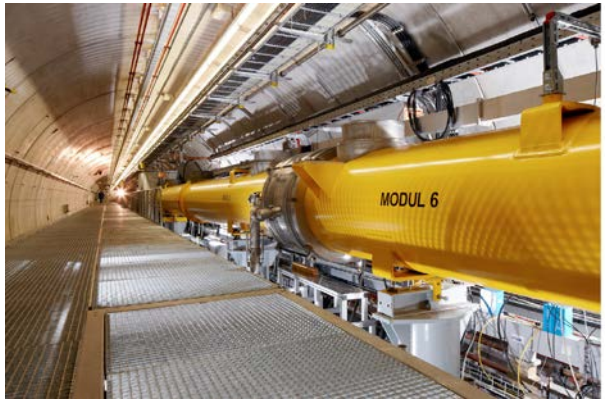
FLASH at DESY

FLASH.
Free-Electron Laser
in Hamburg

The first soft X-ray FEL operating two undulator beamlines simultaneously

Katja Honkavaara, DESY
for the FLASH team

FEL Conference 2014, Basel
25-29 August, 2014



HELMHOLTZ
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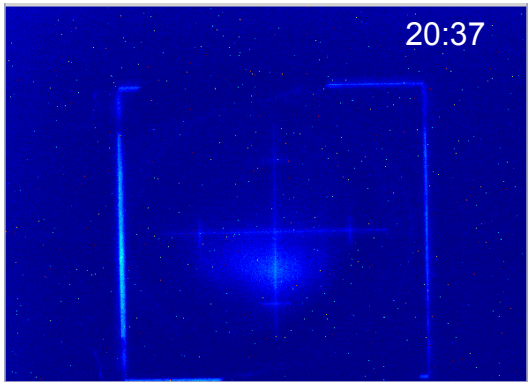
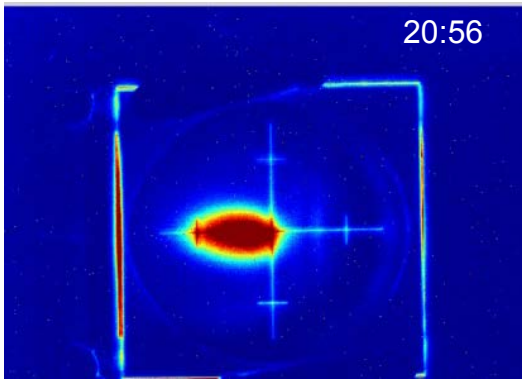
DESY

First Lasing FLASH2

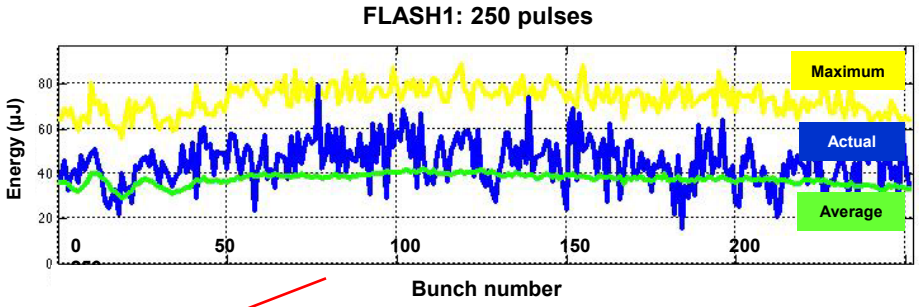
FLASH.
Free-Electron Laser in Hamburg

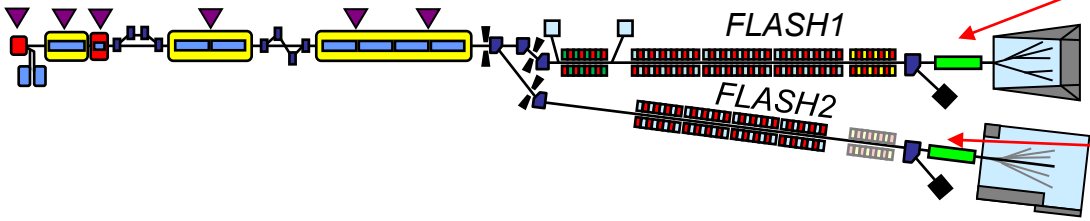
- First lasing FLASH2: August-20, 2014

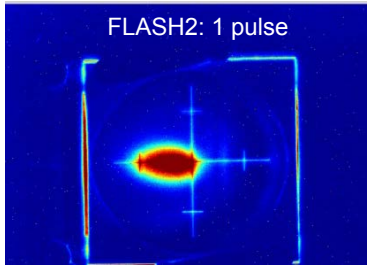




- FLASH1 lasing in parallel with 250 pulses



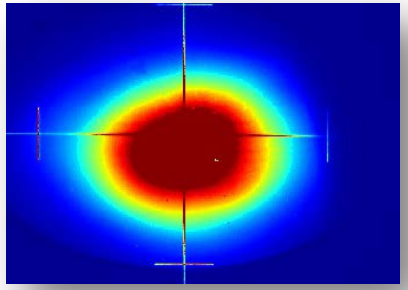




History

FLASH.
Free-Electron Laser in Hamburg

- TESLA Test Facility (TTF) Linac constructed at DESY in mid 1990's
  - to test experimentally high gradient superconducting accelerator technology in the framework of the TESLA linear collider project
  - to drive a pilot VUV SASE free-electron laser (TTF-FEL)
- TTF-FEL operated 2000-2002
  - wavelength range from 80 nm to 120 nm
- FLASH constructed 2003-2004
  - first lasing in January 2005 (32 nm)
  - user FEL facility since summer 2005, first user facility in VUV range worldwide
  - wavelength range from 13 nm to 47 nm



- Energy upgrades
  - summer 2007: Electron beam energy up to 1 GeV → photon wavelength down to 6.5 nm
  - 2009-2010: Electron beam energy up to 1.25 GeV → photon wavelength down to 4.1 nm
- Second undulator beamline (FLASH2) constructed 2011-2014
  - first lasing in August 2014

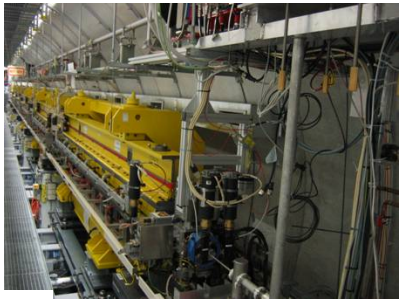
FLASH Layout 2014

FLASH.
Free-Electron Laser in Hamburg

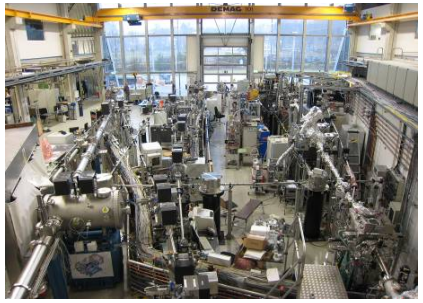
> 3rd harmonic sc module 3.9 GHz

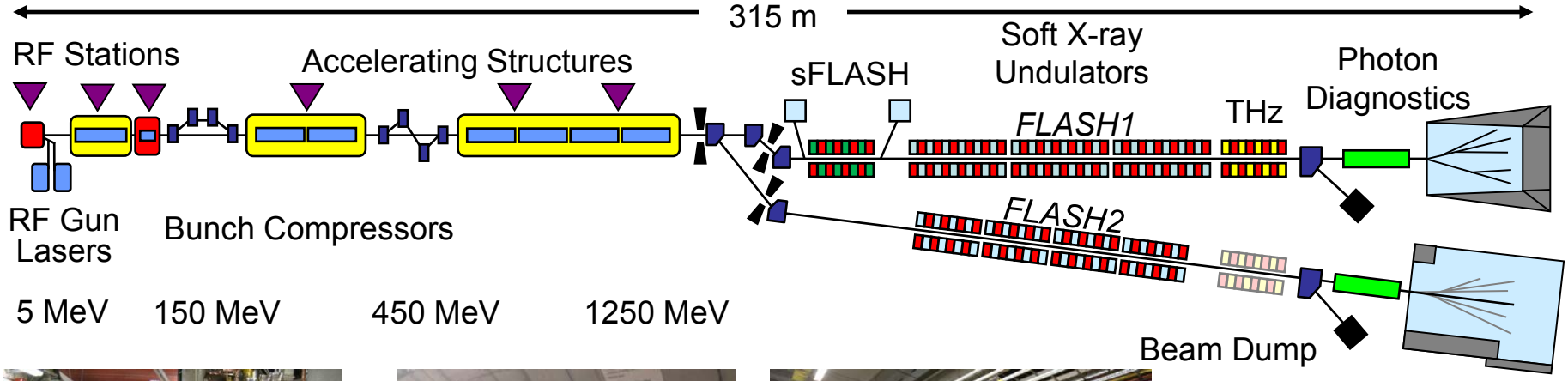
> TESLA type superconducting accelerating modules 1.3 GHz

> FLASH1 fixed gap undulators



> FLASH1 Experimental Hall





> Normal conducting 1.3 GHz RF gun
> Ce_2Te cathode
> Two Nd:YLF based ps photocathode lasers

> Extraction to FLASH2

> FLASH2 variable gap undulators

> FLASH2 Experimental Hall

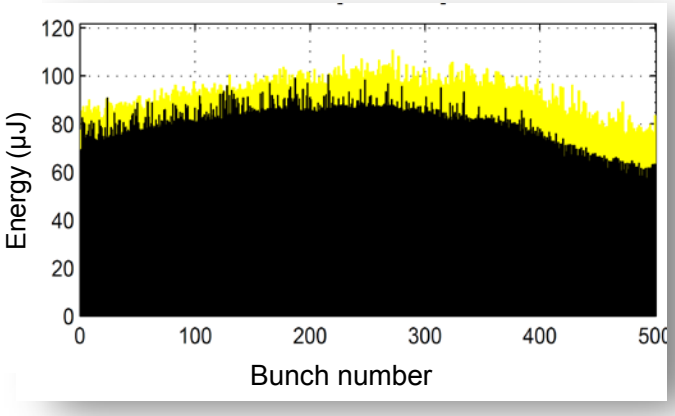
FLASH1 Parameters 2014

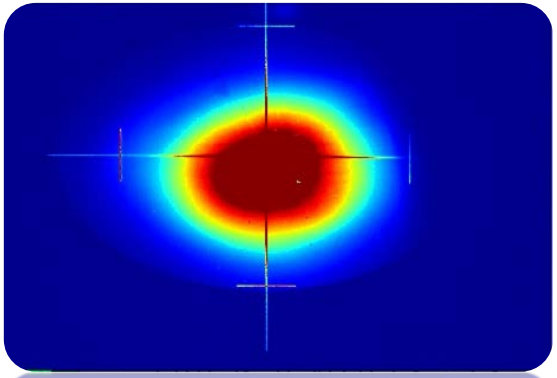
FLASH.
Free-Electron Laser in Hamburg

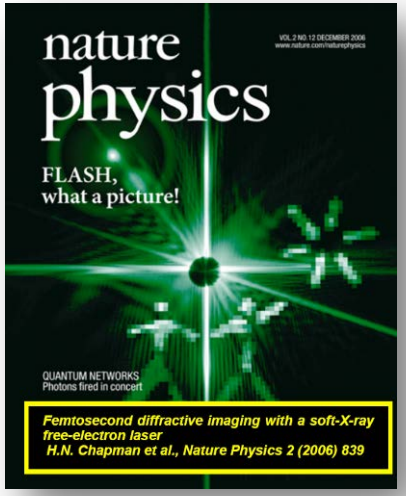
FEL Radiation Parameters

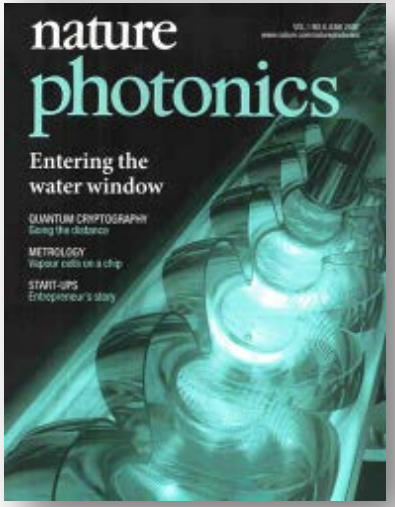
Wavelength range (fundamental)	4.2 – 45 nm
Average single pulse energy	10 – 500 µJ
Pulse duration (FWHM)	< 50 – 200 fs
Peak power (from av.)	1 – 3 GW
Pulses per second	10 – 5000
Spectral width (FWHM)	0.7 - 2 %
Photons per pulse	10^{11} – 10^{13}
Average Brilliance	10^{17} – 10^{21} B*
Peak Brilliance	10^{29} – 10^{31} B*

* photons/s/mrad^2/mm^2/0.1%bw







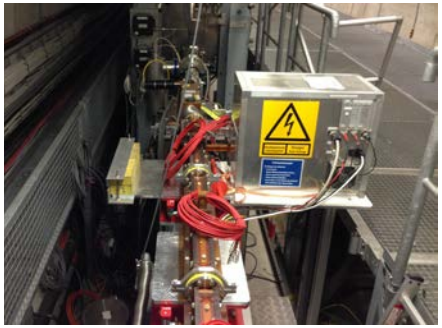


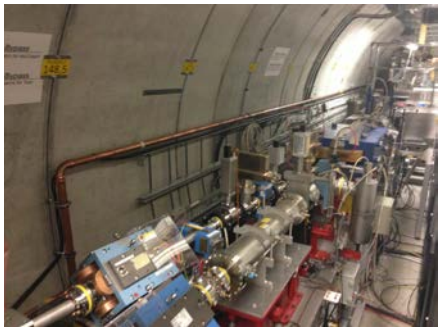
> more than 200 publications on photon science at FLASH, many in high impact journals

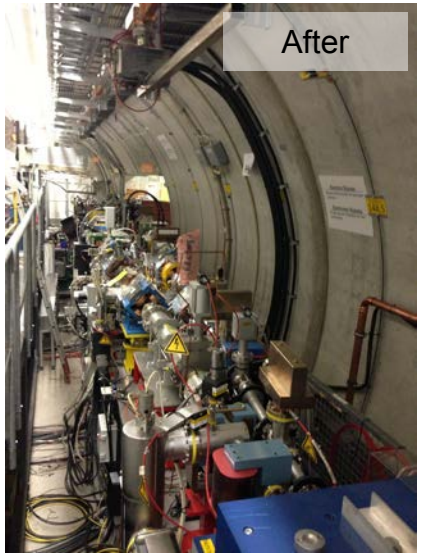
Shutdown February – July 2013

FLASH.
Free-Electron Laser in Hamburg

- Opening wall between FLASH1 Tunnel and FLASH2 Extraction
- Modification FLASH1 beamline from the last accelerator module to the collimator section
  - kicker-septum system installed to extract FLASH2 beam
- Installation of FLASH2 Extraction beamline
- Hardware upgrades of control systems
  - personnel interlock system, LLRF, magnet controls



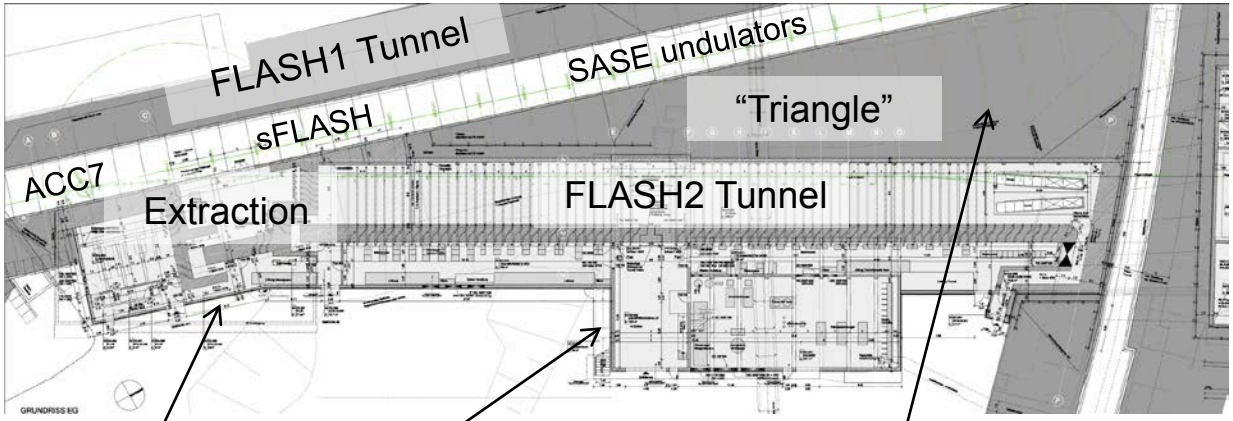




FLASH1 Beamline Alignment

FLASH.
Free-Electron Laser in Hamburg

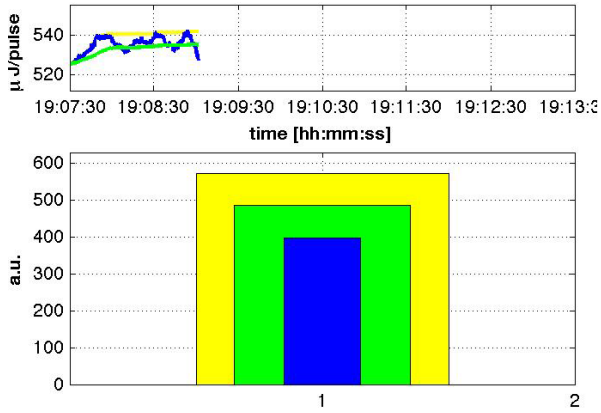
- Ground settlement up to 10 mm expected due to heavy load
  - new FLASH2 buildings
  - filling up the “Triangle” with some kilotonnes of sand
- Complete FLASH1 beamline surveyed and re-aligned in summer and autumn 2013

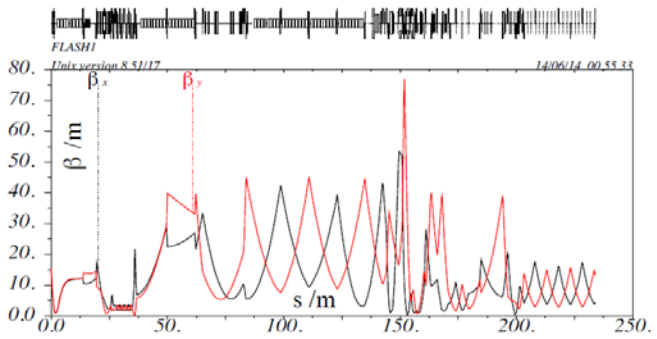


FLASH1 Commissioning

FLASH.
Free-Electron Laser in Hamburg

- Operation of FLASH linac started in August, 2013
  - in September, mainly beamline survey and alignment
- Stable FEL operation re-established by end of 2013
  - including re-alignment and commissioning of photon beamlines
- New record of FLASH SASE performance:
  up to 540 µJ at 8.7 nm
- Commissioning of upgraded control systems
  - µTCA based LLRF system
  - magnet controls
  - timing system for simultaneous operation
- New electron beam optics implemented
  - for simultaneous operation of FLASH1 and FLASH2

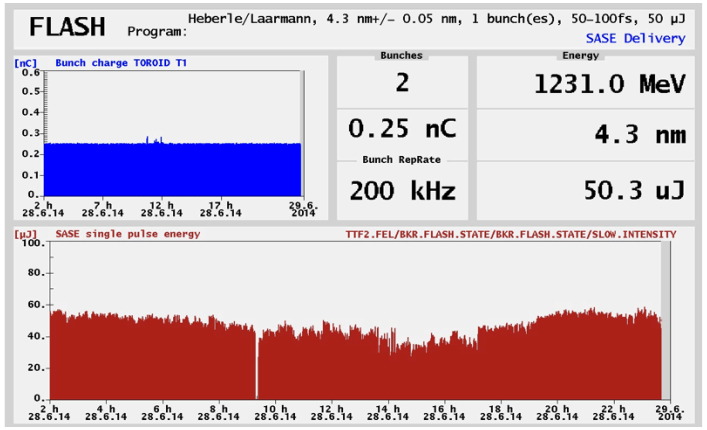


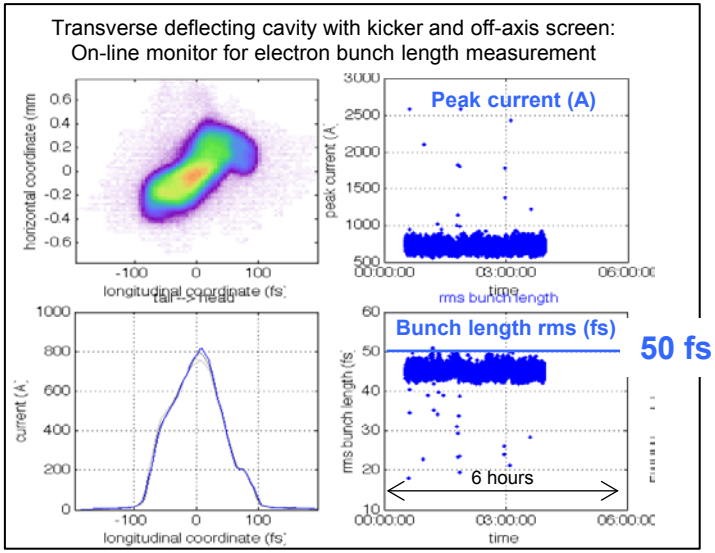


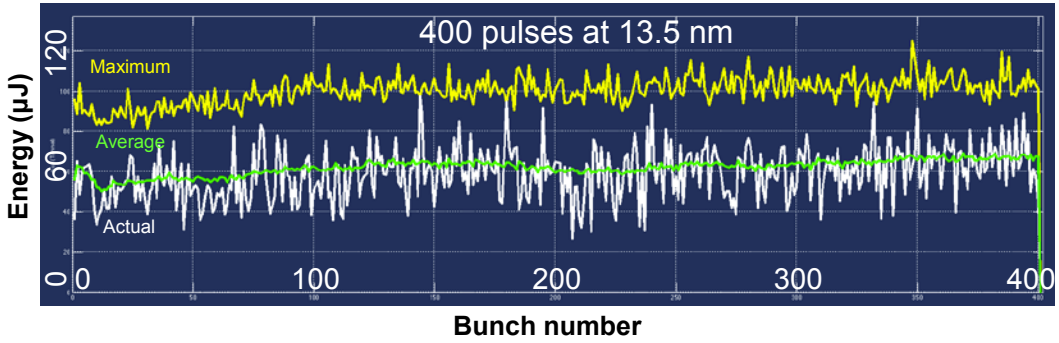
FLASH1 User Operation

FLASH.
Free-Electron Laser in Hamburg

- 5th user period from February 2014 to April 2015
- Examples of realized beam parameters
  - 400 pulses (1MHz spacing) at 7.8 nm and 13.5 nm
  - 50 pulses (200 kHz spacing) at 42 nm
  - 40 pulses (100 kHz spacing) at 15 nm
  - Single pulse at 4.3 nm
- Many experiments request in addition
  - short pulses (< 50 fs)
  - small spectral bandwidth (< 1%)
  - small arrival time jitter (down to 20 to 40 fs level)



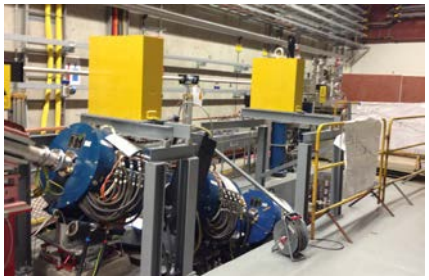


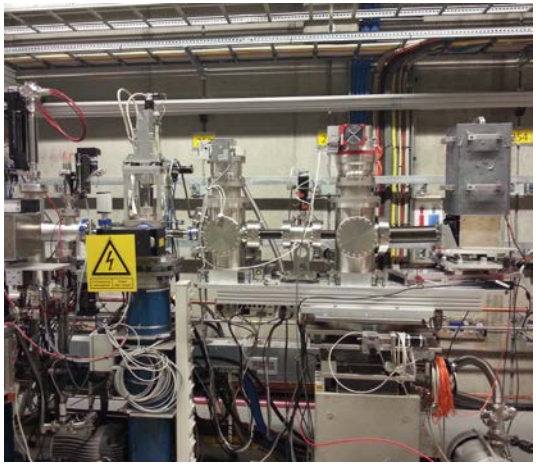


FLASH2 Construction

FLASH.
Free-Electron Laser in Hamburg

- Construction of new buildings 2011 - 2014
- Mounting of electron beamline started in summer 2013, finished January 2014 (inclusive undulators)
- Basic photon diagnostics installed
  - MCP, Ce:YAG screen, spectrometer
- First photon beamline in experimental hall in 2015

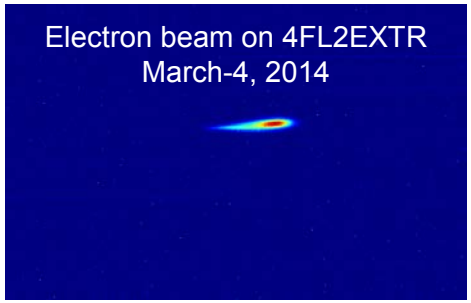


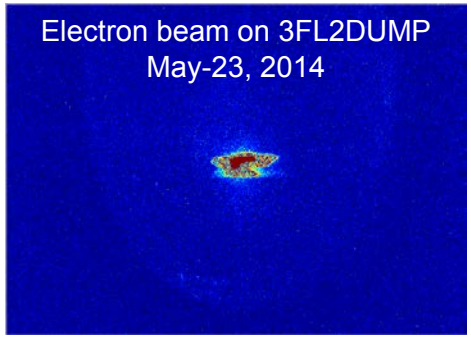


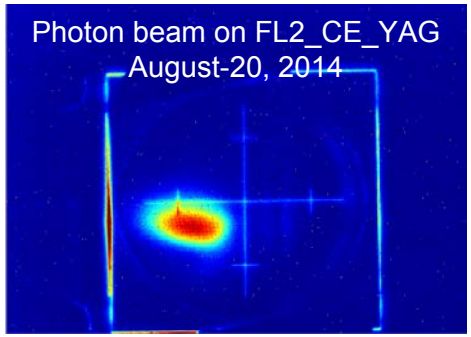
FLASH2 Operation Started

FLASH.
Free-Electron Laser in Hamburg

- Official permission for FLASH2 beam operation February-7, 2014
- Electron beam operation started in March 2014
  - first electron beam in extraction March-4, 2014
  - first beam to dump May-23, 2014
  - only few days available for FLASH2 beam operation before simultaneous operation established
- Simultaneous operation of FLASH1 (SASE) and FLASH2 (electron beam) starting end of May 2014
  - FLASH2 runs now in parallel to FLASH1 whenever possible, mainly during FLASH1 photon user experiments
    → time available for commissioning increased significantly
  - dedicated FLASH2 beam time reserved as well
- First lasing: August-20, 2014



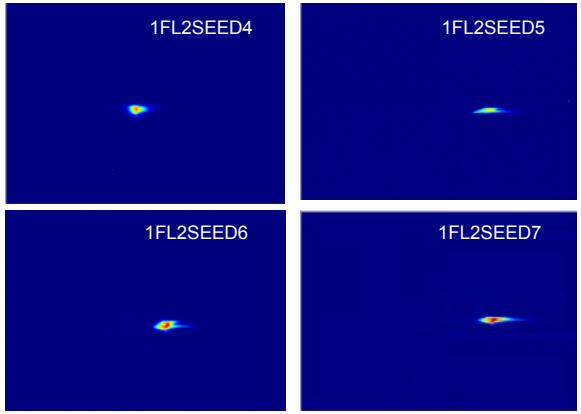


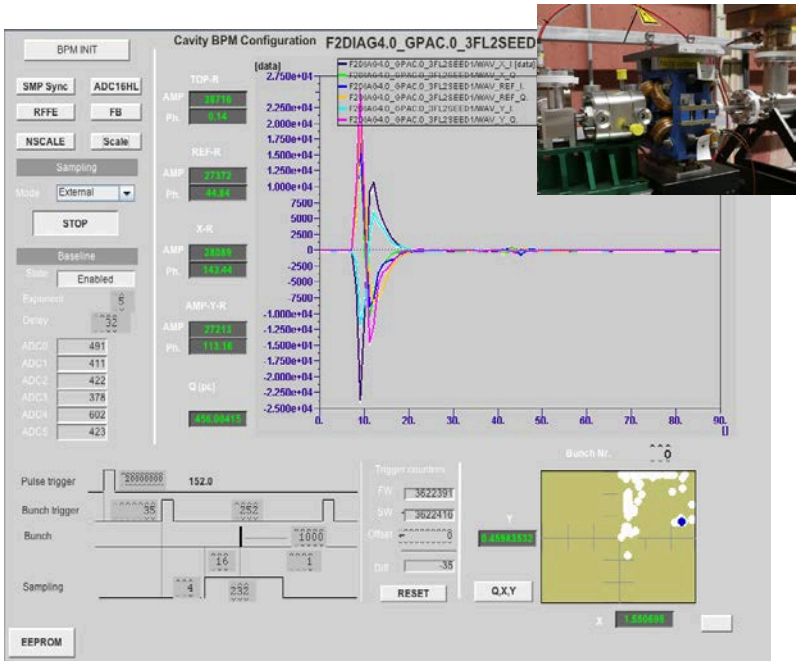


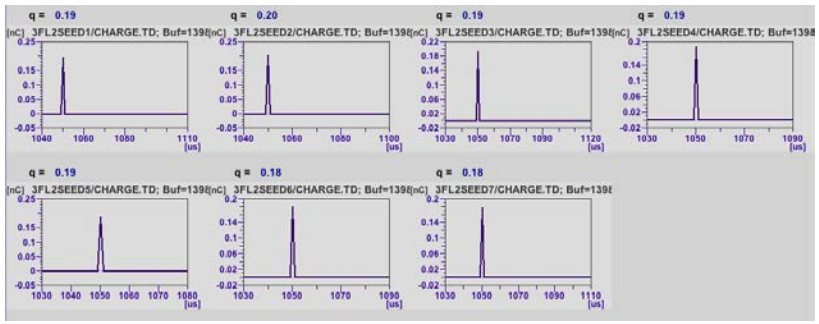
FLASH2 Commissioning

FLASH.
Free-Electron Laser in Hamburg

- Electron beam transport up to dump routinely
- On-going commissioning tasks
  - beam loss monitors and machine protection system
  - electron beam diagnostics (screens, toroids, BPMs)
  - beam optics, matching, dispersion
- Next step: SASE commissioning
- Example of electron beam diagnostics:
  17 Cavity BPMs along FLASH2
  - pick-ups provided by DESY, electronics by PSI
  - expected resolution:
    2 µm for charges between 100 pC and 1 nC







Simultaneous Operation

FLASH.
Free-Electron Laser in Hamburg

- Take advantage of superconducting accelerator: long RF pulse (1 ms)

  → FLASH1 and FLASH2 share a long bunch train, both served at 10 Hz

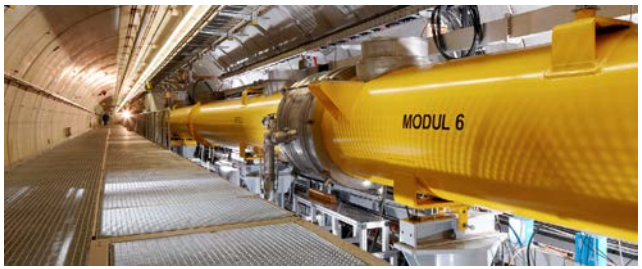
- Flexibility for photon experiments
  - Different wavelengths

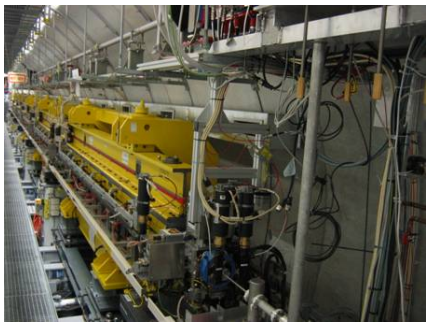
    → FLASH1 (fixed gap undulators): requires change of electron beam energy

    → FLASH2 (variable gap undulators): change of undulator gap

    → small electron beam energy changes independently for FLASH1 and FLASH2
  - Different photon pulse duration

    → different bunch compression and different bunch charge
  - Different pulse pattern

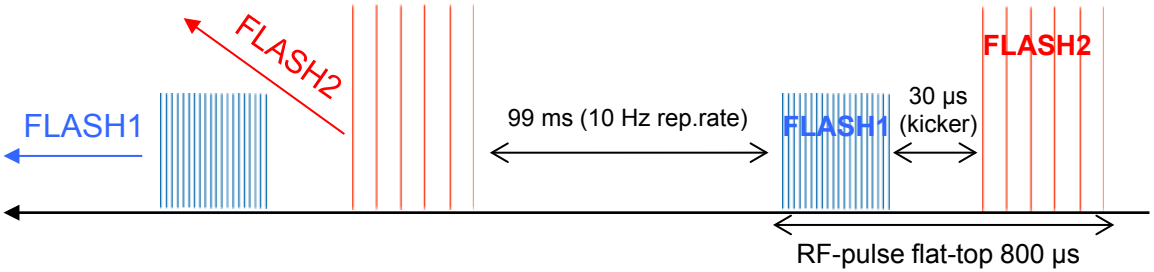


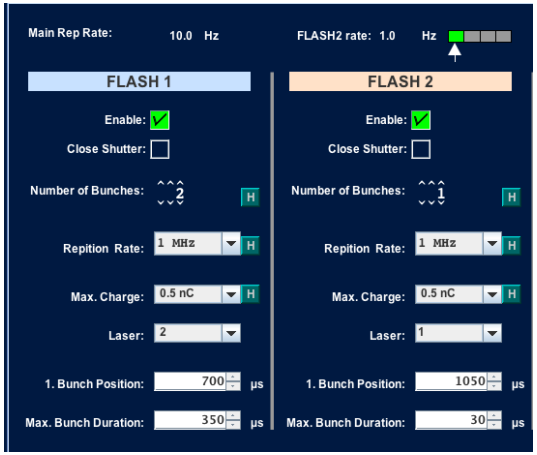


Realization of Simultaneous Operation

FLASH.
Free-Electron Laser in Hamburg

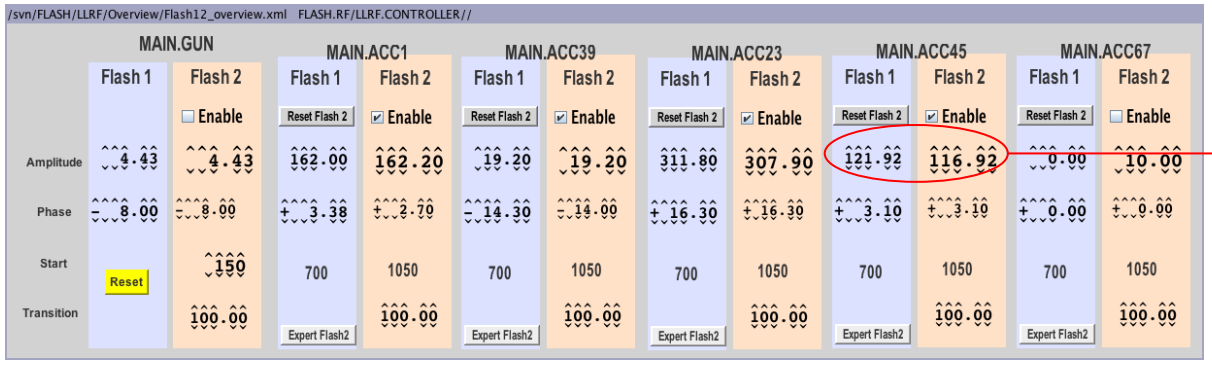
- Fast kicker and Lambertson septum to extract a part of bunch train to FLASH2



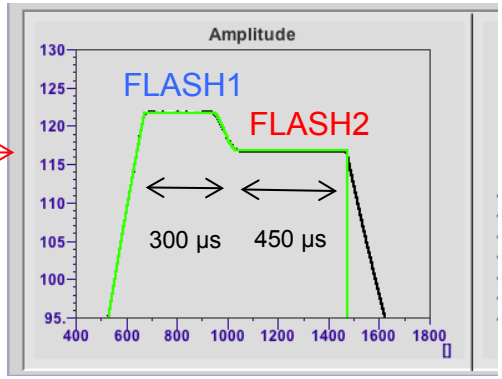


- Two injector lasers: FLASH1 and FLASH2 bunch pattern and bunch charge selected independently

- Flexible RF-system: amplitude and phase adjusted
  - in certain limits - independently for FLASH1 and FLASH2



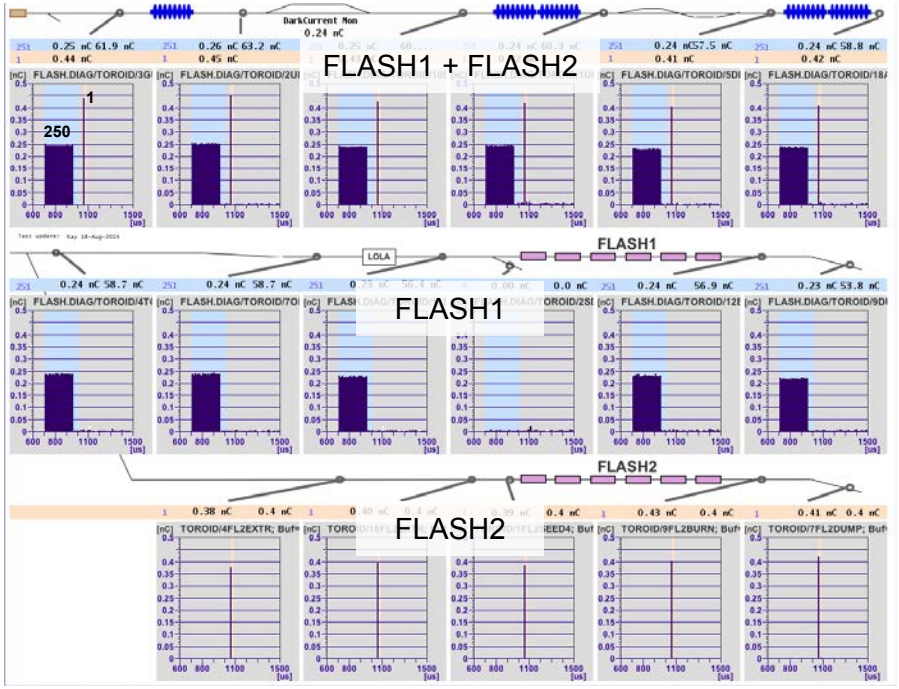
RF-pulse amplitude

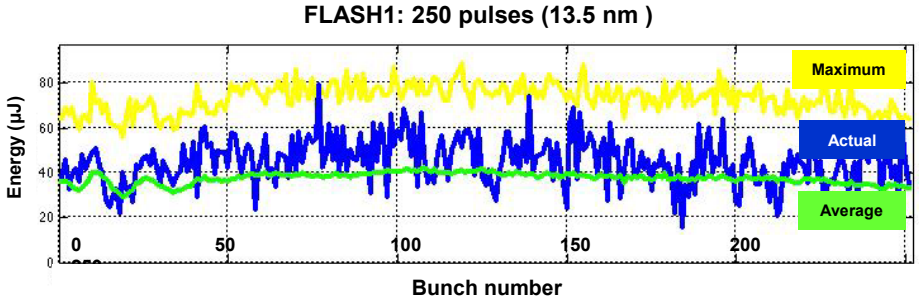


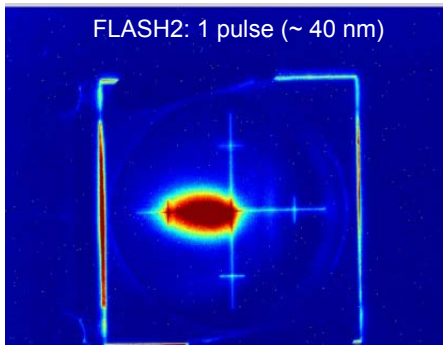
Status Simultaneous Operation

FLASH.
Free-Electron Laser in Hamburg

- Simultaneous FLASH2 electron beam operation and FLASH1 lasing established for several different FLASH1 photon wavelengths
  - FLASH2 runs in parallel to FLASH1 whenever possible
  - Important: parallel set-up of FLASH1 and FLASH2 operation essential
- First simultaneous SASE operation on August-20, 2014







Summary

FLASH.
Free-Electron Laser in Hamburg

- FLASH upgraded with a second undulator beamline
- FLASH1 back in user operation
  - 5th user period from February 2014 to April 2015
- FLASH2 beam operation started
  - first electron beam to dump in May 2014
  - first lasing August-20, 2014
- Simultaneous operation established
  - FLASH2 commissioning mainly in parallel to FLASH1 user operation