Performance of the ALICE Luminosity Levelling Software Architecture in the Pb-Pb Physics Run

G. Valentino*, G. De Cataldo, A. Franco, M. Hostettler, O. Visnyei

University of Malta, Msida, Malta
INFN, Bari, Italy
CERN, Geneva, Switzerland
Hungarian Academy of Sciences, Budapest, Hungary

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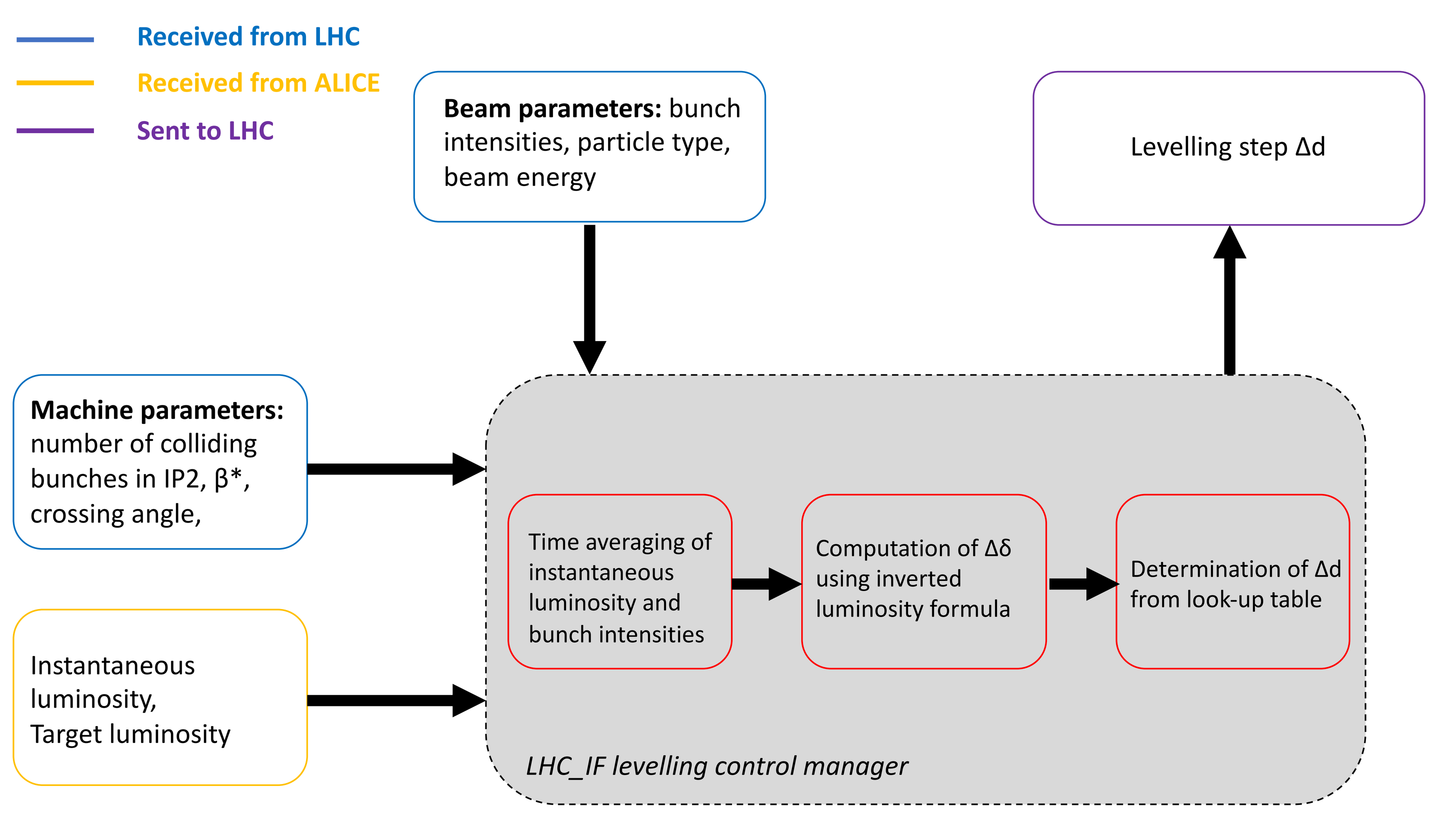
Abstract

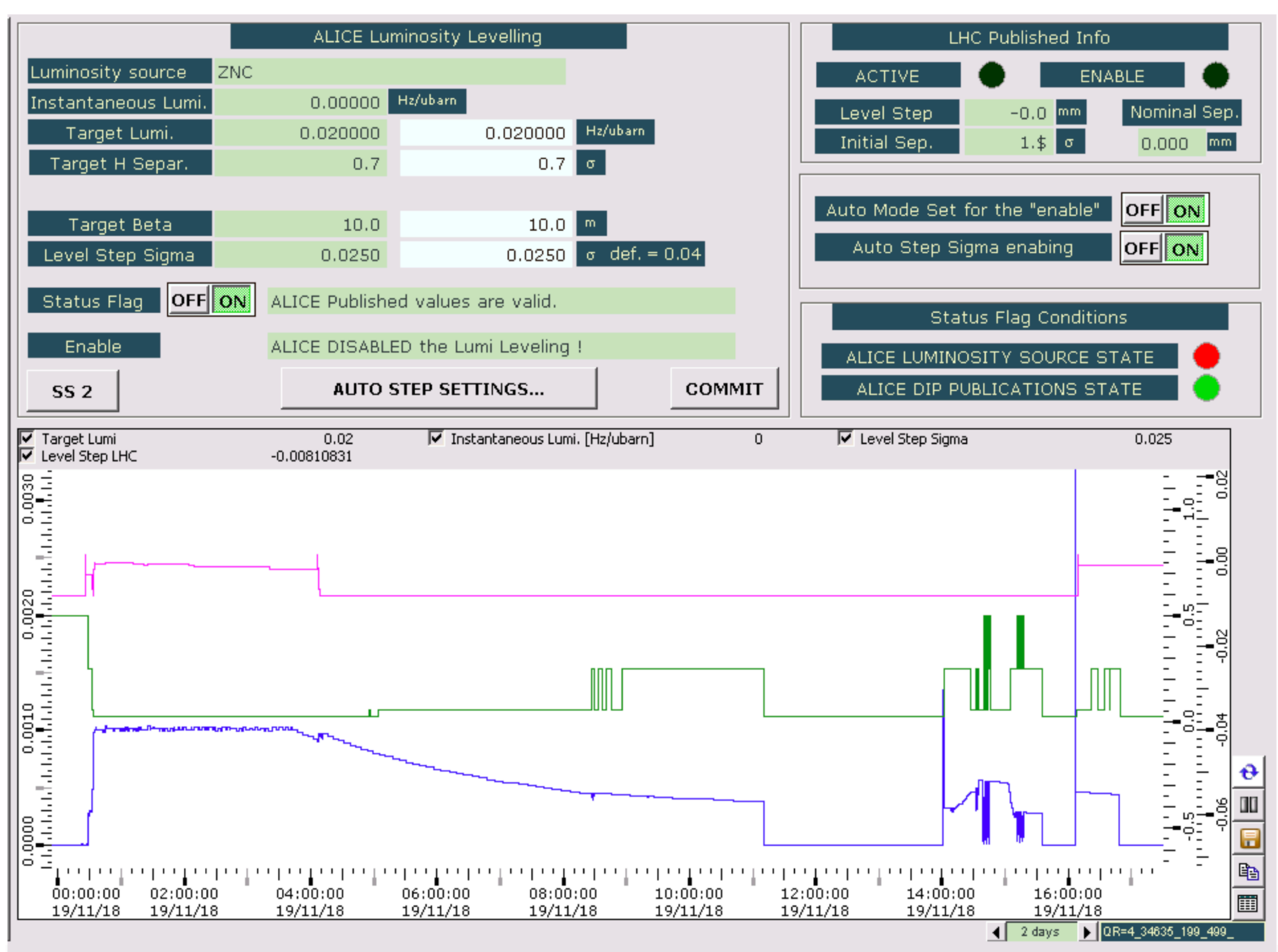
Luminosity leveling is performed in the ALICE experiment of the Large Hadron Collider (LHC) in order to limit the event pile-up probability, and ensure a safe operation for the detectors. It will be even more important during Run 3 when 50 KHz Pb ion-Pb ion (Pb-Pb) collisions will be delivered in IP2. 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.

Software Architecture

- Schematic of the software architecture of the luminosity levelling procedure implemented in the SIMATIC WinCC SCADA environment. Data are sent/received to/from LHC over the Data Interchange Protocol (DIP) [2].

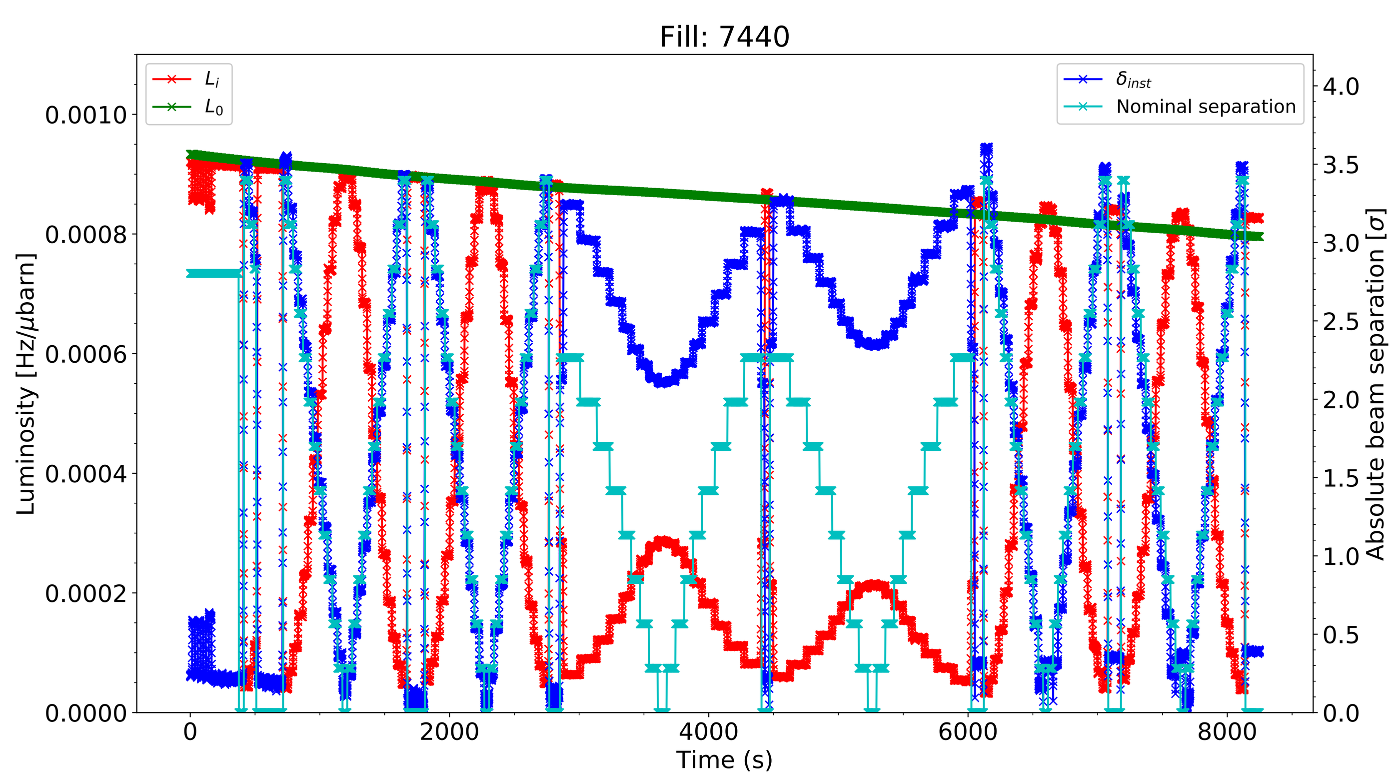


- The luminosity levelling Graphical User Interface in the LHC_IF WinCC expert application is shown below.



Van der Meer scans with heavy ion beams

- Van der Meer scans, in which the beams are scanned across each other to determine the cross-section, are a useful diagnostic tool to evaluate the performance of the luminosity levelling.
- When the beams are colliding head-on, δ_{inst}, which is the beam separation with respect to the absolute luminosity, should be 0, as is the case below.
- This is the case only when the measured beam emittance is used, and therefore this is seen as a useful calibration of the levelling routine.



Luminosity Levelling Procedure

- Luminosity levelling is required to limit the event pile up probability in ALICE to a few percent.
- Maximum luminosity which LHC could provide in 2018 heavy ion run: **6 x 10^{27} cm^{-2}s^{-1}**
- ALICE target luminosity in 2018 heavy ion run: **1 x 10^{27} cm^{-2}s^{-1}**
- **Beam separation** used to achieve desired lower luminosity in ALICE.

The beam separation in units of beam σ between the current luminosity and the target luminosity can be determined by inverting the luminosity formula as follows [1]:

$$L = \frac{N_1 N_2 f_{\mathrm{rev}} N_b}{2\pi\sqrt{\sigma_{1,x}^2+\sigma_{2,x}^2}\sqrt{\sigma_{1,y}^2+\sigma_{2,y}^2}} F \cdot W \cdot e^{\frac{B^2}{A}} \quad (1)$$

$$F = \frac{1}{\sqrt{1+2\frac{\sigma_s^2}{\sigma_{1,y}^2+\sigma_{2,y}^2}\tan\frac{\alpha}{2}}} \quad (2)$$

$$W = e^{-\frac{(d_2-d_1)^2}{2\left(\sigma_{1,x}^2+\sigma_{2,x}^2\right)}}. \quad (3)$$

$$\sigma = \sqrt{\beta^*\epsilon}. \quad (4)$$

$$\log L = \log L_0 - \frac{(d_2-d_1)^2}{4\sigma^2} \quad (5)$$

$$\delta_{\mathrm{ref}} = 2\sqrt{|\log L_0 - \log L_{\mathrm{ref}}|} \quad (6)$$

$$\delta_{\mathrm{inst}} = 2\sqrt{|\log L_0 - \log L_i|}. \quad (7)$$

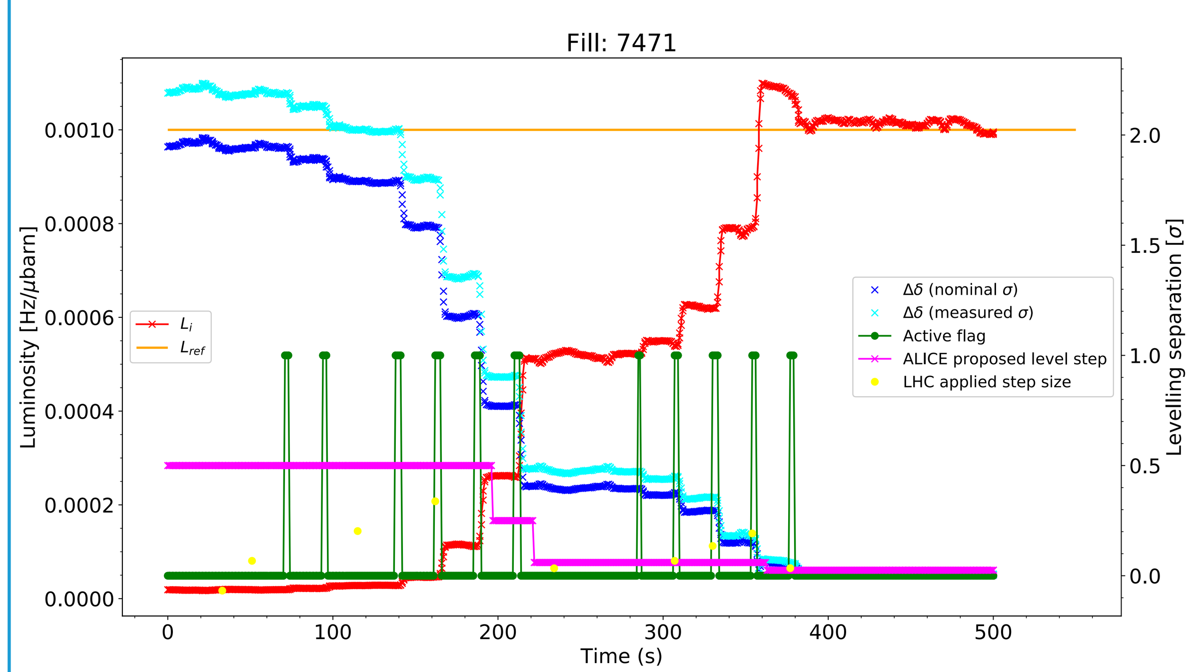
$$\Delta\delta = |\delta_{\mathrm{ref}} - \delta_{\mathrm{inst}}|. \quad (8)$$

The step size Δd to transmit to LHC is then calculated as per the below ranges of validity for Δδ:

If Δδ ≥ 0.52; Δd = 0.5
If Δδ ≥ 0.27 and Δδ < 0.52; Δd = 0.25
If Δδ ≥ 0.07 and Δδ < 0.27; Δd = 0.06
If Δδ < 0.07; Δd = 0.025

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 β* ever of 0.5 m.
- Early on during the run, it was apparent that the luminosity levelling procedure was slow to converge, and the luminosity itself was half what was expected.
- After some beam tests by LHC, the cause was put down to a beam deformation and reduced overlap at the IP due to strong local betatron coupling in IR2.
- This effectively increased the beam size at IP2 by 50%, and reduced the actual steps being applied by a factor 2.

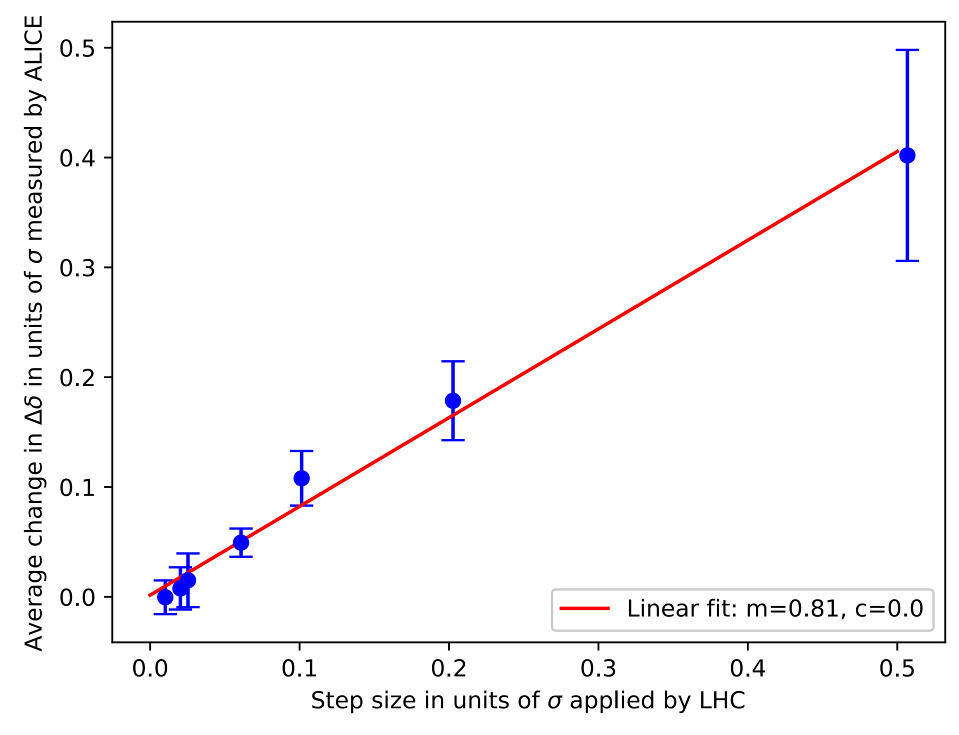


An example of luminosity levelling at the start of stable beams.

The step sizes applied by LHC (yellow) are derived from a different routine to those proposed by ALICE (magenta) due to the beam size and convergence issue.

The change in Δδ measured after each step was compared to the step size applied by LHC, assuming a beam size larger than nominal by 50%.

A linear fit applied to the data shows that the average change in Δδ scales less linearly with the step size applied by LHC than was observed during proton-proton physics.



- **Main conclusions:** 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.

References

[1] G. De Cataldo, G. Valentino, A. Franco, R. Alemany, F. Follin, M. Hostettler, J. Wenninger, "An upgraded luminosity levelling procedure for the ALICE experiment", IEEE Transactions on Nuclear Science, vol. 66, no. 5, pp. 763-770, 2019.

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

*gianluca.valentino@um.edu.mt