LHC Injectors Upgrade

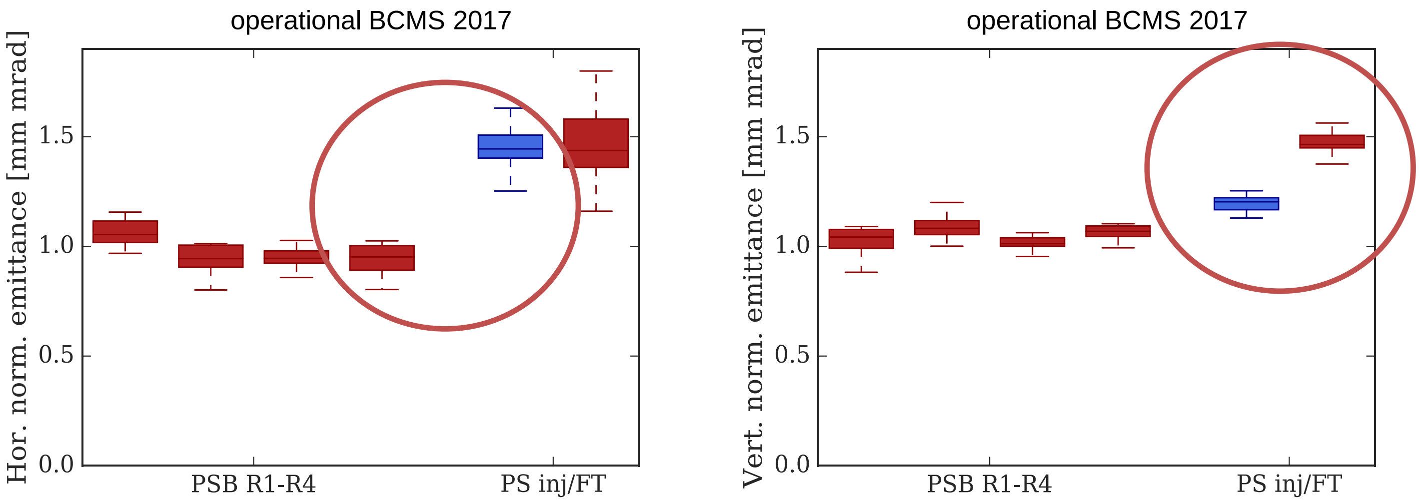
Emittance growth in the PS and experience with the transverse damper

H. Bartosik, V. Forte, M. Fraser, A. Huschauer, S. Levasseur, H. Sandberg, E. Senes, M. Serluca, G. Sterbini, J. Storey, F. Tecker, A. Wegscheider, P. Zisopoulos

Acknowledgements:
PSB and PS OP crew

Introduction

- **Horizontal emittance blow-up experimentally observed at PS injection**
  - Comparison of wire scanner measurements at PSB extraction and PS injection indicates **horizontal blow-up** in the order of **30-40%**
  - **Blow-up** of the **vertical emittance** observed on the flat top



F. Tecker

  - **PS budget** for emittance growth in the LIU era: **5%**

- **LIU baseline crucially relies on bunches with large longitudinal emittance**
  - Need to demonstrate operation with such beam parameters
  - Understand and address possible limitations

Possible contributions to the blow-up

- **Studies on various fronts ongoing to investigate sources of the blow-up**

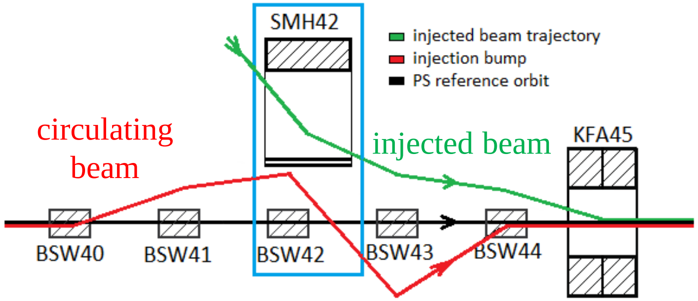
1. Optics matching between transfer line and PS ring

→ see previous talk by V. Forte

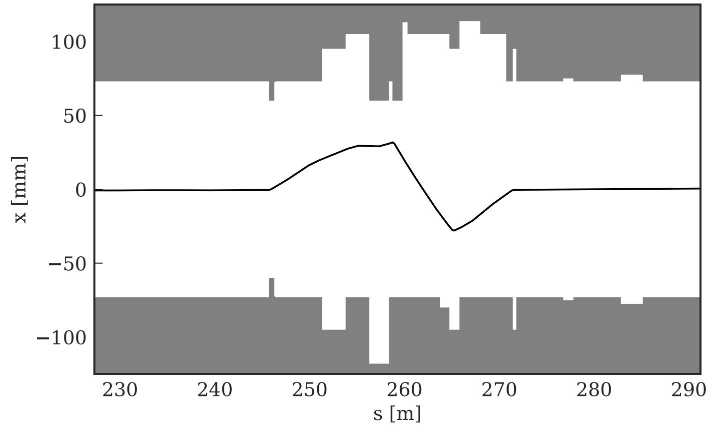
- **Mismatch** of the optics functions (especially **horizontal dispersion**)
- **Horizontal emittance blow-up** in the order of **25%** expected according to latest optics measurements
- Addressed in the LIU-PS baseline by redesigning the transfer line optics

2. Transient period during the collapse of the injection bump

- Very **dynamic situation** – bump collapses during only 500 turns



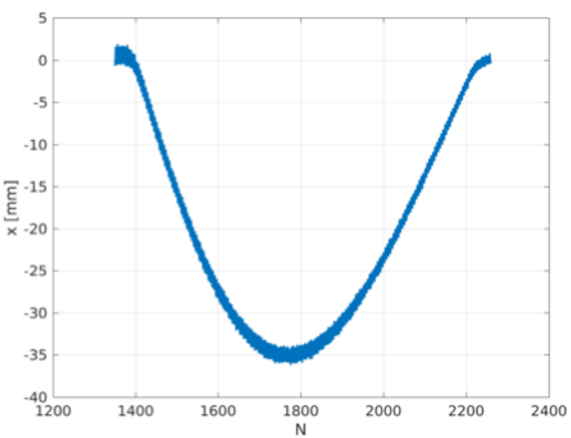
Currently only four dipole magnets producing the injection bump (BSW41 to be added in LS2)

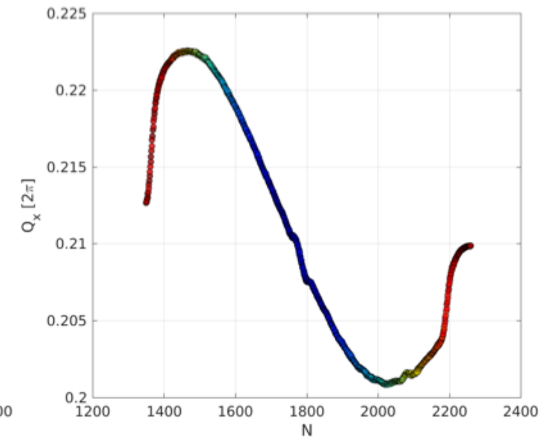


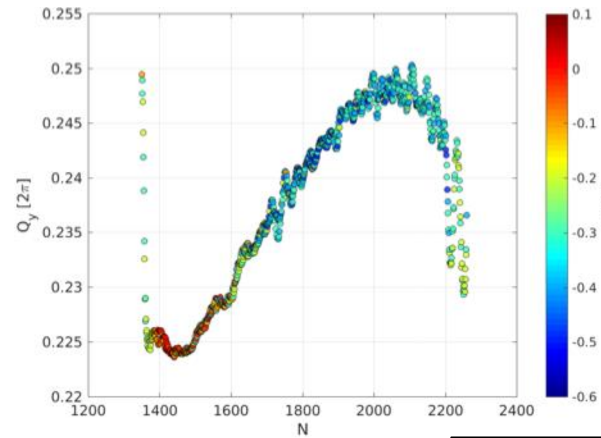
Possible contributions to the blow-up

2. Transient period during the collapse of the injection bump

- Very dynamic situation – bump collapses during only 500 turns
- Tune measurements based on the **mixed BPM method** [1] revealed very peculiar dynamic tune shift

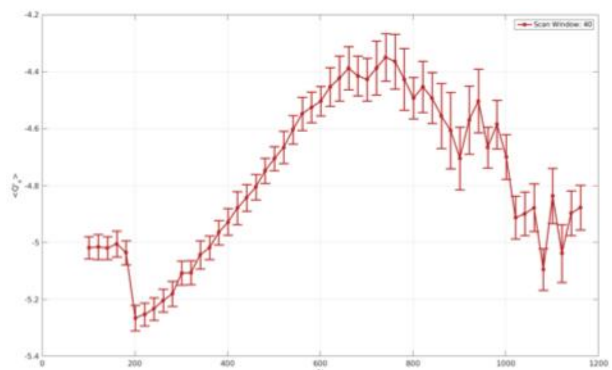






P. Zisopoulos

- **Modulation of the chromaticity** observed as well

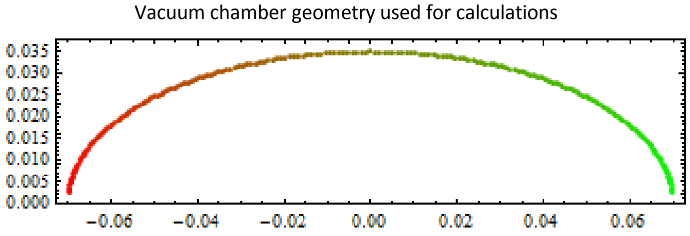


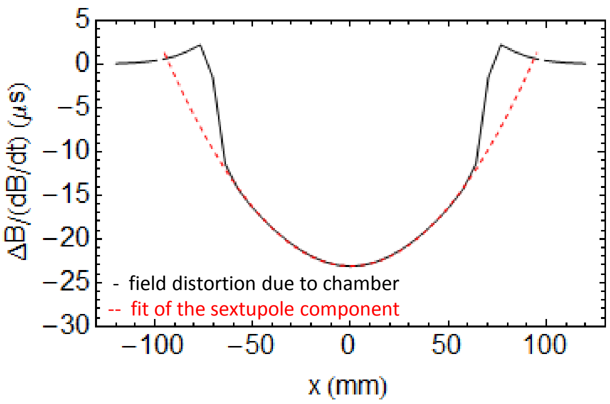
[1] P. Zisopoulos et al., "Fast bunch by bunch tune measurements at the CERN PS", Proceedings of IPAC 2017, MOPAB122, p. 415-418.

Possible contributions to the blow-up

2. Transient period during the collapse of the injection bump

- Tune modulation appears proportional to derivative of bump amplitude → **Bdot effect**
- Hints at presence of **eddy currents** in the metallic vacuum chambers of the dipole bumper magnets due to fast ramping
- **Analytically estimated** tune shift in the order of **0.01** based on PS vacuum chamber geometry → very good agreement with experimental observations





Acknowledgements to C. Carli

- Important input for **design of new injection** bumper magnets
  - passive eddy current compensation foreseen

Possible contributions to the blow-up

2. Transient period during the collapse of the injection bump – next steps

- **Quantify** contribution of injection bump to horizontal emittance blow-up
- Simulations
  - MAD-X simulations have just started to reproduce effect
  - Subsequently move to PyOrbit to study single particle and space charge effects
- Experimental
  - Beta-beat measurements during the bump (challenging due to time scale)
  - Improvement of the model
  - Benchmarking of the simulation results

3. Uncertainties on the emittance measurements

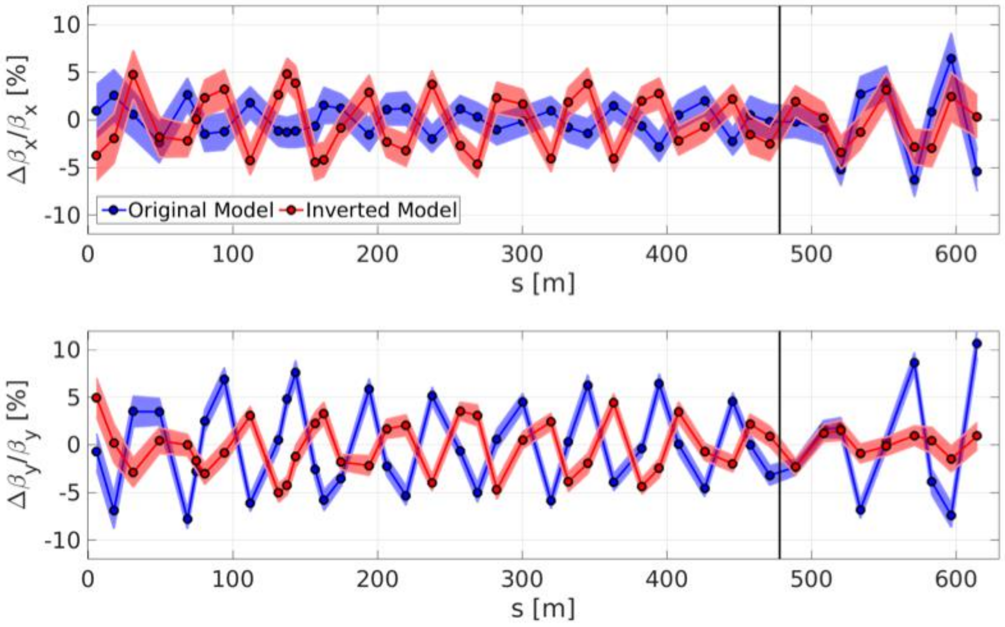
- Discrepancies already between PSB WS and SEM grids in TFL
- Can we quantify the expected **error between machines** (cross calibration,…) for similar instrumentation?
- Large **dispersive contribution** to the beam size – deconvolution vs. conventional approach
- Improved **knowledge of the optics** at the instrumentation in the ring

Possible contributions to the blow-up

3. Uncertainties on the emittance measurements

- Improved knowledge of the optics at the instrumentation in the ring
- **Beta-beating measurements** based on phase advance (**± 5%** peak-to-peak)

Inverted model to be considered only

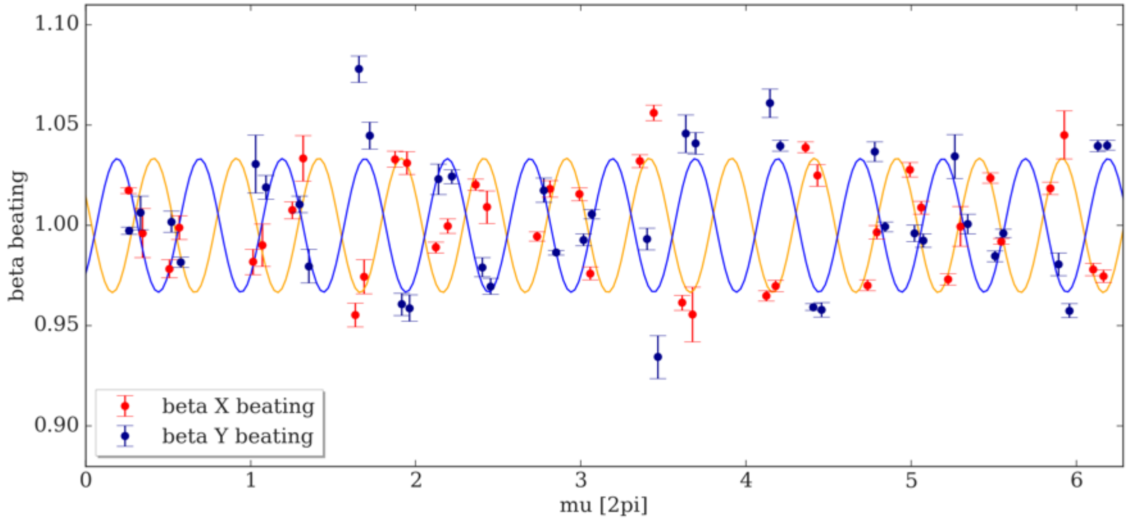


P. Zisopoulos, A. Wegscheider

Possible contributions to the blow-up

3. Uncertainties on the emittance measurements

- Improved knowledge of the optics at the instrumentation in the ring
- Beta-beating measurements based on phase advance (± 5% peak-to-peak)
- Beta-beating measurements using **k-modulation** leading to similar order of magnitude



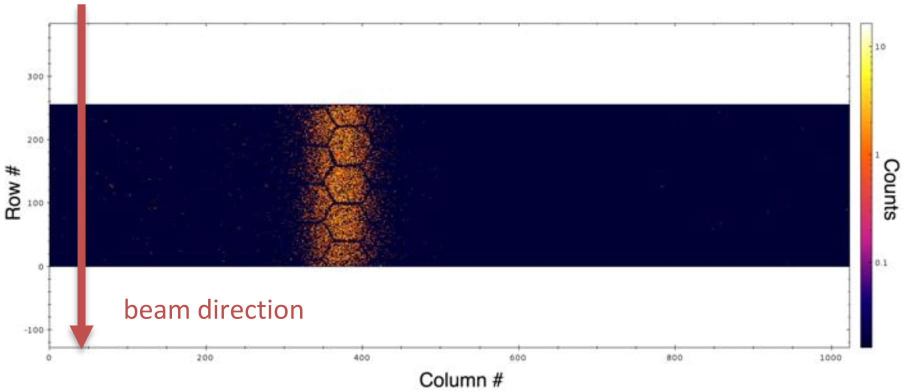
F. Tecker

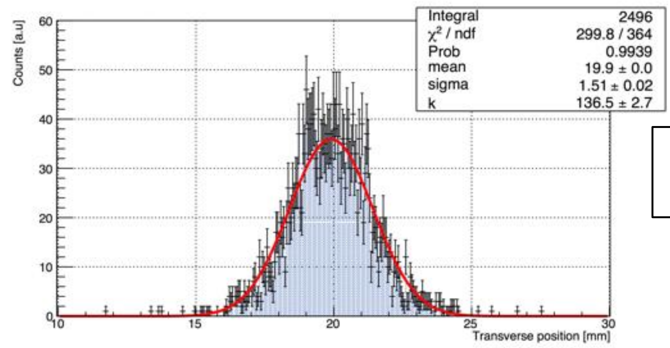
- Experimental studies to be continued this year

Possible contributions to the blow-up

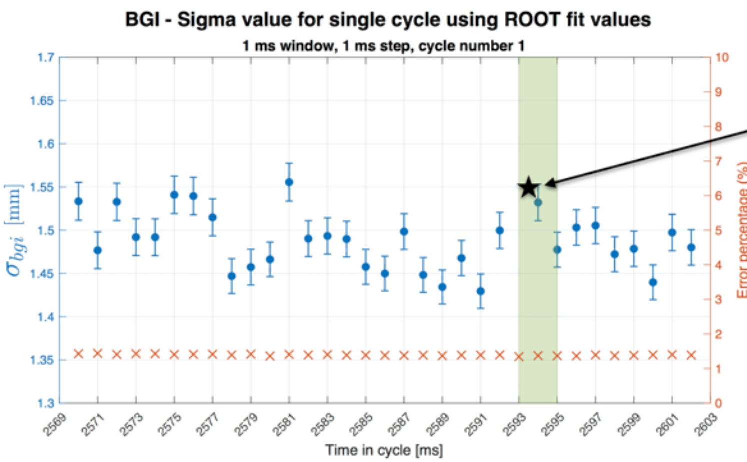
3. Uncertainties on the emittance measurements

- **BGI as independent tool** to verify WS measurements
- Commissioned the magnet, added second power supply to compensate residual dipolar kick
- Multiple studies with beam to commission the detector and compare with WS measurements





J. Storey, S. Levasseur, H. Sandberg

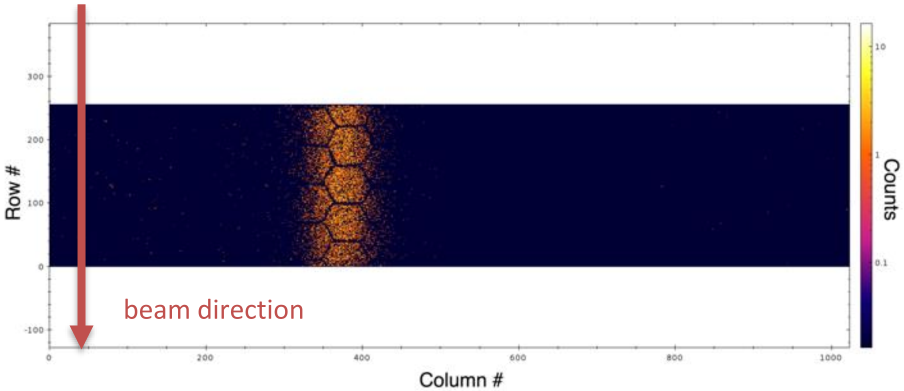


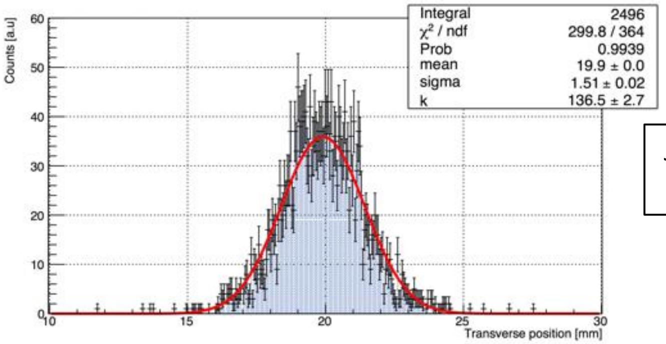
Good agreement with beam size taken from WS logs analysis.

Possible contributions to the blow-up

3. Uncertainties on the emittance measurements

- BGI as independent tool to verify WS measurements
- Commissioned the magnet, added second power supply to compensate residual dipolar kick
- Multiple studies with beam to commission the detector and compare with WS measurements





J. Storey, S. Levasseur, H. Sandberg

- Additional **systematic comparison** to be performed in 2018 (profiting from repaired chip #3)
- BGI has potential to provide insight on **time scale of injection blow-up**

Possible contributions to the blow-up

3. Uncertainties on the emittance measurements

- Turn-by-turn instrumentation:
  - Counting on support by BE-BI for availability of **turn-by-turn SEM grid** after TS1
  - Investigations ongoing concerning the potential use of the **quadrupolar PU**

4. Impact of additional parameters such as RF settings, …

Towards operation with large longitudinal emittance

- **Allow for more flexibility in terms of PS working point control by reducing the chromatic tune spread**

- **This implied setup of dedicated cycle with:**
  - Chromaticity correction at low energy with PFW in 3CM
  - Coupling correction
  - TFB all along the low-energy part (beam otherwise lost immediately after injection)

- **Created reference cycle used also for injection studies:**
  - MD1780_LHC25#48B_BCMS_2

- **Side-effect of this study: operational deployment of the TFB on all LHC cycles in August 2017 (non-LHC already before)**
  - Still operating with enhanced coupling to stabilize head-tail instabilities
  - TFB therefore only active to damp injection oscillations

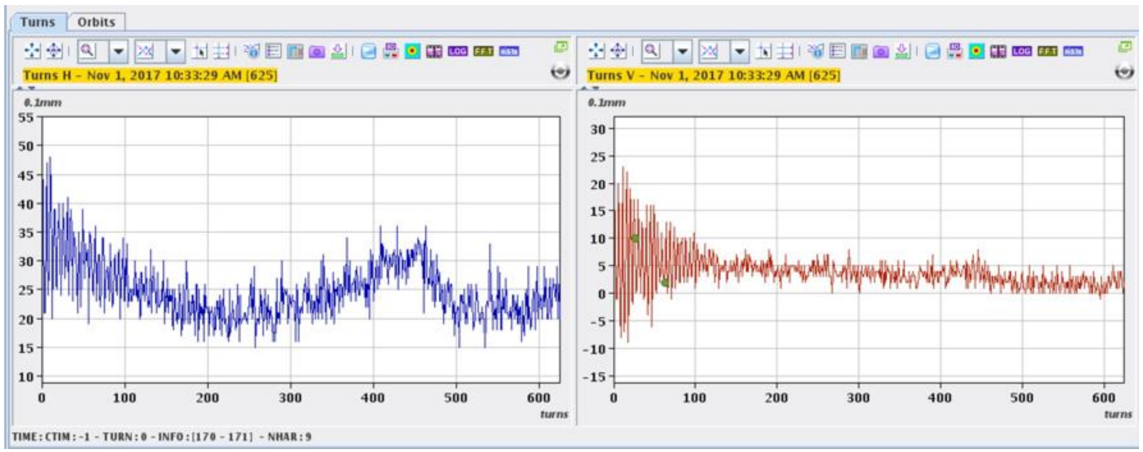
- **Documentation of principle and setup of TFB by M. Coly**
  - OP Shutdown Lecture
  - EDMS 1758969

Operation at low-chromaticity with TFB

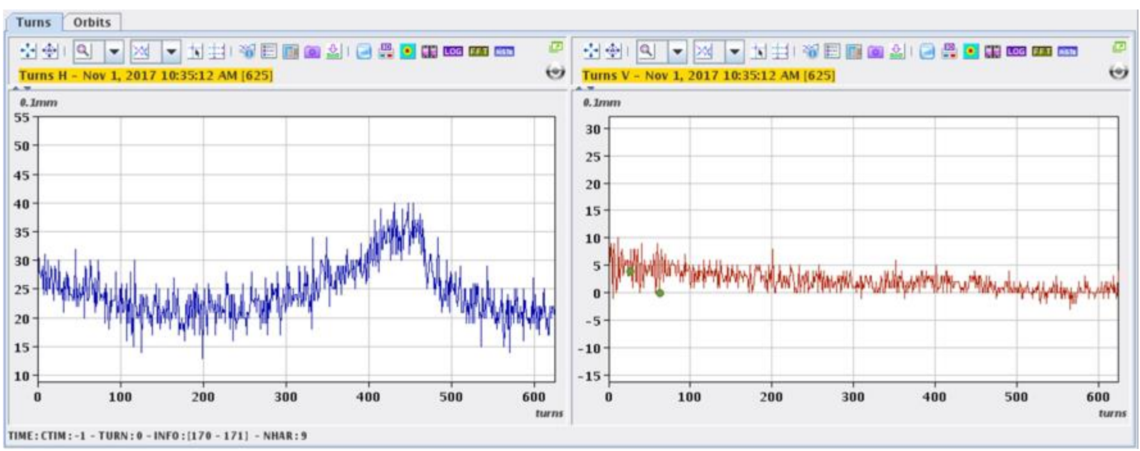
- **Performed comparison between operational (OP) and low-chromaticity (LC) BCMS cycle**
  - Change of chromaticity (configuration prepared by G. Sterbini and M. Serluca in 2016)
    - $Q'_{x,natural} \sim -5 \rightarrow Q' \sim 1$
    - $Q'_{y,natural} \sim -7 \rightarrow Q' \sim -1$
  - Optimized PS injection oscillations for all eight bunches
    - Very tedious manual work
    - Implemented in YASP and to be tested this year
  - Corrected PFW induced tune change with LEQ (Qx = 6.21, Qy = 6.245)
  - Proper tuning of the TFB system
    - Natural chromaticity variant: TFB only active at injection
    - Low-chromaticity variant: TFB also active on injection and intermediate plateau
  - Used wire scanners: 65H, 85V to compare emittances

Correction of injection oscillations

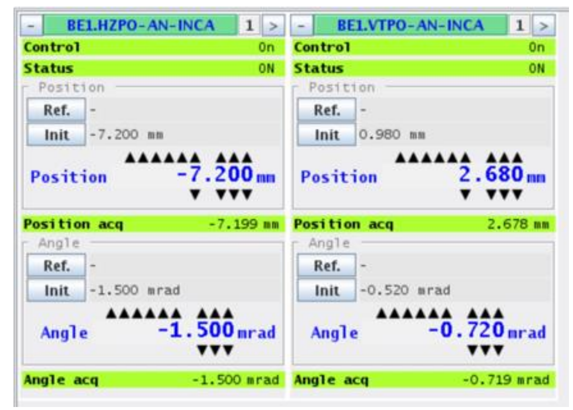
initial



corrected

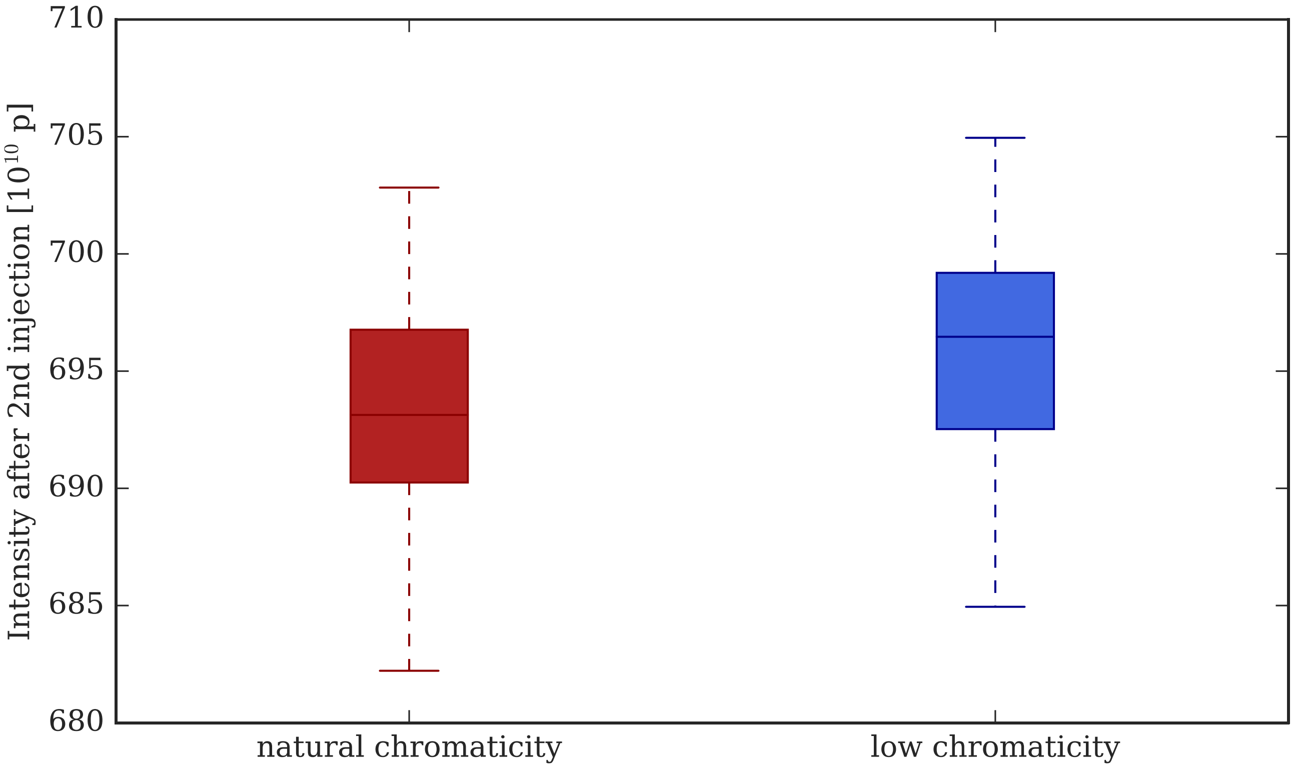


- Tedious manual work to adjust individual bunch trajectories
- 1 mm peak-to-peak in general reachable
- Knobs at PSB extraction have to be trimmed to achieve ring-by-ring correction

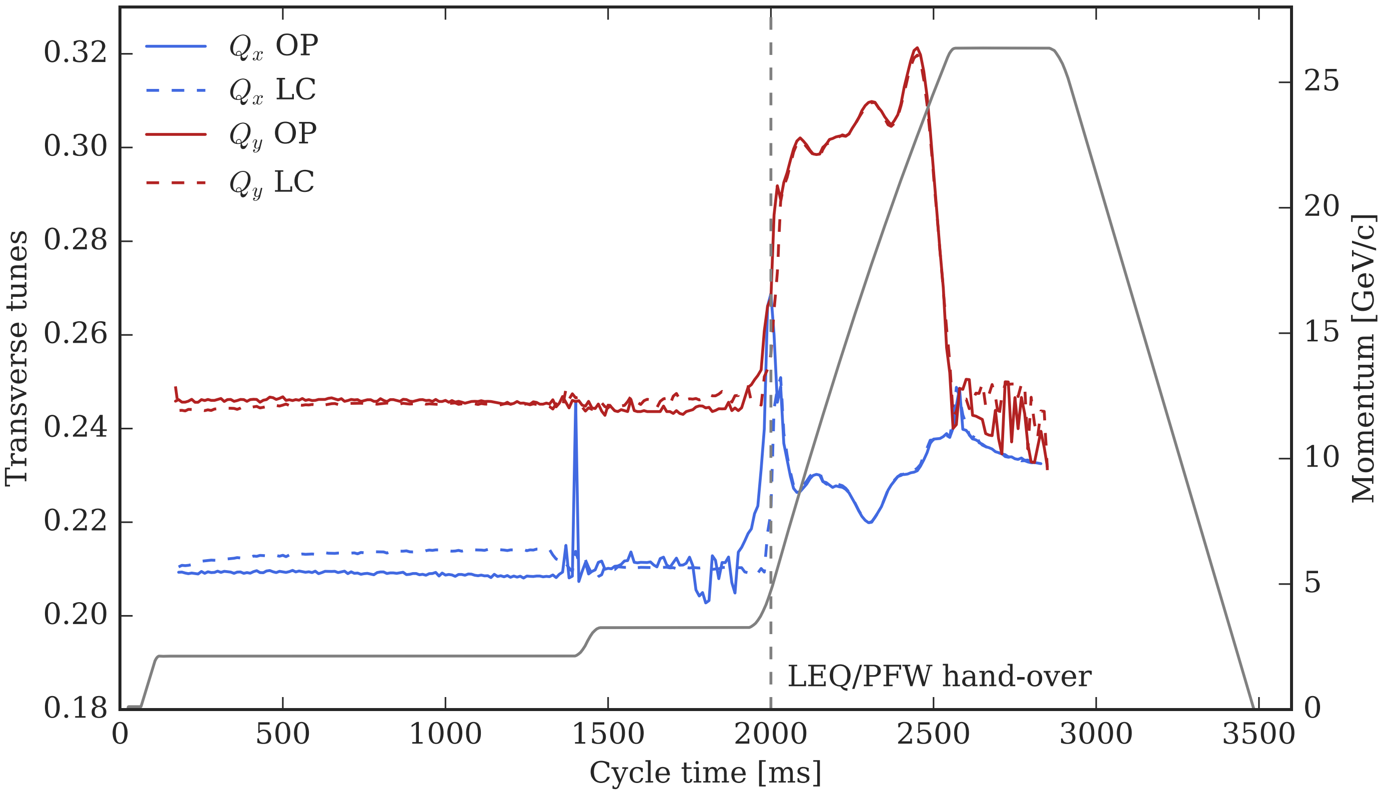


- **New YASP configuration** should also allow this in the future

Intensity comparison between two setups



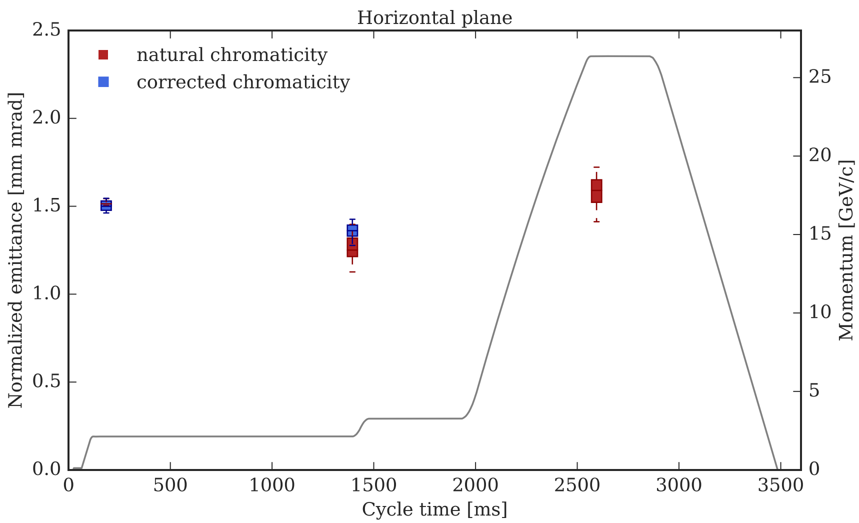
Tunes along the cycle

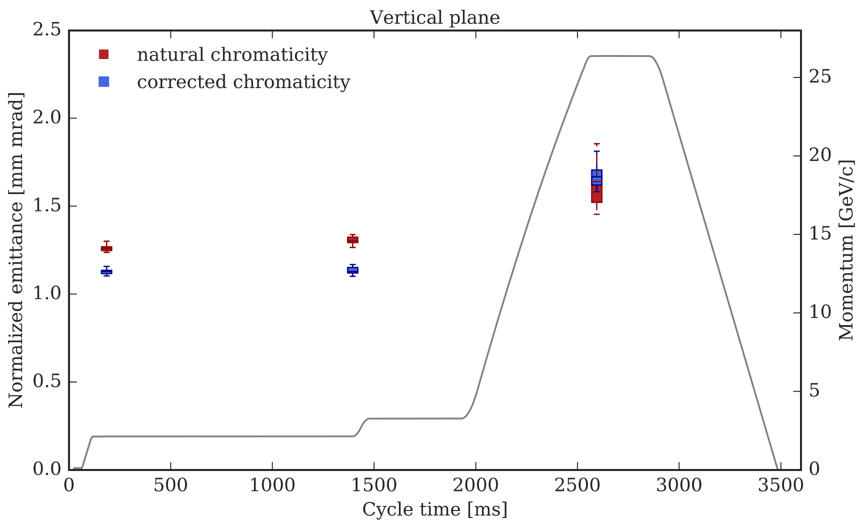


- Tune control important to ensure proper functioning of the TFB
- Tune correction with LEQ in LSA (Auto-Q)
- Hand-over between LEQ and PFW tricky and certainly to be optimized
- Focused rather on the low-energy part

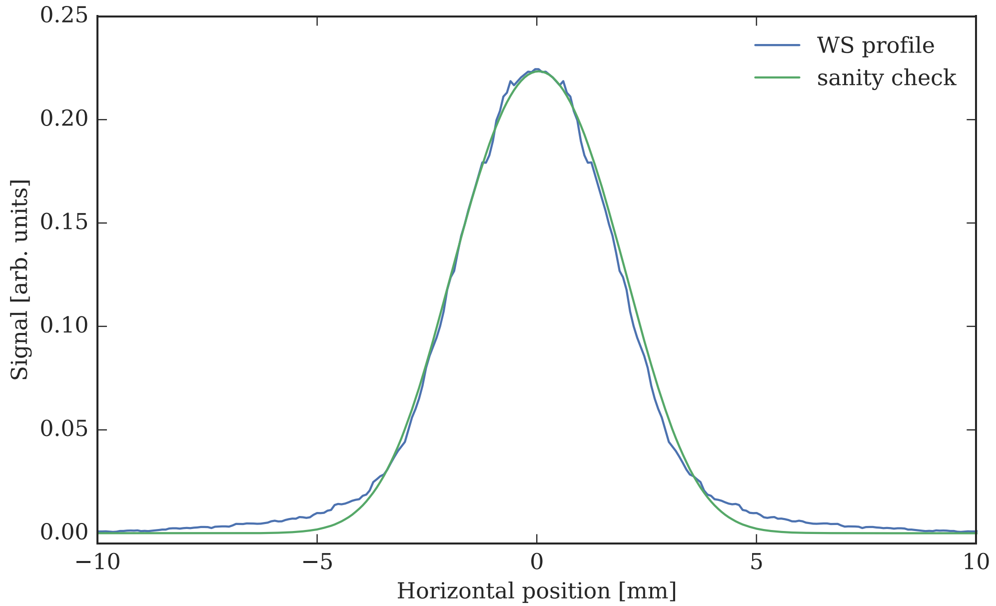
Emittance comparison

- **Important result: emittances can be preserved using this configuration**
  - Equivalent results in the horizontal plane, vertical emittances reduced by ~10% on the low-chromaticity cycle
  - Dispersive contribution removed by deconvolution
  - Horizontal emittance blow-up between PSB and PS still 30-40%
  - Vertical blow-up measured at the flat top (also for the operational beam) → to be addressed next





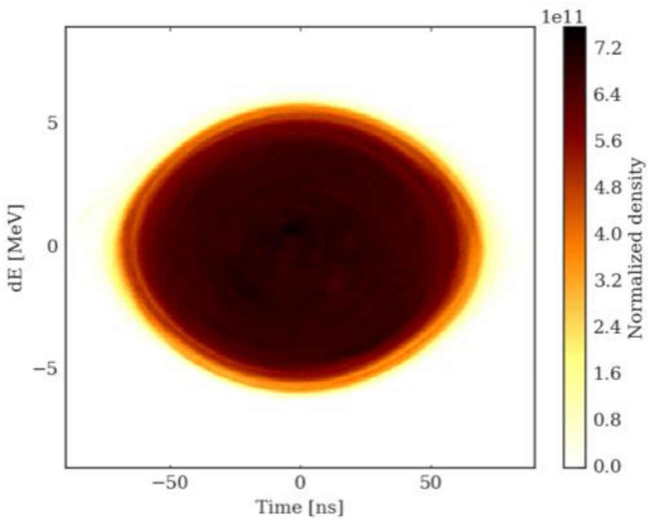
Emittance measurements at top energy

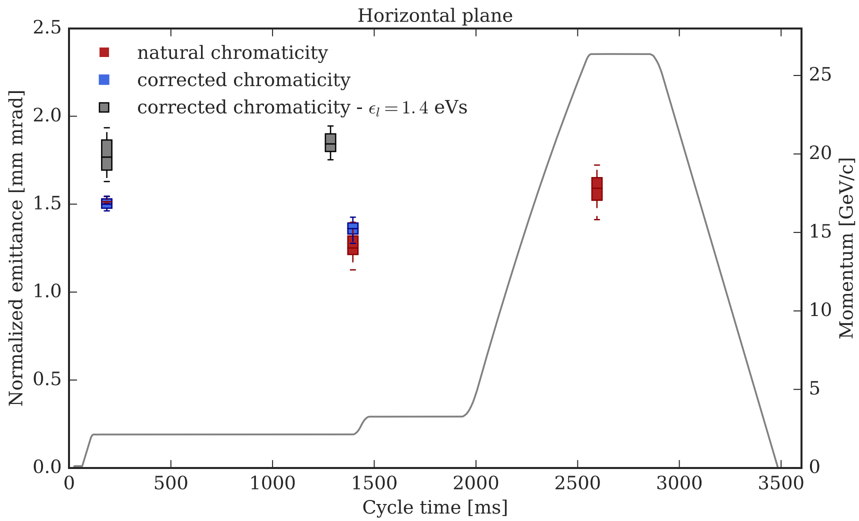


- Rather large tails observed in both planes
- Focus was however on the low-energy part
- High-energy working point to be optimized

Experience with large longitudinal emittance

- **BCMS beams with larger longitudinal emittance (ε_l = 1.4 eVs, dp/p = 1.4x10^{-3}, $\varepsilon_{0,n}$ = 1 um) are subject to more significant blow-up**
  - Measurements reveal blow-up of 60-70%
  - Analytically expected horizontal blow-up for this configuration: 44%





- **Sensitivity of blow-up and initial emittance in the PSB to dp/p needs to be further investigated**

Outlook for 2018

- **Injection bump studies**
  - Experimental
    - Beta-beat measurements during the bump (challenging due to time scale)
    - Improvement of the model
    - Benchmarking of the simulation results
  - Simulations
    - MAD-X simulations have just started to reproduce effect
    - Subsequently move to PyOrbit to study single particle and space charge effects

- **Continuation of:**
  - beta-beat measurements in the ring
  - BGI commissioning with beam

- **Studies with low-chromaticity cycle**
  - Emittance comparison by measuring at the same time in the PSB to quantify blow-up more exactly
  - Optimization of the high-energy part of the cycle
  - Sensitivity of blow-up to momentum spread
  - Chromaticity correction with sextupoles instead of PFW