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Collider in the Sea

Physics potential at 100 TeV and then at 500 TeV…

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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 physics prospects for such a larger vision.

The various models of supersymmetry motivated many searches for gauginos at LHC, but to date no candidates for the particles of SUSY have been observed. Nevertheless the phenomenology of those searches provides a useful paradigm by which to estimate the the mass reach at a hadron collider. Fig. 1 shows the cross-sections and discovery limits for one example channel – a gaugino produced via vector boson fusion [2,3]. The mass reach is typically ~10-20% of collision energy for a high-luminosity hadron collider. Consequently the 500 TeV collider would dramatically extend the ability to probe of the origin of the electroweak scale by a great extent.

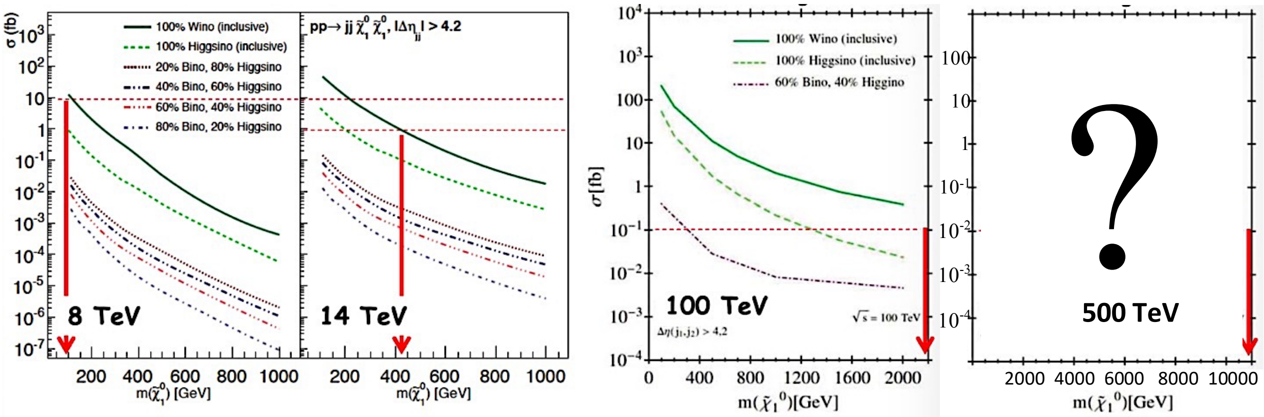

Fig. 1. Production cross-sections for SUSY gaugino production via vector boson fusion for collision energies of 8 TeV and 14 TeV (from Ref. 2), 100 TeV (from Ref. 3).

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. The cost/TeV of the superconducting magnets increases steeply with magnetic field above ~6 T and has a broad minimum in the window ~3-4 T. Tunnel cost/m depends strongly upon the stratigraphy of each site. The tunnel for the SSC in Waxahatchee, TX was bored in Austin Chalk, one of the most favorable rock strata for tunneling with cost ~\$3000/m. The LEP tunnel (now used for LHC) was bored in less favorable rock, and its cost/m was >3 times greater. The ~100 km tunnel proposed for FCC [4] would pass through many difficult rock strata with even higher cost/m.

Those considerations led us to consider a way to eliminate the tunnel altogether [5], 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. 2. 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 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 [5].

A choice of ~3.5 T dipole field, 1,900 km circumference (the yellow ring in Fig. 2) provides a collision energy of 500 TeV. Beam dynamics is dominated by synchrotron radiation (SR) damping [6], which sustains luminosity for >10 hours and supports bottoms-up injection to replace losses and sustain high luminosity indefinitely. Fig. 3 shows a cross-section of the dual dipole. Each dipole winding is configured as a C-

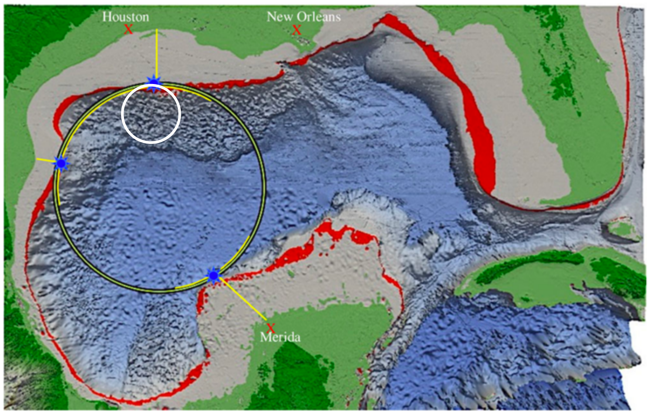

Fig. 2. Bathymetry of the Gulf of Mexico, showing one potential alignment of a 1,900 km circumference hadron collider. Red=100→200 m isobaths; Gray=0–100 m isobaths; blue=detectors. White = 300 km ring for FCC-ee, then 100 TeV FCC-hh, and later as injector for the 500 TeV collider.

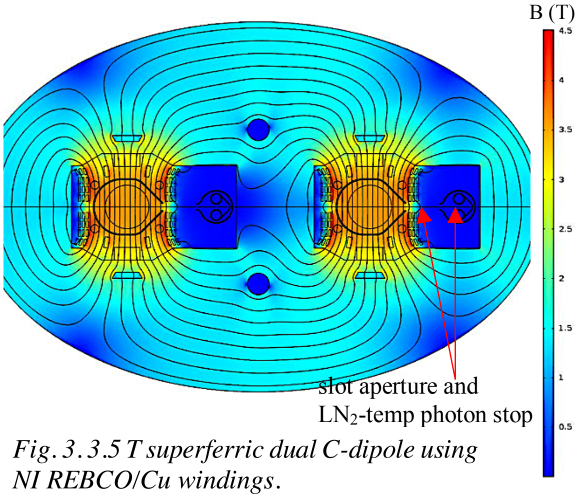

Fig. 3. 3.5 T superferric dual C-dipole using NI REBCO/Cu windings.

Table 1. Parameters of LHC, FCC-hh, and C-in-S.

	LHC	FCC-hh	Collider-in-the-Sea		
Circumference	26.7	100	270	1900	km
Collision energy	14	100	100	500	TeV
Dipole field	8.3	16	4.5	3.2	Tesla
Luminosity/I.P.	1.0	5	5	50	10^{34}cm^{-2}s^{-1}
β*	40	110	50	50	cm
Total synch. power	.004	4.2	1.0	36	MW
Critical energy	43	4.0	1.0	19	keV
Synch rad/m/bore	0.22	26	2	11	W/m
Emitt. damp time	13	0.5	19	3.7	hr
Lum. lifetime	20	18	20	>24	hr
Energy loss/turn	.007	4.3	1.3	117	MeV
RF energy gain/turn	0.5	100	50	2500	MeV
Acceleration time	0.4	.20	.40	2.4	hr
Bunch spacing	25	25	25	30	ns
B-B tune shift	0.01	0.01	0.01	.02	
protons / beam	2.3	10	22	40	10^{14}
Injection energy	0.45	>3	15	50	TeV

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 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 each turn of REBCO 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 [7].

Table 1 compares the main parameters of 100 TeV and 500 TeV versions of the Collider in the Sea with those of LHC and FCC-hh. One approach would be to first build a ~100 TeV hadron collider in the sea, using the 3.5 T superferric dipoles and circumference ~300 km. The white ring shown in Fig. 2 shows such a 100 TeV collider located off-shore near Houston. The manufacture of the magnets for that hadron collider would drive cost reduction of REBCO/Cu tape and provide operating experience with both the REBCO-based magnet ring and the Collider-in-the-Sea, and so build a credible basis of technology, costs and performance for the grand challenge to build the 500 TeV collider thereafter.

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