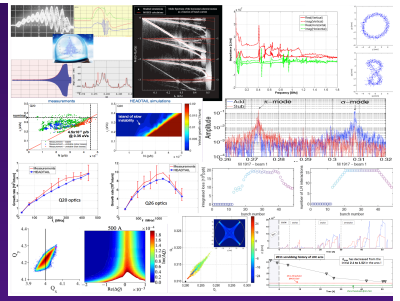
BEAM SIMULATIONS

Elias Métral (BE/ABP/HSC)



- **ABP = Accelerators and Beam Physics Group**
  - … Studying and understanding the beam dynamics over the complete CERN accelerator complex from the sources to the LHC …
  - … Development and maintenance of accelerator physics computer codes (e.g. MADX, SixTrack, PyECLOUD, PyHEADTAIL, PATH, etc.) …

Ongoing GPU (single-particle) studies by R. De Maria

- **HSC (as of 01/01/16) = Hadron Synchrotrons Coherent effects**
  - … Studies of the coherent effects limiting the performance of the present and future CERN accelerators (e.g. beam coupling impedance, space charge, beam-beam and electron cloud) and of their mitigation …

Ongoing GPU studies (PIC solver) by A. Oeftiger and S. Hegglin

  - … Development and maintenance of software tools to study coherent multiparticle beam dynamics (e.g. PyHEADTAIL, PyECLOUD, etc..) …

=> The parallelization strategies depend on the DATA DEPENDENCIES

- Plans
- (Some) achievements
- Challenges

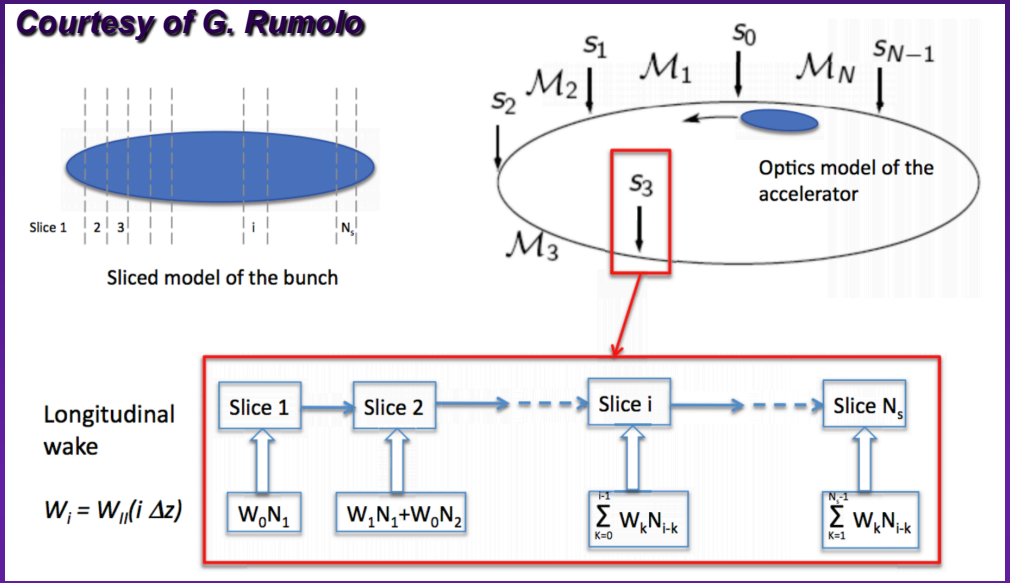
PLANS

1) Source (self-induced) perturbations we are studying

- **Interaction within the beam itself: SPACE CHARGE => PIC (Particle-In-Cell) Poisson solver needed to solve electric field self-consistently (e.g. PTC-ORBIT or PyORBIT)**
- **Interaction between the beam and its environment: IMPEDANCE (in frequency domain) or wake field (in time domain) => To be obtained from commercial codes (e.g. CST Particle Studio or HFSS)**
- **Interaction between the beam and another beam**
  - **Counter-rotating beam in a collider: BEAM-BEAM => PIC Poisson solver needed (e.g. COMBI or BeamBeam3D)**
  - **Another beam created: ELECTRON CLOUD => E- distribution usually calculated beforehand by means of an e- cloud build-up code (e.g. PyECLOUD). PIC Poisson solver also needed**

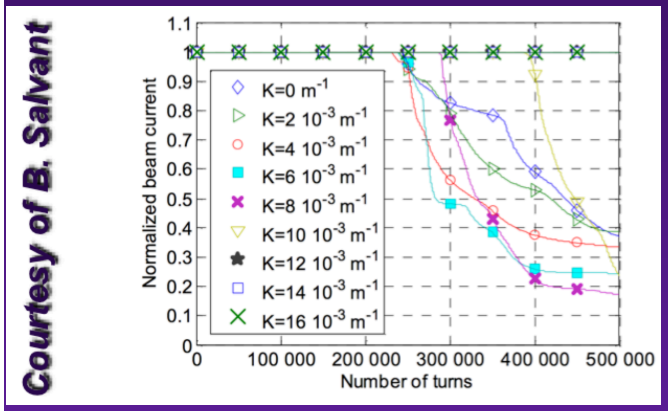
PLANS

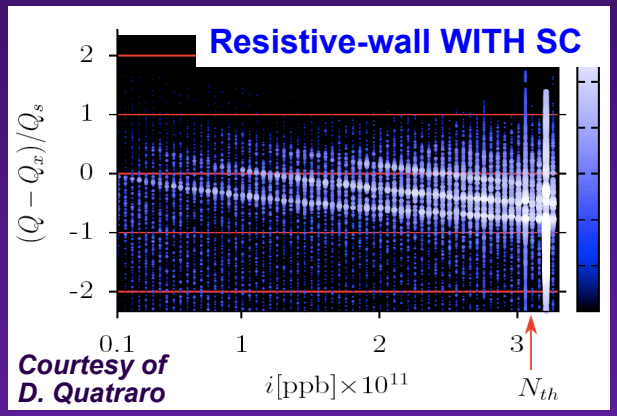
2) Beam dynamics studies

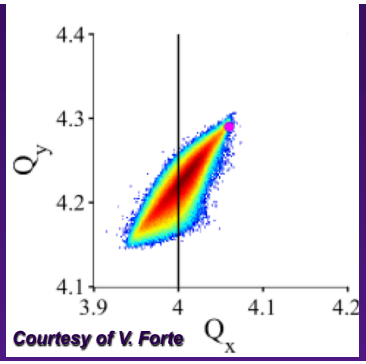


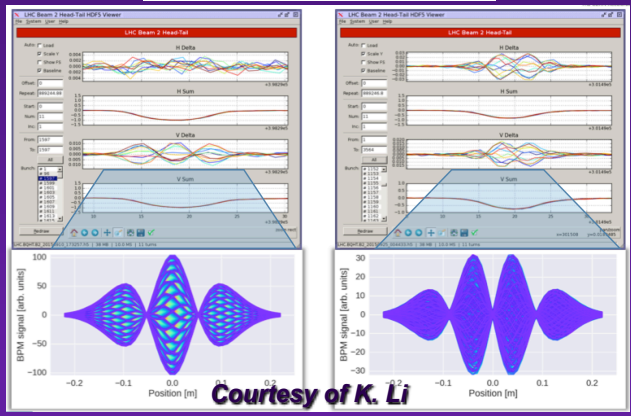
- Beam = Ensemble of bunches and Bunch = Ensemble of MacroParticles (up to several 1E6) in several longitudinal slices (up to several 1E2)
- Phase space coordinates of each MP (2 to 6) studied
- Beam initialization and transport along the accelerator => Transformation matrices describing the accelerator optical model
- Kicks (from the mechanism(s) under study) at some interaction points
- Longitudinal / transverse, single / multi bunch, single / multi turn

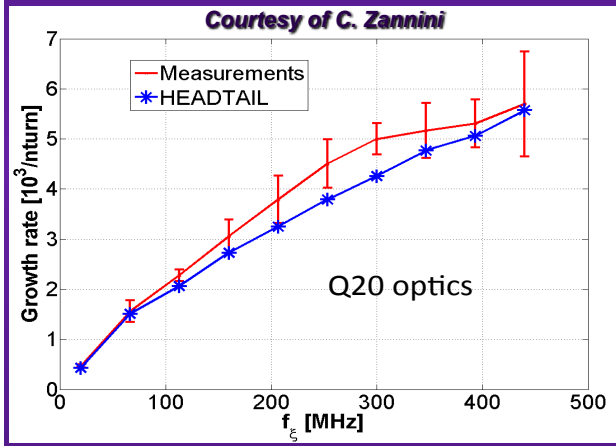
(SOME) ACHIEVEMENTS

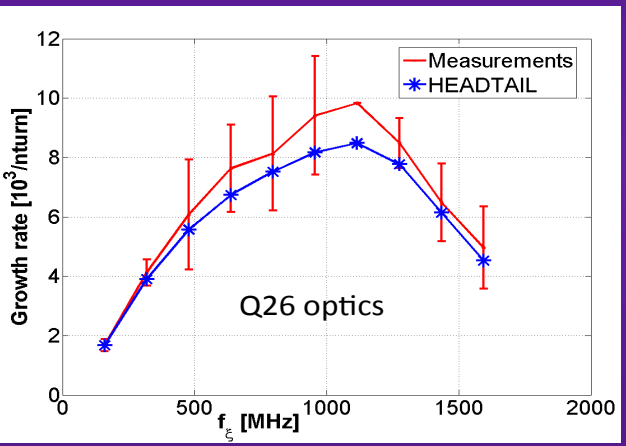


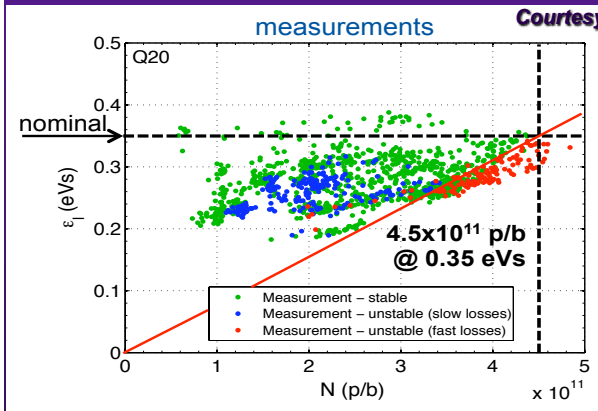


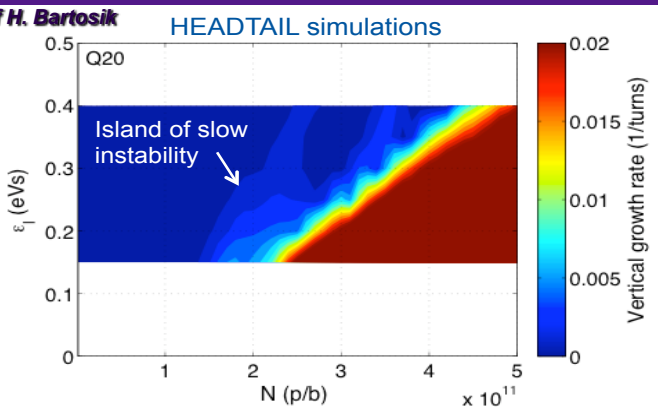


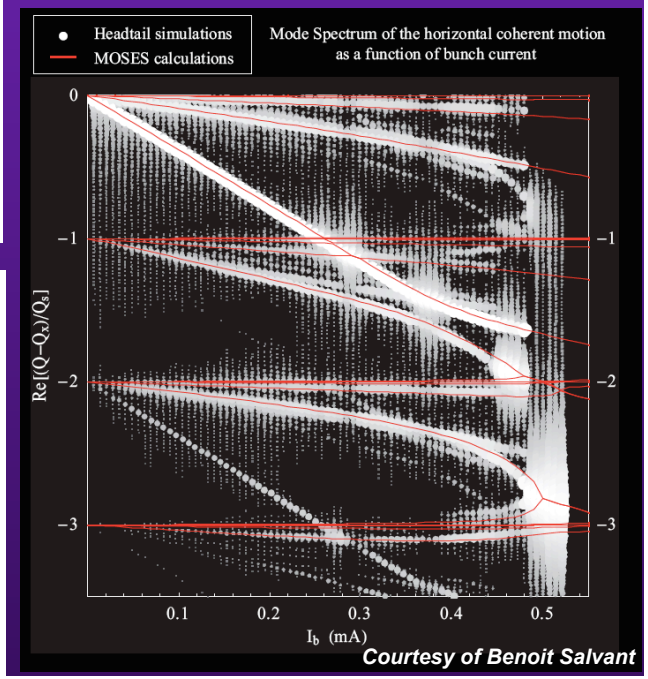












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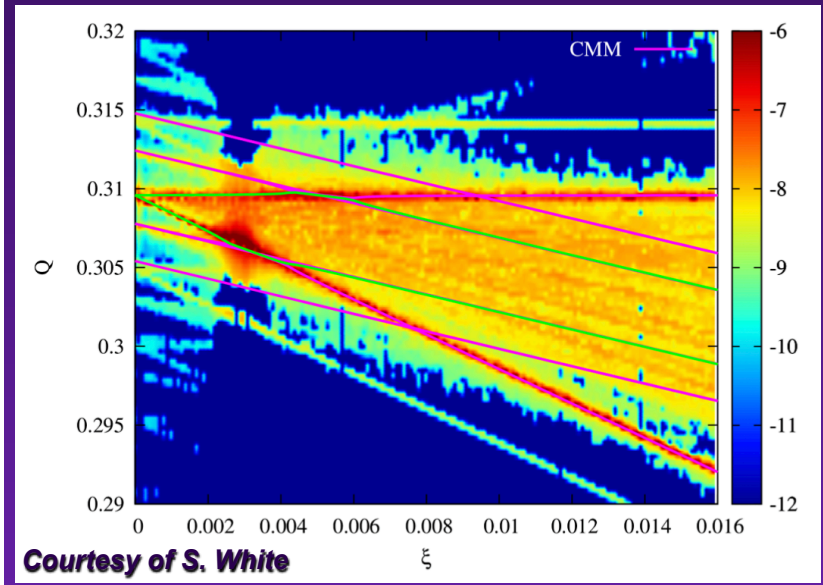
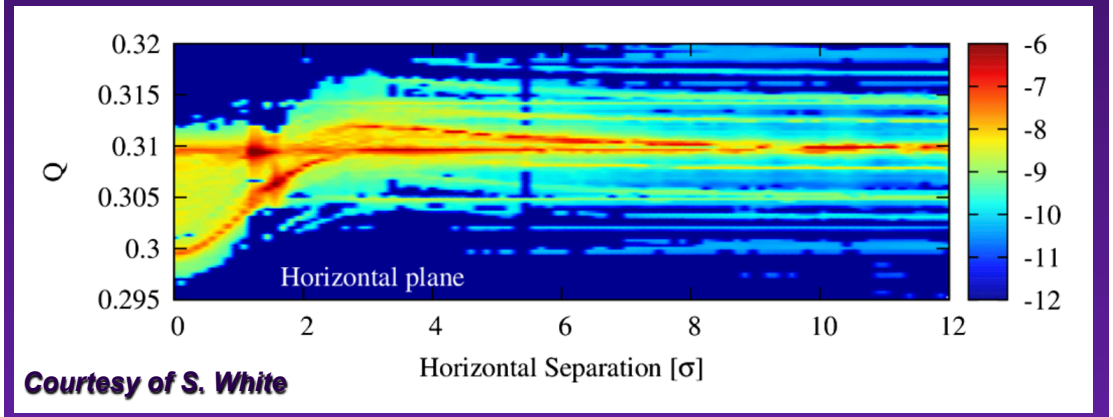


Courtesy of S. White



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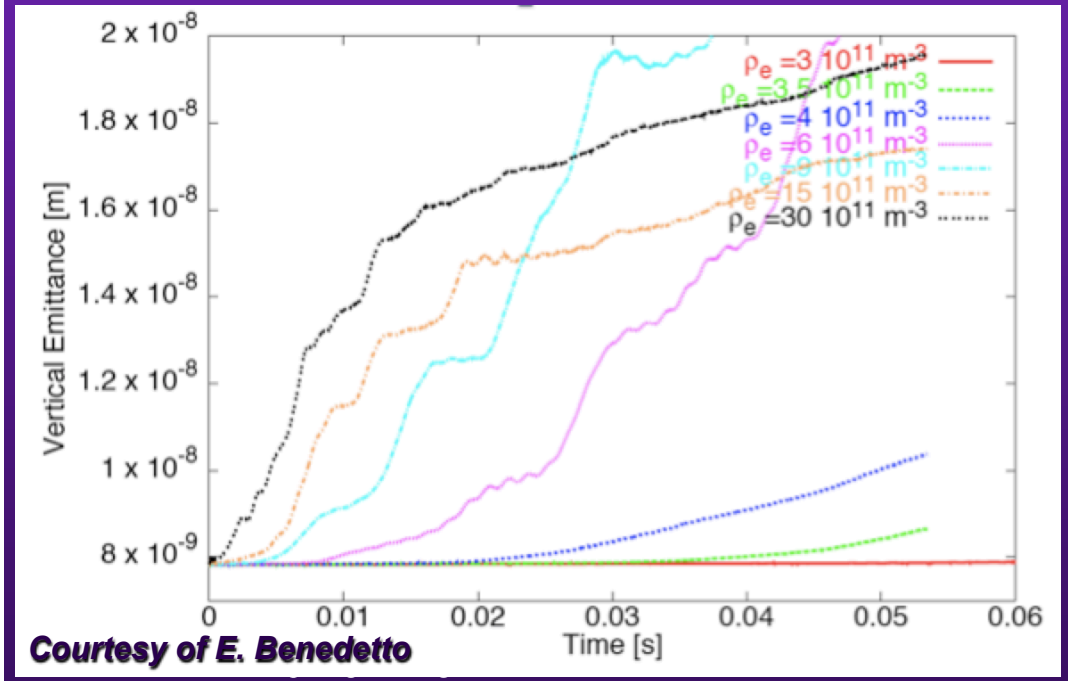
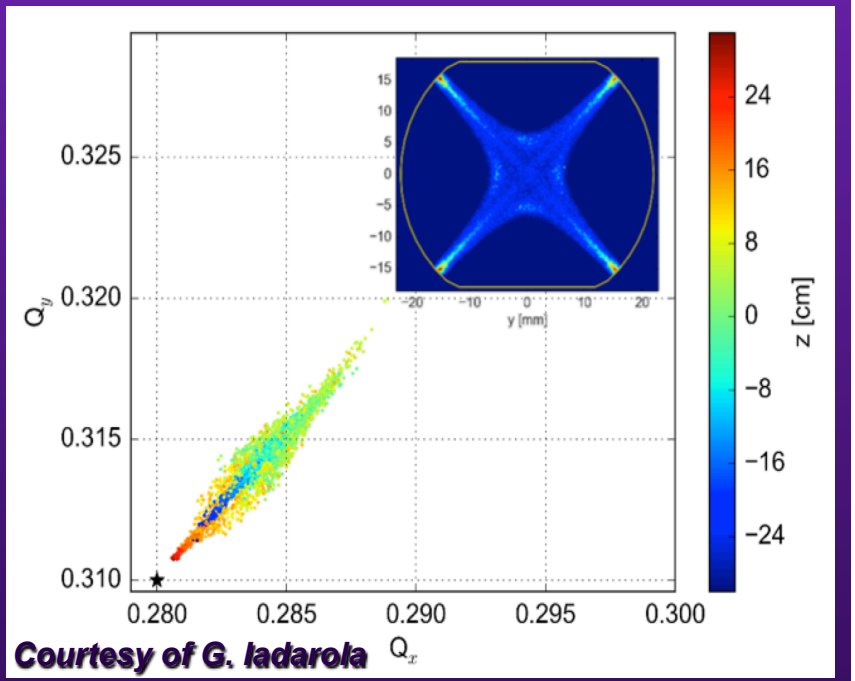


Courtesy of E. Benedetto



Courtesy of G. Iadarola

(SOME) ACHIEVEMENTS

- **HEADTAIL code has been parallelized over the number of bunches (N. Mounet)**
  - **Multiprocessor architecture**
  - **Each processor is assigned a certain number of bunches**
  - **All bunches can be treated almost independently => Only requirement: after each slicing, the processors exchange for all the bunches the positions and number of particles of each slice, such that the wakes can be computed in all bunches**

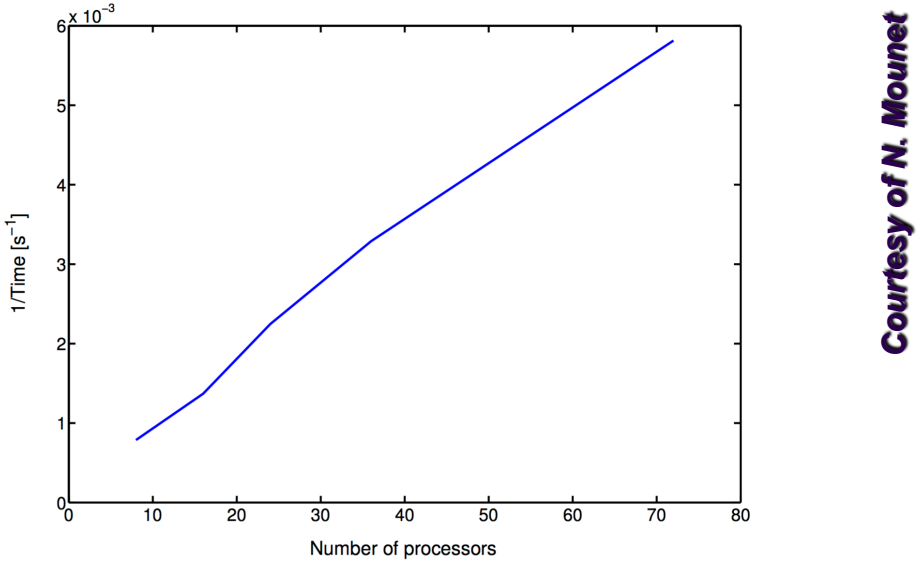


Figure 3.1: Inverse of the computational time vs. number of processors used, in the case of a HEADTAIL simulation on 72 bunches with 10 slices per bunch.

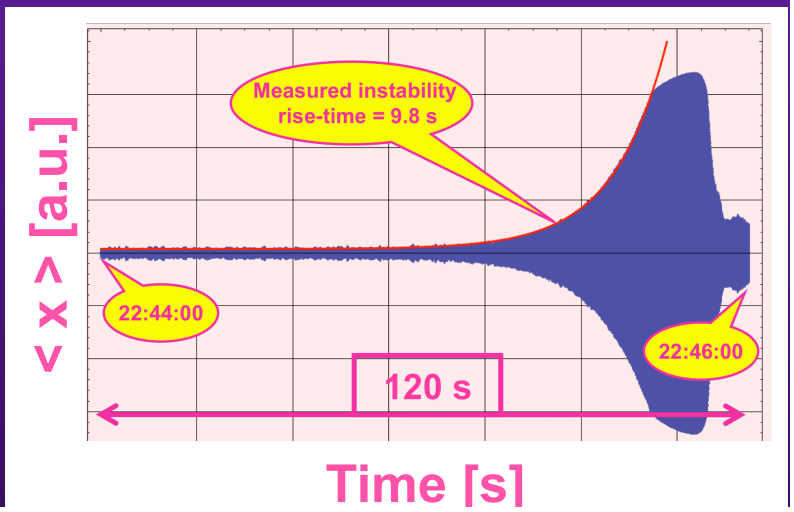
(SOME) ACHIEVEMENTS

- A. Oeftiger and S. Hegglin parallelized PIC on the GPU => See talk from A. Oeftiger

CHALLENGES

- Programs tracking simultaneously (self-consistently) e- and p+ are presently not available, due to the massive memory and CPU requirements to solve this type of problems => Ongoing work

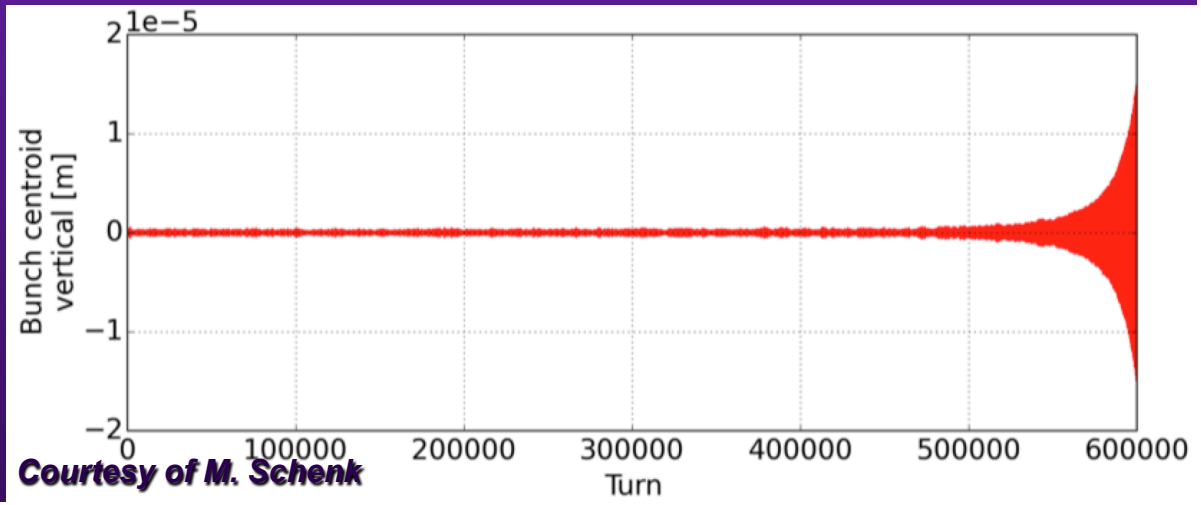
- Studies of interplay(s) between different mechanisms
  - Instabilities from e-cloud in the LHC in the presence of impedance and then beam-beam… (3-beam instability?)
  - Effect of space charge on instabilities (PS, SPS and LHC)
  - Studies of the long instabilities in the LHC => Sometimes appearing few min after some changes (with rise-times of few 10s of seconds ≈ few 1E5 turns)
  - Etc.



CHALLENGES

- **Example of (current) instability studies in the LHC**
  - Single-bunch impedance-induced instability studies at 3.5 TeV
  - 6E5 MP
  - 6E5 Turns => Several 1E6 to be studied
  - Intensity of 3E11 p/b => To have faster studies (but ideally ~ 1E11)
  - Transverse emittances of 2 um
  - Q' of +6 in both planes
  - Kskew = 0.0004

    => Take of the order of 1 week and many simulations are required
  - Next
    - Damper and Q”
    - Multi-bunch
    - Etc.



Courtesy of M. Schenk