
CERN

emittance observations

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for the OP/ABP-HSI luminosity follow-up team:

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with thanks to:

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overview

- emittance preservation through the cycle
  - injected emittances
  - blow-up during injection, ramp & squeeze
  - emittances & roundness at the start of Stable Beams

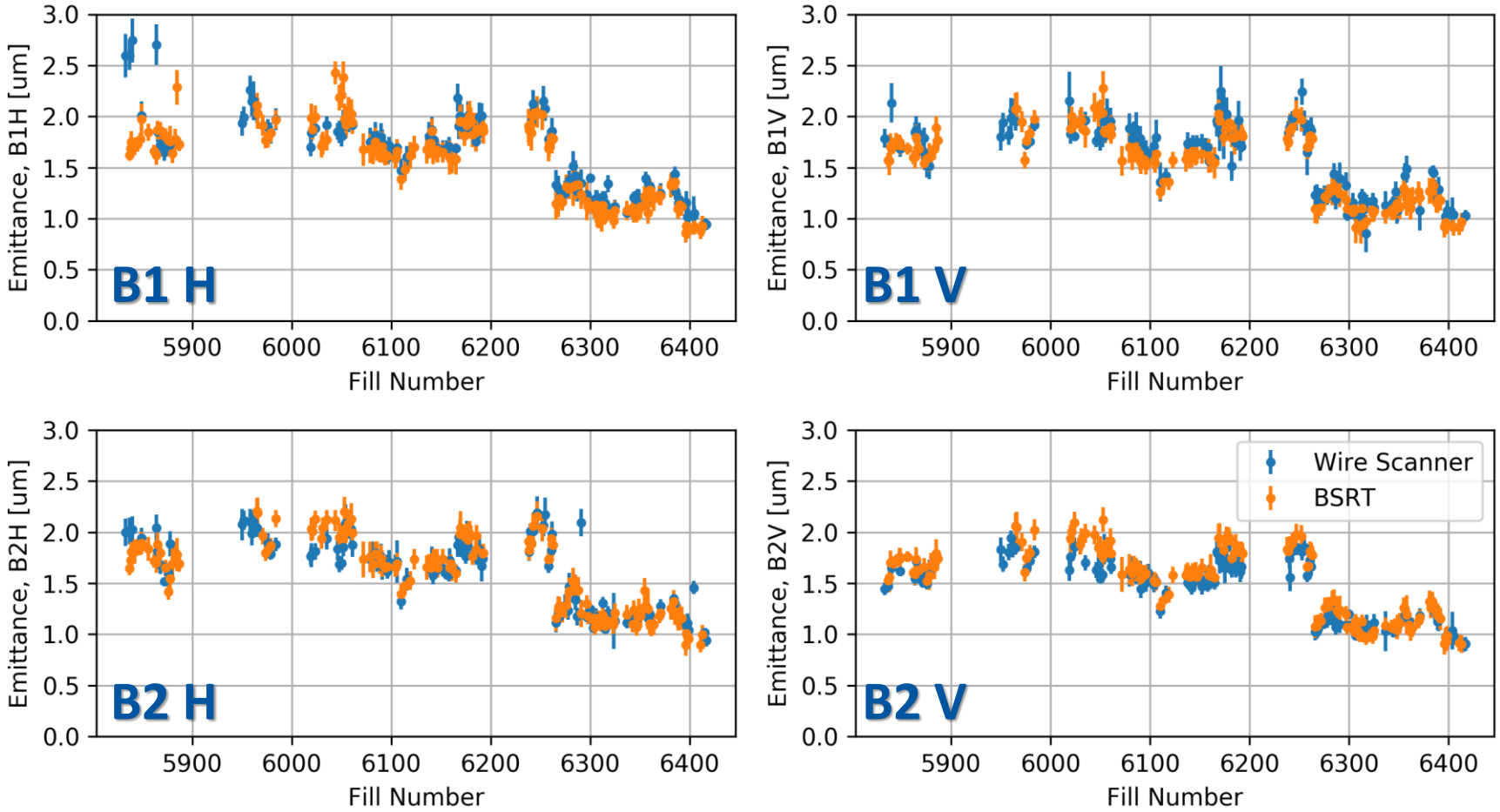
➢ considering …

- the impact of different beam types
  - BCMS, 8b4e, 8b4e BCS, …
  - the 2.51 TeV cycle
- the different emittance data sources & their caveats

emittance measurements

- operational: BSRT
  - continuous measurement throughout the cycle
  - main source of data in the following
  - good performance in 2017 with some caveats (degradation)
    - see Georges' talk!
- additional at injection: wire scanners
  - first ~200 bunches
  - reference measurement!
- additional in collisions: luminosity, emittance scans, luminous region
  - independent of beam instrumentation
  - only in Stable Beams
    - if levelling, after the levelling period if levelling in IP5

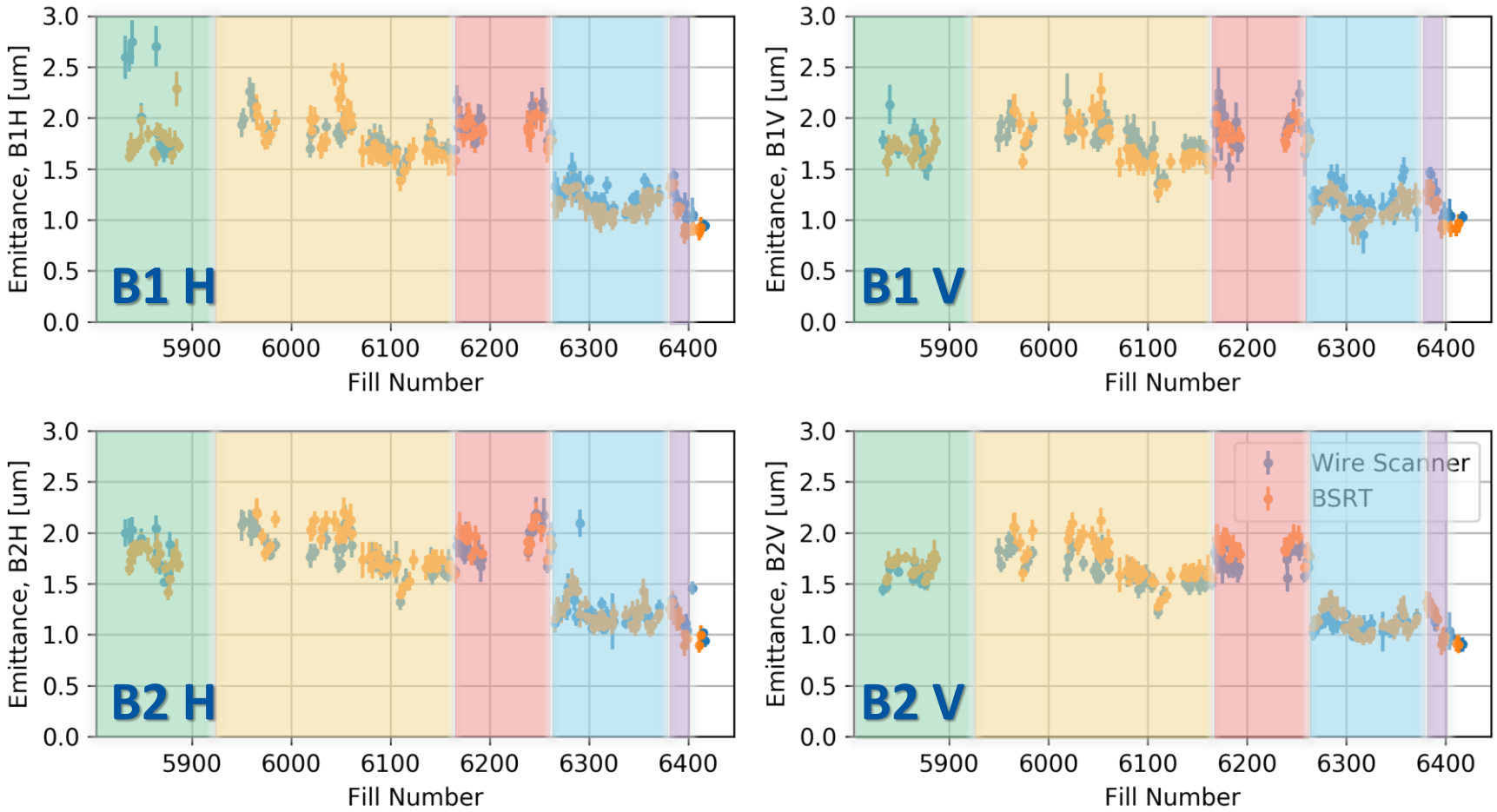
injected emittances



good agreement (< 10%) between BSRT and Wire Scanners!

… so we can trust the BSRT data at flat bottom.

injected emittances



Int. Ramp Up (BCMS)

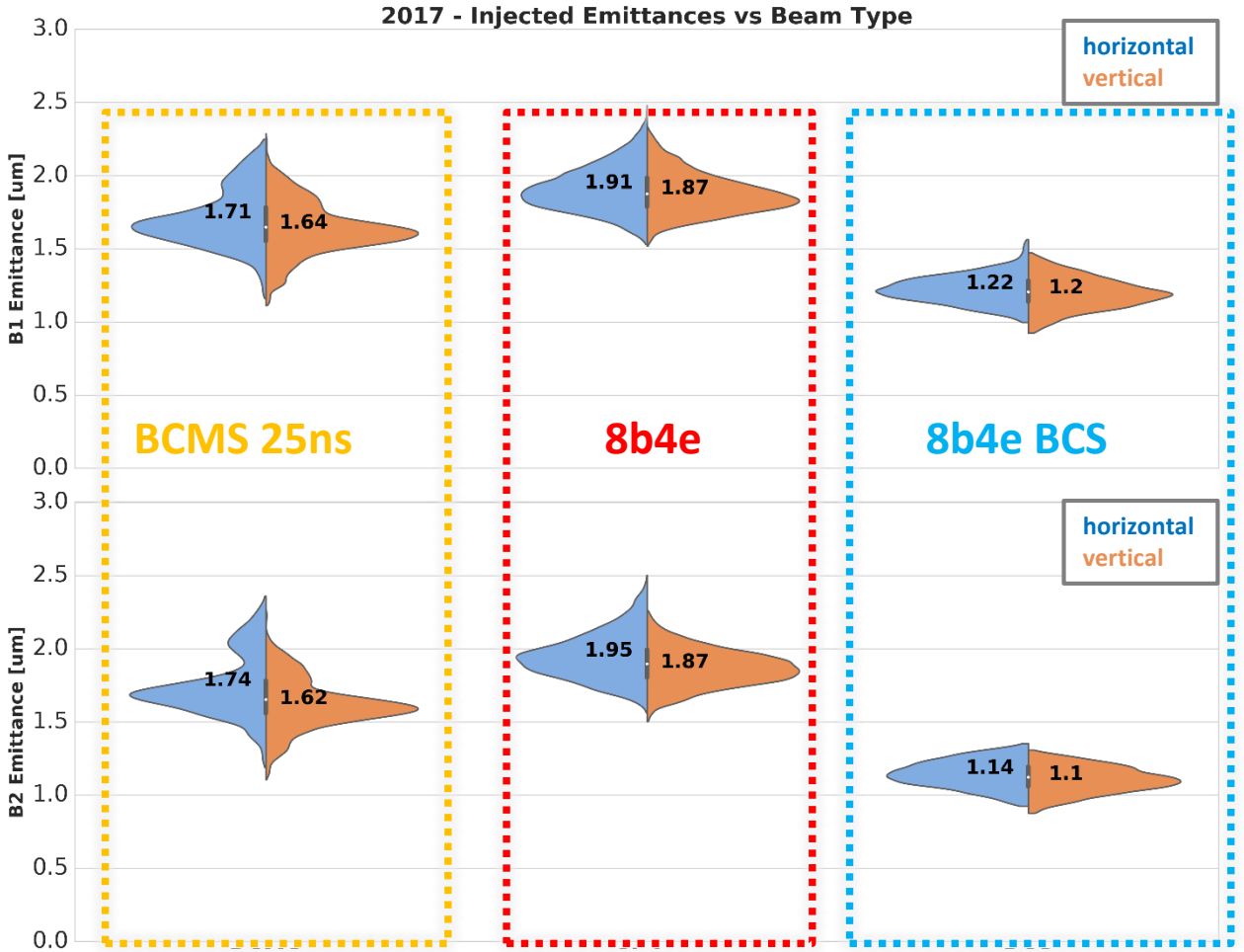
BCMS 25ns

8b4e

8b4e BCS

2.51 TeV

injected emittances by beam type



achieved injected emittances:

[um]	BCMS	8b4e	8b4e BCS
B1H	1.71	1.91	1.22
B1V	1.64	1.87	1.20
B2H	1.74	1.95	1.14
B2V	1.62	1.87	1.10
convoluted	**1.7**	**1.9**	**1.2**

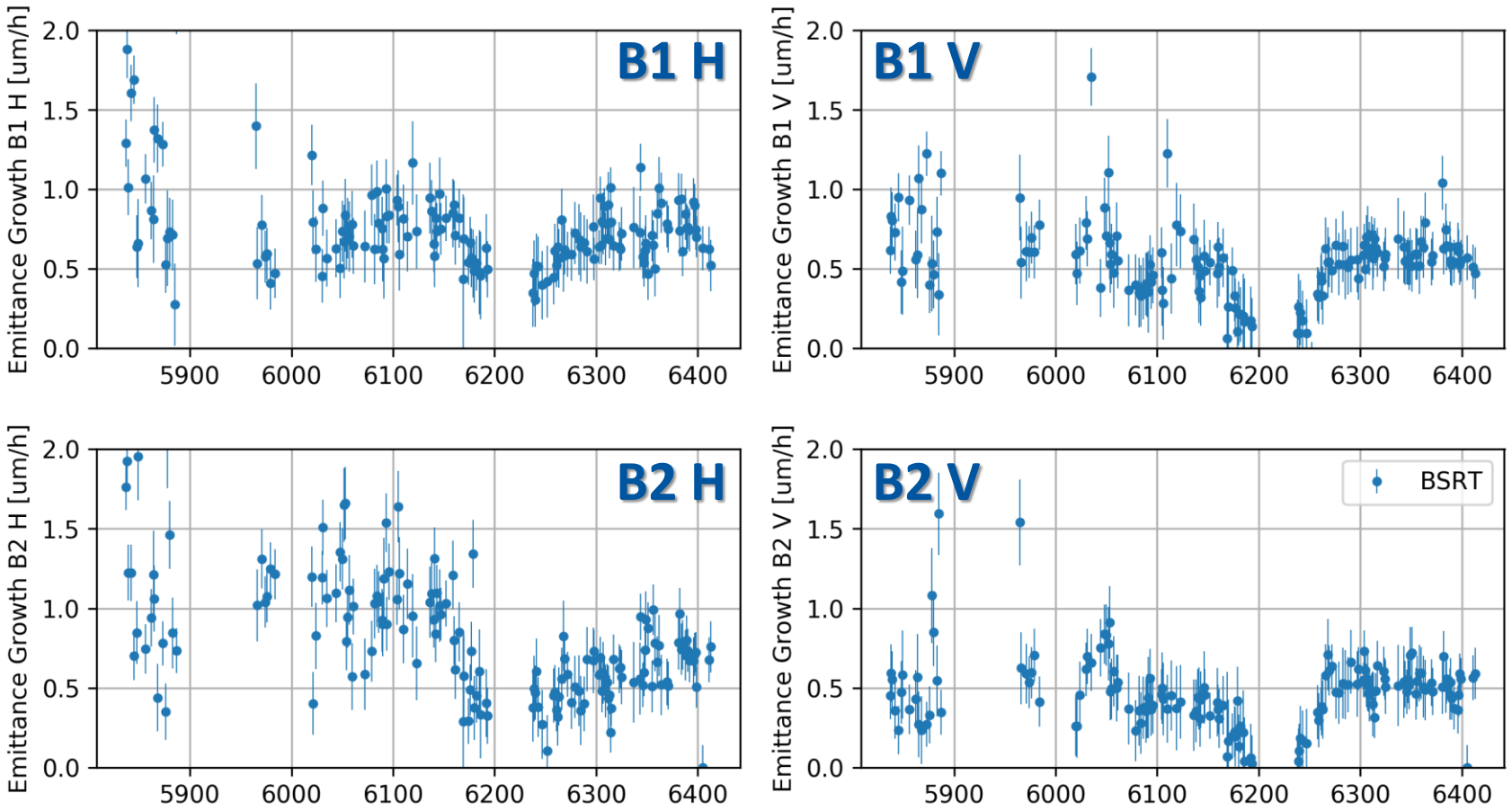
predicted emittances from injectors:

25 ns BCMS (like 2016)	1.7 (1.4)
25 ns BCMS (max. intensity)	1.9 (1.6)
8b4e (like 2016)	1.8 (1.6)
8b4e (max. intensity)	2.4 (2.1)

Emittances in parentheses should be achievable, to be demonstrated operationally

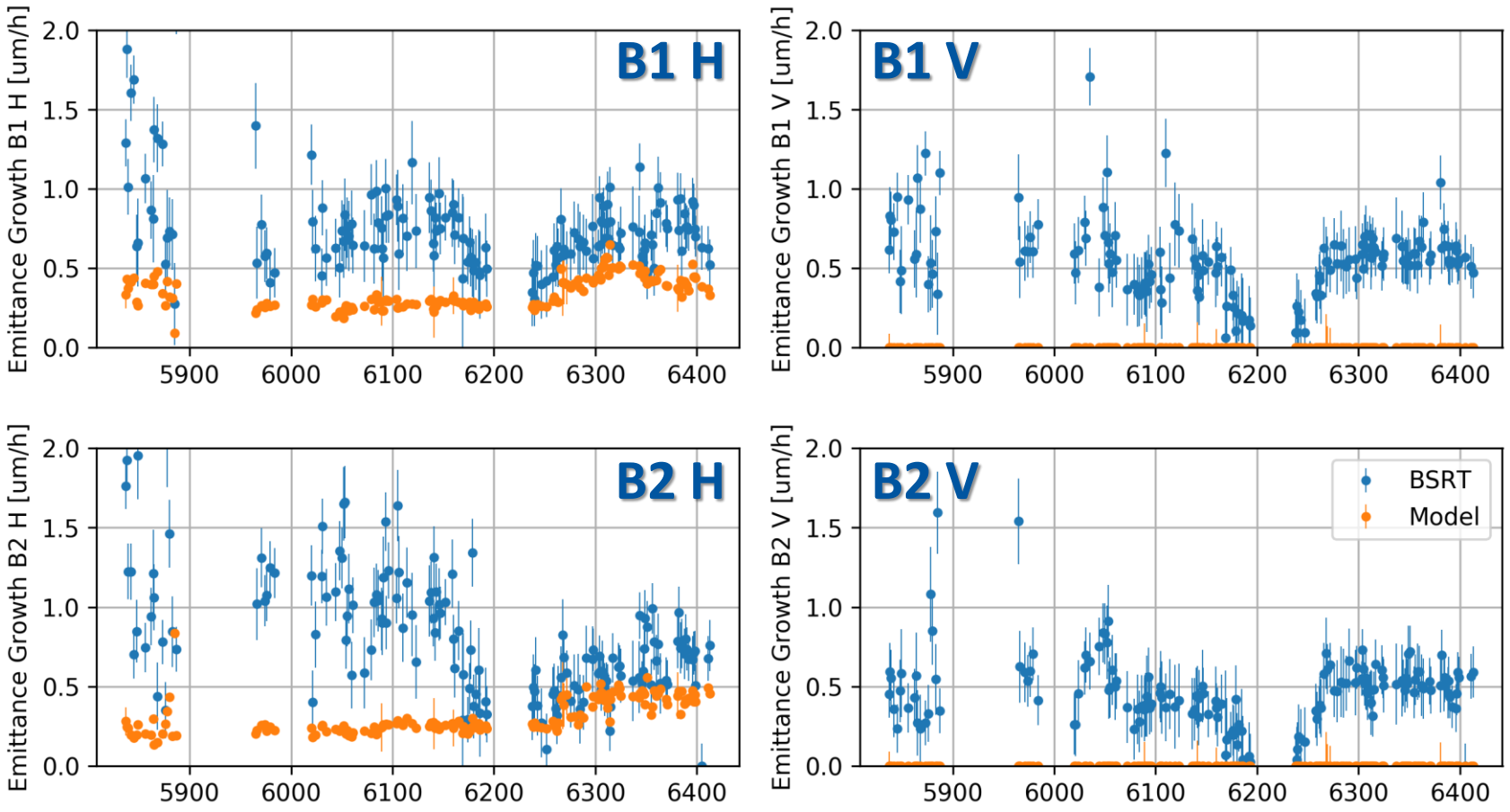
(*B. Mikulec - Chamonix 2017*)

emittance evolution at flat bottom



- BSRT data: difference of first and last scan of each bunch
  - normalized by time at injection (bunch by bunch!)
  - relative – only weakly dependent on the BSRT calibration
- strong intra-beam scattering at injection energy, mainly H
  - we can model this …

emittance evolution at flat bottom

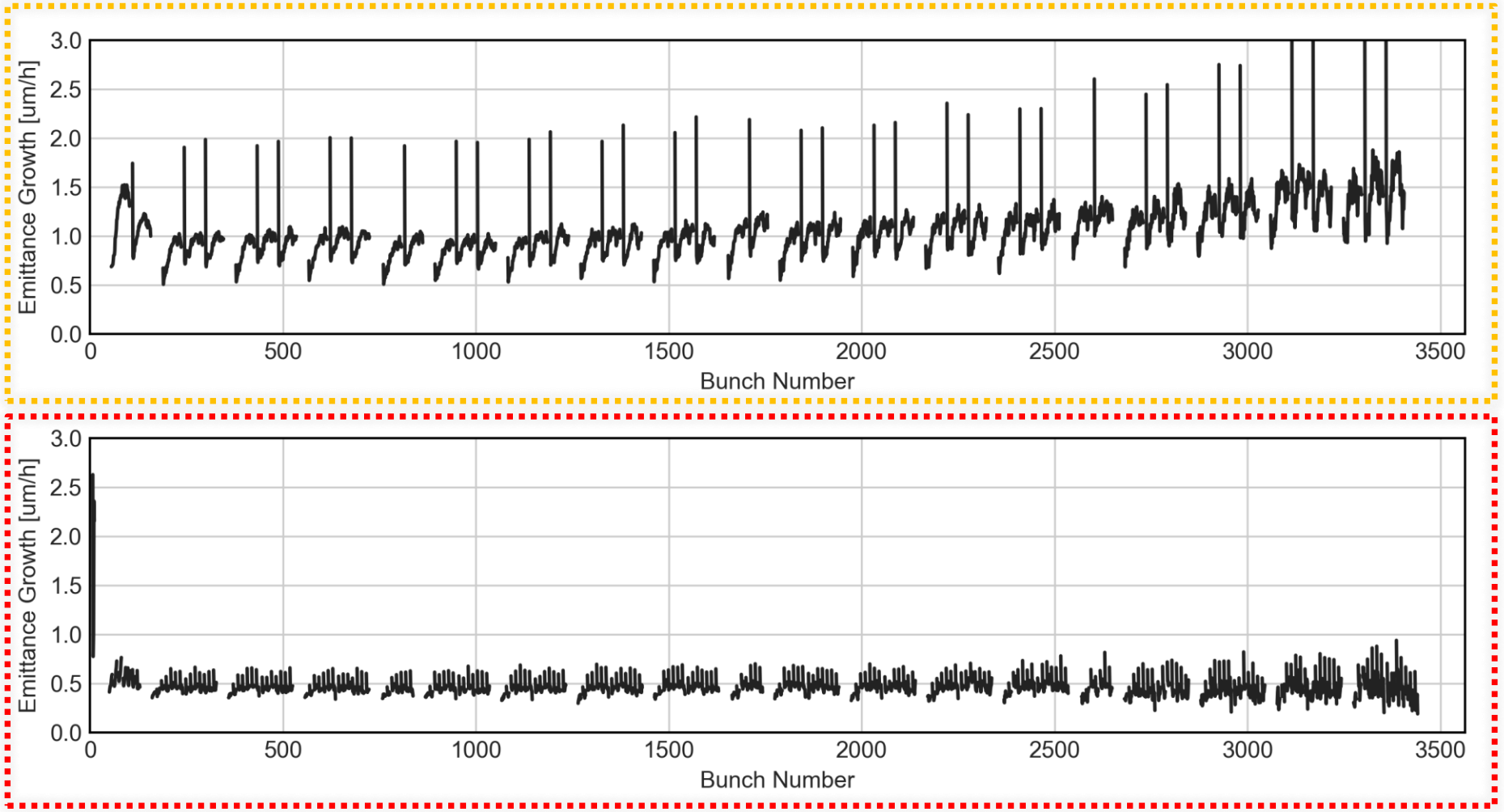


emittance growth:

[um/h]	BCMS	8b4e	8b4e BCS
H meas.	0.90	0.47	0.65
H model	0.27	0.26	0.47
V meas.	0.45	0.20	0.56

- IBS model *[Fanouria et al.]* predicts 0.3-0.5 um/h in H
  - extra blow-up:
    ~0.6 um/h (BCMS)
    ~0.2 um/h (8b4e)
    electron cloud effect?
- V emittance growth not (yet) explained by the model
  - IBS + coupling?

extra blow-up at flat bottom: electron cloud ?



BCMS 25ns

(H emittance growth, average of all fills)

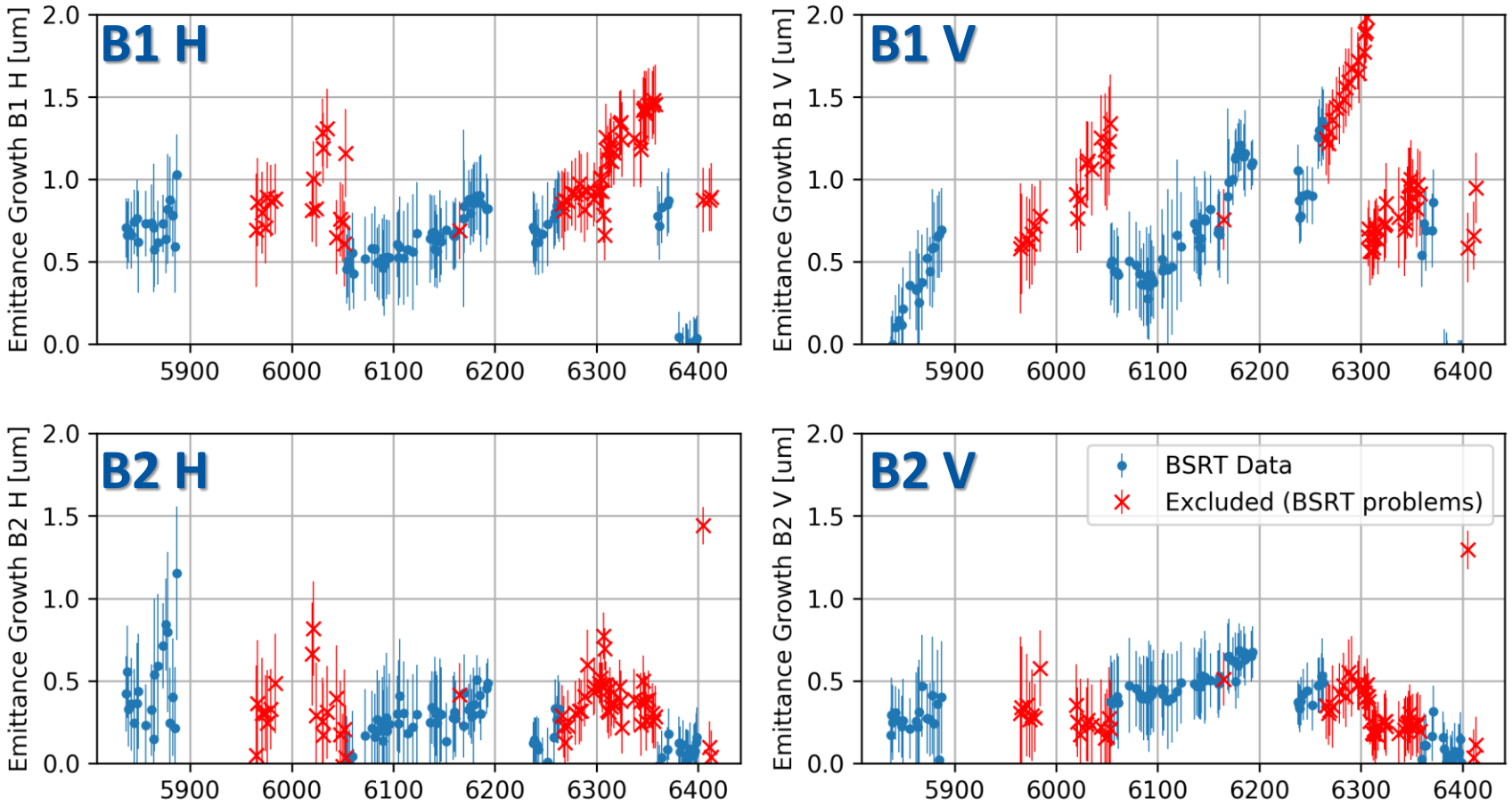
pattern looks convincing!

(and the contribution of ~0.5 um/h is in the right order of magnitude)

8b4e

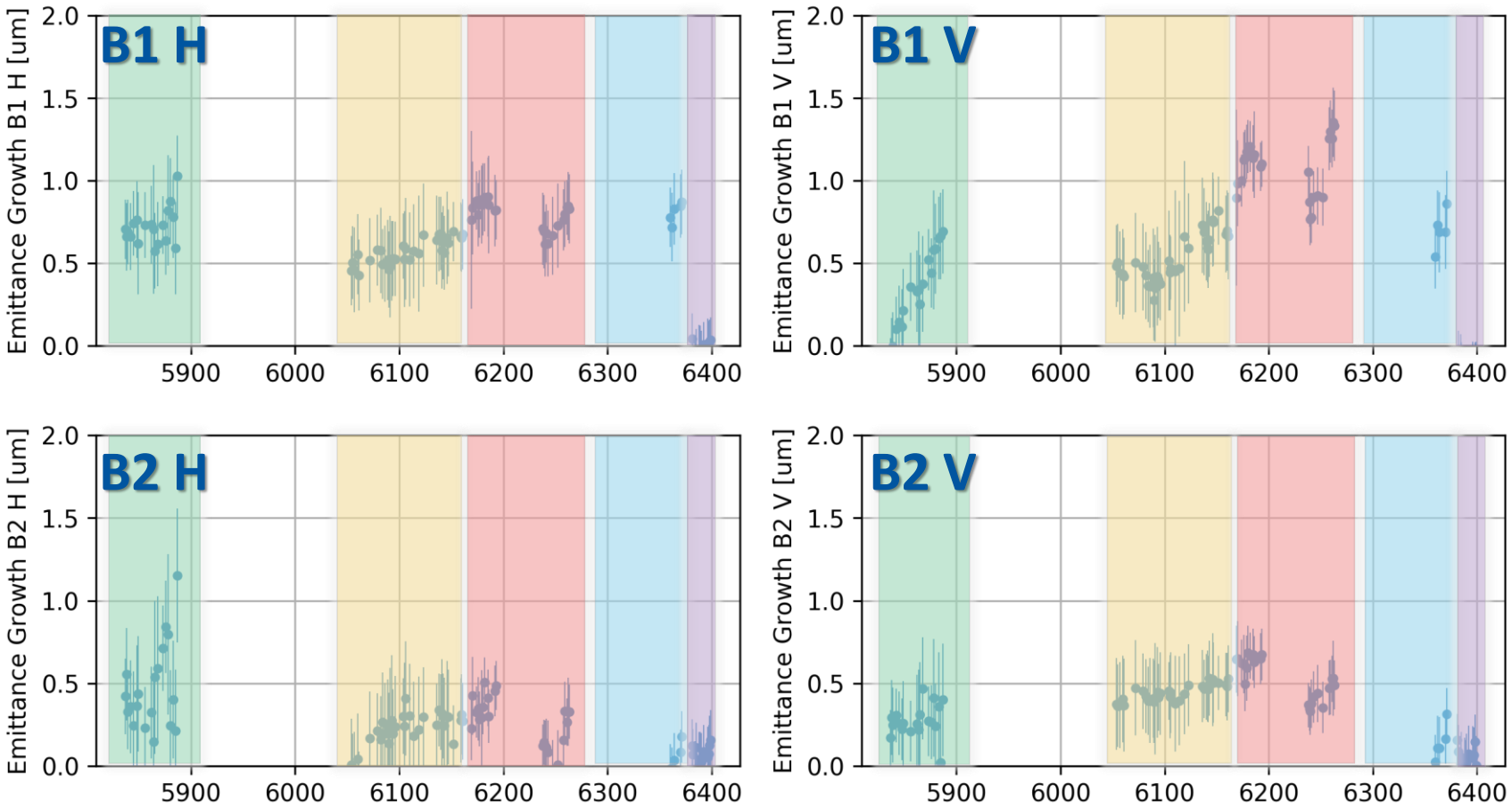
(H emittance growth, average of all fills)

emittance growth during the ramp?



- BSRT: last point at flat bottom compared to first point at flat top
  - no continuous emittance measurement during the ramp
  - **dependent on the absolute BSRT calibration at flat bottom & flat top!**
  - exclude bad measurements (BSRT degradation, affecting mostly flat top)

emittance growth during the ramp?



Int. Ramp Up (BCMS)

BCMS 25ns

8b4e

8b4e BCS

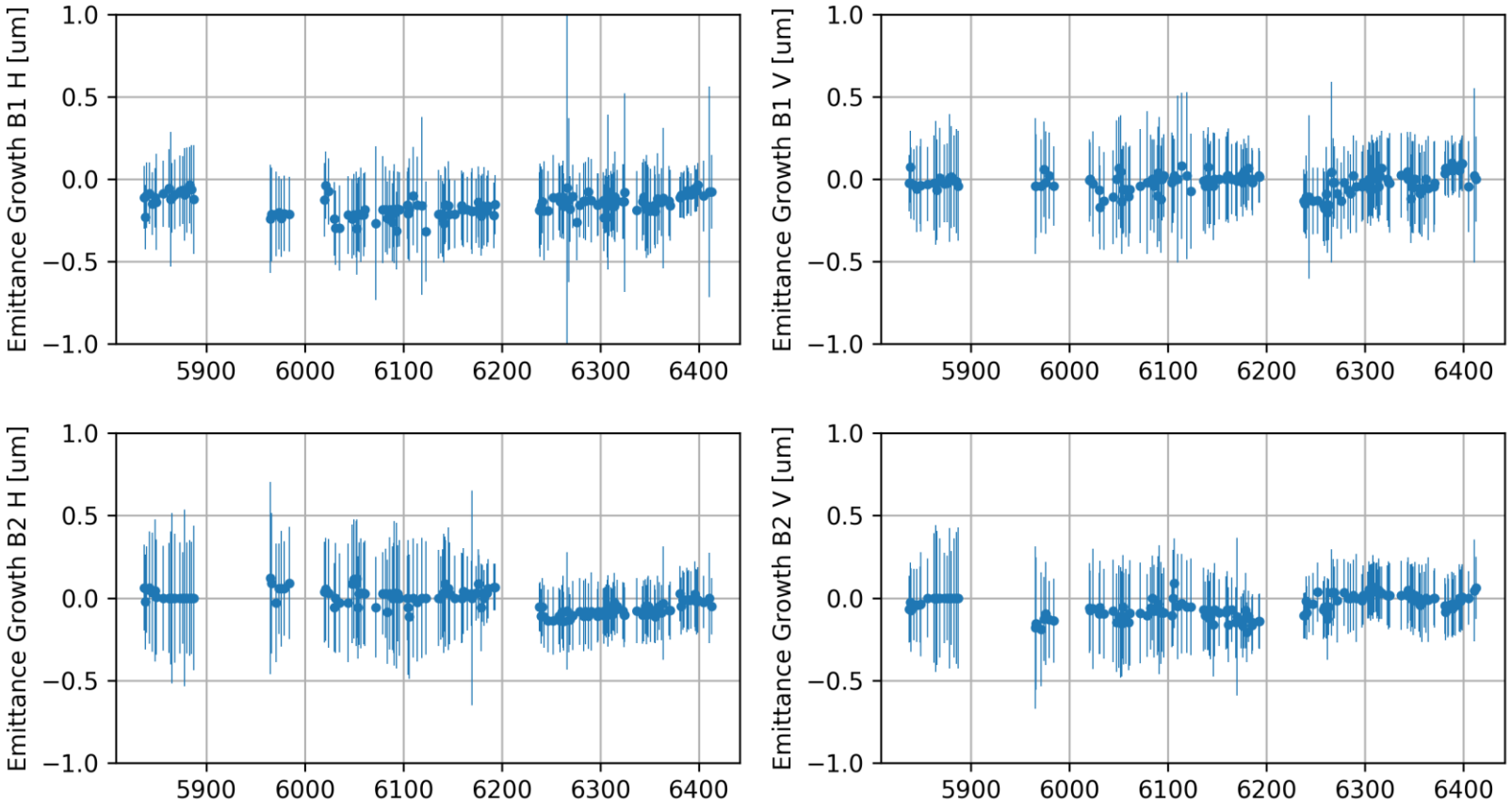
2.51 TeV

[um]	BCMS	8b4e	8b4e BCS	2.51 TeV
B1H	0.56	0.82	0.82 ?	-0.01 ?
B1V	0.48	1.11 ?	0.68 ?	-0.14 ?
B2H	0.24	0.29	0.04 ?	0.07
B2V	0.44	0.52	0.10 ?	0.05

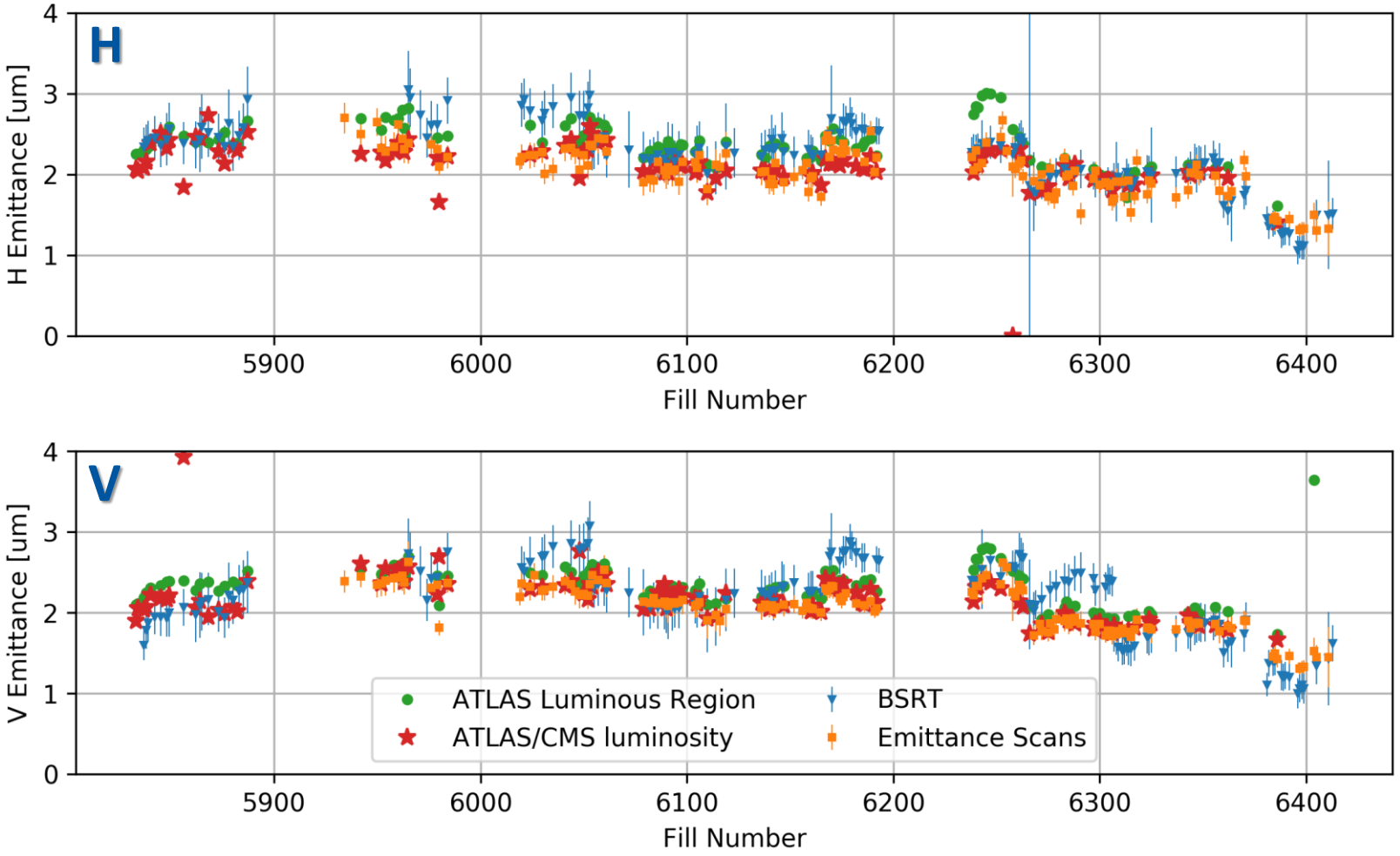
- B1 grows more than B2
- ~ no growth in the 2.51 TeV ramp
  ("modulo BSRT calibration")

emittance (non-)evolution at flat top

- BSRT values after the ramp and at the start of collisions
  - relative – only weakly dependent on the BSRT calibration
- BSRT calibrated in collisions
  - optics in IR4 change (only) slightly during the squeeze
  - small residual effect possible due to optics change
- ~ zero emittance evolution at flat top before collisions
  - end-of ramp
    = start of collisions!
  - in collisions, we have complementary measurements

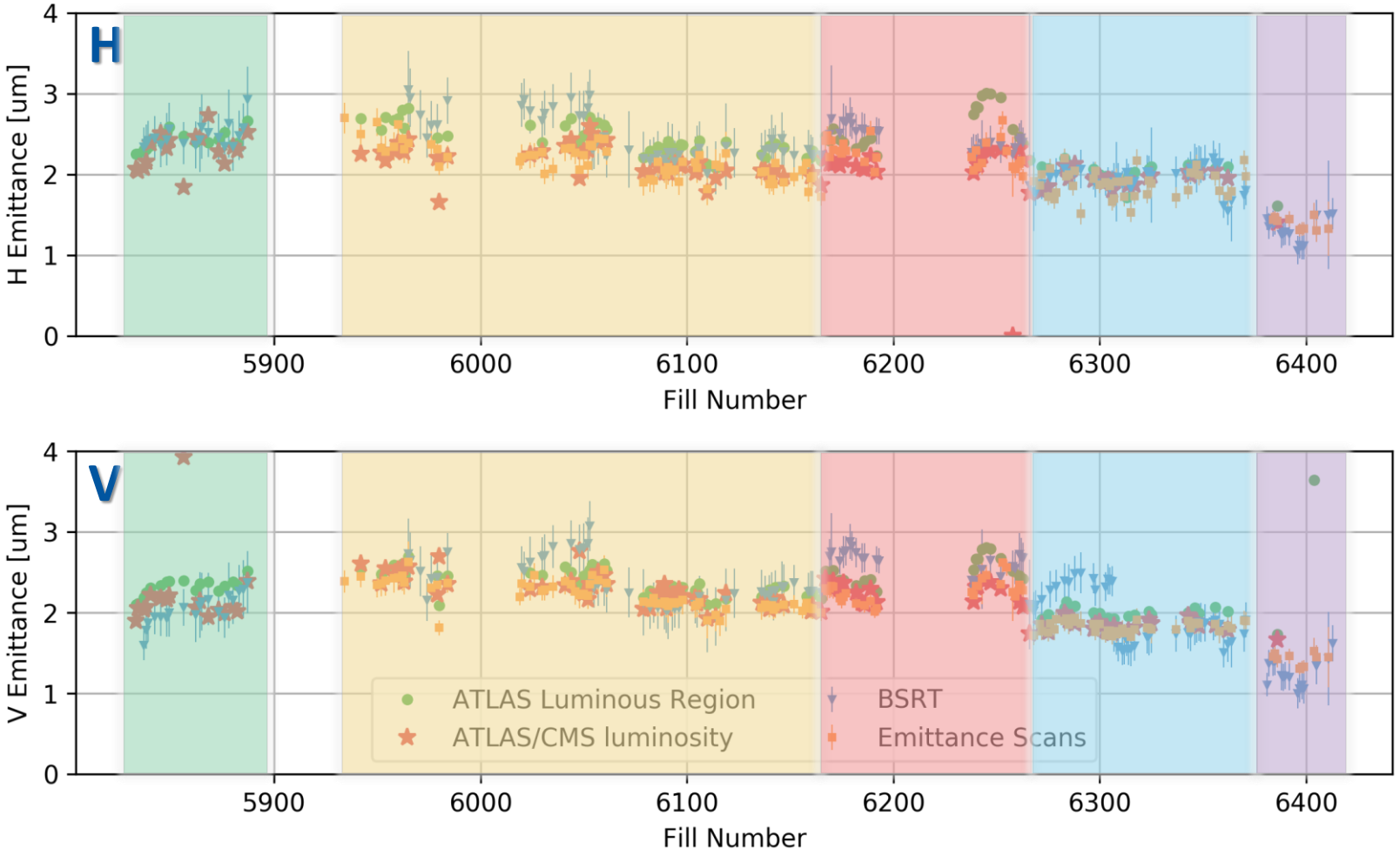


emittances at the start of collisions



- additional measurements
  - emittance scans (IP 5)
  - ATLAS luminous region data
  - emittance from absolute luminosity
    - H/V from ATLAS/CMS ratio
  - levelling after fill 6263
    - luminosity & emittance scan data taken after levelling
    - corrected for SB emittance growth (Stefania's talk - next)
- good agreement in general
  - BSRT degradation clearly visible
  - complementary measurements are important!

emittances at the start of collisions



Int. Ramp Up (BCMS)

BCMS 25ns

8b4e

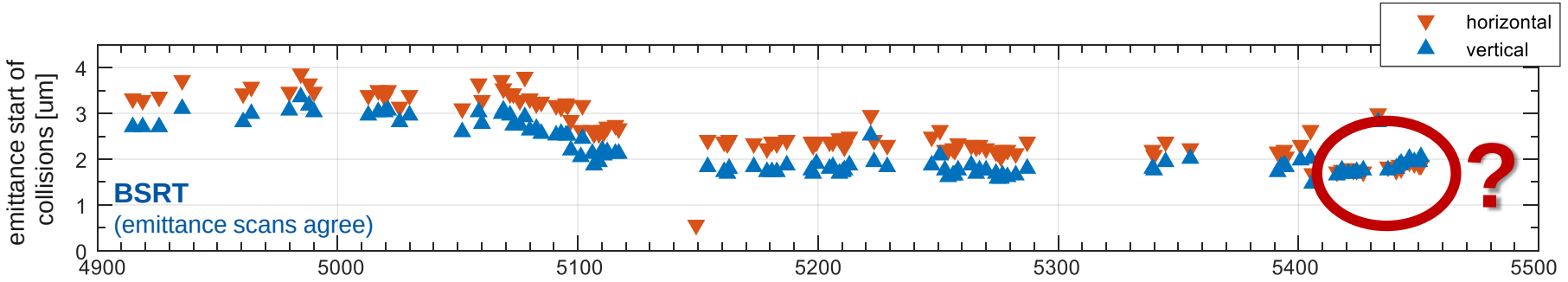
8b4e BCS

2.51 TeV

[um]	BCMS	8b4e	8b4e BCS	2.51 TeV
H emittance scan	2.0	2.3	1.9	1.4
V emittance scan	2.1	2.3	1.9	1.4
H BSRT	2.3	2.5	1.7 ?	1.3 ?
V BSRT	2.2	2.7 ?	1.6 ?	1.2 ?

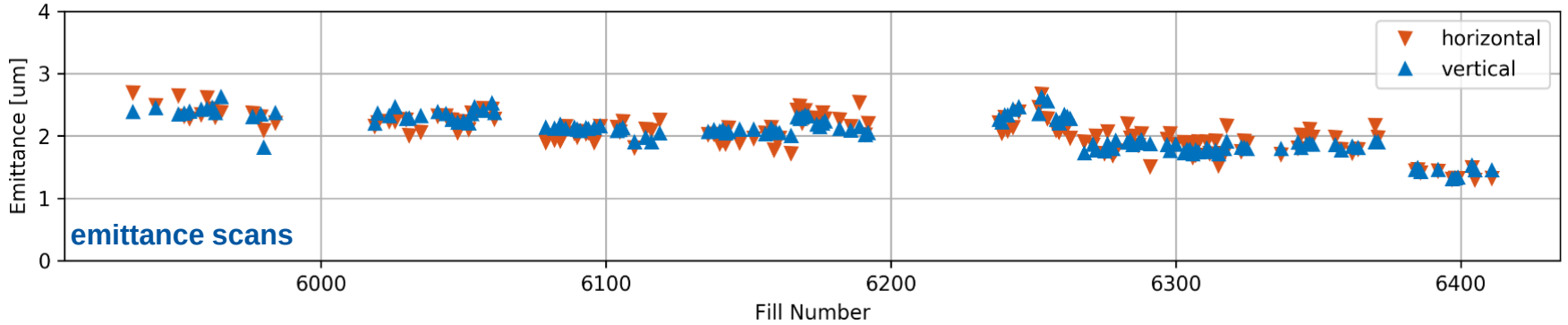
beam roundness in collisions

- 2016: ATLAS/CMS luminosity ratio of ~0.95



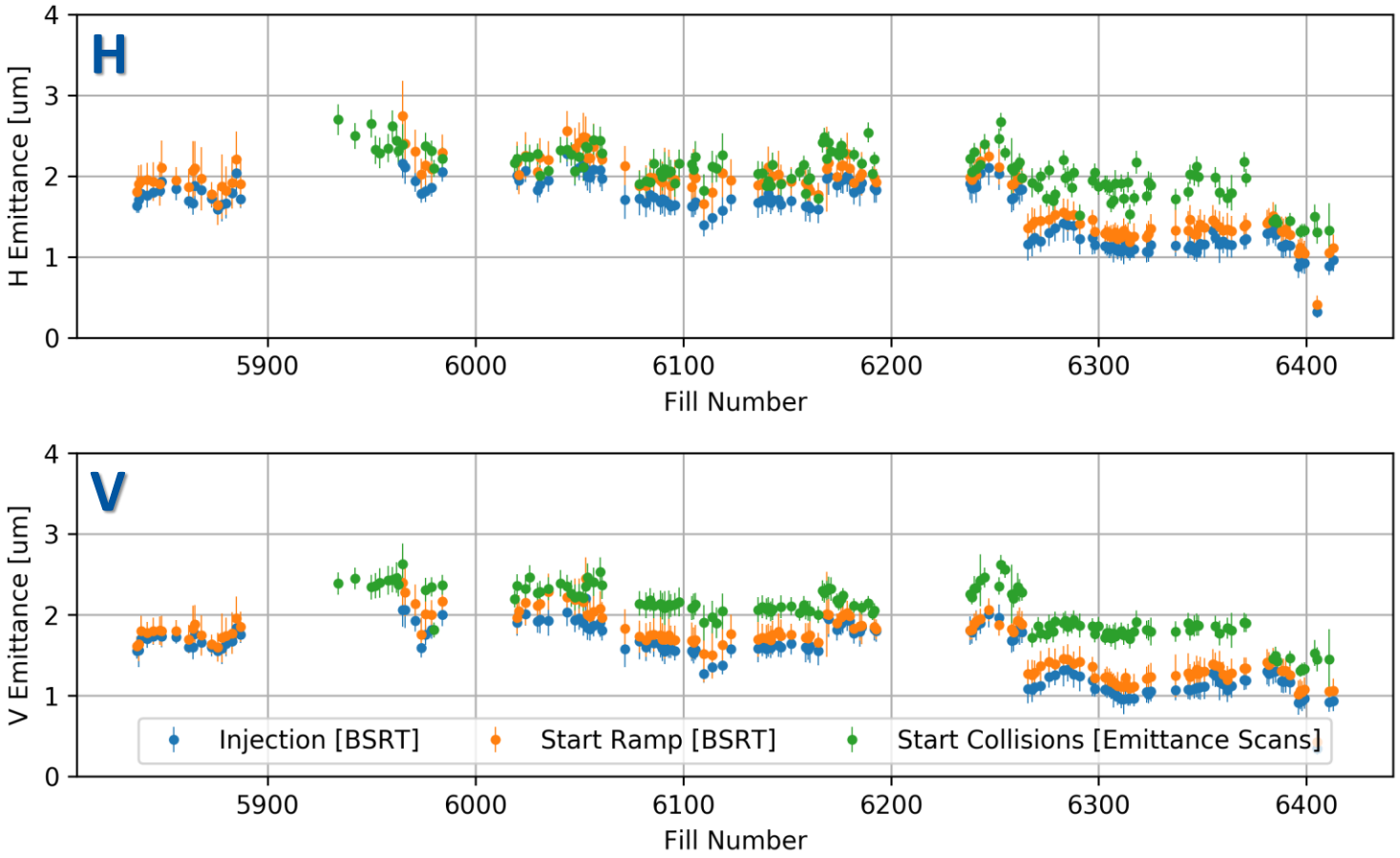
significantly non-round beams

- 2017: ATLAS/CMS luminosity ratio of ~1



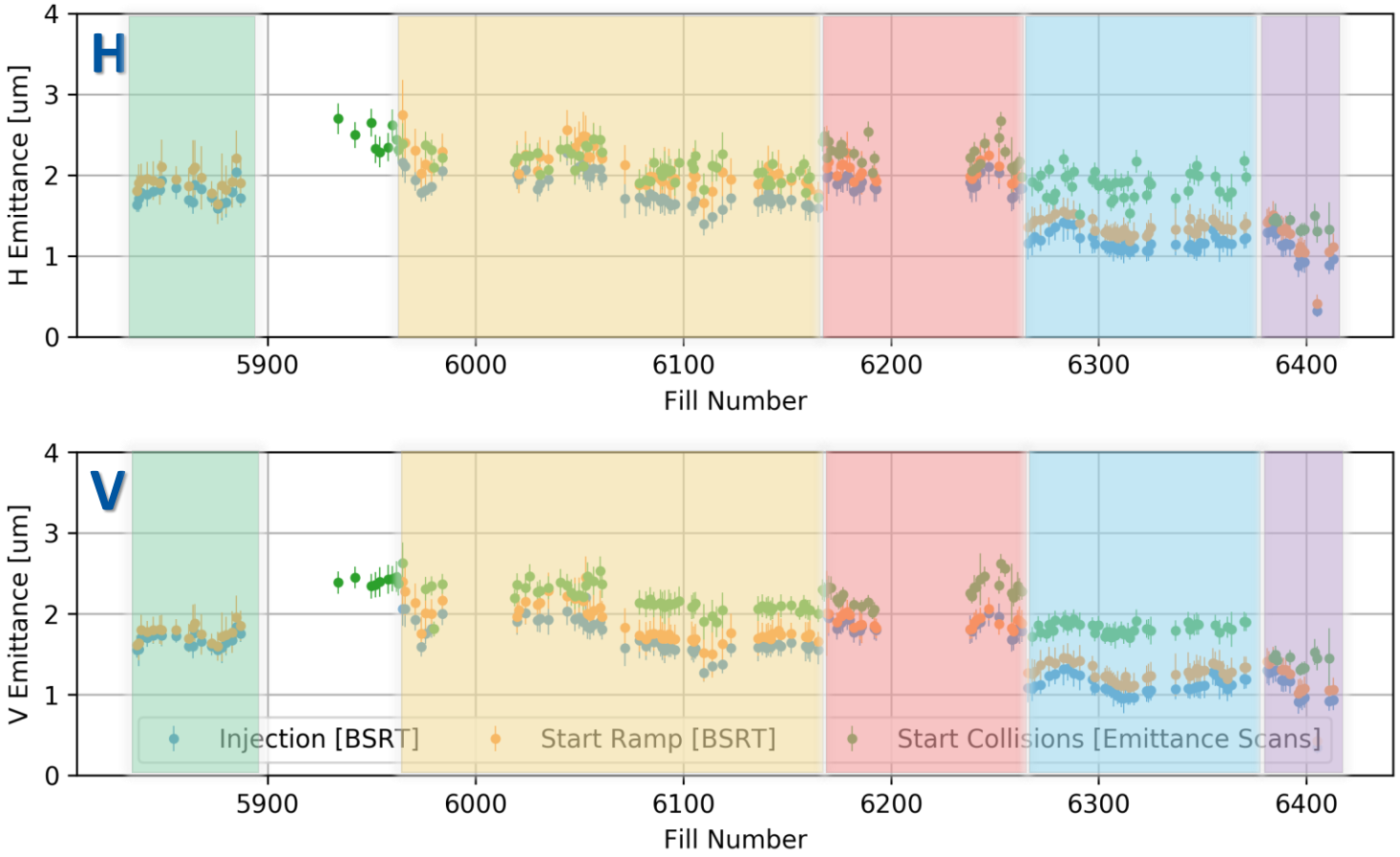
beams ~round

putting it all together: the full cycle



- BSRT at flat-bottom
  - less sensitive to degradation
  - calibration easier
  - agrees with wire scanners
- emittance scans at flat top
  - end of ramp = start of collisions: blow-up negligible
  - agrees with emittances reconstructed from absolute luminosities
  - distinction of B1/B2 not possible

putting it all together: the full cycle



Int. Ramp Up (BCMS)

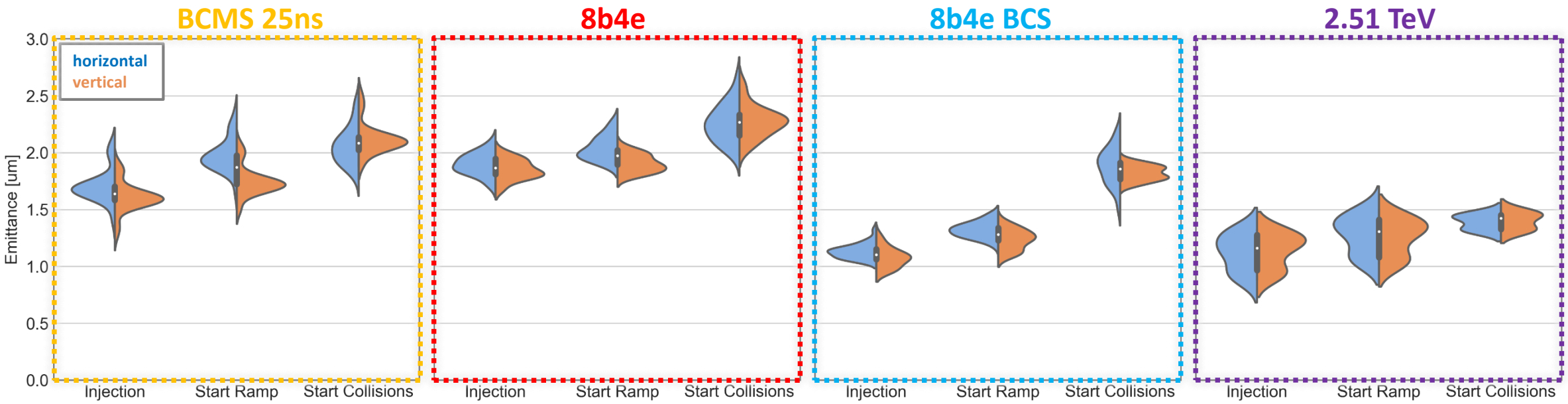
BCMS 25ns

8b4e

8b4e BCS

2.51 TeV

emittance evolution during the cycle



- most blow-up occurs during the ramp!
  - in particular for the “small” BCS type beams
  - H and V likewise – indications from BSRT that beam 1 is worse than beam 2
  - 2.51 TeV ramp better in this respect!

blow-up during the cycle: in numbers

Relative Emittance Blow-Up [%]
(flat bottom from BSRT, flat top from emittance scans)

BCMS	H [%]	V [%]
flat bottom	15 % 0.3 um	9 % 0.1 um
ramp	5 % 0.1 um	22 % 0.4 um
total injection - collisions	21 % 0.4 um	31 % 0.5 um

8b4e BCS	H [%]	V [%]
flat bottom	17 % 0.2 um	15 % 0.15 um
ramp	43 % 0.6 um	45 % 0.6 um
total injection - collisions	68 % 0.8 um	68 % 0.7 um

8b4e	H [%]	V [%]
flat bottom	6 % 0.1 um	3 % 0.05 um
ramp	12 % 0.3 um	20 % 0.4 um
total injection - collisions	19 % 0.4 um	24 % 0.45 um

2.51 TeV	H [%]	V [%]
flat bottom	16 % 0.2 um	11 % 0.1 um
ramp	8 % 0.1 um	8 % 0.1 um
total injection - collisions	25 % 0.3 um	21 % 0.2 um

same beams (8b4e BCS),
but different ramp:
factor of ~6 less blow-up!

- 2.51 TeV ramp is ~3 times shorter
- does the majority of the blow-up occur after 2.51 TeV ?
- better emittance preservation with PPLP ?

not straightforward to tell!

- no operational emittance measurement during the ramp (for physics beams)
- optics during the ramp not well known (between matched points)

conclusions

- injected emittances
  - ~1.7 um for BCMS, ~1.9 um for 8b4e and ~1.2 um for BCS
  - consistent with predictions of injectors
- blow-up at flat bottom
  - H: IBS (~0.4 um/h) + extra blow-up (0.2-0.6 um/h), likely electron cloud related
  - V: 0.2-0.5 um/h, not fully understood (e-cloud + coupling? + ?)
- the most blow-up occurs during the ramp!
  - up to ~45% for 8b4e BCS - < 10 % in the 2.51 TeV cycle
  - beam 1 worse than beam 2
- emittance in collisions
  - ~2 um for BCMS, ~2.3 um for 8b4e, ~1.9 um 8b4e BCS (~1.4 um in the 2.5 TeV cycle!)
  - beams round, consistent with ATLAS/CMS luminosity ratio
  - complementary emittance measurements are crucial

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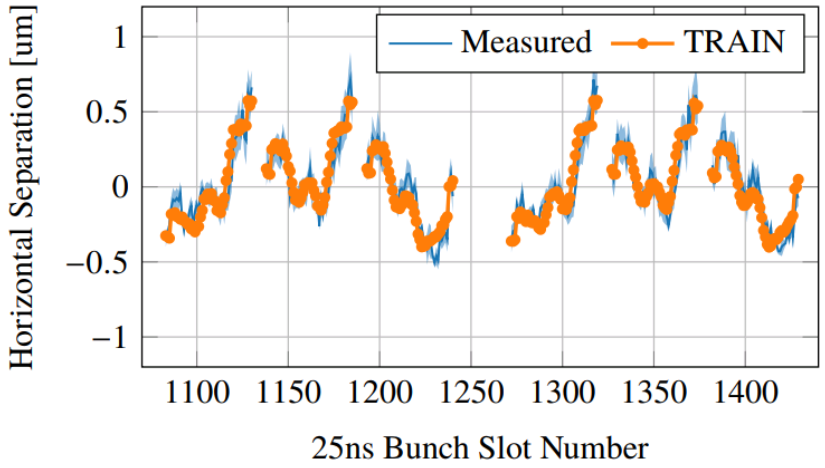
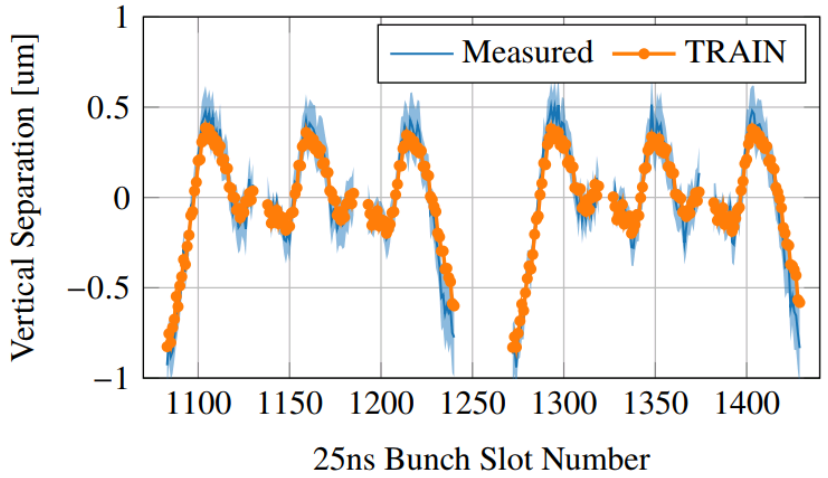
“emittance” scans in 2017

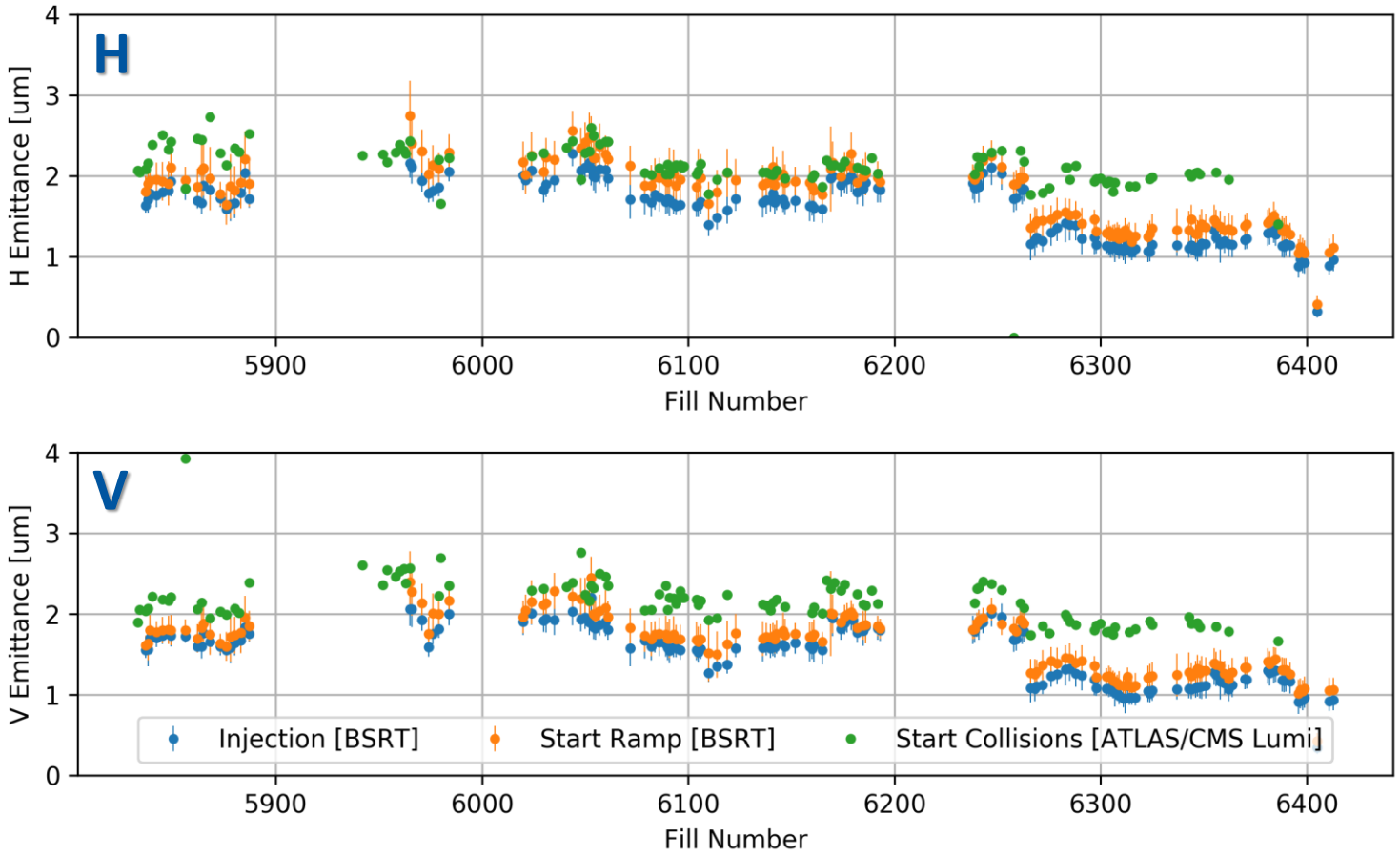
- emittance measurements as in 2015 & 2016
  - CMS V (separation) plane better than H (crossing)
    - impact of the longitudinal distribution – compensation improved
- extra usage:
  - CMS luminosity monitor tracking (“mini-VdM” scan, see Jamie)
  - beam-beam long-range observations, consistent with (improved) simulations





n.b. reproducible for the 2017 “zoo” of filling schemes!

putting it all together: the full cycle



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