ADVANCED BEAM DUMP FOR FCC-ee

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Abstract

A modified beam dump for the future electron positron circular collider FCC-ee is discussed. The extraction line with a dilution kicker system distributes bunches at different transverse locations on the face of the beam dump. For a standard absorber the maximum energy deposition of all bunches occurs at the same longitudinal position inside the beam dump. This region experiences an enormous temperature rise compared with the surrounding parts of the beam dump. We propose a novel type of beam dump which spreads out the deposited energy over its whole volume quasi-uniformly, thereby reducing the maximum temperature rise. Results of Monte-Carlo simulations are shown for a multi-material "mosaic" beam dump and for absorbers with distorted shapes.

INTRODUCTION

The Future Circular Collider (FCC) study includes the design of a high-luminosity high-precision e^+e^- collider (FCC-ee) serving as Z, W, Higgs and top factory, with luminosities ranging from $\approx 10^{36}$ to $\approx 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ per collision point at the Z pole and $t\bar{t}$ threshold, respectively. The design of FCC-ee provides separate e^+e^- channels allowing very large luminosities to be considered in each of two (or perhaps four) interaction points. In a 100 km tunnel, the accessible centre of mass energy range spans from the Z pole (90 GeV) to above the top pair threshold (350 GeV) [1].

The FCC-ee will have two beam dumps for electron and positron beams, respectively. The proposed FCC-ee beam dump system must have the capability to absorb an energy of 0.4 MJ/beam (for the $t\bar{t}$ threshold) to 20 MJ/beam (for the Z factory). The general details of the proposed beam dump design for low and high current FCC-ee were presented at the FCC week [2] and eeFACT 2016 [3], respectively. These studies have shown that the beam must be spread over a large surface on the beam dump in order not to damage the absorber or the window which separates the ring from the dump. The proposed extraction line, consisting of abort kicker and dilution kicker systems, transports the electron and positron beams to the main beam dumps. The energy deposition by the primary beam in the dump was simulated using the FLUKA [4] or GEANT4 [5] Monte Carlo simulation codes.

In this paper we present two modifications of the proposed beam dump design for the FCC-ee collider. The two proposed concepts should help smear the energy deposition inside the whole volume of beam dump, and ensure that the beam dump will not suffer any dangerous temperature rise or temperature shock.

GENERAL CONSIDERATIONS

Monte-Carlo simulations were performed to investigate the energy deposition in the absorber and, thus, to calculate the associated local temperature rise. In this study we assume that the bunches of the electrons are distributed on the face of the beam dump according to a spiral pattern, similar to the present LHC [6]. For the Z-pole operation, up to seventy thousand bunches could hit the beam dump after an emergency beam abort. We assume that always a few of the bunches are allowed to hit (nearly) the same place on the face of beam dump.

For a standard absorber (e.g. block or cylinder of single material) the maximum energy deposition of all bunches occurs at the same longitudinal position inside the beam dump [2, 3]. This region experiences a higher temperature rise than the surrounding parts of the beam dump.

We have examined several candidate absorber materials, ranging from low to high Z (graphite, aluminum, iron, nickel, copper, tungsten), and taking into account the critical material properties, especially the melting temperatures. First we consider a dump made from a single block of material with a full length of 600 cm and transverse size of 80×80 cm. All our simulated scenarios correspond to realistic beams. The beam parameters used in the simulations are given in Table 1 for $\beta_x = \beta_y = 1000$ m, based on the optics in Refs. [7, 8] .

Table 1: Beam Parameters Used in Monte-Carlo Simulations

FCC-ee	Units	Z
beam energy	GeV	45.6
beam current	mA	1390
bunches\beam		70 760
bunch population	10^{11}	0.4
ε_x	nm	0.26
ε_y	pm	1.0
σ_x	mm	0.51
$\sigma_{x'}$	μrad	0.51
σ_y	μm	32
$\sigma_{y'}$	nrad	32
σ_p	%	0.083

Monte-Carlo simulation results for the energy deposition penetration depth in various materials are shown in Fig. 1. The depth at maximum energy deposition is 4 cm for Tungsten and increases to 110 cm for graphite. The energy penetration depth is decreasing for higher Z materials. High Z

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materials dissipate the beam energy over a short distance underneath the dump-block surface, i.e., the energy deposition would be concentrated in the first 10-20 cm of the block. As a consequence, the resulting temperature rise would be high [3].

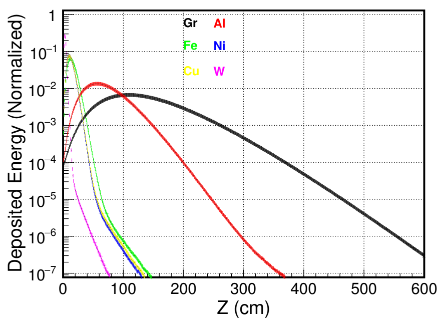

Figure 1: Longitudinal distribution of the deposited energy in various absorbers.

We have chosen graphite as one main material for the FCC-ee beam dump, because of its high melting (sublimation) temperature. Using a material like graphite ensures that the beam energy is distributed throughout the block, and that the block will last for many years. The temperature distribution in the graphite is illustrated in Fig. 2. The maximum energy deposition density from seventy thousand bunches of electrons distributed like a spiral on the graphite is found to be ~63 J/cm^3, which is equivalent to 37 J/g. The associated peak temperature rise in the unit volume of graphite due to the impact of FCC-ee beam is ΔT = 52°C.

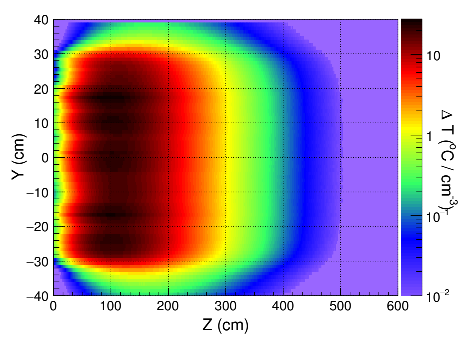

Figure 2: Temperature distribution in the longitudinal-vertical plane considering a 1 cm wide horizontal slice of graphite from the center of the regular dump block.

GEOMETRICALLY DISTORTED DUMP

The distribution of the electron bunches on the surface of the beam dump solves the problem partially. From Figs. 1 and 2 it is clear that the energy deposition in the longitudinal direction is concentrated at a distance of ~110 cm from the beam dump front surface.

The main idea for an improved dump design is to smear the energy deposition over the whole volume of the absorber, i.e. the parts of the beam dump volume situated before and after the energy deposition peak. This would allow to better distribute the deposited energy over the whole volume and, thereby, also to decrease the temperature gradient inside the absorber (see Fig. 1).

One of the possible solutions is to use distorted geometrical shapes instead of the regular cylinders or blocks of materials. The change in the geometrical shapes should break the symmetry in the distribution of of beam particles hitting the beam dump and redistribute them spatially wider inside the absorber. For example, one could use a trapezoidal shape for the beam dump as is shown in Fig. 3.

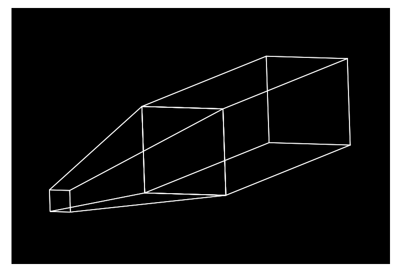

Figure 3: Beam dump shape used in Monte-Carlo simulations.

This distorted beam dump consists of two parts. The front half of the beam dump is a truncated square pyramid with 300 cm length. The front side of the truncated pyramid is a square with 20×20 cm and the back side is a square with 80×80 cm dimensions. The second part is a regular block with 300 cm length. The whole beam dump is made of graphite. The edges of the truncated pyramid modulate the longitudinal position where individual bunches enter the dump block.

The Monte Carlo simulation results of the deposited energy density contours for the regular and distorted beam dumps are shown in Fig. 4. For the distorted beam dump the energy deposition is more widely distributed, which was exactly the purpose of the added pyramidal front part.

Figure 5 compares the longitudinal distributions of the deposited energy for the regular and distorted beam dumps. Gaussian fits of the longitudinal extents of the energy deposition yield the standard deviations σ_z = 53 cm for the regular and σ_z = 90 cm for the distorted beam dump, respectively. In other words, the longitudinal energy deposition is 1.7 times wider in case of the distorted beam dump. This will decrease the temperature gradient inside the absorber.

MOSAIC BEAM DUMP

As another mitigation method, we considered mosaic beam dumps, e.g. compposite dump blocks made from by sets of different materials. Such a mosaic beam dump can redistribute the deposited energy since the penetration depth of the energy deposition varies for different materials. We used blocks made from graphite and iron with dimensions

ISBN 978-3-95450-182-3

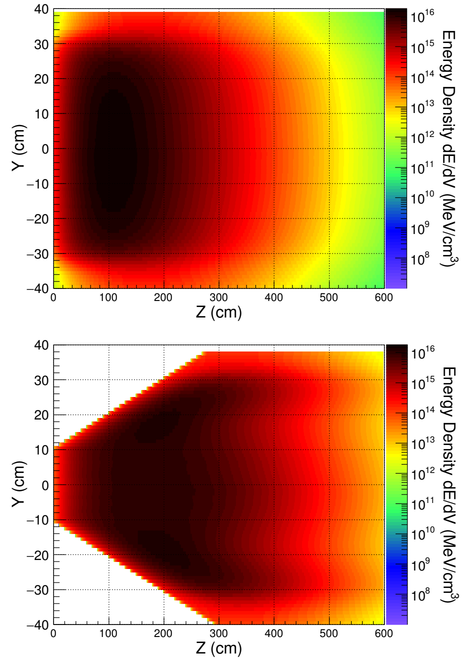

Figure 4: The energy density deposited inside the graphite for regular (top plot) and distorted beam dump (bottom plots), in the vertical-longitudinal (y-z) plane.

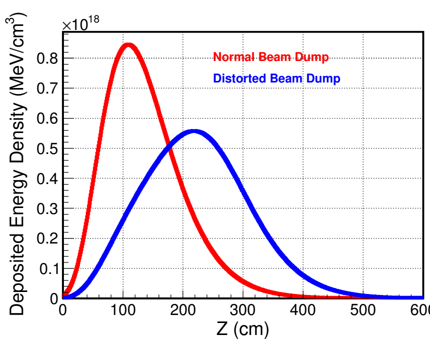

Figure 5: Longitudinal distribution of the deposited energy in regular (red) and distorted (blue) absorbers.

of 10×10×600 cm, transversely in alternation, instead of a larger monolithic block from a single material with dimensions 80×80×100 cm. The peak of the deposited energy is situated around 110 cm depth for pure graphite and at a depth of 14 cm in the case of pure iron, as is shown in Fig. 1. During the shower formation, beam and secondary particles may traverse several subblocks and, as a result, deposit their energy at different depths inside the beam dump. As a result the energy deposition of the particles can be more evenly spread over the entire volume of the mosaic beam dump.

The deposited energy density in the mosaic beam dump is shown in Fig. 6. One can see that, compared with pure graphite, the energy deposition peak is shifted towards a shorter distance from the surface, since the interleaved iron subblocks have less penetration depth.

Figure 7 shows the longitudinal distribution of the deposited energy in a mosaic beam dump made from

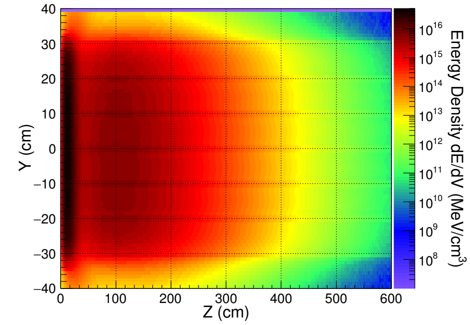

Figure 6: The energy density deposited on the mosaic beam dump in the vertical-longitudinal (y-z) plane.

C(graphite)-Fe blocks. The plot reveals two peaks of the deposited energy. The first peak corresponds to the peak energy deposition in the iron blocks and the second one to the peak energy deposition in the graphite blocks. This figure demonstrates that with such a mosaic dump more energy is deposited in the region closer to the beam dump surface. The exact distribution could be taylored by changing the relative volume of the mosaic materials.

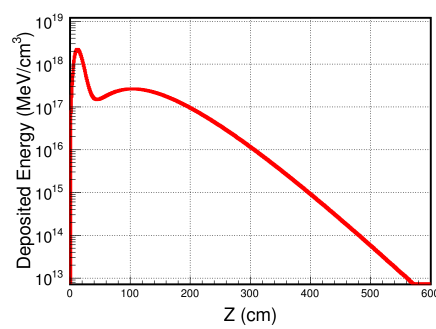

Figure 7: Longitudinal distribution of the deposited energy in mosaic beam dump made from C(graphite)-Fe blocks.

CONCLUSIONS

Our Monte-Carlo simulations illustrate that both distorted or multi-material mosaic beam dumps are promising devices for future high energy and intensity colliders. Most effective would be a combination of the two concepts, namely a distorted mosaic beam dump, which might achieve an almost perfectly uniform distribution of the deposited energy inside the beam dump. For the FCC-ee collider the expected temperature rise of the graphite is not dramatic, and the rate of beam dumps low; at the very most one dump could occur every 30 minutes. For this specific application, also a conventional regular graphite block might suffice. The novel concepts presented here may be of great interest for other future colliders, e.g. the FCC-hh hadron collider.

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ISBN 978-3-95450-182-3