CHAMONIX'10 SUMMARY

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Abstract

The summary session of the LHC Performance Workshop in Chamonix, 25-29 January 2010, synthesized one week of presentations and intense discussions on the near- and long-term strategy for the LHC. In particular, Chamonix'10 developed a road map for establishing 7-TeV beam operation, estimated the luminosity evolution over the coming decade, and critically reviewed plans for a future high-luminosity upgrade, including various scenarios for the LHC injector complex. Other workshop themes included the preconditions for operation at 5 TeV, future magnet and splice consolidation, optimized interventions and future recovery from collateral damage, safety for personnel underground, access systems, radiation monitors, and radiation to accelerator electronics.

INTRODUCTION

The LHC Performance Workshop was organized in nine sessions, covering the preconditions for operating at 5 TeV in 2010, the consolidation of magnets and splices during the 2010/2011 shutdown, optimised interventions and recovery from collateral damages in cold sectors, safety for personnel underground and He evacuation, access system and radiation monitors, radiation to electronics, future upgrade scenarios for the injector complex, LHC upgrade plans for the "first long shutdown", and additional LHC upgrade scenarios. These were followed by a summary session featuring a presentation on the outcome of the "Evian workshop" on the LHC beam commissioning, which had taken place a week earlier, and an overall synthesis of the Chamonix workshop. The latter synthesis is summarized in this report, where we describe the discussion topics more or less in the order of the corresponding workshop sessions.

SPLICE MONITORING

The new Quench Protection System (nQPS) allows for continuous measurements of the cold splice resistance (in units of nΩ) during "coast". Two questions which arise are:

- what is a critical resistance increase? and
- do we have the software for the analysis?

A related question concerns observations made during a quench and if these would permit extracting useful information about the copper-stabilizer state [1].

For the nQPS, a potential problem is related to the radiation weakness of the latest version of the field-bus chip (MicroFip^{TM}), which however affects only the supervision, but not the protection function [2,3]. A temporary workaround for the QPS boards is available. **A long-term solution is required for all QPS systems.**

SPLICES AND BEAM ENERGY

The updated simulations for the safe magnet current are based on rather pessimistic input parameters (e.g. RRR values), but they include no other safety margins. **For 2010, operation at 3.5 TeV is safe. The RRR value of the bus should be measured a.s.a.p., using the nQPS, to confirm the safety margin for 3.5 TeV per beam and possibly allow a small increase in the beam energy.**

Without repairing the copper stabilizers, operation at 5 TeV is risky [4]. For confident operation at 5 TeV, the "outlier" splices should be repaired, and a better knowledge of the input parameters is needed (i.e. RRR values for the cable and the bus). With the present input parameters the "limit" splice resistances at 5 TeV are 43 μΩ (RB) and 41 μΩ (RQ). These values are close to the resolution limit of the measurements for the RBs at 300 K.

For confident operation at 7-TeV beam energy all "outlier" splices must be repaired by re-soldering and new clamps and shunts [4,5,6] must be added to all existing inter-magnet splices. Experimental validation of the proposed solution from the "Splices Task Force" through a test in FRESCA should be foreseen.

Figure 1 compares measured and simulated thermal-runaway curves for the three splice samples so far studied in FRESCA [4]. It has been conjectured that this figure might indicate a pessimistic bias of the simulation at low currents, e.g. below 8 kA.

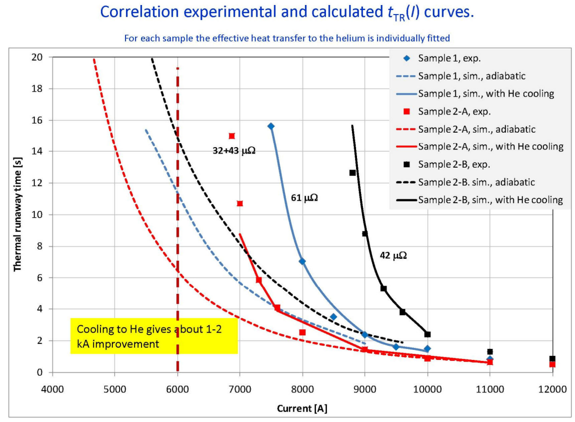

Figure 1: Thermal-runaway time for three splice samples tested in FRESCA as a function of current [4]. Solid and dashed lines refer to simulations with or without He cooling, respectively. The plotting symbols represent the measured values.

Tables 1-3 summarize the maximum allowable splice resistances for safe operation at 3.5, 5, and 7 TeV, extracted from simulations using the model benchmarked at FRESCA [4]. For 5 TeV a better knowledge of RRR_{bus} might provide another 10 μΩ margin. For operation around 7 TeV, excess resistances of $R_{addit,RB}$<11 μΩ for dipole splices, and $R_{addit,RQ}$<15 μΩ for quadrupole splices are required. At this energy, a better knowledge of RRR_{bus} will hardly increase these tolerances [4].

Table 1: Splice excess resistance requirements at 3.5 TeV [4].

circuit	τ [s]	Condition	Max R_{addit} for RRR$_{bus}$=100	Max R_{addit} for RRR$_{bus}$=160
RB	50	GHe with t_{prop}=20 s	>100	>100
		LHe with He cooling LHe without He cooling	58	65
			76	83
RQ	10	GHe with t_{prop}=20 s	>150	>150
		LHe without He cooling	74	80
		LHe with He cooling	**80**	84

Table 2: Splice excess resistance requirements at 5 TeV [4].

circuit	τ [s]	Condition	Max R_{addit} for RRR$_{bus}$=100	Max R_{addit} for RRR$_{bus}$=160
RB	75	GHe with t_{prop}=20 s	46	51
		LHe without He cooling	23	28
		LHe with He cooling	**43**	48
RQ	15	GHe with t_{prop}=20 s	>120	>120
		LHe without He cooling	35	40
		LHe with He cooling	**41**	47

Table 3: Splice excess resistance requirements at 7 TeV [4].

circuit	τ [s]	Condition	Max R_{addit} for RRR$_{bus}$=100	Max R_{addit} for RRR$_{bus}$=160
RB	100	GHe with t_{prop}=10 s	**11**	12
		LHe without He cooling	8	9
		LHe with He cooling	15	21
RQ	20	GHe with t_{prop}=10 s	18	22
		LHe without He cooling	13	14
		LHe with He cooling	**15**	17

POSSIBLE SCENARIOS (2010-11)

Two possible scenarios for 2010/11 have emerged at the workshop:

1) Running at 3.5 TeV/beam up to a predefined integrated luminosity with a date limit. Then consolidating the whole machine for an energy of 7 TeV/beam.
    - For this scenario, it will be necessary to determine the detailed needs for the shutdown (resources, coactivity etc).
2) Running until the second half of 2010. Then doing the minimum repair on the splices to allow 5 TeV/beam in 2011 (in this scenario 7 TeV/beam would come much later).
    - Should one add the missing DN200 pressure release valves at the same time as the splice repair for 5-TeV operation?
    - Will one need to warm up all sectors in order to re-measure splice resistances? The answer seems to be yes, as re-measurements appear to be mandatory for the dipole splices in 7 octants and for the quadrupoles in all 8 octants. (See the measurement results presented [7] and refer to Table 4.)
    - How many splices would need to be repaired to reach the "limit" copper stabilizer resistances? In particular, what should be done about the RQ's?

Table 4: RB busbar-segment resistances measured in five sectors at room temperature using the "biddle". The worst splices were opened up and repaired. The numbers show the situation after these repairs [7].

Circuit/ Sector	Temperature spread (K)	Excess resistance spread	Highest remaining excess resistance	Excess resistance limit 90%CL
A12 RB	1.1	13	37	51
A34 RB	1.9	10	35	47
A45 RB	0.9	17	53	78
A56 RB	0.4	9	20	34
A67 RB	0.6	14	31	48

Comparing the two scenarios it is clear that the first scenario entails the minimum risk, and that it probably represents the more effective approach when considering the lifetime of the LHC. In addition it is preferred for reasons of minimizing the radiation dose to workers (As Low As Reasonably Achievable, ALARA, principle). This scenario implies a re-design and testing of the splices, for which sufficient time should be allocated.

The second scenario implies a higher risk. It would require a reduced running in 2010 followed by a long shutdown 2010-2011, and it would delay the LHC operation at the highest energy. It is in conflict with ALARA, and it urgently needs development of the new technique for the measurement of the warm resistance (thermal amplifier) which is not yet available. In addition, due to the choices to be made and the uncertainties in the decisions, it may require as much (or even more) shutdown time as for scenario 1, in order to allow a lower energy of only 5 TeV per beam.

Moreover, the additional inherent risk associated with an inadvertently "missing" bad splice needs to be seriously considered [8].

The workshop participants expressed a unanimous preference for scenario 1.

A related question is how to respond to any unforeseen stop, caused e.g. by a degrading S3-4 vacuum.

Comments and discussion on the 2010-11 scenarios: The experiments are in favour of scenario 1 [9]. A target value for the integrated luminosity at 3.5 TeV of 1 fb^{-1} has been given as an indication. At this luminosity the LHC physics would be more than competitive with the Tevatron's, and LHC would be firmly established as the energy frontier machine. To obtain the maximum (required) integrated luminosity over this period, the machine parameters should be carefully evolved while maintaining operational efficiency [10].

Concerning the response to an unforeseen stop, in such a case the electronics in Point 8 could be addressed [11].

DEFINING THE RISK AT 3.5 TEV

A question which should be answered to better define the risk is:

> what (in detail) will be the sequence of events if the "allowable" values for the splice resistance are exceeded while running at 3.5 TeV/beam?

The situation in 2010 is much improved with respect to 2009. There are now additional pressure release valves, faster energy extraction (new dump resistors), and a new QPS including fast inter-magnet splice protection, as well as asymmetric quench protection. The potential damage and the repair time in case of an accident should be evaluated for this new situation.

BEAM LOSS MONITORS

The beam-loss monitor (BLM) system is crucial to reach the full protection level. Beam tests are required to determine the safe setting of the threshold levels. And the specified procedures must be fully applied.

An impressive system performance has already been demonstrated [12]. One of the most important results from the early LHC beam commissioning is that scraping in the SPS is mandatory and that a clean injection is critical. The injection efficiency did not receive any attention until now, but it will be optimised (using the injection damper etc.) for higher injected currents.

MACHINE PROTECTION & FUTURE HARDWARE COMMISSIONING

The maximum stored beam energy achieved in 2009 was 30 kJ. For the goal peak luminosities in 2010 ($\sim 2 \times 10^{32}$ cm^{-2}s^{-1})., a beam stored energy of around 35 MJ is needed. Collimation protection is crucial to avoid beam-induced damage. Following MD studies, the beam parameters must be restored to the physics operational conditions to avoid subsequent damage by the beam.

Proposals, authorization mechanisms and procedures are needed, in particular for the following:

- operational strategy for the beam intensity increase,
- authorization procedure for masking and unmasking of interlocks [13].

Pertinent proposals will be presented at the **LMC**.

Concerning the organization of hardware commissioning (HWC) in 2010 and beyond [14], a new working group will be established (chaired by Rüdiger Schmidt), which will report to the LMC.

OPTIMIZATION OF RECOVERY FROM COLLATERAL DAMAGE

In general, reducing the nitrogen part of the cool-down, if this were possible, would shorten the time needed for interventions [15].

Following the accident in September 2008, the vacuum group had to develop a super clean vacuum cleaner [16]. A new methodology was introduced and applied for the clean-up process of Sector 3-4. Now 6 sets of tooling are available "on the shelf" to intervene in case of need. The vacuum group hopes that these tools will now remain on the shelf forever.

Fast valves for the LHC need further development work. Additional rupture discs to limit the collateral damage in the beam-vacuum chambers are envisaged for the arcs and/or for the experimental areas [17].

Repairs with localised warm up of cold sectors are an appealing option. Indeed local warm up is part of the LHC baseline [18]. It allows for local repairs, while avoiding a thermal cycle of a whole arc. The method must be adapted with regard to the possibility of PIM (plug-in module) buckling.

The example of a repair of the insulation vacuum using localised warm up produces a saving of 17 days (69 versus 52 days in total).

The X-ray tomography which has recently become available represents a huge leap forward, by avoiding systematic beam vacuum venting and endoscopy to check the PIMs after an intervention.

The answer to the question "can we change a magnet without warming up the full arc?" is probably yes, but it still requires the development of suitable tools and procedures.

UNDERGROUND SAFETY

The safety session was interesting and raised many points to pursue. As a follow up of the task force on underground safety [19], the experimental areas are now sealed. Still outstanding are the sealing of service areas from the tunnel, the alternative He release path, a proposal to link access with powering system, and the question of a 5th safety coordinator.

ACCESS SYSTEM AND RADIATION MONITORING

No problems have been found with the personnel safety, but some issues with the availability of the LHC have been highlighted [20]:

- There is the never ending story of the Material Access Device (MAD).
- The access is very slow when there is a large throughput.

A detailed proposal was made for the consolidation of the access system, with some open question:

- Reduce the size of the sectors? (more doors)
- Should the Safety System (LASS) be extended to include other hazards such as electricity, high pressure, and lack of oxygen...?

A new procedure for access requests – AET ("Avis Execution Travaux") – was introduced.

One question concerned the need for more people who are trained to give access.

A working group should be set up to provide the functional specifications for a new access system.

RADIATION TO ELECTRONICS

The detectors attacked the problem at the right time (>10 years ago) [21]. For the LHC machine, the present situation is difficult: mitigation is mandatory. The mitigation will involve one or several of the following possibilities [22]: shielding, relocation to existing areas, redesign of electronics, and relocation to newly generated areas (civil engineering). The implied lead times are long, calling for an evolutionary approach. The cost could be very high for the generation of new underground areas. Superconducting links may help for the relocation of power converters.

A first rough estimate of the required material and manpower resources for the various mitigation steps has been presented [23]. The perfect solution is still being looked for.

UPGRADES - FOREWORD

Studies on the upgrade strategy have been launched about one year ago and are ongoing. The performance aim is to maximize the useful integrated luminosity over the lifetime of the LHC. Targets set by the detectors are 3000 fb^{-1} (on tape) by the end of the life of the LHC, which translates to 250-300 fb^{-1} per year in the second decade of running the LHC. The goals of the present upgrade studies are to assess the performance of the current upgrade plans, and to check their coherence with respect to the accelerator performance limitations, the detectors, the manpower resources, shutdown planning, etc.

UPGRADE OR NOT

Figure 2 illustrates schematically that it takes several years to profit from an upgrade. Recent examples from the HERA and Tevatron Run-1 upgrades are shown in Figs. 3 [24] and 4 [25].

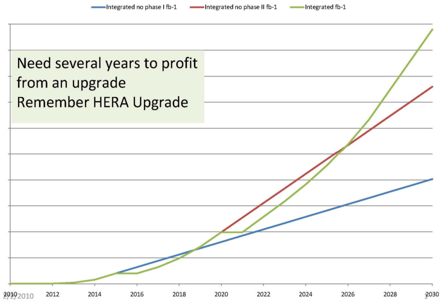

Figure 2: Schematic evolution of integrated luminosity with no upgrade (blue), one upgrade (red), and two upgrades (green) [Courtesy R. Bailey].

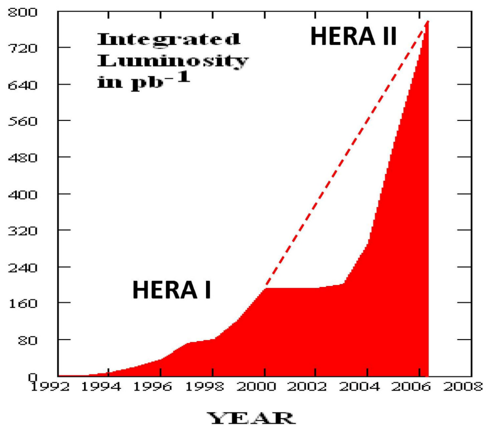

Figure 3: Integrated luminosity over the lifetime of HERA [24]. The upgrade from HERA I to HERA II happened from 2001 to 2003.

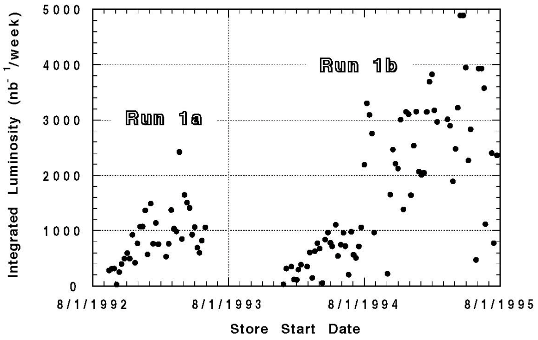

Figure 4: Weekly integrated luminosity reported by CDF for Tevatron Runs 1a and 1b. Between these two runs, the injector linac was upgraded to 400 MeV, ultimately leading to a bunch intensity increase in the Tevatron by a factor 2-3 [25] [Courtesy V. Shiltsev].

INJECTORS: PERFORMANCE, CONSOLIDATION, AND UPGRADES

From the LINAC2 to the SPS the LHC injectors are aging machines. Consolidation or replacement is needed. The proposed scenario in the "White" Paper, (2006) was to replace LINAC2, PSB and PS by LINAC4, SPL, and PS2 [26]. A recent study has shown that the time scale for first operation of the PS2 is at the earliest 2020 and likely 2022. The conclusion is that we need to aggressively consolidate the existing injector chain to allow reliable operation of the LHC until at least 2022. **A consolidation task force** had been set up late in 2009 [27]. It is also clear that the resources needed for the consolidation of the existing injectors are in direct competition with those needed for the construction of SPL/PS2.

On the other hand, the required consolidation of the existing injectors [27] will already provide an improved reliability. And the present performance limitation, in terms of intensity limit is in the SPS (or perhaps in the LHC itself), as illustrated in Table 5. The presently known bottleneck is the SPS, where e-cloud instabilities, transverse instabilities driven by high impedance and RF limitations, limit the present intensity to about 0.7 of the ultimate needed for the LHC [28].

A "new" idea/scenario was presented. By maintaining the existing injector chain (and including LINAC4), and increasing the extraction energy of the PS Booster to 2 GeV, intensities of up to $3x10^{11}$ protons per LHC bunch with 25-ns spacing may be possible at the extraction of the PS [29]. This scenario may be a faster and cheaper way to attain the needed LHC intensity.

Therefore, an alternative upgrade scenario to SPL/PS2 is to consolidate the existing injectors for the life of the LHC (2030), and during the same consolidation, improve the performance of PSB/PS as injectors for the LHC, e.g. by increasing the extraction energy of the PSB.

Reliable running of the existing injector chain for another >20 years will require serious consolidation of many of the components. A detailed study of the consolidation requirements covering the machines, the experimental areas, the services and the infra-structure is already under way.

The preliminary presented time line for the implementation of a **new PSB extraction energy** is of the order of three to four years (design and construction of new hardware [29]. The hardware concerned includes for the PSB, the main magnets, the main power supply, RF, septa and kickers, and for the transfer lines, the magnets, septa and kickers, and power converters. In addition the PS may need new injection septa, injection kickers and a slow bump scheme for the higher injection energy [29].

Other areas of study in view of additional injector improvements are the PS working point control, a faster pulsing of the PS (26 GeV/c in 1.2 s), and reduction of the losses at the PS extraction (new thin septum or additional thin septum) [29].

Table 5: Summary of present and forecast LHC proton-beam intensity limitations (protons per bunch).

Intensity Limitations (10^{11} protons per bunch)			
	Present	SPL-PS2	2GeV in PS
Linac2/LINAC4	4.0	4.0	4.0
PSB or SPL	3.6	4.0	3.6
PS or PS2	1.7	4.0	3.0
SPS	1.2	>1.7?	>1.7?
LHC	1.7-2.3?	1.7-2.3?	1.7-2.3?

Comments and discussion on the injector upgrade: The cost & resources should be discussed separately, but the estimate presented is considered correct [30]. It is a good idea to optimize the performance of existing machines, e.g. by raising the PSB energy. However, the pertinent performance estimates presented at this workshop may not be based on the same degree of realism, compared with the numbers shown for PS2 & SPL [30], while it does represent an interesting option.

Indeed, the results presented for the PSB study had been reached on a different, much shorter time scale and with quite a different level of resources compared with the PS2 study [31]. Nevertheless certain elements seem to indicate the feasibility of this option. Some components required or helpful for this option could be included in the injector consolidation programme [31].

The extraction energy of the PS would be a factor of 2 lower than that from PS2 [32]. The present space-charge tune shift at SPS injection is 0.07, much less than the 0.3 value which is common in the PSB or PS [33], and, therefore, this does not seem to be a fundamental limitation. Past beam experiments at SPS injection did not reveal any space-charge (SC) related lifetime reduction at least up to SC tune shifts as high as 0.2 [34]. The 2-GeV upgrade of the PSB will allow much faster tests of intensity limits in the SPS [35].

The number quoted for the SPS intensity limit might be on the pessimistic side [30]. The primary intensity limitations in the SPS for the LHC beam need to be clearly worked out [36]. The quoted bunch intensity limitation of $1.2x10^{11}$ in the SPS refers to the fact that at this intensity the value of the transverse emittance approaches the limit of what can be accepted for the LHC. In this sense the electron cloud represents the most important limitation [37]. In fact, the transverse emittance can presently not be maintained at this intensity [38]. A programme is underway to mitigate the electron cloud [39]. A general concept for the entire accelerator chain should be developed so that actions launched for the various machines fit together [40]. In particular, the fundamental limits for the SPS and the LHC should be identified. At the moment three SPS limitations (as well as their mitigation) are known: electron cloud (vacuum chamber coating), transverse mode coupling instability (impedance reduction and/or transverse feedback), and RF effects such as beam loading etc. (redesign of existing RF system or build a new system) – it is hoped to solve all these issues [41]. The next limit beyond these is not known presently. Immediately after Chamonix a **task force has been set up to investigate the removal of the SPS bottleneck**.

There is currently no proposal to operate the sLHC with more than $2.3x10^{11}$ ppb at 25 ns spacing [42], so that the LHC plan will never be coherent with $4x10^{11}$ protons per bunch, which would be available from the PS2. Even to reach and go above the ultimate intensity of $1.7x10^{11}$ ppb (at 25 ns spacing) may require substantial upgrades of many LHC components [43].

The future of the laboratory might require something else, e.g. a new machine, that is not closely tied to the LHC performance over the next ten or twenty years. The ~2030 perspective might determine the right decision. For Fermilab the Main Injector had proven to be the right decision [44]. While this argument is important and will be considered by the CERN top management, the Chamonix workshop focuses specifically on the LHC performance [45].

INSERTION UPGRADE PLANS

The goal of the Inner-Triplet (IT) upgrade [46] is to ensure reliable operation at $2x10^{34}cm^{-2}s^{-1}$ at beam intensities below ultimate and above nominal. The improvement offered by the pertinent upgrade optics [47] with respect to the present optics has not yet become entirely evident.

As for IR4 upgrades, the justification for 200-MHz (ACN) cavities appears very weak [48]. In contrast, a cryo-upgrade for IR4 to allow autonomy of the sc RF cavities seems very useful. Crab cavity studies are ongoing. The space which might accommodate such cavities in IR4 should be reserved.

A clear proposal for collimation phase 2 has been presented [49]. The present intensity "limitation" from collimation is soft, and needs to be confirmed by beam studies during the next years. The collimation phase 2 proposal implies the displacement of a total of 48 sc magnets to free the needed space for new collimators. An approval of this installation phase is required soon. The break point is summer 2011 for completion by 2014-2015.

A possible integration issue in the tunnel has been highlighted [50]: the planning is presently assumed to require 9 months for IT phase 1, idem for the matching sections (modification of the region from D2 to Q6). The activities for the matching sections are very similar to the installation of the new triplets, requiring the same expertise, and implying intense and tightly dependent co-activities. In view of these conflicts, successive modifications of the matching sections should be minimized by implementing a solution that would remain valid for the later phase-2 upgrade of the triplet.

Perhaps more seriously, the splice consolidation and the IT upgrade also compete for resources.

Two tough questions were raised:

1. Will the phase 1 IT upgrade produce an increase in the integrated luminosity? Here the installation time and the re-commissioning time needed afterwards for the "new" machine should be taken into account.
2. Are sufficient resources available to complete IT phase 1 on a time scale which is reasonable with respect to IT phase 2?

A **task force has been set up immediately after Chamonix to answer above questions** within 4-5 weeks.

Comments and discussion on the IT upgrade plan: It might be "unfair" to compare the phase I upgrade plan with the ultimate LHC parameters [51]. The luminosity evolution forecast now is much slower than what had been expected before.

How much the present collimation is limiting the luminosity needs to be investigated [52]. This will indeed be done, and analyses of loss rate have already started [53]. However, the 2009 experience is insufficient to draw any definite conclusions.

The initial goals of phase-I upgrade had been two-fold [54]: to take advantage of the available sextupole strength in order to decrease beta* to 25 cm, and to relax the collimator impedance issue through an increased triplet aperture. Two types of difficulty had been envisioned: an intensity limitation, and the constrained emittance budget (translating into an aperture budget). Now it was a good time to re-evaluate how close the present phase-I plan is to meeting the initial goals for this upgrade. For example, initially the time of installation had been assumed to be 6 months; meanwhile this had increased to 1 year [54].

Cryo-collimators are also strongly motivated by the heavy-ion programme, independently of the triplet upgrade, but with a similar installation plan. In IR2 an initial set of cryo-collimators is required for heavy-ion collisions, but only half as many as called for by the proton luminosity upgrade [55].

There may be a severe resource conflict for the upgrade of the Inner Triplet, the injector consolidation (and upgrades), and the splice consolidation [56].

FUTURE UPGRADE SCENARIOS "PHASE 2"

The parameter space beyond $10^{34}cm^{-2}s^{-1}$ has been explored [57]. Beam intensity was identified to be the most important parameter for higher luminosity. Reducing β^* does not significantly change the average luminosity unless it is complemented by crab cavities (or by smaller emittance).

Numerous limitations exist on the path towards higher intensities (important reality check!) [58]. Indeed, there are many, many problems with higher intensities. As a result it was concluded that the upgrade should be presently limited to about ultimate beam intensity.

Alternative luminosity scenarios should be developed for limitations either in total intensity or in intensity/bunch (2nd reality check) [59].

Crab cavities are only efficient for low β^* values around 0.25 m and below [60]. Conversely they represent almost the only efficient way to operate at such low beta values. The crab-cavity studies should be continued (with regard to machine protection, etc.).

For LHC high luminosities, the luminosity lifetime becomes comparable with the turn-around time, implying a low efficiency. In this situation luminosity leveling would be an asset [61], and allow for very efficient operation. Preliminary estimates show that the useful integrated luminosity is greater with a maximum luminosity of $5x10^{34}$ $cm^{-2}s^{-1}$ and luminosity leveling than with 10^{35} $cm^{-2}s^{-1}$ and a luminosity lifetime of a few hours. Leveling could be accomplished by varying β^* or the crossing angle, or, quite elegantly and less invasively, through the use of crab cavities, and finally possibly via changes of the bunch length.

The LHC high-luminosity experiments wish to collect a lifetime total integrated luminosity of 3000 fb^{-1} on tape, as well as to receive a clear plan for the technical developments over the next 5-6 years [62]. In addition, after 2020 the (s)LHC operation scheme should allow running LHCb with a luminosity of $5x10^{33}$ $cm^{-2}s^{-1}$ and provide higher luminosity with lead ions in ALICE.

Rough and very preliminary estimates of the integrated luminosity for the next decade ("crystal ball") suggest that LHC may reach between 9 and 24 fb^{-1} by 2014, 40 to 100 fb^{-1} by 2016, and a rate of 100 fb^{-1}/year by about 2019 [63].

Better estimates for the coming five years should be available at this time next year. These estimates will be developed in a more formal way via the LHC Machine Committee, and the numbers for future runs will be proposed in Chamonix each year.

The luminosity targets set by the detectors are 3000 fb^{-1} (on tape) by the end of the life of the LHC implying an integrated luminosity goal of 250-300 fb^{-1} per year in the second decade of LHC running.

Comments and discussion on future upgrade scenarios:

Concerning luminosity levelling, the bunch length could be doubled, by a factor 16 reduction in RF voltage [64].

An increase in intensity beyond ultimate is not excluded from first principles. A rather fundamental limit is set only by the beam screens [65]. This hard limit corresponds to a bunch intensity of about $2.3x10^{11}$ at 25 ns spacing, and $\sim5x10^{11}$ at 50 ns spacing [66].

Splice consolidation and collimation (soft limit) must be addressed with high priority, while it is difficult to see how the phase-I upgrade increases the integrated luminosity. Therefore, the latter was a "very difficult sell" [67].

If the interconnects are anyhow opened there might be a possibility to also consolidate the PIMs at the same time [68]. Most of the suspicious PIMs have already been replaced, however. And there is no clear reason for a systematic repair [69].

What could be done during an unforeseen shutdown? Are there ideas what to do in parallel [70]? The scenario 1 should be defined very clearly [71]. The repair time with a local warm up was 52 days. This down time should not be extended more than necessary. And therefore only those activities should be executed that could be completed within this time [71]. During LHC shutdowns there would be plenty of work on the injectors [72].

The importance of the upgrade for the particle-physics community should not be underestimated [73]. An upgrade decision or plan in 5 years from now is too late; the detector-upgrade project now underway has 1/2 the size of the initial detector construction. A project of this size cannot be based on a very weak assumption. There should be a clear plan and goal providing the motivation [73]. On the other hand, the money should not be wasted either [74]. The present plan must be refined. The need for a clear sign is agreed by everybody involved. The learning experience from operating the machine will be important. A concrete plan will be presented sooner than in 5 years' time [74]. At this Chamonix workshop two very large upgrade proposals have been discussed (SPL & PS2, IT upgrade phase I). The ultimate plan is a phase-II triplet. The plan which had been pursued so far had resulted in a pile up of the same people having to do an incredible amount of work.

UPGRADE CONCLUSIONS

The luminosity targets set by the detectors are: 3000 fb^{-1} (on tape) by the end of the life of the LHC translating to 250-300 fb^{-1} per year in the second decade of running the LHC. The upgrades needed to attack these goals are:

- SPS performance improvements to remove the bottleneck;
- aggressive consolidation of the existing injector chain for availability reasons;
- performance improvement of the injector chain to allow phase 2 luminosities; and
- a newly defined sLHC which involves luminosity levelling at ~5-6x $10^{34}cm^{-2}s^{-1}$ (crab cavities etc…), and at least one major upgrade of the high luminosity insertions.

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