POST LS1 SCHEDULE

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Abstract

The scheduling limits for a typical long year taking into account technical stops, machine development, special physics runs are presented. An attempt is then made to outline a ten year post LS1 schedule taking into account the disparate requirements outlined in the previous talks in this session. The demands on the planned long shutdowns and the impact of these demands on their proposed length will be discussed. The option of using ion running as a pre-shutdown cool-down period will be addressed.

INTRODUCTION

The next 10 years or so will see the exploitation of the LHC at energies at, and above, 6.5 TeV. In parallel there will be preparation for the High Luminosity LHC (HL-LHC). The various demands on CERN's medium term and long term operations schedule are considered below. Open issues include the following.

- LHC Machine
  - For what length of contiguous time can the LHC operate for? Here one worries about cryogenics and maintenance of key technical infrastructure.
  - How long can the operations group and hardware support teams run for without impacting efficiency?
  - What are the requirements of the ion program in both the North Area and the LHC?
- Injectors
  - Are the risks of running with Linac2 until 2018/2019 acceptable?
  - What are the optimum timing of, and time required for, the Linac4 connection and another LIU upgrades?
- Experiments
  - Finalization the schedule for phase 1 of the detector upgrade program.
  - The need for an extended year end technical stop around 2017.
  - Developments and plans for phase 2 of the upgrade program.

Also to be taken into account in the longer-term strategy are: accelerator technology development time; detector technology development time; and funding profiles for the phase 2 upgrades. The corresponding implications of these issues for the schedule are necessary vague but indications are that there is a need to stretch the present temporal envelopes.

The present baseline schedule foresees:

- a 3 year Run 2 2015 through 2017;
- a 1 year LS2 in 2018;
- a 3 year Run 3 2019 through 2021;
- the start of a 2 year LS3 for HL-LHC upgrade in 2022.

The experiments have tentatively mapped the necessary stages for HL-LHC operation onto this schedule: R&D; engineering design; construction; production; installation and commissioning. These phases have been discussed in detail at a recent ECFA workshop [1]. Clear scheduling tensions exist which will be explored below.

NOMINAL YEAR

The longer term operational model appears to be settling into a series of three to four long years of operation interspersed with long shutdowns of order of a year or more. The long shutdowns are foreseen for essential plant maintenance, experiments' upgrades, injector upgrades (LS2) and LHC upgrades (LS3).

The approximate breakdown of a generic long year is:

- 13 weeks Christmas technical stop including 2 weeks hardware commissioning (this would count 3 weeks at the end of a year and 10 weeks at the start of the following year); Around 10 days are required before the CERN Christmas closure to secure the helium inventory (worth approximately 7 MCHF) and be protected again serious failure with only minimal "on-call" support [2].
- around 160 days of high luminosity proton-proton operation;
- three technical stops of 5 days duration during the year;
- a 4 week ion run;
- and time for special physics runs and machine development.

A more detailed breakdown is shown in table 1.

A longer period for scrubbing will be required after shutdowns during which a significant fraction of the machine will be warmed-up and vented to air.

When considering extended periods of operation it is interesting to consider the operational period 2009 to 2103

- 2009: 23rd November to 16th December
- 2010: 22nd February to 6th December with a special AMS run 4th to 9th February

Table 1: Potential breakdown of a standard HL-LHC year

Activity	Days
Christmas technical stop including HWC	91
Commissioning with beam	21
Machine development	22
Scrubbing	7 (to 14)
Technical stops	15
Technical stop recovery	6
Proton physics running including intensity ramp-up	160
Special physics runs	8
Ion run setup	4
Ion physics run	24
Contingency	7

- 2011: 21st February to 7th December
- 2012: 14th March to 17th December
- 2013: 14th January to 16th February

It should be noted that the injectors started around 2 weeks before these dates to have beam ready for the LHC. This represented an intense and prolonged running period with long operational years and short winter stops and certainly the strains on injectors, hardware, operations and support were at the limit at the end.

RUN 2

Extended Year End Technical Stop (EYETS)

The main motivation for an extended year end technical stop some time in 2017 is for CMS to install its new 4 layer pixel detector which will be ready at the end of 2016. CMS require 19 weeks beam to beam extending the normal winter technical stop by some 6 weeks. Some contingency should be foreseen.

ATLAS have stated that they do not need the EYETS. It is not of any significant benefit to ALICE and LHCb but, as will be discussed below, the extended stop would naturally push back the start of LS2 buying them useful time in their preparations for the planned upgrades in LS2.

During the EYETS cryogenics would plan to keep the magnets cold below 80K to ensure that conditioning is not lost. One could imagine some sectors being kept in nominal conditions for some training quenches in order to probe the requiring training for 7 TeV operation. The stop would also provide the opportunity for selective cryogenics maintenance [2].

Even sandwiching the extended stop between ion runs it would appear to be too short for a possible Linac4 connection. This has been estimated to required around 9.5 months [3]. However, the stop could be used to perform LIU preparation work, in particular cable clean-up in the Booster. This activity is very much on the critical path for the eventual Linac4 connection and the shift to H^- injection in the Booster.

Length of Run 2

The nominal run length is assumed to be 3 years. However, a reasonable question is: "could it be longer?". In the specific case of Run 2 the following options may be considered.

A four year run without an extended stop This is unacceptable for CMS.

A four year run with an extended stop Here we talk about the operation of LHC for 3.5 to 4 years with around 5 months out in the middle. This implies operation of injector complex for 4 to 4.5 years with around 5 months out in the middle. As mentioned above this option has the attraction of buying at least two LHC experiments important contingency in their preparation for major upgrades in LS2.

On the down side it extends the risk of running with Linac2 until 2018/2019.

The machinery and global cryogenics maintenance plan have periodicity of maximum 40,000 hours (5 years at 8'000 hours (or 11 months)) including cool-down, hardware commissioning before beams and warm-up before next long shut-down. This would give 1 year of technical set-up and 4 years of physics. Experience so far shows that some equipment reliability falls before these accumulated hours. Some effort is being brought to bear but limited extension in time can be expected. Bearing in mind that cryogenics starts operation mid 2014 for the cool-down of the LHC, cryogenics would not rule out either a four year run or a four year run with EYETS. The intermediate 5 months extended technical stop would give time to treat most sensitive machines and allow for another 1 or 2 years operations at hopefully something like full reliability [2].

To summarize the options for Run 2 are:

- Baseline: 3 years run 2015 through 2017;
- Slipped baseline plus 6 months: EYETS plus extended run through to the middle of 2018;
- Slipped baseline plus 12 months: EYETS plus extended run through to the end of 2018.

Options that are assumed to be ruled out are: a 4 year run straight through; extending EYETS to 9 months to allow the connection of Linac4.

LONG SHUTDOWN 2 (LS2)

A breakdown of the requirements of the LHC experiments, LHC machine and injectors regarding LS2 is shown below. The clear conclusion is that LS2 will need to be of the order of 18 months.

Experiments

ALICE foresee a major upgrade of their detector for installation in LS2 which they are assuming to be 18 months. They would not violently object if LS2 shifts to 2019 this would provide important contingency.

LHCb requires 18 months for the installation of their upgrade. A later start of LS2 at end 2018 would be advantageous for LHCb for similar reasons to ALICE. Further delay of the start of LS2 beyond 2018 would be disfavoured.

ATLAS are assuming the baseline i.e an LS2 of 14 months starting at the beginning of 2018.

CMS require an LS2 of 14 to 18 months and prefers that it starts towards the end of 2018 ("to collect sufficient data (with the upgraded tracker) LS2 must not start before summer 2018").

There is a concern about potential overheads that might be caused by radiation levels forcing potential constraints such as cool-down time.

Injectors

The baseline planning is for the Linac4 connection to the Booster to take place during LS2. Detailed planning is available elsewhere in these proceedings [3]. It is estimated that a total of 16 months is required for the Booster works including 1.5 months of cool-down. An additional 4 months of beam commissioning is foreseen. Cabling will be on the critical path and it might be possible to claw some time back in EYETS.

The PS upgrade is determined mainly by magnet program (replacement of the pole face windings etc.). The estimate is about 1 year plus 1 month cool-down.

The SPS foresees 12 months for the 200 MHz upgrade and 7 months for amorphous carbon coating of main bending magnets (to be confirmed).

It can be seen the key activity is the connection of Linac4 to the Booster with a total duration work required in LS2 of 20.5 months. Some co-commissioning of the injectors and the LHC might be necessary. This is certainly imaginable with the LHC only requiring limited beam during the initial commissioning phase foreseen to be about 2 months.

LHC

At present the main items planned for LS2 are:

- 16 months for cryogenics and cooling/ventilation maintenance (also required in LS4);
- installation of dispersion suppressor collimators;
- vacuum consolidation in IR2;
- installation of RF cryogenics plant;
- possible HL-LHC preparation (e.g. space for crab cavities, TAS aperture change).

There is apparently nothing which would push the required time beyond 18 months.

RUN 3

Given the EYETS and the extension of Run 2 into 2018, and the necessary extension of LS2 to 18 months, Run 3 necessarily gets pushed. Tentatively accepting a slip of the start of LS3 to the start of 2023 gives a Run 3 of 2.5 to 3 years spanning 2020 through 2022. (see figure 2). The exact length of Run 3 can, of course, be better optimized nearer the time.

LONG SHUTDOWN 3 (LS3)

Regarding the length of LS3, for the experiments 30 months seems feasible for CMS while ATLAS estimate 27 months (with an outside possibility for 35 months). Again there are concerns that LS3 could become longer due to activation aspects, infrastructure increase and maintenance, longevity issues still to discover and "our usual packing in of whatever we can".

For the LHC this is the HL-LHC upgrade and there are major infrastructure implications which include:

- 20 months for cryogenics and cooling/ventilation maintenance;
- major upgrades of insertion regions: new triplets, 11 T dipoles, collimators, cryogenics, crab-cavities, cold powering;
- possible civil engineering in the tunnel (crab-cavities);
- possible civil engineering on surface.

Clearly it is too soon to give a detailed breakdown but 2.5 years seems a reasonable working hypothesis.

For completeness it is noted that 16 months is foreseen for LS4 and 20 months for LS5 - essentially driven by cryogenics and CV.

IONS

Ions are an integral part of the HL-LHC program. Extended periods of running greater than 1 to 2 months have been ruled out as an option. The scheduling of longer ion run before LS3 ($\approx$2 months) plus any other low luminosity running such as proton-proton reference data, high β^*, MD etc. before a long shutdown is clearly a possibility.

CONCLUSIONS

Given the above, three main variations seem possible.

Firstly a modified baseline would exclude EYETS, accept an extended LS2 of 18 months and keep the LS3 start in 2022. This is clearly disfavours CMS, and given upgrade development and funding considerations unrealistically forces the pace.

The second option which we call "Slipped baseline+6" sees:

- a EYETS in 2017;
- an extended Run 2 to mid-2018;
- a 3 year Run 3 with LS3 starting in 2023.

The third option which we call "Slipped baseline+12" sees:

- a EYETS in 2017;
- an extended Run 2 to end-2018;
- a slightly shortened Run 3 with LS3 starting in 2023.

The three options are detailed in figures 1,2 and 3.

ACKNOWLEDGEMENTS

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REFERENCES

[1] ECFA High Luminosity LHC Experiments Workshop, http://indico.cern.ch/conferenceDisplay.py?confId=252045, Aix-les-Bains, October 2013.

[2] S.Claudet, private communication.

[3] B. Mikulec, J-B. Lallement, Work Effort in the LHC Injector Complex, including Linac4 connection, for the Upgrade Scenarios, these proceedings.

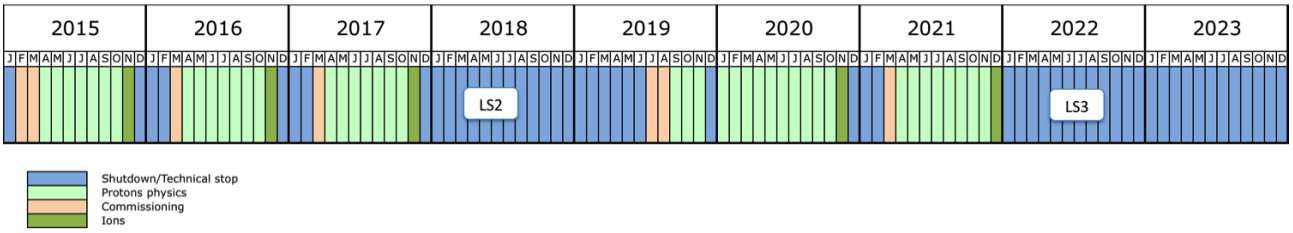

Figure 1: Baseline with LS2 extended to 18 months

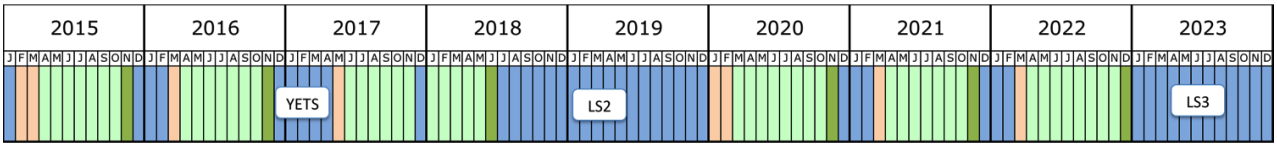

Figure 2: Slipped baseline plus 6 months

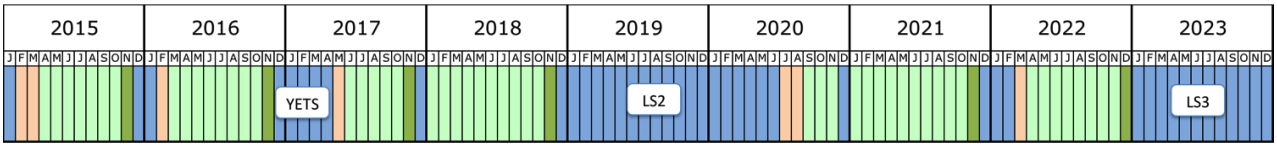

Figure 3: Slipped baseline plus 12 months