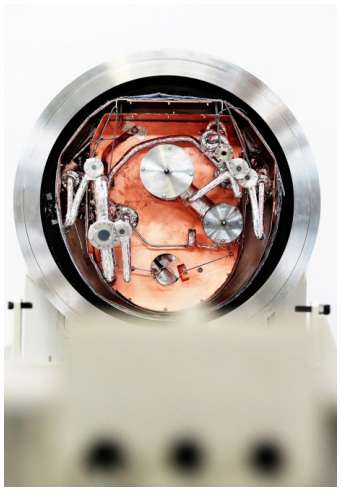
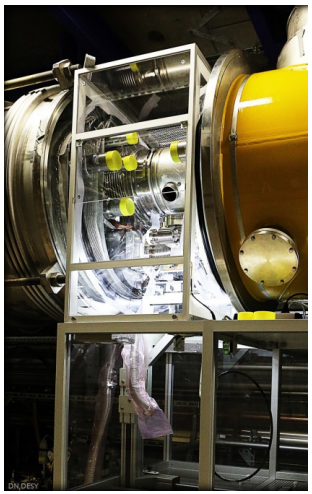
Commissioning of the European XFEL

Dirk Nölle, DESY, on behalf of the European XFEL Commissioning Team

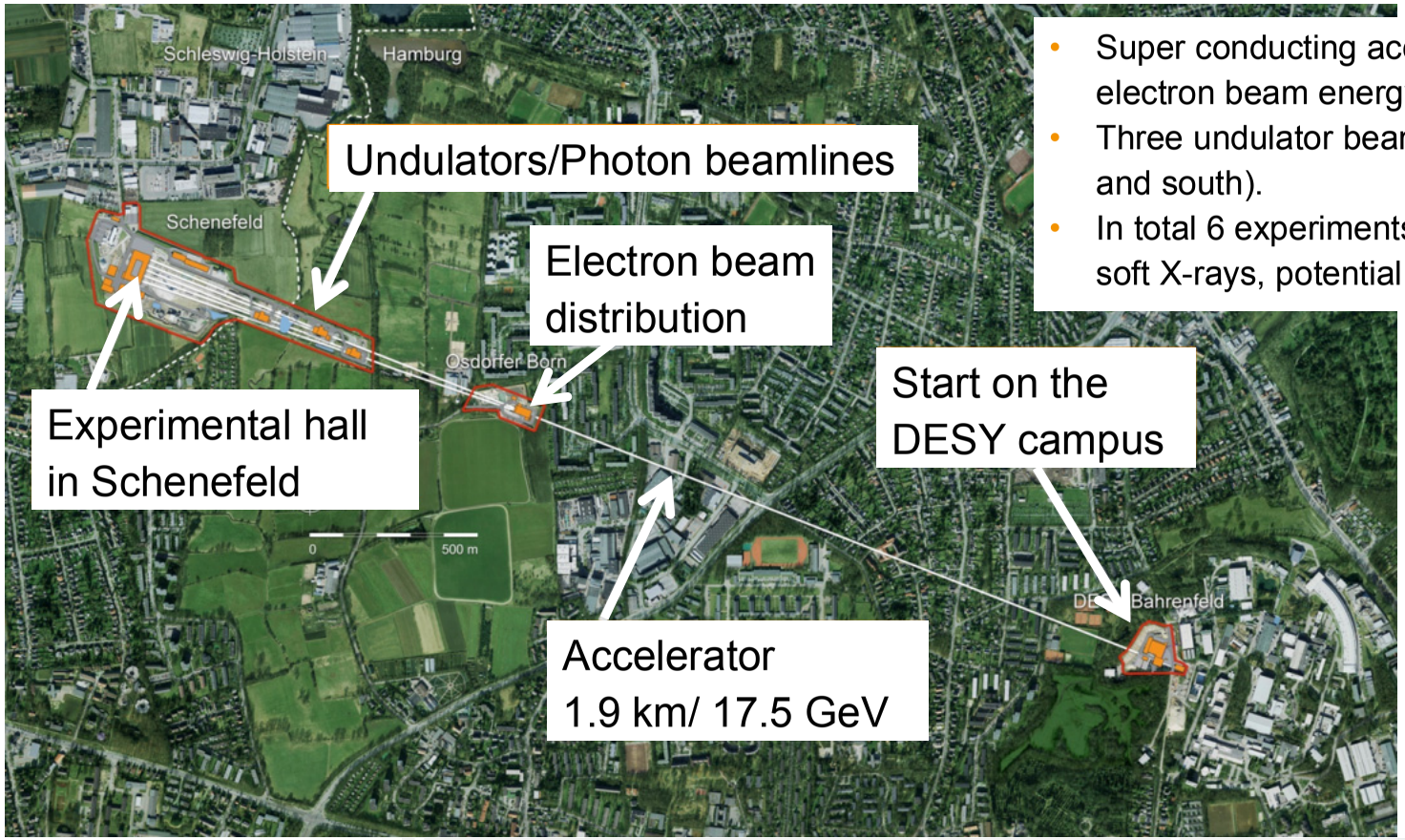
LINAC'18, September 21st, 2018





European XFEL

The European XFEL between Hamburg Bahrenfeld and Schenefeld



- Super conducting accelerator with up to 17.5 GeV electron beam energy.
- Three undulator beamlines in two branches (north and south).
- In total 6 experiments, 4 for hard X-rays and 2 for soft X-rays, potential for 2 more FELs

European XFEL

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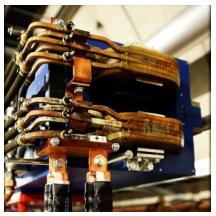
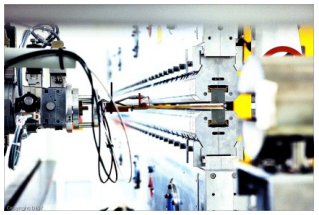
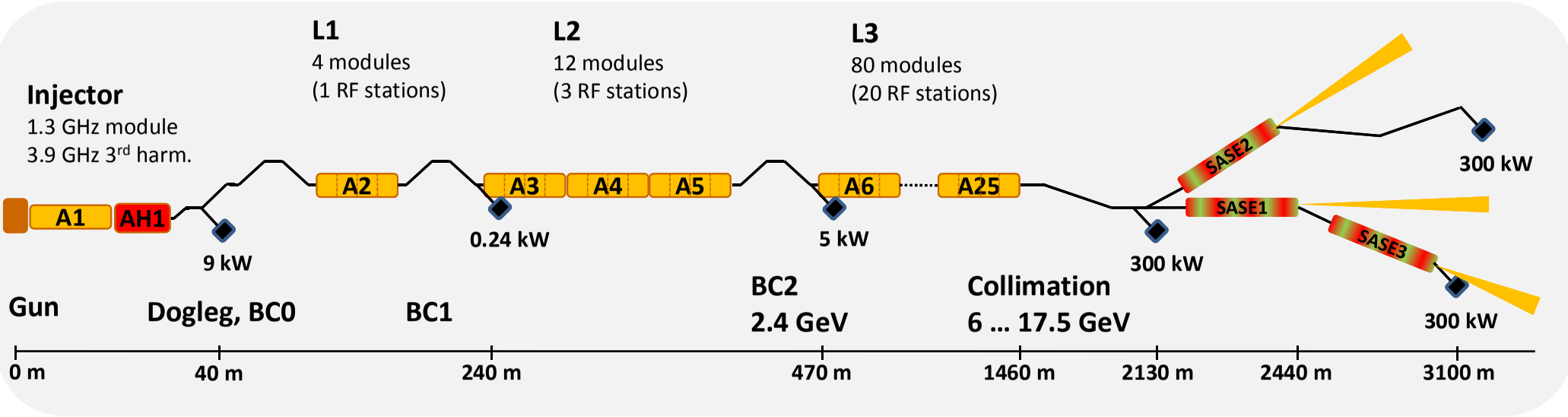
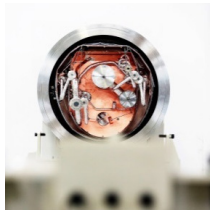
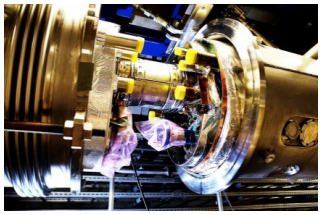
Schematic accelerator overview





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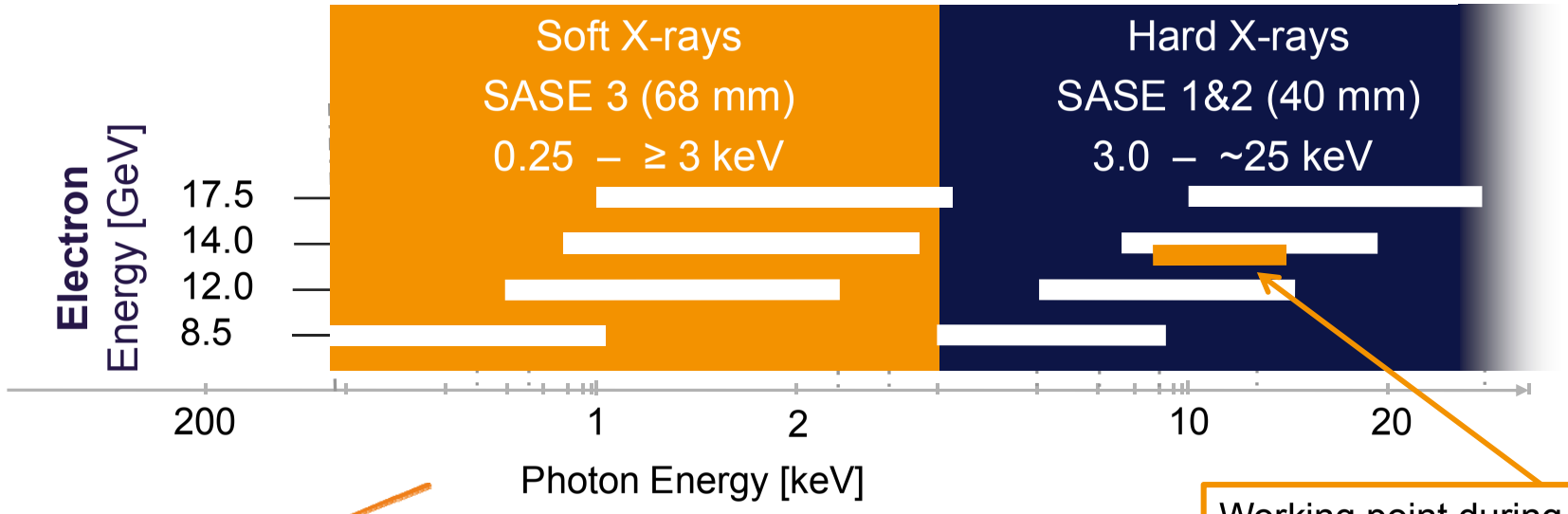
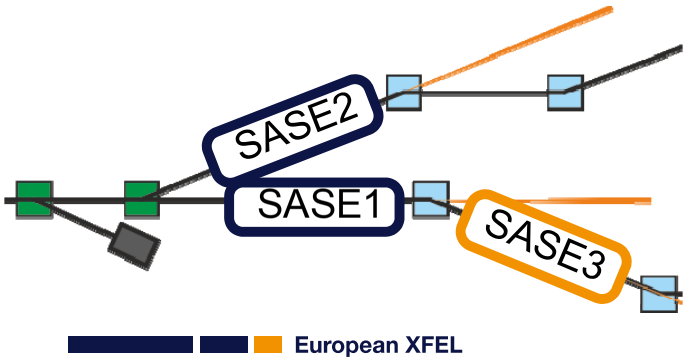
The European XFEL covers photon energies from 0.25 keV to 25 keV





Working point during user runs:

- 14 GeV electron beam energy
- 7.5 - 14 keV photon energy (SASE1).

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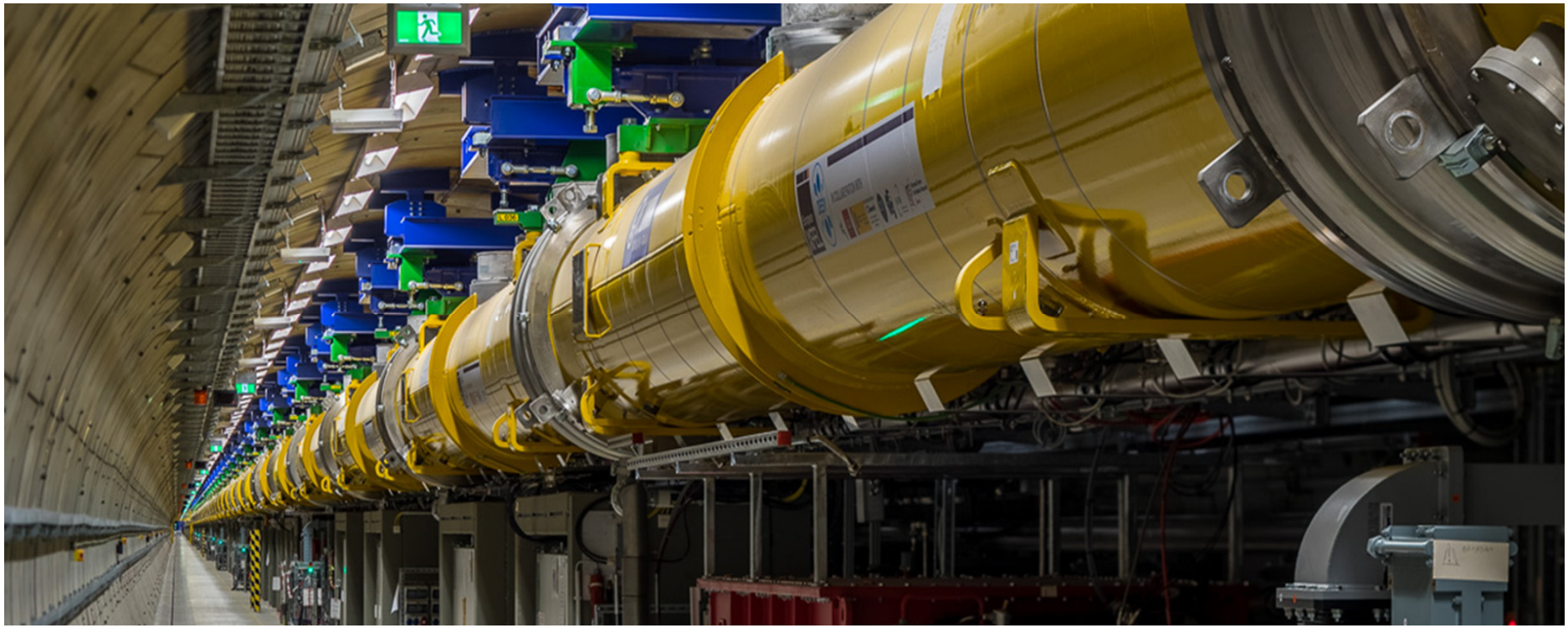
The longest superconducting linac in the world is in operation



- 96 superconducting modules in a single cryostat in the main tunnel
- plus 2 injector modules
- RF components and electronics rack are located below the accelerator.

European XFEL

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Operation of the Cryogenic System

- The system performs well, reliable, with excellent pressure stability and elaborate compensation of dynamic loads.

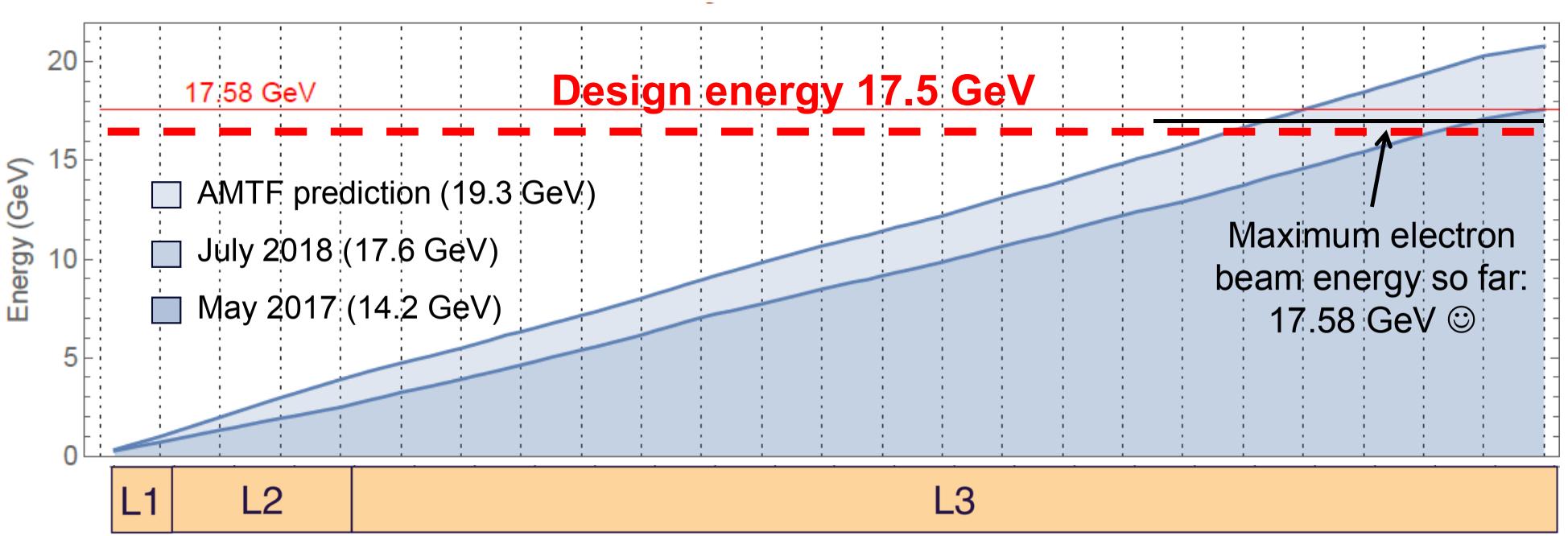
- Only problem:
  - Still MTBF of the cold compressor stages
  - Two failures of CC motors in 2018 user runs: March and May
  - Poor statistics makes it difficult to rate improvement measures

- New and updated designs are implemented but no final conclusion
  - Manufacturers commitment to solve issue was renewed management level meeting in June

	Bearing failures	Specified lifetime	Max. lifetime	Current run
CC-stage 1	0	16000	7600	2156
CC-stage 2	5		9900	11556
CC-stage 3	10		3700	3888
CC-stage 4	3		6400	2158*

* Exchanged for preventive maintenance

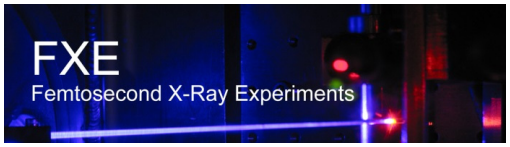
Energy reach of European XFEL

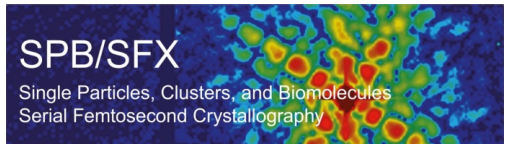


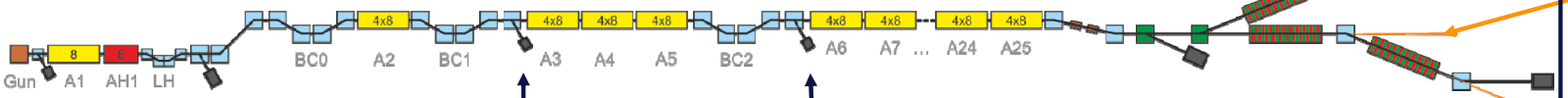
- The accelerator is commissioned accordingly to schedule and towards expected parameters.
- All 25 RF stations are in operation
- The maximum electron beam energy so far is **17.5 GeV**, user operation with **14.0 GeV.**
- There is still potential to increase the RF performance. (Branlard, Poster MOPO038)

Commissioning timeline

First user runs started in September 2017 (SASE1 beamline)





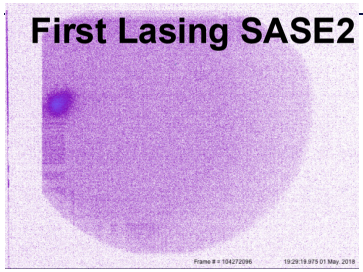


Jan 13, 2017

Jan 15, 2017 @ 130 MeV
Jan 19, 2017 @ 600 MeV

Feb 2, 2017 @ 600 MeV
Feb 22, 2017 @ 2.5 GeV

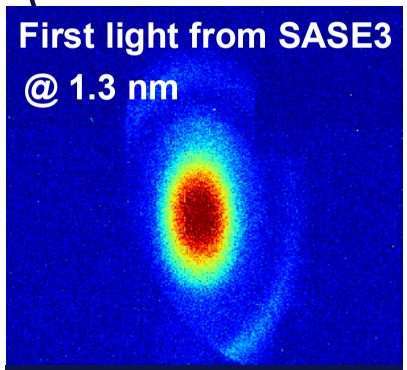
Feb 25, 2017@ 2.5 GeV
March 19, 2017 @ 6 GeV
July 12, 2018 @17.6 GeV



May 1, 2018

May 2-3, 2017

April 27, 2017



February 8, 2018

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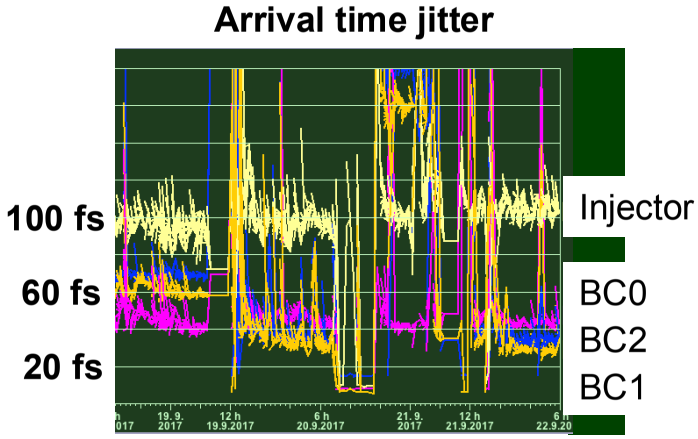
Fast Feedback Systems: Take advantage of long bunch trains

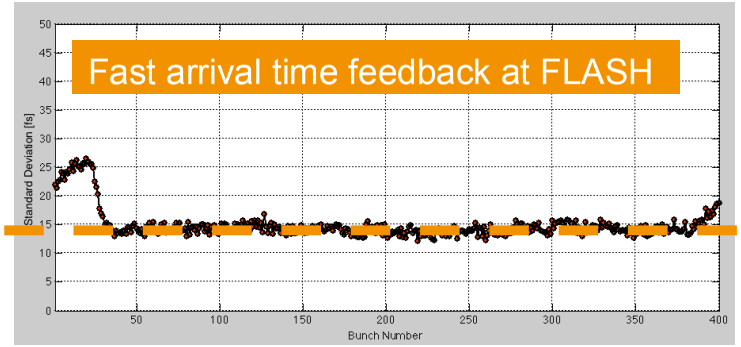
Intra bunch train orbit feedback

Arrival time stability



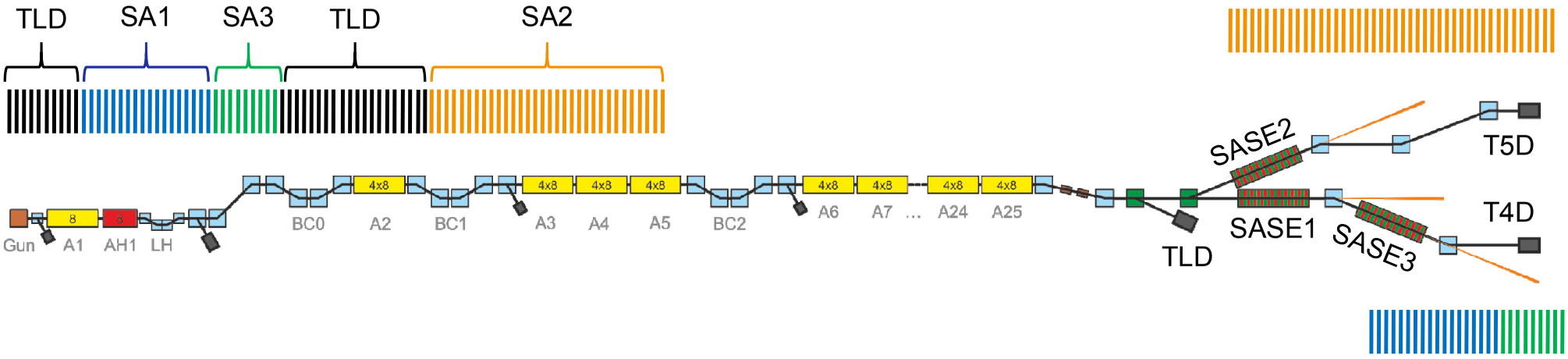
We expect an arrival time jitter in the range of 10 fs as soon as the arrival time feedback is commissioned.

Fast arrival time feedback at FLASH



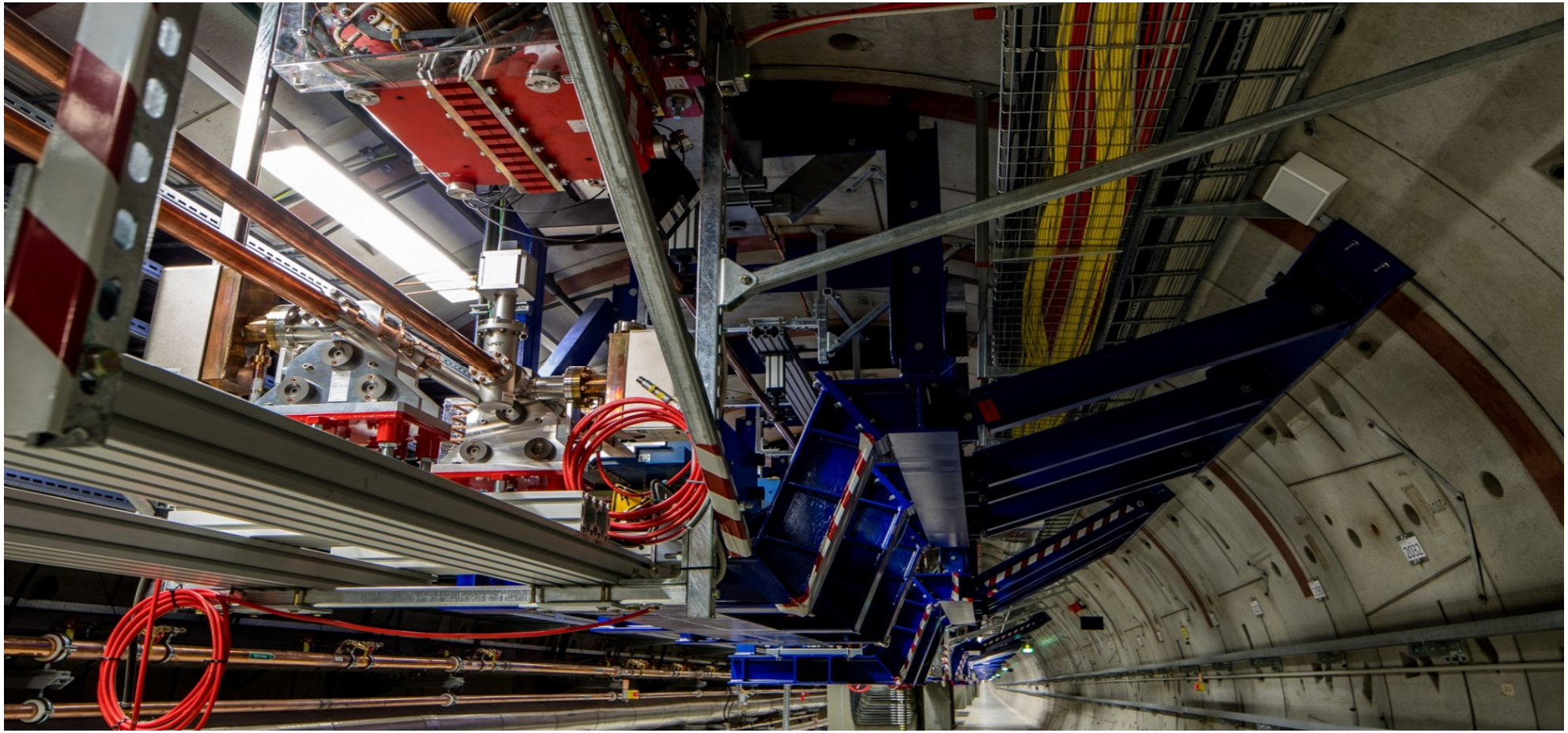
HowTo: Operate 3 beamlines in parallel

… driving SASE1, SASE2, and SASE3 simultaneously.



- 2 Switchyards
  - Fast Kicker System able to separate at 4.5 MHz
  - Precise (Slow) Flat-Top Kicker to switch between Branches
  - “Spare” Fast Kicker with “soft” kick suppresses Lasing of SASE3 bunches in SASE1

Beam Distribution: This is how it looks in the tunnel



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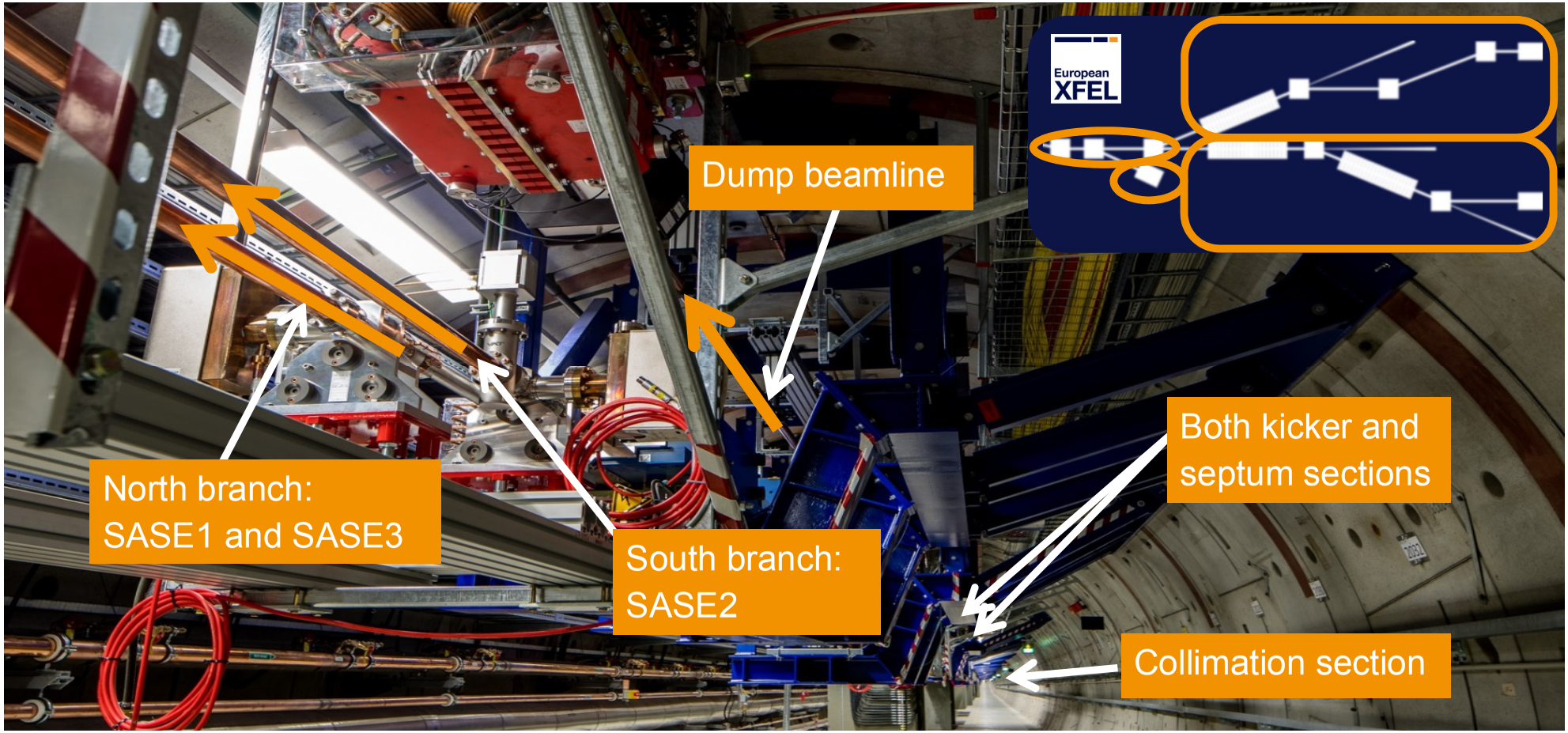
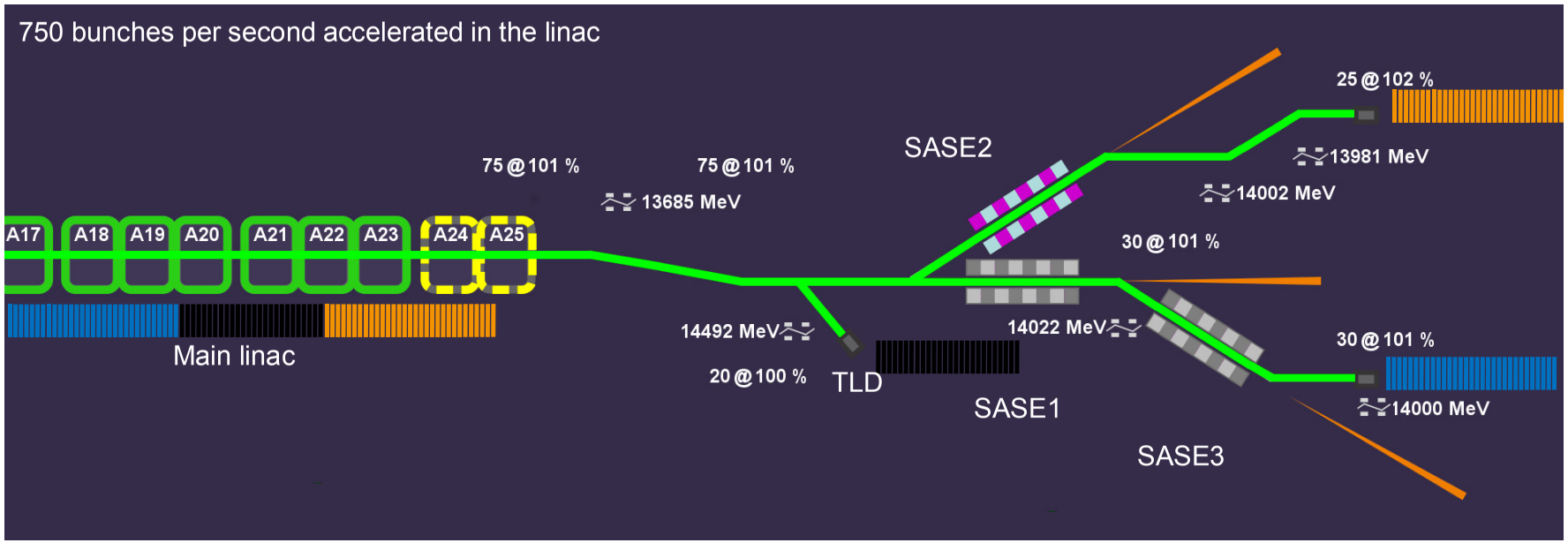
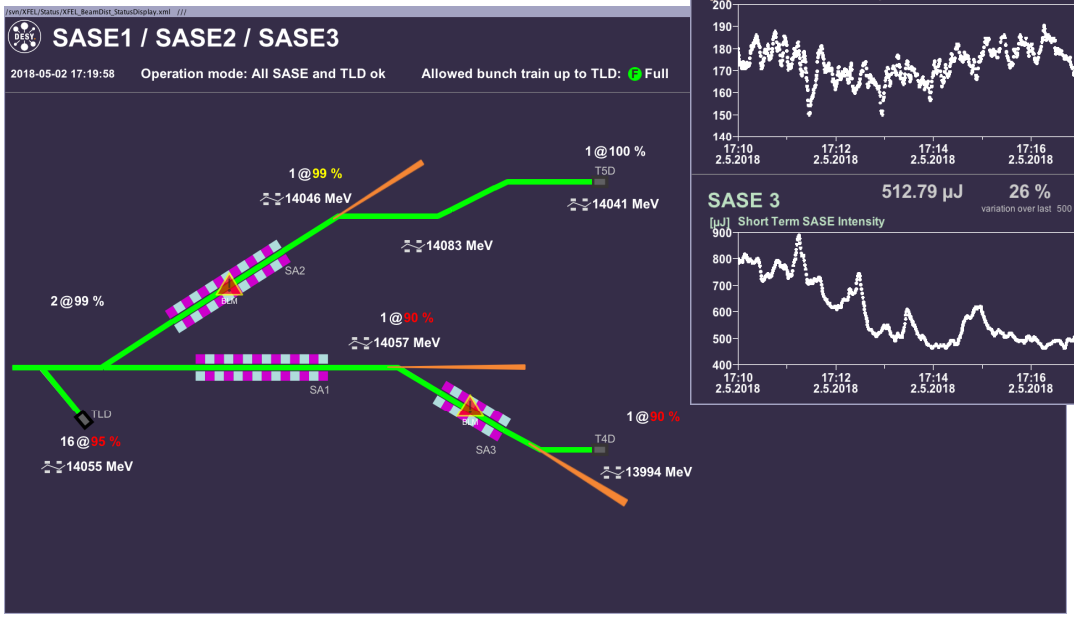


Parallel operation of three beamlines



- Bunches send to TLD during rise time of the distribution kicker.

… and now with 3 FELs “switched on”.



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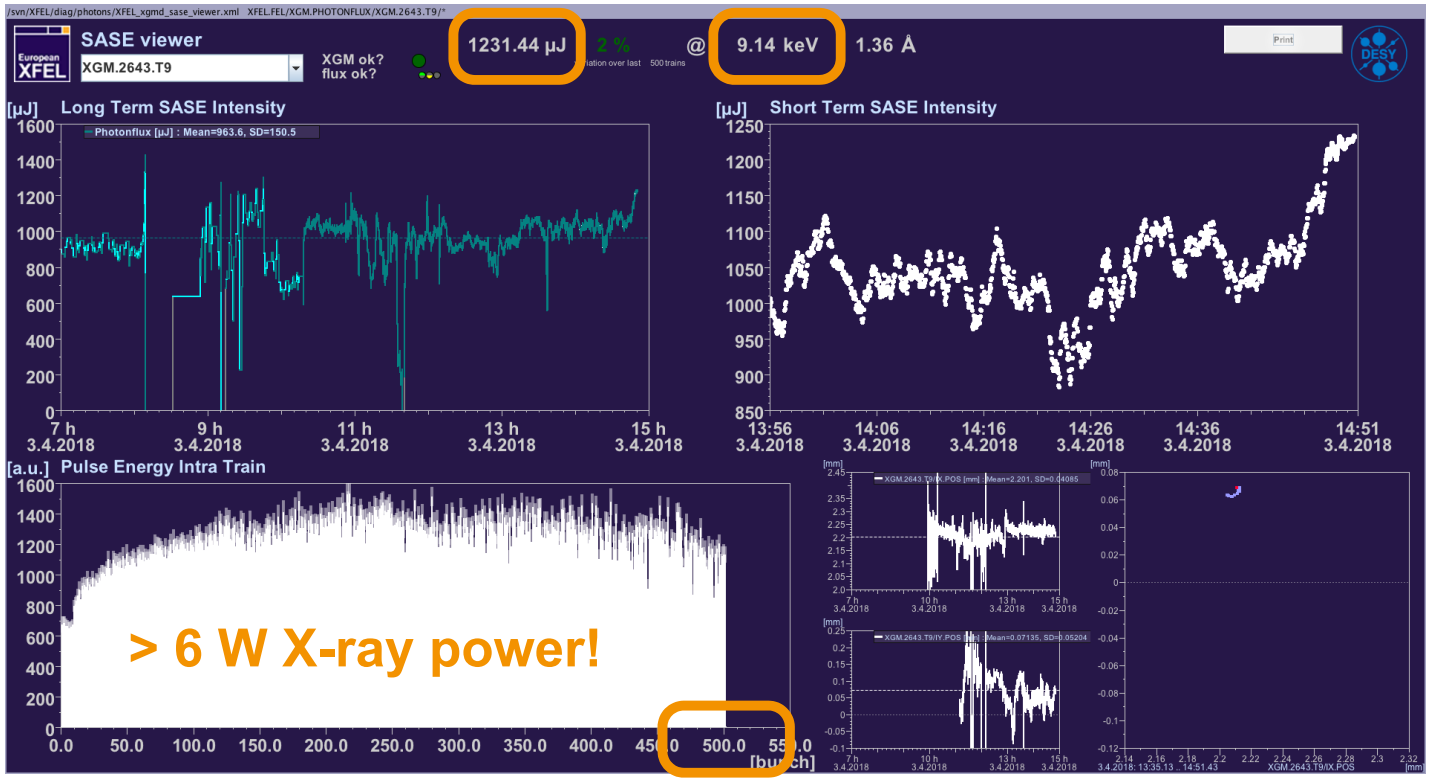
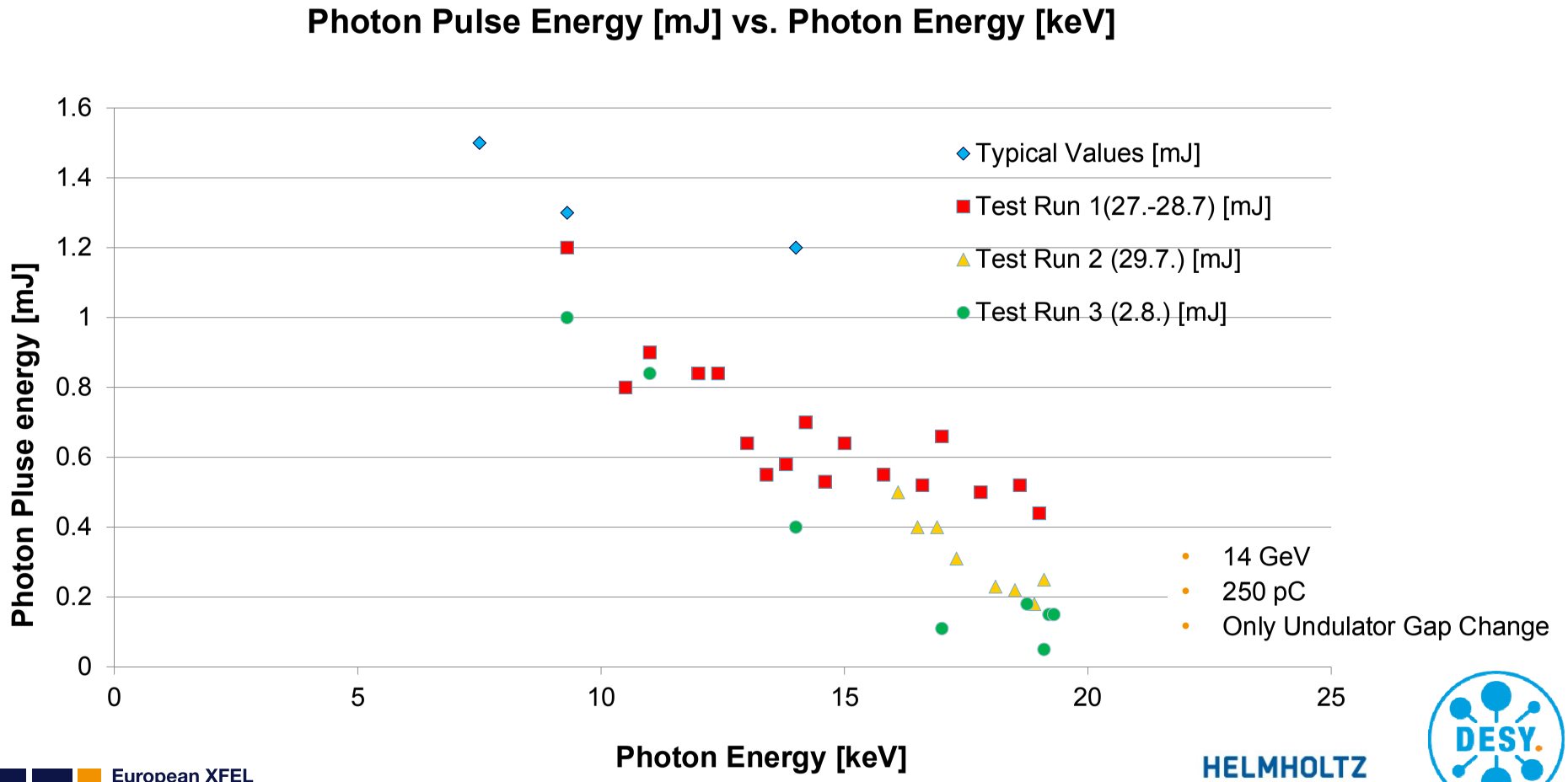
SASE delivery with 5000 bunches per second

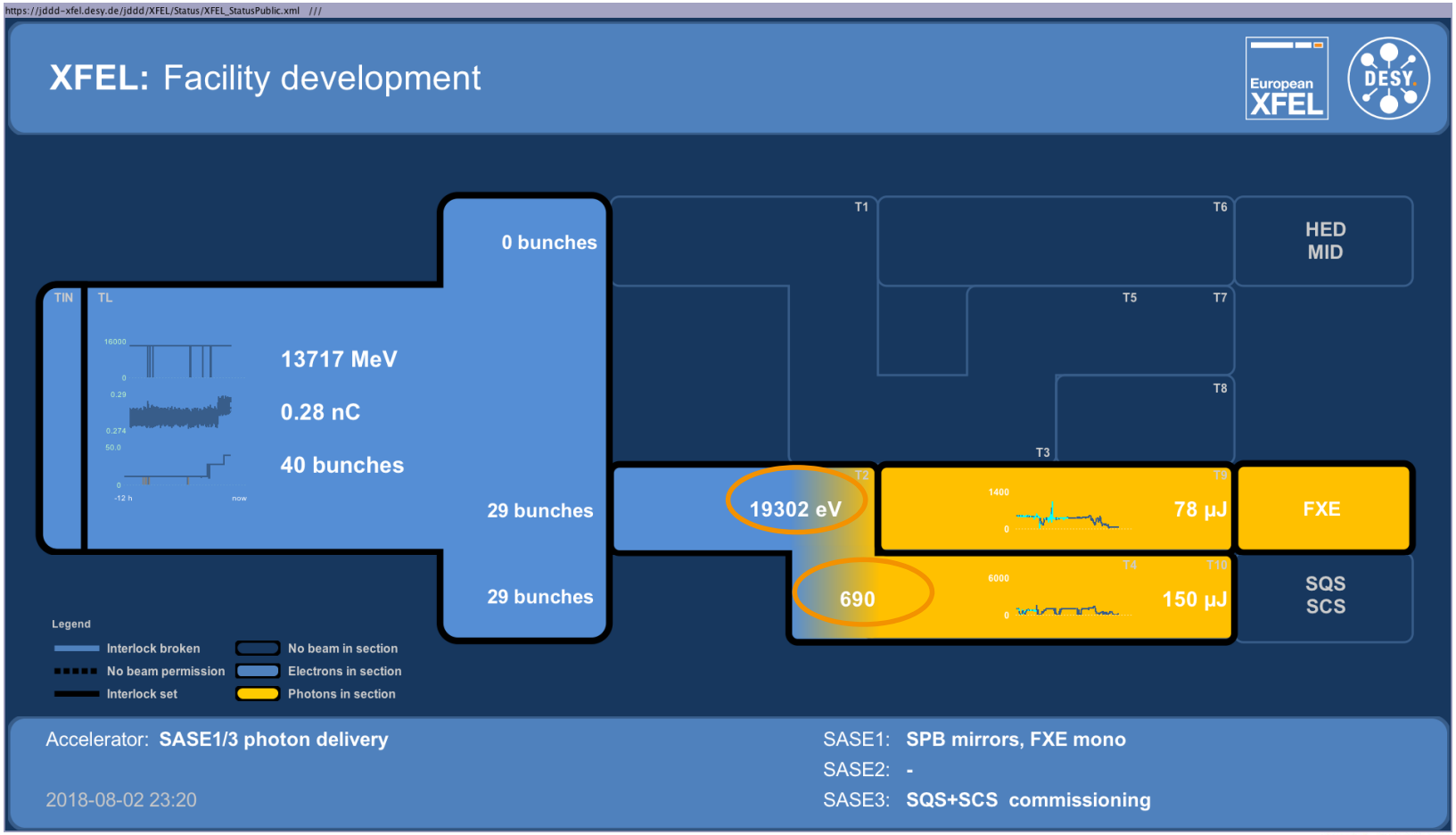
- The maximum number of SASE pulses generated so far in the SASE1 beamline was 5000/s.
- The pulse train was lasing homogeneously over almost all bunches.
- Limitation by safety to 2.5W (150 bunches/train @ 1.5 mJ/pulse).
- This number will be increased step by step driven by the upgrade of safety systems in the photon beamlines.



Highest Photon Energy Operation at SASE1

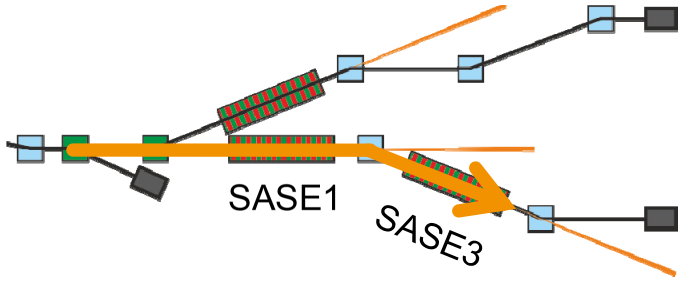


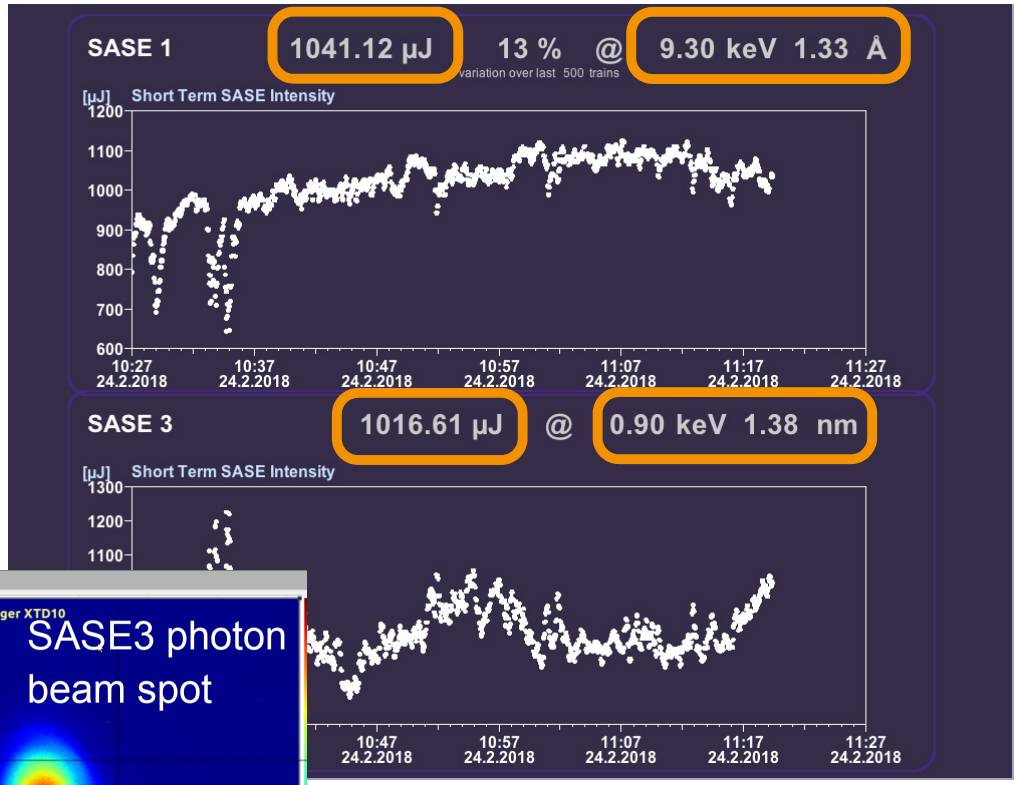
Current Wavelength or Photon Energy Span

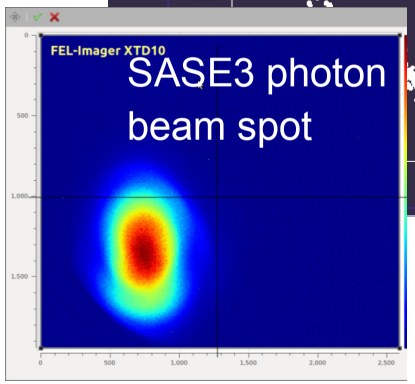


Serial operation of the hard and soft X-ray beamlines SASE1 and SASE3

- The undulator beamlines SASE1 and SASE3 are in series.
- Bunches that lased in SASE1 contribute also to SASE3 power.
- The level of photon pulse energy in SASE3 depends on the level in SASE1.







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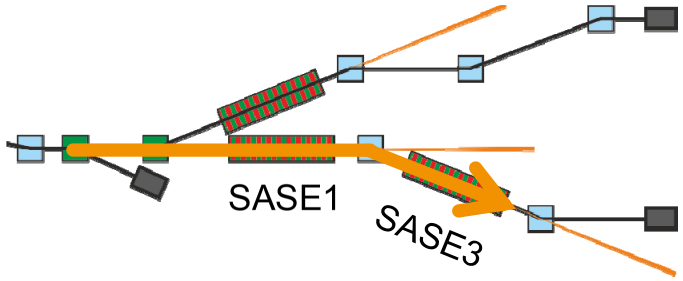

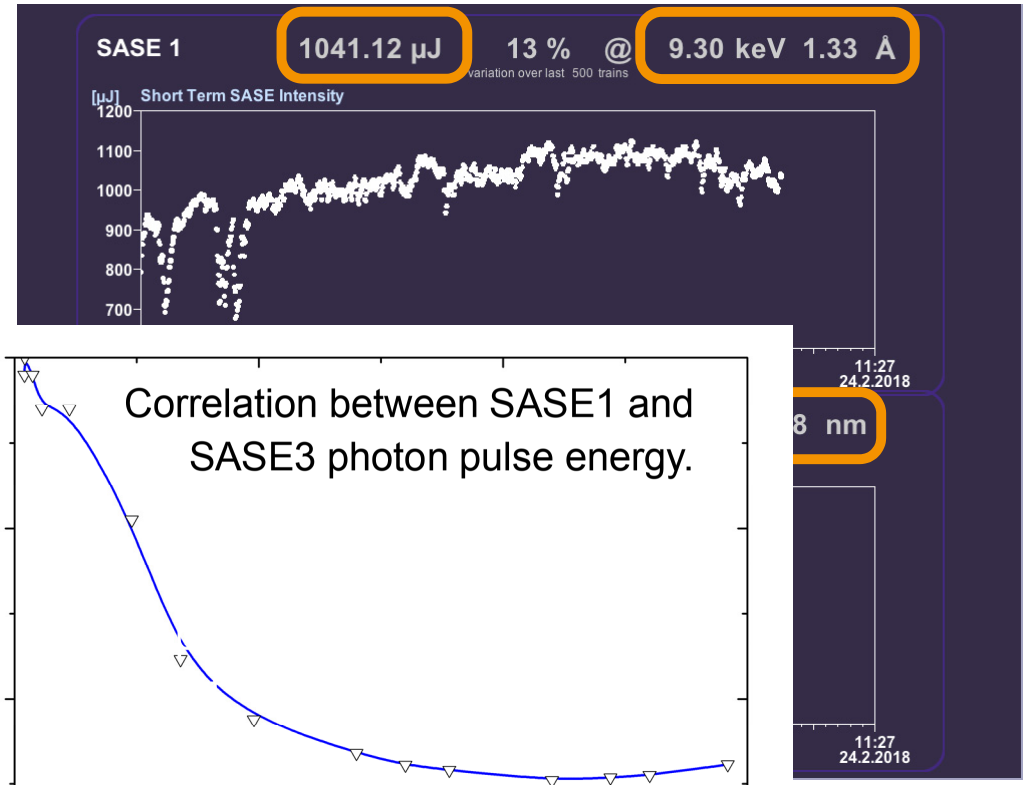

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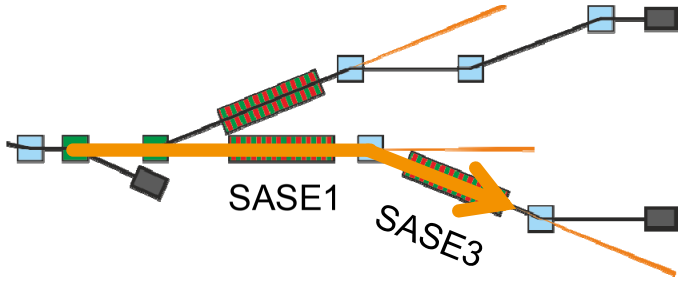
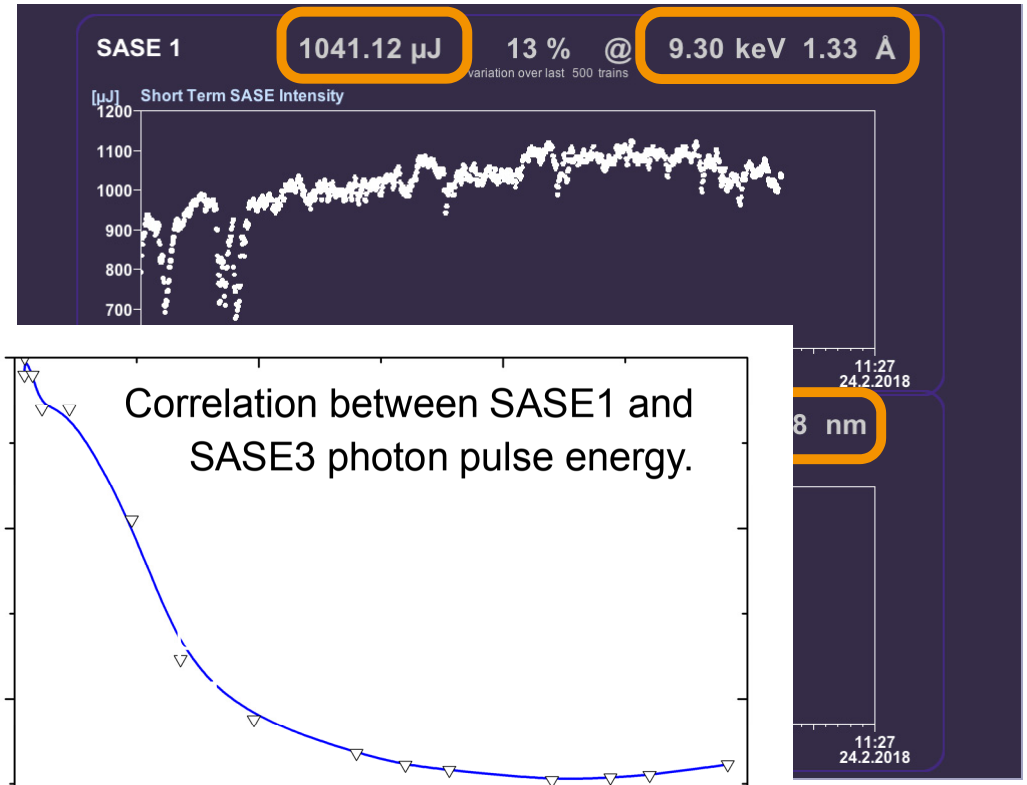
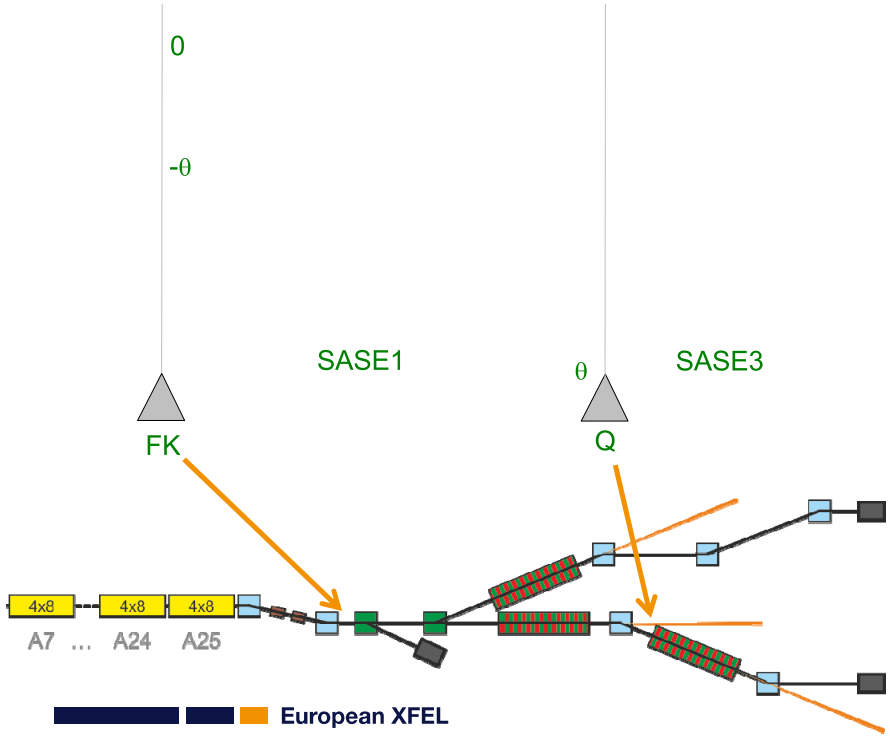




A Decoupling technique is required!

- The fast dump kickers can be used to start a betatron oscillation for bunches that should not lase in SASE1 but in SASE3.
- A DC corrector upstream SASE3 cancels the oscillation and brings fresh bunches to the SASE3 lasing orbit.
- SASE1 bunches can still produce some lasing, but emit light under different angle, allowing for spatial separation in the photon beamline



Fresh bunch lasing in SASE3!

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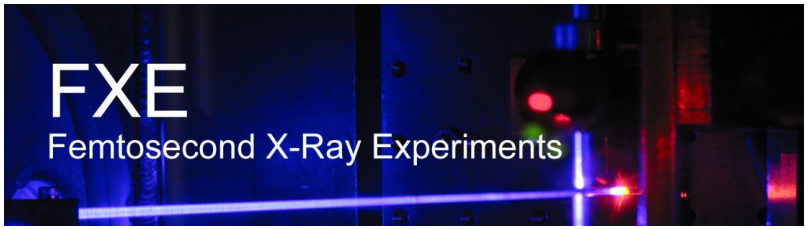
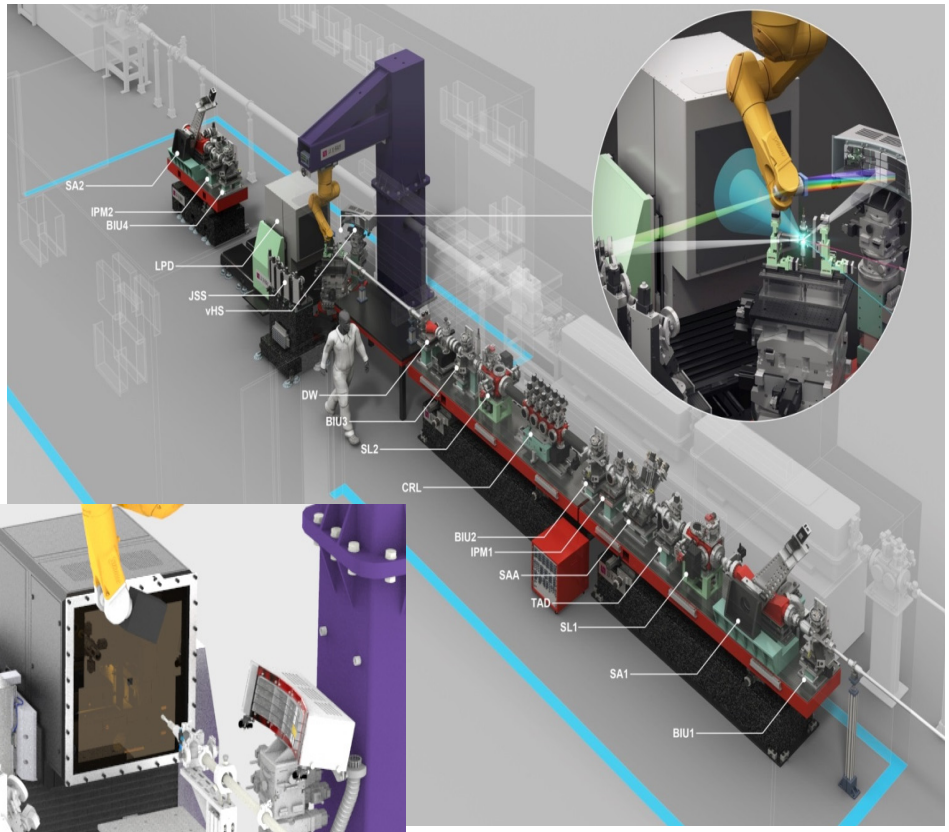
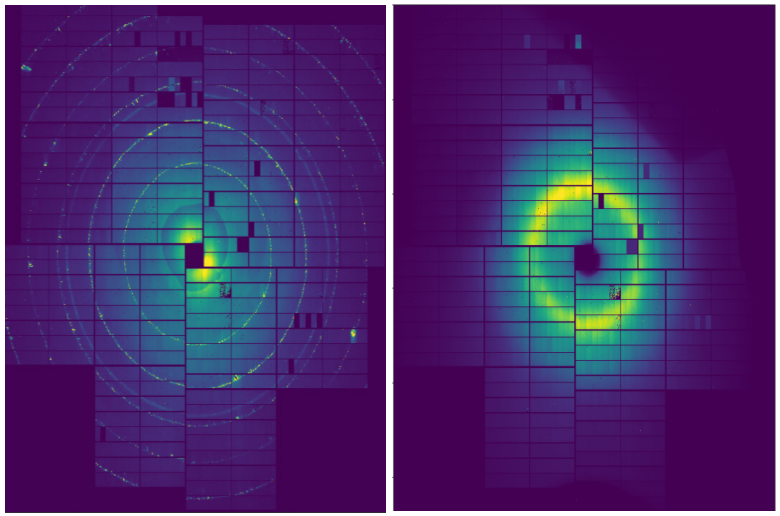
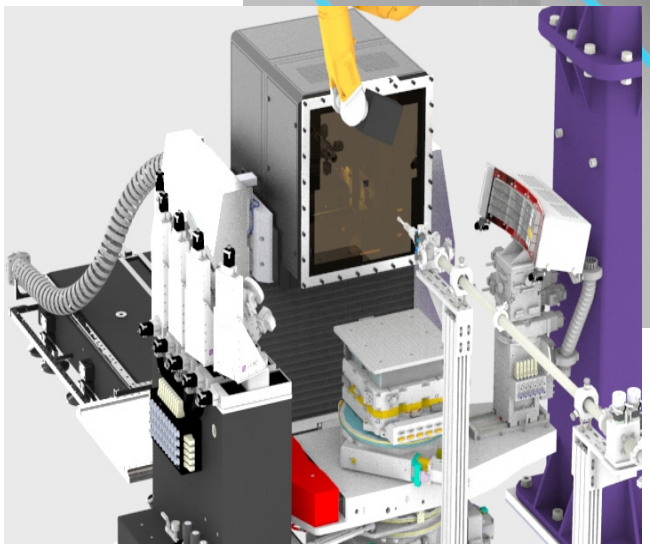
FXE instrument





LaB_6 calibration powder, ~140 mm to detector
LPD single shot images





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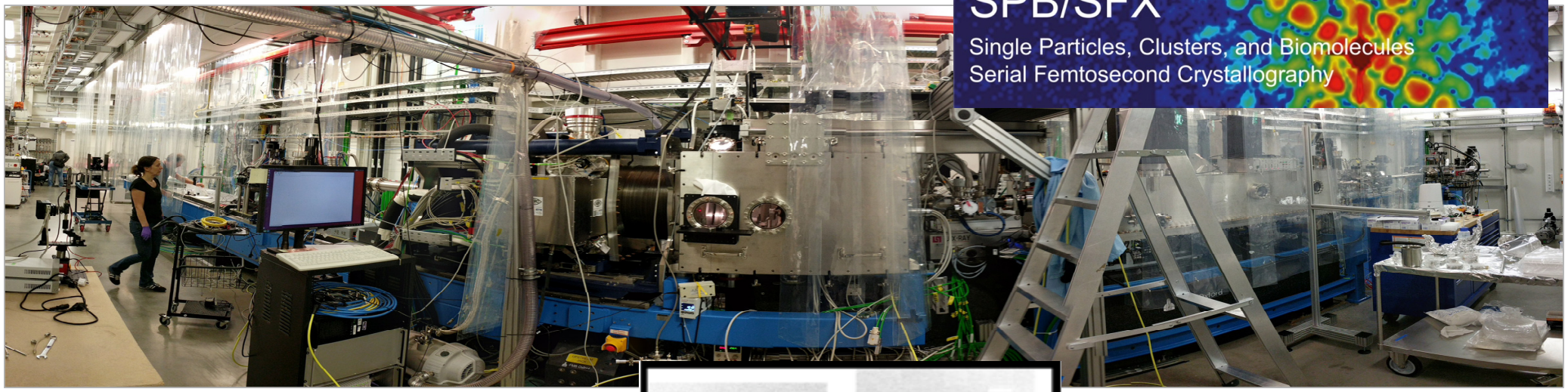
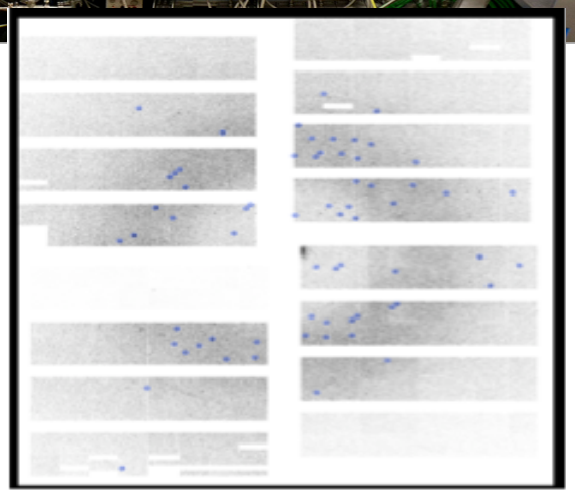
The SPB/SFX instrument at the European XFEL



The SPB/SFX instrument is used for serial crystallography and other structure determination experiments (particularly biology).



(Left) Early crystallography data from SPB/SFX, which has been successfully used to determine the structure of a test biomolecule.

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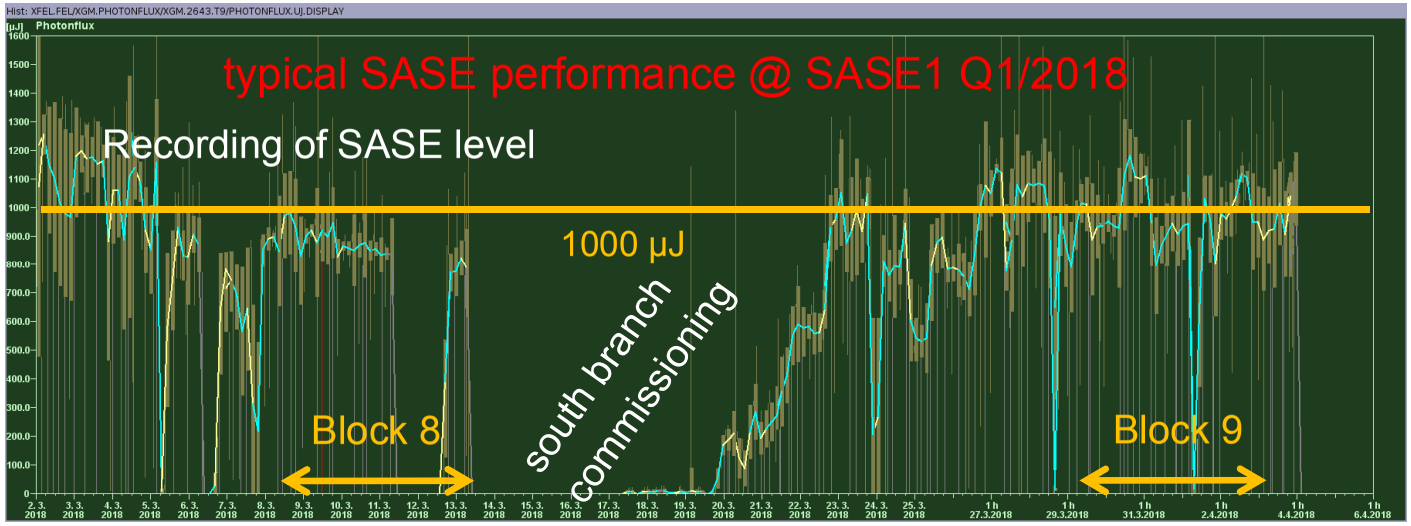
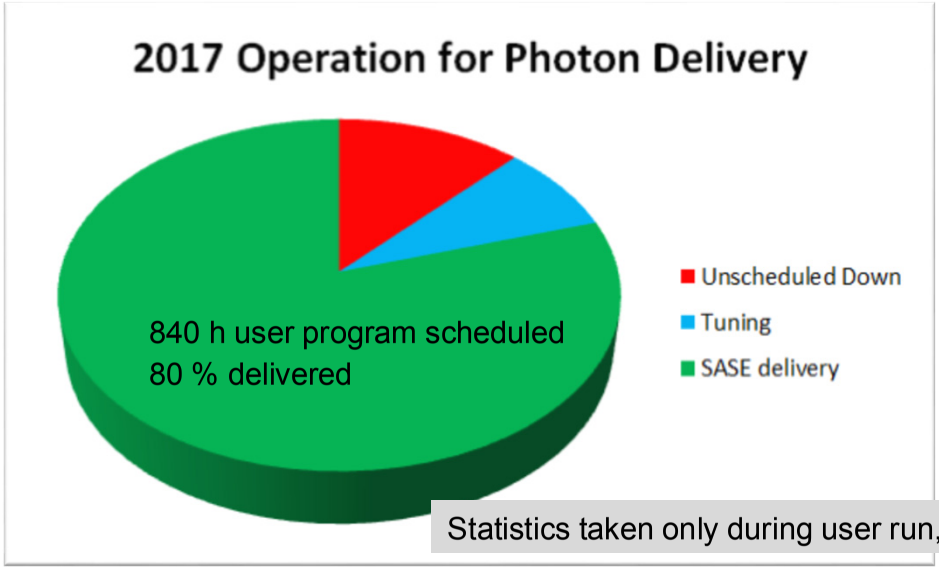
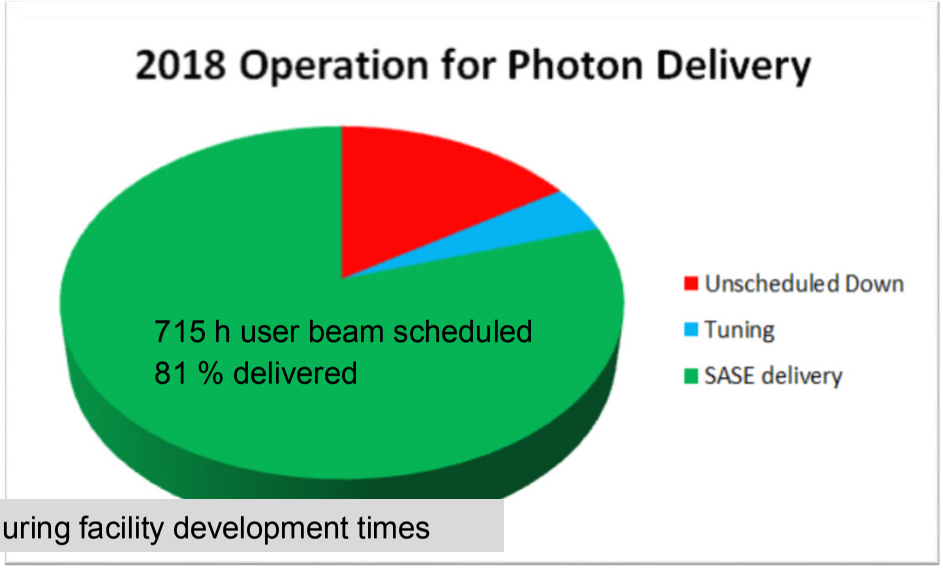
User Runs



- User operation: mainly 1 – 120 bunches, 9,3 – 14 keV, 14 GeV, Change of Instrument every 12 hours
  - 2017: 7 Blocks/Weeks with Photon Delivery of 5 days in a row: 840 h
  - 2018: 1720 hours of scheduled user run
    - 6 Blocks/Weeks in 1st 6 months of 2018: 720 h
    - 11 Blocks/Weeks or 1000 h to be provided in 2nd half of 2018

1st Operation Statistics for 2017 and 2018 until June





Statistics taken only during user run, not during facility development times

- Down dominated a few events > 24 h
  - M1 bender failure and subsequent long tuning time → 13% delivered

- Down dominated by a few events > 24h
  - 2 cold compressor motor failured → 70%
  - Magnet power supply → 70%
- 94% without these events

(Accelerator) Parameter Space (Status Summer 2018)

Quantity	Unit	Project Goal	Achieved	Routine
electron energy	GeV	8 – 17.5	6 – 17.5	14
bunch repetition within pulse	MHz	Up to 4.5	Up to 4.5	1.1
bunch charge	pC	20 – 1000	100 – 500	250
electron bunch length after compression (FWHM)	fs	2 – 180	20 – 90	50
max. beam power	kW	500 kW	18 kW	1.8 kW
undulators in operation (lasing)		SASE1-3	SASE1-3	SASE1
photon pulses / s / undulator		27000	5000	<1200
photon energy (SASE1)	keV	0.25 - 25	7-19.3	9.3, 14
photon pulse intensity (SASE1) @ 14 GeV, 250 pC, 9.3 keV	mJ		1.5*	1.2
photon pulse intensity (SASE3) @ 14 GeV, 250 pC, 600 – 900 eV	mJ		7	<1*
photon pulse intensity SASE2 (@ 14 GeV, 250 pC, 7.5 keV	mJ		0.9	

* Restricted by safety limitations of SASE1/3 photon beamlines

Plans

- Full bunchtrain (27000 bunches/s) after linac by end of 2018.
- Installation of self-seeding chicanes (Winter shutdown 2018/19).
- Increase #pules/s to 3000/s for SASE1 and SASE2.
- First user experiments SASE3, soft X-ray, 11 GeV: Nov. 2018.
- First user experiments in SASE2, hard X-ray: Spring 2019.
- Ramp up user program to about 4000 h in 2019.
- Facility Development 2019: about 1400 h
  - Improving performance and flexibility of all beamlines.
  - Establish a high energy (16-17 GeV) standard working point
  - Go beyond 20 keV photon energy
  - Low charge/short pulse operation

Operation in 2019

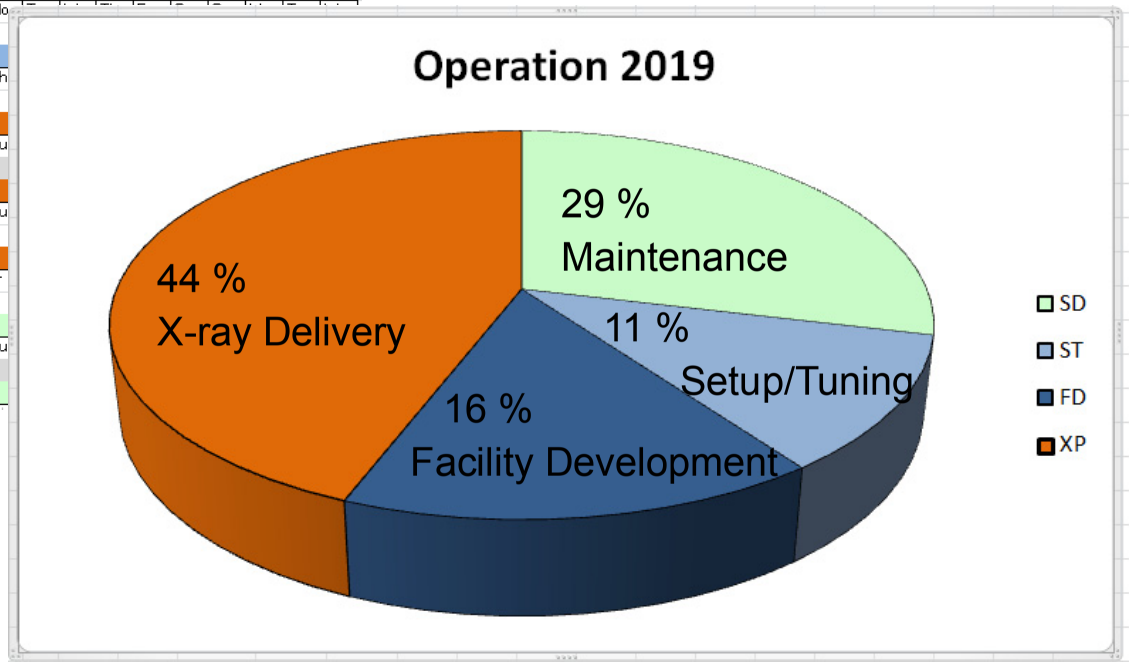
total 8780 h/365 d

- 105 d: Maintenance
- 984 h: Setup and tuning
- 1392 h: Facility Development
- 3864 h: X-Ray Delivery

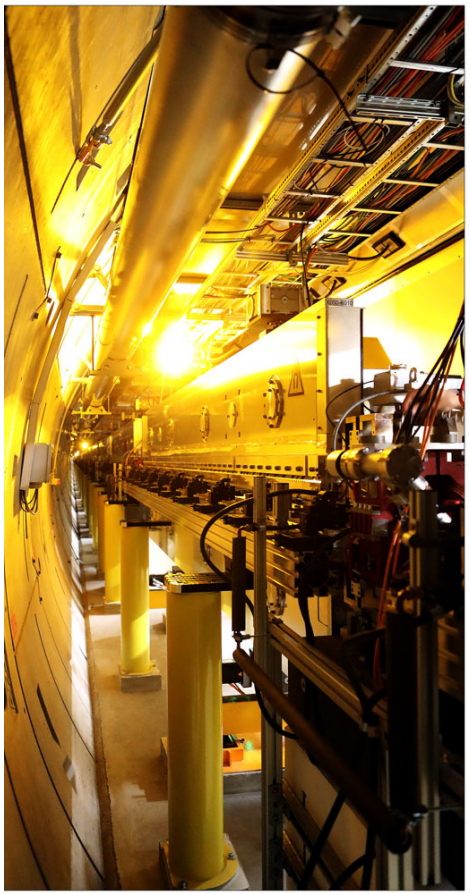
Outline Annual Operation Schedule 2019 (DRAFT, rev13, 20/08/2018)

Legende: Weekend | Bank holiday | Scheduled down | RP | ST | FD | XP

2019	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jan	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th
Program																															
Feb	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th			
Program																															
Mrz	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
Program																															
Apr	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	
Program																								Start 11.5 GeV							
Mai	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr
Program										End 11.5 GeV																				
Jun	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	
Program																															
Jul	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo									
Program																															
Aug	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th									
Program																															
Sep	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su									
Program																															
Okt	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu									
Program																															
Nov	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr									
Program																															
Dez	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su									
Program																															



Conclusion … 21 months after start of beam commissioning …



- All 3 FELs are lasing
  - Hard X-ray SASE1 is in standard User Operation
  - SASE3 and SASE2 will follow in the next few months
  - Parallel and decoupled operation of 3 FELs demonstrated
  - Photon energies: 0.65 – 1 keV (SASE3) and 7- 19.3 keV (SASE1)
  - Pulse energies (standard working point 14 GeV)
    - ► Hard X-ray: up to 1.5 mJ
    - ► Soft X-ray: up to 7 mJ (currently limited to 1 mJ due to safety restrictions)
  - Already 1500 h of user operation between Sept. 2017 and July 2018
- Accelerator performs to specifications
  - 17.5 GeV, low emittance beams
  - Bunch trains at 1.1 and 4.5 MHz repetition rate with up 500 bunches per RF-pulse
  - Standard user operation at 130 bunches per RF-pulse or 130 X-ray flashes/s
- Progress of the facility is driven by the potential of the accelerator

… there is light at the end of the tunnels!

European XFEL

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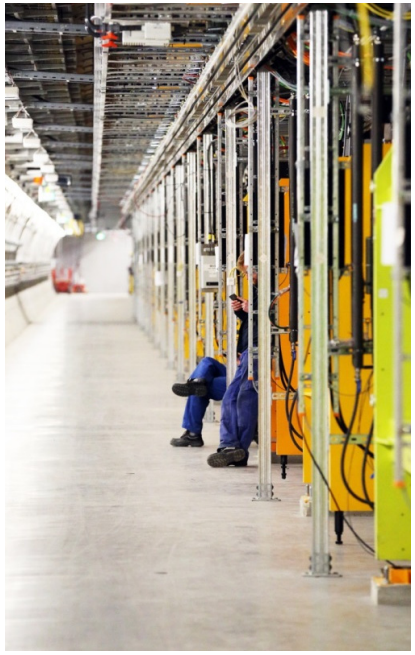
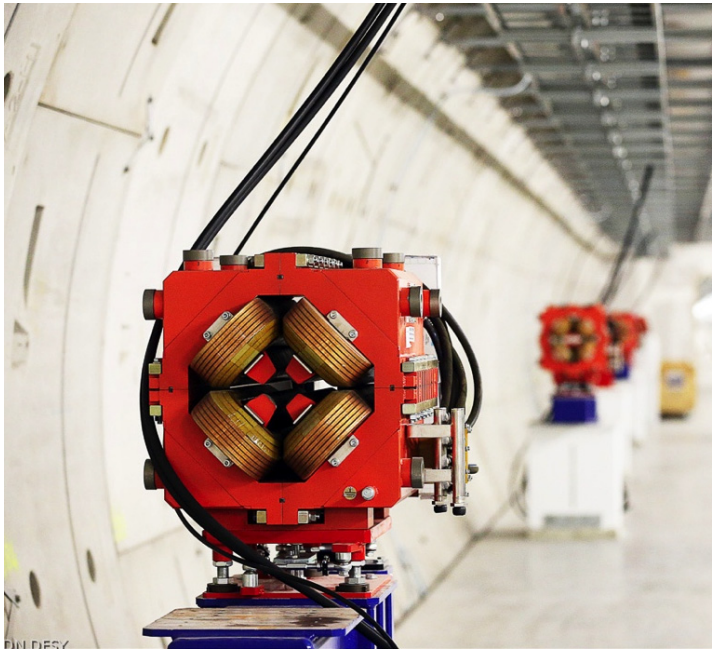
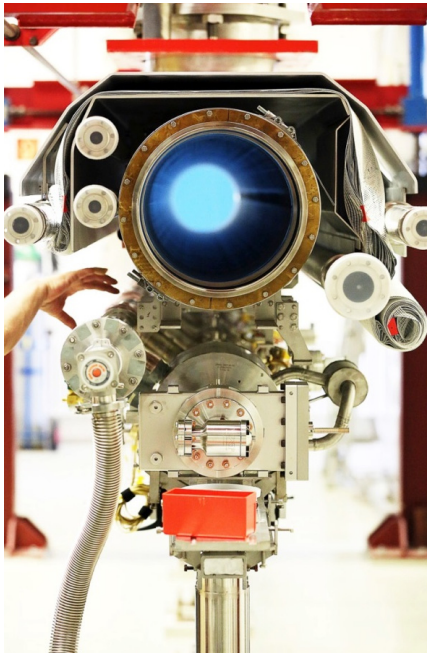
DESY.



Thank you for your attention

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