



# Status of WP4 Crab Cavities & RF

HL-LHC WP4 & Collaborations

CERN

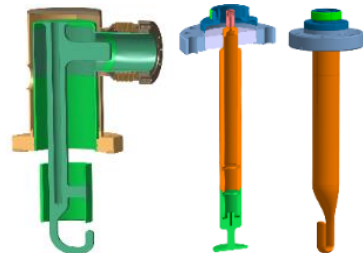
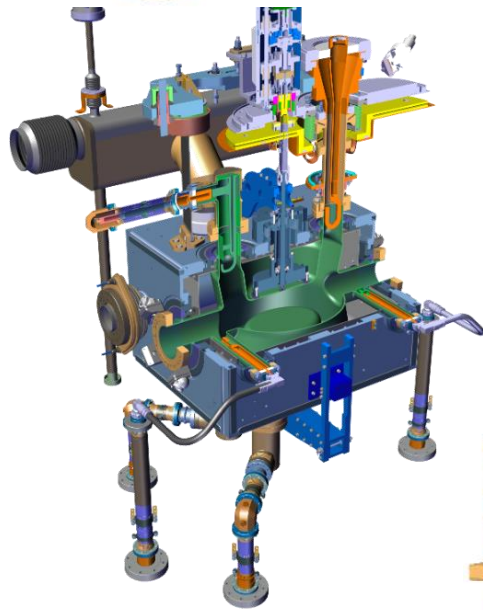


# Reminder: Cavity Geometries

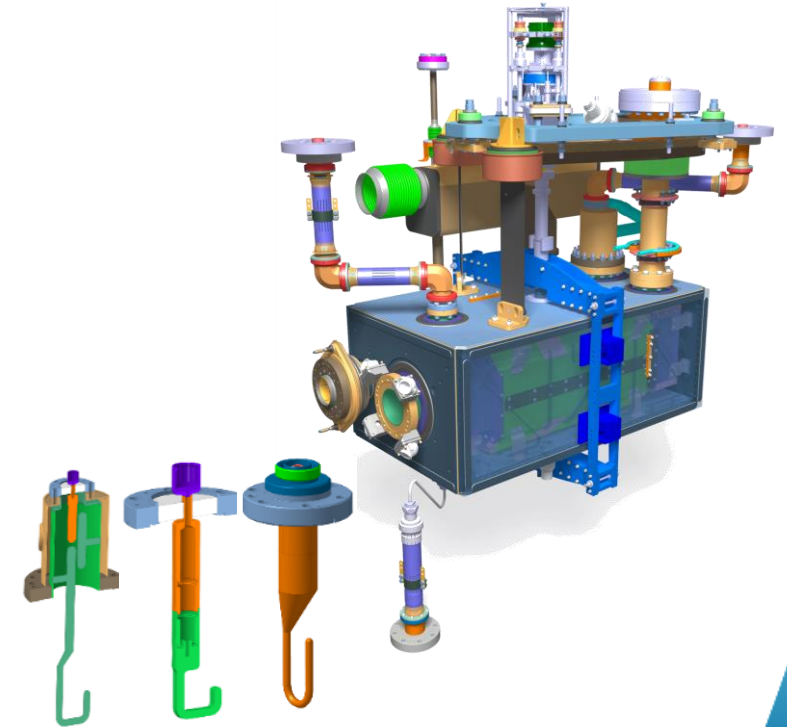
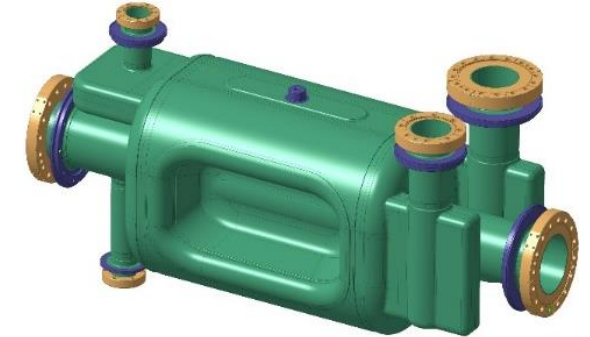
Double Quarter Wave  
(CMS)



$f_0 = 400 \text{ MHz}$   
 $V_T = 3.4 \text{ MV/cavity}^*$   
( $E_p, B_p < 40 \text{ MV/m}, 70 \text{ mT}$ )  
Beam aperture = 84 mm  
RF power = 40 kW-CW  
Operating Temp = 2 K

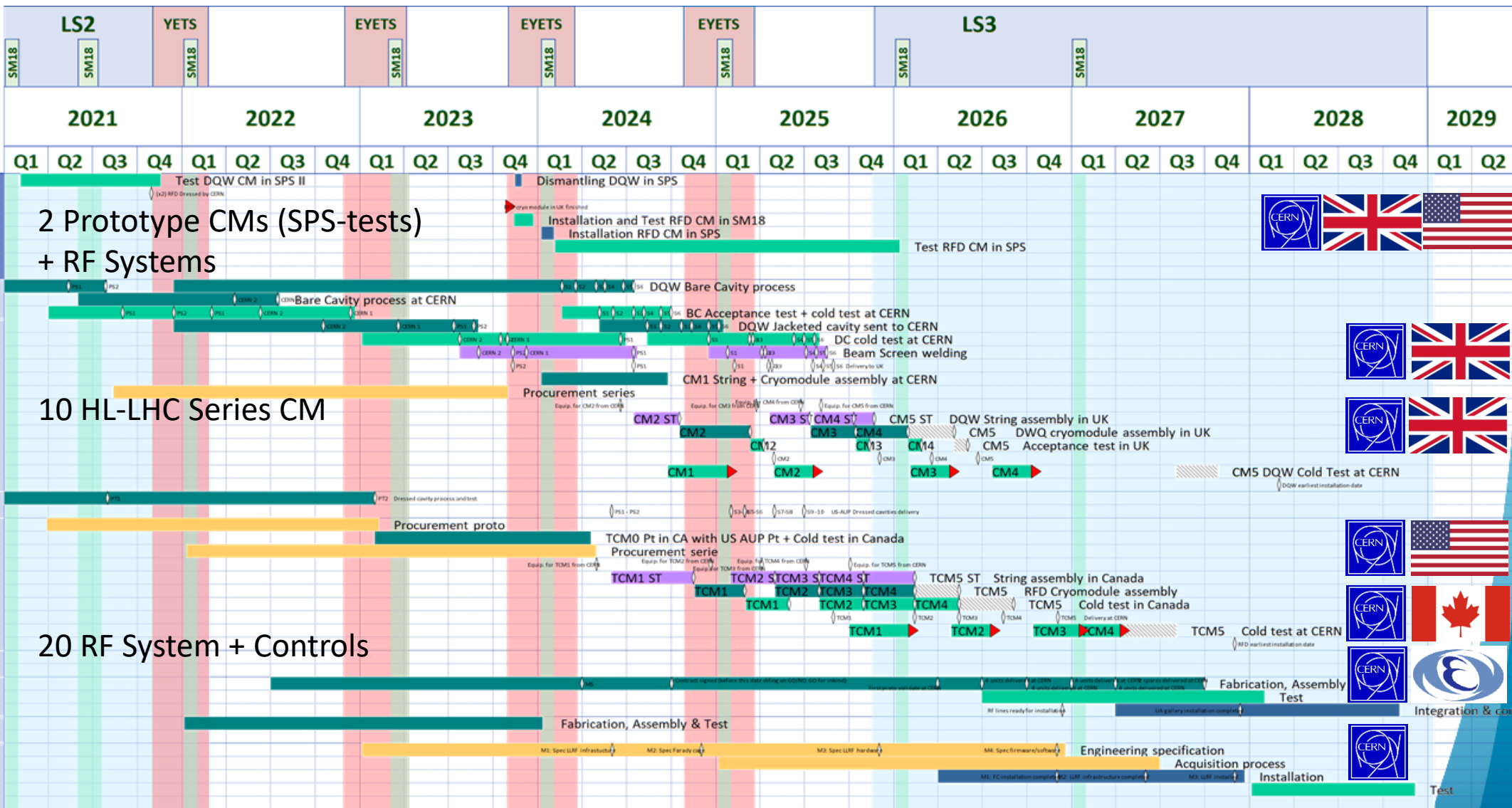


RF Dipole  
(ATLAS)



# Master Schedule, WP4

WP4 - Schedule in work for CSR23



Specifications Assembly Installation Test Installation Spare Milestone Output

# Timeline, Crab Cavities

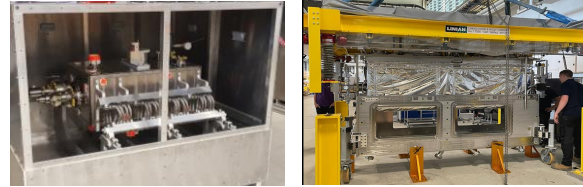
← High Power RF system not shown below →

2018-2022	2023	2024	2025	2026	2027	2028
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DQW CM SPS-tests



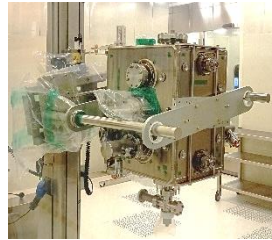
RFD CM SPS-tests



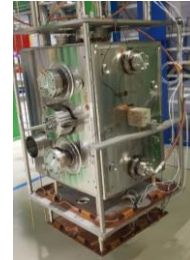
USAUP-RFD proto (x2)



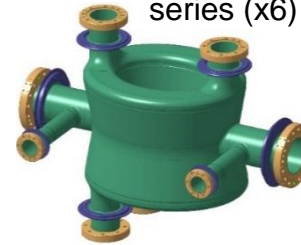
CERN-DQW series (x2)



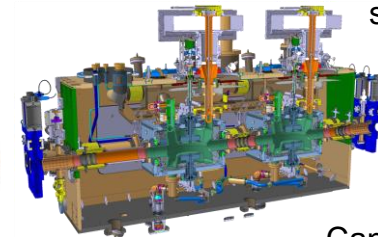
RI-DQW pre-series (x2)



RI-DQW series (x6)



UK-CERN DQW CCs series (4 + 1)



Canada-CERN RFD CCs series (5)



USAUP-RFD pre-series (2)



USAUP-RFD series (10)





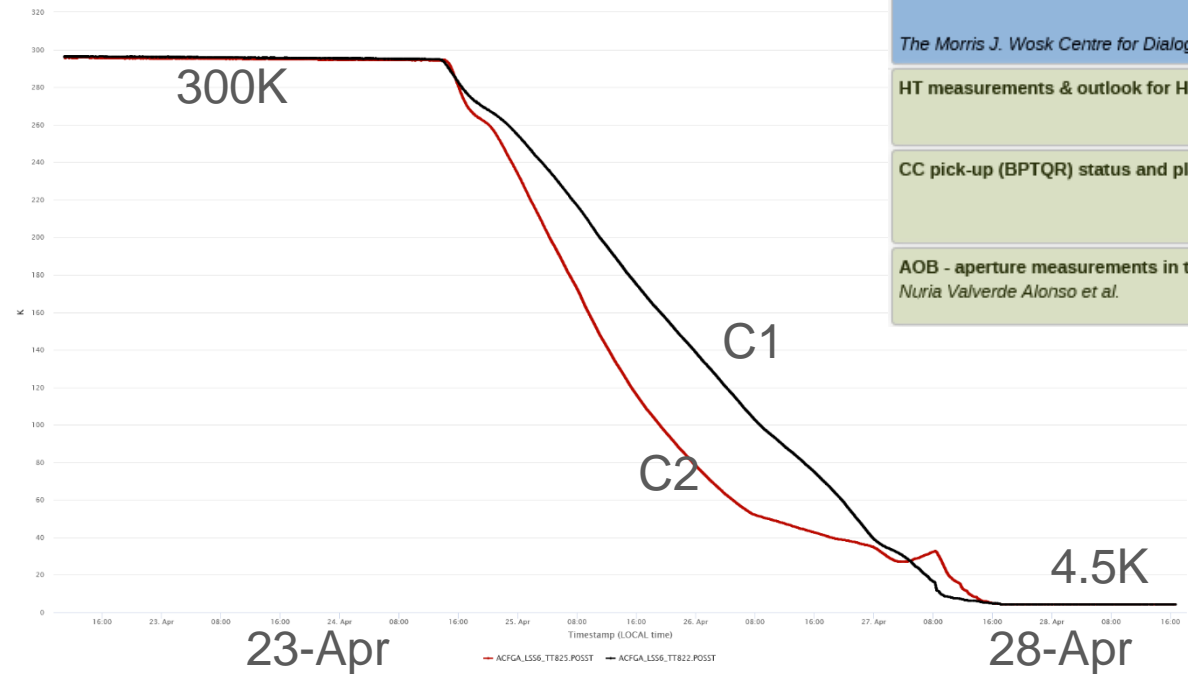
# DQW-SPS, 2023 Experience

- 4 MDs performed in 2023 (May 2 – Jul 27)
  - MD 1-2: high intensity setup & instability studies
  - MD 3-4: CC amplitude noise & emittance growth
  - MD 5: RF-ON sequence with high intensity (72b & 8b4e)

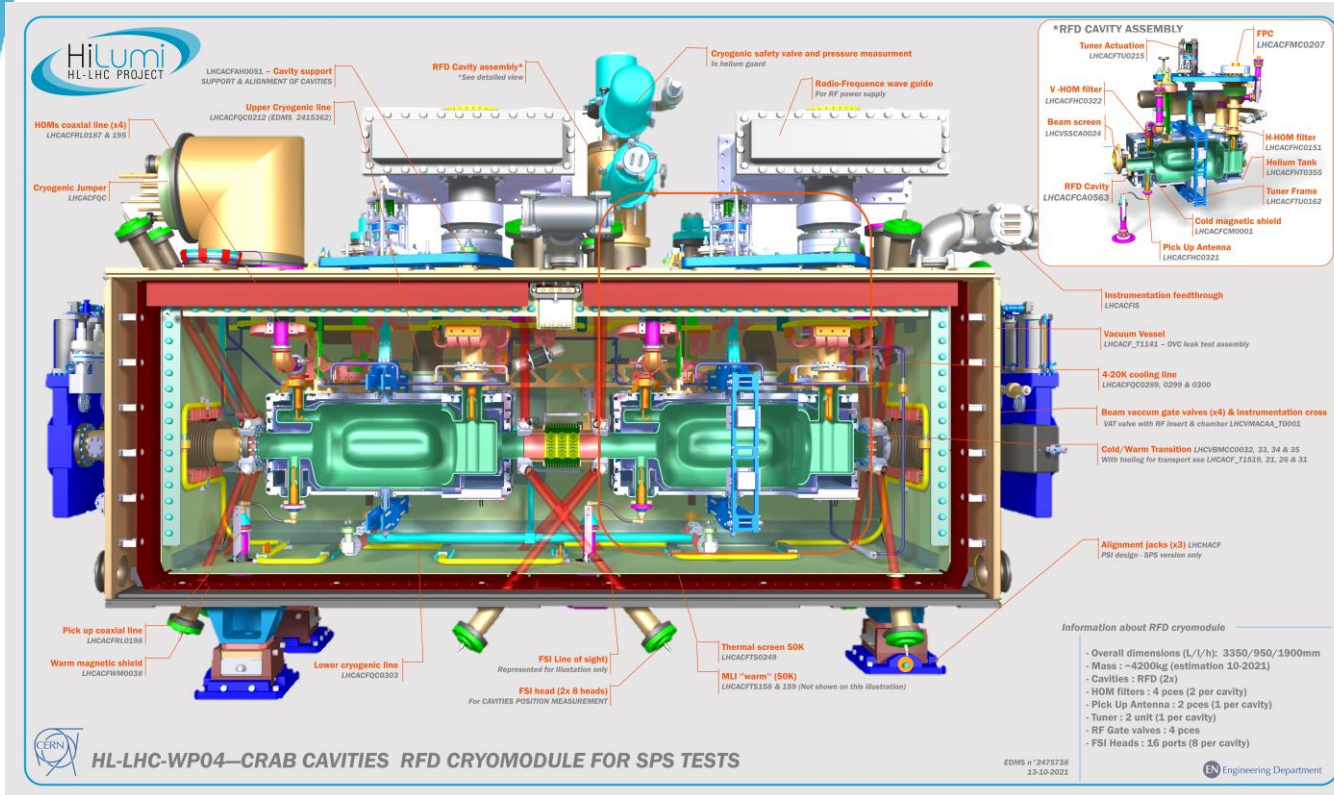


Thur morning WP2/4/13 parallel session

LHC longitudinal studies (remote talk)	Helga Timko
Machine protection studies	Daniel Wollmann
SPS-CC instability studies (remote talk)	Lorenzo Giacometti
SPS-CC high intensity, RF measurements	Rama Calaga
Coffee break	
The Morris J. Wosk Centre for Dialogue, Simon Fraser University	
HT measurements & outlook for HL-LHC	Tom Levens
CC pick-up (BPTQR) status and plans	Michal Krupa
AOB - aperture measurements in the series DQW Nuria Valverde Alonso et al.	



# What is next



RFD module (horizontal crabbing) for SPS-tests built jointly with UK

In its final stage of assembly at UK-STFC

RFD cryomodule build for SPS test  
Edward Stephen  
Jordan

CERN contributions (RFD-CM for S...  
Marco Garlasche ...

RFD assembly project structure (Bo...  
Niklas John Tempel...

SM18 validation of RFD Prototype f...  
Katarzyna Turaj

Tue afternoon WP4 parallel session

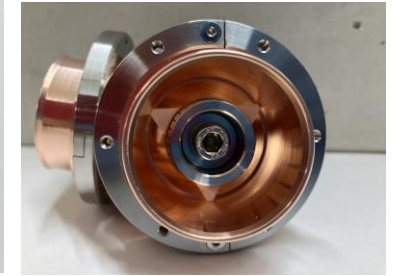
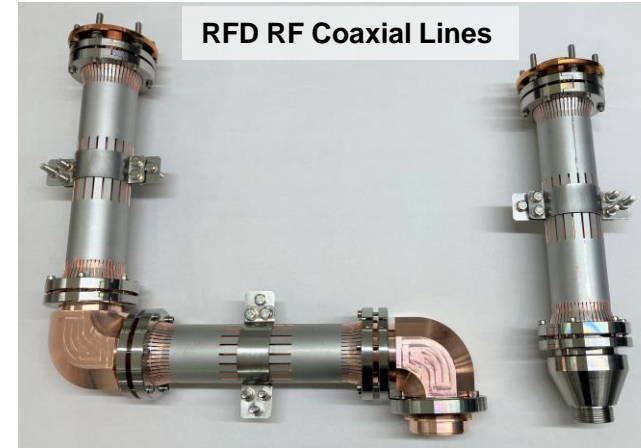
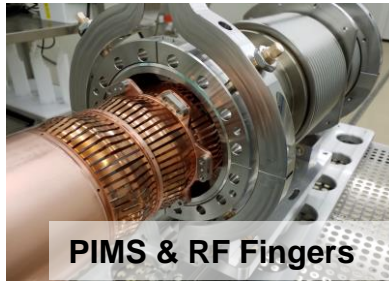


# RFD Prototype, CERN Deliverables

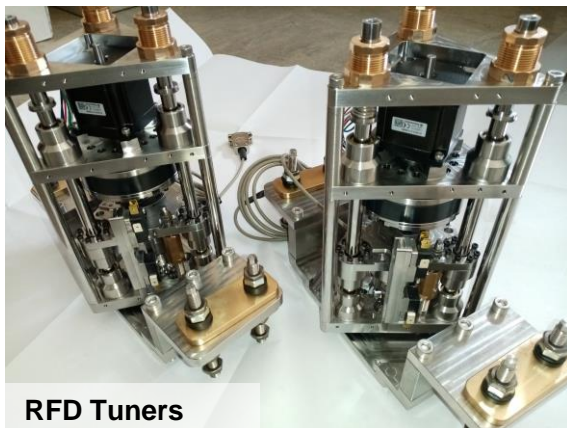
Dressed Cavity



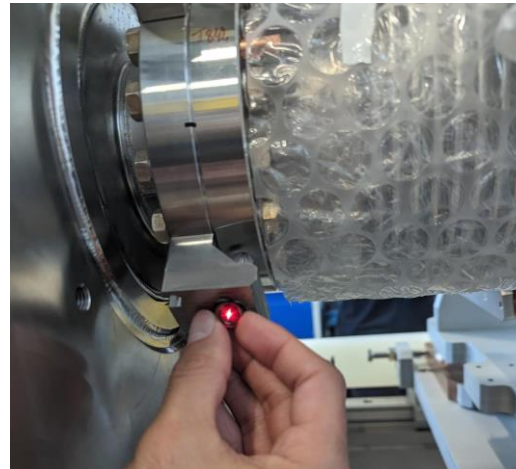
Additional Components for string assembly



Components for cryostating Tuner frames & actuation



Alignment Equipment

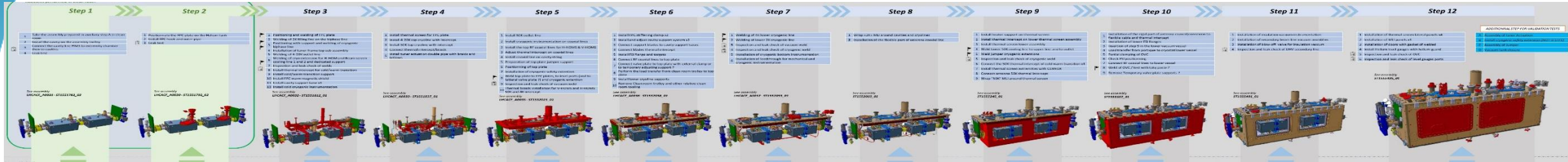


Thermal shield & cooling lines





# RFD Prototype, Assembly in UK



Jul 2022 (string assembly in IS04)



Sep 2023 (Top plate insertion)

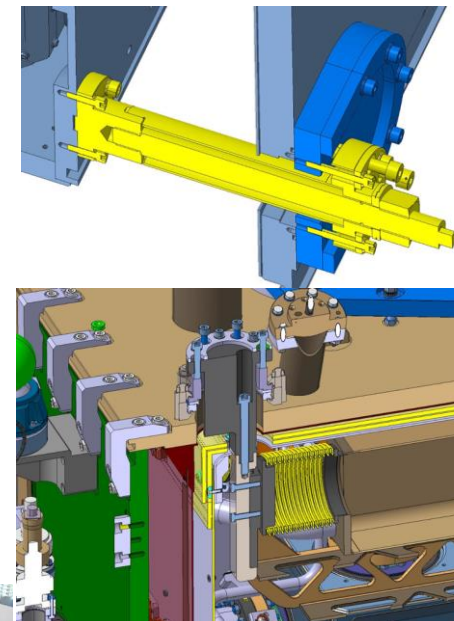
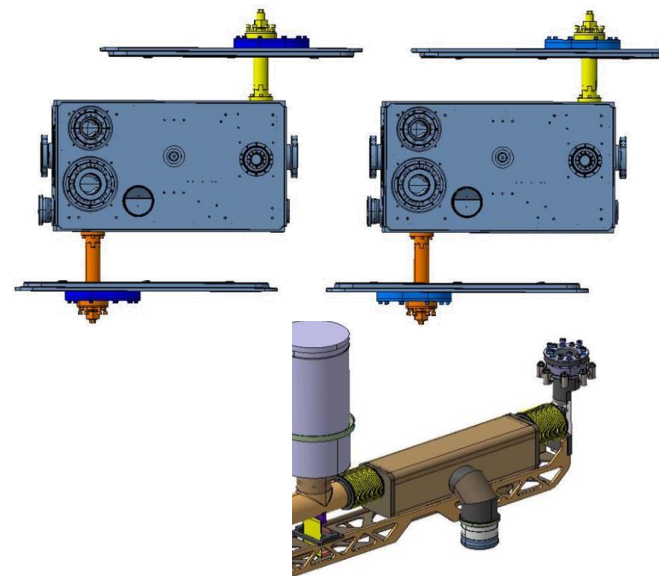


Expected to arrive at CERN end-Oct (see N. Templeton tomorrow)



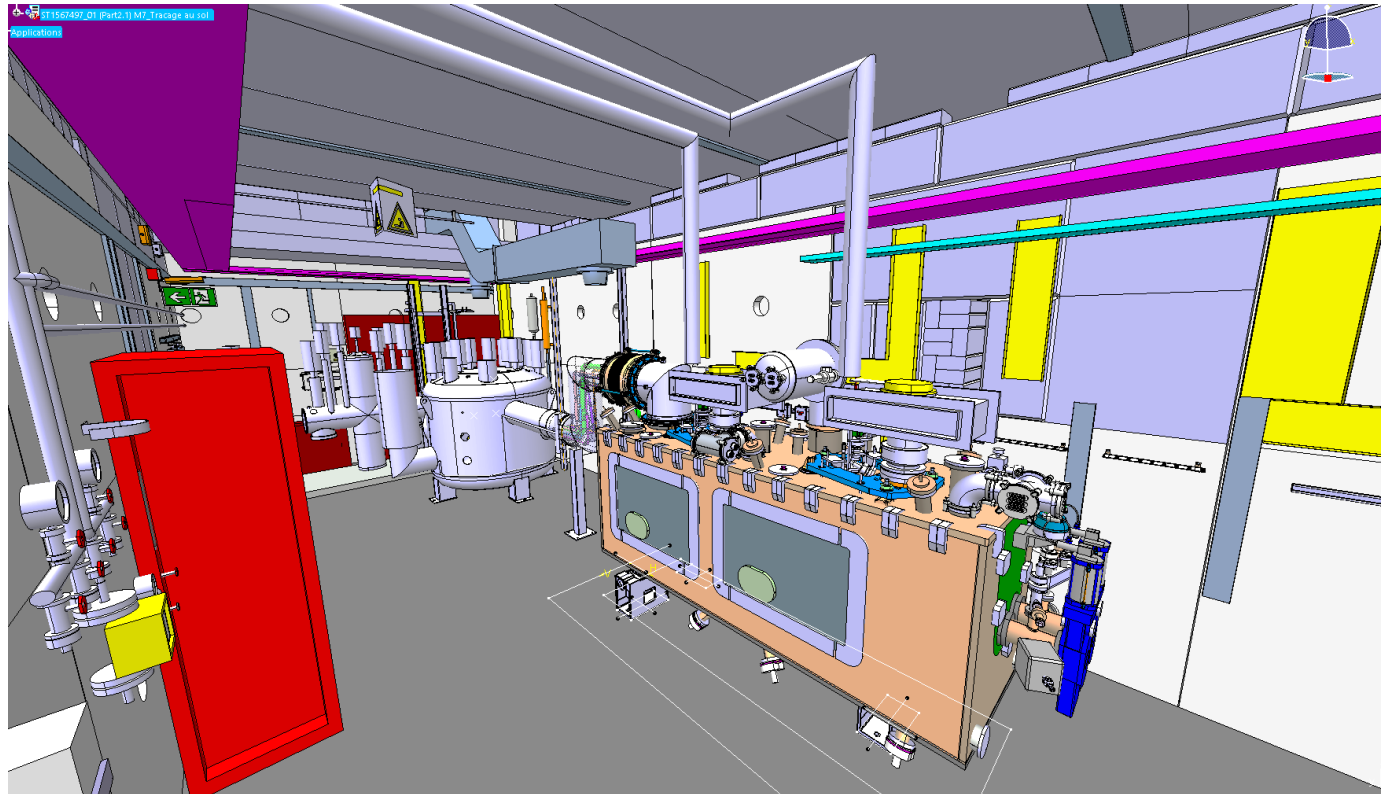
# Cryomodule transport to CERN

- Transport frame ready & restraints sent to UK-STFC for installation
- Monitoring of mechanical instrumentation
  - Strain gauges on FPC and blades.
  - Shock logs and accelerometers
- In SM18, special transport wheels being completed



# Cryomodule tests in SM18

- SM18 infrastructure ready for testing RFD & series cryomodules (see K. Turaj, Tue afternoon WP4 parallel). Extensive preparations put in place for 2K testing





# HL-LHC Crab Cavity Series



## 5 DQW cryomodules

- Cavities + processing + helium vessels by Research Instruments (**DE**) & **CERN**
- Cold magnetic shields by **UK**
- HOM couplers + antennas by **CERN**
- 4 CM by **UK** (STFC) & 1 CM at **CERN** with some components from **CERN**
- All cavities & CM cold validation tests at **CERN** (and a back up at Uppsala-Sweden)

## 5 RFD cryomodules

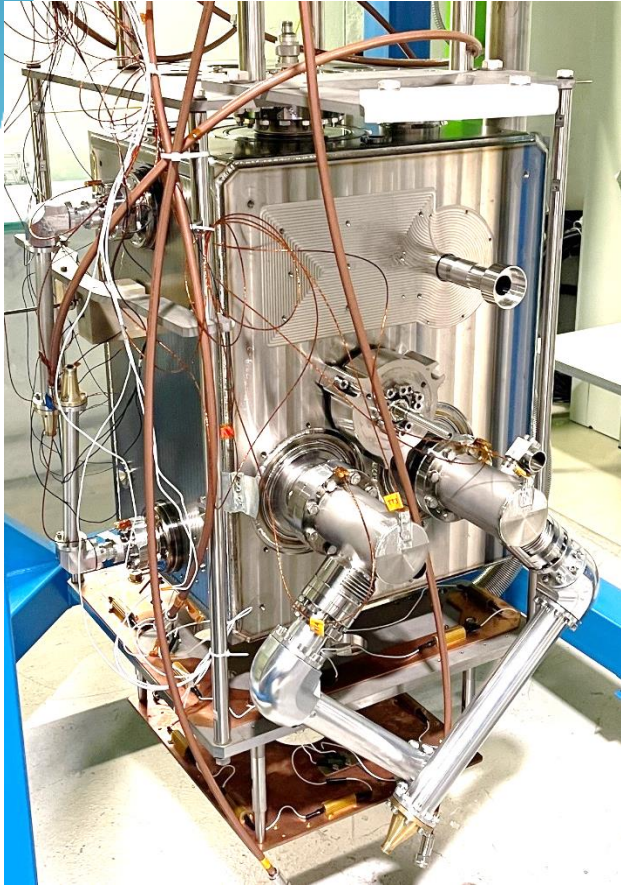
- Bare cavities by Zanon (**IT**) under **US-AUP**
- Processing + cold magnetic shield + helium vessel + HOM couplers + antennas + cold tests by **US-AUP**
- 5 CM by **TRIUMF-Canada** with some components by **CERN**
- CM cold validation tests at **CERN**

## 20 RF Systems

- High power amplifiers (IOT) **CERN-KEKB**
- High power RF lines, circulators, loads by **CERN-KEKB**
- $\mu$ TCA platform for LLRF by **CERN**



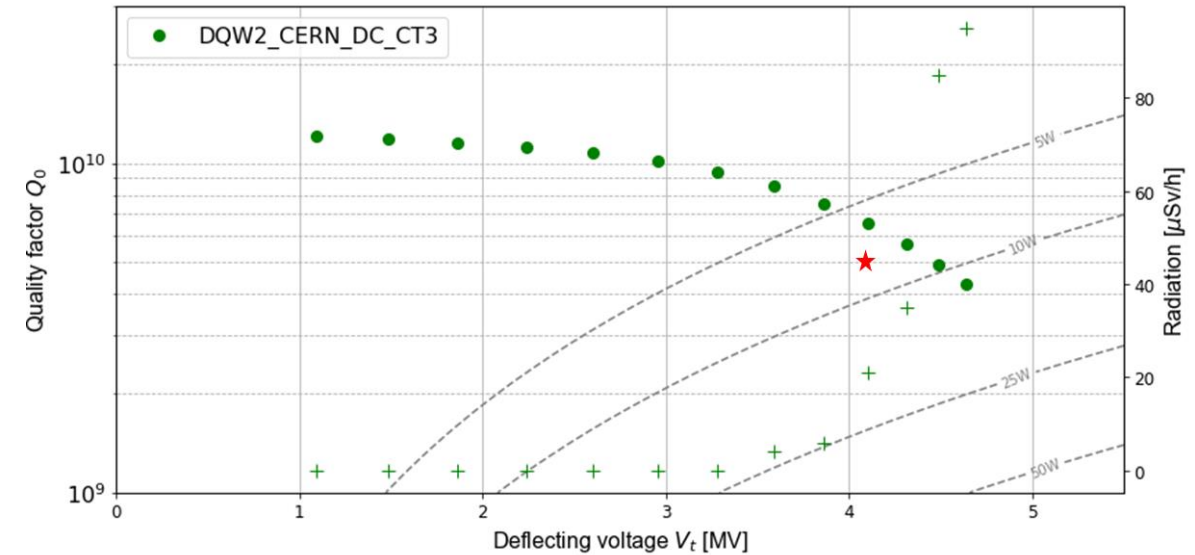
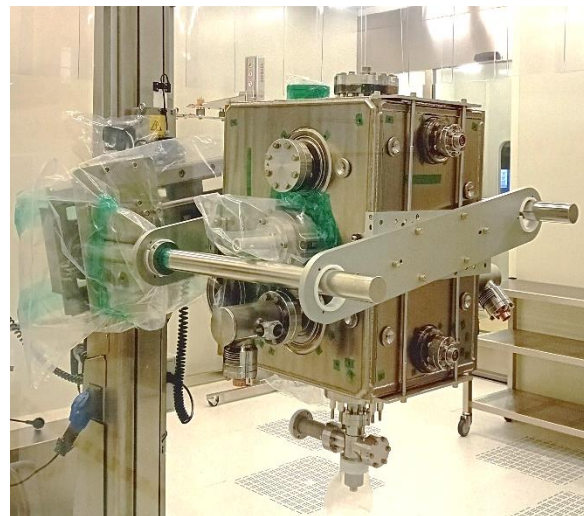
# CERN-DQW, Series (1 & 2)



CERN built two series DQW cavities

1<sup>st</sup> series in final HL-LHC configuration qualified!

2<sup>nd</sup> series cavity being prepared for cold tests



DQW industrial cavity production *Nuria Valverde Alonso*

Room 320, Morris J. Wosk Centre for Dialogue 09:20 - 09:40

DQW CERN cavity tests *Katarzyna Turaj*

Room 320, Morris J. Wosk Centre for Dialogue 09:40 - 10:00

DQW CC frequency & HOM evolution during manufacture and cold testing

*Amelia Veronica Edwards*

DQW HOM couplers challenges & FPC *Simon Barrière*

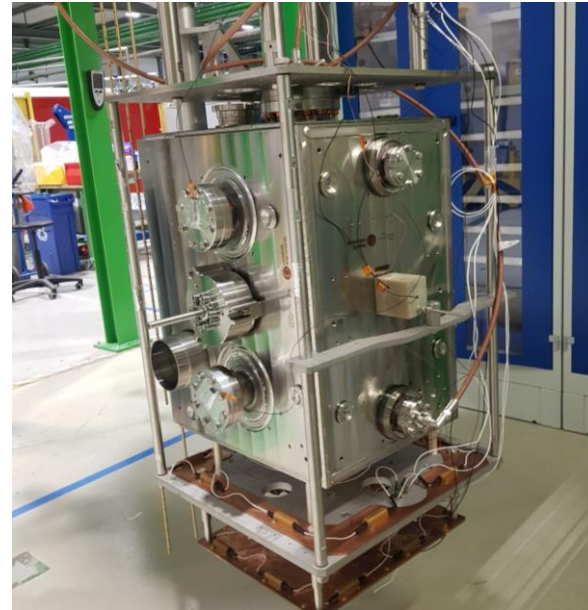
Room 320, Morris J. Wosk Centre for Dialogue 11:20 - 11:40

Wed morning WP4 parallel sessions

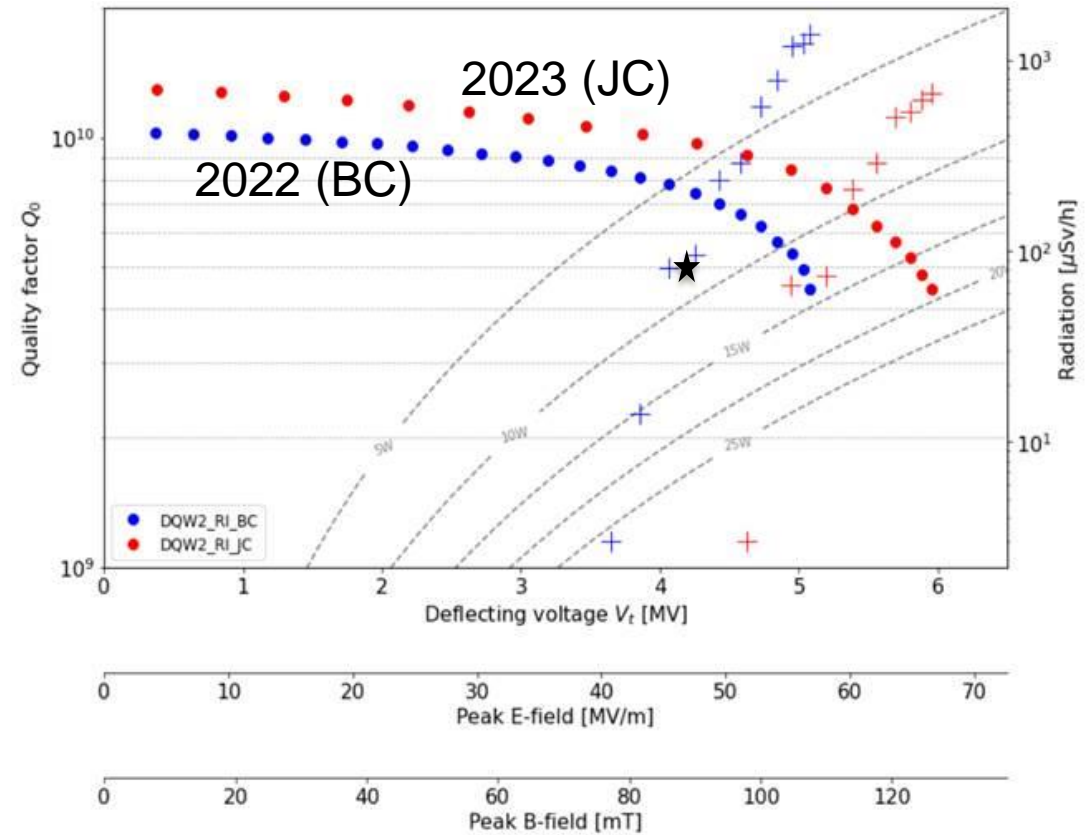


# DQW Industrial Series (RI)

- 8 series DQW jacketed cavities produced in industry (Research Instruments, DE)
- 1<sup>st</sup> jacketed cavity with excellent results & qualified
- 2<sup>nd</sup> jacketed cavity cold tests soon

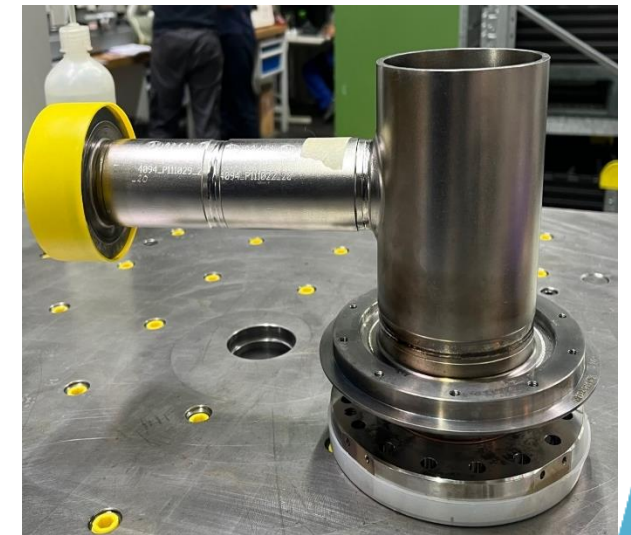
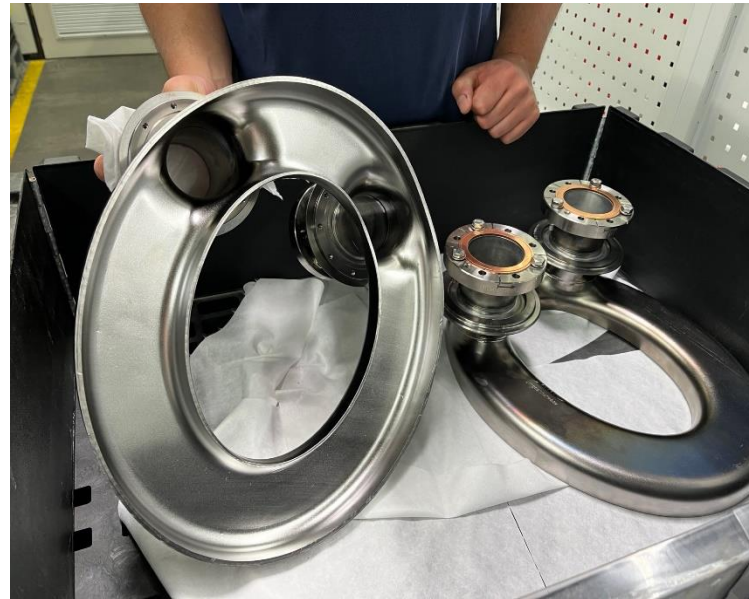


Research Instruments (DQW1 & DQW2)



## DQW Industrial Series (RI)

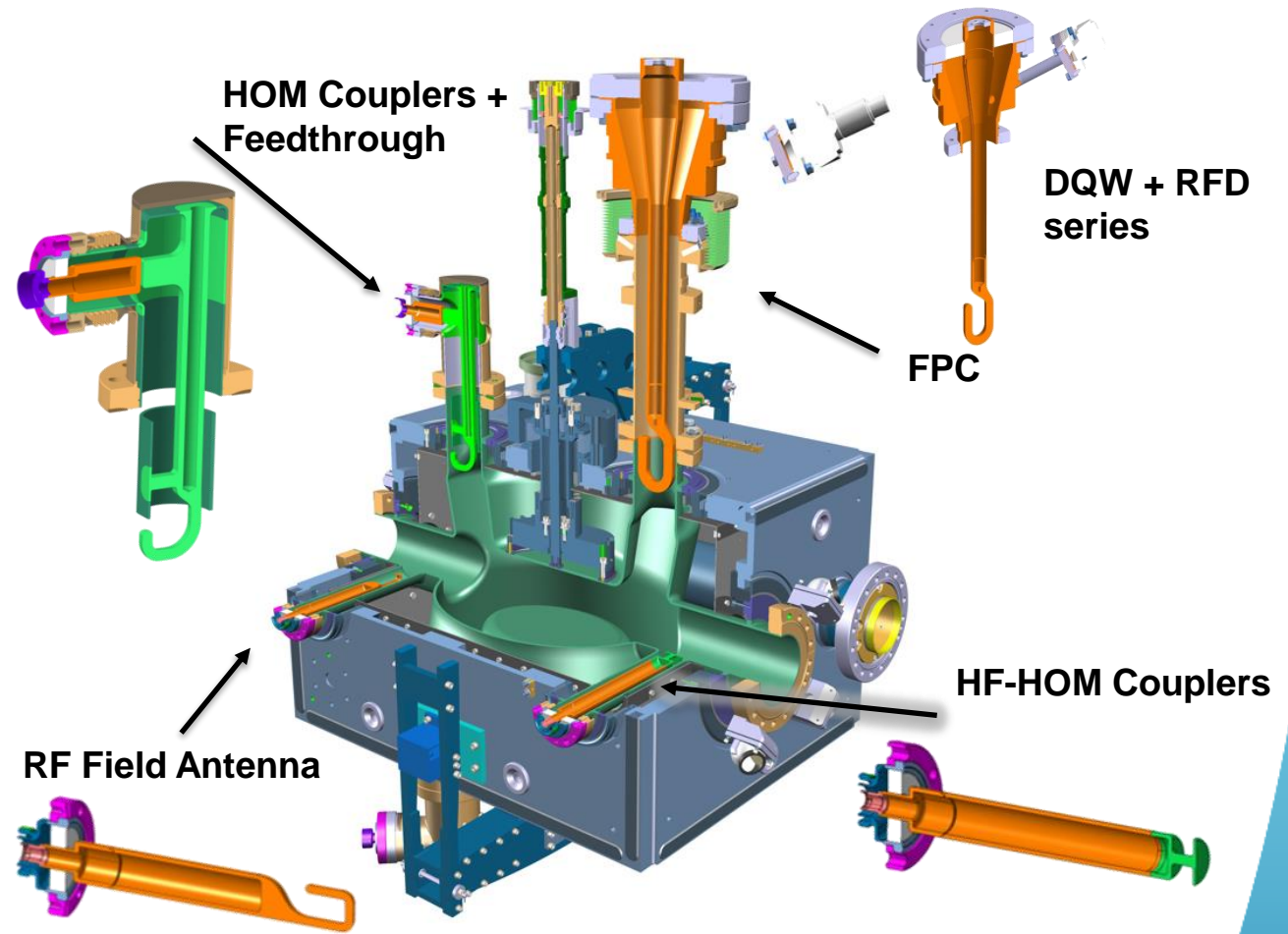
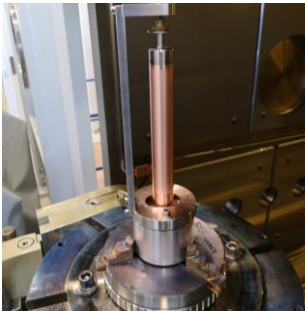
- Fabrication of the final 6 series bare cavities started and expected to arrive between Nov 2023 – Mar 2024
- Industry successfully achieved critical steps in cavity manufacturing. CERN support vital for this technology transfer





# DQW HOM Coupler Production (Series)

Major undertaking at CERN after de-scoping from the collaboration – excellent progress



# RFD Series Cavities (US-AUP)

- US-AUP pre-series cavity production progressing well
  - Prototypes successfully demonstrated, tests with HOMs ongoing
  - Production schedule challenging given schedule constraints
- HOM couplers & feedthroughs technical challenges being solved

Wed morning WP4  
parallel sessions

## Next talk

**US-AUP contribution and Zanon contract** *Leonardo Ristori et al.*  
*Asia Pacific Hall, Morris J. Wosk Centre for Dialogue* 14:45 - 15:10

**RFD industrial cavity production** *Manuele Narduzzi*

*Room 320, Morris J. Wosk Centre for Dialogue* 08:30 - 09:00

**US-AUP RFD testing** *Alejandro Castilla Loeza*

*Room 320, Morris J. Wosk Centre for Dialogue* 09:00 - 09:20

**RFD HOM coupler challenges** *Naeem Huque*

*Room 320, Morris J. Wosk Centre for Dialogue* 11:00 - 11:20

**Acceptance criteria A & B revision** *Leonardo Ristori et al.*

*Room 320, Morris J. Wosk Centre for Dialogue* 11:40 - 12:00



# DQW Series Cryomodules

- Series DQW cryomodules (1 CERN + 4 UK-STFC)
- CERN contribution of special components for the UK built CMs

Tue morning plenary

Status of CC cryomodules

Niklas John Templeton et al.

Asia Pacific Hall, Morris J. Wosk Centre for Dialogue

11:30 - 11:50

Wed afternoon WP4  
parallel sessions

Series cryomodule design

Teddy Capelli

Cavity/cryomodule alignment

Vivien Rude

Vacuum aspects & procurement status

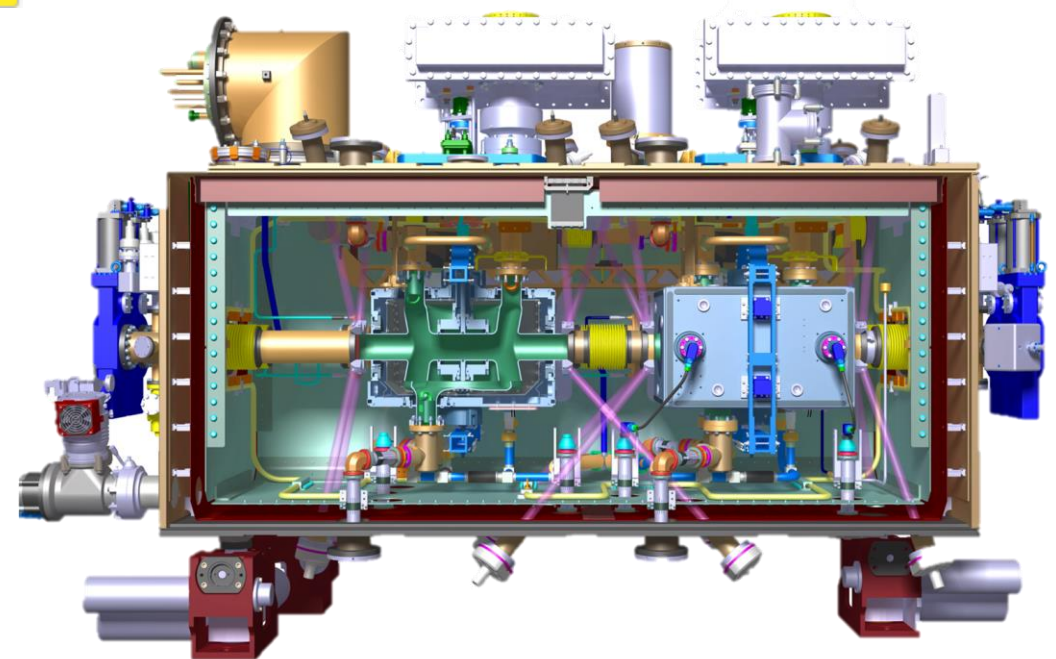
Vincent Baglin et al.

CC cryogenics and status

Vanessa Gahier

UK CM-series challenges, schedule & discussions

Niklas John Templeton et al.



# RFD Series Cryomodules

- TRIUMF-Canada preparing for manufacturing prototype cryomodule (TCM0). CERN deliverables of special components
- Cavity test infrastructure ready for accepting AUP deliverables

## Next talk

Status of Canadian Contribution to WP4

Robert Edward Laxdal

Asia Pacific Hall, Morris J. Wosk Centre for Dialogue

15:10 - 15:30

Wed afternoon WP4  
parallel sessions

RFD-CM drawing status and strategy

Benjamin Jon Matheson

RFD engineering issues – Interpreting European standar...

Oliver Law

Series cryomodule design

Teddy Capelli

Cavity/cryomodule alignment

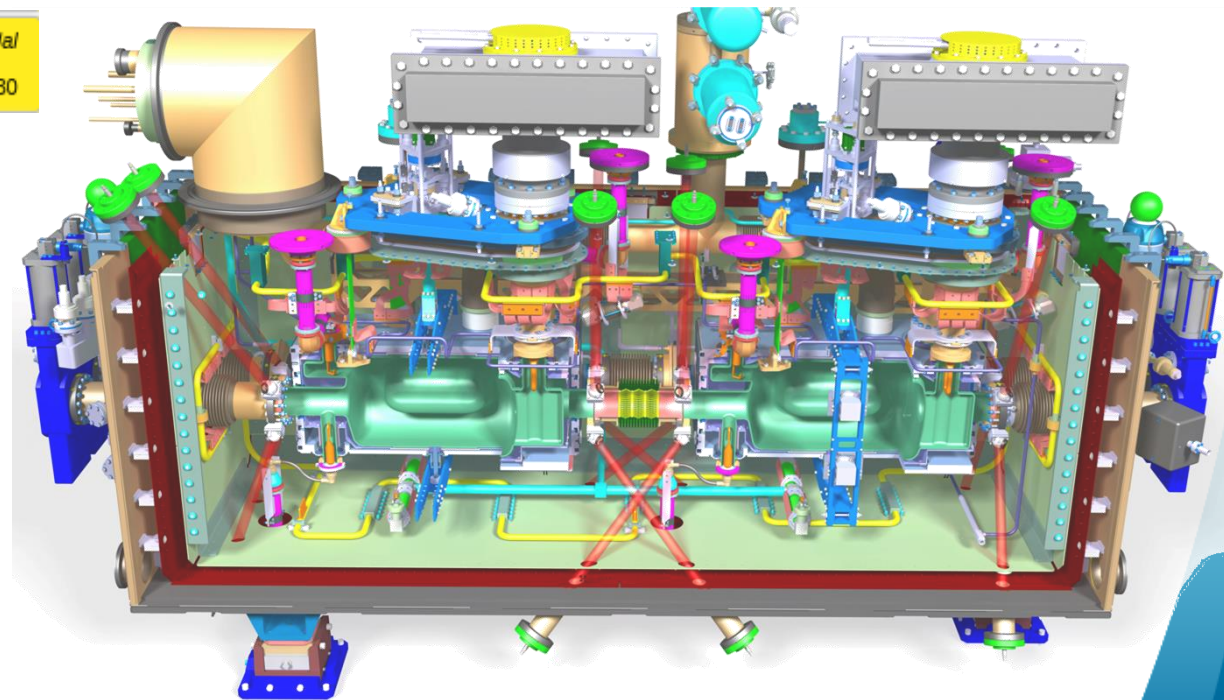
Vivien Rude

Vacuum aspects & procurement status

Vincent Baglin et al.

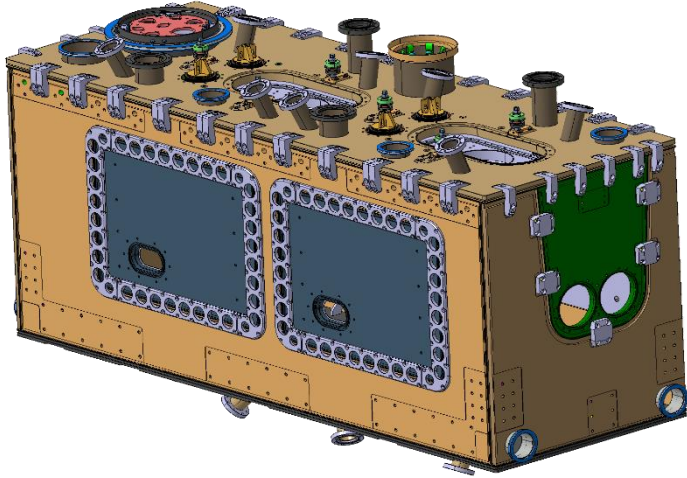
CC cryogenics and status

Vanessa Gahier

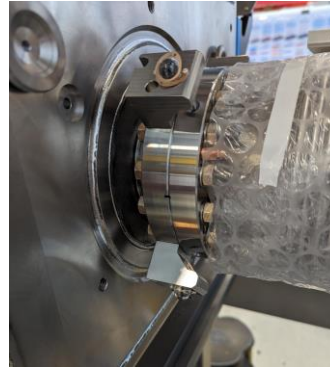


# Series Production, Cryomodule Components

Outer Vacuum Vessel for CERN-DQW



Alignment equipment

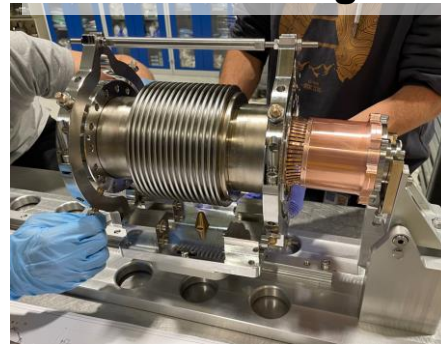


Series cryomodule procurement & manufacturing started and some components already ready

Beam Screens for DQW series



PIMS & RF Fingers



Pumping crosses

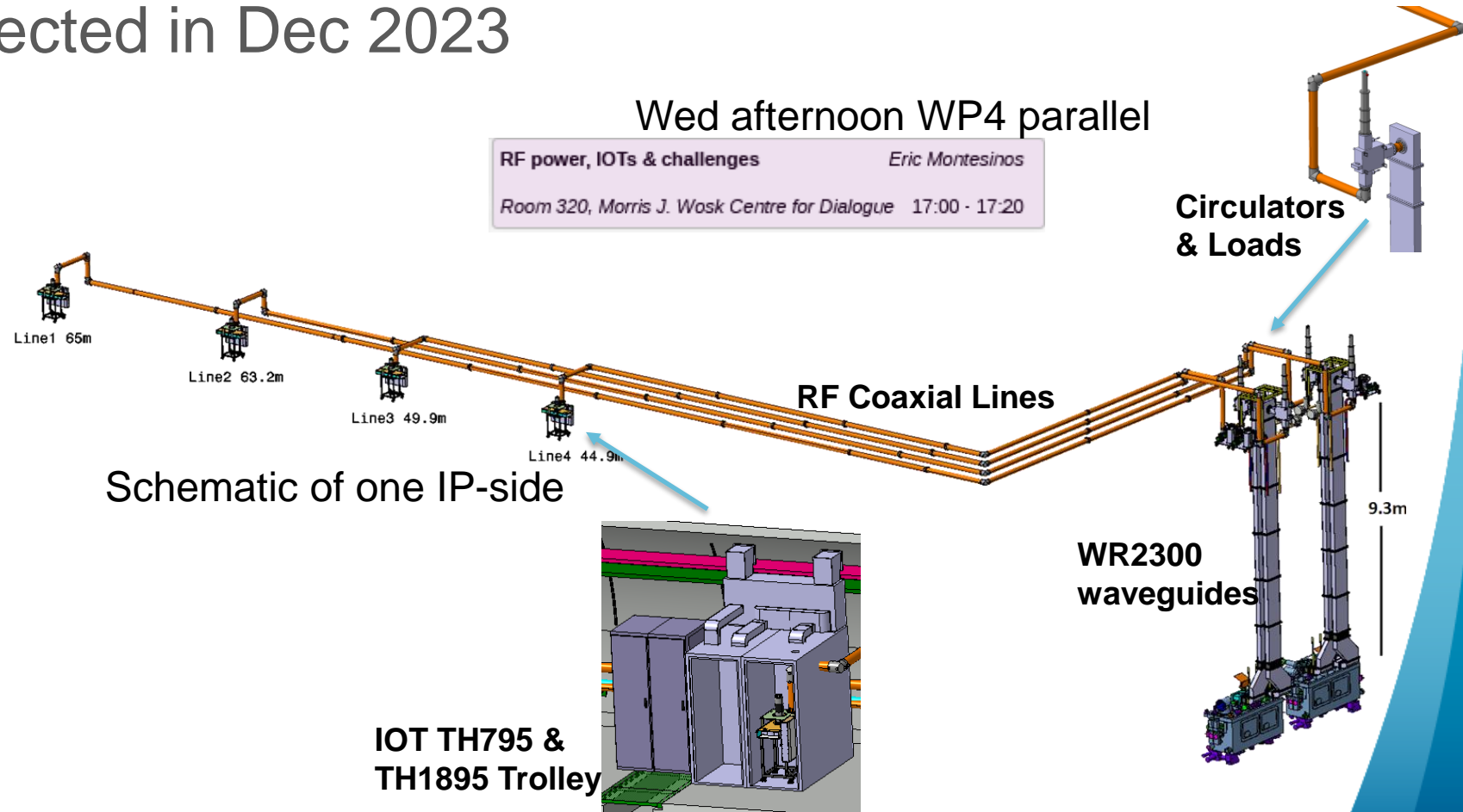
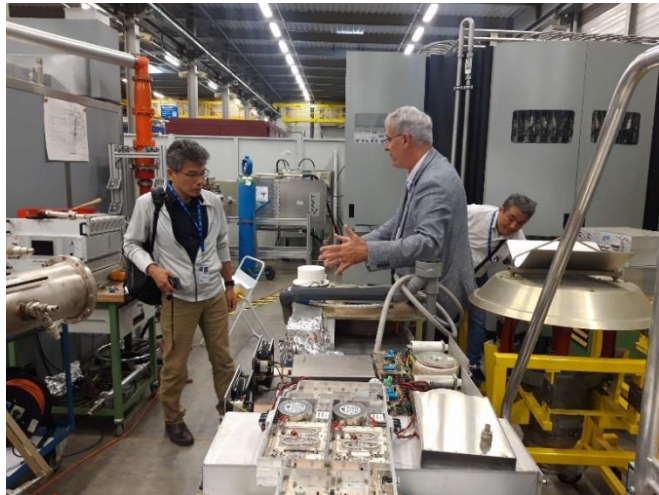


Wed afternoon WP4 parallel sessions



# High Power RF (Amplifiers & Lines)

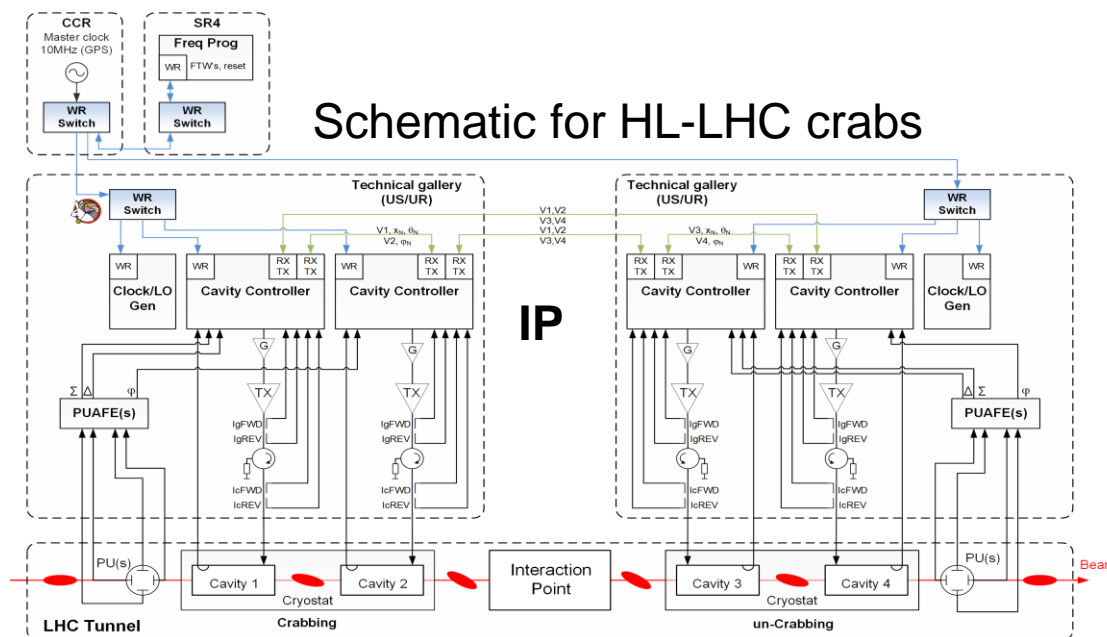
- In 2023, significant effort from KEK & CERN to finalize the proposal to the Japanese funding agency & ministry
- Final decision expected in Dec 2023



# Low Level RF developments

- Important operational experience from SPS (to be contd.)
- New  $\mu$ TCA platform (following LIU-SPS upgrade), RF over White-Rabbit (need upgrade of LHC Beam Control)
- 4 Faraday cages with independent cavity controllers including Direct RF feedback & Digital serial link between cavity controllers

White-rabbit RF-train



LLRF MTCA crate



3U Analog front-ends

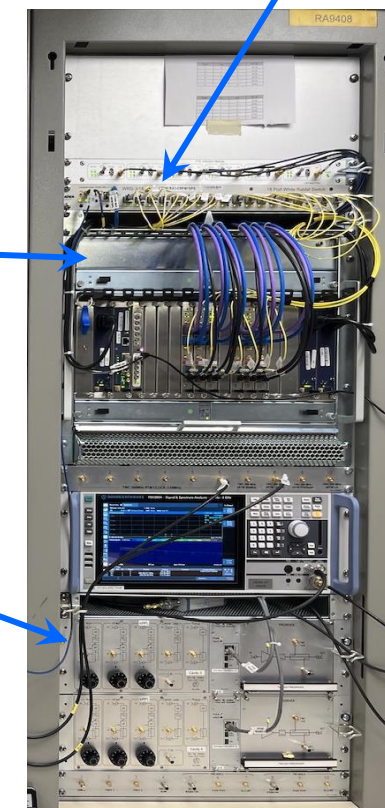


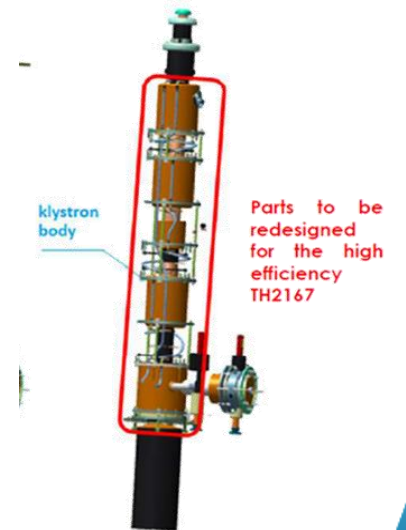
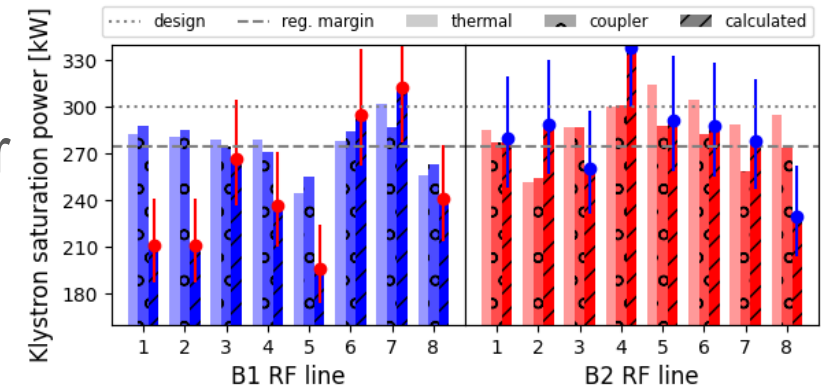
Fig – SPS 200MHz LLRF MicroTCA crate and analog front-end



# LHC Accelerating RF & HE-Klystrons

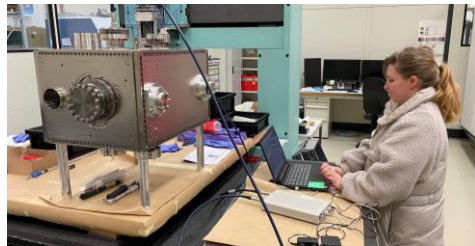
- MDs in the LHC from 2022-23
  - Injection of 72b train up to  $2 \times 10^{11}$  p/b feasible (capture losses pending)
  - Beam based measurements in the LHC show lower power than the theoretical expectations
- High efficiency klystron (TH2167-HE) under development to increase the peak “theoretical” power 300 kW  $\rightarrow$  350 kW
  - Prototype validation expected end-2024
  - Proposal to replace 3-4 Kly/yr to fully replace by 2030 being prepared

Thursday morning parallel session (H. Timko)





# Thank you





# Specifications, Series

- Released
- Under approval
- In Work
- To be reviewed

Scope	ID code	Eng. Spec. [EDMS nr]	Guideline for compl. with CERN Saf. Req. [EDMS nr]
			2043016 v.0.1
Full Cryomodule, including beam screens and references to requirements for vacuum components (Sector valves, Plug-in modules)	ACFGA	<a href="#">2514225 v.1.0</a>	
Safety Request WP4 - Co CONTENT FOR THE DQW & RFD CRYOMODULE FOR LHC	ACFGA	<a href="#">2706475 v.1.2</a>	
HL-LHC LHC CRAB CAVITIES: welded joints for cryomodule assembly	ACFGA	<a href="#">2632333 v.1.0</a>	
Minimum Material Requirements for Austenitic Stainless Steel and Aluminium Alloys to be employed in non-critical applications			

Dressed cavities, HOMs couplers, Pick-up antennas, Cold magnetic shield	ACFDC,ACFHC, ACFPU, ACFM	<a href="#">1389669 v.2.6</a>	<a href="#">2058183 v.1.0</a>
Cryogenic circuits	ACFQC	<a href="#">2093032 v.1.2</a>	<a href="#">2101920 v.1.0</a>
Thermal shield	ACFTS	<a href="#">2101922 v.1.0</a>	<a href="#">2101923 v.0.6</a>
He guard	-	<a href="#">2806004 v.1.2</a>	TO BE PREPARED
MLI	ACFTS	<a href="#">2144140 v.1.2</a>	-
Vacuum vessel	ACFVT	<a href="#">2101924 v.1.4</a>	<a href="#">2101925 v.1.0</a>
Warm Magnetic shield	ACFWM	<a href="#">2101926 v.1.2</a>	-
Alignment monitoring system	ACFAM	-	-
Support and alignment system	ACFAH	-	-
Instrumentation (ONLY FOR RFD SPS)	ACFIS	<a href="#">2450567 v.4</a> + <a href="#">CRNLSQLj0070 v.AA (PID)</a>	-
Fundamental Power Coupler	ACFMC	<a href="#">2101934 v.1.0</a>	
RF internal lines	ACFRL	<a href="#">2605345 v.1.0</a>	-
Tuning system	ACFTU	<a href="#">2101938 v.0.1 / Mat. Cert. 2.2</a>	-
Safety protecting devices	ACFGA	<a href="#">2101940 v.1.0</a>	<a href="#">2101943 v.1.0</a>
Sector Valves (beam line)	VVG (TBC)	<a href="#">§ 7.7 of 2043014 v.1.0</a>	-
Plug-in modules for Cold-Warm transition + Intercavity bellow	ACFVW + ACFVC (TBC)	<a href="#">§ 7.7 of 2043014 v.1.0</a>	-
Beam screen	VSSC_	<a href="#">§ 7.7 of 2043014 v.1.0</a>	-

