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Considerations on operation schedule and maintenance aspects of FCC-hh

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Abstract

The Future Circular Hadron Collider (FCC-hh) has ambitious goals for integrated luminosity production. Reaching these goals requires reducing the time for planned technical stops and commissioning, compared to the LHC. This note describes potential options for an FCC-hh operation schedule. Special attention is given to considerations on how to accomplish the required maintenance activities in a limited time frame. The note recommends to study further the feasibility and cost-efficiency of operating without annual stops and longer intervals between long shutdowns.

Keywords: FCC-hh, operation schedule, technical stops, long shutdowns.

1 Introduction

The preliminary baseline assumption for the FCC-hh lifetime is 25 years, consisting of five 5-year long operation periods ("runs") [1]. The exploitation is divided into two phases: baseline parameters will be used in the first ten years and ultimate parameters during the last 15 years of operations. The first run starts with an extensive commissioning period, which could overlap with the end of the construction, since some of the systems can already be commissioned while the collider is still being completed. Later runs start with a 1.5-year shutdown.

Within a run, the time allocated for proton physics is assumed to be 2.5 years, while 3 months are foreseen for ion physics. Combining proton and ion physics yields a total of 165 months of physics over the FCC lifetime. This leaves per run 9 months for machine commissioning, studies and scheduled stops. The number and strategy for managing stops can be reviewed, based on the needs imposed by individual system designs, but should not exceed the allocated time.

The challenge related to short maintenance, commissioning and machine development periods can be appreciated when comparing it to the planned operational schedule for the High-Luminosity Large Hadron Collider (HL-LHC). During a standard operational year only about 6.5 months are foreseen for proton, ion and special physics [2]. Over a 25 year lifetime including shutdowns such a schedule would result in 114 months for physics. In a 3-year run it reserves about 17 months for machine commissioning, studies and scheduled stops.

2 Examples of possible operational schedules

Alternatives can be conceived of how to arrange the stops during a run; this section introduces some of them. They shall not be seen as definitive, but rather as potential options for an operation schedule.

Few simplifications were made in drawing up these schedules. The document does not differentiate between hardware and beam commissioning. It is assumed that straight after commissioning the machine is ready for operation with full beam intensity. In reality the switch from commissioning to production is not binary; the intensity is typically ramped up gradually. The ion runs are presented as 1 or 1.5 month long periods before each stop. However, it is currently unclear whether it is more optimal to arrange ion physics in few long runs or several smaller periods [3].

Traditionally the LHC has annual stops, scheduled at the end of the year. Figure 1 shows that with this arrangement the time reserved for the stop and the following recommissioning is only two months.

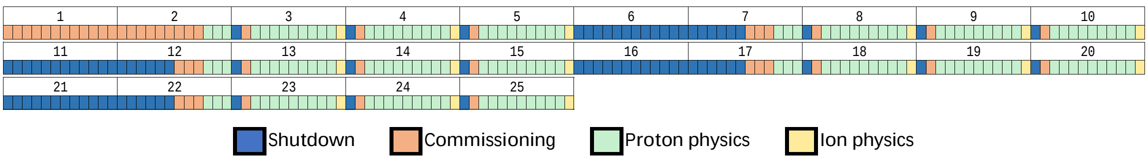

Fig. 1: Schedule with annual technical stops.

If the LHC will be the final injector for FCC, the maintenance and recommission of the injector chain will take at least 3.5 months. This can be accommodated if succesive annual stops are combined into one longer stop. Figure 2 shows a schedule with a longer stop in the middle of each run. In this arrangement the time reserved for the stop and recommissioning is 5 months. This version provides in total 170 months for physics operations.

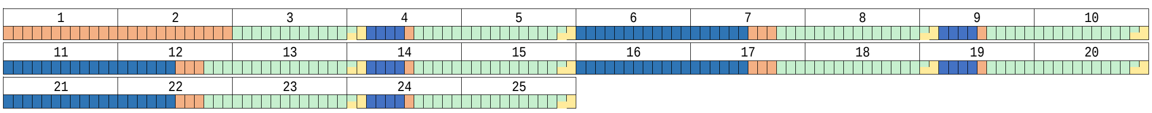

Fig. 2: Schedule with one longer stop during each run.

If the preliminary requirement [1] for long shutdowns every 5 years is abandoned, a schedule with three runs can be imagined. Figure 2 shows a schedule with only two long shutdowns. During the first one, FCC is converted from phase 1 to operate with ultimate parameters. The second long shutdown is placed in the middle of phase 2. The cryogenic system is assumed to require maintenance every 2.5 years [4]. This schedule provides about 185-190 months for physics. The end of the schedule is not developed to detail; an additional stop might be required to operate through to the end of year 25. Such an additional stop, however, could also extend the FCC lifetime for another 2 years.

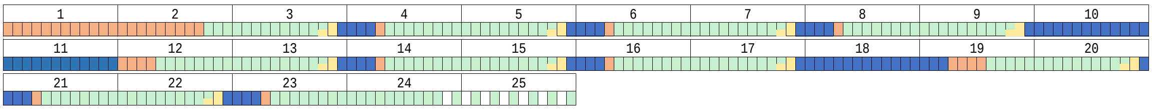

Fig. 3: Schedule with only two long stops and shorter stops every other year. The final ion physics run could be at the end of the lifetime (not drawn).

3 Maintenance during technical stops

This note focuses on the cryogenics system as it is the maintenance time driver for a superconducting accelerator. The presented scenarios assume that maintenance of the cooling water system is scheduled in parallel to cryogenics maintenance. The effect on the total intervention time from adding backup cooling towers and cryogenics interconnection boxes is studied. The study is divided in three cases: (1) with backup cooling towers and interconnection boxes; (2) with backup cooling towers but no interconnection boxes; and (3) no backup cooling towers and no interconnection boxes.

The backup cooling towers would provide cooling to the cryogenic system while the primary cooling facilities are being cleaned. The cryogenics interconnection boxes would be located in points B, L, F and H in figure 4. This allows to distribute the cryogens to the adjacent sectors when the primary cryoplant in point A or G is unavailable. Additional basic assumptions for all scenarios are: (i) 10 cryogenics plants with a cooling tower in each of the six technical points; (ii) cryogenics plant maintenance is carried out by 5 individual teams and takes 2 weeks; and (iii) cooling tower maintenance is carried out by 3 individual teams and takes 3 weeks.

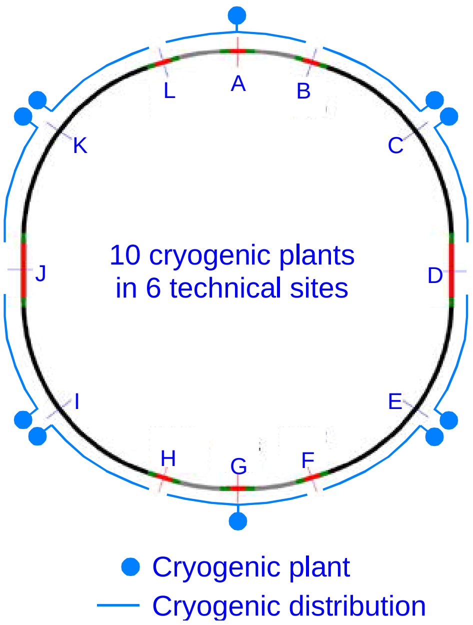

Fig. 4: Layout of the FCC-hh cryogenics system [5].

Table 1 shows the maintenance time in the three different cases; the associated Gantt charts are contained in appendix A. In case 1, the downtime is caused solely by the cryoplant maintenance and magnet powering tests which take 7 weeks. In case 2, due to the lack of interconnection boxes, liquid helium needs to be emptied during the maintenance from sectors L-A-B and F-G-H. This, combined with re-cooling and resulting electronic integrity tests, lead to 11 weeks of maintenance time. In case 3, without backup cooling towers, all sectors need to be warmed up during a maintenance, which results in 15 weeks of downtime.

Table 1: Study cases and minimum time for cryogenic maintenance

Case	Interconnection boxes	Back-up cooling	Maintenance time
1	Yes	Yes	7 weeks
2	No	Yes	11 weeks
3	No	No	15 weeks

4 Discussion and recommendations

The above shows that a cryogenic plant maintenance can be carried out in 7 weeks, provided additional hardware is foreseen. However, if annual stops are assumed (Figure 1), the current requirement for physics production days allows for a maximum of two months for maintenance and commissioning per year. Cryogenic plant maintenance can thus not be carried out annually. This is not a major problem, assuming that the maintenance frequency is driven by rotating elements with a useful life of about 40000 hours (2.5 years).

Also, maintaining the injector chain (with LHC as final injector), requires at least 3.5 months before FCC beam commissioning can start. The above requirements can be fulfilled with a scenario with only one stop during a 3.5-year operation period (figure 2). This provides the same physics production time as in the preliminary baseline [1].

Going further along this line, a reduction of the number of long shutdowns as well (figure 3) offers various advantages. Such a scenario could increase the overall physics potential of the FCC or relax its performance requirements (luminosity, availability). It could also provide more margin for machine development, short technical stops or commissioning.

Experience from LHC [6] and older accelerators [7] has shown that long shutdowns allow to upgrade and improve a machine which has led to significant gains in luminosity.

The following recommendations can be given, concerning the extension of maintenance intervals:

- Operation with schedule 2 or 3 depends on the ability to extend the maintenance interval for cryogenics system to 2.5 years, as it is the maintenance time driver. The interconnection boxes, for the sectors at points A and G, can shorten the maintenance by 4 weeks and improve the operability.
- Operation with any of the presented schedules will require backup cooling towers, assuming that regulations will demand annual cleaning of the water towers (to avoid the threat of water born bacteria). Alternative ways to prevent this threat exist and should be studied.
- FCC operation will rely on the injector chain. The maintenance of the injectors needs to fit to the schedule such that the injector chain is operational when FCC-hh recommissioning starts. Additional work is required to understand if and how this can be accomplished with the current pre-injector complex and the LHC and or an scSPS [8] as final FCC injector. However, with LHC 3.5 months seem to be the minimum time for a stop.
- Less frequent maintenance stops require accelerator systems and experiments to sustain longer periods without maintenance.
- Maintaining a sufficiently good machine alignment for long periods without intervention is a challenge. Options for achieving this should be studied.

5 Conclusion

Extending the interval of planned stops and long shutdowns seems necessary to provide the operation time required to reach the FCC physics goals. This will need additional investment in systems in the FCC and the injector complex. Capital and operational expenditures for different operation scenarios should be studied. The scenarios should be ranked by cost-effectiveness, comparing the expenditures to the potential increase in integrated luminosity.

6 Acknowledgements

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7 References

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Appendices

A Gantt charts for maintenance study cases

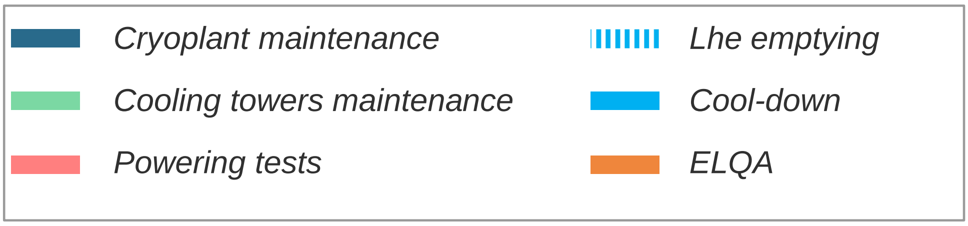

Fig. A.1: Colour notation for the Gantt charts. Lhe stands for liquid helium and ELQA for electrical quality assurance testing.

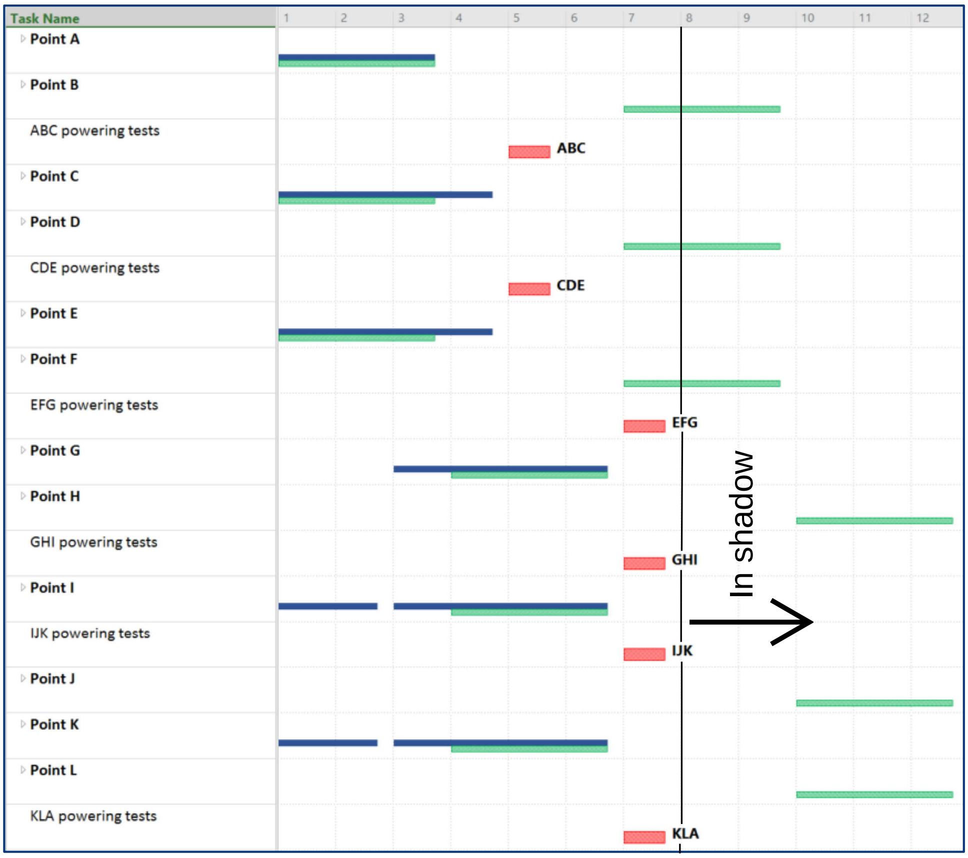

Fig. A.2: Gantt chart for case 1. After week 7 the maintenance activities do not affect the operation.

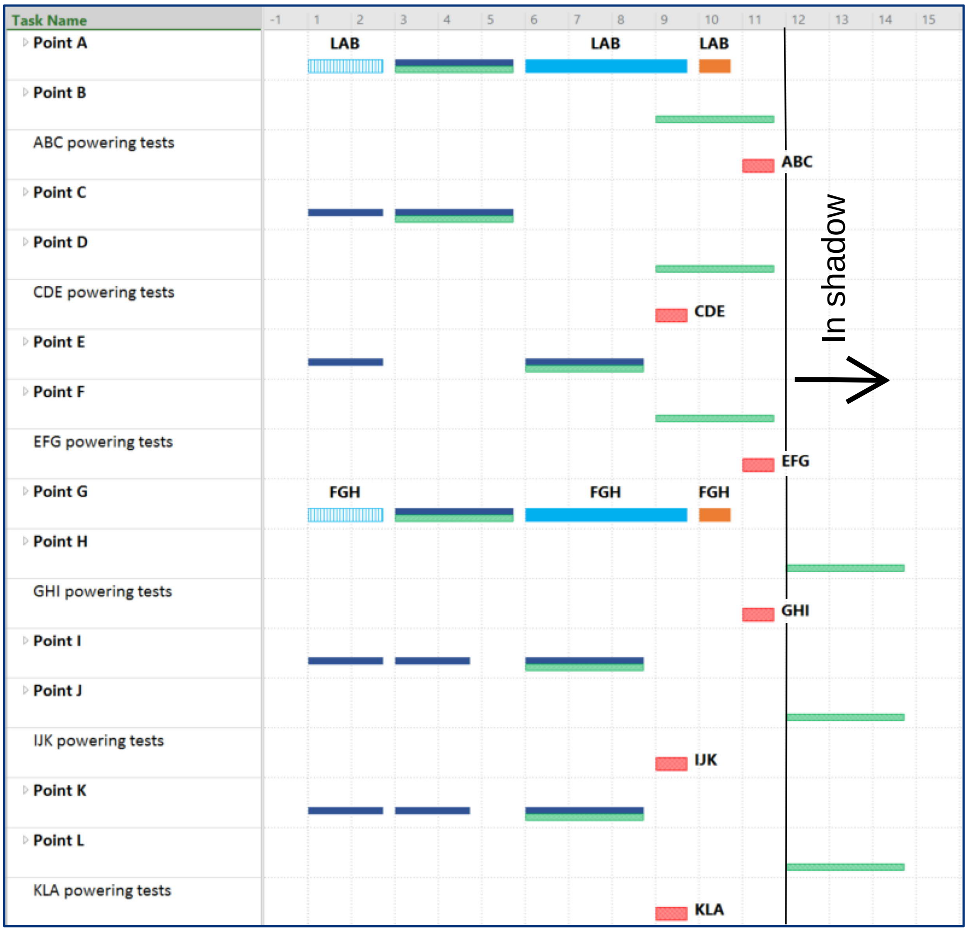

Fig. A.3: Gantt chart for case 2. Without the connection boxes, sectors at points A and G need to be warmed up during cryogenics maintenance. After week 11 the maintenance activities do not affect the operation.

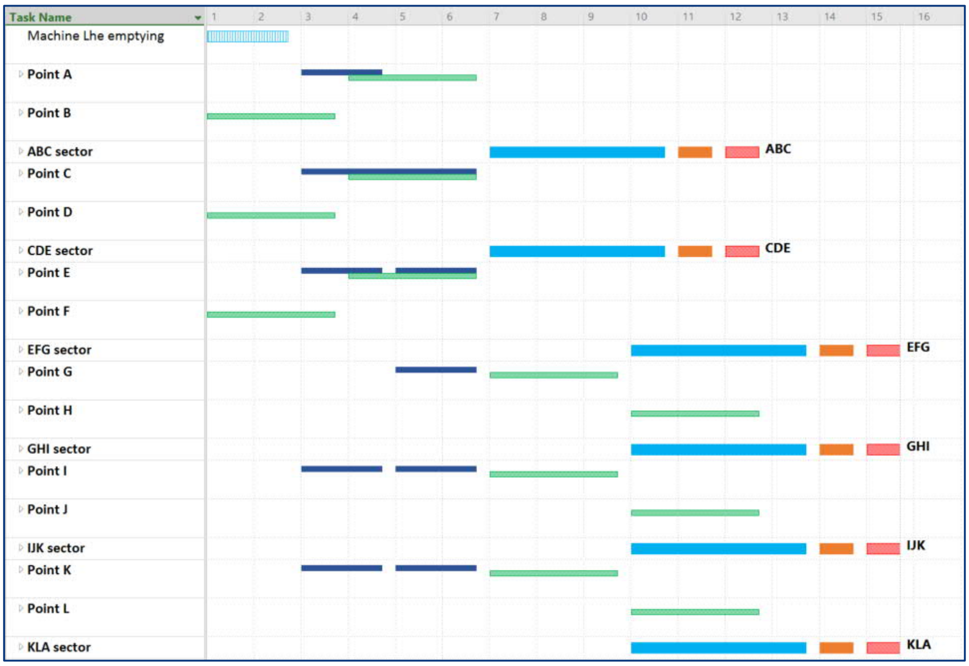

Fig. A.4: Gantt chart for case 3. All sectors needs to be warmed up. Maintenance activities take 15 weeks.