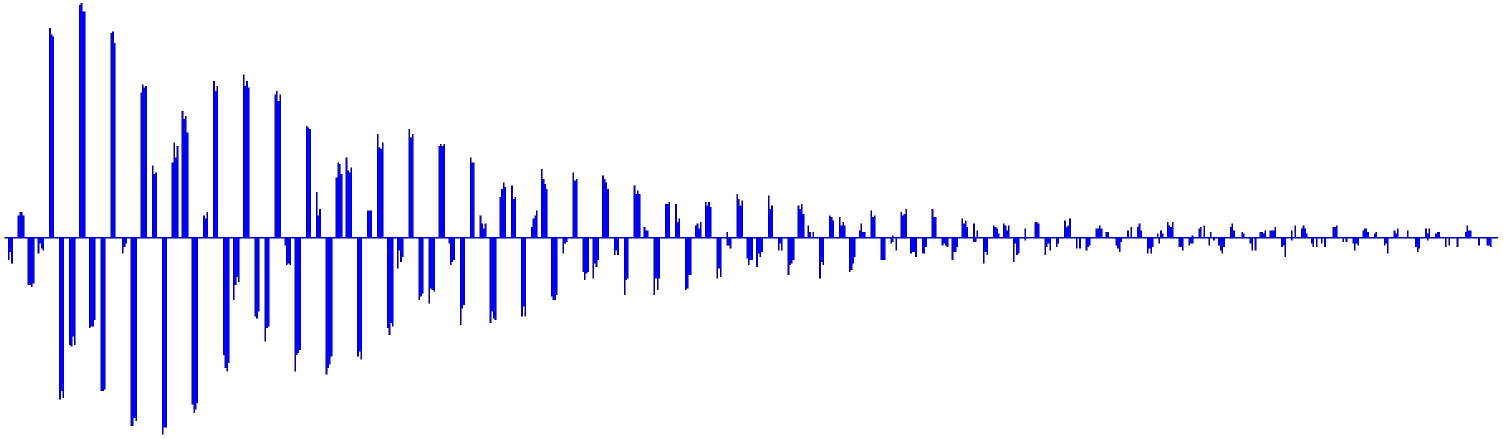
Excitation by ADT and active bunch-by-bunch tune measurements

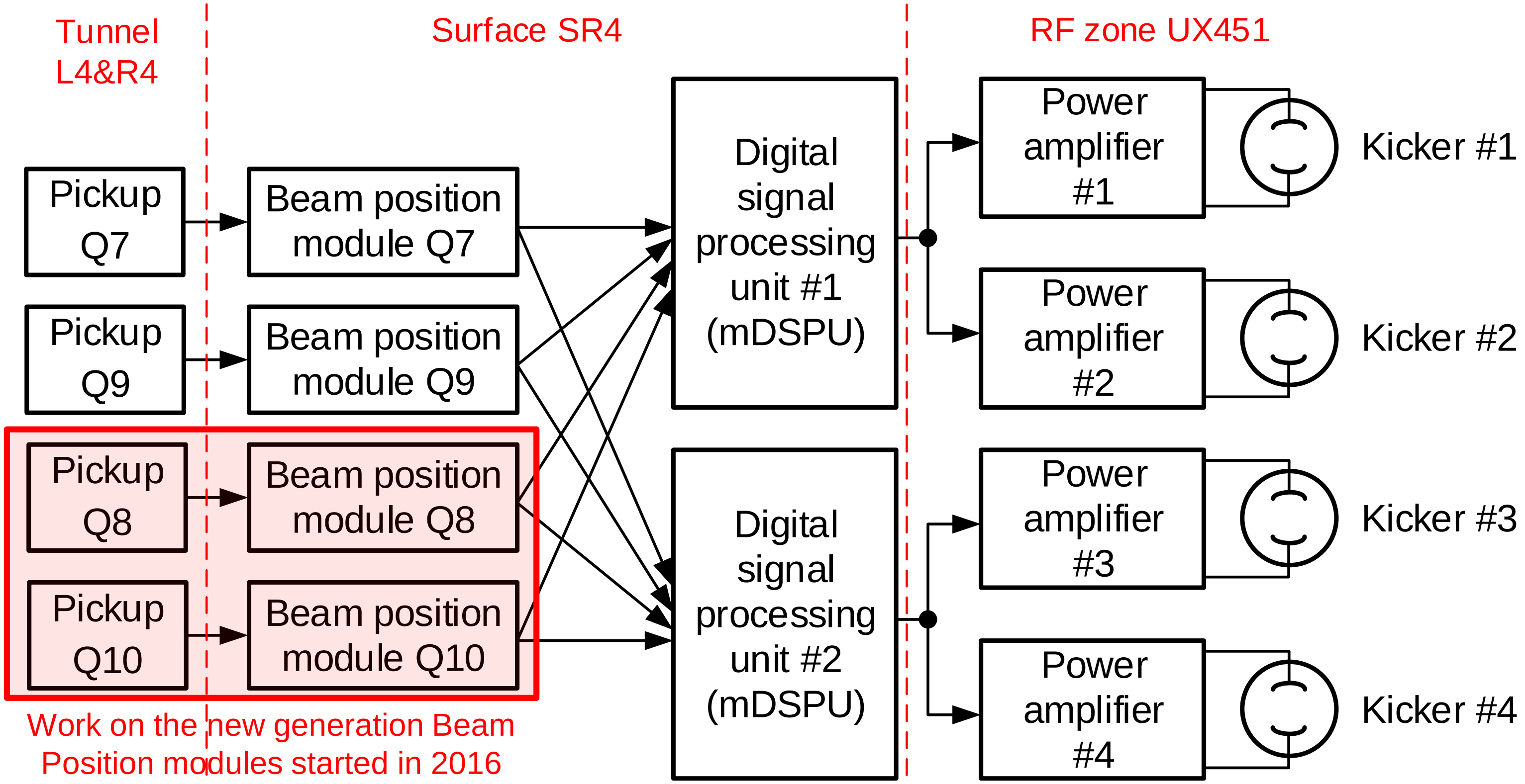


Wolfgang Hofle , Gerd Kotzian, Daniel Valuch

ADT – Overall System Architecture

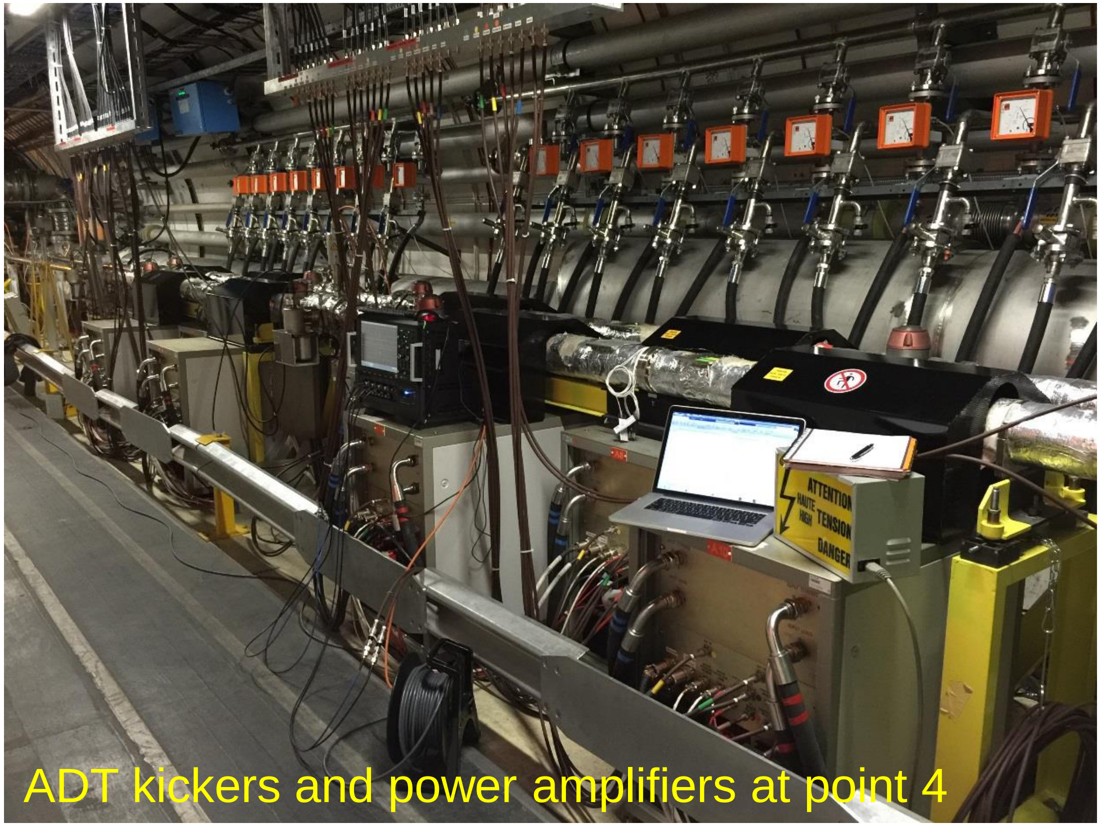
- Pickups in the tunnel (pt. 4), signal processing on the surface (SR4), driver amplifiers and controls UX45, power amplifiers and kickers in the RF zone (UX451)

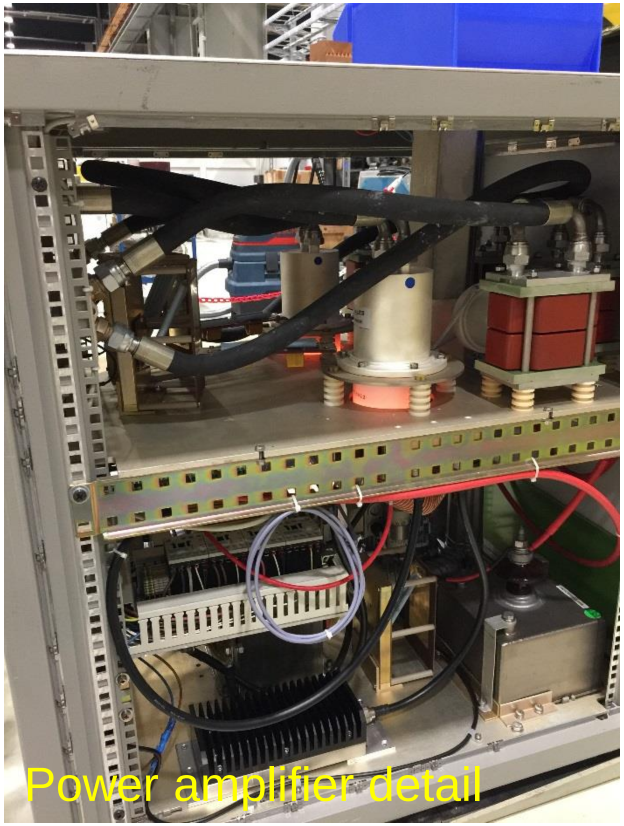
- **Multiple redundant system**



ADT Kickers and the Power System

- Four kickers per beam, per plane (16 total), located in RF zone (UX451) at point 4
  - Electrostatic kicker, length 1.5 m, powered by a class AB, tetrode push-pull amplifier
  - Max. differential voltage ~10 kV**, providing a kick of ~2 μrad** @ **450 GeV** (all 4 units combined). Useful bandwidth ~1 kHz – 20 MHz* (* terms and conditions may apply)


ADT kickers and power amplifiers at point 4


Power amplifier detail

ADT as Exciter

- Four measurements involving active beam excitation by ADT are currently being discussed

1. **Bunch by bunch tune measurement** for e-cloud induced bunch by bunch tune shift along a batch – modelling by Elias Metral & co.
2. **Bunch by bunch controlled emittance blow-up** for p-Pb run – John Jowett & co.
3. **ADT as AC dipole** for optics measurements – Rogelio Thomas & co.
4. **Pulsed excitation for the e-lens MD** – Miriam Fitterer & co.

- More or less all can be done in an “expert mode” already now
- For a proper operational tool 1,3,4 requires the ADT mDSPU firmware update
- …but all require MPP to be informed and/or approval of

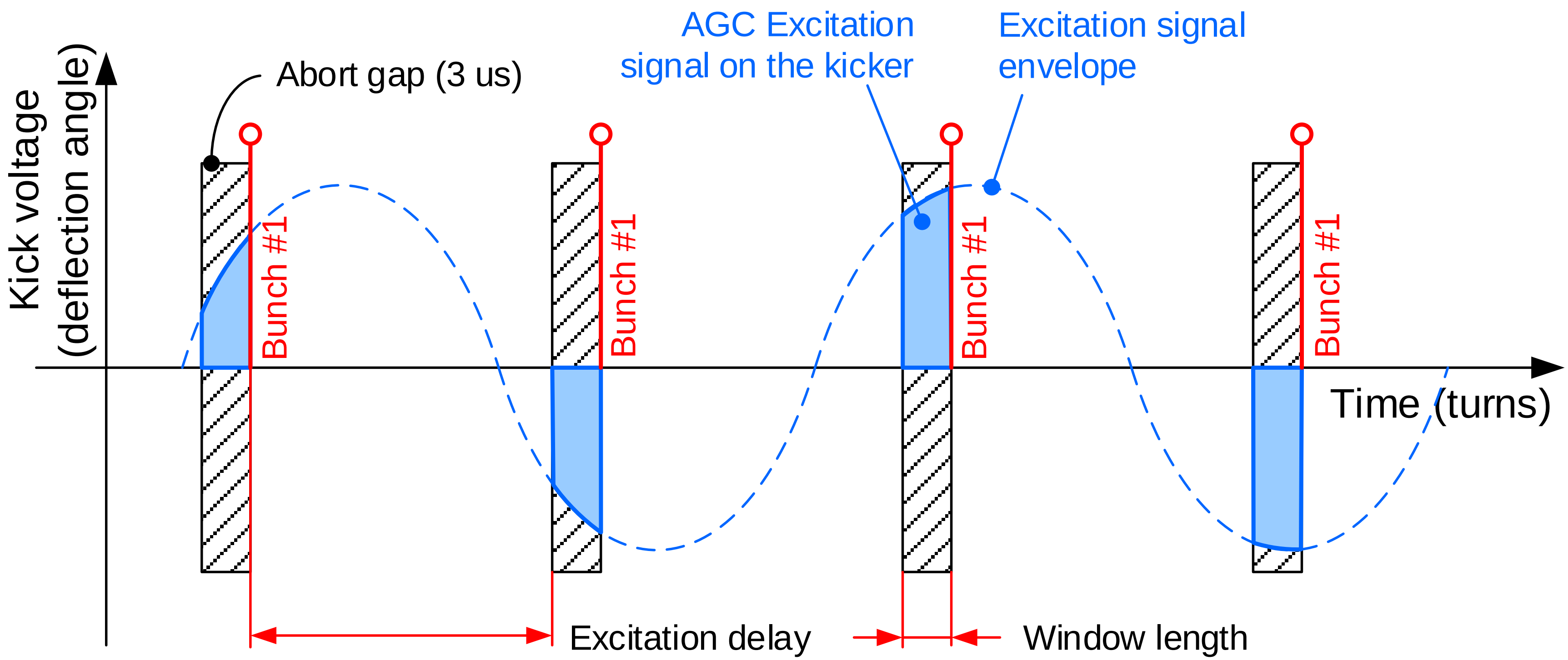
ADT as Exciter

- Thanks to the state of the art digital LLRF system, the ADT can synthesize virtually any signals, which can be used for beam excitation

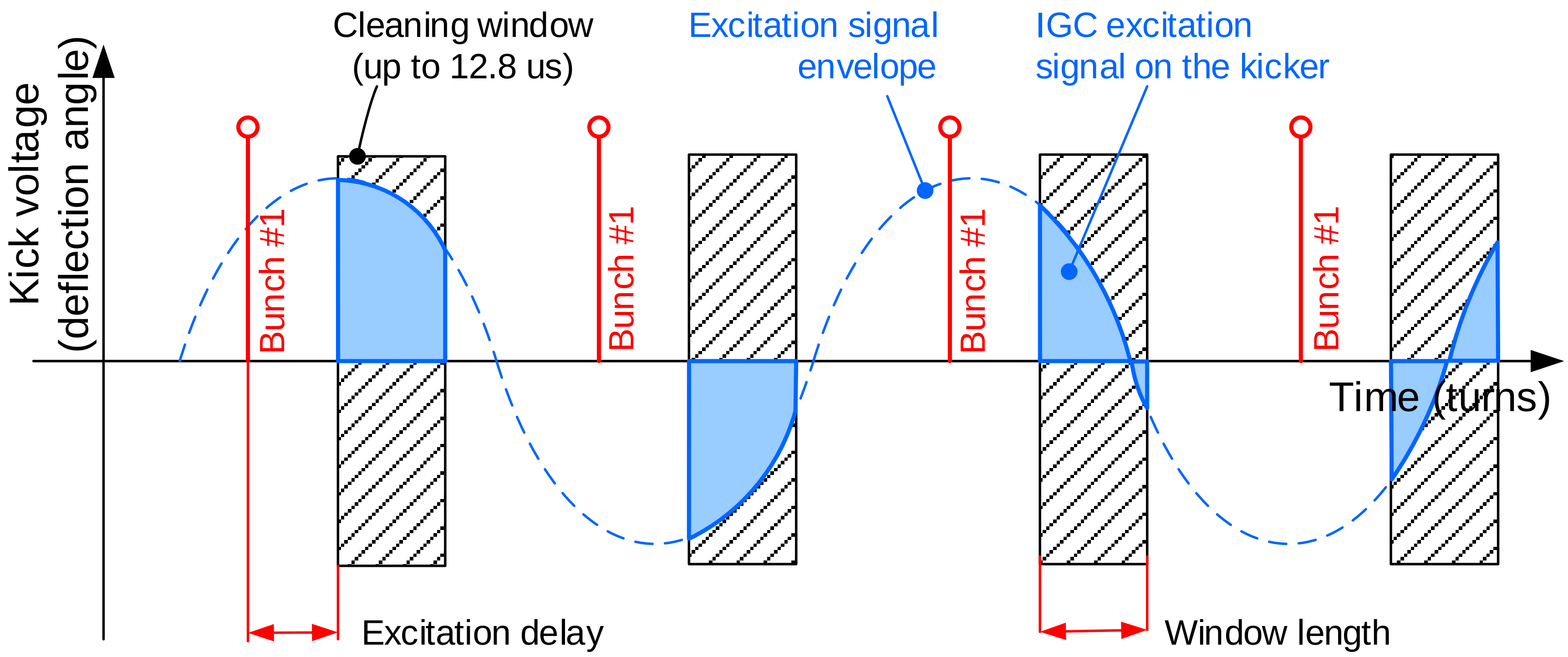
- Currently implemented and **routinely used** excitation modes:
  - Coherent excitation (with many modulation modes). Used for **abort gap** and **injection gap cleaning**, tune measurement, chirp, MDs
  - Wideband **white noise excitation**. Used for transverse emittance blow-up, loss maps, MDs
  - External analogue input for BI signals

- **What we discuss today:**
  - Active beam excitation by repetitive single-turn kicks at flat top
  - ADT validation after a firmware update

Excitation, Definition of Terms

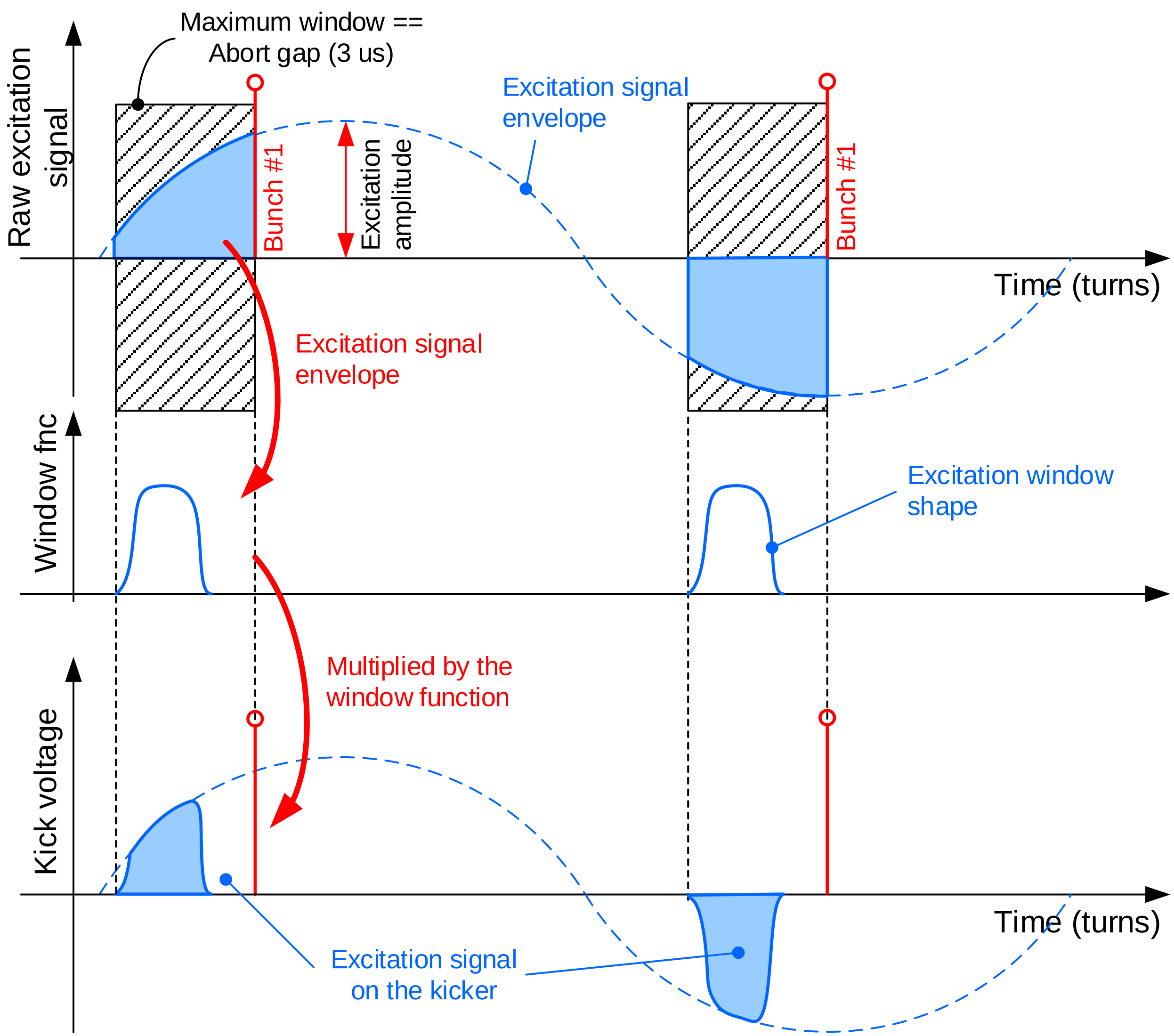


Excitation, Definition of Terms



Maximal window length for white noise excitation (blow-up) is also 12.8us (512 bunch slots).

Excitation, Definition of Terms



Active Excitation – What Are We Doing Already

- Abort gap cleaning (AGC)
- Injection gap (IGC)

- Blow-up for loss maps, bunch intensity reduction etc.

Abort Gap Cleaning

- Abort gap is cleaned in the vertical plane
- A machine critical setting tells the mDSPU which excitation mode it should execute (abort gap/injection gap)
- For AGC, the excitation window length is limited to 120 bunch slots (3μs). The limit is hard wired in the FPGA firmware
- For AGC, the gating delay is fixed and it is a machine critical setting
- AGC is running during the whole “Injection Physics Beam” process
- At flat top, the AGC can be triggered on demand by operator, or automatically by SIS

Injection Gap Cleaning

- Injection gap is cleaned in the horizontal plane
- For IGC, the excitation window length is limited to 512 bunch slots (12.8μs). The limit is hard wired in the FPGA firmware
- For IGC, the gating delay is programmed by the injection sequencer
- Injection gap cleaning is activated before every injection
- The excitation is stopped by OR of the three sources: 1) by the sequencer just before the injection, 2) beam-in pulse, 3) time-out after 19 seconds
- When going to Prepare for Ramp, all IGC settings are programmed to zero to prevent accidental activation

White Noise Excitation and Controlled Blow-up

- A pseudo-random number generator provides a white noise-like signal, one value per bunch. The frequency response is shaped by a digital filter*

- For blow-up, the excitation window length is limited to 512 bunch slots (12.8μs). Limit is hard wired in the FPGA firmware

- The gating delay is programmed by LSA

- The excitation can be triggered only when in possession of special RBAC role

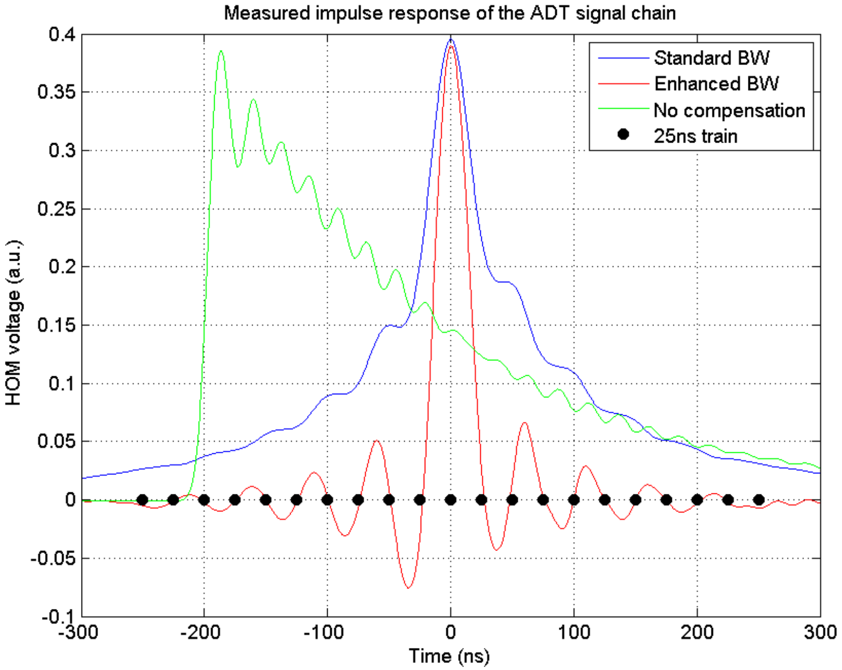
- Strength adjustable from "*gentle blow-up*" to "*exterminate*"

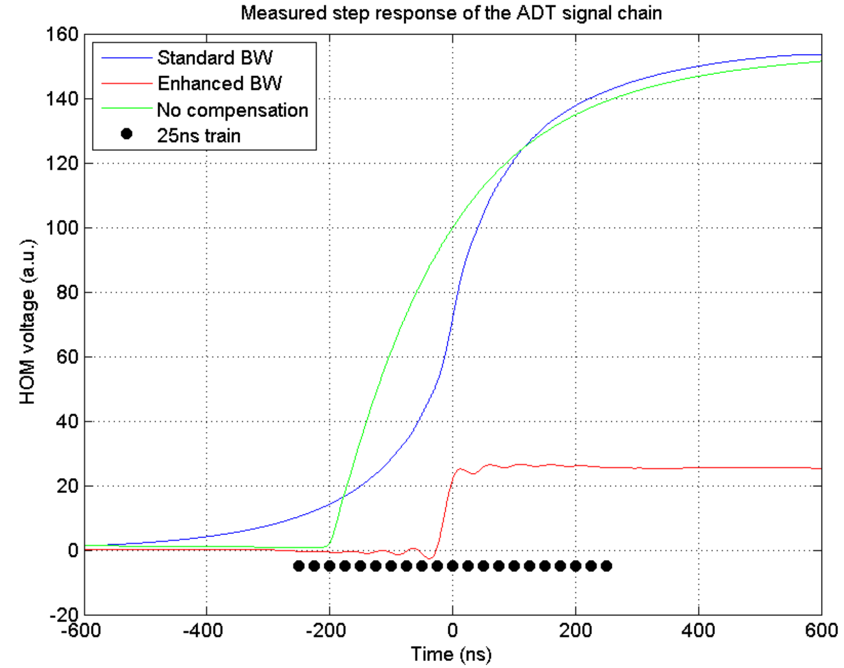
- Used anytime during the whole cycle.

* for reasons of simplicity only the variable part of the response shaping devices is mentioned

How Well Do We Control the Excitation?

- The excitation can be gated to individual/group of bunches, and the response is then shaped by digital filters*



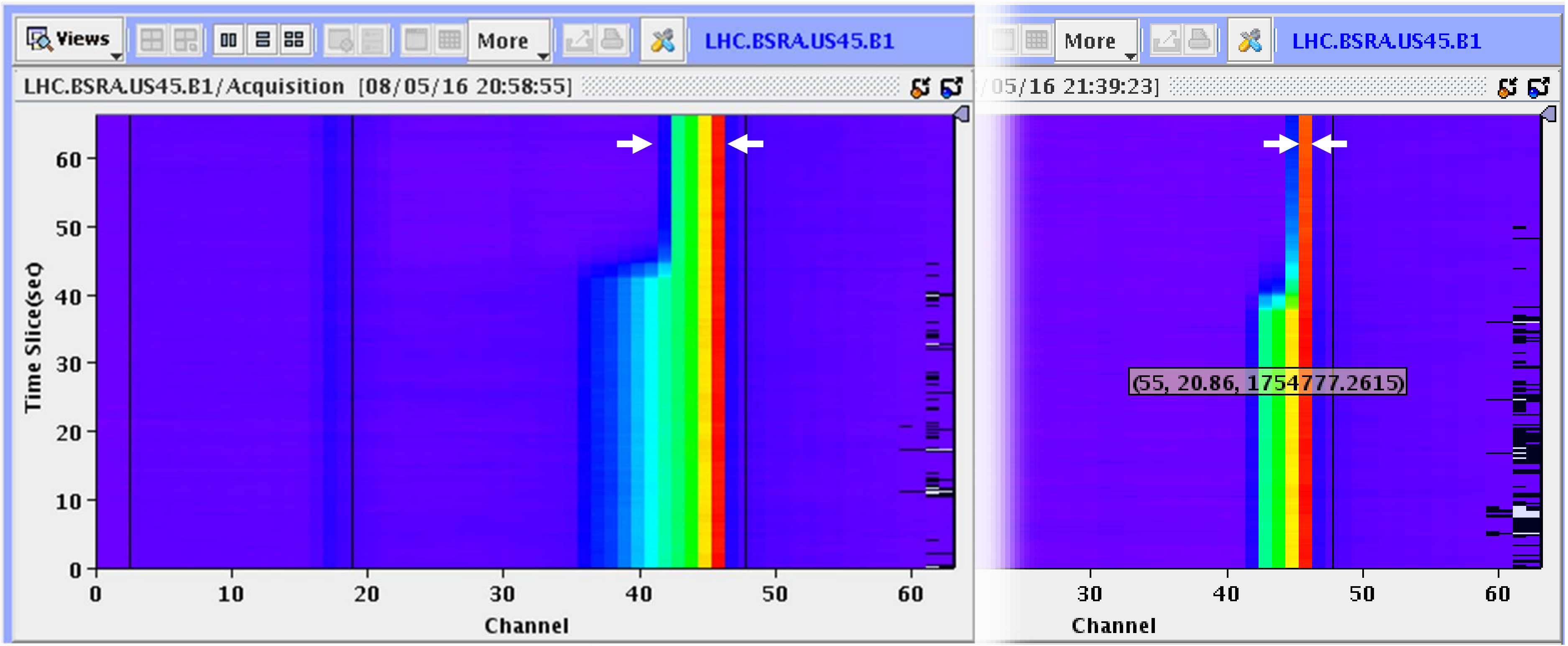


- The response can be engineered to be surgically precise (at bunch by bunch level), very powerful (full kick with ~700ns rise time), or a combination of both

* for reasons of simplicity only the variable part of the response shaping devices is mentioned

How Well Do We Control the Excitation?

- Comparison of the standard “conservative” and the “aggressive” AGC cleaning response at flat top. The latter was cleaning with full strength **only 50ns** from the incoming bunch #1



Conservative AGC settings. Only 1.5μs of the 3μs cleaned

“Aggressive” AGC settings. Almost all of the 3μs cleaned

How Well Do We Control the Excitation?

- Controlled emittance blow-up at bunch level within a 25ns train…

From Stefano Redaelli <Stefano.Redaelli@cern.ch>

Reply | Reply All | Forward | Archive | Junk | Delete | More

Subject **Re: single bunch blowup** 15/12/2012 17:10

To Me <daniel.valuch@cern.ch>

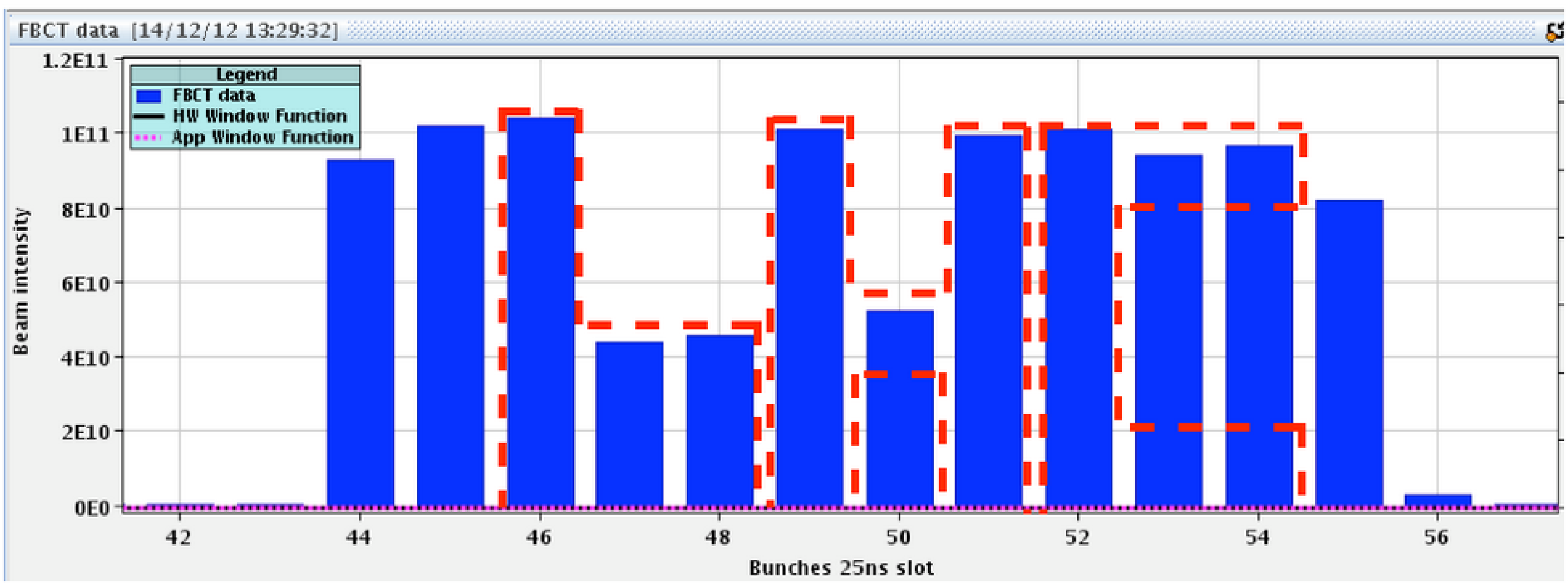
Cc Stefano Redaelli <Stefano.Redaelli@cern.ch>, Mike Lamont <Mike.Lamont@cern.ch>, Bernhard Holzer <Bernhard.Holzer@cern.ch>, Jorg Wenninger <Jorg.Wenninger@cern.ch>, Gerd Kotzian <Gerd.Kotzian@cern.ch>, Wolfgang Hofle <Wolfgang.Hofle@cern.ch>

Hi,

Just for the fun of it, see what we could "write" along the train!

Cheers,

Stefano



What Do We Want To Do?

- **Bunch by bunch tune measurement at flat top**

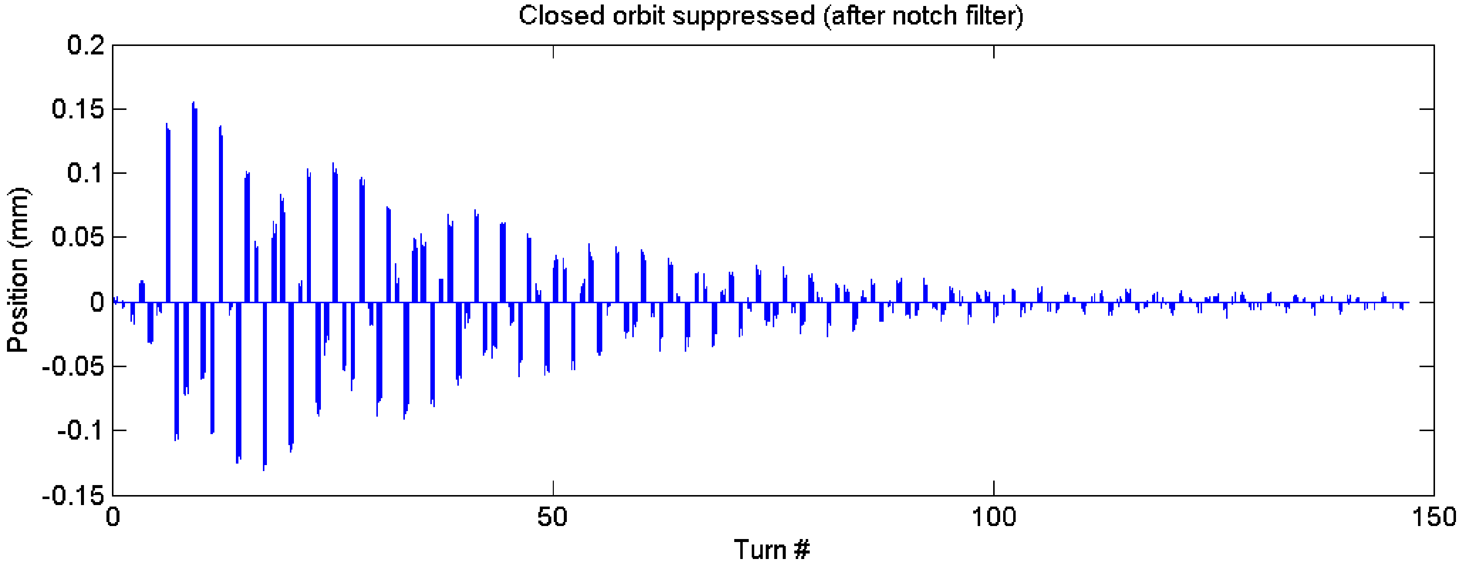
- Input from Elias Metral: *"We believe we have an e-cloud TMCI-like instability during stable beam and the observable is the e-cloud induced bunch by bunch tune shift along a batch of 72 bunches during stable beam… And ideally we would like to see how this bunch by bunch tune shift along a batch evolves during time as it should increase at the moment of the instability."*

- *"The order of magnitude of the coherent tune shift along the batch that we would like to measure at 6.5 TeV is ~1E-4, i.e. quite small."*

- What ADT can do?

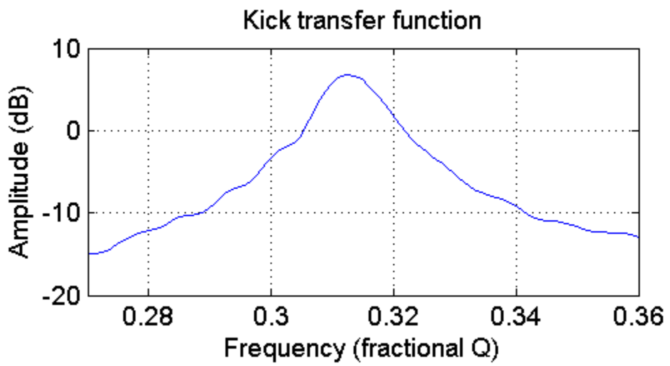
Vector Mode Excitation and b-b-b Tune

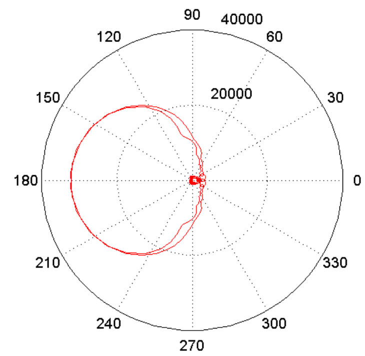
- Vector excitation mode provides a constant kick, or I-Q excitation for given number of turns. It is used for ADT closed/open loop beam transfer function measurement, ADT system setting up, diagnostics, tune measurement, MDs
- **A single turn kick generated by the ADT allows to extract the beam transfer function, bunch by bunch tune or bunch by bunch damping time. Can be done on-demand, any time within the cycle. Including the analysis…**

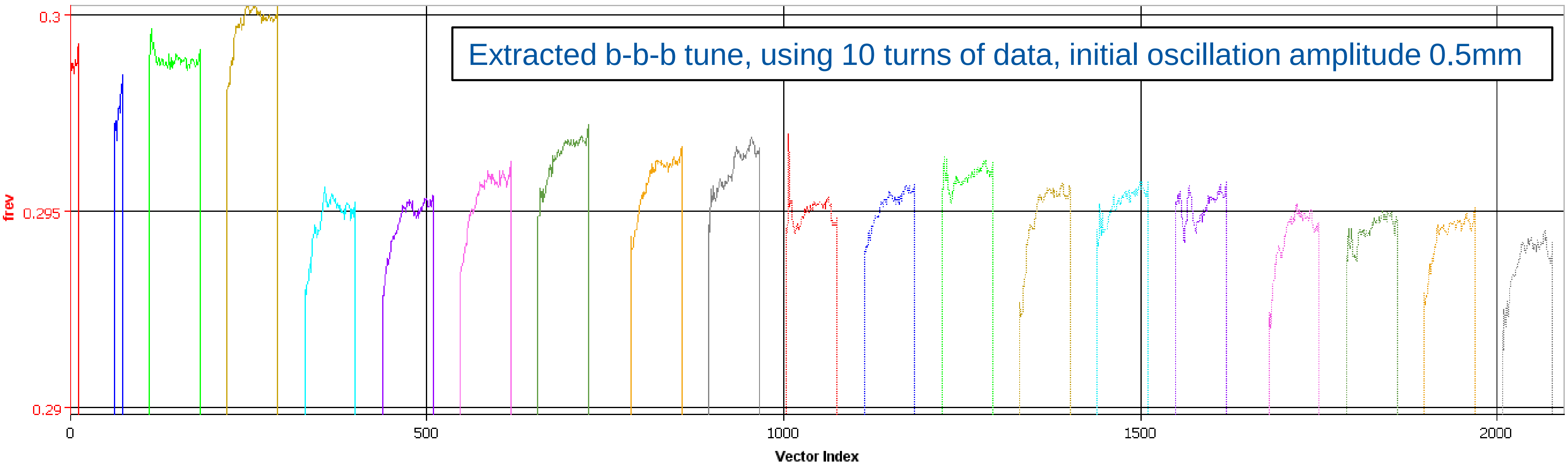


Vector Mode Excitation and b-b-b Tune

- Example of a closed loop transfer function measured by the ADT kick method. The b-b-b tune is extracted as a 'side product'







Vector Mode Excitation and b-b-b Tune

- The procedure:
  - Kick the selected batches, or a full turn by ADT. **Excitation length 1 turn**. Exact oscillation amplitude limit is subject of MPP approval. Start negotiations at 100um@ pickups at point 4…
  - **Transverse feedback is active** during the test, i.e. regular damping ~50 turns
  - Collect the bunch by bunch position data
  - Compute the required parameters (e.g. b-b-b tune)
- **A feasibility test (e.g. end of fill study) is needed. Functionality exists already, as a very expert diagnostics tool. No changes to the operational system required.**
- If successful, the method should be properly implemented as operational tool. **Involves FPGA code update** with hard wired excitation limits (length, number of turns etc.)

Bunch by bunch controlled emittance blow-up

- In order to achieve better performance during the p-Pb run, it might be necessary to actively equalize individual bunch emittances of the proton beam (J. Jowett & heavy ion team)

- This can be done with already existing infrastructure. A simple controller would collect the individual bunch emittance data, program a bunch by bunch excitation window and trigger the excitation. Repeat for all trains. The whole procedure takes few seconds

- **No changes to the ADT**, nevertheless if used operationally a proper application is needed

- **A feasibility test at injection, or end of fill study is needed** to find the tweak factors

ADT as AC dipole

- The optics team (Rogelio & co) uses AC dipole for optics measurements. The excitation is strong and lasts for few thousand turns
- For some measurements a more gentle excitation, lasting for 50-100k turns would provide better results (limit the losses, use of nominal bunches, excite only selected bunches etc.)
- This functionality requires **FPGA code update** (implement ramps into the excitation amplitude setpoint)

Pulsed excitation for the e-lens MD

- Request to provide gated excitation (only every n-th pulse executed) for the e-lens MD
- This functionality requires **FPGA code update** (implement pulsing into the excitation amplitude setpoint)
- Modified FPGA code can be flashed only for this particular MD…
- However, there is no former experimental feature which is not used as an operational tool today... **Release requires a full transverse feedback re-validation with beam** (~1 hour with few short trains)

ADT Validation After an Intervention

- New FPGA code can be released during a TS, **release requires a full transverse feedback re-validation with beam** (~1 hour with few short trains

- Full transverse feedback re-validation with beam means
  - Injection of one, or few short trains
  - Measurement of the open loop beam transfer function for each modified module (up to 8 mDSPUs, rules out unintentional group delay changes caused by a re-compiled FPGA)
  - Test of the modified functionality in operational environment (e.g. does it still clean?) with operational FESA classes

- Firmware update is usually done during a technical stop

- Experience: normally transparent. Nevertheless one case of delay change due to a different version of FPGA synthesis tool since 2008

Summary (1)

- ADT is a very versatile device. Apart of the primary feedback, it can excite the beam by very sophisticated signals
- Excitation can target individual bunches within a 25ns train while not affecting the neighbours
- Full power, or a very fine excitation is already routinely used in operation
- Bunch by bunch tune measurement should help better understanding the currently observed instabilities. ADT can do it with already existing infrastructure, but active excitation at flat top is needed. If used operationally implementation requires mDSPU firmware update, followed by a full system validation.
- Active bunch by bunch emittance control might be needed for the p-Pb run. ADT can do it with already existing infrastructure, but active excitation at injection is needed.

Summary (2)

- ADT as AC dipole will help the optics team to do finer, and more precise measurements. Implementation requires mDSPU firmware update, followed by a full system validation.

- Gated excitation for pulsing the e-lens MD. Implementation requires mDSPU firmware update, followed by a full system validation.

- **Where the MPP needs to act?**
  - Approval and final green light to use excitation **on live beam** at flat top
  - If successful, approval to use the method operationally
  - Advise on approval process in such cases
  - Advise on limits and conditions of use
  - Advise on required testing and validation

Thank you for your attention

Abort Gap Cleaning

- **At injection**, AGC excitation is a gated, sinusoidal signal, with frequency swept in range Q_{ver}±0.01, in 15 steps, one full sweep cycle lasts 1 second. **The sweep needs to be re-triggered every second by a timing pulse**

- **In physics**, AGC excitation is a gated, sinusoidal signal, with frequency swept in range Q_{ver}±0.01, in 30 steps, one full sweep cycle lasts 2 seconds. **The excitation sweep is started by software. Then free running, until stopped by software**

Injection Gap Cleaning

- IGC excitation is a gated, sinusoidal signal, with frequency swept in range Q_{hor}±0.01, in 15 steps, one full sweep cycle lasts 1 second and it is repeated up to 19 times.

- The excitation is stopped by **OR** of the three sources: 1) by the sequencer just before the injection, 2) the beam-in pulse, 3) time-out after 19 seconds