ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPR006

PERFORMANCE OF THE ALICE LUMINOSITY LEVELING SOFTWARE ARCHITECTURE IN THE Pb-Pb PHYSICS RUN

G. Valentino*, University of Malta, Msida, Malta
G. De Cataldo[1], A. Franco[1], M. Hostettler, CERN, Geneva, Switzerland
O. Visnyei, Hungarian Academy of Sciences, Budapest, Hungary
[1]also at INFN, Bari, Italy

Abstract

Luminosity leveling is performed in the ALICE experiment of the Large Hadron Collider (LHC) in order to limit the event pile-up probability, and ensure a safe operation for the detectors. It will be even more important during Run 3 when 50 KHz Pb ion-Pb ion (Pb-Pb) collisions will be delivered in IP2. On the ALICE side, it is handled by the ALICE-LHC Interface project, which also ensures an online data exchange between ALICE and the LHC. An automated luminosity leveling algorithm was developed for the proton-proton physics run, and was also deployed for the Pb-Pb run with some minor changes following experience gained. The algorithm is implemented in the SIMATIC WinCC SCADA environment, and determines the leveling step from measured beam parameters received from the LHC, and the luminosity recorded by ALICE. In this paper, the software architecture of the luminosity leveling software is presented, and the performance achieved during the Pb-Pb run and Van der Meer scans is discussed.

INTRODUCTION

A Large Ion Collider Experiment (ALICE) [1] is optimized to study the collisions of nuclei at ultra-relativistic energies, which provide a phase of matter known as the quark-gluon plasma. It is one of the major experiments of the CERN Large Hadron Collider (LHC) [2], which is a 27-km long particle accelerator designed to collide protons and heavy ions with center-of-mass energies of $\sqrt{s}$ = 14 TeV and 2.759 TeV/nucleon, respectively. The LHC Interface project [3] (LHC_IF) ensures the online data exchange between the LHC and ALICE, as well as the safe operation of the complex experiment-collider interface.

One of its main tasks is to coordinate the luminosity levelling, which is necessary in order to limit the event pile up probability to a few percent. In the 2018 heavy-ion run, the LHC could provide up to 6×10^{27} cm^{-2}s^{-1} of instantaneous luminosity, however in the ALICE experiment this value had to be reduced through luminosity levelling to a value of 1×10^{27} cm^{-2}s^{-1} by applying a beam-beam separation in the horizontal plane of up to several σ (beam size units). When collisions between the beams are established and the LHC is in stable beams mode, a controlled and automatic luminosity ramp up kicks in to reach the target luminosity defined by ALICE. During the remainder of the fill, minor corrections are applied to the beam separation in order to maintain the luminosity at a constant value. Luminosity levelling was also required during special very low luminosity runs in order to measure and map the distortions in the ALICE Time Projection Chamber with the two B-field polarities.

In this paper, following an description of the luminosity levelling procedure, an overview of the software architecture is provided, and the operational experience with levelling in the Pb-Pb physics run in 2018 is presented and discussed.

LUMINOSITY LEVELLING PROCEDURE

Luminosity levelling via beam separation was first carried out in ALICE with proton-proton collisions in May 2011 [4], and for the first few years of operation made use of a fixed step size in σ to displace the beams until the target luminosity was reached. In 2015, due to the higher beam intensity and the running in main-main beam mode, the fixed step size was deemed no longer viable due to the long and not always convergent levelling procedure. As a result, the LHC machine operator was required to manually steer the beams until the target luminosity was reached, resulting in a loss of data taking time and luminosity overshooting which can damage ALICE's detectors. Therefore, the luminosity levelling procedure was upgraded in 2016 to calculate a dynamic levelling step size based on an inversion of the luminosity formula and taking into account measured beam and machine parameters such as the bunch intensities, number of colliding bunches and β^* (which defines the beam size at the ALICE experiment) [5].

The following intervals of validity for $\Delta\delta$ with the corresponding values of Δd were defined:

$$\begin{aligned} \text{if } \Delta\delta \geq 0.52; &\quad \Delta d = 0.5 \\ \text{if } \Delta\delta \geq 0.27 \text{ and } \Delta\delta < 0.52; &\quad \Delta d = 0.25 \\ \text{if } \Delta\delta \geq 0.07 \text{ and } \Delta\delta < 0.27; &\quad \Delta d = 0.06 \\ \text{if } \Delta\delta < 0.07; &\quad \Delta d = 0.025 \end{aligned}$$

SOFTWARE ARCHITECTURE

The LHC_IF control software is implemented in the SIMATIC WinCC SCADA environment [6] and comprises over 200 control processes, called managers. LHC_IF subscribes to the beam conditions published by the LHC via the data interchange protocol (DIP) [7]. Depending on the particle type (protons or heavy ions), the geometric beam

* gianluca.valentino@um.edu.mt

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPR006

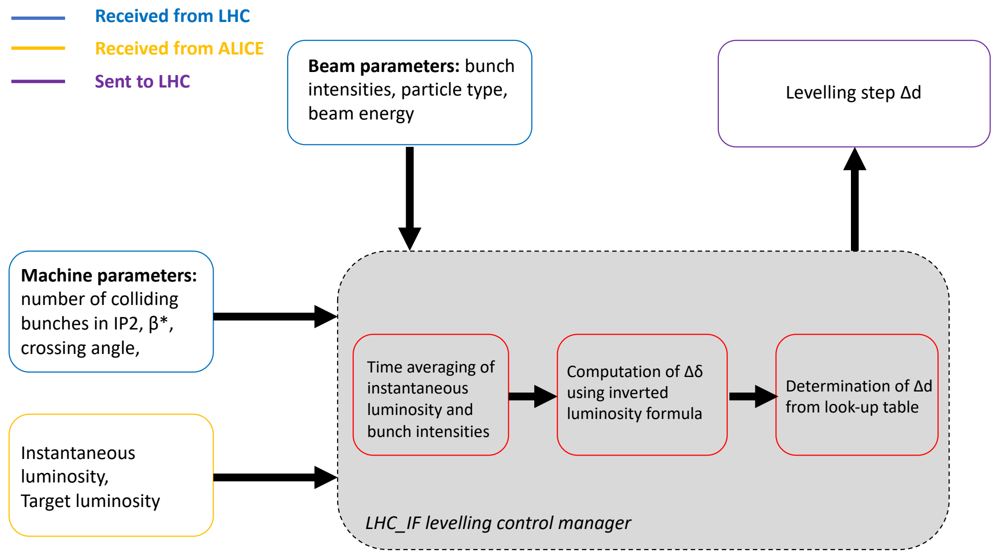

Figure 1: Schematic of the software architecture of the luminosity levelling procedure implemented in the SIMATIC WinCC SCADA environment.

emittance is computed via the well-known formula from the beam energy, atomic number and atomic mass. The 1 σ beam size is then obtained via the square root of the product of the β^* at IP2 received from the LHC and the geometric beam emittance. It is assumed that the beams are round, i.e. the beam size is identical in both the horizontal and vertical planes.

To prevent oscillation in the $\Delta\delta$ calculation and, consequently, in the Δd, the instantaneous luminosity and the bunch intensities are averaged over the previous 5 s and 10 s respectively. A hysteresis interval of $\pm$ 0.005 σ is applied on each $\Delta\delta$ threshold. This hysteresis corresponds to the residual instantaneous fluctuation of $\Delta\delta$. Finally, before its publication, a check on the stability of Δd over 5 s is also applied. An overview of the processes and software architecture of the luminosity levelling procedure as implemented in the WinCC SCADA environment is shown in Fig. 1.

Together with Δd, the other parameters leading to its determination are also logged as data points with a 1 Hz sampling rate for offline analyses. These include $\Delta\delta$, the time-averaged luminosity and bunch intensities, and all the parameters received from LHC. The panel through which LHC_IF project members can view the status of the luminosity levelling is shown in Fig. 2. Apart from an instantaneous numeric display of the most relevant parameters, a trend view showing their evolution over time is also provided. The name of the current luminosity source used in ALICE and the status of the levelling ("ACTIVE" and "ENABLE" flags) are also visible. From this panel, experts can also modify the thresholds used to determine the $\Delta\delta$.

EXPERIENCE WITH LEVELLING IN Pb-Pb PHYSICS

The Pb-Pb physics run at LHC commenced on 8th November 2018 during Fill 7427, and lasted until 3rd December 2018 during Fill 7494. A new optics was put in place in ALICE, with the smallest ever β^* of 0.5 m. Initially, the same luminosity levelling routine operational in the proton run was used, with the appropriate corrections to take into account the heavy ion particles. However, early on during the run, it was apparent that the luminosity in ALICE was lower than expected, and the luminosity levelling procedure was slow to converge and level the beams to the target luminosity.

Following some beam tests performed by LHC operation, the cause of this was put down to a beam deformation and reduced overlap at the IP introduced by strong local betatron coupling in IR2. This had the effect of increasing the apparent beam size at IP2 by approximately 50%. A correction with skew-quadrupoles was implemented to solve this issue during the ALICE polarity reversal, which took place mid-way during the physics run. Due to the issue with the beam deformation, the steps proposed by the automatic luminosity levelling procedure, which assumed a nominal 1 σ beam size of 16 μm, resulted in smaller effective step sizes in terms of real beam σ, leading to a very slow convergence to reach the target luminosity and hence loss of physics data for ALICE. As the problem was only understood much later in the physics run, the ALICE Run Coordination took the decision to ask the accelerator operation to perform the levelling using a backup routine [8], rather than use the steps proposed by ALICE.

An example of such a fill in which the levelling was performed in this manner is shown in Fig. 3. The step size (Δd computed by ALICE based on $\Delta\delta$ is shown in magenta, however the actual steps applied by LHC are shown in yellow. This plot also shows the difference between the $\Delta\delta$ calculated assuming a nominal value of σ, and using a σ value which is 50% larger. Although there are differences between these two values (which increase with beam separa-

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPR006

Figure 2: View of the luminosity levelling Graphical User Interface in the LHC_IF WinCC expert application.

tion), the plot demonstrates that as expected, once the target luminosity is reached then $\Delta\delta = 0$.

The step applied by LHC is logged in units of mm, and therefore in order to compare the step size applied with the change in $\Delta\delta$ to validate the performance of the ALICE levelling routine (as was also done for proton-proton physics), the LHC step size was converted to units of σ assuming a 1-σ value greater than nominal by a 50%. The result is shown in Fig. 4, with the error bars representing the standard deviation. A linear fit applied to the data shows that the average change in $\Delta\delta$ scales less linearly with the step size applied by LHC than was observed for levelling during proton-proton physics. This may be due to the fluctuations in the apparent beam size at the IP over the entire heavy-ion physics run either due to emittances or the strong betatron coupling as mentioned earlier.

Van der Meer scans [9], in which the beams are transversally scanned across each other to determine the cross-section, have already proven to be a useful diagnostic tool in order to evaluate the performance of the luminosity levelling routine during proton-proton operation. The Van der Meer scans performed in ALICE during the heavy-ion run were analysed, and are shown in Fig. 5. At the moment when the beams are colliding head-on, δ_{inst}, which is the beam separation with respect to the absolute luminosity, should be zero, which is in fact the case. The values of L_0 and L_{inst} have been calculated assuming the measured beam emittance.

CONCLUSION

The LHC operation uses luminosity levelling via beam separation to limit the event pile up in ALICE and ensure safe and correct operation of its detectors. In the 2018 Pb-Pb run, a procedure for calculating the levelling steps developed by ALICE for the previous proton-proton run and implemented in the framework of the ALICE-LHC Interface software architecture was deployed. However, due to initially unknown issues with the effective beam size at IP2, the automatic levelling procedure which guarantees convergence to the target luminosity without luminosity overshooting was replaced by a feedback loop running on the LHC side. In this paper, an overview of the software architecture used to implement the ALICE levelling routine was presented, together with some passive results obtained during the Pb-Pb physics run. In order to detect issues with the LHC beams which could affect the luminosity levelling procedure earlier, a possible solution is to conduct scans during the intensity ramp-up phase when the beam intensities are still low and it is possible to collide the beams head-on without causing issues for ALICE.

ACKNOWLEDGEMENTS

The authors would like thank Jorg Wenninger for discussions concerning LHC operation during the Pb-Pb physics run.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPR006

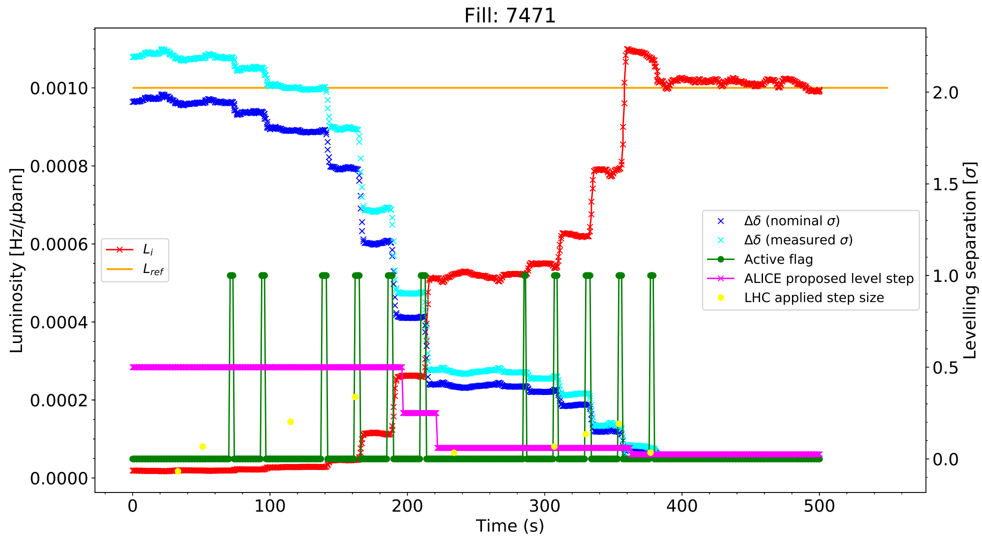

Figure 3: Luminosity levelling during Fill 7471, showing the step sizes proposed by ALICE and the actual steps applied by LHC.

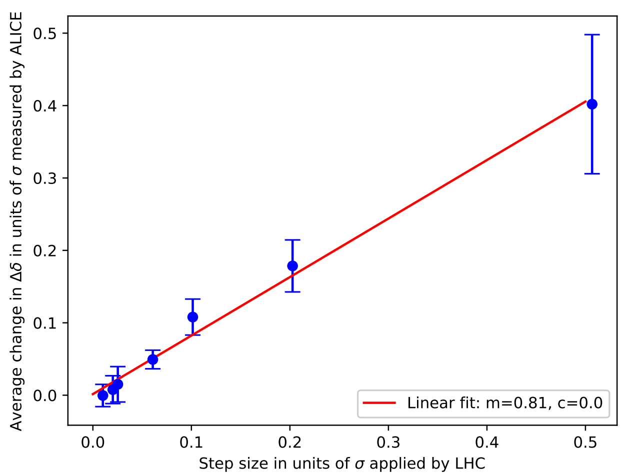

Figure 4: Linear fit applied to the averaged change in $\Delta\delta$ measured following a step made by LHC.

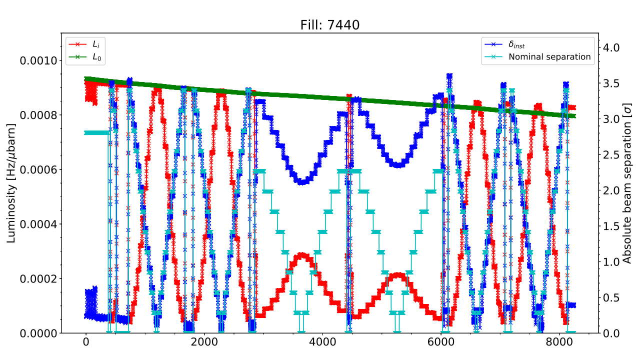

Figure 5: Horizontal and vertical Van der Meer scans in ALICE, showing the comparison between the nominal beam separation and the δ_{inst} beam separation measured by ALICE, as well as the luminosity.

REFERENCES

[1] "ALICE technical proposal for a large ion collider experiment at the CERN LHC", ALICE Collaboration, Geneva, Switzerland, Tech. Rep. CERN/LHCC/95-71 LHCC/P3, 1995.

[2] O. S. Bruning *et al.*, "LHC design report", Geneva, Switzerland, Tech. Rep. CERN-2004-003-V1, 2004, vol. 1.

[3] G. de Cataldo, The ALICE-LHC Interface, ALICE Matters, `http://alicematters.web.cern.ch/?q=content/node/954`, 2016.

[4] F. Follin, D. Jacquet, "Implementation and experience with luminosity levelling with offset beam", Proc. ICFA Mini-Workshop Beam-Beam Effects Hadron Colliders, pp. 183-187, 2013, `doi:10.5170/CERN-2014-004.183`

[5] G. de Cataldo, G. Valentino, A. Franco, R. Alemany, F. Follin, M. Hostettler, J. Wenninger, "An upgraded luminosity leveling procedure for the ALICE experiment", *IEEE Transactions on Nuclear Science*, vol. 66, no. 5, pp. 763-770, May 2019, `doi:10.1109/TNS.2019.2907227`

[6] SIMATIC WinCC SCADA, `https://w3.siemens.com/mcms/human-machine-interface/en/visualization-software/scada/pages/default.aspx`

[7] W. Salter, "LHC Data Interchange Protocol (DIP) Definition", document no. 457113, EDMS, 2004.

[8] M. Hostettler *et al.*, "Online luminosity control and steering at the LHC", *in Proc. ICALEPCS 2017*, Barcelona, Spain, pp. 989-993, 2017, `doi:10.18429/JACoW-ICALEPCS2017-TUSH201`

[9] S. White, R. Alemany-Fernandez, H. Burkardt, M. Lamont, "First luminosity scans in the LHC", *in Proc. International Particle Accelerator Conference*, Kyoto, Japan, MOPEC014, pp. 486-488, 2010.