Operation of a 6 BCHF collider: do we fit the expectations?

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Abstract

The way a complex machinery is operated has a direct impact on the production efficiency. In the case of the Large Hadron Collider (LHC), which required huge efforts to design and build, it is of the utmost importance to assure an adequate operation quality. The exceptional results obtained in 2016 prove that all LHC systems and all teams, including the operation (OP), have reached an excellent maturity level. This presentation will review the present status of the operation, by highlighting areas where further improvements could be investigated.

INTRODUCTION

Operation constitutes a very important factor in particle accelerators. In fact, the efficiency at which a large complex like the LHC is exploited depends in large part on the quality of its operation.

Looking back at 2016 a number of facts has to be acknowledged. The end of YETS on March 4 marked the start of the powering tests that lasted till March 23. The first beam was injected on March 25 and two days later we already reached the end of squeeze.

On March 29 we started operating with nominal bunches and by April 23, that is less than a month later, we declared the first stable beams with 3 bunches per beam. On May 18 we were well advanced with the intensity rump-up operating regularly with more than 1000 bunches per beam in physics production as it can be seen in Fig. 1.

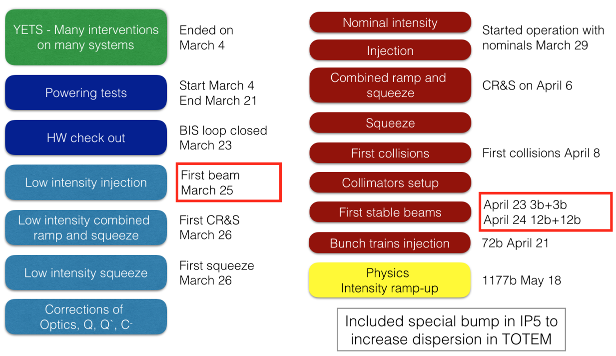

Figure 1: Commissioning milestones for 2016.

Figure 2 shows how during the year we managed to deliver something of the order of 40 inverse femto barns, much more than the target of 25. Also the peak luminosity, shown in Fig. 3, reached the value of $1.4\,10^{34} cm^{-2} s^{-1}$, that is 40% above design value, despite the various limitations like the SPS internal dump.

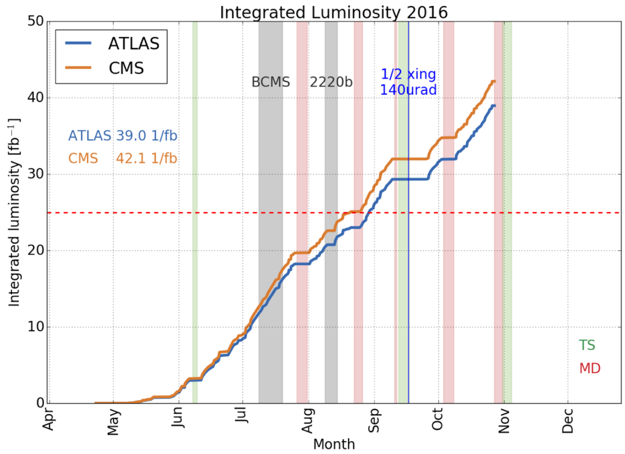

Figure 2: Production of p-p physics in 2016.

On the top of that we also had an intensive programme of proton-nucleus, with Pb-p and p-Pb collisions at different energies. We should also not forget the special forward physics run, the LHC-f run and the more than 60 MDs.

All this could be achieved thanks to the excellent availability of the LHC, in the order of 75%, and the direct consequence of spending about 50% of the available time in stable beams[1].

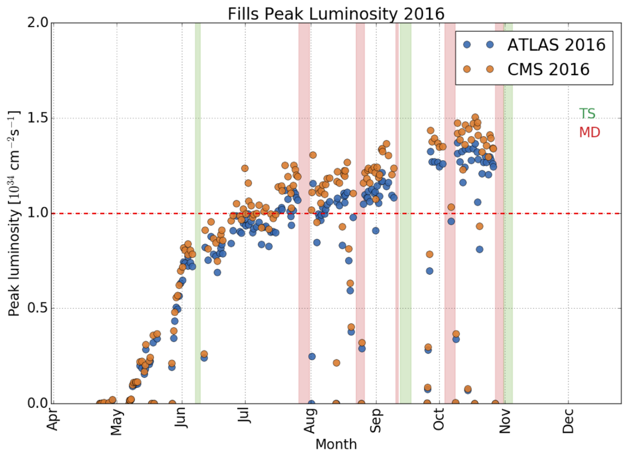

Figure 3: Peak luminosity in CMS and ATLAS vs. time for p-p physics in 2016.

From this we can already take a first conclusion. In 2016 the LHC surpassed the most optimistic expectations. If you now take into consideration the assioma that in any complex system the result can only be as good as the weakest link allows, we have to conclude that all systems, including operations, fulfilled the expectations.

But this immediately triggers the question: "how high should we set the bar for the future?"

POSSIBLE IMPROVEMENTS

Looking at the professional sports world, we can see how athletes after achieving great results do not sleep on their success. They keep on improving and over the years they surpass what seemed extraordinary results. With the LHC we should do the same as there are still margins for improvement.

And this triggers the next question: "how can we improve the operation even further?"

First of all, we need to clarify what operation is and what responsibilities it has.

The main tasks of operation are:

- To operate the various systems for a safe and efficient exploitation of the LHC.
- To document what is being done.
- To inform people outside the control room of what is going on.

OPERATION IN DETAIL

Operation is made of: people, tools, procedures, documentation and communication.

People

At the moment we have a competent and experienced operation crew. The engineer in charge and operators have often different backgrounds. This has positive sides as it helps OP cover all aspects of the machine, but it also has the downside that response to a given situation may be quite different, going against the common quality assurance criteria. Also, at the moment, there is a very steep learning curve for the new arrivals in the operation team as learning is done exclusively by shadowing and try and error. In 2008, at the start of the LHC, there was a lot of time to coach and learn, now there is much less as the pressure to produce physics is very strong. In addition, certain key knowledge is concentrated in few people introducing single point failure possibilities.

Tools

There is an impressive code base used to operate the LHC. We have a lot of specific tools, that is tools created with one particular purpose in mind, and we lack homogeneity between the different tools. The consequence is that the operators have to learn how to do similar things in several different ways. There are also a few generic tools. These are very powerful tools enabling many possibilities, but they also open the doors to mistakes. take the FESA navigator as example, a must have tool for development, but to be avoided at all costs in operation, or EquipState another very dangerous tool. Sometimes unfortunately the generic tools are all that there is available for certain actions.

Another point to highlight is that the operation of the LHC could profit from having more intelligent tools, meaning tools in which the experts knowledge is fixed into the coding. This would be particularly useful for all the cases where an analysis is required, being it the decoding of a measurement or the deciphering of a failure.

Extending the documentation of the existing and future tools would also be of great benefit to operation.

What tools can we add? There are many time consuming cases for which human analysis is the only available tool at the moment, an example for all diagnosing injection problems. For this example a tool that could help the operators understand in a few seconds if the problem comes from losses in the transfer lines, from excessive/insufficient scraping in the SPS or from longitudinal losses would be very useful, as it would allow the concerned people to act on the relevant parameters.

A tool that diagnoses the injection mechanisms would also be very useful. We have many interlocking signals from different machines, we also have a complex timing and control infrastructure that synchronises the different rings during the injection phase. Having a self-diagnosing system that responds fast and indicates immediately what the problem is would be of great help.

One could extend this principle to most systems. Adhoc self-diagnostic tools would allow a faster response in case of problems or failures. They could help reducing the time needed to identify the right expert to call; with some failures this is not at all obvious.

Procedures

The operation team has well established procedures for all operation scenarios. Large part of these procedures are coded into the sequencer and the state machine. This part covers nearly 100% of the physics production tasks. On the other hand, for commissioning operations and MDs the procedures are mostly only embedded into the EiC and operators knowledge. This situation leads to frequent recurrent problems (ever heard of the safe beam flag forced false by mistake?) and introduces an additional human effect based on who is in shift, another clear problem of quality assurance.

Written procedures could help improving the situation and would have several benefits. First, it would preserve the present knowledge; secondly, it would share and consolidate the knowledge among the different people in the operation team, and lastly, it would act as the "LHC user manual" for the new arrivals.

Human mistakes

Mistakes are part of any human activity. In the operation of an accelerator we can have direct human mistakes, bugs inside the tool, new situations never seen before etc. Mistakes can happen and there is no way we can remove them entirely.

For 2016 there are 52 records of operational mistakes in the LHC fault tracking tool[2], documenting only the human errors. Most of these events are at injection, meaning that the time lost is relatively small, nevertheless they testify how relying on personal knowledge and experience is not sufficient.

A few examples to illustrate the situation: during the ion run at the end of 2016 there are 4 events where the operator turned on accidentally the injection cleaning, leading to a beam dump, where the operational procedure was clearly to leave it off, or other cases where the tune or orbit were trimmed with the feedbacks on. More severe are the cases where the safe beam flag was forced to false during MDs, deactivating all the masks on the interlocks leading to beam dumps later in the cycle, often compromising the whole MD or commissioning cycle. Similarly, there are cases where it was forgotten to mask certain interlocks leading again to major loss of time.

Communication

Communication is a key aspect of operation. The tools and structure for an effective documentation and communication are in place but not always optimised or properly used. We should improve the communication between the machines coordinators and the operation crew, by having clear written instructions on the programme of the day with an outlook on the following days. We can also improve the communication between shifts; the shift handover is often not complete, based only on the short-term memories of the outgoing crew. After a long shift people are tired and may forget to pass over important information. There should be a systematic preparation for the shift handover, with written notes, during the dead times in operations, ”consignes” should be entered in the logbook in the corresponding area.

The use of the logbook can also be improved. There are lot of screenshots in the logbook but these often lack the comment that would make them much more useful. A systematic reediting of the logbook entries during the dead time would improve the situation. To complicate even more the situation of the logbook we have dozens of automatic entries, making the reading unnecessarily complicated by diluting the important information inside a lot of non-relevant information. One option would be to store the automatic entries into a separate logbook or allow to disable them in the normal logbook viewers. We can also improve the use of the vistars by updating them regularly, making sure that people outside the control room understand what is going on and what is the programme for the coming hours. It is indeed not uncommon to still read on page one ”preparing for injection” many hours after stable beams have been declared.

Parallel activities

All engineers in charge and operators have other activities beside the operation shifts, what is often referred to as the second job, with some not only having a second job but also a third, fourth or fifth job. However, it is important to ensure that during a shift operation is the main activity. All other activities done in parallel during a shift can only be accepted if these do not have negative impact on the operation. It is of course very difficult to draw a line on what is allowed and what should be avoided. The limit should however come as part of the professionalism and conscience of the people in shift.

THE CONTROL ROOM

Another important point in the operation of the accelerators is the control room (CCC). The control room and the people that occupy it constitutes a complex ecosystem. The main purpose of the control room is to provide a place to operate the accelerators together with the relative infrastructure. the CCC is, however, also used as: office space, meeting place, visitor centre and also as chatting place.

The frequent and varied frequentations of the CCC help the communication between people and help keeping everyone better informed of the situation, but this also dilutes the concentration of the shift crews leading to more mistakes or misunderstandings.

CONCLUSIONS

The 2016 results indicate that the operation of the LHC fulfills expectations at least as well as any other system of the LHC, but there are still margins for improvement and it is of particular importance to consolidate the high point that has been reached.

Fixing the present knowledge and expertise into documents and procedures is of paramount importance, in particular because of the continuous turnover of people and the need for faster and more effective learning tools than the shadowing method presently used.

Additionally, the communication inside the control room, between islands and between crews, and outside of the control room, between OP and other groups and experiments, can and has to be improved.

REFERENCES

[1] A. Apollonio, “LHC availability and outlook”, in *Proc. 7th Evian Workshop on LHC beam operation*, Evian-les-Bains, France, Dec. 2016

LHC availability and outlook

[2] `https://aft.cern.ch/#/home`