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BEAM-MACHINE INTERACTION AT TLEP: FIRST EVALUATION AND MITIGATION OF THE SYNCHROTRON RADIATION IMPACT

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Abstract

In the framework of post-LHC accelerator studies, TLEP is a proposed high-luminosity circular e+e- collider, aimed at measuring the properties of the Higgs boson H(126) with unprecedented accuracy, as well as those of the W boson, the Z boson and the top quark.

In order to calculate the impact of synchrotron radiation, the latter has been implemented in the FLUKA code as new source term. A first account of escaping power as a function of the vacuum chamber shielding thickness, photo-neutron production, and activation has been obtained for the 80 km circumference 175 GeV (beam energy) TLEP option. Starting from a preliminary layout of the FODO cell and a possible dipole design, energy deposition simulations have been carried out, investigating the effectiveness of absorbers in the interconnections. The results provide inputs to improve the cell design and to support mechanical integration studies.

INTRODUCTION

The discovery of a light Higgs boson at the Large Hadron Collider (LHC) re-opens the doors to the discussion of a possible future e+e- collider.

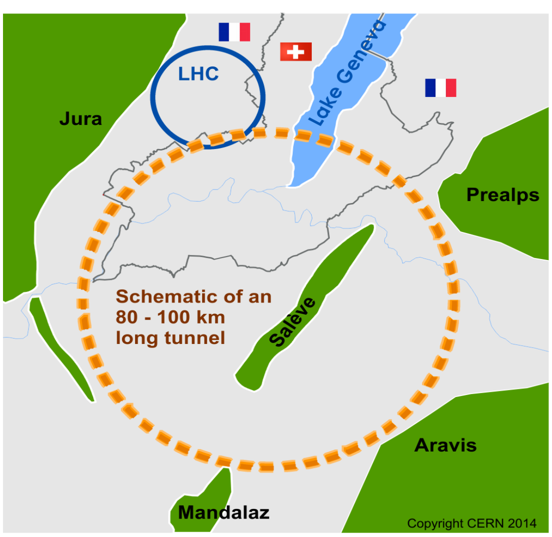

Figure 1: Map of the Geneva area; the blue line marks the LHC tunnel; the dashed yellow one represents the 80 km or the 100 km option.

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Before 2012, the energy limitation imposed to such a machine by the synchrotron radiation was considered too severe for allowing the study of the top quark or the Higgs boson itself with a reasonable small radius machine.

From that date, different options were taken into account, starting from the idea of a possible LEP3 re-installed in the LHC tunnel, up to the most promising study of a new 80 or 100 km accelerator in the Geneva area (see Fig. 1).

It has to be pointed out that in the case of a new tunnel, the choice of its length is driven by the requirements on a possible co-located hadron collider rather than by the ones for the lepton machine. For this reason, the 100 km option seems now the better solution.

However, to evaluate the impact of synchrotron radiation in a lepton machine, the 80 km option is the more conservative choice, since the critical energy decreases with the radius at the dipole.

These studies are currently on-going at CERN in the framework of Future Circular Collider (FCC) design study for the next European Strategy Update review (2018) [1].

Table 1 summarize the main parameters of the 80 km option, used as reference in this study.

Table 1: Key parameters of a possible 80 km long e+e- collider TLEP also called FCC-ee.

Main parameters	80 km
Beam Energy [GeV]	175
Fill factor	81%
Dipole Bending Radius [km]	9.8
Critical Energy [MeV]	1.21
Energy lost per turn [GeV/turn]	8.5
Energy lost in the dipole [keV/cm]	1.375
Beam current [mA]	10
Power lost in the whole accelerator [MW]	85
Power lost in the dipole [W/cm]	13.75

Synchrotron radiation is one of the main concerns in the design of a lepton machine. It poses energy deposition and activation challenges and calls for suitable shielding solutions. In this paper, we explore the effectiveness of localized absorbers of reduced aperture.

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METHODOLOGY

For the purposes of this work, a new source routine was implemented in the FLUKA code [2-4] in a general way, allowing to sample from any synchrotron radiation spectrum and properly accounting for the photon angular distribution and polarization. Emitting particles are assumed to follow arcs or helical paths in a constant magnetic field, with arbitrary orientation with respect to the latter. On the other hand, accurate photon transport down to 100 eV was already available in FLUKA, including polarization effects for Compton, photoelectric and coherent scattering, as well as bound electron effects.

Starting from a 25 m long half FODO cell, five 24 cm long absorbers, with an inner 25 mm copper wing, were included in the lattice layout (see Fig. 2). The internal dimension of the elliptical beam pipe considered was 90x30 mm (HxV).

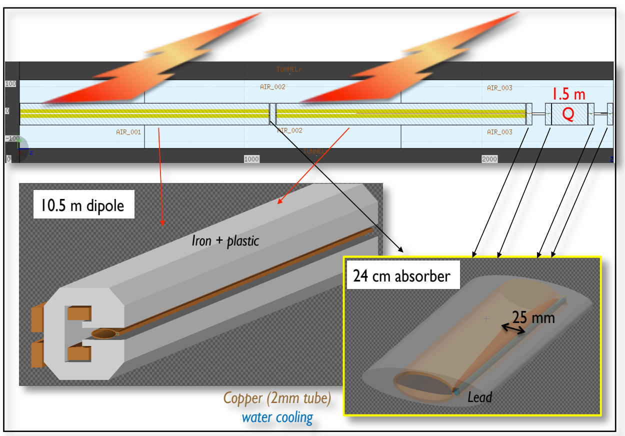

Figure 2: FLUKA geometry layout of the half FODO cell on top, details of the geometry implementation on the bottom: the 10.5 m dipole is shown on the left, while the preliminary design of a possible absorber is on the right, including an external lead shielding of 5 cm.

In this preliminary evaluation the choice of the number of absorbers and their length was driven mainly by lattice constraints. The absorber internal design is the result of vacuum considerations and ray-trace MonteCarlo calculations of synchrotron radiation. The dipole design is taken from the resistive LHeC [4] type, while the quadrupole magnets were implemented in FLUKA just as analytical magnetic field. A proper change of coordinates was applied to particles exiting from the end of the half FODO cell, re-injecting them back at its beginning, in order to account for the contribution of all relevant upstream cells.

RESULTS

Total Power Deposition

A major reduction of the power deposited in the dipoles by synchrotron radiation is found in presence of absorbers (see Fig. 3).

In particular, the two absorbers located downstream of the dipoles are the most effective ones, collecting a large power fraction.

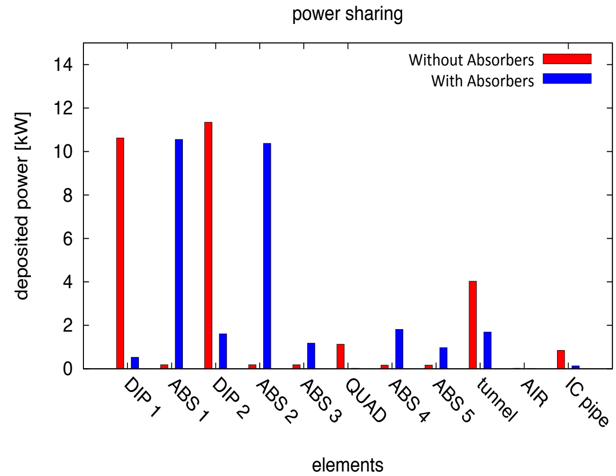

Figure 3: Total power deposited in the different beam line elements and in the tunnel, the air and the interconnections (last 3 labels). Red bars show the results without any absorber, while five absorbers were included for the blue case. Results are normalized to 10 mA beam current.

Peak Power Density in the Dipole Beam Chamber

In presence of absorbers, only the last few meters of the dipole vacuum chamber are less effectively shielded (see Fig. 4), ideally suggesting shorter magnets.

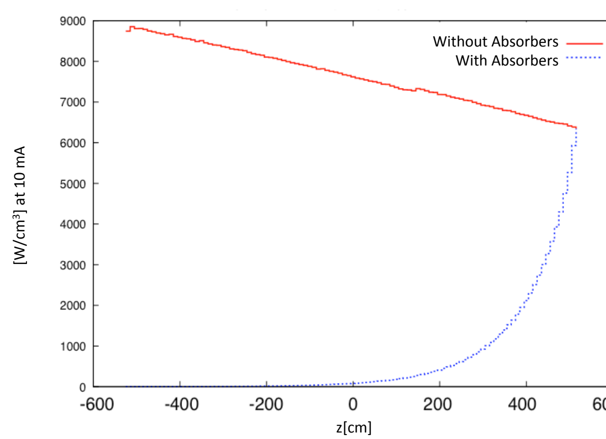

Figure 4: Peak power density in the dipole beam chamber (external side). The red (blue) line refers to the case without (with) absorbers.

Dose on the Dipole Coils

Figure 5 shows the peak dose profile in the dipole coils, which benefit from their internal location with respect to the circulating beam.

Once more, the absorbers assure a remarkable reduction, except for the upstream and downstream front faces where dose values are even increased due to low

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energy photons, which could be effectively intercepted by suitable masks not interfering with the beam aperture.

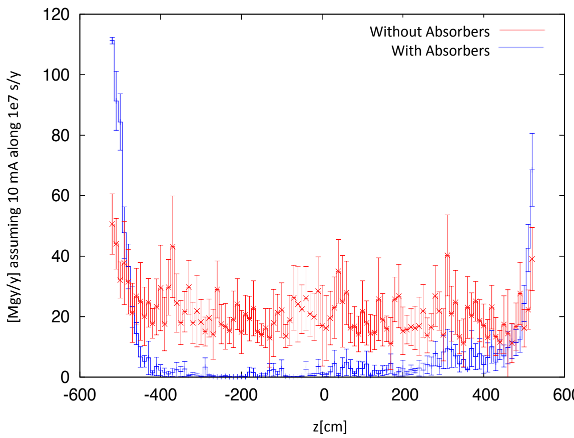

Figure 5: Longitudinal profile of peak dose (in MGy) in the dipole coils. Values are normalized to 10 mA beam current run over 107 s (i.e. 116 days). The red (blue) line refers to the case without (with) absorbers.

Ozone Production

Considering a power of 10 W deposited in a volume of air of the order of 10^8 cm^3 and a renewal rate of 0.1 per hour from ventilation, the concentration of ozone would reach a saturation value of 1-2 ppm.

CONCLUSIONS

This preliminary study shows that localized absorbers are an attractive option to intercept synchrotron radiation in a new generation circular lepton collider.

Optimized shapes can be explored, including the investigation of absorbers integrated inside the dipole, in parallel to alternative magnet designs.

For the purposes of the latter ones, one should consider that coils located on the external side of the beam would be significantly exposed in case of long dipoles.

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