RFD Crab Cavity Contribution from the U.S.

Status, Issues and Delivery Dates

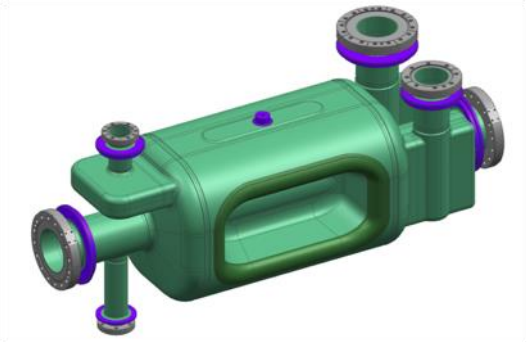
Leonardo Ristori – Fermilab

13th HL-LHC Collaboration Meeting – 25th September 2023

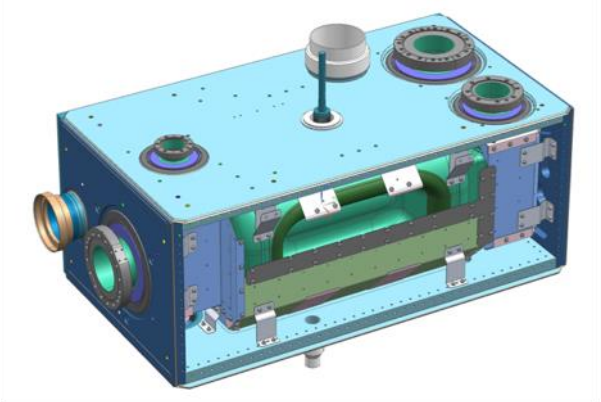
Outline

- Scope, Team
- One Year in Summary
- Performance of AUP Prototypes
- Bare Cavity Fabrication
- HOM Dampers Fabrication
- Helium Tanks Integration
- Plans for Acceptance
- Delivery Dates

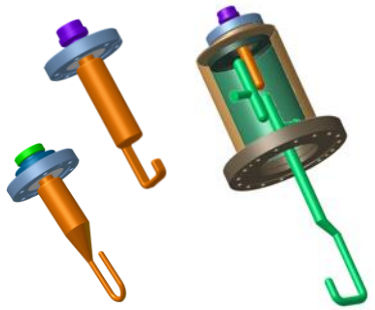
Scope and Deliverables



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**
- Bare Cavities: Intermediate Qualification **at FNAL** at 2K
- Integration: Bare Cavity + Magnetic Shields + Helium Tank
- Dressed Cavities: Final Qualification **at JLAB** at 2K + HOMs
- Transport to TRIUMF for acceptance by CERN:
  - 10 qualified dressed cavities (mix of pre-series + series)
  - Warm/Cold tests at TRIUMF → formal acceptance by CERN → hand-off

U.S. RFD Team

Institutions in alphabetical order:

- **Fermilab** (RF/Mech Design, Procurements, Cold Tests):
  - Leonardo Ristori, Paolo Berrutti, Manuele Narduzzi, Alexander Netepenko, Timergali Khabiboulline, Colin Narug, Damon Bice
- **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 Design, Coordination):
  - Alessandro Ratti, Zenghai Li

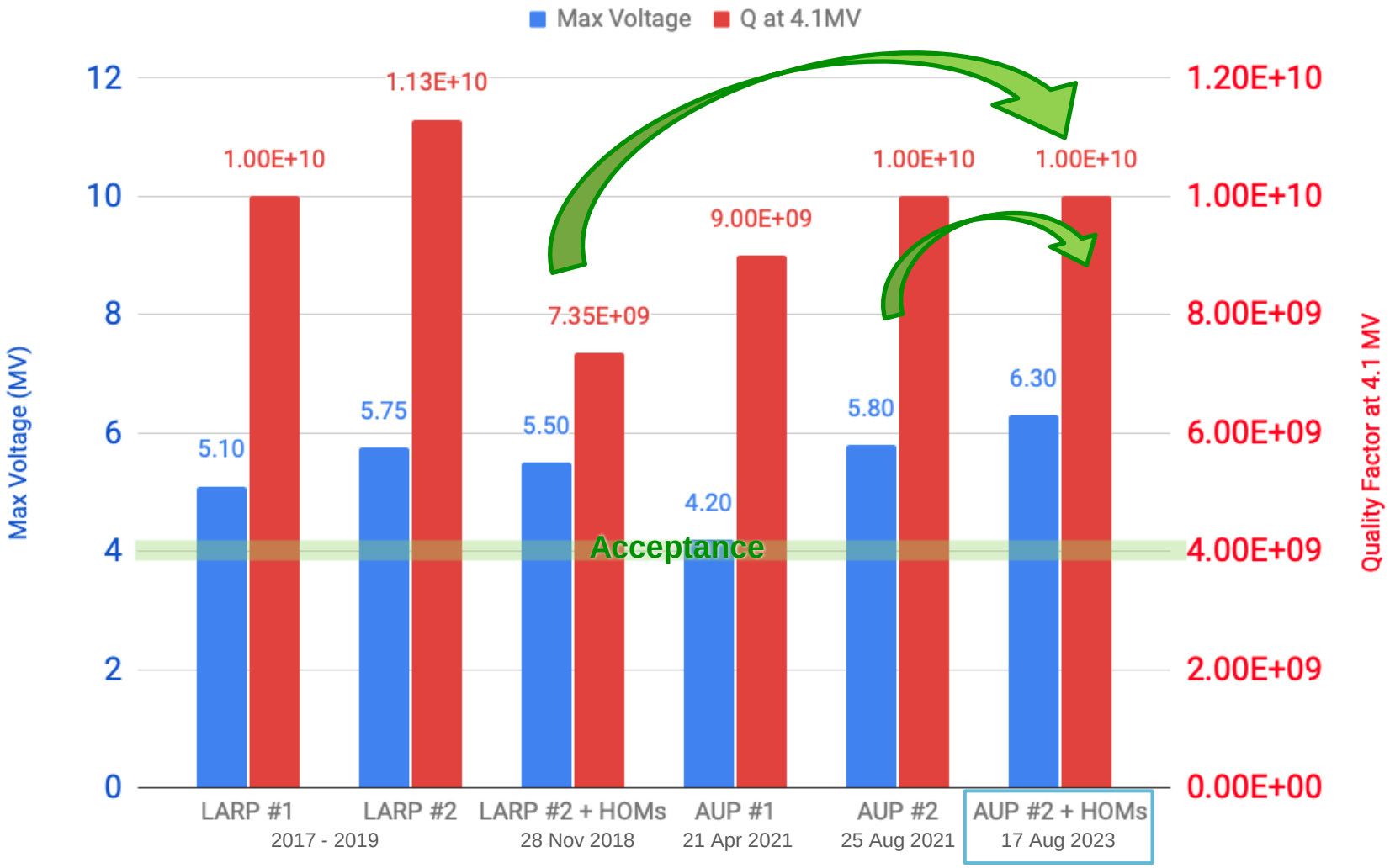
One Year in Summary

- Prototype bare cavity + HOMs exceeded LARP performance.
- 2 Pre-Series bare cavities undergoing final EBW, showing improvement in shape accuracy, compared to prototypes.
- Series cavity fabrication in full swing, progressing not without surprises, with NCRs being managed successfully, raw materials yield within estimates.
- All contracts with industrial partners are (almost!) in place to cover all deliverables.

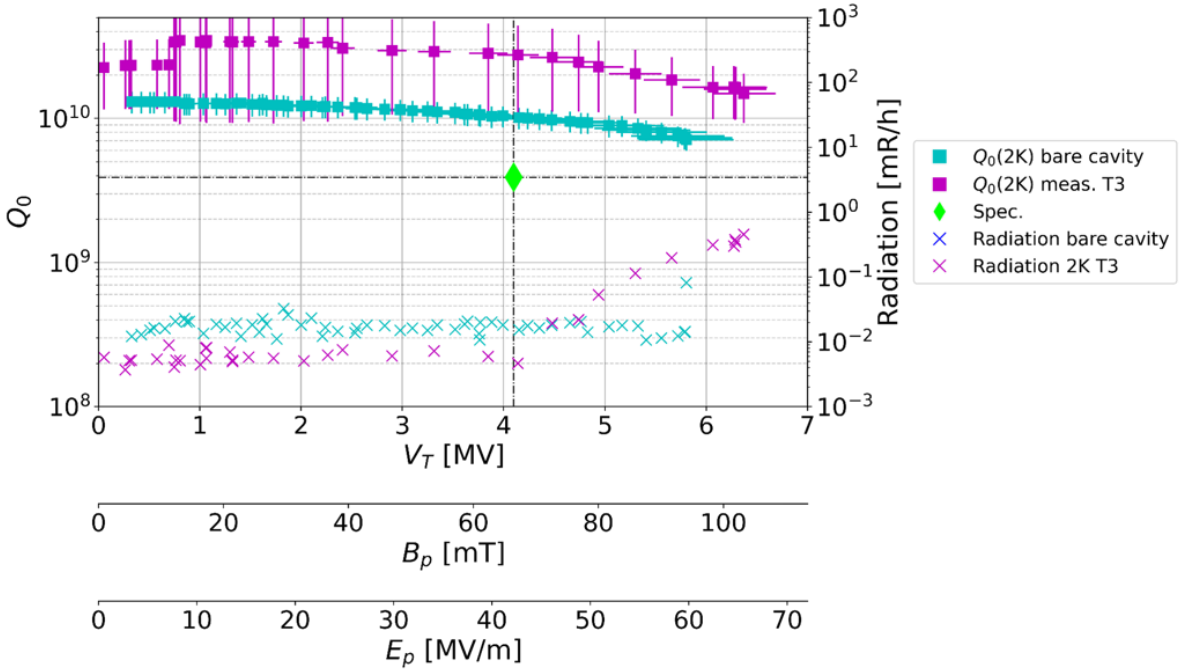
Open issues/risks:

- Failed qualifications of pre-series HOMs ceramics.
- Discrepancy of test results between FNAL/Jlab
- Jacketing activities and shipping of dressed cavity not yet validated.

LARP + AUP Cold Test Summary



Proto Bare Cavity NRFDP002 + HOM Dampers



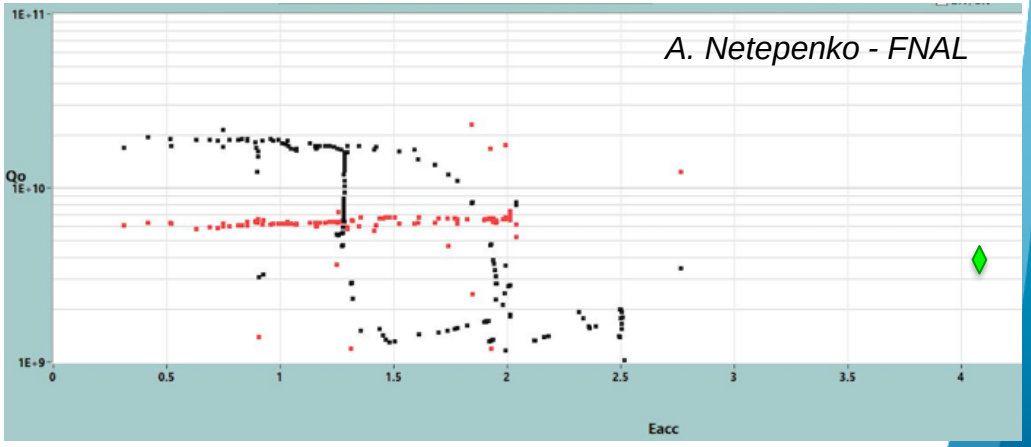
- Multiple tests at Jlab this year hindered by challenges with leaks and RF losses at the HOM interfaces.
- Collaborative effort, progressive understanding and implementation of measures, culminated finally in a successful test in August.
- Apparent increase in performance still to be explained, likely due to different calibration at the facilities. Important aspect to be understood in view of acceptance.

Proto Bare Cavity NRFDP001

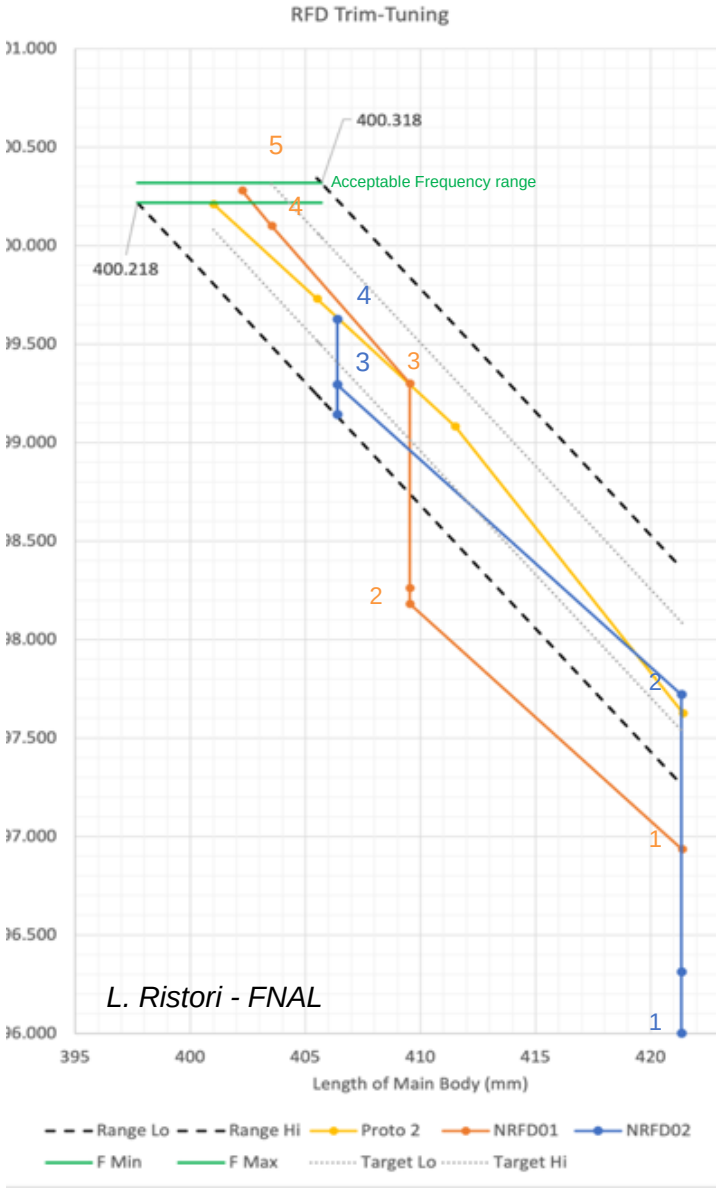
- Previously processed and prepared at ANL/FNAL, reached 4.2 MV with Q_0 9E9, not stellar, possibly limited by surface defect or inclusion.
- Selected to validate processing at Zanon (top right), low-field Q_0 is high but unable to surpass ~50% of acceptance level (black dots bottom right).
- We had observed this degradation in LARP, and we were able to restore by repeating bulk processing.
- Under investigation at JLAB.

HPR at Zanon

650ºc Bake at Zanon



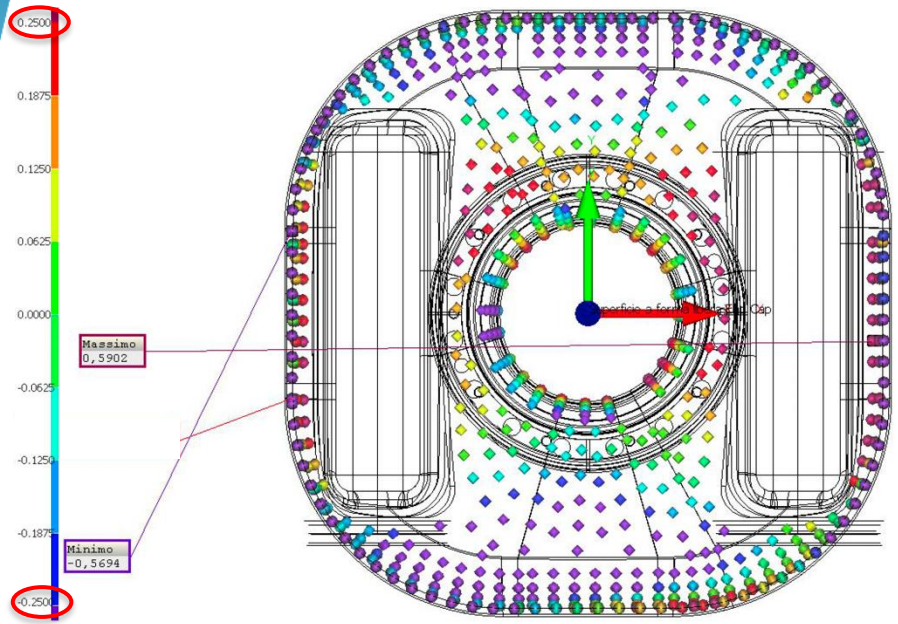
Pre-series Trim-Tuning Activities



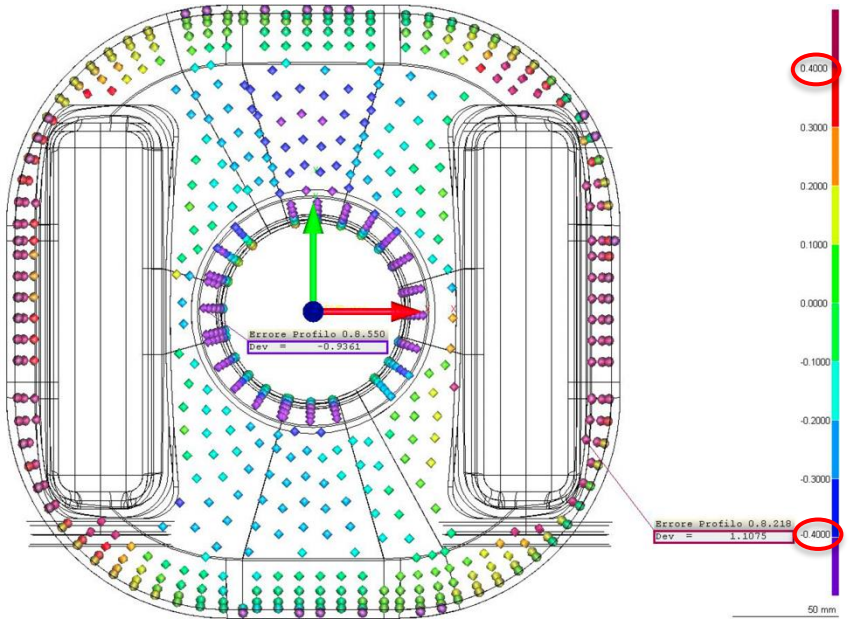
Pre-series vs Prototypes Metrology:

V-HOM End Group

M. Narduzzi - FNAL



Pre-series V-HOM End Group
{+/-0.25mm scale}



Prototype V-HOM End Group
{+/-0.4mm scale}

- Several improvements in manufacturing have been implemented by ZRI:
  - Forming tooling slightly reworked.
  - EBW and CNC fixtures updated.
- Significant improvement in shape accuracy from 2.22mm to +1.18mm.

RFD Series manufacturing at ZRI

End-Caps

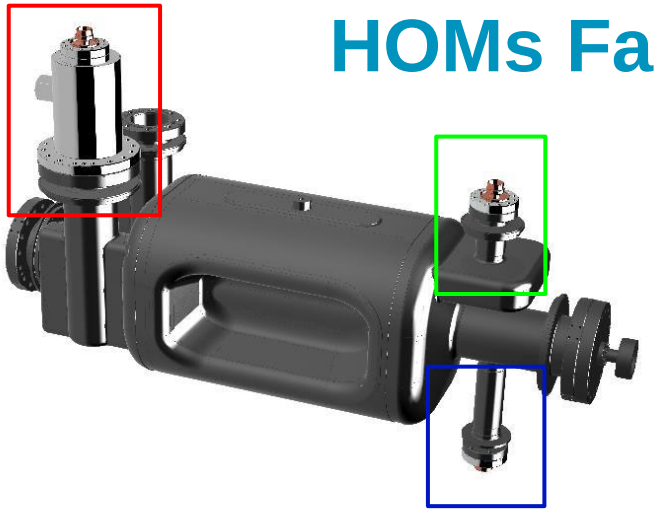
Pole Corners

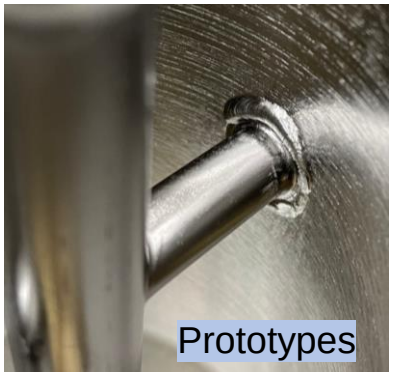
Residual issues with pole-forming, discarded ~15% of parts.

Acceptable deflecting poles

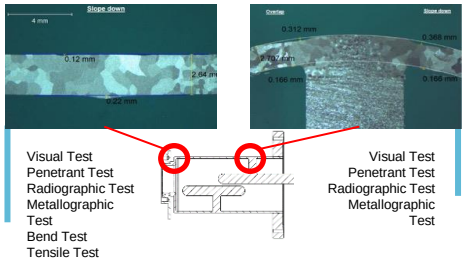
Waveguide Boxes

HOMs Fabrication at JLab





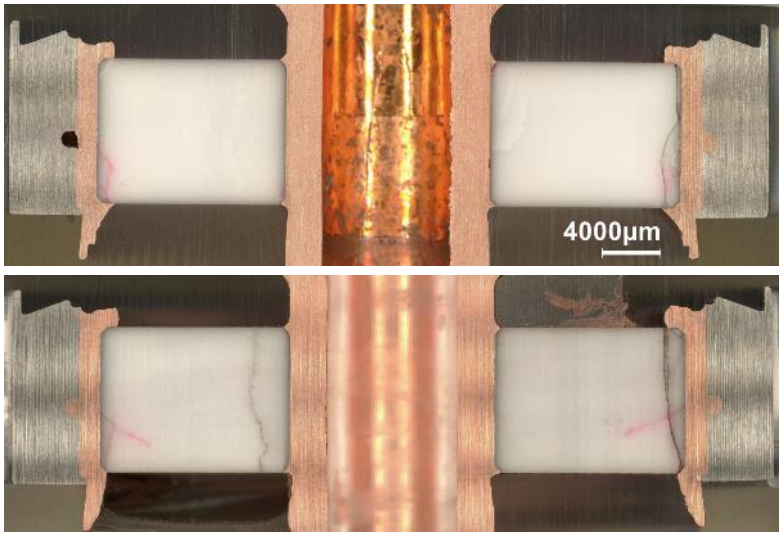
- PRR held in May 2022
- Prototype: 3 sets (FY21/FY22)
  Complete (only 1 usable set)
- Pre-Series: 3 sets (FY24)
- Series: 8 sets (FY24)



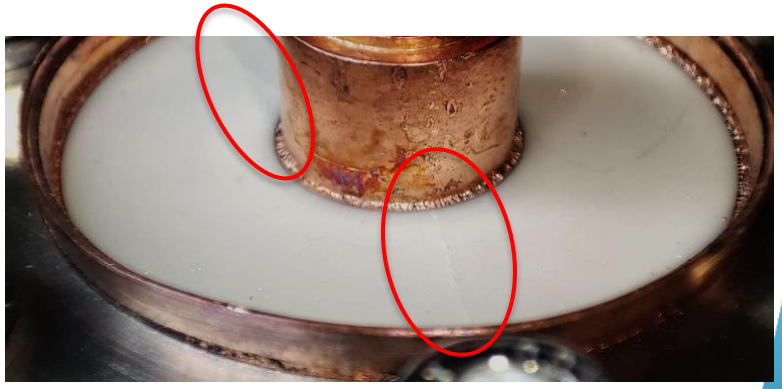
- Quality of Hook/Tee EBW are improved (top right).
- The most critical dimensions are the gap and parallelism between the hook and tee (bottom right). Pre-Series deviations are smaller than prototypes, which passed simulations and RF check.

Failures of Ceramic Windows

- First set of tests were carried out at CERN in **February 2023**. Parts held vacuum with no visible surface damage.
- After sectioning, internal cracks were discovered. Observed both on JLab and CERN ceramics. Preexisting and caused by cutting
- Tests were repeated in **August 2023**. Samples had radial cracks during installation (bottom right).
- JLab is fast-tracking one set based on integrity of prototypes, with additional measures implemented. Two additional sets will be made using CERN-provided ceramics.



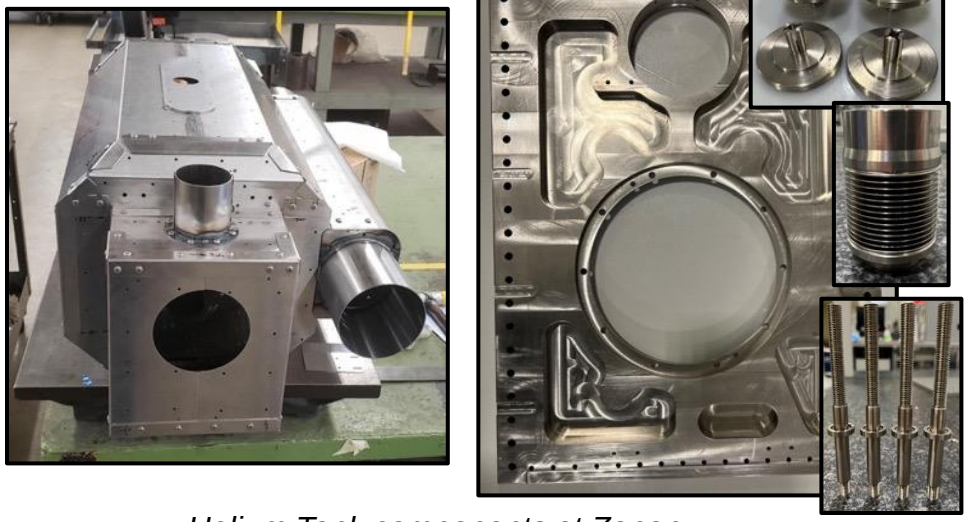
Liquid penetrant testing on sectioned ceramic windows



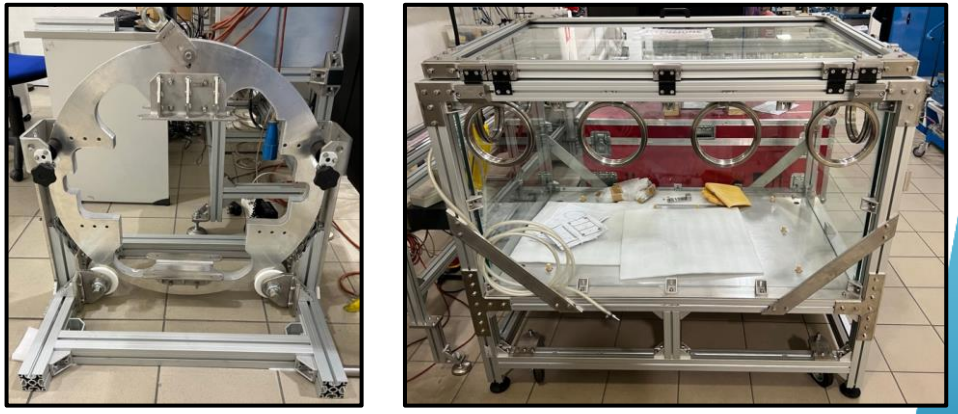
Surface fractures appearing during installation

Prototype Helium Tanks

- Integration activities started at Zanon on Proto #2. Currently machining interface adapter rings.
- All components including magnetic shields are in hand.
- Glove box is completed.
- Jacketed cavity will be shipped to Jlab for cold tests without/with HOM dampers.
- After validation (Acceptance Part A) will be **shipped to TRIUMF** using the CERN-designed shipping frame (ETA Spring 2024).
- Contract for production tanks is imminent with Zanon.



Helium Tank components at Zanon



Tooling and Glove-Box at Zanon

Transition Plan: Prototypes, Pre-Series, Series

- LARP prototypes (2017-2019):
  - Validation of cavity design in achieving key performance requirements (e.g. deflecting voltage, quality factor).
  - Validation of FNAL/ANL facilities and processes for surface chemical processing, heat-treatments and cold test.
- AUP prototypes (2020-2021):
  - First development of fabrication process at Zanon.
  - First development of QA documentation.
  - Practice with CERN system for Manuf. Records & NCRs.
  - Confirmation of FNAL/ANL facilities and processes.
  - Validate Zanon facilities for processing.

1 year ago

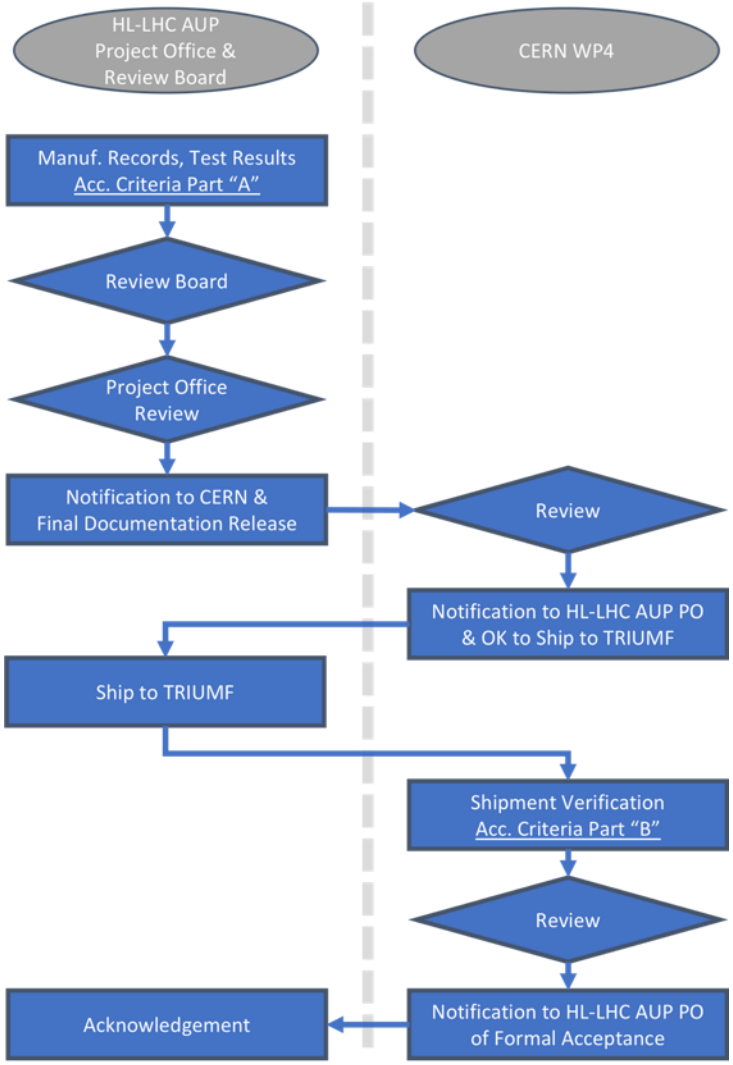
- AUP Pre-Series (2021-2022):
  - Convergence with CERN on fabrication and QA documentation (DWGs, MIP, welding book, NCRs,..).
  - Validate fabrication process, including processing, at Zanon.

NOW

- AUP Series (2023-2024):
  - Repeat process of pre-series, deliver cavities to FNAL ready for VTS.

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.
- **Currently updating documents to reflect 2K capability at TRIUMF, and dressed tests at JLab.**



Recommendations from Rebaseline Review

December 2022

- *"Working with **JLAB**, develop a resource loaded schedule for the production of the RF ancillaries. Integrate this schedule into the Crab Cavities new baseline schedule by end of January 2023."*

  Status: **CLOSED**. A schedule received by Jlab has been fully integrated into the AUP.

- *"Before the test of the first jacketed cavity at Fermilab verify that **TRIUMF** can perform the cold test at 2K as well. If not, perform measurements at 2K and 4.2K at Fermilab for consistency. Update appropriate documents accordingly before the test of the first jacketed cavity (by June 2023)."*

  Status: **CLOSED**. TRIUMF confirmed commissioning of test facility with 2K capability. Acceptance criteria A and B have been revised accordingly and will be routed for comments/approval from CERN.

- *"Add external milestones that require **CERN** approvals for dressed cavity production to the existing project milestone document. Continue discussion with CERN on achieving the intermediate milestones. Do this by March 2023."*

  Status: **CLOSED**. We have identified all CERN external dependencies and integrated these into the schedule.

Rebaseline Delivery Dates

- Dates in AUP Rebaseline were formally accepted by CERN (see EDMS 2781934)

Detailed Description

Following the preparation for the rebaselining process by US-AUP with its Funding Agency (DOE), new delivery dates were proposed to CERN for the delivery of the AUP RFD Dressed Cavities to TRIUMF. The dressed cavities will be validated according to the Acceptance Criteria – Part B, EDMS 2339758) upon reception at TRIUMF and later integrated into the RFD Cryostats at TRIUMF. The new dates of delivery are tabulated below and compared to the previous baseline shown at CSR2021:

	Early delivery date	Late delivery date	CSR21 – Early delivery date
DC1 & DC2	May 2024	Apr 2025	May 2023
DC3 & DC4	Jul 2024	June 2025	Sep 2023
DC5 & DC6	Aug 2024	Jul 2025	Oct 2023
DC7 & DC8	Oct 2024	Sep 2025	Feb 2024
DC9 & DC10	Nov 2024	Oct 2025	Apr 2024

Consistent with AUP Rebaseline

Delivery Dates

- First jacketed prototype: Bare cavity (#2) successfully tested at Jlab with HOMs in August 2023, currently back at Zanon, expected at Jlab (jacketed) ~ Jan 2024 and ready for shipment to TRIUMF Spring 2024**.**
- Second jacketed prototype: Unsure future. Bare cavity (#1) processed by Zanon not yet qualified (2 failed tests).
- Deliveries to TRIUMF of **10 (Deliverable) dressed cavities** span **May 2024 – Apr 2025** according to working schedule.

	Agreed Early Delivery Date	July 2023 working Schedule				Agreed Late Delivery Dates
Cavities 01 & 02	May-24					Apr-25
Cavities 03 & 04	Jul-24	Sep-24				Jun-25
Cavities 05 & 06	Aug-24			Dec-24		Jul-25
Cavities 07 & 08	Oct-24			Feb-25		Sep-25
Cavities 09 & 10	Nov-24				Apr-25	Oct-25

1 cell = 1 month

External Milestones

- External milestones were introduced to give enough notice and to better track progress towards final deliveries.

✓ Approval of Bare Cavity Processing/preparation procedures: **Jul 2023**

➢ Approval of Helium Tank fabrication drawings/procedures: **Oct 2023**

  ➢ **As soon as SERIES contract is placed, we will share documentation with CERN**

➢ Endorsement of Bare Cavity cold tests: **Nov 2023 - Oct 2024**

➢ Approval of Dressed Cavity Drawing “as delivered to TRIUMF”: **Oct 2023**

  ➢ **We need to converge, as we are procuring hardware**

➢ Approval to ship to TRIUMF (Part A): **May 2024 - Mar 2025**

➢ (After delivery) Acceptance at TRIUMF (Part B): **Jul 2024 - Jun 2025**

Summary

- Successful cold test of prototype with HOM dampers.
- Failed qualifications on ceramics for pre-series HOM dampers. Looking forward to fruitful discussions this week.
- All contracts (almost!) in place with industrial partner.
- Pre-Series cavities imminent completion with clear signs of improved quality compared to prototypes.
- Series cavities reaching peak production without showstoppers.
- First jacketed prototype expected at JLab in ~ Jan 2024, and at TRIUMF ~ Spring 2024.
- Deliveries of 10 cavities to TRIUMF range May 2024 - Apr 2025.
- Acceptance Plan between CERN and AUP is being revised based on 2K commissioning at TRIUMF.

THANK YOU!