Simulations of Damage to Carbon Collimators Caused Due to Full Impact of LHC Beam*

N.A. Tahir, GSI, Darmstadt, Germany
R.Schmidt, Y.Kadi, CERN, Geneva, Switzerland
A. Shutov, IPCP, Chernogolovka, Russia
A.R. Piriz, University of Castilla-La Mancha, Ciudad Real, Spain
D.H.H. Hoffmann, GSI, Darmstadt, Germany

Abstract

This contribution presents two-dimensional numerical simulations of heating of solid carbon target by full impact of an LHC beam. This work has been carried out to assess the damage caused to carbon collimators in case the beam is deflected towards them. The calculations show that the beam has the potential to cause substantial damage to the collimators.

Introduction

The LHC will operate at 7 TeV with a luminosity of $10^{34}\ cm^{-2}s^{-1}$. This requires two beams, each with 2808 bunches. The nominal intensity per bunch is 1.1×10^{11} protons and the transverse particle intensity profile is Gaussian with a standard deviation, σ = 0.2 mm. The bunch length is 0.5 ns and two neighboring bunches are separated by 25 ns. The energy stored in each beam of 362 MJ. In previous papers [1, 2] the mechanisms causing equipment damage in case of a failure of the machine protection system was discussed, assuming that the entire beam is deflected into a copper target. Another failure scenario is the deflection of beam, or part of it, into carbon material. Carbon collimators and beam absorbers are installed in many locations around the LHC to absorb beam losses, since carbon is the material that is most suitable to absorb the beam energy without being damaged. Since collimators and absorbers are close to the beam, it is very likely that they are hit first when the beam is accidentally deflected. In this paper the results of two-dimensional hydrodynamic simulations of the heating of a solid carbon cylinder with a radius of 5 cm whose one face is irradiated by the LHC beam with nominal parameters are presented. The hydrodynamic simulations have been carried out using the BIG-2 computer code [3] while the energy loss of the 7 TeV protons in carbon is calculated using the well known FLUKA code [4]. Our calculations suggest that the LHC beam may penetrate up to 10 m in solid carbon.

Simulation Results

In Fig. 1 we plot the specific energy deposited by a single bunch of 7 TeV protons and their cascade particles, calculated by the FLUKA code in solid carbon which is compressed powdered graphite with a density of 2.2 g/cm^3 along the beam axis. It is seen that the maxima of energy deposition occurs at a longitudinal position, L = 135 cm and is 0.16 kJ/g. In Fig. 2 are plotted specific energy deposition vs transverse coordinate at four different values of L = 40 cm, 135 cm, 240 cm and 350 cm respectively.

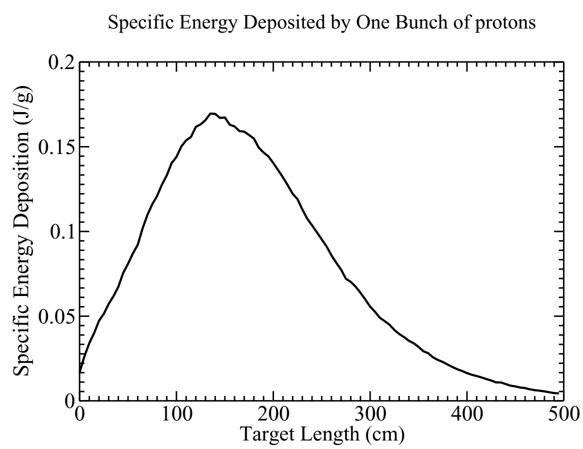

Figure 1: Specific energy deposited in solid carbon by a single LHC bunch along the axis.

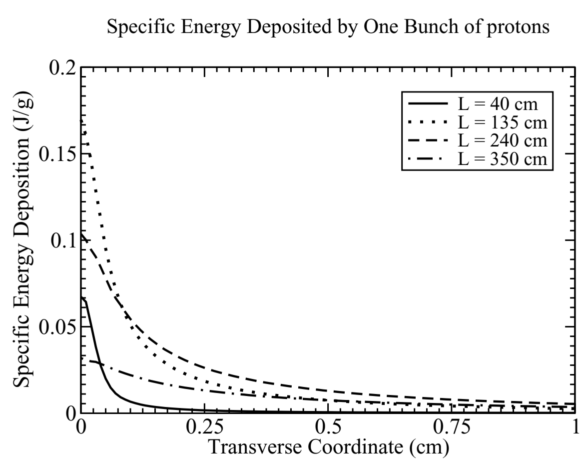

Figure 2: Specific energy deposited in solid carbon by a single LHC bunch in transverse direction at four different longitudinal positions.

Using the energy deposition data provided by the FLUKA code as input to to the BIG2 code, we have cal-

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culated the hydrodynamic and thermodynamic response of a solid carbon cylinder whose one face is irradiated with the LHC beam. We note that the energy deposition profile generated by the FLUKA code is three-dimensional while the BIG2 code is two-dimensional. To overcome this difficulty we consider four different longitudinal positions and study the hydrodynamic and thermodynamic response of the target along the transverse direction.

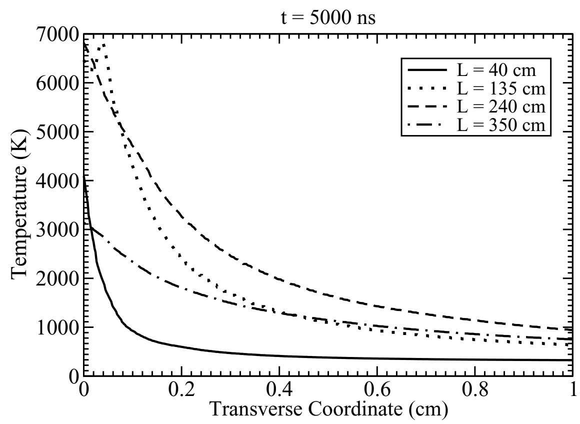

Figure 3: Temperature vs transverse coordinate at t = 5 microsecond at four different longitudinal positions.

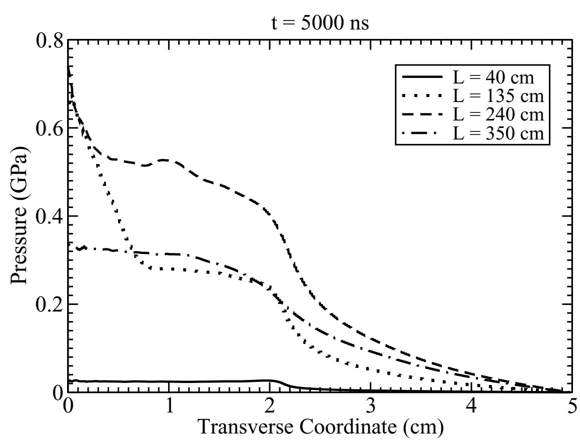

Figure 4: Pressure vs transverse coordinate at t = 5 microsecond at four different longitudinal positions.

In Fig. 3 we plot the target temperature vs transverse coordinate corresponding to the energy deposition profiles shown in Fig. 2 at t = 5 microsecond. By this time, only 250 out of 2808 bunches have been delivered. It is seen that a maximum temperature of 7000 K has been generated at the beam axis at L = 135 cm, where the maximum of energy deposition occurs. This leads to a maximum pressure of the order of 0.7 GPa, as is seen from Fig. 4. This high pressure drives a radially outgoing shock wave that leads to a substantial reduction in density (0.4 gm/cm^3) which is shown in Fig. 5. This means that the protons will penetrate further into the material thereby increasing the penetration depth of the beam. This means that the energy deposition peak that lies at L = 135 cm for solid density will continuously shift along the longitudinal direction.

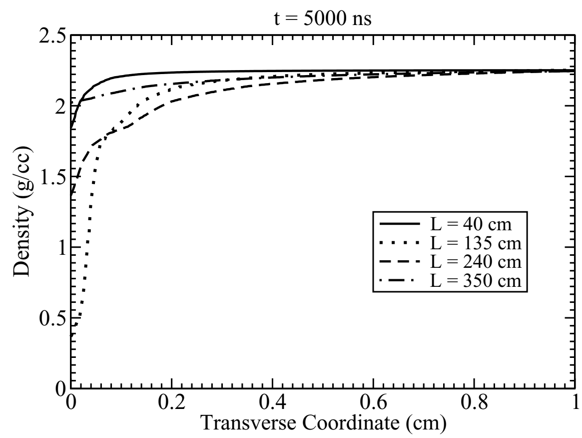

Figure 5: Density vs transverse coordinate at t = 5 microsecond at four different longitudinal positions.

Due to lower energy deposition at other longitudinal position, the material damage is relatively lower. We note that as the energy material density is reduced at a given position, the production of the secondary particle decreases that leads to a reduction in specific energy deposition. This in turn will slow down the hydrodynamic expansion of the material in transverse direction. This effect however is not included in the present calculations and is intended for the future work. We estimate that the LHC beam may penetrate about 10 m in solid carbon.

(please contact: n.tahir@gsi.de).

References

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