Operational and beam dynamics aspects of the RF system in 2015

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BE-RF

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Outline

RF operation in 2015

- LS1 changes & recommissioning
- Operational parameters
- Operation with other beams
- New diagnostics
- LLRF & controls reliability (RF reliability in O. Brunner's talk)

Beam dynamics aspects

- MDs in 2015
- Longitudinal beam stability
- Controlled emittance blow-up

Outlook for 2016

OPERATIONAL ASPECTS:

RF SYSTEM IN 2015

LS1 changes & recommissioning

LS1 Changes

- Migration of LLRF CPUs to linux: went quite smoothly
- Migration to FESA3: was supposed to happen during LS1, but in the beginning of LS1 the framework was not yet ready to use

  Continued in coming YETS for part of the classes. Needs to be done latest by mid-LS2, but FESA2 support stops end of 2015
- SR4 works: air conditioning
- High-power RF: see Olivier's talk

Recommissioning

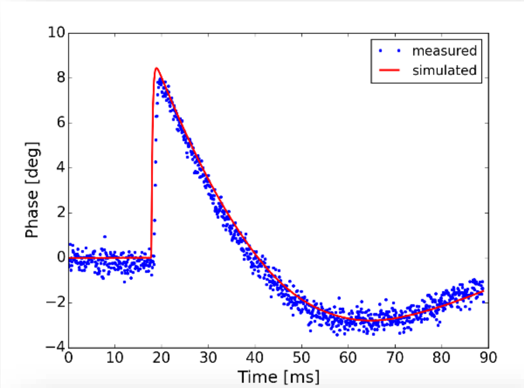
- LHC reference for bucket 1 adjusted after SPS LLRF re-cabling
- RF noise level ~ 10 dB larger in B1 than in B2

  VCXO of B1 changed during last ion run, leading to a somewhat larger abort gap population in B1, but not posing an issue for operation

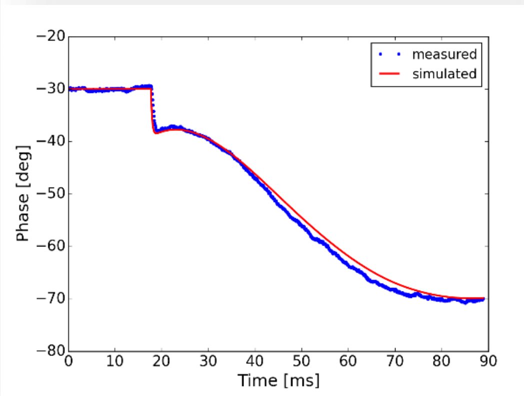
Studies during recommissioning

- Synchronisation loop step response measured

  Fits design & beam simulations

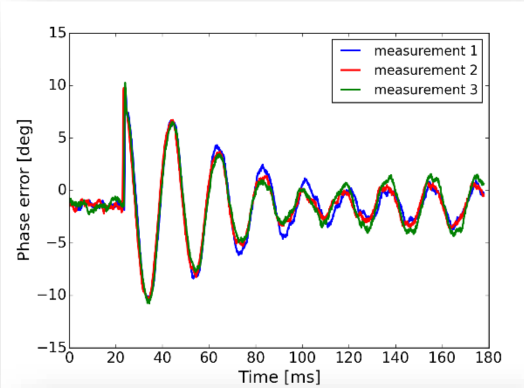


Phase error at 6.5 TeV

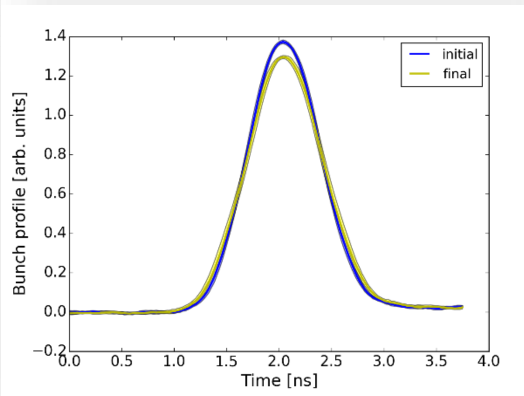


Synchronisation error at 6.5 TeV

- Beam transfer function measured via step in RF phase



Phase error with 10° step at 450 GeV



Beam profile before and after step at 450 GeV

Operational parameters in 2015

Operational voltage was 10 MV at 6.5 TeV (2012: 10 -> 12 MV)

- Choice combining bunch length requirements & power limitations
- Preparations for 300 kW klystron power (see talk by O. Brunner)

Beam-loading compensation using half-detuning scheme

- Tuning algorithms works as expected

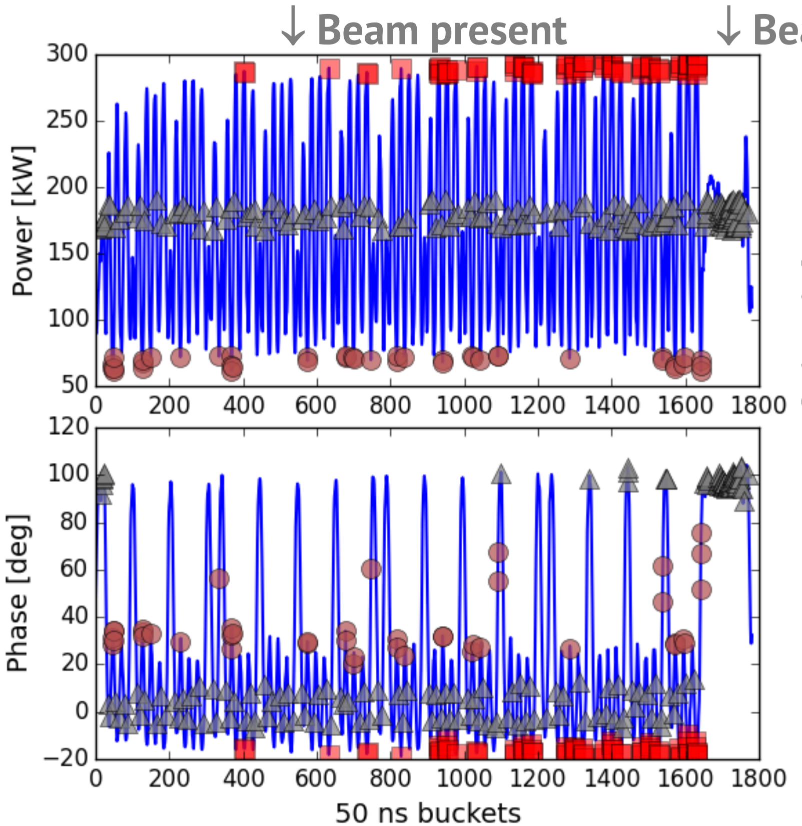
  Adjustment becomes critical as power grows quickly with detuning

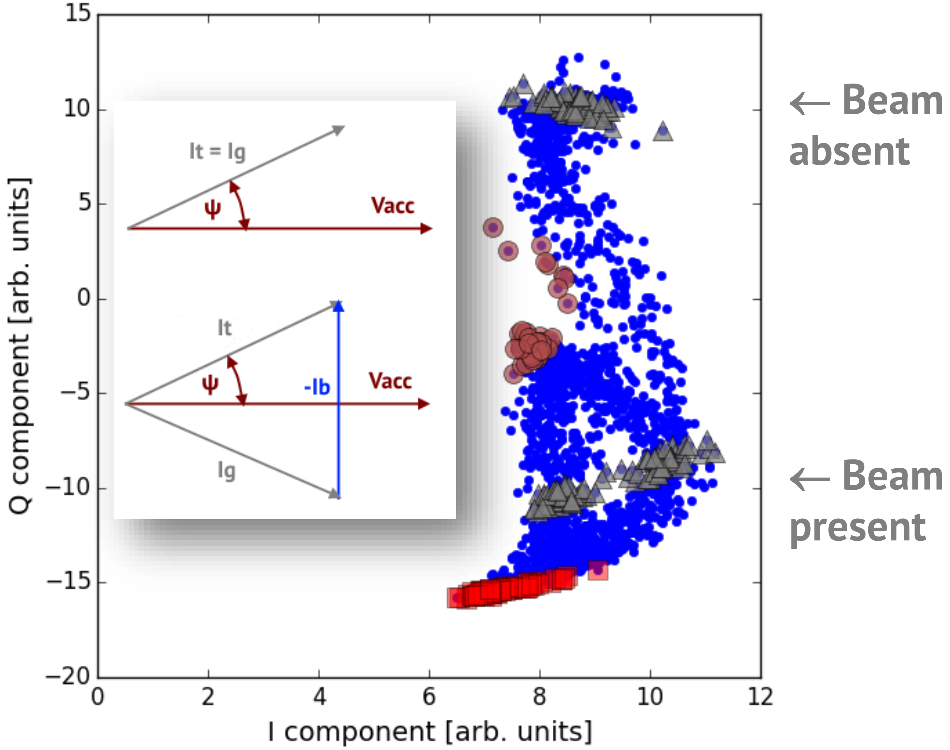
Increased target bunch length to 1.35 ns for the blow-up

- Letting the bunches shrink on flat top
- In long fills, can reach the limit of stability, but worked fine with 1.15×10^{11} ppb with up to 2244 bunches

Half-detuning (1)

Power transients with a full machine (2244 bunches, fill 4565, 2nd November)

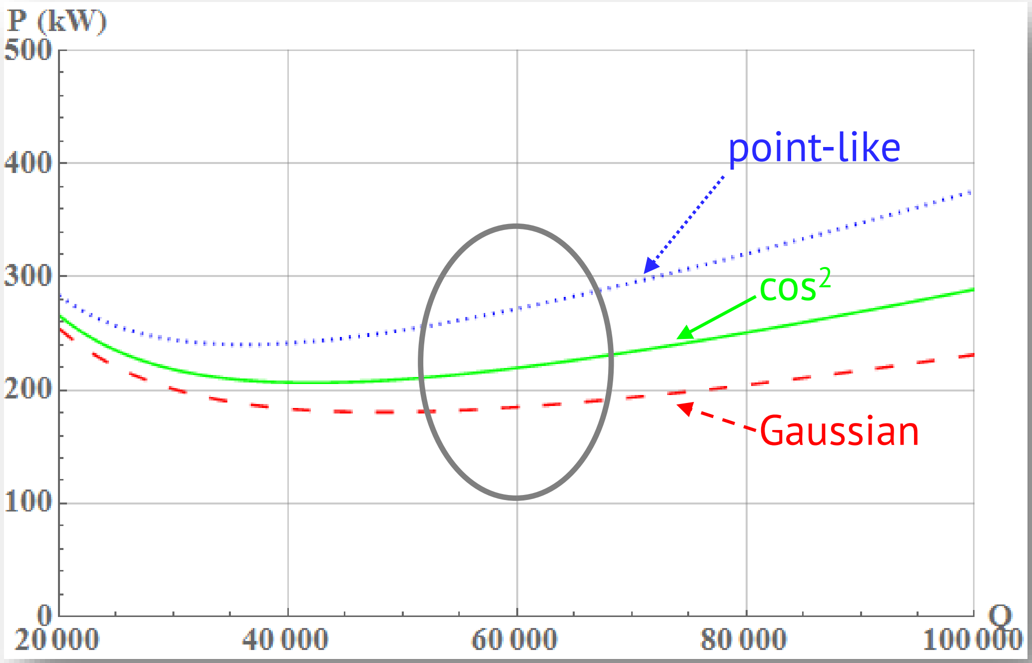




Half-detuning (2)

Demanded RF power $P = ⅛\, V \times I_{peak,RF}$

- With 1.25 MV/cavity, we are operating at the limit of the present system with up to P = 210 kW (peaks up to 250 kW)
- By commissioning to 300 kW, can gain another 20 % (P = 250 kW)

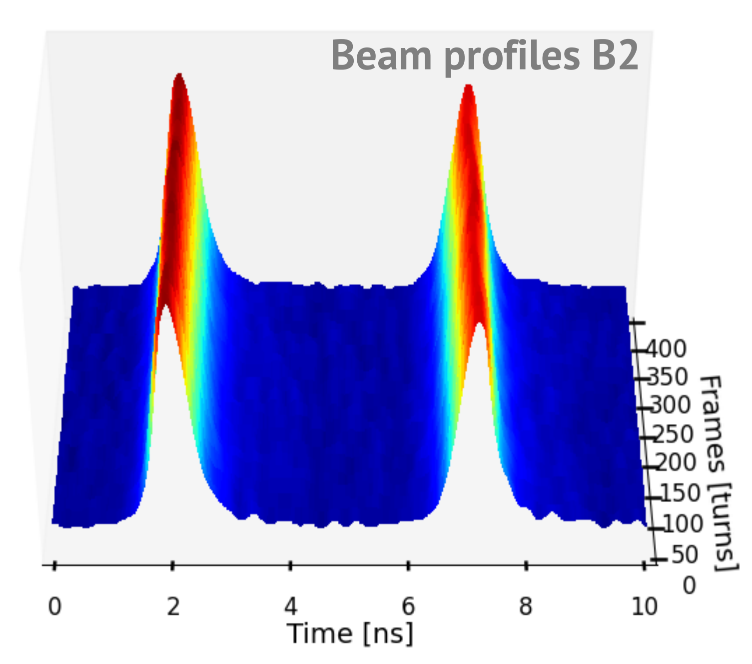


Present operating point assuming different bunch distributions

Operation with other beams

Operation with doublets

- Need 1 single nominal to adjust injection and stable phases
- Otherwise unproblematic



Operation with ions

- Capture and acceleration unproblematic
- Different proton/ion settings for beam phase acquisition due to different intensity

Settings to be added to LSA

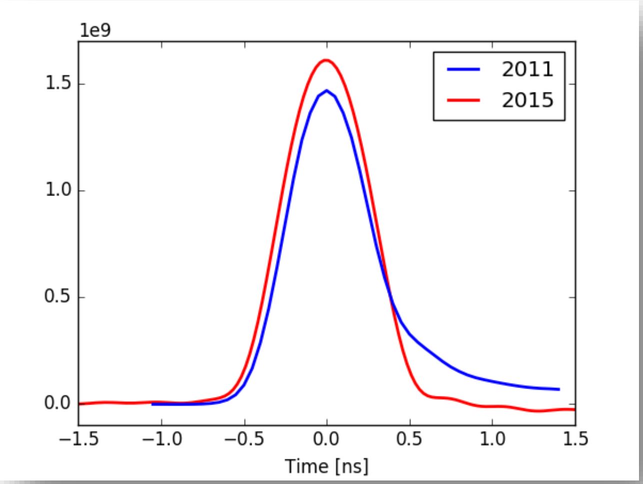
First injection of ions in bucket 1, B2

Diagnostics (1)

High-resolution beam profiles at 40 Gs/s

- Fast scopes (1/beam) installed in ex-klystron galleries

Expert only at the moment; user interface planned



2011: using scope in SR4

2015: using scope in UA43, corrected for transfer function of shorter cables

Beam spectrum logged in timber

- Now a fixed display is available

Frequent problems with interface to spectrum analyser, to be made more robust. Source of problems under investigation

Diagnostics (2)

Improved peak-detected Schottky spectra

- Faster rise time for better resolution of bunch centre

  Available only for one beam; further modules needed

Observation Box extensively used for longitudinal observation (see also talk by T. Levens)

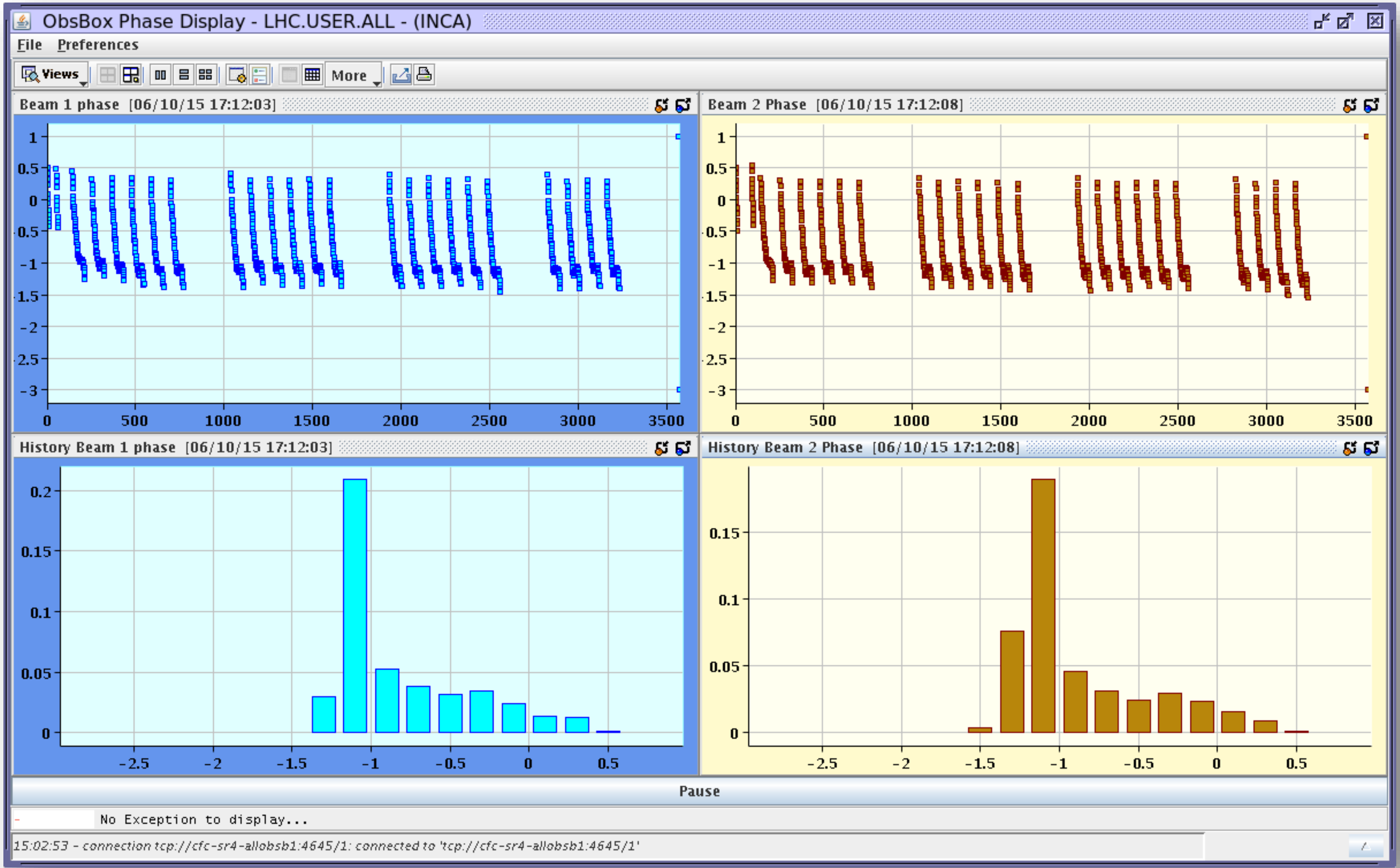
- Used during scrubbing run & MDs
- Stable phase acquisition for e-cloud monitoring: fixed display available, but no logging yet

  Logging is expert only at the moment; logging FESA class to be written

Beam profile screens in CCC (using 1 GHz scopes in SR4)

- New hardware for streaming to make it more robust
- Software upgrade planned for next year

ObsBox beam phase display



LLRF & controls reliability

- Few false alarms from RF frequency interlock

  Single spike filtering of beam energy signal and diagnostics implemented; if recurrent, data to be analysed

- Some electronics failures: (i) a Clock Generation module during recovery from TS2, (ii) a Tuner module (DSP core voltage failure), (iii) a 5V power supply on the Tuner crate

  First electronics failure since LHC start-up in 2008. More spares needed to keep system operational. High-priority effort needed!

- Long recovery time after power cut on VME crates in the Faraday cage; recovery took > 6 hours in one case

  Unresolved problem with reloading persistent data requiring software improvement, presently under investigation

- Spurious dump due to PLC receiving an RF off command

  Source of command unidentified, occurred only once

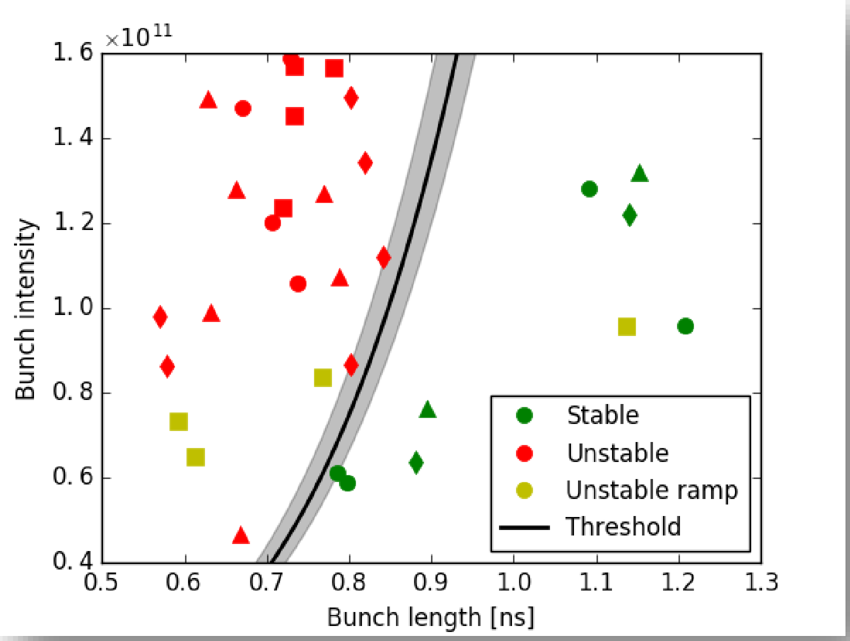
BEAM DYNAMICS ASPECTS:

BEAM STUDIES IN 2015

MDs – Longitudinal beam stability

- Successful identification of single-bunch stability threshold
- First attempts of measuring the coupled-bunch threshold

Studies to be continued

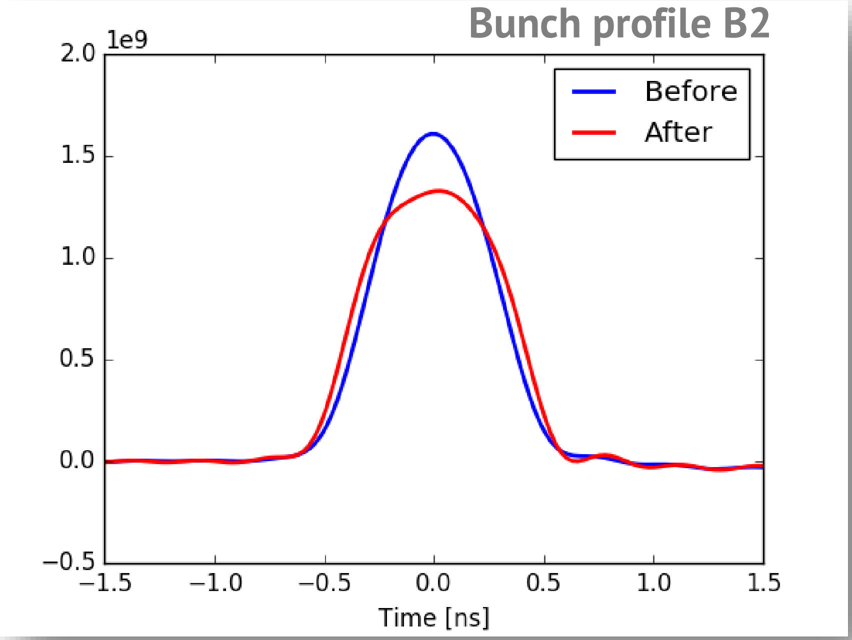


Single-bunch threshold based on several measurements

MDs – Shaping the bunch profile

- Uses single-frequency sinusoidal RF phase modulation targeting the core of the bunch
- Bunch flattening is an optional tool for heat load reduction, beam stabilisation in physics, and pile-up density reduction

Well-tested & ready to use, but application expert only at the moment



Measured on 28th October 2015 at the end of a physics fill

Controlled emittance blow-up

Theoretical & simulation studies during LS1

- To better understand the relation of noise spectrum and resulting profile in the presence of acceleration and feedback loops

  Single-bunch effects well understood, but multi-bunch to be studied

Optimisation of noise spectrum during commissioning

- Shaping noise spectrum to counteract the beam phase loop action

  Noise shape depends on bunch profile

Bifurcation of bunch lengths in multi-bunch case

- Observed in MD when the initial spread in bunch length is large

  In operation we're close to the limit

  Effect not yet understood (e.g. how much contribution from intensity effects?), simulation studies needed

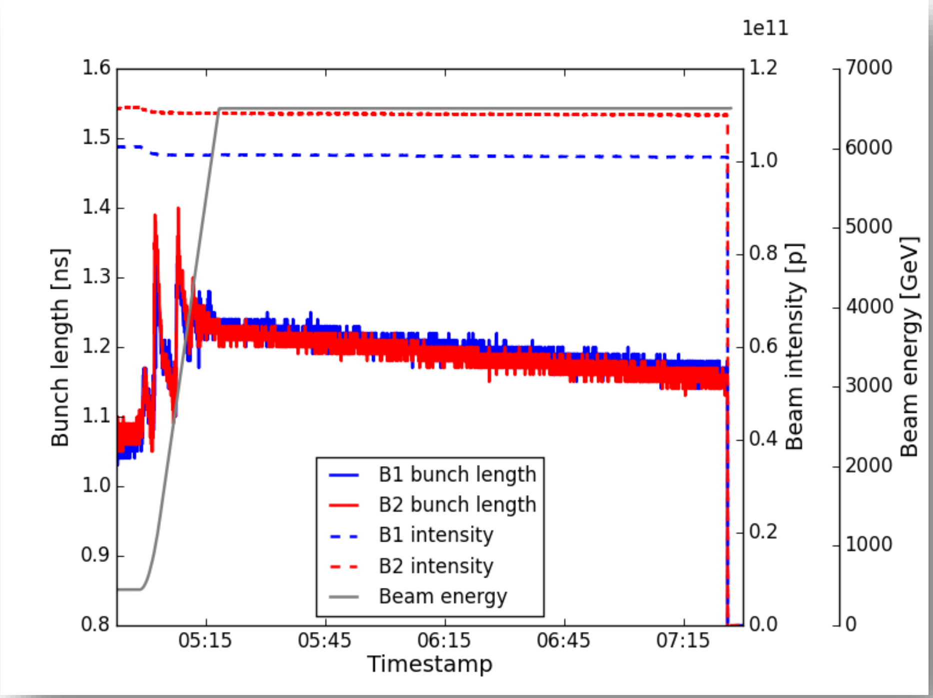
Tests to optimise off-momentum loss maps with blow-up

- To minimise the number of ramps. Gain at flat top is marginal

Longitudinal beam stability (1)

Longitudinal emittance damping time due to synchrotron radiation at 6.5 TeV: 16.2 h

- Observations confirm that emittance growth time due to RF noise & IBS is much slower



Single bunches (nominals) at 6.5 TeV, 26th May

Rough estimate of bunch length shrinkage

- Observed: 58 ps (B1), 53 ps (B2) in 2 h
- Predicted by SR*: 73 ps (B1), 72 ps (B2)

(*) scaled from emittance

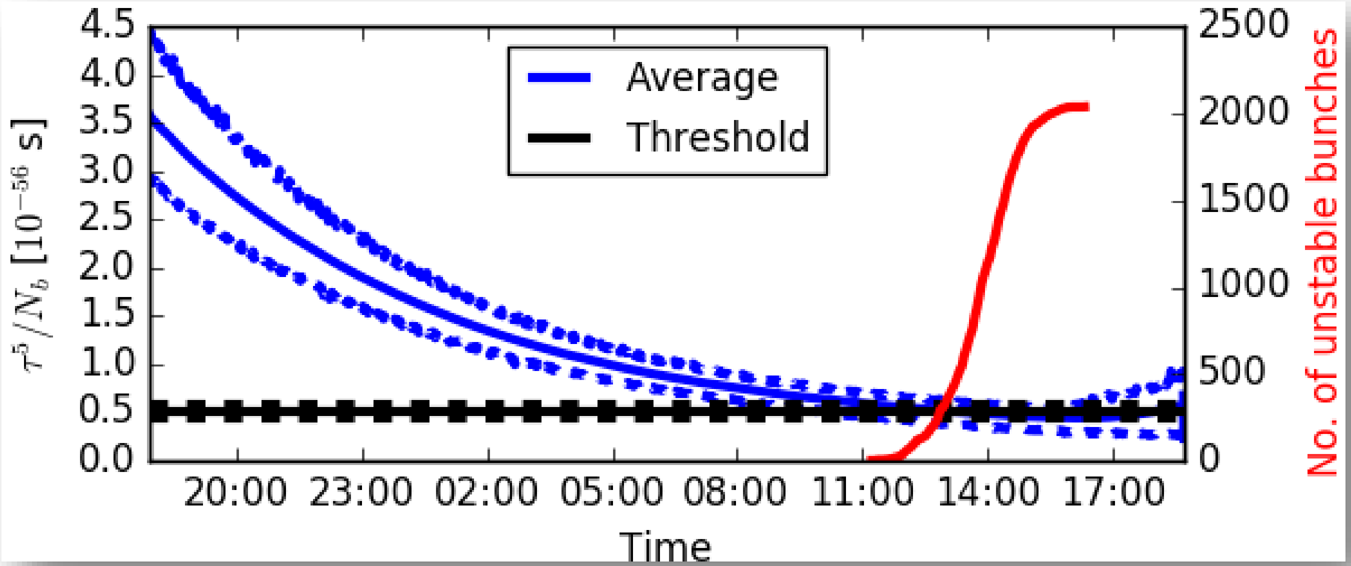
N.B. *round bunches at arrival to flat top, becoming Gaussian gradually; a proper estimate requires particle simulations!*

Longitudinal beam stability (2)

At the end of long physics fills, Landau damping was lost

- With 2015 end-of-fill beam parameters, coupled-bunch instability not observed, only single bunch instability

Bunch flattening can be used as a mitigation if needed



Loss of Landau damping in the longest fill of the year.

Single-bunch threshold obtained in MDs.

Outlook for 2016

Commission klystrons to a power of 300 kW (see O. Brunner's talk)

Continued studies on

- Voltage phase modulation (full-detuning) scheme

  Top priority to demonstrate its feasibility in case intensity is increased already in Run3; to be detailed by P. Baudrenghien in Chamonix 2016

- Coupled-bunch instability threshold due to
  - full machine impedance
  - cavity impedance at fundamental component (HL-LHC study)
- Controlled longitudinal emittance blow-up to understand multi-bunch effects (bifurcation of bunch lengths)

Controls development

- Continue migration from Fesa2 to Fesa3
- Consolidate longitudinal diagnostics tools & make them user-friendly

References

- Half-detuning scheme

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- Longitudinal beam stability

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- Controlled longitudinal emittance blow-up

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  S. Y. Lee, *Accelerator Physics (3rd edition)*, World Scientific, 2012.

  LHC Design Report Vol. 1, 2004.

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Thank you!