# Studies of longitudinal single bunch stability in LHC

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*Many thanks to D. Jacquet, A. Macpherson and OP shifts*

# Motivation: loss of Landau damping

Landau damping (m=1) is lost if $|\mathrm{Im}Z|/n < \frac{|\eta|E}{eI_b\beta^2}(\frac{\Delta E}{E})^2\frac{\Delta\omega_s}{\omega_s}f_0\tau,$

During the cycle threshold changes as

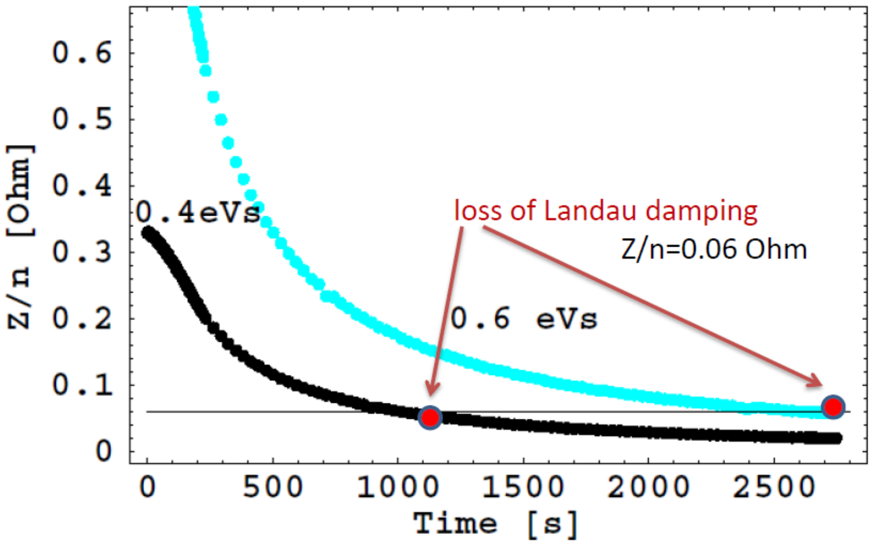
$$\mathrm{Im}Z^{thr}/n \propto \frac{\varepsilon^2\tau h^2}{E} \propto \frac{\varepsilon^{5/2}h^{7/4}}{E^{5/4}V^{1/4}}.$$

→To avoid threshold decreasing during the cycle emittance should be increased at least as $\varepsilon \sim E^{1/2}\,V^{1/10}$

# Motivation and previous results

- Expected loss of Landau damping during ramp without controlled long. emittance blow-up
- Single bunch instabilities observed during the ramp and on the flat top in 2010
- Undamped injection phase oscillations observed for multi-bunch beam in 2011 confirmed in the previous MD with multi-bunch beam (8 May 2011, ATS-Note-2011-031 MD)

Threshold during the cycle



# Experimental conditions

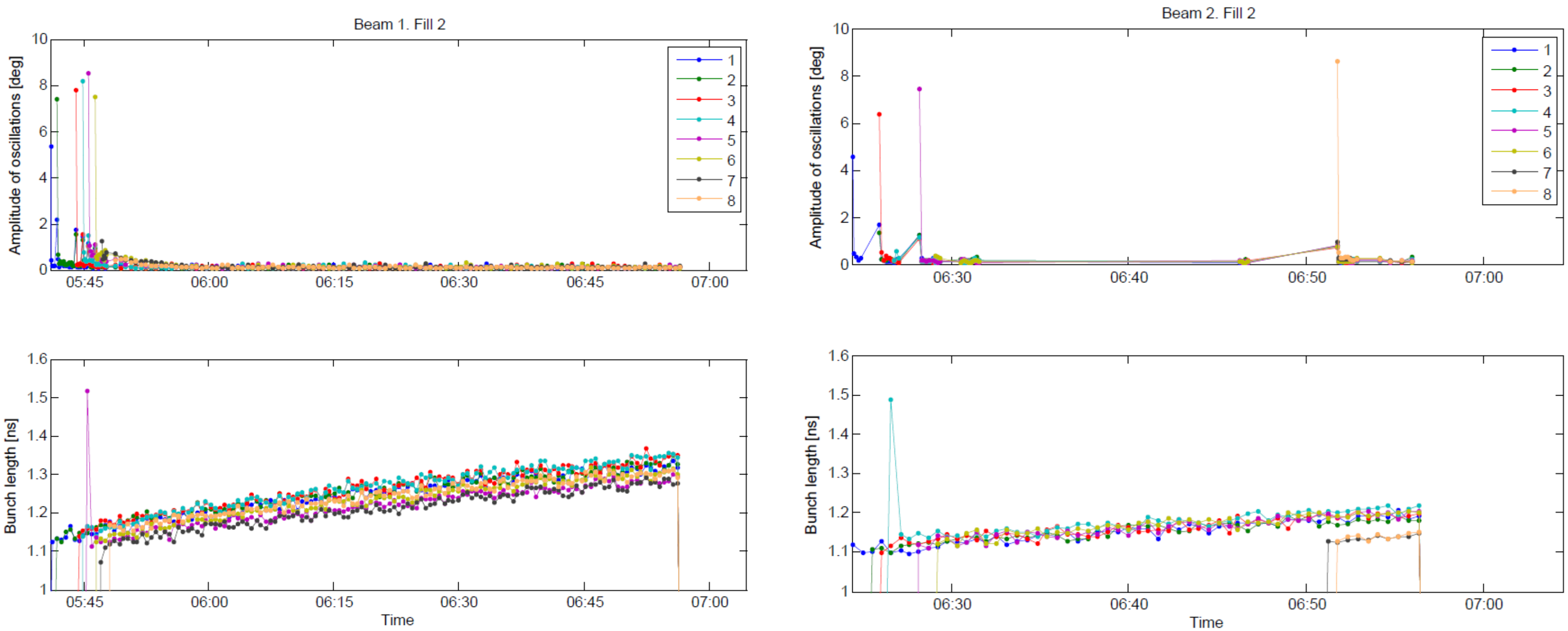
- plan: 3:00 – 16:00 @3.5 TeV, on 1.07
  reality: 3:30 – 14:15 @450 GeV (ADT access)
- 8 bunches per ring (9 equally spaced buckets) + pilot with
  filling pattern: 401 +(k-1)*3960, k=1,..9
- longitudinal emittance:
  - nominal 0.5 eVs,
  - no blow-up, but still 0.45 eVs
  - 0.38 eVs (capture voltage reduction in the SPS, T. Bohl)
- transverse emittance: first small (1.5 um), then asked for controlled emittance blow-up in the SPS & no scrapping $\longrightarrow$ 2.2 um
- injected intensity: (1.2-1.4) x$10^{11}$
- Phase loop settings
  - this MD: as used in normal operation (reference on all bunches)
  - previous MD (5.05.2011): reference on pilot and the first bunch only

# Flat bottom studies

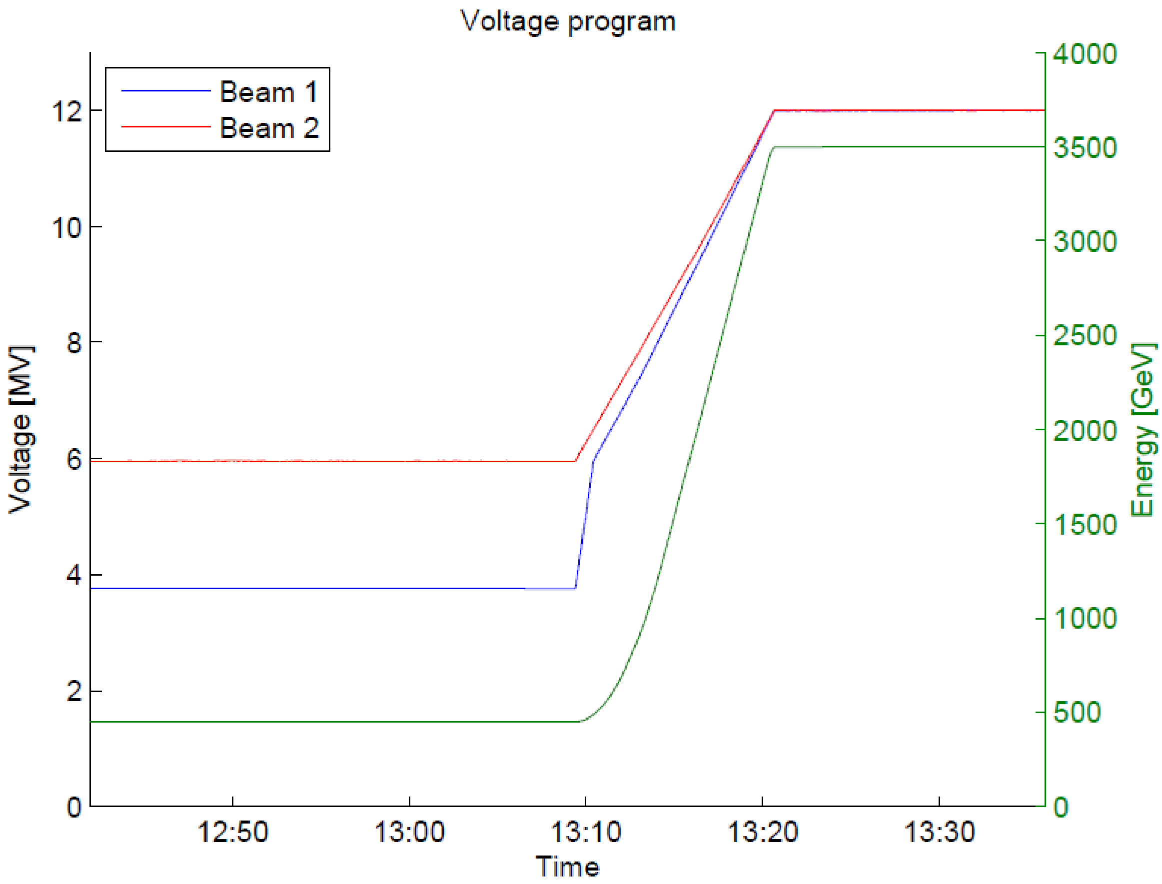
| | Beam 1 | | | | Beam 2 | | | |
|---|---|---|---|---|---|---|---|---|
| fill | 1st inj. time | $\bar{N}$ $10^{11}$ | $\bar{\tau}_{sps}$ ns | $V$ MV | 1st inj. time | $\bar{N}$ $10^{11}$ | $\bar{\tau}_{sps}$ ns | $V$ MV |
| 1a | 4:22:38 | 1.27 | 1.52 | 8.0 | 4:34:48 | 1.27 | 1.49 | 8.0 |
| 1b | 5:03:14 | 1.29 | 1.50 | 8.0 | | | | |
| 2 | 5:40:39 | 1.29 | 1.49 | 8.0 | 6:23:58 | 1.29 | 1.51 | 8.0 |
| 3 | 7:14:26 | 1.30 | 1.50 | 6.0 | 7:26:36 | 1.29 | 1.48 | 6.0 |
| 4 | 8:10:50 | 1.31 | 1.37 | 6.0 | 11:52:30 | 1.39 | 1.36 | 3.5 |
| 5 | 10:24:00 | 1.38 | 1.28 | 3.8 | 10:38:26 | 1.45 | 1.28 | 6.0 |
| 6 | 11:19:02 | 1.38 | 1.26 | 3.8 | 11:18:16 | 1.39 | 1.28 | 6.0 |
| 7 | 11:46:54 | 1.37 | 1.26 | 3.8 | 12:01:04 | 1.42 | 1.27 | 6.0 |

→ With phase loop on injection oscillations were damped in all cases

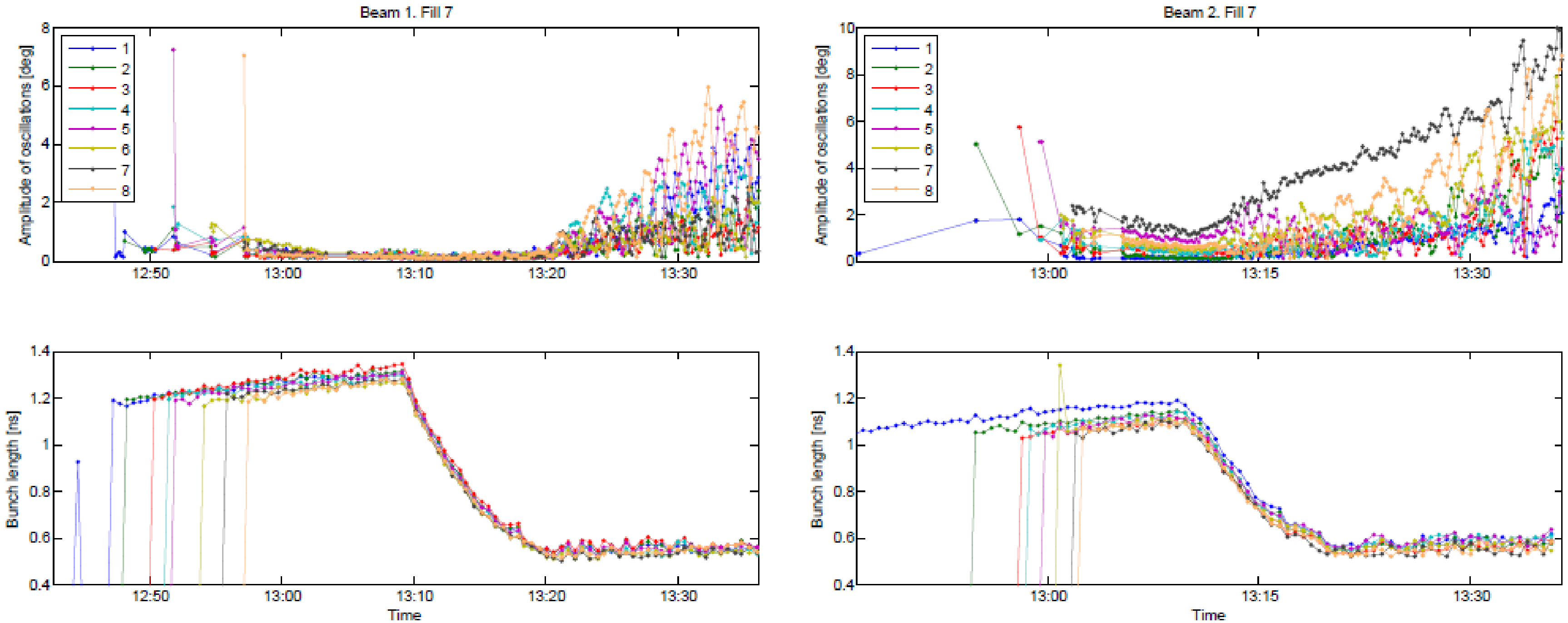
# Flat bottom studies
# 8 MV capture



# Fill N7 with ramp: voltage program



# Fill N7 with ramp




stable on the flat bottom
stable during the ramp
unstable on the flat top

stable on the flat bottom
unstable during the ramp – why?

very similar longitudinal emittances (BQM) but
- B2: phase error not completely damped at the start of ramp?
- different distribution (V1=3.8, V2=6 MV) + time on flat bottom?

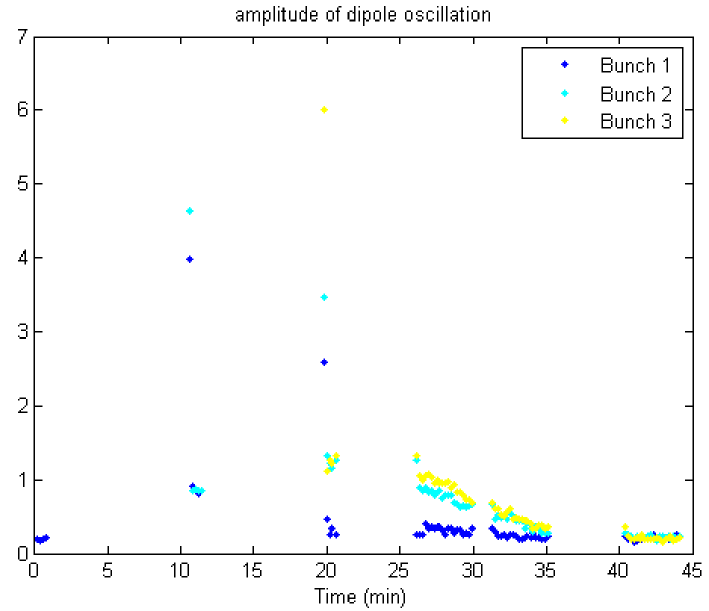
# Preliminary conclusions for MD on 1.07.11

- Damping of dipole oscillations on the flat bottom for single bunches with emit. > 0.4 eVs, V=8, 6, 3.5 MV with phase loop on
- Dipole instability during the ramp for bunches with emit = 0.4 eVs and small, but non-zero initial phase oscillations with phase loop on – the case for multi-bunch injections $\longrightarrow$ controled emit. blow-up
- Dipole and quadrupole(?) instability on the flat top for both beams and phase loop on

- **Issues and next steps:**
  - difference between B1 and B2 during ramp (different initial conditions?)
  - multi-bunch instability during the ramp with phase loop on (nominal)
  - measurement of single bunch instability thresholds with phase loop off

# RF setting-up for high intensity bunches on 30.06.2011 (P. Baudrenghien, T. Mastoridis et al.)

- Conditions:
  - Single bunch 2.8E11 in B1, 2.5E11 in B2
  - No longitudinal blow-up in SPS
  - Capture with 6 MV in LHC
  - Bunch length 1.2 ns after capture
- No dipole oscillation with single bunch injection due to phase loop. The quadrupole oscillations lasted 2-3 min
- Turning the phase loop off had no effect. The bunch length started growing faster (more noise at fs).
- A bunch was reinjected with the phase loop off and a 10 degree injection error. The oscillation got damped really fast again.




3 bunches were injected on beam 2. Again, there was no sign of instability.

# Summary of ADT settings for high intensity single bunches (D. Valuch, W. Hofle et al.)

- BeamPos module settings (gain, phase, delay) were prepared and tested for high intensity bunches. The Sum signals saturate between 3e11 and 3.6e11 (bunch length as at injection). Delta signals were set up to saturate between 3e11 and 5e11 for 2 mm transverse displacement.
- Commutation between high intensity and nominal intensity settings was tested by injections of high/nominal intensity beams.
- ADT was successfully used with high intensity beams in the following MDs.