The LHC transverse damper: a multi-purpose system

G. Kotzian, M. Soderen, D. Valuch*

In close collaboration with:
BE-RF-PM: S. Rains
BE-RF-CS: M. Jaussi, Y. Brischetto
BE-ABP: X. Buffat, S. Antipov, the instability team, the whole optics team
BE-OP: M. Solfaroli, J. Wenninger

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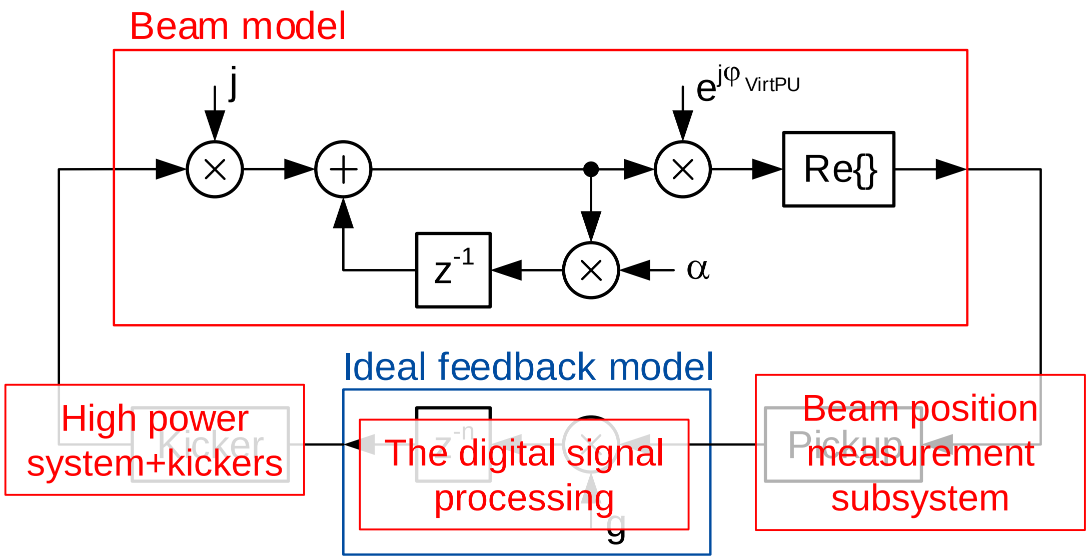
JINR: V. Zhabitsky

* daniel.valuch@cern.ch

LHC transverse feedback

- The LHC transverse feedback system measures the bunch by bunch, turn by turn beam position and tries to keep its oscillatory part zero

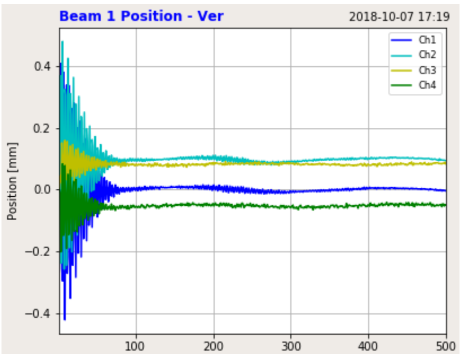


Overall damping rate: $\frac{T_{Rev}}{\tau} = \frac{T_{Rev}}{\tau_{Damping}} - \frac{T_{Rev}}{\tau_{Instability}}$

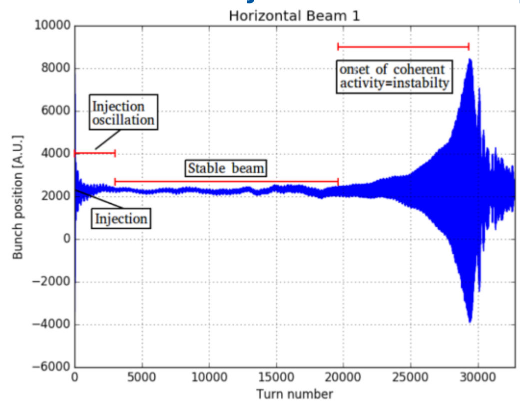
Ref. [1] [2]

What ADT has to do?

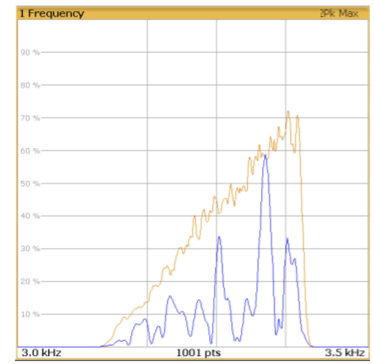
Damping injection oscillations



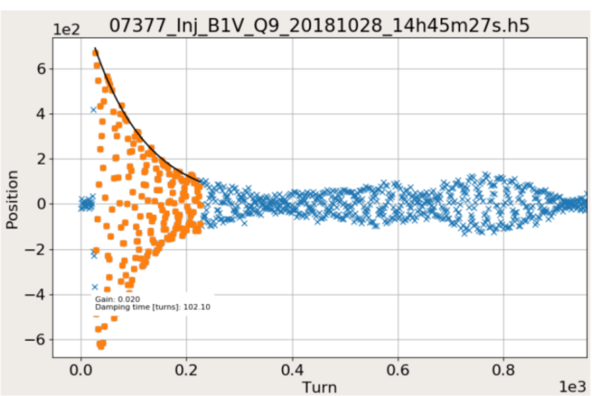
Stabilizing the beam in trans-verse from injection till dump



Abort gap, injection gap cleaning, excitation for loss maps

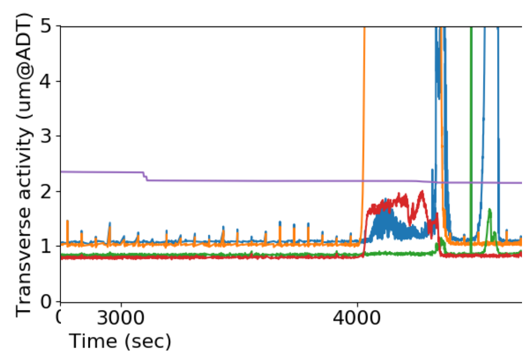


Active instrument for various operational beam measure-ments, machine development



(b) Beam 1, vertical

Providing bunch by bunch, turn by turn data for online and offline analysis, instability detection, post mortem data



On-demand active, or passive bunch by bunch tune measurement

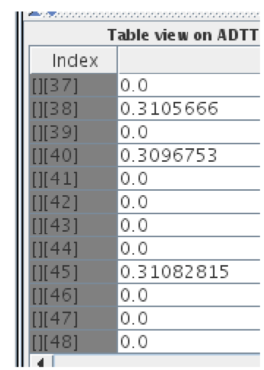


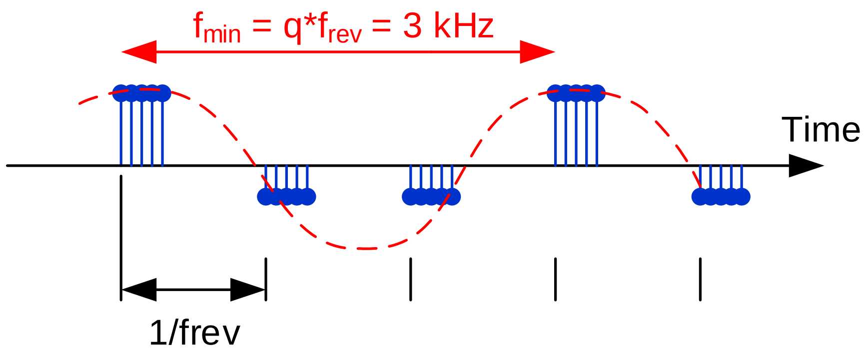
Table view on ADTT

Index	
[][37]	0.0
[][38]	0.3105666
[][39]	0.0
[][40]	0.3096753
[][41]	0.0
[][42]	0.0
[][43]	0.0
[][44]	0.0
[][45]	0.31082815
[][46]	0.0
[][47]	0.0
[][48]	0.0

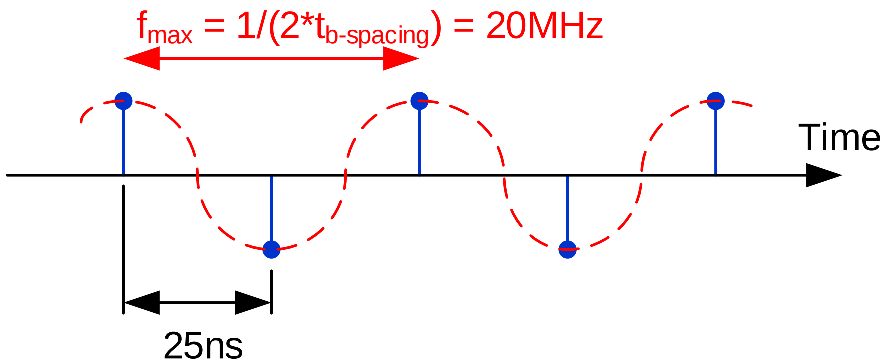
And many more…

ADT bandwidth. Where does it come from?

- The LHC transverse feedback corner frequencies are defined by:
  - Tune and the revolution frequency

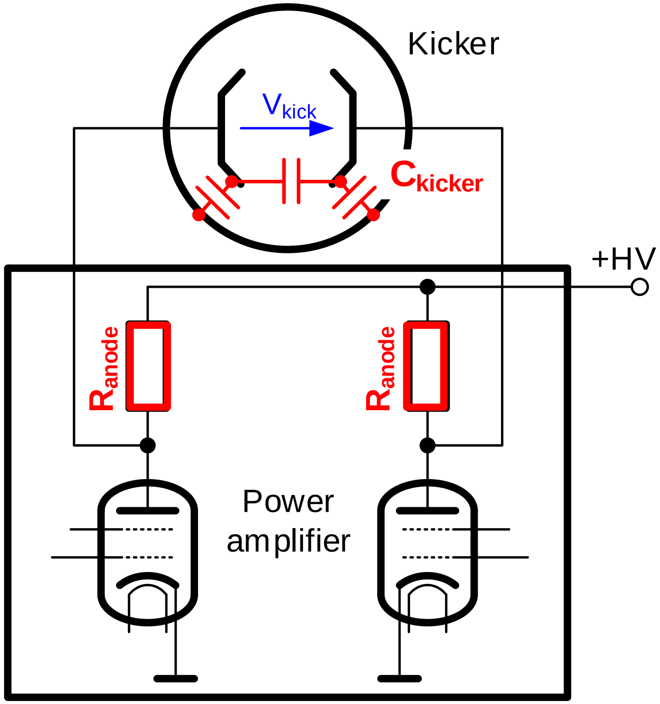


  - Bunch spacing



ADT bandwidth. Where does it come from?

- The full power bandwidth limitation comes from the amplifier output impedance and the loading kicker capacity



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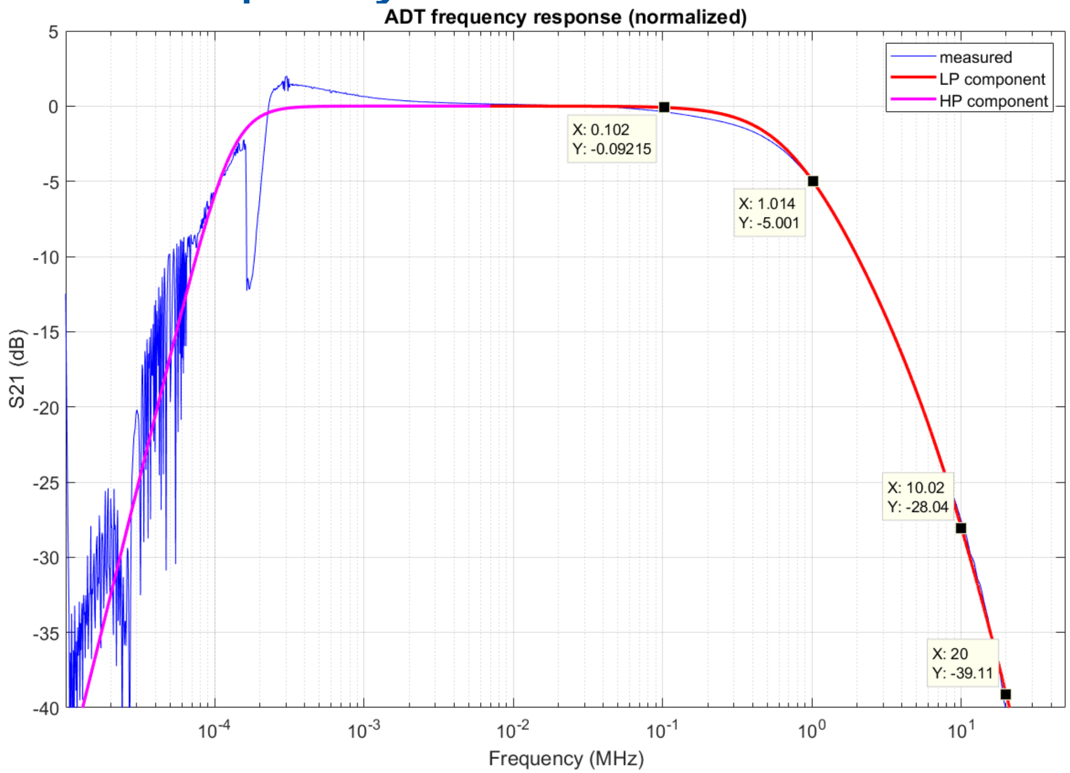
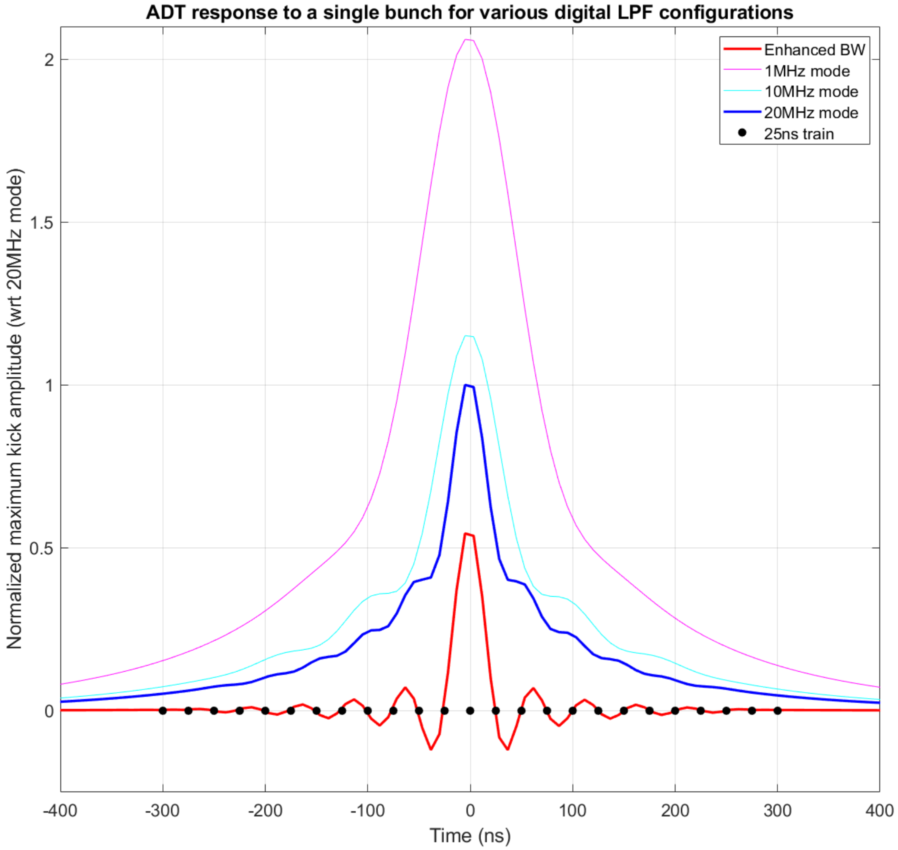


- Full kick strength at low frequencies, but…
- -5dB (56%) available at 1MHz
- -28dB (4%) available at 10MHz
- -39dB (1%) available at 20MHz

- This means different behavior for operation with single bunches/trains and for single bunch/full train motion

ADT bandwidth. Where does it come from?

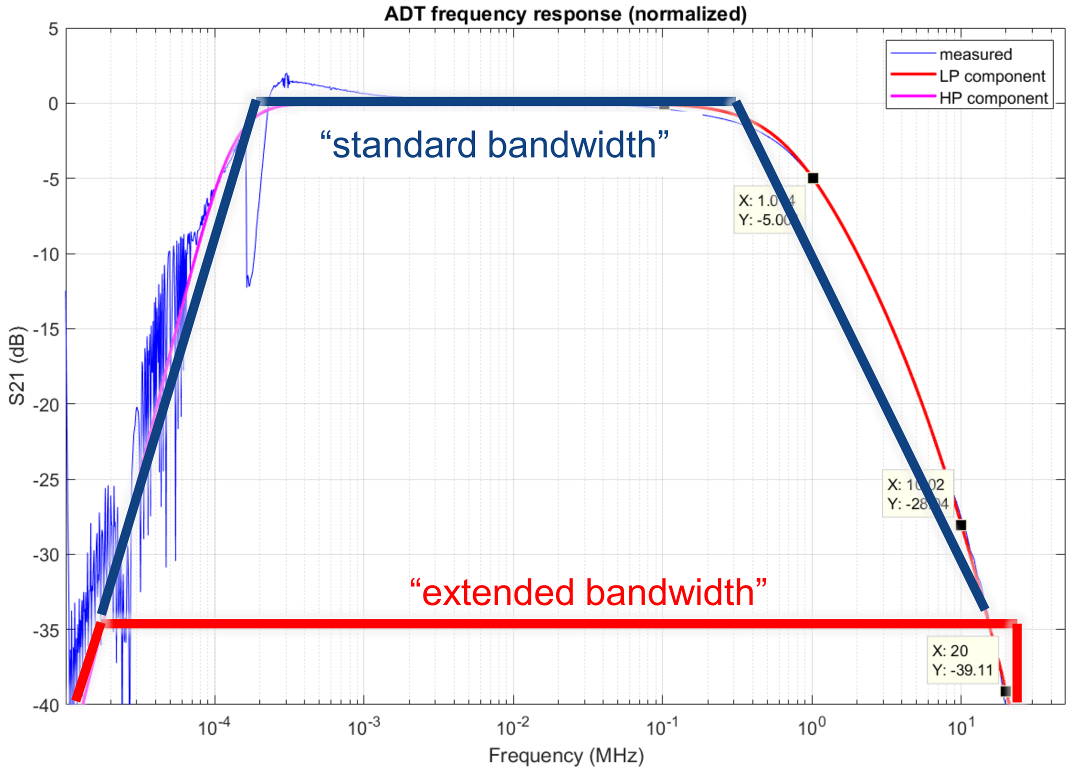
- Different behavior for operation with single bunches/trains, or single bunch/full train motion



- In “Ideal damper mode” (Enhanced BW setting), all bunches have the same damping time, no coupling through the damper
- In “Standard operation mode” (20MHz bandwidth), damping time for a single bunch activity is equal to all bunches regardless if single bunch circulating, or single bunch in a longer train
- In “Standard mode” there is certain coupling between 32 adjacent bunches through the ADT transfer function. Also, long trains experiencing coherent motion will have shorter damping time

ADT bandwidth. Where does it come from?

- With digital signal processing we can adopt the frequency/impulse response to cope with the particular machine mode

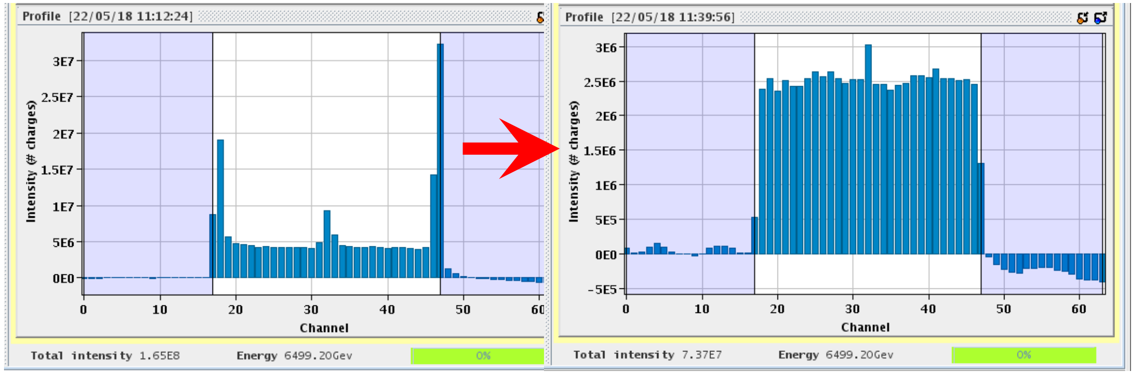


- "Standard bandwidth" for large deflection, i.e. fast injection oscillation damping
- "Extended bandwidth" – ideal damper to cope with tricky individual bunch instabilities i.e. scrubbing, ramp, squeeze
- Very flexible here, can change transparently on demand, anytime during the cycle.

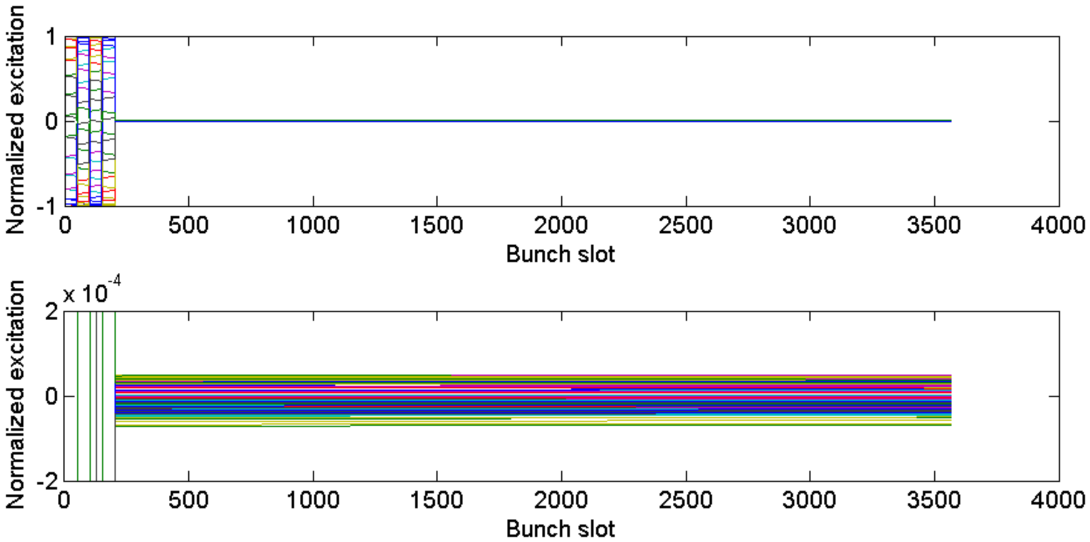
ADT bandwidth. Where does it come from?

- Extreme cases:

After 22/5/2018 we started to clean the full length of the abort gap (120 bunch slots) at flat top, without visible perturbation to the circulating beam and impact on luminosity.



A long, low frequency pulse does leak to the rest of the ring. Injection of very long trains, or not optimized injection gap/abort gap cleaning pulses do perturb a bit the circulating beam…



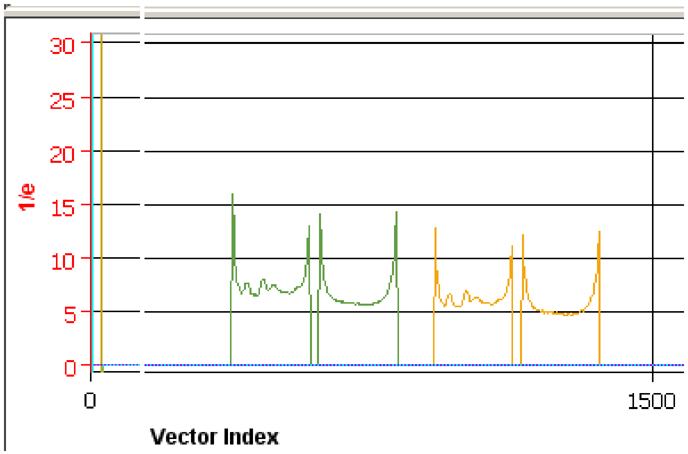
Damping times: values and limitations

- The system is designed to maintain at least 50 turns damping time through the full cycle

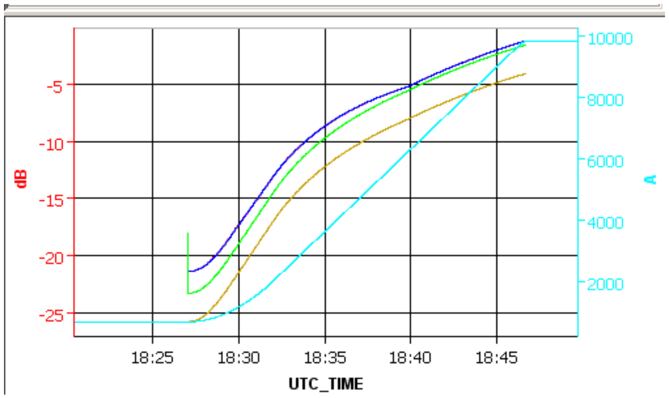
- Typical values from run 2:
  - Injection 10-20 turns
  - Ramp, squeeze 50-80 turns
  - Physics 50-100 turns

- Same performance is requested/expected for Run 3 [4]

Typical damping time at injection



Gain scaling through the ramp to conserve a constant damping time



Damping times: values and limitations

- The limiting factors for the corner cases are:
  - ***Available deflection*** – scales with energy (factor ~15)
  - Some margin using more favourable optics at IR4
  - A little margin by increasing the Anode voltage (12 to 15kV)
  - More kickers at IR4, or else-where

  - ***The system power-bandwidth*** – fixed through the cycle
  - Amplifier redesign
  - Kickers redesign with lower capacity

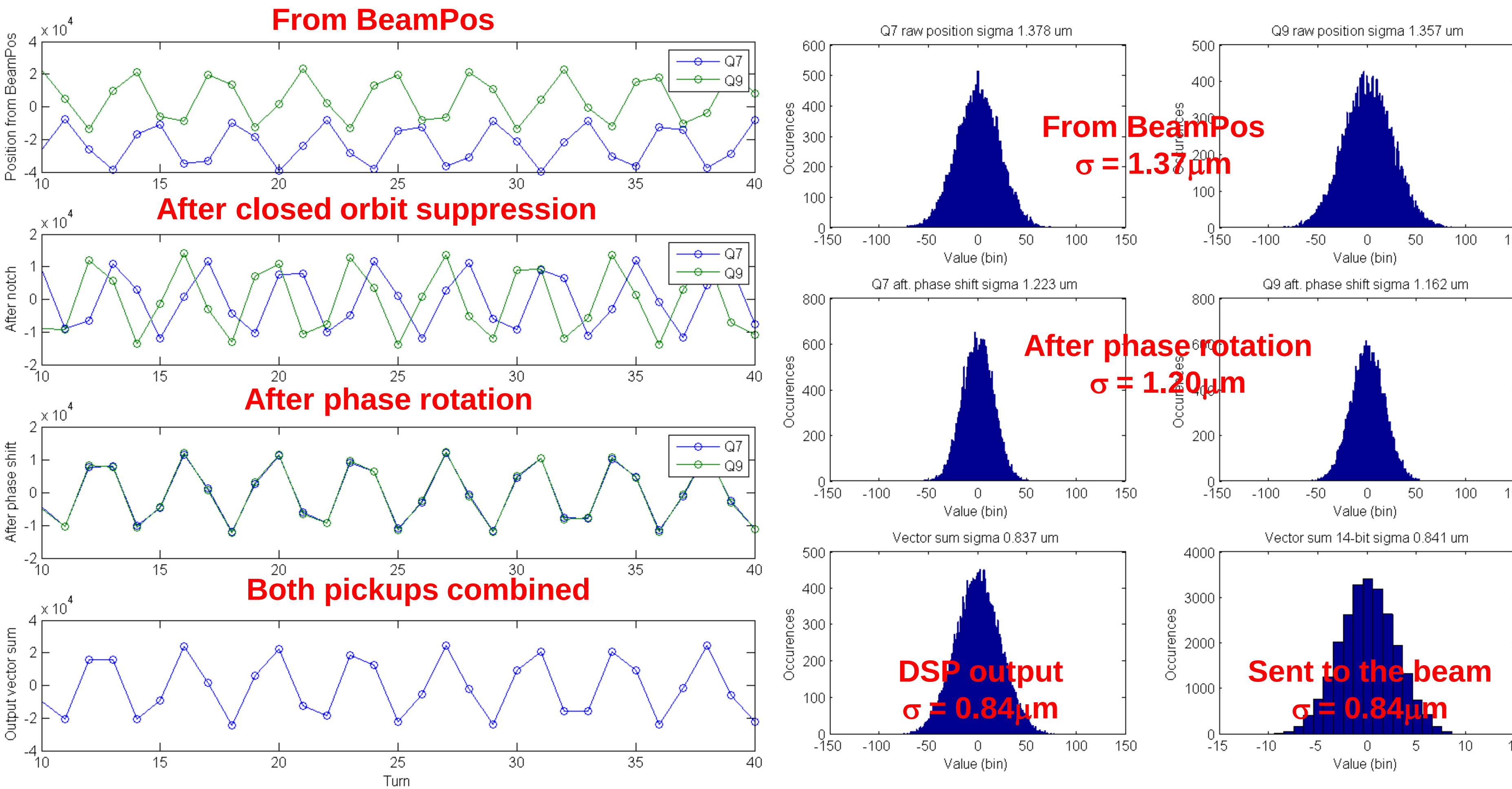
  - ***The digital signal processing delay***
  - Little gain for operation with extremely short damping times [3]

Known imperfections

- Frequency response – discussed earlier

- System noise floor – the ADT noise floor is currently dominated by the beam position measurement noise

Noise performance of the full ADT signal chain



Simulated ideal signals for nominal intensity and 1mm displacement, phase advance between pickups 90°, superimposed on real, measured front-end noise and real digital signal processing algorithm (16bit integer). **Data taken in 2018.** Slide from Valuch D: Plans for improved ADT pick up resolution, presented at 118th HiLumi WP2 Meeting https://indico.cern.ch/event/718322/

What is damper doing?

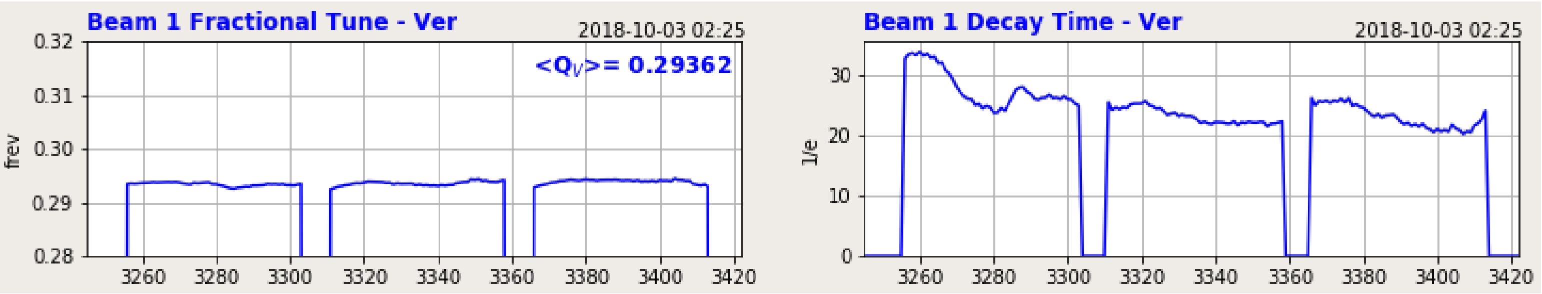
- ADT is a rather complex system
  - Vital for beam stability
  - Hundreds of various settings (standard, machine critical)
  - Powerful enough to cause significant losses within few turns
  - Multi purpose – damping, cleaning, excitation
  - Multi users – machine sequences, operators, MD users
  - “…let me just test this script, it will be transparent”

- Many scenarios for potential mishaps

How do we know what the damper is doing at any moment in time?

- Thorough settings management
- Thorough user and functionality profiling (e.g. RBAC)
- No quick ad-hoc end of fill MDs anymore without prior preparation and testing in laboratory. ***You want it, you give us time for a proper preparation!***

- Automatic performance analysis at each injection (Damping time calculation, Injection oscillation analysis)



How do we know what the damper is doing at any moment in time?

- Logging of all important parameters
  - E.g. was excitation enabled and running at a given time?

- ADTObsBox is a very powerful tool for the ADT system diagnostics too
  - The system transfer function with beam is known, we know how to interpret patters detected e.g. by transverse instability trigger from instability buffers
  - Post mortem data
  - New for Run3 – saving certain internal signals from the Digital signal processing by ADTObsBox (expert use)
  - New for Run3 – greatly extended internal diagnostics with logging

- You might want also to indicate what has been done to have such an excellent ADT in the LHC

…a lot of hard work of competent and very dedicated people

Summary

- ADT – the LHC transverse feedback system is a vital device for the LHC operation
- In 10 years it evolved into a multi purpose system:
  - Damping the injection oscillations and mitigation of certain beam instabilities
  - Sophisticated excitation for all kinds of beam measurements, cleaning, controlled emittance blow-up, loss maps…
  - Provides bunch by bunch, turn by turn data for real time analysis, or offline analysis (instabilities, transverse activity, spectrum, tune…)
  - Indispensable tool for machine development sessions. Excitation, source of controlled impedance…

Summary

- Great collaboration with our beam physicists (BE-ABP) allowed us to exploit and improve the system even further
  - Constraints and parameter requests based on rigorous machine studies (damping times, bandwidth, operation modes)
  - Identification of critical parameters (e.g. max. noise floor)
  - Close collaboration and exchange of ideas on useful operational tools and methods (linear coupling correction, transverse activity monitor, real time instability detection)
  - Many new ideas in the pipeline (ADTObsBox, bunch by bunch tune measurement, 24 hour all bunch/turns data buffer…)
- We have to continue in this direction!

Thank you for your attention

ADT Low Level RF system installed in LHC point 4. Beam position measurement, digital signal processing, all ADTObsBoxes.

References

- [1] Kotzian G.: Possibilities for transverse feedback phase adjustment by means of digital filters. In: J. Phys. : Conf. Ser. 874, 1 (2017) pp.012089, 8th International Particle Accelerator Conference, Copenhagen, Denmark, 14 - 19 May 2017, pp.TUPIK095

- [2] Zhabitsky, V M; Höfle, W.; Kotzian, G.: Beam Stability in Synchrotrons with Notch and All-Pass Filters in the Feedback Loop of a Transverse Damper CERN-BE-2009-013

- [3] Komppula, J; Buffat, X; Kotzian, G; Li, K; Valuch, D: MD4036: New ADT signal processing for large tune acceptance, CERN-ACC-NOTE-2019-0008

- [4] Metral E, et al: Update of the HL-LHC operational scenarios for proton operation, CERN-ACC-NOTE-2018-0002