# Recent Status of Beam Commissioning at the European XFEL

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for the linac team

ALCW, Fukuoka, 2018/05/30

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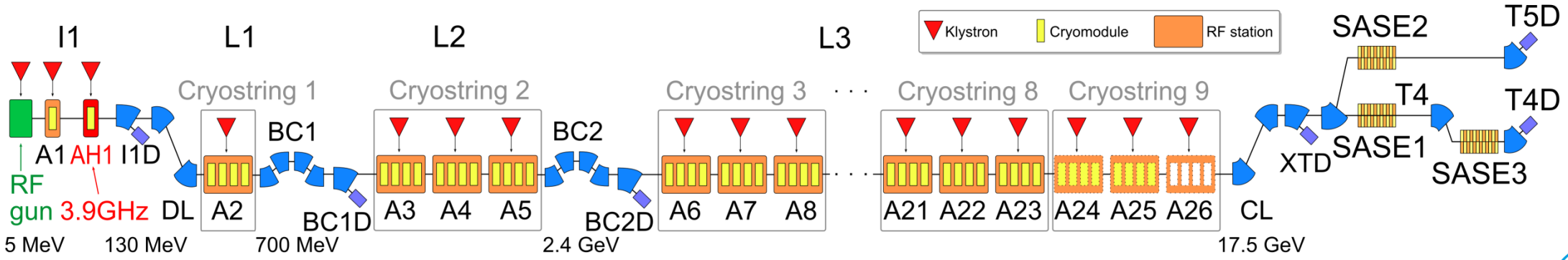
- Introduction
- Beam Commissioning
- SASE Performance
- Linac Performance
- Energy Reach
- Outlook / Summary

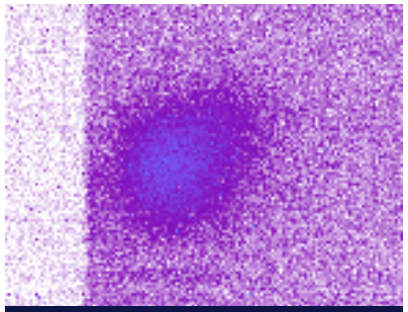
# The European X-ray Free Electron Laser (XFEL)

- Soft and hard X-ray light experiments
- ~800 TESLA-type cavities
- Resonance frequency 1.3 GHz
- 32 cavities per XTL RF station
- Design energy 17.5 GeV
- Pulsed operation 10 Hz
- RF commissioning finished up to cryostring (CS) 8
  → 25 RF stations on beam



# Commissioning Timeline

First light from SASE2 @ 1.77 nm

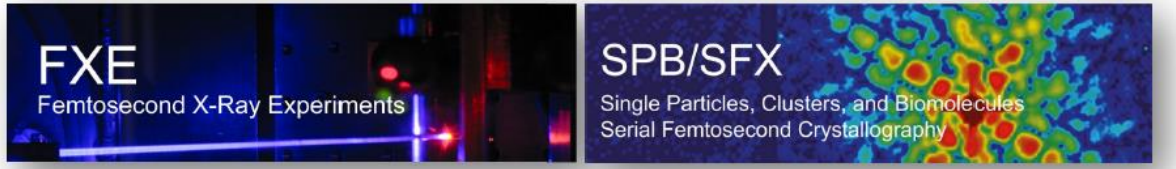


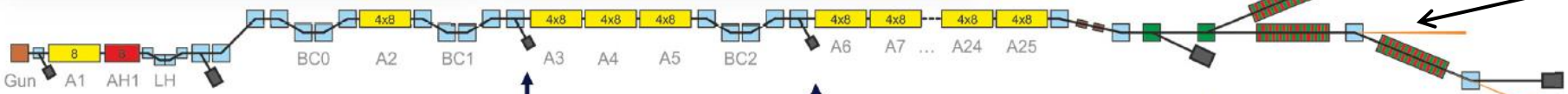
May 1, 2018

March 13, 2018


May 2-3, 2017

**First user runs started in September 2017 (SASE1 beamline)**



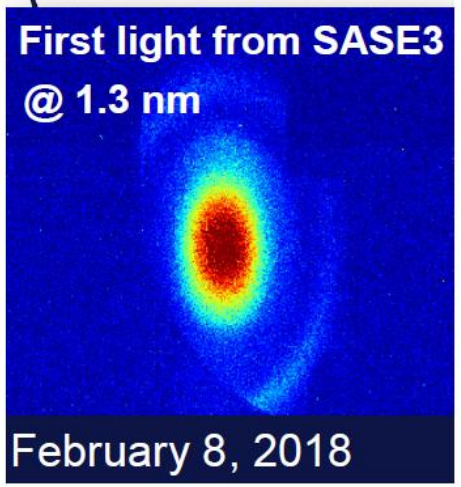

April 27, 2017

Jan 13, 2017

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

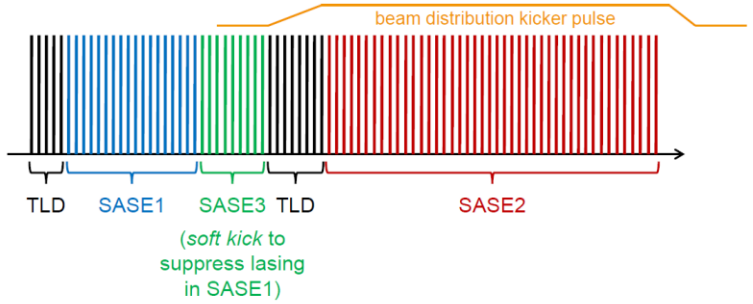
Jan 15, 2017 @ 130 MeV
Jan 19, 2017 @ 600 MeV

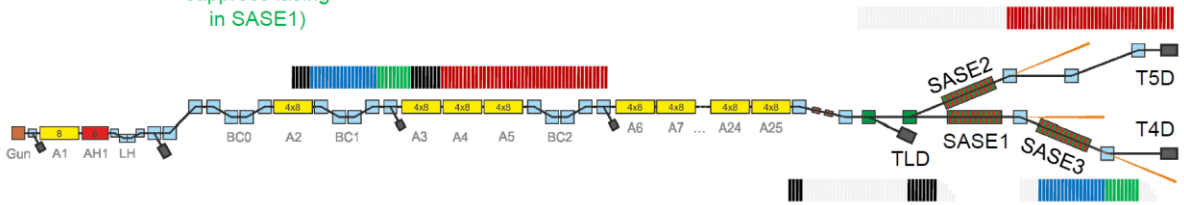
Feb 25, 2017@ 2.5 GeV
March 19, 2017 @ 6 GeV
April 8, 2017 @ 12 GeV

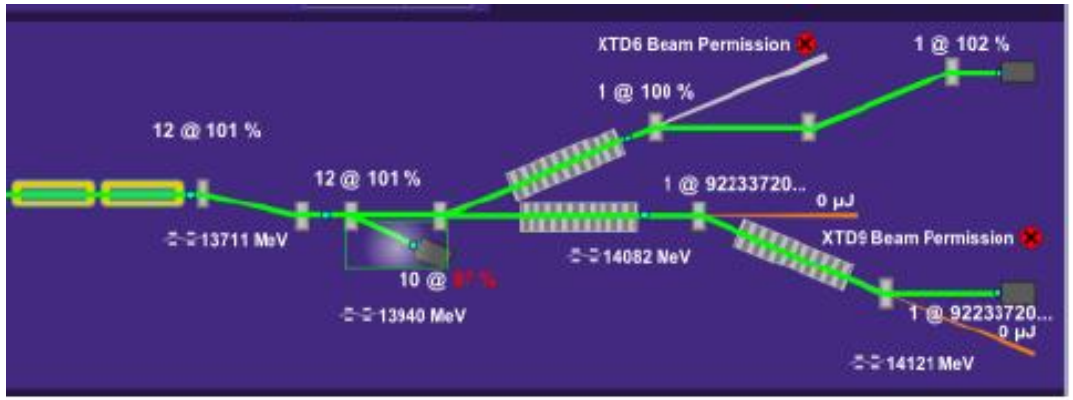


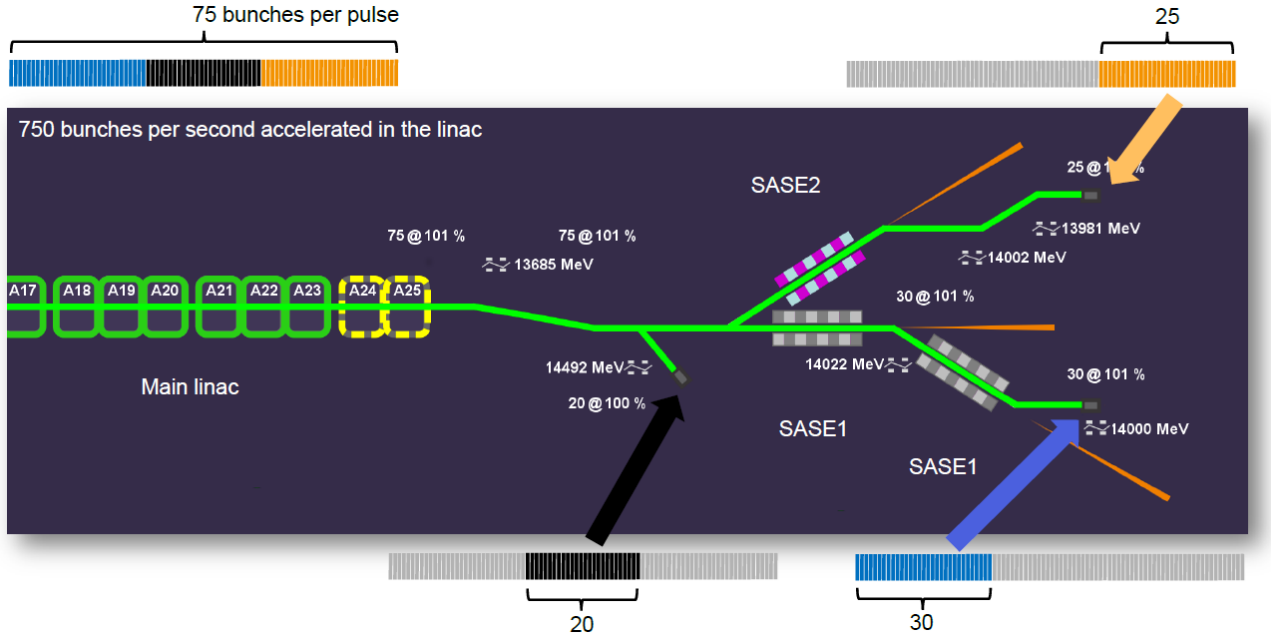

February 8, 2018

# March 15th: First Beam to TLD, T4D, and T5D due to Advanced Bunch Patterns



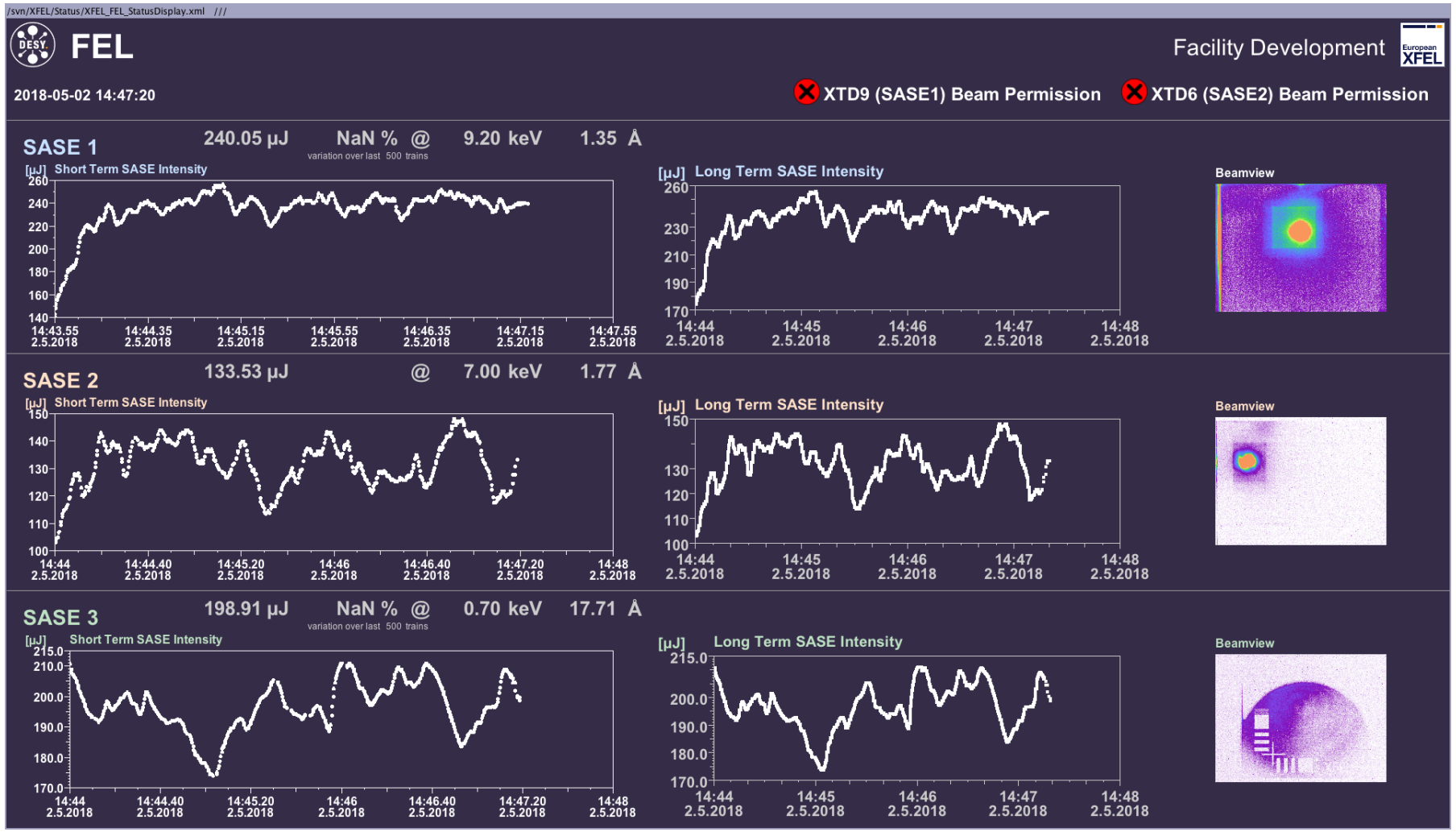



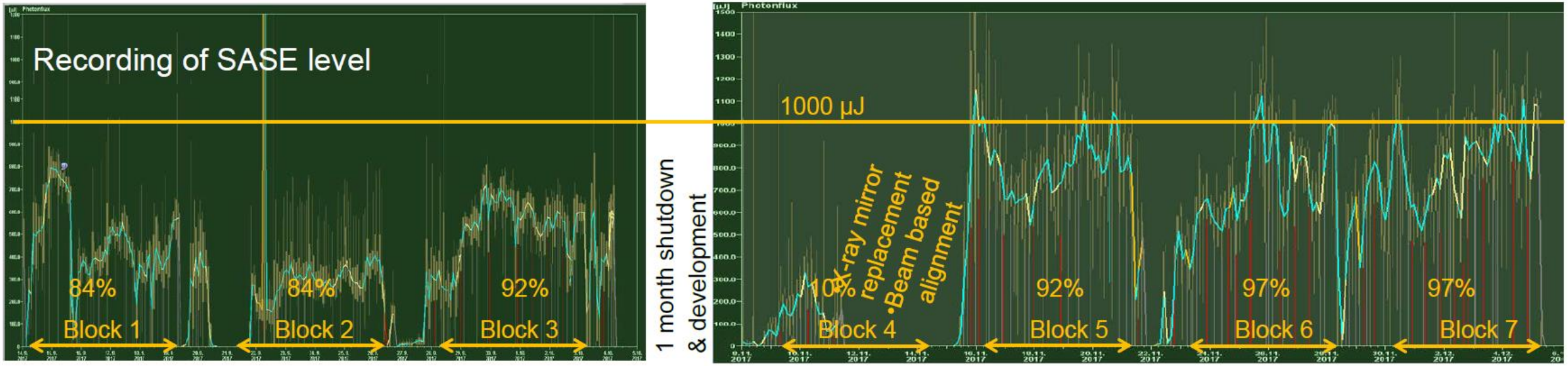




Later example

# May 2nd: First Simultaneous Lasing in all Three Undulators

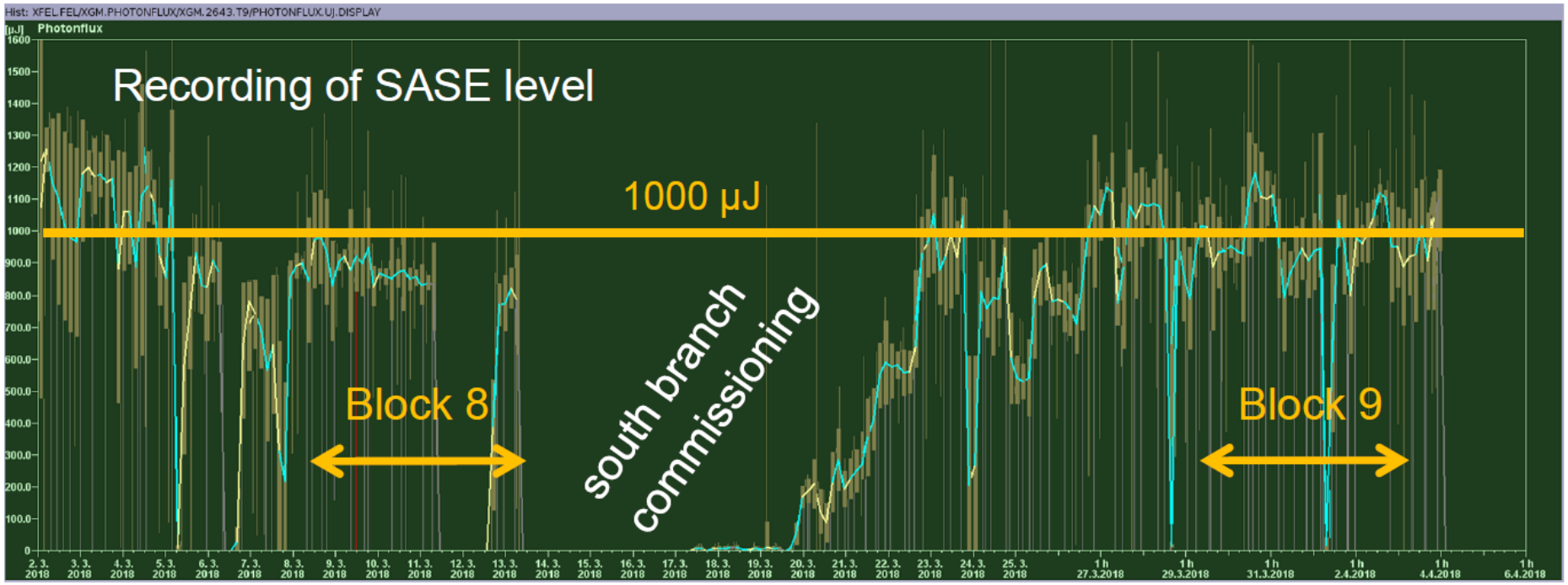


# User Run Blocks 1-7 in 2017: SASE Performance




- Seven 5 day user blocks starting September 14th
- Availability (= SASE delivery above threshold)
- Little tuning needed (because of limited flexibility offered), but frequent small wavelength changes and variation of bunch number (1-30)
- Prominent error sources: operation & controls, RF trips (frequent, but very fast recovery), magnets

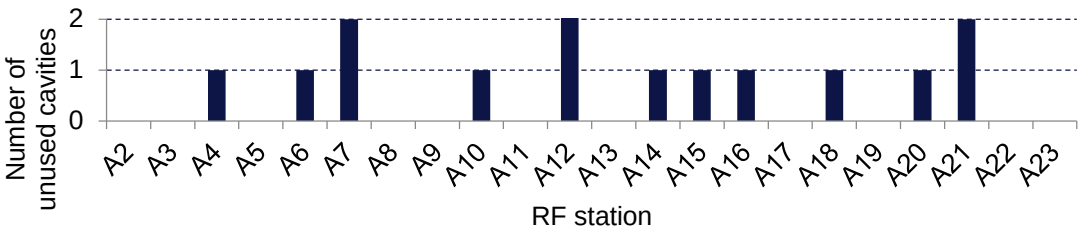
# User Run Blocks so far in 2018: SASE Performance

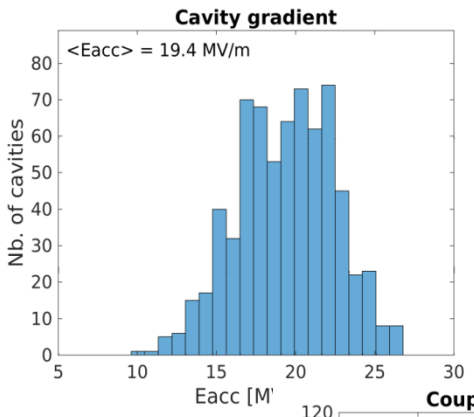


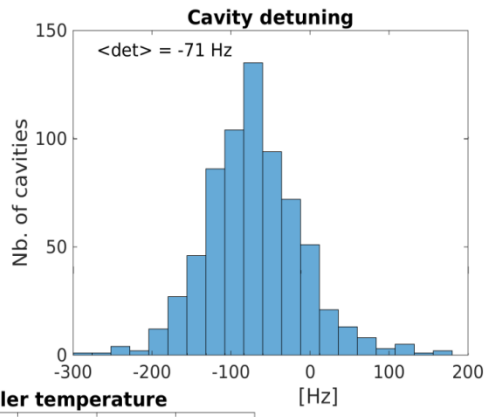

- Two 5 day user blocks so far in 2018
- A higher SASE pulse energy could be provided compared to the user blocks in 2017
- The RF trip rate was reduced

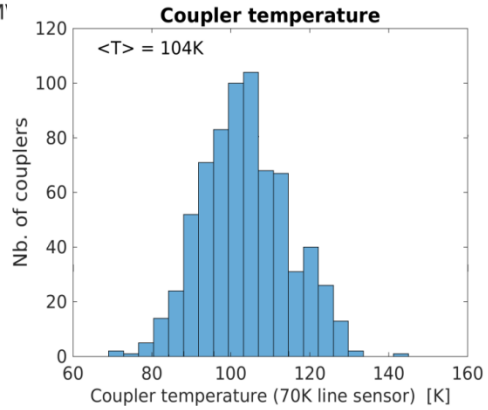
# Some Linac Statistics

- Cavities detuned and/or couplers shortened (as of 21.03.2018)
  - Total number of cavities 704, unusable 15 (2%), used 689 (98%)
  - 11 out of 22 RF stations actually have all cavities tuned
- Operation
  - Data taken during machine setup, just as an example (06.02.2018)
  - Data “as is”: no particular effort made to optimize parameters
  - 14 GeV total energy
    → “only” 19 MV/m average energy (up to 28 MV/m)
  - Detuning offset + large spread
    → clearly piezo compensation is missing
  - Coupler temperature spread, within acceptable range



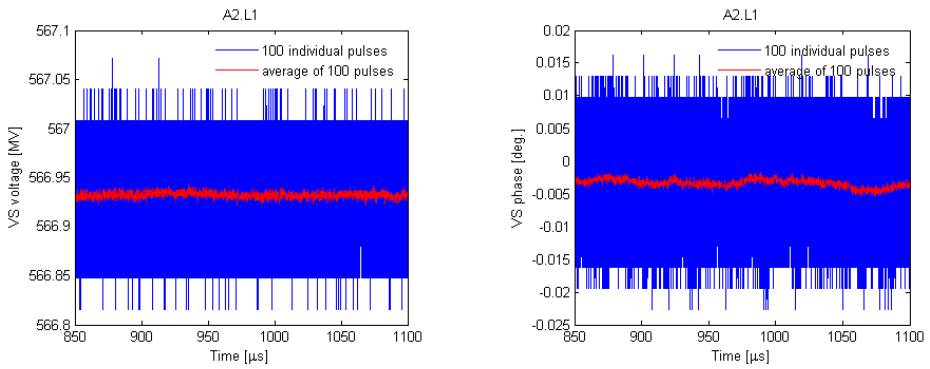



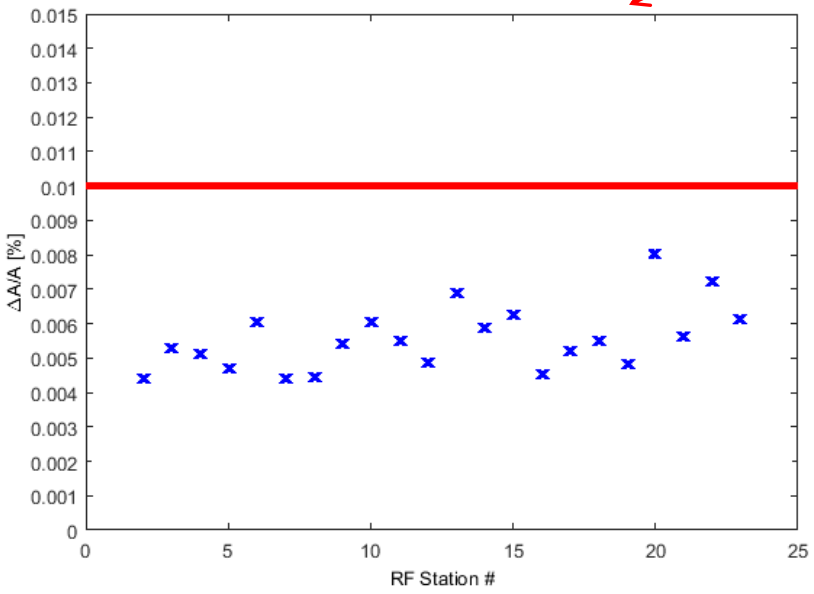



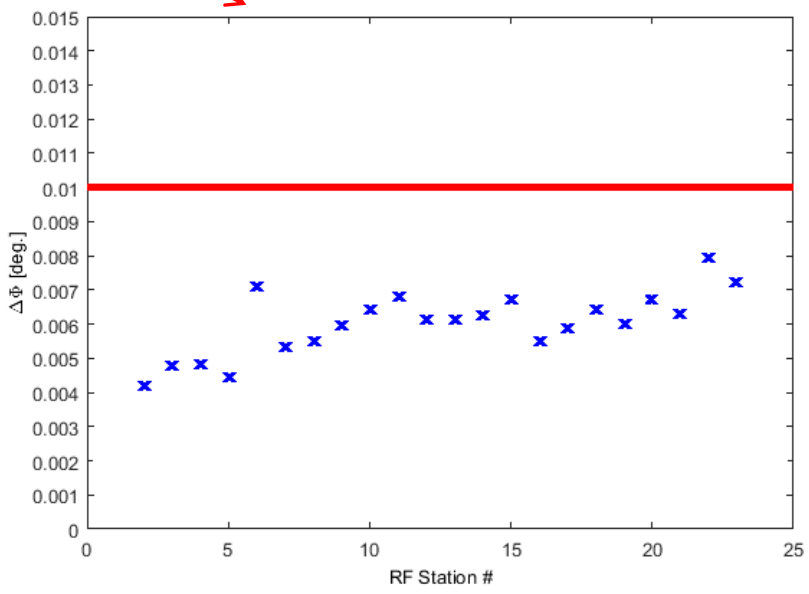
# XTL Station Performance

- RF flattop amplitude and phase stability (RMS)
- A2 as an example
- All XTL Stations



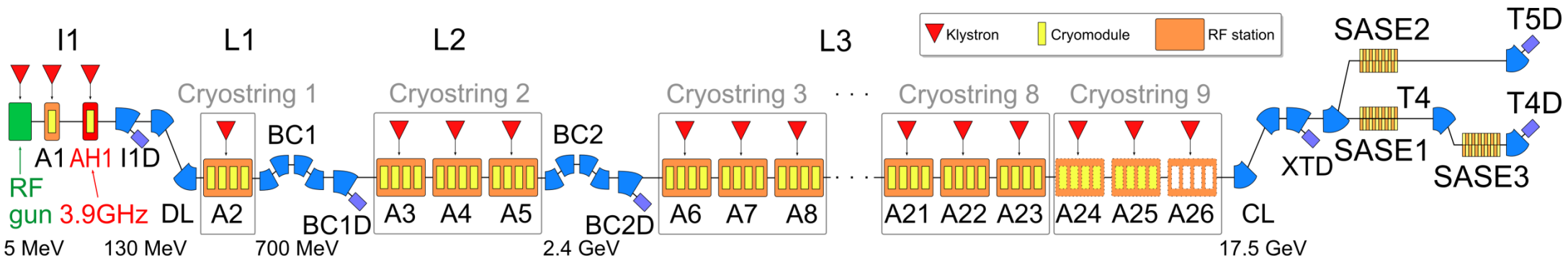

XFEL specifications: ΔA ≤ 0.01%, ΔΦ ≤ 0.01 deg.




- Pulse to pulse stability about a factor of 5 to 6 better

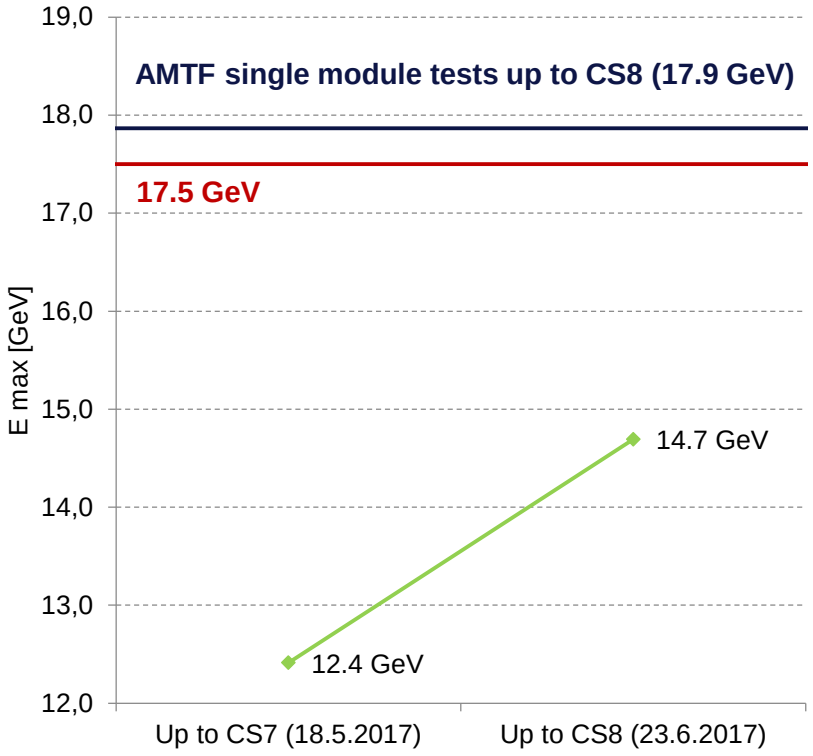
# Electron Beam Energy Stability

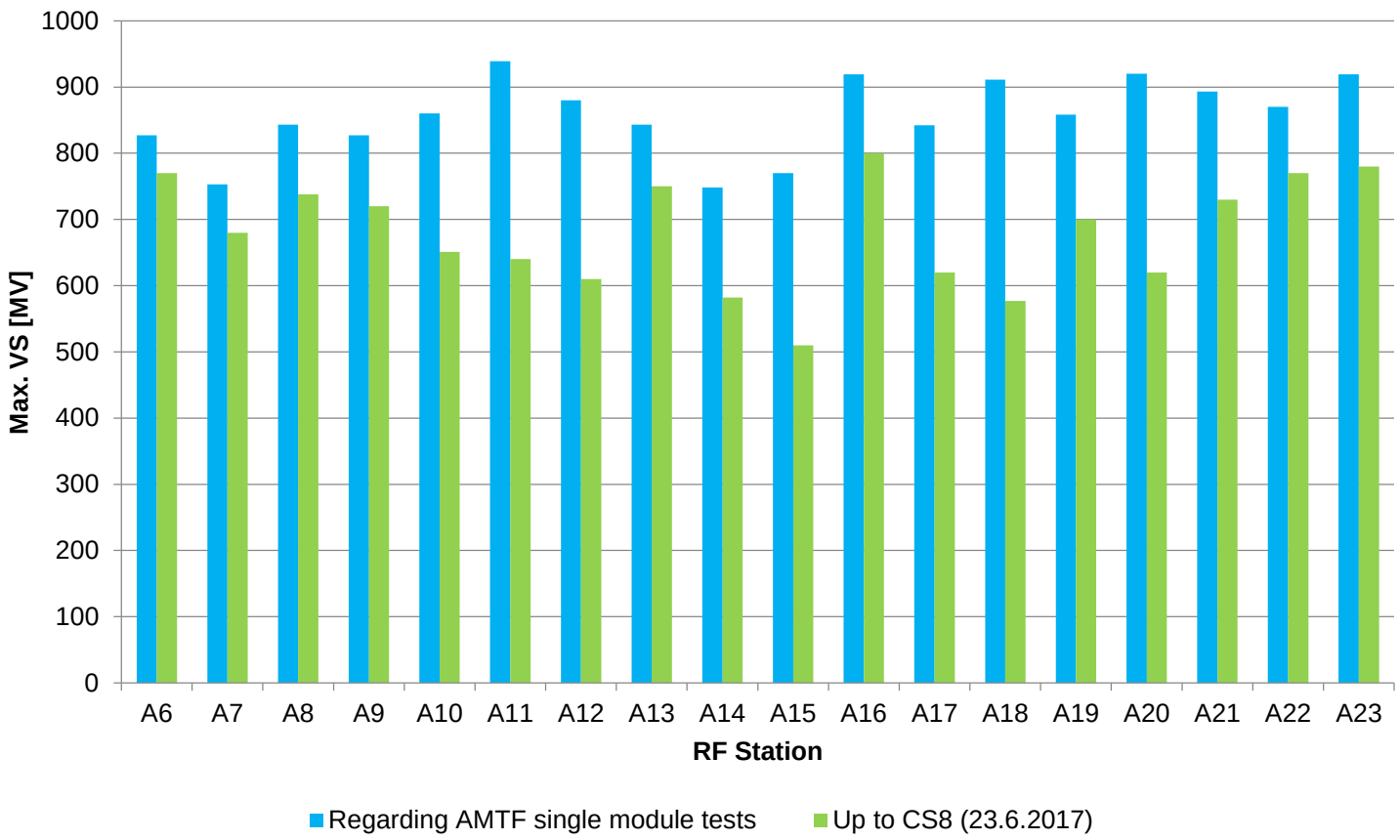



| LH | I1T | B0 | B1 | B2 | CL | T4 | T4D |
|---|---|---|---|---|---|---|---|
| 2.6E-4 | 8.1E-5 | 1.4E-4 | 9.7E-5 | 5.1E-5 | 1.6E-4 | 1.5E-4 | 1.8E-4 |

- Measured on 1st of February 2018
- Mean value over 5 measurements over 4 hours
- Comment by L. Fröhlich:
  „Relative energy stability as measured by the energy servers. This is the standard deviation of the energy of the first bunch over 100 shots, divided by the beam energy. Contains some contribution by BPM noise, obviously. “
- Electron beam energy stability requirement: 1E-4

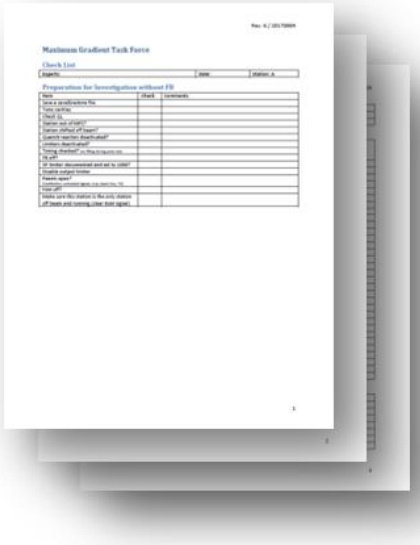
# RF Performance as of 23rd of June 2017



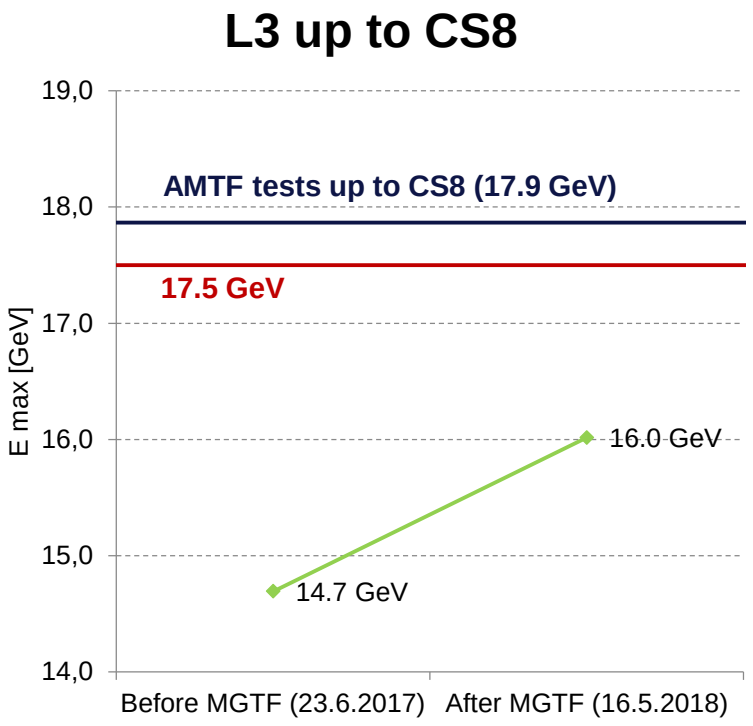



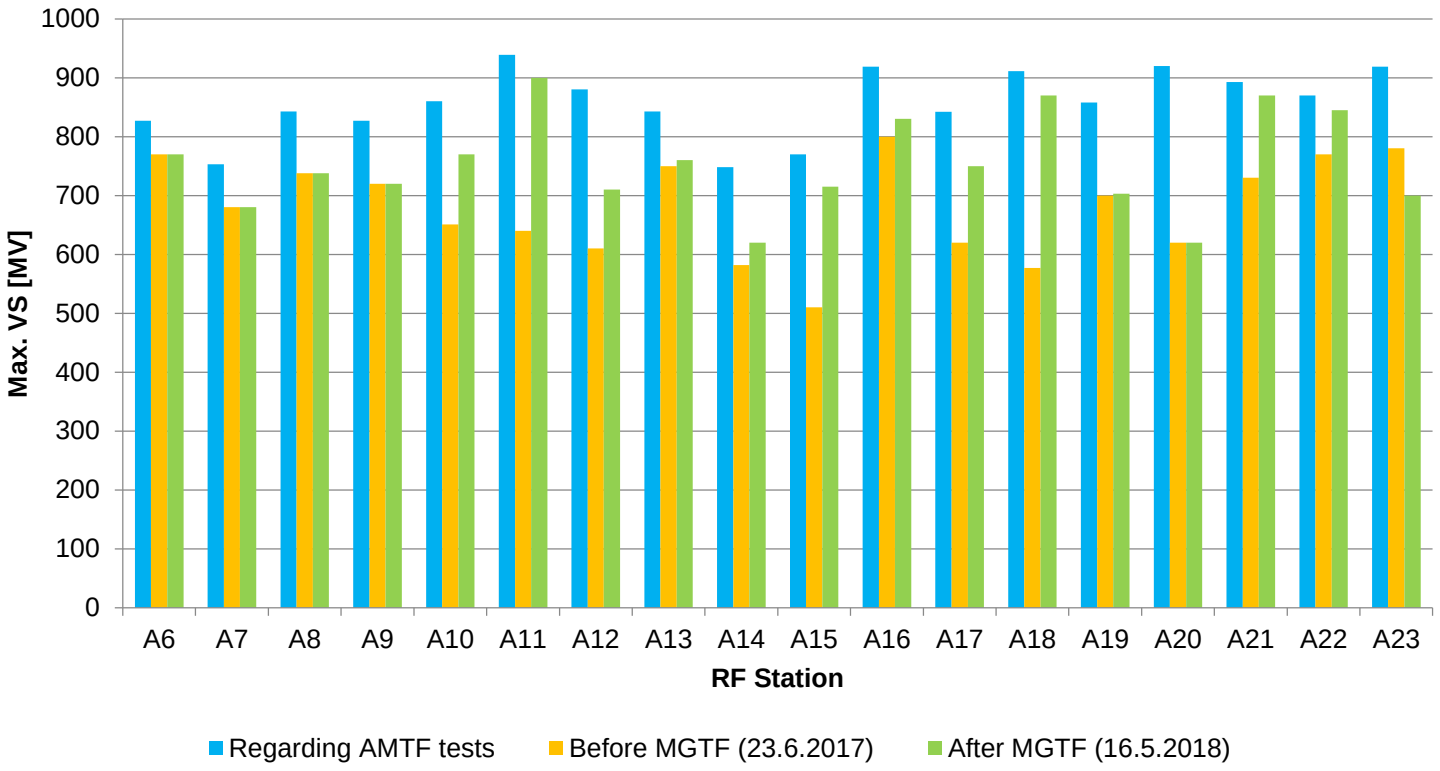
# Maximum Gradient Task Force (MGTF)

- Team of experts (12 members with a core team of 6)
- Investigation of single stations in parallel to regular beam operation
- Investigation on single cavity granularity
- Checklist for unified testing procedure
- Work out solutions for maximal possible gradient (discussions, calculations, simulations, retests, etc.)
- Document findings in station reports



# RF Performance as of 16th of May 2018



# RF Performance as of 16th of May 2018

| RF station | AMTF theoretical energy gain [MeV] | XFEL max energy gain [MeV] (closed loop operation) | Performance regarding AMTF | Limitation |
|---|---|---|---|---|
| A10 | 860 | 770♦ | 89.5%♦ | M3.C8 quenches at 19.8 MV |
| A11 | 939 | 900* | 95.8%* | Coupler heating* |
| A12 | 880 | 710♦ | 80.7%♦ | M2.C5 quenches at 25.8 MV, high rad. |
| A13 | 843 | 750♦ | 89.0%♦ | M4.C1 quenches at 25.4 MV |
| A14 | 748 | 620* | 82.9%* | Soft quenching and probably field emission at M3.C5 and M3.C7* |
| A15 | 770 | 710 | 92.2% | M4.C2 quenches at 19.4 MV |
| A16 | 919 | 830♦ | 90,3%♦ | M3.C8 quenches at 27.0 MV |
| A17 | 842 | 750♦ | 89.1%♦ | M3.C8 quenches at 25.0 MV |
| A18 | 911 | 850 | 93.3%* | M1.C1 quenches at 27.8 MV |
| A19 | 858 | 703♦ | 81.9%♦ | M3.C8 quenches at 18 MV |
| A20 | 920 | 620* | 67.4%* | Waveguide sparking* |
| A21 | 893 | 870*,ǂ | 97.4%*,ǂ | Missing piezo operation, otherwise M1.C5 quenching at 30.3 MV |
| A22 | 870 | 845 | 97.1% | M3.C5 quenches at 19.9 MV |
| A23 | 919 | 700* | 76.2%* | Waveguide sparking* |

- ♦Waveguide system not optimal
- *Still under investigation, thus not final result
- ǂA21: First case cavity degradation (M4.C2: > 31 MV → 22.3 MV) , which would limit maximal VS voltage, thus cavity was detuned and excluded from VS
- Note: The voltage calibrations at AMTF and XFEL are different (power-based vs beam-based)

Test status:
- finished
- to be continued
- to be continued after modification

# MGTF Status and Schedule

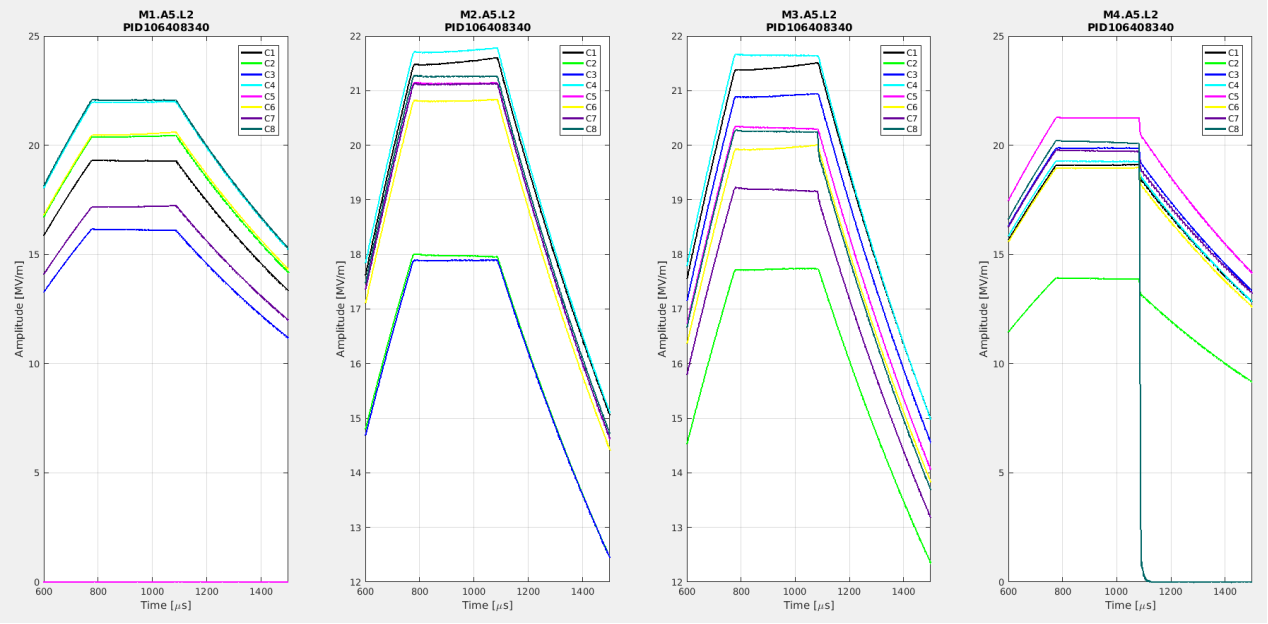
- 14 of 20 stations in L3 investigated
- 8 of 20 stations reached final limit
- Average performance reached compared to AMTF tests for the finished stations: 90.3%
- Energy gain so far due to MGTF work: 1.3 GeV
- 4 cavities detuned in scope of the MGTF, since they were limiting the VS voltage
- Investigations on L3 stations will most likely finish end of summer 2018

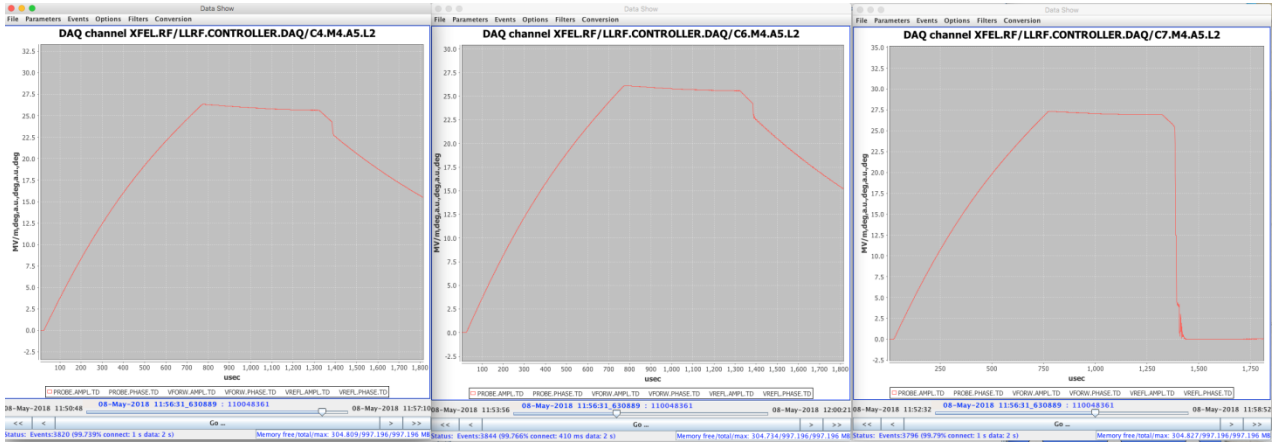
| Date | Station | Comment |
|---|---|---|
| 21.6.2017 | A19 | |
| 12.7.2017 | A19 | |
| 26.7.2017 | A15 | |
| 2.8.2017 | A11 | |
| 10.8.2017 | A20 | |
| 23.8.2017 | A20 | |
| 23.8.2017 | A18 | |
| 30.8.2017 | A21 | |
| 6.9.2017 | A22 | |
| 13.9.2017 | A13 | |
| 20.9.2017 | A14 | user run |
| 27.9.2017 | A10 | user run |
| 4.10.2017 | - | maintenance |
| 11.10.2017 | - | maintenance |
| 18.10.2017 | - | maintenance |
| 25.10.2017 | - | |
| 1.11.2017 | A13 | |
| 8.11.2017 | - | lack of spare station |
| 15.11.2017 | - | lack of spare station |
| 22.11.2017 | - | lack of spare station |
| 29.11.2017 | - | lack of spare station |
| 5.12.2017 | A13 | quick check |
| 6.12.2017 | - | shutdown |
| 13.12.2017 | - | shutdown |
| 20.12.2017 | - | shutdown |
| 27.12.2017 | - | shutdown |
| 3.1.2018 | - | shutdown |
| 10.1.2018 | - | shutdown |
| 17.1.2018 | - | shutdown |
| 24.1.2018 | - | shutdown |
| 31.1.2018 | A13 | |
| 7.2.2018 | - | TTC meeting |
| 14.2.2018 | - | He pressure test |
| 21.2.2018 | - | BBS Travemünde |
| 28.2.2018 | A18 | |
| 7.3.2018 | A14 | |
| 14.3.2018 | A12 | |
| 21.3.2018 | A16 | |
| 28.3.2018 | A17 | |
| 4.4.2018 | - | shutdown |
| 11.4.2018 | - | shutdown |
| 18.4.2018 | - | shutdown |
| 25.4.2018 | - | |
| 2.5.2018 | - | |
| 8.5.2018 | A5 | |
| 16.5.2018 | A23 | |
| 23.5.2018 | A20 | |
| 30.5.2018 | A12 | |
| 6.6.2018 | A14 | |
| 13.6.2018 | A11 | |
| 20.6.2018 | | shutdown |
| 27.6.2018 | | shutdown |
| 4.7.2018 | | shutdown |
| 11.7.2018 | A9 | |
| 18.7.2018 | A8 | |
| 25.7.2018 | A7 | |
| 1.8.2018 | etc. | |

| Station status | | Legend |
|---|---|---|
| A6 | | finished |
| A7 | | to be continued |
| A8 | | to be continued after modification |
| A9 | | untested |
| A10 | | |
| A11 | | |
| A12 | | |
| A13 | | |
| A14 | | |
| A15 | | |
| A16 | | |
| A17 | | |
| A18 | | |
| A19 | | |
| A20 | | |
| A21 | | |
| A22 | | |
| A23 | | |
| A24 | | |
| A25 | | |

# Special Case of L2

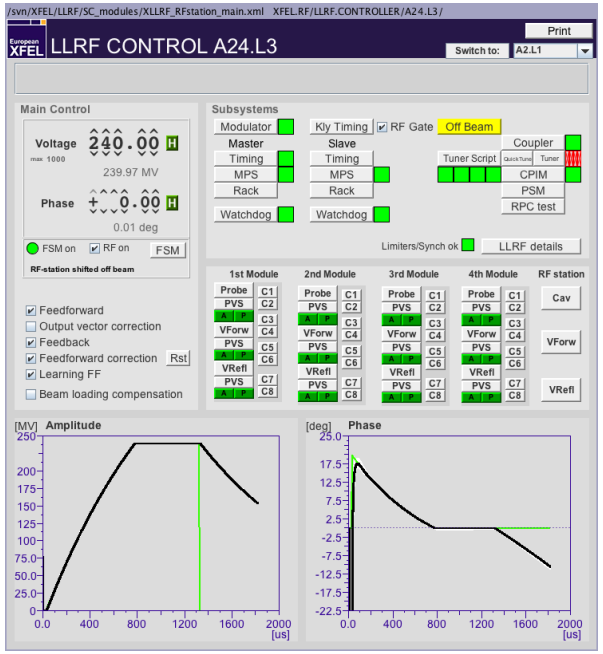
- Requirements
  - Flexibility to ramp gradients up and down anytime (e.g. compression adjustments)
- Experience at A5
  - Generation of dark current, which hits the wall up stream, creates gamma showers and trips coupler spark detectors at multiple couplers at multiple modules
  - We believe at the moment that this can be conditioned away
  - Further investigations are scheduled for middle of July after user run and shut down

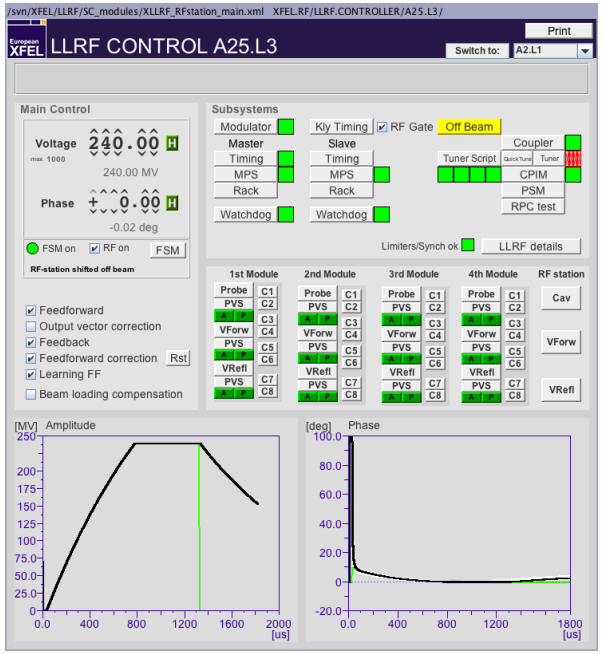


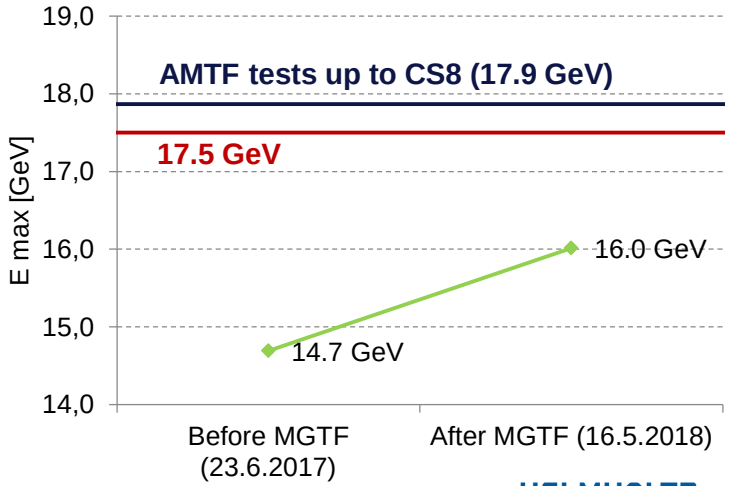
# Outlook

- Energy reach
  - CS9 commissioning nearly done
    - ► A24: 932 MV (AMTF)
    - ► A25: 492 MV (AMTF)
    - ► => 1.42 GV * 90% = 1.28 GV
  - Continued MGTF effort necessary
- Performance
  - Continuing advanced LLRF commissioning
  - Machine operation studies
    - ► Tunnel radiation / dark current studies
    - ► Further RF station characterizations towards performance
    - ► E.g. detuning studies during FB operation
- Availability
  - Trip analysis
  - Software solutions are under development for automatic data recording and statistics generation




## L3 up to CS8



# Summary

- Commissioning schedule
  - Simultaneous lasing in all three undulator sections
- SASE performance during user runs
  - Already excellent availability
- 2% of cavities in the linac are unusable
- Example of 14 GeV operation (<Eacc> = 19.4 MV/m)
- LLRF amplitude and phase stability about factor of 2 below the specifications
- Beam energy stability about a factor of 1.5 above the specification
- Energy reach / Maximum Gradient Task Force
  - 14 out of 20 station investigated in L3, 8 reached final limit
  - Increase of maximal possible beam energy from 14.7 GeV to 16.0 GeV (to be operated at)
  - Investigations most likely to finish end of summer ’18
  - L2 also to be investigated
- Special case of L2 under investigation
- Outlook

# ご清聴有難うございました。

- Thank you very much for your attention!