Emittance preservation in the injectors

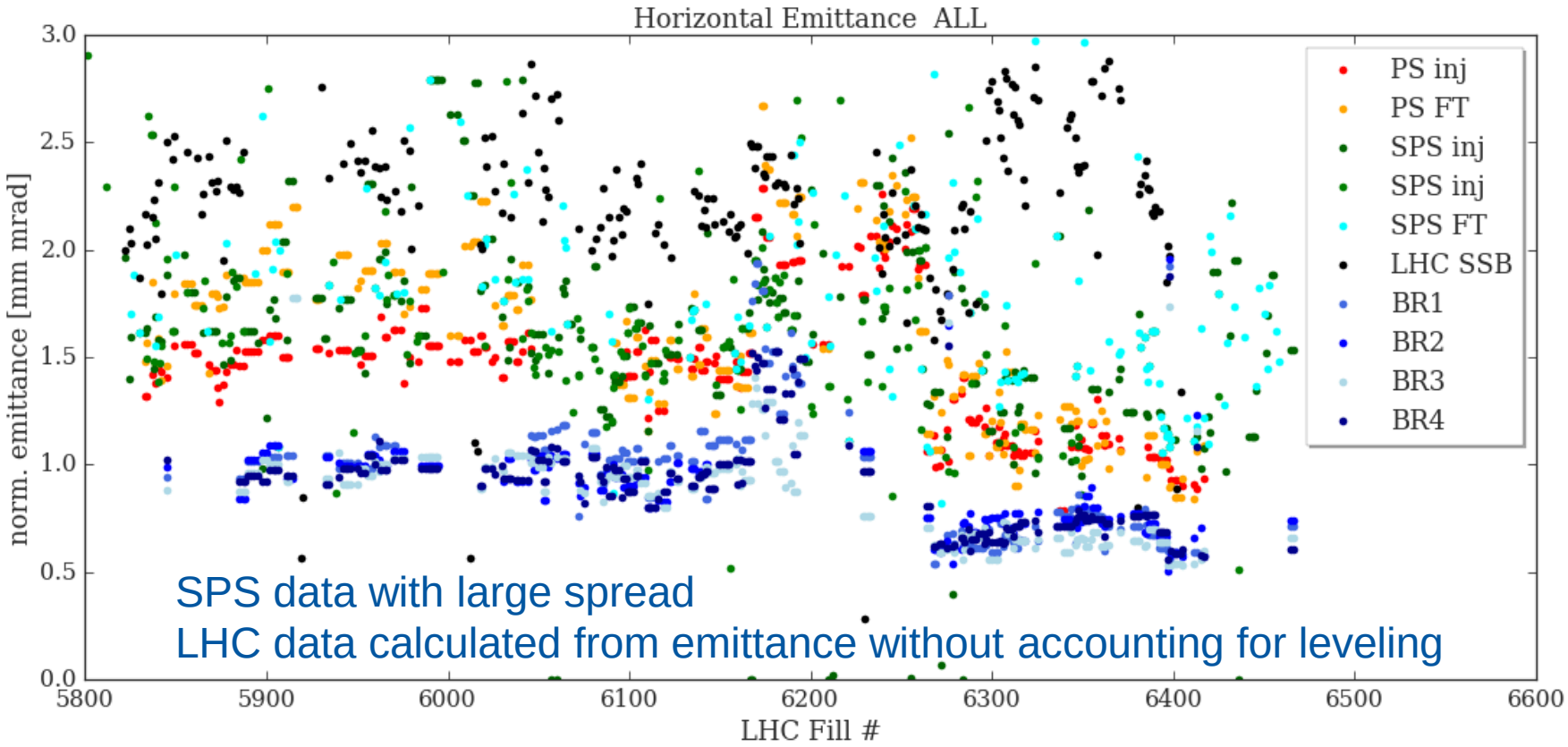
Frank Tecker, with **many thanks** to:

H. Bartosik, J.-F. Comblin, D. Cotte, G.P. Di Giovanni, V. Forte, M. Fraser, A. Guerrero Ollacarizqueta, A. Huschauer, A. Lasheen, S. Levasseur, M. Hostettler, H. Sandberg, E. Senes, G. Sterbini, J. Storey + BI and OP collegues

Contents

- Emittance evolution of operational beams
  - BCMS (before/after constant bucket area)
  - 8b4e
  - 8b4e_BCS
- Emittance measurements
- Emittance studies
- Perspectives for 2018

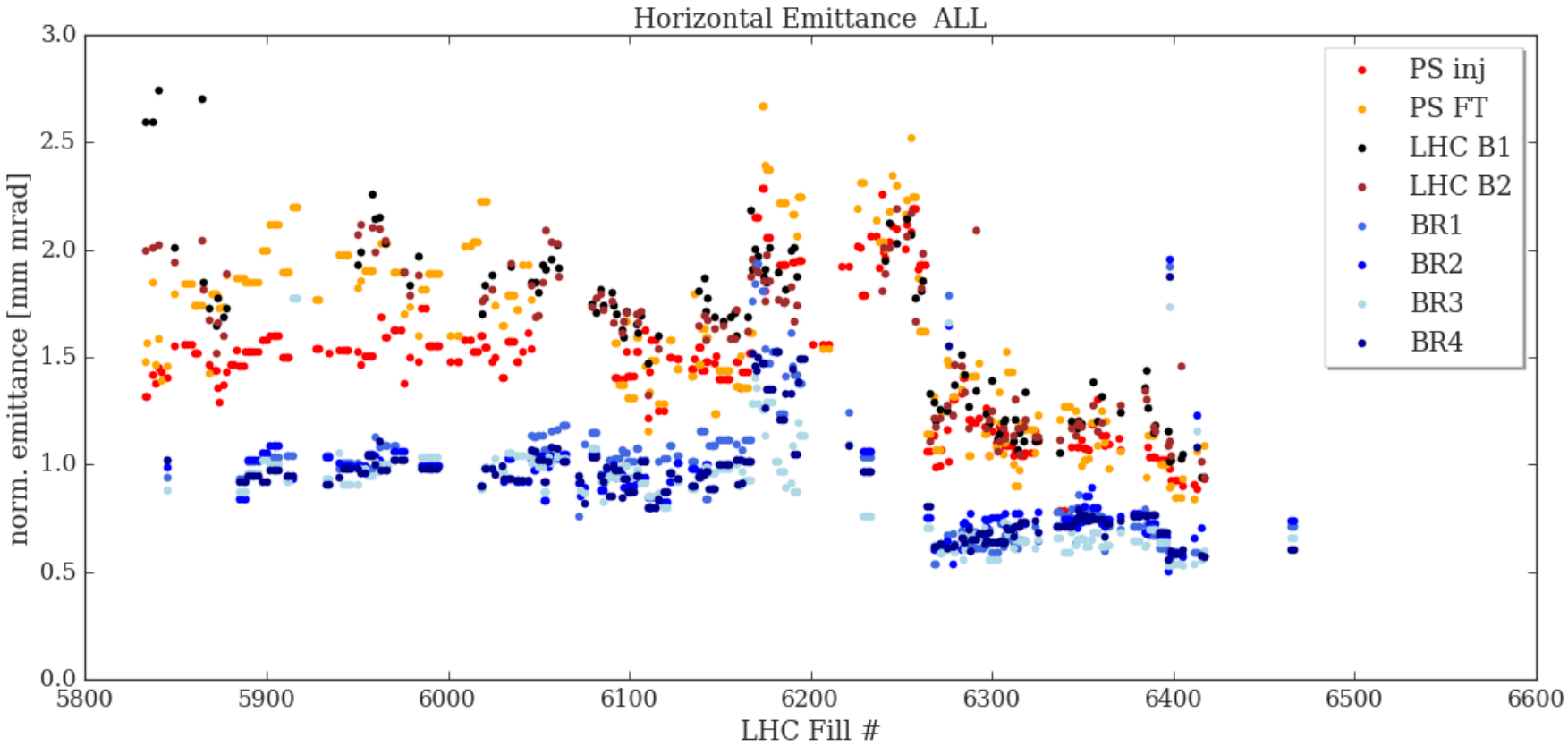
LHC Supertable data



SPS data with large spread
LHC data calculated from emittance without accounting for leveling

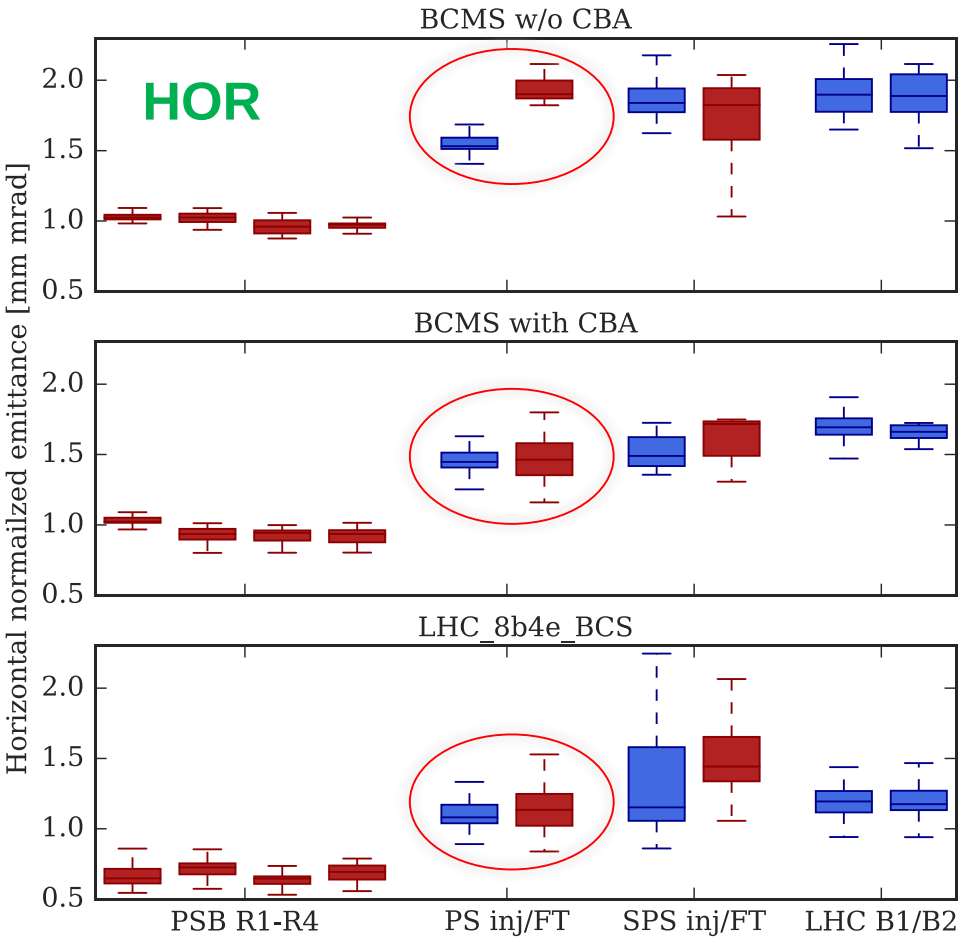
LHC WS data

Thanks to M.Hostettler!



Constant bucket area (CBA) in the PS

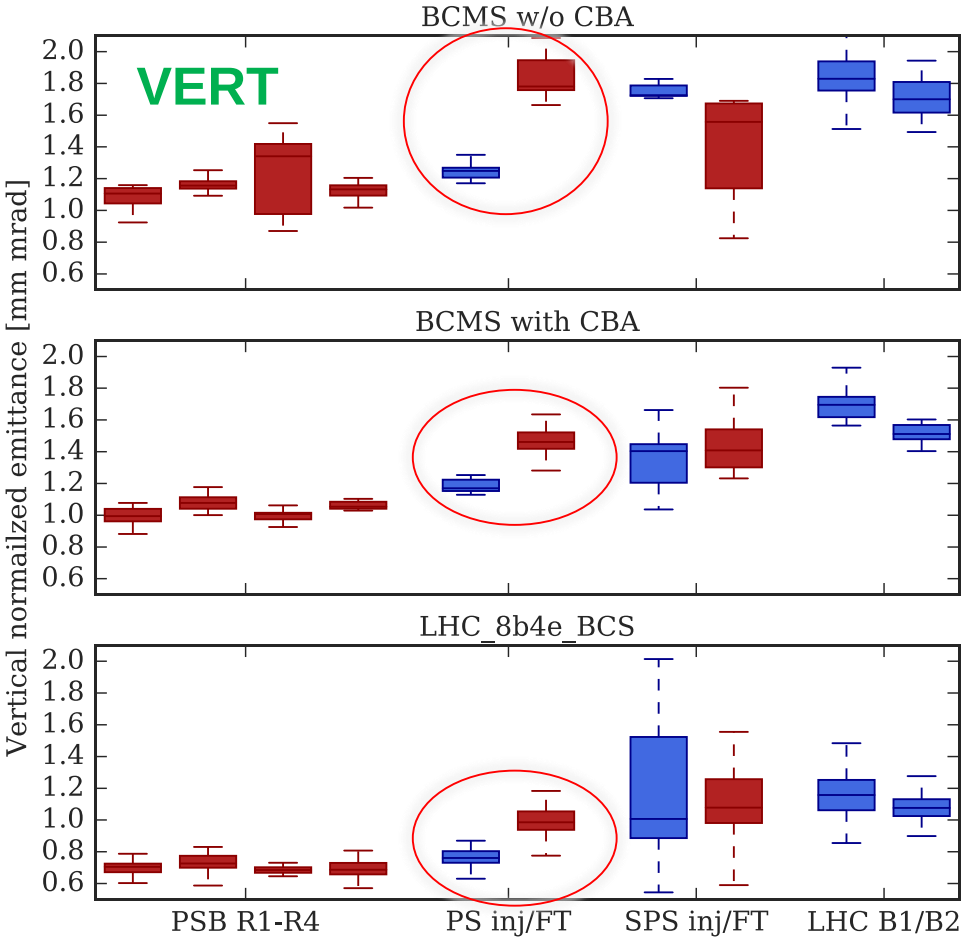
- to keep bunches longer and mitigate space charge
- Tested in 2016, together with optimized working point
- Introduced from 5/08 in MD beam, 9/08 in oper. LHC4
- PS inj -> FT: **no horizontal blowup!**
- BCS with CBA from the start



Constant bucket area in the PS (2)

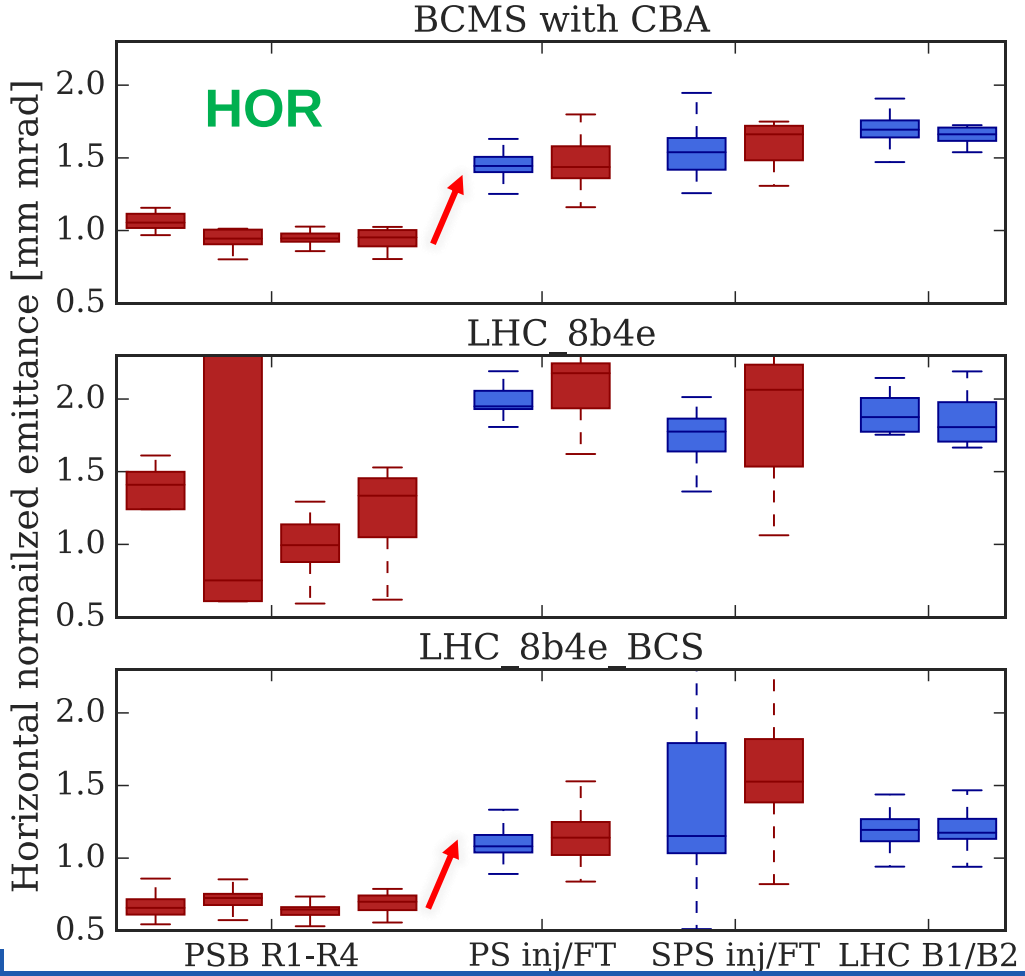
- **reduces** also **vertical** PS inj -> FT **blowup**

- clear reduction in LHC emittances in H and V



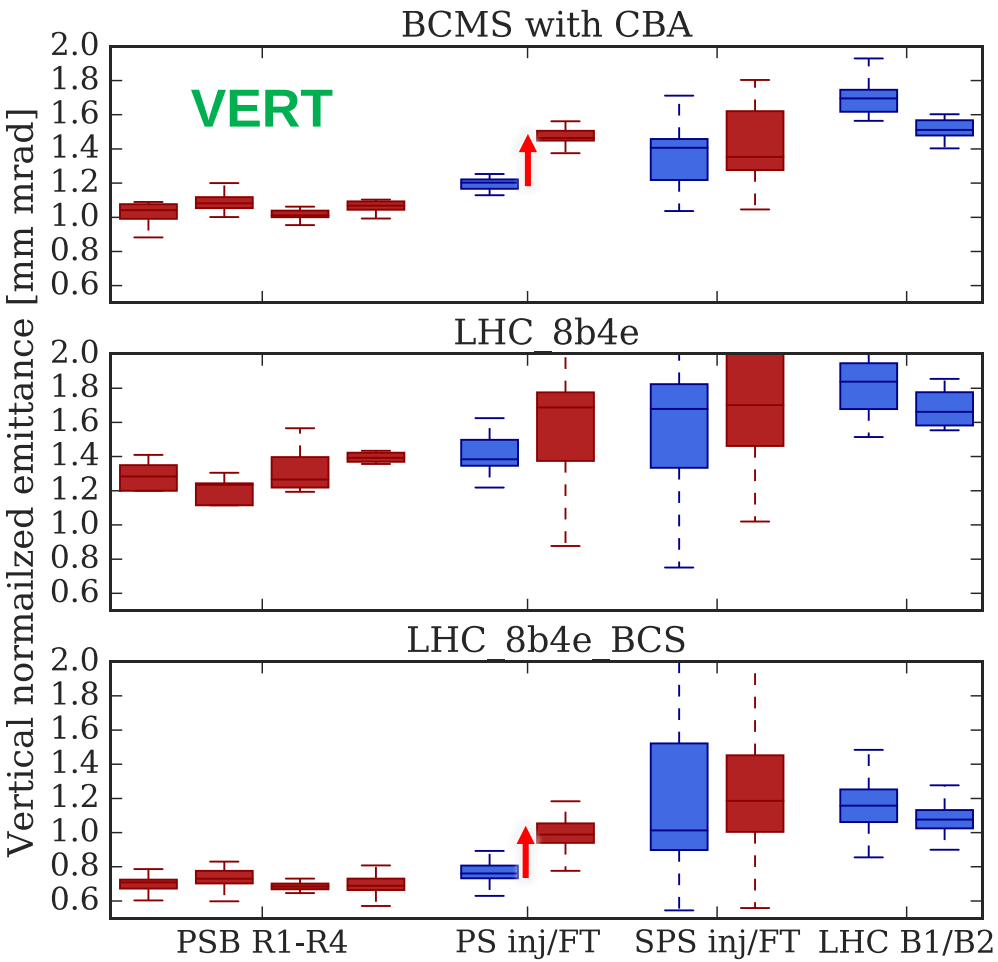
Horizontal summary

- Blowup in **PSB -> PS transfer**
- no significant further increase



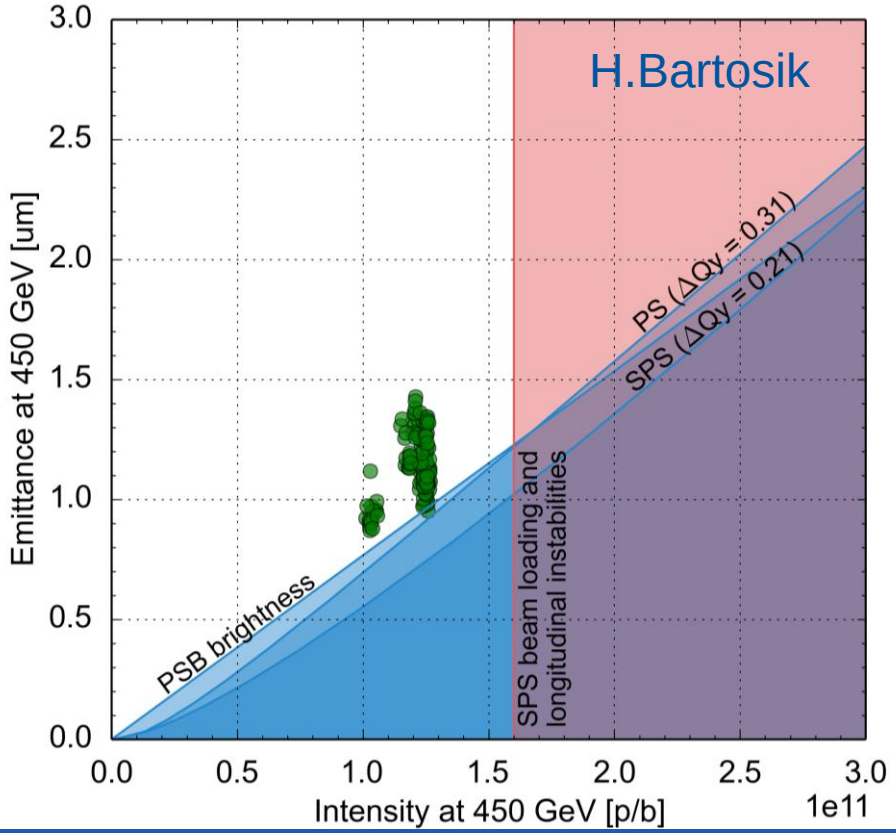
Vertical summary

- Blowup in **PS** from **injection to flat top**
- no significant further increase



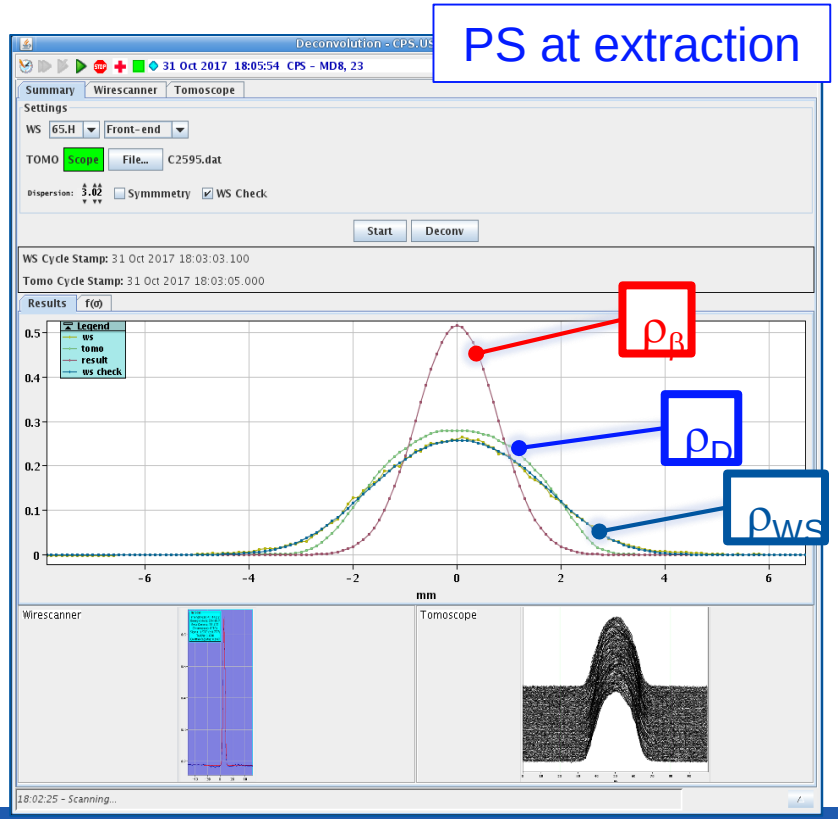
Vertical blowup PS Inj -> FT

- BCS beam had some fills at lower intensity (not much data)
- Smaller blowup for lower intensity
- Just touching space charge limit?
  WP optimization
- To be verified…



Emittance measurements
Emittance studies

Deconvolution



- Profile measurements in presence of Dispersion (both WS and SEMs)
- $x = x_\beta + D\,\frac{\Delta p}{p}$
- Assuming Gaussian profiles:

$$\sigma_\beta = \sqrt{\sigma_m^2 - D^2\left({}^{\Delta p}/_{p}\right)^2}$$

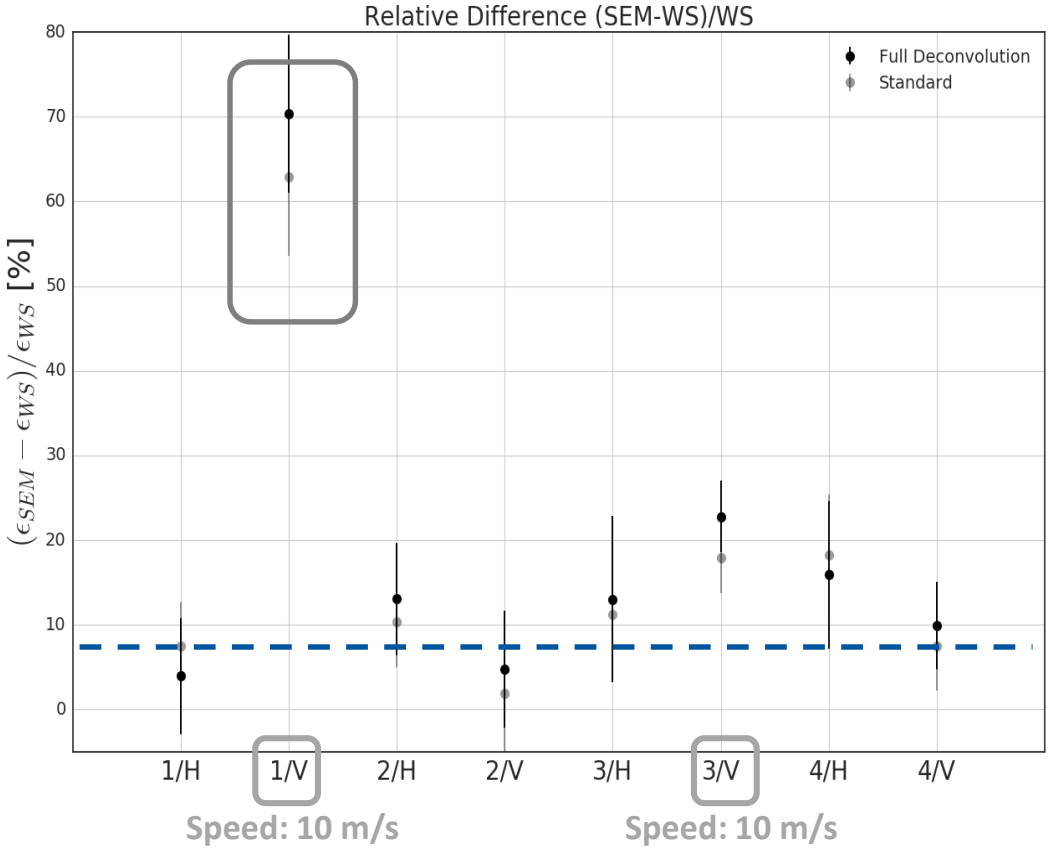
- **Large error for bigger dispersive part**
- Better estimation by deconvolution with measured momentum profile (assuming Gaussian betatronic profile)
- Application by J.-F. Comblin now available

PSB Comparison WS/SEM-Grid

- Emittance measured at PSB SEM grid is **systematically larger by ~10%** than the correspondent measurement at the PSB WS

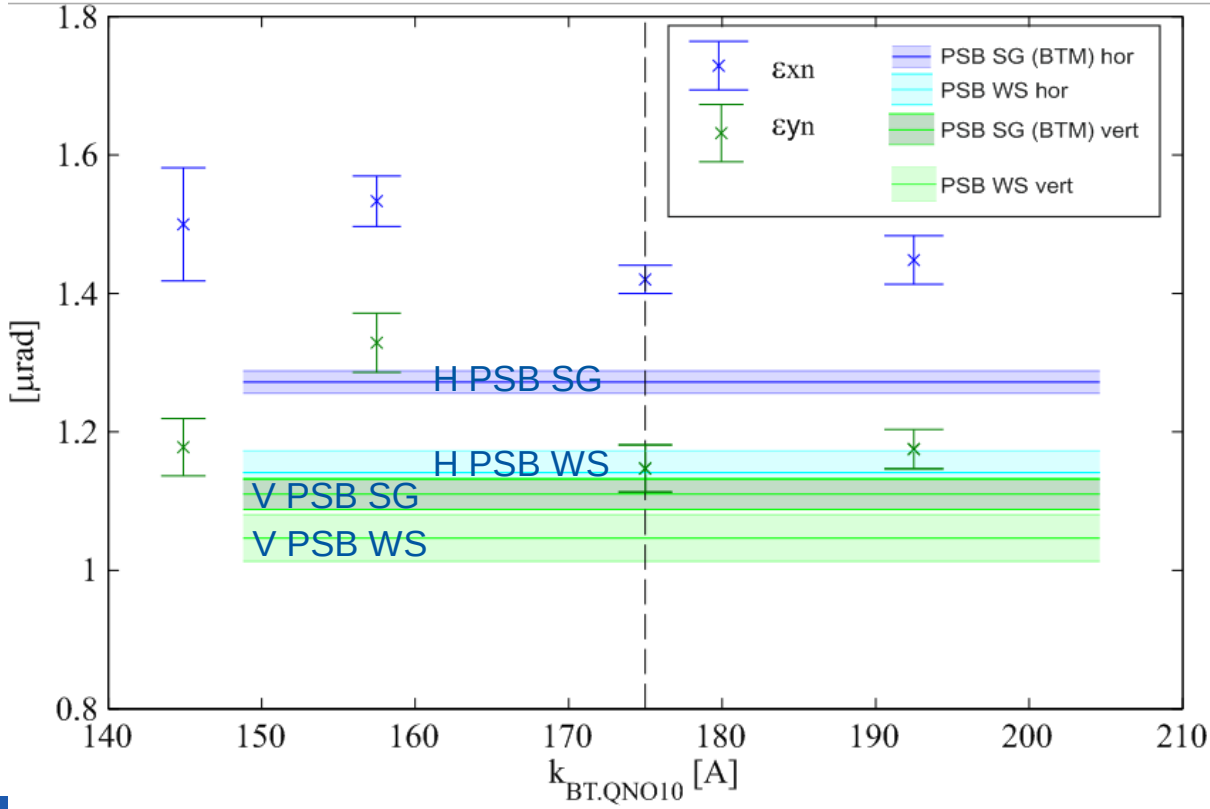
- 1/V and 3/V
  - lower wire speed
  - higher measured discrepancy
  - will be **exchanged** during **YETS**

G.-P. Di Giovanni



WS/SEM comparison – PSB/PS

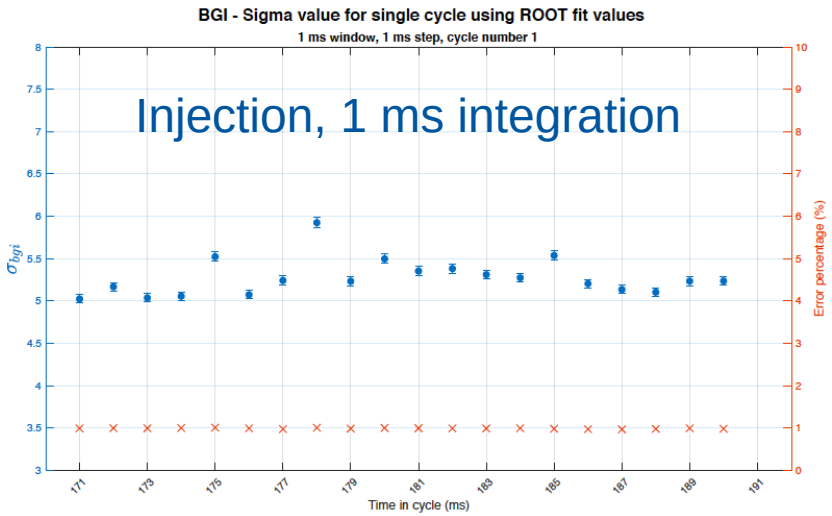
- Emittance from **PS SEM-grids** seems already **larger than** the **PSB WS** and **PSB SEM-grids**

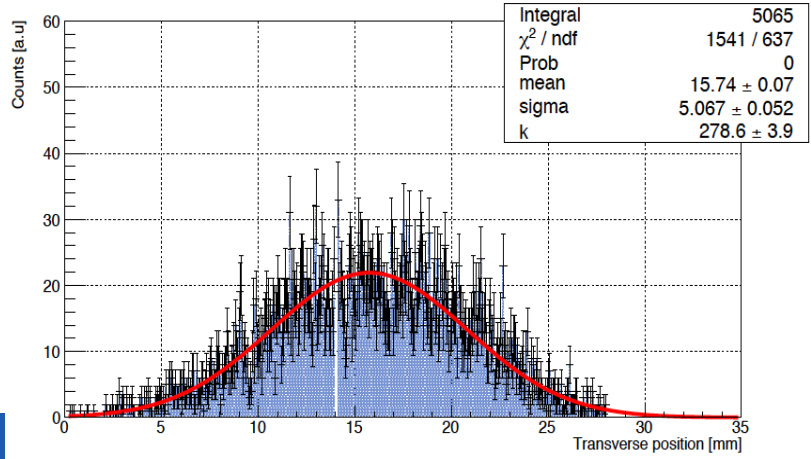


V. Forte

PS BGI - Horizontal

- Very interesting instrument, tested in MDs
- 1 of 4 detector chips has broken cable – will be repaired in YETS
- Allows **time-resolved** transverse profile measurements
- Average over down to ~50 turns
- Beam size in **agreement with WS**
- Shows about constant profile size from injection
- Cannot distinguish between fast oscillation and filamented equilibrium

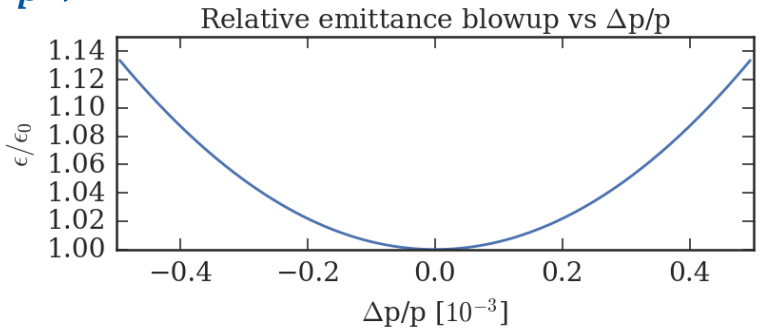




Blowup sensitivity to mismatch

- **Missteering**: $\Delta\varepsilon = \frac{\Delta x^2 + (\beta\,\Delta x' + \alpha\Delta x)^2}{2\beta}$ (also kicker flatness)
- **Twiss**: $\varepsilon = \varepsilon_0 \frac{1}{2}\left[\frac{\beta_m}{\beta_0} + \frac{\beta_0}{\beta_m} + \left(\frac{\alpha_m}{\beta_m} - \frac{\alpha_0}{\beta_0}\right)^2 \beta_0\beta_m\right]$
- **Dispersion**: $\Delta\varepsilon = \frac{\Delta D^2 + (\beta\,\Delta D' + \alpha\Delta D)^2}{2\beta}\left(\frac{\sigma p}{p}\right)^2$
- **Energy**: $\Delta\varepsilon = \frac{D^2}{2\beta}\left(\frac{\Delta p}{p}\right)^2$

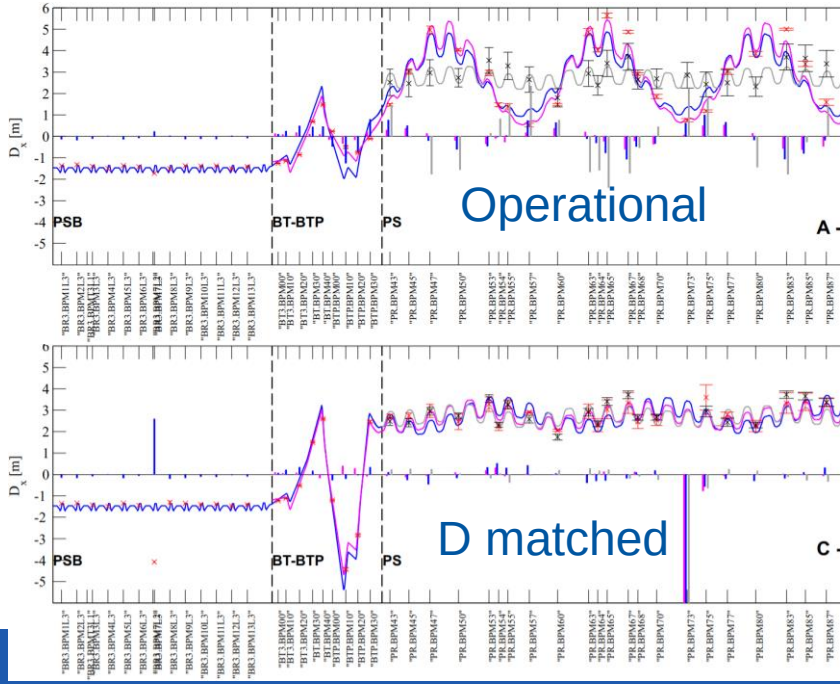
@1 mm mrad:
14% for 0.5‰



Betatron/Dispersion matching

V.Forte

- Operational optics has large dispersion mismatch
  - 25% emittance growth expected for BCMS
- optics with matched dispersion is mismatched in Twiss
- dedicated MD using non-PPM quads to check sensitivity around optimized matching
- should clearly reduce emittance

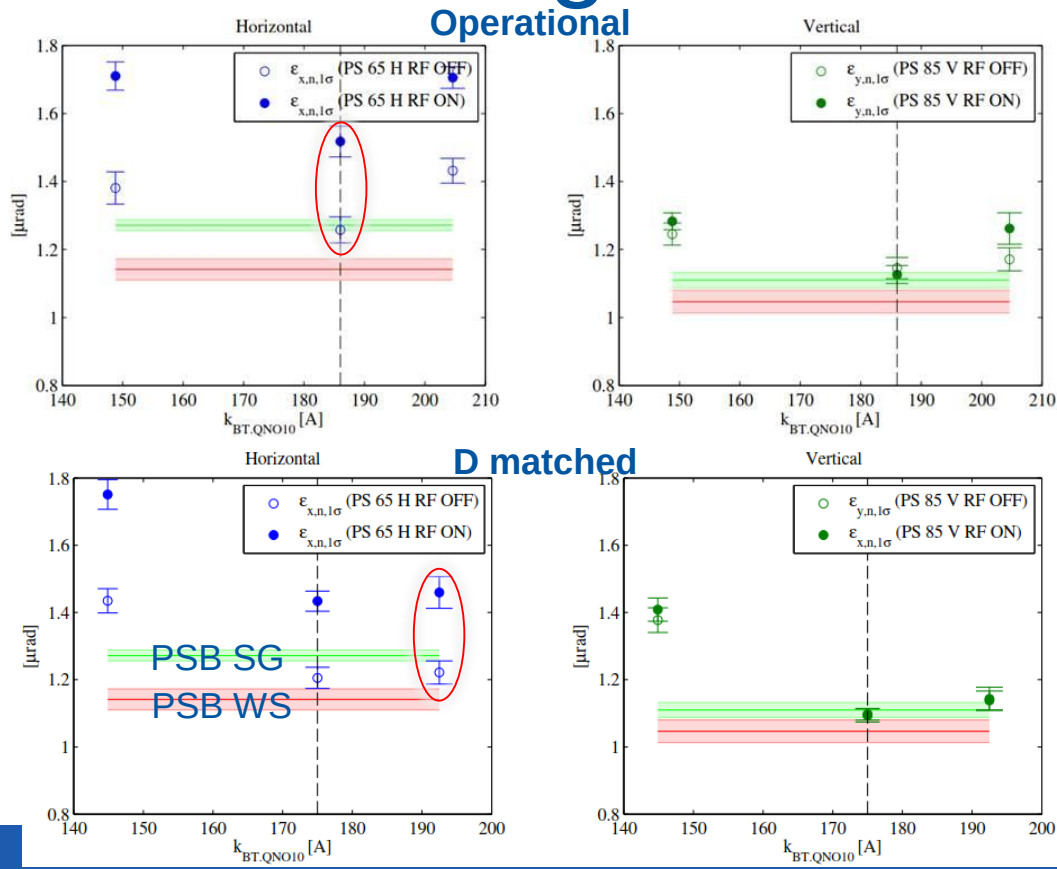


Betatron/Dispersion matching

V. Forte

- Dispersion matched optics could slightly reduce H emittance
- PS WS with RF OFF and ON show big difference in horizontal and small in vertical plane – not understood
- conditions to be verified, work ongoing

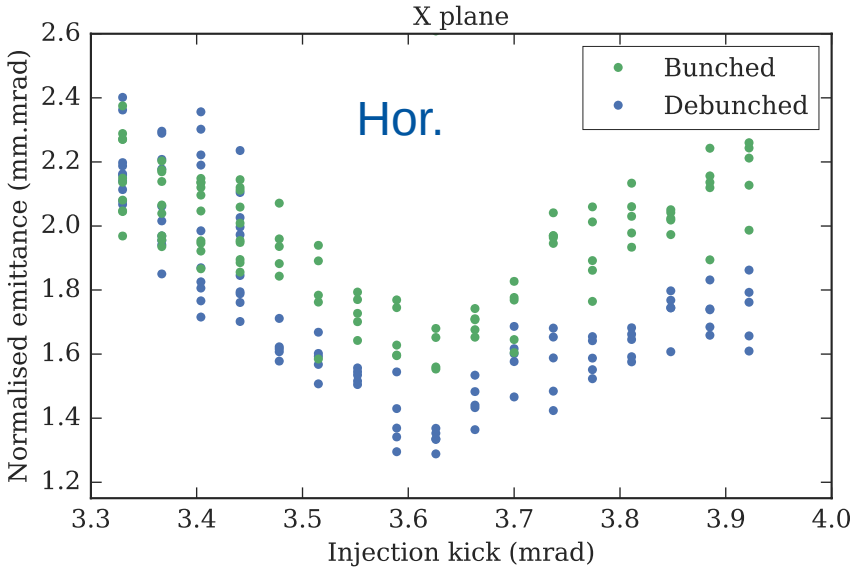
BCMS 0.9 eVs (~0.9e-3 dp/p) and chromaticy-free cycle (I~83e10ppb)

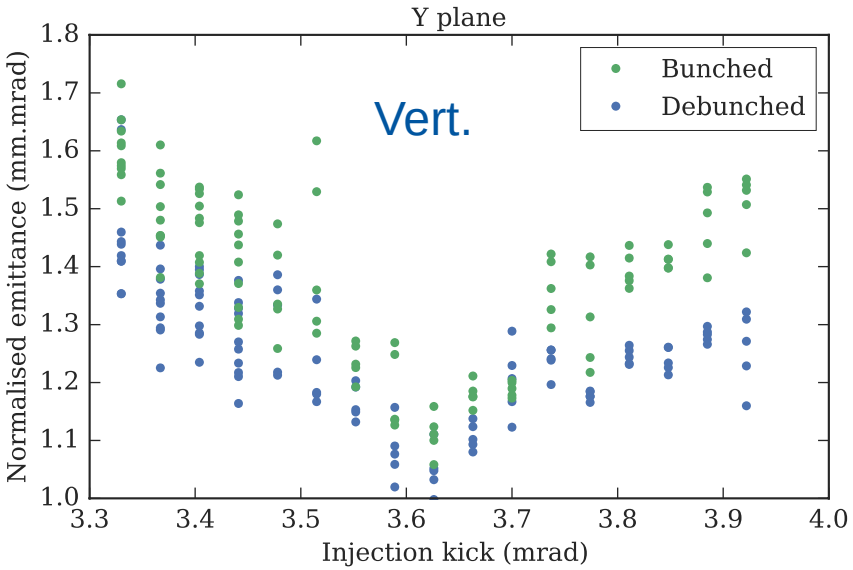


Blowup by Missteering

E.Senes

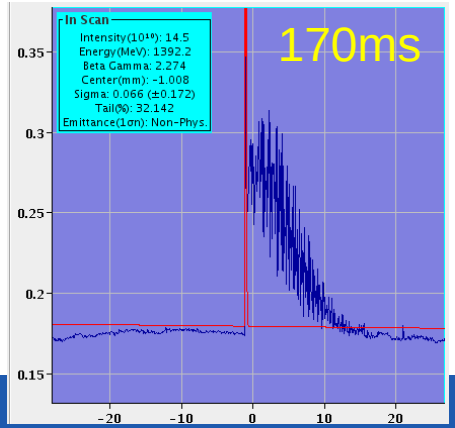
- BCMS (coupled) beam with missteering by injection kicker (@185ms)
- RF effect on blowup not understood, conditions need to be verified
- Space-charge effect should be less for larger missteering (larger emittance from fast filamentation)

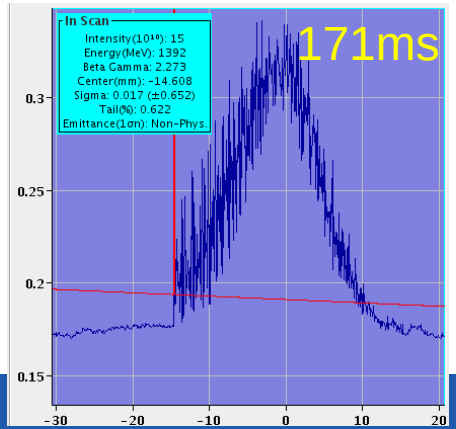


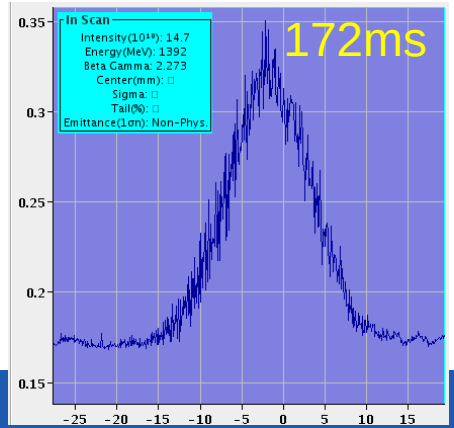


Turn-by-Turn profile observation

- would be really useful to study injection emittance growth!!!
- new PS SEM-grid multi-turn electronics should be available for MDs only from Oct 2018
- Idea: use **WS** at injection **as mismatch monitor**
  - fast oscillation in beam size (and position) seen on scan
  - reduced by filamentation
  - bumper non-closure can give a (slow) shift
- Example of INDIV_VdM beam (inj. corrected by YASP) (MD by E. Senes)







Conclusion

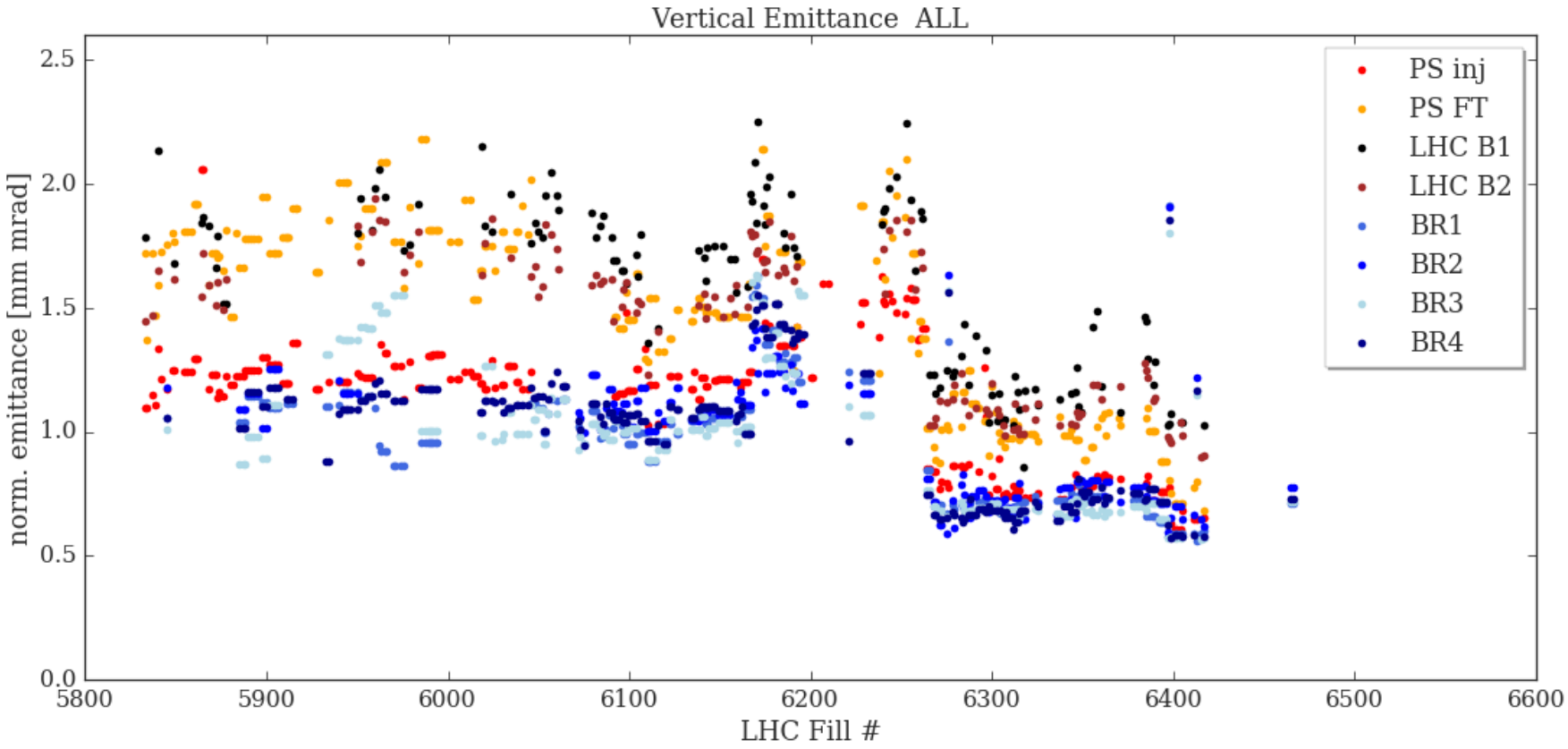
- **Constant bucket area** and WP adjustment at 1st PS ramp
  - eliminated horizontal blowup from PS injection to flat-top
  - significantly reduced the vertical blow-up
- **Main blow-up** in **horizontal** at **PSB -> PS transfer,** in **vertical** at **PS inj. -> FT**
- **LHC** emittance **follows PS FT emittance** without much further blowup
- Difficult to compare measurements at the few-%-level
  - PSB SEM ~10% larger than PSB WS, PS SEM even larger
  - Energy spread contribution is very large
- Turn-by-turn profile measurement from PS would be ideal
  - multi-turn SEM-grid from autumn 2018 for MDs
- Automated measurements in all machines would be useful

Points for discussion

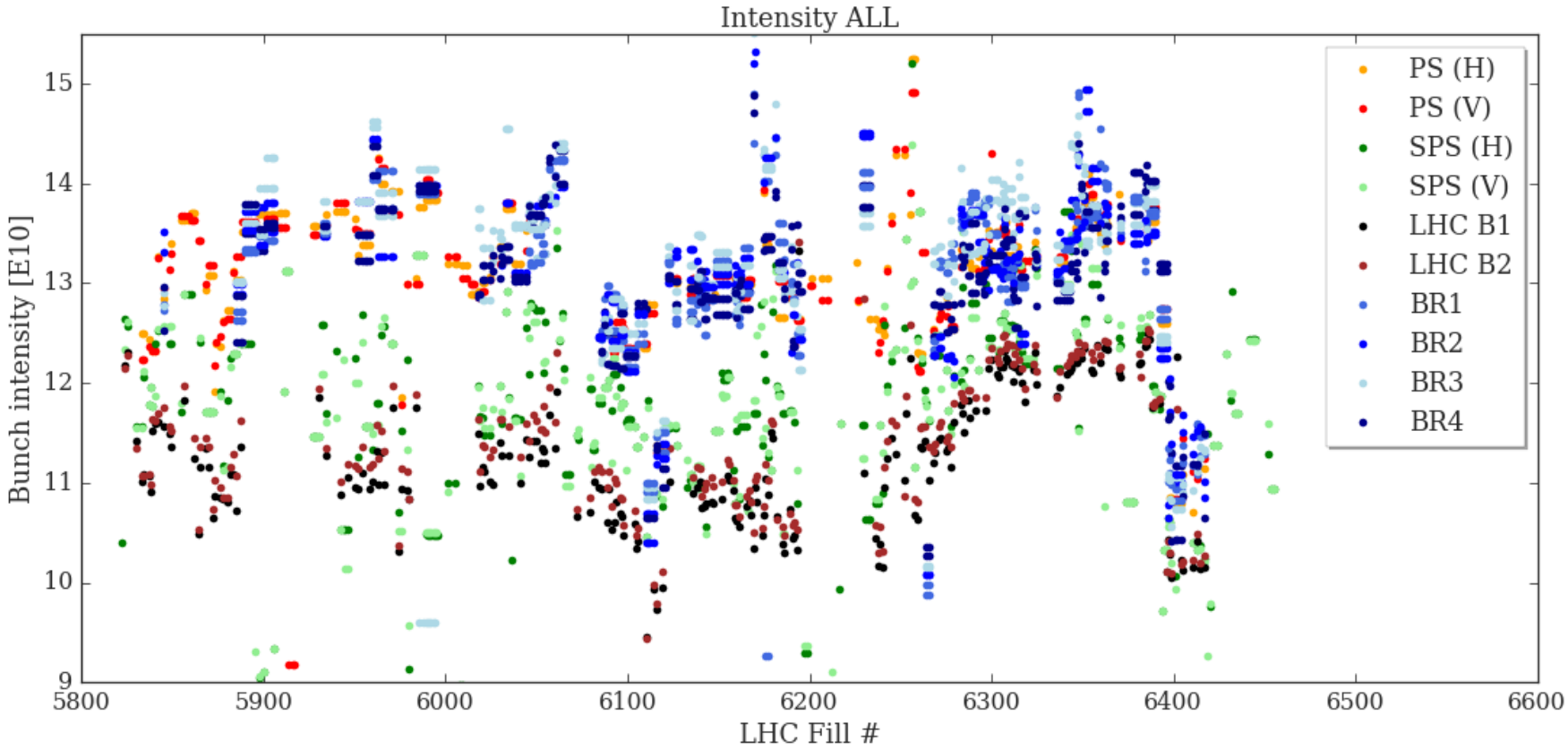
- Better **beta/D values**, WP dependent, measured beta-beat from k-modulation and phase advance studies
- PS **energy matching** at startup (new B measurement)
- Any other way to measure **PS TbT profile** (extraction at 1st, 2nd, 3rd turn to transfer line screen? Present SEM 2-turn integration)
- Can produce **lower vertical emittance by reducing coupling** using longitudinal FB and low-chromaticity optics (or nominal chroma)
- LHC **Supertable** remarks
  - norm_emit_ssb just calculated from Luminosity, not adapted with leveling => add wire scanner
  - SPS entries very noisy (very small beam size, especially at flat top) => would profit from operational BSRT

Thank you very much for your attention!

Vertical emittance evolution 2017

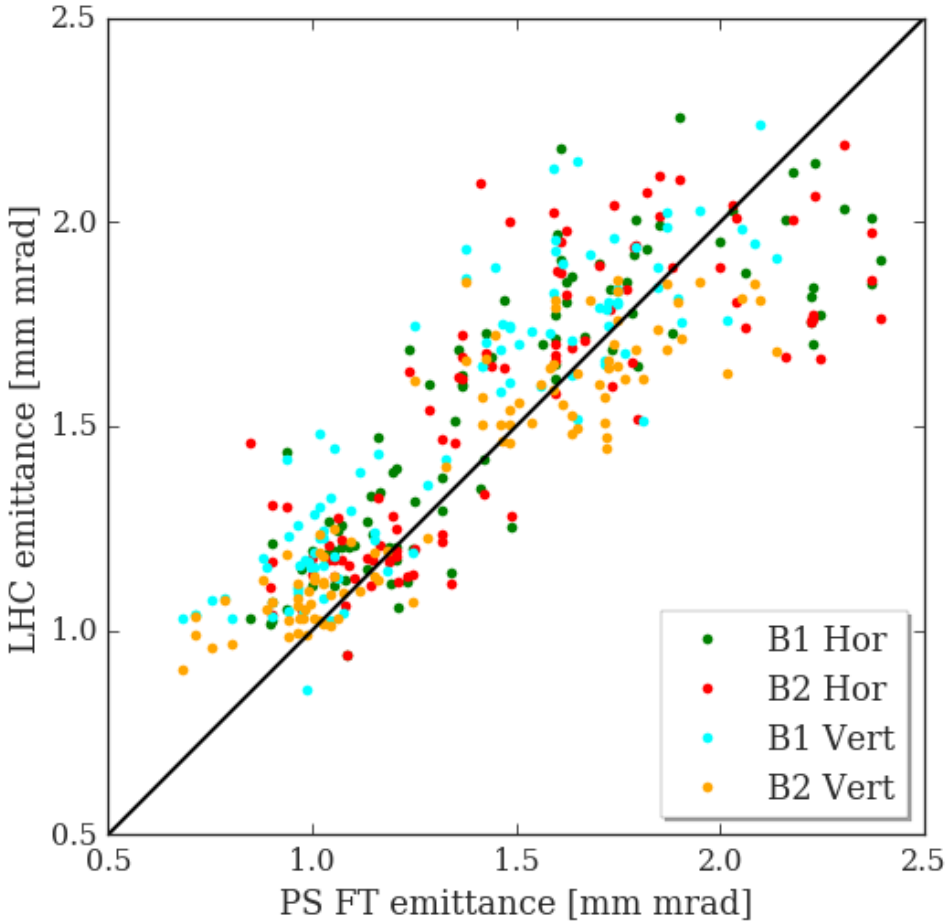


Intensity evolution during 2017



LHC vs PS FT

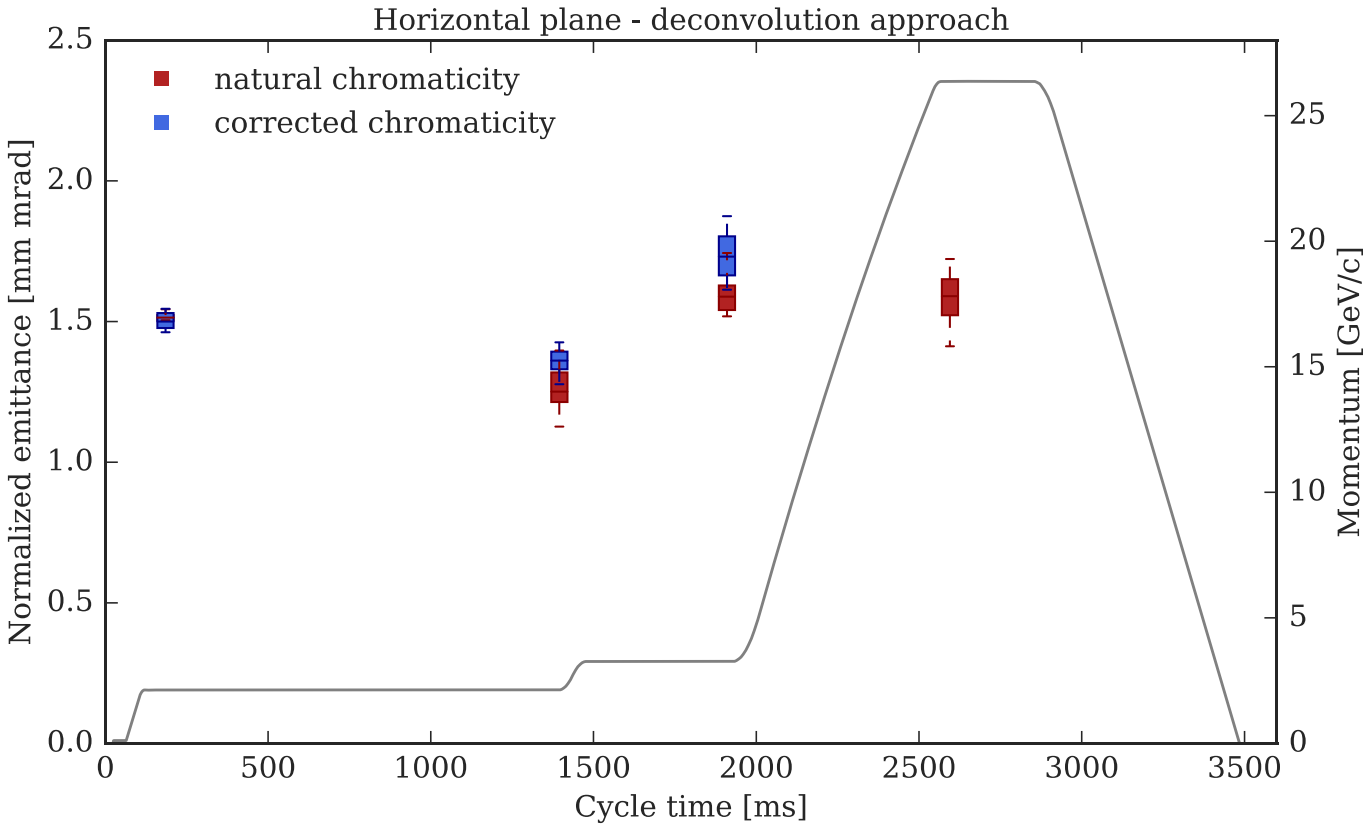
- No significant blowup in either plane between PS flat top and LHC injection
- Only B1 Vertical is slightly growing



Horizontal emittance in PS

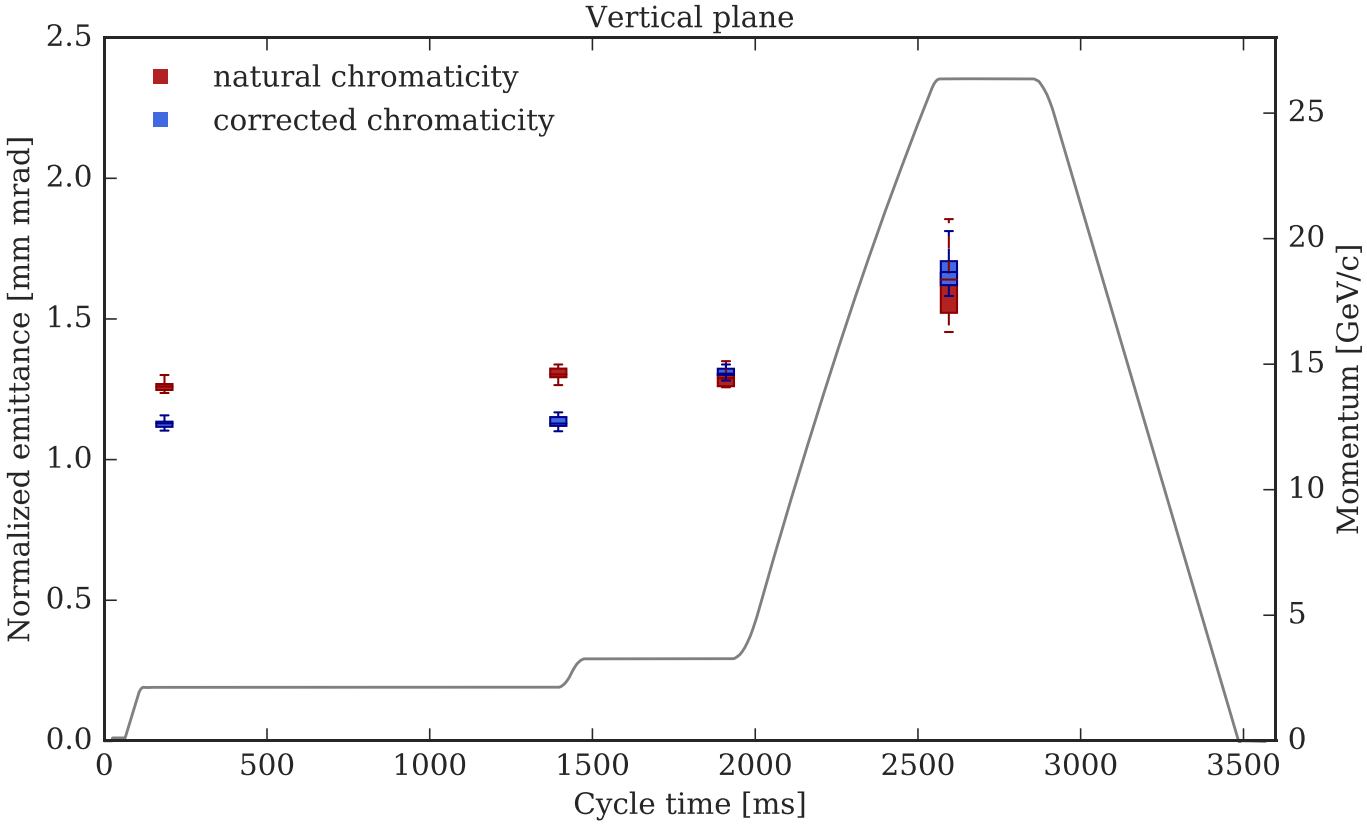
- Comparing OP BCMS with low chromaticy beam

A. Huschauer



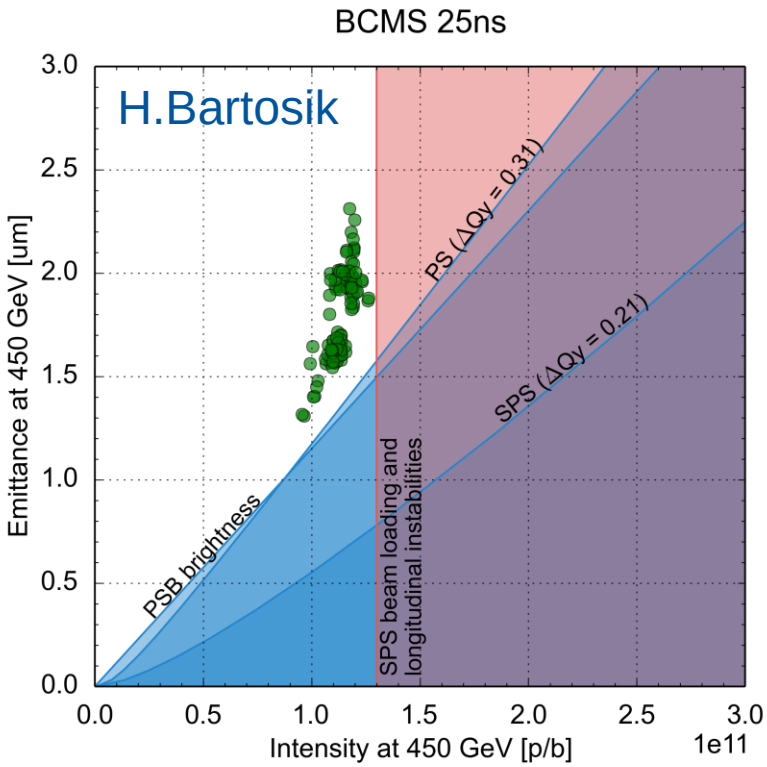
Vertical emittance in PS

- Comparing OP BCMS with low chromaticy beam
- lower at flat bottom
- without ramp optimization



A. Huschauer

BCMS brightness



Blowup from missteering

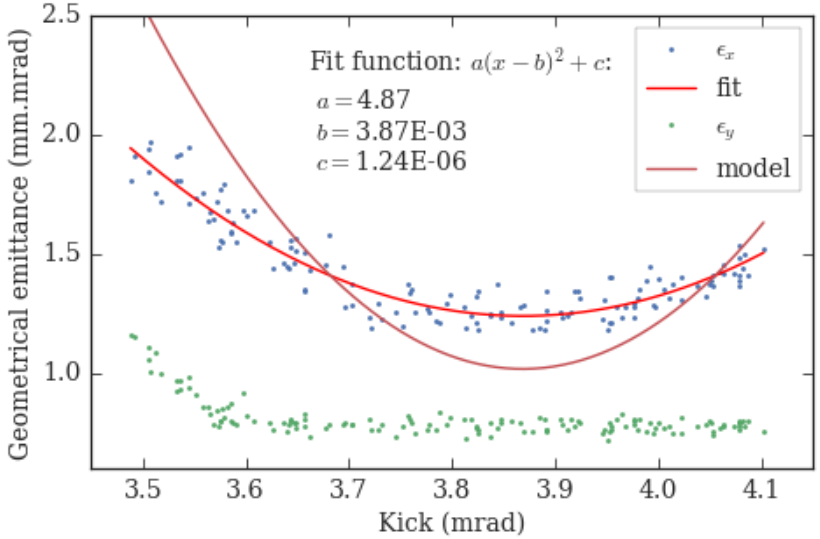
E.Senes

- Less than expected for larger kicks
- Less at 185 ms than at 175 ms!

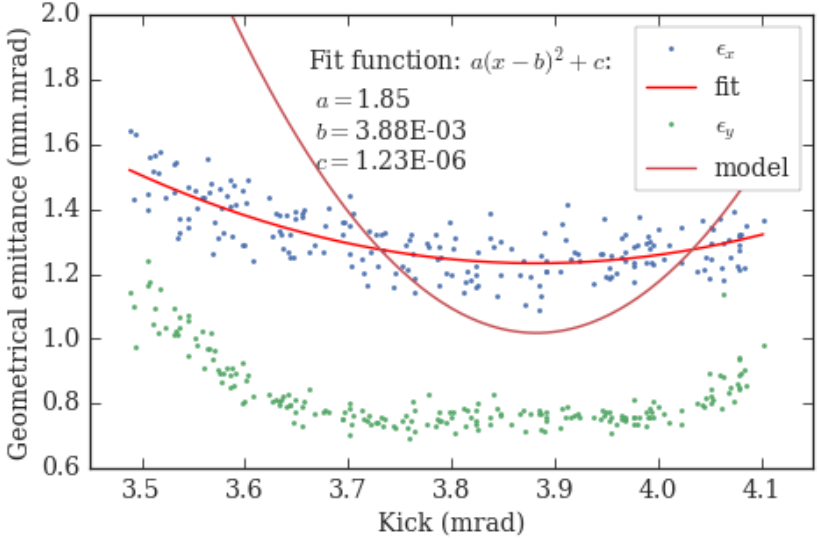
I = 13x10^{10} ppb
ε_{x_norm} = 2.51 +/- 0.12
ε_{y_norm} = 2.01 +/- 0.03
dp/p_rms = 5e-4

Expected
a=11.26

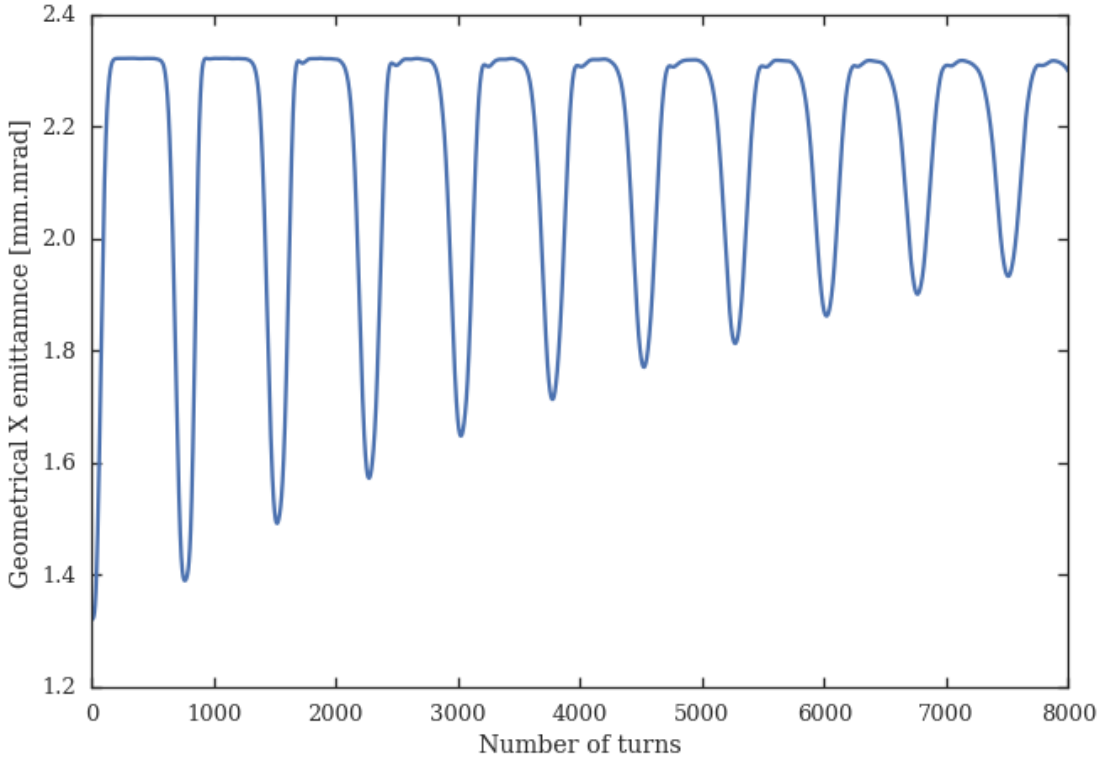
C175



C185



Decoherence / Recoherence

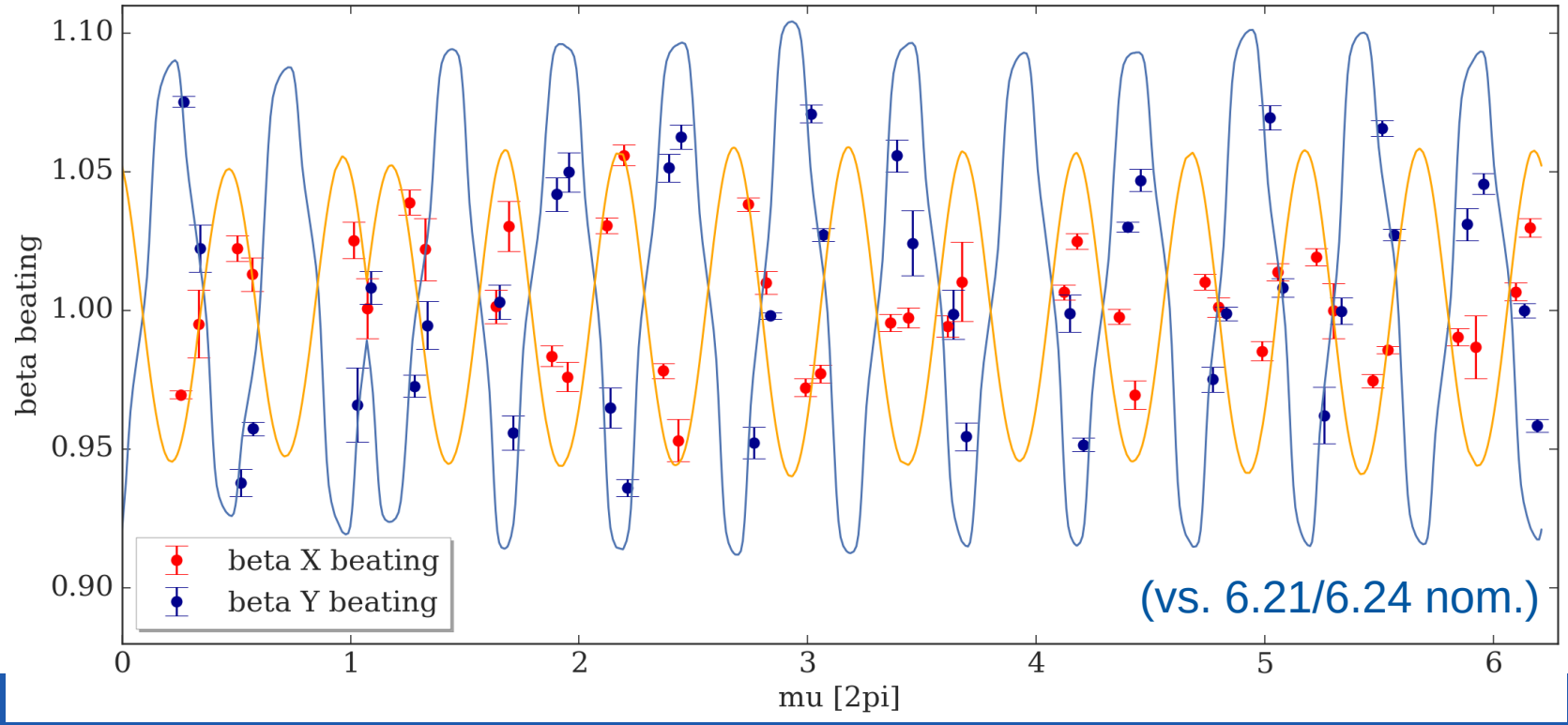


PyHeadTail Simulations, uncoupled
by E. Senes

Obvious recoherence after synchrotron period

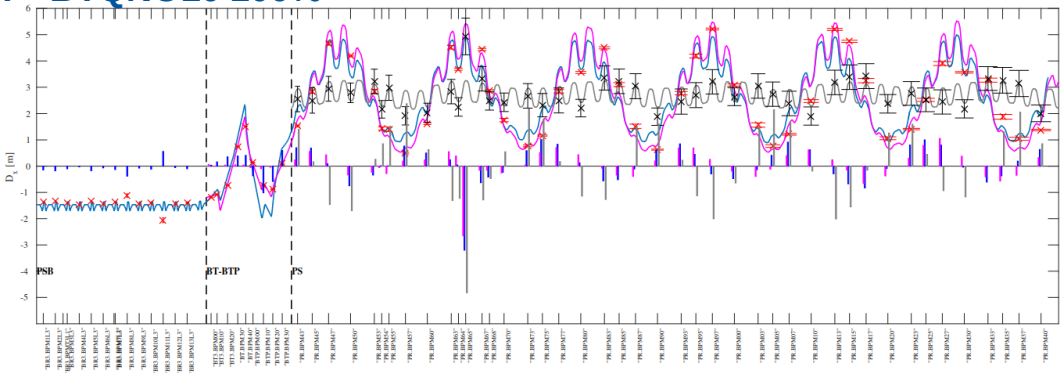
Beta-beating (PS inj) measured by k-modulation

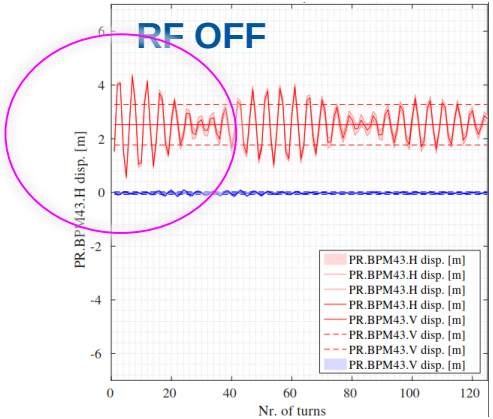
Found PR.QDW18 with inverted polarity

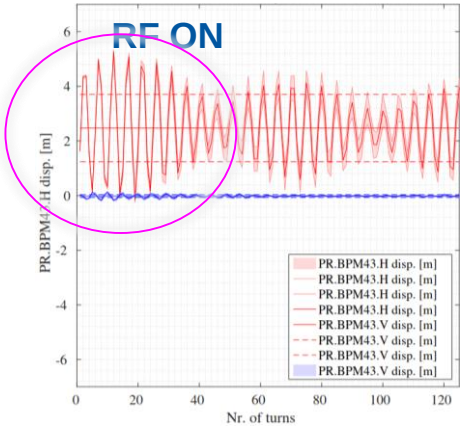


Dispersion measurements

OPTICS A – BTQNO10 100%



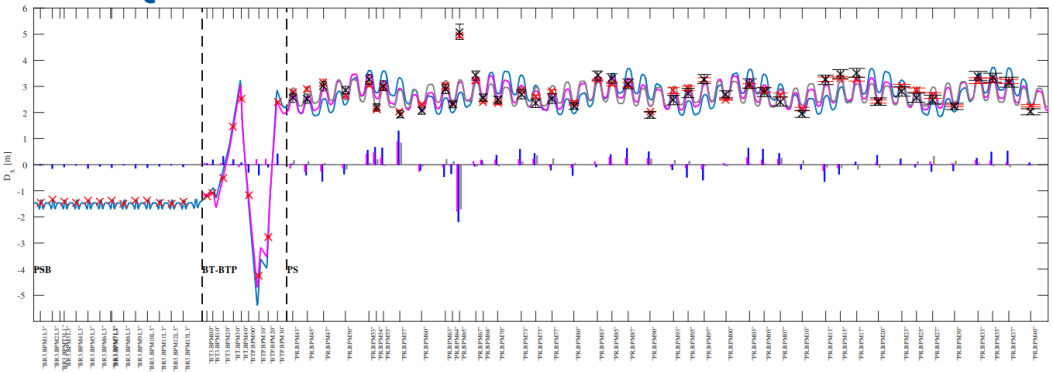


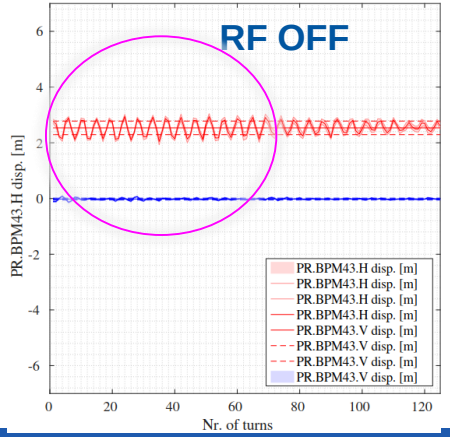


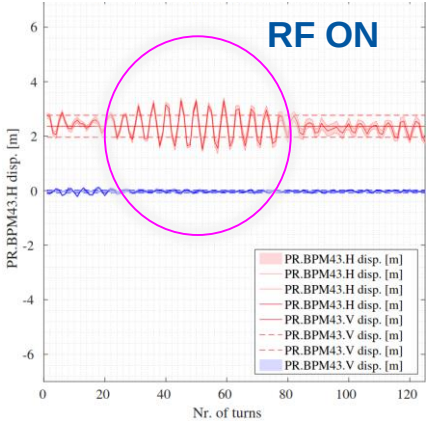
Dispersion measurements

PSB-BTi-BT-BTP-PS
Rematched $D_{x\_PSB\_extr}, D'_{x\_PSB\_extr}$
PS MadX closed solution
Measurement
Closed solution (estimated from measurement)
Errors with respect to Measurement

OPTICS C – BTQNO10 100%



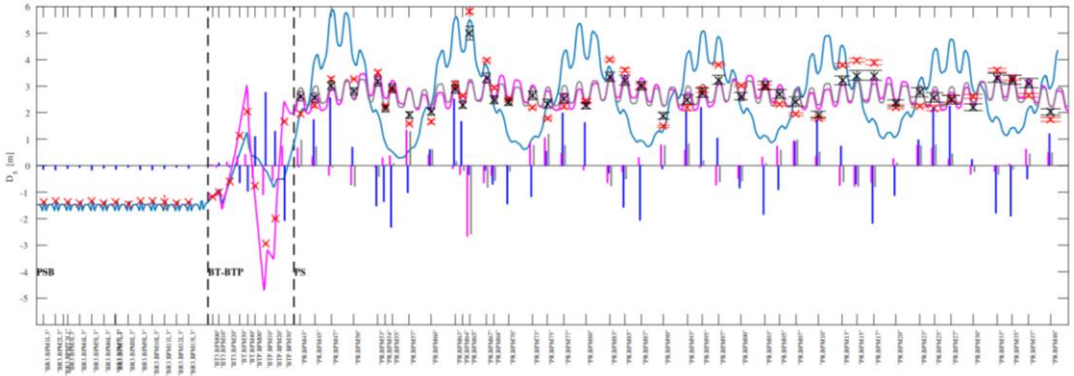


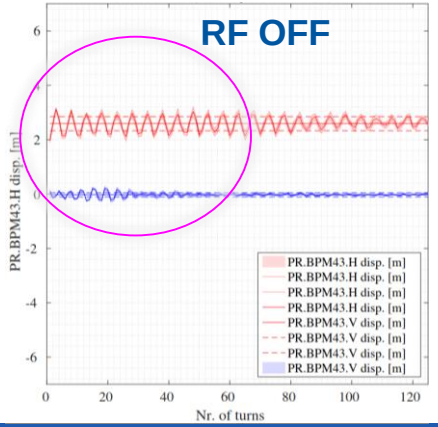


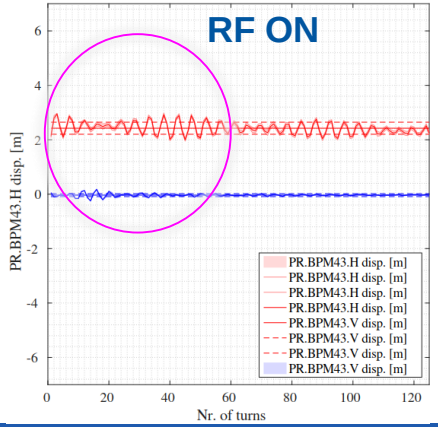
Dispersion measurements

PSB-BTi-BT-BTP-PS
Rematched $D_{x\_PSB\_extr}, D'_{x\_PSB\_extr}$
PS MadX closed solution
Measurement
Closed solution (estimated from measurement)
Errors with respect to Measurement

OPTICS C – BTQNO10 110% → still very good







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