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Very Large Hadron Colliders*

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Issues pertaining to the next generation (post LHC) Hadron Colliders have been addressed over the past several years at workshops at Indiana [1], Indianapolis[2], and more recently at Snowmass[3]. Although no attempt has been made to produce a detailed parameter set, most work has addressed energies in the range of 80-100 TeV centre-of-mass with a peak luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. This is sufficient to illuminate the potential problems associated with this class of machines. There have been two distinct design concepts were examined; the low-field and high-field options. It is significant to note that while an SSC-like approach to access this energy range is technically feasible the cost of such a device is deemed prohibitive. There is general agreement that new technologies are necessary to achieve a cost breakthrough and as such that the dominant technical challenges for the future are driven by cost considerations, unlike linear or muon colliders, where cost is merely important. The organizing committee at Snowmass challenged the sub-group with a cost goal of \$50M per TeV, and although neither option is sufficiently mature at this point to attempt any meaningful cost estimate, this figure gives an indication of the potential challenge facing the machine designers. The basic accelerator concept for an VLHC is perceived to be similar to today's machines: long repetitive arcs in a 2-in-1 magnet scheme with a few interaction regions encompassing the experimental regions and accelerator utilities. While a wide variety of design have been examined it has not been deemed terribly important to produce any integrated VLHC design at this point in time.

The low-field option [4] is essentially a direct attack on the problem on lowering the unit costs of the repetitive structures. Based around a novel 1.5 -> 2 T superferric 'double-C transmission line magnet', this approach offers the possibility of dramatically reducing the magnet costs per Tesla with a highly efficient use of superconductor and a simple magnet structure with most of the magnet warm. Since the field strength in a superferric magnet is limited, a long machine circumference is unavoidable (~600 km) low cost tunneling and magnet installation become very important. Other issues associated with a very large machine size involve the stored energy in the circulating beam arising from the large number of bunches, beam stability problems driven by the high impedance, and unit costs associated with the non-magnetic arc elements (instrumentation, vacuum, corrections etc.). Applying the 'Snowmass cost criteria' of \$50M per

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TeV together with a 3-4 fold increase in length from an SSC like object, then relative cost reductions of a factor of ~ 20 are needed from today's techniques. It is undemonstrated at this time that simplifications of this scale can be achieved, and indeed it can be observed that simple concepts tend to become more complex (and thus costly) as reality sets in.

The high-field option [5] follows a different line of attack from the low-field one. Based on an as yet unproven magnet operating at 12.5 T, this design relies on exploiting the emittance damping resulting from synchrotron radiation. With damping times in the 2-4 hr range the integrated luminosity during a 10-20 hr store is essentially independent of the initial beam parameters. Figure 1 shows an emittance evolution during a store. Very bright beams, which can not be achieved by conventional techniques arise quite naturally in this dynamical framework. Since the low field performance requires little more than getting the beam to 'stay in the pipe', cost savings are therefore hoped to arise from tolerance reduction in the emittance preservation requirements, field quality requirements, the use of a lower injection energy, and the shorter tunnel. Issues associated with this approach involve handling the radiated power into the bore tube ($\sim 1-2$ W/m), ensuring acceptable vacuum in the presence of desorbed gases, and, of course, the dominant fact that there is no accelerator magnet capable of achieving the necessary 12.5 T field. The desired field strength and synchrotron heating lead naturally to a magnet approach based on high temperature superconductor (HTS) technology, but lower temperature approaches based on existing superconductors are possible though probably much too expensive.

A major topic of discussion during the past several years involved the potential use of HTS technology for future hadron machines. During the last several years great progress has been made in this area, and the possibilities of R&D efforts to develop these materials for magnet uses, received much attention. The low-field magnet design could potentially use a BSSCO material in a relatively straightforward way. This material is starting to become available in engineering quantities and is well matched to the lower fields and current densities in the superferic environment. A different material, YBCO, has promise for the high field magnets but is less advanced than BSSCO at this time and to date has only been produced in very thin films. The use of HTS technology is compelling. In addition to the increased cryogenic efficiency arising from a higher operating temperature, these materials have less sensitivity to operating temperature variations which can be exploited to greatly simplify the cryogenic system. The increased Carnot efficiency could also be exploited to simplify cryostat designs by tolerating a higher heat leak. The area of HTS was certainly identified as a key technology within the charge to this sub group for future efforts.

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Emittance evolution at 50 TeV

In addition to work focused on the two machine options, other more generic topics were worked on which would be suited to either approach. An analysis of interaction regions indicated that beta-star values lower than the normally assumed 20 cm appear feasible with a free space of ± 25 m and a quadrupole gradient of 300 T/m. With the inclusion of crab crossing schemes beta-star's as low as 5 cm appear possible with second order chromatic correction. Machine lattices with long arc cells have potential advantages including cost savings. During the workshop it was concluded that adequate beam dynamics performance could be achieved with cell lengths of the order of 500 m with the optimum length determined primarily by systematic rather than random field harmonics in the magnets. Beam stability appears to be a problem for the low-field option where the small bore tube and large circumference result in rapid resistive wall growth times. Single bunch stability may also prove to be an issue. One of the more interesting aspects of the machine parameters involves bunch spacing and intensity. For a given luminosity the machine design would prefer fewer bunches with more intensity to minimize stored energy and synchrotron radiation power. For reasonable parameter sets, the number of interactions per crossing varies in the range of 20 - 40, with the accelerator preferring the latter and the experiments presumably preferring the former. At this point in time there has been no consensus reached on the optimum values.

Various options for the vacuum system have been investigated [6]. Distributed pumping is needed in all cases but acceptable vacuum performance can be achieved. The warm bore tube of the low-field option simplifies this system. In the high field case cryo-pumping is needed for the synchrotron desorbed gas which limits the operating temperature to 20K or below. In the absence of HTS technology large cryogenic systems are unavoidable. While there does not appear to be any technical problems with very large cryogenic facilities the fundamental issue is, once again, cost. Other aspects of the machine design such as power supplies, quench protection, beam handling, and installation are covered in the sub group report.

In conclusion, one can say that while no technical problems have been found which would preclude the construction of a 50 x 50 Tev Hadron Collider, present day techniques are simply too expensive to be deemed viable in today's cost cutting climate. Fortunately there appears to be no shortage of ideas on potentially cheaper approaches which would benefit from R&D support. The single most important R&D topic at this time is the use of HTS technology in the area of accelerator magnets.

References

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