RFD Crab Cavity Contribution from the U.S.

Status, Issues and Delivery Dates

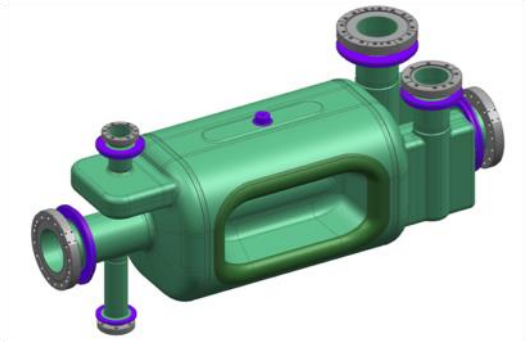
Leonardo Ristori – Fermilab

14th HL-LHC Collaboration Meeting – Genova, 7th October 2024

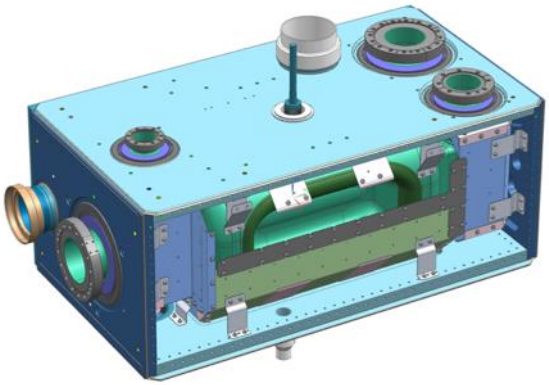
Outline

- Scope
- One Year in Summary
- Succesful Qualification of First Pre-Series
- Bare Cavity Fabrication
- Issues with Processing and Rinsing
- HOM Dampers Fabrication
- Helium Tanks Integration a.k.a. Jacketing
- Plans for Acceptance
- Delivery Dates

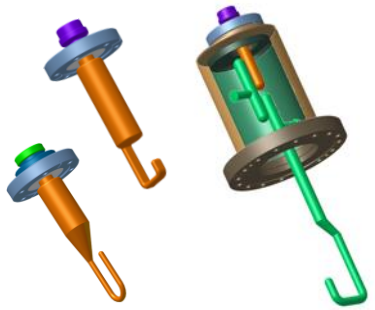
Scope and Deliverables



Bare RFD Cavity



Dressed RFD Cavity
(front wall removed to show internal components)



Higher-Order-Mode Dampers (HOMs)

- **Project Scope includes 2 Prototypes + 2 Pre-Series + 10 Series**
- Deliverables: **10 qualified dressed cavities** (mix of pre-series + series)
- Bare Cavities: Fabrication + Processing **in Industry**; Intermediate Qualification **at FNAL** at 2K; re-processing (when necessary) **in Industry**; re-rinsing (when necessary) **at JLAB**
- Jacketing: Magnetic Shields + Helium Tank **in Industry**
- HOMs: H-HOM **by JLAB**; H-HOM FT, V-HOM, Pick-up **by CERN**
- Dressed Cavities: re-rinse + Install HOMs + Final Qualification **at JLAB** at 2K
- Transport to TRIUMF: Confirm performance at 2K, and acceptance by CERN

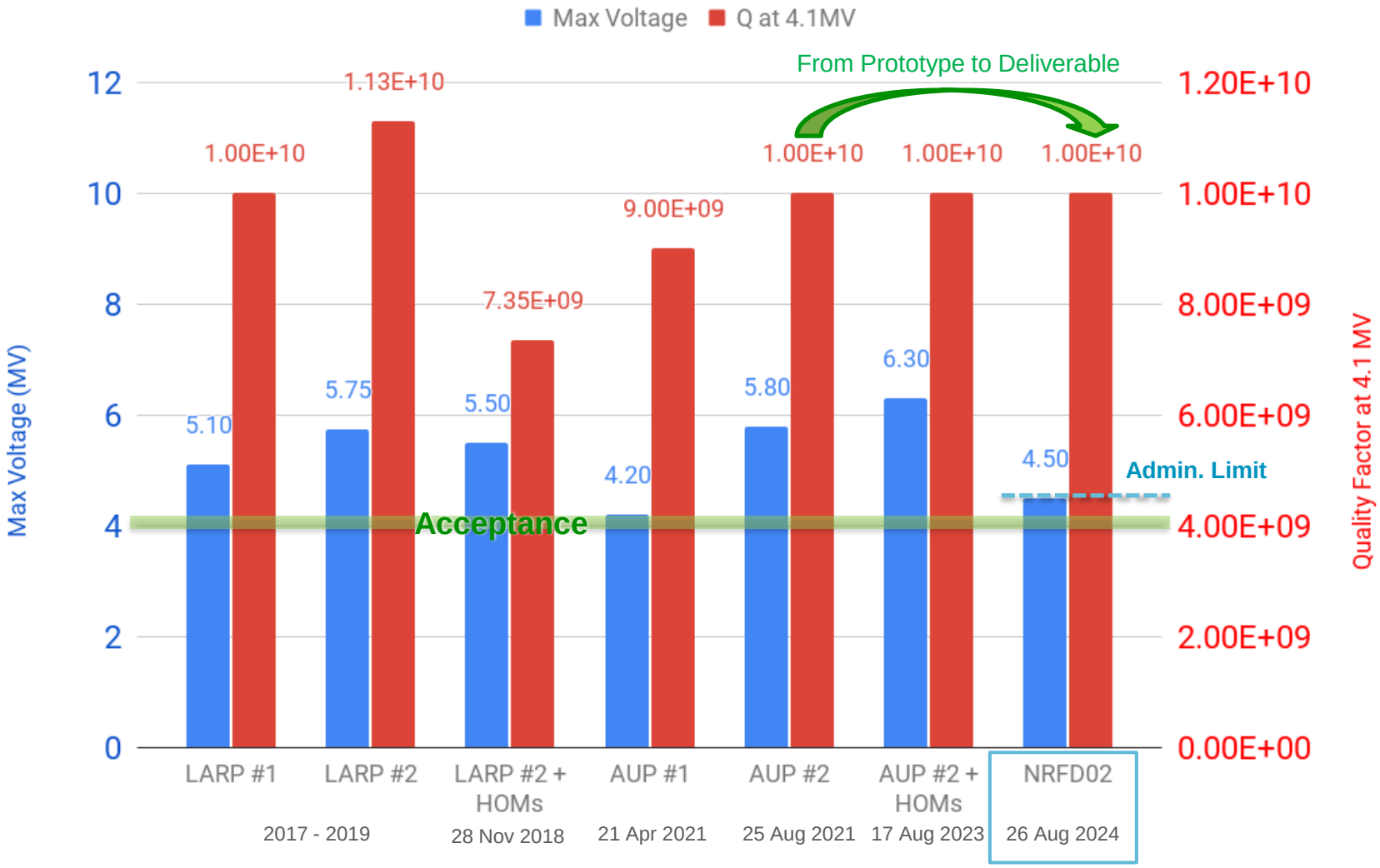
US HL-LHC AUP

One Year in Summary

- First prototype helium tank welded successfully at Zanon without surprises.
- A total of 8 cold-tests were performed in the U.S. since October 2023.
- 2 Pre-Series Bare cavities (NRFD01 & NRFD02) were completed and processed at Zanon.
- 2 Series Bare Cavities (NRFD03 & NRFD04) being completed as we speak. Components formed succesfully for all series.
- One Pre-Series cavity exceeded acceptance levels at bare stage, validating fabrication and processing at Zanon, and also HPR at JLAB.
- Successful investigations uncovered and solved issues with processing and with HPR at Zanon.

Cold Test Records

Best Result for Each Cavity

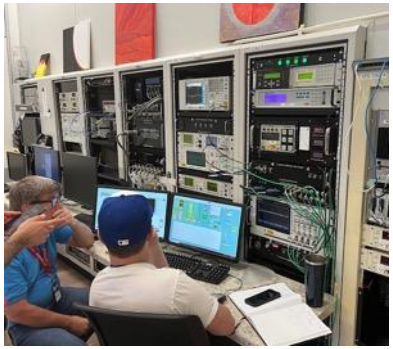


→ *See Talk by A. Castilla - JLAB*

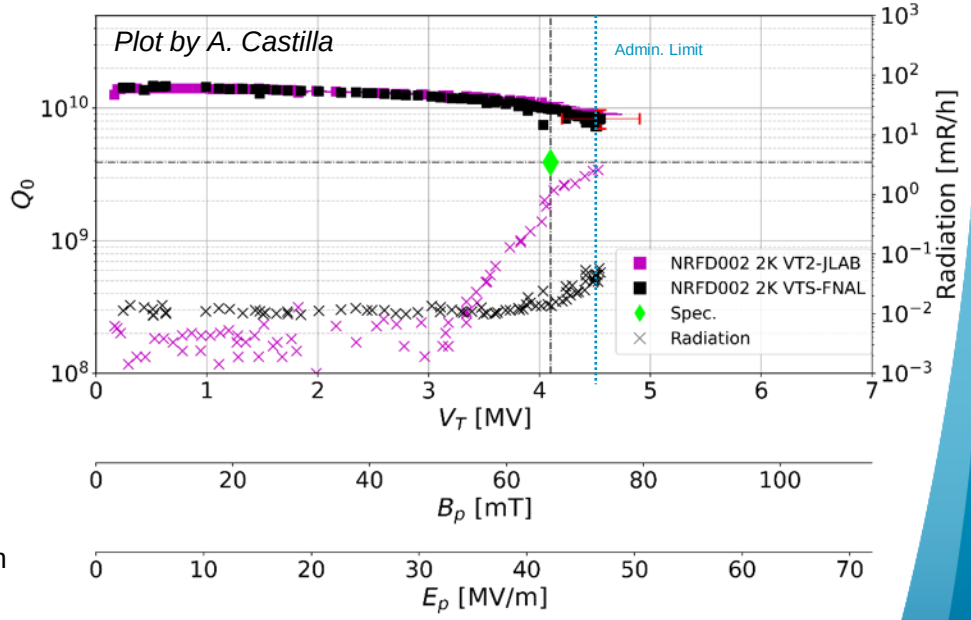
Pre-Series #2 (NRFD02) Test Results

- Performed 3 tests in total, always exceeding acceptance requirements, but with radiation onset (indicative of contamination). Onset level continued to improve after successive high-pressure rinses by JLAB.
- Final test shows no radiation up to acceptance level.
- Low field Q_0 is high: Chemistry by Zanon is successful.
- Radiation onset is at high field: HPR and clean assembly by Jlab is successful.

JLAB Cleanroom



8/26/24: FNAL VTS Control Room

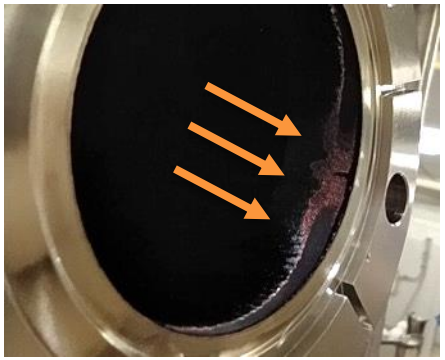


Last 2 tests for Pre-Series Bare Cavity #2

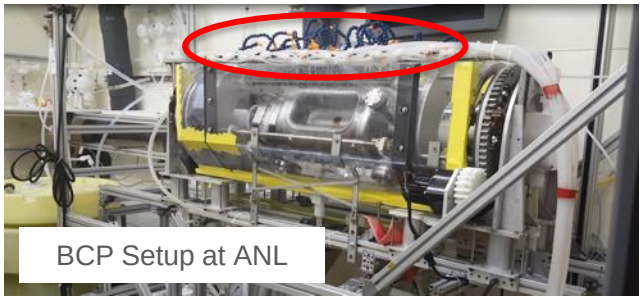
Courtesy of Zanon

BCP Issues at Zanon

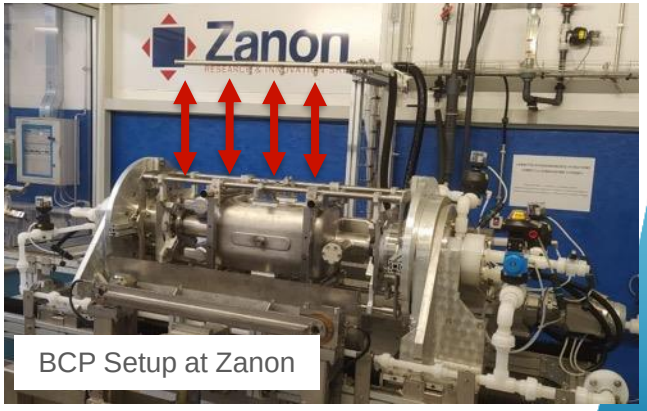
- **Prototype #1** which exceeded acceptance (although marginally) was selected to validate chemistry at Zanon and subjected to a total of 3 bulk chemistries. Full consumption of Niobium material was observed in 2 locations. It is not useable in its current status.
- The outcome of a detailed investigation was that although the removal in most cavity surfaces is very well controlled, the setup at Zanon did not have sufficient water cooling on the outside of cavity and the acid near the cavity flanges was reaching higher than optimal temperatures, causing excessive removal.
- Tests were performed with the improved cooling and yielded positive results with variation of removal near flanges reduced by ~50%.



Prototype #1 after 3+ BCP cycles



BCP Setup at ANL

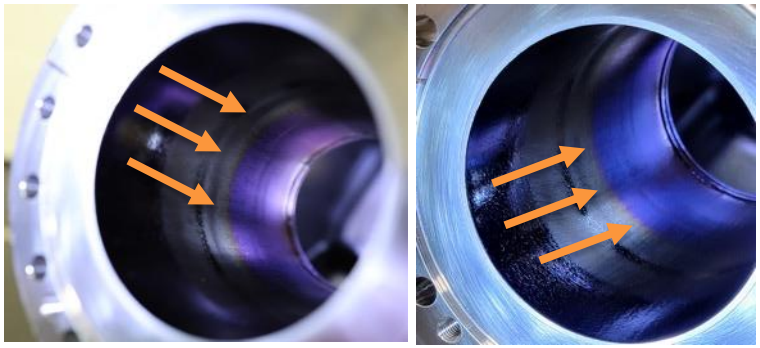


BCP Setup at Zanon

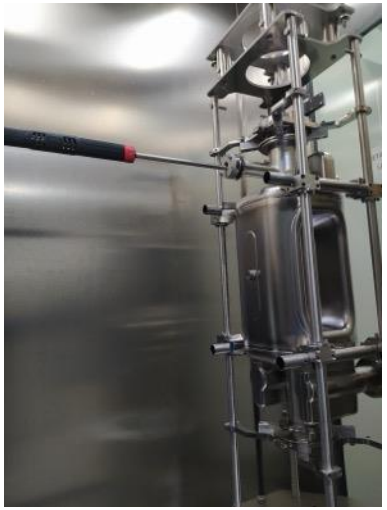
Courtesy of Zanon

HPR Issues at Zanon

- Both pre-series cavities processed and rinsed at Zanon are showing **localized discoloration** (see pictures). Suspecting excessive and localized HPR pressure.
- Thanks to recent validation at JLAB, we facilitated knowledge transfer to Zanon and modified the process to align as much as possible with JLAB.
- **Zanon introduced manual HPR** of ports followed by the automatic process. Also parameters were modified to produce a **faster feed speed and increased total rinse time**.
- Particle counts in cleanroom dropped by more than a factor of 10 and no discoloration is visible now.



Pre-Series #1 with internal discoloration



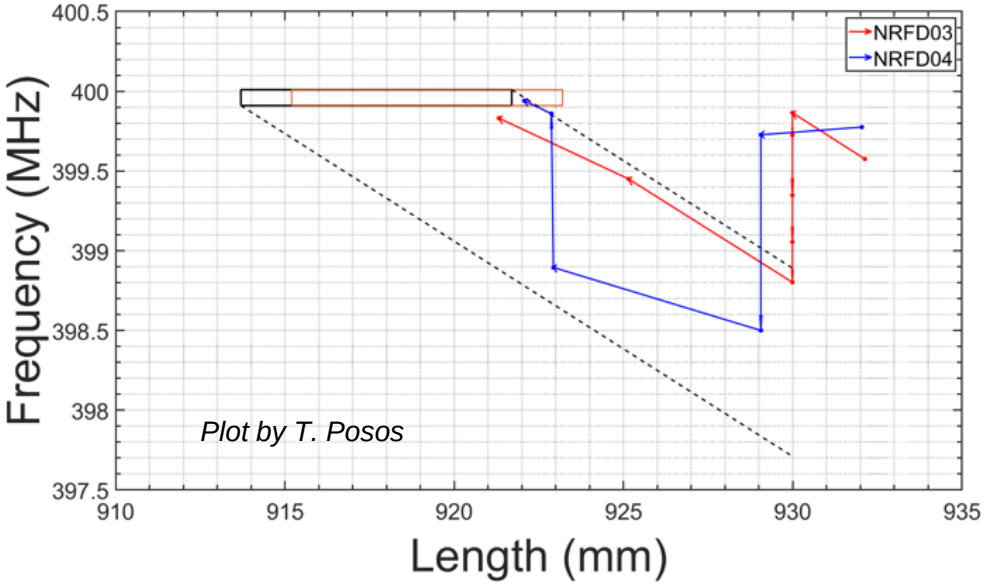
Manual HPR introduced at Zanon

No discoloration visible now

→ See Talk by M. Narduzzi - FNAL

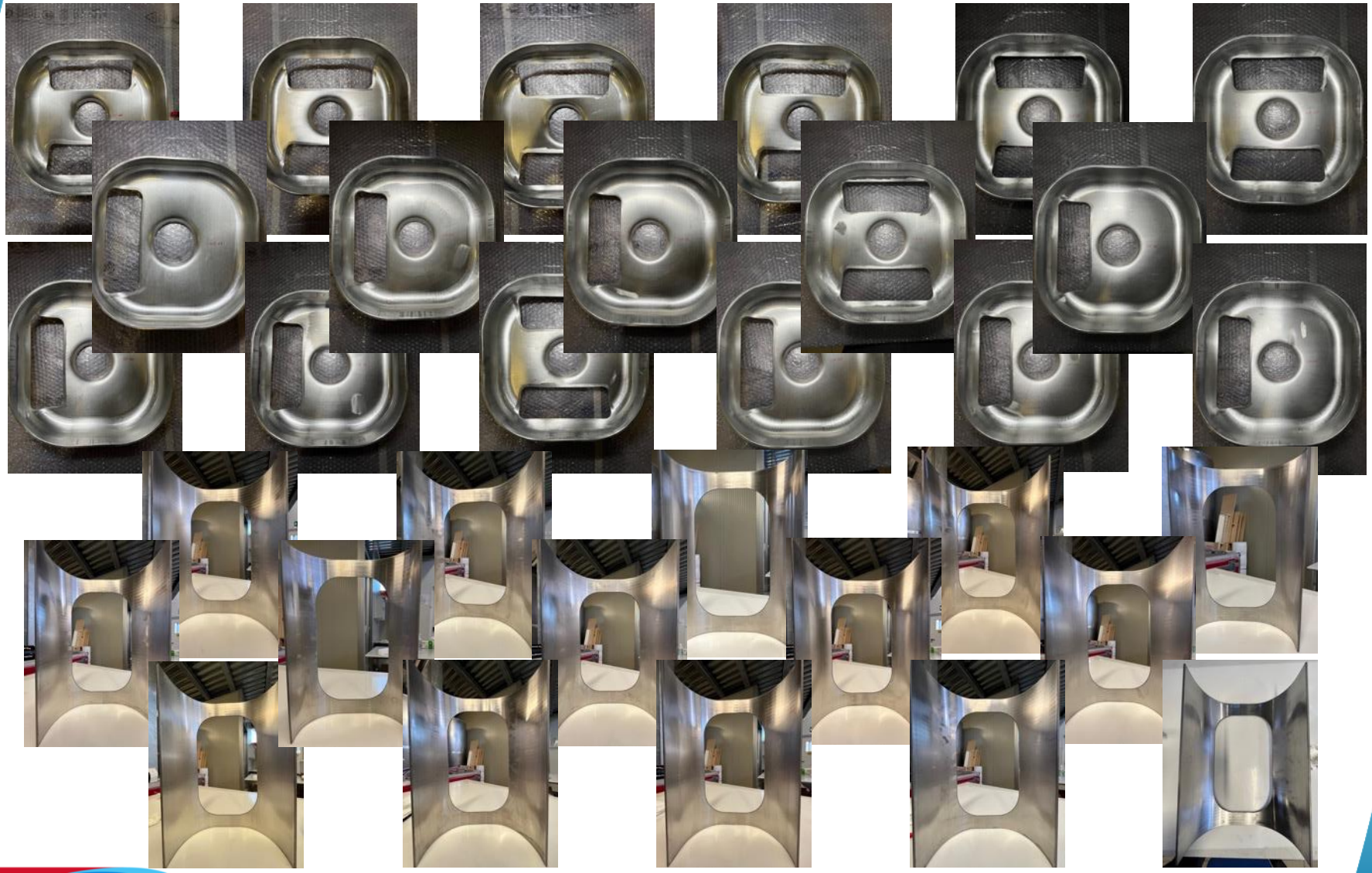
Cavity Fabrication Status at Zanon

- First two series NRFD03 & NRFD04 are undergoing trim-tune operations (see plot and pictures). Cavity length, cavity geometry, and frequency all need to be achieved at the end.
- NRFD04 was presenting non-standard behavior after the first cut (frequency reduction after cut versus expected frequency increase). After reshaping, the following cut was as expected.
- Final welds will be completed later this month.
- All components for series cavities were produced in parallel. Deliveries are expected to ramp up dramatically in the next 6 months.



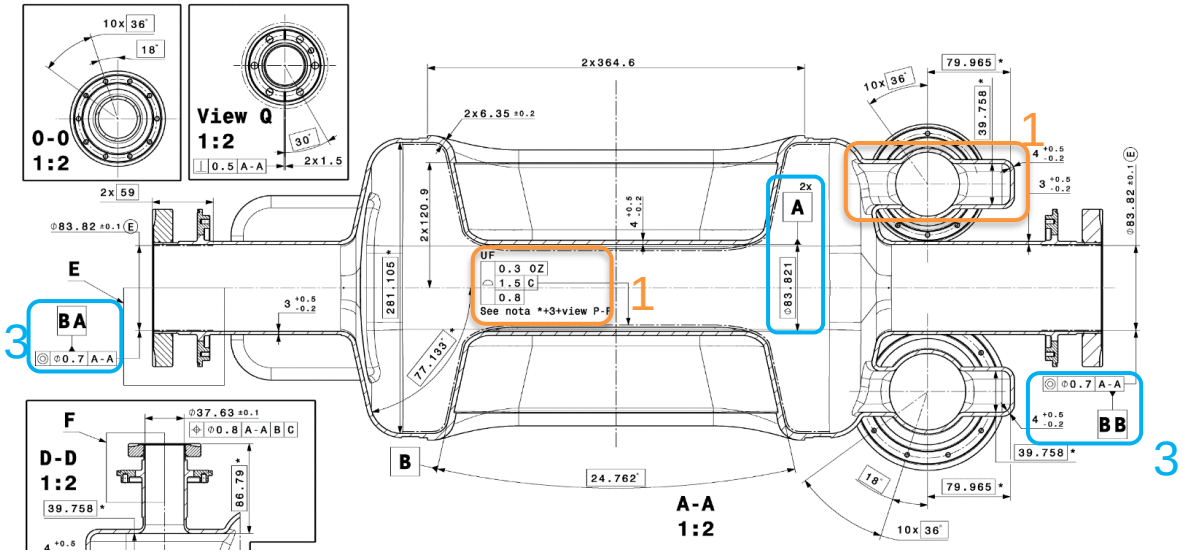
Some Components of Series #3 and #4 ready for trim-tuning

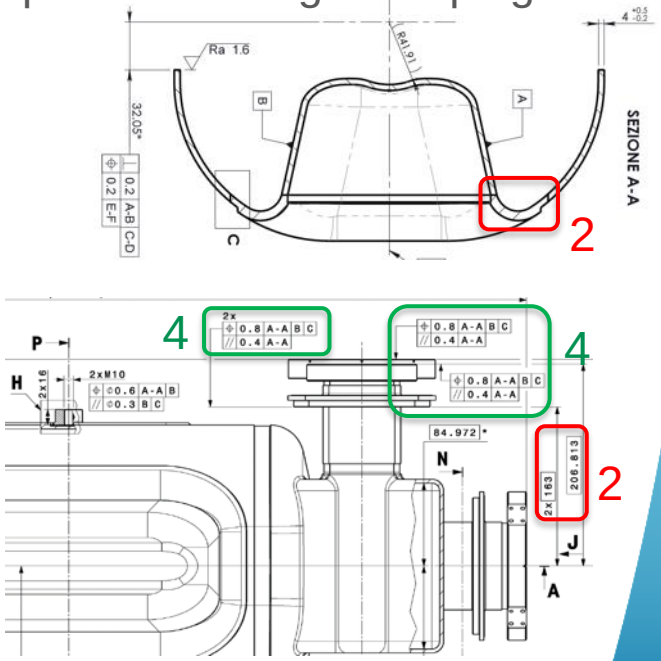
It Was a Year of Visual Inspections…



Fabrication Challenges at Zanon

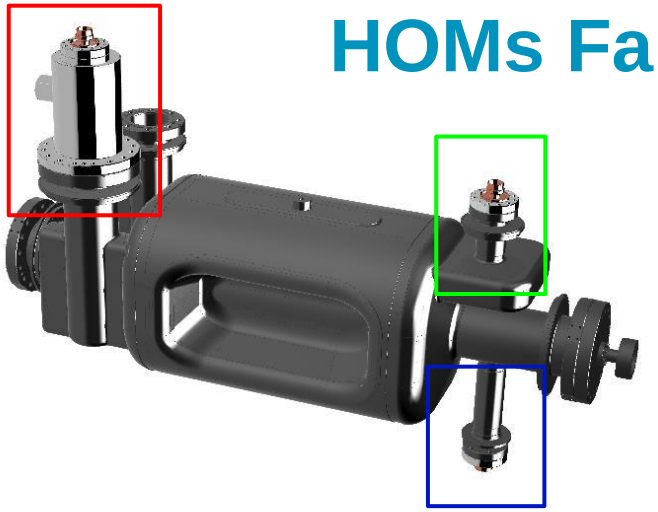
- Arguably this SRF cavity is one of the most complex to build and has some of the tightest tolerances compared to others.
- Rework activities are often necessary to achieve requirements.
  - Geometrical tolerances on stamped/coined subcomponents (pole & waveguides in particular)
  - Complex EBW between *Half Main Body* sub-components and *Waveguides Boxes-End Caps*
  - Alignment between *End Groups-Main Body* during final EBW
  - Non straightforward behavior of cavity, and components during reshaping.

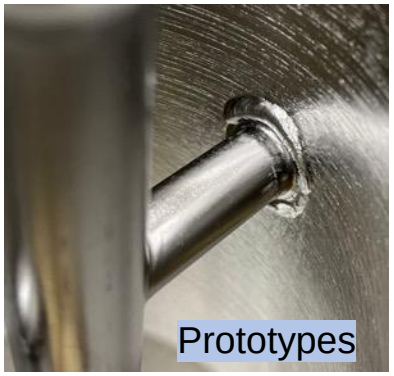




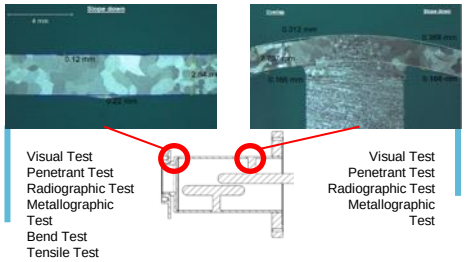
→ *See Talk by N. Huque - JLAB*

HOMs Fabrication at JLab



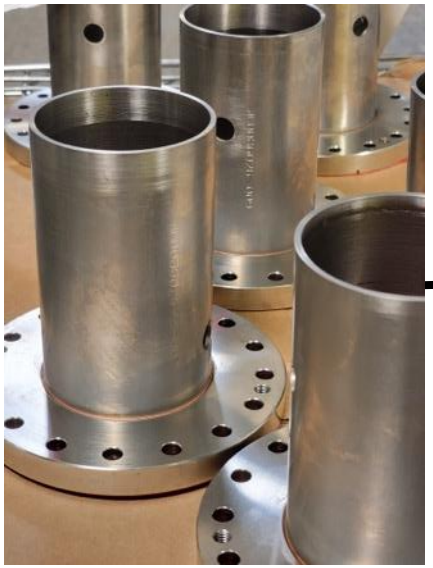


- PRR held in May 2022
- Prototype: 3 sets (FY21/FY22)
  Complete (only 1 usable set)
- Pre-Series: 3 sets (FY24)
  Complete but not deliverable
- Reduced scope to only H-HOMs
- Series: 10 sets (FY24/FY25)

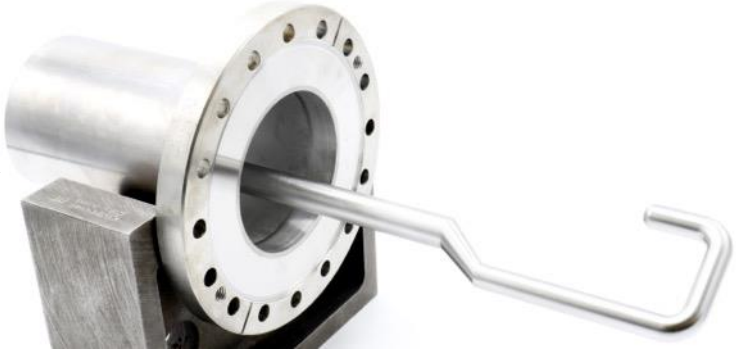


- Quality of Hook/Tee EBW are improved (top right).
- Pre-Series deviations are smaller than prototypes, which passed simulations and RF check.
- All ceramic feedthroughs are now provided by CERN.

Production Status



Hook and Tee Weldment



Hooks/Tees
7 out of 10 complete

DN100 Brazements
5 out of 10 complete

DN40 Brazements
8 out of 10 complete

Inner Can Assembly

Final Assembly

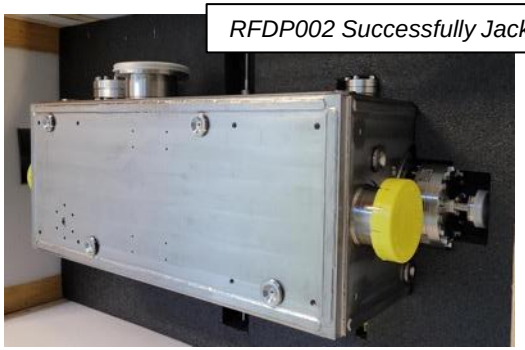
Production Schedule

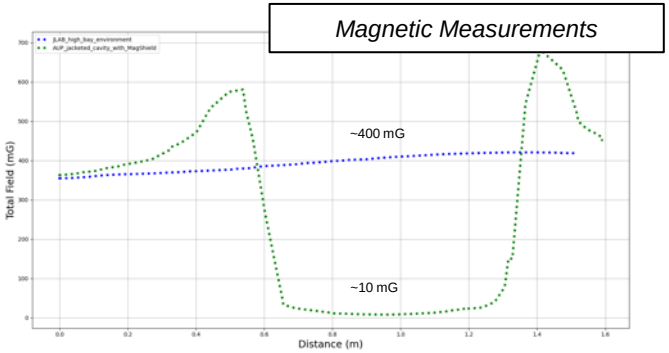
		2024			2025					
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
HHOM 01 - 04	Assembly									
	Testing									
	Acceptance							4		
HHOM 05 - 07	Assembly									
	Testing									
	Acceptance								3	
HHOM 08 - 010	Raw Material Procurement									
	Part Fabrication									
	Assembly									
	Testing									
	Acceptance									3

→ See Talk by M. Narduzzi - FNAL

Prototype Jacketing at Zanon

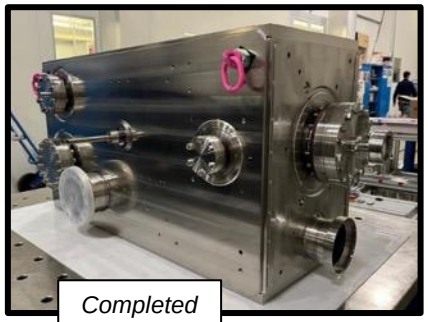
- **Welding of Proto #2 Helium Tank was completed without surprises and with ~zero frequency shift.**
- Cavity is at JLAB waiting for cleanroom equipment to be ready for HPR and preparations for cold test.
- Magnetic measurements were completed, showing an attenuation factor of ~ 40x well above specification.
- No changes foreseen for pre-series / series.

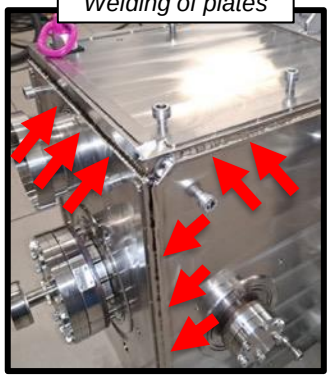

RFDP002 Successfully Jacketed

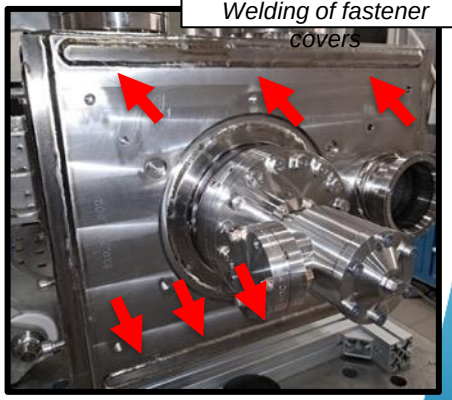


Magnetic Measurements


Start of Assembly


Completed Assembly

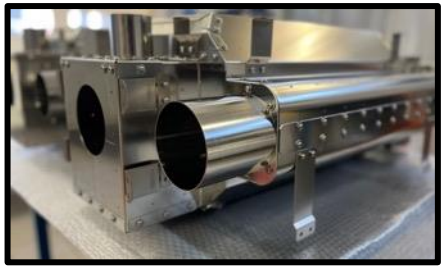

Welding of plates

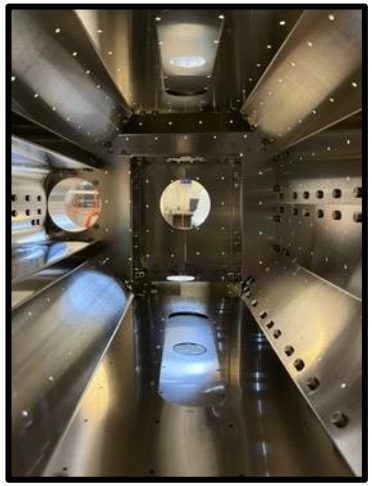

Welding of fastener covers

Courtesy of Zanon

Jacketing of Pre-Series + Series

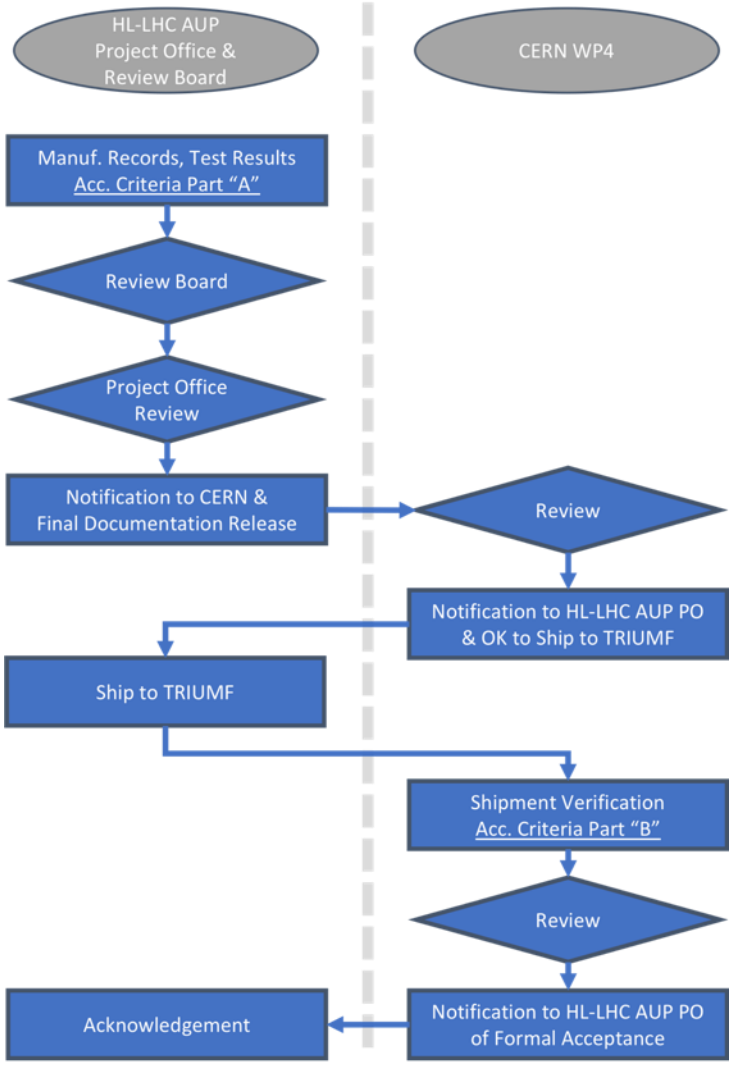
- First two magnetic shield assemblies and all Titanium materials are in hand at Zanon.
- Manufacturing drawings all approved.
- Welding book still not approved, contingent on tests at CERN on bimetallic transitions.





Acceptance of RFD cavities

- Acceptance Plan
  - Describes the process for acceptance between AUP and CERN, including OK to ship from CERN, and final checks at TRIUMF after receiving
- Acceptance Criteria – Part A (at JLab)
  - All requirements from FRS will be verified with a test or a set of measurements during cavity production or during final tests at JLab.
- Acceptance Criteria – Part B (at TRIUMF)
  - Series of tests/measurements to be carried out at TRIUMF under AUP supervision to confirm performance of cavities after shipment.
- Revising to implement:
  - 2K operation at TRIUMF
  - 4.5 MV administrative limit.



Recommendations from DOE Review

July 2024

- *1. "Re-evaluate if the cavity re-processing procedure needs to include the 48h 120C bake by the end of CY24."*

  Status: **OPEN**. Topic for discussion at this annual meeting.

- *2. "Evaluate if cavity High Pressure Rinse (HPR) procedures need to be adjusted to allow multiple re-rinse cycles without surface oxidation by the end of CY24."*

  Status: **ADDRESSED (CLOSURE by end of CY24)**. HPR Process at Zanon was adjusted to better align with the process at JLAB which has proven to be successful. First HPR cycle was performed, particle counts in cleanroom dropped by a factor of ~10. Cold tests later this month.

- *3. "Re-evaluate the required cavity re-rinsing rate, including potential impact on cost and schedule. Adjust the re-rinsing estimate, if necessary, by the end of CY24."*

  Status: **ADDRESSED (CLOSURE by end of CY24)**. Re-rinsing rate assumptions will be increased based on recent experience with 2 pre-series cavities. The scope increase will need to go through the monthly chance control board.

RFD Tests and Delivery Dates

	ZRI Serial	Bare Cavities delivered to FNAL	Bare Cavities qualified and back at Zanon	ZRI Serial	Jacketed Cavities delivered to JLAB	Dressed Cavities Delivered to TRIUMF	CERN Serial
	NRFDP001	6/1/2024	8/1/2024	RFDP001	9/15/2024	1/15/2025	HCACFCA005-UP000001
Proto 2	NRFDP002	8/17/23	9/15/2023	RFDP002	4/16/2024	1/31/2025	HCACFCA005-UP000002
PS 1	NRFD01	10/7/2024	12/1/2024	RFD01	1/30/2025	3/31/2025	HCACFCA002-UP000001
PS 2	NRFD02	4/16/2024	9/20/2024	RFD02	11/19/2024	2/15/2025	HCACFCA002-UP000002
	NRFD03	11/15/2024	1/14/2025	RFD03	2/28/2025	4/29/2025	HCACFCA002-UP000003
	NRFD04	12/6/2024	2/4/2025	RFD04	3/21/2025	5/20/2025	HCACFCA002-UP000004
	NRFD05	12/27/2024	2/10/2025	RFD05	3/27/2025	5/26/2025	HCACFCA002-UP000005
	NRFD06	1/17/2025	3/3/2025	RFD06	4/17/2025	6/16/2025	HCACFCA002-U
	NRFD07	2/4/2025	3/21/2025	RFD07	5/5/2025	7/4/2025	HCACFCA002-U
	NRFD08	2/22/2025	4/8/2025	RFD08	5/23/2025	7/22/2025	HCACFCA002-U
	NRFD09	3/12/2025	4/26/2025	RFD09	6/10/2025	8/9/2025	HCACFCA002-U
	NRFD10	3/26/2025	5/10/2025	RFD10	6/24/2025	8/23/2025	HCACFCA002-U
	NRFD11	4/9/2025	5/24/2025	RFD11	7/8/2025	9/6/2025	HCACFCA002-U
	NRFD12	4/23/2025	6/7/2025	RFD12	7/22/2025	9/20/2025	HCACFCA002-U

Agreed Late Delivery Dates
Apr-25
Jun-25
Jul-25
Sep-25
Oct-25

- Deliveries range from **February – September 2025**.
- Delays since last update can be attributed to challenges with geometrical tolerances, managing NCRs according to QA plan, unexpected JLAB VTA shut-down.
- Dates in red indicate conflict with JLAB shut-down.
- **Prototype** estimated to arrive at TRIUMF in January 2025.
- **Pre-Series** cavities estimated to arrive at TRIUMF shortly after.

Summary

- Successful cold test of Pre-Series cavity, validating the materials, the fabrication, and the chemical processing for the deliverables.
- Issues with processing and high-pressure rinsing appear to be addressed. Confirmations will come with tests in the upcoming months.
- Completed the first helium tank welding without surprises. Cold tests to confirm in Dec-Jan. Zanon is ready for the next tanks.
- Series cavities still at peak production, prioritizing quality, navigating through NCRs, slower than anticipated, but no showstoppers.
- Horizontal HOM dampers are at peak production at JLAB with first deliveries in Spring 2025, in time for dressed cavity tests.
- Acceptance Plan being slightly revised, to be validated with Prototype and executed with Pre-Series soon after.
- We will entertain discussions in WP4 on HPR process, as recommended by the recent DOE review.
- Deliveries of 10 cavities to TRIUMF range Jan-Sep 2025. We have consumed the float to ”late” deliveries.

THANK YOU FOR YOUR ATTENTION!

U.S. RFD Teams

Fermilab

RF/Mech Design, Procurements, Cold Tests

Leonardo Ristori, Paolo Berrutti, Manuele Narduzzi, Sasha Netepenko, Taha Posos, Colin Narug, Marilyn Wodzinsky

Jefferson Lab

HOM Dampers Fabrication and Cold Tests

Naeem Huque, Alex Castilla, Peter Owen

Old Dominium University

General Oversight and RF measurements

Jean Delayen, Subashini De Silva

SLAC National Accelerator Laboratory

RF Simulations

Alessandro Ratti, Zenghai Li

US HL-LHC AUP