Update on:

Tune and Chromaticity Stability during the last 200 Ramps

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Motivation

- Analysed last 209 ramps in terms of Q/Q' (fill 1002 → fill 1431)
  - 191 ramps with complete set of information (E, intensities, trims, …)
  - Only 10 ramps with Q' measurements during the ramp
  - most of the early commissioning excluded (1.2 & 3.5 TeV ramps)

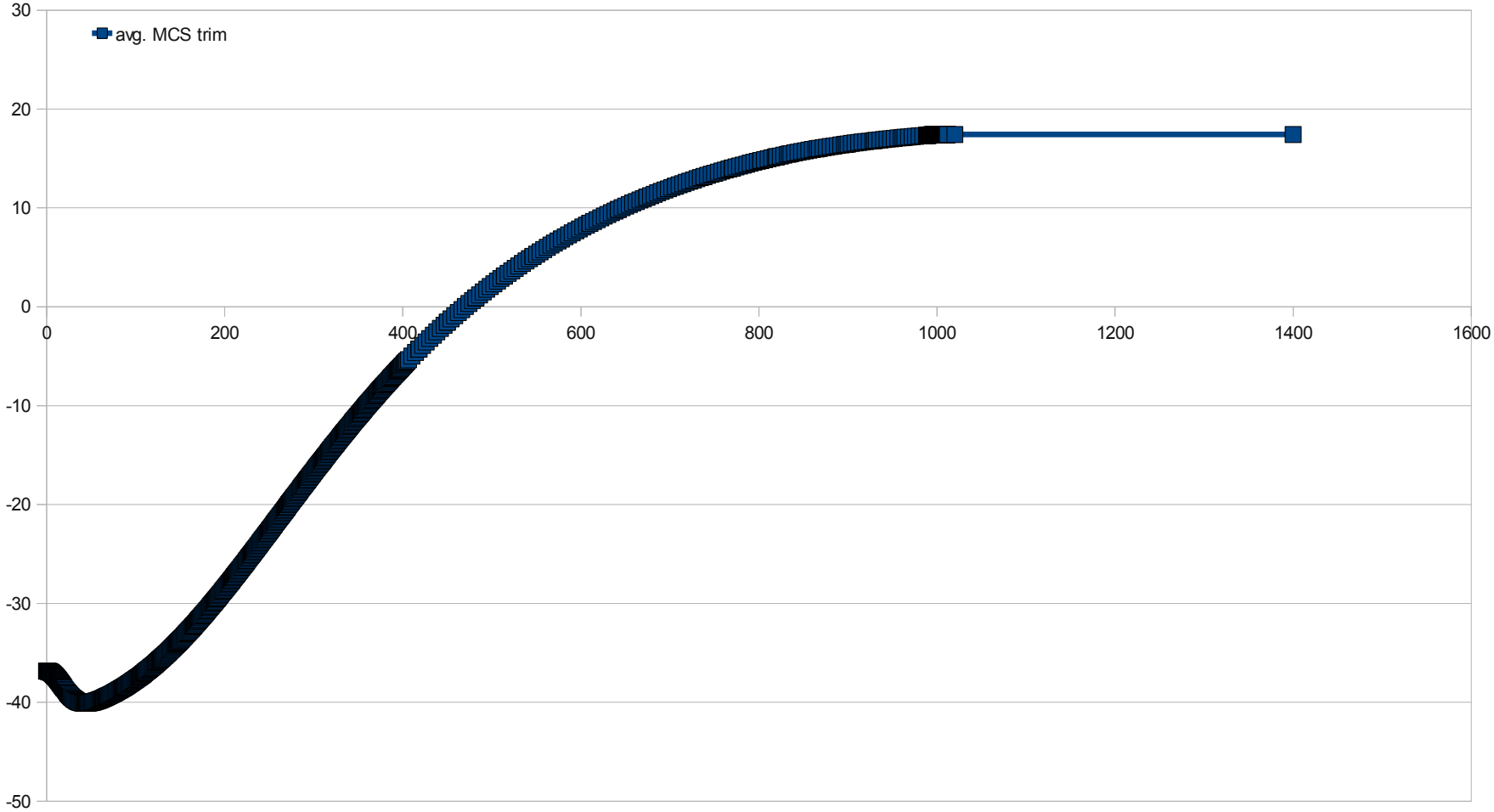
- Main aim was to establish a quantitative estimate of:
  - Reliability
    - What were the main issues? Are they fixed now?
      - most cases yes, after introducing |C-| check & 'Median' filter
      - Some pathological fills (logging issues, timing, etc.)
    - Do and where do we need to improve the performance of the BBQ-based Tune-Feedback/Diagnostics in view of 2010?

    → will provide update in Evian if noteworthy
  - Reproducibility
    - How stable is the LHC in terms of Q/Q'?
    - How stable is the LHC feedback/-forward scheme?
    - Could we do better? Could we do without beam-based feedbacks?

    → this presentation's focus

B3 compensation via MCS spool pieces...

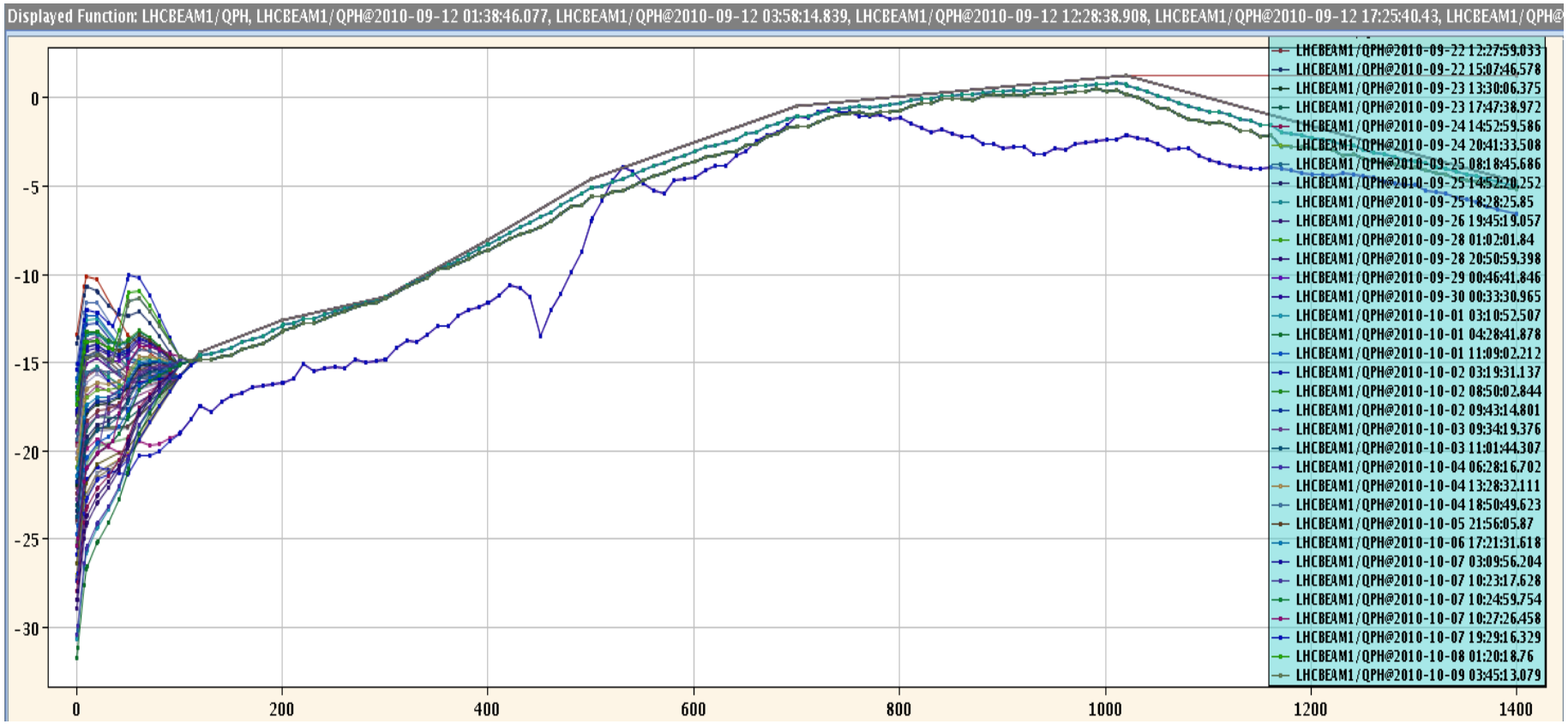
- Status quo, kept the same snap-back compensation as for 2 A/s ramp:



- Measured differences are incorporated into main sextupoles to keep modeled compensation (spool pieces) clean from fill-to-fill variations.

Day-to-Day Q'(t) compensation I/II

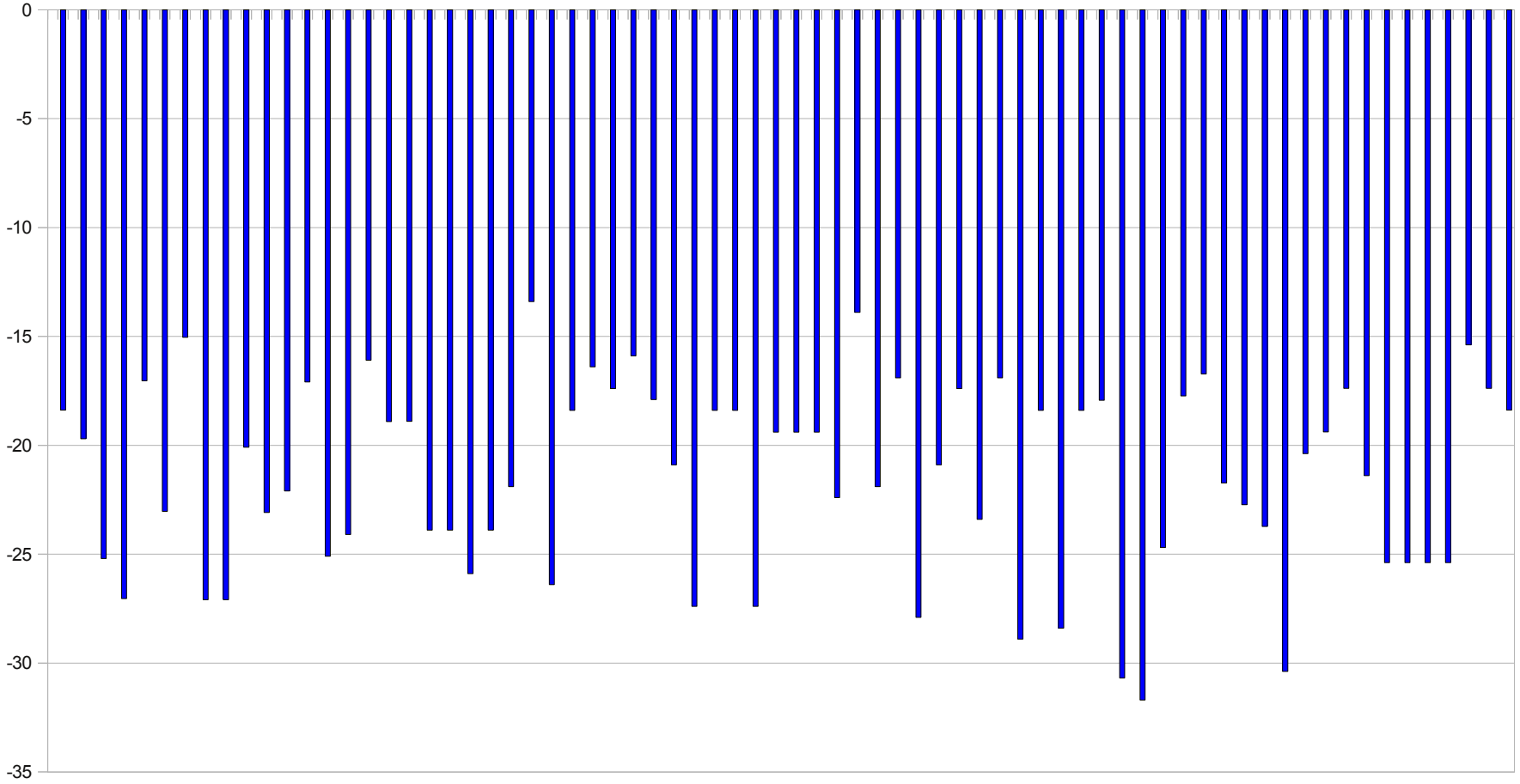
- Q'(t) routinely measured and corrected at injection (target: $Q'_{H/V} := 4$)
- Incorporated into ramp assuming pure b3 decay variations
  - gradual-out within first 120 s (ramp-based measurements)
- Example latest 1400 s $Q'_{B1H}(t)$ operation:



- Fairly large variation of up to 20 units of Q' → but it's justified

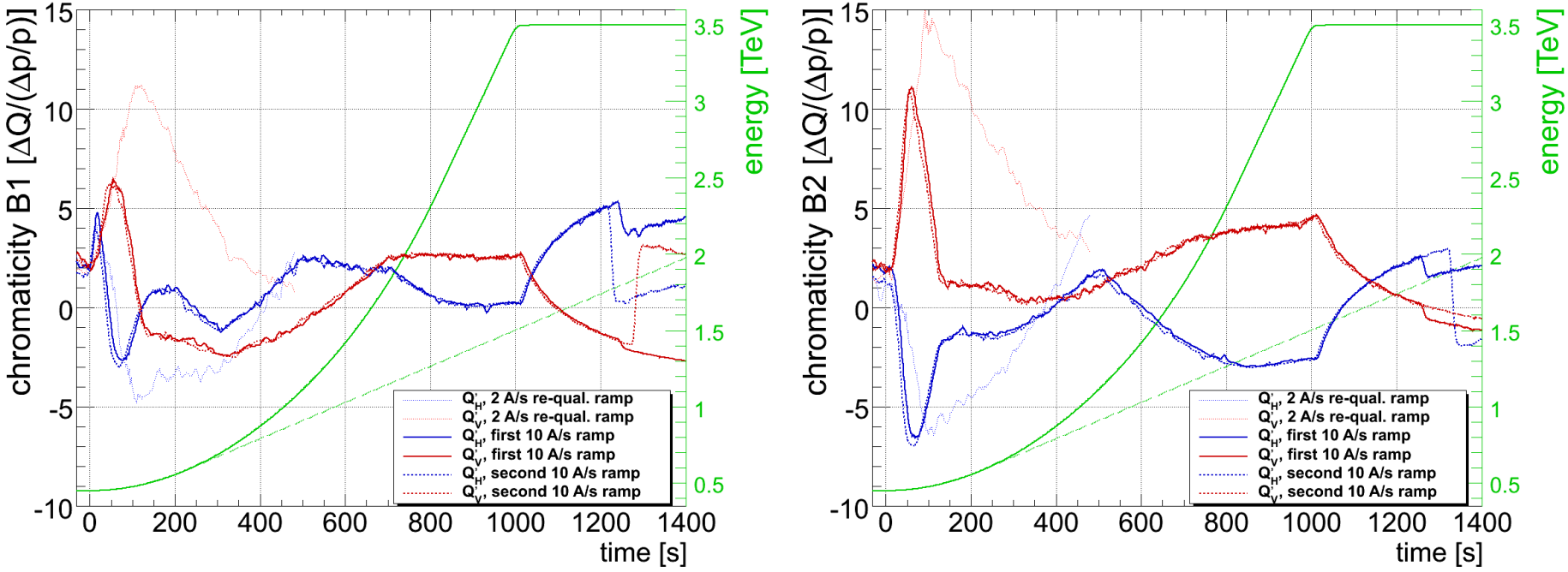
Day-to-Day Q'(t) compensation II/II

- Chroma variations at injection:
  - No clear fill-to-fill trend on injection tune variations visible...
  - Exception: partially or non-standard (≠ physics fill) pre-cycled machine
    - Effect of single re-pre-cycled sector: Q' ~ ± 3-4 units



Chromaticity during the Ramp I/III

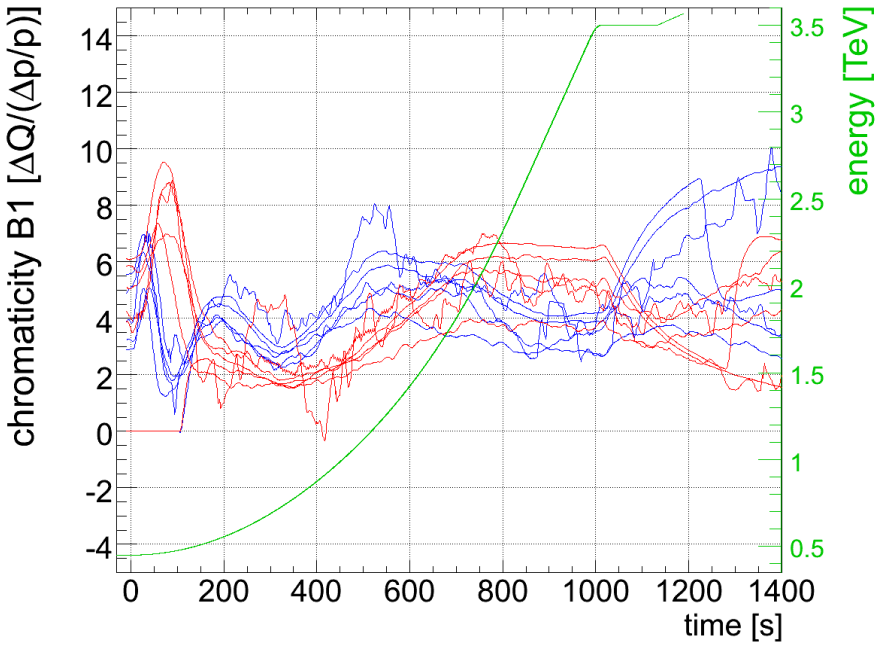
- Most measurement attempts shoot down
  → no long-term monitoring available
  → no pathological examples (e.g. after sector trip)
- Only a few dedicated systematic Q' measurements during the ramp
  - March'10 (semi-automated), ramp re-commissioning 2 A/s → 10 A/s

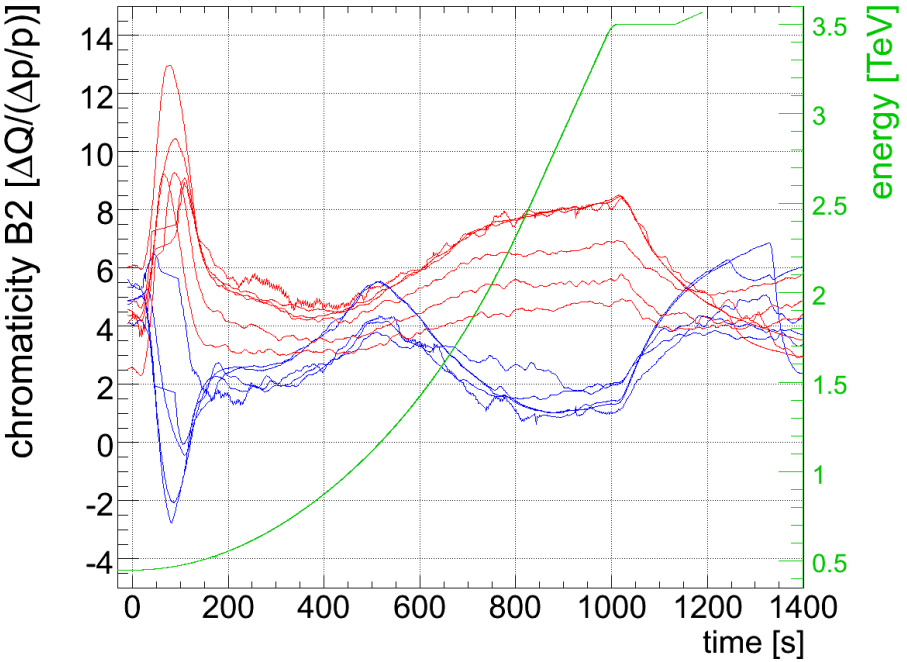


- "Fairly" reproducible (very low statistics of ~7 ramps), assuming
  - Mostly (only) done with "perfect" pre-cycled machine
    - Need to have some more checks with
  - Fill-to-fill re-measuring of Q' and incorporation into ramp

Chromaticity during the Ramp II/III

- Unfortunately, statistics did not increase by much: 6 (useful Q'(t) during ramp)
  - B2 measurements a bit cleaner



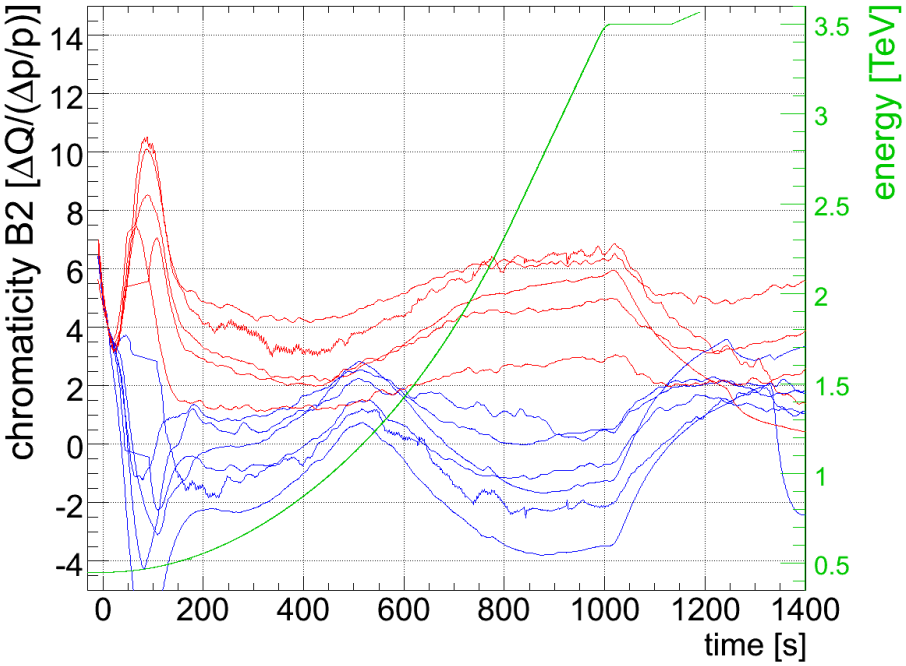


- Besides snap-back, de-facto the same Q'(t) during three consecutive cycles!
  - The machine can be quite reproducible...
- Decay at 3.5 TeV with 10 A/s ramp visible (less/no decay with 2 A/s):
  - ~6 units max, initially ~1 unit/minute decay
  - compensated by qualitative linear trim
  - 450 GeV-like decay

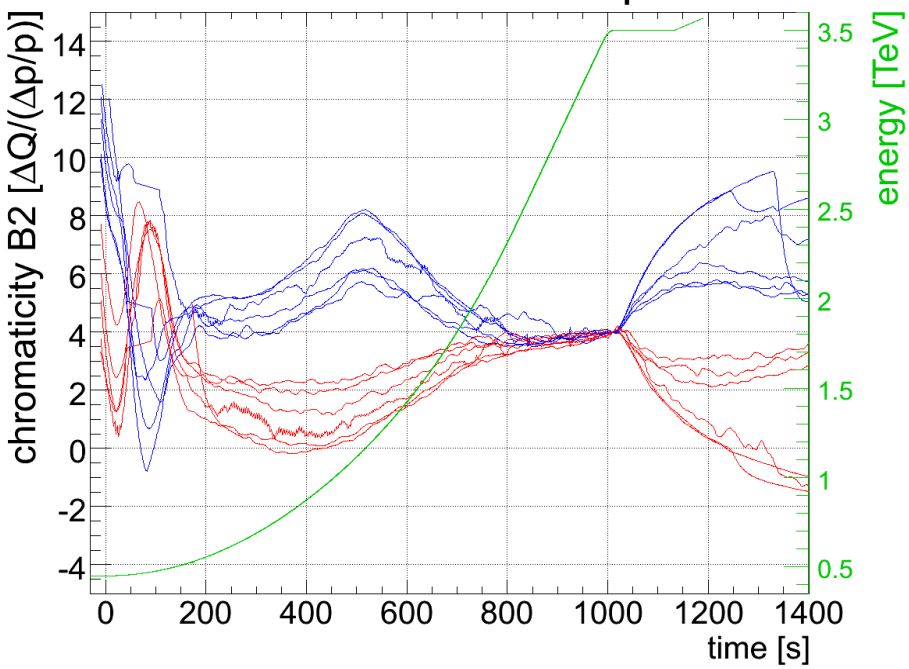
Chromaticity during the Ramp III/III

- Started of ramps with slightly different initial Q' values
  - Normalised (=shifted) for comparisons between ramps

normalised to start of ramp:

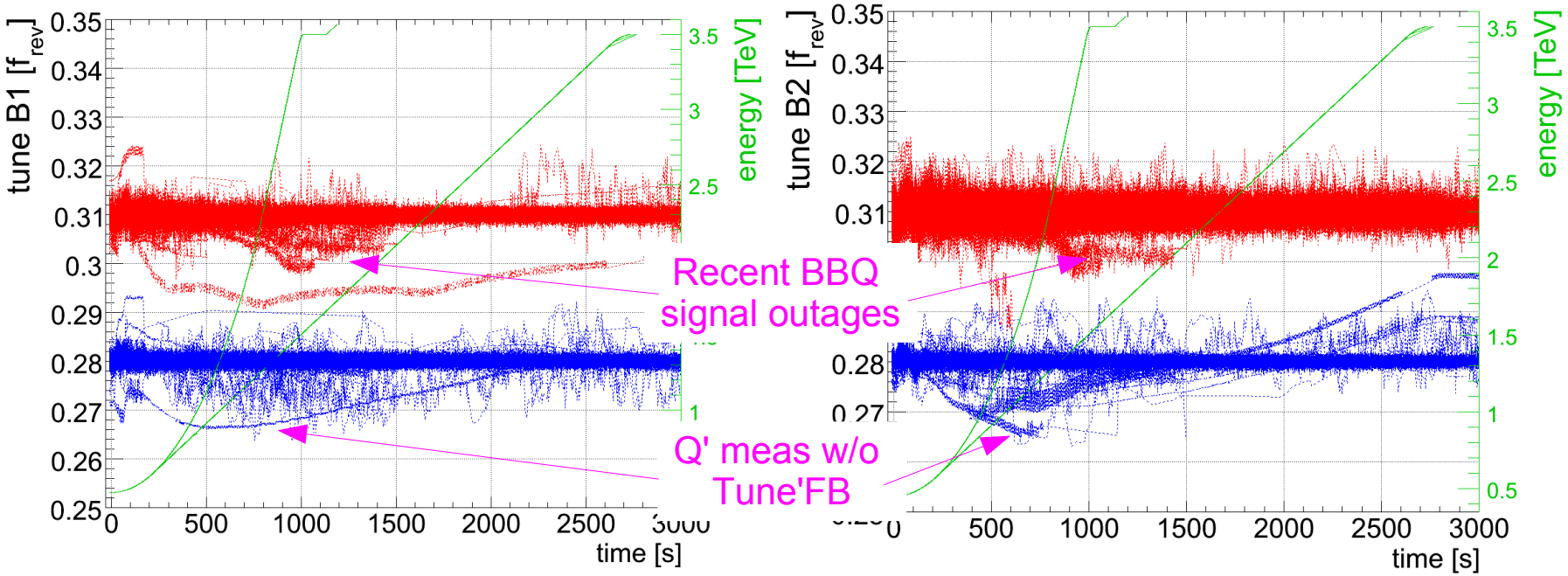


normalised to end of ramp:



- decay-currents (history) is dying-out with energy, remaining variations:
  - during snap-back: ΔQ' ~ 5-10
  - after snap-back: ΔQ' < ~2 !!
- Ramp sometimes run with slightly negative chromaticities with present correction/incorporation scheme → change gradual-out from 120 to 200 s

Tune Variations during last 191 Ramps... I/III
Residual overall Tune Stability



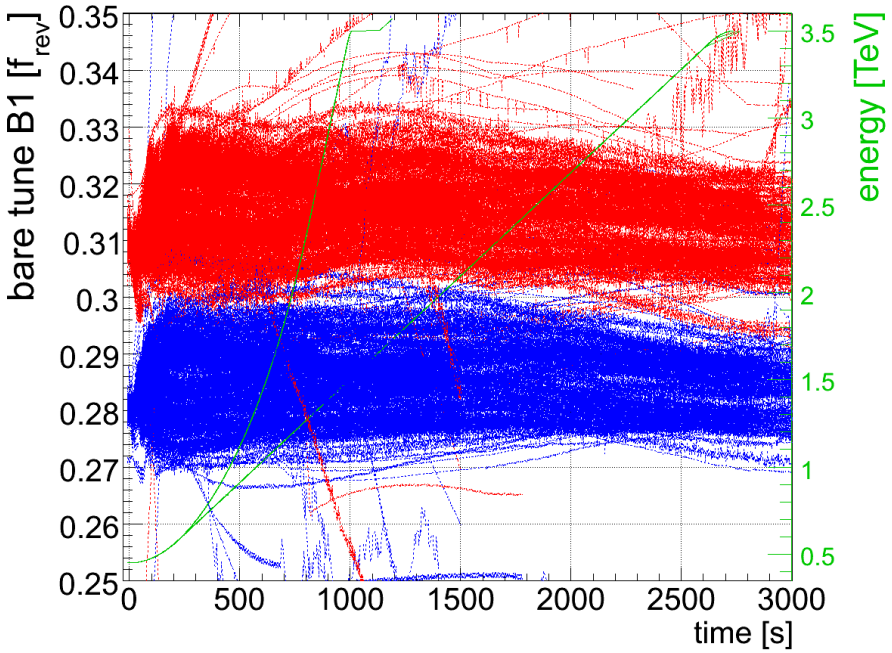
- 155 ramps with > 99% transmission
- 169 ramps with > 98% transmission
- 178 ramps with > 97% transmission
- 12 ramps lost (6 with Tune-FB during initial 3.5 TeV commissioning)

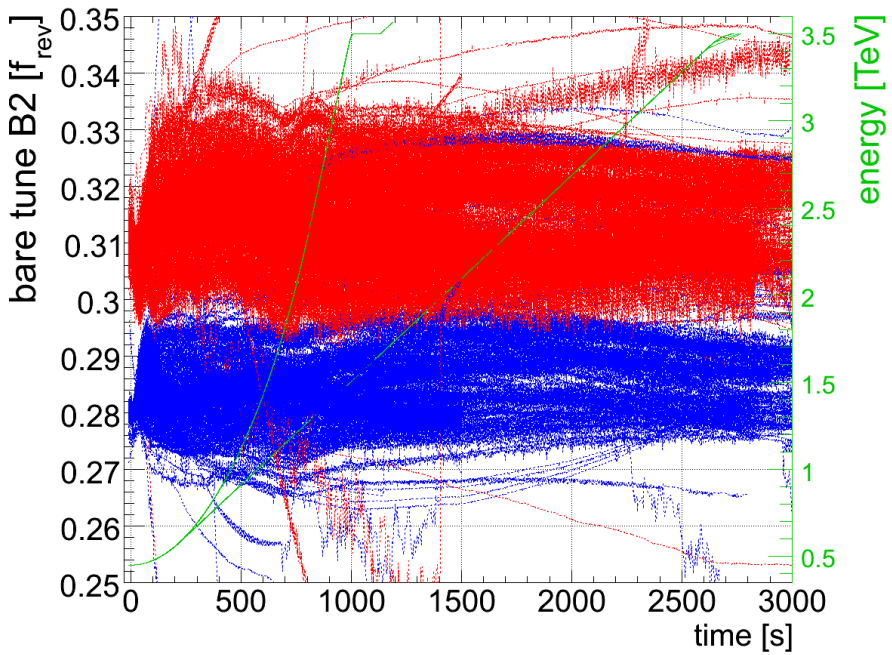
- 122 ramps with > 99% transmission
- 155 ramps with > 98% transmission
- 168 ramps with > 97% transmission
- 10 ramps lost (5 with Tune-FB during initial 3.5 TeV commissioning)

N.B. Correlation between Q and losses is less obvious.
Some of the ramps lost for other reasons (Q'<0, trips, …) → to be further analysed.
Still (to first order): having the Tune-FB on does not harm the machine.

Tune Variations during last 191 Ramp... II/III
'What-if-... Scenario' Analysis – Out of 191 ramps...

- Ramp dynamics and variations are compensated/absorbed by Tune-FB





- … 56 lost due to low-order (3^{rd},4^{th},C^{-}) resonance crossing without Tune-FB
- … 150 exceeding ΔQ=±0.01 tolerance
- … all above nominal ΔQ=±0.0015 limit

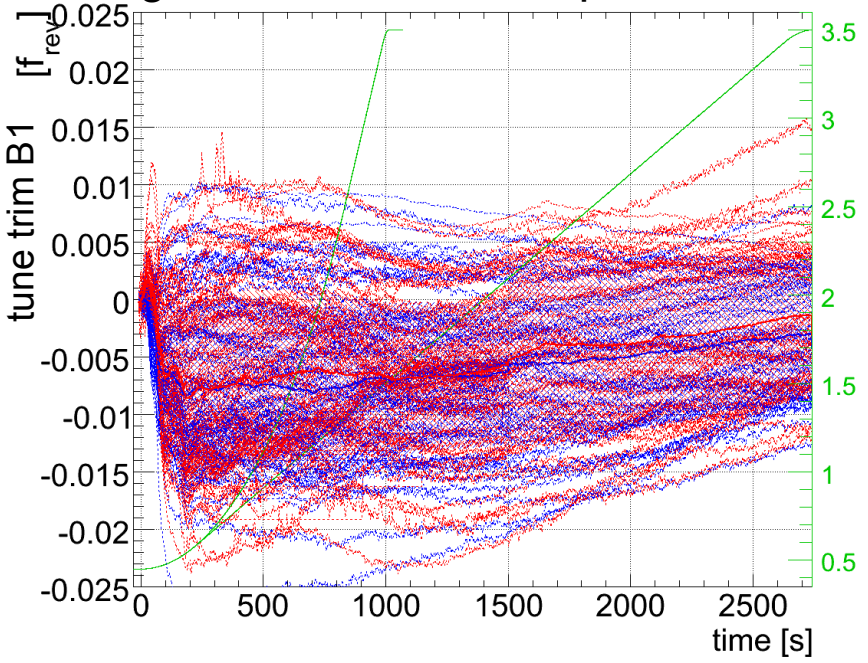
- … 83 lost due to low-order (3^{rd},4^{th},C^{-}) resonance crossing without Tune-FB
- … 157 exceeding ΔQ=±0.01 tolerance
- … all above nominal ΔQ=±0.0015 limit

Still there is an important bias:
operational efficiency/procedures/feed-forward improved with time!

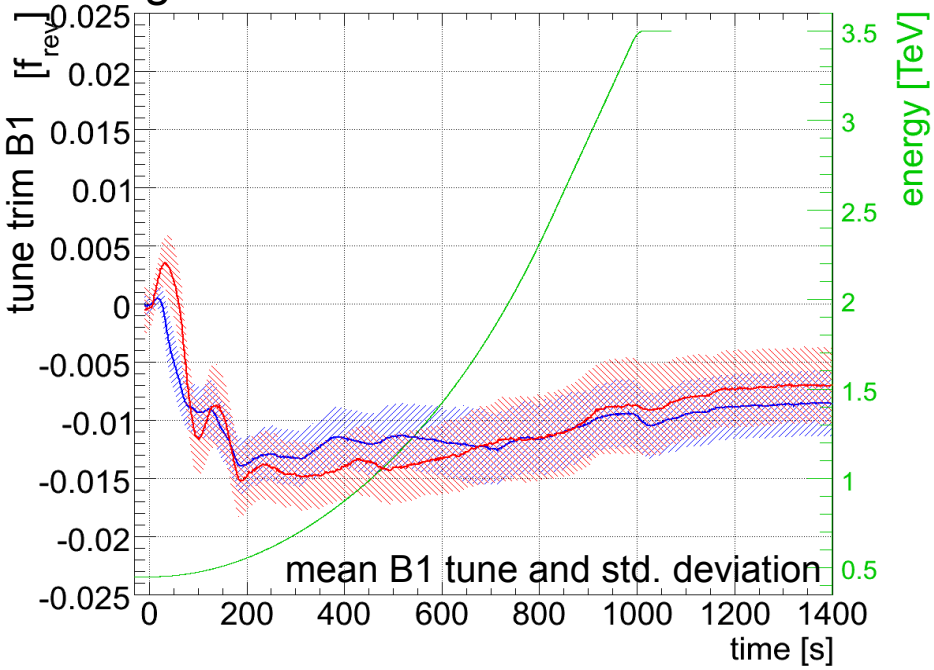
Tune Variations during last 191 Ramp... III/III

- As for Q'(t), no clear fill-to-fill trend on injection tune variations...
  - tune measured & compensated before ramping
  - Initially: gradual out until end-of-ramp
  - Variations possibly due to varying time spent at injection
  - Saw snap-back type structure: gradual-out within first 120 s for 10 A/s
    → improved Tune-FB trim reproducibility (now < 2-3·10^{-3}, 2010-09-05)
  - Smaller (<0.003) but measurable decay at flat-top also visible

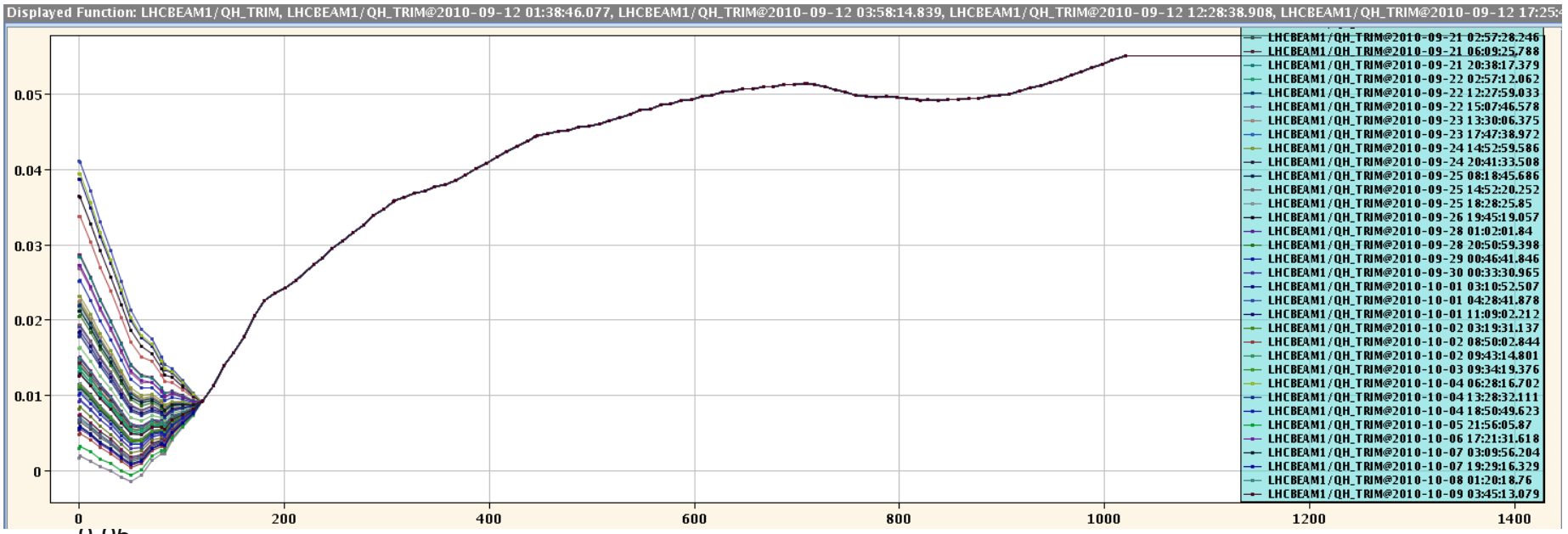
gradual-out until ramp-end:

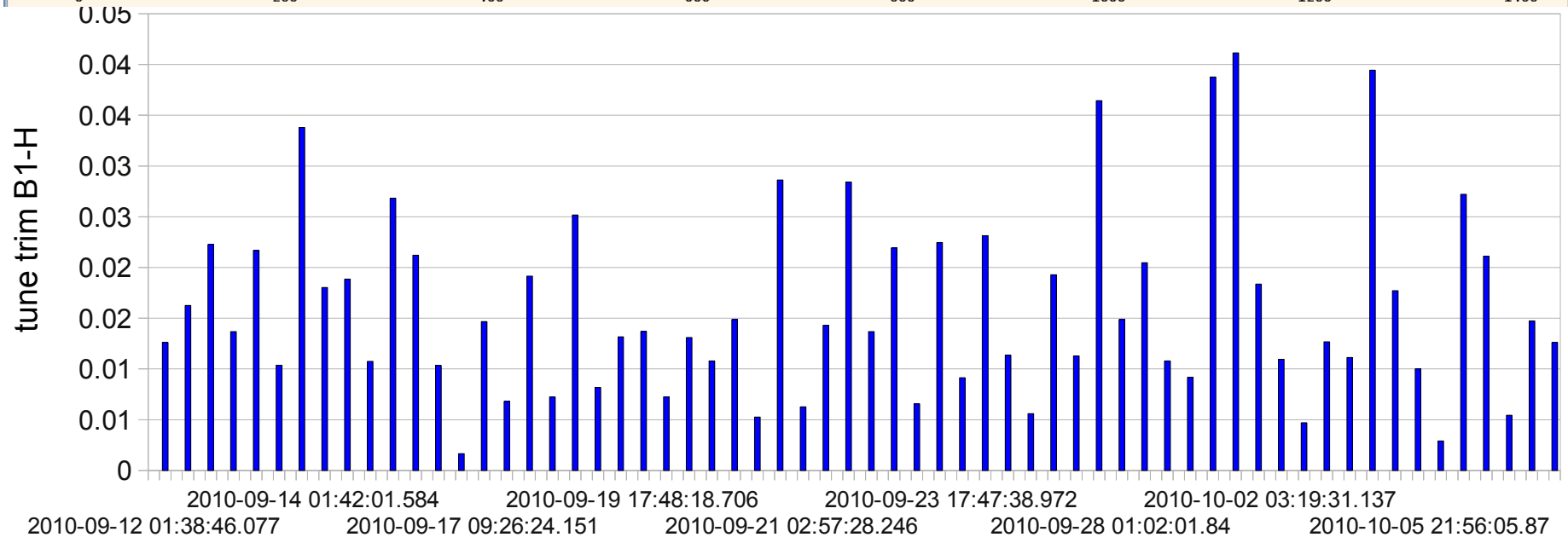


gradual-out within first 120s:



Day-to-Day Q(t) compensation
LSA trims & Feed-Forward Compensation





Summary of Q(t) & Q'(t) Measurements

Analysed last 200+ fills → LHC is/could be a fairly stable machine

- Most dynamic/random variations during the first 200 seconds (snap-back) → propose to change the gradual-out incorporation to reflect this
- Tune:
  - 0.06 units of systematic corrections
  - About 0.06 units pp of variation at the start of ramp between fills
    - believed to be correlated to time spent at injection
  - Gradual-out within first 120 seconds improved significantly reproducibility down to a few 10^{-3}
  - Feedback intercepted more than “random” snap-back perturbations
- Chromaticity:
  - Some remaining measurement-vs-model errors
    - persistent currents of about 15 units missing
    - Snap-back still large, up to 20 units variations from fill to fill
  - 'Decay' at 3.5 TeV: ~ 6 units, ~ 1 unit/minute
  - Not enough statistic to make a long-term assessment or on pathological cases (e.g. trip of sector, quench, partial pre-cycle…)
- Still, haven't analysed all “lost ramps” → will provide an update if necessary

Where to find Q'(t)/Q(t)

- Logging database (LHC→Beam Instrumentation→Tune and Chroma/Beam Feedbacks→ ...):
  - Tune eigen-modes: LHC.BQBBQ.UA[47/43].FFT1_B[1/2]:EIGEN_FREQ_[1/2]
    - excludes effect of $|C^-|$, better meas. precision → source for Tune-FB
  - 'Unperturbed' Tunes: LHC.BQBBQ.UA[47/43].FFT1_B[1/2]:TUNE_[H/V]
    - Tunes in the absences of $|C^-|$,
  - Tune-FB corrections: LHC.BOFSU:TUNE_TRIM_B[1/2]_[H/V]
  - Chromaticity measurement: LHC.BOFSU:CHROMA_B[1/2]_[H/V]
  - Chromaticity-FB corrections: LHC.BOFSU:CHROMA_TRIM_B[1/2]_[H/V]
- Online via BI-QP Fixed-Display → Q' Display (now more routinely used):