

IFMIF-LIPAc LLRF control system development based on EPICS

Julio Calvo

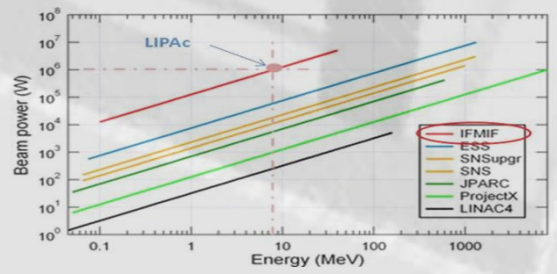
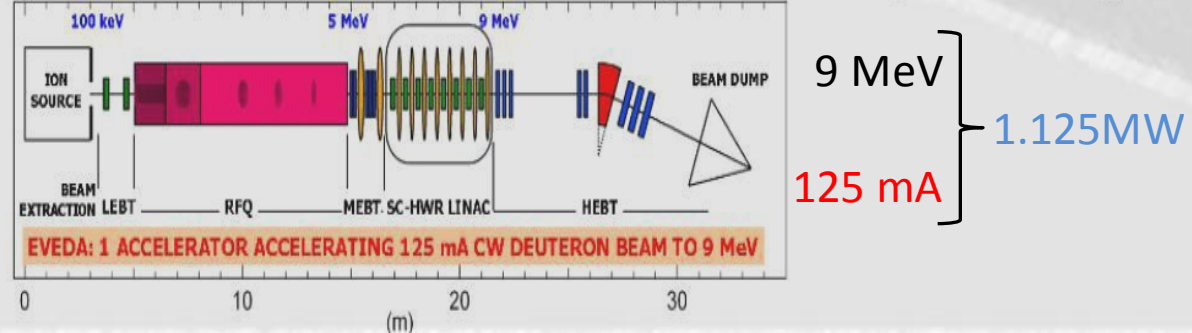
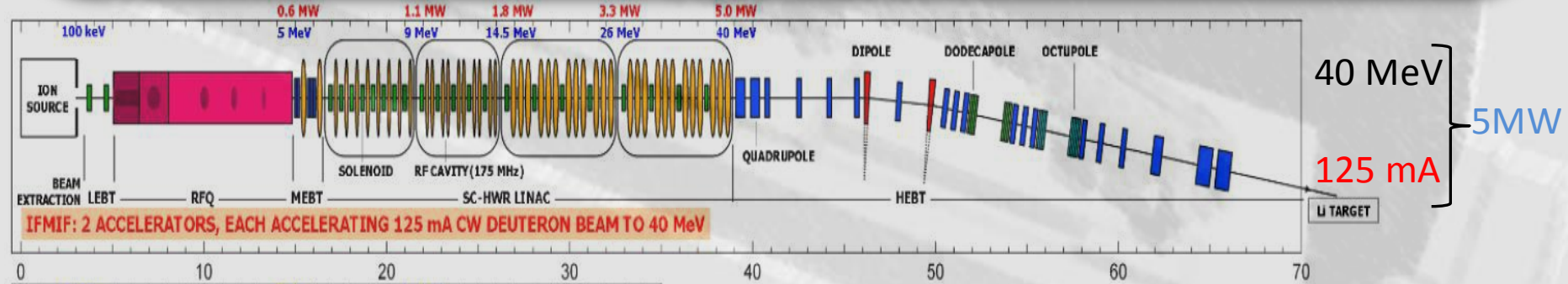
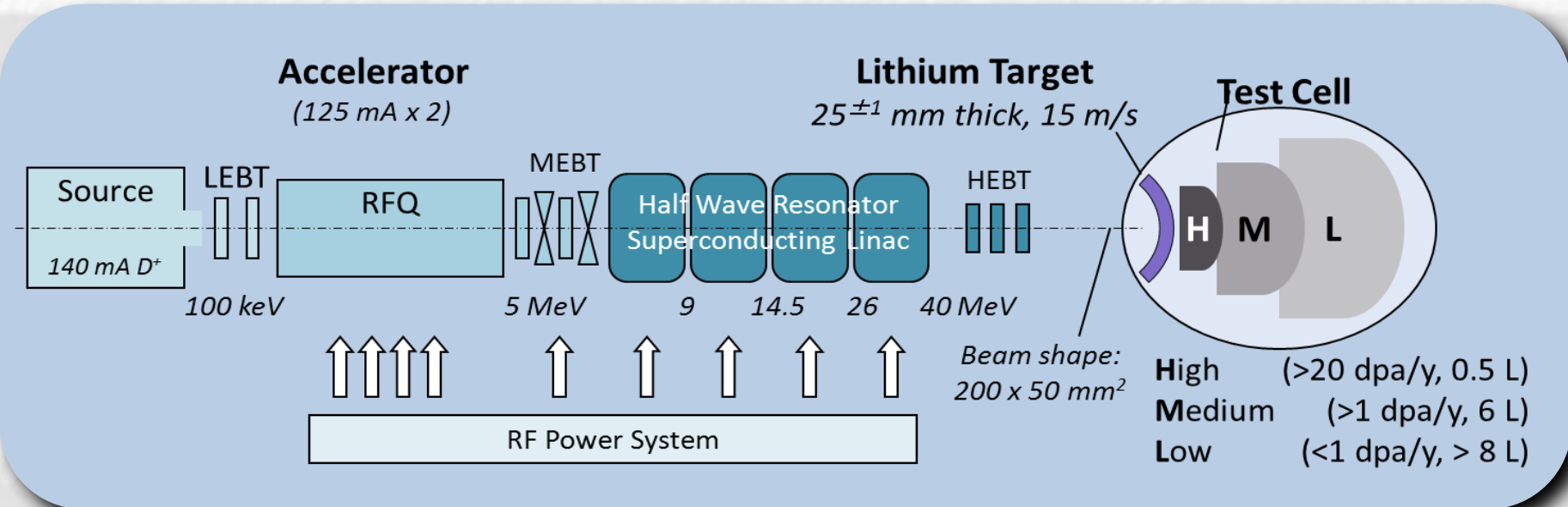
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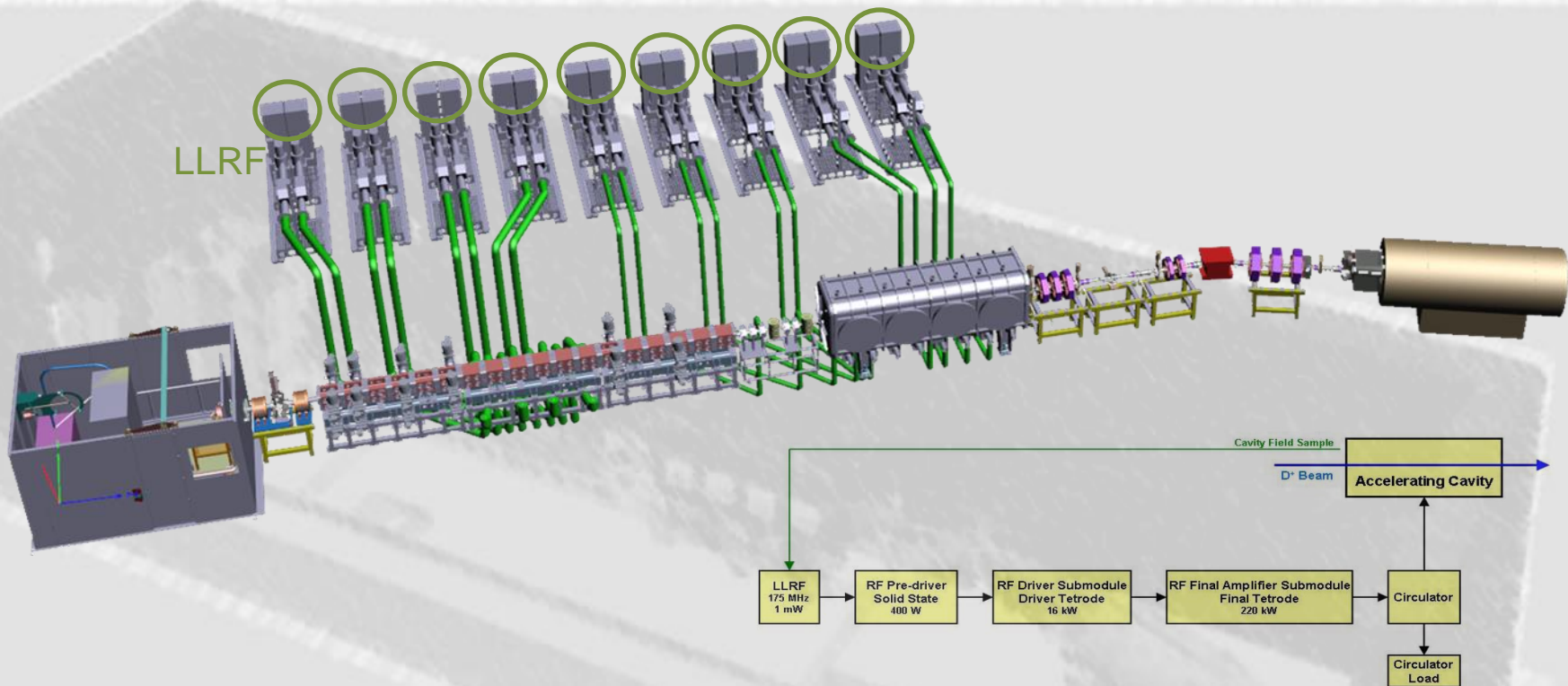
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Motivation





Low Level Radio Frequency (LLRF) Control System

LLRF control system

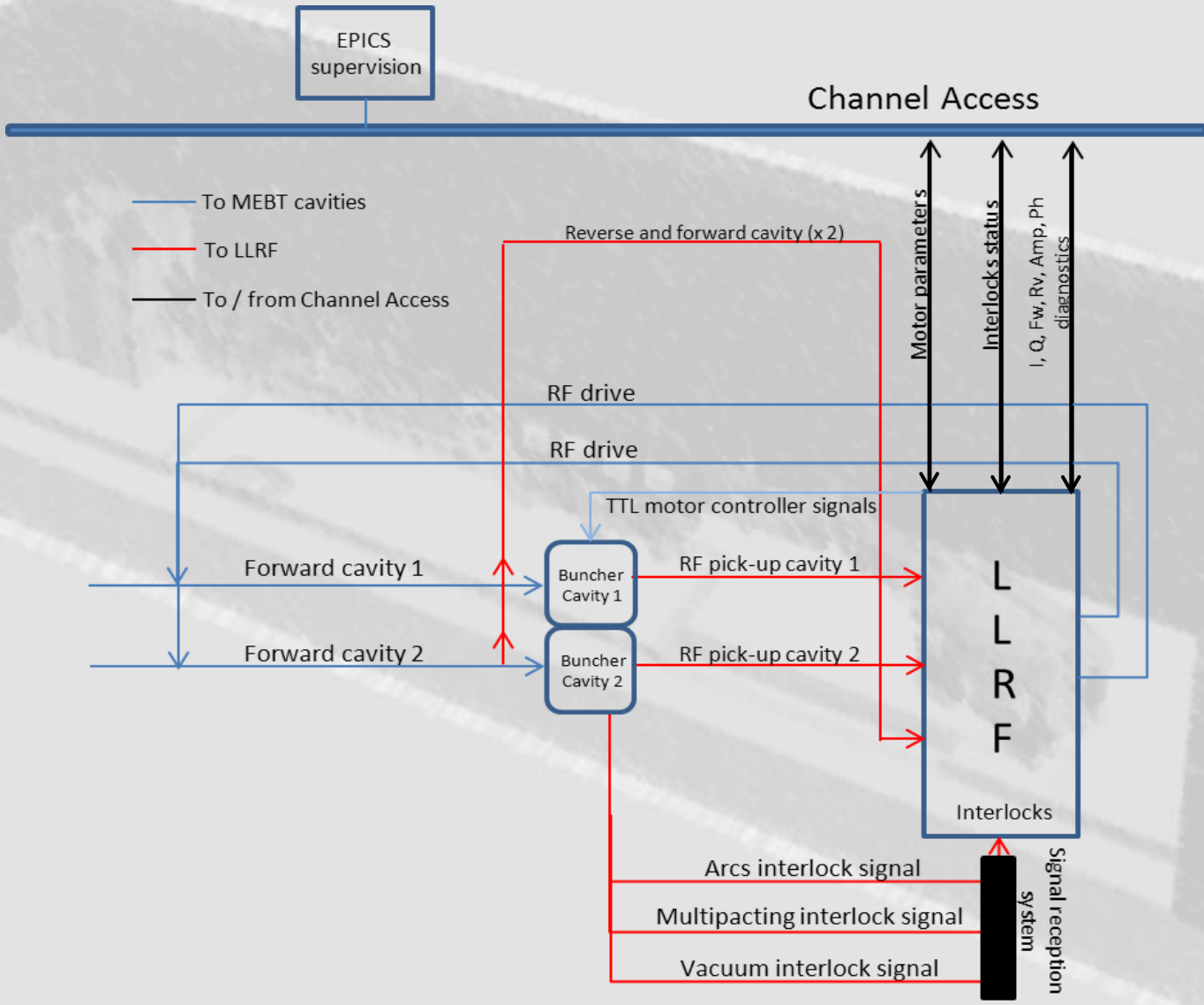
LIPAc LLRF system generates RF power to feed LIPAc cavities. It handles different functionalities for 18 three-stages amplifying chains:

- Amplitude and phase loop
- Cavities tuning
- Start-up

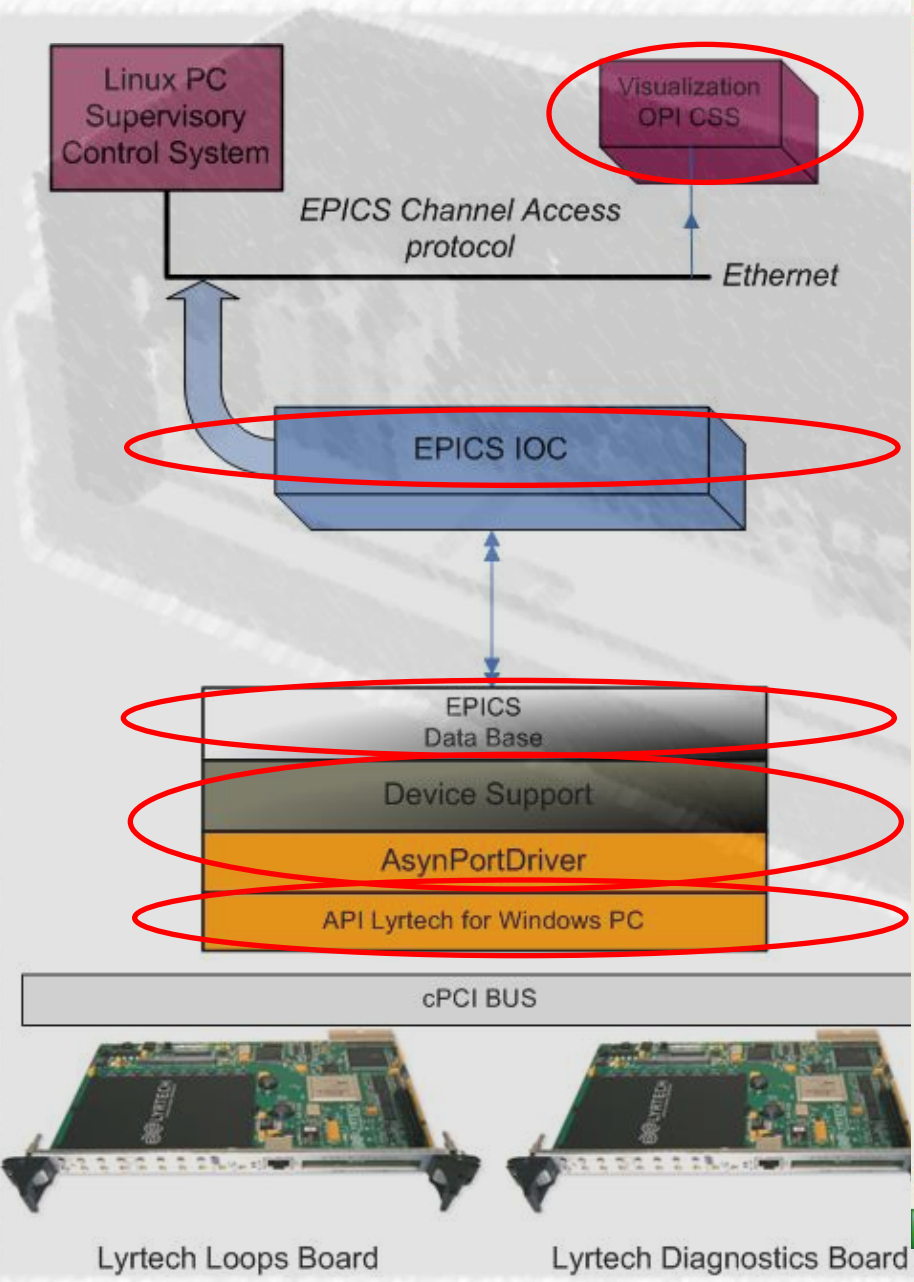
Main control problems encountered:

- More relevant part of the accelerator at control system software level
- Hundreds of signals to control
- Real time decisions bypassing CCS and operator
- Extra functionalities are needed

LLRF control system interfacing with MEBT



LLRF control system – software



The screenshot shows the **CS-Studio** software interface. The top menu includes **File**, **Edit**, **Search**, **CSS**, **Window**, and **Help**. The main window displays the **LLRF Expert GUI** with various control buttons like **Start**, **Stop**, **Load Parameters**, **Send Parameters**, **Save Parameters**, **Read Parameters**, and **Refresh Parameters**. There are also status indicators for **Loops FPGA Clock**, **External Front in Loops**, **VCXO Program**, **OVR Loops**, **Diag FPGA Clock**, **External Front in Diag**, **NO reference signal**, and **OVR Diag**. A large red text overlay reads **806 PVs**. A blue text box contains the following record definition:

```
record(ai ,(P)(R)CAVA :IrvCircRdbk)
field(DTYP, asynFloat64)
field(INP,@asyn$(PORT), $(ADDR)irwcirc))
field(HIHI, "1000")
field(HHSV, "MAJOR")
field(HIGH, "900")
field(HSV, "MINOR")
field(PREC, 2)
field(SCAN, I /O Intr")
```

The bottom of the screenshot shows the Windows taskbar with the **Inicio** button and several open applications. The system tray shows the time as **13:21**. At the very bottom, there is a status bar with the text **RP: LLRF_CAVA: I Ref Rdbk** and **RP: LLRF_CAVA: I Uo IRdbk**.

LLRF control system – Amplitude and phase closed loop

LYRTECH MENU: Load Parameters, Send Parameters, Save Parameters, Read Param..., Refresh Parame...

Start Stopped | Loops FPGA Clock: External | ExternalFront in Loops: LOCKED | VCO Program | Amplitude in control action readback in closed loop mode

Stop Running | Diag FPGA Clock: External | ExternalFront in Diagn: LOCKED | VCO Locked

Program Loops: FPGA Version Loops: 2.013.112.101 | Program Diag...: FPGA Version Diag: 2.013.092.920

Block Parameters: Off

Main Parameters: Write Zero to Main

Main Diagnostics

| AmpPhase | I | Q | Amp | dBm | Ph |
|----------------|--------|-------|--------|--------|--------|
| Cavity Ref | 80,11 | 0,00 | 80,11 | -21,93 | 0,00 |
| Cavity Volt | 79,84 | 0,21 | 79,84 | -17,98 | 0,15 |
| Error (Prop) | -0,09 | -0,21 | 1,29 | | 246,80 |
| Error (Acc) | 107,49 | 1,68 | 17,50 | | 0,89 |
| Control Action | 107,49 | 1,68 | 107,50 | -19,38 | 0,89 |

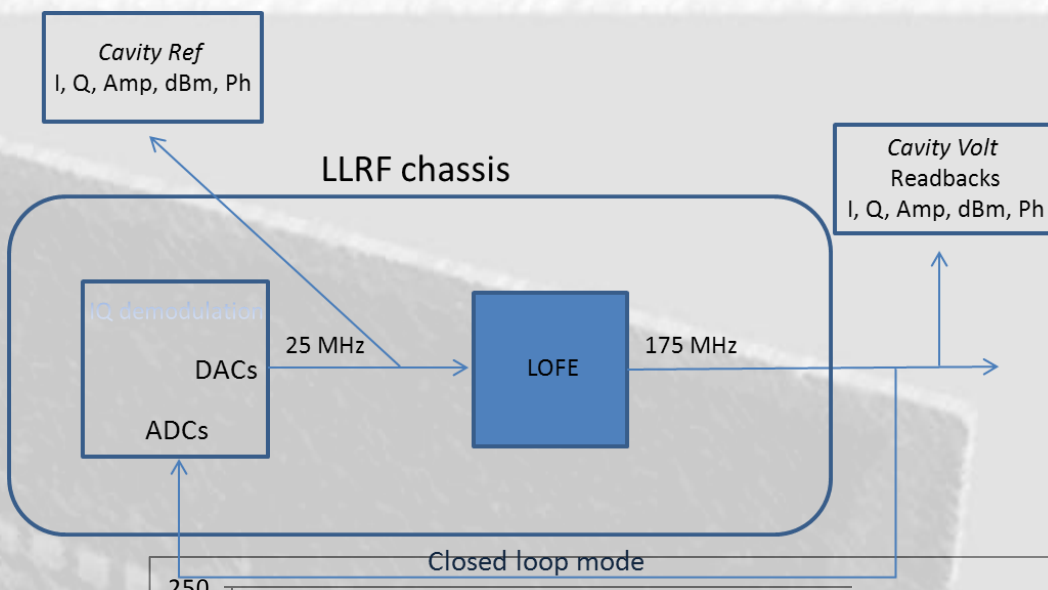
Amplitude signal readback at the input of the LOFE

Amplitude signal readback at the output of the LOFE

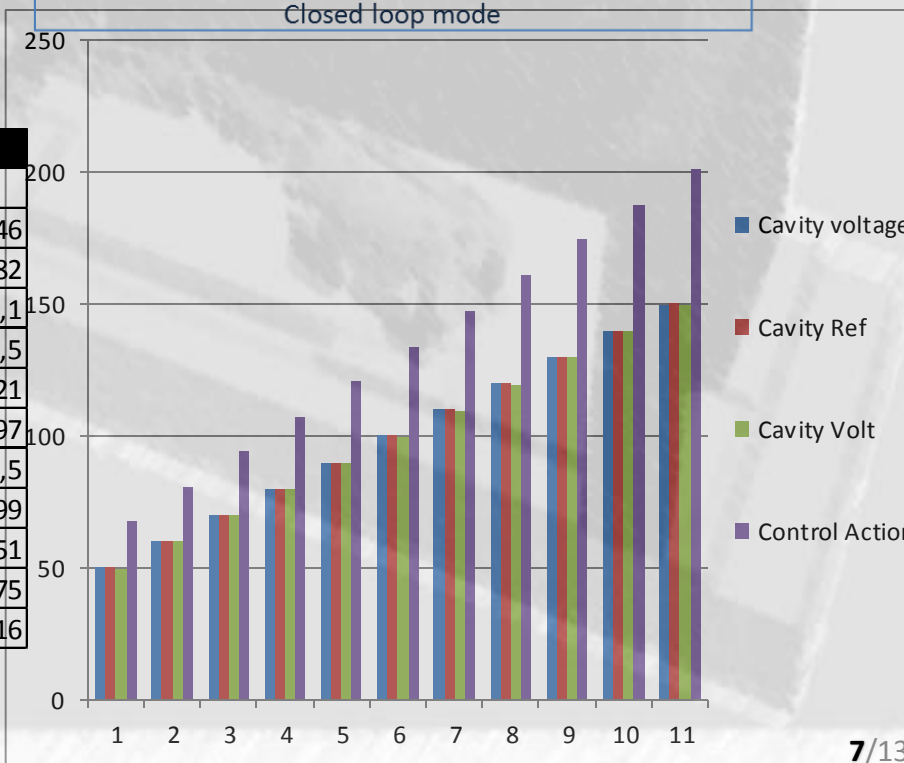
RF Chain A: Amp, dBm, Ph

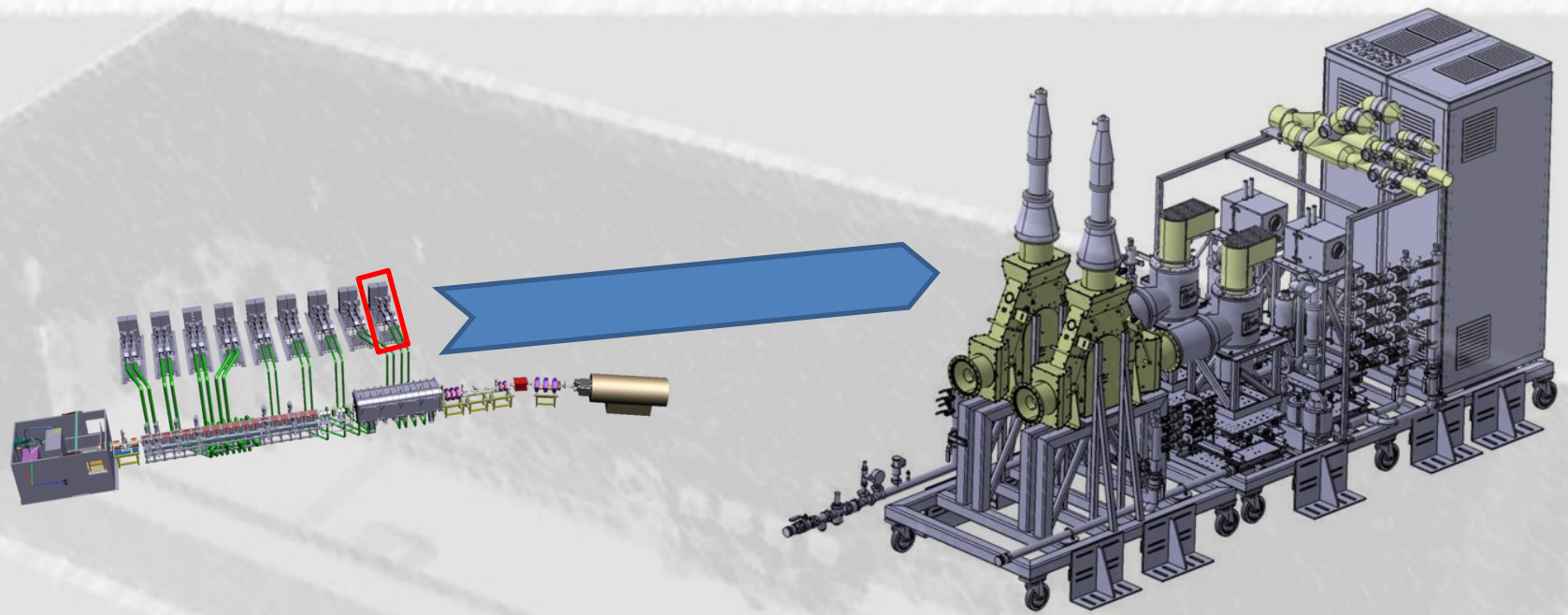
RF Chain B: Amp, dBm, Ph

Diagnostics: Cav Volt



| Closed Loop | | | | |
|----------------|------------|-------------|----------------|--|
| Cavity voltage | Cavity Ref | Cavity Volt | Control Action | |
| 50 | 50,11 | 49,9 | 67,46 | |
| 60 | 60,09 | 59,85 | 80,82 | |
| 70 | 70,16 | 69,89 | 94,1 | |
| 80 | 80,11 | 79,84 | 107,5 | |
| 90 | 90,12 | 89,75 | 121 | |
| 100 | 100,07 | 99,65 | 133,97 | |
| 110 | 110,05 | 109,65 | 147,5 | |
| 120 | 120,09 | 119,6 | 160,99 | |
| 130 | 130,1 | 129,58 | 174,51 | |
| 140 | 140,11 | 139,59 | 187,75 | |
| 150 | 150,09 | 149,48 | 201,16 | |

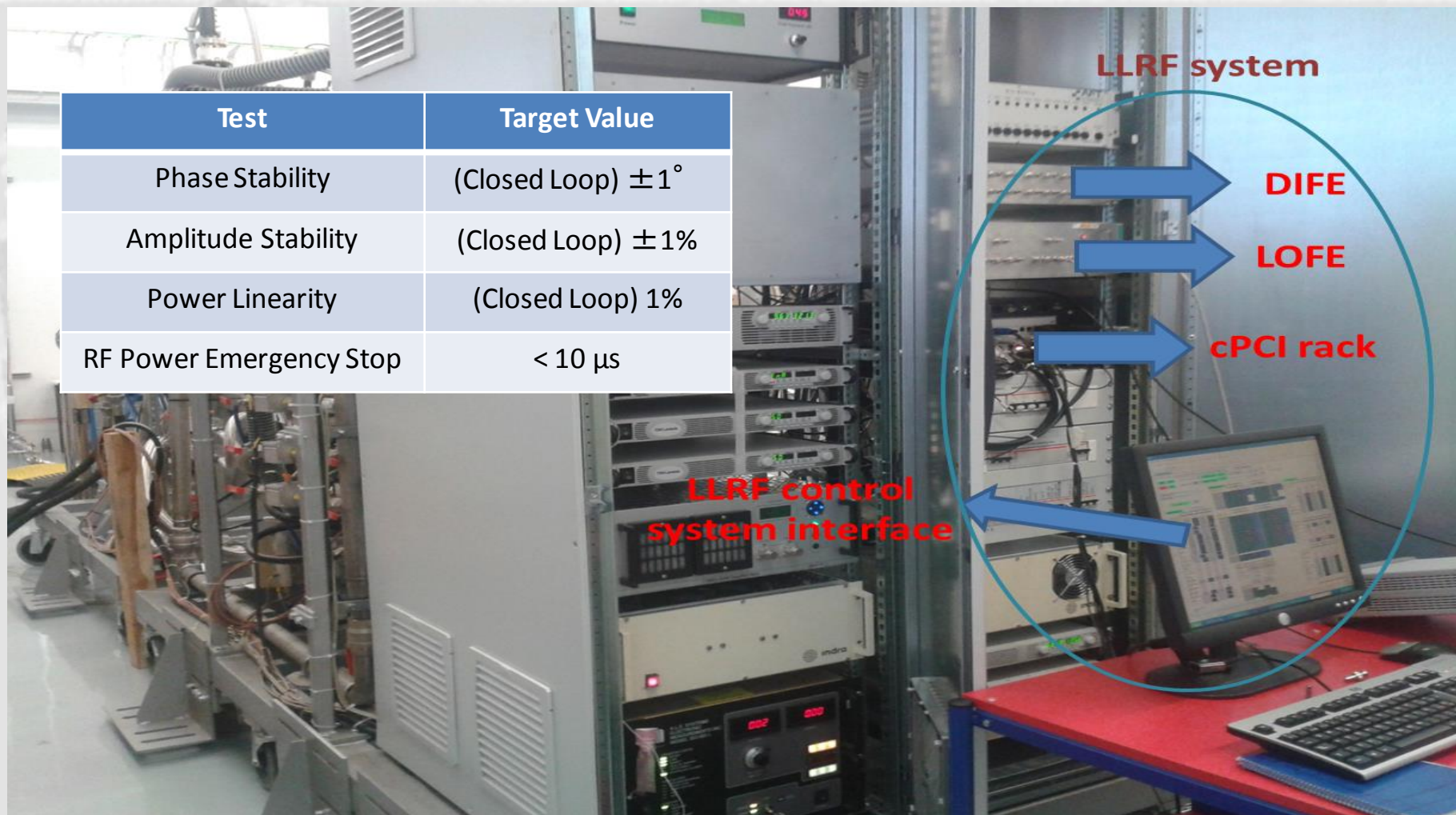




Tests on the RF Prototype Chain

Test on the RF Prototype Chain

| Test | Target Value |
|-------------------------|-----------------------------|
| Phase Stability | (Closed Loop) $\pm 1^\circ$ |
| Amplitude Stability | (Closed Loop) $\pm 1\%$ |
| Power Linearity | (Closed Loop) 1% |
| RF Power Emergency Stop | $< 10 \mu\text{s}$ |



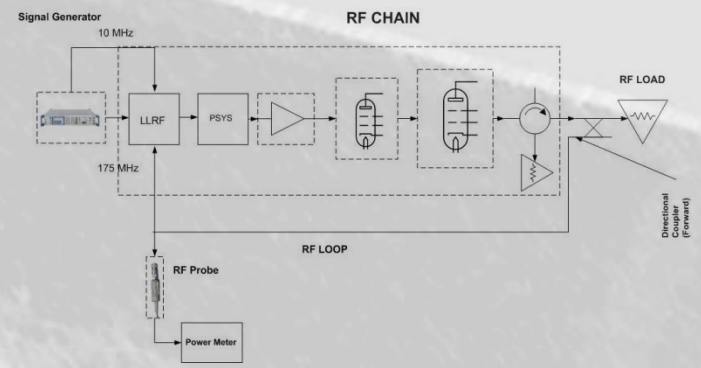
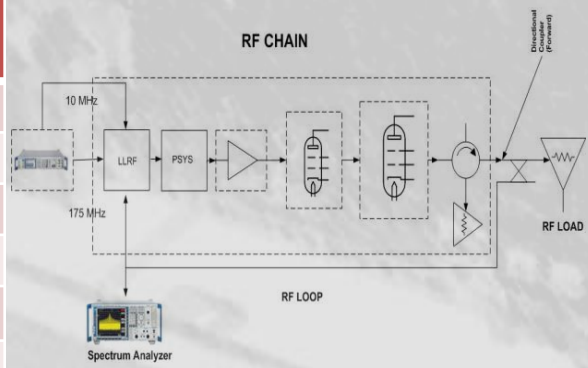
Any operation must be carried through the LLRF control system built over the explained solution and using the showed LLRF control interface

Tests on the RF Prototype Chain

Phase stability ($\pm 1^\circ$)

Amplitude stability ($\pm 1\%$)

| Time | rms Jitter (s) |
|--------|----------------|
| T0 | 1.1255 ps |
| T0+1' | 1.1283 ps |
| T0+2' | 1.1156 ps |
| T0+3' | 1.1128 ps |
| T0+4' | 1.1151 ps |
| T0+5' | 1.1121 ps |
| T0+6' | 1.1234 ps |
| T0+7' | 1.1271 ps |
| T0+8' | 1.1275 ps |
| T0+9' | 1.1231 ps |
| T0+10' | 1.1421 ps |
| T0+11' | 1.1207 ps |
| T0+12' | 1.1371 ps |
| T0+13' | 1.1411 ps |
| T0+14' | 1.1271 ps |
| T0+15' | 1.1383 ps |



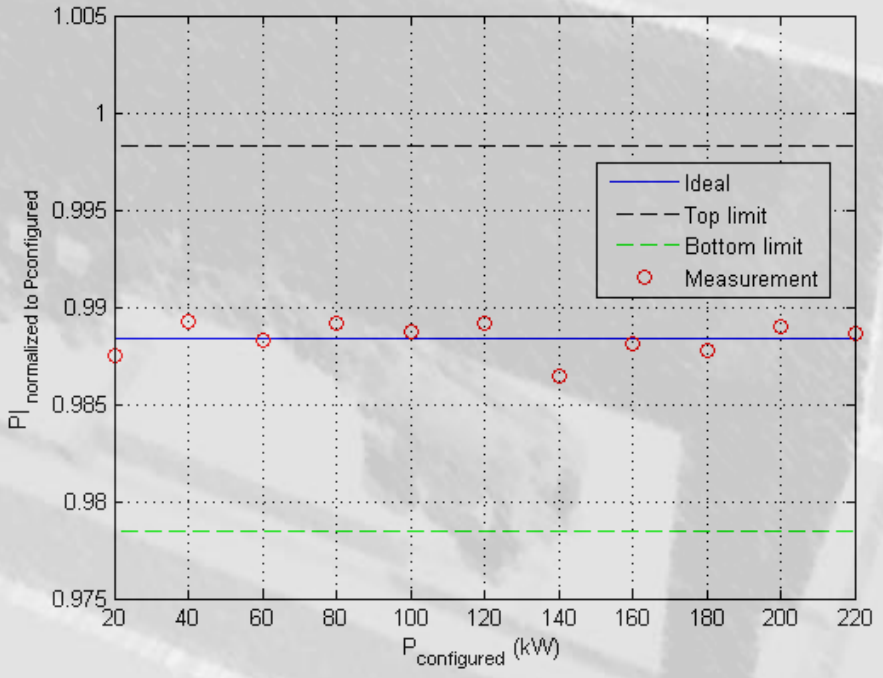
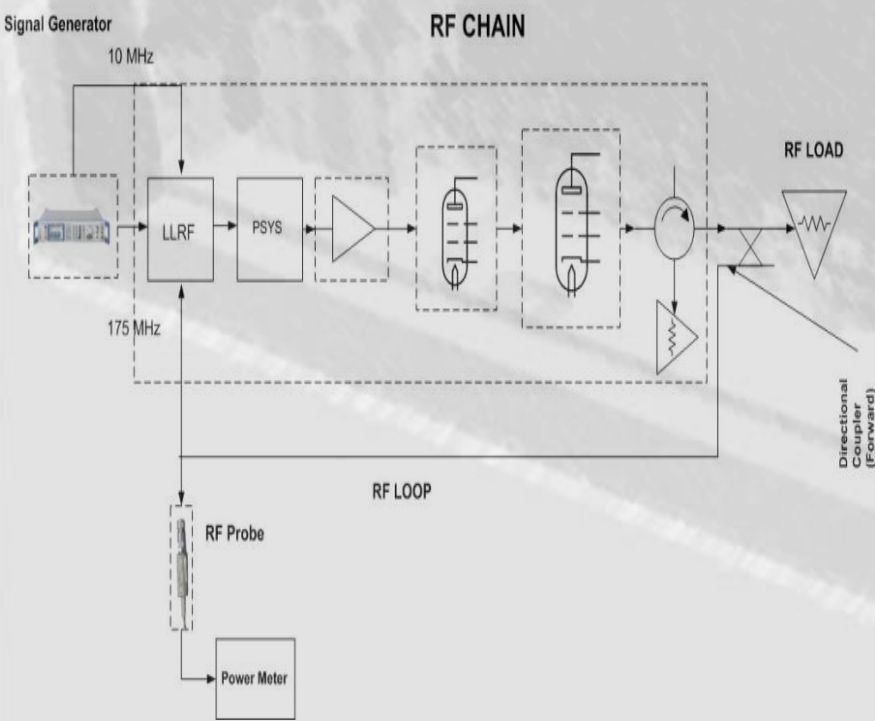
$$\Phi = 2\pi ft = 0.0895^\circ$$

15 minutes at 220kW. Worst values are recorded:

- 0.2% , 219.54 KW
- 0.4% , 220.88 KW

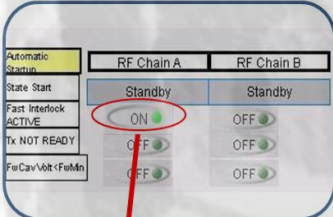
Tests on the RF Prototype Chain

Linearity ($\pm 1\%$)



Tests on the RF Prototype Chain

Interlock alarm -> Emergency stop



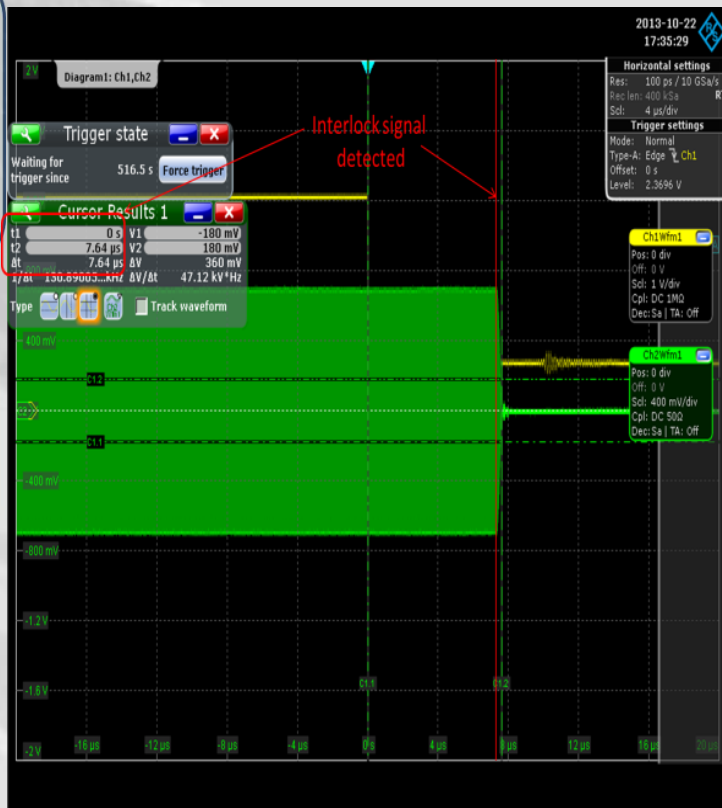
If ON means that one or more interlocks have been detected
RF:LLRF_CAVAFimDelayRdbk


| | RF Chain A | | RF Chain B | |
|----------------------|------------|---------|------------|---------|
| ITCKs Inputs | write | Read | write | Read |
| ITCKs Inputs Disable | OFF | OFF | OFF | OFF |
| Rv Cav | OFF | OFF | OFF | OFF |
| Fu Load | OFF | OFF | OFF | OFF |
| Rv Ciro | OFF | OFF | OFF | OFF |
| Arcs | OFF | OFF | OFF | OFF |
| Vacuum | OFF | OFF | OFF | OFF |
| Multipacting | OFF | OFF | OFF | OFF |
| MPS | OFF | OFF | OFF | OFF |
| Spare | OFF | OFF | OFF | OFF |
| Manual | OFF | OFF | OFF | OFF |
| | All ON | All ON | All ON | All ON |
| | All OFF | All OFF | All OFF | All OFF |

| | RF Chain A | | RF Chain B | |
|---------------------|------------|---------|------------|---------|
| ITCKs output | write | Read | write | Read |
| DACs OFF | OFF | OFF | OFF | OFF |
| Pin Switch | OFF | OFF | OFF | OFF |
| Trigger to FDL | OFF | OFF | OFF | OFF |
| ITCK Output for PLC | OFF | OFF | OFF | OFF |
| ITCK Output for MPS | OFF | OFF | OFF | OFF |
| Spare ITCK Output | OFF | OFF | OFF | OFF |
| | All ON | All ON | All ON | All ON |
| | All OFF | All OFF | All OFF | All OFF |

List of interlocks detected. Green means no interlock
RF:LLRFilkDiagDac

List of actions carried out by the LLRF system after an interlock happens. Green means no action
RF:LLRFilkDiagDAC





Thank you!!

Author's publications related with this work

- **J. Calvo**, Mark L. Rivers, Miguel A. Patricio and A. Ibarra. EPICS Based Low-Level Radio Frequency Control System in LIPAc. Journal of Fusion Engineering and Design. Volume 87, Issue 11, November 2012, Pages 1872-1879, ISSN 0920-3796. <http://www.sciencedirect.com/science/article/pii/S0920379612004218>
- **J. Calvo**, Mark Rivers, M.A Patricio, Angel Ibarra. IFMIF LLRF Control System Architecture Based on EPICS. Proceedings of ICALEPCS, 2011, Grenoble, France. <http://accelconf.web.cern.ch/accelconf/icalepcs2011/papers/mopms009.pdf>
- E. Bargalló, G. Martínez, J. M. Arroyo, J. Abal, P.-Y. Beauvais, R. Gobin, F. Orsini, M. Weber, I. Podadera, D. Regidor, **J. Calvo**, A. Giralt, J. Dies, C. Tapia, A. De Blas, A. Ibarra and J. Mollá. RAMI analyses of the IFMIF accelerator facility and first availability allocation between systems. Journal of Fusion Engineering and Design. Volume 88, Issues 9-10, October 2013, Pages 2728-2731, ISSN 0920-3796. <http://www.sciencedirect.com/science/article/pii/S0920379612004772>
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- D. Regidor, A. Arriaga, **J. Calvo**, A. Ibarra, I. Kirpichev, P. Méndez, J. Mollá, A. Salom and M. Weber. IFMIF-EVEDA RF Power System. In Proceedings of IPAC, 2011, San Sebastián, Spain. <http://accelconf.web.cern.ch/accelconf/IPAC2011/papers/mopc135.pdf>
- A. Salom, A. Arriaga, **J. Calvo**, I. Kirpichev, P. Méndez, D. Regidor, M. Weber, A. Mosnier, F. Pérez. Digital LLRF for IFMIF-EVEDA. In Proceedings of IPAC, 2011, San Sebastián, Spain. <http://accelconf.web.cern.ch/accelconf/IPAC2011/papers/mopc160.pdf>

Author's publications

- J. Mollá, P. Méndez, B. Brañas, M. Weber, I. Podadera, **J. Calvo**, J.M. Carmona, A. García, J.M. Arroyo, J.C. Mora and A. Ibarra. Spanish contribution to the IFMIFEVEDA Project. 16th International Conference on Emerging Nuclear Energy Systems, 2013. <http://www.icenes2013.org/ViewFile.aspx?codReg=76>
- J. Marroncle, P. Abbon, J.F. Denis, J. Egberts, F. Jeanneau, J.F. Gournay, A. Marchix, J.P. Mols, T. Papaevangelou, M. Pomorski, **J. Calvo**, J.M. Carmona, D. Iglesias, C. Oliver, I. Podadera, A. Guirao and M. Poggi. IFMIF-LIPAc Diagnostics and its Challenges. Proceedings of the International Beam Instrumentation Conference (IBIC), 2012. <http://www.researchgate.net/publication/235060771>
- F. Orsini, N. Bazin, P. Brédy, P. Carbonnier, G. Devanz, G. Disset, N. Grouas, P. Hardy, V. Hennion, H. Jenhani, J. Migne, A. Mohamed, J. Neyret, B. Renard, J. Relland, D. Roudier, P. Abramian, J. Calero, **J. Calvo**, J.L. Gutiérrez, T. Martinez, J. Munilla, I. Podadera and F. Toral. Progress on the SRF Linac Developments for the IFMIF-LIPAc Project. In Proceedings of IPAC, 2013, Shanghai, China. <http://accelconf.web.cern.ch/accelconf/IPAC2013/papers/thpfi004.pdf>
- A. Arriaga, **J. Calvo**, I. Kirpichev, P. Méndez, J. Molla, D. Regidor, A. Salom, M. Weber, M. Desmons and D. Vandeplassche. LIPAc RF Power System Engineering Design Report, 2013. Technical Report.
- **J. Calvo**, J. González, J.F. Gournay, J.Y. Rouse, D. Bogard, J.F. Denis, J. Relland, M. Giacchini, L. Antoniazzi and M. Montis. LIPAc Local Control Systems Engineering Design Report, 2013. Technical Report.

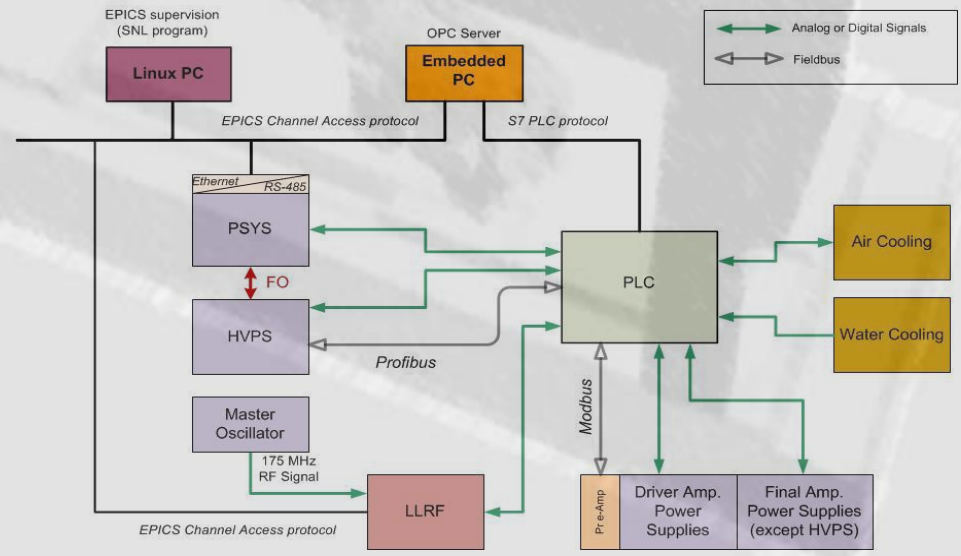
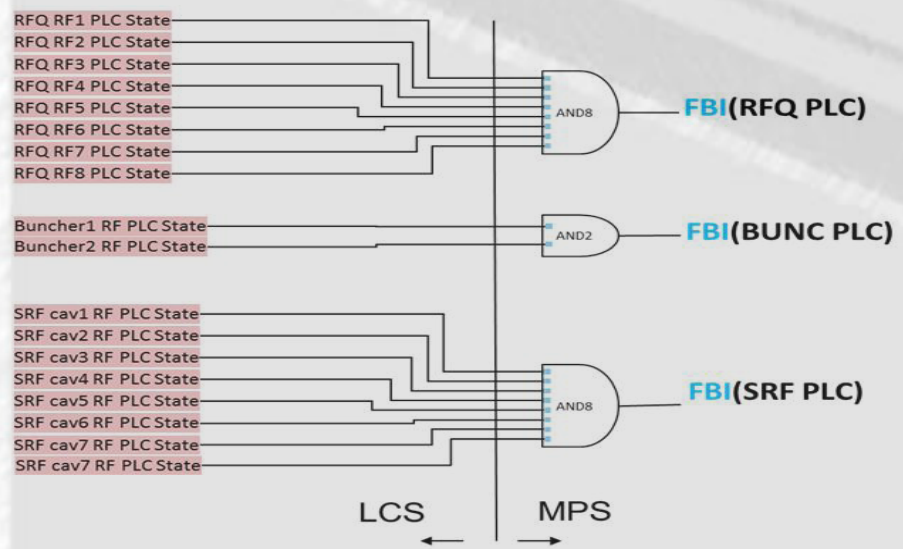
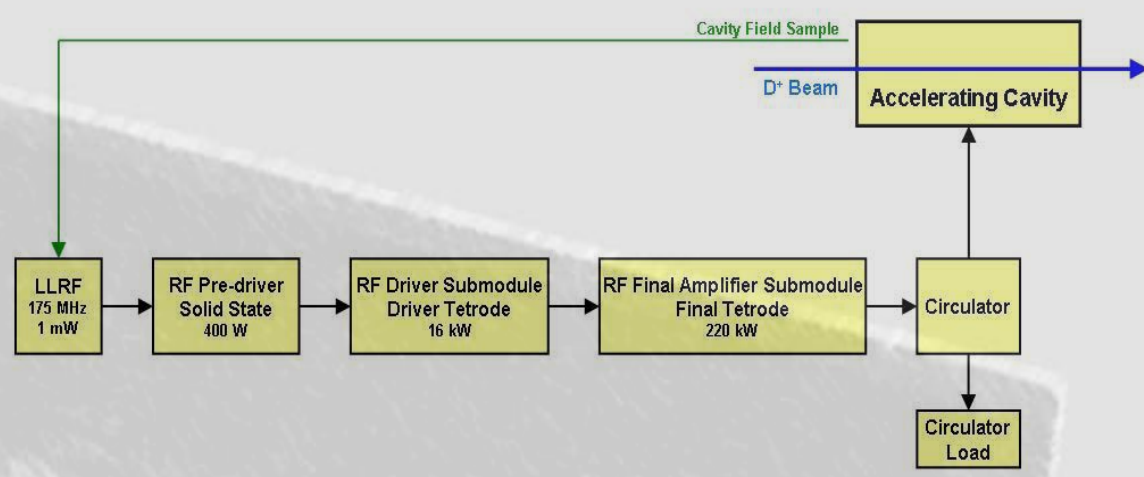
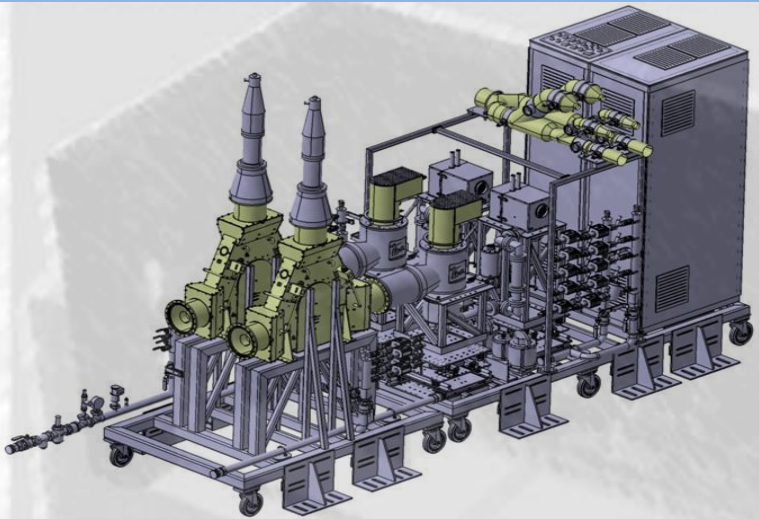
A grayscale micrograph showing a cross-section of a material with a layered or fibrous structure. A prominent red horizontal bar is overlaid across the center of the image, containing the word "Conclusions" in bold black text. The background image shows various textures and boundaries between different material layers.

Conclusions

Future work lines

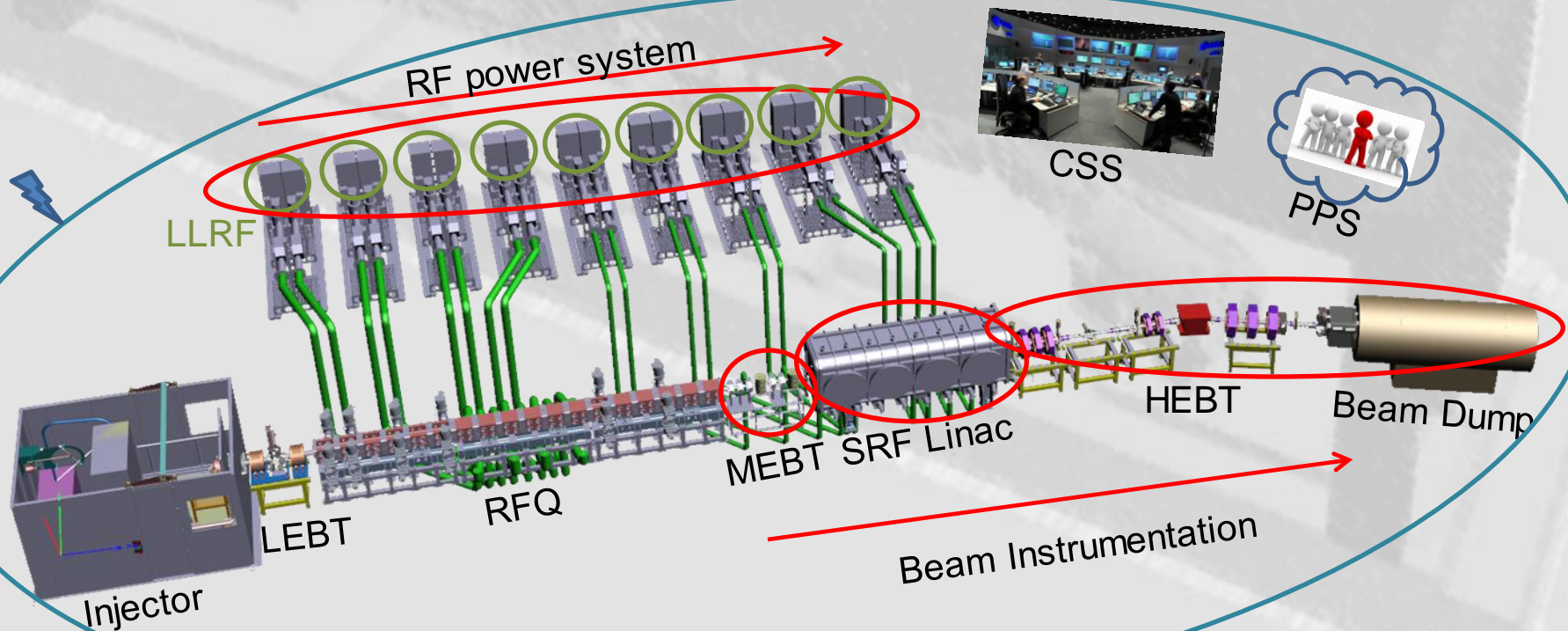
- ❑ Local control systems integration at accelerator site.
- ❑ IFMIF Lithium target control system challenge.
- ❑ LLRF device support validation in other hardware.
- ❑ Virtual control system for IFMIF based on LIPAc results.

Radio Frequency (RF) LCS



Objectives

- ☉ To carry out the design and development of the local control system for some of the explained subsystems.
- ☉ To achieve the design and development of Low Level Radio Frequency (LLRF) control system.
- ☉ To contribute to the design on the Machine Protection System (MPS), Personal Protection System (PPS) and the Central Control System (CCS).



Main results

Local control and protection systems

- Control of transport and focalization devices in MEBT subsystem
- Control of solenoid package in SRF Linac
- RF local control system architecture definition
- Control of transport and focalization devices in HEBT and BD subsystem
- Control of BPMs, FPMs and slits in BI subsystem
- Essential protection signals detection and definition

Low level radio frequency control system

- More than 800 hundreds PVs are controlled.
- Real-time and accurate communication with other subsystems
- Essential functionalities developed
- Successfully tested in the RF Prototype Chain