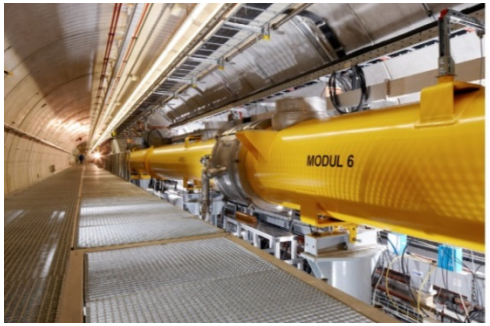
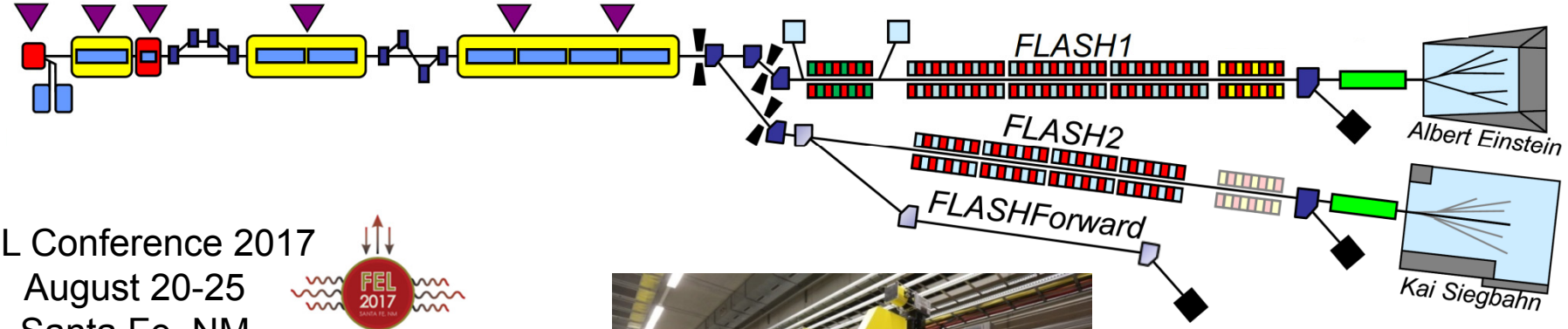
FLASH Status

FLASH.
Free-Electron Laser
in Hamburg

FLASH: the first soft X-ray FEL operating two undulator beamlines simultaneously

Katja Honkavaara, DESY
for the FLASH team





FEL Conference 2017
August 20-25
Santa Fe, NM

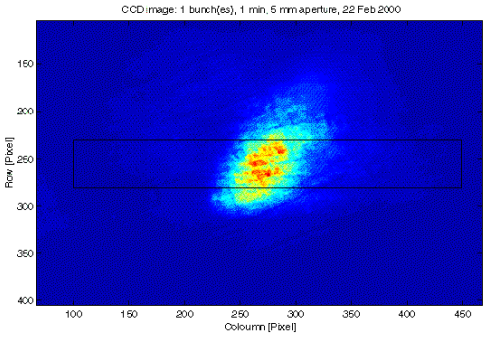
HELMHOLTZ GEMEINSCHAFT

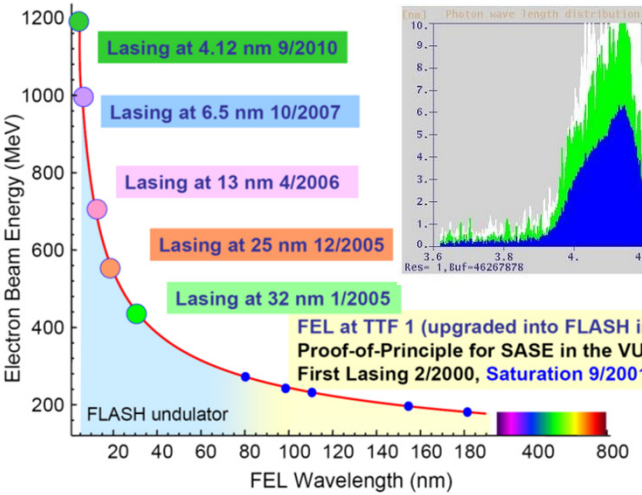
DESY

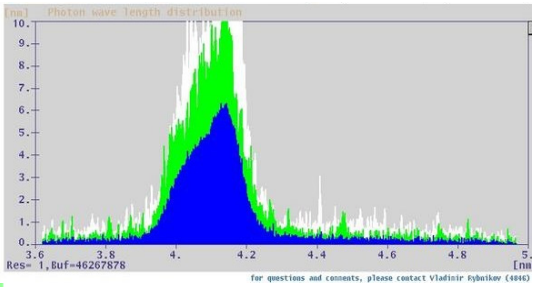
FLASH Facility

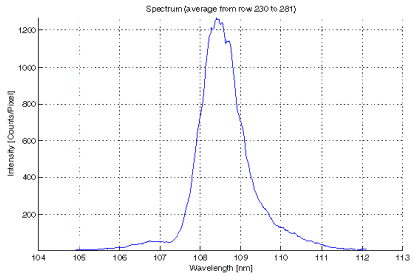
FLASH: the Pioneering Soft X-ray SASE FEL

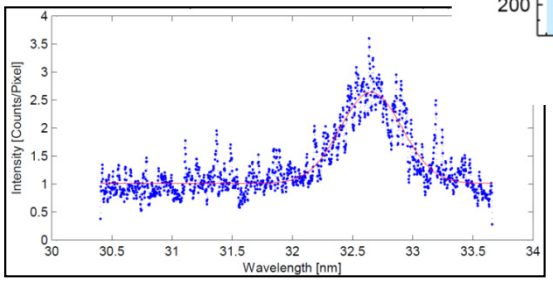
FLASH.
Free-Electron Laser in Hamburg

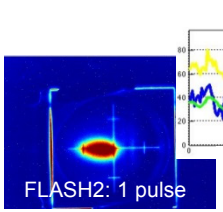


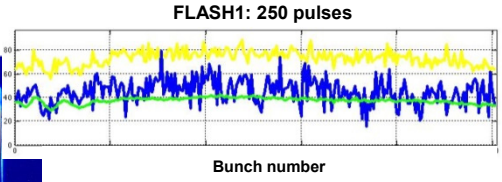


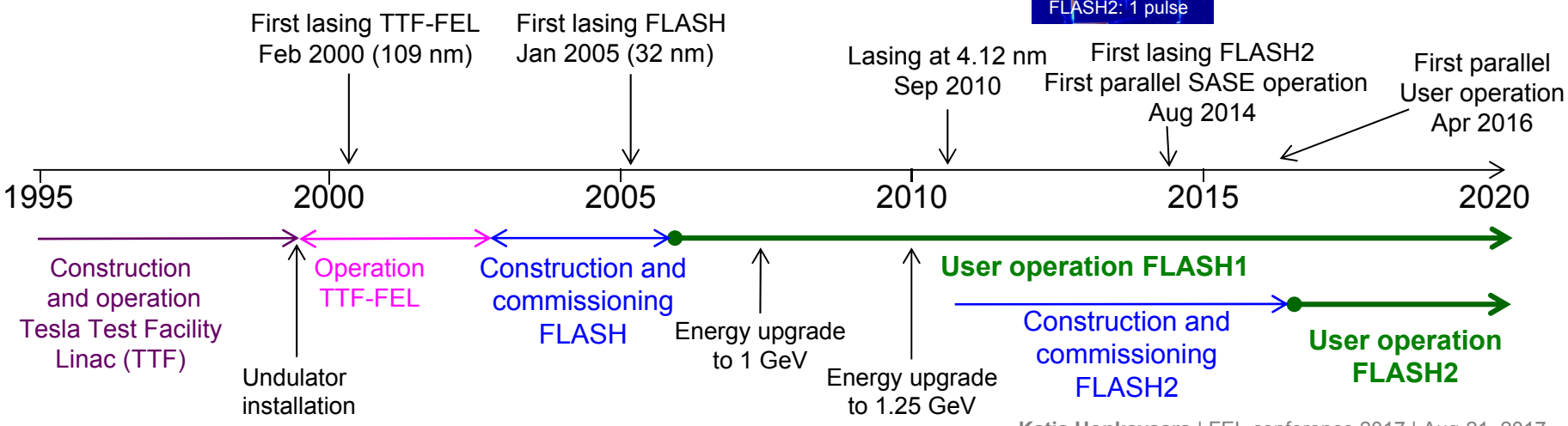












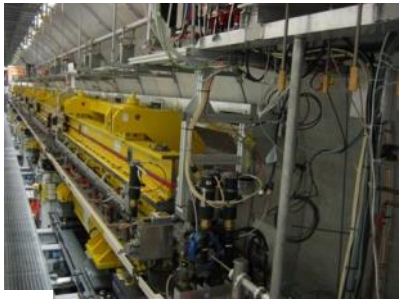
FLASH Layout 2017

FLASH.
Free-Electron Laser in Hamburg

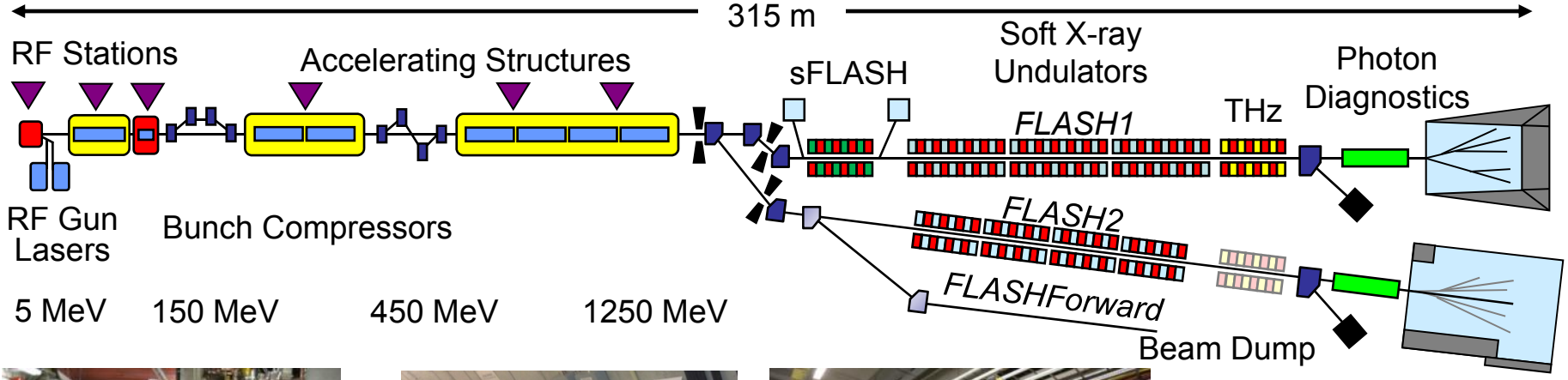
> 3rd harmonic sc module 3.9 GHz

> TESLA type superconducting accelerating modules 1.3 GHz

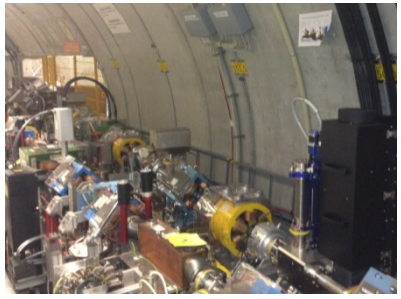
> FLASH1 fixed gap undulators



> FLASH1 Hall Albert Einstein



> Normal conducting 1.3 GHz RF gun
> Ce_2Te cathode
> Three photocathode lasers



> Extraction to FLASH2

> FLASH2 variable gap undulators

> FLASH2 Hall Kai Siegbahn

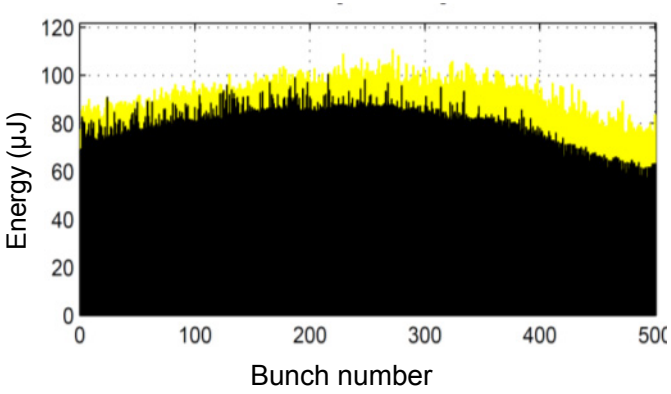
FLASH Parameters

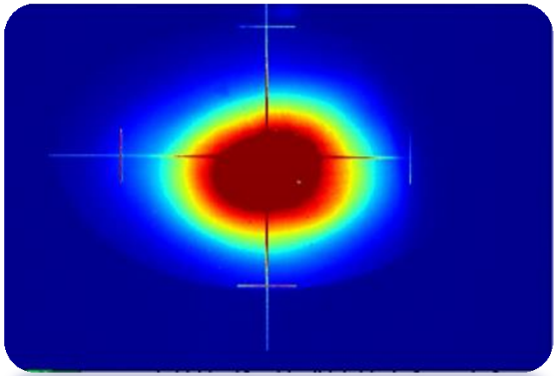
FLASH.
Free-Electron Laser in Hamburg

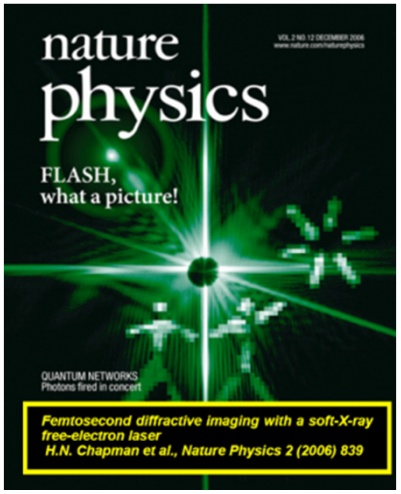
FEL Radiation Parameters FLASH1 / FLASH2

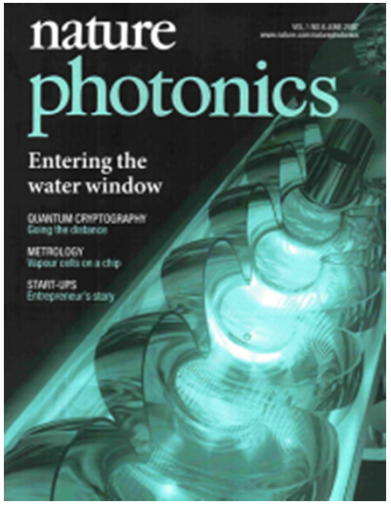
Wavelength (fundamental)	4.2 – 51 nm / 4 – 90 nm
Single pulse energy	1 – 500 µJ / 1 – 1000 µJ
Pulse duration (FWHM)	< 30 – 200 fs
Peak power	1 – 5 GW
Pulses per second	10 – 5000
Spectral width (FWHM)	0.7 – 2 % / 0.5 – 2 %
Photons per pulse	10^{11} – 10^{14}
Peak Brilliance	10^{28} – 10^{31} B*

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







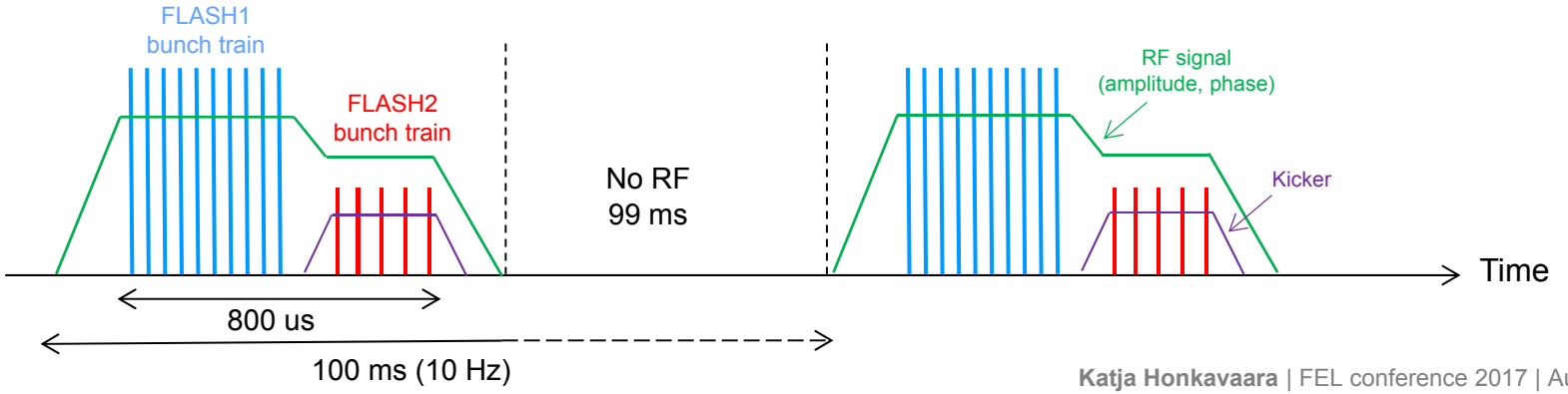


> more than 250 publications on photon science at FLASH, many in high impact journals
http://photon-science.desy.de/facilities/flash/publications/scientific_publications

Simultaneous Operation

FLASH.
Free-Electron Laser in Hamburg

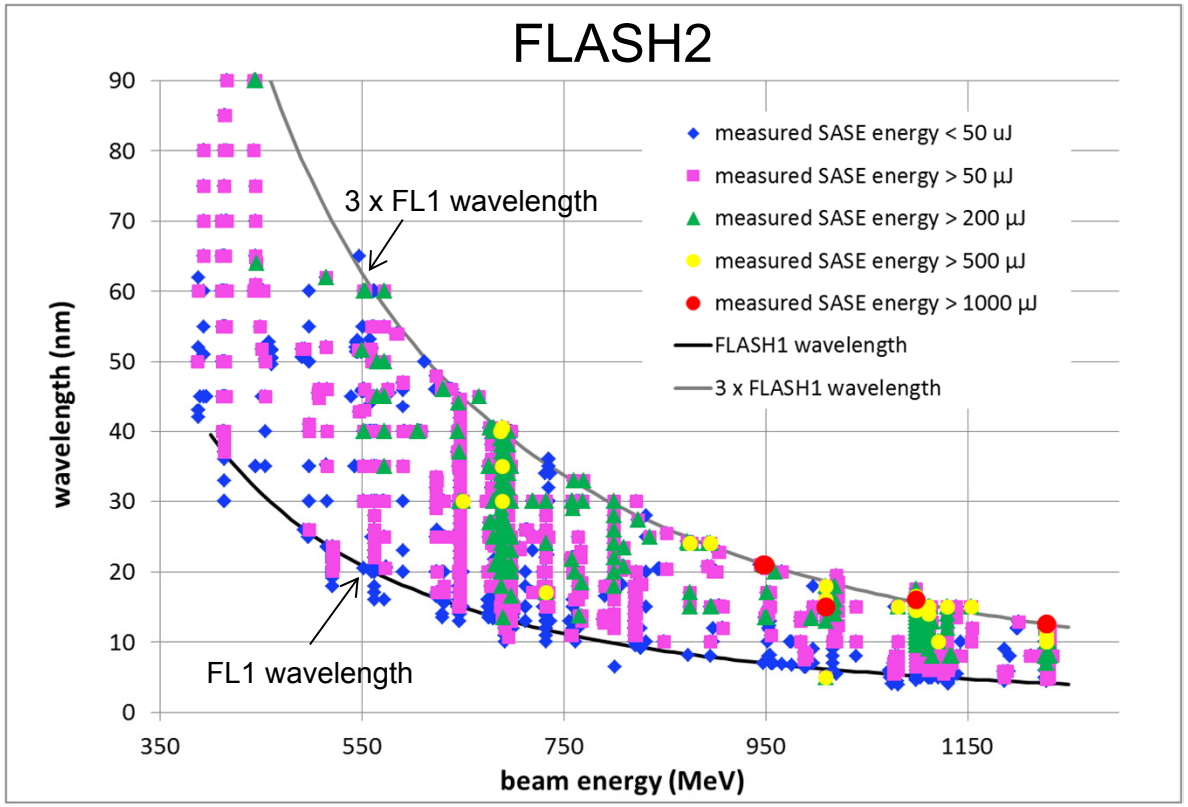
- Two photon experiments - one at FLASH1 and one at FLASH2 – are served simultaneously, both with a 10 Hz pulse train repetition rate
- Take advantage of superconducting accelerator: long RF pulse (1 ms) → long electron bunch train shared between FLASH1 and FLASH2
  - fast kicker and Lambertson septum to extract a part of bunch train to FL2
- Flexibility for photon experiments
  - two undulator beamlines → different wavelengths
  - three photocathode lasers → different bunch pattern and bunch charge
  - flexible RF-system → different amplitude and phase
  - different bunch charge and compression → different pulse durations



Wavelength Tunability

FLASH.
Free-Electron Laser in Hamburg

- FLASH1 (fixed gap undulators): wavelength defined by the electron beam energy
- FLASH2 (variable gap undulators): wavelength tunable (1 – 3 x FL1 wavelength)
  - with a fixed electron beam energy: small undulator gap = long wavelength
    large undulator gap = short wavelength



User Operation

User Operation at FLASH2 started April 2016

FLASH.
Free-Electron Laser in Hamburg

First user operation at FLASH2

DESY News 13.4.2016

Since Friday, 8 April at 12:14 h FLASH is running in parallel operation for two user experiments, one in the experimental hall "Albert Einstein" (FLASH1) and one in the new hall "Kai Siegbahn" (FLASH2). First official FLASH2 users are the researchers around Sven Toleikis and Andreas Przystawik at beamline FL24 who focus the FLASH2 pulses with the help of a multilayer mirror onto rare gas clusters and study the fluorescence of the resulting nanoplasma as a function of cluster size.

Download [893KB, 2876 x 1743]
FLASH is the first X-ray laser worldwide which can serve experiments at two beamlines at the same time.

Right after the successful start last Friday the first record for this doubled user operation was set: On Saturday, FLASH delivered 4000 pulses per second with up to 140 micro joule (µJ) per pulse to an experiment of Mark Dean et al. (Brookhaven National Laboratory, New York) at FLASH1 beamline PG1 and in parallel 110 pulses per second with about 100 micro joule each for FLASH2 making it a successful start at both ends.

The second free-electron laser line, FLASH2, has been realized from 2011 to 2015. Soon after the first successful generation of extremely intense FEL radiation on FLASH2 in August 2014, parallel operation of the two soft X-ray free-electron lasers, FLASH1 and FLASH2, has been established. Now, the first FEL beamline in the new hall "Kai Siegbahn" is operational making it possible to run two experiments simultaneously on FLASH1 and FLASH2, both delivering intense, ultra-short laser pulses with user-specific parameters.

FLASH2
Free-Electron Laser FLASH

Feldhaus/Toleikis, 13.5 nm+/- 0.10 nm, 30 bunch(es), 1MHz, 100 fs, max µJ, FL24
SASE Delivery

Bunches	10 Hz
11	
Charge	
0.31 nC	
Rep.Rate	
1003 kHz	

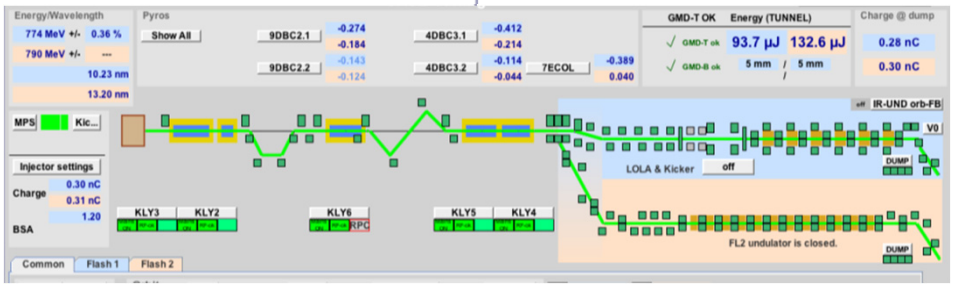
Beam Energy
790.2 MeV
Wavelength
13.2 nm
SASE Energy
137.8 µJ

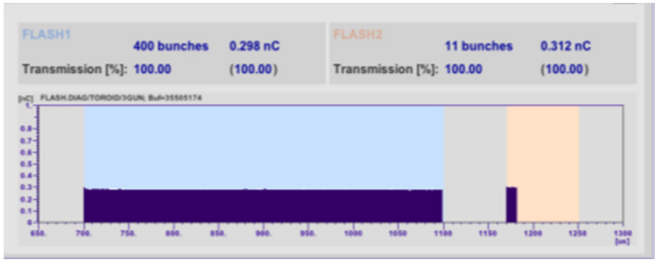
FLASH1
Free-Electron Laser FLASH

Setup, 1h / Dean, 10.2 nm+/- 0.20 nm, 400 bunch(es), 1MHz, >100 fs (uncritical)
SASE Delivery

Bunches
400
Charge
0.30 nC
Rep.Rate
1003 kHz

Beam Energy
774.9 MeV
Wavelength
10.2 nm
SASE Energy
95.1 µJ

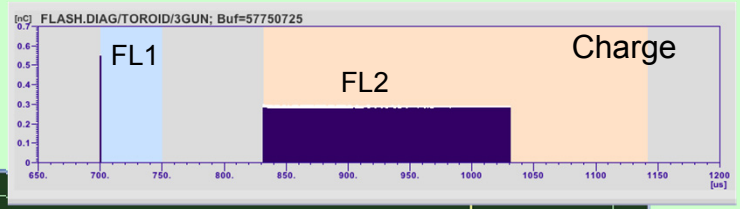


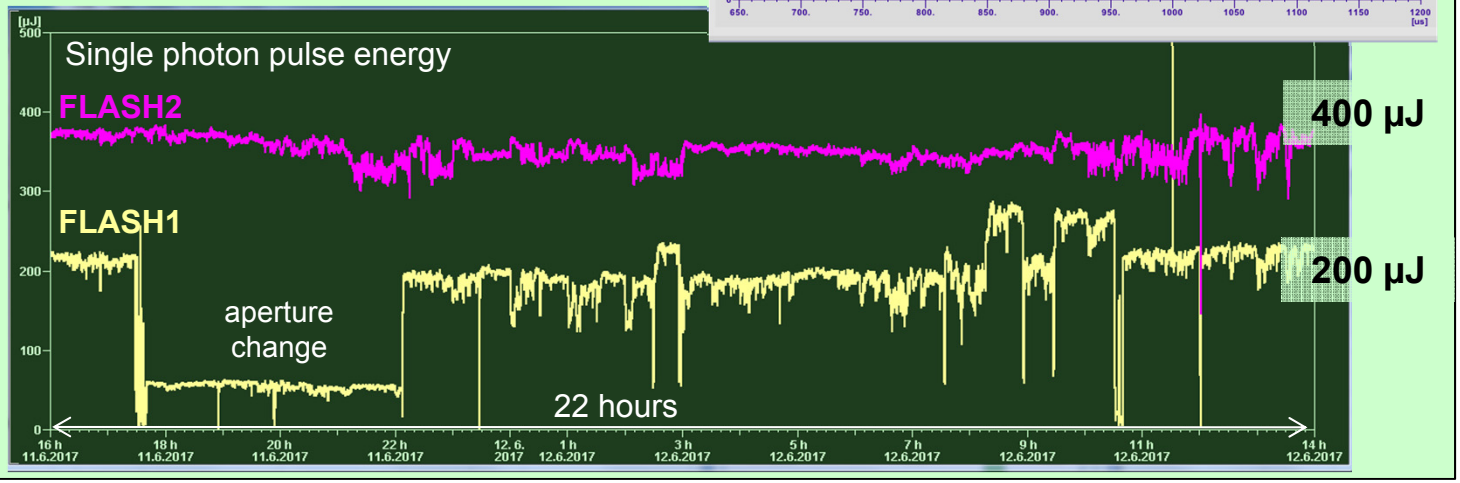


Examples of FL1 and FL2 Parallel User Operation

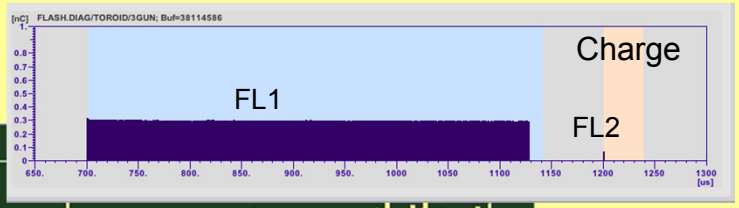
FLASH.
Free-Electron Laser in Hamburg

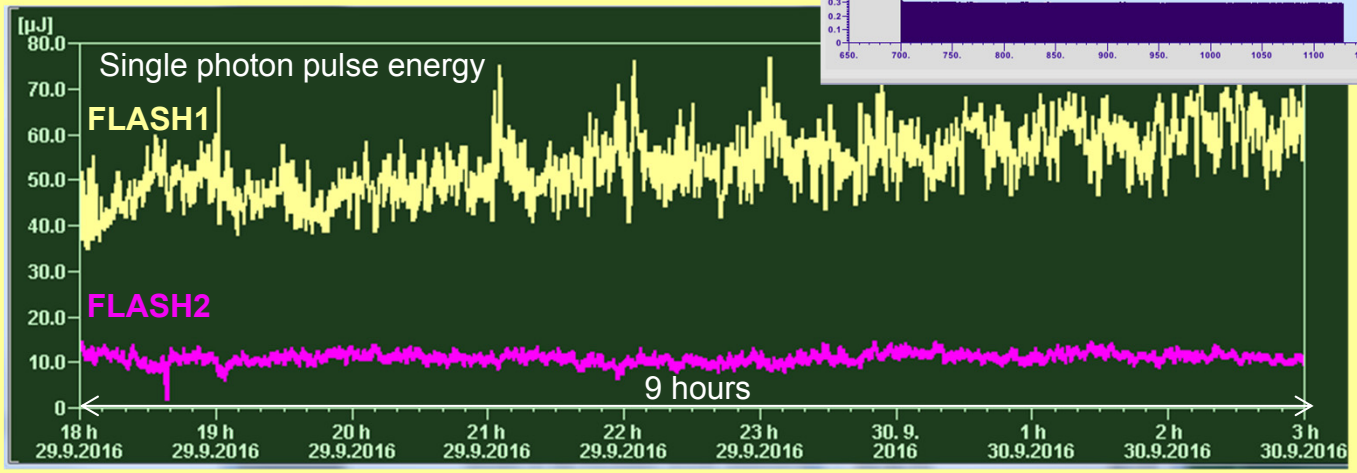
FL1: 13.4 nm, 1 bunch, 550 pC
FL2: 26 nm, 200 bunches, 300 pC





FL1: 9.8 nm, 430 bunches, 320 pC
FL2: 20.6 nm, 1 bunch, 70 pC (short pulses)

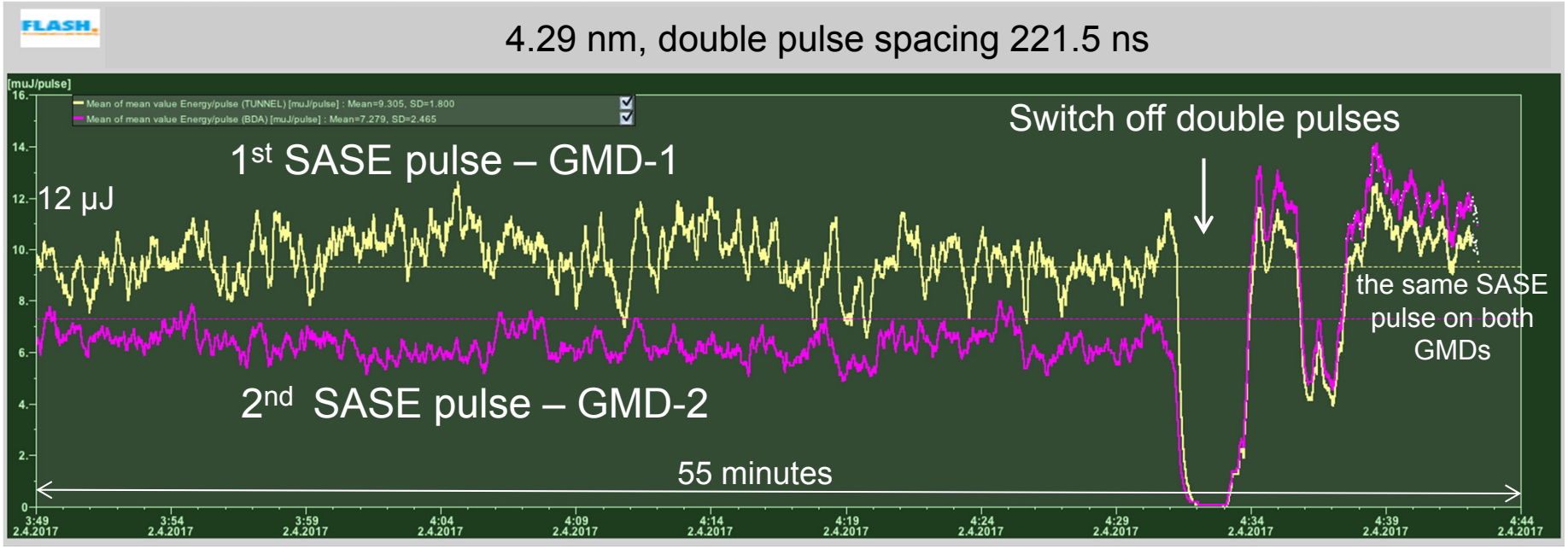




Example of Special Operation Mode

FLASH.
Free-Electron Laser in Hamburg

- New double pulse scheme: operation of FLASH1 with two photocathode lasers at the same time to provide SASE double pulses with variable nanosecond spacing
- Commissioned and operated for an external user experiment in spring 2017



Talk: Tue 8h30 “Recent FEL Experiments at FLASH“

Operation Organization

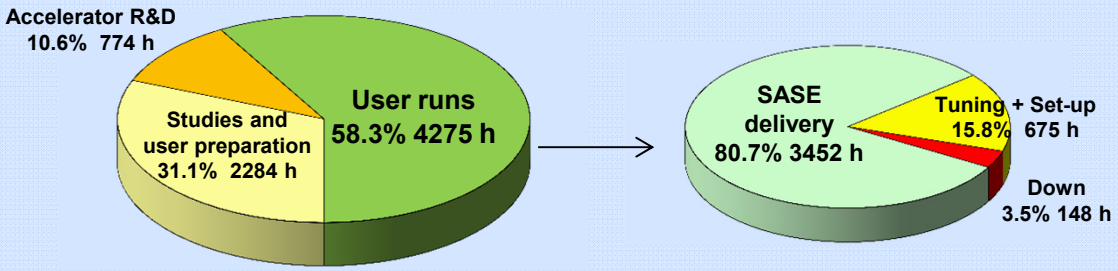
FLASH.
Free-Electron Laser in Hamburg

- 2 user periods / per year
  - user blocks alternating with study blocks
- FLASH2 user operation started in April 2016
  - FLASH2 photon beamlines not yet fully equipped
  - FL2 pump-probe laser and split-and-delay unit available in 2018

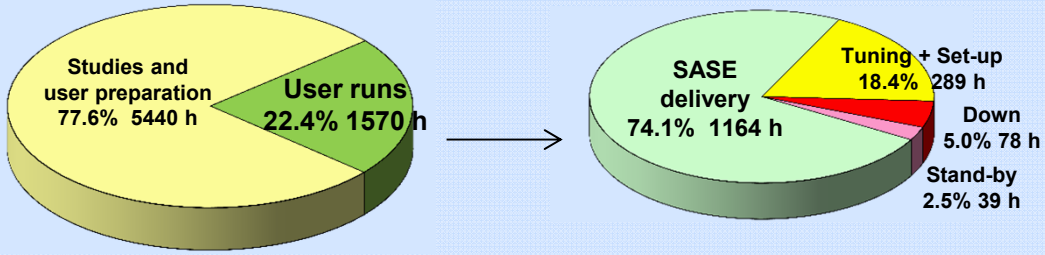
  → amount of FLASH2 user experiments will increase

Operation statistics 2016

FLASH1: 7333 h operation hours



FLASH2: 7010 h operation hours
(of which 1645 h stand-by)



2016	1	4-Jan - 10-Jan	Start-up	
	2	11-Jan - 17-Jan		FLASH personnel interlock test
	3	18-Jan - 24-Jan	Accelerator R&D	
	4	25-Jan - 31-Jan	FLASH Studies	
	5	1-Feb - 7-Feb		preparation user run
	6	8-Feb - 14-Feb	User Run	
	7	15-Feb - 21-Feb	Block 1	
	8	22-Feb - 28-Feb		
	9	29-Feb - 6-Mar		
	10	7-Mar - 13-Mar	FLASH Studies	
	11	14-Mar - 20-Mar		preparation user run
	12	21-Mar - 27-Mar	User Run	
	13	28-Mar - 3-Apr	Block 2	
	14	4-Apr - 10-Apr		
	15	11-Apr - 17-Apr		
	16	18-Apr - 24-Apr		
	17	25-Apr - 1-May	Accelerator R&D	
	18	2-May - 8-May	FLASH Studies	
	19	9-May - 15-May		preparation user run
	20	16-May - 22-May	User Run	
	21	23-May - 29-May	Block 3	
	22	30-May - 5-Jun		
	23	6-Jun - 12-Jun		
	24	13-Jun - 19-Jun	Shutdown/Contingency	
	25	20-Jun - 26-Jun		
	26	27-Jun - 3-Jul	FLASH Studies	
	27	4-Jul - 10-Jul		preparation user run
	28	11-Jul - 17-Jul	User Run	
	29	18-Jul - 24-Jul	Block 4	
	30	25-Jul - 31-Jul		
	31	1-Aug - 7-Aug		
	32	8-Aug - 14-Aug	Accelerator R&D	
	33	15-Aug - 21-Aug	FLASH Studies	
	34	22-Aug - 28-Aug		preparation user run
	35	29-Aug - 4-Sep	User Run	
	36	5-Sep - 11-Sep	Block 2	
	37	12-Sep - 18-Sep		
	38	19-Sep - 25-Sep		
	39	26-Sep - 2-Oct	FLASH Studies	
	40	3-Oct - 9-Oct		
	41	10-Oct - 16-Oct	Accelerator R&D	
	42	17-Oct - 23-Oct		preparation user run
	43	24-Oct - 30-Oct	User Run	
	44	31-Oct - 6-Nov	Block 3	
	45	7-Nov - 13-Nov		
	46	14-Nov - 20-Nov		
	47	21-Nov - 27-Nov		
	48	28-Nov - 4-Dec	FLASH Studies	
	49	5-Dec - 11-Dec	Shutdown FLASH	
	50	12-Dec - 18-Dec		
	51	19-Dec - 25-Dec		
	52	26-Dec - 1-Jan		
2017	1	2-Jan - 8-Jan		

Operation schedule 2016

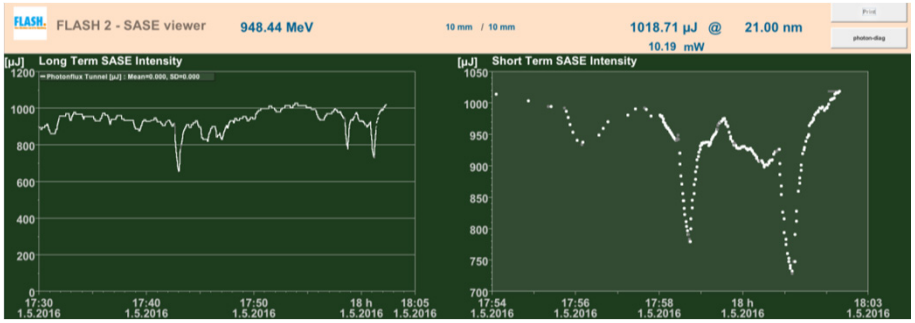
Operation in 2017 similar to 2016

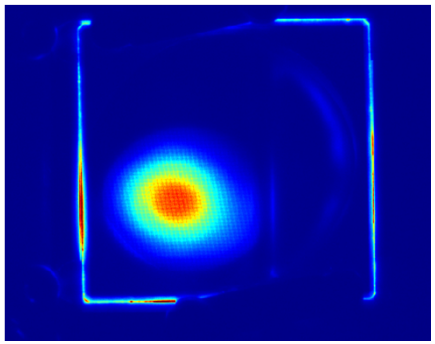
Developments

FLASH2 with Variable Gap Undulators

FLASH.
Free-Electron Laser
in Hamburg

- FLASH2 variable gap undulators allow operation optimization and experiments, which are not possible with fixed gap FLASH1 undulators
- FLASH2 optimization with tapering
  - up to 1 mJ single pulse energies
  - up to 10^{14} photons / single pulse
- Advanced operation modes under study at FLASH2
  - post-saturation tapering
  - reverse tapering
  - harmonic lasing self-seeded FEL
  - frequency doubling





Talk: Tue 8h30 “Recent FEL Experiments at FLASH“
Posters: MOP031, MOP032, MOP035, MOP036

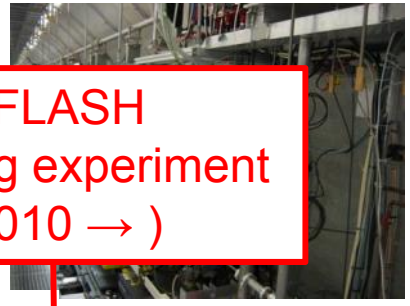
sFLASH and FLASHForward

FLASH.
Free-Electron Laser in Hamburg

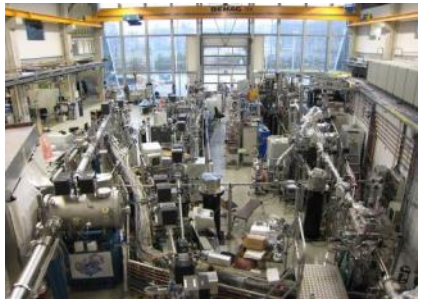
> 3rd harmonic sc module 3.9 GHz

> TESLA type superconducting accelerating modules 1.3 GHz

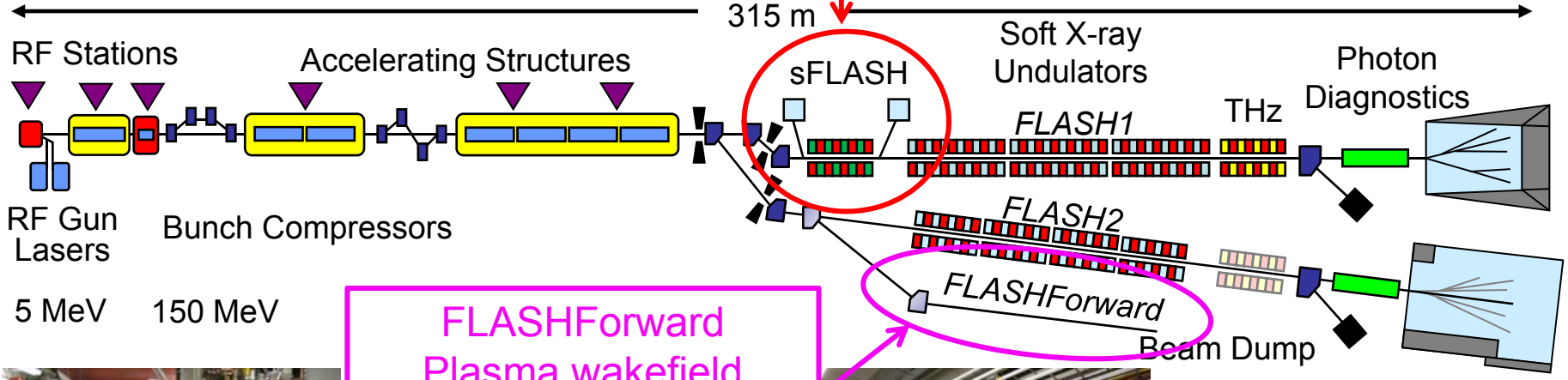
> FLASH1 fixed gap undulators



> FLASH1 Albert Einstein Hall

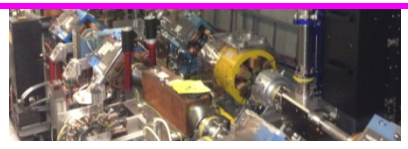


sFLASH
Seeding experiment
(2010 →)



FLASHForward
Plasma wakefield acceleration experiment
(2017 →)

> Normal conducting 1.3 GHz RF gun
> Ce_2Te cathode
> Three photocathode lasers



> Extraction to FLASH2

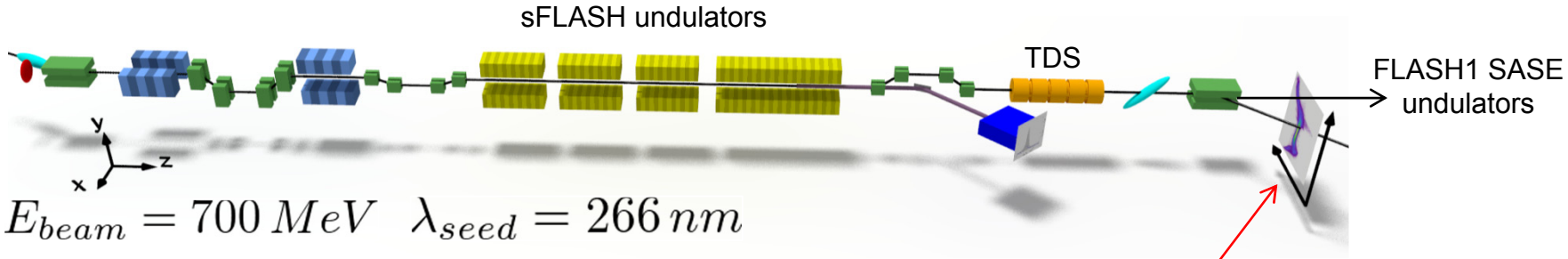
> FLASH2 variable gap undulators

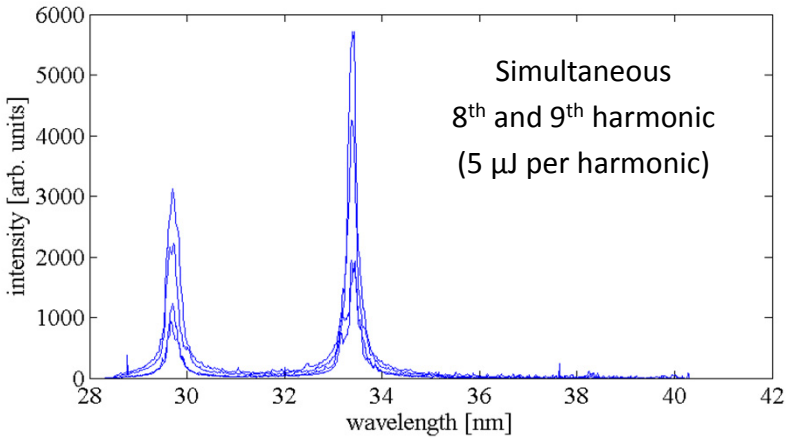
> FLASH2 Kai Siegbahn Hall

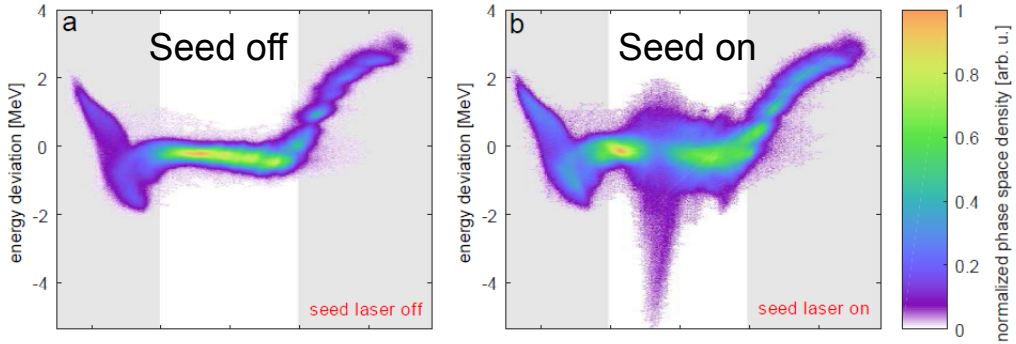
sFLASH Seeding Experiment

FLASH.
Free-Electron Laser in Hamburg

- Seeding experiment installed upstream of FLASH1 SASE undulators
- Present status: HGHG operation up to 9th harmonic







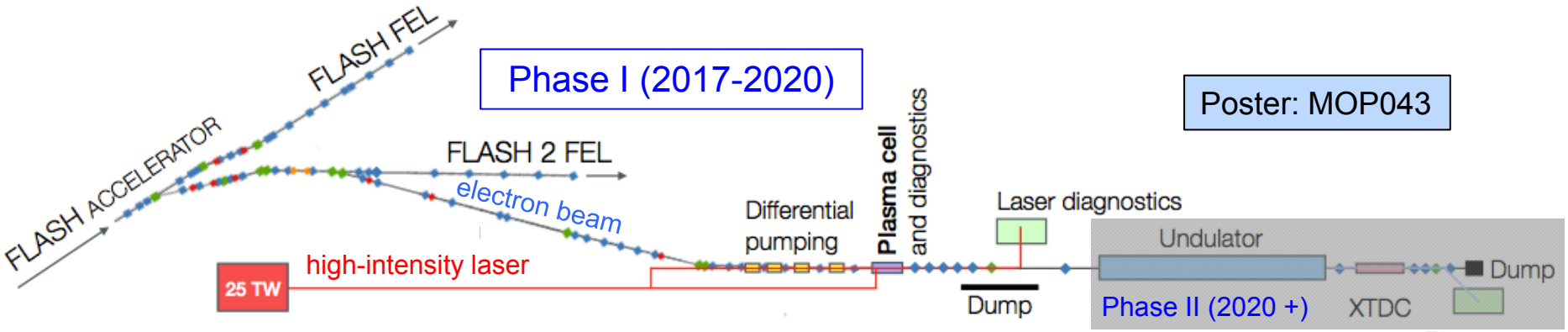
T. Plath et al., Scientific Reports 7, 2431 (2017)

Posters: MOP028, MOP042, TUP042

FLASHForward

FLASH.
Free-Electron Laser in Hamburg

- Next generation experiment for beam driven plasma wakefield accelerator research
- Under construction at the FLASH3 beamline in the FLASH2 Tunnel
- Uses FLASH electron beam
- Goals
  - high brightness electron beams with 1 GeV energy gain in plasma
  - beam quality conservation
  - demonstration of FEL gain from plasma-accelerated beams (post 2020)



A. Aschikhin et al., Nucl. Insr. Meth. A 806, 175 (2016)

Summary

Summary and Outlook

FLASH.
Free-Electron Laser in Hamburg

- FLASH1 and FLASH2 in simultaneous user operation
- ~ 7500 h operation hours / year
  - 60% user experiments
  - 30% FLASH studies
    machine studies and improvements, photon beamlines, user preparation
  - 10% accelerator R&D
- Short-term upgrades (on-going)
  - upgrades of synchronization system
  - arrival time stabilization with a warm RF cavity
  - low charge electron beam diagnostics
- Mid-term refurbishments
  - refurbishment of two old accelerator modules
  - next generation photocathode laser
  - TDS at FLASH2

FLASH related Posters in FEL 2017

FLASH.
Free-Electron Laser in Hamburg

MOP003: Concept for a seeded FEL at FLASH2

MOP028: Extraction of the longitudinal profile of the transverse emittance from single-shot RF deflector measurements at sFLASH

MOP030: Study of the next major FLASH upgrade: FLASH2020

MOP031: First operation of a harmonic lasing self-seeded FEL

MOP032: Reverse undulator tapering for polarization control and background-free harmonic production in XFELs: results from FLASH

MOP035: Optimum undulator tapering of SASE FEL: Theory and experimental results from FLASH2

MOP036: Frequency doubling mode of operation of Free Electron Laser FLASH2

MOP042: Status of seeding development at sFLASH

MOP043: Towards a beam driven plasma accelerator Free Electron Laser

TUP042: Determination of the slice energy spread of ultra-relativistic electron beams by scanning seeded coherent undulator radiation by coherent harmonic generation

WEP002: Double pulse FEL operation at FLASH

WEP003: Update on the lifetime of Cs2Te photocathodes operated at FLASH