HiLumi
HL-LHC PROJECT

LARP

From LARP to HL-LHC AUP
Report to HEPAP

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Agenda
High Energy Physics Advisory Panel
Hilton Washington North / Gaithersburg
620 Perry Parkway
Gaithersburg, MD 20877
December 1-2, 2016

Summary

- Introduction
- Technical Progress in LARP
  - Mostly Magnets & Crab Cavities
- Preparation for HL-LHC AUP
  - Deliverables and Key Performance Parameters
  - Cost Model
  - Contingencies Discussion
    - Cost, Scope, Schedule, Risk
  - Preparation for ICR (Independent Cost Review)

HiLumi HL-LHC PROJECT LARP

Goal of High Luminosity LHC (HL-LHC) as fixed in November 2010

From FP7 HiLumi LHC Design Study application

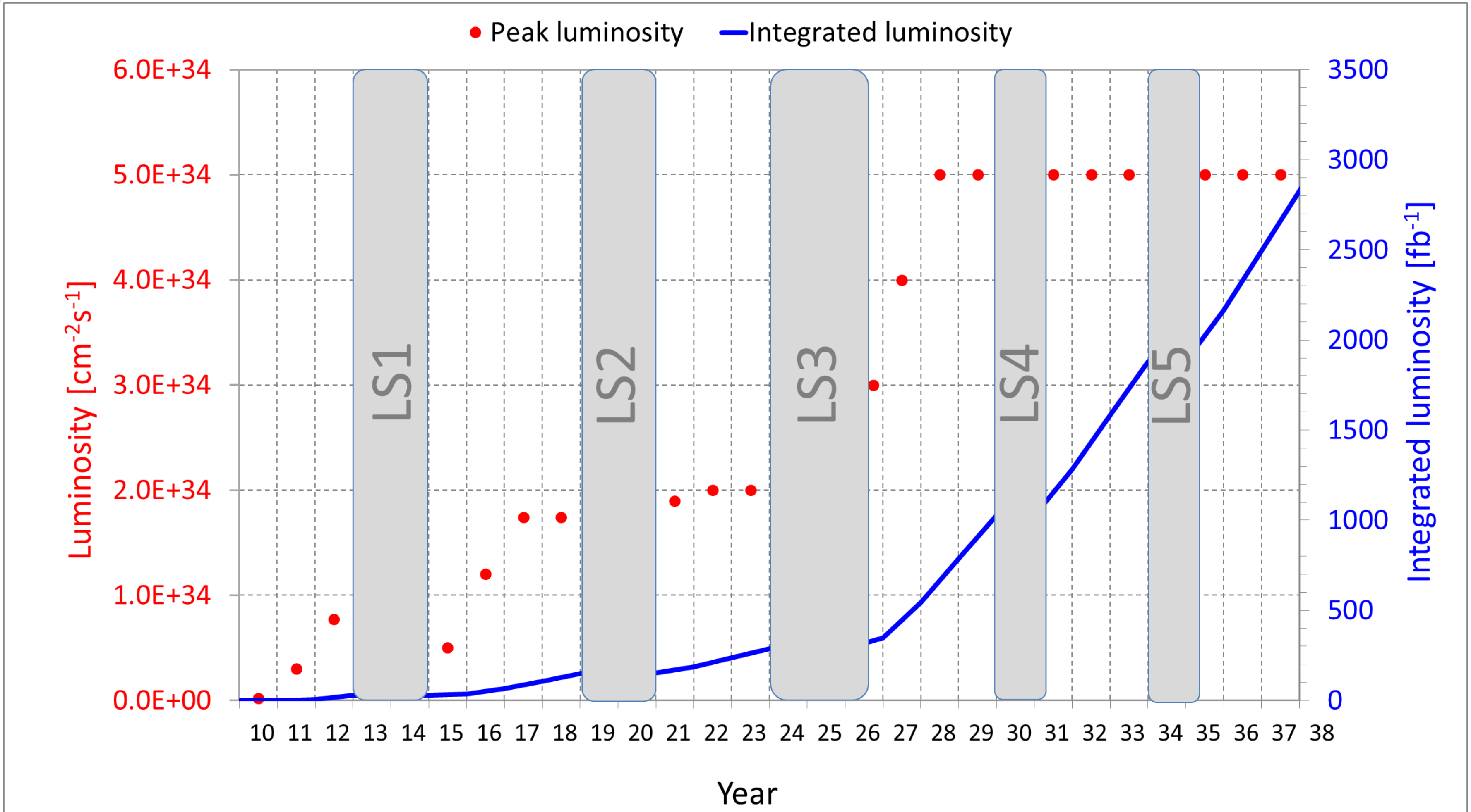
The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

A peak luminosity of L_{peak} = **5×10^{34} $cm^{-2}s^{-1}$ with levelling**, allowing:

An integrated luminosity of **250 fb^{-1} per year**, enabling the goal of **L_{int} = 3000 fb^{-1}** twelve years after the upgrade.
This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

Ultimate performance established 2015-2016: with same hardware and same beam parameters: use of **engineering margins:**
$L_{peak\ ult}$ ≅ 7.5 10^{34} $cm^{-2}s^{-1}$ and **Ultimate Integrated $L_{int\ ult}$ ~ 4000 fb^{-1}**
LHC should not be the limit, would Physics require more…

Luminosity profile : NOMINAL

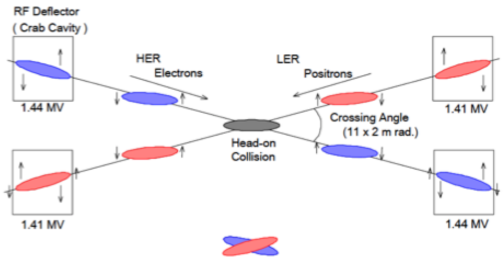


After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220

HL-LHC in a Nutshell

$$L = \gamma \frac{n_b N^2 f_{rev}}{4\pi \, \beta^* \, \varepsilon_n} R; \quad R = 1/\sqrt{1 + \frac{\theta_c \, \sigma_z}{2\sigma}}$$

1. More Luminosity: increase squeeze at interaction region
   - Increase magnet aperture, therefore increase field.
   - Use Nb_3Sn Technology as *Baseline*
2. More beam: larger beam-beam interactions in region where they are brought close together.
   - Solution 1: keep beam as separated as possible increasing crossing angle from 300 μrad to 600 μrad. Use Crab Cavities as *Baseline*
   - Solution 2 (Plan B): If solution 1 does not work, reduce crossing to 300 mrad and mitigate beam-beam interaction with Long Range Beam Beam Wire (*R&D effort*).



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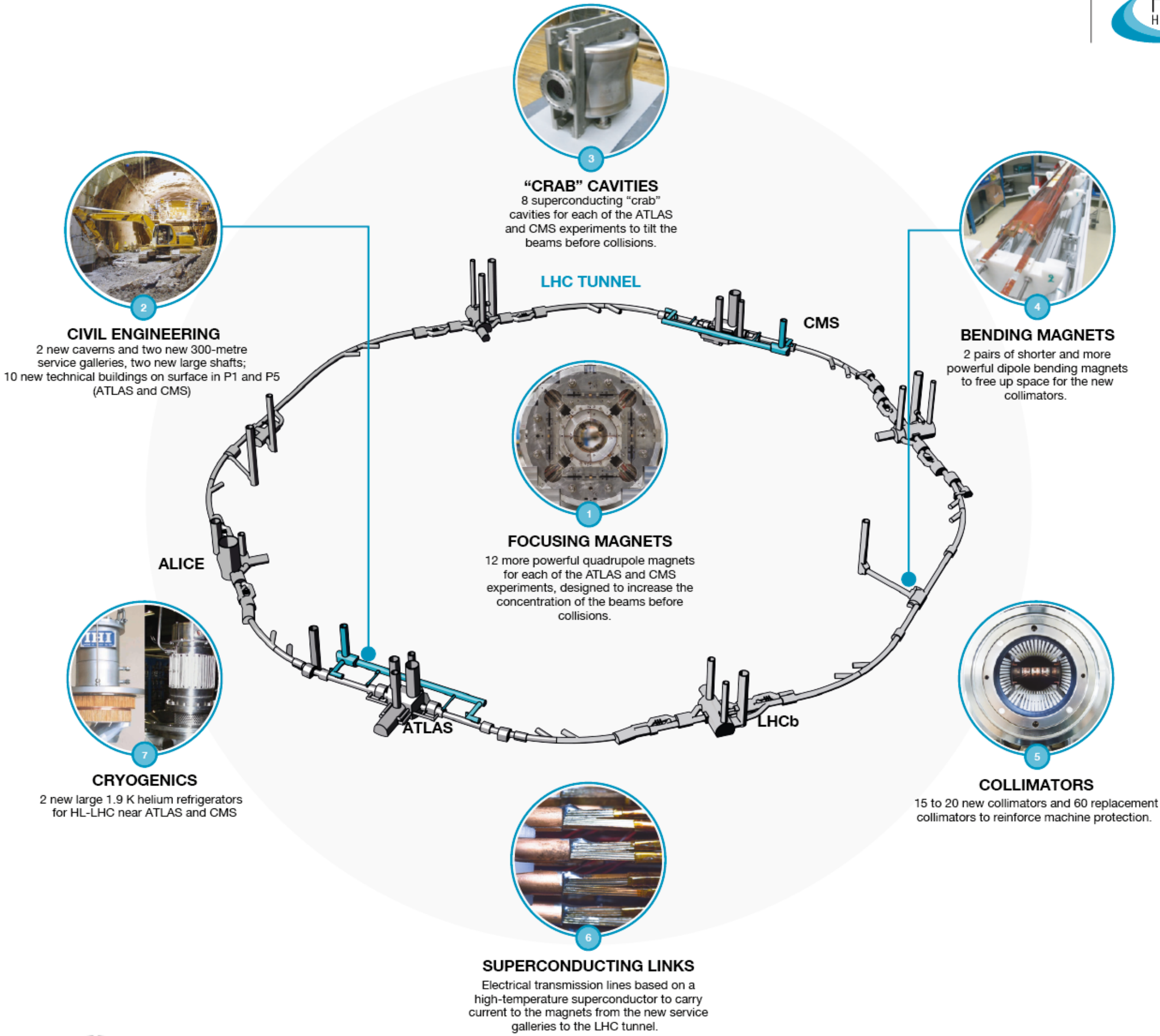
HiLumi LHC landmarks

HiLumi HL-LHC PROJECT

CERN May 2016



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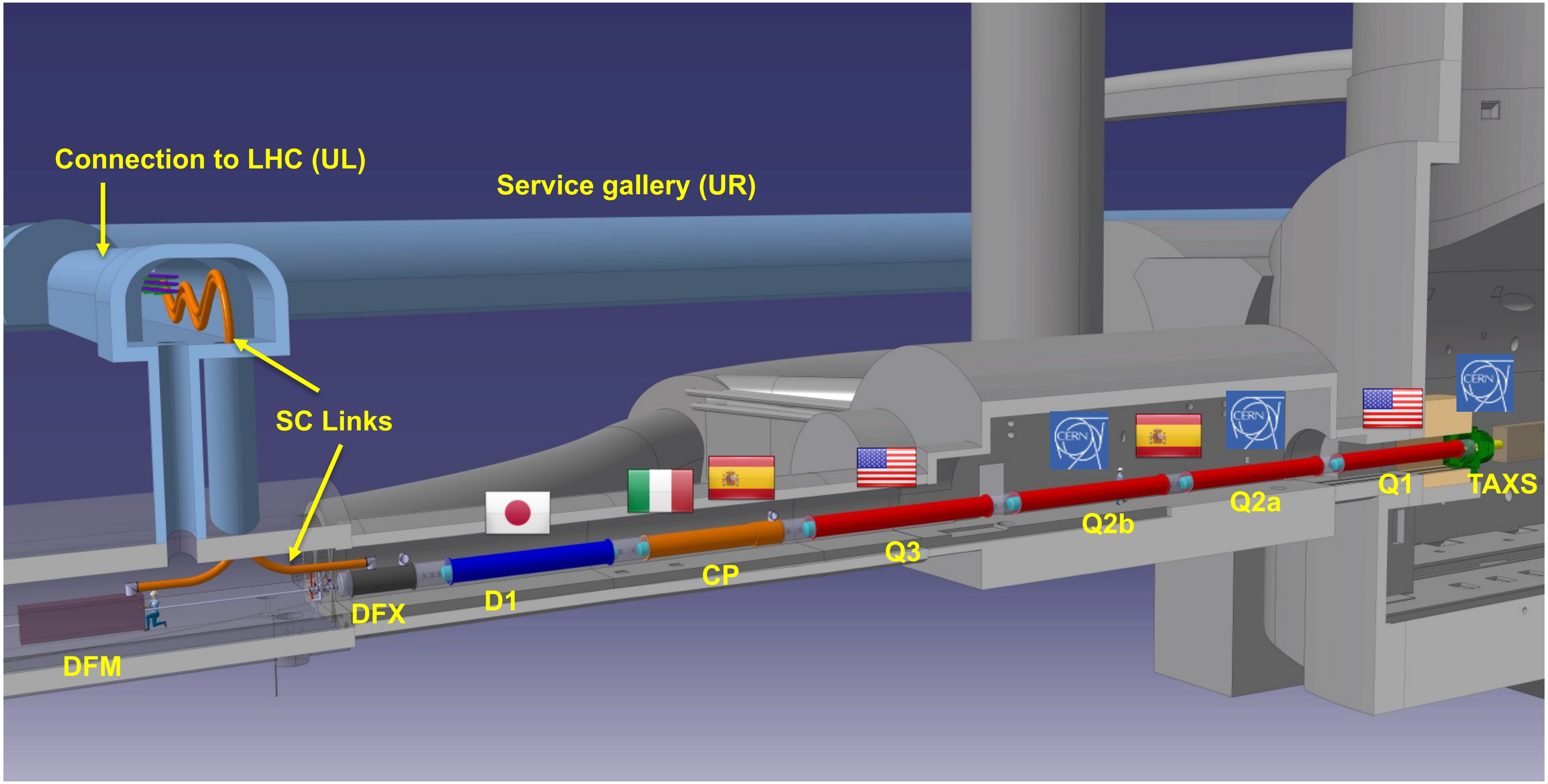
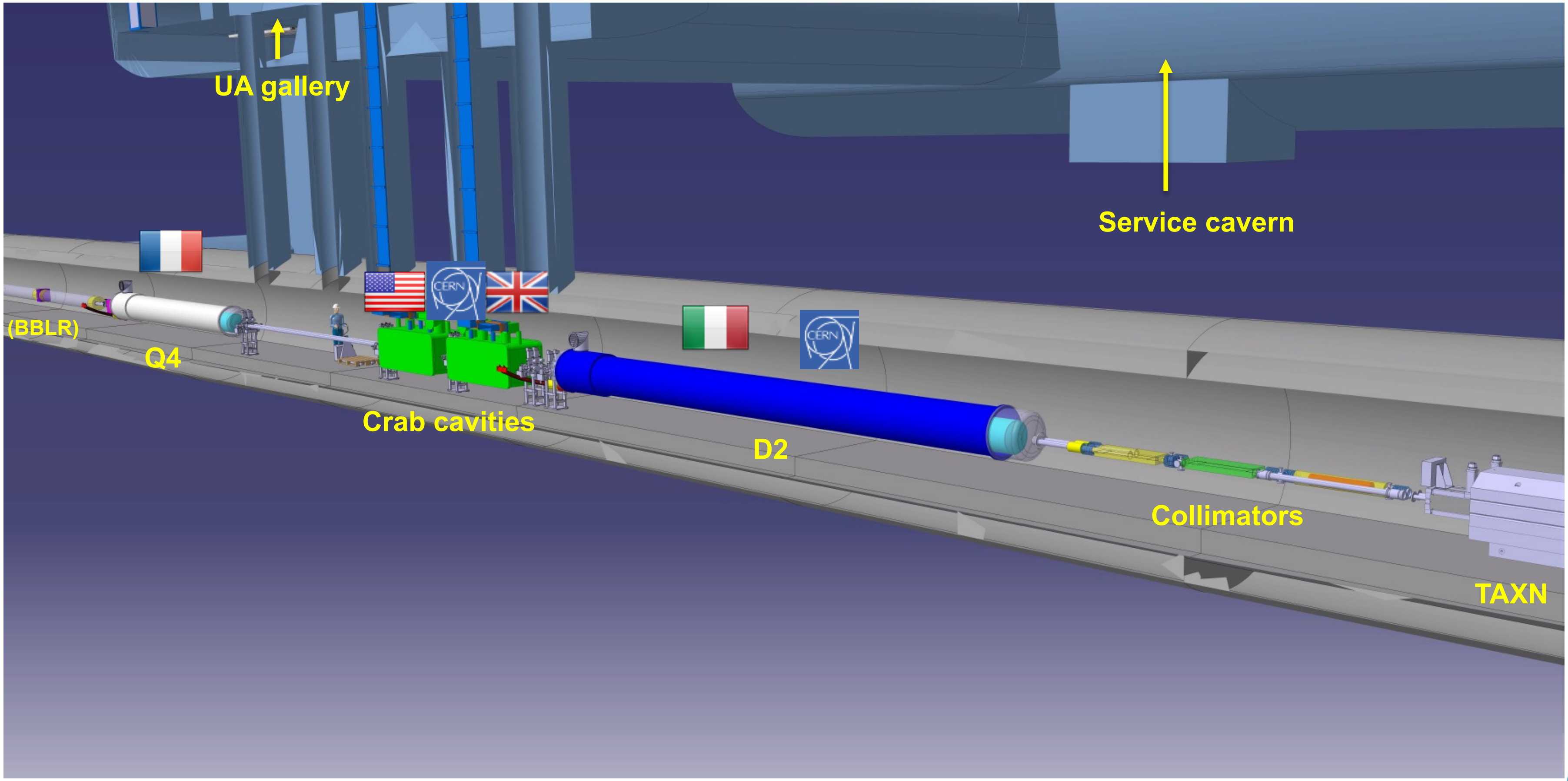
The Inner Triplet region with in-kinds



The MS regions with in-kinds



LARP & HL-LHC Accelerator Upgrade Project

- LARP is an R&D *Program* funded by DOE to explore technology for future upgrades to the LHC.
  - Started in ~2004 with focus on Nb_3Sn Magnets and Accelerator system Research (CC, Rotatable Collimators, e-lens, WBFS, etc)
  - Run since FY14 with clear Risk Reduction mandate to minimize the technical risk for possible US contributions to HL-LHC.
- DOE plans to contribute to the HL-LHC upgrade through a *Project* called HL-LHC Accelerator Upgrade Project (AUP)
  - Governed by DOE Order 413.3B which applies to capital assets projects having a Total Project Cost greater than or equal to $50M
  - DOE projects progress through five Critical Decision (CD) gateways, which serve as major milestones marking an authorization to increase the commitment of resources by DOE and requires successful completion of the preceding phase or CD
- A Properly managed handshaking between LARP and HL-LHC AUP will be a major element of the future success of the US contribution to HL-LHC.

US Scope and Deliverables (1)

- At this time (pre-CD-1) the following deliverables are entertained for the US contribution to HL-LHC:
  - From the PPEP Draft exchanged with AUP FPD

Parameters	Threshold Performance	Objective Performance
Inner Triplet Focusing Quadrupoles (Q1 and Q3)	5 Q1-Cryoassemblies and 5 Q3-Cryoassemblies are accepted by CERN after testing at HL-LHC nominal temperature and ultimate gradient for the magnets, and functionality for the Cryoassembly. The Cryoassemblies will be assembled from Cold Masses built by HL-LHC AUP and Cryostat kits provided by CERN.	Up to 1 additional Cold Mass is accepted by CERN after testing at HL-LHC nominal temperature and ultimate current for the magnet, and functionality for the Cold Mass.
SRF Crab Cavities	10 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 will include HOM couplers, pick-ups, He Vessel and magnetic shields.	Up to 1 additional Dressed RFDs and financial support for the execution of up to 10 DQW (bare or dressed) at a vendor selected and managed by CERN.

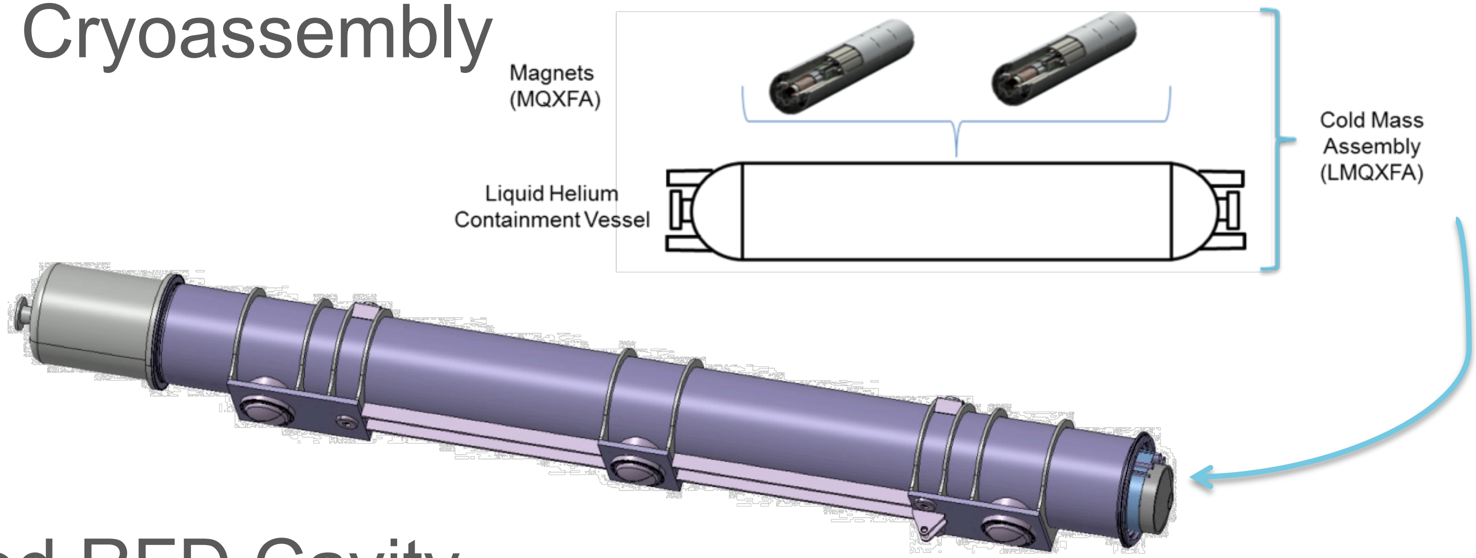
Slightly more than 50% of the Q1/Q2a & b/Q3 Final Focusing Triplets of HL-LHC

50% of the total number of Crab Cavities for HL-LHC

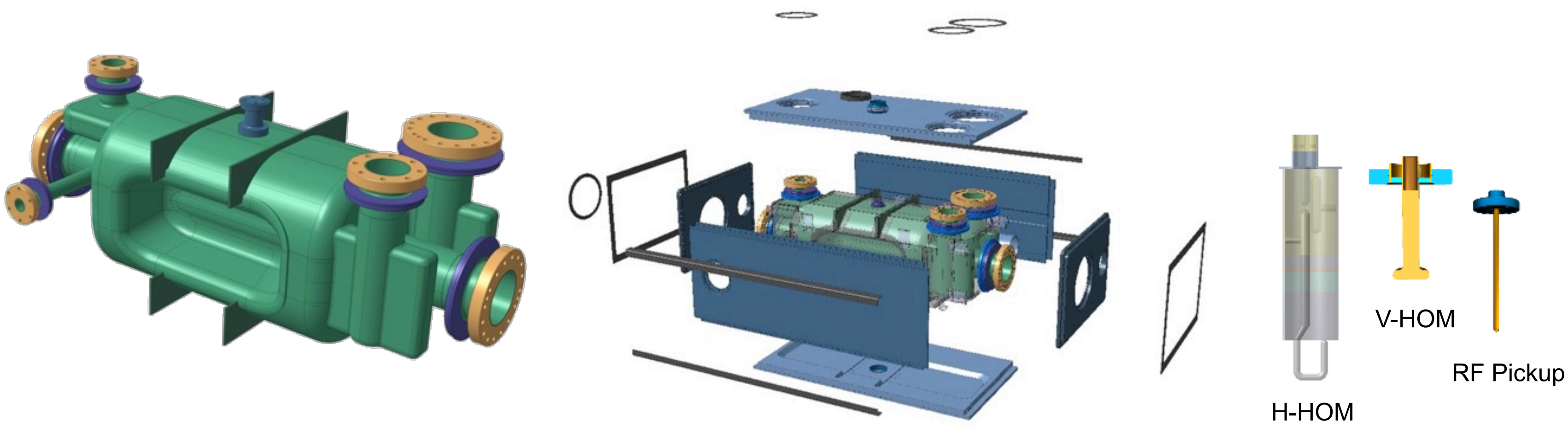
- Delivery Date Needs (from CERN):
  - Q1/Q3 Cryoassembly #1 at CERN by Late '21
    Cryoassembly #8 at CERN by Summer '24
  - RFD Dressed Cavity #1 at CERN by Late '22
    Dressed Cavity #8 at CERN by Summer-Fall '23

US Scope and Deliverables (2)

- Q1/Q3 Cryoassembly



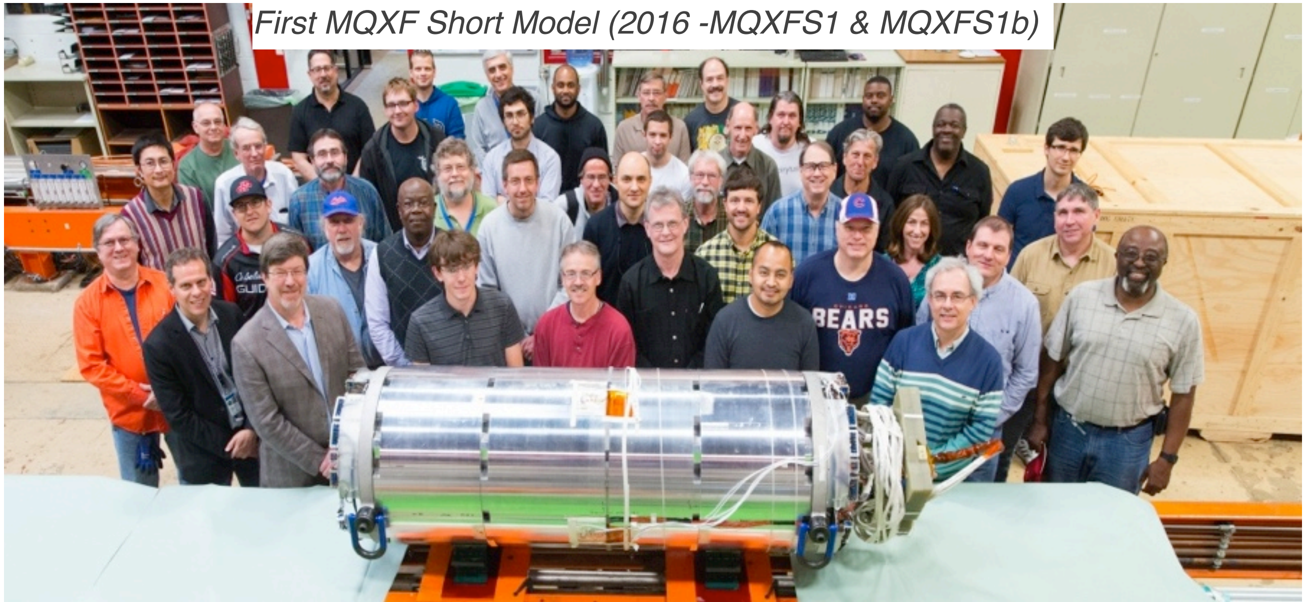
- Dressed RFD Cavity



Magnets:
Technical Progress in LARP and LARP/HL-LHC AUP Handshaking

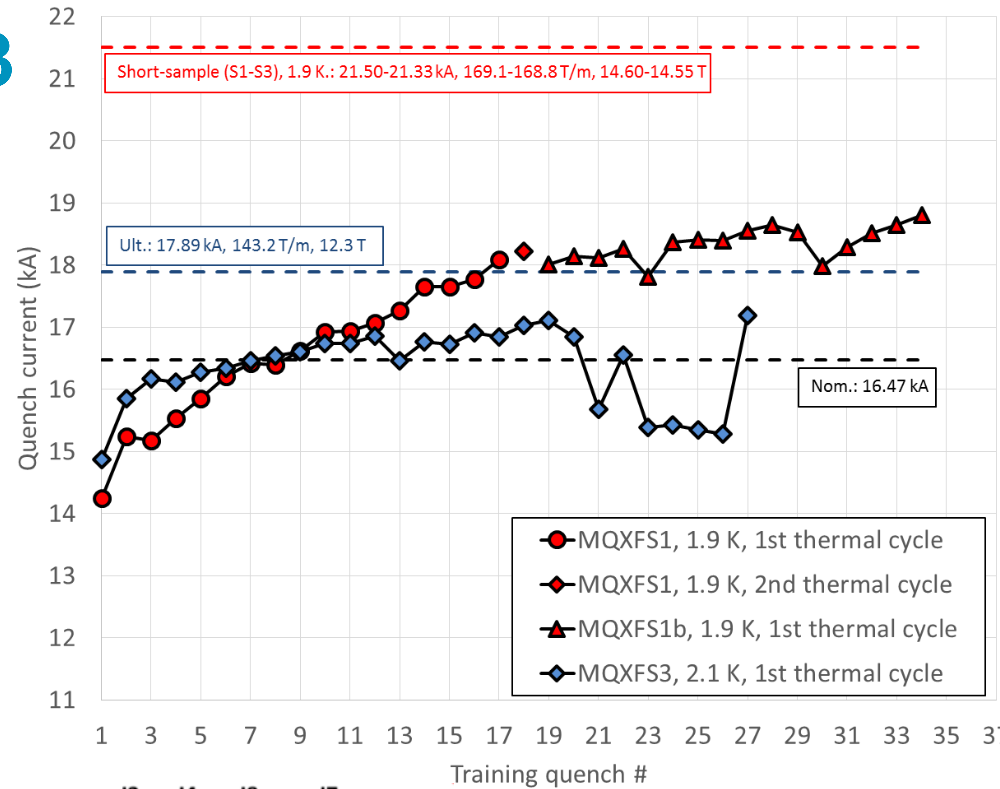
LARP+CERN: Short Models Status

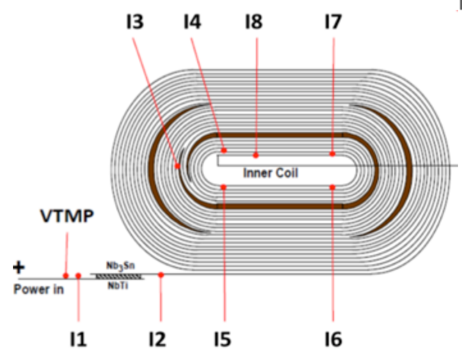
- 22 coils fabricated (14 by CERN, 8 by LARP)
- 3 mechanical models assembled
- 1 coil tested in mirror structure
- 2 quadrupoles assembled & tested
  - 1 azimuthal pre-stress increase & under test
  - 1 longitudinal pre-stress increase to be tested soon

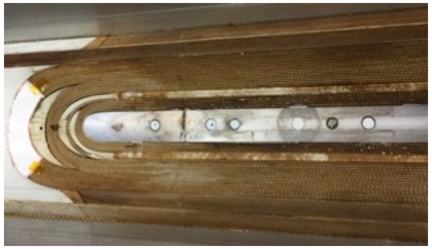


LARP+CERN: Short Models Status (2)

- **MQXFS1b** vs. **MQXFS3**
  - Very **similar** axial and azimuthal **pre-load**
    - wrt MQXFS1, same axial, +20 MPa azimuthal
  - **Similar training** slope
    - Although at different current level
      - …but 1b not virgin
    - Slower than MQXFS1a
  - **Similar quench** locations
    - End region, I3I4 segment



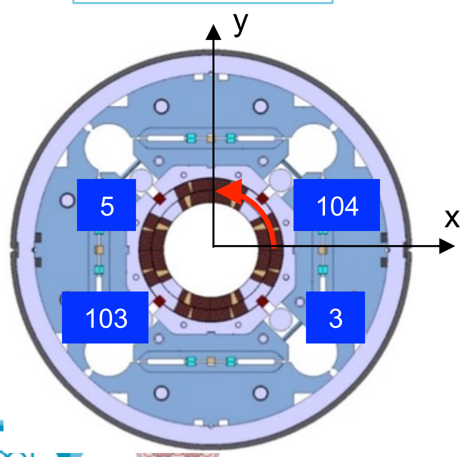




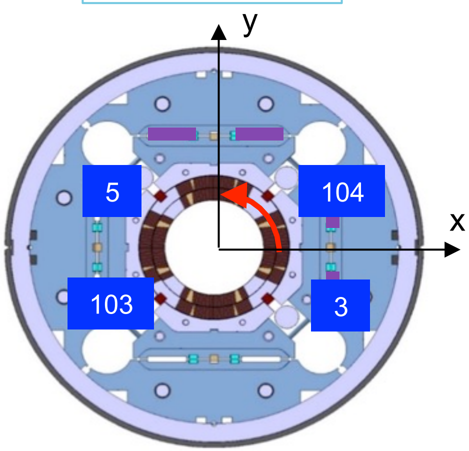
LARP+CERN:
Magnetic Measurements Summary

- Good agreement with expected field quality in terms of saturation, allowed harmonics and persistent currents.
- The dominant source of field errors is the coil geometry and its initial assembly because harmonics not altered from assembly to powering.
- Magnetic shimming:
  - Demonstrated the capability to correct 3 units of b_3 and a_3 in MQXFS1b
  - Successfully corrected 3 units of b_4 in MQXFS3a.
- Some of the measured geometric field errors are above our correction capabilities.

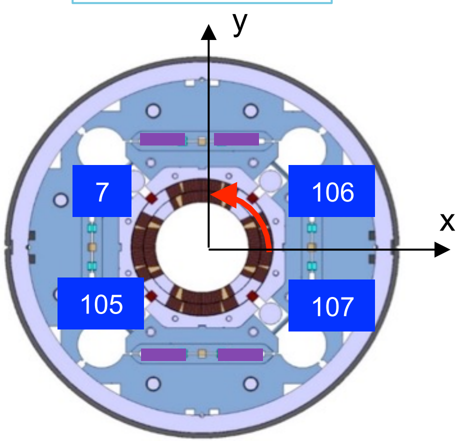
MQXFS1a



MQXFS1b



MQXFS3



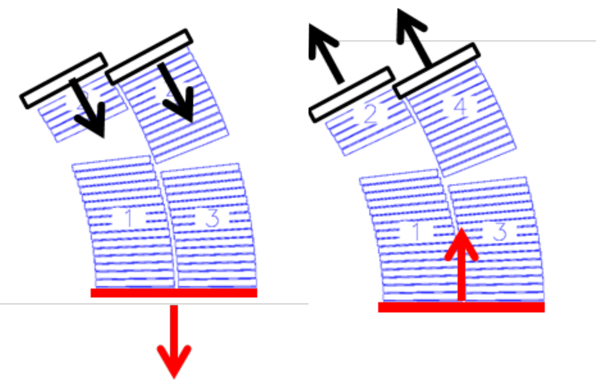
LARP+CERN: Plans for MQXFS3 and MQXFS1

- **MQXFS3b**
  - Retest with **axial pre-load increased**
    - Pre-load increased by about a factor two at cold last Friday
    - Test expected in December 2016
- **MQXFS3c**
  - Full disassembly and coil visual inspection
  - Reassembly and re-loading with higher azim. pre-stress
- **MQXFS3d**
  - Welded stainless steel shell test
- **MQXFS1c** (currently stainless steel shell test)
  - Increase of axial pre-load under consideration

CERN: Short model program
Upcoming tests (I)

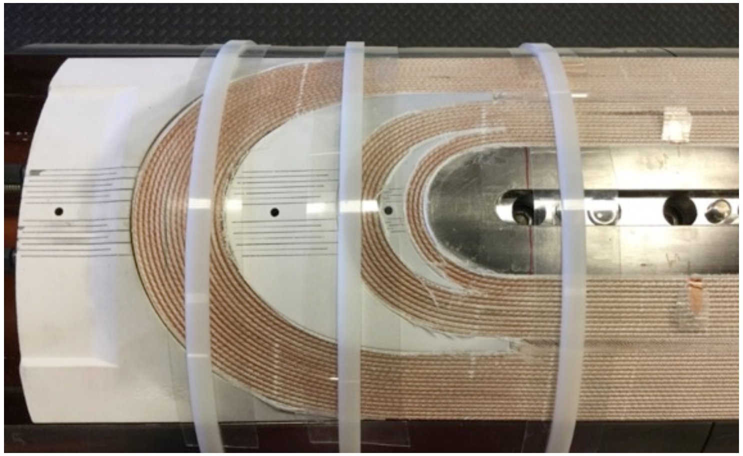
- ## MQXFS5 & MQXFS6
  - Test of four PIT* coils (203,204,205,206) with 2nd generation cable design
    - Strand without and with bundle barrier

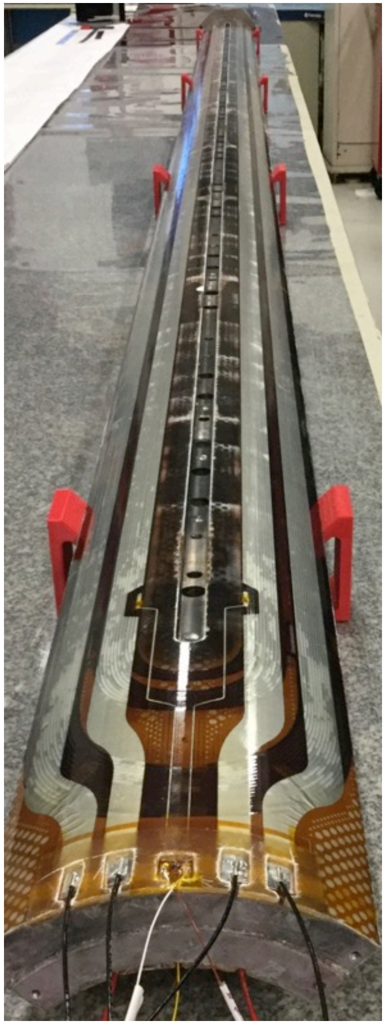
- ## <u>MQXFS4</u>
  - Second RRP 2nd gen. magnet, as S3
    - **Reproducibility**
  - Test of **pole/mid-plane shims** to correc allowed harmonics
  - 1st test of **laminated structure** by LARP



* Up to Nov 20th, test of Alternative Vendor, now only test of Alternative Technology (more on this later)

LARP prototype program

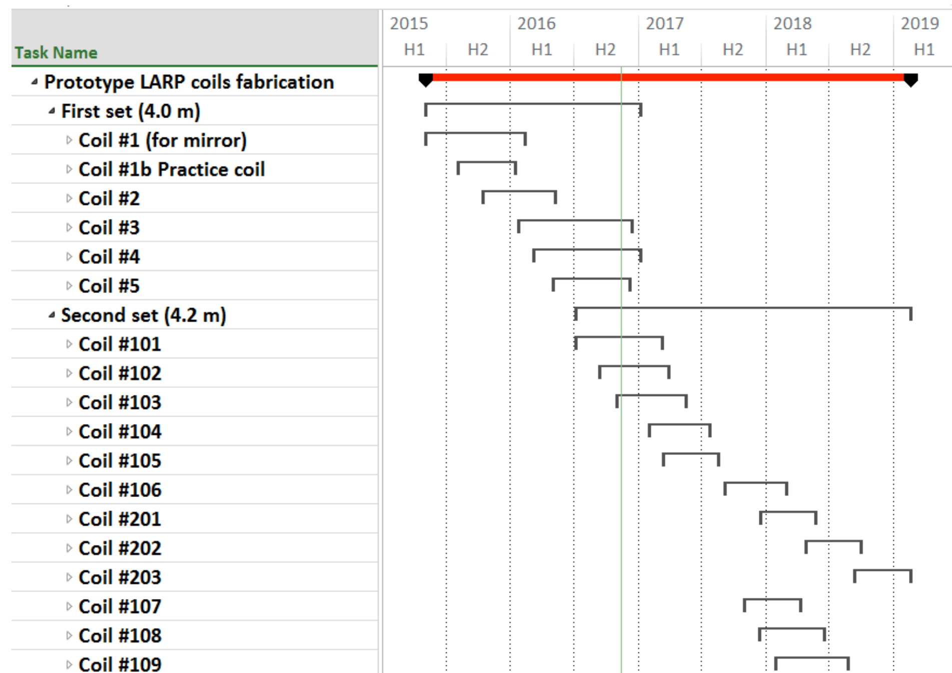




LARP prototype program
Coil fabrication

- Coils for practice & mirror: **2** coil, 4 m long, completed
  - Coil 01 for mirror (1st generation cable)
  - Coil 01b practice (1st generation cable)
- Coils for MQXFA1: **4** coils, 4 m long, ~completed
  - Coil 02 (1st generation cable)
  - Coil 03,04,05 (2nd generation cable)

- **12** Coils for MQXFA2-3 & for practice of BNL W&C line (4.2 m long)
  - **9** W&C at FNAL
    - 6 R&I at FNAL
    - 3 R&I at BNL
  - **3** W&C, R&I at BNL



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LARP prototype program
Coil test

- **MQXFPM1**
  - Vertical Test Facility @ BNL commissioned in September-October 2016
  - Test results at 1.9 K
    - **First quench**: 14387 A, **65%** of I_{ss} (22.1 kA)
      - Outer layer mid-plane block
    - **Second quench**: 16040 A, **73%** of I_{ss}
      - Inner layer pole turn straight section
  - Replacement of IGBT blown at discharge of quench 2 in progress
  - *Training resuming soon, but first long Nb_3Sn coil with HL-LHC design is behaving like the short models !*

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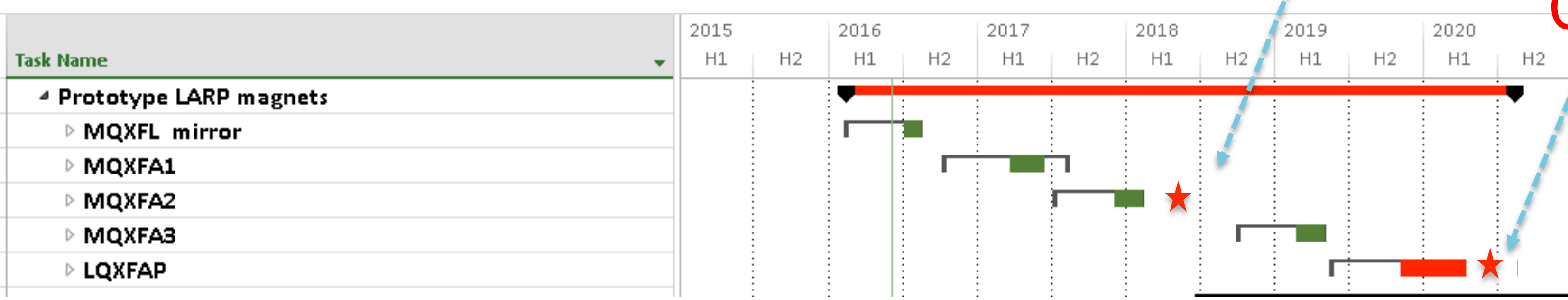
Q1/Q3 Prototypes

- 4 m coil in mirror magnet is under test
- First prototype magnet test in spring/summer 2017
  - 4 m coils: one 1st gen + three 2nd gen coils
- Second prototype magnet test in 2017-2018

CD2/CD3b

  - 4.2 m coils: all 2nd gen coils (first tunnel ready MQXF)
- Third prototype magnet test in early 2019
  - 4.2 m coils, 1st structure changing thick➔thin laminations
- First prototype cryostated magnet test in early 2020

CD3c



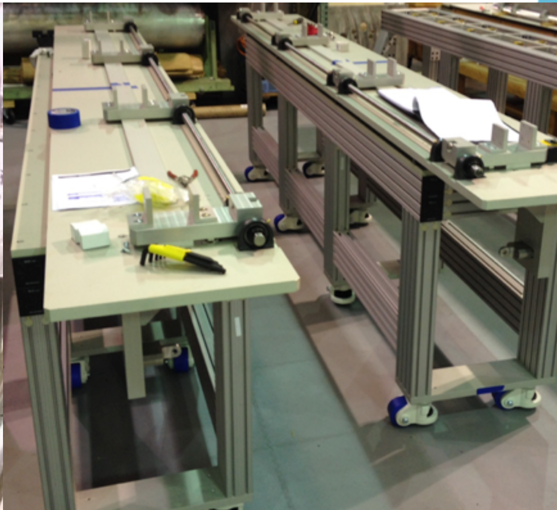
Q1/Q3 Prototypes (MQXFA & Cold-Mass)

- Progress so far:
  - 5 Coils completed + 4 in progress
  - 1 Coil under test in mirror structure
  - 1 Structure procured & instrumentation in progress (MQXFA1)

QXFA1b outer coil winding

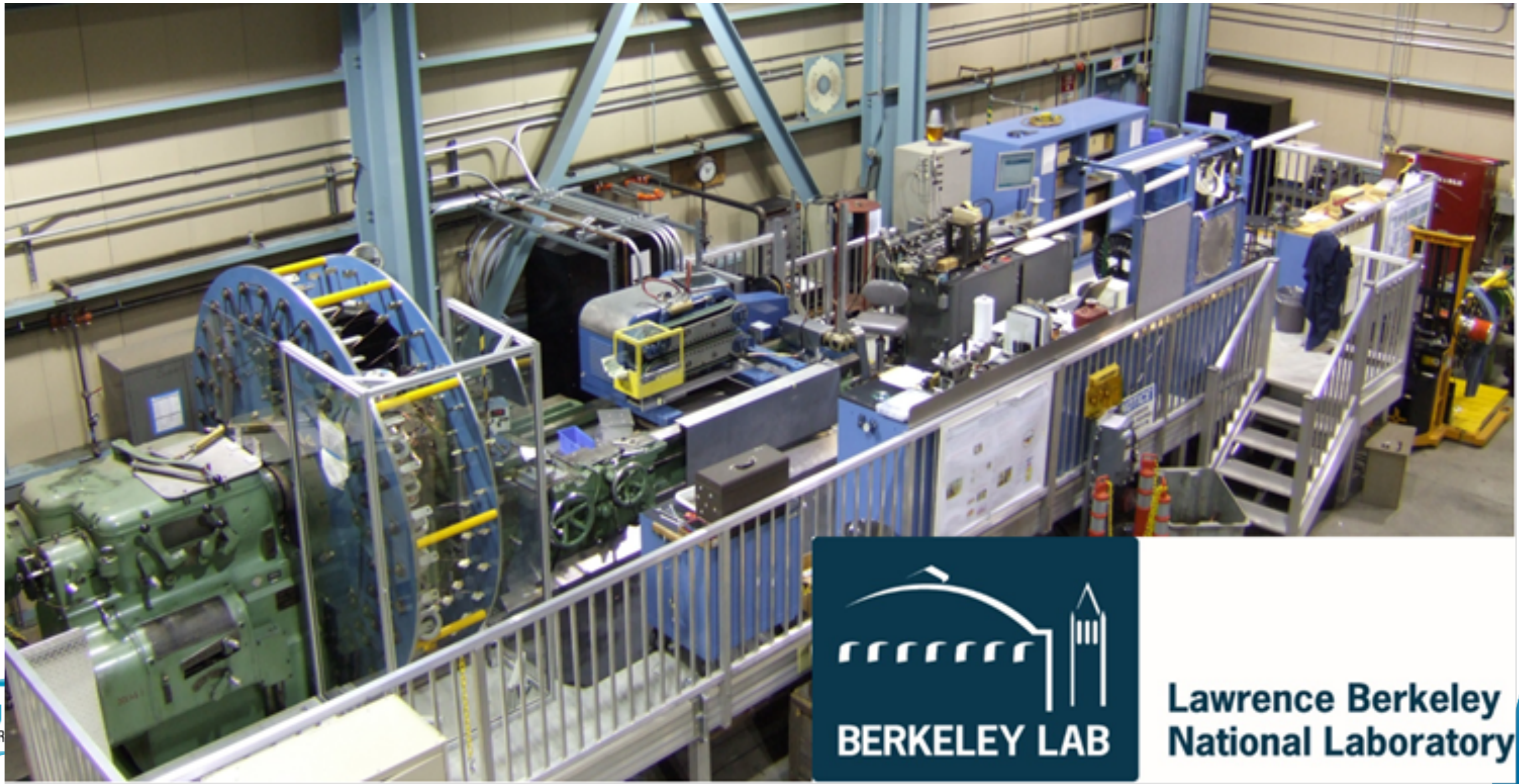
BNL oven recently upgraded

Tables for MQXFA assembly



Facilities & Equipment: Conductor

- Strand procurements and QC ✓
- Cabling @ LBNL ✓
- Cable insulation @ vendor ✓



Facilities & Equipment: Coils

	@FNAL	@BNL
Winding	✓	FY17
Curing	✓	FY17
Reaction	✓	✓
Impregnation	✓	✓

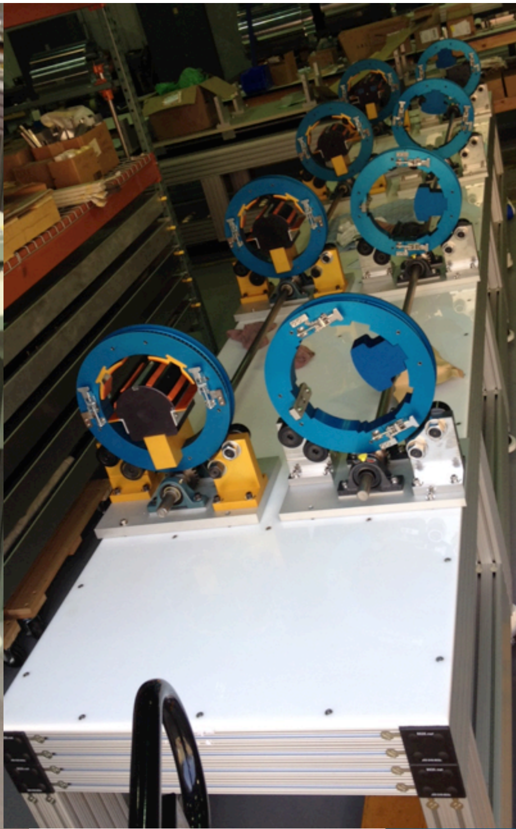
QXFA1b outer coil winding

BNL oven recently upgraded

Facilities & Equipment: Magnet Assembly

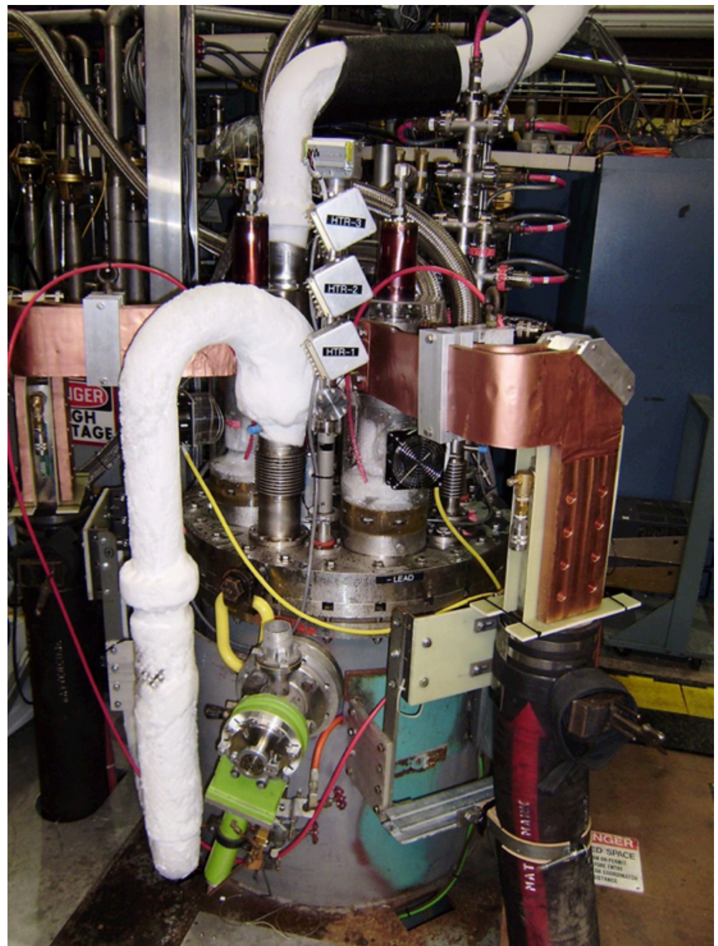
- Parts procurement ✓
- Sub-assembly & instrumentation ✓
- Magnet assembly @ LBNL ✓





Facilities & Equipment: Magnet Test

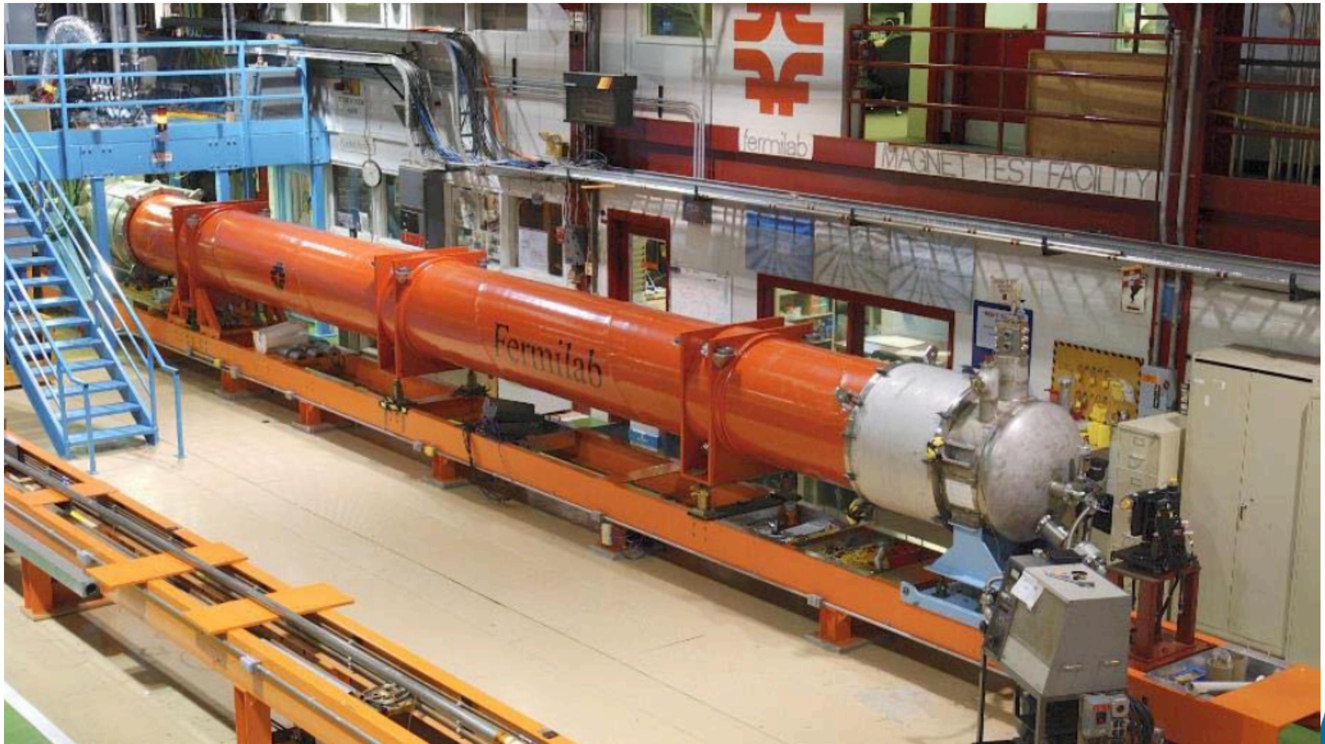
- Vertical Test Facility @ BNL ~ ✓
  - Commissioning successfully completed
  - T = 1.88 K
  - I = 22 kA



4m coil ready for test

Cold Mass & Cryostat

- Plans for assembly of Cold Mass & Cryostat have to be finalized
  - Cryostat kit from CERN
- Horizontal Test facility @ FNAL to be upgraded



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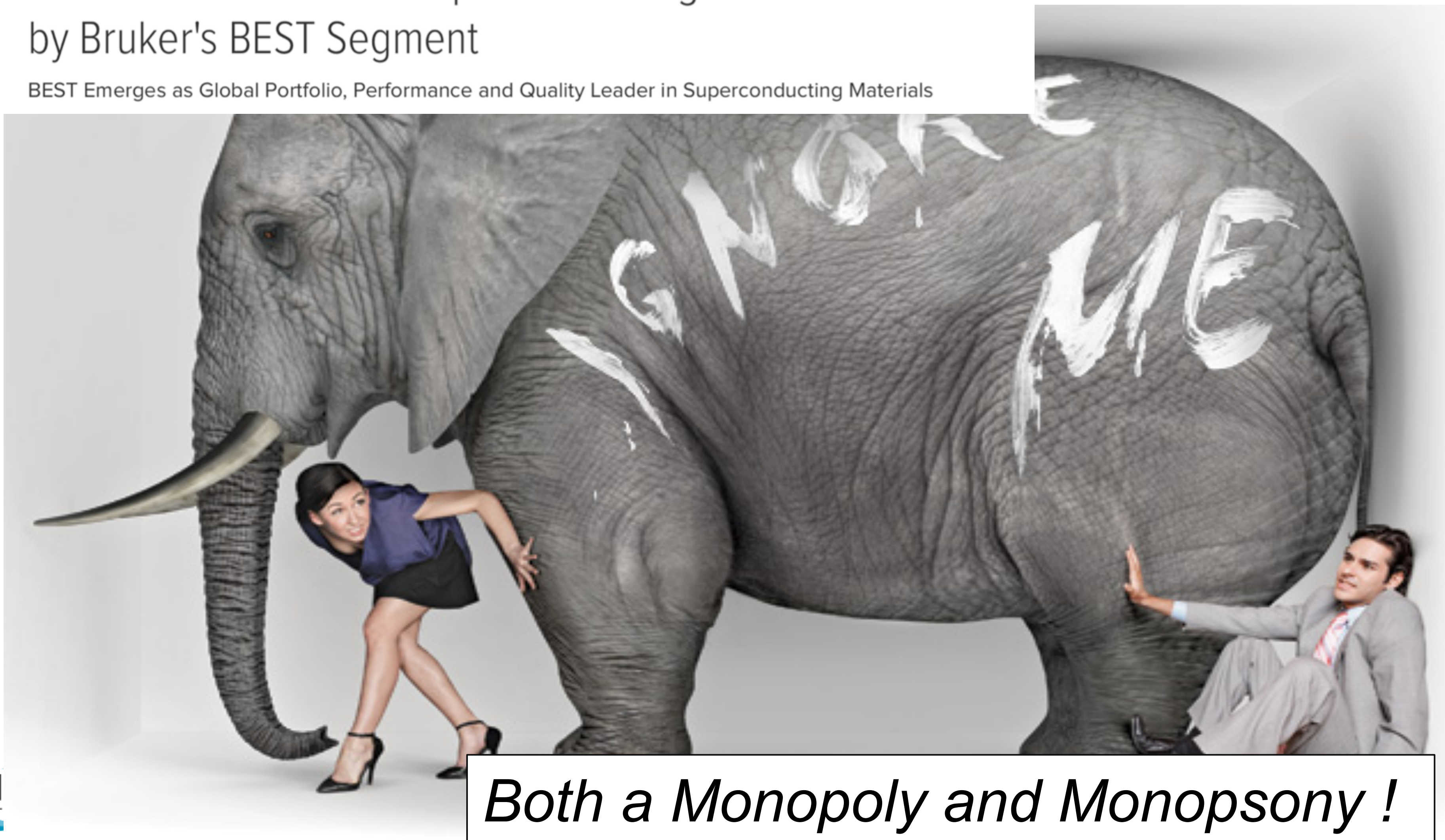

Both a Monopoly and Monopsony !

Update on HL-LHC AUP strand procurement

- July 15th 2016 review recommendation: "Execute a time phased procurement of the required Nb_3Sn strand in a timely manner so as not to endanger the proposed magnet production schedule."
- 3 magnet delivery scenarios:
  - (A) last magnet by Jun 30th 2023 → last strand by Jun 30th, 2021
  - (B) last magnet by Dec 31st 2023 → strand Dec 31st, 2021
  - (C) last magnet by Jun 30th 2024 → last strand Jun 30th, 2022
- RFI issued Aug 1st 2016, 1 response (OST)
  - Cost respons in agreement with expectations
- Oct 28th 2016 Draft RFP completed, Nov 7th 2016 revised
  - Proceeded with ~250km strand procurement for LARP prototype activities + Options for Scenarios mentioned above.
- Anticipate early Jan 2017 response, PO by Feb 2017

Crab Cavities:
Technical Progress in LARP and LARP/HL-LHC AUP Handshaking

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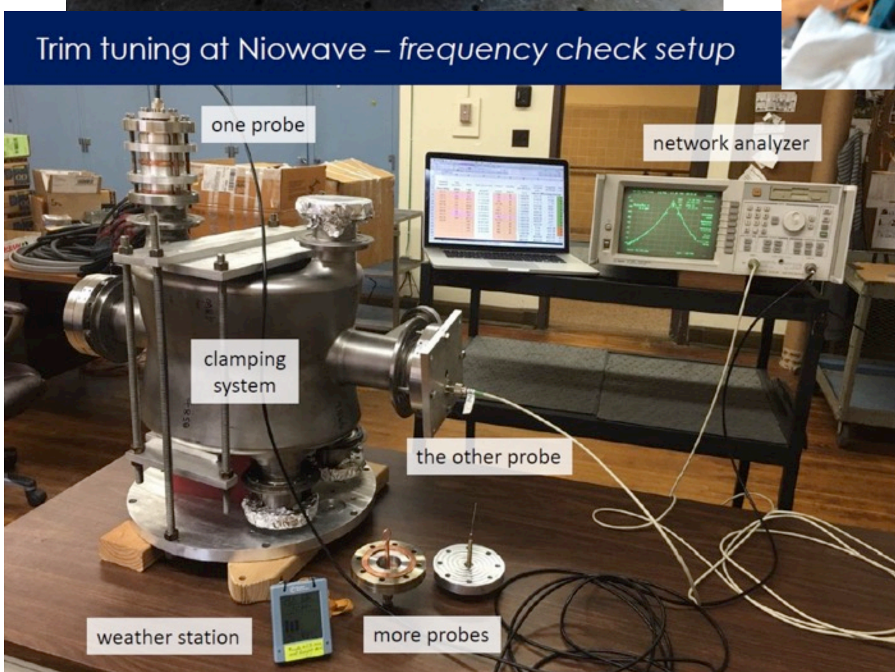
SBIR Crab Cavities Effort in LARP

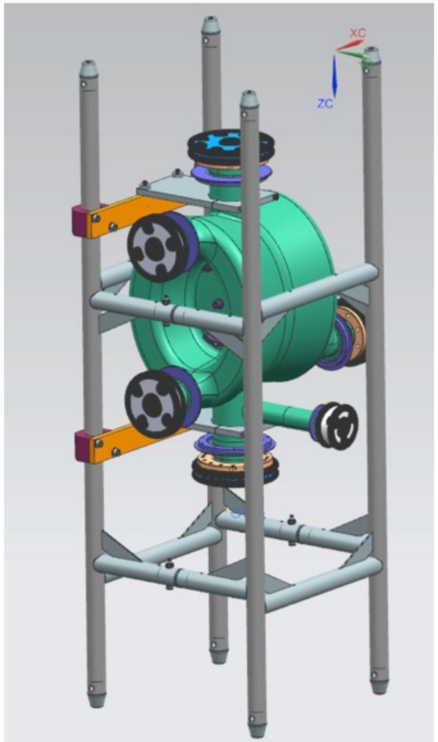
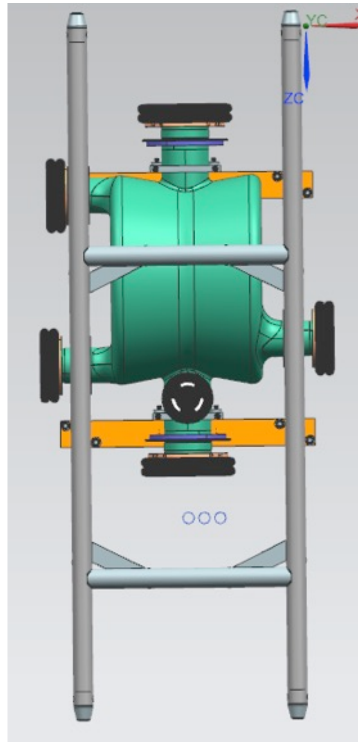
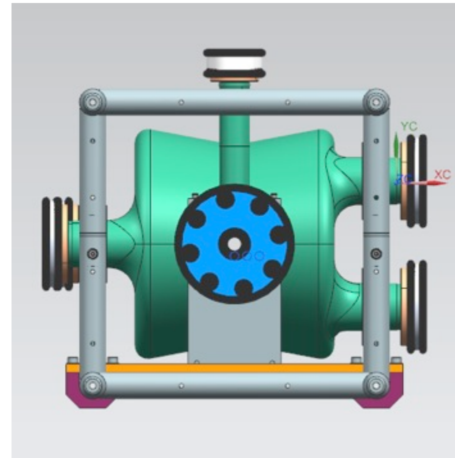
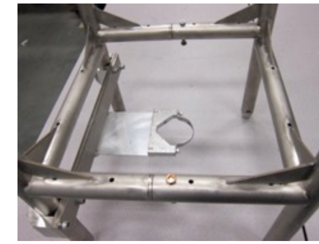
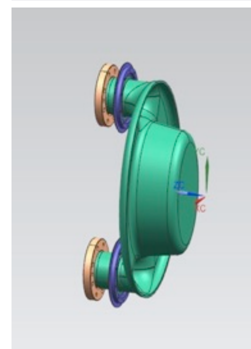
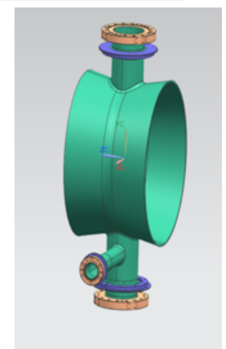
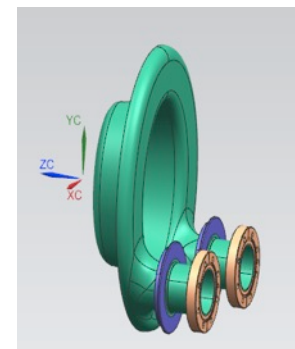
- Soft Landing for Niowave SPS Prototypes in the U.S.
  - Cavities not “installable” in CERN machines due to a number of CERN certifications at fabrication time that could not be met in an SBIR framework
  - CERN has initiated production of DQWs for SPS Test. Positive !
- To reduce risk and insure completion under LARP Scientists and Engineers Control, transfer of semi-assembled cavities to JLAB has been negotiated with Niowave
- All four cavities (2+2) are at JLAB now, and have been trimmed to final dimensions:
  - DQW awaiting welding
  - RFD completing first pass of bulk BCP on parts
- Overall Goal: Acquire experience for HL-LHC AUP and CERN construction activities

DQW Final Trimming at Niowave

15 Sep 2016



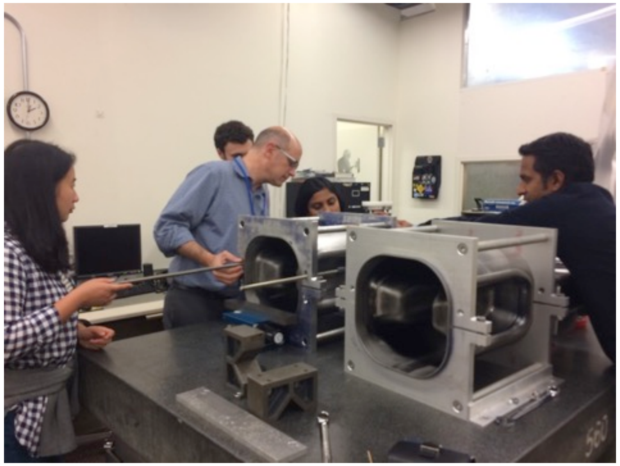
DQW Processing

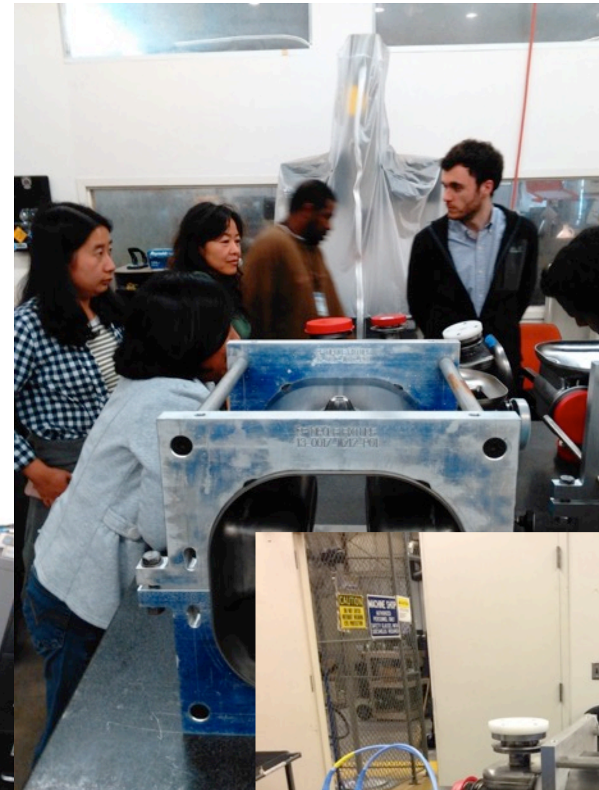








- JLAB Standard Cage fits the DQW cavity
  - (Clamps are shared with the RFD Cavity)
- Flange protectors are also the same as for the RFD cavity with the exception of the Pick up Port)

RFD Cavities Processing at JLAB

RFD final Machining at JLAB
27 Oct 2016





RFD Frequency Recipes

CAV-001

Step (Recipe for 20 C, 50 % and 1013.25 mbar)	Δf	f_n
	[kHz]	[MHz]
Cavity after trimming and thinning		**399.840296**
Shift due to bulk BCP (140 microns)	-39.441	
Cavity after bulk BCP		399.800855
Weld shrinkage	115.645	
Weld bead	5.000	
Cavity after final weld		399.921500
Shift due to light BCP (20 microns)	-5.762	
Cavity after light BCP		399.915738
Shift due to mounted couplers	4.906	
Fully assembled cavity with HOM couplers		399.920644
Pressure effect (760 Torr differential)	-60.800	
Dielectric effect air to vacuum	130.341	
Evacuated cavity at 20 C		399.990185
Thermal shrinkage	572.877	
Colled down cavity at 4.2 K		400.563062
Shift due to change in skin depth	28.000	
Cavity frequency adjusted for skin depth		400.591062
Pressure from 760 Torr to 23 Torr in He tank	58.960	
Cooled down cavity at 2.0 K		400.650022
Shift due to tuner activation to its mid range	150.000	
Cavity with tuner activated		400.800022
Lorentz detuning	-10.022	
Operational cavity with RF on		400.790000

Achieved after trimming - 399.845874 MHz

CAV-002

Step (Recipe for 20 C, 50 % and 1013.25 mbar)	Δf	f_n
	[kHz]	[MHz]
Cavity after sub-assembly fabrication		399.843949
Shift due to bulk BCP of End Plates (140 microns)	-26.988	
Cavity after trimming and thinning		**399.816961**
Shift due to bulk BCP of Center Body (140 microns)	-16.106	
Cavity after bulk BCP		399.800855
Weld shrinkage	115.645	
Weld bead	5.000	
Cavity after final weld		399.921500
Shift due to light BCP (20 microns)	-5.762	
Cavity after light BCP		399.915738
Shift due to mounted couplers	4.906	
Fully assembled cavity with HOM couplers		399.920644
Pressure effect (760 Torr differential)	-60.800	
Dielectric effect air to vacuum	130.341	
Evacuated cavity at 20 C		399.990185
Thermal shrinkage	572.877	
Colled down cavity at 4.2 K		400.563062
Shift due to change in skin depth	28.000	
Cavity frequency adjusted for skin depth		400.591062
Pressure from 760 Torr to 23 Torr in He tank	58.960	
Cooled down cavity at 2.0 K		400.650022
Shift due to tuner activation to its mid range	150.000	
Cavity with tuner activated		400.800022
Lorentz detuning	-10.022	
Operational cavity with RF on		400.790000

Achieved after trimming - 399.809239 MHz

AUP General Strategy – A Fresh Start

- The same model adopted for projects such as XFEL, LCLS-II, FRIB... will be followed.
  - Contracts managed by a laboratory, raw material inspected by laboratory, cavities built in industry (more in next slides) with heavy supervision, processing/testing in laboratory
  - The key aspect is: maximize direct control by the laboratory by placing direct contracts with industry
- Effort will be centralized at Fermilab
  - Leverage Fermilab SRF infrastructure and experience with other SRF cavity projects (ILC R&D, LCLS-II, PIP-II, etc.)
  - All contracts (with industry and with other laboratories) will be managed through Fermilab procurement
  - Received Support from Lab Senior Management for FNAL as the SRF Lab for HEP

Plan with Clear Intermediate Milestones

- Organize 2 Phases:
  - Phase #1 for RFD Prototypes (FY17-FY20)
  - Phase #2 for RFD Production (FY20-FY23)
- Phases #1: Prototypes Fabrication contracts series
  - Evaluate proposals and award (2, ideally 3) contracts only to suppliers meeting minimum requirements (**extensive and successful SRF experience**, existence of QA system, …)
  - Fund initial development of representative samples for electron-beam welded joints of RFD cavity (qualification phase)
  - Down-select based on quality of samples, etc. and fund fabrication of 1 cavity at each of 2 suppliers (ideal), or 2 cavities at one supplier.
- Phase #2: Fabrication of HL-LHC Cavities
  - Vendor performance risk mitigated by prior vendor qualification steps and successful delivery of HL-LHC RFD bare and jacketed prototypes.

How do we turn all of this into HL-LHC AUP, a 413.3b DOE Project ?

HL-LHC AUP – CD-0 (or Mission Need) Approval

Department of Energy
Washington, DC 20585

November 19, 2015

MEMORANDUM FOR CHERRY A. MURRAY
DIRECTOR
OFFICE OF SCIENCE

FROM: JAMES L. SIEGRIST
ASSOCIATE DIRECTOR OF SCIENCE
FOR HIGH ENERGY PHYSICS

SUBJECT: ACTION: Approval of Mission Need Statement for the HL-LHC Accelerator Upgrade

ISSUE: This action memorandum transmits the Mission Need Statement for the subject project. The attached Mission Need Statement complies with Department of Energy Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and was prepared to support Critical Decision-0, Approve Mission Need.

BACKGROUND: The High Energy Physics (HEP) strategic plan developed by the Particle Physics Project Prioritization Panel (P5) called continuing involvement in the Large Hadron Collider (LHC) program the highest priority for the field. This involvement should include full participation in the high luminosity upgrade of the LHC (HL-LHC) and its detectors.

P5 also found that the field of particle physics is global in scope with no one region being capable of implementing the largest and most challenging efforts. The European Strategy for Particle Physics also recognized this and recommended that European neutrino physicists should seek work in the U.S. or Japan.

HEP has been actively developing an enhanced partnership with the European Organization for Nuclear Research (CERN) since the P5 report was issued. An international cooperation agreement with CERN has been signed and protocols on neutrinos, the LHC experiments, and contributing to the HL-LHC accelerator upgrade are nearly complete.

The U.S. has developed expertise superior to CERN's in several areas including superconducting magnets made from niobium-tin and superconducting Radio Frequency crab cavities. These are now the primary candidates that will be considered for contributions to upgrade.

Given these considerations, now is an appropriate time to approve a Mission Need Statement and begin planning for the U.S. contributions to this upgrade.

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Mission Need Statement
HL-LHC Accelerator Upgrade

Submitted by:

Bruce P. Strauss, Program Manager
Office of High Energy Physics, Office of Science, DOE
Date: 12-17-15

Michael Procario, Director of Facilities Opera...
Office of High Energy Physics, Office of Scie...

James Siegrist, Associate Director
Office of High Energy Physics
Office of Science, DOE

Concurrence:

Stephen W. Meador, Director
Office of Project Assessment, Office of Science, DOE

Patricia Dehmer, Deputy Director for Science Programs
Office of Science, DOE
Date: 3/7/2016

Approval:

Cherry Murray, Director
Office of Science
Date: 3/7/2016

2

Approval:

Cherry Murray, Director
Office of Science

- ESAAB meeting approved CD-0 for HL-LHC Accelerator Upgrade Project on April 13th 2016.
- Next step: CD-1 (Approve Alternative Selection and Cost Range)

HiLumi HL-LHC PROJECT

LARP

Project Scope

- KPP Deliverables:

Threshold KPPs	Objective KPPs
10 Q1/Q3 Cryo-assemblies	1 Cold Mass Assembly
10 RFD Dressed Cavities	1 RFD Dressed Cavity & Financial support for DQW cavities

- Threshold KPPs have been agreed with CERN Technical Management (Lucio Rossi)
  - It now includes installing the cold mass assembly in the final cryostat supplied by CERN
- Objective KPPs constitute Scope Contingency
- (*As of Nov 29th 2016*) Scope **does not** include prototypes
  - Assumed to be funded by LARP

Project Scope

- KPP Deliverables:

Threshold KPPs	Objective KPPs
10 Q1/Q3 Cryo-assemblies	1 Cold Mass Assembly
10 RFD Dressed Cavities	1 RFD Dressed Cavity &
	Financial support for DQW cavities

In project baseline

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  - It now includes installing the cold mass assembly in the final cryostat supplied by CERN
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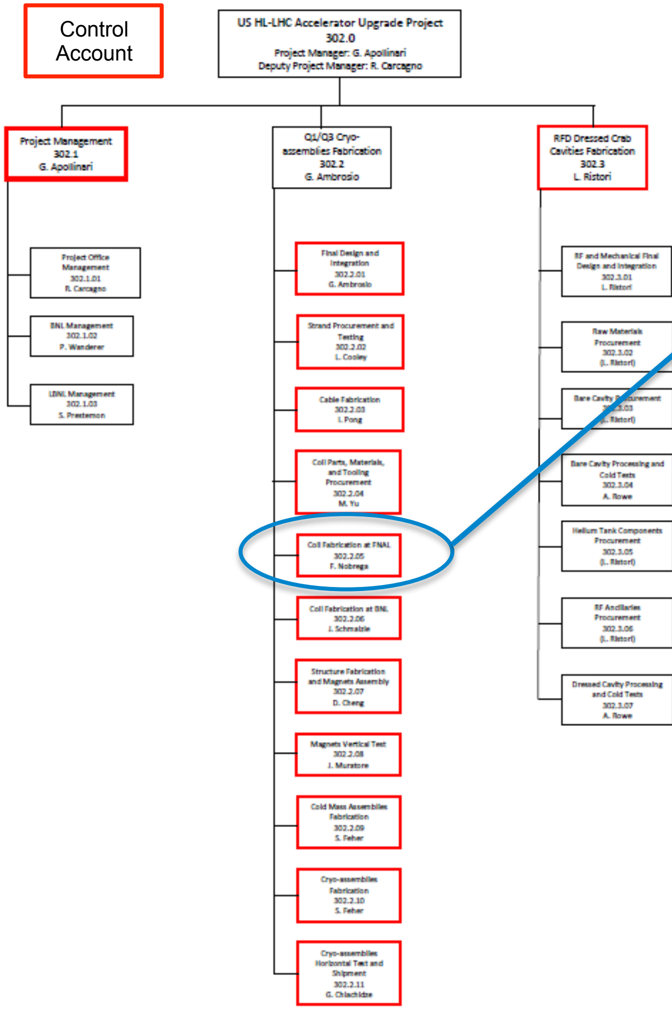
- (*As of Nov 29th 2016*) Scope **does not** include prototypes
  - Assumed to be funded by LARP

Work Breakdown Structure (WBS)

WBS Chart (US-HiLumi-doc-104)



WBS Dictionary (US-HiLumi-doc-39)
Each L3 WBS has a WBS Dictionary entry. Example:

WBS Code	**WBS Name**	**Control Account**
302.2.05	Coil Fabrication at FNAL	Yes
WBS Description		

Scope of Work

Fabricate 50 QXF coils at Fermilab. Fabrication steps include Winding and Curing, Reaction, and Impregnation. Includes shipping of accepted coil to LBNL for magnet assembly. Detailed description of QXF coil fabrication process provided by US-HiLumi-doc-95

Scope Assumptions/Exclusions

- One set of coil fabrication tooling is available from LARP, installed and fully functional in Fermilab Industrial Building 3 (IB3). This includes a winding machine with one mandrel, a curing press, a reaction oven and an impregnation fixture, an impregnation station (in IB2) and an impregnation fixture.
- Coil witness sample testing is covered under the scope of WBS 302.2.02 Stand Procurement
- 1 out of every 8 coils is assumed to be rejected and scrapped (see Risk Register in US-HiLumi-doc-79)

Deliverables

A minimum of 40 accepted QXF coils with their corresponding QC reports

- 13 Control Accounts
- L3/CAM Identified

Basis of Estimate (BOEs)

- Each **Control Account** has a BOE DocDB Document with several supporting BOE files in a standard format (DocDB upload in progress). Example:

http://us-hilumi-docdb.fnal.gov/

US-HiLumi

US-HiLumi DocDB Document 115-v8
BOE 302.2.05 Coil Fabrication at FNAL

Document #:
US-HiLumi-doc-115-v8
Document type:
MS Excel
Submitted by:
Ruben Carcagno
Updated by:
Linda Valerio
Document Created:
27 Oct 2016, 10:45
Contents Revised:
17 Nov 2016, 14:44
DB Info Revised:
17 Nov 2016, 14:44

Update Document
Update DB Info
Add Files
Watch Document

Abstract:
Basis of Estimate for WBS 302.2.05, "Coil Fabrication at FNAL".

Files in Document:

- BOE 302.2.05.docx (45.9 kB)
- BOE 302.2.05.pdf (357.8 kB)

Other Files:

- Coil Impregnation (302-02-05-1040.xlsm, 39.7 kB)
- Coil Reaction (302-02-05-1030.xlsm, 39.3 kB)
- Coil Storage and Shipment (302-02-05-1050.xlsm, 38.3 kB)
- Coil Winding and Curing (302-02-05-1020.xlsm, 41.5 kB)
- L3 Management (302-02-05-1010.xlsm, 38.3 kB)

Get all files as tar.gz, zip.

Topics:

- Project Management:Cost:BOEs

Authors:

- Alfred Nobrega

Notes and Changes:
Updated "other files" with corrected WBS structure.

Related Documents:

- US-HiLumi-doc-95: Fermilab MQXFA Coil Production Analysis

Viewable by:

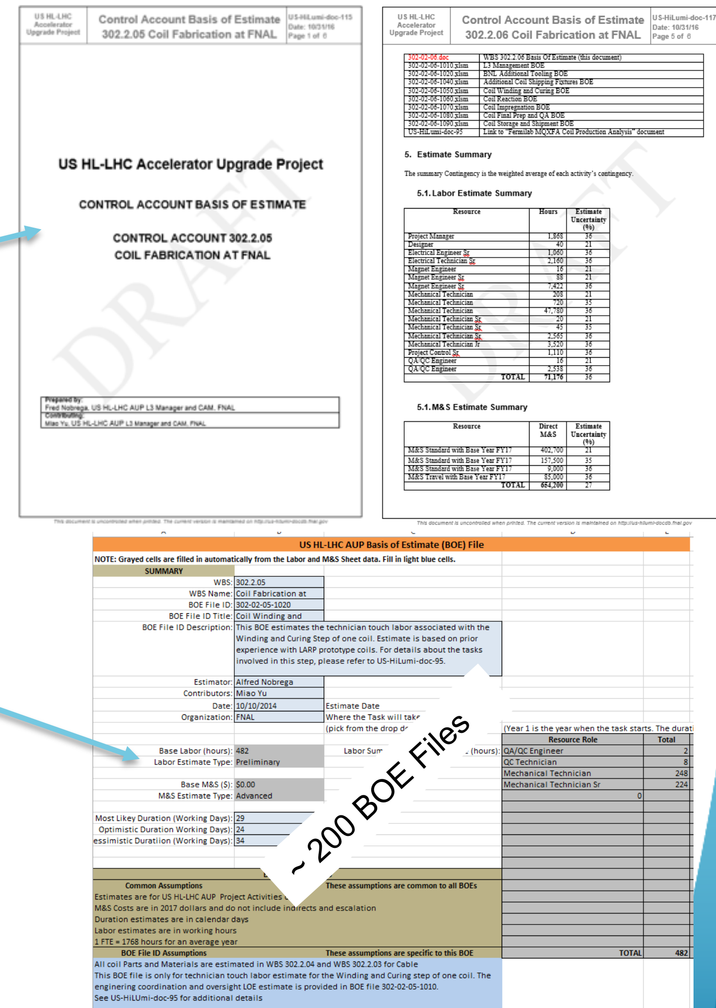
- us-hilumi
- Management

Modifiable by:

- us-hilumi
- Management

Other Versions:

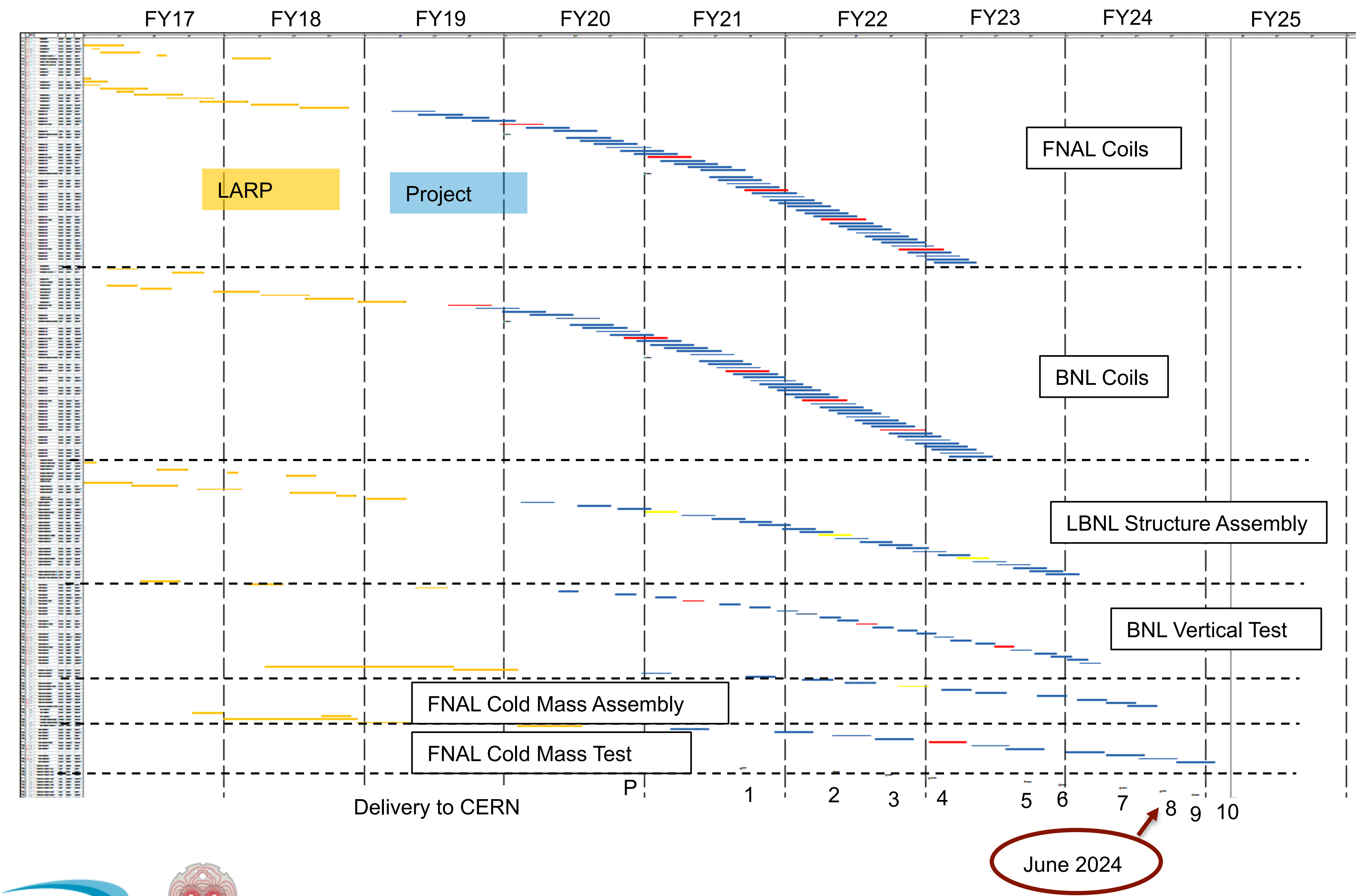
US-HiLumi-doc-115-v7
15 Nov 2016, 08:59
US-HiLumi-doc-115-v6
11 Nov 2016, 14:22
US-HiLumi-doc-115-v5
03 Nov 2016, 14:16
US-HiLumi-doc-115-v4
31 Oct 2016, 13:12
US-HiLumi-doc-115-v3
31 Oct 2016, 13:02
US-HiLumi-doc-115-v2
27 Oct 2016, 10:50
US-HiLumi-doc-115-v1
27 Oct 2016, 10:45



Risk Mitigation Actions

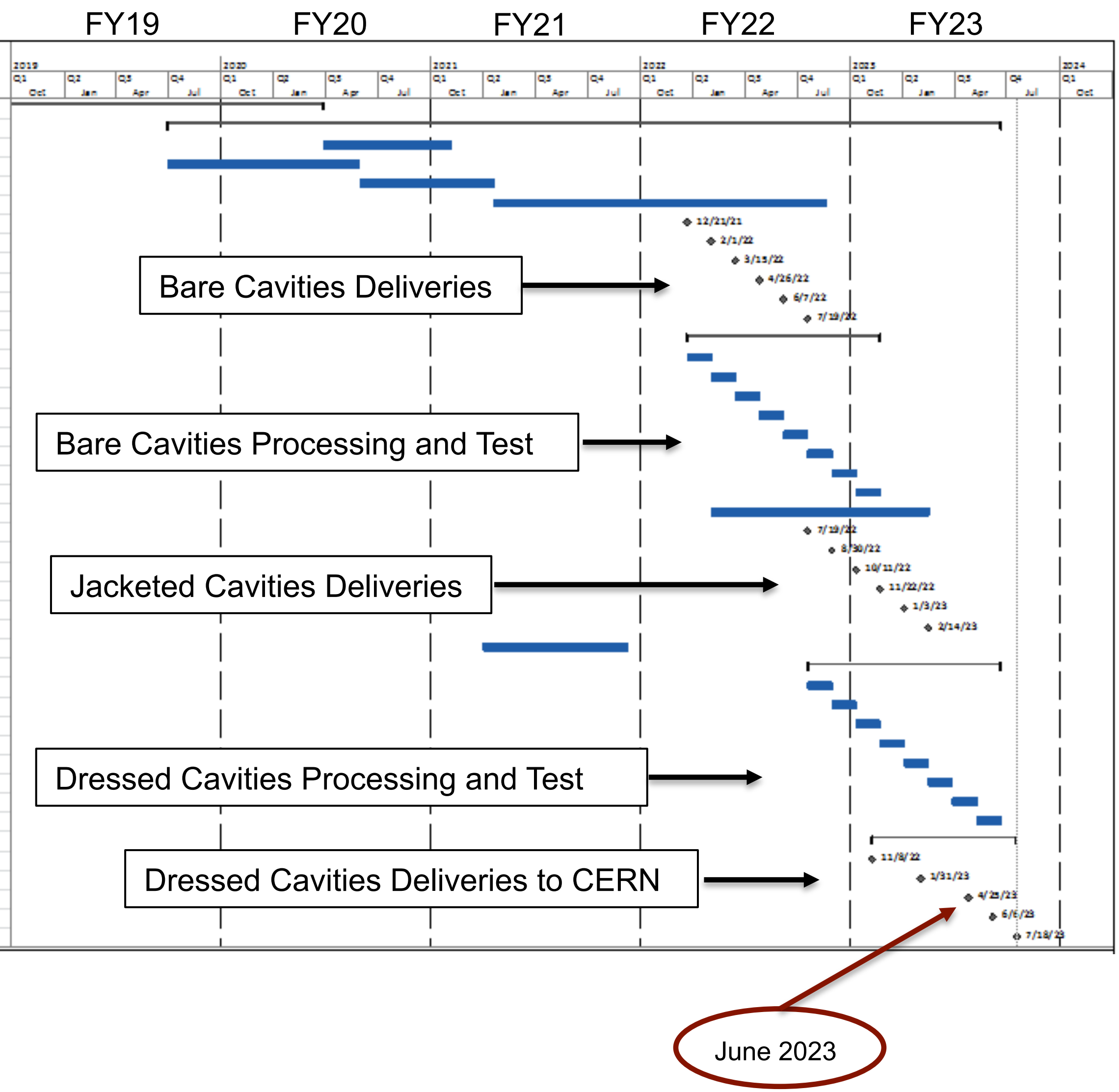
- Project baseline includes risk mitigation actions to make up for estimated product failures
  - Details in Risk Register (US- HiLumi-doc-79, in progress)
- Failure Assumptions:
  - 1 out of 10 cables is rejected
  - 1 out 8 coils is rejected
  - 3 out of 20 magnets have to be re-worked and re-tested
  - 1 out of 10 cold mass assemblies has to be re-worked and re-tested
  - 1 out of 5 RFD cavities is rejected
- Uniform distribution of failures is assumed

Q1/Q3 Preliminary Integrated Schedule (Q1/Q3 #8 delivered by June 2024)



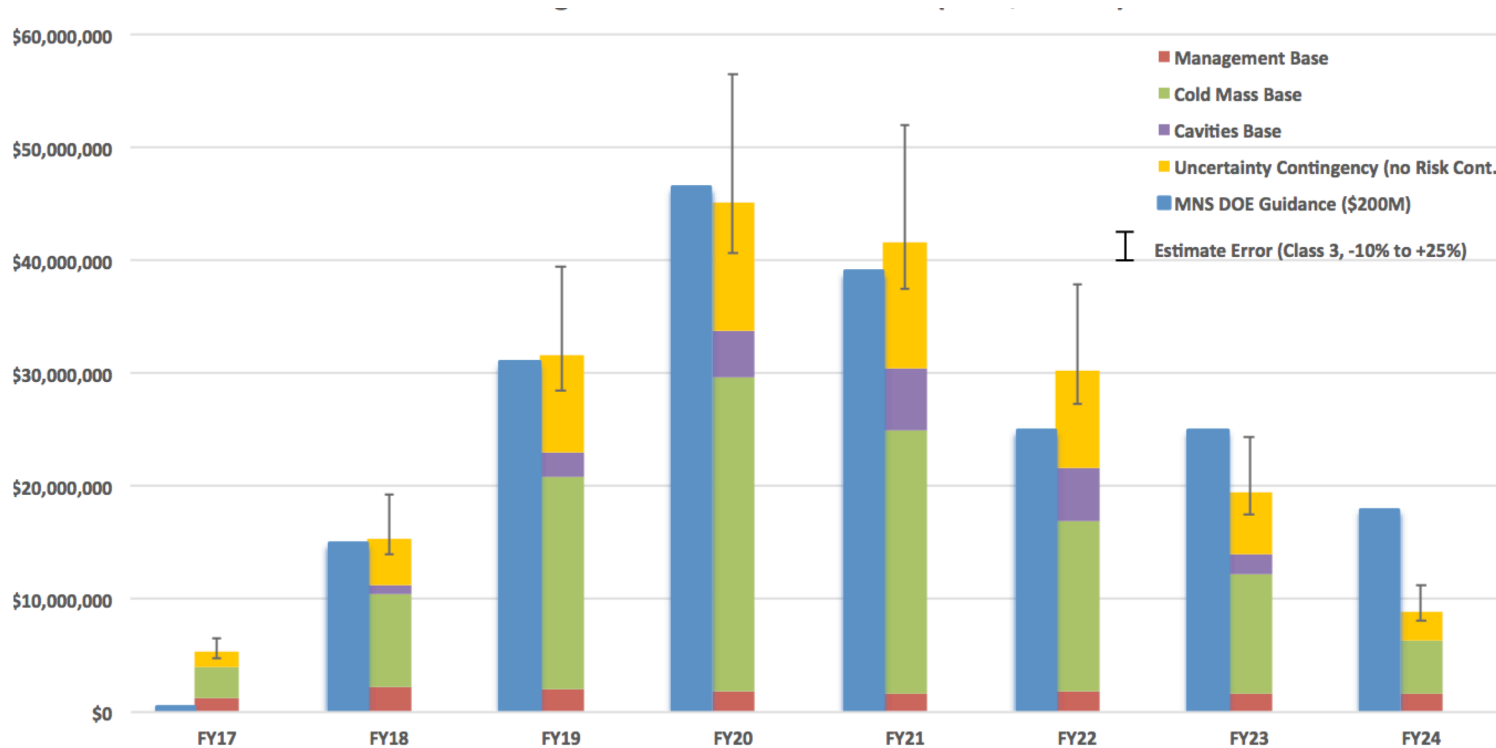
RFD Preliminary Integrated Schedule
(“Dressed” RFD #8 delivered by June 2023)

ID	Task Name	Duration	Start	Finish
1	**RFD Prototypes (2 RFDs)**	**940 days**	**8/22/16**	**3/27/20**
13	**RFD Series Fabrication (10 RFDs)**	**1037 days**	**7/1/19**	**6/20/23**
14	Final Design and Integration	8 mons	3/30/20	11/6/20
15	Raw Materials Procurement	240 days	7/1/19	5/29/20
16	Braze Joints	167 days	6/1/20	1/19/21
17	**Bare Series Fabrication (12)**	413 days	1/20/21	8/19/22
18	Bare Cavity 1-2 Delivered	0 days	12/21/21	12/21/21
19	Bare Cavity 3-4 Delivered	0 days	2/1/22	2/1/22
20	Bare Cavity 5-6 Delivered	0 days	3/15/22	3/15/22
21	Bare Cavity 7-8 Delivered	0 days	4/26/22	4/26/22
22	Bare Cavity 9-10 Delivered	0 days	6/7/22	6/7/22
23	Bare Cavity 11-12 Delivered	0 days	7/19/22	7/19/22
24	**Bare Cavities Processing and Test**	**240 days**	**12/22/21**	**11/22/22**
25	Bare Cavities 1-2 Processing and Test	30 days	12/22/21	2/1/22
26	Bare Cavities 3-4 Processing and Test	30 days	2/2/22	3/15/22
27	Bare Cavities 5-6 Processing and Test	30 days	3/16/22	4/26/22
28	Bare Cavities 7-8 Processing and Test	30 days	4/27/22	6/7/22
29	Bare Cavities 9-10 Processing and Test	30 days	6/8/22	7/19/22
30	Bare Cavities 11-12 Processing and Test	30 days	7/20/22	8/30/22
31	Bare Cavities Re-Processing and Re-Test (2)	30 days	8/31/22	10/11/22
32	Bare Cavities Re-Processing and Re-Test (2)	30 days	10/12/22	11/22/22
33	**Jacketed Series Fabrication (12)**	271 days	2/2/22	2/15/23
34	Jacketed Cavity 1-2 Delivered	0 days	7/19/22	7/19/22
35	Jacketed Cavity 3-4 Delivered	0 days	8/30/22	8/30/22
36	Jacketed Cavity 5-6 Delivered	0 days	10/11/22	10/11/22
37	Jacketed Cavity 7-8 Delivered	0 days	11/22/22	11/22/22
38	Jacketed Cavity 9-10 Delivered	0 days	1/3/23	1/3/23
39	Jacketed Cavity 11-12 Delivered	0 days	2/14/23	2/14/23
40	**RF Ancilliaries Fabrication**	180 days	1/1/21	9/9/21
41	**Dressed Cavities Processing and Test**	**240 days**	**7/20/22**	**6/20/23**
42	Dressed Cavities 1-2 Processing and Test	30 days	7/20/22	8/30/22
43	Dressed Cavities 3-4 Processing and Test	30 days	8/31/22	10/11/22
44	Dressed Cavities 5-6 Processing and Test	30 days	10/12/22	11/22/22
45	Dressed Cavities 7-8 Processing and Test	30 days	11/23/22	1/3/23
46	Dressed Cavities 9-10 Processing and Test	30 days	1/4/23	2/14/23
47	Dressed Cavities 11-12 Processing and Test	30 days	2/15/23	3/28/23
48	Dressed Cavities Re-Processing and Re-Test (2	30 days	3/29/23	5/9/23
49	Dressed Cavities Re-Processing and Re-Test (2	30 days	5/10/23	6/20/23
50	**RFD Dressed Cavity Deliveries to CERN**	**180 days**	**11/8/22**	**7/18/23**
51	Delivered 2 RFD Dressed Cavities	0 days	11/8/22	11/8/22
52	Delivered 4 RFD Dressed Cavities	0 days	1/31/23	1/31/23
53	Delivered 6 RFD Dressed Cavities	0 days	4/25/23	4/25/23
54	Delivered 8 RFD Dressed Cavities	0 days	6/6/23	6/6/23
55	Delivered 10 RFD Dressed Cavities	0 days	7/18/23	7/18/23



Time-Phased Cost Estimate – *30,000 feet view*

- The "Preliminary Integrated Schedules" for Magnets and CC (to be shown later) allow HL-LHC AUP to plan for funding profile.
- **Cost Estimate at ~198 M$ Level**
  - 128 M$ (Base) + 47 M$ (Estimate Contingency) + 21 M$ (Escalation)
  - 128 M$ (Base) = 99 M$ (Magnets) + 17 M$ (CC) + 12 M$ (Management)
  - Estimate Contingency: Magnets (36%) vs CC (43%)
- Residual <u>Risk Contingency</u> not included in the cost estimate



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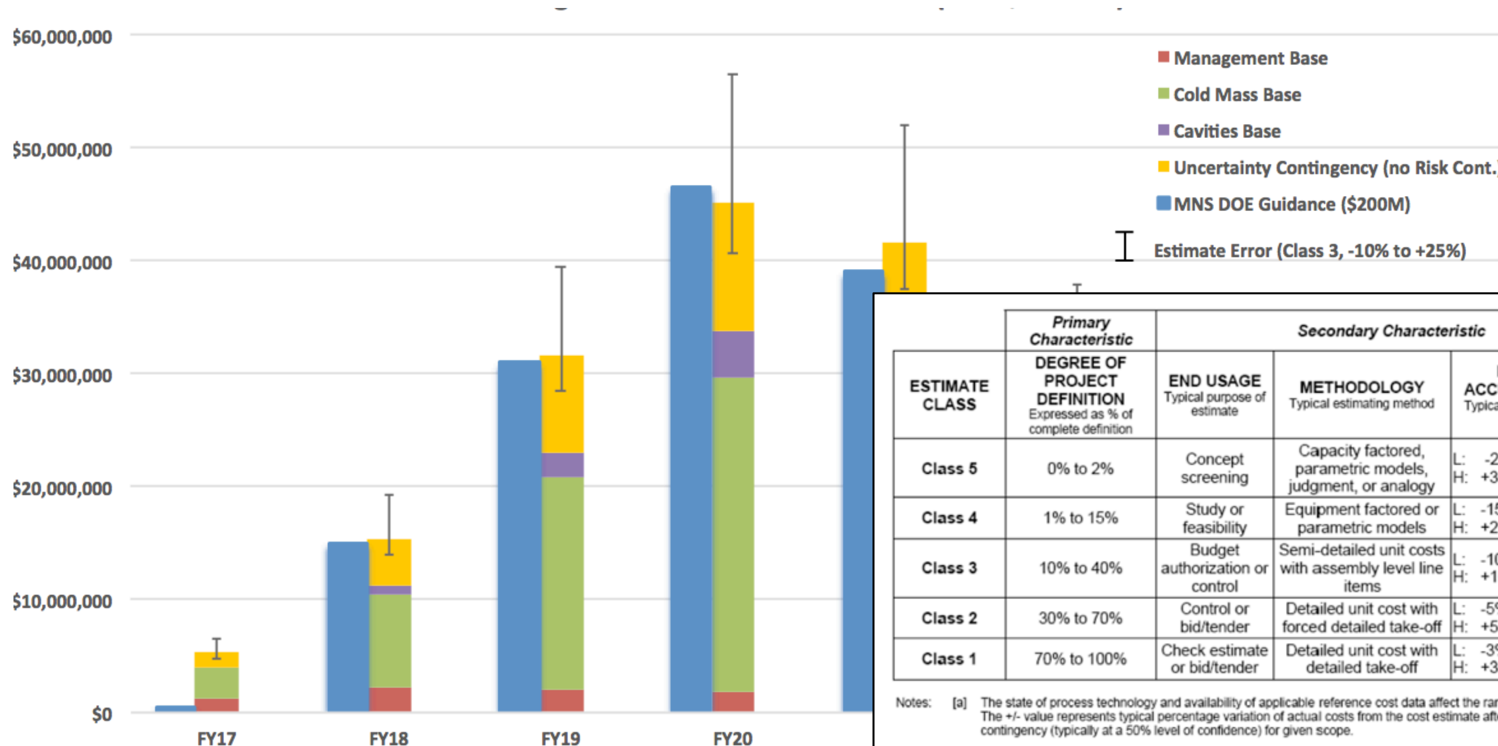

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Table 4.3 – Cost Estimate Classification for Process Industries

Time-Phased Cost Estimate – *30,000 feet view*

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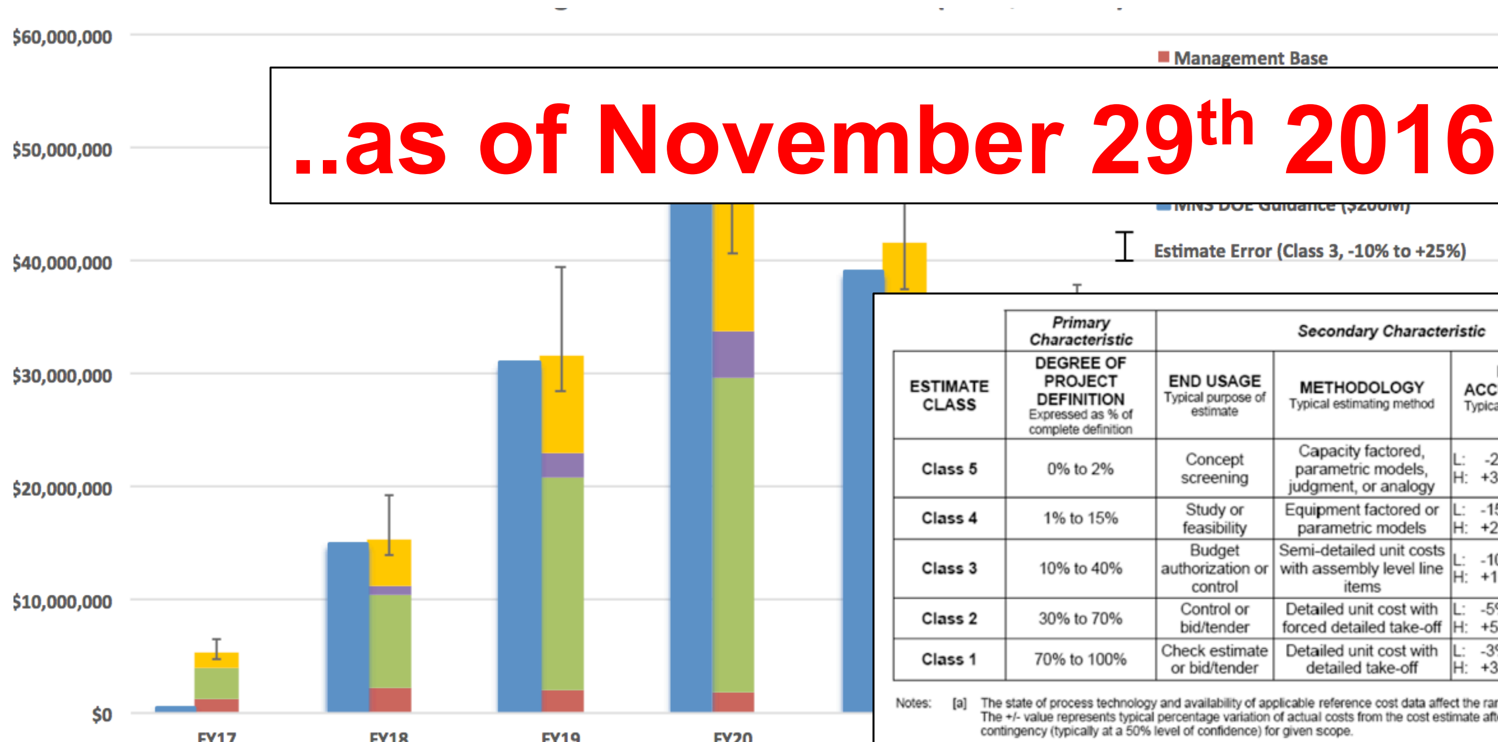

..as of November 29th 2016

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
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Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
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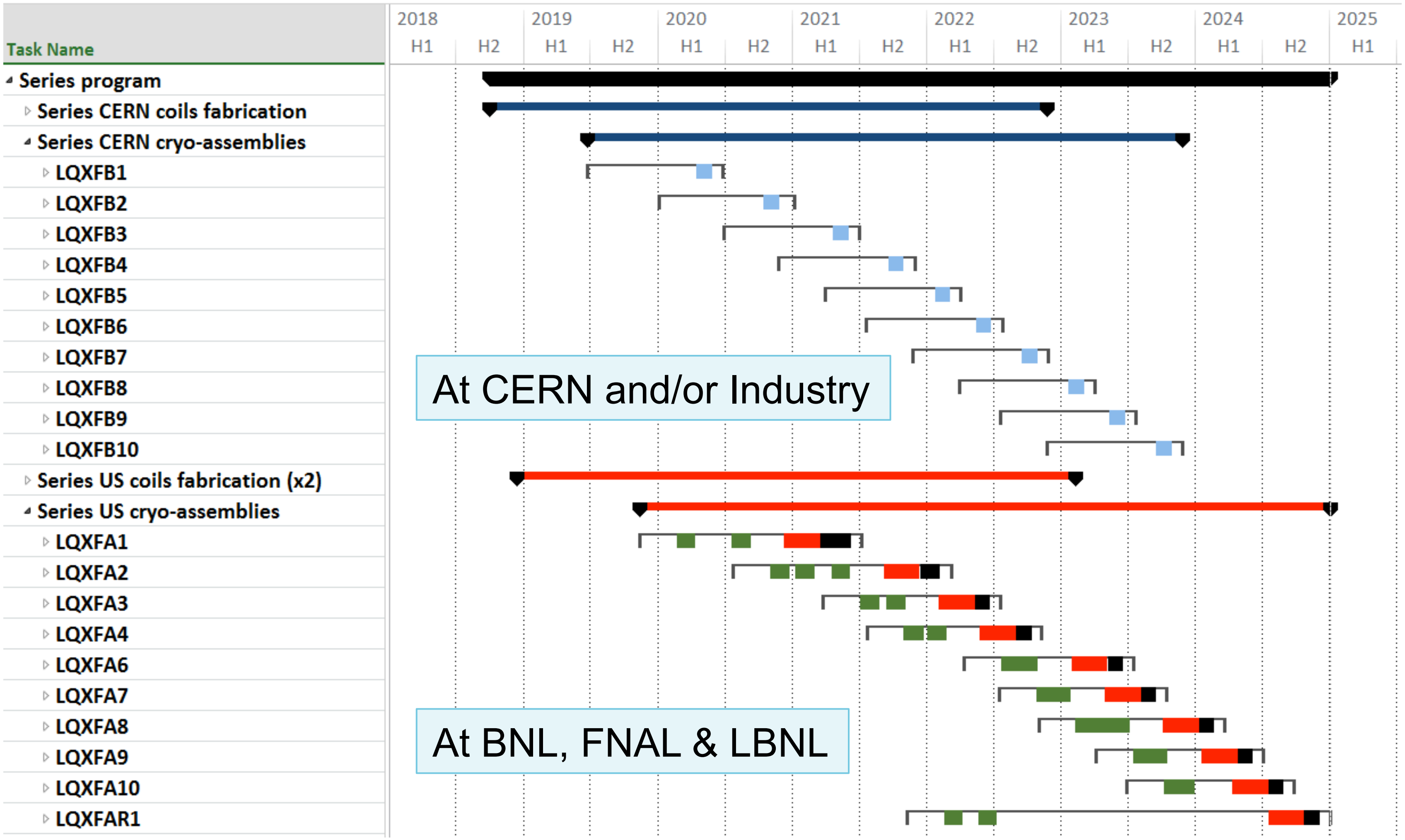
Table 4.3 – Cost Estimate Classification for Process Industries

Series production



LARP

Contingency Analysis

- Contingency Categories
  - Scope Contingency
  - Estimate Uncertainty Contingency
  - Risk Contingency
    - Risk Mitigation Actions
  - Schedule Contingency

Scope Contingency

- Scope Contingency is provided by the following Objective KPP scope:
  - 1 cold mass assembly and 1 RFD cavity
- Objective scope provides additional spares to CERN
  - CERN requires a minimum of 2 spares cryo-assemblies and 2 spares RFD cavities to be part of the threshold scope, so the objective scope is for a 3rd spare
- Strand for the objective cold mass assembly must be procured by late FY21/early FY22
  - It means relatively early commitment to objective scope
- Objective scope total cost is~ $11.4M (~6% TPC)

Risk Contingency

- Risk Management Plan adopted (FNAL procedure, in US-HiLUmi-doc-89)
- Project Risk Register development in progress (draft in US-HiLumi-doc-79)
  - More than 70 risks have been identified
  - Major mitigation actions already in Project Baseline (next slide)
- Risk Workshop with all project CAMs scheduled at FNAL for December 1st 2016 (yesterday)
  - First pass at quantitative analysis of residual risks

Risk Mitigation Actions

- Risk mitigation actions included in baseline

Risk	Probability	Mitigation Actions
Cable for coil rejected	10% (1 every 10 cables)	Fabricate 23 additional cables
Coil rejected	12.5% (1 every 8 coils)	Fabricate 12 additional coils
Magnet poor performance	15% (3 every 20 magnets)	Re-assemble and re-test 3 magnets
Cold Mass poor performance	10% (1 every 10 cold masses)	Re-assemble and re-test 1 cold mass
RFD cavity rejected	20% (1 every 5 cavities)	Fabricate 2 additional RFD cavities

  - More details in Risk Register (in progress)
  - Risk Mitigation Actions Cost and Schedule Impact
    - ~ $21M (11% TPC), ~ 12 months

Estimate Uncertainty Contingency

- Estimate Uncertainty Contingency follows the FNAL Project Support Office rules for Labor and M&S:

Code	Type of Estimate	Contingency %	Description
M&S Guidelines			
M1	Existing Purchase Order	0%	Items that have been completed or obligated. (Note: Contact Change Orders are considered a Risk and should not be included as estimate uncertainty contingency)
M2	Procurements for LOE / Oversight work	0%-20%	M&S items such as travel, software purchases and upgrades, computers, etc. estimated to support LOE efforts and other work activities.
M3	Advanced	10%-20%	Items for which there is a catalog price or recent vendor quote existing design with little or no modifications and for which the
M4	Preliminary	20%-40%	Items that can be readily estimated from a reasonably detailed designs but with moderate modifications, which have docume (e.g., budgetary quote, vendor RFI response) based on a prelim
M5	Conceptual	40%-60%	Items with a documented conceptual level of design; items ada modifications, which have documented costs from past project
M6	Pre-Conceptual - Common work	60%-80%	Items that do not have a documented conceptual design, but d estimate type indicates little confidence in the estimate. Its us estimate.
M7	Pre-Conceptual - Uncommon work	80%-100%	Items that do not have a documented conceptual design, and h should be minimized when completing the final estimate.
M8	Beyond state of the art	>100%	Items that do not have a documented conceptual design, and h requirements are beyond the state of the art.

Code	Type of Estimate	Contingency %	Description
LABOR Guidelines			
L1	Actual	0%	Actual costs incurred on activities completed to date.
L2	Level of Effort Tasks	0%-20%	Support type activities that must be done to support other work activities or the entire project effort, where estimated effort is based on the duration of the activities it is supporting.
L3	Advanced	10%-25%	Based on experience with documented identical or nearly identical work. Development of activities, resource requirements, and schedule constraints are highly mature. Technical requirements are very straightforward to achieve.
L4	Preliminary	25%-40%	Based on direct experience with similar work. Development of activities, resource requirements, and schedule constraints are defined at a preliminary (beyond conceptual) design level. Technical requirements are achievable and with some precedent.
L5	Conceptual	40%-60%	Based on expert judgment using some experience as a reference. Development of activities, resource requirements, and schedule constraints are defined at a conceptual level. Technical requirements are moderately challenging.
L6	Pre-conceptual	60%-80%	Based only on expert judgment without similar experience. Development of activities, resource requirements, and schedule constraints are defined at a pre-conceptual level. Technical requirements are moderately challenging.
L7	Rough Estimate	80%-100%	Based only on expert judgment without similar experience. Development of activities, resource requirements, and schedule constraints is largely incomplete. Technical requirements are challenging.
L8	Beyond state of the art	>100%	No experience available for reference. Activities, resource requirements, and schedule constraints are completely undeveloped. Technical requirements are beyond the state of the art.

- Contingency allocated at the activity level, total contingency is a weighted average
- Total estimate uncertainty contingency is ~ $47M, which is ~ 37% of the base cost and ~ 24% of the TPC

Schedule Contingency

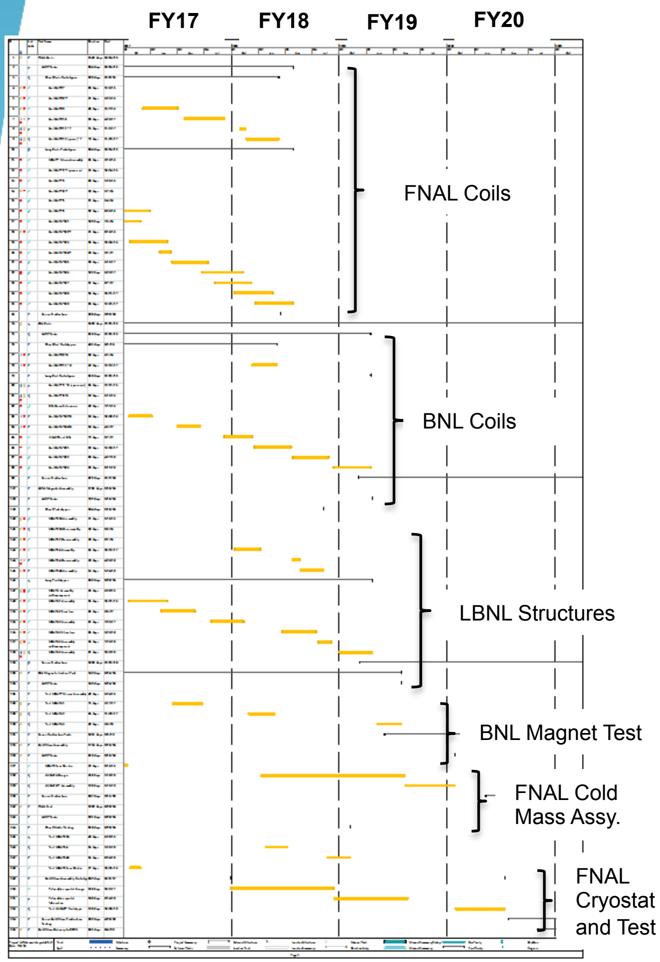
- With the assumption of uniform distribution of product failures, **there is no schedule float** for the critical milestone of cryo-assembly #8 at CERN by June 2024
- To create schedule float, funding would need to be shifted from the later years to the earlier years to accelerate the production rate
  - The needs were communicated in a letter to S. Rolli in August 16, 2016.
- Working with DOE to create at least ~6 months of float in HL-LHC AUP Project (Cryoassembly #8 shipped by Dec. '23 rather than June '24)

LARP and HL-LHC AUP

- A Key Project Assumption is that all prototypes are funded by LARP.
  - (*As of Nov 29th*) Project scope was only **series production**
- LARP prototypes are a critical project external dependency
  - Successful performance and timely completion of LARP prototypes essential to obtain CD-3 on schedulea:
    - CD-3b (magnets) mid-FY18
    - CD-3c (cryo-assemblies and RFD cavities mid-FY20
  - FY18-FY20 LARP funding request to execute prototype scope has been requested

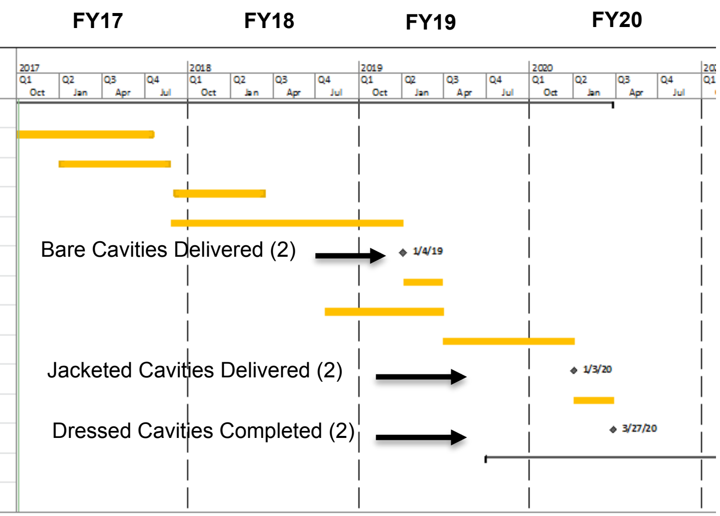
LARP Funding Needs in FY18-FY20 (DOE Review of LARP, July 2016)

LARP Magnet Schedule



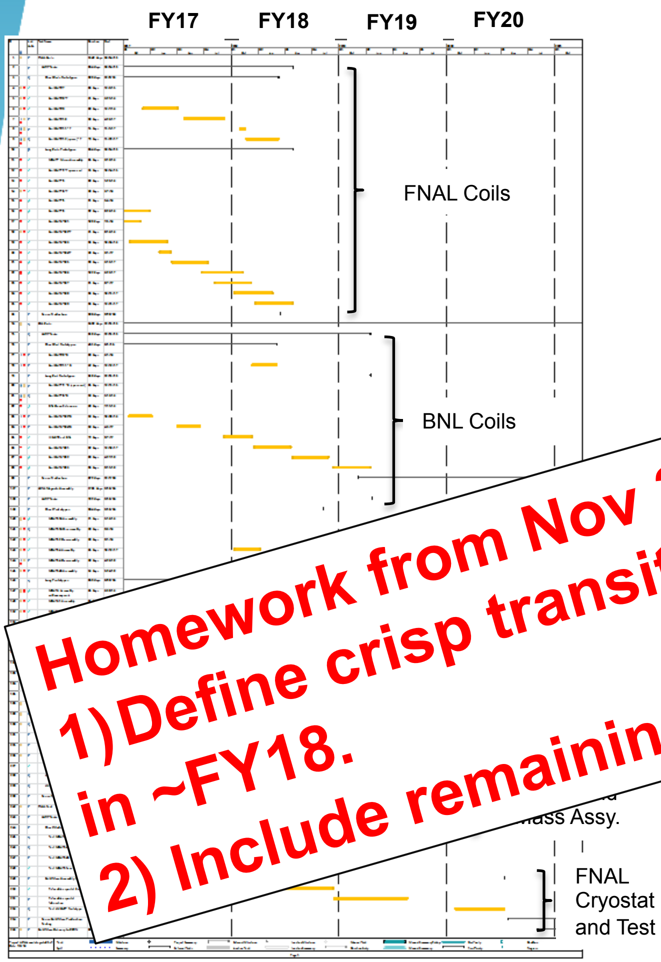
LARP RFD Cavities Schedule

ID	Task Name	Duration	Start	Finish
1	**RFD Prototypes (2 RFDs)**	**940 days**	**8/22/16**	**3/27/20**
2	Raw Materials Procurement	240 days	8/22/16	7/21/17
3	Vendor Qualification	170 days	1/2/17	8/25/17
4	Braze Joints (2 Sets)	140 days	9/4/17	3/16/18
5	Bare Cavities Prototypes 1-2 Fabrication	355 days	8/28/17	1/4/19
6	Bare Cavities Prototypes 1-2 Delivered	0 days	1/4/19	1/4/19
7	Bare Cavities Prototypes 1-2 Processing and Tes	60 days	1/7/19	3/29/19
8	RF Ancilliaries Fabrication (2 Sets)	180 days	7/23/18	4/1/19
9	Prototype Cavities 1-2 Jacketing	200 days	4/1/19	1/3/20
10	Jacketed Prorotype Cavity 1-2 Delivered	0 days	1/3/20	1/3/20
11	Dressed Cavity Prototypes 1-2 Processing and T	60 days	1/6/20	3/27/20
12	Prototype RFD Dressed Cavities 1-2 Completed	0 days	3/27/20	3/27/20
13	**RFD Series Fabrication (10 RFDs)**	**1037 days**	**7/1/19**	**6/20/23**
50	**RFD Dressed Cavity Deliveries to CERN**	**180 days**	**11/8/22**	**7/18/23**

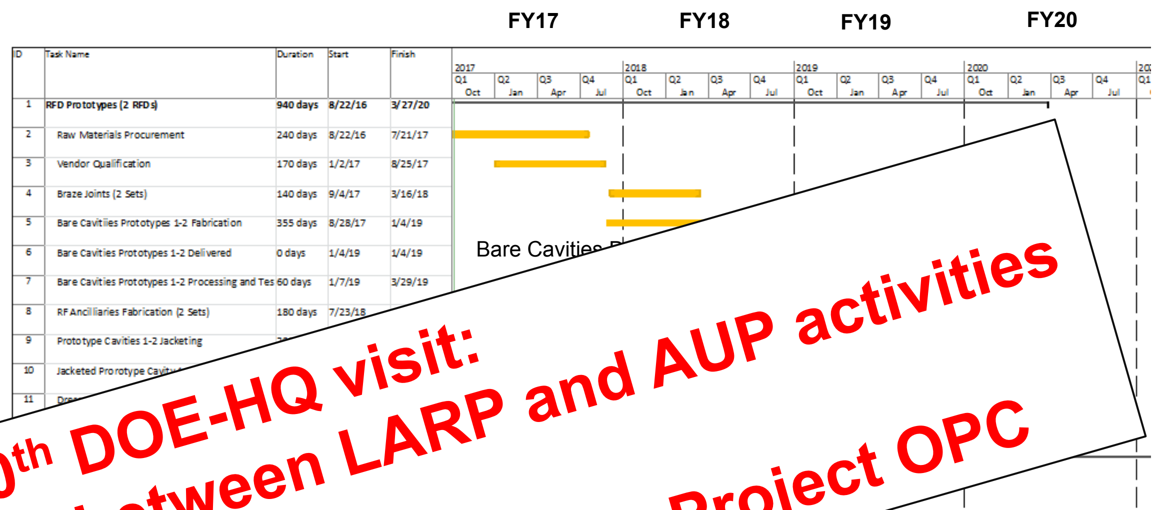


LARP Funding Needs in FY18-FY20 (DOE Review of LARP, July 2016)

LARP Magnet Schedule



LARP RFD Cavities Schedule



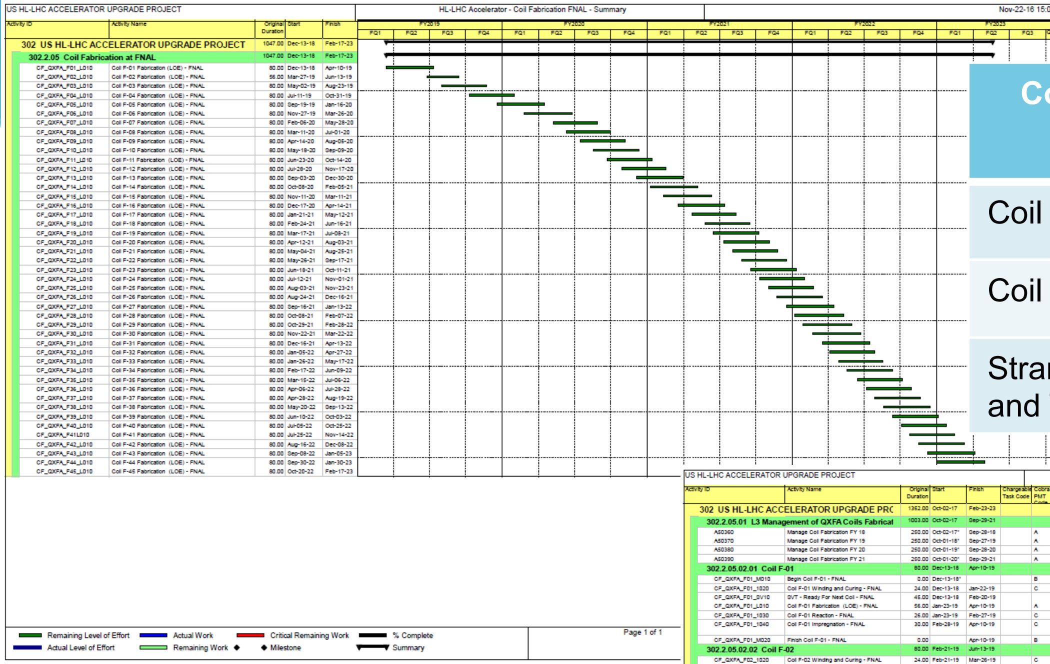
Homework from Nov 30th DOE-HQ visit:

1) **Define crisp transition between LARP and AUP activities in ~FY18.**
2) **Include remaining work on Prototypes in Project OPC**

Preparation for ICR

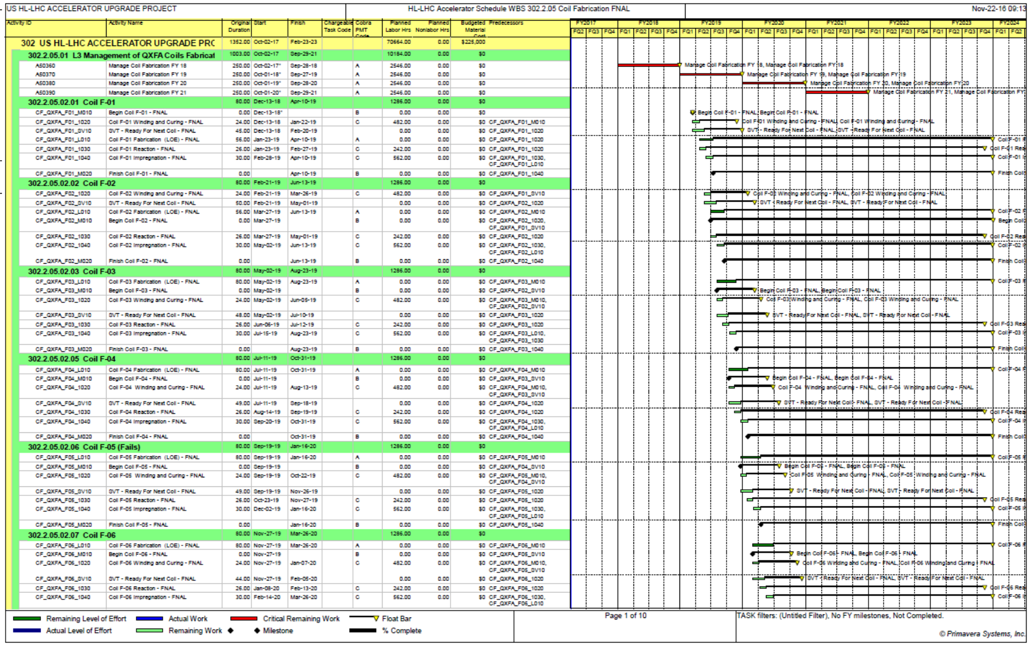
- DOE Independent Cost Review (ICR) expected to start ~ February 2017
- Project Office staffing ramping up
- Cost Model is being migrated to FNAL resource loaded schedule (RLS) Primavera (P6)/Cobra system
  - Three control accounts already loaded, 10 more to go
- Will continue using Cost Model for quick “what-if” scenario analysis
  - P6/Cobra will focus on a particular scenario for the ICR
- BOEs are being uploaded to controlled “DocDB” documents, one document per Control Account with an overview CA BOE and several BOE support files
  - BOE “scrubbing” ongoing, verifying estimates traceability, source documentation, etc.
  - ~ 200 BOE files
- Draft “CD-1” documents in progress

P6/Cobra Output Example
Coil Fabrication at FNAL and BNL



Comparison with Cost Model

Control Account	P6 / Cobra	Cost Model	% Diff
Coil Fab at FNAL	$11.8M	$11.2M	5.1%
Coil Fab at BNL	$18.0M	$17.6M	2.2%
Strand Procurement and Testing	$31.4M	$32.1M	-2.2%



- Using latest FY17-FY24 labor rates for FNAL, BNL, and LBNL
- 3% labor escalation, 2% M&S escalation

Conclusions

- LARP activities have seen several successes in the last year on the front of HL-LHC Magnets assembly and tests.
  - Crab Cavities activities are finally under full LARP control, with promising progress on the "SPS Prototypes" and a re-planning of activities for HL-LHC cavities.
- Project planning on track to support ICR in ~Feb 2017 and CD-1 in ~Summer 2017
  - Issues to address:
    - No schedule float for mid-2024 delivery of cryo-assembly #8
    - FY21-FY22 apparent funding shortfall after adding Crab Cavity production plan
  - Include prototype efforts for HL-LHC as part of HL-LHC AUP.

Backup Slides

Risk Management Plan

- Risk Management Plan Document (US-HiLumi DocDB #89) and Preliminary Risk Register (US-HiLumi DocDB #79) available
- Describes procedures for main processes:
  - Plan Risk Management
  - Identify Risks
  - Perform Qualitative Risk Analysis (*Risk Ranking)*
  - Perform Quantitative Risk Analysis
  - Plan Risk Responses
  - Monitor and Control Risks
- Risk mitigation actions are part of the project baseline (scope, schedule, and cost)

	Negligible impact	Low impact	Medium impact	High impact
Technical	• Quality not affected	• Quality slightly below the required standard	• Quality moderately below the required standard	• Quality significantly below the required standard, or • KPP in jeopardy
Cost If Project TPC < 100M$	• 0.05% of TPC	• 0.05% – 0.5% of TPC	• 0.5% – 5% of TPC	• > 5% of TPC, or • Lack of funds halts Project
If Project TPC > 100M$	• < 50k$	• 50k$ – 500k$	• 500k$ – 5 M$, or	• > 5M$, or • Lack of funds halts Project
Schedule	• No schedule impact	• Critical path change of < 2 months, or • Tier-4 milestone (Project -owned) moves by > 1 month	• Critical path change of 2-6 months, or • Tie (FP mo	• Critical path change of > 6 months, or

Risk ID	Risk Owner	Risk Type	Risk Title	Risk Description	Detailed Risk Cause	Detailed Risk Effect	Initial Response Plan	Comments
Cable								
	Dietderich	Threat	Cable Loss	Cable Loss due to LBNL cabling machine failure during a cable run	The main concern for loss of a cable during a run is failure of a magnetic brake, or a mandrel tip breaks.	Up to 1 UL of strand may be lost, resulting in a loss of up to $TBDK	Failure of a magnetic brake has not happened recently at LBNL. The plan is to inspect magnetic brakes after every 8 runs (it takes two techs 2 days to remove the brakes from the spools, open the housings, inspect the permanent magnets inside, and re-mount them in the spools), and if necessary re-use magnetic brakes that have been used before and have demonstrated to be of good quality. New brakes have been problematic in the past (cracked during operation because they were not sintered properly, producing free particles that would cause the brake to stop rotating). A 2nd mandrel will be fabricated and ready to install when the present mandrel has too much wear or appears to show effects of fatigue. It takes 1-2 weeks to fabricate a mandrel by LBNL staff.	
							In the case of gears or drive shafts, the plan to have spare parts. LBNL is looking for a spare machine that was in the LBNL shop at one time, and also exploring the possibility of having parts made in the LBNL repair and maintenance shop if necessary. In the case of the measurement machine, LBNL recently upgraded the hardware (new PC and	

Probability		Negligible impact	Low impact	Medium impact	High impact
Very High	64 - 100%	No rank	Medium rank	High rank	High rank
High	39 - 64%	No rank	Medium rank	High rank	High rank
Medium	21 - 39%	No rank	Low rank	Medium rank	High rank
Low	9 - 21%	No rank	Low rank	Medium rank	Medium rank
Very low	0 - 9%	No rank	Low rank	Low rank	Medium rank

Preliminary Project Planning

- Draft “Key Assumptions” Document available:
  - https://us-hilumi-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=78

U.S. High Luminosity LHC	Key Assumptions U.S. HL-LHC Accelerator Upgrade	US-HiLumi-doc-78 Date: Draft 3/8/16 Page 1 of 15

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U.S. HL-LHC Accelerator Upgrade Project

KEY ASSUMPTIONS

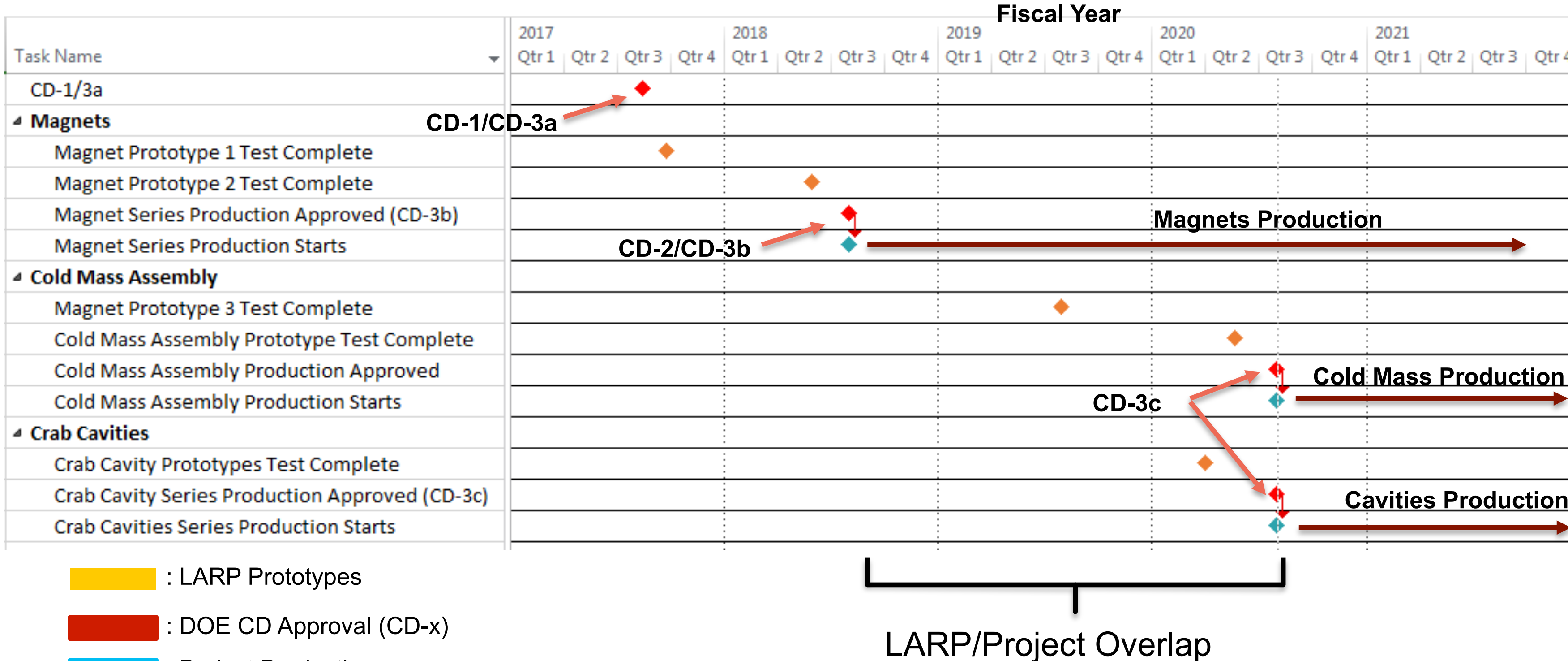
Prepared by: Date: Name, title	Organization FNAL	Contact
Reviewed by: Date: Name, title	Organization BNL	Contact
Reviewed by: Date: Name, title	Organization LBNL	Contact
Approved by: Date: Name, title	Organization CERN	Contact

U.S. High Luminosity LHC	Key Assumptions U.S. HL-LHC Accelerator Upgrade	US-HiLumi-doc-78 Date: Draft 3/8/16 Page 3 of 15

TABLE OF CONTENTS

HiLumi HL-LHC PROJECT
LARP

LARP Prototypes - Milestones

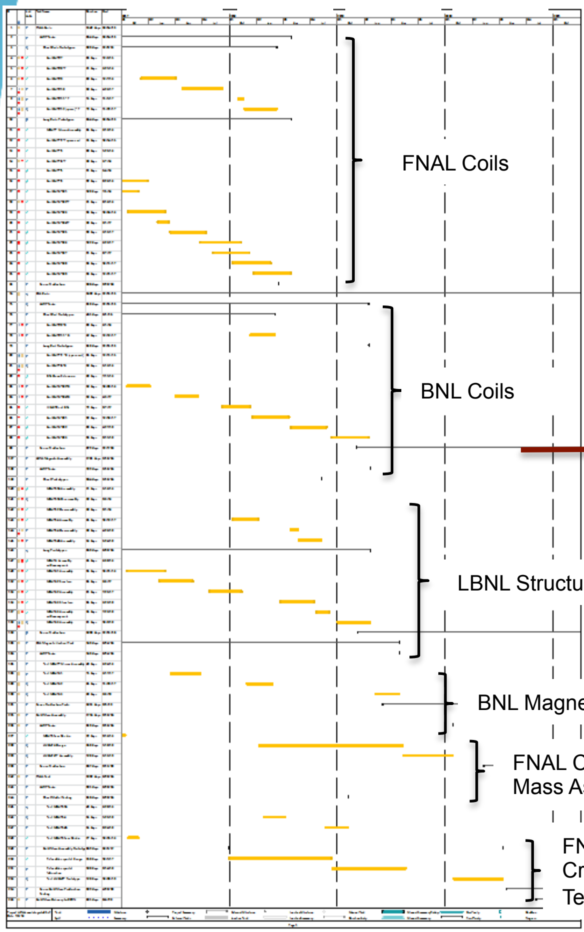


- There is an overlap of ~ 2 years (mid-CY18 to mid-CY20) between LARP prototypes and project series production
  - First two magnet prototypes needed to approve start of magnet series production (CD-3b)
    - Series production starts with coil fabrication
  - Last two magnet prototypes needed for HL-LHC tunnel ready cold mass assembly
- LARP funding slow ramp down (FY18-19-20) while project funding ramps up

HiLumi HL-LHC PROJECT
LARP

LARP Magnet Prototypes (Rough) FY18-20 Estimate

LARP Magnet Schedule



LARP Magnet Quantities

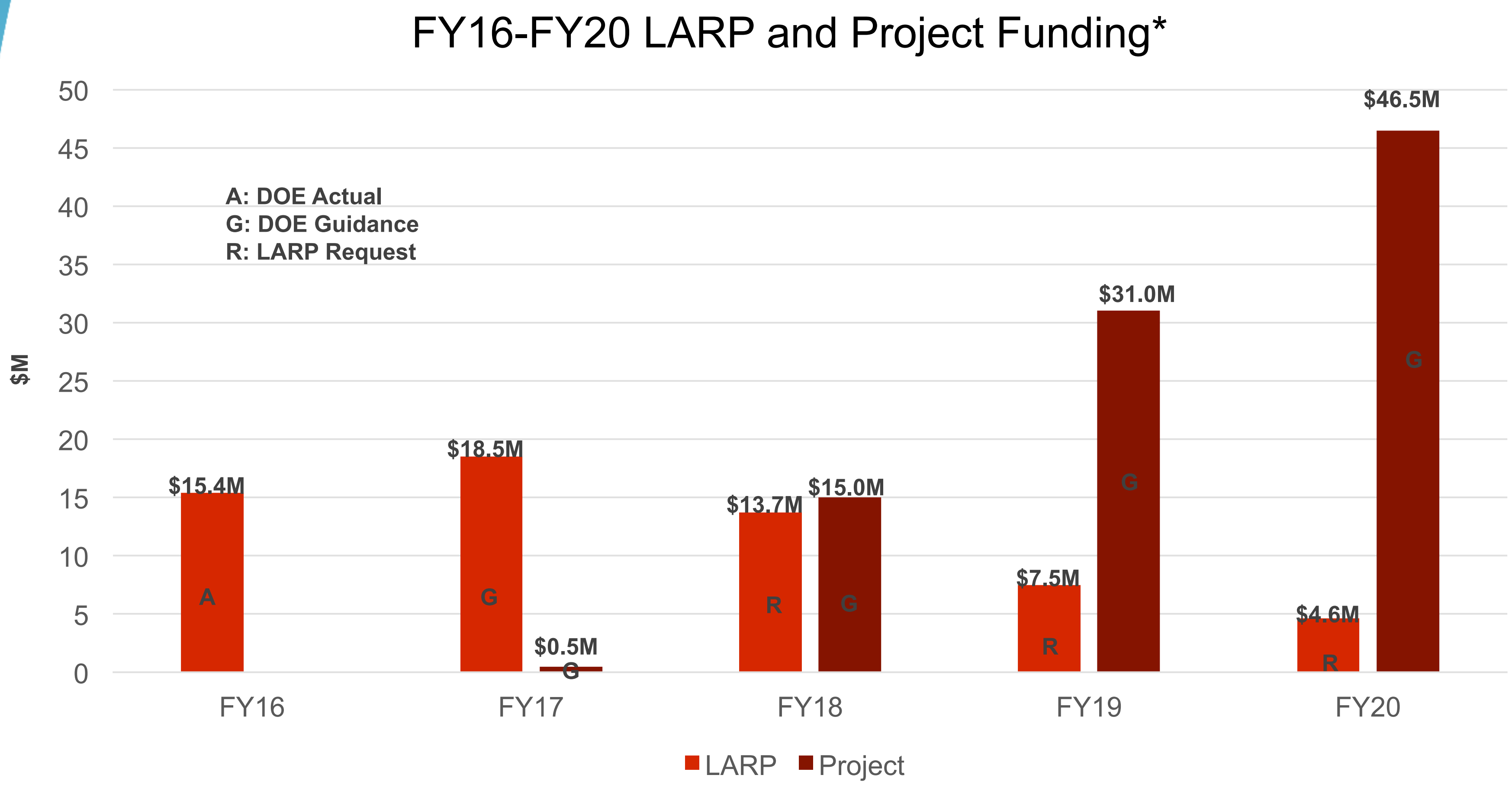
	FY17	FY18	FY19	FY20
Short Coil Prototypes				
QXFS-9	1			
QXFS-10	1			
QXFS-11		1		
Total Short Coil Prototypes	**2**	**1**		
Long Coil Prototypes				
QXFA-101	0.5			
QXFA-102	0.7			
QXFA-103	1			
QXFA-104	1			
QXFA-105	1			
QXFA-106	0.6	0.4		
QXFA-107	0.4	0.6		
QXFA-108		1		
QXFA-109		1		
W&C PC		0.8		
QXFA-201		1		
QXFA-202		1		
QXFA-203			1	
Total Long Prototypes	**5.2**	**5.8**	**1**	
Short Magnet Model				
MQXFS1c Test	1			
MQXFS4 Assembly		1		
MQXFS4 Test		1		
Long Magnet Prototype Assy				
MQXFA1 Assembly	1			
MQXFA1 Test	1			
MQXFA1b preload incr & test	0.1	1		
MQXFA2 Assembly	0.5	0.5		
MQXFA2 Test		1		
MQXFA3 Assembly			1	
MQXFA3 Test			1	
Cold Mass Prototype				
LMQXFP Design	0.2	0.8		
LMQXFP Assembly			1	
LMQXFP Test and Shipment				1

LARP Magnet Estimates

	FY18	FY19	FY20
QXF Management			
Coordination	$101.85	$0.0	
Meetings, Reviews	$65.35	$0.0	
Project Preparation	$0.00	$0.0	
Sub-total	**$167.2**	**$0.0**	
QXF Design			
Magnets	$77.60	$0.0	
Energy Deposition	$0.00	$0.0	
Accelerator Physics	$0.00	$0.0	
Toohigh Fellowship	$0.00	$0.0	
Sub-total	**$0.0**	**$0.0**	
Conductor			
LOE	$40.00	$0.0	
Procurement Follow-up	$23.00	$0.0	
QC	$331.00	$0.0	
Cable Fabrication	$650.10	$0.0	
Sub-total	**$1,044.1**	**$0.0**	
Coils			
Coils LOE	$519.95	$0.0	
Toohigh (Holik)	$0.00	$0.0	
Short Coils	$360.85	$0.0	
Long Coils	$2,012.30	$402.5	
Sub-total	**$2,893.1**	**$402.5**	
Structures and Assembly			
LOE	$66.00	$0.0	
MQXFS4 structure	$0.00	$0.0	
MQXFA1 Assembly	$0.00	$269.3	
MQXFA1 Disassembly	$0.00	$0.0	
MQXFA2 Assembly	$975.10	$0.0	
MQXFA3, only 1/3 M&S	$0.00	$0.0	
MQXFA1b Loading	$0.00	$0.0	
QA and procurement support	$98.70	$0.0	
Sub-total	**$1,139.8**	**$269.3**	
Tests			
LOE	$84.15	$0.0	
MQXFS1c Test	$0.00	$0.0	
MQXFA1 Test	$857.05	$857.1	
Data Analysis	$361.80	$361.8	
Sub-total	**$1,303.0**	**$1,218.9**	
Prototype Cold Mass & Cryostat			
Cold Mass Design	$633.80		
Cryostat Design and Interfaces	$400.00		
Cold Mass Tooling	$476.00		
Cryostat Tooling	$200.00		
Cryostat Assembly		$350.0	
Cold Mass Assembly		$742.5	
Install Cryostat on Cold Mass		$325.0	
Upgrade Test Stand	$600.00	$600.0	
Horizontal Test			$642.50
Shipment to CERN			$342.0
Sub-total	**$2,309.8**	**$2,017.5**	**$984.5**
GRAND TOTAL	**$8,857.0**	**$3,908.1**	**$984.5**

~ $8.9M $3.9M $1M

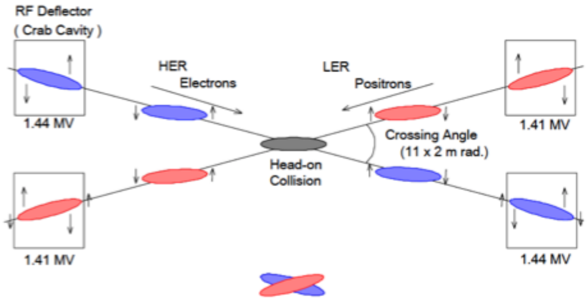
FY16-FY20 LARP/Project Funding Transition



*Project funding guidance from approved DOE "Mission Need Statement" (US-HiLumi-doc-82). This profile does not meet CERN delivery schedule for HL-LHC (explained in separate talk)

Comments on KEK Crab Cavity Experience – Lessons Learned

- Purpose for installing crab cavities in KEKB was twofold: address the geometrical factor loss and improve the beam-beam limit.
  - Geometrical Factor Loss. *Cavities performed as expected from the 1st day of operations !*
    - Due to the short KEK bunches, the geometrical factor allowed only a modest increase in luminosity.
    - In LHC, with longer bunches, the correction of the geometrical factor loss provides the large improvement in the Luminosity expected with Crab Cavities



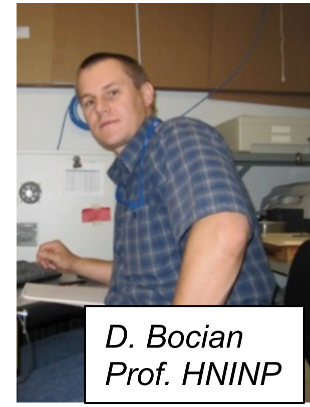
  - Improvement of Beam-Beam limit. This was the main reason for installation of Crab Cavities at KEK, with an expectation of improvement of KEK beam-beam limit from 0.06 to 0.15
    - In real crab cavity operation at KEKB this factor two was not achieved, but only some 20-30% (http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/weoamh02.pdf)
    - Although the reason for underperformance was not identified, one suspects the presence of other uncorrected aberrations, since the introduction of skew sextupole enhanced the gain obtained from the crab cavities leading to record luminosities.
- In LHC, no improvement of the beam-beam limit is assumed from the CC. *Only the geometrical factor loss is assumed to be corrected by CC*
  - This is very conservative. If there is a gain (which simulations do predict) this could lead to an additional luminosity gain beyond the baseline HL-LHC parameters.

Toohig Fellowship

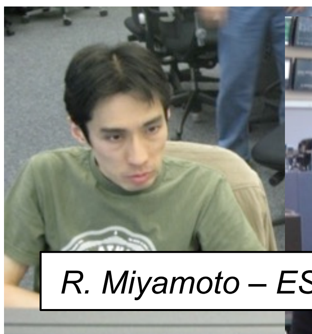
- Due to changed nature of activities, asked G.L. Sabbi to lead Toohig Fellow selection in the next ~5-6 years, replacing the outstanding effort of J. Fox (SLAC)
- E. Ravaioli selected at USLUA for Congressional Visit in Spring '17


R. Calaga – CERN


H. Felice – CEA


D. Bocian
Prof. HNINP


R. DeMaria –CERN

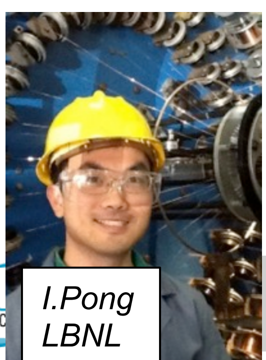

R. Miyamoto – ESS


T. Mastoridis
Prof. CPU


V. Previtali
Teacher, Geneve

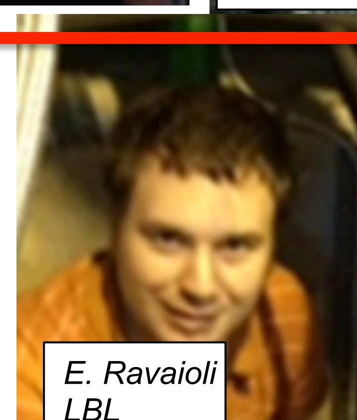

S. White – ESRF

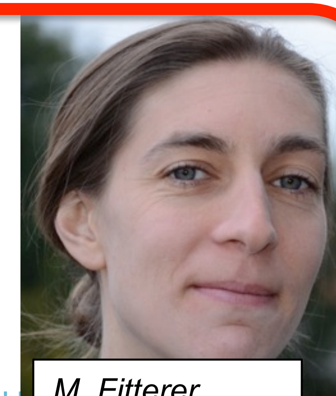

J.Cesaratto
Phillips


I.Pong
LBNL

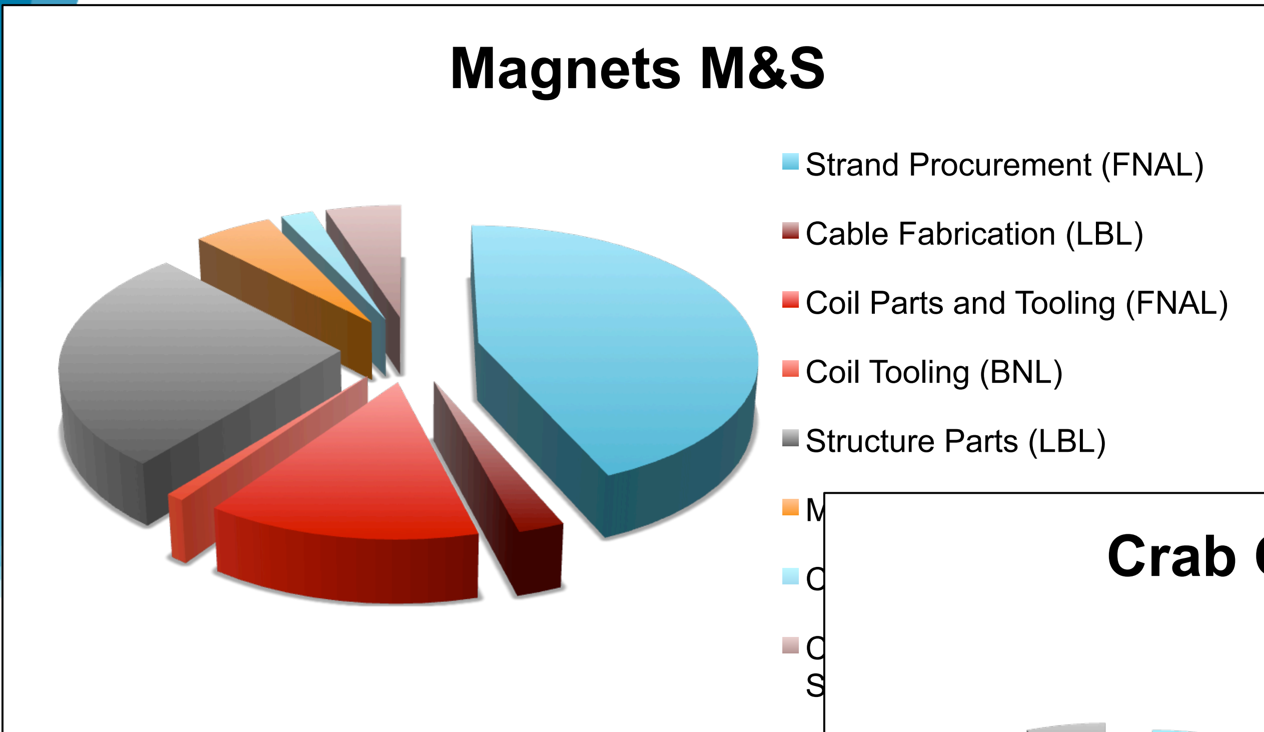

S. Verdu
BNL


T. Holik
FNAL

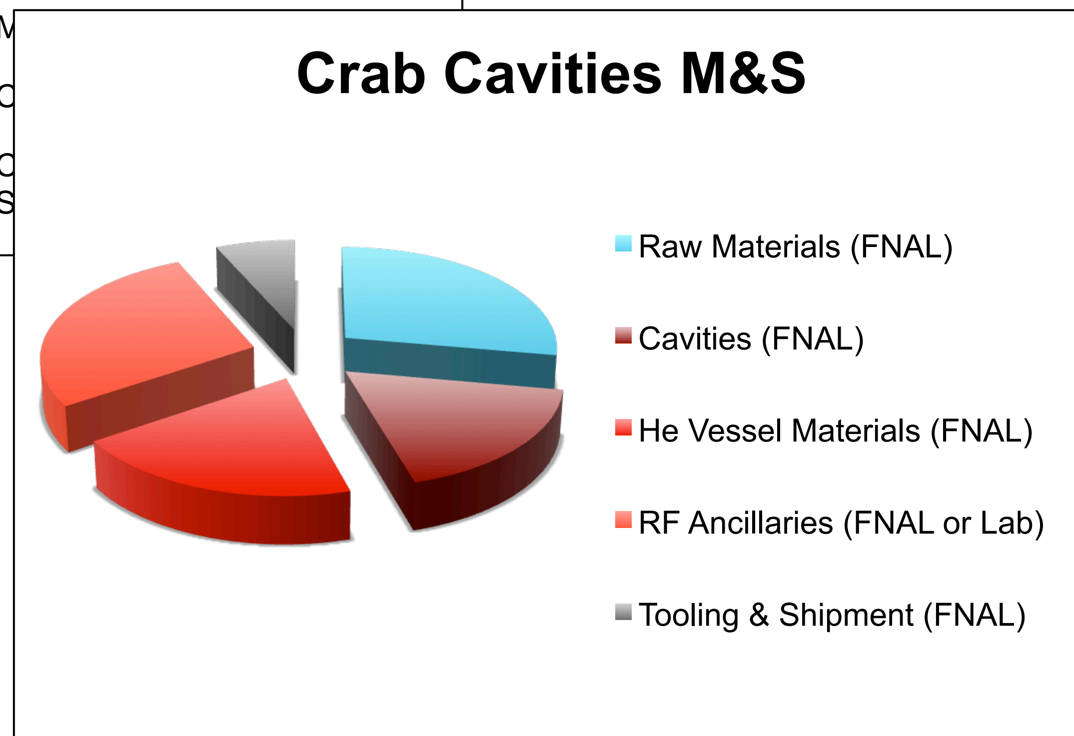

E. Ravaioli
LBL


M. Fitterer
FNAL

HL-LHC AUP M&S Expenditures



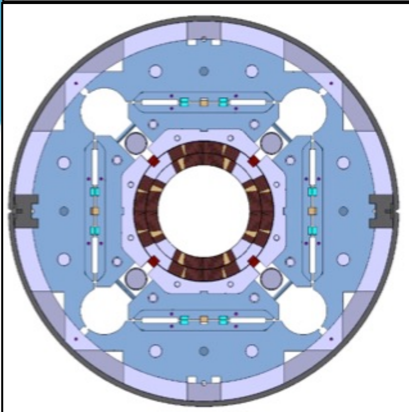
- Magnet Procurements estimated at ~42.5 M$



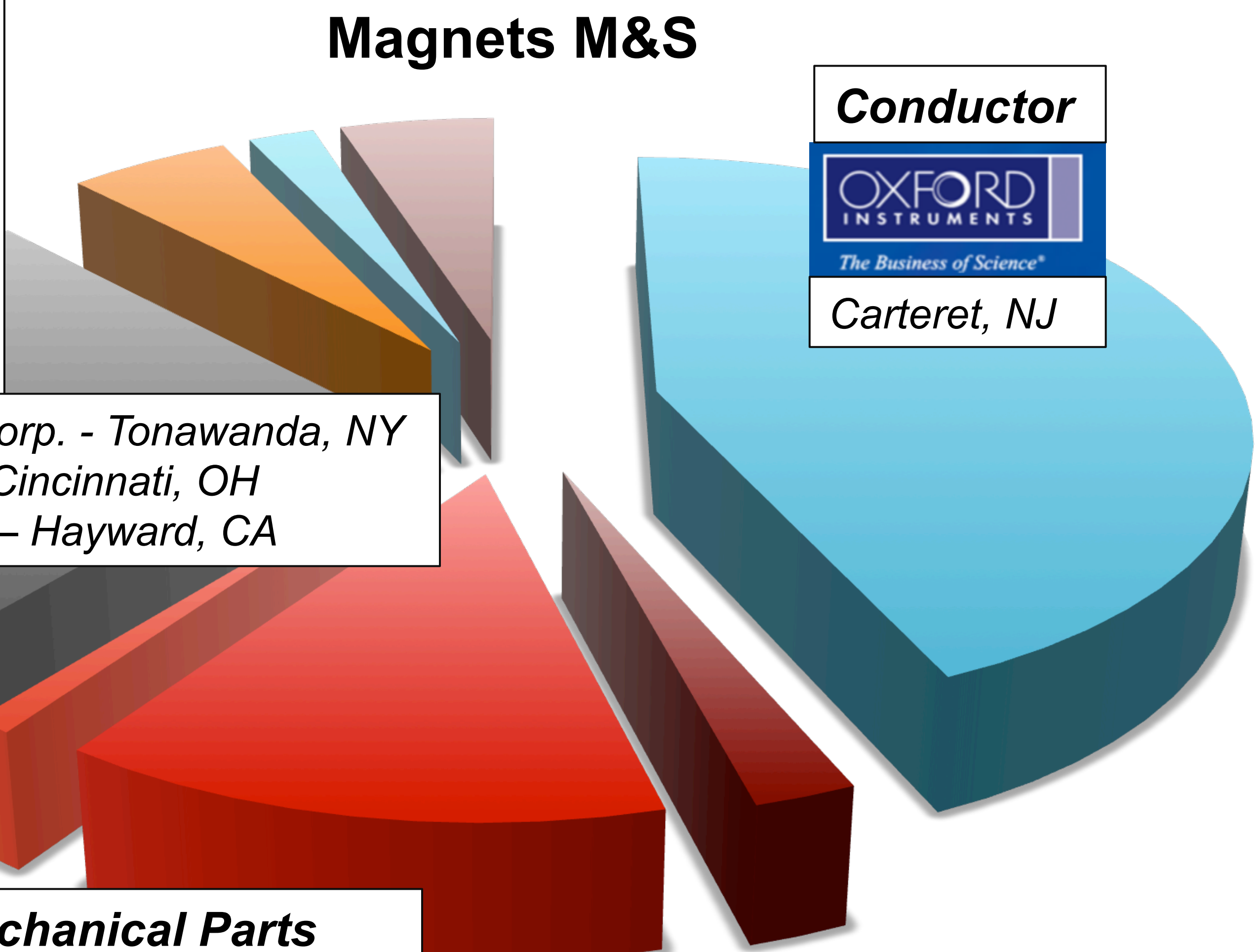
- CC Procurements estimated at ~9.0 M$
  - FNAL: ~6.5 M$
  - FNAL or Other Lab: ~2.5 M$

HL-LHC AUP Magnets M&S Expenditures: Candidate Companies based on LARP Experience

Structure Parts



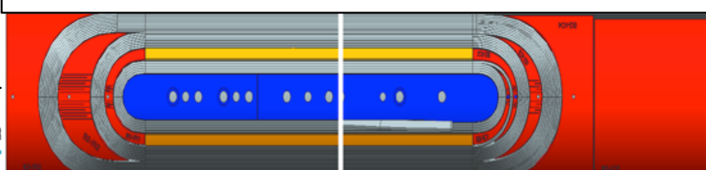
Keller Technology Corp. - Tonawanda, NY
Metalex Mfg. Inc. – Cincinnati, OH
IMTP Precision Inc. – Hayward, CA



Conductor

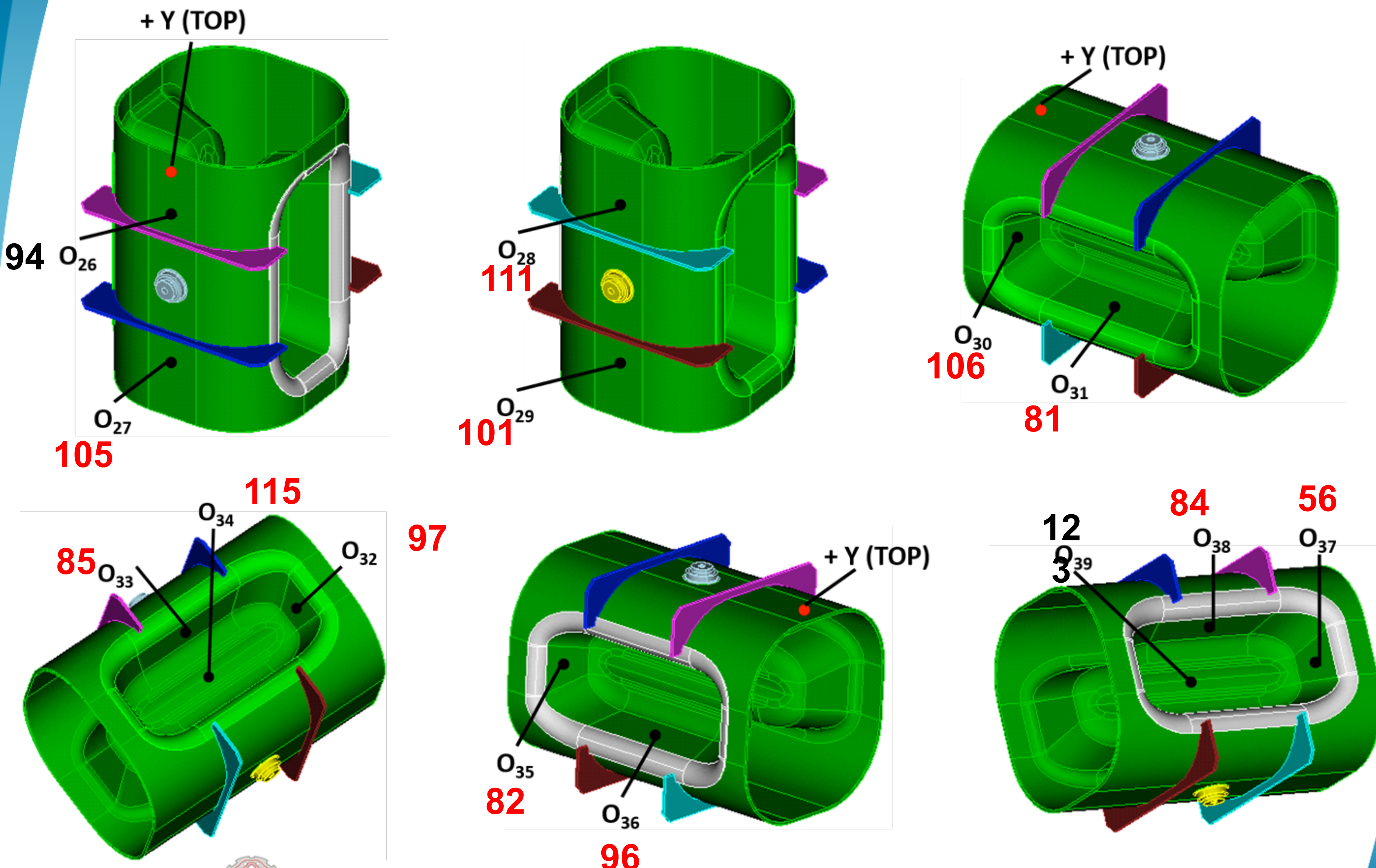
Carteret, NJ

Coil Mechanical Parts



Moritz Micro Mfg. Inc. - Wauconda, IL
Metal Fusions Inc. – Rwd City, CA
Rathbone Precision Metals Inc. – Rwd City, CA

RFD Thickness Measurements Results – CTR-002



Average removal – 95 micron

HL-LHC AUP Project Office

▪ Project Manager & Deputy Project Manager	
	Yours Truly
▪ ES&H Manager	M. Bonkalski, ESH&Q
▪ QA Manager	J. Blowers/A. Hammati
▪ Financial Manager	C. Trimby
▪ Procurement Liason	T. Powers
▪ Lead Project Control	F. Leavell-R. Marcum
▪ P6 Scheduler	K. Kozak
▪ Risk Liason	L. Taylor

Documentation in Support of CD-2/CD-3

- Tailoring for CC (CD-3c in ~'20)
- Specification Documentation
  - ✓ Functional Requirement Specifications in preparation
  - Conceptual/Technical Design Report in preparation
  - Technical Specifications/Vendor Qualification Assessment in preparation for RFD Prototypes procurements
- Project Documentation
  - BOEs/RLS/Dictionaries to be described in Ruben's

U.S. HL-LHC Accelerator Upgrade Project	Dressed RFD Cavities Functional Requirements Specification	US-HiLumi-doc-xx xxxxxxx v.0.1 LHC-xxxx-ES-xxx Date: October 25, 2016 Page 1 of 17

U.S. DEPARTMENT OF ENERGY | Office of Science

U.S. HL-LHC Accelerator Upgrade Project

DRESSED RFD CAVITIES

FUNCTIONAL REQUIREMENTS SPECIFICATION

DRAFT

	Organization	Contact
Prepared by: Date: XXX Giorgio Apollinari, US HL-LHC AUP Project Manager Ruben Carcagno, US HL-LHC AUP Deputy Project Manager	FNAL	apollina@fnal.gov (630) 840-4641 ruben@fnal.gov (630) 840-3915
Reviewed by: Date: Leonardo Ristori, US HL-LHC AUP MQXFA L2 Manager	FNAL	leoristo@fnal.gov (630) 840-xxxx
Reviewed by: Date: Ofelia Capatina, HL-LHC WP4 WP Engineer .... GianLuigi Arduini HL-LHC WP2 WP Leader Amalia Ballarino HL-LHC WP6A WP Leader Jean-Paul Burnet HL-LHC WP6B WP Leader Daniel Wolmann HL-LHC WP7 WP Leader Paolo Fessia HL-LHC WP15 WP Leader Isabel Bejar Alonso HL-LHC Quality, Resources and Risk Officer	CERN	Ofelia.Capatina@cern.ch
Approved by: Date: Giorgio Apollinari, US HL-LHC AUP Project Manager	FNAL	apollina@fnal.gov (630) 840-4641
Approved by: Date: Rama Calaga HL-LHC WP4 Work Package Leader Lucio Rossi, CERN HL-LHC Project Coordinator	CERN	Rama.Calaga@cern.ch

Revision History

This document is uncontrolled when printed. The current version is maintained on http://us-hilumi-docdb.fnal.gov

HiLumi HL-LHC PROJECT

LARP

Phase #1: RFD Prototype Schedule

ID	Task Name	Duration	Start	Finish
1	**RFD Prototypes (2 RFDs)**	**940 days**	**8/22/16**	**3/27/20**
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