Low Level RF for SRF accelerators.

… based on the European XFEL experience

1. **Interfaces to LLRF ?**
2. **LLRF for large scale accelerators**

Julien Branlard, DESY
for the LLRF team

LLRF for SRF accelerators
Geneva, September 3rd 2014

HELMHOLTZ ASSOCIATION

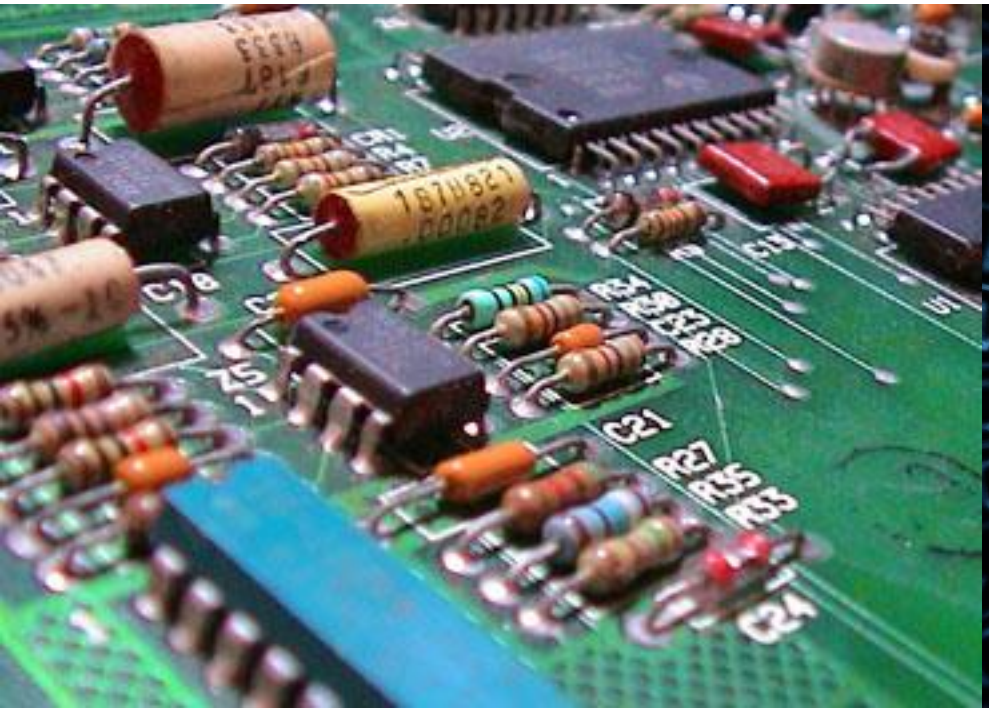
DESY

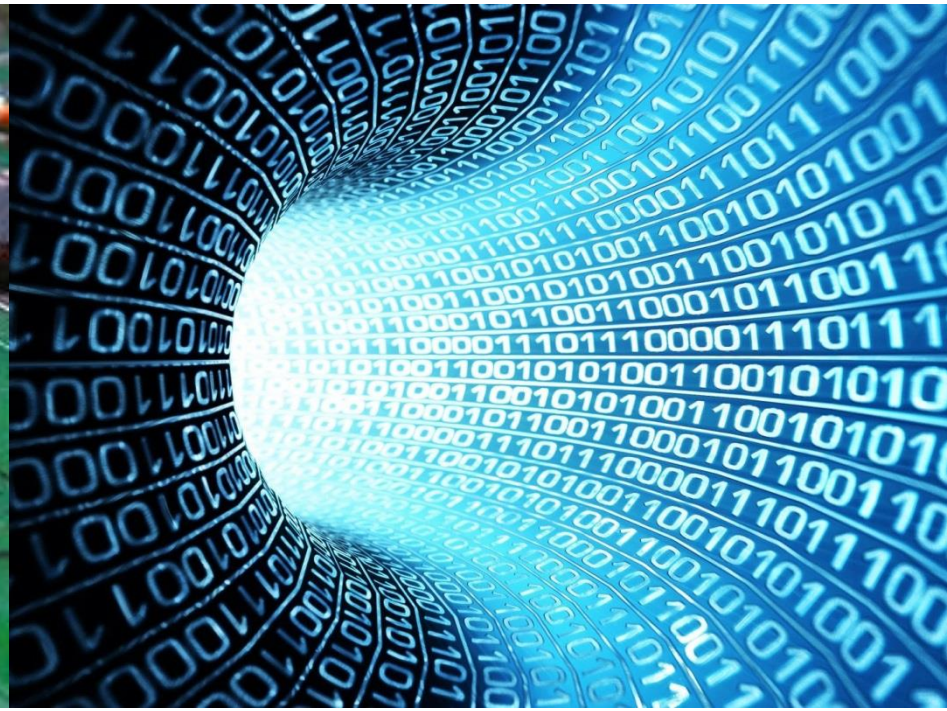
WHY TALK ABOUT LLRF ?

- "Everything already demonstrated since analog LLRF systems."

BUT

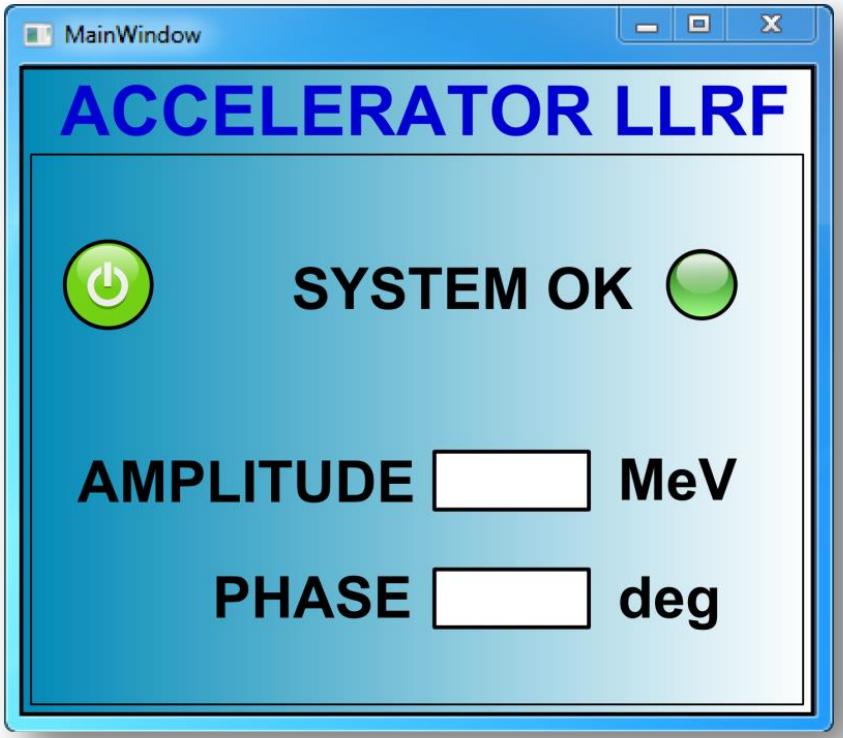
- "New technologies open new possibilities, offer new challenges."



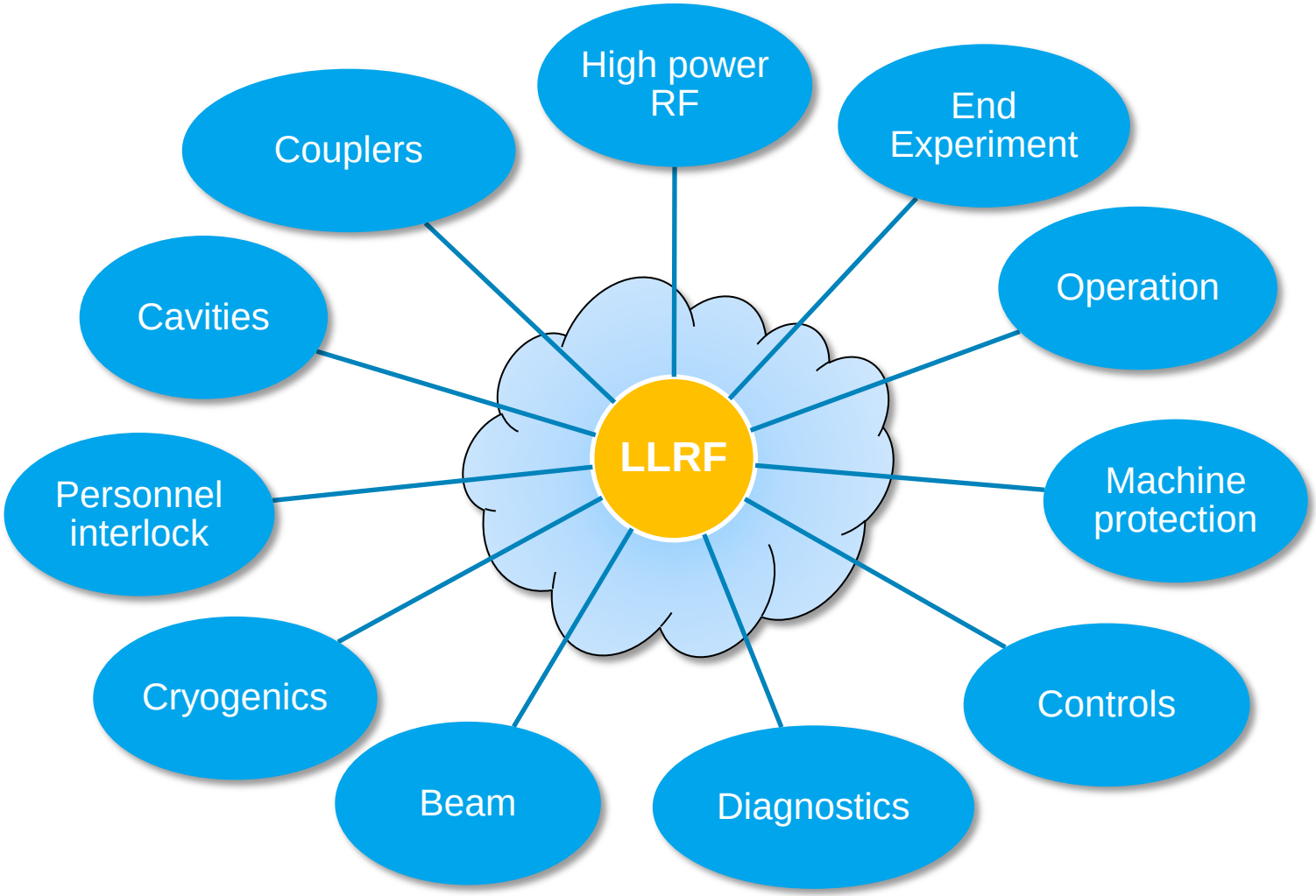


WHAT IS LLRF ?

- Interface to **« The Ultimate LLRF System »**



WHERE DOES LLRF STOP ?

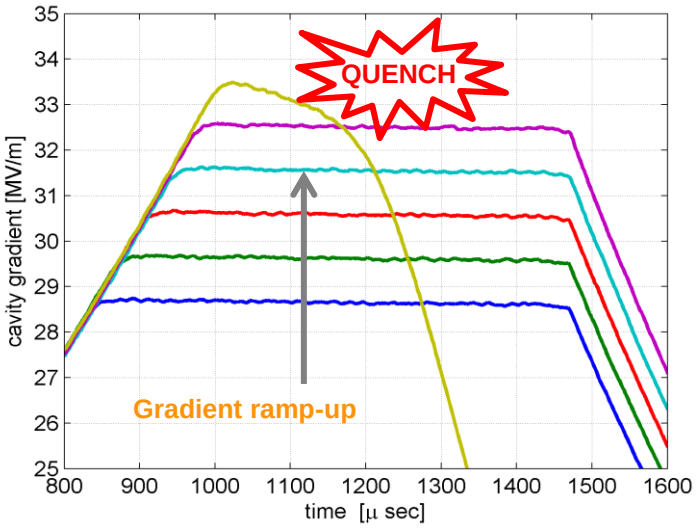


> INTERFACES TO LLRF

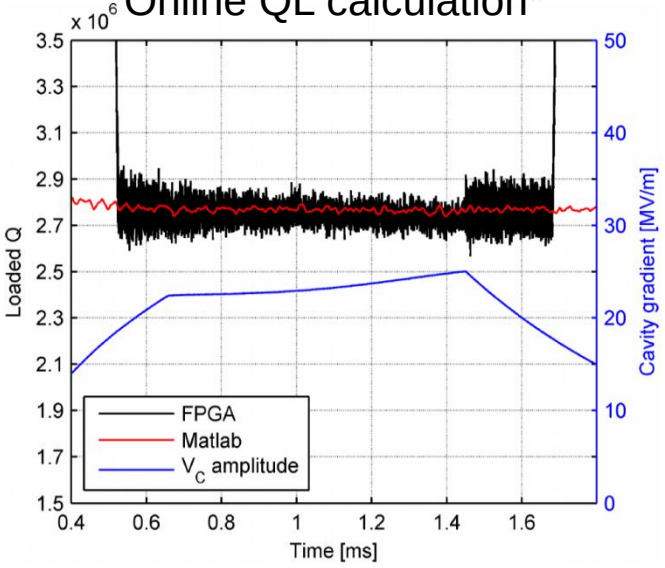
> LLRF FOR LARGE SCALE ACCELERATORS

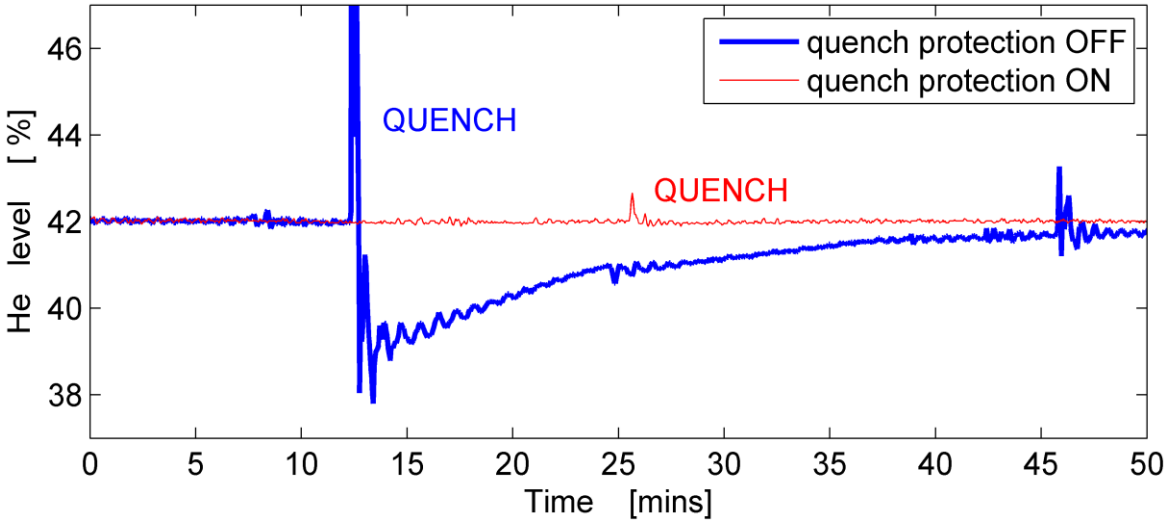
LLRF and Cryogenics

- **Quench** detection
- **Heat load** anticipation / compensation
- **Cryo OK** → tuners, piezo



Online QL calculation*

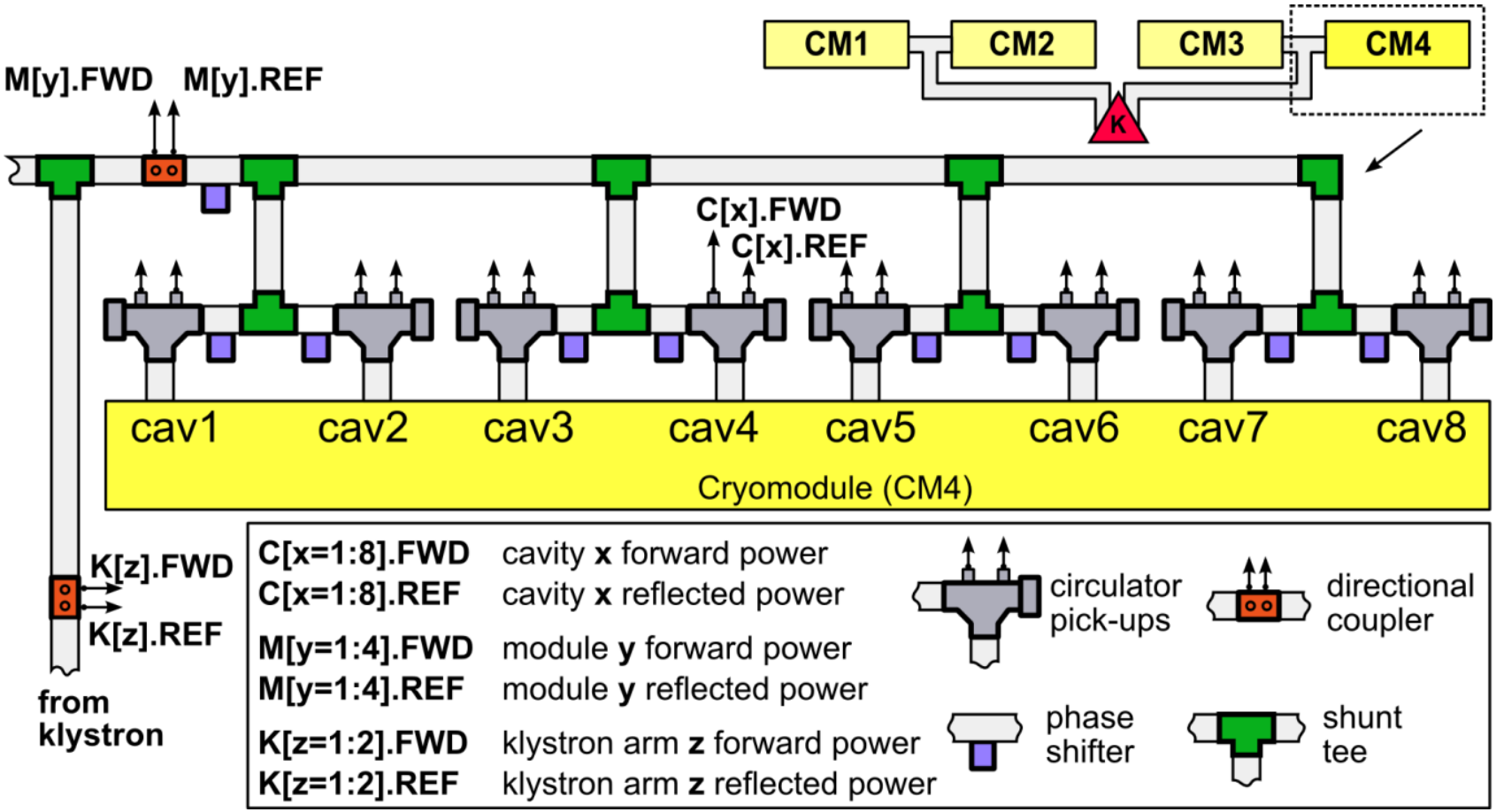




* Courtesy: R. Rybaniec
"***Real-time Estimation of Superconducting Cavities Parameters***"
IPAC 2014, Dresden Germany

LLRF and High Power RF (1/2)

- Power **sub-distribution** and **phase shifters** control

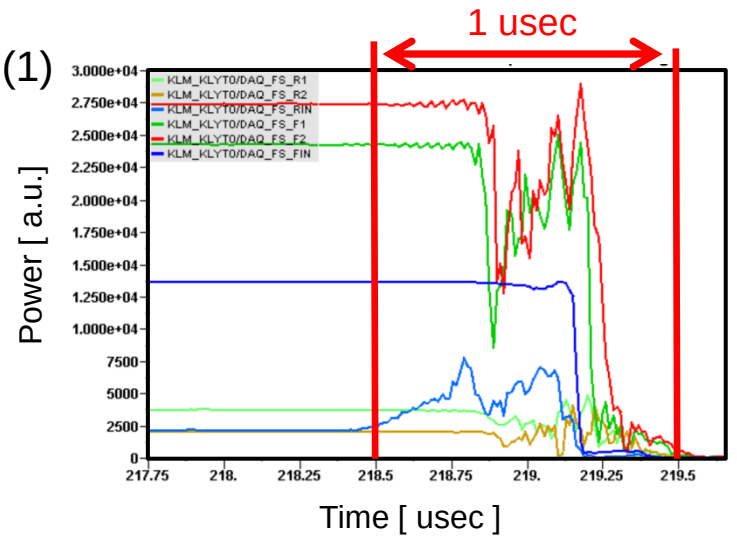


LLRF and High Power RF (2/2)

- **Klystron** monitoring
  - (1) - RF break-down
  - (2) - “Too-high” reflected power
  - (3) - High voltage break-down

  - Fast interlock of the LRF drive
  - 200 nsec reaction time

(1)



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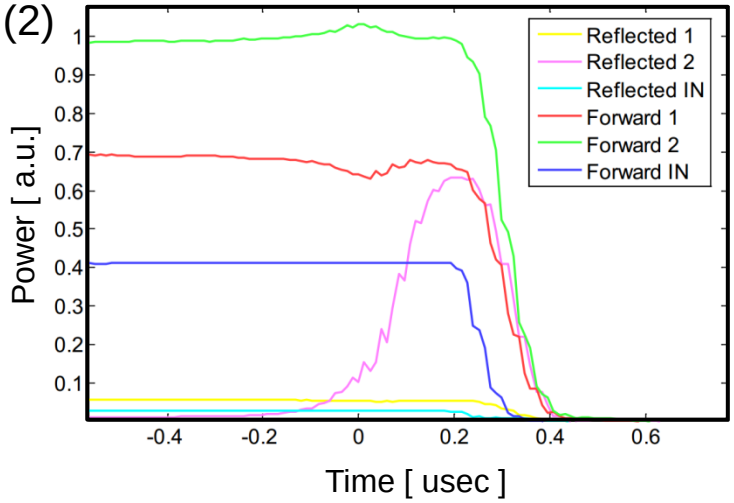

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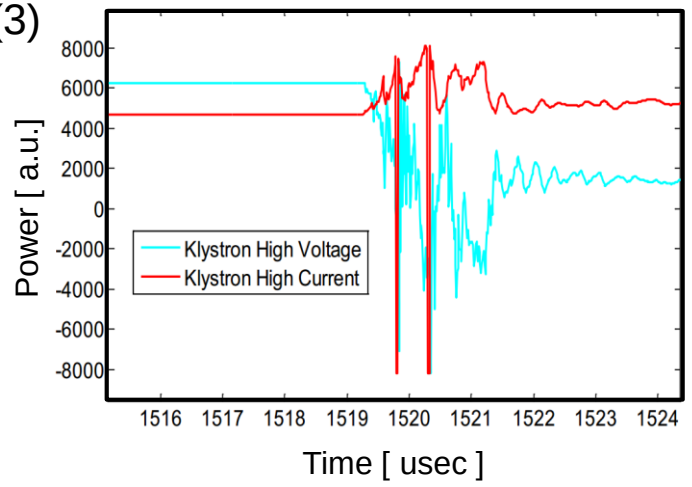
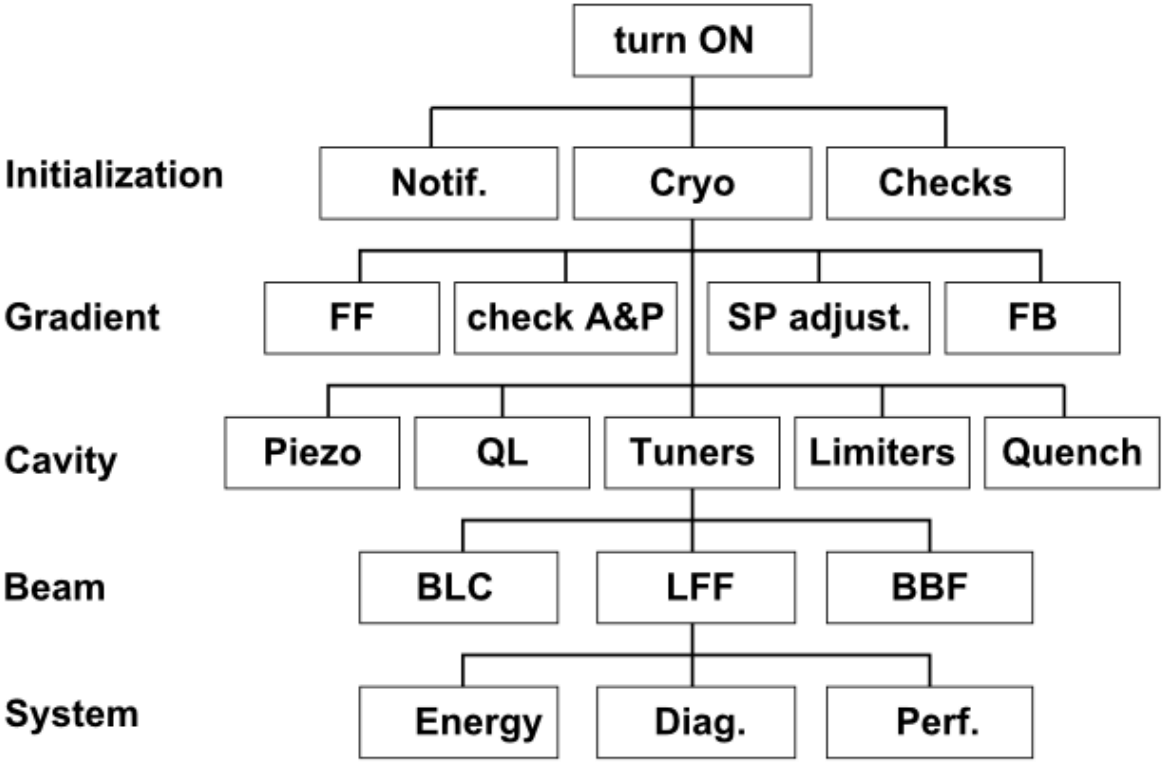


Courtesy: L. Butkowski
“Klystron Measurement and Protection System for XFEL on the MTCA.4 Architecture” ICALPECS 2013, San Francisco, CA, USA

LLRF and Operation (1/2)

- RF station ON/OFF
- Finite State Machine
- Exception handling



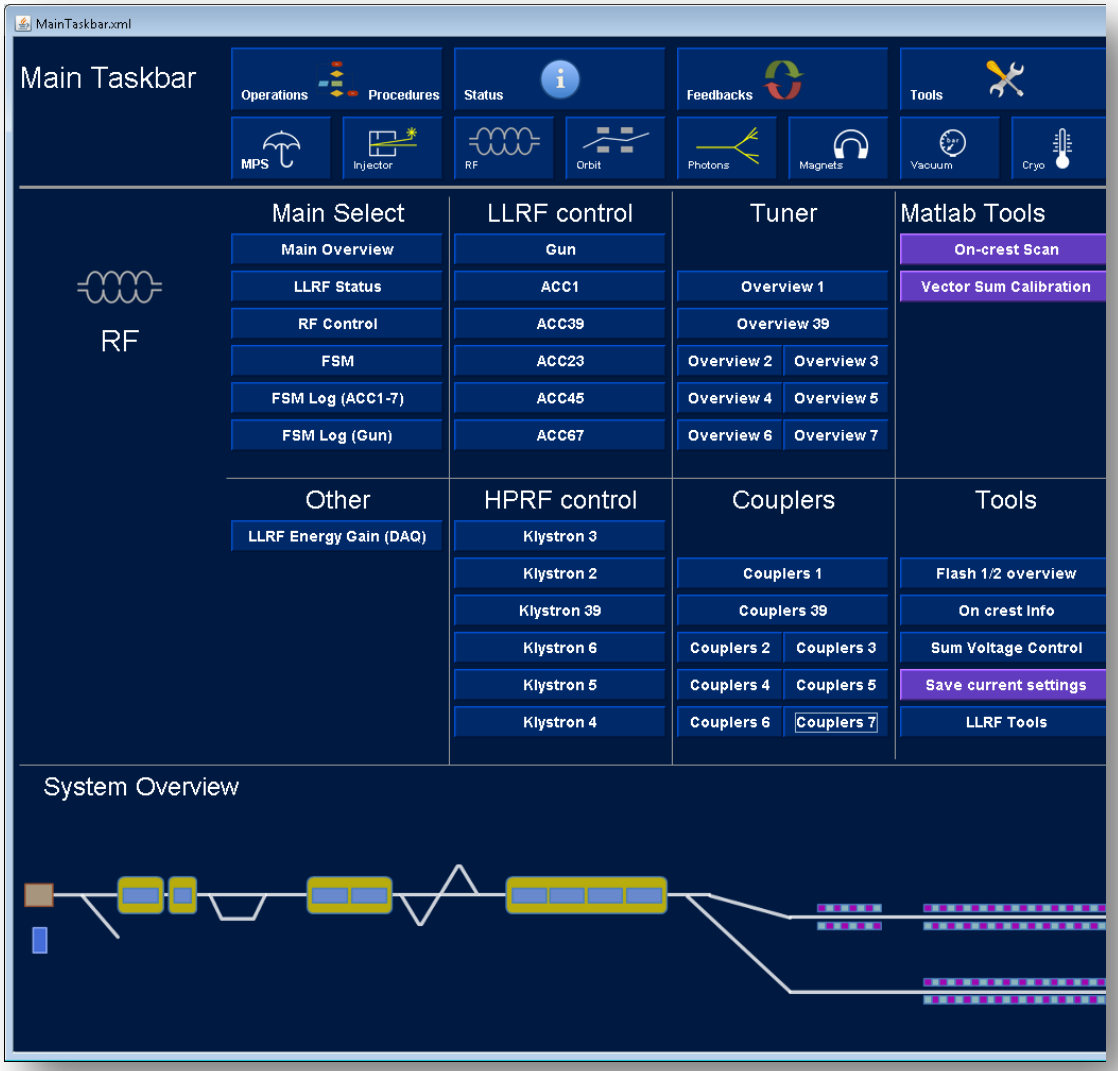
FSM example

LLRF and Operation (2/2)

- RF station ON/OFF
- Finite State Machine
- Exception handling
- Operator interface GUI
- Alerts / warning visibility

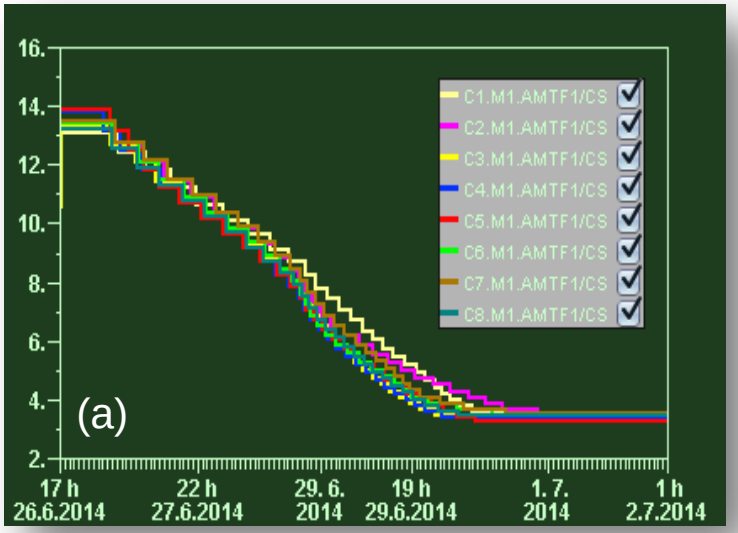
Intuitive GUIs
Layered complexity
Explicit alarms
Panel navigation
Complexity abstraction
Concentration of relevant data
Same data, different representation
…

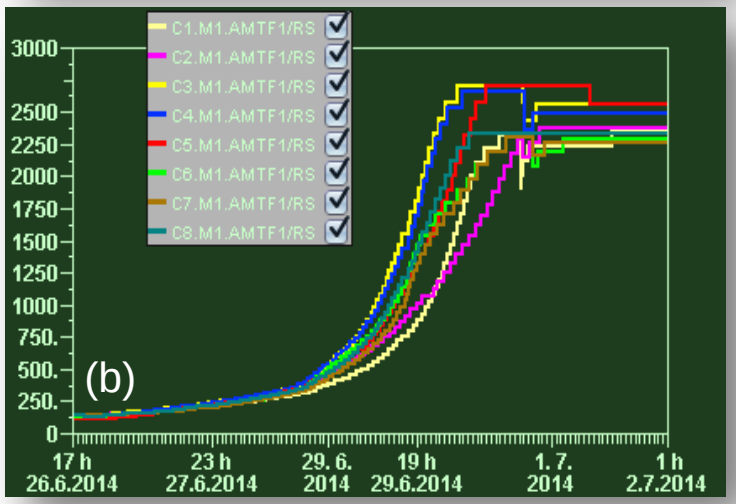
- **Automation**



LLRF and Cavity Resonance Control

- **Tuner motor**
  - Tuning
  - Detuning
  - Cool down / warm up
  - Piezo relaxation
- **Piezo**
  - Microphonics
  - LFD compensation
  - Cavity fine tuning
  - Piezo capacitance measurement
- **Gun**
  - Cooling (water temperature)
  - Flat-top length regulation

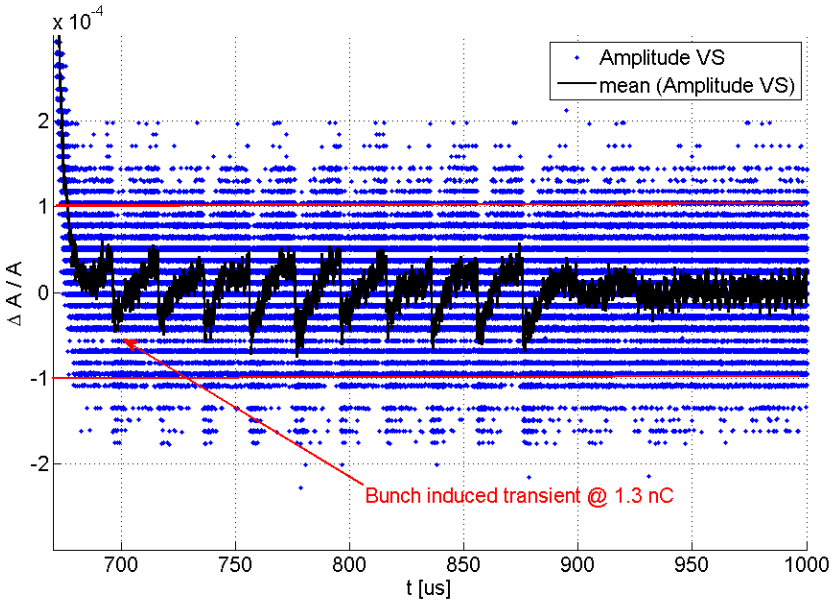




Piezo capacitance (a) and resistance (b) during cool down

LLRF and Beam (1/2)

- BAM, BCM ➔ BBF
- Toroid ➔ BLC
- Beam phase
- Beam transients ➔ channel alignment

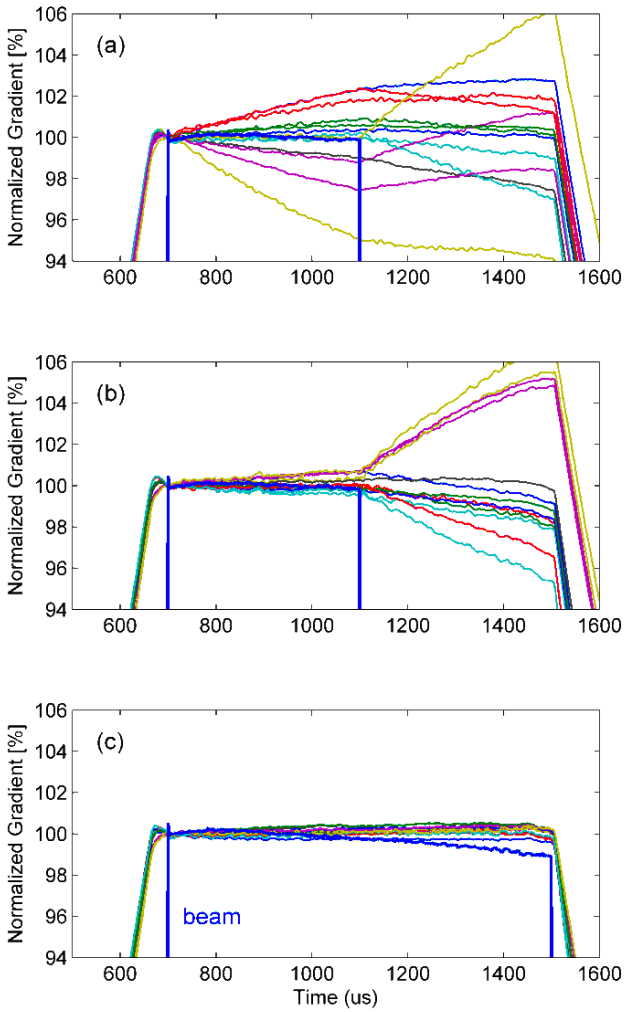


Channel delay alignment using single bunch transients

LLRF and Beam (2/2)

- BAM, BCM ➔ BBF
- Toroid ➔ BLC
- Beam phase
- Beam transients ➔ channel alignment
- Beam profile ➔ TDS, BC
- Beam energy ➔ VS calibration
- Beam loading ➔ Q_L adjustments
- …

Reference: J. Branlard *et al.*
"***LLRF Automation for the 9mA ILC Tests at FLASH***"
LINAC 2012, Tel Aviv, Israel



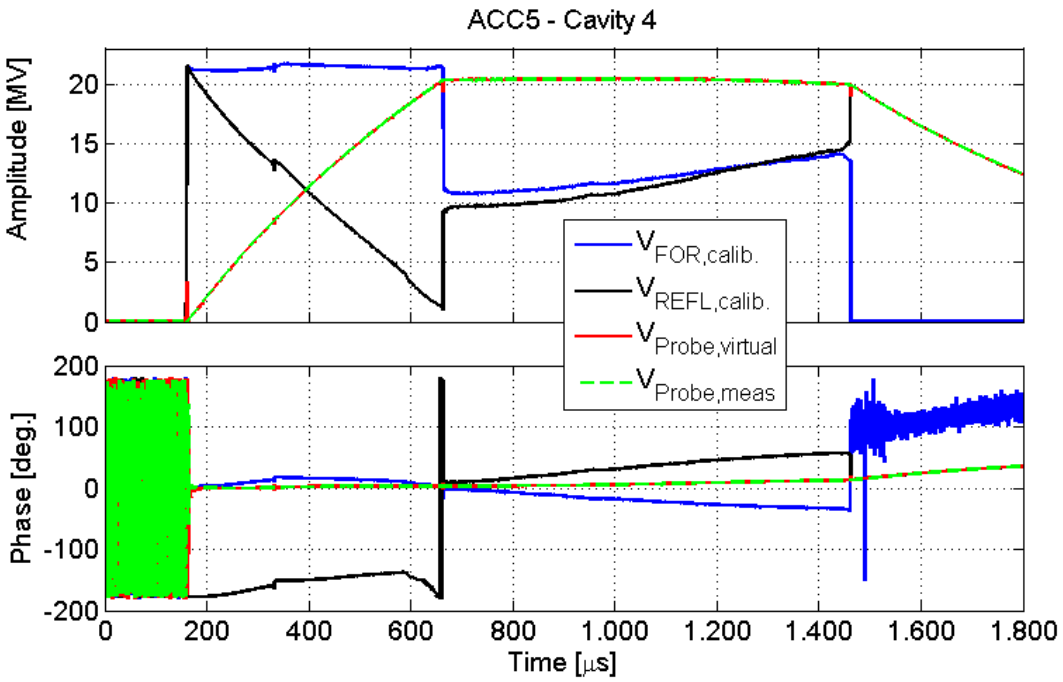
(a) short beam default Q_L

(b) short beam optimized Q_L

(c) full beam optimized Q_L

LLRF and Diagnostics (1/2)

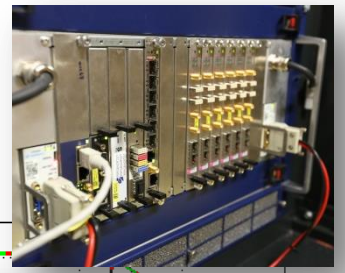
- Beam diagnostics (BPM, BLM, BAM, toroid, etc..)
- LLRF diagnostics
  - Performance (intra- inter-train)
  - Heat load estimation
  - Virtual probe

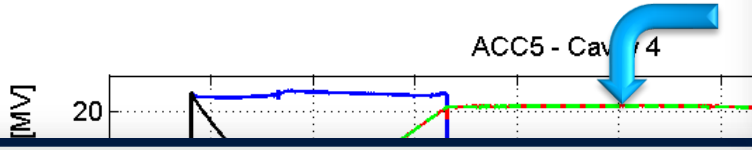


Virtual probe calculation

LLRF and Diagnostics (2/2)

- Beam diagnostics (BPM, BLM, BAM, toroid, etc..)
- LLRF diagnostics
  - Performance (intra- inter-train)
  - Heat load estim
  - Virtual probe
- HOM
- Radiation
- System health
  - Temperature
  - Fan speed
  - Piezo
  - CPU load
  - …



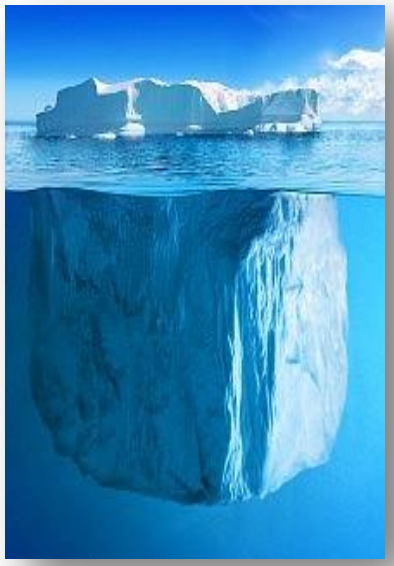


Modules in selected crate: **XFEL.CRATE/XFELMCHLLA2S** | Crate | Fans | Power Modules | Show Graphical

													Serial:
CRATE :	Schroff GmbH	IPMB:0x72 Sensor N:131 Type: Temperature Event: Upper Critical going high										info	0000000000000001
AMC12 :	SIS8300L	Struck Innovative Systeme GmbH				U=	1.5		Temp=	33.0		info	077
AMC11 :	SIS8300L	Struck Innovative Systeme GmbH				U=	1.5		Temp=	33.0		info	077
AMC8 :	SIS8300L	Struck Innovative Systeme GmbH				U=	1.5		Temp=	38.0		info	077
AMC7 :	SIS8300L	Struck Innovative Systeme GmbH				U=	1.5		Temp=	36.0		info	077
AMC10 :	SIS8300L	Struck Innovative Systeme GmbH				U=	1.5		Temp=	35.0		info	077
AMC1 :	AM900/412	Concurrent Technologies				U=	0.8		Temp=	32.0		info	M22816/003
AMC4 :	DAMC-TCK7	DMCS				U=	1.1		Temp=	24.0		info	0004A391D99A
AMC9 :	SIS8300L	Struck Innovative Systeme GmbH				U=	1.5		Temp=	38.0		info	077
COOL_UNIT2 :	Fan speed=	1740	1800	1800	3000		Temp=	27.0		27.0		info	1031400411AA
COOL_UNIT1 :	Fan speed=	1860	1800	1800	3120		Temp=	30.0		29.0		info	1031400412AA
AMC3 :	DAMC2	Deutsches Elektronen-Synchrotron				U=	3.3		Temp=	30.0		info	1065
AMC2 :	X2TIMER	Stockholm University				U=	3.3		Temp=	29.0		info	0040
RTM2 :	RTM_Trg1	Stockholm University										info	004
RTM12 :	RTM-DWC	Struck Innovative Systeme GmbH										info	074
RTM11 :	RTM-DWC	Struck Innovative Systeme GmbH										info	075
RTM10 :	RTM-DWC	Struck Innovative Systeme GmbH										info	076
RTM9 :	RTM-DWC	Struck Innovative Systeme GmbH										info	073
RTM8 :	RTM-DWC	Struck Innovative Systeme GmbH										info	077
RTM7 :	RTM-DWC	Struck Innovative Systeme GmbH										info	072
MCH :	NAT-MCH	v1.3, R130927	current=	2.2		Temp=	30.0	33.0	30.0	30.0		info	104
POWER_UNIT2 :	MTCA Power Sup...									Temp=		info	01886001

LLRF and…

- **Controls**
  - Real time capabilities
  - DAQ
  - Front-end (controls)
  - Middle layer (Diagnostics)
- **Machine Protection**
  - Interlocks (MPS)
  - Cryo OK ?
  - LLRF alarm
- **RF Couplers**
  - QL control (motor / 3 stub tuners)
  - Conditioning
  - Interlocks (e-, light)
  - Heating
- **Personnel Protection**
  - Personnel interlock
  - RF permit
- **Experiments**
  - RF Reference distribution
  - Beam stability (BAM, energy)
- **…**

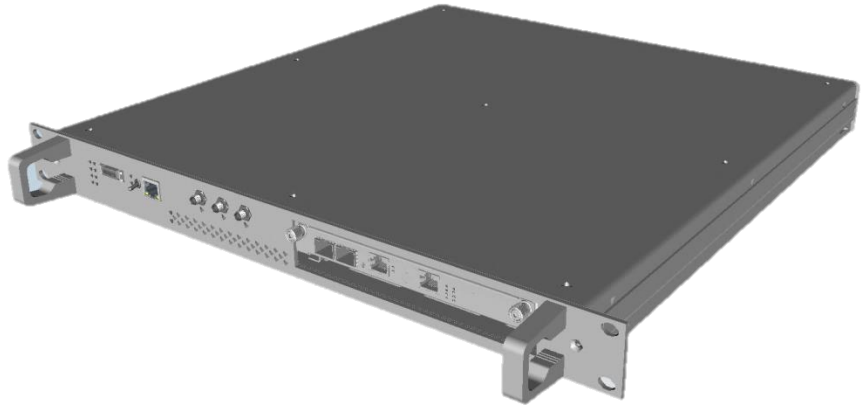


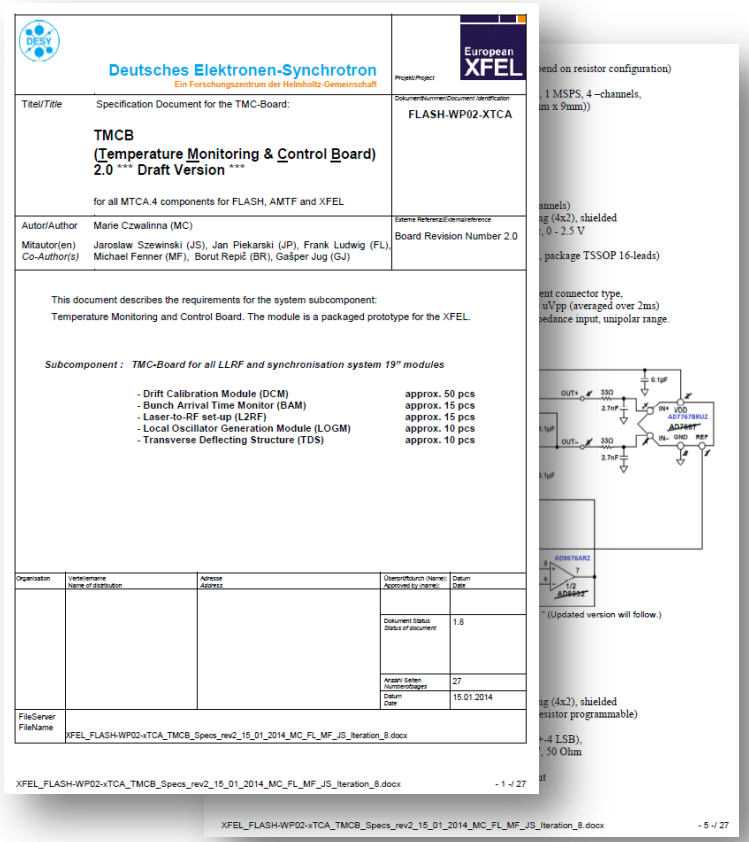
> INTERFACES TO LLRF

> LLRF FOR LARGE SCALE ACCELERATORS

> Mass production

- Specifications
- Call for tender
- Documentation
- 3D models
- Test procedure with firmware
- Non-conformity report
- Etc…





Deutsches Elektronen-Synchrotron
Ein Forschungszentrum der Helmholtz-Gemeinschaft

European XFEL

Titel/Title: Specification Document for the TMC-Board:

TMCB
(Temperature Monitoring & Control Board)
2.0 * Draft Version *****

for all MTCA.4 components for FLASH, AMTF and XFEL

FLASH-WP02-XTCA

Autor/Author: Marie Czwalinna (MC)

Mitautor(en) Co-Author(s): Jaroslaw Szewinski (JS), Jan Piekarski (JP), Frank Ludwig (FL), Michael Fenner (MF), Borut Repič (BR), Gašper Jug (GJ)

Externe Referenz/External reference: Board Revision Number 2.0

This document describes the requirements for the system subcomponent:
Temperature Monitoring and Control Board. The module is a packaged prototype for the XFEL.

Subcomponent : TMC-Board for all LLRF and synchronisation system 19" modules

- Drift Calibration Module (DCM)	approx. 50 pcs
- Bunch Arrival Time Monitor (BAM)	approx. 15 pcs
- Laser-to-RF set-up (L2RF)	approx. 15 pcs
- Local Oscillator Generation Module (LOGM)	approx. 10 pcs
- Transverse Deflecting Structure (TDS)	approx. 10 pcs

Organisation | Verteilername / Name of distribution | Adresse / Address | Überprüfdurch (Name) / Approved by (name): | Datum / Date

Dokument Status / Status of document: 1.8

Anzahl Seiten / Numberofpages: 27

Datum / Date: 15.01.2014

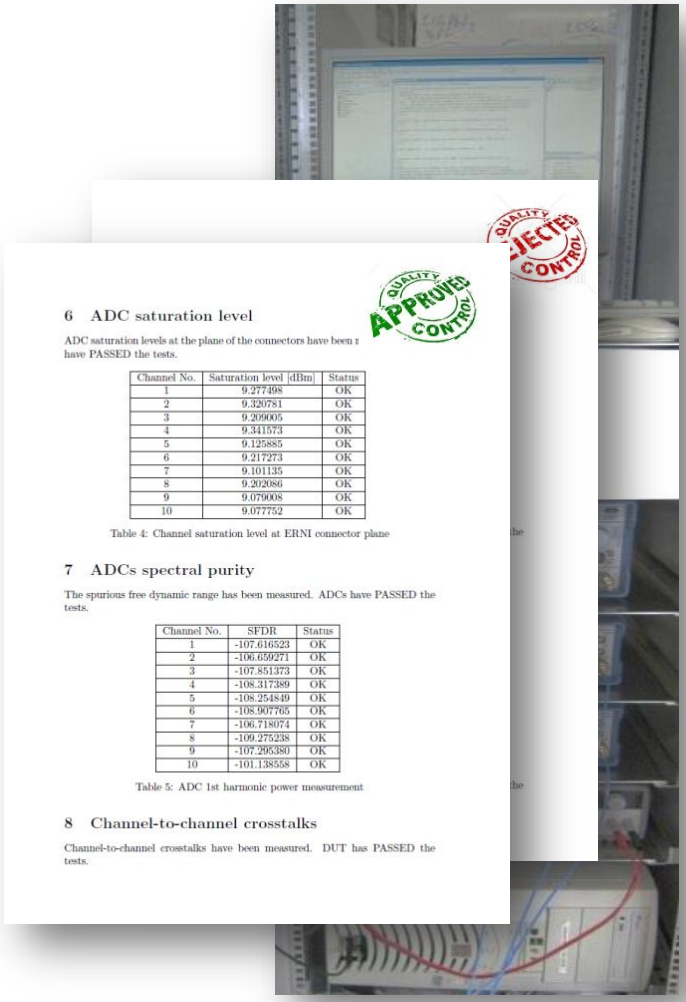
FileServer FileName: XFEL_FLASH-WP02-xTCA_TMCB_Specs_rev2_15_01_2014_MC_FL_MF_JS_Iteration_8.docx

XFEL_FLASH-WP02-xTCA_TMCB_Specs_rev2_15_01_2014_MC_FL_MF_JS_Iteration_8.docx - 1 -/ 27

XFEL_FLASH-WP02-xTCA_TMCB_Specs_rev2_15_01_2014_MC_FL_MF_JS_Iteration_8.docx - 5 -/ 27

> Quality Control

Test Stands



6 ADC saturation level

ADC saturation levels at the plane of the connectors have been r
have PASSED the tests.

Channel No.	Saturation level [dBm]	Status
1	9.277498	OK
2	9.320781	OK
3	9.209005	OK
4	9.341573	OK
5	9.125885	OK
6	9.217273	OK
7	9.101135	OK
8	9.202086	OK
9	9.079008	OK
10	9.077752	OK

Table 4: Channel saturation level at ERNI connector plane

7 ADCs spectral purity

The spurious free dynamic range has been measured. ADCs have PASSED the tests.

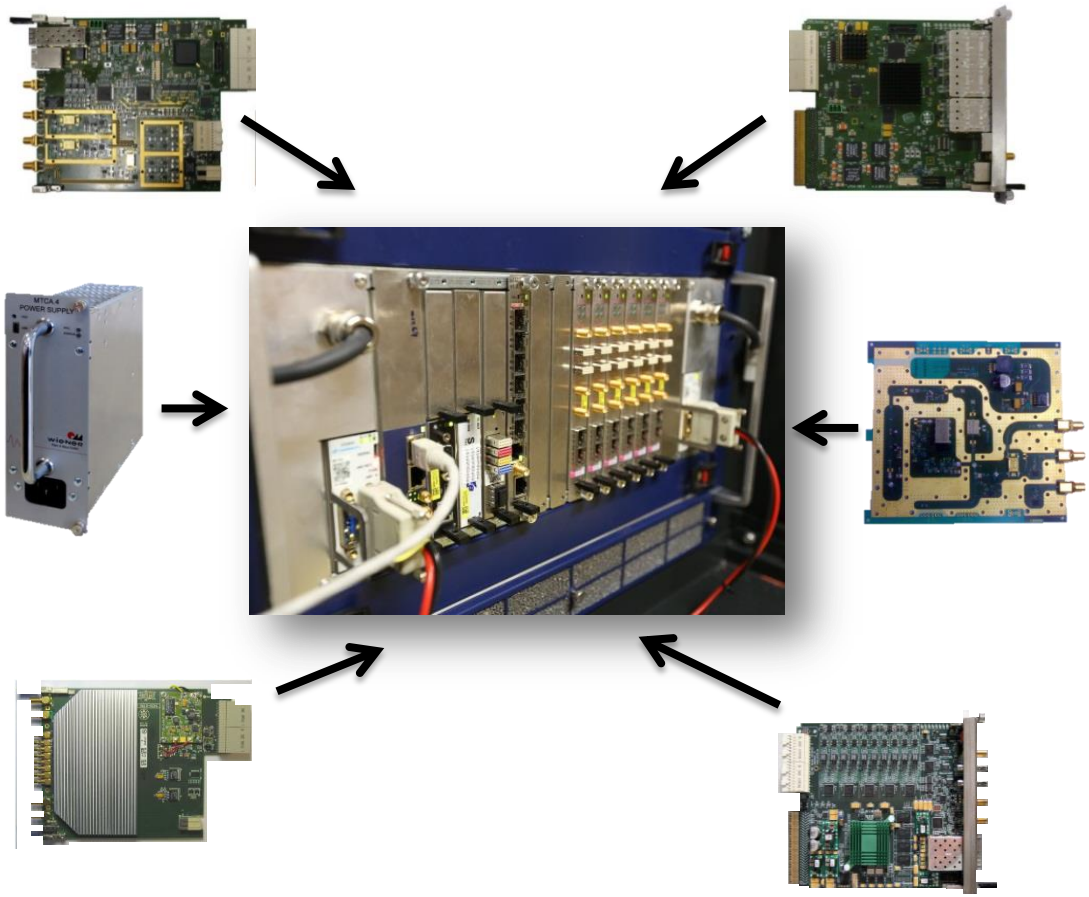
Channel No.	SFDR	Status
1	-107.616523	OK
2	-106.659271	OK
3	-107.851373	OK
4	-108.317389	OK
5	-108.254849	OK
6	-108.907765	OK
7	-106.718074	OK
8	-109.275238	OK
9	-107.295380	OK
10	-101.138558	OK

Table 5: ADC 1st harmonic power measurement

8 Channel-to-channel crosstalks

Channel-to-channel crosstalks have been measured. DUT has PASSED the tests.

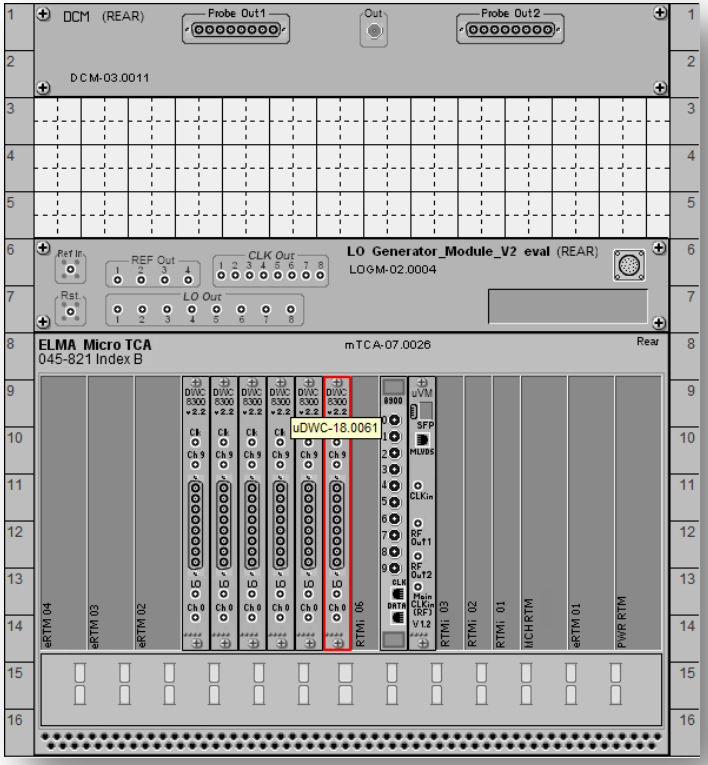
System Integration



> Installation

- Procedure
- Check list
- Labelling
- Device tracking

LOGM-02.0003



WP02 - LLRF

Deutsches Elektronen-Synchrotron
Ein Forschungszentrum der Helmholtz-Gemeinschaft

Title: WP02 LLRF MTCA crate installation check list

Destination	☐ INJ ☐ L1 ☐ L2 ☐ L3	RF station #		☐ MASTER ☐ SLAVE	
CPU name					
MCH name					

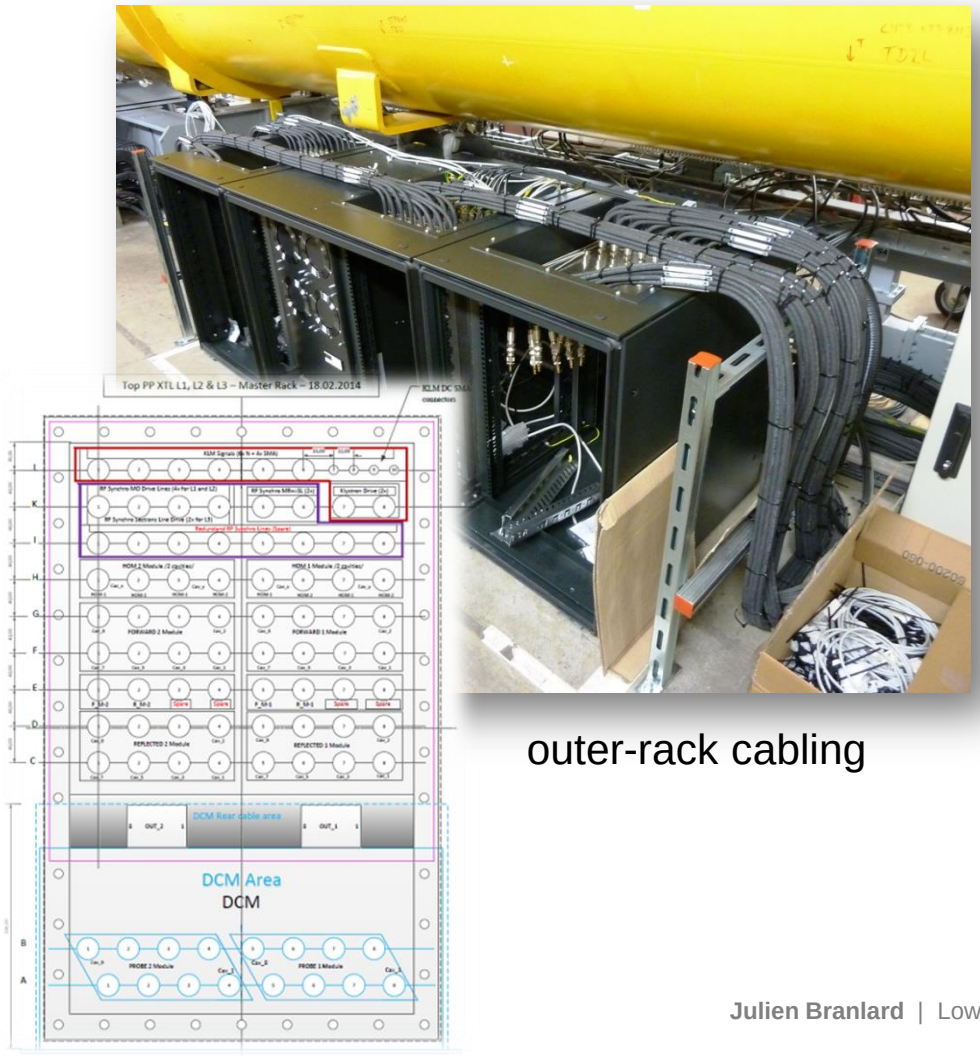
	KDS number	Model
MTCA crate		☐ ELMA ☐ SCHROFF ☐ RFB

Slot	AMC	KDS #	Version	RTM	KDS #	Version
-1	uPM					
0	MCH					
1	CPU					
2	TMG					
3						
4	uTC			uVM		
5						
6						
7	uADC			uDWC		
8	uADC			uDWC		
9	uADC			uDWC		
10	uADC			uDWC		
11	uADC			uDWC		
12	uADC			uDWC		
13	uPM			uDWC		
14						
15						

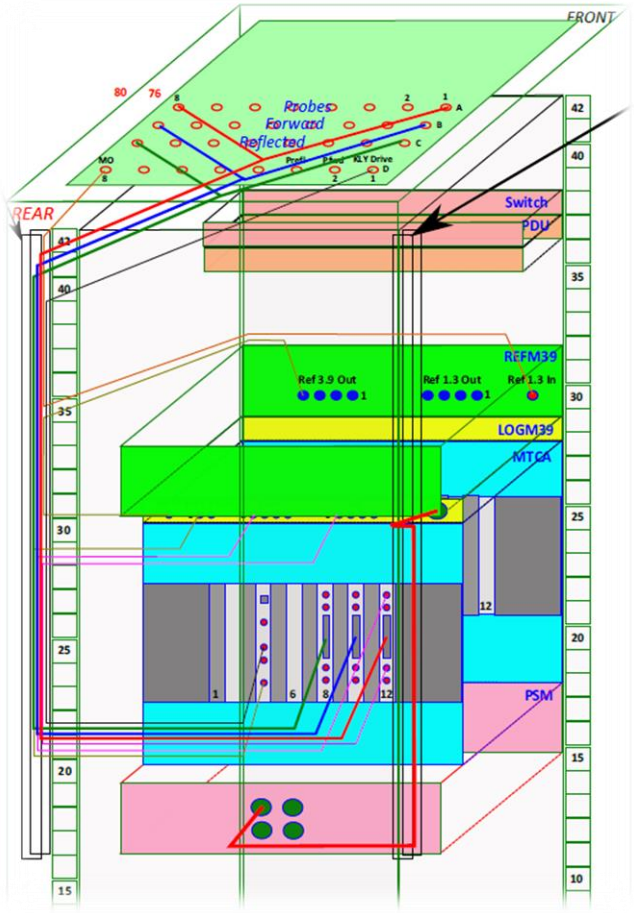
Notes:

XFEL LLRF system installation procedure.docx Page 10

> Large channel integration



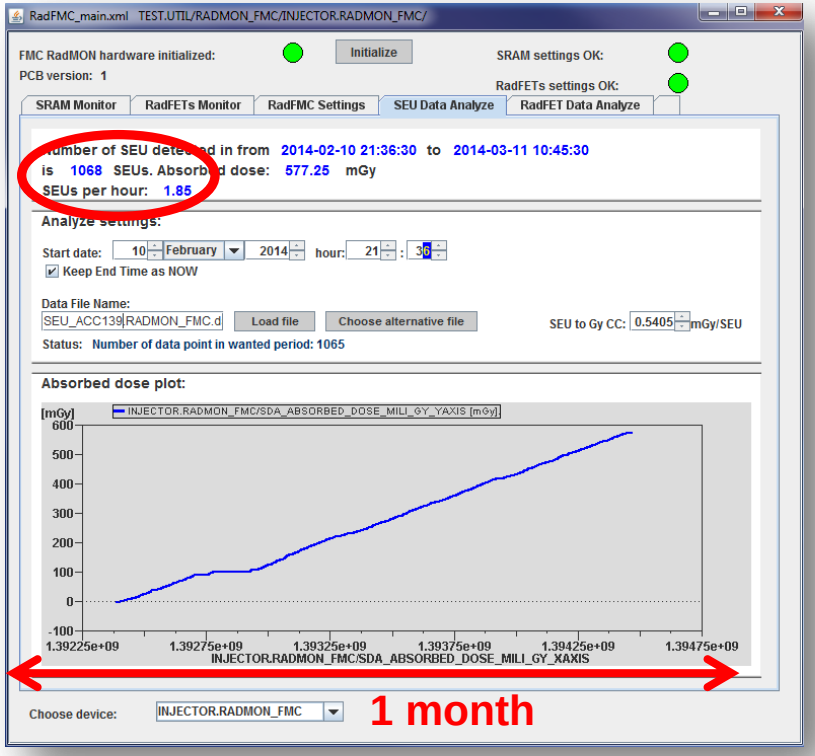
outer-rack cabling



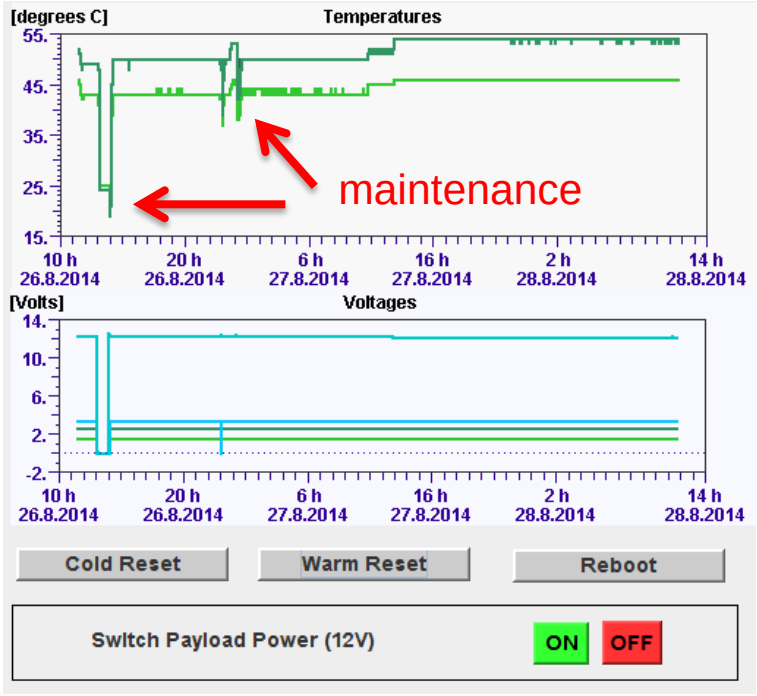
inner-rack cabling

> Remote “everything”

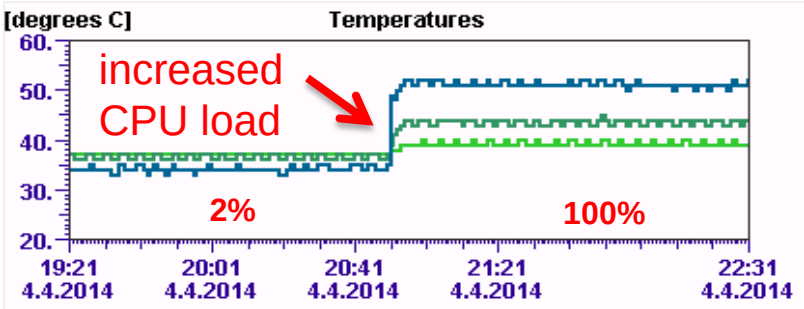
- System health **monitoring**
- System **upgrades** (FW / SW)
- **Management** (on / off / swap)



Radiation monitoring in tunnel

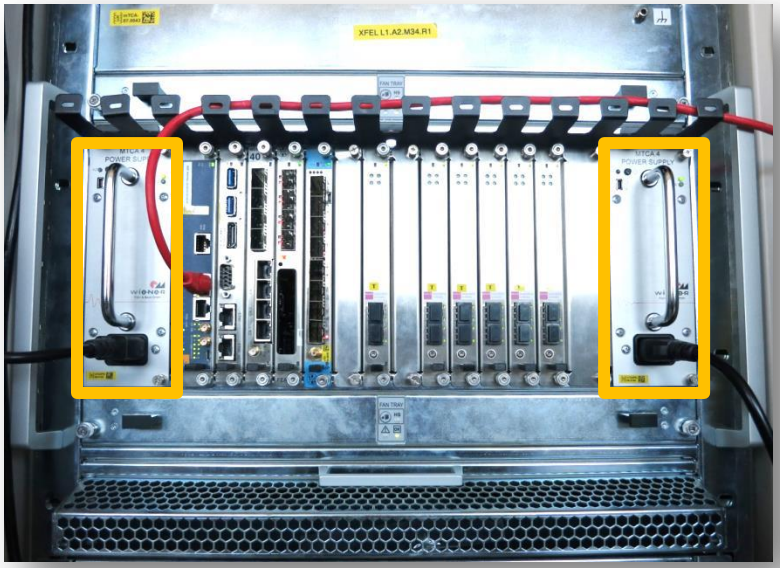


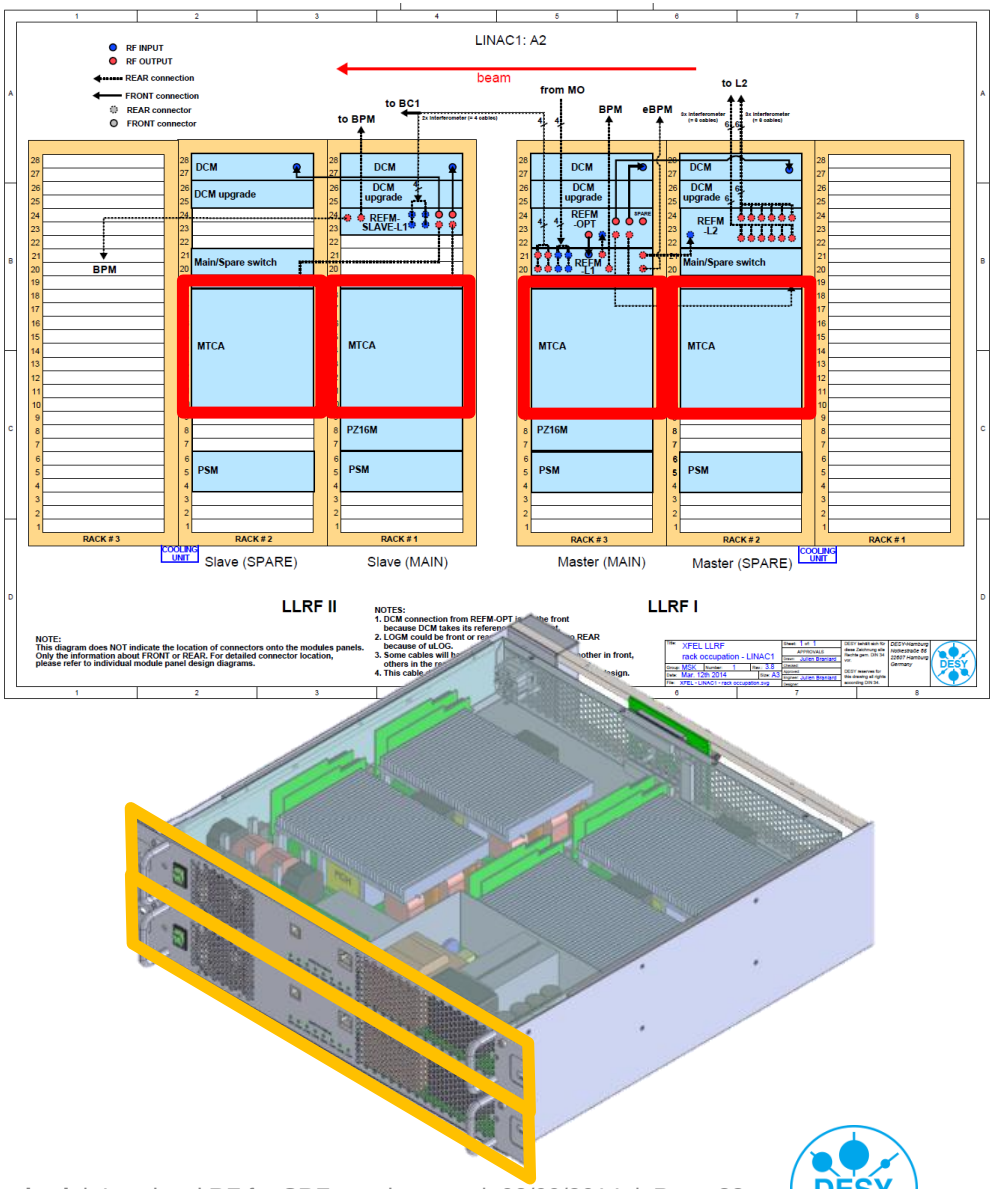
Temperature monitoring



LLRF FOR LARGE SCALE ACCELERATORS

- **Remote “everything”**
  - System health **monitoring**
  - System **upgrades** (FW / SW)
  - **Management** (on / off / swap)
- **Redundancy**





> Automation

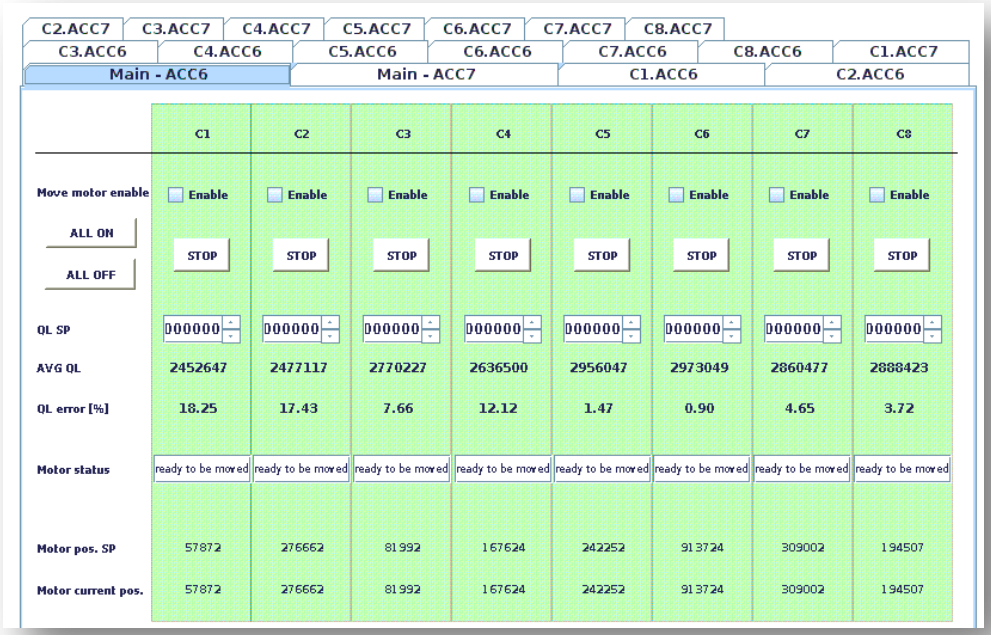
- For operation
- For machine protection

Frequency tuning / detuning
Bandwidth control
Diagnostics
Quench
Startup/shutdown
Calibration
Performance
…

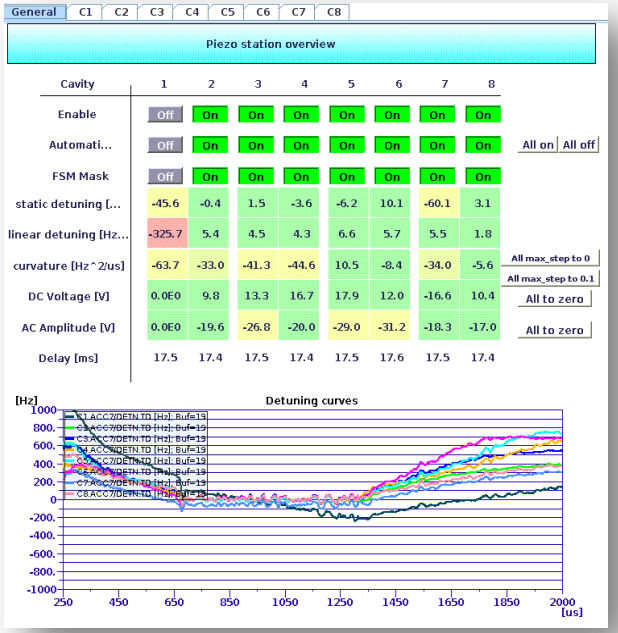
Exception Handling

Automation Priorities

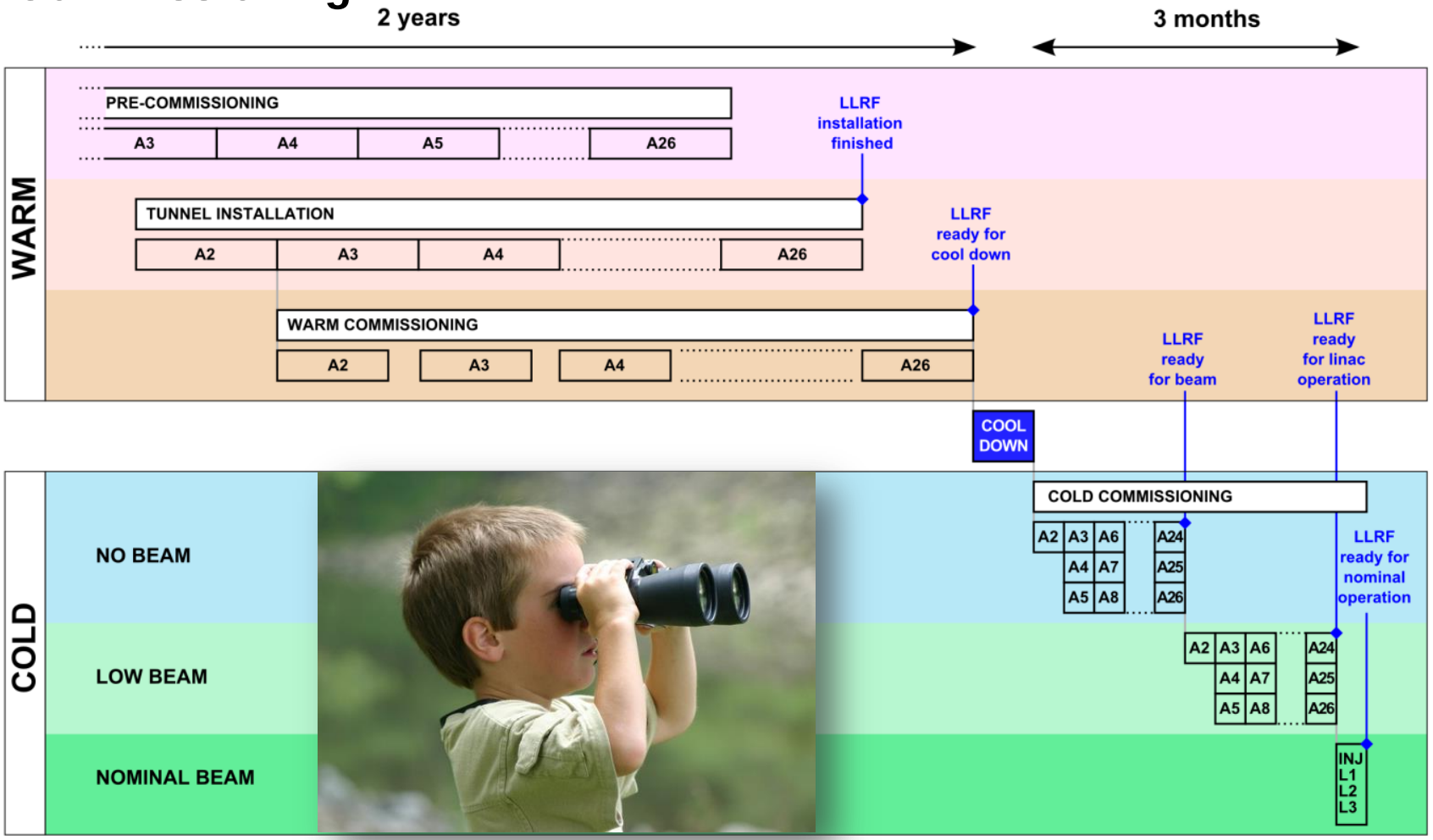
Cavity bandwidth control



Cavity resonance control



> Commissioning



QUESTIONS?

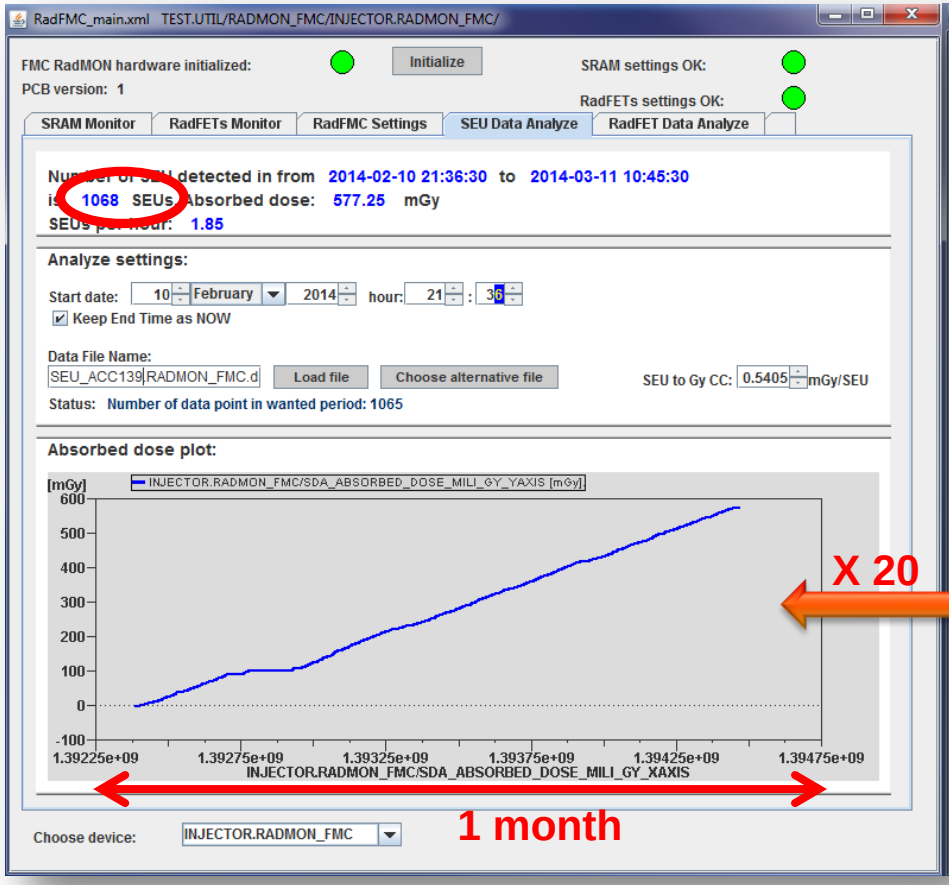
Photo courtesy: D. Noelle, DESY

BACK UP SLIDES

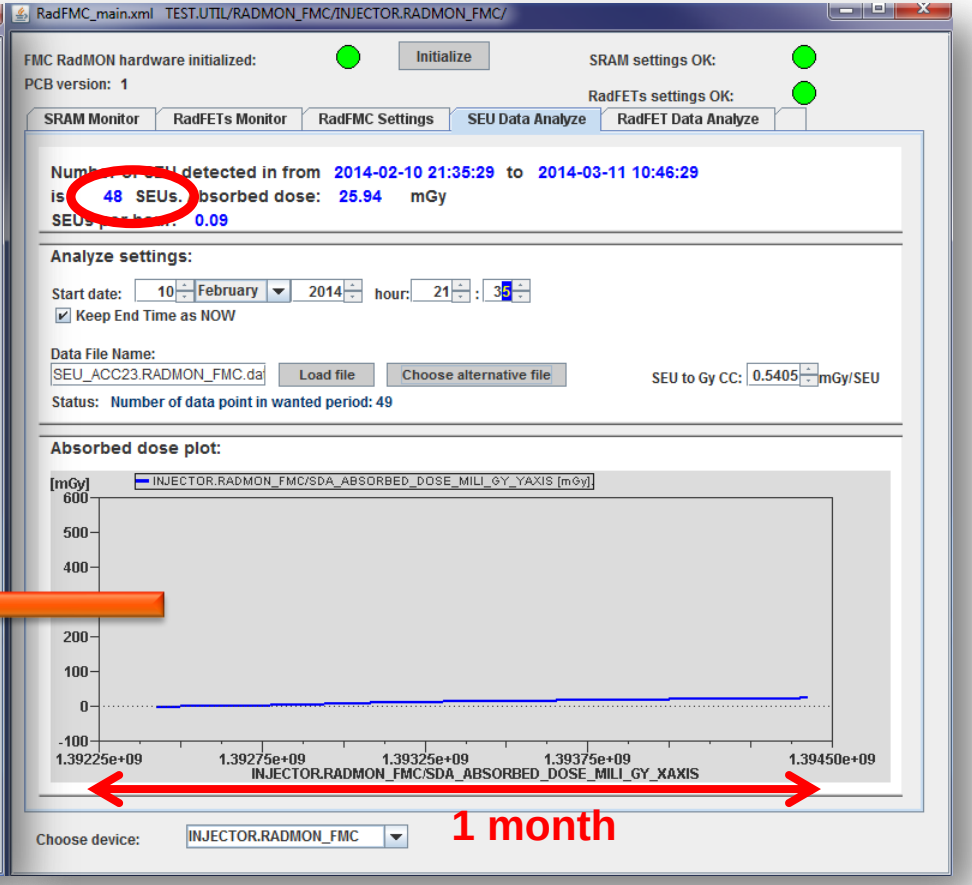
RADIATION MEASUREMENTS : first results at FLASH

- Counting Single Event Upsets (SEU) on SRAM

ACC1 / 39



ACC23



X 20

1 month

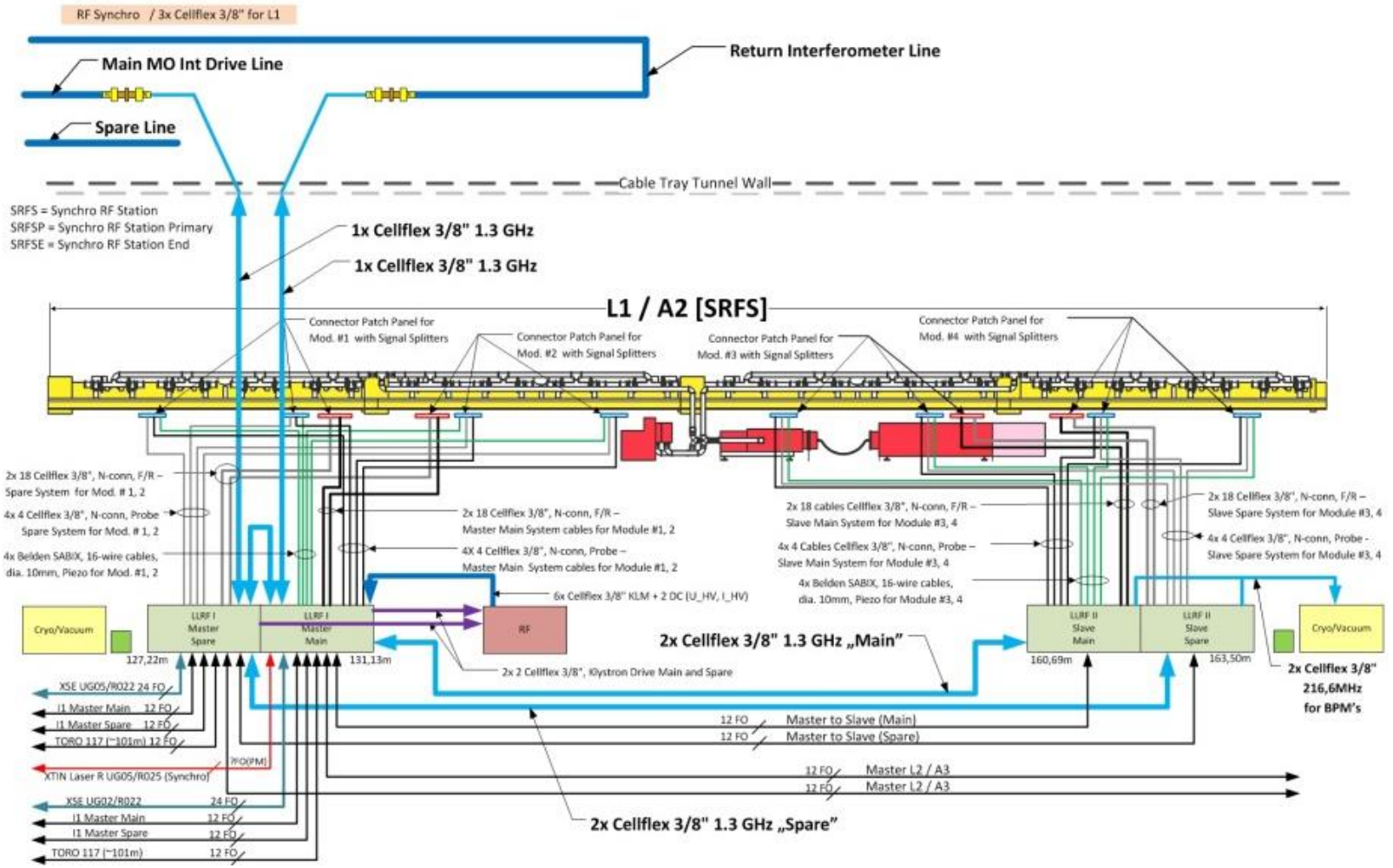
1 month

1.85 SEU / hour

0.09 SEU / hour

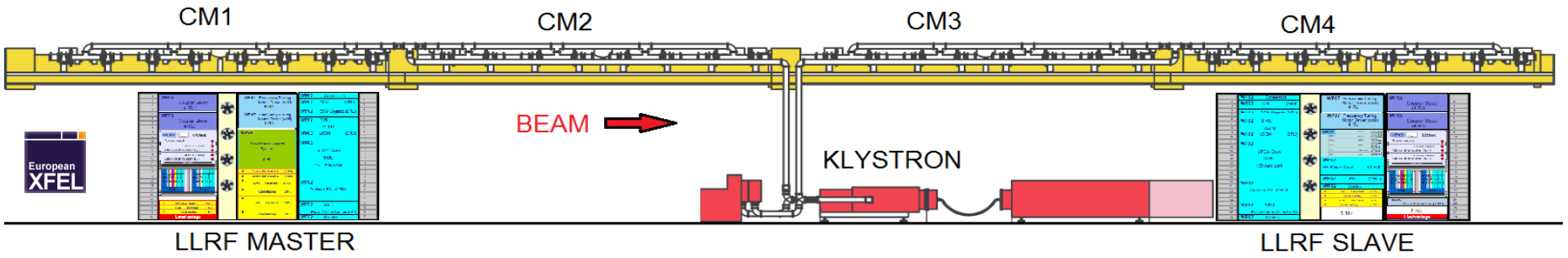
Courtesy T. Kozak

- Large channel count

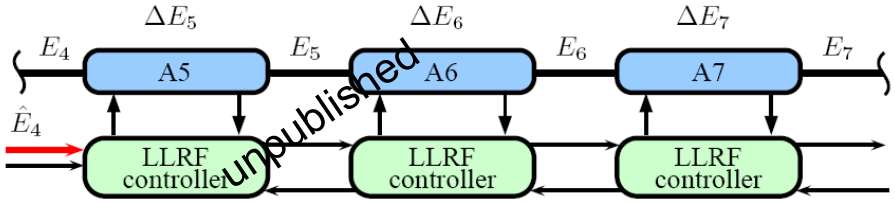


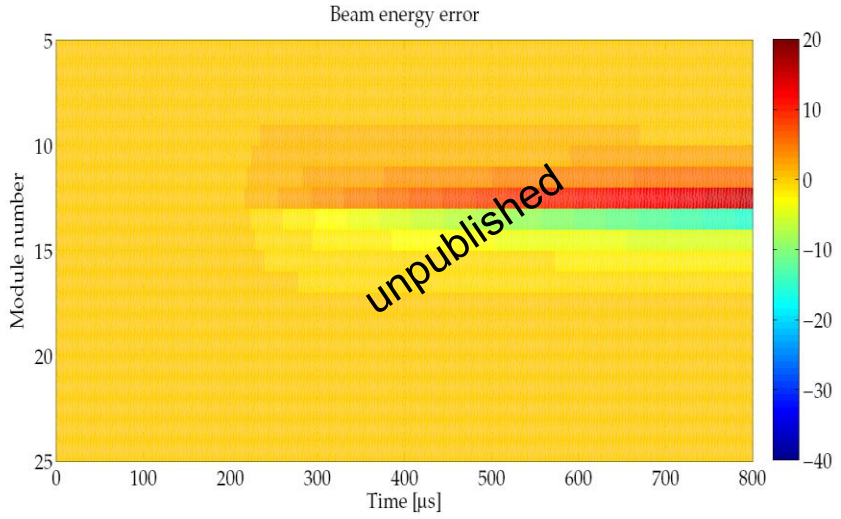
HIGH LEVEL SERVERS (example)

> INTRA-STATION communication



> INTER-STATION communication





Courtesy S. Pfeiffer