# COMPARISON OF CARBON AND HI-Z PRIMARY COLLIMATORS FOR THE LHC PHASE II COLLIMATION SYSTEM*

L. Keller, T. Markiewicz, J. Smith, SLAC National Accelerator Laboratory, Menlo Park, California
R. Assmann, C. Bracco, CERN, Geneva, Switzerland
T. Weiler, University of Karlsruhe, Karlsruhe, Germany

*Abstract*

A current issue with the LHC collimation system is single-diffractive, off-energy protons from the primary collimators that pass completely through the secondary collimation system and are absorbed immediately downbeam in the cold magnets of the dispersion suppressor section. Simulations suggest that the high impact rate could result in quenching of these magnets. We have studied replacing the 60 cm primary graphite collimators, which remove halo mainly by inelastic strong interactions, with 5.25 mm tungsten, which remove halo mainly by multiple coulomb scattering and thereby reduce the rate of single-diffractive interactions that cause losses in the dispersion suppressor.

## INTRODUCTION

The principle function of LHC collimation system is to protect the superconducting magnets from quenching due to particle losses. The collimation system must absorb upwards of 90 kW in the steady state operating condition (1 hr beam lifetime) and withstand transient periods where up to 450 kW is deposited for no more than 10 seconds (transient condition) [1]. The system must also be robust against an accident scenario where up to 8 full intensity, 7 TeV bunches ($9x10^{11}$ protons total) impact on one collimator jaw due to an asynchronous firing of the beam abort system. For the Phase I collimation system it was decided to use fiber-reinforced graphite (CFC), in both the primary and secondary collimators which can withstand the accident scenario with no damage, but gives reduced collimation efficiency and high impedance. For Phase II it is presently assumed that the primary collimators will remain 60 cm CFC, and the secondary collimators will be replaced with a lower impedance material that will not withstand an accident but can be moved so as to present a fresh surface to the beam halo.

An issue with the current Phase II plan is that single-diffractive (SD) protons produced in the three CFC primary collimators can pass completely through the 11 secondary collimators and be swept into the walls of the beam pipe inside the superconducting magnets in a region called the dispersion suppressor. If there are enough of these lost SD's, magnet quenches can occur; and the present simulations [2] show that this process will prevent the LHC from reaching design intensity.

This study looks at the possibility of replacing the CFC primary collimators with a thin, Hi-Z material to reduce the SD production and as a bonus, to smooth out and reduce the radiation dose to beam line elements downstream from the primary collimators.

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## CHOICE OF THE HI-Z PRIMARY COLLIMATOR

The goal of this study is to reduce the halo loss from inelastic nuclear interactions in the primary collimators and therefore reduce the probability of SD production while at the same time increasing the halo loss by multiple coulomb scattering (MCS). Since MCS scales as 1/√ radiation length, this is accomplished by minimizing the ratio, R, of radiation length to nuclear interaction length. For CFC, R = 24cm/48cm = 0.5 and for tungsten, R = 0.35cm/9.6cm = 0.036, i.e. more than an order-of-magnitude smaller with tungsten. The tungsten thickness should be chosen so that the probability of losing a proton in the secondary collimators by MCS is much greater than the probability of producing a SD proton in the energy range that is lost in the dispersion suppressor. Tracking studies with DECAY TURTLE [3] show that:

a) 7 TeV protons must scatter by at least 8 μrad to be lost on a secondary collimator, otherwise they go around the ring again.
b) SD protons in the energy range $\Delta E/E$ = -15% to -0.8% are lost in the dispersion suppressor.

For 1.5 radiation lengths of tungsten the probability of MCS >8 μrad is $9x10^{-4}$, and a FLUKA [4] run gives the probability of SD production in the energy range $\Delta E/E$ = -15% to -0.8% to be $1x10^{-4}$. Since the probability of loss by MCS is nearly a factor of ten larger than the probability of SD loss in the dispersion suppressor, a tungsten thickness of 1.5 r.l. = 0.525 cm was chosen.

## TRACKING RESULTS

Starting at the primary collimators, Program SIXTRACK [5] is used to simulate the proton halo loss points in apertures around the entire ring, including losses from MCS and the SD mechanism.

### *Conditions for SIXTRACK Runs*

a) 7 TeV, V6_500 optics, halo $\Delta E/E$ = 0, low beta, beam 1, sextupoles on, "perfect " machine.
b) Halo on horizontal primary collimator (TCPH), $4x10^{11}$ p/s loss rate unless otherwise specified.

c) Collimator gap settings and material: primary, 6σ carbon or tungsten; secondary, 7σ copper; tertiary, 8.3σ tungsten; absorbers, 10σ tungsten.

### *Losses in the Dispersion Suppressor*

Figure 1 is a comparison of loss rates/m on cold magnet apertures in the dispersion suppressor for carbon and tungsten primary collimators. Overall there are 2.2 times more losses with the carbon primary compared to the tungsten primary.

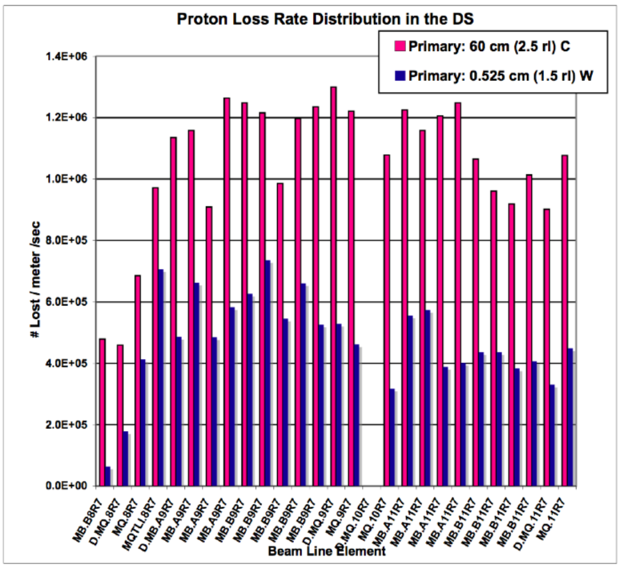


Figure 1. Loss rate/meter on cold magnets in the dispersion suppressor for carbon primary (red) and tungsten primary (blue). In this plot the four long dipoles are divided into sections. In total there are approximately twice as many losses with a carbon primary.

Because SIXTRACK flags the source of the lost protons, i.e. coming from a primary or secondary collimator, about 30% of the losses in the dispersion suppressor with the tungsten primary have re-scattered in the copper secondary collimators, whereas with the carbon primary, essentially all of the losses in the dispersion suppressor have come directly from the primary.

## ENERGY DEPOSITION IN THE BETATRON CLEANING SECTION

SIXTRACK also produced a map of inelastic interactions in the primary and secondary collimators for both carbon and tungsten primary collimators. These maps are used as input to a FLUKA model of IR7 that contained the collimators, warm magnets, and copper beam pipes. The FLUKA output gives the energy deposition in each dipole, quadrupole, collimator, and absorber in IR7.

### *Collimators and Magnets*

Figure 2 shows two histograms that compare the power distribution in a one hour beam lifetime for carbon and tungsten primary collimators in the beam line elements in the betatron cleaning section of IR7. The top histogram shows that with a tungsten primary, the power is more evenly distributed among the secondary collimators, reflecting the fact that the predominate loss mechanism is due to MCS in the tungsten primary causing hits on several secondary collimators. In particular, the power in the first secondary collimator, TCSM.A6L7, is 2.5 times smaller with tungsten (8 kW vs. 20 kW). This is important for reducing the steady state deformation of TCSM.A6L7 and relaxing the cooling requirements. In addition the secondary collimators are absorbing 50% more total power with a tungsten primary than with a carbon primary, thereby causing less radiation damage to equipment in the surrounding tunnel.

The lower histogram in Figure 2 shows that with the tungsten primary the dose to dipoles and quadrupoles is spread more evenly along the beam line, and the total dose received by the magnets is about 30% less (14.7 kW vs. 10.1 kW).

### *Tungsten Radiator*

A rough estimate of the power in the thin tungsten radiator can be obtained simply by multiplying the dE/dx ionization loss at 7 TeV by the proton loss rate. The actual power must also include showers from inelastic interactions and especially $\pi^0$'s that immediately result in electromagnetic showers. A FLUKA run for a one hour beam lifetime, $8 \times 10^{10}$ p/s loss rate, on the tungsten gives 0.4 w/jaw in the tungsten radiator.

For the 7 TeV accident described in the Introduction, it is assumed the jaws of the horizontal tungsten primary are positioned $5\sigma_x$ from the beam axis and that $9 \times 10^{11}$ protons are spread uniformly on the jaw between 5 and 10 $\sigma_x$ and have a Gaussian distribution in $\sigma_y$. Inputting this distribution into FLUKA and finding the volume bins with the largest energy gives an instantaneous temperature rise of about 1000 °C, i.e. less than a third of the tungsten melting point. The corresponding temperature rise in the 60 cm CFC primary collimator is 800 °C [1]. During injection at 450 GeV it is possible that 288 bunches ($3.2 \times 10^{13}$ protons) could be mis-steered onto a primary collimator. In that case, since the energy deposited in a thin radiator is mostly proportional to the number of incident protons and not the total energy, the primary collimators would be damaged; so that the tungsten primary collimators must be withdrawn during injection.

In practice the primary collimators would be tungsten with approximately 25% rhenium. This alloy is stronger and more ductile than pure tungsten. It remains to be shown whether three of these thin radiator assemblies, rf shielding, and beam position monitors can be put into the existing 2 meter drift space reserved for a fourth primary collimator.

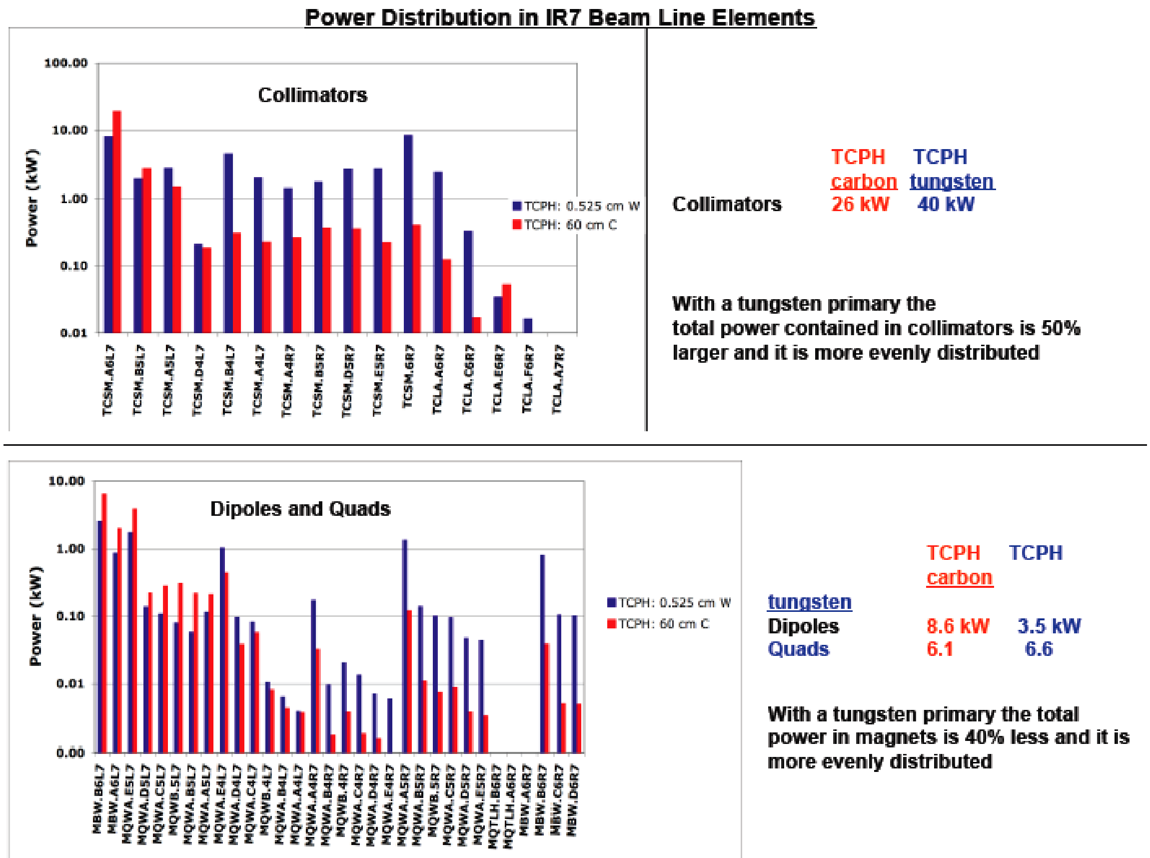


Figure 2. Power distribution in the collimators and warm magnets in IR7 for carbon (red) and tungsten (blue) primary collimators. Note that with tungsten the power is more evenly distributed along the beam line, there is less radiation damage to warm magnets near the primary collimators, and more energy is contained in the secondary collimators.

## SUMMARY

In phase II with 5.25 mm tungsten primary collimators (compared to 60 cm carbon primary collimators):

a) "Cold" losses in the dispersion suppressor are 2.2 times smaller.
b) The radiation dose is a factor of three smaller in nearby warm magnets.
c) The energy deposition in the first secondary collimator is a factor of 2.5 smaller.
d) The jaws receive a small steady state power and easily survive an 8 bunch asynchronous firing of the beam abort system.

## FURTHER WORK

a) Run SIXTRACK with halo on the vertical and skew tungsten primary collimators.
b) Run SIXTRACK with another tungsten thickness.
c) Simulate an ion beam on a tungsten primary to compare with carbon.
d) Do preliminary engineering to see if three small tungsten collimators can fit into a single 2m tank.
e) Simulate residual activation of a tungsten primary and compare with the existing carbon primary (including the copper cooling plate).

## REFERENCES


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