INITIAL STUDIES AND A REVIEW OF OPTIONS FOR A COLLIMATOR SYSTEM FOR THE LINAC4 ACCELERATOR

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Abstract

Linac4 is a 160 MeV H^- linac which will replace the existing Linac2, a 50 MeV proton linac, at CERN as a first step of the upgraded LHC proton injector chain. No collimation system is foreseen in the baseline design but it will become mandatory for operation at highest duty cycle in order to reduce activation of the machine. Such a system will also help to reduce activation at low duty cycles. A review of different collimation options, initial studies on collimator designs capable of intercepting beam power of 10, 25 and 50 Watts at energies between 50 and 160 MeV, the activation of such designs are discussed in this paper.

INTRODUCTION

The layout of Linac4 [1] is sketched in Figure 1. It consists of a RF volume source which provides a 400 µs, 80 mA H^- beam at 45 kV with a repetition rate of 2 Hz. The first RF acceleration (from 45 keV to 3 MeV) is done by a Radio Frequency Quadrupole which resonates at 352 MHz. At 3 MeV the beam enters a 3.6 m long chopper line, consisting of 11 quadrupoles, 3 bunchers and two sets of deflecting plates. This system has the capability of removing micro-bunches on the RF scale and re-matching the beam to the subsequent system of accelerators. The beam is then further accelerated to 50 MeV in a conventional 19 m long Drift Tube Linac at 352 MHz. In Linac4 the acceleration from 50 to 100 MeV is provided by a Cell-Coupled Drift Tube Linac (CCDTL) at 352 MHz. The CCDTL is made of 21 tanks of 3 cells each for a total length of 25 m. The acceleration from 100 to 160 MeV is done in a PI-Mode structure (PIMS), which also resonates at 352 MHz. The PIMS is made of 12 tanks of 7 cells each for a total of 22 m. Focusing is provided by 12 electro-magnetic quadrupoles. Collimation will help to reduce the activation of the machine already at low duty cycles and it will certainly become mandatory for Linac4 operation at the high duty cycle (50 Hz) as injector for a high-power superconducting linac (SPL) [2]. The collimators could be positioned along the machine at the transition between structures, starting at 50 MeV.

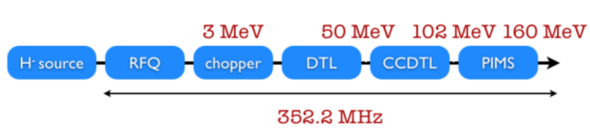

Figure 1: Block diagram of Linac4.

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COLLIMATION STUDIES

For the design of the collimators several steps and issues need to be addressed:

1) The study of collimators to intercept beam power of 10, 25, 50 Watts at energies between 50 and 160 MeV. The output of this study should be the definition of the collimator geometry, collimation material and the necessity to cool the various levels of intercepted power. After this step a decision on the feasibility of collimation in the linac can be taken (issue of space available).

2) The study of the activation of the collimators themselves and of downstream elements together with the shielding requirements for each collimation section.

3) The study of a collimation system for the 160 MeV transfer line between the Linac4 and the booster (low duty cycle operation only, no severe space restrictions) to have the possibility to "clean" the linac beam before injection in the booster with the aim to reduce the activation of the injection septum.

H^- linacs are used mainly in spallation sources such as the SNS [3], the ESS [4] and JPARC [5]. In the SNS case collimation is done using a foil scraper to convert the H^- into protons and a quadrupole downstream defocuses this proton halo towards a local beam dump. This system has the advantage of not needing to increase the quadrupole apertures in the beam line as the scraped halo is not transported along the H^- beam but has a disadvantage of the activation generated in the local dumps. JPARC uses FODO cells and a remote beam dump. Stripped and un-stripped particles are transported together which requires a larger magnet aperture to avoid losses. Local activation is not important as the collimated halo is transported into a beam dump away from the line.

With Linac4, where the optics are already set, a scheme of local absorber-collimator is proposed to stop the halo particles. A similar system is used in the ISIS linac. Different collimators should be used not only to collimate the beam in different locations but also to distribute the activation that the stopped halo would induce in the absorbers. Shielding will be required to reduce the dose in neighboring areas.

One of the positions to place these collimators is at the end of Linac4, 3.5 m after the PIMS, in the beam transport line, offering the advantage of not presenting space constraints. Table 1 summarizes the beam sizes and divergences at this position.

To approximate a halo in the FLUKA [6,7] simulations a 1/r distribution attached to a Gaussian beam was used as shown in Figure 2. The apertures for the collimator to absorb the equivalent of 10, 25 and 50 W were extracted from this model (see Figure 3) considering that the total of the energy of the halo particle, 160 MeV, was lost in the collimator and that the pulse frequency is 50 Hz. A full pulse has 10^{14} particles. The half apertures for this model are: 83.3 mm, 63.2 mm, 39.9 mm, respectively, for each of the different absorption power values (10, 25 and 50 W).

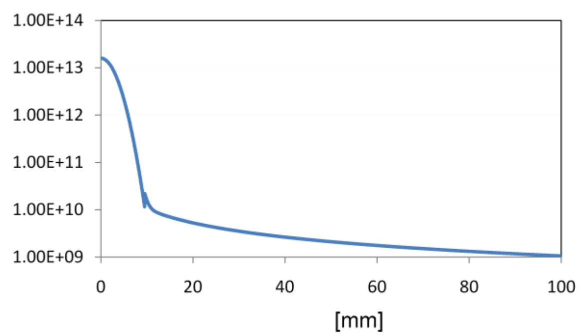

Figure 2: Beam and halo model. Vertical scale: number of particles per pulse.

Table 1: Beam sizes and divergences 3.5 m after the PIMS module

x RMS [m]	2.36E-03
x' RMS [rad]	2.75E-04
y RMS [m]	2.57E-03
y' RMS [rad]	6.66E-04

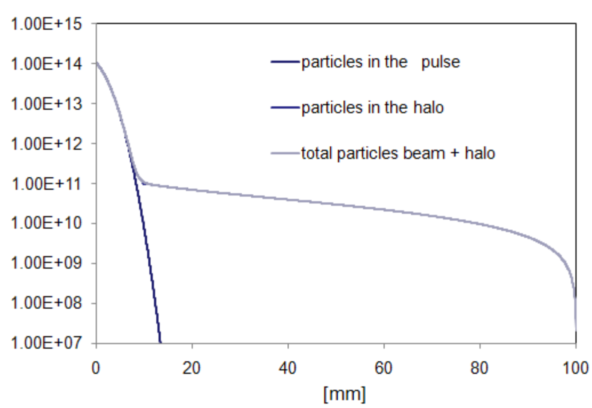

Figure 3: Integrated number of particles per pulse that a collimator would absorb for any given aperture.

In the simulations, a simple cylindrical geometry with the apertures mentioned earlier was used as the absorber. Protons, of 160 MeV energy, instead of H^- were the particles used as the two electrons would be easily stripped when hitting the collimator, therefore the total energy deposited and the activation generated would not differ from H^-. In order to avoid a high generation of neutrons a low Z material such as graphite was used to collimate the beam. The energy density deposited by primary halo particles assuming the 50 W aperture model is shown in Figure 4. Most of the energy is absorbed in the first 10 cm of graphite which could lead to a rather short collimator option. Such a short collimator solution would, however, require more shielding material.

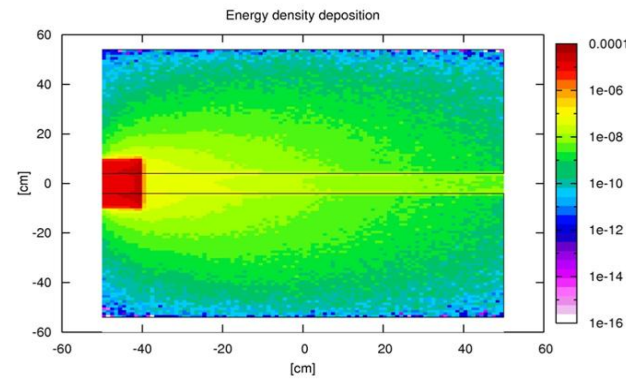

Figure 4: Energy density deposited by the halo for an aperture corresponding to 50 W of absorption power in graphite. The units are GeV/cm^3/primary.

RESIDUAL EQUIVALENT DOSE RATE AND SHIELDING OPTIONS

Different combinations of shielding materials were simulated using graphite as absorber body: Lead, concrete and borated paraffin. Lead is a good material to stop photons and charged particles whereas concrete and borated paraffin are good at stopping neutrons.

Figure 5 shows the residual equivalent dose rate (in pSv/s) after 1 month of constant machine operation for a 50 cm graphite collimator using concrete and then lead as shielding and 1 day of cooling time. The simulation and geometry takes into account a power absorption of 50 W for a rate of 50 Hz. The option of using borated paraffin instead of concrete gives similar results.

Figures 6 to 9 compare the neutron and charged particle fluences per primary particle for both shielding configurations.

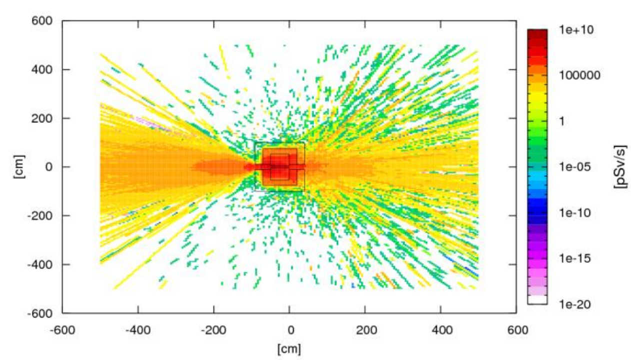

Figure 5: Residual equivalent dose rate after 1 month of operation and 1 day of cooling time for a graphite collimator with a concrete covered with lead shielding.

All simulations were done for the most challenging case (50 W at 50 Hz). The lower power cases still need to be tested in order to see how much space we need for each power level. In the end this will determine how much power we will be able to intercept with these collimators.

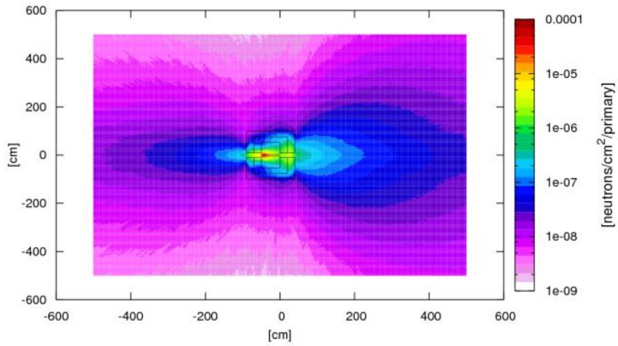

Figure 6: Neutron fluence per primary beam particle for a graphite collimator with concrete and lead shielding.

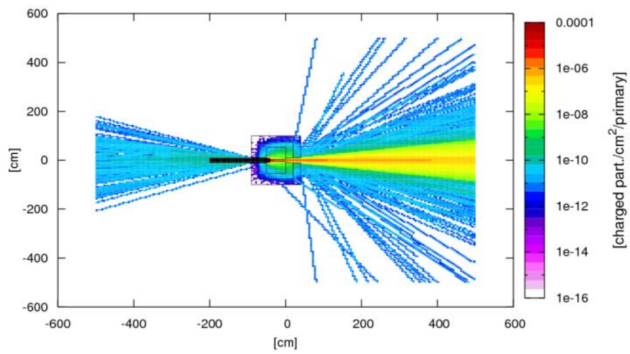

Figure 7: Charged particle fluence per primary beam particle for a graphite collimator with concrete and lead shielding.

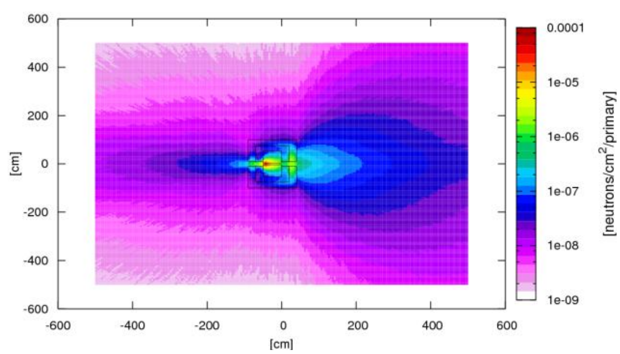

Figure 8: Neutron fluence per primary beam particle for a graphite collimator with borated paraffin and lead shielding.

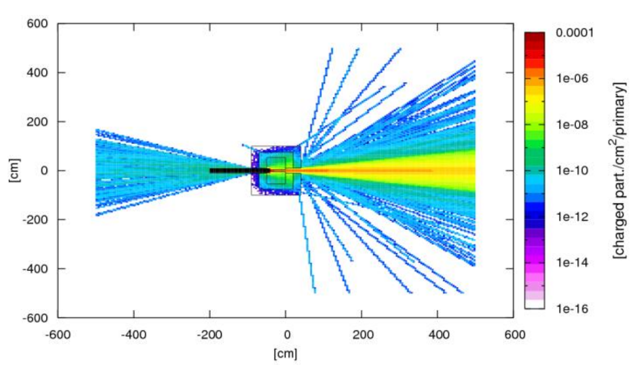

Figure 9: Charged particle fluence per primary beam particle for a graphite collimator with borated paraffin and lead shielding.

CONCLUSIONS

Graphite is used as absorber material because of its good thermal properties and low neutron generation. Such a collimator behaves almost as a beam dump therefore needs to be properly shielded. A combination of borated paraffin, to stop the generated neutrons, and lead, to help stop photons and charged particles, arises as the best shielding combination. The length of the absorber as well as the thickness of the shielding will have to be decided taking into account the threshold levels of accepted ambient dose.

Further studies need to be performed in order to design an optimum collimator system, which will collimate at different phases at different locations in the linac. Total power absorbed and activation would be shared between them.

Apertures that would absorb the given power of 10, 25 and 50 W are based on a simple halo model that may be different for the real linac beam. In that case the apertures will have to be adapted to the actual transverse density profile.

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