



Emittance evolution

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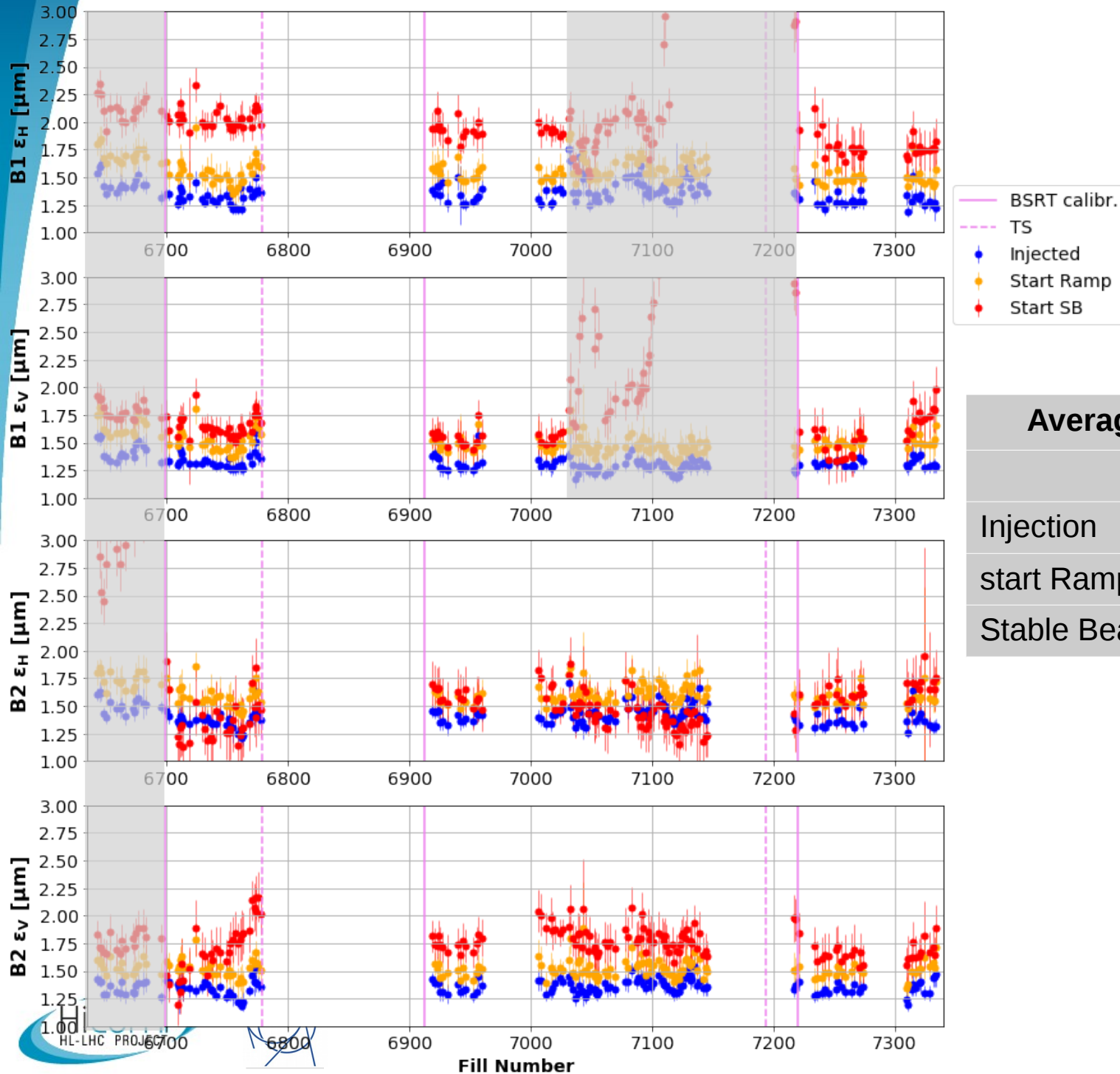
CERN, Geneva



160th HiLumi WP2 Meeting, 24 September 2019

Measured emittance along the cycle

2018 emittances along the cycle

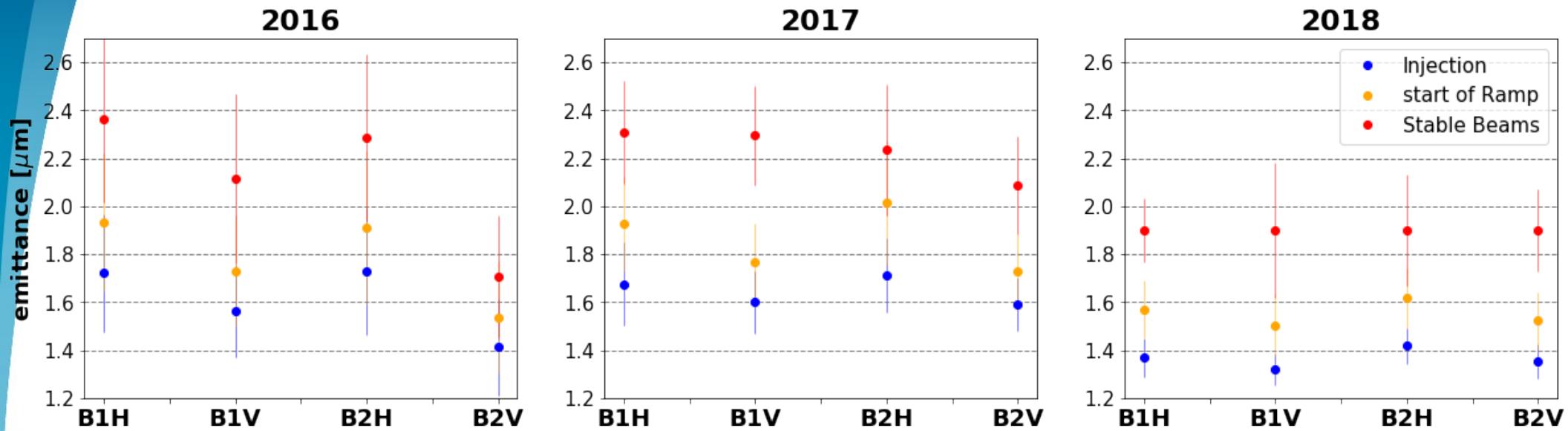


Average emittance values [μm]

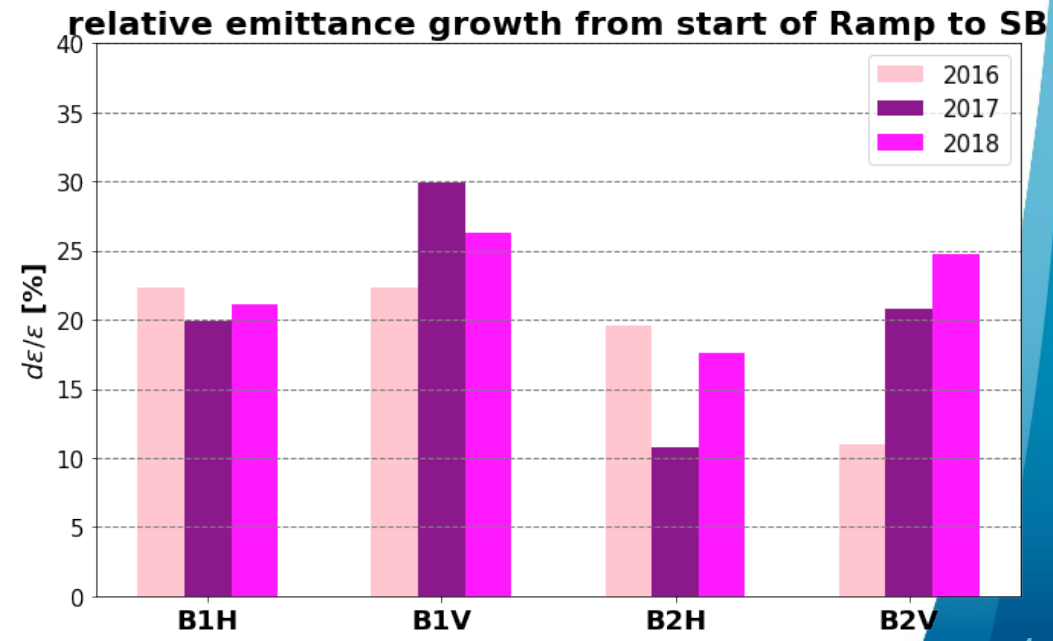
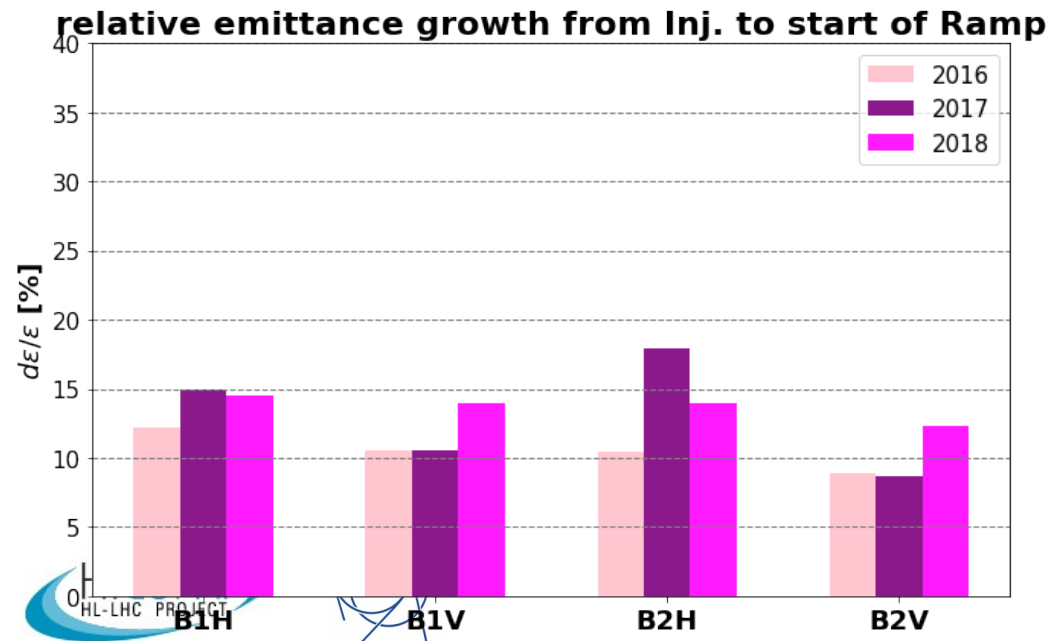
	B1H	B1V	B2H	B2V
Injection	1.4	1.3	1.4	1.4
start Ramp	1.6	1.5	1.6	1.5
Stable Beams	2.0	1.7	1.5	1.7

Unphysical B2H emittance at start of SB (smaller than at FB), according to BI this is within the 20% accuracy of BSRT. It improves after last BSRT calibration (Fill 7220)

Run 2 BCMS emittances along the cycle



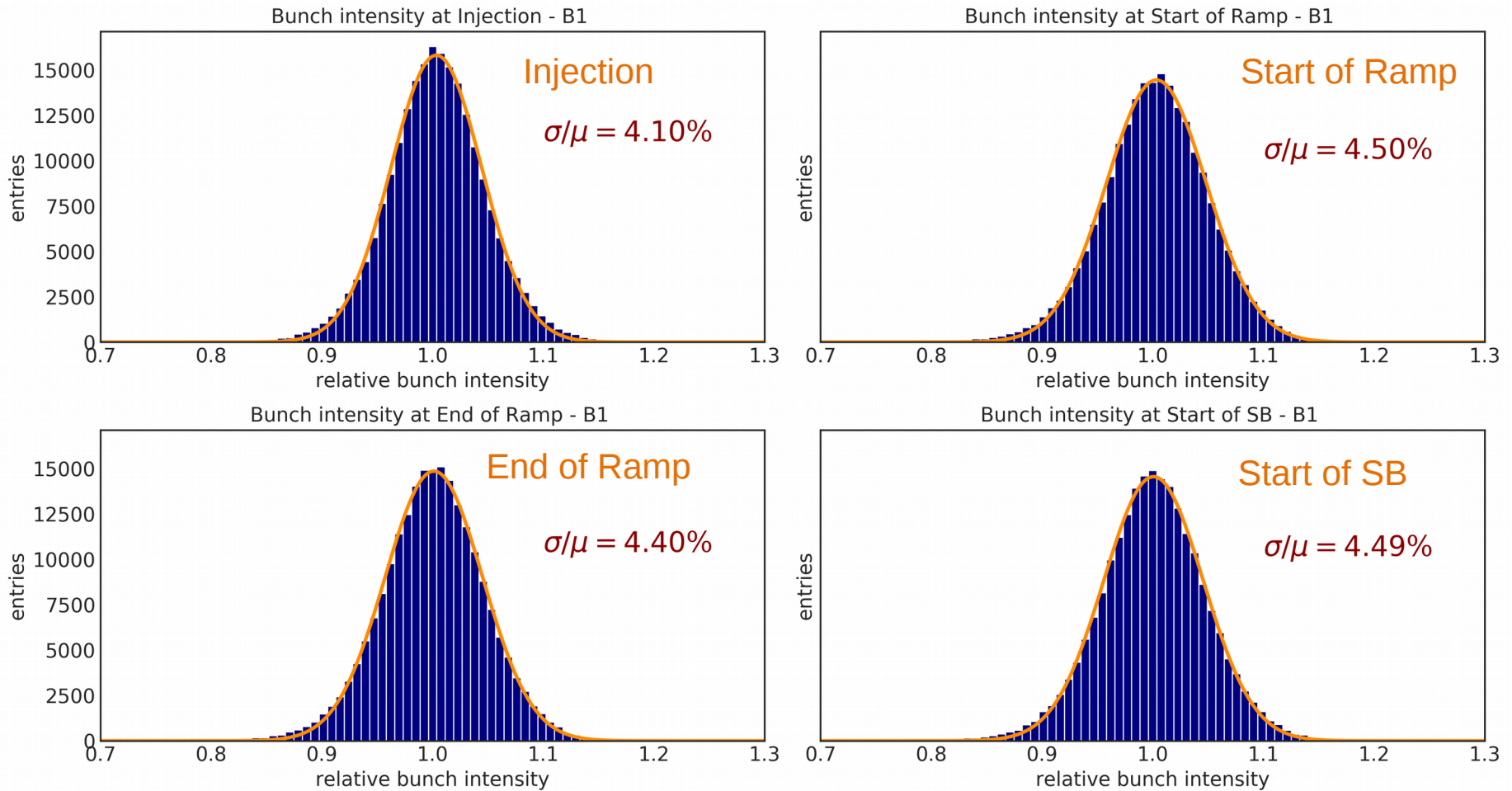
Considering only 2018 Fills for which the convoluted emittances from Luminosity and BSRT at start of SB differ less than 15%



Intensity, Emittance and Luminosity fluctuations

Beam Intensity Fluctuations in the cycle

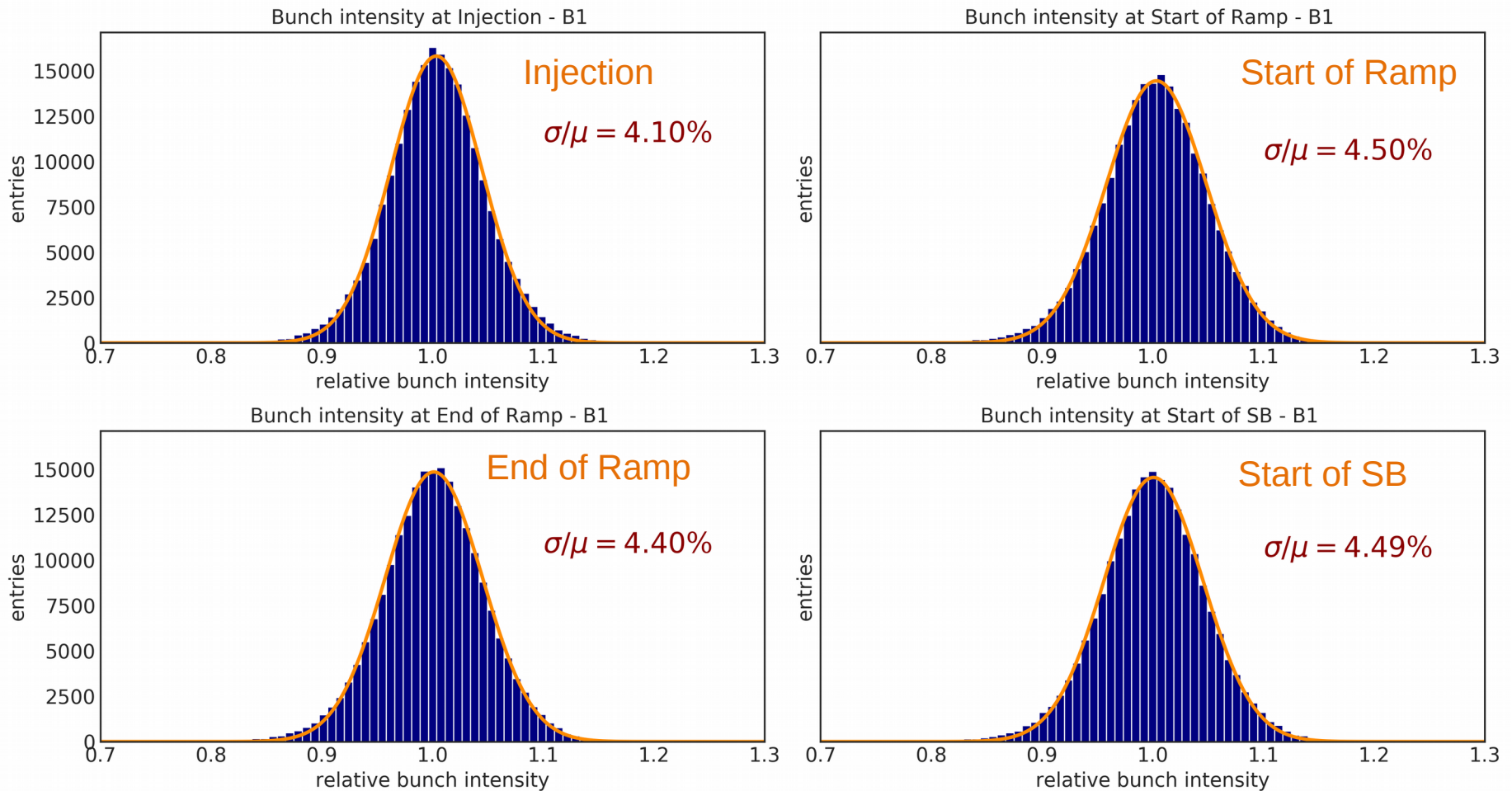
Selected 2018 Fills (43 fills) - B1 bunches



Bunch intensities normalized to the mean of each fill

Beam Intensity Fluctuations in the cycle

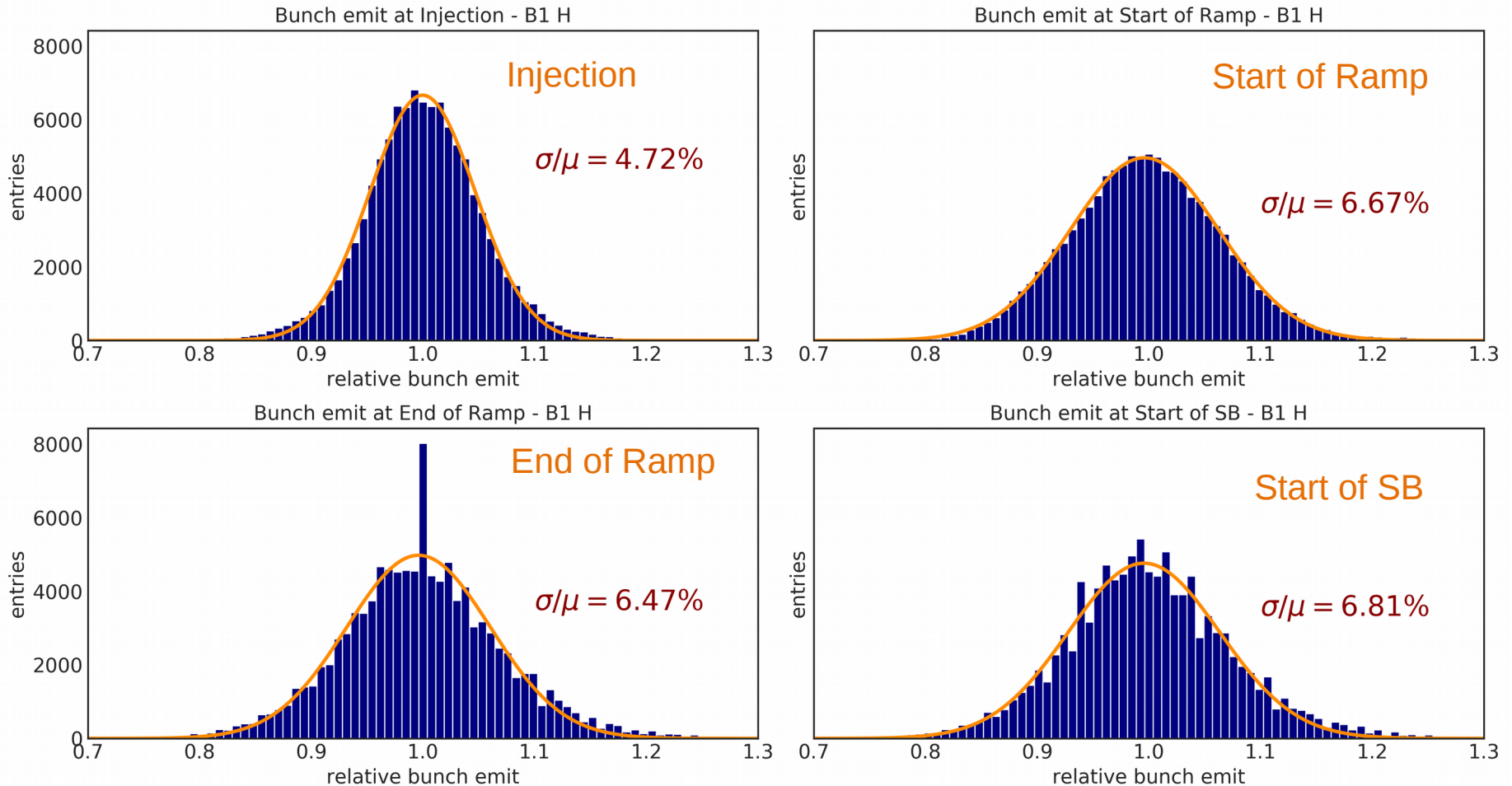
Selected 2018 Fills (43 fills) - B1 bunches



Bunch intensities normalized to the mean of each fill

Emittance Fluctuations in the cycle

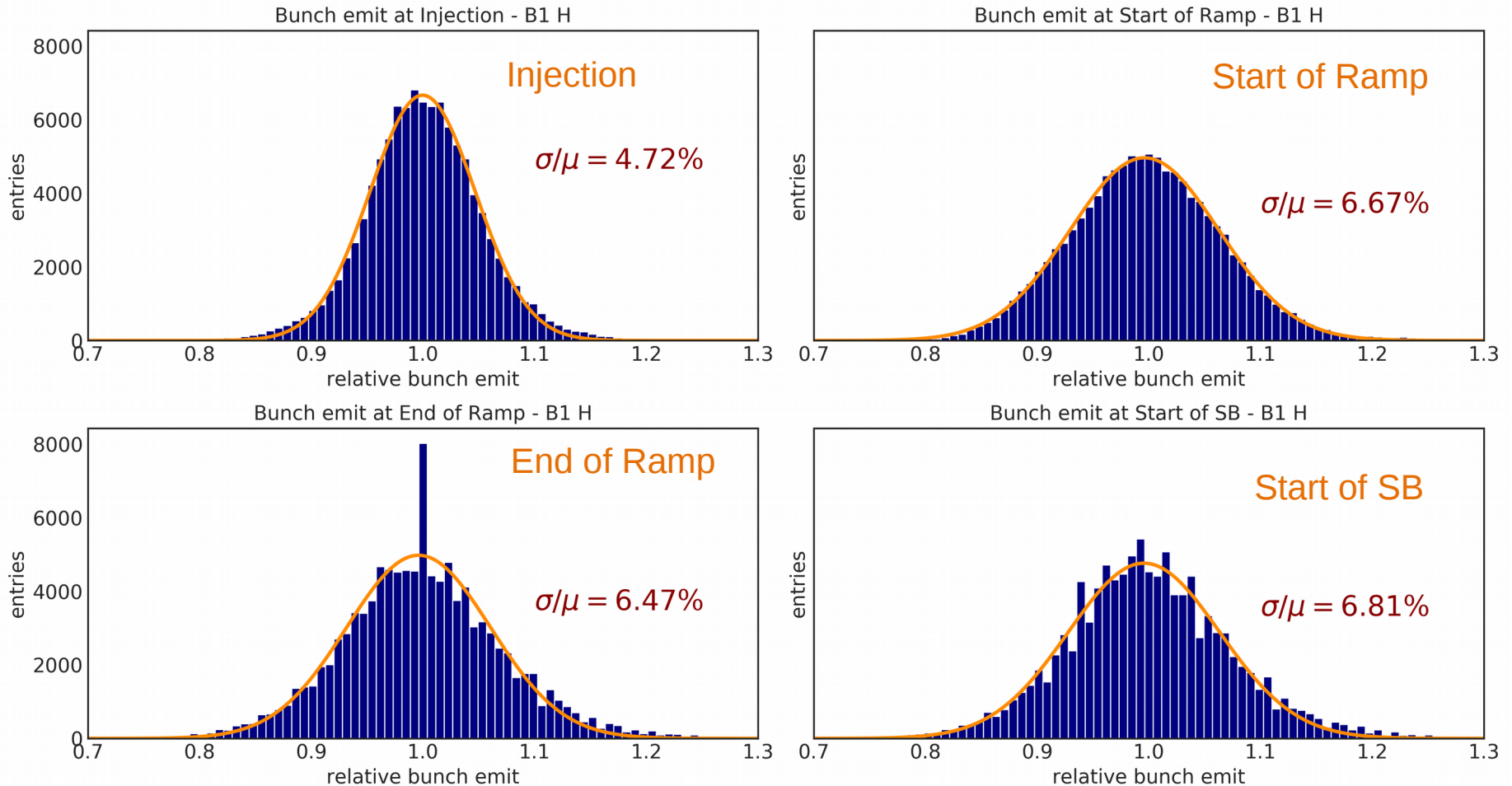
Selected 2018 Fills (43 fills) - B1-H



Bunch emittances normalized to the mean of each fill

Emittance Fluctuations in the cycle

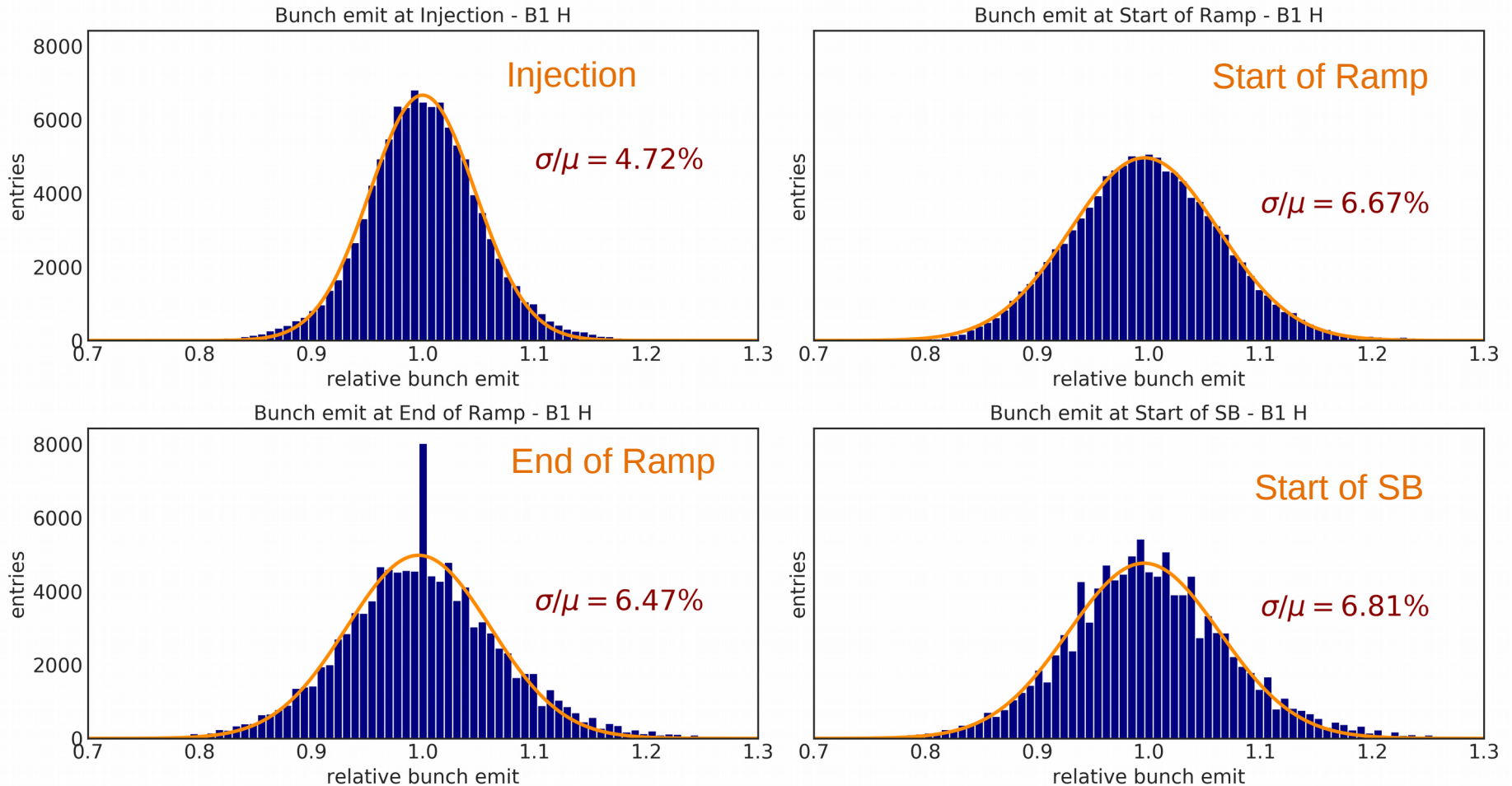
Selected 2018 Fills (43 fills) - B1-H



Bunch emittances normalized to the mean of each fill

Emittance Fluctuations in the cycle

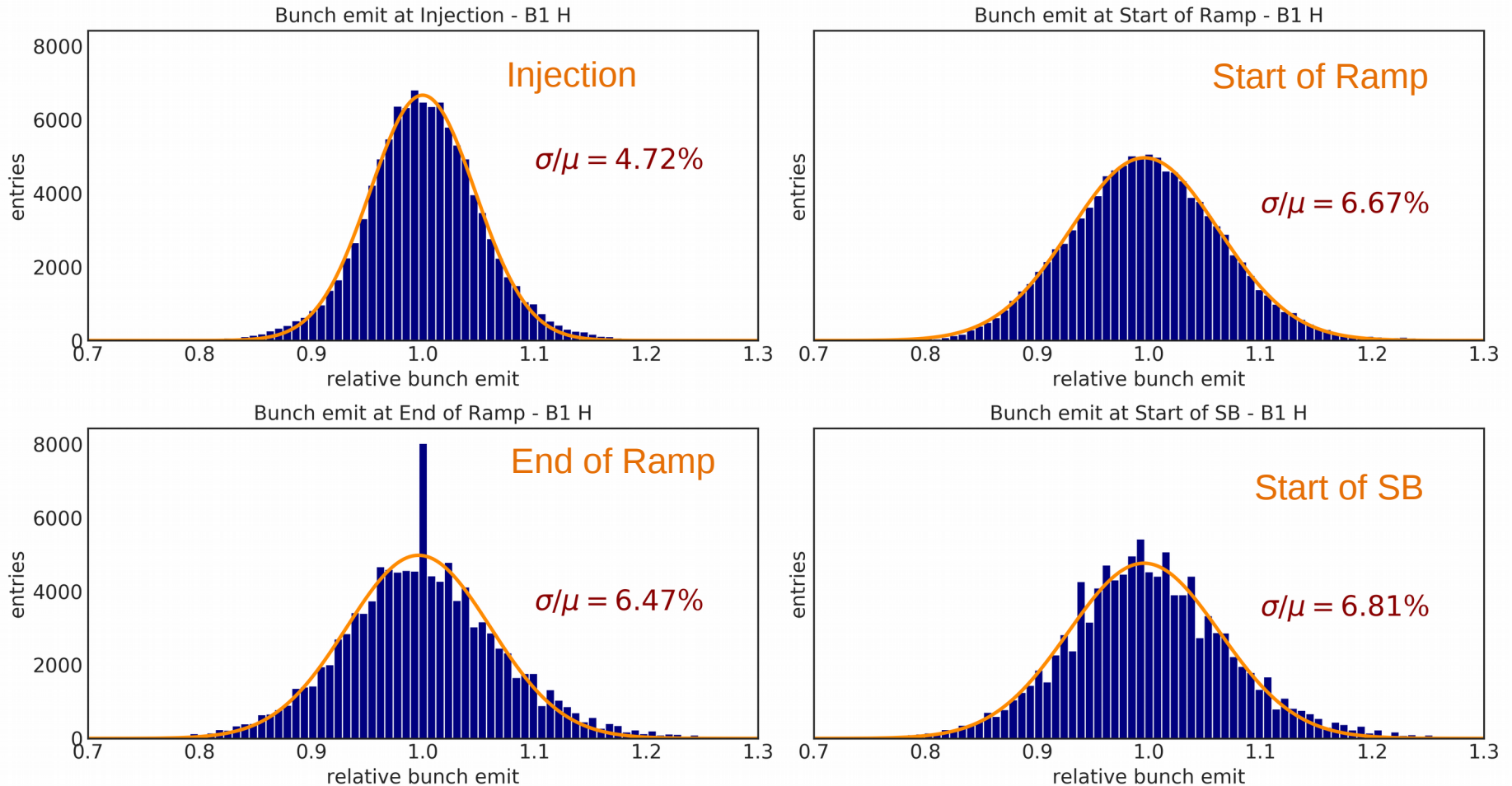
Selected 2018 Fills (43 fills) - B1-H



Bunch emittances normalized to the mean of each fill

Emittance Fluctuations in the cycle

Selected 2018 Fills (43 fills) - B1-H



Bunch emittances normalized to the mean of each fill

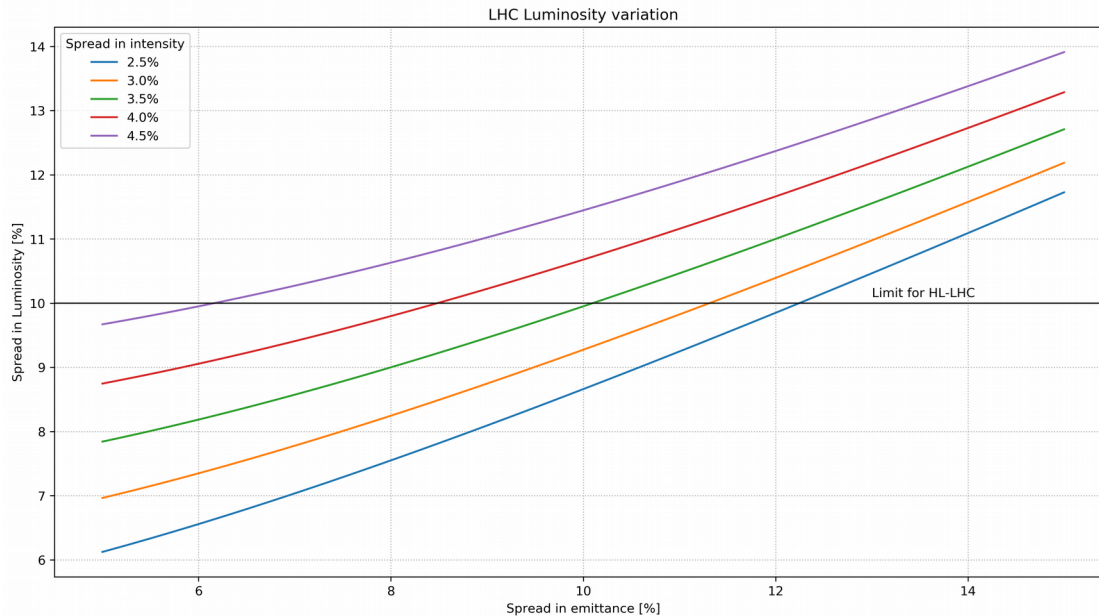
Luminosity fluctuation in Run 2

Reminder:

$$\begin{aligned} \mathcal{L} &= \frac{N_1 N_2 f N_b}{4\pi\sigma_x\sigma_y} \\ &= \frac{N_1 N_2 f N_b}{2\pi\sqrt{\sigma_{1x}^2 + \sigma_{1y}^2}\sqrt{\sigma_{2x}^2 + \sigma_{2y}^2}} \\ &= \frac{N_1 N_2 f N_b}{2\pi\sqrt{\beta_{1,2x}^* \beta_{1,2y}^*}\sqrt{\epsilon_{1x} + \epsilon_{1y}}\sqrt{\epsilon_{2x} + \epsilon_{2y}}} \end{aligned}$$

$$\mathcal{L} = \frac{N_1 N_2 f N_b}{4\pi\sqrt{\beta_x^* \beta_y^*}\sqrt{\epsilon_x}\sqrt{\epsilon_y}}$$

$$\frac{\delta\mathcal{L}}{\mathcal{L}} = \sqrt{4\left(\frac{\delta N}{N}\right)^2 + \frac{1}{4}\left(\frac{\delta\epsilon_x}{\epsilon_x}\right)^2 + \frac{1}{4}\left(\frac{\delta\epsilon_y}{\epsilon_y}\right)^2}$$



- Luminosity fluctuations dominated by intensity

- In the selected fills:

- **4.37% in intensity** (average B1, B2)

- **9.77% in emittance** (average over beams and planes)

Luminosity variation to **~11%**

Goal for HL-LHC : 10%

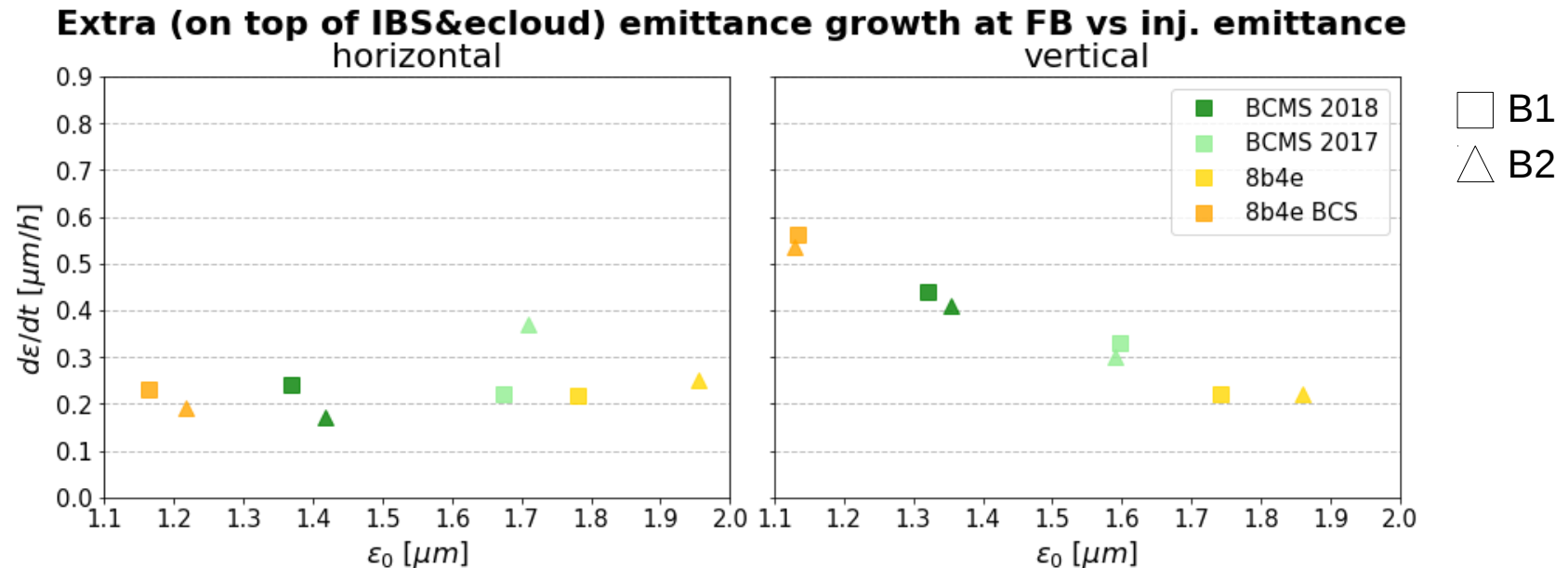
- can be met with:

- **3%** relative spread in intensity, and
- **11%** spread in emittance (average over beams and planes)

Emittance growth on top of the model

Emittance growth on top of the model @ FB

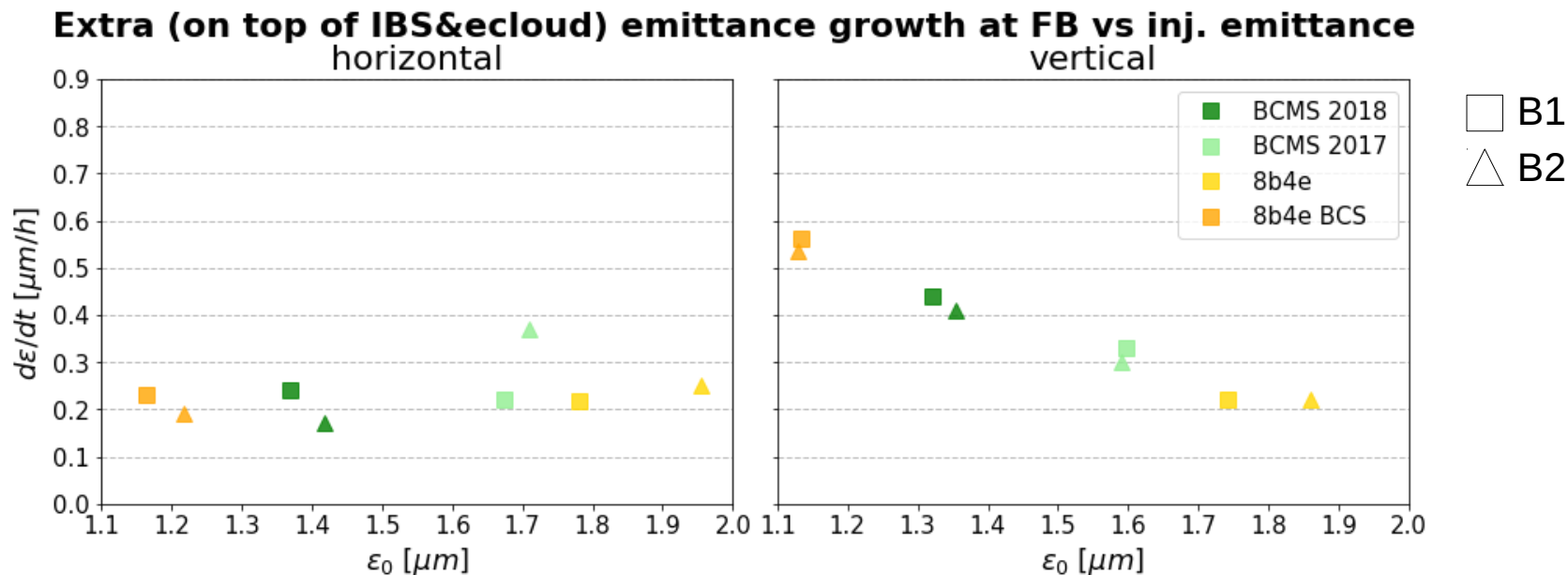
Measured (BSRT)-Model emit. difference over time at FB vs the initial emittance averaged over all Fills for each beam flavor, for both beams and planes



- In vertical, correlation of the extra growth with injected emittances, smaller emittances \rightarrow larger extra growth
- No correlation of extra growth with intensity

Emittance growth on top of the model @ FB

Measured (BSRT)-Model emit. difference over time at FB vs the initial emittance averaged over all Fills for each beam flavor, for both beams and planes



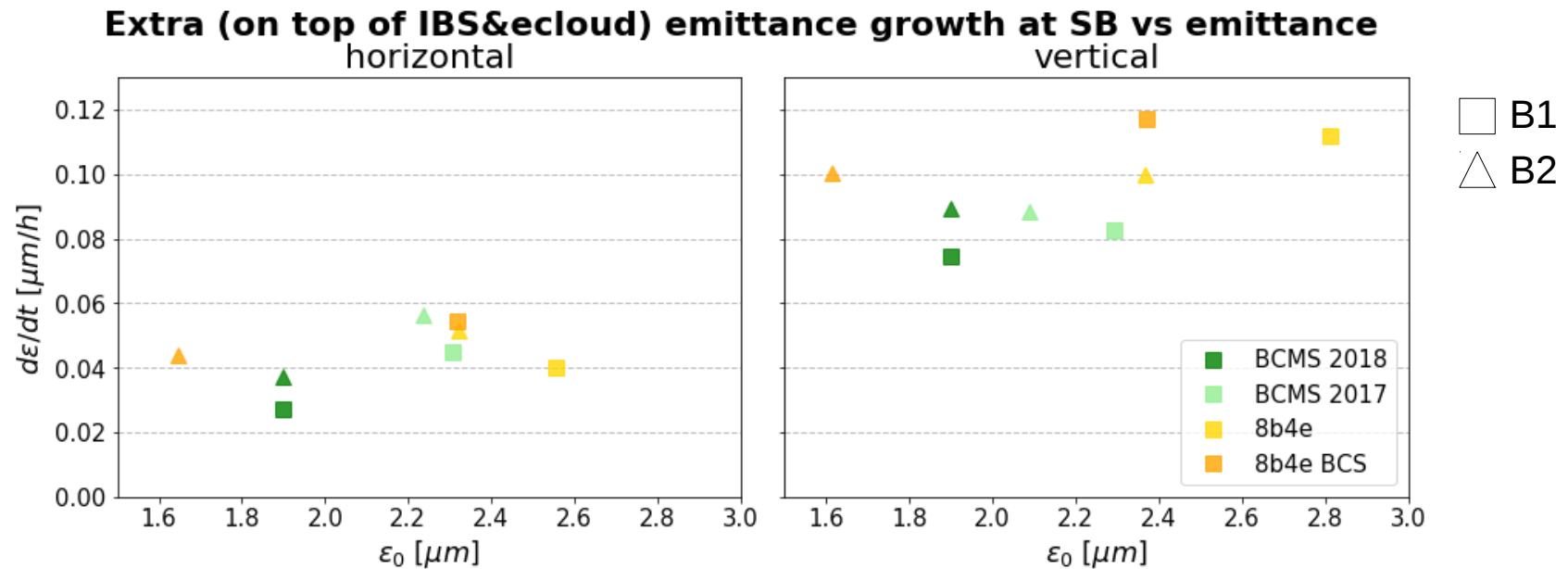
- In vertical, correlation of the extra growth with injected emittances, smaller emittances → larger extra growth
- No correlation of extra growth with intensity

2018	Emit. growth [$\mu\text{m}/h$]	
	H	V
extra	0.21	0.42
noise	0.10	0.14
unknown	0.11	0.28

Rough estimation of emittance growth due to **noise** explains 30-50% of the extra (on top of IBS&ecloud) growth

Emittance growth on top of the model @ collisions

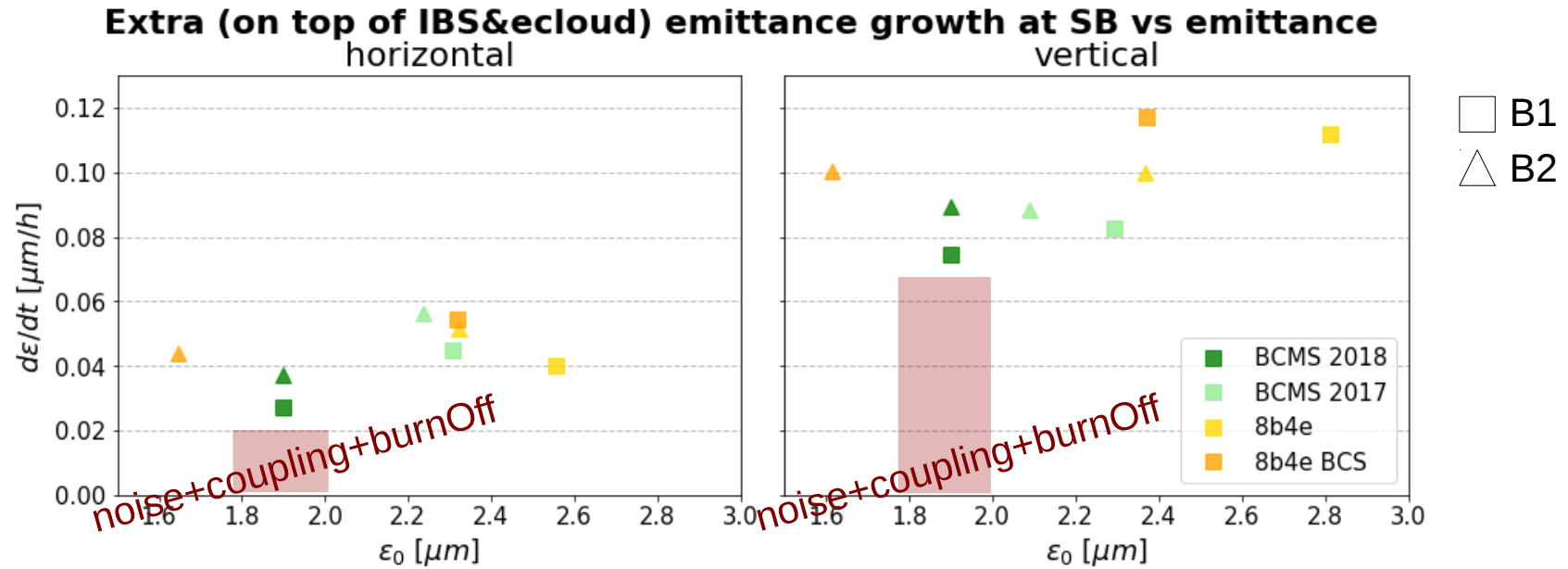
Measured (BSRT)-Model emit. difference over time vs the initial emittance averaged over all Fills for each beam flavor, for both beams and planes



- No correlation of the extra growth with initial emittances at SB
- No correlation of extra growth with intensity

Emittance growth on top of the model @ collisions

Measured (BSRT)-Model emit. difference over time vs the initial emittance averaged over all Fills for each beam flavor, for both beams and planes



- No correlation of the extra growth with initial emittances at SB
- No correlation of extra growth with intensity

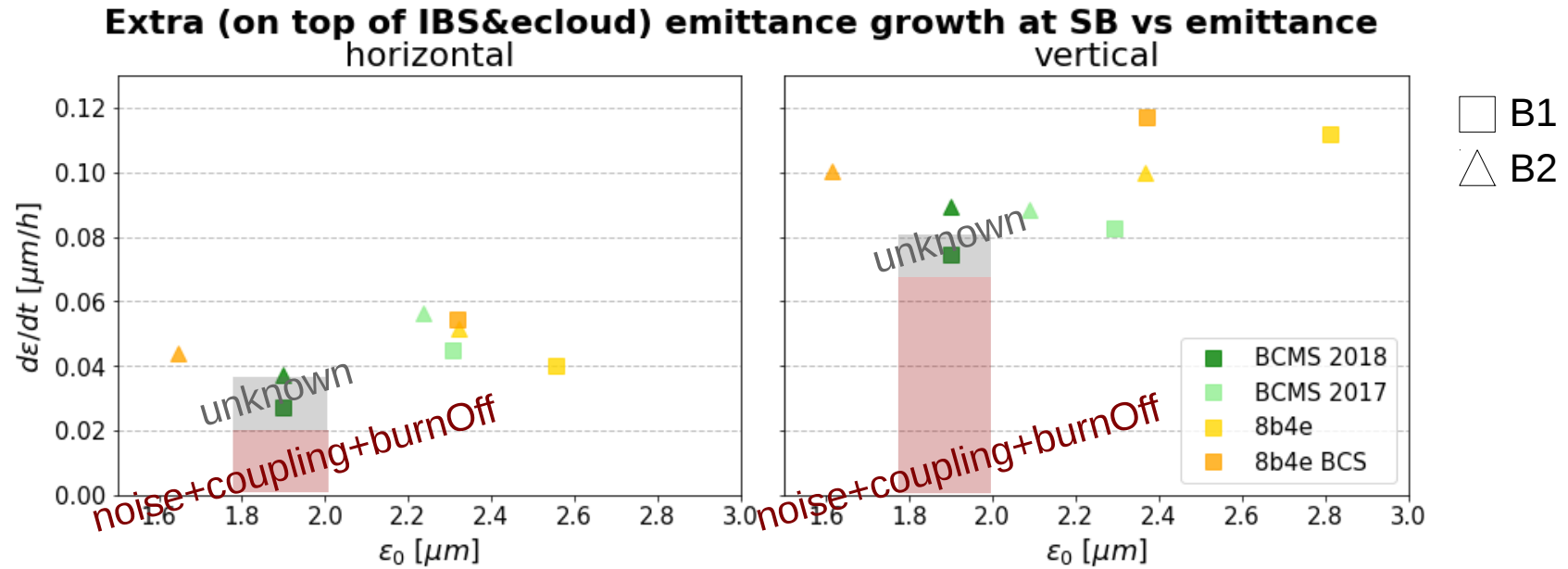
2018	Emit. growth [$\mu\text{m}/\text{h}$]	
	H	V
extra	0.04	0.08
-(noise+coupling+burnOff)		

	H	V
noise	0.04	0.05
coupling	-0.02	+0.02
burn-off	0.003	0.003

link → [upLuminosityModel_WP2_stef](#)

Emittance growth on top of the model @ collisions

Measured (BSRT)-Model emit. difference over time vs the initial emittance averaged over all Fills for each beam flavor, for both beams and planes



- No correlation of the extra growth with initial emittances at SB
- No correlation of extra growth with intensity

2018	Emit. growth [$\mu\text{m}/\text{h}$]	
	H	V
extra	0.04	0.08
-(noise+coupling+burnOff)		
unknown	0.02	0.01

	H	V
noise	0.04	0.05
coupling	-0.02	+0.02
burn-off	0.003	0.003

link → [upLuminosityModel_WP2_stef](#)

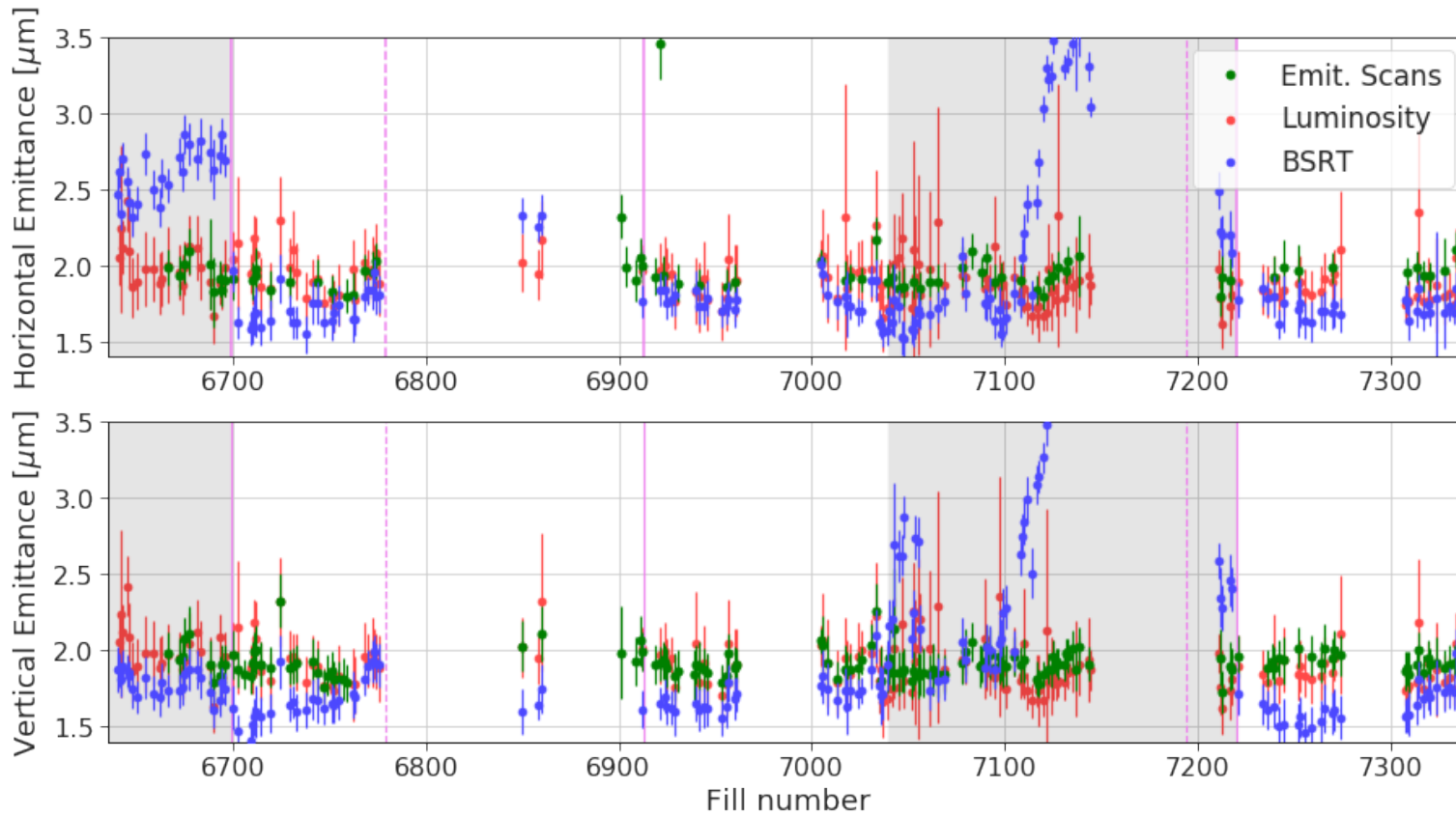
Summary

- The **emittance growth at FB is 10-15%** and at **Ramp 20-30%** for Run 2
- The 2018 **emittances along the cycle** are smaller compared to previous years
- In 2018, the comparison of WS and Emit. scans with Luminosity emittances during a BSRT calibration Fill, explains the **discrepancy observed between the different measurements** along the year → understanding this discrepancy is important
- For both FB and FT energies, the observed **extra emittance growth (on top of the model)** is similar for both beams and there is no clear correlation of with brightness
 - at **FB**, e-cloud explains 30-50% of the observed extra growth. **In vertical, smaller emittance → larger extra growth**
 - at **SB**, no correlation of extra growth with e-cloud
- Including the mechanisms of **coupling&noise&burn-off** for the emittance growth calculations in the model → **significantly better emittance and luminosity predictions**
- Extra emittance blow up plays an important role in the degradation of the **cumulated integrated luminosity** (extra losses have a smaller impact)

Thank you!

extra slides

2018 convoluted emittances at start of collisions



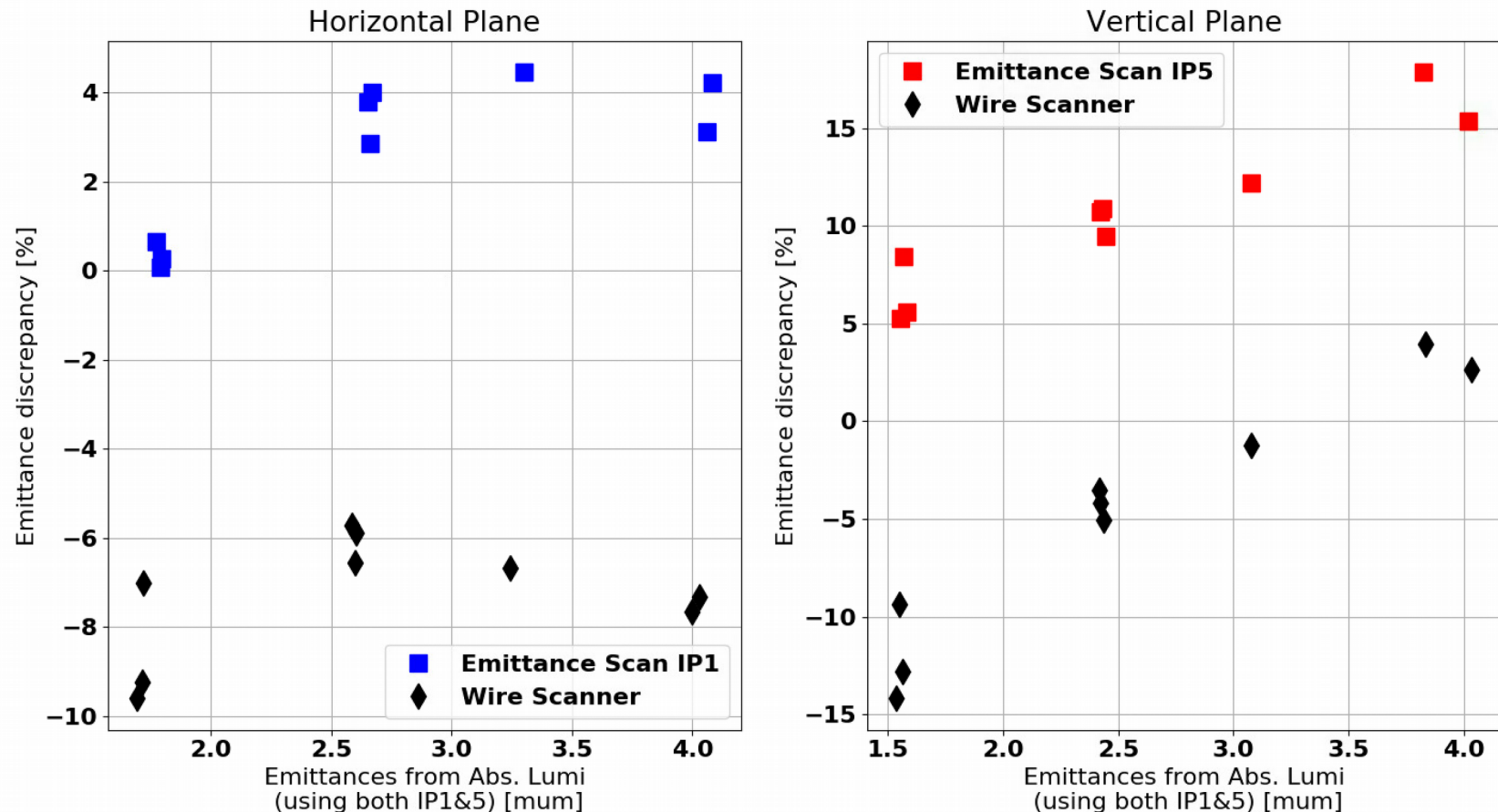
Emittances from Luminosity agree within 10-15% with the ones from Emittance Scans and BSRT

Considering only Fills for which the convoluted emittances at start of SB from Luminosity and BSRT differ less than 10%

	Average emittance values [μm]		Relative emittance blow-up [%]		
	B1H, B2H	B1V, B2V		B1H, B2H	B1V, B2V
Stable Beams	1.9	1.9	Ramp	~20	~25

BSRT calibration Fill 7220

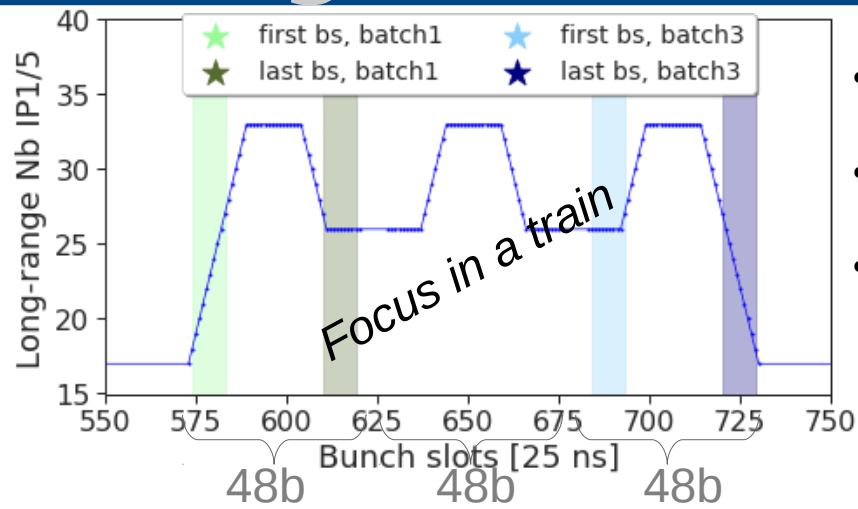
Comparison of convoluted emittances from Emittance Scans and WS with Luminosity



- Agreement of Emittance Scans with the ones from Luminosity is 5-20%
 - Emittances from WS up to 10-15% lower than the Luminosity ones
- Revealing discrepancy between BSRT (calibrated against WS) and emittance from Luminosity → understanding this difference is important

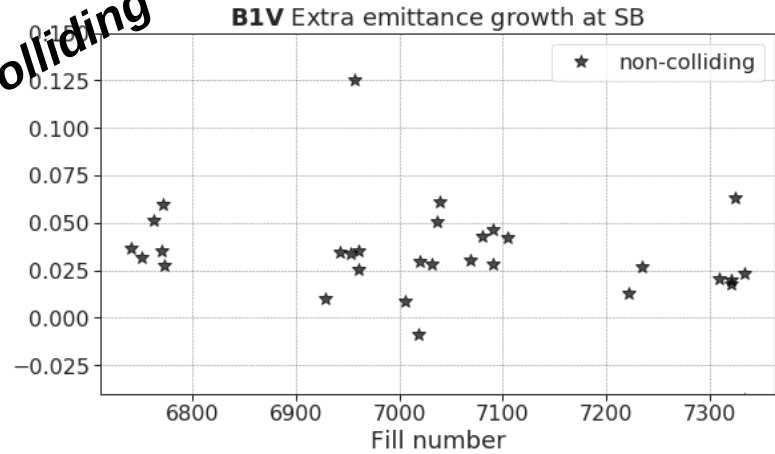
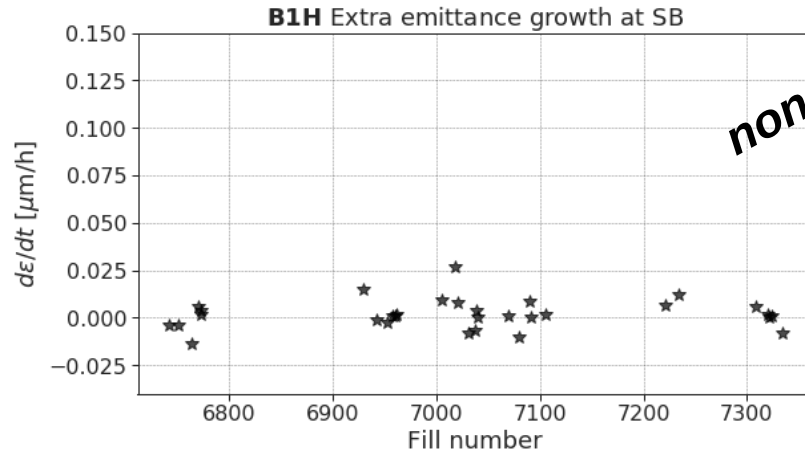
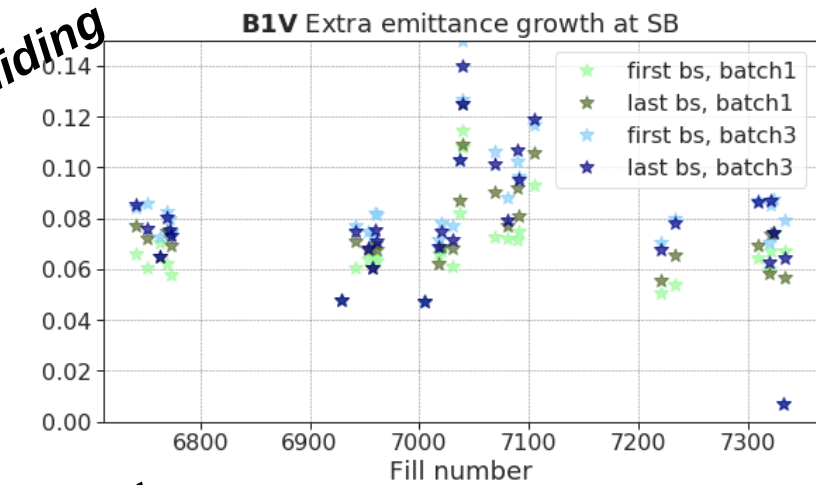
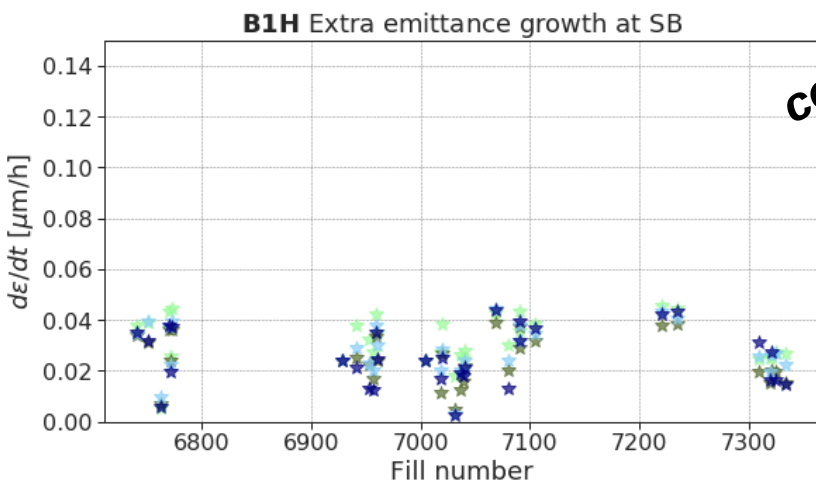
Extra emittance growth at SB, 2018

Definition of bunch classes based on the position of bunches in the batches and train



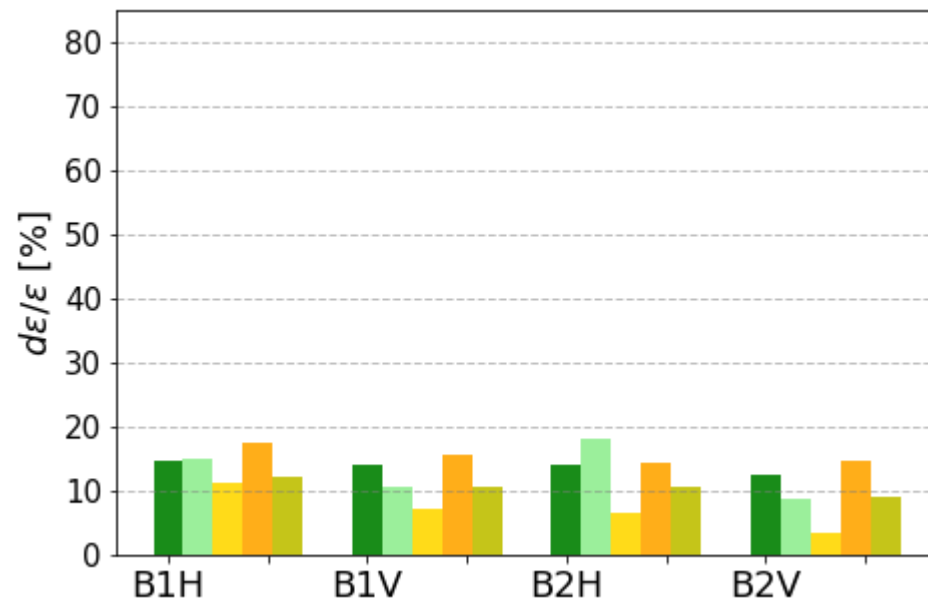
- Averaging over 10 bunches per class
- Model: emittance from model and losses from data
- Time considered at SB before β^* change (at ~8h)

Extra emittance growth
Measured (BSRT)-Model emit. difference

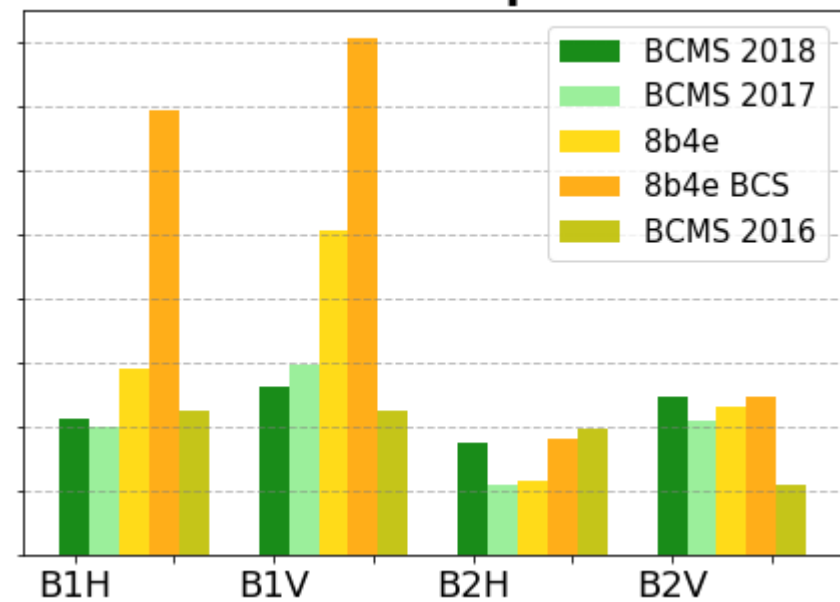


Emittance & intensity for Run 2

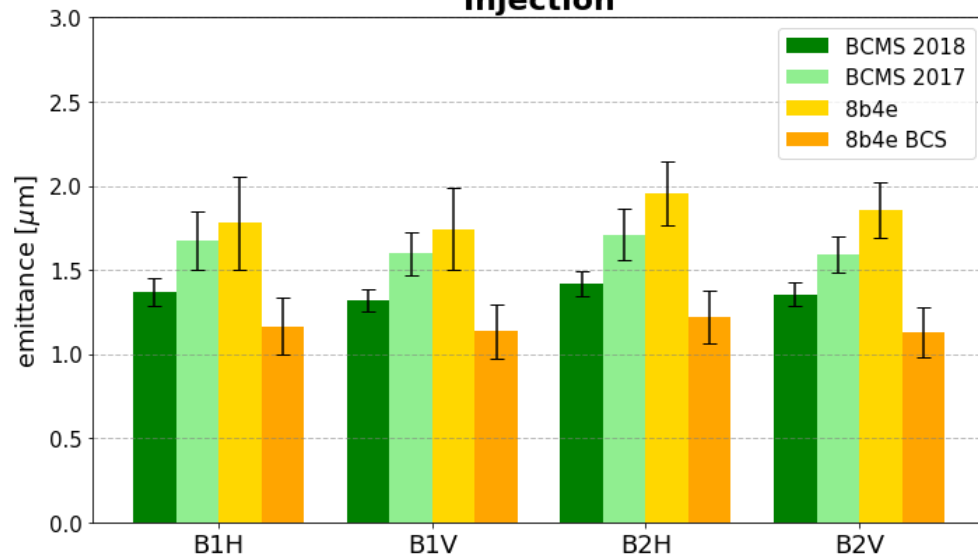
at FB



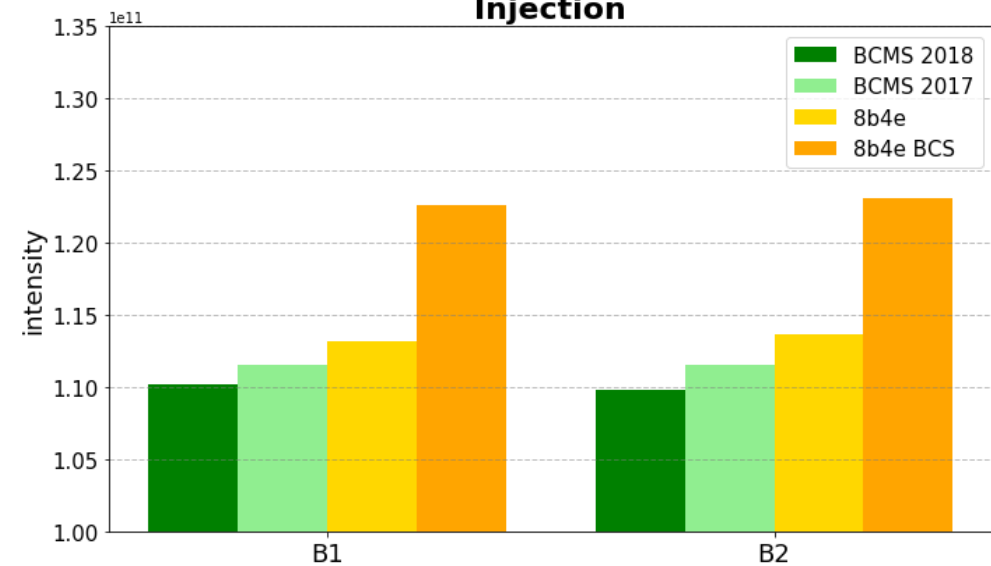
at Ramp



Injection

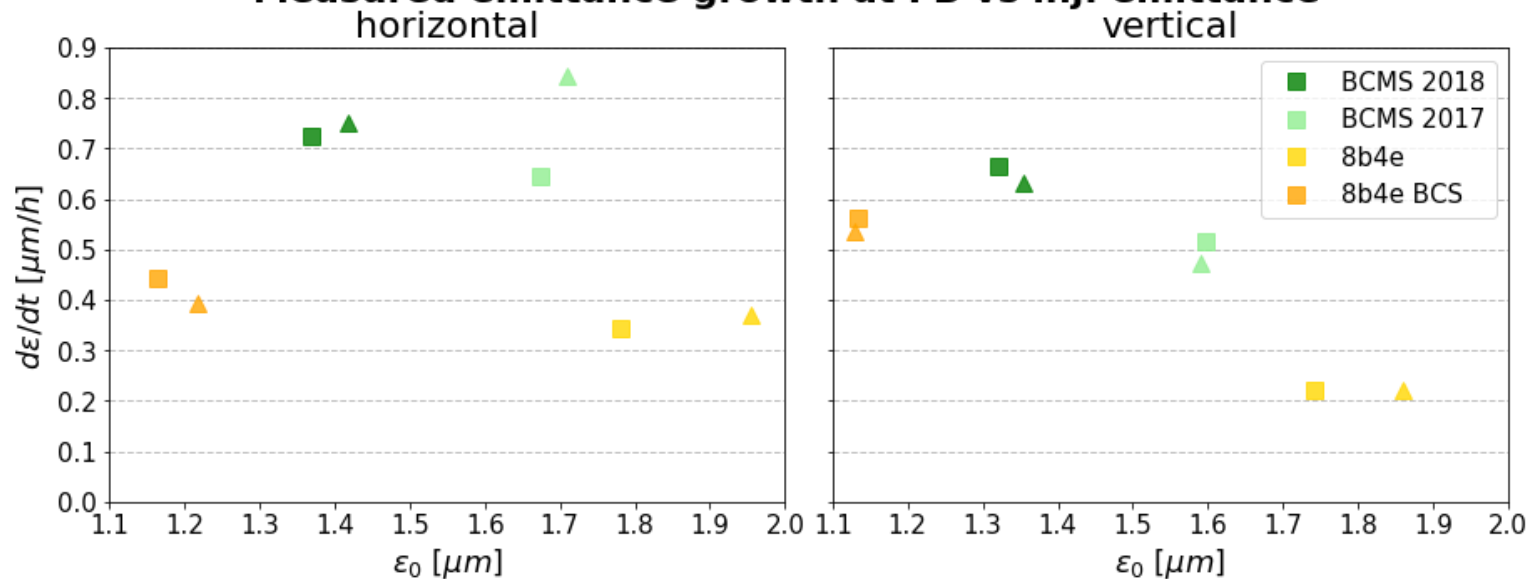


Injection

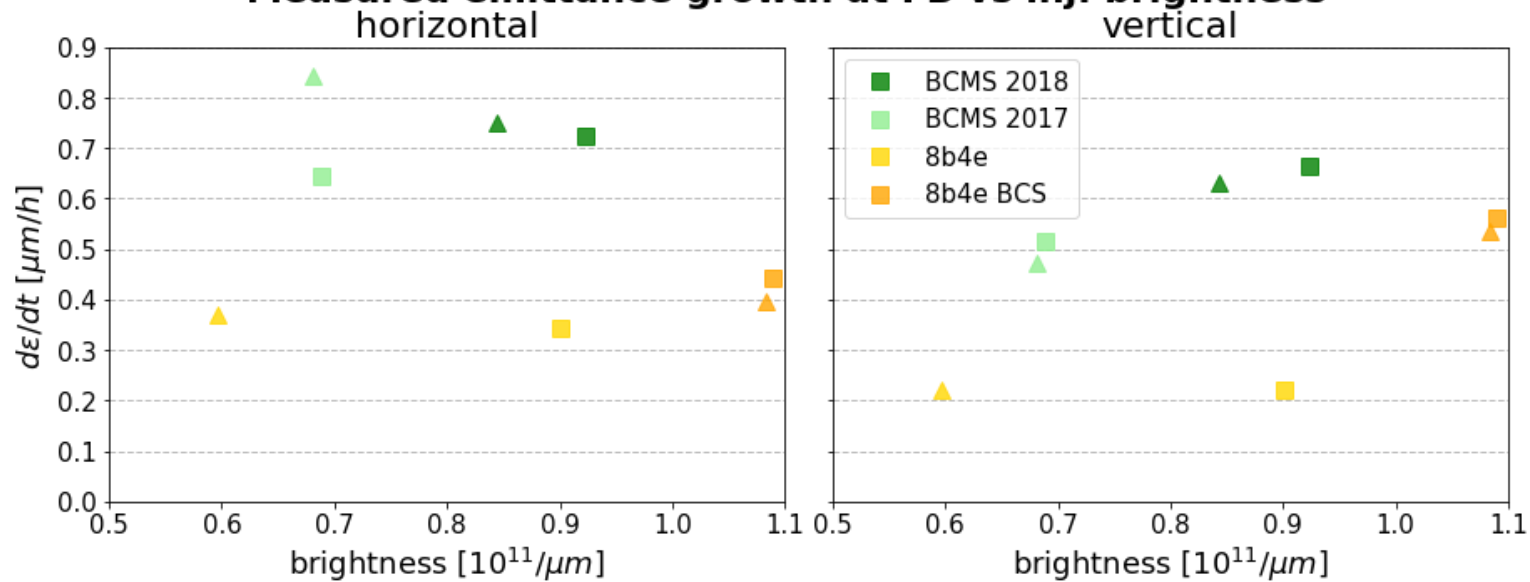


Emittance & intensity for Run 2

Measured emittance growth at FB vs inj. emittance



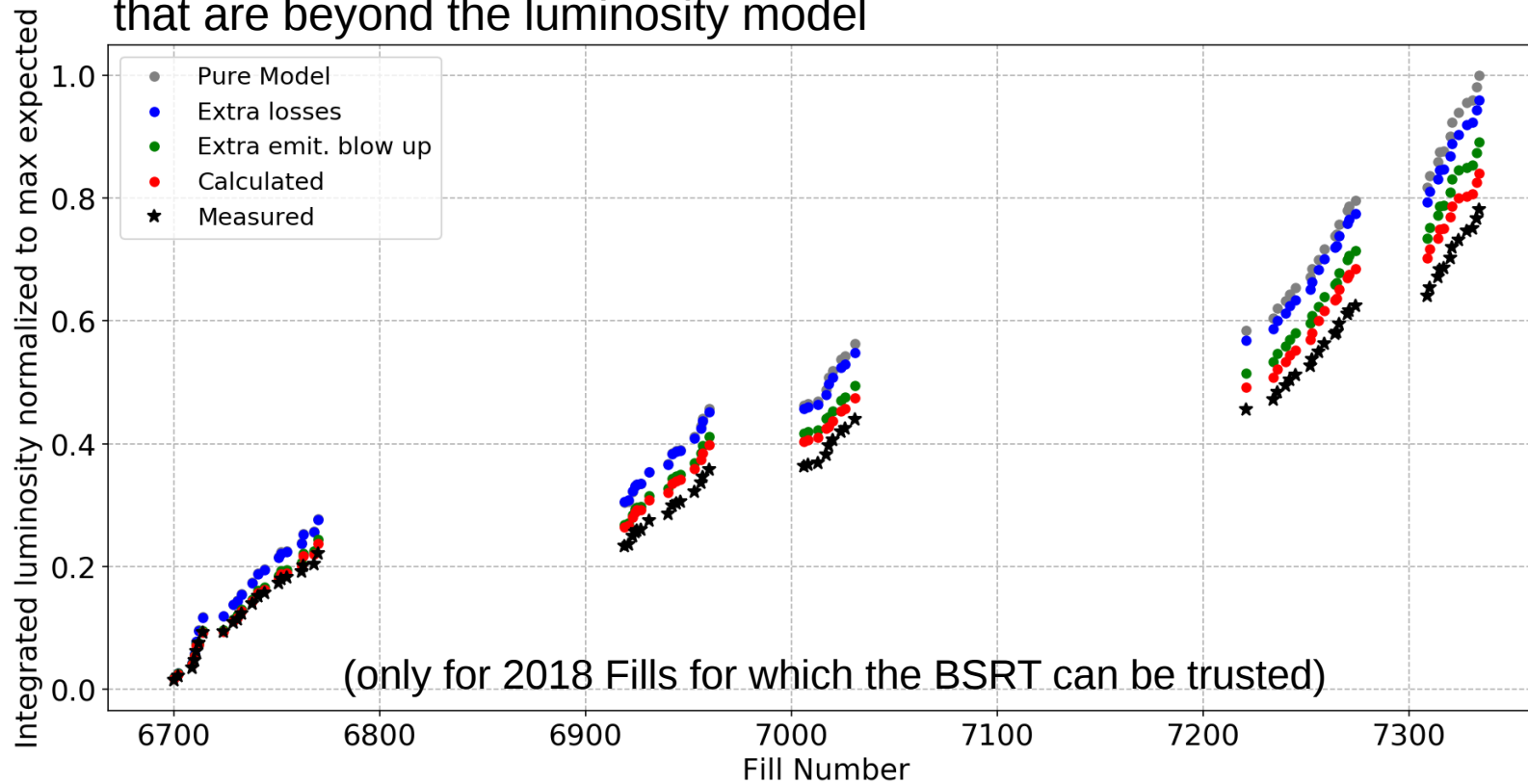
Measured emittance growth at FB vs inj. brightness



□ B1
△ B2

Cumulated integrated Luminosity

2018 Luminosity degradation due to mechanisms that are beyond the luminosity model



2018

-5%
-11%
-22%
-16%

2017

-1%
-10%
-11%
-12%



	Pure model	Extra losses	Extra emit. growth	Calculated
Emittance	model	model	data	data
Intensity	model	data	model	data

2018 BSRT emittances lower by ~10% than the luminosity ones → explains difference between **measured** (by the experiments) and **calculated** luminosity