Coupled bunch stability and tune shifts

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Outline

- Introduction

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

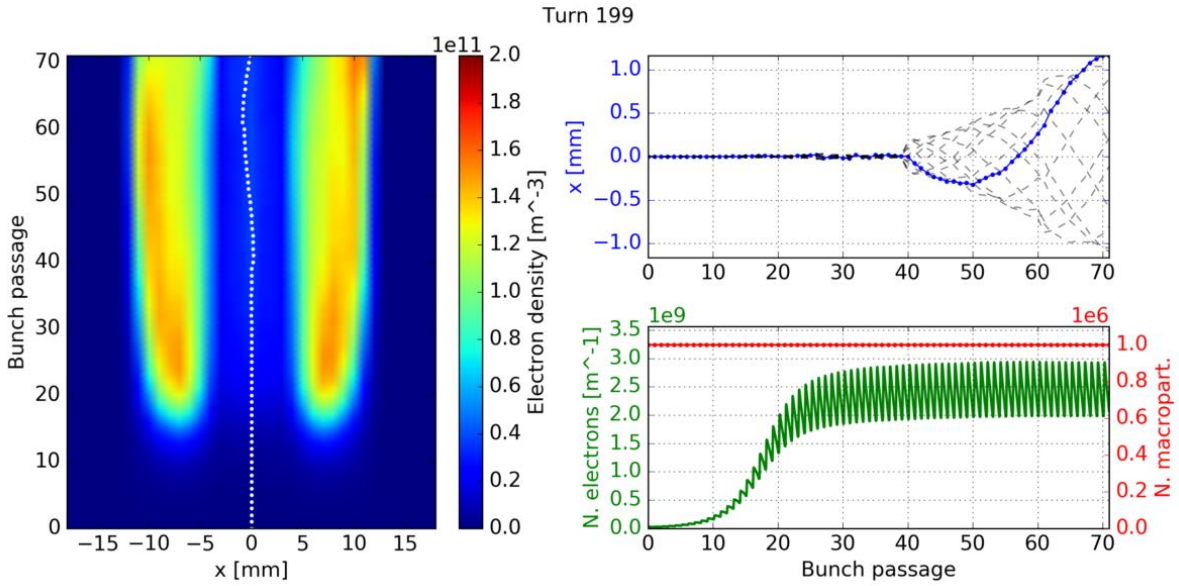
- Further tune shift studies
  - Effect of kick pattern along the train
  - Effect of kick size

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 HL-LHC, as well as in the PS
  - *LHC, HL-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 the LHC dipoles



Coherent tune shifts in the LHC

The horizontal and vertical tune shifts from e-cloud in the dipoles have been determined for LHC and HL-LHC intensities

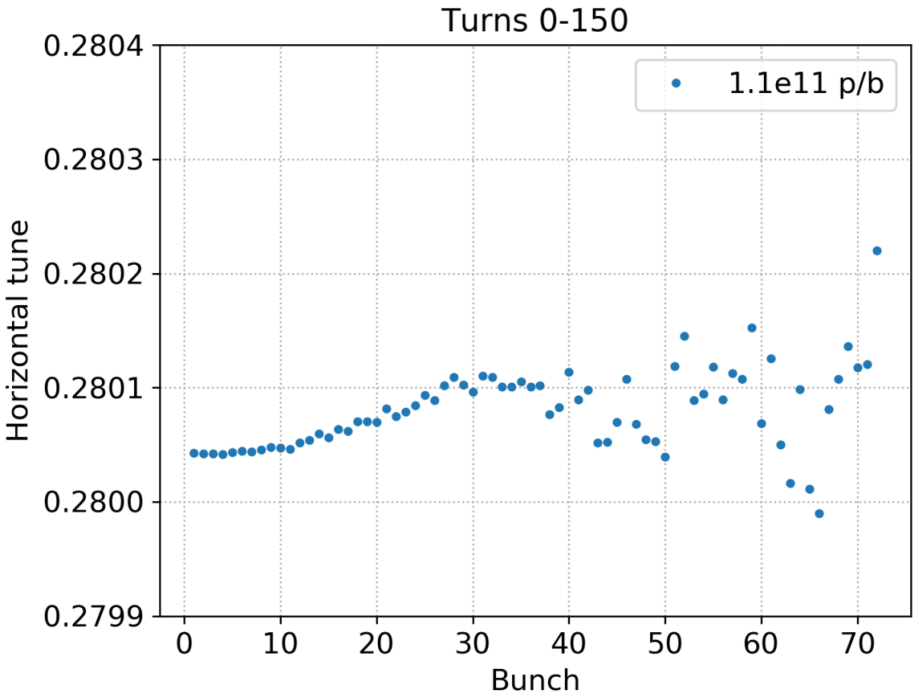
Scan parameters				
Beam energy	450 GeV		6.5 TeV	
Bunch intensity	1.1e11	2.3e11	1.1e11	2.3e11

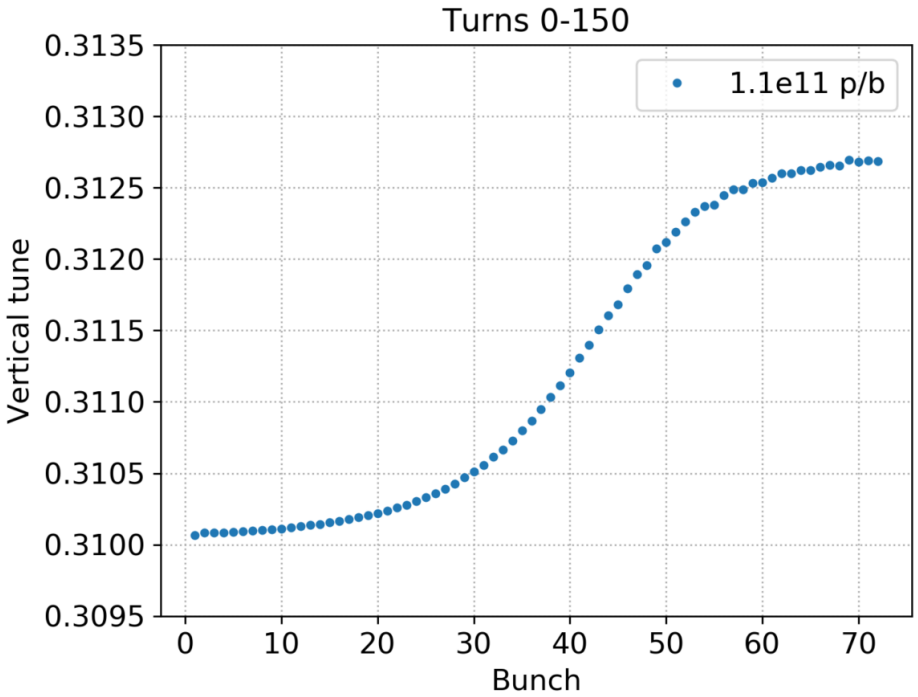
- We have considered e-cloud in the dipoles with SEY = 1.4
- We have simulated a single bunch train long enough to allow for the e-cloud to reach saturation along the train
  - For LHC intensity a train of 72 bunches
  - For HL-LHC intensity a train of 200 bunches
- The coherent motion was seeded with an initial displacement of the full bunch train by 0.25 beam sigma

LHC injection

Tune shifts at 450 GeV with 1.1e11 p/b

- The horizontal tune shift is of the order of 2e-4
- The vertical tune shift is around 3e-3

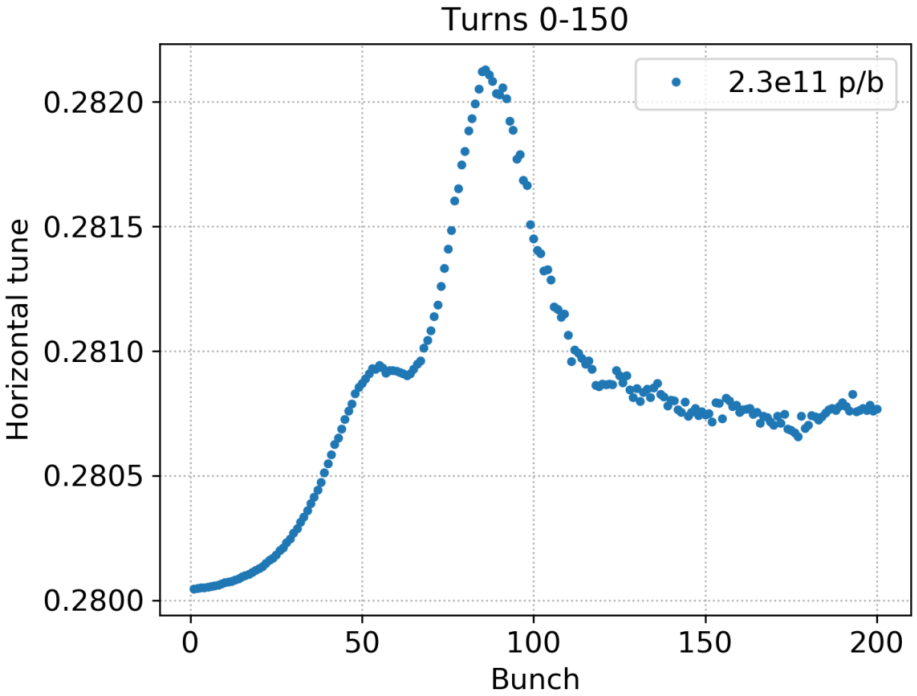


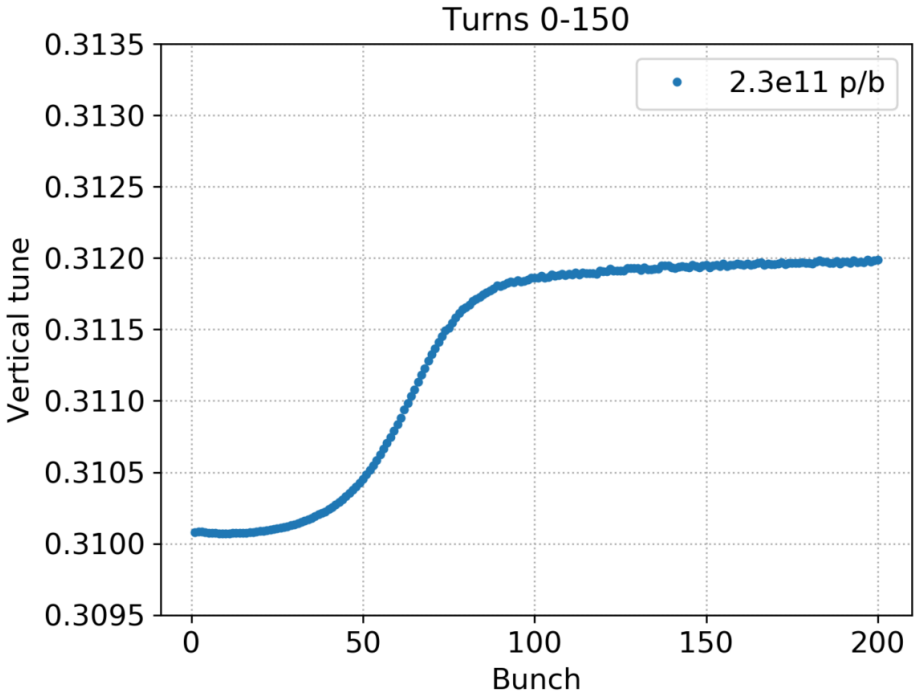


HL-LHC injection

Tune shifts at 450 GeV with 2.3e11 p/b

- The horizontal tune shift reaches up to 2e-3
- The vertical tune shift is around 2e-3

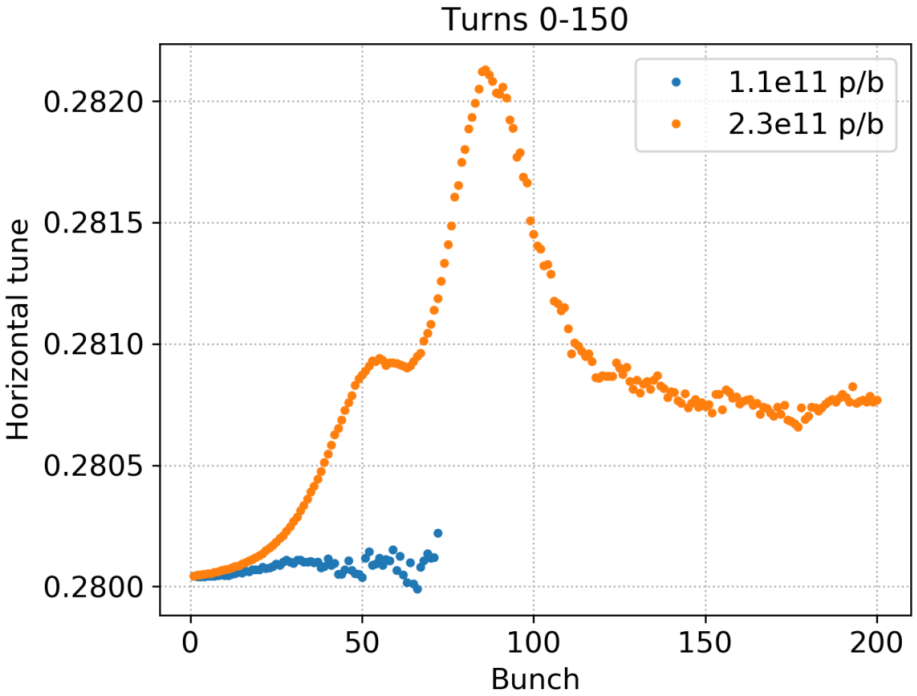


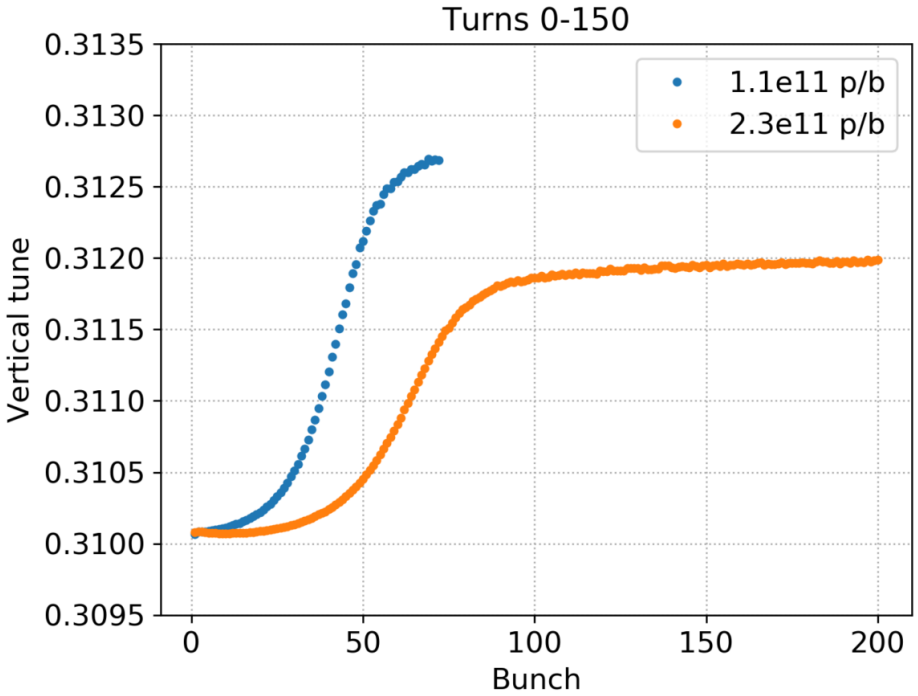


LHC vs HL-LHC injection

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





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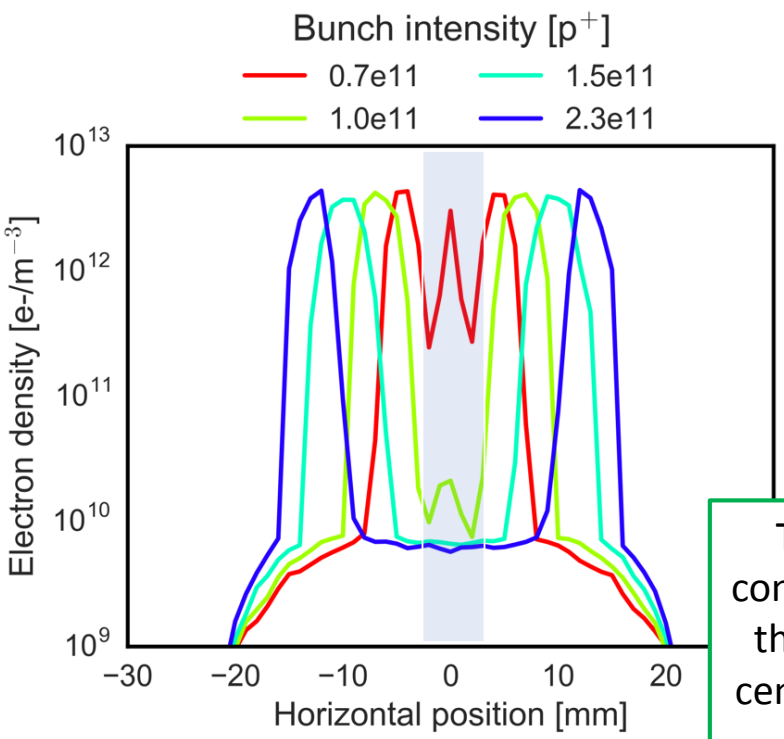
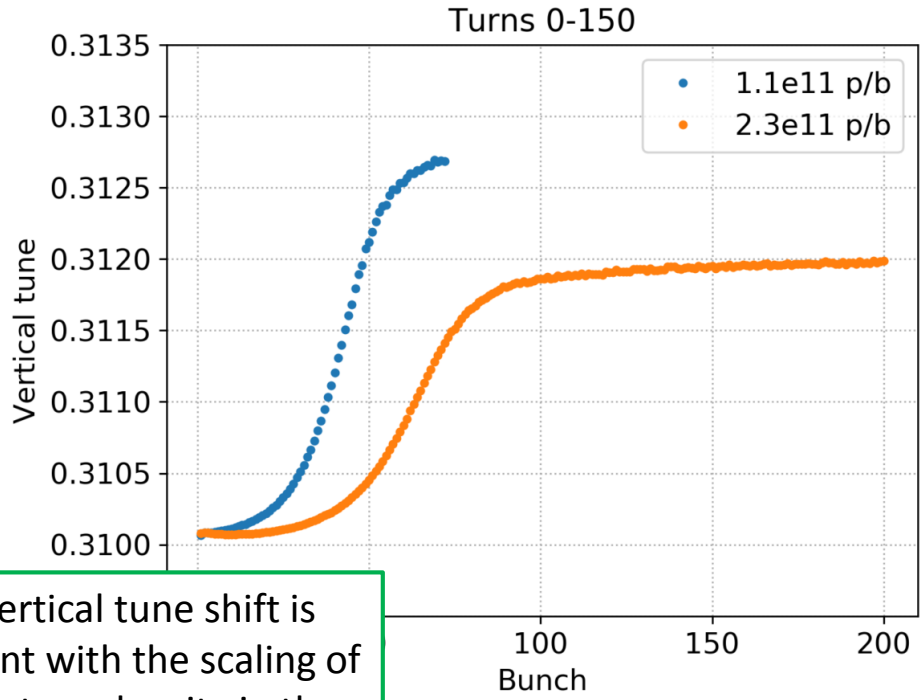
Simulations by A. Romano et al





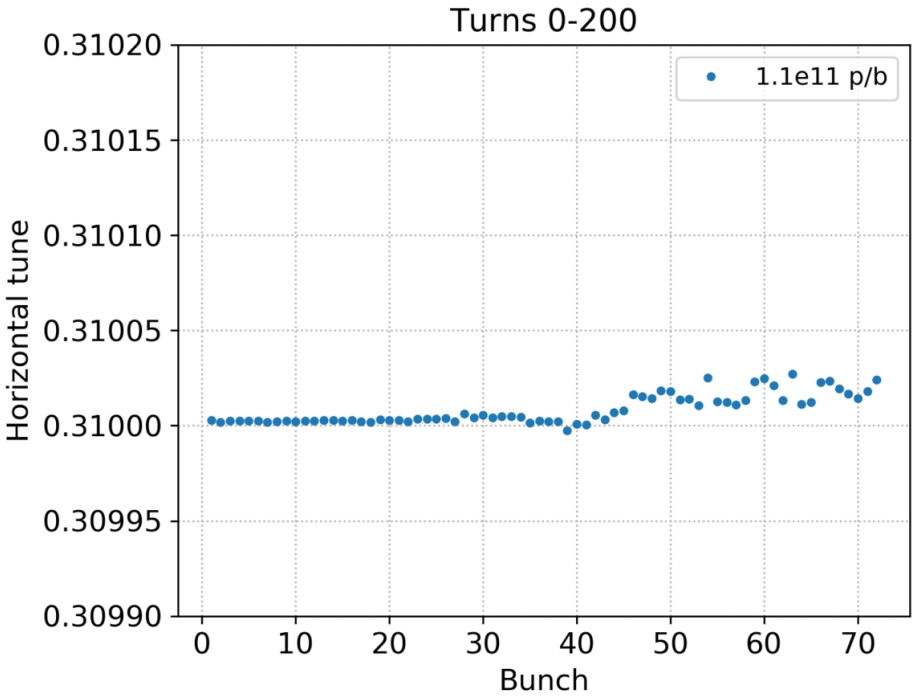
The vertical tune shift is consistent with the scaling of the electron density in the centre of the beam chamber with intensity

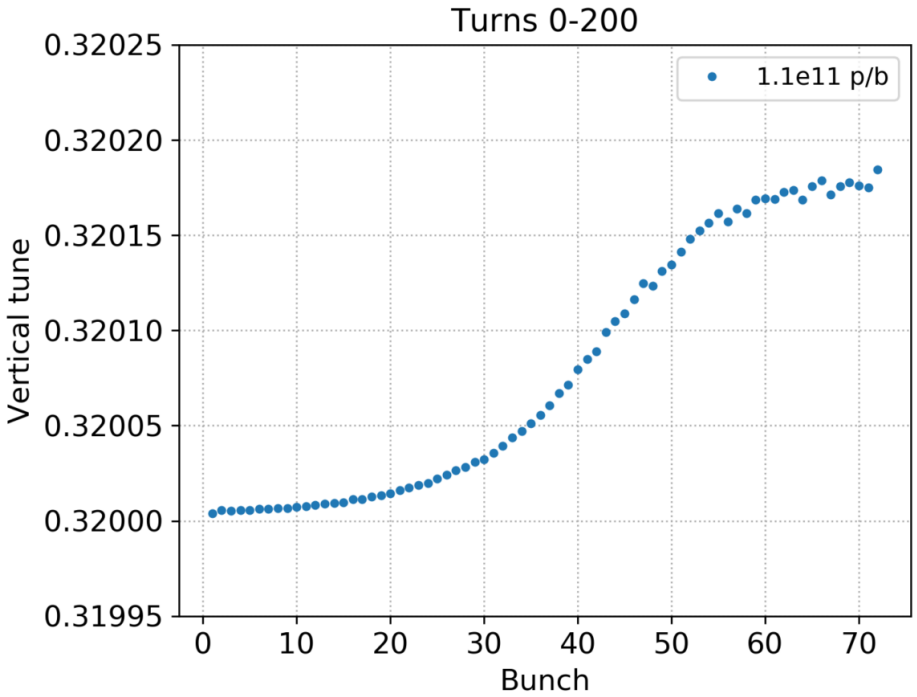
LHC collision

Tune shifts at 7 TeV with 1.1e11 p/b

- The horizontal tune shift is of the order of 1e-5
- The vertical tune shift is around 2e-4

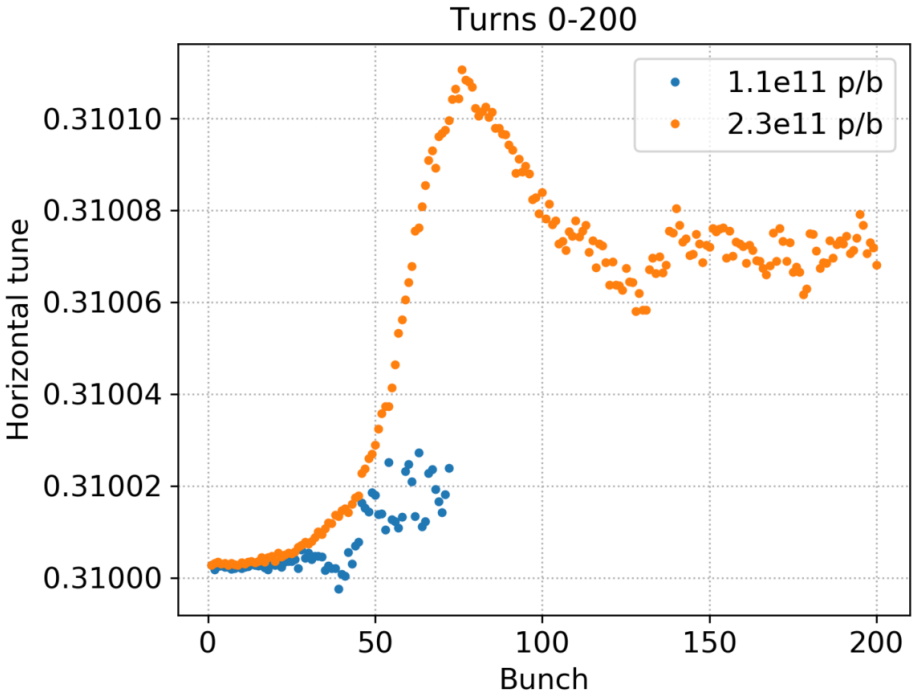
The tune shifts are roughly an order of magnitude smaller than at injection

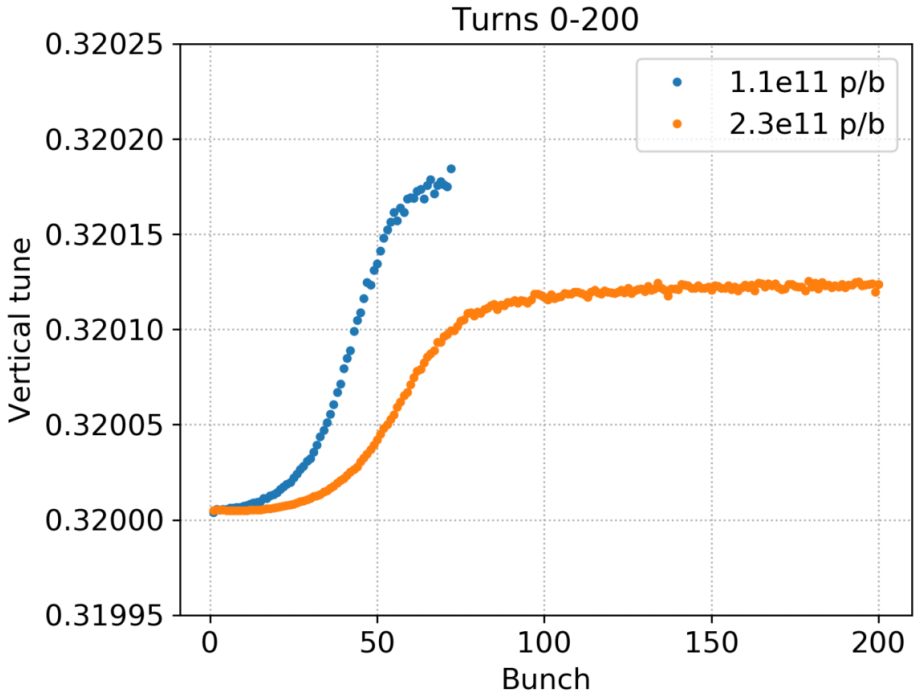




LHC vs HL-LHC collision

- 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





In both cases the tune shifts are roughly an order of magnitude smaller than at injection

Further tune shift studies

To gain a deeper understanding of the nature of the tune shifts, we have also studied the effect of how the initial kick is applied to the beam

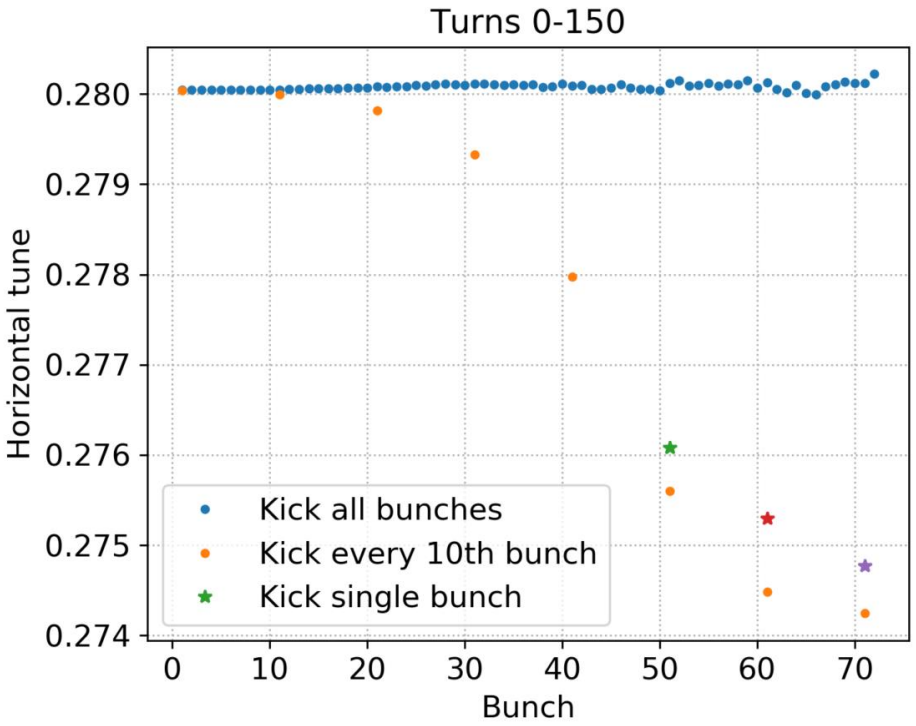
- We investigated the effect of the kick pattern along the bunch train
  - Otherwise identical simulations repeated, applying an initial displacement to
    - All bunches in the train
    - Every 10^{th} bunch in the train
    - Individual bunches towards the end of the train

- We also investigated the effect of the magnitude of the initial displacement

Effect of kick pattern - horizontal

Effect of kick pattern at 450 GeV with 1.1e11 p/b

- 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

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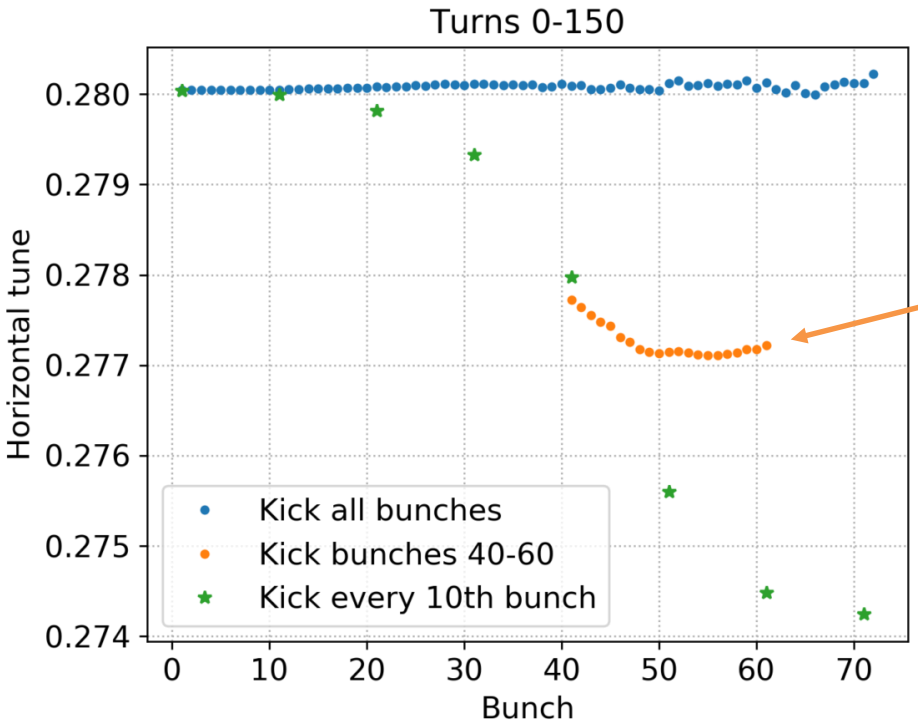
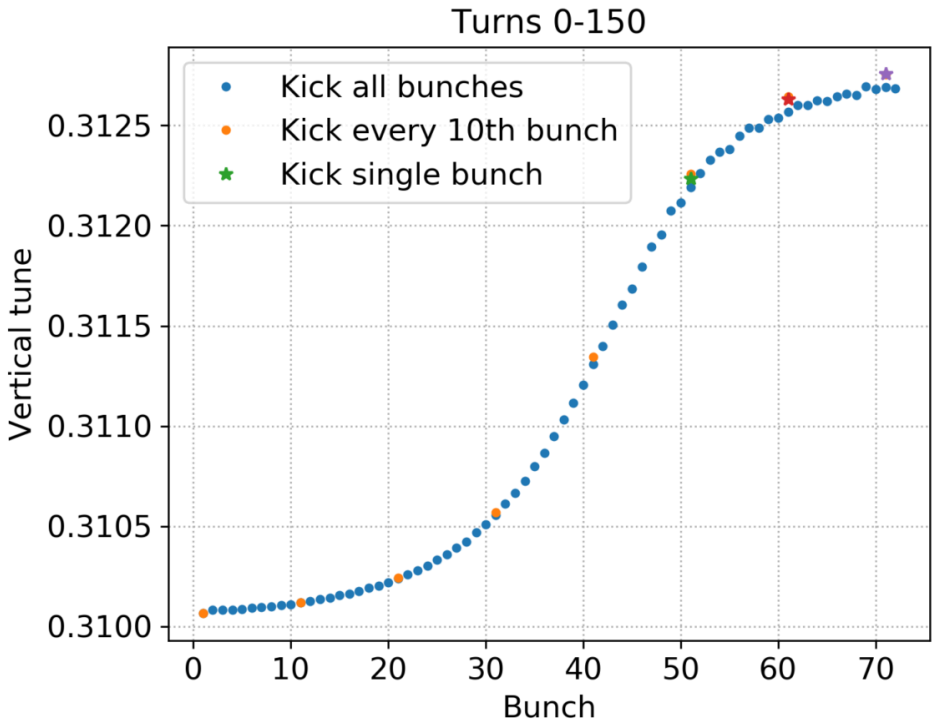


When a consecutive sub-train of bunches is kicked, one could expect the stripes to (partly) adjust to the displacement → consistent with the observed flattening of the tune shift along the sub-train

Effect of kick pattern - vertical

Effect of kick pattern at 450 GeV with 1.1e11 p/b

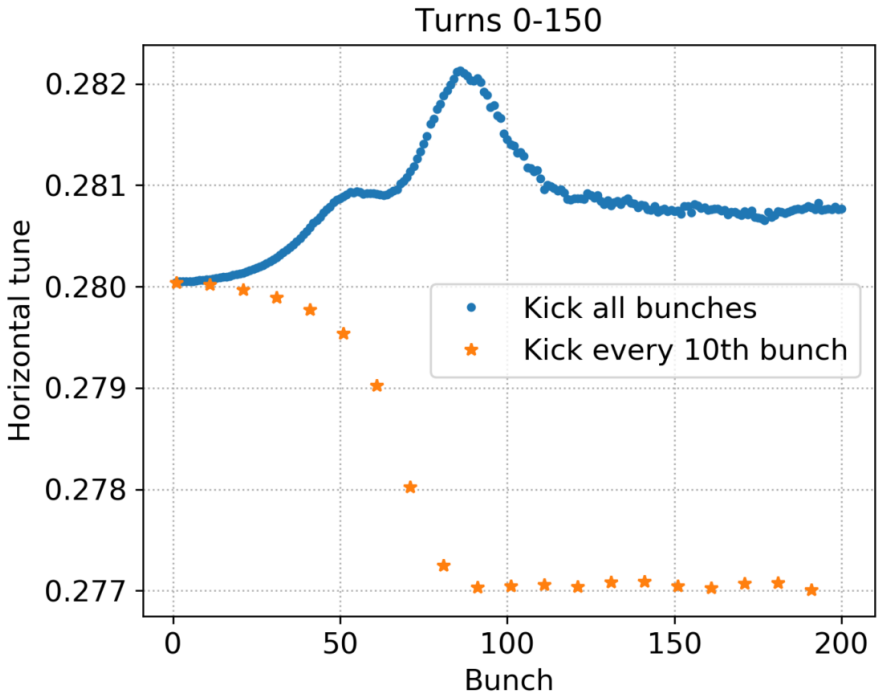
- The vertical tune shift of an individual bunch is not affected by the kicks applied to other bunches → single-bunch effect

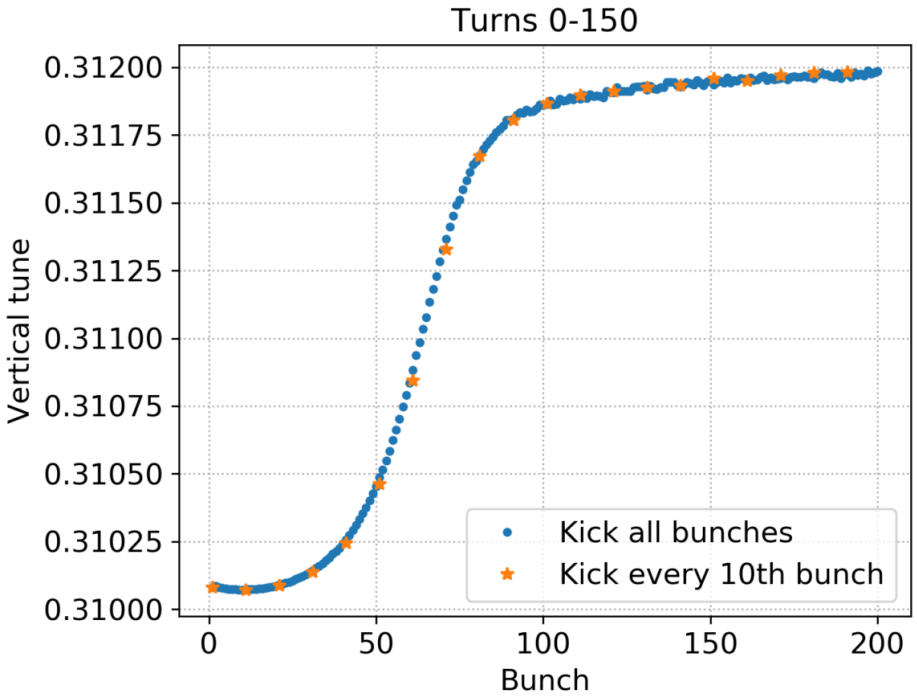


Effect of kick pattern

The same effect occurs for all the cases considered here

- With HL-LHC intensity

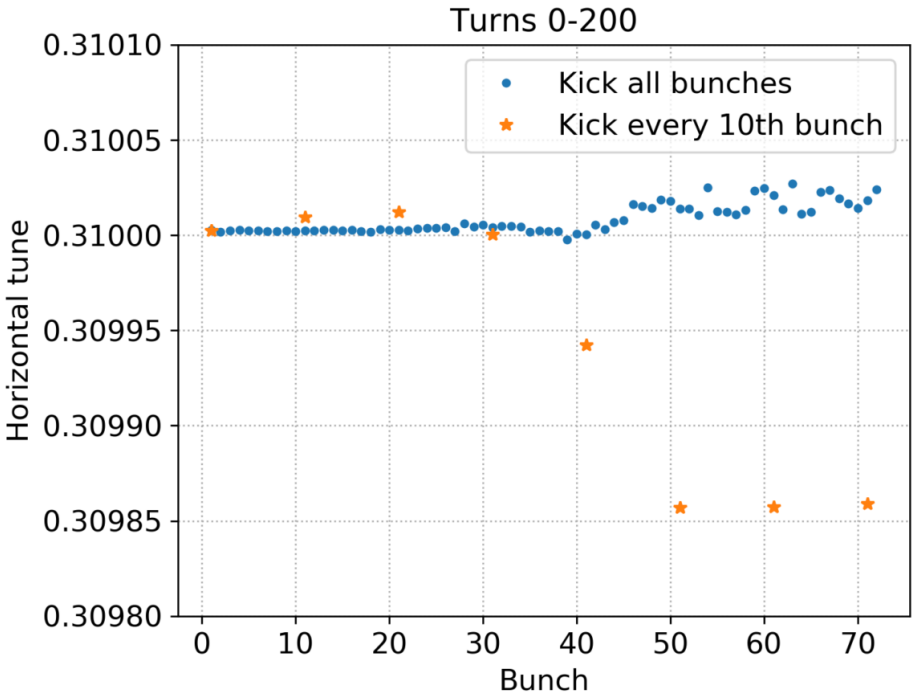


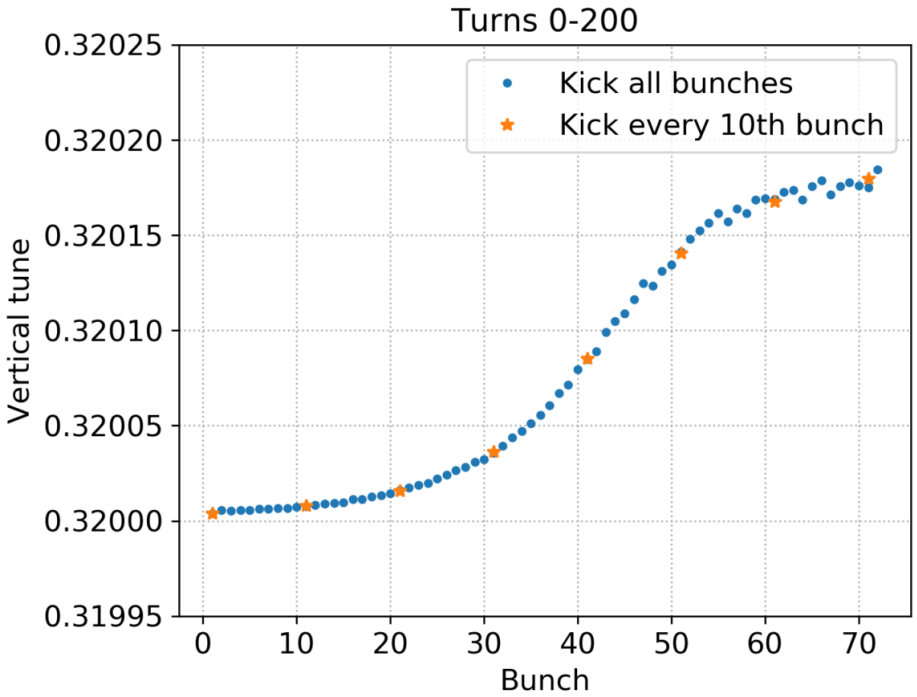


Effect of kick pattern

The same effect occurs for all the cases considered here

- With HL-LHC intensity
- At collision with LHC intensity





Effect of kick pattern

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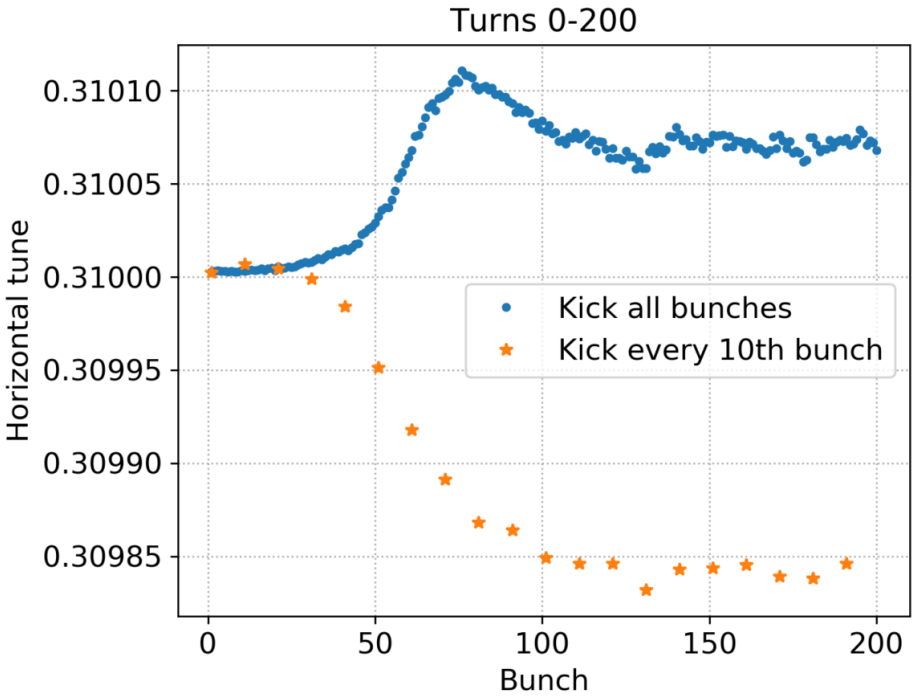
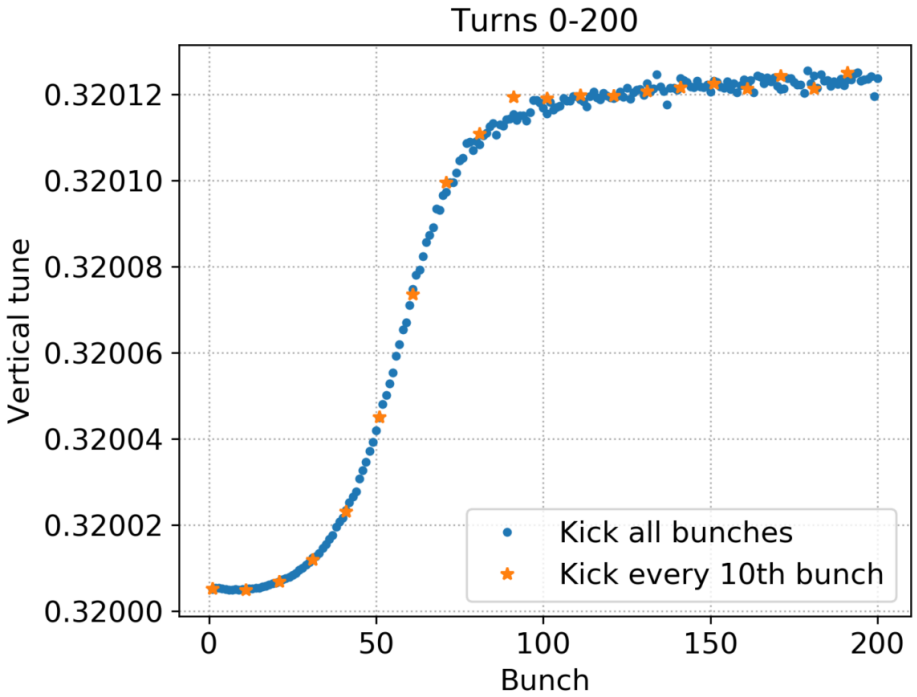
- With HL-LHC intensity
- At collision with LHC intensity
- At collision with HL-LHC intensity

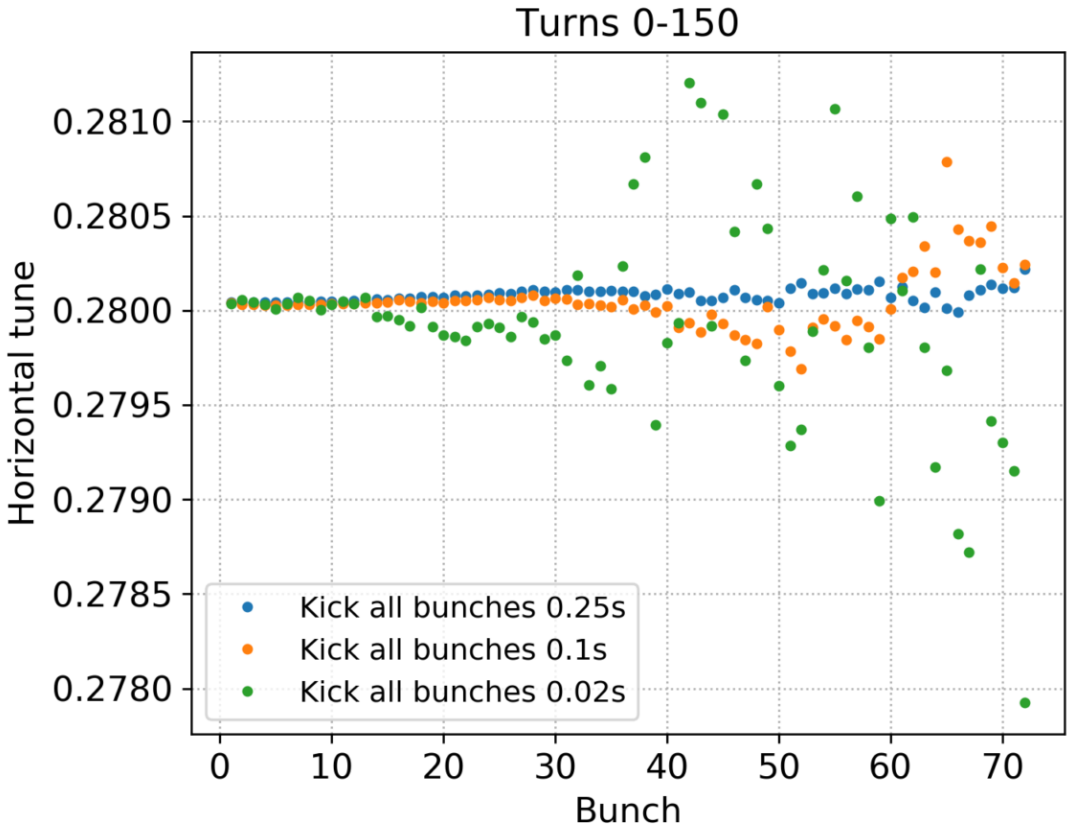




Dependence on kick size

The previous studies were done with initial displacements of 0.25 beam sigma

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



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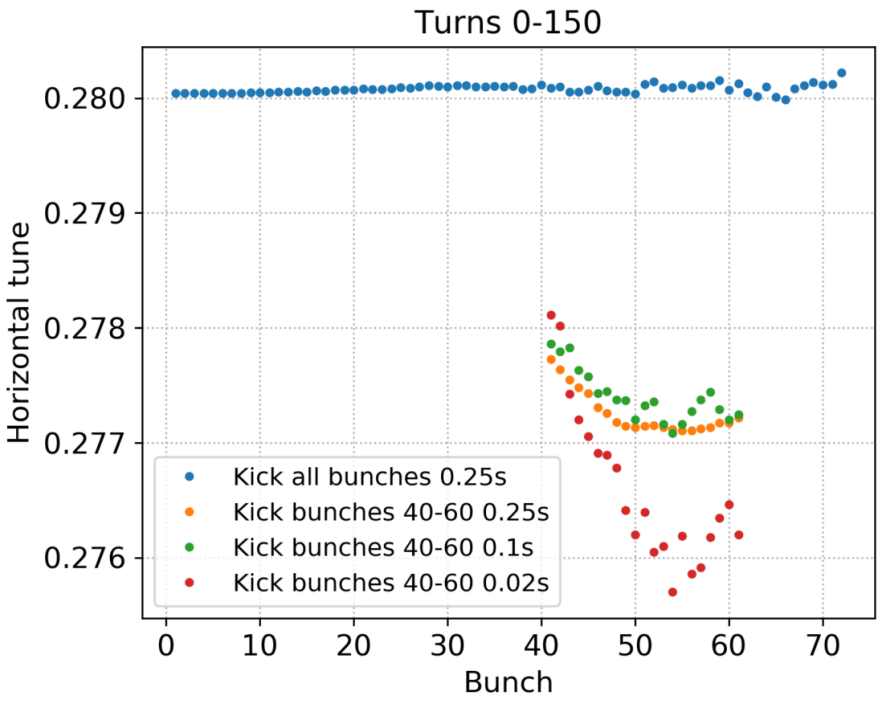
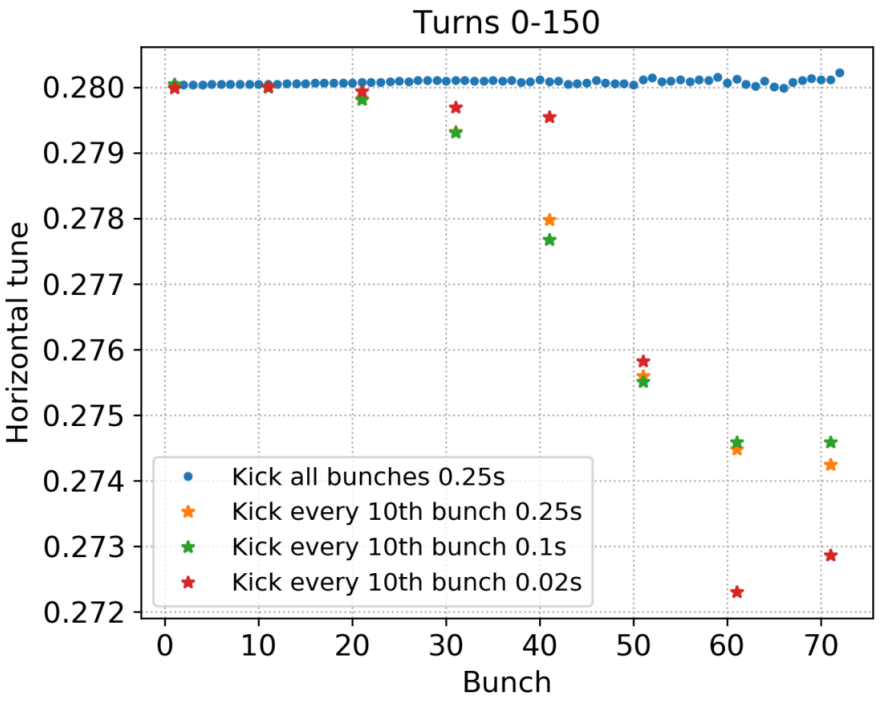
- Apart from that, no clear trend is visible in the effect on the tune shift





Summary & Outlook

Tune shifts from e-cloud in the LHC dipoles (max values)							
450 GeV				6.5 TeV			
1.1e11		2.3e11		1.1e11		2.3e11	
H	V	H	V	H	V	H	V
2e-4	3e-3	2e-3	2e-3	1e-5	2e-4	1e-4	1e-4

- 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
  - Individually kicked bunches acquire a negative tune shift that can be at least an order of magnitude larger than the tune shift when the full train is kicked

- The vertical bunch-by-bunch tune shift is positive and corresponds to the single bunch tune shift

- The effect of quadrupoles on both beam stability and tune shifts still to be considered