RFD Dressed Crab Cavities

Status, Issues and Delivery Dates

Leonardo Ristori – Fermilab

L2 Manager – RFD Dressed Crab Cavities Fabrication

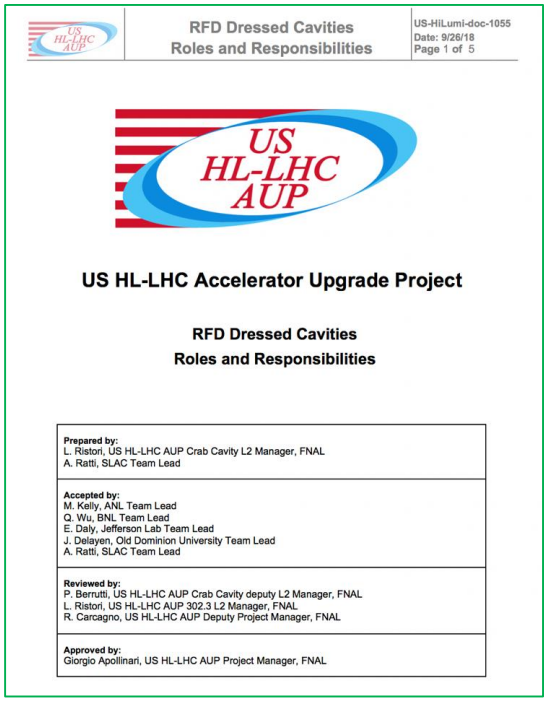
11th HL-LHC Collaboration Meeting – 19th October 2021

U.S. RFD Team

US-HiLumi-doc-1055

Institutions in alphabetical order :

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



RFD Dressed Cavities
Roles and Responsibilities

US-HiLumi-doc-1055
Date: 9/26/18
Page 1 of 5

US HL-LHC AUP

US HL-LHC Accelerator Upgrade Project

RFD Dressed Cavities
Roles and Responsibilities

Prepared by: L. Ristori, US HL-LHC AUP Crab Cavity L2 Manager, FNAL A. Ratti, SLAC Team Lead
Accepted by: M. Kelly, ANL Team Lead Q. Wu, BNL Team Lead E. Daly, Jefferson Lab Team Lead J. Delayen, Old Dominion University Team Lead A. Ratti, SLAC Team Lead
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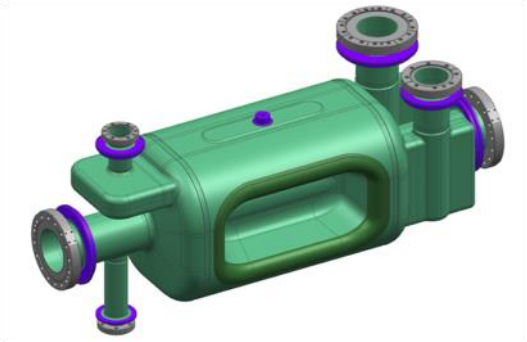
Approved by: Giorgio Apollinari, US HL-LHC AUP Project Manager, FNAL

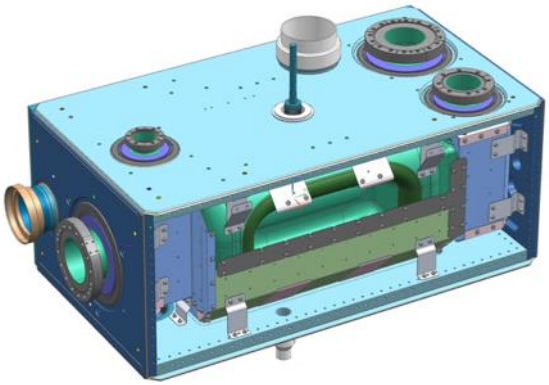
Roles & Responsibilities
Response to CD-1/3a recommendation

US HL-LHC AUP

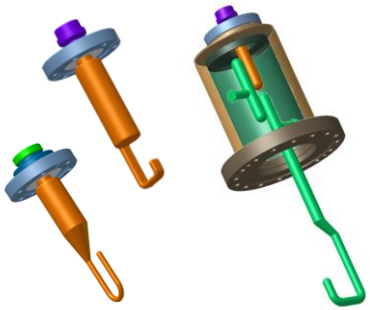
Scope and Deliverables



Bare RFD Cavity



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

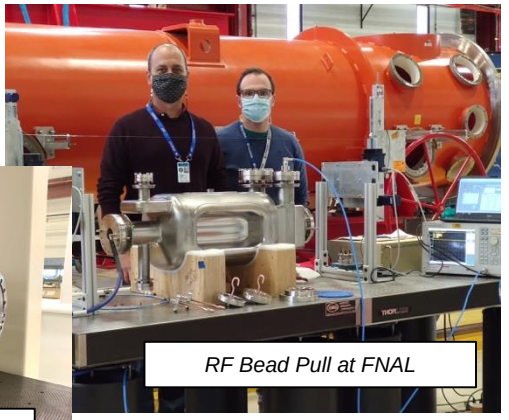


RF Ancillaries

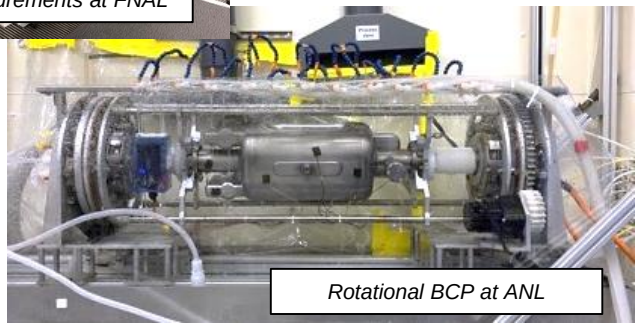
- **Project Scope includes 2 Prototypes + 2 Pre-Series + 10 Series**
- Bare Cavities: Intermediate Qualification at FNAL at 2K
- Integration: Bare Cavity + Magnetic Shields + Helium Tank
- Dressed Cavities: Final Qualification at FNAL at 2K + RF Ancillaries
- Transport to TRIUMF for acceptance by CERN: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

AUP Prototype #1 - Timeline

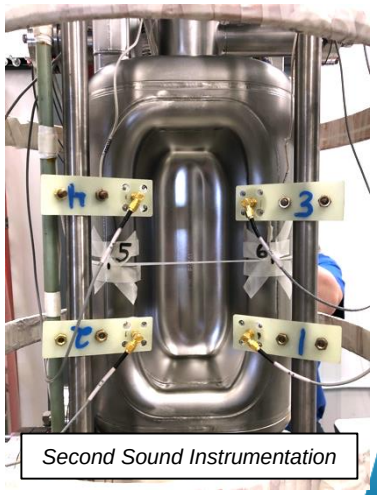
- 9/2020: Cavity received from Zanon
- 10/2020: RF inspection complete
- 12/2020: Metrology and optical inspections complete
- 1/2021: Bulk BCP and heat treatment
- 2/2021: Light BCP
- 3/2021: Flange issues and repairs
- 4/2021: HPR, assembly
- 4/21/21: Succesfull VTS test, achieved **4.2MV** (4.1MV requirement)


RF Bead Pull at FNAL


CMM Measurements at FNAL


Rotational BCP at ANL

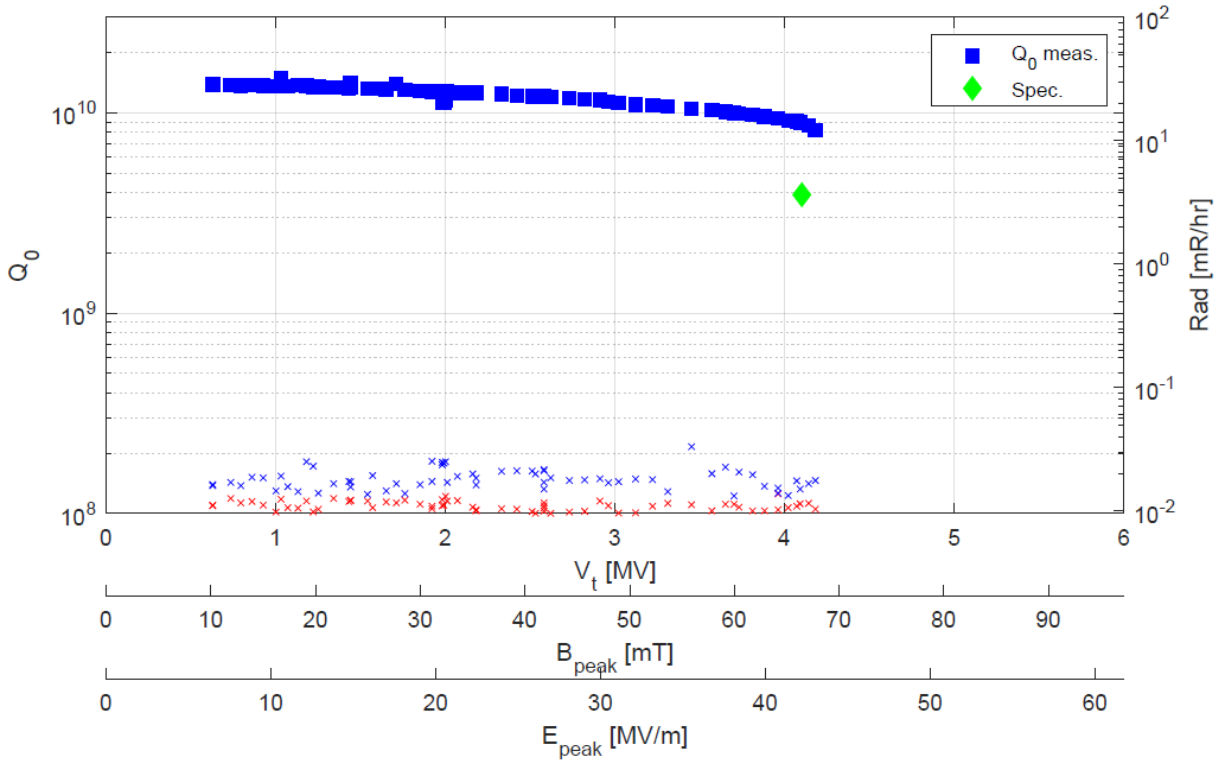

VTS Preparations


Second Sound Instrumentation

See talk by Paolo Berrutti

Prototype #1 – Status and Plans

- "Somewhat" successful test exceeding acceptance requirements only marginally.
- Still under vacuum since April, we were awaiting results of Proto #2.
- Now it can be released for rework and will be shipped to Zanon for bulk rotational chemistry.



- 2 Goals for Prototype #1:
  - Improve performance of cavity
  - Validate Zanon facility as we transition to production

Flange Issues and Repairs

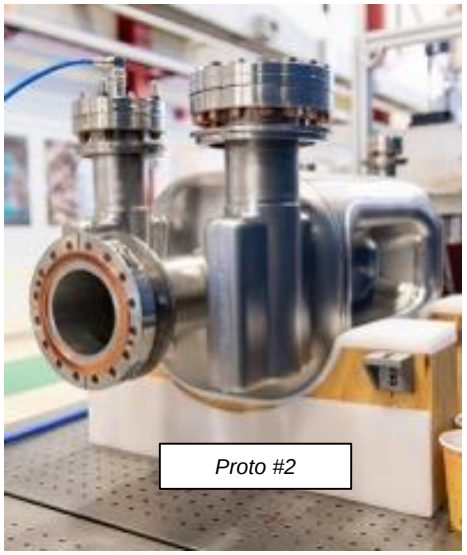
- Successful maintenance allowed to achieve leak tight connections and maintain momentum towards VTS.
- 4 cycles of high-pressure rinsing, assembly, evacuation and leak checking were needed.
- Received input from CERN on details of gaskets, hardware and procedures employed.
- Received one complete hardware kit shipped from CERN.
- Looks like we succeeded!

After maintenance

Leaks in Clean Room

AUP Prototype #2 - Timeline

- 12/2020: Cavity received from Zanon
- 2/2021: RF Inspection complete
- 3/2021: Metrology and optical inspection complete
- 4/2021: Leak check successful
- 5/2021: Bulk BCP, Heat Treatment
- 6/2021: Light BCP, HPR, leak issues, unsuccessful VTS
- 7/2021: HPR, leaks issues
- 8/2021: HPR, leak tight, successful VTS, achieved 5.8MV (4.1MV requirement)

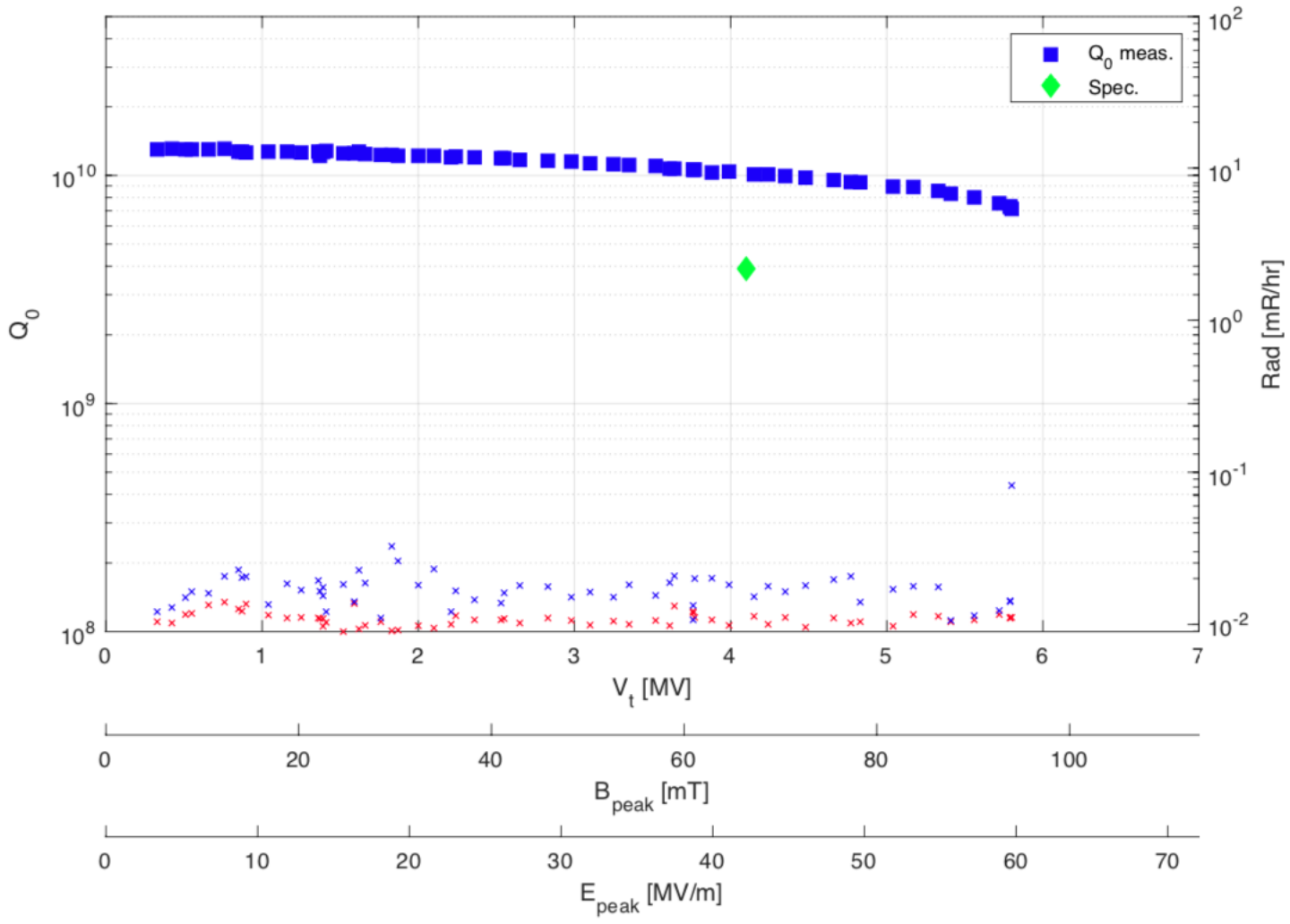


Proto #2

Proto #2 inspections

See talk by Paolo Berrutti

Prototype #2 Successful Test 8/25/21



LARP Cold Tests Summary 2017-2019

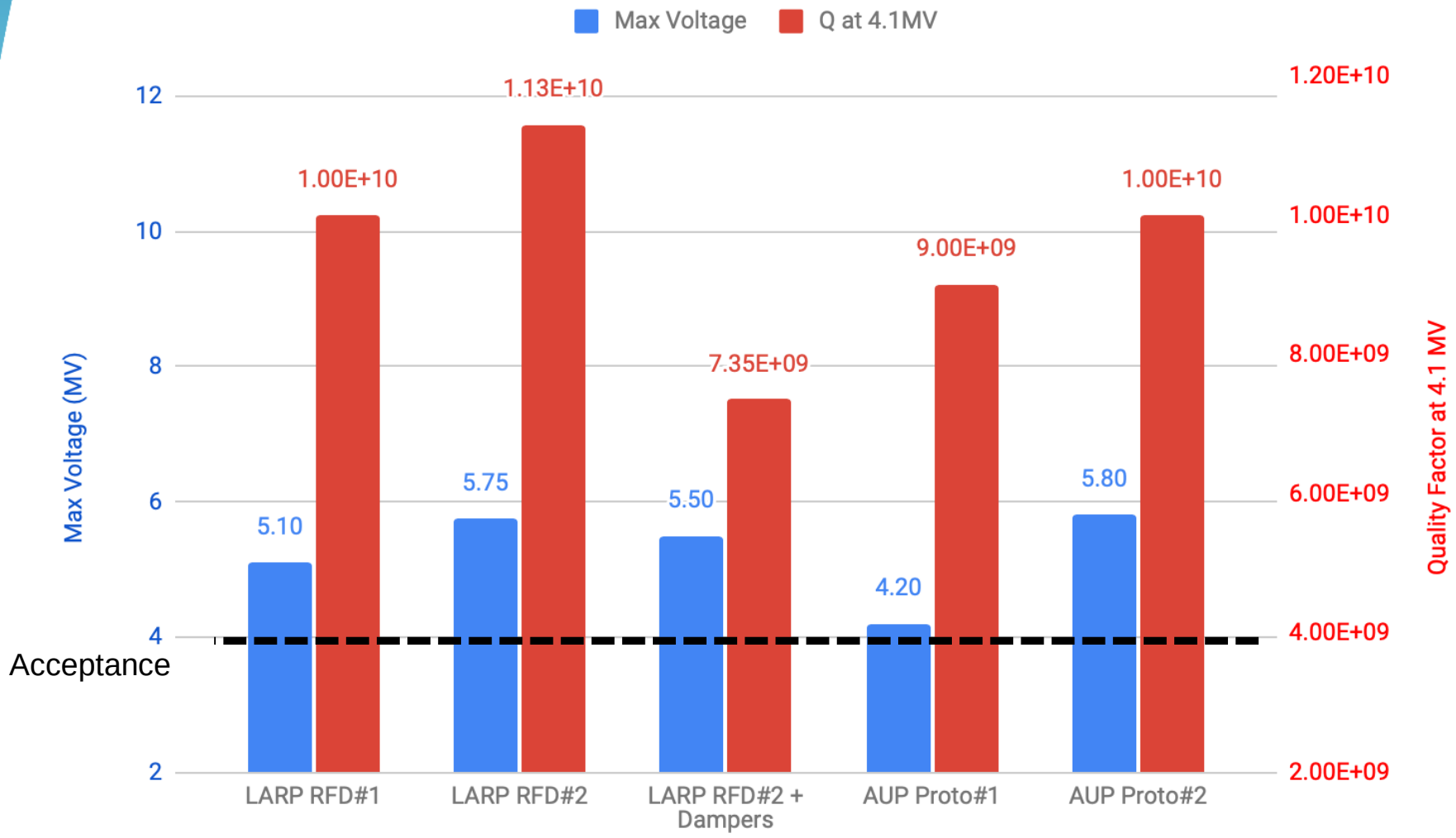
Test Date	Cavity #	Location	HHOM	VHOM	Max Voltage	Q at 4.1MV
2/12/2017	LARP RFD#1	JLab	☐	☐	4.04	1.60E+09
3/23/2017	LARP RFD#1	JLab	☐	☐	4.38	8.21E+09
6/2/2017	LARP RFD#2	JLab	☐	☐	5.75	1.13E+10
8/20/2017	LARP RFD#1	FNAL	☐	☐	4.70	1.10E+10
4/30/2018	LARP RFD#1	FNAL	☐	☐	3.54	N/A
5/8/2018	LARP RFD#2	JLab	☑	☑	4.77	1.22E+09
5/31/2018	LARP RFD#2	JLab	☑	☑	5.03	1.32E+09
6/13/2018	LARP RFD#1	FNAL	☐	☐	3.47	N/A
8/16/2018	LARP RFD#2	JLab	☑	☐	5.26	6.60E+08
10/9/2018	LARP RFD#2	JLab	☑	☐	4.18	1.08E+09
11/14/2018	LARP RFD#2	JLab	☑	☑	5.50	5.00E+09
11/28/2018	LARP RFD#2	JLab	☑	☑	5.50	7.35E+09
3/27/2019	LARP RFD#2	JLab	☑	☑	5.33	6.50E+09
5/2/2019	LARP RFD#1	FNAL	☐	☐	5.10	1.00E+10

A

B

- 2 available LARP prototypes (RFD#1, RFD#2) exceeded Voltage and Q_0 requirements
- All 14 tests (with and w/o dampers) exceeded nominal voltage of 3.4MV
- Highest Q_0 achieved at 4.1 MV with dampers = 7.3 10^9 (~2x requirement)
- (A): Solved issues with RF losses in dampers
- (B): Removed surface defect causing early quench

LARP + AUP Cold Test Summary



See talk by Manuele Narduzzi

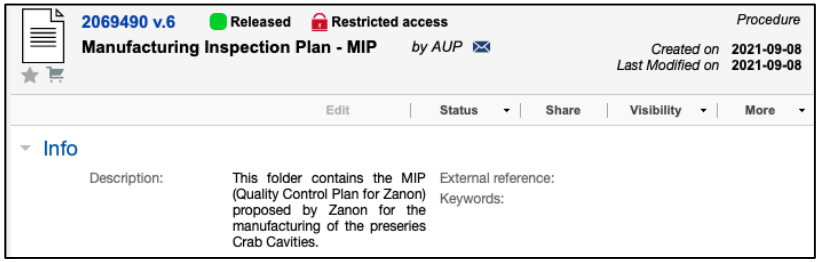
Zanon – Resuming Fabrication after PRR

- Zanon is (FINALLY!) cutting metal as we speak thanks to the approval of MIP →

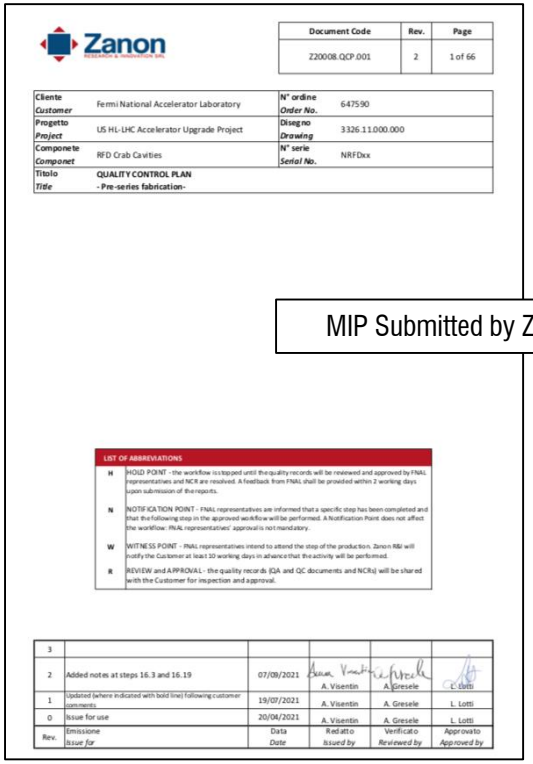
1. **Fabrication drawings**
   - approval ETA ~1 month
2. **Weld test plan / Welding book**
   - approval ETA ~2 weeks
3. **Manufacturing Procedures**
   - next slide

Holding productive 3-way meetings (FNAL-Zanon-CERN) to facilitate convergence.

CERN Approval of MIP



MIP Submitted by Zanon



Status of Procedures – Fast Recent Progress

Snapshot from ~1 month ago, now only 2 procedures remain to be approved!

Description Procedure	Procedure N.	Revision	Status	
Niobium Sheets	PO 657756	NA	QC Approved	
Niobium & Nb55Ti (Rods/Plates/Disks)	PO 671157	NA	QC Approved	
Niobium Tubes	PO 671490	NA	QC Approved	
RFD Crab Cavity Drawing Package	3326.1.000.000	1	Update Ongoing (ZRI)	
Welding Book	3326.W.001	NA	New version available after WPQR approval	
- section 1: Welding Map	3326.W.001	NA	New version available after WPQR approval	
- section 2: WPS	3326.W.001	NA	New version available after WPQR approval	
- section 3: Test Coupon (WPQR)	3326.W.001	4	Update Ongoing (ZRI)	
- section 4: WOPQ	3326.W.001	3	New version available after WPQR approval	
MIP – Pre-series (QCP @ ZRI)	Z20008.QCP.001	2	Approved	
Cleaning & Chemical Etching	Z20008.BCP	0	Approved*	* administrative update ongoing
Identification, Marking, Traceability	Z20008.IMT	0	Approved*	* administrative update ongoing
Radiographic Examination (RT)	Z20008.RT	0	Approved*	* administrative update ongoing
Radiographic Test Extent	NA	NA	Update Ongoing (ZRI)	
Manufacturing Sequence	NA	NA	Update Ongoing (ZRI)	
Helium Leak (LT)	Z20008.LT	0	Approved*	* administrative update ongoing
Dimensional Control	Z20008.DIM	0	Check Ongoing (CERN)	
Visual Inspection	Z20008.VT	0	Approved*	* administrative update ongoing
Packing Procedure	Z20008.SH	0	Check Ongoing (CERN)	
Grinding Procedure	ZGEN.GR	0	Check Ongoing (CERN)	

Zanon – Risks in Resuming Fabrication

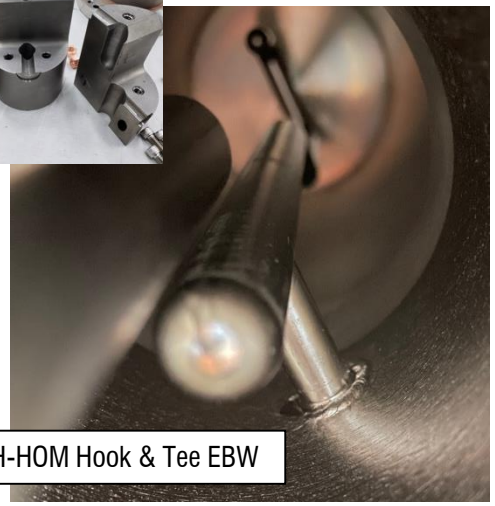
- As of today, KEY documents and procedures are still not approved by CERN.
- AUP projections show that due to delays this year, we have consumed all float with respect to “late” delivery dates agreed with CERN (see final slide).
- In the interest of schedule, factoring the approved MIP, and extremely advanced stage of drawings, AUP decided to give OK to Zanon to start fabrication of 2x Pre-Series cavities.
- Approval was limited to cutting Niobium sheets and performing deep-drawing of Niobium components.
- Any activity is contingent on the approval of applicable procedures.

Nb sheet cutting at Zanon

See talk by Naeem Huque / Subashini De Silva

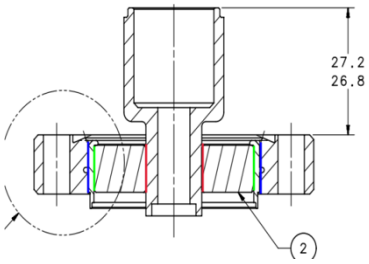
RF Ancillaries Fabrication – Jlab

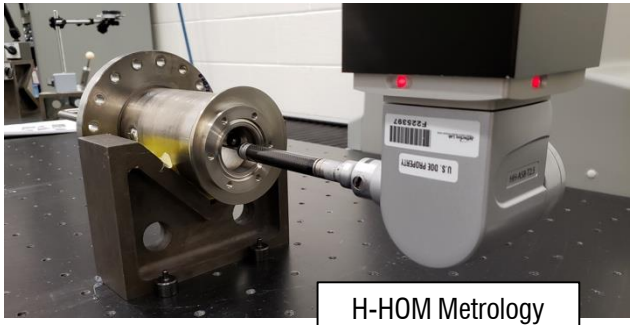
H-HOM Fabrication



H-HOM Hook & Tee EBW

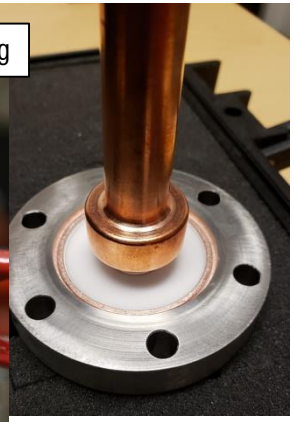
V-HOM Feedthrough Brazing

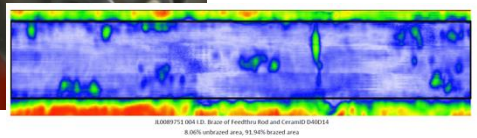


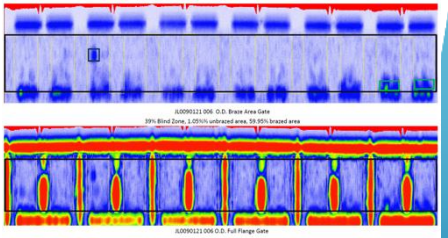


H-HOM Metrology

H-HOM Feedthrough Brazing







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.

NOW

- 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.
- AUP Series (2022-2023):
  - Repeat process of pre-series, deliver cavities to FNAL ready for VTS.

Niobium & Raw Materials Procurement

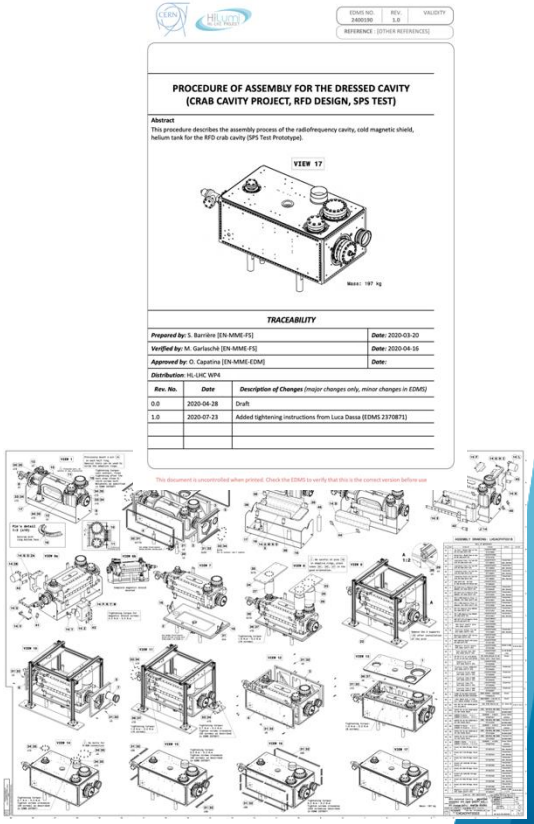
- Virtually all material for pre-series is already at Zanon. One last procurement imminent, plus some pieces for certain weld qualifications.
- All (83) Niobium sheets for series have been received from China. Inspection at FNAL completed. Accepted by CERN. Now verifying tensile and RRR properties.
- One last order of material for series (Niobium Tubes) not yet placed with Ningxia as negotiations on payment terms continue. Supplier requested 100% payment before shipment. FNAL proposing maximum 95% payment at acceptance of material certs and inspection reports and remaining 5% after receiving.
- QA contractor hired to tackle increased QA activities (for raw materials, and rest of scope as well).

Niobium Sheets for Series at FNAL

Helium Tanks

- Prototype magnetic shields were procured from Ad-Vance (U.S.) and are at FNAL.
- Helium Tank fabrication + welding: “lowest cost technically acceptable” proposal received from Zanon (Ita). Only other bid was received from Roark (USA).
- Contract with Zanon is imminent. Will include jacketing operations for 2x prototypes at this moment, a change order will be issued to add quantities for series.
- To allow a seamless transition to series in spring 2022, a final release by CERN of all drawings and supporting documents is needed by end of 2021, early 2022 at the latest.

3 Shield Assemblies are at FNAL (Ad-Vance)



PROCEDURE OF ASSEMBLY FOR THE DRESSED CAVITY
(CRAB CAVITY PROJECT, RFD DESIGN, SPS TEST)

Abstract

This procedure describes the assembly process of the radiofrequency cavity, cold magnetic shield, helium tank for the RFD crab cavity (SPS Test Prototype).

VIEW 17

TRACEABILITY

Prepared by: S. Barrière [EN-MME-FS]	Date: 2020-03-20
Verified by: M. Garlasché [EN-MME-FS]	Date: 2020-04-16
Approved by: O. Capatina [EN-MME-EDM]	Date:
Distribution: HL-LHC WP4	

Rev. No.	Date	Description of Changes (major changes only, minor changes in EDMS)
0.0	2020-04-28	Draft
1.0	2020-07-23	Added tightening instructions from Luca Dassa (EDMS 2370871)

Delivery Dates

- Deliveries are starting to fall outside the delivery window which was agreed with CERN before Covid. Dates will need to be re-negotiated prior to AUP rebaseline in April 2022.
- Delays are driven (A) by the additional work necessary to fully comply with CERN requirements prior to launching pre-series (~10mo); (B) Covid inefficiencies and impacts at suppliers are also affecting our schedule, to a smaller extent.

Cavity Delivery Dates with Current Plan of 1 bare cavity and 1 dressed cavity failure

	Agreed Early Delivery Date	August 2021 Status Schedule	Agreed Late Delivery Dates	
Cavities 01 & 02	Jun-22	May-23	Jun-23	
Cavities 03 & 04	Sep-22		Sep-23	
Cavities 05 & 06	Nov-22			Dec-23
Cavities 07 & 08	Jan-23			Feb-24
Cavities 09 & 10	Mar-23			May-24

Cavity Delivery Dates with no failures

	Agreed Early Delivery Date	Success Oriented August 2021 Status Schedule	Agreed Late Delivery Dates	
Cavities 01 & 02	Jun-22	May-23	Jun-23	
Cavities 03 & 04	Sep-22		Sep-23	
Cavities 05 & 06	Nov-22	Oct-23		Dec-23
Cavities 07 & 08	Jan-23			Feb-24
Cavities 09 & 10	Mar-23			Apr-23 May-24