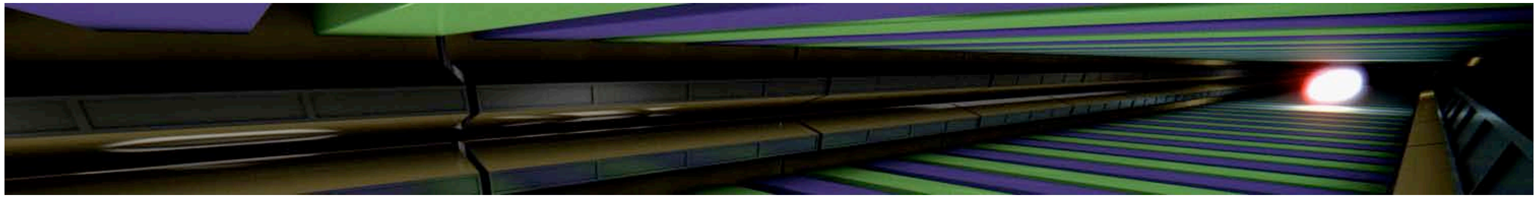

New developments and missing components of an optical synchronization system

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Motivation

Present status & evaluation of optical synchronization system

- Proof-of-principle experiments performed for Master Laser Oscillator, Link stabilization, Laser to RF conversion and Laser to Laser locking (<1-10fs achievable)
- Engineering of individual components on the way
- Optical synchronization system is very complex (reliability), cost and labor intensive
- Unclear for an accelerator and a larger system (>10 links)

  how much diagnostics and redundancy is required (remote control, software development)
- Rigid system: time overlap with electron/photon beam,

  within cross-correlator required + dispersion compensation,

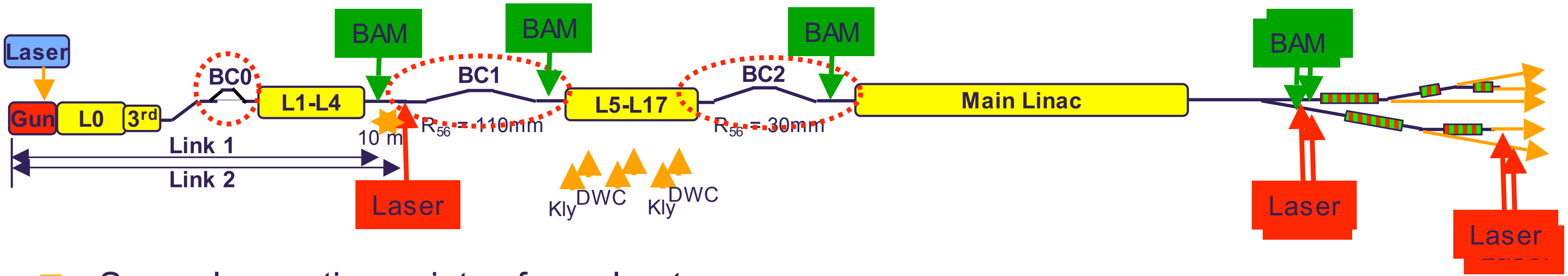
  phase shift of generated RF not simply possible

  Advantage: unambiguousness of synchronization (bucket jump can be excluded)

  Disadvantage: significant overhead required for implementation and commissioning as well as loss of flexibility
- Some solutions are not appropriate for requirements (cost versus benefit)

Next steps: simplification of system components and cost reduction

Optical synchronization system



- Several operation points of accelerator
  ⇒ e.g. BC0 is turned off it requires to shift timings of
  - Beam arrival monitor (schemes based on direct zero-crossing sampling)
  - Two-color optical cross-correlator for laser locking

Missing: alternative to optical delay lines for timing shifts (open)

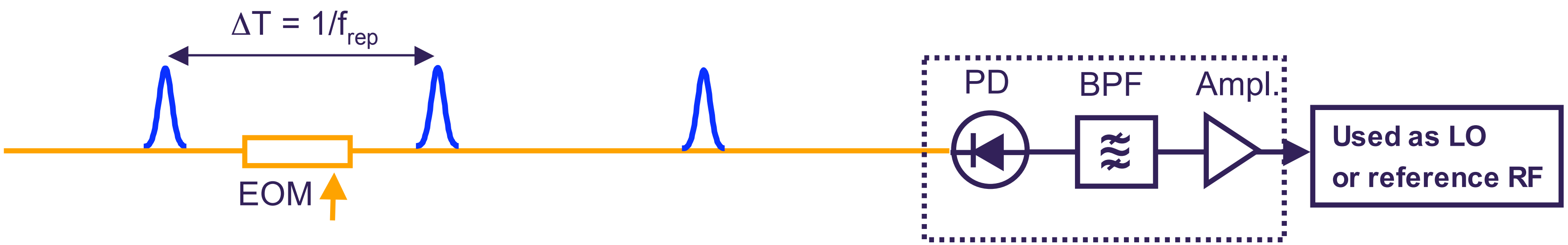
- 2 end-stations in close vicinity (two links are too expensive!!!!)

Missing: inexpensive optical link stabilization for short distances

- RF generation at many locations (low cost version at reduced performance ~20fs)

Missing: either an appropriate RF sub-distribution or fiber link stabilization + L2RF converter

RF generation by direct conversion

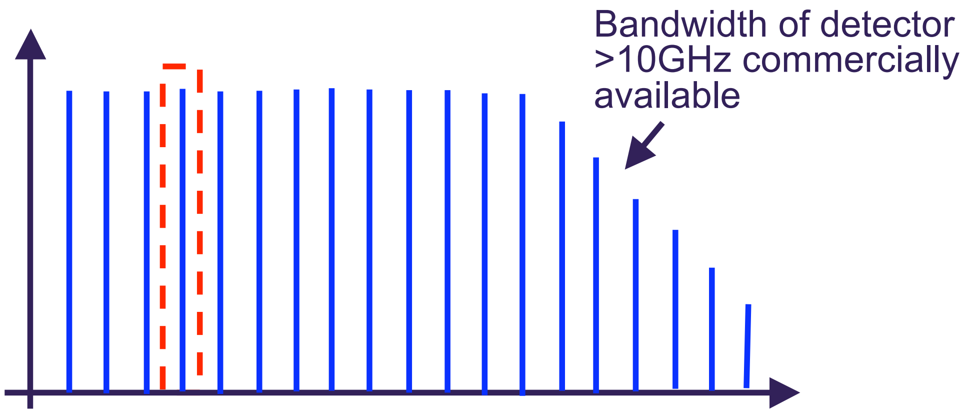


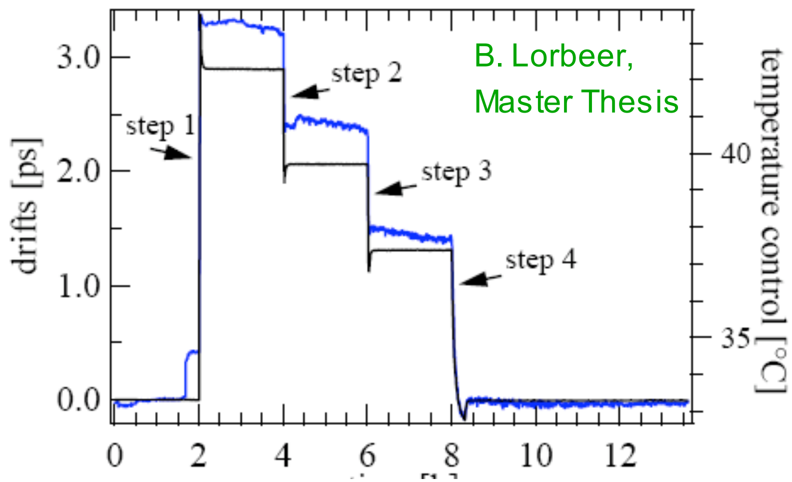
Pro:

- Small optical input power required ~ 5-10 mW sufficient
- Very cheap and easy to build (<1k€ for good components)
- Excess to entire frequency comb
- Gating or amplitude mod. allows to generate other freq.
- Drift stability <10fs over hours have been demonstrated (see talk Frank Ludwig)

Cons.:

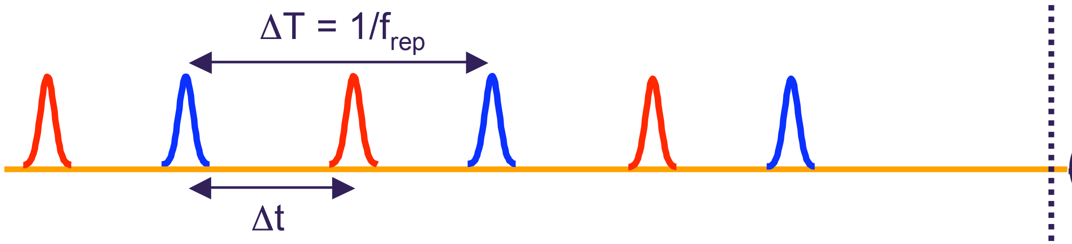
- Amplitude dependence (AM to PM conversion)
  1-2 ps/mW@10mW hence $\sigma_{dP/P}$ < 1e-3 ⇒ <10 fs
- Temperature dependence
  340fs/°C hence σT < 0.03 °C ⇒ <10 fs
- If high power amplifier is used: no control

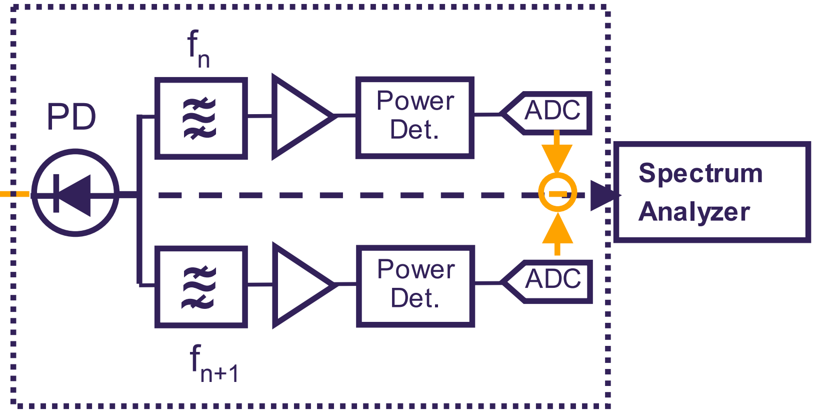




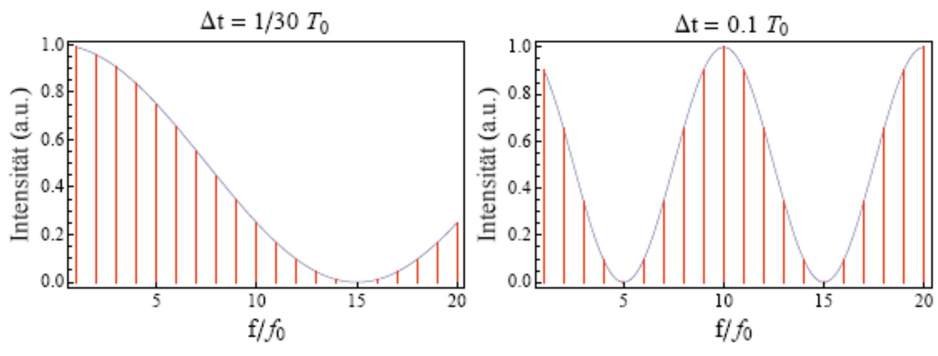
Missing: compact direct conversion module including temperature stabilization suited for frequencies between 500 MHz – 3 GHz (PD selection, Ethernet interface, PD/BPF + Ampl. packaged, P_{out}=10dBm)

RF based synchronization without phase det.





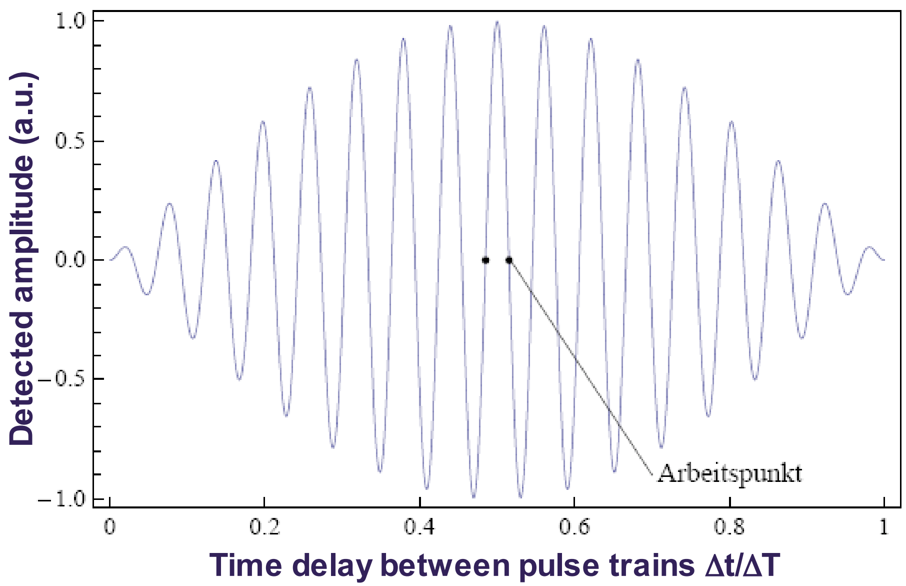
Beat in frequency domain by adding second pulse train



(a) (b)

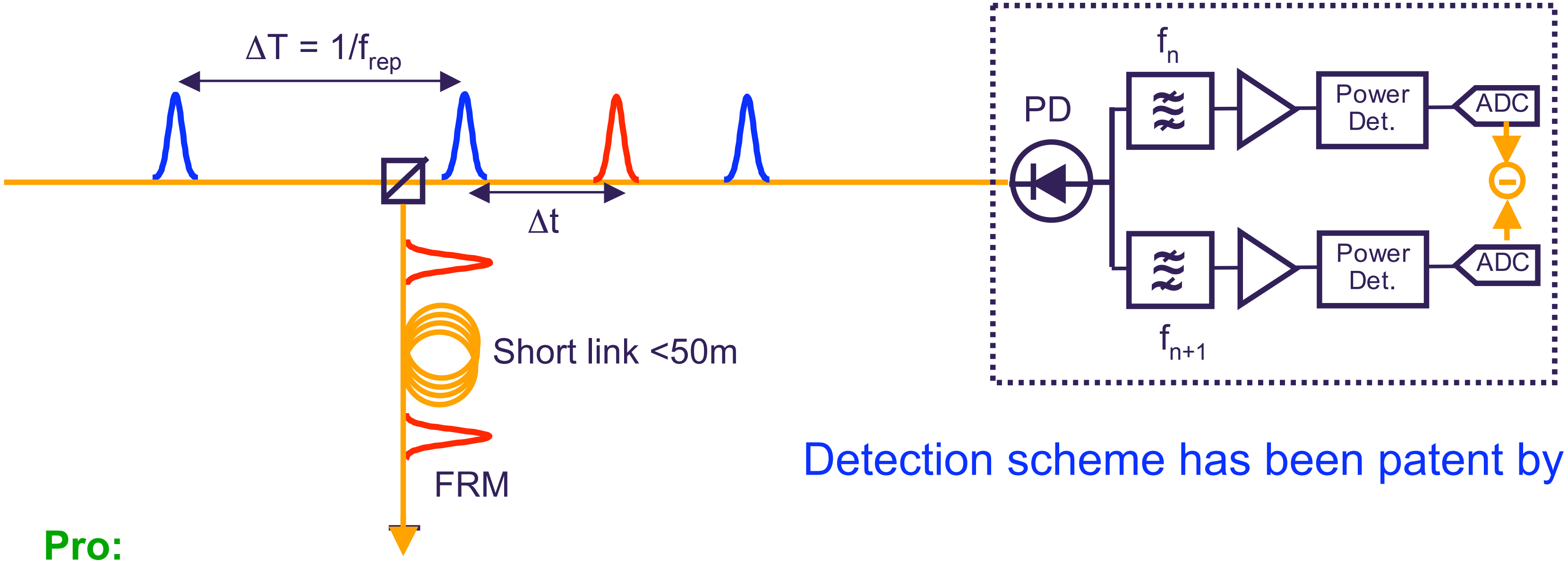
(c) (d)

Balanced detection $P(f_{n+1})-P(f_n)$



J. Zemella, Diploma thesis, F. Loehl

Link stabilization



Detection scheme has been patent by DESY

Pro:

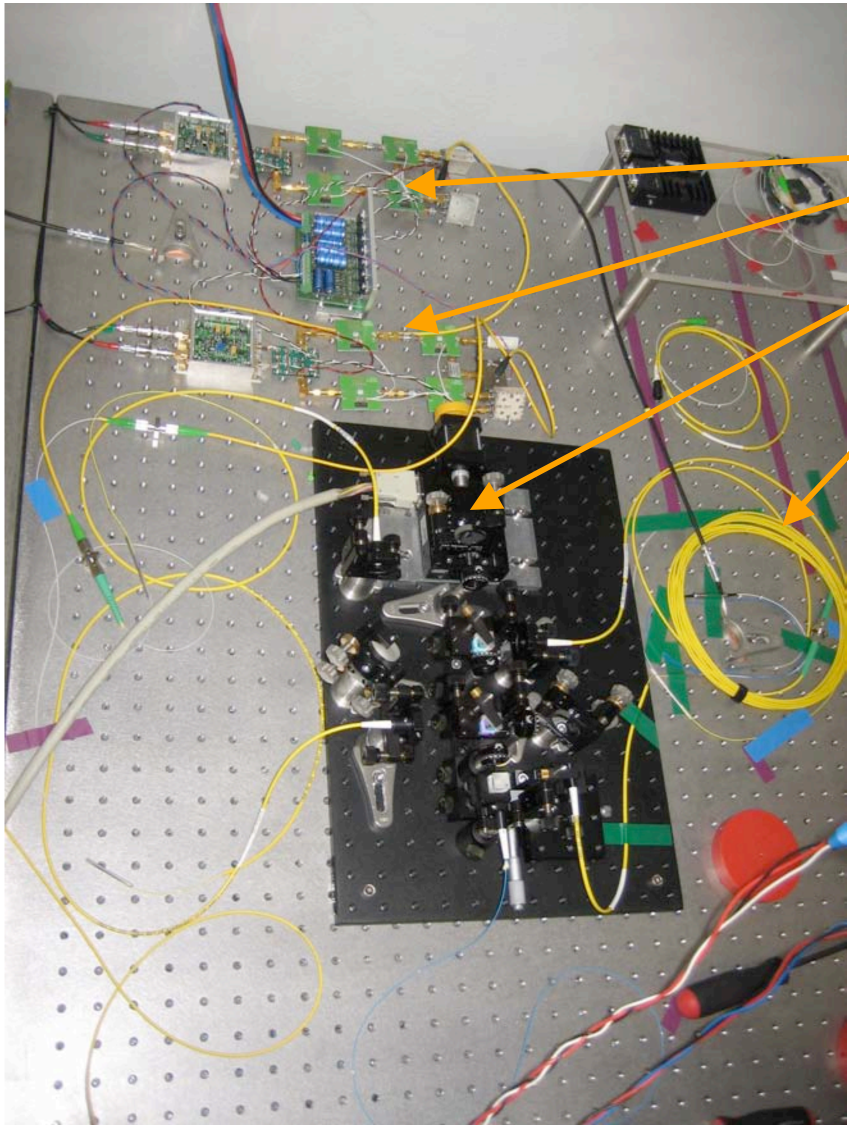
- Problem of photo detector is eliminated since only amplitudes are detected
- No dispersion compensation is required (as long as pulse is short enough)
- Timing overlap is not difficult (many working points, does not need to be exact!
- Selection of filter: higher accuracy but smaller dynamic range
- Can be used to monitor the fiber length variation without correction (expensive)

Cons:

- 1 fs is not realistic
- Loss changes at link arm would be detected as timing changes

J. Zemella, Diploma thesis

Short link experiment setup

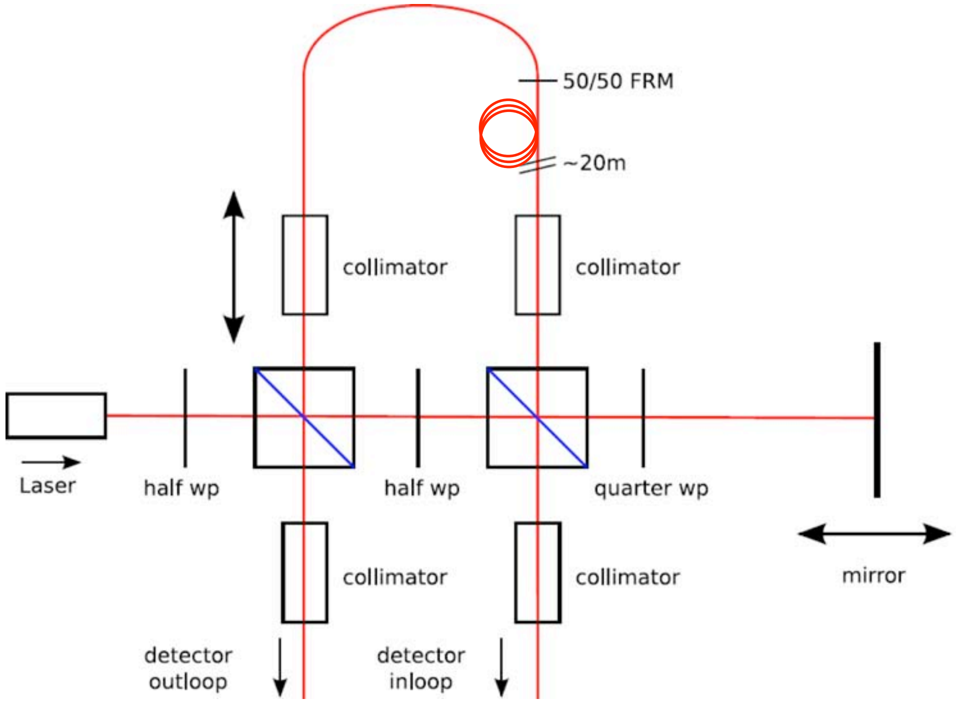


Inloop and out-of-loop detector

Delay line (presently used for calibration)

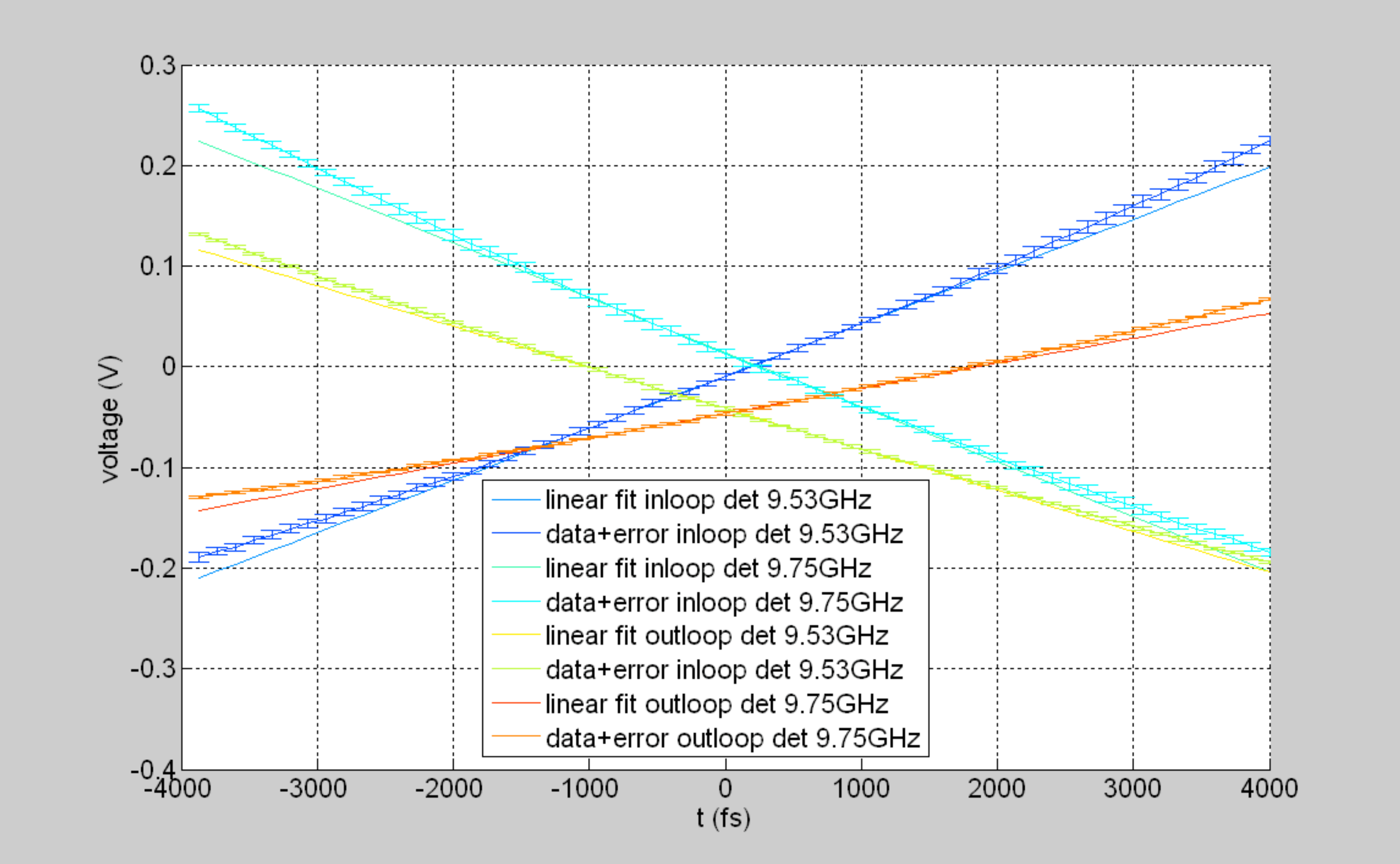
Fiber (meanwhile exit room)

Sketch of experimental setup

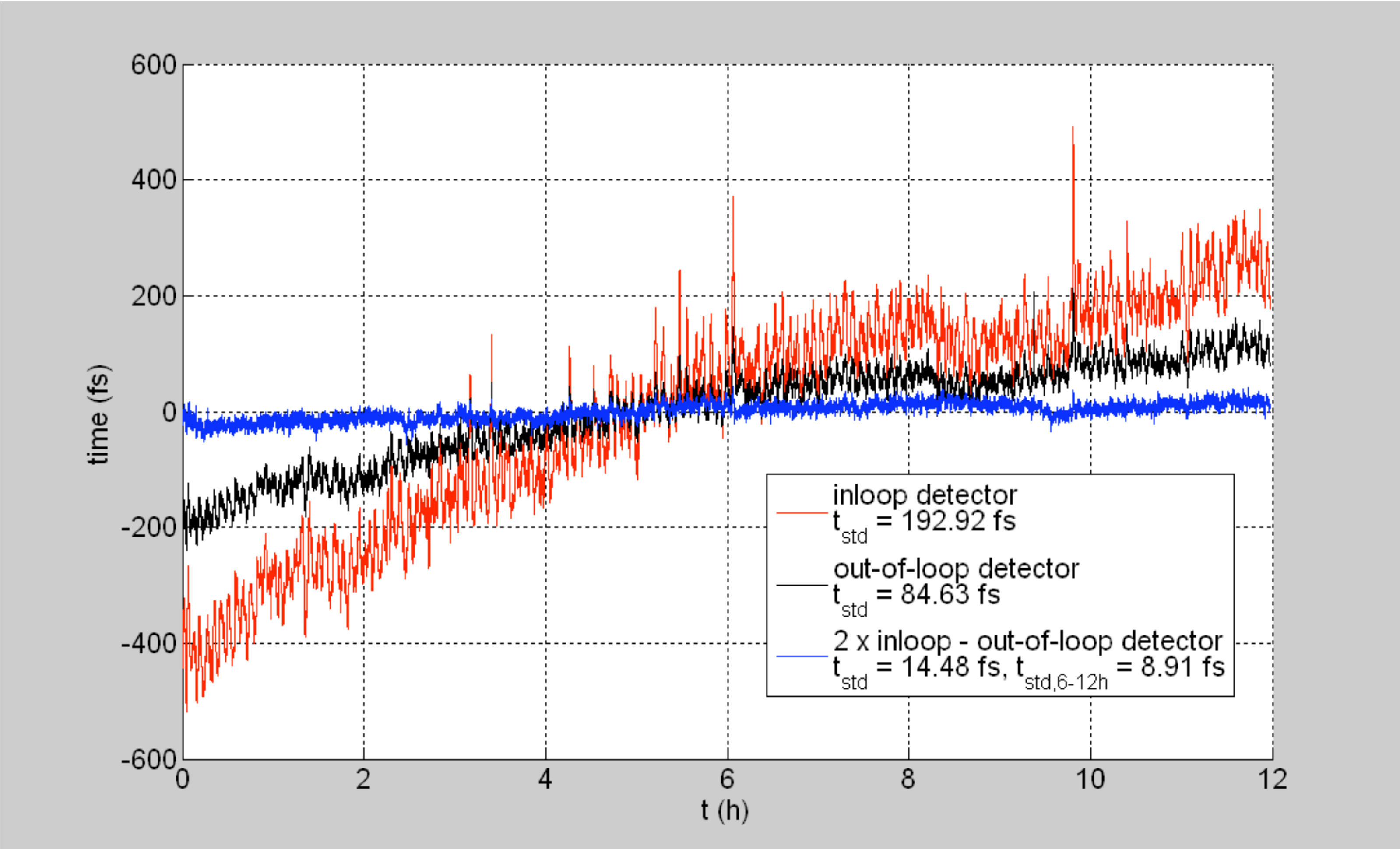


Courtesy: J. Zemella

Short link experiment setup

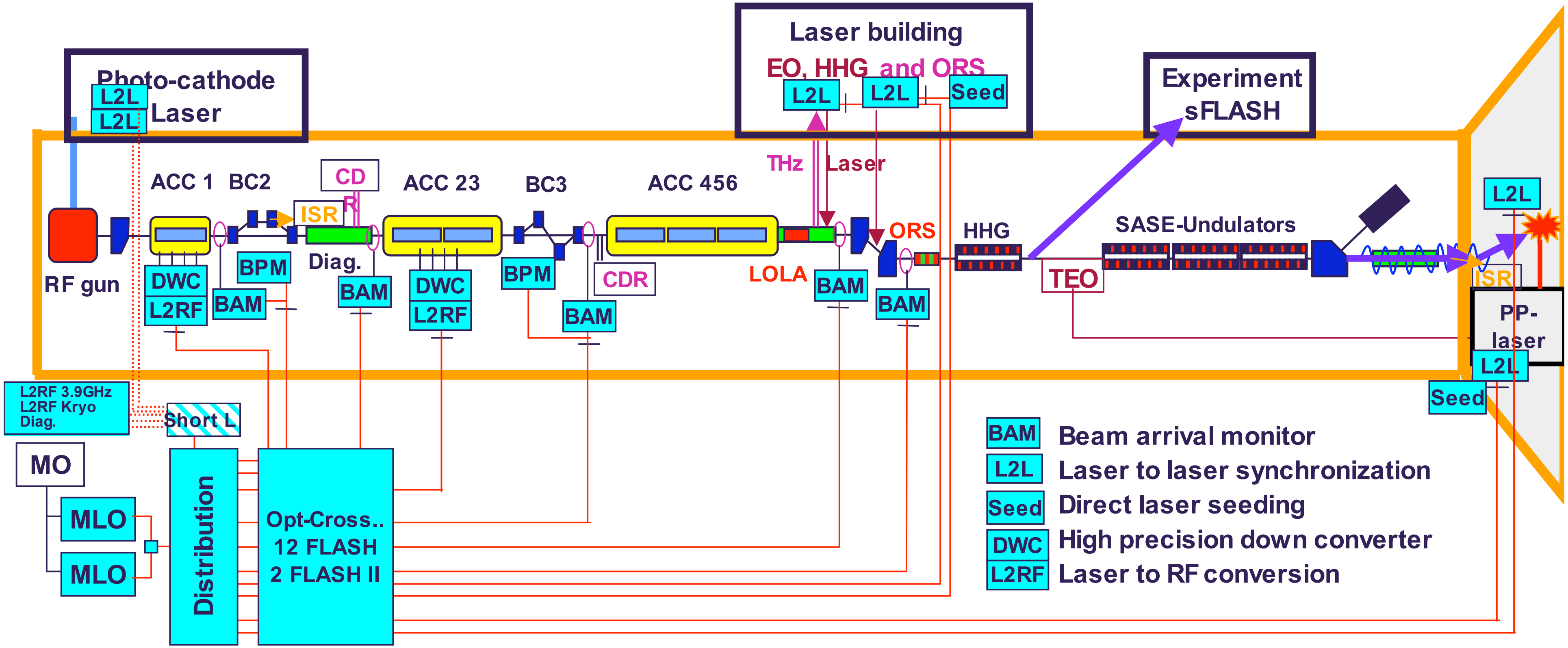


Short link experiment setup



Layout of synchronization system at FLASH

- Implementation of entire system 06/2008 - 2010



- Short link to server more end-stations
- Synchronization of both photo injector lasers &
- Providing RF for 3th cavity (monitoring/source)
- Monitoring for 1.3GHz at Kryo hall
- Engineered version ~ spring 2010

Other interesting developments

- PM fiber link to avoid polarization control (cost/reliability)

  Problem: no PM DCF fiber exists

  Option: PM link but SMF-DCF (stability)

- Optical down converter to avoid RF generation entirely

  Problem: 1) for amplitude detection a dynamic range of laser pulse readout of better than 80dB is required (10MHz BW), 60dB is typically achieved)

  2) cannot cope with large phase changes (< 1deg)

  3) too large costs

  Option: for CW machines, split A and φ detection

- XFEL 10MHz has been chosen

  Problem: 216MHz incompatible, have to switch to MLO with f_{rep}=200MHz but now 1.3GHz $\neq$ n f_{rep}

  Option: Modification of Sagnac loop operation point

  Other interferometer style of L2RF converters

- Fiber with lower temperature coefficients

  Problem: index of refraction ~ 7e-6 /°C but expansion coefficient ~ 1e-7/°C

Thanks for your attention