Results from the MD #11786 Loss of Landau Damping Thresholds

M. Zampetakis

T. Argyropoulos, R. Calaga, H. Damerau, L. Intelisano,
B. E. Karlsen-Bæck, I. Karpov, H. Timko

Acknowledgements: S. Albright, A. Lasheen, and CPS/SPS/LHC OP teams

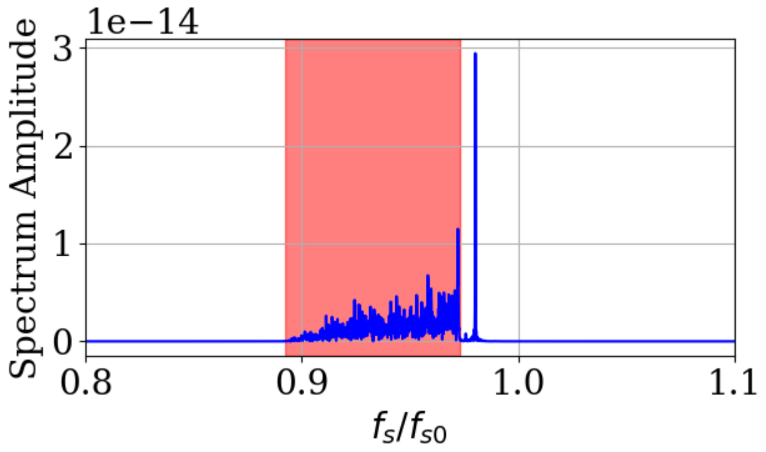
Outline

- Introduction
- LHC MD #11786: Thresholds of longitudinal loss of Landau damping
  - Preliminary results
  - Comparison with simulations
- Conclusions & next steps

Introduction

Landau damping is an efficient beam stabilization mechanism

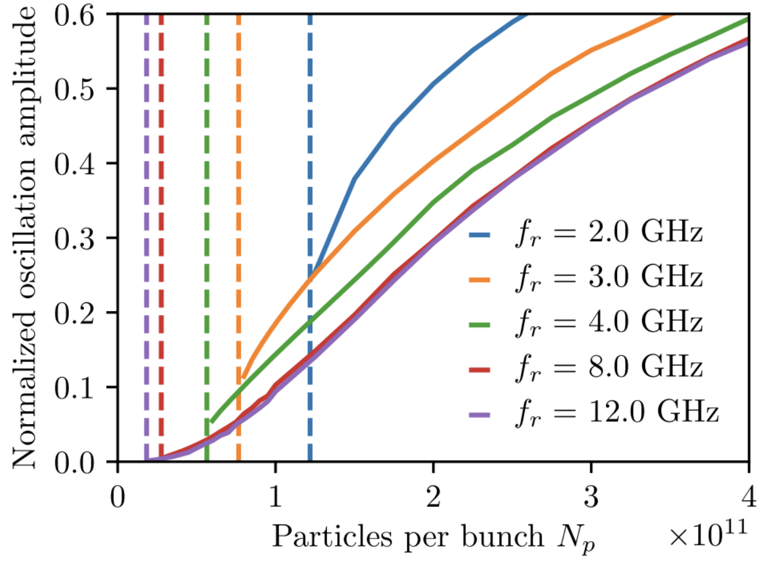
- Damps the coherent oscillations of the bunch
- Caused by the bunch frequency spread
- When the frequency of the coherent bunch oscillations moves outside of the incoherent frequency band of the bunch ⇒ Loss of Landau damping (LLD)



Two important parameters for the LLD[1]:

- The **effective cut-off frequency** of the broad-band impedances and the **effective Im(Z/n)** affect the threshold of the single-bunch LLD mechanism
- The **effective cut-off frequency** affects the amplitude of the persisting bunch oscillations

$$N_p^{th} = -\frac{\pi V_0 \cos(\varphi_{s0})\varphi_{max}^5}{32qh^2\omega_0\mu(\mu+1)\chi(y_{max},\mu)(\mathrm{Im}Z/k)_{eff}}$$



[1] I. Karpov, T. Argyropoulos, E. Shaposhnikova, *Phys. Rev. Accel. Beams* **24**, 011002, 2021

MD on LLD Threshold 14/5/2024 & 7/6/2024

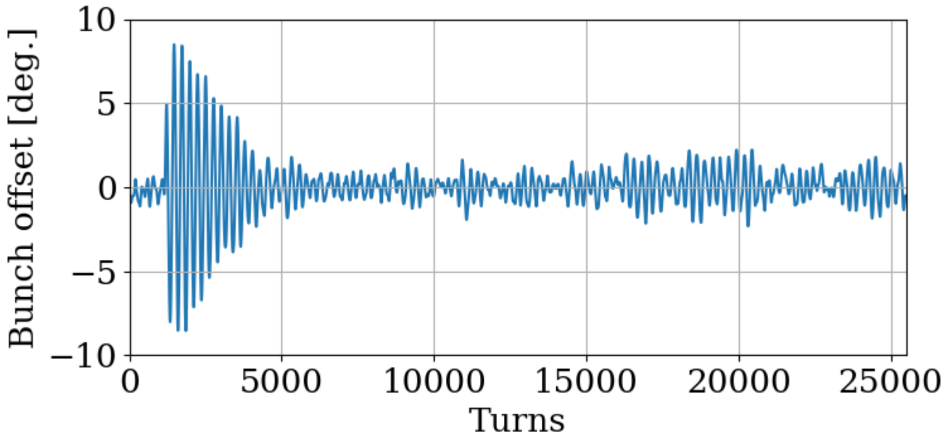
LHC MD #11786: Thresholds of longitudinal loss of Landau damping

- Scan the LLD thresholds in intensity and bunch length to better understand the longitudinal impedance model of (HL-)LHC (i.e., effective broad-band impedance and cut-off frequency)

Parameter space:

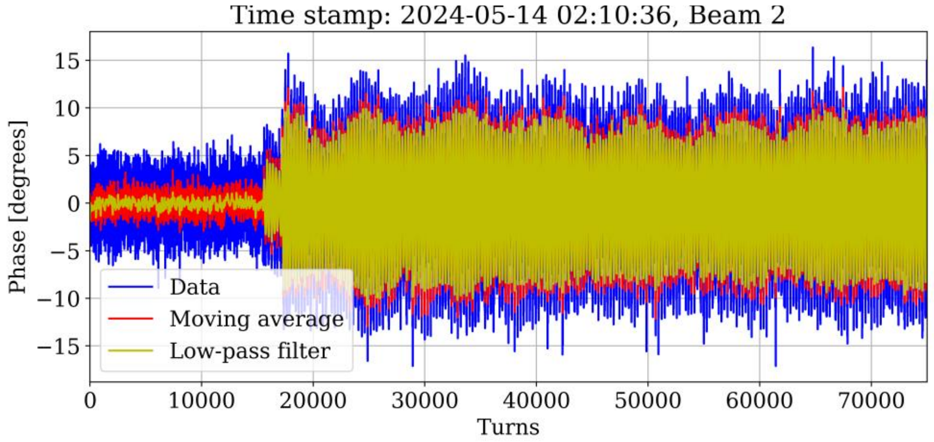
- LHC at Flat-bottom with constant RF voltage $V_{\mathrm{RF}} = 3.5$ MV
- Lowest possible longitudinal emittance from SPS, bunch length of ~ 0.8 ns
- Single bunches with intensities of $5 \cdot 10^{9} - 7 \cdot 10^{10}$ p/b

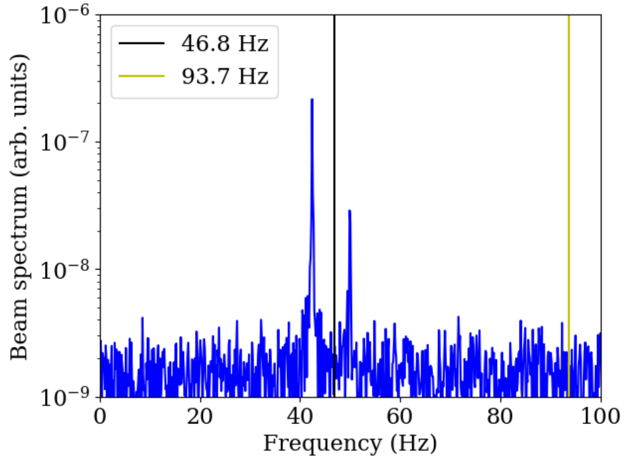
$$Inject \Longrightarrow filament \Longrightarrow phase\ kick \Longrightarrow observe \Longrightarrow dump$$



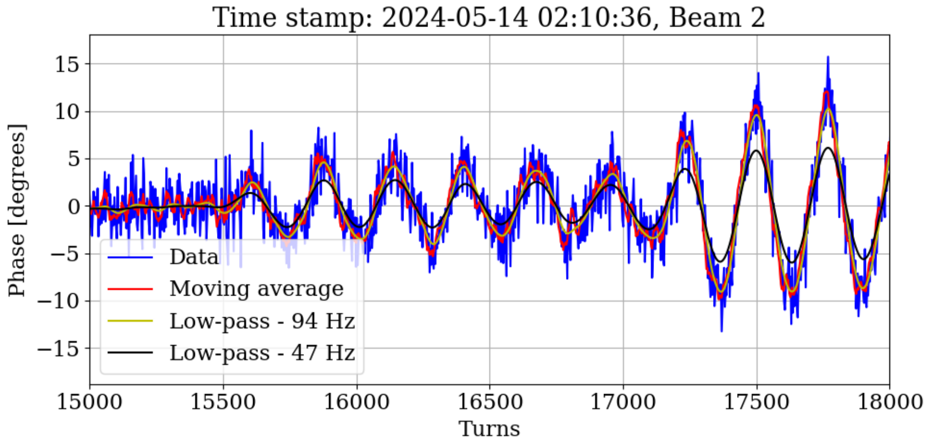
Beam spectrum and analysis

A striking example:





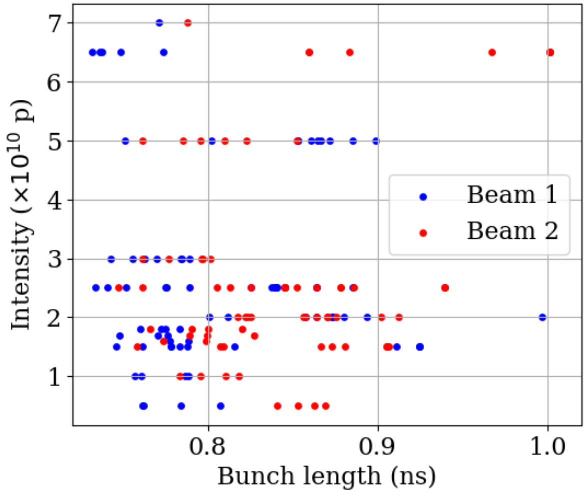
- Two peaks observed in the spectrum
  - At $f_{s0} = 43.7$ Hz or slightly below, depending on intensity
  - At 50 Hz due to the electrical network
- Low-pass filter $f_c = 93.7$ Hz seems to be accurate
- Low-pass filter $f_c = 46.8$ Hz to remove the 50 Hz band gives lower amplitude

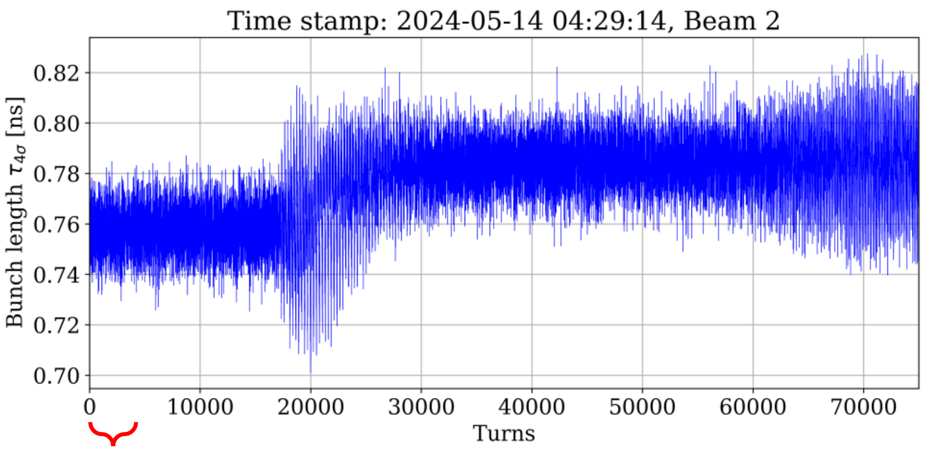


Preliminary results

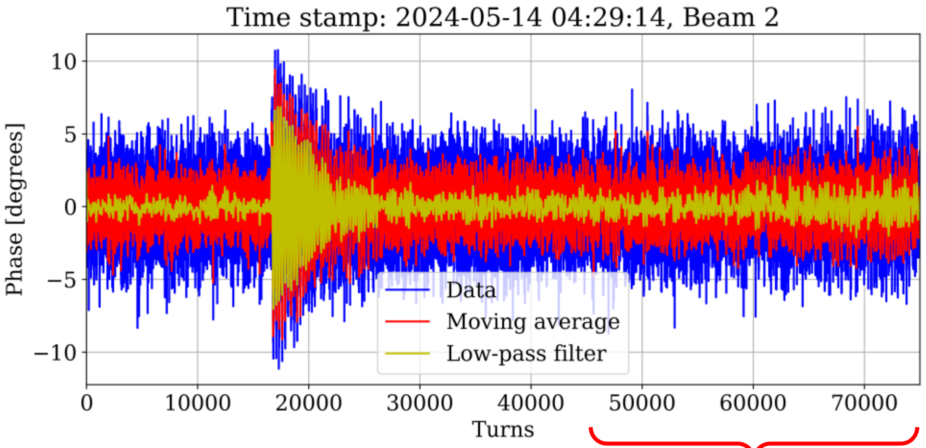
Disclaimers:

- Intensity is the requested and not the measured
- Background oscillations are not considered
- Data is not filtered in terms of kick strength (0°, 2°, 5°)
- Initial bunch length: the average over the first 3000 turns
- Maximum oscillation amplitude for the last 30000 turns (filtered)



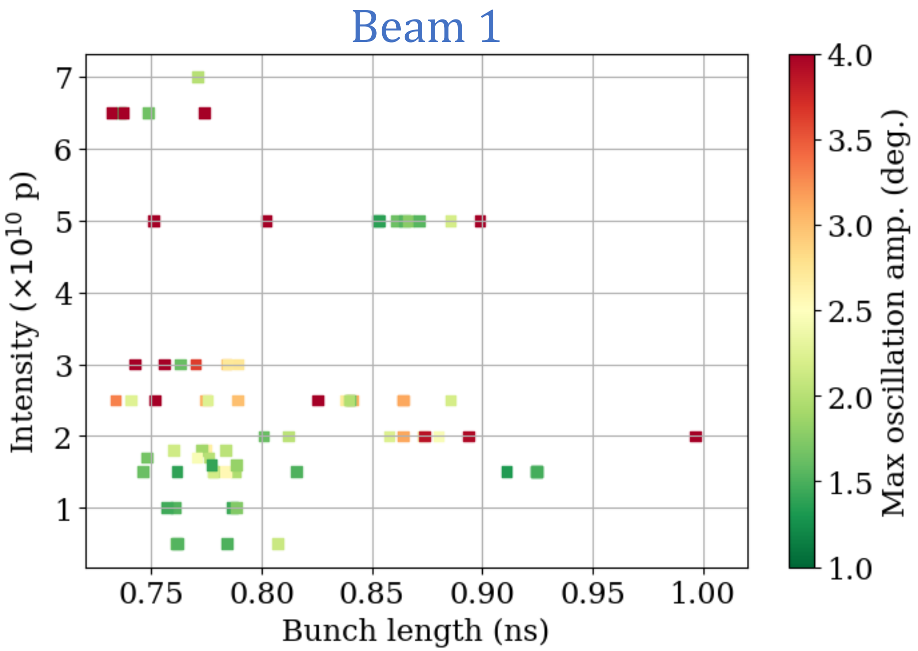


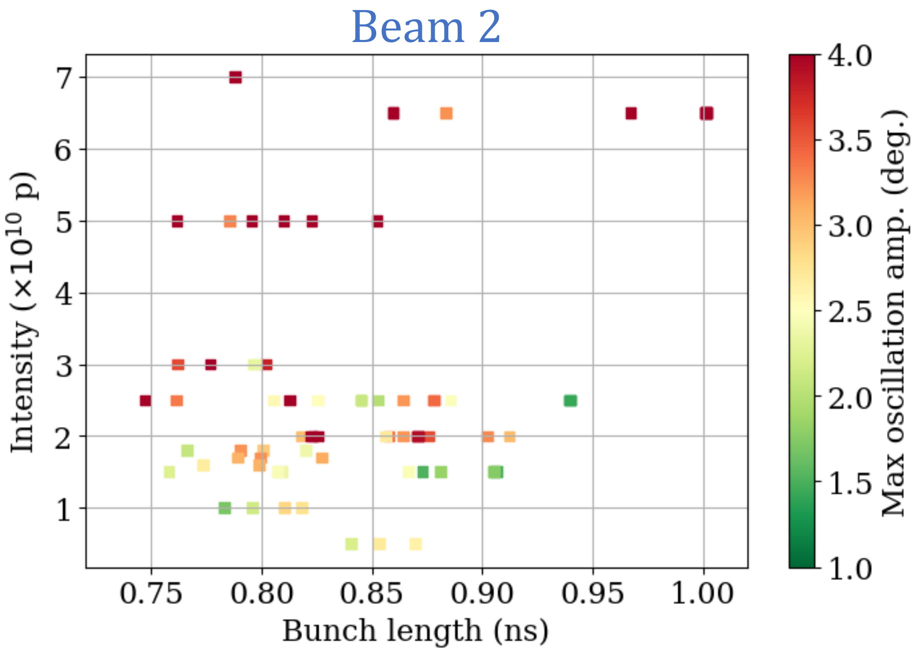
Initial bunch length



Max oscillation amplitude

Preliminary results

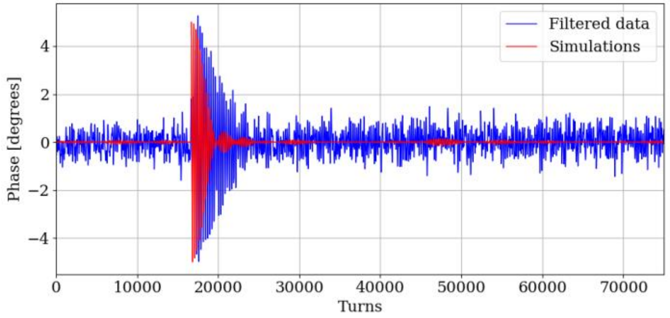


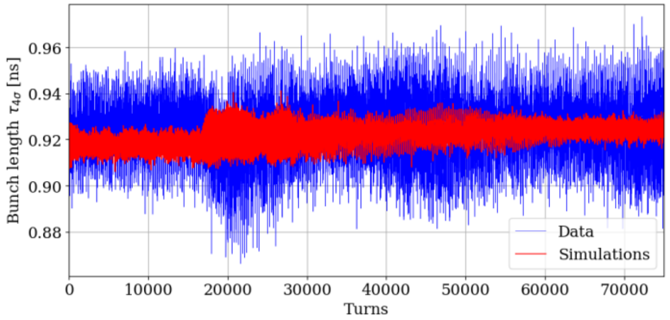


- For $\tau_{4\sigma} = 0.8$ ns, the LLD threshold is expected to be around $1.5 - 1.7 \cdot 10^{10}$ p/b with the current impedance model
- Results appear to be more evident for Beam 2
- Further analysis is required to consider the strength of the kick and the real intensity

Comparison with simulations

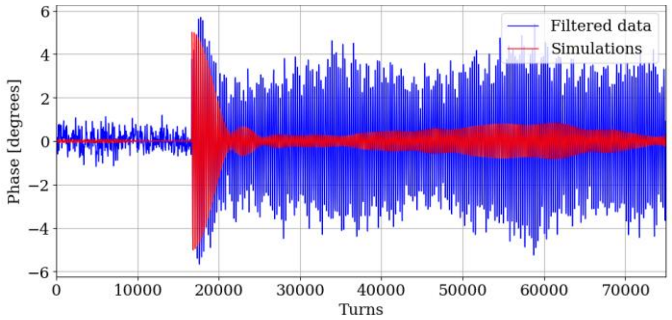
Case 1: Beam 1, $\tau_{4\sigma} = 0.91$ ns, $N_p = 1.5 \cdot 10^{10}$ p/b, below the LLD threshold

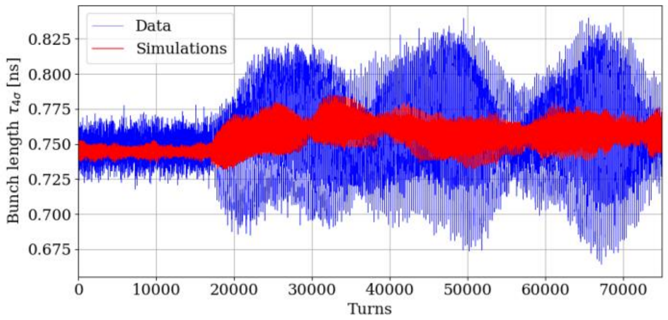




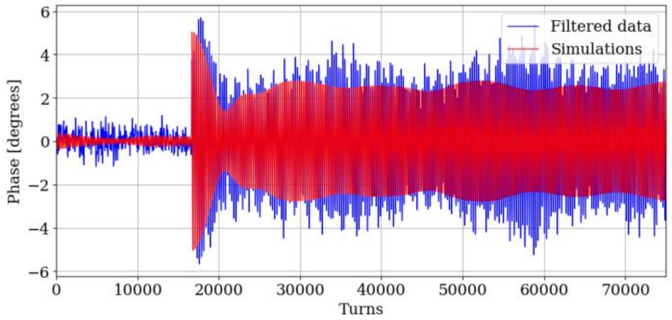
- Simulated in BLonD with $f_r = 5$ GHz and a BB impedance of $Z/n = 0.082\ \Omega$ to get the effective impedance of the full model of $\mathrm{Im}(Z/n)_{\mathrm{eff}} = 0.069\ \Omega$
- Good agreement

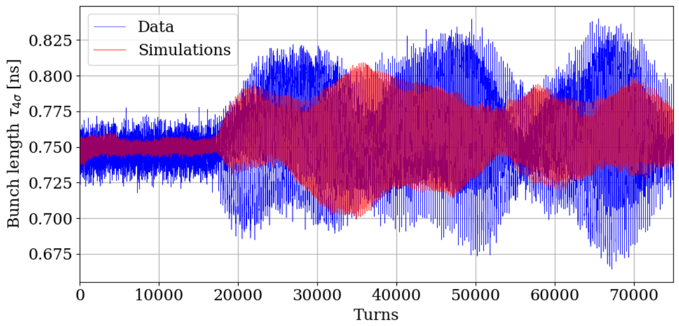
Case 2: Beam 2, $\tau_{4\sigma} = 0.75$ ns, $N_p = 2.5 \cdot 10^{10}$ p/b, above the LLD threshold





- $f_r = 5$ GHz, $\mathrm{Im}(Z/n)_{\mathrm{eff}} = 0.069\ \Omega$
- Measurements show larger oscillation amplitudes, cannot be explained by the simulations

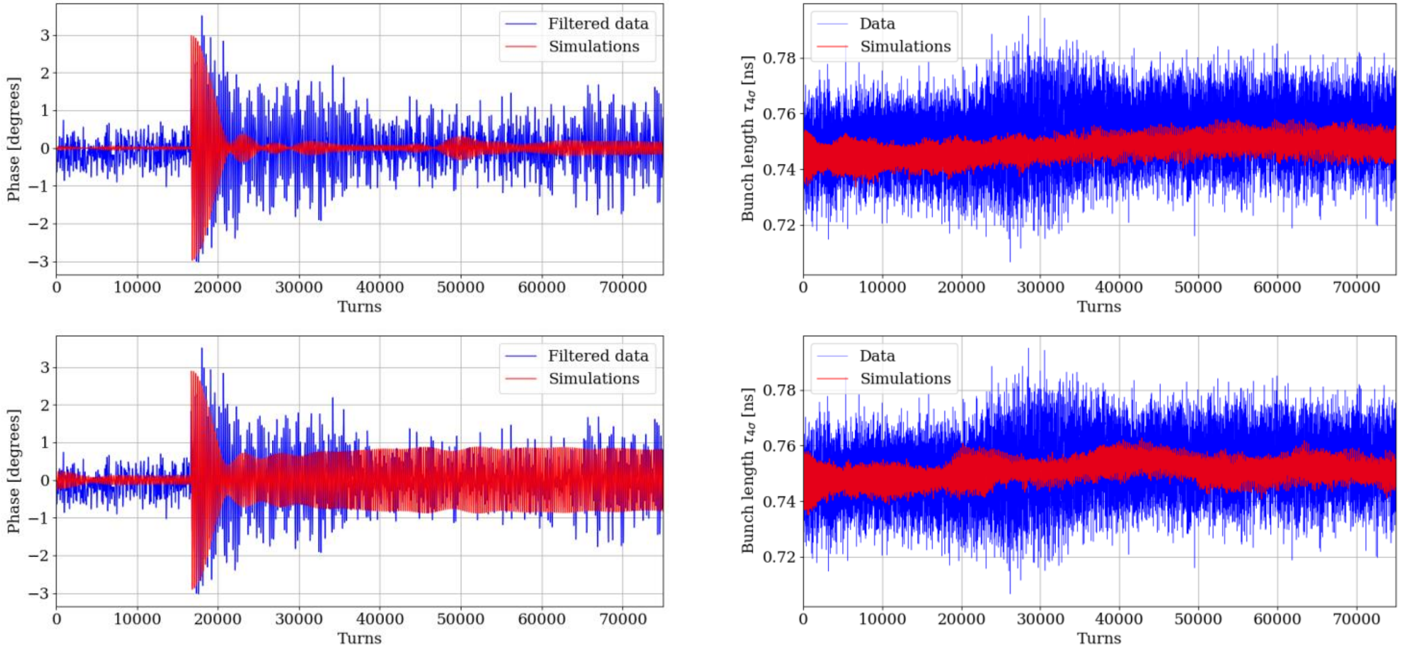




- Maintain the LLD threshold but increase the oscillation amplitudes: $f_r = 2.5$ GHz, $\mathrm{Im}(Z/n)_{\mathrm{eff}} = 0.13\ \Omega$
- Better agreement

Comparison with simulations

Case 3: Beam 1, $\tau_{4\sigma} = 0.74$ ns, $N_p = 1.7 \cdot 10^{10}$ p/b, above the LLD threshold

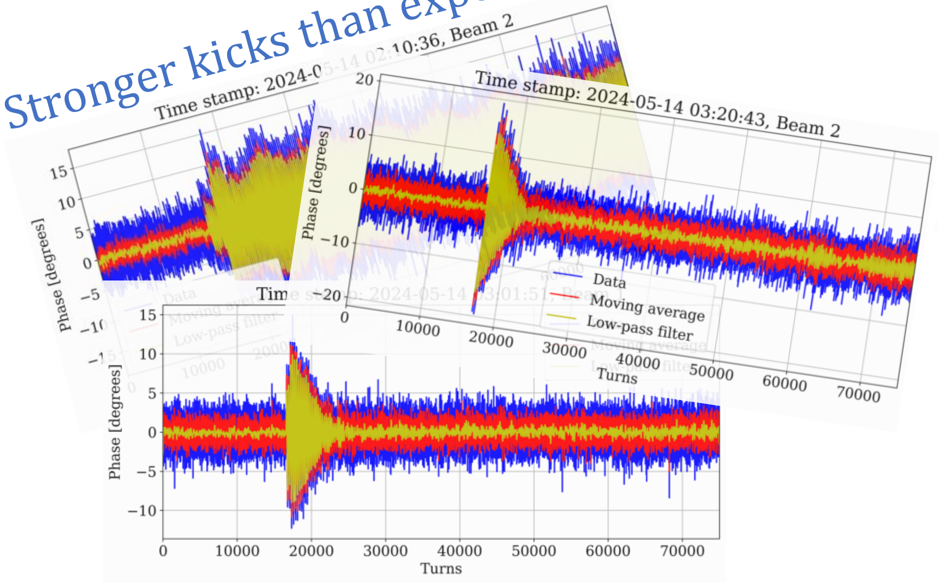


- $f_r = 5$ GHz, $\mathrm{Im}(Z/n)_{\mathrm{eff}} = 0.069\ \Omega$
- Measurements show larger oscillation amplitudes, cannot be explained by the simulations

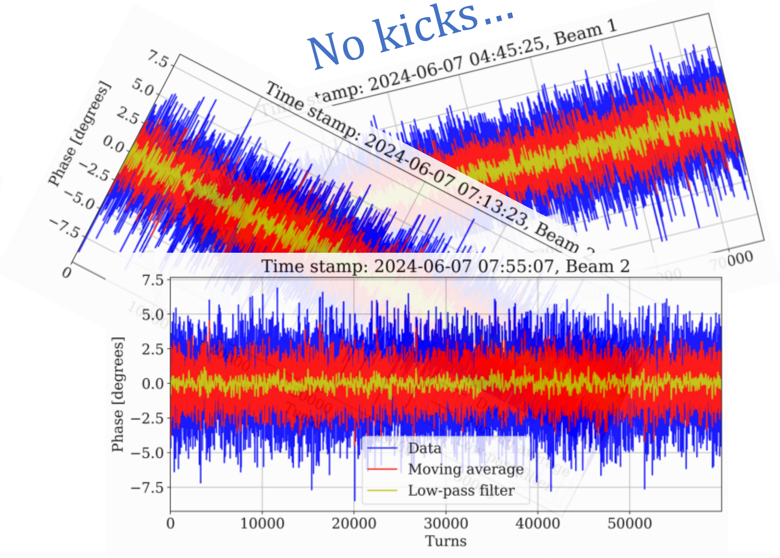
- Maintain the LLD threshold but increase the oscillation amplitudes: $f_r = 2.5$ GHz, $\mathrm{Im}(Z/n)_{\mathrm{eff}} = 0.13\ \Omega$
- Better agreement

Not everything is perfect…

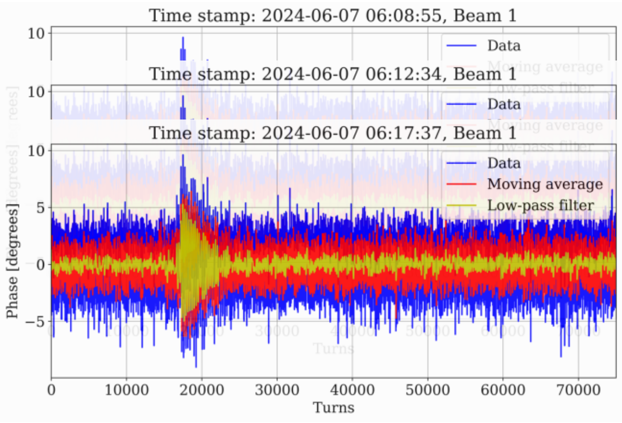
Stronger kicks than expected…



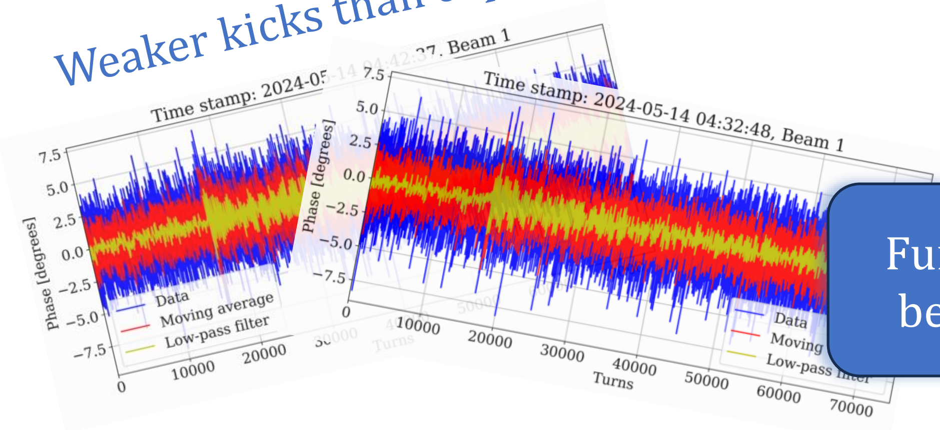
No kicks…



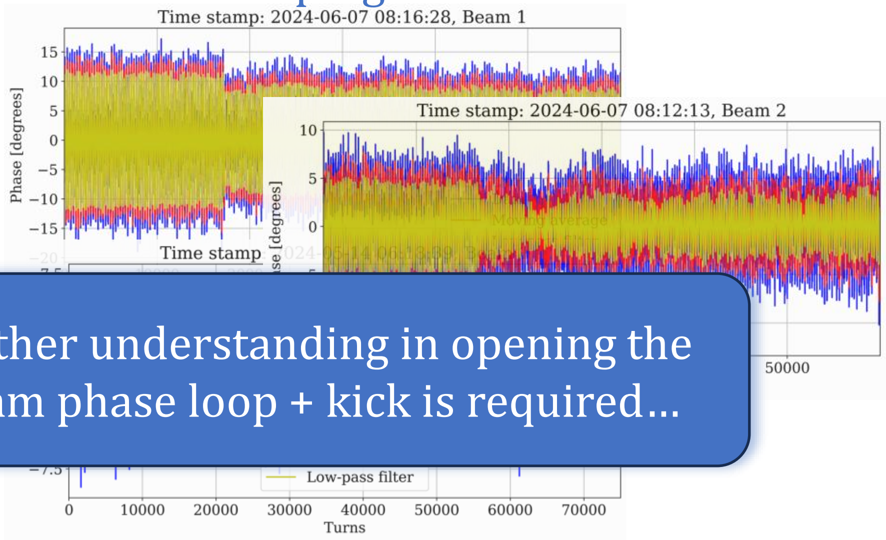
Identical acquisitions…



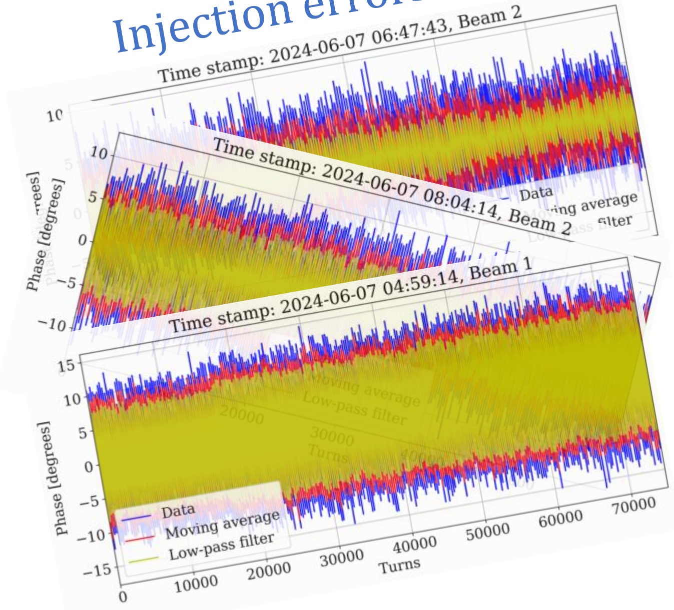
Weaker kicks than expected…



“Damping” kicks…



Injection errors…



Further understanding in opening the beam phase loop + kick is required…

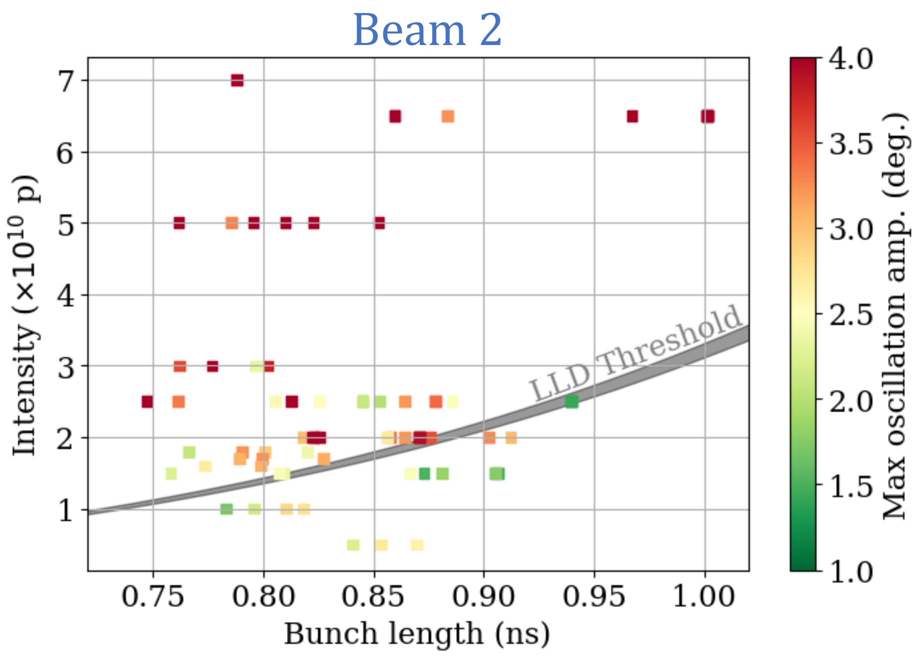
Conclusions & next steps

- A summary of some preliminary results from the LHC MD #11786: Thresholds of longitudinal loss of Landau damping was presented
- Additional careful analysis of each individual case is required
  - ⇒ Include exact intensity
  - ⇒ Consideration of the kick strength (0°, 2°, 5°) of each case
  - ⇒ Further filtering of the background noise and oscillations
  - ⇒ Discard identical or false acquisitions
- Further undestanding is required for the procedure of opening the beam phase loop and applying the phase kick, to accuretely apply the desired phase kick
- LLD threshold appears to be close to the expected regime
- Investigation on the validity of the longitudinal impedance model is required, to justify the discrepancy between the measurements and the simulations

Thank you!!!

Backup Slides

Preliminary results



- LLD Threshold calculated for μ = 1.5-2, $V_{\text{RF}} = 3.5$ MV, $\text{Z}/n = 0.07\ \Omega$ and $f_c = 5$ GHz
- This calculation method might have up to 30% error in some cases