



Status of US AUP Contribution

Giorgio Apollinari – FNAL
HL-LHC AUP Project Manager

13th HL-LHC Collaboration Meeting
Vancouver, Canada - September 2023

The poster for the 13th HL-LHC Collaboration Meeting in Vancouver, Canada, from September 25-28, 2023. It features logos for HiLumi, CERN, and TRIUMF at the top. The main image shows a cityscape with a large "13th" overlaid. Below the image, it lists the meeting dates and provides a detailed description of the meeting's purpose: to update all collaborators on the latest schedule changes, discuss the production of the Crab Cavity, and provide the framework for additional collaborative meetings. It also lists the organizing committees for CERN and TRIUMF, along with their respective members.

13th
HL-LHC Collaboration Meeting
Vancouver, Canada,
25-28 September 2023

The 13th HL-LHC Collaboration Meeting, jointly organized by TRIUMF and CERN, will take place in Vancouver, Canada, from 25th to 28th September 2023, as an in-person meeting. The main objectives will be to update all HL-LHC collaborators on the advancement of the series. Based on the traditional programme with plenary and work package parallel sessions, this meeting will serve as a technical update forum for the 7th Cost and Schedule Review planned at CERN in November 2023, the kick-off of the Canadian contribution to the production of the Crab Cavity cryomodules and provide the framework for additional collaborative meetings between the project partners.

CERN - Organizing Committee
Oliver Brüning, Project Leader
Markus Edelhoff, Plenary Project Leader
Cecilia Neale, Project Office
Inese Garcia Olivero, Project Office

TRIUMF - Local Organizing Committee
Oliver Keizer, Chair, Director of Accelerator Division
Bill Lucifora, Plenary Coordinator
HL-LHC Crab Cavity cryomodules
Jana Thompson, Conference Facilitator
Pauline Dato Zilber, Administrative Assistant
Accelerator Division

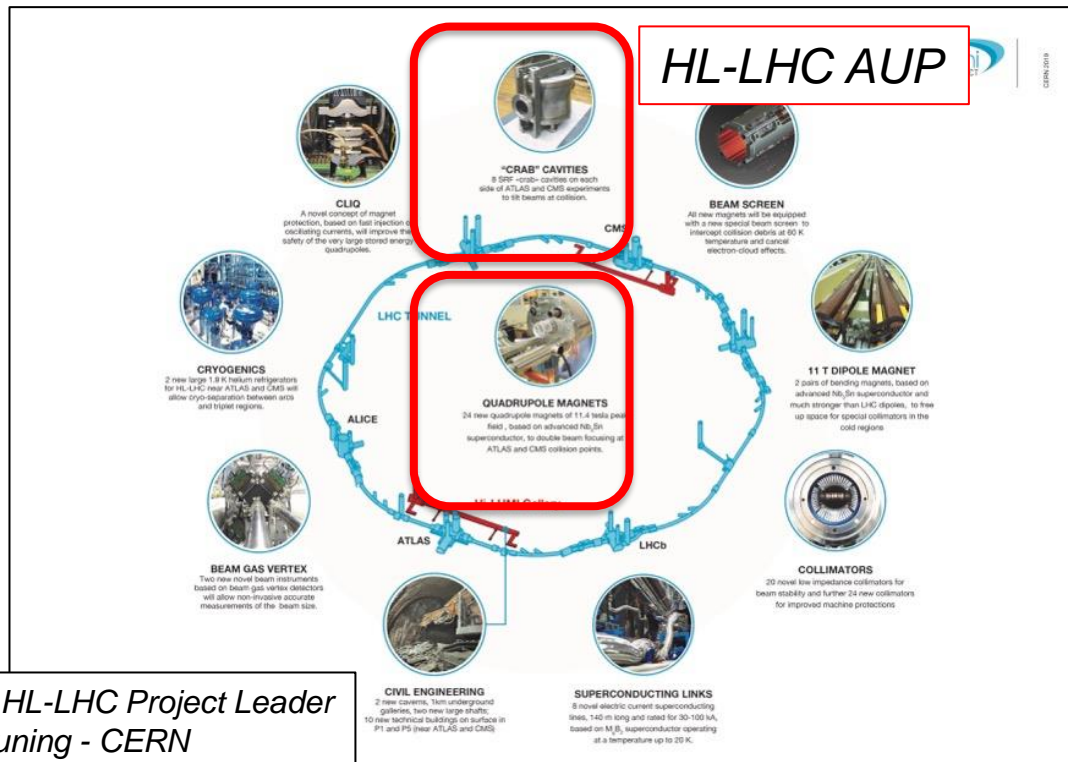
For more details and registration: HL-LHC Secretariat@cern.ch / hilumilhc.web.cern.ch



Outline

- Introduction
- Project Overview
- Overview of AUP Status
- Summary

US Contribution to HL-LHC

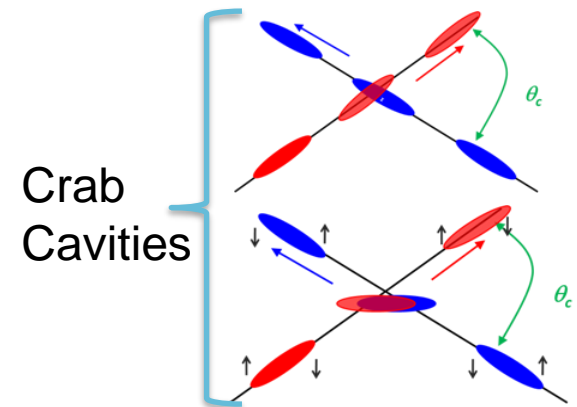


From HL-LHC Project Leader
O. Bruning - CERN

Quad Magnets

$$L = \gamma \frac{f_{rev} n_b N_b^2}{4\pi\epsilon_n\beta^*} R$$

Beam size



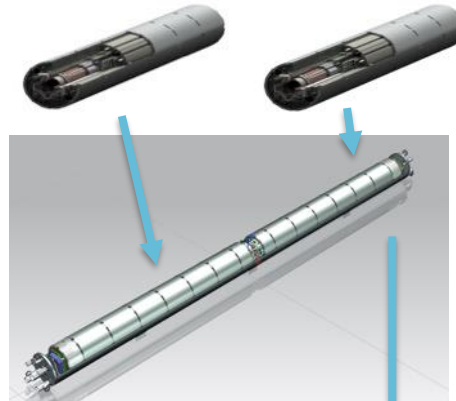
- HL-LHC: from 300 fb⁻¹ to 3000/4000 fb⁻¹
- LARP (DOE supported R&D Program) established the necessary technology for the HL-LHC Focusing Magnets and Crab Cavities
- DOE *baselined* HL-LHC AUP Project in 2019 (FNAL, BNL, LBNL with contributions from ANL, SLAC, JLAB, ODU & FSU)
- DOE *re-baseline* AUP in 2023 to absorb COVID impacts on Cost and Schedule

HL-LHC AUP Deliverable Scope

Technical Details

- Q1/Q3 Cryoassembly
(10 CryoAssemblies with 20 Magnets)

MQXFA
Magnet

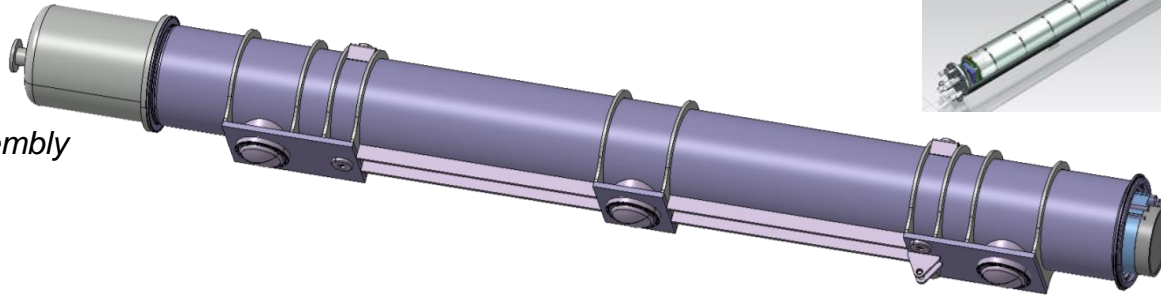


Cold Mass
Assembly

302.2

302.4

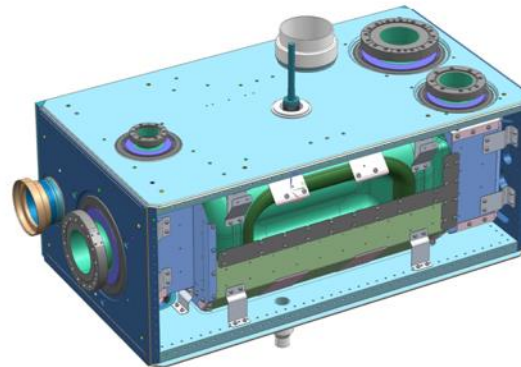
Cryo-Assembly



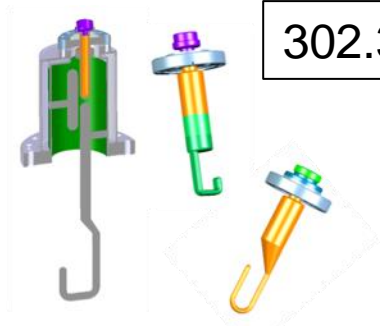
- Dressed RFD Cavity
(10 Dressed Cavities & Ancillaries)



Bare RFD Cavity



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



302.3

High Order Mode
Antennas

AUP Q1/Q3 and RFD Cavities KPPs

| Parameters | Threshold Performance | Objective Performance |
|---|---|---|
| Inner Triplet Focusing Quadrupoles (Q1 and Q3) | <p>a) 6 Q1/Q3 Cryoassemblies are accepted by CERN after testing at HL-LHC agreed upon Acceptance Criteria for the Cryoassembly. The Cryoassemblies will be assembled from Cold Masses built by HL-LHC AUP and Cryostat kits provided by CERN.</p> <p>b) 3 Q1/Q3 Cold Masses built with magnets tested vertically at HL-LHC agreed-upon Acceptance Criteria</p> <p>c) Complete coils and remaining components for 1 additional Q1/Q3 Cold Mass</p> | <p>4 additional Q1/Q3 Cryoassemblies are accepted by CERN after testing at HL-LHC agreed-upon Acceptance Criteria for the Cryoassembly. The Cryoassembly will be assembled from Cold Masses built by HL-LHC AUP and Cryostat kits provided by CERN</p> |
| SRF Crab Cavities | <p>a) 8 Radio Frequency Dipoles (RFDs) Dressed cavities for the HL-LHC Crab Cavity System are accepted by CERN after being tested at HL-LHC nominal temperature, nominal frequency, and ultimate cavity voltage. Dressed cavities include HOM couplers, pick-ups, He Vessel and magnetic shields.</p> <p>b) Procurement of components for 2 additional RFD Dressed Cavities</p> | <p>2 additional Radio Frequency Dipoles (RFDs) Dressed cavities for the HL-LHC Crab Cavity System are accepted by CERN after being tested at HL-LHC nominal temperature, nominal frequency, and ultimate cavity voltage. Dressed cavities include HOM couplers, pick-ups, He Vessel and magnetic shields.</p> |

10 Q1/Q3 Cryoassemblies
(8 Operations + 2 Hot Spares)

10 RFD Dressed Cavities
(8 Operations + 2 Hot Spares)

- HL-LHC AUP Project includes Objective KPPs



Progress since last CM on Magnets

G. Ambrosio in Plenary +
6 AUP Talks in WP3

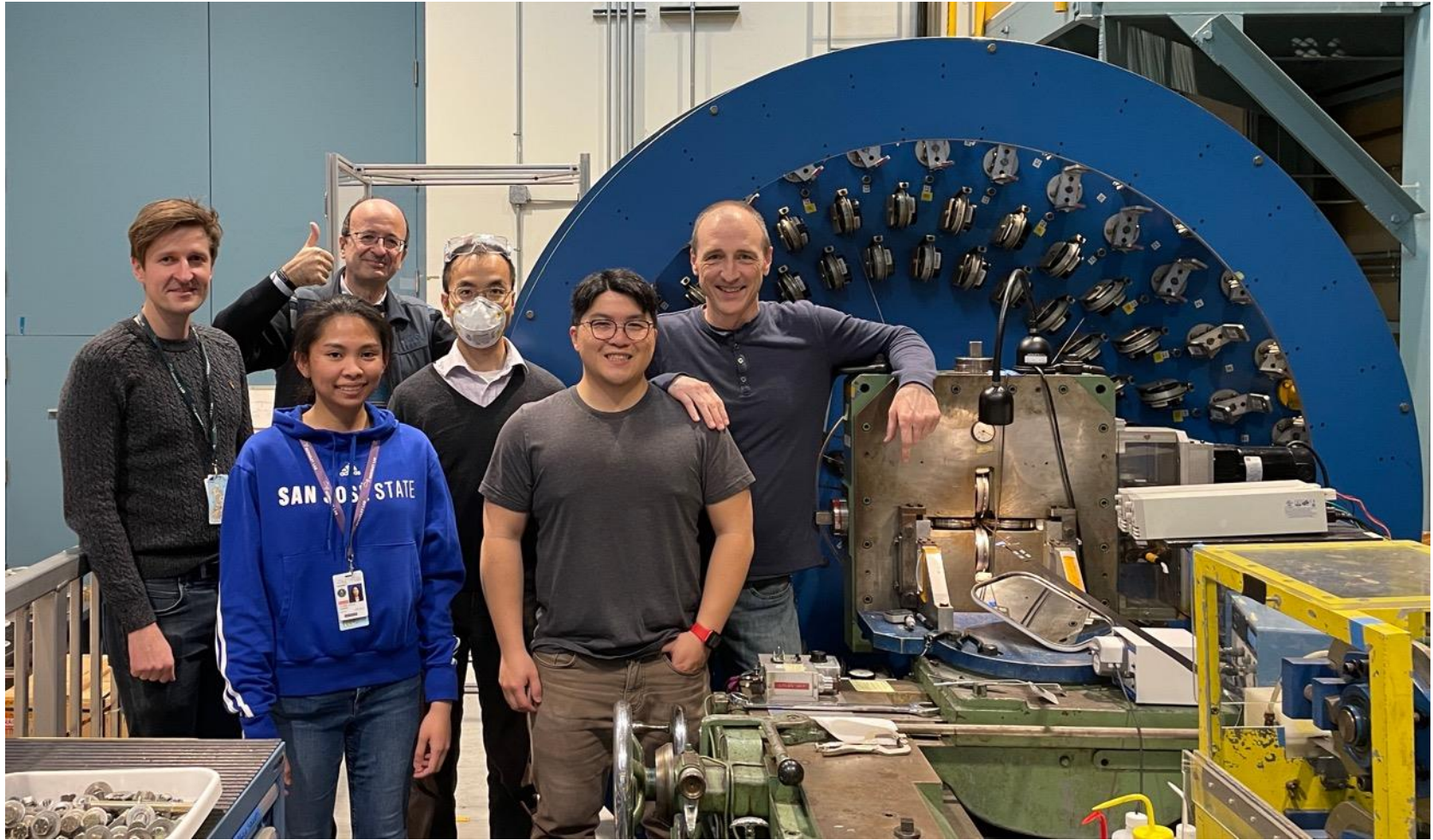
- LBNL Cable Factory ~completed Production
 - 2 more cables recently added to absorb Coils yield impact
- FNAL and BNL Factories at end of Production (~2-3 coils left)
- MQXFA11 assembled and tested
 - ✓ Successfully passed BNL Vertical Test
- MQXFA08b (COVID impact) had coil replaced
 - ✓ Successfully passed BNL Vertical Test
 - ✓ First demonstration of Coil replacement in long (4.2m) production magnet
- MQXFA13 assembled and tested
 - Failed BNL Vertical Test on ramp-rates NC, probably due to insufficient azimuthal pre-load on Magnet ends
 - Plan to replace limiting coil.
- MQXFA14b assembled and tested
 - ✓ MQXFA14 failed on QH Hipot during Fabrication. Coil Replaced. Also benefited from lesson learned in MQXFA13 with increase in pre-stress
 - ✓ Fastest training to date among AUP magnets.
- MQXFA15, MQXFA16 and MQXFA17 in various states of completion
 - MQXFA07b to be tested next in Nov. '23, after BNL cryo system maintenance

Magnets Assembly & Test History

| | | | |
|----------------|--|---------------------|--|
| MQXFA03 | VTS Tested OK | LQXFA/B-01 | |
| MQXFA04 | VTS Tested OK | | |
| MQXFA05 | VTS Tested OK | LQXFA/B-02 | |
| MQXFA06 | VTS Tested OK | | |
| MQXFA07 | VTS COVID Limitations, coil replaced | MQXFA07b | TBT₁ |
| MQXFA08 | VTS COVID Limitations, coil replaced | MQXFA08b | VTS Tested OK |
| MQXFA09 | Assembly NCR (2 coils affected by folded Kapton) | Cannibalized | 2 coils rejected 2 coils used in 14b and 5, structure used in 11 |
| MQXFA10 | VTS Tested OK | LQXFA/B-03 | LQXFA/B-04 |
| MQXFA11 | VTS Tested OK | | |
| MQXFA12 | Assembly NCR (Hipot fail) coils to be replaced | MQXFA12b | TBT₄ |
| MQXFA13 | VTS Limitations (end prestress), coil replaced | MQXFA13b | TBT₃ |
| MQXFA14 | Assembly NCR (QH hipot fail), coil replaced | MQXFA14b | VTS Tested OK |
| MQXFA15 | TBT₂ | | |

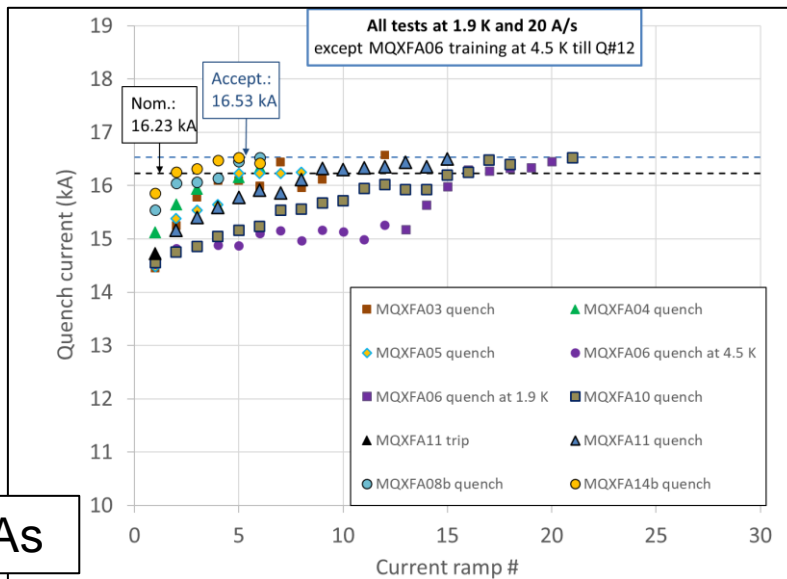
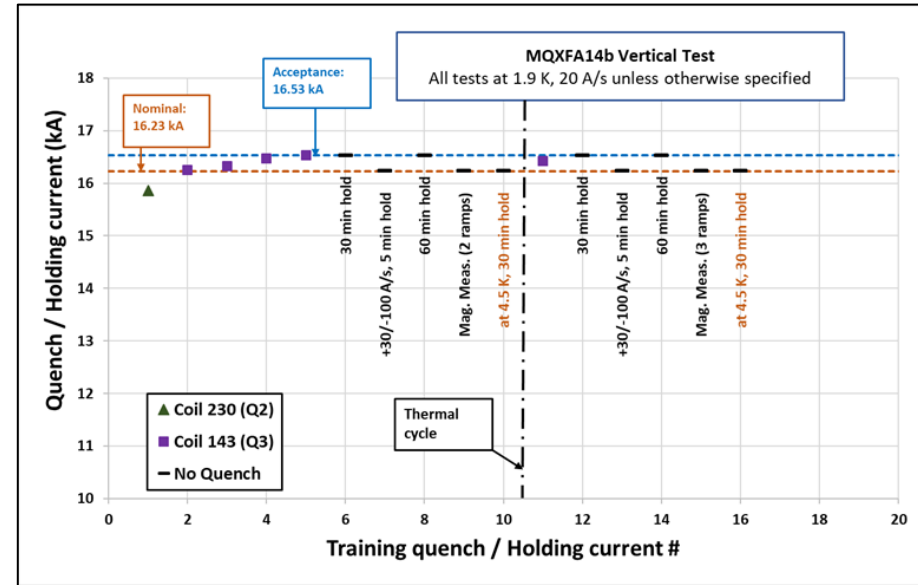
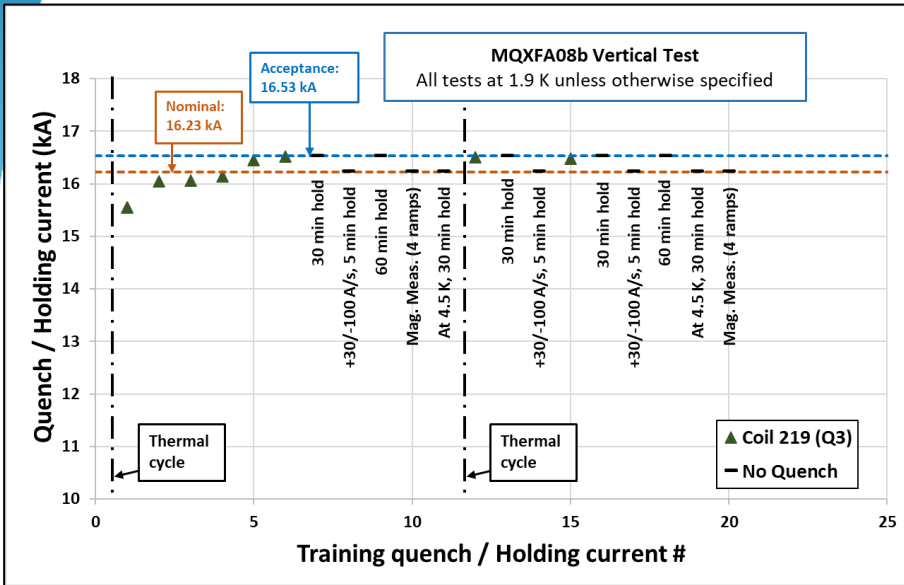


Celebrations for Last Cable Completed @ LBNL



<https://newscenter.lbl.gov/2023/08/30/cabling-for-lhc-upgrade-wraps-up/>

MQXFA08b and MQXFA14b



8 MQXFAs

- Approximately 60% MQXFA Magnets Produced
- 40% MQXFAs Magnets (8/20) Accepted for CM/CA

LQXFA/B-01 Progress & Achievements



Insertion in Cryostat (shown at Uppsala)



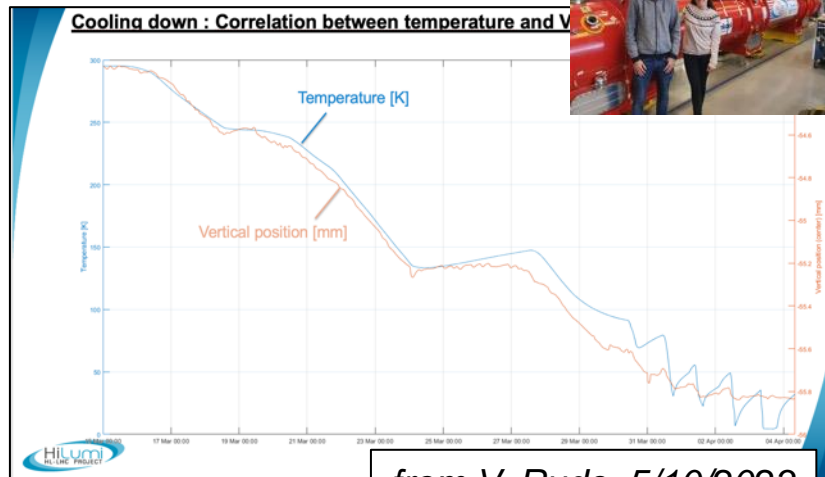
Installation in FNAL TS4 (Jan-Feb '23)



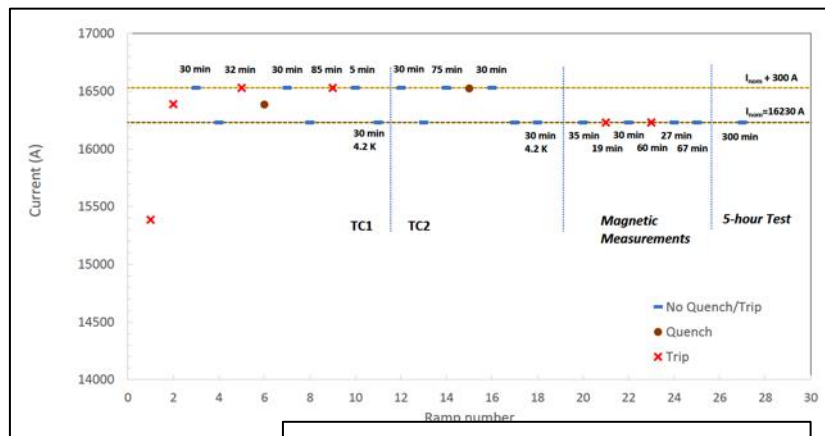
Test Completion/Warm-up Start (Aug. '23)

LQXFA/B-01 Progress & Achievements (cont.)

- Validated Cold Mass design
 - Magnet alignment, quench performance, pressure test, etc.
- Validated Cryostat Design and FSI (CERN)
 - 1.9K, 80K, heat loss, etc.
- Re-validated Magnet performance
 - Nominal and Acceptance, 1.9K and 4.2K, 5h test, ramp rates, field measurements, etc.



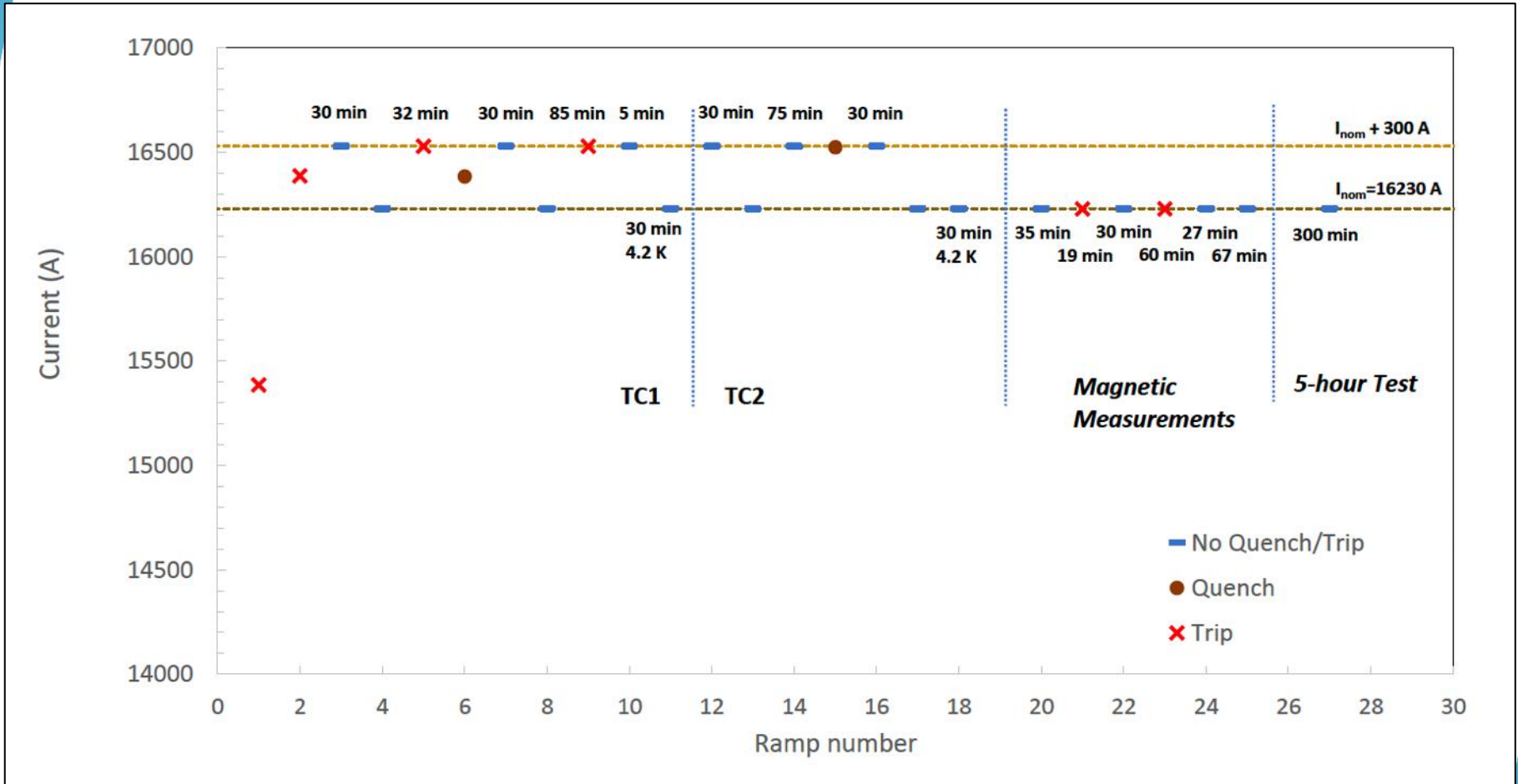
from V. Rude, 5/10/2023



from G. Chlachidze, 9/8/2023



LQXFA/B-01 Horizontal Test



LQXFA/B-01 Path to Acceptance by CERN

- 2 major type of NCRs in LQXFA01
 - Welded by ASME Code in Jan. 2022
 - No formal and timely (i.e. before weld execution) approval by CERN for WPS/PQR according to “Safety Agreement”
 - For LQXFA/B-01 used the same welding rod, WPS/PQR and volumetric inspection eventually approved by CERN in April 2023.
 - 2 missing QH in one of the magnets (2 out of 16)
 - Lack of redundancy in QP if installed in the tunnel
- Mutual suggestion for Acceptance of LQXFA/B-01 + *1 additional vertically tested MQXFA Magnet (+ misc.)* for potential swap of magnet at CERN at a later date if necessary.
 - Important for US to be a reliable partner to support the CERN String Test schedule. In addition, timely experience on Integration and Shipments to CERN is critical.
 - Letter from AUP PO to HiLumi Leader with response starting the clock.

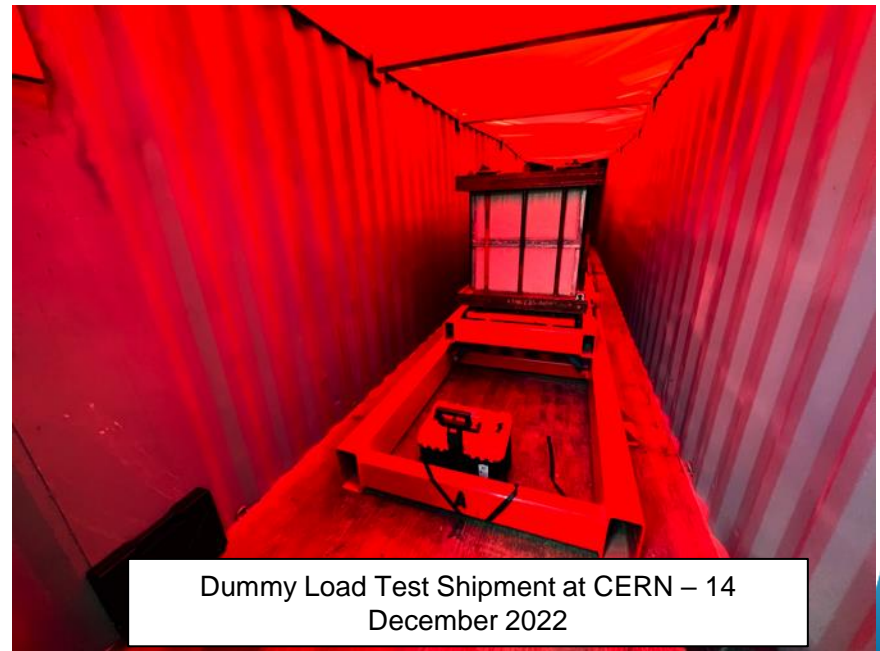
Q1/Q3 Transportation Readiness Review

LQXFA/B-01 Delivery to CERN

- Review of testing results from local road testing and full-scale dummy load test shipment to CERN
 - Included discussion of previously-reviewed shipping matters for a thorough examination of the transportation process.
- Results show the transportation frame performed nominally, attenuating expected shipping loads to acceptable levels.
- With one minor process recommendation, the committee endorsed proceeding with the first Q1/Q3 shipment.
- Ship for LQXFA/B-01 reserved for Nov. 5th 2023 anticipating LQXFA/B-01 convergence on acceptance path by late September

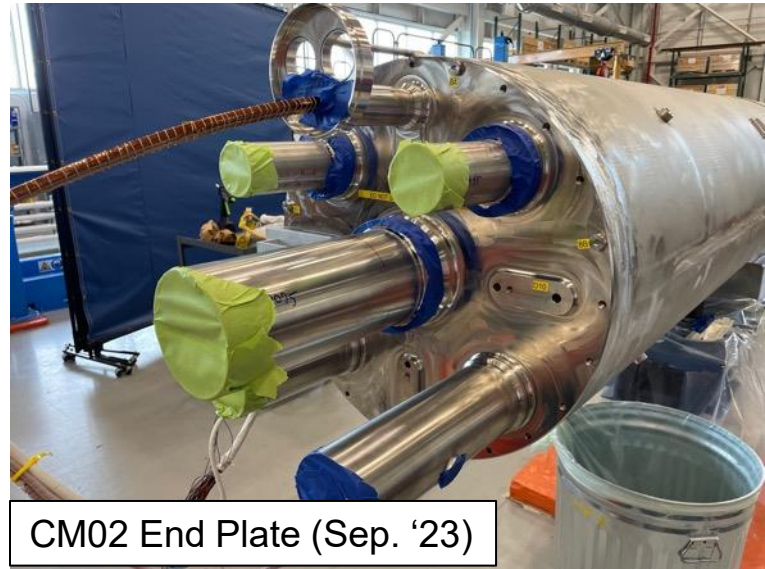


Dummy Load Test Shipment Leaving FNAL – 11
November 2022



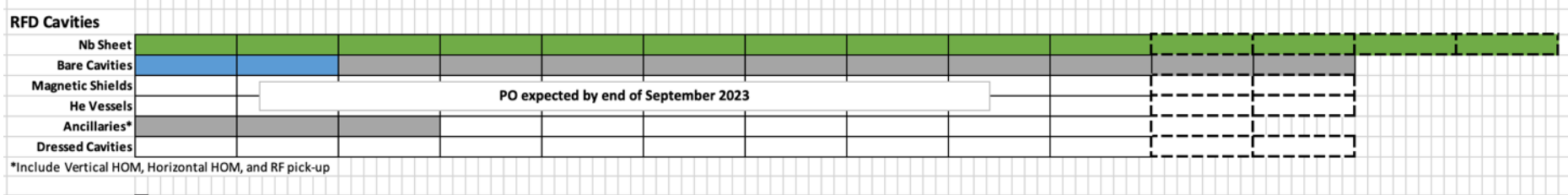
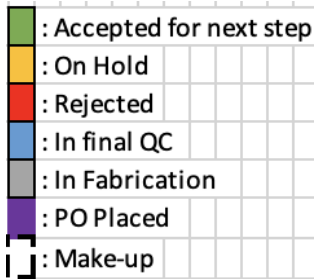
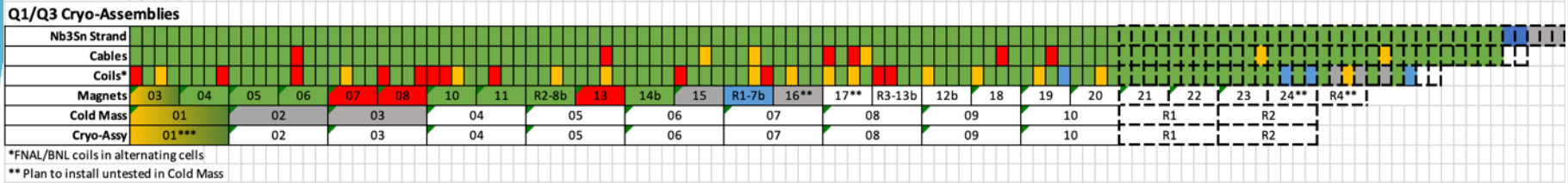
Dummy Load Test Shipment at CERN – 14
December 2022

CM02 and CM03



Production Dashboard

“Basic” deliverables
80 coils, 20 magnets, etc.



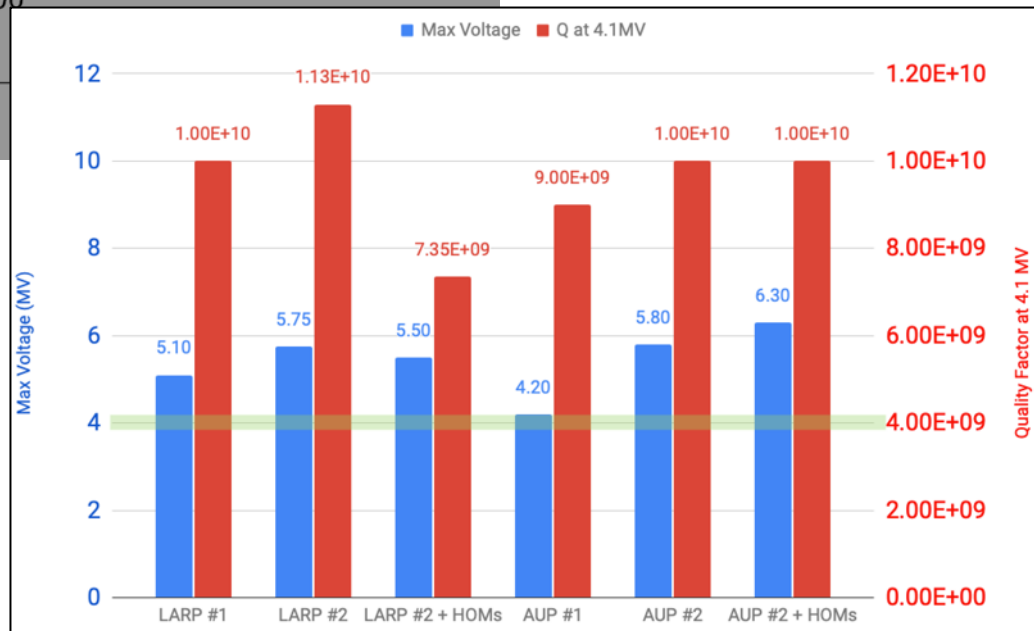
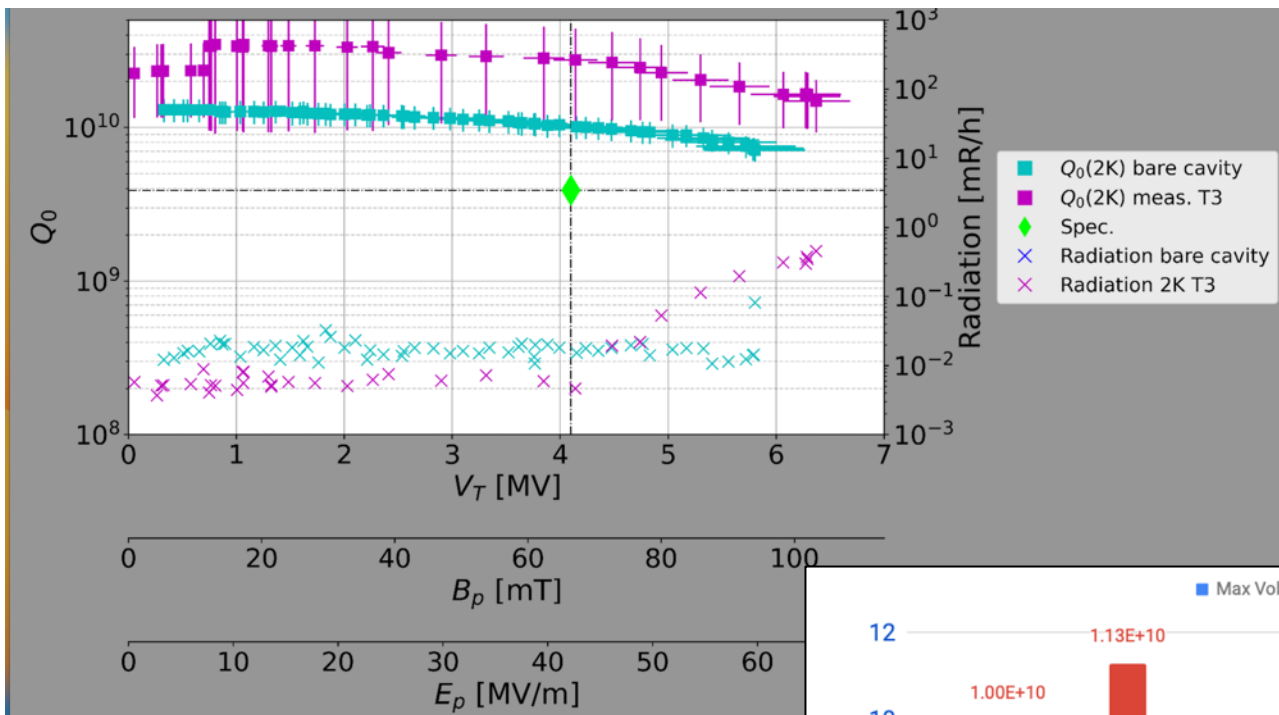
- Technical Production Details in WPs presentations

Progress since last CM on RFD Crab Cavities

- Demonstrated RFD HOMs at JLAB
- Completed receipt of all Nb Raw Material at ZANON
- 2 Pre-series at ZANON in final phases
 - Unable to polish a small damage on beampipe flange. Will need complex re-machining process with estimated delay of 1-2 months.
- Documentation under control
- Placed order for 10 Series Cavities, production at peak with majority of components formed.
- 1st Prototype Cavities at ZANON for He Vessel installation
 - 2nd Prototype at FNAL (for validation of ZANON processing) might require additional HPR.
- Cracked ceramic window at CERN in leak test preparation
- Order for He Vessels expected to be placed by the end of September '23

NRFD002+HOMs 3rd Test Summary

14th – 18th Aug. '23



Pre-Series RFD Cavities

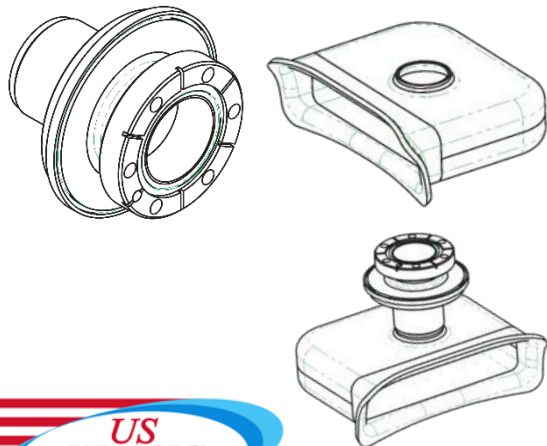
- NRFD01: Reshaping and trim-tuning completed successfully, needs re-machining prior to EBW.
- NRFD02: Reshaping complete, undergoing trim-tuning.



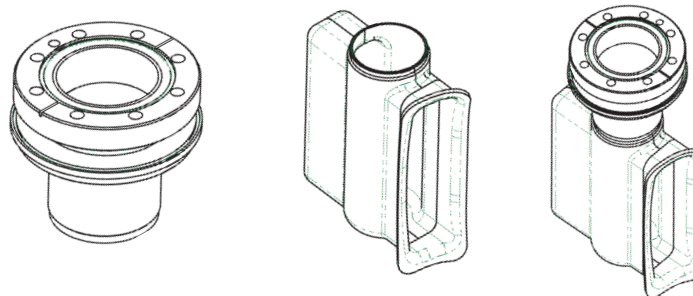
Series RFD Cavities

Series RFD Bare Cavity @ ZRI

- Processing procedures approved by CERN
- ZRI QCP/ MIP global advancement: 11% completed

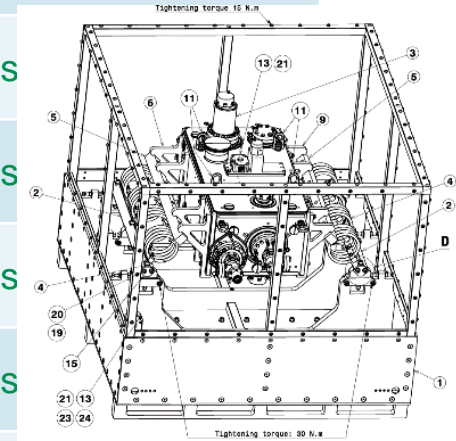


| QCP STEP No. | 1 | 2 | 3 | 4 | 5 | 6 |
|--------------|---------------------|----------------------|-------------------|-------------------|--------------------|-----------------|
| Items | V-HOM Port Weldment | V-HOM WG with Insert | V-HOM WG Weldment | FPC Port Weldment | FPC WG with Insert | FPC WG Weldment |
| Drawing | 3326.14.121.000 | 3326.14.122.000 | 3326.14.120.000 | 3326.12.131.200 | 3326.12.132.000 | 3326.12.130.000 |
| NRFD03 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD04 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD05 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD06 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD07 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD08 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD09 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD10 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD11 | 13% | 15% | 0% | 13% | 16% | 0% |
| NRFD12 | 13% | 15% | 0% | 13% | 16% | 0% |



RFD Pre-series QA: *EDMS Status*

| | | |
|--|--------------|----------|
| Manufacturing Drawings RFD Bare Cavities | EDMS 2080712 | Released |
| Test Plan PQR | EDMS 2479595 | Released |
| Welding Book | EDMS 2397280 | Released |
| Manufacturing and Inspection Plan | EDMS 2069490 | Released |
| Cleaning & Etching Procedure | EDMS 2069492 | Released |
| Identification, Marking and Traceability Procedure | EDMS 2069496 | Released |
| Procedure of Radiographic Examination of Welds | EDMS 2069497 | Released |
| Leak Test Procedure | EDMS 2080831 | Released |
| Dimensional Control Procedure | EDMS 2080834 | Released |
| Visual Testing | EDMS 2100569 | Released |
| Grinding Procedure | EDMS 2630567 | Released |
| RF measurements & Trimming | EDMS 2080833 | Released |
| Packing Procedure | EDMS 2642947 | Ongoing |



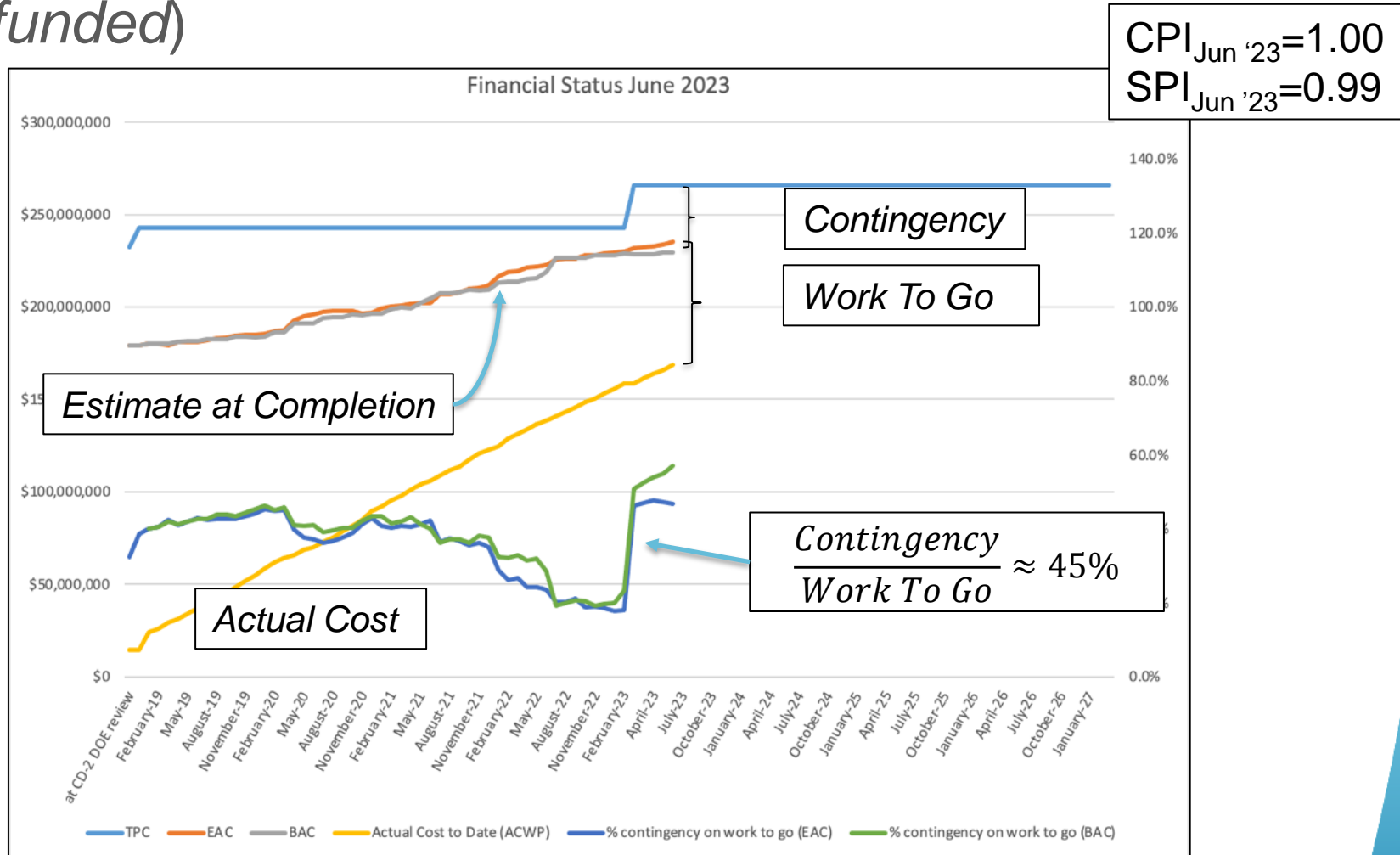
- Pre-Series Production Procedures fully approved by CERN

Rebaseline Process

- DOE has acknowledged that the impact of unexpected events such as COVID and Abnormal Cost/Escalations due to geopolitical events are placing AUP in jeopardy of not completing its KPPs and has allowed AUP to “*apply for rebaseline*” in late 2022
- A “Rebaseline Process” was initiated with funding agency (DOE) with the following goals:
 - Maintain Objective Deliverables to CERN as approved in 2019 (10 Q1/Q3 CA, 10 Dressed RFD Cavities)
 - Modify TPC and CD-4 dates:
 - 2019 Baseline TPC_{CD2} = \$242.7M CD4_{CD2} = Mar. '28
 - 2023 Re-Baseline TPC_{Reb} = \$266.0M CD4_{Reb} = Dec. '29
 - Rebaseline Reviews and Approval:
 - DOE Review in Dec. 13th-15th '22 (*thanks to Oliver for help !*)
 - **ESAAB approval in February 2023.**

Financial Situation (Past)

- DOE has disbursed \$266M to the US-AUP (*fully funded*)



- AUP is in the “last leg of the race” (~3/4 complete)



Delivery Dates to CERN

Fermilab
Fermi National Accelerator Laboratory

November 10th 2022

Attn: Dr. Oliver Brüning, High Luminosity LHC Project Leader
Address: CERN, CH-1211 Geneva 23, Switzerland
From: Dr. Giorgio Apollinari, HL-LHC AUP Project Manager, FNAL
Subject: Deliverables and delivery dates from HL-LHC AUP to CERN
cc: Dr. Markus Zerlauth - High Luminosity LHC Deputy Project Leader, CERN
Ruben Carcagno - HL-LHC AUP Deputy Project Manager, FNAL
Dr. Simona Rolli - HL-LHC AUP Federal Program Manager, DOE
Dr. Athanasios Hatzikoutelis - HL-LHC AUP Project Manager, FNAL
Dr. "Jerry" Kao - HL-LHC AUP Project Manager, FNAL

Fermilab
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P.O. Box 500, MS 314
Kirk Road and Pine Street
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apolinari@fnal.gov

Dear Oliver

The High Luminosity LHC Project at CERN and the HL-LHC AUP in the US are continuing their execution. Specific (Construction) approval by our funding agency, DOE, of the HL-LHC AUP is required.

The US deliverables are identified as Key Performance Indicators (KPIs) in the HL-LHC AUP Plan (PEP) approved by DOE on Dec. 21st, 2020 as well as the HL-LHC AUP (CA) assembled from Cold Masses built in the US and RFD Superconducting Crab Cavities. The deliverables are CA, 3 Q1/Q3 Cold Masses and completed coils and remaining RFDs and parts for 2 additional RFD cavities and "Objectives" allow for the possibility of Scope Contingency. Deliverables in EDMIS #2303166 following the AUP CD-2 (Baseline) AUP.

In Spring 2020, the whole world was impacted by the COVID-19 pandemic which resulted in the CERN facilities lock-down for several months, followed by years at a much reduced efficiency due to the applicable mandates.

The 2020 COVID-19 pandemic event has seriously affected the scope and the original Total Project Cost. Our funding agency process, that, if successful, will insure the preservation of the HL-LHC AUP.

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Fermilab
Fermi National Accelerator Laboratory

On the other hand, with the present letter, the AUP Project Office intends to communicate the new delivery dates for the Objective KPIs following the impacts from COVID-19 and other technical-related delays.

LQXFA/B Cryo Assemblies

| | |
|------------|---------------|
| LQXFA /R01 | October 2024 |
| LQXFA /R02 | May 2025 |
| LQXFA /R03 | July 2025 |
| LQXFA /R04 | October 2025 |
| LQXFA /R05 | February 2026 |
| LQXFA /R06 | May 2026 |
| LQXFA /R07 | July 2026 |
| LQXFA /R08 | October 2026 |
| LQXFA /R09 | March 2027 |
| LQXFA /R10 | July 2027 |

All the previous dates include 11 months of schedule float (or schedule contingency) over the early dates shown in the present HL-LHC AUP plan. This float is introduced to mitigate extant schedule risks in the execution of AUP activities.

RFD Dressed Cavities

| | |
|--------------------|----------------|
| HCACFD002-UP000001 | April 2025 |
| HCACFD002-UP000002 | April 2025 |
| HCACFD002-UP000008 | September 2025 |
| HCACFD002-UP000009 | October 2025 |
| HCACFD002-UP000010 | October 2025 |

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science www.fnal.gov

CERN
European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

HiLumi
HL-LHC PROJECT

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HL-LHC AUP Project Manager
TD/HQ
P.O. Box 500, MS 314
Kirk Road and Pine Street
Batavia, Illinois 60510-5011
USA

Our reference: ATS/OB/cn/2022-016
Geneva, 14th November 2022

Subject: Your letter dated November 10th, 2022

Dear Giorgio,

Many thanks for sending us at CERN the updated delivery dates for the LQXFA Cryo Assemblies and the RFD Dressed Cavities following the impacts of the world-wide COVID pandemic.

As previously discussed, these updated delivery dates are fine for us and compatible with the HL-LHC installation plan.

We understand that the US HL-LHC AUP baseline plan, without risks, includes delivery of the cryomodules 11 months earlier than the communicated dates. I would like to take this opportunity to reiterate, that the IT String schedule at CERN is driven by these success oriented AUP delivery dates for the first and second Cryo assemblies. Delays in these first two success oriented delivery dates will have a direct impact on the IT String schedule.

We would also like to underline that the delivery of the final RFD Cryo Modules at CERN is the relevant parameter for the Crab Cavity installation in the HL-LHC. Delivery of the last RFD Cryo Module by end 2026 or, at the latest beginning 2027, are assumed for the HL-LHC installation schedule which implies a careful coordination by CERN between the AUP and TRIUMF contributions.

www.cern.ch

As previously discussed, these updated delivery dates are fine for us and compatible with the HL-LHC installation plan.

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science www.fnal.gov

Oliver Brüning
HL-LHC Project Leader
CERN ATS-DO
www.cern.ch

- Delivery dates agreed with CERN



Delivery Dates to CERN

| Assembly Optimistic Delivery Dates | | | |
|------------------------------------|----------------------------|-------------------------------------|----------------------------|
| | Agreed Early Delivery Date | July 2023 Success Oriented Schedule | Agreed Late Delivery Dates |
| Q1/Q3 Delivery 01 | Nov-23 | | Oct-24 |
| Q1/Q3 Delivery 02 | Jun-24 | | May-25 |
| Q1/Q3 Delivery 03 | Aug-24 | Oct-24 | Jul-25 |
| Q1/Q3 Delivery 04 | Nov-24 | Jan-25 | Oct-25 |
| Q1/Q3 Delivery 05 | Mar-25 | May-25 | Feb-26 |
| Q1/Q3 Delivery 06 | Jun-25 | Aug-25 | May-26 |
| Q1/Q3 Delivery 07 | Aug-25 | Oct-25 | Jul-26 |
| Q1/Q3 Delivery 08 | Nov-25 | Jan-26 | Oct-26 |
| Q1/Q3 Delivery 09 | Apr-26 | | Mar-27 |
| Q1/Q3 Delivery 10 | Aug-26 | | Jul-27 |
| 1 cell = 1 month | | | |
| Cavity Optimistic Delivery Dates | | | |
| | Agreed Early Delivery Date | July 2023 Success Oriented 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 | Nov-24 | Jul-25 |
| Cavities 07 & 08 | Oct-24 | Jan-25 | Sep-25 |
| Cavities 09 & 10 | Nov-24 | Mar-25 | Oct-25 |

- Success Oriented Schedule provided to CERN WPs as input for upcoming C&S Review

Conclusions

- AUP is ~3/4 complete
- Steady progress on MQXFA Construction
 - 8 magnets passed vertical test, one more ready for test now.
- LQXFA/B-01 Horizontal Test successfully completed, cryomodule soon to be on its way to CERN.
- RFD Crab Cavities series order placed.
 - Pre-production cavities in final assembly completion.
 - Order for He Vessel soon to be placed
- Successful approval of AUP Rebaseline due to COVID/Abnormal Escalation impact with ~10% increase in funding