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62-TEV CENTER OF MASS HADRON COLLIDER WITH CAPABILITY FOR SUPER BUNCH BEAMS

R. Yamada*, FNAL, Batavia, IL 60510, USA
K. Takayama, J. Kishiro, M. Wake, T. Toyama, Y. Shimosaki, KEK, Tsukuba, 305-0801, Japan

Abstract

A two staged 62 TeV center of mass hadron collider is proposed. In the first stage the center of mass energy will be 14 TeV with 2 Tesla dipole magnets. With Superbunch beams, the luminosity is expected to be increased by a factor of 15, compared with conventional acceleration using RF cavities. To accelerate Superbunch beams, the barrier bucket induction cells and acceleration induction cells will be used, which are made of FINEMET material. The core loss of the FINEMET is estimated to be acceptable. The synchrotron radiation of the collider is also estimated. In the second stage, 10 Tesla high field dipole magnets will be installed, and the application of Superbunch is being studied.

1 INTRODUCTION

As a future project in US high energy physics, the VLHC has been proposed for the future hadron collider [1,2]. As a variant scheme a two-staged 25-30 TeV P-P collider was proposed [3]. The LHC, 14-TeV Center of mass hadron collider [4] is being constructed now at CERN, and probably will be in operation in 2006. We should design and build a hadron collider in US, which eventually surpass the luminosity and energy of the LHC, but it should be conceived as a realizable machine, budgetwise, spacewise, and timewise. The machine should be designed also as easily maintainable with present-day's technology.

Recently proposals of applying induction acceleration to synchrotrons and hadron colliders were made, with the increase of the luminosity about 15 times as their advantage over the RF cavity acceleration [5,6,7]. We apply this induction acceleration to the design of the 62 TeV center of mass hadron collider with Superbunch beams in both stages.

2 GENERAL DESCRIPTIONS

This collider complex will be based at Fermilab site, and built in two stages, utilizing a same tunnel. The Fermi Main Injector of 150 GeV proton beams will be used as the injector to the first stage. In the first stage a low field magnet ring made of 2 Tesla superferric magnets will be installed [1]. The beams will be accelerated to 7 TeV with accelerating induction cells and barrier bucket induction cells to produce Superbunch beams [5,6]. The maximum center of mass colliding energy will be 14 TeV with the expected luminosity of 1.5 x10^{35} /cm^2/sec. This will be used for high energy experiments with two detectors.

In the second stage we will use the twin-aperture 10 Tesla superconducting magnets. The operational dipole magnetic field of 10 Tesla using Nb_3Sn conductor, is achievable with the present technology. The maximum accelerated proton energy will be 31 TeV, resulting in the center of mass energy of 62 TeV. In this second stage, the application of Superbunch beams is being studied to get the expected luminosity of 5x10^{34}/cm^2/sec without generating too much synchrotron radiation loss. The basic parameters of this hadron colliders complex are given in Table 1.

3 TUNNEL

The tunnel will be placed at a depth of 130 meters from the surface. The 62 TeV collider has the total circumference of 87.25 kilometers. The layout of the 87.25 kilometer tunnel is shown in Fig.1. Inside the Fermilab site there will be two major 1km long straight sections, where two major 62 TeV hadron collider detectors will be installed. These two detectors will be used for the collider experiments with the 14 TeV center of mass energy in the first stage. In the second stage, the low field ring will be lifted up by 2 meters to make room for the high field magnet ring, keeping the two major detectors at the same position. Also the part of the low field ring inside Fermilab site will be moved into an outward bypass.

In addition to two long straight sections, there will be three 300 meter utility straight sections in the Fermilab site. Two of them will be used for the injection from the Main Injector to the low field magnet ring. They will be used also for transferring two proton beams from the low field magnet ring to the high field magnet ring. The induction cells and the liquid Helium connection will be placed in the central 300 meter long straight section. The abort lines will start from the injection straight sections, and share partly the outward bypass lines. On the other side of the tunnel, opposite to Fermilab site, there will be two 1km long straight sections and three short 300 meter utility straight sections for future usage.

The cross section of the proposed tunnel for the 62-TeV collider is shown in Figure 2. The high field superconducting magnet for the 62-TeV collider is shown together with the magnet of the 14-TeV collider ring. A cryogenic pipeline for transporting liquid helium is also shown. For reasonable maintenance of the collider components, the radius of the tunnel is chosen to be 3

*yamada@fnal.gov

meters. It is imperative to have a fast transit system to be installed inside the tunnel for the initial installation of components and for transportation of personnel as well as for moving parts for maintenance.

4 INDUCTION CELL ACCELERATION SYSTEM

With the induction cell acceleration, the acceleration and longitudinal focusing are independently achieved. It allows ultimate use of longitudinal phase-space and is quite effective to substantially increase the beam intensity in synchrotrons [5]. We need two types of induction cells for this system, one for the accelerating induction cells, called A-IC, and the other for the barrier bucket induction cells, called BB-IC. These induction cells are now being developed at KEK [7].

4.1 Design and Coreloss of Acceleration Induction Cell

A set of four FINEMET FT-3M cores, each with dimensions of ID=10cm, OD=50 cm and width=1cm, is used to generate a 2.5 kV pulse with 0.45 μs pulse width. Two sets of cores will be used as a unit induction cell for the first stage, and only one set for the second stage.

The coreloss for unit induction cells are 4 kW and 0.45kW, and the maximum total peak coreloss will be 1.7 and 0.52 MW for the first and second stages respectively, including synchrotron radiation effect. The cooling of cores is a challenging job, but can be done.

5 SUPERBUNCH PRODUCTION

With the circumference of 87.25 km, it takes 291 microseconds to go around the ring. In the first stage we can divide the circumference into 114 units, 765 meter long each. The bunch spacing is 2.55 μsec. In one induction unit cell there are two sets of cores, each set of cores generating a 0.45 μsec pulse in succession, making a 0.9 μsec composite long acceleration pulse. At the both ends of this pulse, there are barrier bucket pulses. And in the following 1.5μsec, both sets of cores are reset. These cores are triggered by high current semiconductor switches, which can be operated precisely and reliably.

6 INJECTION INTO 7 AND 31 TEV RINGS

The 150 GeV Main Injector will provide proton beams to both bores of the 7 TeV Low Field Magnet Ring, as shown in Fig.1. These two proton beams are accelerated to 7 TeV simultaneously. Later in the second stage, these 7 TeV beams are injected into the two bores of the High Field Magnet Ring, and accelerated to 31-TeV beams simultaneously.

7. BEAM PHYSICS ISSUES AND LUMINOSITIES

In the Superbunch scheme the continuous parasitic collision is a big issue. Certainly the tune shift for particles within 1σ is remarkably suppressed by utilizing the hybrid crossing, as explained in a previous paper [6]. To suppress the amplitudes of large amplitude particles, the crossing angle should be increased to 400 μ rad. at the expense of 50% loss in the luminosity. Even with this, a 14 TeV center of mass Superbunch hadron collider can deliver the luminosity of $1.5 \times 10^{35}/cm^2/s$. Since the 62 TeV center of mass Superbunch hadron collider has the same situation, we could expect the luminosity over $1 \times 10^{35}/cm^2/s$. But due to the big synchrotron radiation loss we should like to limit the luminosity in the order of $5 \times 10^{34}/cm^2/s$.

In the Superbunch scheme the bunch length is extremely long, about 150 to 300 m, compared with that in the RF bunch scheme. However the bunch is not continuous because it is confined in a barrier bucket with a small synchrotron oscillation frequency. The growth time in the longitudinal direction due to intrabeam scattering is negligible, while that in the transverse direction it is of similar order as the growth time in the RF bunch scheme.

8 EFFECTS OF SYNCHROTRON RADIATION AND BEAM SCREEN

In the first stage, the synchrotron radiation loss is 0.18 W/m/beam with full beam intensity as designed. And as it is in the vacuum tube at room temperature, there is no serious problem.

In the second stage, we have to install a beam screen inside the vacuum tube, because of synchrotron radiation of the beam. The beam screen has a very complicated and delicate mechanical structure that also makes the vacuum problem a complex subject to be studied carefully [1].

The energy loss per meter of the synchrotron radiation scales as $E^2 \times B^2 \times I$, where I is the beam current. For the 62-TeV CM P-P collider the estimated energy loss due to the synchrotron radiation is 89 W/m/beam, if we consider the extension from the first stage. Therefore we should like to limit the average current, by reducing the number of Superbunches. By selecting the number of Superbunches to be 26, the Synchrotron radiation can be cut to 12 W/m/beam, and the luminosity can be $5 \times 10^{34}/cm^2/s$. We still have to optimize the situation.

9 CONCLUSIONS

As a scenario, we should start building the 7-TeV first stage ring as soon as possible. At the same time we should start designing and building the collider detectors, which will be used first as the 14-TeV CM collider detector, but with the intention to expand them into 62-TeV CM collider detectors. After several years of experiments at 14 TeV CM energy and whenever the high field magnets are ready to be installed, we should switch to the 62-TeV CM collider. In this way, we can keep the high energy physics experiments running and high energy physicists working in the USA.

The 62-TeV P-P collider should be started with a lower luminosity. Eventually we should get the luminosity of

$1x10^{35}$ /cm^2/sec. The only components to be developed for this collider are the long 10-T high field superconducting magnets with good beam screen.

The induction cells can be built with the present industrial material, but we hope the industry will make material with less core loss in the near future.

10 REFERENCES

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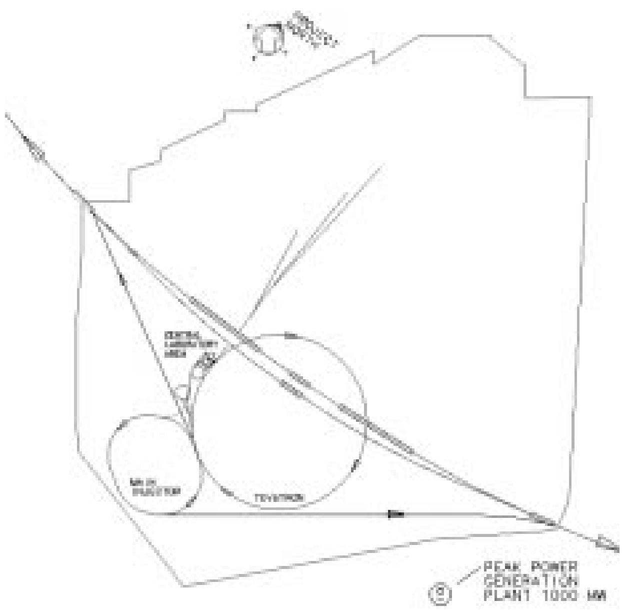

Figure 1. Layout of the tunnels for the low and high field magnet rings inside Fermilab site. The inside tunnel will be used for the 14 and 62 TeV collisions and for their collider detectors. In the second stage the outward bypass is used for the low field magnet ring.

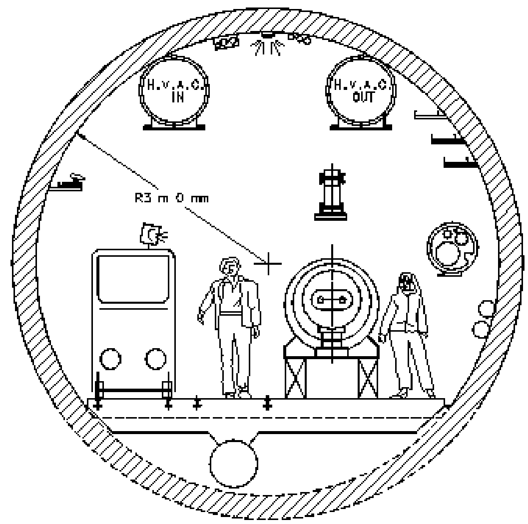

Figure 2. Cross-section of the 62-TeV collider tunnel. It houses the 14-TeV collider magnet and the 62-TeV collider magnet.

Table I. Parameter List of 14-TeV and 62-TeV Colliders.

	Unit	14-TeV	62-TeV
Energy of Ring	TeV	7	31
Dipole Field	Tesla	2	10
Injection Energy	TeV	0.15	7
Injection Field	Tesla	0.0429	2.258
Luminosity	/cm^2/s	1.5×10^{35}	5×10^{34}
Ring Circumference	km	87.249	87.249
Arc Circumference	km	73.304	64.926
Dipole Filling Factor	%	90	80
Dpl Mag. Field Radius	km	11.667	10.333
No. of P / Bunch		1.3×10^{14}	7.8×10^{13}
No. Bunch / Beam		114	26
No. of P / Beam		1.5×10^{16}	2×10^{15}
Ave. Beam Current	A	8.16	1.1
Synchro. Rad. Loss/B	W/m	0.18	12
Unit Ind. Cell Lngth	m	0.2	0.1
Unit Ind. Cell Volt	kV	2.5	2.5
Rotation Period	μsec	290.83	290.83
Acceleration Energy	TeV	6.85	24
Acceleration Period	sec	1620	3620
Accele. Voltage /turn	kV/t	1090.6	1938.8
Syn.Rad. Loss /cycle/p	keV	1.9	940
Min.Ttl V. for BB-IC	kV	12.6	2.8
Ttl No. of Ac IC/B	#	437	1152
Ttl Length of Ac IC/B	m	87.4	115
Coreloss of Unit Cell	kW	2.0 x2	0.45
Total Coreloss/beam	kW	1,748	518
SuperBunch Spacing	m	765	3356
SuperBunch Length	m	300	150
Time Period /SB	μsec	2.55	11.19
Rep. Rate of IC Pulser	kHz	392	89.4