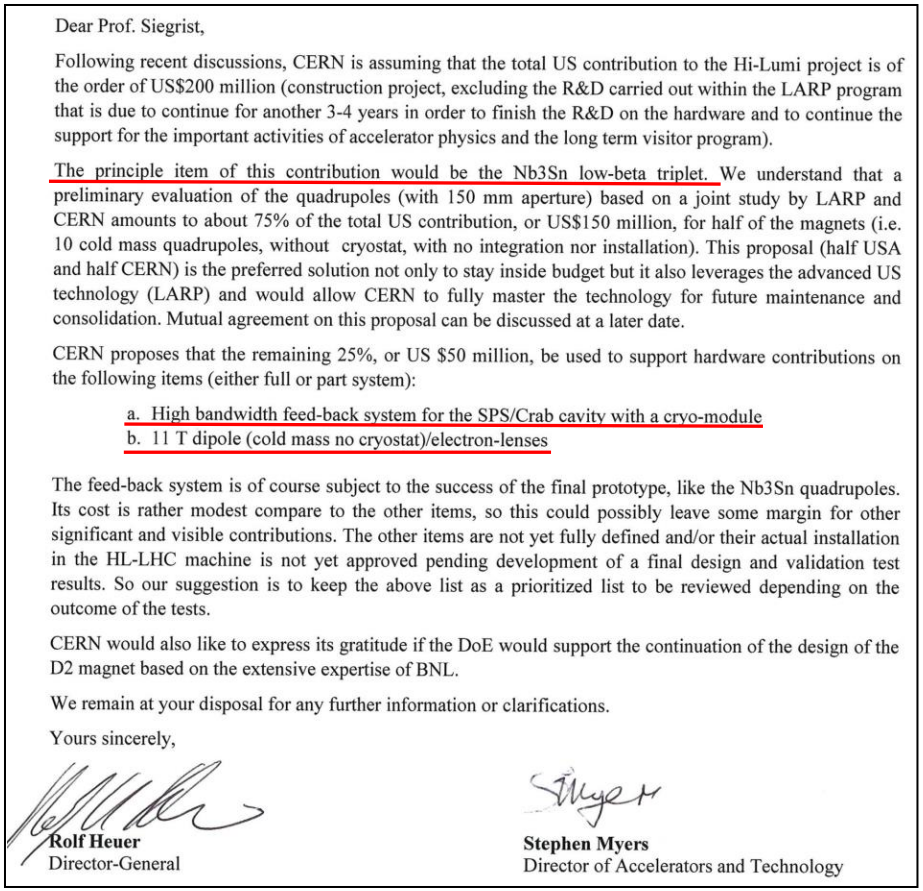
USA Contributions to the HL-LHC Upgrade

Ruben Carcagno
US HL-LHC Project Engineer

HL-LHC Standards and Best Practices Workshop
June 11, 2014

US Contributions – CERN Expectations

- Letter from CERN to DOE stating CERN assumptions:
  - ~ $200M U.S. contribution in construction only funds
    - Excludes R&D (being conducted under LARP funding)
  - ~ 75% is for half of the Nb3Sn low-beta triplets cold masses
    - Excludes cryostats, integration, and installation
    - The other half will be built by CERN using same design
  - The rest used for full or partial systems of:
    - Crab cavities
    - High bandwidth feedback system
    - The 11T dipole /electron lenses are not envisioned as project deliverables at this point
  - Formal agreement between CERN and DOE needs to be written



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):

a. High bandwidth feed-back system for the SPS/Crab cavity with a cryo-module
b. 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

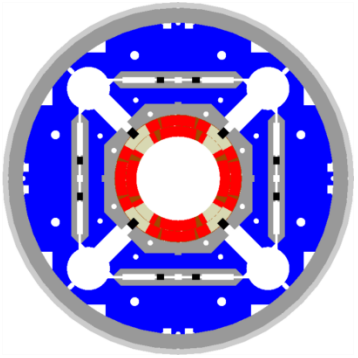
Stephen Myers
Director of Accelerators and Technology

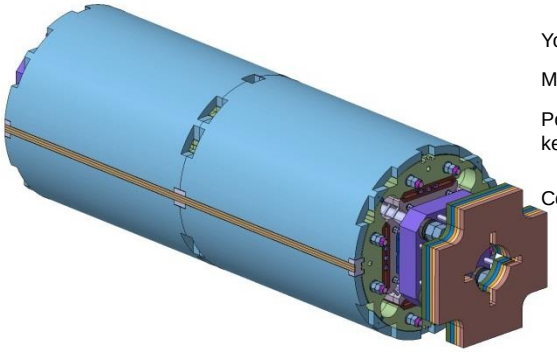
P5 Report

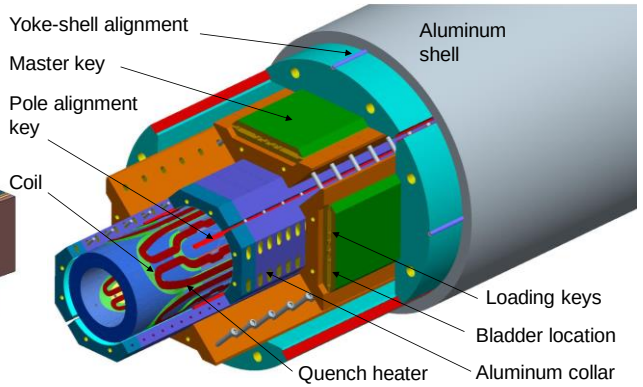
- The Particle Physics Project Prioritization Panel (P5) report was made public on May 22, 2014. Full report at:
  - http://science.energy.gov/hep/hepap/reports/
- P5 was charged by DOE to "…develop an updated strategic plan for U.S. HEP that can be executed over a 10 year timescale, in the context of a 20-year global vision for the field."
- From the P5 report:
  - "The HL-LHC is strongly supported and is the first high-priority large-category project (>$200M). It should move forward without significant delay"
  - "The [HL-LHC] experiments and accelerator upgrades cannot occur without the unique U.S. technical capabilities (e.g., the high-field magnets necessary for the success of the project) and resources"
  - From Recommendation 10:
    - "Continue the strong collaboration in the LHC with the 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. "
  - We expect that this strong P5 recommendation will translate into adequate and timely DOE funding for U.S. contributions to the HL-LHC

HL-LHC Nb3Sn Magnets

- The optics required for the HL-LHC go beyond what is possible with traditional NbTi magnets. The HL-LHC upgrade will use focusing quadrupoles based on newer Nb_3Sn High Field Magnet technology
  - Target is 140 T/m in 150 mm coil aperture. B_{peak} ≈12.3 T (LHC: 8T, 70 mm)
- **First time Nb3Sn magnets will be used in an accelerator machine!**
  - The US LARP program ("LHC Accelerator Research Program") has led the development of Nb3Sn magnets for the HL-LHC since 2004

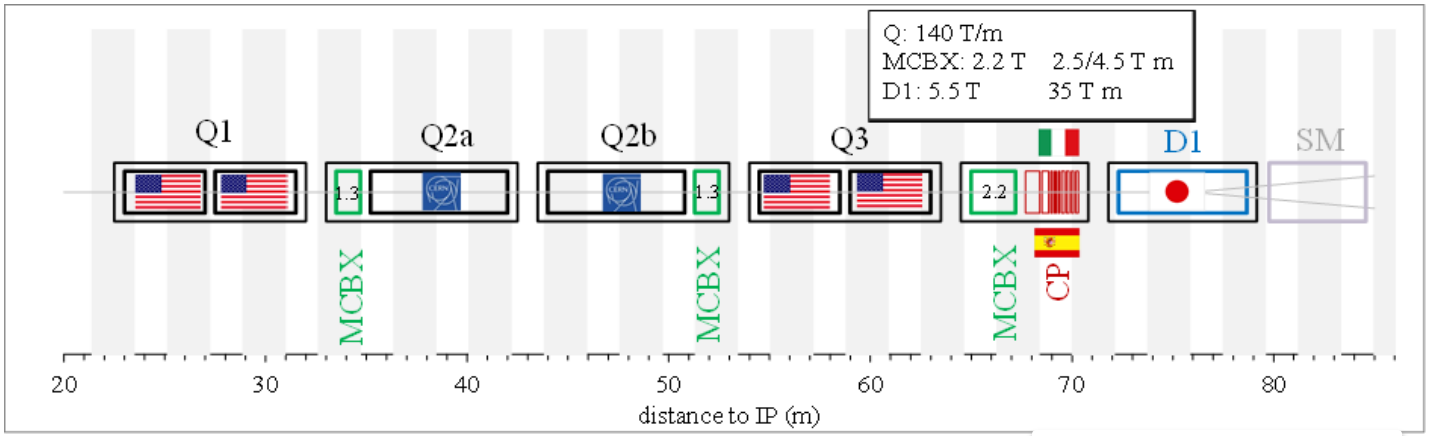






HL-LHC Nb_3Sn Magnets

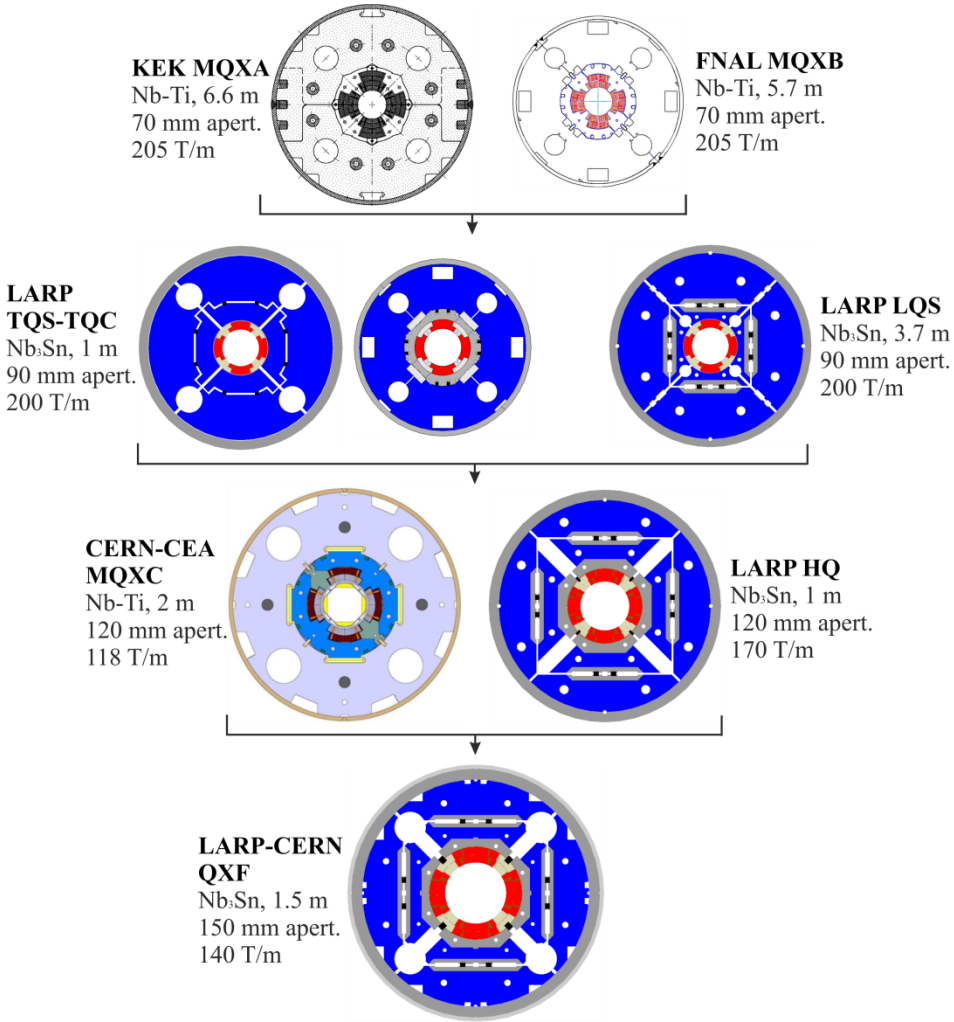
- Interaction Region Magnets
  - 4 Q1 and 4 Q3 (2 per IR) plus 1 spare each from US
    - Q1 and Q3 will probably contain two ~4.5 m long magnets each, for a total of ~20 cold masses
    - US deliverable: cold masses only, CERN will cryostat and install
  - 4 Q2a and 4 Q2b from CERN
    - Same design but longer



E. Todesco

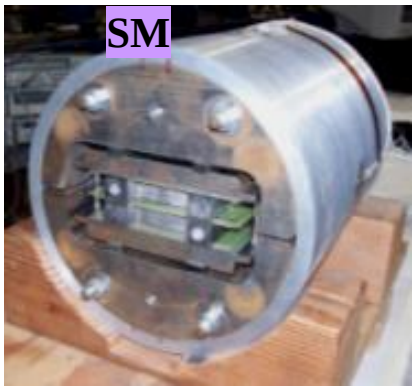
LHC low-β quadrupole overview

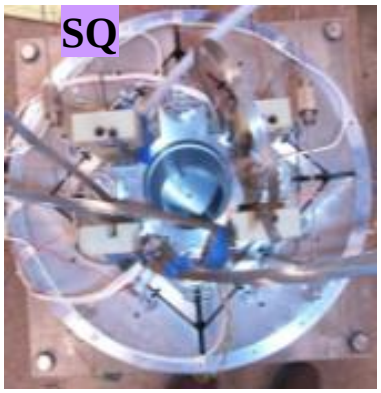
- Present Nb-Ti low-β quadrupole
  - Nominal luminosity
    - $L_0 = 10^{34}$ cm^{-2} s^{-1}
  - Integrated luminosity
    - ~300–500 fb^{-1} by 2021
- 2004, start of LARP Nb_3Sn program
  - Same gradient in larger aperture for ultimate luminosity (2-3 · L_0)
- 2008, two-phase upgrade
  - Phase-I, NbTi for ultimate
  - Phase-II, Nb_3Sn for higher L
- 2012, large aperture Nb_3Sn design
  - Increase the peak luminosity by a factor of 5 and reach 3000 fb^{-1} of integrated luminosity

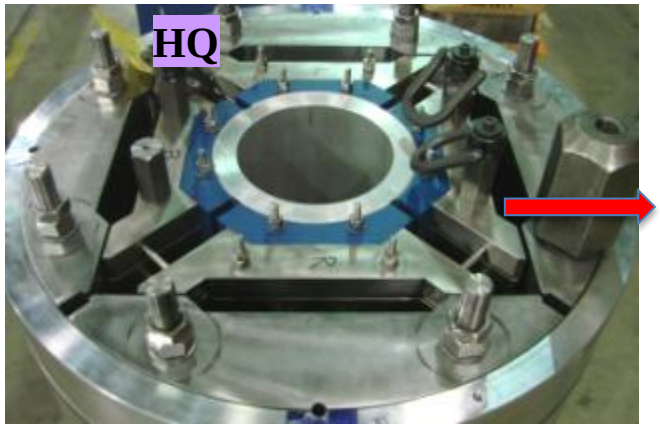


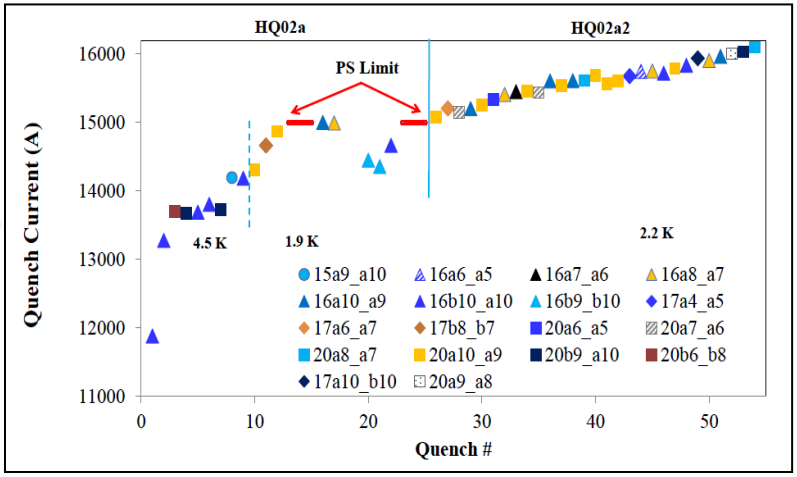
Paolo Ferracin

LARP Quadrupole Magnet Development





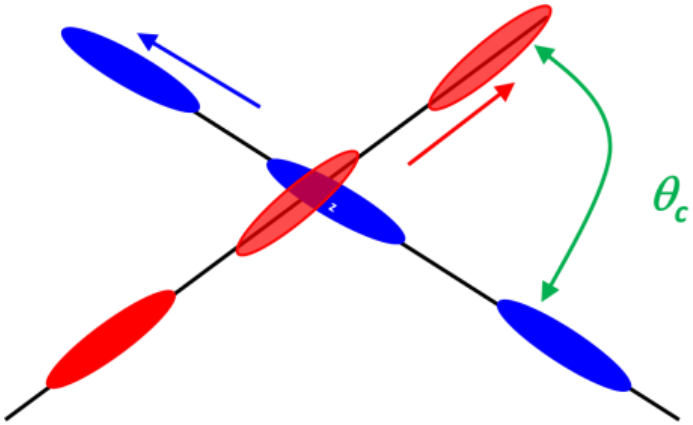




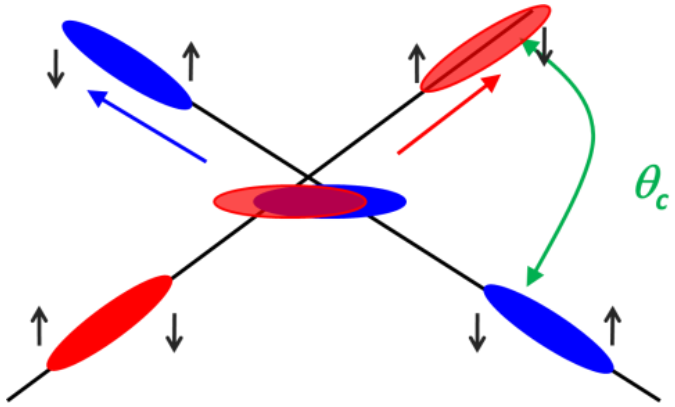
First (and only) ~4m long Nb_3Sn magnet in the world

HL-LHC Crab Cavities

- RF crab cavity deflects bunch head and tail in opposite direction so that collision is effectively "head on" and then luminosity is maximized
- **Crab cavity operation with proton beams has no precedent, and there is some concern over the safe operation of crab cavities in the LHC**
  - A complete crab cavity cryomodule will be tested in the SPS first.
- Construction for the HL LHC requires the fabrication of ten cryomodules with four cavities each, one cryomodule per ring at each side of the two high luminosity interaction points (ATLAS and CMS), plus two spares
- US deliverable (preliminary): dressed crab cavities. CERN will integrate in cryomodule and install
  - A total of 40 crab cavities are needed



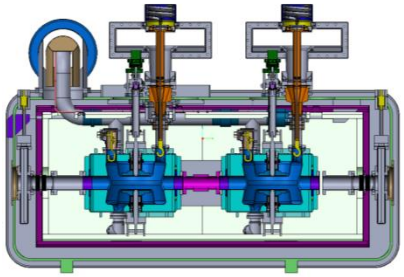
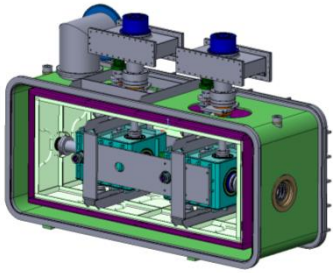
Without Crab Cavities



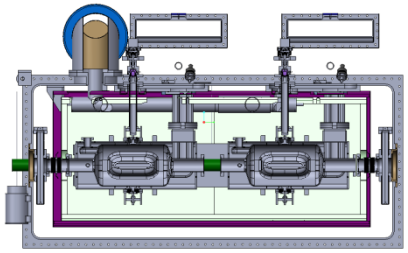
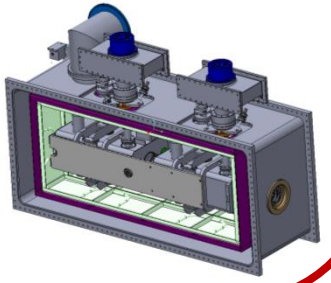
With Crab Cavities

Three Crab Prototypes for SPS Test

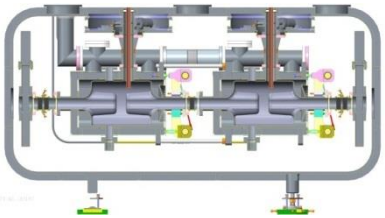
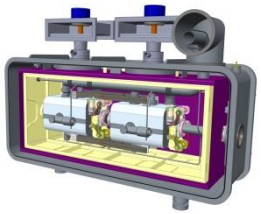
Double Quarter Wave (QW)

RF-Dipole

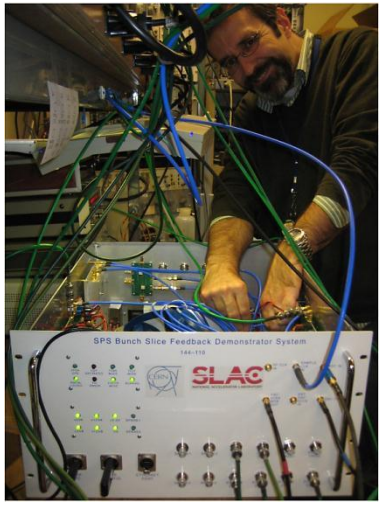
4-Rod

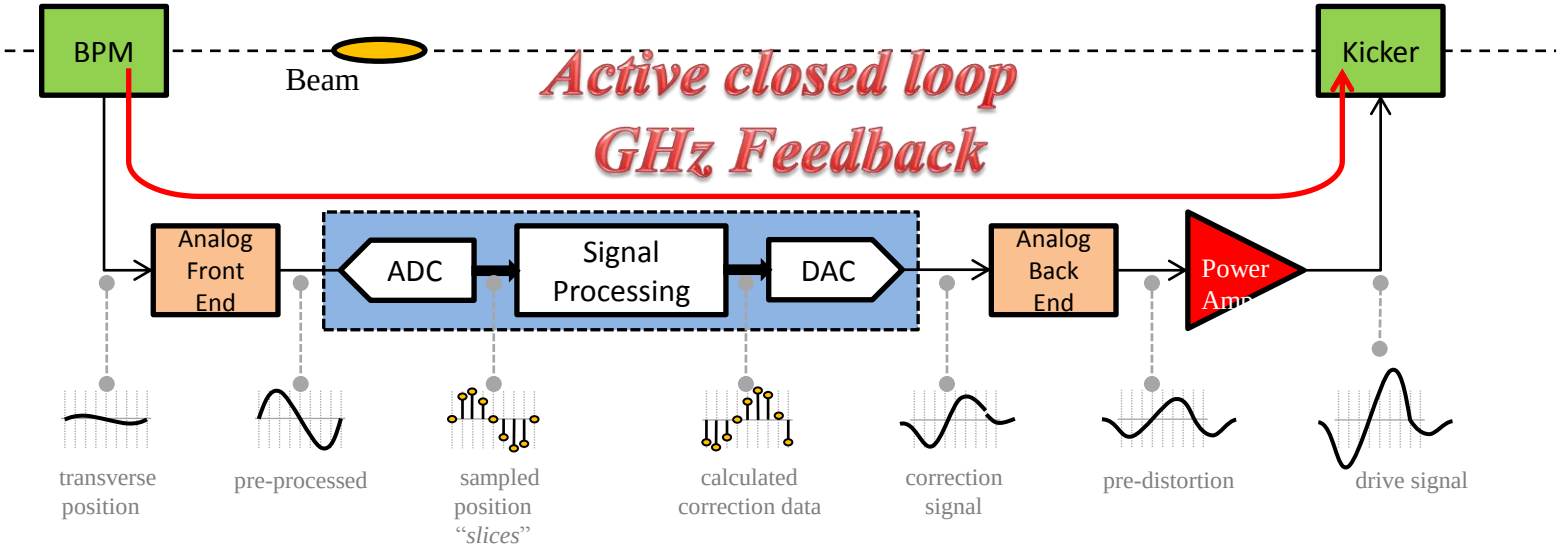




- SPS Beam Tests 2017-2018
- External Cavity Review at BNL May 5-7, 2014
- Recommendations:
  - 3 designs too much
  - Down select:
    - Pursue the Double QW, RF-Dipole designs
    - Put the 4-Rod design on hold

High Bandwidth Feedback System

- Purpose: to combat electron cloud and other intra-bunch instabilities. It is a GHz bandwidth instability control system
  - Increases LHC luminosity via higher SPS currents
- Initial target is an SPS full-function instability control processing system hardware, firmware and diagnostic for use at SPS post LS2.
- Technology applicable to LHC providing beam diagnostic as part of control.





US HL-LHC Collaboration

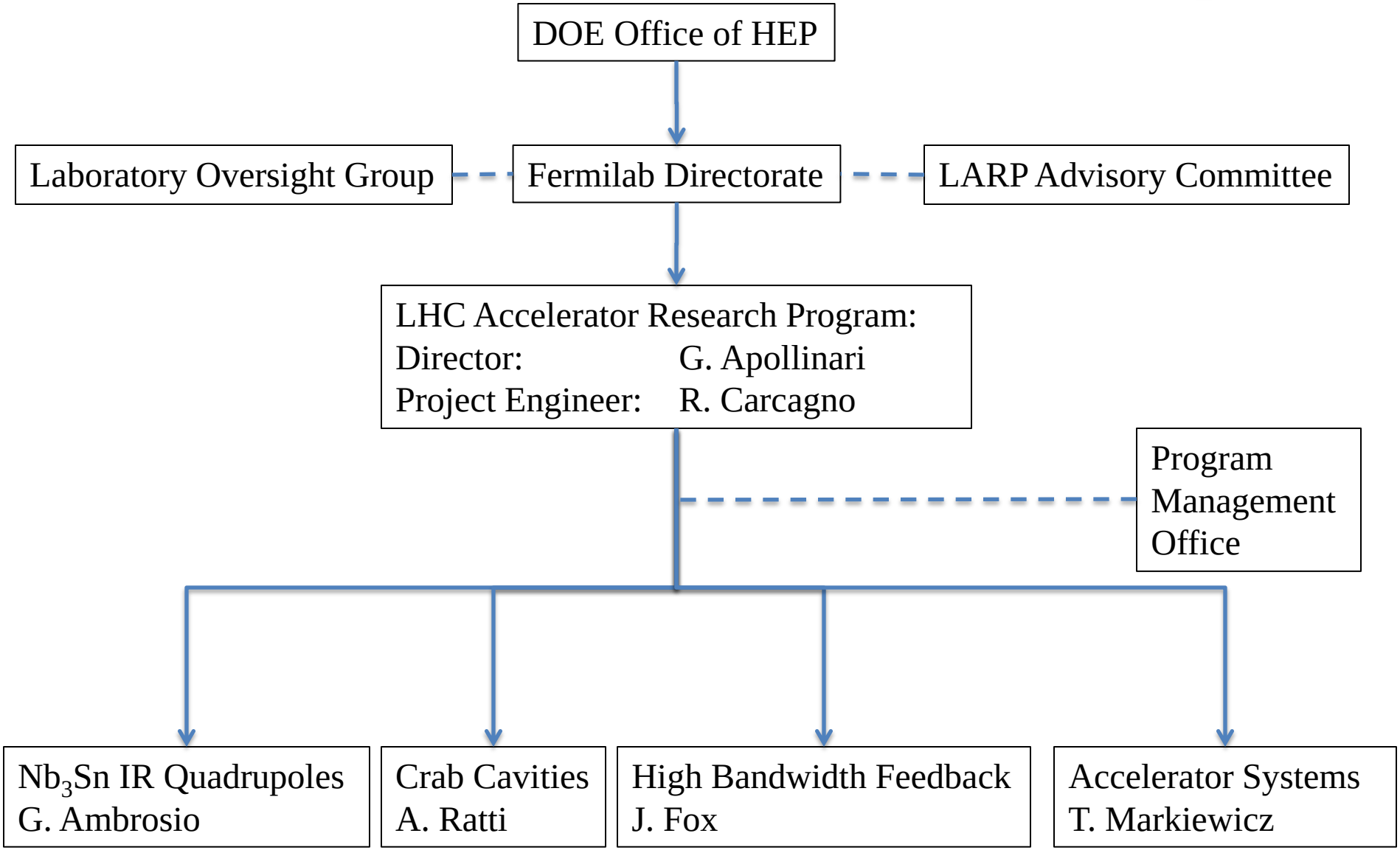
U.S. Institutions

European Institutions

HS HL-LHC Collaboration

- US Effort spread out in multiple Laboratories and Universities
- FNAL is the Lead Laboratory
  - Nb3Sn Magnets: FNAL, BNL, LBNL
  - Crab Cavities: BNL, ODU, SLAC, LBNL, FNAL
  - Wideband Feedback System: SLAC, LBNL
- Very tight coordination and collaboration with CERN (and UK for crab cavities). Examples of CERN scope:
  - Cryostat the US Nb3Sn cold masses for Q1 and Q3
  - Build the entire Q2 Nb3Sn magnets using same design
  - Cryomodule for crab cavities and test at SPS support
  - Supply kickers, cables, etc. for the WBFS system and support testing at SPS

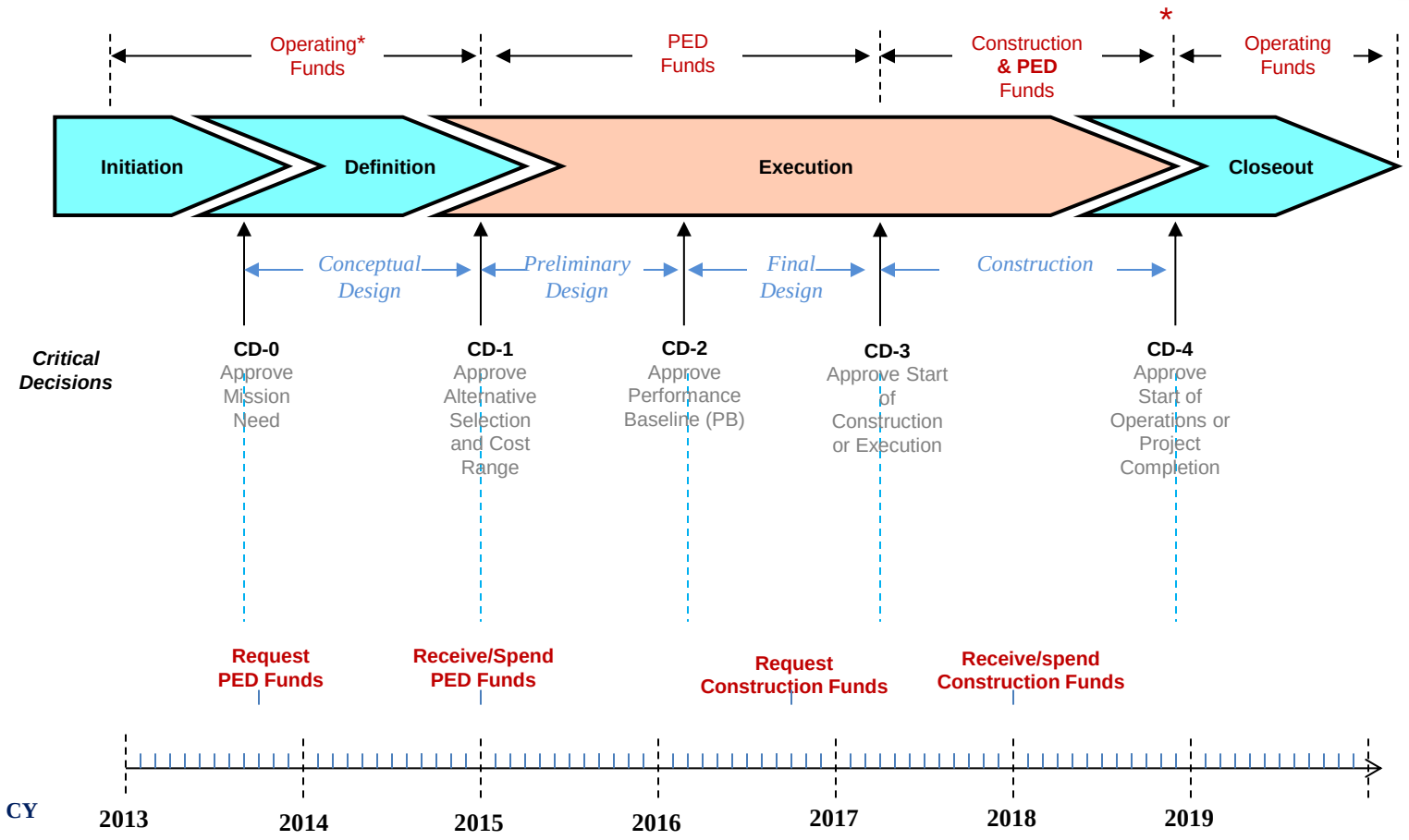
Organization



From LARP R&D to US HL-LHC Project

- The R&D and prototyping of US contributions to HL-LHC are being done under LARP since 2004
- This effort is in transition towards a DOE Order 413.3B construction project for the fabrication of US contributions deliverables to HL-LHC
  - DOE construction project governed by “Critical Decision” Gateways:
    - CD-0: Approve Mission Need
    - CD-1: Approve Alternative Selection and Cost Range
    - CD-2: Approve Performance Baseline
    - CD-3: Approve Start of Construction/Execution
    - CD-4: Approve Project Completion
  - CD-0 officially marks a project start. All costs from CD-0 forward accrue to the Total Project Cost (TPC)
  - A project shall be completed at CD-4 within the original approved performance baseline at CD-2

Project and Budget Process—Standard Scenario



•Operating Funds are used for conceptual design between CD-0 and CD-1.

Tailoring for US HL-LHC

- Consolidate CD-0/1/2 by mid-FY17
- CD-3 by early FY18
- CD-4 by end FY23
- Before CD-2, a firm Performance Baseline (PB) for US HL-LHC deliverables must be established.
  - The PB includes scope, cost, schedule, and minimum Key Performance Parameters (KPPs)
  - Represents DOE's commitment to Congress
- Before CD-2 , an Earned Value Management System (EVMS) must be fully functional and reporting monthly to DOE
  - Red triggers for cost and schedule variance requires a variance analysis report to be written with explanations and corrective actions

PM Actions Prior to CD-0/1/2

- Required by DOE O 413.3B
  - Examples of activities prior to CD-0/1/2:
    - Finalize Scope (deliverables)
    - Finalize Work Breakdown Structure (WBS)
    - Finalize Organizational Breakdown Structure (OBS)
    - Define Responsibility Assignment Matrix (RAM)
    - Define Control Accounts (CA)
    - Appoint CA Managers (CAMs)
    - Finalize Master Schedule
    - Finalize Cost Estimates and Time-phased budget baseline
    - Finalize Performance Baseline (PB)
    - Setup Change Management Control
    - Setup Earned Value Management System (EVMS)
  - Examples of required documentation for CD-0/1/2:
    - Mission Need Statement
    - Acquisition Strategy
    - Project Execution Plan
    - Project Management Plan
    - Risk Management Plan
    - Preliminary Design Report
    - Performance Baseline (PB)

Scope and Schedule

- Finalize Scope (Deliverables)
  - The US HL-LHC scope must fit within the DOE budget guidance (to be provided… strong P5 recommendation…)
    - Once DOE guidance is known, agree with CERN on scope of final US deliverables for HL-LHC
      - Example: individual cold mass sections for Q1 and Q3, or a full cold mass in a stainless steel helium pressure vessel ready to be inserted in a cryostat?
- Finalize Master Schedule
  - The US HL-LHC schedule must fit within the CERN overall HL-LHC LS3 schedule
    - The DOE CD process may force freezing of design parameters sooner than CERN would like or need!
      - Example: freezing the final length of individual cold mass sections for Q1 and Q3
    - A DOE Review of LARP in February 2014 recommended locking down the technical parameters for the Nb3Sn strand procurement by end of FY-2014

Policies and Manuals

- DOE Office of Science Project Decision Matrix
  - Includes requirements for documentation and reviews for each Critical Decision (CD) gateway
  - Mandatory for DOE Order 413.3B construction projects
  - http://science.energy.gov/~/media/opa/pdf/processes-and-procedures/Project_Decision_Matrix_11_2010_n.pdf
- As the lead laboratory, FNAL policies and manuals are expected to be customized and adopted for the US HL-LHC Project when appropriate, with input from the collaborating institutions
- FNAL Engineering Manual
  - http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual.pdf
  - FNAL/TD Engineering Work Procedures Policy
    - http://tdserver1.fnal.gov/tdweb/hq/policies/2300.pdf

Policies and Manuals (Cont)

- FNAL Environment Safety and Health Manual (FESHM)
  - http://esh.fnal.gov/xms/ESHQ-Manuals/FESHM
  - Specifies adherence to US National Codes. Examples:
    - ASME BPVC, Sections VIII and IX (Welding and Brazing)
    - ASME B31.3 Piping Code
    - ANSI/ASME Y14.5M - Dimensioning and Tolerancing
    - OSHA – Occupational Safety and Health Administration
    - ANSI/NFPA 70– National Electrical Code (NEC)
    - IEEE C2 - National Electrical Safety Code
- FNAL Quality Assurance Manual
  - http://esh.fnal.gov/xms/ESHQ-Manuals/QAM
  - FNAL/TD Quality Management Program
    - http://tdserver1.fnal.gov/tdweb/hq/policies/2010.pdf

CERN Requirements

- CERN will have additional requirements
  - This workshop will start addressing
  - Hopefully there will be considerable overlap and equivalences to minimize cost of compliance
    - US HL-LHC will operate under a fixed budget
  - There is precedence: the present US LHC IR quad US deliverables. Example:

		CERN/LHC – US/LHC MOU ON ACCELERATOR MECHANICAL SAFETY	
US LHC Accelerator Project Document No. (if required) N/A	*CERN LHC Document No. (if required)* TIS-TE-MB-98-74	*Created* 14-DEC-98	*Page* 1 of 6
		Modified	*Rev. No.* 1.0

MEMORANDUM OF UNDERSTANDING

I. Purpose

This Memorandum of Understanding (MOU) defines the mutual interactions between the CERN Technical Inspection and Safety Commission (TIS) and the US LHC Accelerator Project with respect to the structural safety of mechanical equipment manufactured or purchased by the US Laboratories and delivered to CERN for installation in the LHC. This MOU is compliant with the Implementing Arrangement between CERN and the US Laboratory Collaboration and the US LHC Accelerator Project Management Plan. This MOU does not address non-safety related QA tests, inspections, certifications, etc. that will be required such as leak checks or acceptance tests upon arrival at CERN. These requirements will be defined in other documents.

Done in two copies in the English language and agreed to by:

Helmut Schönbacher, Head, Technical Inspection and Safety Commission, CERN — 14.1.99 (Date)
Lyndon Evans, Director, LHC Project Leader, CERN — 15/1/99. (Date)
Michael Harrison, RHIC Associate Project Director (Collider), BNL — 25 Jan 9 (Date)

Maurizio Bona, Head, TIS-TE Group, CERN — 14 Jan 99 (Date)
Thomas Taylor, LHC Deputy Division Leader, CERN — 14.1.99 (Date)
Peter Limon, Technical Division Head, Fermilab — 25 Jan 99 (Date)

Gunther Rau, LHC Project Safety Officer, CERN — 14.01.99 (Date)
William Barletta, Accelerator and Fusion Research Division Head, LBNL — 25 Feb 99 (Date)

James Strait, US LHC Accelerator Project Manager, Fermilab — 14 Jan 99 (Date)

Engineering Teams and Tools

- The design of the US deliverables is at an advanced stage
  - Strong design teams have been in place as part of the LARP R&D effort
- Examples of engineering tools in use by various collaborating institutions:
  - ANSYS, NX, PTC Pro, Teamcenter, Engineer Wildfire, PTC Intralink, Vector, BEND, ROXI, etc.
- No standards for engineering tools and document control have been adopted for the US HL-LHC project yet.
- More details of design and engineering tools in Helene and Dan's presentation for the LBNL scope of work on magnets

Summary

- The US deliverables for HL-LHC have been narrowed down to three items: (1) cold masses for Q1 and Q3; (2) crab cavities; and (3) a wideband feedback system
  - Several US institutions involved: FNAL, BNL, LBNL, SLAC, ODU
  - FNAL is the lead laboratory
- The P5 report recently released provides a strong recommendation for US support of HL LHC upgrades
- A DOE budget and formal agreement between CERN and DOE is not available yet
- The design of US deliverables for HL-LHC is at an advanced stage as part of the US LHC Accelerator Research Program (LARP)
- LARP is now in transition towards a formal DOE O 413.3B construction project
  - The DOE project will impose strict project management requirements for documentation, reviews, monitoring, control, etc.
  - FNAL safety, quality, and engineering policies and manuals are expected to be used as a basis for the US HL-LHC project
  - CERN requirements and specifications to be incorporated
    - Hopefully will find significant overlap and equivalency
    - There is a precedence for the present US LHC IR quadrupoles