Title

Synchrotron Radiation and Beam Tube Vacuum in a Very Large Hadron Collider, Stage 1 and Stage 2 VLHC

Authors

Pivi, M
Turner, W C
Bauer, P
et al.

Publication Date

2001-06-01

LBNL-48683

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

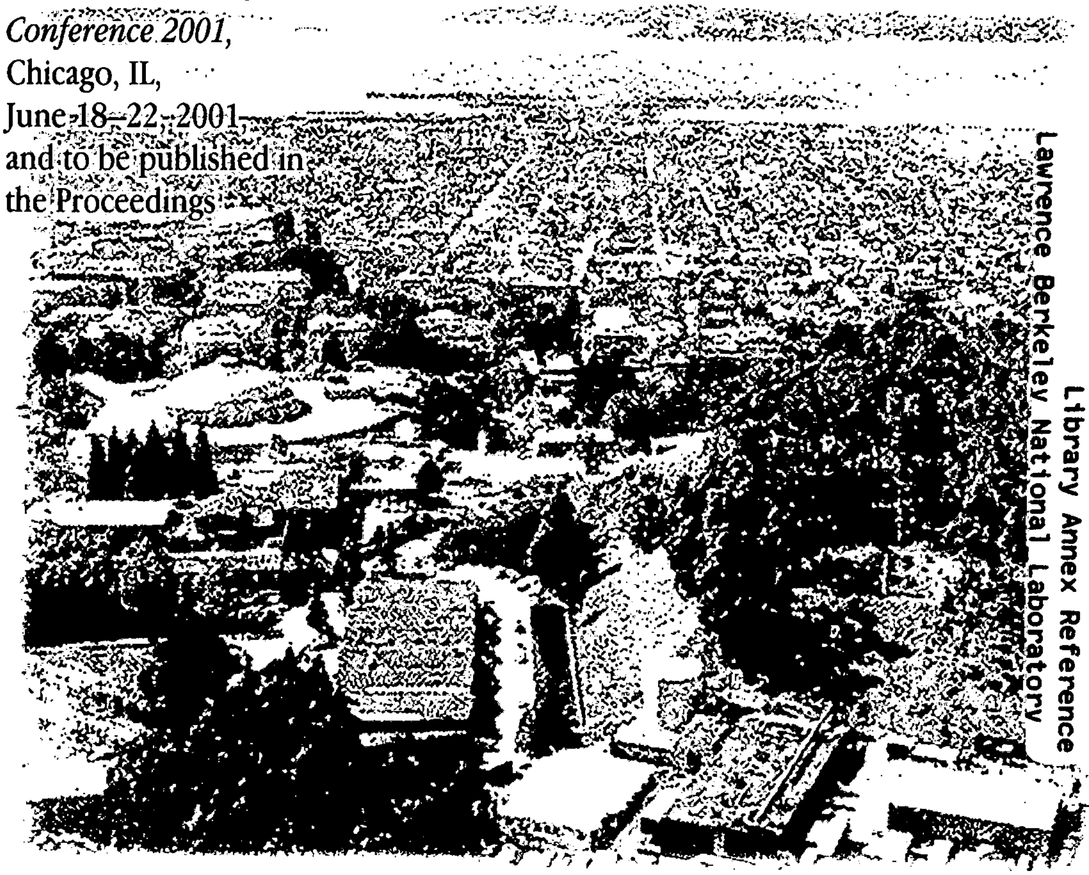
Synchrotron Radiation and Beam Tube Vacuum in a Very Large Hadron Collider, Stage 1 and Stage 2 VLHC

M. Pivi, W.C. Turner, P. Bauer, and P. Limon

Accelerator and Fusion Research Division

June 2001

Presented at the
Particle Accelerator Conference 2001,
Chicago, IL,
June 18–22, 2001,
and to be published in
the Proceedings



LBNL-48683

Synchrotron Radiation and Beam Tube Vacuum in a Very Large Hadron Collider, Stage 1 and Stage 2 VLHC

M. Pivi,[1] W.C. Turner,[1] P. Bauer,[2] and P. Limon[2]

[1]Accelerator and Fusion Research Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

[2]Fermi National Accelerator Laboratory
Batavia, Illinois 60510

June 2001

This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

SYNCHROTRON RADIATION AND BEAM TUBE VACUUM IN A VERY LARGE HADRON COLLIDER, STAGE 1 AND STAGE 2 VLHC[ℵ]

M. Pivi*, W.C. Turner, LBNL, Berkeley, CA 94720, USA
P. Bauer and P. Limon, FNAL, Batavia, IL 60510 USA

Abstract

Synchrotron radiation induced photodesorption in particle accelerators may lead to pressure rise and to beam-gas scattering losses, finally affecting the beam lifetime [1]. We discuss the beam tube vacuum in the low field Stage 1 and Stage 2 Very Large Hadron Collider VLHC. Since VLHC Stage 1 has a room temperature beam tube, a non-evaporable getter (NEG St101 strip) pumping system located inside a pumping antechamber, supplemented by lumped ion pumps for pumping methane is considered. In Stage 2, the ~100°K beam screen, or liner, illuminated by the synchrotron radiation, is inserted into the magnet cold bore. Cryo-pumping is provided by the cold bore kept at 4.2°K, through slots covering the beam screen surface. Possible beam conditioning scenarios are presented for reaching design intensity, both for Stage 1 and 2. The most important results are summarized in this paper.

1 INTRODUCTION

In the present report the required pumping speed, a possible beam current conditioning scenario, and the beam-gas scattering lifetime are discussed for Stage 1 and Stage 2 VLHC. A self-consistent calculation is performed assuming that the beam lifetime depends on the beam tube vacuum gas pressure and on the pp collision rate at two interaction points (IPs). The vacuum tube pressure, and therefore the beam-gas scattering lifetime, is a function of the beam intensity. The parameters necessary for evaluating the beam tube vacuum in the two VLHC stages are shown in Tables 1. In Table 1, τ_{pp} represents the proton lifetime determined by pp collisions at two IPs at the design luminosity, with the p-p total cross section assumed to be σ_{pp}=137 *mb* at 40 *TeV* c.m. and σ_{pp}=178 *mb* at 175 *TeV* cm.

2 VACUUM SYSTEM FOR THE STAGE 1 VLHC

In the low field Stage 1 VLHC, we will consider a distributed NEG strip plus lumped ion or cryo pump system for pumping methane, in a pumping antechamber connected to the beam tube with long slots.

We assume lumped ion pumps, with pumping speed S=30 *l/s*, are connected to the pumping antechamber at an axial interval of L=22.5*meters*. The effective cylindrical diameter of the antechamber is 8.3*cm*. The pumping speed of the lumped ion pumps will be conductance limited by the beam tube and the antechamber, and the effective pumping speed for CH_4 is then S_{eff}~2.2 *l/s-m* [2].

We will define the beam-gas scattering lifetime to be negligible when $\tau_g>5\ \tau_L$, with $\tau_L = \tau_{pp}/2 = 46.5$ *hrs*. Once $\tau_g = 5\ \tau_L$ =232 *hrs* is fixed, we estimate the average beam tube gas pressure for each gas species taken separately, with the results given in the second column of Table 2. From Table 2, we can see that the CO scattering equivalent tube pressure should be less than 0.33 *nTorr* to reach $\tau_g>5\ \tau_L$.

Table 1.VLHC parameters for the low field Stage 1, the high field Stage 2, and related synchrotron radiation parameters.

Parameter	Symbol	Stage 1	Stage 2
Beam energy	*E, TeV*	20	87.5
Dipole field	*B, T*	2	9.7
Circumference	*C, km*	233	233
Bunch population	N_b	2.5×10^{10}	7.5×10^{9}
Total beam current	*I, mA*	190	57.4
Luminosity	*L*, $cm^{-2}s^{-1}$	1×10^{34}	2×10^{34}
Beam pipe semi-axis	*a,b cm*	0.9x1.4	1.0x1.5
Beam pipe temperat.	*T, °K*	~294	~100
IP pp collision lifetime	τ_{pp}, *hrs*	93	11
Critical photon energy	E_c, *eV*	86	8030
Photon flux	$\dot{\Gamma}$ *ph/s-m*	7.9×10^{15}	1.2×10^{16}
SR power per meter	*P', W/m*	0.033	4.7

[ℵ]Supported by the US DOE under contract DE-AC03-76SF00098.
*mpivi@lbl.gov

Table 2: Numerical bounds on beam tube pressure Stage 1, ambient room temperature equivalent pressure.

gas	$\overline{P}_j$ [at τ_g=5τ_L]	P_j [at 0.1 *W/m*]
	(nTorr)	*(nTorr)*
H_2	4	76.6
CH_4	0.54	12.6
H_2O	0.45	12.3
CO	0.33	8
CO_2	0.2	5

We estimate the beam tube pressure that would result in a scattered beam power of 0.1 *W/m,* results for each gas species are given in the third column of Table 2, where we can see that the pressure limiting factor is given by beam-gas scattering particle loss rather than the power loss.

2.1 Photodesorption in Stage 1

The inverse power dependence of the photodesorption yield on the photon dose implies the so called conditioning effect, or the decreasing photodesorption yield due to the removal of gas molecules from the near surface oxide layer with continued exposure to photons. The photodesorption coefficients are key parameters for the beam tube vacuum in a storage ring. For the calculations in this paper the data given in Ref [3], obtained for in situ baked Al at a critical photon energy of 86*eV*, are used.

As a result, the required pumping speed decreases in time as a function of the integrated beam current. This can have implications for the frequency of NEG regeneration. We will estimate the CO equivalent pumping speed necessary to achieve the vacuum pressure indicated in Table 2, within a reasonably short conditioning time.

We may define as "reasonably short" equivalent to a few tenths of a year of operation, e.g. 0.3, when the machine is running at design beam intensity. An operational year is typically taken to be ~ 10^7 *sec.*

From this, we estimate the CO equivalent pumping speed needed to reach $\tau_g=5\tau_L$ by I*t=158 *A-hrs*.

A pumping speed S=32 *l/s-m* is required to reach a beam-gas scattering lifetime of $\tau_g=5\tau_L$ after an integrated beam current I*t=158 *A-hrs* for the Stage 2 VLHC.

2.2 Conditioning Scenario for Stage 1

The conditioning effect will improve the beam lifetime which is itself then a function of the integrated beam current. We present here a possible conditioning scenario, for Stage 1 VLHC, where we increase the initially injected beam current from 50 *mA* up to 190 *m A* (nominal), in four steps. Our procedure is to inject the beam, firstly with increased current, then with current at nominal value, whenever the luminosity lifetime reaches τ_L=46.5 *hrs*, corresponding to the design parameter value.

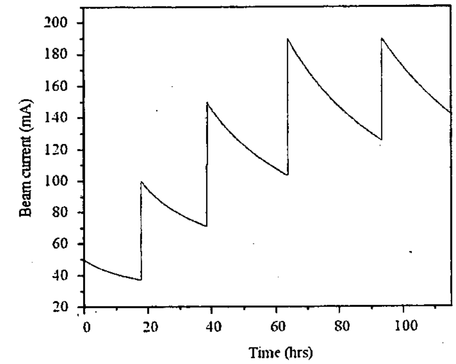


Figure 1. Beam current intensity possible scenario, during the conditioning period in the VLHC, Stage 1, increasing the current from 50*mA* to 190*mA* (nominal), in four steps.

The possible beam current program for our conditioning scenario is plotted in Fig. 1.

The beam lifetime τ_b is related to the vacuum pressure and to the pp collision rate at the interaction point, and is defined as $1/\tau_b=1/\tau_{pp}+1/\tau_g$. In Fig. 2 the beam lifetime is shown as a function of time, for our conditioning scenario. The luminosity lifetime is then given by $\tau_L=\tau_b/2$.

The total beam tube vacuum gas pressure decreases as the surface is progressively cleaned, and is shown in Fig. 3 as the CO scattering equivalent pressure. We can see from Fig. 3 that CH_4 is the gas having the largest CO scattering equivalent pressure.

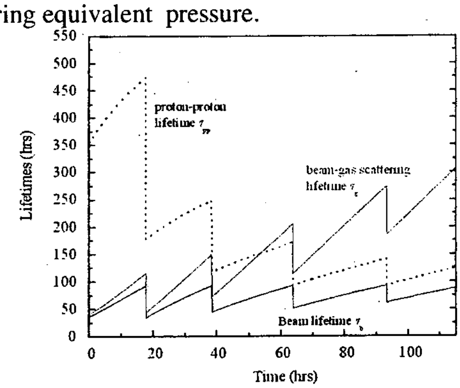


Figure 2. Beam lifetime, beam-gas scattering lifetime, proton-proton scattering lifetime in the conditioning scenario, Stage1.

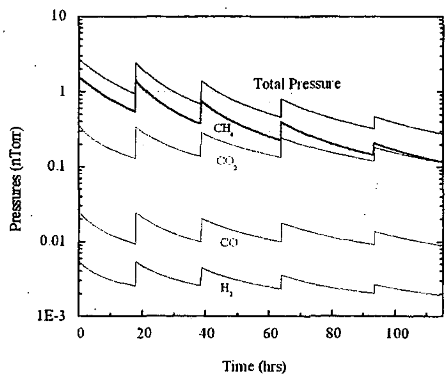


Figure 3. CO scattering equivalent partial pressures and total pressure in the possible conditioning scenario, Stage1.

3 VACUUM SYSTEM FOR THE STAGE 2 VLHC

A beam screen design has been proposed for Stage 2 VLHC, inserted in the magnet cold bore providing cryo-pumping through slots in the beam screen surface. The synchrotron radiation power deposited on the beam screen in the Stage 2 VLHC, 4.7 *W/m*, requires a cooling system and possibly the use of room-temperature photon-stops, to intercept most of the synchrotron radiation power [4].

Table 3: Numerical bounds on beam tube pressure Stage 2, ambient room temperature equivalent pressure.

gas	$\overline{P}_j$ [at $\tau_g=5\tau_L$]	P_j [at 0.1 *W/m*]
	(nTorr)	*(nTorr)*
H_2	42	50.3
CH_4	7.8	9.3
H_2O	7.3	8.7
CO	5	6
CO_2	3.2	3.8

From Table 3, we can see that the CO scattering equivalent tube pressure should be less than 5 *nTorr* to reach $\tau_g > 5\ \tau_L$. The beam tube pressure that would result in a scattered beam power of 0.1 *W/m*, corresponding to a typical limit for the global capacity of a cryogenic refrigeration plant, is given in the third column of Table 3, where we can see that the pressure bounds of beam-gas scattering particle loss are slightly less than of power loss. Nevertheless, the beam scattered power may be a concern for Stage 2, and the heat load of 0.1 *W/m* will be the limit considered in the present evaluation.

We estimate the CO equivalent pumping speed needed to reach $\tau_g=5\tau_L$ after 1/3 of a year of operation, at nominal beam conditions.

A pumping speed S=2.3 *l/s-m* is required to reach a beam-gas scattering lifetime of $\tau_g=5\tau_L$ after an integrated beam current I*t=48 *A-hrs* for the Stage 2 VLHC. A pumping speed 2.3 *l/s-m* then requires a slot area of 0.5 cm^2/m, or equivalently the slots perforate 0.06% of the wall area of the actual beam screen design [5]. Nevertheless, for the purpose of our calculations, we consider a larger pumping speed, 60 *l/s-m*, resulting in a faster conditioning. A pumping speed 60 *l/s-m* then requires a slots area of 14 cm^2/m, or equivalently the slots perforate 1.6% of the wall area; as a comparison, the LHC holes area is 4.3% of the beam screen surface.

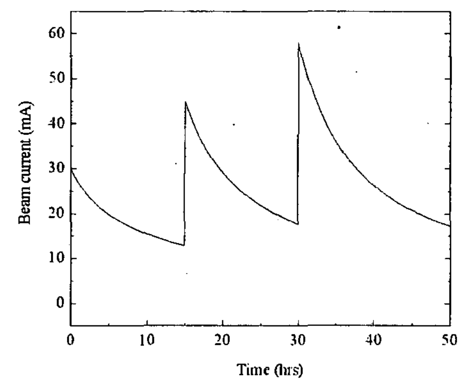


Figure 4. Beam current intensity possible scenario, during the conditioning period in the VLHC, Stage 2, increasing the current from 30 mA to 58 mA (nominal), to avoid large beam scattered power.

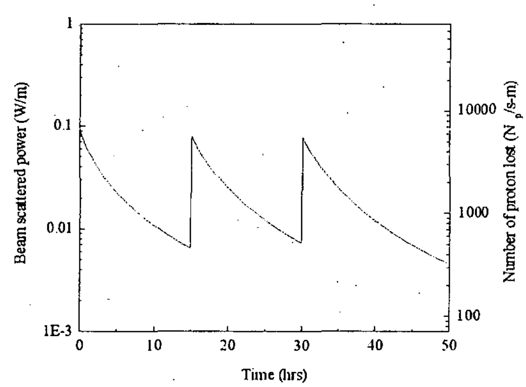


Figure 5. Beam-gas scattered power, and beam-gas scattering proton losses. In Stage 2, the beam is injected increasing the current in three steps to result in a beam scattered power < 0.1 W/m.

3.1 Conditioning Scenario for Stage 2

Our procedure is to inject the beam with increasing current from 30 *mA* up to 58 *mA* (nominal), to avoid a beam scattered power deposition on the magnets cold bore larger than 0.1 *W/m*. In the calculations for Stage 2, the photodesorption data given in Ref [6], obtained for baked OFHC copper at a critical photon energy of 3 *keV*, are used. The possible beam current program for our conditioning scenario, and the related beam-gas scattered power are plotted in Fig. 4 and Fig. 5 respectively.

In Fig. 6 the beam-gas scattering lifetime, the proton-proton lifetime and the beam lifetime are shown as a function of time during the conditioning.

The total beam tube vacuum gas pressure decreases as the surface is progressively cleaned, and is shown in Fig. 7 as the CO equivalent pressure, with the equivalent CO scattering pressure of each gas species.

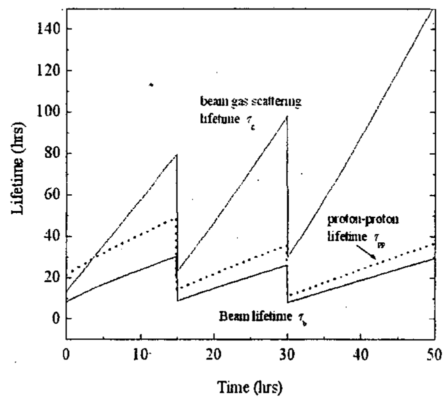


Figure 6. Beam lifetime, beam-gas scattering lifetime, proton-proton scattering lifetime in the conditioning scenario, Stage2.

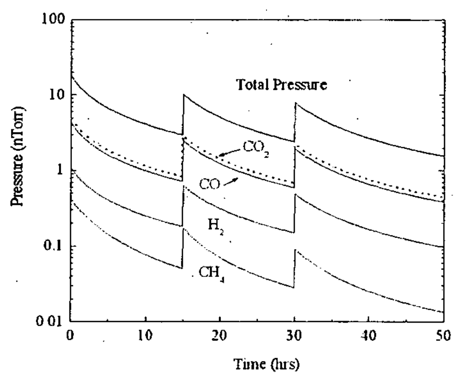


Figure 7. CO scattering equivalent partial pressures and total pressure in the possible conditioning scenario, Stage2.

5 REFERENCES

[1] W. Turner *"Beam Tube Vacuum in Low Field and High Field Very Large Hadron Collider"*, LBNL-39482, UC414, presented at the Snowmass Conference, CO, October 1996.

[2] C. Benvenuti, *"Molecular Surface pumping: the getter pumps"*, CAS CERN Accelerator School - Vacuum Technology, CERN Yellow book, pg. 48.

[3] J. Gomez-Goni, O. Gröbner and A.G. Mathewson *"Exposure of a baked Al lined stainless steel chamber to photons"*, CERN, Vacuum Technical Note 94-10 pg. 9, AT-VA/JGG.

[4] P. Bauer, P. Limon et al. *"Synchrotron radiation issues in the VLHC"* these proceedings.

[5] *"Design Study for a Staged VLHC"* Fermilab TM-2149 (18/5/01), http://vlhc.org/.

[6] J. Gómez-Goñi, O. Gröbner and A. G. Mathewson, J. Vac. Sci. Tech. A 12(4), p.1714, (1994).

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
ONE CYCLOTRON ROAD | BERKELEY, CALIFORNIA 94720

Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098