Status of LHC operations

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LPCC 11.6.2010

Outline

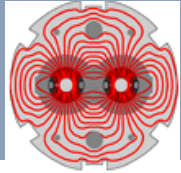
State of operation for physics

New operation mode

Preparation for operation with nominal bunches

Conclusions

Recap



- At LPCC of 21st May, we were just about to switch to from 6 bunch to 13 bunch operation for physics…

  >> First fill with 13 bunches of 2.1E10 p/b on Monday 24th May.

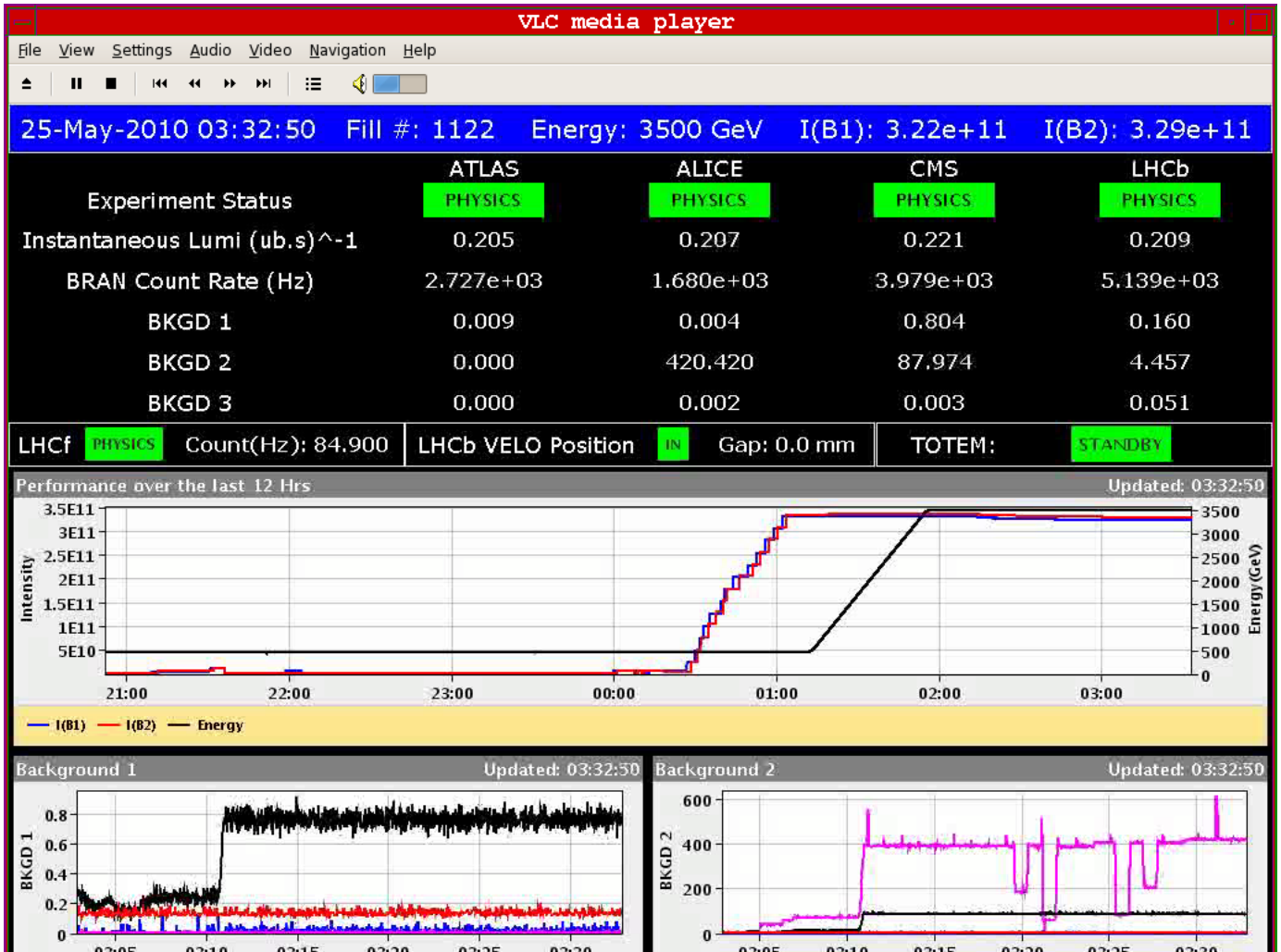
- During commissioning of operation with nominal bunches, an instability was observed when ramping the beams to 3.5 TeV. First cures were identified and tested:
  - *Octupolar fields: introduces frequency spread among particles of different amplitudes and helps to prevent build-up of coherent bunch instabilities.*
  - *Longer bunches (in fact larger longitudinal emittance*) from the SPS and longitudinal emittance blowup in the LHC.*

**Longitudinal emittance $\propto$ energy spread x bunch length. At LHC ε_L = 0.3-2.0 eVs.*

Latest state of physics operation

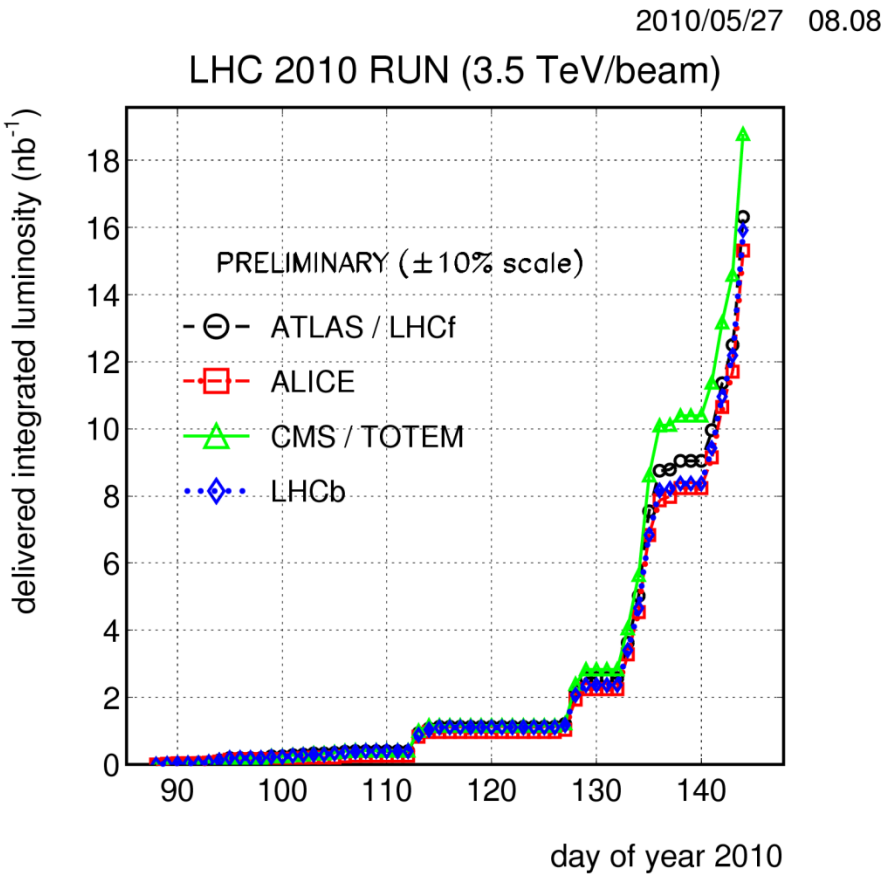
13 bunches 2.4E10 p/b, β* 2 m

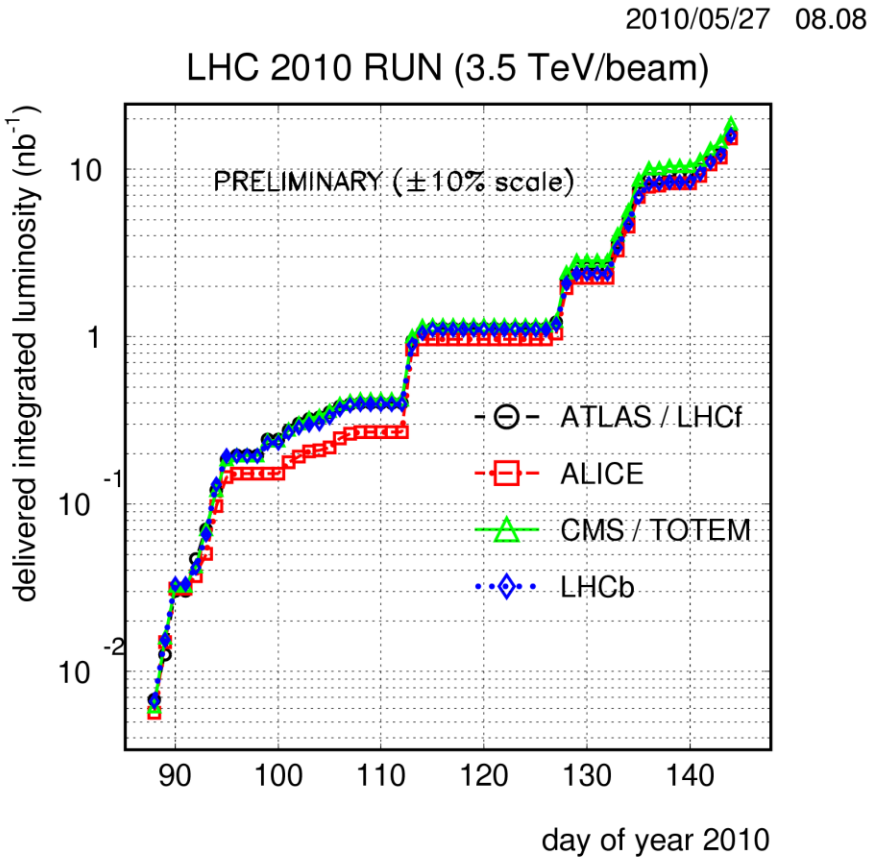
Luminosity **~ 2 × 10^{29} cm^{-2} s^{-1}**



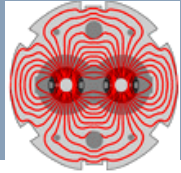
Integrated luminosity

Courtesy M. Ferro-Luzzi



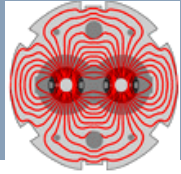


Commissioning – new strategy



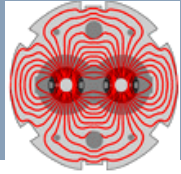
- In the past 3 weeks we have moved to an OP mode with commissioning Monday-Friday, physics over the weekends.
- Eventually this turned out to be somewhat inefficient (for physics), because quite some time was spend switching back and forth.
  - *Low(er) intensity bunches for physics, nominal bunches for commissioning.*
  - *This was exacerbated by a major power cut over one weekend, and a somewhat tedious technical stop recovery last weekend.*
- In a meeting last Wednesday, the machine proposed to switch to **full steam 100% beam commissioning** to push operation with nominal bunches.
  - *Establish the base for the long term now (before the summer holiday period).*
  - *We profit from this change to perform a complete ramp and squeeze cleanup.*
  - *Aim is to provide collisions of high intensity bunches in the time scale of 2 weeks or so.*

Commissioning – machine protection



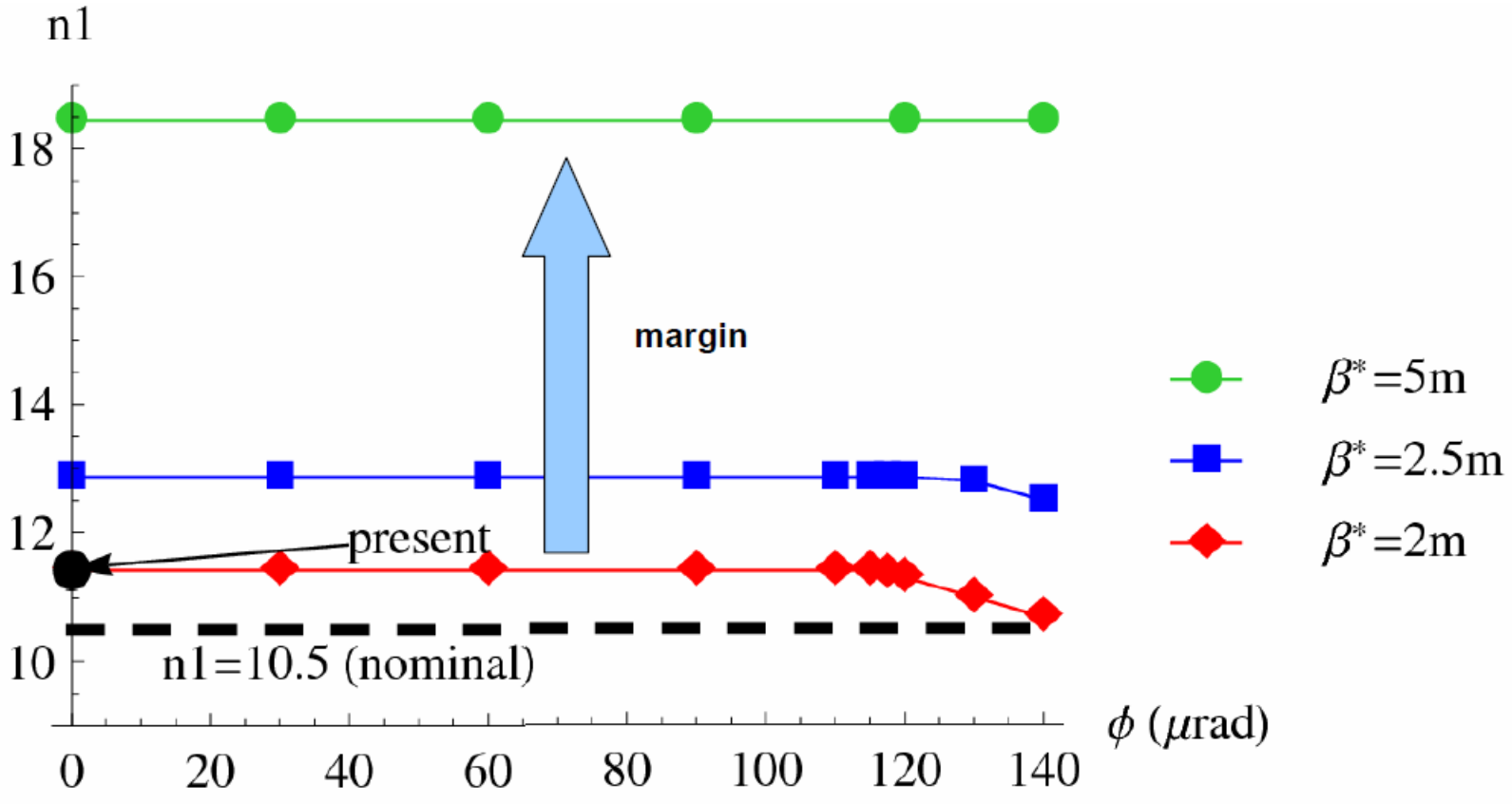
- From the machine protection side, we would like to reach a target of around 1-2 MJ of stored energy by mid-july.
  - *No show-stoppers in sight.*
  - *Achievable from present situation (150 kJ) in 3 steps of factor ~2 in stored energy.*
  - *Corresponds to 20-40 nominal bunches, L ~ few x 10^{30} $cm^{-2}s^{-1}$.*
- We would also like to have a ~4 week stable running period in the 1-2 MJ regime – ideally in August.
  - *Constant machine conditions: β^*, crossing angle (if any).*
- Why 1-2 MJ?
  - It's the present state-of-the-art (Tevatron,SPS).
  - With 1-2 MJ it is even possible to damage the robust primary and secondary collimators!

Conditions for nominal bunch OP



- A few weeks ago, it was agreed to back off to **5 m** with β* to gain operational margin (more relaxed tolerances).
- After a closer analysis of the required tolerances, the target β* value was revised and the new target is now **3.5 m**.
  - *Crossing angles of ~100 μrad can be accommodated : LHCf request and preparation for train operation.*

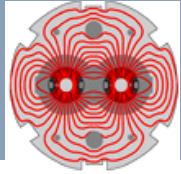
Conditions for nominal bunch OP



Min. aperture (hor/vert in beam sigma) = 1.2 x n1

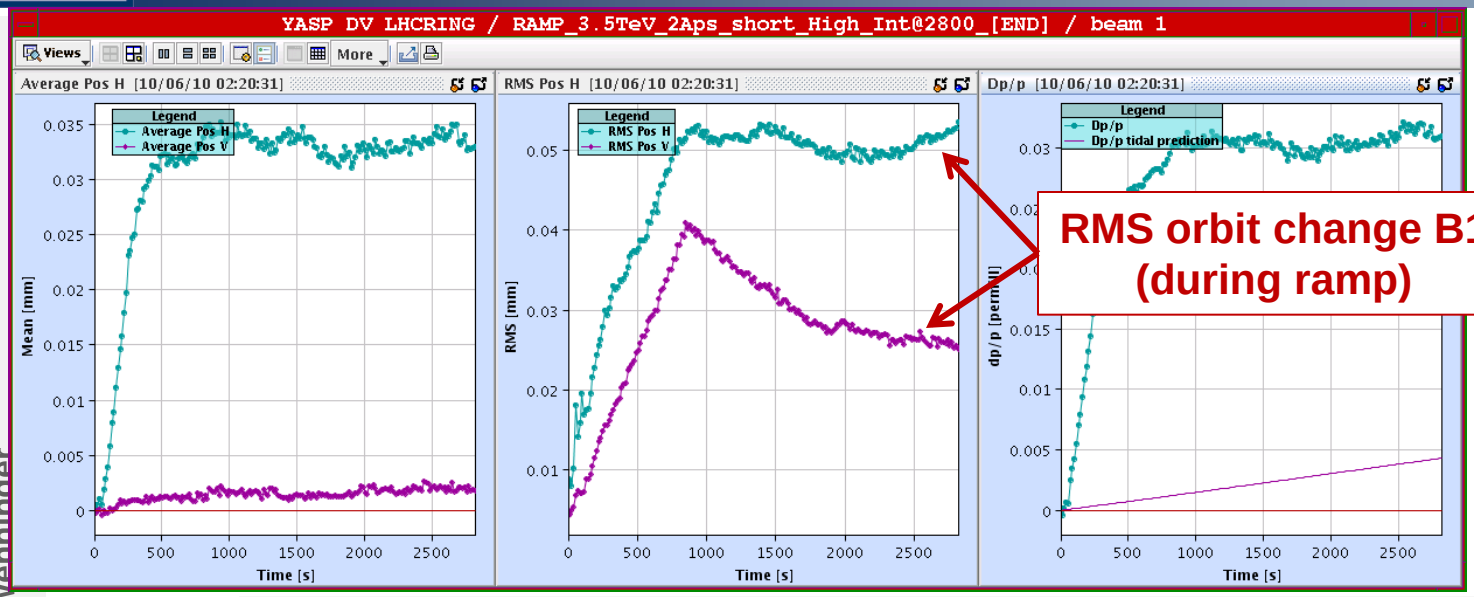
The n1 definition includes alignment tolerances, margin of optics errors, orbit etc

New ramp, new squeeze

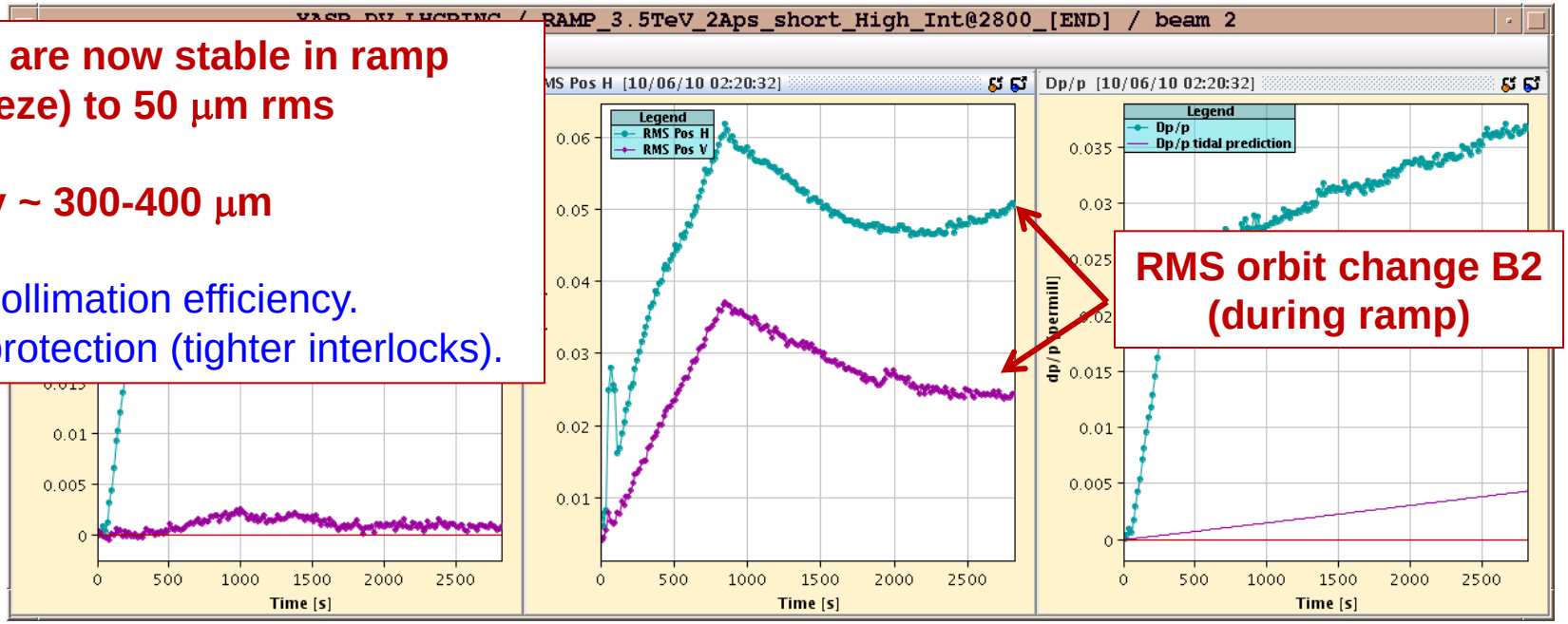


- The machine settings used for 13 bunches integrated the OP history of 2010 and became tedious to use (issues with safety for high intensity operation).
  - *Change of orbit references, collimator settings …*
- Since Wednesday we have launched a clean-up of the ramp and squeeze with consistent references all along (new settings).
  - *Also to pave the way for a simpler collimator setup, and safer operation.*
- Ramp and squeeze to 5 m β^* are already cleaned !
- To come over the weekend:
  - *Cleaning of the squeeze from 5 m to 3.5 m.*
  - *Squeeze with separated beams.*
  - *Collimator setup for the new flat top and squeeze.*

Cleaned Ramp (and squeeze) with orbit feedback



RMS orbit change B1 (during ramp)



RMS orbit change B2 (during ramp)

The orbits are now stable in ramp (and squeeze) to 50 μm rms

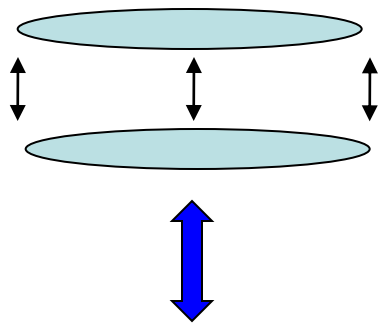
Previously ~ 300-400 μm

>> Better collimation efficiency.
>> Better protection (tighter interlocks).

Head-tail instability

- The instability observed on the nominal bunches seems to be a ‘classical’ head-tail instability.
  - *Simulations reproduce the observations rather well.*
- The head-tail instability/movement is characterized by a number of bunch oscillation modes. *Simplified* description:

Mode 0 **Mode 1** **Mode 2** **etc**



Can be stabilized with the transverse feedback !

The growth rates depend on bunch parameters: Intensity, **bunch length**, synchrotron frequency, **chromaticity** etc

Head-tail at the PS

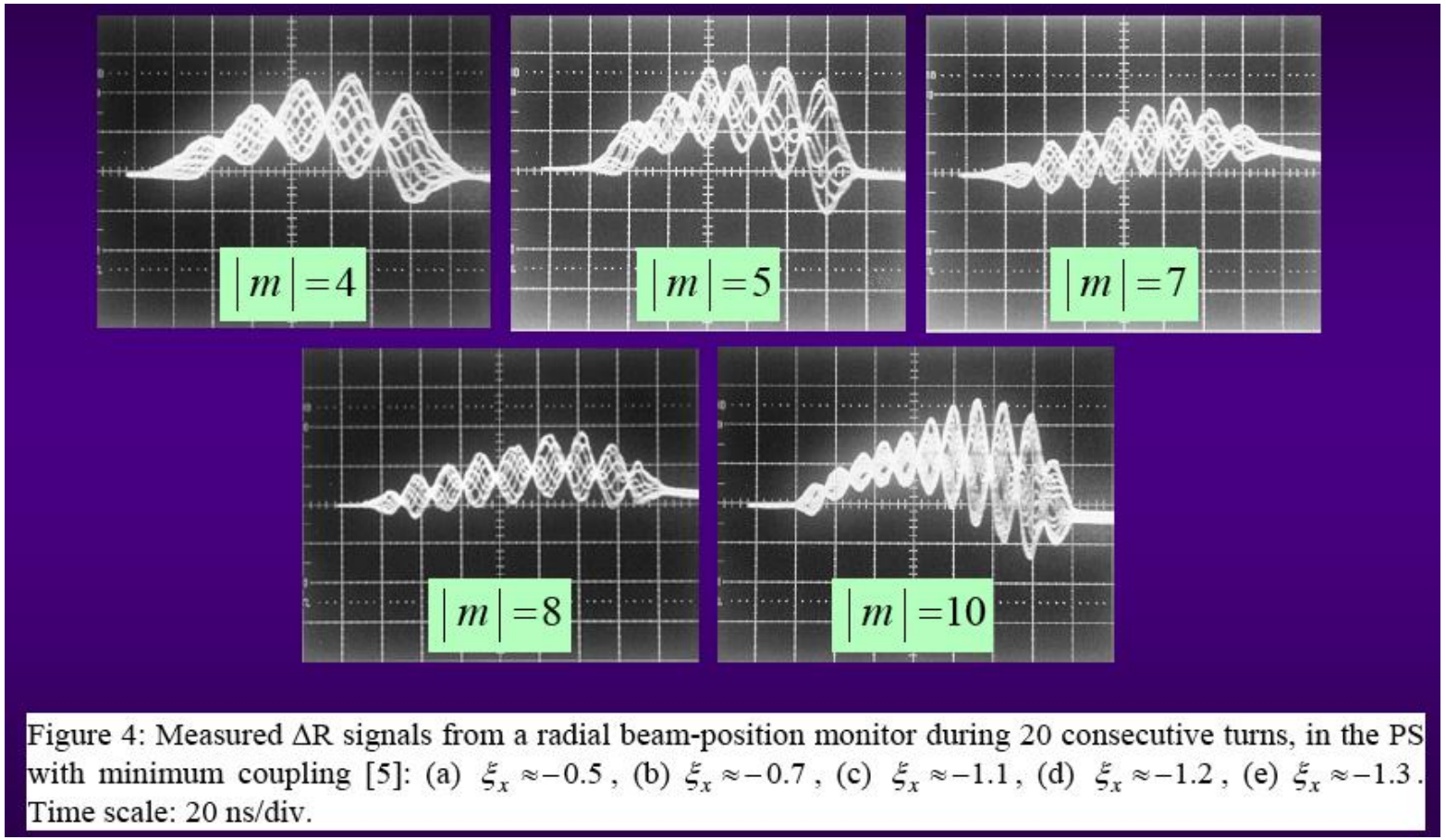


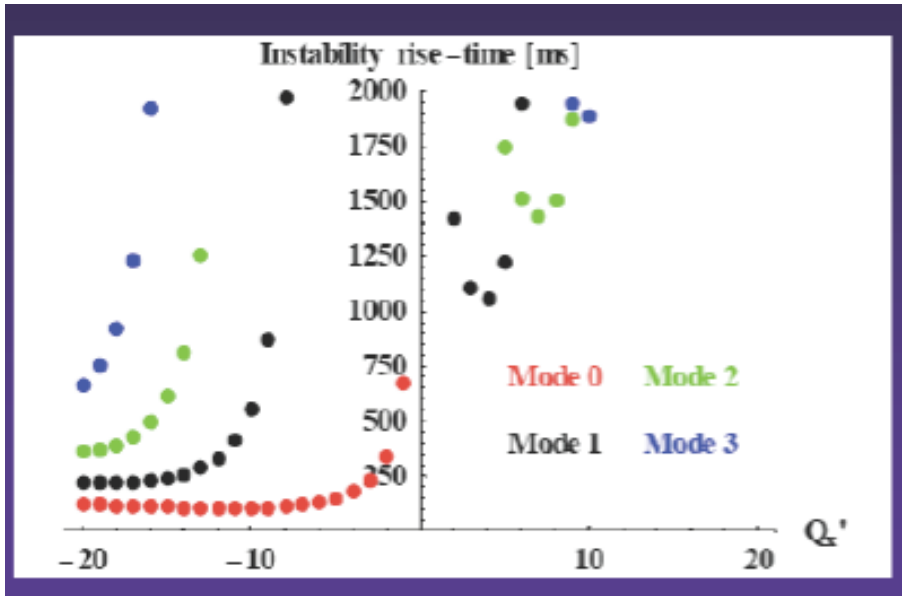
Figure 4: Measured ΔR signals from a radial beam-position monitor during 20 consecutive turns, in the PS with minimum coupling [5]: (a) $\xi_x \approx -0.5$, (b) $\xi_x \approx -0.7$, (c) $\xi_x \approx -1.1$, (d) $\xi_x \approx -1.2$, (e) $\xi_x \approx -1.3$. Time scale: 20 ns/div.

E. Metral, G. Rumolo

Head-tail and chromaticity

- Influence of Q' (controlled with sextupoles):
  - *Low Q' (below 0): instability is driven by the dipole mode 0.*
  - *High(er) Q' (> ~ 3): instability driven by modes 1,2,3….*
  - *We presently run with Q' in the range 3-6, but excursions down to 0 or up to 12 occur regularly.*
  - *Too high Q' is not good for lifetime (machine is too non-linear…).*
  - *Octupoles can be used to prevent the growth of the coherent instability.*

Simulation for injection, hor. Plane



E. Metral et al

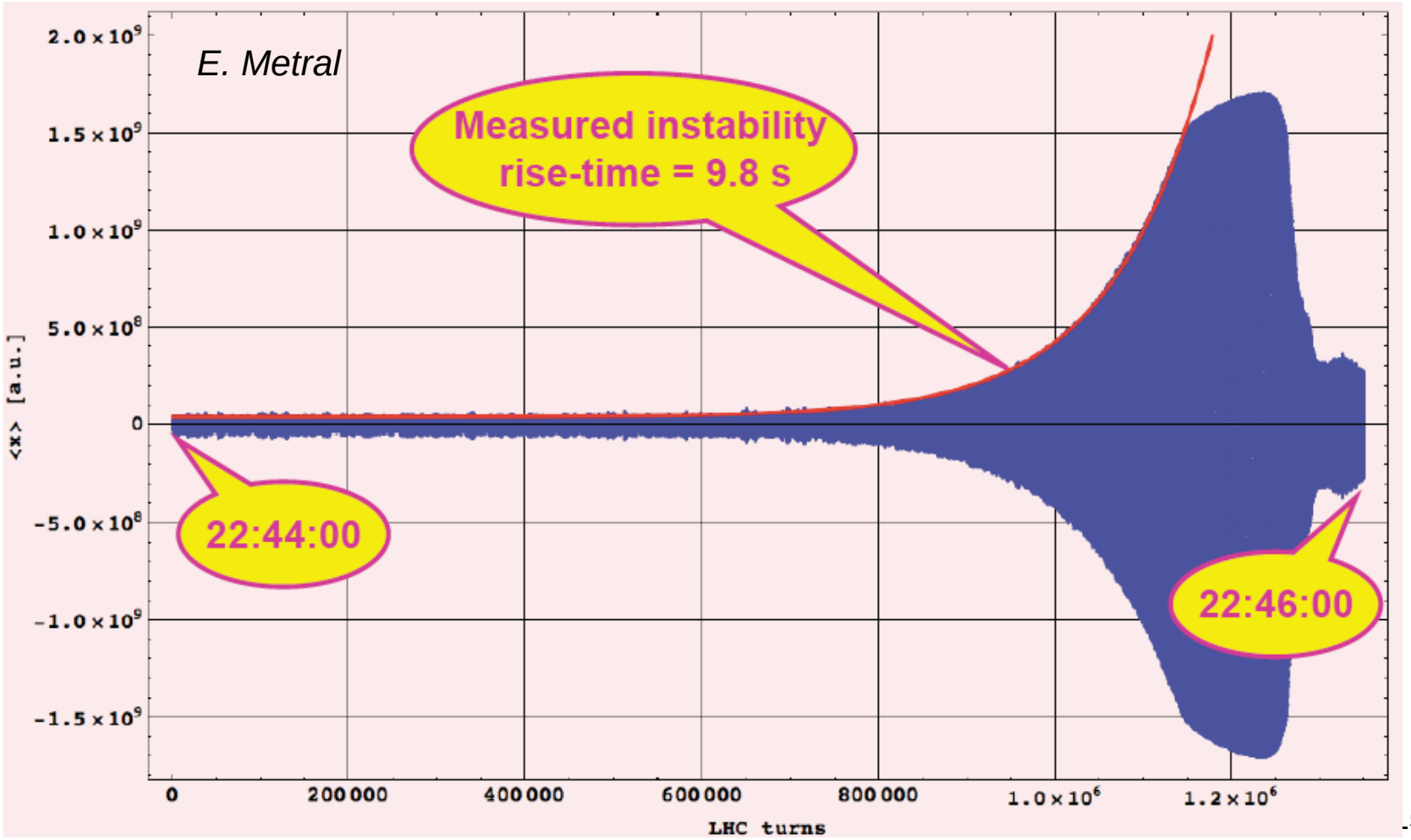
The best operating point is near Q' ~ 1-2, which can only be done with the transverse damper (in case Q' drifts below 0).

Commissioning of the transverse damper (ADT) has high priority !

Instability at 3.5 TeV

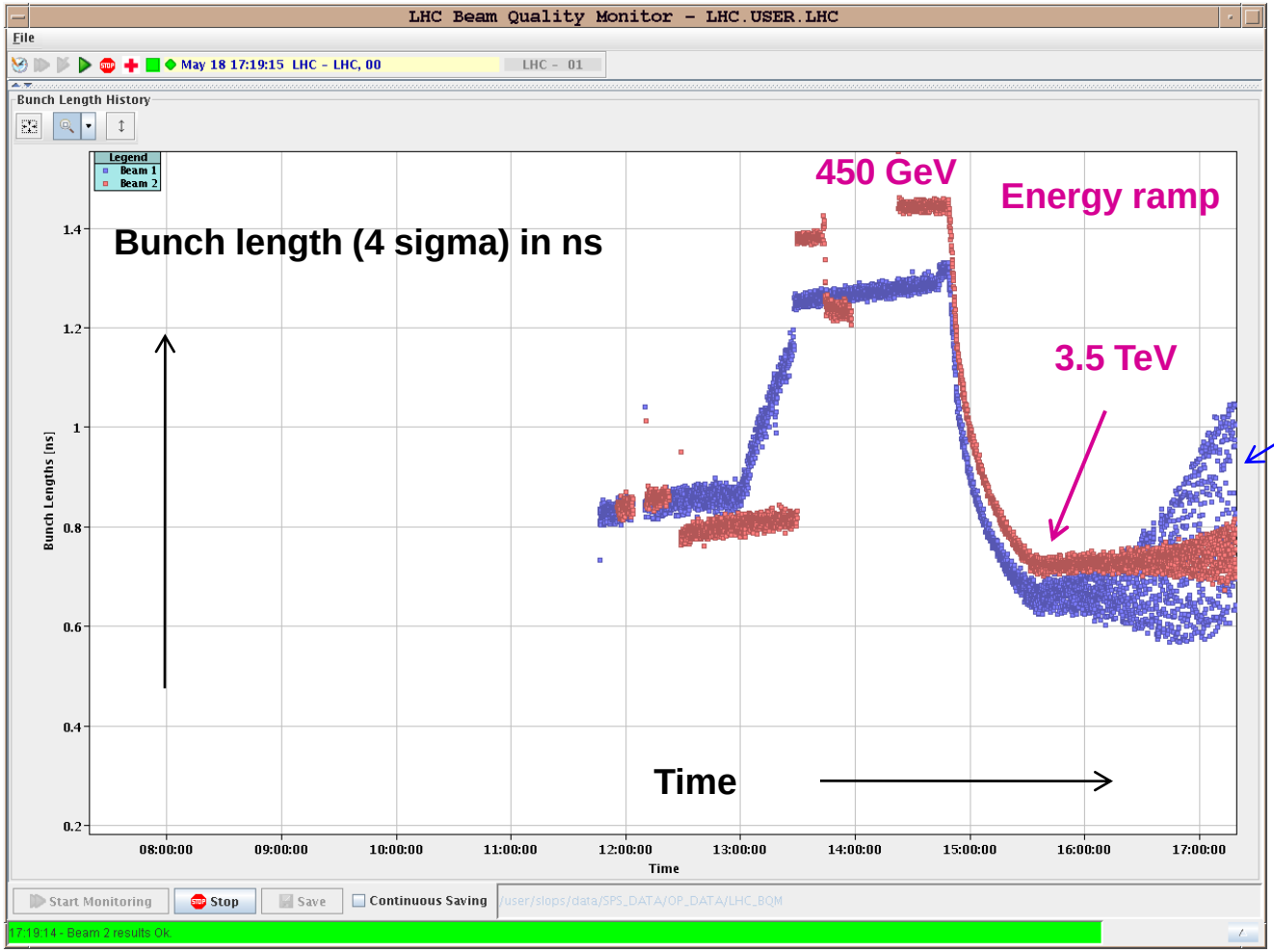
Instability development of mode 1 at 3,5 TeV when octupolar fields are reduced.

- *Predicted rise-time is ~ 4-5 s*



‘Dancing’ bunches at 3.5 TeV

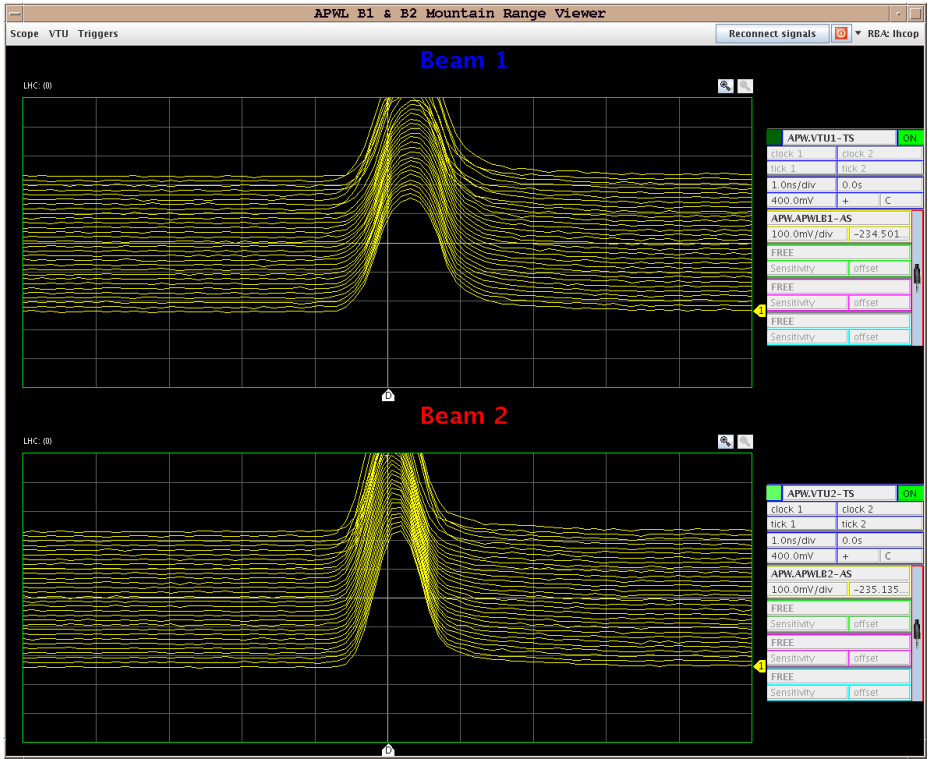
- From the last LPCC: ‘dancing’ unstable bunches, visible here over the bunch length



Beam 1 (blue) is very unstable: the length / shape is oscillating

Longitudinal emittance blow-up

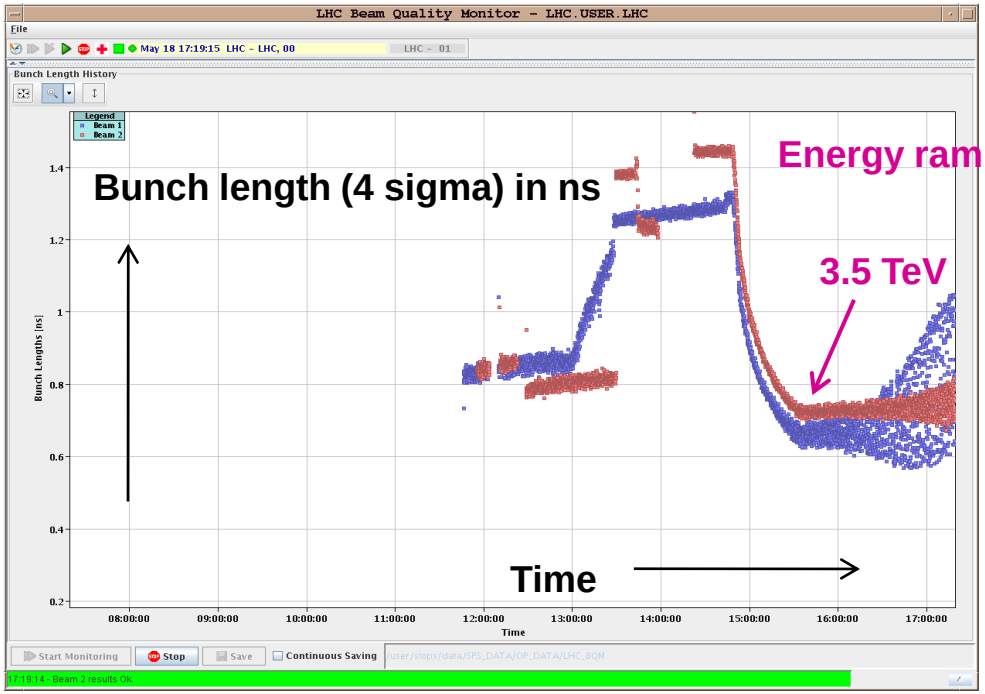
- We have now the possibility to inject bunches with larger longitudinal emittance from the SPS (~ factor 2).
- The RF group has successfully tested the hardware for controlled emittance blowup during the ramp.
  - *Inject band-limited noise (range ~20-45 Hz – synchrotron frequency) on the RF phase control to excite the particles in the center of the RF bucket.*



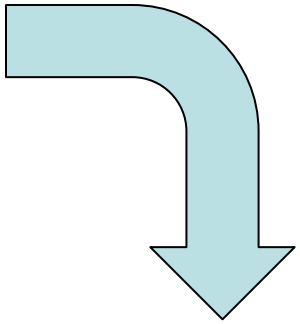
B1 with emittance blow-up,

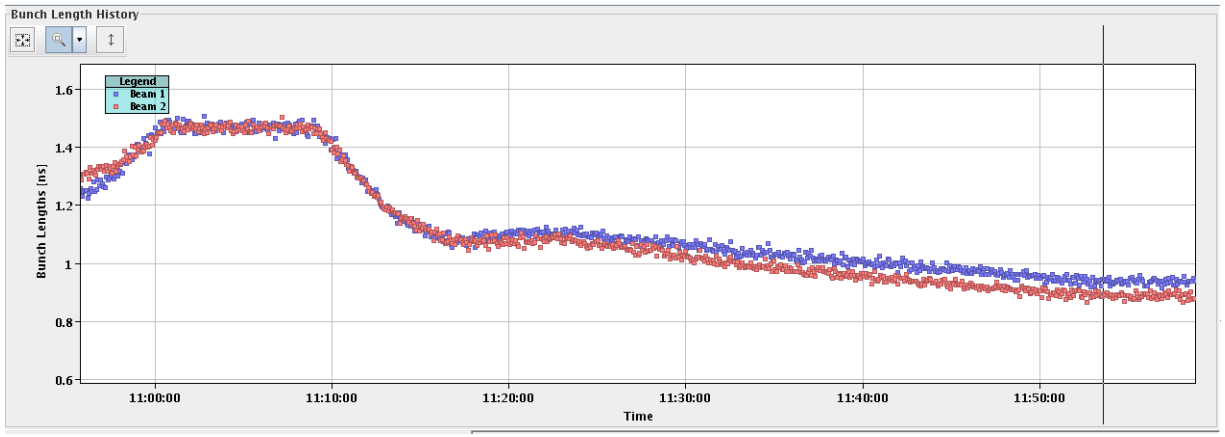
B2 without blow-up.

Bunch lengths in the ramp

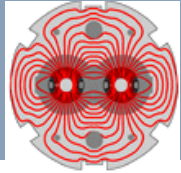


With controlled emittance blowup





Progress on nominal bunches



- We can presently accelerate nominal bunches without losses to 3.5 TeV, and have a stable bunch at 3.5 TeV.
  - *For the moment we rely mostly on longitudinal blowup and octupoles for beam stability.*
  - *Latest collision tests at 10 m β* are encouraging.*
- But the nominal bunches (1E11 p/b) still suffer from strong emittance growth at injection and in the ramp:
  - *The emittance increases from 2-3 μm at injection (below nominal value of 3.5 μm – thank our injectors !) to 5-10 μm at 3.5 TeV.*
  - *For 8E10 p/b the situation seems better: ~4-5 μm at 3.5 TeV*.

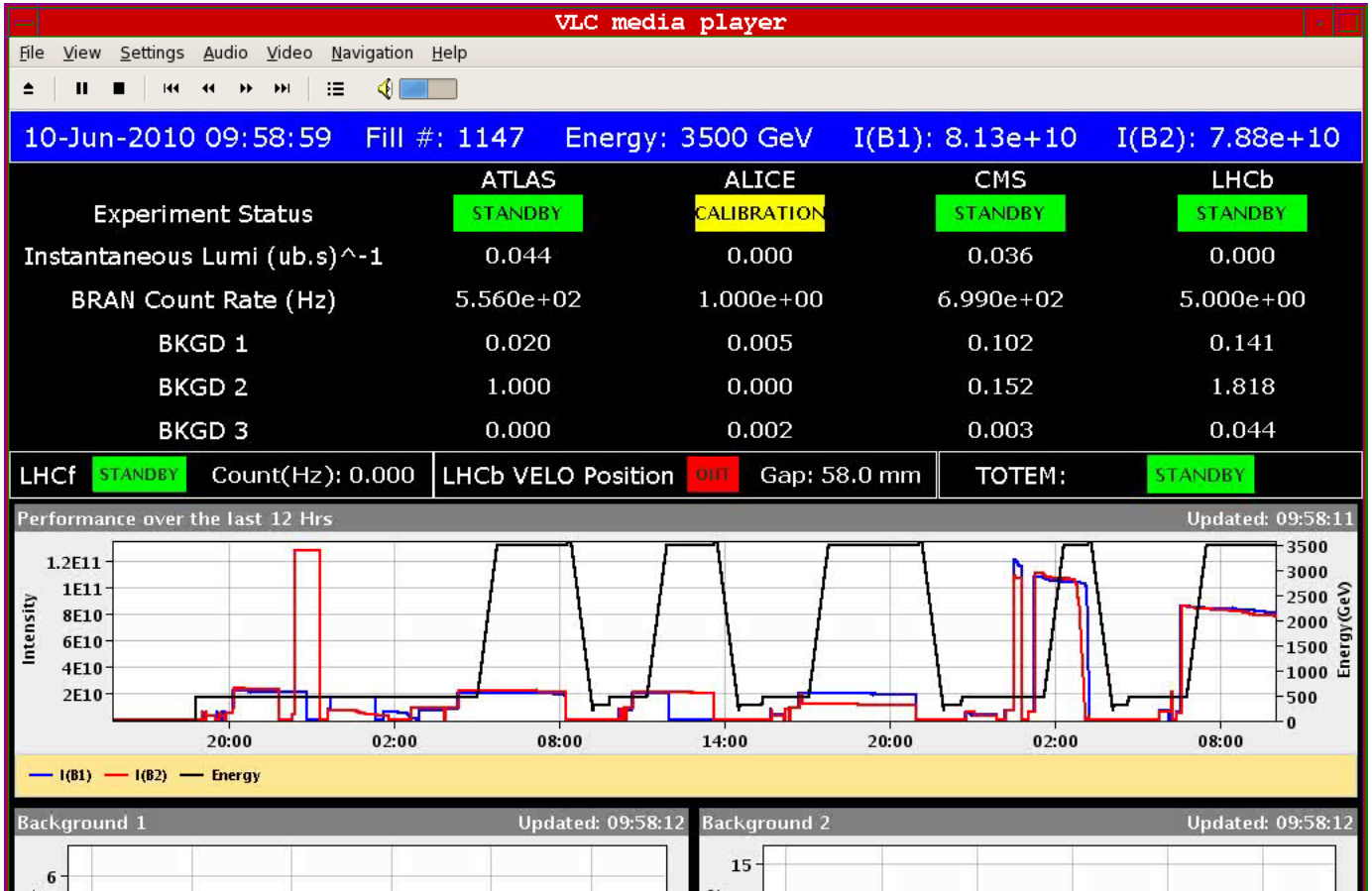
>> The transverse damper should help !

‘Stable’ collisions

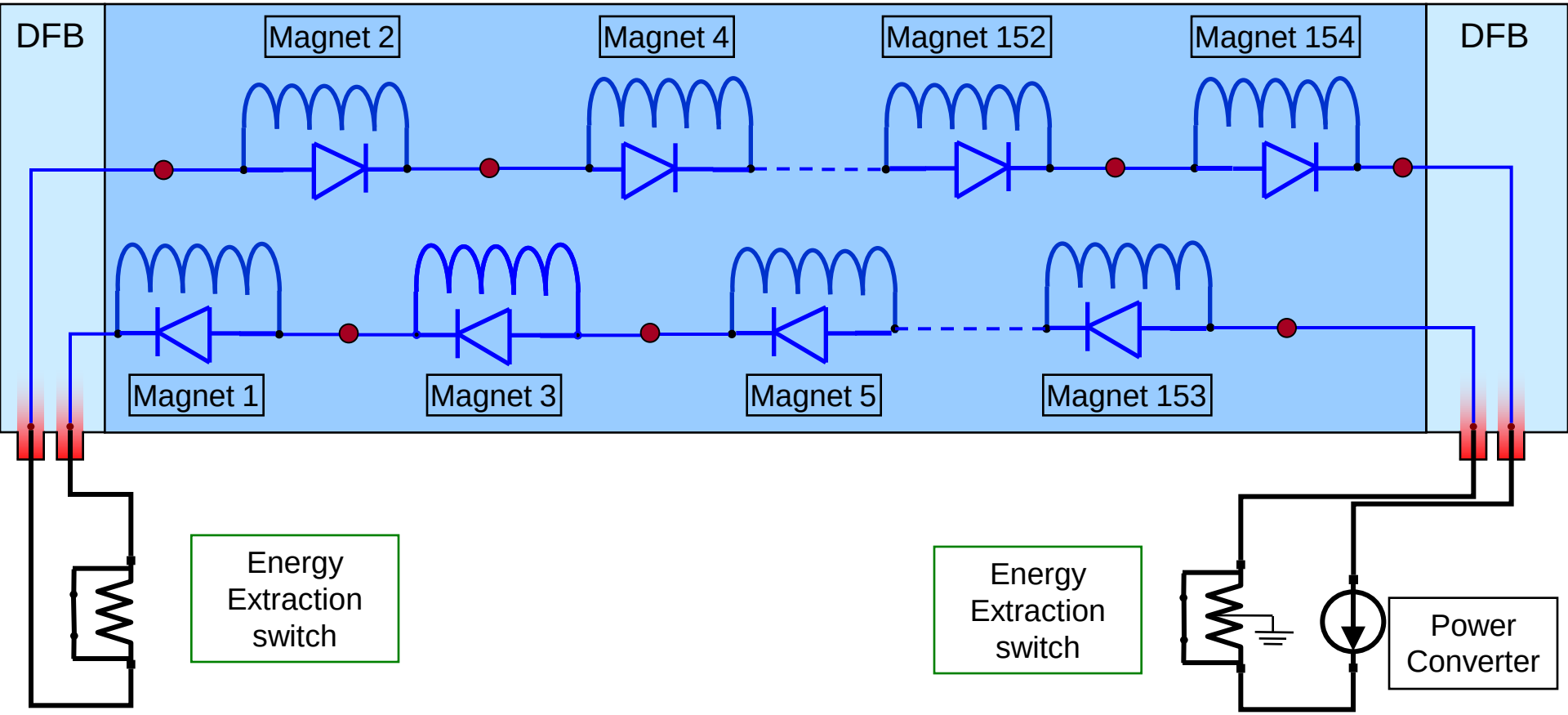
- Stable collisions with 8E10 p/bunch and β^* 10 m, ε ~5 μm.

  $L \sim 4 \times 10^{28}$ cm^{-2} s^{-1}

- Projection for β^* of 3.5 m and 8 colliding pairs : **$L \sim 10^{30}$ cm^{-2} s^{-1}**

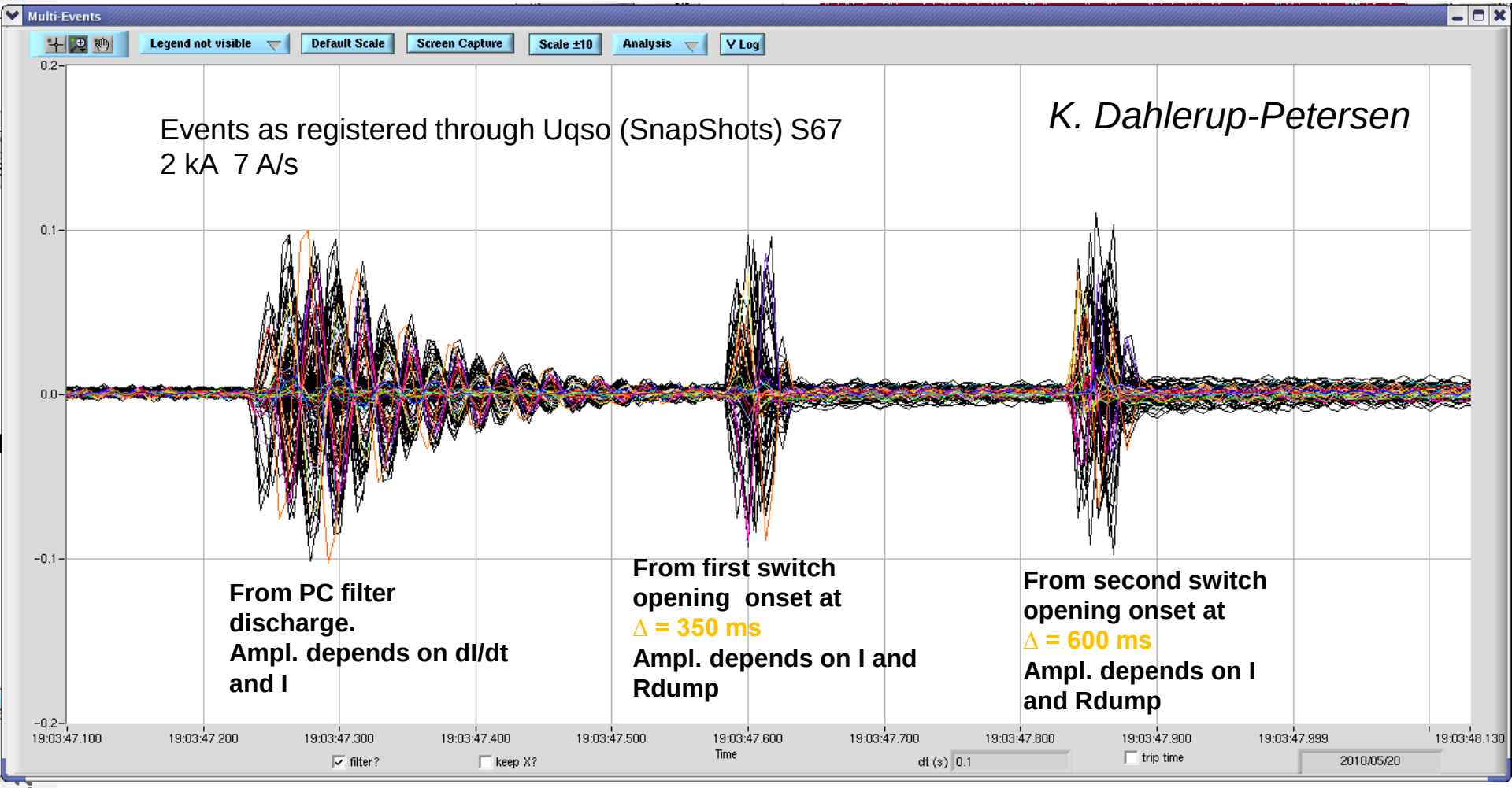


Faster ramp: main circuits

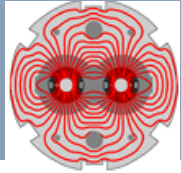


Delayed energy extraction switch opening

Circuit powering abort as seen by the quench detection system



Faster ramps



- During last week's technical stop, all the hardware modifications to be able to (safely) ramp the magnets at 10 A/s were completed.
  - *Delayed opening of the energy extraction switches to avoid spurious (fake) quench triggers due to the superposition of voltage perturbations due to the PC switch off and the switch opening – consequence of the shorter discharge time (busbar / slice protection).*
- The modifications have been tested in all but one sector.
  - *About 1-2 h of commissioning to complete.*
- Changing the ramp rate will have a significant impact on operation (persistent current effects) through larger perturbations of tune, chromaticity at injection and in the first part of the ramp.
  - *Requires significant work on the ramp (few days?).*

>> We decided to stay with ramp rates of 2 A/s for the coming few weeks to avoid diverting time and effort into faster ramps.

Summary

- LHC commissioning and operation is now concentrated fully on preparation for nominal bunches.
  - Prepare the base for future. Luminosities of 10^{32} $cm^{-2}s^{-1}$ are out of reach with low bunch populations !
  - Initial progress was slow because we had to put many tools/systems in place – but now we are starting to harvest the first encouraging results !
- Machine operation and commissioning teams must be given the time to do their job properly, even if some periods may be frustrating.
  - Time estimate for physics with nominal bunches is 2 weeks (from now) – includes contingency for machine uptime.

We need your support, and a little bit of patience !