PAUL SCHERRER INSTITUT

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Paul Scherrer Institut

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The Bunch Arrival Time Monitor (BAM) at PSI

Overview

- Specification & Requirements
- Conceptual Design
- Technical Realization / Implementation
- Prototype Results
- Summary and outlook

Motivation

Single-shot, non destructive electron bunch arrival time diagnostic with high resolution and high bandwidth

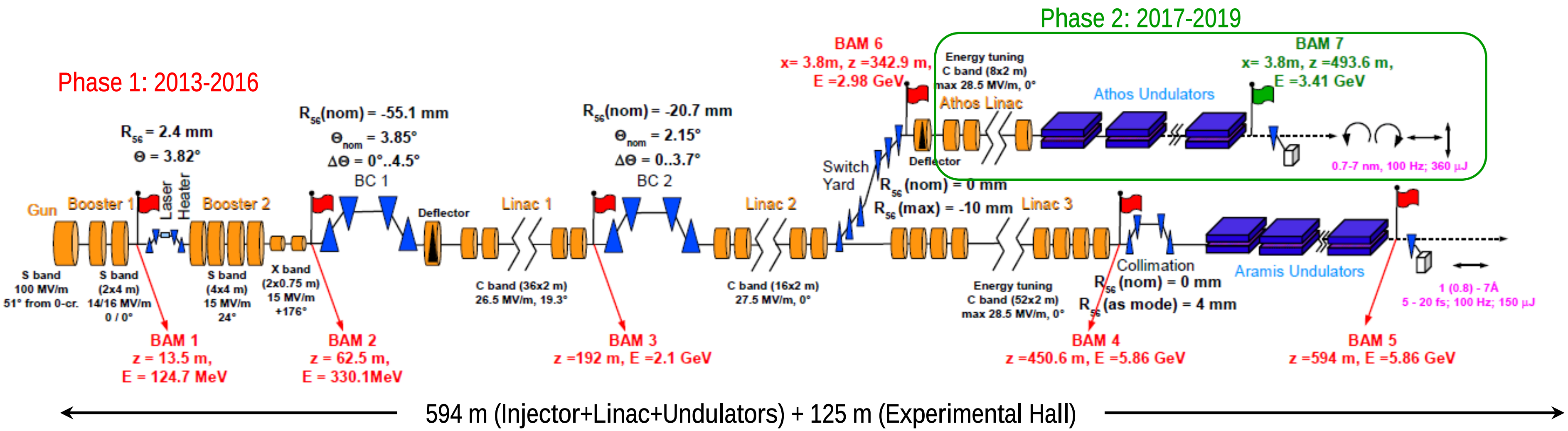
- SwissFEL:

Linear machine, bunch compression in movable magnetic chicanes, synchronization between lasers (photo injector/experiment) and RF

- CLIC:

Two-beam acceleration scheme: precise synchronization between the Main Beam and the RF to keep the beam energy constant

Layout and parameters of SwissFEL



Design parameters of the two beamlines

- Charge: 10 .. 200 pC
- Beam energy for 1 Å: 5.8 GeV
- Core slice emmittance: 0.18 .. 0.43 mm.mrad
- Energy spread: 250 .. 25000 keV (rms)
- Peak current at undulator: 1.6 .. 15 kA
- Bunch length: 0.3 .. 25 fs (rms)
- Bunch compression factor: 125 .. 5000
- Repetition rate: 100 Hz, 2 bunches @ 28 ns

- Wavelengths: 1 .. 7 Å (linear polarization); 0.1 .. 7 Å (linear/circular polarization)
- Pulse lengths: 0.06 .. 20 fs
- Peak brightness: $< 1.3 \cdot 10^{33}$ phot/s·mm^2·mrad^2·0.1%BW

Parameters, Specifications, Purpose

Main Parameters & Specifications:

Parameter	Specification	Unit	Remarks
dynamic range (time of flight comp.)	**< 300**	**ps**	compensation for changes in the BC angles
dynamic range (arrival time jitter)	**20 (100)**	**ps**	slope pickup signal (combination of two slopes)
dynamic range (charge)	10 - 200 (and higher)	pC	for ps to fs bunches
RMS resolution (S/N) (before/after BC1)	<50 / <10	fs	monitored online; within the SwissFEL charge range of 10pC -200 pC
T° stability	0.05	°C	active temperature stabilization of the optical front-end
calibration	dynamic	-	periodic scan of the ref. laser pulse over the pickup
measurement mode / rep. rate	single-shot / 100	Hz	2-bunch operation for SwissFEL phase-2 (@ 28 ns bunch distance)
CS-interface	digital output	-	BAM provides shot to shot arrival time offset and drift (over larger period) with fs precission. Unused pickup signals (analogue) can be also delivered outside the tunnel
other interfaces	beam-based FBs	-	commissioning: beam-based FBs on high level (10 Hz) user operation: beam-based FBs on low level (100 Hz)
operation modes	machine studies user runs	-	BAM measures the arrival time non-destructively

Main Purposes:

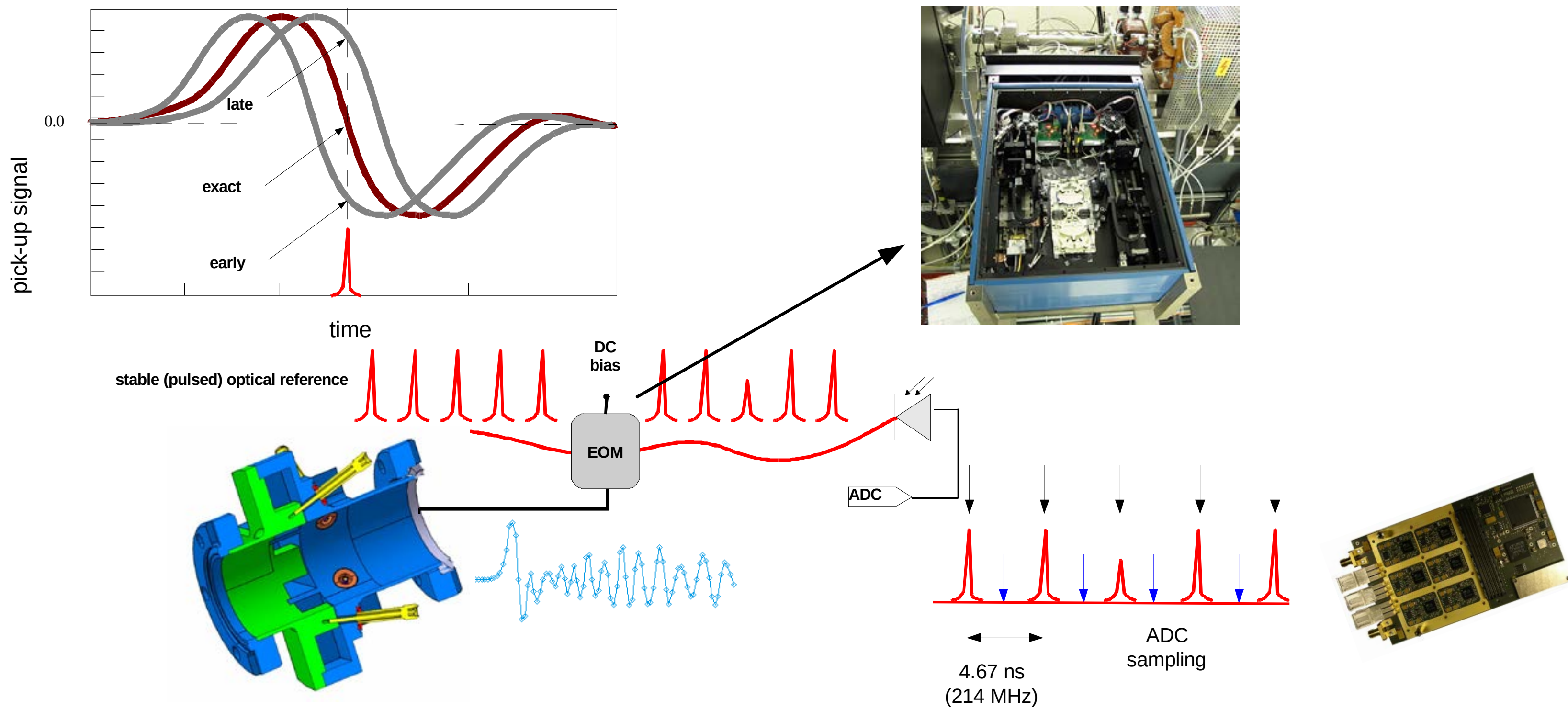
→ **high precission (<10 fs rms) arrival time measurement at selected locations (e.g. magnetic** chicanes/undulators) relative to a highly stable optical reference system (resolution: <5fs, drift: 10fs/day)

→ **decouple sources of drifts and phase errors during commissioning and setting of the machine**

→ **feedback on accelerator cavity phases, tuning of BC, etc.**

→ **correlation with other events, e.g. pump-**probe experiments

BAM Detection Principle



SITF Pickup Prototypes

I. Button (38 mm chamber):
- 80 GHz design BW,
- good resolution and sensitivity:

  200pc – 60 pc: 20 fs

  60 pC-10pC: 30fs -170 fs

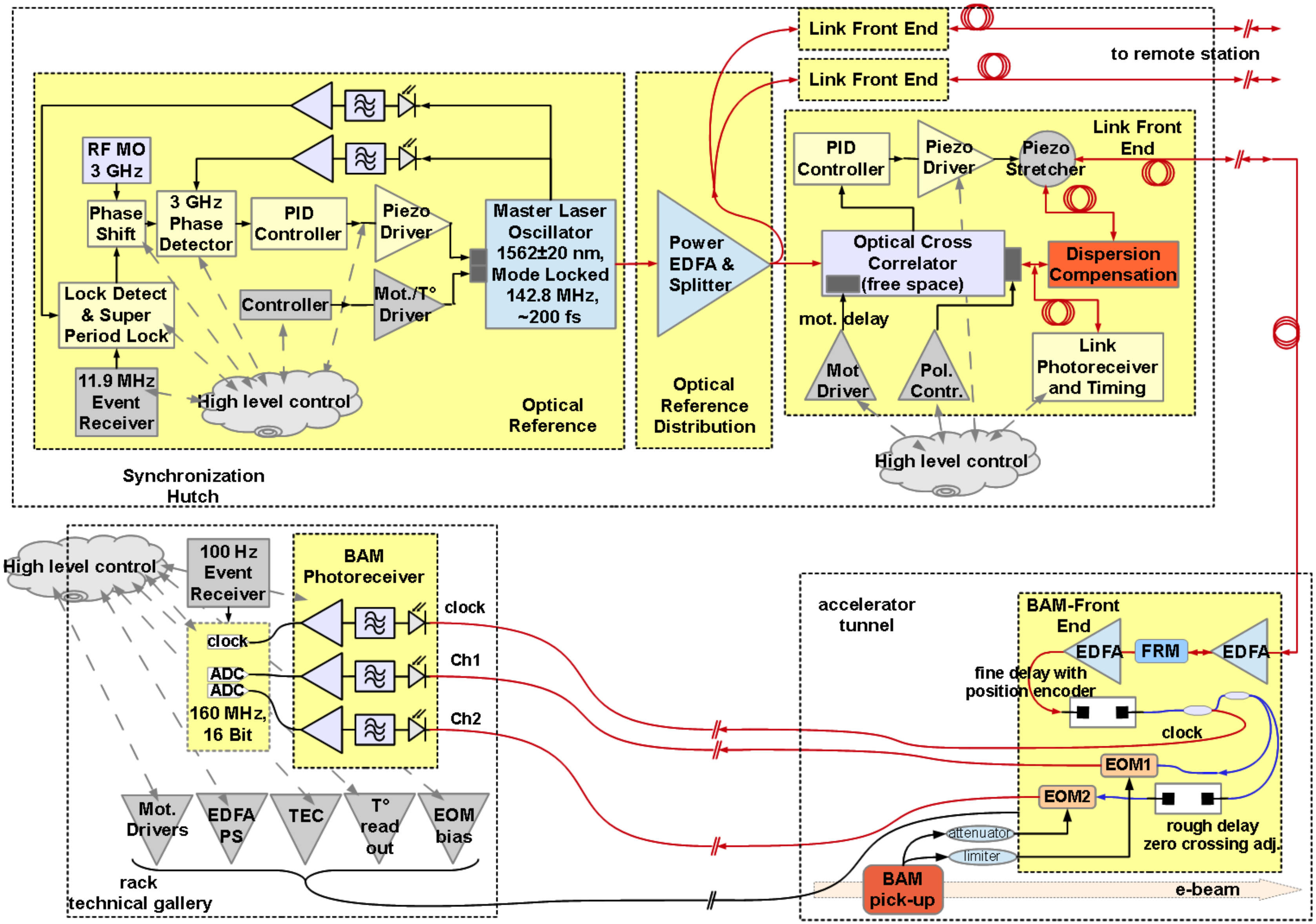
II. Ridge waveguide (RWG) (38 mm chamber):
- strong signal, but in combination with the RF-front end: non linear
- insufficient resolution, ringing,

SITF BAM-Data Acquisition (GPAC ADC12FL)

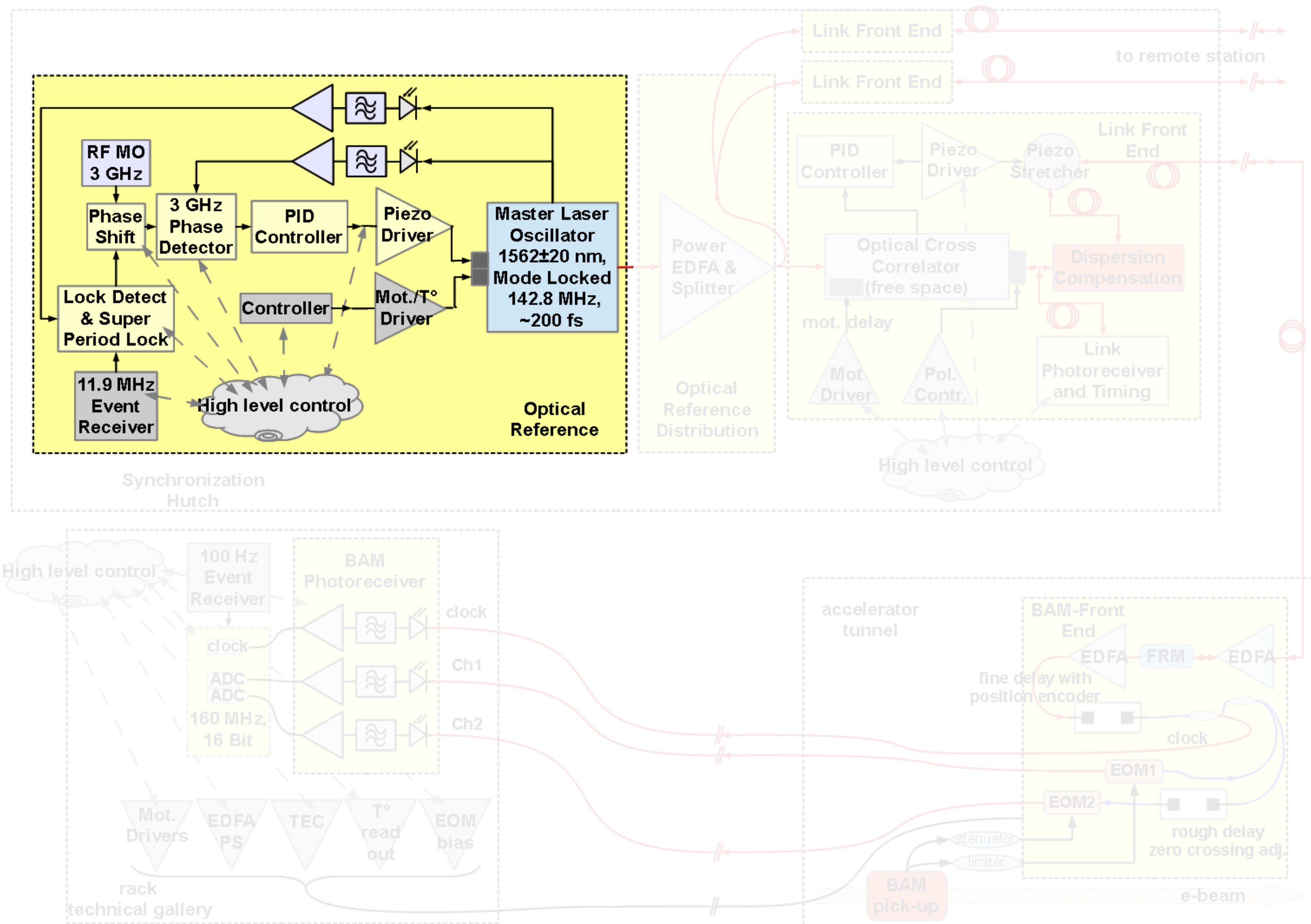
- The ADC clock is generated by the laser pulses and is shifted simultaneously with them
- The laser pulse amplitude is normalized pulse-to-pulse
- The laser amplitude jitter is monitored online

*Florian Löhl, DESY-THESIS-2009-031, March 2009

Layout of the Pulsed Distribution and BAM



Master Laser Oscillator

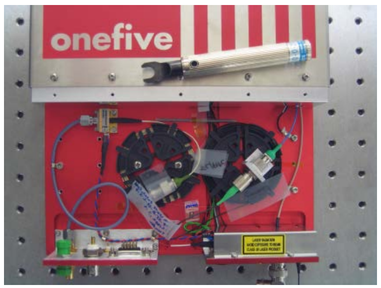


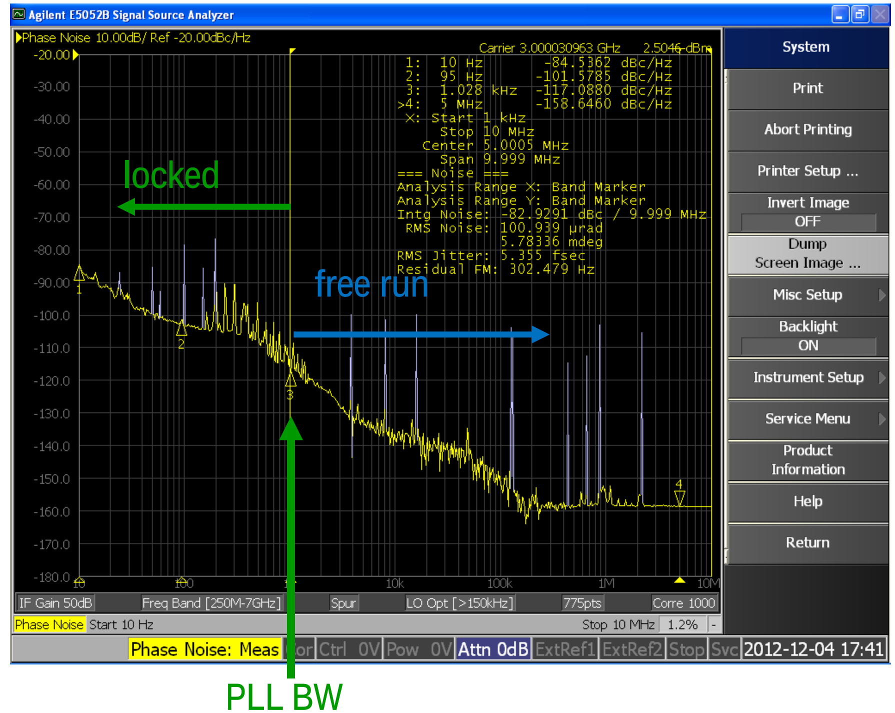
Master Laser Oscillator

MLO: OneFive Origami – 15

Er-Yb:glass soliton laser oscillator

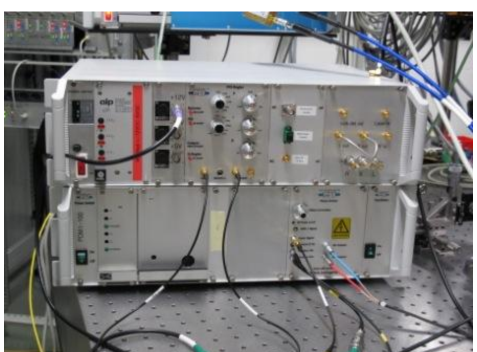
- λ = 1565 $\pm$13 (FWHM) nm
- f_{rep} = 214.13656 MHz
- τ = 160 fs ($sech^2$)





In-house developed PLL:

- Analogue PID (digital under development)
- Piezo driver, Photoreceiver and Phase detector
- Superperiod synchronization



Timing Jitter

- Free running: 3.3 fs (rms) 1kHz..10MHz
- Added by the PSI lock box:
  - <6fs within the lock BW (dominated by environment, EMI)
  - 5.4fs fs above the locking BW
  - Total < 8 fs (10Hz..10 MHz) /Mains EMI and setup limited/

Optical Fiber Link

Propagation of a short laser pulse through a standard single-mode fiber, e.g. Corning SMF28e

1. Timing Drift (length variation):

a) temperature: 40 fs/°C/m → for 50 m fiber: 200 fs/0.1°C (stabilized tunnel temperature)
b) Humidity: 12 fs/%RH/m → for 50 m fiber: 600 fs/%RH (no RH stabilization)
c) Mechanical vibrations (can be minimized by proper laying);
round trip time: 10 ns/m (below 5 km acoustics /20 kHz/ can be compensated)

Can be measured and compensated with high precision < 1 fs

2. Dispersion (pulse broadening):

a) chromatic: 18.2 fs/nm.m → for 50 m fiber @ λ = 1565 ± 13 nm: 11.8 ps (can be compensated)
b) PMD: < 100 fs/√km → for 50 m fiber: < 22 fs (can not be compensated, but negligible)

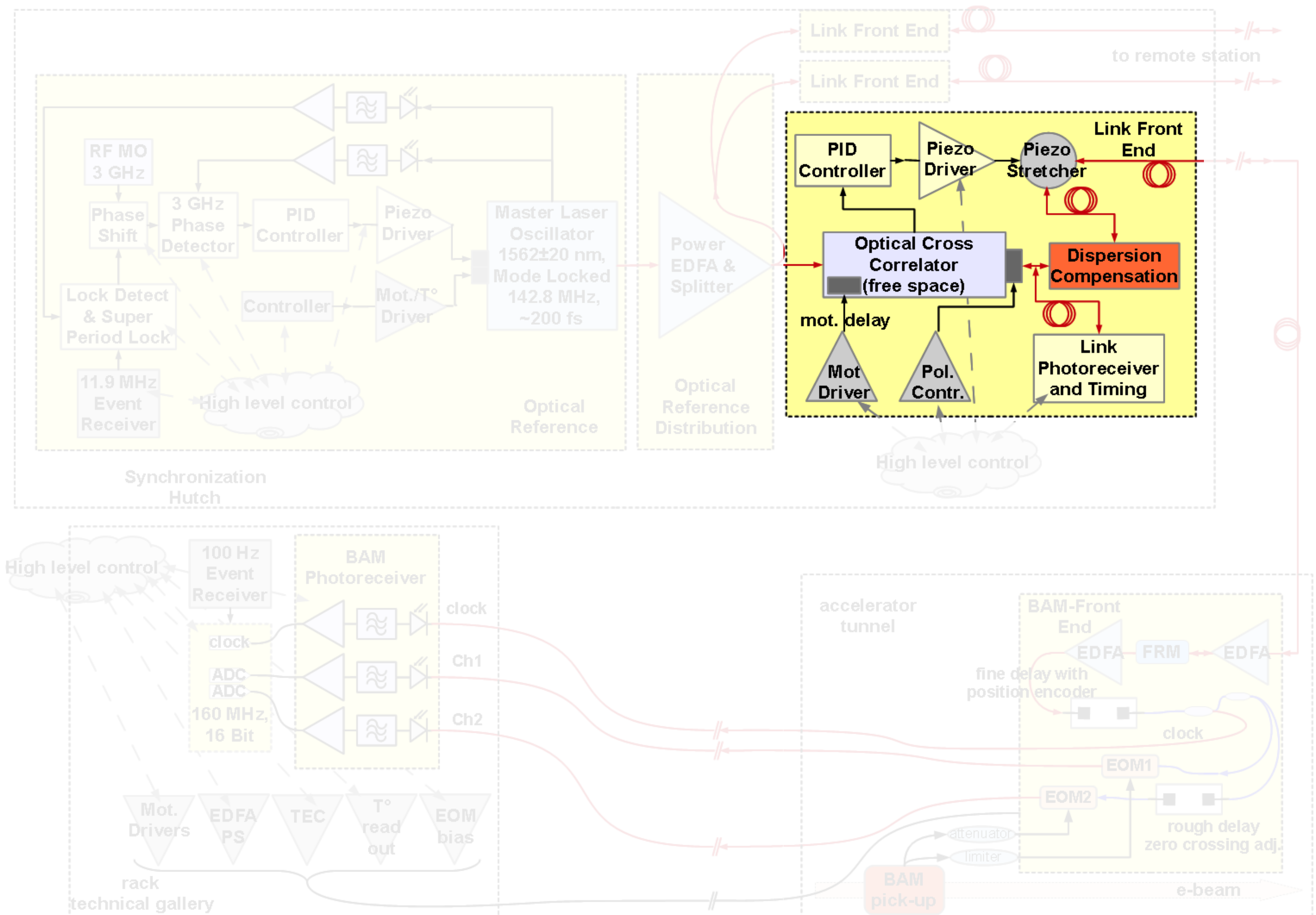
3. Absorption loss: <0.2 dB/km @ λ = 1550 nm (negligible)

4. Radiation susceptibility:

- Depends on fiber doping (Ge, F); radiation type (γ, n) , dose rate, duty cycle, beam loss, dark current etc.
  - For SwissFEL (assume damage and attenuation degradation, proportional to the n-flux)
    $\sim 3.3 \cdot 10^7$ Gy/s → $\sim 4.3 \cdot 10^3$ n/cm$^2 \cdot$s → $\sim 2.5 \cdot 10^{-9}$ dB/s ⇒ 3dB/km reached after 60 Years
  - An experiment with support from the Frauenhofer Institute, Euskirchen is planned

5 EMI susceptibility: none

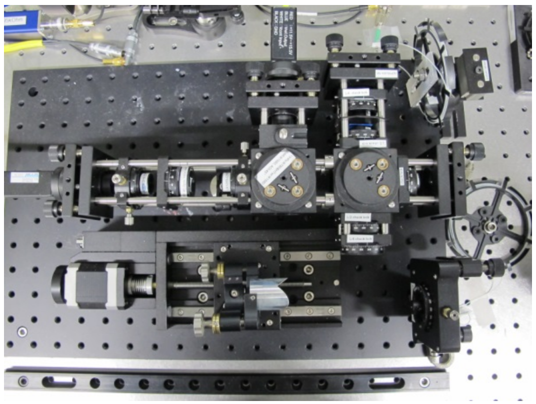
Optical Link and Link Front-End

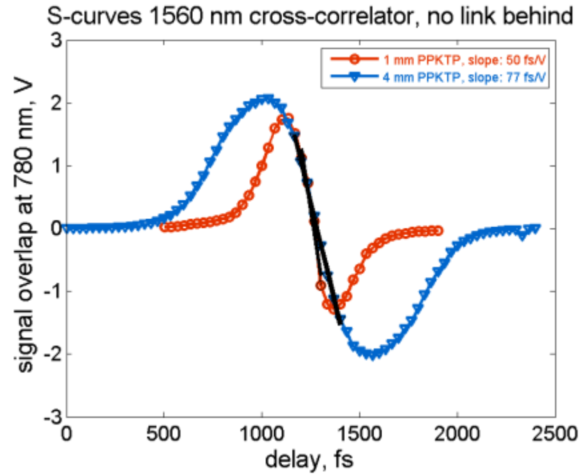


Optical Link Front-End

In-house developed balanced optical cross-correlator:

- Resolution < 1 fs
- 1 mm PPKTP: 50 fs/V; 4 mm PPKTP: 77fs/V
- Reduced walk-off (weaker focusing, f=30mm)
- Active polarization control
- Dynamic range: 13.3 ps jitter; 670 ps drift

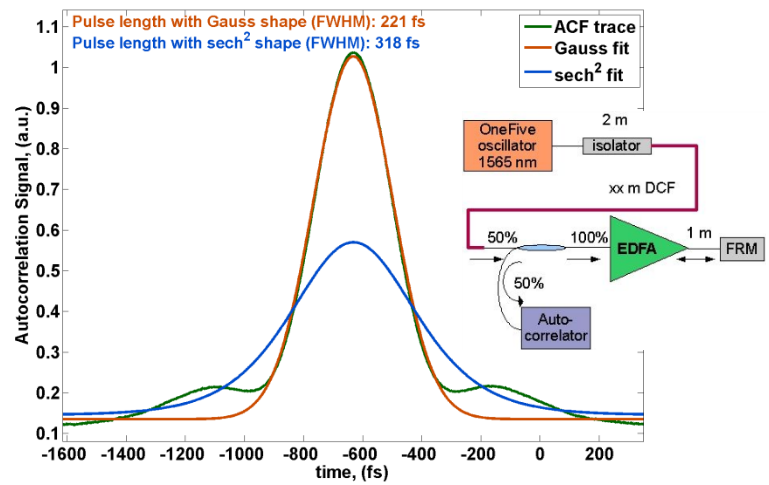




Optical error signal for different PPKTP crystal lengths

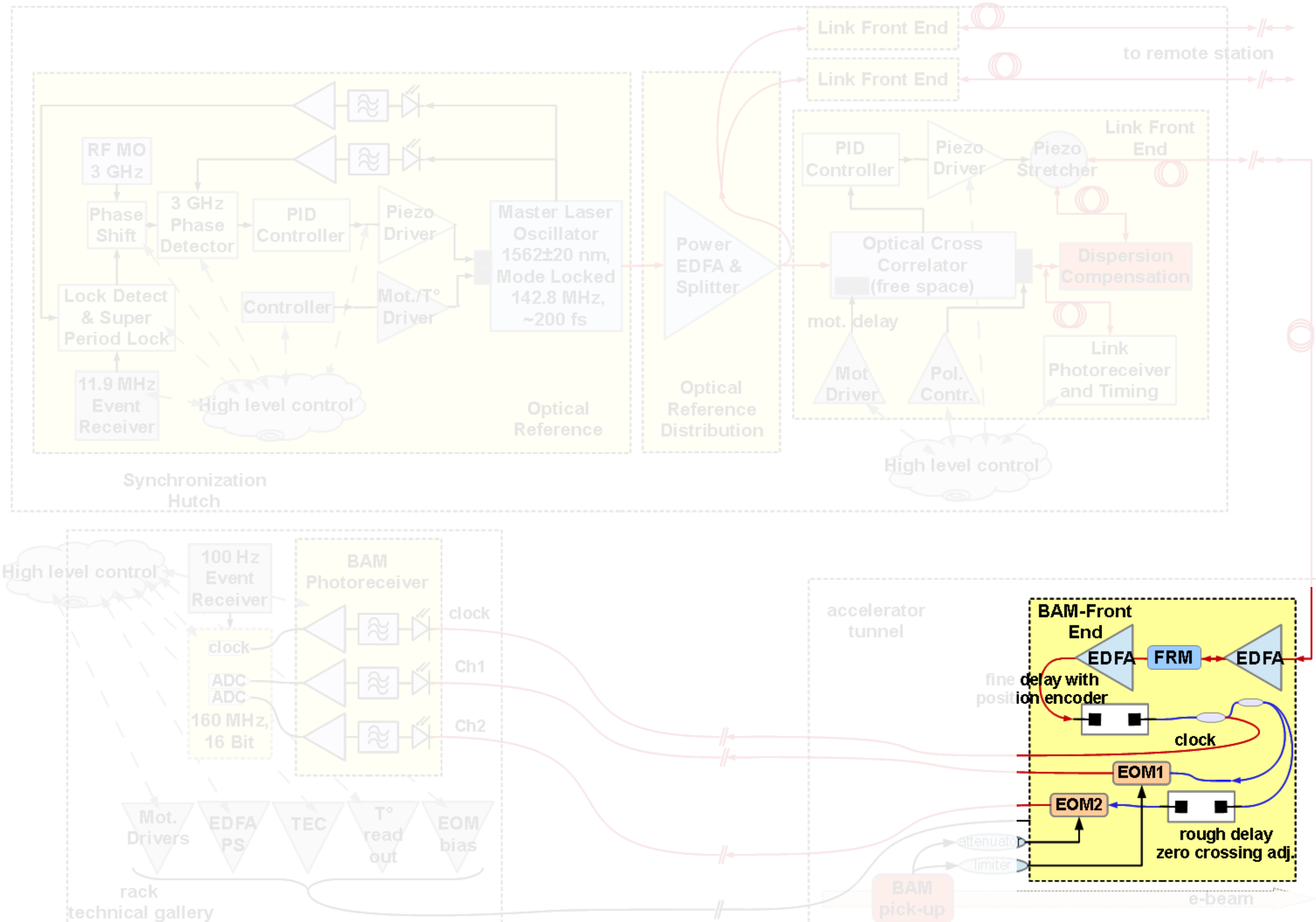
In-house developed PLL:

- Analogue PID (digital under development)
- Piezo driver, Photoreceiver and Phase detector
- Link power, link timing

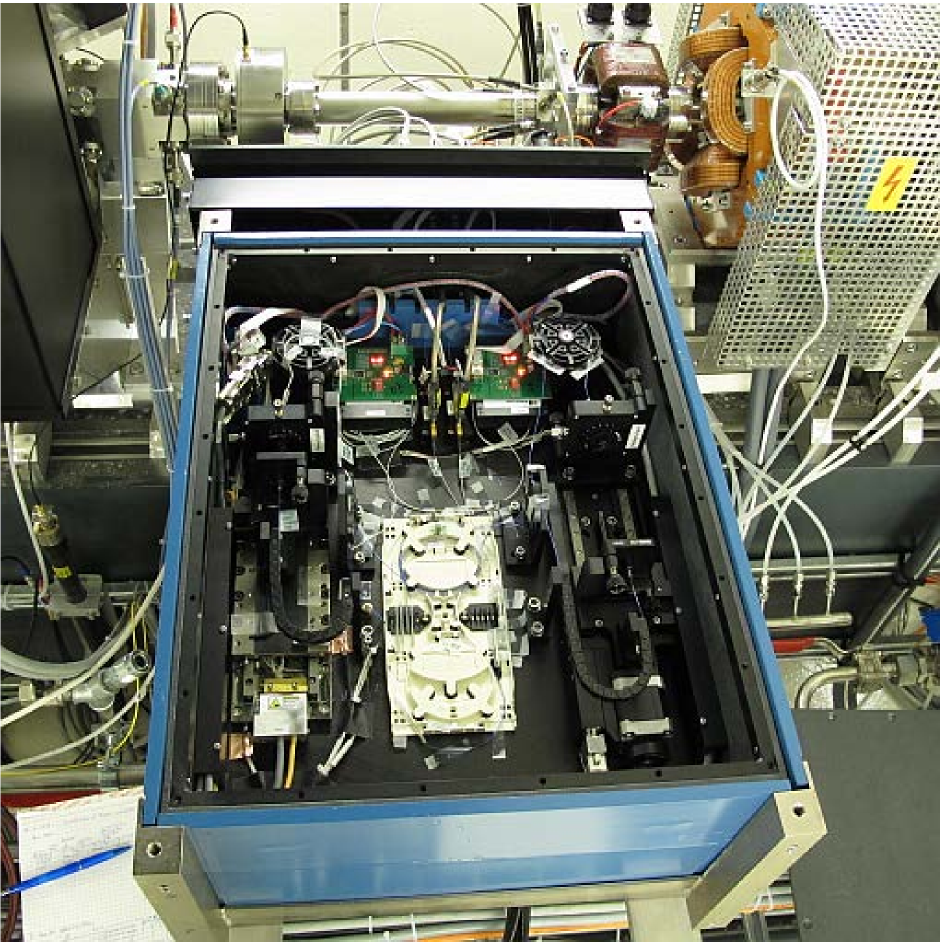


Pulse recompression after 2x-pass in the EDFA
- 220 fs (FWHM, Gauss); 320 fs (FWHM, sech^2)

BAM Front-End



BAM Front End Design (Box. Var.1)



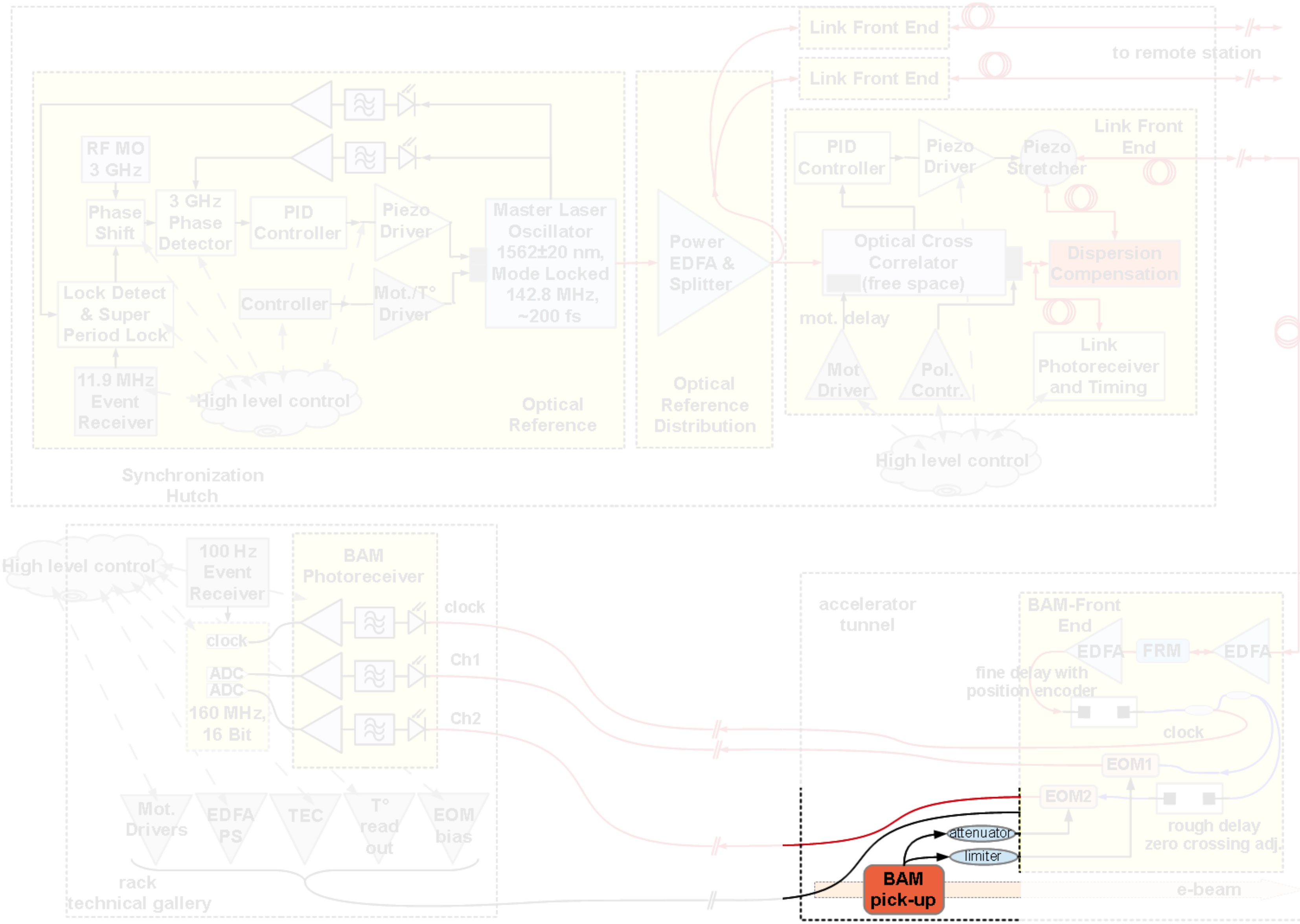
Dimensions (with the shielding):

640x450 mm (cables and cable radii not included)

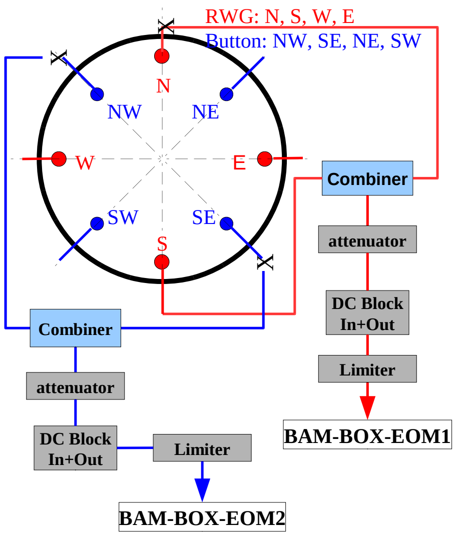
Basic Components:

- EOMs: 12 GHz (Covega); 40 GHz foreseen (Box2)
- EDFAs with controllers (custom design, Photop, CN)
- linear motor with 10 nm encoder (Parkem)
- linear motor controller
- stepper motor
- T° stabilization of the baseplate ($T_{pk-pk} < 0.05°$ C)
- T° & RH monitoring
- EPICs control, archiver channels
- EOM bias control and WP setting
- Radiation shielding (sufficient for SITF, insufficient for SwissFEL)
- possibility for channel extension (further EOMs)
- ∃ Box Var. 2 with improved thermal management

BAM RF Front-End

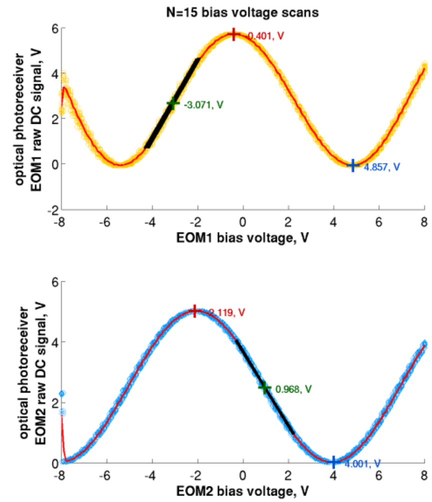


BAM Pickups and RF Front-End

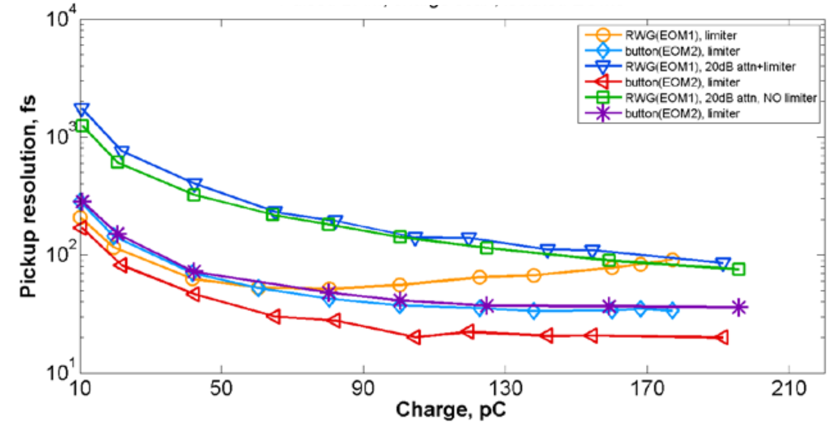


- balanced cable group delay
- insulated EOMs
- matched length on both channels

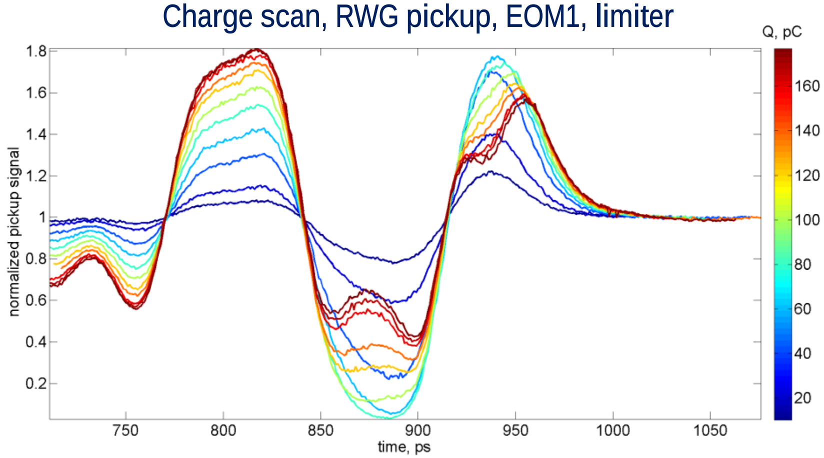
EOM DC bias scans for Vπ and working point selection. No RF modulation



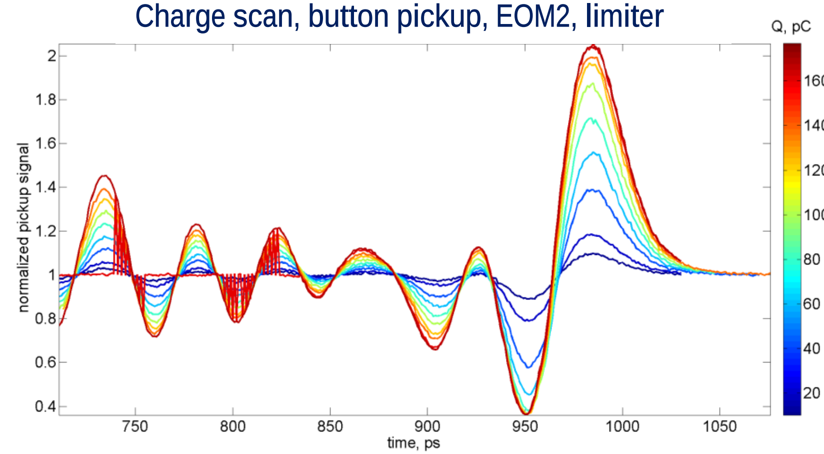
RWG and button pickup resolution for different configurations of the RF Front ends



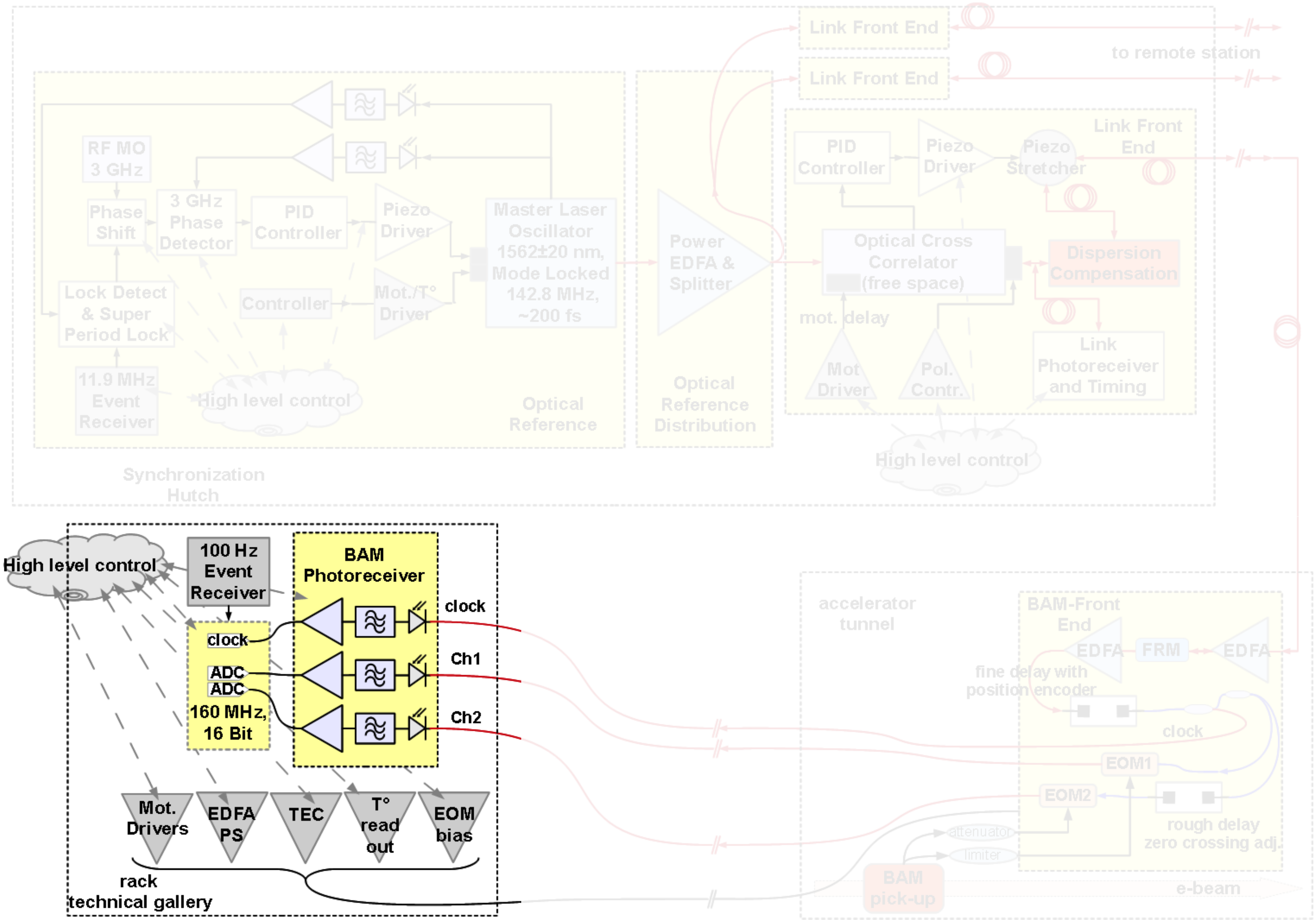
Charge scan, RWG pickup, EOM1, limiter



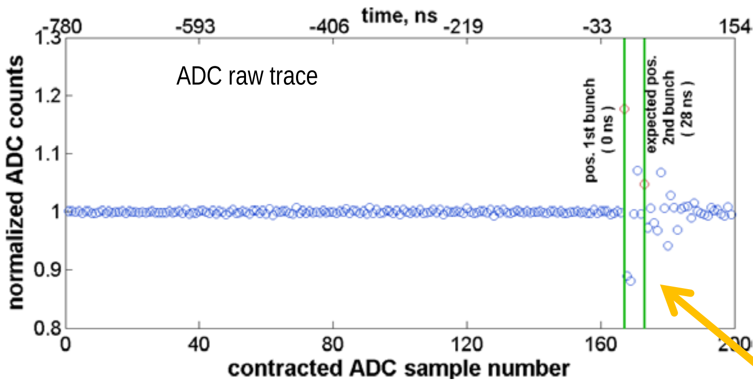
Charge scan, button pickup, EOM2, limiter

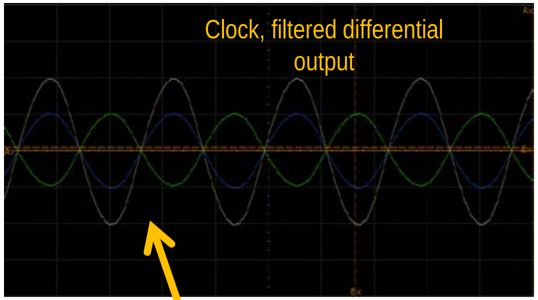


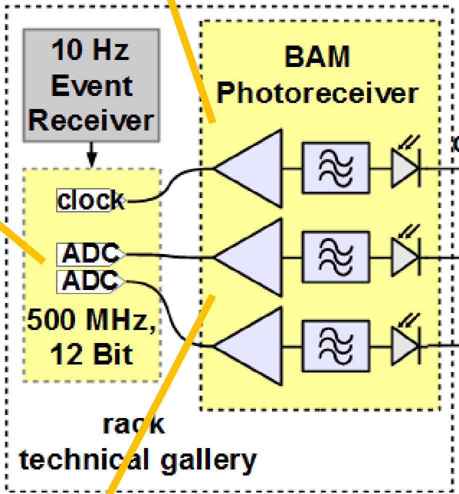
BAM Back-End and Readout

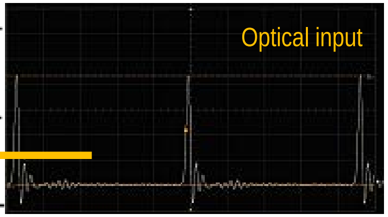


BAM Back-End and Readout

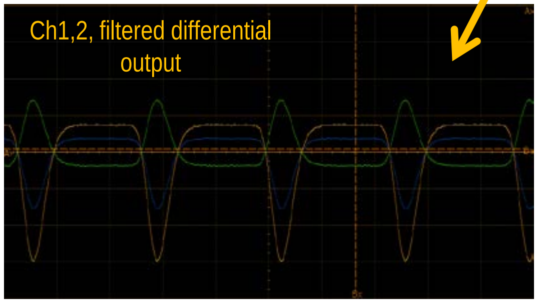








- Machine synchronous acquisition
- The amplitude modulation is detected always at the same ADC sample position
- The laser pulse amplitude and the baseline are sampled with the same channel @ 428 MHz
- The laser pulse amplitude is normalized pulse-to-pulse
- The laser amplitude jitter is monitored online: information of the instantaneous resolution
- Calibration of some following modulated laser pulses allows online charge information
- Pickup ringing/wake fields 28 ns after the 1st bunch $\Rightarrow$ reading of the 2nd bunch is compromised



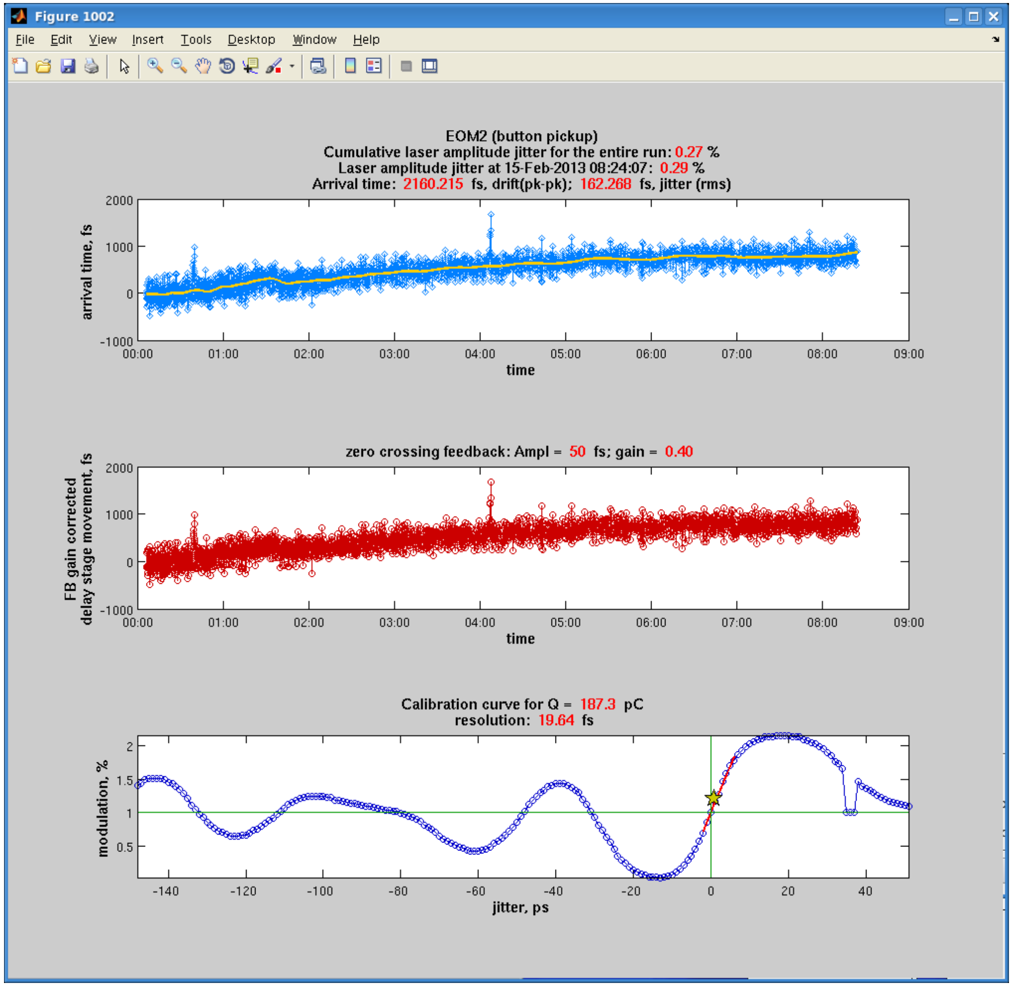
Photoreceiver Optimized Design (S. Hunziker)

- PD with high intrinsic BW
- minimized photoreceiver noise
- broadband transimpedance amplifier, high dynamic range
- optimized filter for low sampling jitter sensitivity
- optimized interval between the pulses

BAM: Operator display for drift acquisition

Features:

- Matlab (for the time being)
- Zero-crossing feedback
- User-defined amplitude and gain
- Display of:
  - arrival time drift
  - arrival time jitter
  - delay stage correction
  - laser amplitude jitter
  - calibration slope
  - resolution



Summary and Outlook

- The BAM is a drift stable system with a resolution <5fs and a drift of <10 fs/day.
- Presently, the resolution is limited by the BW of the EOM and the Feedthrough, as well as the ADC card and its front end
- The first BAM station at SITF (PSI) is operational, the functionality is demonstrated.
- The button pickup has better performance than the RWG and will be further optimized

  (reduce ringing for 2 bunch operation, transport its high BW to the EOM)
- Development of 40 GHz Feedthroughs. Vacuum and RF tests ongoing
- Implementation of 40 GHz EOMs (foreseen for the 2nd and 3rd stations at SITF)

Thank you for your attention!