Horizontal instability studies at 160 MeV mimicking the future injection energy in the PSB

Eirini Koukovini-Platia

Acknowledgements

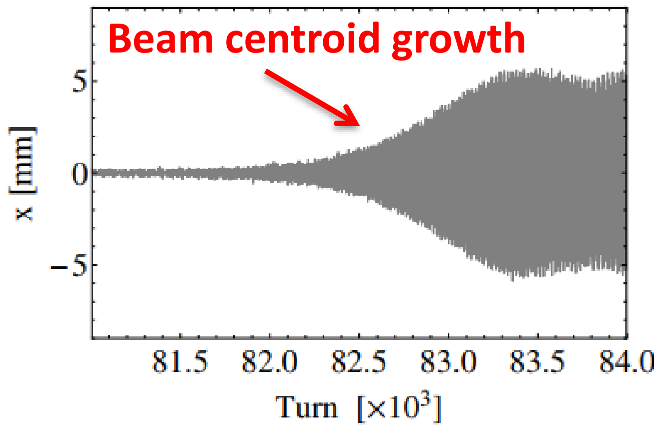
A. Akroh, S. Albright, F. Antoniou, H. Bartosik, A. Findlay, G. P. Di Giovanni, A. Huschauer, B. Mikulec, G. Rumolo, A. Santamaria, M. Schenk, C. Zannini, PSB OP

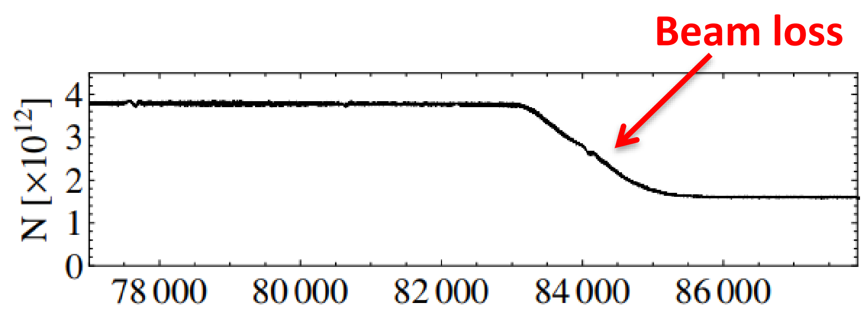
MSWG meeting #14, 28/09/2018

https://indico.cern.ch/event/758054/

Motivation

- Above a certain intensity a **horizontal instability** develops in the PSB causing transverse coherent oscillations and **significant beam loss**





M. McAteer et al, THPRO082, IPAC14

- The transverse feedback (TFB) is able to suppress the instability but the **origin** of the instability is **not yet understood**
- **After LS2, injection energy** will increase from 50 MeV to **160 MeV**, i.e. exactly where the instability appears for certain tunes
- Higher intensity beams after LIU
- Apart from ISOLDE, all beams will be accelerated to 2 GeV. Will there be another critical energy for beam stability?

Measurements

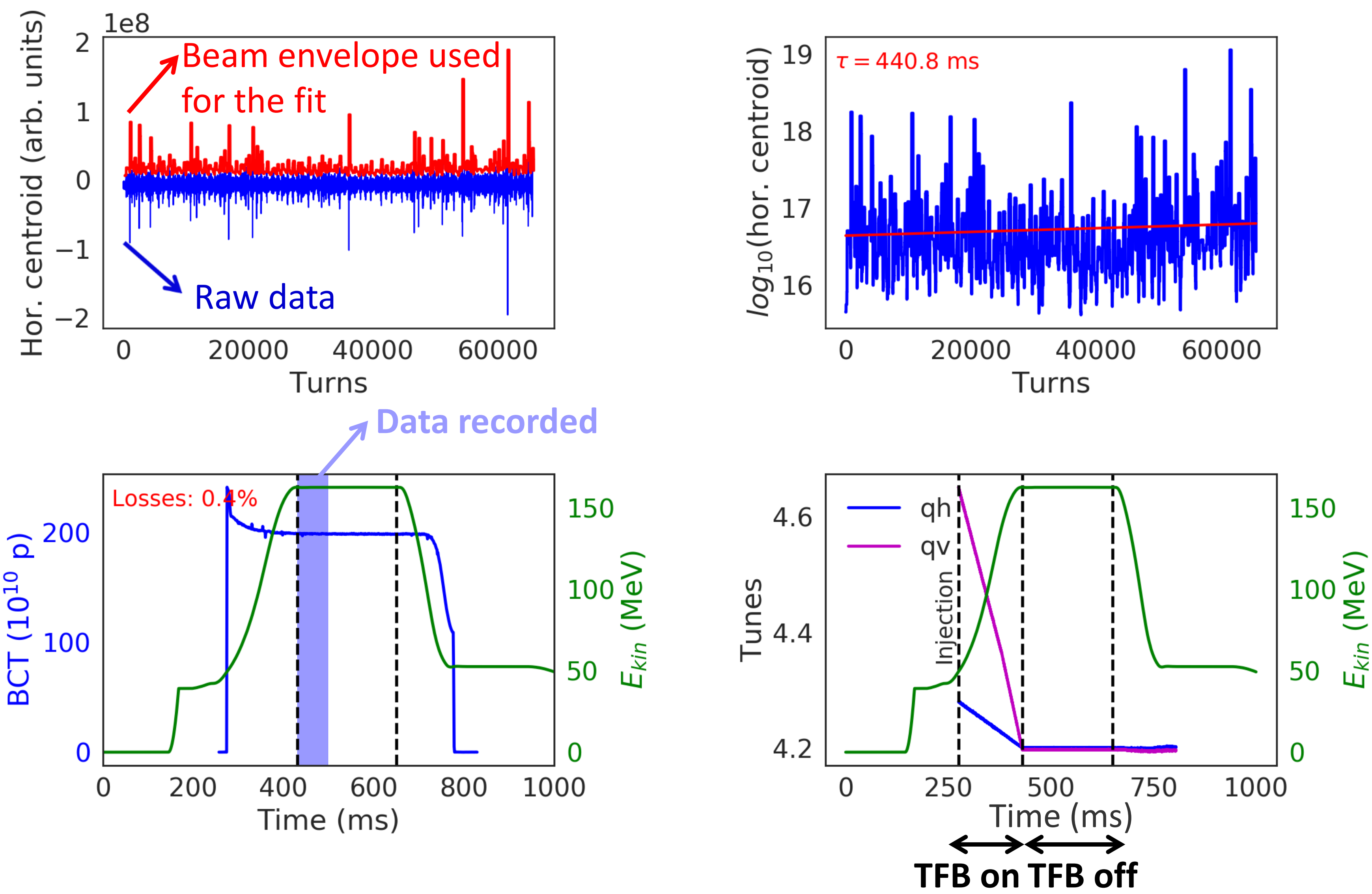
- A measurement campaign has been undertaken to characterize the instability at a constant energy plateau of **160 MeV** for the first time, **mimicking the future injection energy with Linac4**
- Identify the horizontal tune working points that cause significant beam loss at 160 MeV
  - For different beam intensity
  - For different chromaticity values
- Record rise time and head-tail modes
- Measurements with and without the TFB to disentangle clearly the losses due to the instability from those due to the resonance crossing

Setup of the MD

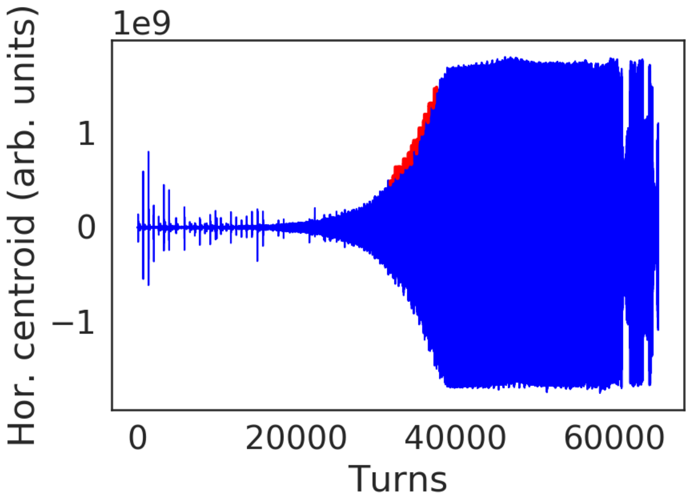
- Cycle **MD3723_BetaBeat_160MeV_2018** (clone of MD_BetaBeat_160MeV)
- Q_STRIP are disabled
- Multipoles are on (as in operational BCMS beam)
- **Single RF** harmonic
- Measurements in **Ring 3**
- Measured chromaticity with **80 A** in GSXNOHO: **ξh = - 1.6 ± 0.1**, **ξv ≈ 0**
- Measured chromaticity with **0.1 A** in GSXNOHO (remnant of 10 A in power supply, close to natural chromaticity): **ξh = - 0.8 ± 0.1**, **ξv = - 1.45 ± 0.15**
- Tunes follow the ISOHRS settings until 430 ms. After 430 ms, tunes qv and qh remain stable along the 160 MeV energy plateau
- The TFB is always active from injection until the start of the constant energy plateau of 160 MeV. When necessary for the studies, it is switched off at 431 ms
- Horizontal tune is changed between 4.1 and 4.5 with step of 0.01
- Data recorded between 16/7/18 and 26/7/18 for different intensities, chromaticity and TFB settings

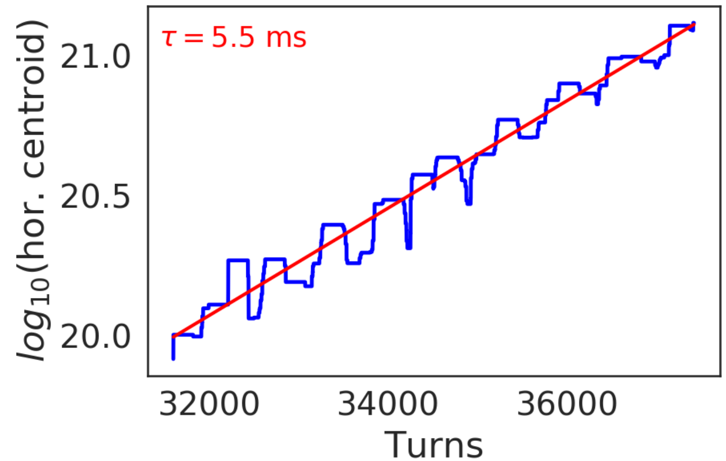
I = 200 x 10^{10}, TFB off after 431 ms, qh = 4.20

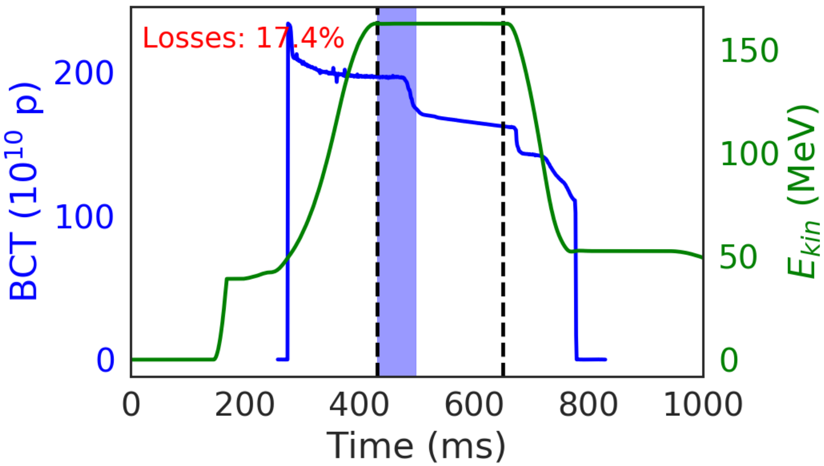
Stable case for qh = 4.20 (ξh = - 1.6, ξv ≈ 0)

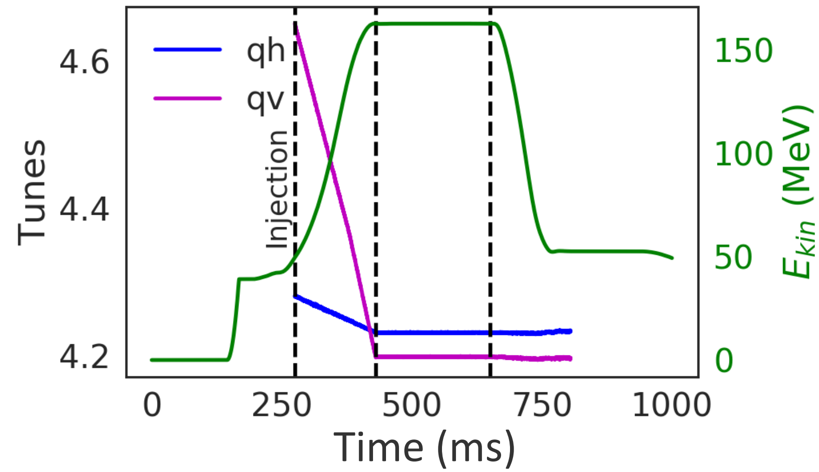


Some losses occur for qh = 4.23 (ξh = - 1.6, $\xi v \approx 0$)



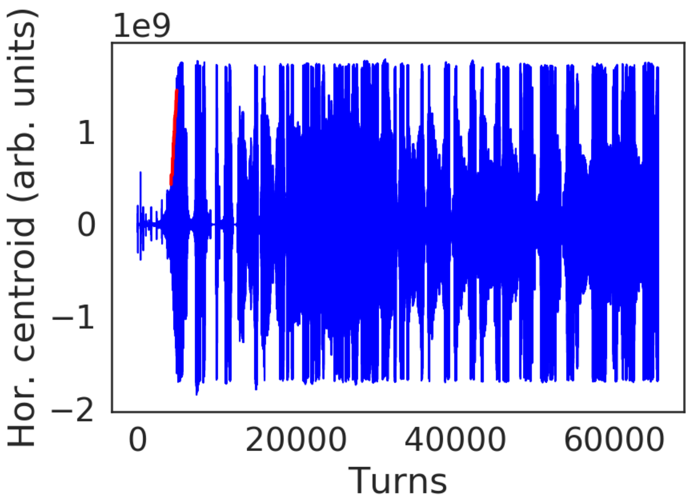


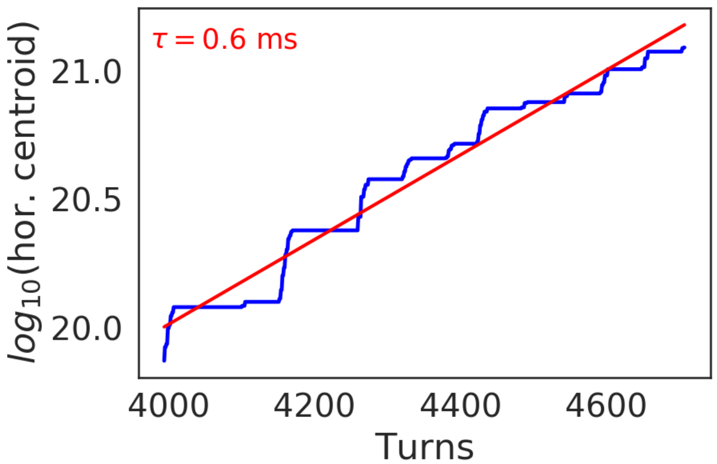


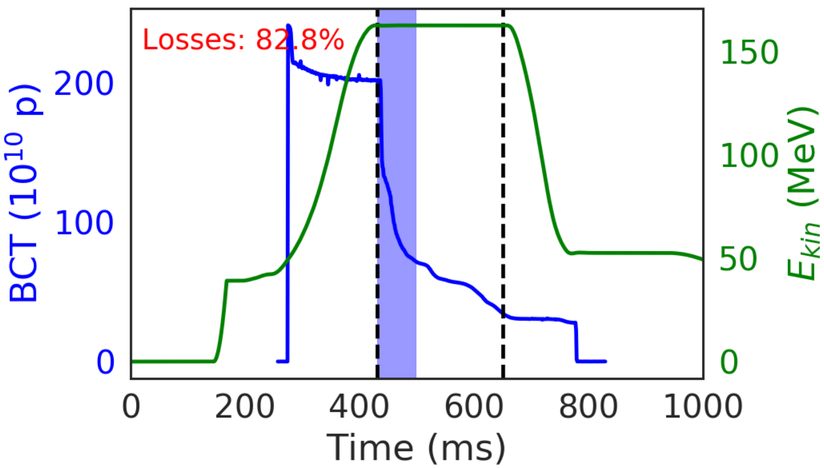


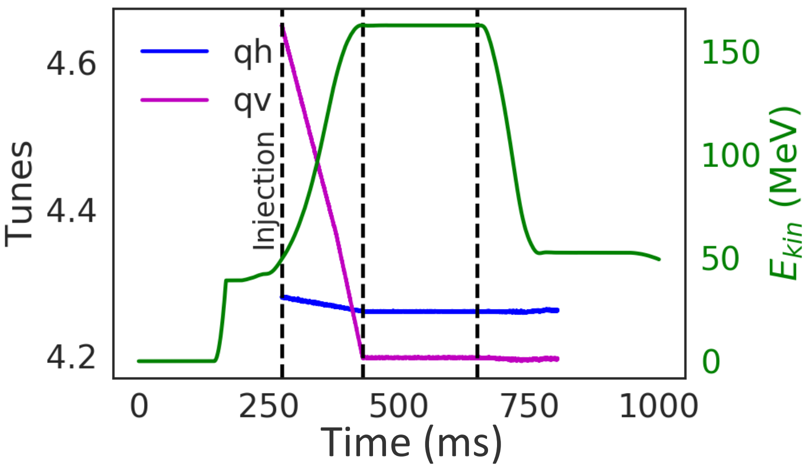
I = 200 x 10^{10}, TFB off after 431 ms, qh = 4.26

Significant losses occur for qh = 4.26 (ξh = - 1.6, ξv ≈ 0)



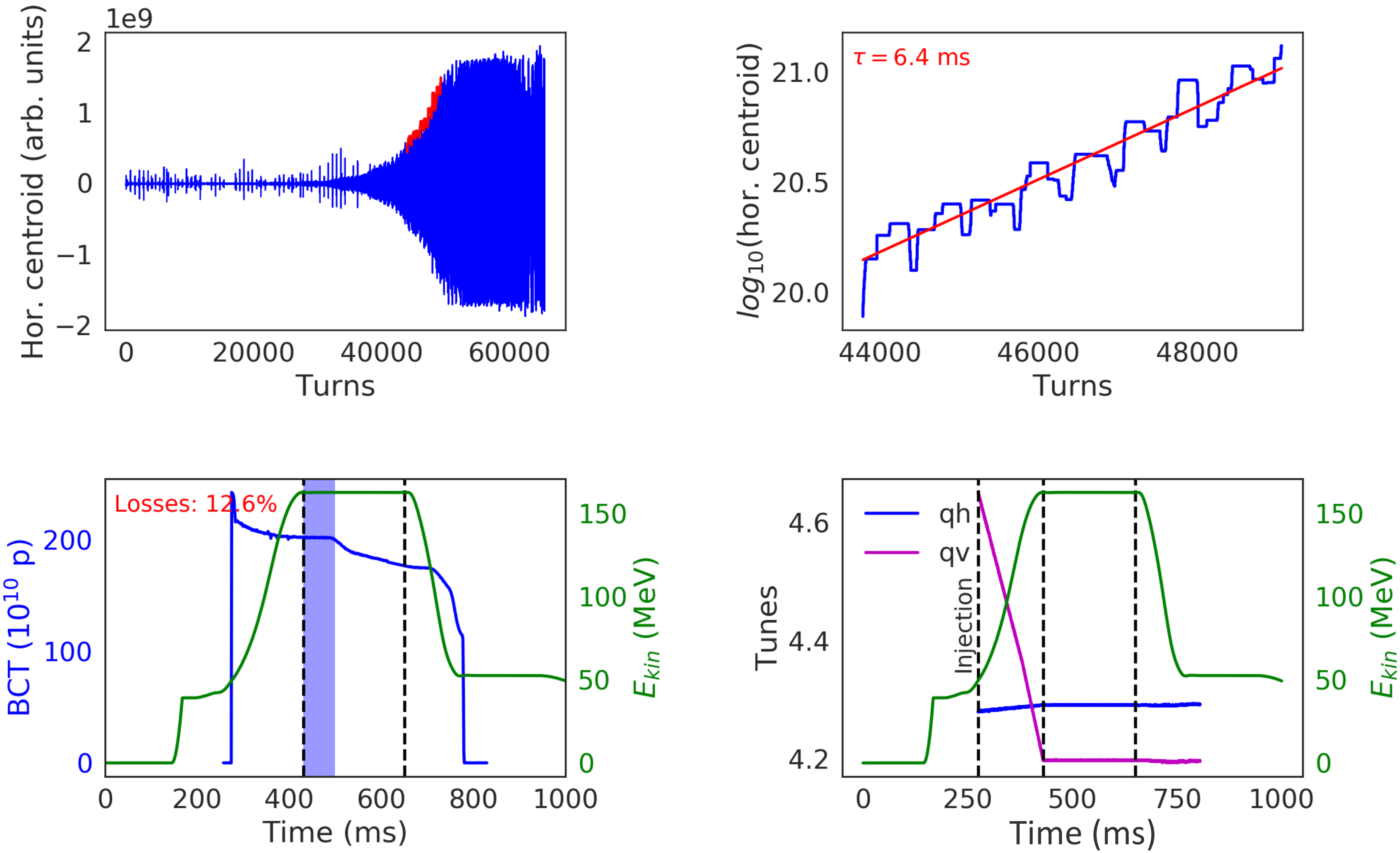






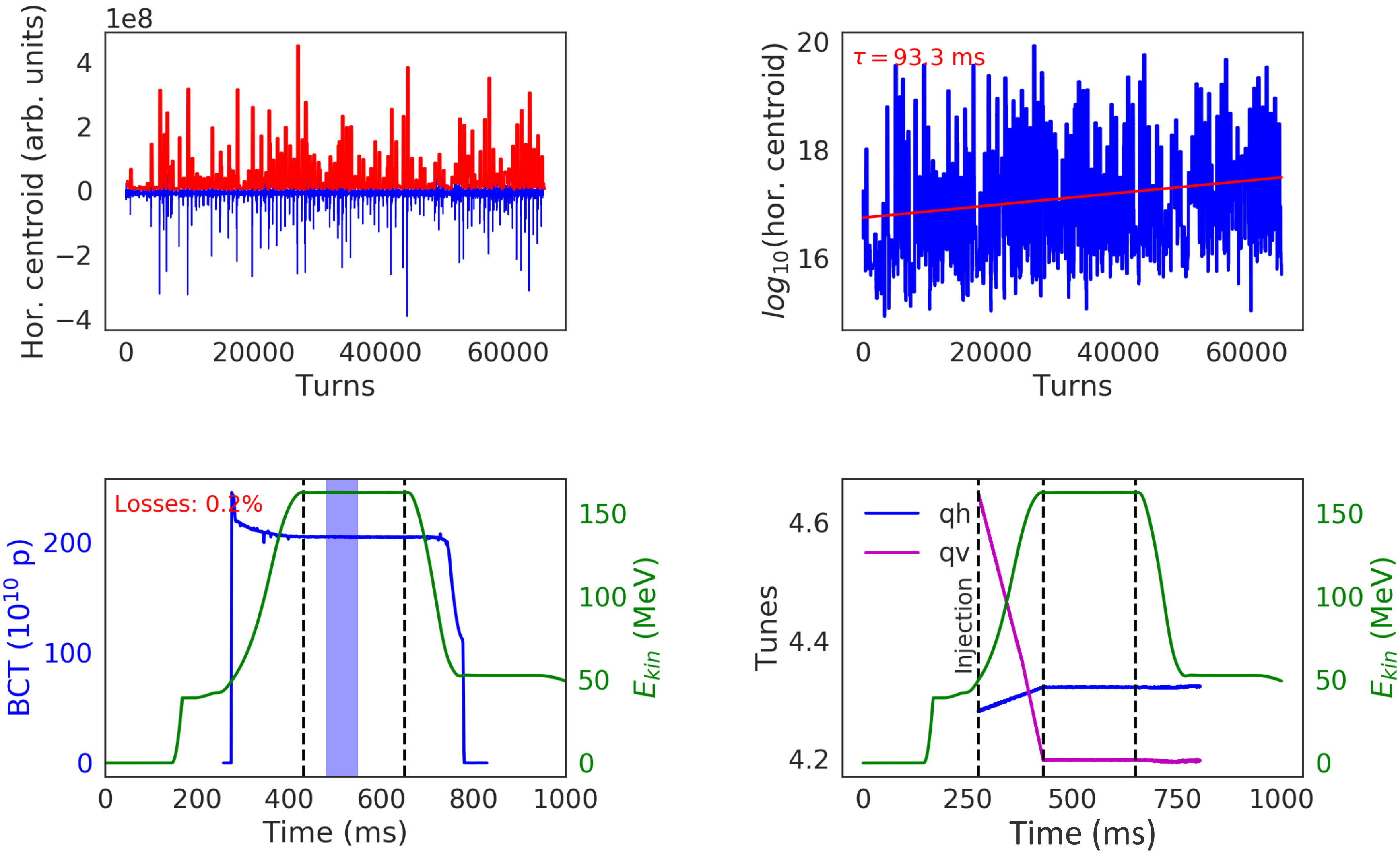
I = 200 x 10^{10}, TFB off after 431 ms, qh = 4.29

Losses reduce for qh = 4.29 (ξh = - 1.6, ξv ≈ 0)



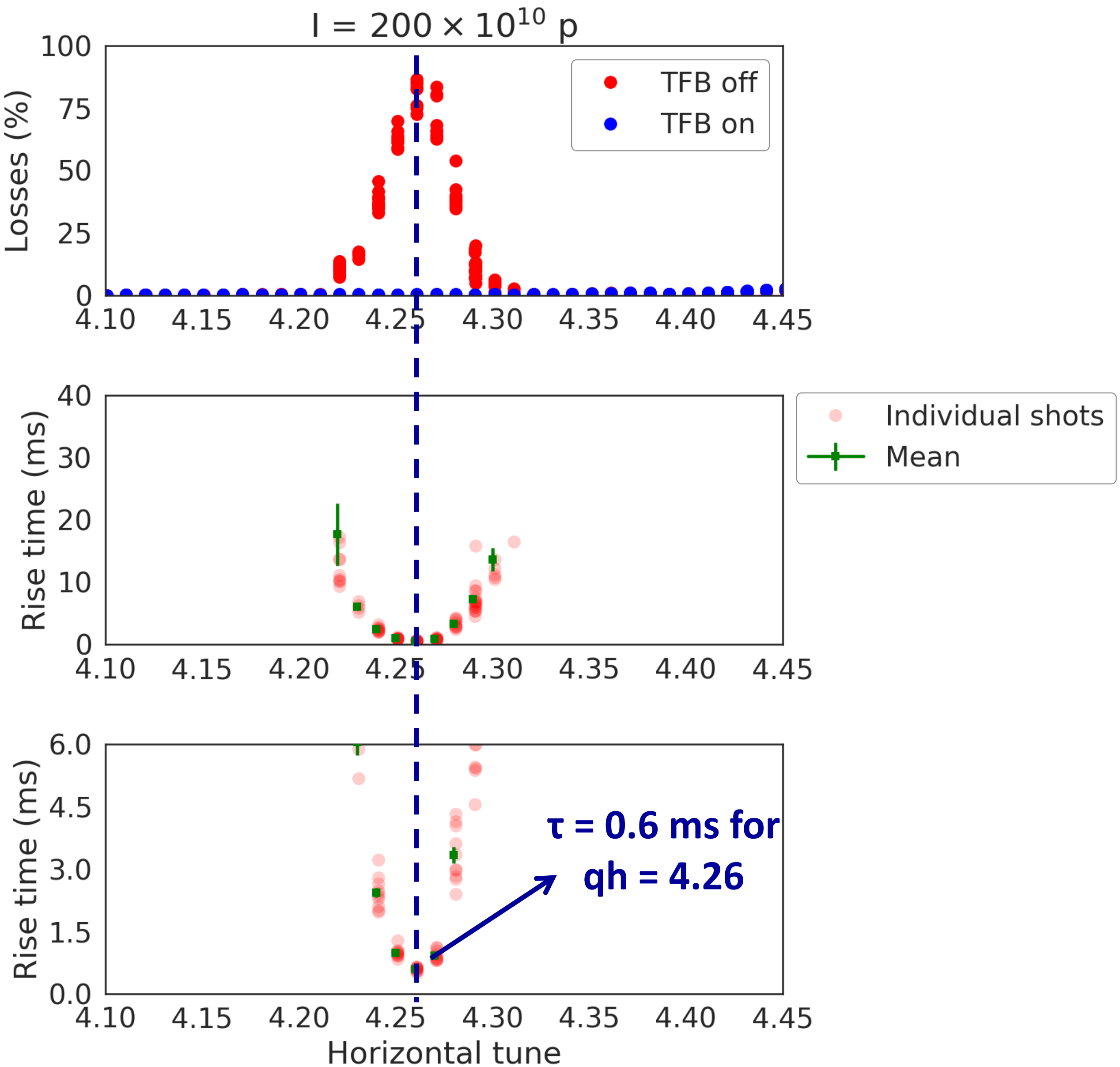
I = 200 x 10^{10}, TFB off after 431 ms, qh = 4.32

Stable case for qh = 4.32 (ξh = - 1.6, ξv ≈ 0)



 E. Koukovini-Platia

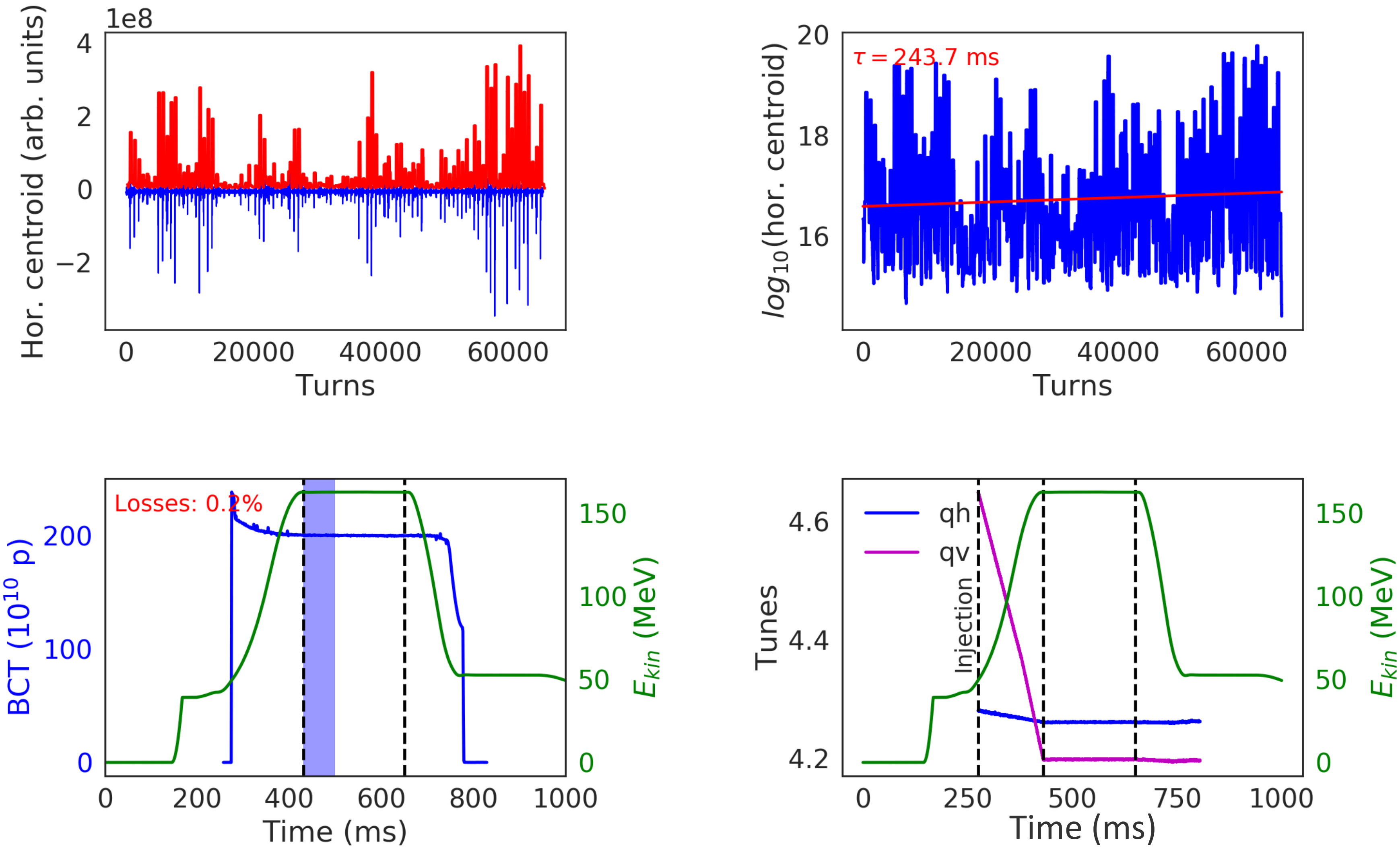
I = 200 x 10^{10} (ξh = - 1.6, ξv ≈ 0)



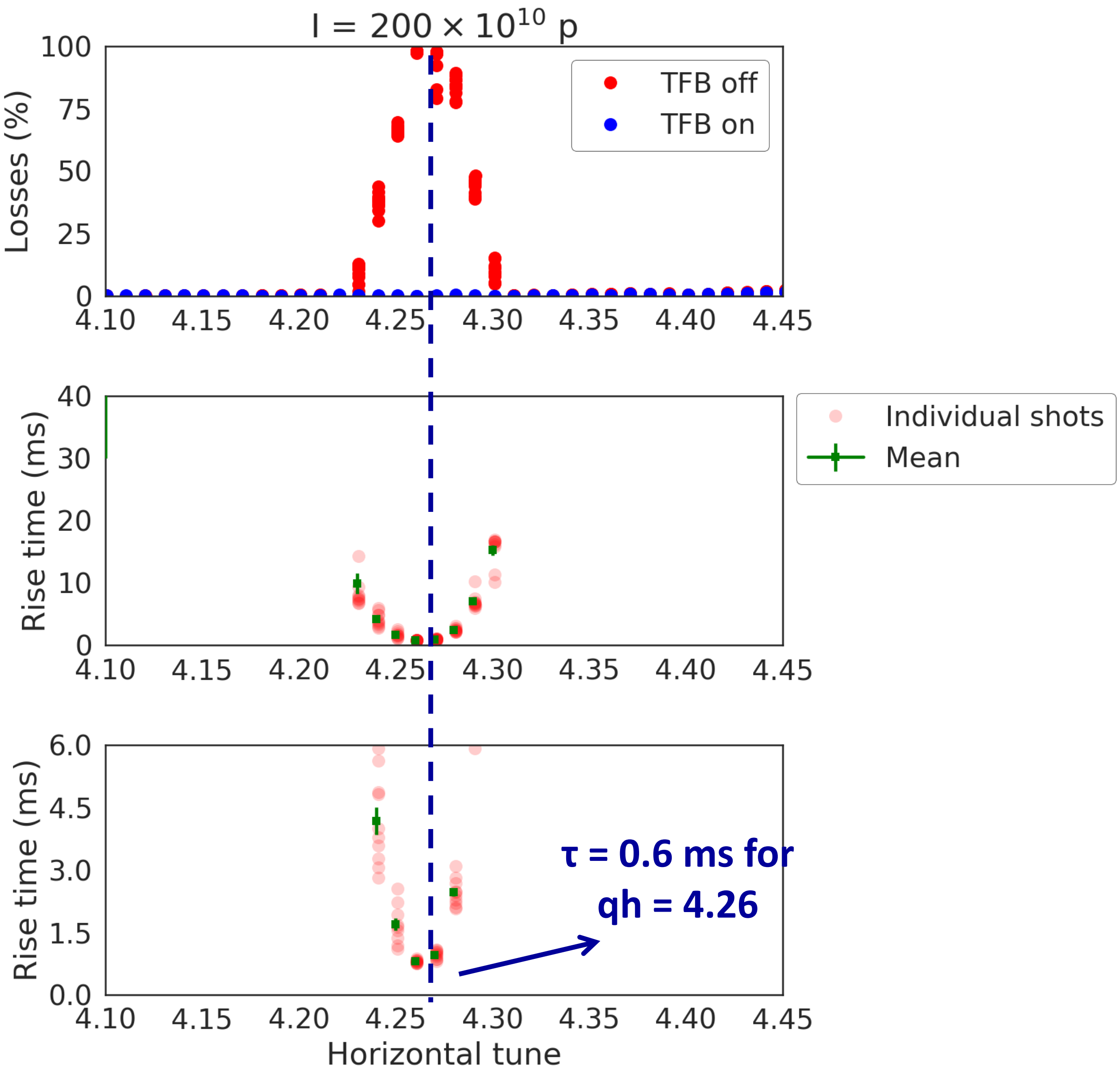
- Above 150 x 10^{10} p a **horizontal instability** appears
- Beam **loss up to 87%**
- Scanning the horizontal tune it was found that values between **4.21 up to 4.29** cause losses, **with maximum losses at qh ≈ 4.26**
- Rise time **below 1 ms** is found for qh = 4.25, 4.26, 4.27
- When the TFB is on, the beam is stable

I = 200 x 10^{10}, TFB on, qh = 4.26

With TFB ON along the cycle, no losses are observed
(qh = 4.26 with ξh = - 1.6, ξv ≈ 0)

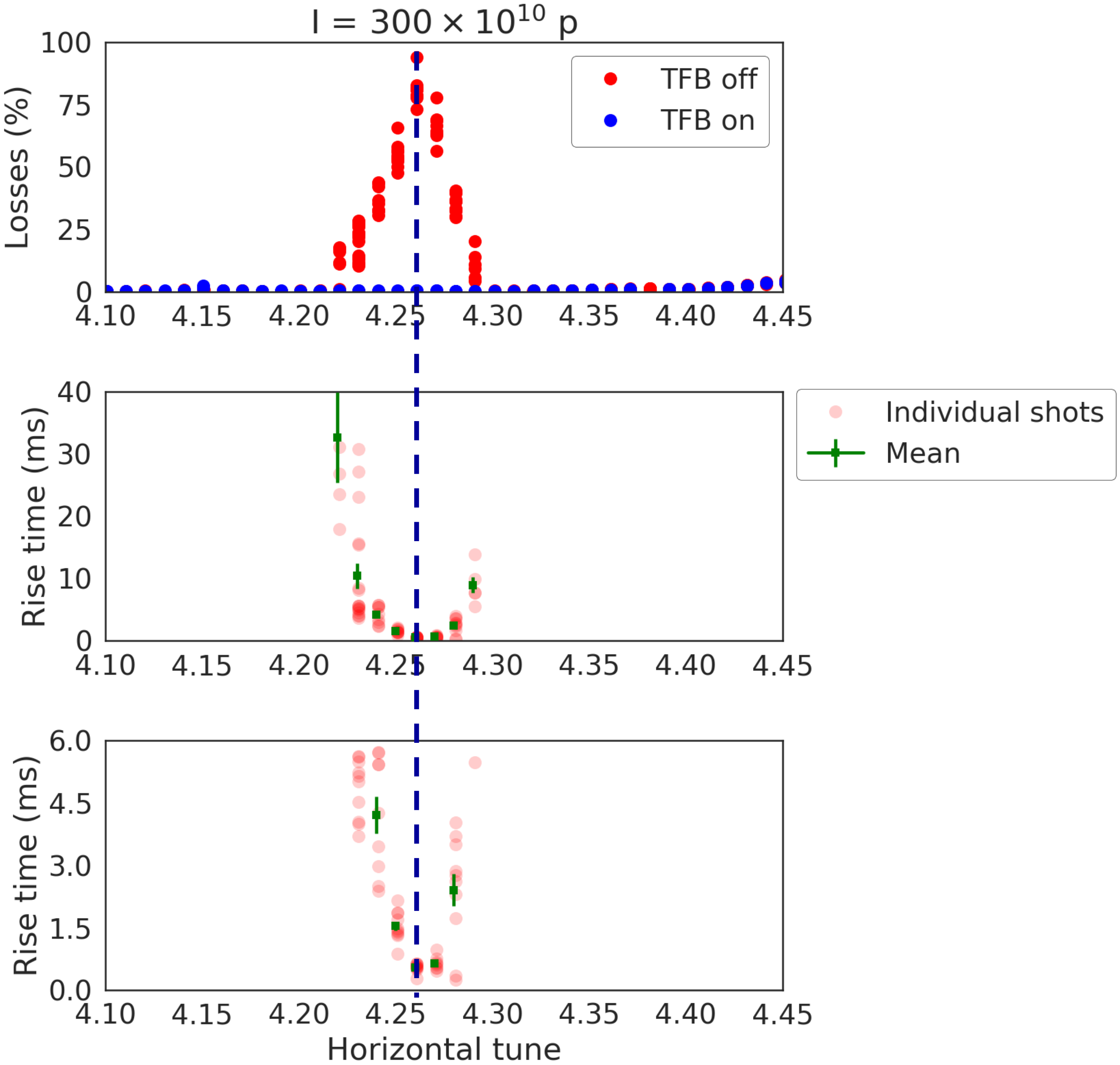


I = 200 x 10^{10} (ξh = - 0.8, ξv = - 1.45)



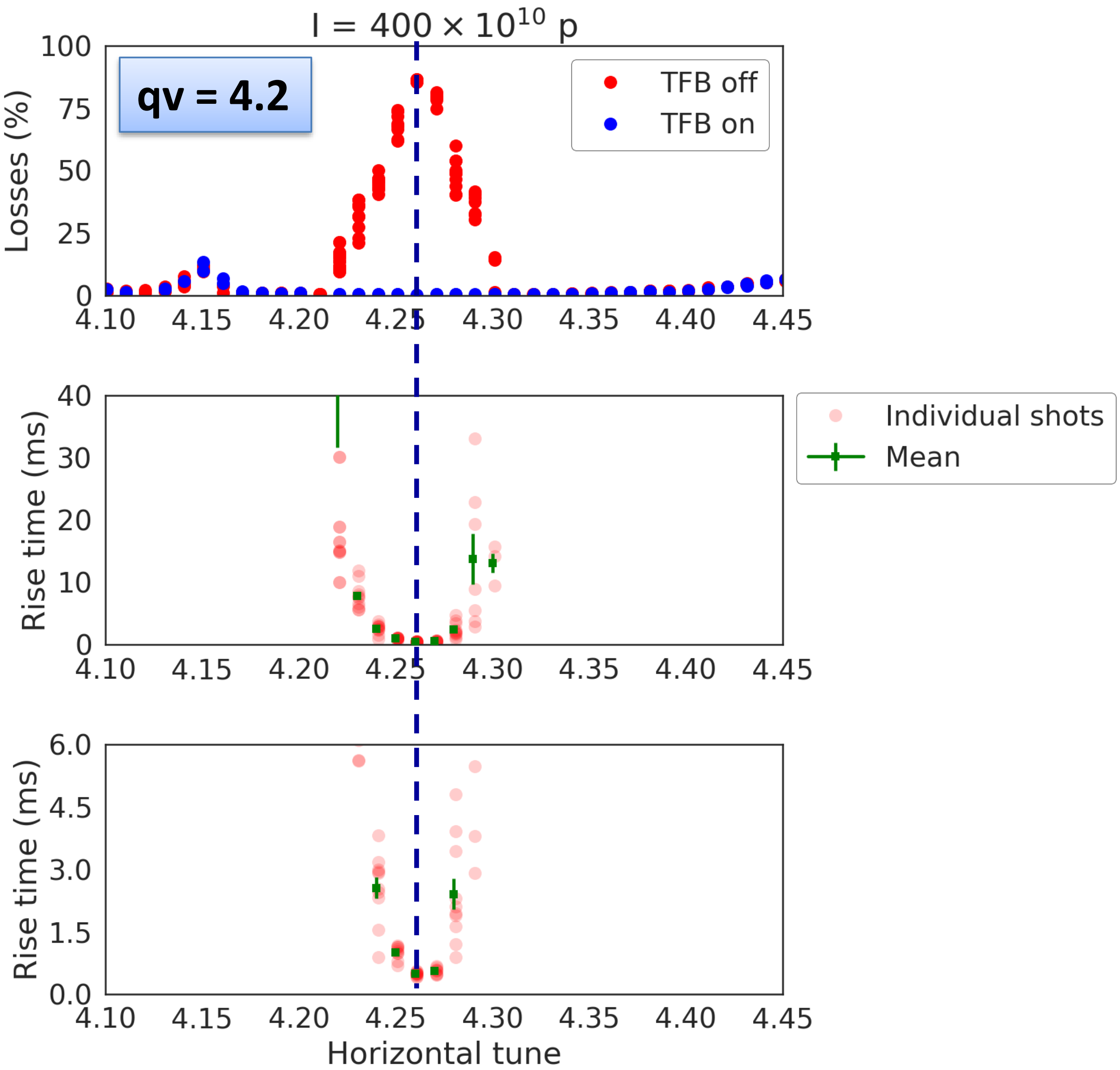
- Similar observations with natural chromaticity
- Enhanced beam losses reaching 100%
- Losses for qh between 4.23 and 4.30

I = 300 x 10^10 (ξh = - 1.6, ξv ≈ 0)



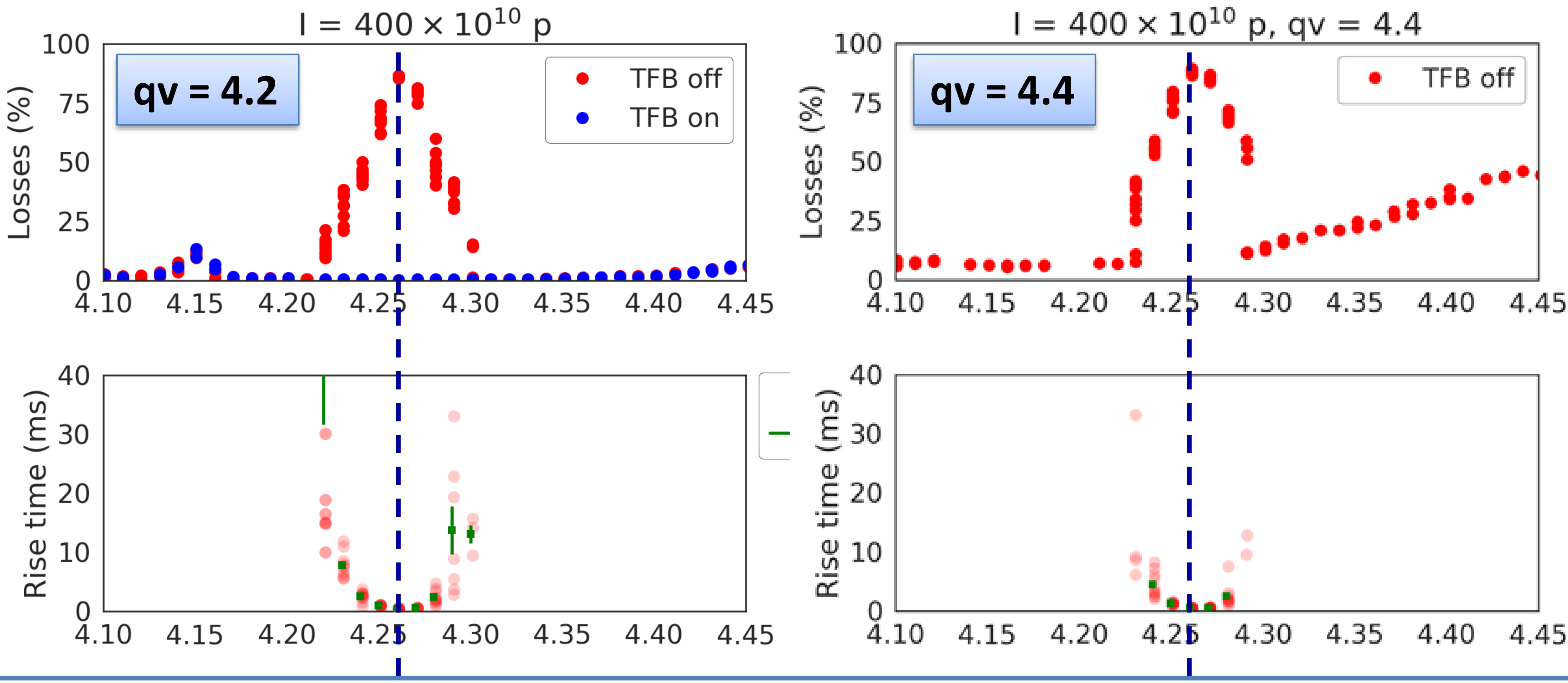
- Similar observations for higher intensity
- Losses for qh between 4.23 and 4.30
- When the TFB is on, beam is stable

I = 400 x 10^{10} (ξh = - 1.6, ξv ≈ 0)



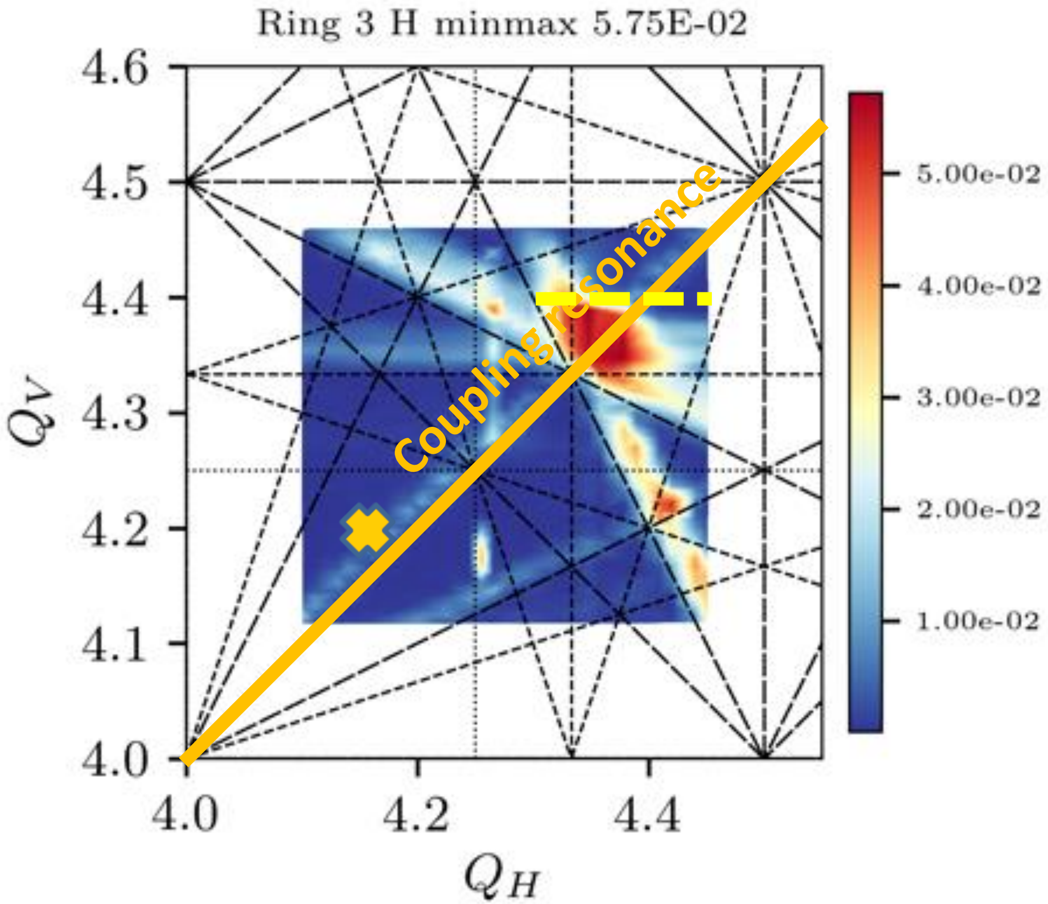
- Losses due to resonance appear around qh = 4.15
- TFB is unable to cure such losses
- Vertical tune has been unchanged so far at 4.2

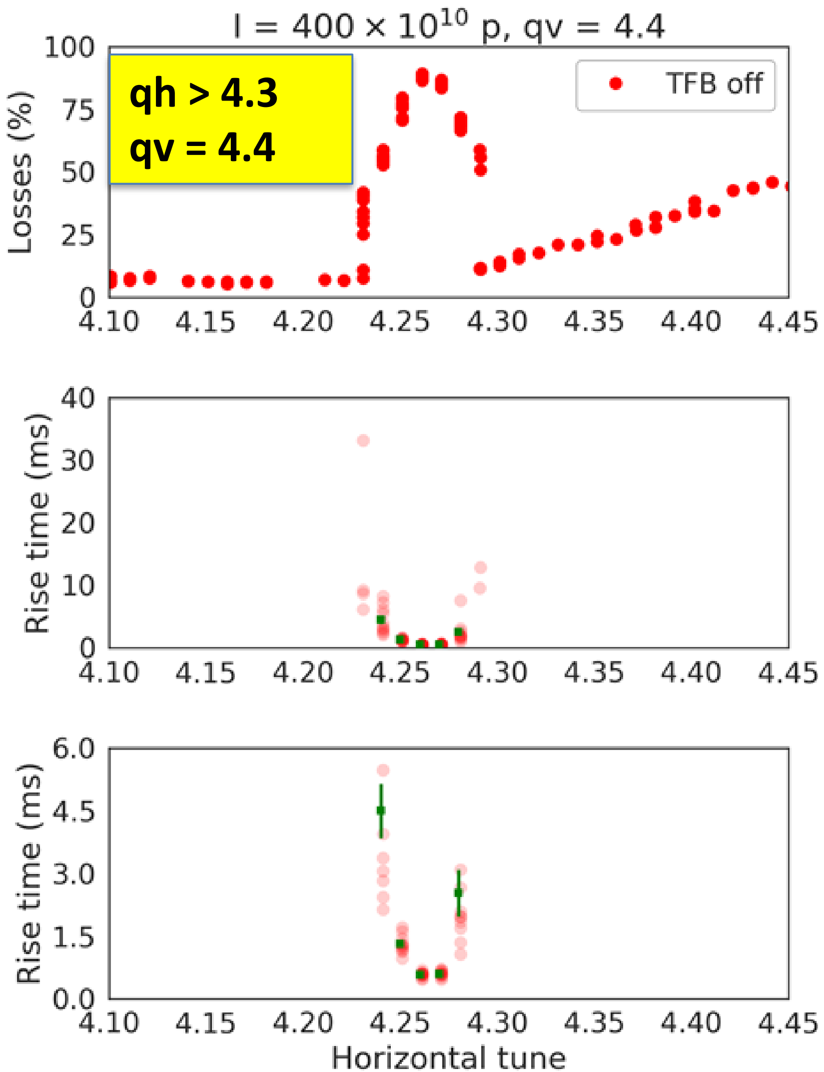
I = 400 x 10^{10}, with different vertical tune



- Change the vertical tune to qv = 4.4 instead of 4.2
- Losses from qh = 4.23 until 4.29 due to horizontal instability observed in both cases
- Shifted and reduced losses around 4.15 with qv = 4.4
- Resonance losses beyond qh = 4.3 enhanced for qv = 4.4

Loss maps in the PSB

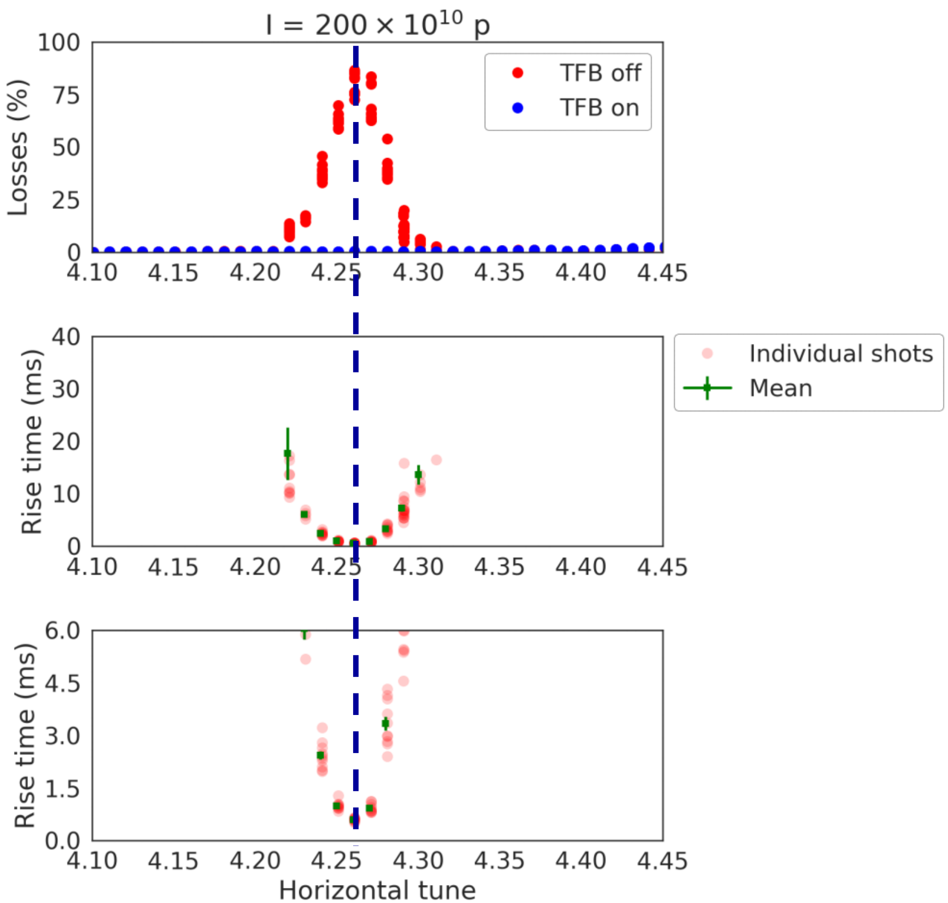




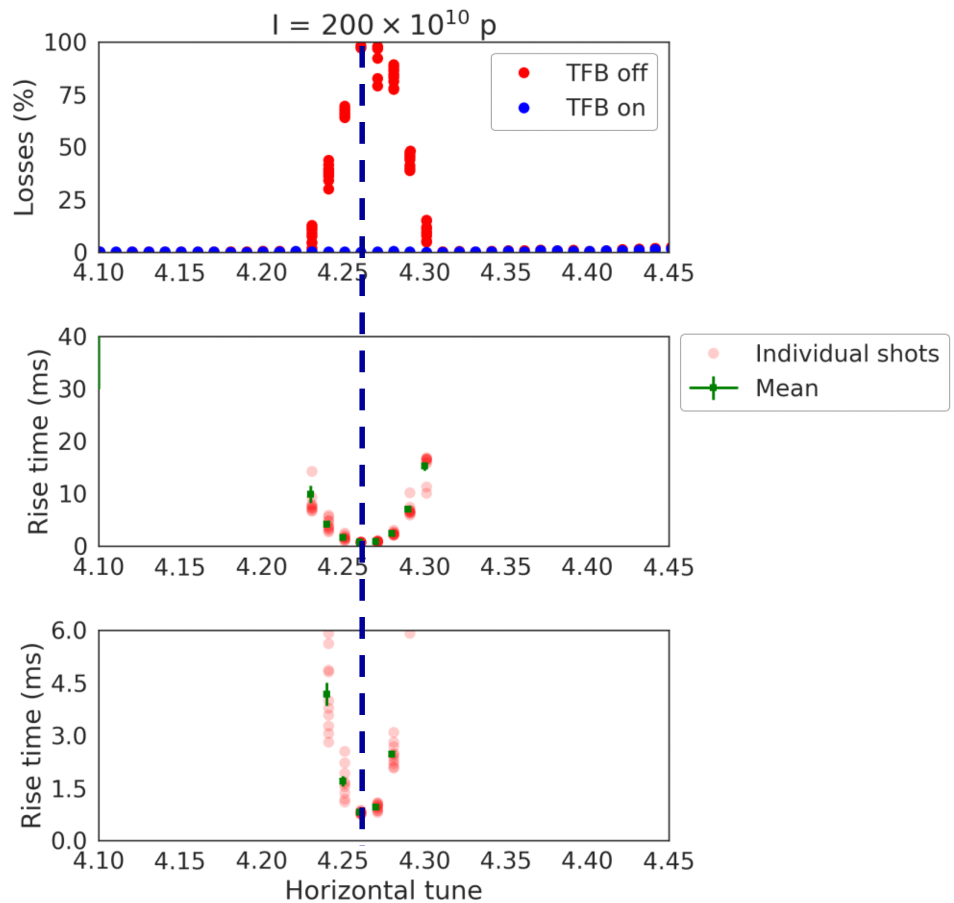
Courtesy A. Santamaria

Which working points cause significant beam loss?

$\xi h = -1.6$ / $\xi v \approx 0$

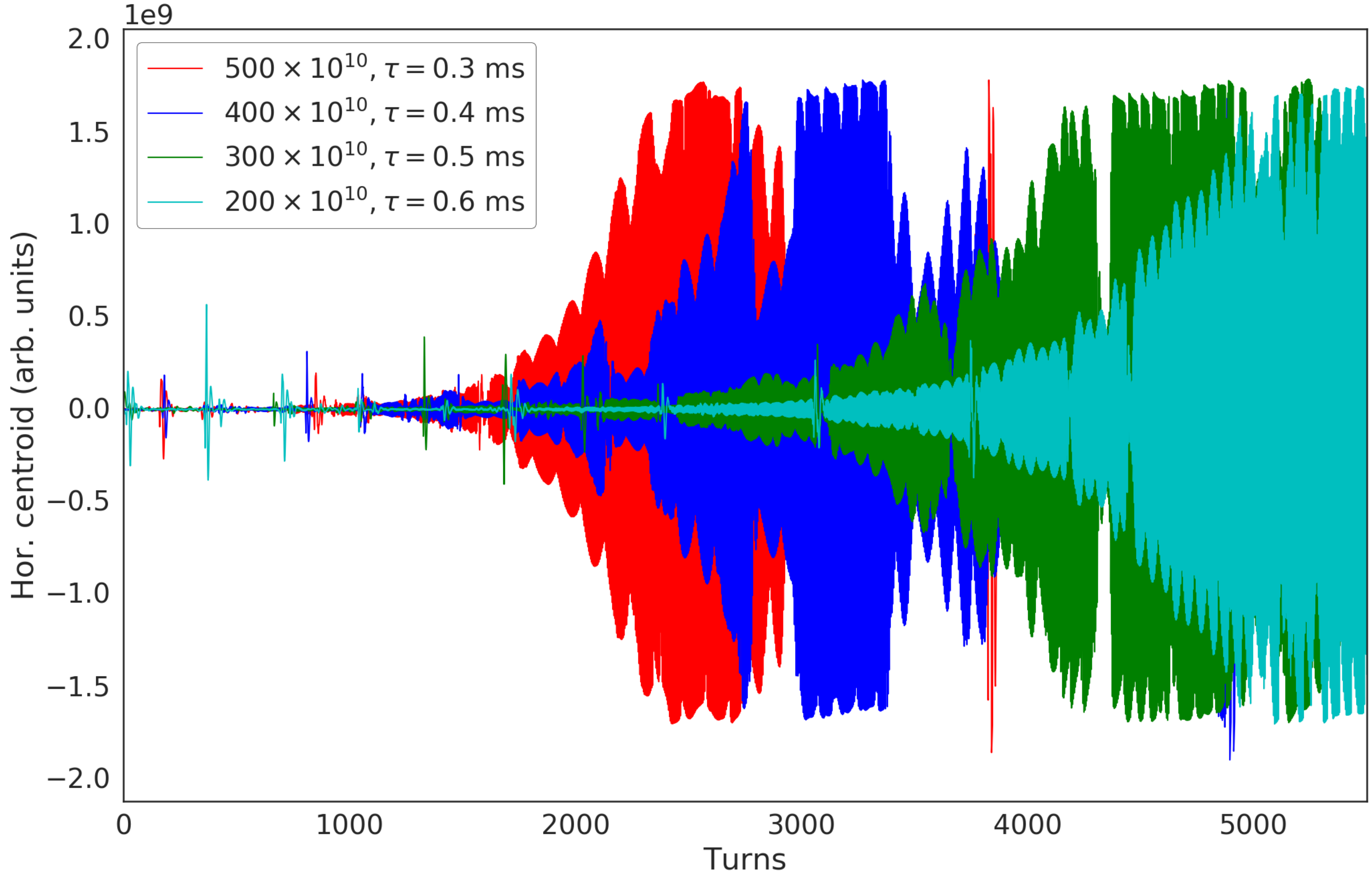


$\xi h = -0.8$ / $\xi v = -1.45$



- Losses observed for qh between **4.21** and **4.30.** Maximum losses at qh ≈ **4.26**
- Beam loss at qh = 4.26 reach 100% for close to natural chromaticity (right) but resonance losses are less severe

Compare rise times for different intensities (qh = 4.26)

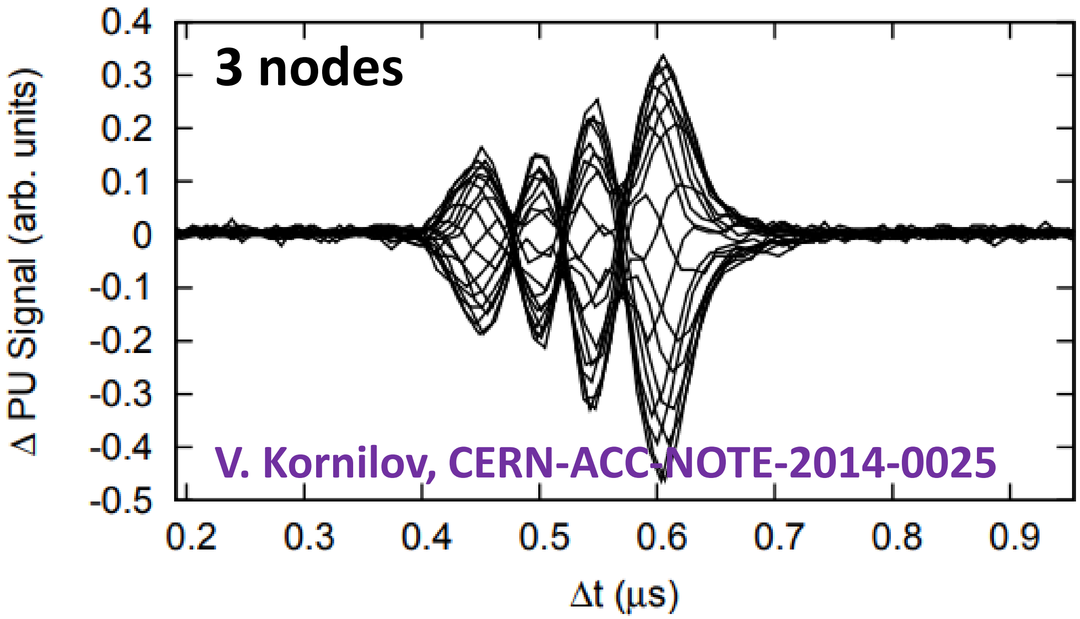


Im → growth rate

$$\Omega^{(l)} - \omega_\beta - l\omega_s \approx -\frac{1}{4\sqrt{\pi}} \frac{\Gamma(l+\frac{1}{2})}{l!} \frac{N r_0 c^2}{\gamma T_0 \omega_\beta \hat{z}} i(Z_1^\perp)_{\text{eff}}$$

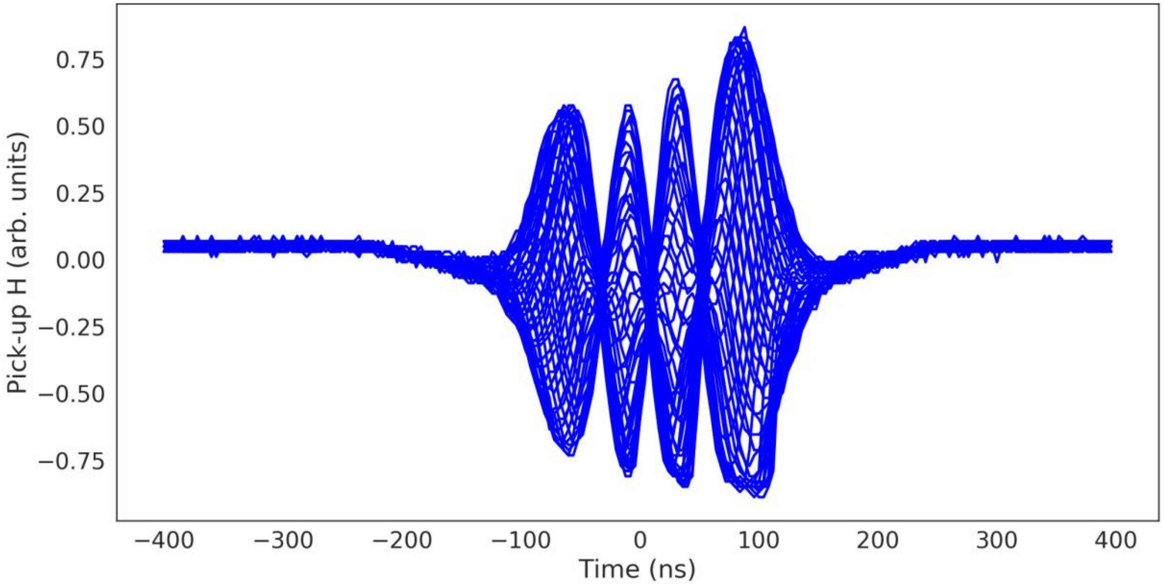
A. Chao, Physics of collective beam instabilities in high energy accelerators, p. 346

Head-tail modes from pick-up signal for I = 600 x 10^{10}



$\xi h = -1.6 / \xi v \approx 0$

qH = 4.21

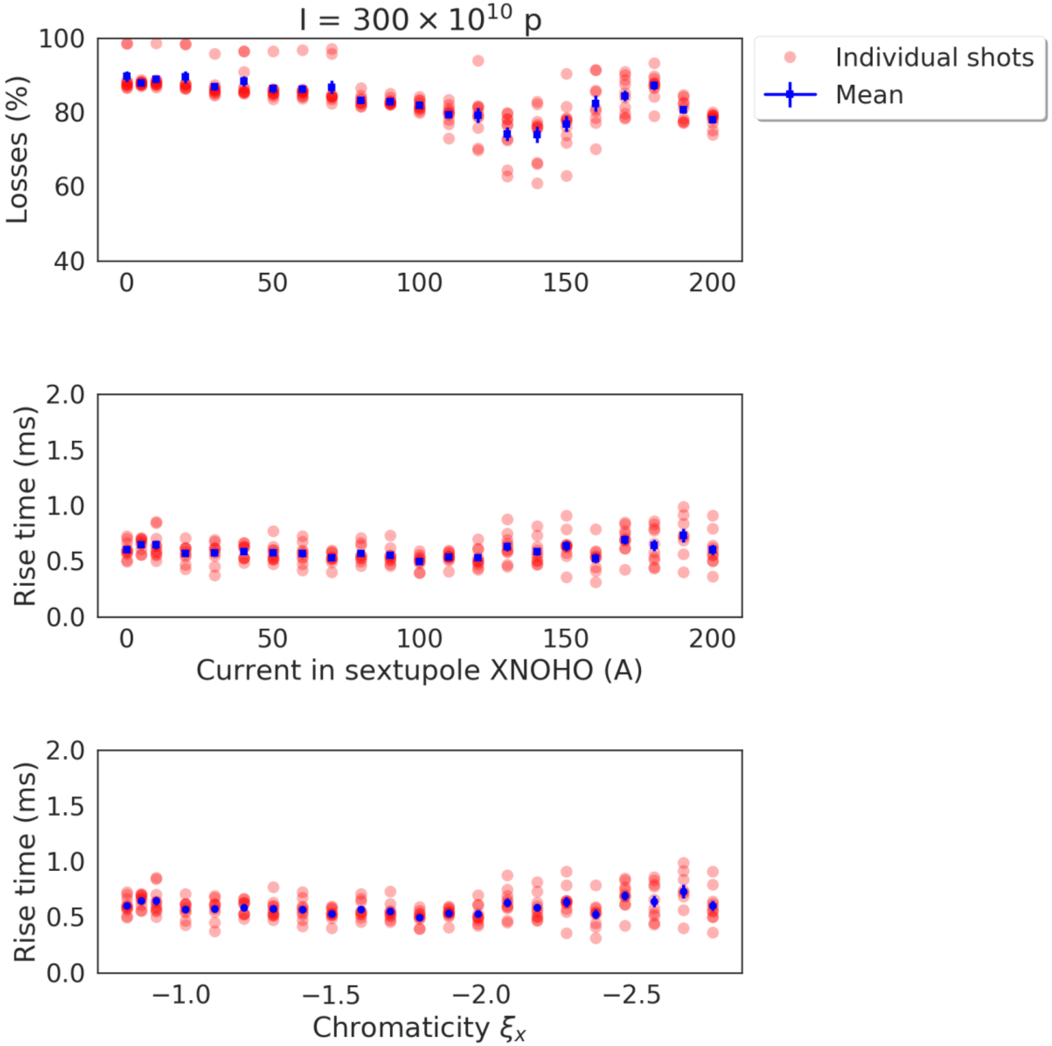


$\xi h = -0.8 / \xi v = -1.45$

qH = 4.21, 3 nodes

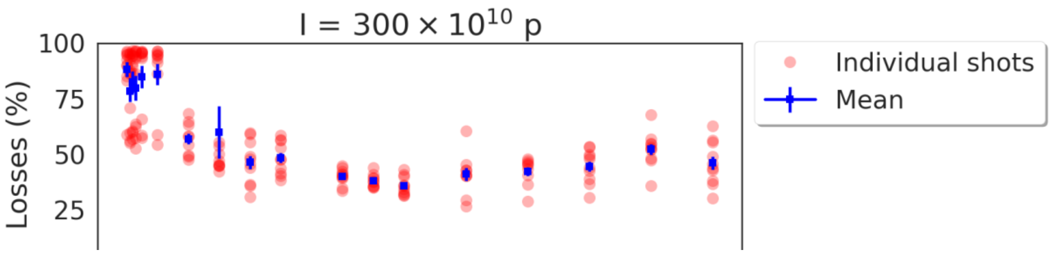
Chromaticity scan for qh = 4.26, qv = 4.2

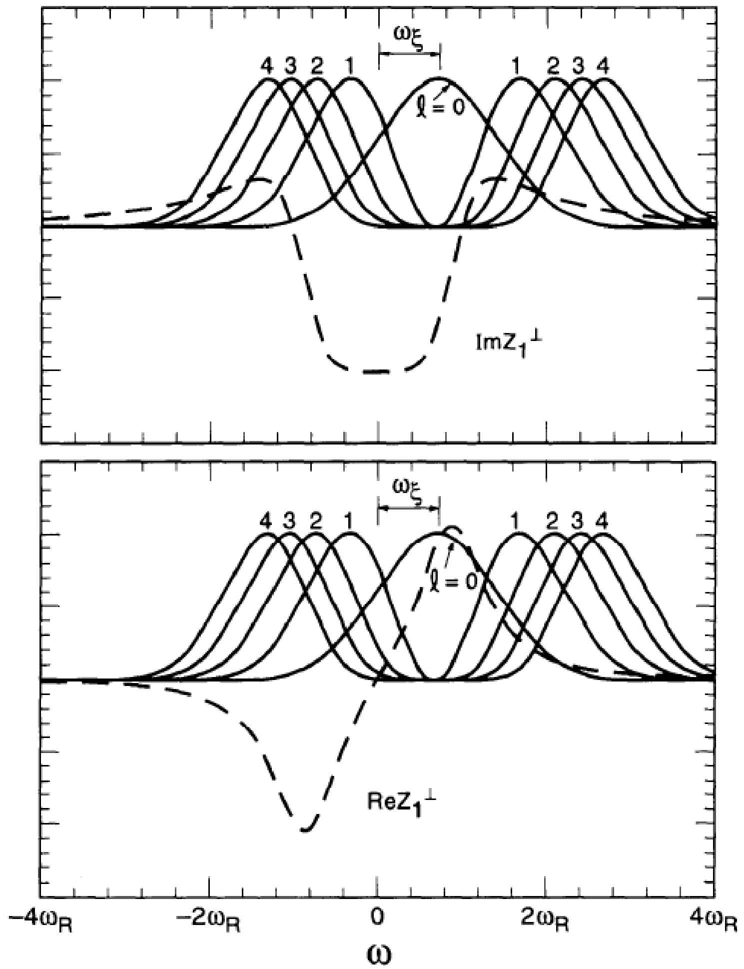
- I = 300 x 10^{10}
- Vary chromaticity by changing sextupole current from 0.1, 5, 10, 20…180, 200 A



- Losses seem to reduce a bit with ~130 A in the sextupole
- No visible trend in the rise times, instability is very fast with ~0.5 ms rise time and no impact for different chromaticity values is observed when qh = 4.26
- Need to fully rely on the transverse feedback from the very start of the cycle

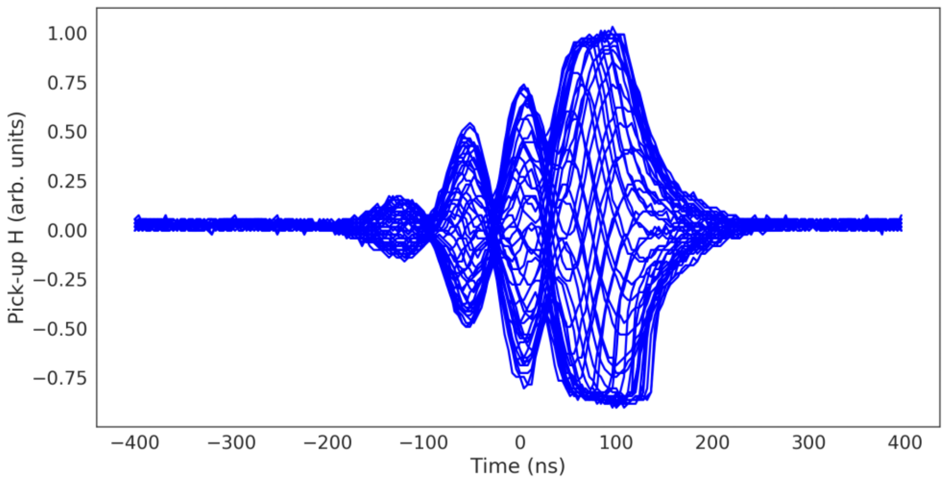
Chromaticity scan for qh = 4.28, qv = 4.2





- For **qh = 4.28**, losses reduce with sextupole current > 20A
- Increase of rise times visible with sextupole current > **125 A** ($\xi_x \approx$ -2)

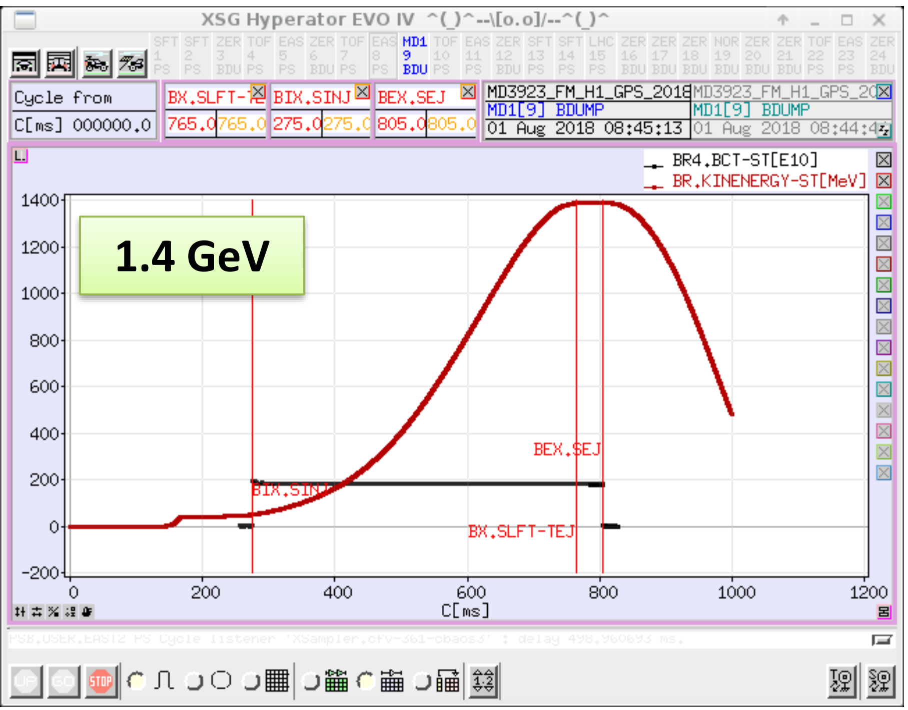
Head-tail modes as a function of chromaticity

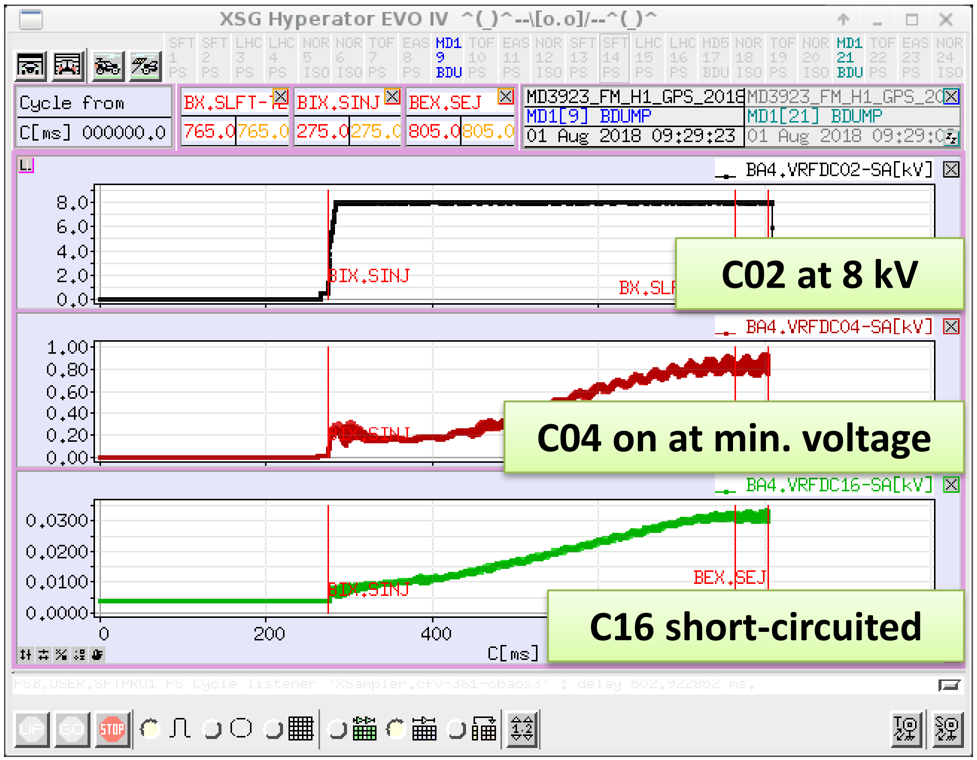


ξ_x = -0.82, 3 nodes

MD with Finemet system on 1/8/18

- Goal of the MD was to test if the normal rf cavities C02, C04, C16 are the source of the horizontal instability
- Copy of ISOLDE cycle as it is today (MD3923_FM_H1_GPS_2018)
- Tried different combinations with the cavities. Example:

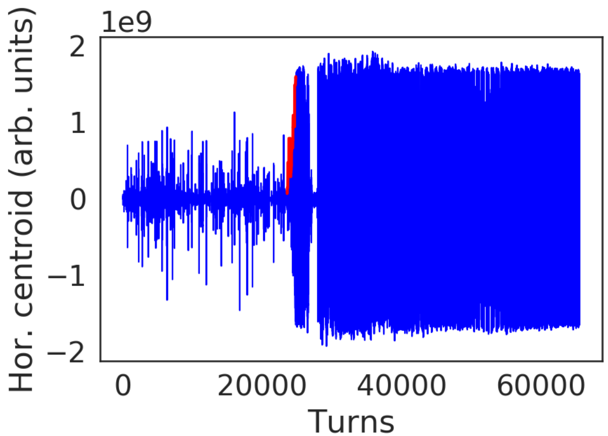


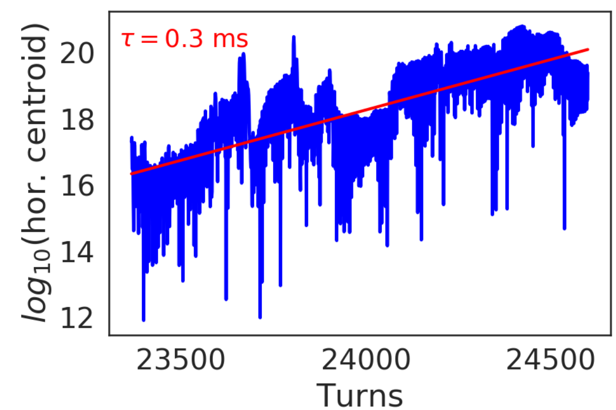


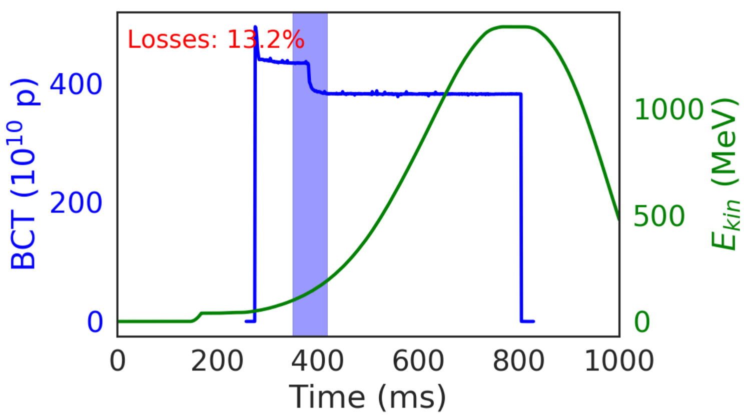
- Eventually short-circuited C02, C04 and C16 and used the Finemet system in place of C02 in R4

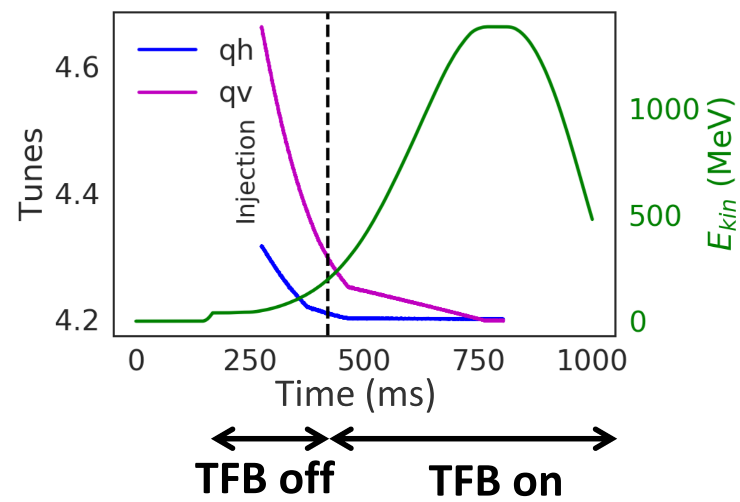
C02 on, C04 and C16 on with min. voltage

- First observe the instability. TFB off until 420 ms, then enabled to avoid losses



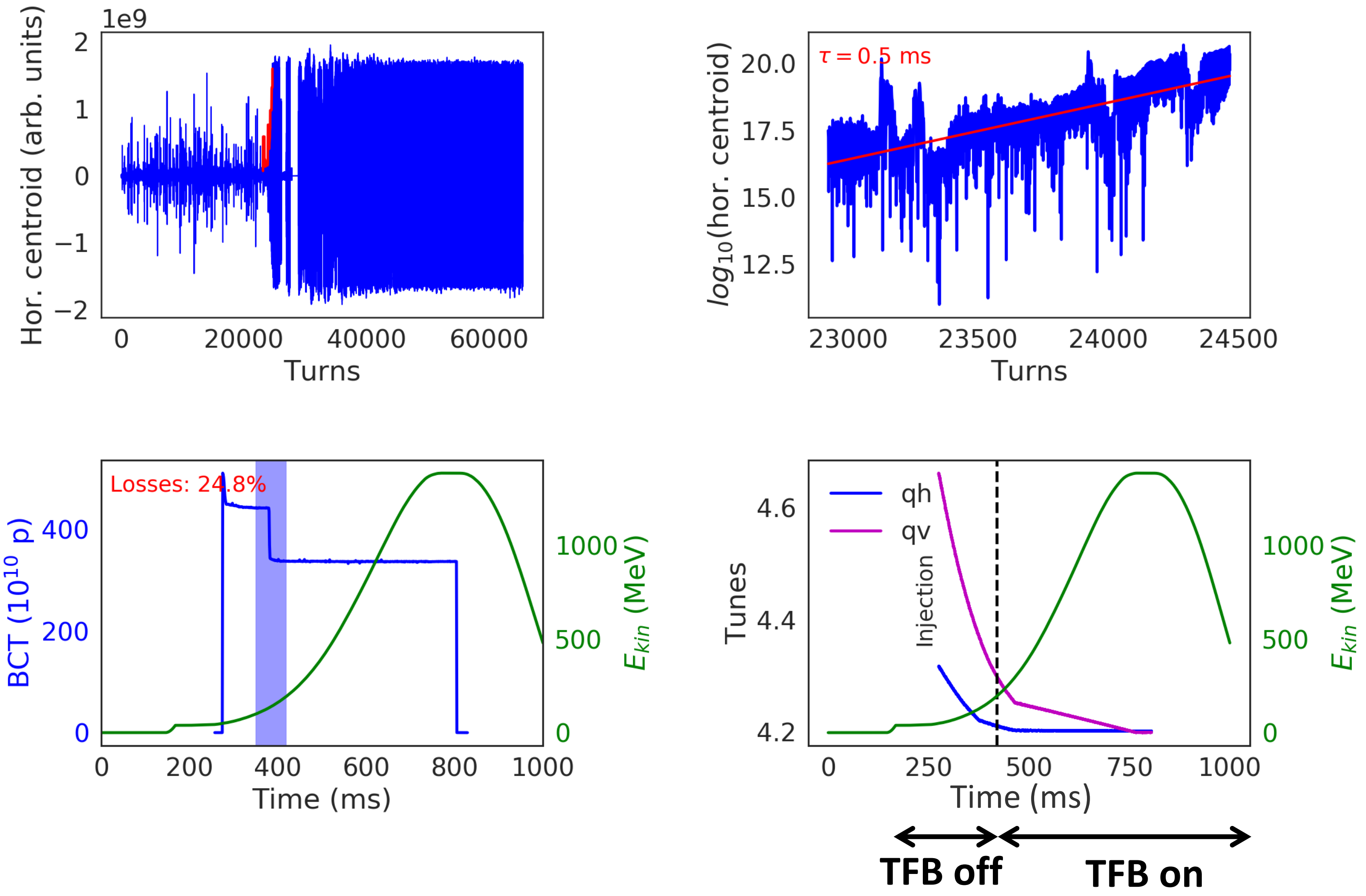






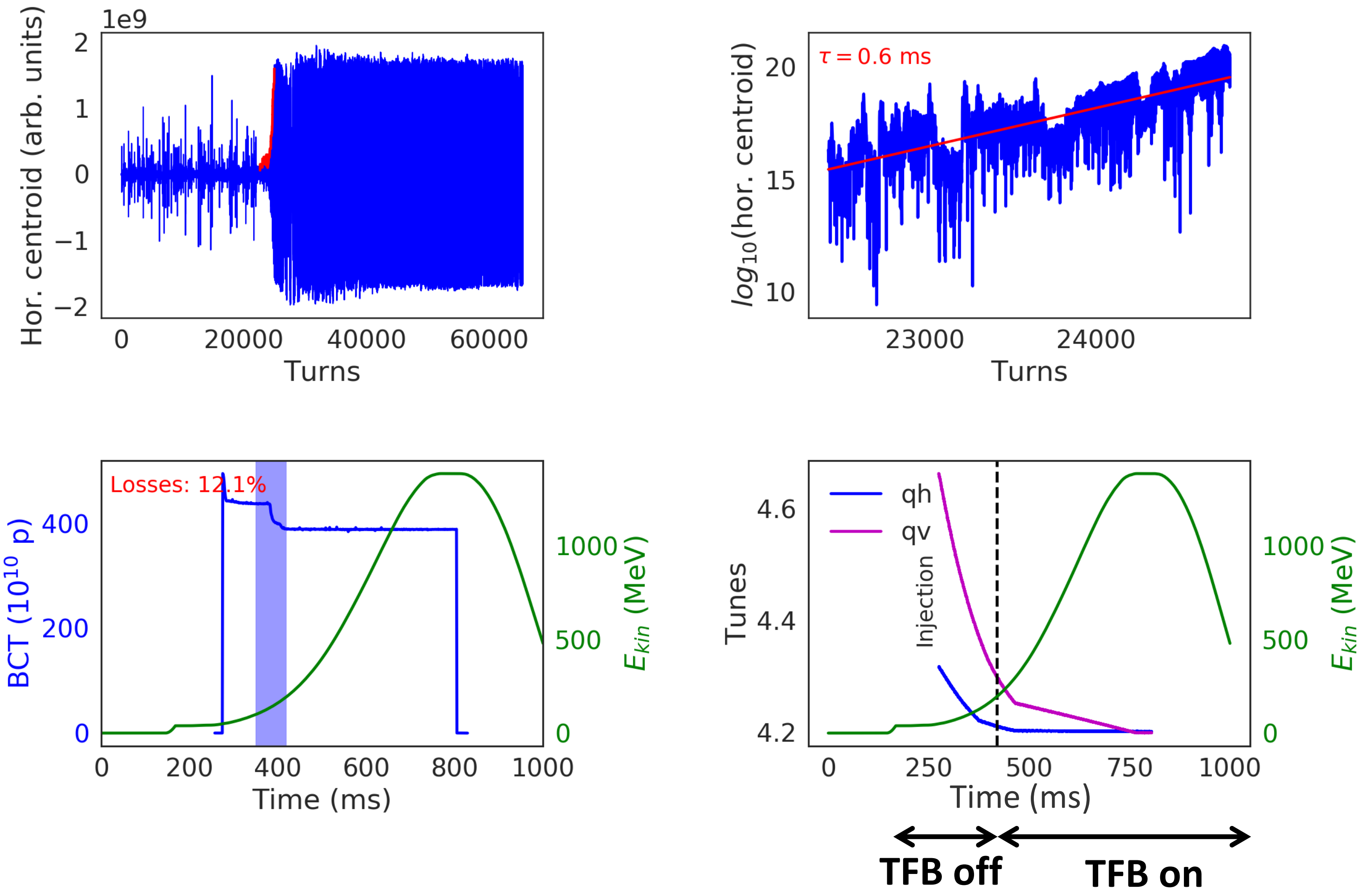
- Losses of ~13% with 0.3 ms rise time occur at 380 ms with qh = 4.22, qv = 4.36

C02 on, C04 on min. voltage, C16 and Finemet short-circuited



- Losses of ~25% with 0.5 ms rise time occur at 380 ms with qh = 4.22, qv = 4.36

C02 on, C04, C16 and Finemet short-circuited

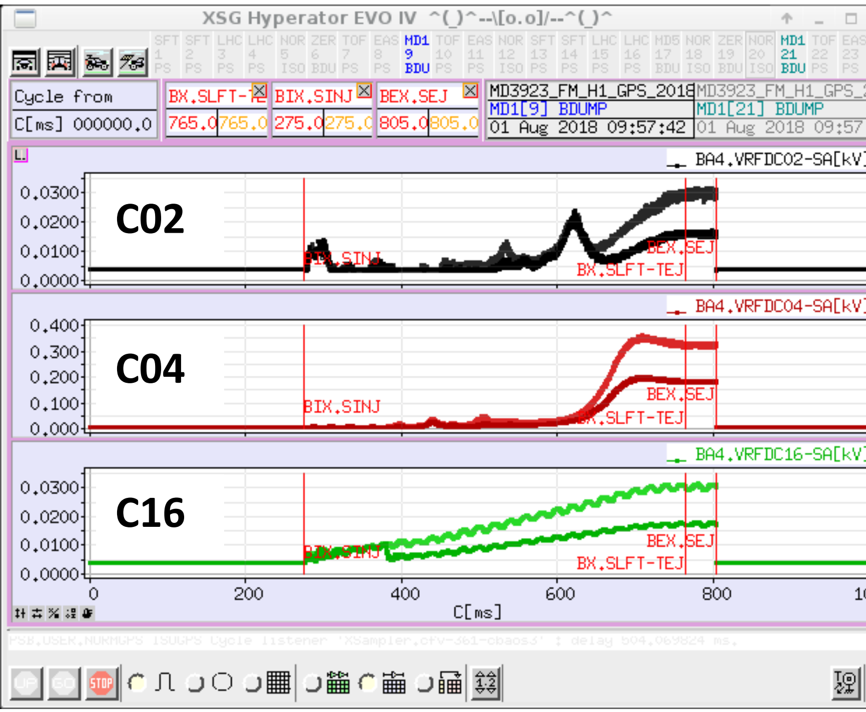


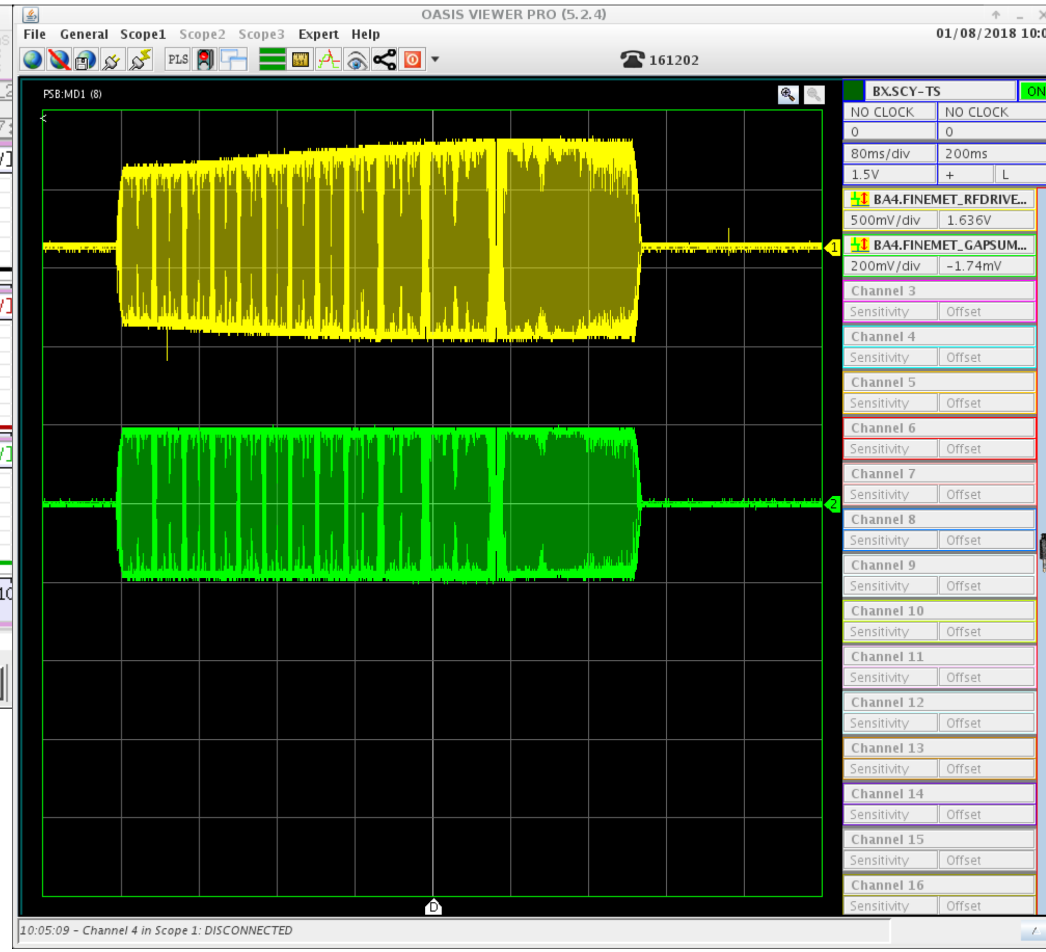
- Losses of ~12% with 0.6 ms rise time occur at 380 ms with qh = 4.22, qv = 4.36

Finemet on as C02, C02, C04 and C16 short-circuited

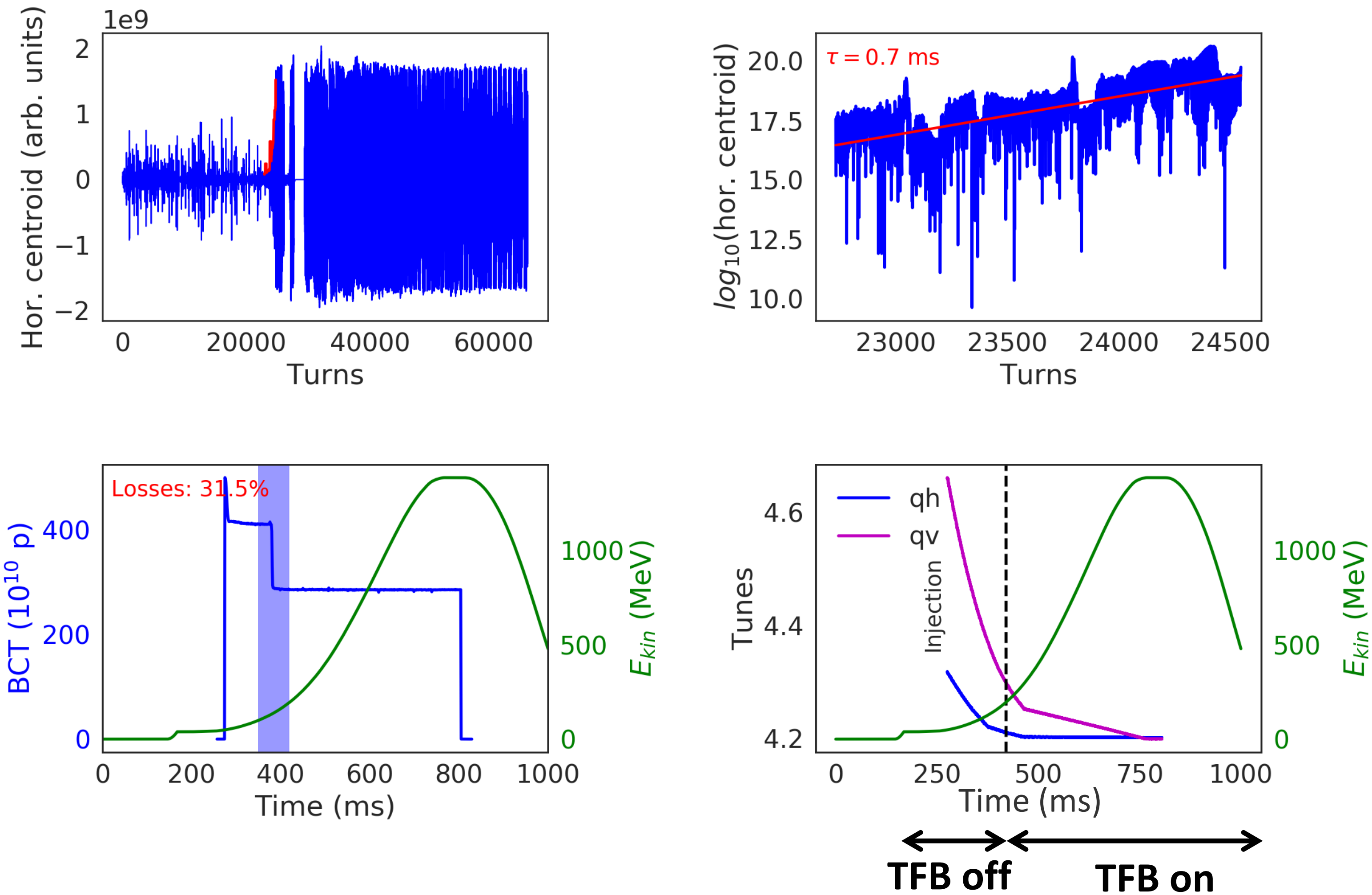
C02, C04, C16 short-circuited

Finemet on





Finemet on as C02, C02, C04 and C16 short-circuited



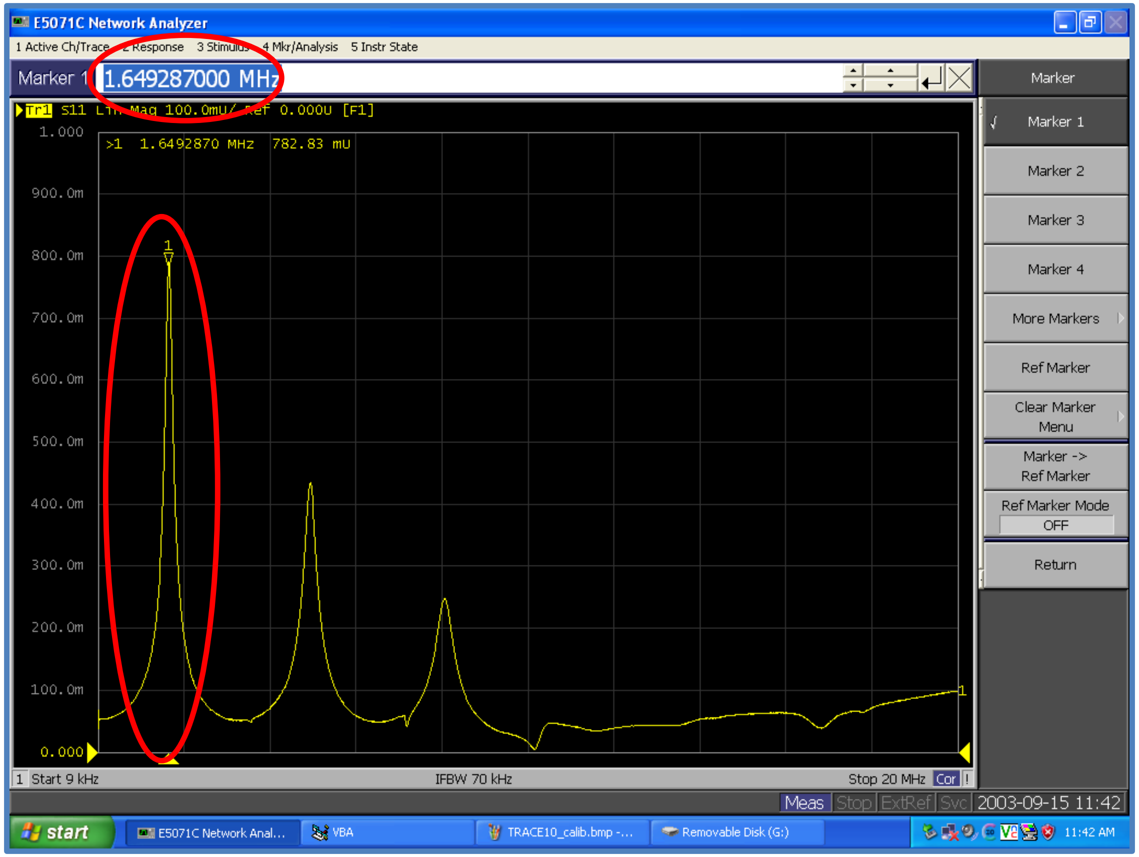
- Losses of ~31% with 0.7 ms rise time occur at ~380 ms with qh = 4.22, qv = 4.36
- Instability was present in all combinations
- **Conclusion: the normal rf cavities are not the source of the instability**

Other possible sources?

A **narrow-band resonator impedance**? *G. Rumolo,* MSWG 27/08/10

✓ A line at this frequency had been singled out on a spectrum analyzer during previous instability measurements at the PSB (M. Chanel, C. Carli)

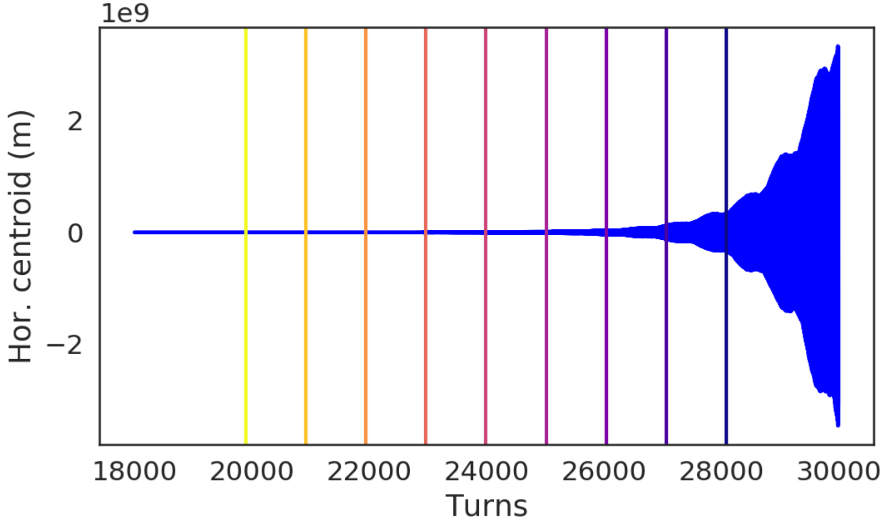
✓ This value is also likely to be associated to the lowest resonance due to the unmatched terminations on the PSB ejection kickers

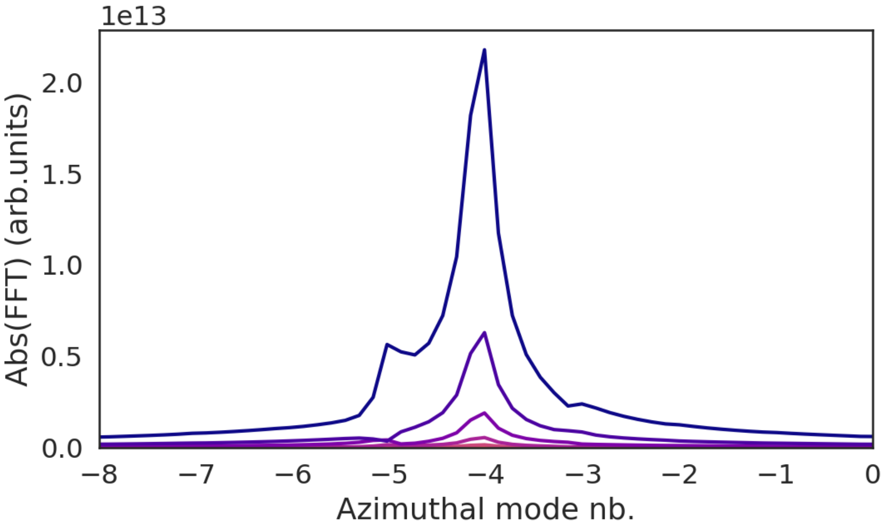


The beam coupling impedance due to unmatched terminations of the extraction kicker has been a long-lived suspect for the horizontal instability...

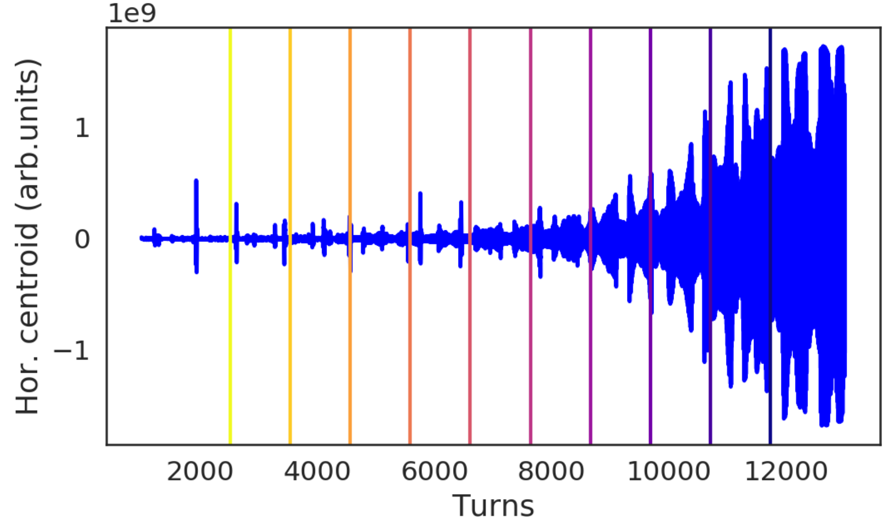
Considering a narrow-band resonator peaked at ≈1.7 MHz

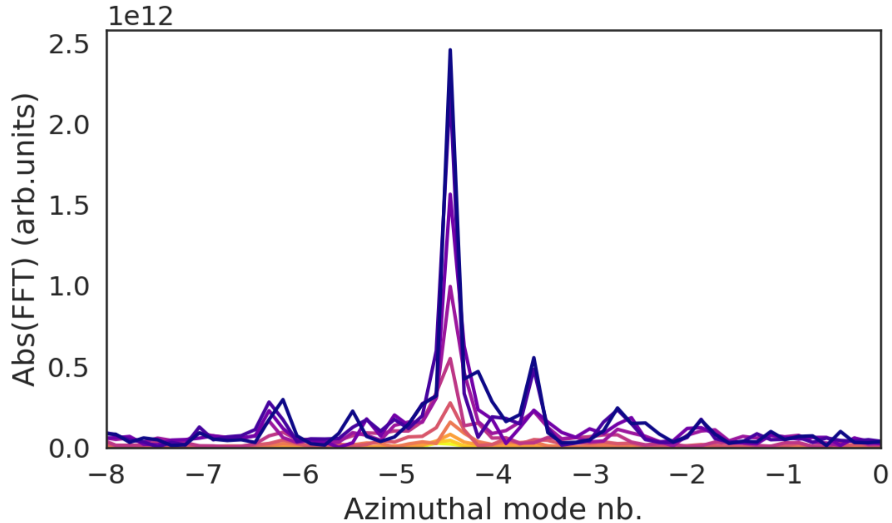
PyHEADTAIL simulation





Measurements





Summary

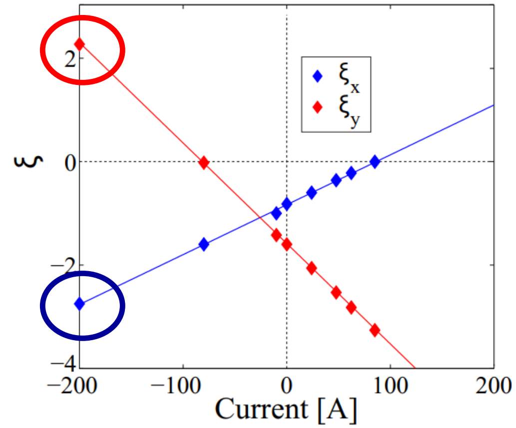
- Experimental data have been collected and analyzed for different intensities, chromaticity and tune values at 160 MeV
- A range of horizontal tunes between 4.21 and 4.30 causing detrimental beam loss has been identified when the TFB is off
- Chromaticity increase, which is a common cure for head-tail instability, will not be useful for qh = 4.26, given the sextupole's range
- Need to fully rely on the TFB from the very start of the cycle → what about the saturation of the Beam Orbit Signal Suppressor (BOSS) unit?
- Expected linear dependency of the rise time with intensity was found
- The head-tail modes with chromaticity have been measured
  - Close to natural chromaticity a head-tail mode m = 3 is observed
  - As chromaticity increases, the head-tail mode increases to m = 13
  - Higher-order modes showed slower rise times
- The normal rf cavities C02, C04 and C16 have now been excluded as possible source of the instability
- Other potential impedance candidate is the peaked impedance at ≈1.7 MHz from unmatched terminations on the extraction kicker cables

Future steps

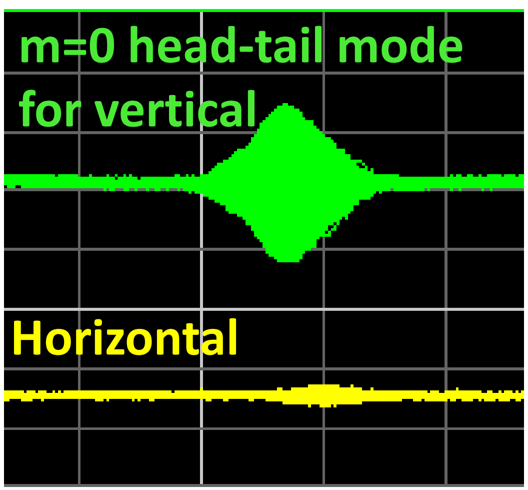
- Macroparticle tracking simulations with PyHEADTAIL and semi-analytical codes
  - Try to identify the source of the instability using the full PSB impedance model
  - Can we reproduce measured characteristics of the instability when the full PSB impedance model is used?
  - Can we reproduce the measured tune shift with intensity?
- MDs
  - Change the termination of the extraction kicker at the end of the run (12^{th} November?) and check if we observe a change on the instability
  - Other measurements before LS2?

Vertical instability for Isext = 200 A and I = 300 x 10^{10}

- For **Isext = 200 A**, which is at the limit of the available sextupoles' current, ξ_x is the **most negative** possible, while ξ_y is **positive**
- Horizontal feedback was active with 6 dB attenuation to suppress the horizontal instability while the vertical feedback was set to 15 dB (very weak, almost inactive)
- Observe a vertical instability developing



V. Forte CERN-THESIS-2016-063



OASIS signal for intra-bunch motion