Snowmass 2021 Letter of Interest

Brookhaven Engagement with Integrated Magnet Development for Future Accelerators and Particle Physics Experiments

Accelerator Frontier (AF), Multi-TeV Colliders (AF4)

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High field and high precision magnets are at the heart of particle accelerators and many other experiments for high energy and nuclear physics (axion search, alpha-g, etc.). Brookhaven National Lab's (BNL's) Superconducting Magnet Division, along with BNL partner labs like MIT and other sister national labs (FNAL, LBNL, NHMFL), have been central to the development of the highest performance high field magnets needed for high energy physics accelerators world-wide. The US has invested in and played a significant role in both the development of the Large Hadron Collider and the current High Luminosity Upgrade at CERN, developing cutting-edge IR focusing magnets to reach the high luminosities necessary to fully exploit the research frontier at the LHC energies. The expertise and impact of the US high field magnet development community extends from world leading high field magnet technology for accelerators to a broad range of high field magnet applications ranging from fundamental physics, materials science, fusion energy, NMR, MRI, and future applications like offshore wind and electric aircraft. Since the first summer study on superconductivity, the seminal meeting that defined the role of superconducting magnets in accelerators, BNL and its sister labs have played a central role in the development of robust superconducting conductors, cables and magnets for accelerators and other applications. BNL has a strong history of developing low temperature superconducting dipoles and multipoles from concept through building, testing and operations in accelerators. In addition to LTS magnet development, BNL has a strong history of high field magnet development in the HTS magnet space, starting from the discovery of the conductors to current programs in the high field magnet space in fusion and accelerator development. BNL developed robust high-field superconducting dipoles, specialty magnets such as snakes, and special focusing IR magnets using a novel direct wind technology for the RHIC collider. BNL did one of the first successful transitions of large-scale production of superconducting dipole magnets to industrial production with the RHIC project and helped to transfer their experience and knowledge to CERN, paving the way for a successful LHC project. BNL also made significant contributions to the LHC project, and is working in close partnership with FNAL and LBNL to manufacture and vertically test magnets for the LHC Accelerator Research Program (LARP) and the ongoing Accelerator Upgrade Project (AUP), which is part of the Hi-Lumi upgrade at CERN. The novel direct wind technology that has been developed at BNL has become a crown jewel technology for high precision multipole magnets around the globe. This technology has been used in RHIC, the LHC, and SuperKEKB, among others, and BNL's expertise in this space has been sought for future projects like the FCC, e^+e^- linear colliders, and proposed SuperKEKB upgrades. With the Electron Ion Collider (EIC) project underway, BNL will be the site for the next large collider in the US. The Superconducting Magnet Division (SMD) is playing a central role in the design of the magnet**s** for the IR region, and with its direct wind technology, is able to push the limits of magnet technology while keeping the cost under control ~~of~~ for this highly advanced machine. Current thrusts include the development of tapered accelerator magnets, which allows placement of magnets as close as possible to the interaction point of a collider, to provide improved machine performance at facilities such as the EIC.

BNL and its partners are committed to continued engagement with the magnet technology needs of the particle physics community. To support this goal, the BNL magnet team has been working in partnership with leaders from other labs to develop an integrated strategy for magnet development in the US. Part of this strategy is to define the current thrust areas for BNL, both near- and long-term. Key thrusts are:

- Construction of coils and magnet testing for the AUP project
- Development of robust IR magnets for the EIC: conventional, specialty, and direct wind, including tapered double-helix (CCT) magnets.
- Partnership with industry in magnet construction
- High field (10 T) cable and coil testing for both MDP and the fusion magnet community
- Exploration of HTS high field magnet and conductor concepts for accelerators, fusion magnets and power applications of superconductivity
- Developing strong partnerships with universities and industry on applications of superconductivity – fusion, offshore wind, electric aircraft, NMR, and MRI
- Developing a robust and innovative talent pool for magnet technology in the US

The proximity of BNL to and its historical partnership with universities (e.g., MIT, Columbia, and Stony Brook), with innovation hubs that exist in Boston and NYC, and with multiple companies in the northeast (i.e., Philips, GE, Raytheon Research Center, and Superpower), uniquely position BNL to help foster a collaborative northeast network for the superconducting magnet community and the industries it serves. The key strategic thrusts at BNL can greatly benefit the HEP community by leveraging this broad ecosystem both in the northeast and indeed across the US, to deliver unique and innovative technologies to HEP accelerators.

The BNL crown jewel technology of direct wind magnets that has been sought for use in IR regions around the globe can play a key role in the development of linear e+e- colliders, electron-ion machines, proton-proton machines, muon colliders, and many other applications. BNL seeks to develop new methods for the construction of magnets for extremely high energy colliders. BNL is partnering with MIT on the development of HTS solenoids, leveraging the vast experience of these teams to develop the following applications:

- 30-50T small bore for muon collider final cooling
- 20T large bore for HEP experiments (e.g. axion searches)
- >15T large bore for muon collider 6D cooling

As part of the MDP program and the leading-edge R&D LOI from FNAL, BNL and its partners will continue to work on technologies that enable very high dipole fields in the 20-25T range. This will include cable tests as well as magnet design studies to understand how to handle the high forces seen at this field strength. These dipoles will enable greater energy reach for proton-proton colliders and improved luminosity for muon colliders where the integrated luminosity scales inversely with the machine circumference. An integrated approach will also address the higher order multipole magnets required for the interaction region of any very high energy machine.