US HL-LHC AUP: Ready for Production

Giorgio Apollinari – FNAL

8th HiLumi Collaboration Meeting – CERN, Oct 2018

Outline

- Introduction
- Deliverables
- Schedule *(and Cost)*
- AUP Needs to *"Really"* Start
- Conclusions

Introduction

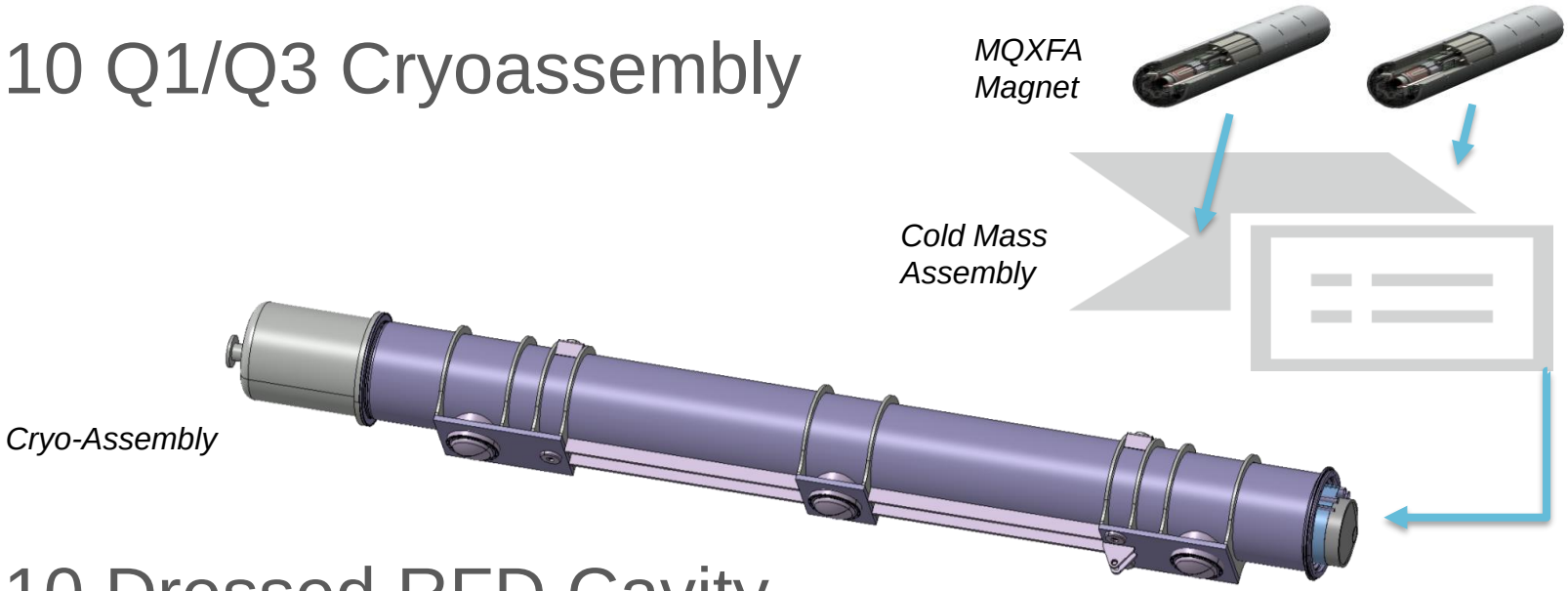
- US HL-LHC AUP has been properly introduced by Simona yesterday
- HL-LHC AUP is a 413.3b Project established to fulfill a US contribution to HL-LHC
  - CD-0 (Mission Need) approved in 2016
  - CD-1 (Cost Range) approved 2017
    - Also obtained CD-3a (Long Lead Procurement) for Nb3Sn
  - CD-2 (Project Baseline) in progress

    "Plan the Work, Work the Plan"

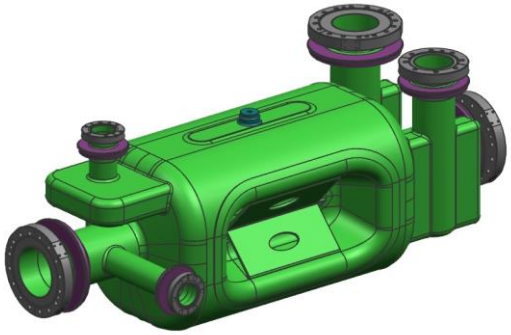
    We are Here
  - CD-3 (Start of Construction)
  - CD-4 (Project Completion)

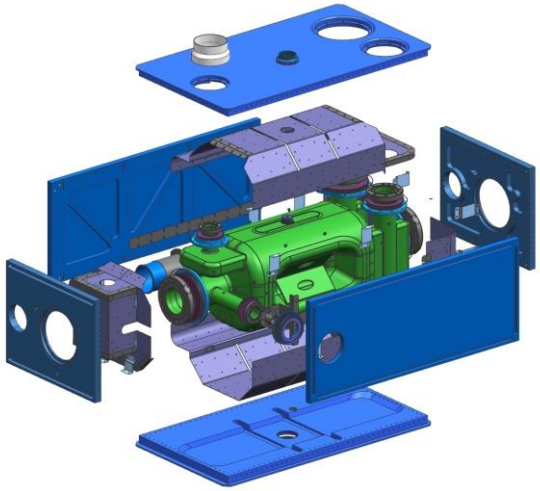
HL-LHC AUP Scope – Technical Details

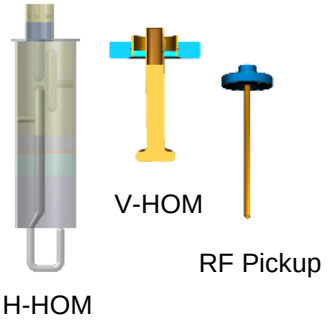
- 10 Q1/Q3 Cryoassembly



- 10 Dressed RFD Cavity

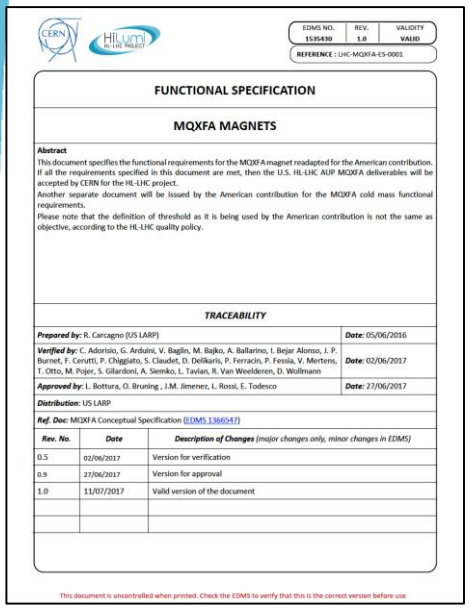






Performance Requirements

- Performance Requirements are documented in “Functional Requirements Specifications” documents
  - Approved by CERN
  - Accepted by HL-LHC AUP
- Under Document Control at CERN and US



FUNCTIONAL SPECIFICATION

MQXFA MAGNETS

Abstract

This document specifies the functional requirements for the MQXFA magnet readapted for the American contribution. If all the requirements specified in this document are met, then the U.S. HL-LHC AUP MQXFA deliverables will be accepted by CERN for the HL-LHC project.
Another separate document will be issued by the American contribution for the MQXFA cold mass functional requirements.
Please note that the definition of threshold as it is being used by the American contribution is not the same as objective, according to the HL-LHC quality policy.

TRACEABILITY

Prepared by: R. Carcagno (US LARP)	**Date:** 05/06/2016
Verified by: C. Adorisio, G. Arduini, V. Baglin, M. Bajko, A. Ballarino, I. Bejar Alonso, J. P. Burnet, F. Cerutti, P. Chiggiato, S. Claudet, D. Delikaris, P. Ferracin, P. Fessia, V. Mertens, T. Otto, M. Pojer, S. Gilardoni, A. Siemko, L. Tavian, R. Van Weelderen, D. Wollmann	**Date:** 02/06/2017
Approved by: L. Bottura, O. Bruning , J.M. Jimenez, L. Rossi, E. Todesco	**Date:** 27/06/2017
Distribution: US LARP	
Ref. Doc: MQXFA Conceptual Specification (EDMS 1366547)	

Rev. No.	Date	Description of Changes (major changes only, minor changes in EDMS)
0.5	02/06/2017	Version for verification
0.9	27/06/2017	Version for approval
1.0	11/07/2017	Valid version of the document

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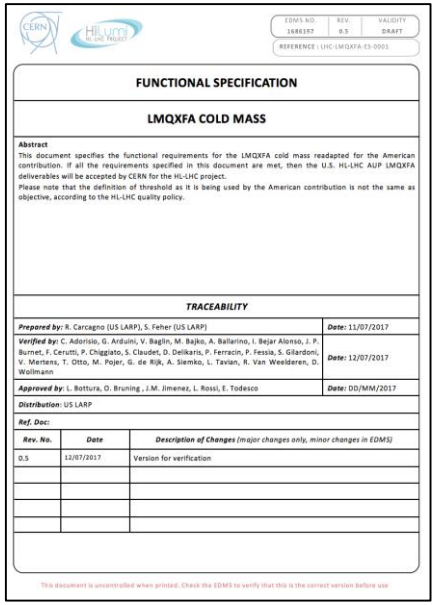

FUNCTIONAL SPECIFICATION

LMQXFA COLD MASS

Abstract

This document specifies the functional requirements for the LMQXFA cold mass readapted for the American contribution. If all the requirements specified in this document are met, then the U.S. HL-LHC AUP LMQXFA deliverables will be accepted by CERN for the HL-LHC project.
Please note that the definition of threshold as it is being used by the American contribution is not the same as objective, according to the HL-LHC quality policy.

TRACEABILITY

Prepared by: R. Carcagno (US LARP), S. Feher (US LARP)	**Date:** 11/07/2017
Verified by: C. Adorisio, G. Arduini, V. Baglin, M. Bajko, A. Ballarino, I. Bejar Alonso, J. P. Burnet, F. Cerutti, P. Chiggiato, S. Claudet, D. Delikaris, P. Ferracin, P. Fessia, S. Gilardoni, V. Mertens, T. Otto, M. Pojer, G. de Rijk, A. Siemko, L. Tavian, R. Van Weelderen, D. Wollmann	**Date:** 12/07/2017
Approved by: L. Bottura, O. Bruning , J.M. Jimenez, L. Rossi, E. Todesco	**Date:** DD/MM/2017
Distribution: US LARP	
Ref. Doc:	

Rev. No.	Date	Description of Changes (major changes only, minor changes in EDMS)
0.5	12/07/2017	Version for verification

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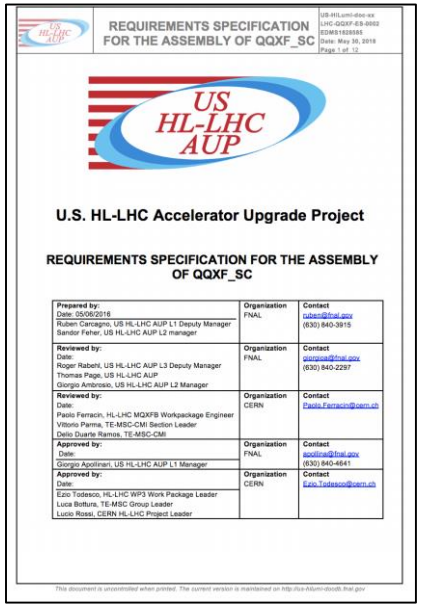

REQUIREMENTS SPECIFICATION FOR THE ASSEMBLY OF QQXF_SC

US HL-LHC AUP

U.S. HL-LHC Accelerator Upgrade Project

REQUIREMENTS SPECIFICATION FOR THE ASSEMBLY OF QQXF_SC

Prepared by: Date: 05/06/2016 Ruben Carcagno, US HL-LHC AUP L1 Deputy Manager Sandor Feher, US HL-LHC AUP L2 manager	Organization FNAL	Contact ruben@fnal.gov (630) 840-3915
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Approved by: Date: Ezio Todesco, HL-LHC WP3 Work Package Leader Luca Bottura, TE-MSC Group Leader Lucio Rossi, CERN HL-LHC Project Leader	Organization CERN	Contact Ezio.Todesco@cern.ch

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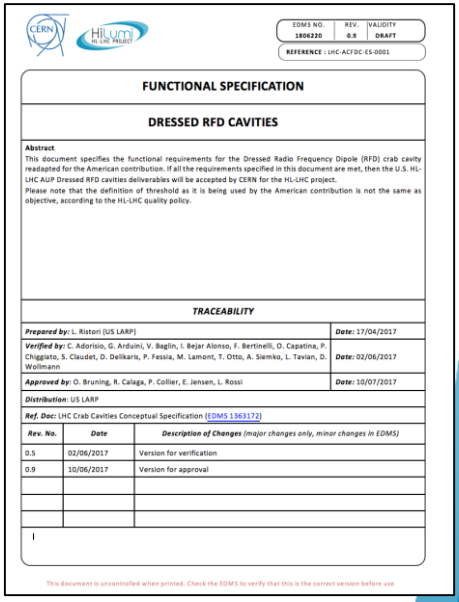
Under Convergence



FUNCTIONAL SPECIFICATION

DRESSED RFD CAVITIES

Abstract

This document specifies the functional requirements for the Dressed Radio Frequency Dipole (RFD) crab cavity readapted for the American contribution. If all the requirements specified in this document are met, then the U.S. HL-LHC AUP Dressed RFD cavities deliverables will be accepted by CERN for the HL-LHC project.
Please note that the definition of threshold as it is being used by the American contribution is not the same as objective, according to the HL-LHC quality policy.

TRACEABILITY

Prepared by: L. Ristori (US LARP)	**Date:** 17/04/2017
Verified by: C. Adorisio, G. Arduini, V. Baglin, I. Bejar Alonso, F. Bertinelli, O. Capatina, P. Chiggiato, S. Claudet, D. Delikaris, P. Fessia, M. Lamont, T. Otto, A. Siemko, L. Tavian, D. Wollmann	**Date:** 02/06/2017
Approved by: O. Bruning, R. Calaga, P. Collier, E. Jensen, L. Rossi	**Date:** 10/07/2017
Distribution: US LARP	
Ref. Doc: LHC Crab Cavities Conceptual Specification (EDMS 1363172)	

Rev. No.	Date	Description of Changes (major changes only, minor changes in EDMS)
0.5	02/06/2017	Version for verification
0.9	10/06/2017	Version for approval

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HL-LHC AUP Project Completion

- AUP is complete when 10 Q1/Q3 Cryoassemblies and 10 RFD Dressed Cavities are delivered to CERN and have undergone inspection to exclude shipment damage.
  - Performance Requirements Acceptance of US deliverables is agreed upon before shipment from the US to CERN (see, for example, US-HiLumi-doc-1148: “Q1/Q3 Cryoassembly Acceptance Plan”)
- It is in the common interest of US-AUP and CERN to find *“good use”* for Prototype elements
  - Prototype Cryo-Assembly usage in String Test @ CERN
  - RFD Prototype Cavities @ CERN for Integration Develop.
- *AUP does not contain any activity of Installation or Commissioning at the HL-LHC.*

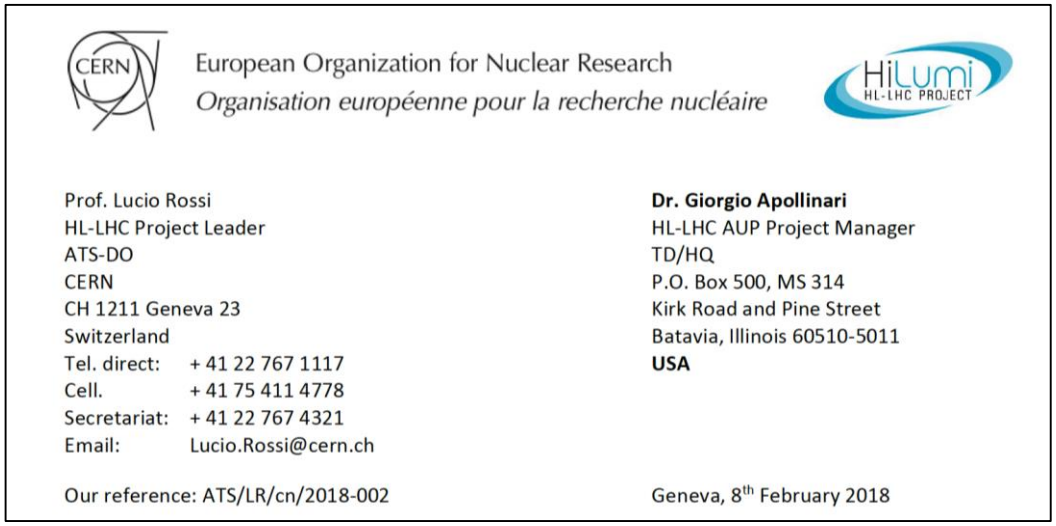
Compliance & Integration with CERN Requirements

- CERN is final user of HL-LHC AUP deliverables
- First and foremost: magnet cryo-assemblies and RFD crab cavities must meet the CERN requirement of being compliant to the Essential Safety Requirements of the European Pressure Equipment Directive (PED).
  - In addition, both assemblies must be compliant with the FNAL ES&H Manual in order to be tested at FNAL.
- Compliance on several other aspects are documented and in various stages of approval between HL-LHC AUP and CERN:
  - Usage & Approval of materials
  - Performance: FRS and Acceptance Criteria
  - Quality of Manufacturing & Documentation:
    - Manufacturing and Inspection Plans (including holding points), Manufacturing and Test Folders and Deliverables Drawings
  - Definition and Signoff of Interfaces

More on this later

Agreement with CERN on Delivery Dates

- The AUP deliverables need to be at CERN well in advance of the HL-LHC operations to allow for installations and commissioning of the equipment.
- AUP-CERN have negotiated and agreed upon on “Early Delivery” and “Late Delivery” dates.
  - Difference between Early and Late Delivery can also be represented as “Schedule Float”
- During the latest DOE gate review (CD-1) in US, AUP was requested to increase the “Schedule Float”.
  - AUP plans toward a minimum of 11 months of float on CryoAssemblies and RFD Cavities delivery dates.
  - Dates agreed upon in Feb ‘18.



CERN

European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

HiLumi HL-LHC PROJECT

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Our reference: ATS/LR/cn/2018-002

Geneva, 8th February 2018

US HL-LHC AUP

Agreement with CERN on Delivery Dates (cont.)

Q1/Q3

	Early Delivery Date: HL project schedule	Late Delivery Date: US project schedule
LQXFA/B01	April 2021	March 2022
LQXFA/B02	August 2021	July 2022
LQXFA/B03	April 2022	March 2023
LQXFA/B04	August 2022	July 2023
LQXFA/B05	February 2023	January 2024
LQXFA/B06	June 2023	May 2024
LQXFA/B07	October 2023	September 2024
LQXFA/B08	December 2023	November 2024
LQXFA/B09	May 2024	April 2025
LQXFA/B10	October 2024	September 2025

RFD Dressed Cavities

	Early Delivery Date: HL project schedule	Late Delivery Date: US project schedule
HCACFDC002-UP000001	July 2022	June 2023
HCACFDC002-UP000002	July 2022	June 2023
HCACFDC002-UP000003	September 2022	September 2023
HCACFDC002-UP000004	September 2022	September 2023
HCACFDC002-UP000005	November 2022	December 2023
HCACFDC002-UP000006	November 2022	December 2023
HCACFDC002-UP000007	January 2023	February 2024
HCACFDC002-UP000008	January 2023	February 2024
HCACFDC002-UP000009	March 2023	May 2024
HCACFDC002-UP000010	March 2023	May 2024

- The AUP baseline (to be approved in Dec ‘18) aims at delivering items to CERN by the “Early Delivery Date”.
- CERN selected to use the “Early Delivery Date” to build the HL overall Project schedule.

US HL-LHC AUP

AUP Funding and Funding Profile

- CD-2/3b DOE IPR Review:
  - TPC: ~240 M$
    - BAC of ~178-180 M$ and **~36%** Cont. on work-to-go
  - Schedule Float:
    - Minimum **11** Months to CERN "Drop-Dead Need-by" date
    - 36 Months to DOE CD-4

From Simona's Presentation

- Funding Profile requested to DOE-HEP

FY16+17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	Total
0.6 M$	27 M$	50 M$	50 M$	~43 M$	~40 M$	~20 M$	~10 M$	~240 M$

- TPC and Funding Profile would support:
  - Planned Scope and CryoAssemblies/RFD cavities delivered to CERN by "Early Delivery" date.

US HL-LHC AUP

Tailoring Strategy

- **Approvals phases for Procurement/Construction**
  - ✓ *Approval of Long-lead Procurements (July '17)*
    - ✓ Requested and obtained at CD-1 to advance the Nb_3Sn superconductor strand procurement due to schedule need
    - ✓ Obtained budget authority for 17.7 M$
  - *Approval for Fabrication Start of coils and magnets*.
    - Requested at CD-2 time to advance the critical path activities of magnets assembly.
    - CD-3b will also support the procurement of low-risk Crab Cavities raw materials.
    - Request budget authority for ~130 M$

    Dec '18
  - *Approve Full Construction on balance of Project* (CryoAssemblies and Crab Cavities Fabrication)
    - No other subsystem is expected to have remaining final design activities at time of CD-3

US HL-LHC AUP

Design Reviews

- Preliminary and Final Design Reviews executed by independent external teams:
  - *MQXFA Design Criteria Review*
    - FNAL, Apr. 23rd -24th, 2018 (*US-HiLumi-doc-1247*)
  - *MQXFA **Final Design** Review and Q1/Q3 Cold Mass and CryoAssembly Preliminary Design review*
    - FNAL, May 21st – 22nd, 2018 with follow-up on July 10th 2018 (*US-HiLumi-doc-1187*)
  - *RFD Dressed Cavities Preliminary Design review and Nb Raw Material Final Design review*
    - FNAL, Jun 20th-21st, 2018 (*US-HiLumi-doc-1190*)
  - *Mini-Review of MQXFAP2 Results*
    - Requested to show performance to MQXFA FRS for DOE to approve Magnet Construction (CD-3b)

"Optimizations"

- Opportunities for "Optimization" (or Changes) will inevitably present themselves during execution of the Project.
- The essence of changes in a DOE 413.3b Project like AUP is that they must be "controlled". In AUP, changes proposals go through a process called Baseline Change Request (BCR). BCRs are:
  1. Proposed
  2. Examined for effects on
     - Cost
     - Schedule
     - Technical Performance & Interfaces
     - Resources
  3. Approved or Rejected
  4. Implemented in Project Baseline
- The AUP Change Control Board looks at 1) and 2) above.
- Approvals above 1M$ (Cost) or 6 months (Schedule) are beyond AUP Project Management/Laboratory authority

Optimizations/Changes need to be controlled (and minimized).
"Forward Looking" Optimizations are slightly easier to implement.
"Retroactive" Optimizations can quickly become the kiss-of-death for AUP scope

Contingency Discussion

- Setbacks during FY18 (both within and outside AUP) are indicating that at this stage of the Project the low contingency (~32%) presented earlier to the funding agency might be overly optimistic.
  - Initial shaky EVMS Performance of some Control Accounts during “test period” before Baseline (Cold Mass and CryoAssembly efforts)
  - Large number of substantial changes with a risk of a rapidly escalating budget
  - Feb. ‘18 failure of MQXFAP1 for insufficient impregnation/erroneous operational procedure and failures and subsequent refurbishment of BNL Magnet Vertical Test facility (*with addition of 3rd Cryo operator*)
  - Failure of LCLS-II Cryomodule Shipment
  - AUP FY18 Funding level decrease by 2.5M$ in June ’18.
  - Risk of CERN “optimizations” after AUP Baseline and/or external dependencies on CERN provided components
- Event with important repercussion on the Total Cost require a course correction at this stage. A ~35-40% Contingency is more in line with Projects with CERN (CMS, ATLAS in early 2000) at this stage of execution.

Emojical Snapshot of (pre)Production Performance - MQXFA Magnets

- Cables:
  - Fabricated: 26 (12 by LARP, 14 by AUP)
  - Accepted: 25
  - Quarantined: 1 (cross-over close to minimum length)

- Coils at FNAL:
  - Fabricated: 10 (completed) + 3 (under fabrication)
  - Accepted: 6
  - Rejected: 1 (damage during curing)
  - Quarantined: 3 (electrical weakness to coil parts)

- Coils at BNL:
  - Completed commissioning of new winding & curing equipment for MQXFA coils
  - Completed winding and curing of 1st production coil

- Structures:
  - Assembled MQXFAP2
  - Procurement of MQXFAP3 parts in progress.
  - Issues with procurement of Magnets #4 to #7 ARMCO iron

- Vertical Test
  - MQXFAP2 under test at BNL

Technical Progress - Magnets

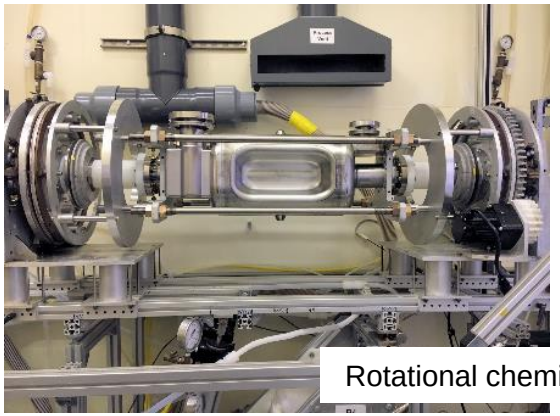
- All eyes on MQXFAP2 Vertical Test at BNL
  - Visit from FNAL team during setup and QP Tests
  - Magnet cooled-down to 4K by mid-September.
    - HiPot: 1.15 kV Coils to Gnd.
    - 7 quenches performed:
      - 13.27 kA(#1) to 14.97 kA(#9), Δ~200 A
    - Goals: 16.5 kA (Objective) and 17.9 kA (Ultimate)
  - Early Finish Date (30 training quenches): 11/1
  - Late Finish Date: (50 training quenches): 11/14
- MQXFAP1 stopped ~400A from Ultimate and saw Δ~120 A

ID	Task Name	Duration	Start	Finish	Predec
1	**MQXFAP Cold Test**	**100 days**	**Fri 8/10/18**	**Wed 1/2/19**	
2	**prepare for test**	**18 days**	**Fri 8/10/18**	**Wed 9/5/18**	
3	epoxy pot connectors	8 days	Fri 8/10/18	Tue 8/21/18	
4	upright magnet / install in wiring stand	0.25 days	Wed 8/22/18	Wed 8/22/183	
5	install top hat / lambda plate	0.25 days	Wed 8/22/18	Wed 8/22/184	
6	solder main leads	3 days	Wed 8/22/18	Mon 8/27/185	
7	connect instrumentation hypertronics	2 days	Mon 8/27/18	Wed 8/29/186	
8	300K electrical checkout	2 days	Wed 8/29/18	Fri 8/31/187	
9	move cold mass to dewar	0.25 days	Fri 8/31/18	Fri 8/31/188	
10	lower vessel into dewar	0.25 days	Fri 8/31/18	Fri 8/31/189	
11	install (not connect) power leads, Nash, vacuum, inst., etc.	2 days	Tue 9/4/18	Wed 9/5/1810	
12	**Cold Test (includes 1 thermal cycle)**	**75 days**	**Thu 9/6/18**	**Thu 12/20/18**	
13	cryogenic system controller & sensor replacements	8 days	Thu 9/6/18	Mon 9/17/1811	
14	start CTI4000 / build He inventory	3 days	Fri 9/14/18	Tue 9/18/18	
15	300K electrical checkout	1 day	Fri 9/14/18	Fri 9/14/1811	
16	commission magnetic measurements	2.5 days	Fri 9/14/18	Tue 9/18/18 1SS5	
17	cool magnet to 4.5K	1.5 days	Wed 9/19/18	Thu 9/20/1814	
18	4.5K electrical checkout	0.5 days	Thu 9/20/18	Thu 9/20/1817	
19	QPH validation checks	3 days	Fri 9/21/18	Tue 9/25/1818	
20	investigate current lead voltages	2 days	Wed 9/26/18	Thu 9/27/1819	
21	training quenches 1 & 2	2 days	Fri 9/28/18	Mon 10/1/1820	
22	warm up refrigerator, clear blockage	4 days	Tue 10/2/18	Fri 10/5/1821	
23	cool refrigerator	2 days	Sat 10/6/18	Sun 10/7/1822	
24	liquefy helium / fill storage dewar	2 days	Mon 10/8/18	Tue 10/9/1823	
25	quench tests 3-30 (28)	14 days	Wed 10/10/18	Mon 10/29/1824	
26	remove quench antenna / install mag msmt equip	1 day	Tue 10/30/18	Tue 10/30/1825	
27	holding test/splice msmts/mag msmt start	2 days	Wed 10/31/18	Thu 11/1/1826	
28	magnetic measurements completion	8 days	Fri 11/2/18	Wed 11/14/1827	
29	quench propagation / ramp rate tests (10)	3.5 days	Thu 11/15/18	Tue 11/20/1828	
30	energy loss measurements	0.5 days	Tue 11/20/18	Tue 11/20/1829	
31	warm to 4.5K	0.5 days	Wed 11/21/18	Wed 11/21/1830	
32	quench tests (10)	5 days	Wed 11/21/18	Fri 11/30/1831	
33	ramp rate measurements	1 day	Fri 11/30/18	Mon 12/3/1832	
34	warmup	4 days	Mon 12/3/18	Fri 12/7/1833	
35	300K electrical checkout	0.5 days	Fri 12/7/18	Fri 12/7/1834	
36	cooldown to 1.9K	2 days	Mon 12/10/18	Tue 12/11/1835	
37	1.9K electrical checkout	0.5 days	Wed 12/12/18	Wed 12/12/1836	
38	quench tests (3)	2 days	Wed 12/12/18	Fri 12/14/1837	
39	warmup	4 days	Fri 12/14/18	Thu 12/20/1838	
40	final electrical checkout	0.5 days	Thu 12/20/18	Thu 12/20/1839	
41	**breakdown test**	**7 days**	**Fri 12/21/18**	**Wed 1/2/19**	
42	disconnect power leads, Nash, vacuum, inst., etc.	2 days	Fri 12/21/18	Wed 12/26/1840	
43	raise vessel from dewar	0.25 days	Thu 12/27/18	Thu 12/27/1842	
44	move cold mass to wiring stand	0.25 days	Thu 12/27/18	Thu 12/27/1843	
45	disconnect hypertronics	0.5 days	Thu 12/27/18	Thu 12/27/1844	
46	unsolder main leads	1.5 days	Fri 12/28/18	Mon 12/31/1845	
47	remove top hat / lambda plate	0.25 days	Mon 12/31/18	Mon 12/31/1846	
48	lower cold mass to horizontal	0.25 days	Mon 12/31/18	Mon 12/31/1847	
49	prepare for shipping	2 days	Tue 1/1/19	Wed 1/2/1948	

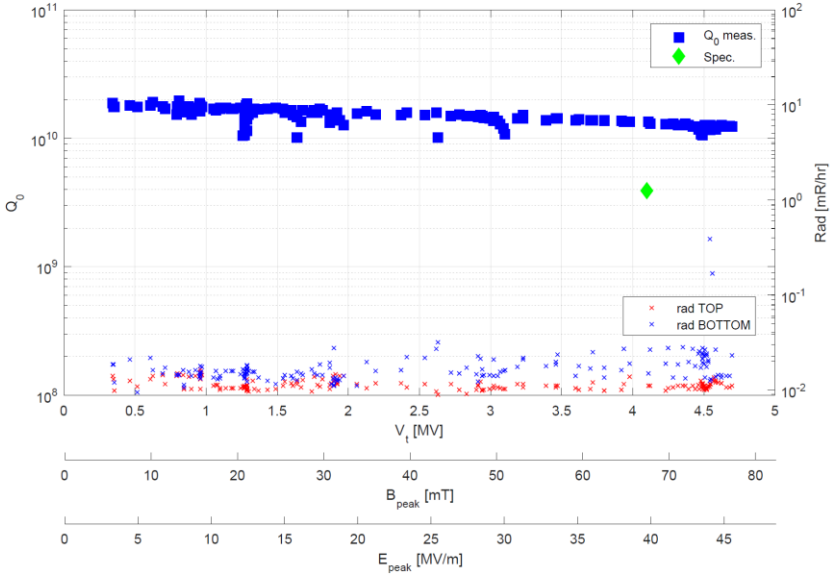
US HL-LHC AUP

Technical Status - RFD Cavities

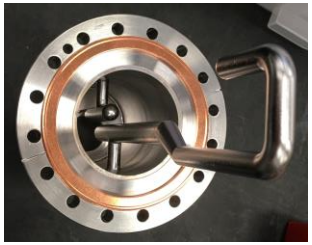
- Validated new rotational-BCP tool at ANL
- Newly fabricated HOM dampers by JLab
  - Warm and cold tests performed at Jlab/ODU
- Continued cold-tests on LARP prototypes
  - Exceeded requirements of field and quality factor (FNAL)
  - Still troubleshooting damper losses (ODU/Jlab/FNAL)
- Placed contract for bare cavity fabrication
  - Prototype + Option for full Production



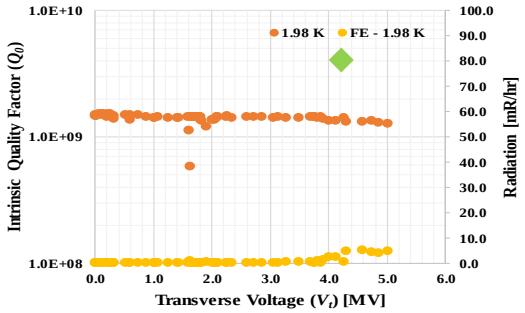
Rotational chemistry at ANL



Successful test of bare cavity at 2K (Fermilab).
Exceeded field and quality factor requirements.



Horizontal HOM Damper
designed by SLAC, built by JLab



2K Test of cavity with HOM dampers
showing successful field (~5MV) and low
Quality Factor (ODU/Jlab).

US HL-LHC AUP

Compliance & Integration with CERN: Requirements to Satisfy US Funding Agency

- HL-LHC AUP approach to approval status:
  - **Baseline for Cavities, CM & CA** (CD-2 Scope):
    - FRS approved by CERN and accepted by AUP
    - Materials List in *draft* form within AUP
    - Acceptance Criteria in *draft* form within AUP
    - Interfaces Identification completed within AUP
  - **Magnets Construction** (CD-3b Scope):
    - Materials List approved by CERN and accepted by AUP
    - MIPs approved by CERN and accepted by AUP
    - Acceptance Criteria approved by CERN and accepted by AUP
    - Interfaces fully documented and approved, including CERN approval of AUP-CERN external interfaces

Draft = Collaborative document with full interaction with appropriate CERN WP

What we really need to obtain DOE Approval (i.e. "start AUP")

- **Magnet Construction (**CD-3b)
  - CERN Approval of Magnet Acceptance Criteria. ***Good Progress***
    - EDMS 2031083 – US HiLumi Docdb 1103
  - Interface Documents from CERN
    - Q1/Q3 Electrical Schematic & Quench Protection Specification
  - MQXFA Interface Specification:
    - EDMS xxx – US HiLumi Docdb 1674
  - Definition of all MQXFA Materials – EDMS 1786261 & 1786913
    - Approval on CLIQ Leads and of MQXFA Material list with G11 (vs. G11-CR)
  - Approval of MIPs. ***Good Progress***
    - ✓ LBNL Cable MIPs – EDMS 1866230
    - ✓ FNAL Coils MIPs – EDMS 1866237
    - BNL Coil MIPs – Last touches from AUP, EDMS 1995810
    - LBNL Magnet MIPs – Last touches from AUP, EDMS 1866238
  - Approval of AUP Conductor QA Plan – EDMS 2004979 and Parts/Cost Exchange – EDMS 1825173. ***Good Progress***
- Interactions with WP3 in full swing for the last few months
  - Friday satellite Meeting
- *After DOE Approval, will call PRR (and MRR) with CERN representatives*

“AUP start” (cont.)

- **Baseline for Cavities, Cold Mass & CryoAssembly** (CD-2 Scope):
  - CERN Approval for Cryo-Assembly FRS. ***Good Progress***
    - EDMS 1828585 - US HiLumi Docdb 246
  - Other documents (Acceptance Criteria, Interfaces identification and Material List) needed in draft form, and are being developed by AUP in Collaboration with the appropriate WP.

Summary

- AUP continued with steady progress in 2018
- Experience from (pre)Production in line with expectations

- HL-LHC AUP is ready for Baseline
- MQXFA Magnet Fabrication is ready to Start

…with help from CERN on documents approval…