Buch-by-bunch Luminosity Variations in Run 3

A first look at the Run 3 fills of 2022

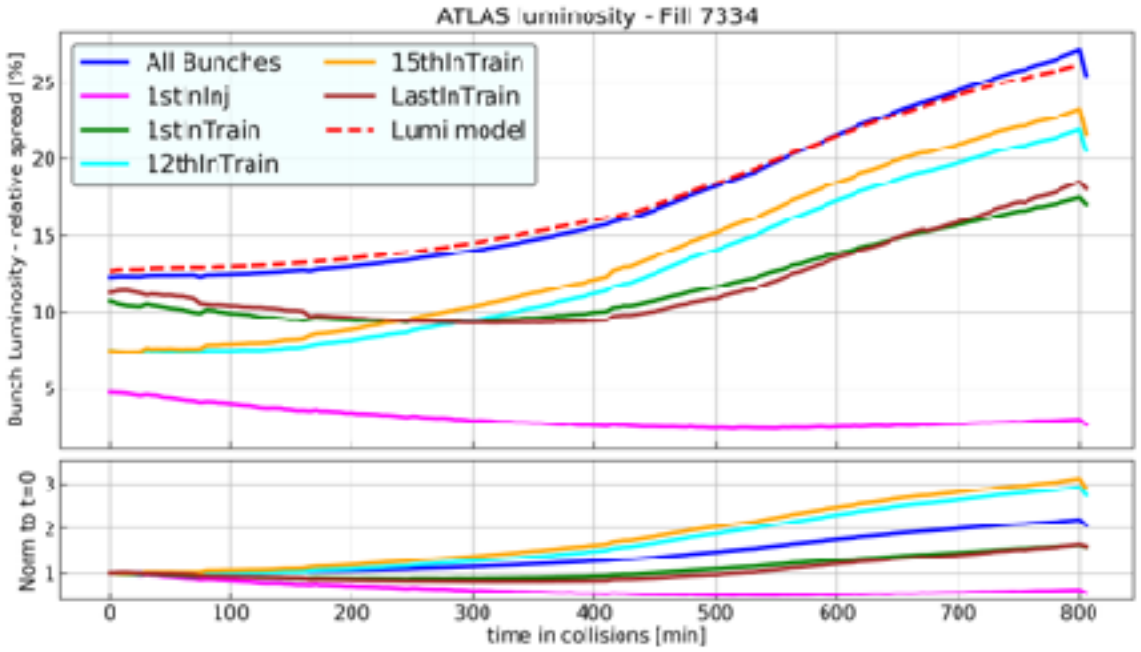
WP2 Session - 12th HL-LHC Collaboration Meeting

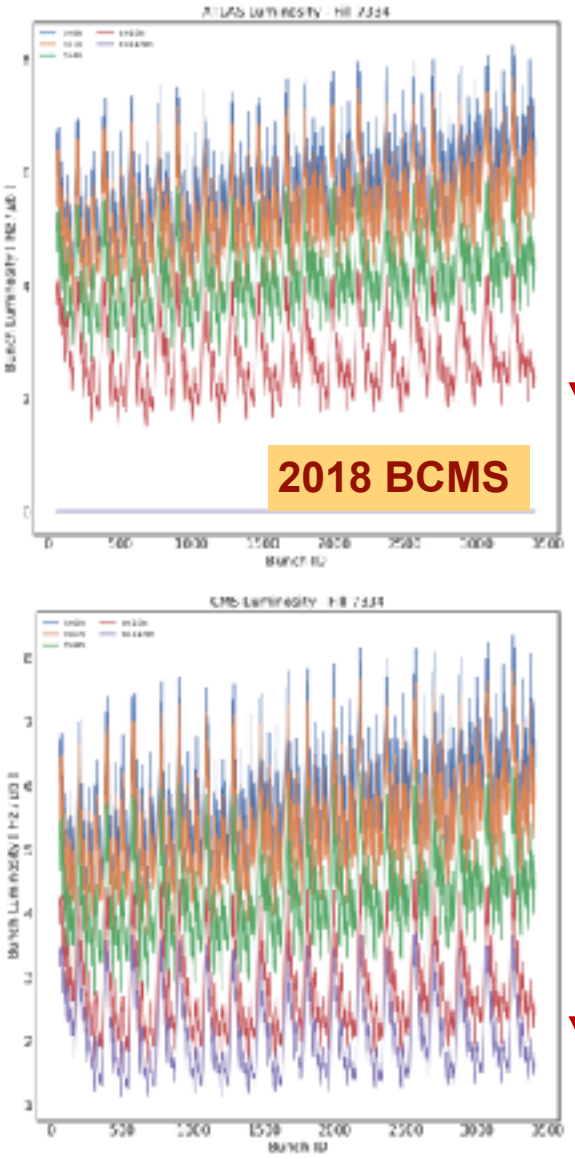
I. Efthymiopoulos

..with many thanks to G.Sterbini for the help with NXCALS

Bunch-to-Bunch Luminosity Variations in LHC Run 2 Reminder

- A large b2b-variation in the luminosity was observed, growing with time in collisions : from the initial 12-15% to ~25% @ 10h mainly for the BCMS fills, reduced for 8b4e
- Level dependant on the bunch position in the train pointing to combined effects of e-cloud and BB
- Not a major issue in Run 2 as the luminosity was decaying with time - however for HL-LHC operation with the levelled luminosity may cause problems to the experiments





B2B Luminosity Variation in HL-LHC

$$R_{\text{inst}} = \sigma_{\text{vis}}\,\mathcal{L}_{\text{inst}} = \sigma_{\text{vis}} \sum_{N_b} \mathcal{L}_{b,\text{inst}}$$

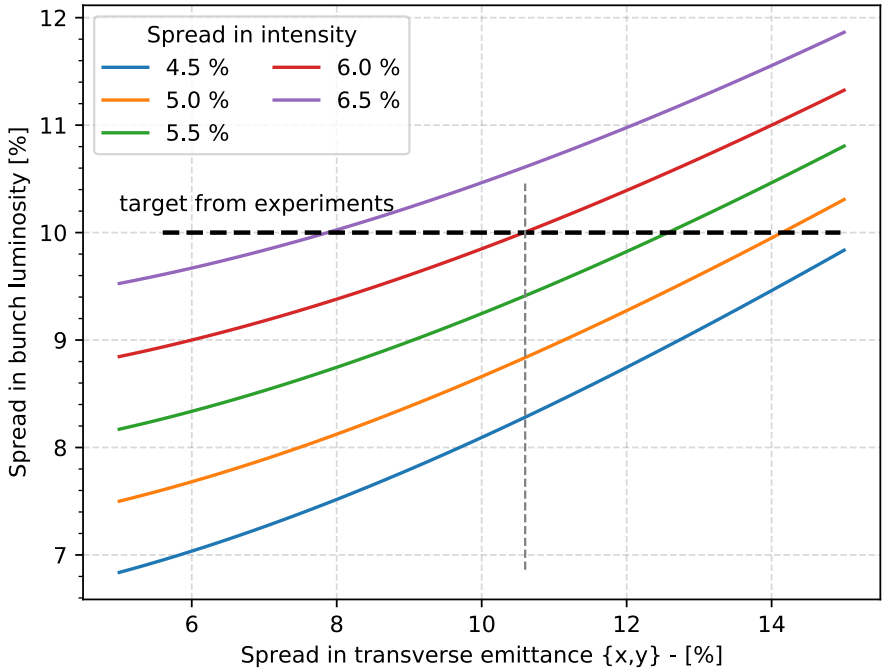
$$\mathcal{L}_{b,inst} = \frac{f N_1 N_2}{2\pi \sqrt{\beta^*_{1,2\,x}\,\beta^*_{1,2\,y}}\sqrt{\epsilon_{1x}+\epsilon_{1x}}\sqrt{\epsilon_{1y}+\epsilon_{2y}}} S_{\sigma_s,\sigma_\times,\phi_\times}$$

$$\frac{\delta\mathcal{L}}{\mathcal{L}} = \sqrt{2\left(\frac{\delta N}{N}\right)^2 + \frac{1}{8}\left(\frac{\delta\epsilon_x}{\epsilon_x}\right)^2 + \frac{1}{8}\left(\frac{\delta\epsilon_y}{\epsilon_y}\right)^2}$$

Pile-up event @ HL-LHC

Limit for the experiments :

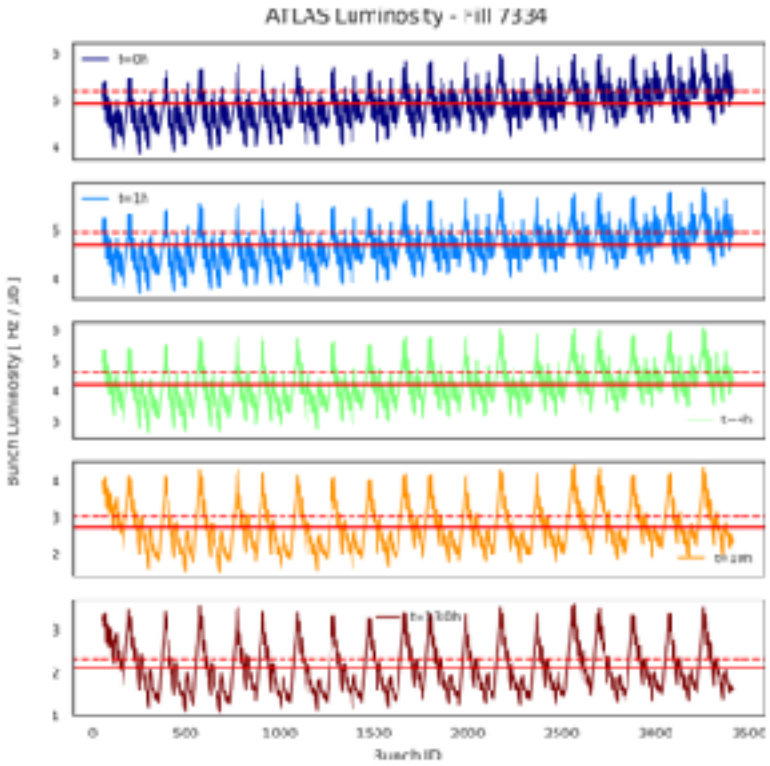
- **<10% at the Start-of-Collisions** to remain within the capacity of the DAQ and Trigger systems and in the shadow of the natural Poisson PU spread
- **Target values for Injectors:**
  - **10% in transverse emittance**,
  - **6% in intensity**

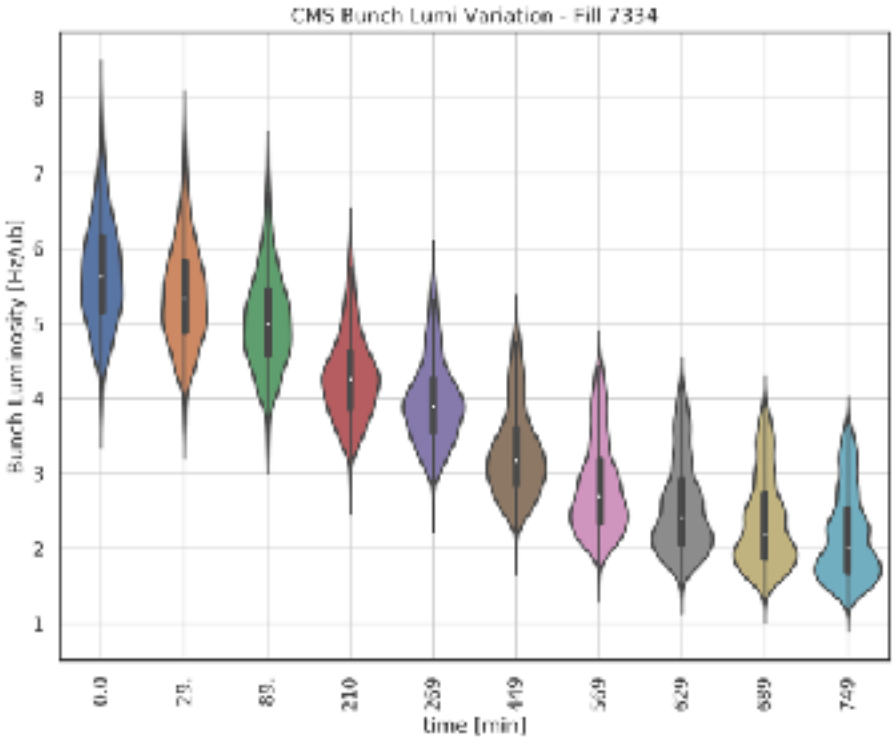


Fill 7334 – 2018 BCMS LHCb/neg

Bunch lumi vs time

- red line = mean luminosity
- Dashed line = +10%





Luminosity Variations in Run 3

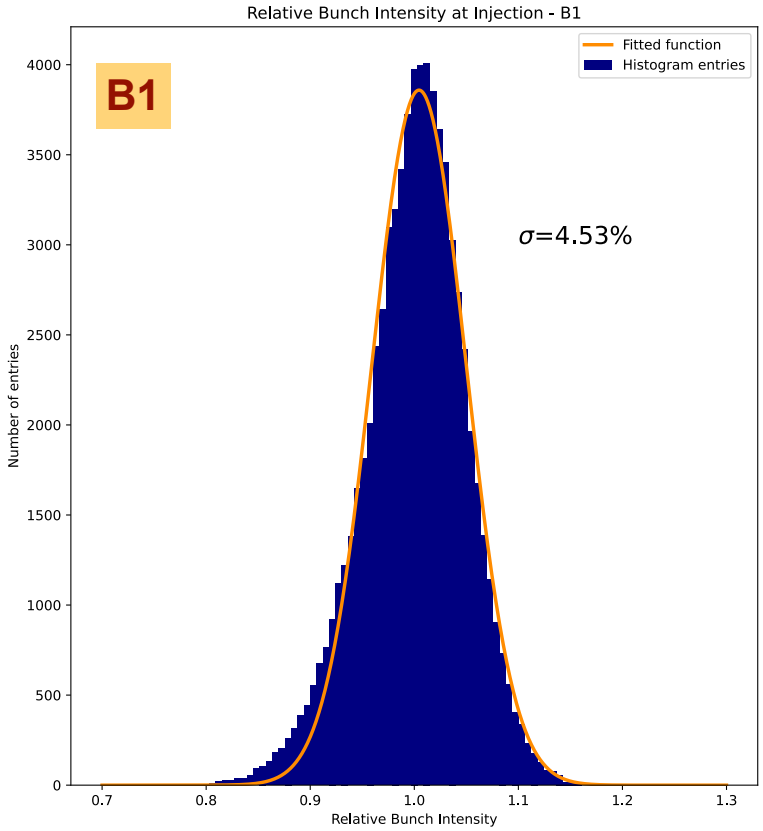
- First look at the fill data recorded so far
  - Total 65 fills with collisions (>30min)
  - Variety of filling schemes and bunch types
    - Selected fills with at least 1000 bunches/beam

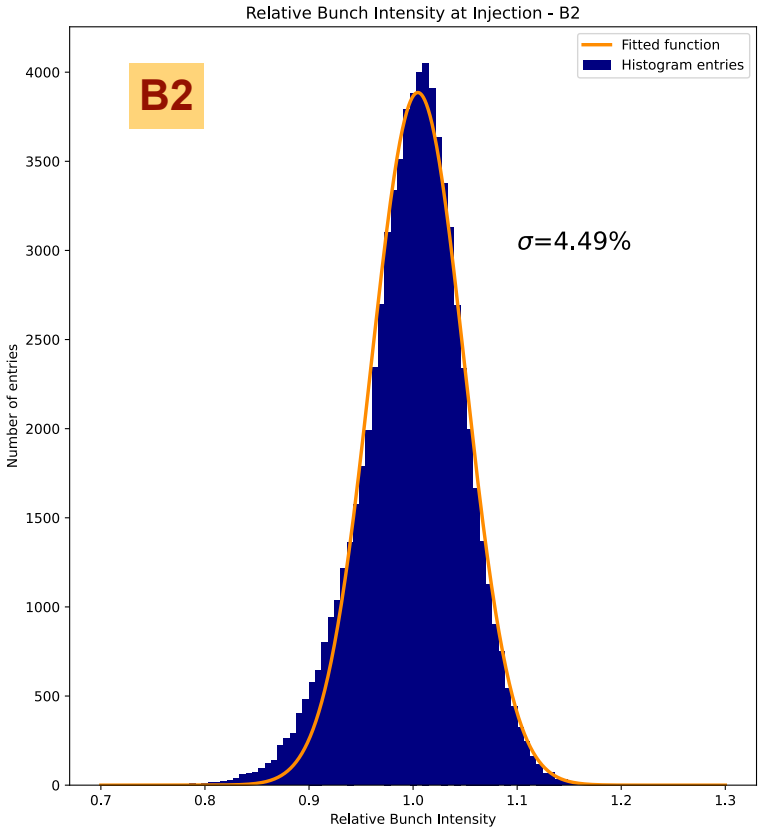
- Use the online luminosities from the experiments (ATLAS & CMS), FBCT and BSRT data

- Study variations along the cycle and evolution during collisions

Run 3 - variations along the cycle

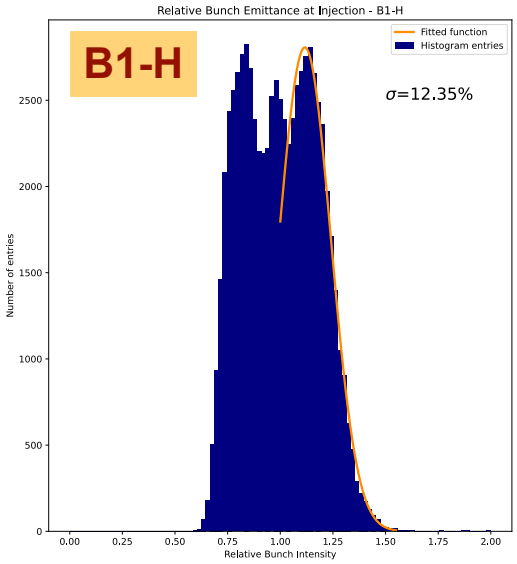
- Injection - FBCT data

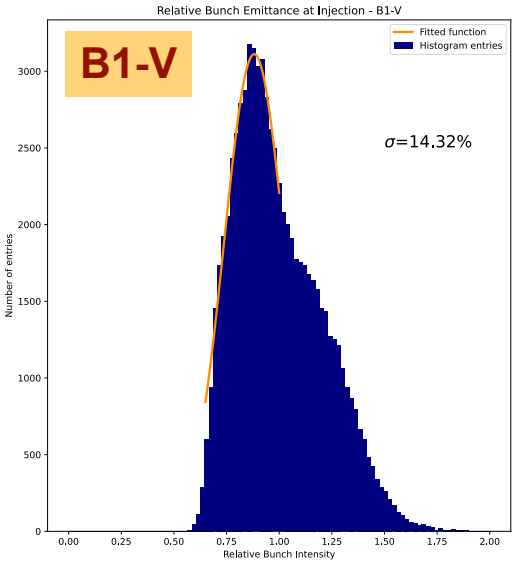


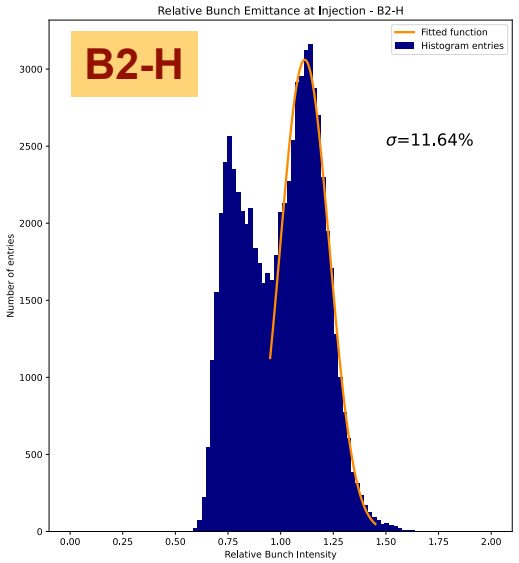


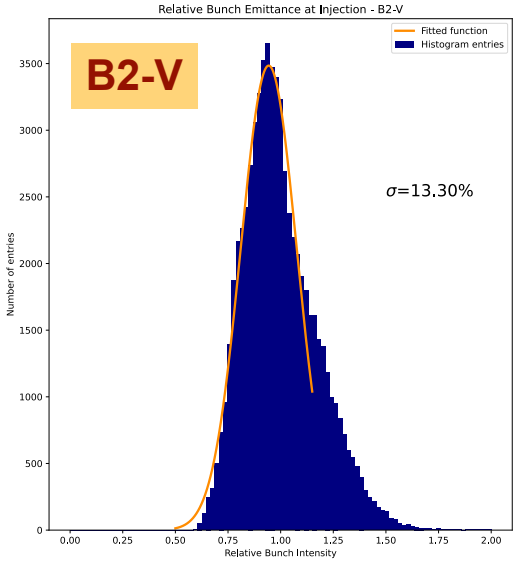
Run 3 - variations along the cycle

- Injection - BSRT data





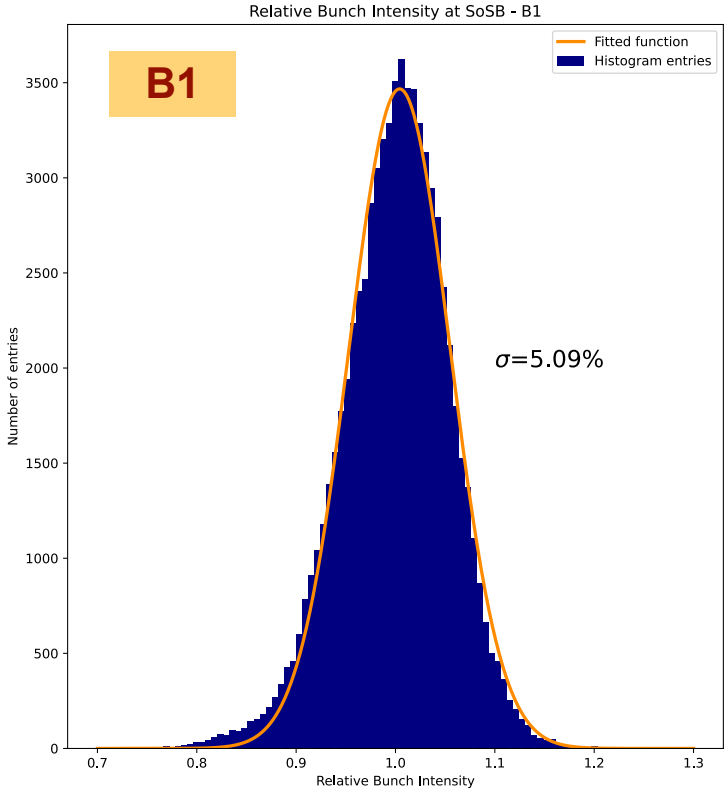


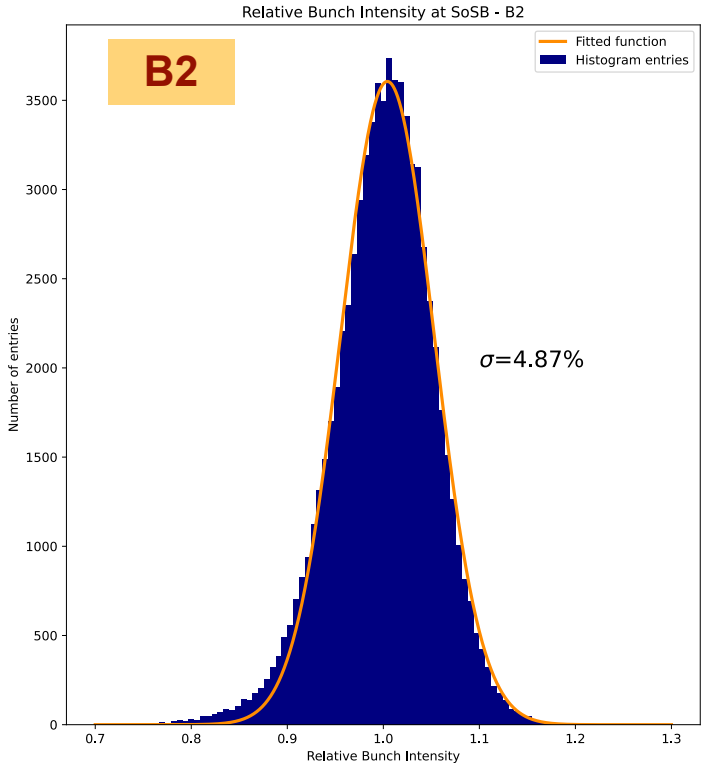


- All bunches, including INDIVs and within trains, 8b4e, … which can explain the tails and the double distributions
  - decided not to clean the bunches to have an (worse-case?) estimate for the hybrid schemes under discussion

Run 3 - variations along the cycle

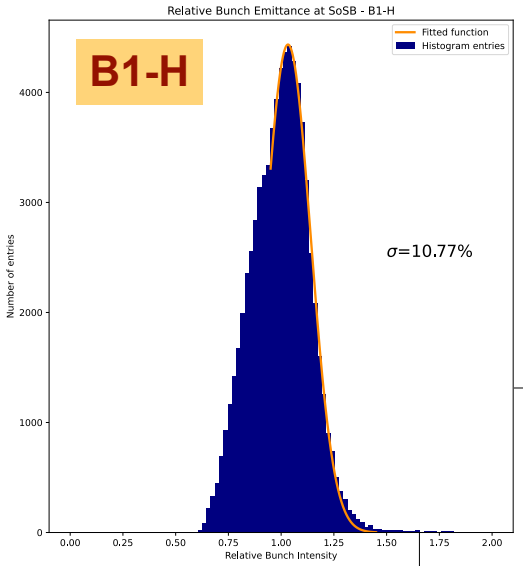
- Start of Collisions - FBCT data

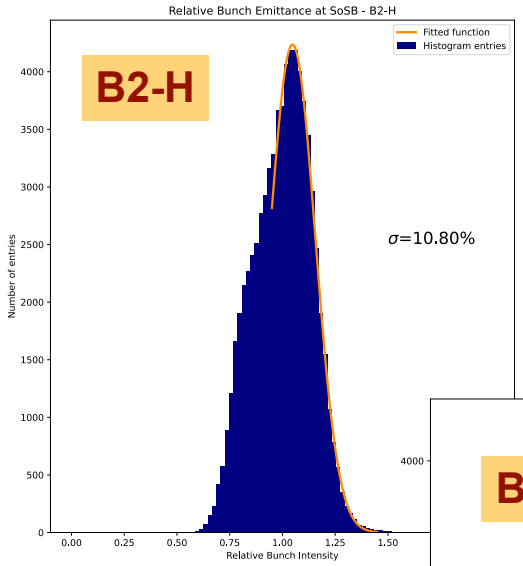


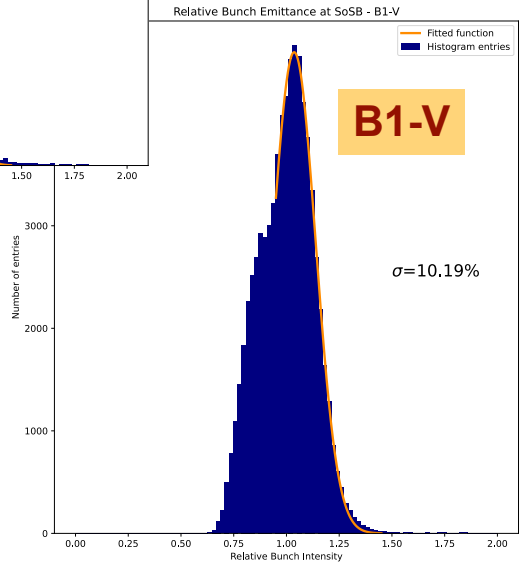


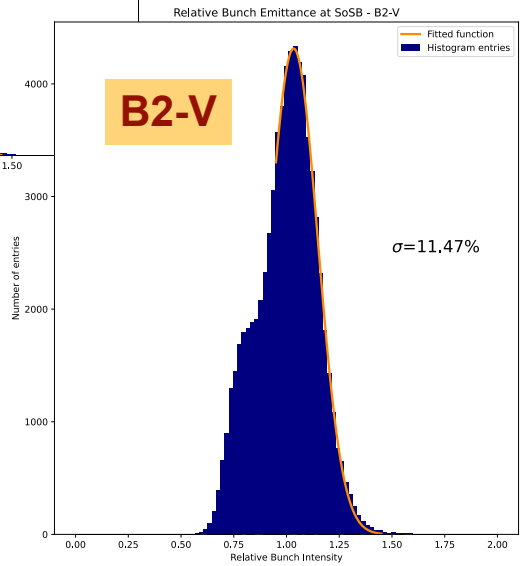
Run 3 - variations along the cycle

- Start of Collisions - BSRT data



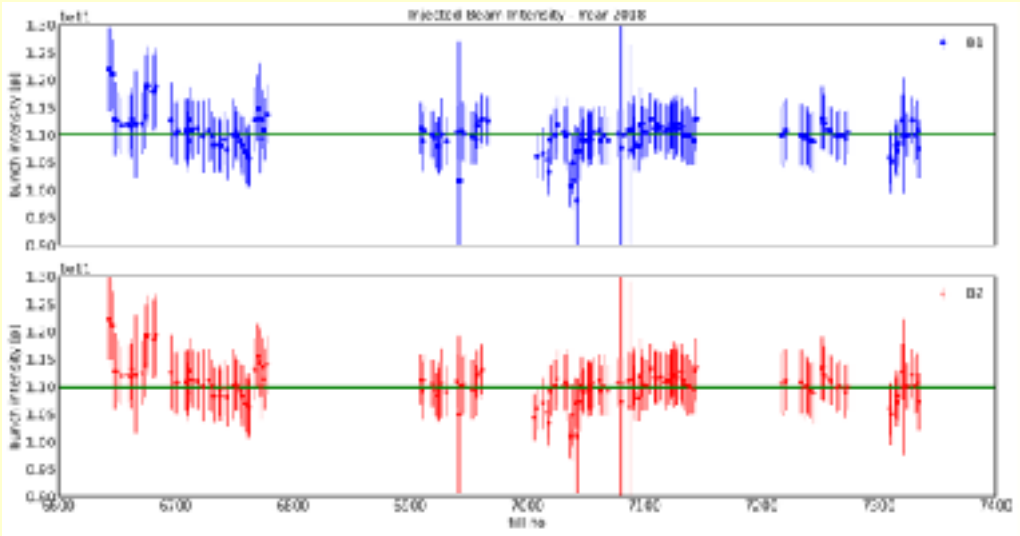


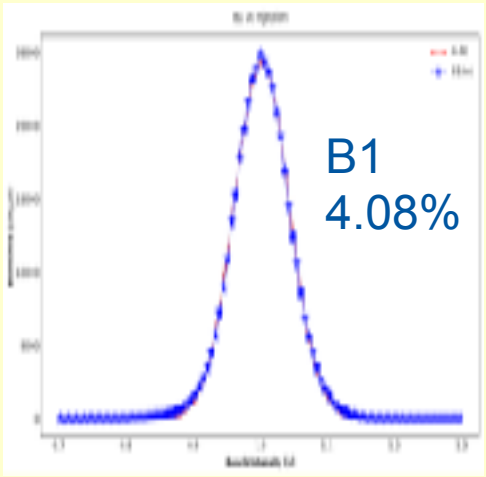


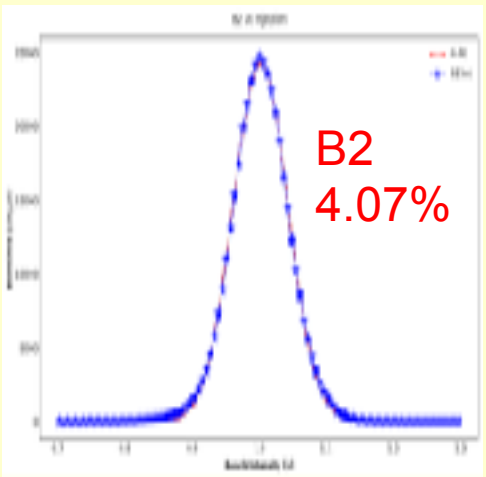


Run 2 : Intensity fluctuations in the cycle

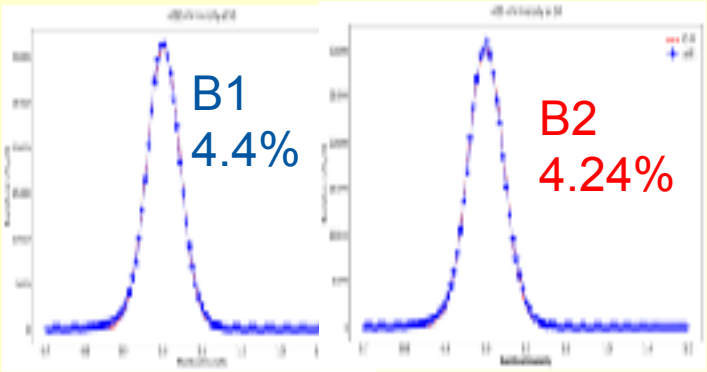
Injection – beam intensity 2018







Stable Beam – Intensity



Emittance

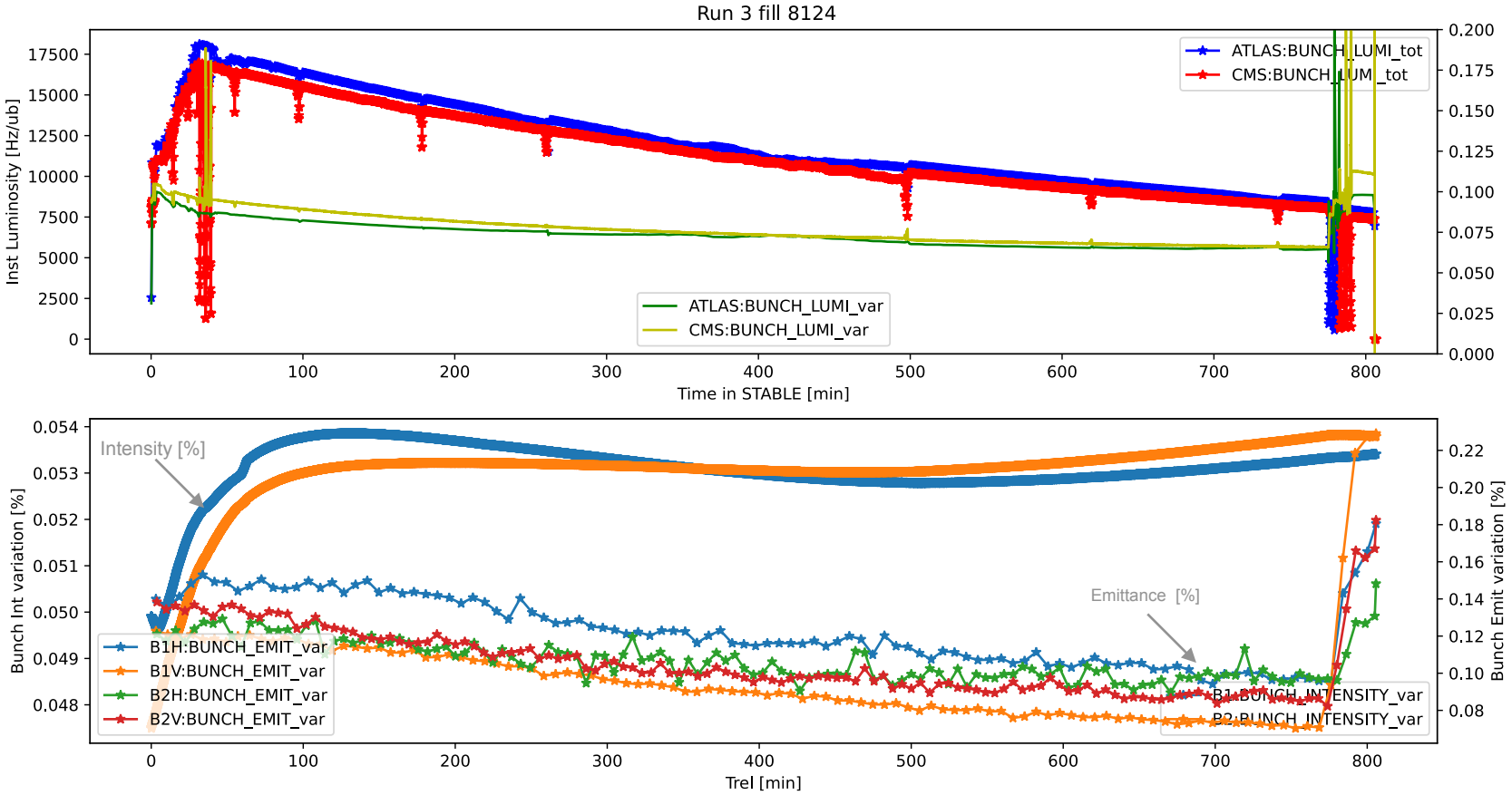
	B1H	B1V	B2H	B2V
Inj	4.78%	4.6%	4.96%	5.1%
SB	6.54%	7.78%	*13.64%*	9.86%

From BSRT data – all fills without any selection !

Luminosity Variations in Run 3

- Fill **8124** - b2b variations decrease with time in collisions !

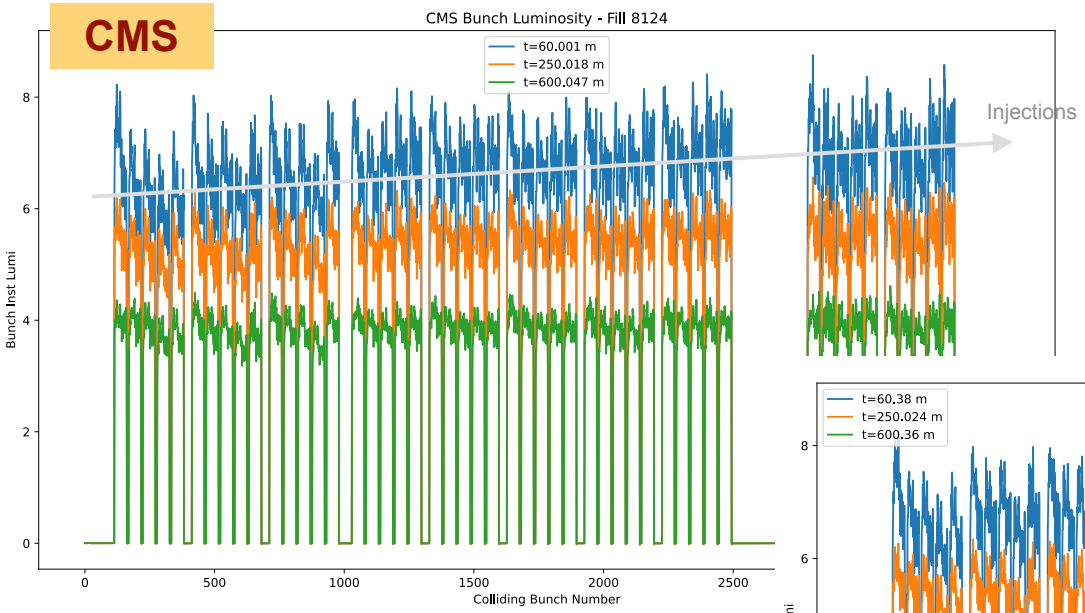
25ns_2413b_2400_1836_1845_240bpi_12inj_1INDIV

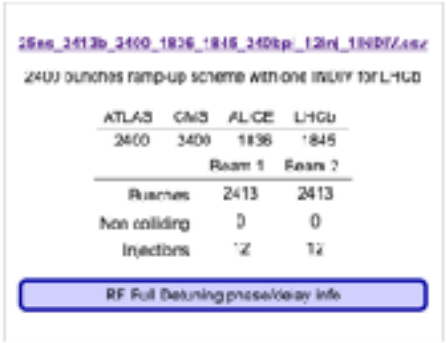


Luminosity Variations in Run 3

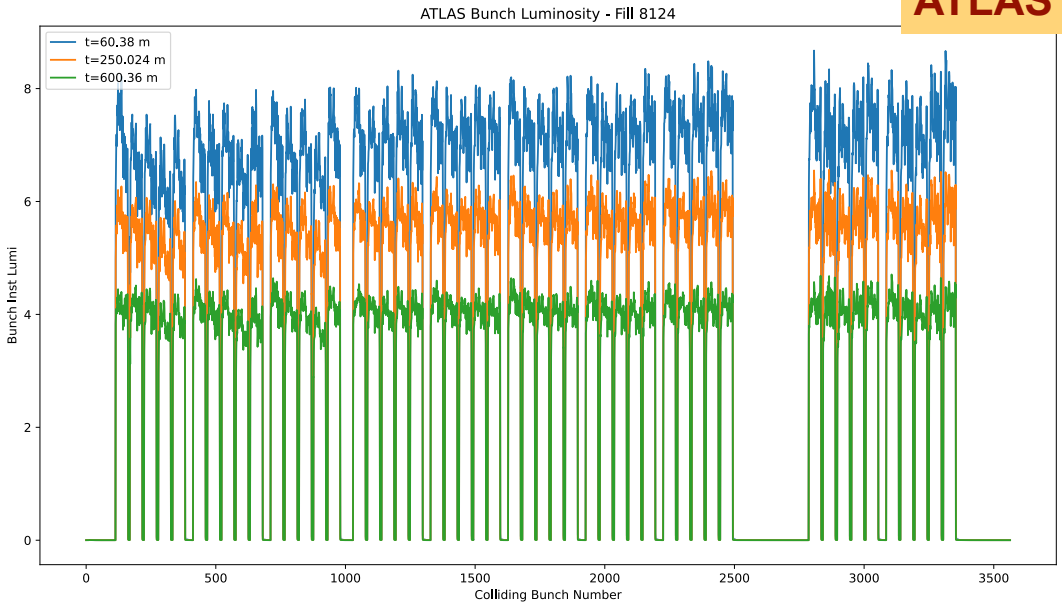
- Fill **8124** - bunch luminosity in collisions

CMS





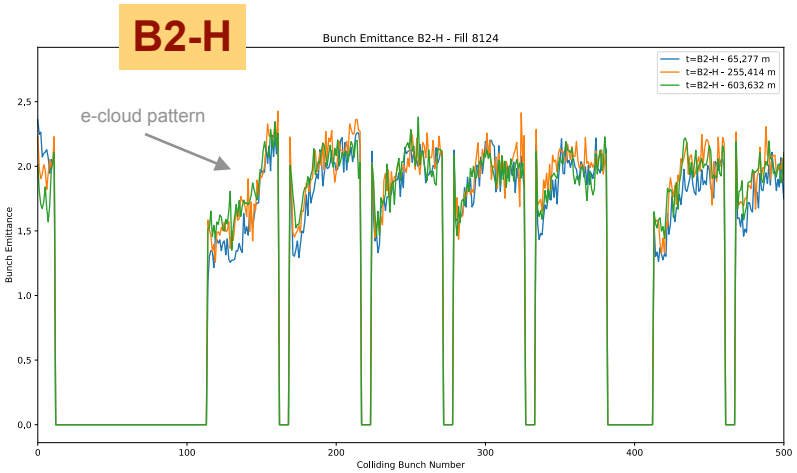
ATLAS

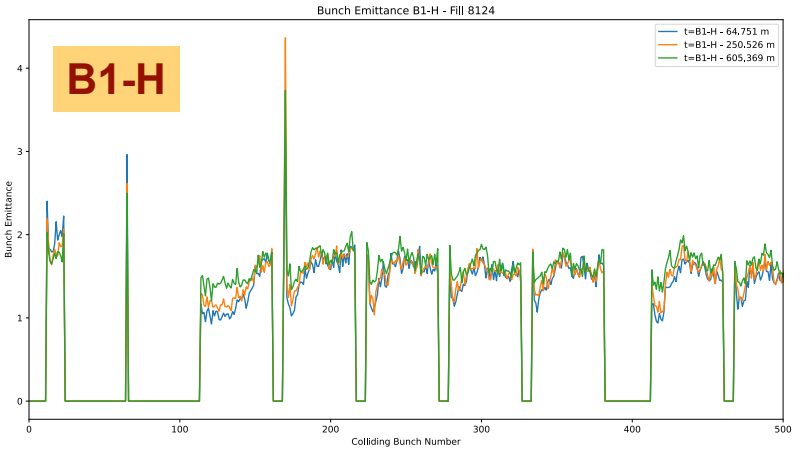


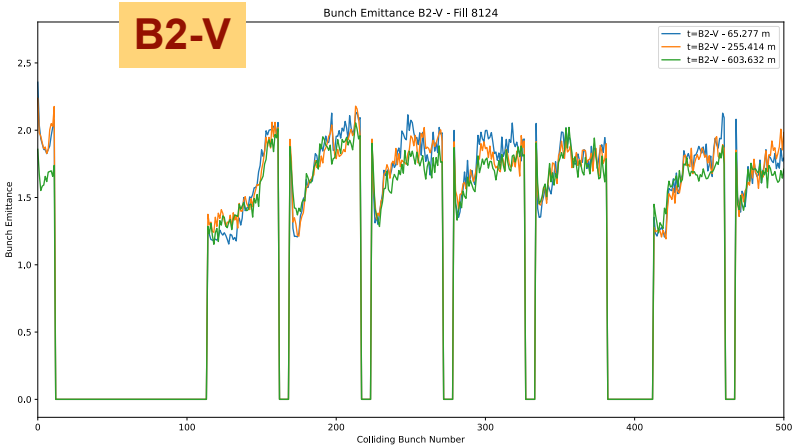
- Signature of time-at-flat bottom visible in the bunches at SoSB
  - spread within the trains reduced inversely with time at FB
  - overall slope ~15% from early to late injected trains

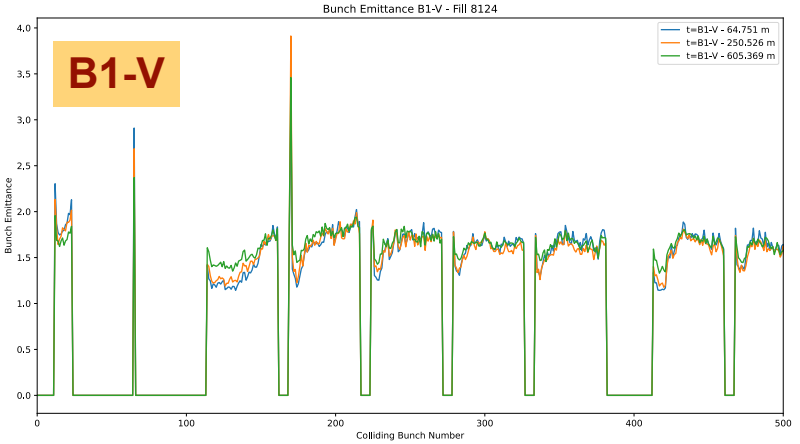
Luminosity Variations in Run 3

- Fill **8124** - bunch emittance in SB





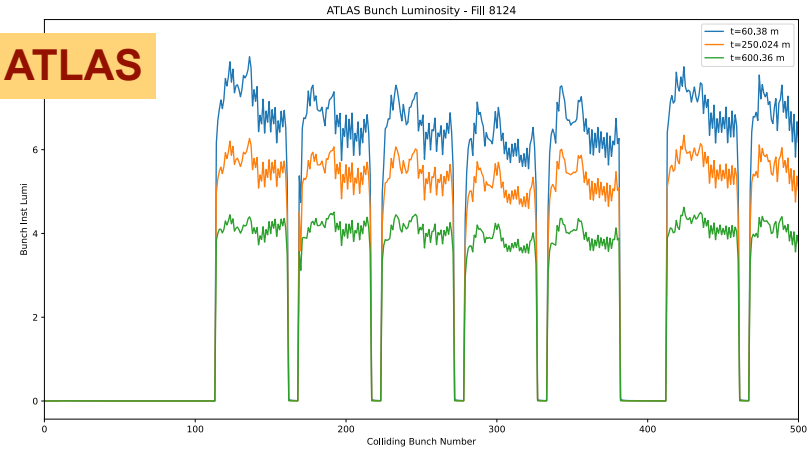




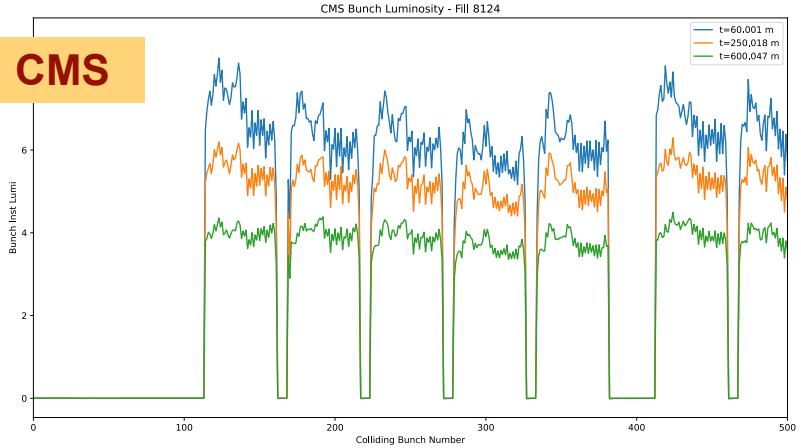
Luminosity Variations in Run 3

- Fill **8124** - bunch intensity & luminosity in SB

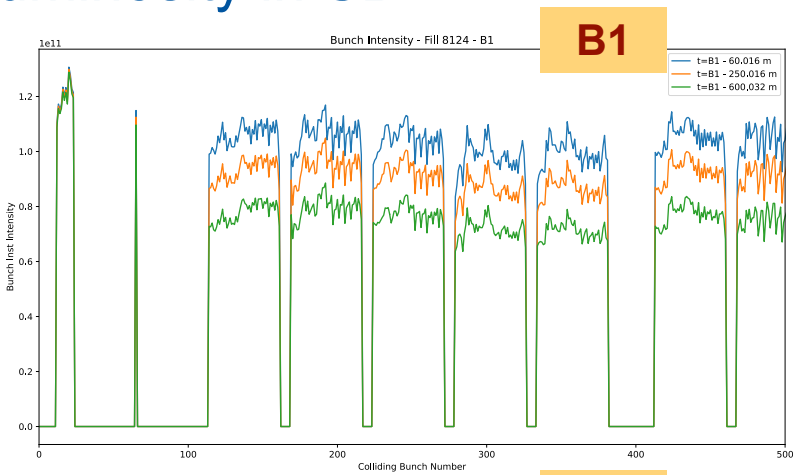
ATLAS



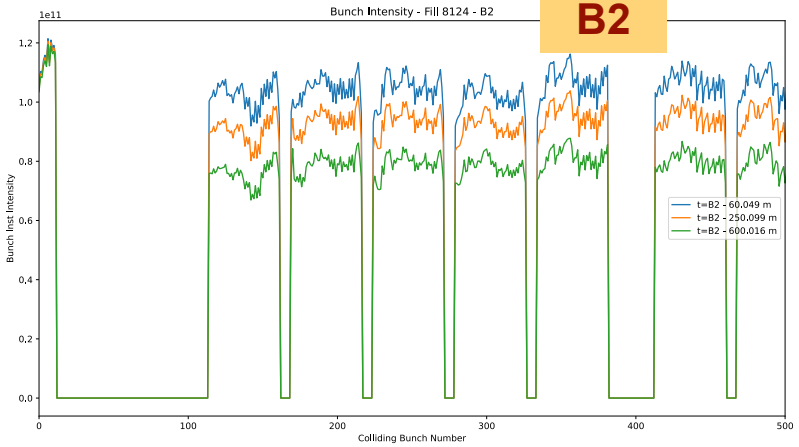
CMS



B1

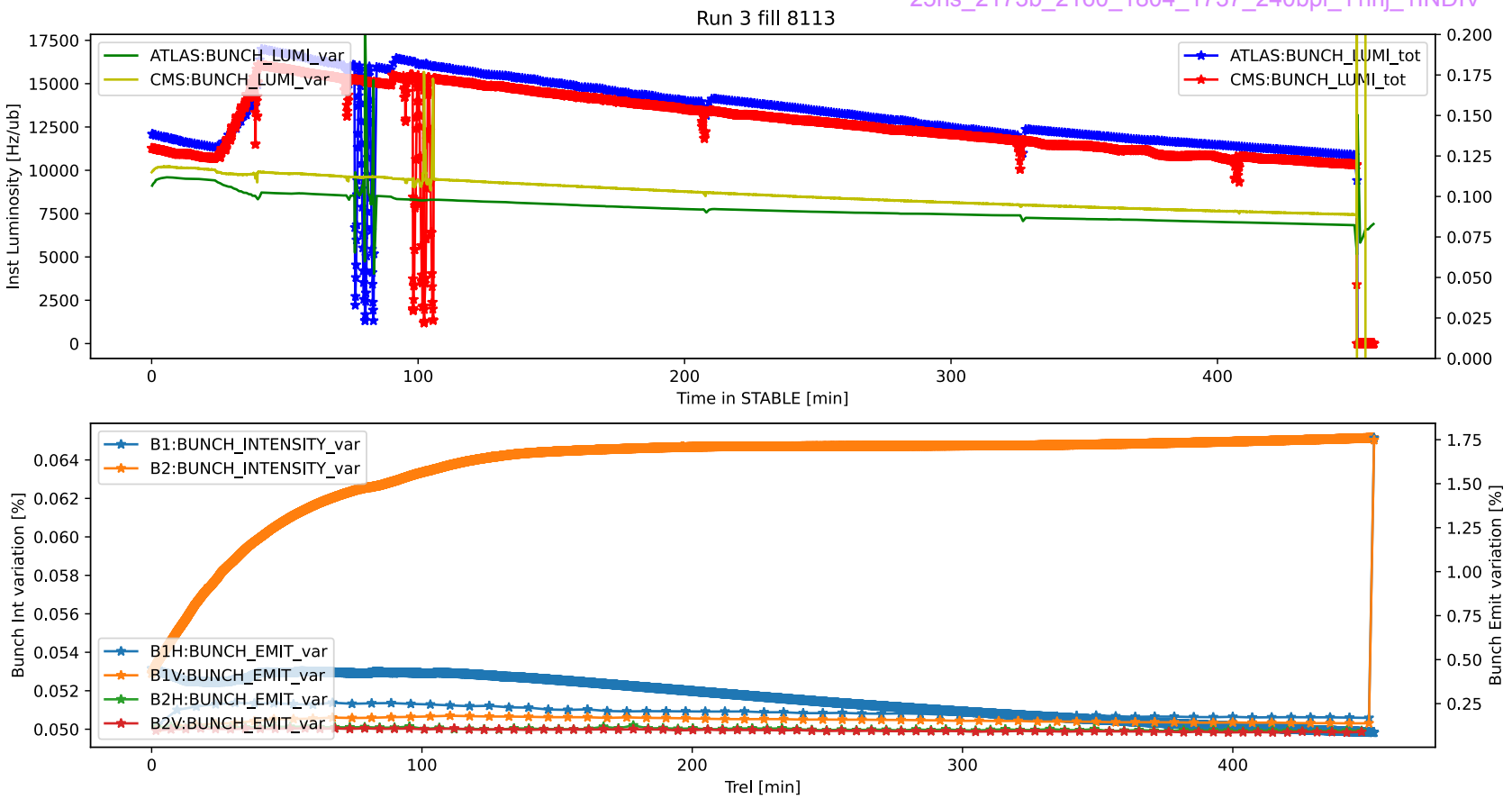


B2



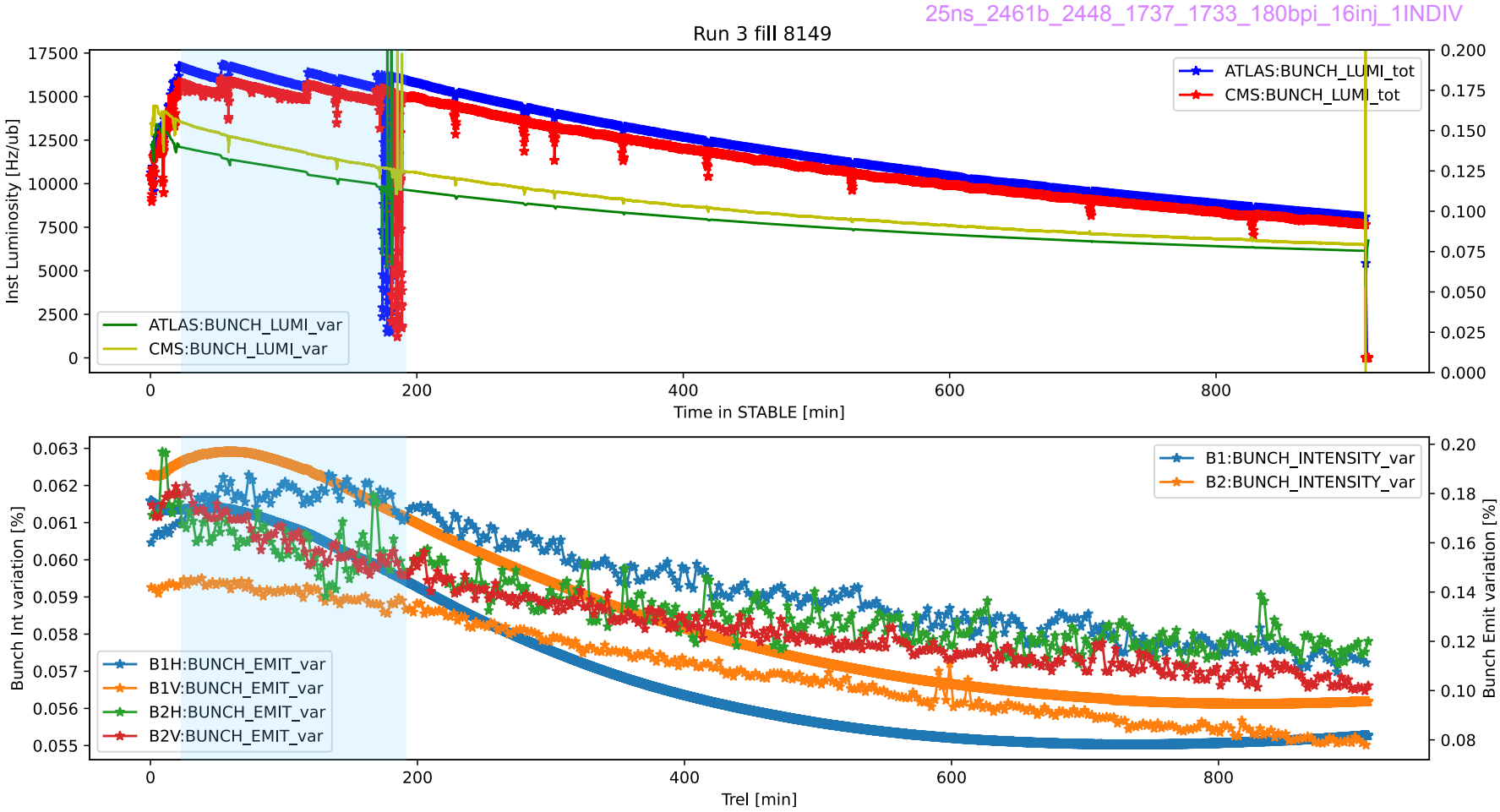
Luminosity Variations in Run 3

- Fill **8113** - b2b variations decrease with time in collisions !



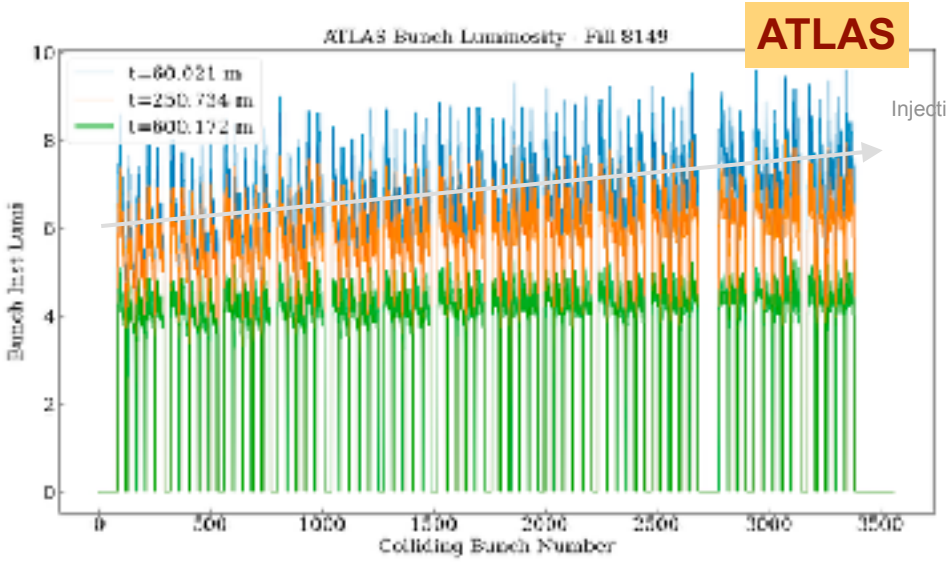
Luminosity Variations in Run 3

- Fill **8149** - levelling for ~3h



Luminosity Variations in Run 3

- Fill **8149**



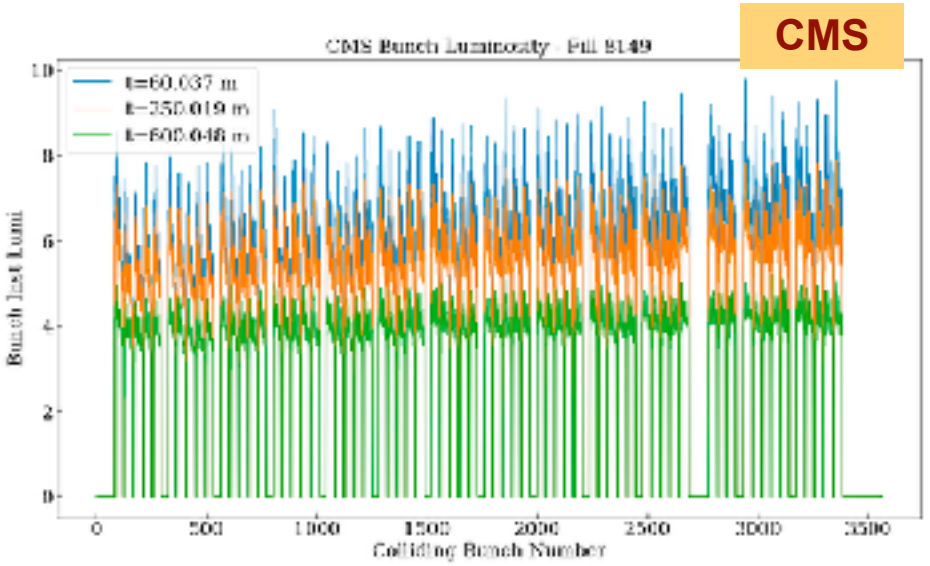
ATLAS

25ns_2461b_2448_1737_1733_180bpi_16inj_1INDIV.csv

Machine full with 36b trains and one INDIV for LHCb

	ATLAS	CMS	ALICE	LHCb
	2448	2448	1737	1733
		Beam 1	Beam 2	
Bunches		2461	2461	
Not colliding		0	0	
Injections		16	16	

RF Full Detuning phase/delay info

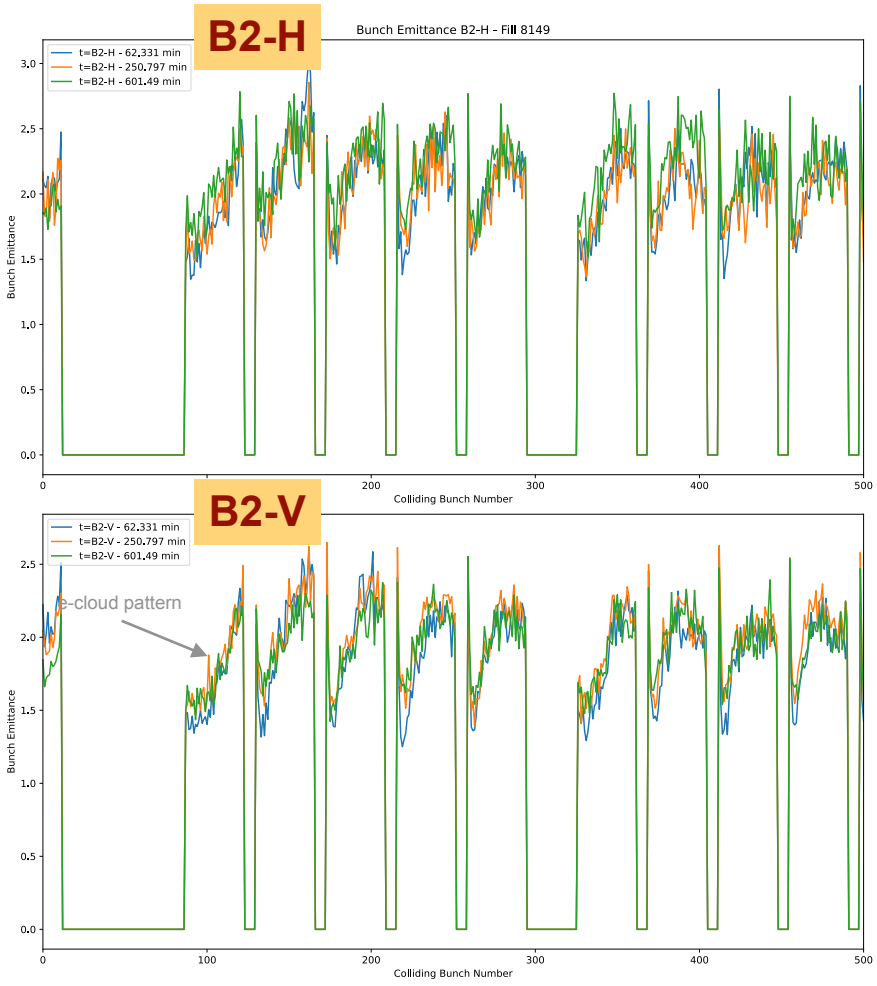


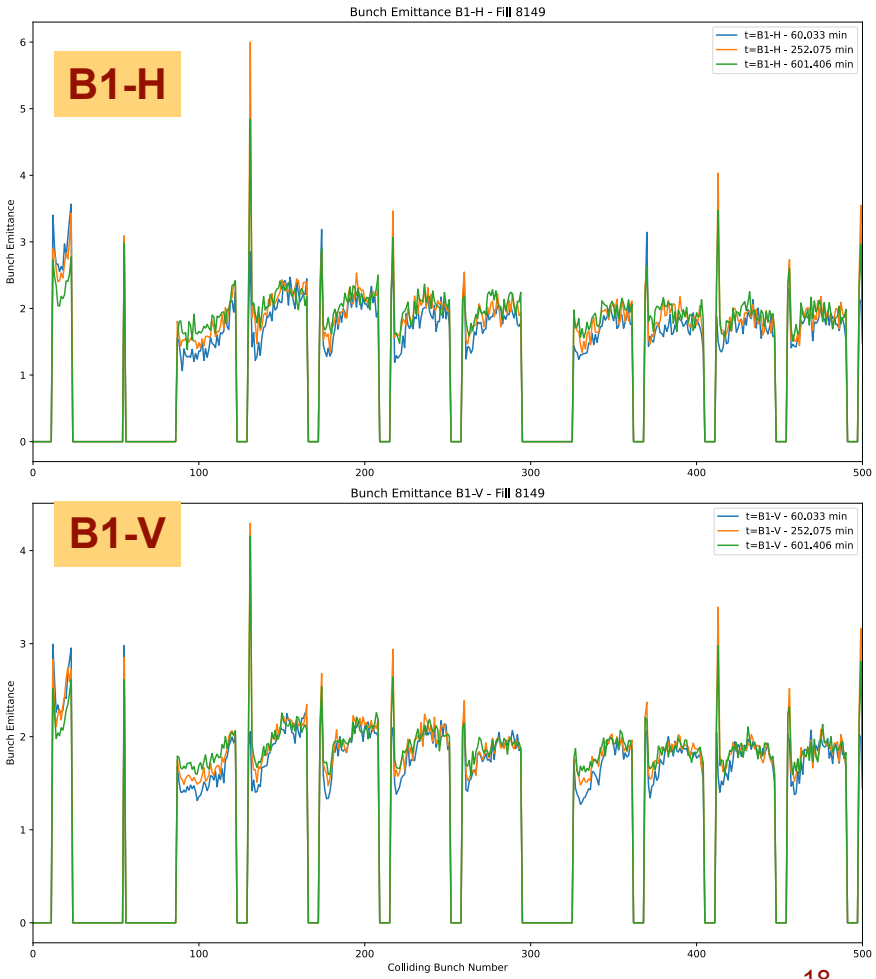
CMS

- Signature of time-at-flat bottom visible in the bunches at SoSB
  - spread within the trains reduced inversely with time at FB
  - overall slope ~20% from early-to-late injected trains

Luminosity Variations in Run 3

- Fill **8149** - bunch emittance in SB

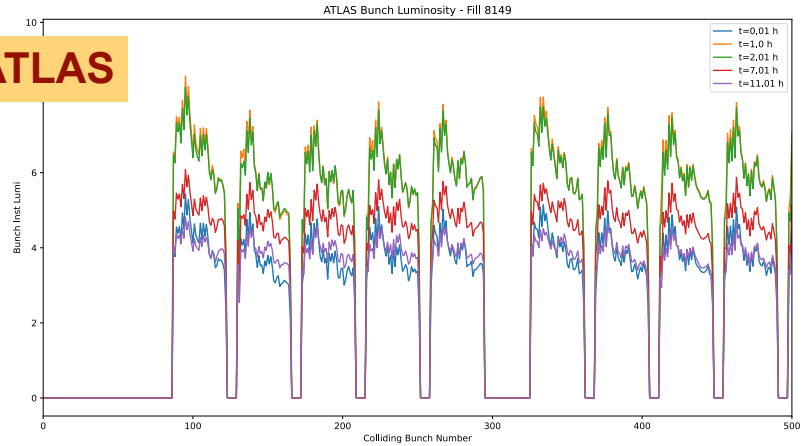


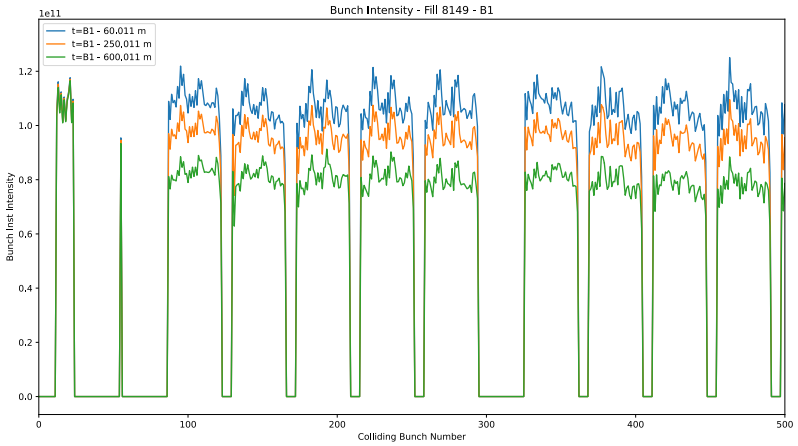


Luminosity Variations in Run 3

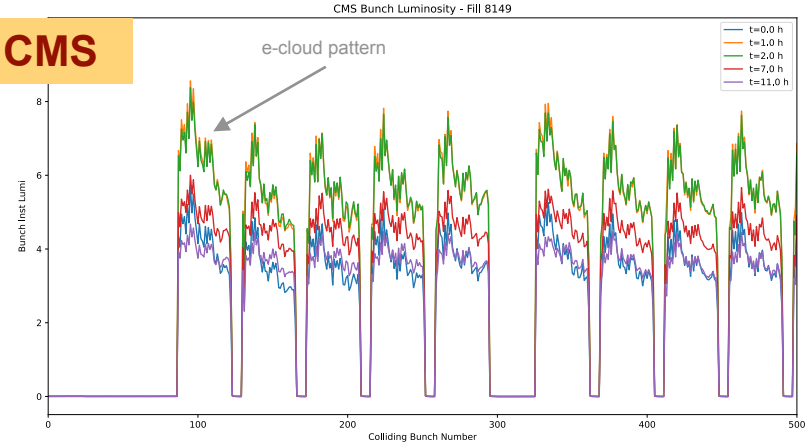
- Fill **8124 -** bunch intensity & luminosity in SB

ATLAS

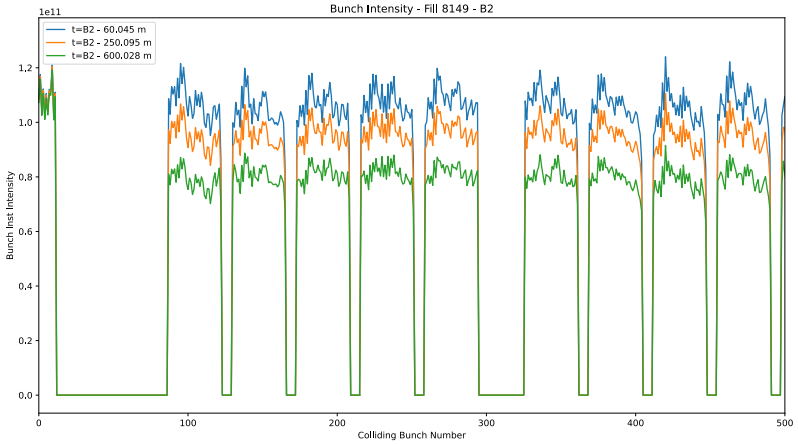




CMS



B2



Summary

- First results on the b2b variations in the Run 3 data shown
  - few representative fills, a complete analysis of all fills is ongoing

- From the few fills analysed, a dumping of the relative b2b luminosity variations is observed
  - the damping of the b2b variations is present in luminosity, intensity and emittances, and is the inverse picture from Run 2!
  - the picture seems consistent in several fills, even in fills where the e-cloud is at similar levels (if not higher) compared to Run 2

  - If confirmed, will be good news for HL-LHC operation!

However more work is needed to fully understand this change!

- The b2b luminosity variations at SoSB is **~15-17%**, similar to Run 2
  - higher than the target value for HL-LHC (< 10%) but we are in early stages and improvements should be expected with experience in operations and handling of the new upgraded beams from the injections, along with calibrated data from BSRT to confirm the figures shown

- Work will continue with new new data of 2022 along with some model and ideas to understand and possibly explain the observations!