Preparation for RFD Cavity & CM Testing @ TRIUMF

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Canadian Contribution, WP4, HL-LHC

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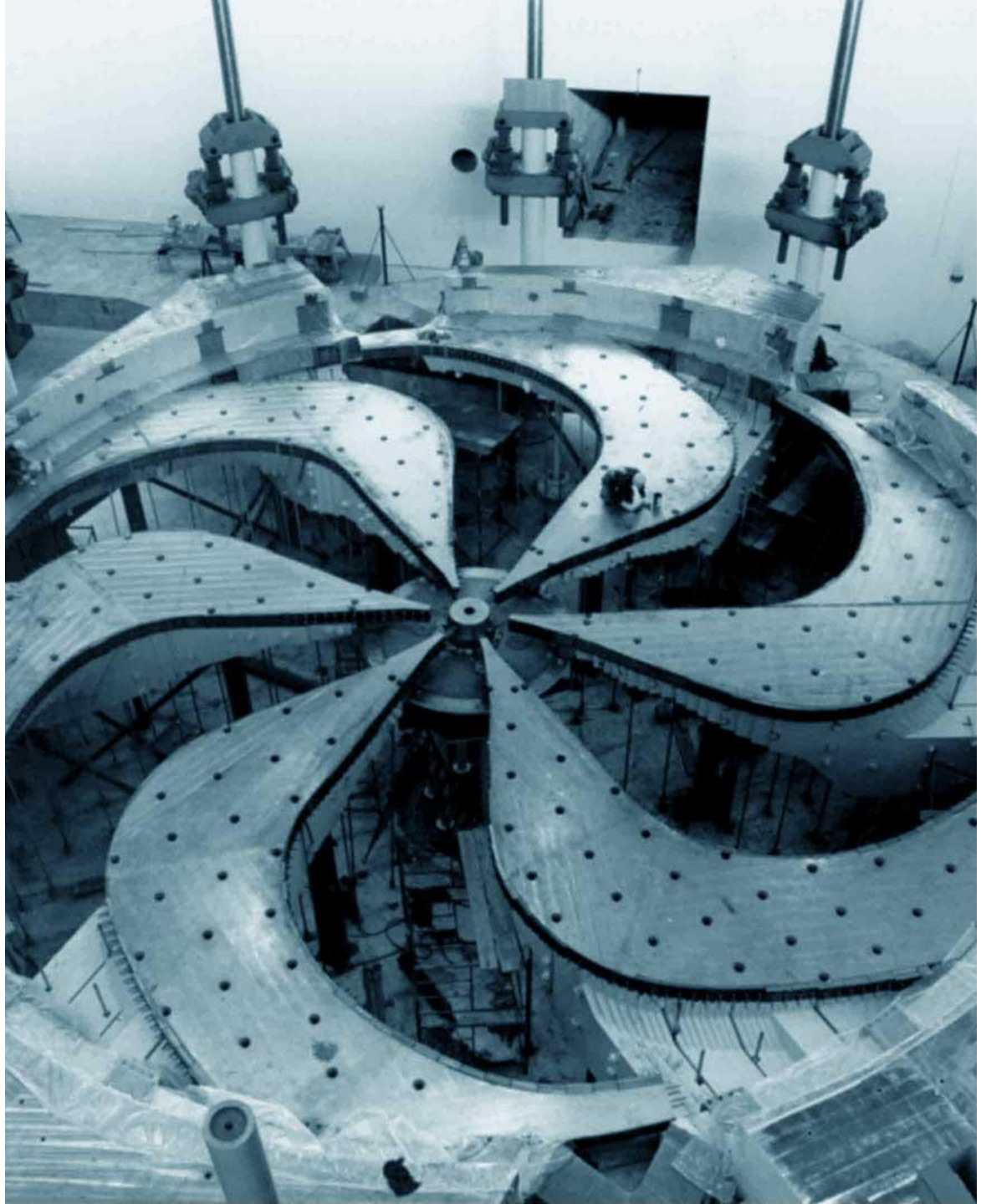
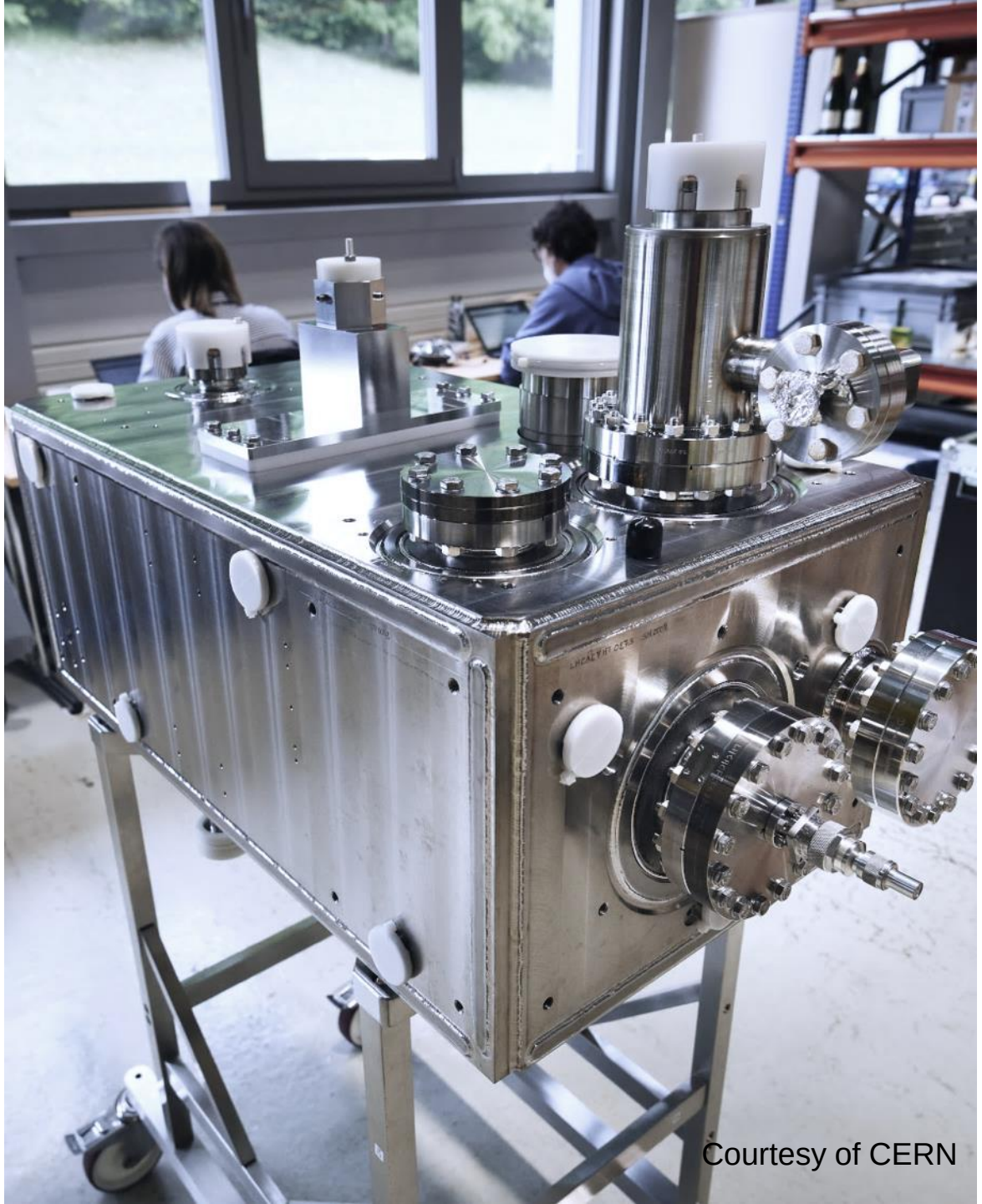


Dressed RFD Cavity Test

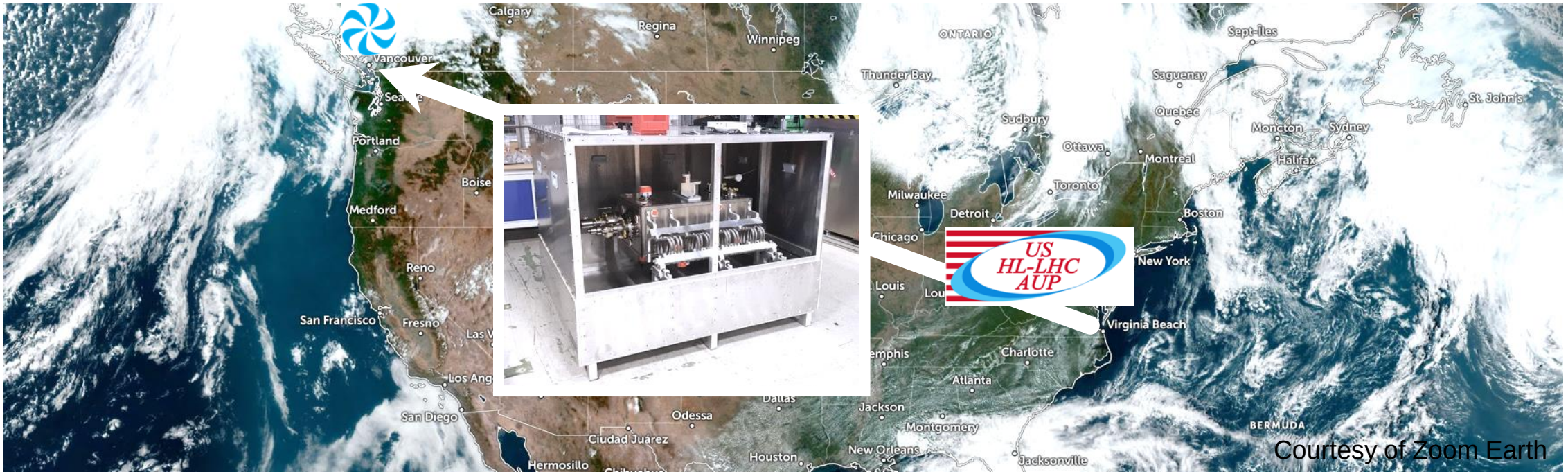
Part 1



Courtesy of CERN

Acceptance Test @ TRIUMF

- TRIUMF will receive qualified dressed cavities from AUP under vacuum and with test coupler
- Goal is to confirm the cavity has not been degraded during transport and is acceptable to be installed in the CM

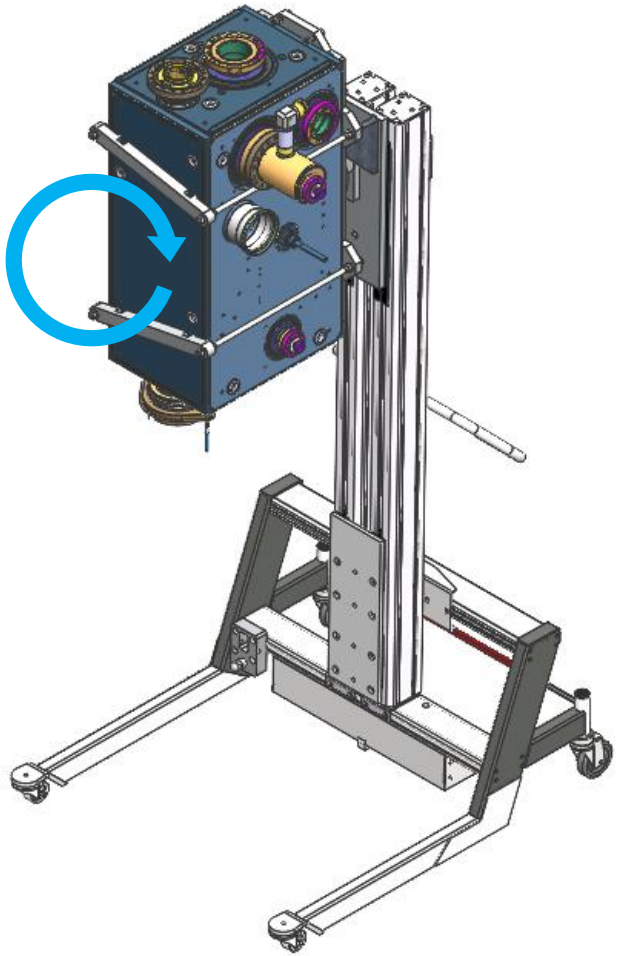


Acceptance Criteria & Test Plan

- Acceptance criteria are established in a document from AUP following CERN's engineering specification
- Part B document (EDMS 2339758) has been revised after the latest release
  - Administrative limit and failure mode analysis added
  - Being discussed with CERN
- TRIUMF drafted a step-by-step test plan (unreleased)
  - To be updated according to the new release of Part B document

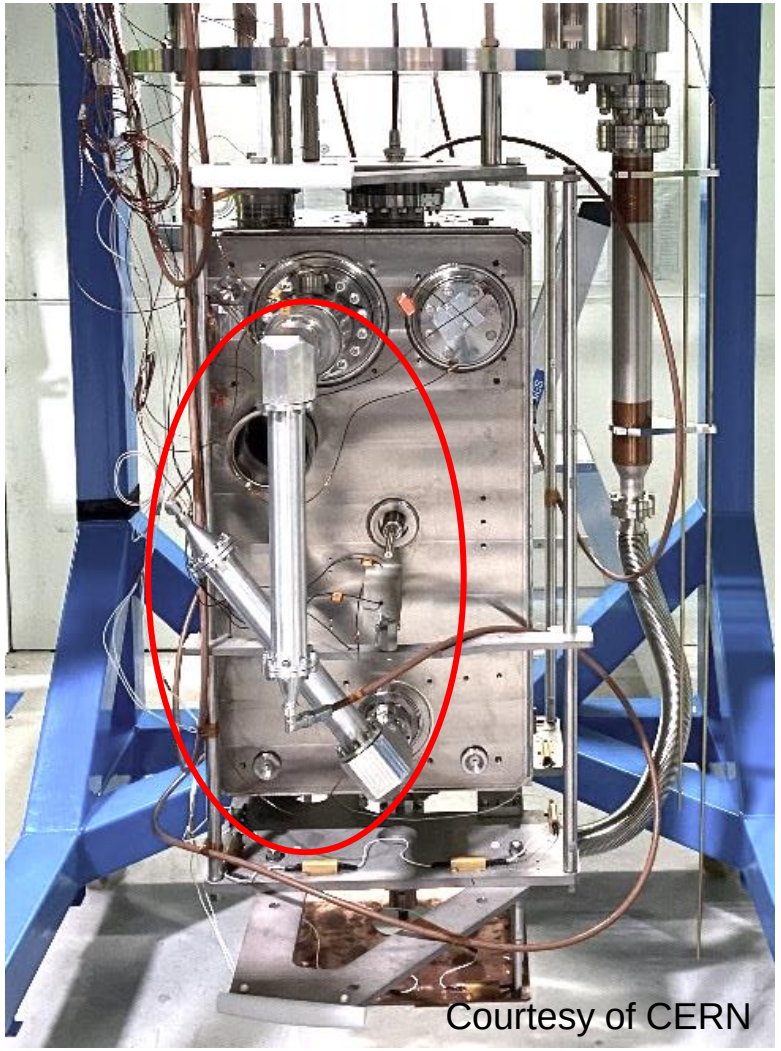
Cavity Handling Cart & Fixture

- Dressed cavity will be taken out of shipping container according to CERN unpacking guidelines (EDMS 2620111)
- Cavity will be moved around by cavity handling cart
  - Cart picks cavity up in horizontal orientation
  - Manipulation fixture allows to rotate cavity to vertical orientation for cryogenic insert assembly
  - Cart and fixture are ready to use



RF Measurements

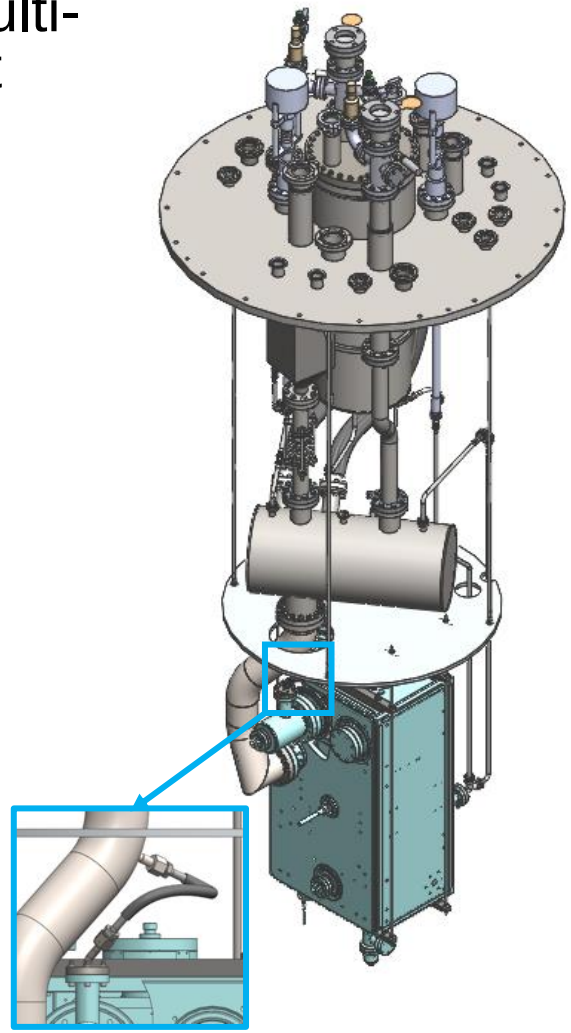
- Cavity will be tested ‘as delivered’
- Visual inspections and review transport shock data will be included
- RF measurements include VNA measurements at warm and cold tests at both 4K and 2K
  - 2K results as the verification of acceptance
- A full set of 25/50Ω adapters is required before any RF measurement



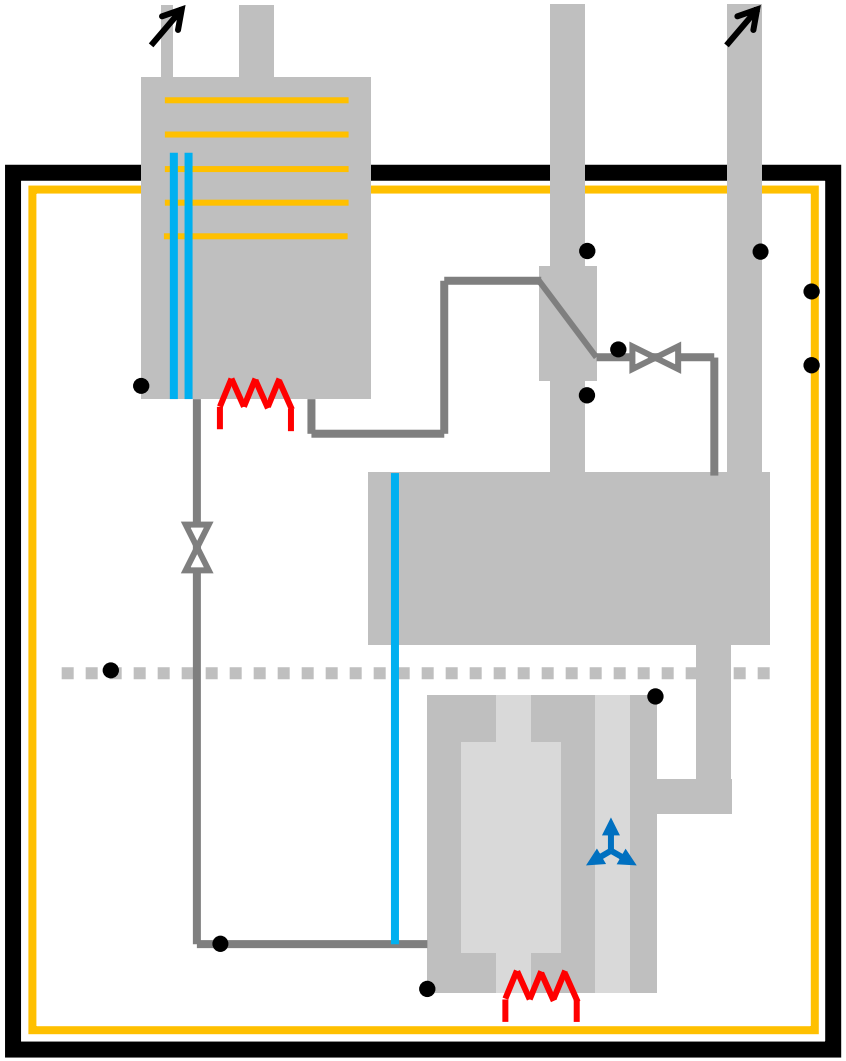
Courtesy of CERN

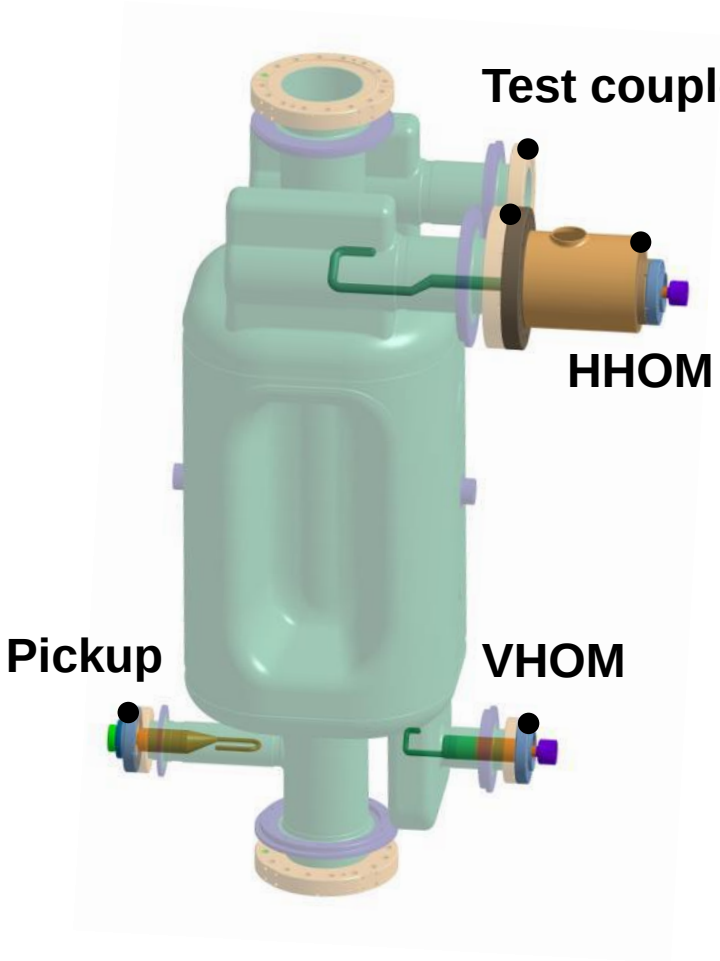
Cryogenic Insert

- 4K/2K unit to produce 2K LHe inside multi-purpose cryostat for jacketed mode test
  - Commissioned with a dummy load
    - Dynamic load up to 25W at 2K
    - Sufficient for cavity acceptance test (≤ 10W at 4.1MV)
  - To be tested with the dummy cavity later this year
    - To verify cooldown speed with a proper cold mass
    - Dummy cavity is ready to use
- Assembly with dressed cavity
  - Cavity mounted to support plate
  - Cryogenic connections to LHe inlet, exhaust and HHOM cooling



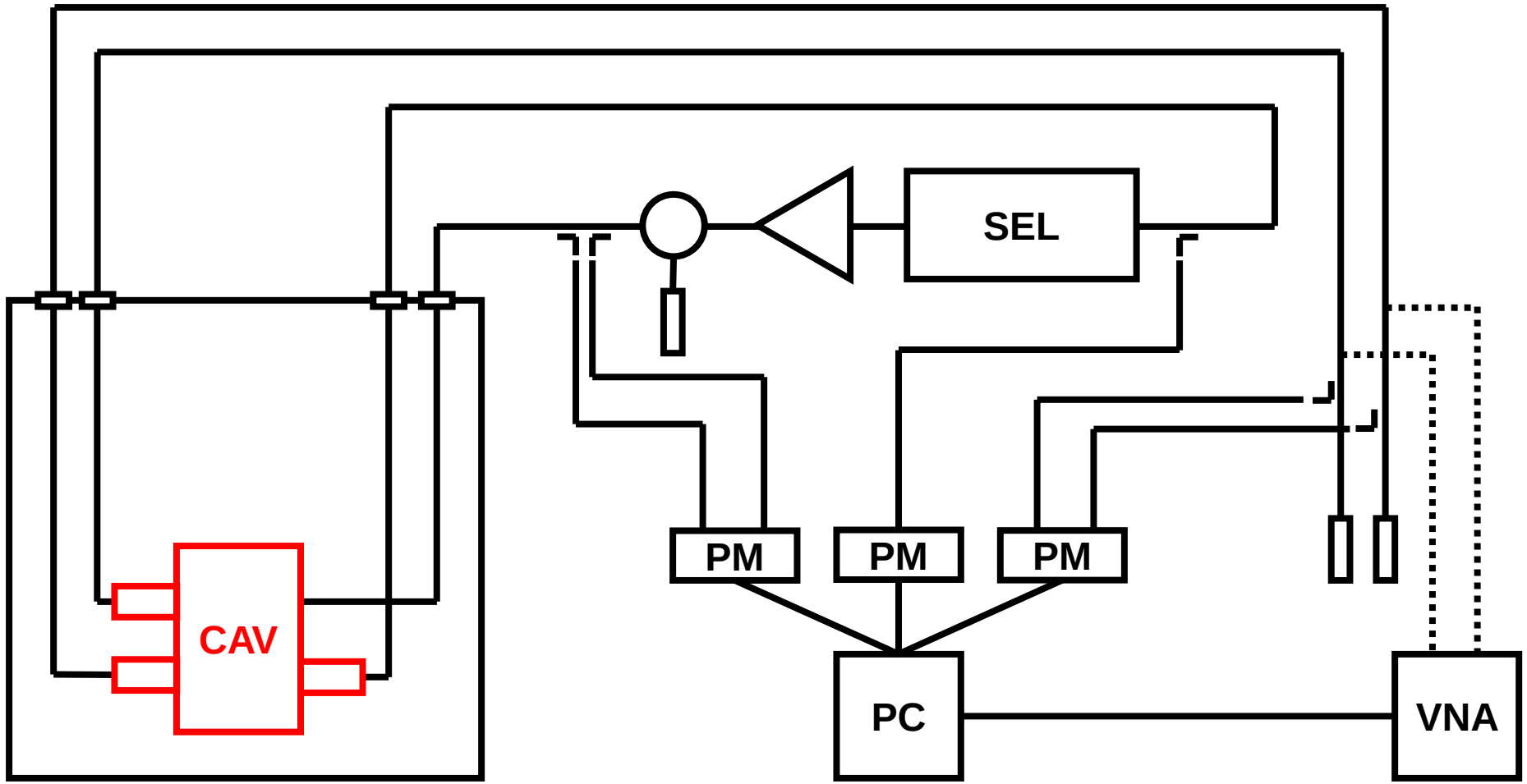
Cold Test – Diagnostics





- pressure gauges
- temperature sensors
- cryogenic valves
- level probs
- fluxgates
- heaters

Cold Test – RF

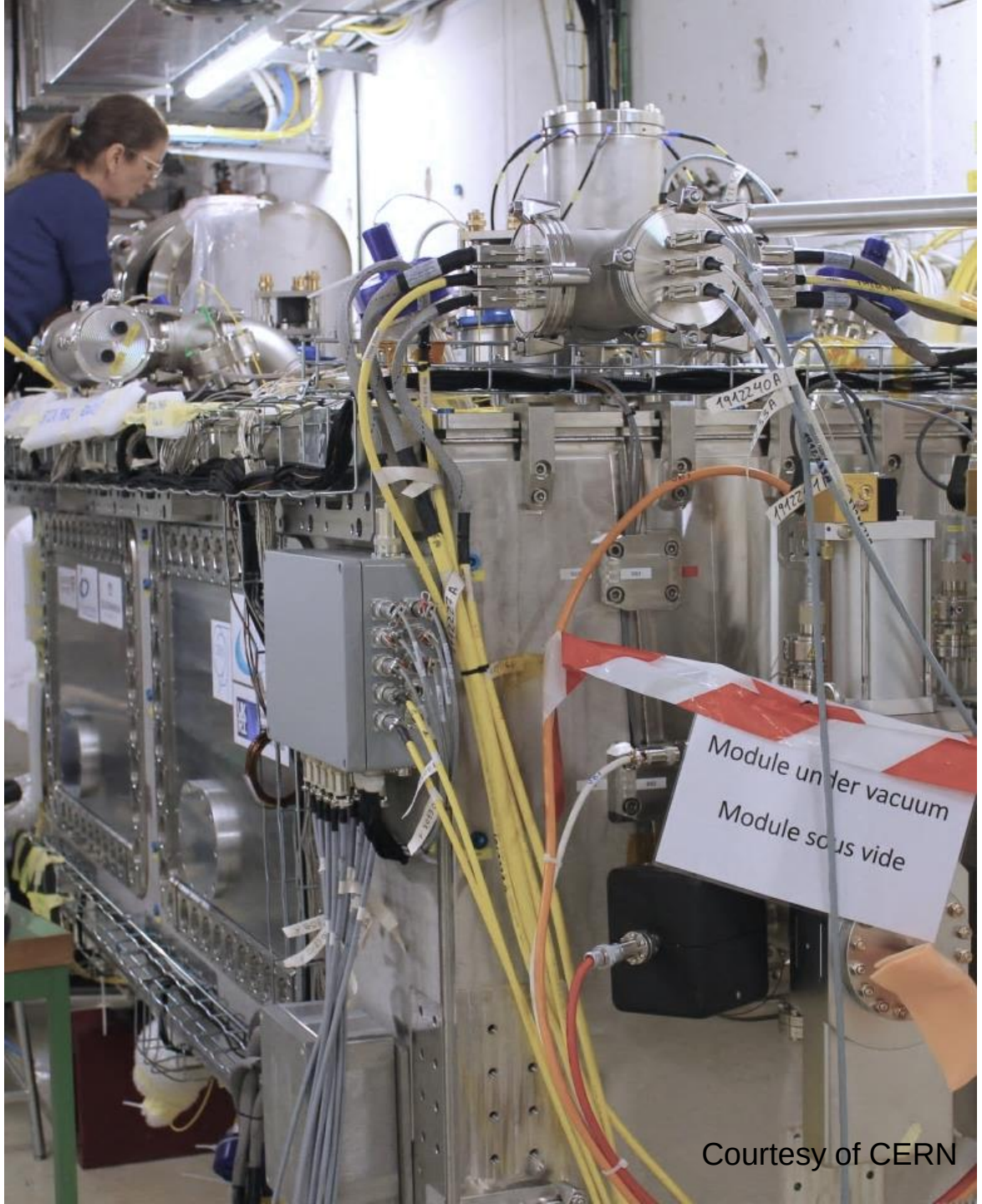


Summary – Cavity Test

- Documentation preparation
  - Discussion and revision in progress
  - To be approved by CERN prior to releasing and the series production cavity tests
- Technical preparation
  - Cavity manipulation, cryostat and RF are ready to use
  - 4K/2K unit will be tested again with the dummy cavity before dressed cavity arrival
- Schedule
  - The 1st dressed cavity is scheduled to be delivered by **Jan. 31st, 2025** from AUP
  - The full set of 25/50Ω adapters will be required to be delivered by **Dec., 2024** from CERN

Cryomodule Test

Part 2



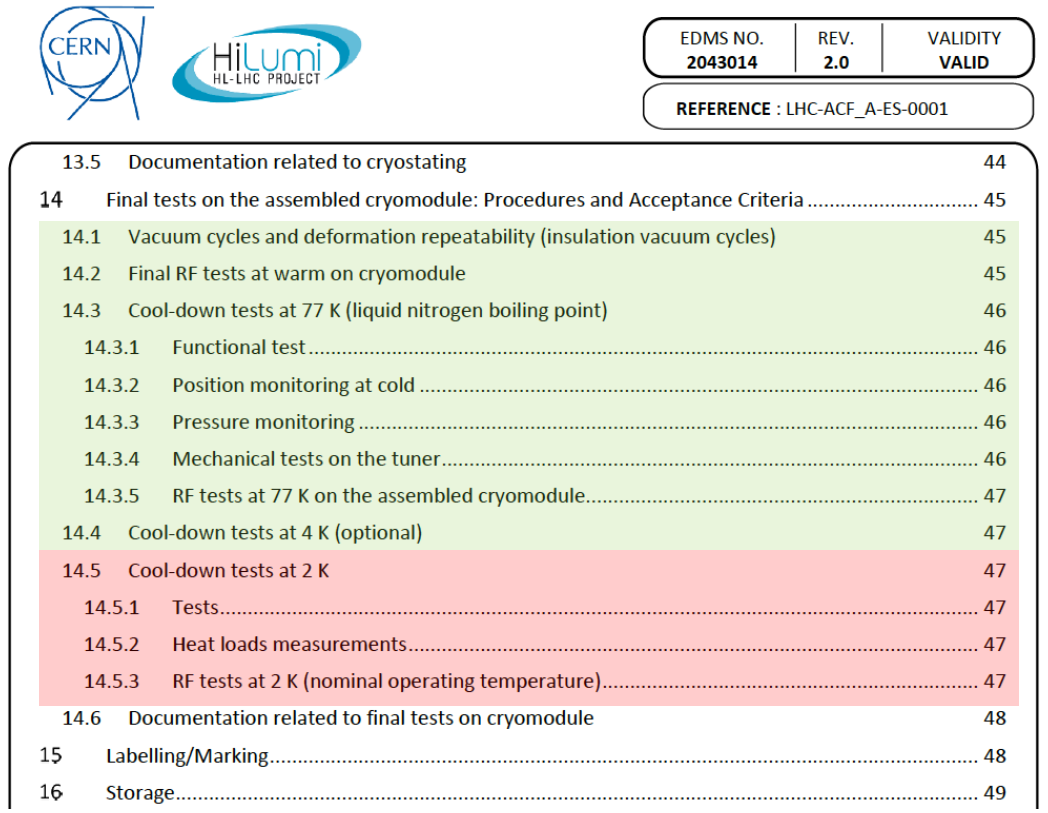
Courtesy of CERN

RFD Cryomodule Test

- RFD cryomodule will be cold tested at TRIUMF prior to shipping to CERN
- Cold test will partially verify functionality and performance
  - To demonstrate the quality of CM assembly
  - To expose CM issues before shipment
  - To mitigate risks of failure on arrival at CERN
- Cold test at TRIUMF will not replace the acceptance test in CM engineering specification (EDMS 2043014)
- The final acceptance test will be performed at CERN

Test Strategy

- To verify as many performance requirements as possible in cold test
- Requirements can be found in section 14 of CM engineering specification (EDMS 2043014)
  - Vacuum cycles
  - Warm RF checks
  - Cooldown to 77K (w/ LN2)
  - Cooldown to 4K
    - Heat loads at 4K
    - RF tests at 4K
  - No 2K test



EDMS NO.	REV.	VALIDITY
2043014	2.0	VALID

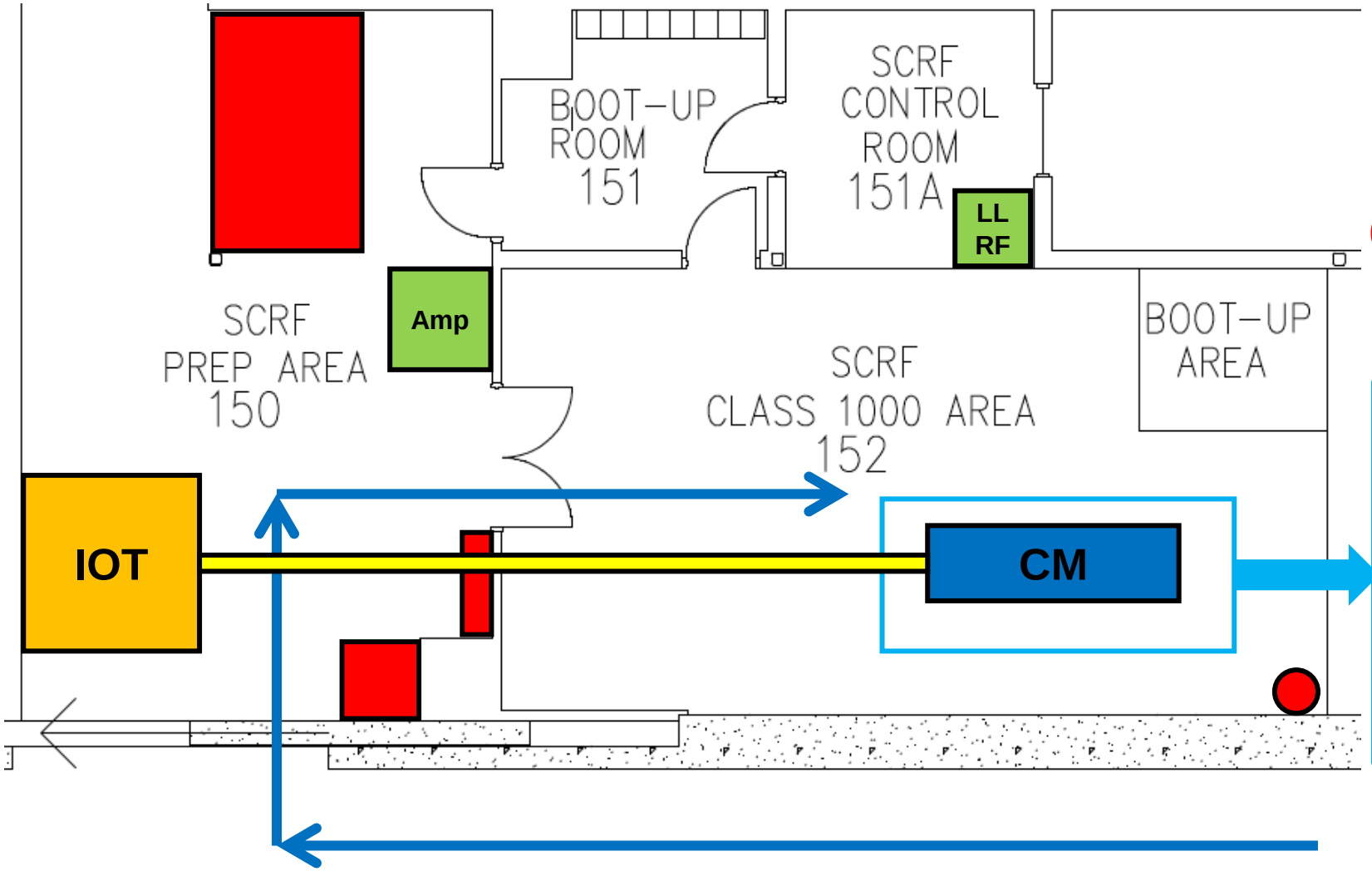
REFERENCE : LHC-ACF_A-ES-0001

Can the second beam pipe be left w/o LHe cooling like the SPS configuration?

4K Tests Goals

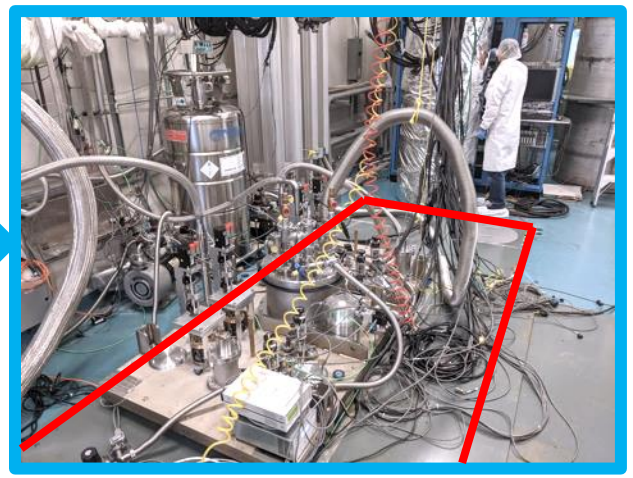
Test	CERN Spec. (EDMS 2043014)	TRIUMF Capability
Frequency of deflecting mode	400.79 ± 0.15MHz @ 2K	Spec. @ 4K
Q_0-V_t curve w/ P_0 at 4.1MV	≤ 10W @ 2K	Spec. @ 4K and 3.4MV (~27W)
Quench field value	No spec.	✗
LFD	≤ 865Hz/MV^2	✓
df/dp	≤ 300Hz/mbar	Positive or negative?
HOMs frequencies & Qs	Full spectrum	✓
Output power via HOM couplers	≤ 6.7W H & ≤ 3.4W V @ 4.1MV	≤ 4.6W H & ≤ 2.3W V @ 3.4 MV
Test on modes around 760MHz	728~754MHz, Q_e150~500	✓
Coupling of ancillaries	P_{pu} 0.95~1.5W @ 3.4MV	✓
Field emission onset	< 50μSv/hr	Feasibility TBD
Multipacting levels (FPC)	< 1×10^{-8}mbar @ full power	Spec. of cavity MP and FPC @ 13kW
Thermal cycling (15K-2K)	≤ ±5% changes in 3 cycles	15K-4K
Tuner test	Linearity, hysteresis and backlash	Spec.
Stability of operation	12hr stable operation	✗

Test Area



Footprint of RFD CM test in SM18?

4.37x1.83m pit



Required RF Components

- 100kW IOT – to receive operator manual during this meeting
- 6” coaxial transmission line – TRIUMF to provide route to CERN
- Coaxial bi-directional coupler
- 6” coaxial to WR2300 adaptor
- WR2300 waveguide if needed
- Circulator and dummy load
- Interlocks w/ manual
- 25/50Ω adapters (same set as cavity test)
- Internal 25Ω coaxial lines
- RF windows on OVC
- All above will be provided by CERN, inventory confirmation and detailed technical/delivery information will be very helpful

Required Components/Information

- Tuner controller – to be provided by CERN
- FSI system and procedure – to be provided by CERN
- Controllers of beam vacuum instruments –to be determined
- Isolation vacuum
  - Pressure relief – to be provided by CERN
  - Gauge assembly w/ controllers –to be determined
- He guard w/ gauge controller – to be determined
- Full list of sensors and heaters – require information ASAP for procurements

Summary – CM Test

- TRIUMF will perform CM test according to specification except 2K cold test
- 4K test will verify as many requirements as possible to derisk failures of the delivery at CERN, but can not replace the 2K acceptance test
- Detailed tests and requirements need to be discussed and agreed between CERN and TRIUMF
- Planning of test site and RF setup is in progress
- Deliverables for CM test need to be confirmed with CERN
  - The 1st CM test is anticipated in **Q4 2026**
  - Deliverables are required to be received before **Q4 2025**

Thank you
Merci
Grazie

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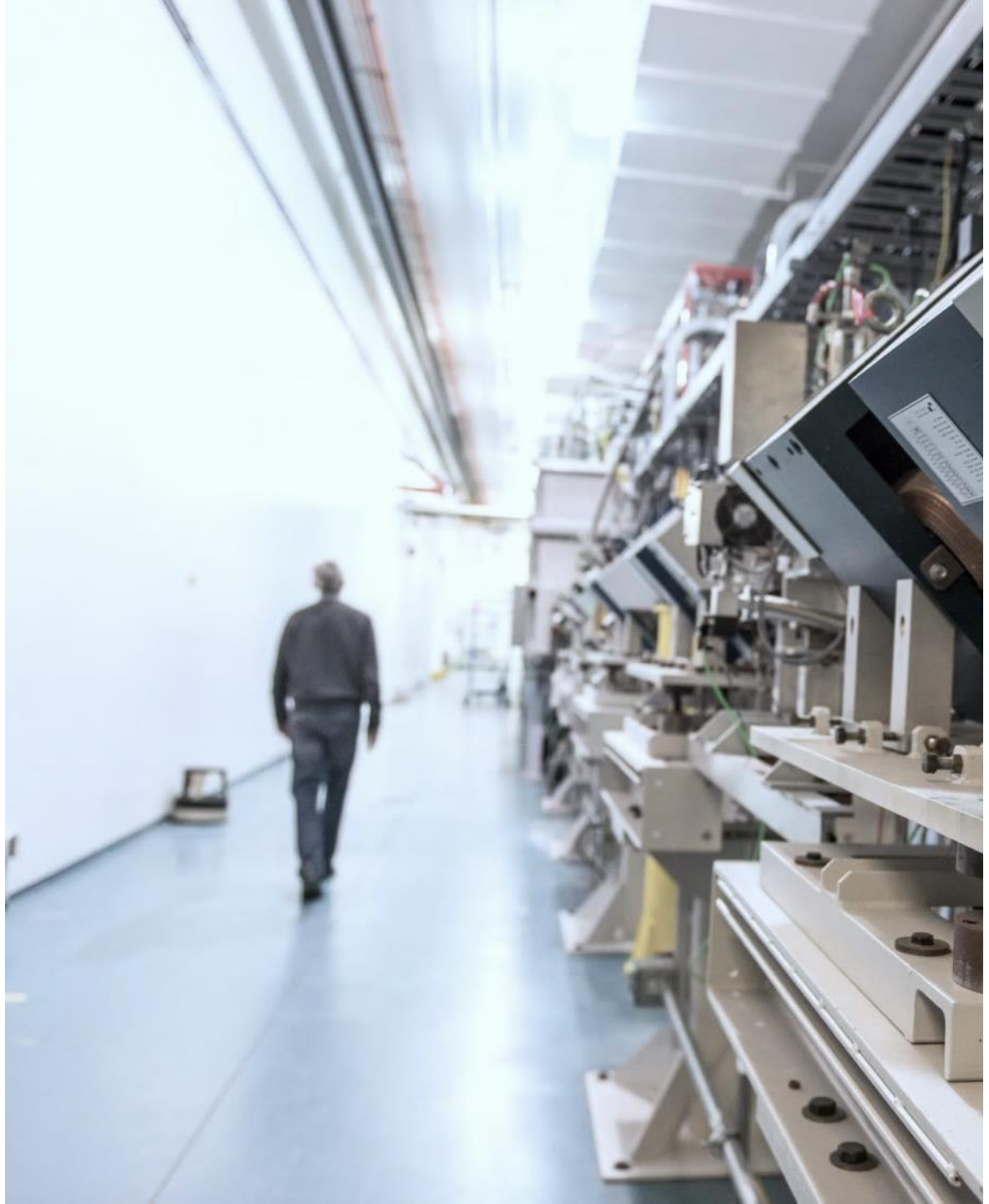


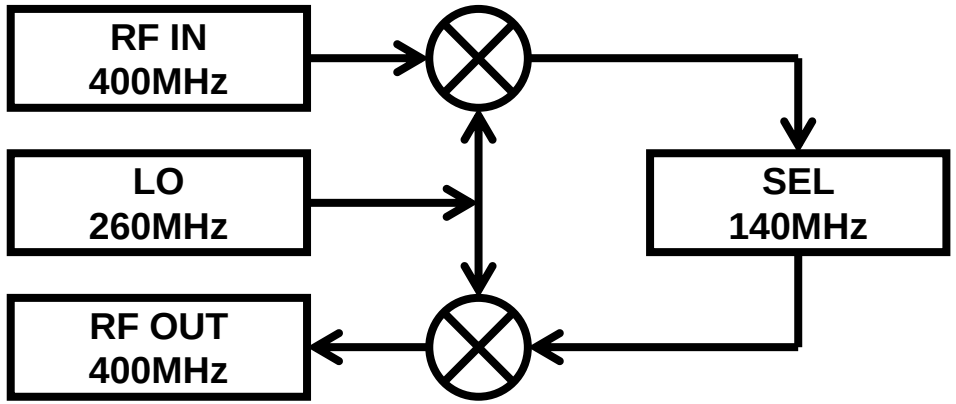
Discovery, accelerated

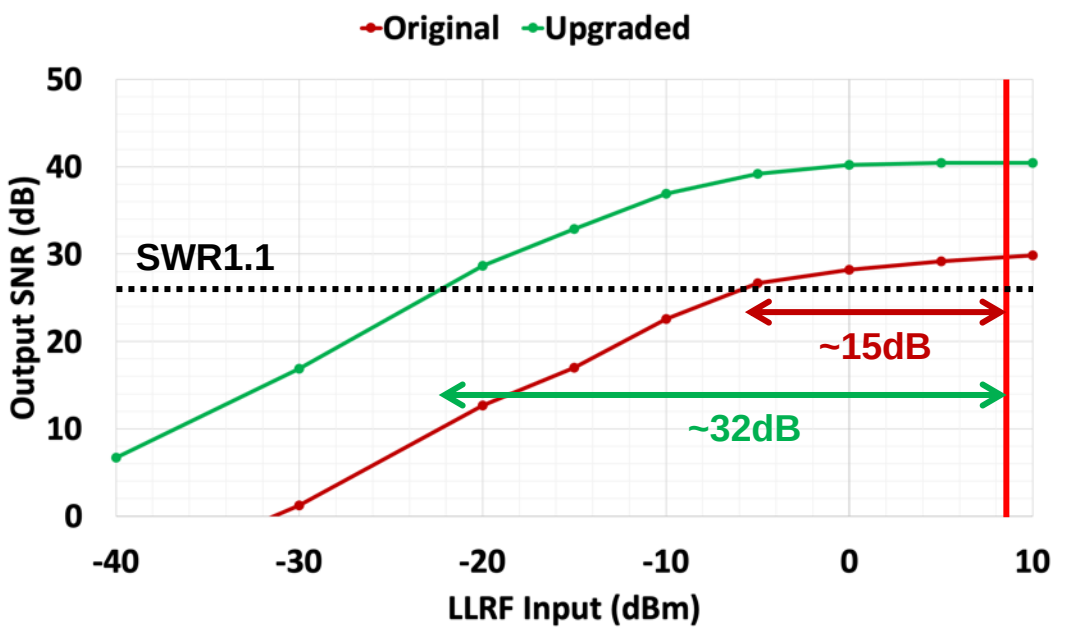
Cavity Test – HPRF

- Amplifier – 500W Solid-state 69-651MHz
- Circulator – 500W 350-400MHz
- Dummy loads
  - Drive – 1500W
  - HOMs – 20W 10dB attenuator in front of 2W dummy load
- Directional couplers
  - Drive – 1000W 40dB bi-directional 100-500MHz
  - HOMs – 2W 20dB 1-1000MHz
- Power meters – Agilent E4419B 0.01-18GHz -70-+20dbm

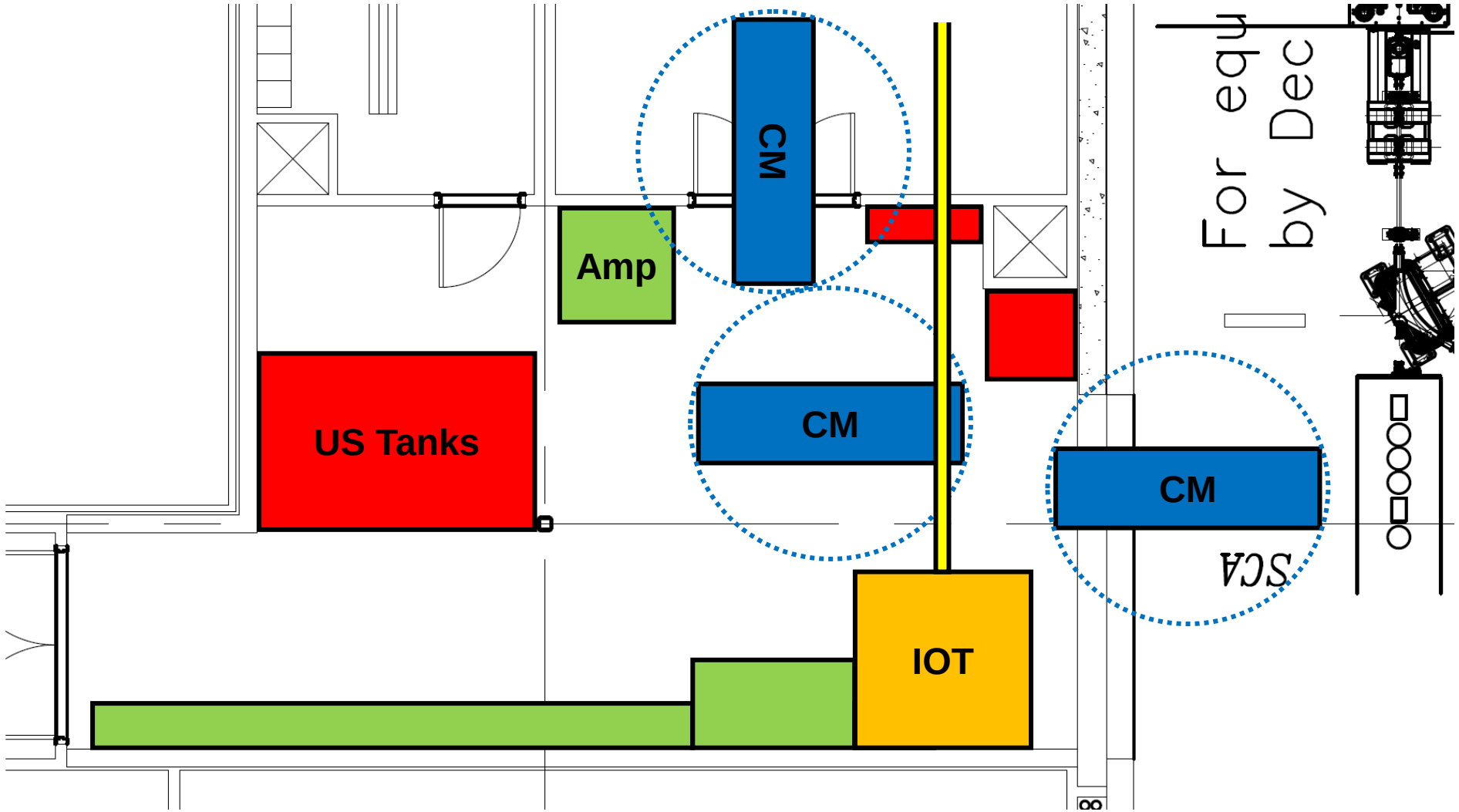
Cavity Test – LLRF

- Multi-purpose 140MHz SEL
- Freq. up/down converter
- Required voltage range
  - Vt 0.1~4.1MV – 32dB
- Modified LLRF to provide the required dynamic range with an equivalent SWR<1.1



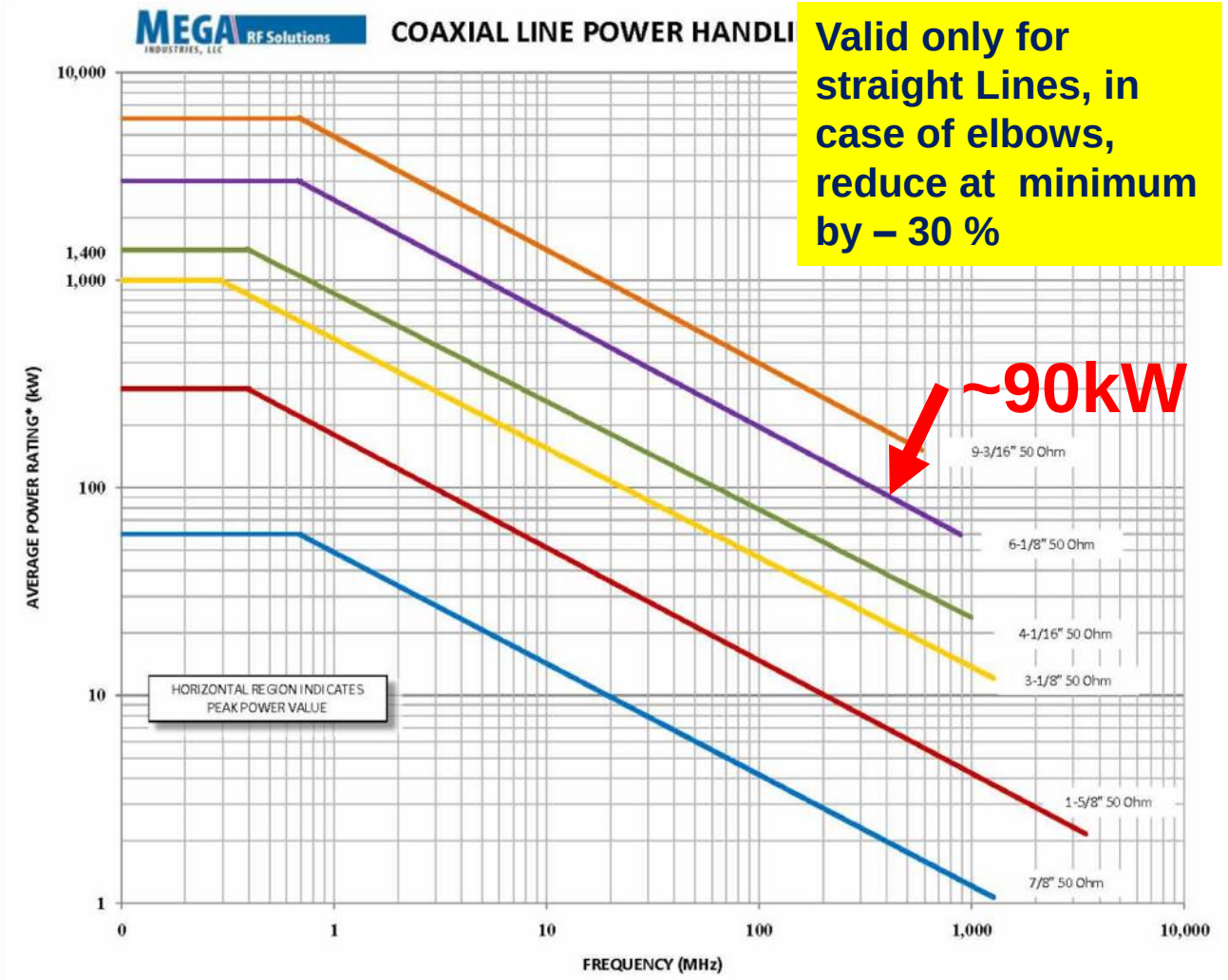


CM Test – IOT



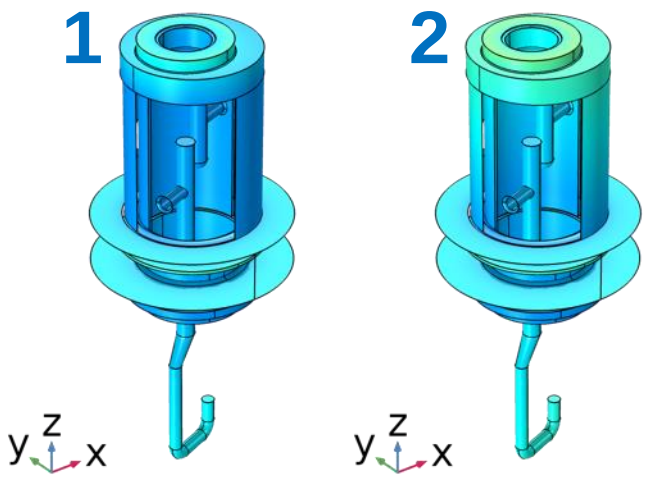
CM Test – Transmission Line

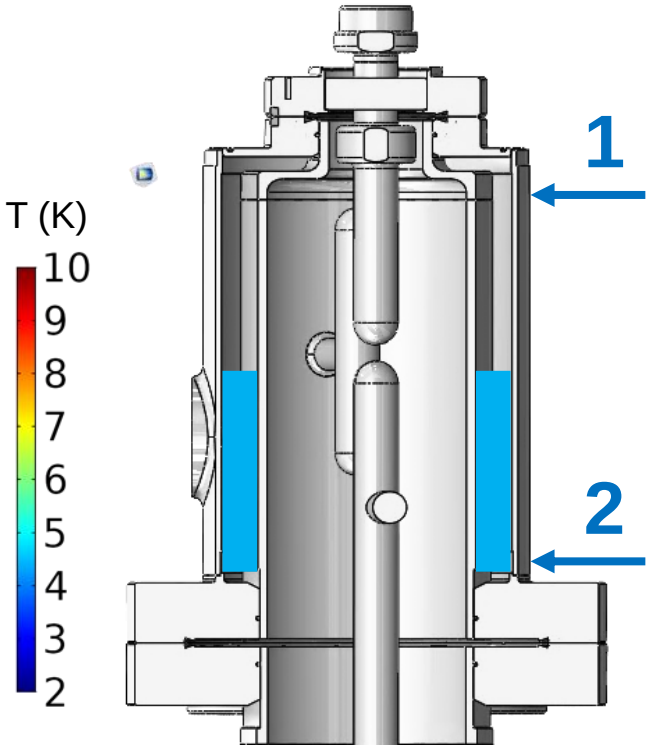
- 6-1/8” coaxial line
  - Capable for ~60kW
  - Required RF power
    - 20kW @ 4.1MV
    - 13kW @ 3.4MV
  - 4.1MV OK for TW
    - WG circulator required
  - 3.4MV OK with SW

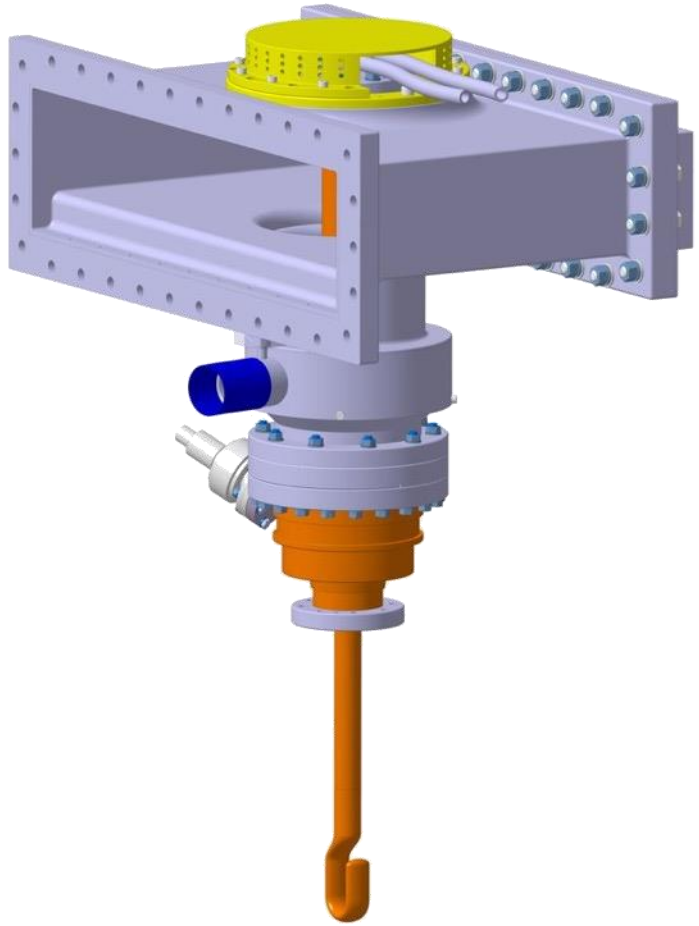


CM Test - Couplers

- FPC
  - Air cooling OK for 13kW power?
- HHOM
  - 4K LHe cooling

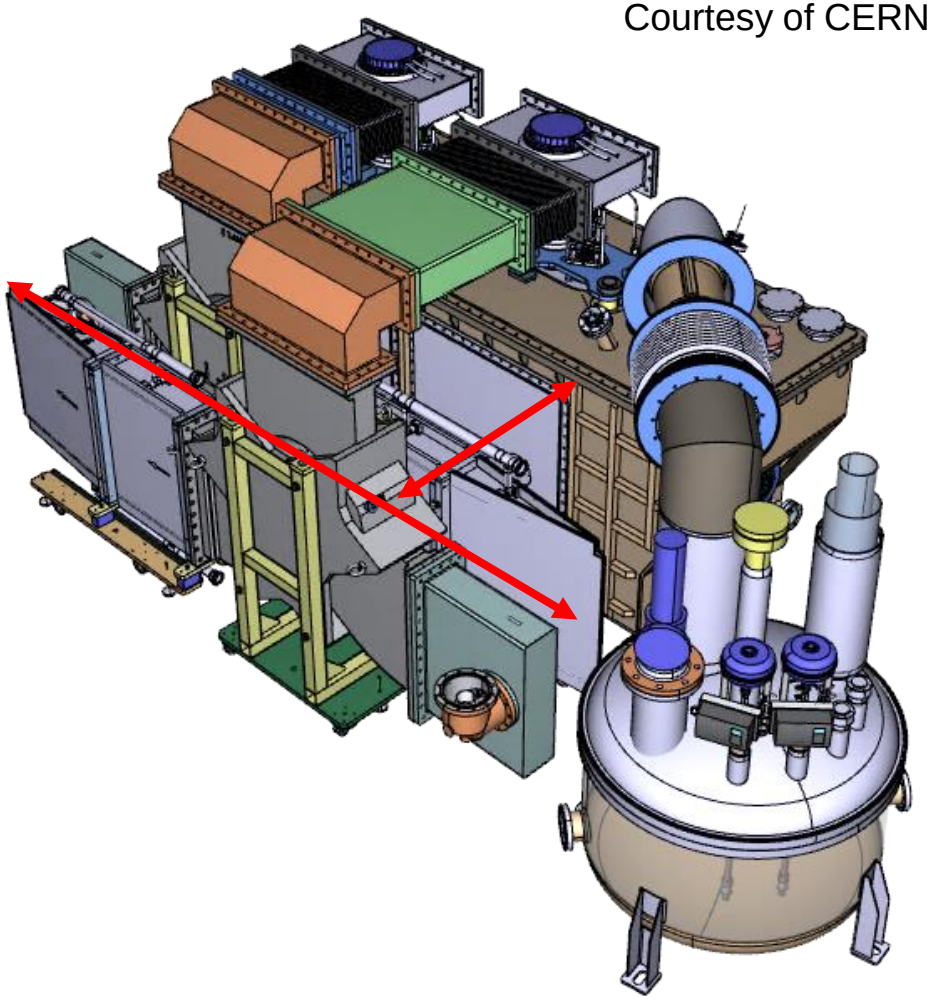


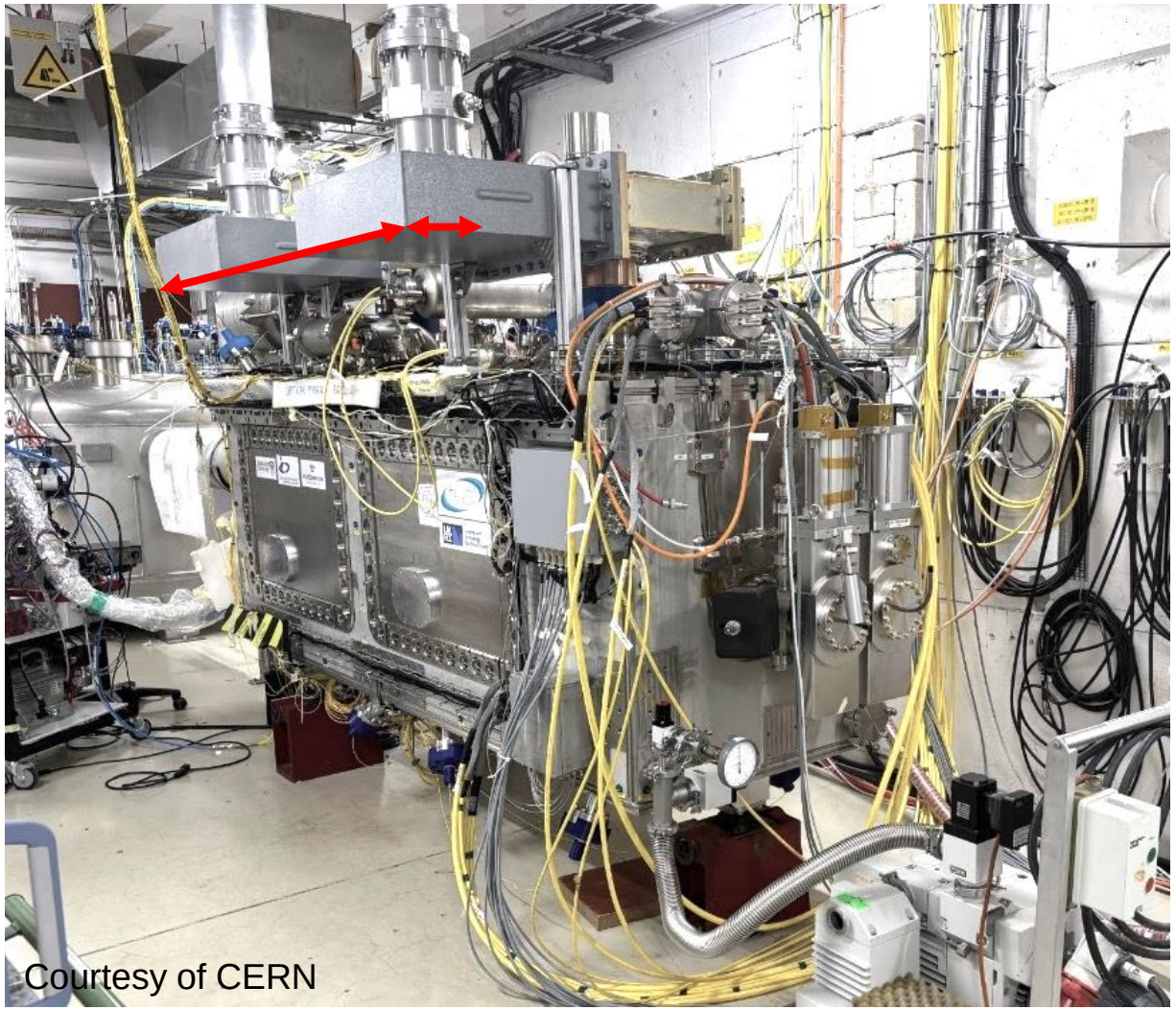




CM Test in M7

Courtesy of CERN





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