MACHINE CONFIGURATION AND PARAMETERS

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Abstract

2017 has been a remarkable year for the LHC with more than $50fb^{-1}$ delivered to ATLAS and CMS and the peak luminosity largely overtaking the design value. Moreover, quite some time was spent to increase operational knowledge with technics that will be extremely important in the future, such that RF detuning, levelling, ATS optics. 2018 will be also a very important year, as a challenging target will be set to accumulate as much data as possible before the LS2, while marking the road toward HL-LHC. A careful and precise choice of machine parameters is crucial to ensure success. A critical review of 2017 accomplishments is presented with a final proposed of machine configuration.

BETA* REACH

The 2017 strategy adopted for collimation and β^* reach was presented and approved in Evian and Chamonix workshops [1][2]. Due to the reversal of the crossing angle in IR1 (bottleneck) with respect to 2016 operation, some aperture margin was gained. Following the CMAC recommendation it was decided to start with a β^* of 40 cm, but tighter collimator settings, in order to test the configuration for a further reduction of β^* at a later stage. However, during commissioning the optics at 30 cm was measured and corrected. The crossing angle value was maintained at 150 µrad to guarantee a beam-beam separation of 10 σ. In September, after TS 2, it was decided to operate at 30 cm β^*, with a beam-beam separation of 8.6 σ (150 µrad crossing angle). This allowed to gain about 8% in integrated luminosity. Two configurations are proposed for 2018. Keeping the primary and secondary settings like in 2017 configuration, but bringing the tertiary collimators 0.5 σ closer to the beam. This would allow a small gain in β^* (also depending on the beam-beam separation chosen), without violation the TCT-MKD phase advance limit. The second option is to reduce the retraction between primary and secondary collimators to 1 σ (presently at 1.5 σ). The gain of 0.5 σ in aperture, nevertheless, would come with a price. Some concerns have been risen about impedance and on the fact that a possible hierarchy violation during the year might appear. At present stage, the first option looks more reasonable, while some additional studies can be done to investigate the second option. Finally, under the assumption to maintain the same crossing angle polarity in IR1 as in 2017 and that the aperture measurements give similar results, the β^* reach is between 25 and 27 cm, depending on the beam-beam separation required (Fig. 1).

CYCLE MODIFICATION

Following experience and studies, three possible modifications of the cycle are envisaged.

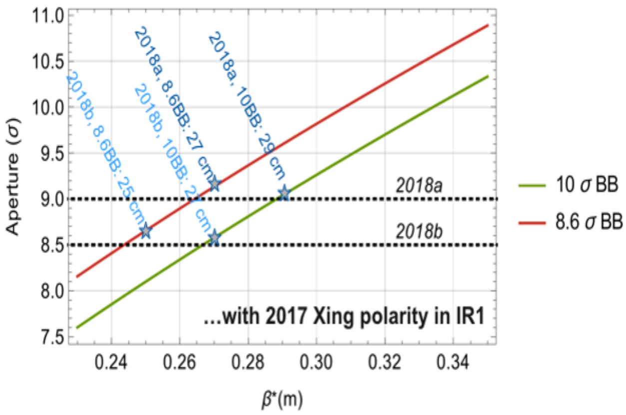

Figure 1: β^* reach as function of the aperture for different beam-beam separation.

Enhanced combined Ramp & Squeeze

The possibility to combine the energy ramp and the betatron squeeze has been addressed through systematic studies at CERN since 2011 [3][4], then proposed [5] and implemented for operation since the end of 2015. Combined ramp and squeeze is today the baseline of LHC operation. For the intermediate energy run (2.5 TeV) performed at the end of 2017, a more aggressive version of combined ramp and squeeze was used, starting the optics change just before 1 TeV (normally done around 1.7 TeV). This would allow to insert a larger number of optics into the ramp, landing at 6.5 TeV in a more squeezed configuration. The time gain, however, has the drawback of reducing the flexibility for MDs.

Squeeze improvements

A larger improvement in the time required by operation could come from a review of the optics distribution in the betatron squeeze. In 2017 the squeeze was performed until 40 cm then an optics modification was implemented to increase cttps acceptance. This configuration was maintained also when the 30 cm squeeze was introduced, to avoid recommissioning. A new configuration where the variation of Q6 currents to allow cttps acceptance is done during the squeeze to 30 cm, maintaining the last optics, would allow a gain of a few minutes. Besides, merging the squeeze to 40 cm and to 30 cm into the same beam process would also allow some time gain. The beam processes were separated in 2017 for the reasons discussed in the previous chapter, but the sequence execution and settings load take about four minutes and this time can be recovered.

The PPLP ramp

The present energy ramp of the LHC (so-called PELP) is composed of four parts [6]:

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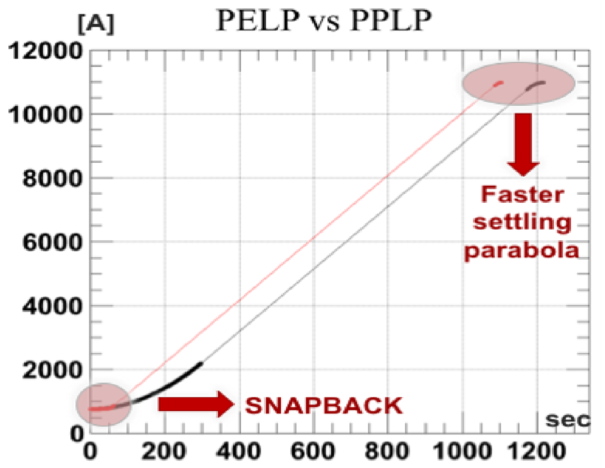

Figure 2: Present LHC energy ramp (PELP) versus new proposed design (PPLP).

- parabolic to smoothly passed through the snapback phase;
- exponential to minimize non-linear field imperfections;
- linear;
- parabolic to settle up.

With increase knowledge of the powering and magnetic system and thanks to the high quality of the magnetic field in the LHC, a review of this process was proposed. The new momentum function (so called PPLP) has the first parabolic phase untouched to smoothly transit across the snapback. A second parabola replaces the exponential part to get into the linear phase more rapidly. Finally, the settling parabola is slightly more aggressive. This new design results in a gain of 10% in the ramp length (see Fig. 2). The new version of the momentum function was tested during a machine development phase in 2017 [7]. As no evidence of larger losses nor of reduce beam quality was observed, the PPLP was used for the intermediate energy run that took place in November 2017. As operated with full intensity beam, it is now the baseline for 2018 operation.

LEVELLING

Controlling the instantaneous luminosity is very important in the LHC and allows a big flexibility in operation. This can be done in three main ways: by beam separation, by crossing angle variation and by change of β^*. The first technique was regularly used to limit peak luminosity in ALICE and LHCb since the beginning of LHC operation. Separating the beams in the high luminosity interaction points, however, may lead to instability due to loss of landau damping. At the end of 2017, a low pile-up run was requested by ATLAS and CMS. With bunch intensity of about $1.15 \cdot 10^{11}$ p/bunch, separation levelling was used in all points without any problem. This allowed to increase knowledge with the process, making it an important tool for 2018. Levelling by crossing angle modification was used for the first time in 2017 to regularly increase the luminosity in IR1/IR5 whenever the beam-beam limit allowed it. This operation is now controlled with a big level of quality so that a continuous change of crossing angle during the fill is proposed for 2018. β^* levelling is the most complex operation to control luminosity. Nevertheless, developing this method is crucial, as it is baseline for HL-LHC. β^* levelling was extensively tested during machine development [8] and, although some improvements are still needed, it is ready to be used.

LUMINOSITY

The luminosity production clearly depends on many choices. A realistic option for 2018 would be to use BCMS beam. Due to its reduced emittance, this beam can provide very good luminosity. The partial warm-up of sector 12, together with the vacuum pumping should have lifted the limitation due to the losses generated in 16L2. This would allow a bunch intensity higher than $1.2 \cdot 10^{11}$ p/bunch. This choice, however, has an impact on the allowed beam-beam separation (thus on the crossing angle). All these options have to be considered together to make a meaningful decision. In Fig. 3, some parameters have been fixed to help visualizing the parameter space. Figure 3 shows the variation of peak luminosity as a function of crossing angle and β^*, under the assumption of:

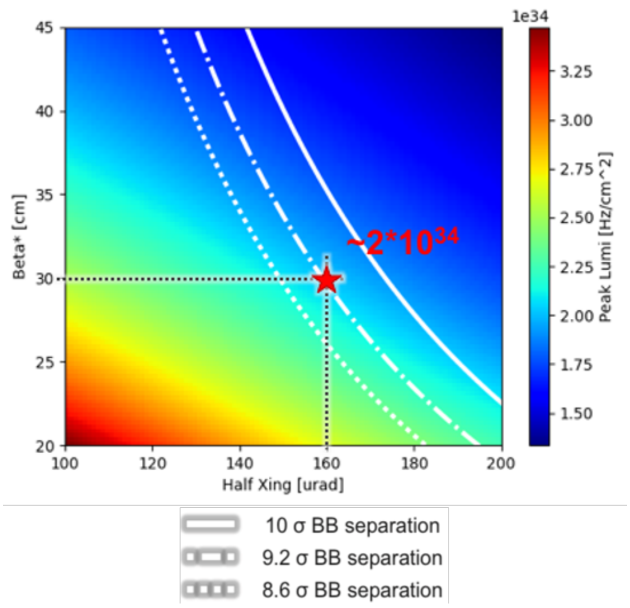

Figure 3: LHC peak luminosity as function of β^* and Xing angle.

- bunch intensity = $1.25 \cdot 10^{11}$ p/bunch
- emittance = 2.5 μm
- total number of bunches = 2544

The three lines on the figure, represent different beam-beam separation options. The option chosen in the figure shows that assuming an initial value of beta* of 30 cm and a crossing angle of 160 µrad (resulting in 9.2 σ beam-beam separation) would give an initial luminosity of about $2 \cdot 10^{34} cm^{-2} \cdot s^{-1}$. This conservative choice would also allow a further modification of parameters (crossing angle and β^* reduction) to control the integrated luminosity, without exceeding too much in pile-up. With this estimate and the present 2018 LHC schedule, it is possible to extrapolate a prediction for the integrated luminosity. Assuming an average production of about 3.5 fb^{-1} per week (about 10% higher than what assumed for 2017) and four weeks of intensity ramp-up, it is possible to integrate almost 60 fb^{-1} in 2018.

OPTICS OPTIONS

2017 marked the way to HL-LHC also with the introduction of Achromatic Telescopic Squeeze (ATS) optics. The optics used has a pre-telescopic squeeze to 40 cm and becomes telescopic on the way to 30 cm. Some more aggressive scenarios are possible for 2018 to gain more experience with the telescopic part. Three possible configurations are considered:

- keep 2017 configuration: this has the advantage of a limited commissioning with a fast ramp-up into production;
- "ligh" telescopic starting at 60 cm (factor 2.3): the gain in landau dumping would be paid in time for commissioning;
- "strong" telescopic (factor >3): even more stability margin, but at the price of a complete re-commissioning.

2018 CONFIGURATION AND PARAMETERS

Taking all the above into consideration, a configuration for 2018 operation is presented. Due to the limited time presently allocated in the planning and the goal of maximize integrated luminosity before LS2, it is suggested not to change the optics to ensure a fast re-commissioning. Combined ramp and squeeze may be performed in a more aggressive version, using PPLP ramp function and starting the squeeze at lower energy than in 2017; possibly arriving at flat-up with 80 cm β^*. A unique squeeze to 30 cm would be then performed arriving at the cttps preferred configuration on the âĂIJdiagonalâĂİ but commissioning the optics to 25 cm for later use (same strategy as in 2017). Continuous crossing angle levelling will probably be performed to control luminosity peak. β^* levelling could be initially used at end of fill to go from 30 cm to 25 cm. This strategy (similar to what done with crossing angle levelling in 2017) would allow to acquire knowledge, limiting the risk of compromising performance. The parameters suggested for 2018 operation are shown in Table 1.

Table 1: 2018 machine parameters.

Parameter	Value
Beam type	BCMS
Bunch intensity	$1.2 - 1.45 \cdot 10^{11}$ p/b
Max # bunches per train	144
Total number of bunches	2556
Injection tunes	27.3/29.5
Injection chroma	15/15
Final beta*	27/25 cm
Xing angle	160/200/160/-250 same as in 2017
Separation	-0.55/1.4/0.5/-1
CMS bump (TBD)	Between -1.5 and -2 mm

CONCLUSIONS

2017 was a very important year for the LHC. Not only the goal was overtaken, despite the difficulties occurred, but also a lot of important operational knowledge has been gained. The strategies used for crossing angle levelling and β^* commissioning proved to be extremely efficient and a similar one will be used in 2018 for β^* levelling. Several studies were performed and allowed to develop tools that will be useful to further improve performance in 2018. The choice of parameters and machine configuration is crucial to maximize results. Due to the peculiar situation of 2018, with the upcoming LS2, a short time has been allocated for commissioning. This suggests to implement limited changes in the cycle, in order to profit at most of 2017 commissioning.

ACKNOWLEDGMENT

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REFERENCES

[1] R.Bruce "Beta* reach for the different scenariosâĂİ, LHC operation workshop Evian 2016.

[2] M.Lamont "Putting all together: Machine configuration for 2017âĂİ, LHC performance workshop, Chamonix 2017.

[3] N.Ryckx "Combined energy ramp and betatron squeeze at the large hadron collider", CERN-THESIS-2012-004.

[4] J.Wenninger et al. "First beam test of a combined ramp and squeeze at LHC", CERN-ACC-NOTE-2015-0023.

[5] M.Solfaroli "LHC Nominal Cycle" Proceedings of the 6th Evian workshop pp. 45-48.

[6] L.Bottura et al. "LHC main dipoles proposed baseline current ramping", LHC Project Report 172.

[7] M.Solfaroli et al. "Studies with Parabolic Parabolic Linear Parabolic (PPLP) momentum function in the LHC", CERN-ACC-NOTE-2018-019.

[8] M.Hostettler et al. "B* levelling using the LHC lumi server (MD2427)", CERN-ACC-NOTE-2018-0001.