



RFD Crab Cavity Contribution from the U.S.

Status, Issues and Delivery Dates

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Leonardo Ristori – Fermilab

12th HL-LHC Collaboration Meeting – 19th September 2022



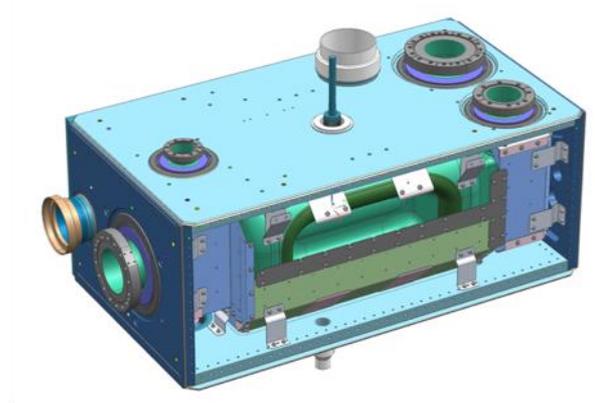
Outline

- Scope
- Performance of AUP Prototypes
- Progress in Bare Cavity Fabrication
- Status of Helium Tank Integration
- HOM Dampers Fabrication
- Plans for Acceptance
- Deliveries

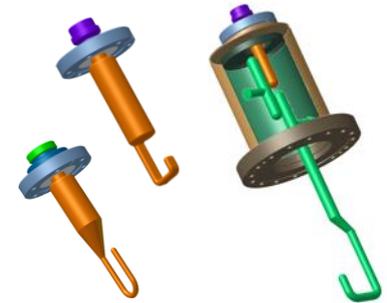
Scope and Deliverables



Bare RFD Cavity



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



RF Ancillaries

- **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 FNAL at 2K + RF Ancillaries
- 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

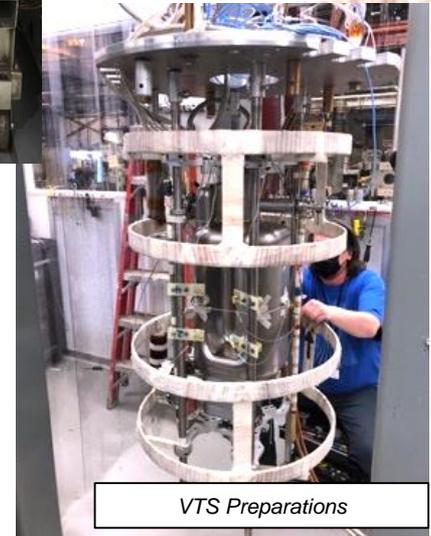
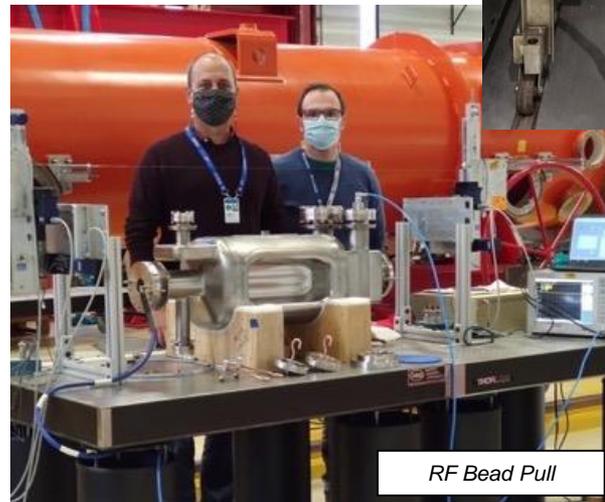
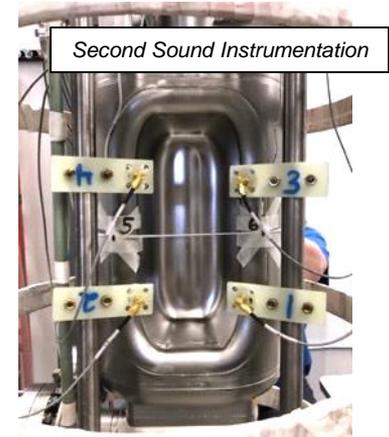
Participating Institutions in alphabetical order:

- **Argonne National Laboratory** (Brazing and Cavity Processing):
 - Mike Kelly, Mark Kedzie, Tom Reid, Bill Toter
- **Fermilab** (RF/Mech Design, Procurements, Cold Tests):
 - Paolo Berrutti, Manuele Narduzzi, Alex Melnichuk, Damon Bice
- **Jefferson Lab** (HOM Dampers Fabrication and Cold Tests):
 - Naeem Huque, Alex Castilla
- **Old Dominion University** (General Oversight and RF measurements):
 - Jean Delayen, Subashini De Silva
- **SLAC National Accelerator Laboratory** (RF Design, Coordination):
 - Alessandro Ratti, Zenghai Li

Integration and Coordination Remarks

- **Requirements unchanged.**
- Key documents finalized and officially released by CERN **allowing AUP to fully transition into production** (e.g., Helium Tank specification drawings).
- AUP is participating in ~ Bi-monthly WP4 coordination meetings and other technical meetings with WP4 engineers on a ~ weekly basis.
- Bi-weekly meetings with CERN RF Group on HOM Dampers allowed fast response to recent issues (cold leaks).
- AUP able to continue traveling during COVID although very limited. **Now resuming more regular visits to CERN and suppliers.**
- Cross-participation at CERN and FNAL reviews (e.g., PRRs).

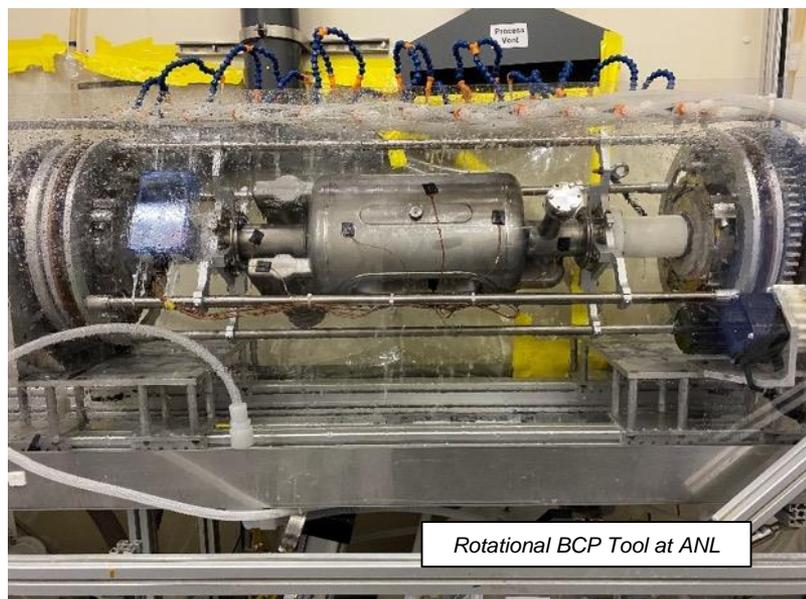
AUP Prototypes at FNAL (2021)



Despite Covid Lock-Downs we were able to receive, process and test 2 AUP prototypes in 2021.

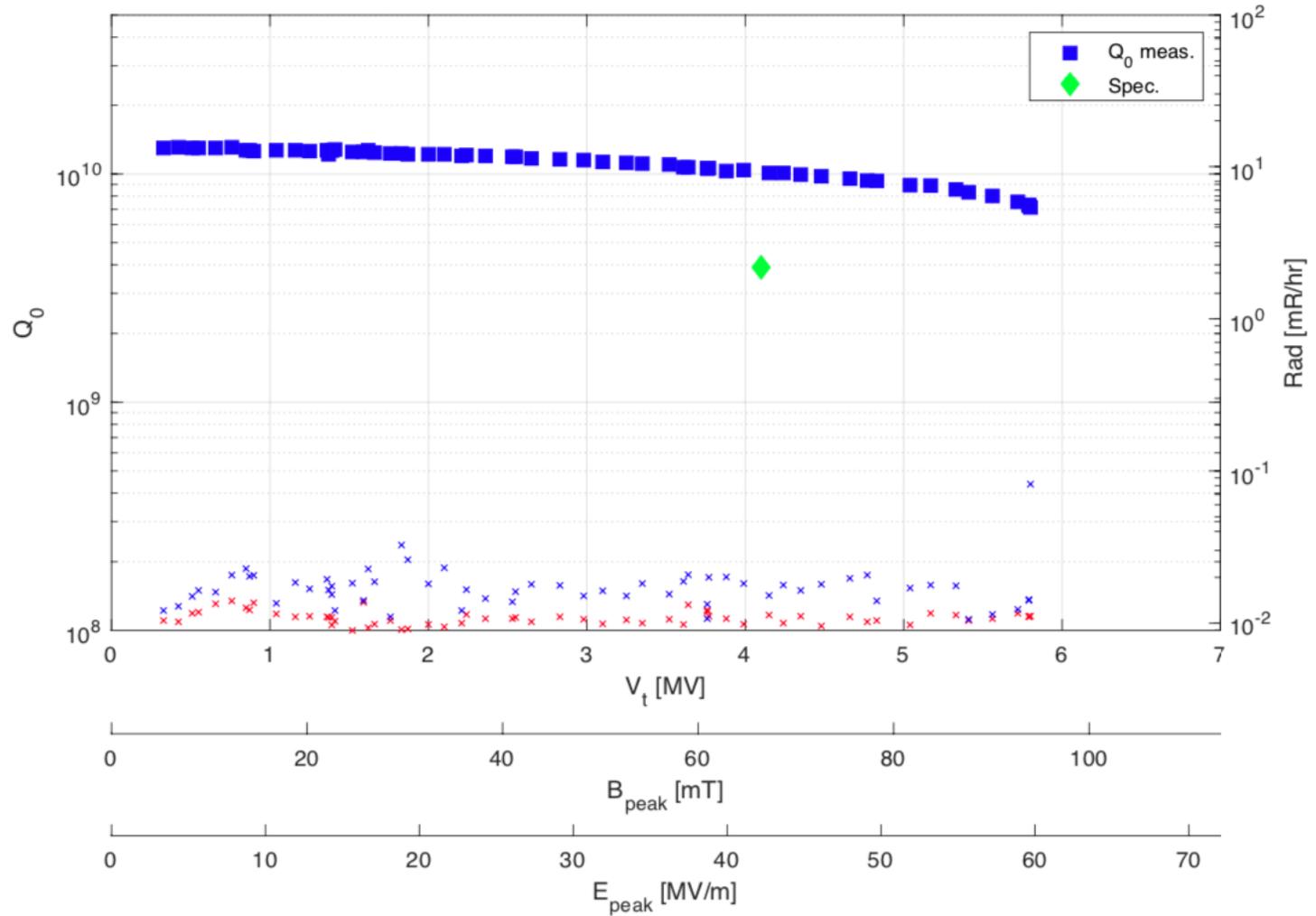
AUP Prototypes at ANL (2021)

- Rotational BCP at ANL yielded better results than conventional (static) BCP.
- Acid and Nb temperatures were controlled well with sensors on the cavity surface and cooling water sprayed on the exterior Nb surface.
- BULK removal: average 130 microns
- Light removal: average 40 microns
- All US thickness locations match locations used by CERN

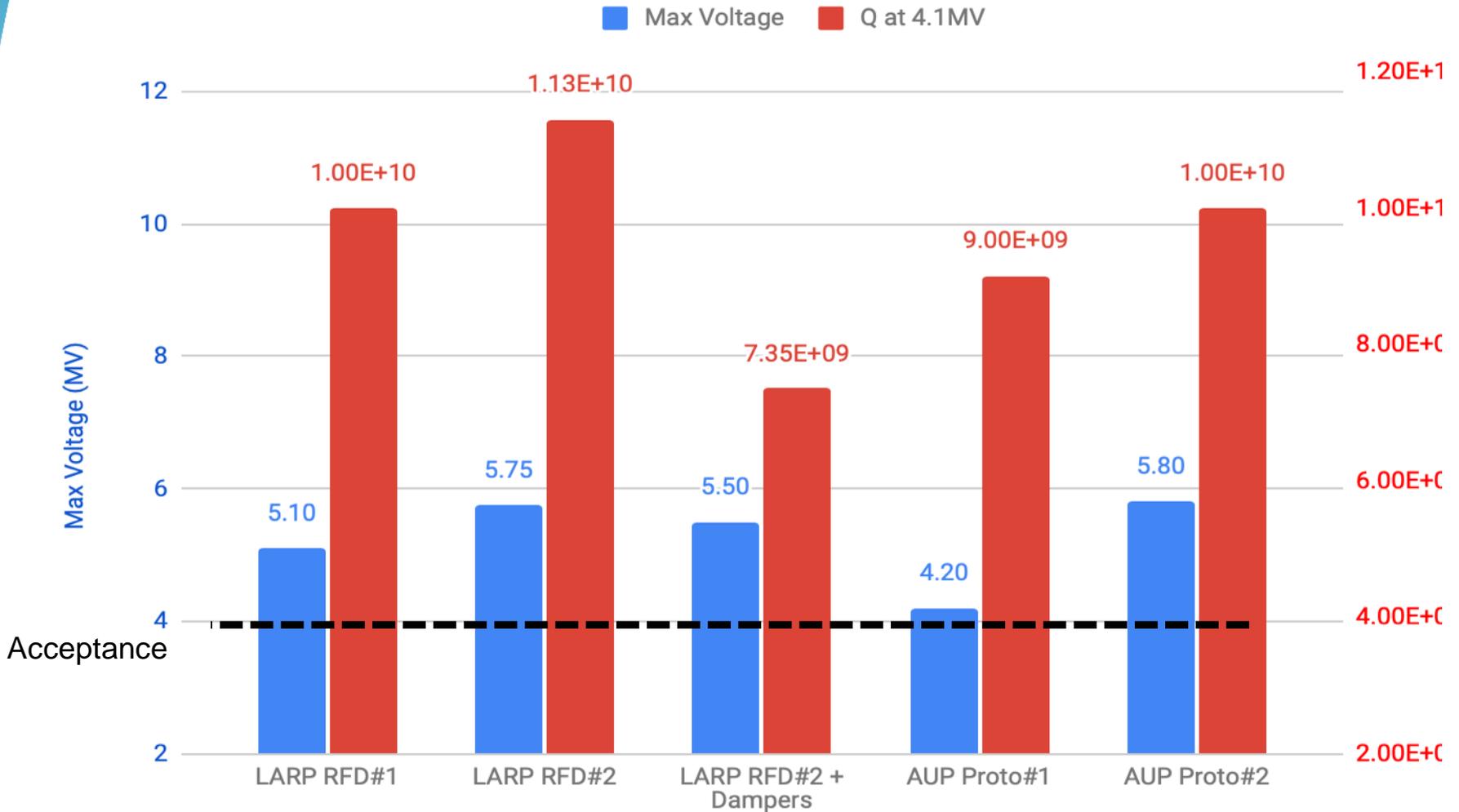


Location	rotational BCP target 48 μm	conventional BCP target 40 μm
HHOM	46.1	22.5
VHOM	55.0	58.6
FPC	48.6	28.4
BODY	44.5	25.1
POLE (left)	51.8	26.2
POLE (right)	51.3	28.7
MAX	66	213.7
MIN	25.4	8.5

Zanon Prototype #2 + ANL Processing 8/25/21 at FNAL

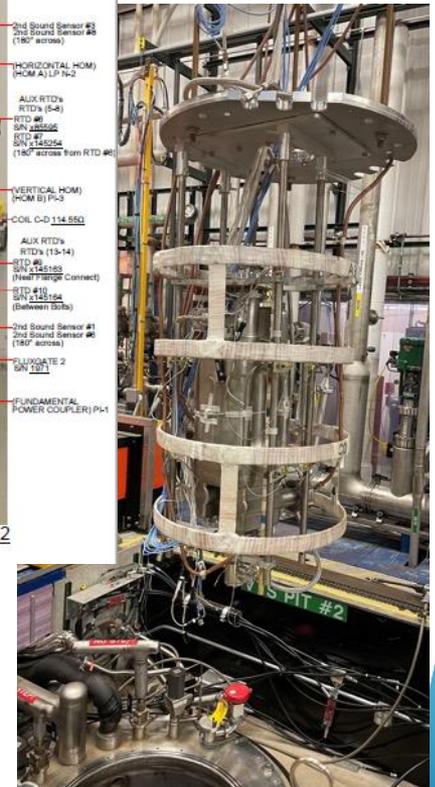
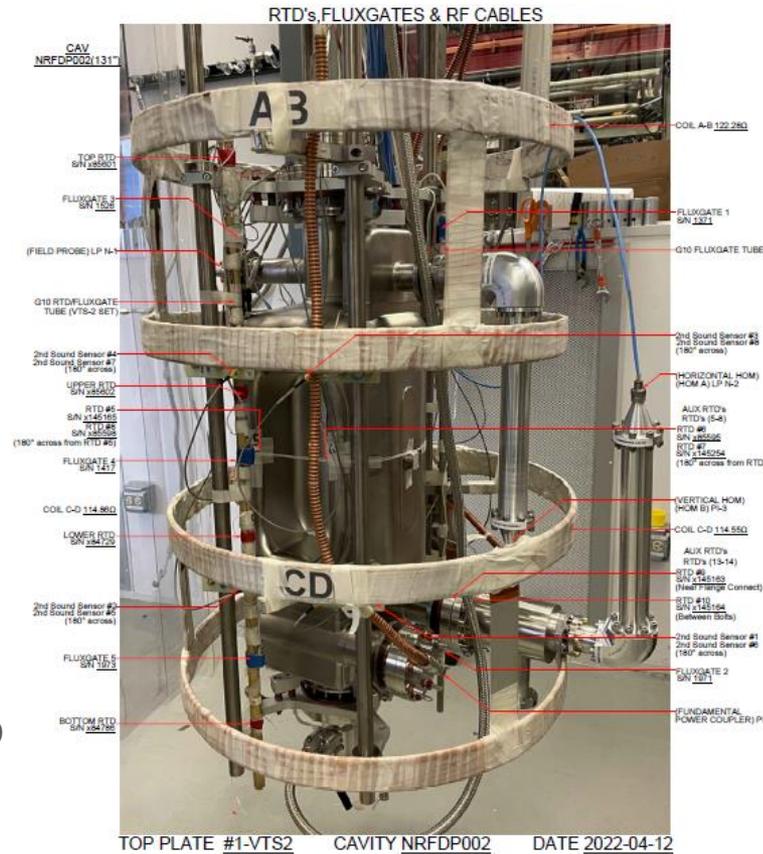


LARP + AUP Cold Test Summary



Cavity with HOMs installation at VTS

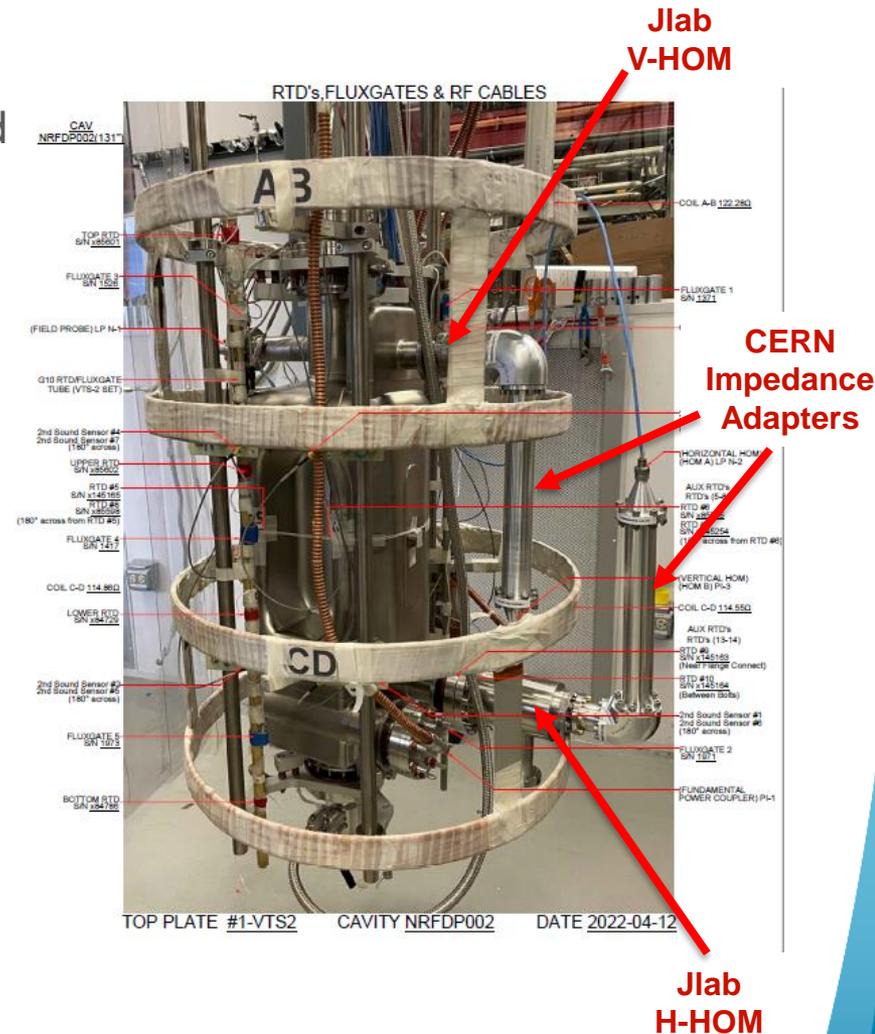
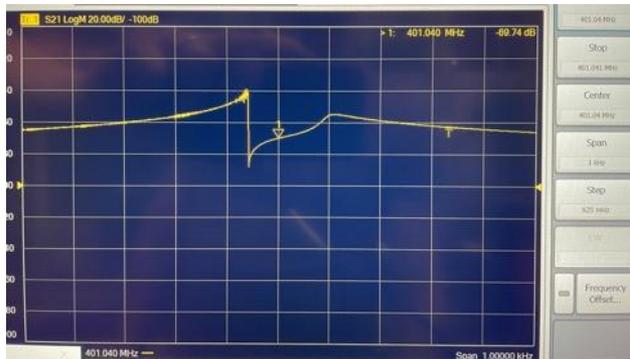
- NRFDP002 was installed on the top plate for vertical cold test after all warm vacuum issues were sorted out: **HHOM and VHOM flange gasket leak tight at room temperature**, with custom gaskets.
- The cavity received usual sensors installation plus additional thermometry on the HHOM-cavity interface to monitor potential temperature increase due to unwanted RF losses.



TOP PLATE #1-VTS2 CAVITY NRFDP002 DATE 2022-04-12

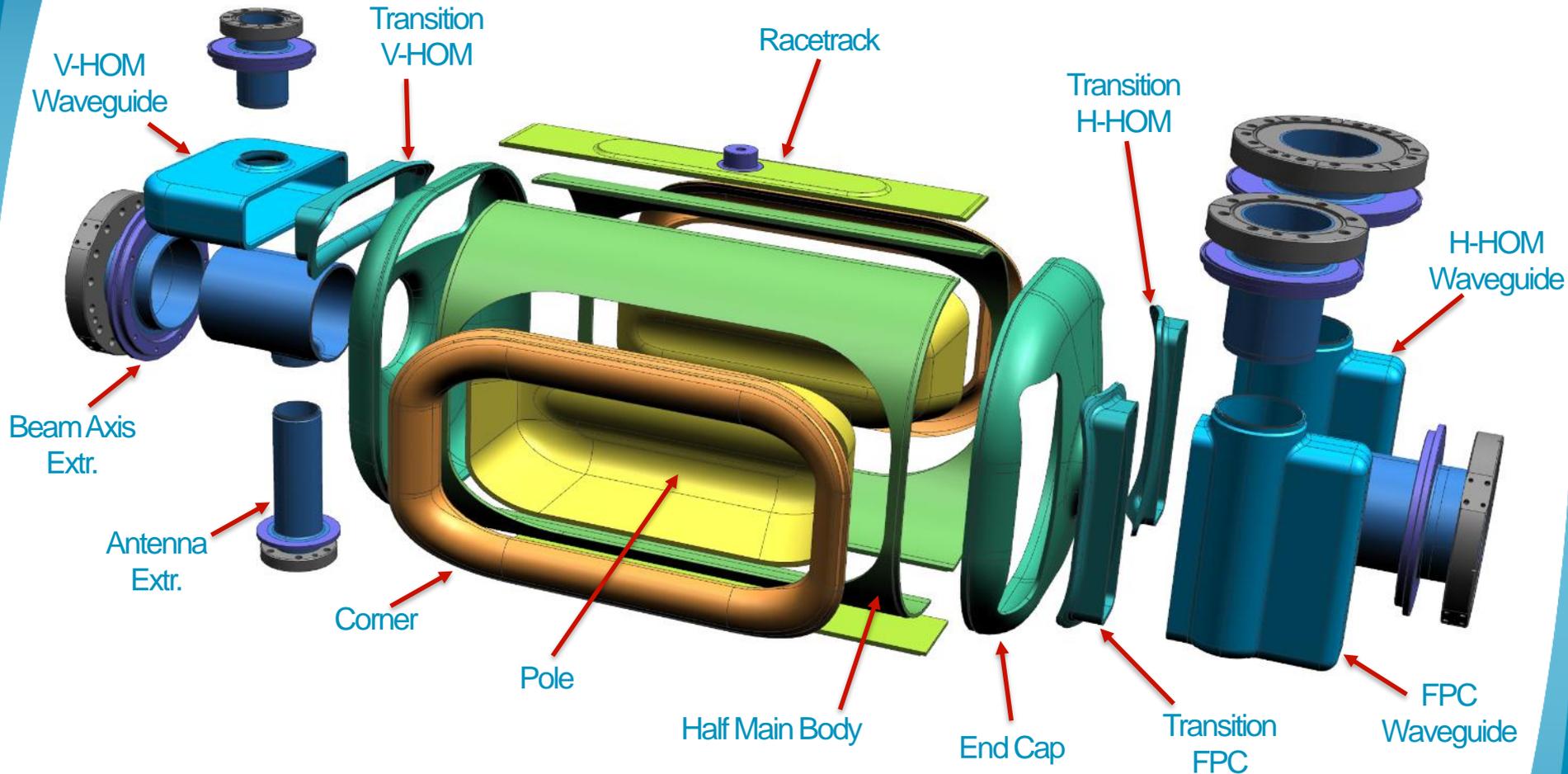
Failed Attempt with Cavity + HOM Dampers

- Installed HHOM and VHOM with custom gaskets. Leak check was successful.
- When both HOMs were submerged in liquid He (4.2K) the fundamental mode frequency tracking stopped working: **RF breakdown at 100 mW** of forward power made the test impossible: a screenshot of the NWA is shown below.
- Prototype cavity #2 is currently at JLAB where it will be tested with HOMs after complete HPR and assembly in JLAB cleanroom.
- More information on prototype HOMs couplers in N. Huque's talk.



Bare Cavities Fabrication at Zanon: Strategy

Fabrication Details in Manuele's Talk



- ✓ Adopted CERN specification drawing for Pre-series RFD fabrication
- ✓ Extremities tubes machined from Nb **seamless pipes** (no roll-forming)
- ✓ **Single** design for all the Transitions (machined from a block)
- ✓ CNC interfaces and EBW joints handled as **ZRI know-how**

Pole Forming Issues: Now Resolved

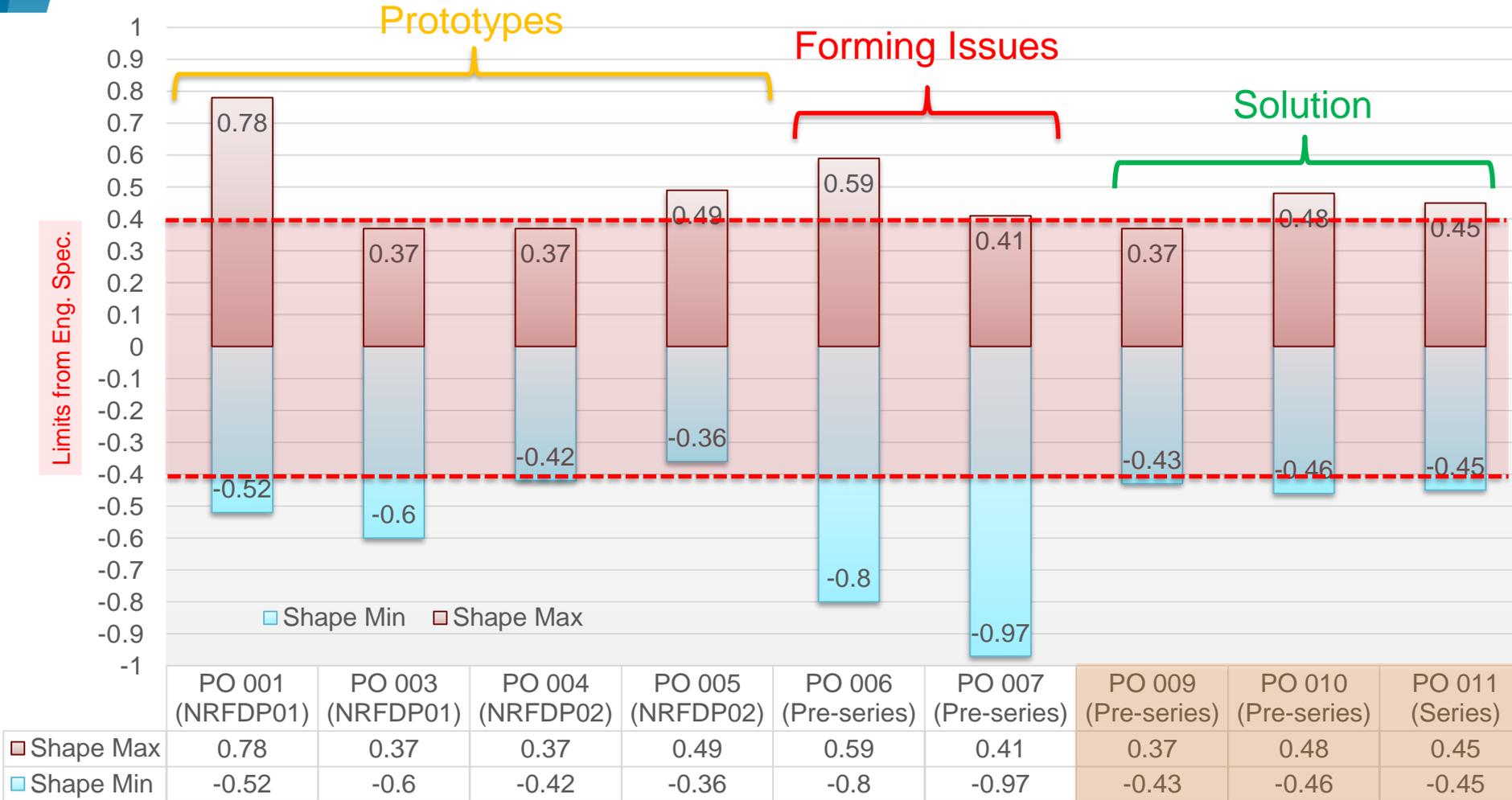
- First trials with Nb batch for Pre-Series cavities were not ideal. Excessive thinning and orange peel effect was observed in the corners.



- Trials with Nb batch for Series produced better results, also thanks to an improved 2-step process developed by Zanon consisting of a partial drawing followed by cutting of the crown and final drawing.



Pole Forming: Process Finally Under Control



Pre-Series Advancement at Zanon

- ✓ Components for 2 pre-series cavities in advanced/final stages of manufacturing. Electron-beam welding started with all necessary approvals in place (see pictures).
- First Pre-Series bare cavity should be ready for frequency trim-tuning before the end of the year and should be completed in early 2023.
- Option to process/prepare at Zanon is being considered.

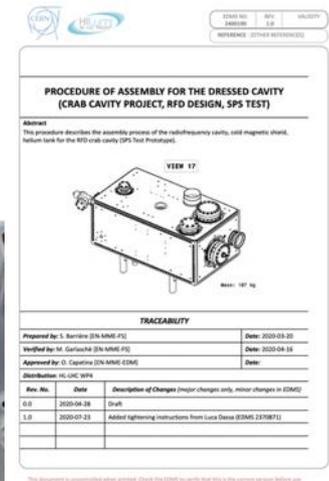
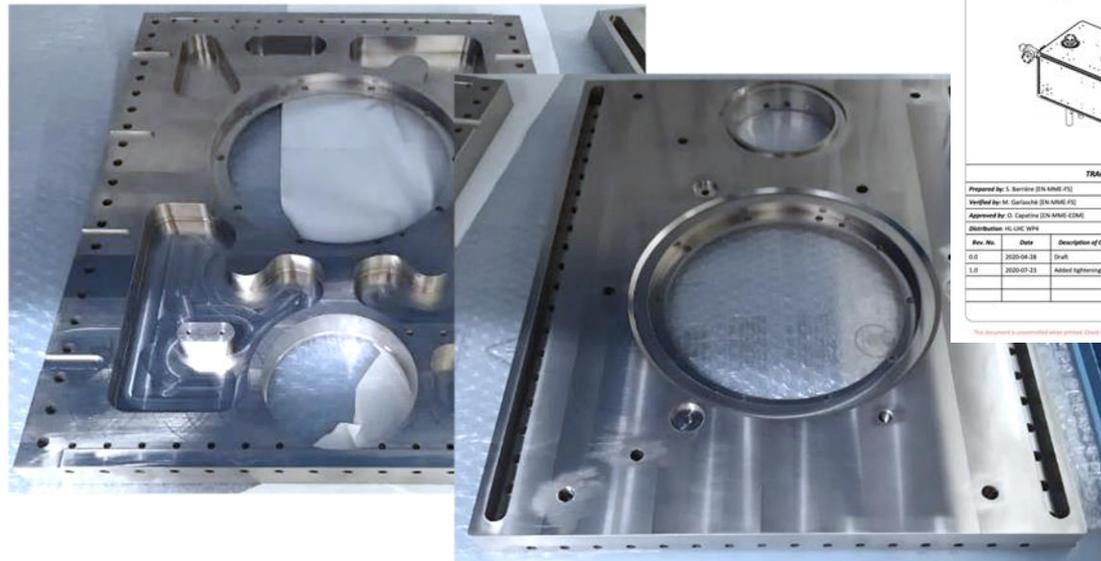
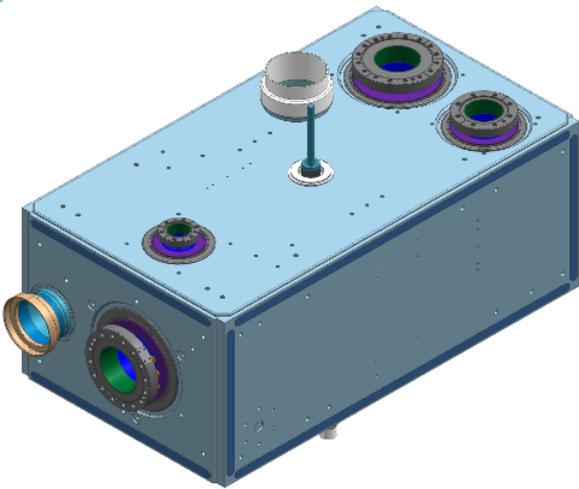


Helium Tank Advancement at Zanon

- ✓ Contract is in place for 2x He Tanks prototypes fabrication at Zanon.
- ✓ Most of the Sub-components have been manufactured (see Titanium plates below).
- RFD proto#1 and Magnetic Shields (Ad-Vance) are at Zanon for integration.



3 Shield Assemblies are at FNAL (Ad-Vance)



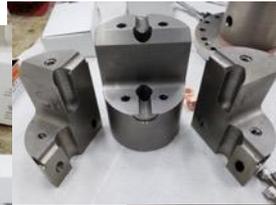
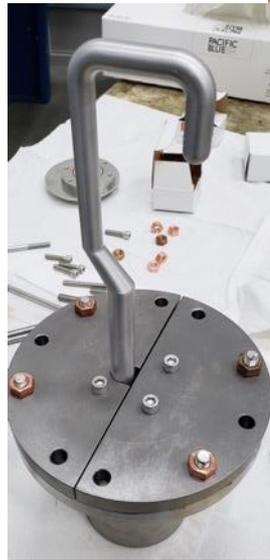
Prototype #1 Plans

- Prototype #1 is now at Zanon to receive a full processing cycle in Nov-Jan (Bulk BCP, 600C bake, light BCP).
- Subsequently Zanon will proceed with Helium Tank integration on this cavity.
- Finally, it will be fully prepared for a cold test by means of HPR, clean room assembly + RF probes, and shipped to FNAL for cold test.
- Goal is to validate multiple processes with Prototype #1.
- Processing and cold-test preparations at Zanon of pre-series/series cavities is a possibility.
- Jacketed Prototype #1 expected at FNAL ~ Spring 2023 for cold test.

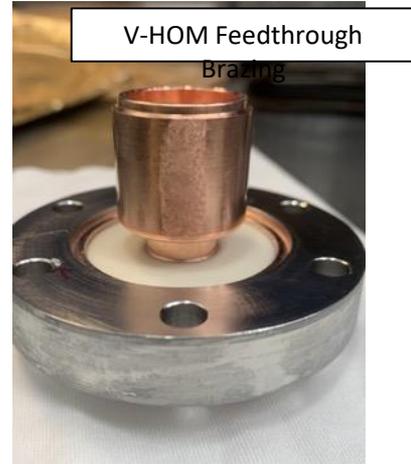
HOM Dampers Prototypes at Jlab



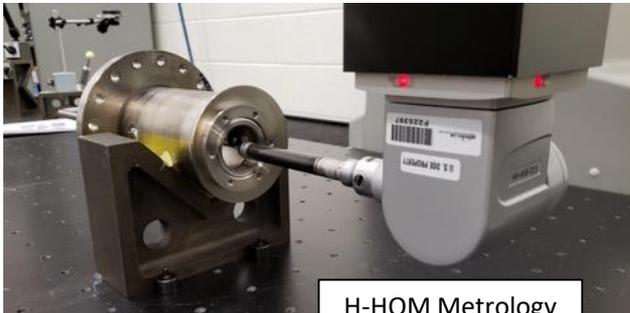
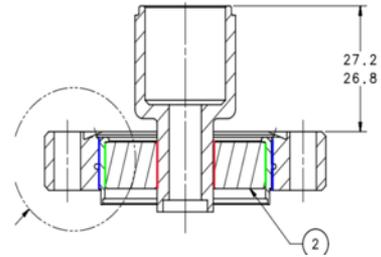
H-HOM Fabrication



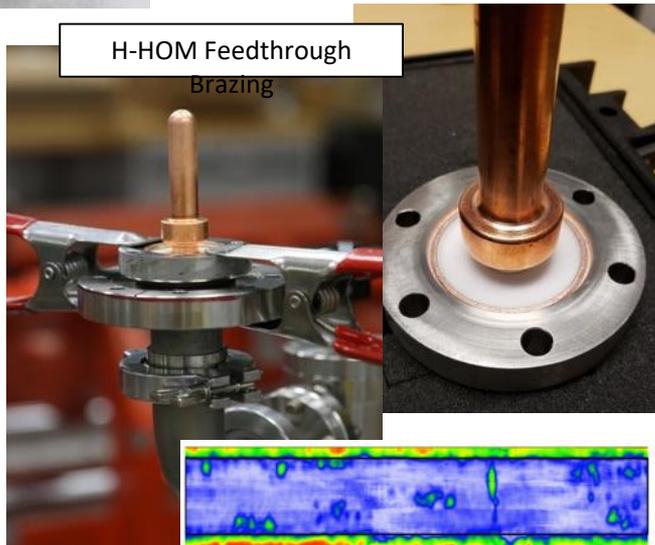
H-HOM Hook & Tee



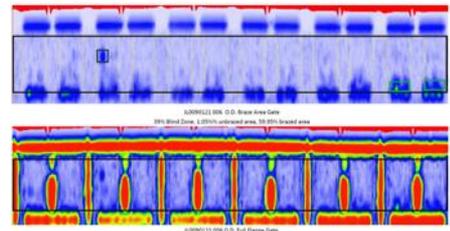
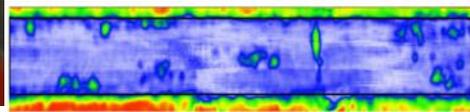
V-HOM Feedthrough
Brazing



H-HOM Metrology



H-HOM Feedthrough
Brazing



HOM Dampers - Status

- Continued troubleshooting prototype ancillaries that caused leaks at FNAL during cold tests.
- Achieved leak tightness for 1 set at liquid nitrogen temperature on test bench (see pictures below).
- Thanks to Eric for sending test spool piece from CERN (pictured below).
- Jlab will be installing this set on Prototype #2 and perform a cold test at Jlab vertical test facility.
- Minor interface tooling being finalized to allow the cold test in the next month.



Cold shocks

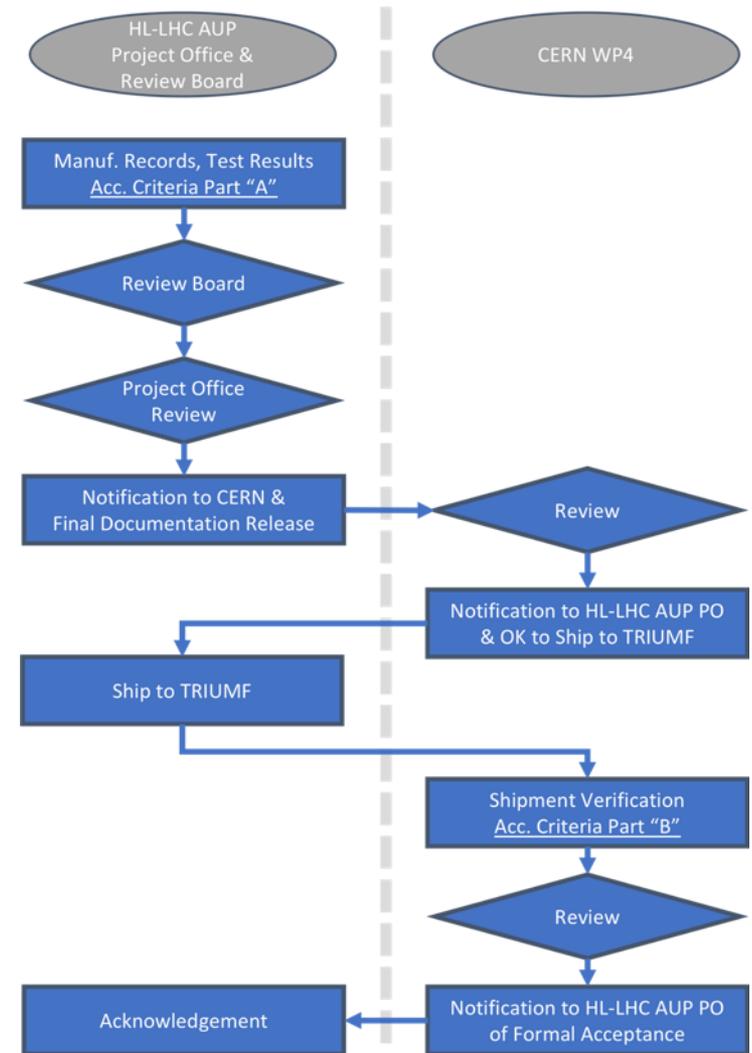
Cold leak-checks

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.
- 1 year ago
 - Validate Zanon facilities for processing.
- AUP Pre-Series (2021-2022):
 - Convergence with CERN on fabrication and QA documentation (DWGs, MIP, welding book, NCRs,..).
- NOW
 - Validate fabrication process, including processing, at Zanon.
- AUP Series (2022-2023):
 - Repeat process of pre-series, deliver cavities to FNAL ready for VTS.

Acceptance of RFD cavities

- Acceptance Plan
 - US-HiLumi-doc-1744
 - 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 FNAL)
 - US-HiLumi-doc-1154
 - All requirements from FRS will be verified with a test or a set of measurements during cavity production or during final tests at FNAL.
- Acceptance Criteria – Part B (at TRIUMF)
 - US-HiLumi-doc-2896
 - Series of tests/measurements to be carried out at TRIUMF under AUP supervision to confirm performance of cavities after shipment
- Formal acceptance by CERN
 - Cavity becomes property of CERN
 - TRIUMF begins cryomodule integration



Delivery Dates

- First jacketed prototype expected at FNAL early 2023 and possibly ready for shipment to TRIUMF in Spring-Summer of 2023.
- Second jacketed prototype has unsure future, currently used to troubleshoot HOM dampers issues at Jlab. Ideally a successful cold test before the end of year and jacketing at Zanon first part of 2023 for a delivery to TRIUMF in Fall of 2023.
- Deliveries to TRIUMF of **10 (Deliverable) dressed cavities** span **March 2024 – Oct 2024** according to working schedule. Will need to be agreed upon with CERN prior to DOE Rebaseline Review in Dec. 2022.

	(To Be) Agreed Early Delivery Date									(To Be) Agreed Late Delivery Date
Cavities 01 & 02	Mar-24									Feb-25
Cavities 03 & 04	Jun-24									May-25
Cavities 05 & 06	Jul-24									Jun-25
Cavities 07 & 08	Sep-24									Aug-25
Cavities 09 & 10	Oct-24									Sep-25

1 cell = 1 month

Summary

- Scope and Deliverables have been stable, with key documents recently released by CERN allowing AUP to fully transition into production.
- AUP Prototypes exceeded project requirements in 2021.
- Pre-Series cavities in advanced stages of fabrication at Zanon also thanks to successful EBW qualification obtained.
- Unexpected pole-forming issues were solved leveraging Zanon know-how.
- First jacketed and processed prototype expected at FNAL in ~ Spring 2023.
- Cold Test with HOM Dampers will be re-attempted before the end of 2022 at Jlab.
- Acceptance Plan between CERN and AUP is unchanged, but delivery dates (post-COVID) need to be agreed upon urgently in preparation of DOE Re-baseline review.