CHAMONIX'12 SUMMARY: PROPOSALS FOR DECISIONS

S. Myers (Chair), F. Zimmermann (Scientific secretary)

CERN, Geneva, Switzerland

Abstract

The summary session of the LHC Performance Workshop in Chamonix, 6-10 February 2012, synthesized one week of presentations and intense discussions on the near-, medium- and long-term strategy for the LHC and LHC upgrades. In particular, Chamonix'12 discussed the lessons from 2011, the strategy, beam energy and beam parameters for 2012, the planning for the Long Shutdown no. 1 (LS1), the measures and schemes for improving or maintaining the machine availability at higher beam energy, the injector performance and injector upgrade schedule, the HL-LHC project as well as possible additional or future LHC upgrades like LHeC and HE-LHC. Key workshop themes included the risk associated with 4 TeV beam energy in 2012, the beam energy after LS1, the turnaround time, the physics goal and optimized running schedule for 2012, the achievements and plans for *Pb-Pb* and *p-Pb* collisions, beam-beam effects, electron-cloud phenomena and UFOs.

We report the proposals for decisions which have emerged at the Chamonix'12 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 and advice from the CERN Machine Committee before making its final decisions.

The 2012 LHC Performance Workshop was organized in nine sessions, covering the lessons from 2011 (chaired by M. Lamont & C. Bracco), LHC machine studies (R. Assmann & G. Papotti), the strategy for 2012 in two parts (chaired by J. Wenninger & R. Tomas, and O. Brüning & L. Ponce), the planning, activities and schedule for the first long shutdown LS1 in two parts (F. Bordry and K. Foraz), the beam operation after LS1 (R. Schmidt & M. Pojer), and LHC related projects and studies in two parts (R. Garoby & L. Ponce and L. Rossi & R. De Maria).

These nine sessions were followed by an overall synthesis of the Chamonix workshop in the form of proposals for decisions. These latter proposals are summarized in this report.

The members of the CERN Machine Advisory Committee (CMAC) participated in the Chamonix workshop and held several separate executive meetings including during the weekend after the workshop.

Decisions on the LHC strategy have been taken by the CERN management after hearing the recommendations of Chamonix and of the CMAC.

POINTS AWAITING DECISION

Major decisions were needed on:

- safe beam energy for 2012;
- priorities for the 2012 run,
  - *p-p,*
  - *p*-ion,
  - machine studies;
- date of start of LS1;
- "ready for beam" date after LS1 (CMS only ready on 1 September 2014);
- high energy and luminosity after LS1.

SAFE BEAM ENERGY FOR 2012

A beam energy of 3.5 TeV as in 2011 entails lower risk, lower integrated luminosity and a lower Higgs-production cross section. Conversely, a beam energy of 4 TeV means higher risk (by a factor of 5), higher integrated luminosity (about 15%), and a higher Higgs cross section (about 30%), and it also allows for a slightly lower β^*.

The maximum safe beam energy had been discussed at the previous Chamonix workshop in 2011, based on Fig. 1, where the different lines refer to the two different beam energies and two different energy extraction time constants as indicated. The extraction time constant in 2011 and 2012 is 50 s (the two lower curves). It had been concluded that going from 3.5 TeV to 4 TeV (at 50 s) implied a significant increase in the risk of burning an interconnect.

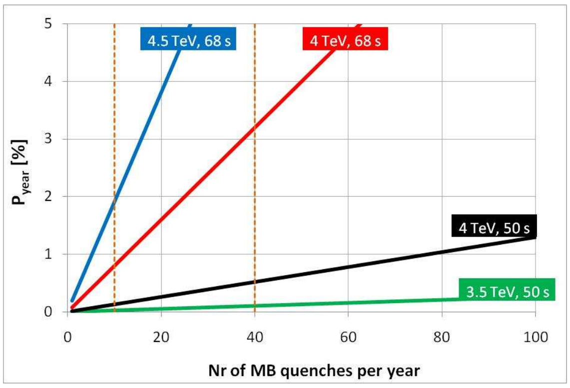

Figure 1: Probability per year of burning an interconnect versus the number of MP dipole quenches per year, as presented at Chamonix 2011 [1].

The proposal – later accepted – from Chamonix 2011 had been to stay at 3.5 TeV for 2011. In addition it had been decided that one should operate in 2011 with the "snubber" capacitors installed so as to further reduce the possible number of quenches. A "thermal amplifier" method (also known as the "copper stabilizer continuity measurement" - CSCM) was to be developed during 2011 in order to enable investigations during the Christmas shutdown 2011 for arriving at a deterministic decision on a possible energy increase for 2012.

At this Chamonix 2012 workshop an update on the burn-out probability was presented; see Fig. 2. The probability appears essentially unchanged, even slightly worse, since an additional resistance in the by-pass diode stacks (discovered during the 2011 run) has now been taken into account (the dotted black curve).

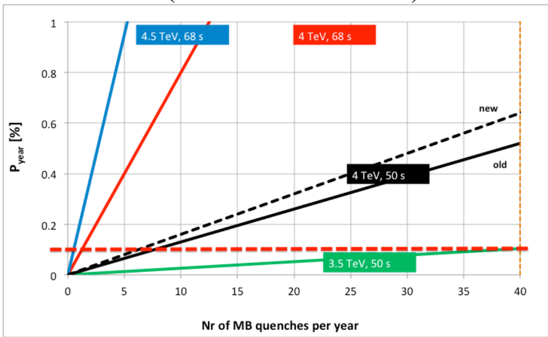

Figure 2: Probability per year of burning an interconnect versus the number of MP dipole quenches per year, as presented at Chamonix 2012 [2].

However, important other **new information and measurements from 2011** include:

- Copper-stabilizer continuity measurements during the 2011 Christmas shutdown had to be excluded for time and risk reasons.
- Multiple quenches due to electromagnetic coupling were greatly reduced [3] by a suite of measures:
  - **snubber resistors** (were) very effective in 2011;
  - modification of the power-converter passive filters;
  - modification of the energy extraction.
- Results of copper-stabilizer **RRR measurements** add margin (RRR=100 is assumed, while measured values are in the range 200-300).
- **Balance of anomalous resistances** also adds margin, namely the assumption made that all the measured excess resistance is concentrated at a single splice represents the most pessimistic case, and the anomalous resistance of the diode contacts has been localized near the heat sinks.
- **There has not been a single beam induced quench with circulating beams in 2011**.

A total **power cut** which occurred on 18 August 2011 **on the ramp near maximum current** did not result in a single quench, providing strong confirmation that the modified systems are working extremely well and that electromagnetic coupling is no longer a serious concern.

The risk factor equals the product of probability and impact. From the above new information, the **probability of a splice burn out at 4 TeV/beam in 2012 is inferred to be equal to, or less than, the probability which had been estimated in 2011 for 3.5 TeV/beam.** In addition, following the improvements made in 2009 the impact of any burnout would now also be less than in 2008 by about a factor of two.

In view of all the above arguments, the **proposal** is to **operate the LHC at 4 TeV/beam in 2012.**

2012 PRIORITIES

As a top priority the LHC machine must produce enough integrated luminosity to **allow the ATLAS and CMS experiments an independent discovery of the Higgs before the start of LS1**. Secondly, the **proton-lead ion run** at the end of the year must also be prepared. Finally, the necessary **machine experiments** must be scheduled (in 2012) to allow high energy, useful high luminosity, 25-ns running after LS1.

Figure 3 recalls the Chamonix'11 picture describing the effect of higher beam energy on the Higgs production rate. In the year 2011 about 5/fb were delivered to ATLAS and CMS, resulting in a signal of 2.5 sigma or higher. In 2012 at the same beam energy of 3.5 TeV three times more integrated luminosity, or 15/fb, would be needed to go up to 5 sigma (assuming that the signal strength stays as it was in 2011). At 4 TeV the needed luminosity decreases to only about 11.5/fb by virtue of the higher cross section. Adding 15% for pile-up effects and margin (e.g. for higher background) yields an **estimate for the required luminosity of about 13.3/fb**. Table 1 summarizes the scaling arguments leading to this estimate of the amount of integrated luminosity needed for a 5σ Higgs discovery. The **ATLAS and CMS experiments** have already announced that they would like to have MORE luminosity in 2012, namely **20/fb**.

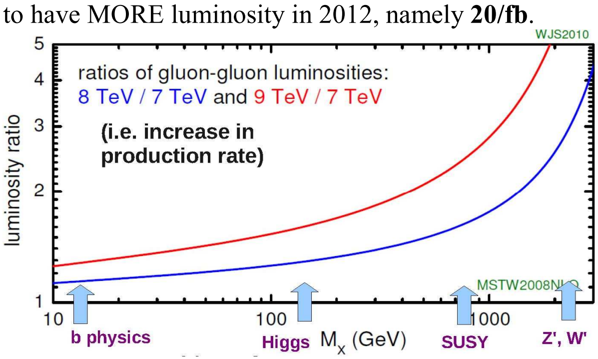

Figure 3: Effect of increasing the beam energy expressed as relative increase in production rate of various particles (James Stirling) [4,5].

Table 1: Estimated integrated luminosity needed for the discovery of the Higgs particle.

year	fb^{-1}	signal (in σ)	beam energy [TeV]	
2011	5	2.5	3.5	delivered
2012	15	5	3.5	needed
2012	11.5	5	4.0	needed
2012	13.3	5	4.0	additional 15% for pile up and background

Figure 4 illustrates a **luminosity evolution forecast for 2012**, which suggests that 13.3/fb would be reached around September 2012. The analysis leading to Fig. 4

assumes the same machine and beam availability as in 2011. However, as discussed in numerous presentations during Chamonix'12, the **performance in 2012** is **likely to be bigger than the forecast** due to:

- many improvements for faster turnaround;
- numerous improvements in procedures (loss maps, orbit and tune feedback,…);
- several significant improvements in beam instrumentation;
- R2E mitigation measures (resulting in fewer radiation-induced beam dumps);
- abort gap cleaning;
- improvement of beam transfer lines stability;
- measured large IR aperture allowing a lower **β* of 0.6 m** (while Fig. 4 assumes 0.7 m), and
- an expected reduction in magnet powering faults of 30%.

It, therefore, appears reasonable to expect that the estimated luminosity evolution of Fig. 4 is fairly conservative.

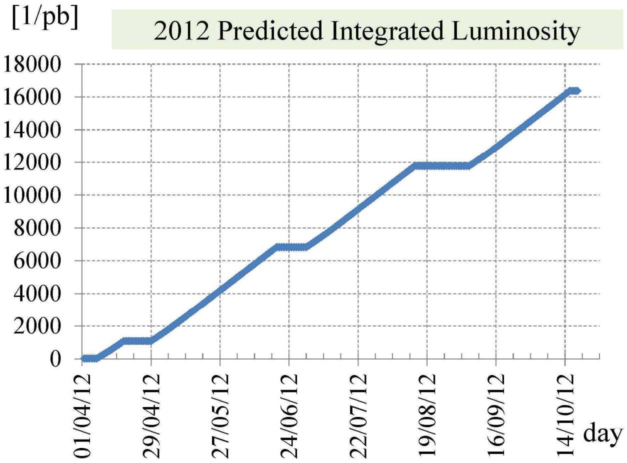

Figure 4: Predicted evolution of integrated luminosity versus calendar day during 2012 for 4 TeV beam energy, 50-ns bunch spacing, β*=0.7 m, and 148 days of physics [6].

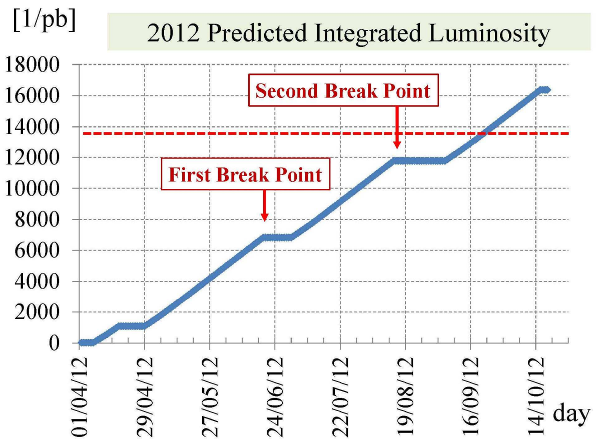

Figure 5: Predicted evolution of 2012 LHC integrated luminosity versus calendar day as in Fig. 4, highlighting two breakpoints for possible corrective actions.

Nevertheless **two breakpoints** are envisaged, as indicated in Fig. 5, at which it will be checked if the LHC is on track to produce sufficient integrated luminosity for the Higgs discovery. The first breakpoint, in June 2011, should be before the ICHEP conference. There should have been 6-7/fb accumulated by then. The second – less critical – breakpoint will be in August 2012.

If needed to complete the Higgs discovery the start of LS1 could be delayed by up to 2 months (thanks to CMS) without any significant impact on the end date of Long Shutdown 1 (LS1).

The path to high luminosity includes **smaller β*** (as already mentioned values down to 0.6 m seem possible) **and tighter collimation** settings. The key question here is whether one should take a conservative path (changing the parameters adiabatically) or rather "go for bust" by starting with a low value of β*. A **pertinent proposal** was requested **from the operations group**. Following the Chamonix'12 workshop, such proposal was presented and **at the LHC Machine Committee** meeting on 22 February 2012 "**it was decided** that the machine will **start up with tight collimator settings**, that the squeeze will be prepared for both 70 and 60 cm, and that the **machine will be commissioned to 60 cm β***. It was also agreed that the choice of 70 or 60 cm β* for the intensity ramp-up will be made when more information is available from the initial commissioning phase" [7].

The second priority is preparing for the LHC proton ion run scheduled towards the end of 2012 [8].

Also, other necessary machine experiments must be performed during 2012.

Comments and discussion on the 2012 priorities:

If there is no Higgs LHC could run forever trying to discover the Higgs in vain, unless the objective "or exclude the Higgs" is added [9].

Going **from 3.5 TeV to 4 TeV** indeed there is a 30% gain in the Higgs cross section, but the background also increases. The **actual increase in relevant physics cross section (signal to noise) is about 20%** [10]. On the more positive side the **analysis of the experiments will also improve**. The 2.5 sigma signal is a conservative result (based on only 2 channels). The signal should be higher than this after including all the recorded luminosity for all channels [11].

LS1

The LS1 planning [12] is in excellent shape. **CMS will be "ready for beam" in September 2014** (two months later than originally planned). The **start of LS1 might be affected by the LHC luminosity progress and by the strength of the Higgs signal in the fall of 2012.**

ENERGY & LUMINOSITY AFTER LS1

After LS1 the LHC needs to quickly get back into operation with high energy and high luminosity. For this period there are some **potential issues** related to (1)

magnet re-training [13], (2) **UFO induced quenches** [14], and (3) **25-ns operation** (e.g. [15]).

Concerning the **beam energy after LS1**: a strong recommendation is issued, namely not to go for 7 TeV/beam due to the risk associated with the expected number of many hundreds (or thousand) of training quenches, and to stick to an energy **around 6.5 TeV**, which is considered to be safer and sufficient.

As for **UFOs** and UFO-related losses, the estimated number of arc-UFO induced beam dumps per year (extrapolated from 2011 data) is 108 at 50 ns and many more with 25 ns bunch spacing. In response to this potential threat, a **high priority should be assigned to studies related to UFOs and quench levels**.

SUMMARY OF PROPOSALS

The safe beam energy for 2014 is proposed to be 4 TeV. The **priorities for the 2012 run** are:

- proton-proton run (integrated luminosity) with Higgs discovery or exclusion;
- proton-ion run; and
- machine studies and **tests related to UFOs and quench levels**; a **detailed proposal** should come **from the Machine Protection team**.

The **date of the start of LS1** will be **reviewed at the luminosity breakpoints.**

The **"ready for beam" date after LS1** is 1 September 2014, determined by CMS.

After LS1 the beam energy will be around 6.5 TeV/beam to limit the number of re-training quenches.

Many other **Chamonix'12 topics** will be **followed up at** the weekly meetings of the **LHC Machine Committee**.

Comments and discussion on all proposals:

Concerning **UFOs** T. Baer had made a proposal how to proceed [16]. It is difficult to perform dedicated UFO MDs except for the MKIs [16]. Key uncertainties are the quench level and the shower generated by the UFOs. One proposal is to **increase the BLM dump threshold in four "good" sectors by a factor 3**, in order to observe if under these conditions there are any UFOs that dump the beam. It is somewhat uncertain if a UFO could indeed quench a magnet [17] though a quench test with a wire scanner did lead to a magnet quench. The estimated quench level had been lowered as a result of this wire scanner quench test [18]. In any case the proposed test would allow seeing how high the UFO-induced BLM readings could go without any quench. On the other hand, if the UFOs started to quench magnets the BLM threshold could be decreased again.

MDs of this type could be scheduled at the end of the year, after the Higgs discovery [19]. These MDs also need to be discussed with the management beforehand [20]. Actually, these are not true MDs, but rather a (semi-) permanent change of the BLM configuration [21].

Some information will be obtained for free by comparing the UFO rate scaled from the 2011 observations with the actually observed rates in 2012 [22]. Several MDs on quench margins have already been performed, in many cases demonstrating that one had to increase the thresholds in order to quench [23]. It is however very difficult to conclude on the quench margins at 6.5 TeV [24]. One should make sure that all machine time is spent wisely. The proposal remains to raise the threshold in safe sectors and to monitor if as a result any additional quenches occur.

The **MD time for quench-margin tests** could be scheduled at the end of the year, after the ion run, in order to make discussions with management easier [25]. There had been a concern about the orbits for protons and ions [26] – in this context, is it sure that one can come back to **many proton bunches after the ion run?**

Other priorities for the MDs relate to the goal to operate with **25-ns bunch spacing** after LS1, which implies assigning priorities to 25-ns beam tests [24]. These indeed are part of the baseline MD plan. Only additional MD items, which have not yet been part of the baseline, had been highlighted above [28]. It was remarked that it would still be nice to make 25-ns studies appear in the workshop summary [29], as is now done in this report.

Delaying the start of LS1 by 2 months would not be easy [30]. If it is likely that the end of the 2012 LHC run is later than foreseen perhaps two months could be added to the schedule as of now [31]. This would eliminate any margin from LS1 [32]. However, announcing a delay by two months in September would be much more difficult [33]. The **decisive breakpoint is in June 2012**. At that time one could revise the time estimates [34] and check for any brick wall. The schedule will be physics driven, not MD driven.

The important quantity this year is not the luminosity per se, but the ***integrated useful luminosity***. Optimizing the latter requires a lot of flexibility from both experiments and machine. Nothing should be cast in stone now, but conditions will be optimized during the run [35]. This statement from ATLAS was supported by CMS [36].

An open question related to **25 ns** is: when do we decide about the scrubbing run and its length? Should it be 3 days or 2 weeks long? Clearly scrubbing is a "must" for doing meaningful 25-ns studies afterwards [37]. The scrubbing recovery after a Christmas stop also needs to be understood, as well as the continued evolution of the secondary emission yield versus time [38]. Despite the importance it appears difficult to delay physics while LHC does scrubbing [39]. There was an obvious need to decide how and when to do the scrubbing; but this would not be before ICHEP. If a lot of luminosity would have been accumulated at the breakpoint one could schedule the scrubbing run. More generally, the breakpoints would be used to discuss MDs. Discussions on possible 25-ns studies and on schedule flexibility have to be included in the first breakpoint. Pertinent proposals are encouraged for how these issues should be approached.

It had been slightly disappointing to notice that there has been no discussion on the *p-Pb* run, For example, discussion is needed on how to choose between 3.5 TeV and 4 TeV *p* energy for the *p-Pb* run [40].

Studies on **luminosity levelling** can be performed parasitically, during the intensity ramp up. Unless LHC performance improves much more than expected, in 2012 luminosity levelling will not be needed for the high luminosity experiments [41].

The "breakpoint" for LHeC upgrade decision (ring or linac) would be the next Chamonix workshop in early 2013 [41]. Proton-antiproton collisions could be an alternative option for HE-LHC. These would allow a big gain in the cost of dipoles at the expense of the challenge of pbar production [42,43].

Very optimistic numbers for the luminosity expected after LS1 and before LS2 may confuse the community in terms of the upgrade [44]. It was noted that the forecast for 6.5 TeV with 25 ns spacing is a peak luminosity of 7.5×10^{33} $cm^{-2}s^{-1}$ with an average peak pile-up of $\mu \sim 17$ [45], though there are other possibilities [46]. A reasonable minimum luminosity has been promised.

At the end of the discussion the CERN DG, Prof. R. Heuer, added a few words [47]: It is necessary in 2012 to deliver substantial integrated luminosity; the decisive breakpoint would be before the summer conferences; at that time one could better judge the date for the beginning of the shutdown, and for the MDs, without hurting the *p-Pb* physics. What LHC will do this year is not only important for CERN, but for particle physics across the globe. Care is needed when deciding which way to go, as the LHC will establish the important direction for particle physics in general.

At the beginning of this summary session, Michel Spiro, the President of the CERN Council, had made a couple of remarks [48]: He had greatly appreciated the open discussions and the atmosphere at the Chamonix workshop, as well as the important results. Most importantly, he stressed that 2012 will be a historical year for CERN and for all of particle physics. As a new practice, in December 2011 and also in 2012, at the year's last session of Council, one has shared, and will share and celebrate, the LHC achievements, which have become possible thanks to the great solidarity between governments, users, and the CERN staff.

In his written message to the Council delegates about the outcome of the LHC Chamonix'12 meeting, sent soon after the workshop, Michel Spiro stressed both similar and also additional points [49]:

"The Director-General, the Chairman of the SPC and I attended part of the workshop and were very impressed by the motivation, the dynamism and the creativity of the participants. Discussions took place on the short-term (2012), medium-term (repair and re-commissioning) and long-term (upgrades) planning for the LHC. The messages were the following:

- After a brilliant year in 2011, 2012 should be historic, with either the discovery of the Standard Model Higgs boson or its exclusion.

- The first long shutdown period, from the end of 2012 until late 2014, will be challenging, with multiple activities running in parallel and many requests already saturating the realistic possibilities. Global planning is in good shape and a detailed schedule is being implemented. Priorities will have to be set by the management, with constant input from the accelerators and the experiments (to approach the nominal energy of 7 TeV; to prepare for reliable operations; to accomplish CERN approved projects; and, to leave room for bright initiatives).

- Finally, the long-term upgrades of the LHC, studied in Chamonix, will be a very important topic of the European Strategy update, the outcome of which should help in decision-taking after its conclusion in 2013, although some iteration with Council delegates should start now."

ACKNOWLEDGEMENTS

Special thanks go to Tjitske Kehrer for a superb organization of the Chamonix workshop (as usual), to Pierre Charrue and the CERN micro club for technical assistance and desk-top support, to the CERN DG and the CERN Directorate (excluding the author), to the President of Council (Michel Spiro, attending the workshop), to the members of the CERN Machine Advisory Committee (participating in the workshop and finishing the CMAC report on Sunday night), to the Session Chairs and Scientific Secretaries, to the Speakers, and, most importantly, to all the participants for the many lively and animated discussions.

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