20 T hybrid magnets

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As stated on the 2014 Particle Physics Project Prioritization Panel (P5) strategic plan report for U.S. High Energy Physics (HEP), high-energy proton-proton colliders are the most powerful tool for direct discovery of new particles and interactions [1]. In a circular accelerator, the most effective way to achieve very higher collision energies is to maximized the field strength of the main bending dipoles. So far, particle accelerators like the Tevatron [2], HERA [3], RHIC [4], and LHC [5] have used Nb-Ti, a low temperature superconducting (LTS) material in their main dipole magnets to achieve fields up to the 9 T level. In the High-Luminosity LHC, for the first time, superconducting magnets based on Nb_3Sn, also an LTS material, and operating at a 10-12 T field level will be installed 1) in the LHC interaction regions, to increase the collision rate, and 2) in the LHC arc, to provide space for additional collimators [6]. In parallel, R&D programs in Europe, within the FCC collaboration [7], and in the US, as part of the Magnet Development Program (MDP) [8], are developing superconducting magnets aiming at a bore fields of 15 to 16 T, which is considered the practical limit for Nb_3Sn accelerator magnets.

In order to further push the magnetic field of the dipole magnets beyond the Nb_3Sn limits, a new type of superconducting materials, called High Temperature Superconductors (HTS), needs to be included in the magnet design. For particle accelerator magnets, the most promising HTS materials currently under consideration are Bi2212 [9] and REBCO [10]. However, their outstanding performance in term of maximum achievable field still comes with a significantly higher cost with respect to Nb_3Sn. Therefore, an economically viable option towards 20 T dipole magnets could consist in an "hybrid" solution, were HTS materials are used in the high field part of the coil winding with so-called "insert coils", and Nb_3Sn and Nb-Ti material is adopted in the lower field region with so-called "outsert coils". Preliminary design studies of 20 T dipole hybrid magnets were carried out in 2005 [11] and 2014 [12], [13], whereas a full HTS option was analyzed in 2018 [14] (see Fig. 1, from left to right).

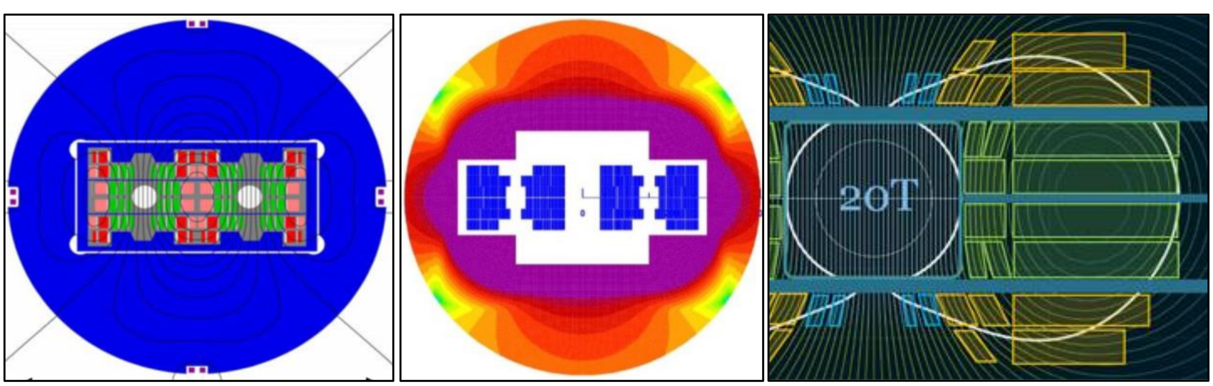

Fig. 1: Cross-section of 20 T magnets: stress-management design [11], block design [12] [13], and aligned blocks design [14].

With this letter we express our interest in developing a 20 T hybrid magnet composed by both Nb_3Sn and HTS superconducting coils. Such a magnet constitutes a remarkable challenge in particular from the point of view of mechanical integration of different coils, testing, and protection, and it therefore requires significant effort both in terms of design and analysis, and of fabrication and test of sub-scale models.

The initial part of this development should be focused on investigating different design options and comparing them from the viewpoint of magnetics, mechanics, and quench protection. The MDP program is currently performing R&D on large aperture cos-ϑ Nb_3Sn dipole magnets with stress-management designs, where the accumulation of electro-magnetic forces is prevented by mandrels (spars) and ribs [15], [16]. Additional possible design options under investigation are block-coil [17] and common-coil [18], [19] configurations. In parallel, still within the MDP, insert coils made both with Bi2212 [20] and REBCO [21] conductor are being fabricated and tested. The development of the 20 T hybrid should take advantage of the aforementioned efforts and, through computational and experimental work, it should aim at addressing fundamental questions related to these combined LTS - HTS magnets, like

- How do we best define operating margin and field for hybrid accelerator magnets?
- What are the mechanical limits and possible stress management approaches for 20 T hybrid LTS/HTS magnets?
- Do hybrid designs benefit from the best features of LTS and HTS, or inherit the difficulties of both materials?
- Is there a design option (cos-ϑ, block, common-coil) more suitable for hybrid magnets?
- How do we power and protect a hybrid accelerator magnet?
- What drives the cost of 20 T accelerator magnets? How can it be minimized?
- Can we build practical and affordable accelerator magnets with HTS conductor(s)?

We believe that a strong R&D program towards 20 T hybrid magnets will be extremely beneficial to the entire High Energy Physics community and will pave the way towards very high field magnets for the next generation of particle accelerators.

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