

DESIGN PARAMETERS FOR THE VERY LARGE HADRON COLLIDER

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Abstract

The goal of the Very Large Hadron Collider (VLHC) is to extend the energy frontier beyond LHC. The proposed design center-of-mass energy for the VLHC pp collider is 100 TeV, with a luminosity of $1e34 \text{ cm}^{-2} \text{ sec}^{-1}$. At present accelerator designs and calculations are being carried out for two different magnet technologies, one using superferic magnets at 2 Tesla (T), the other using high-field design with $B > 10 \text{ T}$. This paper will summarize the accelerator parameters for these two designs. We discuss the design parameters that have the largest effects on the performance of the accelerator and therefore need careful optimization.

1. INTRODUCTION

Hadron Colliders are the “discovery machines” for high-energy physics (HEP). The HEP and accelerator physics communities are working together to extend the energy frontier beyond LHC, and to understand the physics opportunities and the technical issues presented by the colliders.

A VLHC Steering Committee [1] was formed in response to the HEPAP subpanel Report [2] recommendation. The Steering Committee has representations from Fermilab, BNL, LBNL and Cornell University's Laboratory of Nuclear Studies and coordinates R&D efforts in the United States.

The main technical issue is cost reduction. Considerable R&D is needed in accelerator technology, superconducting magnets, accelerator physics, and to reduce the overall cost of the accelerator construction and operation.

Initially, the U.S. site for the VLHC is assumed to be Fermilab. Hence, the injection chain comprise a 400 MeV Linac, an 8.9 GeV Booster, and the newly commissioned 150 GeV Main Injector. The VLHC will have two new accelerators, a High Energy Booster (HEB) of 3 to 5 TeV and a 50 TeV per beam, pp collider.

Since the Indiana workshop in 1994 [3], work has been proceeding on the design parameters for the VLHC. During the Snowmass 96 meeting, the first set of comprehensive and self-consistent parameters was published [4]. Since that time we have modified several aspects of accelerator, resulting in a new set of parameters presented here.

2. ACCELERATOR ENERGY

The injection energy into the HEB is fixed near 150 GeV, because we want to use the Main Injector as an injector. Several discussions have taken place to use the Tevatron and inject at 1 TeV. However, the Tevatron requires 30 MW for its cryogenic plant. This high load for an injector that will be used for only a few moments each day seem excessive. Over the long run, the operating cost of the Tevatron is too high.

The VLHC magnet R&D groups are investigating two different magnet technologies: high field (HF) (10-14 Tesla) [5-9] and low field (LF) (2 Tesla) [10]. The magnetic field quality at injection, eddy currents, persistent current and hysteric effects limit the ratio of energy at collision to injection for a synchrotron (SF). The Main Injector has a scale factor of 16.8, Tevatron 6, HERA 23, and LHC is designed to achieve 15.5. We have assumed this scale factor to be 20 for our primary accelerator design. This assumption needs study from the magnet, beam dynamics, and cost optimization points of view. For an HEB that is entirely on the Fermilab site, high-field magnets operating at 4K could result in energy as high as 3-5 TeV. Operating injector at 1.8k is judged unreasonable due to cyclic energy loss. Obviously, a slightly larger machine could result in a lower vlhc SF at an expense of higher HEB SF. This problem could be eased by rebuilding a conventional accelerator, an MEB, in the existing Main Ring tunnel to increase the beam energy from 150 GeV to 300 GeV. Such a machine could

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be quite inexpensive. For the low-field magnet, the HEB is limited by circumference of tunnel one is willing to build. A 3 TeV low field HEB requires about 35 km.

3. LUMINOSITY

The Fermilab accelerators have a minimum bunch spacing is 18.9 ns. The expense of reducing the spacing and the detector triggering requirements encourages us to leave this the same. The design goal for the VLHC luminosity is $1 \times 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$. This has been chosen due to of detector limitation, but could easily be a factor of 10 higher. At 1×10^{34} luminosity a detector in VLHC will have less than 30 interactions per crossing. Table 1 gives the luminosity goals for the two VLHC options. It is important to note that the luminosity is not limited by proton economics, also there are several parameters that can be adjusted to achieve the same luminosity, for example smaller emittance and smaller bunch current. Smaller emittance in the HF option is due to the emittance damping caused by synchrotron radiation at colliding energy.

	50 TeV Collider p p option (Low Field)	50 TeV Collider p p option (High Field)
Proton Per Bunch	1.7E+10	1.2E+10
Number of Bunches	100000	16000
Revolution Frequency (kHz)	0.5	3.2
Beta Star at IP(m)	0.1	0.1
Proton Emittance(95%)	15	8*
Form Factor	0.48	0.48
Typical Luminosity ($\text{cm}^{-2}\text{sec}^{-1}$)	1.1E+34	1.1E+34
Integrated Luminosity ($\text{fb}^{-1}/\text{year}$)	112	112
Interactions Per Crossing	28	28
Bunch Spacing (ns)	19	19
Inelastic Cross Section (mb)	127	127

Table 1. The Luminosity goals of the VLHC at 100 TeV center of mass. *HF option includes the effect of synchrotron radiation damping.

4. MACHINE CIRCUMFERENCE & BEAM PIPE RADIUS

The circumference of the low field (2 Tesla) machine is 520 km, whereas for high field (12 Tesla) machine it is 95 km. The radius of the beam pipe for these machines is important because of beam instabilities. Smaller radius is desirable for cost reduction; magnet field errors, beam dynamics requirements, and alignment errors might lead

to a larger radius. The proposed beam-pipe radius for the LF magnet is 9 mm. The beam-pipe radius for HF magnet designs varies from 12 to 20 mm. The beam pipe aperture is reduced from the physical magnet aperture by the thickness of the synchrotron radiation beam screen for the HF design.

The instability threshold for the transverse mode coupling instabilities (TMCI) is an issue for the LF design. This instability threshold is proportional to the cube of the beam pipe radius. It is expensive to increase the beam pipe radius and we are investigating several solutions to this instability.

The effect of ground motion, alignment, alignment drifts and vibration needs to be understood. Because of the large size of the ring in either design this could have implications on the correction system, when beam-pipe radius is small.

5. LATTICE PARAMETERS

Table 2 summarizes the lattice parameters for the two designs. The LF option uses combined function magnets. These magnets will have quadrupole and sextupole components. The phase advance per cell is chosen to be 60 degree. This reduces the requirement of large quadrupole strength and higher order correction schemes are easier to implement. These parameters are totally free and can be optimized, as the magnet data becomes available.

Parameters	Units	Low-Field	High-Field
½ Cell Length	M	122	260
Phase Advance per cell	Degree	60	60
Average Beta	M	130	600
Max Dispersion	M	5	23

Table 2. VLHC lattice parameters.

6. RF PARAMETERS

The frequency of the HEB and Collider must be a multiple of 53 MHz, which will make synchronization and injection easier. The VLHC will most likely use superconducting RF for acceleration although there is no serious problem using the normal conducting RF. Some of the RF parameters of general interest for superconducting RF system being discussed for the VLHC are summarized in Table 3 [11]. A total voltage of 200 MV for the Low field option and 40 MV for the high field option have

been chosen to keep the acceleration time to less than 15 minutes.

<i>Parameters</i>	<i>Units</i>	<i>Value</i>
f_{RF}	MHz	478
Operating temp	K	4.2
E_{acc}	MV/m	6
Volts/Cavity	MV	7.5
Length of Bucket	Cm	21
No of cavities for 200 MV LF injection		27
No. of cavity for 40 MV HF injection		5

Table 3. VLHC Superconducting RF parameters.

Finally the longitudinal parameters of the VLHC are summarized in Table 4. Most of these parameters can be optimized as design progress. The longitudinal emittance and bunch length effects the stabilities of the machine.

<i>Parameter</i>	<i>Units</i>	<i>LF</i>	<i>HF</i>
Long. Emitt	eV.sec	2	0.3
Long Damping time	Hrs	40	1.3
RF freq	MHz	478	478
RF harmonic number		8.28×10^5	1.2×10^5
Bucket Area	eV-sec	18	4
Synch tune (coll/inj)		0.2/5	1/14
Bunch Length (coll/inj)	Cm	7.6(5.5)	5.6(7.2)

Table 4. Longitudinal parameters for the VLHC.

7. SUMMARY

This paper gives a snapshot of some of the parameters being used in the accelerator design of the low field and high field VLHC. Collaborative efforts between magnet builders, accelerator technology developers and accelerator physicists throughout the process of accelerator design will be used to refine these parameters.

8. REFERENCES

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