HHH-2008 DISCUSSION, COMMENTS, AND QUESTIONS

W. Scandale, E. Todesco, F. Zimmermann, CERN, Geneva, Switzerland

Abstract

We attempt to summarize the discussions, comments and questions from the CARE-HHH workshop "HHH-2008" in Chavannes-de-Bogis, 24-25 November 2008, which was devoted to scenarios for the LHC upgrade and FAIR, and from some follow-up meetings.

LHC PHASE-1 UPGRADE

It was debated whether an optics with interaction-point (IP) beta functions down to $\beta^* = 0.25$ m is feasible using Nb-Ti technology without moving the quadrupoles $Q4$ and $Q5$ longitudinally. The answer was most likely not [J. Miles]. At the LHC IR upgrade review the Phase-1 IR parameters were determined to be 120 mm diameter, 120 T/m gradient, and β^* equal to 0.25 m. However, no optics solution has yet been found which matches these conditions exactly. A close solution with 126 T/m exists, but it proved to be unstable. A shift of the longitudinal position of the matching quadrupoles Q4 and Q5 would provide a more robust optics. Without moving the quadrupoles, a target value $\beta^* \approx 0.3$ m may be realistic. A final optics is needed as soon as possible. The present scheme of correcting the off-momentum beta beating in the two cleaning insertions, involving asymmetric excitation of the arc sextupole families, introduces a lower bound on β^* of about 0.25 m [S. Fartoukh].

The reduction of β^* provides about 50% improvement of luminosity; the rest has to be obtained by an intensity increase. To get to 2.5×10^{34} cm^{-2}s^{-1}, an intensity increase of about 30% is needed. The induced head-on beam-beam tune shift appears to be reasonable. However, the number of long-range collisions grows significantly and the resulting beam intensity limit for the Phase-1 interaction region (IR) may turn out to be more severe than the corresponding limit for the nominal LHC. In addition, the Phase-1 IR might lose the $\beta_x \approx \beta_y$ location that is well qualified for accommodating a long-range beam-beam compensator in the nominal LHC layout. The trade-off between β^* and intensity limitations from long-range beam-beam effects may need to be explored both for the nominal and the Phase-1 optics.

Schedule is a very critical issue, for the near-term planning as well as for the longer-term operation. Radiation issues can affect the duration of the Phase-1 operation. According to the design specification, the new Phase-1 IR quadrupoles can sustain about 3 times more integrated luminosity than the present quadrupoles before radiation damage occurs. Since the Phase 1 is supposed to have a 2.5 times larger luminosity, the actual lifetime of the Phase-1 inner triplet will be approximately the same as for the present one, i.e. a replacement after about 5 years of operation will again be needed. This matches the Phase-2 upgrade schedule.

LHC PHASE-2 UPGRADE

With Nb_3Sn magnet technology at 1.9 K for the inner triplet, and keeping the 23 m of distance between the triplet and the IP, one can reach a $\beta^* \approx 0.14$ m, if the LHC sextupoles are only used for correcting the linear chromaticity. Another solution must then be found for the off-momentum beta beating. If the distance to the IP is reduced to 13 m, and under otherwise identical assumptions, one can arrive up to $\beta^* \approx 0.11$ m. The lifetime of the Nb_3Sn magnets needs to be determined, and should be larger than the lifetime of the inner triplets for the nominal LHC and for Phase 1, i.e. its radiation resistance should be at least a factor four larger than for the Phase-1 magnets.

Five scenarios for Phase 2 have been suggested. The first two rely on a minimum $\beta^* \approx 0.14$ m, and recover the geometric reduction factor either through an early separation scheme or via crab cavities. In these cases the Phase-2 goal can be reached with a moderate increase of beam intensity. The third scenario relies on a large Piwinski angle to allow a higher beam intensity without reaching the beam-beam limit. Two new alternative scenarios have been proposed at HHH-2008 and in a follow-up meeting. The first of these, the fourth scenario in the list [R. Garoby], considers a smaller transverse emittance, a higher brightness, and a large Piwinski angle, the second one, scenario no. 5 [S. Fartoukh], a blow up of the emittance after acceleration, achieving a similar effect as the large Piwinski angle, i.e. allowing for a much larger beam intensity. In the third and fifth scenario, the number of proton per bunch needed to reach a luminosity of 10^{35} cm^{-2}s^{-1} is about $4-5 \times 10^{11}$ at either 50 ns or 25 ns spacing. The feasibility of this large intensity in the LHC and possibly in the injector chain, especially for 25-ns spacing, may be a challenge. The fifth scenario seems to imply an unacceptable heat load in the LHC itself, and might not be maintained.

Concerning the feasibility of the lower transverse emittance, it was noticed that the electron-cloud instability and intrabeam scattering (IBS) get worse with lower emittance. Since the luminosity lifetime also decreases, the shorter IBS rise time might not be a problem. With smaller emittance, the sensitivity to injection errors, to kicker ripple etc. becomes more critical, however. So far these errors are not much better than the nominal specification [G. Arduini]. The damage limit for collimation is already "at the edge" for the nominal LHC. The situation will deteriorate with lower emittance [R. Assmann]. In fact, it was reported that the present emittance represents an approximate optimum (smaller emittance is bad in regard to collimator damage, whereas larger emittances are bad with respect to cleaning efficiency [R. Assmann]). Also transverse Landau damping will be reduced for a smaller emittance [S. Fartoukh]. On the other hand, a large emittance could lower the TMCI threshold in the SPS as the beneficial effect of space charge would be reduced [G. Rumolo].

Beam-screen heat load, due to synchrotron radiation, image currents, and electron cloud, introduces important constraints on the bunch population. For the nominal bunch spacing of 25 ns, the maximum acceptable bunch charge corresponds to about 2.3 or 2.4×10^{11} protons. For increased spacings, larger bunch charges are possible.

The upgrade will profit from a higher beam intensity, entering a regime that cannot yet be accessed experimentally in the LHC or the SPS. At present, already the ultimate bunch charge of 1.7×10^{11} protons is difficult to achieve in the SPS; however, the PS Booster can already deliver the ultimate intensity with 20% margin and an emittance smaller than the one finally needed in the LHC [E. Metral]. An SPS study at this intensity was planned for 2009. A bunch-intensity level of 2.4×10^{11} protons will be explored once the new Linac4 is operational, from 2012 onwards. In addition to the beam availability from the injectors, other intensity limits are encountered in the LHC itself. Collimation is a prominent example (both cleaning efficiency and impedance effects seem to prevent reaching the nominal LHC intensity). A second limit, equal to the ultimate bunch charge of 1.7×10^{7} protons comes from the LHC RF system [J. Tuckmantel]. Bunch charges higher than ultimate will require an upgrade of this RF system.

The question was raised, based on two talks at this workshop (by N. Hessey and E. Tsesmelis) whether one should assume that the number of events per bunch crossing must always stay below a value of 200 rather than 300, the limit which had been considered in the past. It was also asked whether the maximum acceptable pile up depends on the extent of the luminous region. Unfortunately, a larger extent of the luminous region improves the situation only for a few detector subsystems [N. Hessey]. Another question pertained to the cost of this limitation.

Given the stringent limit on the event pile up, a leveling of the luminosity during a physics store is clearly desired. A leveling demonstration or test could be attempted in the LHC, once a reasonable performance level has been established. The feasibility of leveling is controversial. It has not been successfully applied at operating colliders, but there was no need for leveling in these machines either. Orbit correction during the store is possible both at RHIC and at the Tevatron without losing the beam or other negative consequences [W. Fischer, J.-P. Koutchouk]. This experience bodes well for leveling at the LHC. Leveling also is a very natural option for crab cavities [R. Calaga].

ENERGY DEPOSITION

Energy deposition does not appear to be a fundamental issue, as far as quenches are concerned. One can always add shielding (possibly at the expense of a larger β^*). The energy deposition for Phase 1 looks acceptable. Applying a simple scaling argument, the energy deposition for Phase 2 should be about equal to 4 times the one of Phase 1. On the other hand, Nb_3Sn has a factor 3 higher quench (or radiation) tolerance with respect to NbTi. For this reason, the energy deposition might not be a problem for either upgrade phase. However, critical parameters like the quadrupole gradient, crossing angle etc. can affect the loss pattern in the inner triplet region, and should be taken into account [F. Cerutti]. If this rule is followed, there is no obvious showstopper. A question concerned the adequacy of the triplet cooling capacity. It was pointed out that the modeling of heat deposited in the yoke was incomplete, due to some missing thermodynamics in the FLUKA code. How does the projected magnet lifetime for Phases 1 and 2 vary with β^* and the crossing angle?

LESSONS FROM HERA UPGRADE

The experience of the HERA upgrade highlighted the importance of magnet alignment and stability. The question was raised if this HERA experience is taken into account for the LHC upgrade Phases 1 and 2 [B. Holzer]. In the workshop discussion, the problems at HERA were attributed mostly to insufficient preparation and design, which would not be a problem for the LHC. However, it was stressed that the effect of the CMS stray field on nearby ramping magnets could lead to effects similar to those seen at HERA and should be evaluated [B. Holzer].

EARLY-SEPARATION DIPOLES

A slot inside the detector at about 13–14 m from the IP may be available for both ATLAS and CMS. It was asked which other inputs were missing to advance the early-separation solution. One constraint may come from the IR vacuum chamber, which must fulfill a number of requirements: the longitudinal extent of the innermost chamber is of order +/-50 cm. The two beams will be separated at injection. Operation with different values of β^* should remain possible.

LHC INJECTOR UPGRADE & FAIR

What will be the brightness, emittance and intensity available from LINAC4, SPL, PS2 and the upgraded SPS for the LHC? How are emittance and intensity correlated in this new complex, and how do they depend on the LHC bunch spacing (25 ns vs. 50 ns)? How will the beam for the LPA scheme—flat bunches of 5×10^{11} protons spaced by 50 ns—be generated?

Some concern was voiced regarding the low periodicity of the proposed “racetrack” PS2 optics and the associated high density of structure resonances [O. Boine-Frankenheim].

How flat (longitudinally) do the bunches of the “Large Piwinski Angle” scenario for Phase 2 need to be, and which tolerances apply to the bunch-by-bunch flatness variation? A generation and maintenance scheme for the LHC must be defined, either in the injector complex and/or in the LHC itself.

For FAIR, is a beam-pipe aperture of 2-3 σ sufficient [F. Zimmermann], and can one rely on space charge for beam-loading compensation & pre-compression (presentation by O. Boine-Frankenheim) [E. Shaposhnikova]?

The presentation by F. Méot triggered some questions on FFAGs. Can they be used at CERN? Are they a viable (and cheaper) alternative to a linac [O. Bruning]?

ADVANCED S.C. MAGNETS

The following questions arose: Will Nb_3Sn, MgB_2 and/or Bi_{2212} magnets provide a path to smaller β^* and/or to higher energy? Are fast-cyling s.c. magnets a viable alternative technology for the PS2? Will they allow for an SPS2 at 1 TeV?

BEAM-BEAM EFFECTS

Can we predict LHC beam-beam lifetime within a factor of 2 [W. Fischer, S. Peggs]? It seems that we still cannot compute the tune shift limit in hadron colliders. Where and how can the functionality of electron lenses for head-on beam-beam compensation be verified? Can long-range beam-beam compensation be made to work for Phase 1, e.g. what is the efficiency of a compensator at a place with unequal beta functions?

ELECTRON CLOUD

Electron-cloud build up is predicted to be more severe in the PS2 than in the higher energy SPS [G. Rumolo]. What is the impact of the electron cloud on the PS2 design (e.g. choice of chamber dimensions)?

Which is the role and a proper model of the re-diffused electrons?

The electron cloud could have an effect on collimation and, e.g., trigger an ion avalanche, both in the LHC and in some of the new injectors. Do the novel coatings and clearing schemes solve the electron-cloud problem at least for the future machines?

COLLIMATION

Machine protection considerations yield a limit on the total energy stored in the beam. For higher intensity, the beam dumping system and the collimators require upgrades.

With realistic errors the beam intensity will be limited to 3-4% of the nominal value for the present collimation system. It is expected that the collimator set-up time can be reduced from initially 15 hours to a practical value of 1 minute. What is the cleaning efficiency for the “phase 2” of the collimation system with realistic errors - is the ideal gain by a factor 10 with respect to the present “phase-1” collimation system maintained when errors are included, and is it sufficient if the collimator phase 1 only allows for 4% of the nominal intensity? The so-called n_1 number should never decrease below about 7, as the collimators cannot approach the beam to less than 5 σ [R. Assmann].

There is little margin against collimator destruction for an asynchronous beam dump. The present system might not withstand a train of ultimate bunches in case of such asynchronous dump.

Hollow electron lenses acting as low-amplitude scrapers are an interesting refinement option for the collimation system [R. Assmann]. Are rotatable collimators, cryogenic collimators, crystals, hollow electron lenses or a combination thereof the solution for higher intensity? Beam impact on the rotatable collimators would be detected by temperature sensors and microphones.

For the LHC Phase-2 upgrade, a new dispersion suppressor will be needed in addition to a new inner triplet.

CRAB CAVITIES AND FP7 EUCARD

There has been an excellent progress on crab cavities. One open question concerned the procedure for the planned down selection.

The formats of the meetings and of the dissemination in FP7 EuCARD deserve attention.

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