SUMMARY SESSION 08: HIGH LUMINOSITY (HL-LHC)

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Abstract

Session 8 of the 2011 Chamonix LHC Perfomance Workshop addressed the scenarios for the High Luminosity LHC upgrade project (HL-LHC). It covered the performance expectations without any upgrade, with very low beta* optics using a new scheme called ATS and with the full spectra of the hardware and beam parameter enhancements. In addition the session integrated a synthesis of the lessons from past colliders and a survey of the possible requests of the experiments Alice and LHCb.

INTRODUCTION

The HL-LHC project aims at exceeding the design LHC nominal performance to reach in a decade from the upgrade a total integrate luminosity of 3000 fb^{-1}, which roughly translates to 250 fb^{-1} per year, or 1 fb^{-1} per day. The goal can be achieved with an initial luminosity of $5 \cdot 10^{34}$ cm^{-2} s^{-1} sustained for several hours. This implies a potential (virtual) peak luminosity of at least $1 \cdot 10^{35}$ cm^{-2} s^{-1} with a leveling mechanism in which a parameter controlling the luminosity is kept below its maximum potential at the beginning and then pushed during the run to compensate the proton burning and keep the luminosity constant [1]. The session featured five talks: LHC performance expectations without an upgrade by Oliver Brüning [2], consequences and opportunities of a novel LHC optics scheme (ATS) for luminosity improvements by Stephane Fartoukh [3], an overview of the upgrade ingredients and possible roadmap by Frank Zimmermam [4], lessons on management and performance evolution from Tevatron and other collider by Vladimir Shiltsev [5] and future scenarios for Alice and LHCb in the HL-LHC era by Sergio Bertolucci [6].

DO WE REALLY NEED THE LHC LUMINOSITY UPGRADE?

Oliver Brüning explored the expectations of the LHC performance without an upgrade. Emphasis was given on the possibility of reviewing the limits coming from the head on beam beam perturbations, together with possibility to fine tune the long range beam-beam interactions. One can possibly target a beam-beam parameter of 0.02 or more since 0.03 was achieved in other machines although operation conditions did not satisfied the user needs. This would allow circulating higher beam current with smaller emittance by taking full advantage of upgraded injector performance. It was also noted that limits on beta* with the exiting triplets can be reviewed based on direct aperture measurements instead of relying on design margins. In that configuration the performance achievable may exceed the nominal goals up to around a peak luminosity of $4 \cdot 10^{34}$ cm^{-2} s^{-1}, but cannot reach the HL-LHC goals. Emphasis was given to 50ns bunch spacing solutions. Other ingredients are then needed, in particular leveling tools such as crab cavities and long-range beam beam wire compensator. In the course of the presentation it was mentioned that IBS growth rates should be controlled to be smaller than the radiation damping rate and that, besides loss thresholds, attentions should be focused on the 3 sigma beam life time where resides the beam participating to the luminosity.

In the discussion several points were raised. S. Myers remarked that the beam beam limit might be even higher than what has been assumed. W. Fisher pointed out that the LHC has still to operate in conditions where the non-linearities of the triplets and the long range beam beam interactions have an effect on the beam dynamics, therefore the predictions based on 2010 experience might not be precise. R. Garoby pointed out that the presentation was focused on the beam parameters available for physics, while more relevant for the injector upgrade are the beam parameters needed at injection, which may be more demanding. E. Chaposnikova and R. Schmidt remarked that some of the combinations of emittance, intensity total current considered during the talk might be too optimistic for the injectors and LHC. S. Gilardoni commented that it is still difficult to predict the combinations of emittances and currents of the beam injected in the booster from Linac4. R. Brinkmann asked whether the luminosity lifetime should be taken into account for estimating the performance, luminosity lifetime is linked to the total beam current, therefore ideally one would like to operate at the maximum beam current limit of the machine. R. Assman asked if the present triplets will reach the radiation damage limit before the time of the LHC upgrade, the answer read that the damage limit is 300-500 fb^{-1}, which is likely to be reached only after 2020. V. Shiltsev commented that a premature optimization towards smaller emittances at a cost of total intensity may not be optimal for maximizing the integrated luminosity.

BREACHING THE PHASE I OPTICS LIMITATIONS FOR THE HL-LHC

Stephane Fartoukh, after a review of the HL-LHC goals, presented a novel LHC optic proposal, called Acromathic Telescopic Squeezing (ATS) Scheme, that allows very low beta* values with excellent chromatic properties, for instance beta*=15cm in both planes (round optics) or with even smaller beta* in the plane perpendicular to the crossing plane (e. g. 30/7.5cm, called flat optics) Both options needs the same hardware changes to achieve low beta* values, (mainly in IR1 and IR5, triplets, separation dipoles, matching quadrupoles), but also in IR6. For the new triplet, Nb3Sn technology is beneficial, but acceptable backup solutions can be found with NbTi technology as well. At ultimate intensity with 25ns bunch spacing, both optics give a similar (“virtual”) luminosity of the order of $8\text{-}9{\cdot}10^{34}$ cm^{-2} s^{-1} with crab-cavities. Without crab-cavities, the above performance is reduced to $3.5{\cdot}10^{34}$ cm^{-2} s^{-1} and $5.6{\cdot}10^{34}$ cm^{-2} s^{-1} for the round and flat optics, respectively. The latter, obviously preferred, is only more sensitive to magnetic field errors and long range beam-beam interactions. The HL-LHC goals can be then achieved with smaller emittance (2.75 µm) and slightly shorter bunch length (6 cm) within the designed beam beam limit of 0.01. The crossing angle can be used as a luminosity leveling tool with a very modest cost in terms of aperture requirements.. The talk concluded that the ATS scheme is not only a necessary ingredient for most of the upgrade scenarios,but as well a novel path toward the LHC upgrade, based on flat optics and relying only on existing and well-characterized technology. The missing performance to reach the HL-LHC goals can be achieved with increased current, smaller emittance and shorter bunch lengths. Notably the ATS scheme can be tested in the present LHC under special conditions. An alternative bunch pattern with “micro-batches” has been proposed to eliminate the so-called pac-man effect.

In the discussion several points were raised mainly related to the impact of the large beta functions. O. Brüning asked whether there could be an impact on the orbit correction strategies, J. Wenninger replied that the scheme might be feasible although R. Schmidt remarked that machine protection might be more demanding due to faster orbit changes in case of magnet malfunctions. E. Todesco remarked that higher beta in the triplets translates in stricter margins for magnet field quality. Larger beta functions requires also larger aperture magnets, G. Kirby expressed concerns for the newly proposed wider MQY as Q4; S. Farotukh remarked that smaller room available for coils compared to a standard MQY can be compensated by a weaker gradient coupled with a longer magnet. Instead D2 and D1 probably becomes much more challenging challenging as remarked by S. Fartoukh and L. Rossi. Few modifications to the scheme presented have been proposed: eliminating one sextupole instead of adding one in Q10 by N. Catalan, but this would have a direct impact on performance. Answering to a question of R. Brinkmann, S. Fartoukh said that using different horizontal and vertical emittance instead of different beta* would not be compatible with an alternating plane crossing scheme.

HL-LHC: PARAMETER SPACE, CONSTRAINTS AND POSSIBLE OPTIONS

Frank Zimmermann explored the ingredients that are applicable to the HL-LHC upgrade and, after proposing three alternative scenarios, showed a possible road map. In particular a comparison of leveling strategies has been presented: beam offset at the IP, beta* or Piwinski angle with the crossing angle or crab cavity voltage. Once the maximum instantaneous luminosity is fixed the luminosity lifetime depends mainly on the initial beam current and the leveling potential. These three methods perform differently in terms of tune shift changes and it could be envisaged a combined used of them. Quantitative analysis of integrated luminosity were made on one single parameter change. Three alternative scenarios to achieve HL-LHC goals were proposed: low beta* and crab cavities; low beta*, Landau cavity and wire compensators; large Piwinski angle, flat longitudinal bunch profile and wire compensators. Their ingredients are analyzed, as well as intensity limitations, concluding that the performance goal can be achieved with a variety of options. The presentation ended with a road map that starts with machine development studies in LHC, continues installing the hardware for wire compensators, crab cavities, Landau cavities in the following two long shutdown to be ready in 2020 with the installation of the new magnets for low beta* optics.

During the discussions R. Garoby asked what are the schemes that would be more sensitive to the beam quality, that is the bunch by bunch variations of intensity and emittance, but the reply was no one in particular. R. Assman remarked that the beam already shows signs of beam-beam coherent instabilities since the transverse damper is needed during collision, although G. Arduini suggested that bunch by bunch variations might also act as a damping mechanism. V. Kain remarked that sources of emittance growth should be taken into account considering the present machine performance but O. Brüning added that synchrotron radiation damping will be stronger at 7TeV. S. Fartoukh remarked that in absence of crab cavities, the flat beam optimization results in larger luminosity even by just re-increasing beta* in the crossing plane up to 30cm.

EXPECTATIONS ON MANAGEMENT AND PERFORMANCE EVOLUTION: LESSONS FROM TEVATRON AND OTHER COLLIDERS.

Vladimir Shiltsev presented a synthesis of what has been learned from past colliders. He showed that the evolution of the peak luminosity follows an exponential law for a long period of time. The coefficient is related to the complexity of the accelerator defined as the ratio between the time it takes to reach a goal and the logarithm of the performance. In the Tevatron experience, he identified three periods characterized by very quick progress (start-up), moderate progress (development, upgrade phases), slow progress (operation phase). In addition, the improvements are always small in the order of few tens of percent, or even less, but the combinations of many of them may yield an order of magnitude or more. The presentations stressed also the importance of the expectation management and how it depends on the knowledge of the machine. He concluded with a prediction for the LHC: 6-9 years to bring the peak luminosity from 3 10^{33} up to $5 \cdot 10^{34}$ cm^{-2} s^{-1} .

During the discussion M. Ferro-Luzzi asked how much time has been spent in the Tevatron for machine development studies. The answer was that many studies were required at the very beginning as much as 3 slots per week and the number slowly reduced to 2 per month once reached the peak of performance. L. Bottura asked what determined the Tevatron crisis between Run 1 and Run 2. The answer stressed that it was related to a non sufficient understanding of the machine physics issues; in particular, the behaviour of the beam beam long range interactions was unexpected. E. Todesco asked what relative improvement would jusitfy an upgrade. For Tevatron there was not a single isolated upgrade but a campaign of improvements. It tooks 6 years to reach a 10 fold luminosity increase and some of the improvements proved to bevery effective for reasons different from the ones they were designed for. It was again stressed that the key for any improvement passed through a better understanding of the machine behaviour.

ALICE AND LHCB IN THE HL-LHC ERA

Sergio Bertolucci presented a projection of the Alice and LHCb scenarios after the HL-LHC upgrade when the LHC will operate at very high luminosity. The experimental programs need often reassessments driven by luminosity evolution, maintenance scenarios, upgrades and resources. In this moving frame is not always easy to keep the consistency of the decisions in advance. In this context answering to questions is very challenging but a way can be found by looking at the physics motivations that may support the choices. The presentation followed with a list of physics studies of extreme interest for the wide community behind the two experiments. For Alice they are jet quenching and high parton physics. Alice is already undergoing to a set of upgrade to improve the performance in order to extend the physics reach and improve the rate capabilities. LHCb has, as well, a rich physics program: direct searches for Higgs mass, lepton flavor physics, electro-weak physics, central exclusive production. In conclusion there are many compelling and exciting physics motivations to support the physics program for LHCb and Alice.

During the discussions S. Fartoukh asked the level of luminosities Alice and LHCb would likely expect in HL-LHC times. The answer was $1\text{-}2 \cdot 10^{33}$ cm^{-2} s^{-1} for LHCb while for Alice is $2 \cdot 10^{27}$ cm^{-2} s^{-1} and $5\text{-}10 \cdot 10^{29}$ cm^{-2} s^{-1} for ions and protons respectively.

CONCLUSION

The session produced lively discussions and follow up in particular in the close future concerning beam experiments and an exchange of specification between the injector upgrade project (LIU) and HL-LHC. During the summary M. Ferro-Luzzi expressed the opinion that when very high luminosity will come, experiments will prefer 25ns solution even at the cost of part of the integrated luminosity.

At this stage, it is possible to drive the following conclusions. Apart for – extremely important – reasons of hardware changes and robustness, an upgrade of the LHC is needed in order to increase the baseline performance and boost the luminosity leveling potential, as well as an injector upgrade in order to provide higher current at lower emittance. Several ingredients (high brilliance, low beta*, large aperture magnets, crab cavities, leveling strategies, wire compensators, landau RF cavities, flat longitudinal profile), combined in several alternatives ways, can provide a sound base for reaching the HL-LHC performance goals. Next years will be devoted to analyses, designs and experiments in order to understand machine issues, test the feasibility of the hardware solutions and validate the theoretical frameworks. As it has been stressed, the success of an upgrade will depend on the physics understanding of the machine components and behavior, as well as a good match with the injector performance (LIU project). As a final remark the HL-LHC project should make sure that the solutions that will upgrade the performance for ATLAS and CMS will be compatible with the upgrade needs of Alice and LHCb.

ACKNOWLEDGMENTS

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