

Q/Q' during the first LHC ramps

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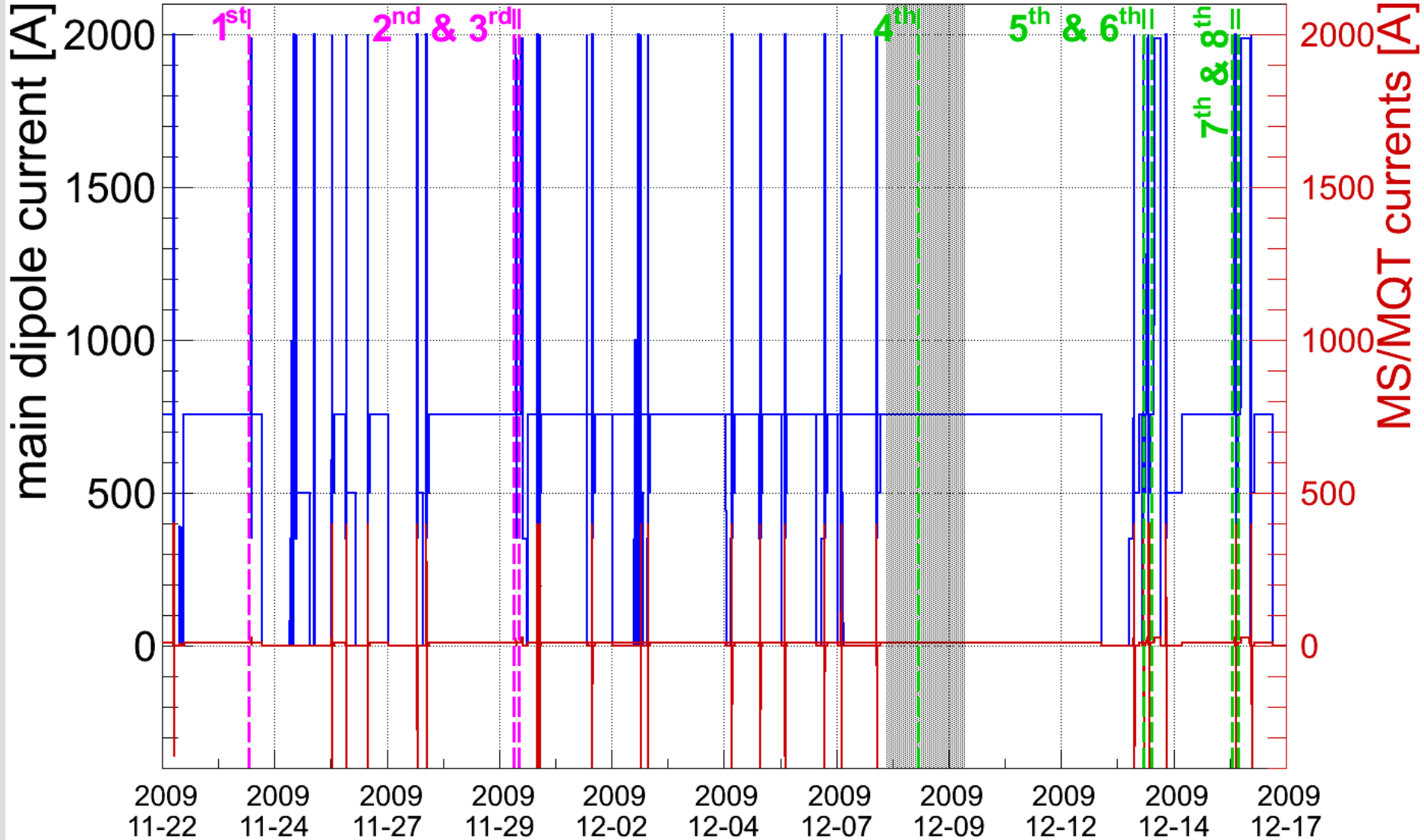
**for the BI-QP team: A. Boccardi, M. Gasior,
S. Jackson, R. Jones, R. Steinhagen**

**special thanks to FB-incorporation/FIDEL team:
M. Lamont, M. Pereira & Marek Strzelczyk**

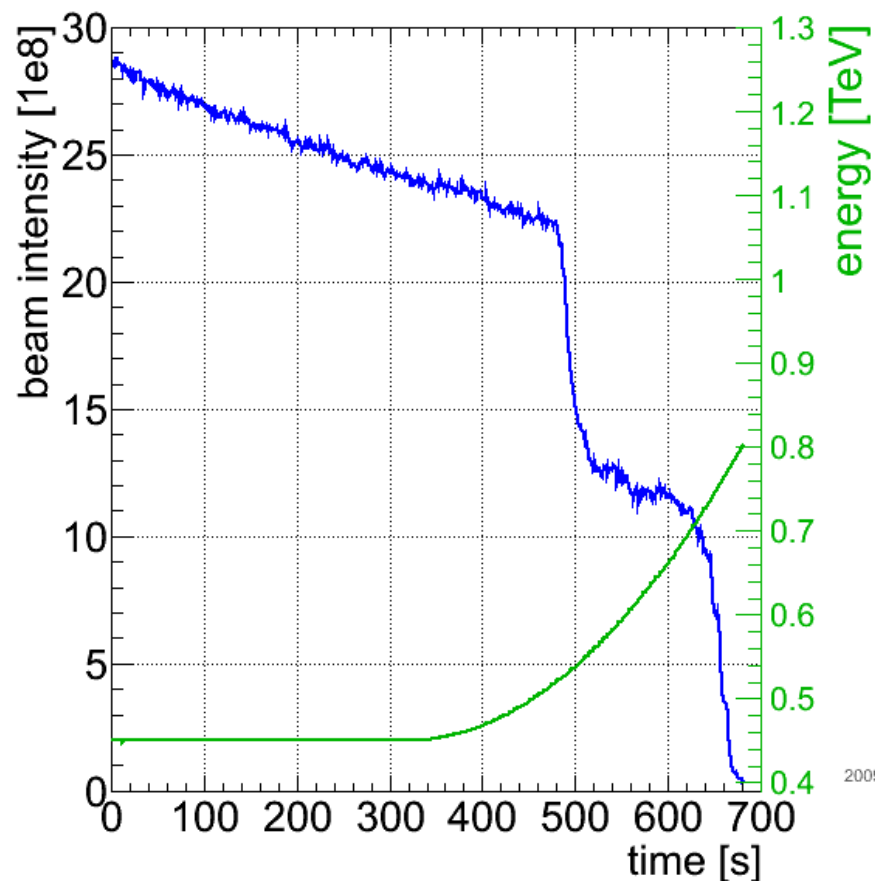
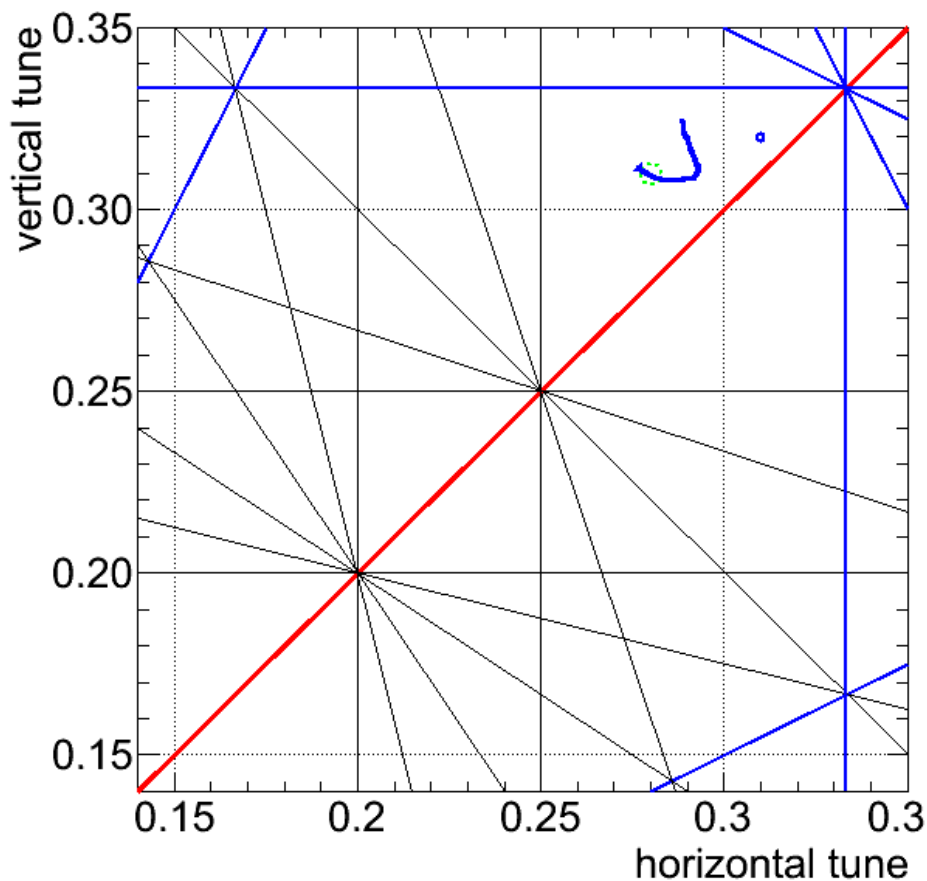


Statistics and Basis of this Analysis

- Total of eight ramps with beam:

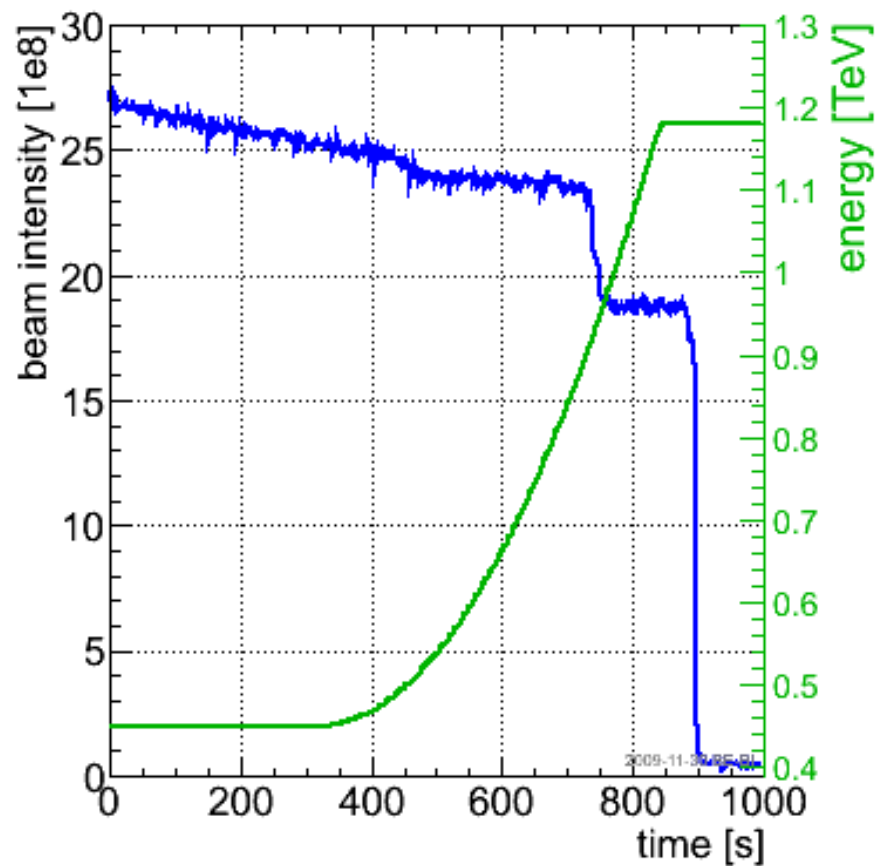
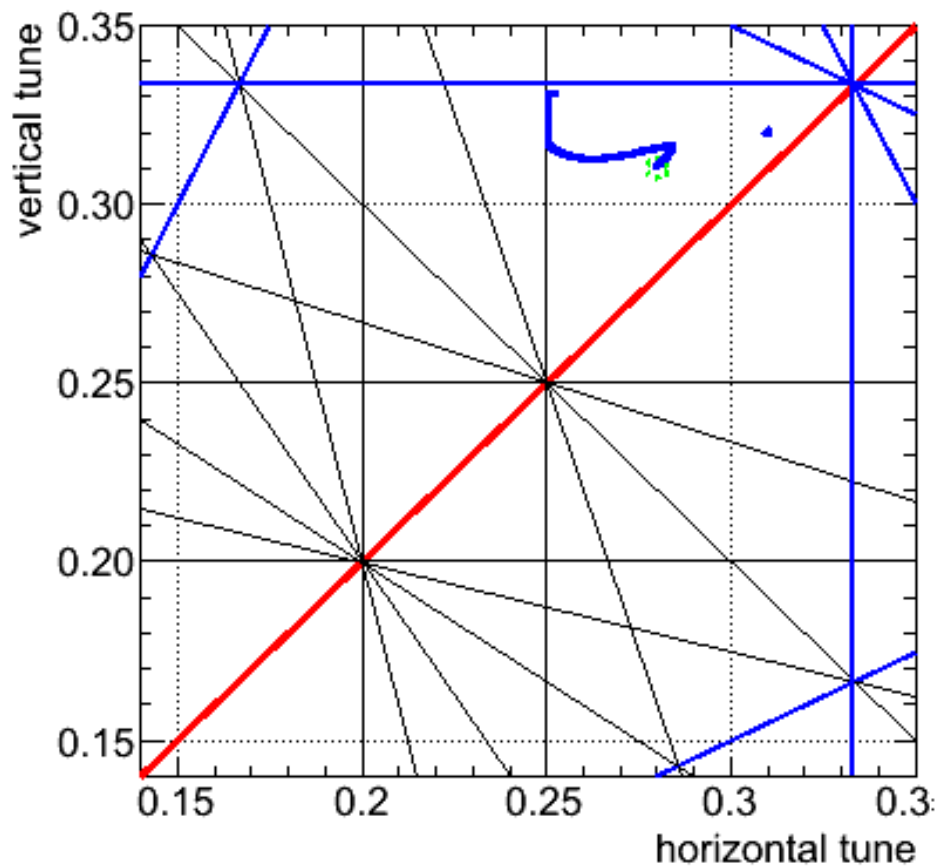


- B1 only & Q-FB 'off'
 - injection plateau Q trims kept constant in strength during ramp



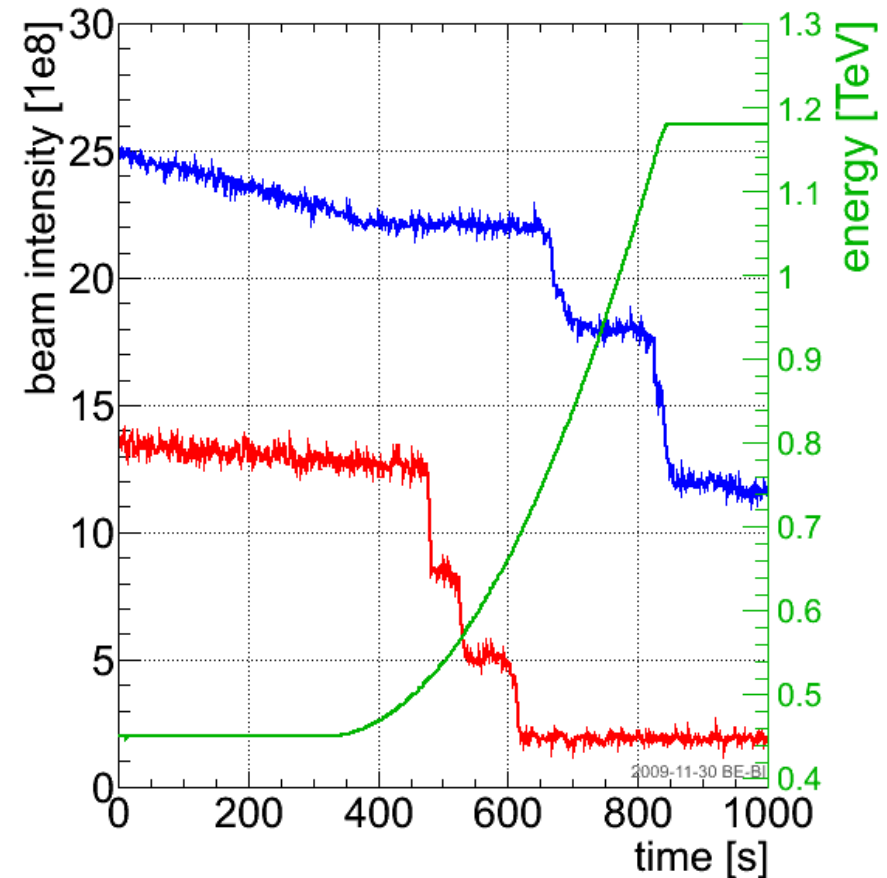
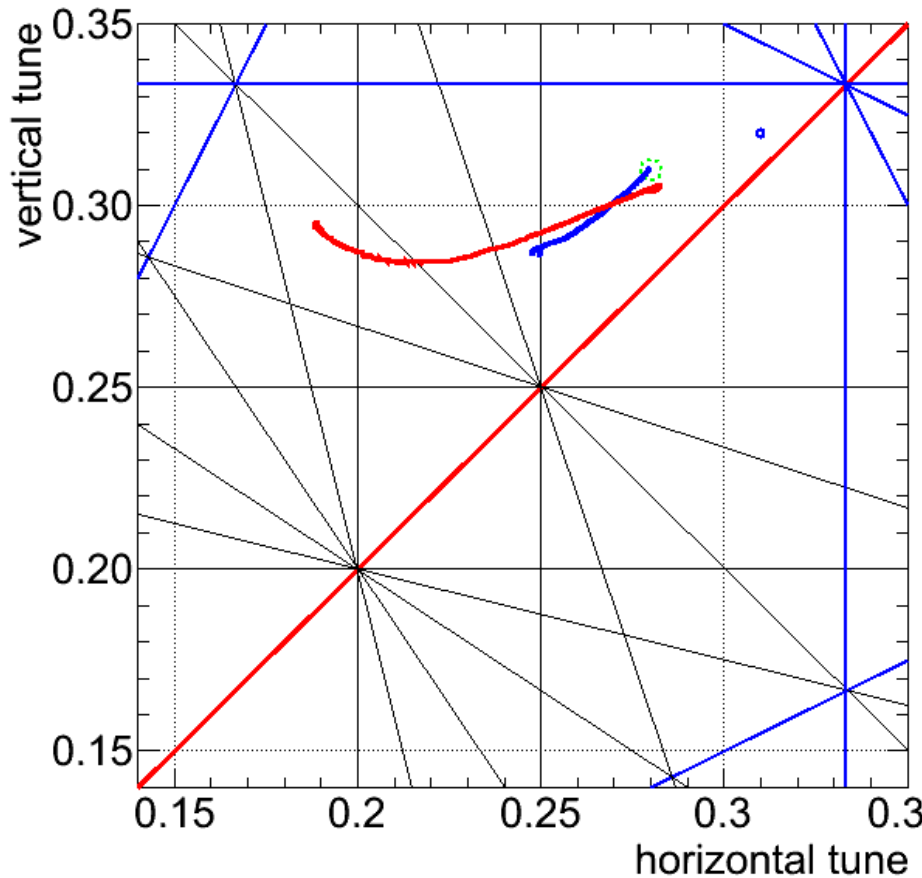
- Q_v moves onto 3rd order resonance → beam lost after 500 GeV
- N.B. a-posteriori: source of tune drift not understood

- B1 only & Q-FB 'off'
 - injection plateau Q trims kept constant in strength during ramp



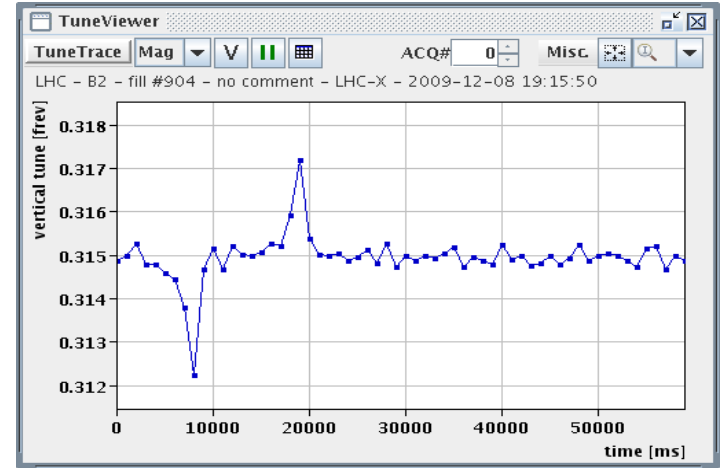
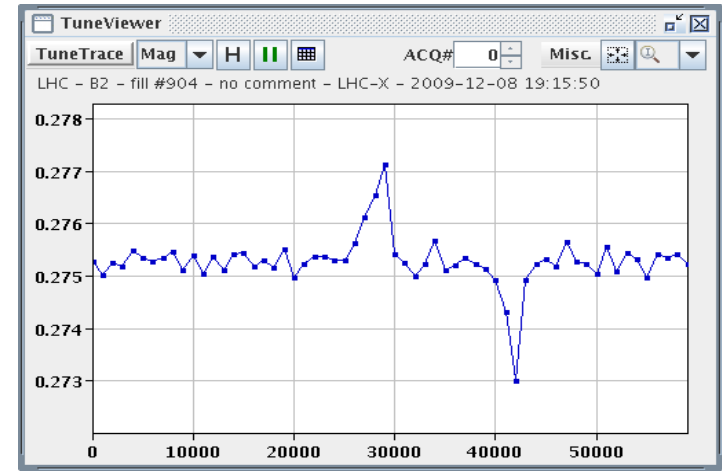
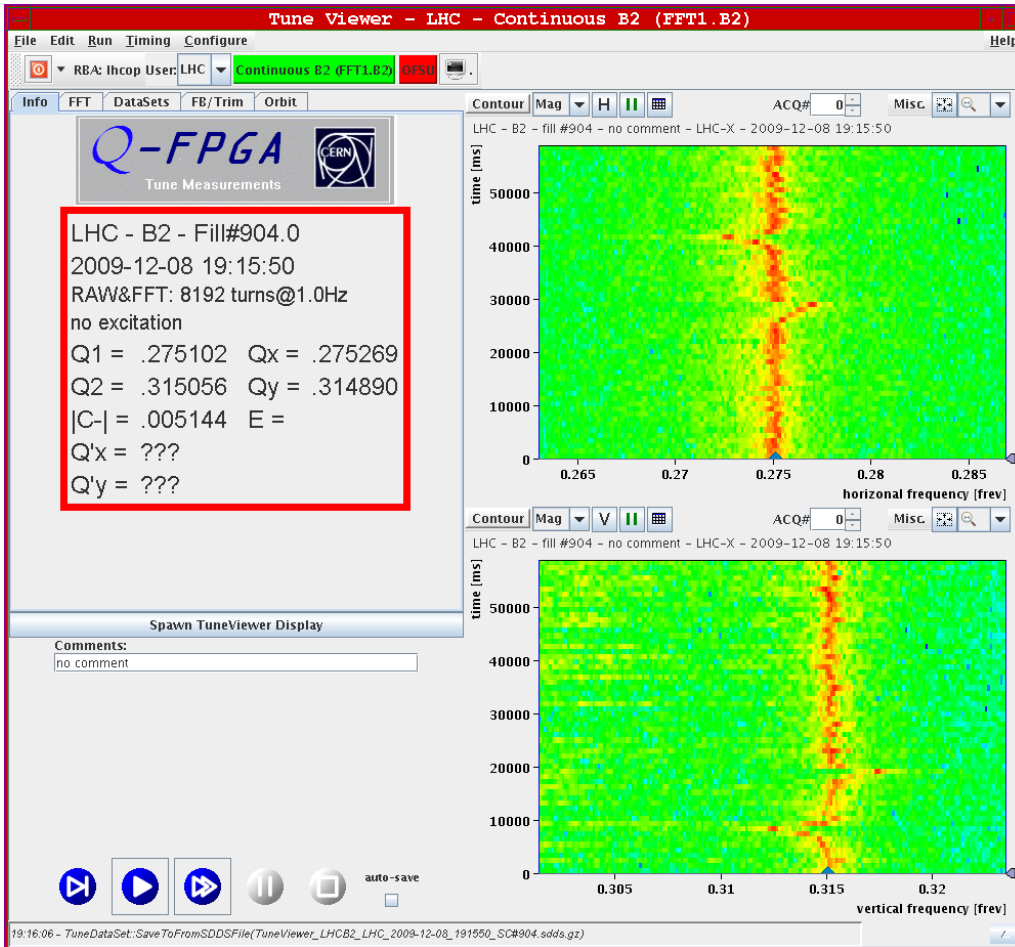
- B1 at 1.18 TeV but soon lost due to instability
 - later measurements confirmed particularly low Q' values (Q'_v negative)

- both beams, Q-FB 'off' but BBQ-based feed-forward function from ramp #2
 - ramp without explicit magnetic pre-cycle



- Both beams made to 1.18 TeV
- Significant losses due crossing of 4th and 7th order resonances
- beams eventually lost due to instability (low Q' → verified with later ramps)

- Quick Q-FB sanity check:



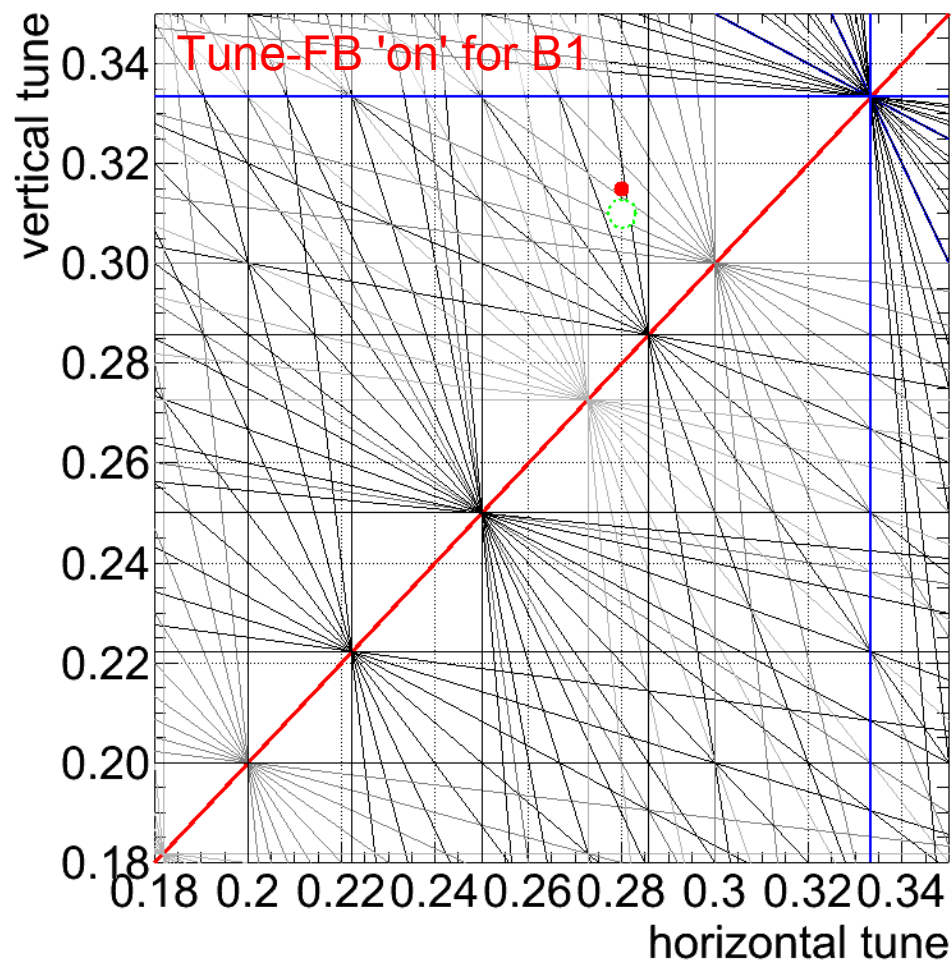
– Here: $\Delta Q_{\text{trim}} = \pm 0.003$ (via LSA) with Q-FB 'on'

- Q-Feedback Operation became de-facto workhorse for successive ramps

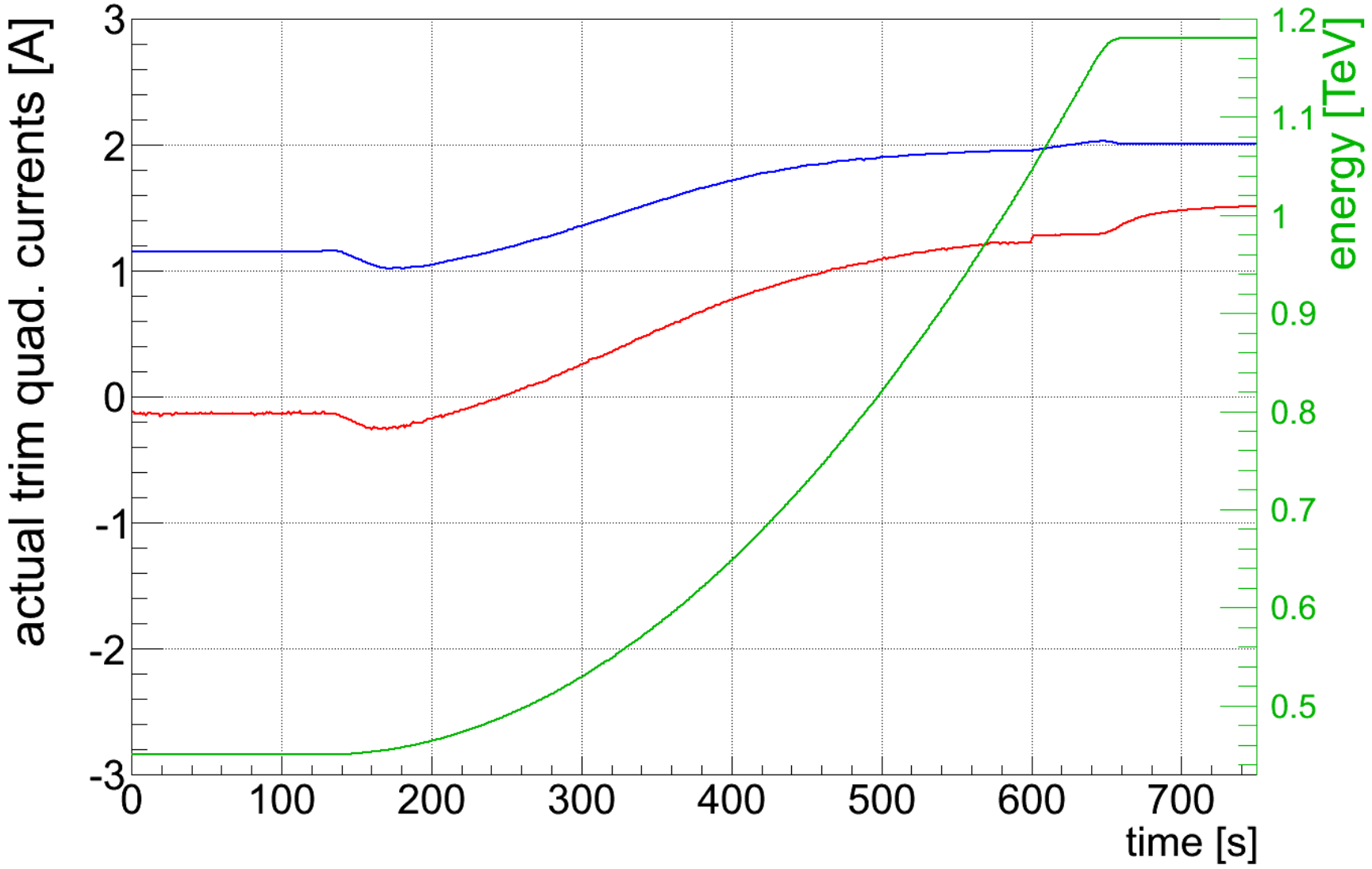


2009-12-08 @21:30 Ramp #4 ... a night to remember

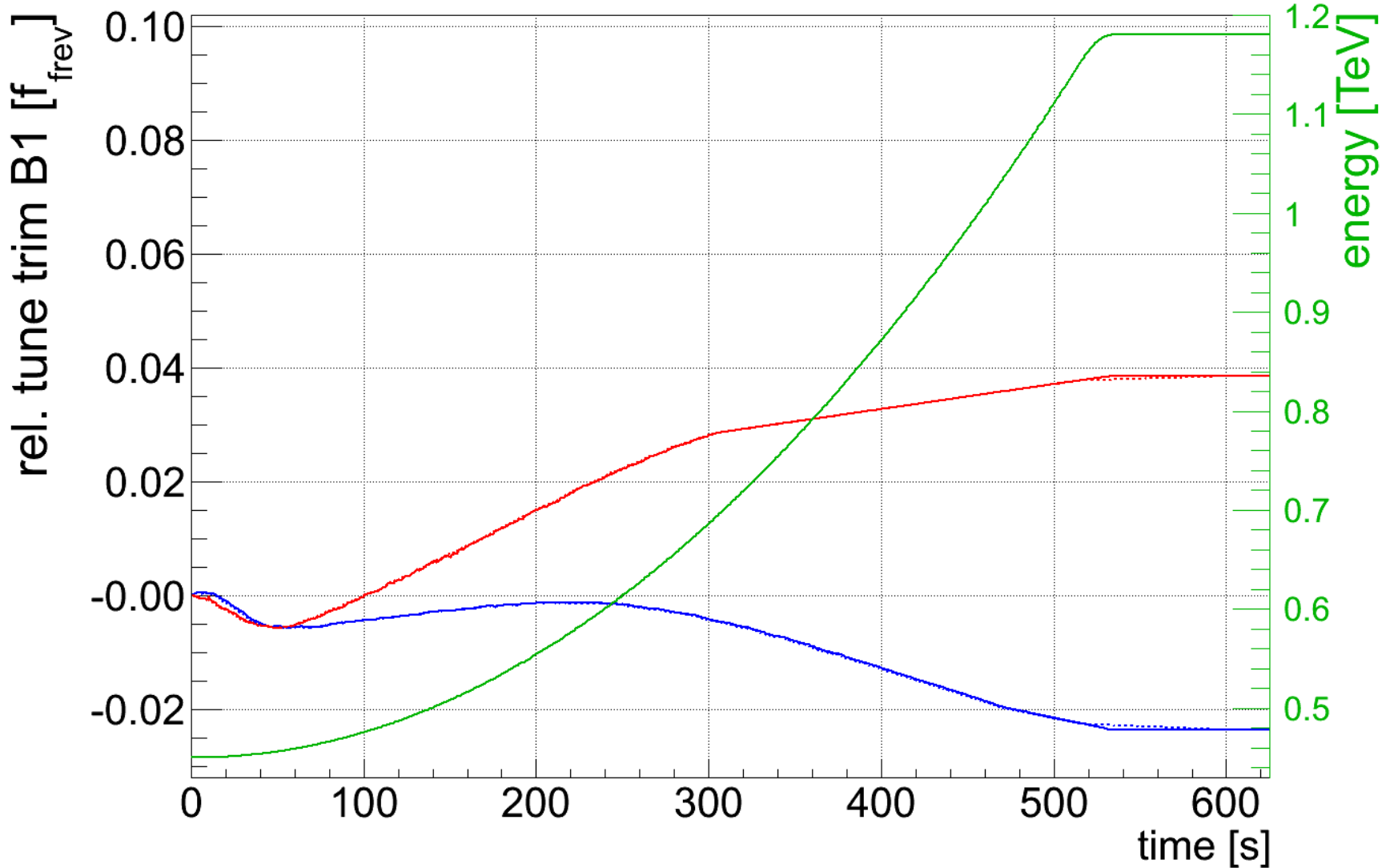
- Logging of equipment failed due to server problems → only Beam 2 data useful for further analysis using MQT[D/F] currents (N.B. $Q = \text{const}$ due to FB)
- B1 with feed-forward function based on ramp #2 BBQ measurements
 - lost due @ 21:33 due to ???
- B2 with Q-FB 'on' up to 1.18 TeV
 - feed-forward correction had wrong sign for B2
 - The “best/worst” case scenario to test the Q-FB function → A Big Thanks!
- Further ramping “philosophy”:
Q-FB establishes ramp
→ off-line analysis of required FB correction currents



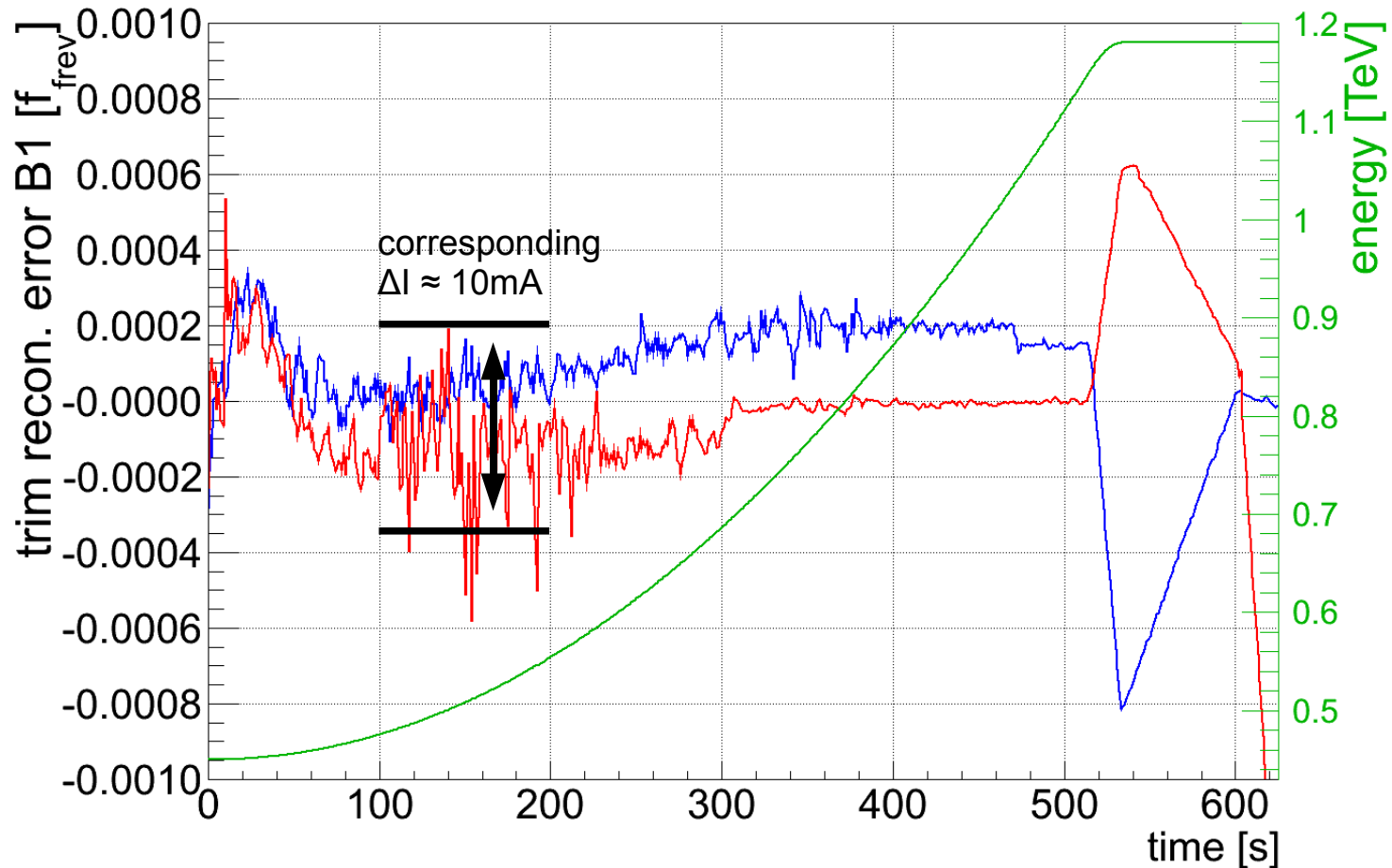
- Absolute trim quadrupole (QTD/QTF) currents:



- Recon. relative tune trim: LSA (solid) vs. actual circuit current (dashed)
 - Small difference, in particular at the end of the ramp but otherwise OK

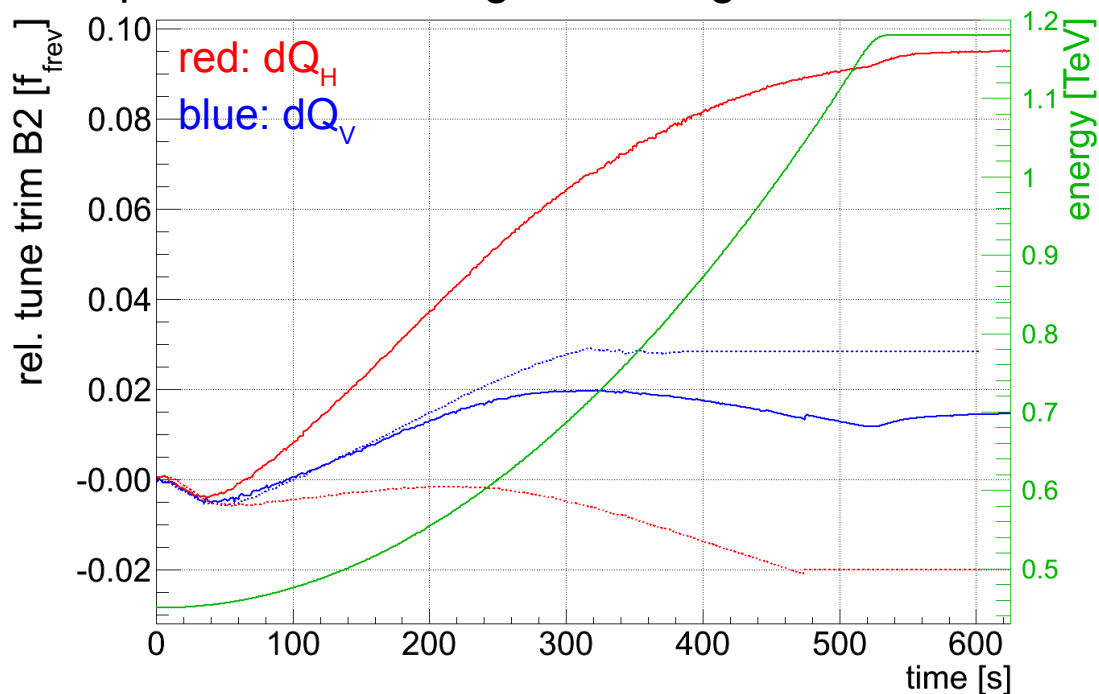


- Reconstruction error partially due to RQT[F/D] circuit noise and parallel protection resistor (courtesy V. Montabonnet et Y. Thurel)



→ dictates limit of this type of reconstruction to 10^{-3}

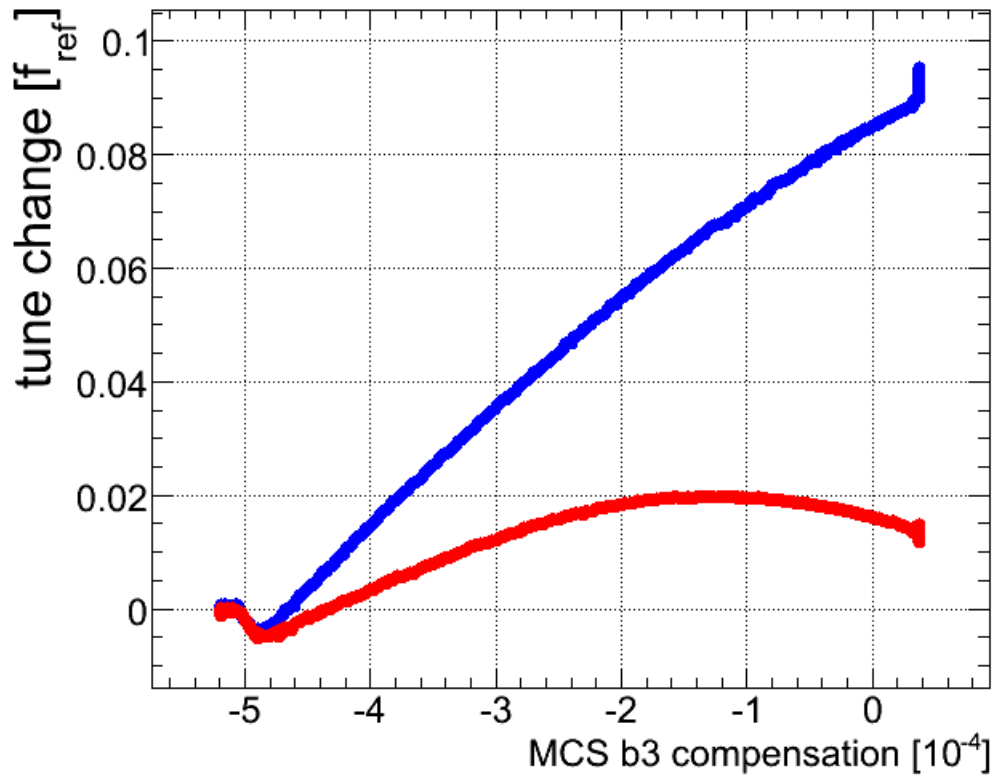
- Reconstructed relative tune trim: RT (solid) vs LSA trims (dashed)
 - esp. vertical plane: different sign and magnitude



- Drift parameter reconstruction and source for tune drift are unclear:
 - Is it a b1 vs. b2 energy mismatch/lag,
 - a 'true' b2 snap-back and persistent currents decay, or
 - b3 feed-down caused by an off-centre orbit in the Mbs & MSs... ?

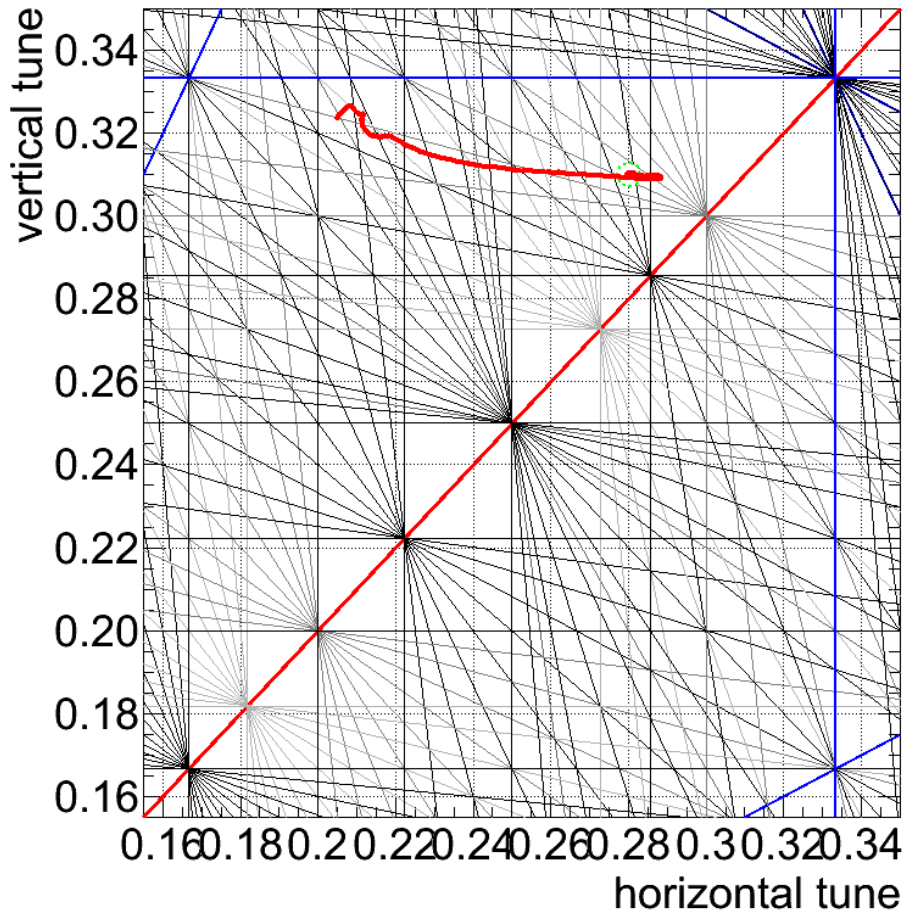
... too many free parameter → FBs would help to pin-down some of them

- Correlation between horizontal (blue) and vertical (red) tune correction w.r.t. b3 compensation as applied by the MCS during the 4th ramp:

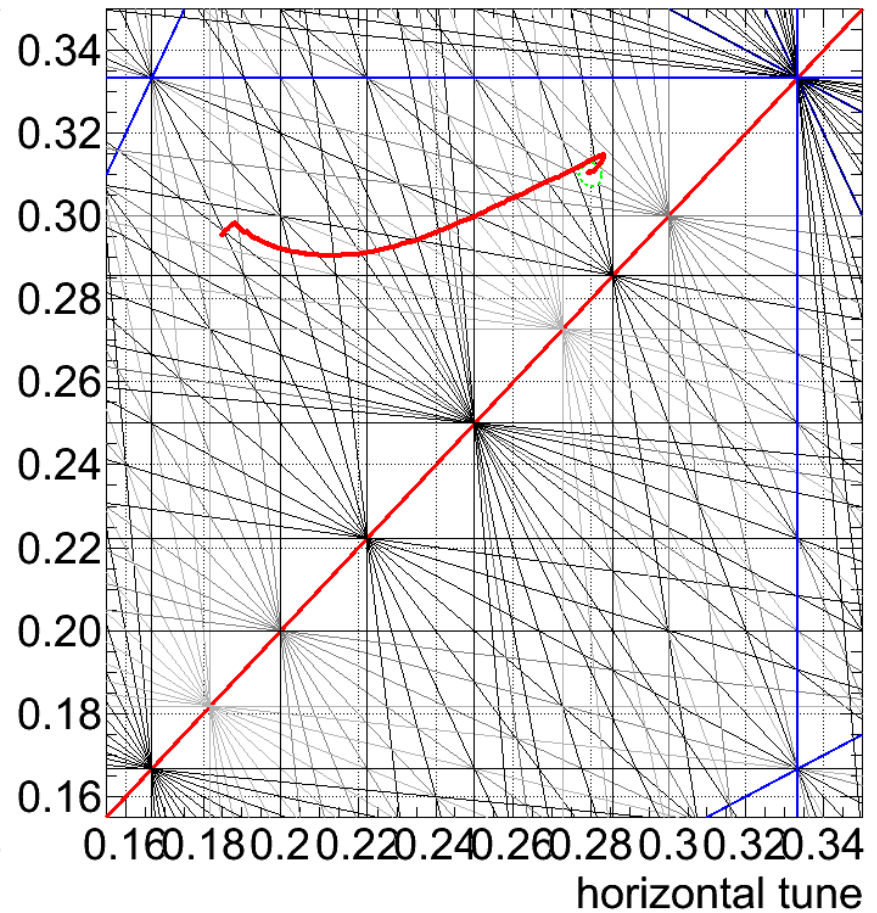


- Correlation coefficients:
 - Q_h vs. MCS-b3: 0.995
 - Q_v vs. MCS-b3: 0.807

- ... the Q-FB would have been 'off'



- ... the Q-FB would have been 'off' and no Q correction be applied



→ “bare tunes”, later used to compare different ramps



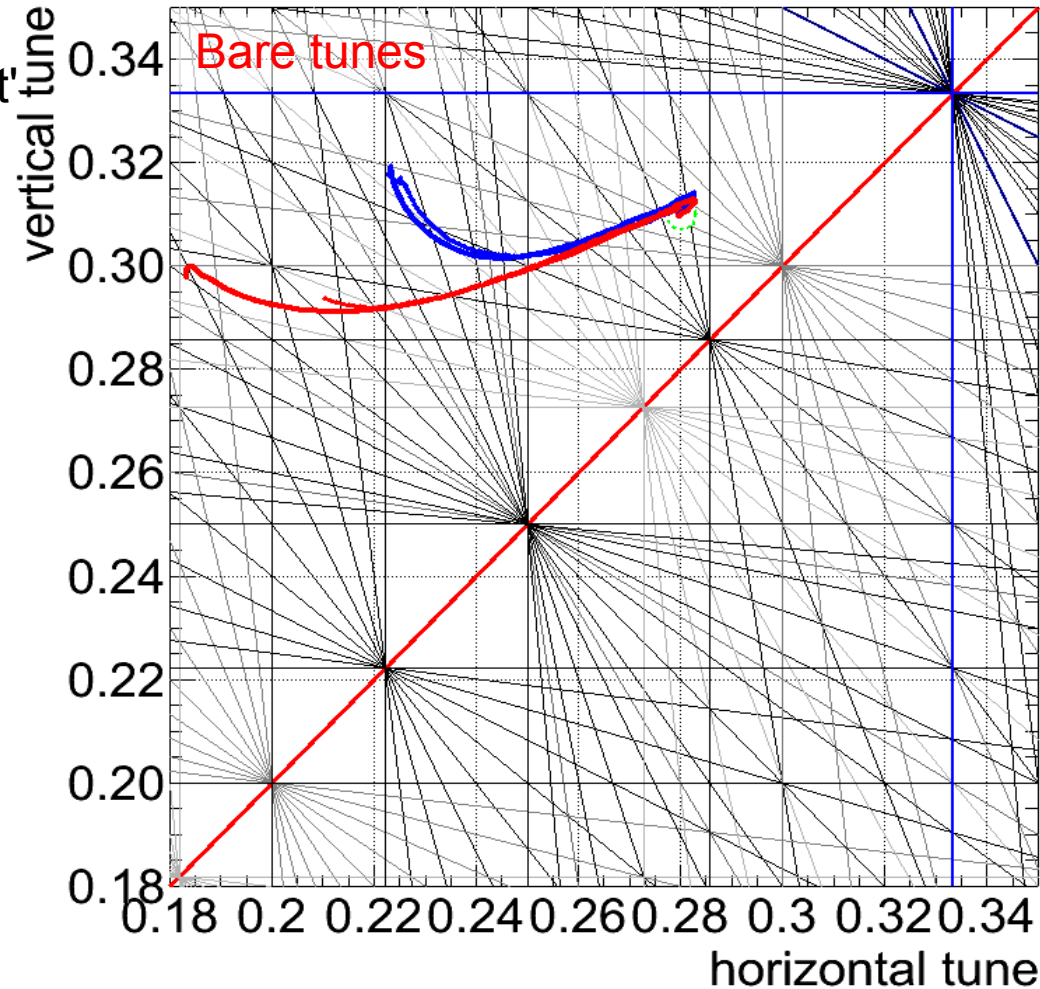
2009-12-08 @21:30 – Ramp #5 – Fill 915

2009-12-14 @02:28 – Ramp #6 – Fill 916

- both beams with Q-FB 'on'
 - B1 made it to 1.18 TeV → tunes kept stable to few 10^{-4}
 - B2 at 800 GeV due to BPM interlock (lost SBF + large orbit excursion)
 - changed incorporation rule: 'gradual decline' → 'constant'
 - two ramps within 5h

- Bare tunes

- Ramp #5 (solid) vs. Ramp #6 (dashed)
- Snap-back at 450 GeV and re-decay at 1.18 TeV visible
- short-term stability $\sim 5 \cdot 10^{-3}$

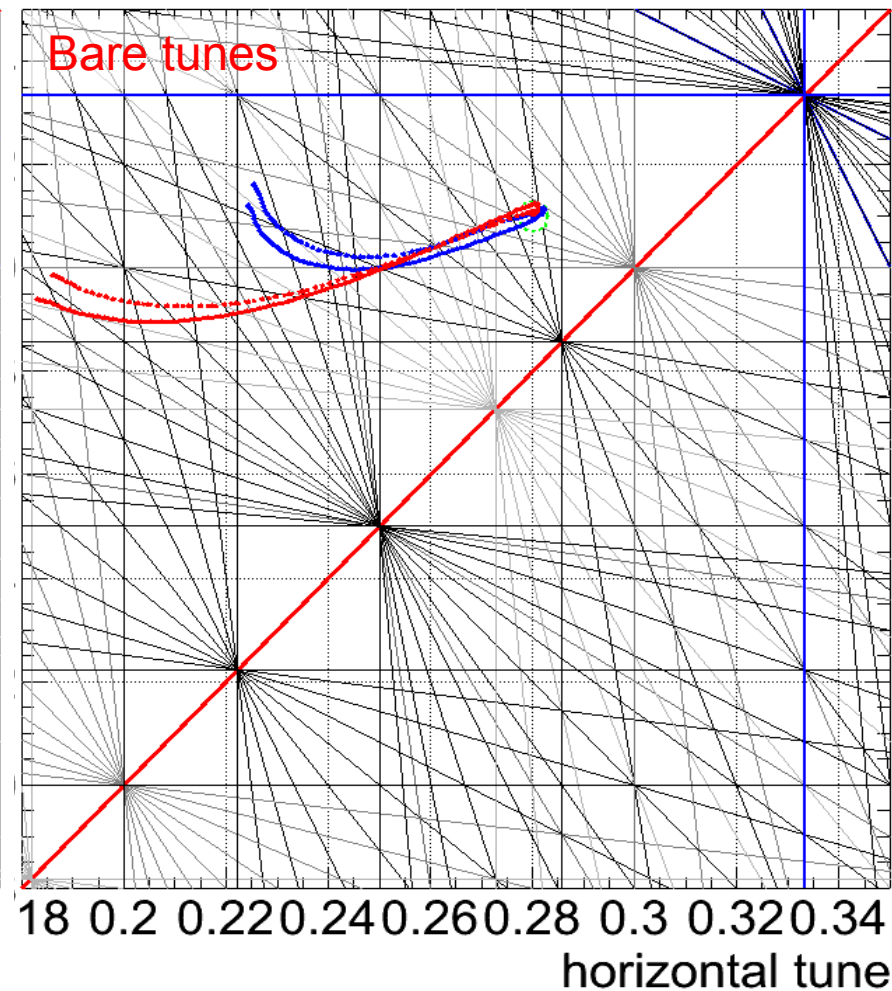
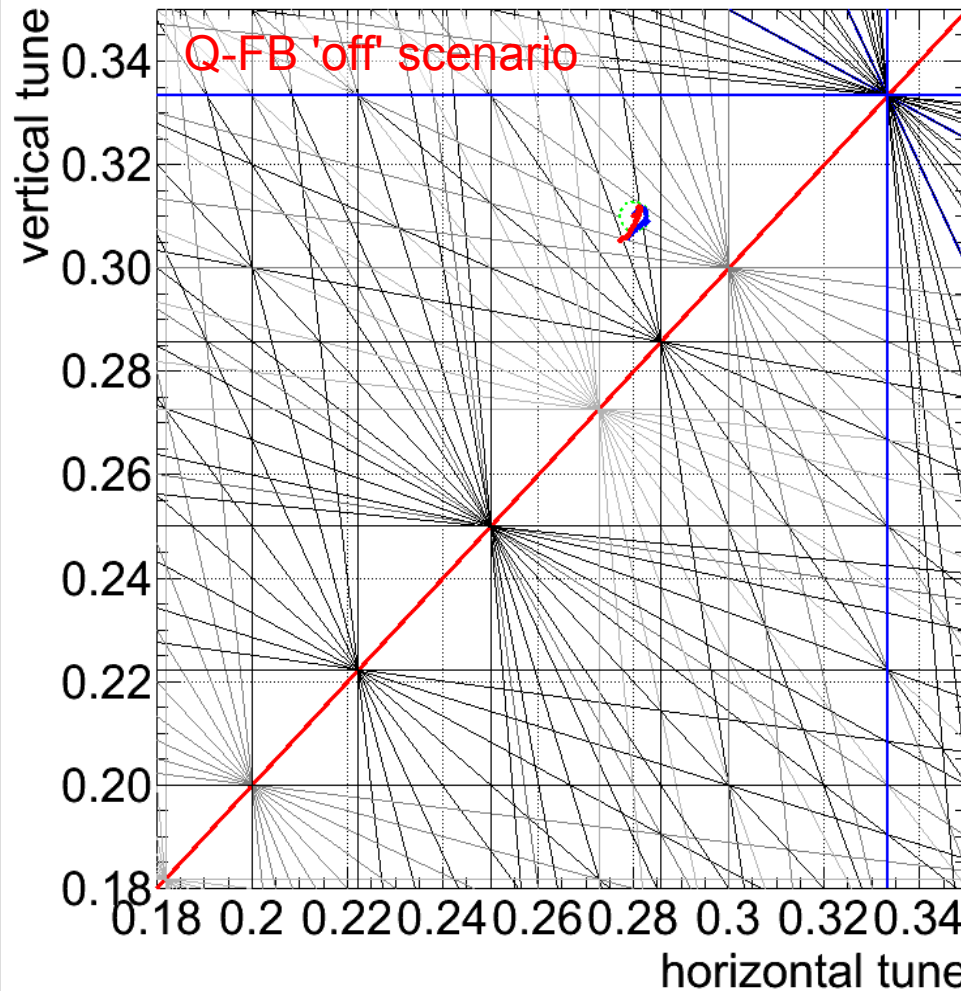




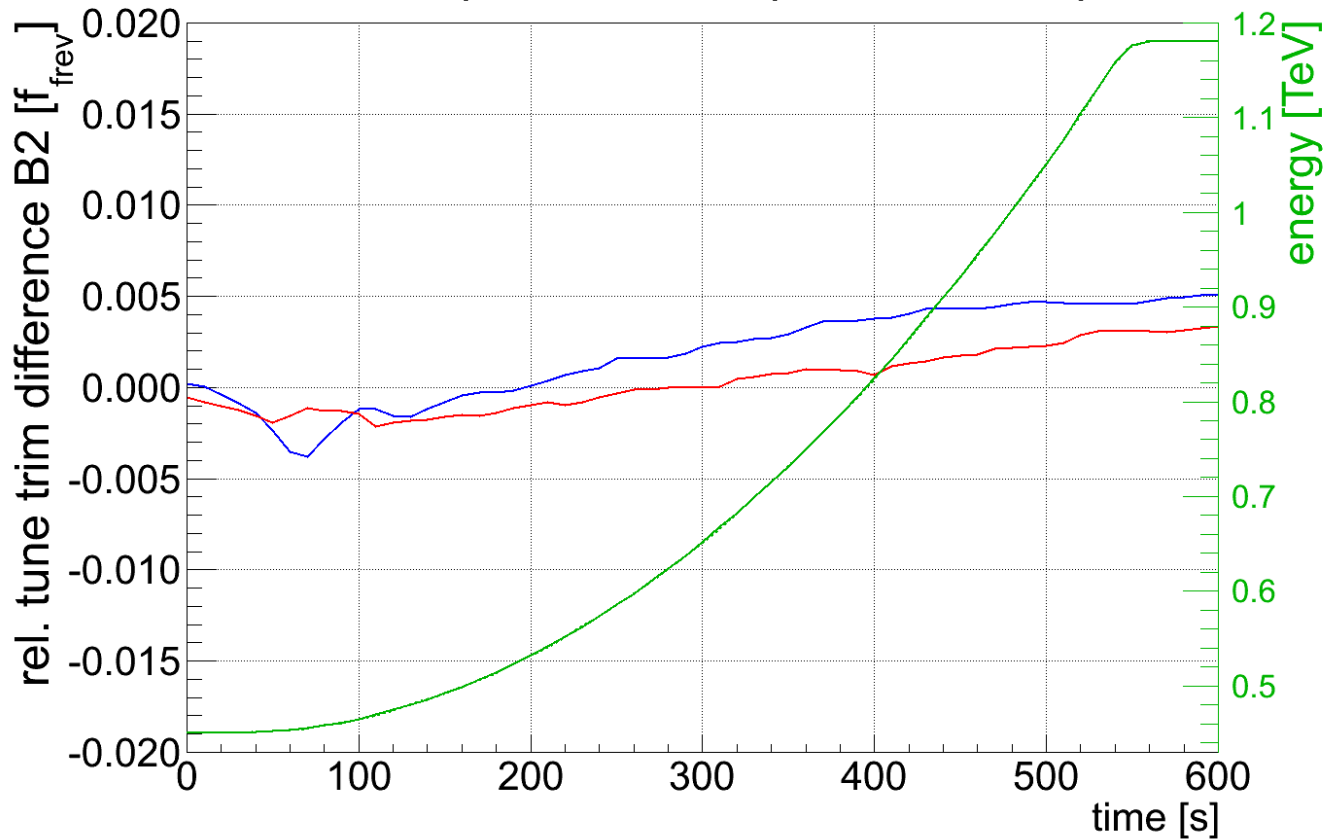
2009-12-15 @21:00 – Ramp #7

2009-12-16 @00:40 – Ramp #8

- Ramp #7: Dumped at 1.18 TeV due to spurious QPS trigger (RCBXH1.R2)
- Ramp #8: first squeeze attempts to $\beta^* = 7$ m
... end of 2009 LHC commissioning with beam

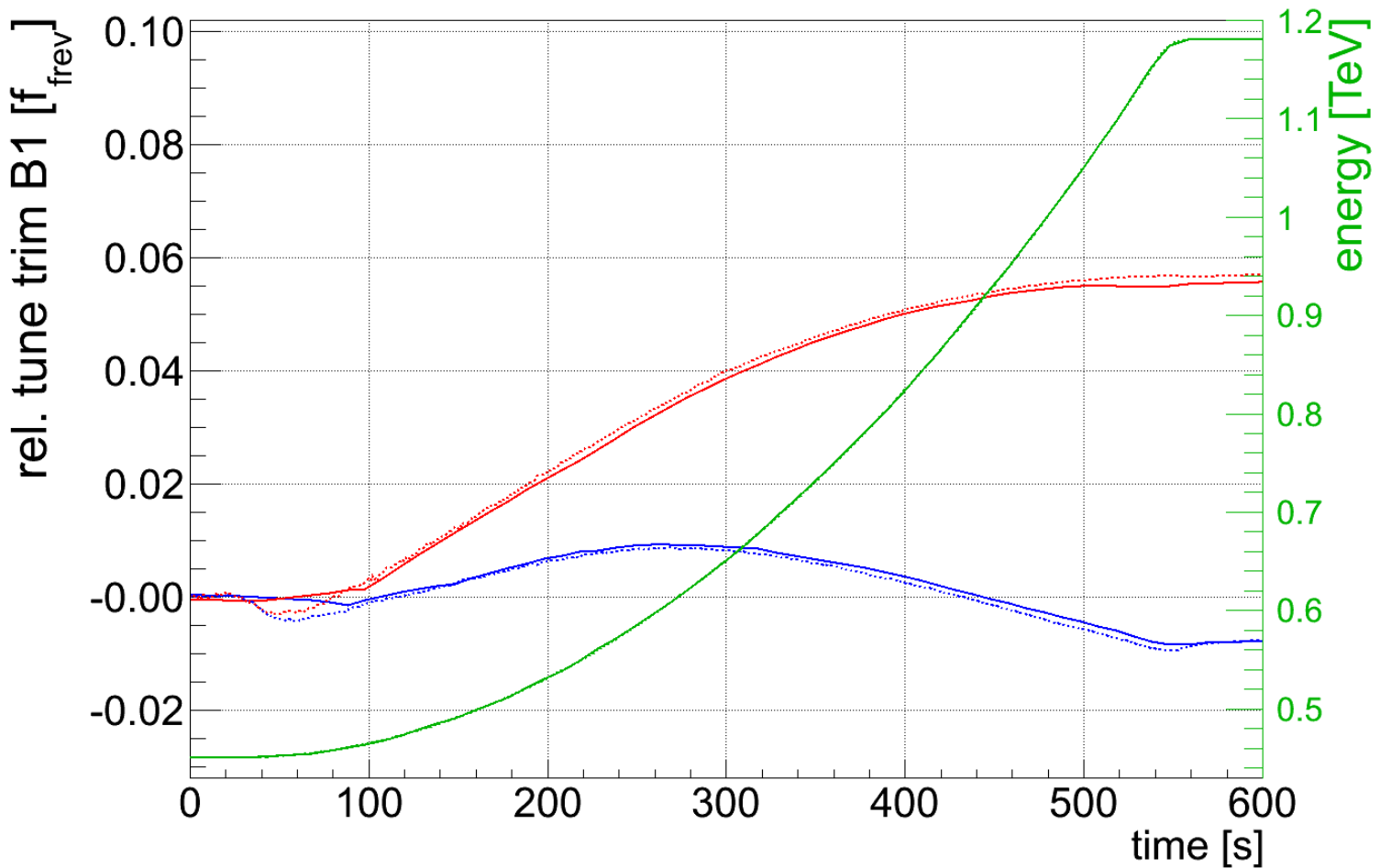


- Bare tune difference between ramps
 - ramp-to-ramp reproducibility $\sim 5 \cdot 10^{-3}$
 - OK for commissioning \rightarrow need to re-evaluate for higher intensities
 - Indication a reduced snap-back for ramp #8 w.r.t. ramp #7 \rightarrow

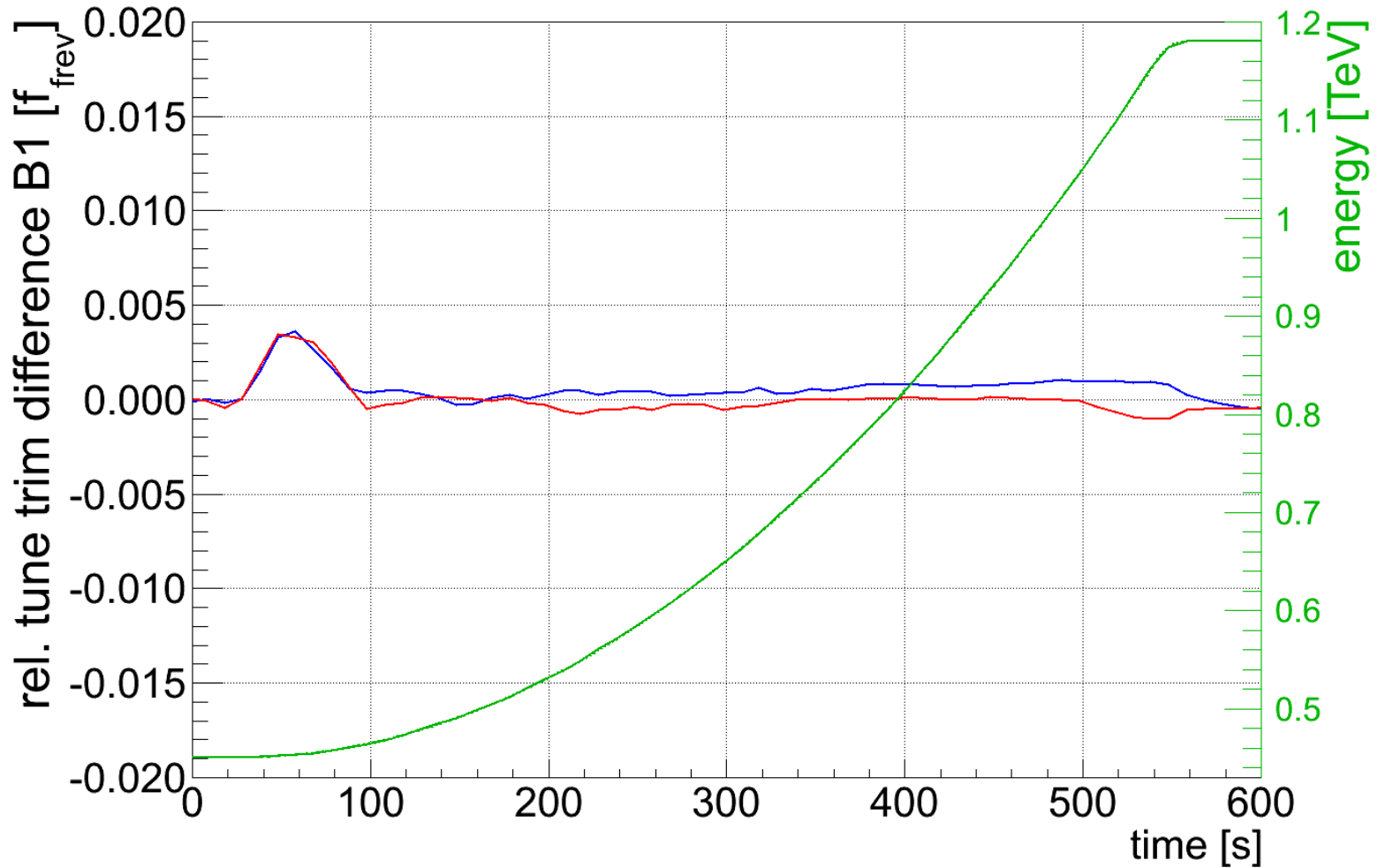


\rightarrow Exp. indication for snap-back dependence on previous cycling history?

- Bare tune drift differences between 'second' ramps much smaller
 - N.B. residual snap-back difference is an artifact of the LDB data reduction

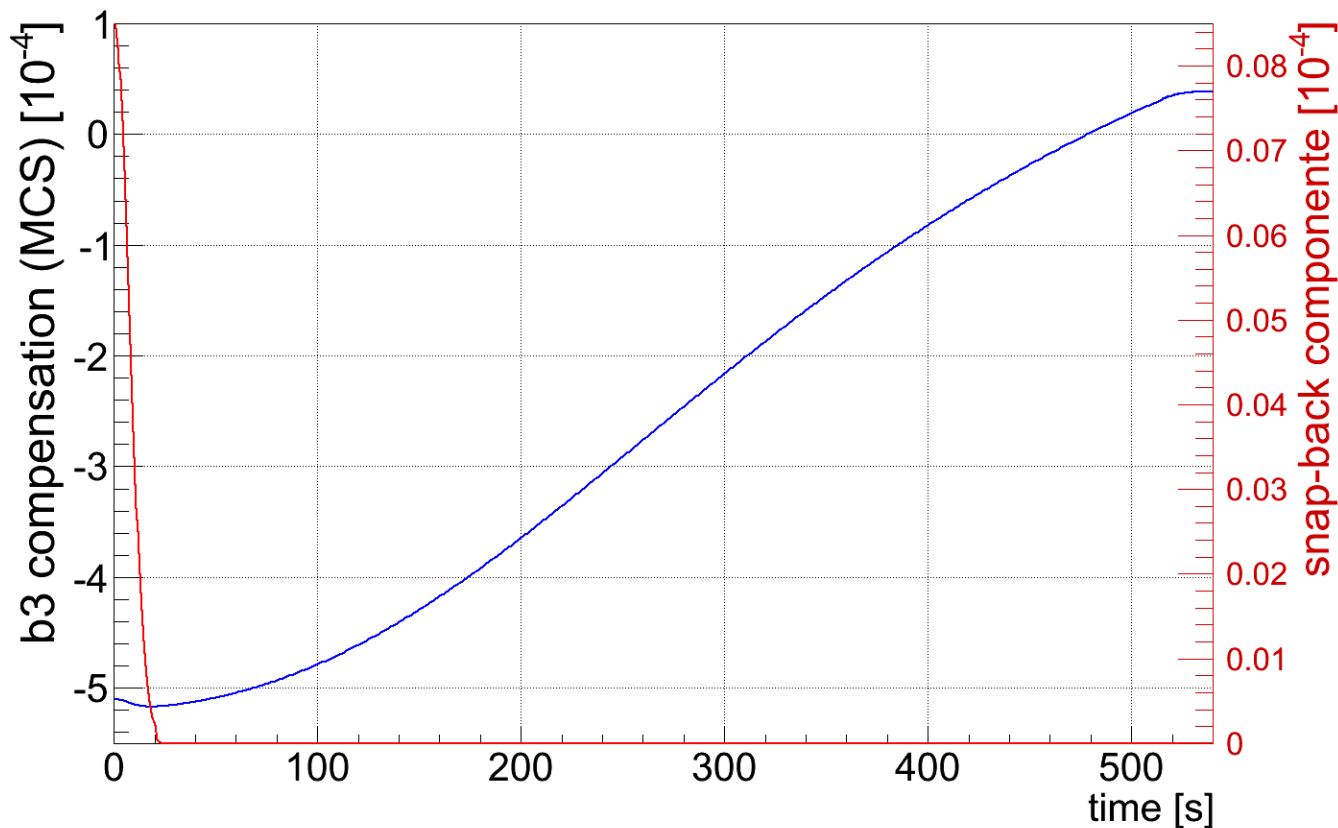


- Relative tune difference between second-in-line ramps #7 and #9:



- rel. tune difference (modulo snap-back/LDB artifact): 10^{-3}

- Each ramp with same snap-back and persistent currents compensation
 - e.g. FIDEL MCS corrections for Sector 12



- No direct time-resolved cross-verification of Q' during ramp but will estimate on absolute Q' drifts using measurements taken directly before and after the ramp possible.

- Ramp #4: Q' during ramp:
 - B1: $Q'_H = 9.9 \rightarrow 3.6$, $Q'_V = 11.4 \rightarrow -3.3 \rightarrow \Delta Q'_H \approx -6.3$ & $\Delta Q'_V \approx -14.7$
- Ramp #5 – Fill 915: Q' during ramp:
 - B1: $Q'_H = 7.9 \rightarrow 9.2$ & $Q'_V = 7.4 \rightarrow 4.2 \rightarrow \Delta Q'_H \approx -2.7$ & $\Delta Q'_V \approx -13.2$
 - Trim: H: $-12 \rightarrow -8$ V: $2 \rightarrow 12$
 - 2nd meas: $Q' = 4.9/3.7$ with $-13/12$ trims
 - B2: $Q'_H = 10.3$ & $Q'_V = 7.1$ (injection) for trims -13 & 2
- Ramp #6 – Fill 916, Q' during ramp:
 - B1: $Q'_H = 9.2 \rightarrow 6.2$ & $Q'_V = 6.7 \rightarrow 3.9 \rightarrow \Delta Q'_H \approx -3.0$ & $\Delta Q'_V \approx -10.8$
 - Trim: H: $-12 \rightarrow -12$ V: $2 \rightarrow 10$
 - B2: $Q'_H = 10.3 \rightarrow 1.1$ $Q'_V = 7.1 \rightarrow -1.0 \rightarrow \Delta Q'_H \approx -9.2$ & $\Delta Q'_V \approx -8.1$
 - Trim: H: -13 V: $+2$
- 2010: Q'-PLL with continuous dp/p modulation to measure and correct snap-back in real-time which may minimise potential feed-down effects

- Ramping the LHC seems to work only during the night (21:30 ↔ 2:28)
→ we should try whether we can do this also e.g. after 8 o' clock
 - Q-FB stability better than residual LHC reproducibility
 - fill-to-(next-)fill reproducibility in the order of a few 10^{-3}
 - may catch operational faults/feed-down effects: wrong feed-forward function, switched off triplet magnets, Q shifts due to Q' trims, ...
 - LSA feed-forward incorporation became consistent for later ramps
 - First indications for snap-back dependence on the last cycle duration seen
 - Q' changes are small w.r.t initial commissioning requirements $|\Delta Q'| < 10$
 - However, what remains unknown
 - Source of Q drifts (B1-B2 energy mismatch?, B2 decay?, B3 feed-down?)
 - Why are drifts of B2 parameter so different than those for B1
- envisage orbit & Q' Feedback to eliminate/pin-down some of the 'unknowns'