

Experience with Commissioning on High-Gradient Cryomodules for the European XFEL



Mathieu Omet
for the linac commissioning team

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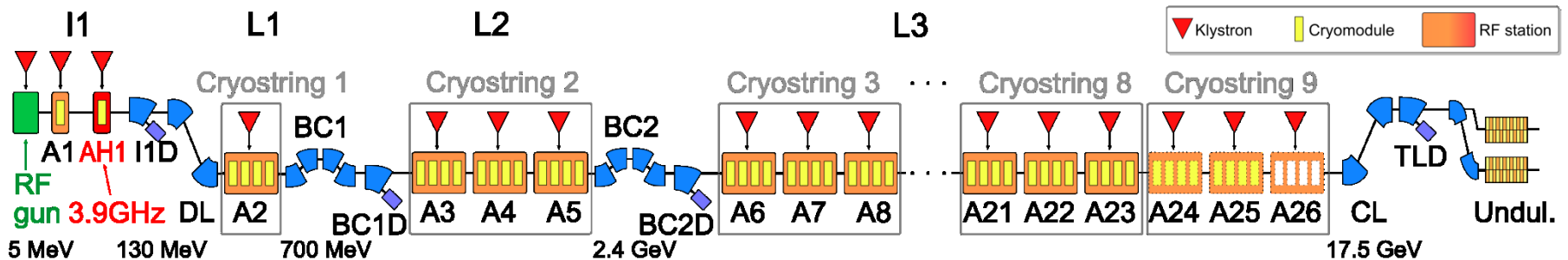


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The European X-ray Free Electron Laser (XFEL)

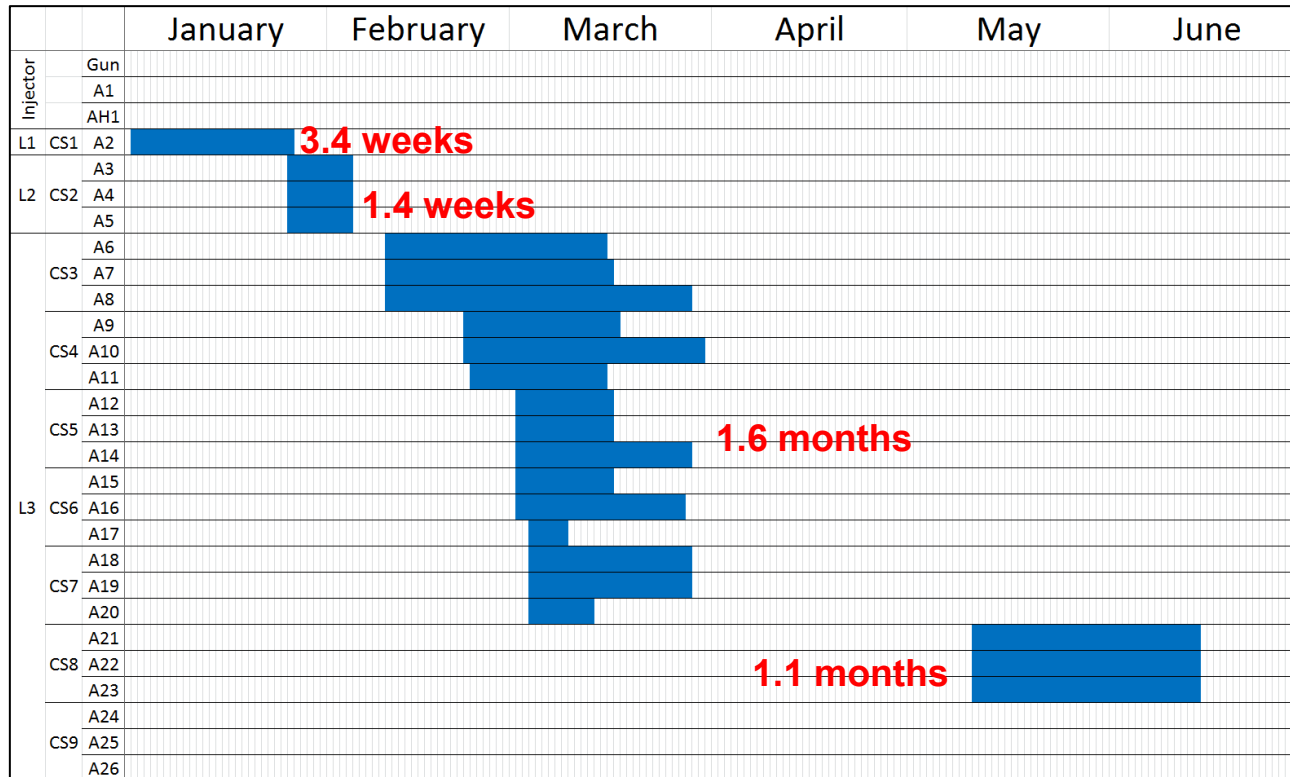
- Soft and hard X-ray light experiments
- ~800 TESLA-type cavities
- Resonance frequency 1.3 GHz
- 32 cavities per XTL RF station
- Design energy 17.5 GeV
- Pulsed operation 10 Hz
- All XTL stations are one continuous cryo plant
- Commissioning up to cryostring (CS) 8 → 25 RF stations
- First users September 2017



Commissioning Overview (LLRF & General)

Estimated schedule

- Injector (gun, A1, AH1) 2 weeks
- L1 (1 RF station) 2 weeks
- L2 (3 RF stations) 2 weeks
- L3 (15 RF stations) 2 months



Commissioning Experience

Frequency tuner driver issues

- Frequency tuner driver electronics had to be reset in the tunnel
- Frequency tuner cabling issues, which had to be fixed in the tunnel
- Tunnel access possible first every week, then every other week
- Created idle time

Use professional cabling companies

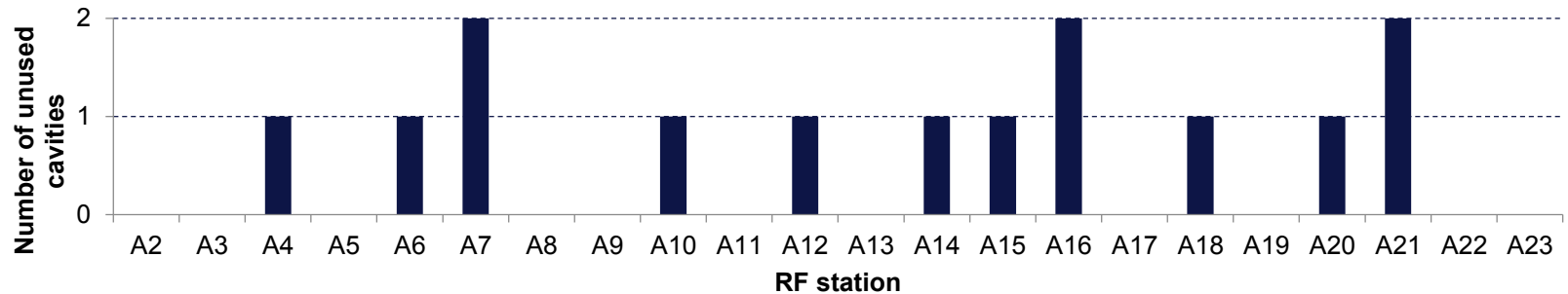
- LLRF cabling issues (~5000 cables checked using dedicated software)
 - ▶ 15 cabling issues (outer rack) identified before cool down
 - ▶ 17 cabling issues (outer rack) identified after cool down
 - ▶ 0 cabling issues (inner rack) identified so far

Multipacting

- Observed on nearly all stations
- Start appearing around 550-600 MV (i.e. ~17-18 MV/m)
- Up to 50% of cavities / cryomodule required conditioning (worse case)
- Conditionable on all stations, required couple of hours per station (@10 Hz)

Commissioning Experience

■ Cavities detuned and/or couplers shortened (as of 02.02.2018)



■ Total number of cavities 704, unusable 14 (2%), used 690 (98%)

■ 11 out of 22 RF stations actually have all cavities tuned

■ Phase jumps after shut down, long recovery time

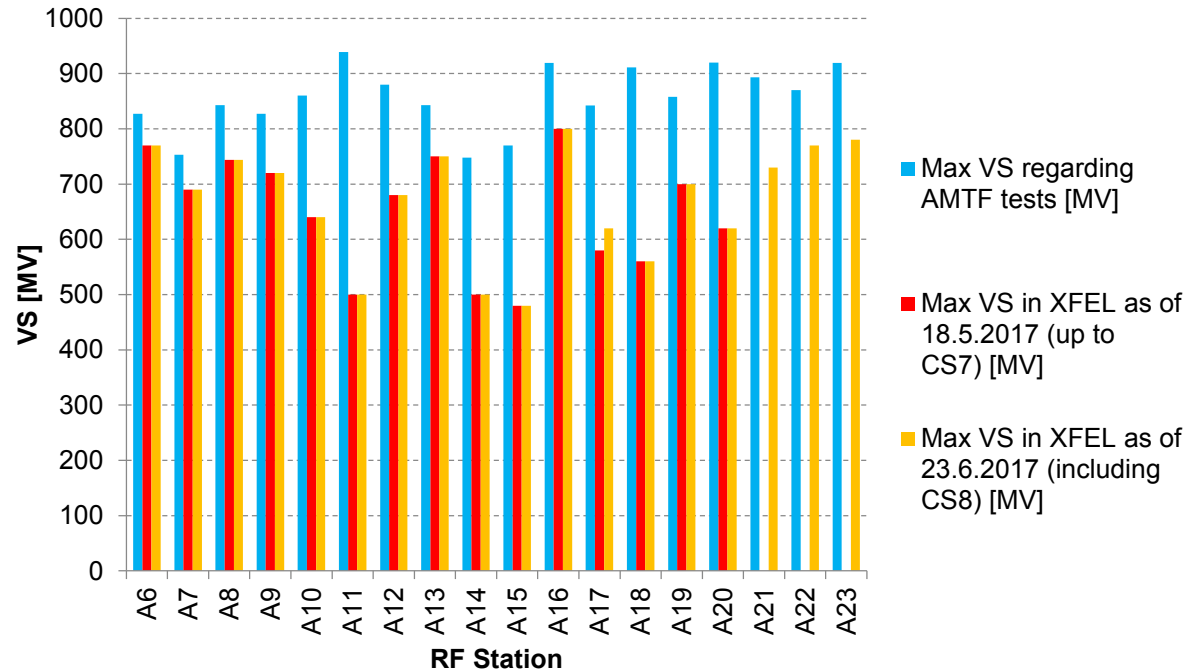
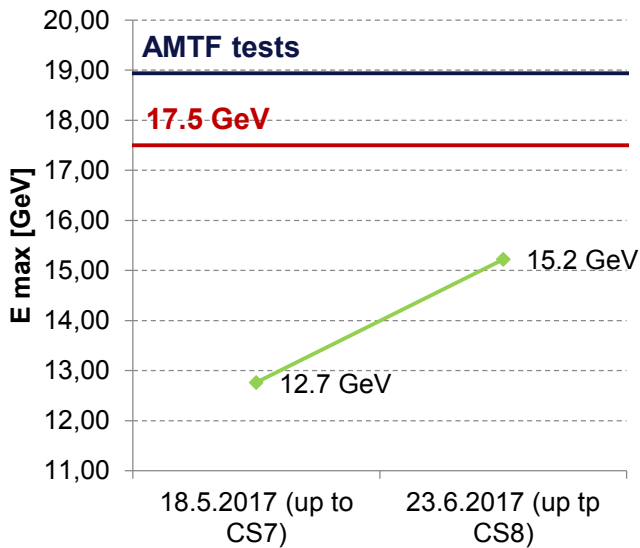
■ Piezo driver, production delayed over 2 years, 1 unit installed

■ Advanced LLRF commissioning (drift compensation modules, optical RF synchronization, beam loading compensation, ...) during operation

Commissioning Experience

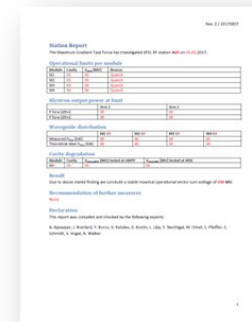
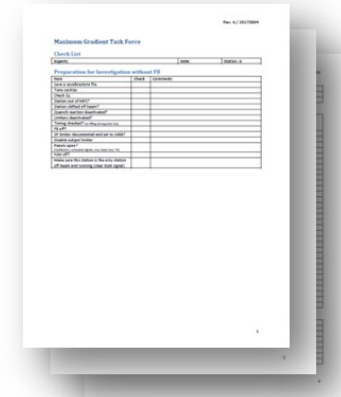
- Install / test as much as possible, as early as possible
- Experience from FLASH
- Automation
 - Cavity frequency tuning
 - Signal integrity
 - Power-based calibration
 - Coupler tuning (QL)
 - Cavity phasing
 - Beam-based calibration
- Availability of cryomodule test data
- Checklists + documentation
- Man power (total of 20 people)

RF Performance as of 23.6.2017

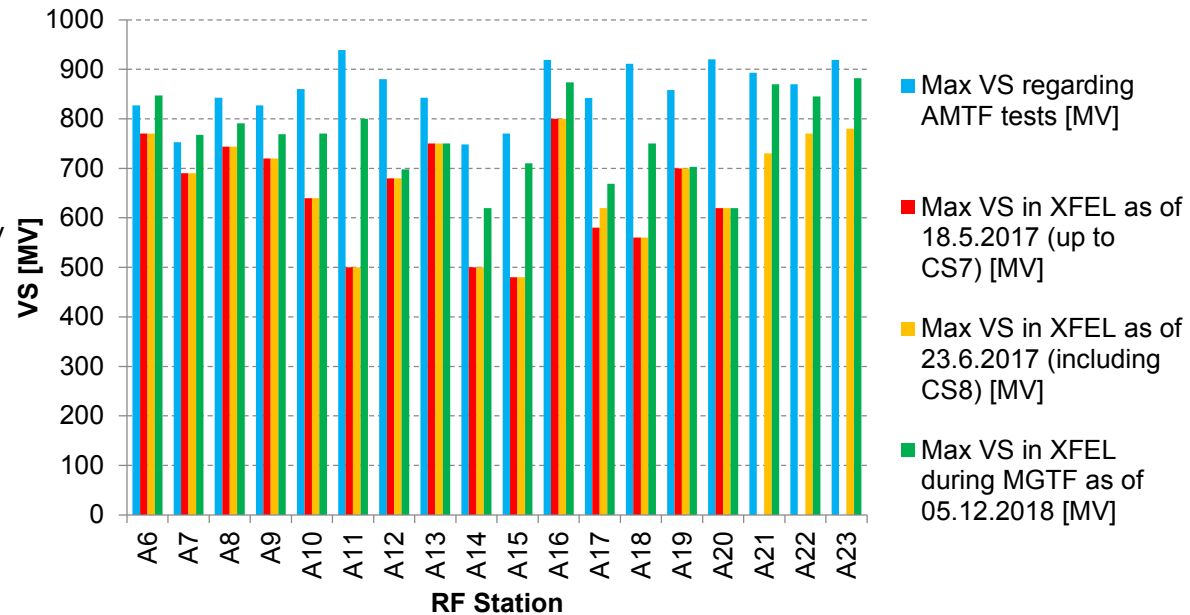
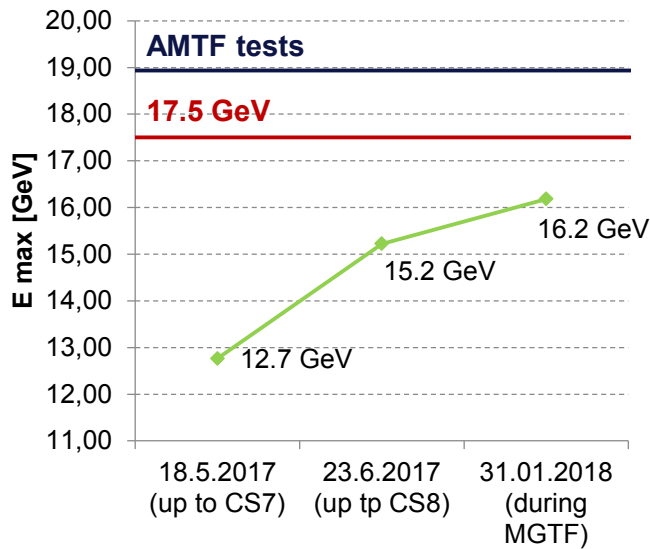


Maximum Gradient Task Force

- 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 31.01.2018



RF Performance as of 31.01.2018

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	800*	85.2%*	Coupler heating*
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
A18	911	750*	82.3%*	Klystron interlock*
A19	858	703♦	81.9%♦	M3.C8 quenches at 18 MV
A20	920	620*	67.4%*	Waveguide sparking*
A21	893	870* [†]	97.4%* [†]	Missing piezo operation, otherwise M1.C5 quenching at 30.3 MV
A22	870	845	97.1%	M3.C5 quenches at 19.9 MV

♦ Waveguide system not optimal

* Still under investigation, thus not final result

† A21: 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)

European XFEL

Test status:

finished
to be continued
to be continued after modification

Summary / Outlook

- LLRF commissioning was performed faster and smoother than expected
- Several issues with frequency tuner, cabling, multipacting, phase jumps, ...
- So far maximal beam energy operated at: 15.2 GeV (goal 17.5 GeV)
- Maximum Gradient Task Force
 - 10 of 18 stations in L3 investigated. 5 of 18 reached final limit
 - Every station has other issues
 - Increase of maximal possible beam energy from 15.2 GeV to 16.2 GeV (to be operated at)
 - Investigations on L3 stations will most likely finish in the second quarter of 2018

Questions?

■ Thank you very much for your attention!

