RF strategy, limits and issues

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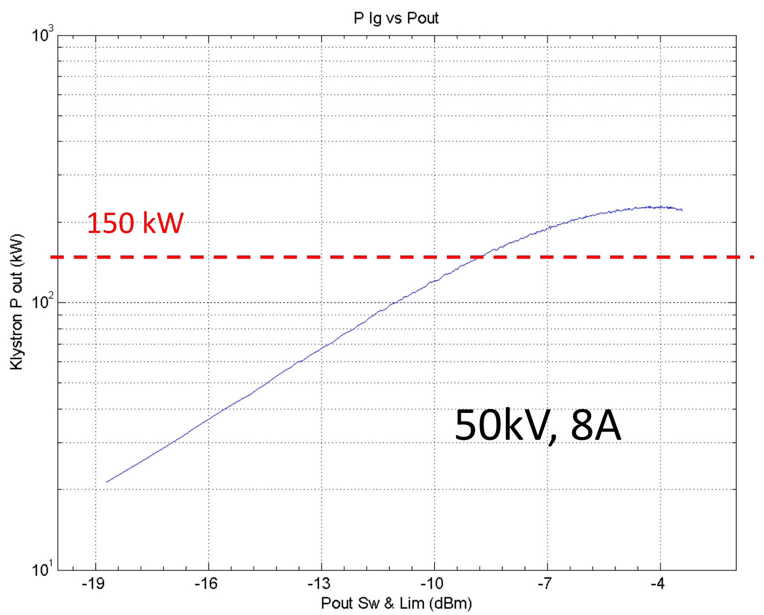
Outline

- How to push the RF voltage at flat top
  - if larger longitudinal emittance is required for reduction of IBS
- Do we have enough available RF power
  - to handle increasing beam intensity?
- Protection of RF equipment at high beam intensity
- Bunch length at injection/ramp
  - reduce heating (kicker, collimators, cryogenics)
- Dipole oscillations at injection
- 25ns bunch spacing
- Conclusions

RF voltage & power on flat top

- Currently 12 MV (1.5 MV per cavity)
  - 120kW klystron power with 1.15e11 x 1380 @ 50ns and Q_{ext} = 60k
  - increasing to around 130kW with 1.5e11
  - With the present DC settings (50kV, 8A) we should not exceed ~150 kW RF to keep far enough from saturation to provide gain for the RF feedback.

$$P = \frac{1}{8}\frac{V_{acc}^{2}}{Q_L \, R/Q} + \frac{1}{2} Q_L \, R/Q \left[\frac{I_b}{4}\right]^2$$



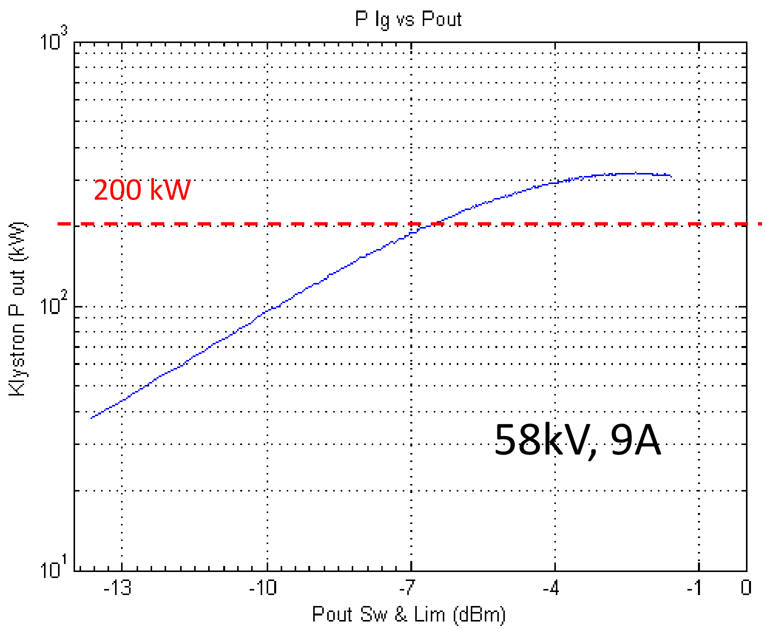
J. Molendijk

Increasing the RF voltage

- Increasing 12MV→14MV would require 165kW @ Q_{ext}=60k
  - already above our 150kW limit

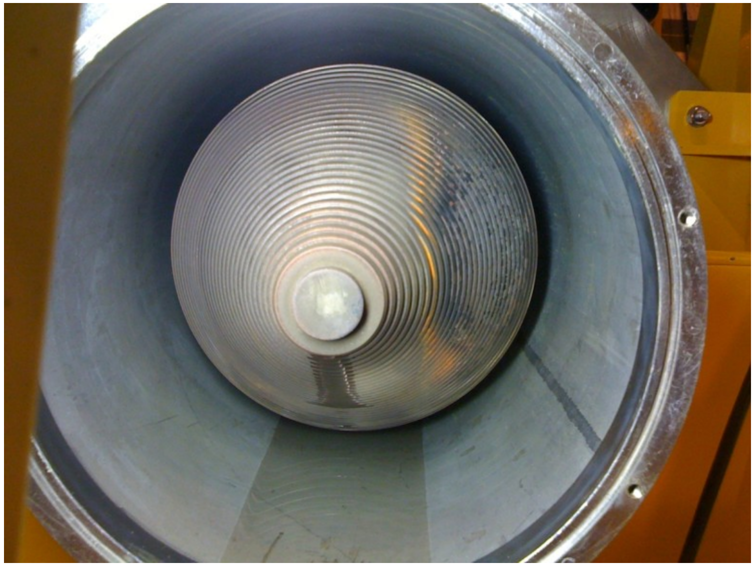
- Increase Qext:
  - with Q_{ext}=80k we could get 14 MV total (1.75 MV/cav) with 134 kW/klystron average.
  - on beam 2, cavity 3B2 is "sick" and stands 1.3 MV only
  - the other 7 cavities would have to provide 1.815 MV, requiring 142 kW
  - gain in bucket area is only 8%
  - cf. bunch length increase from 1.2 to 1.3 ns increases emittance by 17%

- Change DC working point:
  - e.g. 58kV, 8A
  - saturation at 300kW
  - **but** reliability may suffer: probably more crowbar trips



Klystron DC power issues

- Klystron DC working point is currently 50kV, 8A
  - to increase available power, need to increase HV, cathode current or both
- 58kV, 9A has been validated
  - simulation (power distribution on collector)
  - already run >500 hours in 2009/10
  - collectors show signs of overheating
  - need to minimize time spent with full power on collector
  - reduce HV and/or cathode current when no beam (sequencer?)

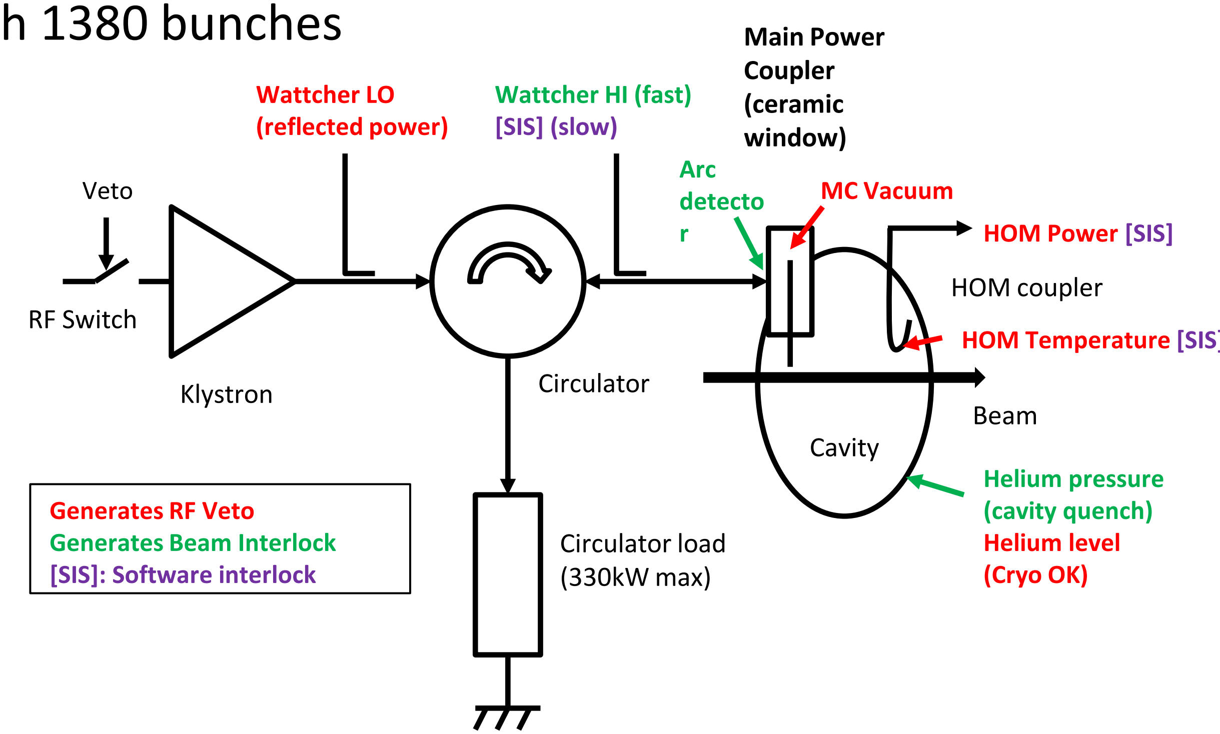


- New collectors, improved cooling:
  - 4 out of 16 klystrons already modified
  - 4 more in Christmas stop 2011/12
  - then will be able to increase voltage without risk in half of the cavities

Please switch off klystrons if no beam for more than a few hours !!

RF equipment protection (1/3)

- Return power from high intensity beam in a tripped cavity can damage the RF equipment
- 200kW return power limit set as safe limit
  - now exceeded with 1380 bunches
- Must protect:
  - **main power coupler window**
  - circulator load
  - HOM couplers
  - klystron



Since 17 June, all RF interlocks also generate a beam dump

RF equipment protection (2/3)

- This configuration leaves us open to spurious dumps…
- The main culprits were the Arc Detectors:
  - Main coupler:
    - new electronics everywhere: shorter coincidence window
    - new system in development with 4 redundant sensors & majority voting (end of year)
    - investigating radiation-tolerant fibres
  - Waveguide:
    - low-pass filters to reject radiation-induced pulses, seems to be successful

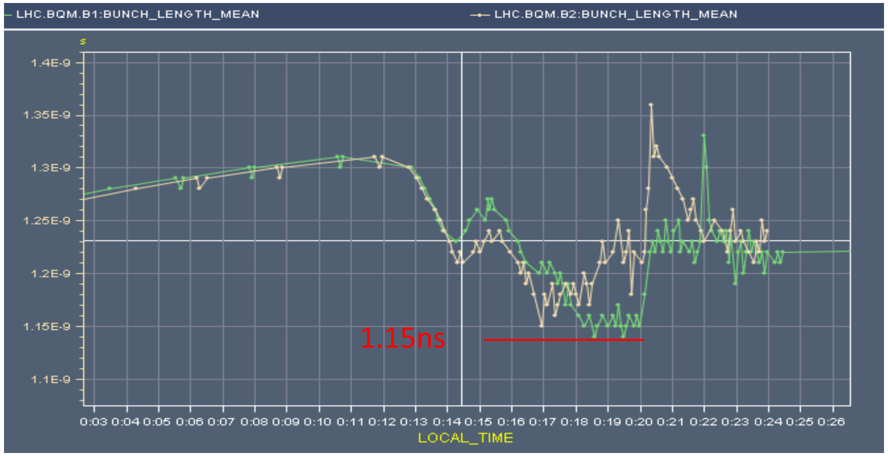
So far we have not seen any dumps due to <u>spurious</u> RF trips

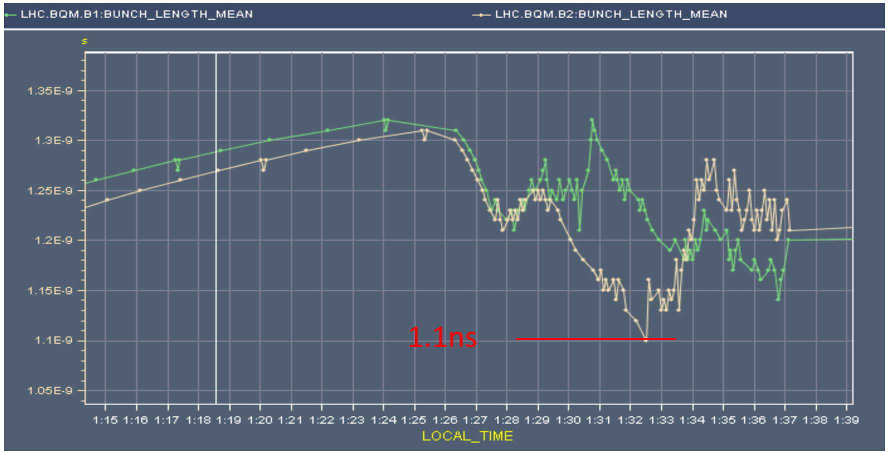
RF equipment protection (3/3)

- The current situation (all RF interlocks generate a beam dump) is conservative but safe
  - in case of excessive false dumps, a new firmware has been prepared for the interlock modules which would remove some of the interlocks from the beam dump chain
    - including some useful ones (Wattcher LO, Cavity vacuum, Cryo OK)
  - decided not to install it unless absolutely necessary
- In the longer term, a rationalization of the interlock system is under study
  - separate RF from beam interlocks
  - for end of year or LS1

Bunch length in ramp

- Optimise blowup in LHC to reduce undershoot?
  - studies done in June
  - revisit parameters
    - start excitation earlier?
  - improve update rate of BQM data
- Bunch length at injection
  - longer bunches from SPS?
  - blowup batch by batch on flat bottom possible in theory using (future) longitudinal feedback system
    - not yet implemented, will take time to develop → not for this year!
- Bunch length on flat top
  - could increase target bunch length but impact on lifetime above ~1.3ns?

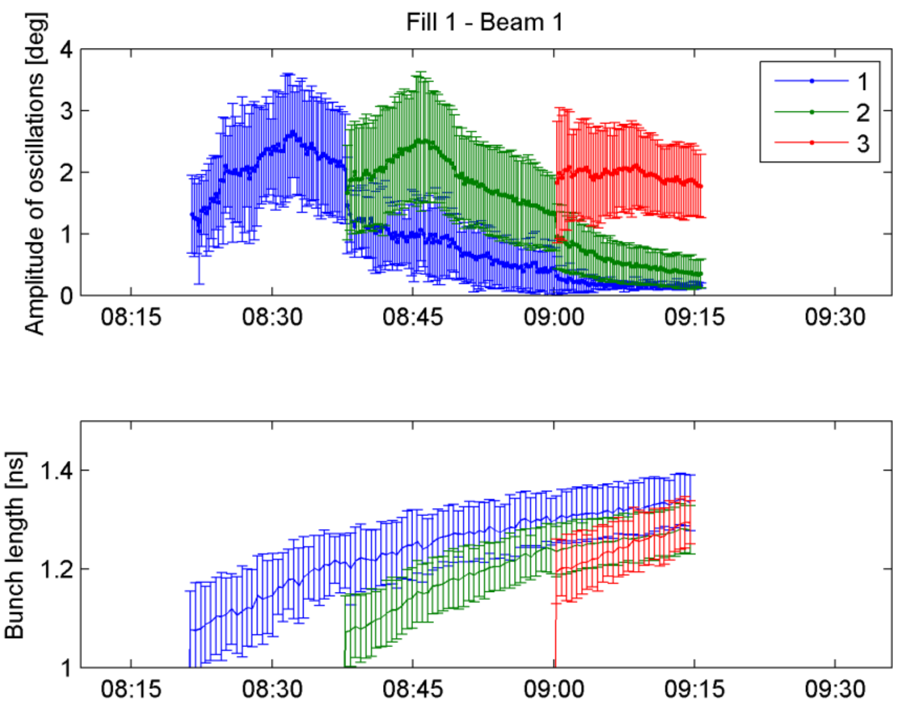




Last 2 physics ramps before TS

Long-lasting dipole oscillations

- Observed at injection:
  - amplitude grows for 5-10 minutes, then damping with a time constant ~ 30 min
  - quite insensitive to total intensity, number of bunches per batch and distance between batches
  - suggests not multi-bunch instability (but more analysis needed)
  - dependence on bunch length
  - not yet a problem for normal operation, but need to keep an eye on it



Top: Amplitude of dipole oscillation (min, max, mean over all bunches of a given batch).
Bottom: Bunch length from BQM. Evolution for Fill 1, Beam1.
(P. Baudrenghien et al.)

25ns bunch spacing: RF

- No hard limit for going to 25ns
  - first tests of capture gave good results
  - still need to analyze our data
  - if vacuum in IP4 is degraded, longer conditioning times

Transverse damper

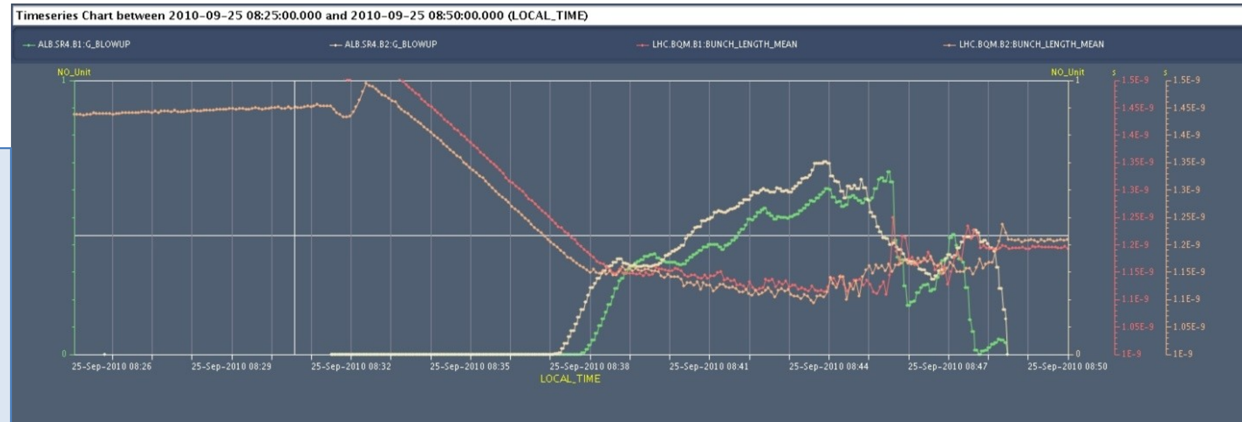
- No issues with 50 ns bunch spacing
- No issues with high bunch intensity, but
  - automatic gain adjustment needed for efficient running at increased and different bunch intensity (settings management)
- Time needed for 25 ns bunch spacing commissioning: delay adjustment critical
- Expect less good noise performance with 25 ns (reflections on cable, addressed in future shutdowns), adaptation of signal processing if gain → 20 MHz an issue
- Ahead:
  - blow-up with noise for efficient loss maps
  - use of damper data for MDs very useful, more work needed (efficient “data mining”)

Conclusions

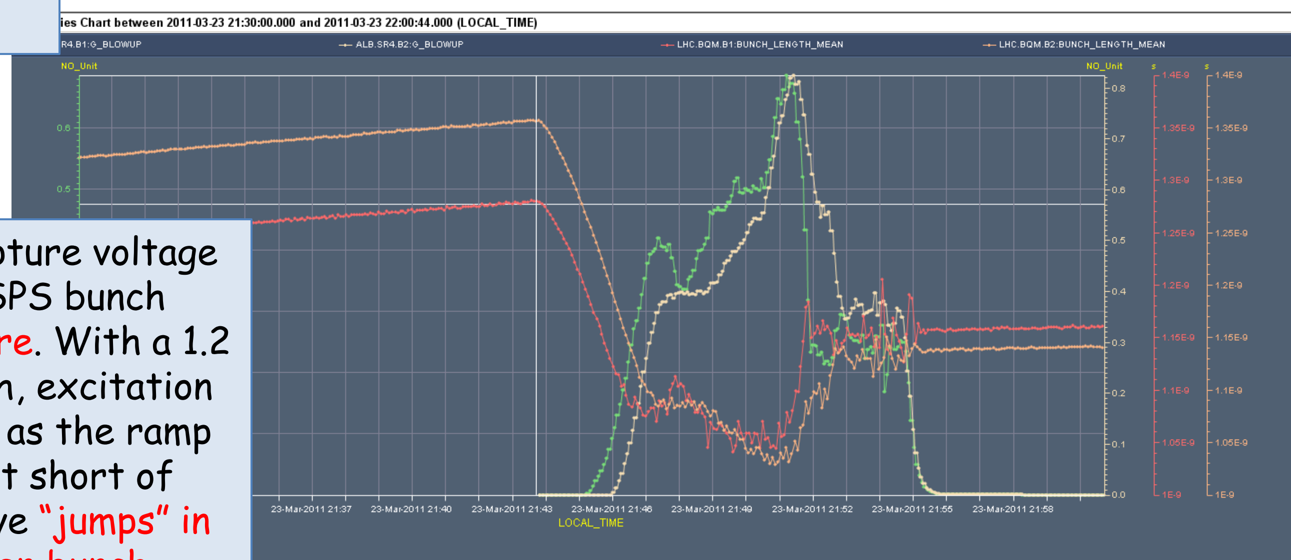
- Ideally we change nothing…
- Some headroom to increase voltage, power, emittance, bunch length if necessary
- but need to be careful with operation of the klystrons
- Equipment protection at high total beam intensity: we play safe with interlocks
- Further improvements to controlled longitudinal blowup?
- 25ns bunch spacing:
  - No show stopper from RF
  - ADT needs time for setting up, expect less good noise performance

Why more tricky in 2011?

Situation 2010: Thanks to the matched capture the bunch shape is not changed much at injection. It is ~1.5 ns at the start of the ramp. The first part of the ramp proceeds smoothly without blow-up, with adiabatic bunch length reduction till it reaches the demanded 1.2 ns.



Bunch Length Mean and Noise Amplitude during Ramp



Situation 2011: Because the capture voltage is mismatched, the 1.5 ns long SPS bunch shrinks to ~1.20 ns after capture. With a 1.2 ns target value for bunch length, excitation must start immediately as soon as the ramp starts. We typically end-up a bit short of the demanded 1.2 ns and observe "jumps" in bunch length measurements when bunch profile changes (non-adiabatic)