# Update on the commissioning status of the European XFEL

Mathieu Omet
for the commissioning team

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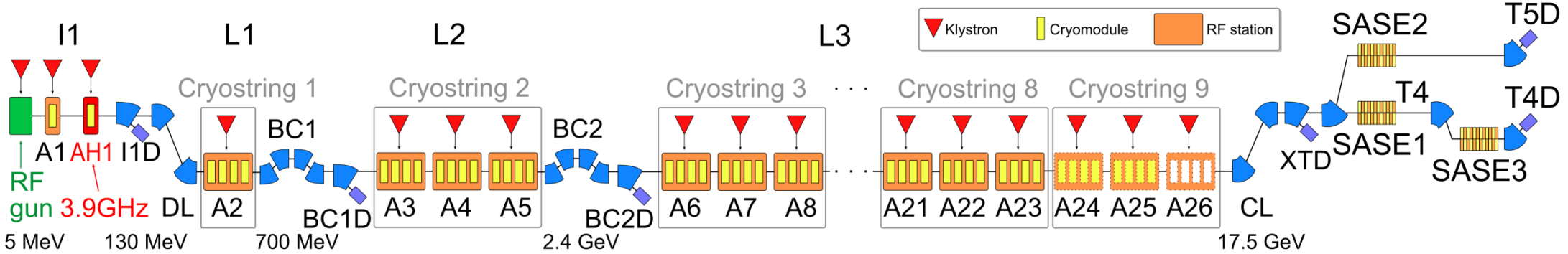
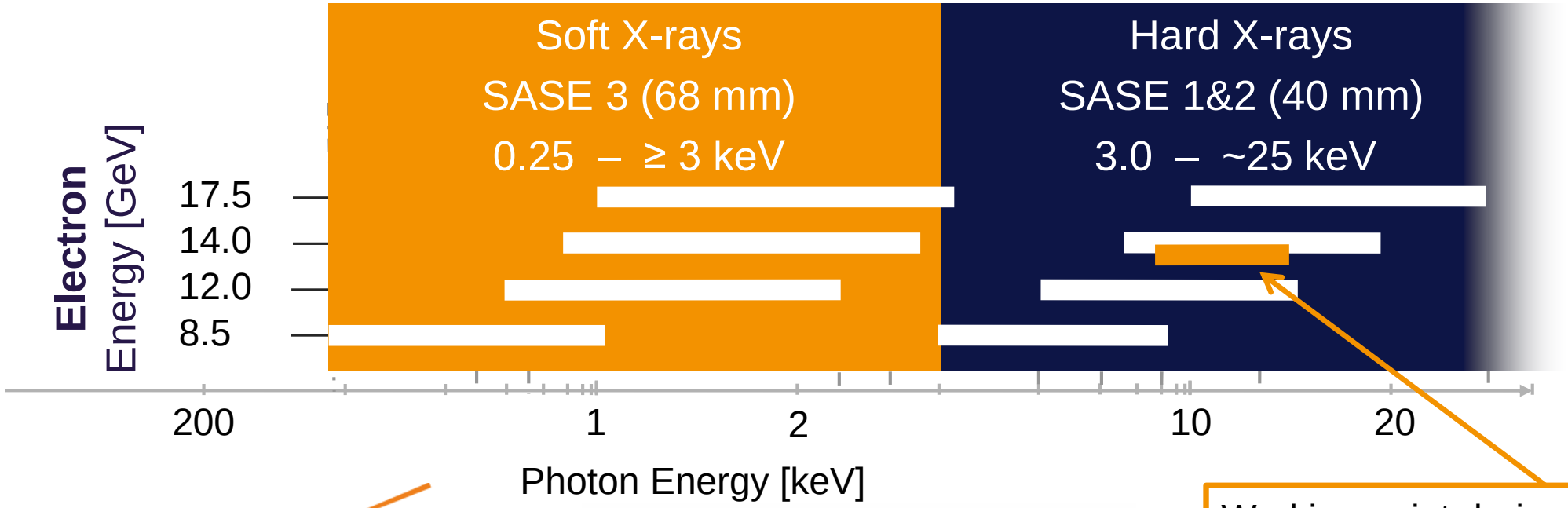
# Contents

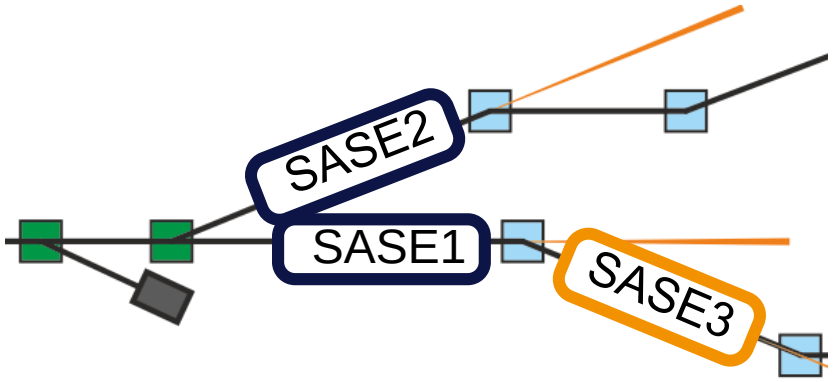
# The European X-ray Free Electron Laser (XFEL)

- 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



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




Working point during user runs:

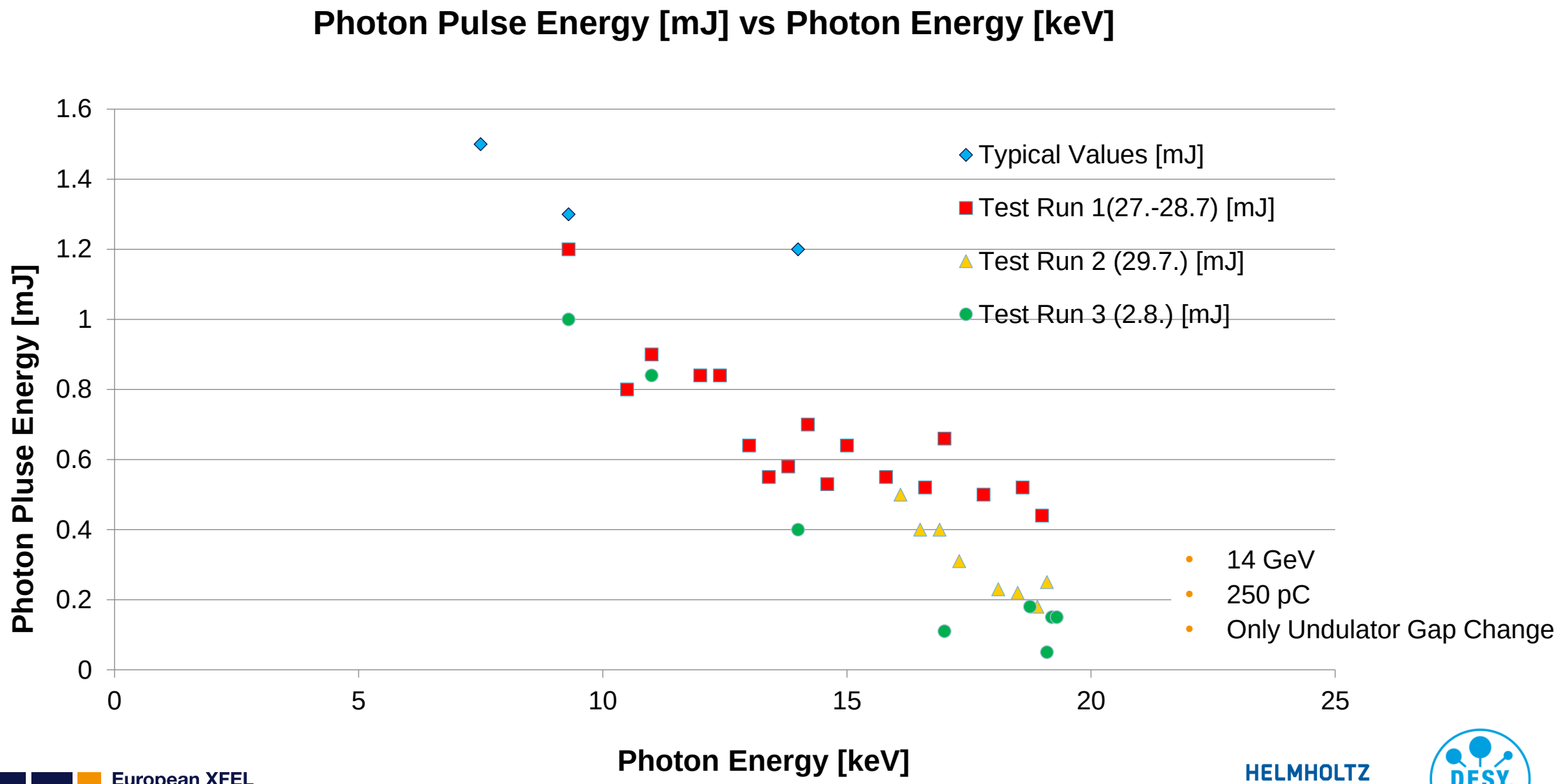
- 14 GeV electron beam energy
- 7.5 - 14 keV photon energy (SASE1).



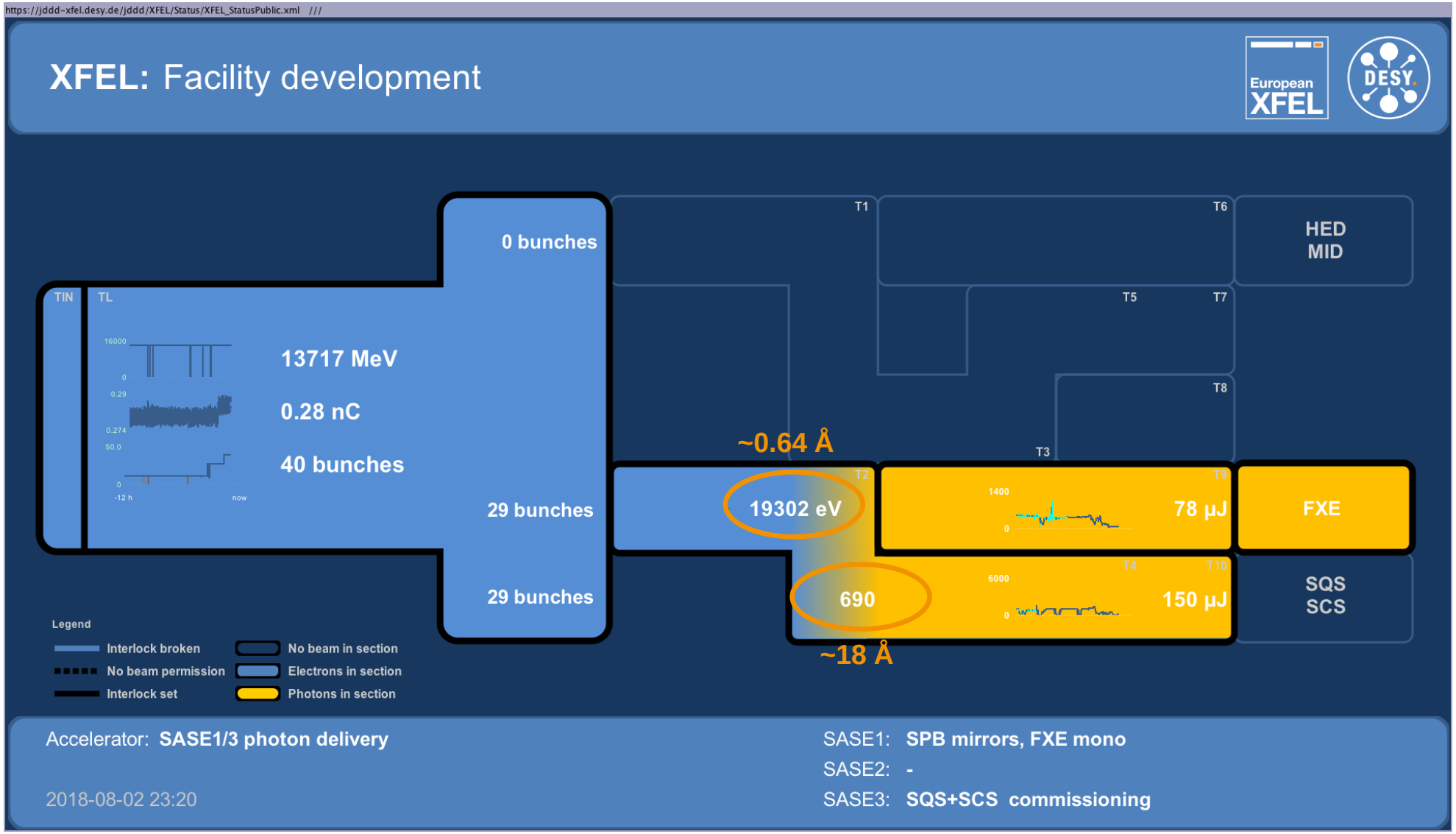
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

# Highest Photon Energy Operation at SASE1

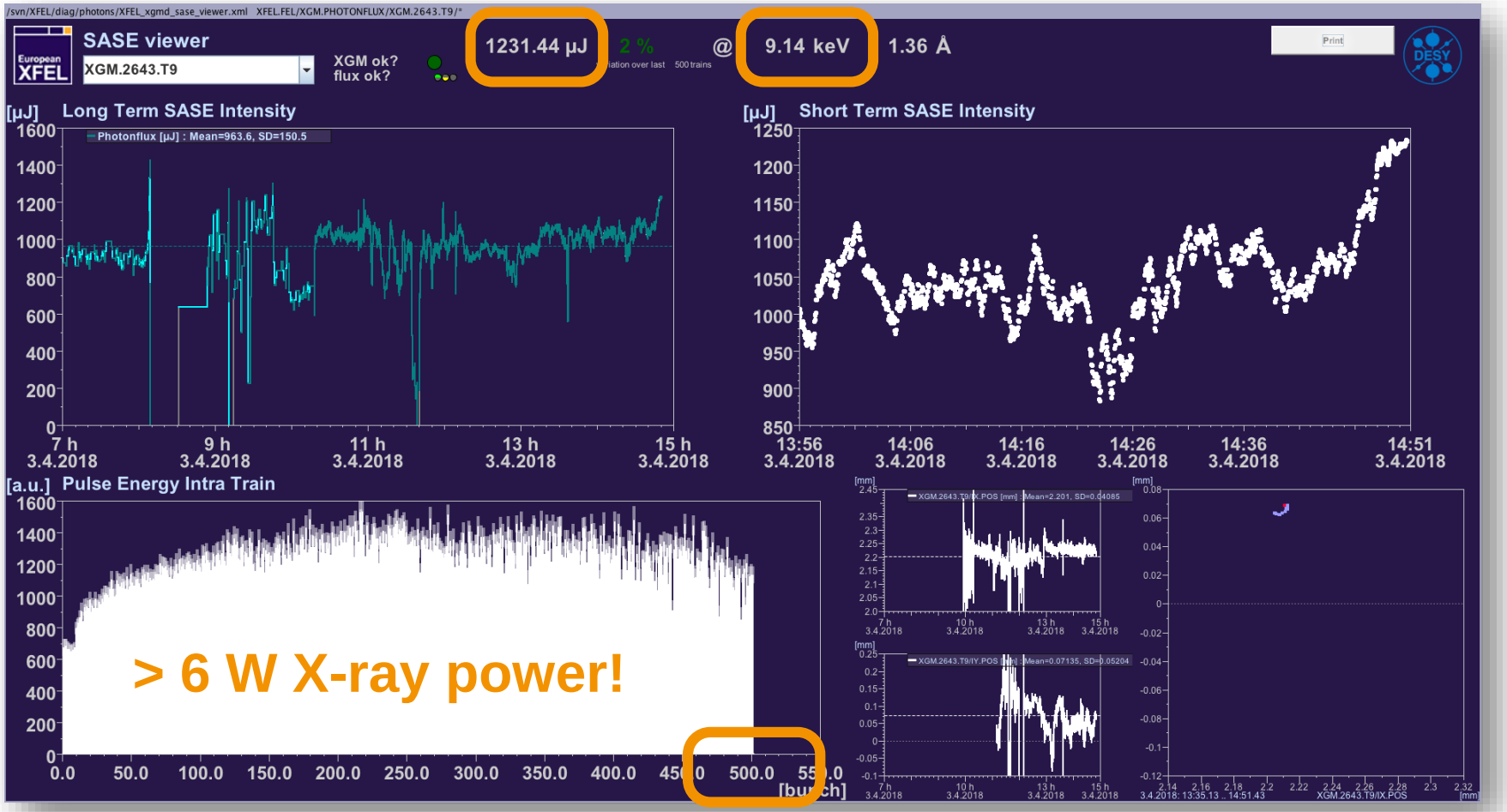


# Current Wavelength or Photon Energy Span

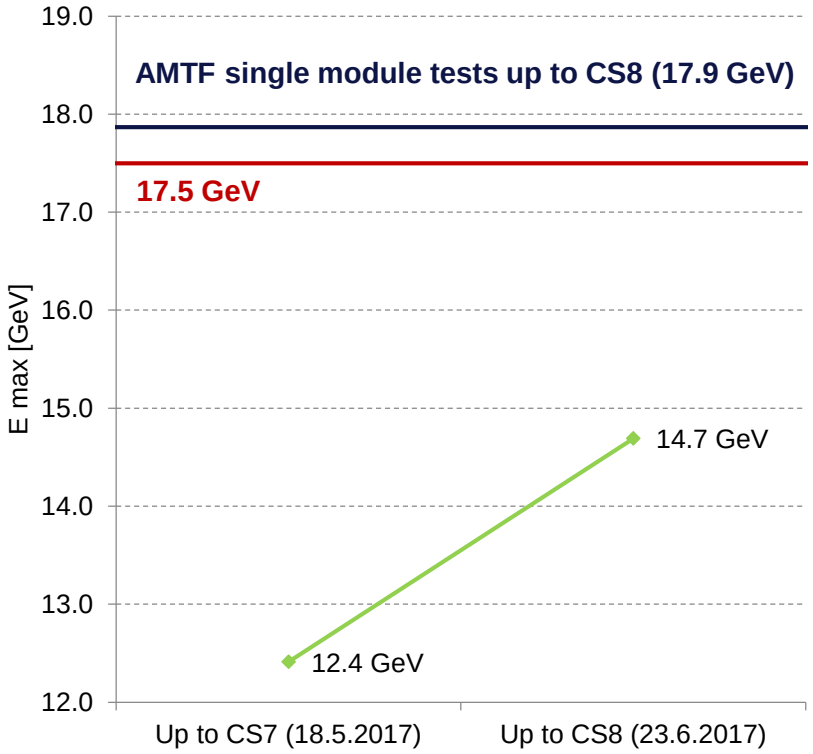


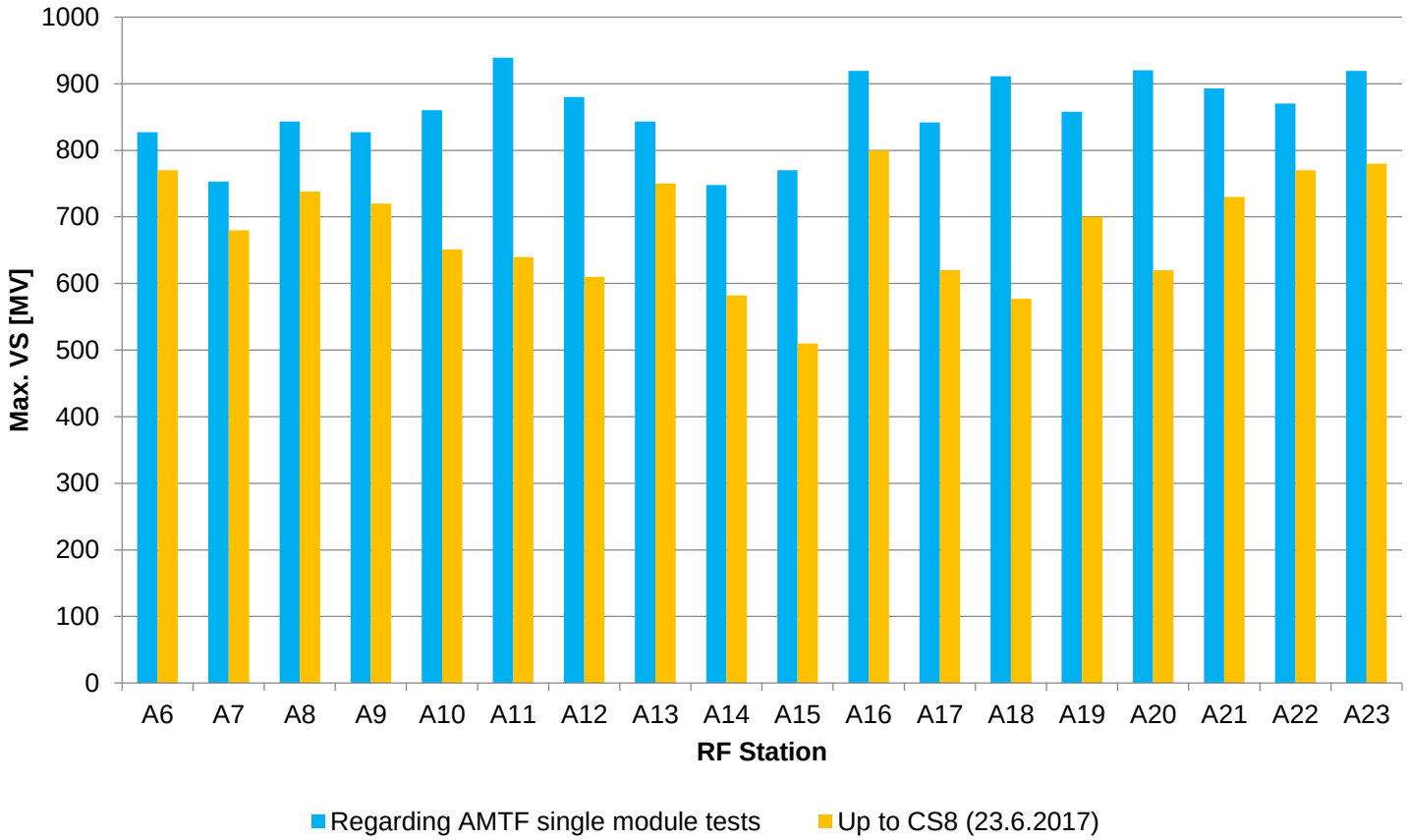
# SASE delivery with 5000 bunches per second

- 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 2.5 W (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.



# RF Performance as of 23rd of June 2017

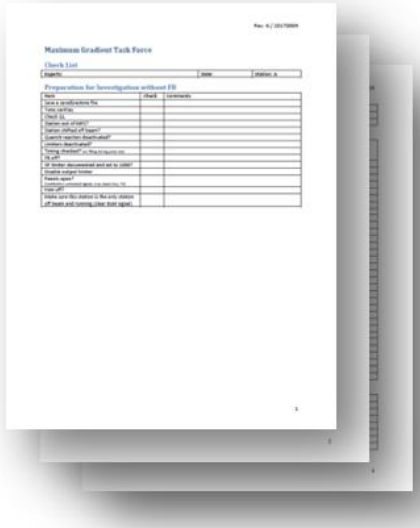


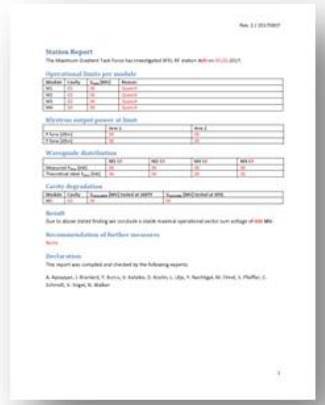




- Formation of the Maximum Gradient Task Force

# Concept

- Team of experts (core team of 7 with more than 7 experts supporting)
- Investigation of single stations in parallel
  to regular beam operation, including user runs
- Investigation on single cavity granularity
- Checklist for unified testing procedure
- Work out solutions for maximal possible gradient
  (discussions, calculations, simulations, etc.)
- Document findings in station reports





# Procedure

- Prepare RF station
- Perform study
  - VS voltage is slowly increased until one of the following limits is hit
    - ► Cavity quench
    - ► Field emission limit
    - ► High power chain limit
    - ► Waveguide sparking
  - If a cavity quenches in a certain regime, try to condition it, other wise confirm quench limit, detune cavity and continue voltage increase
  - Field emission is measured with MARWIN drive-by (if available), otherwise BLM signals give a hint
  - If klystron is close to saturation, klystron high voltage is increased
  - Sparking waveguide part is identified with sound detectors and exchanged when tunnel access is possible
  - Taking data at several points and typically close to the limits
  - The configuration, which yields highest VS voltage is kept and setup in closed loop
- Restore RF station for operation

# Schedule

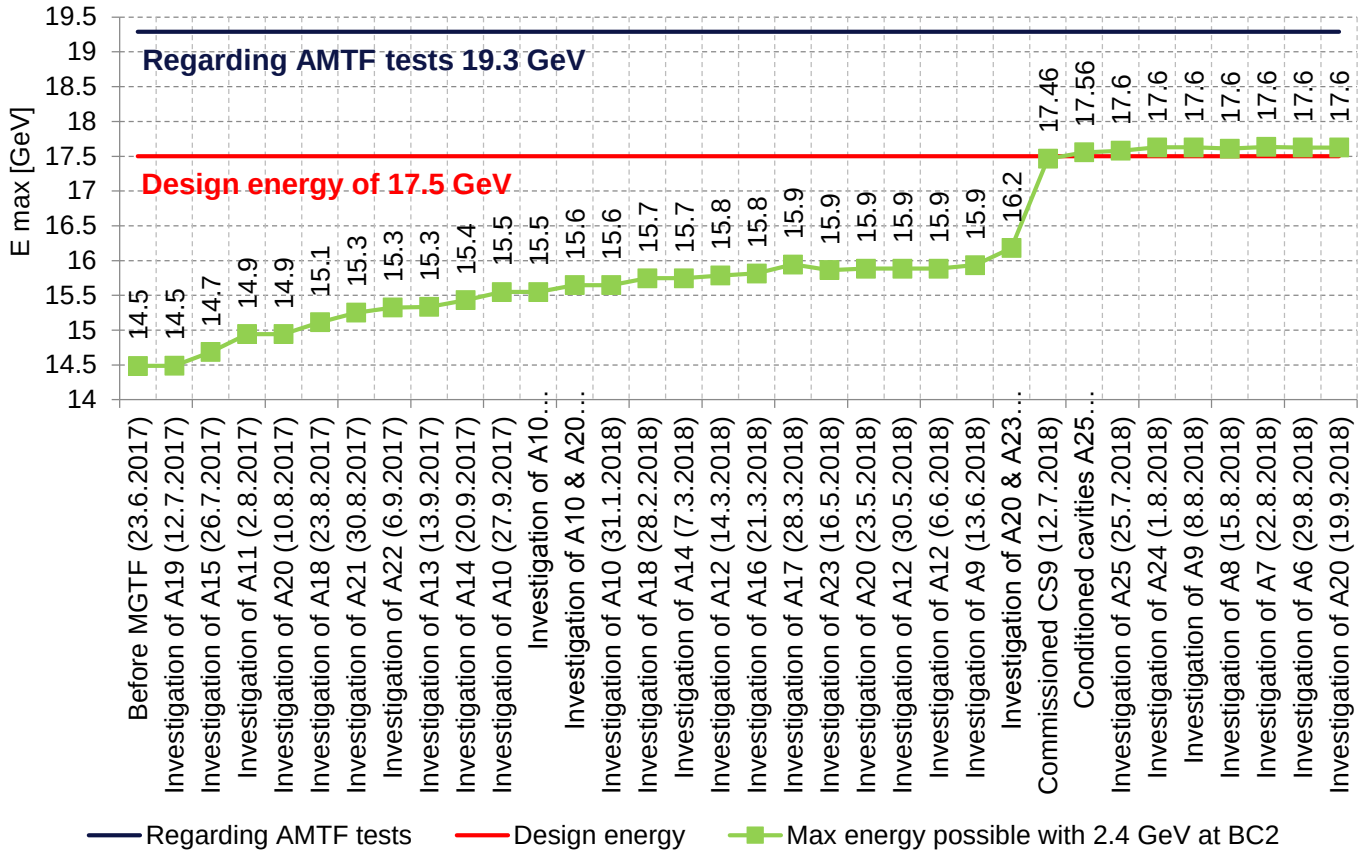
- First investigation on 21st of June 2017
- 33 investigations performed so far
- 20 of 20 stations in L3 investigated
- 1 of 3 stations in L2 investigated

| 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 |

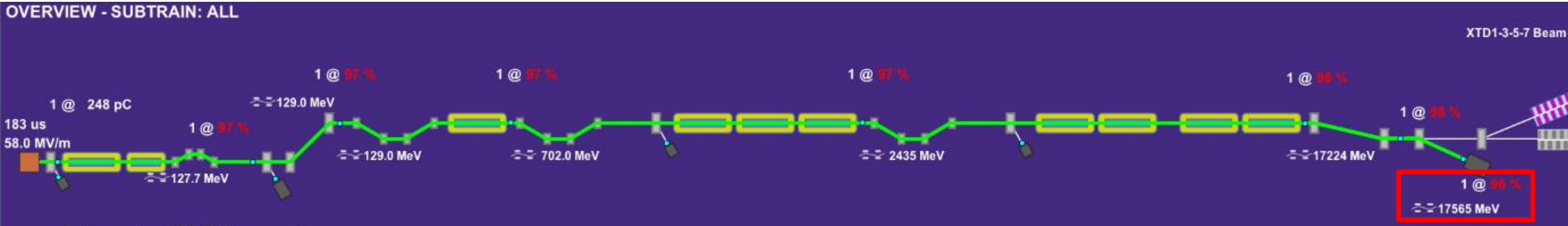
| Date | Station | Comment |
|---|---|---|
| 14.2.2018 | - | He pressure test |
| 21.2.2018 | - | BBS Travemünde |
| 28.2.2018 | A18 | |
| 7.3.2018 | A14 | |
| 14.3.2018 | A12 | |
| 21.3.2018 | A16 | |
| 28.3.2018 | A17 | |
| 4.4.2018 | - | shutdown |
| 11.4.2018 | - | shutdown |
| 18.4.2018 | - | shutdown |
| 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 | A12 | |
| 13.6.2018 | A9 | |
| 20.6.2018 | | shutdown |
| 27.6.2018 | | shutdown |
| 4.7.2018 | | shutdown |
| 11.7.2018 | - | |
| 18.7.2018 | - | |
| 25.7.2018 | A25 | |
| 1.8.2018 | A24 | |
| 8.8.2018 | A9 | |
| 15.8.2018 | A8 | |
| 22.8.2018 | A7 | |
| 29.8.2018 | A6 | |
| 05.09.2018 | - | |
| 12.09.2018 | - | |
| 19.09.2018 | A20 | |

# History of Maximal Energy

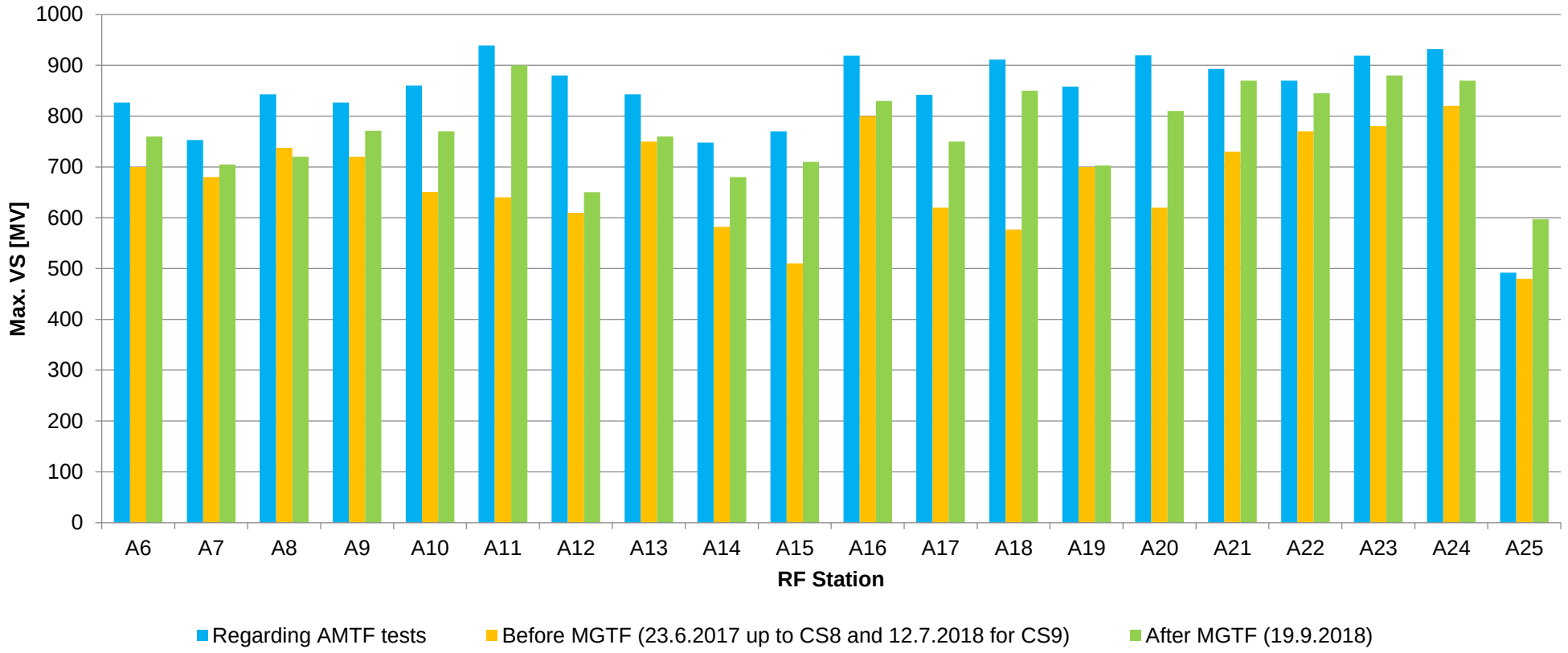
- 17.6 GeV at TLD on 12.7.2018
  - With 2.6 GeV after BC2
  - Further investigations followed
- 17.6 GeV at TLD on 18.7.2018
  - With design energy of 2.4 GeV after BC2
- Energy gain due to MGTF: 1.9 GeV
  - Nearly 11% of final energy
  - Equal to about 2.4 L3 RF stations




18.7.2018



# RF Performance as of 19th of September 2018




- Reached an average of 92.2% of AMTF performance

# RF Performance as of 19th of September 2018



| RF station | AMTF theoretical energy gain [MeV] | XFEL max energy gain [MeV] (closed loop operation) | Performance regarding AMTF | Limitation |
|---|---|---|---|---|
| A6 | 827 | 760 | 91.9% | Quench of M3.C3 |
| A7 | 753 | 705 | 93.6% | Operation in soft quench regime, cryo claims not to see it, limit quench M4.C3 |
| A8 | 843 | 720♦ | 85.4%♦ | Quench of M4.C4. Waveguide imbalance. |
| A9 | 827 | 771 | 93.2% | Primary limit field emission, seconday limit quench of M2.C4. |
| A10 | 860 | 770♦ | 89.5%♦ | Quench of M4.C8 |
| A11 | 939 | 900 | 95.8% | Power, piezos might help |
| A12 | 880 | 650♦ | 73.9%♦ | Primary limit field emission, seconday limit quench of M2.C5. |
| A13 | 843 | 760♦ | 90.2%♦ | Quench of M4.C1 |
| A14 | 748 | 680 | 90.9% | Soft quenching of three cavities |
| A15 | 770 | 710 | 92.2% | Quench of M4.C2 |

Test status: finished / to be continued

♦Waveguide system not optimal

Note: The voltage calibrations at AMTF and XFEL are different (power-based vs beam-based)

# RF Performance as of 19th of September 2018



| RF station | AMTF theoretical energy gain [MeV] | XFEL max energy gain [MeV] (closed loop operation) | Performance regarding AMTF | Limitation |
|---|---|---|---|---|
| A16 | 919 | 830♦ | 90.3%♦ | Quench of M3.C8 |
| A17 | 842 | 750♦ | 89.1%♦ | Quench of M3.C8 |
| A18 | 911 | 850 | 93.3% | Quench of M1.C1 |
| A19 | 858 | 703♦ | 81.9%♦ | Quench of M3.C8 |
| A20 | 920 | 810 | 88.0% | Quench of M1.C6 |
| A21 | 893 | 870* | 97.4%* | Power/piezos, otherwise M1.C5 |
| A22 | 870 | 845 | 97.1% | Quench of M3.C5 |
| A23 | 919 | 880* | 95.8%* | Waveguide sparks fixed, quench limits to be reconfirmed |
| A24 | 932 | 870 | 93.3% | Quench of M2.C3 |
| A25 | 492 | 597♦ | 121.3%♦ | Quench of M3.C4. M4 completely detuned, waveguide has to be retailored |

Test status: finished / to be continued

- ♦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)

# MGTF Status and Outlook

- Phase 1 ✓
  - Status survey ✓
  - Reach maximal VS voltages without hardware modifications ✓
  - Reaching 17.5 GeV ✓
- Phase 2
  - Reach maximal VS voltages with hardware modifications
    - ► Cavity power optimization by waveguide distribution adjustments
    - ► Retune the 19 cavities after power optimization
  - Determine maximal possible beam energy
    - ► Goal would be to run at 17.5 GeV while having one RF station (≥ 800 MV) off beam
  - Possible setup of two different operation modes
    - ► High energy (17.5 GeV) mode with high power consumption
    - ► Low energy (14 or 16 GeV) mode with up to 10% less klystron power consumption (to be investigated)
- Phase 3
  - Long time performance surveillance

# Outlook

- Full bunch train of 27000 bunches/s at the end of October 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: November 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

# Summary

- Demonstrated shortest X-ray wavelength so far (~0.64 Å)
- Demonstration of highest X-ray power so far (> 6 W)
- All RF stations have been commissioned
- Energy reach / Maximum Gradient Task Force
  - Investigated all 20 RF stations of L3
  - Increased maximal possible beam energy by 1.9 GeV
  - Demonstrated electron beam acceleration at 17.6 GeV
  - Major mile stone not only for European XFEL but also for the ILC
- Outlook

# Questions?

- Thank you very much for your attention!