Low Level RF Control Implementation and Simultaneous Operation of Two Undulator Beamlines at FLASH

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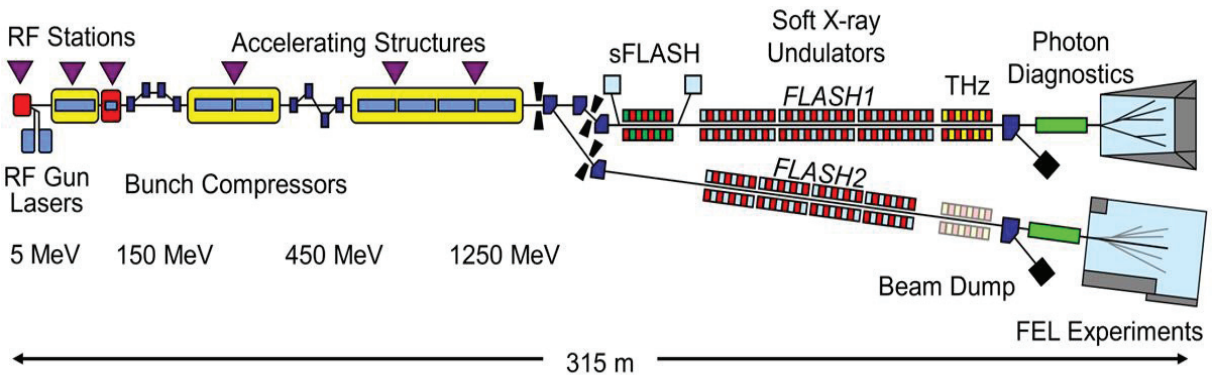
DESY

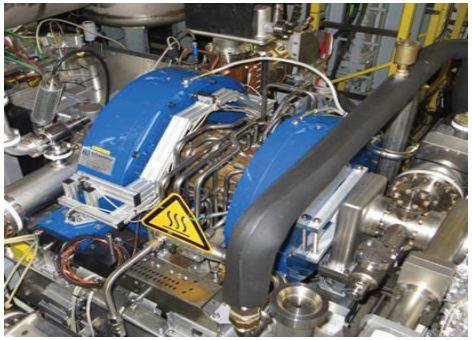
Outline

- FLASH and the FLASH II project
  - Basic layout of the facility
  - Pulsed operation mode and timing aspects
- LLRF control system
  - Schematic view and functionality
  - Regulation performance and limitations
- Operational requirements and results
- Summary

*F*ree-electron *L*aser in *H*amburg - user facility since 2005



Parameter	Value
Wavelength Range (fundamental)	4.2 - 52 nm
Average Single Pulse Energy	10 - 500 µJ
Pulse Duration (FWHM)	<50 - 200 fs
Pulses per second	10 - 5000
Peak Power (from av.)	1 - 3 GW
Average Power	up to 600 mW
Spectral Width (FWHM)	0.3 - 2 %

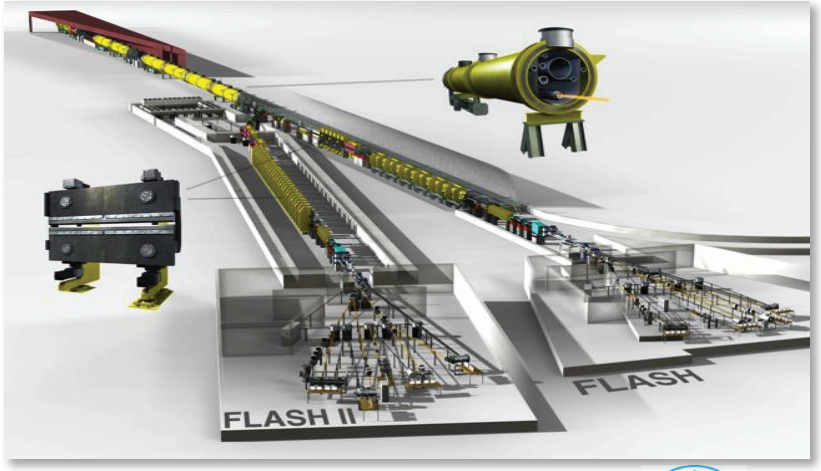


The FLASH II Project

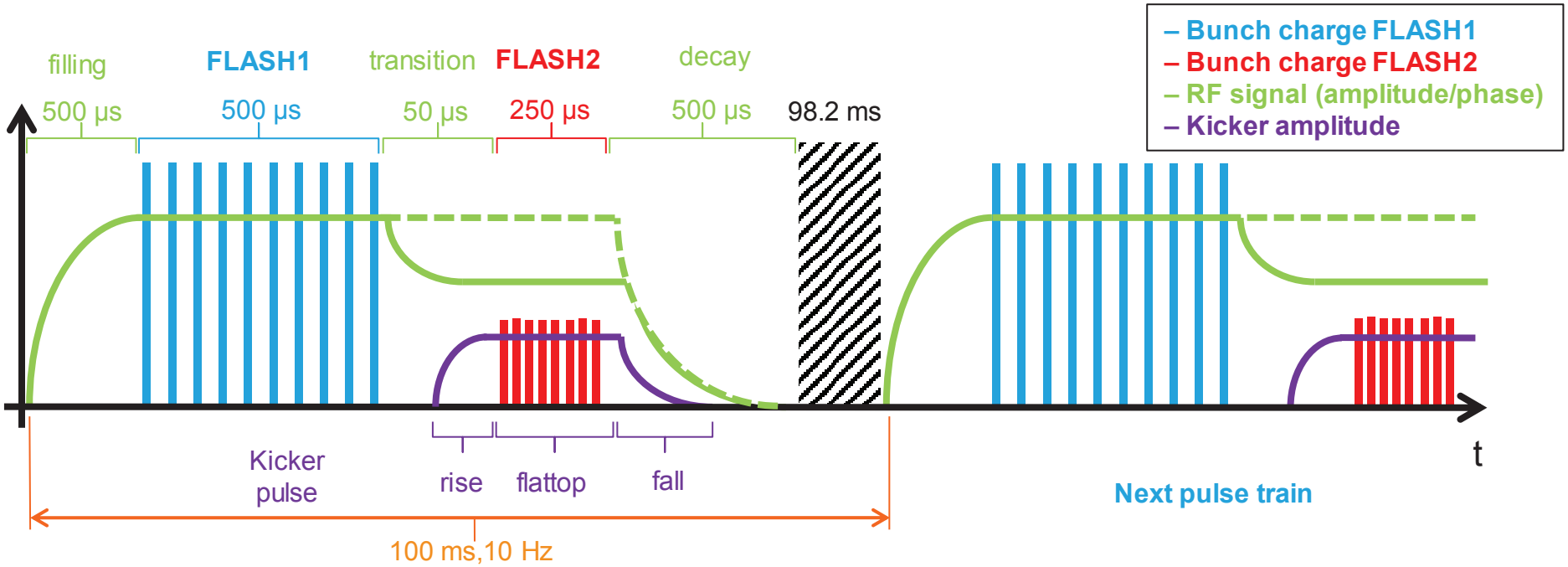
- Installation of a second undulator beamline and experimental hall
  - Using the same acceleration section, separation of the two beamlines (kicker, septum)
- Tuning of FLASH2 wavelength by movable undulator gap
  - Wavelength variation w.r.t fixed undulator gaps in first beamline (tuning by energy change)
- Extend user capacity providing SASE (Self-Amplified Spontaneous Emission)

RF control requirements for Multi-BL operation

- Amplitude and phase can – in certain limits – be independently chosen for both FELs
  - Ability of variation in compression FLASH1 and FLASH2
  - Ability of variation of energy → depending on optics setup
- Handling different beam loading scenarios
  - Bunch repetition rate, number of bunches and charge

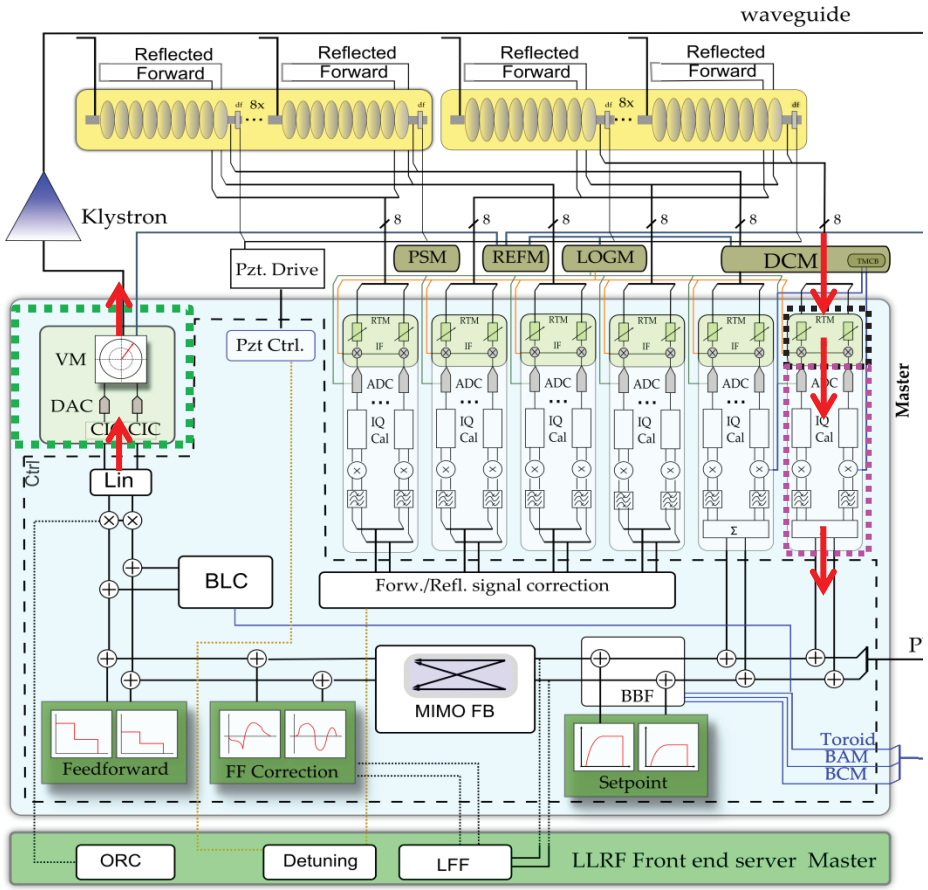


Temporal Structure (An Example)

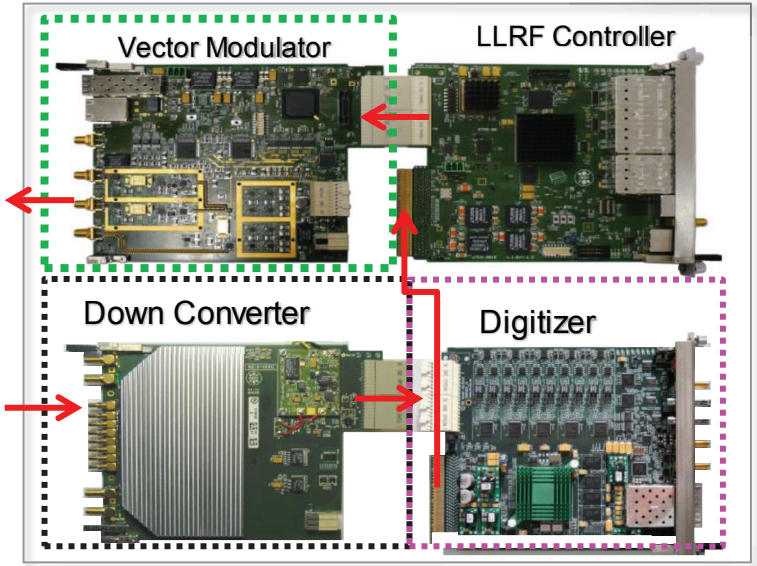


- Same optics setup for both beamlines, limitations of the bunch parameter range
  - Energy acceptance in dispersive sections, slow magnet changes
  - Two lasers operating on one cathode (alignment, orbit)

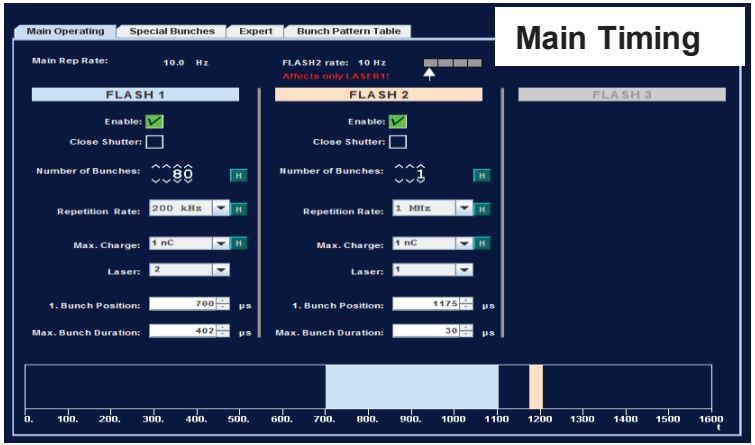
MicroTCA.4 LLRF System – signal flow



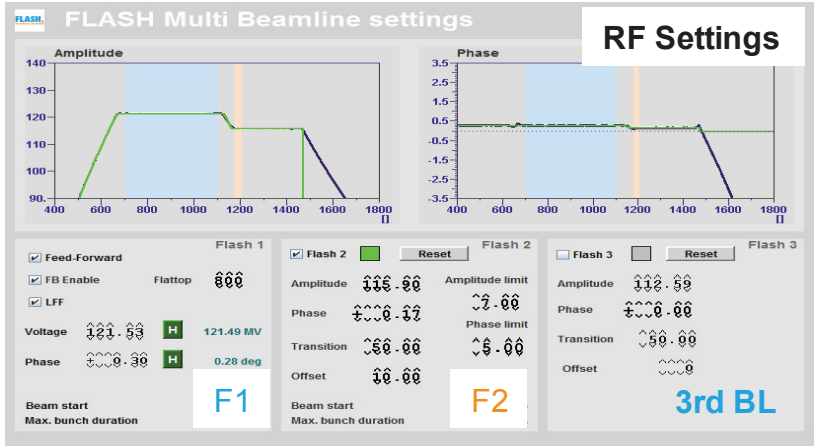
- In operation since 2 years
- New HW development (not only LLRF)
- Software had to be restructured **Poster: WEPGF029**



RF Control Functionality Extension for FLASH2



LLRF

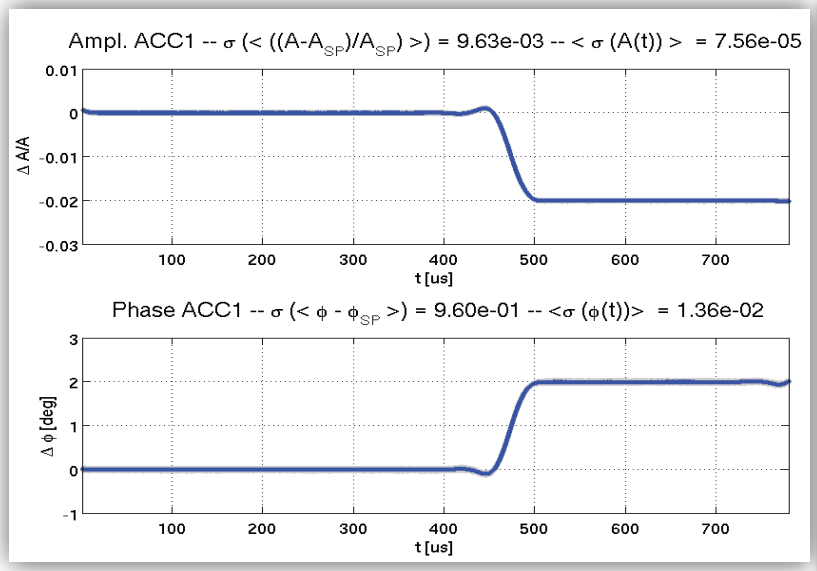


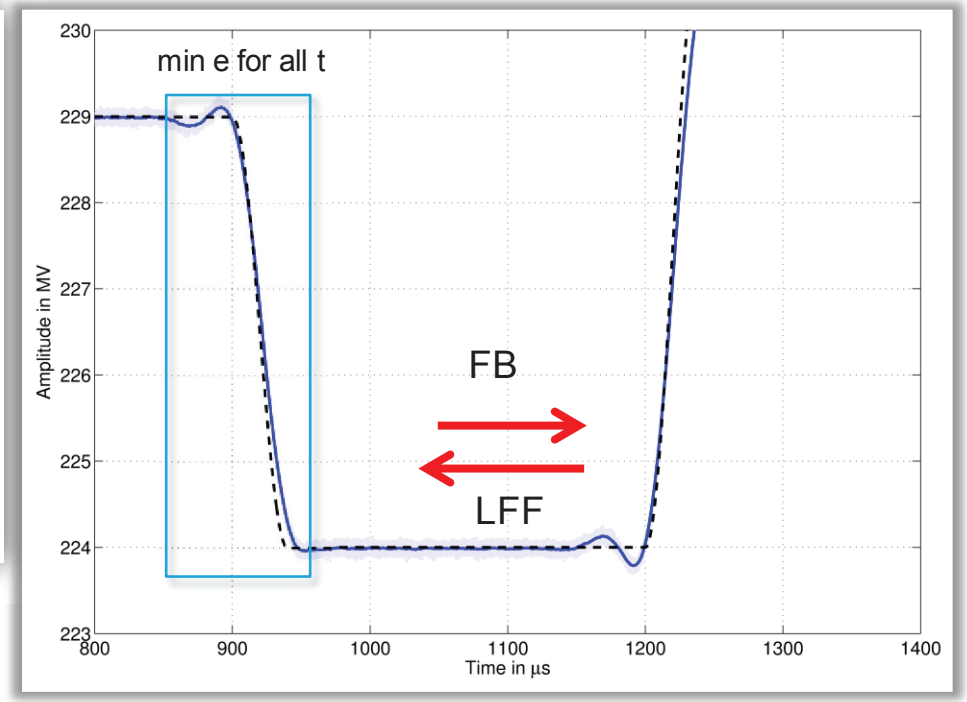
Kicker, BPM, BLM, MPS, Laser ctrl., …

- Beside LLRF, all machine timing triggered systems receive a priori beam information => no manual synchronization
- LLRF control tables are generated from the operational setting according to the provided timing information
- Independent RF operational parameters adjustment (defined limits)
- Colored display indication for overview panels and plots

RF Control Performance

- Vector-sum amplitude and phase stability fulfills given requirements



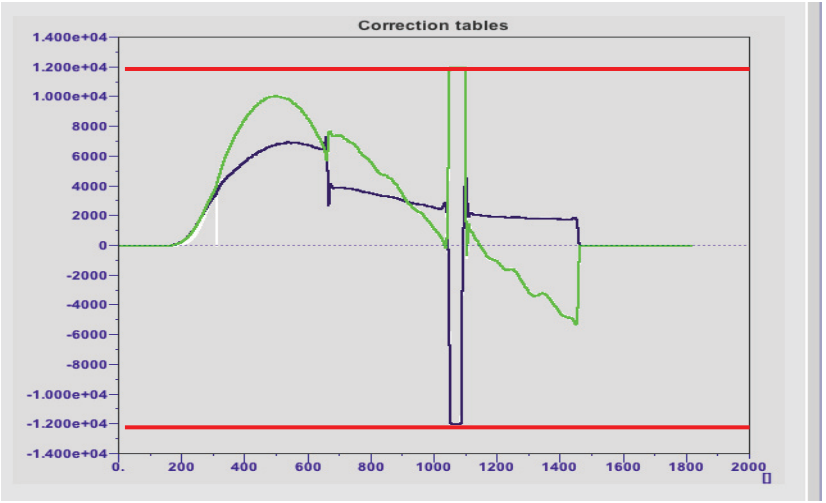


- Kicker given minimum transition time can be achieved
- Smooth transition steps to avoid broadband excitation

Regulation Limitations at Transitions

- Limitations on driving correction tables / driving amplitude (klystron, coupler)
- MIMO system, model-based algorithm – non causal, iterative
  - Phase diff compensation => amplitude comp.
- Solutions:
  - Longer transition times
  - Smaller steps/differences

  } external requirements
  - Temporal non-adaptation
  - Variable weighting for the cost function

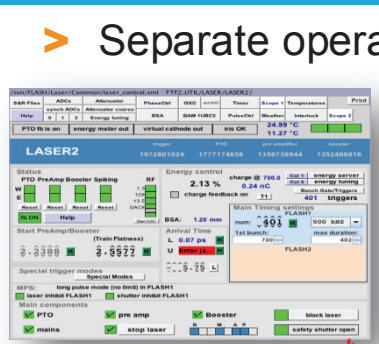


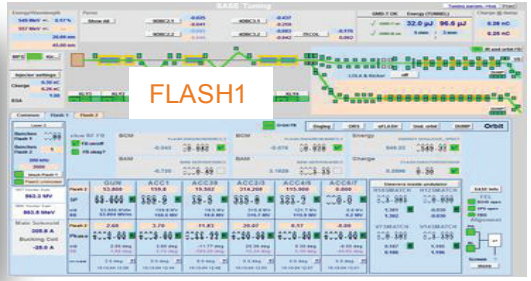
$$J_{k+1}(u_{k+1}) = \frac{1}{2}\sum_{t=0}^{M} e_{k+1}^{T}(t)W_1(t)e_{k+1} + [u_{k+1}(t) - u_k(t)]^T W_2(t)[u_{k+1}(t) - u_k(t)]$$

$$u_{k+1} = \arg\min_{u_{k+1}}\{J_{k+1}(u_{k+1}) : e_{k+1} = r - y_{k+1}\}$$

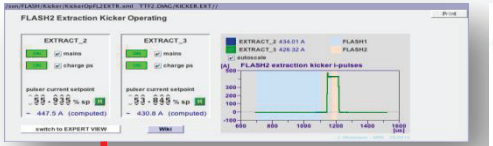
Parallel SASE Operation

- Separate operational panels for FLASH1 and FLASH2

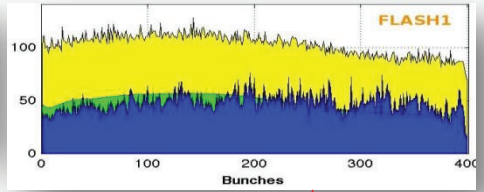




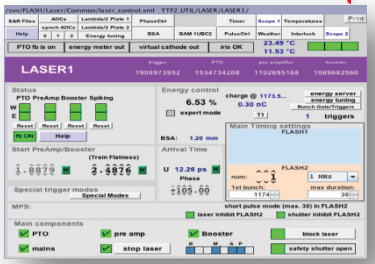
- Fast kicker

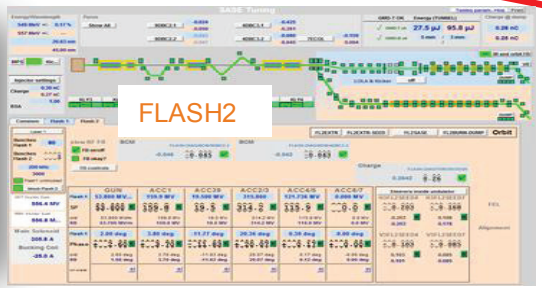


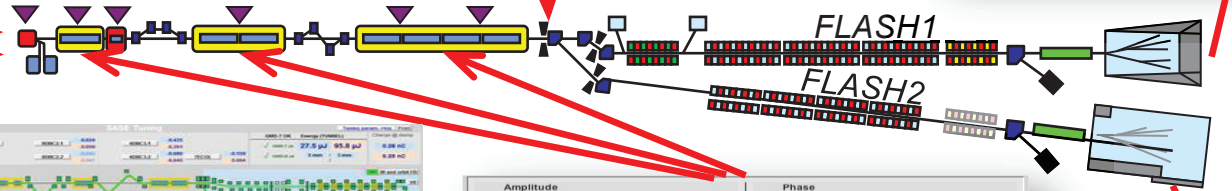
- SASE pulse trains

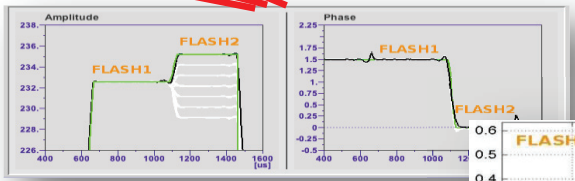


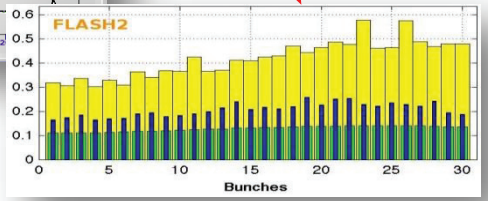
- Two injector lasers







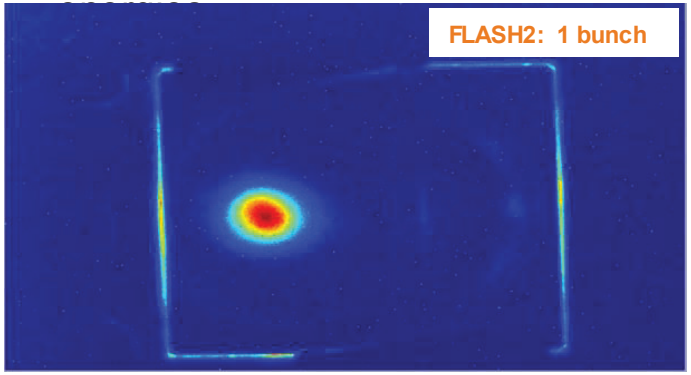


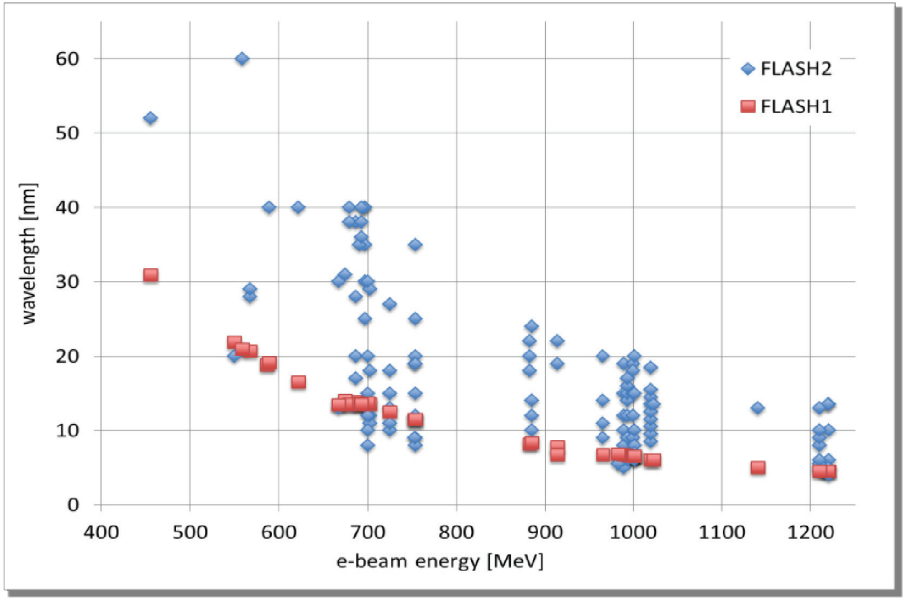


- Two operators controlling two “virtual” machines
- Parameters affecting both BL are blocked from individual panels

First Lasing FLASH2

- Commissioning phase for FLASH2 done in parallel to FLASH1 operation
- First lasing FLASH2: **August 20, 2014**
- SASE operation establish at various wavelengths
- Variable gap undulators in FLASH2 allow different photon wavelength at fixed beam





Achieved photon wavelength 08/2014 to 08/2015

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

Summary and Outlook

- Low Level RF control functionality extended to allow flexible simultaneous RF operation of multi-beamlines
  - Can operate with different compressions, charges and bunch patterns
  - Maintaining RF field amplitude and the phase stability requirements
- Achieved simultaneous operation and lasing of two undulator beamlines
  - SASE operation at various wavelengths was established
- LLRF commissioning for multi-beamlines at European XFEL in progress
  - Operations of alternating RF pulses (from pulse to pulse)

Thanks for your attention