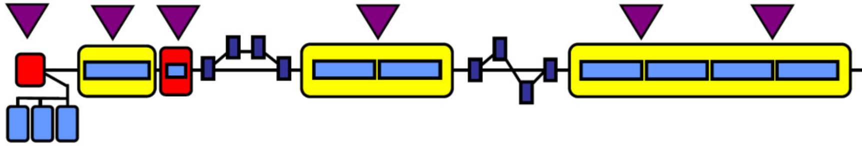
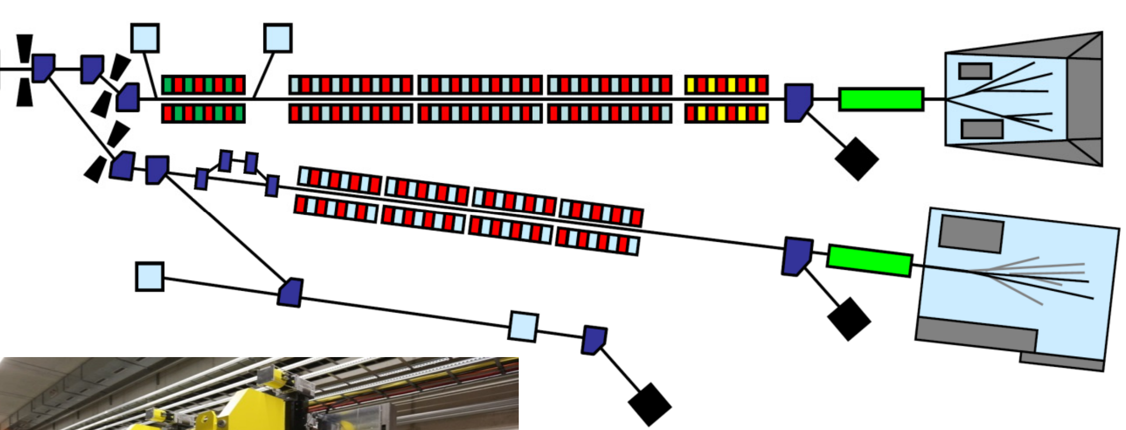
FLASH - Status and Upgrades

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





Juliane Rönsch-Schulenburg
for the FLASH team
DESY

FEL conference
26th – 30th of August, 2019
Hamburg, Germany

FLASH Facility

FLASH – The Free-Electron Laser at DESY

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

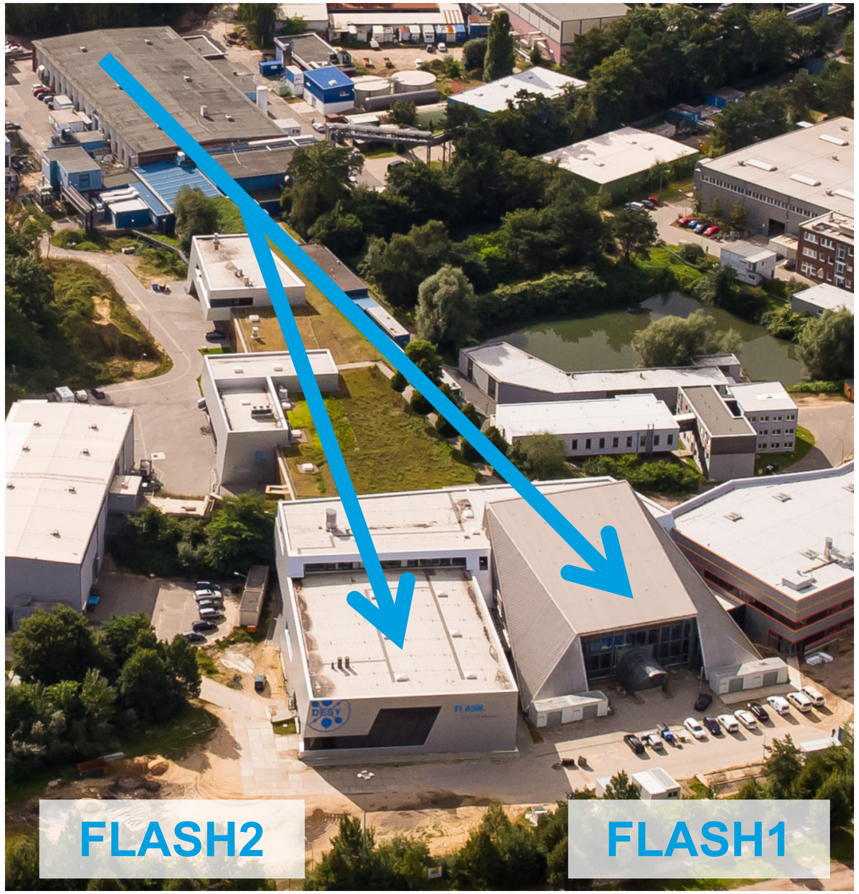
- Single-pass high-gain SASE FEL
- Based on a superconducting accelerator allowing several thousand bunches per second
  - 1.25 GeV using TESLA technology
- Two undulator beamlines: SASE to two experimental halls simultaneously
- Coherent femtosecond scale photon pulses
- Wavelength range from XUV to soft X-rays (90 nm to 4 nm)
  - integrated powerful THz source

FLASH is a user facility

- Since summer 2005 (already 14 years)
- Since 2016 with two undulator beamlines

Includes an accelerating R&D program

- sFLASH (Seeding development)
- FLASHForward (Plasma wakefield experiment)

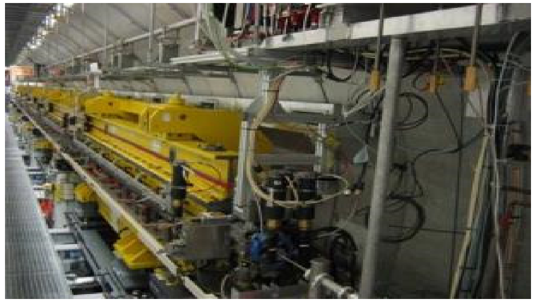


THP074 - *FLASH*: The Pioneering XUV and Soft X-Ray FEL User Facility

FLASH Layout

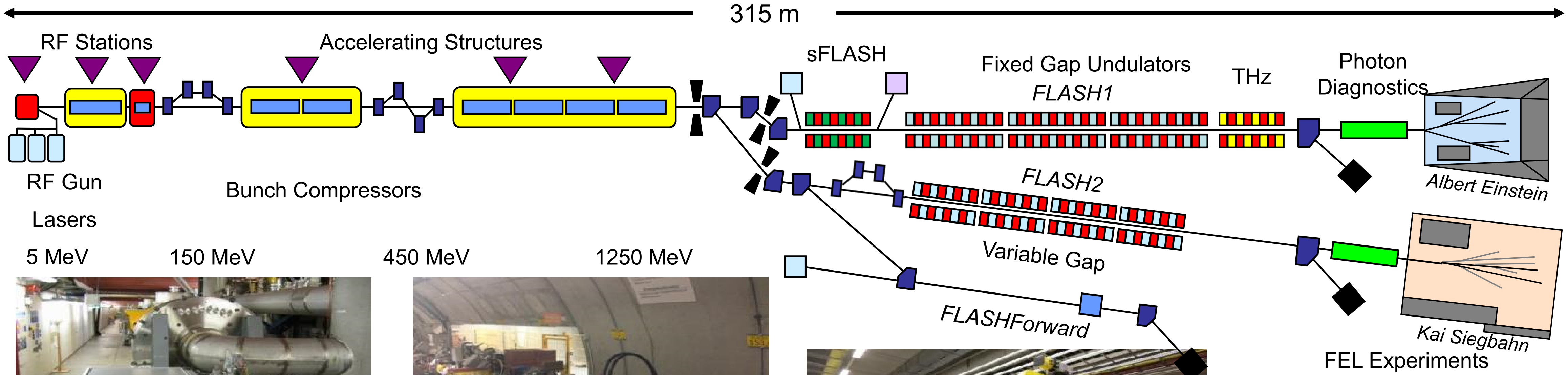
3rd harmonic sc module 3.9 GHz

TESLA type superconducting accelerating modules 1.3 GHz



FLASH1 fixed gap undulators

FLASH1 Albert Einstein Hall



Normal conducting 1.3 GHz RF gun
Ce_2Te cathode / 3 injector lasers

Extraction to FLASH2

FLASH2 variable gap undulators

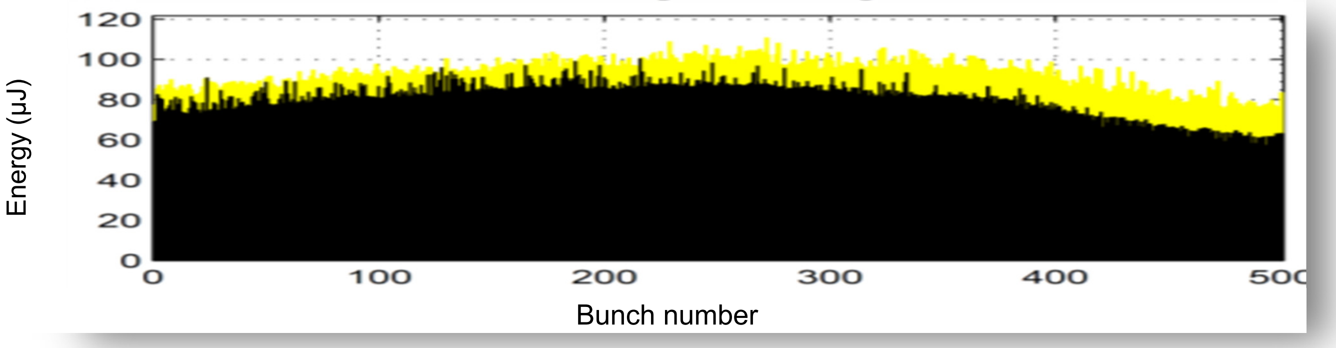
FLASH2 Kai Siegbahn Hall

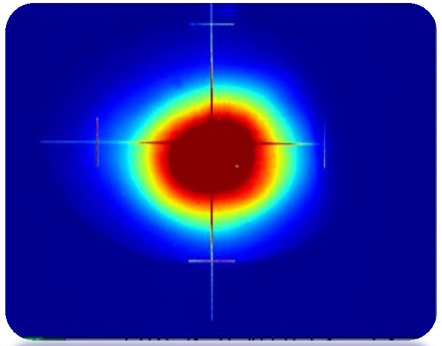
FLASH Parameters

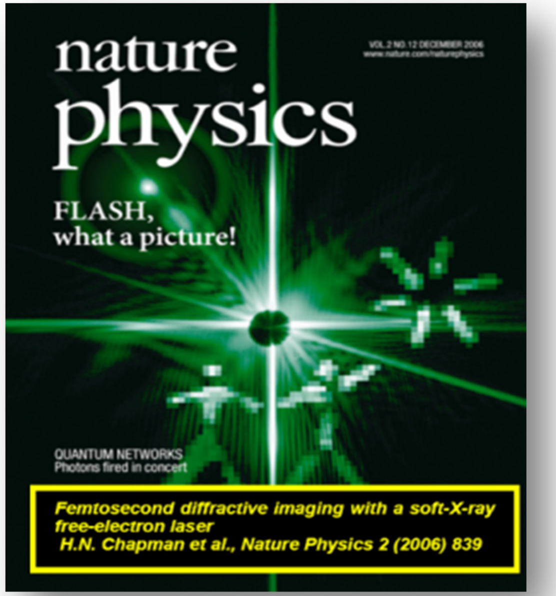
Femtosecond pulses from the XUV to soft X-rays

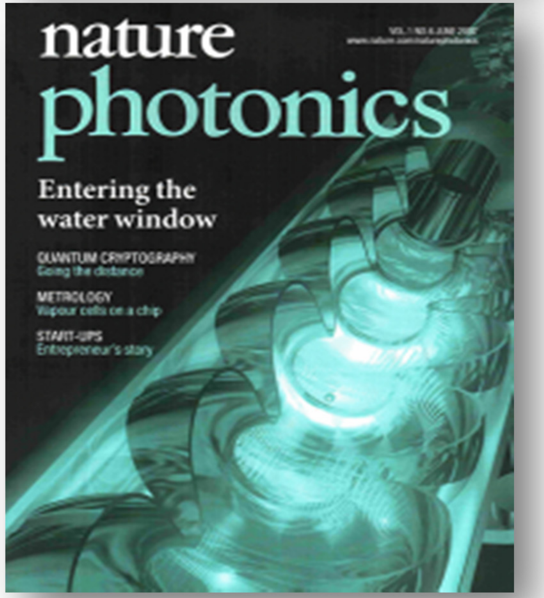
FEL Radiation Parameter FL1 / FL2	
Wavelength range (fundamental)	4.2 – 51 nm / 4 – 90 nm
Average single pulse energy	1 – 500 µJ / 1 – 1000 µJ
Pulse duration (FWHM)	< 30 – 200 fs
Peak power (from av.)	1 – 5 GW
Pulses per second	10 – 5000
Spectral width (FWHM)	0.7 – 2 % / 0.5 – 2 %
Photons per pulse	$10^{11} – 10^{14}$
Average Brilliance	$10^{17} – 10^{21}$ B*
Peak Brilliance	$10^{28} – 10^{31}$ B*

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







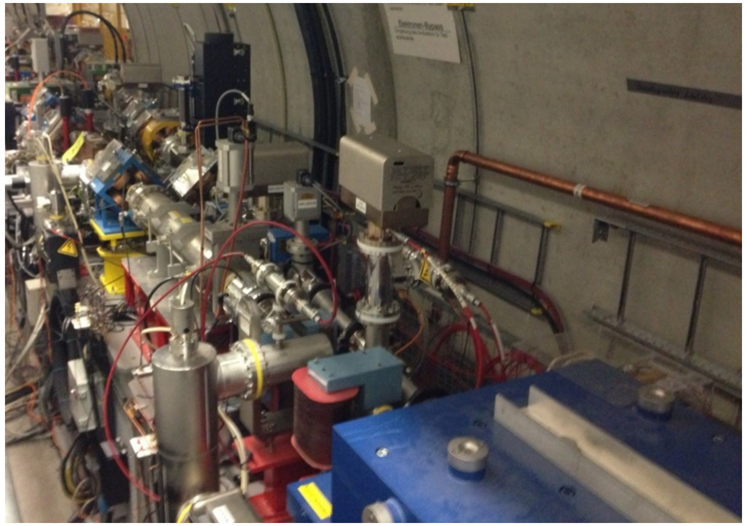


http://photon-science.desy.de/facilities/flash/publications/scientific_publications

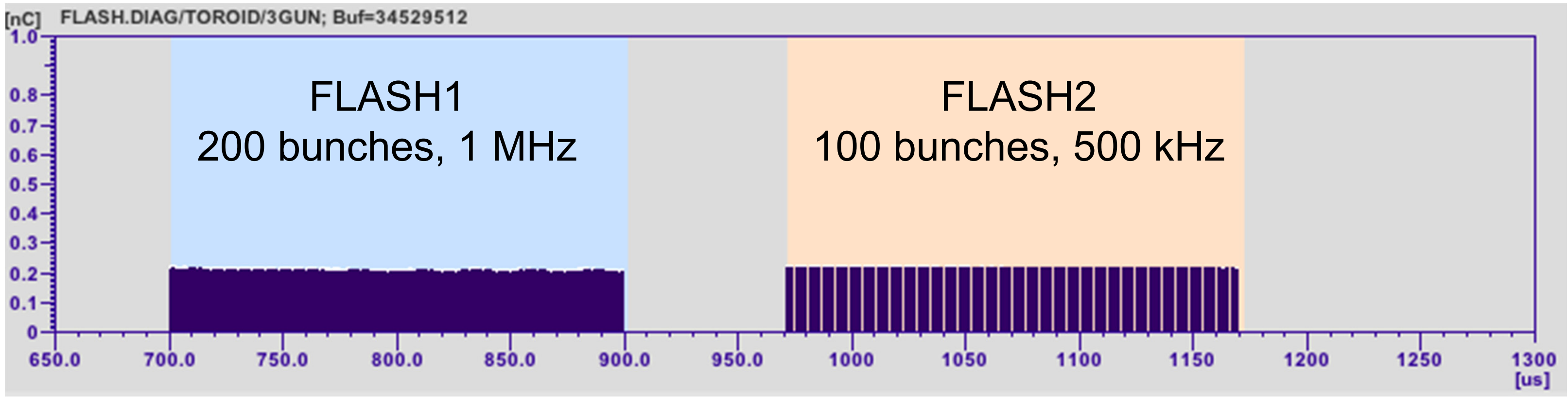
Realization of Simultaneous Operation

Large flexibility in beam parameters

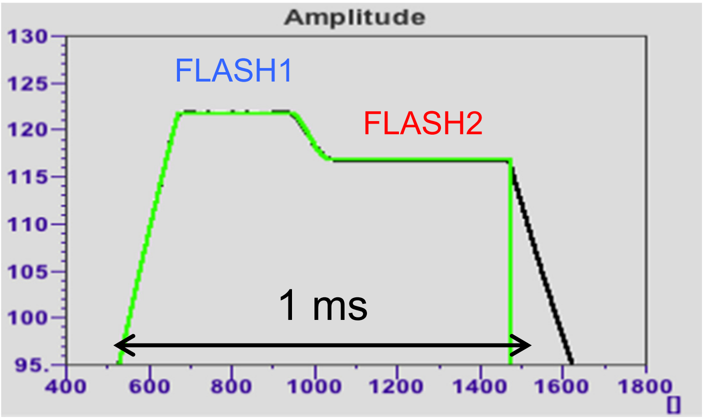
- Fast kicker and Lambertson septum to extract part of the bunch train to FLASH2



- Three injector lasers: Bunch charge, bunch pattern are selected independently for FLASH1 and FLASH2
- Flexible RF-system: amplitudes and phases are adjusted - within certain limits - independently for FLASH1 and FLASH2 → flexible bunch compression



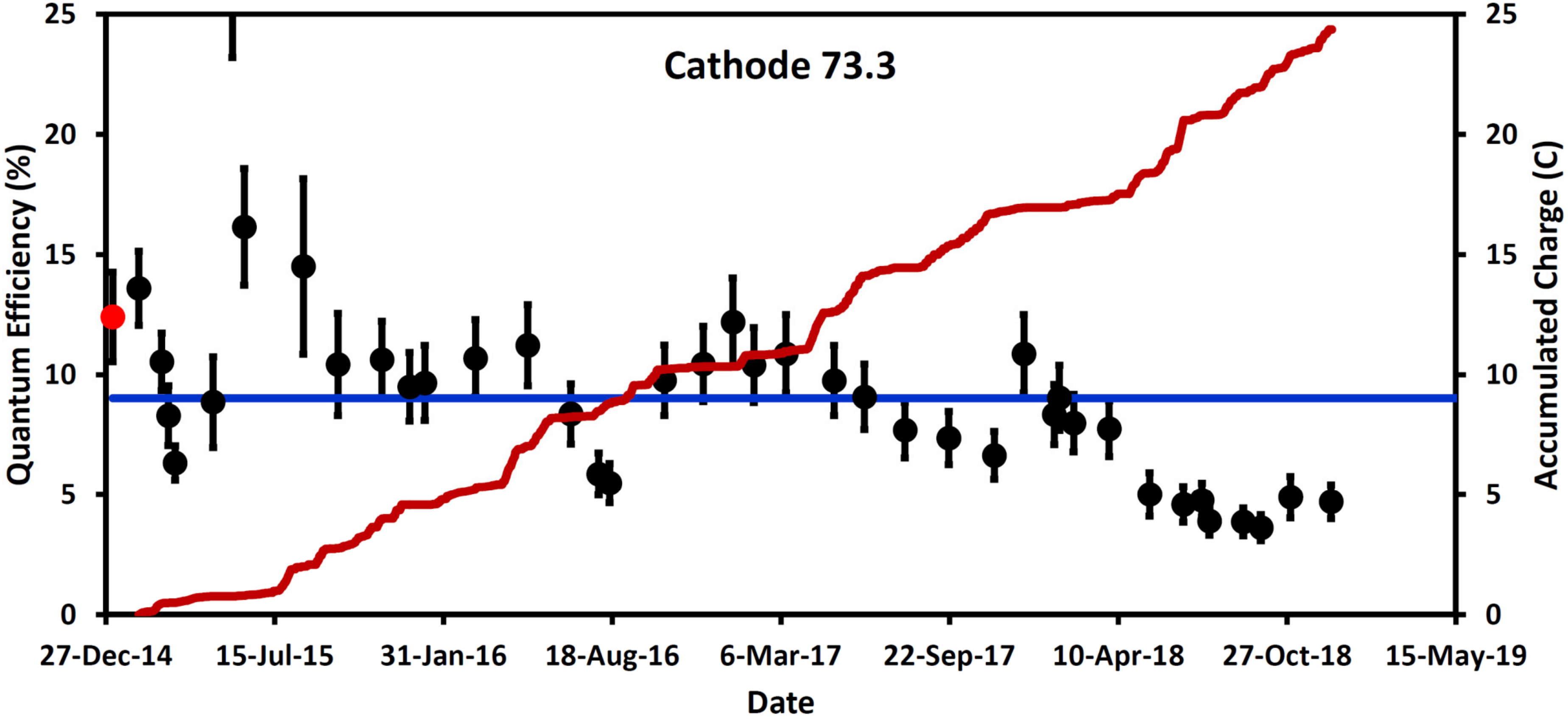
RF-pulse amplitude



FLASH operation

World record in Cs_2Te cathode lifetime

Cathode in continuous operation for 1413 days – accumulated charge 25 C



- WEP048 - *FLASH* Photoinjector Laser Systems

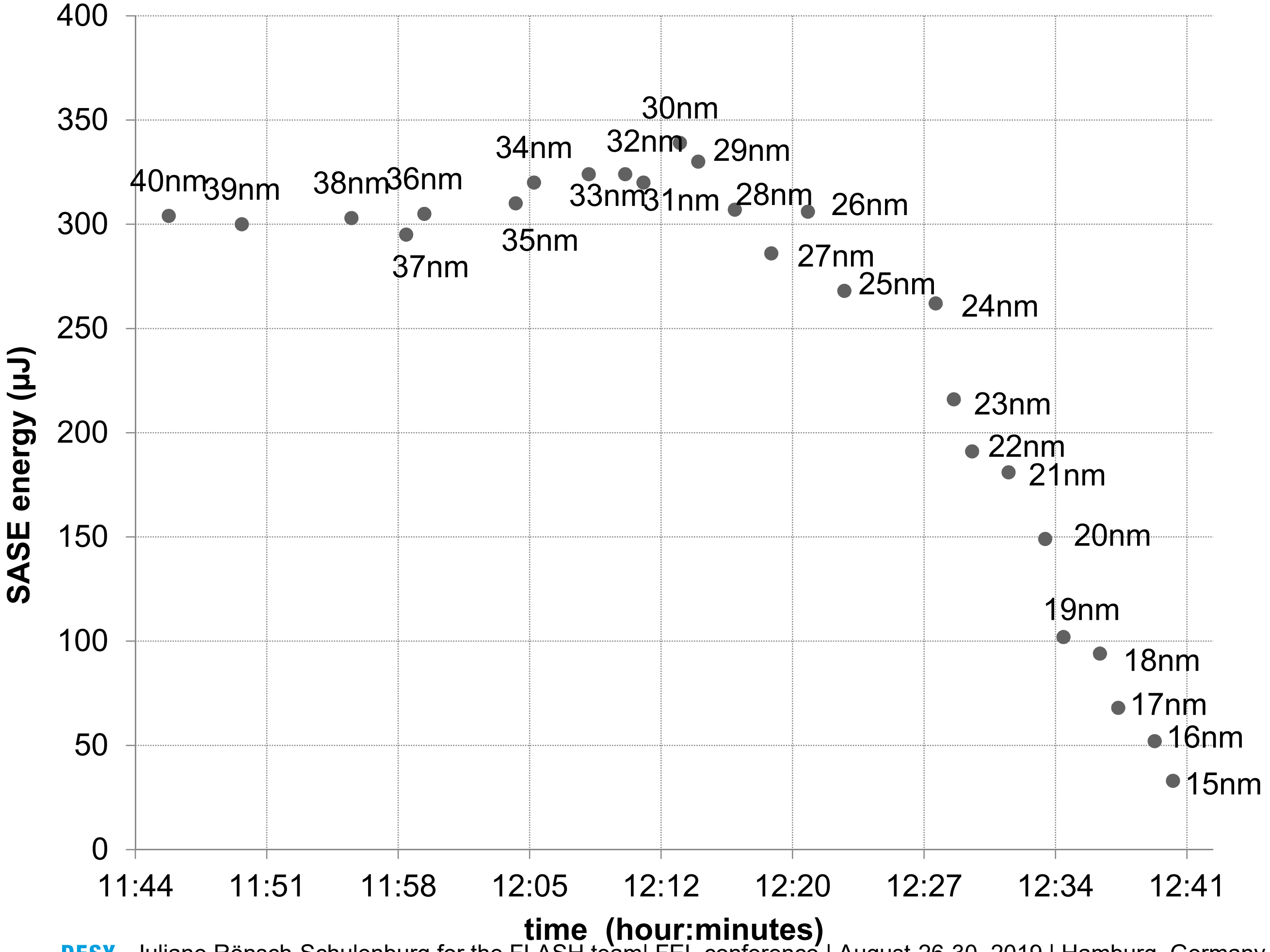
- cathode removed December 2018
- final quantum efficiency: 4.7 ± 0.7 % → still good
- a growing inhomogeneity at the center

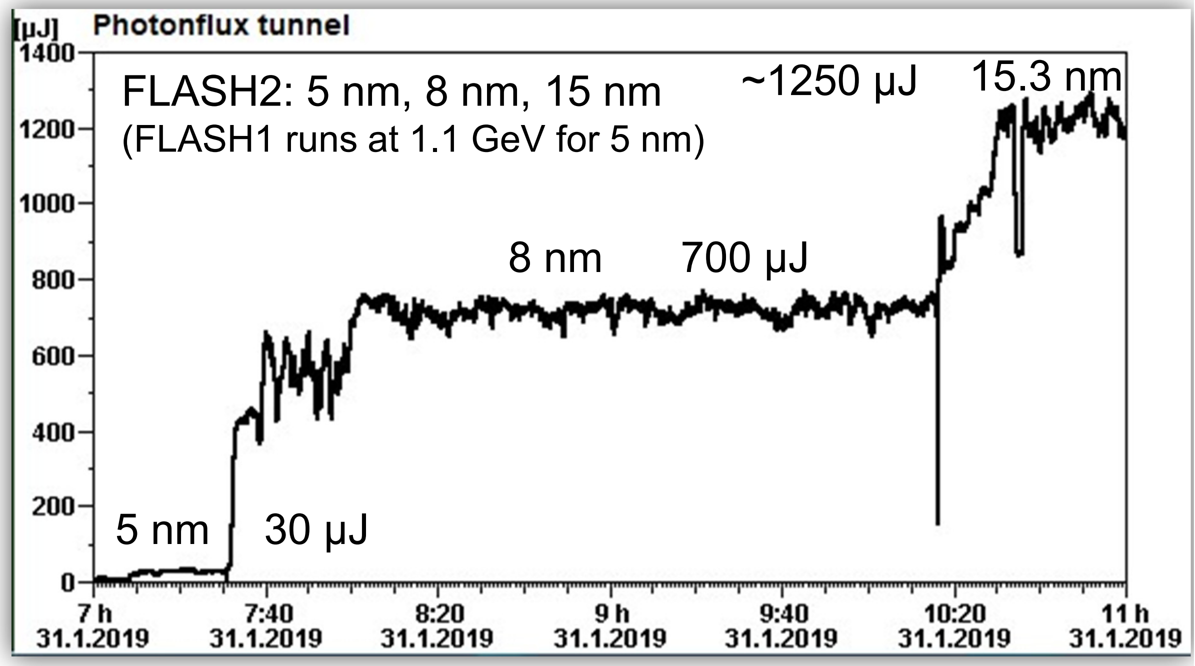
- WEP047 - Update on the Photocathode Lifetime at *FLASH* and European XFEL
- WEA024- Growing and Characterization of Cs2Te Photocathodes with Different Thicknesses at INFN LASA

FLASH2 Wavelength tunability

One accelerator, two undulator beamlines

- FLASH2 has variable gap undulators: wavelength quickly tunable (1 – 3 x FL1 wavelength)

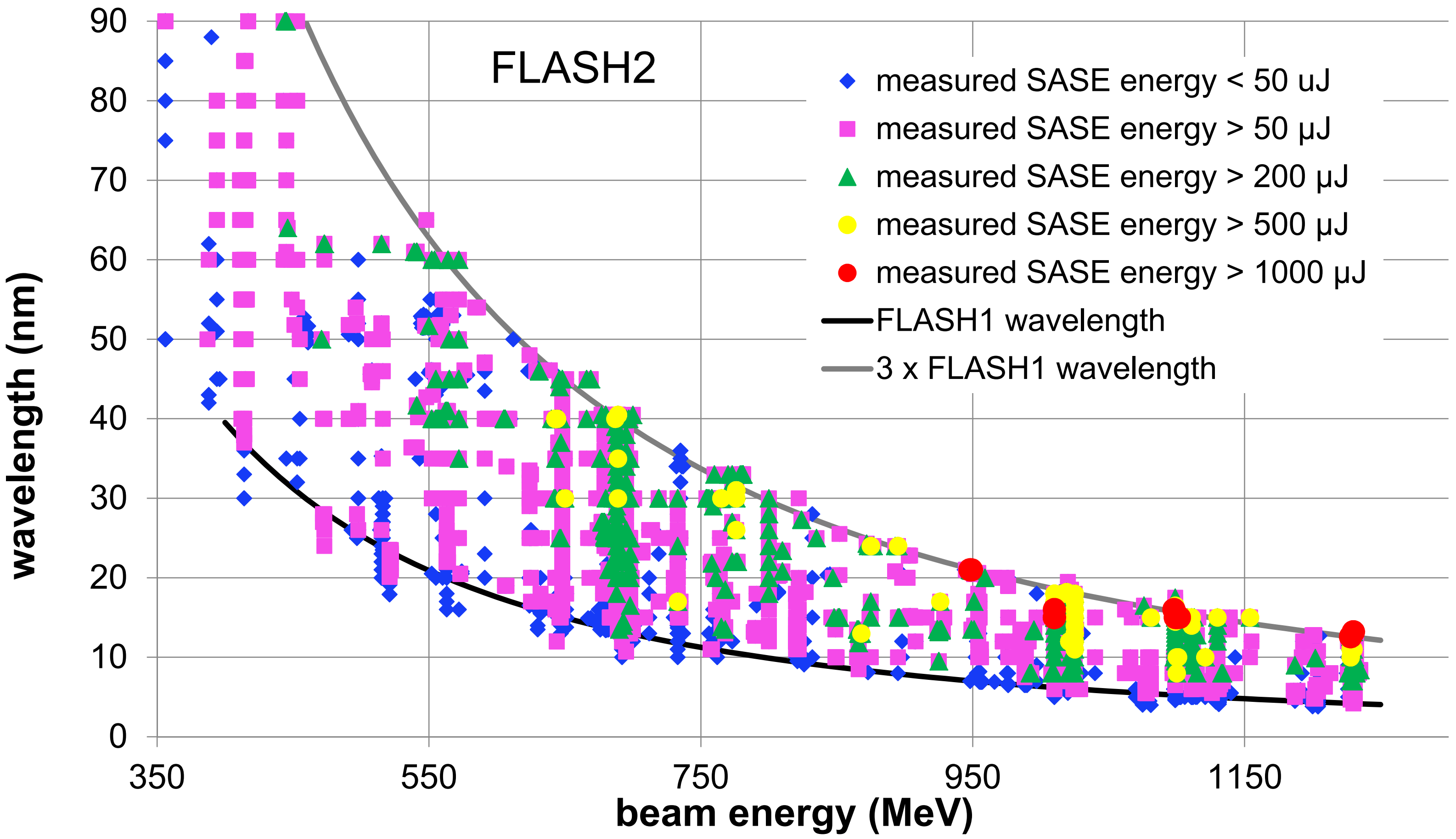




SASE performance

One accelerator, two undulator beamlines

WEP070 - Influence of Radiation Exposure on the FEL Performance at *FLASH*



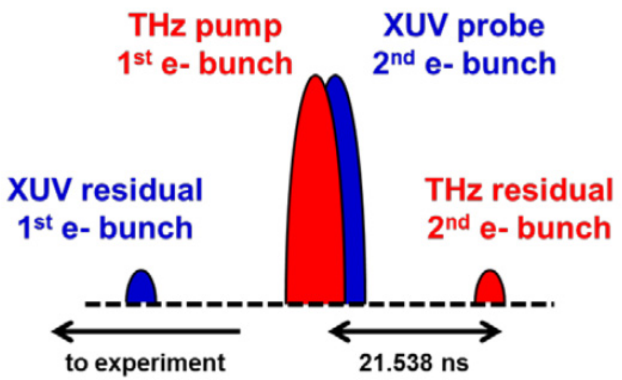
Single spike operation

- Short pulse operation in FLASH1 & FLASH2
- FEL pulses with durations below 10 fs could be demonstrated

Special operation

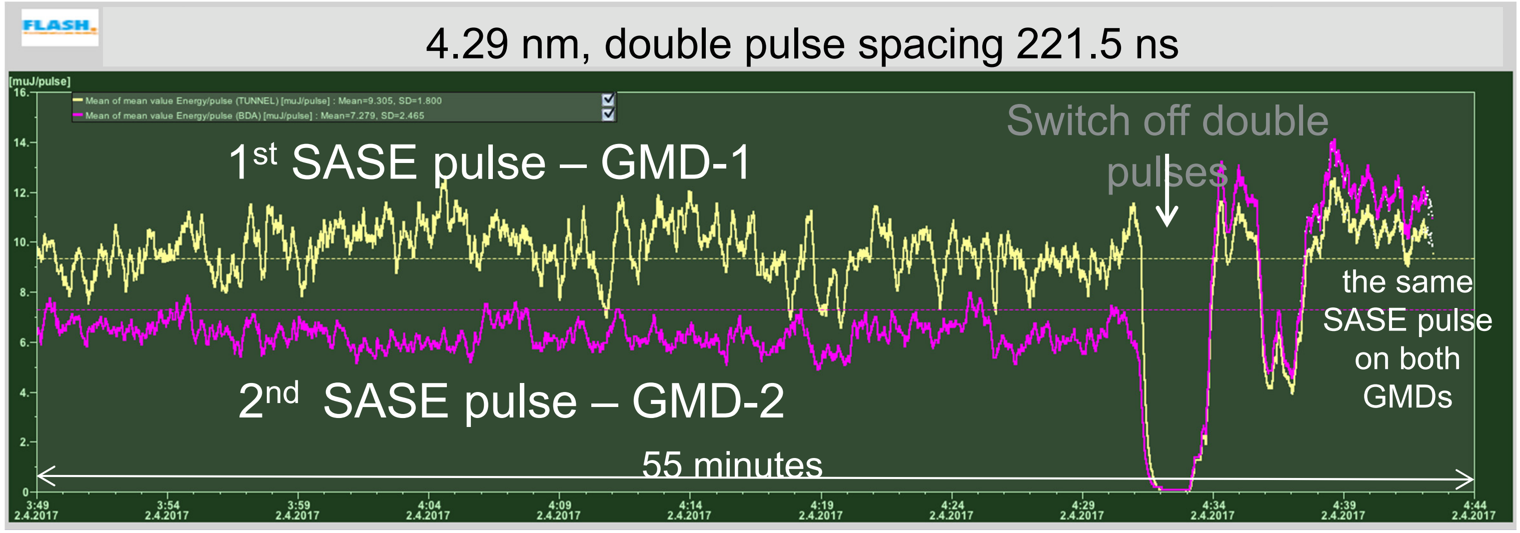
THz doubler

- Goal: THz-pump / XUV-probe experiments with wavelength scan
- Problem: THz beam has a path difference to XUV and this thus delayed by 21.5 ns
- Solution: THz doubler (Split & Delay of injector laser pulses, distance: a few RF-buckets - 21.5 ns)
  - The first bunch generates THz, the second XUV



Double pulses with a large delay

- SASE double pulses with variable nanosecond spacing
- Realized with simultaneous operation of 2 injector lasers in the same beamline
  - delay was adjustable by users in steps of 9.2 ns
  - with a few adjustments of the 2nd laser it is possible to have the same SASE level for both

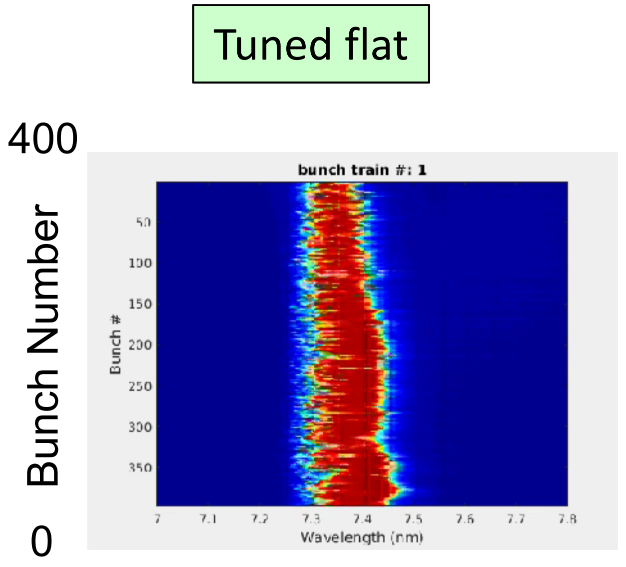


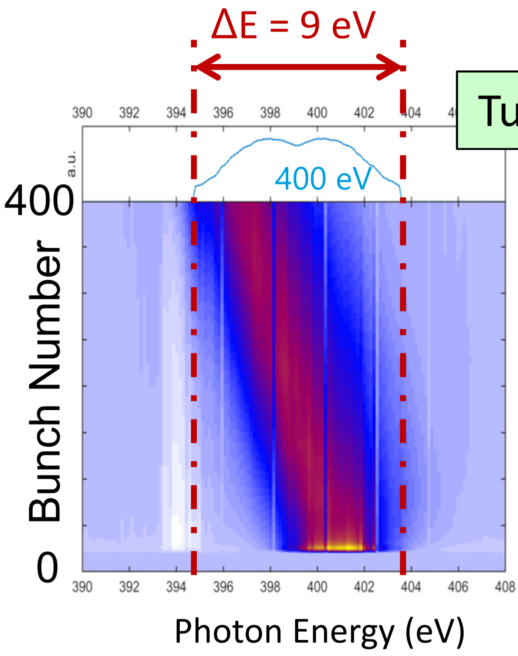
New Possibilities in the Photon Beamline

Single-shot spectra of a train of 400 bunches at 1 MHz

FLASH1 KALYPSO – Fast line detector for intra-train spectrum measurements

- Single shot measurement of XUV spectrum of individual photon pulses in a 1 MHz pulse train
- Integration into FLASH control system DOOCS and DAQ





Tuned with chirp

Doubling the effective FEL bandwidth

THz-streaking

- permanent THz streaking setup for pulse diagnostics has been installed at FLASH2
- recently commissioned

J. Synchrotron Rad. (2018). **25**, 26-31
https://doi.org/10.1107/S160057751701253X

FLASH2 pump probe laser

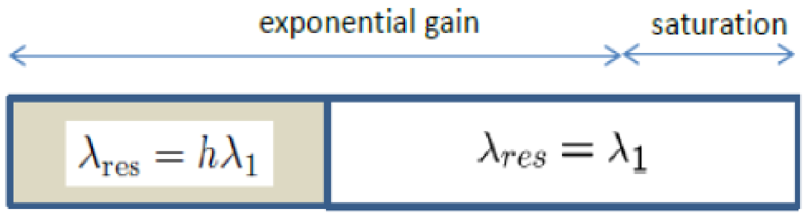
- commissioned in September 2018
- in routine use.

Studies of new lasing concepts at FLASH2

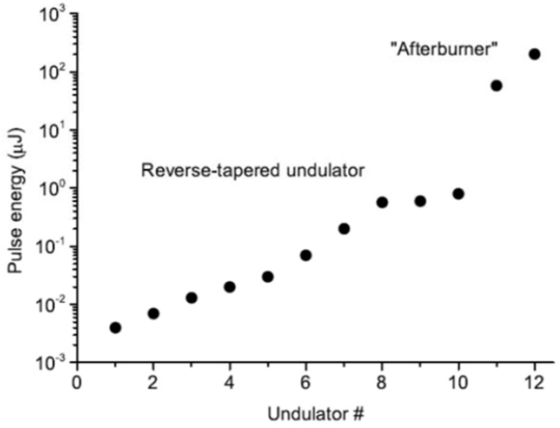
Exploiting the possibilities of variable gap undulators

- **Harmonic lasing self seeding (HLSS)**
  - Improvement of spectral brightness
  - Increase in coherence time

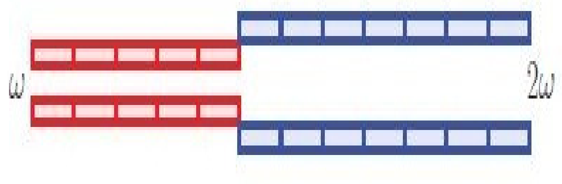
TUA04 Harmonic Lasing Experiment at the European XFEL



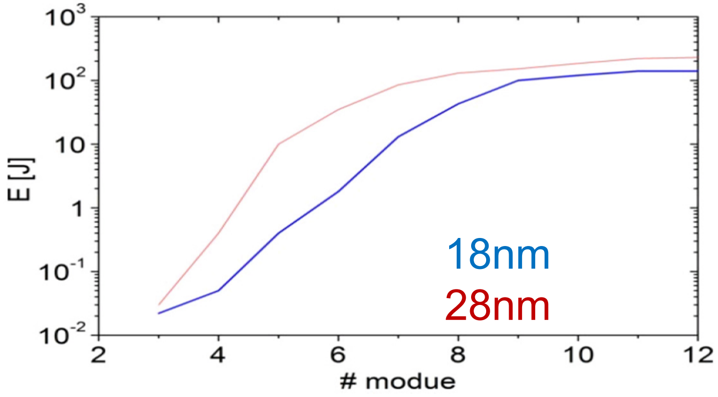
- **Reverse tapering + "afterburner"**
  - Factor 200 intensity increase shown



- **Frequency doubler**
  - shorter wavelengths: down to ~ 3 nm demonstrated at FLASH2



- **Two color lasing**
  - Alternating undulators allow free choice of two colors

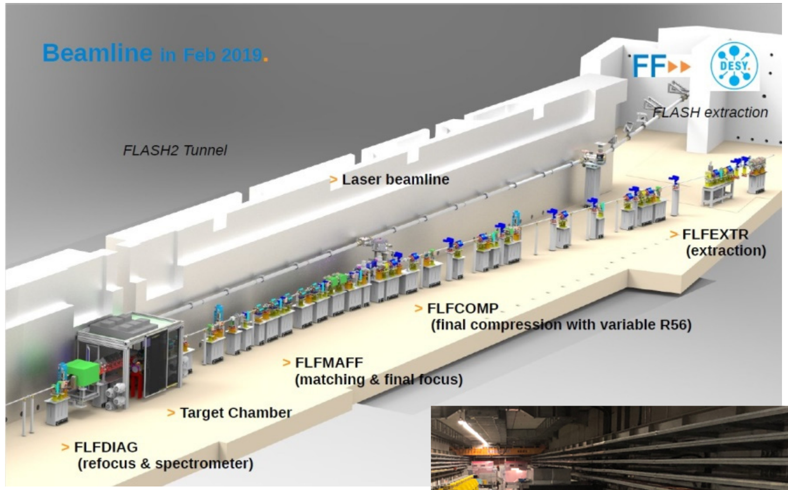


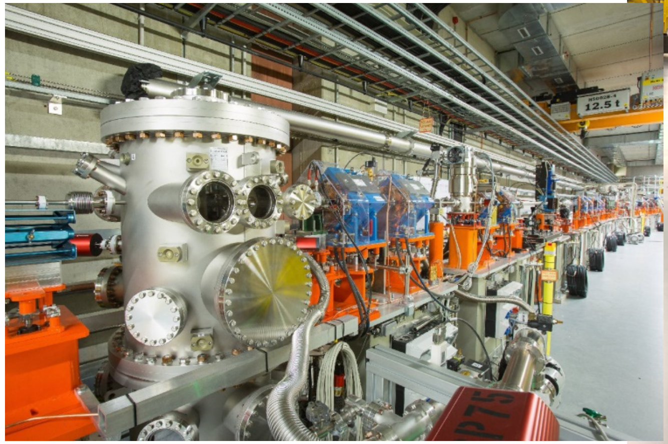
- TUP055 - Two-Color Operation of *FLASH2* Undulator

FLASHForward

Future-ORiented Wakefield Accelerator Research and Development at FLASH

- Third FLASH electron beamline (FLASH3)
- Goals
  - Accelerate external injected bunches in PWFA > 1.5 GeV
  - Preservation of high quality bunch properties
  - Test beam for FEL gain capability
  - Investigation of different injection techniques
  - Explore parameters for high repetition rate and high average power
  - Development of diagnostics for plasmas and “witness” and “driver” electron bunches





sFLASH

Seeding experiment

- Dedicated to the study of external seeding techniques
- HGHG-seeded FEL operation @ 7th & 8th harmonic of the seed laser (38.1 nm, 33.4 nm)
- Development of seed laser diagnostics techniques
- EEHG seeding is under investigation

- TUP075 - Seeding R&D at sFLASH

Mid-term refurbishments

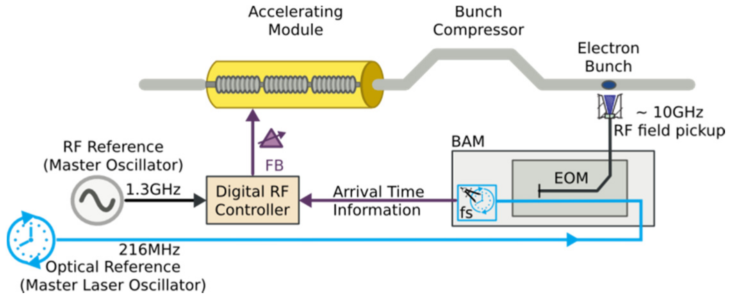
2017 – 2020+

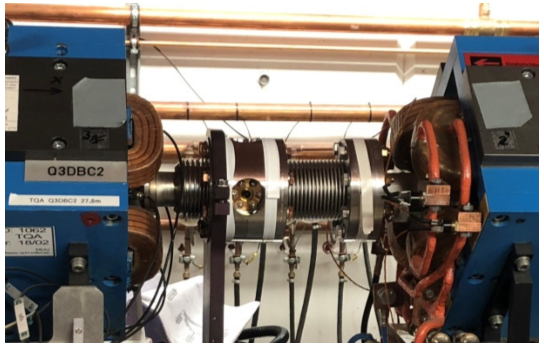
Upgrade Synchronization System

Master laser oscillator, optical links, and BAMs (Bunch Arrival Time Monitors)

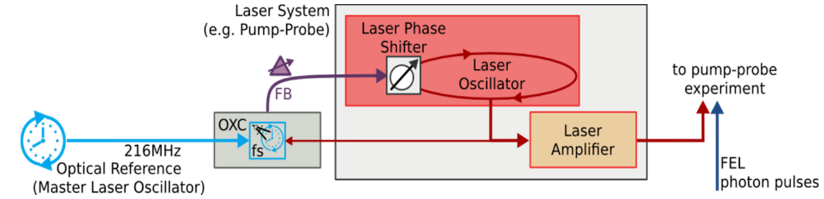
- New BAM pick-ups + new electro-optical front-ends with an improved sensitivity especially for low bunch charges
- The synchronization lab has been completely refurbished
- Optical links through polarization-maintaining optical fibers

Measurement & Stabilization of the Electron Bunch Timing

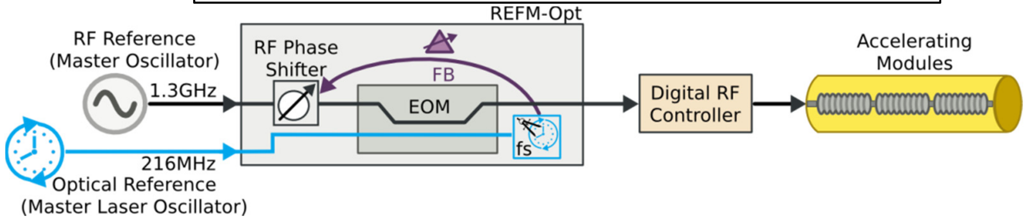




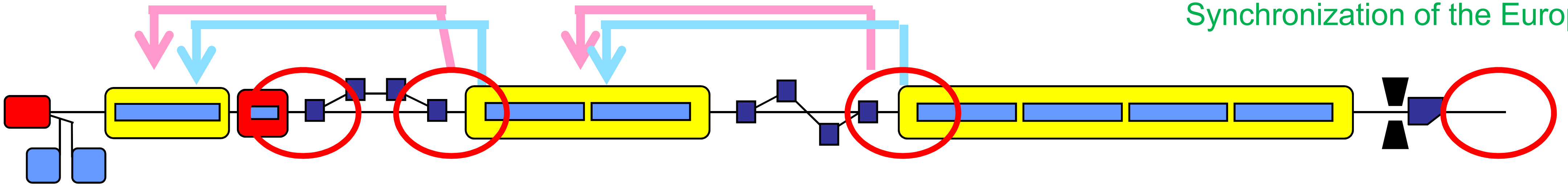
All-Optical Laser-to-Laser Synchronization



Phase Drift Compensation of the RF-Reference used for Acceleration



- WEB04 - Few-Femtosecond Facility-Wide Synchronization of the European XFEL

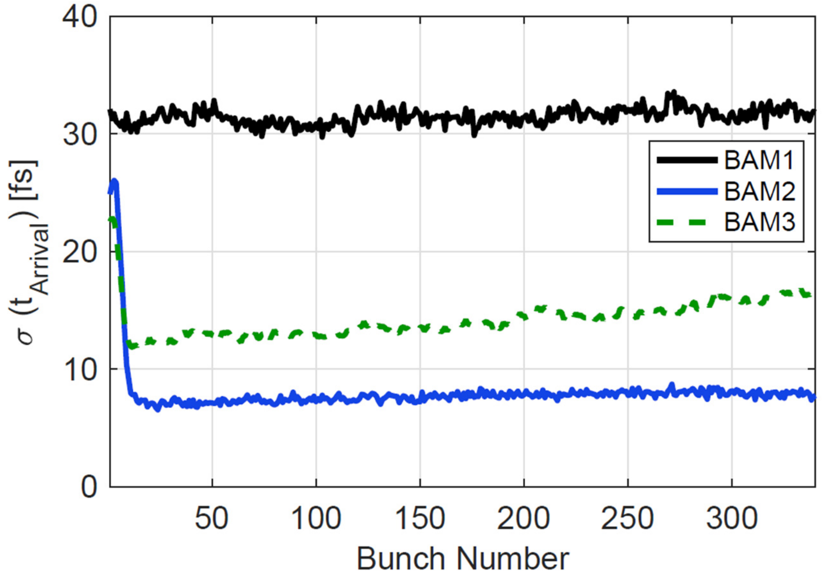


BACCA

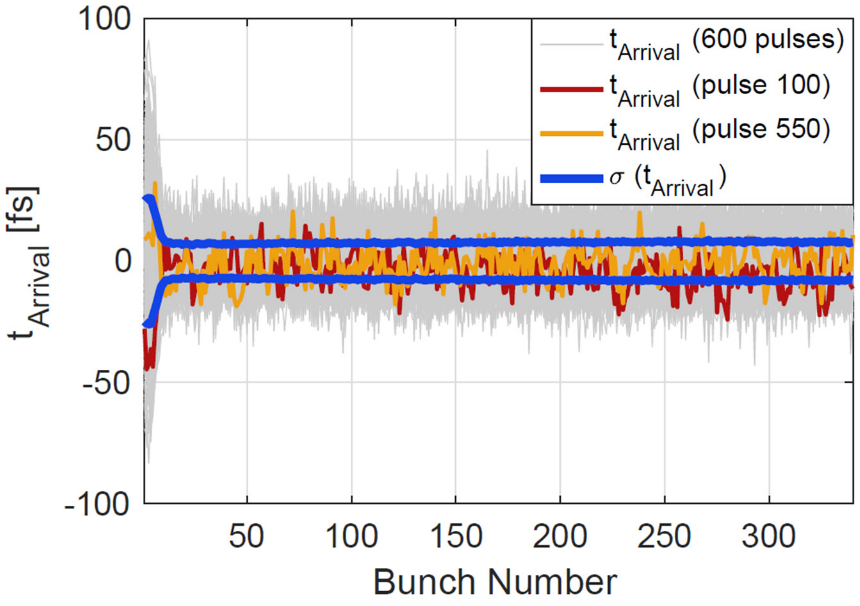
Fast arrival time stabilization with warm RF cavity BACCA

- Normal conducting, S-band cavity “Bunch Arrival Corrector CAvity” (BACCA)
- Larger bandwidth to improve the arrival time stability below 5 fs
- Latest measurements: arrival time stability improved from 25 fs (rms) to 8.5 fs (rms)
- The steady state value of the arrival time stability is reached within the first 10 bunches (10μs for 1 MHz)

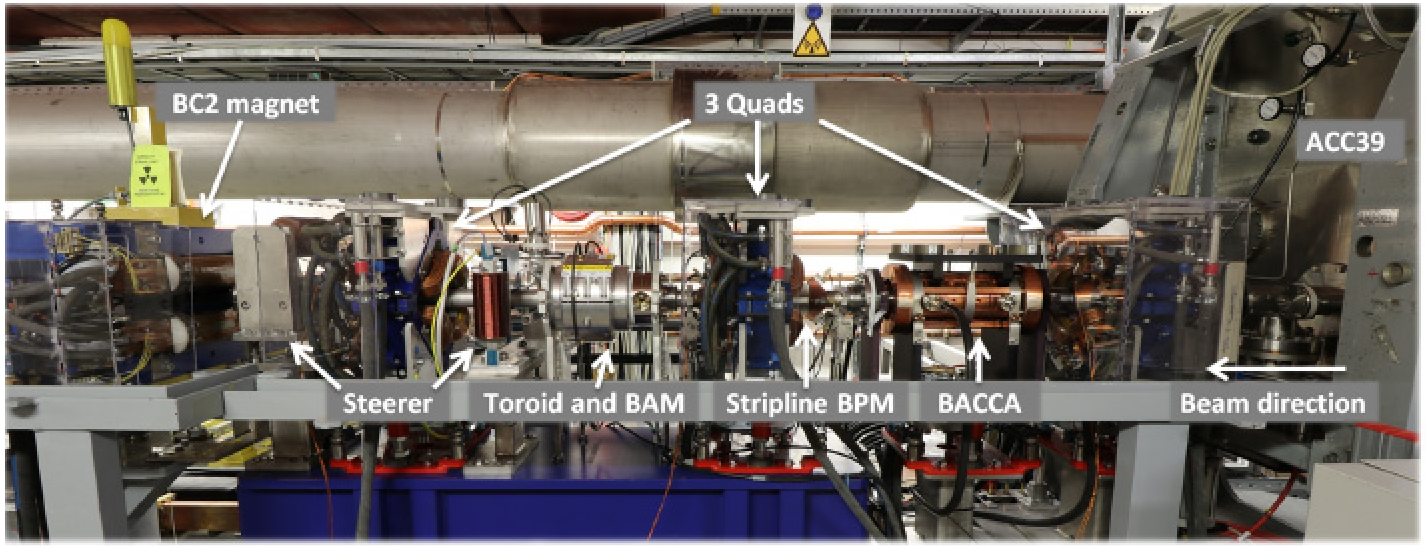
- WEP011 - Longitudinal Intra-Train Beam-Based Feedback at *FLASH*



Standard deviation of the arrival time for all three BAMs



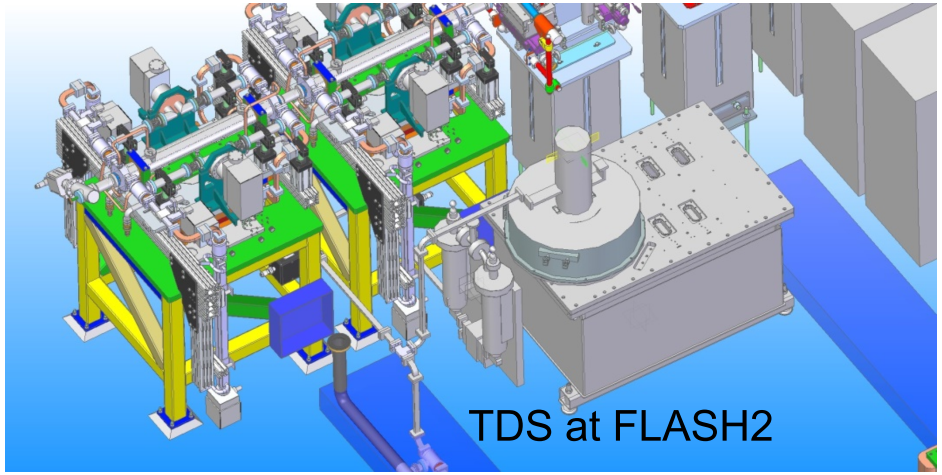
Mean free arrival time of the second BAM.

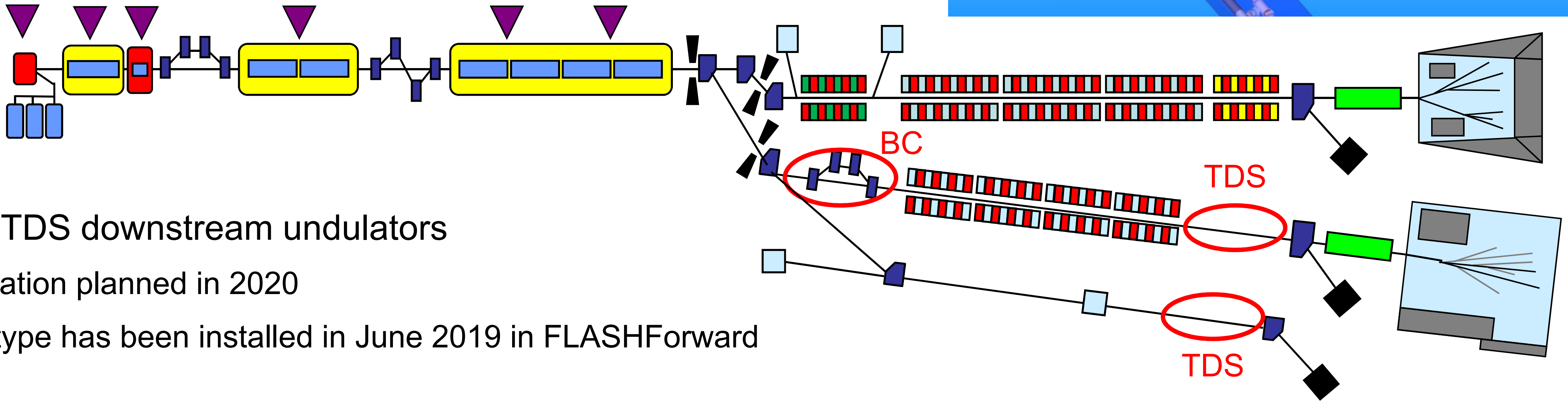


FLASH2

Installations 2019-2020

- Additional bunch compressor downstream extraction
  - Less compression at lower energies
  - Better control of CSR and space charge effects
  - Simulations show a significant improvement beam properties
  - Installed in June 2019, now routinly operated





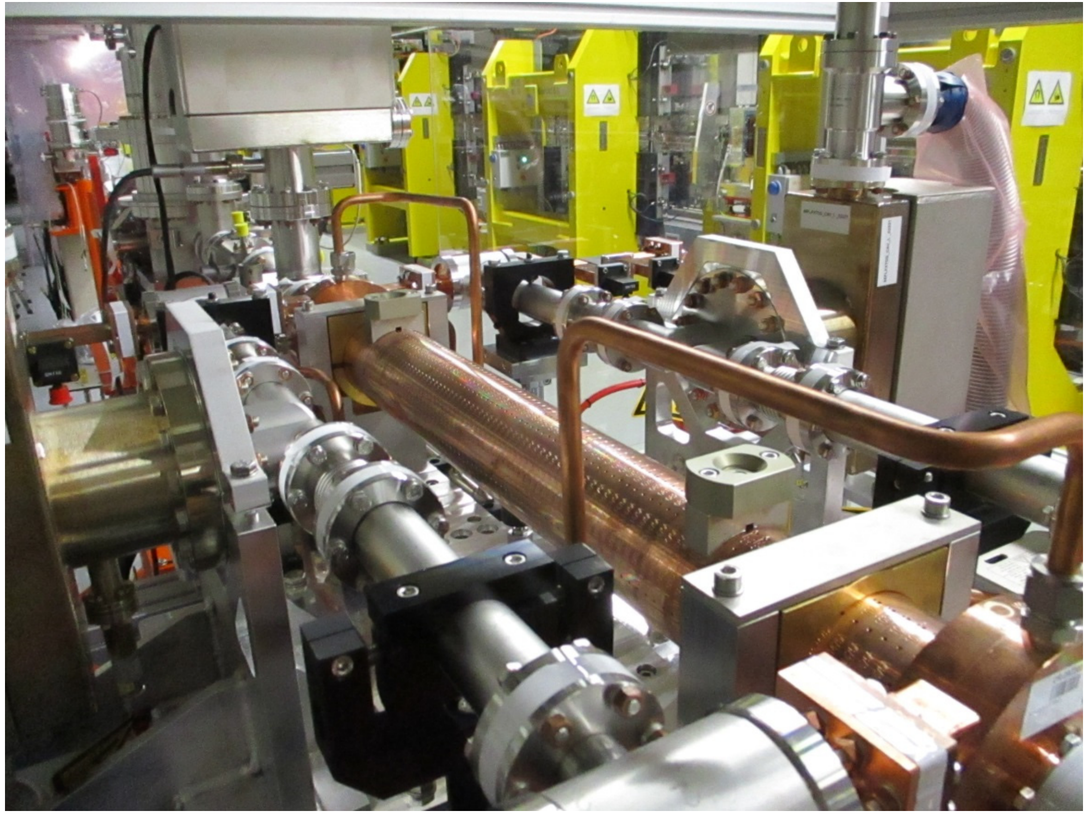
- PolariX-TDS downstream undulators
  - Installation planned in 2020
  - Prototype has been installed in June 2019 in FLASHForward

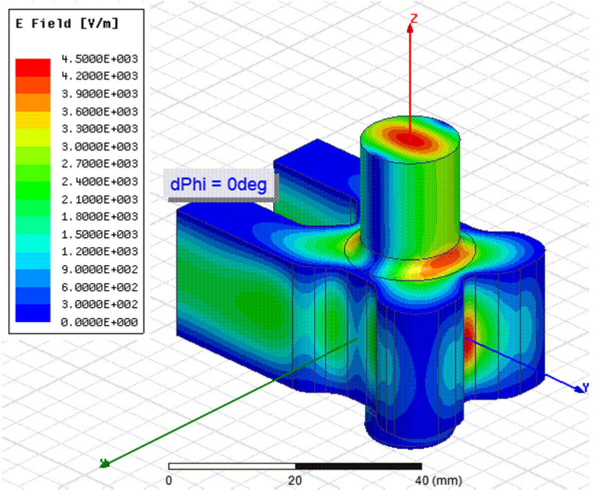
- WEP006 - A PolariX TDS for the *FLASH2* Beamline

PolariX TDS

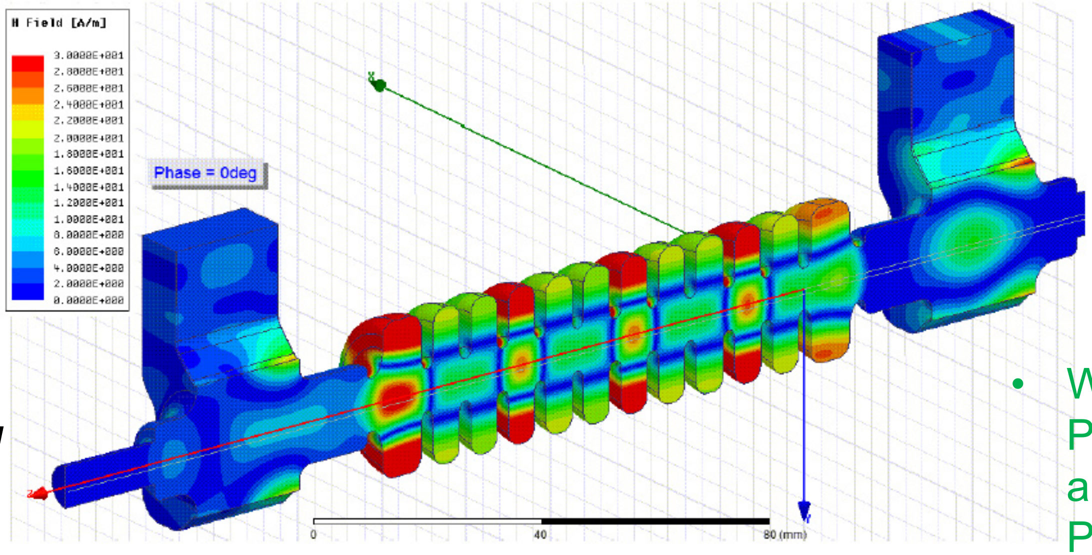
Polarizable X-band Transverse Deflection Structure

- Development of a new X-band (12 GHz) deflector
- In cooperation with CERN and PSI
- New feature: variable polarization
- PolariX @ DESY: SINBAD, FLASHForward, and FLASH2





Courtesy of A. Grudiev, CERN

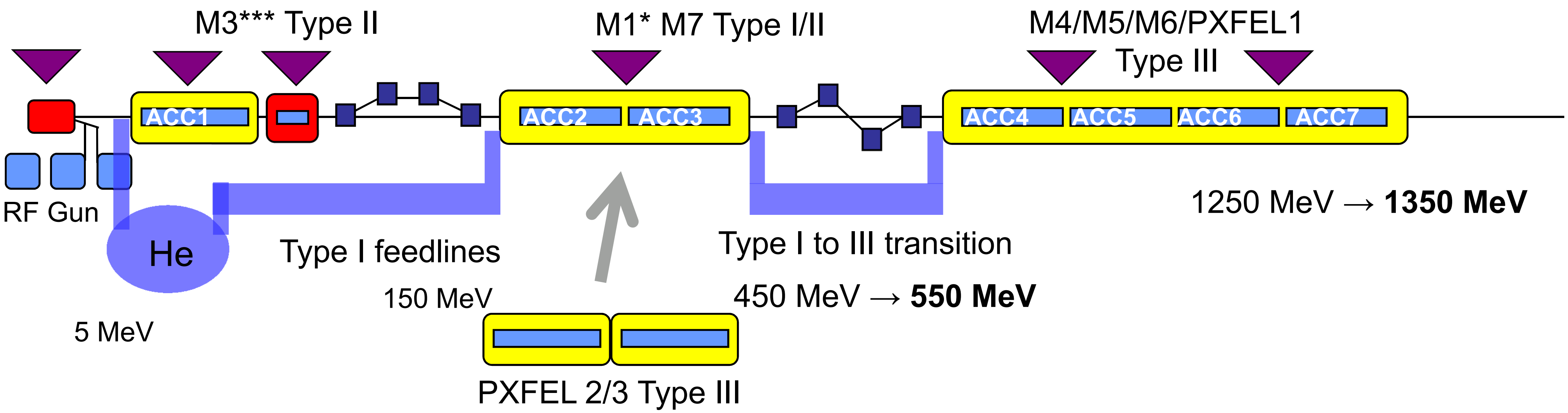


- WEP036 - The *PolariX-TDS* Project: Bead-Pull Measurements and High-Power Test on the Prototype

Refurbishment of old accelerator modules

Increase energy – improve RF control

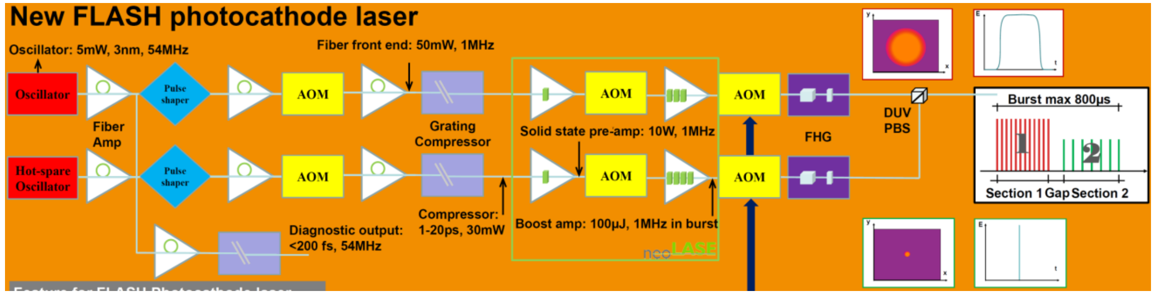
- Replace accelerator modules ACC2 and ACC3 with refurbished XFEL type modules (PXFEL2 and PXFEL3)
- We have good cavities with high gradients: >100 MeV energy gain expected
- Include Piezo tuners
- New waveguide distritibution for ACC2-5
- Installation scheduled in 2021



Refurbishments

Further planed refurbishments

- **New Generation Photoinjector Laser Development**
  - simple and robust architecture, similar to now but with modern laser technology
  - flexible pulse pattern within one train (for FLASH1 and FLASH2): different aperture sizes, charges, pulse durations
- **Polarized photons for FLASH2 → for new type of experiments**
  - allows short wavelengths down to approximately 1.5 nm with variable polarization
- **Fast intra-train orbit feedback**
  - further improve stability along the bunch train
- **Waveguide upgrades ACC45**
- **Coupler interlock electronics**
- **New RF Gun with higher average power**
  - 1 ms pulse length
- **Transverse profile monitors (screen stations)**



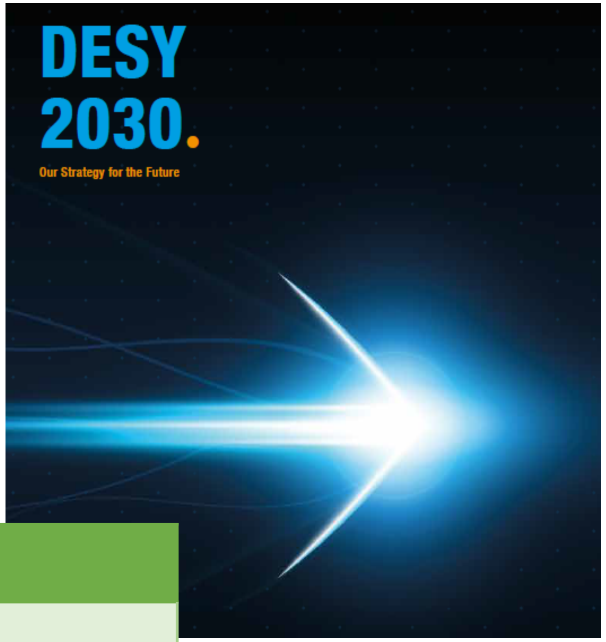
- WEP072 - Expected Radiation Properties of the Harmonic Afterburner at *FLASH2*

FLASH 2020+

Within the DESY 2030 strategy

Proposed Parameter Space FLASH2020+

A seeded high repetition rate XUV and soft X-ray FEL



	FLASH1 (Seeded)	FLASH1 (SASE)	FLASH2	
Wavelength range	4 – 60	4 – 60	1.3 – 60*	nm
Pulse energy	<100	<1000	<1000	µJ
Pulse duration (FWHM)	30	5 – 200	0.1 – 200	fs
Spectral width	Fourier limited	0.5 – 2	0.5 – 2	%
Pulses per second**	10 – 5000	10 – 5000	10 – 5000	

* including third harmonic

** to be shared between FLASH1 and FLASH2 (goal: 1 ms RF pulse length)

Proposed steps towards FLASH 2020+

Our Strategy for the Future

1. **Upgrade accelerator**

   many refurbishment projects, increase beam energy, upgrade compression scheme

2. **New undulators with variable gap for FLASH1**

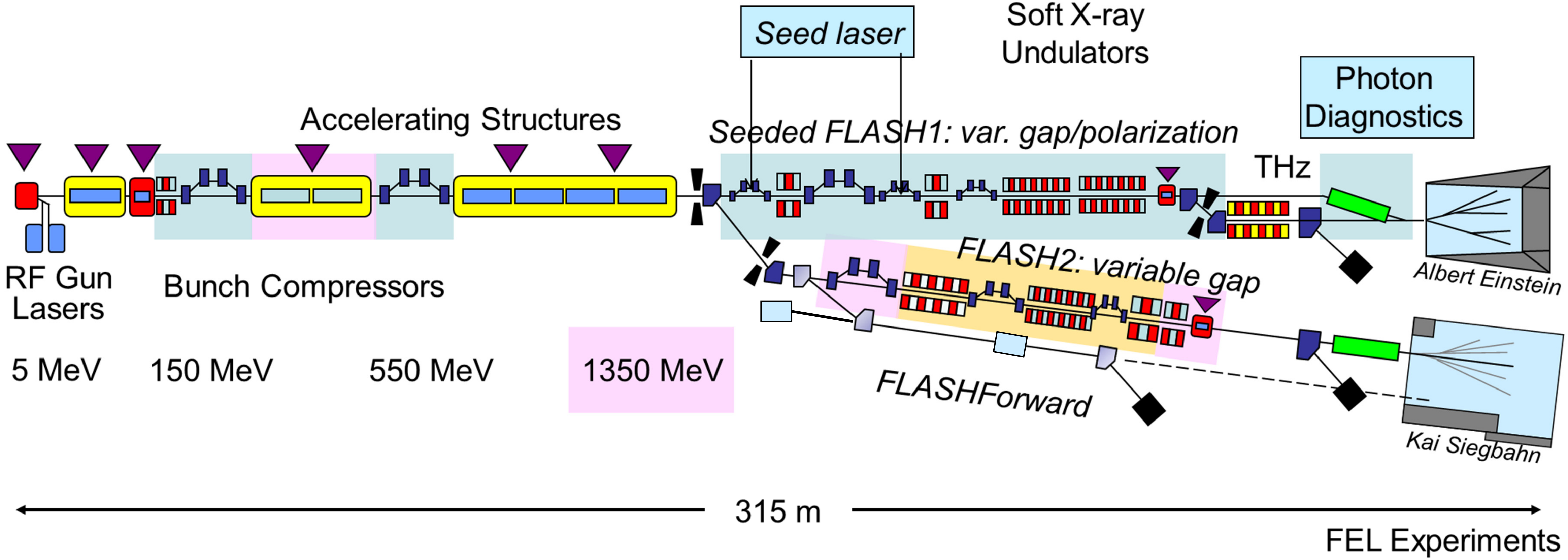
3. **Seeding with high repetition rate**

   high repetition rate high power seed laser (phase 1: 100 kHz; phase 2: 1 MHz)

4. **New configuration of undulator structures at FLASH2 for novel lasing concepts**

Proposed Layout FLASH2020+

Towards a seeded high repetition rate XUV and soft X-ray FEL



Step 1
Energy upgrade
3rd BC (FLASH2)
TDS (FLASH2)
Afterburner FLASH2

Step 2
Variable gap undulators (FLASH1)
Pump-Probe laser (FLASH1)

Laser heater in 1st BC
New 2nd bunch compressor (BC)

Step 3
High rep.rate seeding (FLASH1)
Photon diagnostics (FLASH1)

Step 4
New variable gap undulators + chicanes
for new lasing concepts (FLASH2)

Thanks …

…for your attention

…to the FLASH team & operators