Parallel Operation of SASE1 and SASE3 at European XFEL

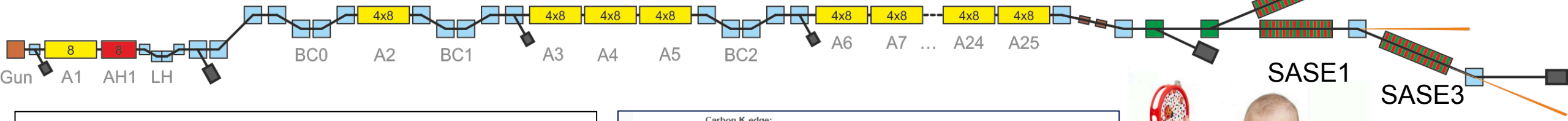
Shan Liu, DESY
on behalf of the European XFEL operation team

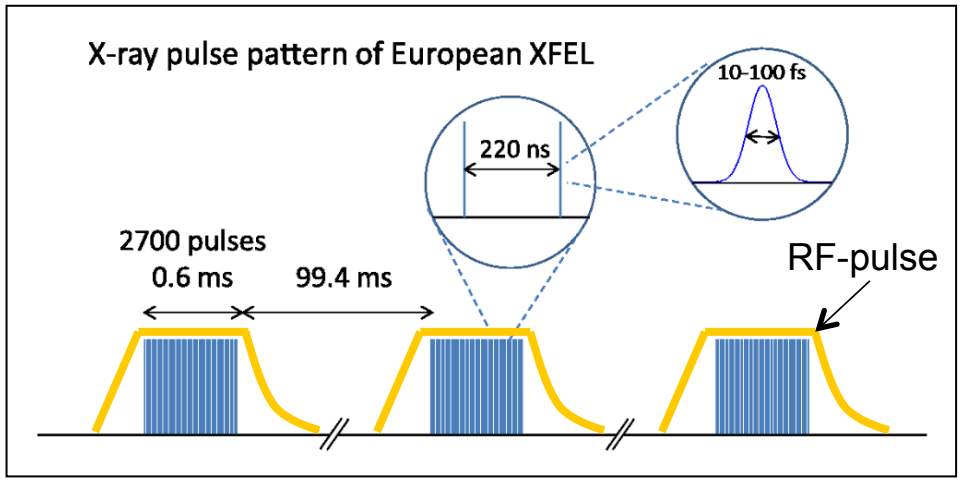
FEL'19 conference
Hamburg, 27.08.19

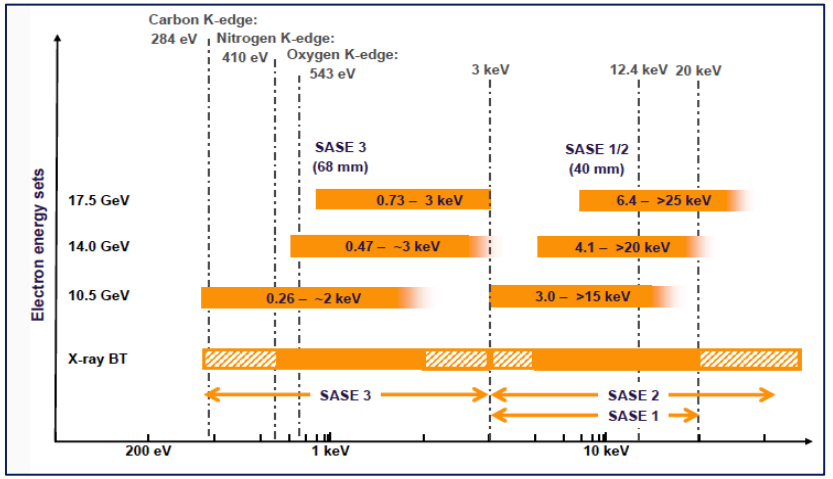
Talk by M. Scholz, MOA04

European XFEL and parallel operation

- Superconducting accelerator in pulsed mode (10 Hz) with up to 17.5 GeV and 27000 bunches/s
- Three variable gap undulators for hard and soft X-rays (250 eV to 25 keV)



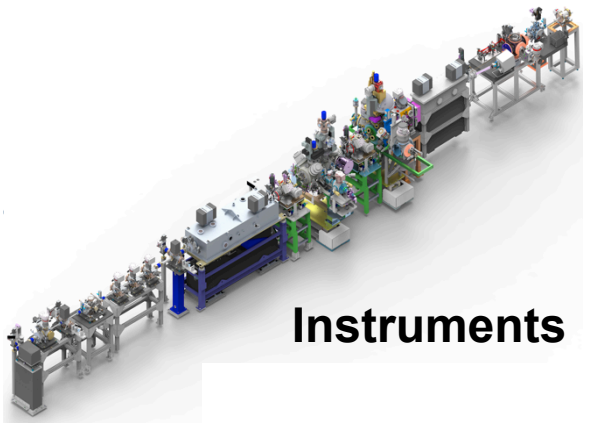


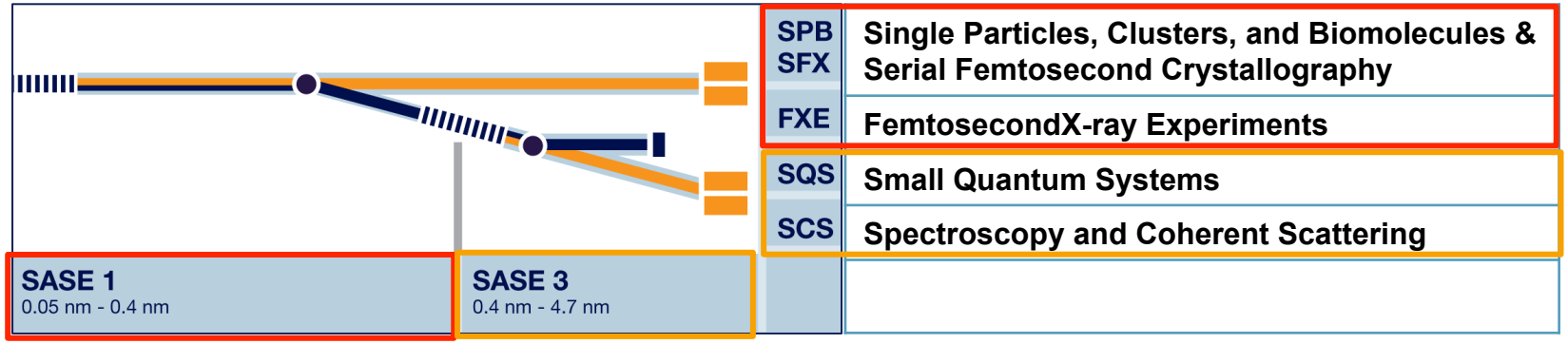


H. Weise, MOC03, FEL'17

Talk by D. Noelle, FRA01

SASE1 and SASE3 parallel operation: user side



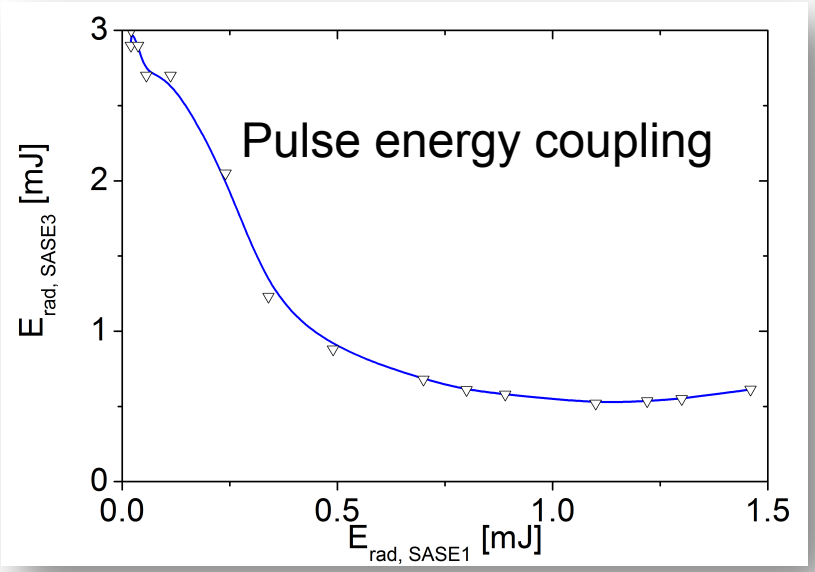


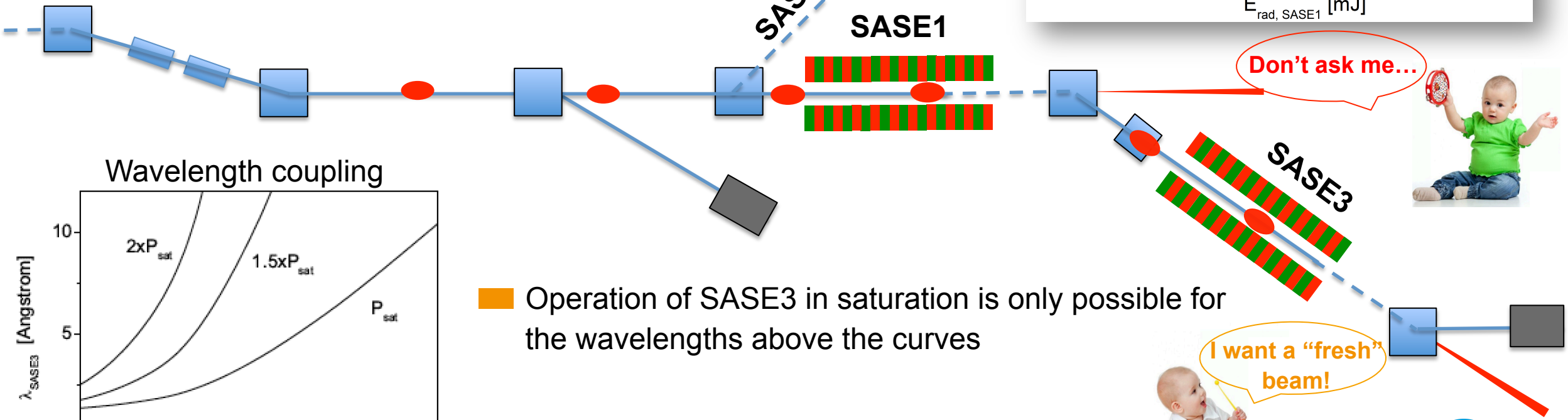
SPB SFX	Single Particles, Clusters, and Biomolecules & Serial Femtosecond Crystallography
FXE	FemtosecondX-ray Experiments
SQS	Small Quantum Systems
SCS	Spectroscopy and Coherent Scattering

	Instrument	Program	Shift	ħw [keV]	Resonance	Min Energy [mJ]	Bunches
SASE 1	SPB/SFX	2304 Martin	Day	9.3 keV	no	1	255 (interleaved acceptable)
	FXE	Set-up/Comm.	Night	7.1 / 9.3 / 13.4 keV /1.1 MHz	no	1	1-200
SASE 3	SCS	Comm.	Day	700-1200 eV	yes	1	maximum 50-100 at 250 kHz (interleaved desired)
	SQS	2370 v. Issendorff	Night	707eV	yes	1	100 @ 1 MHz

SASE1 and SASE3 coupling

- Operation of SASE3 as a succession of SASE1
- Tuning of SASE1 to higher pulse energies leads to higher induced energy spread in the e- beam, and to degradation of the SASE3 pulse energy



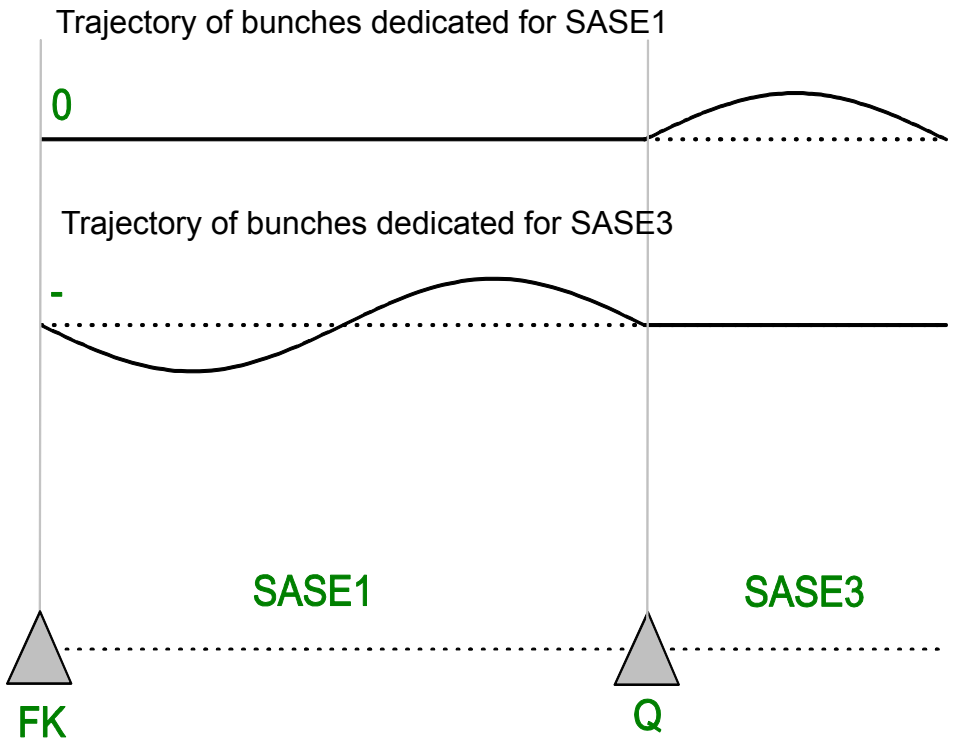


Wavelength coupling

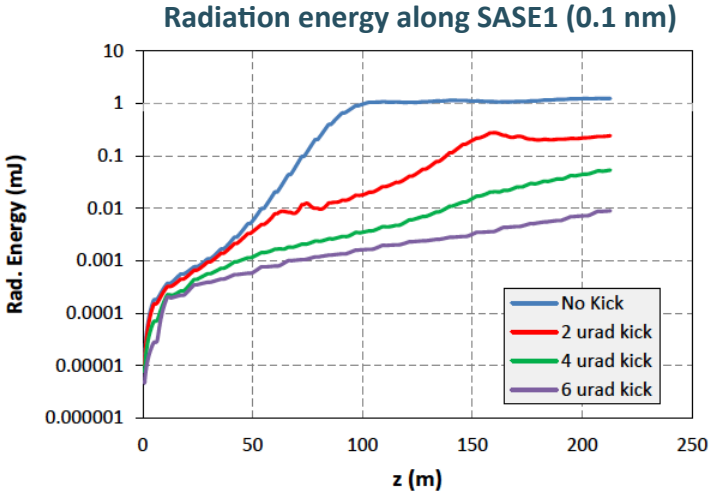
- Operation of SASE3 in saturation is only possible for the wavelengths above the curves

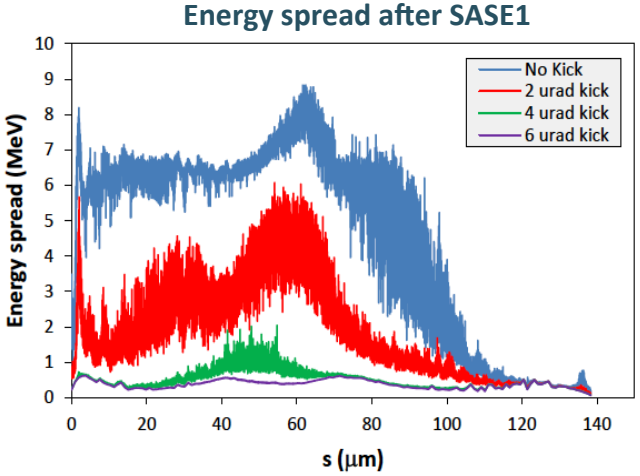
E.A. Schneidmiller, M.V. Yurkov, MOP066, FEL 2014

Betatron Switcher



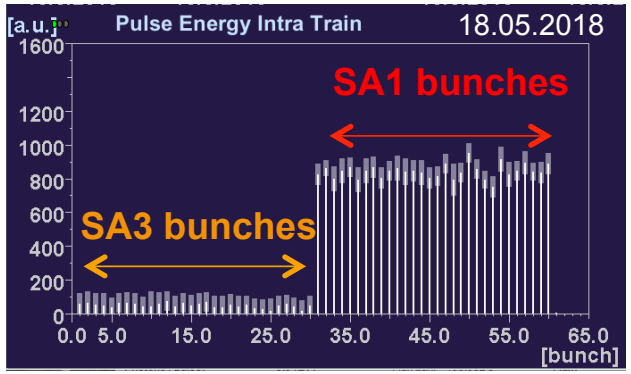
R. Brinkmann, E. Schneidmiller, M. Yurkov, NIMA 616(2010)81



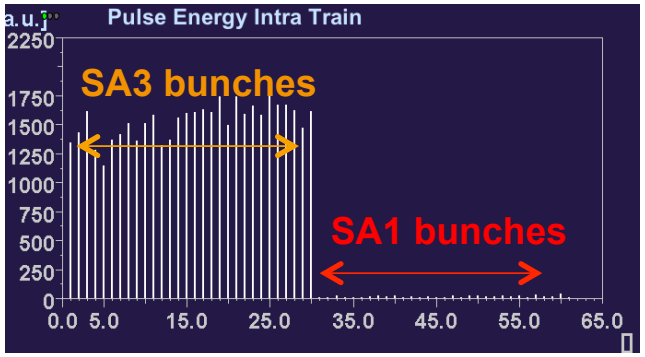


A.A. Sargsyan et.al , WEPAB001, IPAC'17

Pulse Energy Intra Train



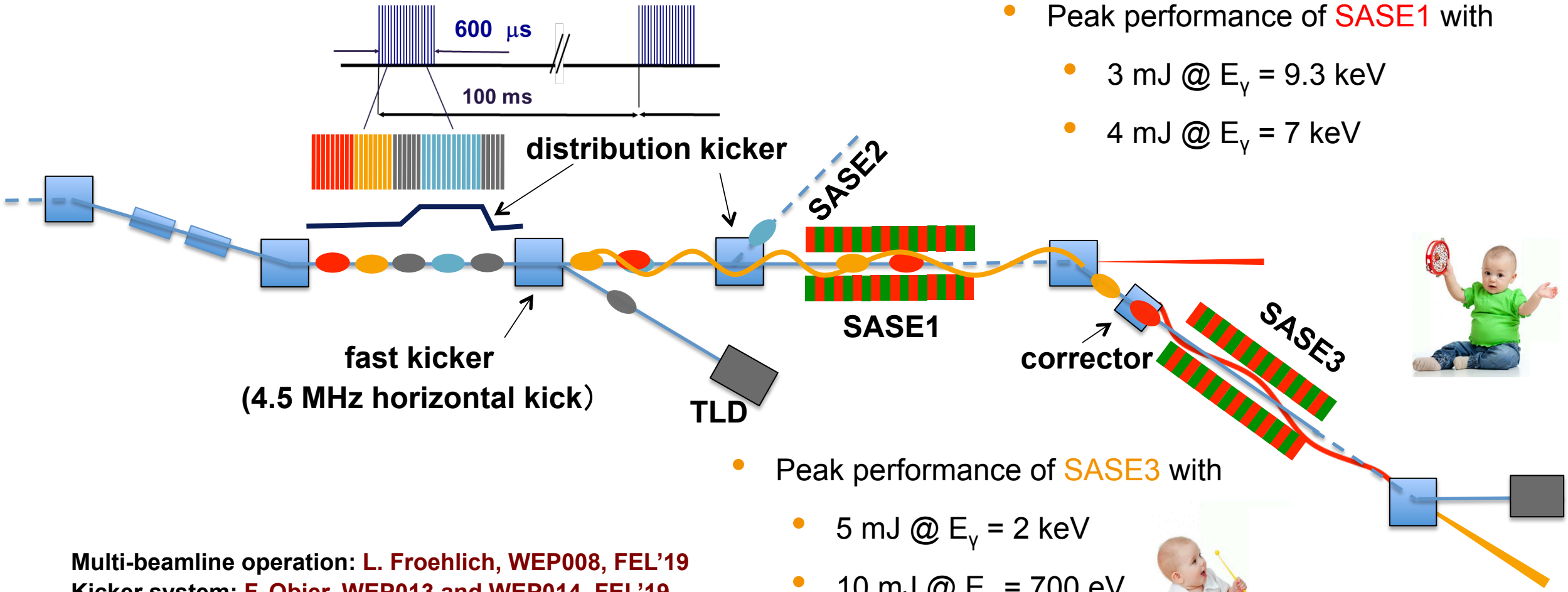
bunch #



bunch #

Talk by J. Grünert, WED03

“Fresh bunch” lasing in SASE3



- Peak performance of SASE1 with
  - 3 mJ @ E_γ = 9.3 keV
  - 4 mJ @ E_γ = 7 keV

- Peak performance of SASE3 with
  - 5 mJ @ E_γ = 2 keV
  - 10 mJ @ E_γ = 700 eV

Multi-beamline operation: L. Froehlich, WEP008, FEL’19
Kicker system: F. Obier, WEP013 and WEP014, FEL’19

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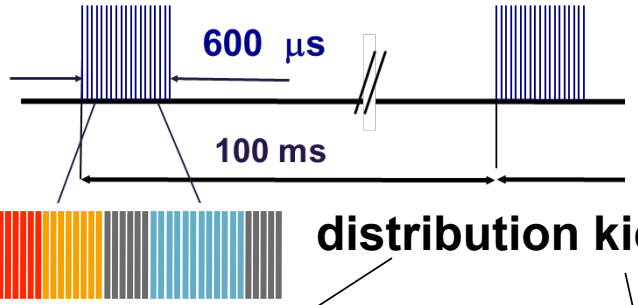

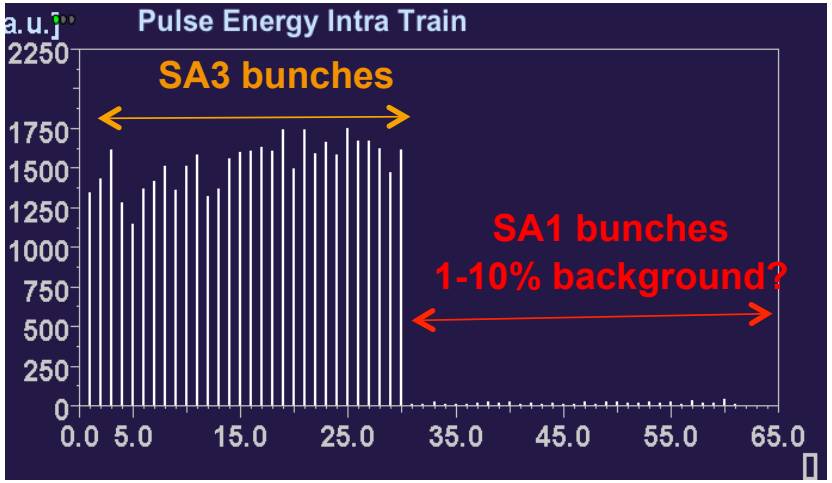

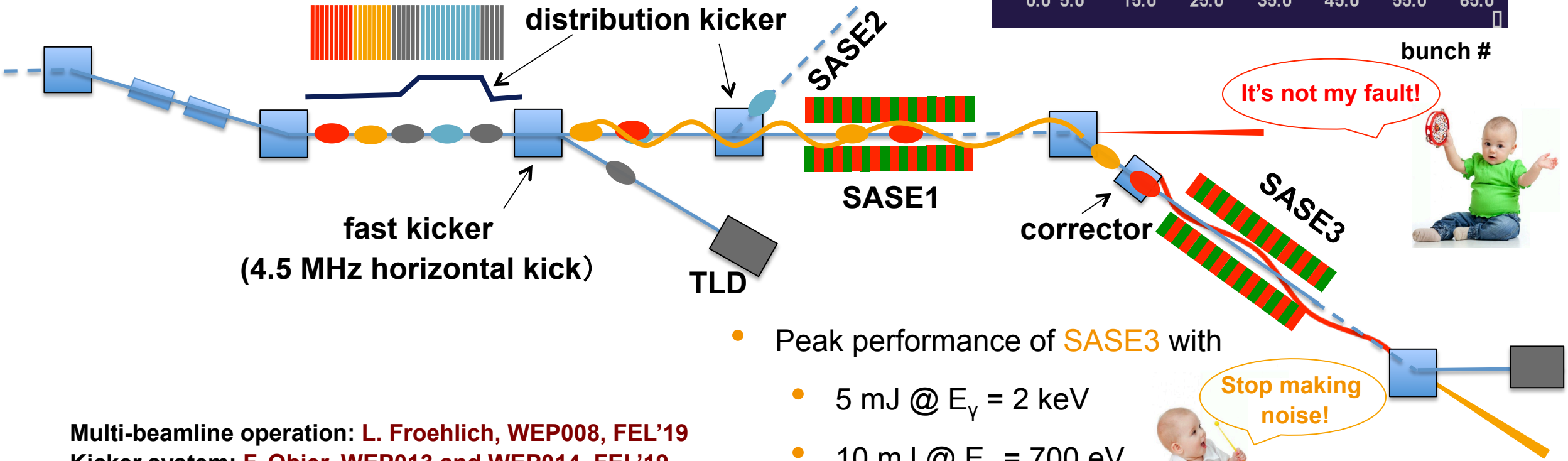

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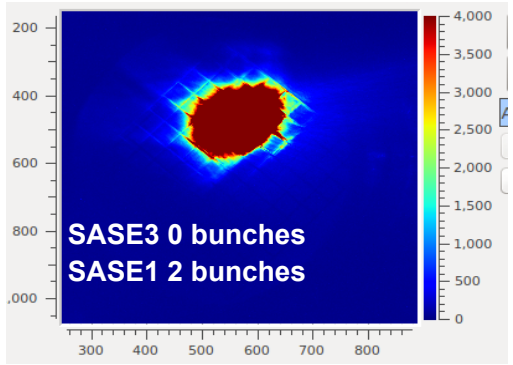
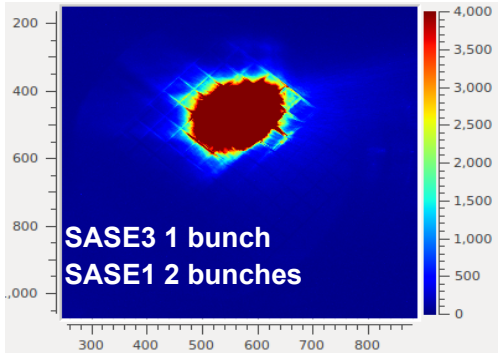
SASE1 background in SASE3: ‘optical light’ (< 15 eV)

- ‘optical light’ from SASE1 bunches observed on SASE3 imagers/ wavefront sensor

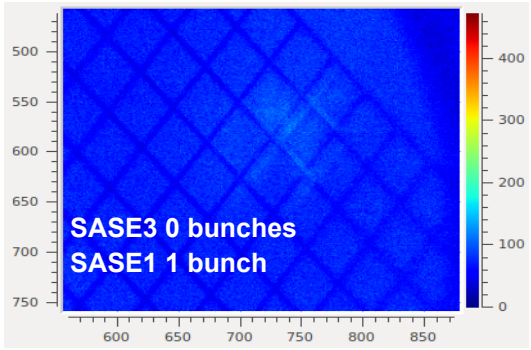


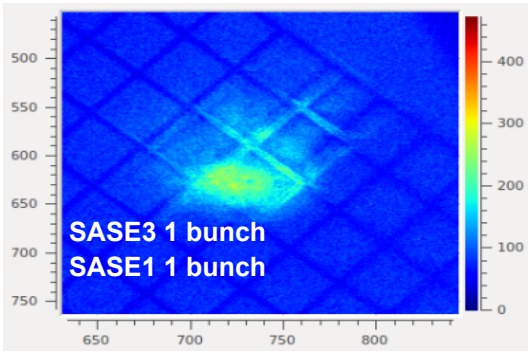


October 13th 2018, SQSlog entry 166

- Al filter can remove part of SASE1 background

Al filter in

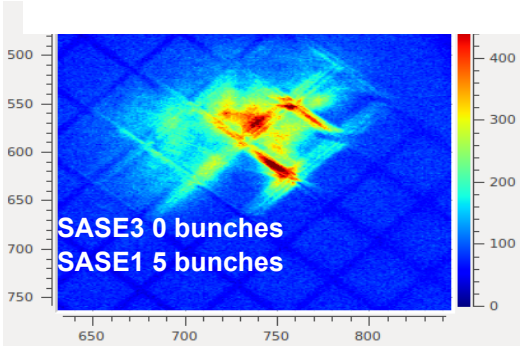


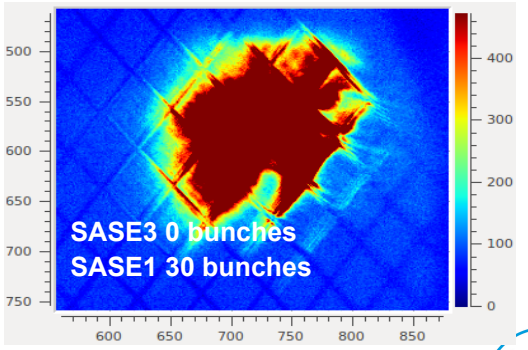


November 18th 2018, SQSlog entry 429

- However, depend on the ratio of of SA3/ SA1 bunches, imagers cannot be used even with Al filters

Al filter in, SASE1 > 1 bunch





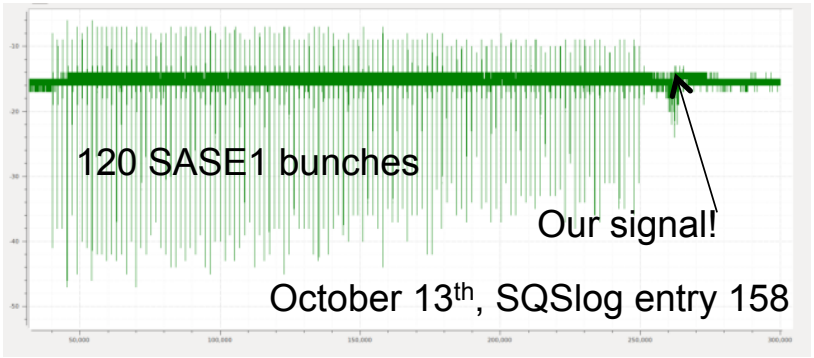
Courtesy of A. Scherz

SASE1 background in SASE3

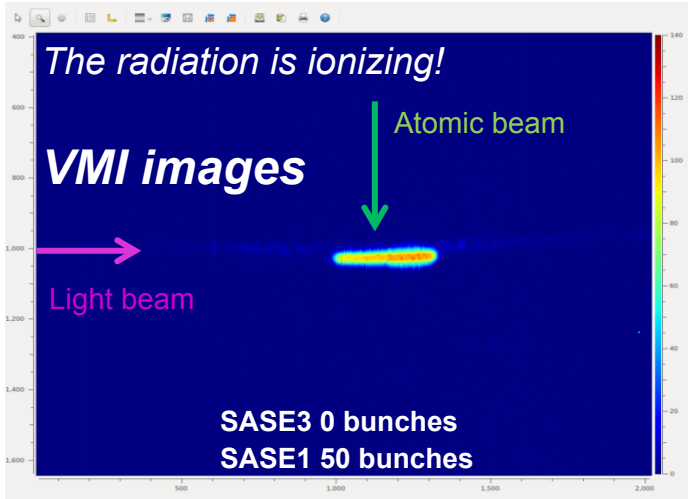
‘XUV light’ (few tens of eV)

- verified by introducing small amounts of nitrogen in the gas absorber
- nitrogen removes some contributions, however attenuation depends strongly on photon energy

The radiation is ionizing: Ion TOF spectra

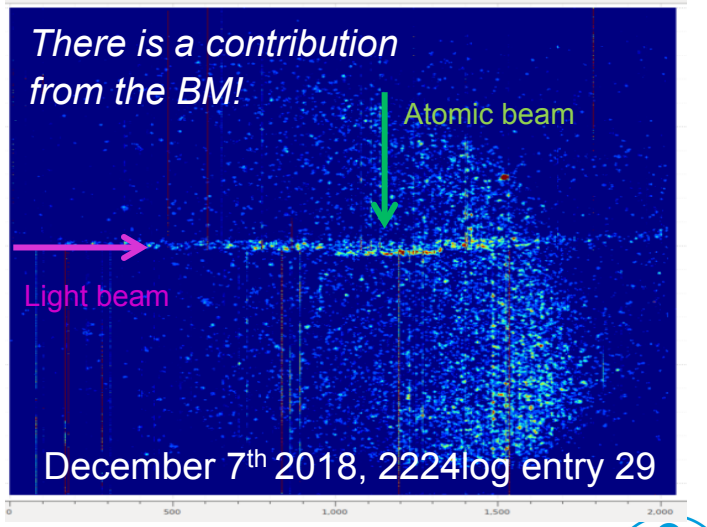


Courtesy of A. Scherz



‘bending magnet radiation’ ?

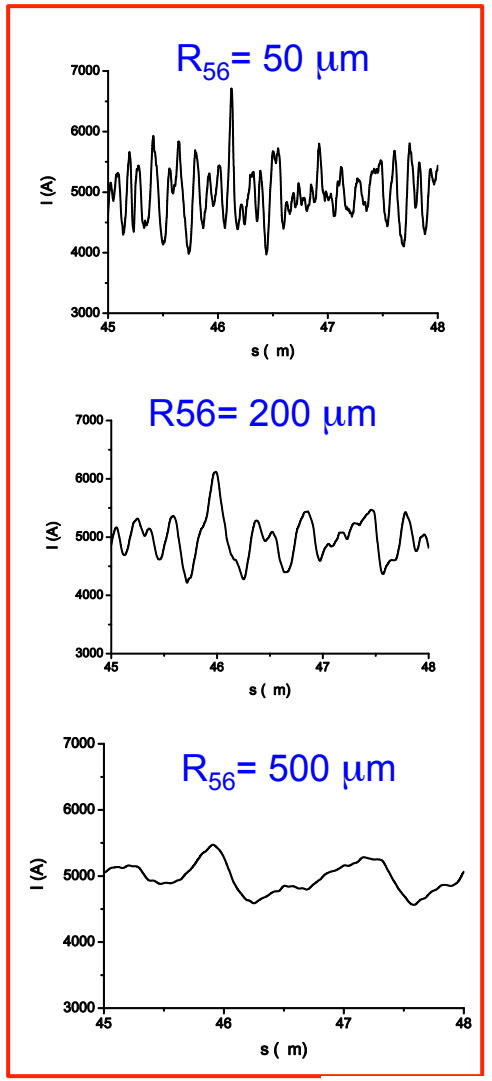
- with <u>all SA3 undulators open</u>
- still observing ionization in experiment (not completely negligible)

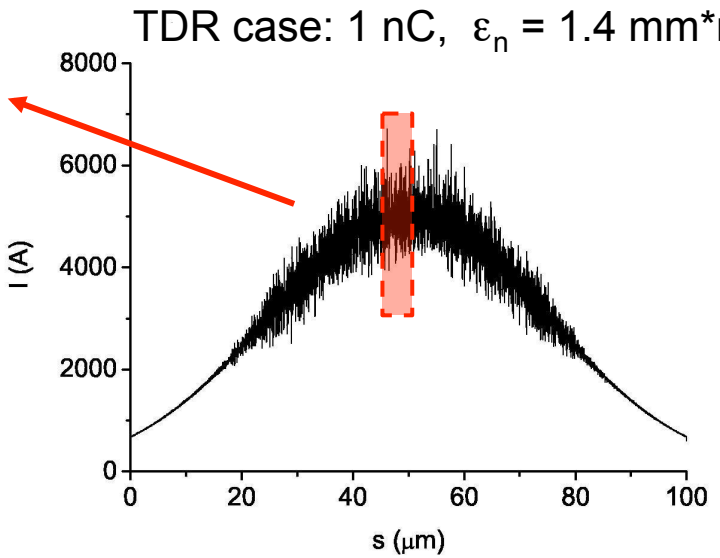


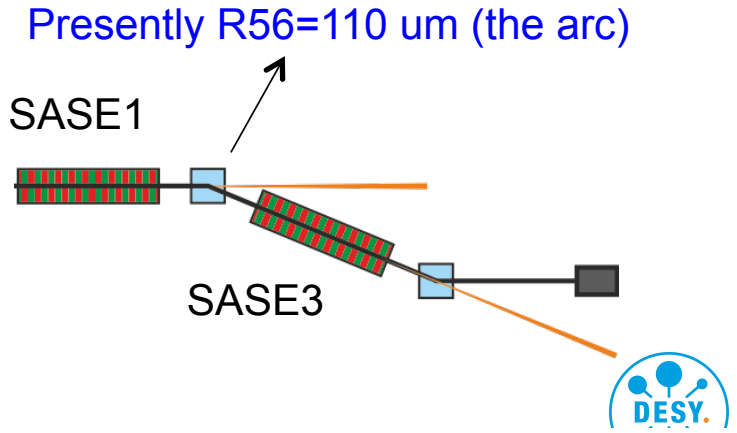
Targets are ionized by SA1 background, difficult for electron and ion spectroscopy experiments!

Possible reason for BG from optical to XUV range: optical afterburner

- Energy modulations -> dispersive element -> broadband density modulations in the optical range
- Radiation (NIR, VIS, UV) can be produced by CSR (dipole), TUR (transition undulator radiation), edge radiation or a dedicated undulator
- One can control modulation scale by changing R_{56} and cancel this effect by either modify the arc or install a chicane (behind or in front of the arc)
- The effect can be used for SASE1 pulse duration measurements or for SASE3 pump-probe experiments.





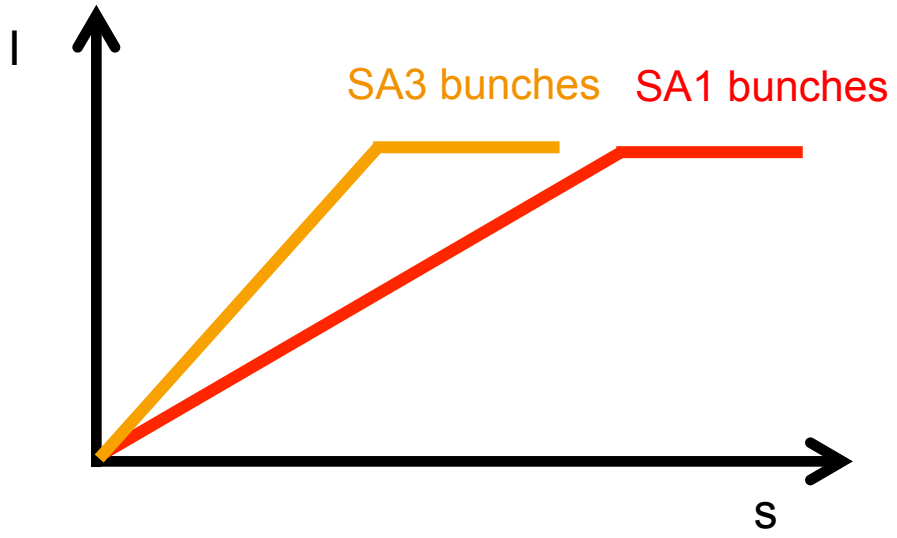


S. Duesterer et al., Phys. Rev. ST-AB 17, 120702 (2014)

E. Saldin, E. Schneidmiller, M. Yurkov, PhysRevSTAB13.030701

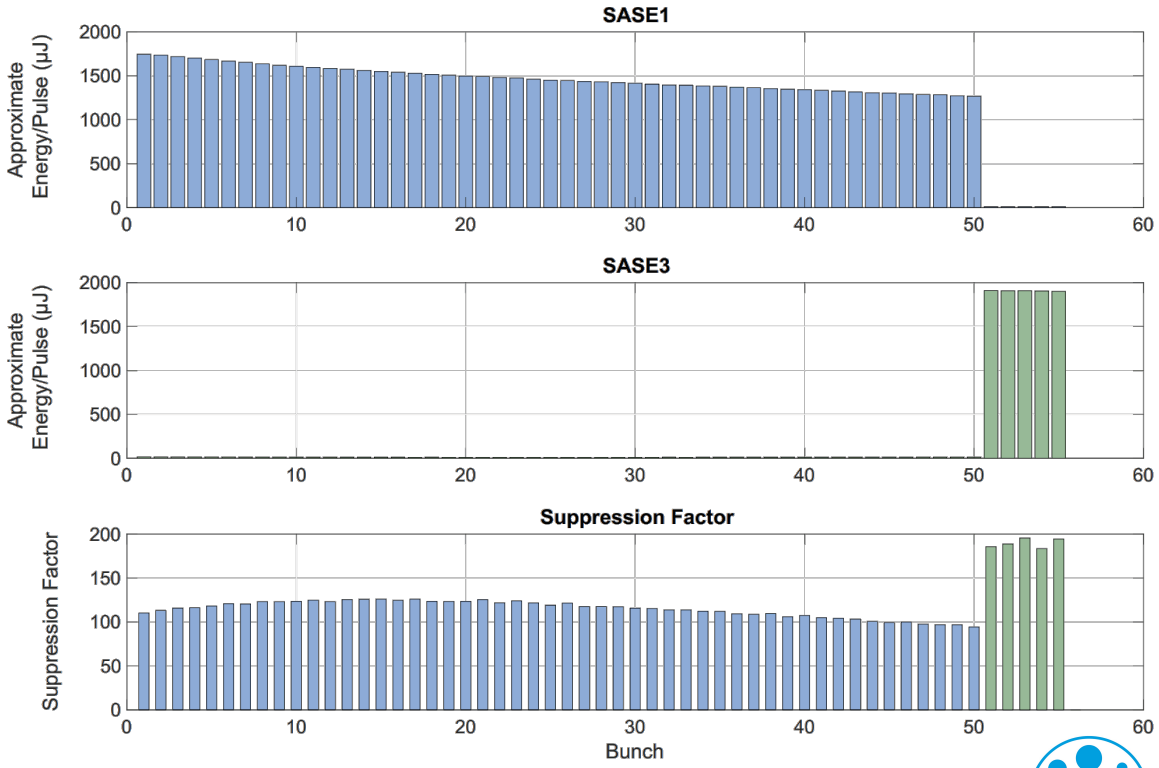
SASE1 background in SASE3: residual lasing

- SASE1 bunches saturate later in SASE3 due to the oscillation but can reach theoretically the same level.



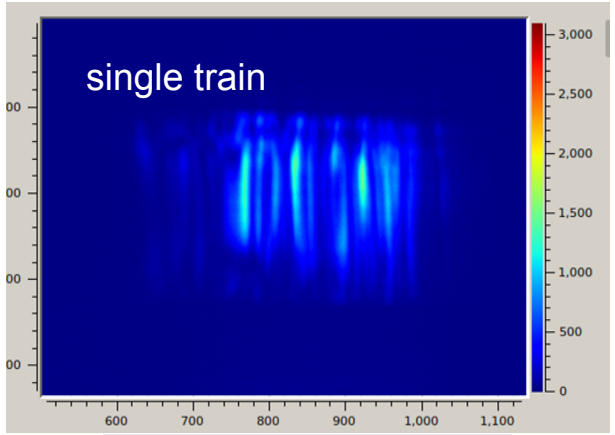
SASE power in the SASE3 undulator beamline

- The suppression of SASE3 bunches in SASE1 is sufficient because hard X-ray undulators are more sensitive to the correct trajectory.

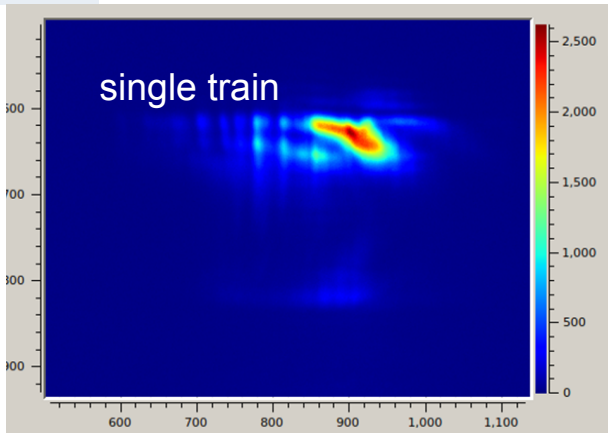


SASE1 background in SASE3: residual lasing

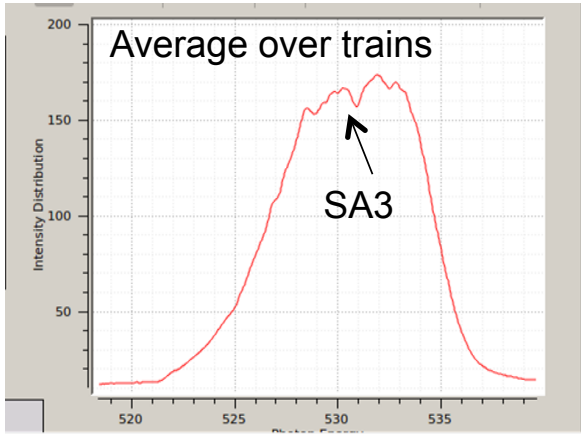
530 eV

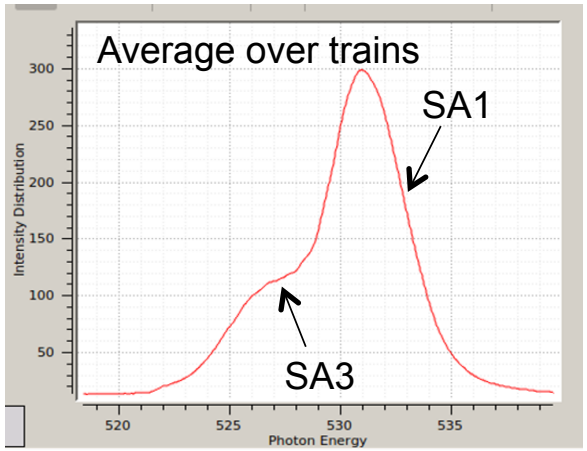


SA3: 1 bunch
SA1: 1bunch

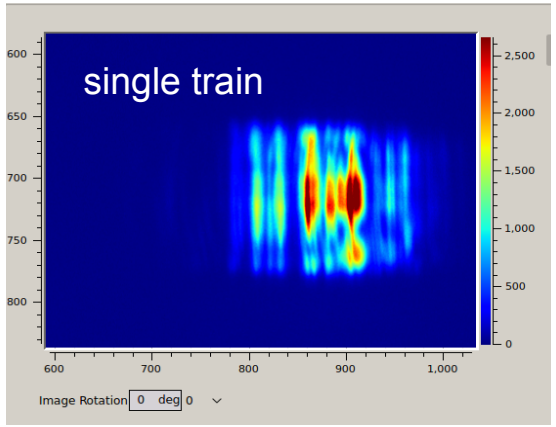


SA3: 1 bunch
SA1: 40 bunches

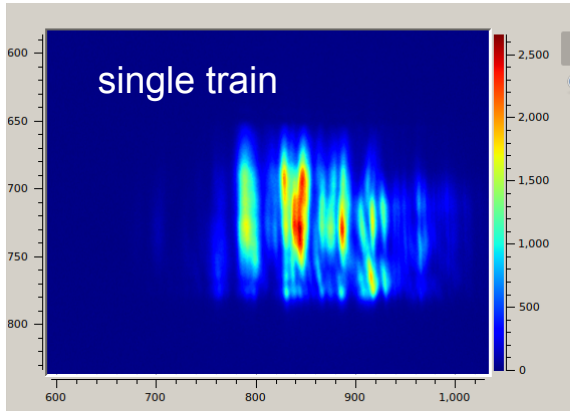




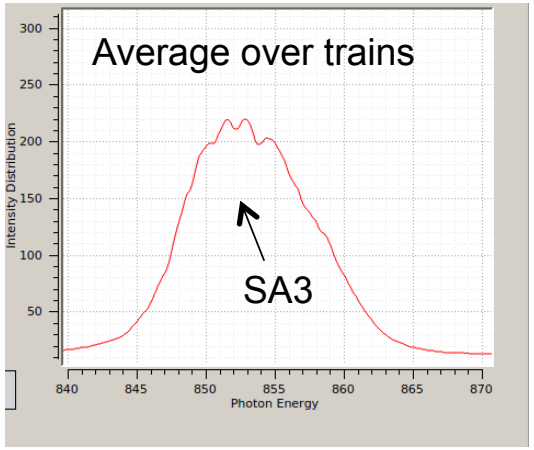
852 eV

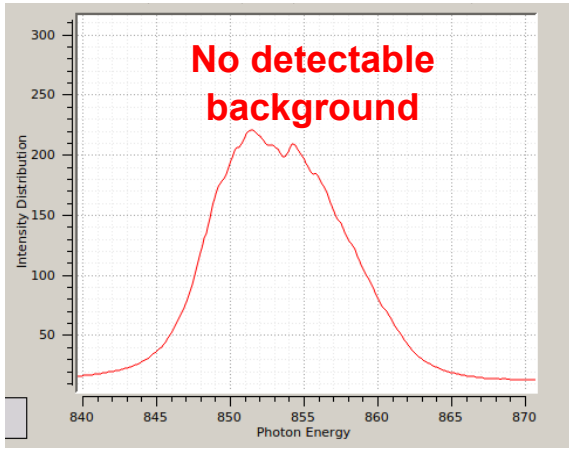


SA3: 1 bunch
SA1: 0 bunches



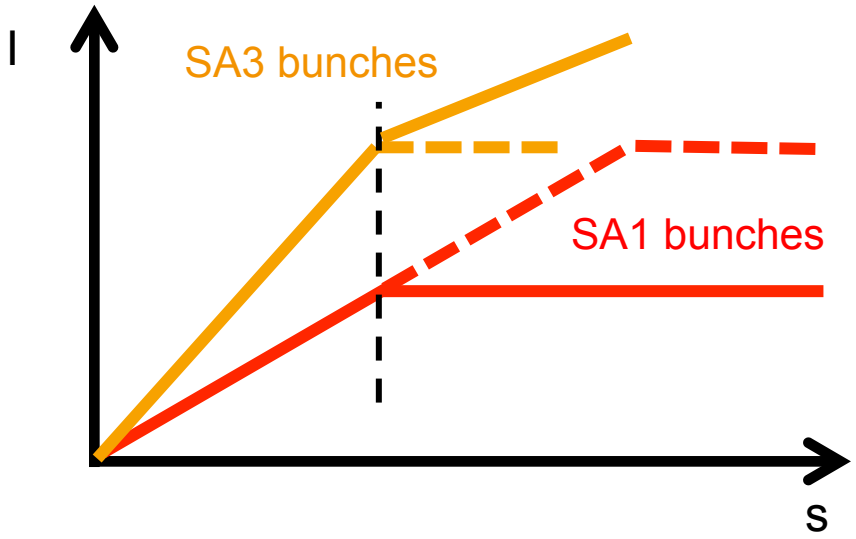
SA3: 1 bunch
SA1: 50 bunches



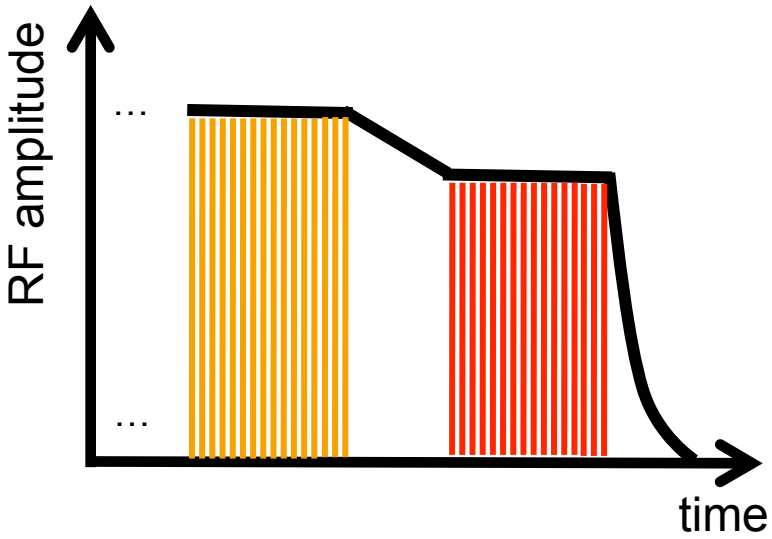


Courtesy of A. Scherz

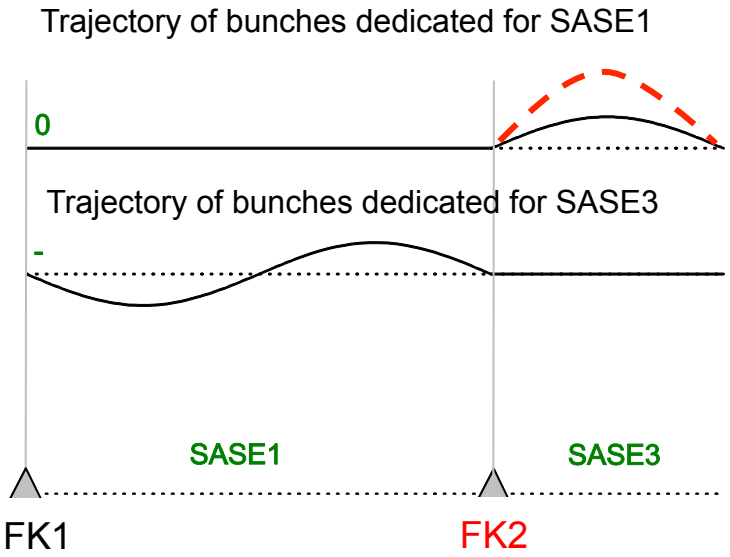
Further suppression techniques for residual lasing



- **Open undulator cells** beyond the saturation point of SASE3 bunches
- **Aggressive quadratic taper** starting with the saturation of SASE3 bunches

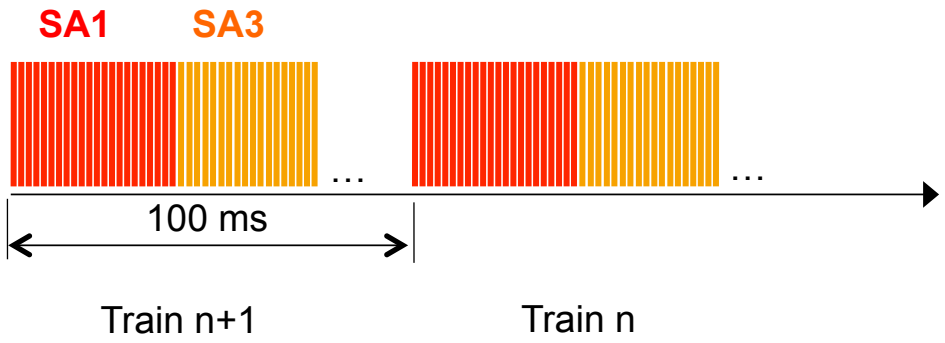


- **Use different RF flat top** and compress the beam stronger to achieve larger peak currents for SASE3 bunches -> shorter gain lengths for SASE3 bunches



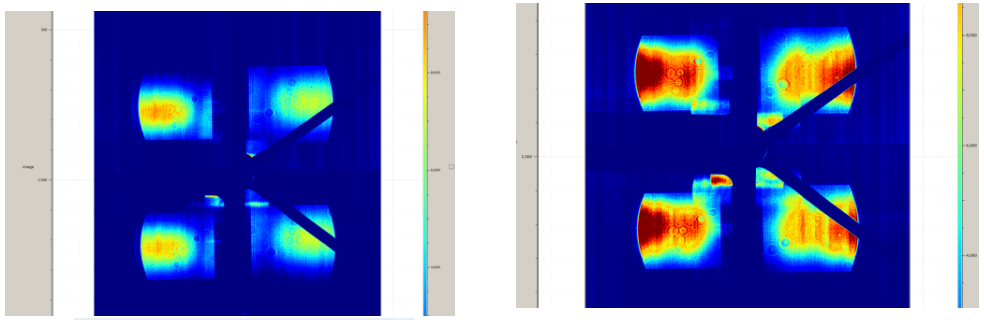
- **Increase the amplitude of betatron oscillations** for SA1 bunches in SASE3 with an additional kicker
- Installed upstream of SASE3 during 2019 summer shutdown, will be tested soon

Typical 10 Hz operation



- Sequential within train: each SA1/3 in separate time window in a train
  - works with **fast (pulse resolved) detectors**. Including electron and ion ToF spectroscopy.
  - does not work with slow detectors because of SA1 background.
  - Fixed targets get heated by SA1 background radiation

Slow detectors are exposed to SA1 background



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SA3: 1 bunch
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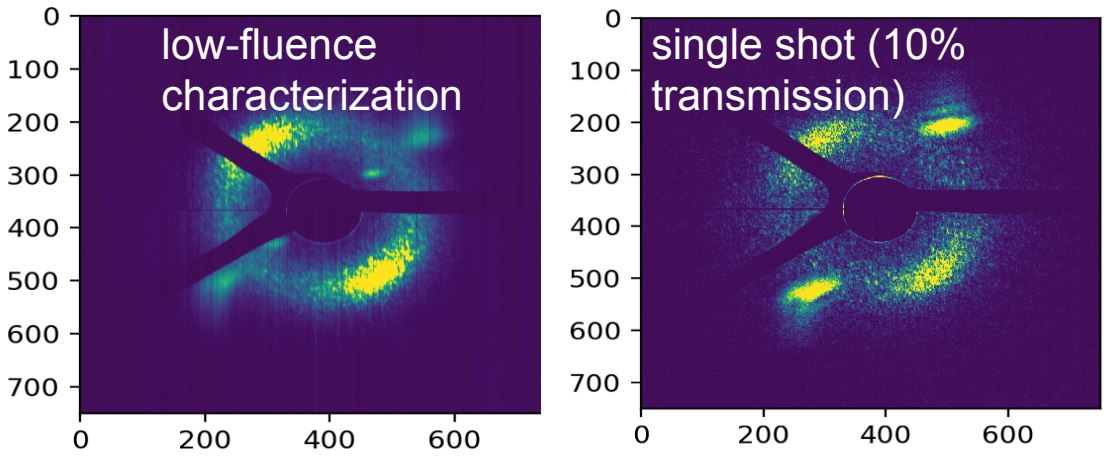
Single shot sample damage at 780eV



Courtesy of A. Scherz

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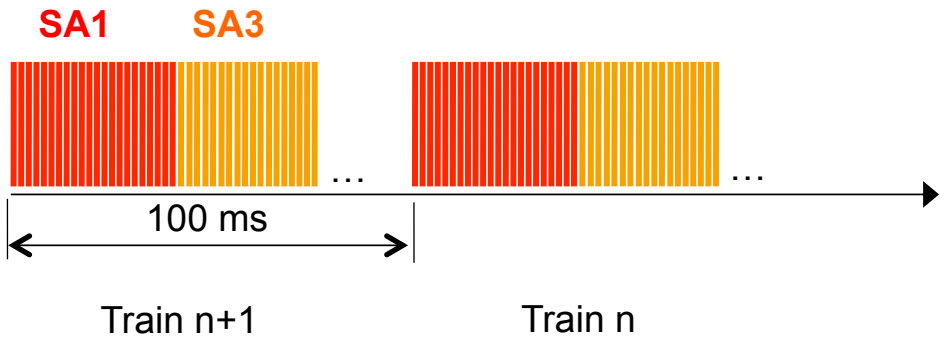

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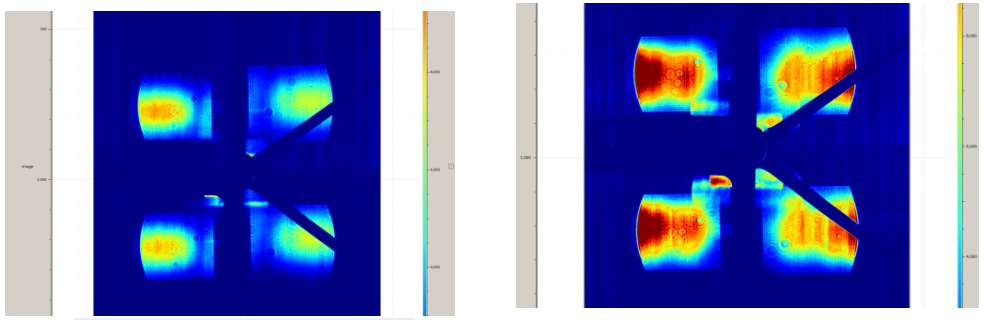

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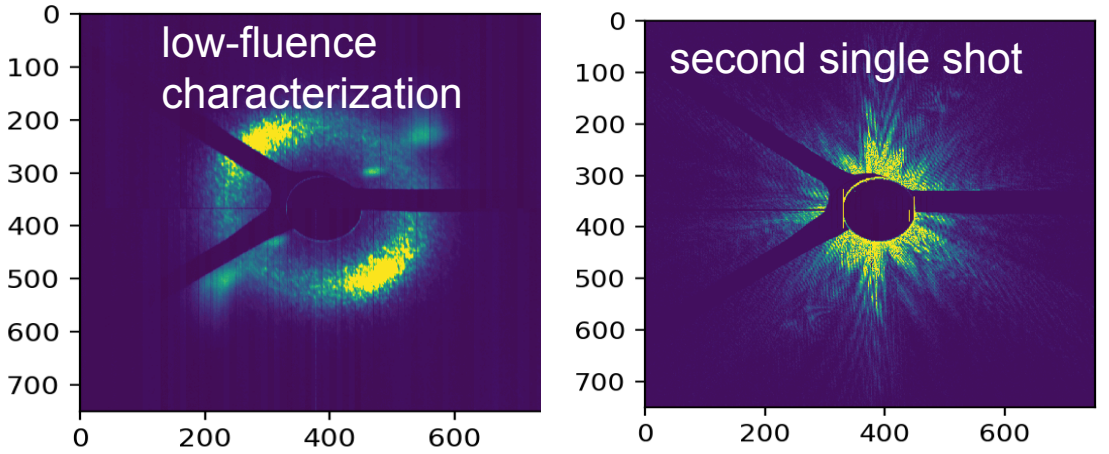
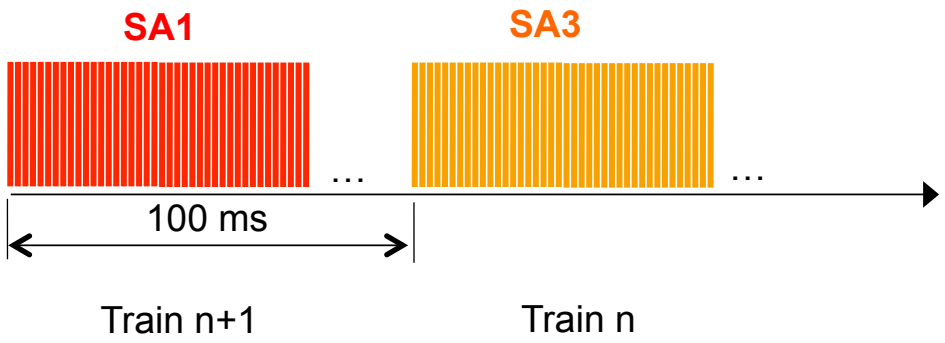
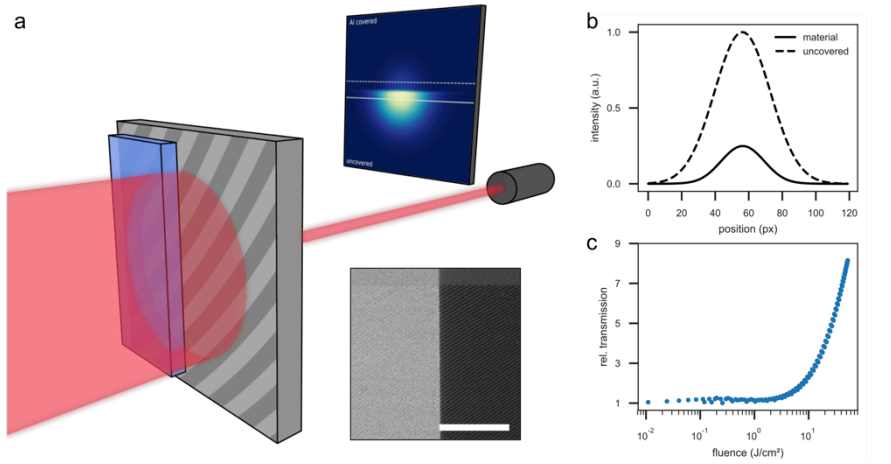


Courtesy of A. Scherz

5 Hz operation

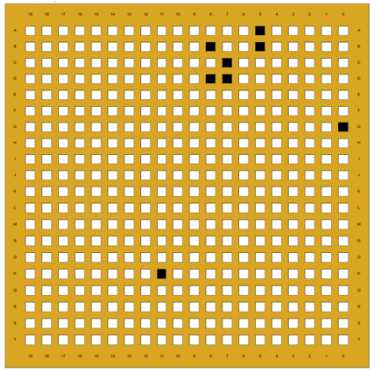


Courtesy of Bastian Pfau (MBI)

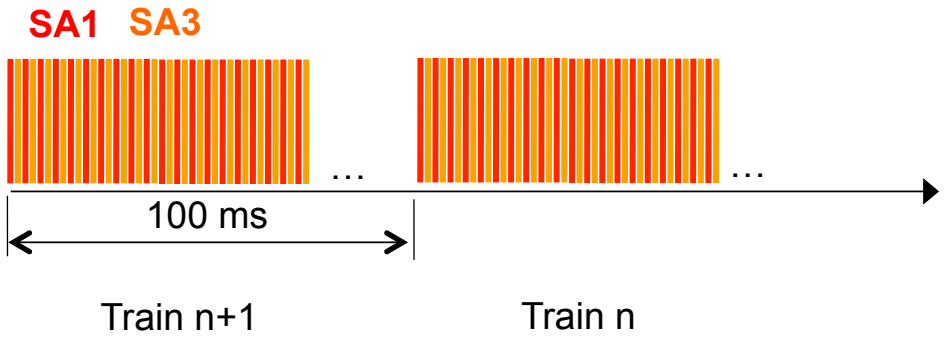


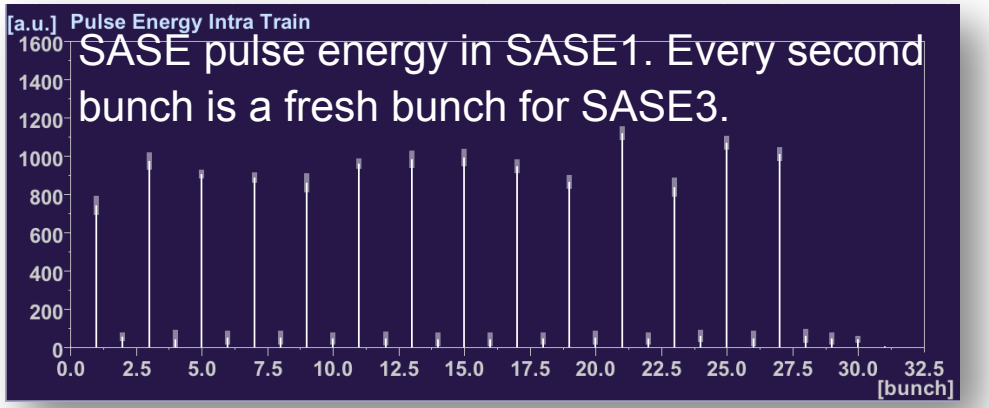
- Sequential by train: consecutive trains for SA1 and SA3
  - works with **slow detectors**. Involving **train pickers** **(**optical chopper**)** enables full separation of the two SASEs.
  - needed for **single shot imaging**, pulse-on-demand experiments or **radiation sensitive** samples (**SA1 radiation can be stopped before sample**).

Single shot, focused x-ray beam with high intensity, scanning across sample array



Interleaved mode

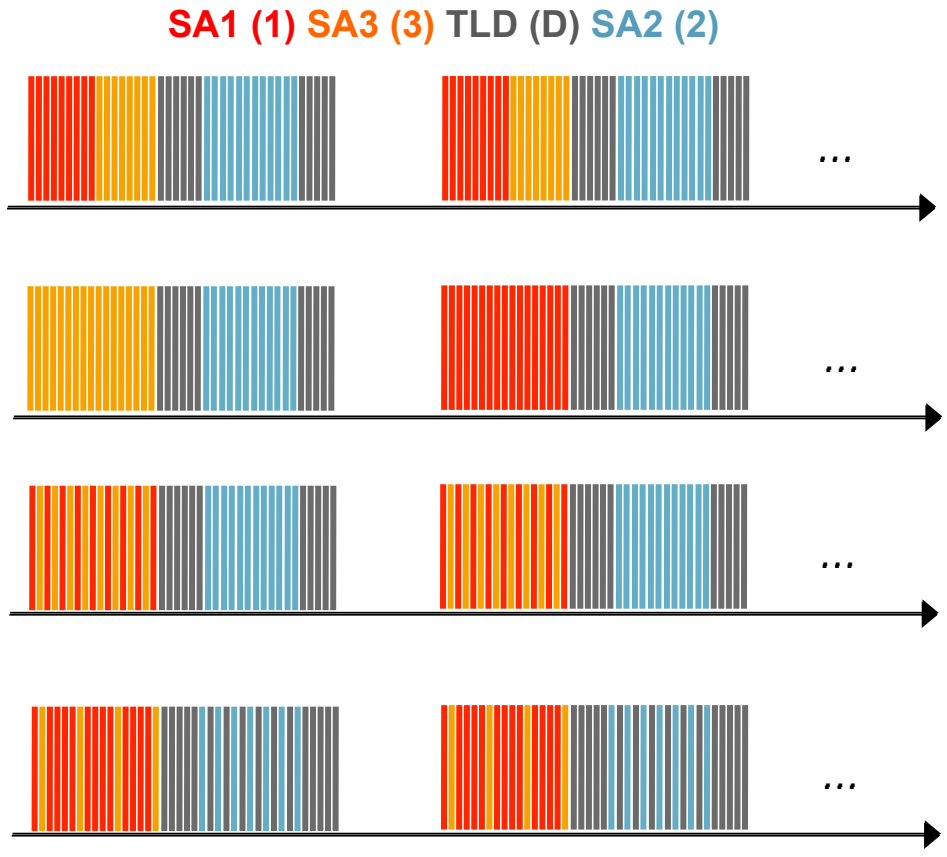




- Interleaved mode SA1 / SA3 within a train
  - does work with fast (pulse-resolved) detectors !
  - allow for **increasing number of usable SA1/SA3 pulses** for **lower rep-rate experiments**
  - can double the data rate for both instruments
    - **80%** of SA1-SPB experiments operate at **1.1MHz**,
    - SA1-FXE often operates at **max. 500kHz**

	Instrument	Program	Shift	ħw [keV]	Resonance	Min Energy [mJ]	Bunches
SASE 1	SPB/SFX	2304 Martin	Day	9.3 keV	no	1	255 (interleaved acceptable)
	FXE	Set-up/Comm.	Night	7.1 / 9.3 / 13.4 keV /1.1 MHz	no	1	1-200
SASE 3	SCS	Comm.	Day	700-1200 eV	yes	1	maximum 50-100 at 250 kHz (interleaved desired)
	SQS	2370 v. Issendorff	Night	707eV	yes	1	100 @ 1 MHz

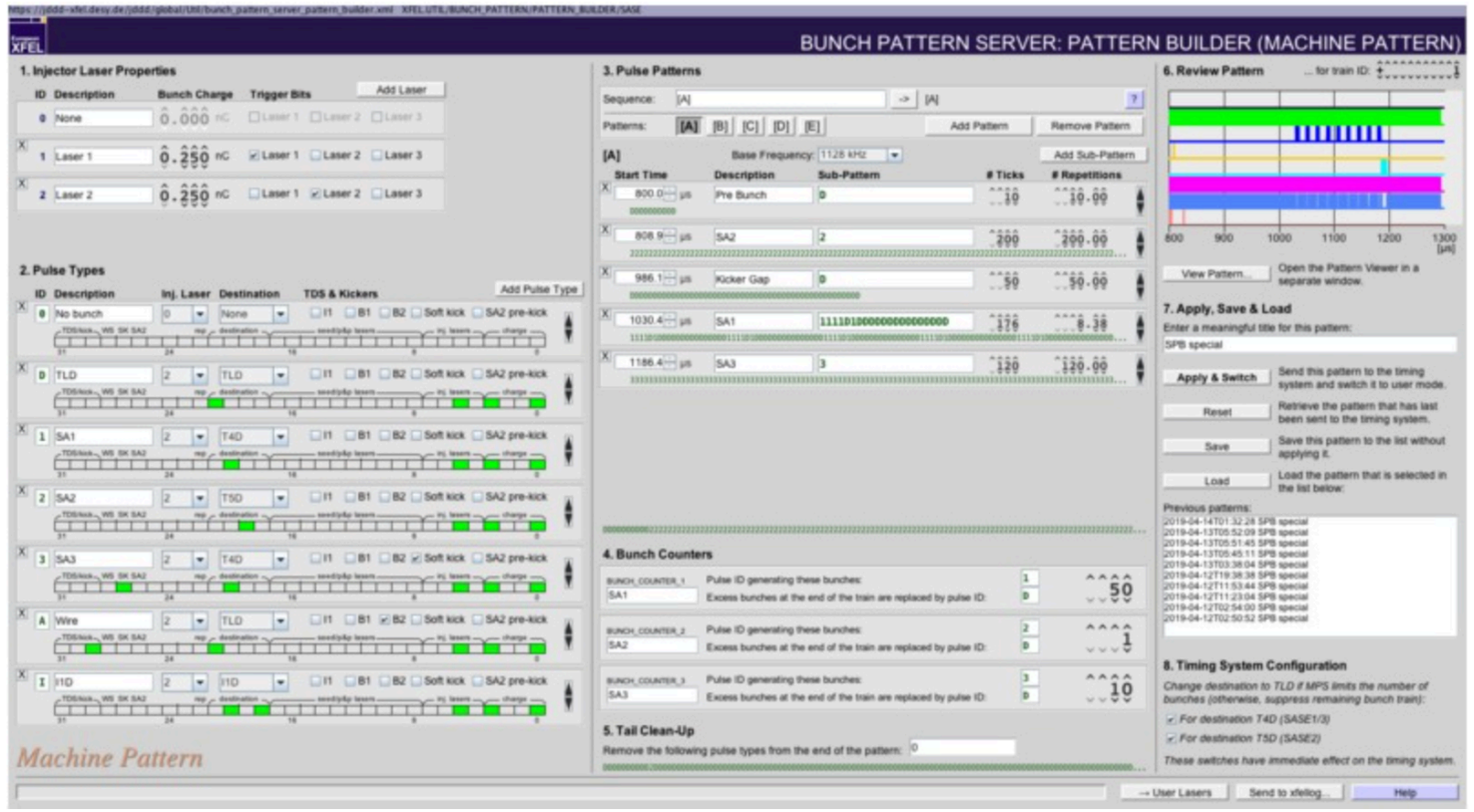
User defined bunch pattern



14.04.2019 01:36 **A3.L2** MEE, TAM, TIS **SPB wants to have the Word 1 pattern**

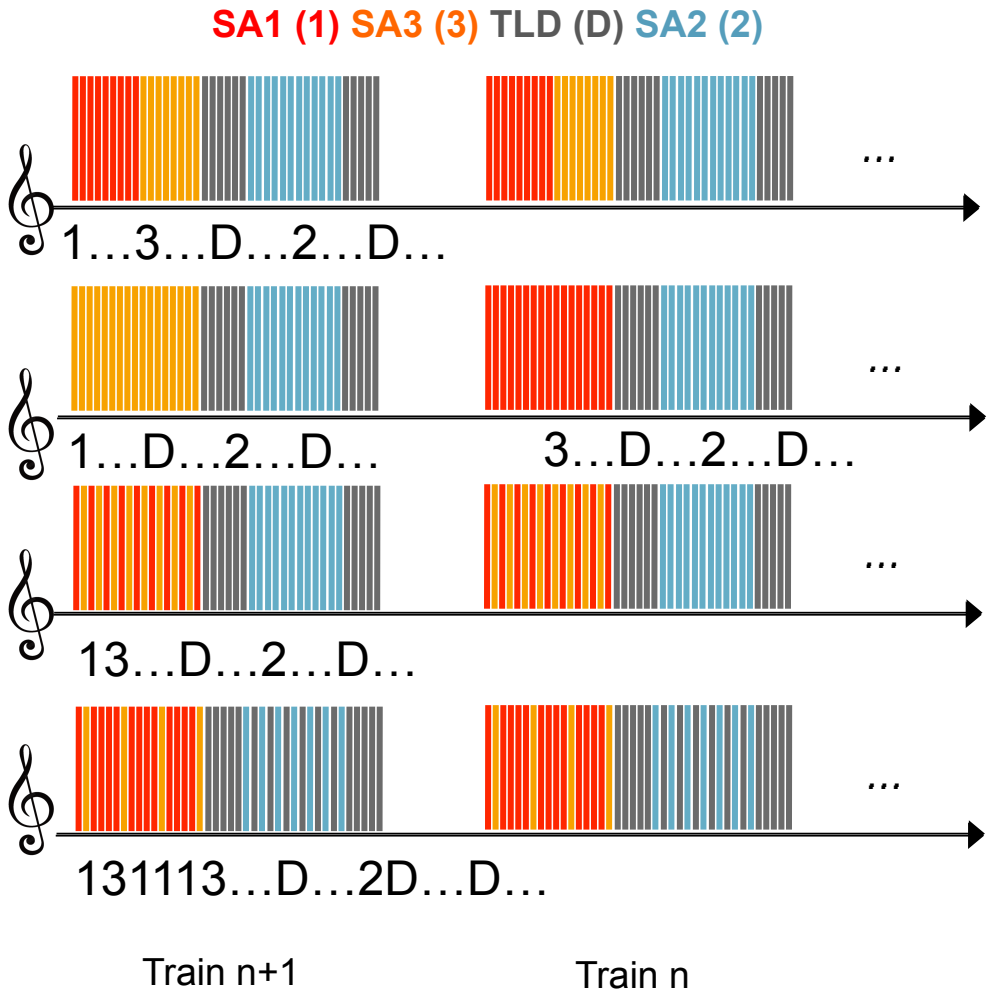
```
SPB patterns:
Word 1:  1111D1DDDDDDDDDDDDDDD  [21 characters total, including 15 consecutive D]
Word 2:  111DD1DDDDDDDDDDDDDDD  [21 characters total, including 15 consecutive D]
```

- needed to crank up the number of bunches to 176
- SCS informed about the timeshift of their first bunch



Multi-beamline operation: L. Froehlich, WEP008, FEL'19

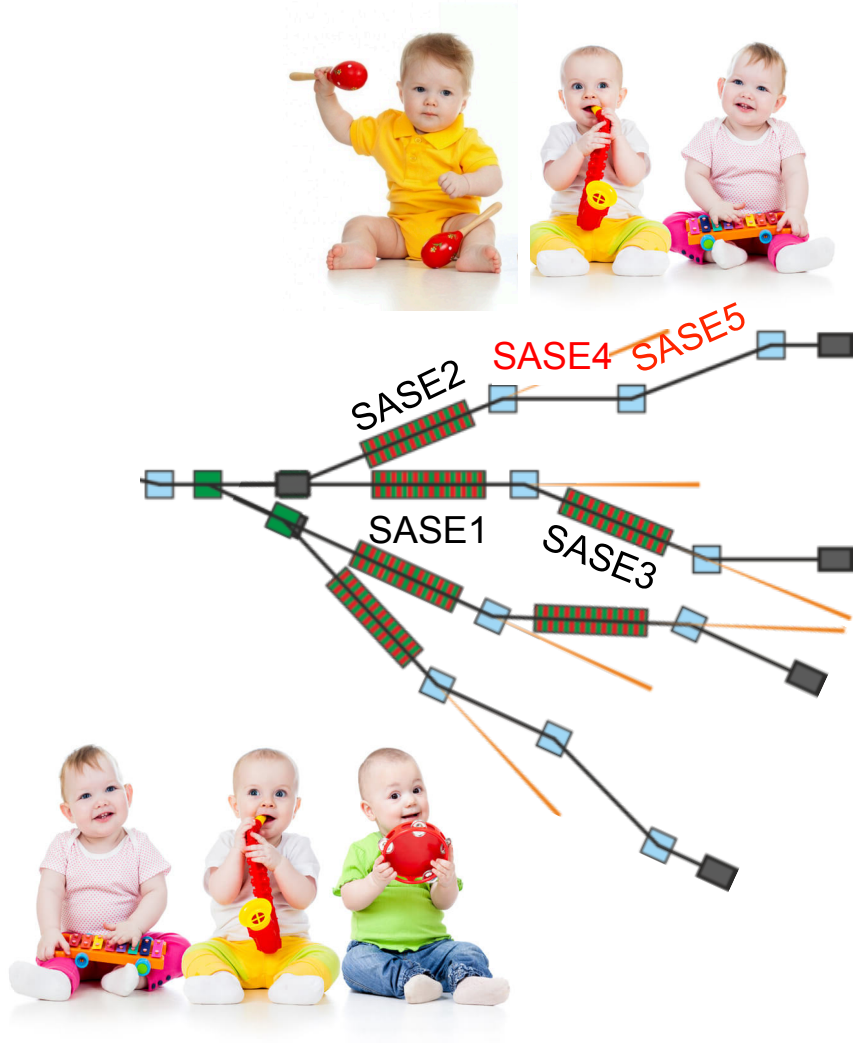
User defined bunch pattern



Multi-beamline operation: L. Froehlich, WEP008, FEL'19

Future applications: SASE4, SASE5 …

- Additional FEL radiators in the two ‘empty’ tunnels SASE4/5 (2024 ??)
  - about 150m available length each
  - Concepts are developed
  - Potential for new radiation schemes and new undulator technologies
- R&D towards doubling FEL beamlines / 2nd fan (2030 ??)



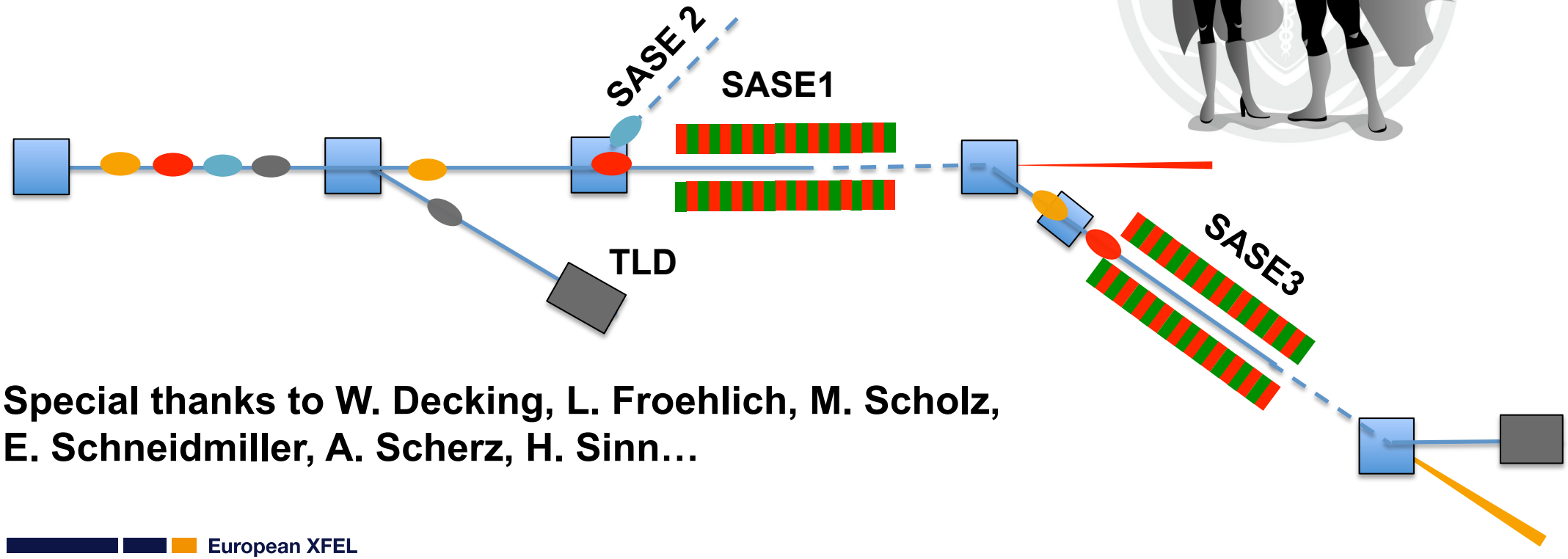
E. Schneidmiller, TUP056, FEL’19
M. Yurkov, TUP057, FEL’19
S. Serkez, TUP061, FEL’19
…

Summary

- Coupling between SASE1 and SASE3 operation
  - decoupling achieved by betatron switcher
  - residual background of SA1 bunches in SASE3
- Type of SA1 background observed in SASE3
  - optical to XUV
  - residual lasing
- Optical burner effect to be confirmed
  - suppression possible by modifying the arc
  - can be used for SASE1 pulse duration measurements
  - or for SASE3 pump-probe experiments
- Residual lasing can be suppressed by
  - changing the undulator setting
  - using different RF flat tops for compression
  - adding a dedicated kicker in front of SASE3
- Flexible bunch pattern
  - 5Hz operation: helps to protect detectors and samples
  - interleaved mode: allow for increasing number of usable pulses for lower rep-rate experiments

Thank you!

Thanks to the European XFEL operation team!



Special thanks to W. Decking, L. Froehlich, M. Scholz, E. Schneidmiller, A. Scherz, H. Sinn…