Emittance growth in the LHC and impact on HL-LHC performance

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Outline

Performance follow-up

Emittance evolution over 2018 run

-BSRT emittances at Flat Bottom, Ramp and Stable Beams

-emittance blow-up along cycle

-convoluted emittance from Emit. Scans, BSRT and Luminosity

HL-LHC expectations at Flat Bottom

-standard and BCMS

-estimations based on the observed extra transverse emittance growth at Flat Bottom

HL-LHC expectations at Stable Beams

-nominal and ultimate scenario

-estimations based on the observed extra transverse emittance growth at Stable Beams

Performance follow-up

Automated tool for performance follow-up (emittance, lifetime, luminosity, …) based on extracted data from the logging system (CALS) and modeling

extracted data

- Intensity data from fBCT
- Emittance data from BSRT
- Bunch length data from BQM
- Luminosities from ATLAS and CMS (Massi files are used)

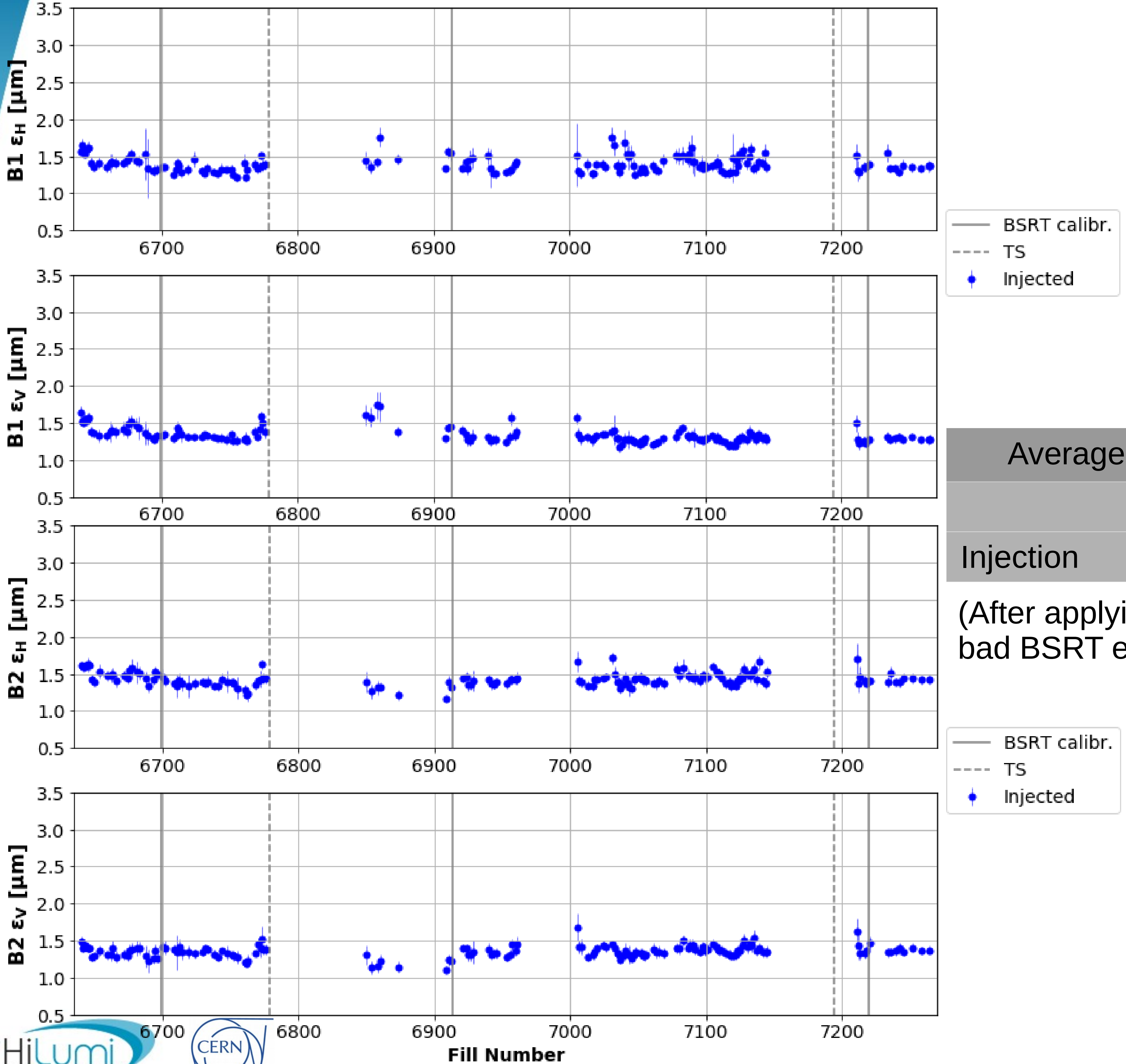
modeling

- Use of a bunch-by-bunch model which is based on the three main mechanisms of luminosity degradation in the LHC: intrabeam scattering (IBS) including **coupling**, synchrotron radiation (SR) and luminosity burn-of
- luminosity leveling with β^* and x-ing angle anti-leveling options

Selection of follow-up fills: Only fills that made it to stable beams

Luminosity follow-up page:
https://lhc-lumimod.web.cern.ch/lhc-lumimod/summaryPlots.html

Emittance evolution over run

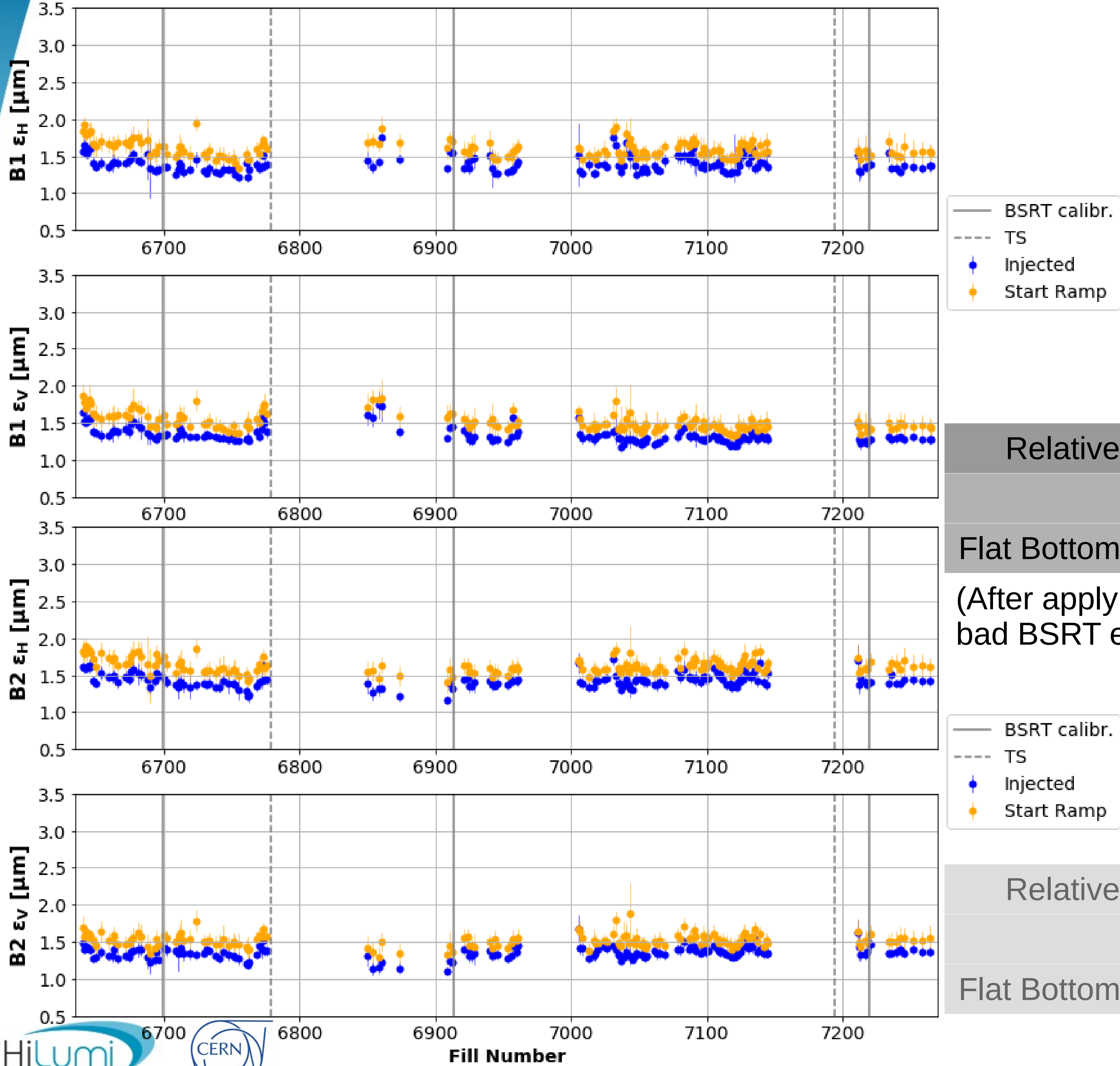


2018

Average emittance values [μm]				
	B1H	B1V	B2H	B2V
Injection	1.40	1.34	1.43	1.36

(After applying some filters to exclude bad BSRT emittances)

Emittance evolution over run



2018

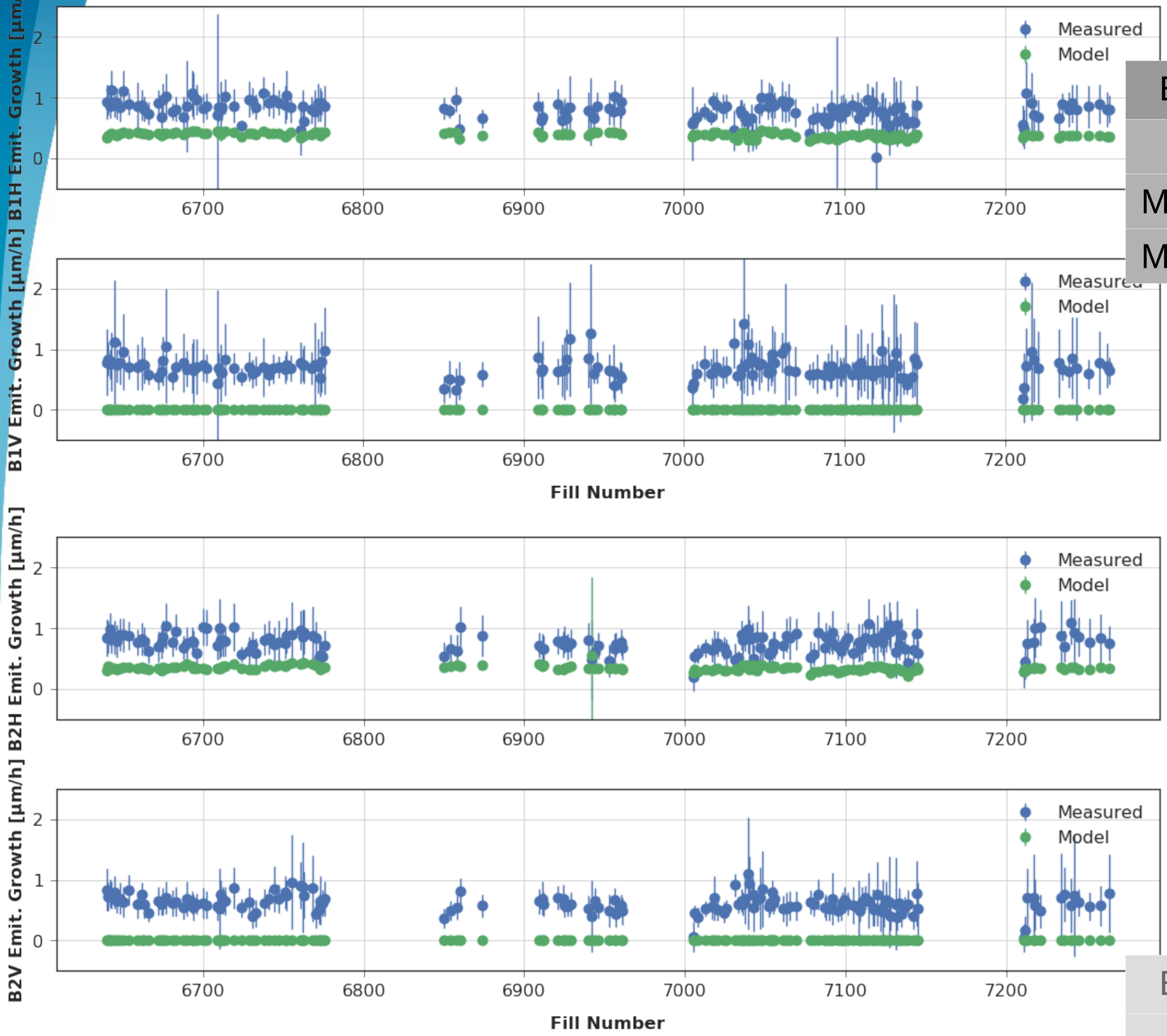
Relative emittance blow-up [%]				
	B1H	B1V	B2H	B2V
Flat Bottom	14.3	13.5	13.7	12.2

(After applying some filters to exclude bad BSRT emittances)

2017 BCMS

Relative emittance blow-up [%]				
	B1H	B1V	B2H	B2V
Flat Bottom	13.9	9.9	16.3	8.1

Emittance growth at Flat Bottom



2018

Emit. growth at Flat Bottom [μm/h]				
	B1H	B1V	B2H	B2V
Measured	0.8	0.7	0.8	0.6
Model	0.4	10^{-3}	0.3	10^{-3}

(After applying some filters to exclude bad BSRT emittances)

The extra (on top of the model) transverse emittance growth is ~0.40 [μm/h] and ~0.65 [μm/h] in the horizontal and vertical plane, respectively

-This extra blow-up is e-cloud driven

-It seems that the extra blow-up has no brightness dependence

2017 BCMS

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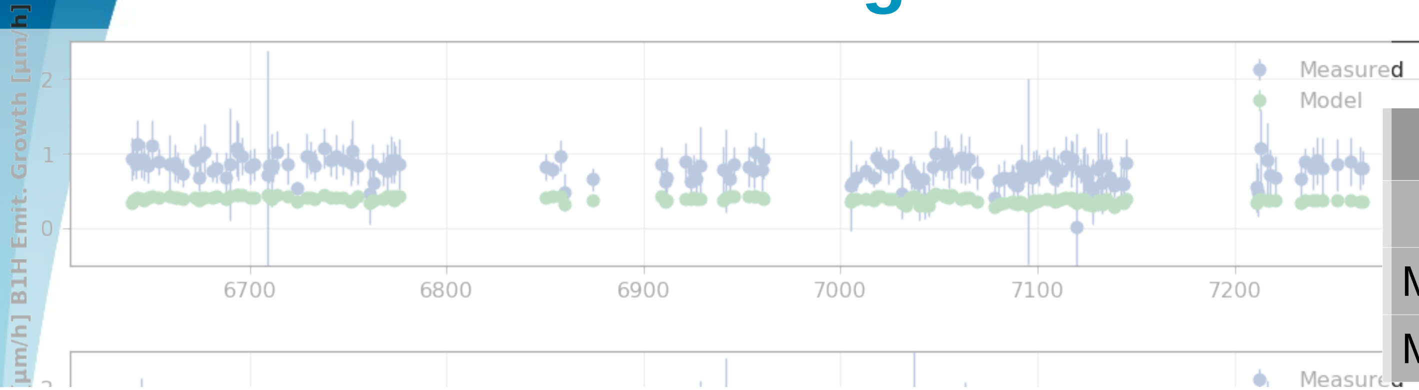
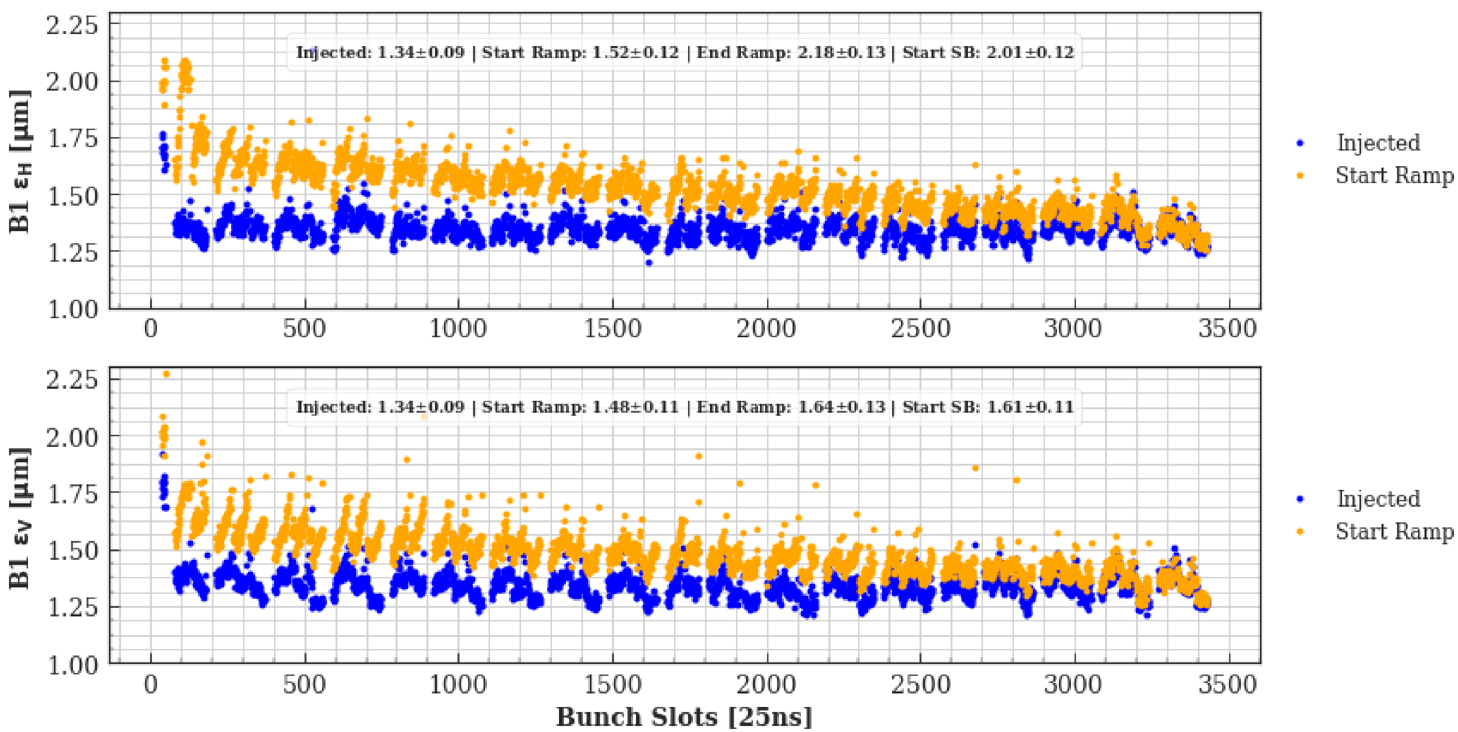
Emittance growth at Flat Bottom



Fill 6702 : Started on 2018-05-19 20:38:59



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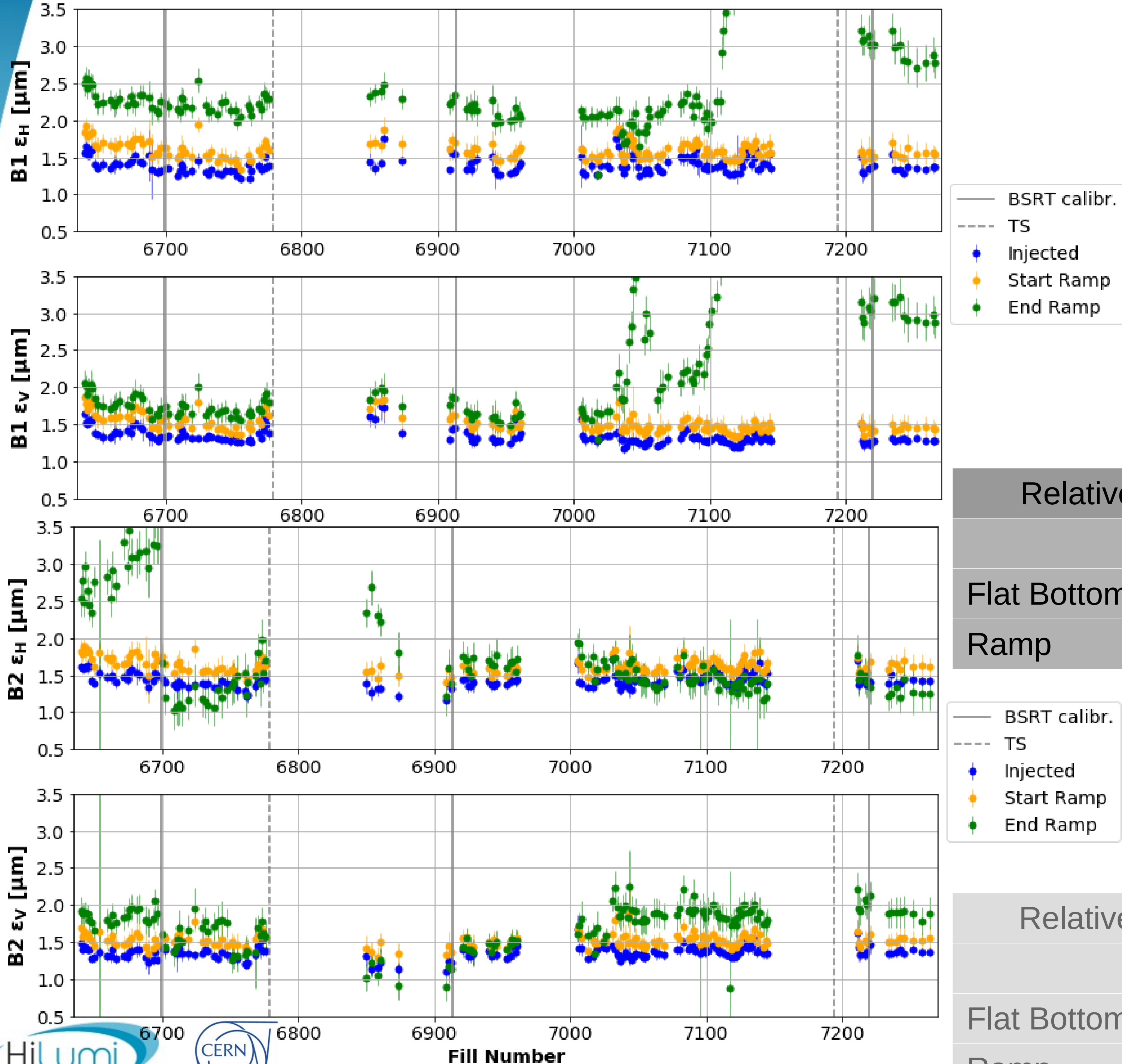
Emittance evolution over run



2018

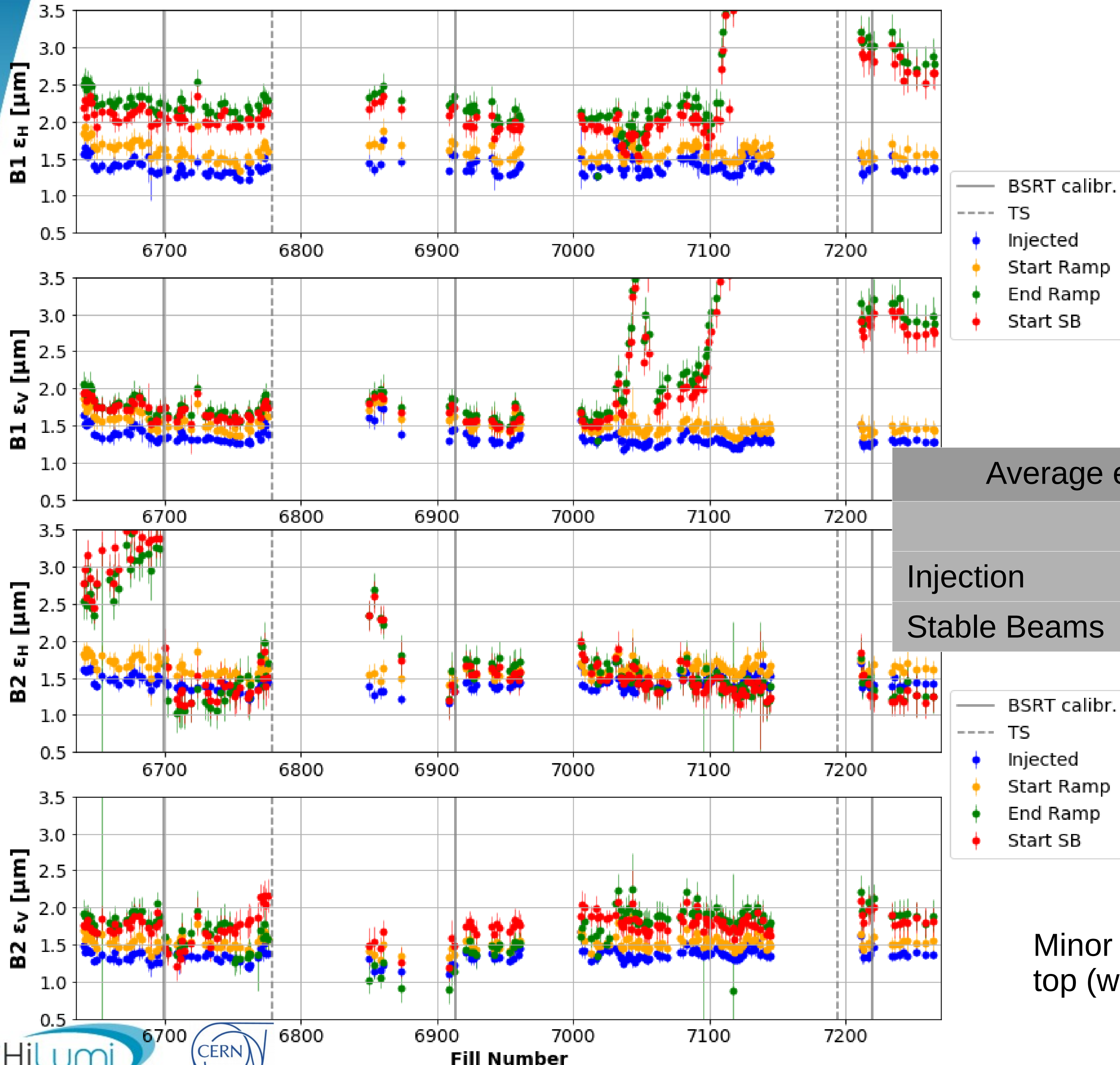
Relative emittance blow-up [%]				
	B1H	B1V	B2H	B2V
Flat Bottom	14.3	13.5	13.7	12.2
Ramp	37.0	11.3	-8.9	11.6

At Flat Top BSRT cannot be trusted

2017 BCMS

Relative emittance blow-up [%]				
	B1H	B1V	B2H	B2V
Flat Bottom	13.9	9.9	16.3	8.1
Ramp	32.7	26.8	15.1	23.1

Emittance evolution over run



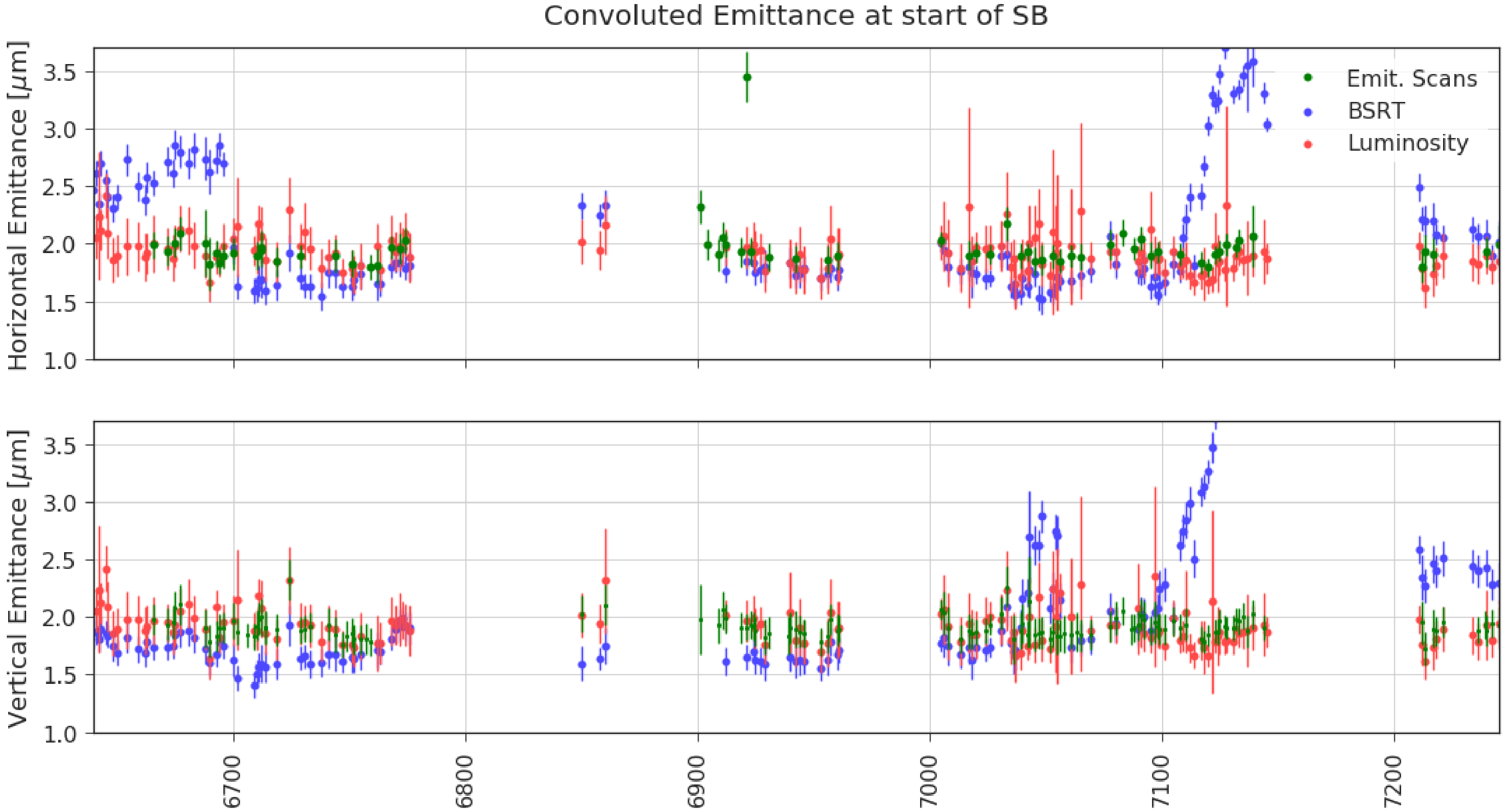
2018

Average emittance values [μm]				
	B1H	B1V	B2H	B2V
Injection	1.40	1.34	1.43	1.36
Stable Beams	2.04	1.68	1.47	1.76

At Flat Top BSRT cannot be trusted

Minor blow-up during flat top (within statistical error)

Emittance evolution over run

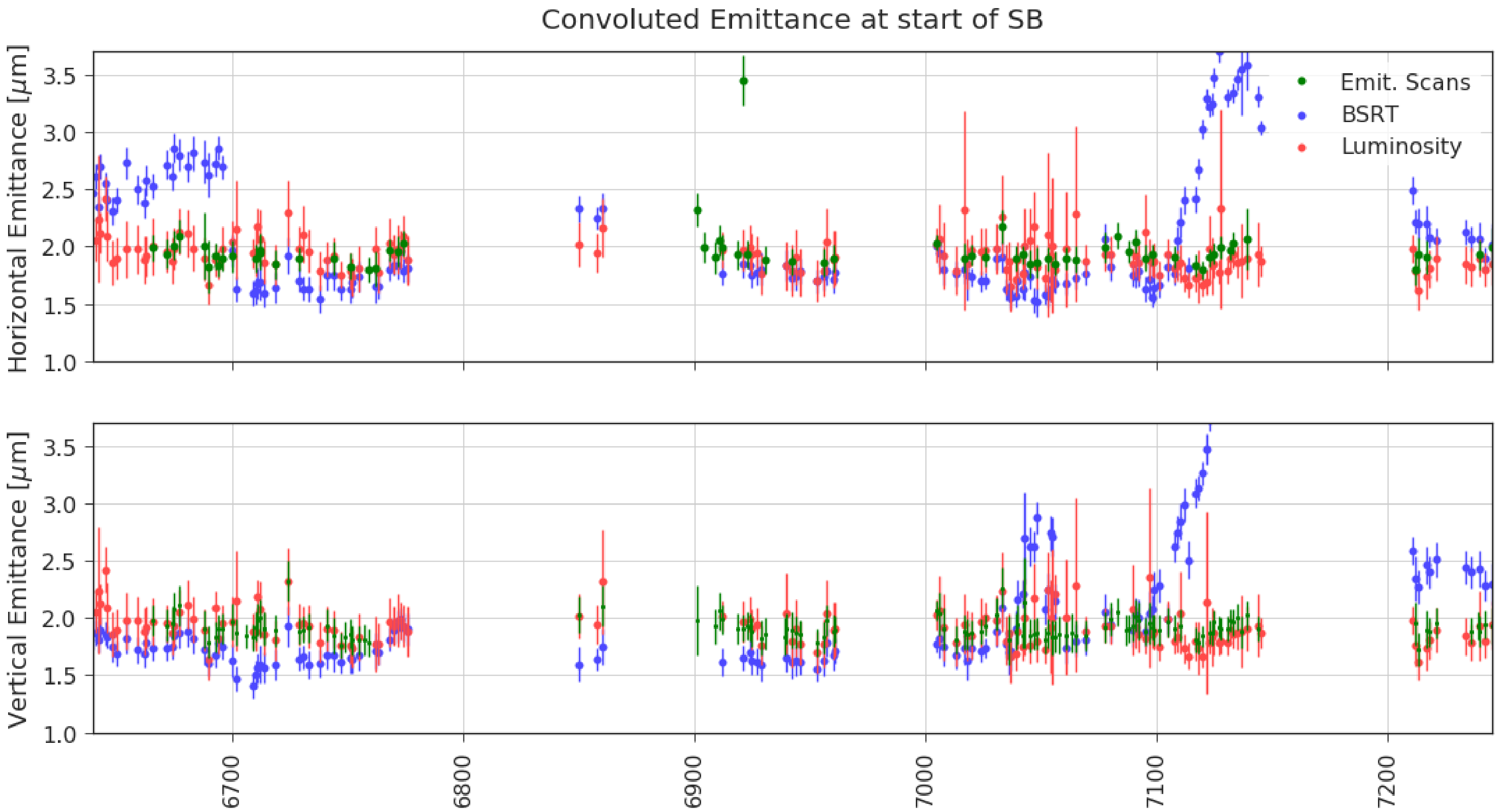


Knowing that the blow-up during the Ramp is larger for B1 than it is for B2, the estimation of the convoluted emittance is affected

Average emittance values [μm]		
	B1H, B2H	B1V, B2V
Injection	1.42	1.35
Stable Beams		

Relative emittance blow-up [%]		
	B1H, B2H	B1V,B2V
Flat Bottom	14	13
Ramp		

Emittance evolution over run

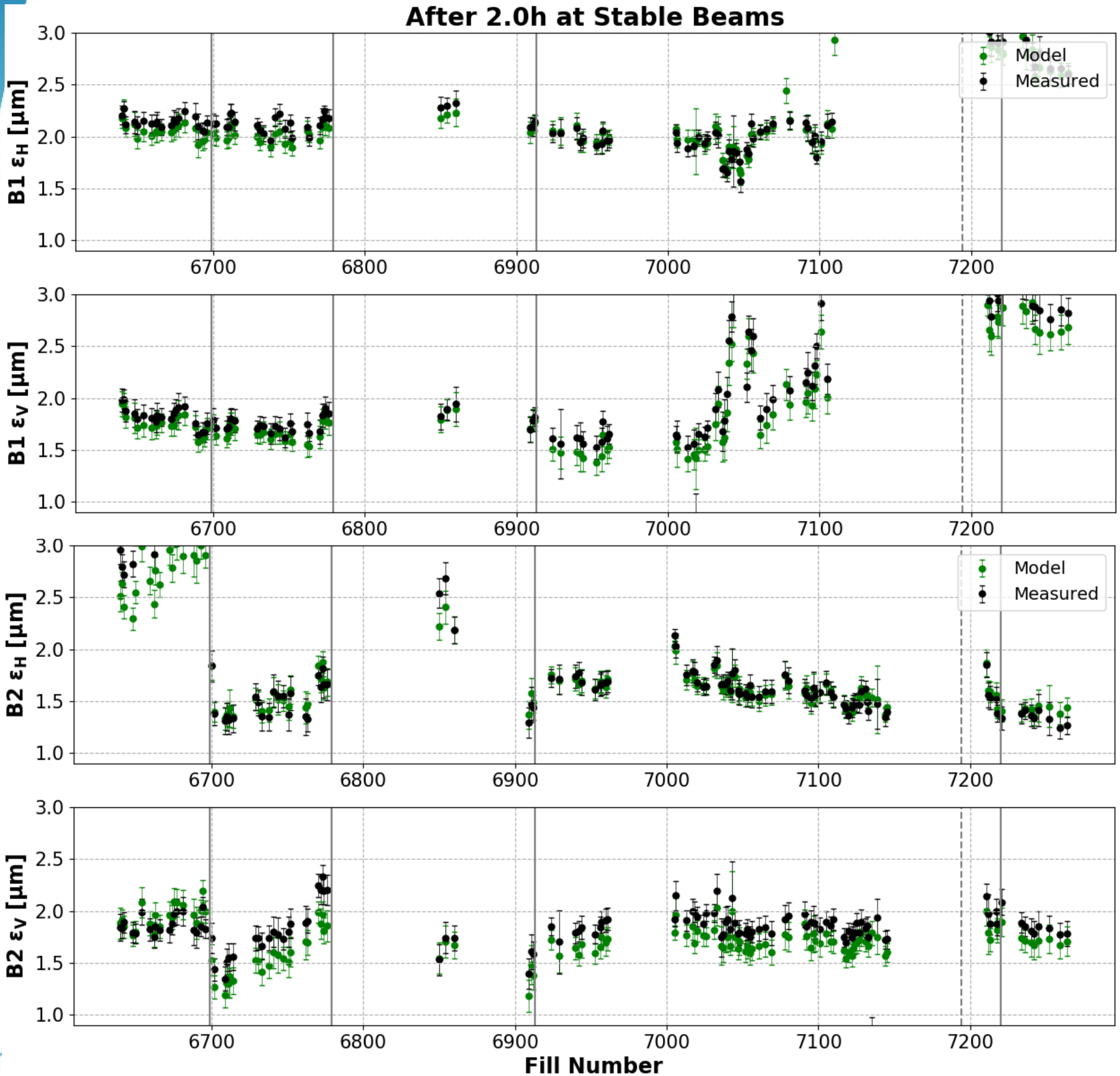


Estimation of the emittances at start of Stable Beams and of the relative emittance blow-up during Ramp based on the mean emittances from Emit. Scans and Luminosity (excluding outliers)

Knowing that the blow-up during the Ramp is larger for B1 than it is for B2, the estimation of the convoluted emittance is affected

Average emittance values [µm]			Relative emittance blow-up [%]		
	B1H, B2H	B1V, B2V		B1H, B2H	B1V,B2V
Injection	1.42	1.35	Flat Bottom	14	13
➡ Stable Beams	1.93	2.08	Ramp	~20	~30

Emittance growth at Stable Beams



Comparison between **Measured emittance** and **Model prediction** (intensity evolution from the data is used) after 2 h in stable beams → extra emittance growth

Taking into account some Fills for which the agreement between Emittance Scans-BSRT-Luminosity emittances is good and, based on estimations of 2017, the extra emittance growth at Stable Beams is assumed to be 0.05 μm/h for both planes and beams

HL-LHC expectations
assumptions

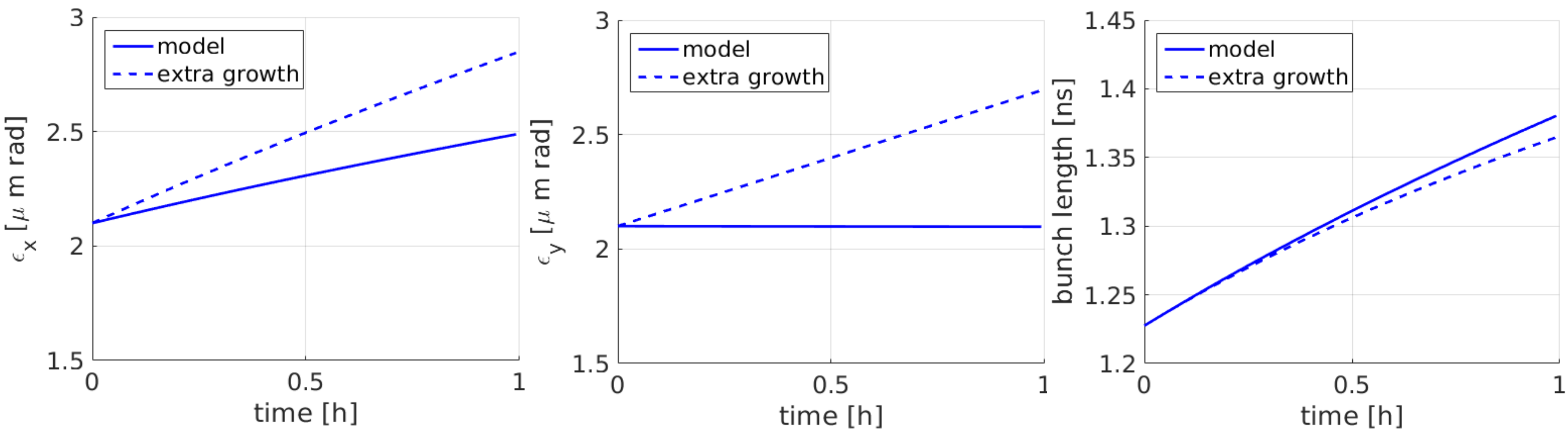
-Taking into account 2018 Fills where the emittances can be trusted
-Considering the same time duration for the Ramp as for the LHC
-Assuming no brightness dependence for the observed extra growth

Flat Bottom				
	B1H	B1V	B2H	B2V
Extra emittance growth [μm/h]	0.4	0.65	0.4	0.65

Ramp				
	B1H	B1V	B2H	B2V
Relative emittance blow-up [%]	~20	~30	~20	~30

Stable Beams				
	B1H	B1V	B2H	B2V
Extra emittance growth [μm/h]	0.05	0.05	0.05	0.05

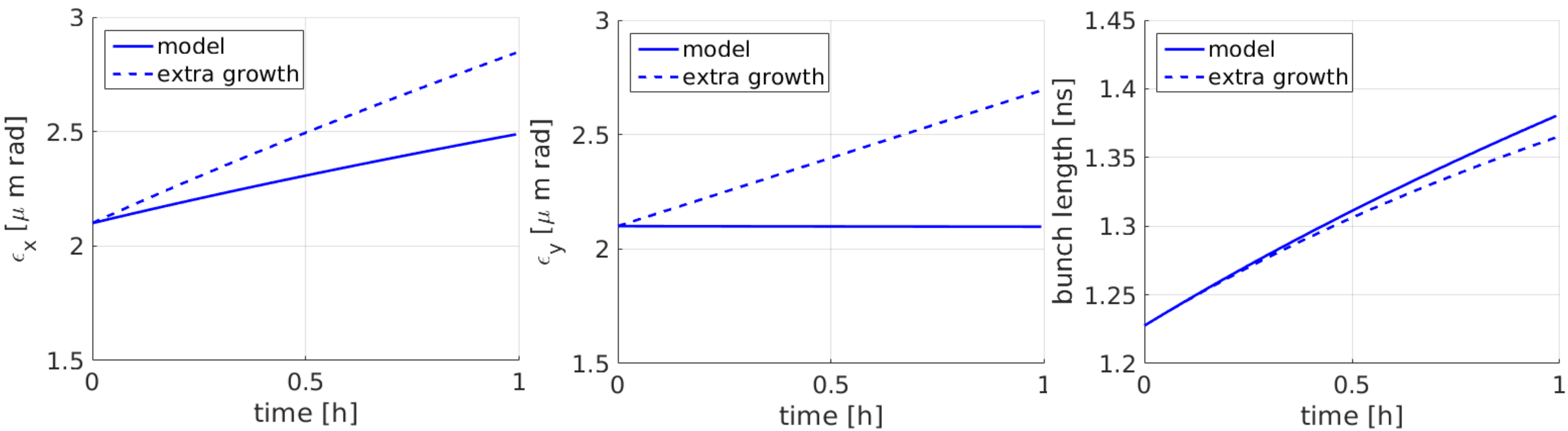
HL-LHC expectations at Flat Bottom (standard)



Horiz. : +0.40 [μm/h]
Vertic. : +0.65 [μm/h]

after 0.5h at Flat Bottom	ε_x [μm]	ε_y [μm]	σ_l [ns]
model	2.3	2.1	1.3
+extra transverse growth at FB	2.5	2.4	1.3

HL-LHC expectations at Flat Bottom (standard)

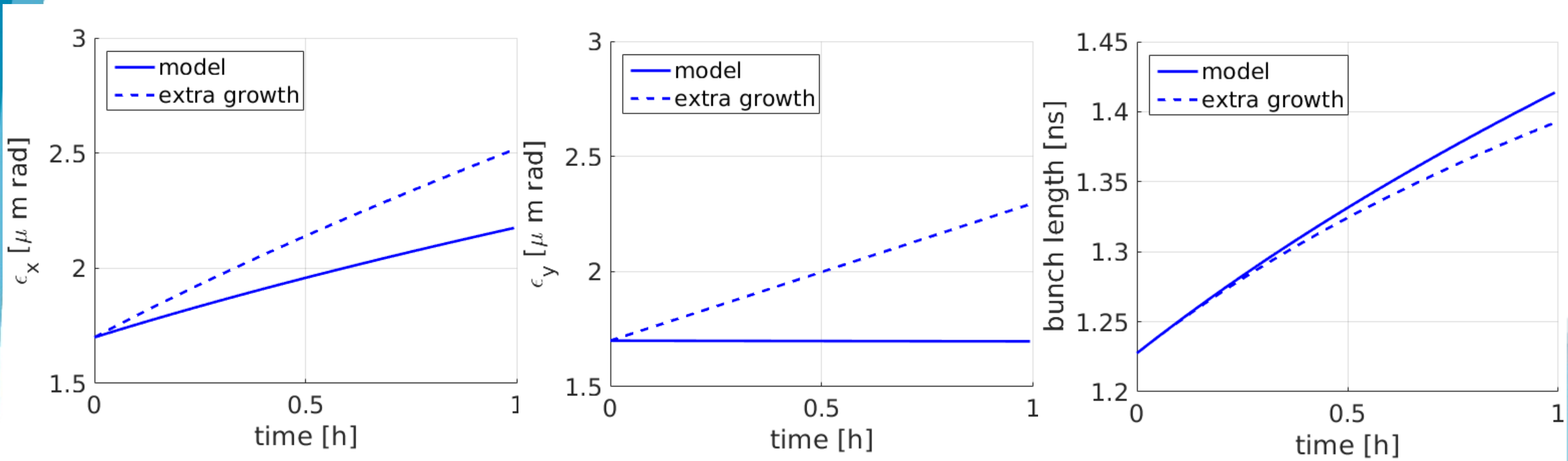


after 0.5h at Flat Bottom	ε_x [μm]	ε_y [μm]	σ_l [ns]
model	2.3	2.1	1.3
+extra transverse growth at FB	2.5	2.4	1.3
		at Stable Beams	
+transverse blow-up at Ramp	**3.3**	**3.1**	1.2

Horiz. : +0.40 [μm/h]
Vertic. : +0.65 [μm/h]

Horiz. : +20%
Vertic. : +30%

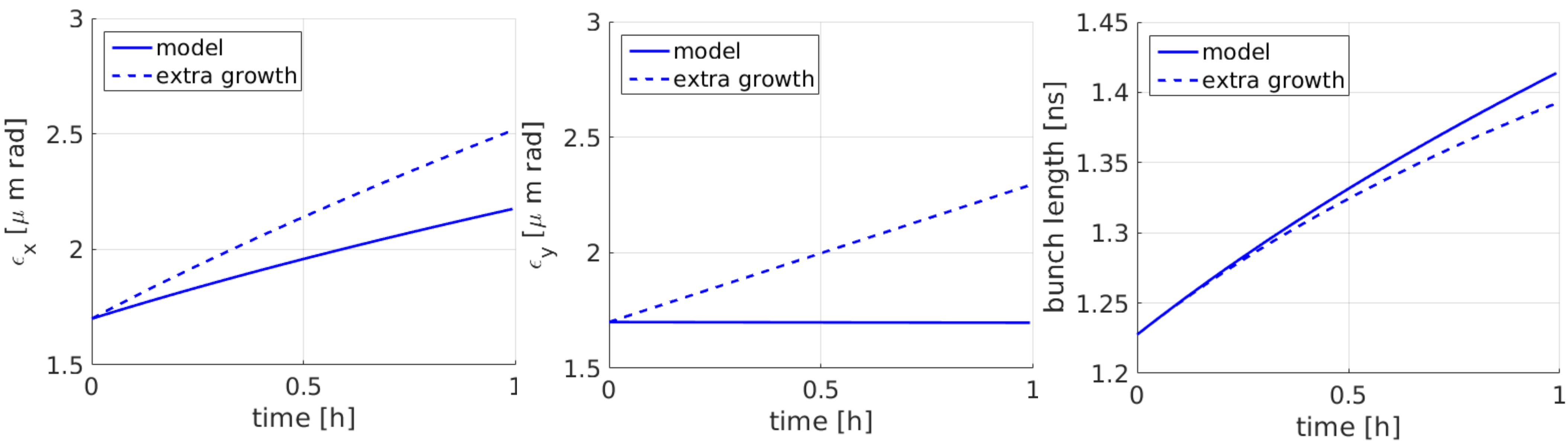
HL-LHC expectations at Flat Bottom
(BCMS)



after 0.5h at Flat Bottom	ε_x [µm]	ε_y [µm]	σ_l [ns]
model	2.0	1.7	1.32
+extra transverse growth at FB	2.1	2.0	1.33

Horiz. : +0.40 [µm/h]
Vertic. : +0.65 [µm/h]

HL-LHC expectations at Flat Bottom (BCMS)

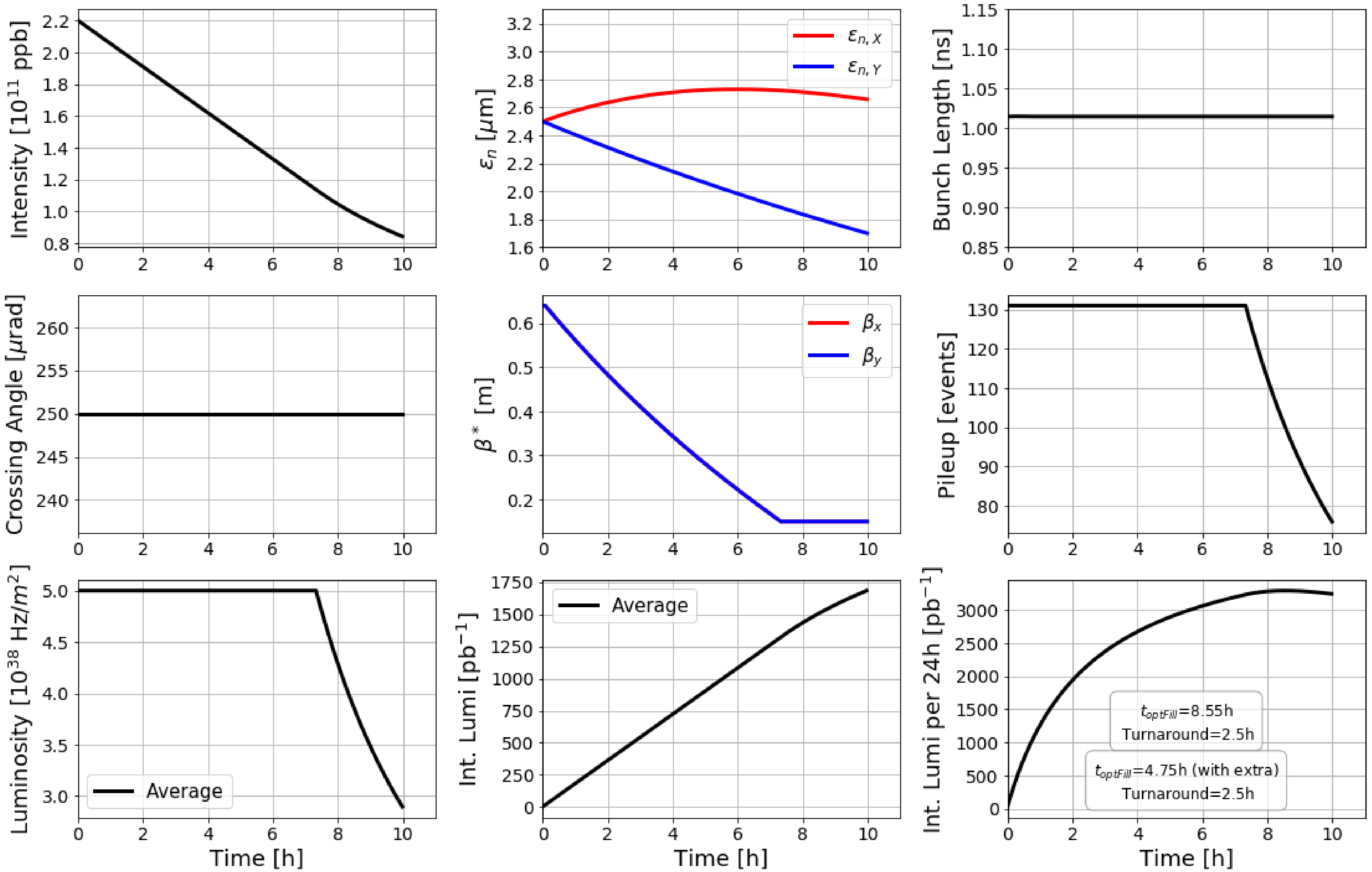


Horiz. : +0.40 [µm/h]
Vertic. : +0.65 [µm/h]

Horiz. : +20%
Vertic. : +30%

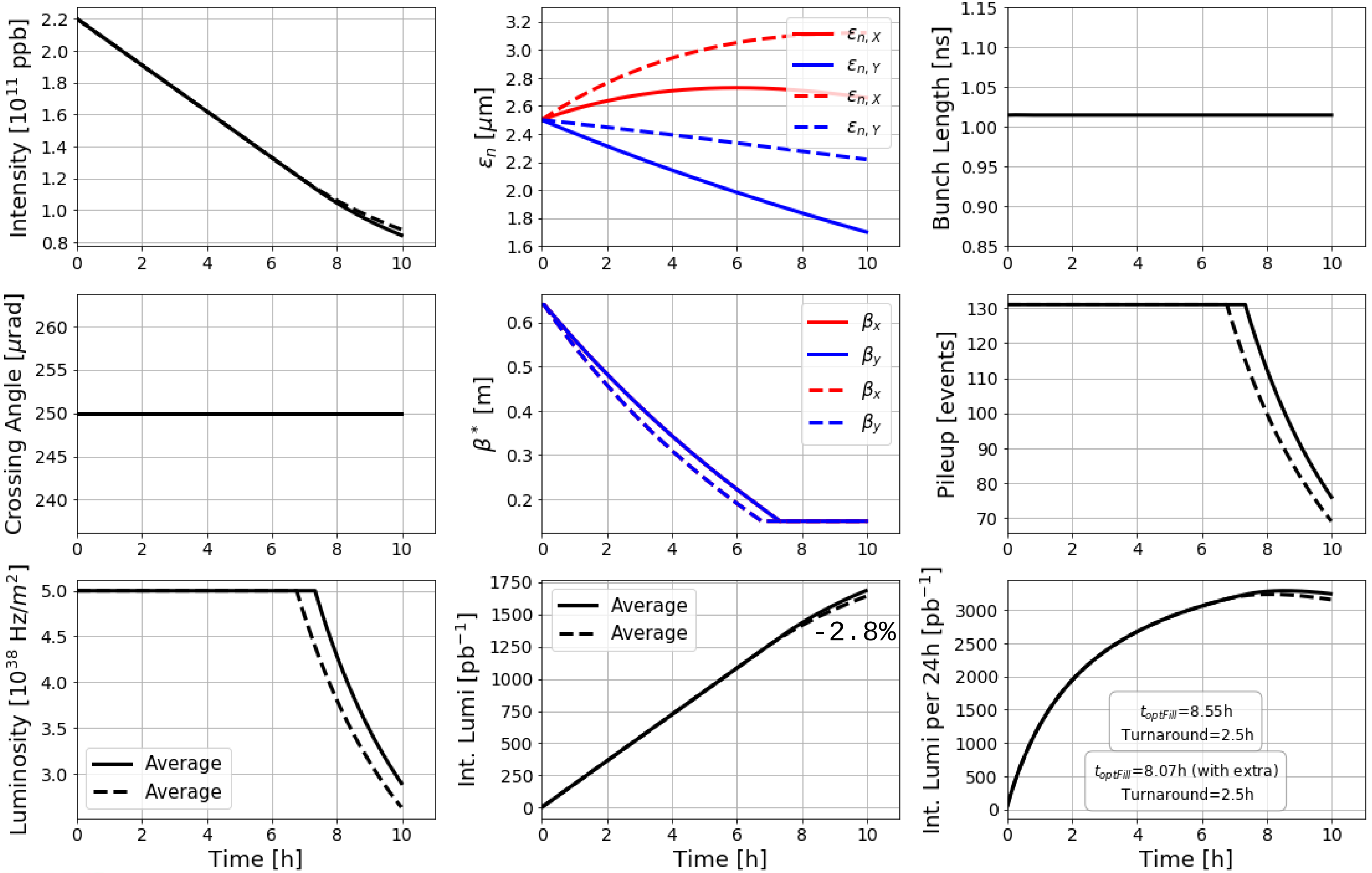
after 0.5h at Flat Bottom	ε_x [µm]	ε_y [µm]	σ_l [ns]	
model	2.0	1.7	1.32	
+extra transverse growth at FB	2.1	2.0	1.33	
	at Stable Beams			
+transverse blow-up at Ramp	**2.5**	**2.5**	1.2	Gaussian
			1.0	q-Gaussian

HL-LHC expectations at Stable Beams
nominal scenario

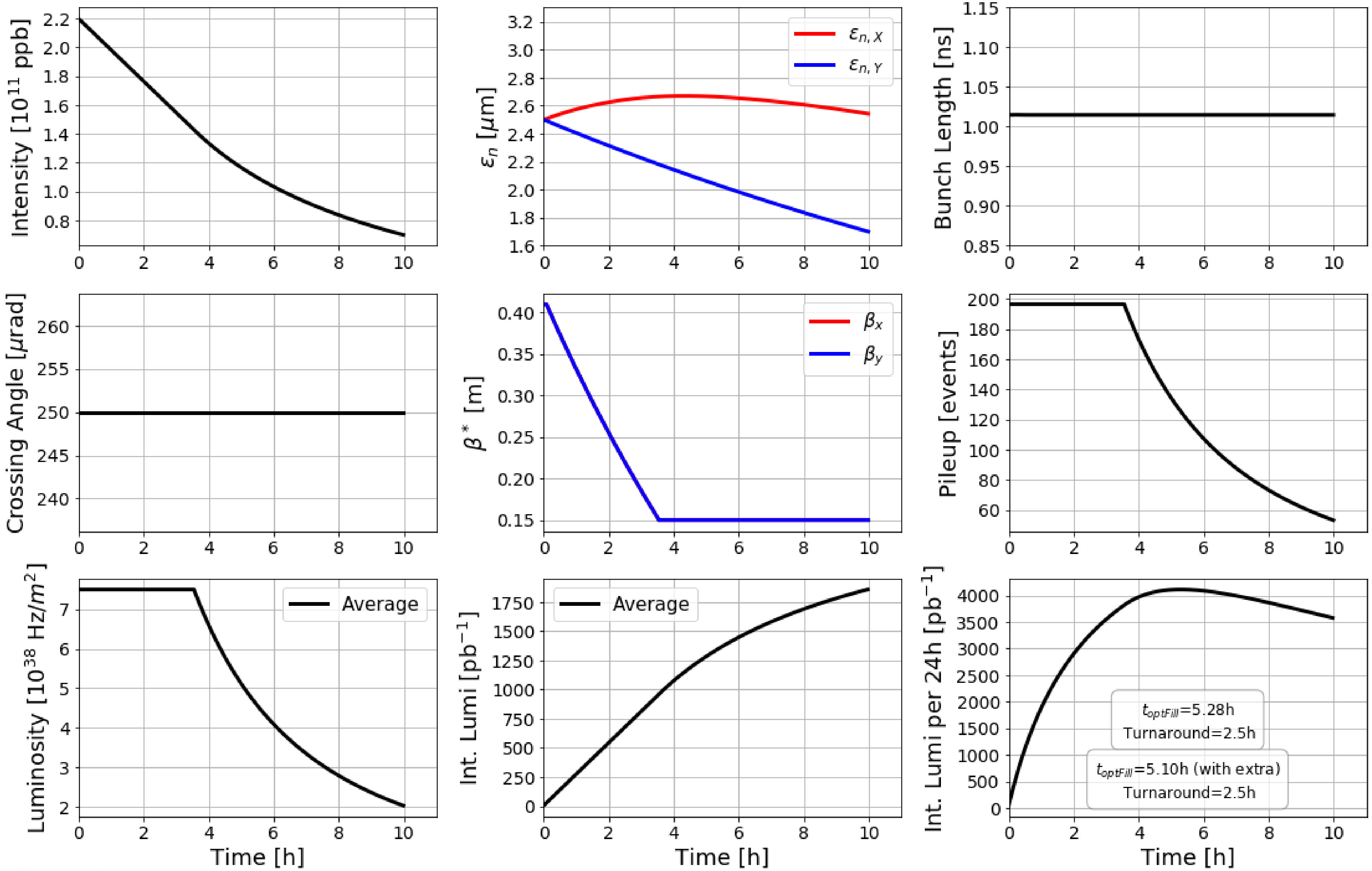


HL-LHC expectations at Stable Beams
nominal scenario

dashed lines=extra transverse emittance blow-up (on top of model)=+0.05 [µm/h]



HL-LHC expectations at Stable Beams
ultimate scenario



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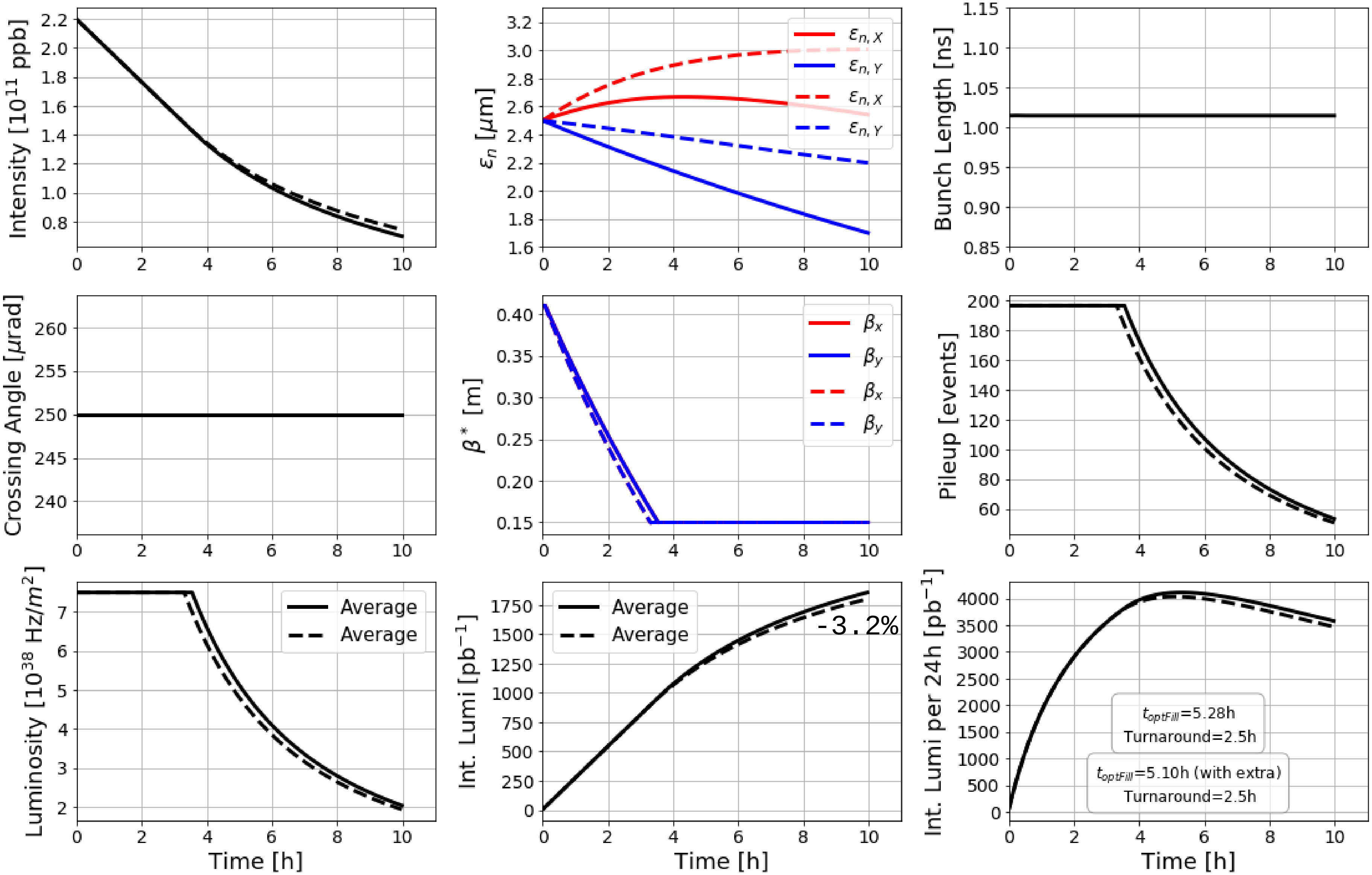
HL-LHC expectations at Stable Beams
ultimate scenario

dashed lines=extra transverse emittance blow-up (on top of model)=+0.05 [μm/h]



Summary

Emittance evolution over 2018 run

- After a careful cleaning of the BSRT emittances, the emittance blow-up at Flat Bottom is around 13.5%
- The extra emittance growth (on top of the model) at Flat Bottom, which comes mainly from e-cloud, is 0.4μm/h and 0.65μm/h in the horizontal and vertical plane, respectively
- Estimation of the emittances at start of Stable Beams based on the mean emittances of the Fills for which the Emit. Scans, the BSRT and the Luminosity emittances agree
- The extra emittance growth (on top of the model) at Stable Beams is ~0.05μm/h for Fills where the BSRT can be trusted (similar to 2017)

HL-LHC expectations

- Estimations based on LHC 2018 Run, taking into account the observed extra transverse emittance growth at Flat Bottom and the emittance blow-up during Ramp
- Considering BCMS, for the nominal and the ultimate scenario, the extra transverse emittance growth at Stable Beams results in a slightly lower integrated luminosity (~3%)

Thank you!

Extra slides

Luminosity model description

- A bunch-by-bunch model based on the three main mechanisms of luminosity degradation in the LHC: intrabeam scattering (IBS), synchrotron radiation (SR) and luminosity burn-of

- **Emittance evolution**

  -Intrabeam scattering (IBS), Synchrotron Radiation (SR), elastic scat.

$$\frac{d\varepsilon}{dt} = \left(\frac{d\varepsilon}{dt}\right)_{IBS+SR} + \left(\frac{d\varepsilon}{dt}\right)_{elastic}$$

$$\left(\frac{d\varepsilon_x}{dt}, \frac{d\varepsilon_y}{dt}, \frac{d\sigma_s}{dt}\right)_{IBS+SR} = f(En, N_b(t_0), \varepsilon_x(t_0), \varepsilon_y(t_0), \sigma_s(t_0), dt)$$

$$\left(\frac{d\epsilon_{x,y}}{dt}\right)_{elastic} = N_{IP}\beta^*_{x,y}\mathcal{L}\sigma_{el}\left\langle\theta^2_{x,y}\right\rangle/(n_b N_p)$$

- **Bunch intensity evolution**

  -Luminosity burn-off

$$\frac{dN}{dt} = \left(\frac{dN}{dt}\right)_{BOff}$$

- **Bunch length evolution**

  -IBS and SR

$$\frac{d\sigma_s}{dt} = \left(\frac{d\sigma_s}{dt}\right)_{IBS+SR}$$

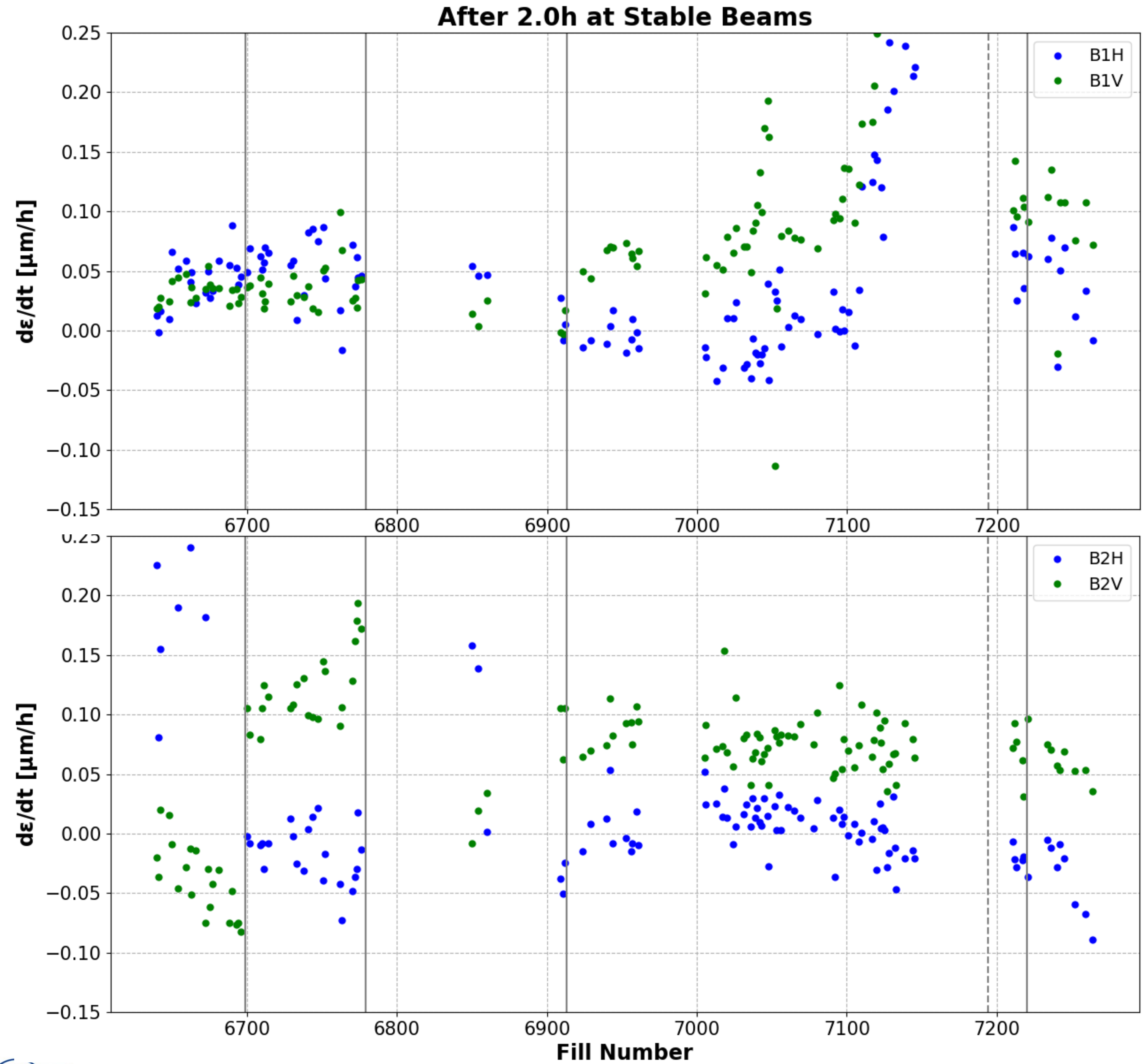
or using data evolution

- Combination of the transverse emittance, bunch length and bunch intensity estimations (or observations) in a self consistent way to compute the luminosity at each time step

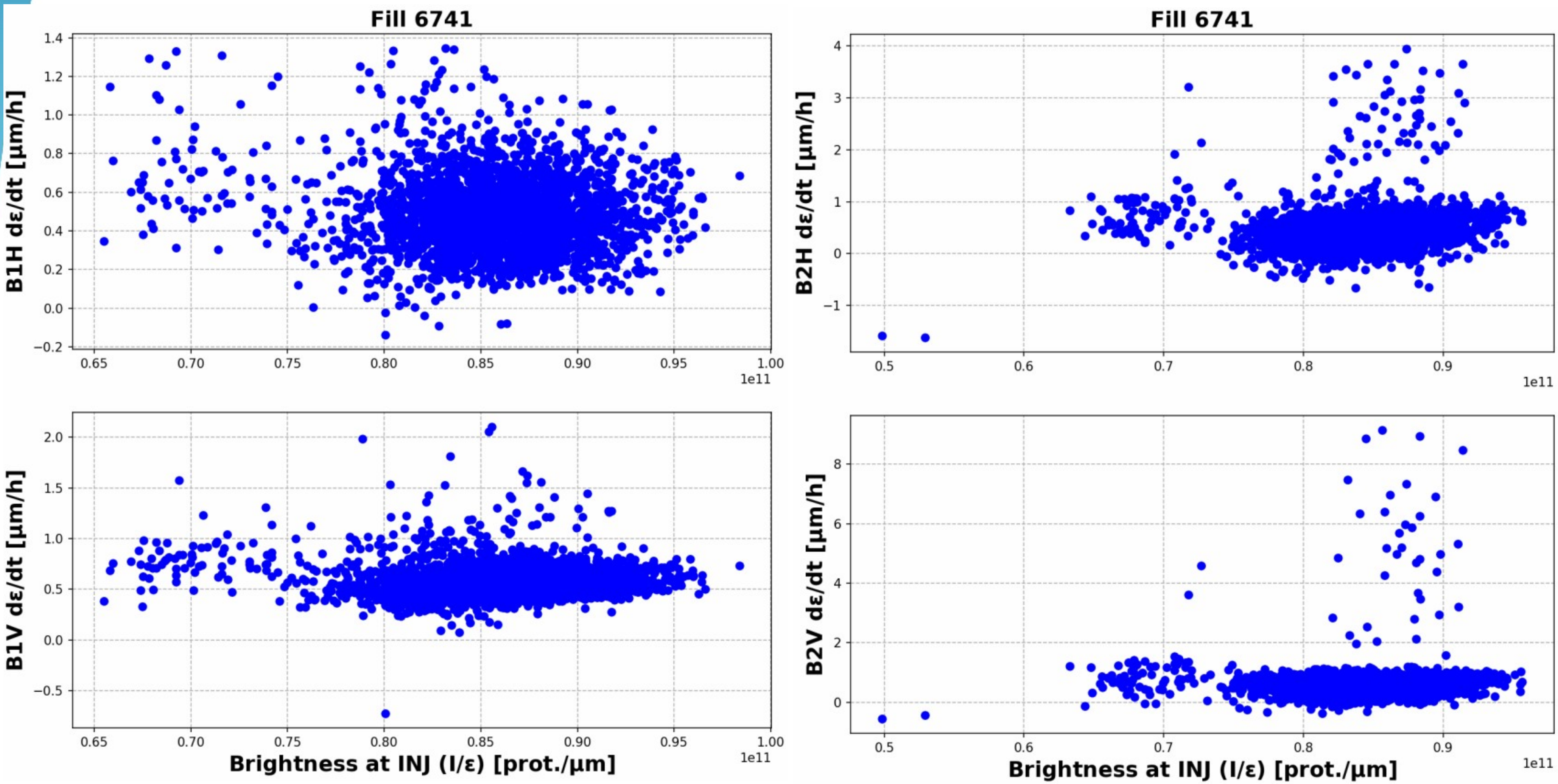
- β^*, luminosity leveling, x-ing angle anti-leveling options

F. Antoniou et al., TUPTY020, proc. of IPAC' 15
F. Antoniou et al., "Can we predict luminosity?", proc. of Evian 2016

Emittance growth at Stable Beams



Extra emittance growth - brightness at Flat Bottom



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Extra emittance growth - brightness at Stable Beams