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Test Plan for Cryomodule testing at ESS Test Stand 2

Emilio Asensi

Test Stand Engineer

With slides and diagrams from Nuno Elias and Cecilia Maiano

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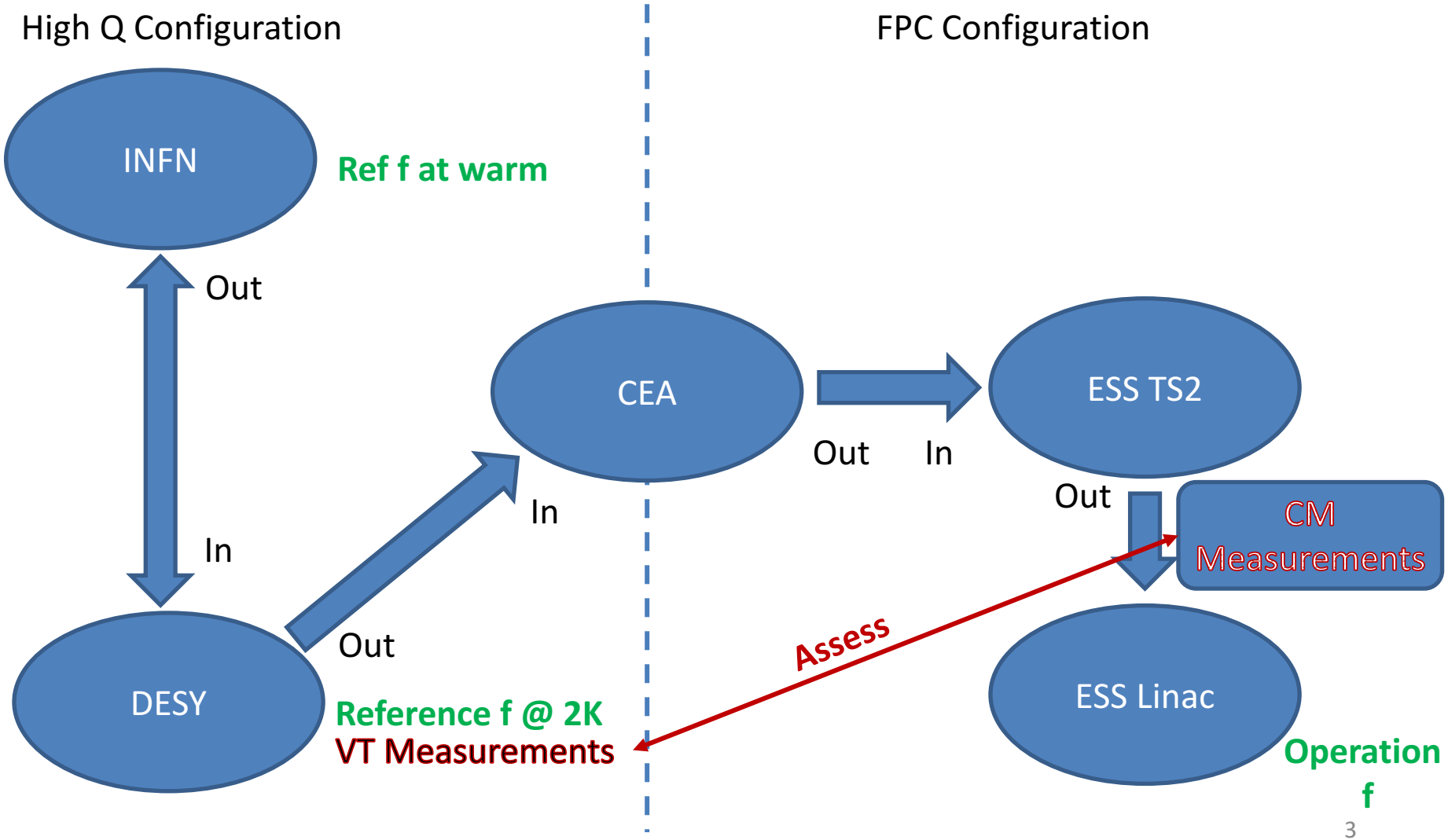
Outline

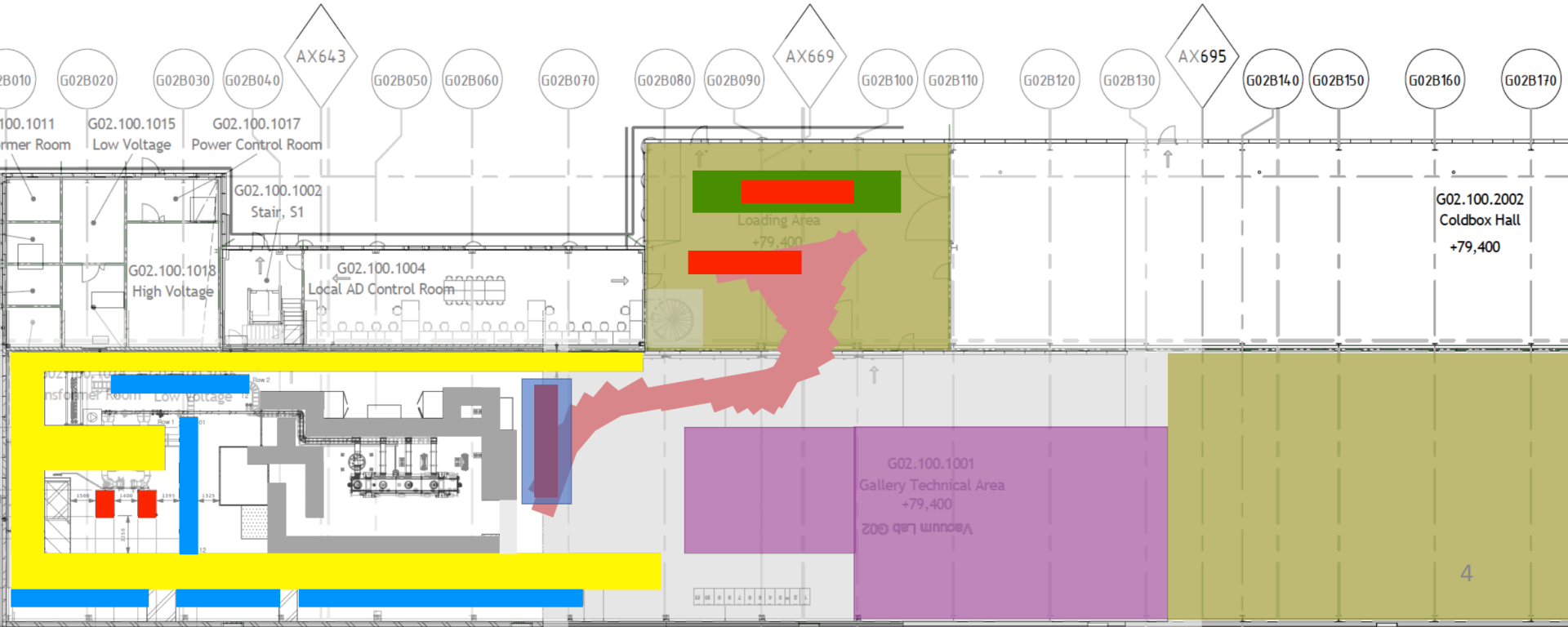
- Prelude: Cavities Flow
- Reception
- Preparation for test stand
- Initial RF measurements
- Installation in test stand
- Warm Tests
- Cool down
- LP Cold Tests
- HP Cold Tests
- Warm up
- Disconnection
- Preparation for dispatch
- Dispatch

Medium Beta Cavities Flow



Reception (1 day)

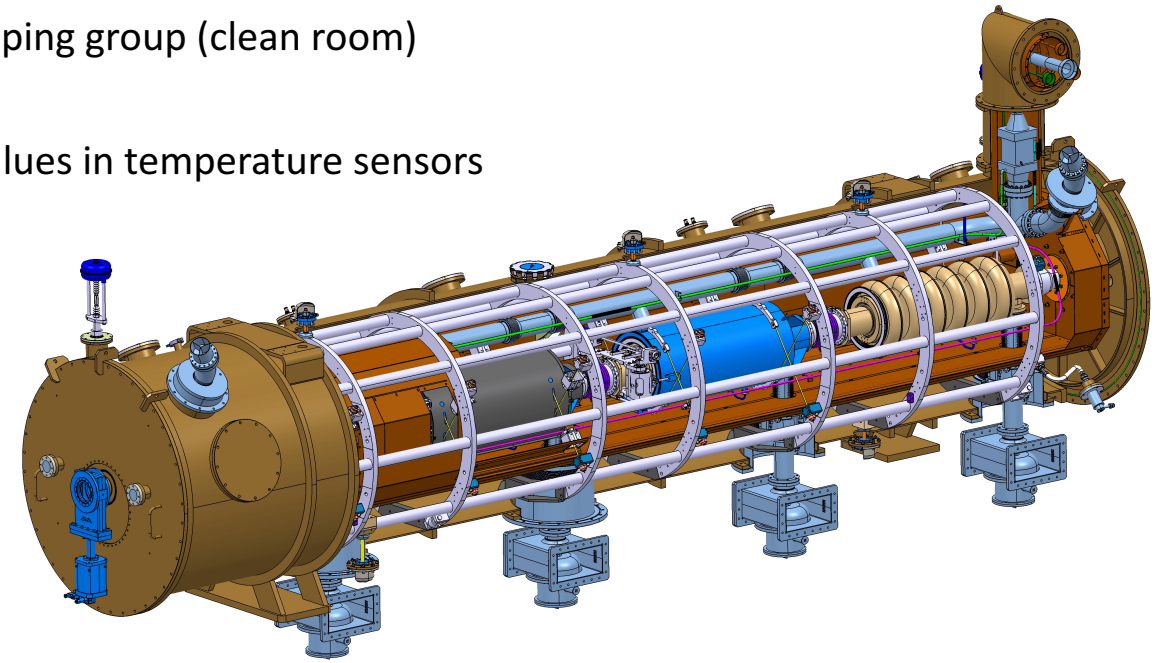
- Prepare reception checklist
- Check transportation documents
- Check if CM is properly fixed in the container
- Check utility box and its content
- Read-out of shock loggers
- Unload CM and place it in a support
- Read-out beam vacuum
- Visual inspection for damage



Preparation for test stand (3 days+)

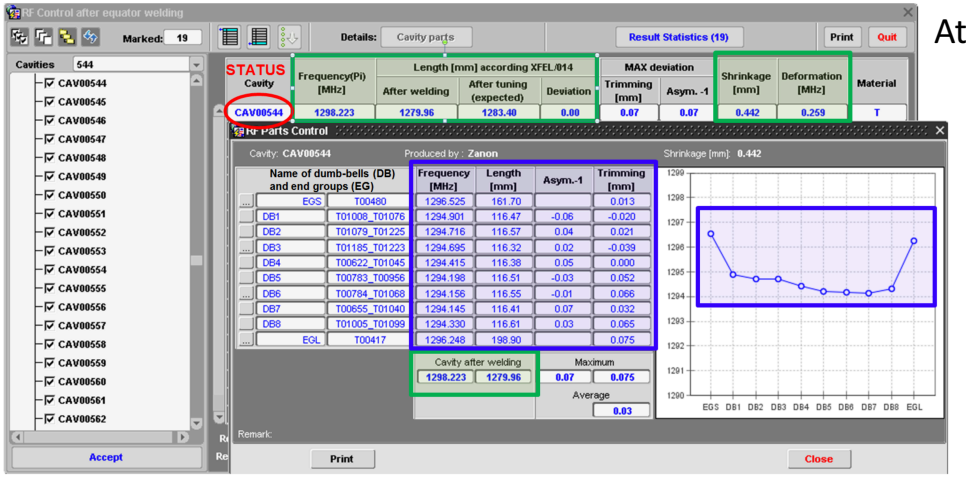
- Mounting of door knobs with cavities at atmospheric pressure? (+3 days)
- Mounting and dismounting of parts
  - Cavities supporting bar
  - Door knobs (1 day+)
- Vacuum leak checks
- Connect insulation vacuum pumping group
- Connect beam vacuum pumping group (clean room)
- Check electrical continuity
- Check nominal resistance values in temperature sensors
- Check step motors

Before **Doorknob assembly** it is NOT possible to perform any RF measurement, unless CEA provides the temporary antenna (used at Saclay).
This "temporary" tool would be useful for the incoming check!

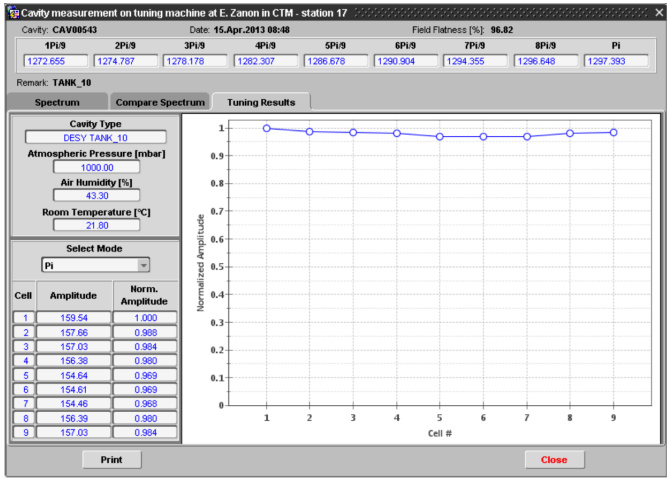


Initial RF measurements (1 day)

- Measure piezo capacitance/Tuner functionality (on short range)
- Measure inner RF cabling (TDR), length and shorts
- Measure Warm spectrum, transmissions and dangerous HOM (WR1150-N transitions-PU flange)
- Compare results with CEA and cavity IKC
- Fill incoming inspection report

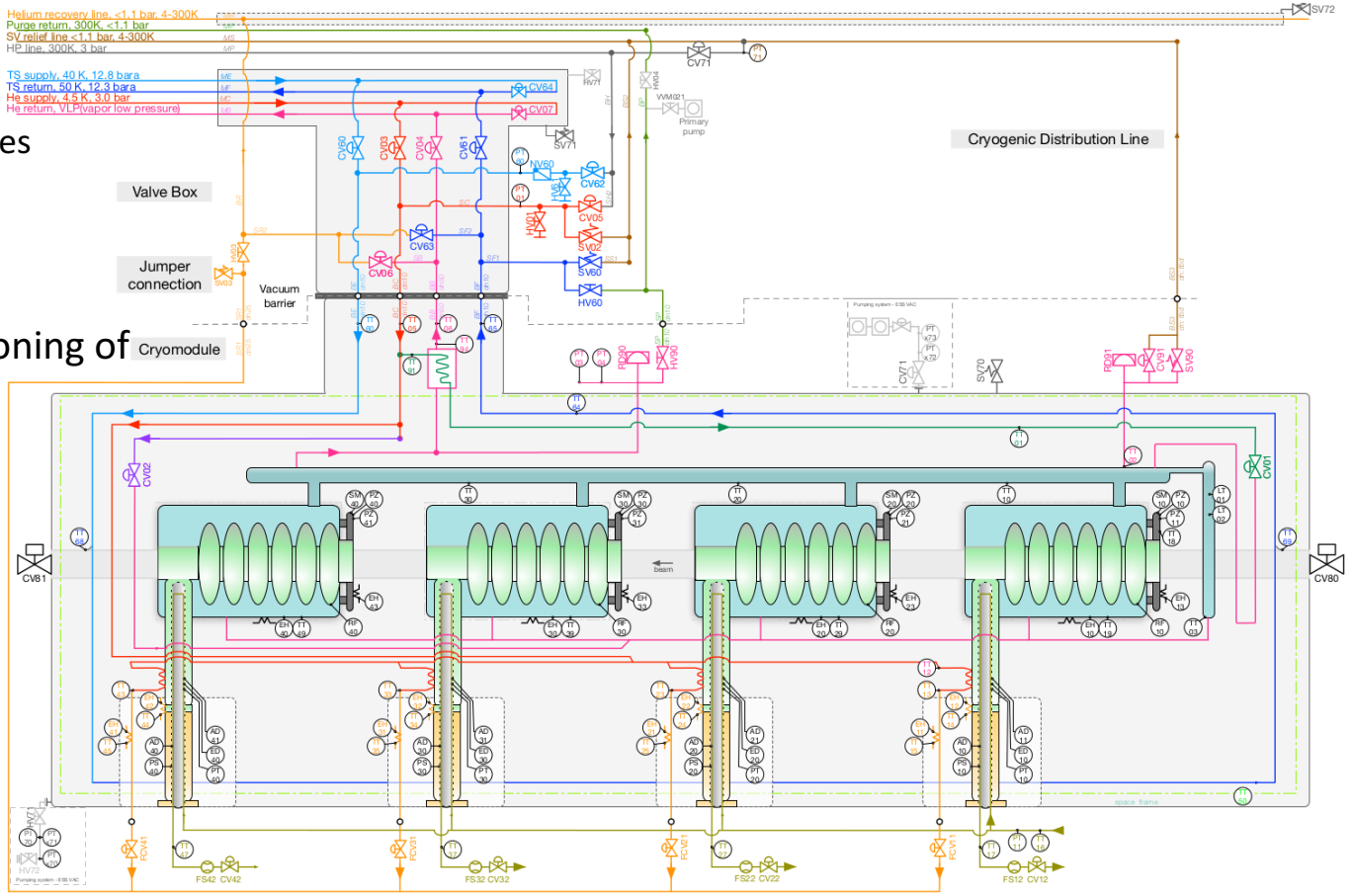


Online cavity data analysis (ex. from XFEL CAV DB)
At ESS being implemented by SRF in the CM3T from ICS



Installation in test stand (3 days+)

- Move Cryomodule inside bunker
- Perform and check interconnections
  - Waveguides
  - Cryolines
  - Cooling water pipes
  - Instrumentation
  - Compressed air
- Check proper functioning of
  - Interlocks
  - Control System



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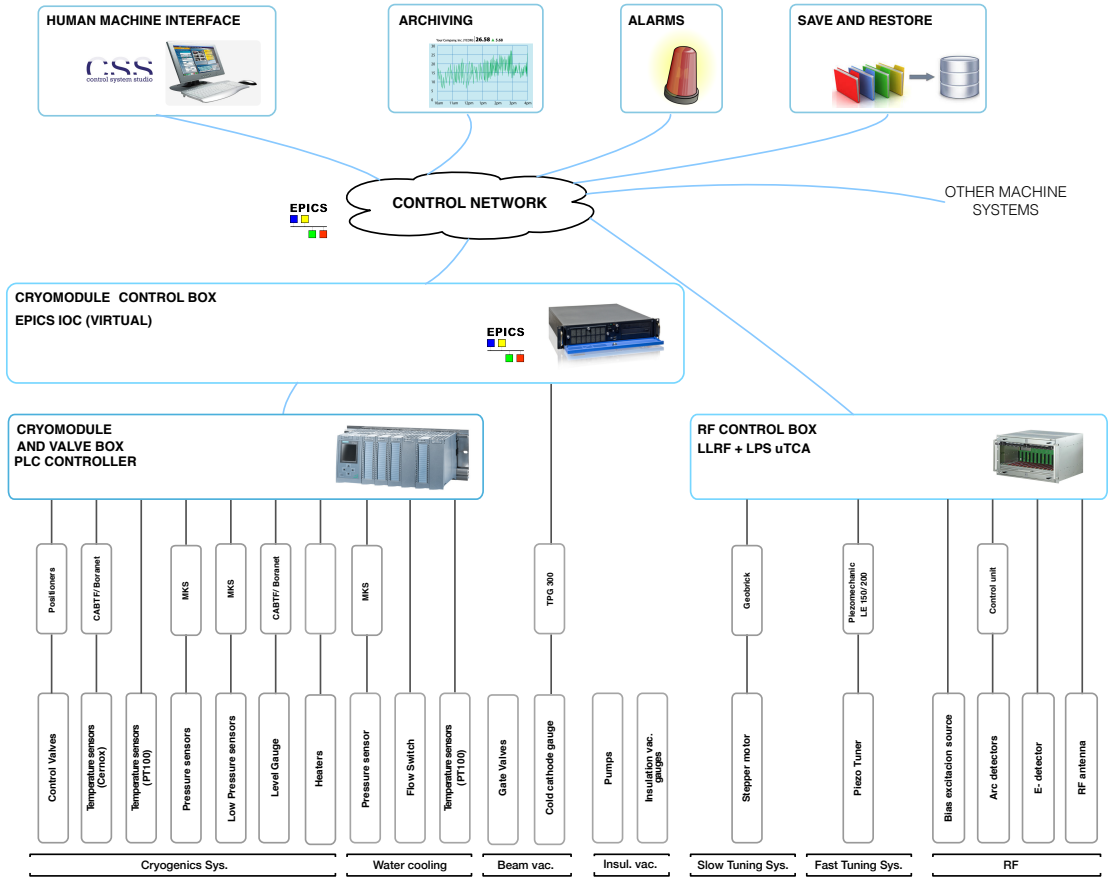


Warm Tests (1 day+)

Spectra Measurements

VNA S21 Coupler/PU – two options:

1. **Instruments Inside bunker**
   - WR1150-N at doorknob, PU on module flange
   - This means that waveguide *cannot* be connected in the previous point
2. **Instruments Outside bunker** **(preferable solution)**
   - WR1150-N installed outside, PU signal available at some patch panel on RF rack
   - This means waveguide installation inside the bunker, but section outside needs to be opened (disconnecting klystron)

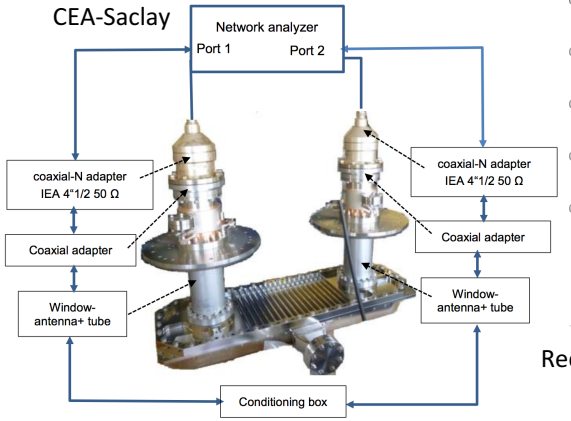
- ***Static* calibration**
  - Dir. Couplers/Circulators: **get** calibration data
  - Calibrate RF power measurement cables with attenuators
  - Document: RF calibration summary table
- **Klystron/LLRF** check on the load
- **WGs** visual check
- **System check / RF leak** check at low power (not if waveguide is not yet reconnected)

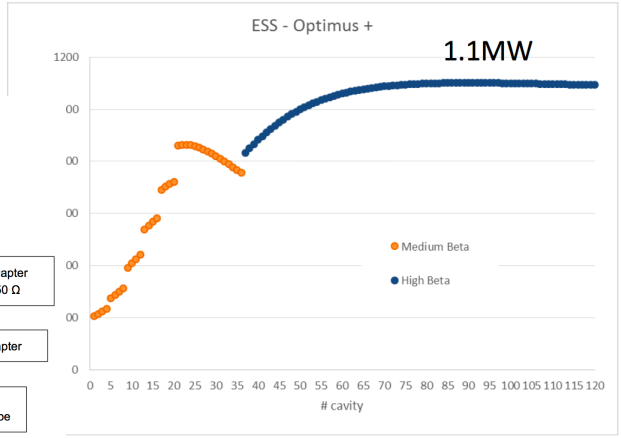
Power Coupler Conditioning (1 day+)

- Taking into account of 30% power overhead need for LLRF regulation, and full reflection at the beginning of cavity filling, **significant high peak power handling** is expected in elliptical cavity/coupler conditioning.
- **CEA** conditioning experience offers valuable and particular high-power input to abstract **high level logical schema**
  - EPICS Procedures will be implemented, using guidance from conditioning experience at CEA and FREIA

1 day allocated but no experience so far in module test stands!

Back-to-back power coupler conditioning system at CEA-Saclay





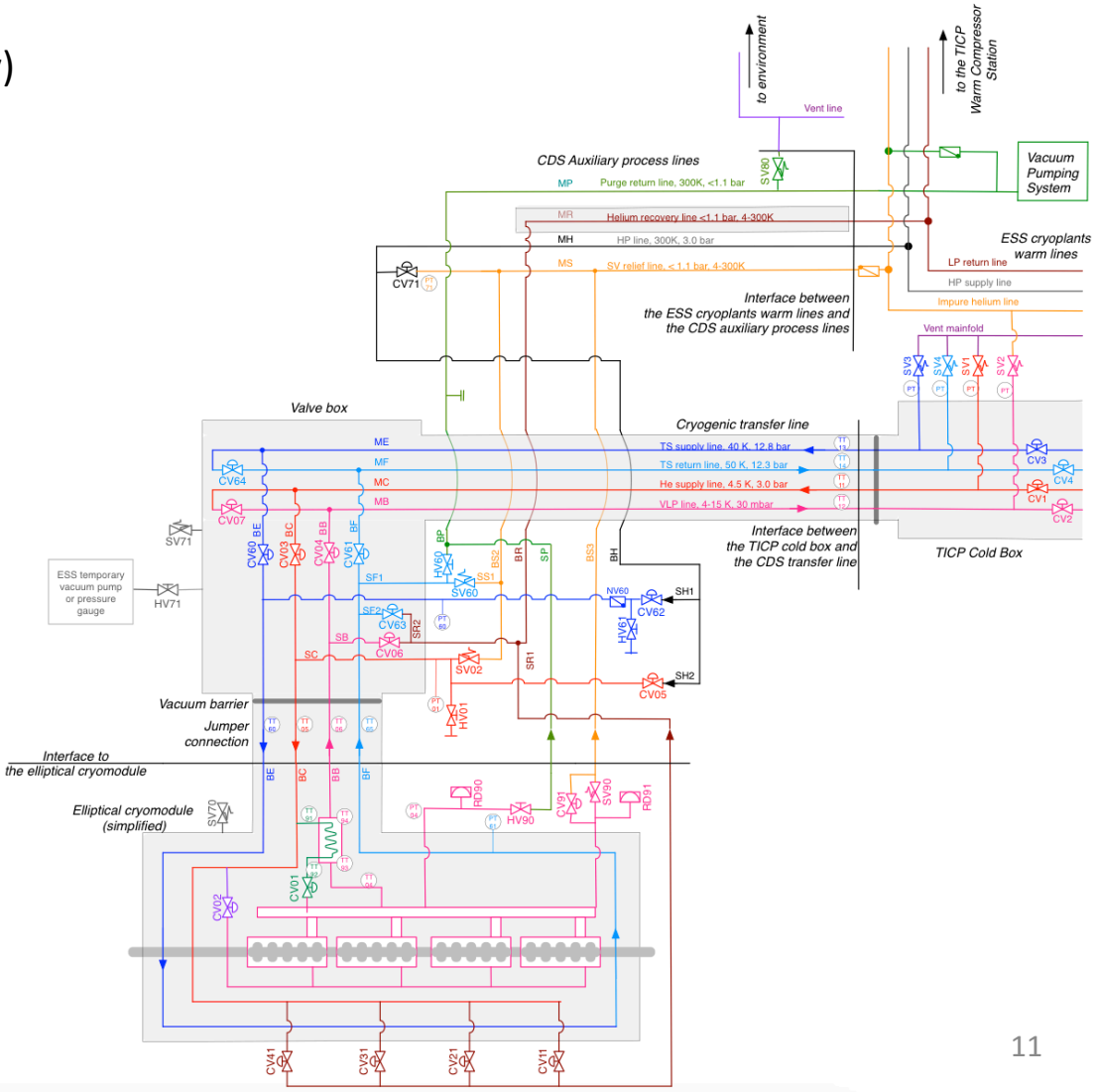
Required peak beam power in ESS elliptical cavities

Parameters to be checked/under control

- vacuum levels
- arc detection events on vacuum and air side (the most of these events are expected to happen on the air side)
- Multipacting events
- RF (f/r power to couplers)
- Temperature (box, window, water)
- Water flowmeter
- Security signals (vacuum, water)
- …

Cooldown (2 days)

- Purge and clean cryolines (-1 day)
- Leak checks (-1 day)
- Cool down to 4.5 K
- Cool down to 2 K
- Fill cool down report
- Complete thermal stabilization



LP Cold Tests: initial actions (1 day)

Initial measurements:

- Fundamental Bandwidth Measurement (inside/outside bunker-transmission or doorknob)- check of proper frequency shift/MSE analysis

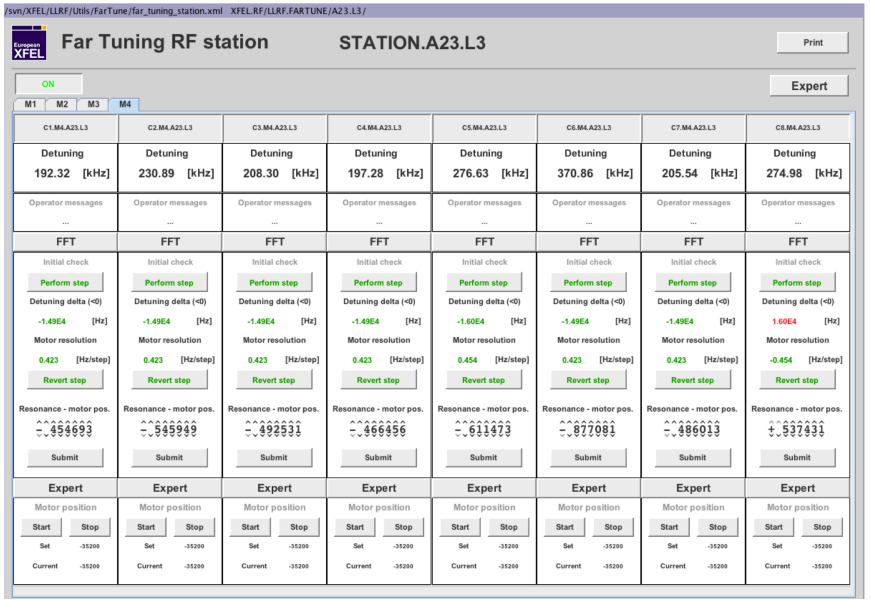
Cold cable calibration

- VNA, S11 measurements at each cold cable (PU)
- Document: RF Power calibration final table

Cavity pretuning to operating frequency

1. Cavity connected to VNA (move motor tuner until frequency is reached on the **VNA** and record the needed number of tuning steps for the tunnel pre-tuning instructions (comparison with the expected steps).
2. (No VNA) e.g. **"EXFEL Far tuning tool"** (LLRF team, W. Cichalewski) FFT of the probe signal from the cavity excited at the nominal frequency to determine the **large** detuning

   Or other LLRF-based mode to detect cavity frequency when it's approx 200 BW away from machine (ongoing discussion with LLRF).



Piezo capacitance measurement

- Dedicated Piezo Operation and Tuner Test Apparatus

LP Cold Tests (2 days+)

- Microphonics measurement
- Piezo scans: cavity detuning transfer function
- Lowest bandwidth mode identification
- Fine tuning with LLRF
  - Drive LLRF in open loop FF pulsed mode (rectangular pulses ok) at low klystron power
  - Maximize level of transmitted power → approaching resonance
  - Use detuning information from LLRF server to perform last tuning steps
  - Record the tuning steps for the final tuning for future operation in Linac
- Calibrate RF pickup signals
  - Extract decay time from Pt at end of pulse, compute QL
  - Evaluate E_{acc} from $P_{forward}$ measurement
  - Measure Pt and determine Gradient calibration constant kt
  - Store and document calibration data in report
  - Correlate with CEA and VT data
- Establish closed-loop, feedback operation
- Detune the cavities (for cold processing)

HP Cold Tests (5 days+)

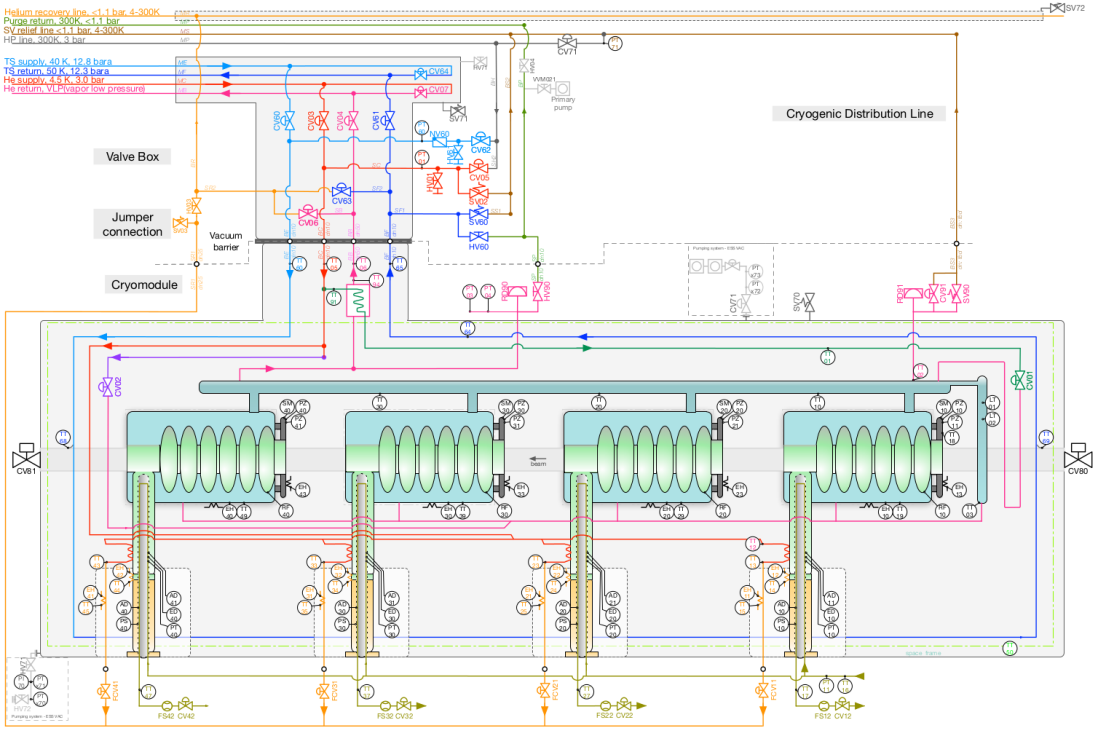
- Cold Coupler and Cavities Conditioning (1 day +) **no experience so far in module test stands!**
- Power rise to nominal gradients (in-kind VT data)
- Open loop and closed loop operation
- Active piezo Lorentz force detuning compensation
- Cryomodule gradient performance assessment *Acceptance*
- P_{for} power used to drive a cavity to the quench limit
- Identification of limiting mechanisms (power, X-ray, quench, ...) **[MV/m]**
- X-rays measurements
  - X_{rays} start – Value of gradient when radiation starts **[MV/m]**
  - X_{rays} quench – Value of radiation just before cavity quench **[mGy/min]**
- Data storage, correlation with VT data Power Rise to nominal gradients
- Optimization of the LLRF parameters
- Heat Loads measurements (1 day+)
- Cavities to parking position
- Fill test report

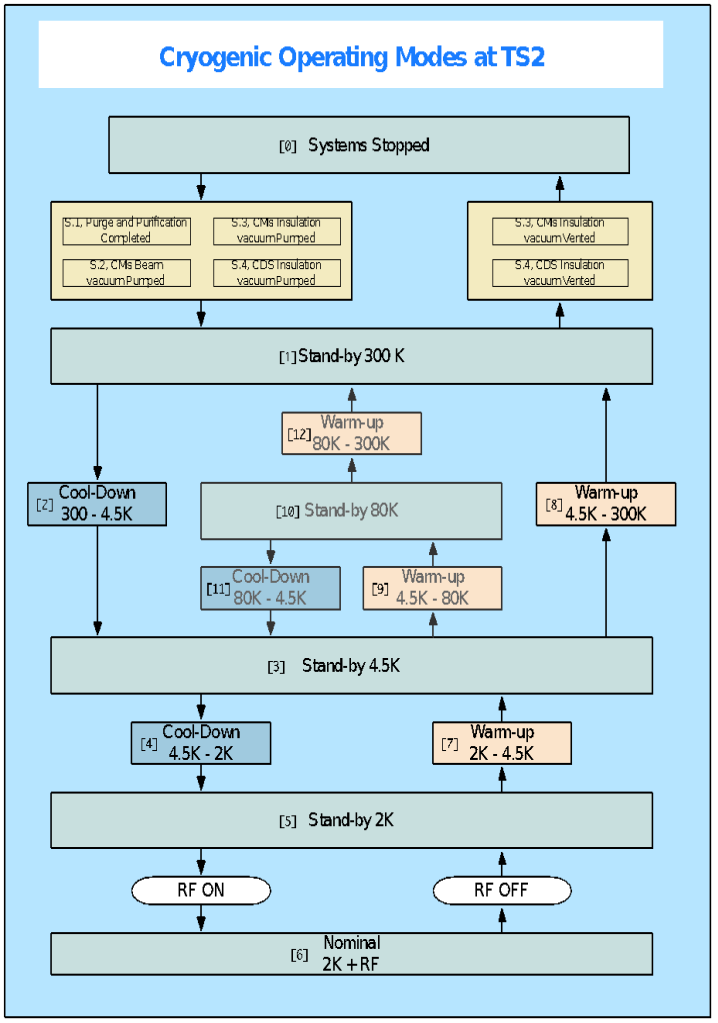
CEA coupler test stand conditioning sequence

Main Power Coupler conditioning sequence		
Parameter	**Value**	**Units**
RF frequency	704.42	[MHz]
Final Repetition rate	14	[Hz]
Vacuum thresholds	???	[mbar]
Travelling Wave (Coupler Test Stand)		
RF ramp up (at each length)	15 – 1200	[kW]
Repetition Frequency	1, then 14	[Hz]
Pulse length	30 – 3600	[μs]
Pulse length steps at different rates		
at 1 Hz	0.03, 0.1, 0.2, 0.4, 0.8, 1.2, 1.6, 2, 2.5, 3, 3.6	[ms]
at 14 Hz	0.2, 0.4, 0.8, 1.2, 1.6, 2, 2.5, 3, 3.6	[ms]
Duration of the procedure	120	h
Standing Wave (Coupler Test Stand)		
RF ramp up (short pulses)	15 – 1200	[kW]
RF ramp up (long pulses)	15 – 300	[kW]
Repetition Frequency	1 – 14	[Hz]
Pulse length	50 – 3600	[μs]
Pulse length and rep rate steps		
at 1 Hz, full power	0.05, 0.1, 0.2, 0.3, 0.4, 0.5	[ms]
keeping 0.5 ms, rep rate increase	2, 4, 8, 14	[Hz]
at 14 Hz, lower power	0.8, 1.5, 2.5, 3, 3.6	[ms]
Duration of the procedure	???	h
Warm Conditioning on cavity		
RF ramp up (at each length)	15 – 1200	[kW]
Repetition Frequency	1, then 14	[Hz]
Pulse length	30 – 3600	[μs]
Pulse length steps at different rates		
at 1 Hz	*TBD*	[ms]
at 14 Hz	*TBD*	[ms]
Duration of the procedure	???	h
Cold Conditioning on cavity		

Warm up (1 day)

- Warm up



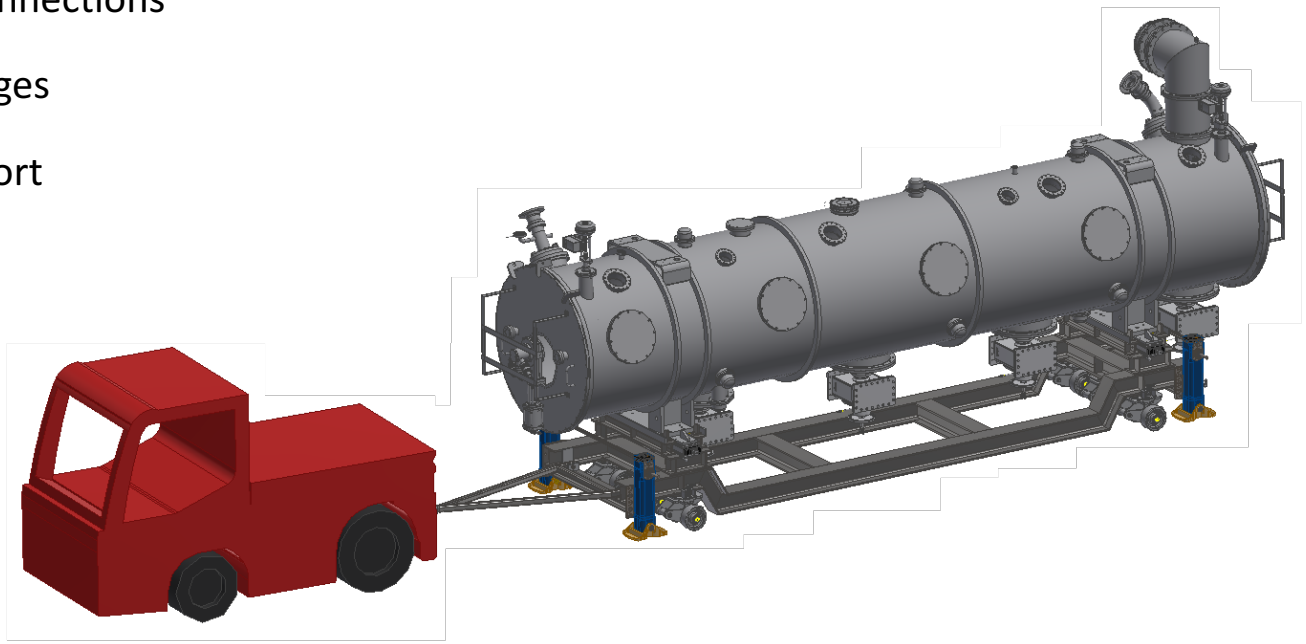


Disconnection (1 day+)

- Perform disconnections
  - Waveguides
  - Cryolines
  - Cooling water pipes
  - Instrumentation
  - Compressed air

Preparation for dispatch (2 days)

- Move Cryomodule outside bunker
- Check frequencies
- Remove vacuum pumping groups
- Cut cryogenic connections
- Install blank flanges
- Fill outgoing report
- Dispatch



Summary

- Detailed testing procedures are being written in collaboration between In-Kind partners, WP10 and SRF specialists.
- Cryomodule Acceptance Criteria comes from WP05.
- Current schedule of 4 weeks/Cryomodule without shifts does not allow margin for retesting, equipment failures or personnel issues (estimated SAT time 24++ days).
  - Coupler RF conditioning time has been estimated in 24 h, but there is no statistics in support of that.
  - We need to gain experience with the ECCTD, also with the firsts series Cryomodules.