



# Emittance and Luminosity across the LHC Cycle

Follow up from Injection to Stable Beams

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Trad*



# Outline

- Luminosity & Emittance Follow up in Run 2
- Emittance Evolution in the LHC Cycle
- Luminosity bunch-to-bunch fluctuations



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# Luminosity Follow Up in Run 2

- Since **2016** we setup a **continuous follow up** of the LHC performance in terms of **luminosity** and **emittance** and optimization

Developed **Tools** to download LHC data from Logging database (CALIS)

- including BSRT raw and WS profile data – (not yet long profiles!)

**Data processing**: produce time-synch information from various instruments, exp. data (Massi files) plus estimates from the **luminosity model**.

- Processed data stored in EOS - **publicly available** for analysis

**Calculate** relevant quantities and produce a set of standard plots per fill and summary trend-like graphs for long-term follow-up

**Fill quality** analysis in weekly meetings during operations

**Feedback** to LHC Machine Operators, OP team and equipment experts

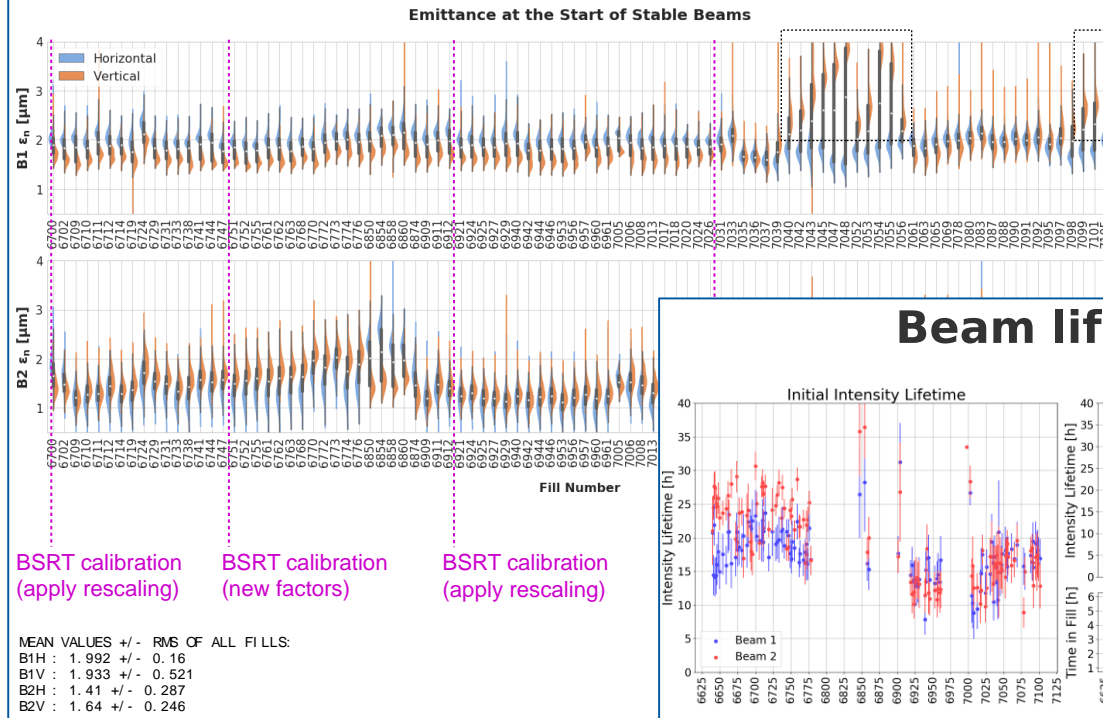
- Reports to meetings



# Weekly Lumi Report - example

## Emittances @ start of SB

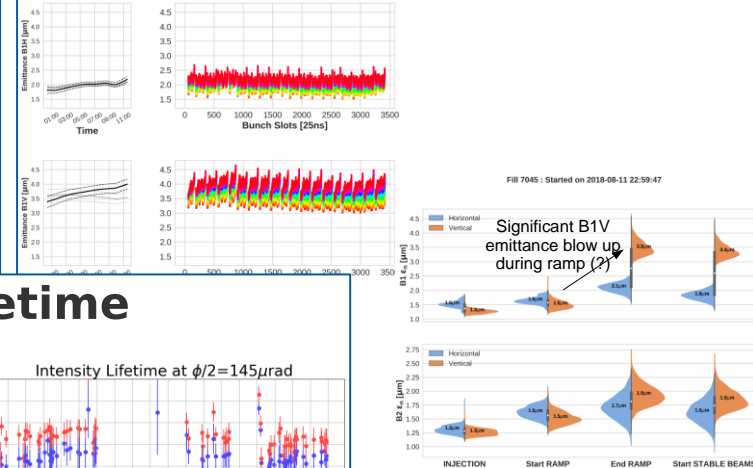
-after Fill 6700



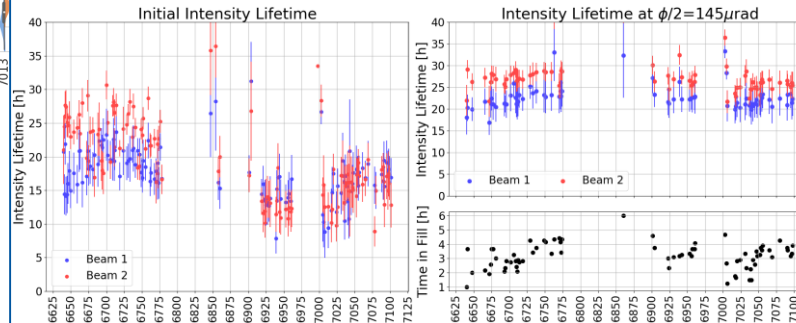
- Activity to continue and hopefully improved for Run 3 !

## Fill 7045

Fill 7045: STABLE BEAMS declared on Sun, 12 Aug 2018 00:24:57



## Beam lifetime



MEAN VALUES +/- RMS OF ALL FILLS

B1 : 17.63 +/- 4.40  
B2 : 19.41 +/- 5.93

MEAN VALUES +/- RMS OF ALL FILLS

B1 : 22.60 +/- 2.79  
B2 : 27.09 +/- 3.83

Lumi Follow up web : <https://lhc-lumimod.web.cern.ch/lhc-lumimod>

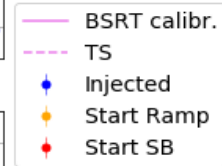
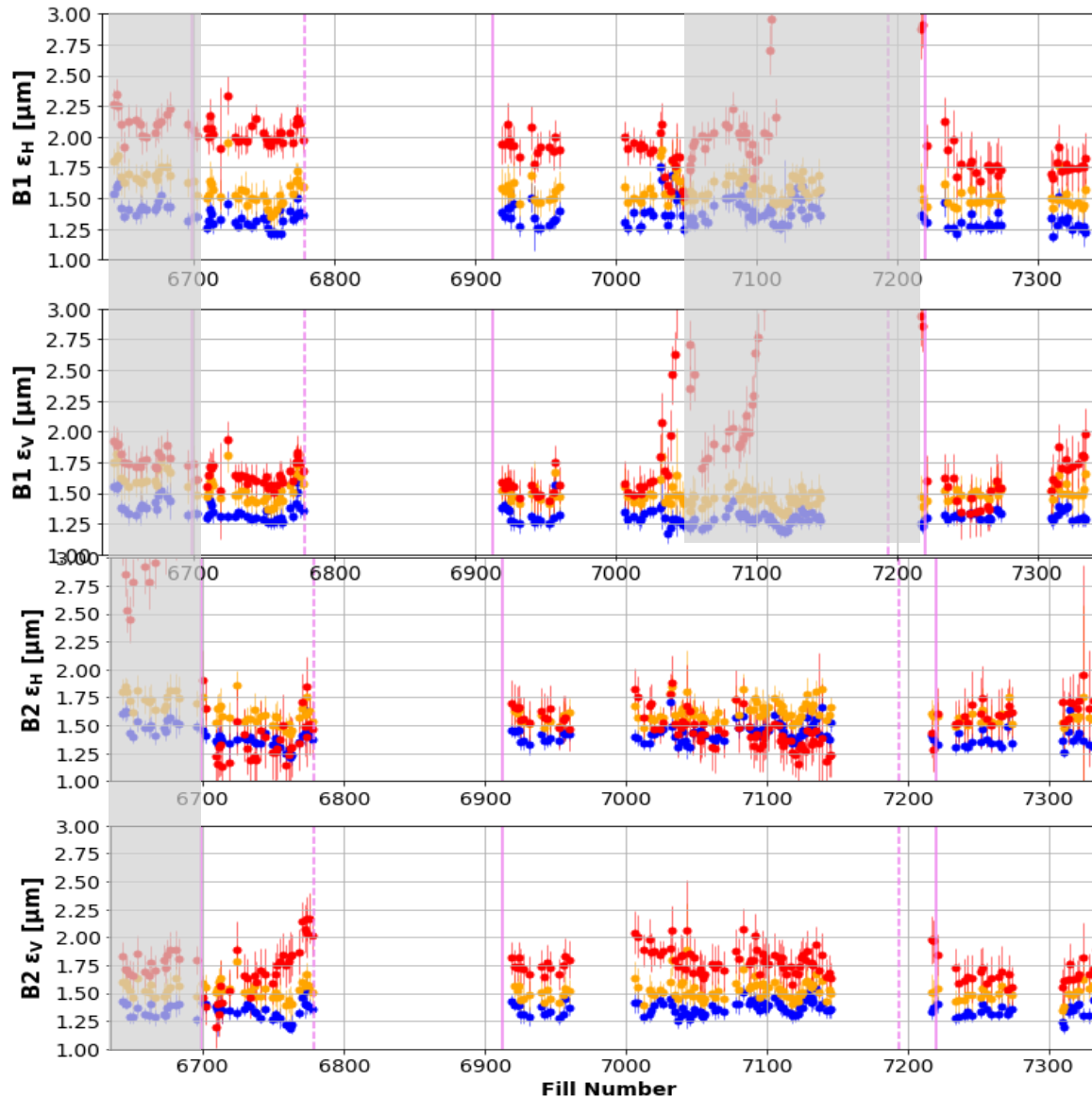


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# 2018 – Emittance along the cycle



**Average emittance values [ $\mu\text{m}$ ]**

	B1 H	B1 V	B2 H	B2 V
Injection	1.4	1.3	1.4	1.4
start Ramp	1.6	1.5	1.6	1.5
Stable Beams	2.0	1.7	1.5	1.7

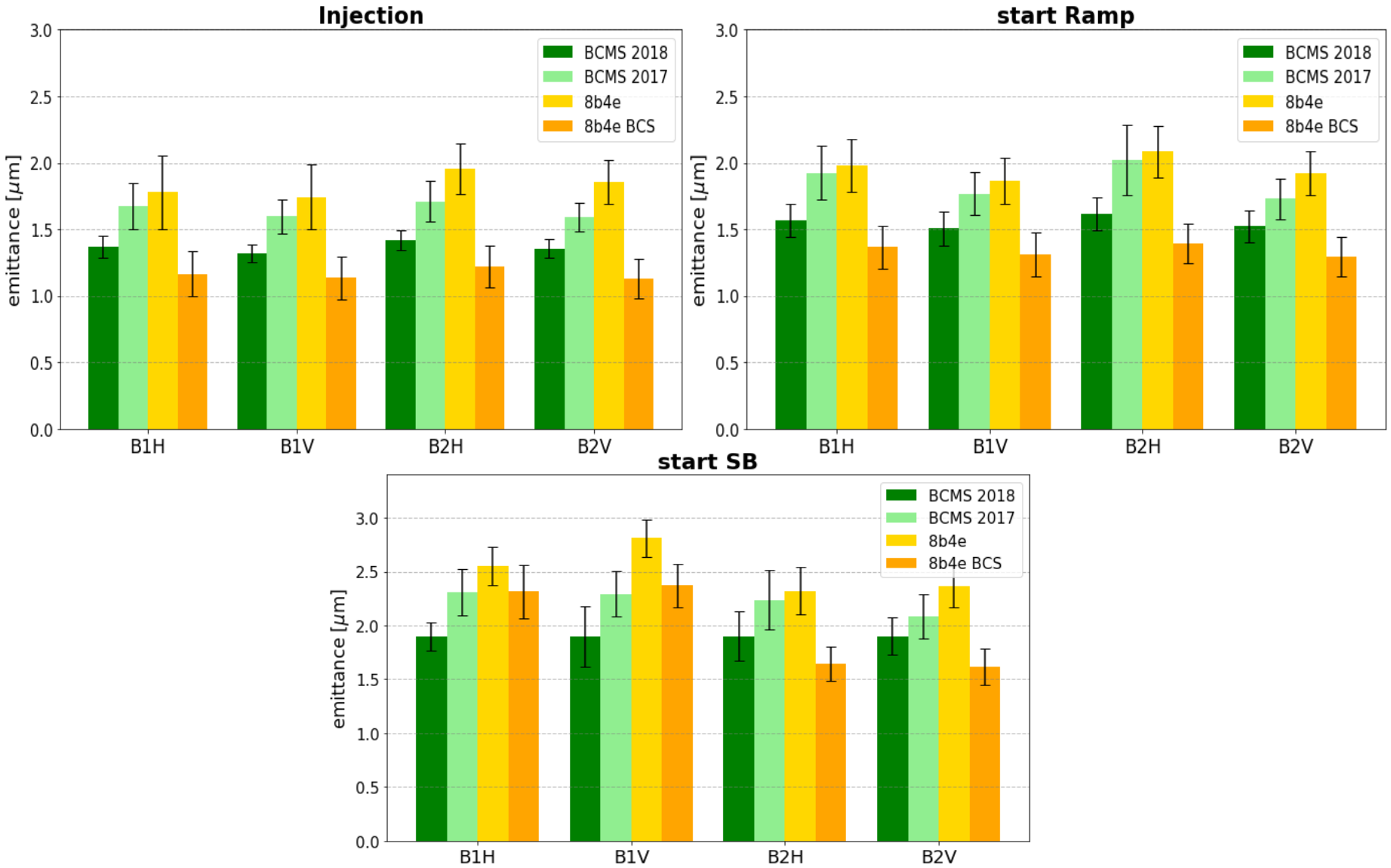
Unrealistic emittance at start of SB (smaller than at FB) – but still within the within the 20% accuracy of BSRT

- improved after applying the calibration of fill 7220, but not fully corrected





# Emittance evolution - Run 2





# Emittance evolution – Run 2

- Average emittance in 2016-2018

2016				
	B1H	B1V	B2H	B2V
Injection	$1.7 \pm 0.2$	$1.6 \pm 0.2$	$1.6 \pm 0.3$	$1.4 \pm 0.2$
Start of Ramp	$1.9 \pm 0.3$	$1.7 \pm 0.2$	$1.9 \pm 0.3$	$1.5 \pm 0.2$
Stable Beams	$2.4 \pm 0.3$	$2.1 \pm 0.4$	$2.3 \pm 0.3$	$1.7 \pm 0.3$

2018			
B1H	B1V	B2H	B2V
$1.4 \pm 0.1$	$1.3 \pm 0.1$	$1.4 \pm 0.1$	$1.4 \pm 0.1$
$1.6 \pm 0.1$	$1.5 \pm 0.1$	$1.6 \pm 0.1$	$1.5 \pm 0.1$
$1.9 \pm 0.1$	$1.9 \pm 0.3$	$1.9 \pm 0.2$	$1.9 \pm 0.2$

2017				
	B1H	B1V	B2H	B2V
Injection	$1.7 \pm 0.2$	$1.6 \pm 0.1$	$1.7 \pm 0.2$	$1.6 \pm 0.1$
	$1.8 \pm 0.3$	$1.7 \pm 0.2$	$2.0 \pm 0.2$	$1.9 \pm 0.2$
	$1.2 \pm 0.2$	$1.1 \pm 0.2$	$1.2 \pm 0.2$	$1.1 \pm 0.1$
Start of Ramp	$1.9 \pm 0.2$	$1.8 \pm 0.2$	$2.0 \pm 0.3$	$1.7 \pm 0.2$
	$2.0 \pm 0.2$	$1.9 \pm 0.2$	$2.1 \pm 0.2$	$1.9 \pm 0.2$
	$1.4 \pm 0.2$	$1.3 \pm 0.2$	$1.4 \pm 0.1$	$1.3 \pm 0.2$
Stable Beams	$2.3 \pm 0.2$	$2.3 \pm 0.2$	$2.2 \pm 0.3$	$2.1 \pm 0.2$
	$2.6 \pm 0.2$	$2.8 \pm 0.2$	$2.3 \pm 0.2$	$2.4 \pm 0.2$
	$2.3 \pm 0.2$	$2.4 \pm 0.2$	$1.6 \pm 0.2$	$1.6 \pm 0.2$

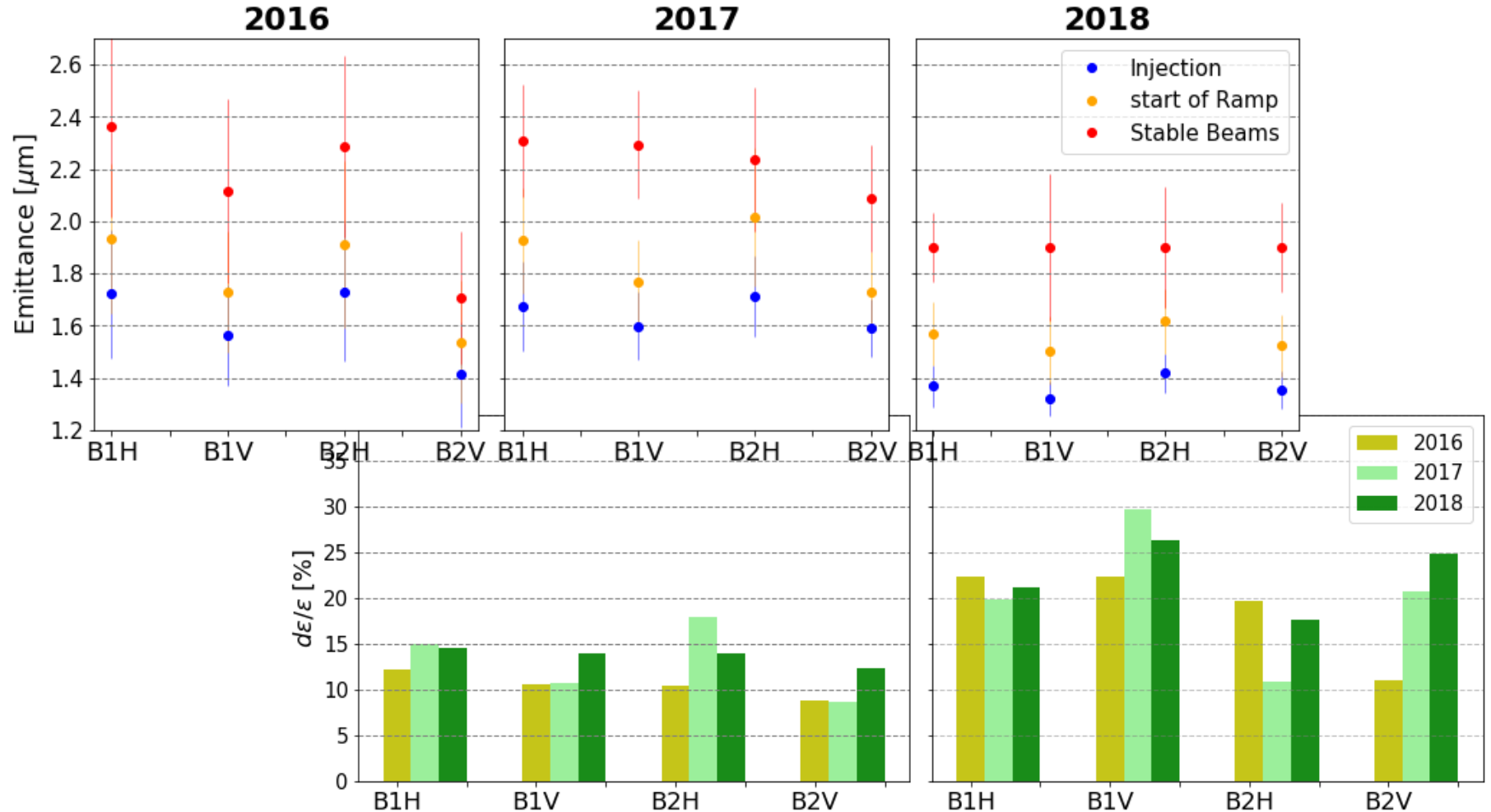
BCMS

8b4e

8b4e-BCS

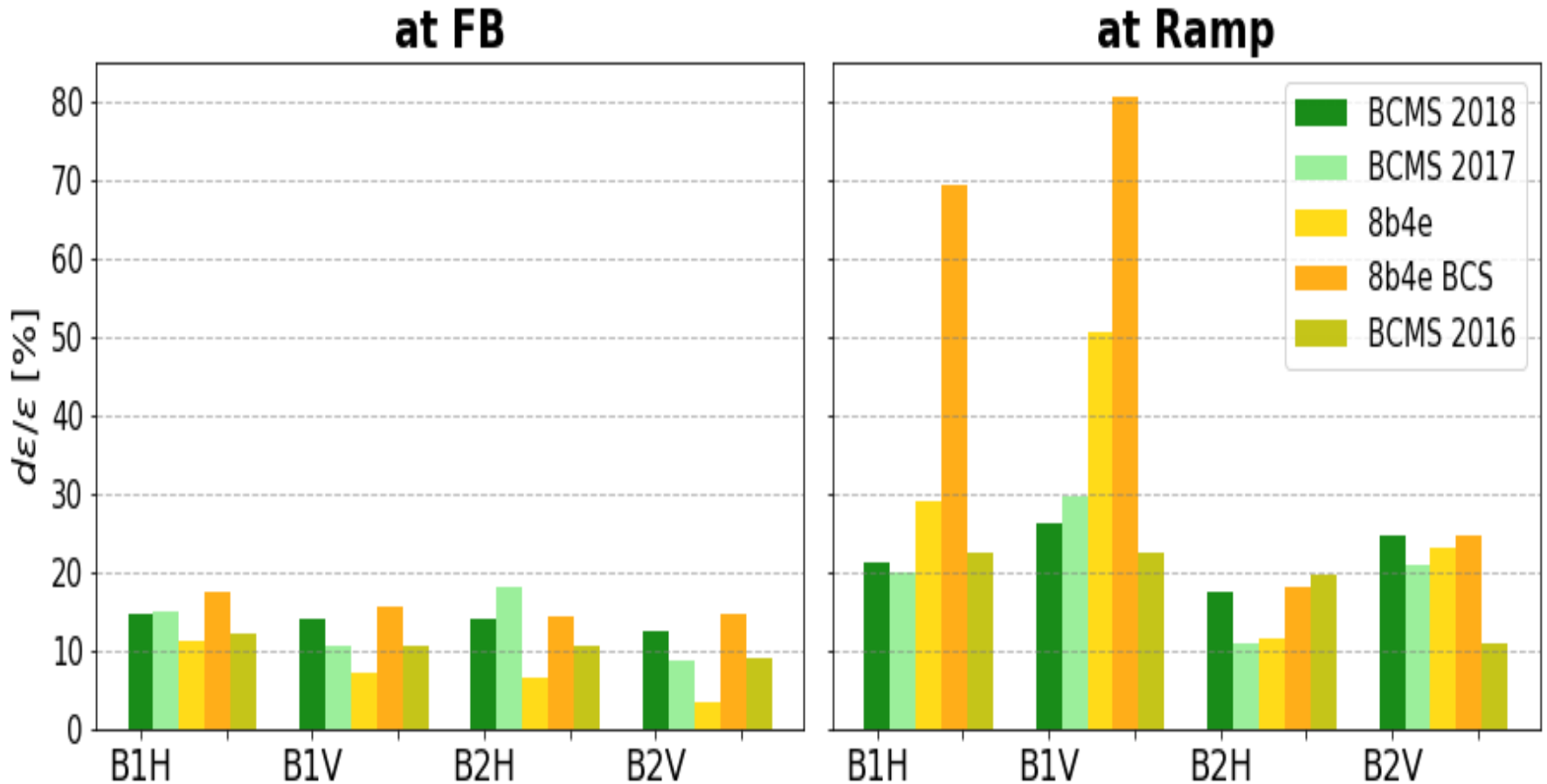
# Emittance evolution – Run 2

- BCMS beam**



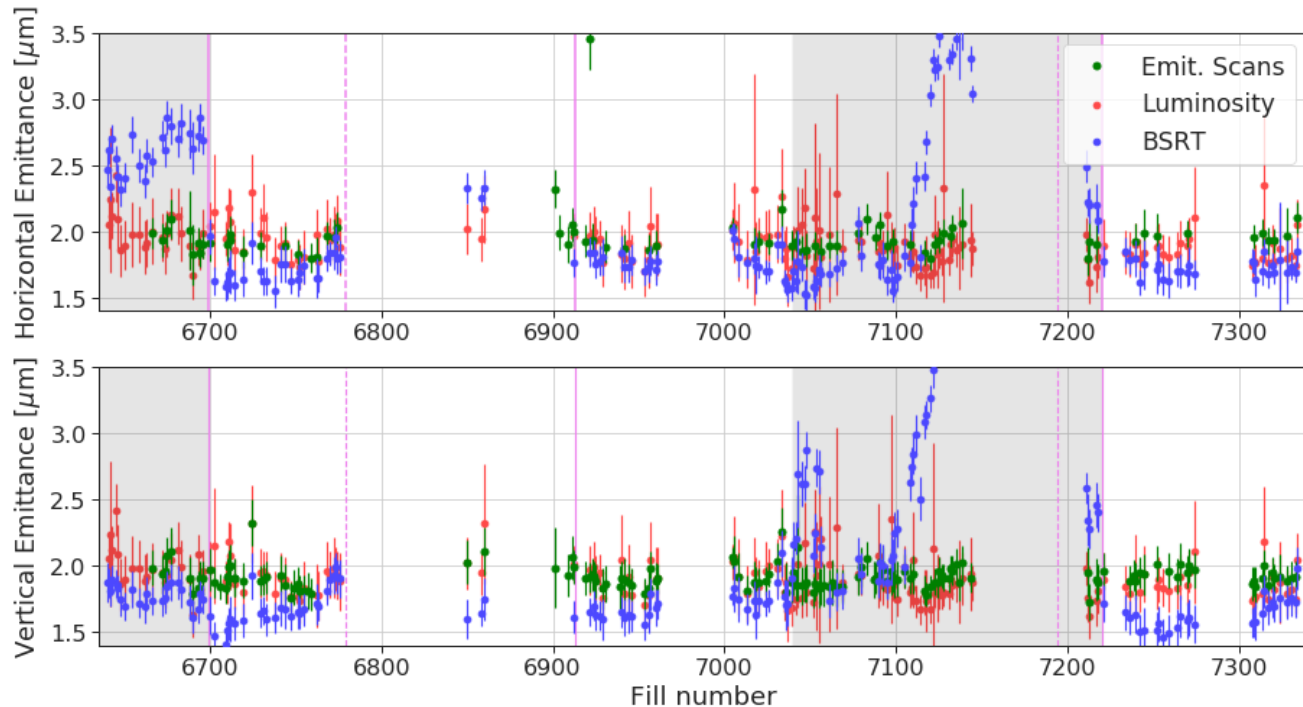
# Emittance evolution – Run 2

- Average relative emittance growth [%]



# Emittance evolution – Run 2

- Compare emittances at start of SB measured by BSRT and extracted from the experiment Luminosity and emittance scans
  - 10-15% agreement, compatible with the BSRT precision



- **Validate the emittance at start of SB → overall growth**



# Emittance evolution – Run 2

- Average relative emittance growth [%]

2016-BCMS					2018-BCMS			
	B1H	B1V	B2H	B2V	B1H	B1V	B2H	B2V
Inj/Ramp	12.2±8.3	10.5±7.8	10.4±4.9	8.9±7.6	14.5±4.2	14.0±4.2	14.0±4.7	12.3±4.7
Ramp/SB	22.3±42.0	22.4±38.2	19.6±12.6	11.0±11.0	21.2±11.1	26.2±13.5	17.6±16.0	24.8±11.8

2017-BCMS				
	B1H	B1V	B2H	B2V
Inj/Ramp	15.0±4.7	10.7±5.3	17.9±6.8	8.7±2.7
Ramp/SB	19.9±5.7	29.7±9.2	10.8±7.0	20.8±3.8

Total growth from injection to SB : ~35%

2017 – 8b4e			
B1H	B1V	B2H	B2V
11.3±41.2	7.1±38.8	6.6±3.5	3.3±3.0
29.0±63.7	50.7±73.6	11.4±17.1	23.2±13.8

2017 - BCS			
B1H	B1V	B2H	B2V
11.3±41.2	7.1±38.8	6.6±3.5	3.3±3.0
29.0±63.7	50.7±73.6	11.4±17.1	23.2±13.8

Details on the understating and modeling of the e-growth and luminosity in following presentation by Stefania



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# Luminosity fluctuations

- Large variation in the relative luminosity between bunches observed during stable beams in 2018 BCMS
  - video : Fill 7314 – 2018, BCMS long (~15h) fill
- The fluctuations develop with time and may result in substantial different conditions between bunches that could affect the experiments already in Run 3 and HL-LHC operation.
- Started investigating to understand it
  - Compare 2018 BCMS fills with different polarities of LHCb dipole
  - Special fill 7006 that had a missed injection for B1, therefore a full non-colliding train in B2 (but experiencing the same e-cloud!)
  - Study 2017 8b43 fills that had little e-cloud effects
- Work in progress, highlights presented here.

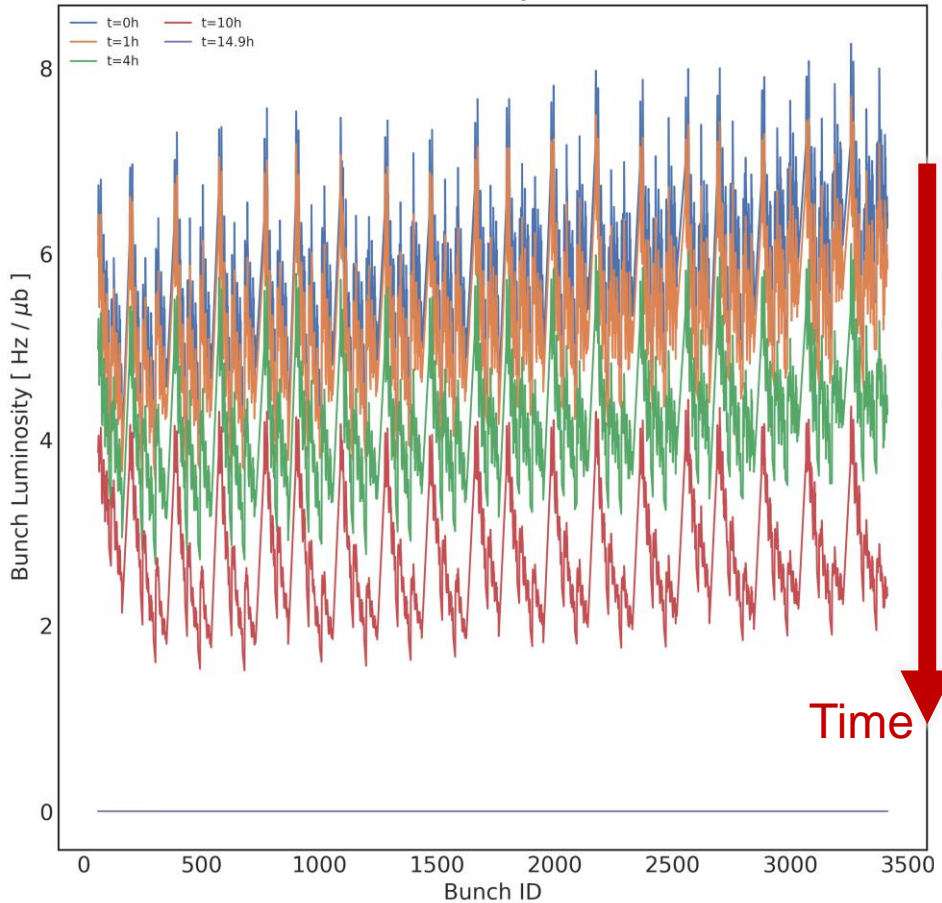




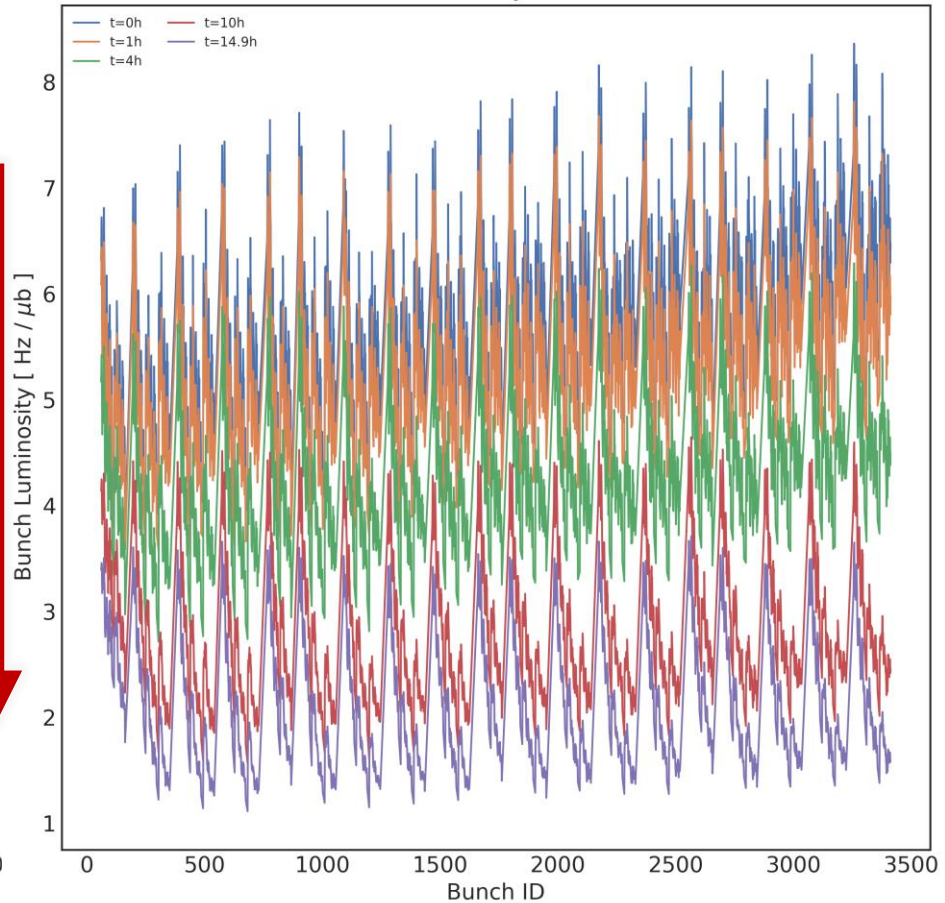
# Fill 7334 – 2018 BCMS LHCb/neg

- Bunch Luminosity from the experiments

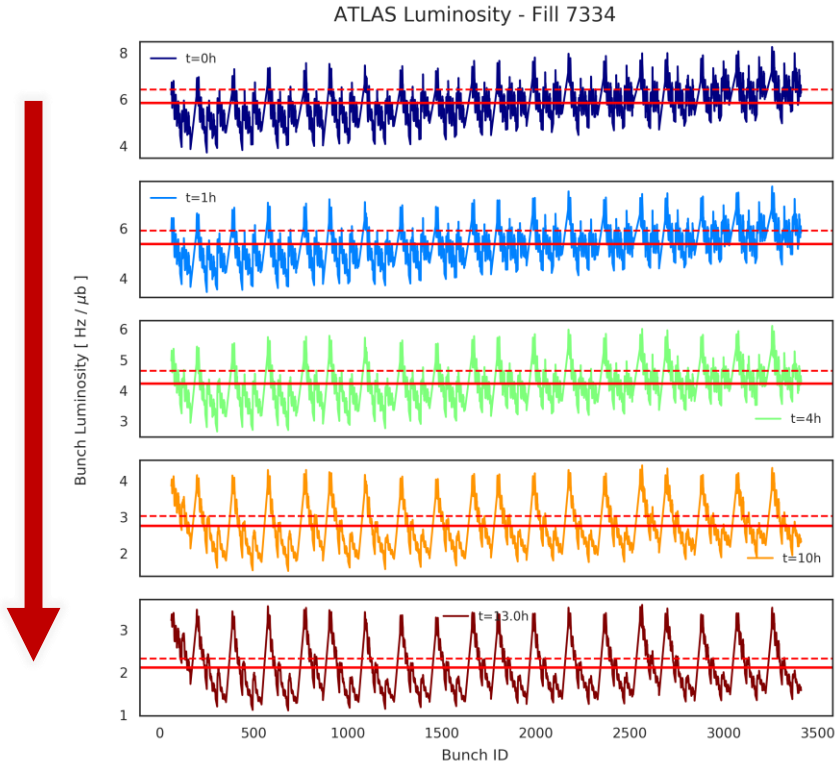
ATLAS Luminosity - Fill 7334



CMS Luminosity - Fill 7334

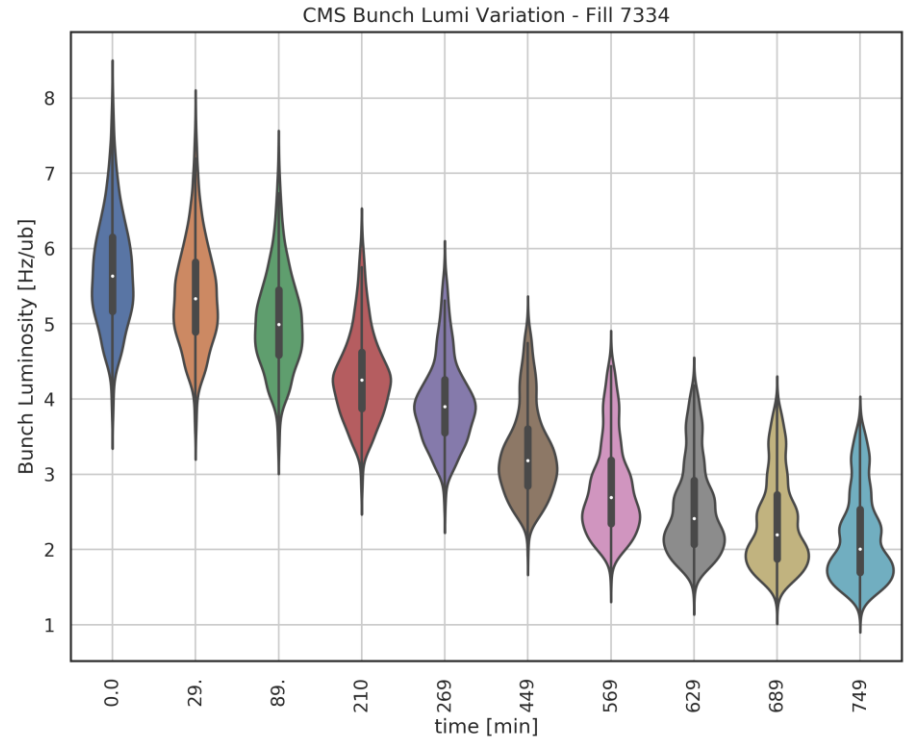


# Fill 7334 – 2018 BCMS LHCb/neg



## Bunch lumi vs time

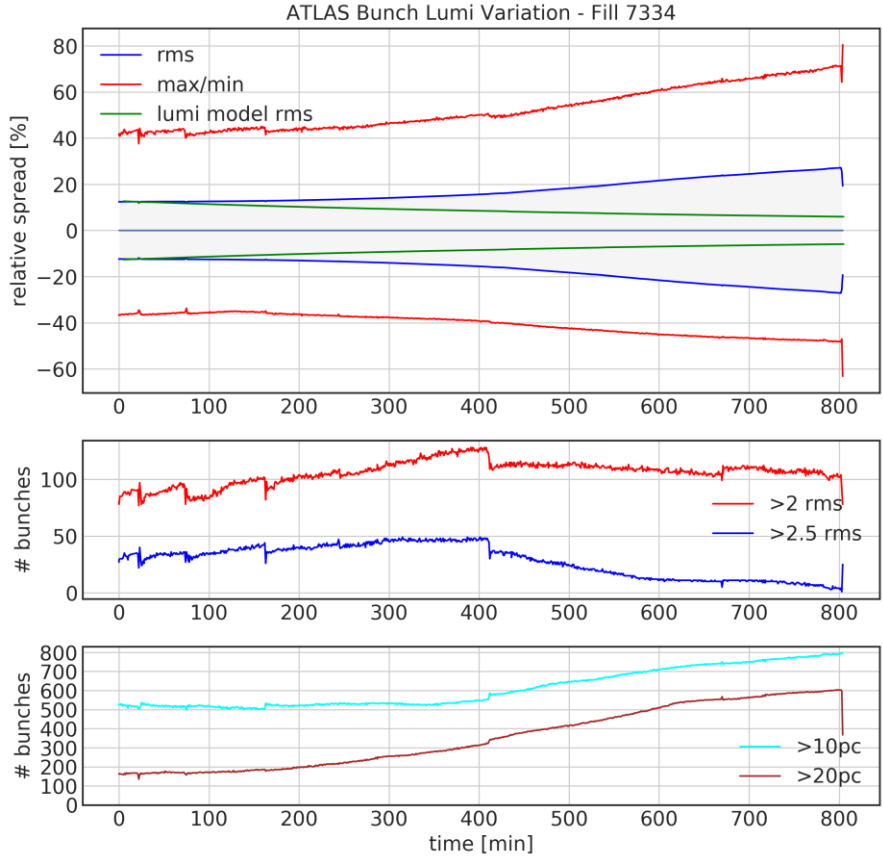
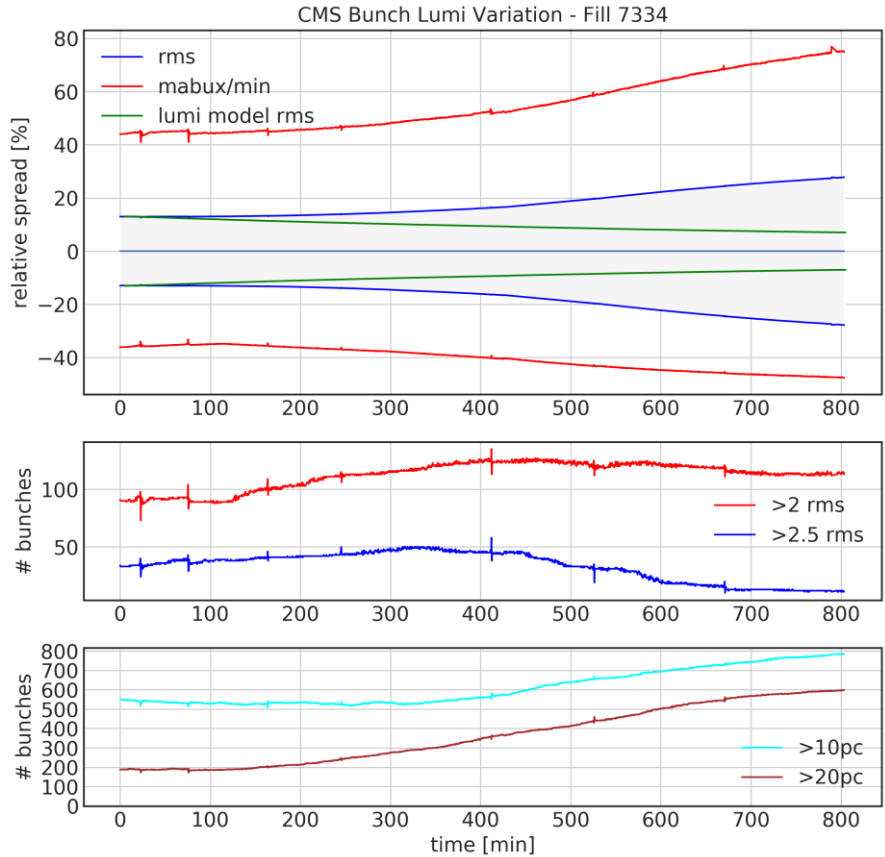
- red line = mean luminosity
- Dashed line = +10%



## Bunch luminosity distributions vs time



# Fill 7334 – 2018 BCMS LHCb/neg



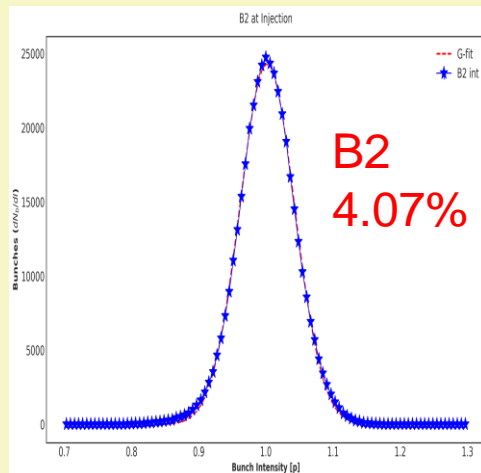
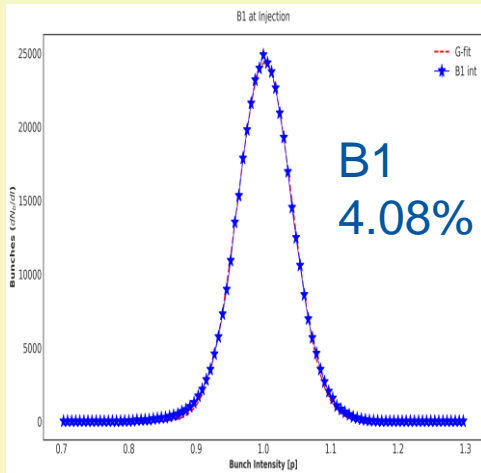
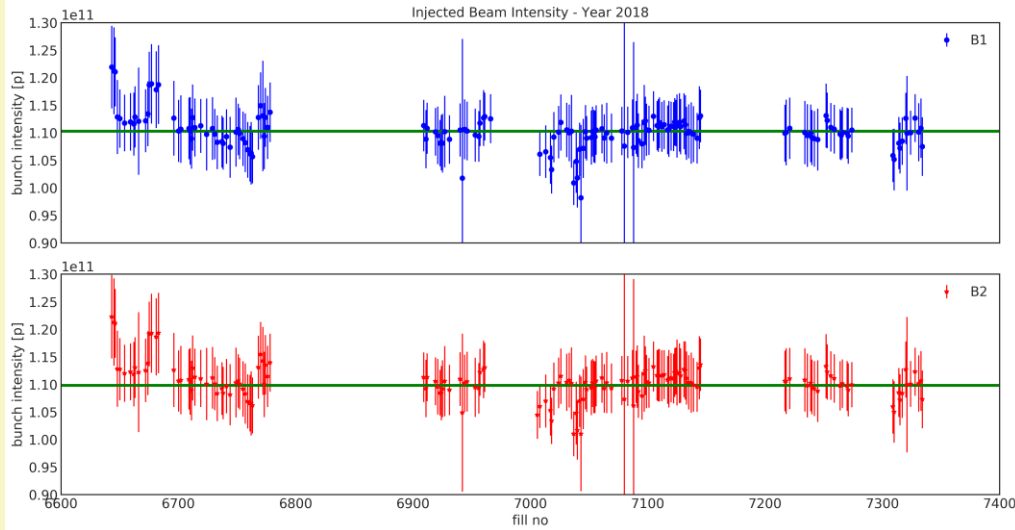
**CMS**

**ATLAS**

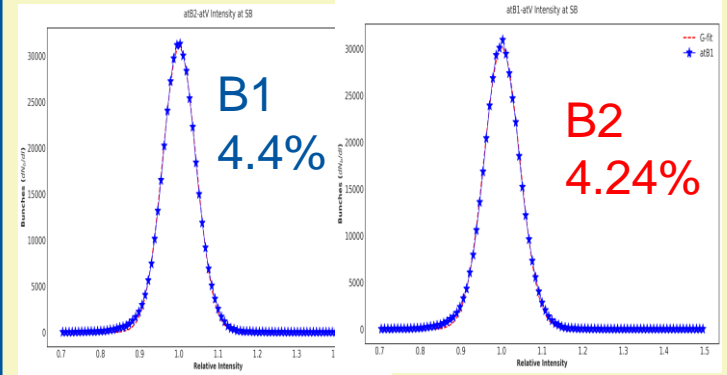
# Look back at injection/ramp

## Injection – beam intensity

2018



## Stable Beam – Intensity



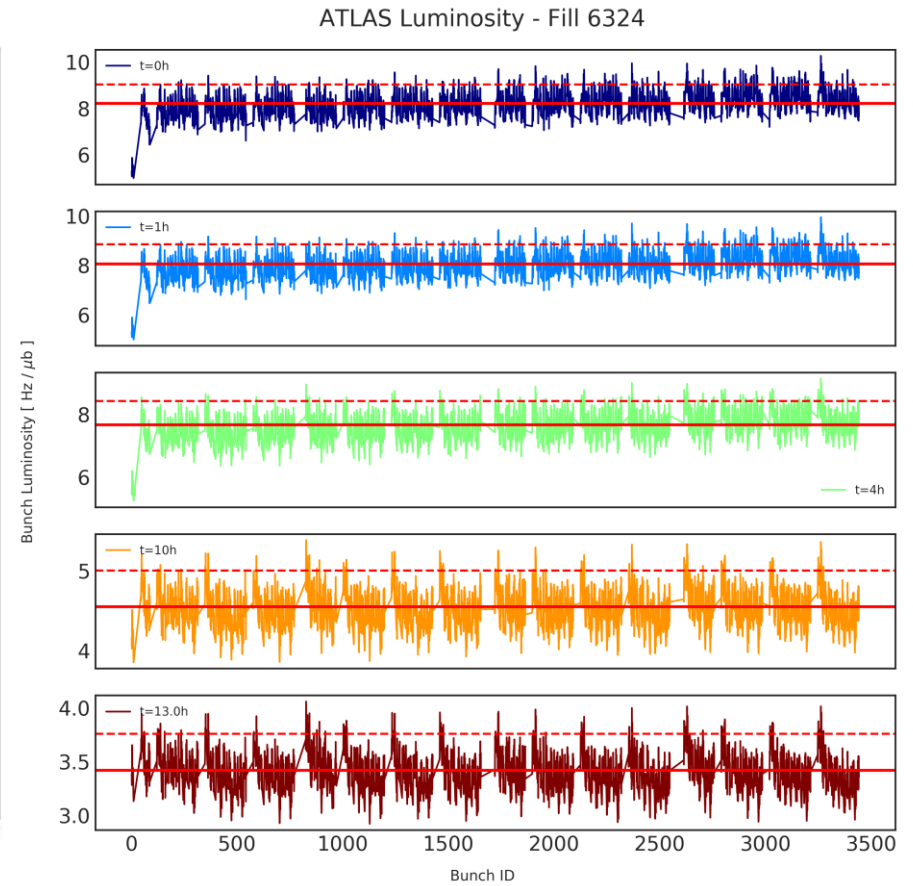
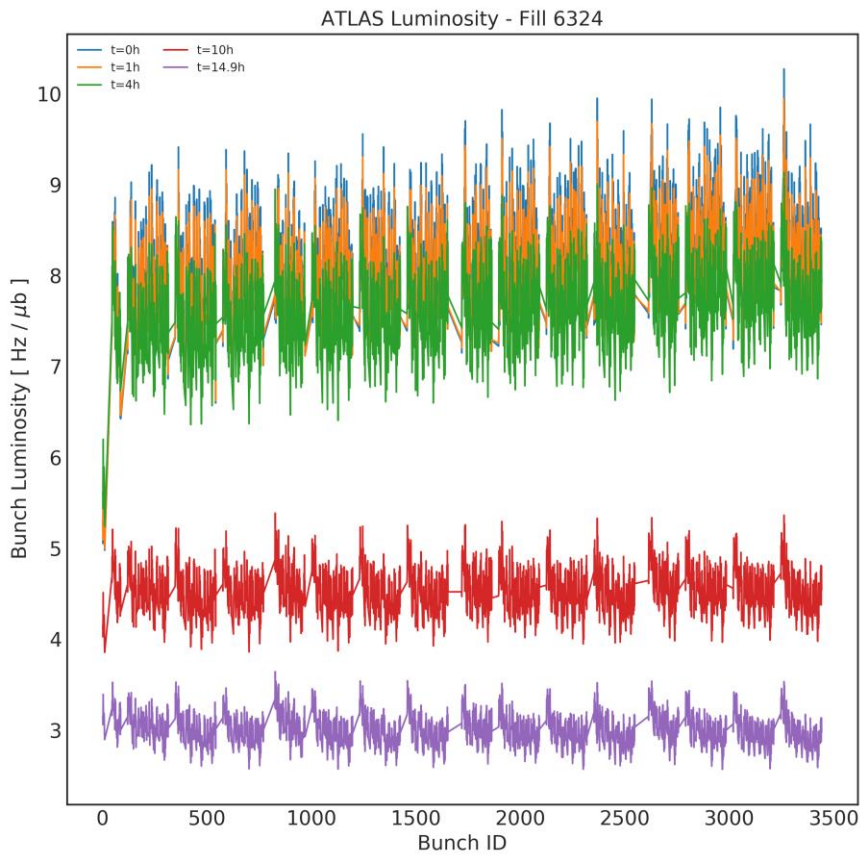
## Emittance

	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 !



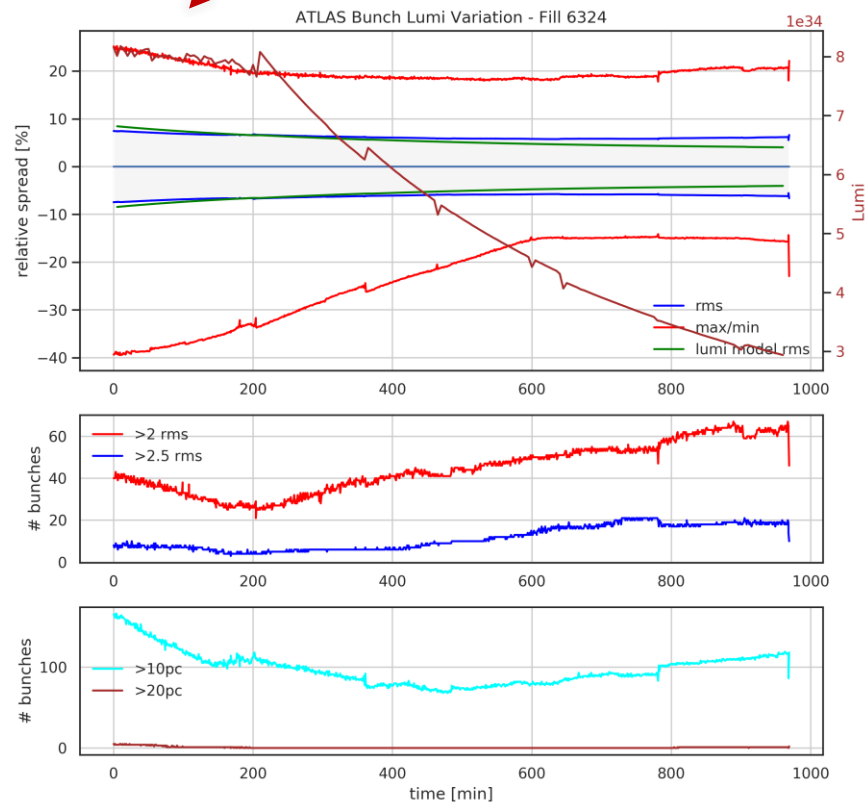
# Fill 6324 – 2017 8b4e



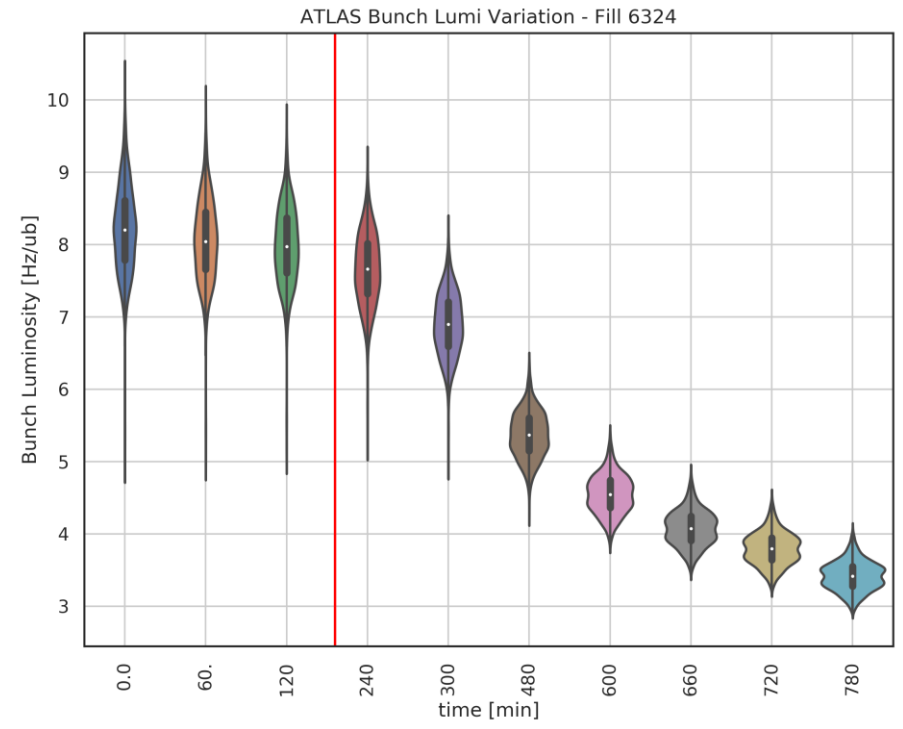


# Fill 6324 – 2017 8b4e

## Lumi leveling



## Lumi leveling

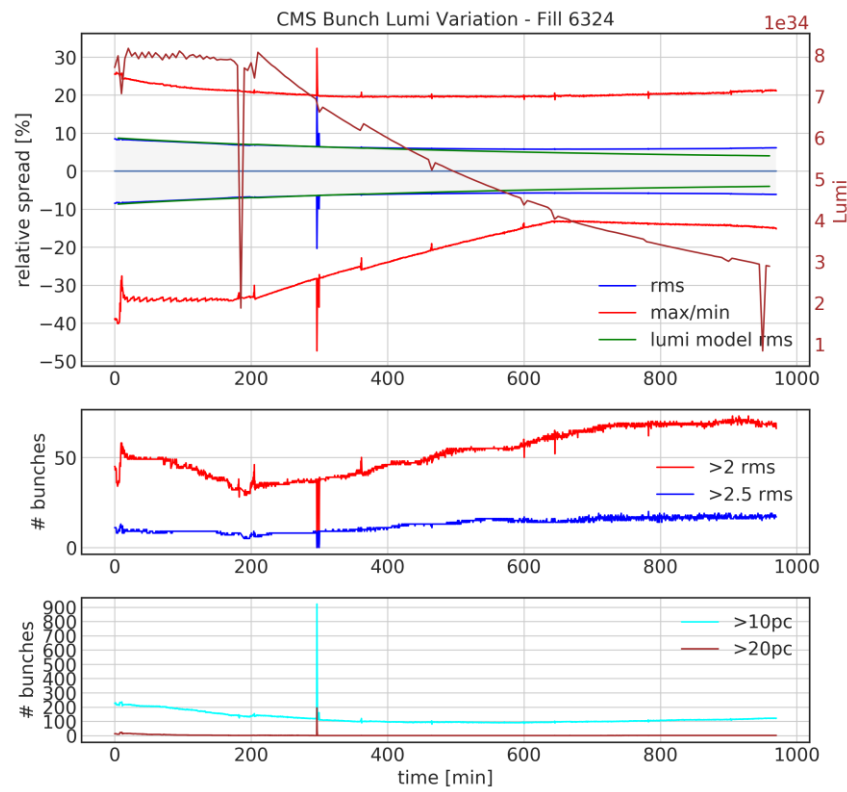




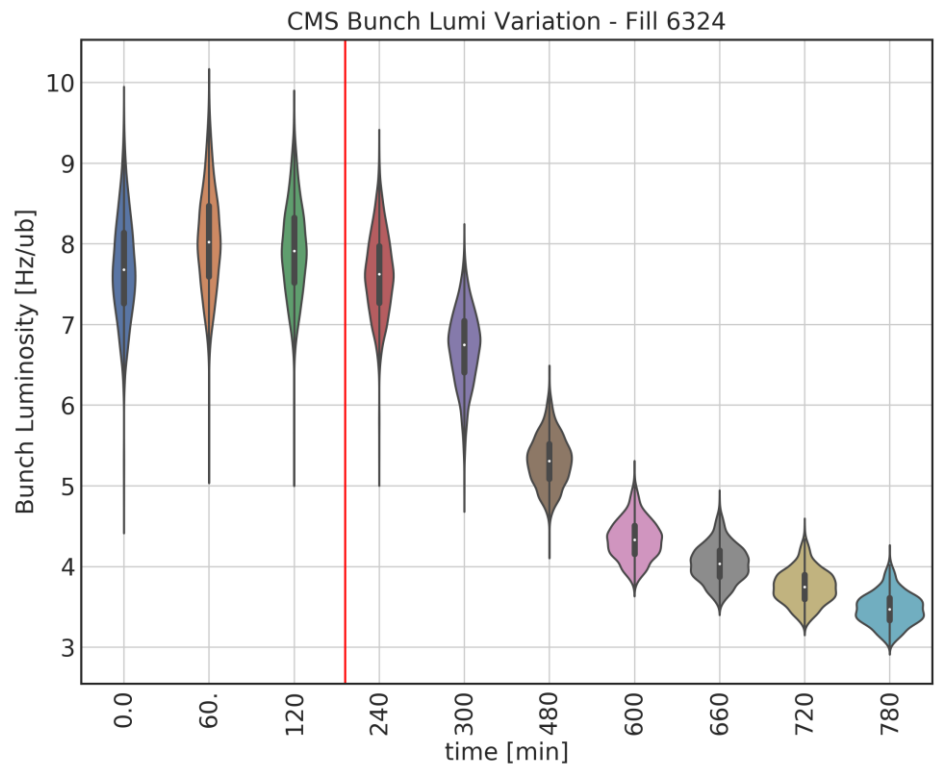


# Fill 6324 – 2017 8b4e

- CMS data



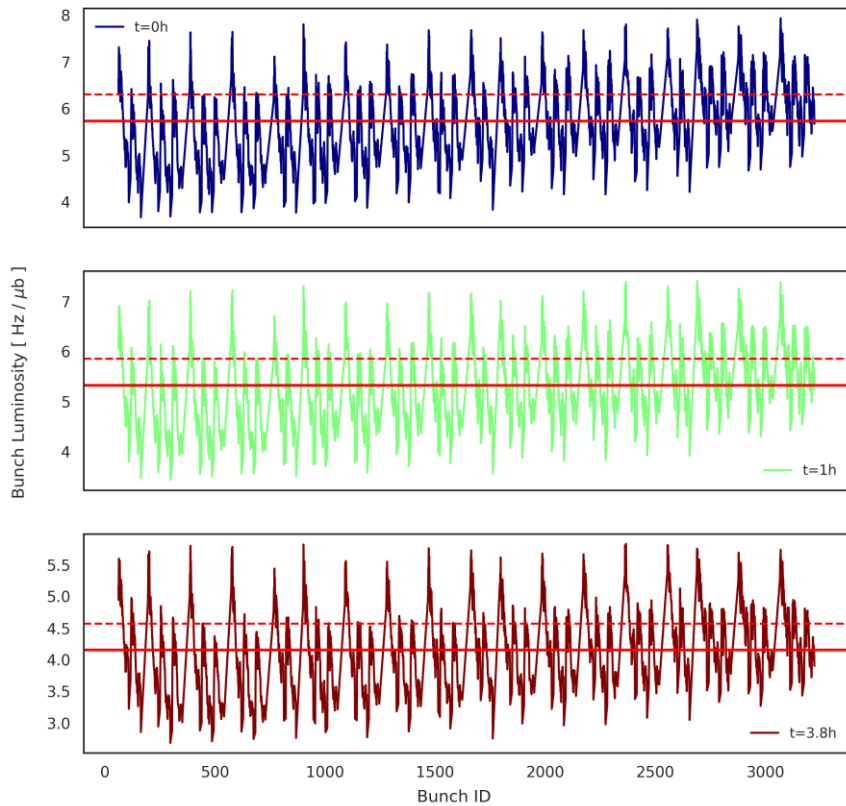
Lumi leveling



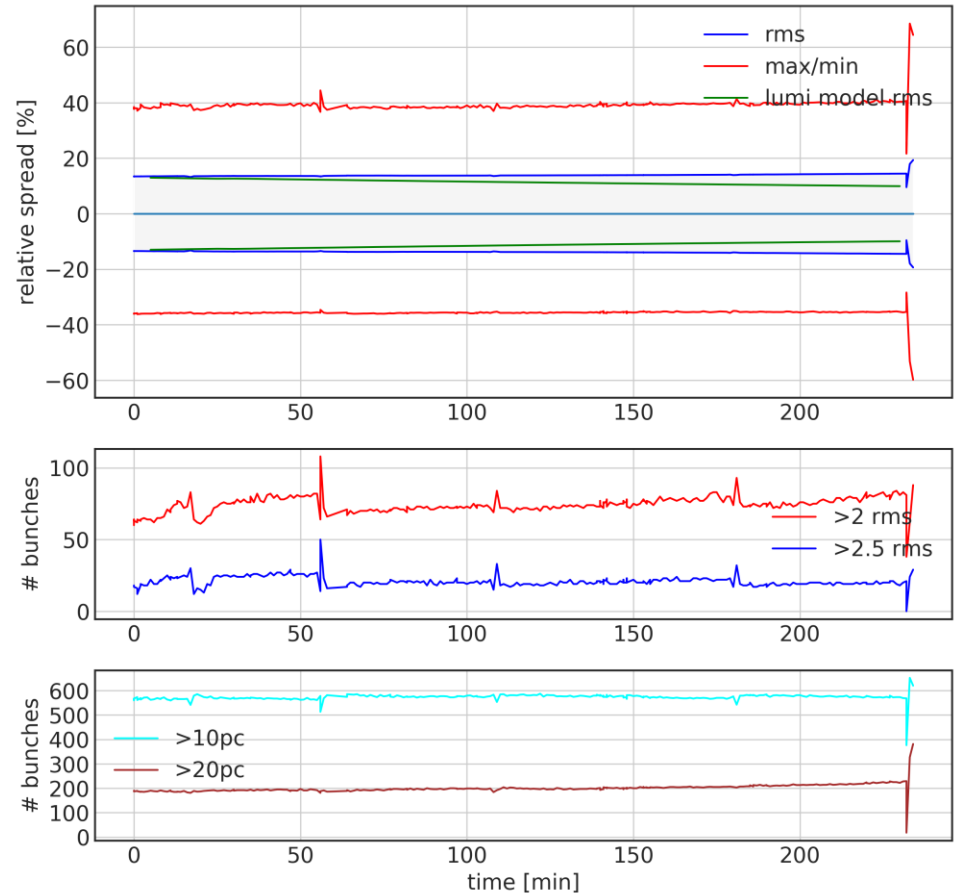
# Fill 7006 – 2018 BCMS

- “nominal” BCMS fill as all others in 2018, except of the missed last injection of B1

ATLAS Luminosity - Fill 7006



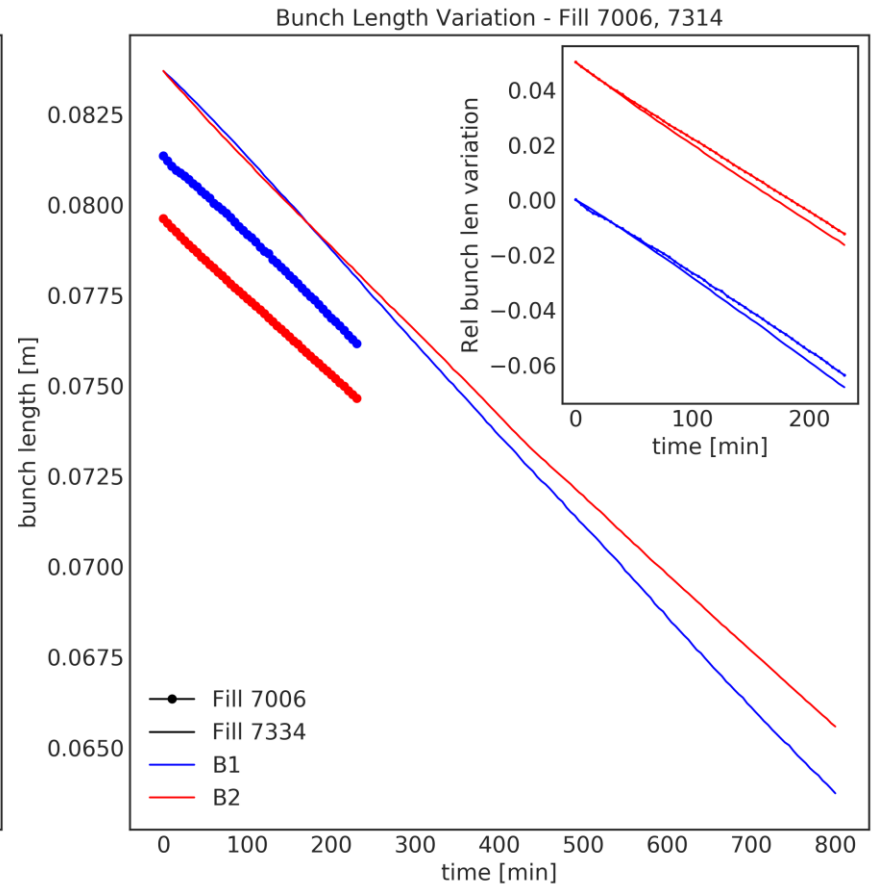
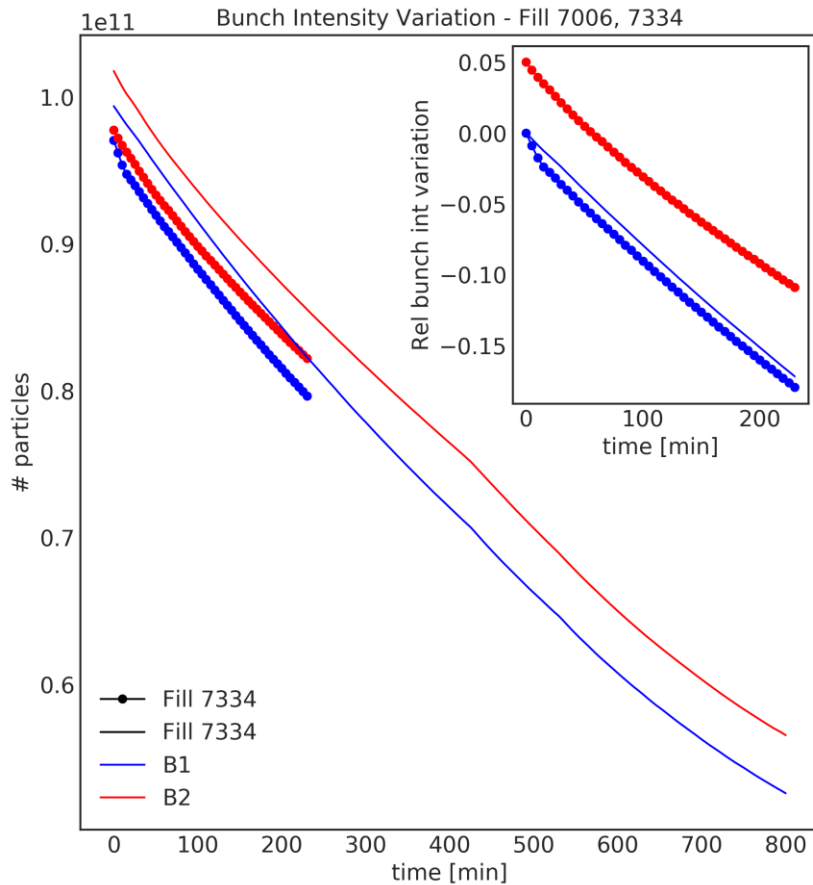
ATLAS Bunch Lumi Variation - Fill 7006



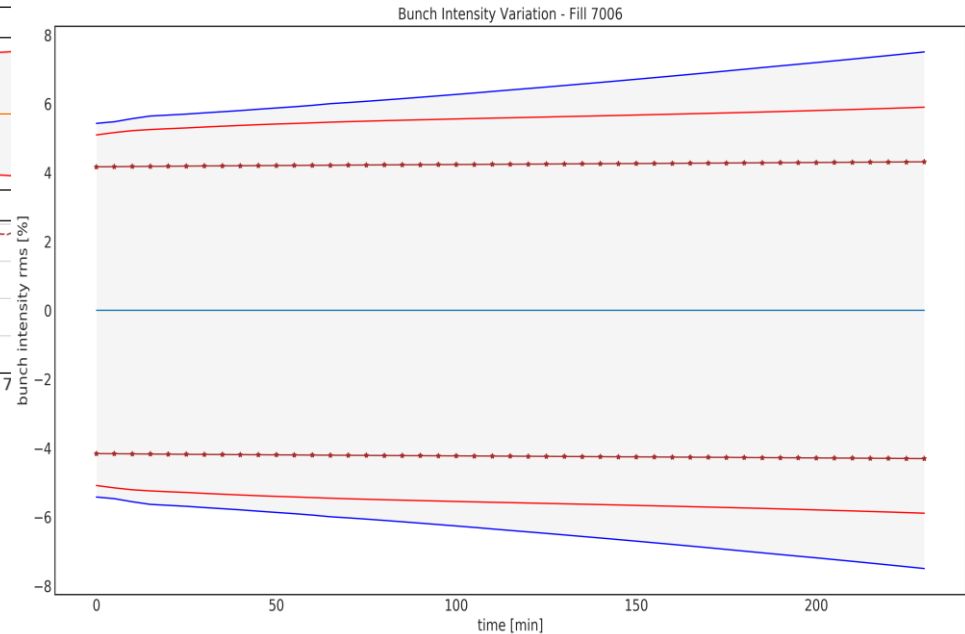
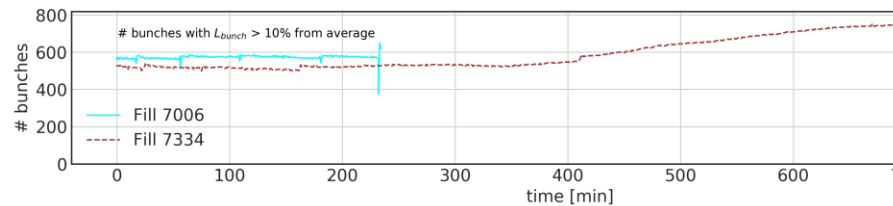
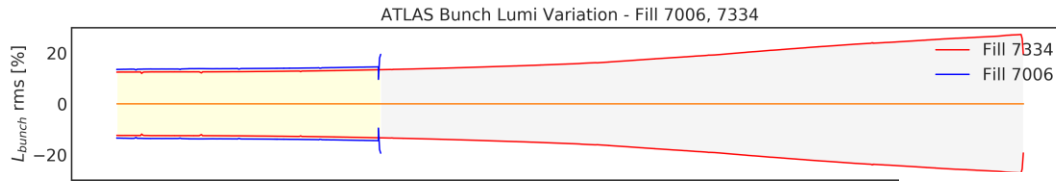


# Fill 7006 – 2018 BCMS

- Compare colliding bunches with another fill
  - good agreement for the duration of the fill



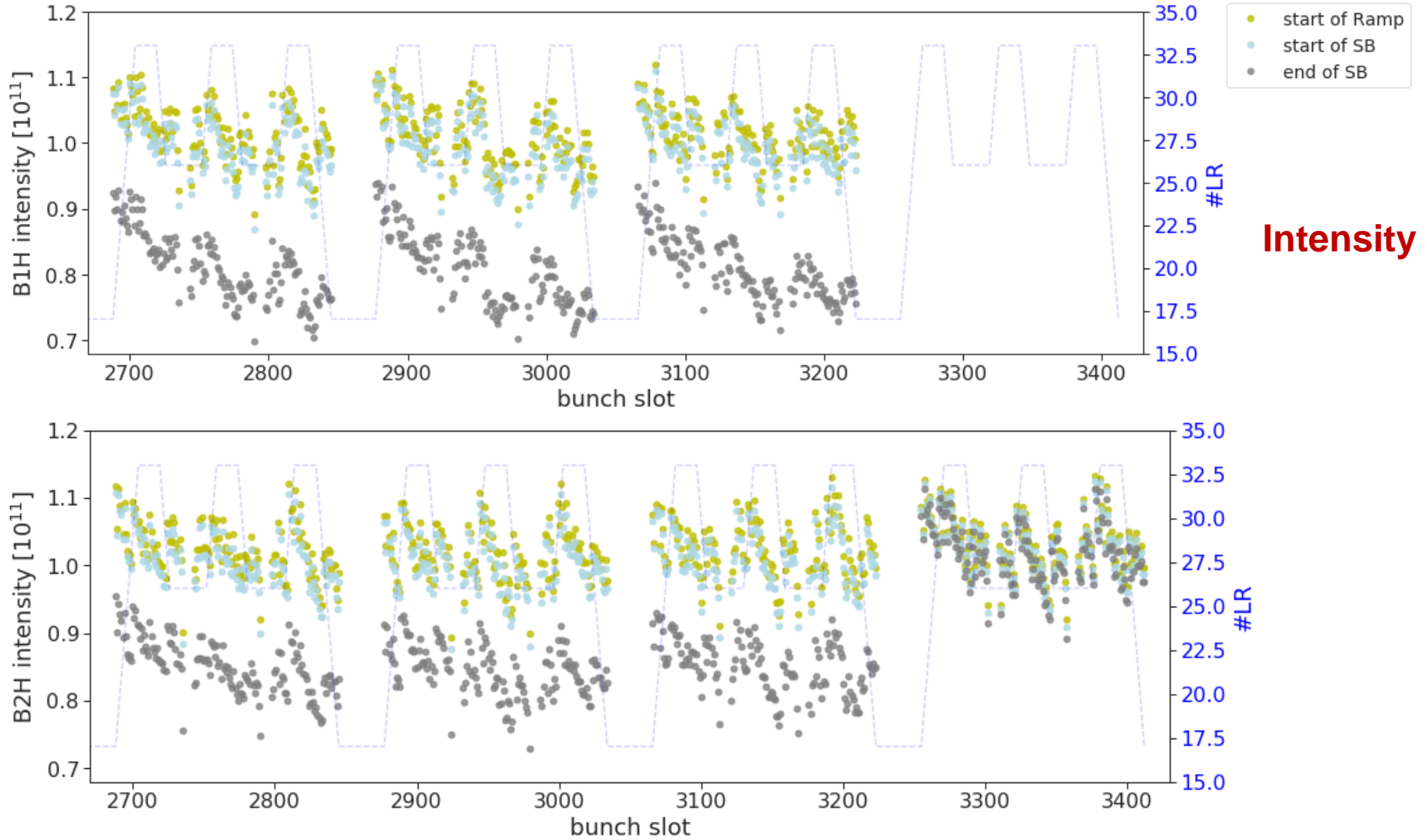
# Fill 7006 – 2018 BCMS



- No RMS growth of the non-colliding train bunches, while the colliding trains show the same increase as in all fills.

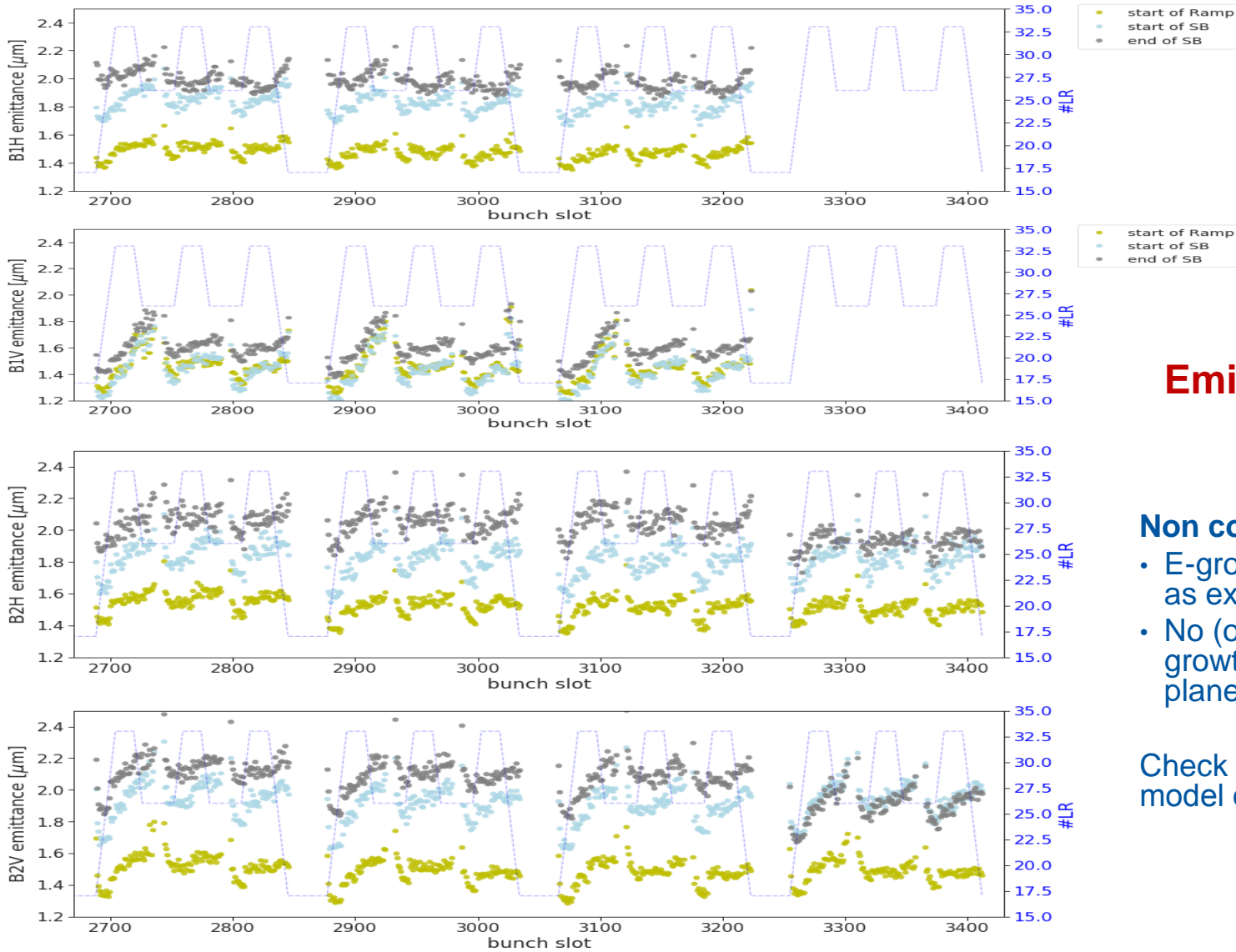


# Fill 7006 – 2018 BCMS





# Fill 7006 – 2018 BCMS



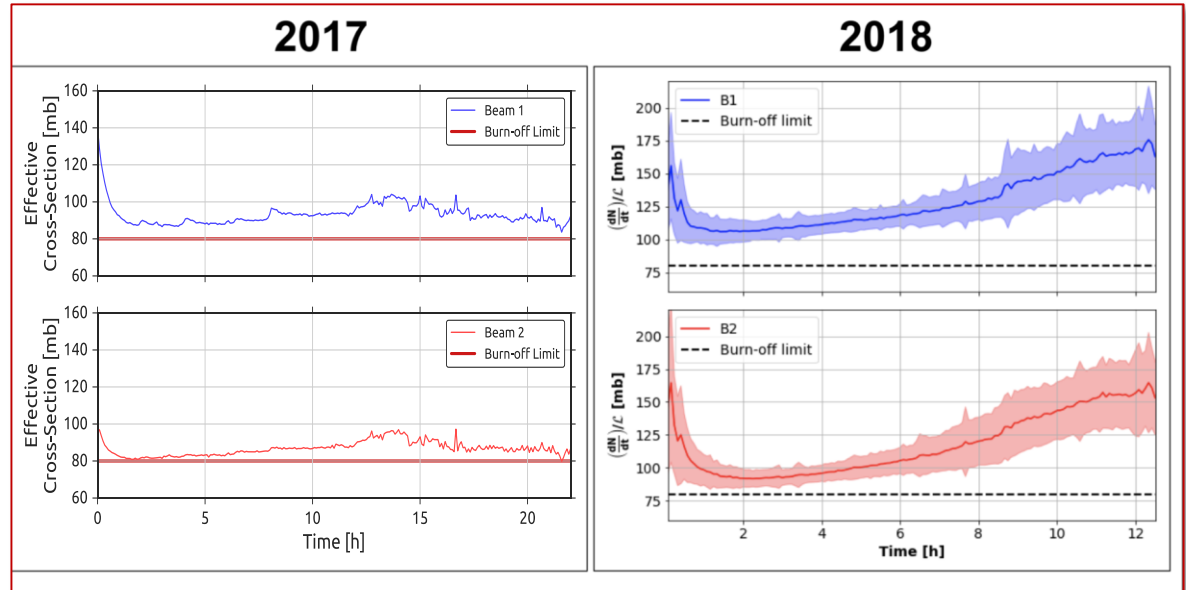
## Emittance

- Non colliding train:**
- E-growth in H-plane as expected
  - No (or minimal) growth in the V-plane

Check with the lumi model ongoing...

# Fill 7006 – 2018 BCMS

- Reminder : additional losses (above burn-off limit) observed in the 2018 for the BCMS beams, correlated to the e-cloud pattern in the trains



- From fill 7006 it seems the non-colliding train that exhibits e-cloud, shows no(?) losses and no(?) e-growth
- *Could be the source of the observed losses are around the IP (e-cloud in the triplets or combined effect of e-cloud + BBLR) – to investigate further*

S Kostoglou – Evian 2019

Beam modeling and optimization

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# Summary

- A continuous monitoring of the beam performance was done during Run 2
- Sets of processed data are available and used for various analysis – open to anyone interested to exploit them!
- As global number we observe an emittance growth from injection to SB of **~35%**, about half of it comes during the ramp. We can understand and model part of it, also during the SB with the develop lumi mode (next presentation)
  - worth setting up an MD program in Run 3, to understand the origin of the e-growth in the rump, and possibly reduce it, that may result in substantial gain to the LHC luminosity!
- First results of the bunch-by-bunch fluctuation presented. It seems the effect is enhanced in 2018 with the BCMS beams, therefore the interest to further understand it as may affect the machine/experiment performance in Run 3 or HL-LHC.
  - work to continue, interesting results from a special fill with a non-colliding train.