SUMMARY OF SESSION 8

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Abstract

Session 8 of the 2010 LHC performance workshop in Chamonix addresses all planned activities for the first upgrade intervention which is currently planned for the 2014-2015 shutdown. The goal of this first upgrade campaign for the LHC is to consolidate the nominal performance of the LHC and to open the door for routine operation with ultimate beam parameters and a peak luminosity above $2\ 10^{34}$ cm^{-2} sec^{-1}. The interventions foreseen in this first upgrade phase include: the connection of LINAC4 to the PSB and the related upgrade of the injection region in the PSB, upgrade of the LHC collimation region with Phase2 Cu collimators and additional absorbers in the dispersion suppressors of the main cleaning insertions, the installation of new triplet and D1 magnets (including the DFBX electrical feedbox for the triplet magnets), the installation of 200 MHz capture cavities and additional transverse damper kickers.

SESSION ORGANIZATION

Session 8 featured 7 presentations:

- Overview of the IR upgrade plan and summary of the scope and goals for this first upgrade intervention for the LHC by Ranko Ostojic.
- Summary of the upgrade plans for the LHC injector complex (e.g. LINAC4 and its connection to the PSB) by Maurizio Vretenar.
- Summary of the optics challenges for the IR upgrade in the LHC by Stephane Fartoukh.
- Summary of the Hardware challenges and limitations for the LHC IR upgrade by Stephan Russenschuck.
- Planned upgrade activities for in IR4 by Edmund Ciapala.
- Summary of the collimation upgrade plans by Ralph Assmann.
- Integration issues in the tunnel and impact on general LHC systems by Sylvain Weisz.

OVERVIEW OF THE IR UPGRADE SCOPE AND CHALLANGES

Ranko Ostojic describes the Phase 1 IR upgrade within the general goal of the long term upgrade plans for the LHC as laid out by the sLHC project and aiming at a steady increase of the LHC performance over its operation period. In this context it is worthwhile highlighting that the first proposals for an LHC IR upgrade were articulated as early as 1999 and that first proposals for large aperture NbTi triplet magnets were made in 2005 when it was assumed that the LHC might reach a performance level corresponding to the end of the lifetime of the existing nominal triplet magnets (ca. 300 fb^{-1} to 500fb^{-1}) by 2015.

Within this context the Phase 1 IR upgrade goals are to:

- Provide more flexibility for focusing of the LHC beams in the ATLAS and CMS insertions,
- Enable reliable operation of the LHC at $2\ 10^{34}$ $cm^{-2}s^{-1}$.

These goals are meant to be achieved while leaving unchanged the interfaces between the ATLAS and CMS experiments with the machine and the existing cryogenic capacity and infrastructure in IR1 and IR5. The upgrade interventions focus on a replacement of the triplets quadrupole with large aperture NbTi magnets and includes upgrades of the D1 magnets (the existing warm magnets will be replaced by more compact superconducting dipole magnets), their electrical feed boxes (DFBX) and the insertion absorber and protection devices TAS and TAN. The upgrade of the Phase 1 optics design aims at an increased flexibility for the machine operation and protection while leaving the matching sections (MS) of the IR1 and IR5 insertions unchanged.

The Phase 1 IR upgrade project started in January 2008 and delivered a Conceptual Design Report (CDR) by end 2008. A Technical Design Report (TDR) and first magnet prototypes are foreseen for end 2010 leading to a pre-series production of the triplet magnets by mid 2011 and the followed by the series production of the triplet magnets from 2011 to 2014. The triplet magnets will be tested in 2014 in dedicated test string prior to assure readiness for installation by the end of 2014. The ambitious planning schedule is made possible by the use of the existing spare LHC dipole cables for the triplet magnet production. All components of the Phase 1 IR upgrade are designed for a lifetime corresponding to an integrated luminosity of 1000 fb^{-1}. First integration studies for the new triplet installations indicate that the available space underground is extremely limited, imposing tight constraints for the powering of insertion magnets. Additional underground caverns could considerably ease the equipment installation and maintenance.

Ranko Ostojic highlights that the Phase 1 IR upgrade project is tightly integrated in international collaborations including the sLHC PP within the European FP7 framework featuring CEA, CERN, CIEMAT, CNRS, STFC as the key collaborators, special French contributions to the CERN White Paper initiatives for 2008 to 2011 via CEA and CNRS, and the American APUL construction and USLARP R&D frameworks.

Questions at the end of the presentation:

- Laurent Tavian remarks that sector 4-5 is the most cryogenically loaded of the LHC cryogenic sectors, but there are 3 good new about the cryogenic requirements in sector 34:
    - The static heat loads are lower than expected
    - The whole package of electrical splices dissipates energy as foreseen or even less.
    - The estimation of heat load due to electron cloud effects have been reduced.
- Lucio. Rossi asks: Do you plan to move the matching section elements during the Phase 1 IR upgrade? Ranko Ostojic replies that it could be done but it is not planned and not integrated in the cost and manpower needs.
- Ezio Todesco remarks the proposed tight planning limits the possibilities for feedback for the magnet production from the prototype development.
- It was remarked that the proposed upgrades only affect the proton physics program without a clear view on the ion physics program.
- Steve Myers comments one year has been lost for the Sector 3-4 repair and the people required for the triplet magnet production are the same that will be involved in the splice consolidation.
- Oliver Brüning remarks that if we are limited to a smaller than nominal luminosity during the coming years, then the life of the present triplet could extend till 2020.

LINAC4

Maurizio Vretenar explains that the LINAC 4 project is composed of 3 main parts:

1. Construction and commissioning of the new linac (up to the LINAC4 dump).
2. Construction of the transfer line with connection to the existing LINAC2 transfer line and upgrade of the measurements lines (up to PSB wall and LBE dump).
3. Modification of the PSB injection region for H- injection at 160 MeV and the commissioning of the new installations. The PSB modifications imply an 8-month stop of proton operation for the LHC. However, during part of this intervention time the LHC can still be operated with Pb ion beams.

Table 1 summarizes the main performance differences in the PS complex between the old LINAC2 and the new LINAC4 injector. In addition to the performance gain, LINAC4 will remove the problems related to the maintenance and repair of the aging equipment of the LINAC2 installation.

The current planning foresees readiness for the LINAC4 connection to the PSB by end 2013. However, the planning for the LIANC4 project provides some flexibility for the final connection of the linac to the PSB. The initial commissioning of LINAC4 is done stand-alone without connection to the PSB and the final connection to the PSB could be delayed until the 2014-15 shut down while the LINAC4 commissioning continues off line from the nominal LHC operation.

Questions at the end of the presentation:

- It was remarked that LINAC4 will require improvement of the diagnostic in PS and in particular in the bunch measurements near the RF system.
- Davide Tomassini comments that to fully profit of the LINAC4 installation, other upgrades are necessary in the LHC injector chain.
- Lucio Rossi asks what will happen if the LINAC4 budget will be cut? He comments that should the budget be cut, the year gained and reserved for commissioning will be required for real assembly work.
- Gianluigi Arduini recommends that the actual limits in the SPS should be studied in more detail.

HARDWARE CHALLENGES AND LIMITATIONS FOR THE IR UPGRADES

Stephan Russenschuck highlights that even though the triplet magnet design is already far advanced and even though the use of the existing LHC dipole cables can speed up the final magnet production, there are still a large number of issues that need to be addressed and resolved before the final magnet production can be launched. Stephan Russenschuck underlines that past experience has shown that 5 years are normally needed from the end of the magnet design to production. With several components of the Phase 1 upgrade still requiring significant design efforts (e.g. nested dipole corrector magnets and horizontal collaring of long quadrupole magnets) the current schedule with a planned production of the triplet magnets by 2014 seems therefore to be very ambitious. However, if the component and tooling procurement starts at the beginning of 2010 a readiness for installation during the 2014-15 shutdown still seems possible.

Questions at the end of the presentation:

- Vladimir Shiltzev asks if one can give an evaluation for present delays?

OPTICS CHALLENGES & SOLUTIONS FOR THE LHC INSERTIONS UPGRADE PHASE I

Stephane Fartoukh that the Phase 1 IR upgrade implies a global new optics design for the LHC that goes well beyond the design of the insertion region optics. A lower gradient and longer than nominal triplet design requires not only larger triplet magnet apertures as compared to the existing triplet magnets, but also implies larger chromatic aberrations inside the triplets due to the increased peak beta-functions inside the triplet magnets and a larger than nominal number of long-range beam-beam effects over the common part of the beam pipes. The increased number of long-range beam-beam interactions implies a larger crossing angle as for the nominal LHC IR design and the maximum acceptable peak beta-function inside the triplet magnets is not only limited by the available aperture of the triplet and matching section magnets but also by the chromatic aberrations induced by the triplet magnets and the available strength of the arc sextupoles to correct them (2 arcs of lattice sextupoles are needed for correcting the chromatic aberration of one single triplet at beta* = 30 cm). A range of optics solutions is available for the Phase 1 IR upgrade, ranging from beta* values between 0.3 meters and 0.4 meters and full crossing angles between 410 microradian and 560 microradian. The optics solution with beta* = 0.3m provides on paper a slightly larger peak luminosity than the beta* = 0.4 solution but does not leave any operational margins and flexibility for the optics and sextupole correction circuits. The solution with beta* = 0.4m yields a slightly smaller peak performance but still leaves some operational tolerances. In any case, due to the required large crossing angle, the luminosity gain due to a smaller beta* value is to a large part lost again by the geometric luminosity reduction factor and partially and both solutions provide peak luminosity values of the order of 2 - 3 10^{34} cm^{-2} sec^{-1} with ultimate beam intensities. In order to assure a maximum overall operational flexibility it would clearly be beneficial to take a more general upgrade approach that includes a revision of the remaining matching section magnets, the dispersion suppressor design and the arc correction circuits.

Questions at the end of the presentation:

- Steve Myers asks what we really gain with this upgrade? Stephane Fartoukh replies: dynamic aperture, 3 sigma in long range beam-beam separation and one can reach a luminosity level of 2 10^{34} cm^{-2} sce^{-1} which is not possible with the nominal triplet.
- Lucio Rossi asks, when the present triplet will become the machine bottleneck? Stephane Fartoukh replies when β* will get smaller than 1 m.
- Ezio Todesco asks: you mentioned the bottleneck on the dynamic aperture. What margin do we have? Stephane Fartoukh replies the used field error estimates are based on scaling from the present LHC triplet magnets.
- Jean Philippe Tock comments that the requirement to shift the position between the D1 and QDXS will make the service module much more complicated.

PLANNED UPGRADE ACTIVITIES IN IR4 FOR THE 2014/15 SHUTDOWN

Ed Ciapala summarises the potentially required interventions in IR4 during a long shutdown in 2014-2015:

- Installation of 200 MHz normal conducting capture cavities (ACN).
- Installation of additional transverse dampers (ADT).
- New cryo power plant in point 4 to establish RF cryogenic autonomy from sector 4-5 and make equal cryogenic capacity between sector 3-4 and 4-5. The upgrade would provide a significant benefit for operation.
- Other upgrade options include the installation of Crab cavities & higher harmonic RF system.

Ed Ciapala underlines that it is not clear yet if the ACN cavities are really required. An upgrade of the 200 MHz RF system in the SPS might be better solution. It is also not yet clear if the additional transverse dampers are actually required for the LHC operation. A final decision on these upgrade options requires more operational experience with beam in the LHC and can probably not be given before the beginning of 2012. For the moment the space required for these installations remains reserved in the IR4 layout with a planning for installation during a longer shutdown in 2014-2015, parallel to the LINAC4 connection to the PSB. However, if the operational experience in the LHC shows that the CAN and ADT installations are not required for the LHC operation, this reserved space could be used for the installation of a global crab cavity implementation or a higher harmonic RF system.

Questions at the end of the presentation:

- Steve Myers comments that the important upgrades are the cryogenic plant at point 4 and the SPS 200 MHz cavities.

SUMMARY OF THE COLLIMATION UPGRADE PLANS

Ralph Assmann underlines that impedance issues with the Carbon reinforced Graphite collimator jaws and the cleaning inefficiency to off-momentum particle losses in the dispersion suppressors of the cleaning insertions are very likely performance limitations for the current LHC installation. Ralph Assmann illustrates that, based on the operational experience from existing and past collider projects; one can project a performance limitation between 10% and 40% of the nominal LHC beam intensities. Exploiting the full LHC performance potential therefore requires two upgrade modifications of the LHC cleaning insertions: the installation of low-impedance secondary collimator jaws and the installation of dedicated collimator jaws inside the dispersion suppressors (so called ‘cryo-collimators’) for the capture of off-momentum particles that are produced by the proton impact on the collimator jaws in cleaning insertions. The first upgrade requirement is facilitated by already prepared plug-in modules for additional secondary collimators and benefits from an advanced design of rotatable Cu collimators within the USLARP collaboration. Two prototypes of this rotatable collimator design are due to arrive at CERN in 2010 and will be tested in the SPS during the 2010 – 2011 operation. The installation of 'cryo-collimators' inside the dispersion suppressors of the cleaning insertions still requires a significant amount of design work. However, Ralph Assmann is confident that solutions can be ready for installation during a long shutdown in 2012.

Table 1: Comparison of the performance reach with the old LINAC2 and the new LINAC4 injectors

LHC INJECTORS WITH LINAC2		Nominal LHC Double Batch	Expected Maximum Double Batch	Original proposal, 1997 Nominal	Original proposal, 1997 Ultimate
PSB out ($\varepsilon^* \leq 2.5\ \mu m$)	ppr	1.62×10^{12} *(1bunch/ring)* ↓ *(6 bunches, h=7)*	1.8×10^{12} *(1bunch/ring)* ↓ *(6 bunches, h=7)*	1.05×10^{12} *(1bunch/ring)* ↓ *(8 bunches, h=8)*	1.8×10^{12} *(1bunch/ring)* ↓ *(8 bunches, h=8)*
PS out, per pulse	ppp	9.72×10^{12}	10.8×10^{12}	8.4×10^{12}	14.4×10^{12}
PS out, per bunch ($\varepsilon^* \leq 3\ \mu m$)	ppb	1.35×10^{11} *(72 bunches)* ↓ *15% loss*	1.5×10^{11} *(72 bunches)* ↓ *15% loss*	1.0×10^{11} *(84 bunches)* ↓ *no loss*	1.7×10^{11} *(84 bunches)* ↓ *no loss*
SPS out	ppb	1.15×10^{11}	*1.27×10^{11}*	1.0×10^{11}	1.7×10^{11}

LHC INJECTORS WITH LINAC4		Nominal LHC Single batch	Maximum Single batch	Maximum Double batch	Single batch + PS h=14, 12 bunches scheme
PSB out ($\varepsilon^* \leq 2.5\ \mu m$)	ppr	3.25×10^{12} *(2bunch/ring)* ↓ *(6 bunches, h=7)*	3.6×10^{12} *(2bunch/ring)* ↓ *(6 bunches, h=7)*	1.8×10^{12} *(1bunch/ring)* ↓ *(6 bunches, h=7)*	*3.6×10^{12} (3bunch/ring)* ↓ *(12 bunches, h=14)*
PS out, per pulse	ppp	9.72×10^{12}	*10.8×10^{12}*	*12.3×10^{12} (scaled 1998 limit, 206ns bunches)*	*14.4×10^{12} (larger ΔQ in single batch)*
PS out, per bunch ($\varepsilon^* \leq 3\ \mu m$)	ppb	1.35×10^{11} *(72 bunches)* ↓ *15% loss*	*1.5×10^{11} (72 bunches)* ↓ *<15% loss*	*1.7×10^{11} (72 bunches)* ↓ *20% loss*	*2.0×10^{11} (72 bunches)* ↓ *20% loss*
SPS out	ppb	1.15×10^{11}	*>1.3×10^{11}*	*1.37×10^{11}*	*1.6×10^{11}*
Goal:		Nominal intensity in single batch: shorter filling time, lower losses and emittance growth.		Potential for ultimate intensity out of PS in double batch .	Potential for > ultimate with a new PS scheme (in PSB: new recombination kicker, new RF gymnastics).

Questions at the end of the presentation:

- Would the optics change due to the modification of the DS in case of the installation of the cryo collimators? Ralph Aassmann replies: No, because only one quadrupole magnet will be moved.
- How can one manage the impedance of the machine? If one needs to reduce it by a factor 4 then the main points would be:
    - With the collimation upgrade, the impedance is improved but not by a large enough factor.
    - the transverse dumper system could be utilised.
    - the margins provided by the larger triplet aperture could be used for the Phase I upgrade (larger opening of the collimator jaws).

- What is the potential for Crystal collimators? It is a newly developed technique and real gains still need to be demonstrated.
- Lucio Rossi asks: what about reducing the impact of the cryo collimators using shorter and stronger magnets? Ralph Assmann replies this would be a very interesting option.

INTEGRATION ISSUES IN THE TUNNEL AND IMPACT ON GENERAL LHC SYSTEMS

Sylvain Weisz summarizes the logistical and coordination challenges for the large number planned activities during the 2014-2015 shutdown and underlines that an overall shutdown planning is required for all interventions prior to the planned 2014-2015 shut down for the LHC upgrade (Phase 1 IR upgrade, LINAC4 connection, RF upgrades and Collimation upgrade) so that some of the required work can already be implemented during the preceding shorter shutdowns. At the moment it is not yet clear how many of the required interventions can be performed in parallel. Several activities require teams of the same expertise and therefore compete for existing teams at CERN (e.g. triplet installation and magnet movement in the dispersion suppressors for the installation of cryo-collimators). Sylvain underlines again that the underground space is very limited and that additional underground alcoves could facilitate significantly the installation of the triplet upgrades. However, with the given time line and planned installation during the 2014-2015 shutdown, the creation of additional underground alcoves seems rather ambitious.

SUMMARY

The discussions of Session 8 evolved around the following main questions:

- Is the Phase 1 upgrade still a reasonable option in 2015 given the current delays (Sept 19 incident in 2008 & splice consolidation) and the projection of reaching ‘only ’ 50 fb^{-1} by 2014 compared to a triplet lifetime of 300 fb^{-1} ?
- Can the injector complex deliver ultimate beam intensities in time for the planned Phase 1 upgrade in 2014/2015?
- Can / should we revise the planning for installation by 2014 / 2015?
- If yes for what parts of the Phase 1 upgrade (LINAC4, Collimation, RF, Triplet, civil engineering) should be rescheduled?
- To what extent will a long shutdown for the splice consolidation impact on the Phase 1 upgrade planning (only 1.5 years of operation between 2 long shut downs)?

The discussions at Chamonix concluded with the creation of 5 task forces:

- One for re-evaluatiomg the scope and planning for the Phase 1 IR upgrade.
- One for analyzing the options and potential for delivering ultimate beam intensities with LINAC4 and an upgraded PSB.
- One for analyzing the upgrade requirements and planning for the SPS.
- One for planning the interventions for a long shut down in 2012.
- One for evaluating the overall consolidation needs of the LHC injector complex over the length of the LHC exploitation.

The task forces will report back to the director of Accelerators by mid 2010. Their input will provide the basis for the shutdown planning over the next years.