Status of the optical synchronization system

Holger Schlarb DESY
for the LbSyn team

V. Arsov, M. C. Behrens, Bock, P. Gessler, M. Felber, K. Hacker, F. Loehl, F. Ludwig, K-H. Matthiesen, B. Schmidt, S. Wesch, A. Winter, J. Zemella
(Deutsches Elektronen-Synchrotron)
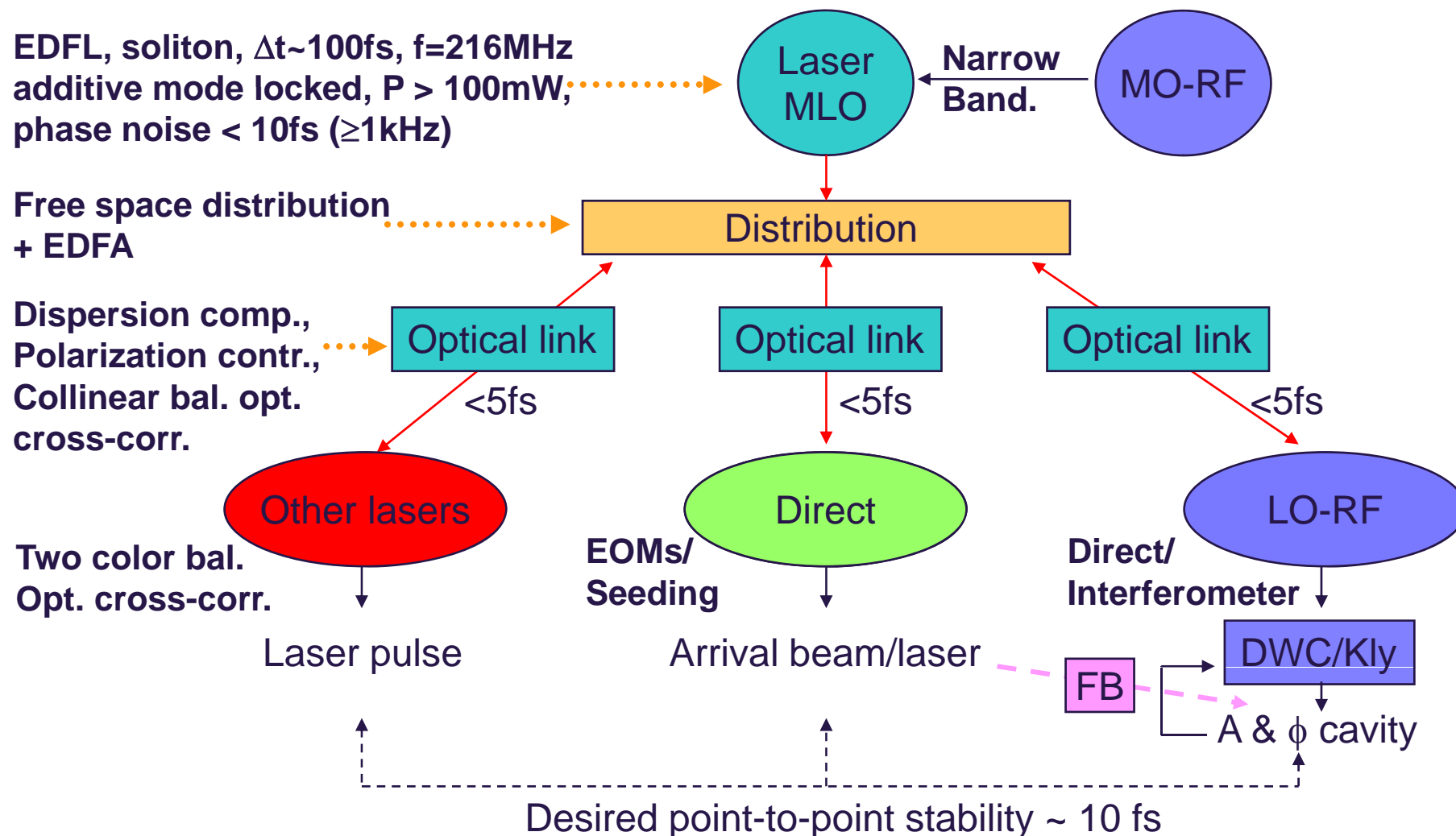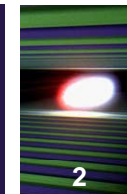
S. Schulz, L. Wissmann
(Universität Hamburg)

J. Szewinski
(Warsaw University of Technology Institute of Electronic Systems)

W. Jalmuzna
(Technical University of Lodz)
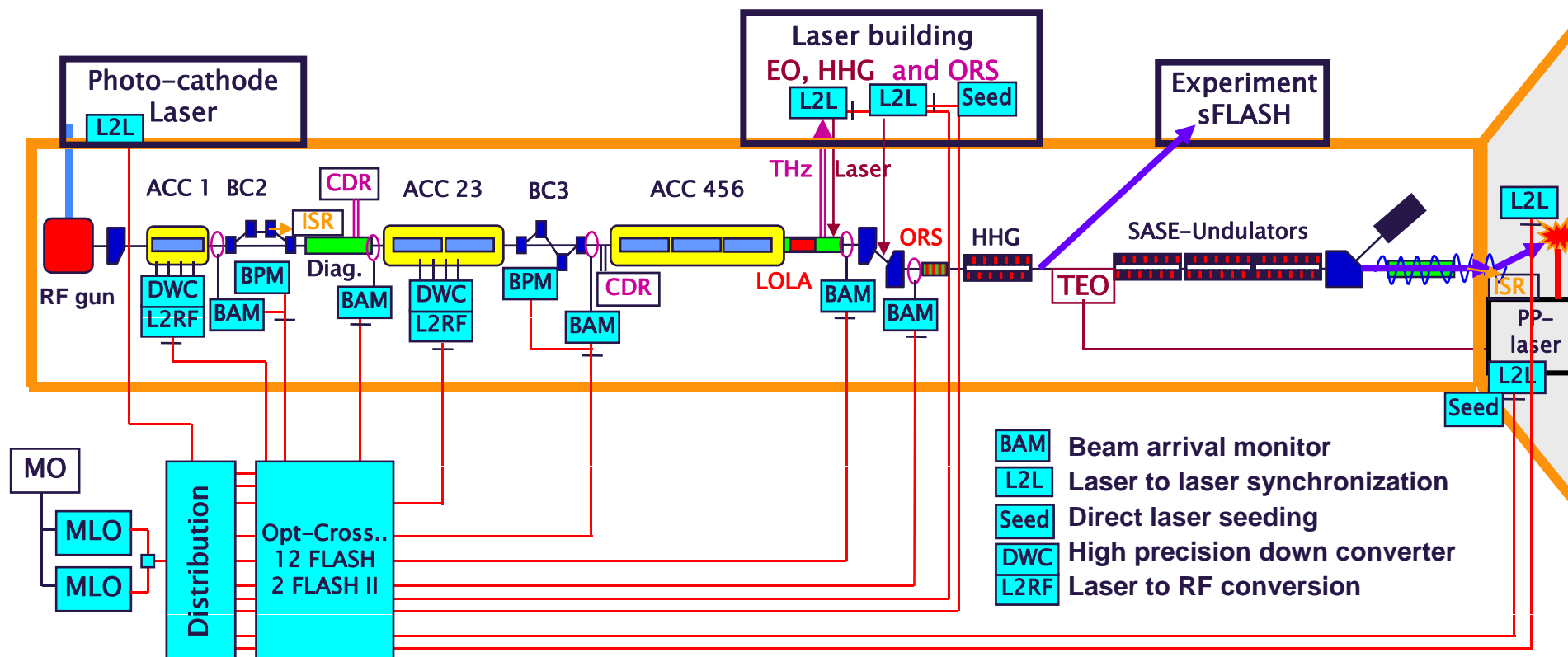
Optical synchronization system

EDFL, soliton, $\Delta t \sim 100\text{fs}$, f=216MHz additive mode locked, P > 100mW; phase noise < 10fs ($\geq$1kHz)

Laser MLO

Narrow Band.

MO-RF

Free space distribution + EDFA

Distribution

Dispersion comp., Polarization contr., Collinear bal. opt. cross-corr.

Optical link   **Optical link**   **Optical link**

<5fs   <5fs   <5fs

Other lasers   Direct   LO-RF

Two color bal. Opt. cross-corr.

EOMs/ Seeding

Direct/ Interferometer

Laser pulse   Arrival beam/laser   FB   DWC/Kly

A & ϕ cavity

Desired point-to-point stability ~ 10 fs

■ Main issue: robustness, stability and maintainability $\Rightarrow$ Prototype at FLASH

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# Layout of synchronization system at FLASH

3
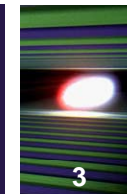
- Implementation of entire system 06/2008 - 2010

- Backbone: beam based stabilization of arrival time
- Conjunction with high precision synchronization of lasers
- Synchronization of all timing critical devices (~ 14 incl. FLASHII)
- Point-to-point synchronization ~ 10 fs rms (e- < 30 fs rms)
- Permanent operation and long term stability /availability investigation

Layout of synchronization system at FLASH

European XFEL

4
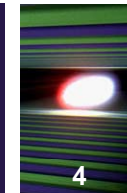
■ Implementation of entire system 06/2008 - 2010
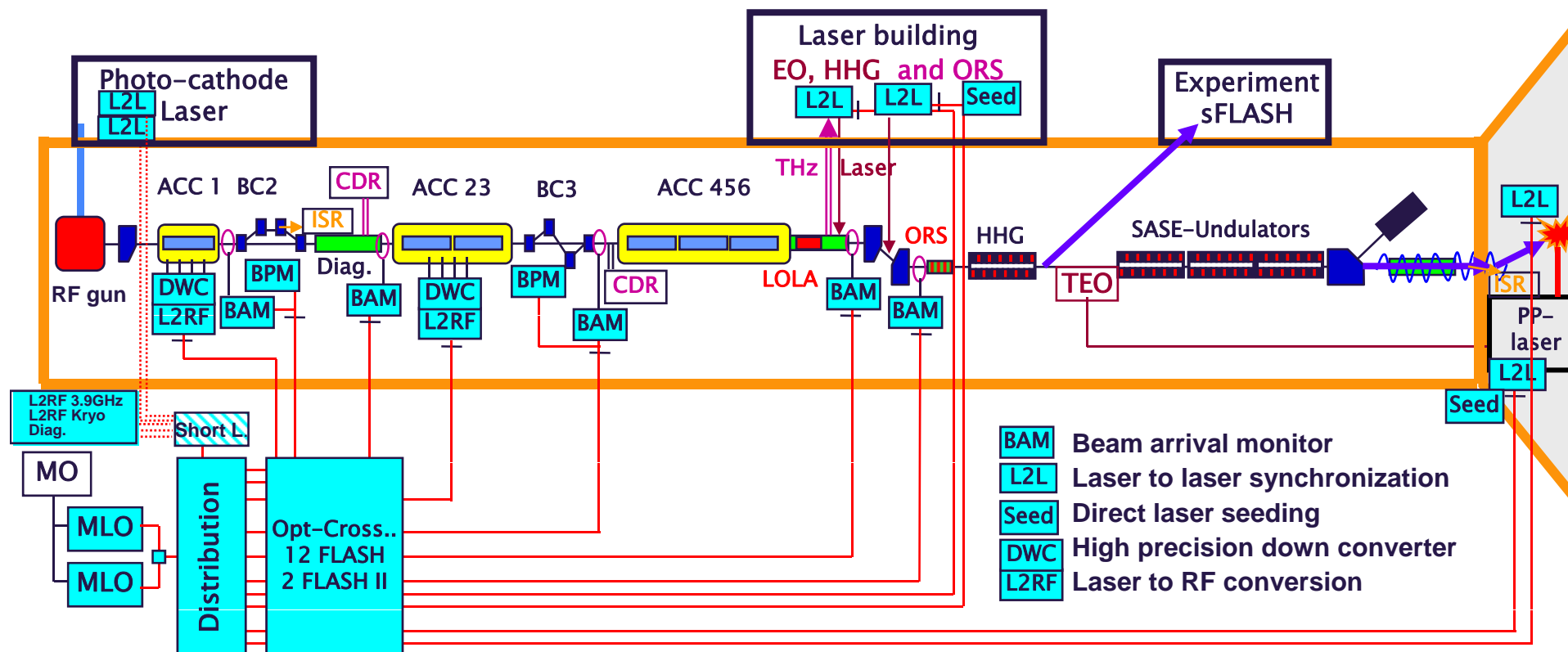
- Short link to server more end-stations
- Synchronization of both photo injector lasers &
- Providing RF for 3th cavity (monitoring/source)
- Monitoring for 1.3GHz at Kryo hall
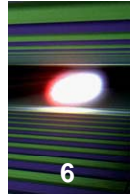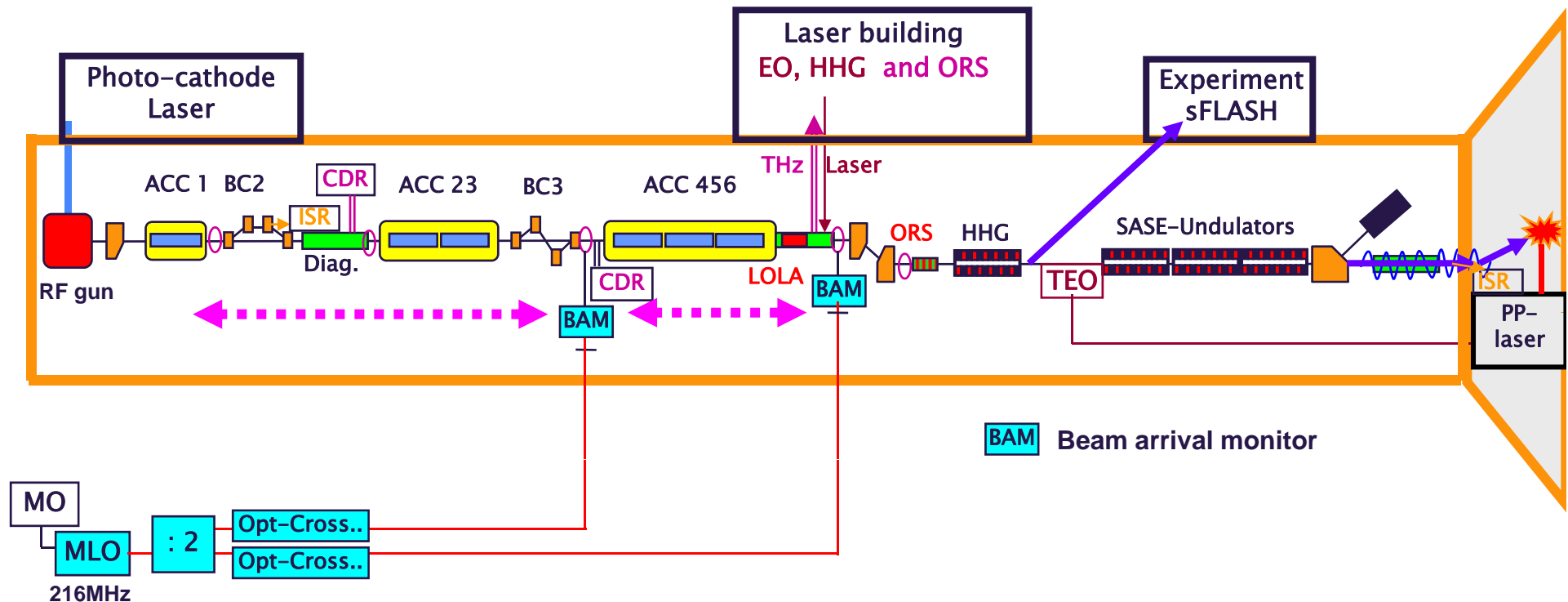- Engineered version ~ spring 2010

Key experiment

To verify method, the mechanical and electrical designs and for software development before assembly

- Fiber link stabilization in accelerator environment ☺
- Complete system test: MLO, one LINK and Beam Arrival Monitor ☺
- Consistency check: two BAM against each other ☺
- Intra-train feedback system (ACC1) partially ☺
- Consistency check: BAM versus EO partially
- Supply to many links + infrastructure
- Optical lock of Ti:Sa laser to fiber laser (OCC-EO)
- High precision Energy Measurement (EBPM)
- L2RF conversion at 1.3GHz with sub 10fs long term stability
- Short link implementation
- Synchronization of photo-injector laser (OCC-NdYLF)
- …

Key experiment: - BAM versus BAM

Laser building
EO, HHG and ORS

Experiment
sFLASH

Photo-cathode
Laser

ACC 1 BC2

CDR

ACC 23

BC3

ACC 456

THz Laser

ORS

HHG

SASE-Undulators

ISR

Diag.

CDR

LOLA

BAM

TEO

ISR

RF gun

BAM

PP–laser

BAM Beam arrival monitor

MO

MLO

: 2

Opt–Cross..

Opt–Cross..

216MHz

- two Bunch Arrival time Monitor in drift section (~60 m distance)
- evaluation of integrated timing jitter (Hz-MHz)
- evaluation of drifts and offsets
- commissioning of two links with precision laser timing requirement
- test of arrival time FB by regulating ACC1 amplitude

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Optical synchronization system: Link

- Installation of two fiber links at FLASH

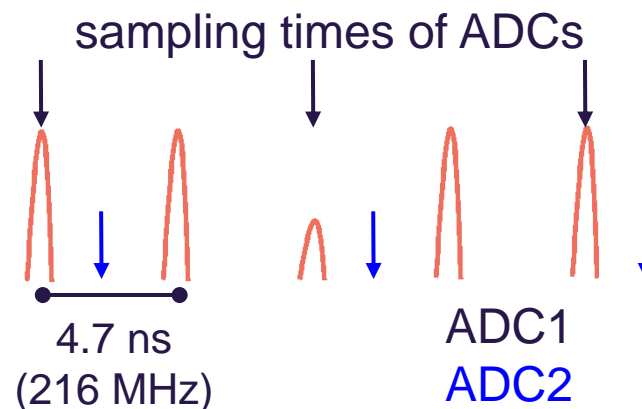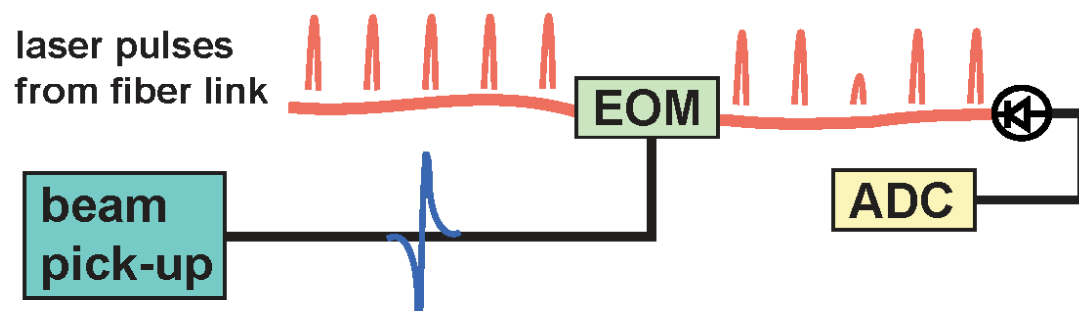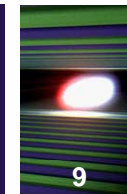Courtesy: F. Löhl
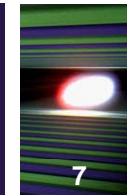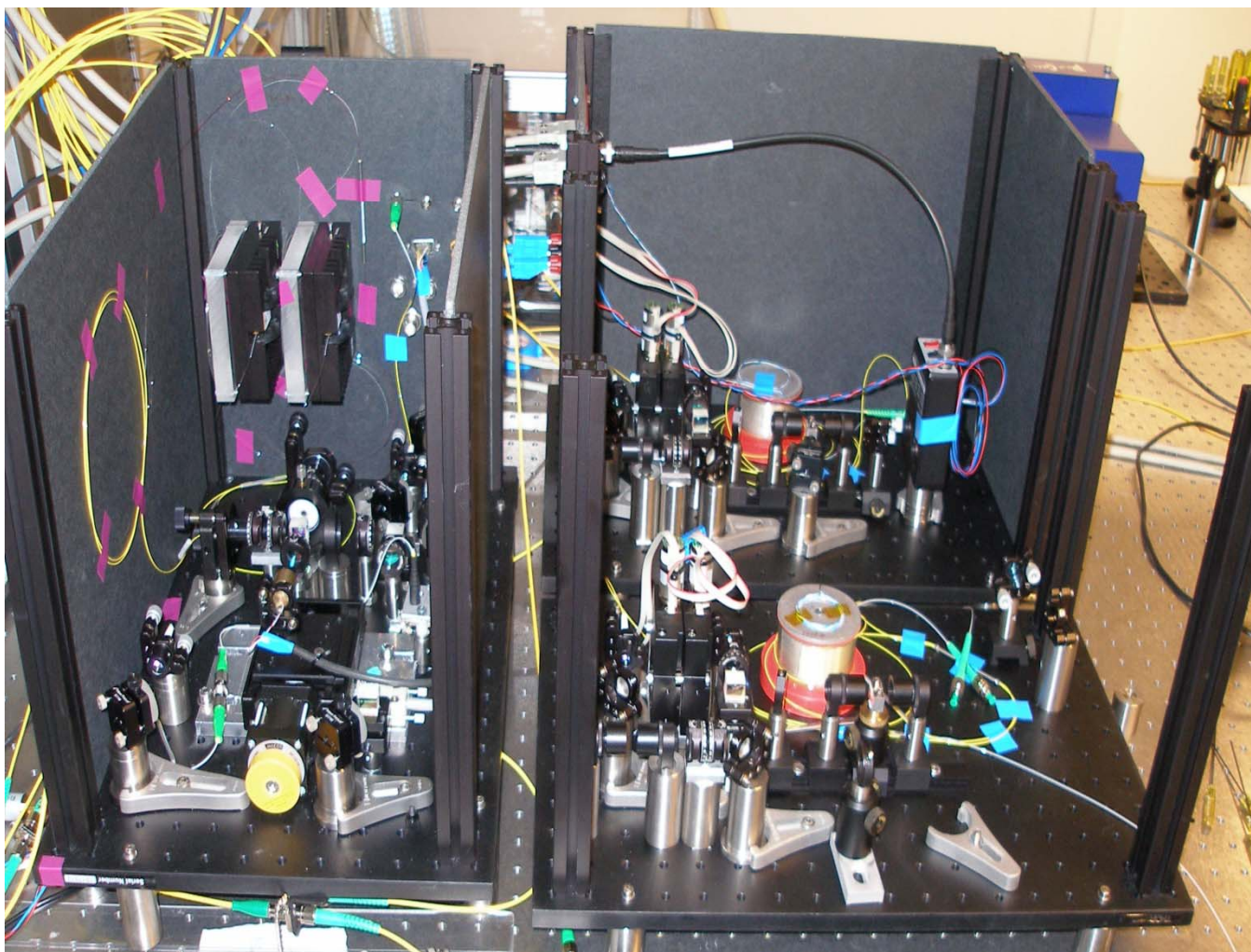
Long term behavior of link
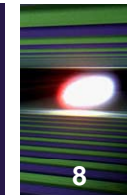
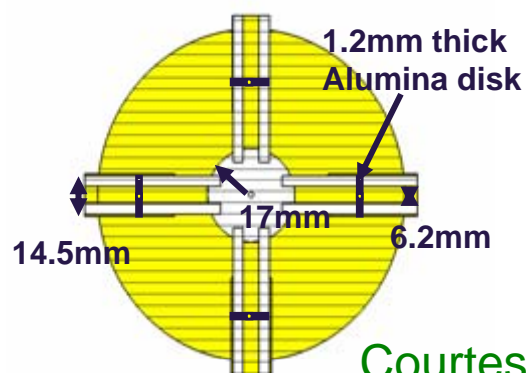## ■ Installation of two fiber links at FLASH

- Much smoother correction
- For 6 month in operation
- Day/night periods & spring -> summer observable
- Smooth operation (interruptions understood)
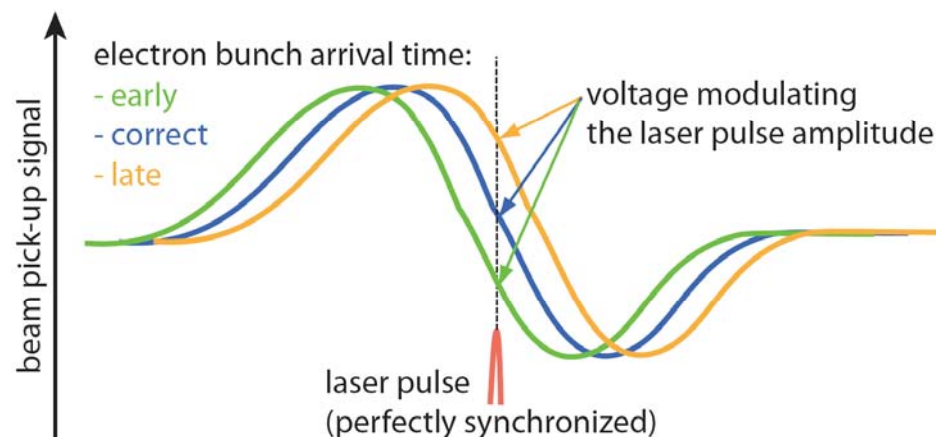
Courtesy: F. Löhl
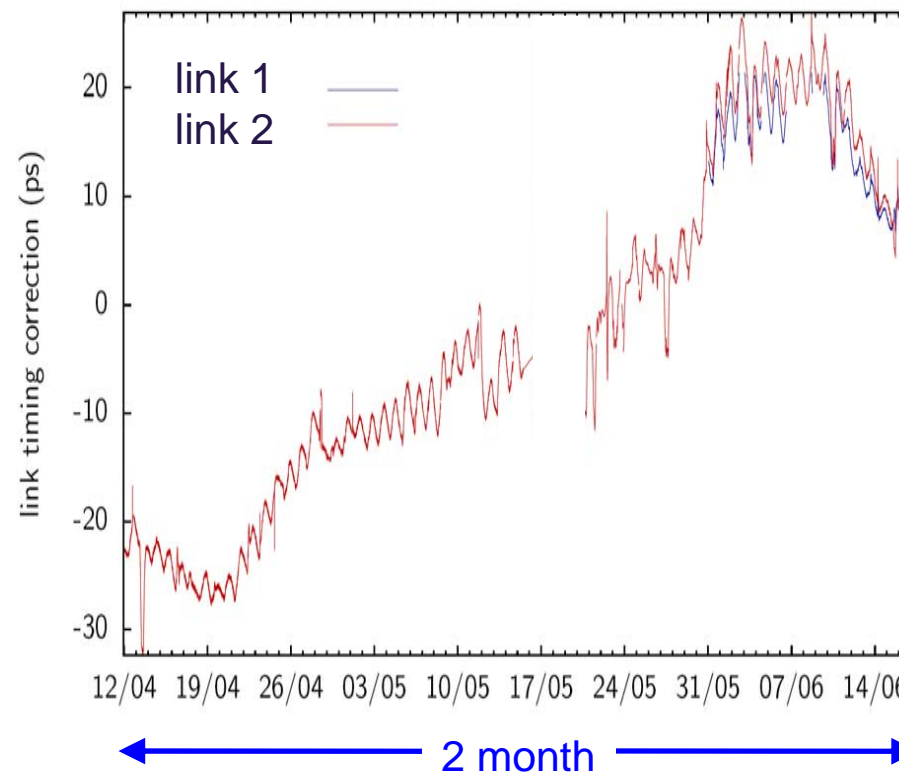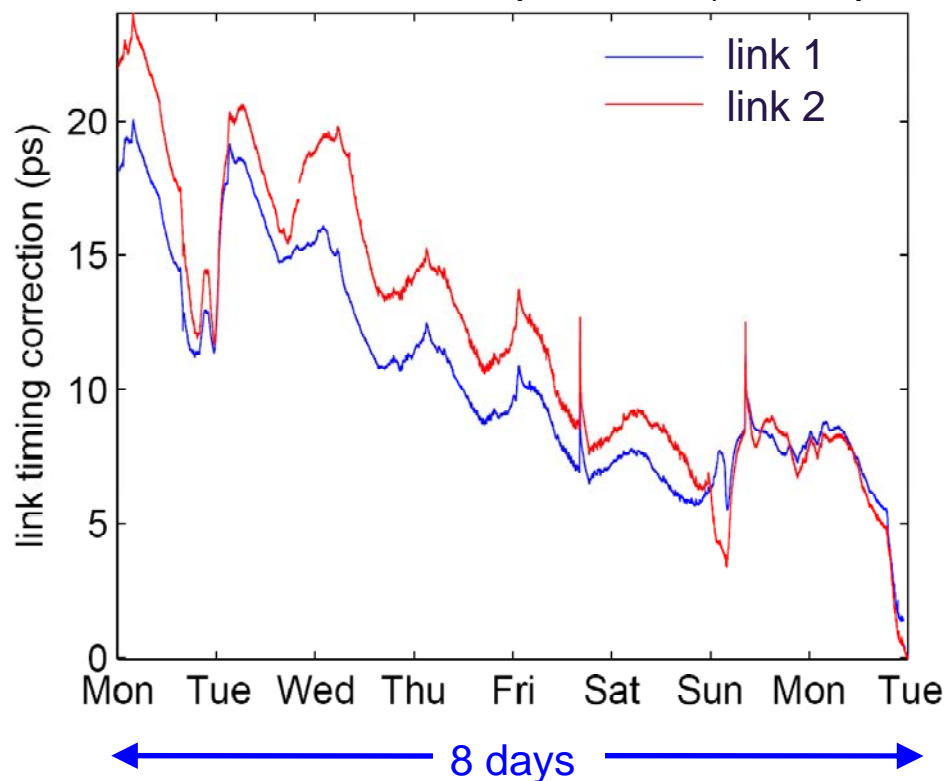
Operation principle bunch arrival time monitor

laser pulses from fiber link

EOM

ADC

beam pick-up

The timing information of the electron bunch is transferred into a laser amplitude modulation. This modulation is measured with a photo detector and sampled by a fast ADC.
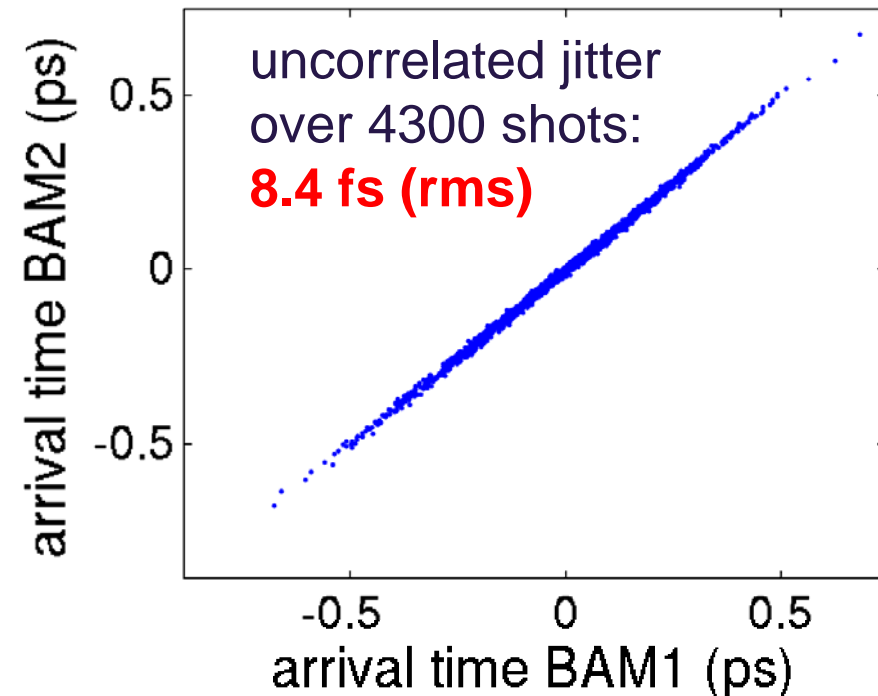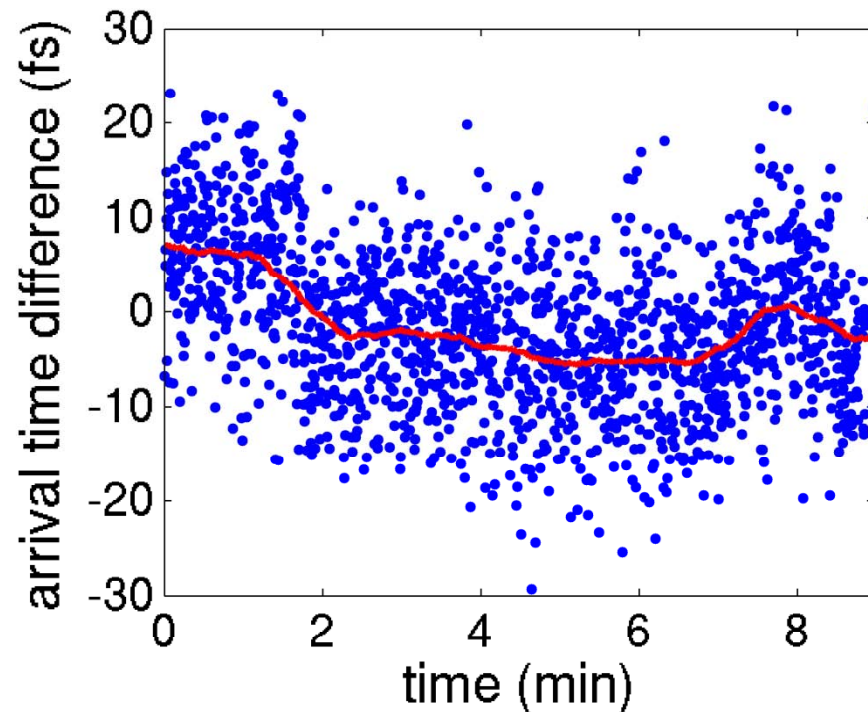
sampling times of ADCs

4.7 ns (216 MHz)

ADC1
ADC2

1.2mm thick Alumina disk

17mm

14.5mm   6.2mm

New pickup design & Improved readout

⇒ resolution < 10 fs

Courtesy: K. Hacker

electron bunch arrival time:
- early
- correct
- late

beam pick-up signal

voltage modulating the laser pulse amplitude

laser pulse (perfectly synchronized)

Courtesy: F. Loehl

See: EPAC'06, Loehl et al., p.2781

Arrival time correlation between two BAMs
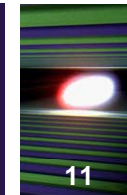

uncorrelated jitter
over 4300 shots:
8.4 fs (rms)

Arrival time difference contains:
- high frequency laser noise (~3 MHz – 108 MHz)
- stability of two fiber links
- two BAMs

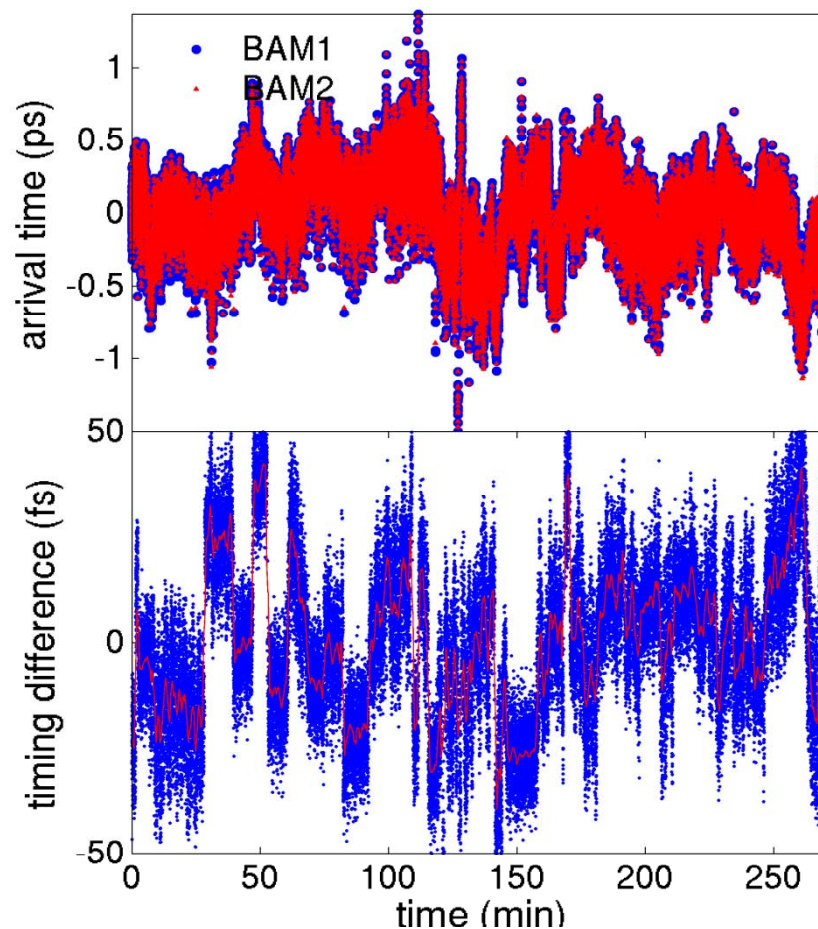Single bunch resolution of entire measurement chain: **< 6 fs (rms)**

Courtesy: F. Loehl

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Arrival time correlation between two BAMs

stability over 1.5 hours:

13.1 fs uncorrelated jitter

→ 9.3 fs resolution of a single BAM
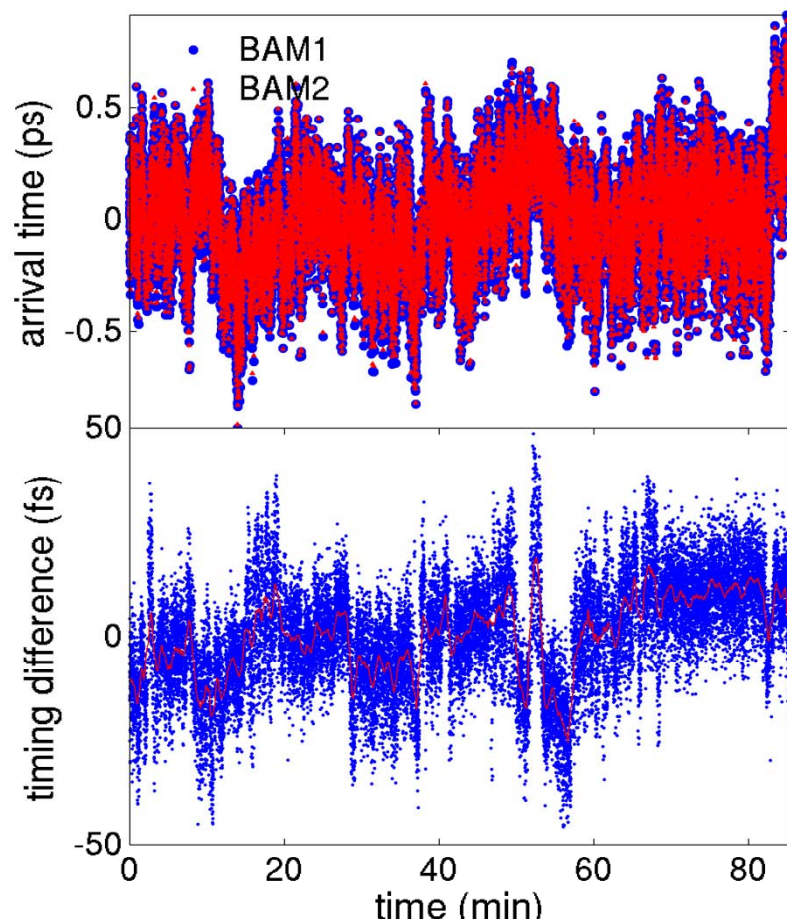
stability over 4.5 hours:

19.4 fs uncorrelated jitter

→ 13.7 fs resolution of a single BAM

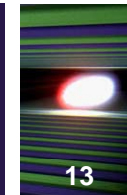Courtesy: F. Loehl

Front-end: bunch arrival time monitors
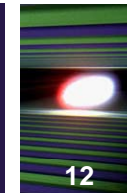
First prototype of bunch arrival monitor

Courtesy: F. Loehl

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Distribution and optical table layout

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MLO1

Final implementation design

Free space opt. distribution
-Switching unit
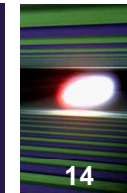-Invar base plate
-Vibration isolated
-16 outputs

Distr. With EDFA for each link
-Special passive thermal stabilization
-One output for MLO lock based on Sagnac loop at 1.3GHz

Fiber link stabilization units (max 14)

MLO2

Courtesy: B. Beyer

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Master laser oscillator (MLO)
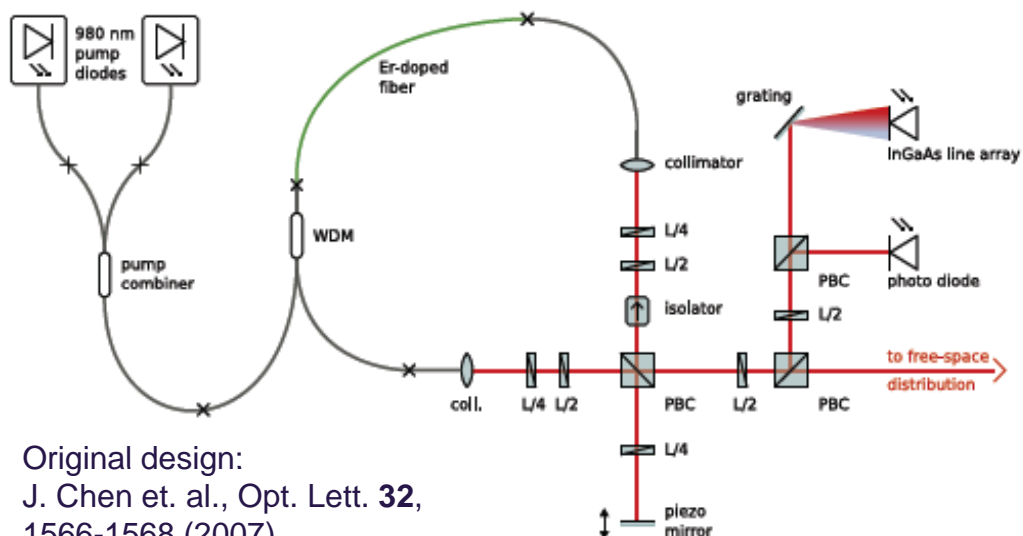
Original design:
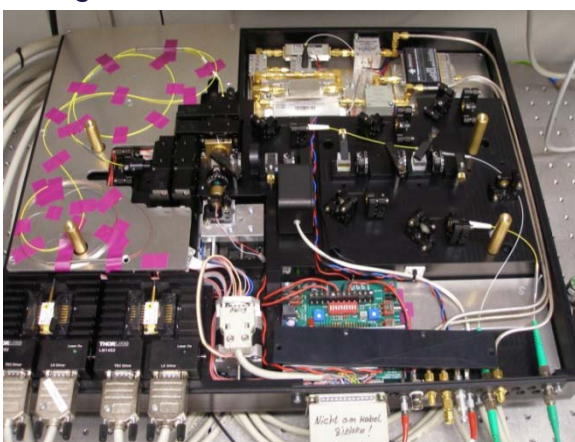J. Chen et. al., Opt. Lett. **32**, 1566-1568 (2007)

- **Specification**

- mode-locked erbium-doped fiber laser
- repetition rate of 216.66MHz
- average power > 100mW
- pulse duration < 100 fs (FWHM)
- integrated timing jitter < 10 fs [10Hz,40MHz]
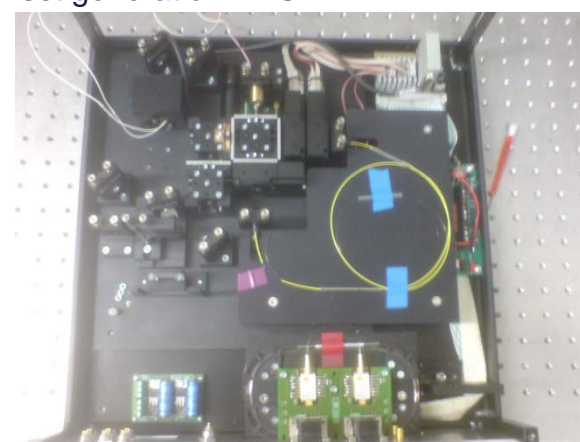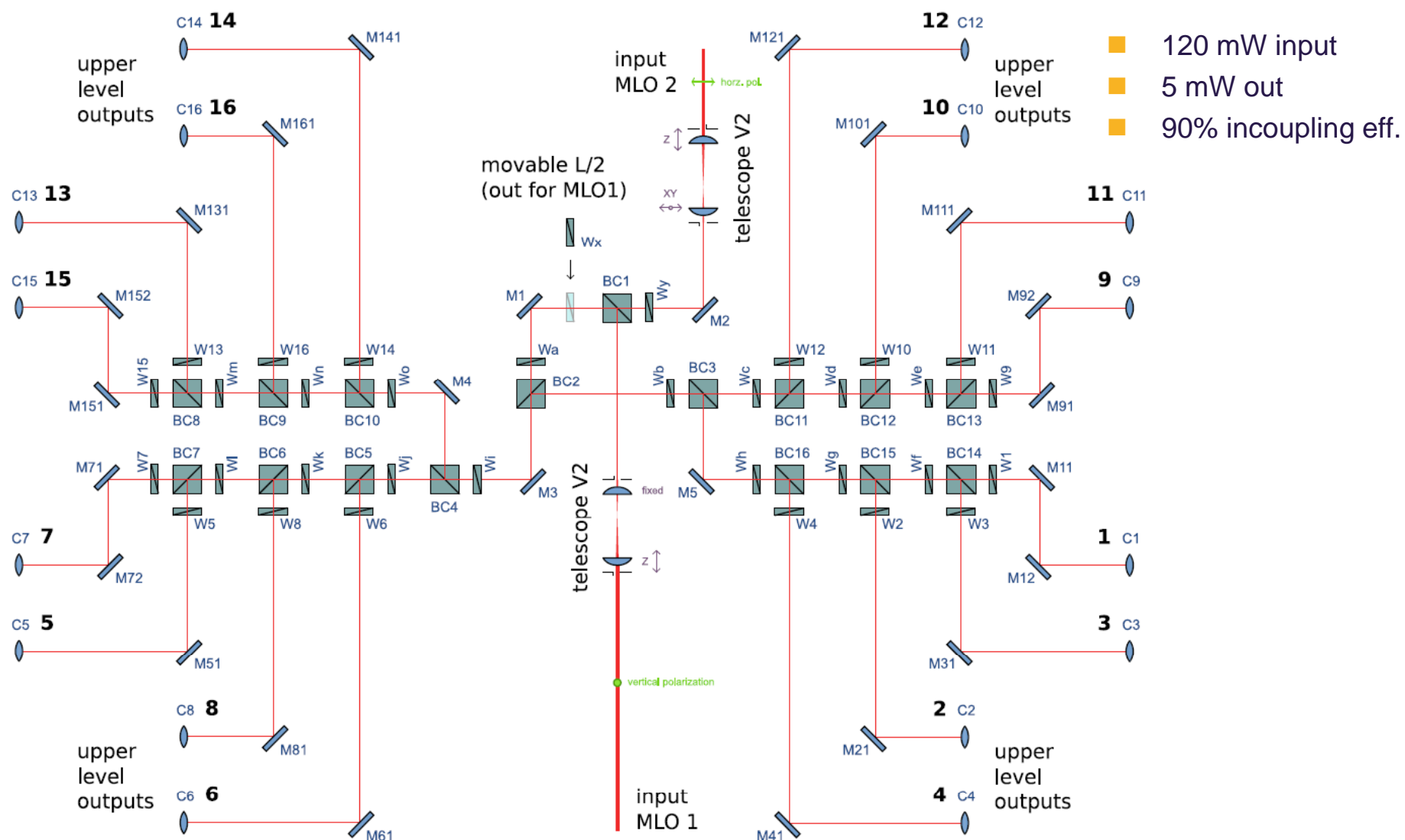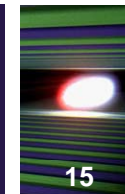- amplitude noise < $2 \cdot 10^{-4}$ [10Hz,40MHz]

1st generation MLO ✓
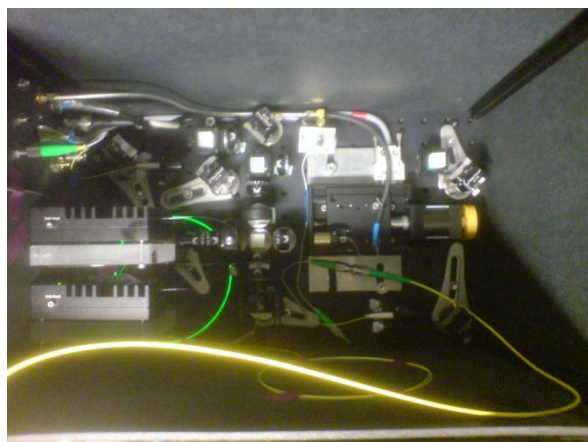
2nd generation MLO ☑

3st generation MLO ✗

Distribution system

- 120 mW input
- 5 mW out
- 90% incoupling eff.

Courtesy: S. Schulz

Distribution system

European XFEL
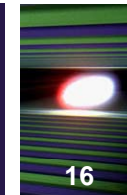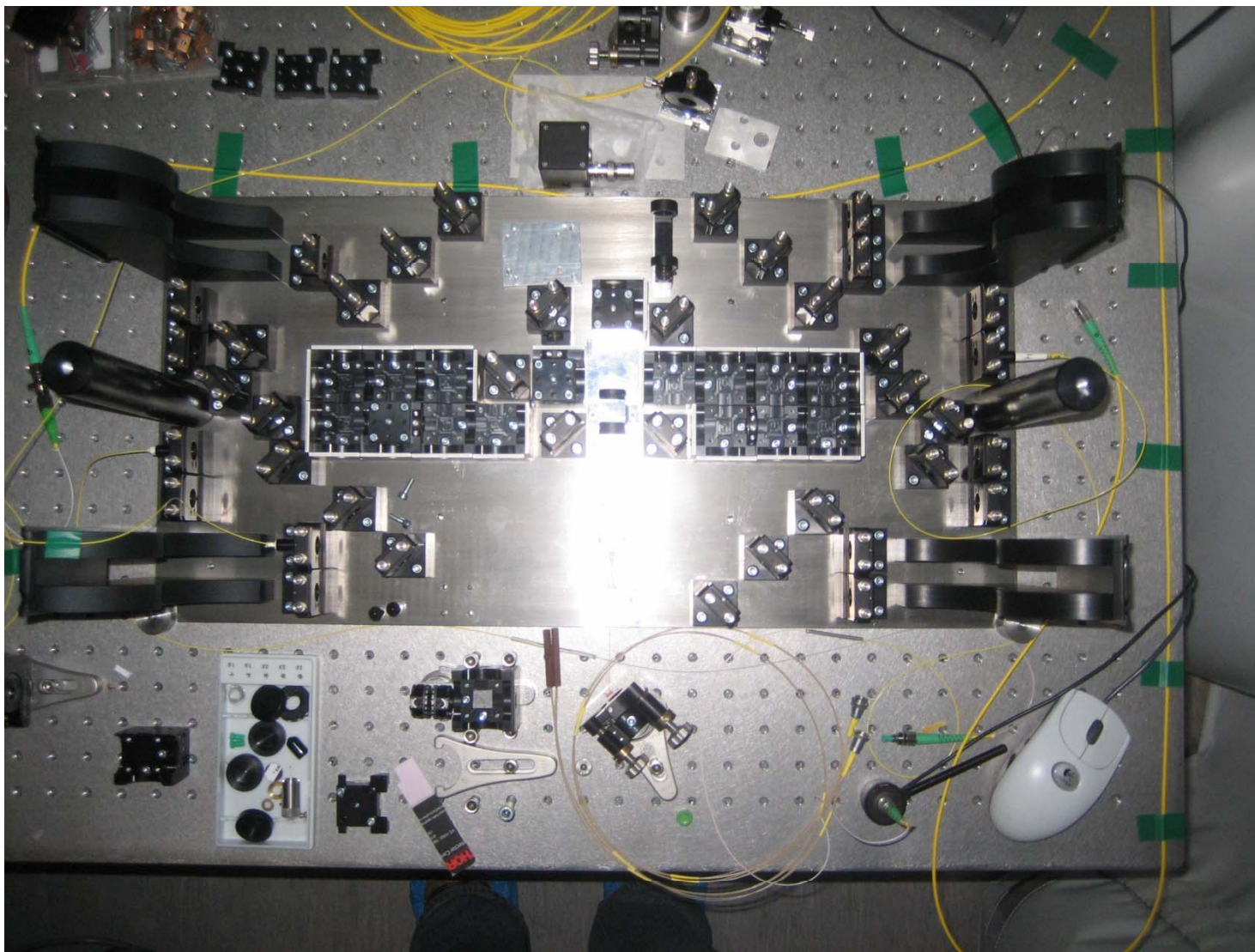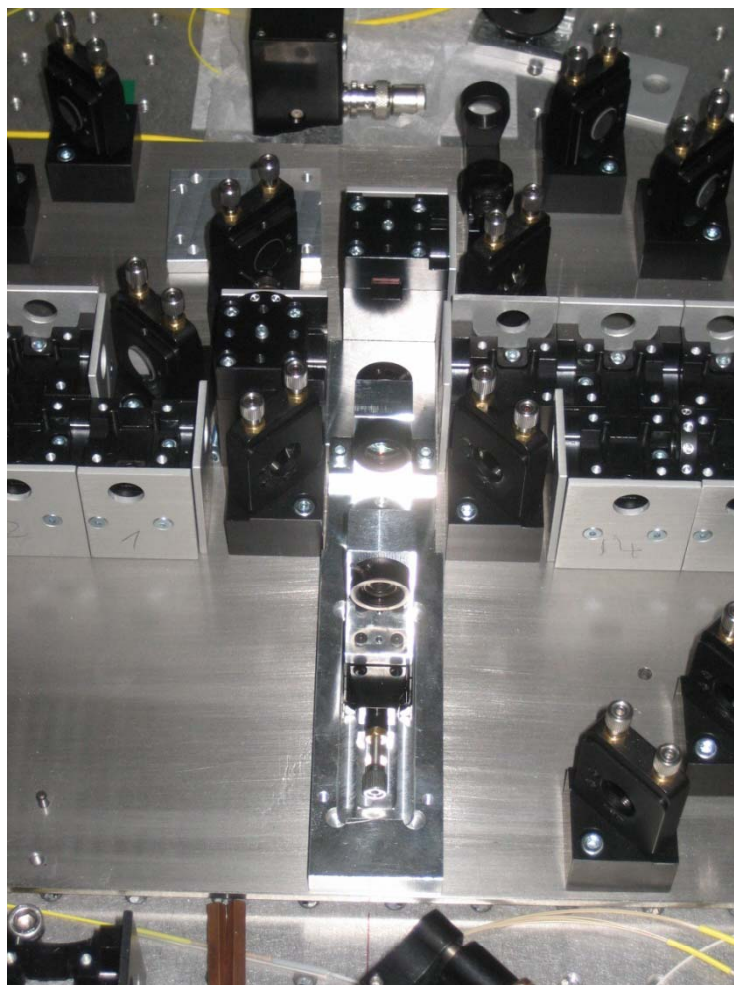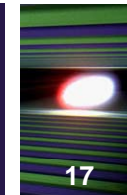
Distribution system

- Tolerance tight:

  Lateral shift ~ 50um maximum

  Lens L1-L2 only ~2um

- New telescope system with z-translation stage and different lenses

- Good incoupling achieved ~ 85-90%

- Drift test need to be carried out

  (first test was reduction at 1 coll. Of 10% observed)

- However, second lens system still missing (next week produced)

- To be proven if this concept is optimal

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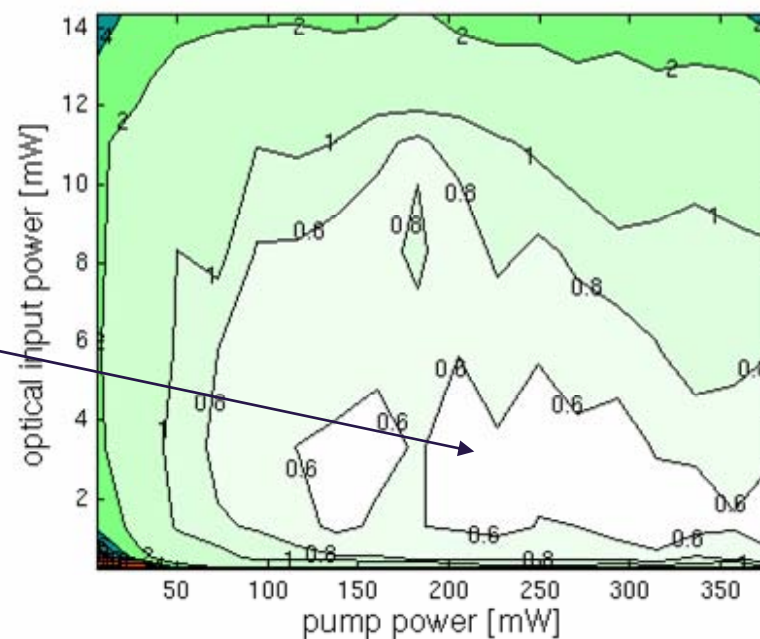# Components test: Timing jitter added by erbium-doped fiber amplifiers
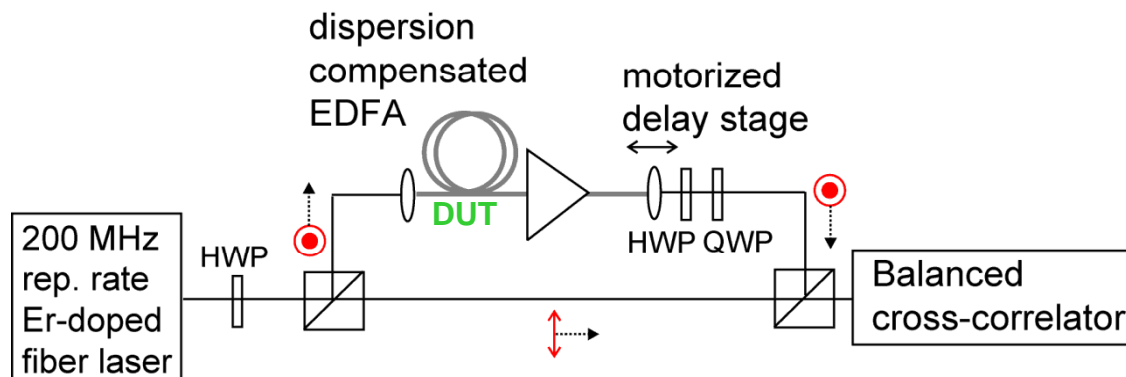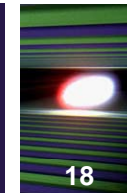
The balanced cross-correlator can be used to measure with sub-fs resolution the timing jitter added by an EDFA.

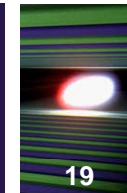Added timing jitter in femtoseconds (500 Hz – 4.5 MHz)

An optimized EDFA adds less than 500 as timing jitter!
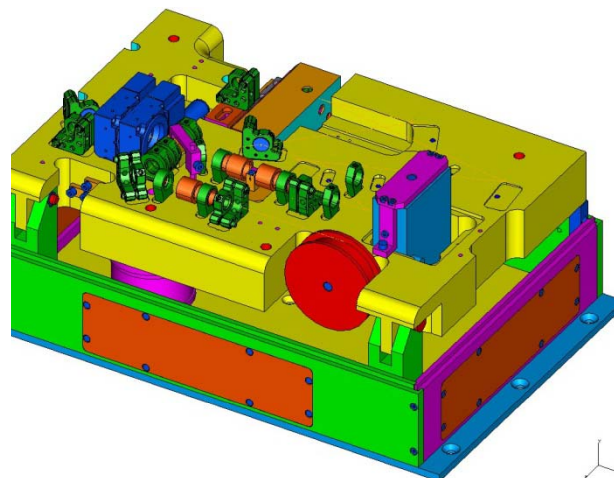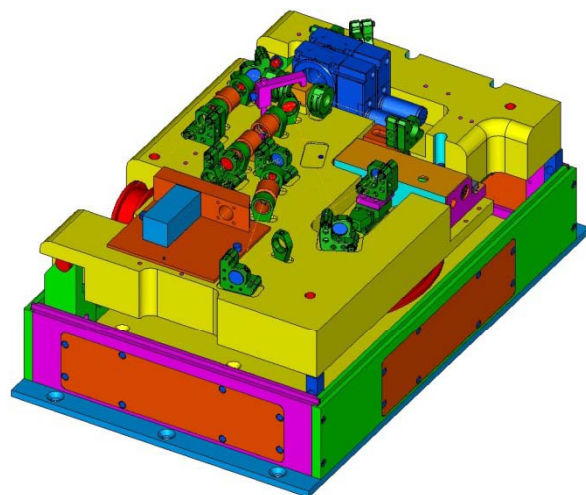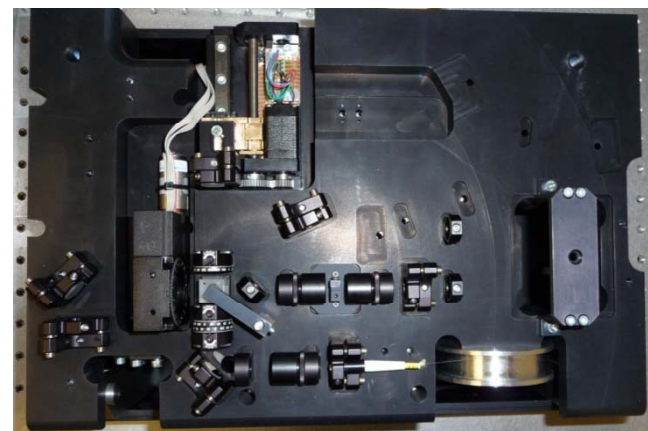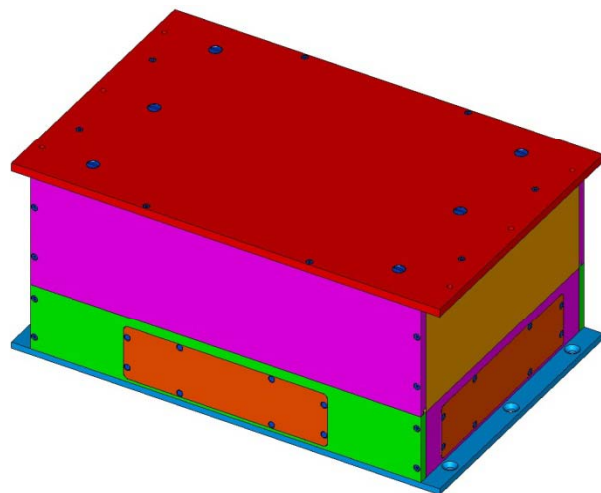
TODO: careful drift investigation

Courtesy: F. Loehl, J. Mueller

Engineered version of link (not yet tested)

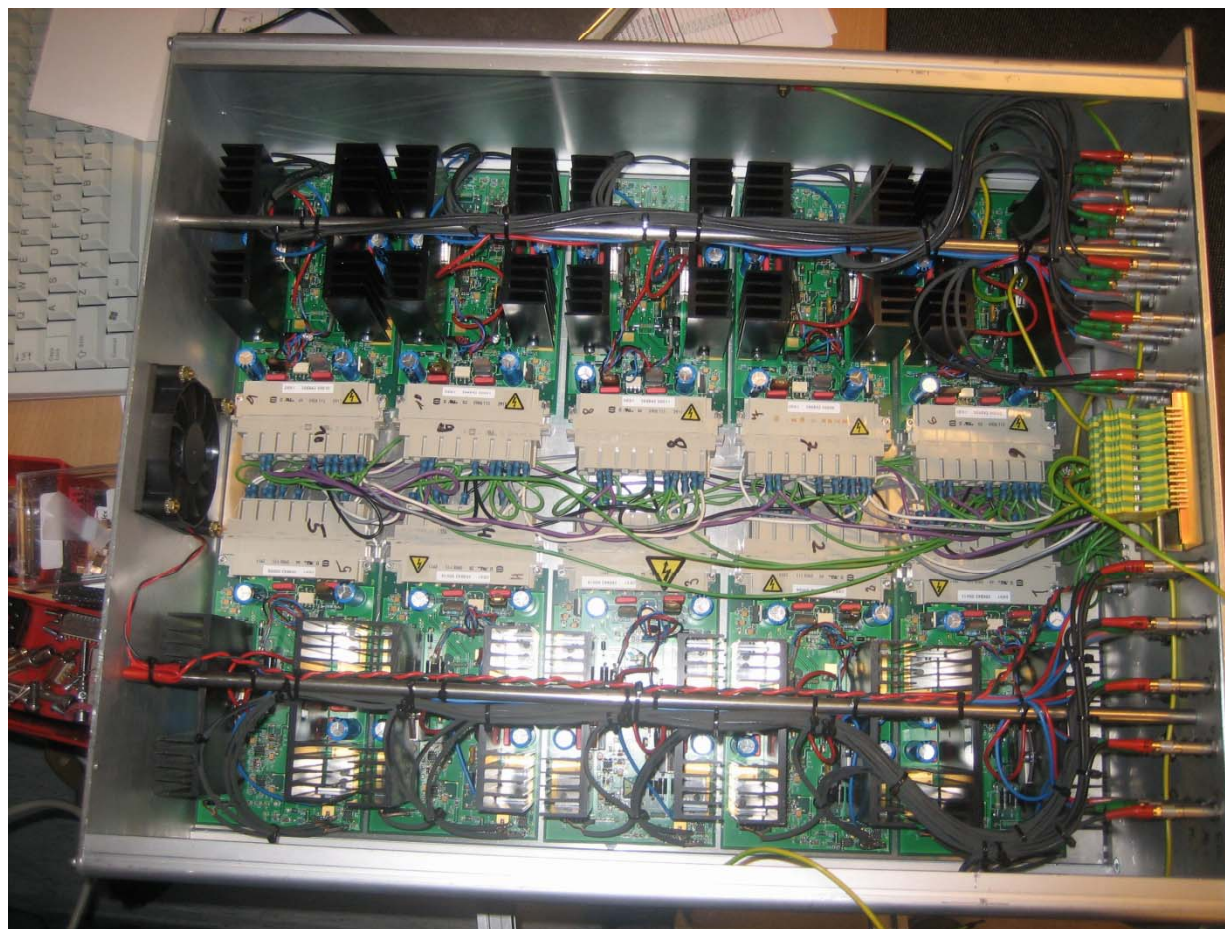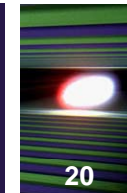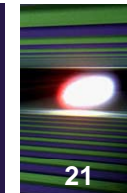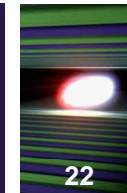3 Links are completely assembled
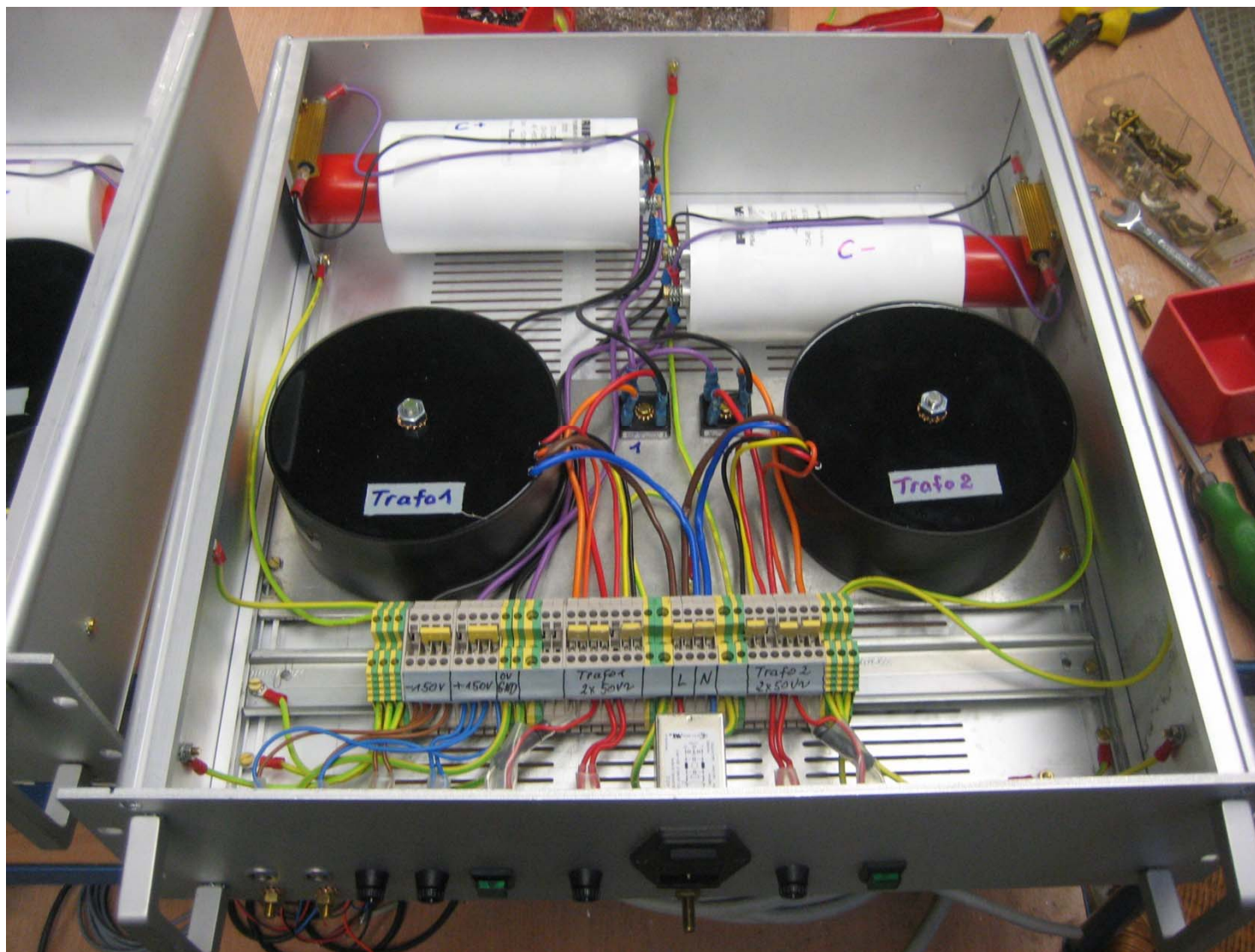Installation scheduled Feb/March 2009
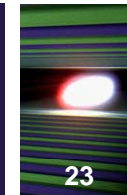
Courtesy: F. Löhl

Piezo driver

Piezo driver

Piezo driver
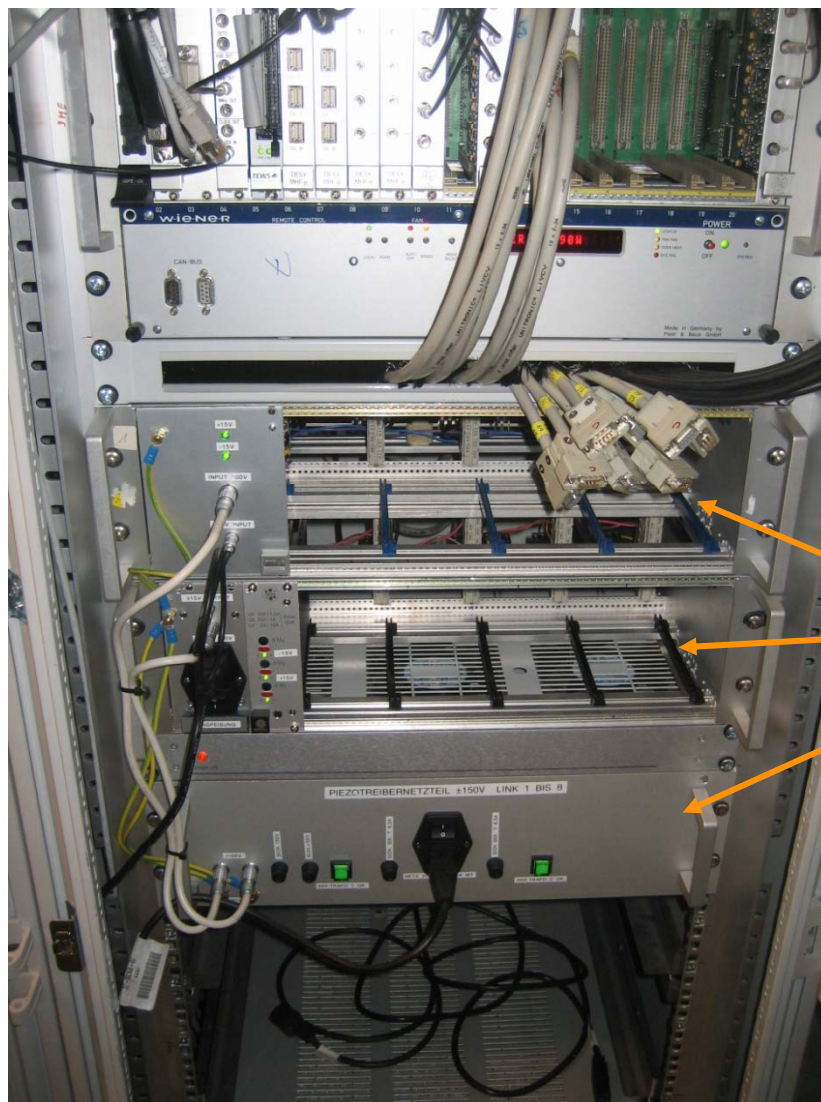
Piezo driver

- New piezo driver chassis
- New power supply
  Separation of +-150V & +-15V
  Fuses accessible, control LEDs

Optical synchronization of Lasers
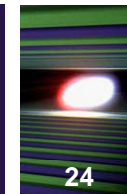
Test set for optical synchronization of Ti:Sa
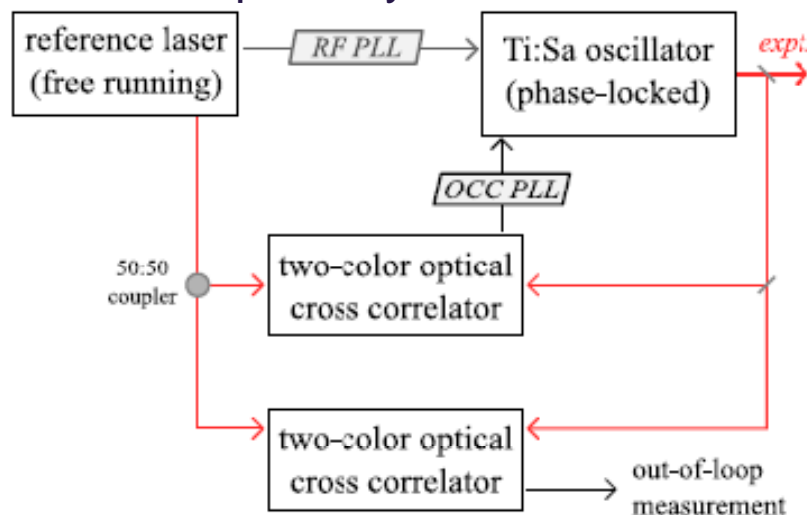
- Reference laser: EDFL

λ = 1550 nm

$\Delta\lambda$ = 90 nm

$<P_{EDFL}>$ = 15mW

$f_{rep,EDFL}$ = 40:5MHz

τ_{EDFL} = 110 fs (FWHM)

- Diagnostic Laser: Ti:sapphire

λ = 800 nm

$\Delta\lambda$ =70 nm

$<P_{Ti:Sa}>$ = 560mW (OXC 50mW)

$f_{rep,Ti:Sa}$ = 81MHz

$\tau_{Ti:Sa}$ = 40 … 60 fs (FWHM)

Working principle of balanced optical cross-correlator
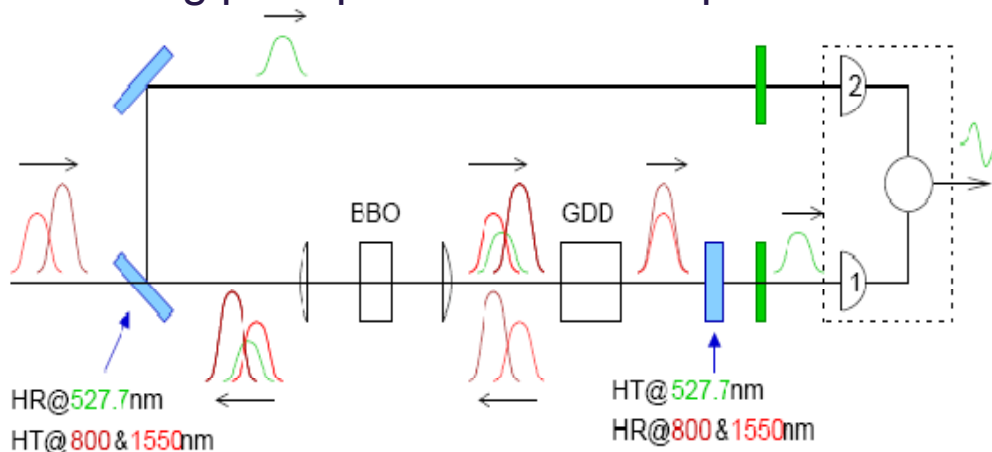
- sum frequency generation in a BBO crystal (type-I(□□), ooe)
- application of a group delay to back-reflected input pulses
- measurement of both SFG intensities
- difference highly sensitive to timing changes
- independent of laser amplitude changes (balanced detection)
- input signal for control loop

Courtesy: S. Schulz, V. Arsov

Optical synchronization of Lasers
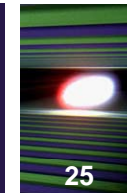
First measurement results:
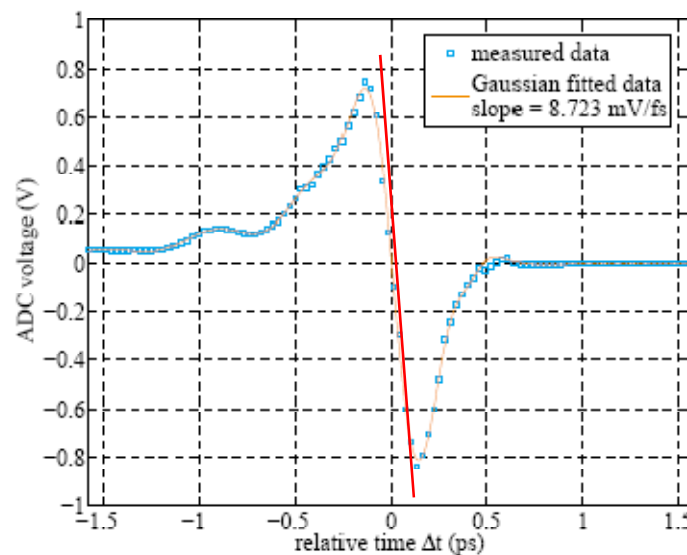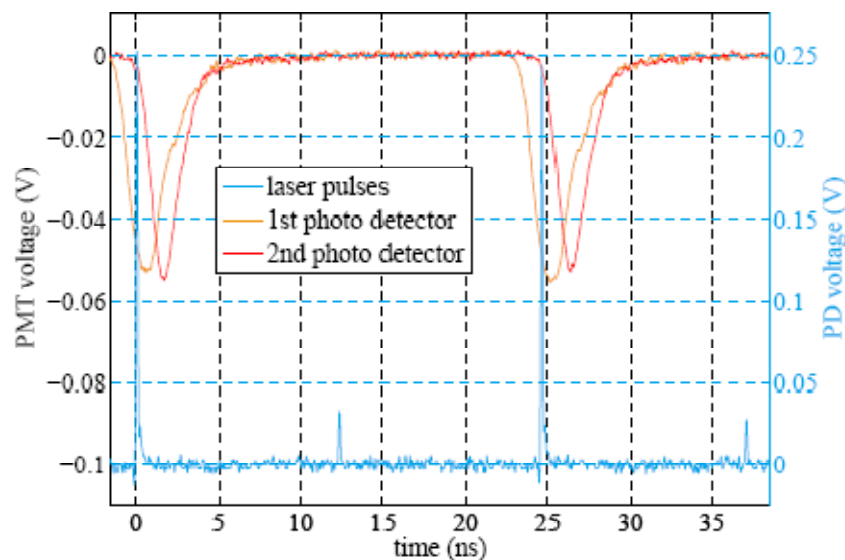
- individual SFG signals at fixed delay Δt
- equal amplitude ⇒ balanced case
- amplitude change direct measure for timing changes
- vector modulator scan (scan timing between laser)
- slope of 8.7 mV/fs (amplifier and ADC noise est. < 1 mV)
- sufficient for control loop
- peak distance of 280 fs
- Optical lock for short times established

Using this scheme a Ti:Sa and a Cr:forsterite laser were locked with 300as precision!!!

See: Opt. Letter, 2003 / Vol. 28, No. 11 p. 947

Courtesy: S. Schulz, V.Arsov

Status of Implementation

- Piezo driver: 6 board can be operated, remaining 9 boards need to be repaired electronic error found
- Motor boxes from link commissioned (16 x 3 Motors)
- Motor box MLO (added T-sensors, and ADCs for Temperature control)
- LDD drivers (32 in operation now, all cables checked)
- Almost all cable work done
- RF lock box in production (old one did not work because of 54MHz laser)

- Preparation of first link is ongoing (this week hopefully)
- BAM DBC3 next
- Installation of free space distribution about 1 month
- New BAM version construction drawing
- L2RF current produced (second loop)
- Good result on short link version

Final version of beam based long. FB with 3rd harm. cavity

Accelerator

| Gun | ACC1 | 3rd | | ACC2 | ACC3 | | ACC4 | ACC7 | |

Laser

Monitor front-end

| OCC | | BAM | EBPM | BAM | EO 1D | | EBPM | BAM | THz 1D | | BAM | BAM | THz 1D |

Fast data processing and signal correction

Patrick Gessler + …

| μTCA | | μTCA | μTCA | | μTCA | μTCA | | μTCA | μTCA |

Correction Algorithm/μTCA

Regulation

Fast
Patrick Gessler

A

Slow

A,ϕ A,ϕ

SRF regulation
Christian Schmidt
Jaroslaw Szewinski

3 GHz NRFcavity

1.3 GHz SRF ACC1 (2&3) Simcon/μTCA

3.9 GHz SRFcavities Simcon/μTCA

• Beam based FB on/off
• Adaptive feed forward A, ϕ, A, ϕ
• Integration piezo regulation ACC1
• Transition RF-FB to BB-FB
• Diagnostics for FB regulation
• Acception handling
• Fast IO communication with μTCA

Requirement
Pkpk ΔE/E < 5·10^4 @ BC2

Process:
a) Tuning of FEL (P, λ, Δt, t)
b) Determination of correction algorithm
c) Switch on FB + gain adjustments

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Thanks for your attention