This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

CERN SRF Cavity Testing Infrastructure

DESY / 15-09-2022 / AMICI Workshop

CERN

Jordan Walker, Franck Peauger, Niall Stapley, on behalf of; Antonio Bianchi, Walter Venturini Delsolaro, Paul Kohler, Alick Macpherson, Nick Shipman, Katarzyna Turaj, Tomasz Wlostowski,

Outline

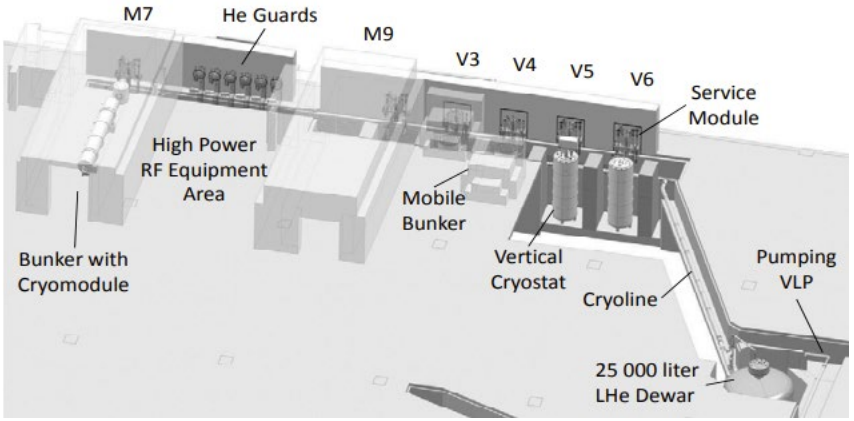
- Overview of infrastructure
- Process - From reception of cavity to end of test
- RF / Testing System
- Future Developments

Testing Infrastructure

SM18

- **4 x** Vertical Test Stands
  - For testing cavities (bare/dressed)
  - Production & R&D

- **2 x** Test Bunkers
  - For verification & conditioning of cryomodules



Credit: Pirotte_SM18_CER-ACC-2014-0314

Cryolab

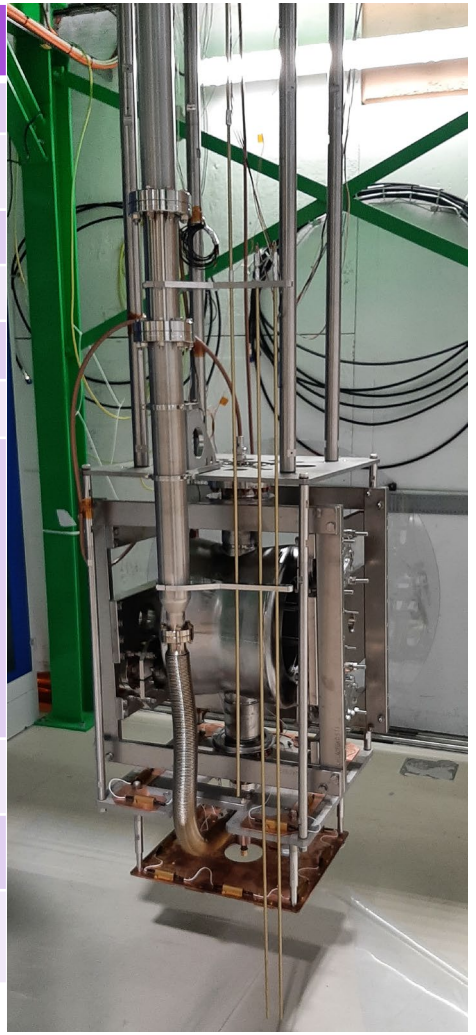
- **1 x** Dedicated Vertical Cryostat
  - 1.3GHz
  - QPR

- **1 x** On-Demand Cryostat
  - Material & Instrumentation R&D


New V6 Cryostat
November 2022

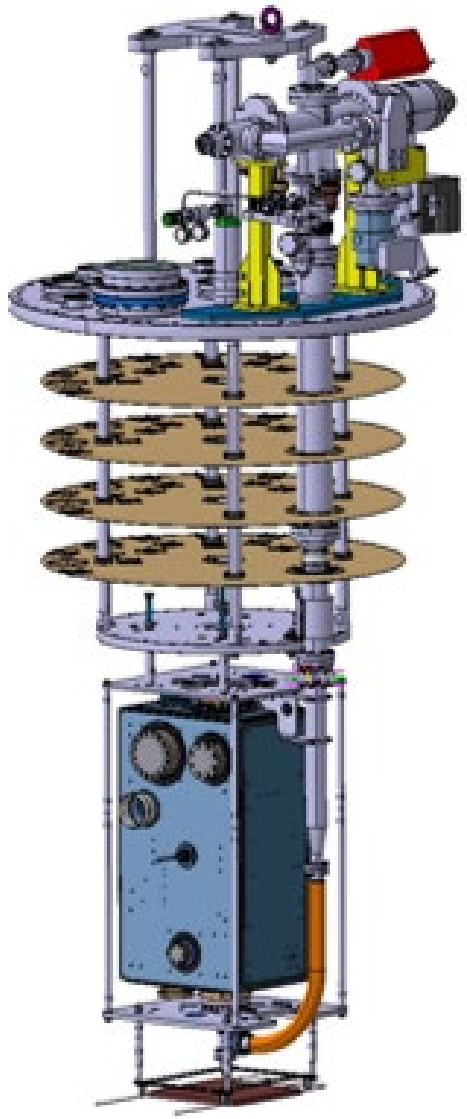
SM18 Test Stand V3 summary

Property name	Value	Unit	Comment
LHe volume	2500	L	
Operating temperature	1.7 - 4.5	K	2 Operating Modes
Diameter / size	1.1	m	
Number of inserts	1		
RF Frequency	350 - 1500	MHz	
Maximum Incident power	300	W	
Additional instrumentation			B-Field Compensation Granular Temperature Mapping Programmable Attenuation Mobile Coupler Quench Detection by 2nd Sound (OST) Top & Bottom Radiation Monitor Thermo-electric current Tuner controls
Typical testing rate (Vts / year)	N/A		Mix of dedicated R&D and production tests (≈2 weeks)
Possibility to test bare cavities	Yes	Y / N	Bare, dressed, cavities with tuners
Infrastructure for small intervention	?	Y / N	Any intervention to be negotiated with CERN SRF program



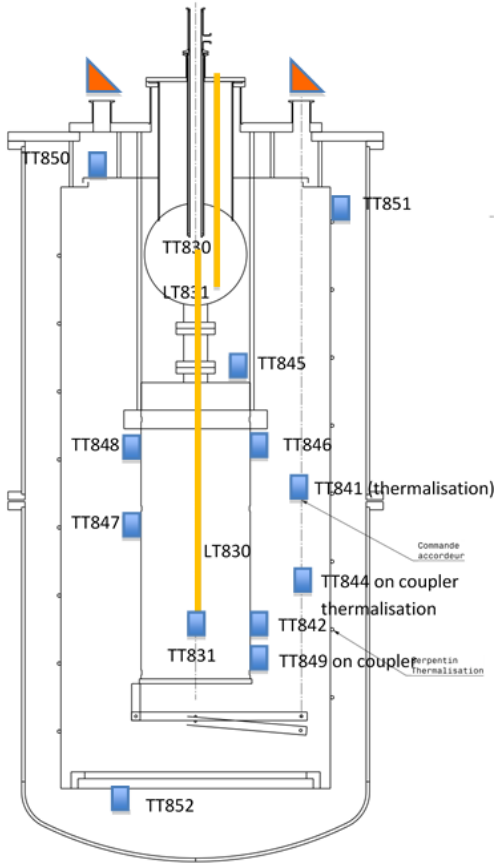
SM18 Test Stand V4 summary

Property name	Value	Unit	Comment
LHe volume	1500	L	
Operating temperature	1.8 - 4.5	K	2 Operating Modes
Diameter / size	1.1	m	
Number of inserts	1		
RF Frequency	100 – 1000	MHz	
Maximum Incident power	300	W	
Additional instrumentation			B-Field Compensation Granular Temperature Mapping Mobile Coupler, Top & Bottom Radiation Monitor Thermo-electric current
Typical testing rate (Vts / year)	8		Based on 2021
Possibility to test naked cavities	Yes	Y / N	
Infrastructure for small intervention		Y / N	Any intervention to be negotiated with CERN SRF program



SM18 Test Stand V5 summary

Property name	Value	Unit	Comment
LHe volume	100	L	
Operating temperature	1.8 - 4.5	K	2 Operating Modes
Diameter / size	1.0	m	
Number of inserts	1		
RF Frequency	100 - 1000	MHz	Upgrade to 1.3GHz foreseen
Maximum Incident power	100	W	
Additional instrumentation			B-Field Compensation Common vacuum system Mobile Coupler
Typical testing rate (Vts / year)	1		Based on 2021
Possibility to test naked cavities	No	Y / N	Cavity must be equipped with He circuit
Infrastructure for small intervention		Y / N	Any intervention to be negotiated with CERN SRF program

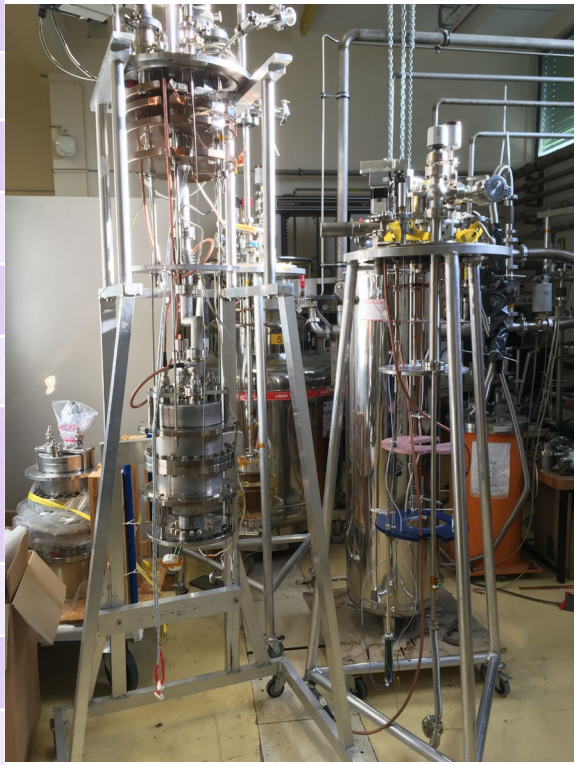


SM18 Test Stand V6 summary

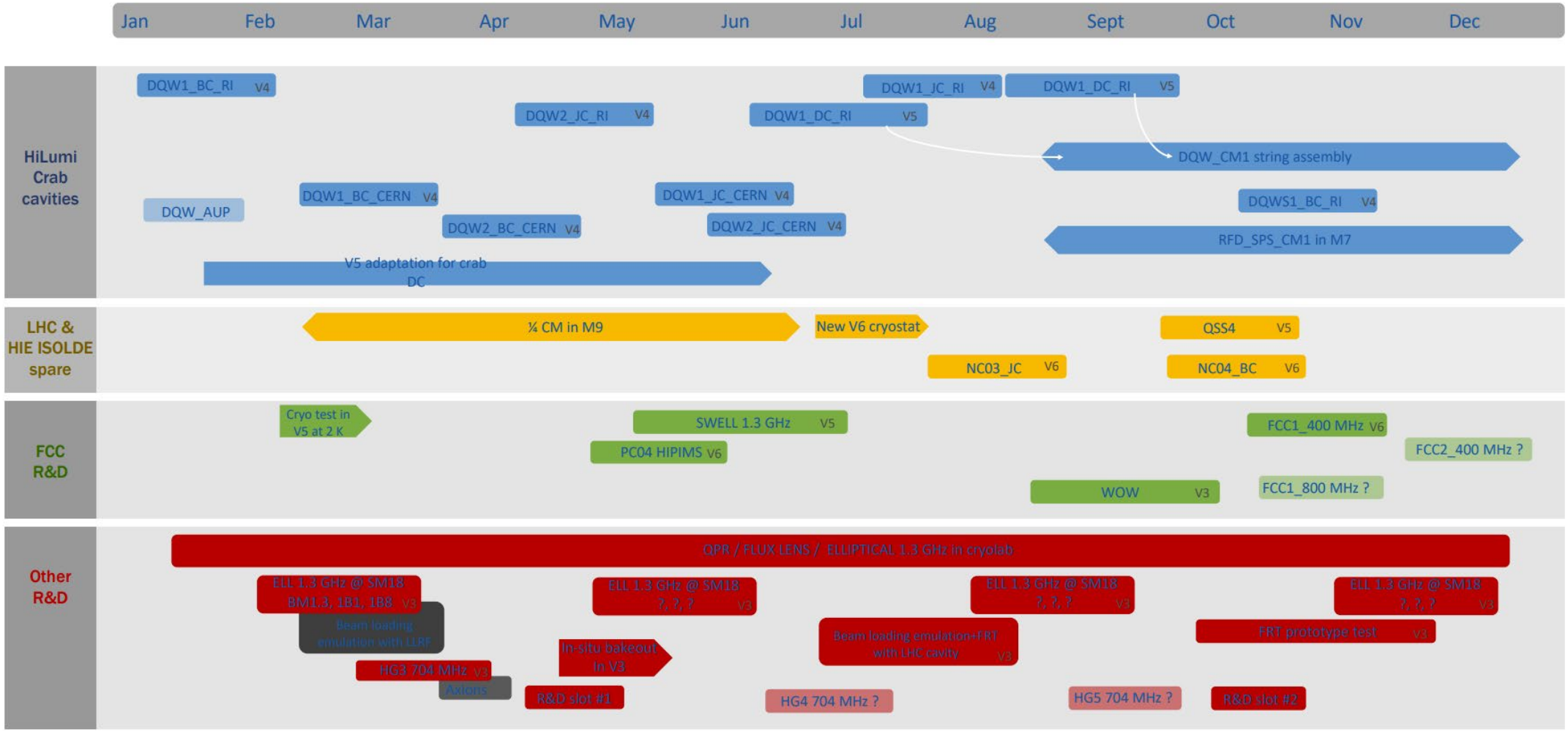
Property name	Value	Unit	Comment
LHe volume	2500	L	
Operating temperature	1.8 - 4.5	K	2 Operating Modes
Diameter / size	1.1	m	
Number of inserts	1		
RF Frequency	100 – 1000	MHz	
Maximum Incident power	300	W	
Additional instrumentation			Mobile Coupler Granular Temperature Mapping Mobile Coupler Top & Bottom Radiation Monitor
Typical testing rate (Vts / year)	5		Based on 2021
Possibility to test naked cavities	Yes	Y / N	
Infrastructure for small intervention		Y / N	Any intervention to be negotiated with CERN SRF program

Cryolab Test Stand Summary

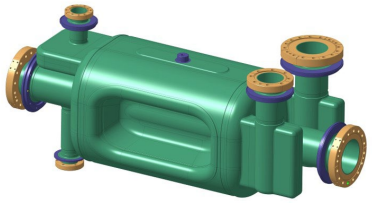
Property name	Value	Unit	Comment
LHe volume	90	L	
Operating temperature	1.5 – 4.22	K	
Diameter / size	0.34	m	
Number of inserts	2		
RF Frequency	400 – 1300	MHz	
Maximum Incident power	25	W	
Additional instrumentation			Temperature Mapping System (Nb on Cu) Mobile Coupler
Typical testing rate (Vts / year)	15		Based on 2021
Possibility to test naked cavities	Yes	Y / N	
Infrastructure for small intervention		Y / N	Any intervention to be negotiated with CERN SRF program

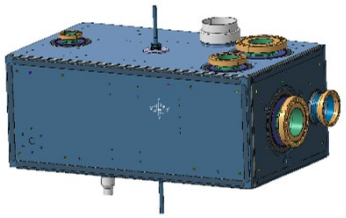


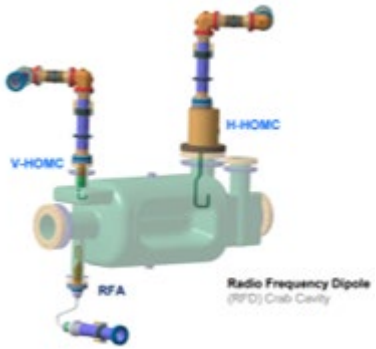
SRF Full Testing Programme 2022



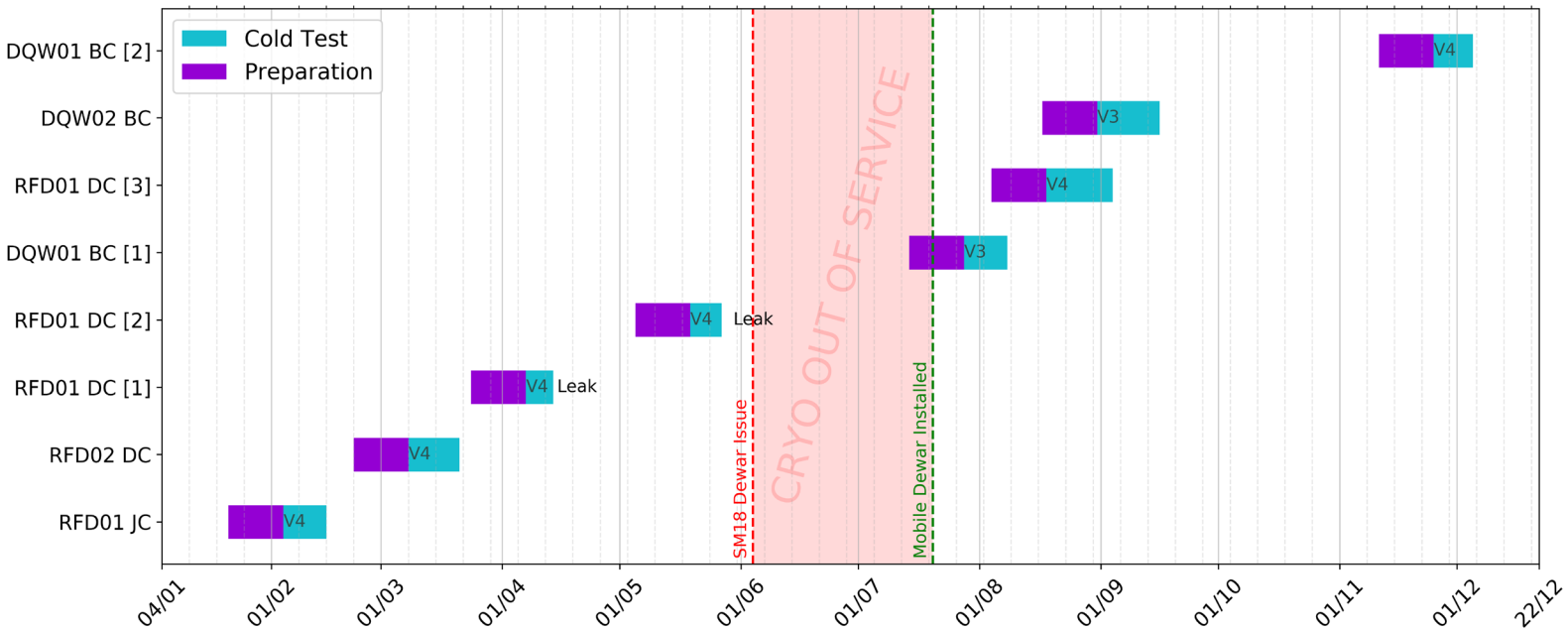
Schedule / Throughput







Crab Cavity Programme 2021



Average Preparation Time:

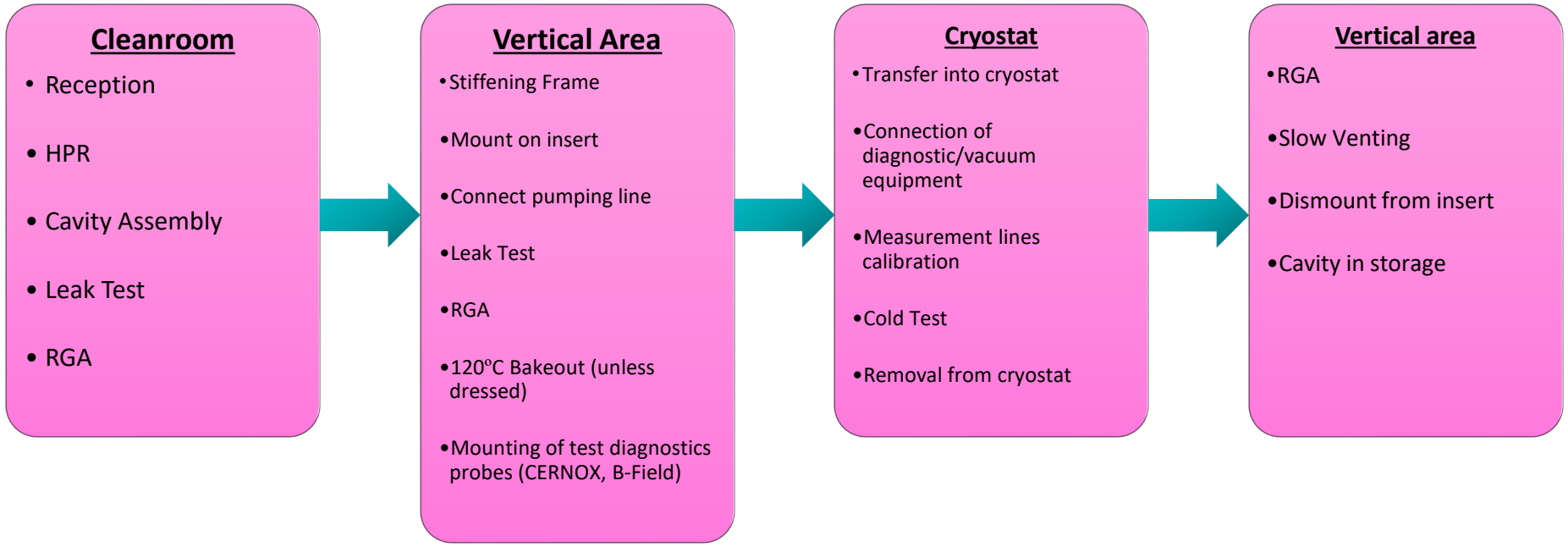
≈ 3 weeks

Average Test Duration:

≈ 11 days*

*During production phase, expected to reduce closer to 1 week

Process Overview



Cavity Preparation

252 Overview

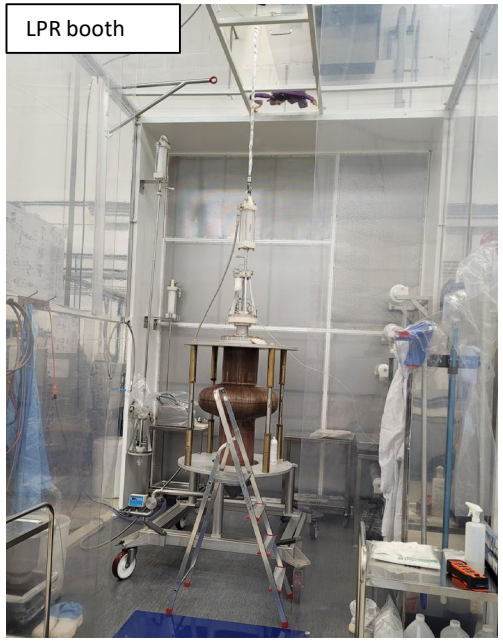
- LPR - Up to 7 bar, ultra-pure water, and alcohol post-rinse
- 2 x Clean Booths (currently)
- Components preparation in new clean booth with washing machine

SM18 Overview

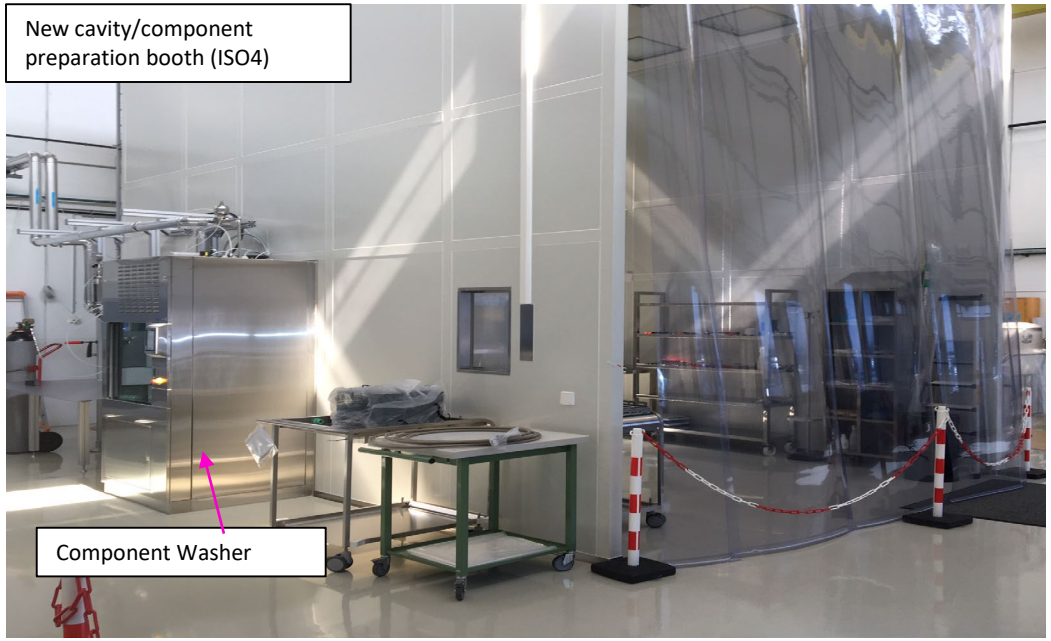
- HPR – Up to 100bar
- 1 x ISO 2 Clean Room
- 4 x Clean booths (1 x horizontal flow, 3 x vertical flow)

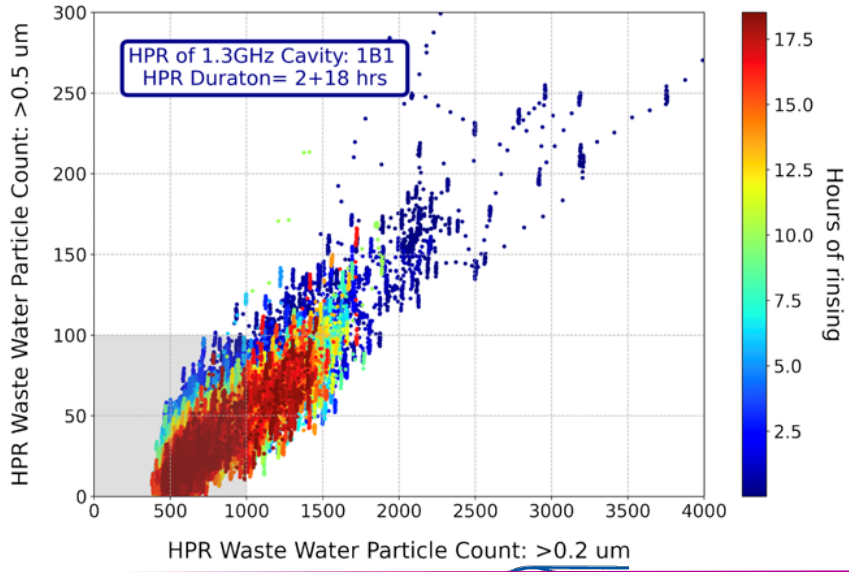
Dynamic
ISO 2 : Static
ISO 4 : During work

LPR booth



New cavity/component preparation booth (ISO4)





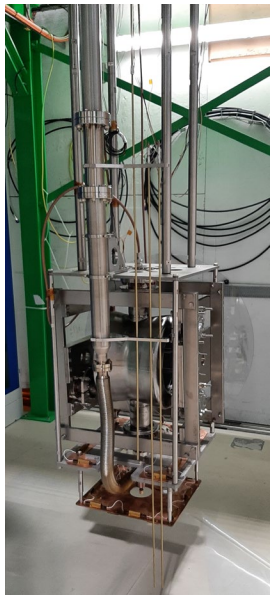
Insert Preparation

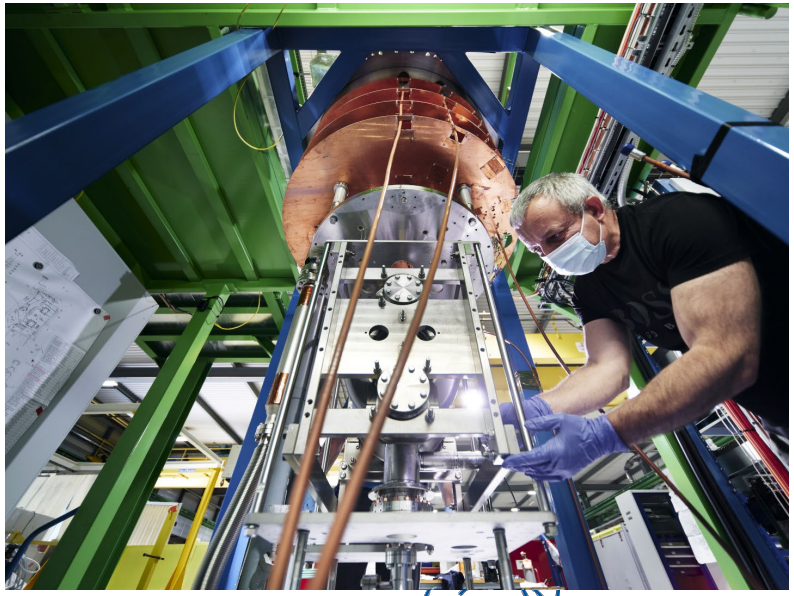
Insert Diagnostics

- **Temperature**
  - 3 x PT100 Temperature Sensors on heat shields of all stands
  - 6 – 16 x CERNOX Temperature Sensors
  - 3 x PT100 and 6x cernox integrated into cryo process control
- **Pressure**
  - Cryostat Pressure
    - 0-2 bar gauge for pressure cycles up to 1.5 bara
    - 0-50 mbar gauge for superfluid helium operation
  - Cavity Vacuum
    - Pirani – 1 x 10^{-3}- 1bar
    - Pening – 1x10^{-2} – 1x10^{-10} (target = 1x10^{-9} prior to cooldown)
- **Helium Level**
  - 3 x Gauges spanning full operation volume of cryostat
- **B-field probes**
  - Vertical, horizontal, azimuthal **(V3 & V4 only)**
  - Achievable compensation below **50 nT**

Process

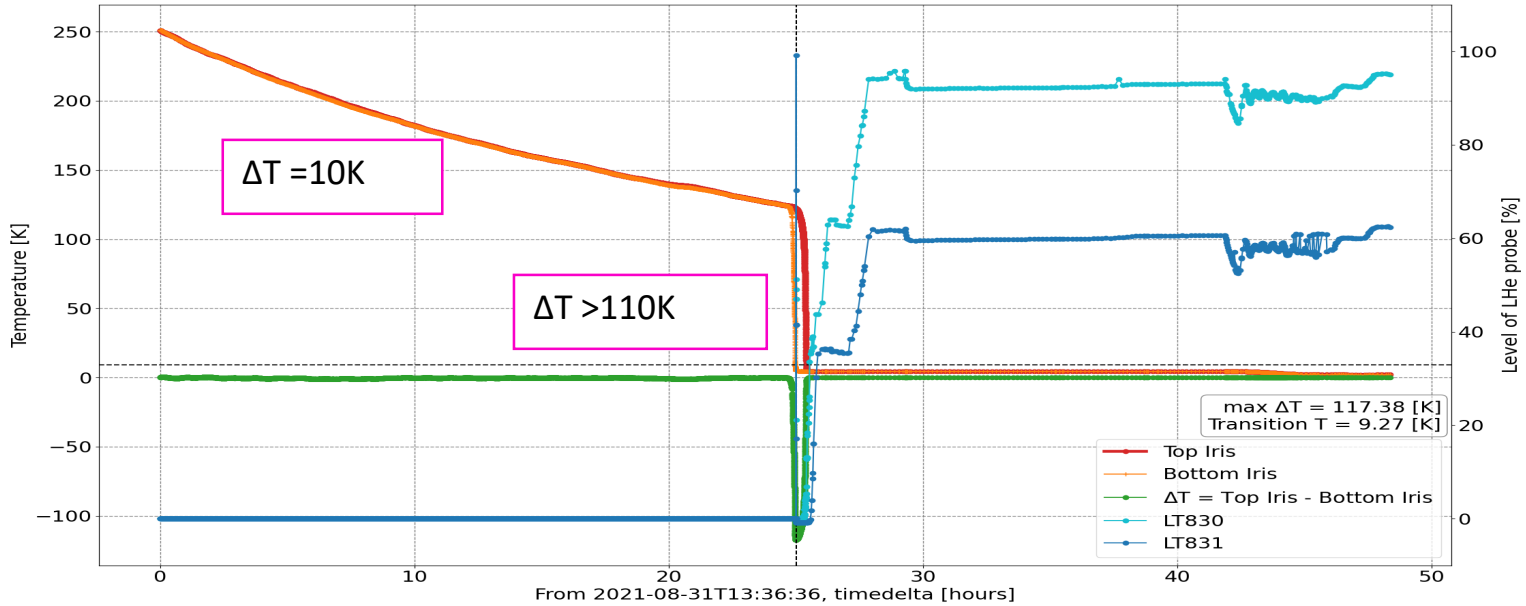
- Stiffening Frame (Crab)
- Mount on insert
- Connect pumping line
- Leak Test
- RGA
- 120°C Bakeout (unless dressed - Crab)
- Mounting of test diagnostics probes (CERNOX, B-Field, Level)





Cooldown / Cryo Conditions

- Overview of cryogenics capabilities/capacity
- Dedicated cooldown ‘recipes’
- Operating modes (4.5K, 2K, detail thermal cycles etc)
- Limitations (Demand from magnets)

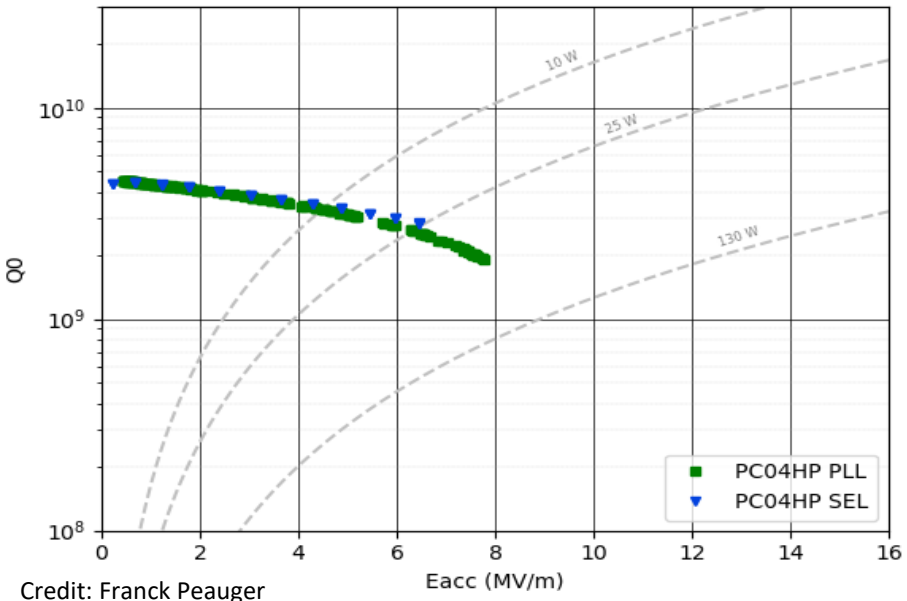


Example of cooldown ‘recipe’ for RFD crab cavity

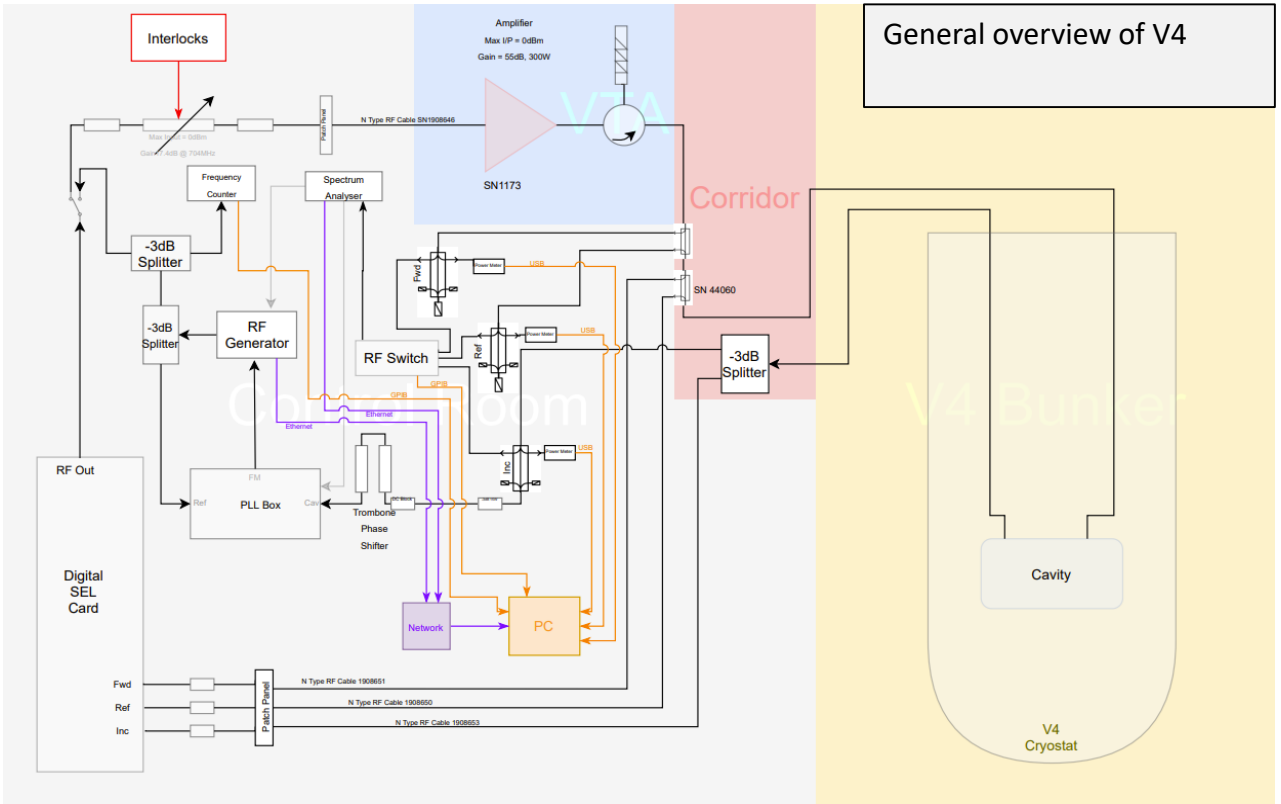
Plots:
Adam Andrzej Starczynski
adam.andrzej.starczynski@cern.ch

Overview of RF System

- Both PLL and UCC systems on V3, V4 and V6
- UCC based on accelerator technology, incorporating SEL and GD
- UCC vs PLL results comparison shown below (NC03 LHC cavity, October 2021)
- PLL operated via LabView application
- UCC has python UI via Spyder



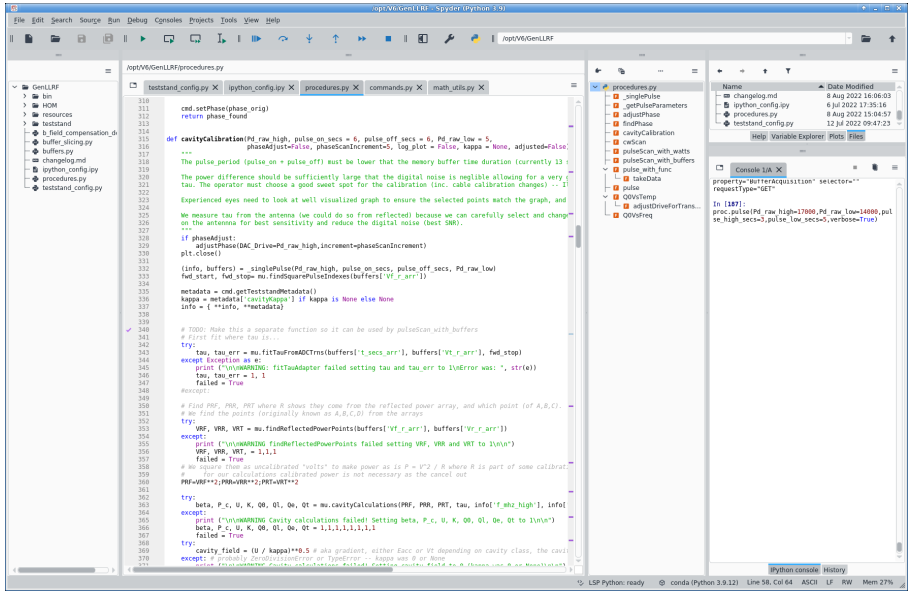
Credit: Franck Peauger

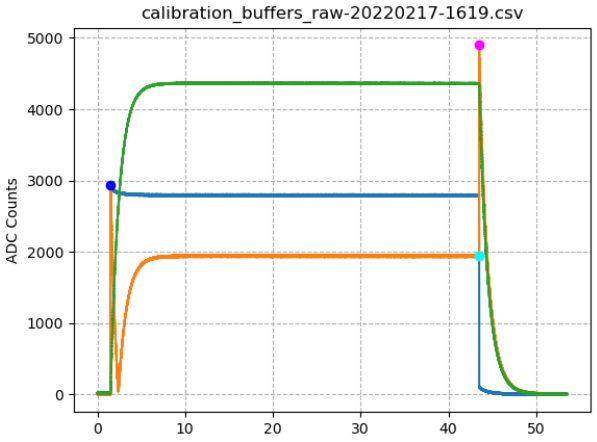


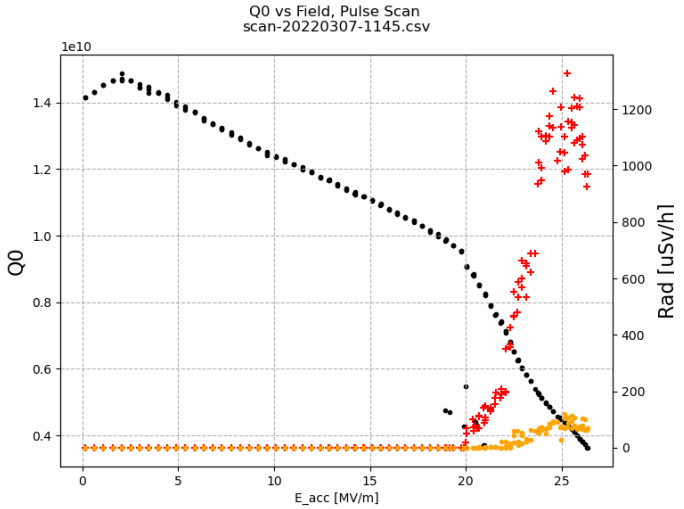
General overview of V4

UCC System

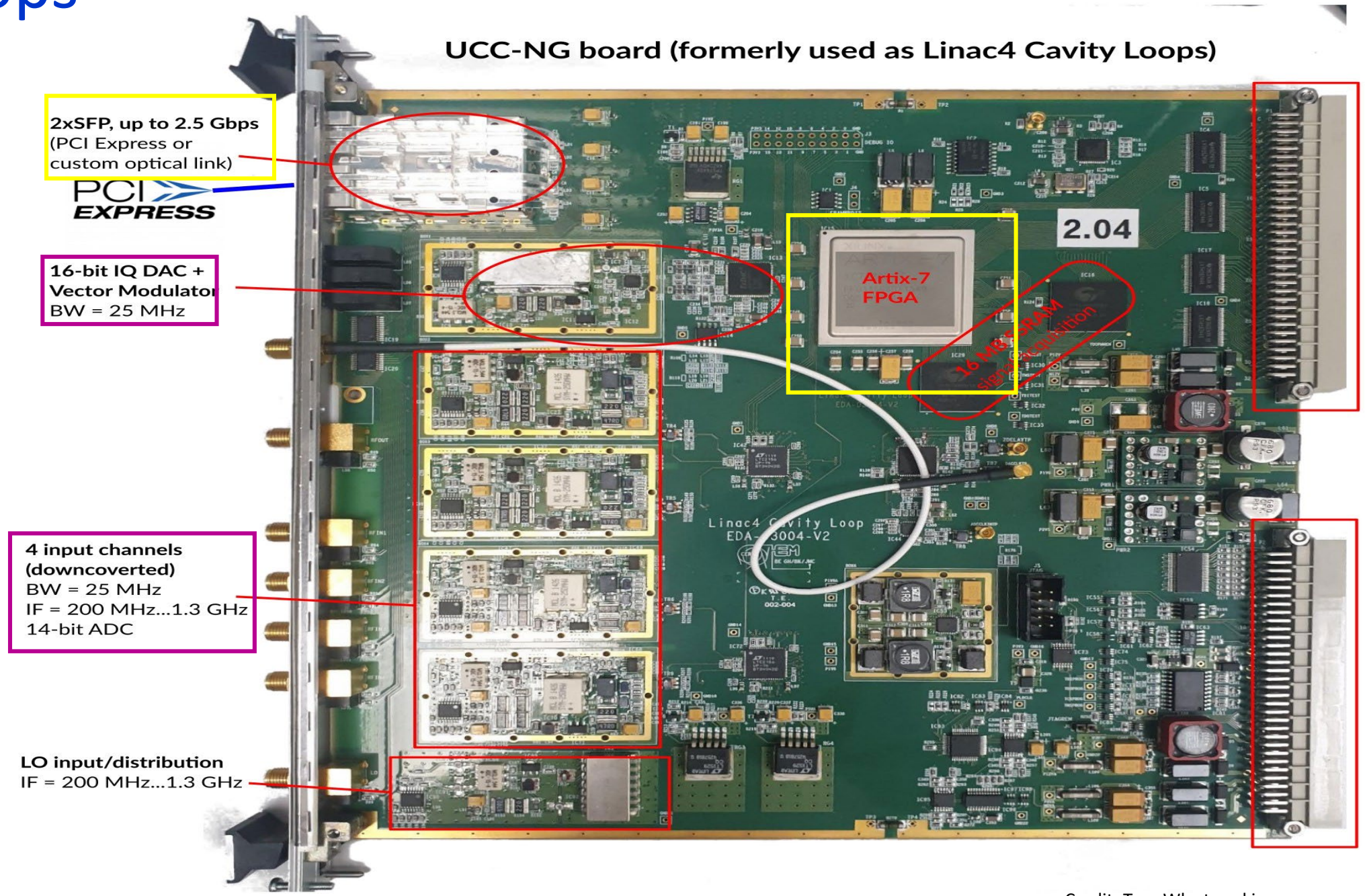
- Extensible framework for operator (Spyder, IPython)
  - Database of adaptable test procedures (calibration, pulse/CW scans etc..)
  - Several methods of calculating Q_0 data from raw measurements
  - Live plotting
- Reused accelerator LLRF & Controls Systems
  - FPGA with multimode drive (SEL, GD), input ADCs (Vf, Vr, Vt), and buffer memory
  - V2 in testing
- Saves all raw data
  - Timestamps, raw scan data, processed data and relevant environmental data (radiation, temperatures, helium level, dark currents etc)







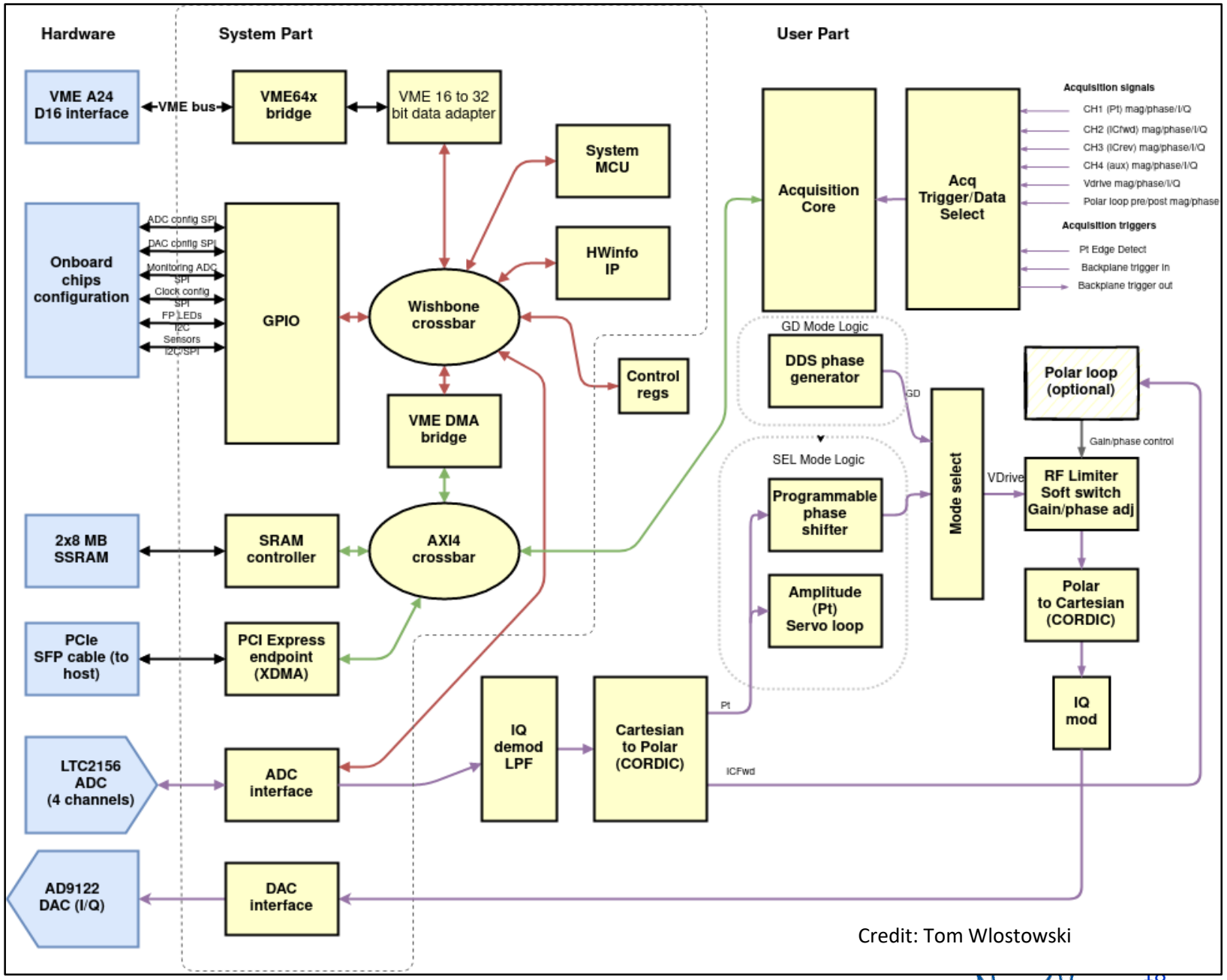
Cavity Loops
UCC Card



Credit: Tom Wlostowski

Cavity Loops UCC

- Ring buffer memory for ADCs
  - 8 x 2^{20} (4 ADCs, 2 channels each)
  - Time range = 1 – 60s (80 – 16MS/s)
  - Freeze on demand
- RF Safety Limit on Drive
- SEL
  - Adapts to changing phase/frequency

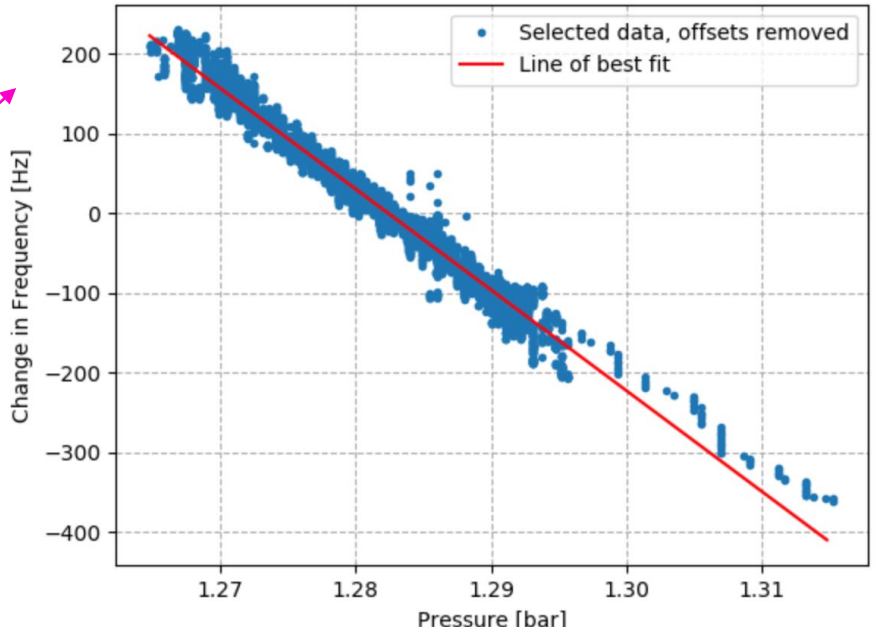


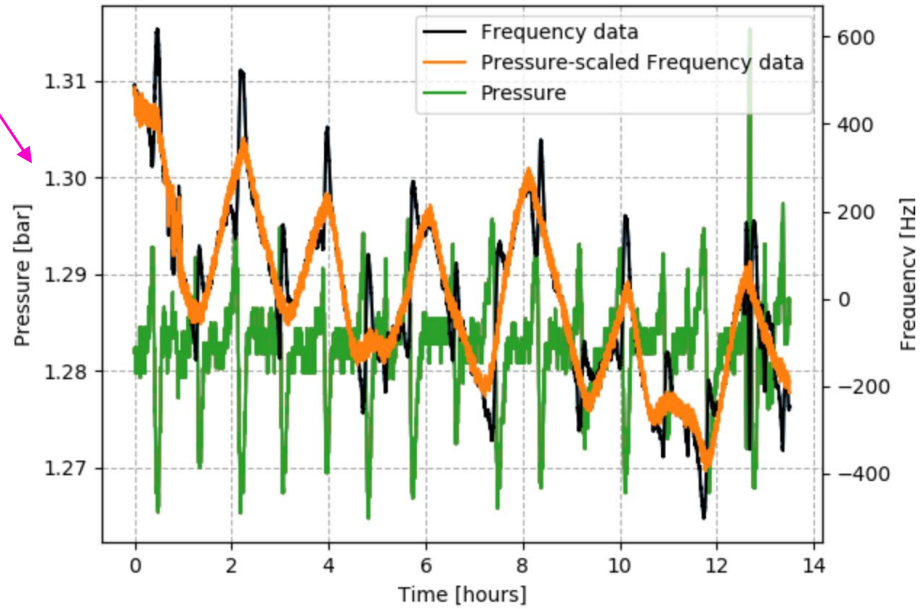
Credit: Tom Wlostowski

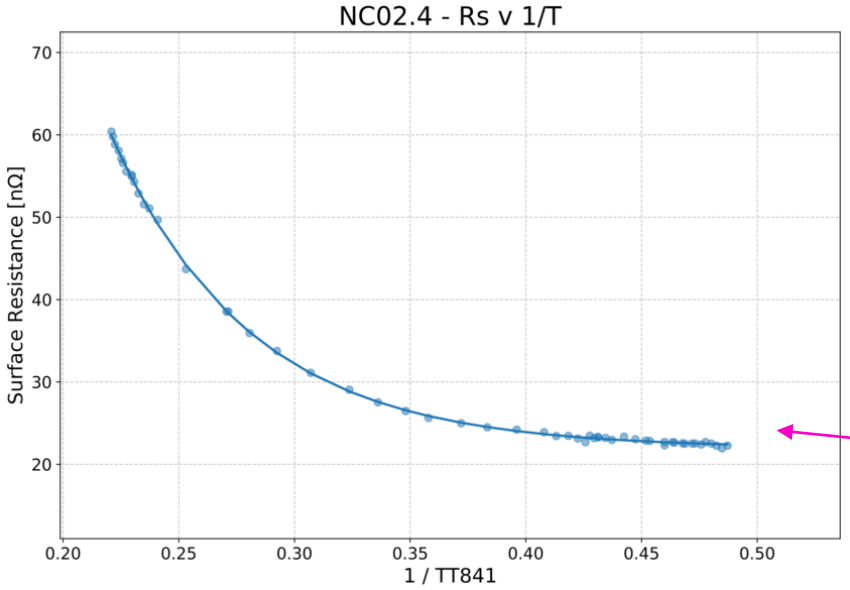
Post-Processing

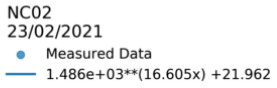
- Cross-checking & report generation

Cavity pressure sensitivity can be measured then modelled onto frequency data during test





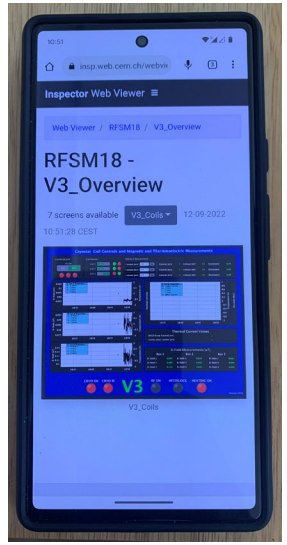


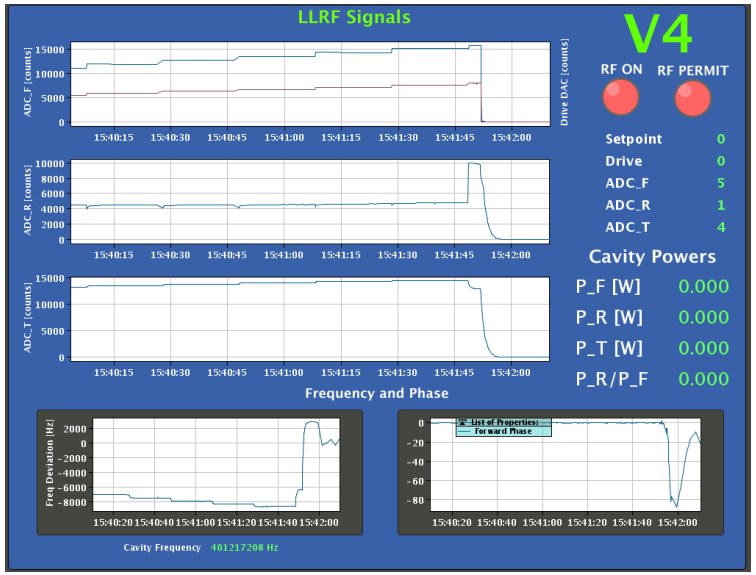


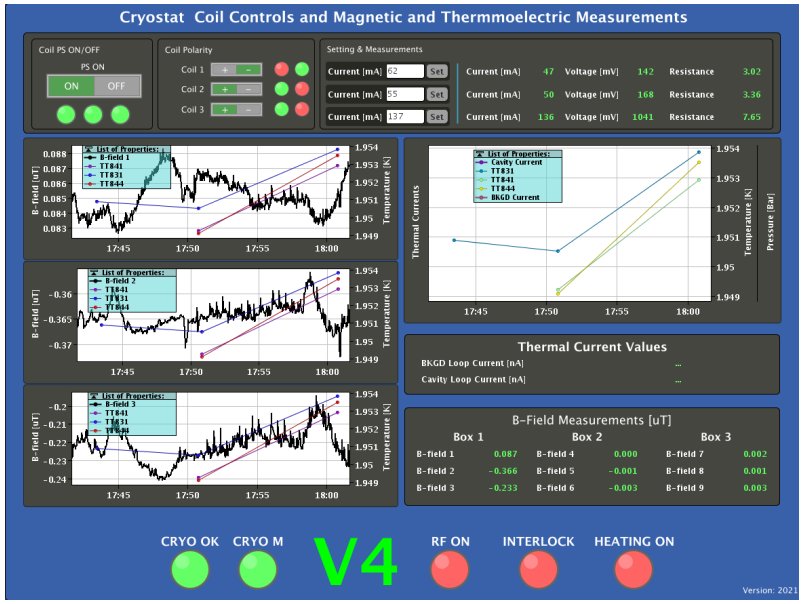
Q0vTemp scan produces R_{res} value, giving indication of surface preparation quality

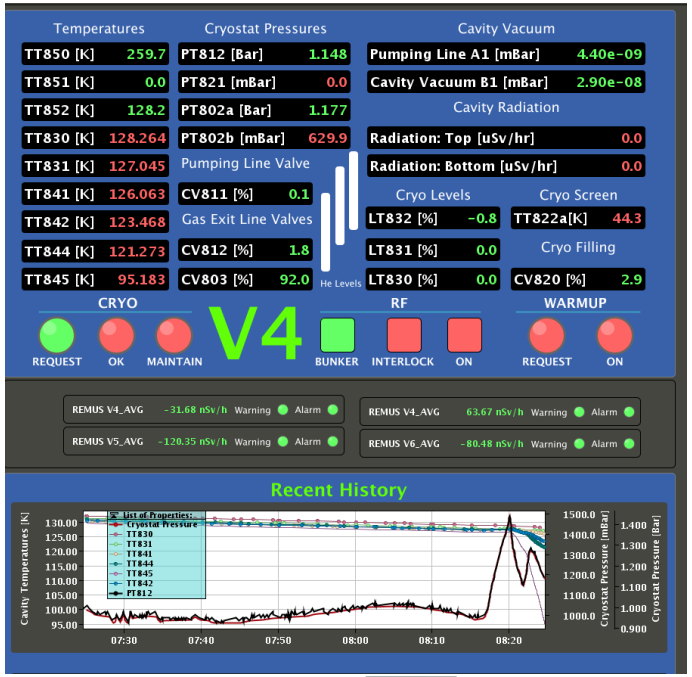
User Interface - Inspector

- CERN Control & Monitoring Interface
- Displays environmental & test data in real-time
- Designed to be both user-friendly & user configurable
- Gives controllable interface to controls layer
- Can also be used to control test stand apparatus such as heaters, magnetic field compensation coils etc.
- Allows remote monitoring of test progress (mobile phone compatible)



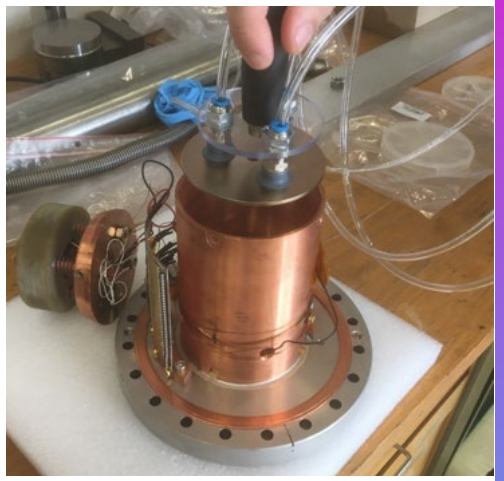




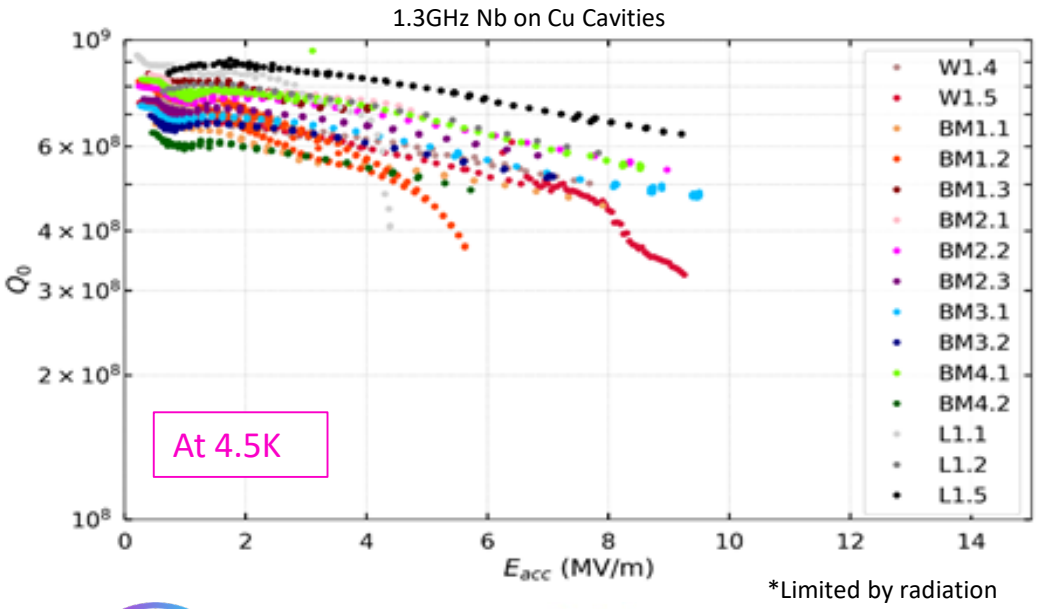


Cryolab

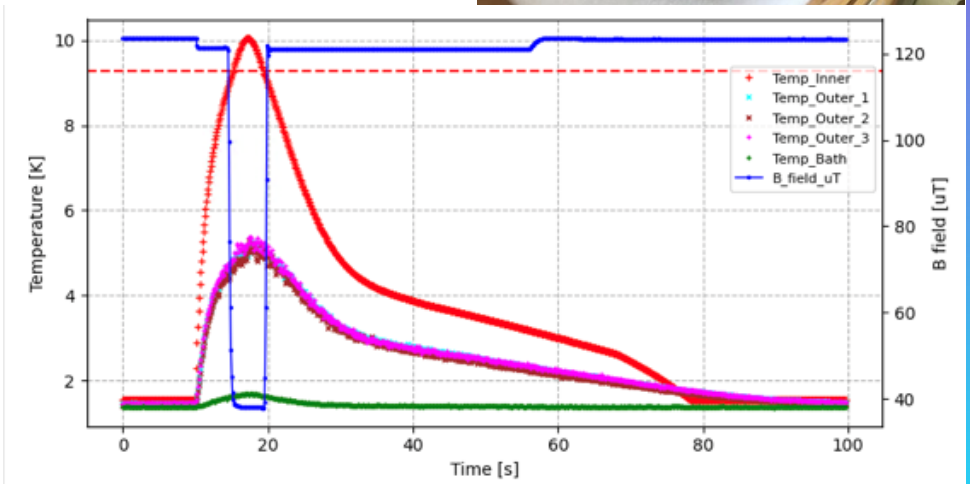
- 1.3GHz Nb on Cu cavities results shown below
- ‘On-demand’ cryostat being used for flux lens project
- Plans for mobile UCC system, like those found in SM18, which can be used in cryolab
- **Limitations**: <u>Radiation</u>



Flux Lens



*Limited by radiation

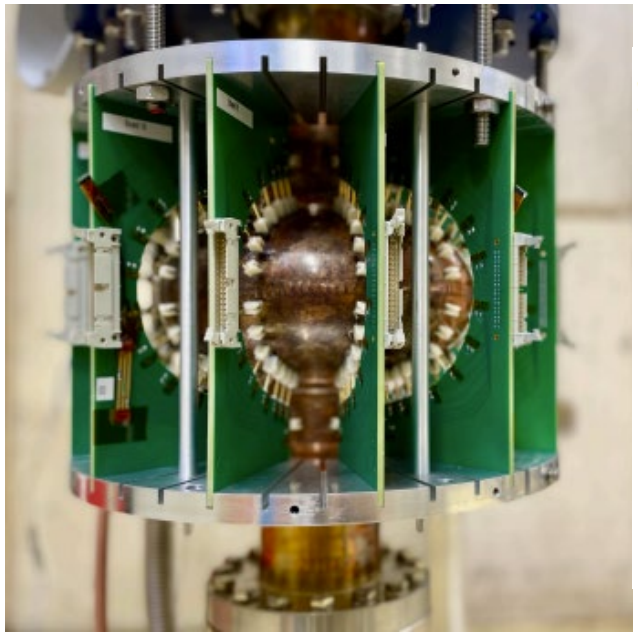


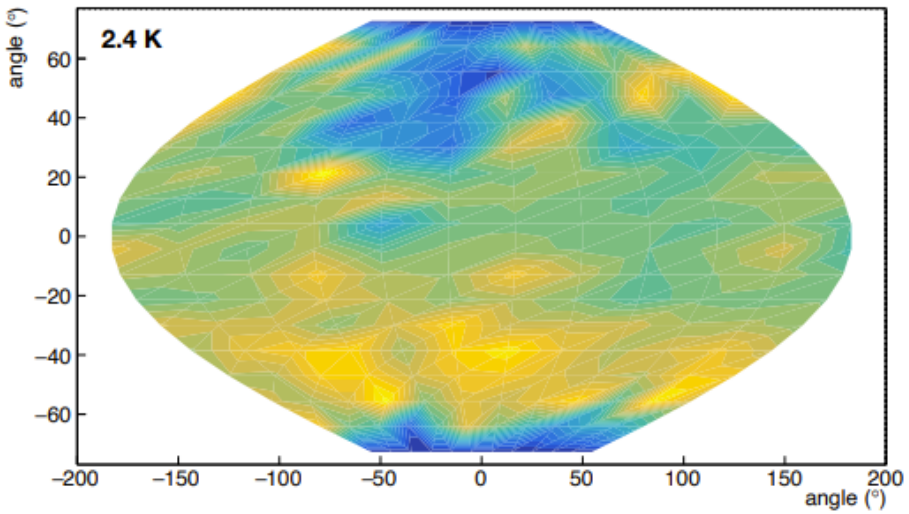
Cryolab Thermal Mapping

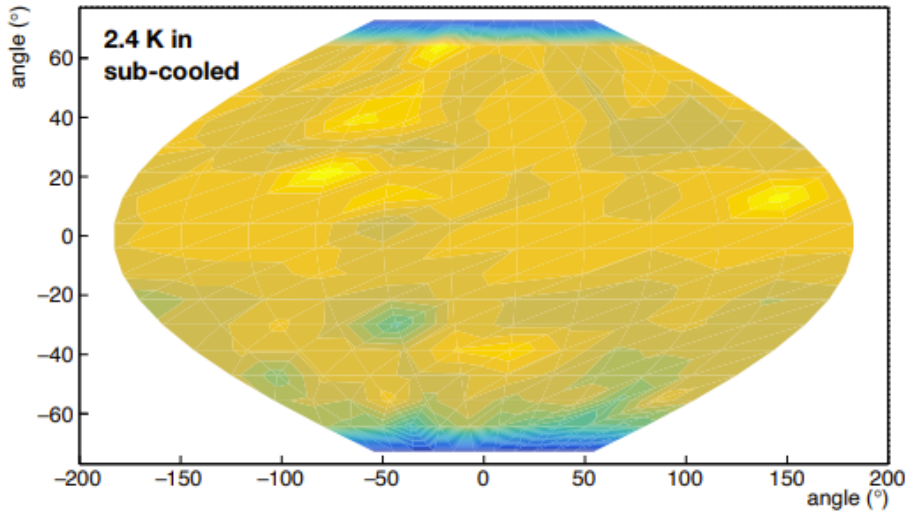
- Designed specifically for measurement of heat dissipation on Nb on Cu cavities

- 192 thermometers in 12 boards
- 4 calibrated thermometers
- 480 feedthroughs in 3 PCBs

- Max sample rate = 100kS/s
- 6 multiplexers + 12 ADC channels





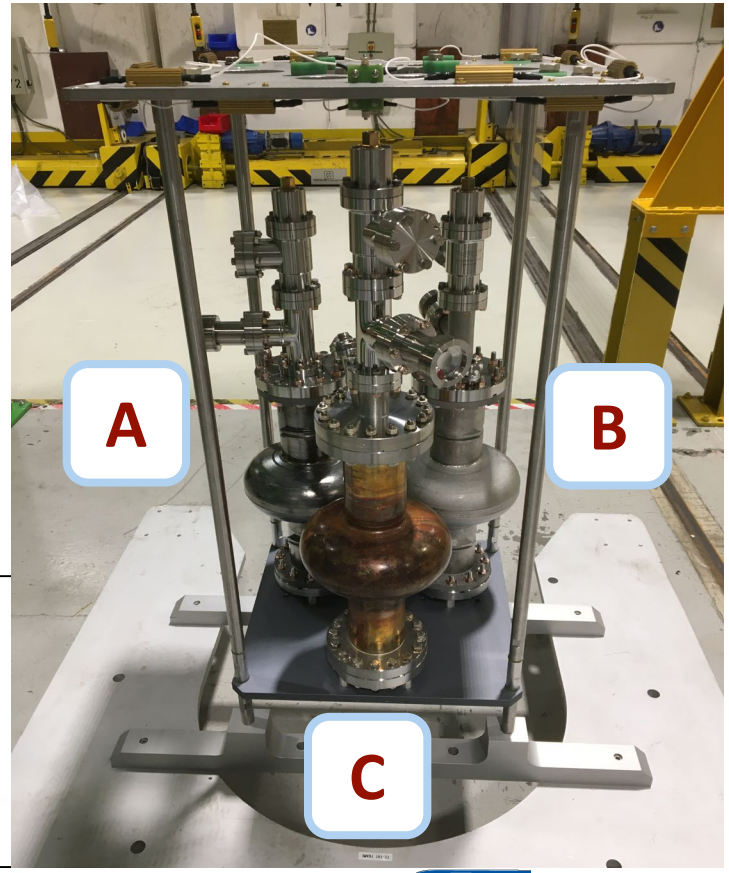


Credit : Antonio Bianchi

3 x 1.3GHz Cavity Insert Configuration

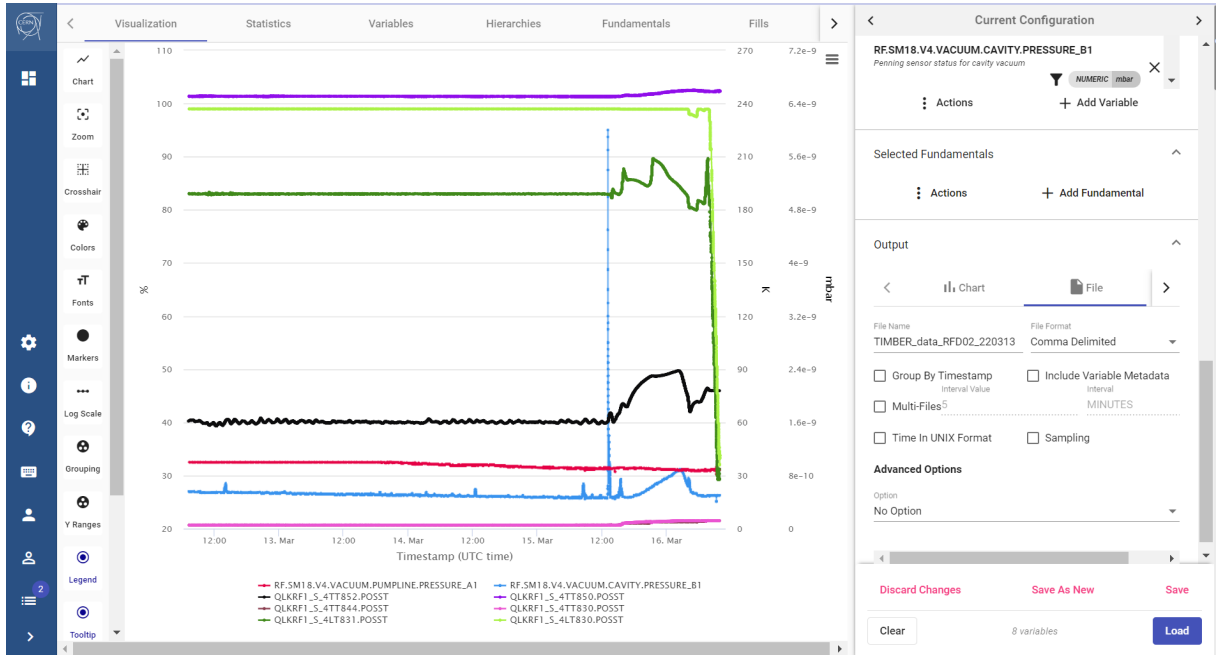
Motivation

- Comparative RF measurement of 1.3 GHz cavities : identical environmental conditions
- Comparison of RF results between Cryolab and SM18
- Validate testing with cavities under static vacuum: simplifies cavity preparation sequence
- Raise field emission threshold (compared to cryolab)
- Increase throughput



Cavity A – 1.3GHz Bulk Nb
Measured as reference Nb Cavity
Cavity B – 1.3GHz Bulk Nb
Cavity micro-mechanical polished
Cavity C – 1.3GHz Thin film cavity
HiPIMMs Nb coated copper cavity

Timber – Data Logging



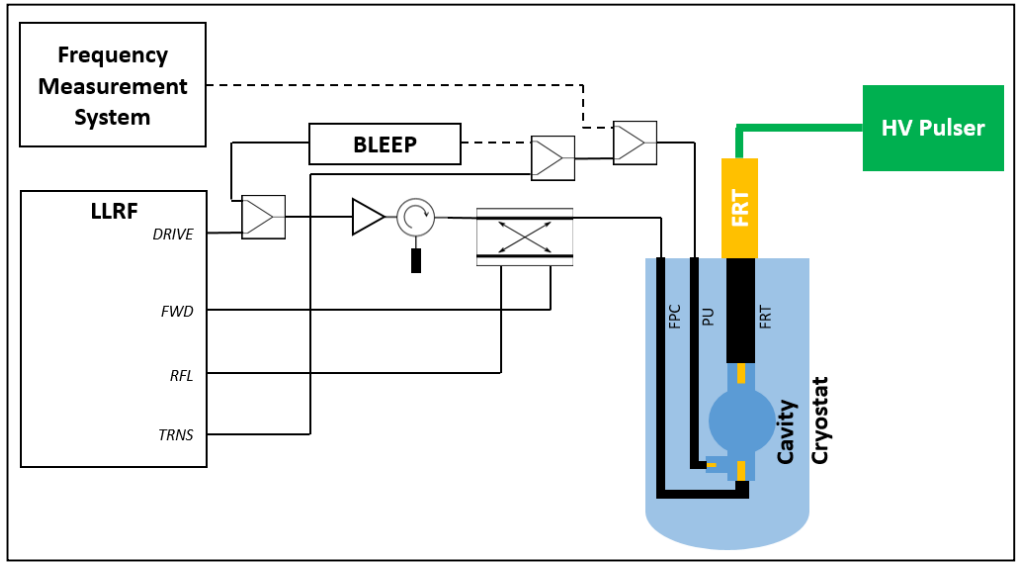
- CERN Accelerator Logging Service
- Includes SM18 environmental data for each test stand
- PyTimber - module for extracting and processing data stored in database

Cavity producers

Pending Projects				
Project name	**Frequency (MHz)**	**Number of cavities**	**Operating temperature [K]**	**Comment**
Crab [Hi-Lumi LHC]	401	DQW - 10 (x3 tests each) RFD - 2	2	Bare / with couplers / with He tank
LHC Spares	400	4	4.5	
HIE-ISOLDE	101	32	4.5	
Foreseen Projects				
SWELL [FCC]	1300	1	4.5	SRF Workshop (INDICO 1103356)
FCC Elliptical	400	2-4	4.5	
R&D				
Nb Multi-cell	704 & 800		1.8	CERN Internal
Single Cell Cavities	1300		1.8 – 4.2	CERN Internal
Tuning Devices	400	N/A	1.8 – 4.5	Transient Detuning Project

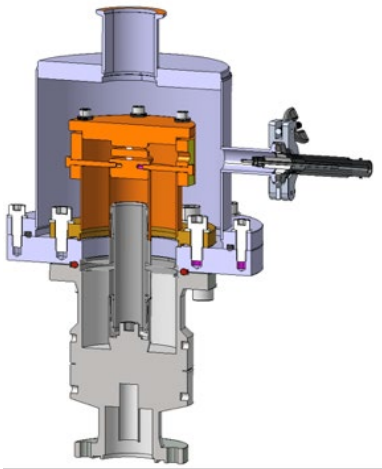
Ongoing R&D

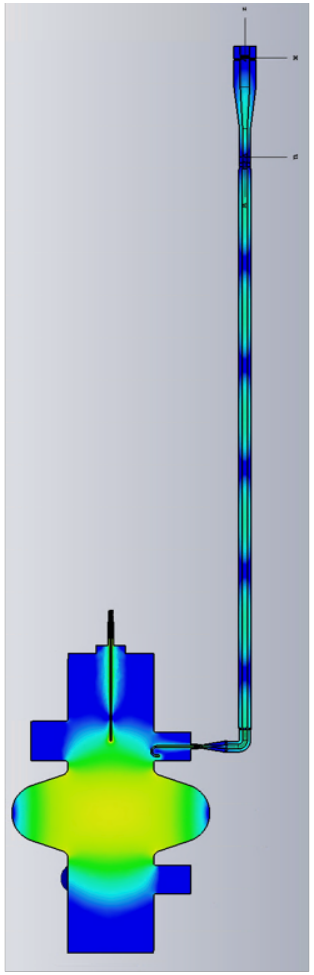
Beam **L**oading **E**lectronic **E**mulation **P**roject

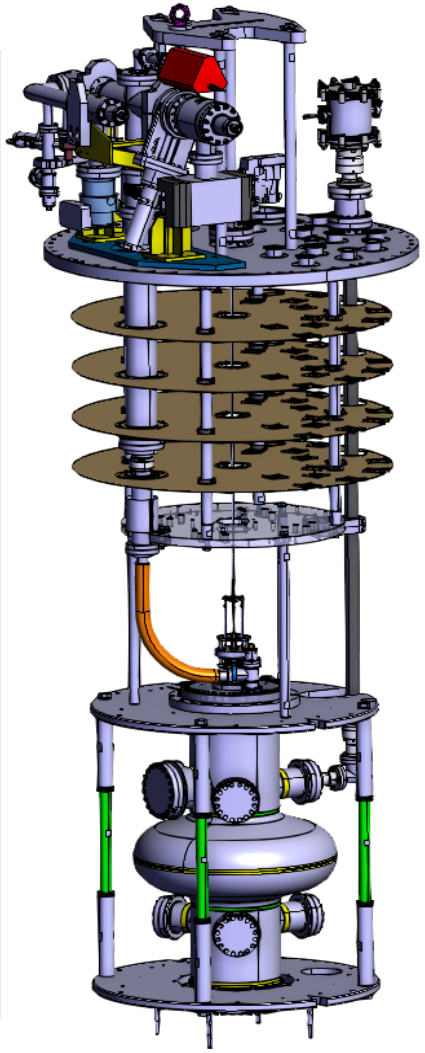


Mobile UCC (cryolab/V5)
UCC Upgrades

Example of transient tuning







Questions?

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

Upcoming Upgrade of SEL

- Built in simple spectrum analyser functionality
- Wider bandwidth (dynamic)
- Latest generation FPGA – custom logic for experiments such as FRT
- Up-rated ADCs – 6 x 14-bit, 100MS/s
  - Ch1-4 : V_{fwd}, V_{rfl}, V_{inc}, V_{cav}
  - Ch5 : Output (Drive)
  - Ch6 : Cavity Antenna Frequency
- Conditioning brake – faster
- Phase-following polar loop on P_{fwd} & Magnitude Loop on P_{trns}
- Peak detection in a window

Range of Operation	350 – 1350 MHz
IF Bandwidth	5MHz (≈0.1dB gain flatness)

Stock	12
Cost per card	≈ 2k CHF
Inc. VME + FEC	≈ 7k CHF