Coherent tune shifts from coupled-bunch simulations for SPS and LHC

L. Mether

G. Iadarola, H. Bartosik, G. Rumolo, C. Zannini

e-cloud meeting
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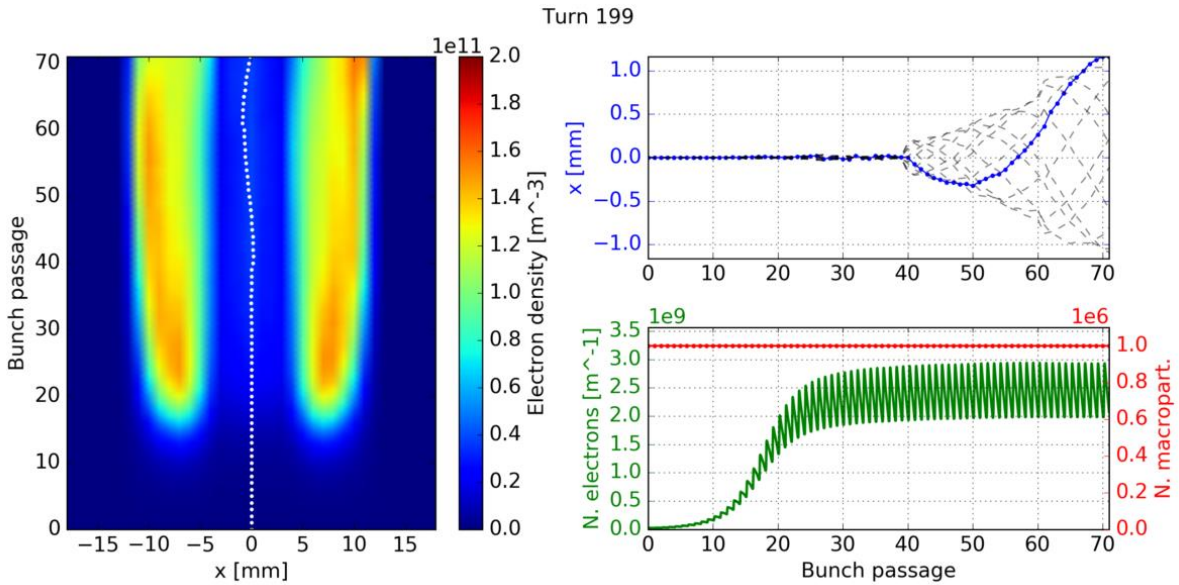
Introduction

- In 2018, the PyECLOUD-PyHEADTAIL suite and its PyPARIS parallelization layer were extended to exploit HPC clusters to perform coupled-bunch e-cloud simulations
  - *G. Iadarola, LMC, Nov 2018*

- Last year the first comprehensive simulation studies with the new tool were done, investigating coupled-bunch instabilities in the LHC and the PS
  - *LHC: WP2 meeting, Dec 2019*, *PS: HSC meeting, Dec 2019*

- Recently, we have applied the tool to studying the coherent tune shifts from e-cloud in dipoles in the SPS and LHC



Outline

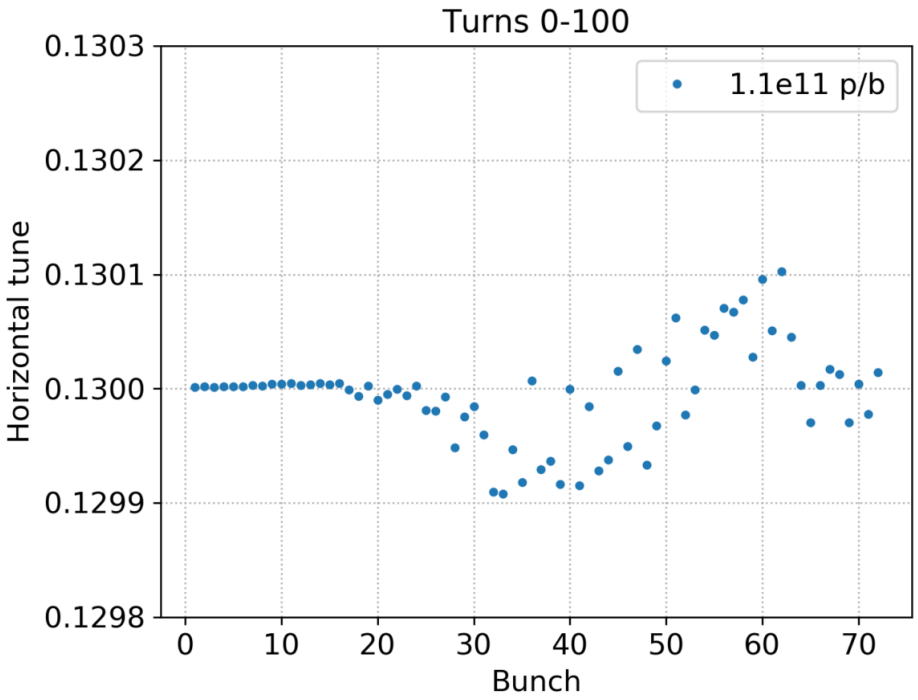
- SPS injection
  - Horizontal and vertical tune shifts
  - Scaling with intensity and comparison to measurements

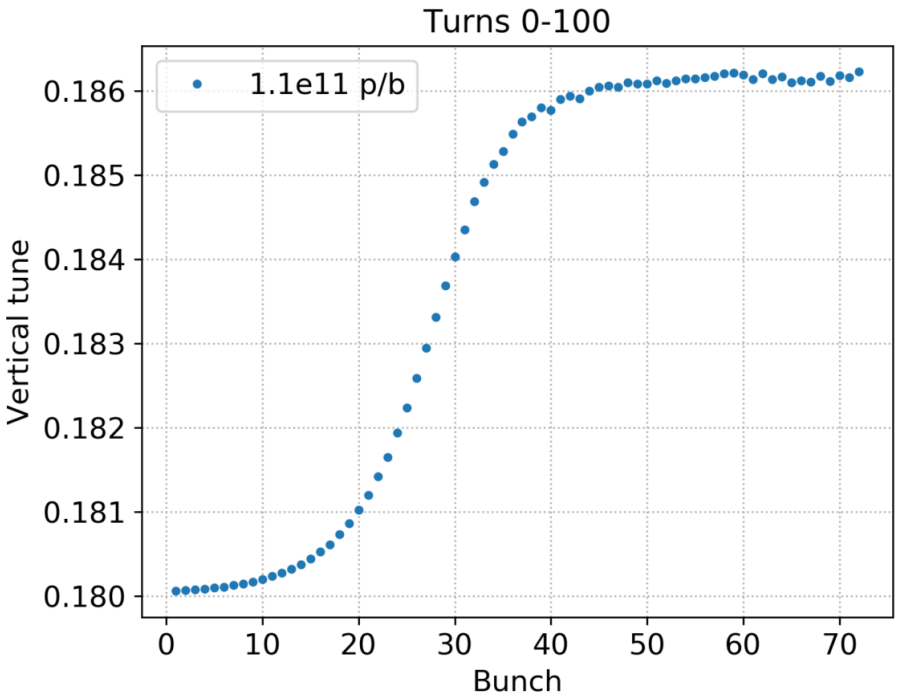
- LHC & HL-LHC
  - Horizontal and vertical tune shifts at injection and collision

- Single bunch vs multi-bunch tune shifts
  - Effect of kick pattern along the train
  - Effect of kick size

SPS injection

- Coherent tune shifts in the SPS at 26 GeV with 1.1e11 p/b have been determined
  - The horizontal tune shift is of the order of 1e-4, positive and negative
  - The vertical tune shift is larger and positive, with a magnitude around 6e-3 (similar tune shift estimated from single bunch instability studies)
- Considered e-cloud only in MBB chambers, with StSt SEY = 1.5



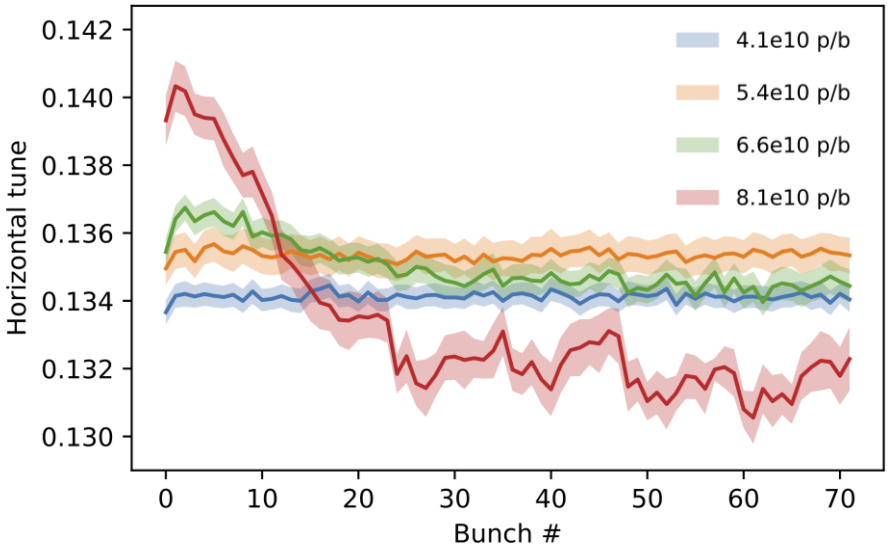


Horizontal tune shift vs measurements

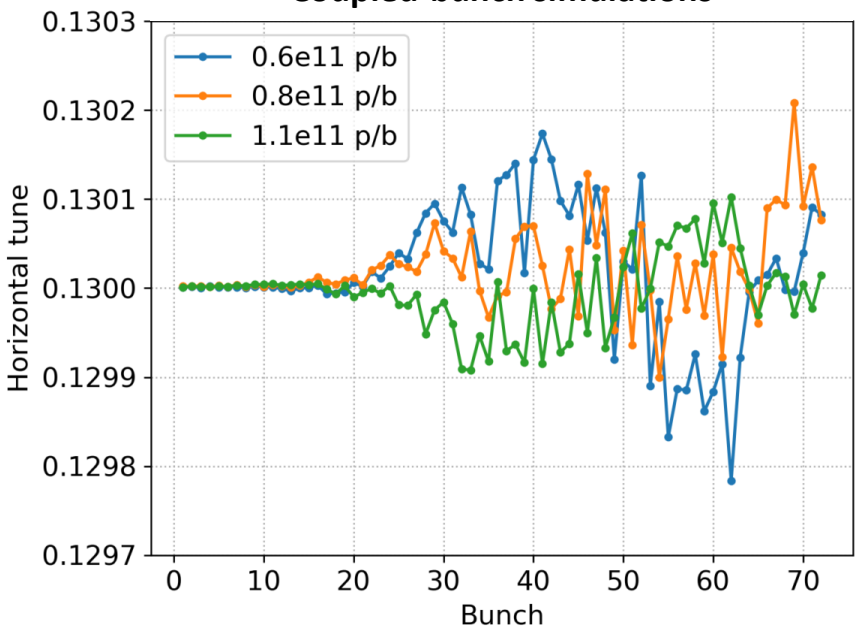
- A negative tune shift along the bunch train is measured for bunch intensities > 6e10 p
  - Tune shift increases with increasing bunch intensity, and reaches 1e-2 for 8e10 p/b

- E-cloud in dipoles was a suspected cause, but is not supported by our simulations
  - The tune shift from e-cloud in dipoles is much smaller in magnitude
  - It doesn't reproduce the observed pattern along the bunch train
  - It doesn't show any threshold nor a clear trend with increasing bunch intensity

Measurements by M. Carla et al



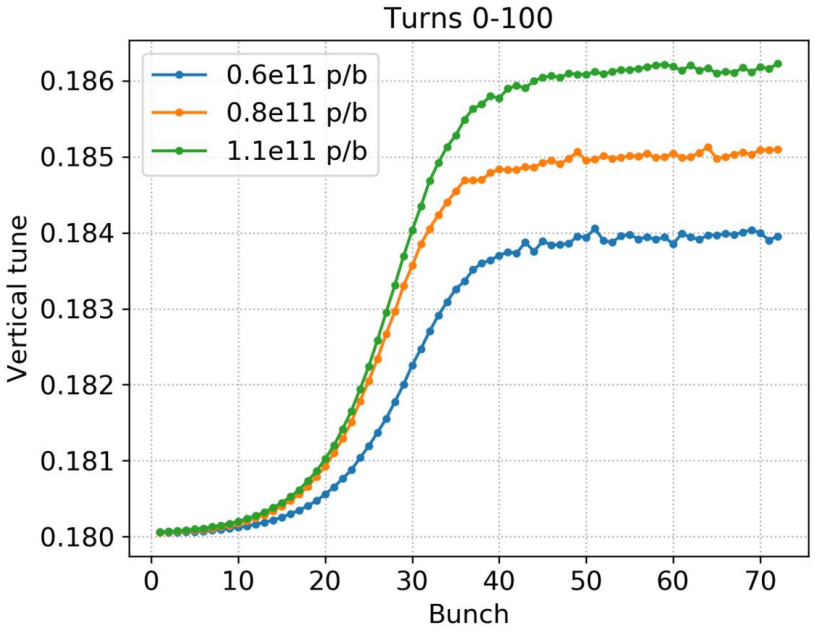
Coupled-bunch simulations

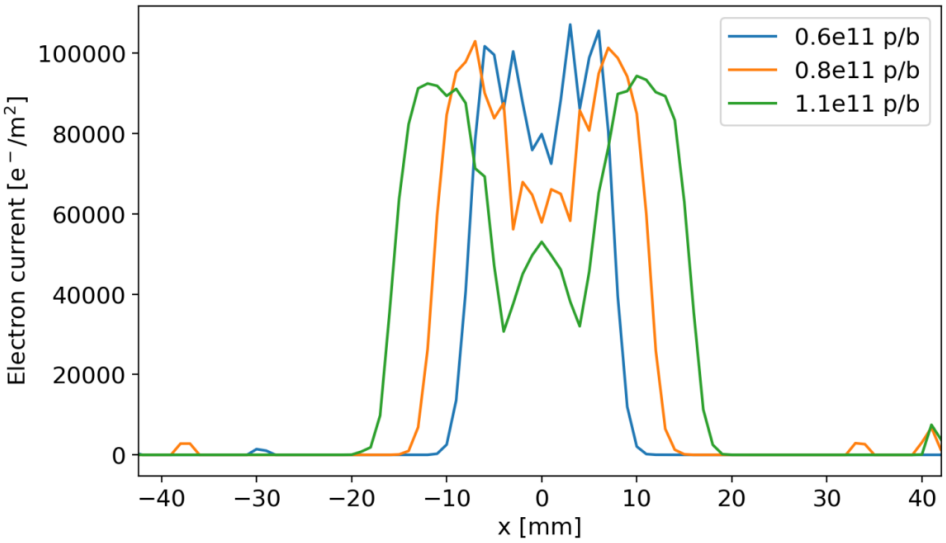


Vertical tune shift vs intensity

- The vertical tune shift shows a clear increasing trend for increasing bunch intensity in the studied interval of 0.6e11 and 1.1e11 p/b

- The magnitude of the tune shift doesn't seem to correspond to the amount of electrons in the centre of the beam chamber, as one could expect





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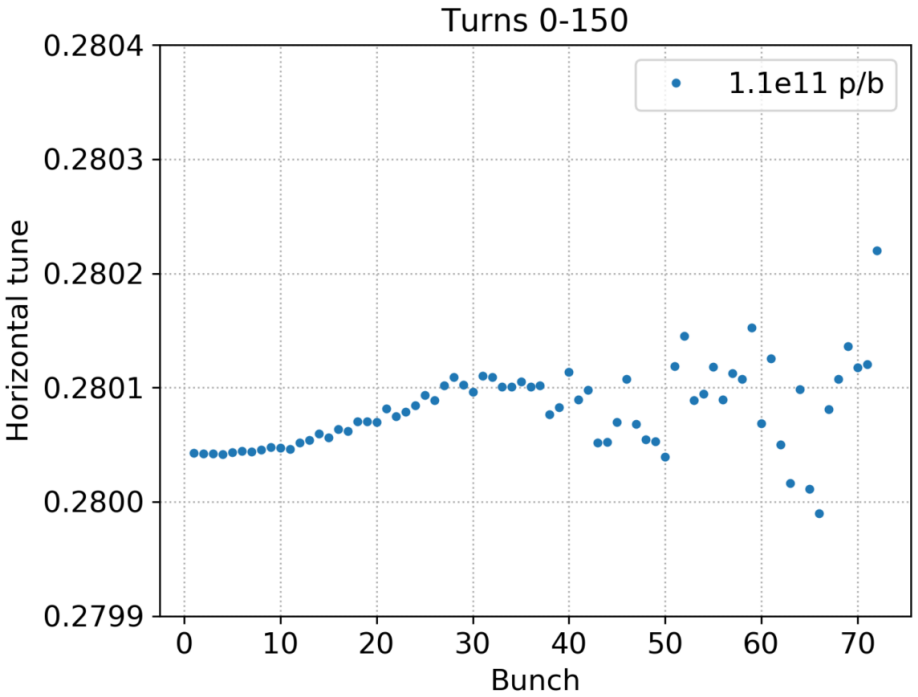
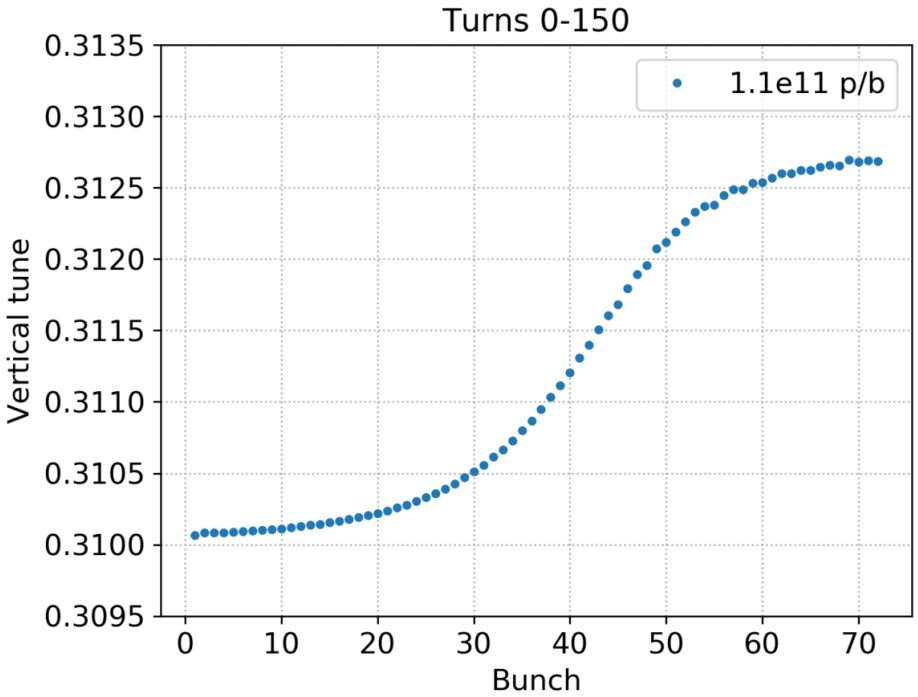
LHC injection

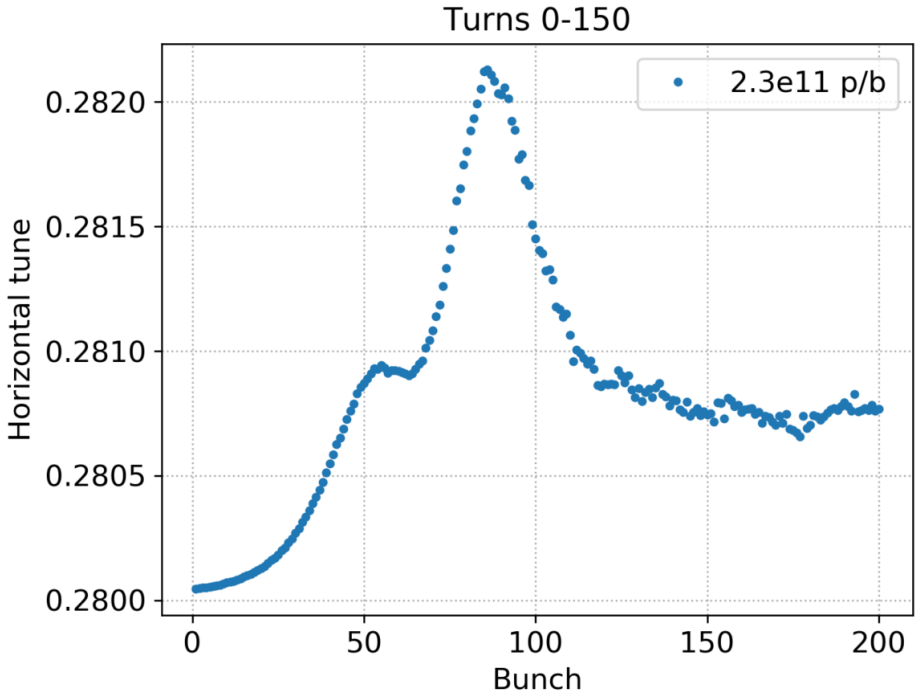
- Coherent tune shifts at 450 GeV with 1.1e11 p/b have been determined
  - The horizontal tune shift is of the order of 2e-4
  - The vertical tune shift is around 3e-3
- Considered e-cloud in dipoles with SEY = 1.4

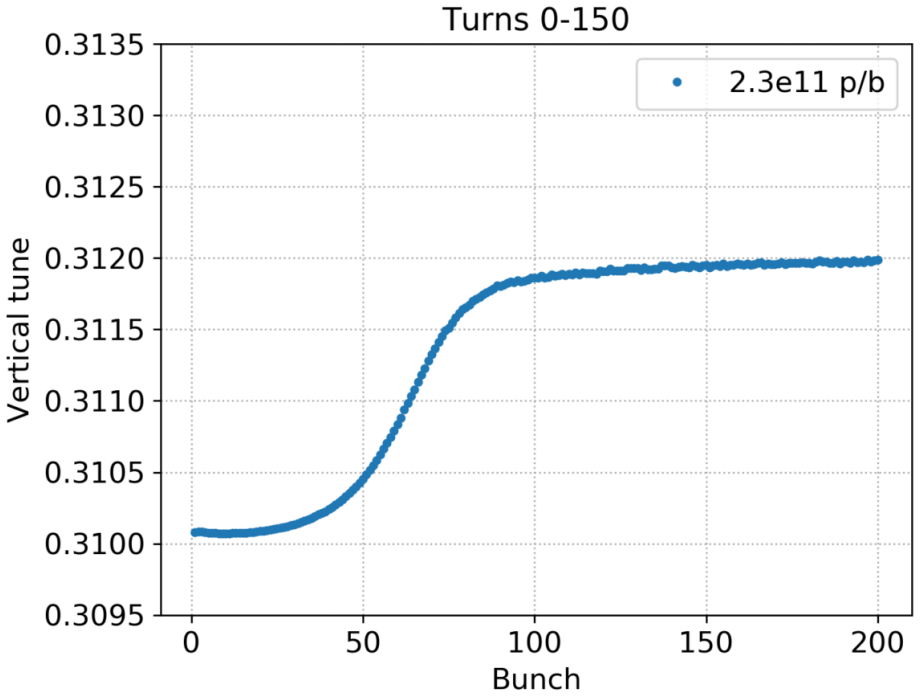




HL-LHC injection

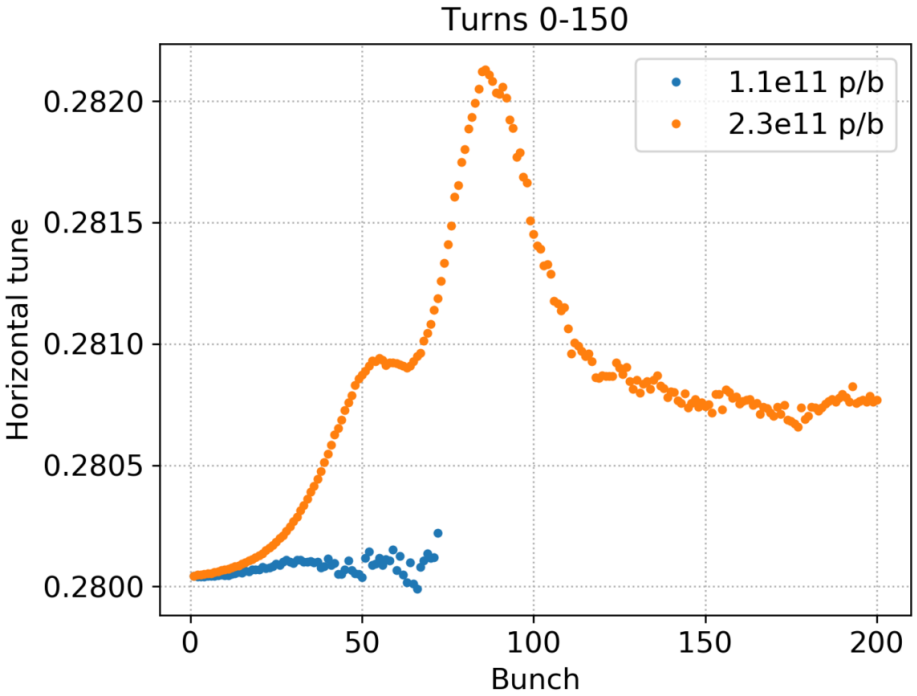
- Coherent tune shifts at 450 GeV with 2.3e11 p/b have been determined
  - The horizontal tune shift reaches up to 2e-3
  - The vertical tune shift is around 2e-3
- Considered longer bunch trains to reach saturation for e-cloud build-up

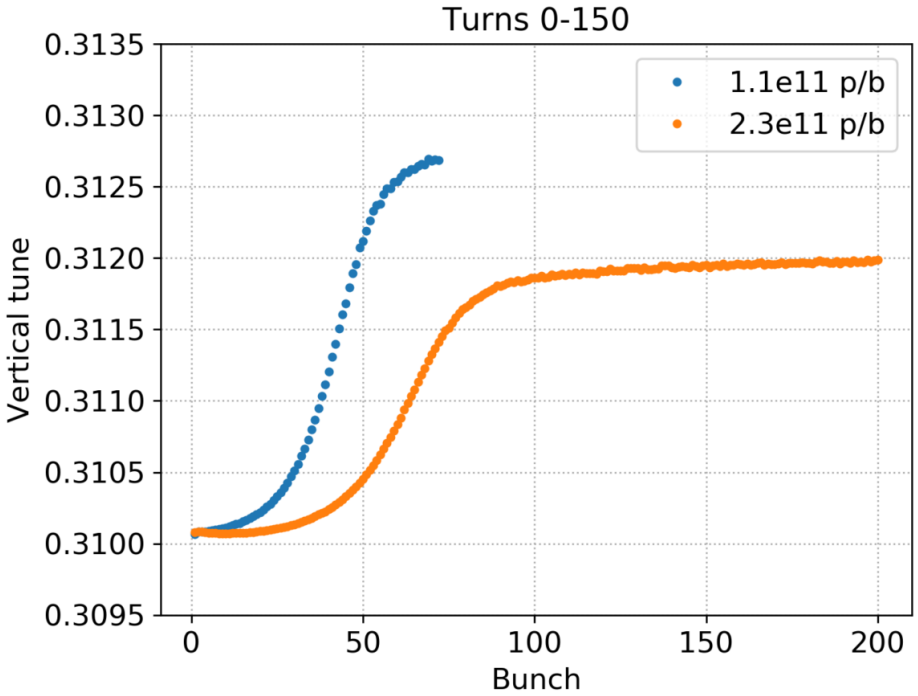




LHC vs HL-LHC injection

- Comparing the tune shifts at 450 GeV with 1.1e11 and 2.3e11 p/b
  - In horizontal, the tune shift for HL-LHC is an order of magnitude larger
  - In vertical, the tune shifts are of similar magnitude, but slightly larger for 1.1e11 p/b



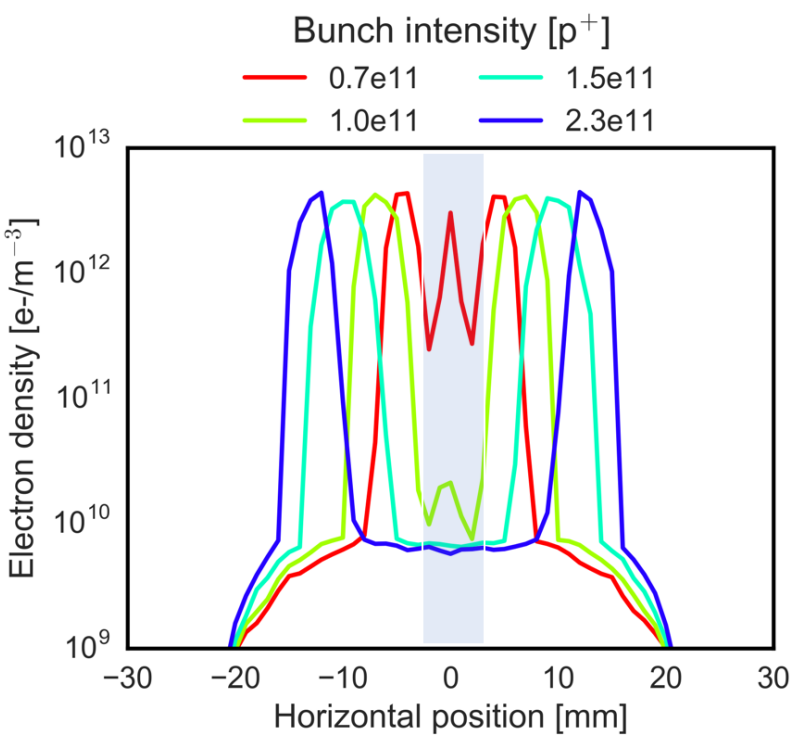


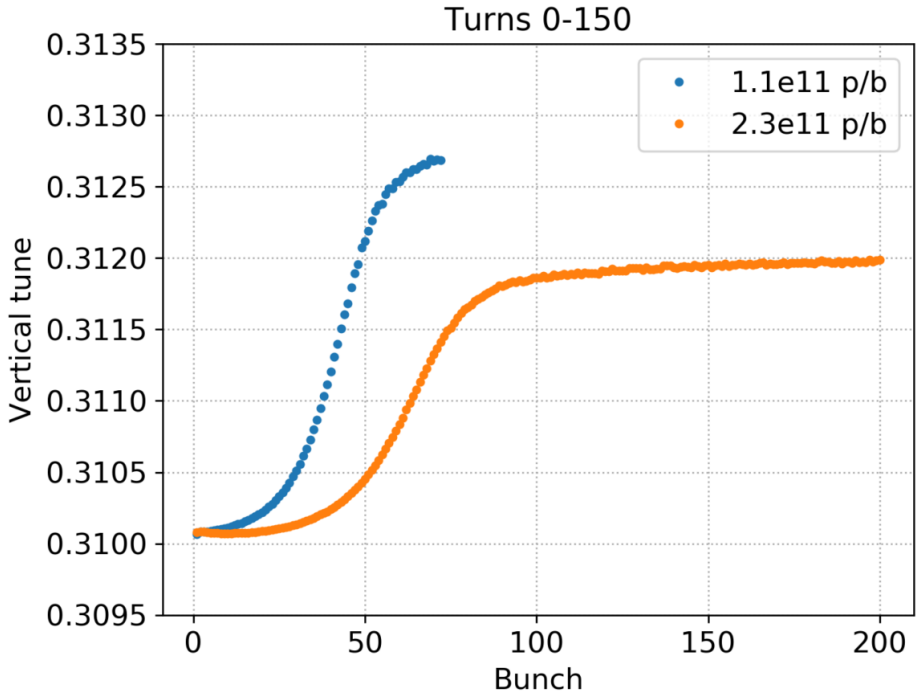
LHC vs HL-LHC injection

- Comparing the tune shifts at 450 GeV with 1.1e11 and 2.3e11 p/b
  - In horizontal, the tune shift for HL-LHC is and order of magnitude larger
  - In vertical, the tune shifts are of similar magnitude, but slightly larger for 1.1e11 p/b

    → Consistent with the scaling of the electron density in the centre of the beam chamber with intensity

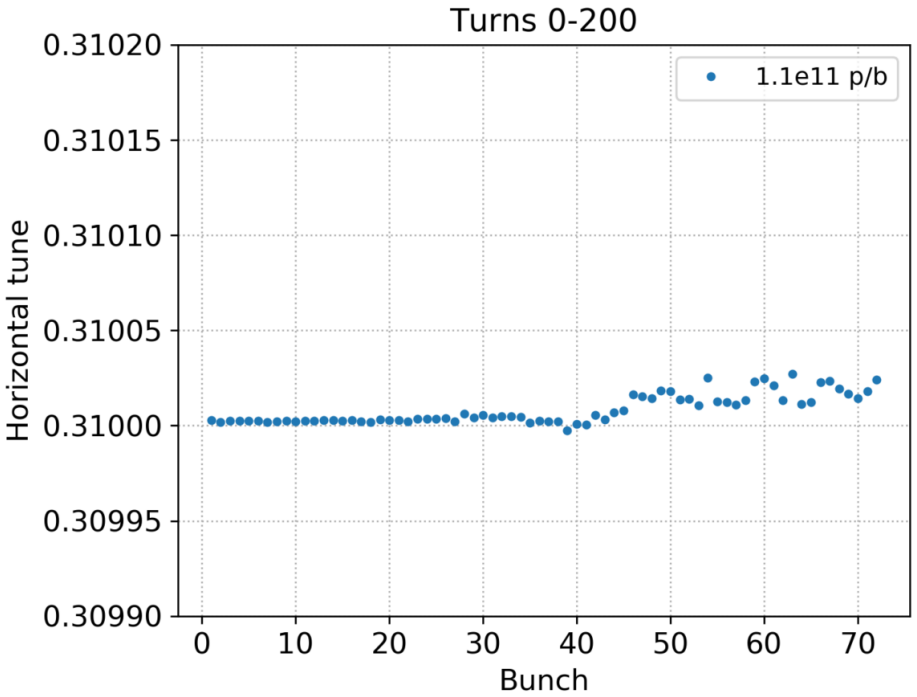
Simulations by A. Romano et al

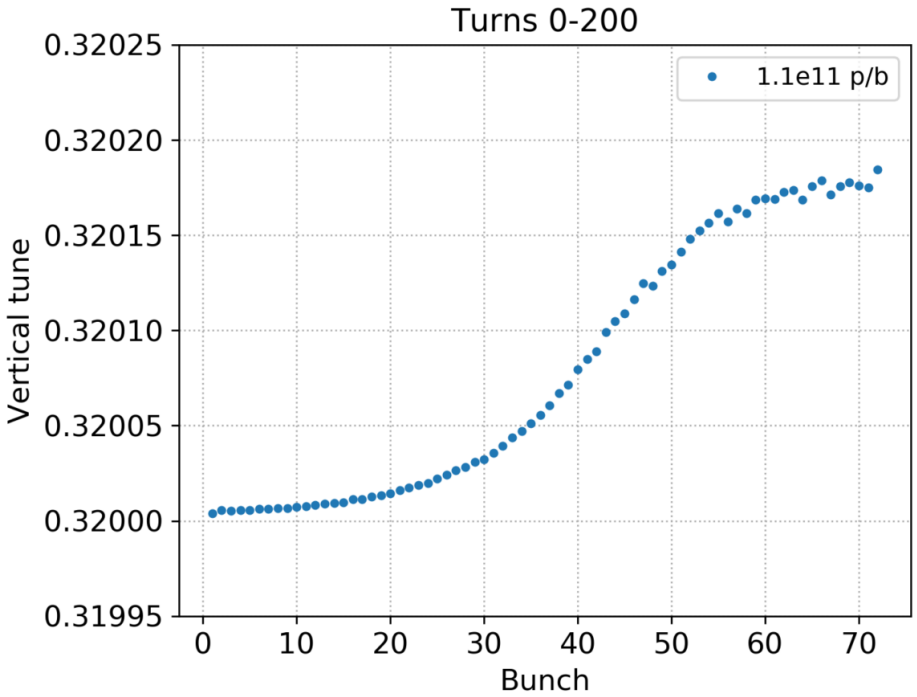




LHC collision

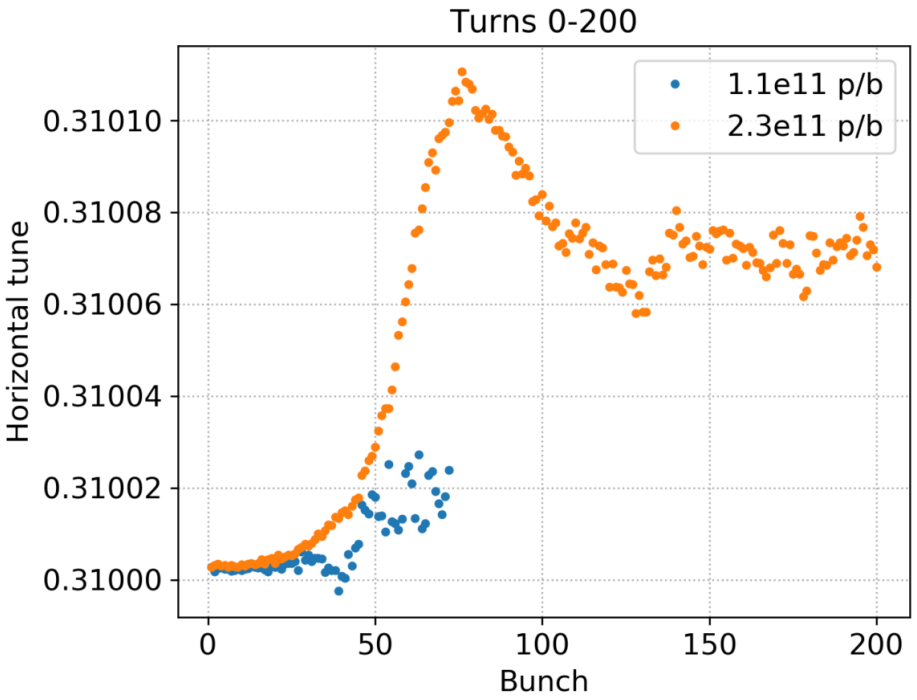
- Coherent tune shifts at 7 TeV with 1.1e11 p/b have been determined
  - The horizontal tune shift is of the order of 1e-5
  - The vertical tune shift is around 2e-4
- The tune shifts are roughly an order of magnitude smaller than at injection

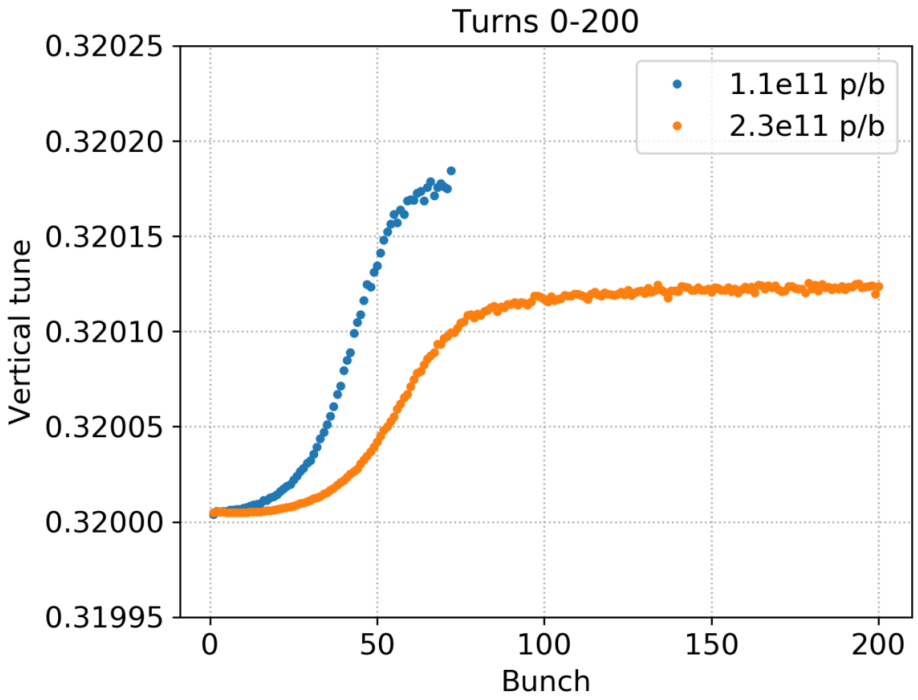




LHC vs HL-LHC collision

- The comparison between 1.1e11 and 2.3e11 p/b at 7 TeV is very similar to 450 GeV
  - In horizontal, the tune shift for HL-LHC is an order of magnitude larger
  - In vertical, the tune shifts are of similar magnitude, but slightly larger for 1.1e11 p/b
- For both cases, the tune shifts are an order of magnitude smaller than at 450 GeV





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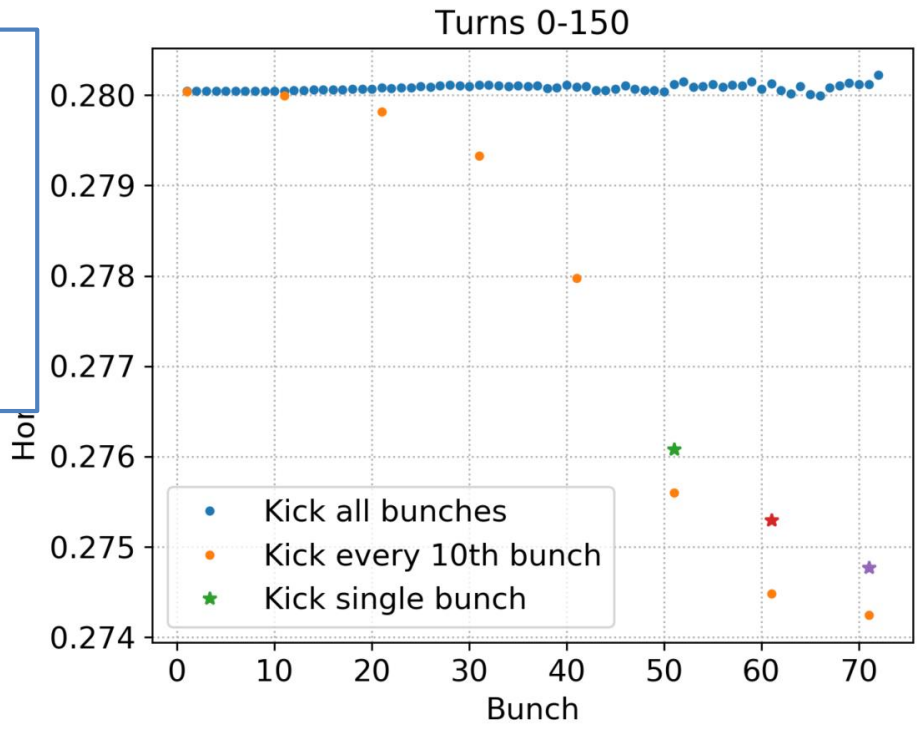
Effect of kick pattern - horizontal

- The same simulation (450 GeV, 1.1e11) has been repeated, applying a kick either to
  - All bunches in the train
  - Every 10th bunch in the train
  - Individual bunches towards the end of the train
- The horizontal tune shift of an individual bunch depends significantly on the kicks applied to the other bunches → coupled-bunch effect!

When the full train is kicked, the dipole stripes follow the displacement of the beam and are merely shifted in the beam chamber



When a single bunch is kicked, it is shifted relative to the stripes created by the previous bunches and feels a much stronger force that is de-focusing

Effect of kick pattern - horizontal

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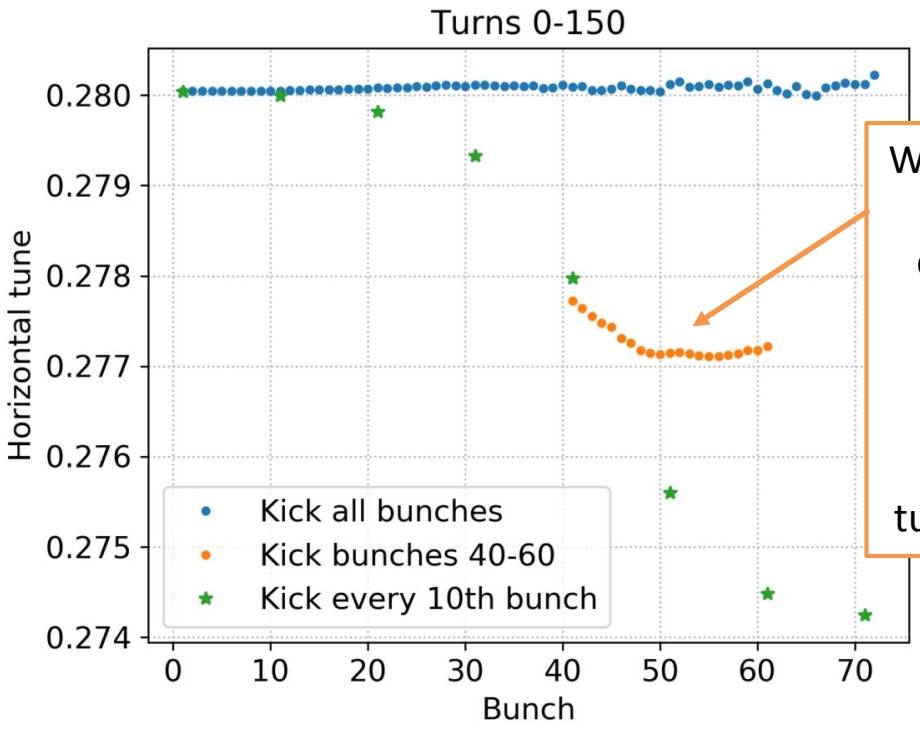
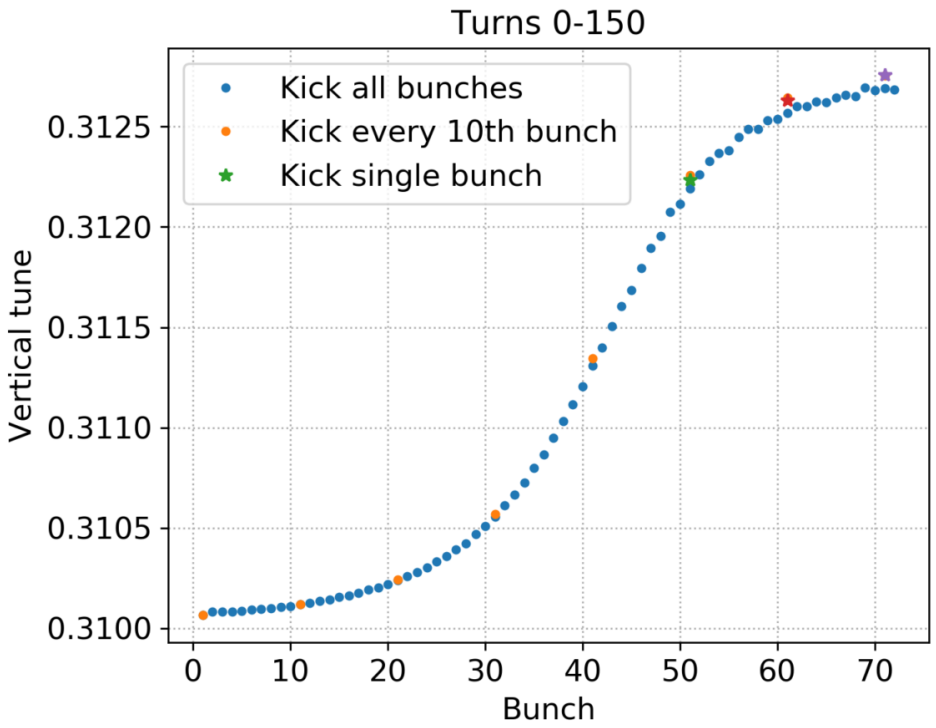


When a consecutive sub-train of bunches is kicked, one could expect the stripes to (partly) adjust to the displacement
→ consistent with the observed flattening of the tune shift along the sub-train

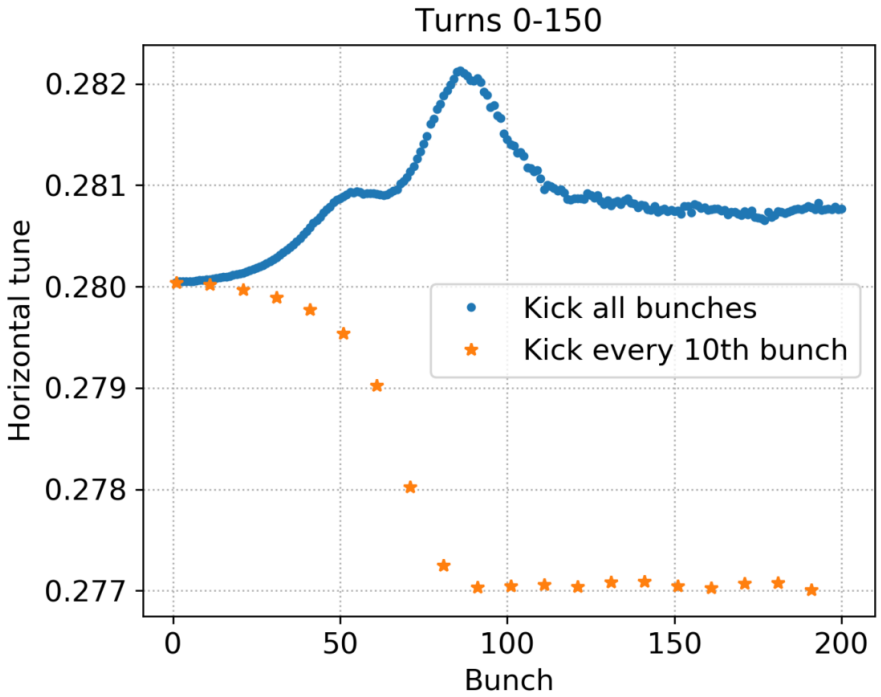
Effect of kick pattern - vertical

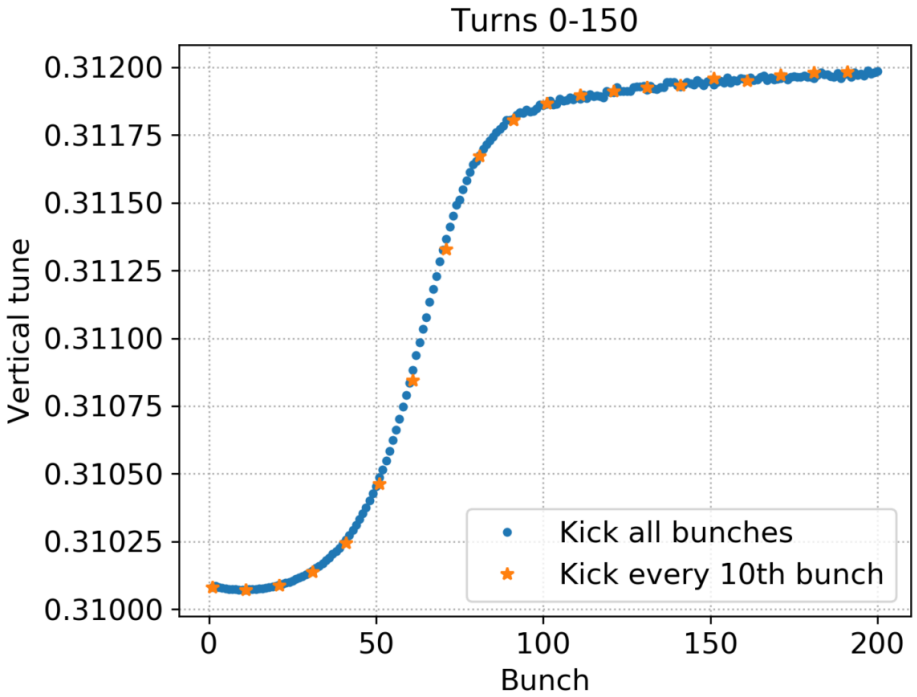
- The same simulation (450 GeV, 1.1e11) has been repeated, applying a kick either to
  - All bunches in the train
  - Every 10th bunch in the train
  - Individual bunches towards the end of the train
- The vertical tune shift of an individual bunch is not affected by the kicks applied to other bunches → single-bunch effect



Effect of kick pattern

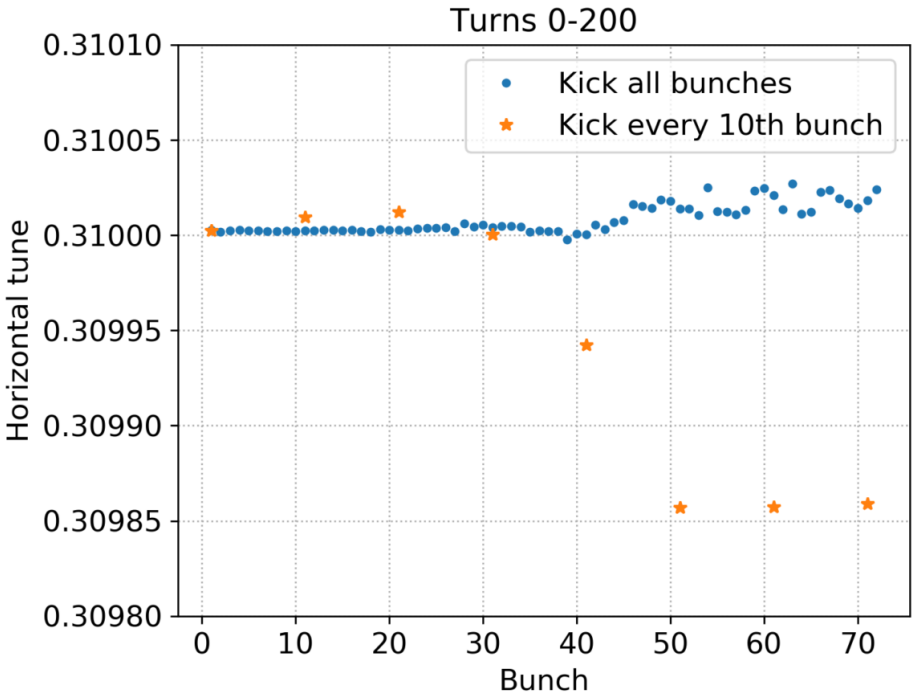
- The same effect can be seen
  - With HL-LHC intensity

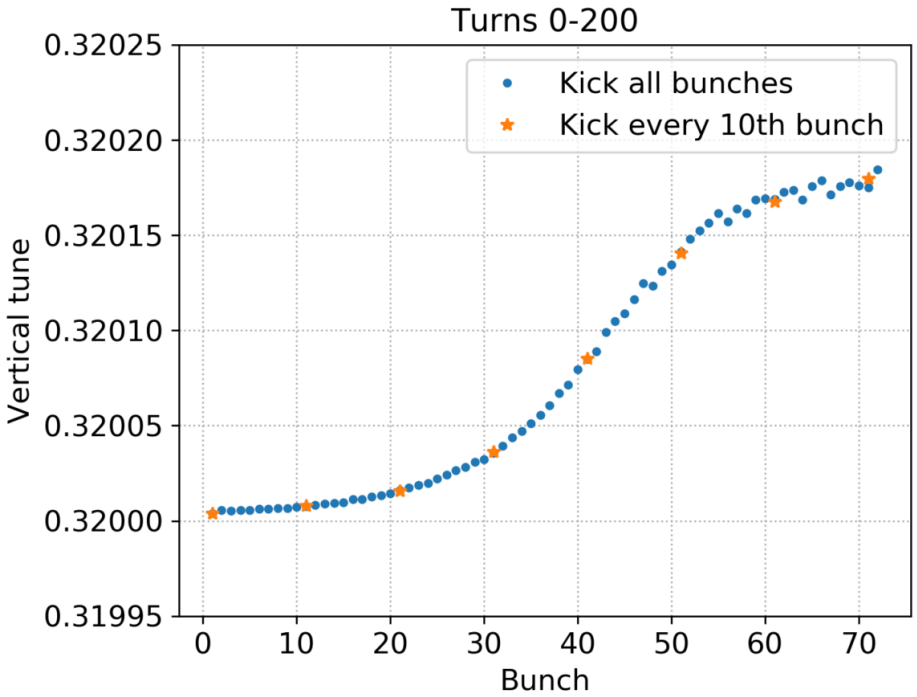




Effect of kick pattern

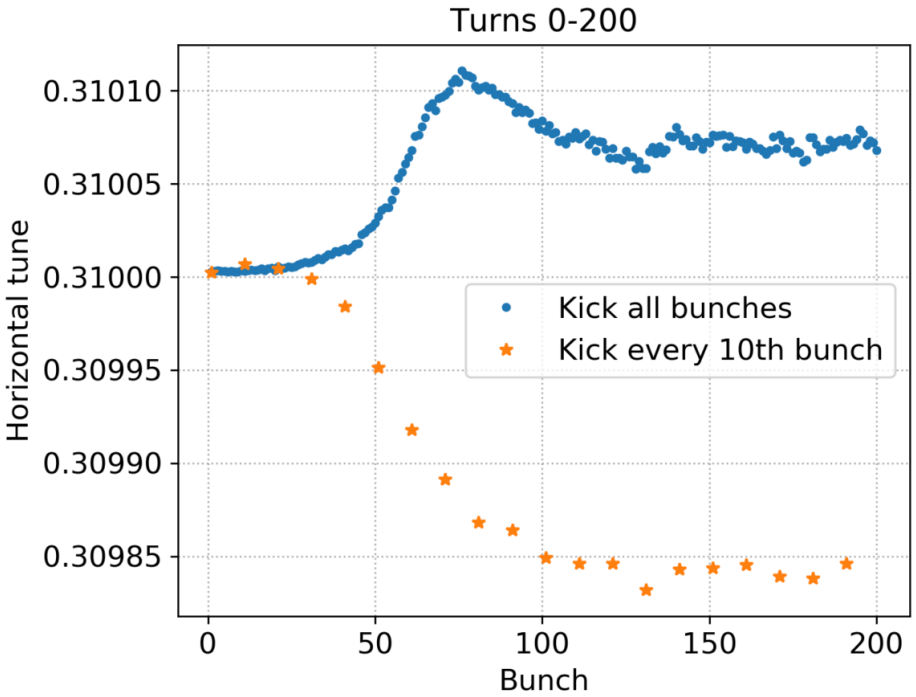
- The same effect can be seen
  - With HL-LHC intensity
  - At collision with LHC intensity

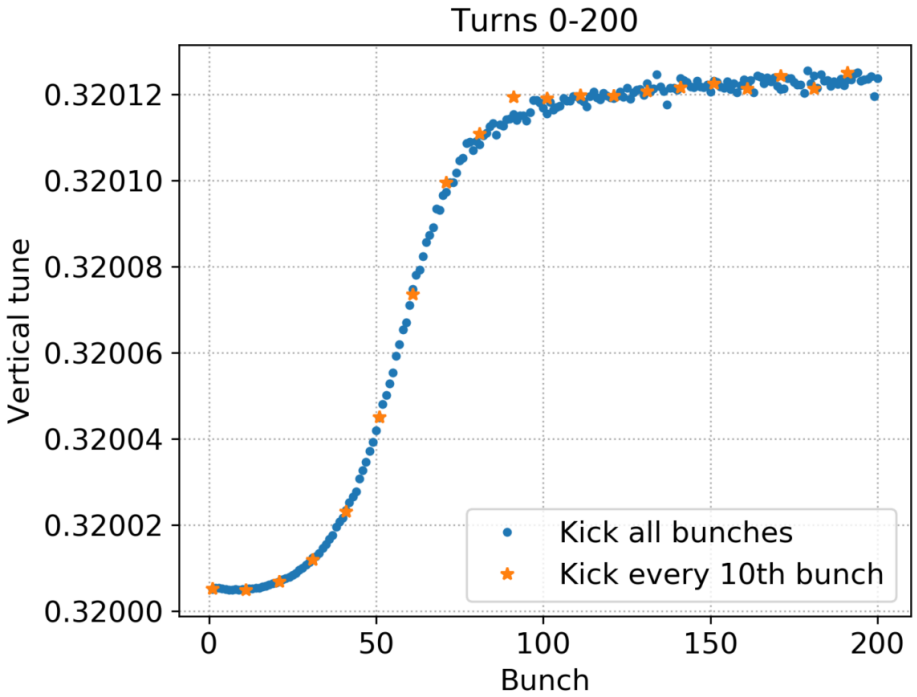




Effect of kick pattern

- The same effect can be seen
  - With HL-LHC intensity
  - At collision with LHC intensity
  - At collision with HL-LHC intensity

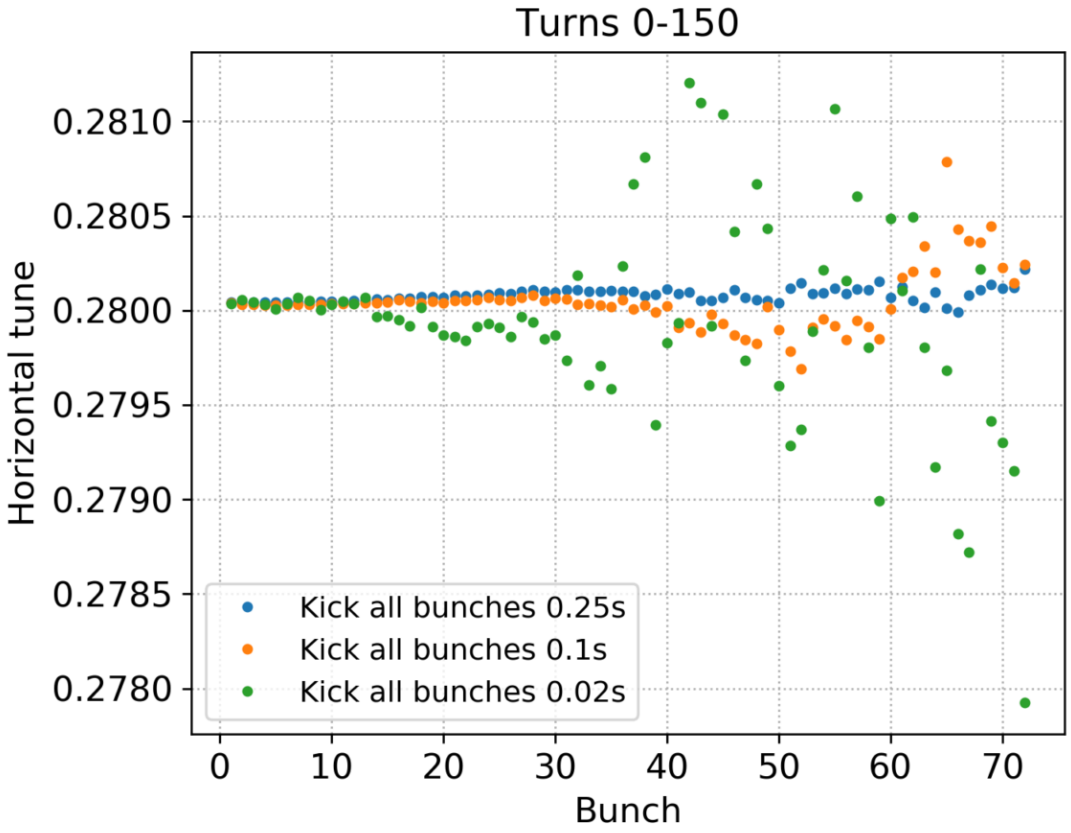




Dependence on kick size

- The previous studies were done with kicks of 0.25 beam sigma
  - Would the tune shift change for a different sized kick?

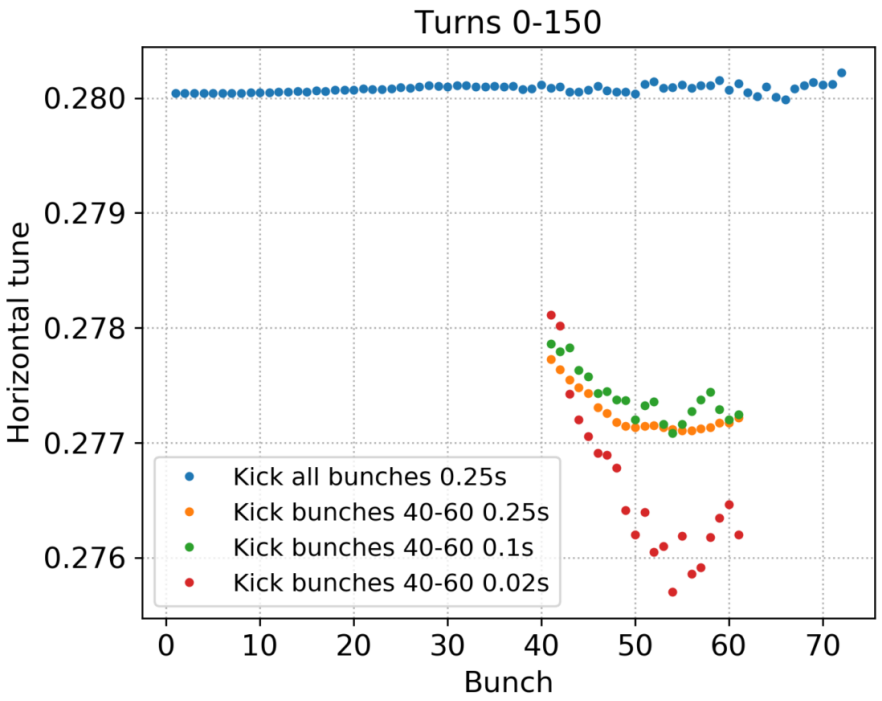
- With a smaller kick, the tune determination becomes significantly noisier

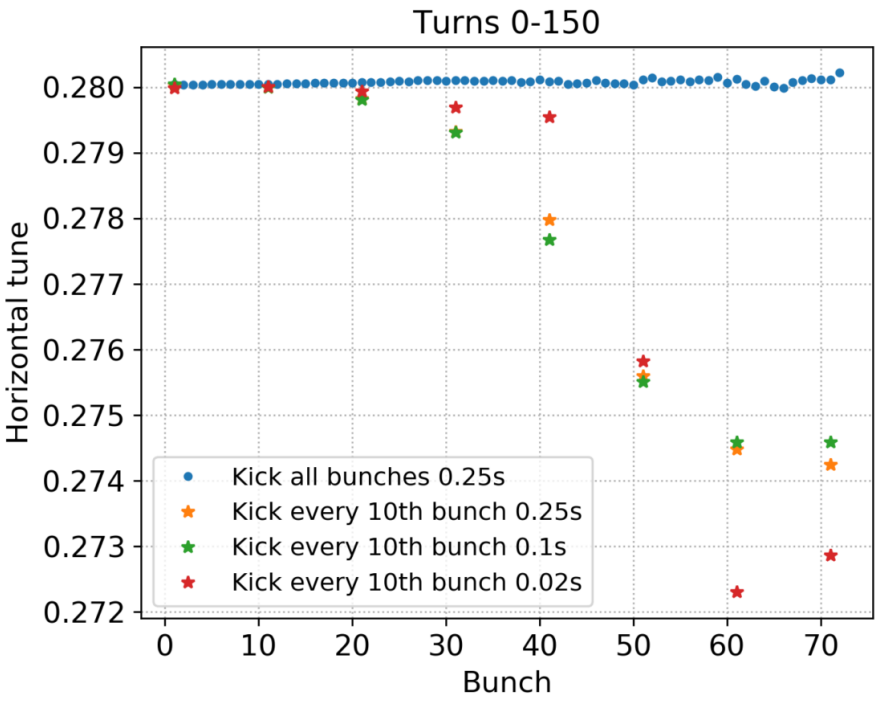


Dependence on kick size

- The previous studies were done with kicks of 0.25 beam sigma
  - Would the tune shift change for a different sized kick?

- With a smaller kick, the tune determination becomes significantly noisier
  - Apart from that, no clear trend is visible in the effect on the tune shift





Summary

- The horizontal and vertical tune shifts from e-cloud in dipoles have been determined for the SPS at injection and the LHC at injection and collision
  - The simulations don't support e-cloud in the dipoles as a cause for the observed horizontal tune shift in the SPS
  - In the LHC, the tune shifts are largest at injection, reaching up to a few 1e-3
- The horizontal bunch-by-bunch tune shift from e-cloud in dipoles is a multi-bunch effect that depends significantly on the motion of other bunches
  - If all bunches are kicked equally, the horizontal tune shift is small
  - Individual bunches that are kicked acquire a negative tune shift that can be at least an order of magnitude larger
- The vertical bunch-by-bunch tune shift is positive and corresponds to the single bunch tune shift