EDMS Document Number: 880178

ORGANISATION EUROPENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

Safety Commission

Technical Note
CERN-SC-2007-074-RP-TN

FLUKA calculations for the beam dump system of the LHC : Energy deposition in the dump core and particle spectra in the beam loss monitors

Joachim Vollaire, Doris Forkel-Wirth, Stefan Roesler

Summary

The tremendous amount of energy stored in the beams of the LHC will be absorbed in the two beam dump cores at the end of the physics runs or in case of abnormal situations. The two beam dump cores located at Point 6 were designed with the constraints of withstanding the temperature increase consecutive to a beam dump while keeping their mechanical integrity over the entire lifetime of the LHC. The mechanical studies of the beam dump core were substantiated using energy deposition calculations performed with the Monte-Carlo code FLUKA. Since those studies, the physics models implemented in the code have improved and the beam dump system design was modified. Thus, new calculations were performed to include those changes. For energy deposition calculations both the hadronic and electromagnetic showers have to be simulated while in most radiological studies only the hadronic shower is considered since the induced activity is usually the quantity of interest. Taking benefit from the fact that most particle types were transported in this calculation, the energy spectra of the different particle types were scored along the beam dump core at the positions where Beam Loss Monitors (BLM) will be installed.

Keywords: LHC beam dumps, FLUKA, energy deposition, Beam Loss Monitor

CERN, 1211 Geneva 23, Switzerland
November 4, 2007

joachim.vollaire@cern.ch

1 Introduction

The beam dump system of the LHC was designed to absorb the 360 MJ stored in each beam at the end of the physic runs or in case of abnormal situations. Most of the beam energy will be dissipated in the 7.7 meters long graphite core which will therefore undergo important temperature increases and strong mechanical stresses. Several FLUKA [1, 2] simulations were performed in the past [3] in order to evaluate the deposited energy profile for different beam parameters. This Note summarizes results of new calculations performed with the latest FLUKA version taking into account a description of the beam dump core as it is now installed in the UD caverns.

Since both the hadronic and electromagnetic particles were transported in this calculation, the spectra of the different particles at the positions where the Beam Loss Monitors (BLM) will be installed along and behind the dump core were also calculated in the same FLUKA runs.

2 The FLUKA simulation

2.1 Geometry

The detailed geometrical model implemented in FLUKA for other radiological studies [4, 5] was not used in this calculation since the quantities of interest are limited to the dump core itself and its close surrounding. While an accurate description of the dump core respecting the characteristics of the materials was used, the shielding blocks were represented by a shell of pure cast iron surrounding the dump core. Figure 1 shows a sketch of the geometry used for the energy deposition and particle spectra calculations with FLUKA. The beam dump is a graphite cylinder with a length of 770 cm and a diameter of 70 cm made of two different grades of carbon material. The first 70 cm and the last 350 cm are made with 70 cm long Polychrystalline Graphite blocks (PG) and the middle part with Flexible Graphite plates (FG). The PG has a density of $1.73\, g/cm^3$ and the FG a lower density equal to $1.1\, g/cm^3$. The graphite core is shrink-fitted in a stainless-steel jacket with an external radius of 36.2 cm. The dump core is connected upstream to the beam dumping line and a titanium window closes the downstream end. The dump core will be permanently filled with an inert gas (nitrogen) with sufficient supply to stop a fire. The window situated ten meters upstream of the dump core front face will be able to withstand the differential pressure between the overpressure of nitrogen (1.4 bar) and the beam line under vacuum.

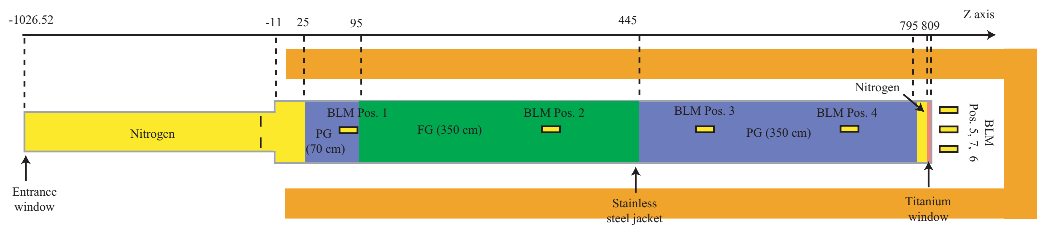

Figure 1: Sketch of the geometry implemented in FLUKA for the calculations of energy deposition and particle spectra at the BLM locations.

2.2 Source

When the beam will be dumped, the 2808 bunches will not impact the dump core at its center. Instead, a set of dilution kicker magnets will be used to deflect the beam horizontally and vertically. The positions where the 2808 bunches will impinge on the dump core front face are indicated in Figure 2. The origin of the graph in Figure 2 corresponds to the center of the beam dump core.

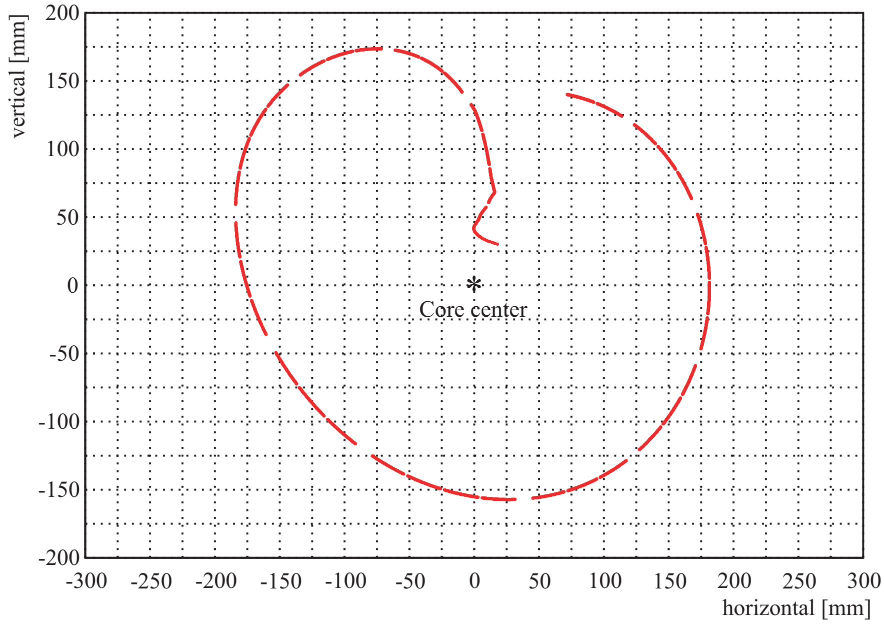

Figure 2: Positions where the 2808 bunches from the beam impinge on the dump core front face in normal operation of the LHC. The origin corresponds to the center of the core front face.

In addition to the shape of the beam shown in Figure 2, protons within the same bunch will follow a Gaussian distribution with a vertical and horizontal spread ($\sigma_{vert} = 0.136\,\text{cm}$ and $\sigma_{hor} = 0.159\,\text{cm}$). To reproduce the shape of the diluted beam in the FLUKA simulation as well as the size of a bunch, a source user routine was written to firstly sample the mean position according to Figure 2 (data taken from an external file), and, secondly, the impact point according to the gaussian distribution within a bunch along the vertical and horizontal axes. The primary proton energy is equal to 7 TeV for this type of calculation.

For some other calculations, the specific shape of the beam shown in Figure 2 is not considered, *e.g.*, in order to calculate the energy deposition in case of a total beam dilution failure. In this case, the beam axis is assumed to be at the center of the dump core with the beam positions sampled using the vertical and horizontal Gaussian distributions. In this case calculations were performed for three different characteristic proton energies, 7 TeV (LHC nominal energy), 2 TeV and 450 GeV (injection energy).

2.3 Transport parameters

While for many radiological studies performed for LHC the transport of electromagnetic particles is not necessary, it is mandatory for energy deposition calculations. Thresholds and defaults settings corresponding to a high simulation accuracy (PRESICIO for SDUM of the DEFAULTS card) were used. With this setting, among others, the electromagnetic particle transport is turned on, all particles except neutrons (transported down to thermal energies) are transported down to 100 keV. The thresholds defined with the PRECISIOn option were overridden for gammas and electrons/positrons using the EMFCUT card with the following options :

EMFCUT -1.0E-04 1E-05 0.0 CoreN2 CoreN2 1.0

EMFCUT -3.0E-04 3E-05 0.0 IrShBot IrShBot 1.0

For some regions as the dump core or its jacket or the air surrounding the dump core, the threshold is set to 100 keV (WHAT (1)) for electrons and positrons and to 10 keV for γ (WHAT (2)). In other regions of lower importance for the quantities of interest as the shielding blocks, the energy cut-offs are set to 300 keV and 30 keV.

In order to reduce the computing time, leading particle biasing was activated using the following settings :

EMF-BIAS 1022 10.0 10.0 CoreN2 CoreN2 1.0 LPBEMF

In this case leading particle biasing is applied after all physical effects below 10 GeV for electrons/positrons and gammas.

2.4 Scoring

2.4.1 Energy deposition

The deposited energy was scored in a three dimensional spatial binning independent of the geometry using the URBIN card. As indicated in Section 2.2, calculations were performed both using the beam profile shown in Figure 2 and with the proton beam impinging at the center of the dump core front face. For the first type of calculations, a Cartesian binning is defined using the following card :

USRBIN 10.0 ENERGY -71.0 202.0 225.0 820.0 NRJ3D

USRBIN 142.0 165.0 60.0 300.0 300.0 38.0 &

When the primary protons are impinging at the center of the dump core, a cylindrical binning defined with the following card is preferred to the Cartesian one due to the radial symmetry of the shower :

USRBIN 11.0 ENERGY -70.0 1.0 195.0 810.0NRJRZ

USRBIN 0.0 172.0 24.0 50.0 1.0 393.0 &

In this case, the bins are really small along the radial coordinate (0.02 cm). The idea is to determine the peak value along the Z axis which would not be possible due to averaging effects if the bins would be to large in the radial direction. Another possibility with this type of binning is to reconstruct the energy deposition deposition in a Cartesian map by adding the distribution obtained with the cylindrical binning for one bunch according to the different bunch positions indicated in Figure 2 [6].

When the deposited energy is scored by FLUKA, results are expressed in GeV/cm^3. However for the calculations presented in this Note, the unit was changed from GeV/cm^3 to Gray (J/kg) using one of the FLUKA user routines (COMSCW routine) which can be called each time energy deposition is being scored (USERWEIG card). To convert deposited energy expressed in GeV/cm^3 to Gray (J/kg), the results are multiplied by a factor equal to $1 \times 10^{12} \times C_{e^-}/\rho$ where C_{e^-} is the electron charge and ρ the material density.

2.4.2 Track-length spectra in the BLM

Some regions were defined in the FLUKA geometry in order to score the energy-dependent track-length spectra for neutrons, protons, gammas, electrons, positrons, π^+, π^-, μ^+, μ^-, K^+, K^- at the positions where BLM are installed [7]. The seven different positions are indicated in Figure 1, four BLM are placed along the core and three behind it. The energy spectra are scored using a equidistant logarithmic binning between 1 MeV and 7 TeV for protons, $\pi^+$and π^-, K^+ and K^- between 30 keV and 7 TeV for e^+, e^-, γ , $\mu^+$and μ^-. The neutron spectra were scored from thermal energy to 19.6 MeV using the FLUKA energy group structure (72 bins) and with a logarithmic binning at higher energies from 19.6 MeV up to 7 TeV.

3 Energy deposition

3.1 Energy deposition with the "e-shaped" beam profile

The primary protons were sampled using the spatial distribution plotted in Figure 2. Since FLUKA computes the average deposited energy for one primary proton, results were multiplied by the number of bunches (2808) times the number of protons per bunch (1.7×10^{11} protons). The quantity which is obtained corresponds to the energy deposited in Gy every time the beam is dumped. The Cartesian binning used has 38 bins, 20 cm wide, along the Z (beam) axis. Two-dimensional maps (along x and y) are plotted for the 38 z-bins in Figures 3, 4, 5 and 6.

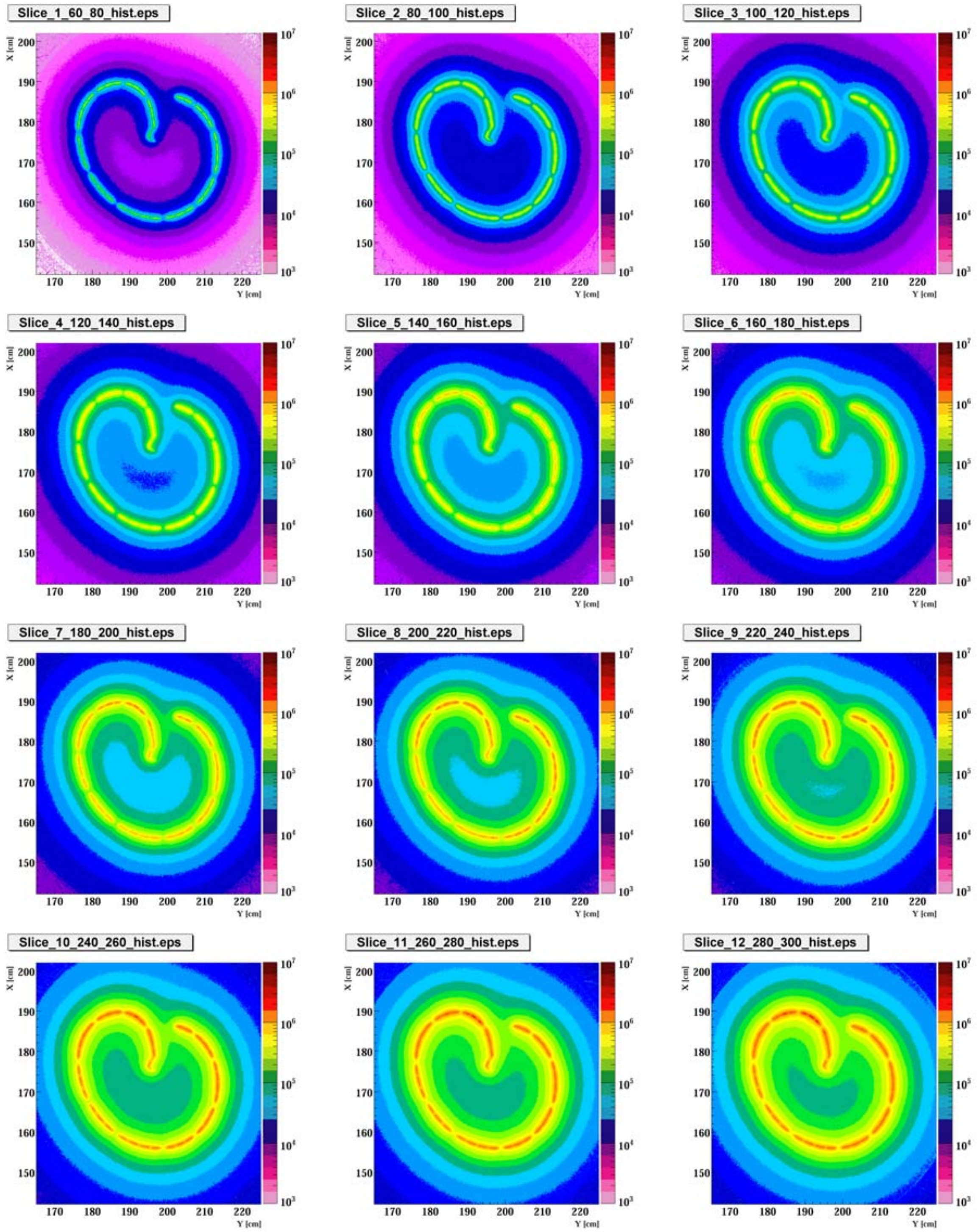

Figure 3: Energy deposition expressed in Gy for one beam dumped ($2808 \times 1.7 \times 10^{11}$ protons). Results are plotted for the upstream part of the graphite dump core ranging from z=60 cm to z= 300 cm.

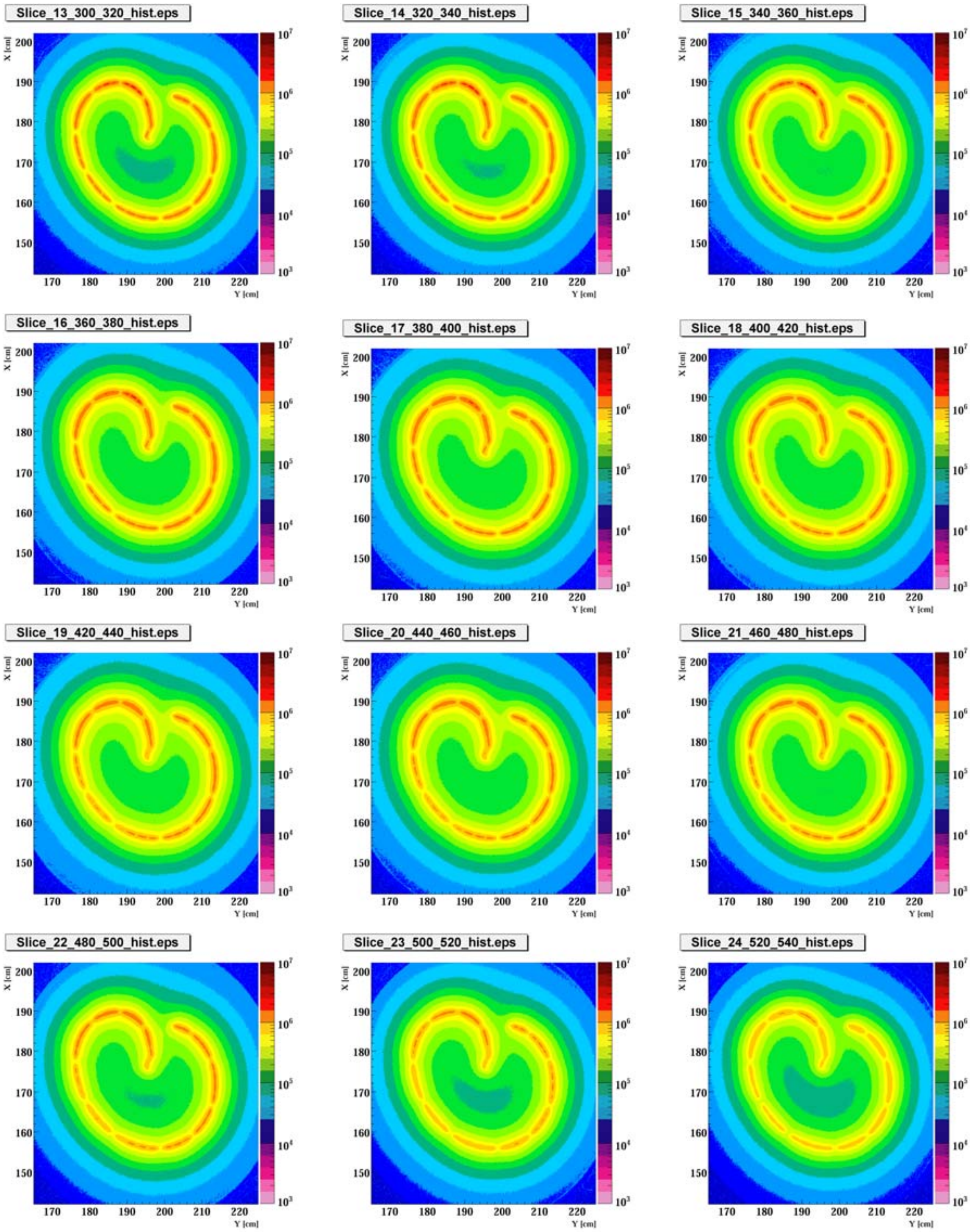

Figure 4: Energy deposition expressed in Gy for one beam dumped ($2808 \times 1.7 \times 10^{11}$ protons). Results are plotted for the middle part of the graphite dump core ranging from z=300 cm to z= 540 cm.

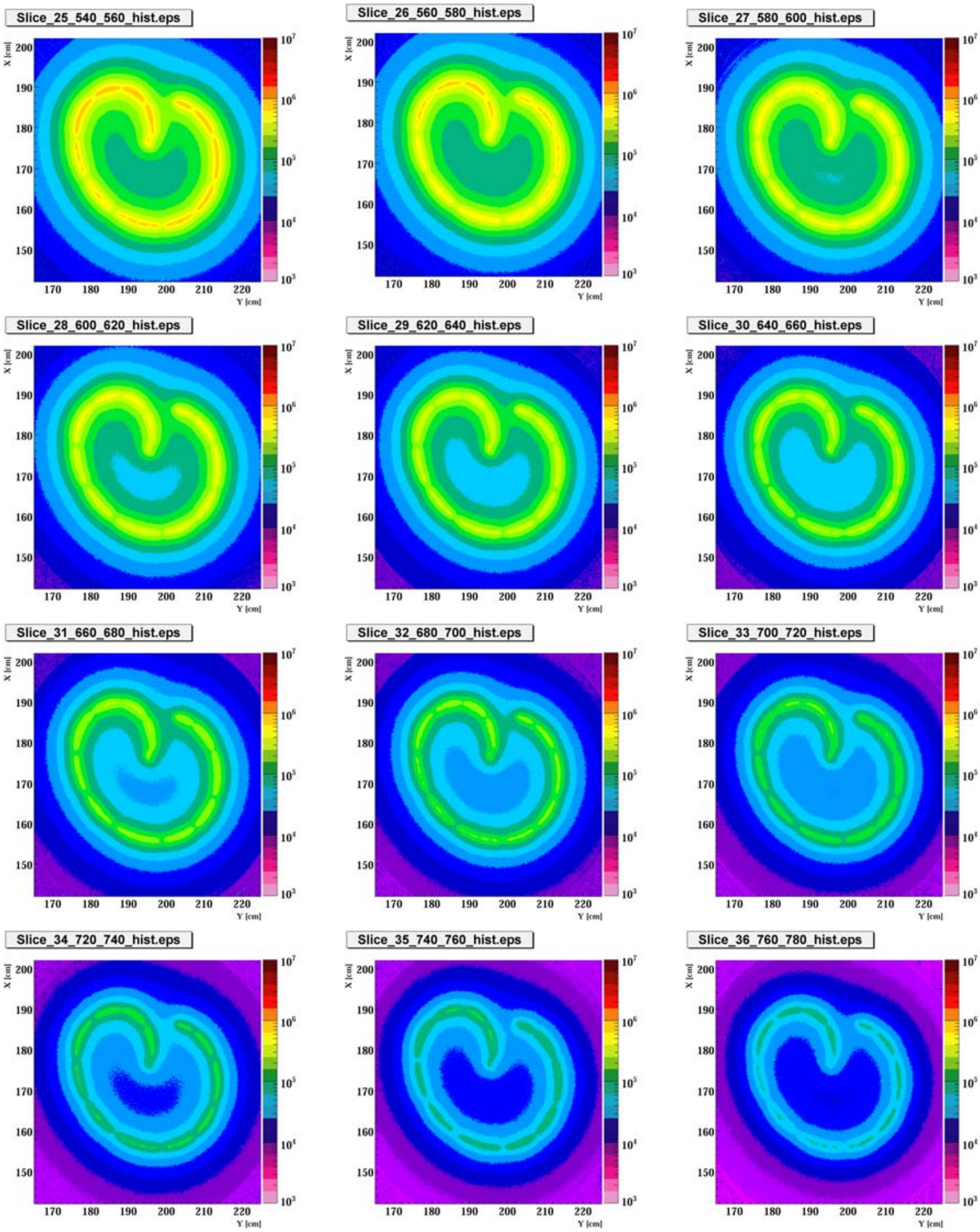

Figure 5: Energy deposition expressed in Gy for one beam dumped ($2808 \times 1.7 \times 10^{11}$ protons). Results are plotted for the downstream part of the graphite dump core ranging from z=540 cm to z= 780 cm.

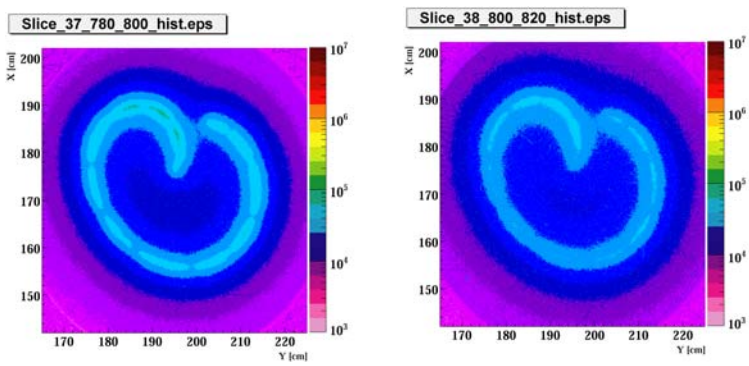

Figure 6: Energy deposition expressed in Gy for one beam dumped ($2808 \times 1.7 \times 10^{11}$ protons). Results are plotted for the downstream part of the graphite dump core ranging from z=780 cm to z= 820 cm.

3.2 Energy deposition for protons impinging the core at the center

For simulations for which the proton beam is impinging on the core at its center, the energy deposition was scored using a very thin binning along the radial axis (50 bins up to a radius of 1 cm) in order to determine the peak energy. The deposited energy inside the inner most r-bin (r = 0 cm to 0.02 cm), the tenth bin (r = 0.18 cm to r = 0.2 cm), the twenty-fifth (0.48 cm to 0.5 cm) and the last bin (r = 0.98 cm to r = 1 cm) are plotted in Figures 7, 8 and 9 for the 7 TeV, 2 TeV and 450 GeV proton beams, respectively. The plotted quantity corresponds to Gy/proton, the results are not scaled to the number of protons per bunch in this case.

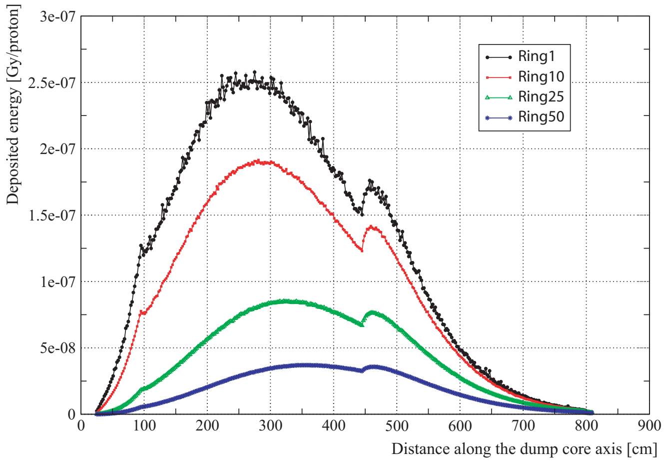

Figure 7: Average energy deposition along the z axis for a 7 TeV proton beam impinging the dump core center. Results are plotted for the inner most bin, the tenth bin, the twenty-fifth bin and the outer bin.

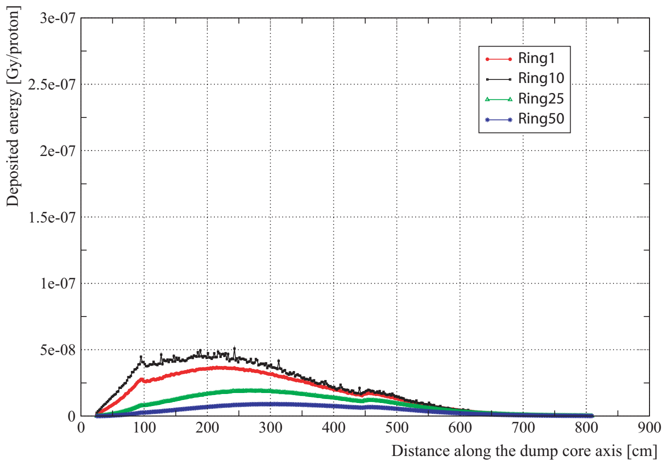

Figure 8: Average energy deposition along the z axis for a 2 TeV proton beam impinging the dump core center. Results are plotted for the inner most bin, the tenth bin, the twenty-fifth bin and the outer bin.

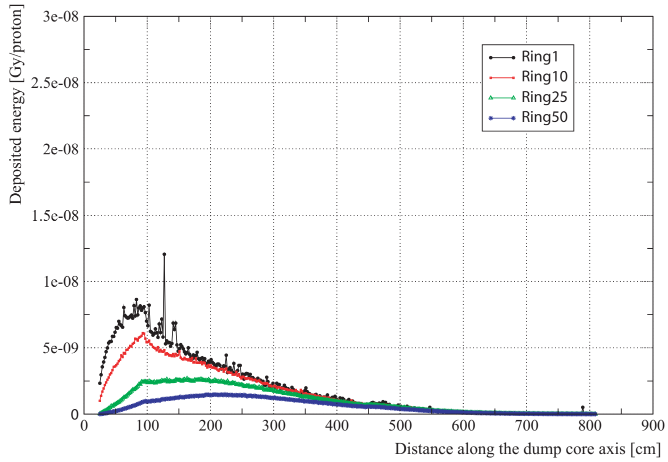

Figure 9: Average energy deposition along the z axis for a 450 GeV proton beam impinging the dump core center. Results are plotted for the inner most bin, the tenth bin, the twenty-fifth bin and the outer bin.

As it could be expected, the maximum is obtained for the most energetic beam of 7 TeV protons. In this case, the maximum is situated approximately 250 cm downstream the core front face for the inner most bin. To visualize how peaked is the radial energy deposition profile, Figure 10 shows the value in the 50 radial bins at different position along the z axis. Two centimeters wide bins were used along the z (beam) axis, therefore the maximum of the cascade is situated around the position of the 125^{th} bin.

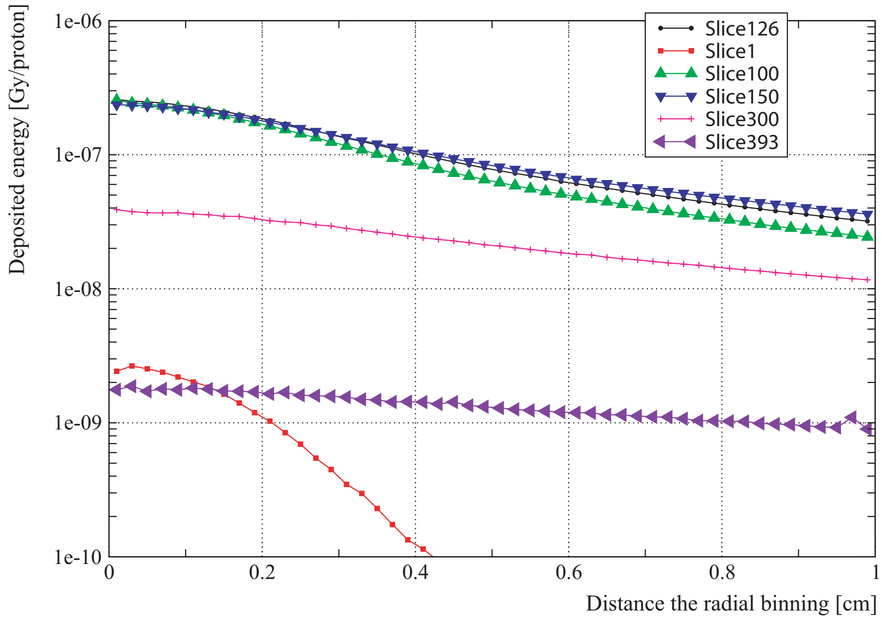

Figure 10: Radial energy deposition profile at different positions along the beam axis (z) for 7 TeV protons.

4 Energy-dependent particle spectra at the BLM locations

In addition to the energy deposition, the particle spectra were scored at the BLM positions. Since FLUKA calculates fluence in $\mathrm{cm}^{-2}/proton$, for results shown in the next subsections a normalization factor equal to 2808 (number of bunches) times 1.7×10^{11} (protons per bunch) is used. Spectra are represented using lethargy units and a logarithmic scale in x and y.

The spectra for the four BLM along the dump core and the three BLM behind the dump core are plotted respectively in Figure 11 and 12 using the beam profile plotted in Figure 2 and 7 TeV protons.

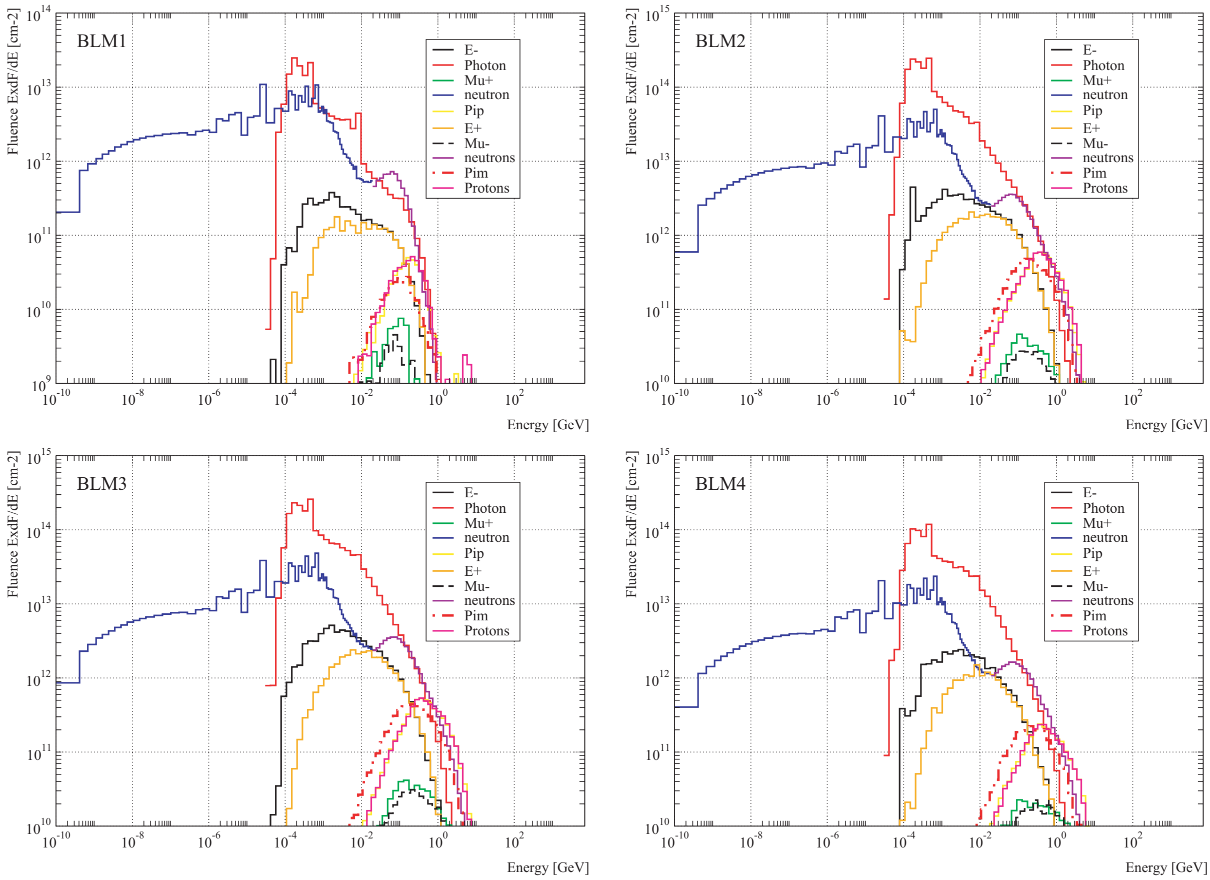

Figure 11: Particle spectra at the position of the four BLM located along the core as indicated in Figure 1. The spectra are normalized to a full dump of the 2808 bunches.

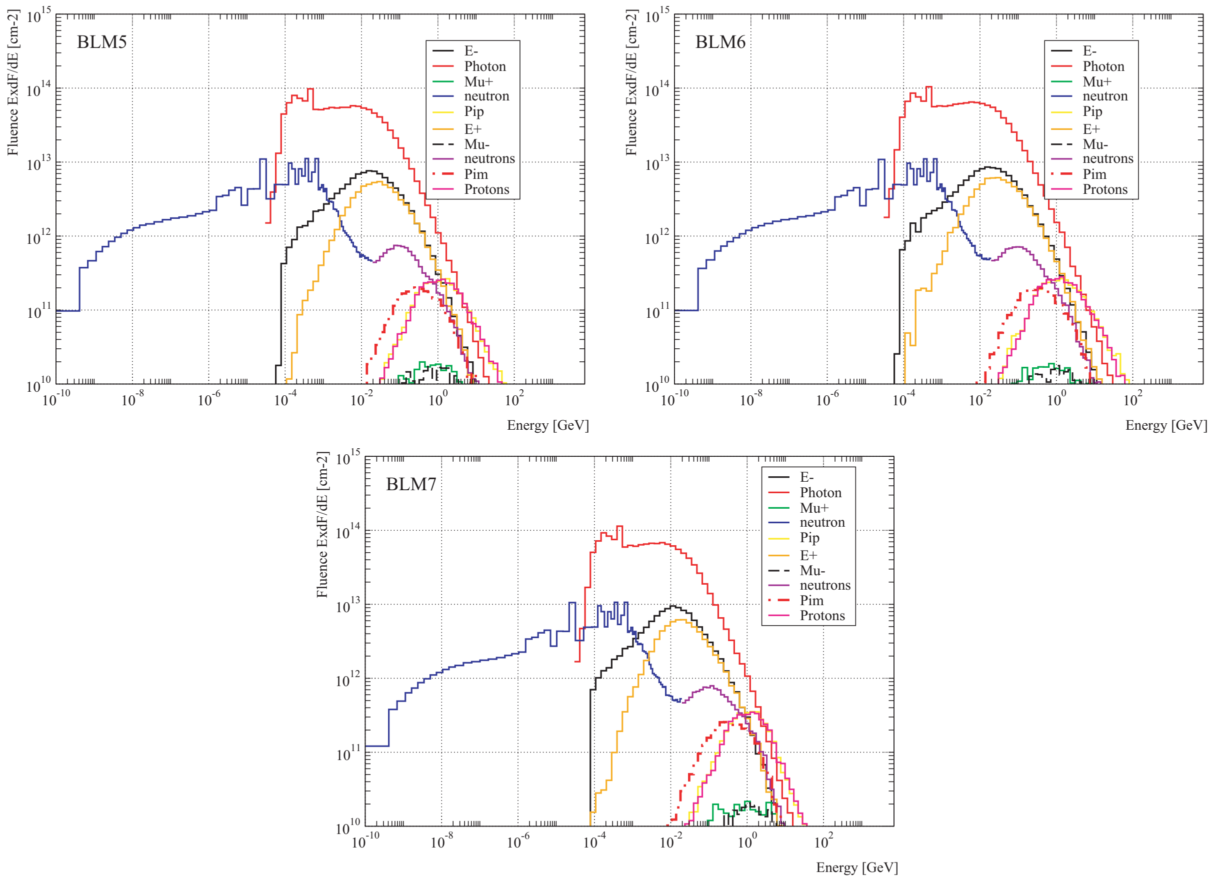

Figure 12: Particle spectra at the position of the three BLM located behind the dump core as indicated in Figure 1. The spectra are normalized to a full dump of the 2808 bunches.

5 Conclusions

The energy deposition for different beam configurations has been calculated. The results can be used to verify that changes in the design did not lead to any increase in the previous estimated peak energy.

The spectra calculated at the Beam Loss Monitor locations along the dump core and behind it can be used to perform an assessment of the BLM response for the different beam configurations.

References

[1] A. Fassó, A. Ferrari, J. Ranft, and P.R. Sala, "FLUKA: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

[2] A. Fassó, A. Ferrari, S. Roesler, P.R. Sala, G. Battistoni, F. Cerutti, E. Gadioli, M.V. Garzelli, F. Ballarini, A. Ottolenghi, A. Empl and J. Ranft, "The physics models of FLUKA: status and recent developments", Computing in High Energy and Nuclear Physics 2003 Conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003, (paper MOMT005), eConf C0303241 (2003), arXiv:hep-ph/0306267.

[3] J. Zazula and S.Peraire, LHC beam dump design study; 1, simulation of energy deposition by particle cascades; implications for the dump core and beam sweeping system, CERN-LHC-Project-Report-80, (1996).

[4] J. Vollaire, D. Forkel-Wirth and S. Roesler, Calculation of Remanent Dose Rate Maps in the LHC Beam Dump Caverns, Technical Note CERN-SC-2006-044-RP-TN, EDMS Document Number: 784972, CERN Geneva, (2006).

[5] J. Vollaire, D. Forkel-Wirth, S. Roesler, P. Vojtyla, Calculation of Air Activation in the LHC Beam Dump Caverns, Technical Note CERN-SC-2006-043-RP-TN, EDMS Document Number: 784894, CERN Geneva, (2006).

[6] Brennan Goddard private communications, (2007).

[7] Bernd Dehning, private communications, (2007).