Transverse optimization of LHC beams in the PS

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Outline

- **BCMS operation at low-chromaticity relying on the TFB**

- **Transverse optimization of high-intensity (LIU-like) LHC beams**

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- **BCMS operation at low-chromaticity relying on the TFB**

- **Transverse optimization of high-intensity (LIU-like) LHC beams**

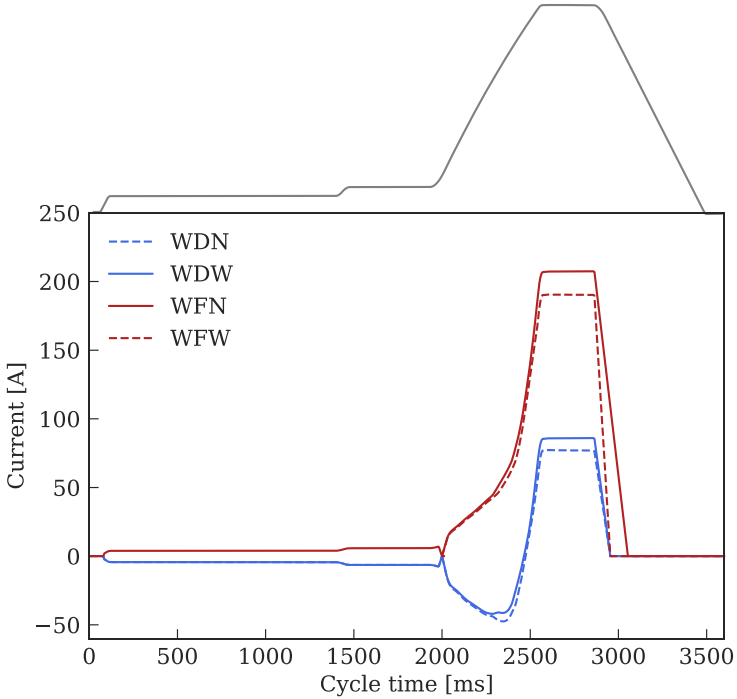
Motivation

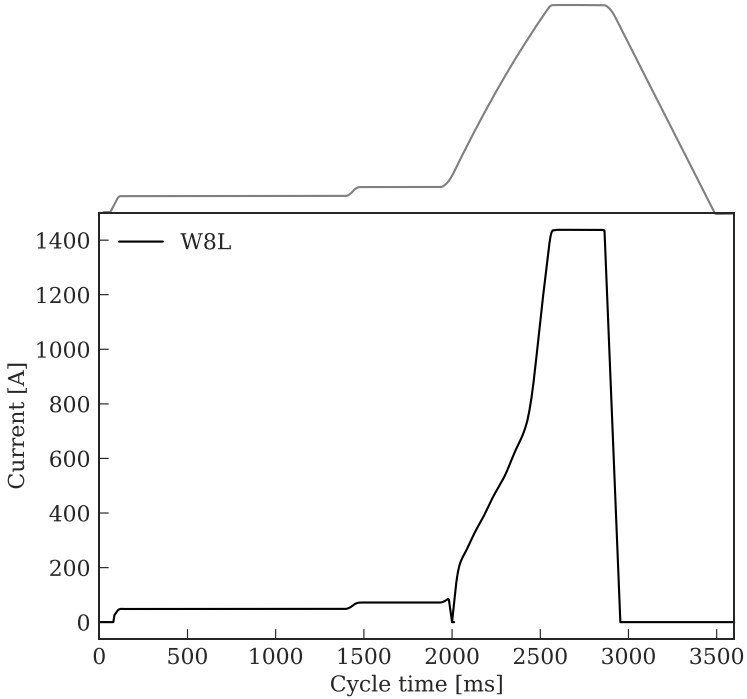
- **LIU baseline crucially relies on bunches with large longitudinal emittance at PS injection**
  - Decreased maximum space charge tune shift for identical beam parameters as today
  - Increased chromatic tune spread due to large natural chromaticity
- **To correct the large chromatic tune spread operation at ideally zero chromaticity on the injection flat bottom has been envisaged**
- **This furthermore requires to uncouple the machine and stabilise the beam with the TFB on the flat bottom against head-tail instabilities**

Chromaticity correction

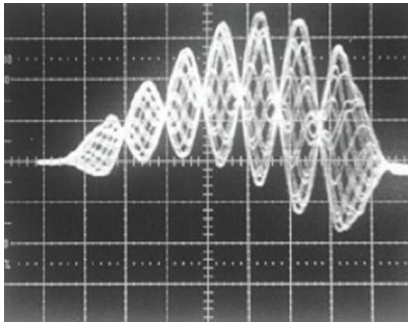
- **Historically the PFW have been used to correct chromaticity at high-energy**
  - From negative values (natural chromaticity $Q_x' = -5$, $Q_y' = -7$) before transition energy
  - To slightly positive values ($Q_{x,y}' \approx 1$) after transition crossing
  - Correction is nowadays performed in 5CM

- **Correction at low-energy**
  - Performed in 3CM to maintain linearity of the machine
  - Therefore less controllable parameters → zero chromaticity not achievable

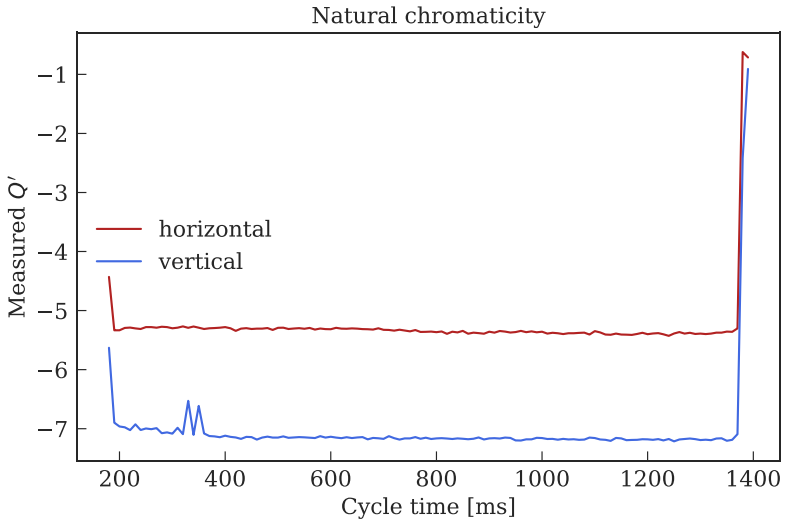


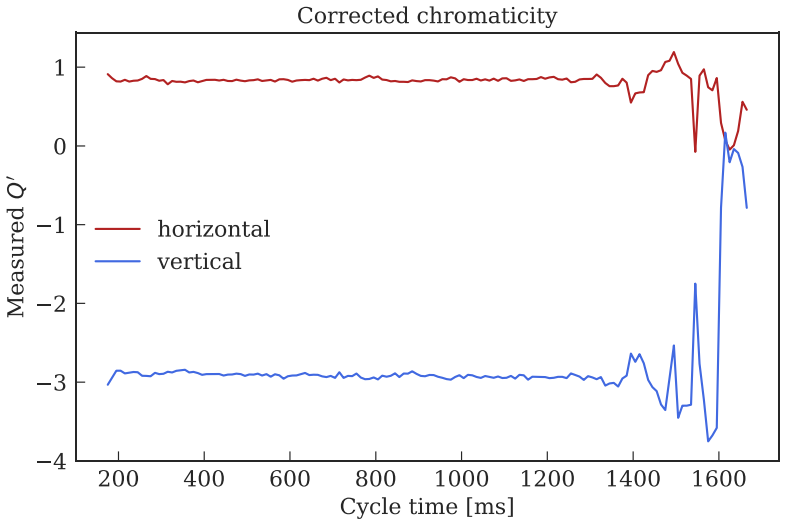


Chromaticity correction



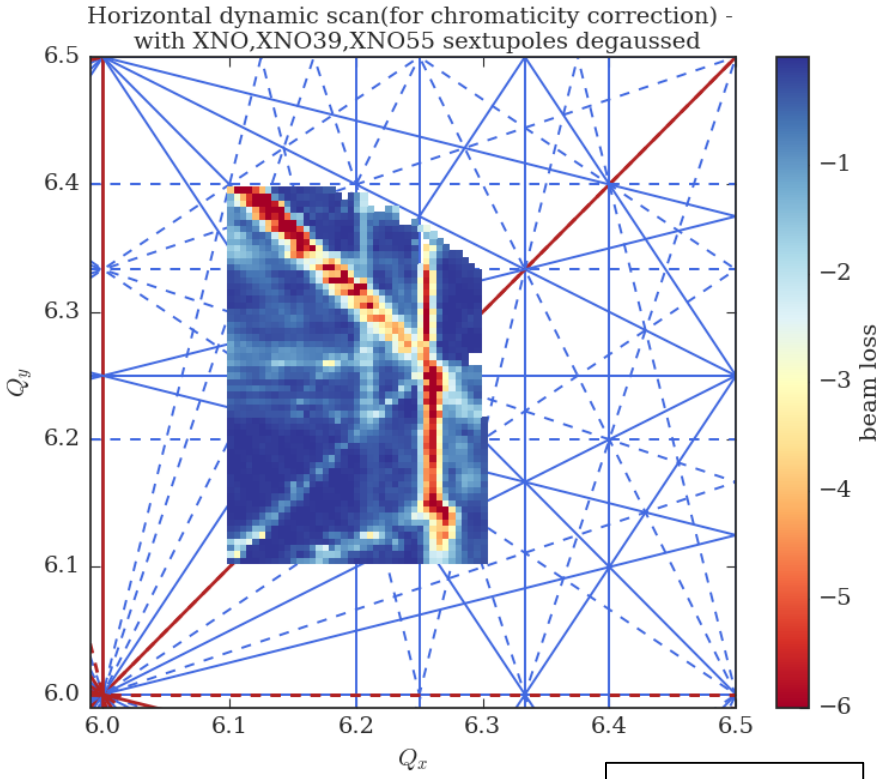
- **Head-tail instabilities only occurring in the horizontal plane**
  - Focus on horizontal chromaticity reduction
  - Nevertheless significant vertical reduction achieved as well
- **Current setup leads to an even slightly positive horizontal chromaticity**
  - Extremely unstable system
  - TFB indispensable for operation under these circumstances





Attempt to use new sextupoles for chromaticity correction

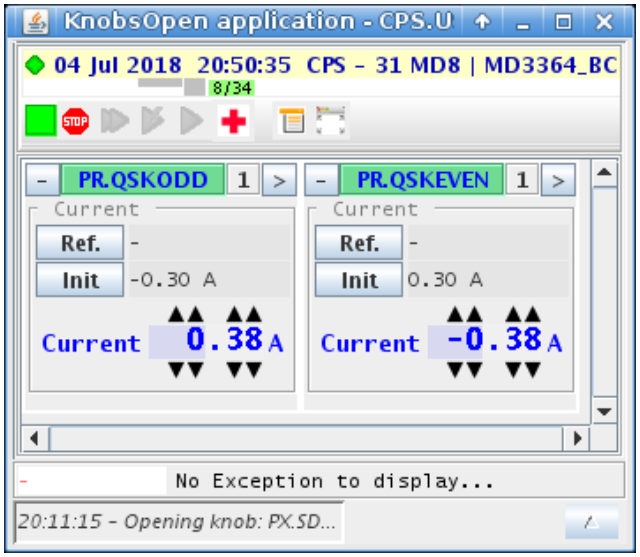
- **A pair of sextupoles has recently been installed in SS60 and SS94**
  - SSs with large vertical β-function
  - Both magnets powered in series
- **Chromaticity correction in both planes in principle achievable using also MTE sextupoles in SS39 and SS55**
  - SSs with large horizontal β-function
  - Independently powered elements
- **Tune diagram measurements showed very strong resonance excitation**
  - Result shown for only ¼ of the required correction
- **Unacceptably high losses on the operational BCMS beam using XNO****



M. Kaitatzi

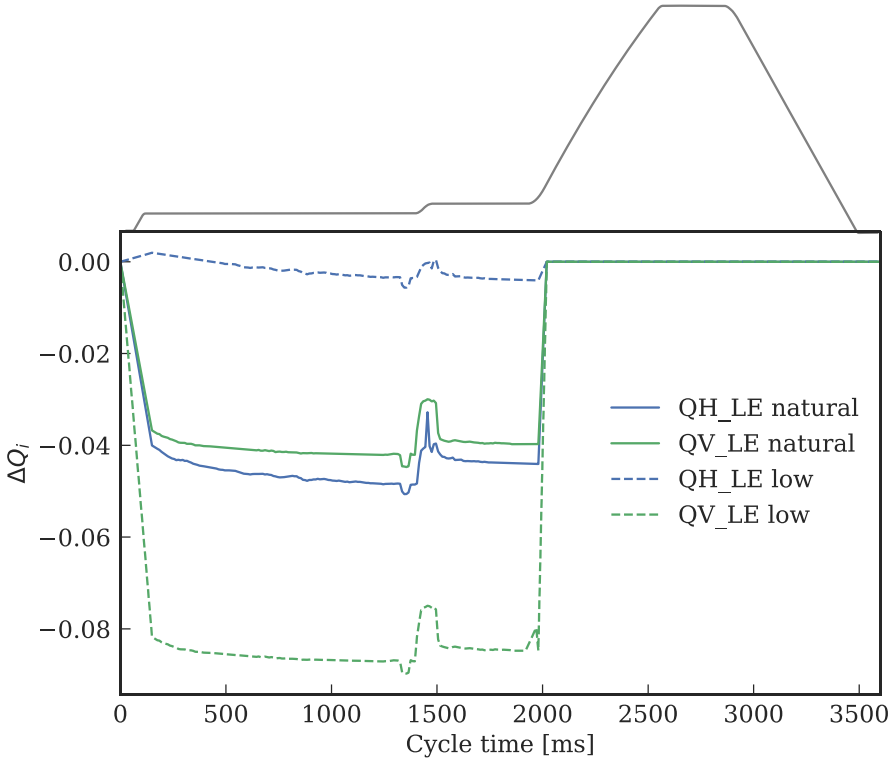
Skew quadrupole settings

- **Globally decoupling the machine with skew quadrupoles based on closest tune approach**
- **Recent optics studies confirm that such a global correction also works well locally**
- **Previous operational skew settings**
  - PR.QSKODD = -0.30 A
  - PR.QSKEVEN = 0.30 A
- **Settings to decouple the lattice**



Tune correction

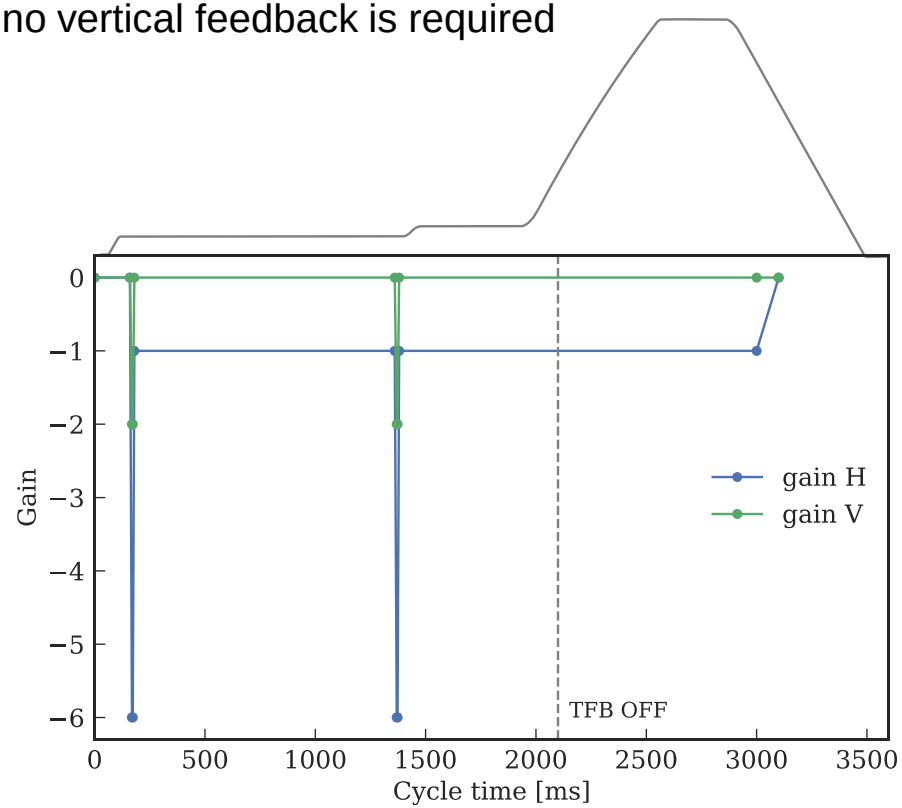
- **Stable horizontal tune along the low-energy plateaus advisable to simplify TFB operation**
- **Using the PFW at low-energy requires an additional iteration on the tune correction**



TFB settings

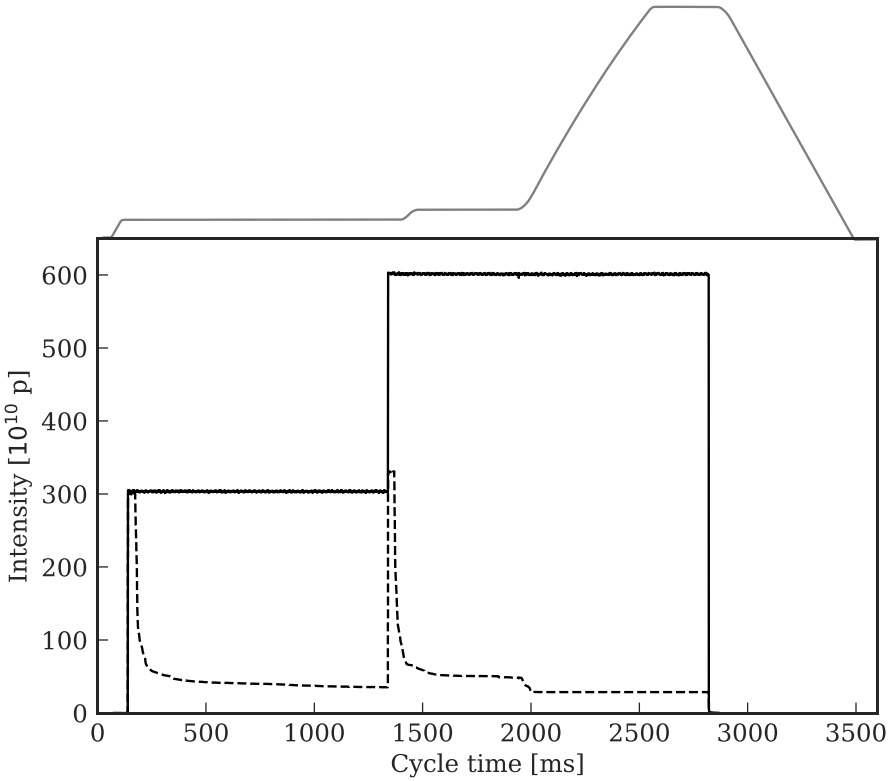
- **Stable tune allows the frequency of the TFB to be controlled by knob rather than function**

- **Only the gain is controlled by function**
  - High gain to damp injection oscillations
  - Lower horizontal gain in-between and after injections to act against instabilities
  - Apart from injection no vertical feedback is required



Beam loss along the cycle

- **With proper functioning TFB beam loss is identical (negligible) to previous operational setup**
- **Failure of the TFB system however rapidly leads to almost complete beam loss**



Conclusion and outlook

- **New transverse beam control used since LHC fill 7123**
- **TFB system is crucial for this new beam production scheme**
  - Performance has been very reliable so far
- **Important step towards the LIU era for LHC beams in the PS**
- **Emittance measurements with WS indicate slightly smaller (≈ 10%) emittances in the PS**
  - Measurements in the SPS and LHC show comparable results to previous operational cycle
  - No clear evidence of gain in luminosity in the LHC
  - To be further analysed during LS2 with larger statistics
- **Further steps to be performed:**
  - Approaching zero chromaticity with PFW in 3CM or 5CM
  - Implementation on the LHC standard beams

Outline

- BCMS operation at low-chromaticity relying on the TFB

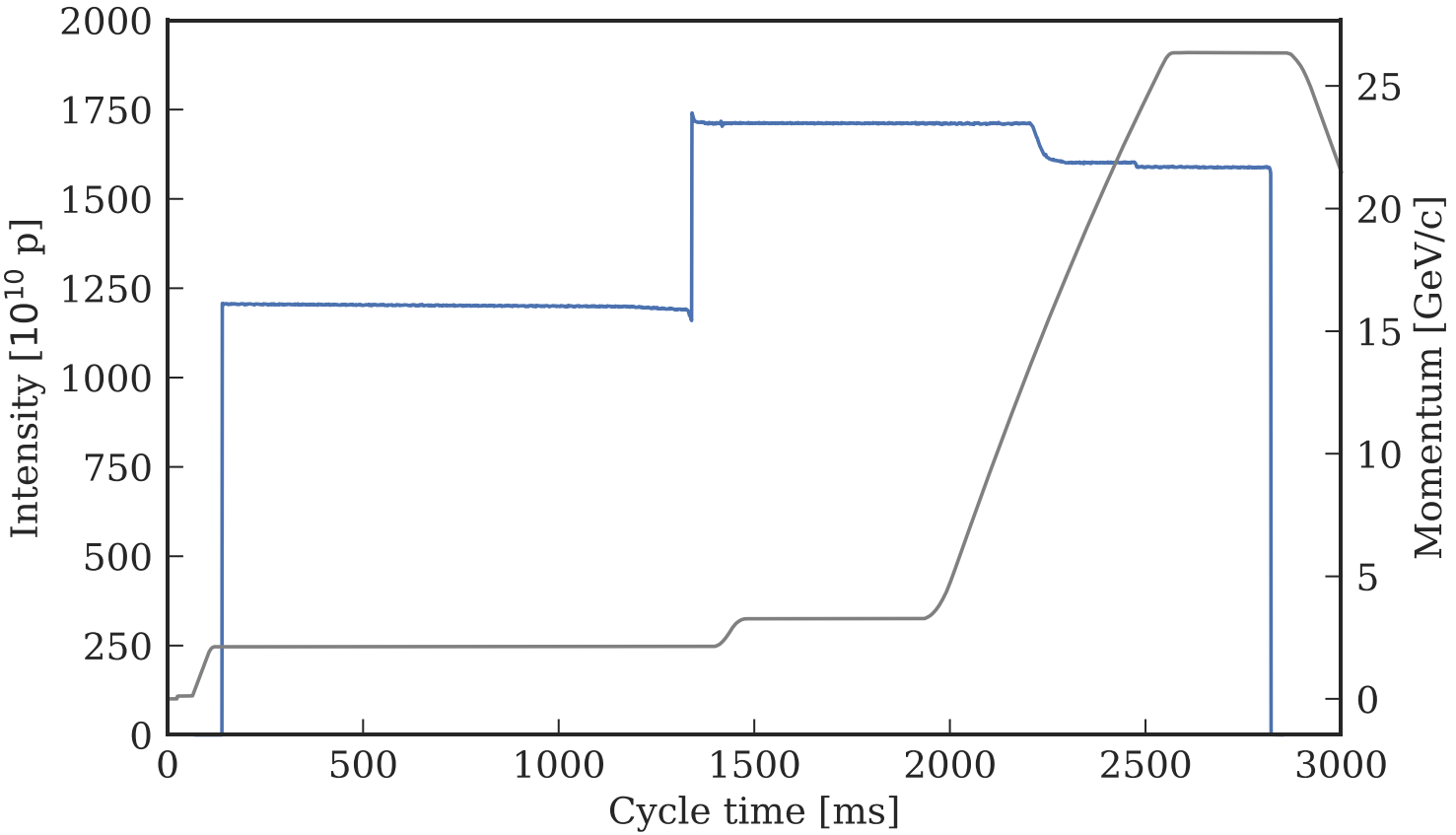
- **Transverse optimization of high-intensity (LIU-like) LHC beams**

Motivation

- **Recent weeks have seen significant progress in the setup of high-intensity LHC-type beams**
  - Intensity of 2.6 x 10^{11} ppb at PS extraction seems within reach
  - All presently available RF upgrades in place:
    - Finemet coupled-bunch feedback
    - Multi-harmonic feedbacks for the high-frequency cavities
    - One 40 MHz system as Landau cavity starting ~ 170 ms after transition
- **During the push to LIU intensities additional losses on the flat bottom and during acceleration appeared**
  - These losses seemed to be rather transverse than longitudinal
  - Investigations were started to allow unperturbed setup of the HI beams

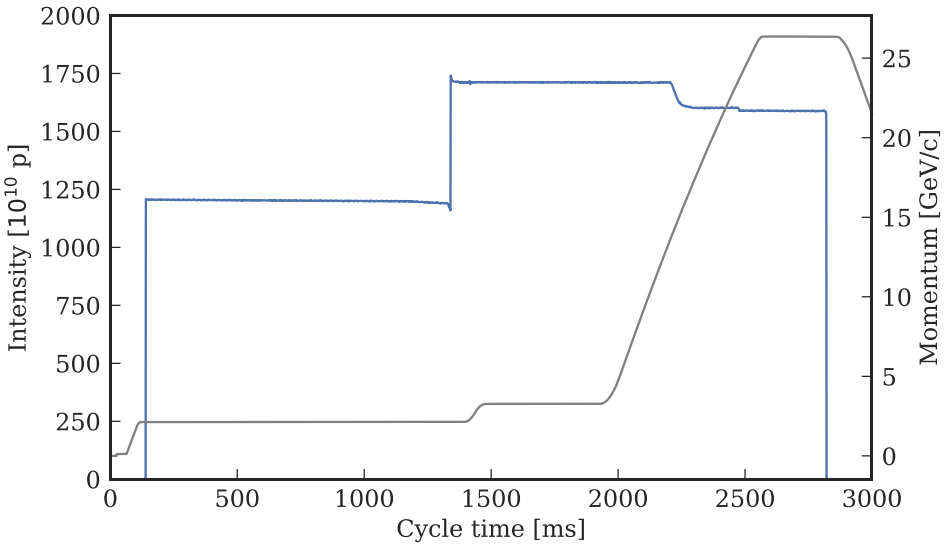
Observed loss pattern

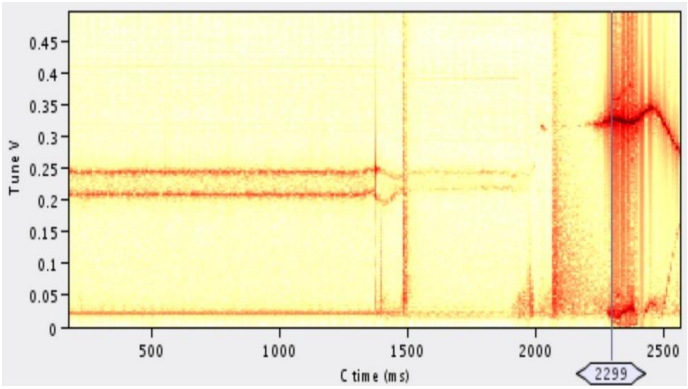
- **Losses mainly observed at two instances in the cycle**
  - At the second injection
  - After transition crossing during the ramp
  - Occasionally also after the first injection on the flat bottom



Losses during the ramp

- **Identified a vertical instability appearing after transition crossing**

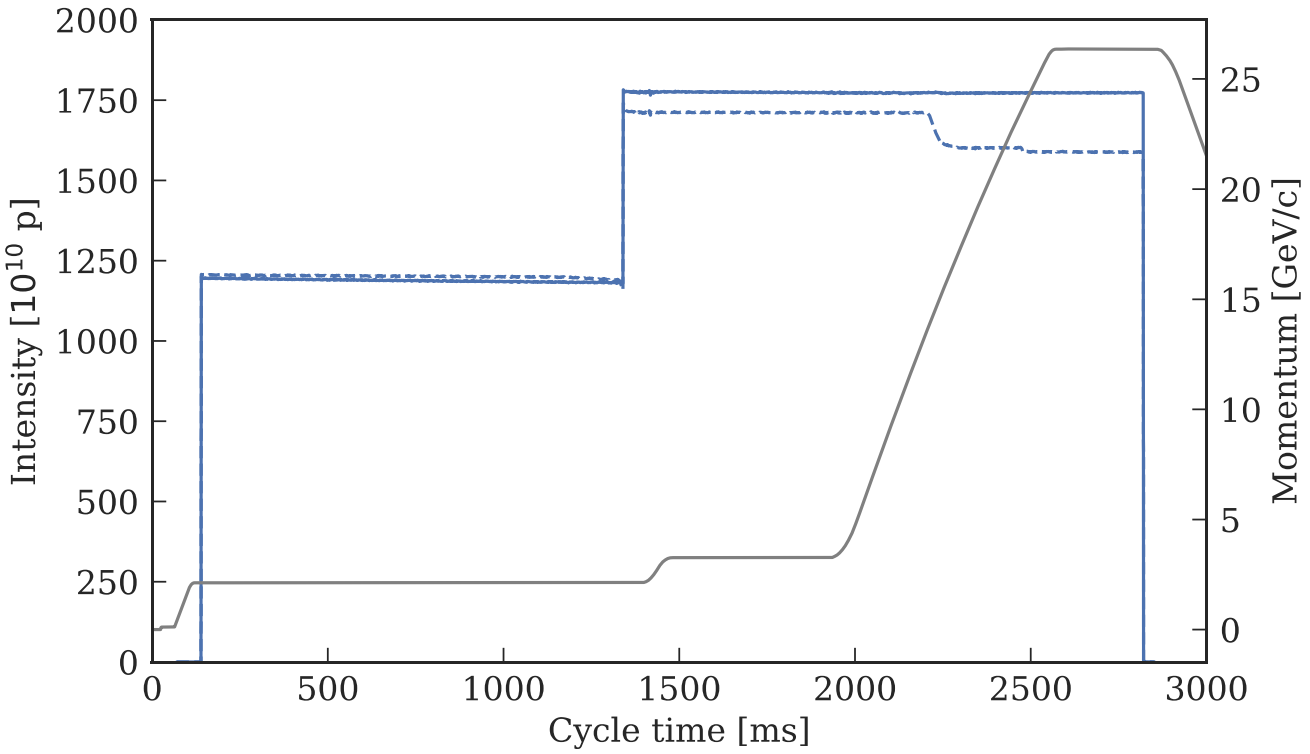




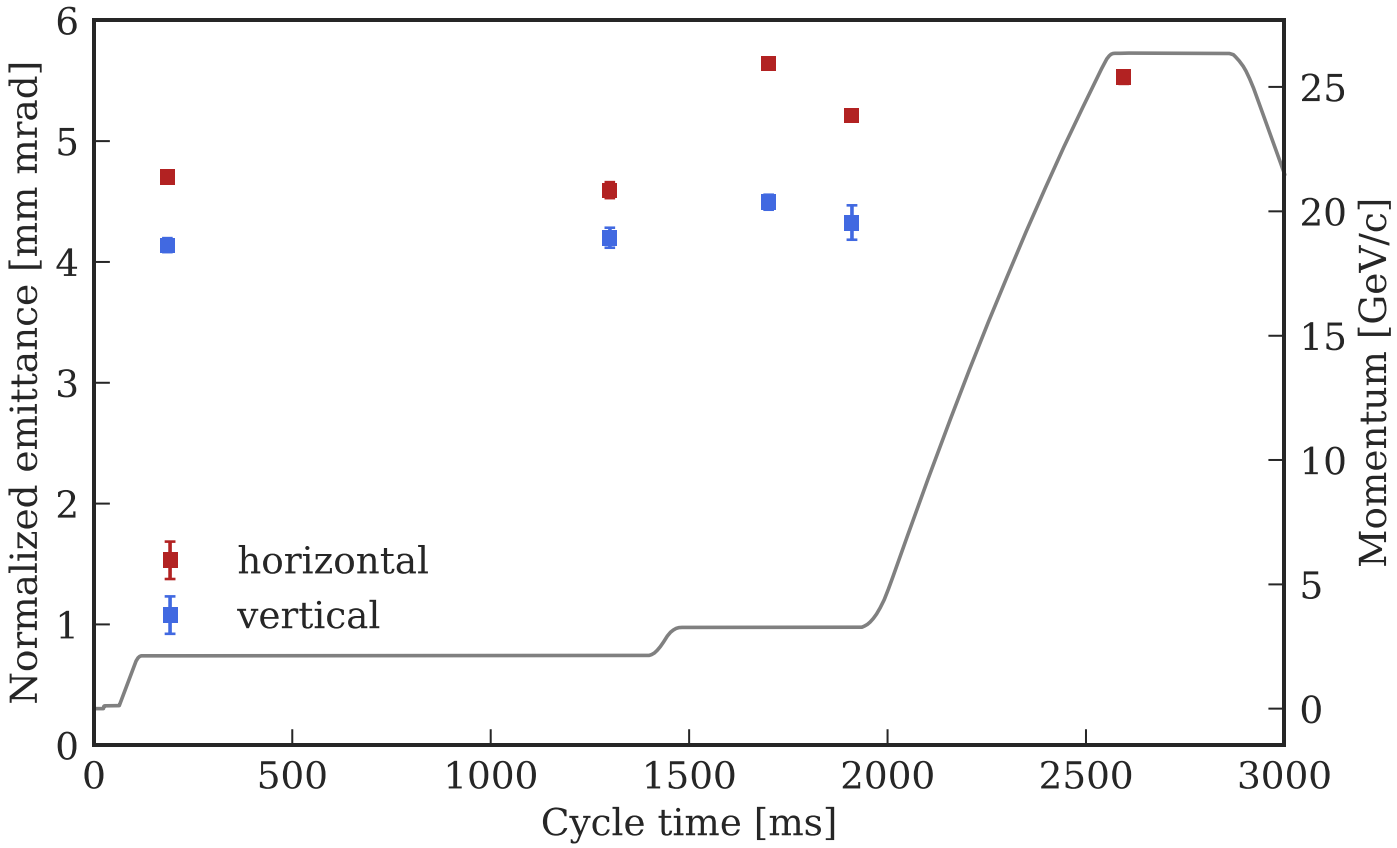
Implemented modifications

- **Transverse tune** optimization along the flat bottom
- Adjustment of the **TFB gain** settings according to increased intensity
- **Vertical chromaticity** increased by $\Delta Q'_y \approx 1$ during the ramp

- **Beam loss well within the allowed 5% budget at 2.6 x 10^{10} ppb**

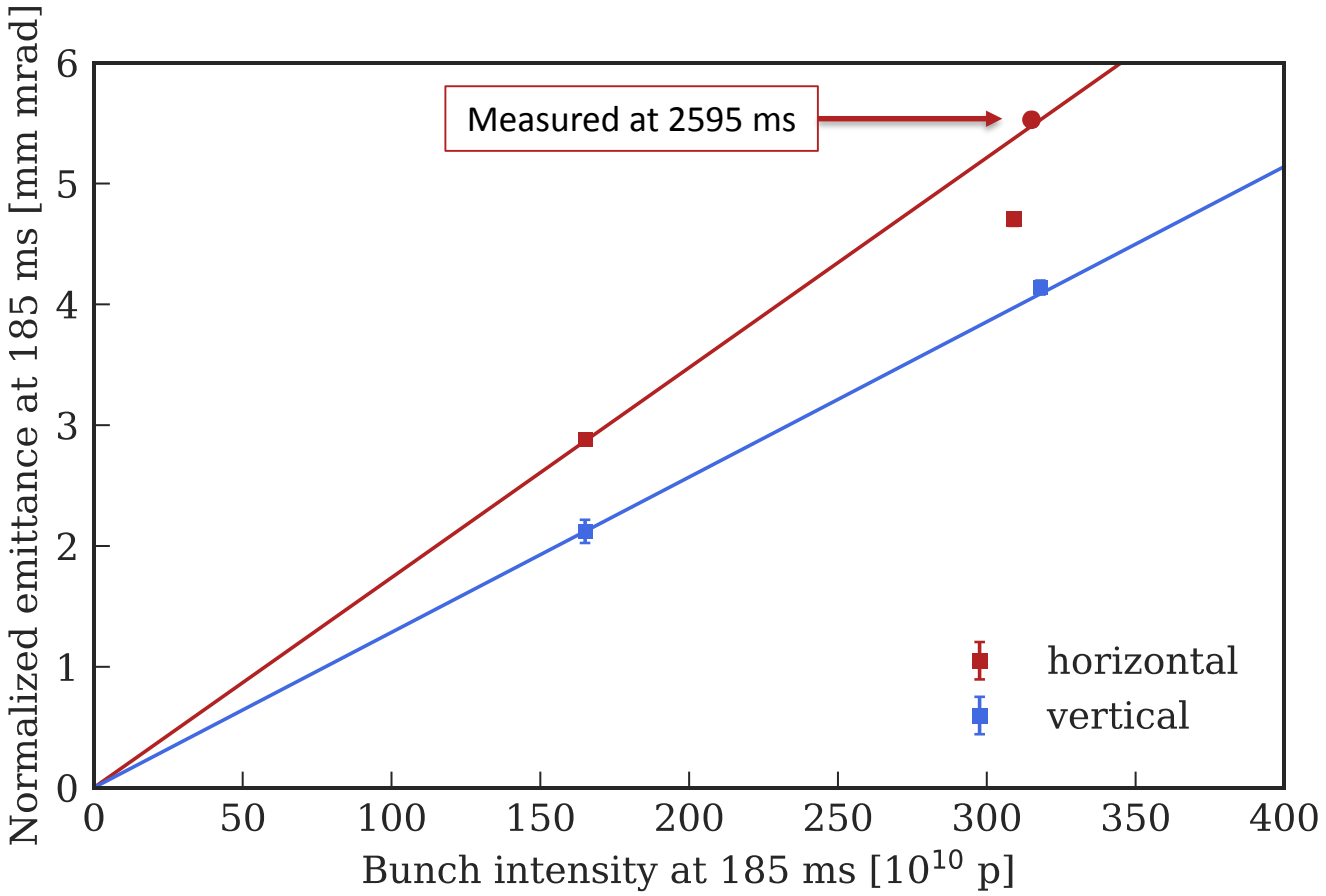


Transverse emittance evolution – Standard 25 ns



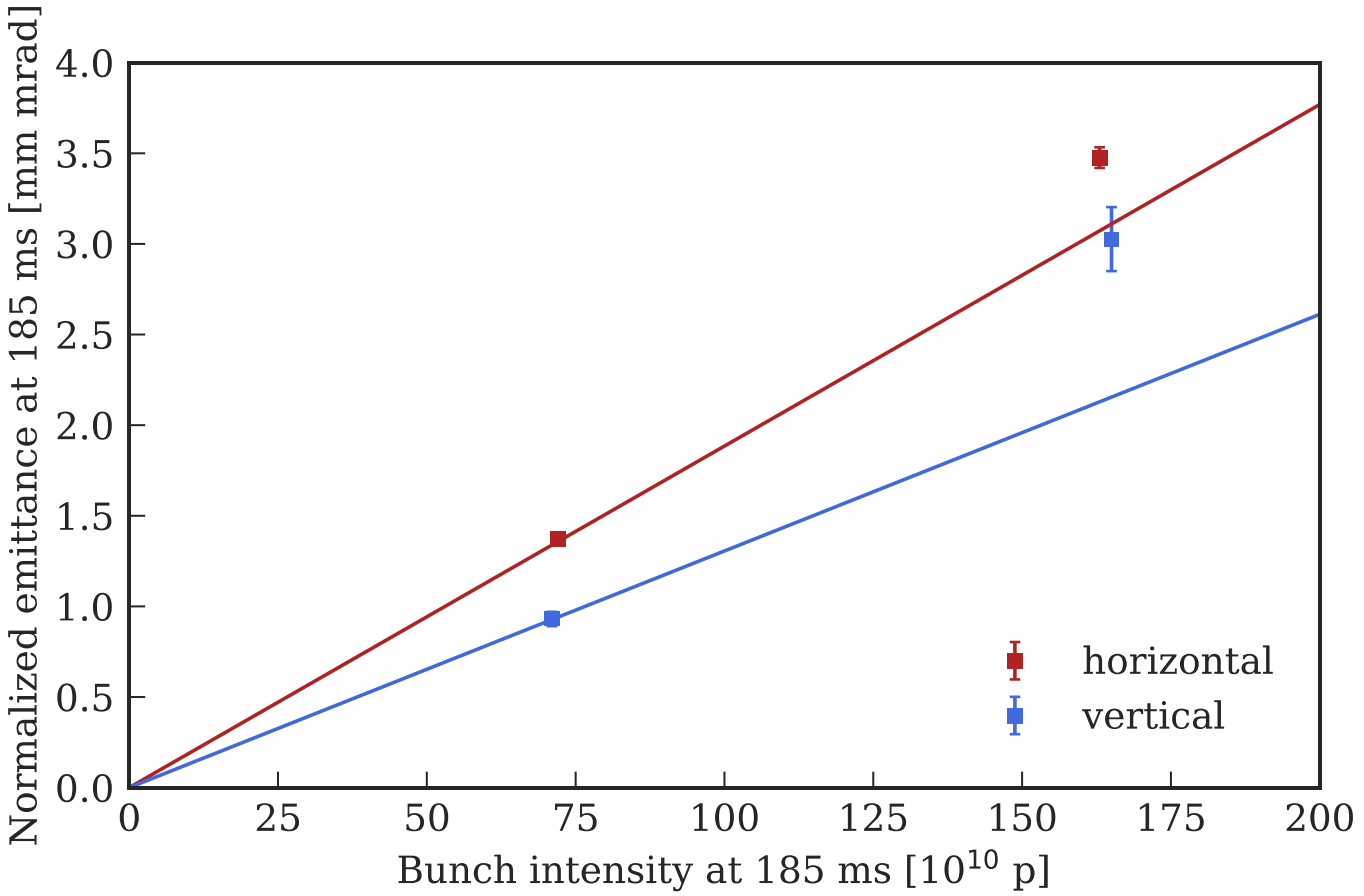
Brightness curve – Standard 25 ns

- **Small horizontal blow-up along the cycle, but overall on the brightness curve**



Brightness curve – BCMS 25 ns

- **Blow-up along the cycle in both planes, but especially vertical**



Conclusion and outlook

- **Improved stability of the HI LHC-type beams by optimization of the transverse setup**
  - Vertical instability in the beginning of the year also seen on the operational LHC cycles
- **Enabled systematic longitudinal studies under reproducible conditions**
  - Longitudinal LIU beam parameters seem to be well within reach
- **HI cycles not yet operating at low-chromaticity**
  - Future optimization to be performed

LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!