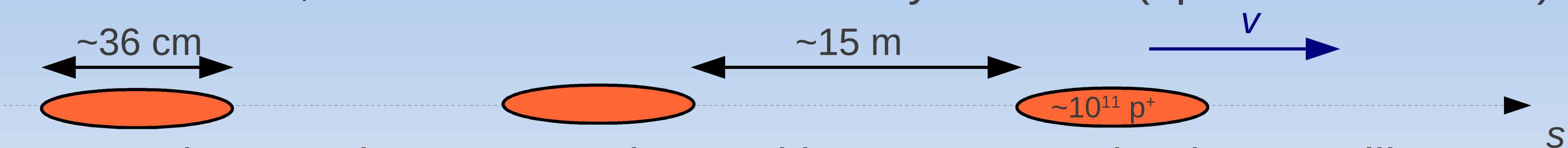
Some coupled-bunch instabilities data, and codes to simulate them

Nicolas Mounet

Mainly extracted from EPFL PhD thesis # 5305 - Supervisors: Elias Métral & Leonid Rivkin

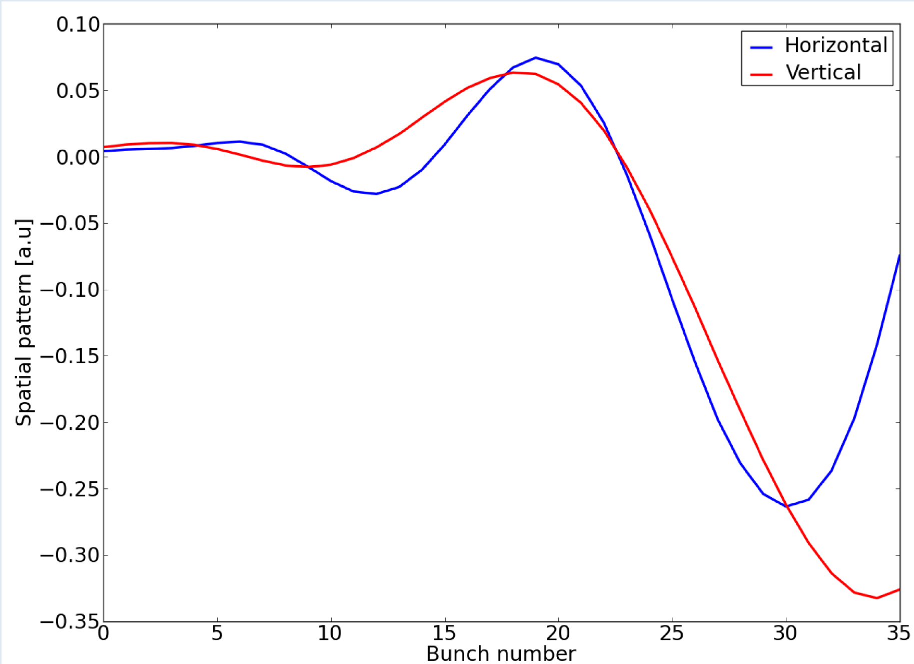
Coupled-bunch instabilities

- In the LHC, the beams are made of many bunches (up to 1380 in 2011)



Bunches can interact together and in some cases begin to oscillate.

Example with 36 bunches in the LHC: oscillation pattern along the bunch train (simulation result):

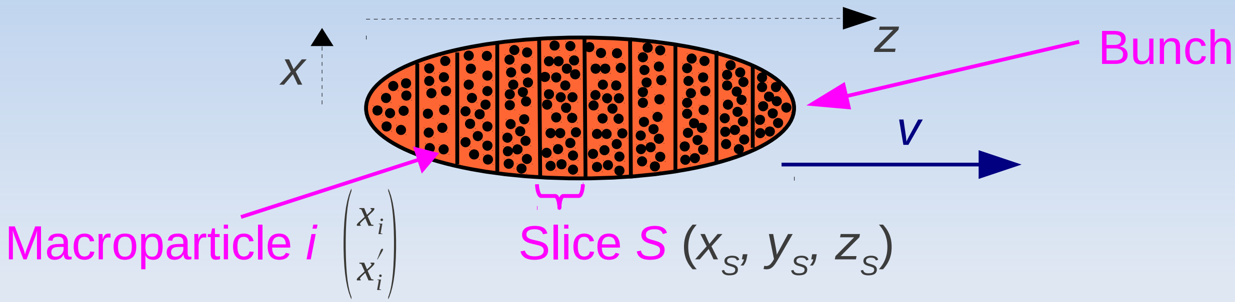


→ **Coupled-bunch instabilities**

- Must be damped by feedback system and/or Landau damping (otherwise beams are lost).
- Important to study them to know if damping mechanisms are sufficient.

Multibunch simulation code

- HEADTAIL: beam dynamics simulation code, using macroparticles
  - Pre-existing single-bunch version (*G. Rumolo et al*, PRST-AB, 2002):

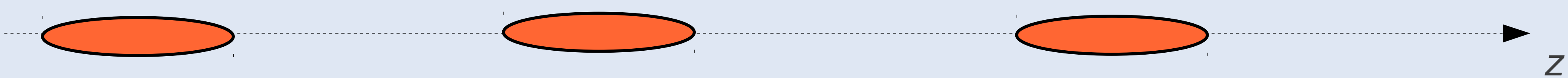


Each turn {
macropart. *i* receives kick from the wake of all preceding slices: $\begin{pmatrix} x_i \\ x_i' \end{pmatrix} \rightarrow \begin{pmatrix} x_i \\ x_i' + \Delta x_i'(x_S, x_{S_i}, z_S - z_{S_i}) \end{pmatrix}$

then it is transported through the machine lattice: $\begin{pmatrix} x_i \\ x_i' \end{pmatrix} \rightarrow M \cdot \begin{pmatrix} x_i \\ x_i' \end{pmatrix}$

(similar treatment for the other components of the macroparticle y_i, z_i).

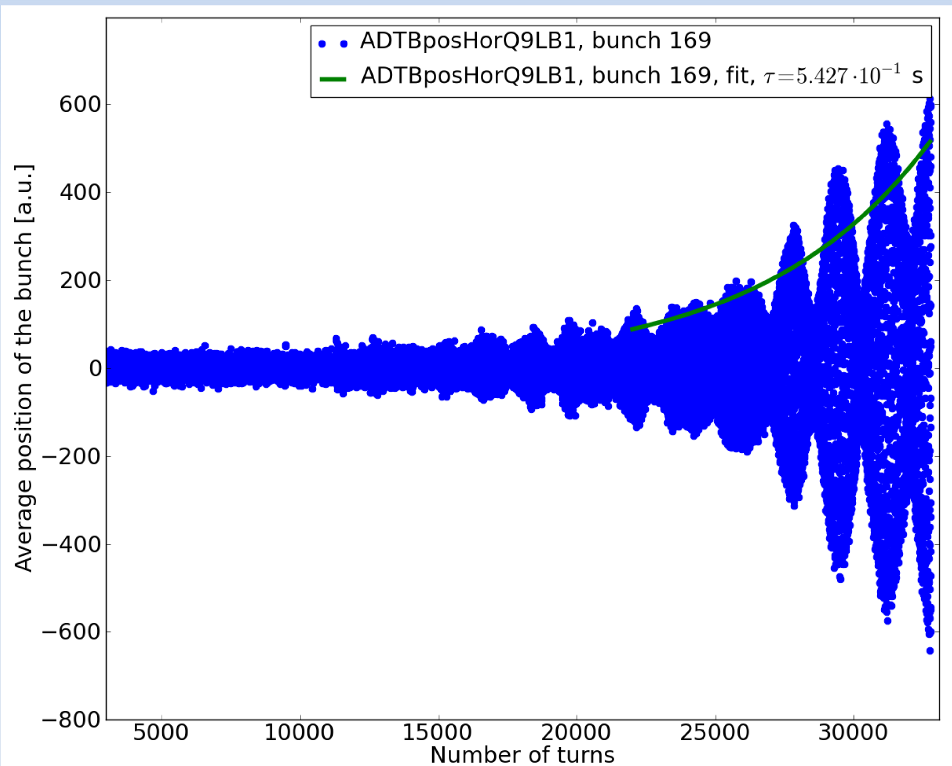
  - Extension of the code: allow several bunches + parallelization over the bunches (extensive use of EPFL clusters).



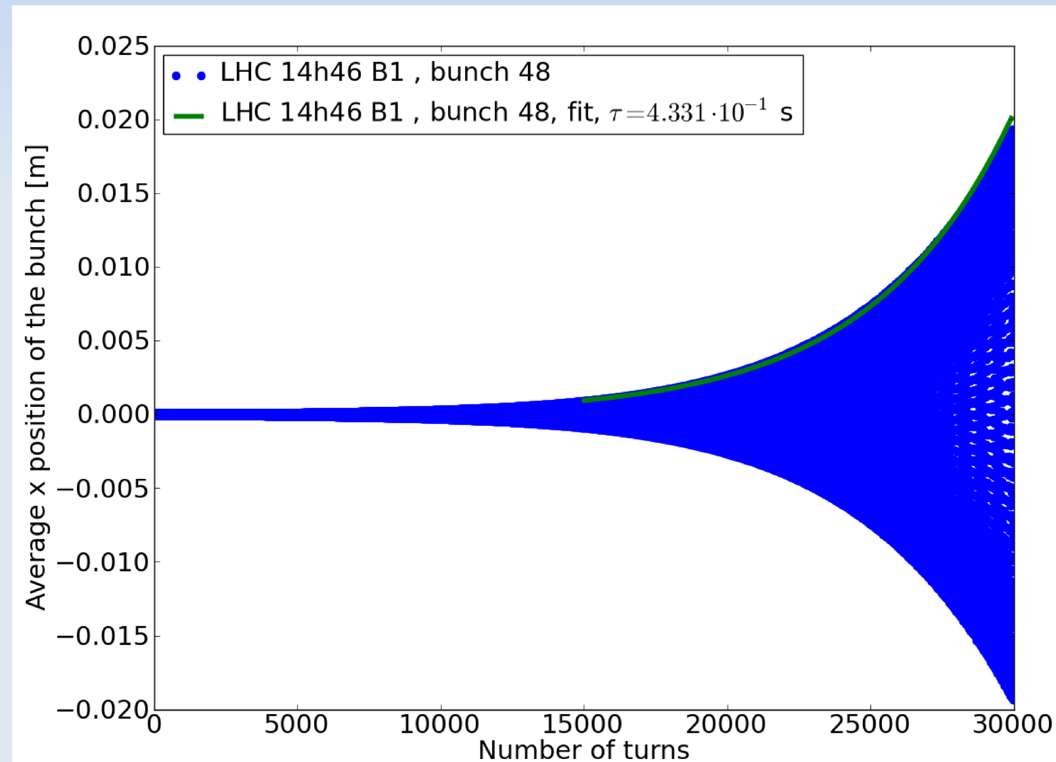
Parallelization quite efficient because each bunch can be treated independently → communication between processors only once per turn.

Comparisons between simulations and beam-based impedance measurements

- At 450 GeV/*c*, 12+36 bunches, switched off feedback for 2.5 s, with $Q'_x=0.4$ → coupled-bunch instability: here for the last bunch of the train



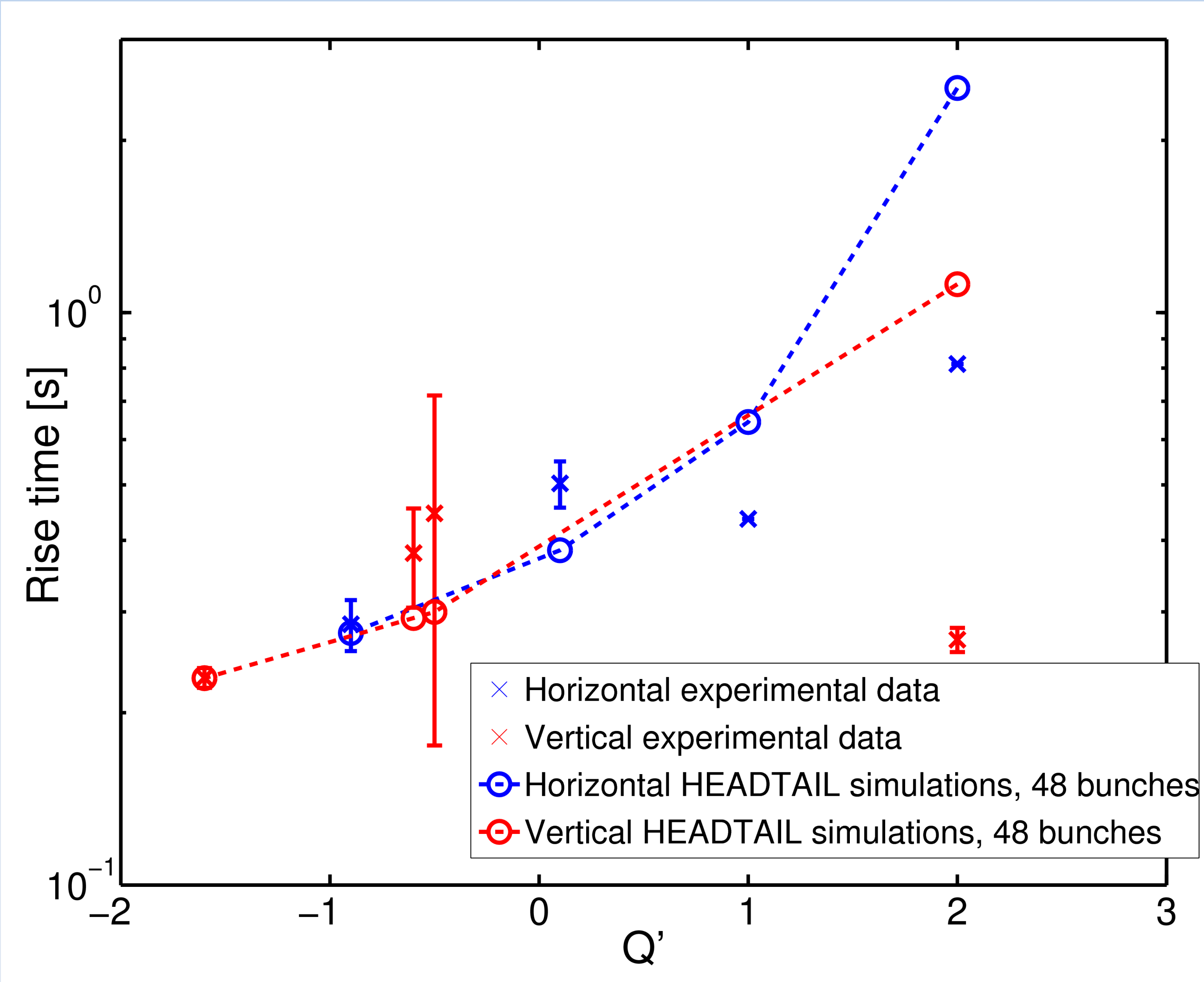
Measurement



Simulation

Comparisons between simulations and beam-based impedance measurements

- 12+36 bunches at 450GeV/*c*, coupled-bunch instability rise times measured vs. simulations (beam 2)



→ at this energy, measured rise times well reproduced by the model.

Note: at 3.5 TeV/c, measured rise times at a factor 2-3 from the model.

Another way to study instabilities

- Using a semi-analytical code that solves linearized Vlasov eq. assuming a small & single-harmonic perturbation of the distribution

  → DELPHI (for Discrete Expansion over Laguerre Polynomials and Headtail modes),

- Based on solution of Sacherer integral equation (Chao's book, Eq. 6.179) written as an eigenvalue problem:

  → using a decomposition over Laguerre polynomials of the radial function (idea from Besnier 1974, used then by Y. Chin in code MOSES - 1985),

  → including azimuthal & radial modes, and mode coupling (like MOSES),

  → including generalization to any kind of impedance, multibunch effects and damper (here we use a flat damper model, i.e. with constant wake),

  → not including Landau damping.