RFD Crab Cavity Contribution from the U.S. Recent Progress and Plans

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With input from: ANL, BNL, JLAB, ODU, SLAC

9th HL-LHC Collaboration Meeting – Fermilab 14th-16th October 2019
Outline

- Scope and Deliverables
- RF Design Iterations by AUP
- Technical Achievements and Validations of 2019
- Cavity Prototype Fabrication at Zanon
- Immediate Needs
- Schedule
- Quality Assurance
- Acceptance Plan
- Goals for 2020
- Topics for discussion
Scope and Deliverables

- **Dressed RFD Crab Cavity**
  - **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 + RF Ancillaries
  - **Dressed Cavities**: Final Qualification at FNAL at 2K + RF Ancillaries
  - **Delivery**: 10 qualified dressed cavities (mix of pre-series + series)
Recent RF design change

RF design change was necessary to address two issues:

- (1) Excessive beam-induced voltage observed at CERN in SPS tests of similar crab cavity (DQW)
  - New requirement by CERN on beam coupling voltage $V_b < 0.3 \text{ V/nC}$
  - (1a) Port rotated by 90 deg, (1b) implemented a hook design
- (2) Structural integrity of ceramic window subjected to transportation loads
  - (a) Increased inner diameter of ceramic 50 Ohm $\rightarrow$ 25 Ohm
  - (b) Adjusted overall length

![Diagram of RF design change](image)

$V_b$: 0.123 V/nC
Design of Feedthrough for Dampers

HOMs feed-thrus RF design change 50 Ohm → 25 Ohm:

- The change has been implemented to reduce transportation risks, increasing structural stiffness of the ceramic at the RF vacuum-RF lines interface.
- CERN and AUP have converged on a design.
- HOMs damping requirements are still satisfied.

L. Ristori - 9th HL-LHC Collaboration Meeting
Summary of RFD Cold Tests

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<th>Test Date</th>
<th>Cavity #</th>
<th>Location</th>
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- All 14 tests (with and w/o dampers) exceeded nominal voltage of 3.4MV
- Highest voltage achieved with dampers = 5.5 MV
- Highest Q₀ achieved at 4.1 MV with dampers = 7.3e9 (~2x requirement)
RFD cavity + HHOM and VHOM validation

- RFD2 cavity has been successfully tested with all RF ancillaries.
- HHOM RF leakage has been resolved. \( Q_0 \) exceeds requirement, quench \( V_t \) is 5.3 MV > 4.1 MV.
- HHOM and VHOM dampers design has been successfully tested.
- Fundamental mode rejection has been tuned for both HHOM and VHOM.

Regular gasket on HHOM coupler (left) and RF gasket (right)
Rotational BCP + HPR Validation

- RFD-LARP-001 has been **successfully tested at FNAL**, after undergoing full processing at APS-TD and ANL facilities: **processing and facilities validation is complete**
- New rotational Bulk & Light BCP
- 600 C degassing
- HPR and clean assembly
- 120 C bake
- VTS test

Rotational BCP tool for RFD cavity (ANL/FNAL facility)

RFD HPR and Cleanroom Assembly (ANL/FNAL facility)
Heat Treatments + Cleanroom Assy Validation

600°C Heat Treatment (FNAL)

120°C Bake (FNAL)  VTS preparation (FNAL)

RFD-LARP-001 exceeded requirements for HL-LHC
Fabrication at Zanon

- PO placed Sep 2018 for 2 Proto bare cavities
- Milestone payments for Prototypes:
  - 20% Fabrication Drawings ✔
  - 20% Forming tooling ✔
  - 30% Sub-components pre-trimming (in-progress)
  - 15% each delivered cavity
- Estimated deliveries of 2x prototypes
  - March 2020
  - April 2020
Fabrication Results: Waveguide Boxes Forming Results

- **Copper H-HOM Box Metrology Results**
  - Shape accuracy after reshaping 300bar:
    - Flat surfaces encouraging $\sim 0.7mm (\pm 0.35mm)$ shape accuracy
    - Tube interface area to be improve by calibration $\sim 1.3mm (\pm 0.65mm)$ shape accuracy
  - Minimum thickness: **3.85mm** (only local area)
Fabrication Results: Waveguide Boxes Forming Results

- **H-HOM Boxes: EBW**
  - No official fixture used
    - tight schedule need creativity!
  - Metrology ongoing
  - External weld bead is homogeneous and clean
  - RF side: smooth and constant welding width
  - No undercut
  - No excessive penetration
  - No misalignments
  - No sagging
Immediate Needs

- Drawings for Magnetic Shields and Helium Tank
  - Mechanical Design is CERN responsibility and recently complete
  - Drawings needed by AUP and will be used for launching prototypes only
- Converge on frequency shift estimates for prototypes
  - Necessary to define frequency goal at supplier
  - Frequency as-built is different from frequency in operation
- Converge and approval of revision of Functional Requirement Specification before end of 2019
  - Clarification and addition of certain requirements
- Address (together) open recommendations collected by AUP at past reviews
Delivery Dates

- 2 Bare Cavity prototypes are delayed at supplier
- Zanon recently split in two independent companies. Before the maneuver, it experienced several months of “financial-freeze” which caused a delay for all outsourced work. Currently all business as usual, but ~4 month delays were accumulated.
- As of now, no effect foreseen for launching bare cavity pre-series (April 2020) and series (end of 2020)
- Final delivery dates of 10 dressed cavities remain unchanged (July 2022 – March 2023)

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Schedule

- T4 DOE CD-1/3a Approval
- T4 DOE CD-2/3b Approval
- T4 DOE CD-3 Approval
- T4 DOE CD-3c Approval
- T4 DOE CD-4 Approval
- T0 DOE CD-4 Approval

CD-3b
- RAW MATERIALS & BRAZED JOINTS PROCUREMENT
- BARE CAVITIES PROCUREMENT
- BARE CAVITIES PROCESSING AND COLD TEST
- HELIUM TANK PROCUREMENT
- RF ANCILLARIES PROCUREMENT
- DRESSED CAVITIES PROCESSING AND COLD TEST

CD-2
- LARP Raw Materials
- RFD Dressed Cavity Deliveries to CERN (T4)

FY2017 FY2018 FY2019 FY2020 FY2021 FY2022 FY2023 FY2024 FY2025 FY2026 FY2027 FY2028

36 month reporting float

10 Cavities Needed by CERN
~1 year float
Quality Assurance

- For each procedure required by CERN, AUP is uploading in EDMS a draft for approval
- Approval process is managed in EDMS. Despite being still at the prototype phase, certain AUP procedures for bare cavity fabrication are already approved
- Plan is for AUP to use MTF for all qualification and production data for pre-series and series cavities
- Convergence on procedures is needed before April 2020 when bare cavity pre-series are launched
QA documentation tracking

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Acceptance of RFD cavities

- **Acceptance Plan (#1744):**
  - Describes the process for acceptance between AUP and CERN, including OK to ship from CERN, and final checks at CERN after receiving

- **Acceptance Criteria (#1154):**
  - Discussions with CERN continuing towards a final version
  - All requirements from FRS will be verified with a test or a set of measurements during cavity production or during final tests at FNAL.

- **Electronic travelers (VECTOR):**
  - Already in place for several activities (see below)
Goals for FY2020

- Launch procurement of magnetic shields and Helium tanks for prototypes
- Complete fabrication of 2x prototype bare cavities at supplier
- Assess quality and 2K performance of prototypes
- Converge with CERN on MIP for bare cavity by February 2020 (PRR)
- Launch fabrication of pre-series bare cavities
- Complete fabrication of 3x sets of Proto-HOM dampers at Jlab and assess quality & performance
Upcoming Project Reviews

- **Procurement Readiness Reviews (Raw Materials) ~ Dec-Jan**
  - AUP soon launching procurement of raw materials for pre-series
  - Material List agreed upon and approved a while back, good (next slide)
  - Small “pilot” order placed earlier this year for small batch of Nb sheets, QA documentation recently approved by CERN, good start.
  - AUP will inform CERN of upcoming PRRs as needed

- **PRR Bare Cavities Pre-Series – Feb 2020 (TBC)**
  - Necessary to launch construction April 2020

- **Final Design Review (Dressed Cavities) ~ Summer 2020**
  - Participation of WP4 necessary (at min.) to defend mechanical design
  - Necessary to seek DOE approval for launching series in ~ Fall 2020.
RFD Bare Cavity Material List

- All materials contained in the deliverables, must meet CERN requirements
- Formal agreement between CERN and AUP on materials for **bare cavities** exists
  - RFD Bare Cavity Material List
  - EDMS 2001102 = US-HiLumi-doc-668

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US-HiLumi-doc-668
Topics for Discussion

- Fully integrated test of dressed cavity + dampers + FPC
  - It’s a necessary validation for entire collaboration
  - Who/how/when/funding?
- Best use of AUP Prototypes in early 2021?
- Details of Final 2K tests at FNAL
  - 50 Ohm ↔ 25 Ohm
  - Converge on Traveler for cold test
- Verification at receiving end (Triumf)
  - Cold tests for prototypes?
  - Warm measurements for series?
- Transportation specification
  - CERN recently defined transportation requirement for the design of all crab cavity components (10g, …)
  - Transportation will need to be carried out avoiding exceeding design requirements
Summary

- Design of bare cavity was recently modified after SPS experience at CERN, and adopted for prototypes at Zanon. Design of HOM dampers was modified to accommodate CERN feedthrough design.
- ANL/FNAL Facilities, tooling and procedures for processing, heat treatment, cleanroom assembly were recently validated thanks to LARP prototype.
- Fabrication of 2 cavity prototypes is progressing well in terms of quality. Heavy oversight of AUP. Delays outside AUP control are not impacting delivery dates originally agreed between AUP-CERN.
- Compliance with CERN QA is defined, tracked and must continue towards a convergence in early 2020.
- Acceptance plan is taking shape but still in draft form with a deadline in mid 2020.
- US RFD Team and CERN WP4 have many topics to discuss this week!