CHAMONIX'11 SUMMARY: PROPOSALS FOR DECISIONS

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Abstract

The summary session of the LHC Performance Workshop in Chamonix, 24-28 January 2011, synthesized one week of presentations and intense discussions on the near- and long-term strategy for the LHC. In particular, Chamonix'11 discussed the timing and activities of the first long shutdown, the choice of beam energy for 2011, the 2011 beam-operation goals and schedule, the strategy for the longer-term LHC luminosity upgrade, the injector performance, as well as plans and options for the injector upgrade. Other workshop themes included a review of the LHC beam operation in 2010, with suggestions for possible improvements, as well as issues related to machine protection and intensity limitations.

We report the proposals for decisions which have emerged at this workshop.

INTRODUCTION

The LHC Performance Workshop at Chamonix is a technical meeting which proposes recommendations to the CERN Directorate. These recommendations are considered by the management, which also takes into account recommendations/advice from the CERN Machine Committee before making its final decisions.

The 2011 LHC Performance Workshop was organized in nine sessions, covering a review of 2010 operations, the planning and activities for the first long shutdown (two parts), the choice of beam energy for 2011, beam-intensity issues, machine protection in 2011 and beyond, the running plan and luminosity expectation for 2011, the high-luminosity LHC (HL-LHC), and the LHC injectors upgrade (LIU).

These were followed by a summary session featuring reports by the session chairs and secretaries, and by an overall synthesis of the Chamonix workshop containing proposals for decisions. These latter proposals are summarized in this report.

POINTS AWAITING DECISION

Two important items needed a (proposal for) decision:

(1) The operation after 2011, and the impact of a delay in the first **long shutdown** ("LS1") from 2012 to 2013, concerning issues such as radioprotection (ALARA etc.), maintenance requirements, impact on future projects, and the effect on the following long shutdown ("LS2"; originally planned for 2016).

(2) The LHC performance in 2011, in particular the **maximum safe beam energy** and the **luminosity** (both peak and **integrated**, with a baseline goal for 2011 still equal to 1 fb^{-1}). The luminosity performance will be determined by the number of bunches, the bunch spacing (possibly limited by electron cloud, bunch instabilities, scrubbing, ...), the intensity per bunch (determined by the injectors, beam-beam effects, impedance and instabilities, …), the values of beta*, and crossing angles, with additional constraints and impact from collimation, machine protection, "unidentified falling objects" (UFOs), single-event upsets, and radiation to electronics, as well as by how ALICE and LHCb will be operated at low luminosity.

2012: PHYSICS OR SPLICES?

All relevant **technical issues** were reviewed. Concerning radioprotection, ALARA considerations with regard to a 1-year delay in the shutdown have turned out not to be a serious issue. For the splice consolidation, postponing the shutdown is beneficial both from the technical and from the resources points-of-view. For the cryo-collimation project the one-year delay would be essential. For kickers and dumps the delay is beneficial too. However, for **CV and EL**, a **delayed maintenance may reduce reliability**. As a possible mitigation for the latter, the possibility of carrying out maintenance during an extended Christmas Technical Stop will be studied. For access and alarms the delay is overall beneficial. The experiments also are in favour of the delay. In addition, they would appreciate a **new 10-year plan** including Christmas/Technical Stops. The CMS activities presently foreseen for the first long shutdown require a 15.5-months stop plus possibly 2 additional months for bake-out.

Postponing the "2012" shutdown (LS1) to "2013" will delay the work to be done in LS1 by one year, may allow some tasks already scheduled for the second long shutdown LS2 (2016) to be advanced to LS1 (**injectors, LINAC4, collimators with integrated beam-position monitors, detectors**, ...), will increase the need for maintenance and repairs to allow for efficient running through 2012 (EN/CV...), and may necessitate an increase in the duration of the technical stop over Christmas 2011-12.

Consequently postponement of the LS1 should be accompanied by a change in the date of LS2 as well as by modifications to the frequency and duration of the Christmas and technical stops.

The proposal, therefore, is to "do physics in 2012", BUT at the same time to study the maintenance and repairs needs for such a long running period (2009-2012), e.g., considering how CV/EL maintenance could be carried out during the Christmas stop in 2011-2012, to make a new 10 year plan including all shutdowns and technical stops (LMC + experiments), and to try to keep to a minimum the duration of the shutdown in 2013, with a **critical review (in June 2011) of the need for including the cryo-collimation system in the LS1 shutdown and of the possibility to delay it to LS2**.

Comments and discussion on the long shutdown:

The first proposal for decision is to run in 2012. This proposal raises the issue of impact on the injector complex [1]. The injectors will have been running for 4 years. Injector maintenance indeed is the reason why 3-months Christmas stops are needed [2].

It is also important to know whether in 2013 the injectors will be running or not. With the dedicated LHC filling mode, less time is available for injector machine developments (MDs). Running the injectors without the LHC in 2012 would, therefore, be very useful for the injectors and the pertinent MDs [3]. Unfortunately, the financial impact demands to halt the full CERN accelerator complex when stopping the LHC [4]. In addition there is the issue of man power required the LHC shutdown activities [5]. However, at the end (and start) of the long shutdown there would be about a month of tests for hardware commissioning without the LHC beam; the injectors could use this time for MDs [6].

The consolidation work in the long shutdown should be done properly to avoid future similar discussions [7]. It is suggested to do the consolidation job of LS1 properly, and ideally aim to complete it within 9 months [8]. When consolidating splices, quality is of uttermost importance. The time of the consolidation should be squeezed while maintaining high quality of workmanship [9]. All teams and efforts should focus on the consolidation of the interconnects. The manpower for the injectors is valuable manpower in this regard. In fact, the key people from the injectors are exactly the supervisors for the LHC shutdown work [10]. The long shutdown requires a lot of careful planning, as well as a global look at the resource allocations [11].

The collimation team is in favor of a review for its proposed shutdown activity; it is also looking at all the work to be done and at the question if the work foreseen for the collimation system can be completed on time. Earlier it has been said that the collimation work could be performed if the injectors were stopped [12]. The need of a collimation upgrade in 2013 should be reviewed [13].

Coordination between accelerators, experiments, and physics department is essential; interference and inefficiency have to be avoided [14].

2011 BEAM ENERGY

An important question is the **return for the risk** associated with a beam-energy increase in 2011. This is illustrated in Fig. 1. Raising the beam energy from 3.5 to 4 TeV would be equivalent to a 30% increase in luminosity.

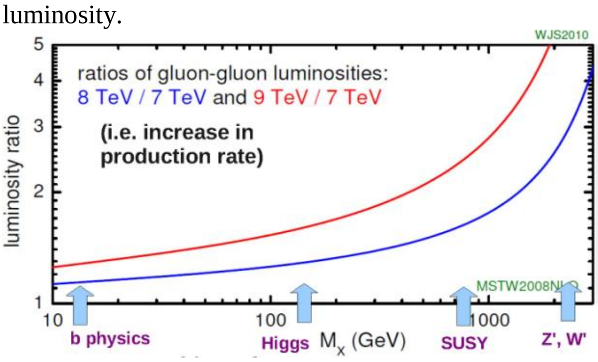

Figure 1: Effect of increasing the beam energy expressed as relative increase in production rate of various particles (James Stirling) [15].

The maximum safe beam energy is related to the **probability of burning an interconnect**, shown in Fig. 2, and to the consequences of a thermal runaway.

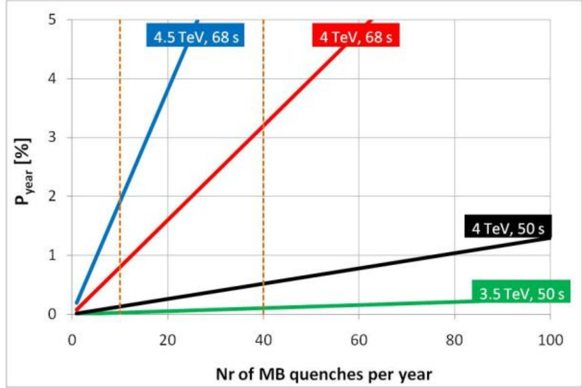

Figure 2: Probability per year of burning an interconnect as a function of the number of quenches per year [16]. The four lines correspond to three different beam energies and two different extraction time constants as indicated.

Operating with an extraction time constant of 68 s at 4.5 or 4.0 TeV implies a probability of a few percent per year for a thermal runaway, which is considered unacceptable. Therefore, the remaining choice is between 4 and 3.5 TeV with the present extraction time constant of 50 s. Going from 3.5 TeV to 4 TeV, at 50 s, still implies a significant increase in the risk of burning an interconnect. This risk is much higher than for any other component of the LHC machine, for example the beam dumping system [17].

The **impact** of an electrical arc in an interconnect is not negligible, even with the reinforcements and consolidation implemented after the 2008 incident [18]. Though the present consolidation, up to 5 TeV, will suppress **mechanical** collateral damages in adjacent sub-sectors, mechanical damage of the multilayer insulation (MLI) in the concerned sub-sector as well as contamination of the beam pipe(s) could require heavy repair work.

With the present consolidation status, a new incident will still imply a significant machine down time (8 to 12 months). PLUS a new incident would cause a severe damage to CERN's reputation.

An important question for judging the risk is the number of quenches expected. In 2010, there had been 20 quenches with current above 5000 A (none of which beam related).

Complementary issues with 4-TeV operation (at 50-s energy extraction time) include the possibility of interconnect quenches due to asynchronous dumps (affecting Sectors 5-6 and 6-7, which fortunately are two "good" sectors with little excess resistance), the UFOs (the event rate of which increases with intensity, whereas the magnitude of the UFO signal depends on the beam energy [19]). One dipole B30R7 (MB1007) has an insulation weakness which presently limits the maximum beam energy to no more than 4 TeV [20]. From the quench protection system, there is a strong preference to install and connect the snubber capacitors at the extraction switches, which will reduce the likelihood of false quench protection. The snubber connection will have little or no impact on the LHC set-up time.

The probability of another incident is relatively low but the impact would be high, i.e. the overall **risk factor is medium**.

In view of the above, and in particular given the unfavorable return/risk ratio of a beam-energy increase, the proposal is to **stay at 3.5 TeV for 2011**. Maintaining the same energy as in 2010 has the added small side benefit of a reduced need for luminosity calibration. The question has been posed if it would be a better risk investment to go for a lower beta* instead of for higher energy.

LHC should operate in 2011 with the "snubber" capacitors. The development of the "thermal amplifier" [21] during 2011 and measurements during the end-of-the-year shutdown will allow a decision about a possible energy increase for 2012, based on more solid information. The 2012 energy could then hopefully be even higher than 4 TeV.

Comments and discussion on the beam energy:

There are four positive facts that would support higher beam energy: revised value of copper-busbar RRR values, asynchronous dumps affecting two good sectors, installation of snubber capacitors, and efficient protection by the BLM system. One key information missing is the effect of the diode on the thermal runaway threshold. A decision could be taken after the measurements on a "good" dipole magnet [22].

From the experiments' point of view a higher energy is obviously better. The ATLAS representatives came to Chamonix'11 to support the idea of a higher energy in 2011. However, operating at 4 TeV would entail more risk than gain. This additional risk does not seem to be justified [23]. This is not only a question of the by-pass diode. There is no news about the splices, the time development of which is unknown. Also UFOs may limit the LHC in 2011. The ATLAS representative's point of view is not to take the risk of 4-TeV operation [23].

The big difference in risk factors for the interconnect burnout and for other LHC systems is striking [24]. The LHC beam dump system complies with security integrity level (SIL) 3 or 4, implying the probability of a catastrophic beam dump failure to be one event every 10,000 or 15,000 years [25]. The much higher risk from the splices is an anomaly [24] for the LHC machine, where otherwise SIL3-4 is the standard [26]. The damage to CERN from a second incident would be tremendous [27]. In any case it may not be possible in 2011 to operate at energies higher than 4 TeV due to a weak dipole magnet [28]. (The weak dipole could possibly be fixed, however.) Snubber capacitors will be installed and connected in any case; the discharging circuit will be modified etc. [29].

There were 20 quenches in 2010. Would the probability-related counting for this year start at 0 or at 20? [30]. More precisely, in 2010 there were 11 high-field quenches, and a total of 20 quenches above 5 kA current. The numbers should indeed be accumulated from year to year [31].

RUNNING IN 2011

The **number of days in 2011 available for LHC physics** is a concern. In a first assessment, from 262 days in total dedicated to LHC proton operation, after subtracting all other needs, less than half are left for high-intensity physics operation, as is illustrated in Table 1. This list will have to be refined and the cost in integrated luminosity be specified. It will be tried to improve the overall efficiency and to still perform all the necessary tasks shown in the list.

Table 1: Tentative beam-time allocation to various commissioning steps and to high-intensity physics proton operation, for the 2011 LHC run [32,33].

item	days
total *p* OP – 37 ½ weeks	262
11 MDs (2 days)	-22
6 TS (4+1 days)	-30
special requests	-10
commissioning	-28
intensity ramp up	-40
scrubbing run	-8
total HIGH INTENSITY	124

Start-up scenarios are under development. The most likely sequence is 75-ns beam re-commissioning, followed by scrubbing with 50-ns beam, and then either 75 or 50-ns operation. The recommissioning with 75 ns bunch spacing should take about 3 weeks. Next, increasing the number of bunches to about 300 will require another 2 weeks and scrubbing with the 50-ns beam, when needed, will take 1.5 weeks more. After the scrubbing experience the decision will be taken to go back to 75-ns spacing or to continue at 50 ns. In the following 50 or 75-ns operation the number of bunches will be further increased, during roughly 2.5 weeks, from 300 over 400, 600, and 800 to 936 or 1404 bunches, including machine protection and operations qualification. Physics operation can then proceed at 50/75 ns with either 936 or 1404 bunches, respectively. As a back-up, e.g. in case of strong electron-cloud effects, one could restore the 150 ns operation, which would require a couple of days.

An alternative sequence would be to start at 150 ns for the beam re-commissioning, then to scrub with 50 ns, and finally to go to 75-ns operation. Yet other bunch-spacing sequences would be "50-ns beam re-commissioning – scrubbing with 50 ns – 75-ns operation," or "50-ns beam re-commissioning – scrubbing with 50 ns – 50 ns operation."

Values of bunch intensity and normalized emittance at the exit of the SPS which have been obtained, or are predicted, for a bunch spacing of 150, 75 and 50 ns are shown in Table 2. The corresponding LHC parameters assumed for luminosity estimates are given in Table 3. For 150-ns bunch spacing, operation with 368 bunches, as listed in the table, was proven in 2010; it is expected that one should be able to go to 424 bunches.

Table 2: 2011 beam parameters at the exit of the SPS [32].

beam parameters	150 ns	75 ns	50 ns
bunch intensity [1e11 p/b]	1.2	1.2 (1-batch) 1.2 (2-batch) tbc	1.2 (1-b) 1.6 (1-b) 1.2 (2-b)
norm. emittance [μm]	2 (1.6 achieved)	2 ~1 to 1.5 tbc	2 3.5 ~1.5

Table 3: Beam parameters in the LHC assumed for 2011 luminosity estimates [32].

beam parameters	150 ns	75 ns	50 ns
bunch intensity [1e11 p/b]	1.2	1.2	1.2
normalized emittance [μm]	2.5	2.5	2.5
colliding bunches	368	936	1404

The **baseline luminosity goals for 2011 remain 2×10^{32} cm^{-2}s^{-1} (peak) and 1 fb^{-1} (integrated)**. But viewing the progress in 2010, there is some confidence to do better. Table 4 presents estimates of peak and integrated luminosity for different running scenarios with a bunch spacing of 150, 75 and 50 ns. According to this table, an **integrated 2011 luminosity of 2-3 fb^{-1} appears within reach**.

Table 4: Luminosity estimates for 2011, considering different operational scenarios and β^*=1.5 m [32].

days	H.F	Comm with	Fills with	kb	Nb e11	ε μm	ξ/IP	L Hz/cm^2	Stored energy MJ	L Int fb^{-1} 4 TeV	L Int fb^{-1} 3.5 TeV
160	0.3	150 ns	150 ns	368	1.2	2.5	0.006	~5.2e32	~30	~2.1	~1.9
135	**0.2**	**75 ns**	**75 ns**	**936**	**1.2**	**2.5** **2** **1.8**	**0.006** **0.007** **0.008**	**~1.3e33** **~1.6e33** **~1.8e33**	**~75**	**~3** **~3.8** **~4.2**	**~2.7** **~3.3** **~3.7**
125	0.15	50 ns	50 ns	1404	1.2	2.5	0.006	~2e33	~110	~3.2	~2.8

Also for lead-lead collisions a substantial factor in luminosity gain is possible for 2011. Options for ion filling etc. will be clarified during the injector commissioning. The experiments are flexible.

The **year 2012** appears to be a g**ood opportunity for *p*-Pb collisions**, at an ideal centre-of-mass energy [34]. Otherwise it might be a long time before such collisions could take place. In addition, a feasibility test MD for *p*-Pb operation can be tried in 2011.

There is a request from ALICE to operate with the lead-ion design parameters already in 2011. More work on ion preparation will be needed in the first half of this year.

Comments and discussion on 2011 running:

The physics output before the end of 2012 should be optimized [35]. Intermediate physics targets were connected to summer physics conferences. In particular, the 2011 plan should aim at delivering physics output for the summer physics conferences of 2011. In view of this goal, the intermediate energy run at 1.38 TeV proton beam energy, presently foreseen for early 2011 [33], could perhaps be pushed to a later time [35]. However, ALICE has pointed out that this intermediate energy *pp* run is not meant for calibration purposes, but indeed important for physics. The run is presently scheduled so as to gather results in time for the Quark Matter Conference in May 2011. The main target is to provide a show case. About one third of the May-conference results depend on these results. According to information received by the accelerator team the intermediate-energy run is needed before May [36].

Contrary to the LHC plan for 2011, with 124 days of high-intensity physics planned, the Tevatron achieves about 260 days of physics per year. The LHC is a 21st millennium machine; why then might it run so few days for physics [37]? There are several answers to this question. First, the LHC has to serve four experiments with very different requests [38]. Second, the ratio of physics to non-physics days has also been quite different in the early year(s) of Tevatron operation [39]. The LHC is a new machine. Third, the LHC machine should be run in very well and at fastest possible speed, but at the same time machine protection should remain the highest priority [39].

The 2010 year of LHC commissioning was excellent and it provides a solid basis for 2011 and 2012 [39].

The CERN Directorate will carefully consider all Chamonix’2010 proposals, in particular those which did not find unanimous support [39].

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