LLRF Operation and Performance of the European XFEL.

An overview

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LLRF, Barcelona, 16.10.2017

HELMHOLTZ ASSOCIATION

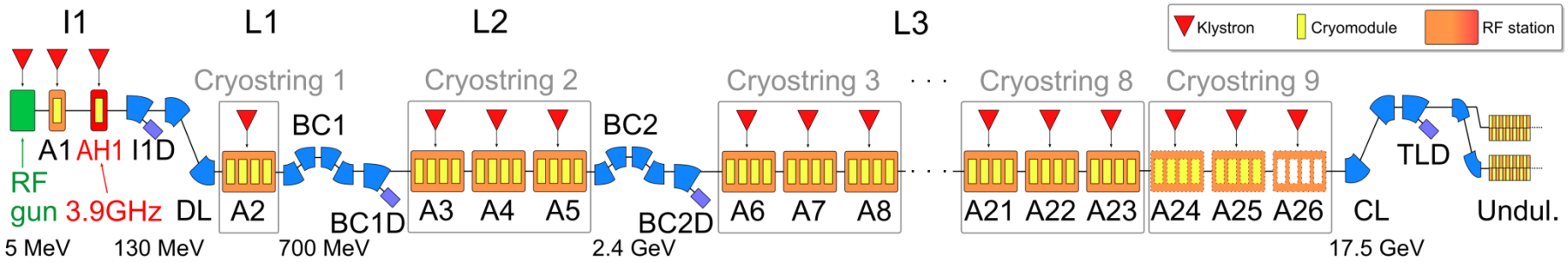
DESY

Contents

- Introduction
- LLRF commissioning
- Energy Reach
- LLRF performance
- Summary / Outlook

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
- First users September 2017



- Commissioning up to cryostring (CS) 8 → 25 RF stations

Commissioning Timeline (LLRF & General)

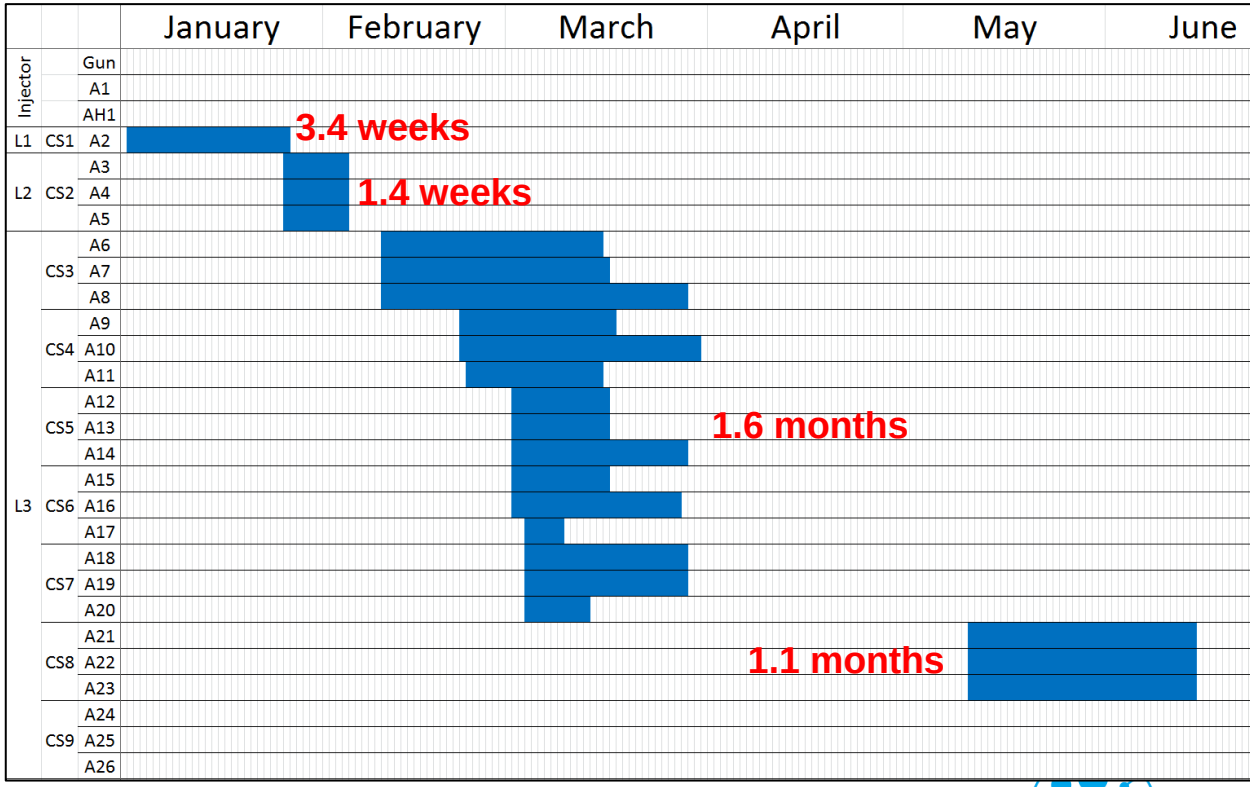
Estimated schedule

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

- IPAC'17 talks by W. Decking (MOXAA1) and J. Branlard (THOAA3)
- SRF'17 Poster by D. Kostin: "European XFEL LINAC RF System Conditioning and Operating Test" (MOPB111)

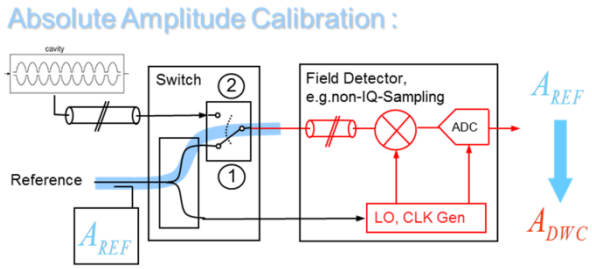
Actual XTL Schedule

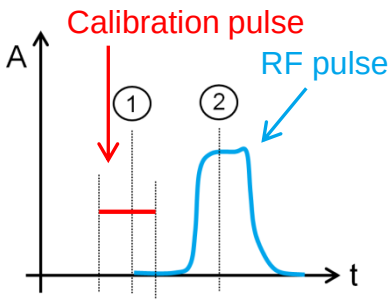
- 02.01.2017 Commissioning start
- 26.01.2017 Finished basic LLRF commissioning of L1 / CS1
- 15.01.2017 First beam to B1D
- 04.02.2017 Finished basic LLRF commissioning of L2 / CS2
- 02.02.2017 First beam to B2D
- 25.05.2017 First beam to XTD
- 30.03.2017 Finished basic LLRF commissioning of L3 / CS3-CS7
- 02.05.2017 First SASE
- 14.06.2017 Finished basic LLRF commissioning of L3 / CS8
- 23.06.2017 First beam to experimental hutch, first experiment



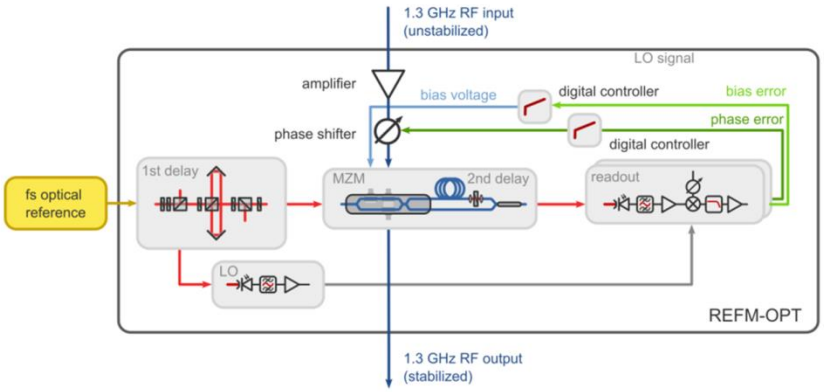
Advanced Commissioning

- Basic commissioning finished, advanced commissioning on-going
- Drift Compensation Module

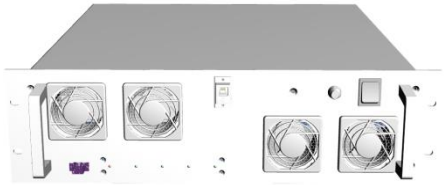




- REFM-OPT



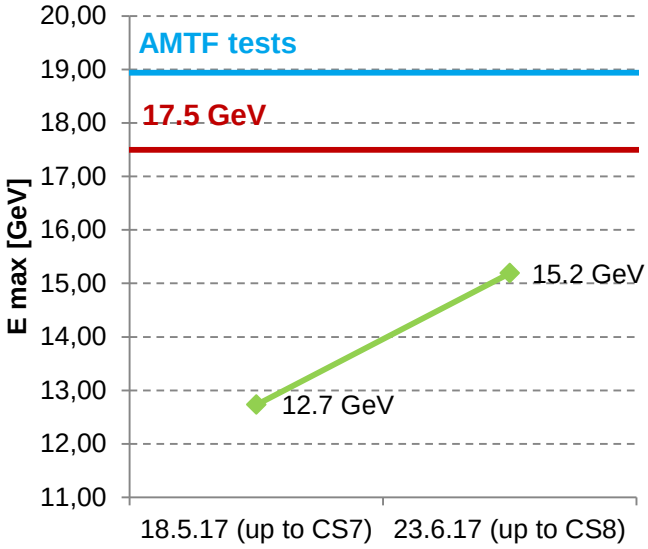
- Piezo driver

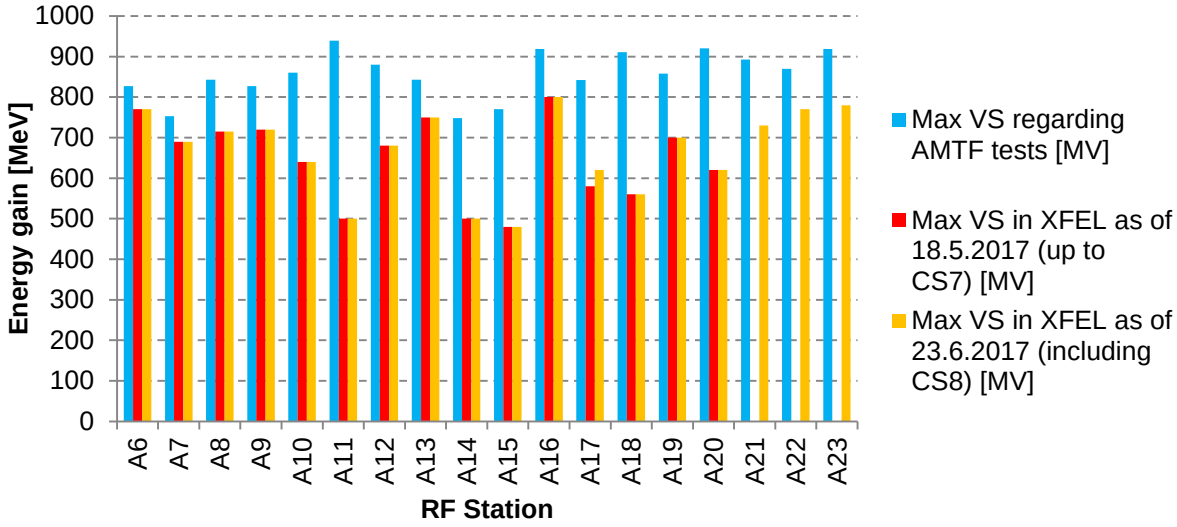


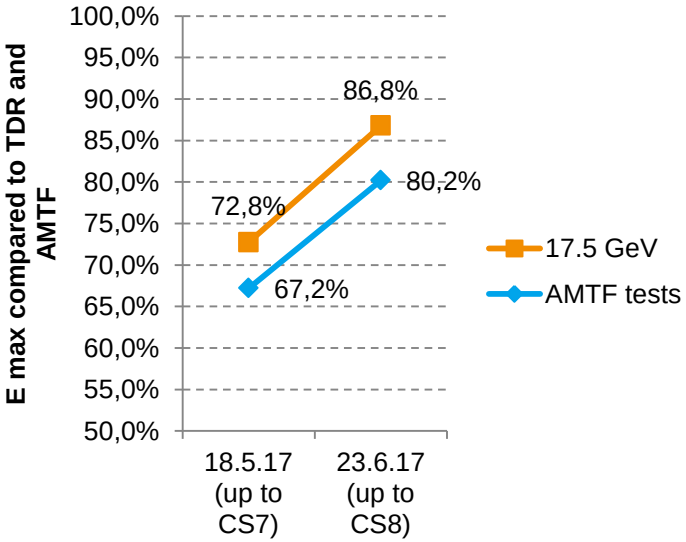
- Etc.

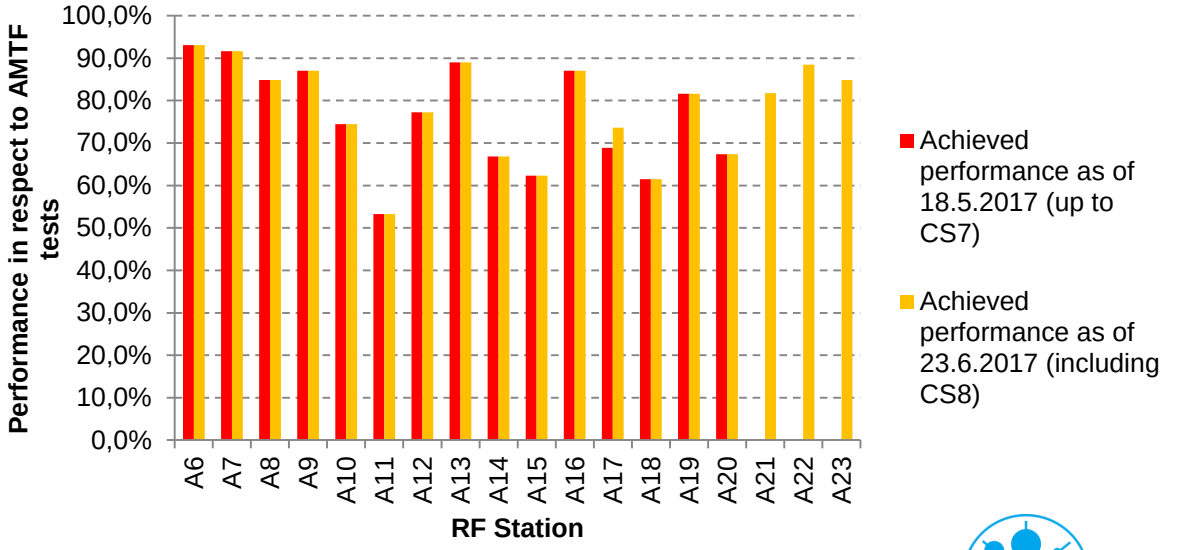
- Frank Ludwig “Drift calibration for the European XFEL” (O-26)
- Holger Schlarb “Laser-to-RF Synchronization with Femtosecond Precision” (P-86)
- Mariusz Grecki “Piezo control for XFEL” (P-73)

RF Performance as of 23.6.2017



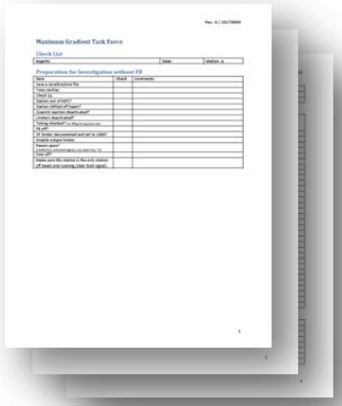


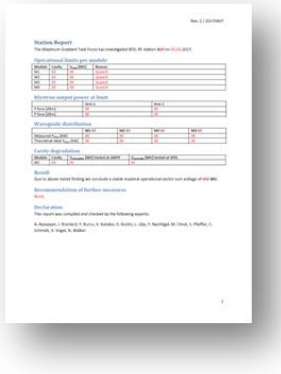




Maximum Gradient Task Force

- 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, tests, etc.)
- Retest if neccessary
- Document findings in station reports





RF Performance as of 28.9.2017

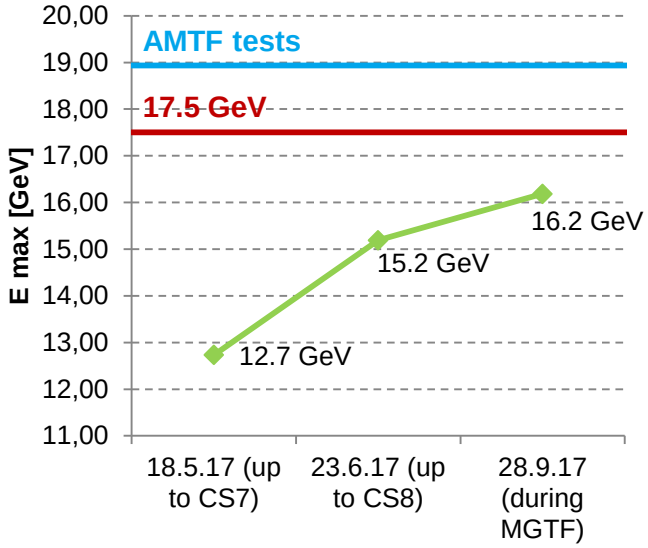
RF station	AMTF theoretical energy gain [MeV]	XFEL max energy gain [MeV] (closed loop operation)	Performance regarding AMTF	Limitation
A10	860	770♦	89.5%♦	M3.C8 quenches at 19.8 MV
A11	939	800*	85.2%*	Coupler heating*
A13	843	500*	59.3%*	Waveguide sparking*
A14	748	620*	82.9%*	Soft quenching and probably 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*,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

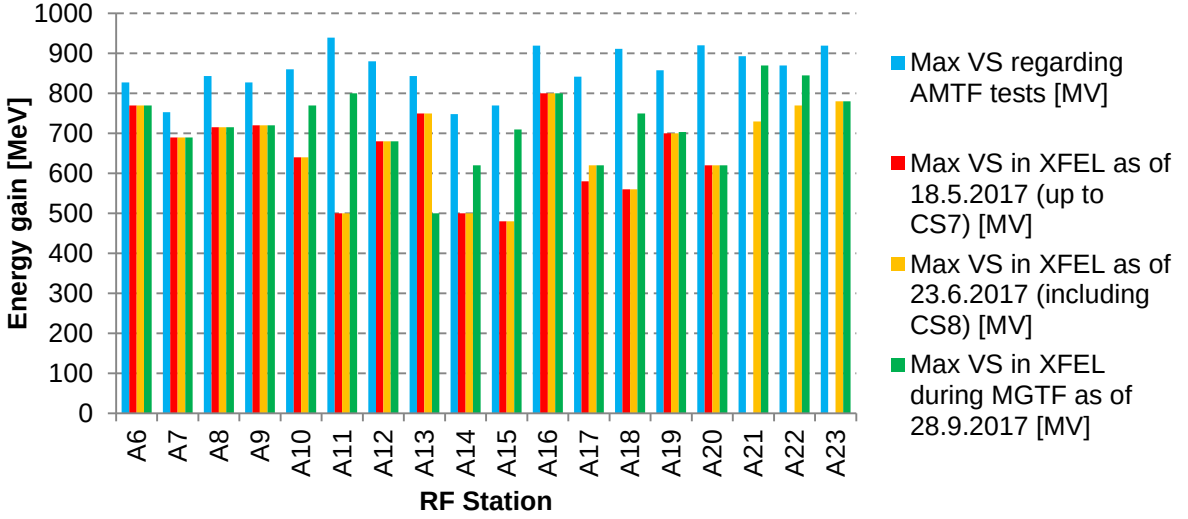
Test status: finished / to be continued / to be continued after modification

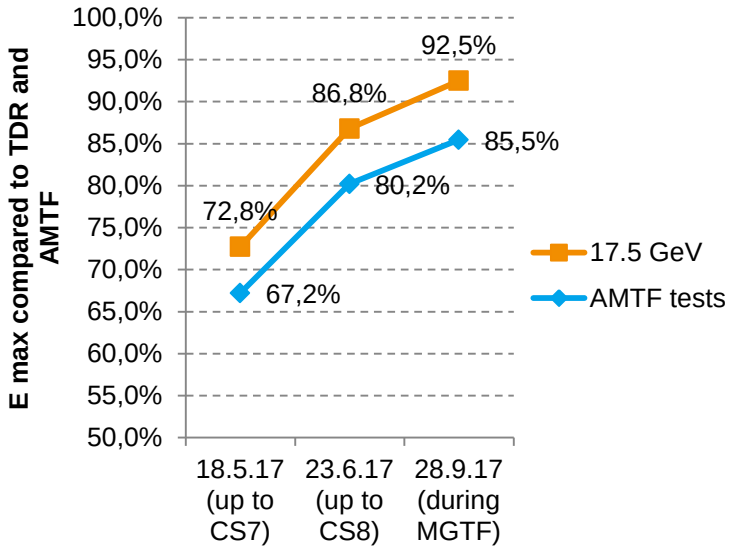
- ♦Waveguide system not optimal
- *Still under investigation, thus not final result
- ǂ A21: First case cavity degradation (M4.C2: > 31 MV → 22.3 MV), which would limit maximal VS voltage, thus cavity was detuned and excluded from VS
- Note: The voltage calibrations at AMTF and XFEL are different (power-based vs beam-based)

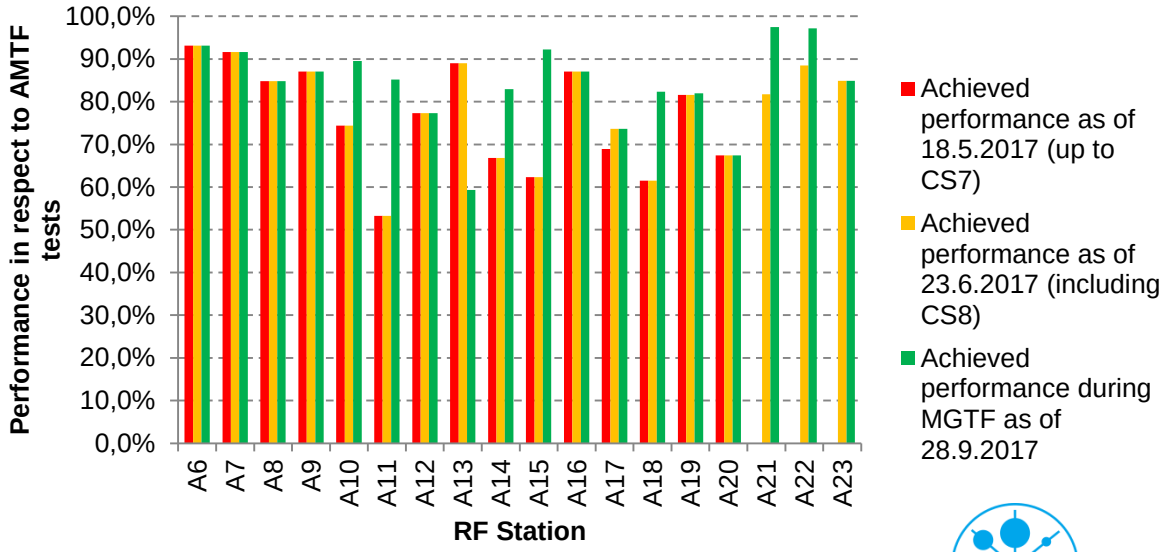
DESY

RF Performance as of 28.9.2017









Time Schedule and Status as of 28.9.2017

Date	Station		Station status
21.6.2017	A19		A6
12.7.2017	A19		A7
26.7.2017	A15		A8
2.8.2017	A11		A9
10.8.2017	A20		A10
23.8.2017	A20		A11
23.8.2017	A18		A12
30.8.2017	A21		A13
6.9.2017	A22		A14
13.9.2017	A13		A15
20.9.2017	A14	user run	A16
27.9.2017	A10	user run	A17
4.10.2017		maintenance	A18
11.10.2017		maintenance	A19
18.10.2017		maintenance	A20
25.10.2017	A11		A21
1.11.2017	A13		A22
8.11.2017	A14		A23
15.11.2017	A18		
22.11.2017	A20		
29.11.2017	A21		
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	A6		
31.1.2018	A7		
7.2.2018	A8		
14.2.2018	A9		
21.2.2018	A12		
28.2.2018	A15		
7.3.2018	A16		
14.3.2018	A17		
21.3.2018	A23		
28.3.2018			

finished
to be continued
to be continued after modification
untested

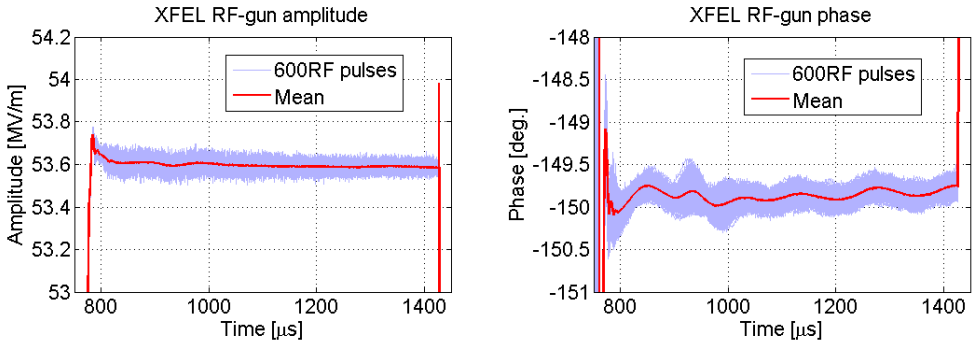
10 of 18 stations in L3 investigated
4 of 18 reached final limit

Injector RF Stability

- Stability reached (intra pulse RMS values)

	Gun	A1	AH1
Amplitude stability ΔA [%]	0.03	0.008	0.018
Phase stability ΔΦ [°]	0.06	0.008	0.024

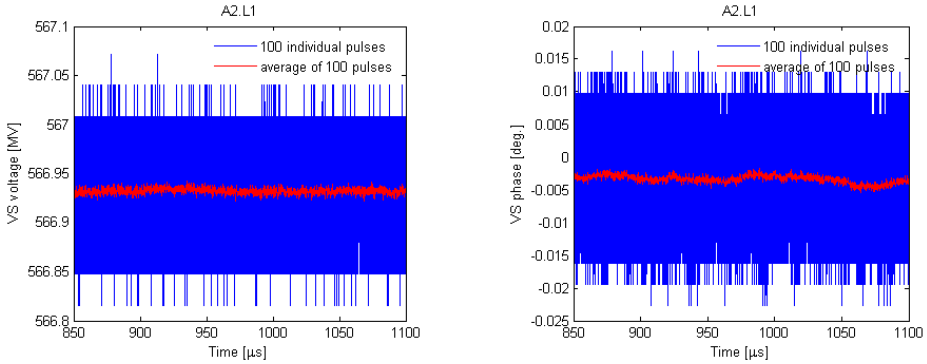
- Gun stability is expected to improve after upgrades



- Overall stable operation

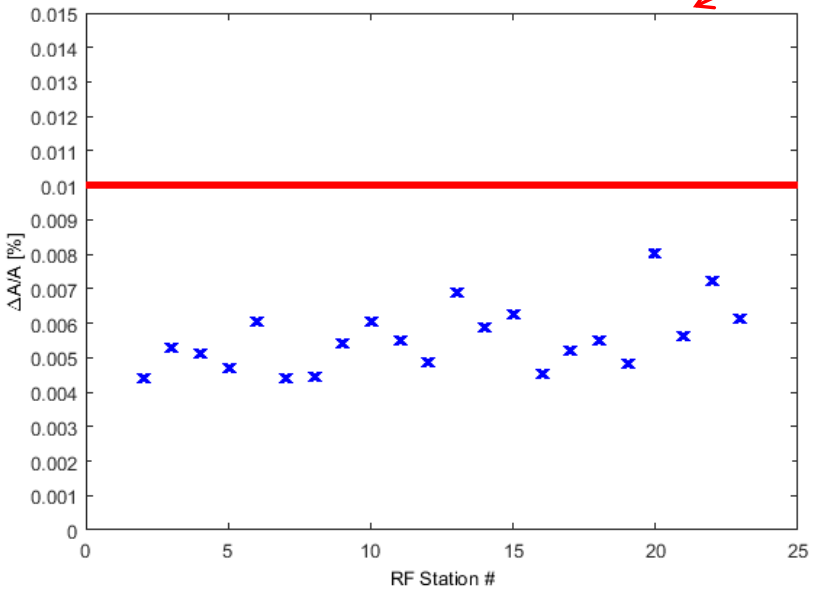
XTL Station Performance

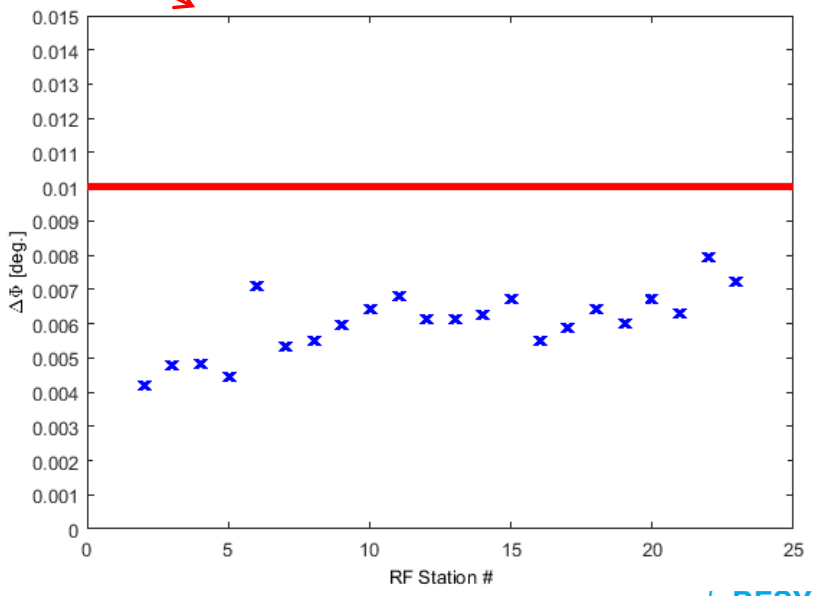
- Flattop amplitude and phase stability (RMS)
- A2 as an example



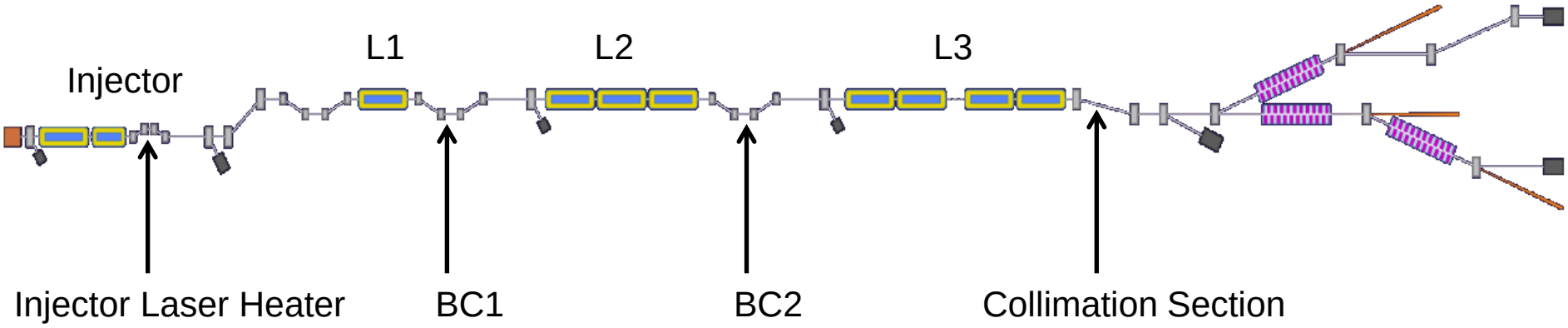
- All XTL Stations

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





Energy Stability Measured with Energy Server



	Collimation Section
$\bar{E}$ [MeV]	13489
σE [MeV]	0.3104
$\sigma E/\bar{E}$	**(0.0023 ± 0.0023)%**

Requirement: 0.01%

Evaluation of 1000 pulses on 22.06.2017

Summary / Outlook

- Basic LLRF commissioning up to CS8 done
- Commissioning of CS9, when preparation work (cabling) finished
- Advanced LLRF commissioning on-going (DCM, Piezo driver, REFM-OPT, etc.)
- Key to smooth commissioning and operation
  - Testing all to be installed components on several levels (board level, crate level, rack level)
  - Automation and scripts (cabling checking, frequency tuning, Q_L tuning, etc.)
  - Flexible timing system allowing to shift individual RF stations on and off beam
- 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. 4 of 18 reached final limit
  - 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
- Intra-pulse amplitude and phase stability about factor two better than specifications
- Energy stability about a factor of four below requirement

Questions?

- Thank you very much for your attention!