



U.S. DEPARTMENT OF
ENERGY

Office of
Science

U.S. Activities on the High-Luminosity LHC: LARP Sustainability & Evolution as a Construction Project

HiLumi-LARP Collaboration Meeting

October 26, 2015

CERN

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Office of Science, U.S. Department of Energy**

GUIDANCE



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HEP Strategy

- **European Strategy for Particle Physics - Update 2013**
 - Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030...
- **US Prioritization for Particle Physics (P5) - May 2014**
 - Recommendation 10: Complete the LHC phase-1 upgrades and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project



US in-kind Contribution to HL-LHC:

A Preliminary Look

- **Various Candidates:**
 - 150 mm aperture Nb₃Sn quadrupoles
 - Crab Cavities and 11 T Nb₃Sn Dipoles
 - High Bandwidth Feedback System
 - Collimation and hollow e-beams
 - ...
- **Process of convergence among CERN-DOE-U.S. Labs-LARP initiated in Dec. 2012**
- **Initial consensus on core Priorities:**
 - Committed to a major stake in Nb₃Sn 150 mm quads
 - Crab cavities up to the SPS test and beyond to production
 - High bandwidth feedback was seen as a high impact contribution for modest resources.
- **Back up options:**
 - Hollow electron beams for halo removal

Dear Prof. Siegrist,

Following recent discussions, CERN is assuming that the total US contribution to the Hi-Lumi project is of the order of US\$200 million (construction project, excluding the R&D carried out within the LARP program that is due to continue for another 3-4 years in order to finish the R&D on the hardware and to continue the support for the important activities of accelerator physics and the long term visitor program).

The principle item of this contribution would be the Nb3Sn low-beta triplet. We understand that a preliminary evaluation of the quadrupoles (with 150 mm aperture) based on a joint study by LARP and CERN amounts to about 75% of the total US contribution, or US\$150 million, for half of the magnets (i.e. 10 cold mass quadrupoles, without cryostat, with no integration nor installation). This proposal (half USA and half CERN) is the preferred solution not only to stay inside budget but it also leverages the advanced US technology (LARP) and would allow CERN to fully master the technology for future maintenance and consolidation. Mutual agreement on this proposal can be discussed at a later date.

CERN proposes that the remaining 25%, or US \$50 million, be used to support hardware contributions on the following items (either full or part system):

- High bandwidth feed-back system for the SPS/Crab cavity with a crvo-module
- 11 T dipole (cold mass no cryostat)/electron-lenses

The feed-back system is of course subject to the success of the final prototype, like the Nb3Sn quadrupoles. Its cost is rather modest compare to the other items, so this could possibly leave some margin for other significant and visible contributions. The other items are not yet fully defined and/or their actual installation in the HL-LHC machine is not yet approved pending development of a final design and validation test results. So our suggestion is to keep the above list as a prioritized list to be reviewed depending on the outcome of the tests.

CERN would also like to express its gratitude if the DoE would support the continuation of the design of the D2 magnet based on the extensive expertise of BNL.

We remain at your disposal for any further information or clarifications.

Yours sincerely,


Rolf Heuer
Director-General


Stephen Myers
Director of Accelerators and Technology



TECHNICAL PROGRESS

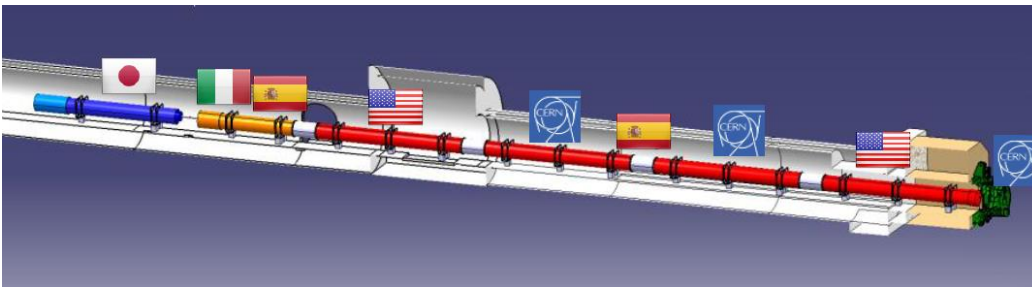


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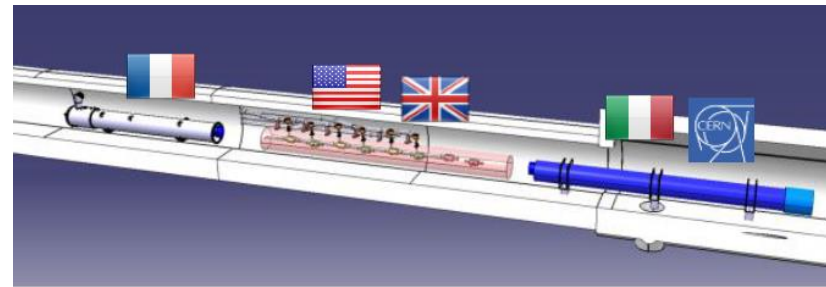
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U.S. LHC Accelerator Research Program (LARP)

- LARP is a national R&D program managed from Fermilab with the goal of preparing the U.S. to actively participate in the LHC High Luminosity Upgrade
 - Collaborating U.S. National Laboratories: BNL, FNAL, LBNL, SLAC
- **Goals of the national program include:**
 - Build and test 5 prototype Intersection Region (IR) quadrupoles
 - Commission the tooling production
 - Deliver crab cavities for SPS test
 - Deliver Wide Band Feedback System for SPS test
 - Support studies of hollow electron beam lens
 - Prepare for meeting milestones of the DOE Project Management process for U.S. contributions to the HL-LHC



HL-LHC Intersection Region Magnets



HL-LHC Crab Cavities



SC Magnet Fabrication and Testing Facilities

- LARP leverages U.S. infrastructure to meet R&D goals
 - Nb₃Sn IR quadrupole magnet efforts build on strand and cable technology developed by the U.S. HFM R&D program



Strand and Cable Lab



Short Coil Winding Table



Coil Reaction Oven



Coil Forming Press



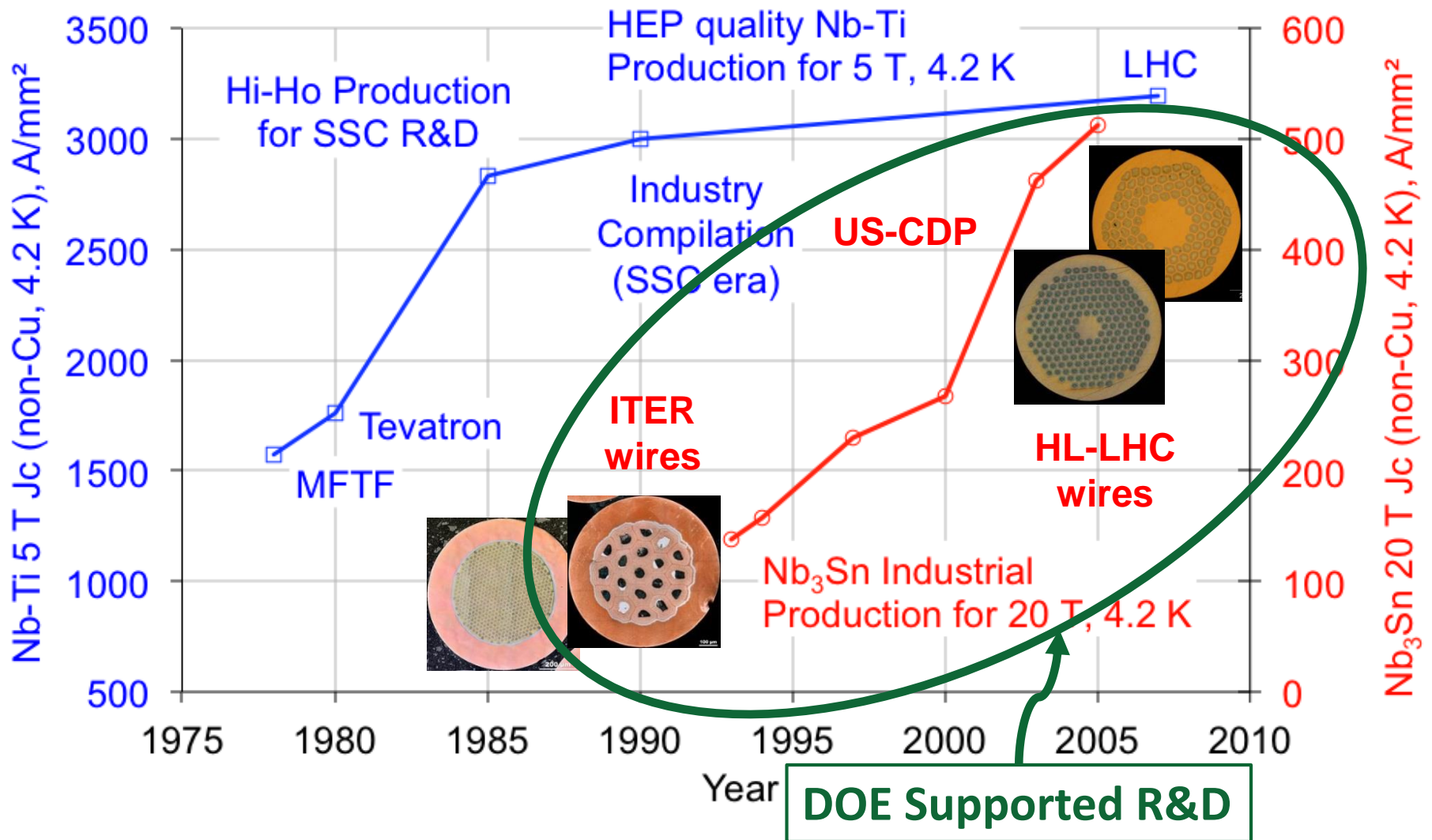
Vertical Magnet Test Facility



The Bar is High!



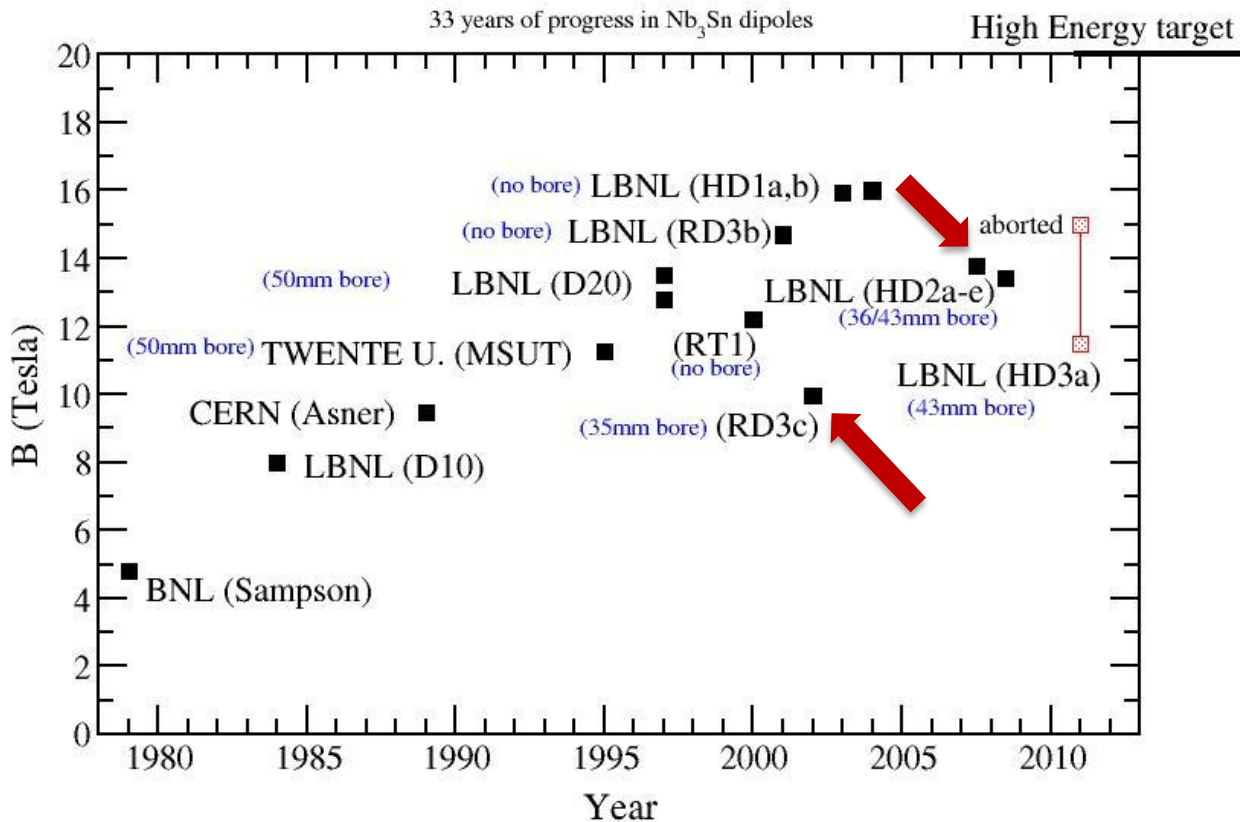
At 54, LTS's Have Reached Maturity **Splendor!**



High Field Magnets: Status & Challenge

A historical perspective:

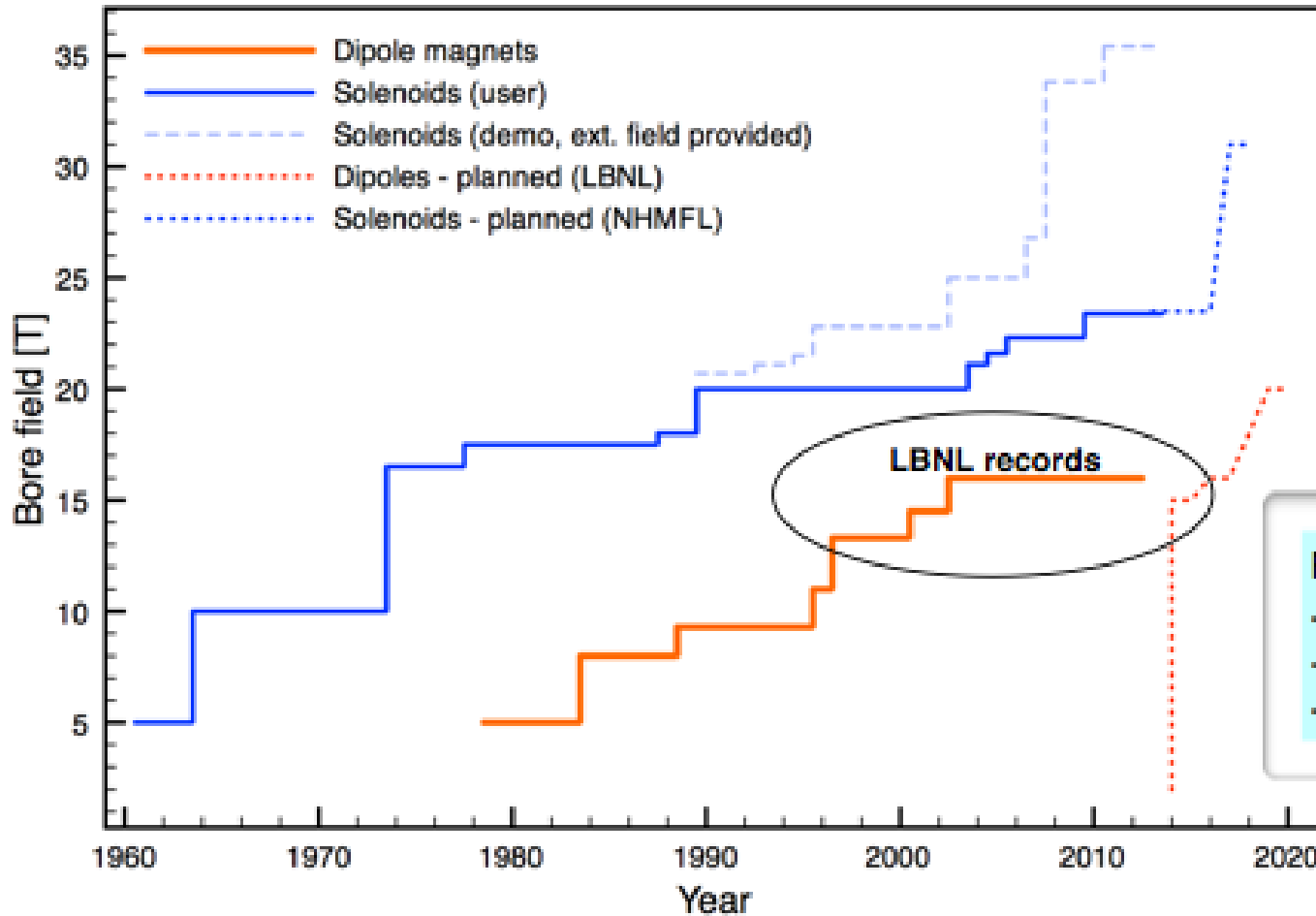
- **20 T - Nb₃Sn**
 - Brittle coils
 - Bore size
 - Coil stress
 - Structure stress
 - Delicate assembly
 - Protection
- **Next:**
 - New design?
 - Revised design?



Introducing a bore is a challenge!



Magnetic Field Growth with Time



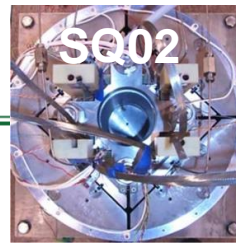
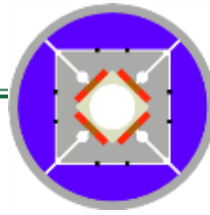
Record...
- Cos(θ): D20
- Common coil: RD3b
- Block: HD1-3



LARP Progress

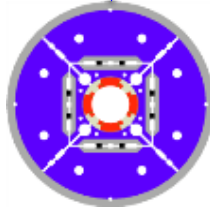
Subscale
Quad. SQ
0.3 m long
110 mm
bore

2004-2006



Technology
Quadrupole
TQS - TQC
1 m long
90 mm bore
2006-2010

Long
Quadrupole
LQS
3.7 m long
90 mm bore
2007-2012

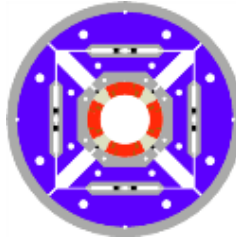


Max gradient **200 T/m**

Achieved:

- 83-87% SSL at 4.5K
- 74-79% SSL at 1.9K

High Field Quadrupole
HQ
1 m long
120 mm bore
2008-2014

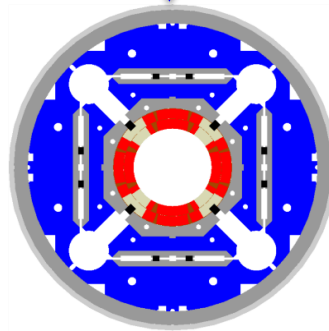


Max gradient **~210 T/m:**

Achieved:

- 98% SSL at 4.5K
- 90% SSL at 1.9K

LARP-CERN MQXF
1.5 m long
150 mm bore
2012-2018



Max gradient **~170 T/m**

Operational gradient **~132.6 T/m**



DELIVERABLES



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International Partnerships

Successful partnerships key to implementing U.S. long-term strategy



New Bilateral U.S.-CERN Agreement

Signed May 7, 2015



U.S.-CERN Agreement

- **Considering:**
 - That research in nuclear and particle physics is important for the further development of fundamental science and technological progress;
 - [U.S.] interest in participating in the scientific programme of CERN;
 - CERN's interest in participating in the scientific programmes of [the U.S.];
 - The established contacts between CERN and [the U.S.], including the activities conducted under the . . . "1997 Agreement";
- **The Parties desire to create a framework to ensure, on a long-term basis, opportunities for participation by scientists, engineers and technicians from one Party in research projects of the other Party, and for the provision of such other contributions as the Parties may agree;**
- **Scope**
 - This Co-operation Agreement ("Agreement") constitutes the framework within which the Parties may, **on the basis of reciprocity, further develop their scientific and technical co-operation.**
- **Implementation**
 - This Agreement shall **be implemented through the conclusion of Protocols** between CERN on the one hand, and [the U.S.] on the other hand

CO-OPERATION AGREEMENT

between

THE DEPARTMENT OF ENERGY
OF THE UNITED STATES OF AMERICA

and

THE NATIONAL SCIENCE FOUNDATION
OF THE UNITED STATES OF AMERICA

and

THE EUROPEAN ORGANIZATION FOR
NUCLEAR RESEARCH

concerning

Scientific and Technical Co-operation in Nuclear and
Particle Physics

2015



U.S.-CERN Agreement Annexes

- U.S. Department of State granted OMB Circular-175 authorization in August 2015 and Annexes (\equiv Protocols) to the Cooperation Agreement are now under negotiation with CERN
 - **Accelerator Protocol (III)**
 - LHC Accelerator Research Program (LARP)
 - U.S. Contributions to the HL-LHC Accelerator Upgrades
 - Future Circular Collider Initiatives with CERN (as an Addendum)
 - **Experiments Protocol (II)**
 - U.S. and CERN responsibilities for HL-LHC ATLAS and CMS detector upgrades
 - U.S. contributions towards the HL-LHC ATLAS and CMS detector upgrades
 - Framework of LHC Resources Review Boards (RRBs) and U.S. contributions to Common Funds
 - **Neutrino Protocol (I)**
 - CERN contributions to U.S.-hosted international neutrino program, including the Fermilab Short-Baseline Neutrino Program and LBNF/DUNE
 - Framework of Fermilab LBNF/DUNE RRBs and CERN contributions to Common Funds
- Protocols do not include detailed cost and scope, which will be specified through MOUs (non-binding) and Addenda (binding)



HL-LHC Deliverables & Funding Profile

- **Initial deliverables:**
 - Ten quadrupole cold masses
 - Crab cavity cold masses up to the SPS test

Fiscal Year	2018	2019	2020	2021	2022	2023	2024
Funding (\$M)	15,000	31,000	46,500	39,000	25,000	25,000	18,500
Total Funding (\$M)							200,000

- **We are planning for CD-0 (DOE Approval of Mission Need) within FY 2016**



U.S. HL-LHC Activities Summary

- **LARP has been successful in advancing R&D towards the accelerator technology needs for the HL-LHC**
 - Toohig Fellowship program has been a very successful element of LARP, and Fellows have gone on to take on major responsibility at CERN!
- **We are moving towards CD-0 (DOE Approval of Mission Need) for the HL-LHC accelerator upgrade project in FY 2016**

