# UPGRADE SCENARIO ONE: WORK EFFORT

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*Abstract*

We give an overview of the scenario aiming to gathering 2000 fb[-1] at the end of the LHC lifetime. The compatibility of the hardware foreseen in the so-called performance improvement consolidation (aiming at 1000 fb[-1]) is verified, and the requirements on the new hardware are outlined.

## SCENARIO

The target of the Upgrade Scenario 1 (US1) is to achieve an integrated luminosity of 2000 fb[-1] in the year 2035, assuming 10 years of operation and starting from an integrated luminosity of 300 fb[-1]. This corresponds to double the final target of the Performance Improvement Consolidation (PIC, see [1,2]), with 2.5 times integrated luminosity per year (170 fb[-1]/year w.r.t. 70 fb[-1]/year).

For the US1, we assume the same magnetic lattice as in PIC, allowing reach 20/40 cm $\beta^*$ with flat optics. W.r.t the full upgrade, we do not change the matching section, which becomes a bottleneck for the aperture. The additional performance comes from 40% more protons in the beam (See Table I), namely increasing bunch population from $1.4 \times 10^{11}$ to $1.9 \times 10^{11}$.

In order to be able to achieve this target, US1 relies on two main hardware components: (i) 11 T dipole allowing additional collimators in IR7, IR1 and IR5, and (ii) the beam-beam compensation wire or an equivalent strategy to compensate long range beam-beam interaction caused by the increased bunch population.

For US1, we assume a peak luminosity of $5 \times 10^{34}$ cm[-2] s^{-1}, as in the full upgrade. There will be no possibility of luminosity levelling, since the peak luminosity is the maximum reachable for this scenario. For more details on the three scenarios outlined in Table I, see [1], [3] and [4].

Table 1: main parameters of the three upgrade scenario

| Scenario | $\beta^*$ (cm) | Bunch pop. (adim) | Emittance (mm mrad) | Peak lumi cm^{-2} s^{-1} | Int. lumi fb[-1] |
|---|---|---|---|---|---|
| PIC | 20/40 | 1.4E+11 | 2.2E+00 | 3.0E+34 | 1000 |
| US1 | 20/40 | 1.9E+11 | 2.6E+00 | 5.0E+34 | 2000 |
| US2 | 15/15 or 7.5/30 | 2.2E+11 | 2.5E+00 | 5.0E+34 | 3000 |

## RADIATION DAMAGE

We first consider the issue of the radiation damage in the magnets around the IP induced by the collision debris. This damage is proportional to the integrated luminosity. The triplet is designed to have all components able to resist to 25 MGy at 3000 fb[-1], so it will be safe for a 2/3 accumulated dose. This is achieved thanks to a thick shielding with tungsten alloy inserts [2,5]. For the rest of the matching section, which will be the same as in the LHC today, we make a first guess by scaling the LHC

baseline results [6]. As shown in Fig. 1, one has a maximum of 2 MGy (average) and 4 MGy (local) for 500 fb[-1] integrated luminosity (see Fig. 1). This provides 16 MGy local for 2000 fb[-1], which is within the 20-30 MGy threshold assumed for degradation in the triplet [7]; one should verify that the MQY and MQM has a similar level of degradation.
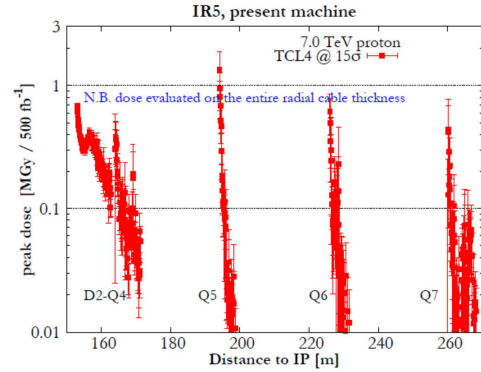


Figure 1: Radiation dose in the LHC matching section for 500 fb[-1] integrated luminosity [6].

## HEAT LOADS

Heat loads are proportional to peak luminosity. The first aspect to be considered is the total cryogenic power. For the triplet+D1 (and correctors), the situation requires an upgrade of the cooling system to be able to evacuate a total heat load in this area of 700 W on the triplet and 600 W on the beam screen. This estimate assumes that the electron cloud does not contribute to the heat load, thanks to a coating of the beam screen. The upgrade of the cryogenic system done in PIC [2] allows to deal with these heat loads.

The second aspect is the local increase of the temperature in the superconducting coils due to the heat load. The triplet+D1 is designed to withstand the peak luminosity of US2 (see Table 1), where there is a wide margin: one expects a heat load of 2 mW/cm^{3} (see Fig. 2), which is half of the baseline of the LHC. Quench limits are set at 4 mW/cm^{3}, that includes a factor three of safety [8]. In the matching section, the rescaling of the baseline gives 1.5 mW/cm^{3}, (see Fig. 3), which is also well within quench limits.

## COLLIMATORS

The plan for collimation in the HL-LHC era will strongly depend on the results of the LHC operation at 7 TeV. With this caveat, today one can define the following baseline [9]: US1 requires the installation of additional collimators in IR7 (2 units), IR1 (4 units) and IR5 (4 units). Here one unit is a 15-m-long module, replacing a LHC dipole, made of two 5.5-m-long 11 T

dipole [10] and a 4-m-long collimator module (see Figs. 4 and 5). This is the same hardware to be used in IP2 for PIC scenario.
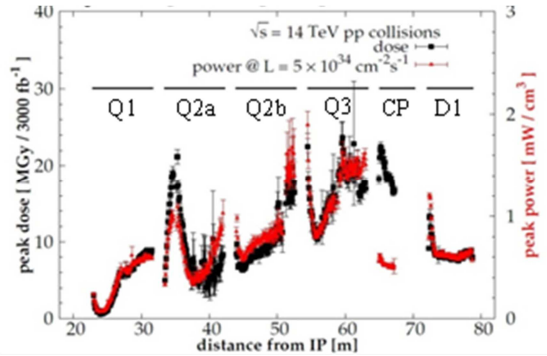


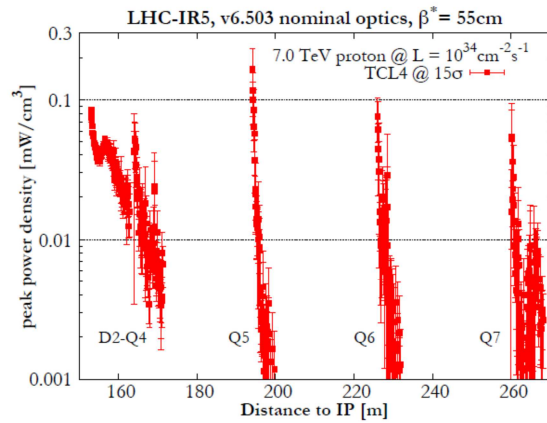Figure 2: Heat load in the HL-LHC triplet+D1for an integrated luminosity of 3000 fb$^{-1}$ [6].



Figure 3: Heat load in the LHC matching section for 500 fb$^{-1}$ integrated luminosity [6].



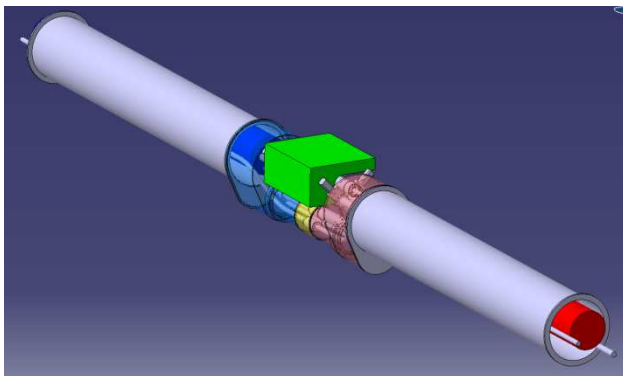Figure 4: sketch of the 5.5-m-long 11 T dipole [10].



Figure 5: sketch of the 4-m-long collimator module [11].

## SUPERCONDUCTING LINK

The aim is to move the power converters of the IR1 and IR5 matching sections from the tunnel to surface. The need of civil engineering is to be verified. This link would rely on the same technology used for the superconducting link for the triplets, based on $MgB_2$ [12]. A cross section of the triplet superconducting link is shown in Fig. 6. A test of the prototype (both distribution feedbox and superconducting link) is foreseen in 2015, and installation during LS2 or LS3.
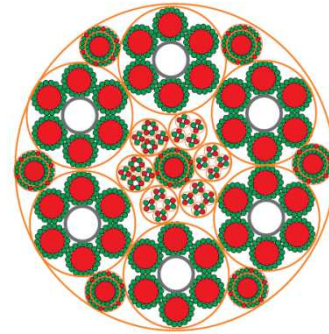


Figure 5: Tentative cross-section of the superconducting link for the triplet+D1

## BEAM BEAM LONG RANGE WIRE COMPENSATOR

The idea of the compensator wire is to use a DC current to cancel the long range beam-beam effect. In this way one can increase the beam current without the need of opening the crossing angle, i.e. all the additional "fuel" is directly converted in peak luminosity.

The first ideas about a beam-beam wire compensator go back to more than one decade ago [13]. In RHIC it has been showed that a wire can make the beam unstable [14]. In the SPS it has been shown that a wire can compensate the effect of another wire [15]. Even though the physics is solid rock, as it is based on electrostatics, a proof of principle on the LHC is needed to test the device, find the minimal interference with nearby equipment. The timing of this proof is between LS1 and LS2; a couple of years of operation are needed to look at all aspects. The wire should be between separation and recombination dipoles D1 and D2 (see Fig. 7). A first tentative proposal is to place it in the collimators, but it poses considerable problems of integration to avoid to break the collimation hierarchy.
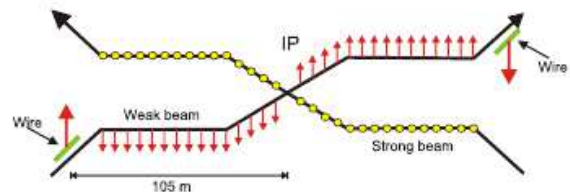


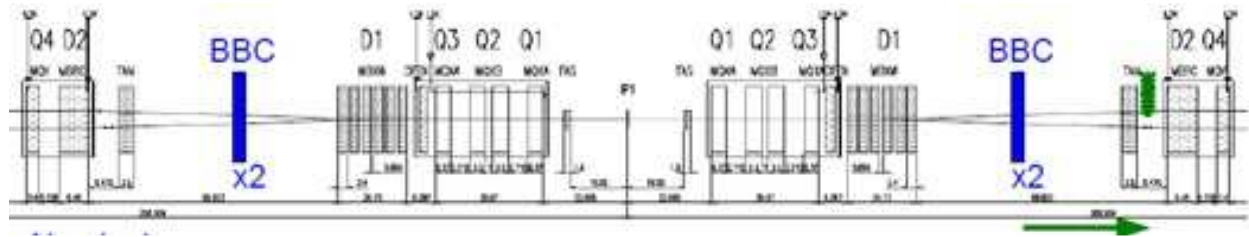Figure 6: Schematic of long range beam beam compensation wire.

Figure 7: Possible position of long range beam beam compensation wire.

Four units would be needed, i.e. two around each high luminosity insertion. There are many delicate points that require further R&R, namely (i) radiation resistance (this is a hot place full of neutrons, and the wire has to stay on the inner side of the beam, i.e. along the neutron beam axis), (ii) compatibility with the flat beams has to be proved, and (iii) integration. As in most hardware related to accelerator physics, evil is in details.

## CONCLUSIONS

We outlined the strategy worked out to deliver an integrated luminosity of 2000 fb$^{-1}$ at the end of the LHC lifetime. It relies on a beam intensity increase, which can be tolerated without opening the crossing angle thanks to the beam-beam long range wire compensator. Even though there are no reasons for doubting on the principle of this device, the feasibility, effectiveness, and integrability of this new hardware in the LHC have still to be proved, and a vigorous R&D effort is needed. Plans foresee to have a prototype in the LHC at the end of this decade.

We showed that the hardware will be able to tolerate the radiation damage and the heat load given by a peak luminosity of $5 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, and that cryogenics upgrade foreseen for PIC will be enough to deal with the total power to be removed from the accelerator.

Two additional pieces of hardware, namely a superconducting link and an 11 T dipole making room for additional collimators, are needed. They are based on the same technologies which are required for PIC scenario.

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