Refining the LHC Longitudinal Impedance Model

M. Zampetakis, T. Argyropoulos, Y. Brischetto, R. Calaga, L. Giacomel, B. E. Karlsen-Baeck*, I. Karpov, N. Mounet, B. Salvant, H. Timko

CERN, Geneva, Switzerland

**also, at the Department of Physics, Sapienza Università di Roma, Rome, Italy*

Research supported by the High Luminosity LHC project

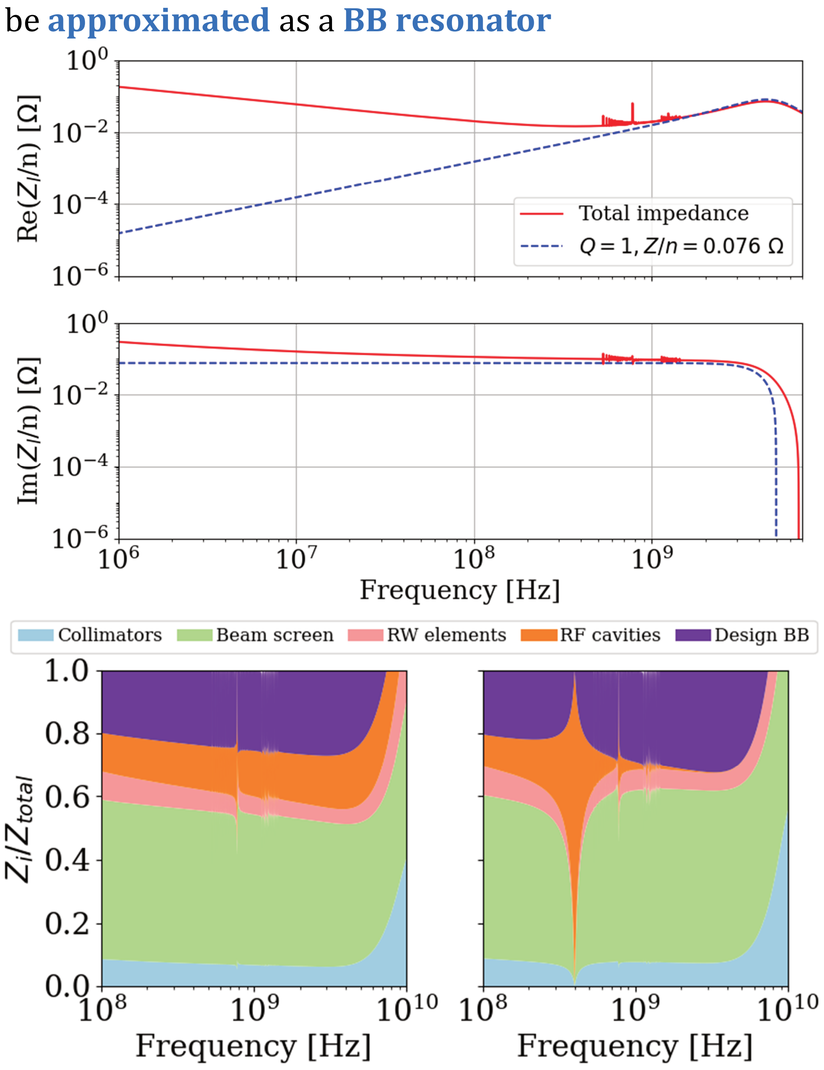
Abstract

Modelling the longitudinal impedance for the Large Hadron Collider (LHC) is an essential input for beam dynamics studies, especially in view of its High-Luminosity upgrade. The main contributing devices from the existing longitudinal impedance model are identified and their refinement is discussed. Loss of Landau damping (LLD) simulations are performed to investigate the dependence of the stability threshold on the completeness of the impedance model and its broad-band (BB) cut-off frequency. Beam measurements are planned to estimate the cut-off frequency by probing the LLD threshold in operation

Previous and Refined Impedance Model

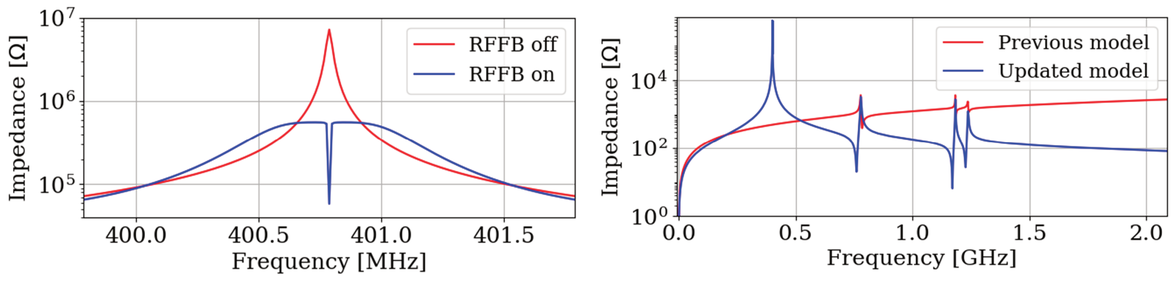
The LHC impedance model has seen several iterations and refinements [1-3].

- Implemented using the *Python Wake and Impedance Toolbox (PyWIT)* [4] and the *Impedance Wake 2D (IW2D)* [5] code
- Most of the relevant LHC devices are included:
  ⇒ *E.g., collimators, vacuum chambers, beam screens, design BB impedance, experimental chambers, RF cavities with higher-order modes (HOMs)*
- **Elements** with the **largest impact** on **transverse** beam stability
- Can be **approximated** as a **BB resonator**



Main contributions:

- RF cavities
  ⇒ Included the **fundamental mode** with **RF feedback**



- Design BB impedance [6]
  ⇒ **Investigating** for any **updated** device
- Beam screen
  ⇒ **Wire measurements** ongoing to verify their model and **characterize** the behavior around the **cut-off frequency**

Conclusions

- The present impedance model was shown, and the **main contributions** were **identified**
  ⇒ **Ongoing work** to refine the **beam screen** model and the **design BB** impedance
  ⇒ Included the **fundamental mode** of the **RF cavities** with **RF feedback**
- A **BB impedance** model is a **good approximation** to describe the **longitudinal LLD** of a single bunch
- **LLD** can be deployed in beam measurements to **estimate** the **cut-off frequency** and the $\mathbf{Im}(\boldsymbol{Z/n})$
- **Measurement technique** has been **successfully demonstrated**

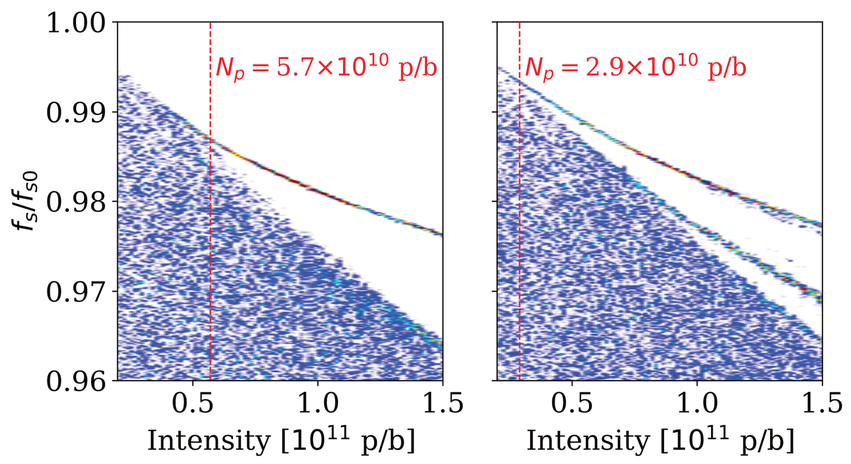
Loss of Landau Damping

LLD can be used to **determine** the **BB part** of the impedance [7].

- Intensity/emittance threshold ⟹ effective cut-off frequency
- Undamped phase oscillations amplitude ⟹ effective $\mathrm{Im}(Z/n)$

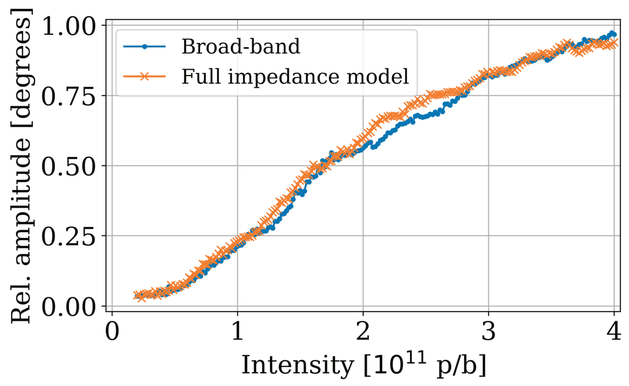
Using the Beam Longitudinal Dynamics (BLonD) [8] simulation suite, two intensity scans were performed at the LHC flat-bottom*:

- Cut-off frequencies of 4 GHz and 8 GHz
- **Higher cut-off frequency** leads to a **lower LLD threshold** [7]



Probing LLD in simulations*: **Apply a 1° phase kick** to a steady-state bunch and **observe** the evolution of the resulting **oscillation amplitudes**

- Impedance models: BB resonator vs. Full model, with $f_c = 4$ GHz
- **The BB impedance contributes most to the LLD**



$V_{RF} = 6$ MV, BB impedance of $Z/n = 0.07\ \Omega$, single bunches with a binomial macro-particle distribution of exponent μ=2 and bunch length of $\tau_{4\sigma} = 0.82$ ns (FWHM scaled to 4σ)

Measurements

Beam measurements** at the LHC flat-bottom to study the **LLD mechanism

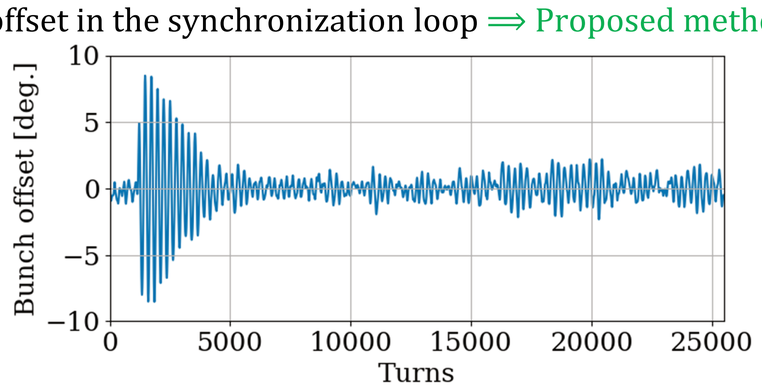
Single bunches from SPS will be injected into the LHC with:

- Intensities of $(0.5 - 2.4) \times 10^{11}$ p/b
- Bunch lengths of $(0.8 - 1.5)$ ns

Inject ⟹ filament ⟹ open phase loop ⟹ phase kick ⟹ observe

Beam time was invested to find the right technique to apply a phase kick:

- Phase error at injection ⟹ mix of dipole/quadrupole oscillations
- Phase offset in the synchronization loop ⟹ Proposed method; step-like



Systematic measurements still to be performed

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[3] B. Salvant *et al.*, "*LHC Impedance Model: Experience with High Intensity Operation in the LHC*", HB2012, Beijing, China, 2012
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[6] O. S. Bruning *et al.*,"*LHC Design Report*", CERN Yellow Reports: Monographs, CERN, Geneva, Switzerland, 2004
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michail.zampetakis@cern.ch

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