

# REVIEW OF LHC AND INJECTOR UPGRADE PLANS - SUMMARY

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

CERN, Geneva, Switzerland

## Abstract

From 29 to 31 October 2013 the Review of the LHC and Injector Upgrade Plans (RLIUP) took place in Archamps (Haute Savoie). This paper summarizes the RLIUP conclusions, which were presented at CERN on 8 November 2013.

## HISTORY & MOTIVATION

The LHC schedule for the next ten years considered prior to the RLIUP workshop had been proposed at a time when much less information had been available and it had not been developed in any self-consistent (iterative) way.

The typical machine performance of a high-energy collider is such that in the early years of operation, spectacular performance increases can be attained by pushing the accelerator physics limitations (intensity, beta\*, emittance ...). After some years of operation, these possibilities become exhausted. Slower performance increases then come about through upgrades and through small (%) improvements on a multitude of fronts including machine availability etc. LHC is entering this new phase, i.e. upgrades and small improvements on many fronts. Both of these need careful planning.

## MAXIMUM PERFORMANCE GOAL

The overriding performance goal for the 10-20 year schedule is to maximize the LHC performance in terms of useful integrated luminosity. The *peak luminosity* of the LHC is limited by pile up in the detectors and by the accelerator performance. The *useful integrated luminosity* (for the 4 detectors) is determined by the time available for physics (iterative with shutdowns) – implying a play-off between the upgrades and the time lost for physics (see Fig. 1 for an educating example) – and, especially, by the *timing of the upgrades* (the sooner the better).

During discussion with the CMAC (whose members participated in the RLIUP review) also the possibility of a future increase of the *beam energy* has been raised.

## SHUTDOWNS – WHEN & HOW LONG?

The *factors for planning the timing* (start) of the shutdowns are:

- the technical lead-time needed (for the experiments and for the machine);
- the funding profiles (mostly for the experiments);
- the radiation damage effects for the experiments and for the machine, which limit the maximum

integrated-luminosity values prior to certain upgrade steps and thereby define date limits; and

- the need for regular preventative maintenance (mostly of the machine, e.g. for cryogenics).

The *factors driving the duration* of the shutdowns are:

- the amount of work to be done (both on the machine and on the experiments);
- the manpower resources needed (and co-habitation);
- the environment (induced *radiation*) with related specific manpower limitations; and
- the efficiency of the work execution (access times etc.).

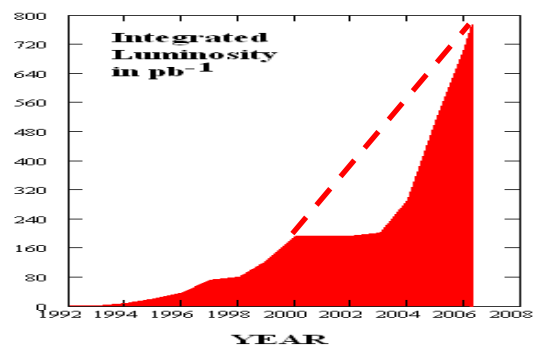


Figure 1: Integrated luminosity evolution of HERA before and after its luminosity upgrade together with an extrapolation (dashed line) how the luminosity would have developed without the upgrade.

## STRUCTURE OF THE REVIEW

At RLIUP five different scenarios have been considered for a comparison of performance and cost. Each scenario encompasses all accelerators in the LHC chain.

For each scenario the tasks have been

- to identify the technical requirements (work needed and shutdowns); and
- to evaluate the peak and integrated yearly luminosities (time available for physics).

We note that in the preparation for the review, these scenarios were meant for *comparison*. Later, it became apparent that they could be better used for the evaluation of the *evolution of the performance with time* over the long time scale examined.

## REVIEW OBJECTIVES

The goal of the review was to assess the *critical* criteria for the evaluation of the long term performance of the LHC, including:

- radiation *limits for the detectors* ( $\text{fb}^{-1}$ ) constraining the start of LS3;
- the radiation *limit for the inner triplets* etc. also defining a latest possible starting date for LS3;
- the *peak luminosity*, including related issues like pile up, operation with 25-ns bunch spacing, brightness from injectors, UFOs, beam heating, instabilities; and
- the machine availability.

## INPUT ON RUNS AND SHUTDOWNS

The runs and shutdowns required by the different experiments and machine teams compiled by M. Lamont are summarized in Table 1. The overriding requirements are highlighted by the red boxes.

Table 1: Required runs and shutdowns per experiment or machine activity [1] (courtesy M. Lamont).

	Run 2	EYETS	LS2	Run 3	LS3
ALICE		Contingency	18 months Shift into 2018		
ATLAS	3 years	No	14 months Start 2018		27 (35) months Start 2022
CMS	EYETS plus N months	5 months	14 – 18 months Not before summer		30 – 35 months Start 2023
LHCb		Contingency	18 months End 2018		
Cryo	4 years max.	Selective maintenance			
Maintenance		Selective maintenance	16 mo.		20 months
LIU		9.5 months for L4 connect/or cable prep.	20.5 months beam to pilot		
LHC	3 years max contiguous	Opens way for year 4	18 mo.	3 years	2 years

## ANSWERS TO IMPORTANT QUESTIONS

The RLIUP workshop provided the following answers to some important questions:

- the *radiation limit* for detectors [2] and machine [3] is 300–500  $\text{fb}^{-1}$  (where the machine possibly is more critical);
- LS2 needs ~18-24 months;
- LS3 needs ~24-36 months; and
- Run2 should last for 3 years.

## LUMINOSITY

The overriding limitation to integrated luminosity is due to event pile-up (PU). The presently proposed upgrade to the detectors foresees an increase to 140 PU (average) with a possible extension to around 200.

Several new schemes have been proposed on the machine side in order to alleviate the PU problem by *reducing the “pile-up density”*. These schemes will be further investigated and tested as soon as possible.

Together machine and detectors should continue to explore new possibilities to allow *even higher PU* than the 140 (200) presently foreseen.

## MACHINE AVAILABILITY & TURN AROUND

The limitation (from the pile up constraints) is one on the *peak luminosity*. Therefore, one should *optimise the time available for physics* by

- *minimising the down time* due to faults, through a more *in-depth analysis of down-time periods and “amplification factor”* and through a *prioritized* (by risk analysis) *mitigation* of the most critical faults by consolidation; and
- *faster turnaround* “physics to physics” through technical *upgrades* to the LHC equipment (e.g. modification of power converters to allow faster ramp down of magnets), and through more *streamlined operational procedures* (e.g. combined ramp and squeeze).

## “TO DO” LIST

At RLIUP the following actions were determined:

Concerning *resources*, a global (i.e. comprising machine, detectors and services) **resources-loaded schedule** is needed as soon as possible. This schedule can then be used to identify and correct weaknesses in some areas of expertise (e.g. cabling...)

In view of the *ALARA* principle, radiation must be optimized by design (minimum access time needed for exchanges and use of the right materials “ActiWiz” [4]).

*Electron-cloud effects* could hinder operation with 25-ns bunch spacing [5]. Both short term mitigation (new scrubbing schemes, alternative intermediate filling schemes such as “8b+4e”) and long term solutions must be sought. This issue is so critical that even very costly new technical schemes should not be excluded such as partial or full coating of chambers, clearing electrodes, etc.

## IMPORTANT COMMENTS

The European Strategy stipulates that “*Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times*

more data than in the initial design, by around 2030” [6].

“The STRONG physics case for the HL-LHC with 3000 fb<sup>-1</sup> comes from the imperative necessity of exploring this scale as much as we can with the highest-energy facility we have today (note: **no other planned machine, except a 100 TeV pp collider, has a similar direct discovery potential**). ...

We have NO evidence of new physics, which implies that, if New Physics exists at the TeV scale and is discovered at  $\sqrt{s} \sim 14$  TeV in 2015++, its spectrum is quite heavy; it will require a lot of luminosity (HL-LHC 3000 fb<sup>-1</sup>) and energy to study it in detail, with important implications for future machines (e.g. most likely not accessible at a 0.5 TeV LC).

**HL-LHC is a Higgs Factory.** It can measure the Higgs coupling with an accuracy of a few %.” [7].

## STRATEGY

LHC has been constructed, operated and will continue to be operated on a CONSTANT BUDGET. The HEP community owns a beautiful scientific facility, unique in the world. It has invested (and is investing) a huge amount of its resources in this unique facility both for construction and for operation.

The FULL operational costs integrated over the future operating years exceed the proposed upgrade costs. **Hence this unique facility should be operated in the most efficient way possible.** This means:

- (1) both upgrades, *LIU* and *HL-LHC*, should *aim for the maximum useful integrated luminosity possible*;
- (2) *LS3* should come as soon as possible in order to maximize the integrated luminosity (every delay by one year of LS3 “costs” 200fb<sup>-1</sup>); and
- (3) LS2 should not delay LS3.

The ultimate goal of 3000 fb<sup>-1</sup> by ~2035 is *challenging* but attainable.

## SHUTDOWN SCENARIOS

Table 2 presents five plausible shutdown scenarios. In Scenario 1 (S1) LS2 (2018) lasts for 1.5 years, and LS3 (2022) for 2 years. S2 equals S1 delayed by 1 year; and S3 is the same as S2, but delayed by 1 year, [or as S1 delayed by 2 years]. In Scenario 4 (S4), LS2 (2018) lasts for 2 years, and LS3 for 3 years. S5 equals S4 delayed by 1 year. Figure 2 compares the predicted time evolution of the integrated luminosity for these various scenarios. For example, the accumulated luminosities at the time of LS3 are 280, 330, 380, 280, and 330 for Scenarios 1 to 5, respectively. It should be noted that the total luminosity numbers given for these five scenarios are meant to allow relative comparisons, but do not represent absolute luminosity forecasts.

## TO BE DONE WITH SOME URGENCY

Actions soon to be done include:

- decision on the shutdown scenario (management of CERN and of the detectors);
- implementation of a *new plan*, entailing a *global resources-loaded schedule* for accelerators and experiments, taking into account *limitations imposed on personnel by radiation* and providing *improved access to the tunnel*; and
- submission and collection of *requests*, to identify and strengthen weak areas of expertise.

Table 2: Five shutdown scenarios. The numbers indicate the expected integrated luminosity per year. The bottom column shows the total integrated luminosity.

	LS2=1.5y, LS3=2y			LS2=2.0y, LS3=3y	
Year	S1	S2	S3	S4	S5
2015	35	35	35	35	35
2016	50	50	50	50	50
2017	50	50	50	50	50
2018		50	50		50
2019	25		50		
2020	60	25		25	
2021	60	60	25	60	25
2022		60	60	60	60
2023			60		60
2024	150				
2025	250	150			
2026	250	250	150	150	
2027		250	250	250	150
2028	200		250	250	250
2029	250	200			250
2030	250	250	200	200	
2031		250	250	250	200
2032	200		250	250	250
2033	250	200			250
2034	250	250	200	200	
2035	250	250	250	250	200
Total	2580	2380	2180	2080	1880

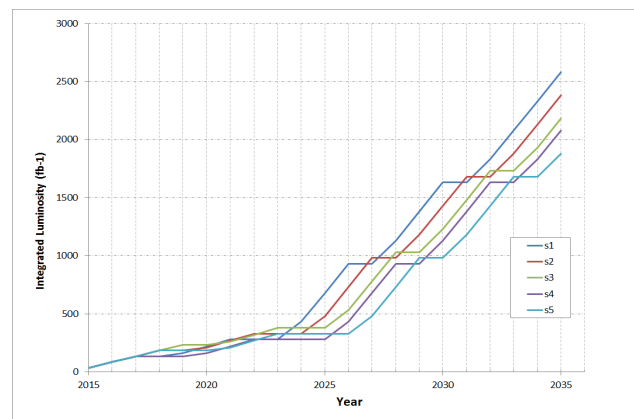


Figure 2: Predicted integrated luminosity evolution for the five shutdown scenarios of Table 2.

## SUMMARY

The LHC/HL-LHC *performance* will be determined by pile-up and pile-up density (detectors and machine); by 25-ns: e-cloud, scrubbing, short term mitigation, long term solution; and by machine availability calling for a *minimisation of down time and speeding up of the turn-around time*.

*Shutdowns* have to be planned well in advance, including a global *resources-loaded schedule*, the identification and rectification of *weaknesses in some expertise areas*, and a design for ALARA with minimum intervention time and use of the correct materials (ActiWiz).

An *increase of the maximum beam energy* in the medium term should be investigated, noting the planned use of 11T magnets for collimation.

## REFERENCES

- [1] M. Lamont, "Post LS1 Schedule," Proc. 2013 RLIUP workshop (2013).
- [2] B. Di Girolamo, "Detector Limits," Proc. 2013 RLIUP workshop (2013).
- [3] L. Bottura, "What could stop us, when and how long?," Proc. 2013 RLIUP workshop (2013).
- [4] H. Vincke, C. Theis, "ActiWiz – optimizing your nuclide inventory at proton accelerators with a computer code," NBI Workshop 2012
- [5] J. Wenninger, "Integrated performance of the LHC at 25 ns without and with LINAC4," Proc. 2013 RLIUP workshop (2013).
- [6] A. Ball, "Highlights from EFCA HL-LHC experiments workshop: 1-3 October 2013," Proc. 2013 RLIUP workshop (2013).
- [7] F. Gianotti, "The Physics Landscape," Proc. 2013 RLIUP workshop (2013).