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Marine Engineering of the Collider in the Sea

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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 new vision for the technical design of a 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. We propose a working group to examine the accelerator physics issues that attend the beam dynamics of a synchrotron-radiation-dominated 500 TeV hadron collider, staged in a ring pipeline in the sea.

The cost for a new collider is dominated by the double-ring of superconducting magnets that guide the proton beams, and the tunnel that contains the magnet rings. We proposed a way to eliminate the tunnel 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. Each collider detector is housed in a double-hull bathysphere the size of the CMS hall at LHC, also neutral-buoyant. 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 to 500 TeV 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].

A choice of ~3.5 T dipole field, 1,900 km circumference (the yellow ring in Fig. 1) provides a collision energy of 500 TeV. Beam dynamics is dominated by synchrotron radiation (SR) damping [3], which sustains luminosity for >10 hours and supports bottoms-up injection to replace losses and sustain high luminosity indefinitely. Fig. 2 shows a cross-section of the dual dipole. Each dipole winding is configured as a C-geometry, and a slot aperture in the midplane opens into 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 1900 km collider is configured with 300 m half-cells, each containing a single dual dipole of that length. The total number of half-cells is thus 5000, 4 times more than in LHC. The super-long dipoles will be manufactured at a facility in a long warehouse typical of major port facilities (*e.g.* Houston or Baton Rouge). The half-cell will be completed there as a self-contained assembly of dipole, quad, correctors, and all cryogenics that is sealed within a stainless-steel pipe and fitted with hermetic interconnect ends (Fig. 3b), and a load of hermetically sealed half-cells will be transported from the port facility to the arc where they are to be installed using a standard 400 m container ship (Fig. 3a). Each half-cell will be lowered to the water by a line of cranes, buoyancy trimmed to neutral, and then taken to 100 m depth and connected

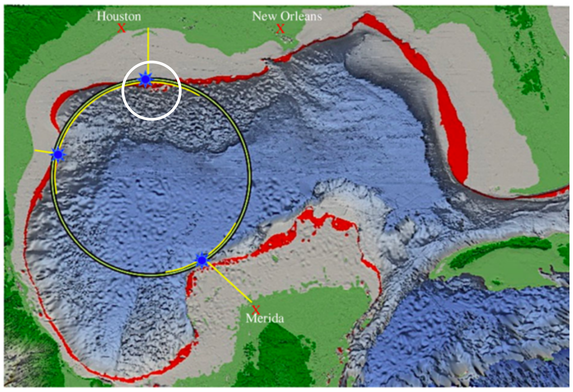
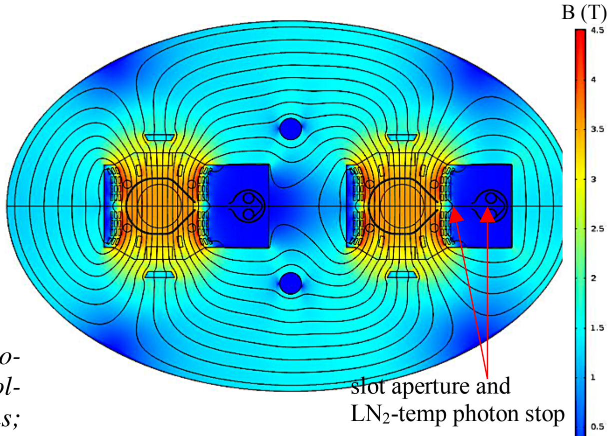


Fig. 1. Bathymetry of the Gulf of Mexico, showing one potential alignment of a 1,900 km circumference hadron collider. Red=100→200 m isobaths; Gray=0–100 m isobaths; blue=detectors. White = 300 km ring for FCC-ee, then 100 TeV FCC-hh, and later as injector for 500 TeV collider.



slot aperture and
LN_2-temp photon stop

Fig. 2. 3.5 T superferric dual C-dipole using NI REBCO/Cu windings.

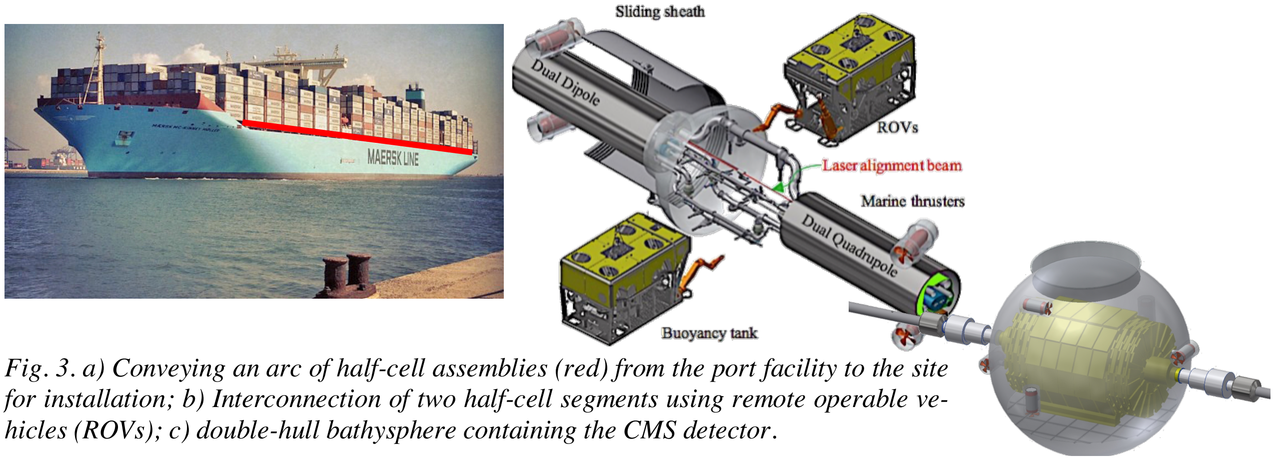


Fig. 3. a) Conveying an arc of half-cell assemblies (red) from the port facility to the site for installation; b) Interconnection of two half-cell segments using remote operable vehicles (ROVs); c) double-hull bathysphere containing the CMS detector.

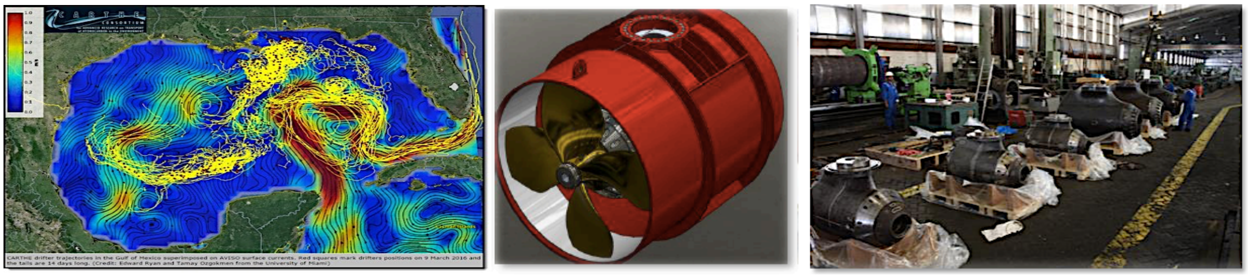


Fig. 4. a) Ocean currents in the Gulf of Mexico; b) marine thruster; c) manufacturing marine thrusters for ships.

using remote-operable vehicles (Fig. 3b). Each collider detector will be assembled in the port facility in a double-hulled bathysphere (Fig. 3c) and then towed to its location on the ring by sea-going tugs. Its buoyancy is then trimmed and it is taken to 100 m depth and connected to the collider lattice. *No human being will ever be required to go below the sea surface for any operation in the installation, operation, or maintenance of the Collider in the Sea.*

This all must seem millennial to an experimental high-energy physicist or accelerator physicist who has spent a career building colliders and detectors in tunnels. But the operations described above utilize marine technology that is used routinely in the world of commercial shipping, undersea oil/gas exploration and drilling, and marine research.

Another challenge for the Collider in the Sea is to position and sustain the ring pipeline in the exact geodesy for which its lattice is designed. The western part of the Gulf has no prevailing ocean current. Secular currents and slow fluctuations are stabilized using a set of swivel-mounted marine thrusters that are located close to the end of each half-cell. A geodesy monitoring system has been designed in concept to precisely monitor the position and geodesy of the collider ring in real time. It uses a ring of lasers, mounted within the circular pipeline of the collider at each quad location, to detect modulations of the geodesy. The marine thrusters can be used to correct slow modulations, and correction dipoles at the half-cells can be used to correct proton orbits for terrain-following small-amplitude long-range perturbations.

The proposed agenda for this AF6 working group is to identify and evaluate the challenges for staging an ultimate-energy hadron collider as a ring pipeline in the sea. I am recruiting participation by marine engineers and experts in precision navigation and positioning at sea, marine thruster systems, corrosion, environmental impact issues, and potential conflicts for operation at 100 m depth in the sea.

Read more: **Accelerator design: SR side-channels, active harmonic control, bottoms-up stacking**
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Superconducting dipoles for the Collider-in-the-Sea: NbTi CIC, Conformal REB

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EF-9: HEP discovery potential at 100 TeV and 500 TeV
AF-7: Superconducting magnets for C-in-S: NbTi CIC @ 5 K or REBCO @ 25 K