Snowmass 21 AF7 LOI
8/31/20

Collider in the Sea

3.5 T dipoles using Conformal REBCO windings for minimum cost/TeV

Peter McIntyre, Texas A&M University

The potential for discovering new gauge fields of nature beyond the Higgs boson relies upon extending the collision of hadron colliding beams as far as possible beyond the present 14 TeV capability of LHC. A vision for the technical design of an ultimate-energy hadron collider has been proposed [1] that would minimize the cost for a 100 TeV collider, and set the stage for a future 500 TeV collider for which it would serve as injector. A key ingredient in this strategy is a novel approach to the superconducting dipoles that are the dominant component cost for a hadron collider - conformal REBCO windings in which all tapes operate with optimum orientation in the magnetic field so the quantity of expensive tape required is reduced by a factor four. I propose to create a working group within the Superconducting Magnets theme to examine the key issues in this new approach and their import for the cost and performance of a Collider in the Sea.

The cost for a new collider is dominated by the double-ring of superconducting increases steeply with magnetic field above ~6 T and has a broad minimum in the window ~3-4 T. That consideration motivated us to consider a way to eliminate the tunnel of a collider altogether [2], and instead house the ring of dual dipoles in a circular pipeline, supported in neutral buoyancy in the sea at a depth of ~100 m, as shown in Fig. 1. Once we eliminate the tunnel cost, we are free to choose a dipole field ~3.5 T to minimize the project cost. This opens the possibility to dramatically increase the collision energy with less project cost, and at the same time accommodate high luminosity without strong bounds from the heat produced by synchrotron radiation. Staging a HEP collider undersea is novel, but it uses proven, widely used marine technology and the performance required of that technology is within its present standards [2].

Eric Willen analyzed the cost drivers that determined the manufactured cost of superconducting accelerator dipoles [3]. He found that the materials cost is driven by the quantity and unit cost of the

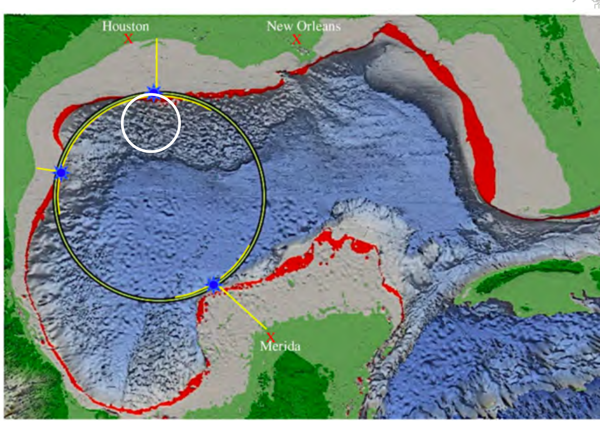

Fig. 1. Bathymetry of the Gulf of Mexico, showing one potential alignment of a 1,900 km circumference hadron collider. Red=100→200 m isobaths; Gray=0–100 m isobaths; blue=detectors. White = 300 km ring for FCC-ee, then 100 TeV FCC-hh, and later as injector for the 500 TeV collider.

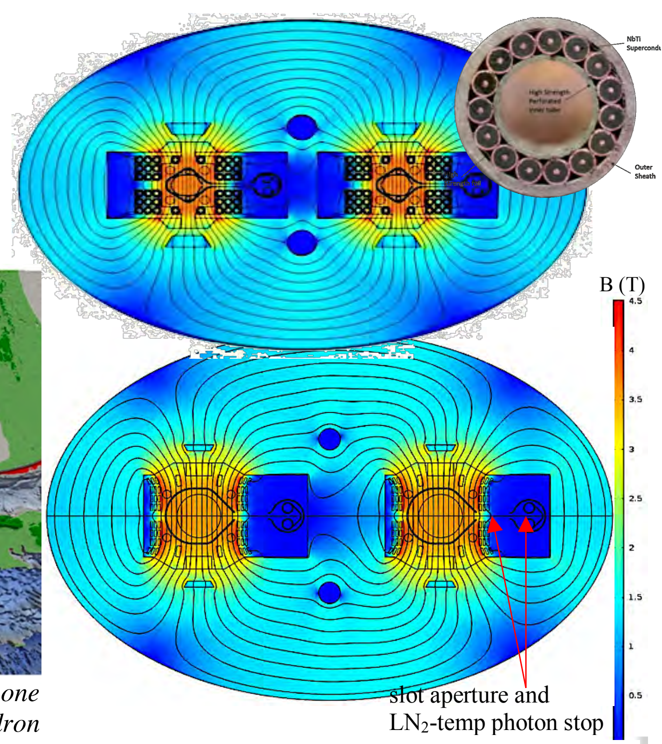

Fig. 2. Cross-sections of two designs for 3.5 T superferric dual block-coil C-dipole for Collider-in-the-Sea; a) NbTi cable-in-conduit @ 5K; b) conformal windings of NI REBCO/Cu tapes @ 25 K.

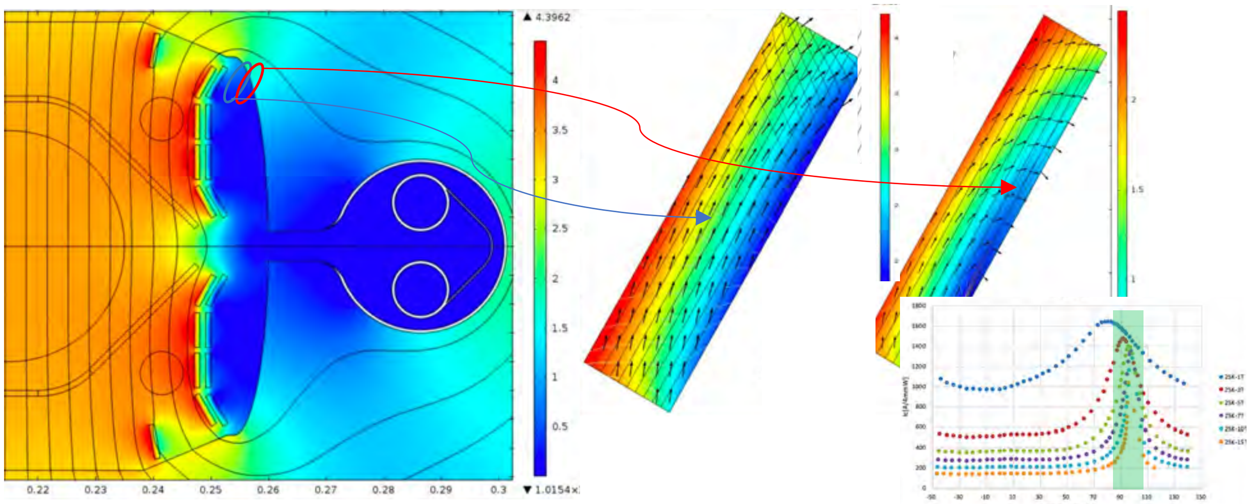

Fig. 3. Details of conformal REBCO/Cu windings: a) right half of the dipole, showing two-layer body winding and sextupole correction windings; b) map of direction and magnitude of $\vec{B}$ in the 10 tapes of the topmost inner turn; c) map in the 8 tapes of the topmost outer turn; c) dependence of I_c on direction and magnitude of $\vec{B}$.

superconducting wire, the manufacturing labor cost scales with the number of dipoles and with the number of turns of cable on each dipole. We have developed conceptual designs for two approaches that minimize the quantity of superconducting wire (by choosing 3.5 T for field), minimize the number of dipoles (by choosing a 300 m dipole length), and minimize the number of turns (18 turns/bore, compare to 56 for LHC).

Fig. 2 shows a cross-section of two embodiments of this approach, one using a NbTi cable-in-conduit conductor operating at 5 K, the other wound from a block of REBCO/Cu tapes, operating at 25 K, in which each the tapes of each block are compressed face-face so that they intimately share cable current. The magnetic designs are closely similar: each dipole winding is configured as a C-geometry, and a slot aperture in the midplane opens to a side channel that contains a photon trap, maintained at a reservoir temperature of 80 K by a flow of liquid nitrogen (LN2). SR is emitted as a thin fan in the horizontal plane, so its copious heat can be pumped to ambient temperature with maximum efficiency.

The 18-turn magnet windings utilize a high-current cable that is fabricated from a non-insulated (NI) block of Cu-clad REBCO tapes and operated at ~25 K using either He vapor or liquid H_2 as cryogen. A key innovation is that the REBCO winding is conformal: each turn of the stacked-tape cable is oriented parallel to the magnetic field at its location, so it can carry maximum superconducting current. The total amount of immensely expensive REBCO tape is thereby reduced by a factor 4 compared to any other approach. The TAMU group has completed a conceptual design in which the issues of field homogeneity, current-sharing, and quench stability are addressed and appear to be benign for collider requirements [4].

The Collider-in-the-Sea Dipole Working Group will do detailed modeling of the magnets, the correction of sextupole and other multipoles over the required working range, and assess current-sharing among the tapes of each turn of tape cable to optimize for AC losses, persistent-current multipoles during ramping, and quench stability and quench protection.

Read more: Accelerator design: SR side-channels, active harmonic control, bottoms-up stacking
Circular pipeline and detector bathyspheres, neutral-buoyant @100 m, marine thrusters
Superconducting dipoles for the Collider-in-the-Sea: NbTi CIC, Conformal REBCO
Discovery potential at 100 TeV and 500 TeV

Join working groups: **Superconducting magnets for the Collider-in-the-Sea *(this LOI)***

EF-9: HEP discovery potential at 100 TeV and 500 TeV

AF-4: Accelerator physics in the Collider in the Sea

AF-6: HEP meets marine engineering – how to stabilize and operate a circular pipeline