DESY

– from a laser scientist's perspective

Bernd Steffen

LA^{3}NET Workshop: Scientists go Industry
Berlin, Nov. 2014

HELMHOLTZ ASSOCIATION

DESY

cv

- Learned precision mechanics in Marburg
- Studied physics in Kiel and Würzburg
- Diploma thesis (experiments at Uni HH, supervisor at DESY, handed in at Uni Würzburg

  Determination of the critical magnetic fields of surface and temperature treated niobium by AC susceptibility measurements
- 2007 PhD at DESY

  Electro-optic methods for longitudinal bunch diagnostics at FLASH
- Post-Doc at PSI, Switzerland
- Since 2010 at DESY
  - planning, building, and soon commissioning longitudinal diagnostics for the European XFEL
  - short pulse project at FLASH

Outline

- DESY – Academia or industry?
  - Site
  - Accelerator lab or laser lab?
  - Employer
- FLASH (as an example Free-Electron Laser)
- Lasers at accelerators
  - Optical synchronization system for FLASH and XFEL
  - Electro-optical bunch length measurement for E-XFEL
  - Short pulse photo-injector laser at FLASH
  - ANGUS - 200 TW laser system for laser-plasma acceleration

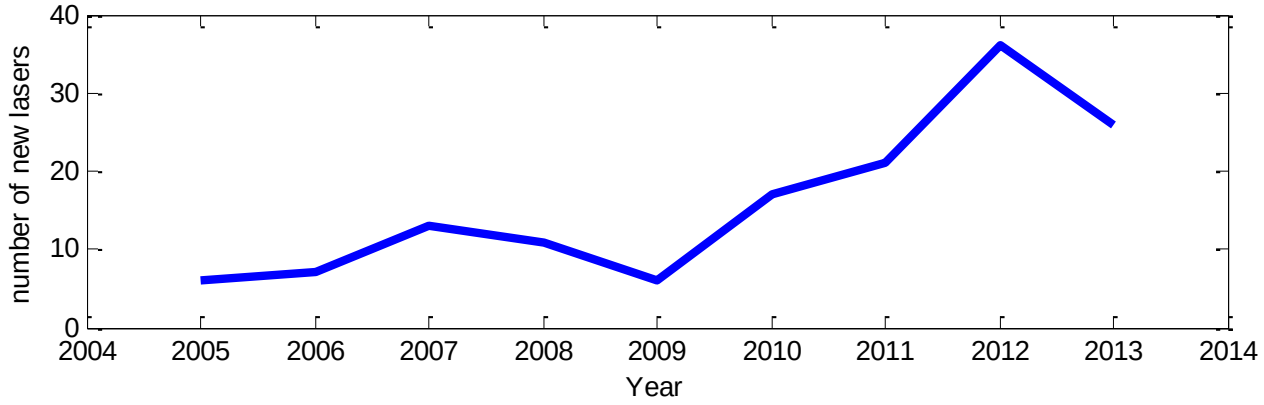
DESY

- **Deutsches Elektronen-Synchrotron**
- National research center of the Helmholtz Association on **accelerators**, **photon science** and **particle physics**
- Located in Hamburg and Zeuthen (Brandenburg)
- Budget: 230 million euro (Hamburg: 210 million; Zeuthen: 20 million)
  Financing: 90% national; 10% Hamburg and Brandenburg
- Employees: approximately 2300, including 650 scientists working in the fields of accelerator operation, research and development
- Additionally more than 3000 guest scientists from over 40 countries each year
- Currently about six running accelerators (plus pre-acc.) for photon science, research and education
- By now lots of lasers…

Lasers at DESY

- 2003 (the laser labs I know of):
  - Laser wire experiment at PETRA (about 5 scientists, PhDs, postdocs)
  - TTF (now FLASH) injector laser (about 5)
  - Electro-optical bunch detection at TTF (4)
  - Some lasers for spectroscopy at HASYLAB
  - Pump-probe lasers at TTF (in preparation)
  - Hamburg University institute of laser physics about to move to DESY site
- 2005 - 2014

  Additional laser (class 3 and 4) announced to the local authorities:



Ranging from small IR-oscillator to TW systems…

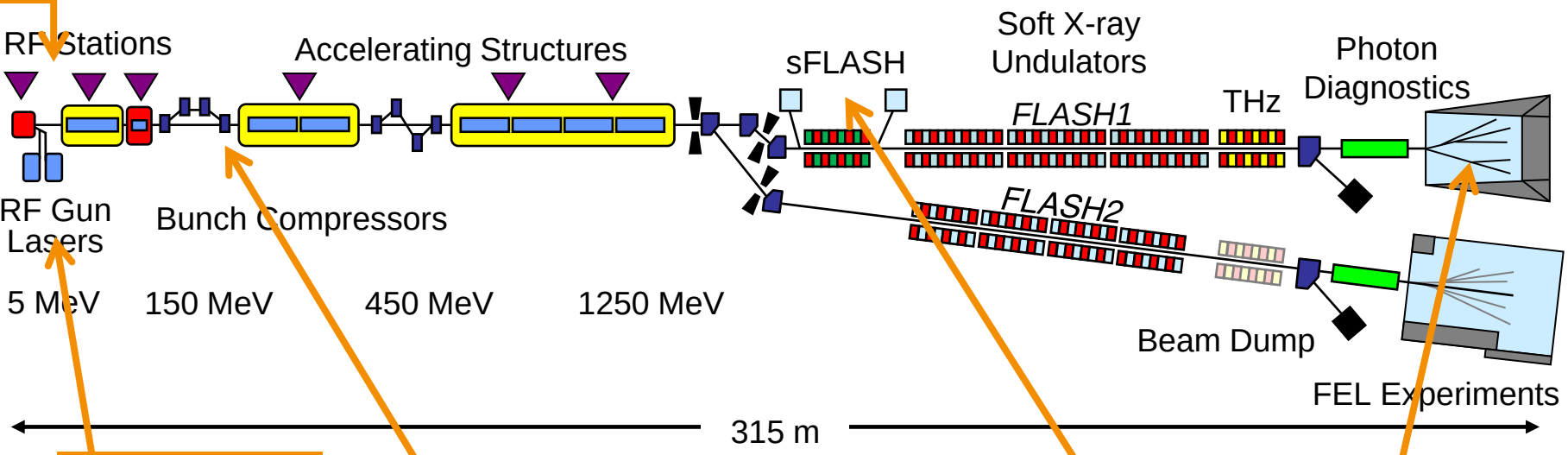
Institutions and outstations on the DESY site

- Center for Free-Electron Laser Science
- Centre for Structural Systems Biology
- European Molecular Biology Laboratory
- University of Hamburg (at DESY site: Institute for Experimental Physics, Institute of Laser Physics, II. Institute for Theoretical Physics (elementary particle physics), Center for Optical Quantum Technologies)
- Helmholtz-Zentrum Geesthacht (material science)
- NanoLab

DESY as an employer – a personal view

- Benefits and disadvantages of public service
- Broad variety of research fields
- Personal (research) interests can be followed
- Experts on a lot of different fields of science on site
- Collaboration with other groups/institutions in and outside of DESY is well supported
- Very international and open-minded science community

FLASH – Free electron LASer at Hamburg



Injector lasers

Laser based diagnostics (EOD)

Seed lasers

Laser master osc

Laser 1 and 2:

Wavelength: 1554

Pulse energy: 0.7

Rep. rate: 216 MH

Pulse length: 200

Laser 3:

Wave

Pulse

Rep.

Pulse

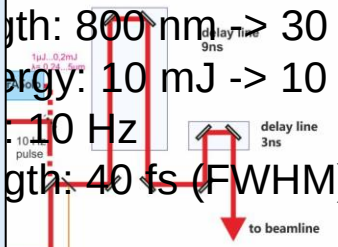
ump-probe lasers

gth: 800 nm -> 30 nm

ergy: 10 mJ -> 10 nJ

10 Hz

gth: 40 fs (FWHM)



FEL Radiation Parameters 2014

Wavelength range (fundamental)	4.2 – 45 nm
Average single pulse energy	10 – 500 µJ
Pulse duration (FWHM)	<50 – 200 fs
Peak power (from av.)	1 – 3 GW
Spectral width (FWHM)	~ 0.7 – 2 %
bunch charge	0.08 – 1 nC

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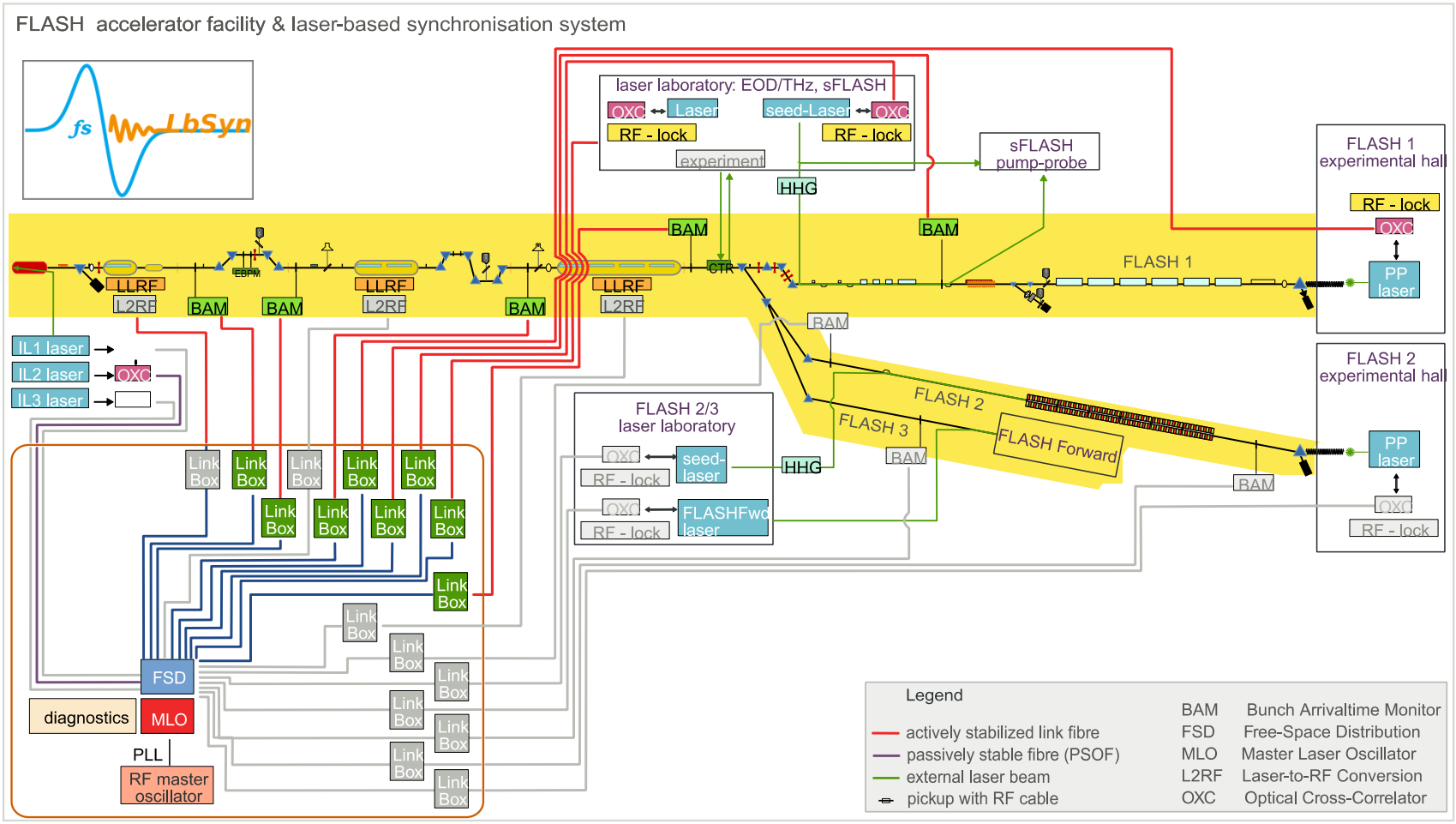
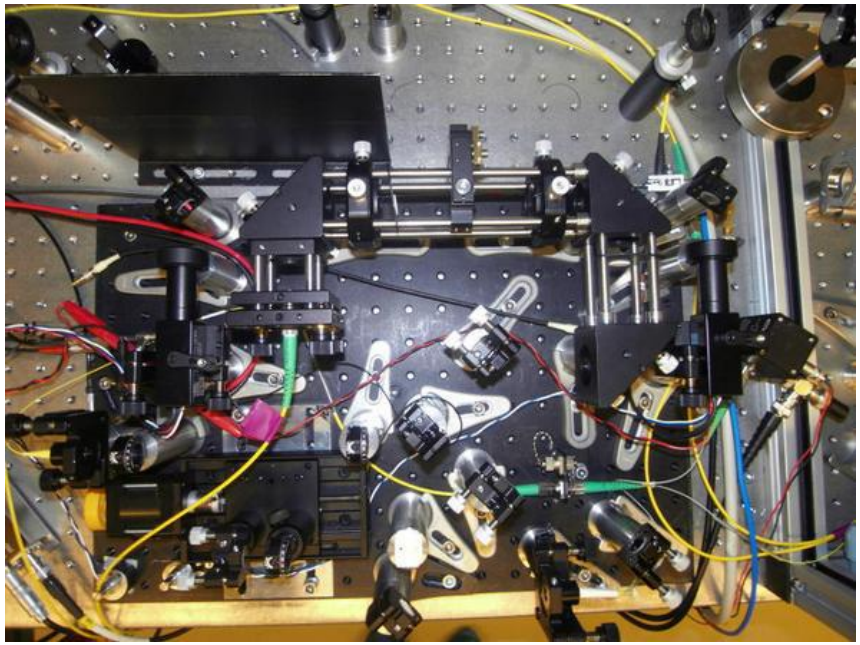
Laser based synchronization system for FLASH and XFEL

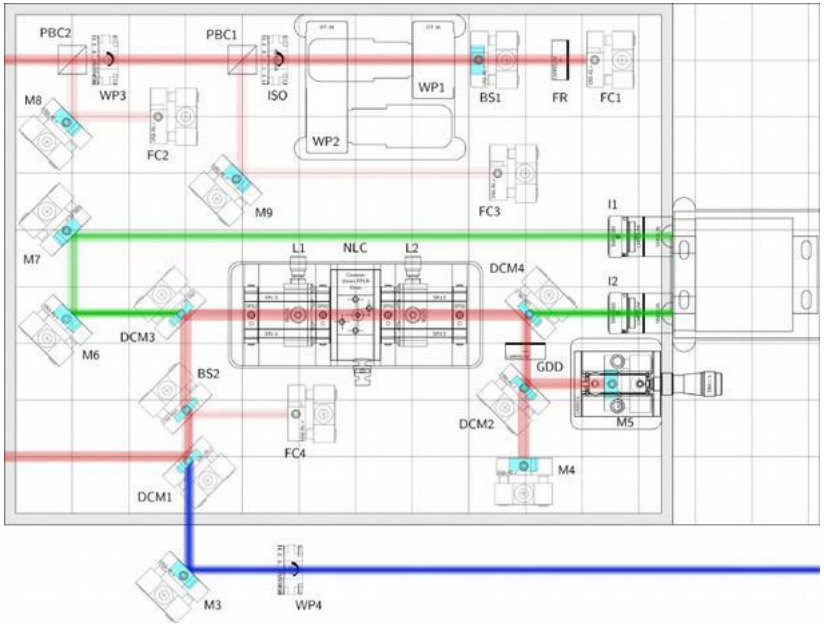


A synchronization system based on the distribution laser pulses via length stabilized fiber links
repetition rate: 216MHz
wavelength: 1550nm

Courtesy: M.K. Czwalinna

LbSyn: Laser to Laser locking

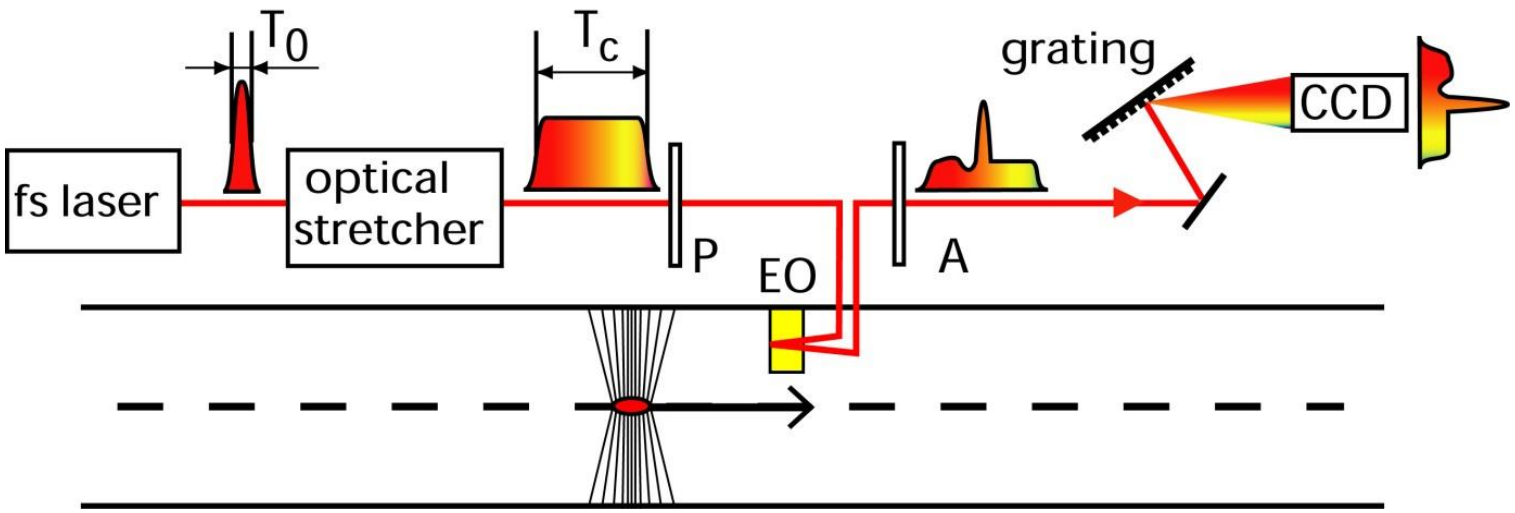




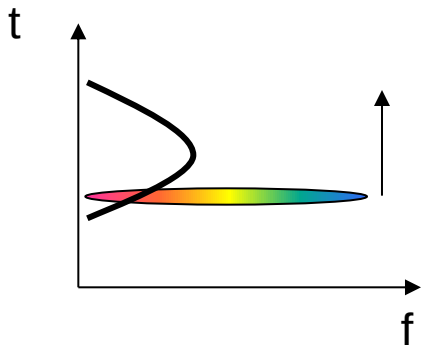
- Balanced optical cross-correlator for pulses of different wavelength and duration
- Last resort of breadboard usage, new design in preparation
  - Standardized design and robust operation for all wavelengths
  - Mounting options for different crystals
  - Space usage reduced to 25cm x 55cm, plus electronics

Courtesy: J. Müller

Electro-optical bunch length detection – Principle

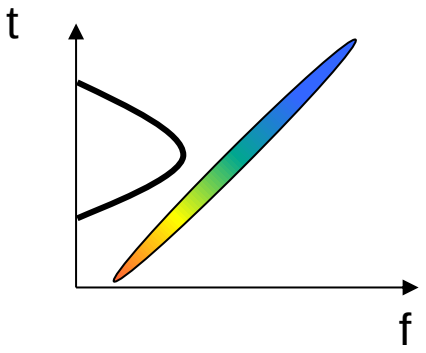


Sampling with laser pulse:



→ Sample electron bunch with many laser pulses

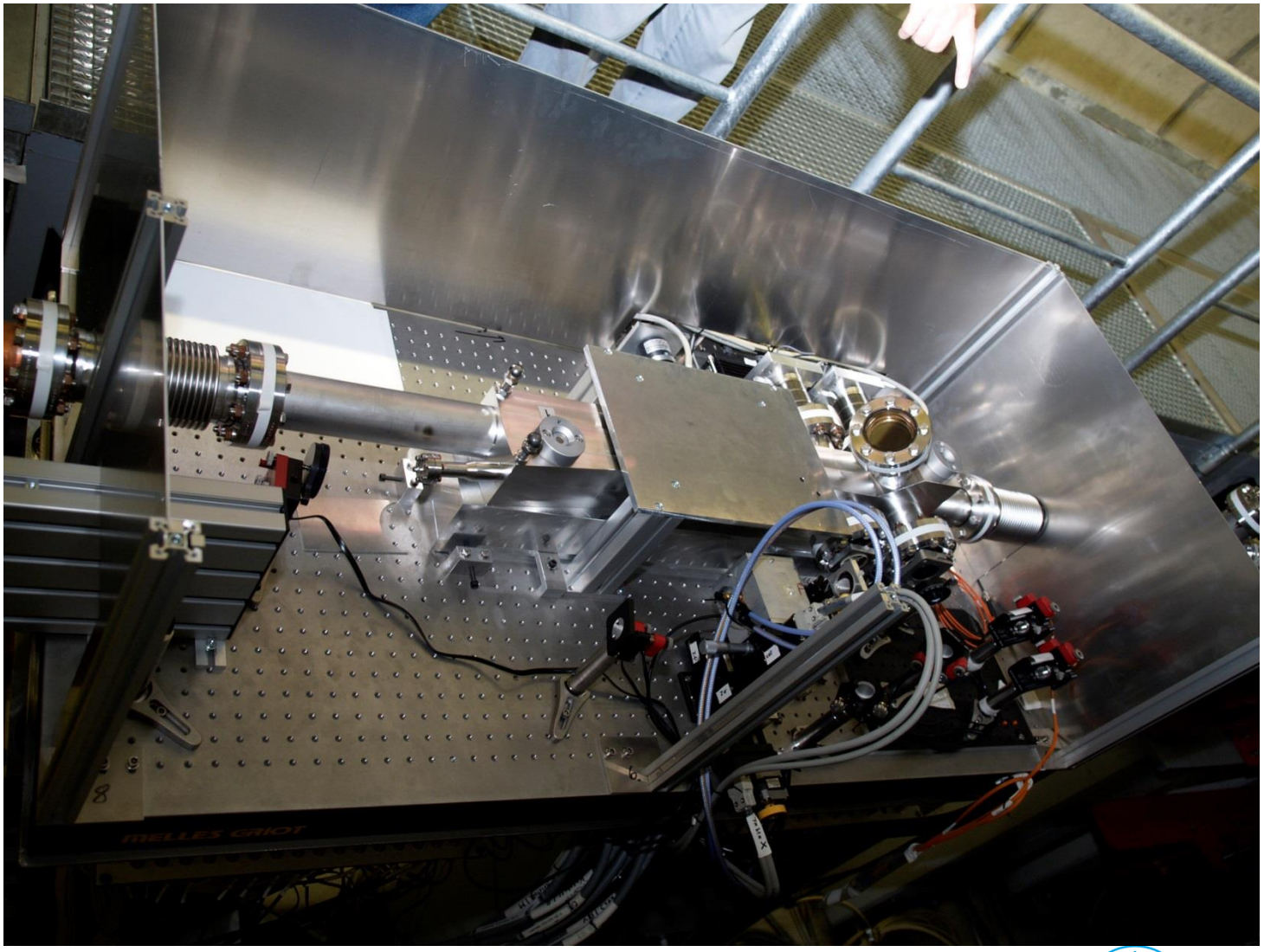
Chirped laser pulse:



→ Defined relation between time and frequency

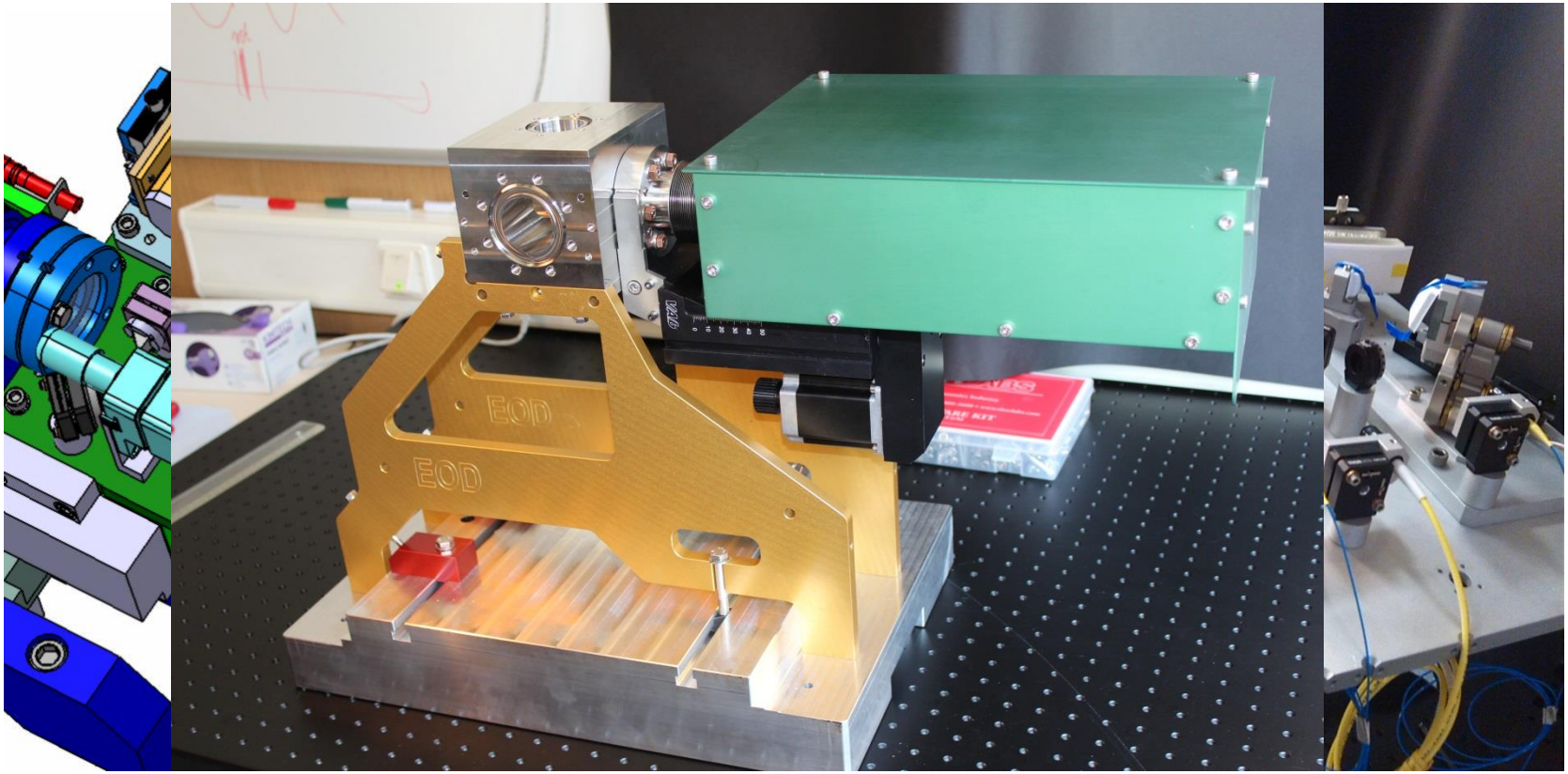
Electro-optical bunch length detection – setup

EOD signal at FLASH from an experimental setup (2004) with a Ti:Sa laser



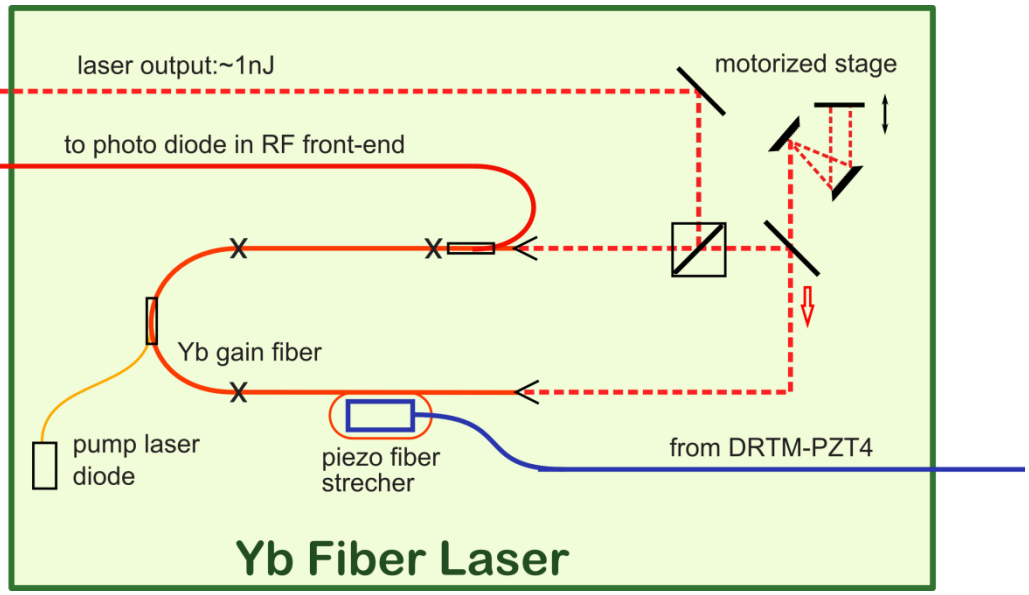
GaP
d = 175 µm
λ = 800 nm
θ = 2°
T_0 = 15 fs
T_c = 3.6 ps

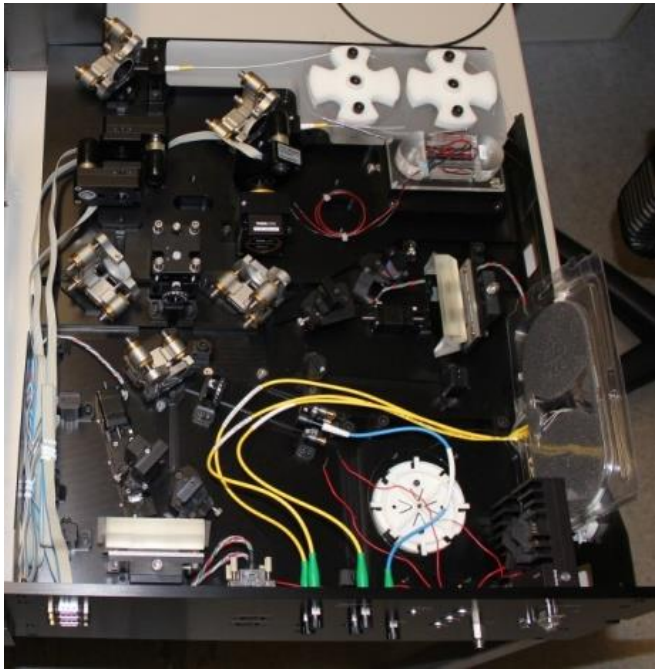
EOD Beamline Unit



EOD Beamline unit developed from DESY and PSI

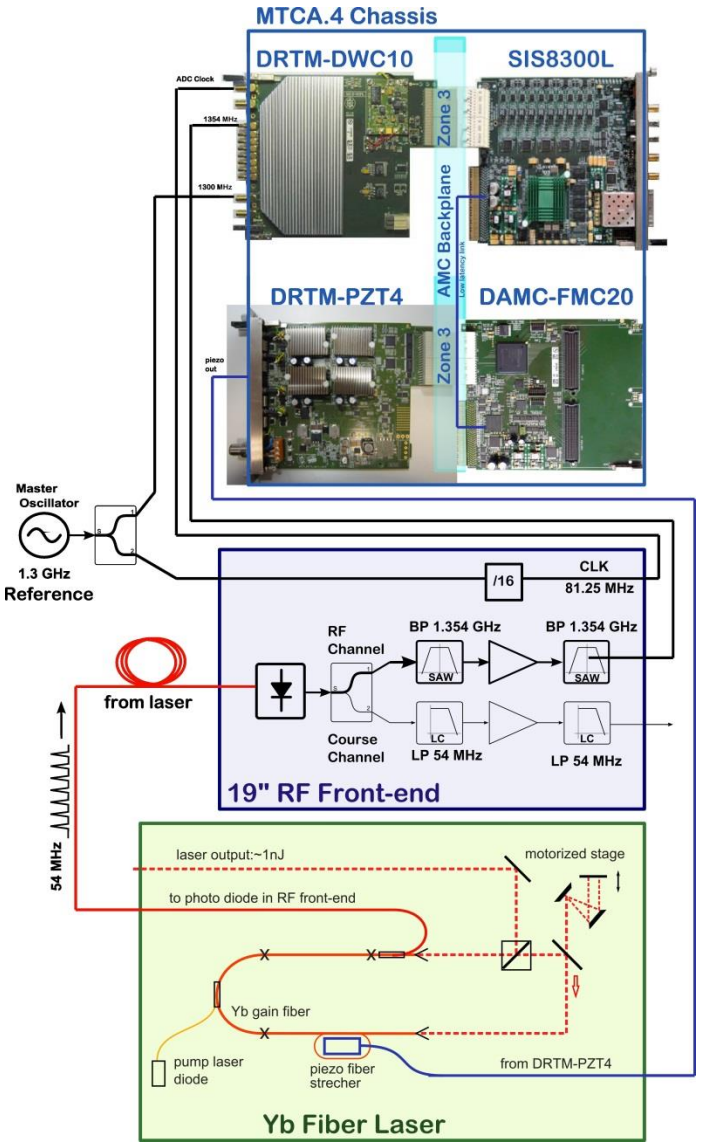
EOD Laser

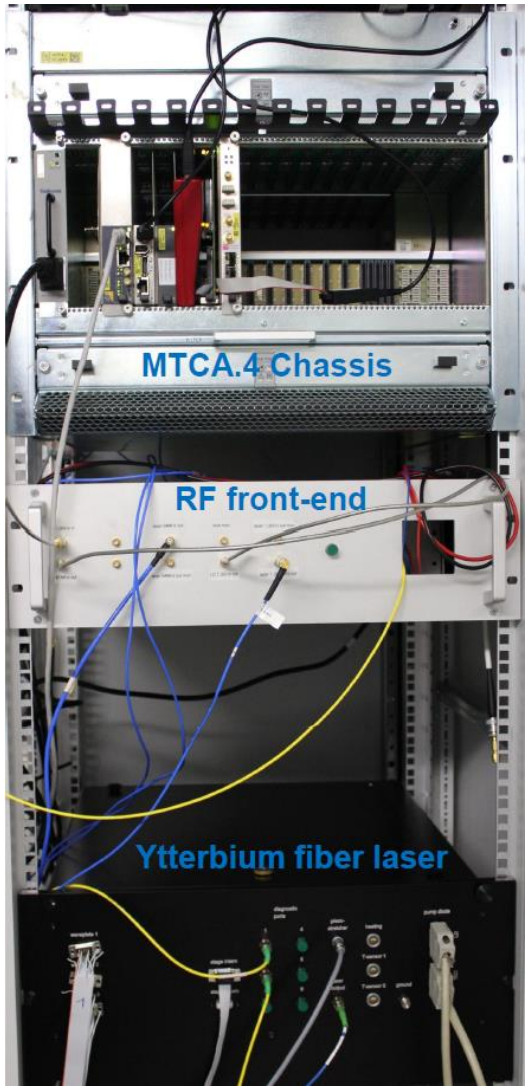




- Optimized laser for electro-optical bunch length measurement at XFEL
- Mode locked Yb fiber laser developed at PSI and assembled at DESY
- Specifications:
  - Wavelength: 1030nm
  - Bandwidth: 25-50nm (amplified: 100nm)
  - Pulse length: 5ps (compressible to <100fs)
  - Pulse energy: 1-2nJ (amplified: 100nJ)
  - Repetition rate: 54MHz (amplified: 1MHz / 4.5MHz)
  - Temperature stabilized to 0.1°C

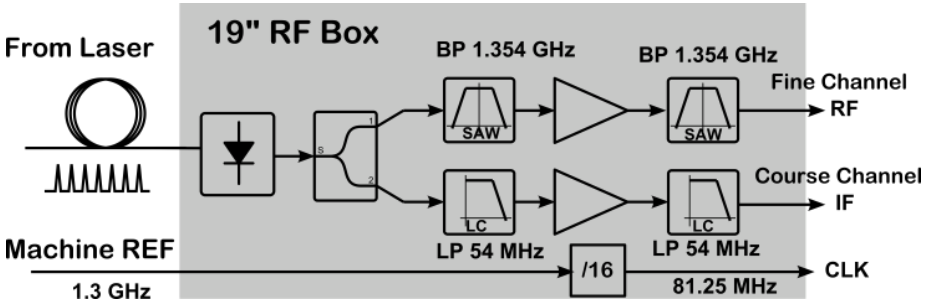
MTCA.4 based laser synchronization



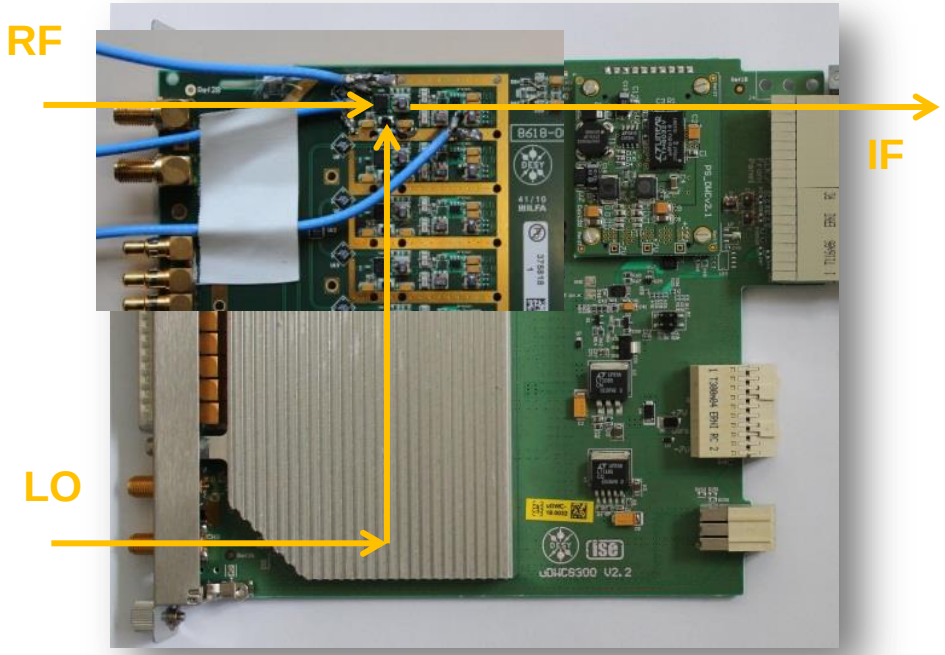


More information on MTCA.4: http://mtca.desy.de

RF Generation and Detection



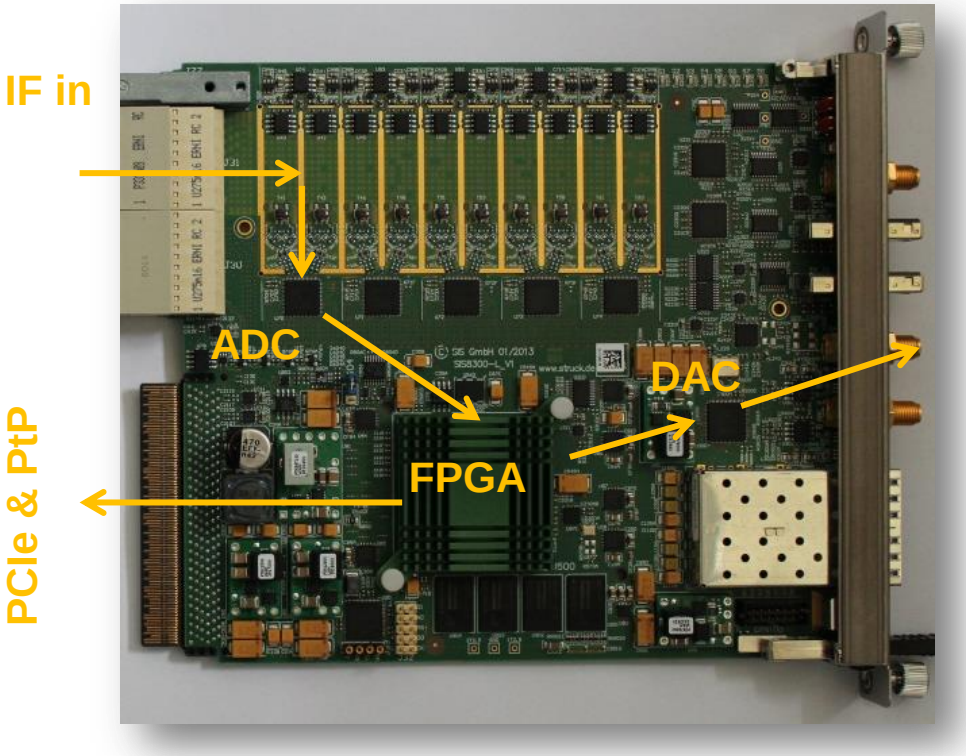
DRTM-DWC10 (DESY in-house development)



- RF generation Box (19”) to generate sinusoidal RF signals from laser pulses
- 10 channel high-frequency down-conversion from 1GHz – 4GHz
- Merge 19” RF box and down-converter board to a single RTM unit

Digitizing and Signal Processing

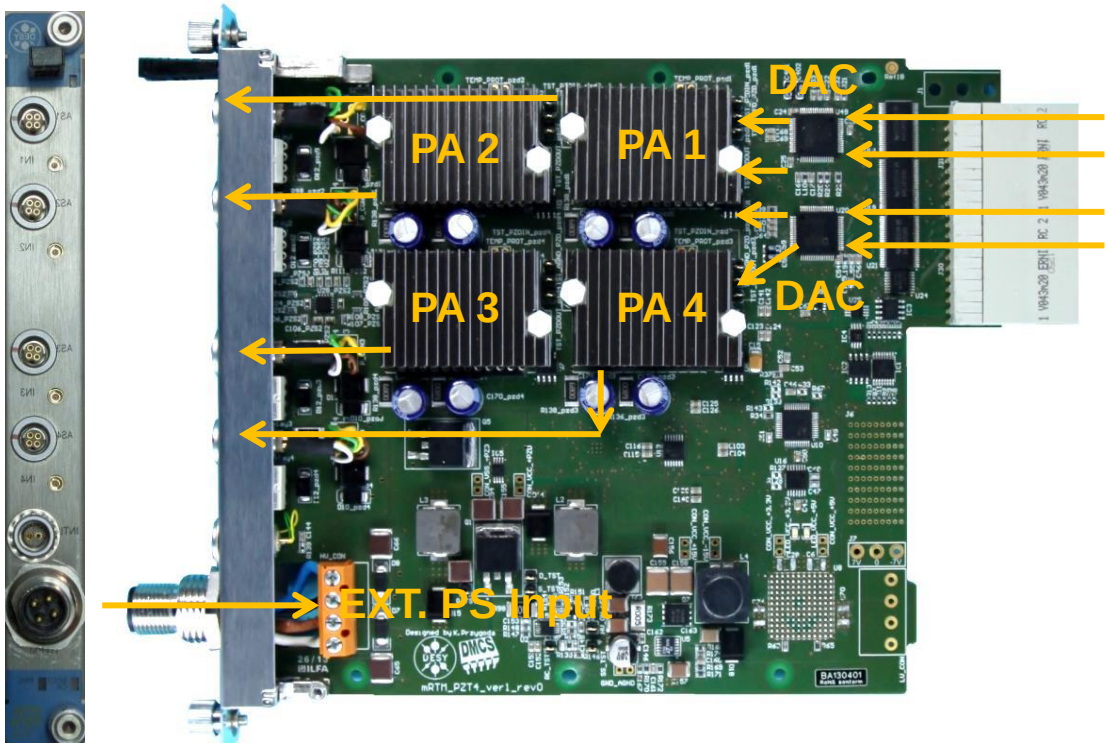
SIS8300-L (struck innovative system)



- 10 channel, 16 bit digitizer (AC or DC coupled) – low noise design
- 10 MS/s to 125 MS/s
- Virtex 6 FPGA
- Two 16bit DACs

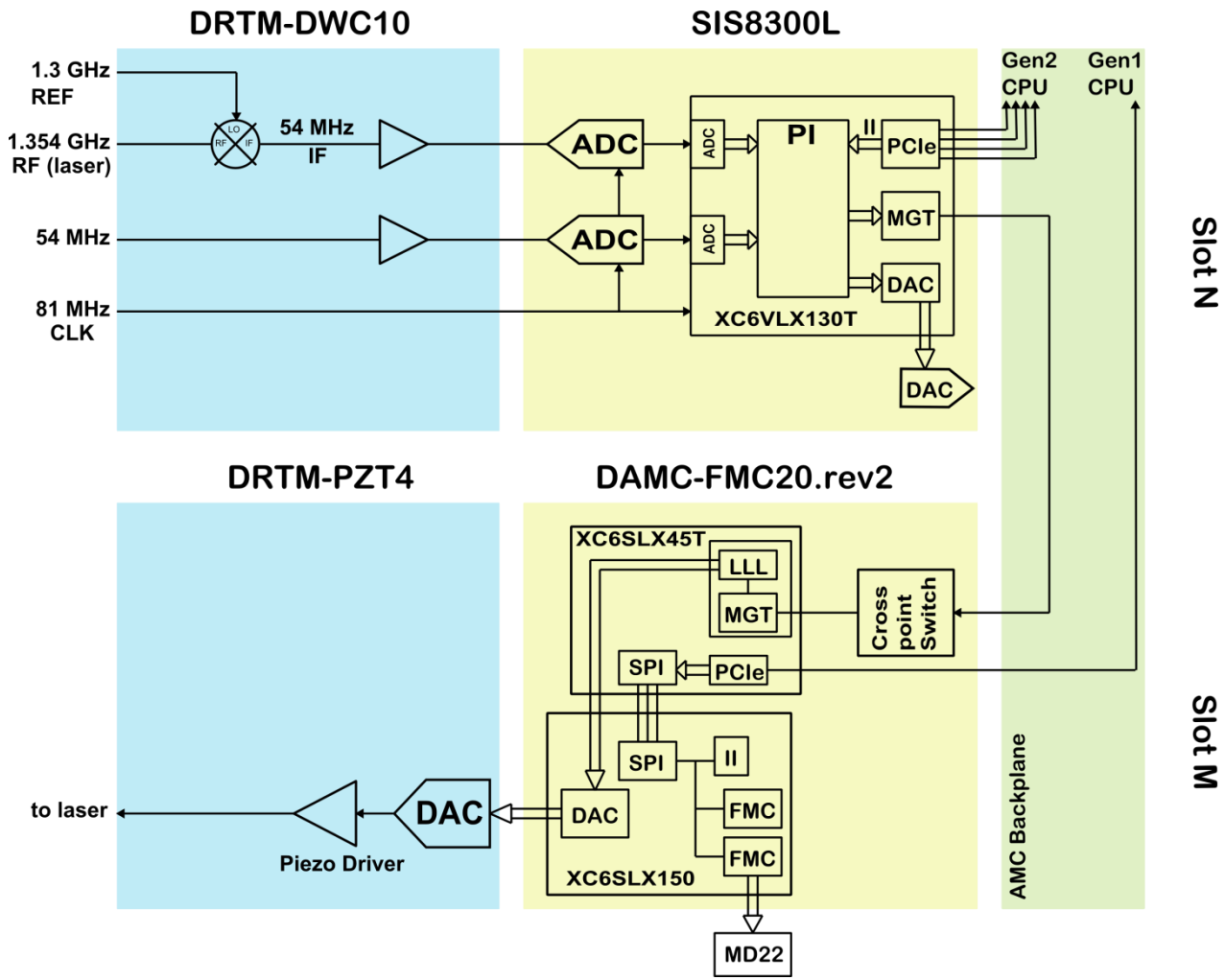
MTCA.4 4-Channel Piezo Driver

DRTM-PZT4 (DESY in-house development)



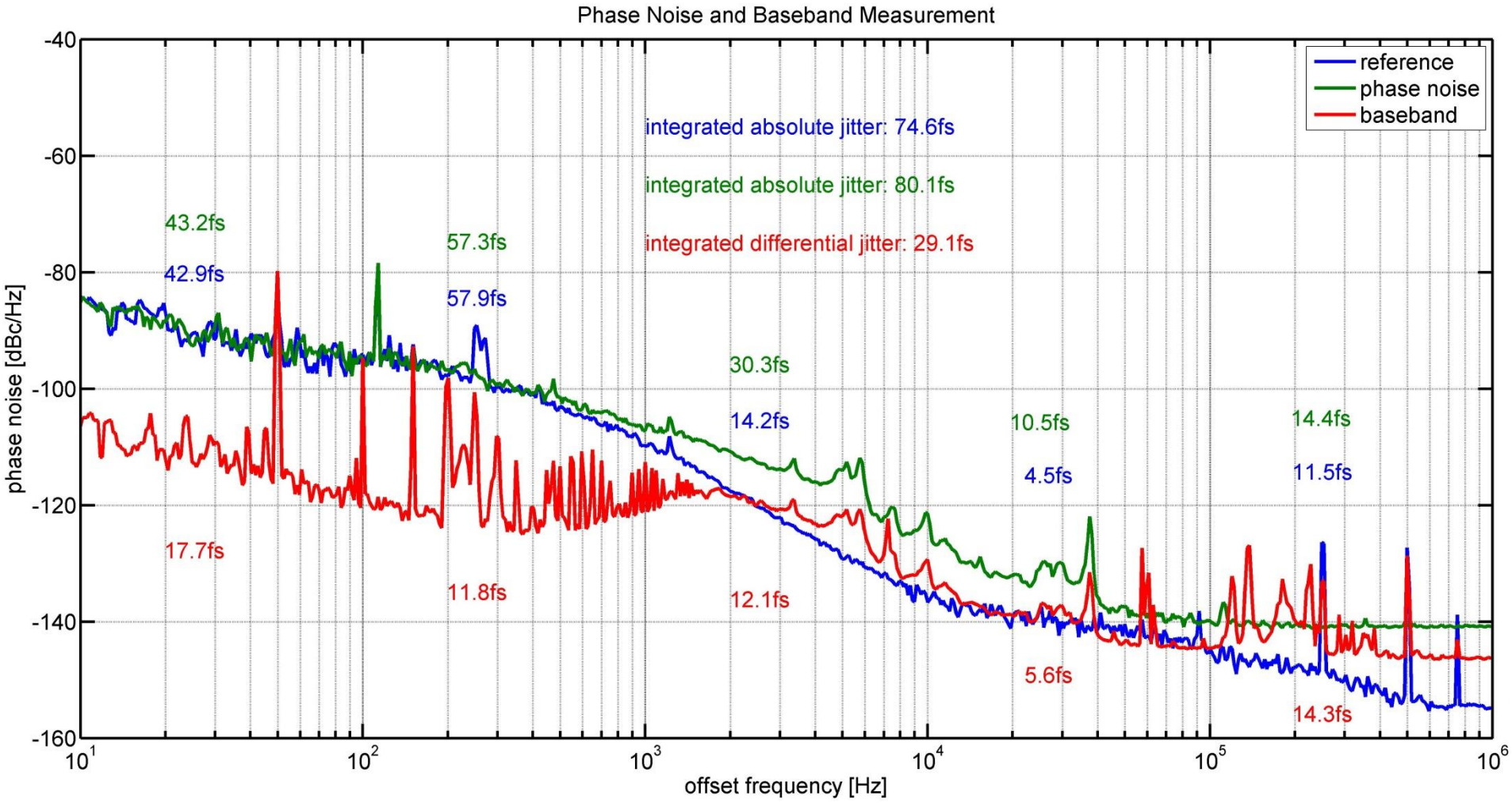
- 4 power amplifier with 0-100V, -85V/+85V
- DAC outputs +/-5V, +/-10V, 0/5V, 0/10V
- Each power amplifier can drive up to 10uF capacitance.
- Applications:
  - Cavity fine tuning
  - Laser to RF synchronization
  - Link Stabilization

Block diagram of Signal Processing

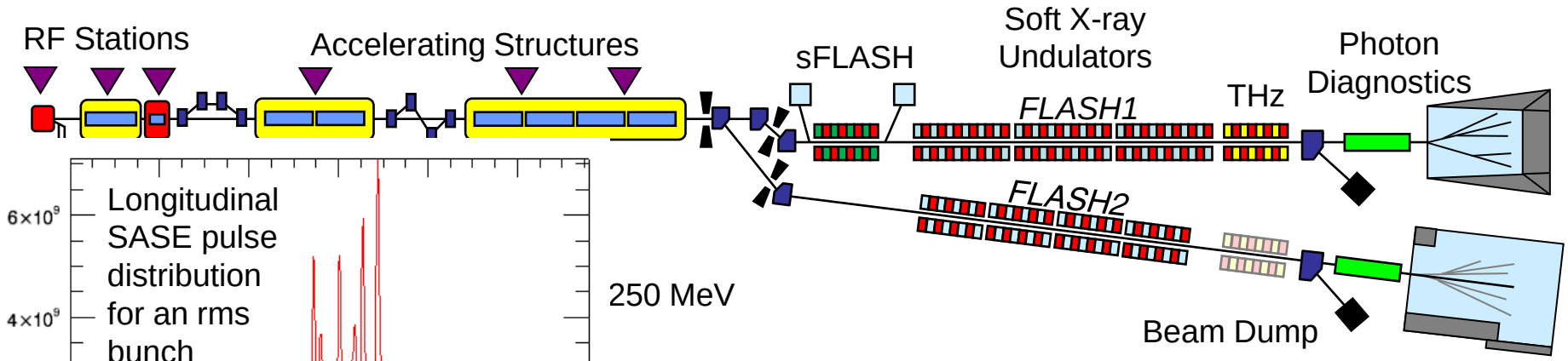


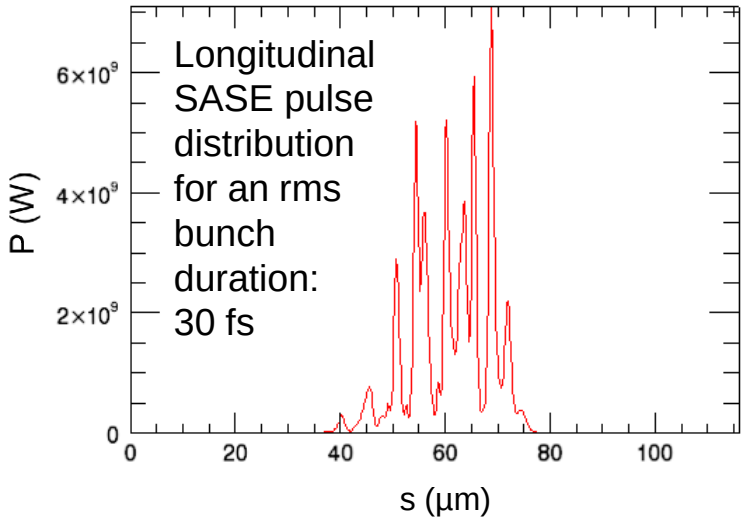
- PI: PI controller
- PCIe: Peripheral Component Interconnect express
- MGT: Multi-gigabit transceiver
- LLL: Low Latency Link
- SPI: Serial Peripheral Interface

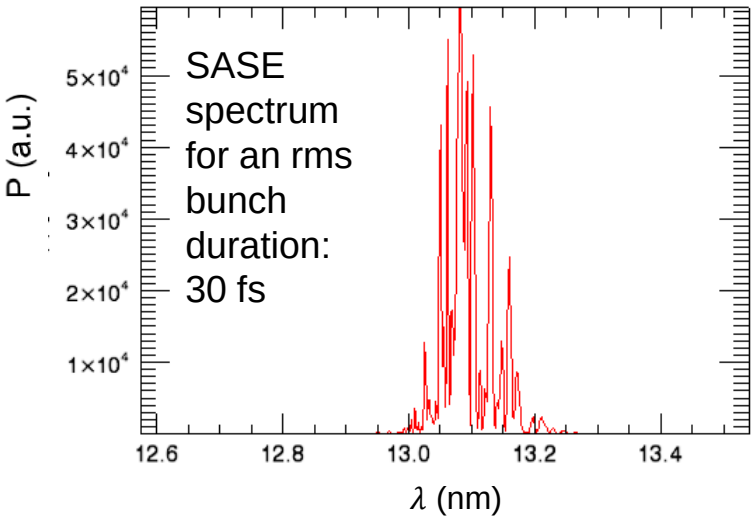
Phase Noise and Baseband Noise



Short pulse photo-injector laser at FLASH







FEL Radiation Parameters 2014

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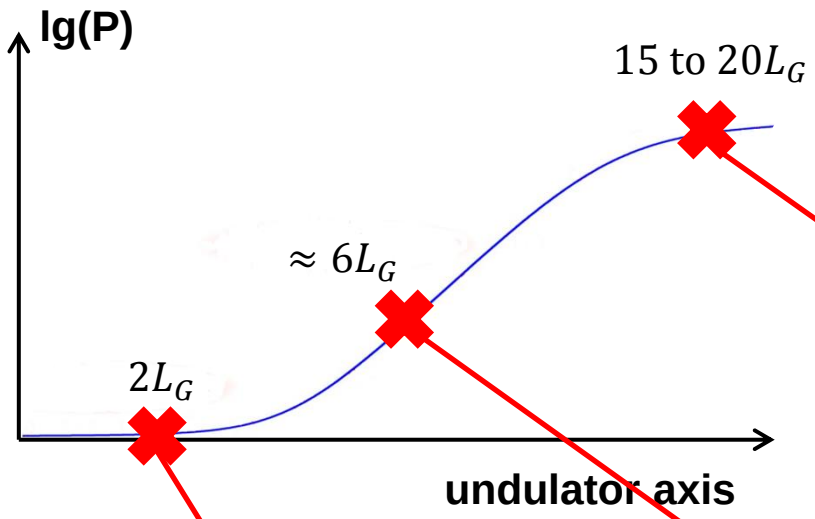
Short pulse operation of FLASH



number of modes in radiation pulse:

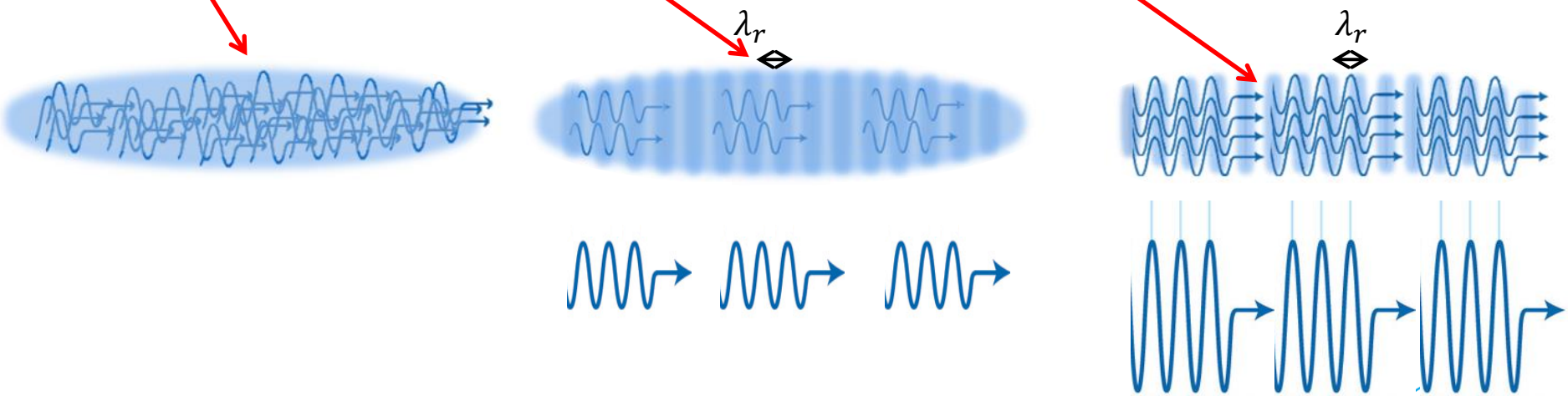
$$M = \frac{\sigma_z}{2\pi * L_{coop}}$$

cooperation length: $L_{coop} = \frac{\lambda_r}{\lambda_u} * L_G$

power gain length: L_G

FEL radiation wavelength: λ_r

undulator periode: λ_u



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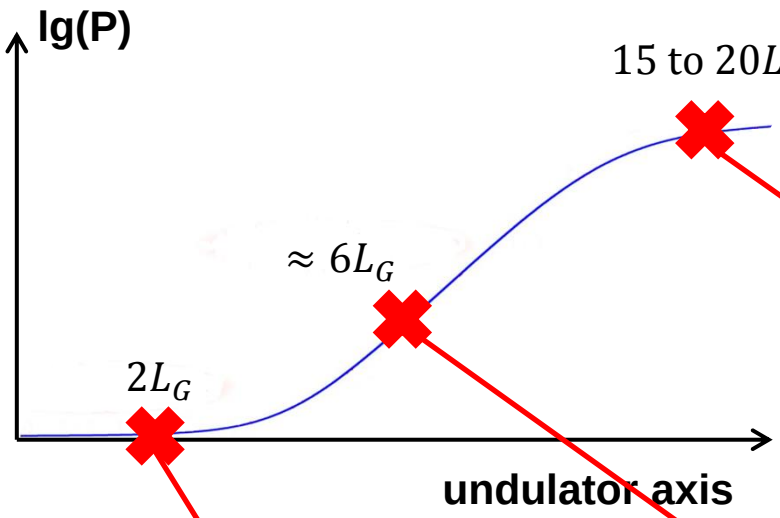
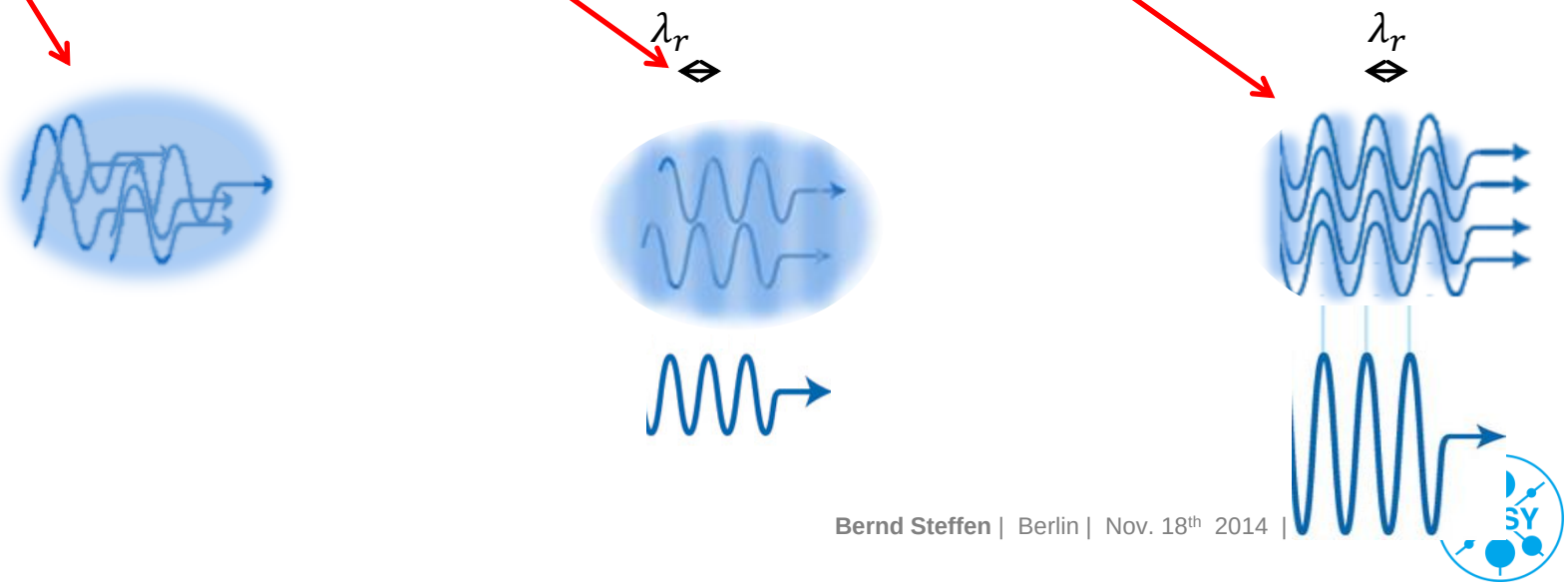


$$M = \frac{\sigma_z}{2\pi * L_{coop}}$$

$$M = 1 \Rightarrow \sigma_z = 2\pi * L_{coop}$$

coherence time measurents at FLASH:

- τ_c=(2.9±0.5)fs at 8 nm [S. Roling et al., PRSTAB **14**, 080701 (2011)]
- τ_c=(1.75±0.01)fs at 8 nm [A. Singer et al., Opt. Express **16**, 19909 (2008))]



Short pulse operation of FLASH

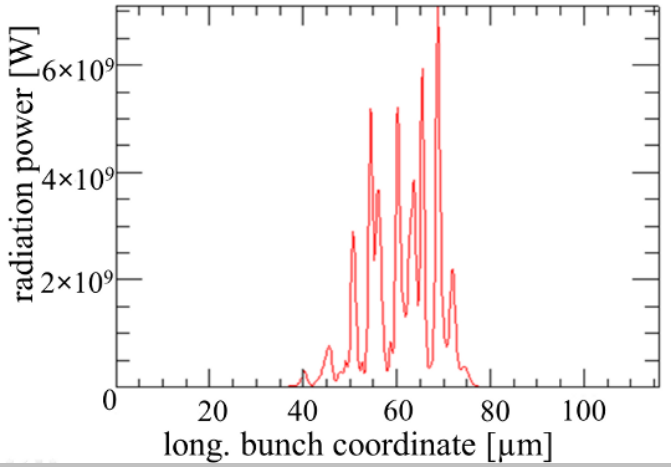
GENESIS 1.3 Simulation

e^- bunch length (Gaussian, rms)

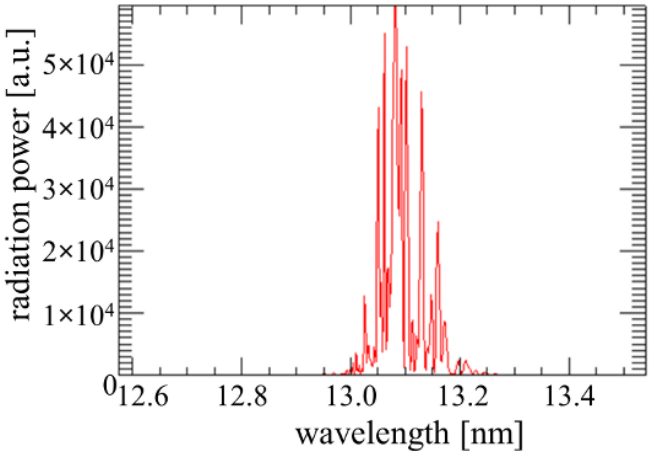
10 µm (30 fs)
200 pC

standard short pulse operation

Long. distribution of FEL pulse



FEL pulse spectrum



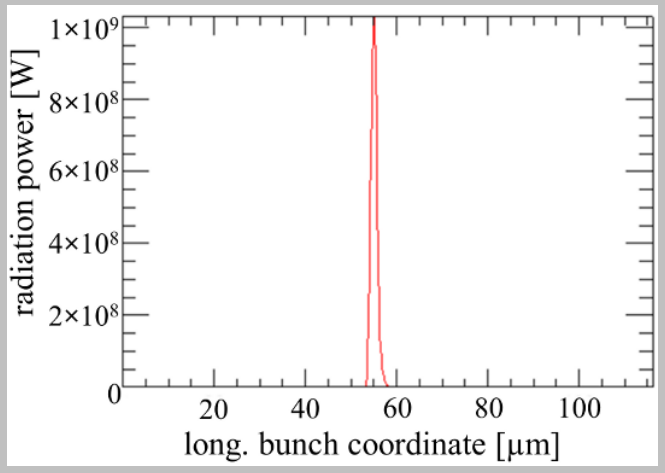
1 µm (3 fs)
20 pC

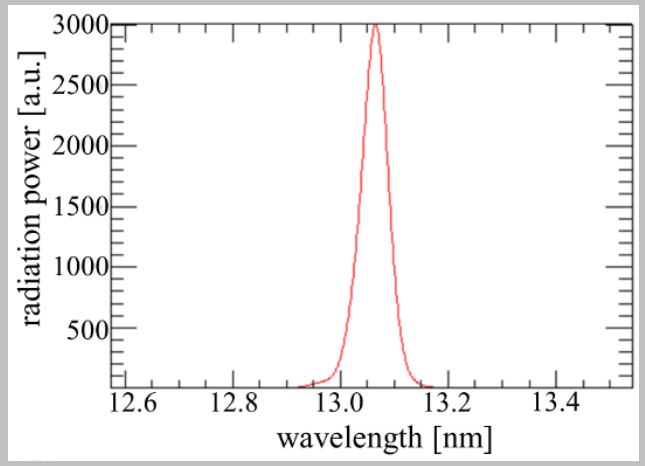
Our final goal:

Single Spike condition:

$\sigma_b \leq 2\pi L_c$

R. Bonifacio et al., PRL 73 (1994) 70





DESY

Short pulse operation of FLASH

	Typ. FLASH parameters	Single spike operation at FLASH	Single spike operation at FLASH
Injector laser pulse duration (FWHM)	15.3 ps	15.3 ps	1-3 ps
Bunch charge	0.08 - 1 nC	20 pC	20 pC
Bunch duration (rms)	30 - 200 fs	3 fs	3 fs
compression	220 - 32.5	**2200**	**140-430**
FEL pulse duration (FWHM)	30 - 200 fs	3 fs	3 fs

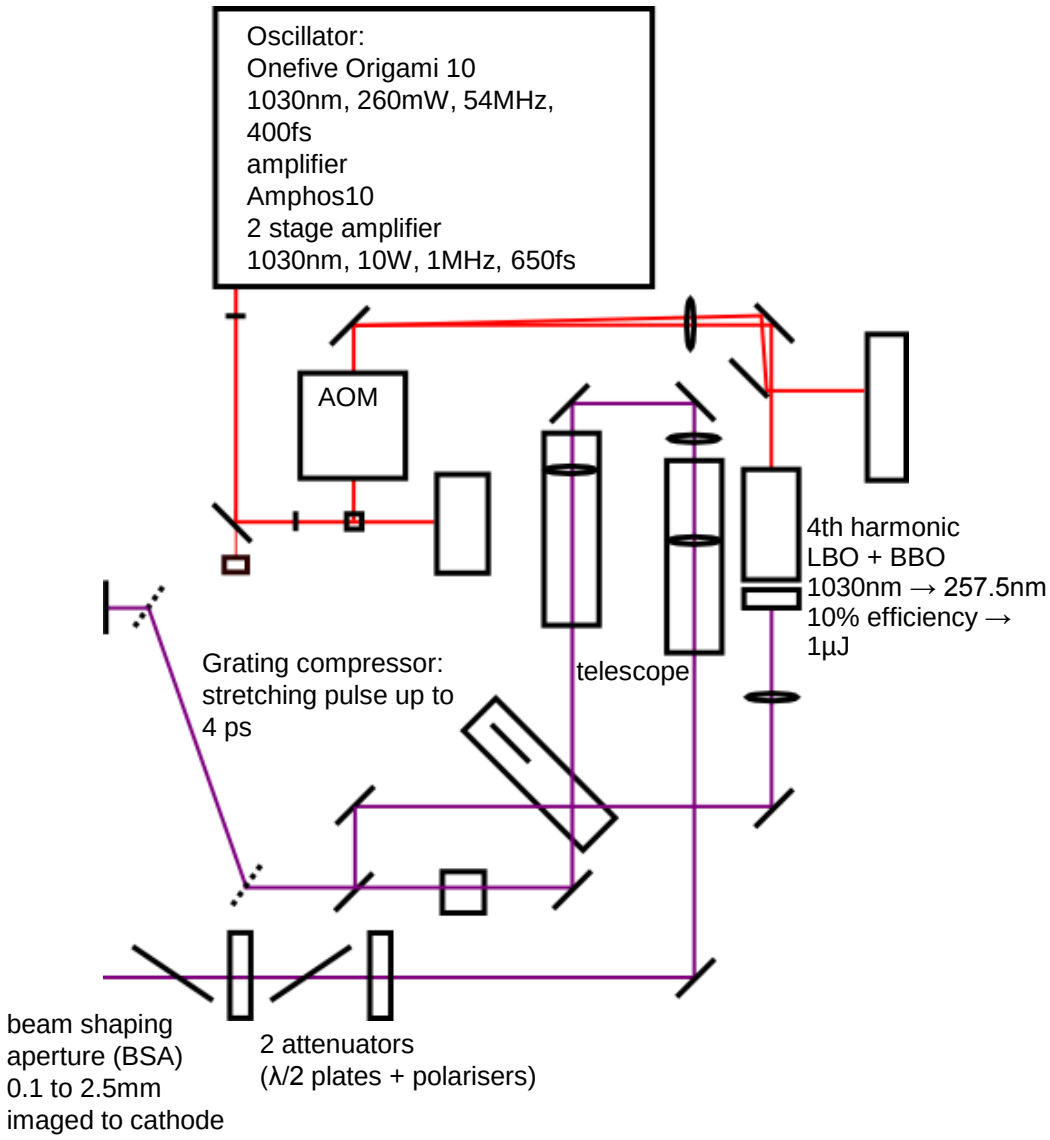
- Advantages of low charge operation:
  - Less sensitive to collective effects (space charge, CSR, etc.)
  - Shorter bunches, reduction of RF curvature
  - Less variation of beam parameters along the bunch

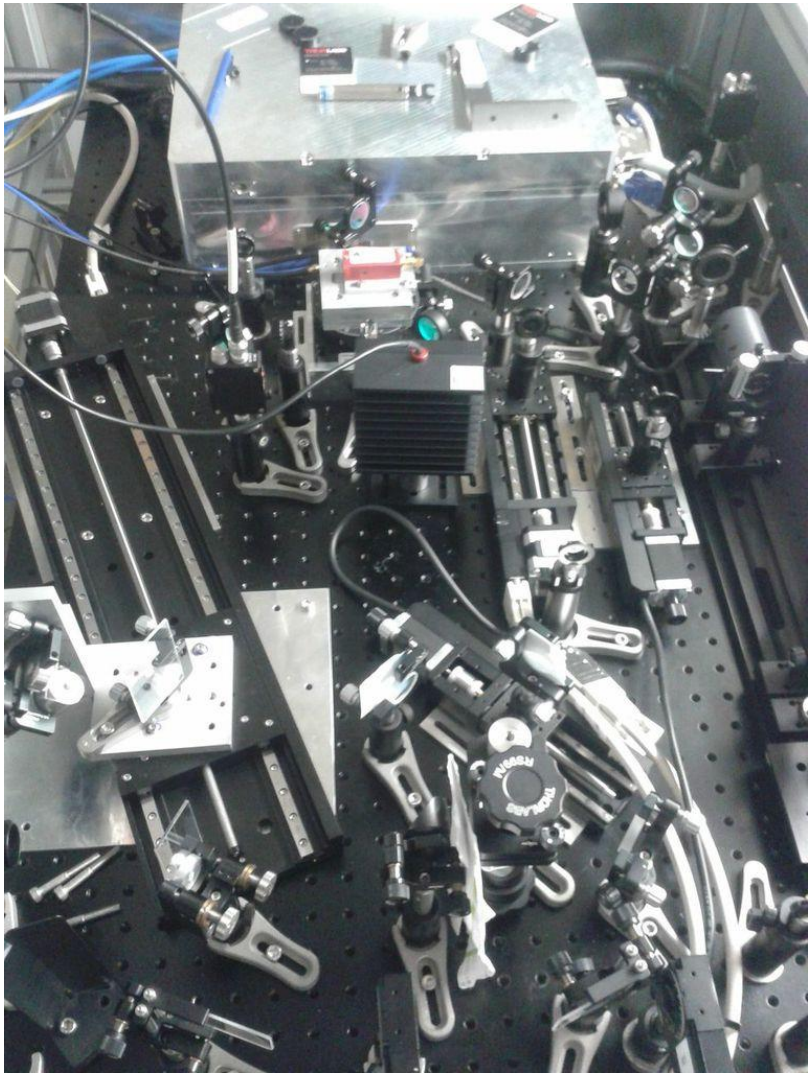
The short pulse laser system

Amplified Laser System:

- Seed laser Origami 10 (OneFive)
  - 1030nm, 260mW, 54MHz, 400fs
- 2 stage Yb:YAG amplifier (Amphos)
  - 1030nm, 10W, 1MHz, 800fs (10µJ)
- AOM pulse picker (1MHz to 10Hz trains)
- LBO/BBO forth harmonic stage
  - 1030nm -> 257.5nm
  - (10% efficiency @ 10µJ) -> 1µJ
- Stretcher to increase pulse length

The short pulse laser system

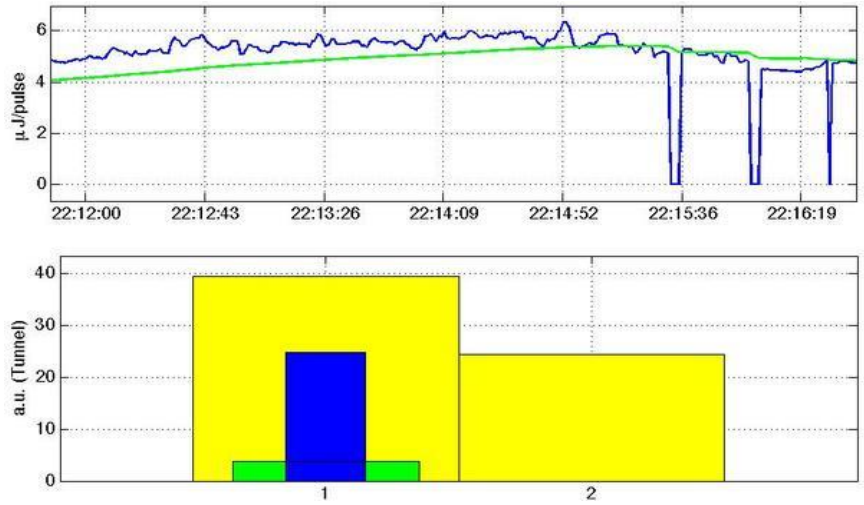


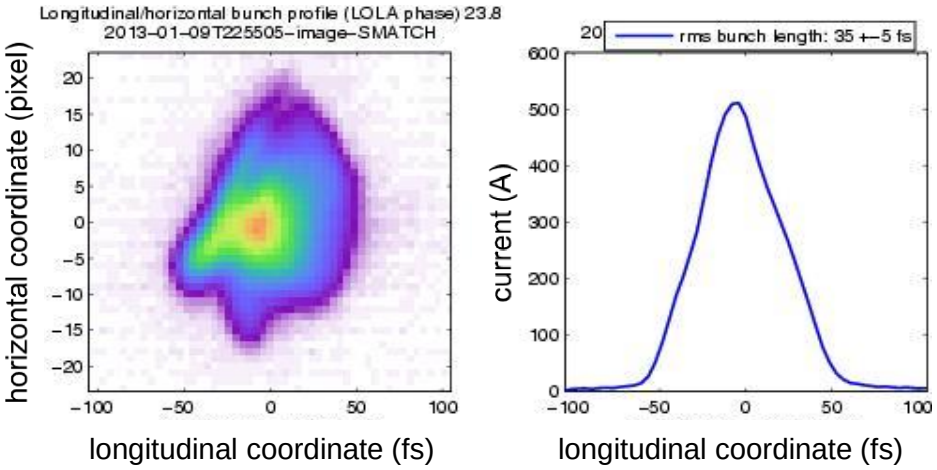


Short pulse operation of FLASH

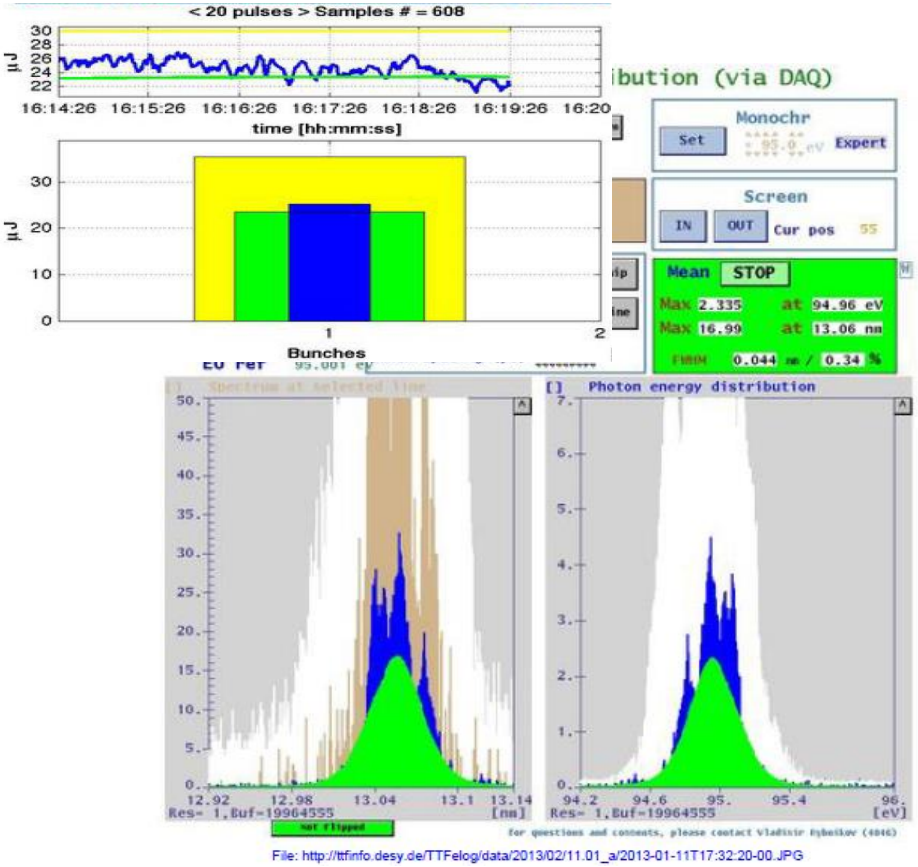
First SASE with short pulse injector laser:

- 9th & 11th of January 2013
- 5 µJ at 13.5 nm, bunch charge 35 pC





- 25 µJ at 13 nm, charge 80 pC
  Narrow bandwidth (0.34 % in linear regime, 0.42% at saturation)



- Radiation pulse duration at full undulator length is estimated as 50 fs.
- rms bunch duration of lasing fraction of the electron beam: 40 fs.

Short pulse operation of FLASH

Measurement: May 2014

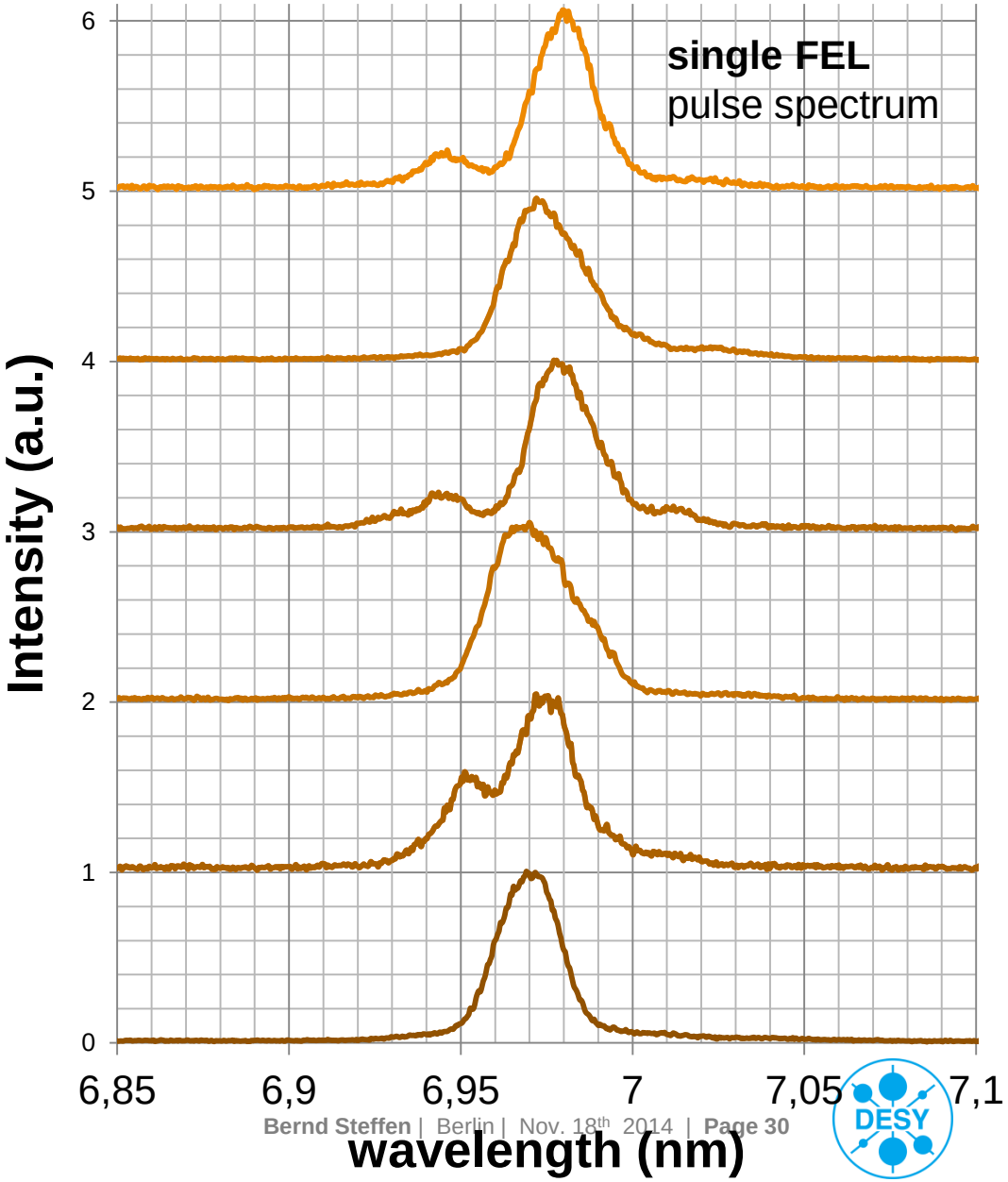
Bunch charge: 55 pC

laser pulse duration: 1 ps rms

Analysis of single FEL pulse spectrum:

- λ = 6.98 nm
- in average: 1.5 spikes within the FWHM

-> rms FEL pulse duration
> 10 fs



Short pulse operation of FLASH

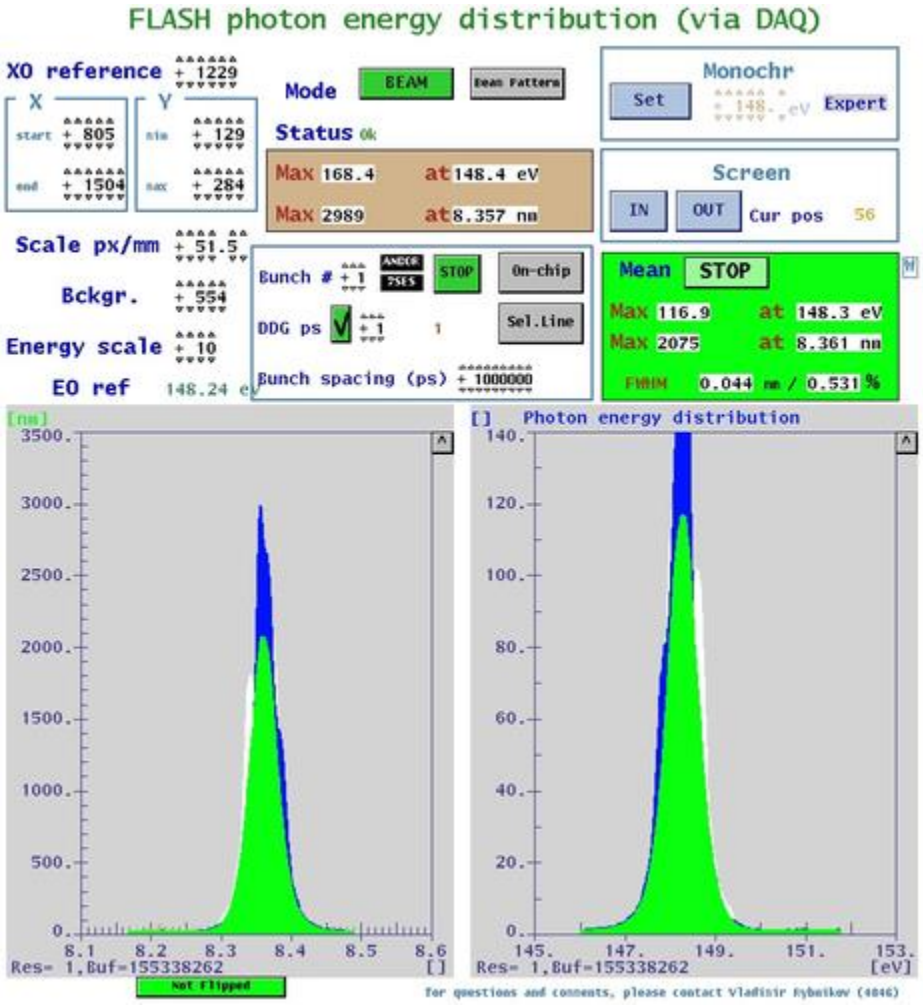
Measurement: September 2014

- after switching to Laser3 and adjusting its phase to Laser2 **immediately transmission and some SASE** were achieved without any tuning

- 13 µJ at 45 pC
- e-bunch duration: 40 fs FWHM

- spectrometer measurement:
  1.8 peaks,
  1.6 within the FWHM,
  10.7 fs (FWHM)

- **first (friendly) users served…**

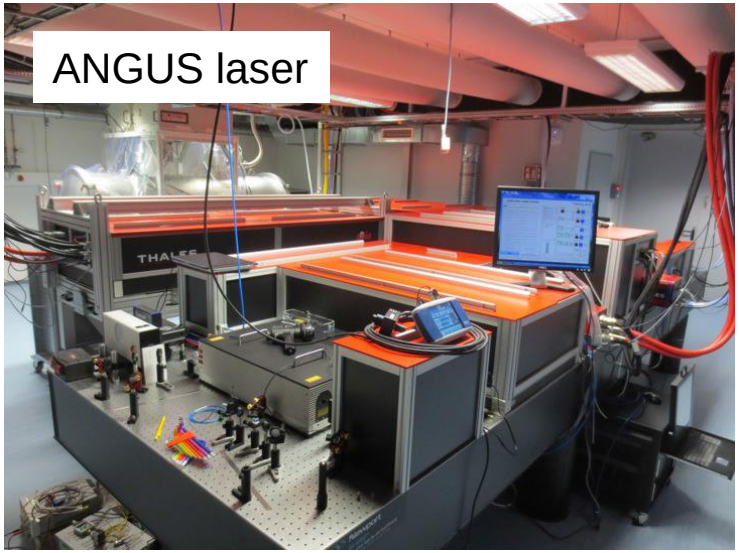


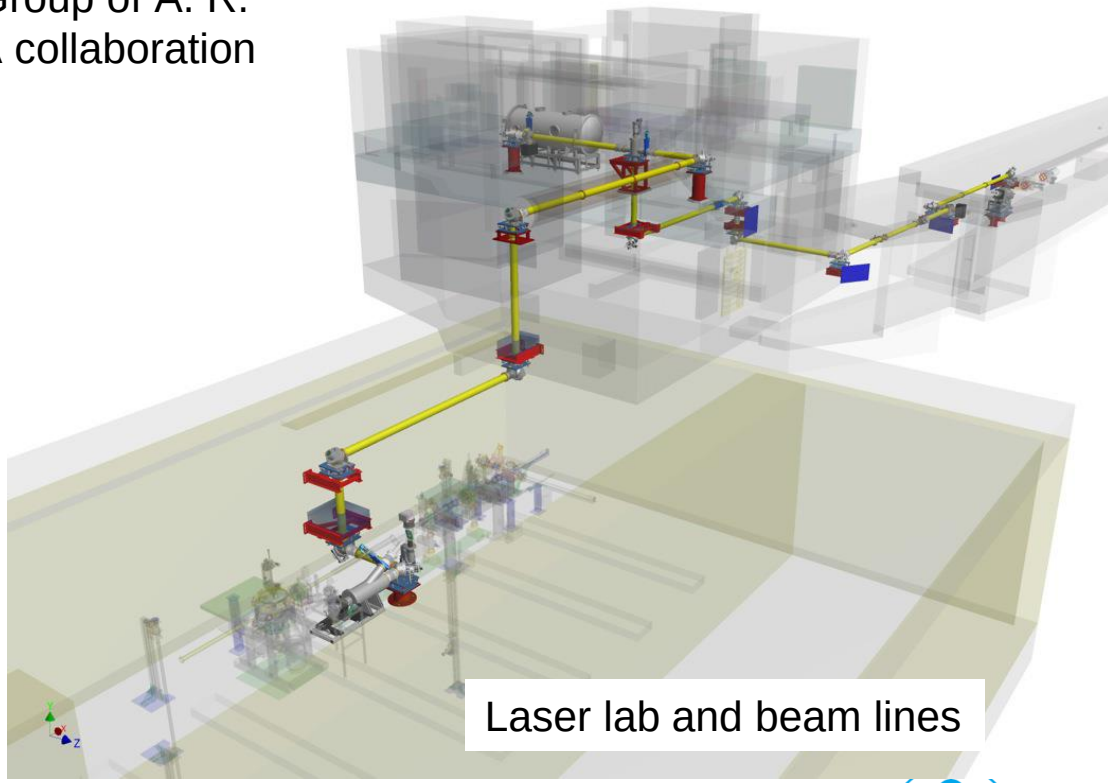
ANGUS - 200 TW laser system for laser-plasma acceleration

- ANGUS - 200 TW laser system for laser-plasma acceleration
- 5 J in 25 fs, 5 Hz rep-rate
- owned jointly by Hamburg University and DESY
- operated by LUX Junior Research Group of A. R. Maier (lux.cfel.de) within the LAOLA collaboration of Hamburg University and DESY

- goals:
  - availability & stability;
  - Integration into accelerator controls system

Courtesy: A.R. Maier





Conclusion

- DESY – academia, service provider and (a bit) industry, accelerator lab and laser lab
- Changing from high energy physics to photon science
- Growing demand of research with laser and on laser

> Thank you for your attention!