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White Paper on

CERN/FNAL Collaboration for the Development and Construction of Nb_3Sn Dipoles for the LHC upgrades

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1 Nb_3Sn Accelerator Magnets Development

Nb_3Sn has been recognized as a viable superconductor for the construction of accelerator magnets since its discovery. In the last decade, the DOE has supported, through its OHEP branch, several R&D efforts aimed at the development of high-performance Nb3Sn strand advanced high-field accelerator magnets, in particular focusing on the quadrupoles to be used at the Large Hadron Collider (LHC) for luminosity increase toward the end of the present decade (2020). This latter effort, called LARP (LHC Accelerator Research Program) has involved the US national labs (LBNL, BNL, SLAC and Fermilab) and has recently successfully achieved the goal of building a ~4 m long 90-mm aperture Nb_3Sn quadrupole reaching the field goal of 200 T/m. Along the way the LARP collaboration has made several important breakthroughs in Nb_3Sn accelerator magnet technologies including the development and demonstration of high-performance strand and cables, reliable and reproducible coil fabrication technology, variety of accelerator quality mechanical structures and coil pre-load techniques.

An outcome of the OHEP investment in in advanced accelerator magnet R&D programs including LARP is the fact that the Nb_3Sn accelerator magnet technology know-how is now firmly in US hands and the rest of the world is looking at the US community as the leader for applications above and beyond those initially considered by LARP. One such application and opportunity is described in this White Paper.

2. High Field Magnets for LHC Insertions

The opportunity for a short-turn around (before the above-mentioned LHC inner triplet upgrade) application of the US-developed Nb_3Sn technology in a working accelerator such as LHC has been firstly recognized in 2010. The opportunity is based on recent CERN plans developed at the LHC Performance Workshop in Chamonix (France) in January 2010 [1]. It has been described in a CERN Project Note [2] and presented by L. Rossi at the Accelerator Physics and Technology Seminar on July 29th 2010 at Fermilab [3].

The proposal involves the replacement in dispersion suppression (DS) areas near Q8 and Q10 of four regular LHC 8.3 Tesla, 14 m long, NbTi dipoles with four 11 T, 11 m long, Nb_3Sn dipoles to create four drift spaces with an approximate length of 3.5 m each in the LHC lattice for the insertion of cryo-collimators (fig 1).

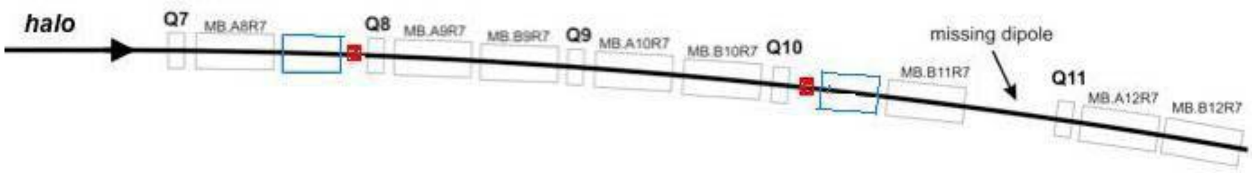

Figure 1. Position of Nb_3Sn dipoles and cold collimators in the LHC DS lattice.

It is important to realize that, due to the size of the work and the complexity of its integration in an operational accelerator, the construction part of the project will be managed by CERN. The opportunity for the US and FNAL is to contribute to the project, transferring the technology, participating in the design of the dipoles and contributing to the construction of the cold masses in such a way as to decrease the overall risk of the project.

3. Straw-man Plan to Pursue the Opportunity

The proposal described in the previous section can be pursued as a CERN-FNAL collaboration with possible input from other institutions or individuals. Both Fermilab and CERN have appropriate infrastructure for the presented proposal including laboratories for SC strand and cable testing; cabling machines to produce multistrand Rutherford-type cables; magnet production facilities with short and long tooling for coil fabrication and equipment for magnet assembly; magnet test facilities to test magnet models and prototypes in superfluid and normal helium. Both labs have skillful personnel including magnet scientists, engineers and technicians capable of designing, fabricating and testing SC accelerator magnets.

A straw-man plan for this proposal includes two phases: a D&D (Design and Development) phase and a construction phase.

The D&D phase, planned for the next 3 years, would be executed at FNAL and CERN and concentrate on the construction, in the first year, of a short (~1.5 m long) 11 Tesla demonstration single-aperture dipole model, followed by the construction of several short coils and dipole magnets to be tested in the single or double-aperture configurations (fig 2). The D&D phase would conclude with the construction of a long (~6 m), double-aperture dipole prototype. The funding for the High Field Magnet R&D core program at FNAL, although limited, is believed to be sufficient to support the D&D effort at FNAL.

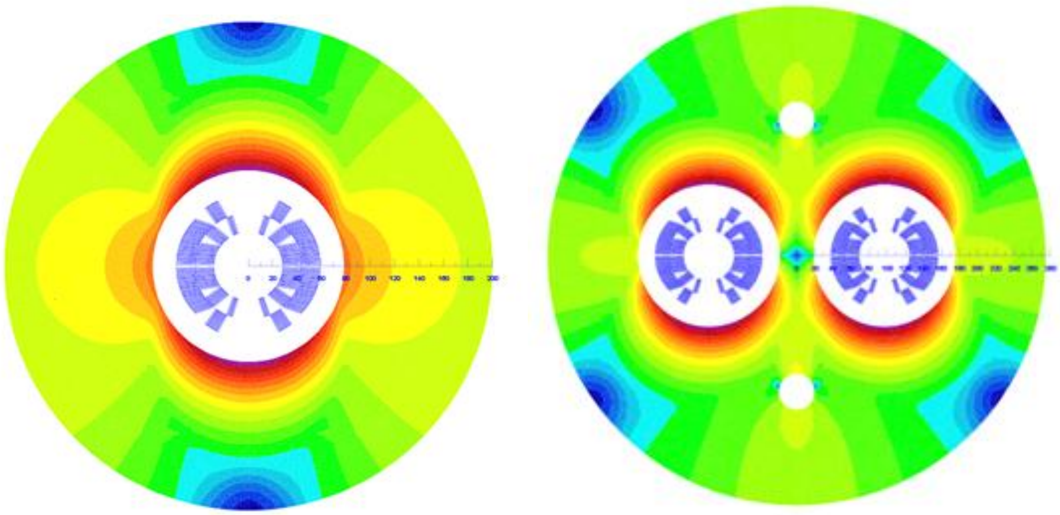

Figure 2. Single-aperture (left) and double-aperture (right) dipole configurations.

Following a successful long dipole prototype and the completion of the LHC consolidation in ~2013, CERN would be in the position to make a decision on the feasibility of the overall scheme to replace NbTi magnets with 11 T Nb_3Sn magnets for the insertion of additional collimators around the LHC ring in IR2 & IR7 (2016), and later, in IR1, IR5 and IR8.

While the planning for the construction phase is still tentative and would be managed by CERN, CERN and FNAL could share the responsibility for construction and collaring of the coils, while CERN would install the coils in yokes, install the cold masses in cryostats, and test the magnets.

In general CERN and FNAL would share responsibilities for the design and production of the first year D&D demonstration model, and they would also share responsibility for coils and collar structures production from the second year onward during the D&D phase with the goal of achieving a complete transfer of coil making technology between the two institutions. The construction phase would be managed by CERN with active participation by FNAL as deemed appropriate and approved by funding agencies.

4. Benefits to US HEP Community

The immediate benefits of a timely and successful execution of this proposal for the US HEP community would be the possibility to participate in the High Energy Frontier physics research allowed by the LHC reaching its ultimate performance. In fact, the creation of sufficient drift space in the LHC lattice for the insertion of cold collimators in 2016 would allow the LHC to reach and possibly even exceed the design luminosity of 10^{34} $cm^{-2}s^{-1}$.

A deeper benefit for the US-HEP community would be a short term (~ 6 years), real life application in an operating accelerator of a unique technology pioneered and developed at FNAL and in the US in the last decade. It would also provide a near-term goal to help focus continued Design and Development on Nb_3Sn magnets. For both CERN and US-HEP, the project will validate Nb_3Sn as the choice for the replacement of the interaction region quadrupole magnets being developed by the US-LARP for the LHC luminosity upgrades planned in 2020-2021.

In the longer term, demonstrating the maturity of the Nb_3Sn technology at this early stage will support the Muon Accelerator Program (MAP) presently pursued at FNAL (where the collider ring requires 10-12 T, Nb_3Sn magnets) and the exploration of HTS-Nb_3Sn-NbTi hybrid magnets for a possible LHC energy increase (LHC-doubler or LHC-tripler) considered around 2030.

Finally, CERN and the european magnet community are extremely interested in acquiring the Nb_3Sn magnet-making technology. As with all new technologies, an increase in the number of adopters, developers and new users can only have beneficial effect on the technology itself and on its applications to the society at large. The US society would be a beneficiary of these world-wide advances such as, for instance, in applications related to use of Nb_3Sn magnets for medicine (MRI).

5. Risks in pursuing the 11 Tesla Dipole Opportunity

Technical risks for the LHC are limited since the proposal is based on positive results achieved at Fermilab during the Nb_3Sn magnet R&D for VLHC[4] and LARP[5,6]. The back-up plan to the construction and installation of Nb_3Sn dipoles in LHC is the painful, but viable, relocation of 24 existing magnets and several cryoboxes in the LHC lattice.

A potential "opportunity" risk for FNAL would be the investment of D&D funds in the initial phase of magnet development that would not pan out in a tangible construction project in the immediate term if the demonstration and model magnets fail to perform appropriately. We believe that the knowledge gained in the development of a real-life practical accelerator magnet would nevertheless represent a good return on the initial R&D investment. An apparent disadvantage of this investment of scarce R&D funds at FNAL would be the need to give lower priority and – possibly - delay the two R&D tasks presently conceived for the future High Field Magnet R&D program at FNAL: collaring of the 4-m long LQ Nb_3Sn quadrupole magnet and development of Nb_3Sn dipole models for MAP. We believe, however, that the experience gained in building the 11 Tesla dipoles would be valuable for the other programs and that a success of this proposal would represent an implied success for the two goals mentioned above.

6. CERN/FNAL Collaboration Timeline

The rough plan introduced earlier needs to be fully negotiated and adopted by all parties involved on a reasonable time-scale. A possible timeline for the overall plan is the following:

Discussion with FNAL Directorate:	Sep ‘10
Convergence with CERN on mutually agreeable D&D Plan:	Oct-Nov ‘10
Discussion with funding agencies (DOE/CERN):	Dec ‘10
CERN-FNAL tentative MOU:	Feb ‘11
Conceptual Design Study Phase	up to Dec ‘11
D&D Phase	Mar’11-Dec’13
Construction Decision (go/no-go)	Jan ‘13
Construction Phase (tentative)	Jun ’13-Jun ‘16

References

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