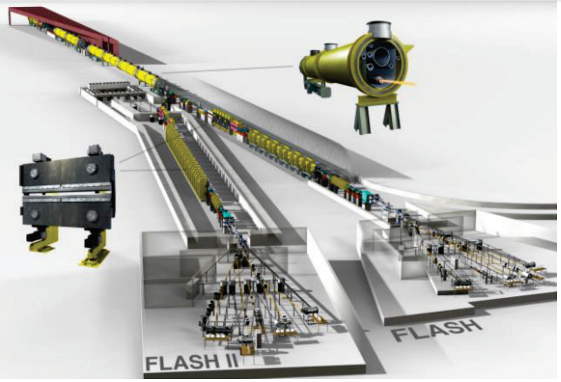


X-ray with extremely short wavelength and high brilliance can capture molecular structures.



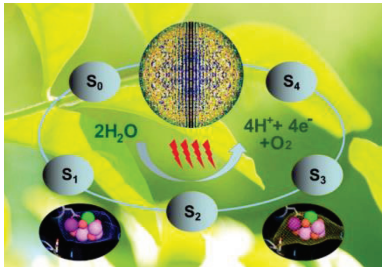
Protein structure by Swiss Light Source (D. A. Pomeranz Krummel, C.Oubridge et al. Nature 458, 475-480)

XFEL (4th generation)



- Billion times higher peak brilliance than synchrotron
- Ultra short pulse (tens of fs)

Not only the molecular structures, but also dynamics can be captured.



Still frames of a molecular complex transition by LCLS (Credit: Shibom Basu/Arizona State University)

For much higher temporal resolution, timing synchronization system is very important in XFEL.

Report of the BESAC Subcommittee on Future X-ray Light Sources

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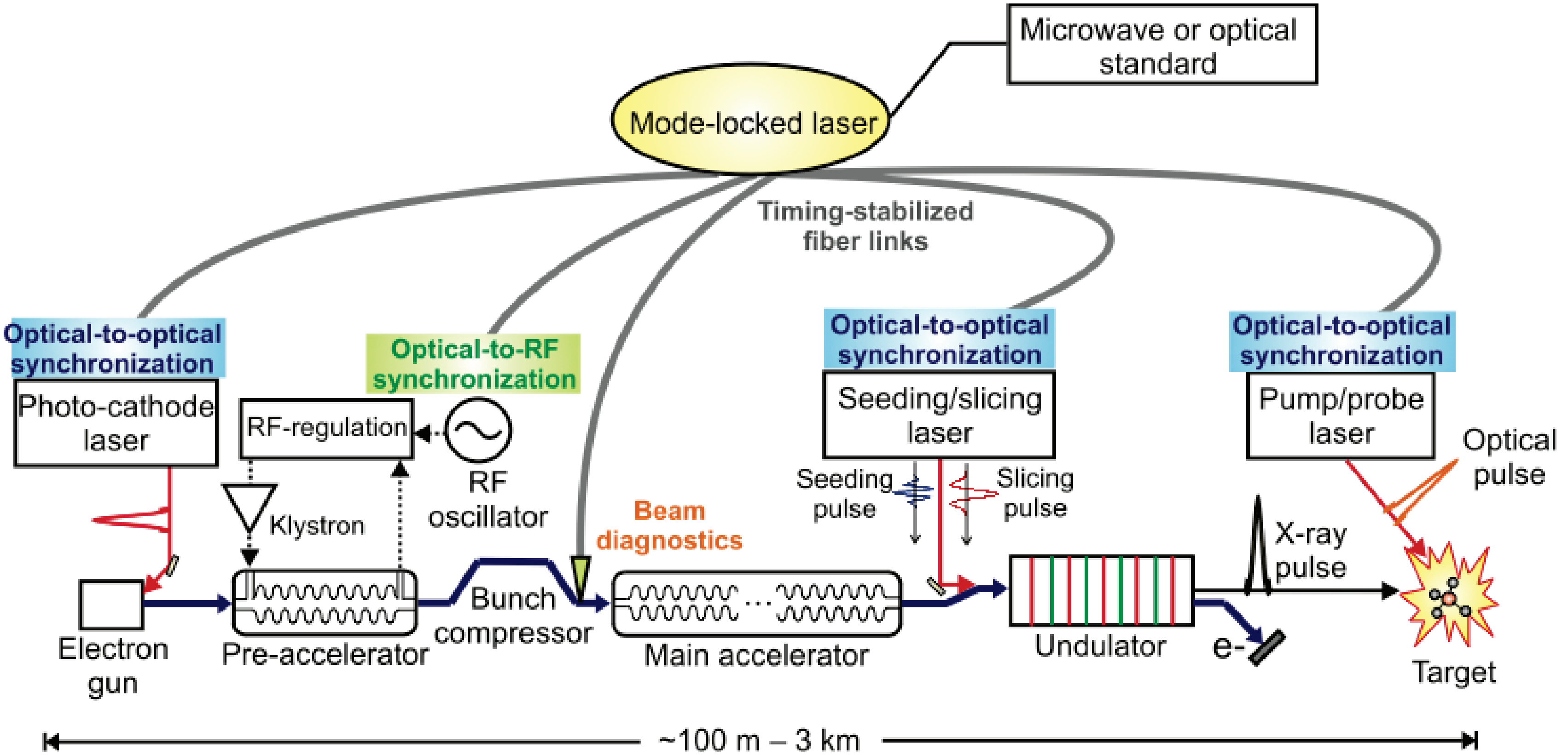
Grand Challenge Science Opportunities

An exciting window of opportunity exists for the U.S. to provide a revolutionary advance in x-ray science by developing and constructing an unprecedented x-ray light source. **This new light source should provide high repetition rate, ultra-bright, transform limited, femtosecond x-ray pulses over a broad photon energy range with full spatial and temporal coherence. Stability and precision timing will be critical characteristics of the new light source.**

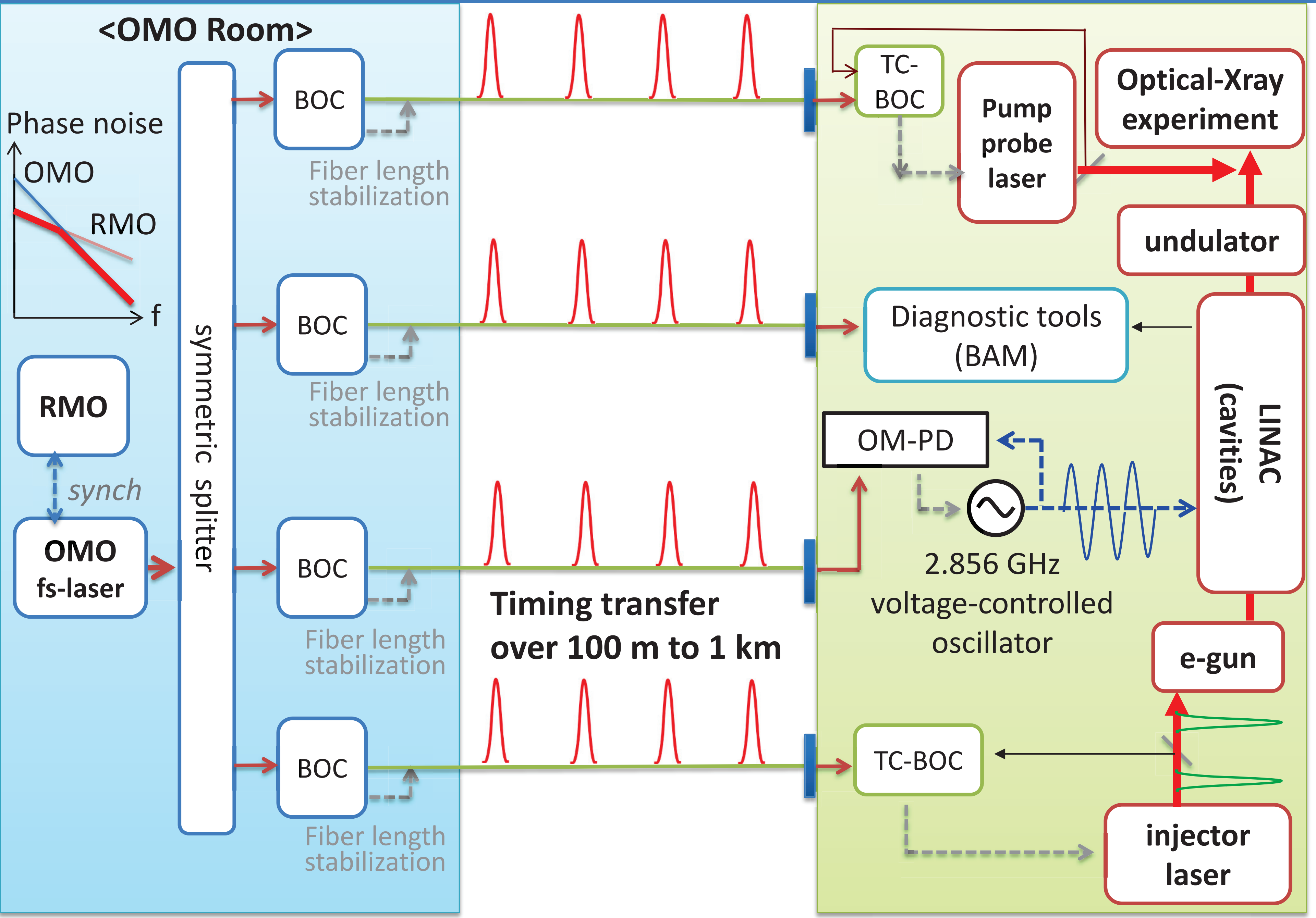
Fully pulsed optical timing system



J. Kim *et al*, Nature Photonics **2**, 733 (2008)

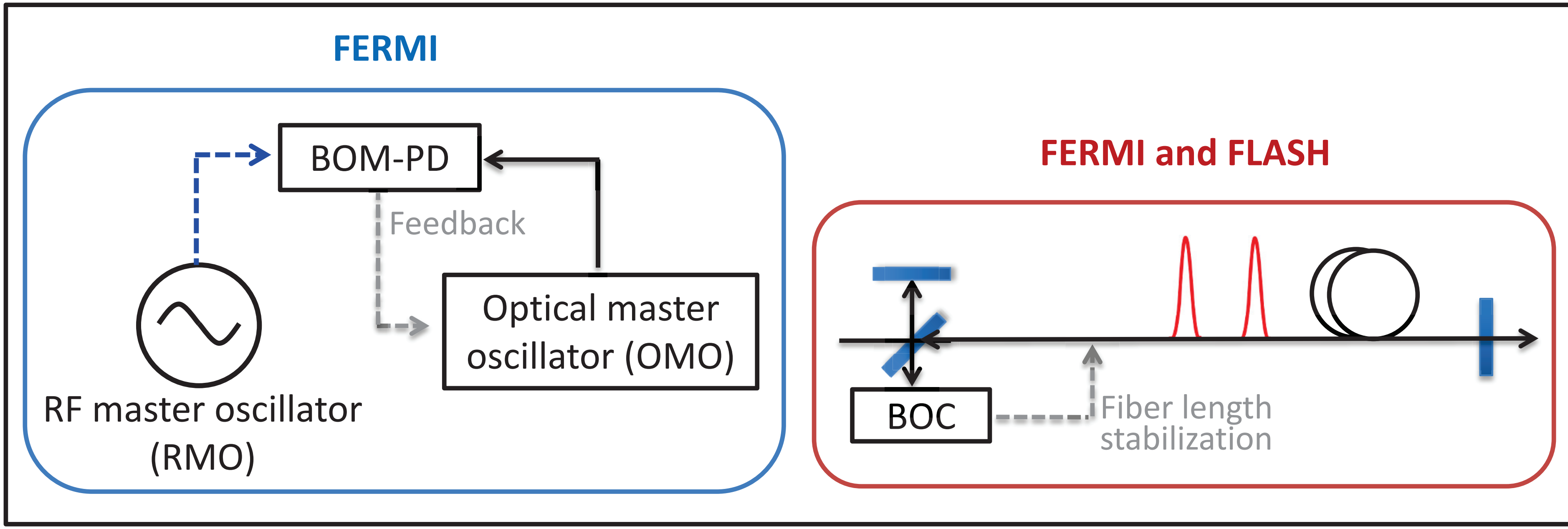
- Timing detection using ultra short pulse -> extremely high resolution and low drift
- Strong electron beam diagnostic tools can be used (BAM).
- Various RF/microwave components and optical pulse trains can be simultaneously used.
- Direct pump/probe experiment is possible.

Pulsed optical timing and synchronization system overview

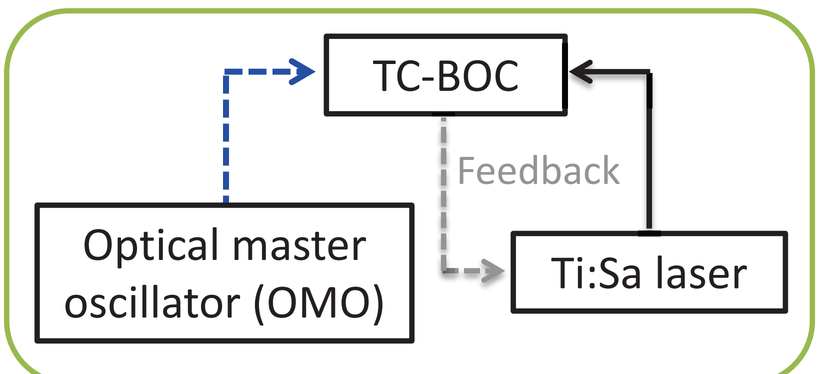


Pulsed optical timing system is being operated at FEL facilities.

FERMI



FLASH



Each unit currently being installed at FLASH (Hamburg, Germany) and FERMI @ Elettra (Trieste, Italy)

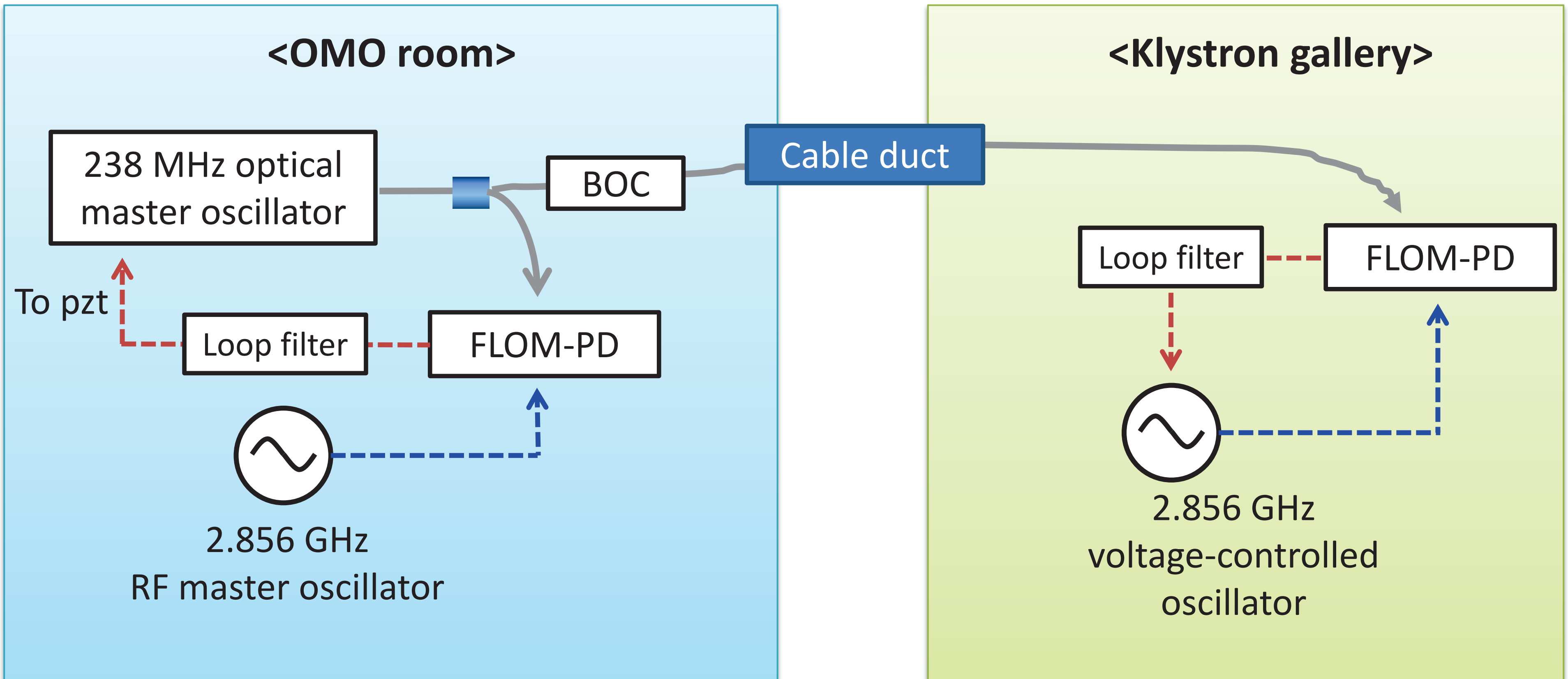
However, the full implementation of OMO vs remote RF synchronization has not been demonstrated so far.

S. Schulz et al, IBIC 2013, Paper WEPC32

S. Schulz et al, PAC 2009, Paper TH6REP091

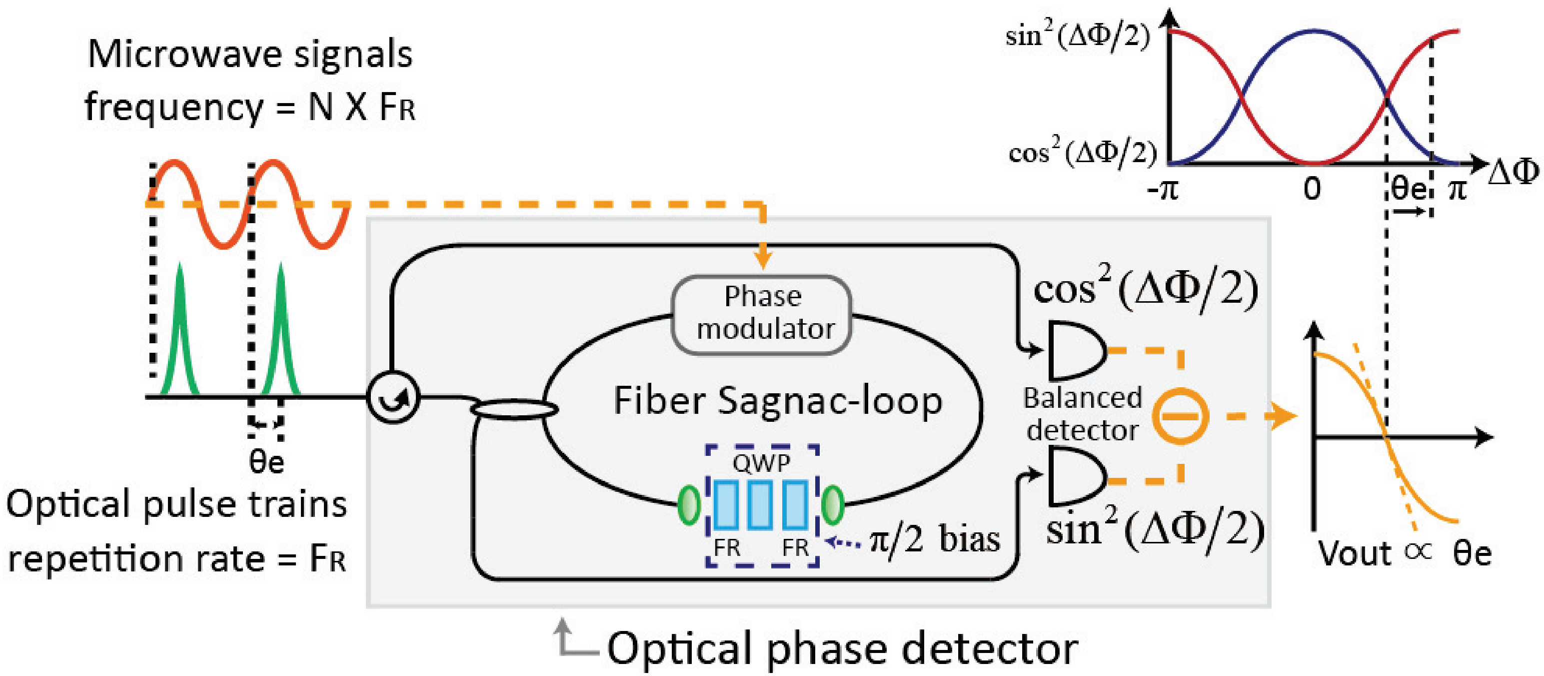
M. Ferianis, PAC 2009

We perform full RMO vs remote RF synchronization.



Optical/RF synchronization method

Fiber-Loop Optical-Microwave Phase Detector (FLOM-PD)

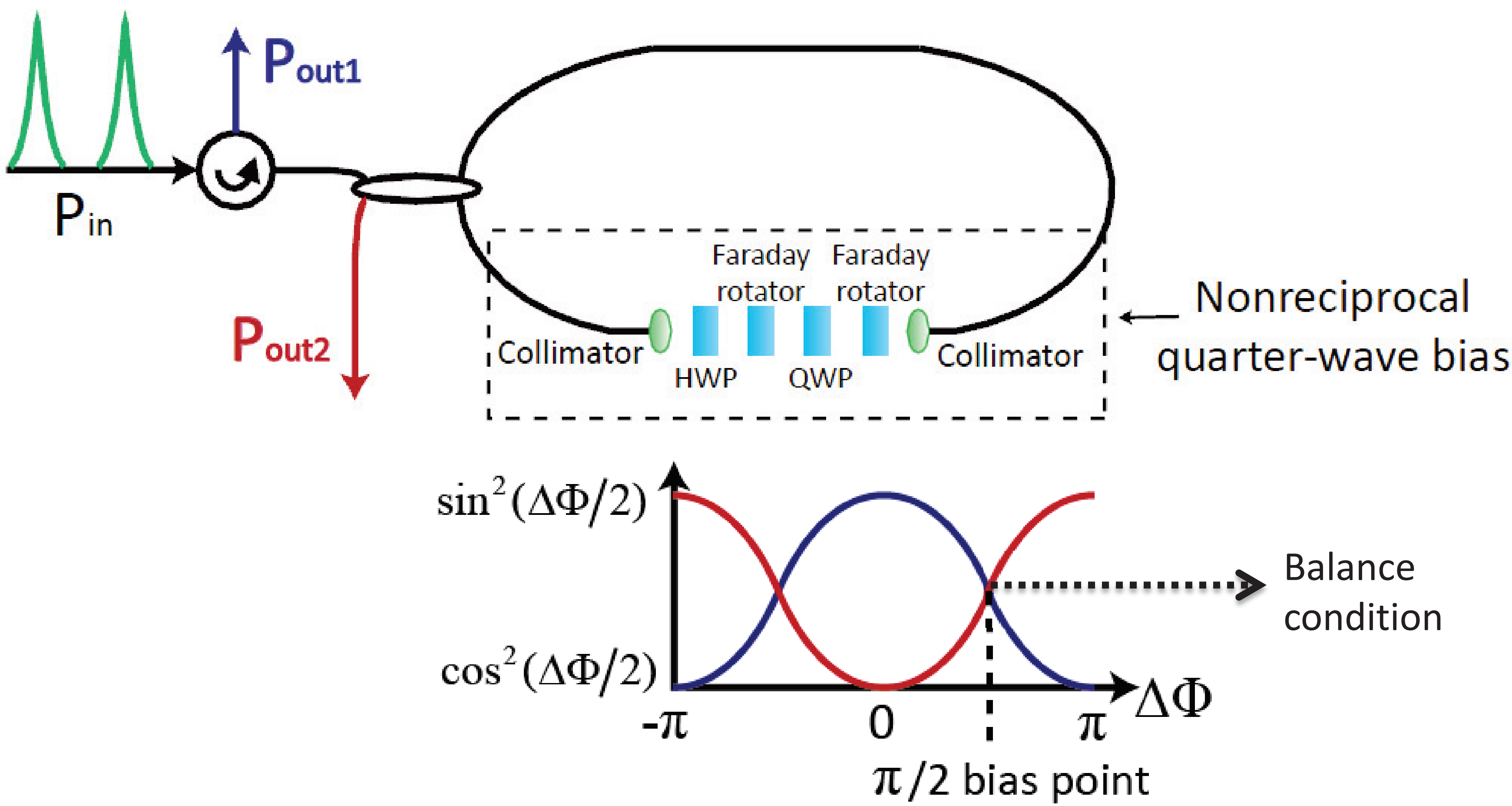


- Excess phase noise in the photodetection process is suppressed.
- Laser intensity noise is also suppressed by balancing scheme.

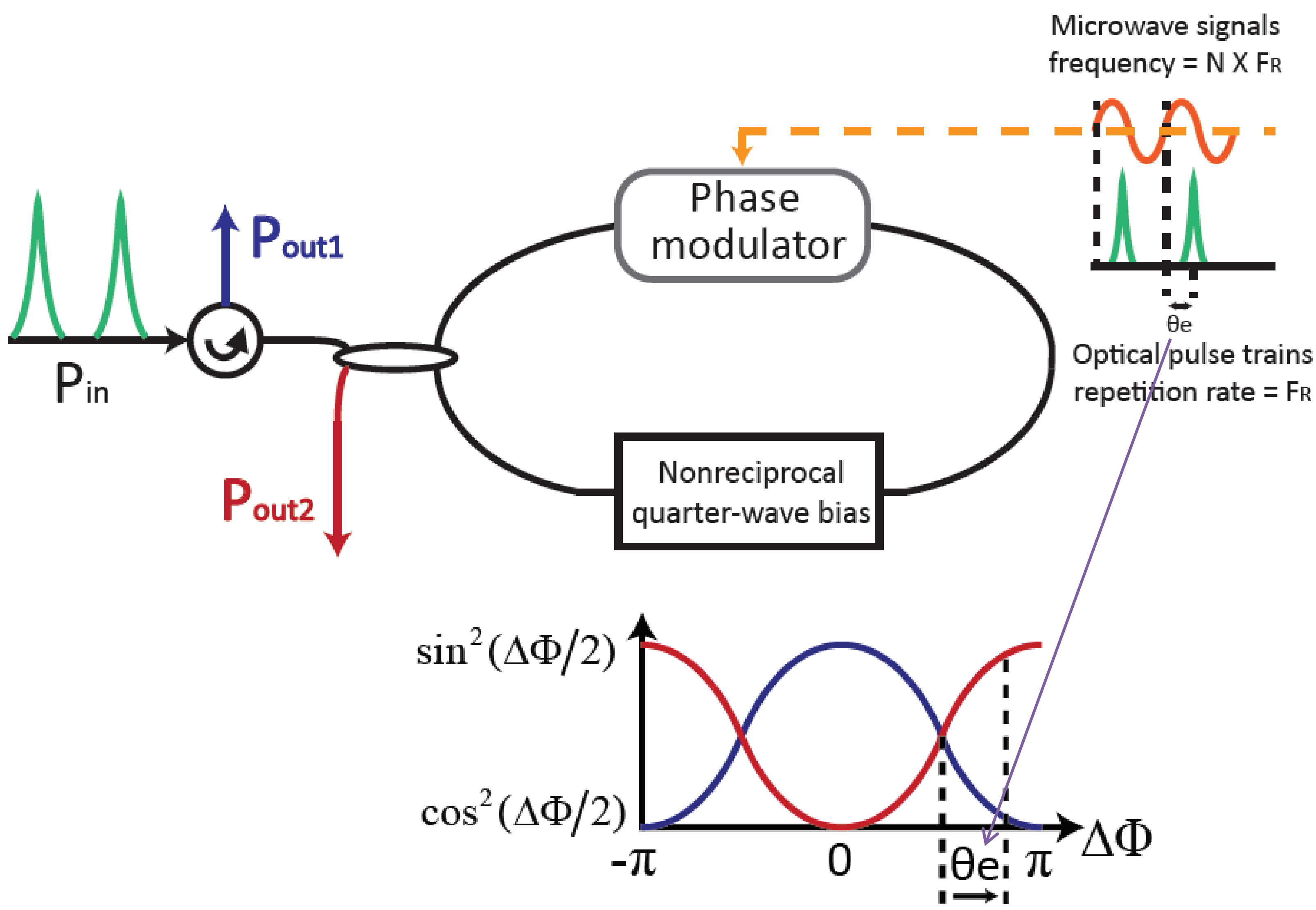
K. Jung and J. Kim, Opt. Lett. **37**, 2958 (2012)

K. Jung et al, IEEE Photon. J. **5**, 5500906 (2013)

Operation principle of the FLOM-PD



Operation principle of the FLOM-PD



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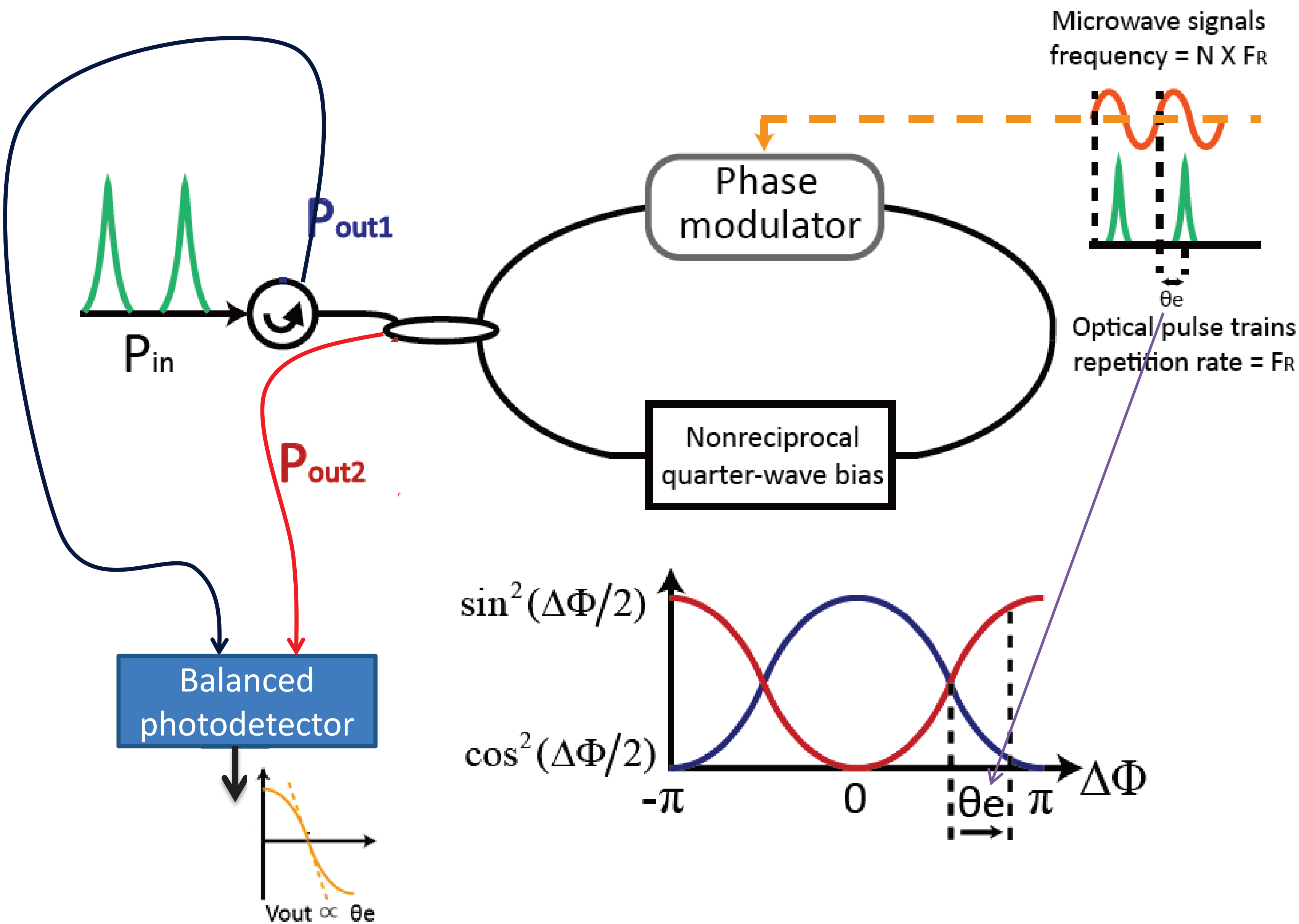
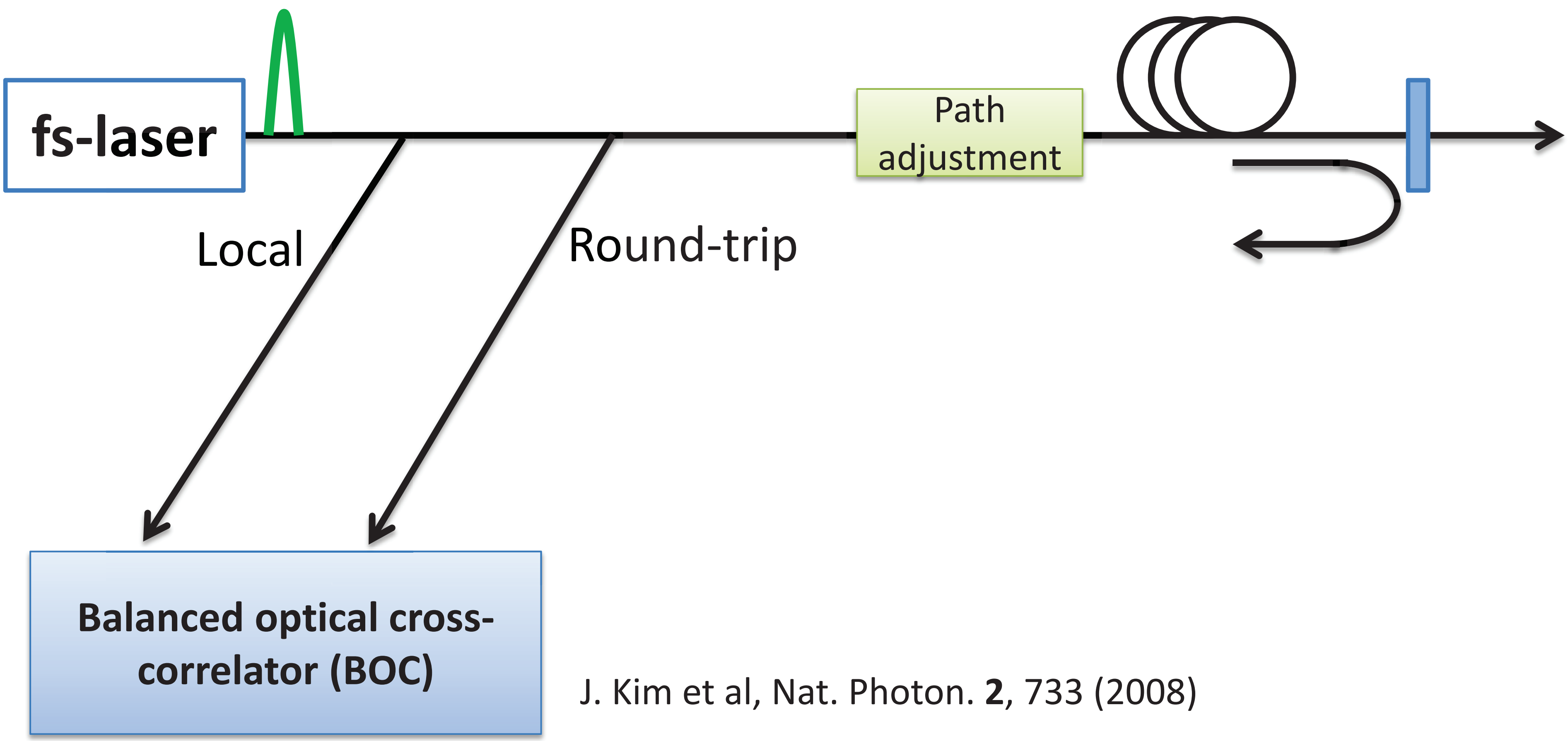


Timing link stabilization method



J. Kim et al, Nat. Photon. **2**, 733 (2008)

- Extremely high resolution and very low long-term drift

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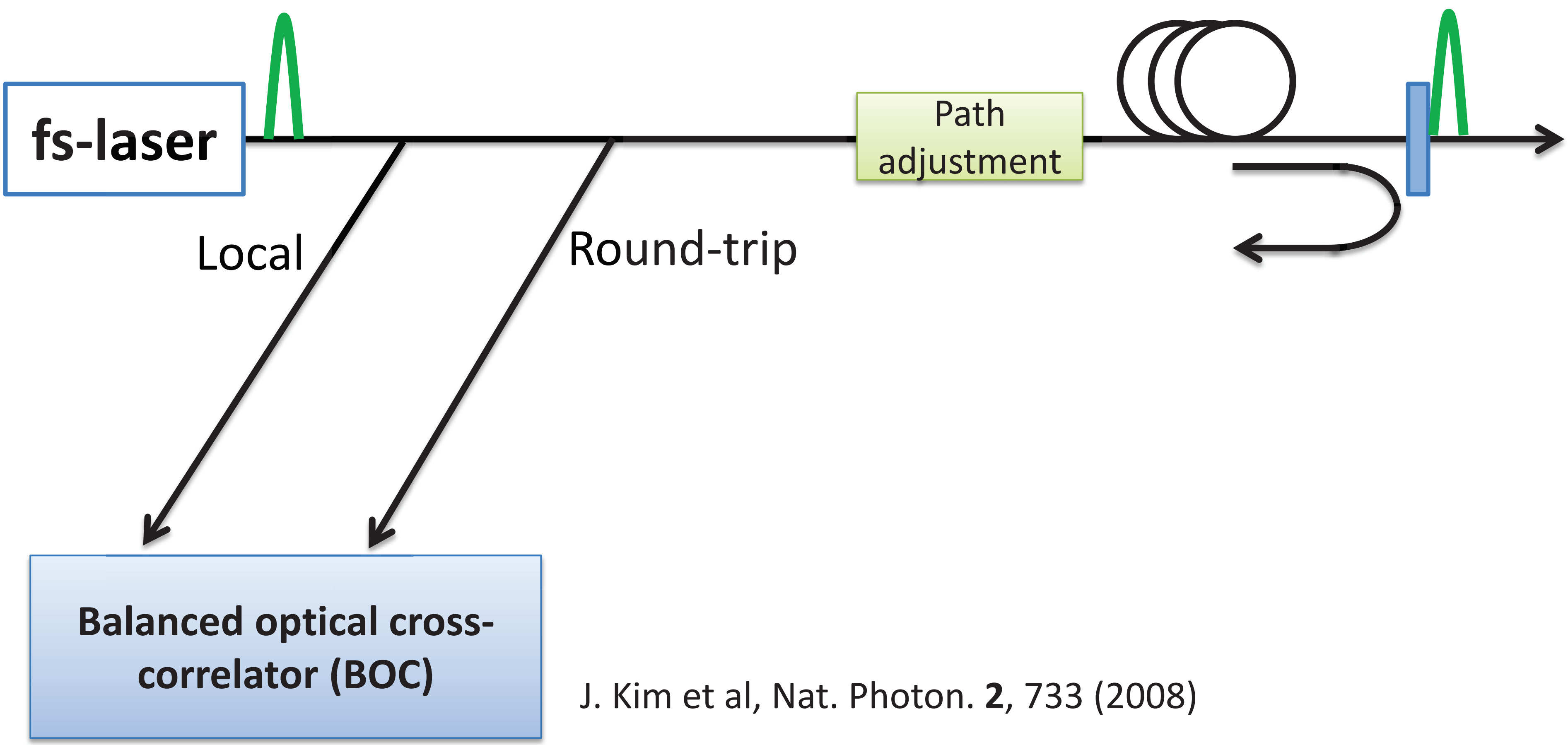

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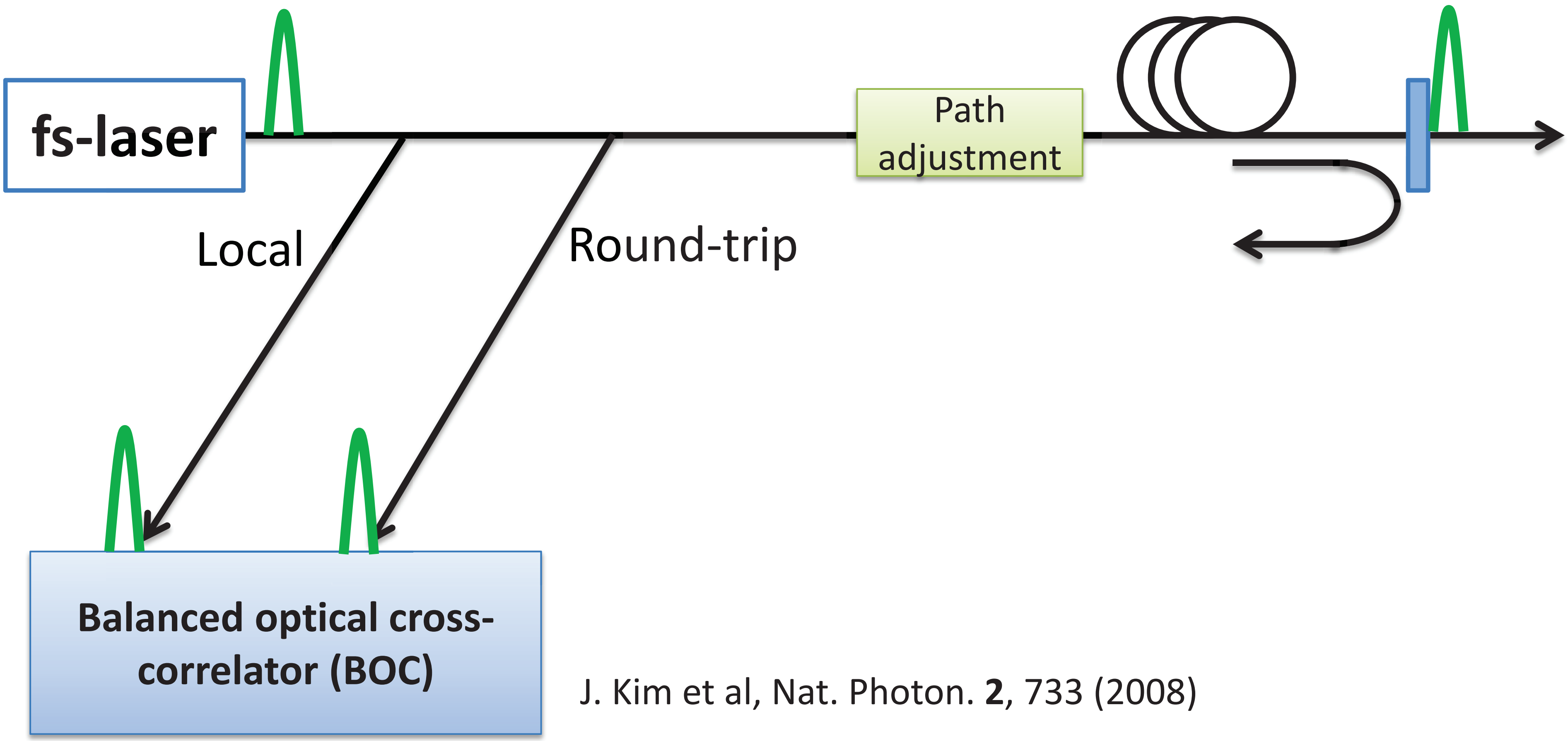

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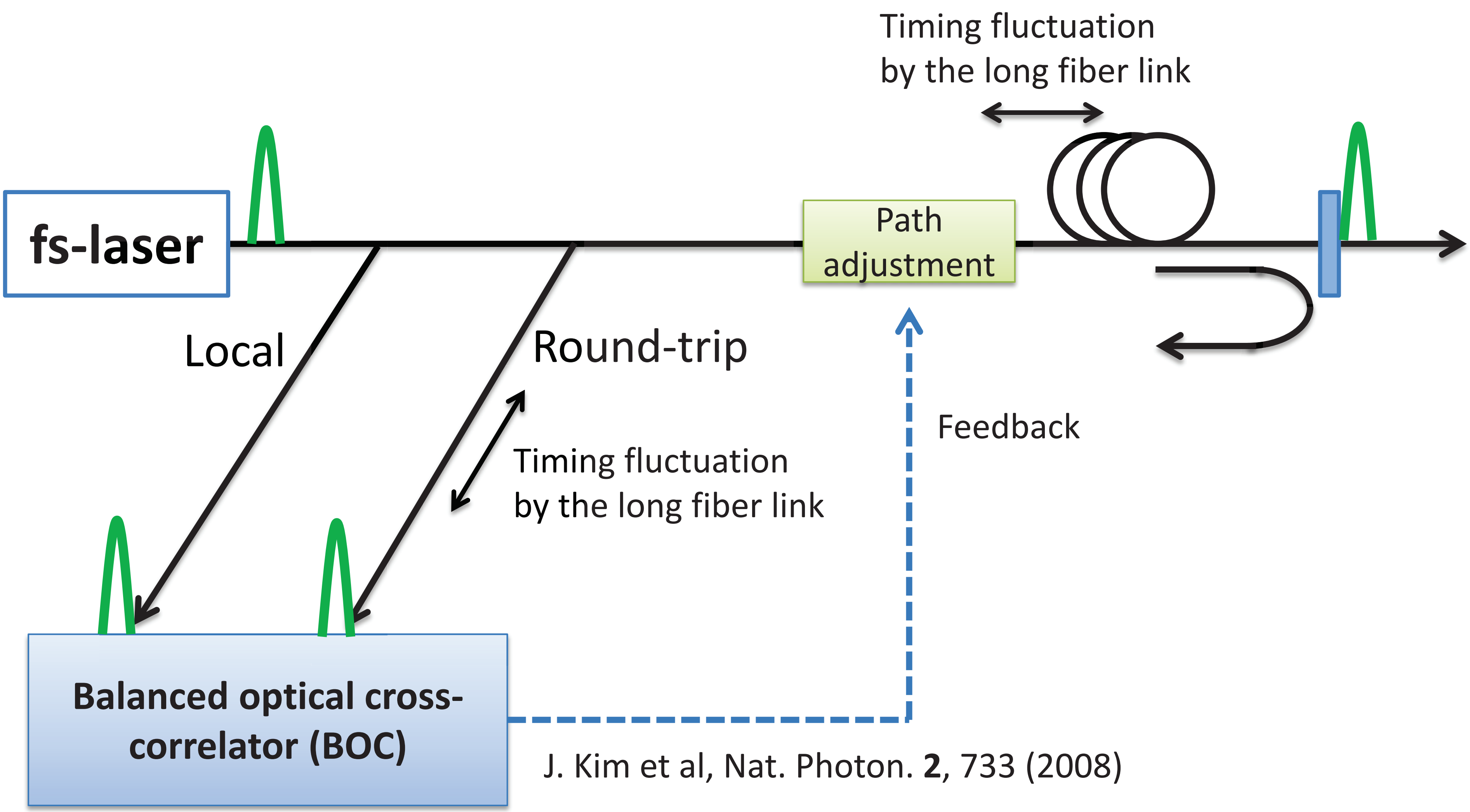
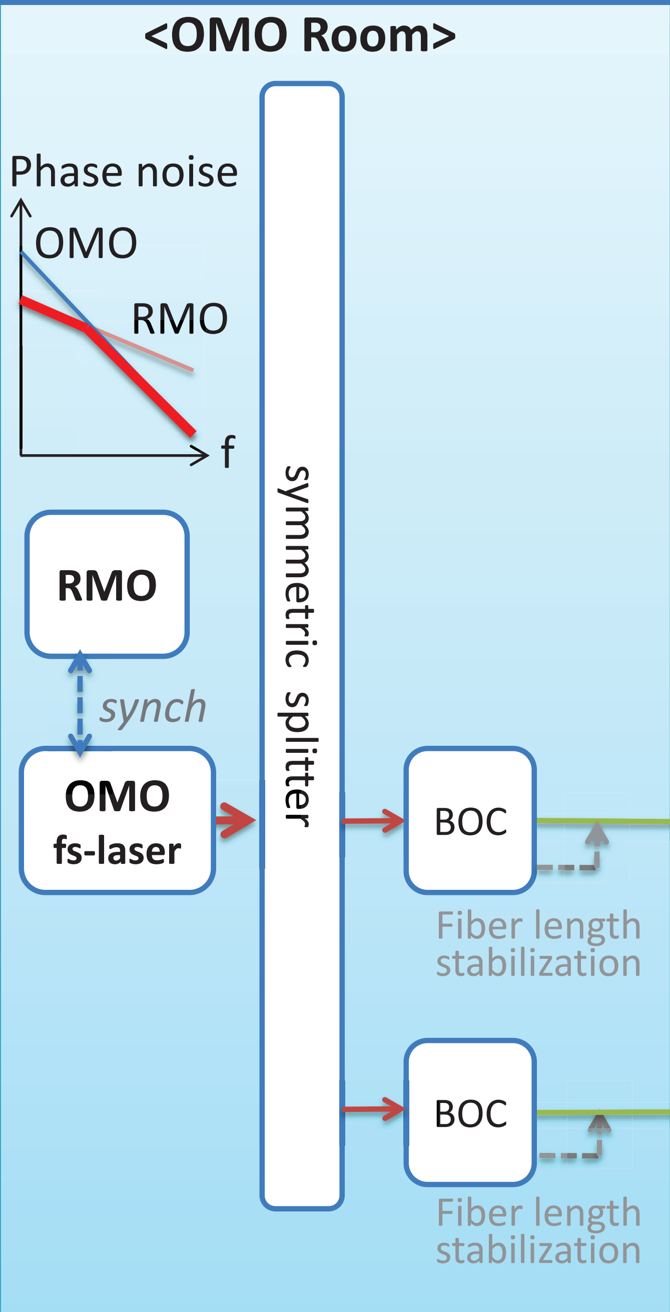
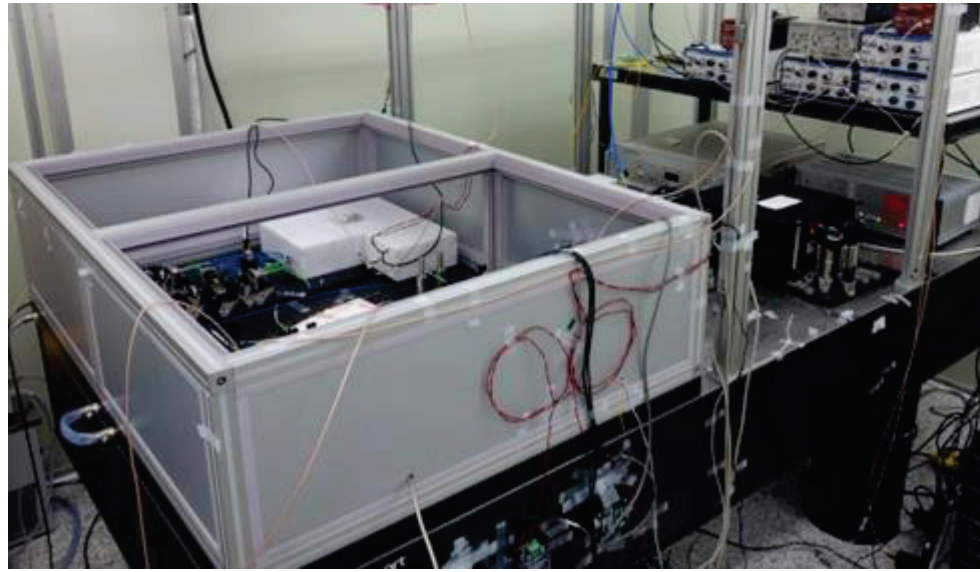


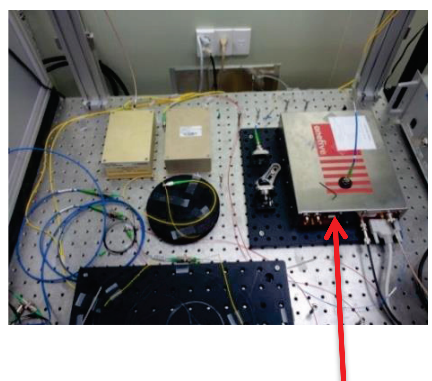
J. Kim et al, Nat. Photon. **2**, 733 (2008)

- Extremely high resolution and very low long-term drift

1.15 km remote RF distribution experimental setup



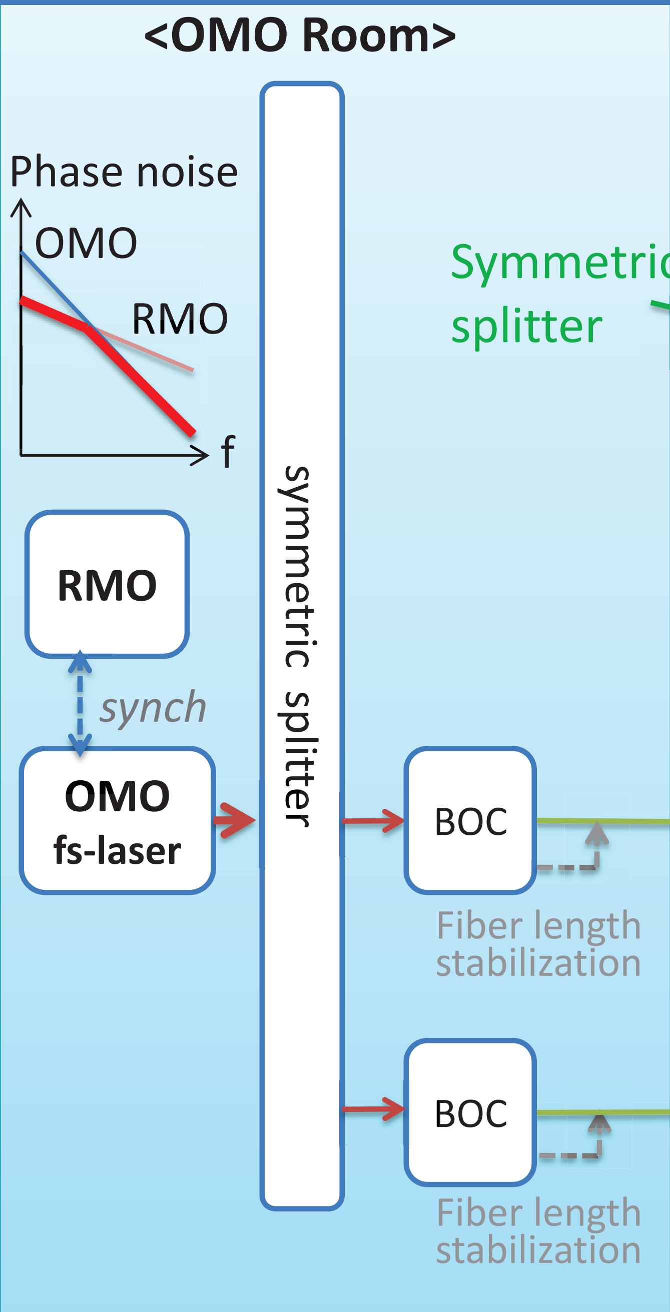


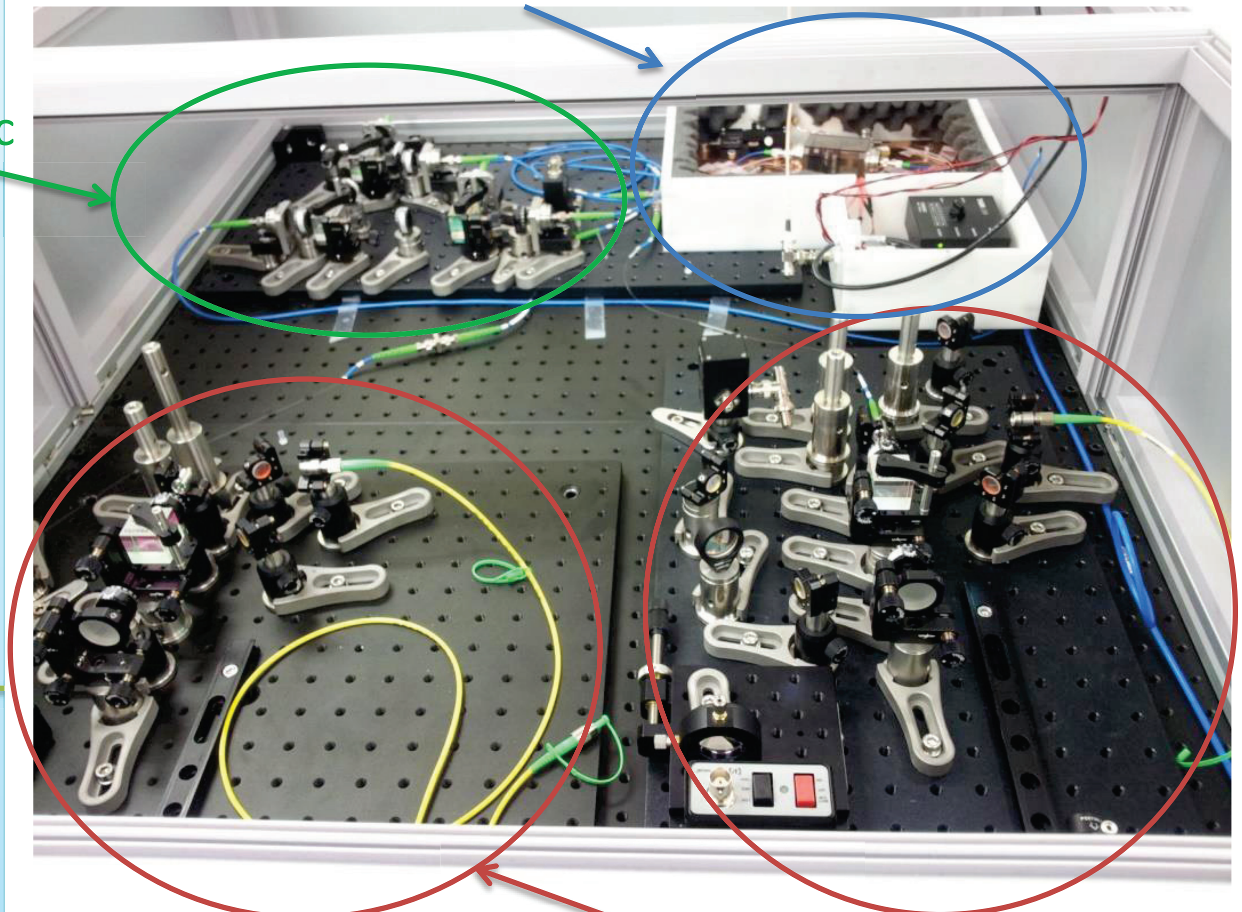


Optical Master Oscillator (OMO)

RF Master Oscillator (RMO)

1.15 km remote RF distribution experimental setup





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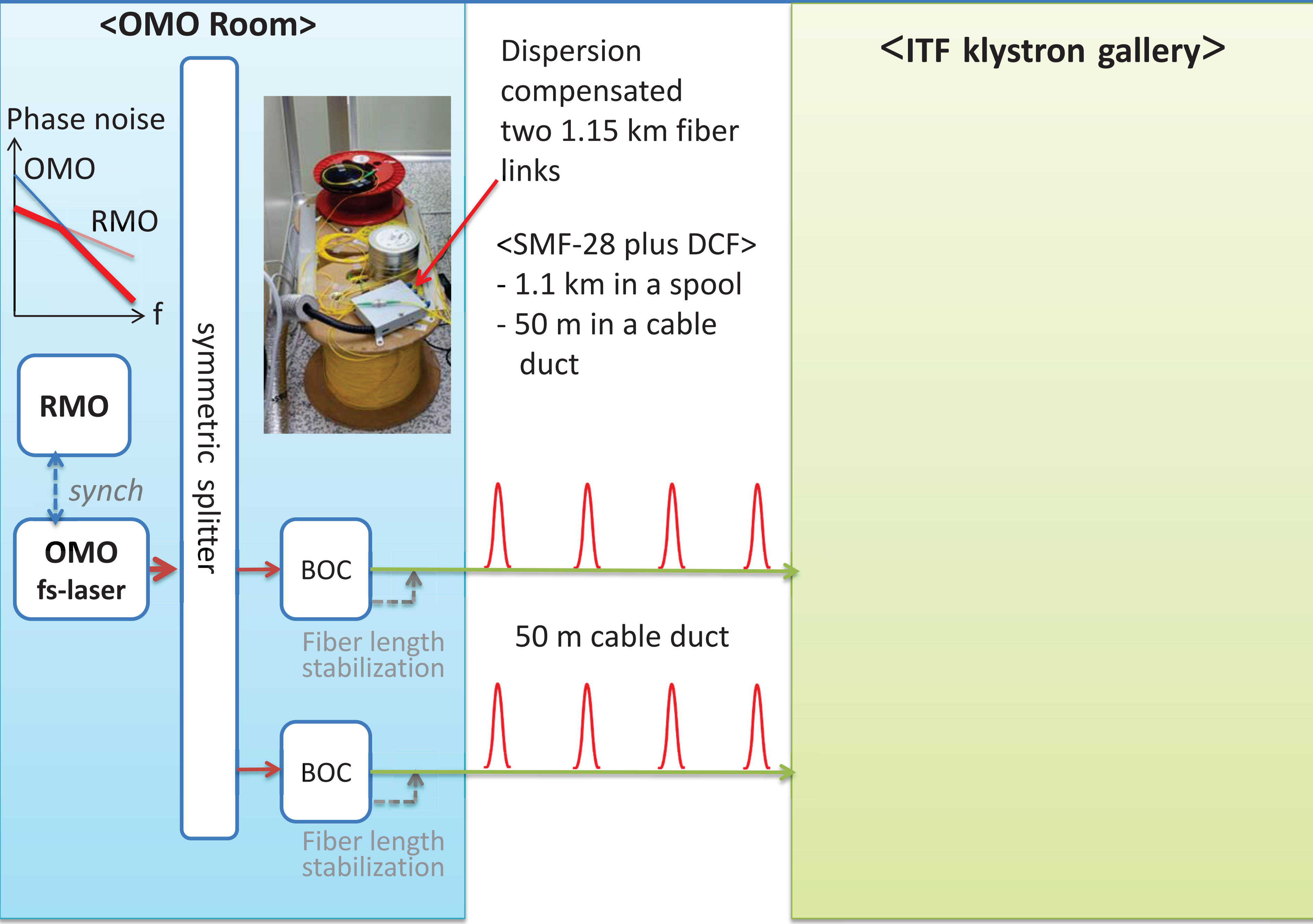

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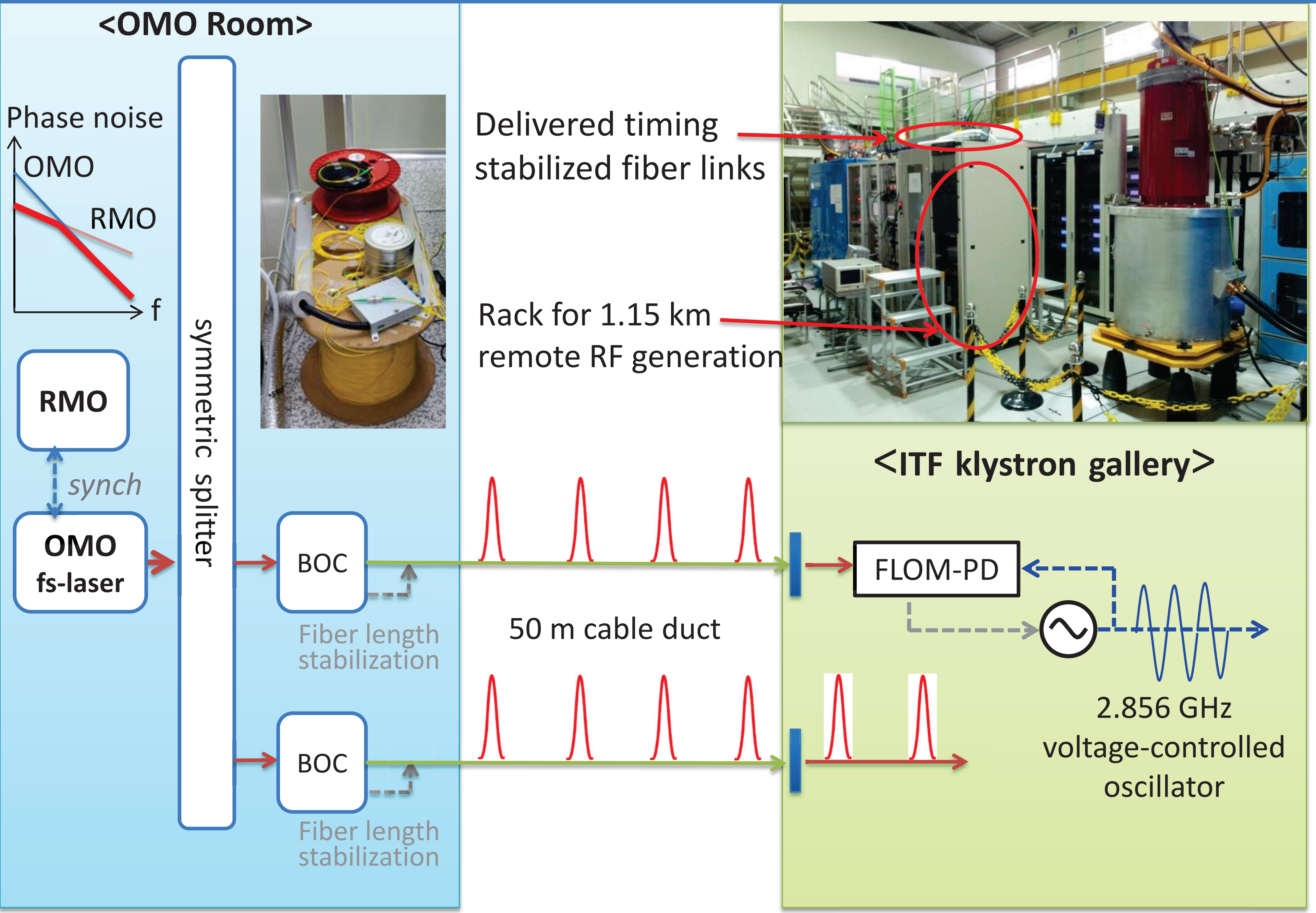

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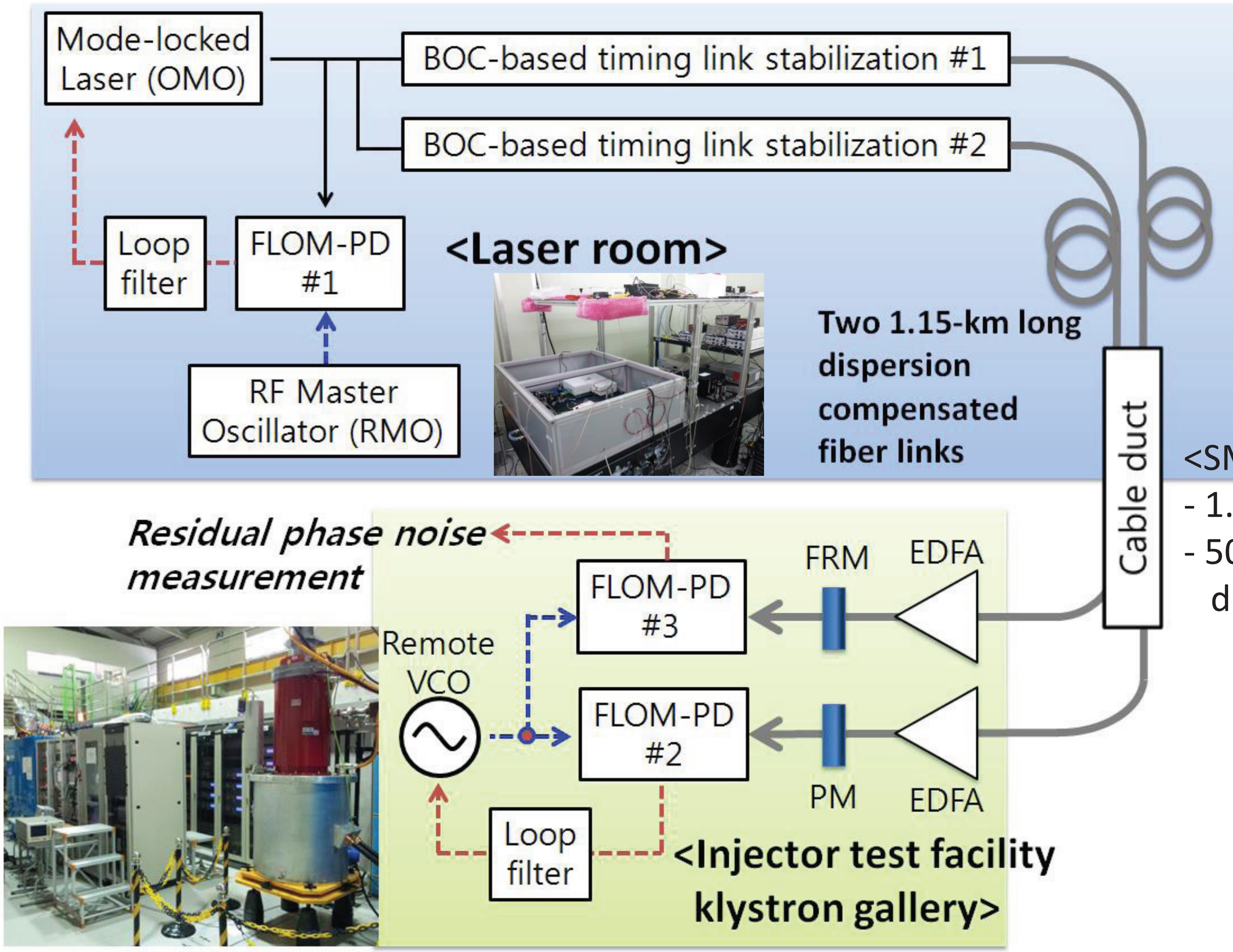
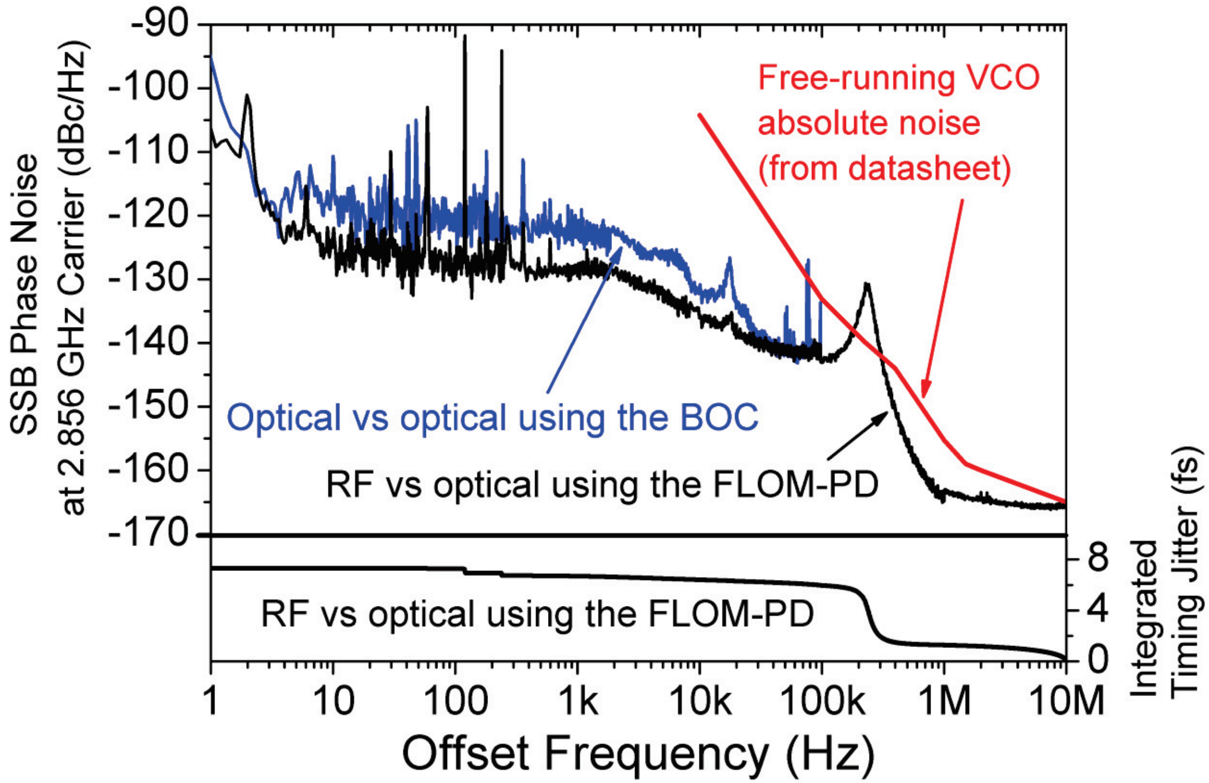


<SMF-28 plus DCF>

- 1.1 km in a spool
- 50 m in a cable duct

Short-term residual phase noise result between delivered 2.856 GHz RF and optical pulse trains

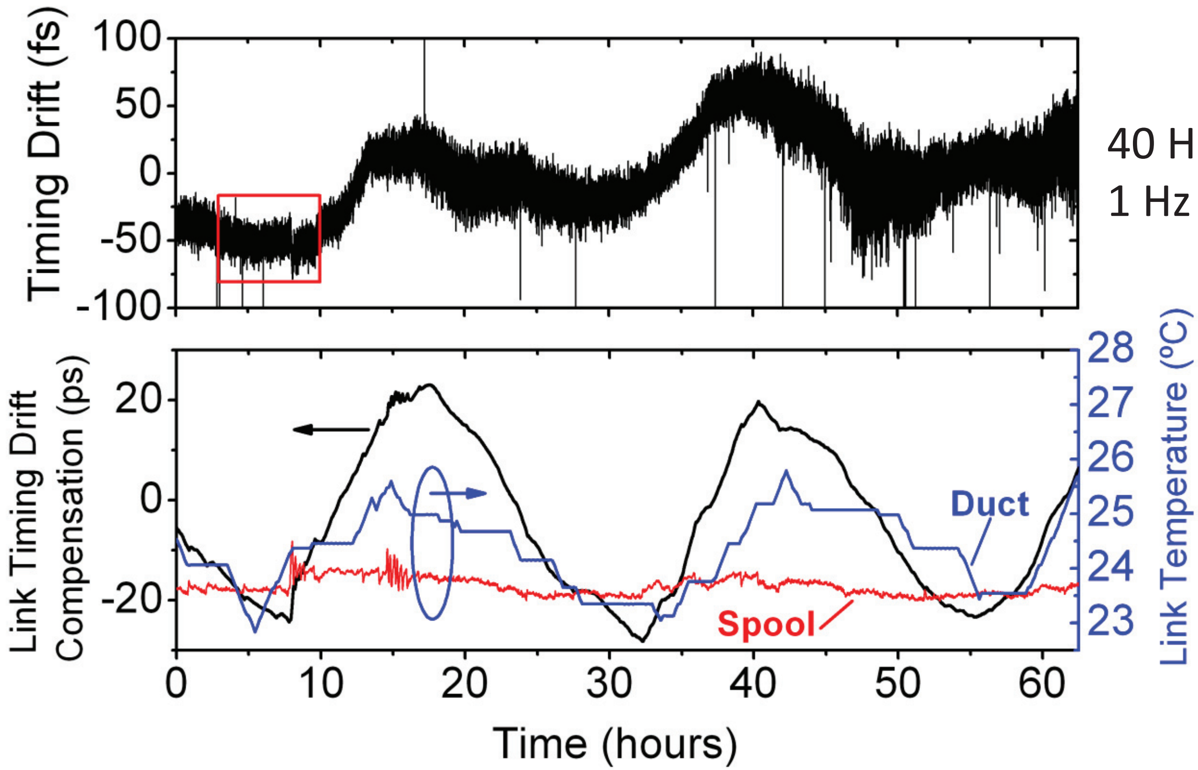


This is the first RF transfer test based on optical pulsed timing system in accelerator environment.

Integrated timing jitter: 7.3 fs [1 Hz - 10 MHz]

K. Jung et al, J. Lightwave. Technol., DOI:10.1109/JLT.2014.2312400 (2014)

Long-term residual timing drift result between delivered 2.856 GHz RF and optical pulse trains



40 Hz lowpass filtered and 1 Hz sampled data

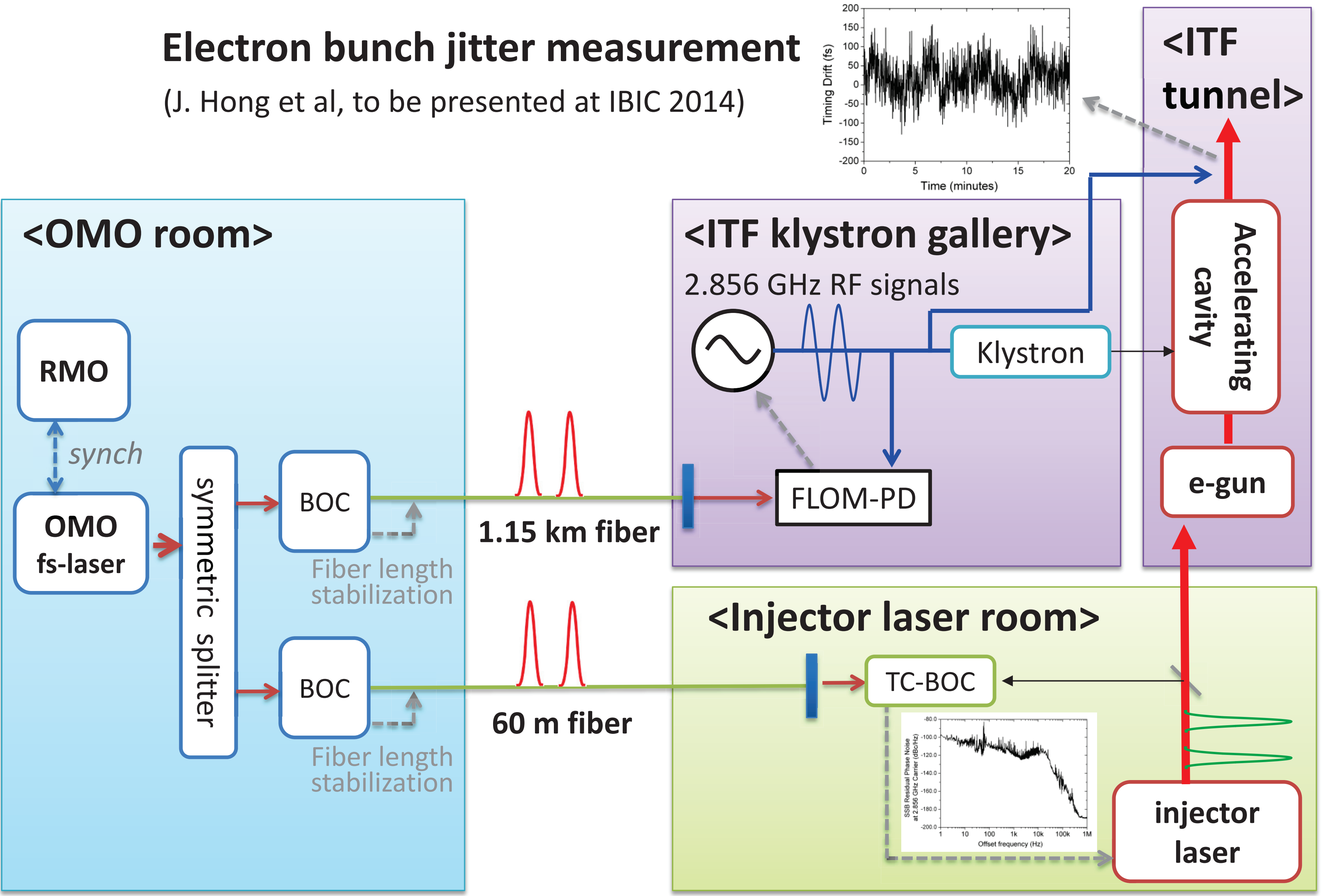
- 6.6 fs in rms for highlighted 3 ~ 10 hours
- 31 fs in rms for whole 62.5 hours
  It was caused by the FLOM-PD temperature change and fiber link PMD (polarization mode dispersion).
- Typically known PMD of the SMF-28 fiber is 60 fs/√km.

K. Jung et al, J. Lightwave. Technol., DOI:10.1109/JLT.2014.2312400 (2014)

Electron bunch timing jitter measurement

Electron bunch jitter measurement

(J. Hong et al, to be presented at IBIC 2014)

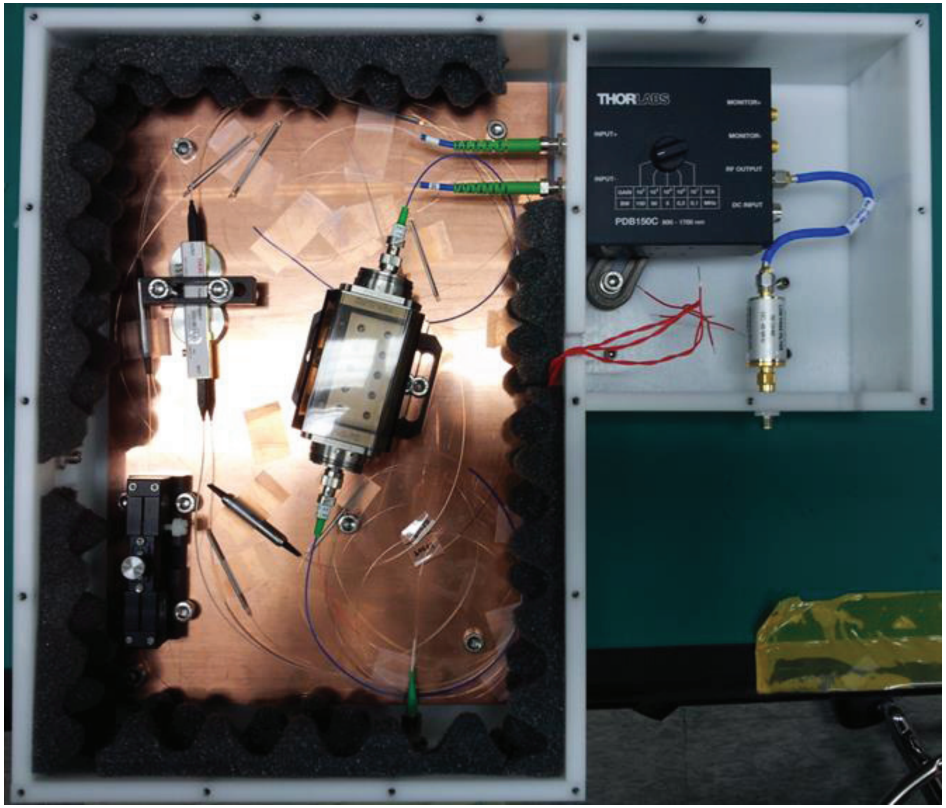


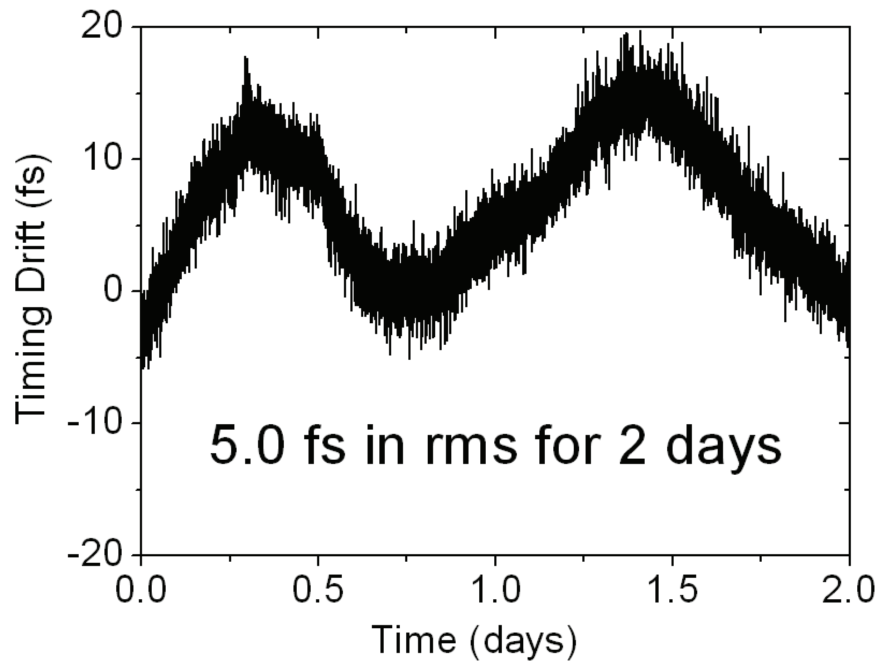
Summary

- We have implemented the optical pulse-based timing distribution system test bed in Pohang Accelerator Laboratory.
- We showed that sub-10 fs synchronization between a RF oscillator and an optical pulse train which are 1 km away can be possible in the real accelerator machine.
- Now, we are measuring electron bunch timing jitter after applying the full optical pulsed timing system including synchronization of an injector laser (Ti:Sa laser) to the optical master oscillator (to be presented at IBIC 2014).

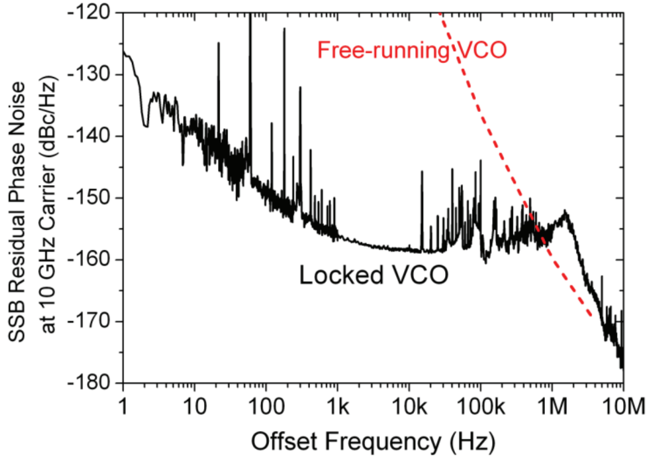
This work was supported by the PAL-XFEL Project and the National Research Foundation (Grant number 2012R1A2A2A01005544) of South Korea.

Appendix

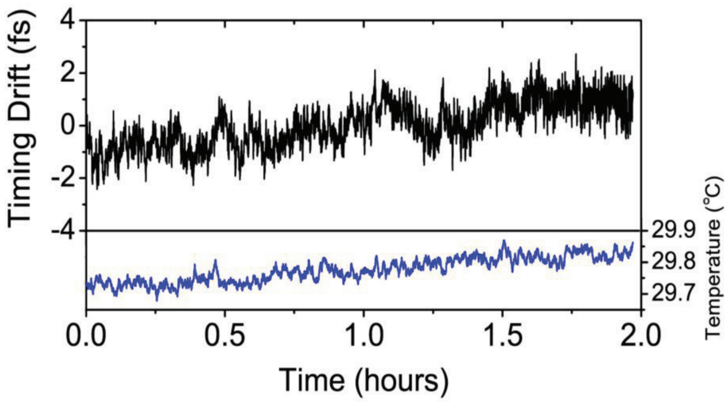

THORLABS
PDB150C


20
10
0
-10
-20
Timing Drift (fs)
5.0 fs in rms for 2 days
0.0
0.5
1.0
1.5
2.0
Time (days)

Out-of-loop local synchronization performance between a mode-locked laser and a microwave source

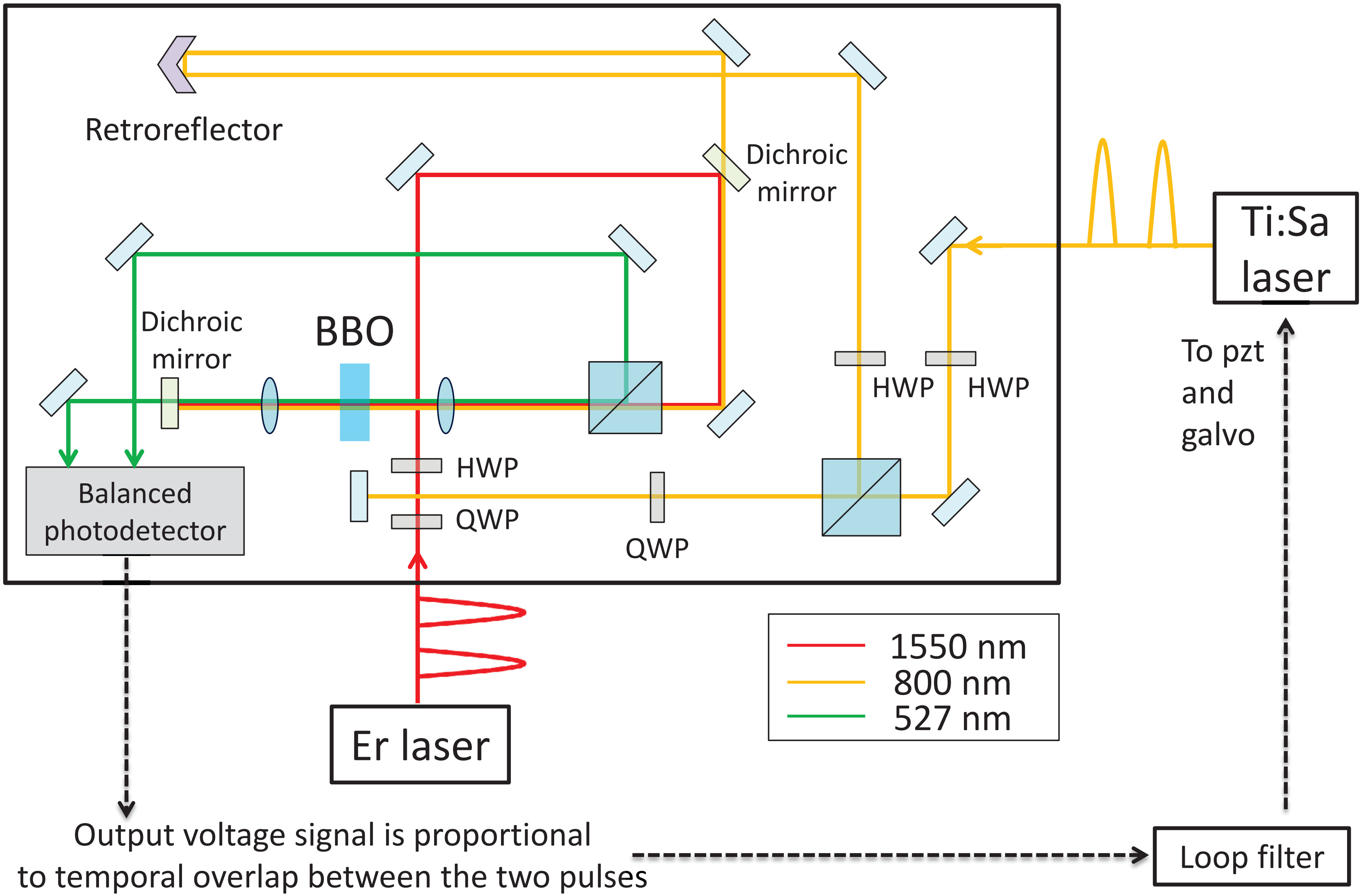


rms timing jitter: 673 as [1 Hz–10 MHz]

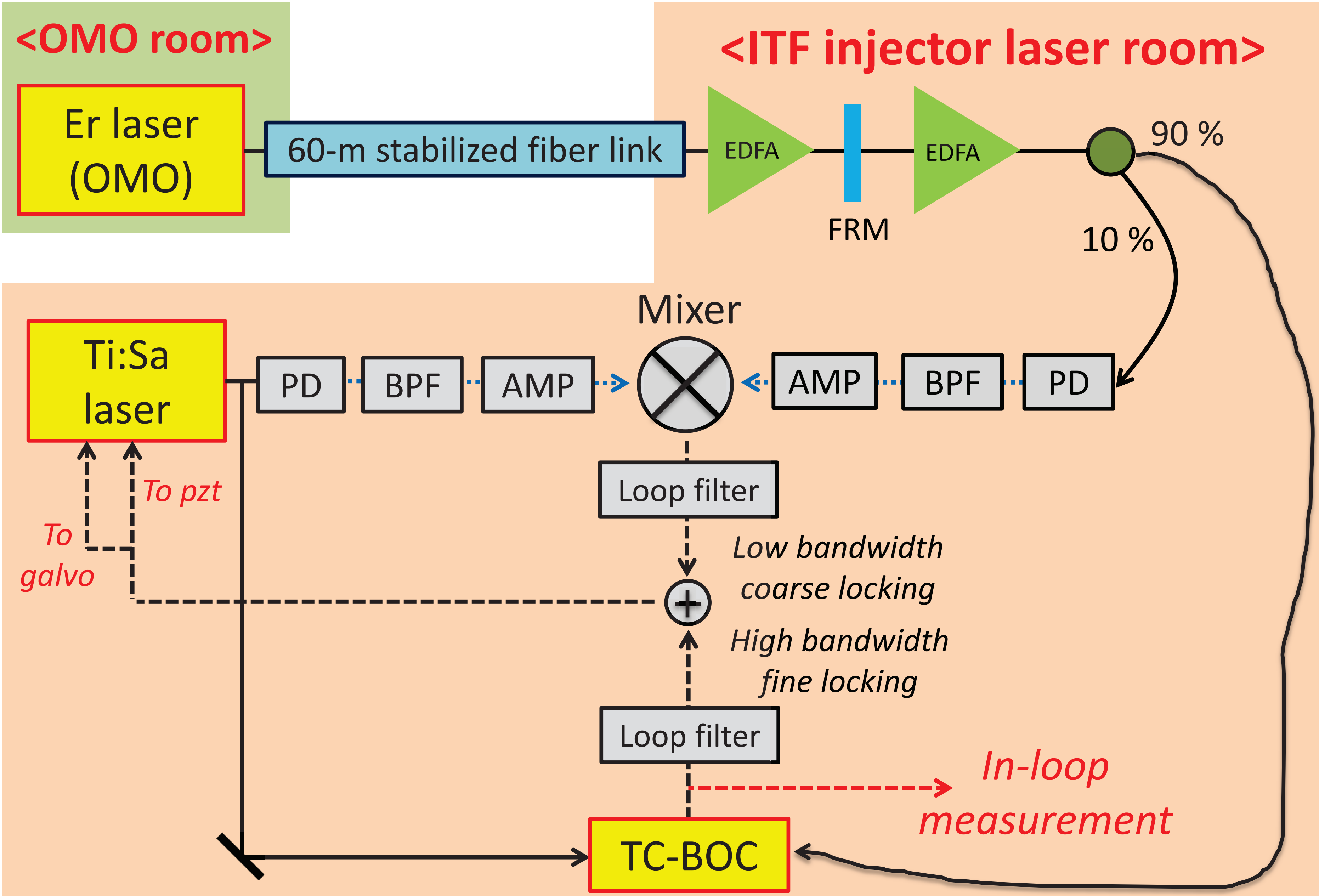


847 as rms timing drift for 2 hours

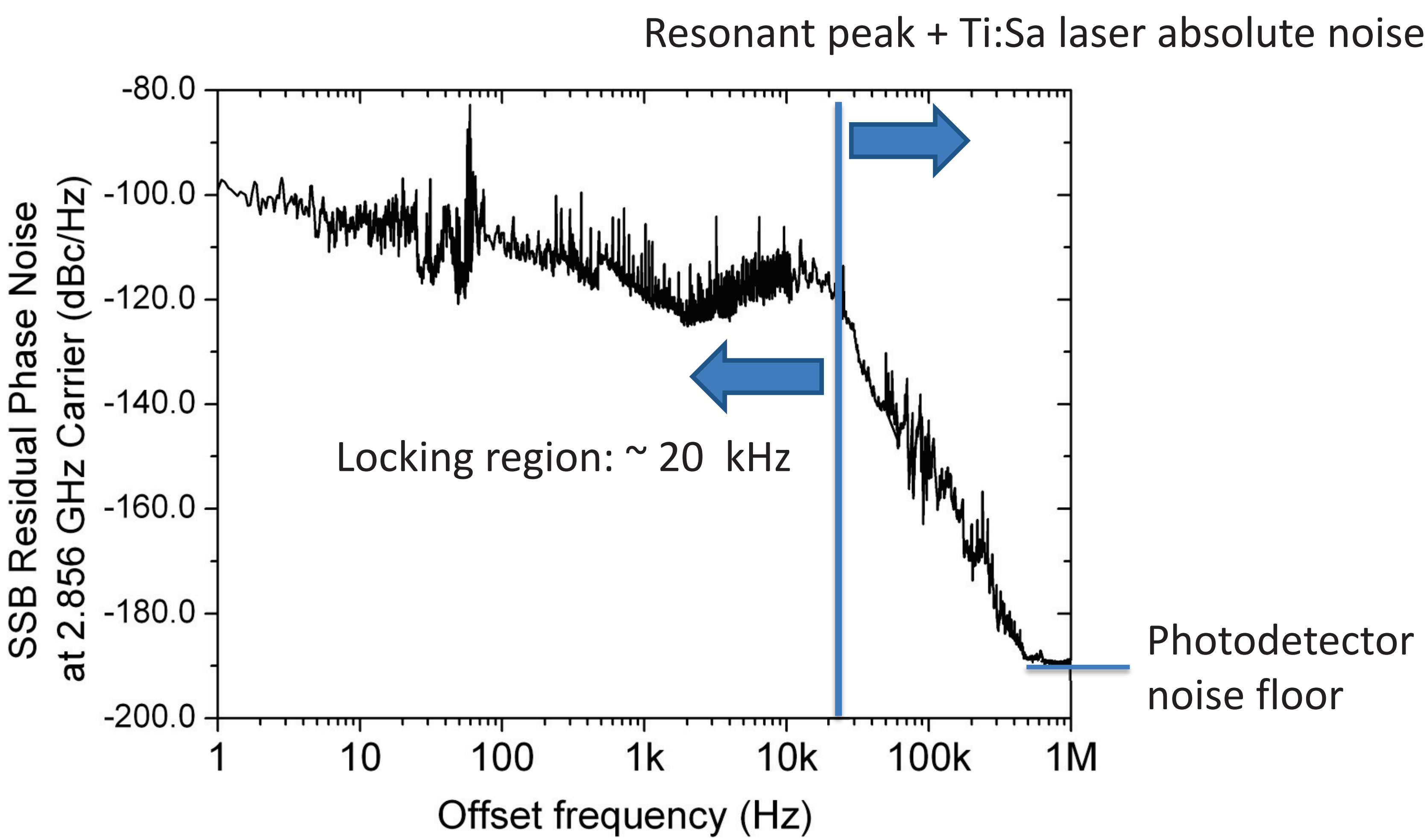
Two color balanced optical cross-correlator (TC-BOC)



Er laser vs Ti:Sa laser synchronization experimental setup



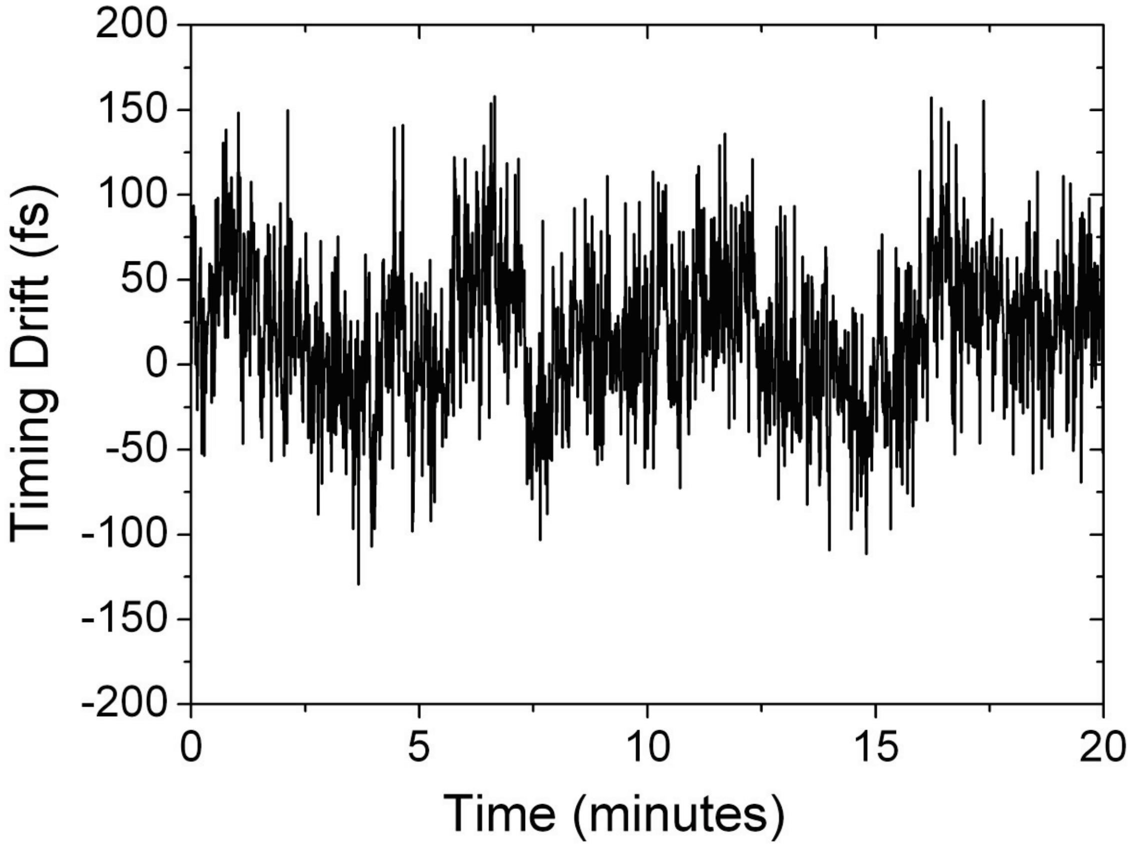
Residual phase noise between injector laser (Ti:Sa) and optical master oscillator (Er laser)



This is a preliminary **in-loop** data.

Integrated rms in-loop timing jitter: 21.7 fs [1 Hz ~ 1 MHz]

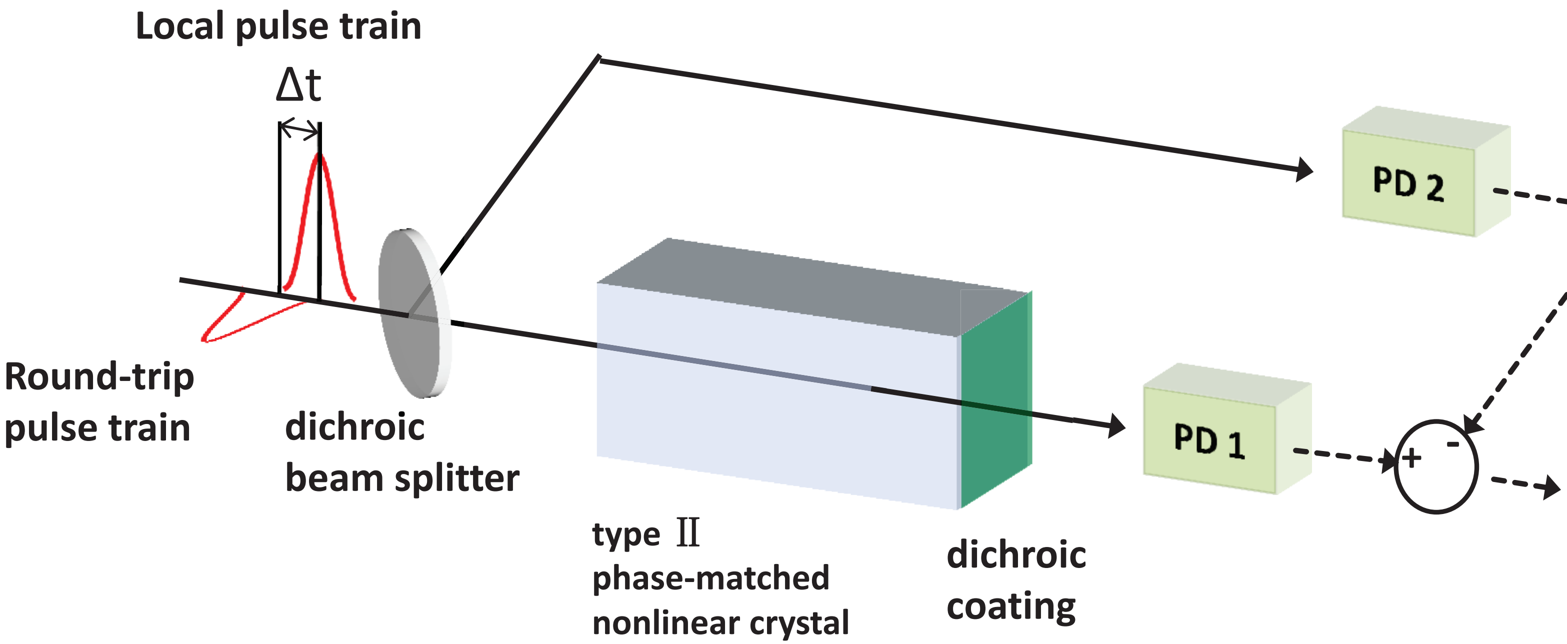
BAM??? 측정 결과



This is a preliminary data.
rms timing drift: 47 fs [Hz ~ MHz]

Balanced optical cross-correlator for the timing fluctuation detection

Balanced optical cross-correlator



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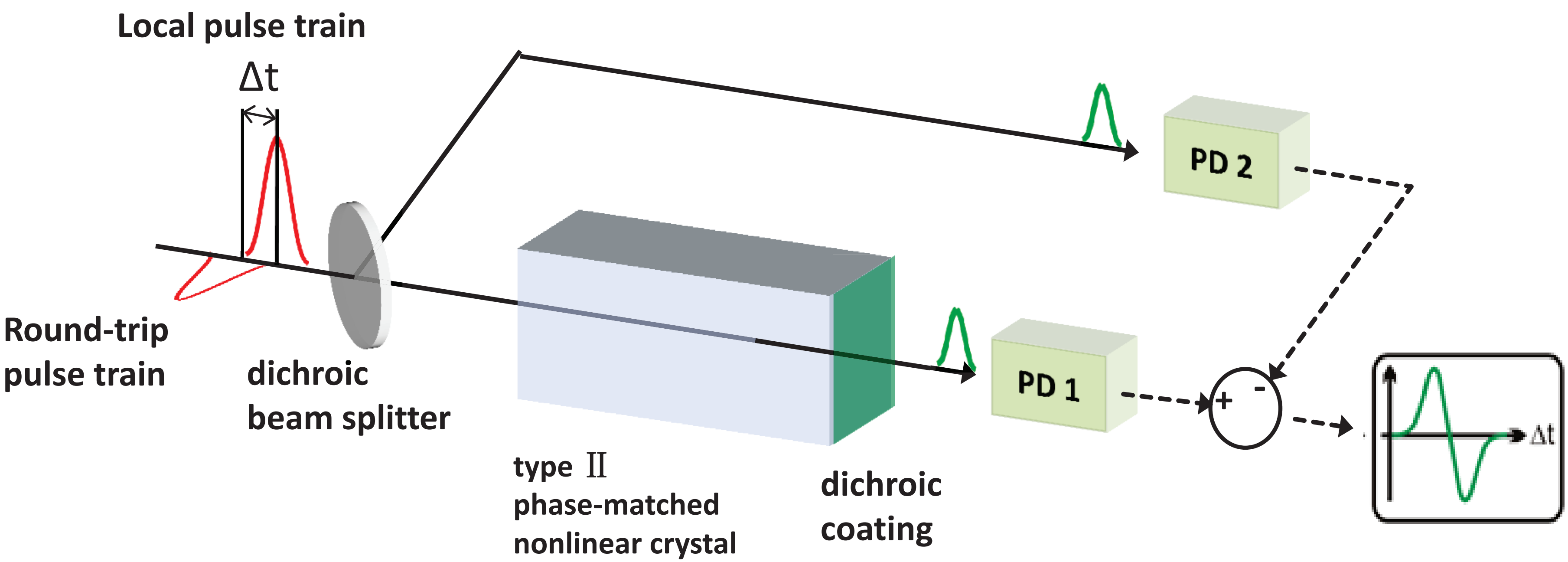

Why optical timing and synchronization at FELs in the 21st century?

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