LLRF Commissioning and First Operation of the European XFEL.

with some insight on operation issues.

Julien Branlard, for the LLRF team

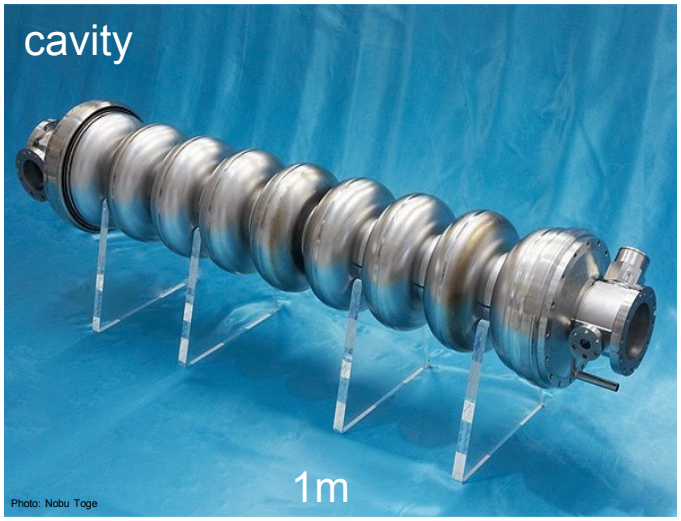
XFEL MicroTCA.4 LLRF installation

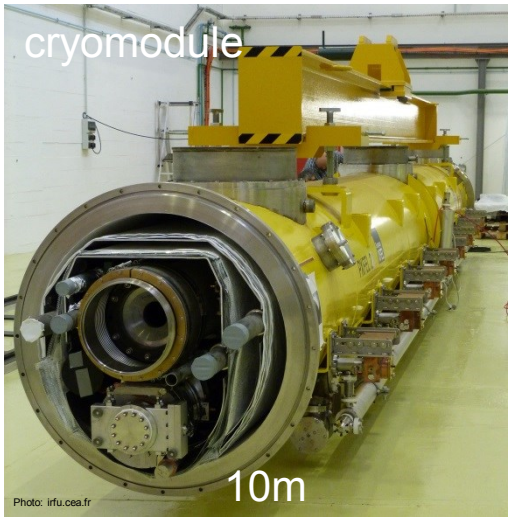
MicroTCA workshop, DESY, 6.12.2017

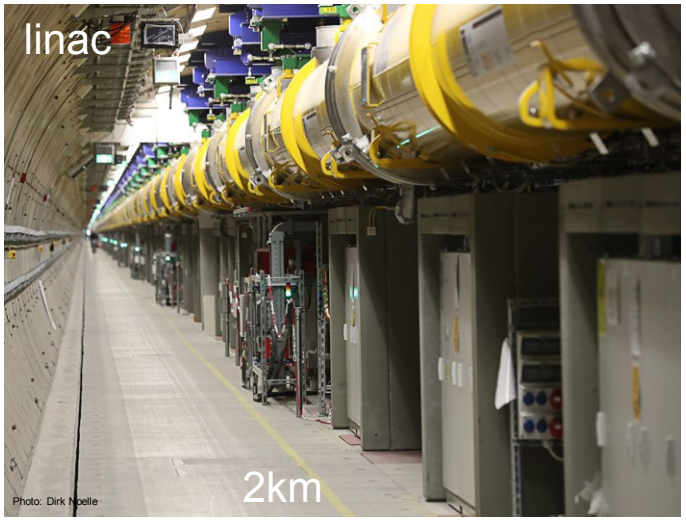
HELMHOLTZ ASSOCIATION

DESY

INTRODUCTION: the European XFEL

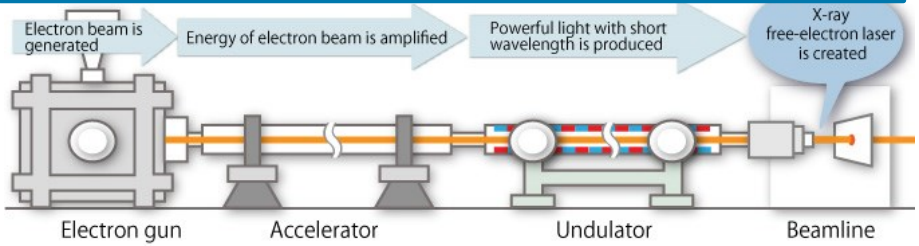






European X-ray Free Electron Laser

- 17.5 GeV light source user facility
- TESLA superconducting 1.3GHz RF cavities
- 1.4 msec pulses at 10 Hz
- e- beam 1.35 mA nom. - 4.5 mA max
- 2009: construction starts
- 2017: commissioning + first user operation



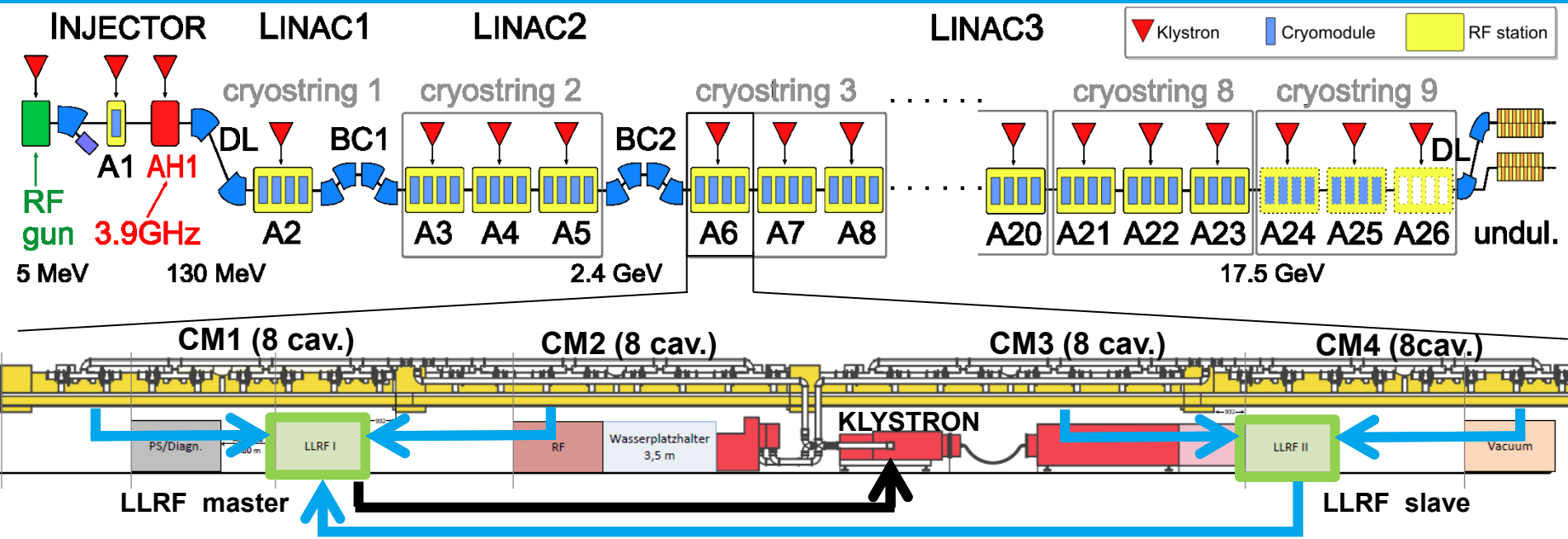
YouTube https://www.youtube.com/watch?v=p3G90p4glQA

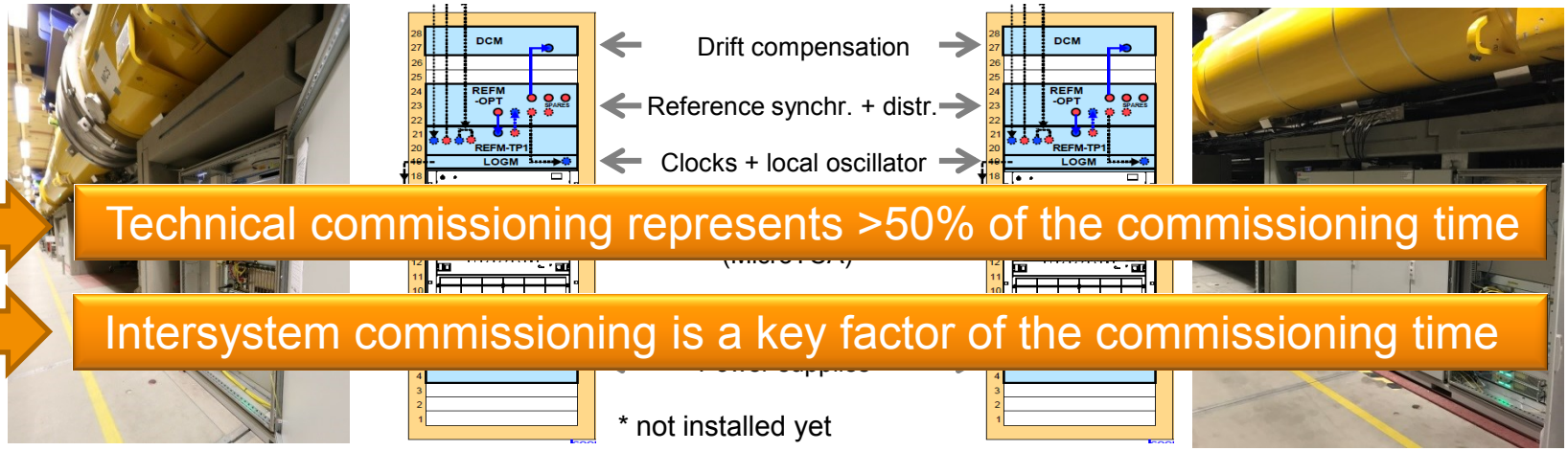
INTRODUCTION: XFEL milestones

- **2006**: Publication *Technical Design Report* (TDR)
- **2009**: Civil engineering starts
- **2013**: End of underground construction
- **Oct. 2013**: First RF tests in the injector
- **2014**: Installation of the first experimental huts
- **Dec. 2015**: First accelerated beam in the injector
- **2015-2016**: Main Linac installation (L1, L2, L3)

- **Sep. 2017**: First user run
- **…**

INTRODUCTION: XFEL RF station



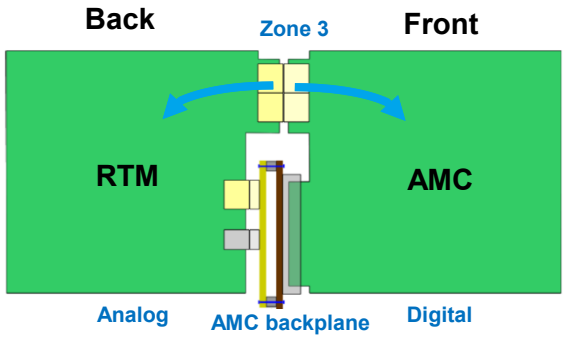


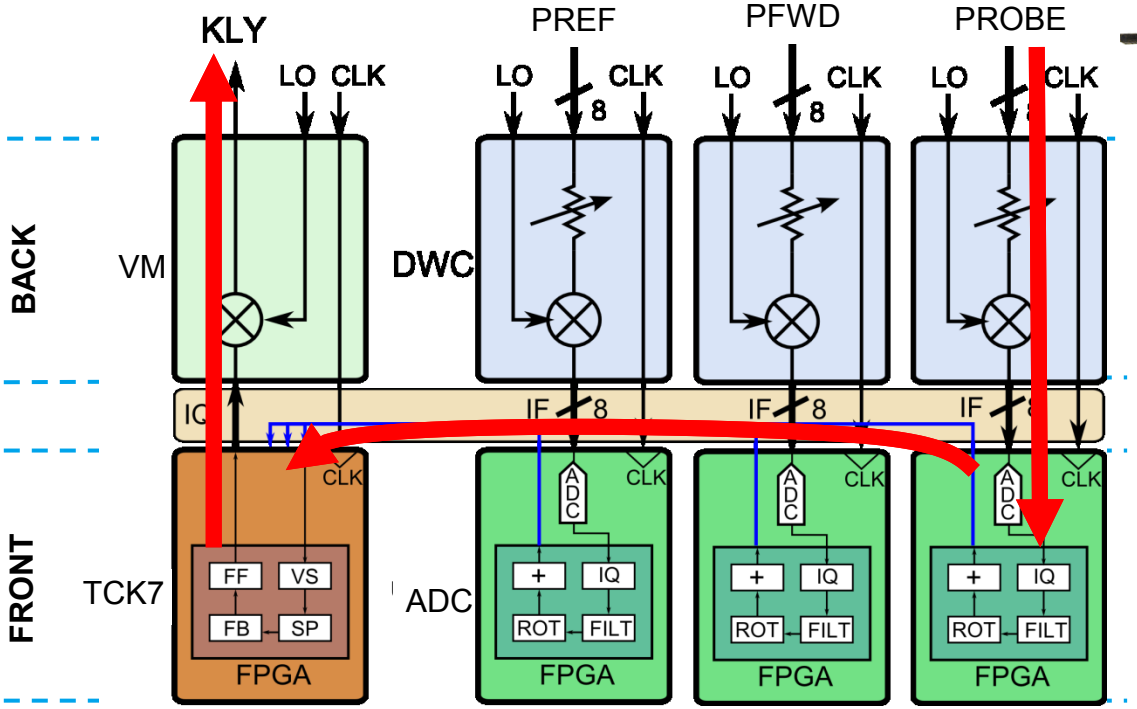
Technical commissioning represents >50% of the commissioning time

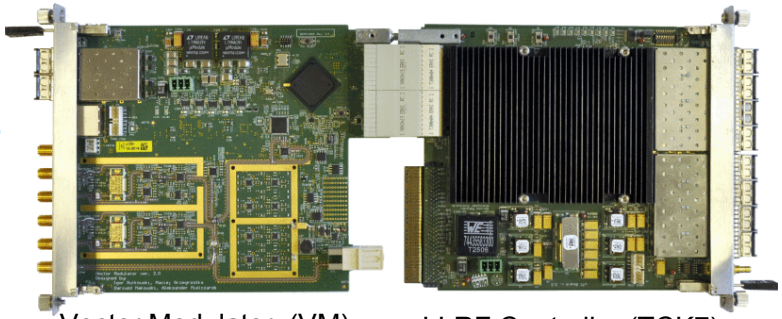
Intersystem commissioning is a key factor of the commissioning time

LLRF for XFEL: system description

- AMC: Advanced Mezzanine Card
- RTM: Rear Transition Module
- 12 slots, hot swap
- Redundant power supply

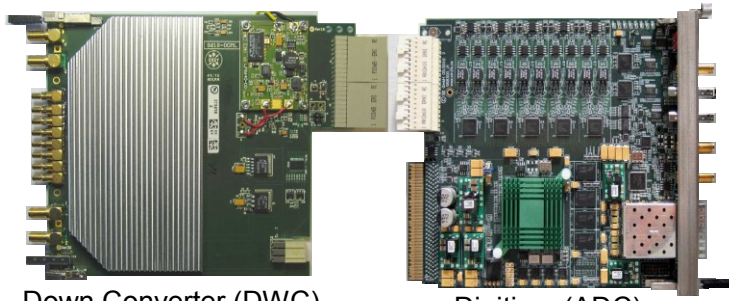






Vector Modulator (VM)

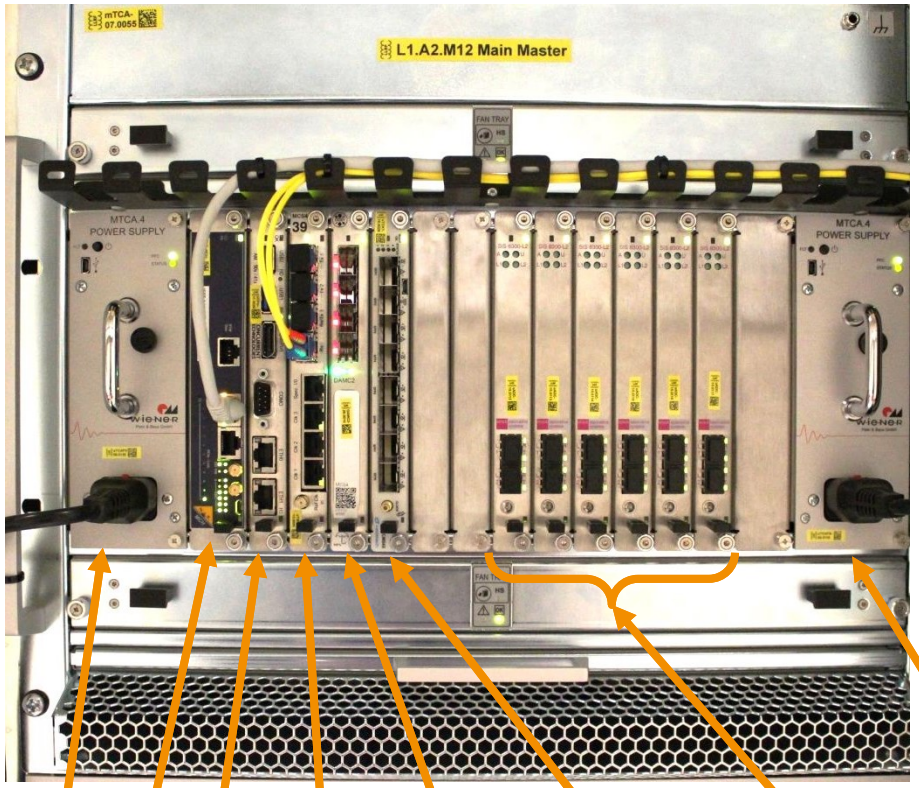
LLRF Controller (TCK7)



Down Converter (DWC)

Digitizer (ADC)

LLRF for XFEL: crate occupation - FRONT



MASTER

uPM	MCH	CPU 1	x2TIMER 2	DAMC02 3	TCK7 4	5	SIS KLM 6	SIS P_{REF2} 7	SIS P_{REF1} 8	SIS P_{FWD2} 9	SIS P_{FWD1} 10	SIS PRB2 11	SIS PRB1 12		

SLAVE

uPM	MCH	CPU 1	x2TIMER 2	DAMC2 3	TCK7 4	5	6	SIS P_{REF2} 7	SIS P_{REF1} 8	SIS P_{FWD2} 9	SIS P_{FWD1} 10	SIS PRB2 11	SIS PRB1 12		

Power module (1kW)

MCH (PHYS80)

CPU (quad core)

Timing

Main controller (TCK7)

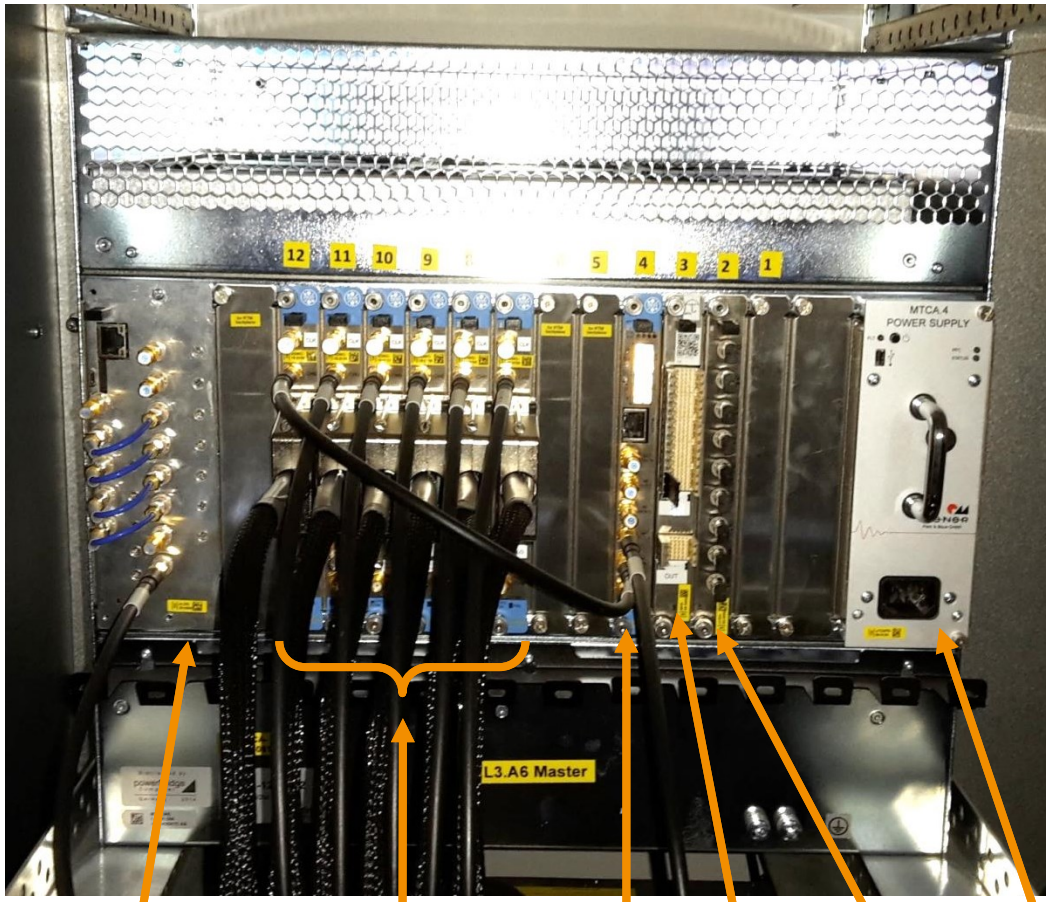
Machine protection (DAMC2)

Digitizers (SIS8300)

Redundant power module

DESY

LLRF for XFEL: crate occupation - REAR



uLOG (Reference, CLK, LO)

Down converters

Vector modulator

Machine protection

Timing

Power module

MASTER

uLOG		DWC-BP PRB1 12	DWC-BP PRB2 11	DWC-BP P_{FWD1} 10	DWC-BP P_{FWD2} 9	DWC-BP P_{REF1} 8	DWC-BP P_{REF2} 7	DWC-BP KLM 6	5	uVM 4	MPS-RTM 3	TIMER-RTM 2	1		uPM

SLAVE

uLOG		DWC-BP PRB1 12	DWC-BP PRB2 11	DWC-BP P_{FWD1} 10	DWC-BP P_{FWD2} 9	DWC-BP P_{REF1} 8	DWC-BP P_{REF2} 7	6	5	CLK-FT 4	MPS-RTM 3	TIMER-RTM 2	1		uPM

LLRF for XFEL: standard system for an RF station

- 2x 9U 12 slot crates (Pentair)
- 4x 1kW power supply (Wiener)
- 2x MCH 80-lane PHYS (NAT)
- 2x CPU quad core (Concurrent)
- 2x timer AMC module (NAT)
- 2x timer RTM module (NAT)
- 2x DAMC2 (DESY)
- 2x MPS-RTM (DESY)
- 2x TCK7 (Vadatech)
- 1x VM (DESY)
- 1x CLKFT (DESY)
- 13x SIS8300 digitizers (Struck)
- 13x DWC1300 down converter (Struck)
- 2x uLOG (DESY/Dynamique)

50 MicroTCA.4
components / RF station

x 26 RF stations

+ non-standard RF stations

+ test setup

+ spares

> 2000 components

COMMISSIONING: planning

- **Pre-commissioning**
  - Board level.
  - Crate level.
  - Rack level.

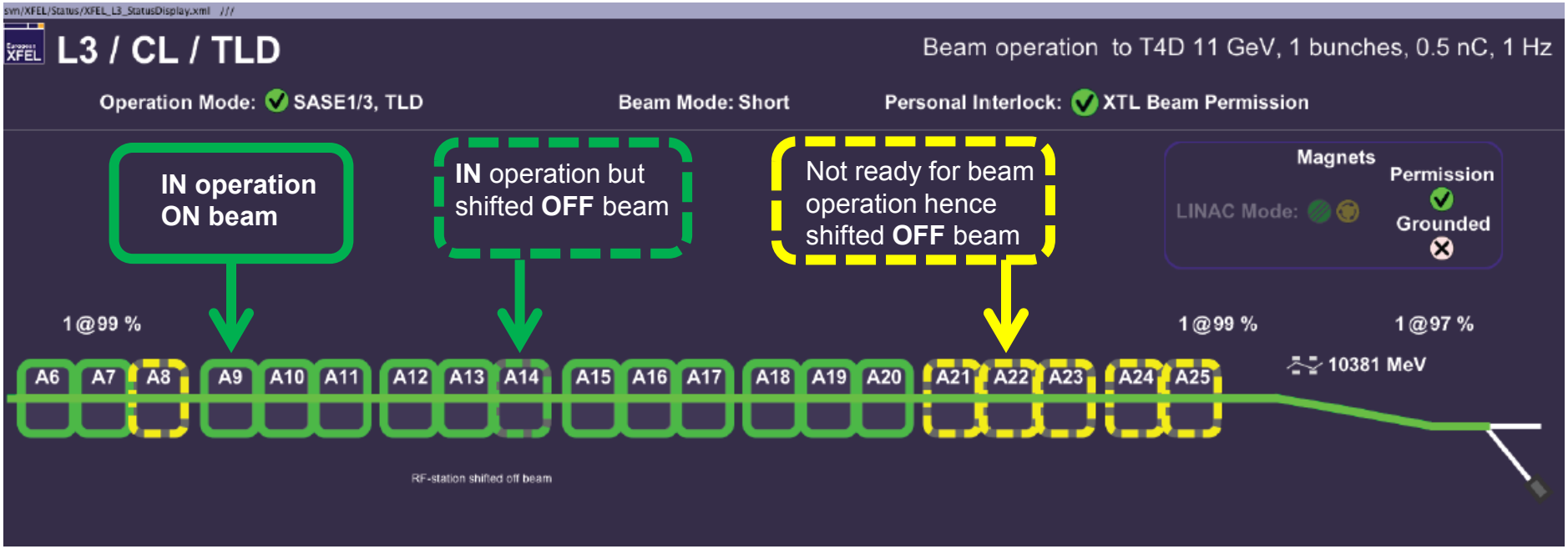
INTEGRATION TEST !!!

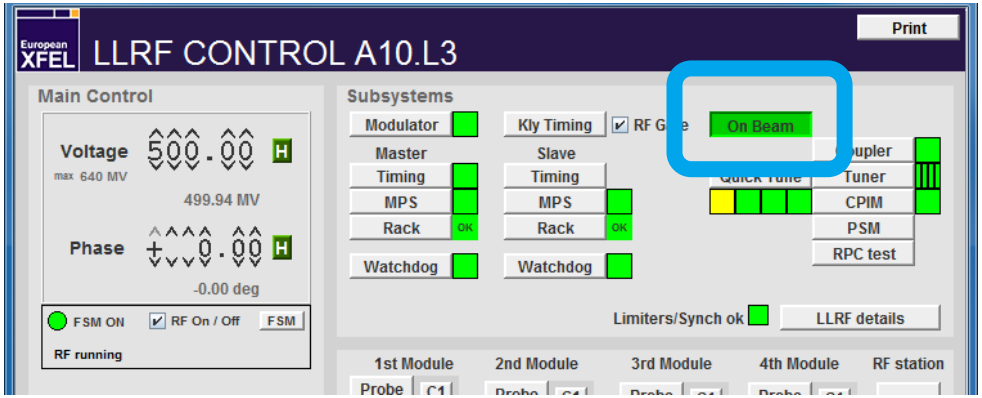
- **Large machine → large team**
  - E.g. for XFEL

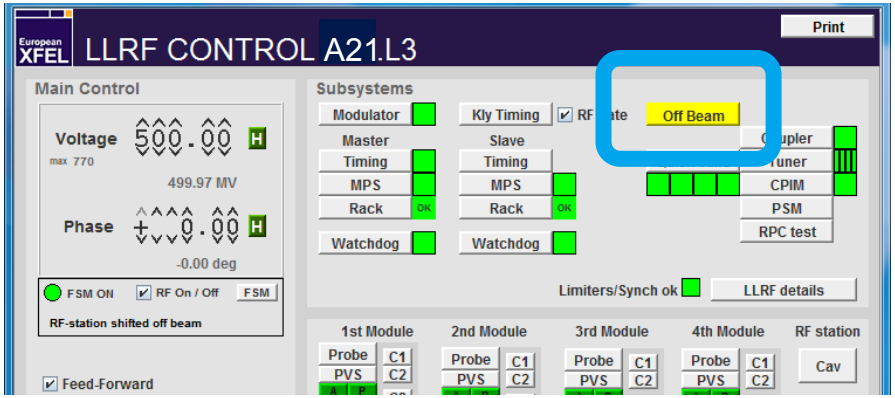
    20 people.
    8 LLRF experts.
    Support from other institutes.

- **Parallel work**
  - RF station wise.

COMMISSIONING: tools







COMMISSIONING: LLRF milestones

RF ONLY

Initial checks.	LLRF system ready for commissioning ?
RF signal checks: Forward and Reflected.	Cabling issues? Signal saturation?
Frequency tuning.	From parking position to resonance.
RF signal checks: Probe.	Cabling issues? Signal saturation?
Coupler tuning.	Target Q_L = 4.6e6.
Power-based gradient calibration.	Coarse
Closed-loop operation.	Feedback, learning feedforward, …

READY FOR BEAM

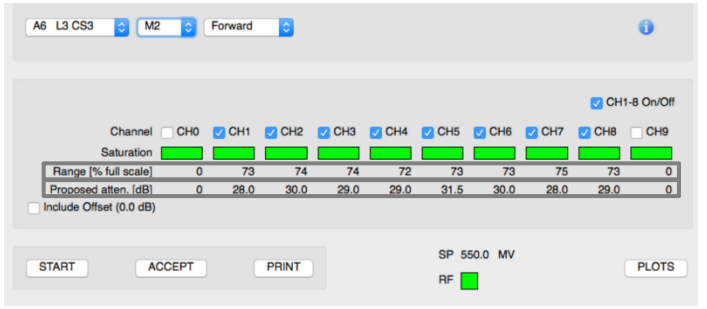
Establish beam transport.	30 bunches, 0.5nC.
Cavity phasing.	Using waveguide phase shifters.
Beam-based gradient calibration.	Fine relative calibration. Absolute validation using energy server.

COMMISSIONING: tool example & automation

> Power-based calibration

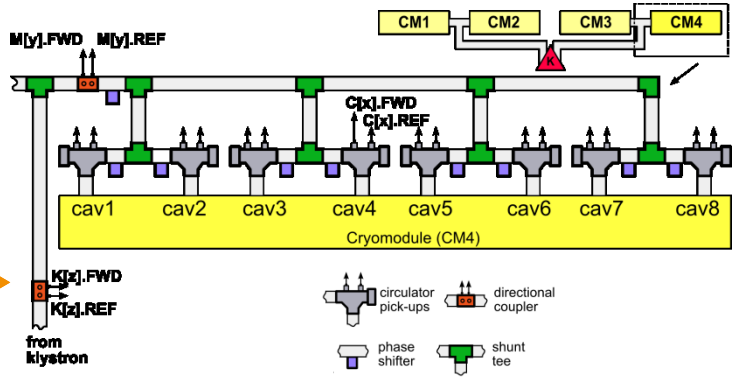
1. Dynamic range optimization

"Adjust attenuation so that available signal uses the optimal range of the digitizers."



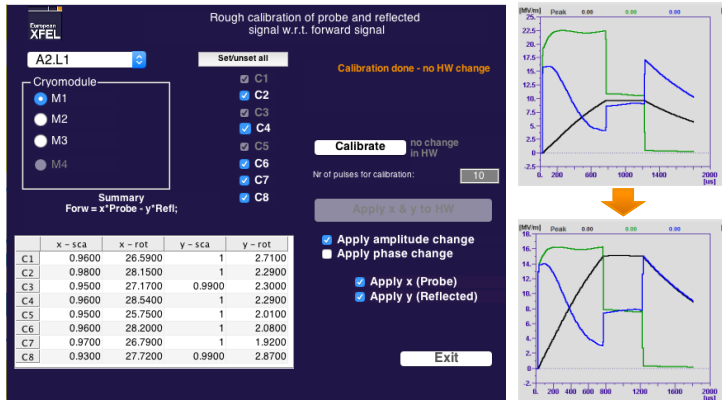
2. Forward power calibration

"Scale forward power signals so they read actual kW, based on the power meter measurements."



3. Probe and Reflected signal calibration

"Scale reflected and probe signals so that Probe = Forward + Reflected."



COMMISSIONING: updates

> Migration to Ubuntu 16

- Installation stretched between 2014 to 2016
- All crates installed by default with Ubuntu 12
- Migration to Ubuntu 16 in Oct/Nov 2016
- Recompilation + deployment of all servers for new OS release
- Kernel update planned for end of this year

> Upgrade to PCIe gen 2

- New firmware implementation (board support package)
- Deployment this winter shutdown (first the SIS8300, later TCK7)
- Benefit: factor 2 DNA transfer speed

COMMISSIONING: software and firmware

> Tests

- Most of the time, test on real HW → not ideal.
- Working on alternative (VirtualLab: virtual time + devices)

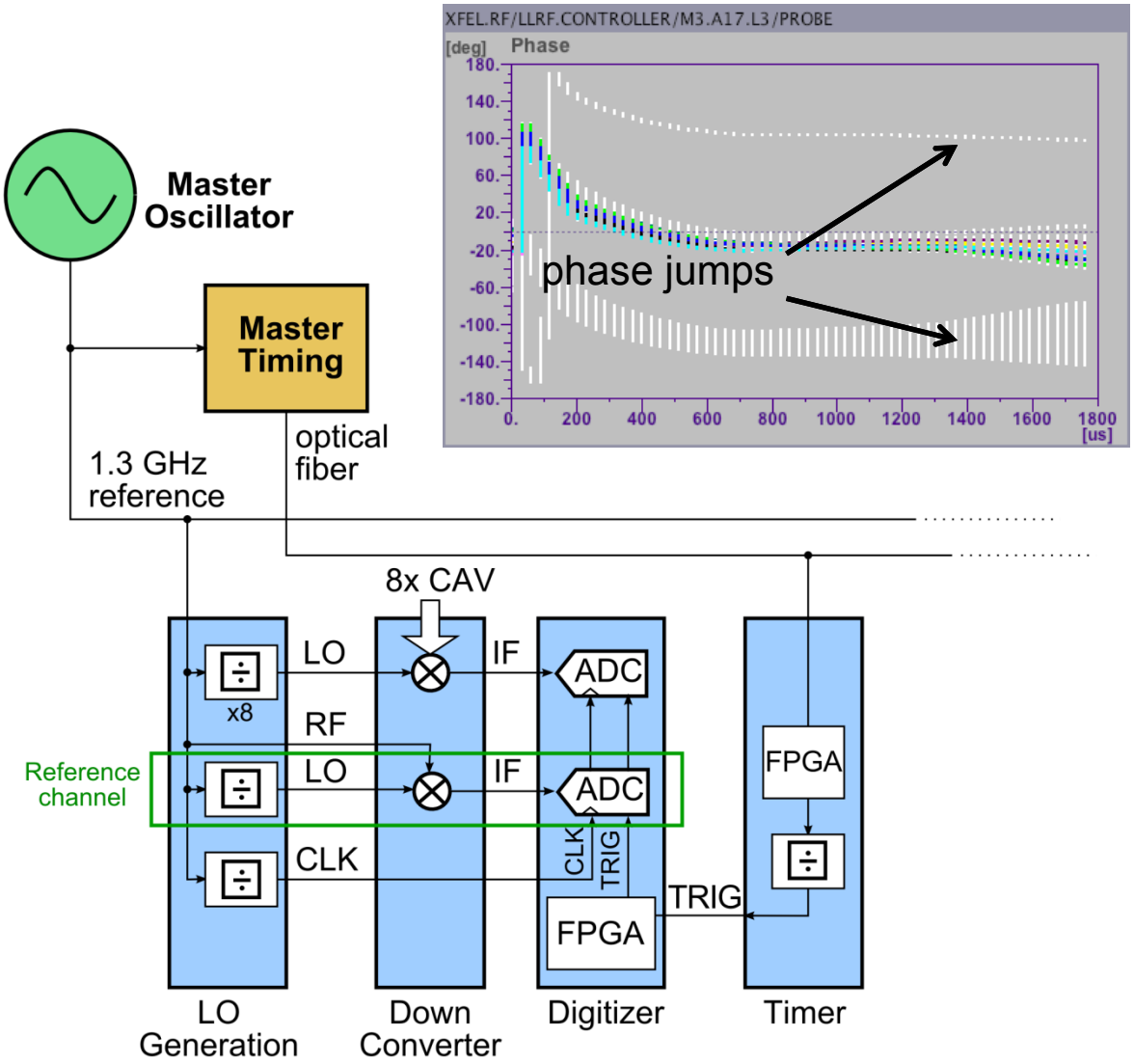
> Deployment / update

- Set of scripts (hand config. station by station inevitably fails).
- Debian package calls configuration script.
  Everything specific to that station.
  Specific names, specific HW config, etc…

> Generic approach

- Same for different servers.
- Same for different facilities.

OPERATION: reset after reboot

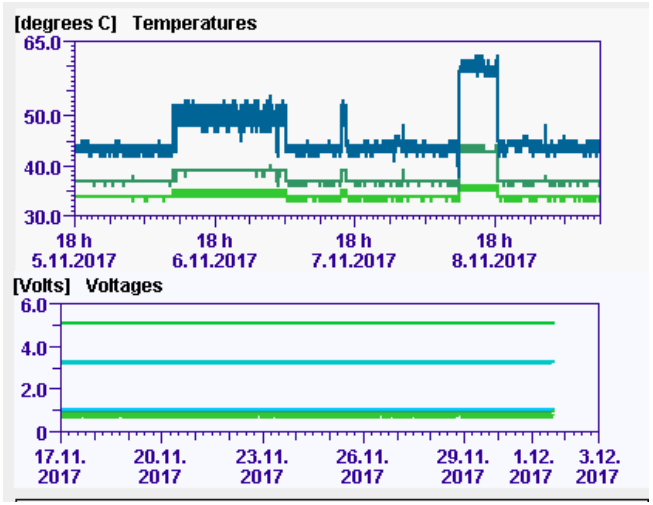


- RESET dividers to a defined state after crate reboot
- Several MicroTCA modules involved
- Fixed relationship between TRIG, CLK and 1.3 GHz reference
- Use the absolute phase offset from the reference channel as template for the other channels

OPERATION: isolated failures (1/2)

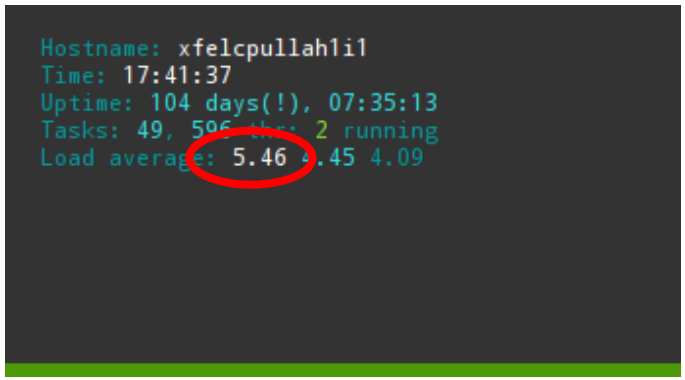
> CPU overheating

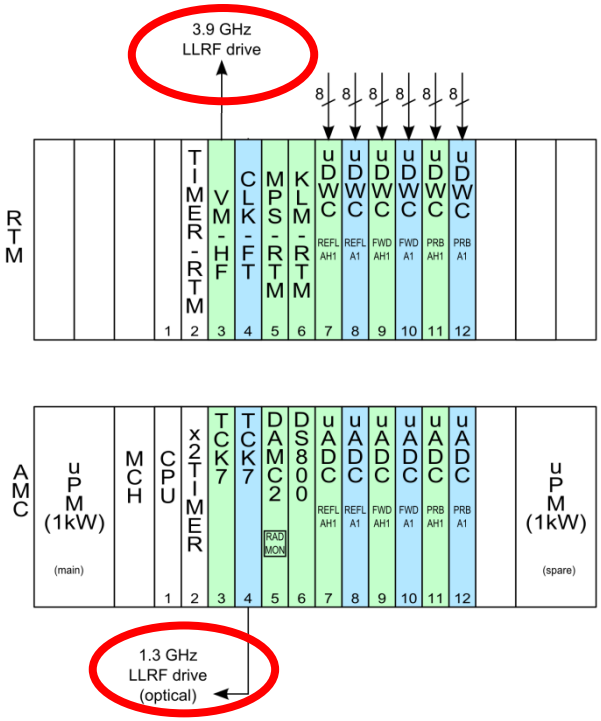
- Reason unknown
- CPU exchange (May 2017 A13S)



> CPU overload

- A1/AH1
- 2x LLRF system in 1 crate
- Investigate a 2-CPU solution ?





OPERATION: isolated failures (2/2)

- **SSDs exchange**
  - RAID redundancy lost, slow writing to disk
  - 3 occurrences so far: (May 2017: A9, Nov. 2017: GUN, July 2017: A6S)
  - *FLASH: 20 occurrences in 6 years*
- **Device needs to be reprogrammed**
  - MCH (x1)
  - TCK7 (x1)
  - *FLASH: 2-3 occurrences*
- **Lost Ethernet communication with device**
  - 1 occurrence so far: (Nov. 2017 TMCB REFM-OPT)
  - *FLASH: 5-6 times (PDU)*

radiation related ?

OPERATION: is radiation an issue ?

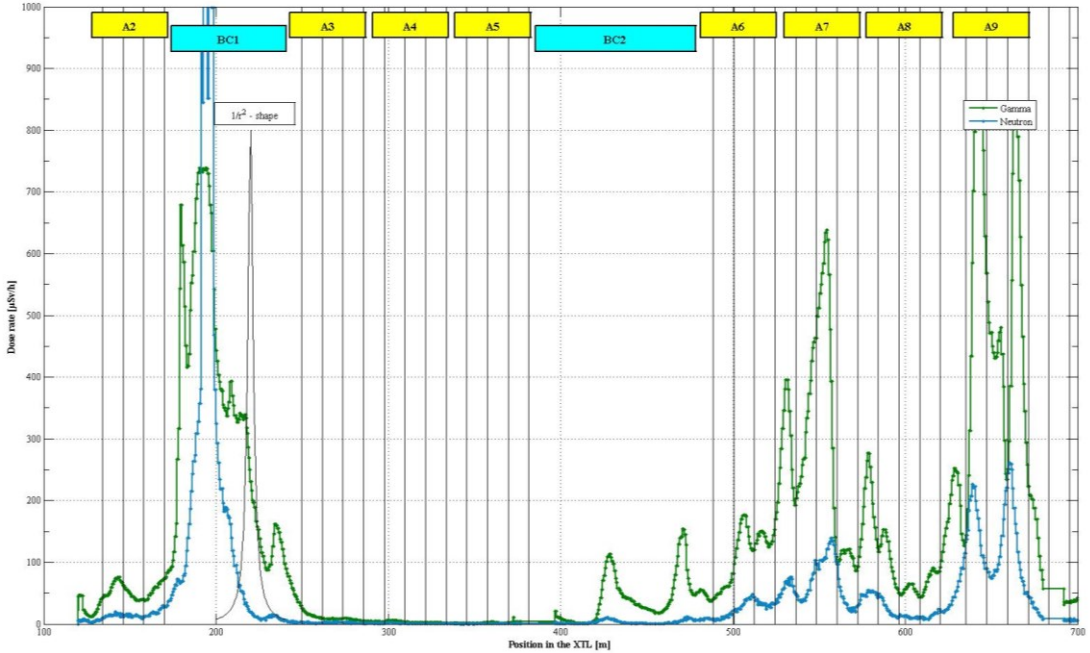
- Regular TLD read outs
- On-line dark current beam loss monitors
- Weekly survey (MARWIN)

OPERATION: is radiation an issue ?

> Radiation

- Online monitor
- Regular survey
- XFEL : MARWIN

MARWIN: Mobiler und **A**utonomer **R**oboter für **W**artung und **IN**spektion



OPERATION: machine-level overview

> Machine-level overviews panels

- Summary panels
- Statistical analysis
- Overview system health

LLRF

LLRF - METER

> Machine-level diagnostics & predictive maintenance

- Monitoring
  CPU load, fan speeds, temperatures , voltages, radiation doses, ...
- Alarm server
  Loss of reference, loss of lock, over temperature
- Data correlation
  Improve fault detection (more signals / model-based).
- Trip logger
  Down time statistics. Where to focus our effort?

OUTLOOK: what's next ?

> XFEL advanced operation

- Performance meas. & improvement (energy, stability, uptime)
  - → study time, advanced commissioning
  - → software / firmware upgrade

> XFEL hardware upgrade

- Improved diagnostics
  - Klystron protection, (KLM-RTM)
  - Beam diagnostics (HOM-RTM)
  - Direct sampling (DS800)
- Hardware upgrades
  - CPU ?, GPU?
  - ADCs ?
  - Main FPGA board ?

QUESTIONS ?

Thank you

for your attention!