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Shower simulations, comparison of FLUKA, GEANT4 and EGS4

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Abstract

Computer simulations with different packages (FLUKA, GEANT4 and EGS4) were run in order to determine the energy deposition of an ILC bunch in a spoiler of specified geometry at various depths. The uncertainty in these predictions is estimated by comparison of their results. Various candidate spoiler designs (geometry, material) are studied. These shower simulations can be used as inputs to thermal and mechanical studies using programs such as ANSYS.

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1 Introduction

Due to the impossibility of actually testing candidate ILC spoilers in the exact same beam conditions of size and energy as the ILC, it is necessary to rely heavily on simulation for a large part of the process of optimising the spoiler jaws. Simulations of both energy deposition via electromagnetic processes and of the resulting mechanical stresses, caused by the rapid heating of the material, need to be considered. This paper compares the predictions for energy deposition and corresponding temperature rises in a variety of different spoiler jaw configurations, obtained using the FLUKA [1][2], GEANT4 [3] and EGS4 [4] Monte Carlos. These studies form part of the R&D for spoiler material optimisation referred to in the ILC Baseline Configuration Document (BCD) for the Beam Delivery System [5].

2 Possible collimation designs for the ILC

Different options, such as a full metal spoiler using either titanium, titanium alloy Ti-6Al-4V (90% Ti, 6% Al, 4% V) or aluminium, and different combinations of graphite and alloy have been simulated. Metal is necessary in order to have the high electrical conductivity that will help to suppress the electric wakefields generated by the electrons in the bunch. Although titanium has lower electrical conductivity than copper, its higher melting point (~1941K versus the 1358K of copper) make it a more suitable candidate to survive the temperature increases generated by the impact of one or more bunches. Aluminium has a lower melting point (933.47 K) compared to titanium, but its radiation length (8.9 cm vs. 3.56 cm for titanium) results in a lower energy density deposition than with the other metals.

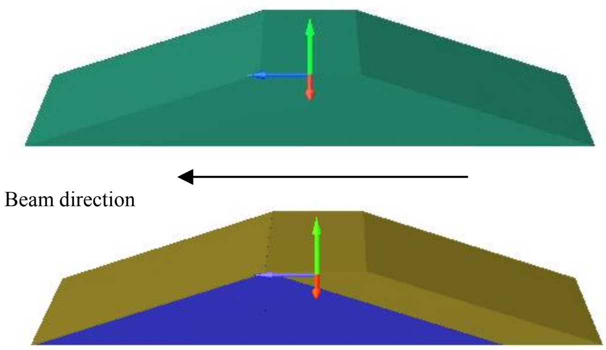

Fig. 1. Two different spoiler options. Top: Full titanium alloy body. Bottom: Graphite core covered by titanium alloy, which for the first taper the length of metal is of $0.6 \cdot X_0$. Visualized using SimpleGeo [7].

In the ILC BCD spoilers are defined to be between 0.5 and 1.0 radiation lengths thick, to ensure appropriately lowered energy density incident on the downstream absorbers. They are also required to be “survivable”, i.e. not be damaged by 2 (1) bunches at 250 (500) GeV. It is desirable to have short spoilers that do not take up large amounts of space along the beamline, but this must be balanced with the requirement to avoid rapid changes in aperture which lead to large geometric contributions to the transverse wakefields. To reduce the transverse wakefield component a smooth transition between the aperture of the beam pipe to the narrowest aperture of the spoiler jaws is recommended. This leads to designs consisting of two tapers, a leading taper (wedge) upstream of the main body of the spoiler and a trailing taper downstream. As the optimisation of the external geometry of the spoiler (taper angle) for wakefields is still in progress [6], a taper angle of 335mrad has been used arbitrarily throughout, motivated by the fact that this corresponds to one of the insertions used in the T-480 run at SLAC in Apr/May 2006. An example of this can be seen in Figure 1.

To achieve reasonable longitudinal dimensions of the spoiler, it is assumed that most of the required number of radiation lengths of material will be in the form of a metal, e.g. Cu. The strong dependence of the number of radiation lengths traversed by a beam entering a tapered spoiler on the displacement from the beam axis, make it attractive to consider using a long radiation length material as a bulk, covered by a thin layer of metal, rather than a homogeneous metal spoiler (Figure 1, bottom).

This extra material makes it interesting to consider a range of options, incorporating metals and graphite. In the following sections several of these options are presented together with the predictions for impact by a bunch of $2 \cdot 10^{10}$ electrons at 250 GeV, with beam size of σ_x=111 µm and σ_y=9 µm, and at 500 GeV, with σ_x=79.5 µm and σ_y=6.36 µm. The beam sizes at 500 GeV energy are scaled from the ones at 250 GeV energy by $\sqrt{(250/500)}$.

3 Shower simulations

Simple targets made of titanium alloy whose lengths were either 0.6 radiation lengths, representing a betatron spoiler, or 1.0 radiation length, representing an energy spoiler, are used to compare the three codes. Simulations performed with GEANT4 and FLUKA with different spoiler geometries are also compared. These simulations give the energy deposited in the material by the particles (in joules/gram or GeV/cm^3) and then this energy density is transformed into a temperature using the material density and specific heat. The results ignore the change in specific heat with temperature

3.1 Results with FLUKA, GEANT4 and EGS4 on simple titanium alloy targets

Tables 1 and 2 summarise the results obtained with each code for different targets and beam sizes. Table 1 shows the maximum temperature increase obtained using a bunch of $2 \cdot 10^{10}$ e^- at 250 GeV. Table 2 shows the maximum temperature increase for a bunch of $2 \cdot 10^{10}$ e^- at 500 GeV.

Differences from one code to the other are generally around 15% (being the maximum difference of 31% and the minimum of 2%), showing then a general good agreement between the different packages

Table 1: Max. temperature increases in different targets with each code package for a bunch of $2 \cdot 10^{10}$ e^- at 250GeV.

Spoiler	Beam size σ_x σ_y [µm]	EGS4 Max. ΔT [K]	FLUKA Max. ΔT [K]	GEANT4 Max. ΔT [K]
0.6 r.l. Ti alloy	28 6	1380	1560	2000
0.6 r.l. Ti alloy	111 9	290	255	255
1.0 r.l. Ti alloy	104 15	260	300	310
30 cm of Cu	20 1.4	25000	25000	25600

Table 2: Max. temperature increases in different targets with each code package for a bunch of $2 \cdot 10^{10}$ e^- at 500GeV.

Spoiler	Beam size σ_x σ_y [μm]	EGS4 Max. ΔT [K]	FLUKA Max. ΔT [K]	GEANT4 Max. ΔT [K]
0.6 r.l. Ti alloy	28/√2 6/√2	2770	3180	3200
0.6 r.l. Ti alloy	111/√2 9/√2	560	450	435
1.0 r.l. Ti alloy	58 11	720	760	770
30 cm of Cu	20/√2 1.4/√2	60000	69000	70000

3.2 Results with FLUKA and GEANT4 on different spoiler configurations

Table 3: Max. temperature increases for different spoiler options for an ILC bunch of $2 \cdot 10^{10}$ e^- at 250GeV or 500 GeV.

Spoiler	250 GeV Max. ΔT[K]	500 GeV Max.ΔT[K]	Code used
Full Ti alloy	420	870	FLUKA
	375	830	GEANT4
Full Al	200	410	FLUKA
	200	370	GEANT4
Full Cu	1300	2700	FLUKA
	1200	2440	GEANT4
Ti+graphite option	290	575	FLUKA
	240	460	GEANT4

Table 3 shows the maximum temperature increases obtained when an ILC bunch of $2 \cdot 10^{10}$ electrons at 250 GeV (second column) or at 500 GeV (third column) collides 2 mm deep from the top edge of the spoiler. Results are given for four different types of spoiler: a full body of titanium alloy, one of aluminium, one made of copper and for a configuration of titanium alloy and graphite (the same configuration as the one shown in Figure 1). Particles entering 2 mm deep from the top edge will encounter approximately 3 cm of material in the case of the titanium alloy spoiler, 6 cm in the case of the aluminium spoiler and around 2 cm for the copper one. For the configuration of titanium alloy and graphite particles will traverse around 2 cm of alloy (0.6 radiation lengths) and almost 1 cm of graphite.

From Table 3 it can be observed that FLUKA and GEANT4 differ by approximately a factor of two between 250 GeV and 500 GeV. This is almost entirely due to the factor of two difference in bunch area for the two energies. The average temperature increment difference calculated from both codes is around 9% (maximum difference in those cases is ~20%, minimum is 0%).

These results show that one ILC bunch (1) exceeds copper melting temperature at both energies, (2) exceeds aluminium fracture temperature at both energies, (3) exceeds titanium alloy fracture temperature at 500 GeV. The titanium alloy and graphite mixture showed no problems of fracture or melting whatsoever for both energies.

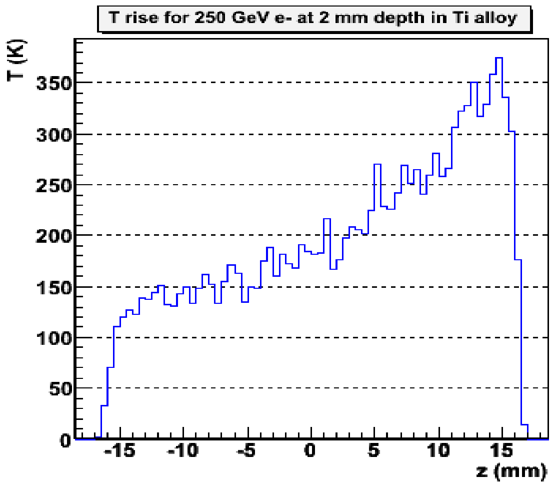

Fig. 2. Temperature rises in the titanium alloy in the bunch volume calculated with GEANT4.

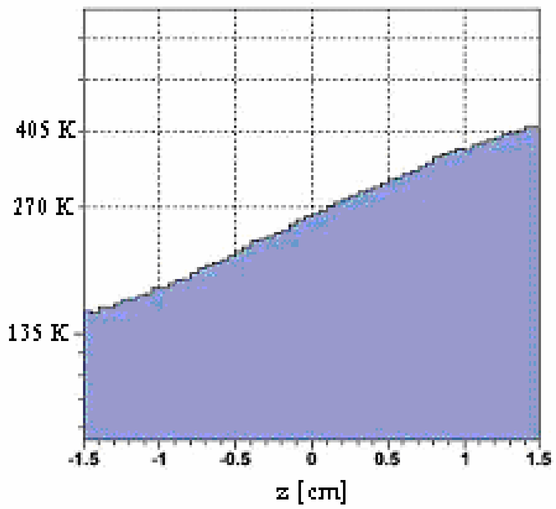

Fig. 3. Temperature rises in the titanium alloy in the bunch volume calculated with FLUKA and extracted using FLUKAGUI.

Figures 2 and 3 show the temperature rise profiles in a titanium alloy spoiler, at a beam energy of 250GeV, for GEANT4 and FLUKA, respectively. These are evaluated in a small volume centred on the bunch trajectory. The more rapid statistical convergence achieved using the track length apportioning algorithm within FLUKA accounts for the relative smoothness of Figures 3 and 2 for an equal number of primary particles simulated.

4 Conclusion

The three different simulation codes give good agreement in estimates of energy deposition for various materials.

A solid, homogenous 0.6 radiation length spoiler was found to be susceptible to damage, using any of the metals considered. One ILC bunch exceeds the melting temperature of copper and the fracture temperature of aluminium. The titanium alloy showed the best results; although its fracture temperature is attained when the bunch has an energy of 500 GeV. The best design option simulated in this study is the titanium alloy plus graphite configuration, shown in Figure 1, bottom.

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