Lasing with Long Bunch Trains

17–22 October 2007 (~15 shifts)

Milestone

- Lasing with 800 bunches, >10 µJ/pulse

Macropulse Views

- Charge, compression, orbit, ...
- Spectra of oscillations

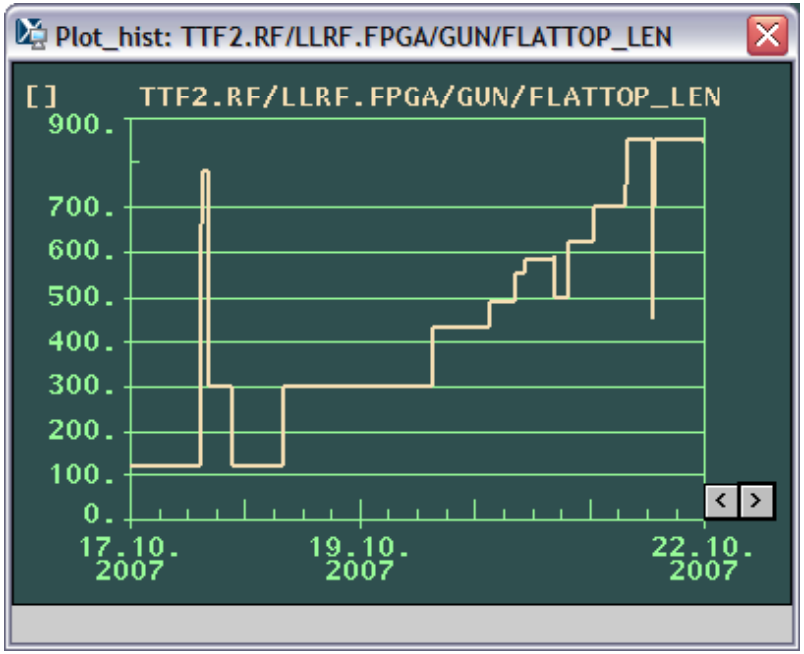
Problems & Improvements

- Gun water regulation
- Beam loading compensation & adaptive feedforward
- ACC1 phase feedback

Milestone

The Way to the Milestone

- Startup: Lasing with few bunches, 10–20 µJ, 690 MeV
- Increased RF pulse lengths to ~850 µs
  - ACC2-6: no problem
  - ACC1: unstable at 122 MeV energy gain, gradient reduced by 5–10 %
  - **Gun:** sparks with long pulses, re-conditioning needed
- Optics: design op2-v4 matched in UBC2, but energy after ACC1 changing frequently



The Way to the Milestone

- LLRF problems solved:
  - No feedback on the gun because P_{fwd} setpoint above soft limit
  - No adaptive feedforward on ACC2–6 because state machines not working

- Limited by beam losses in undulator 1
  - Much manual tuning required

The Milestone

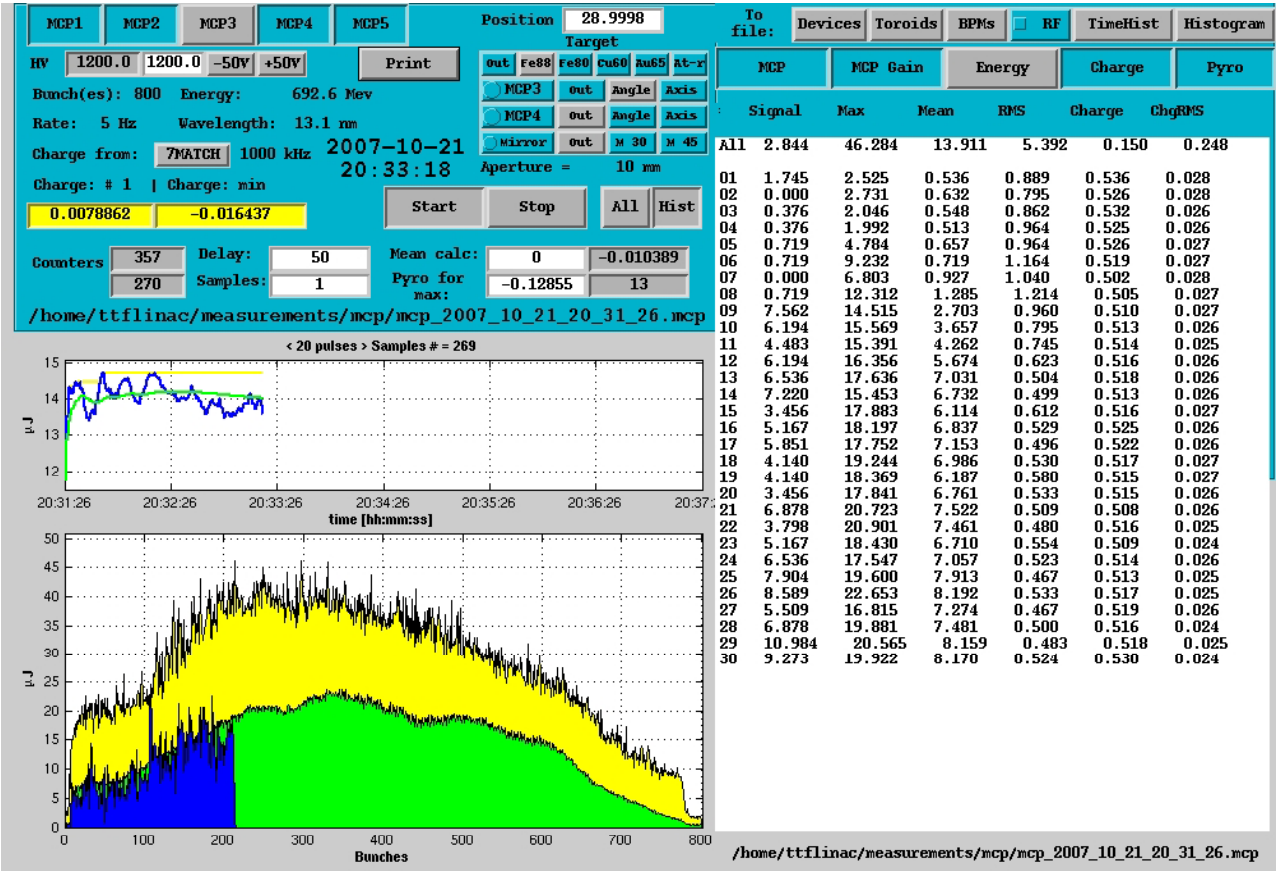
- Milestone: Lasing with 800 bunches, >10 µJ/pulse **achieved**

...without destroying the machine

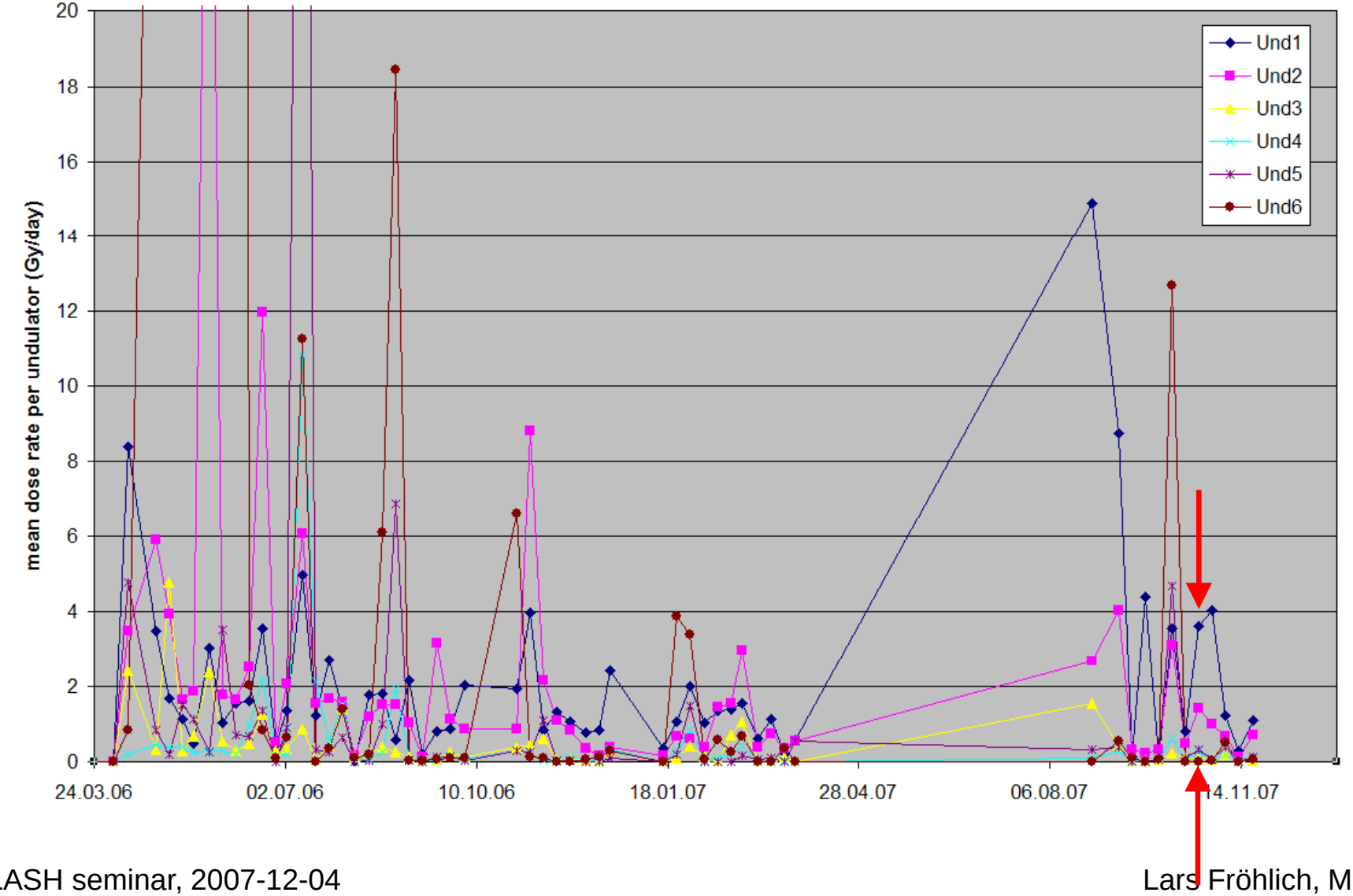
800 bunches at 685 MeV

electron beam: 2.7 kW

photon beam: 56 mW

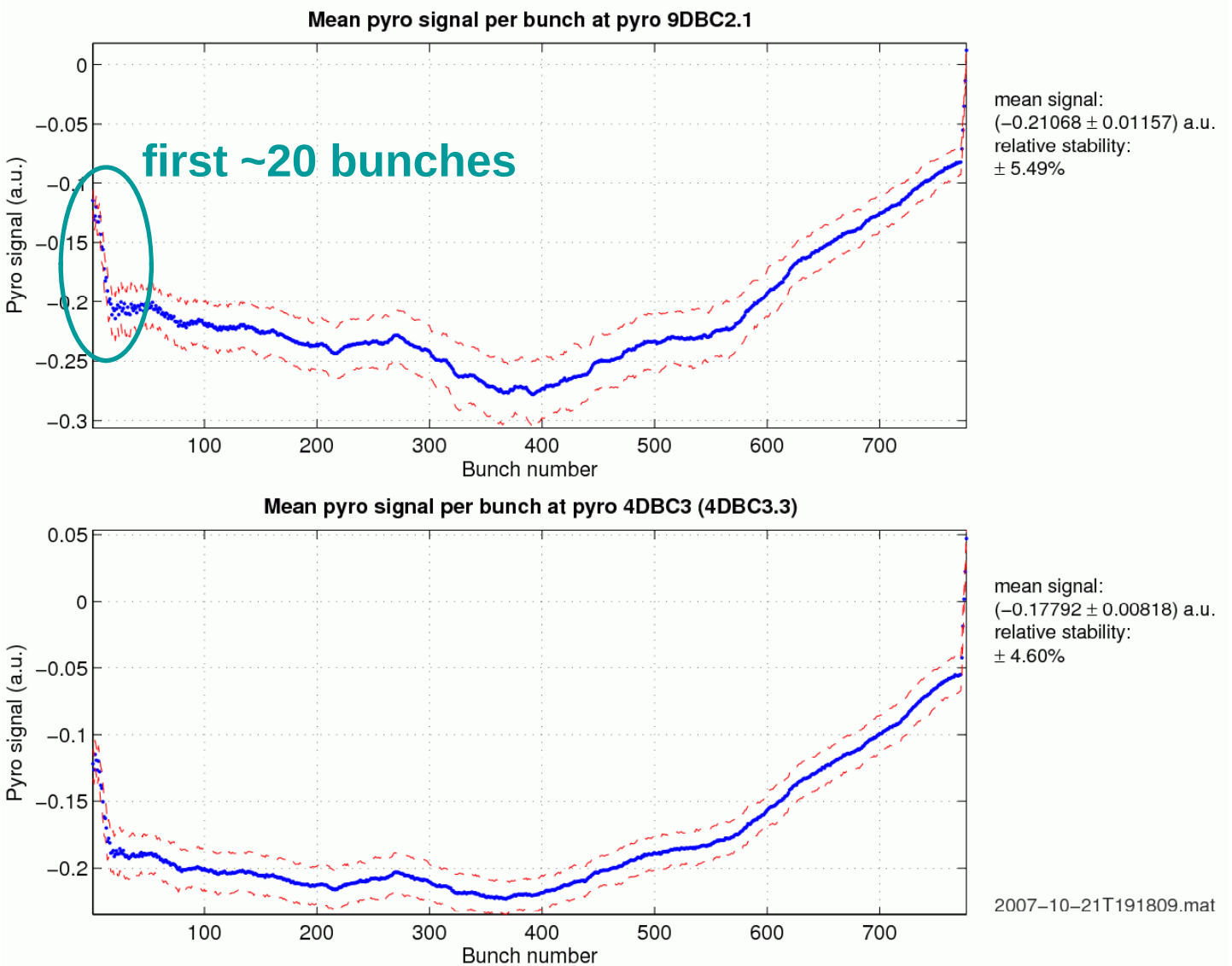


Undulator Dose Rates

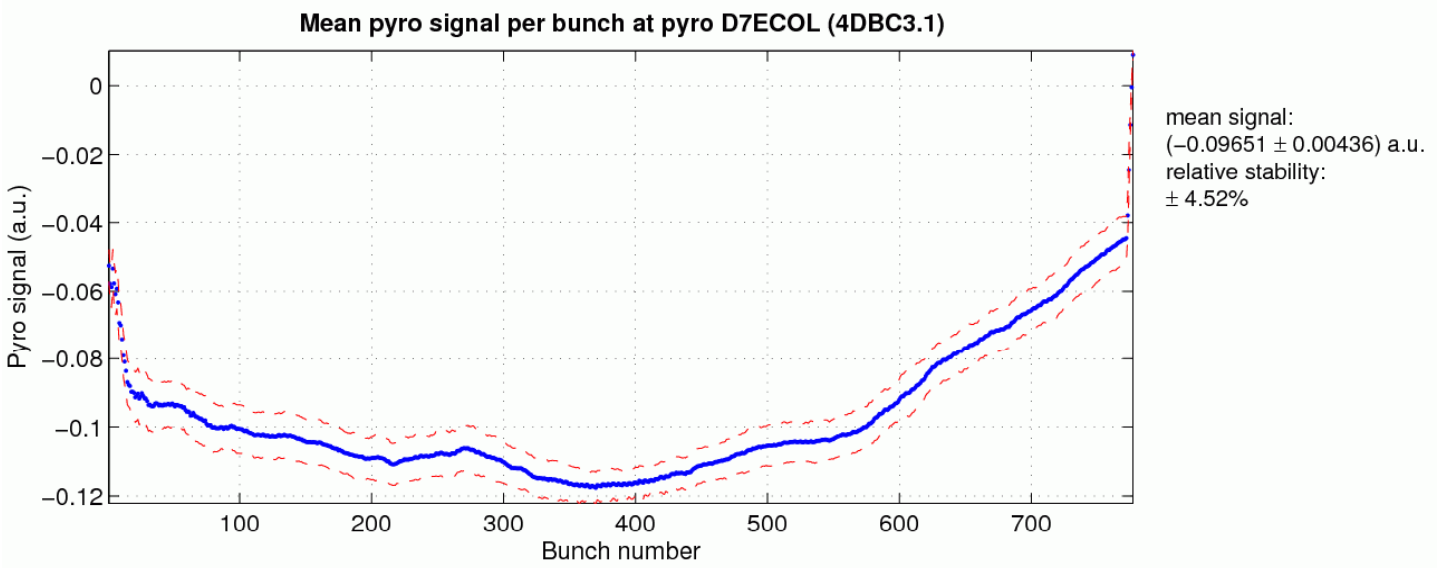


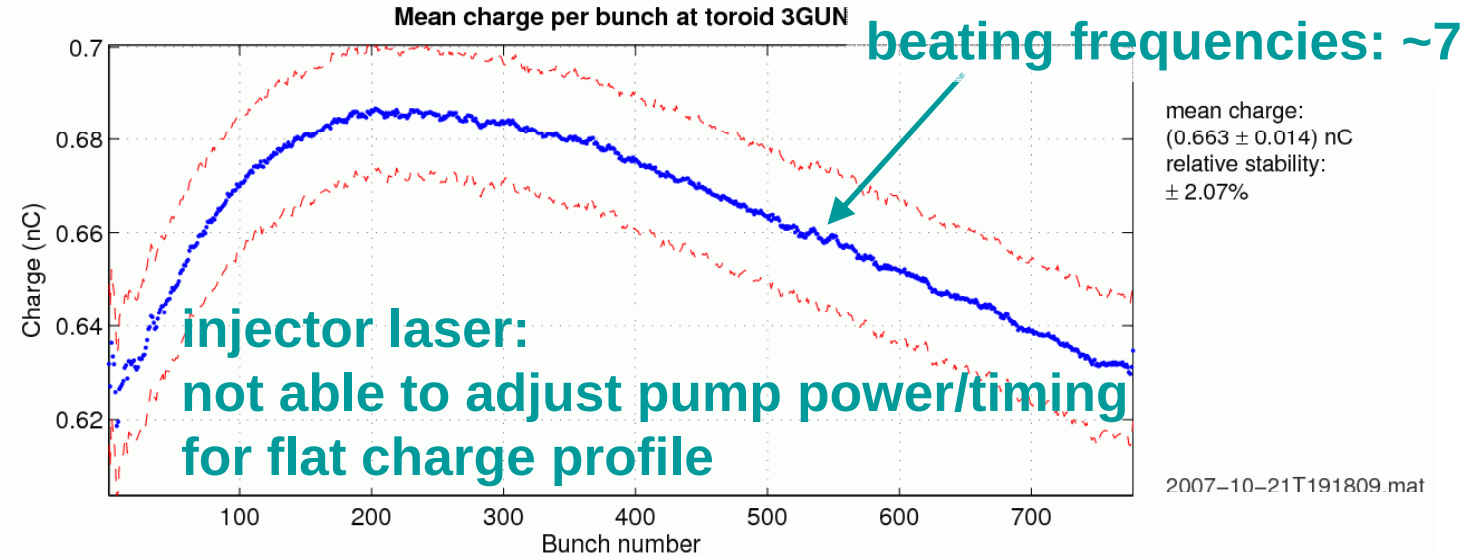
Macropulse Views

Pyros DBC2/DBC3



Pyro ECOL / Charge 3GUN

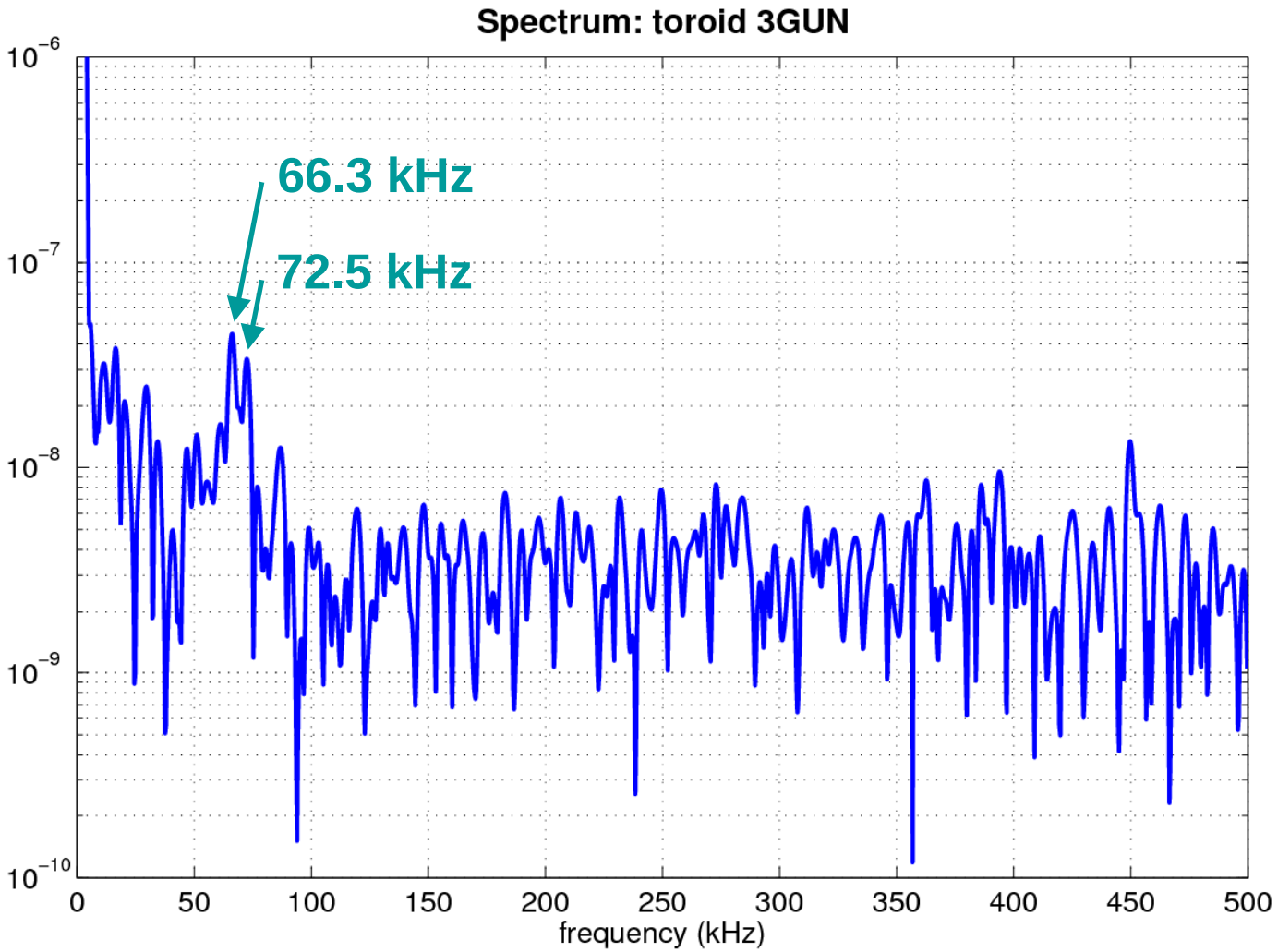




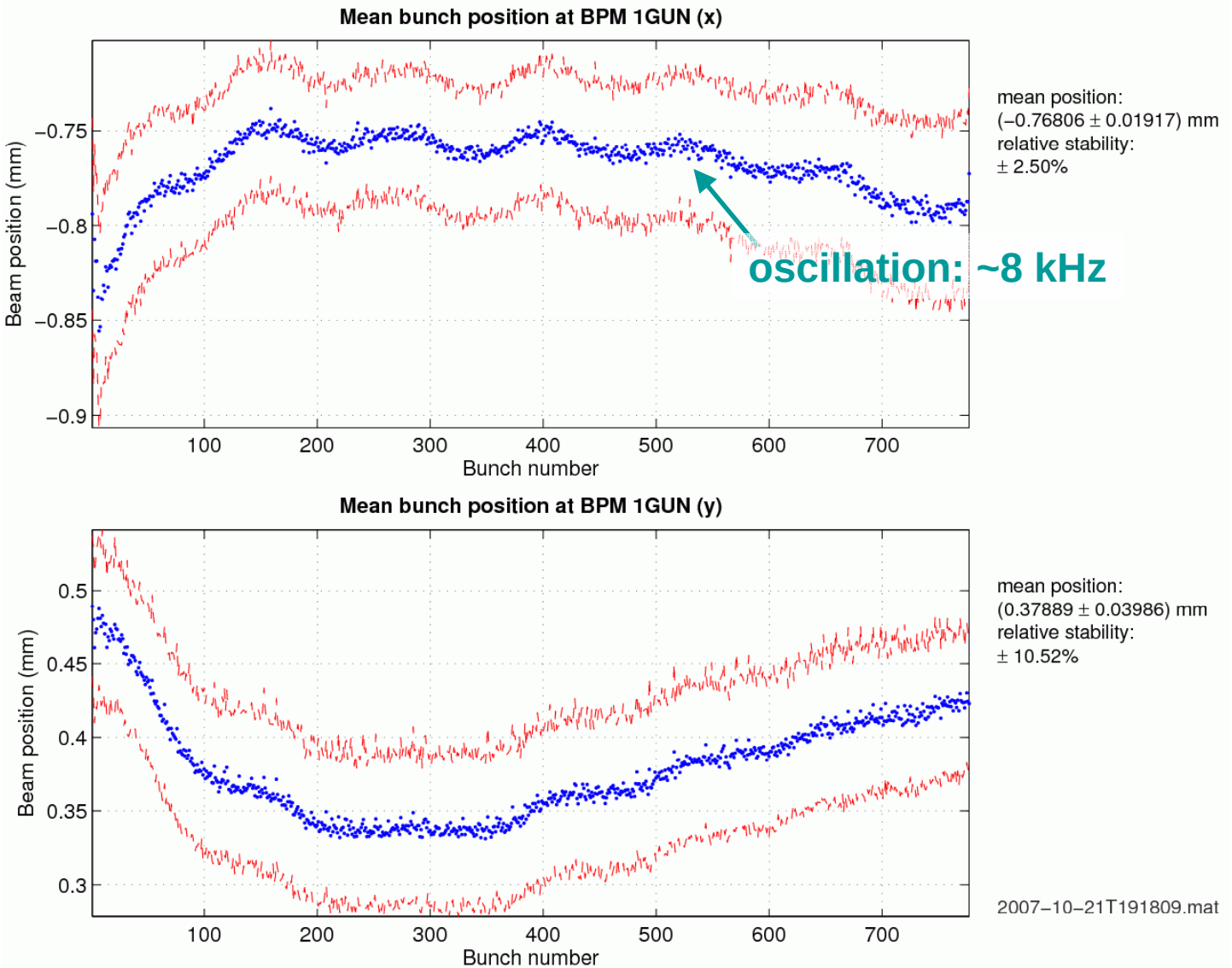
beating frequencies: ~70 kHz

injector laser:
not able to adjust pump power/timing
for flat charge profile

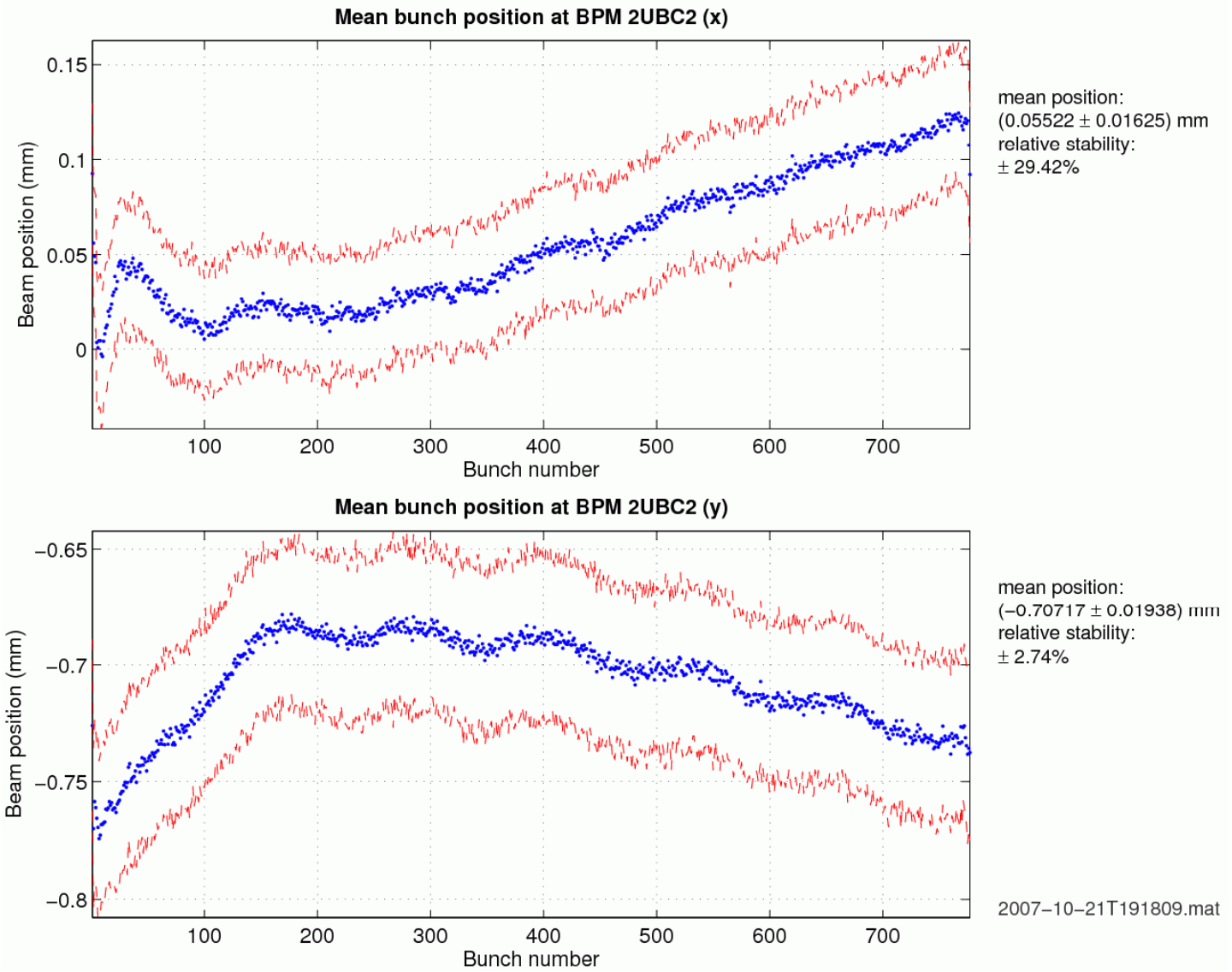
Charge Oscillations



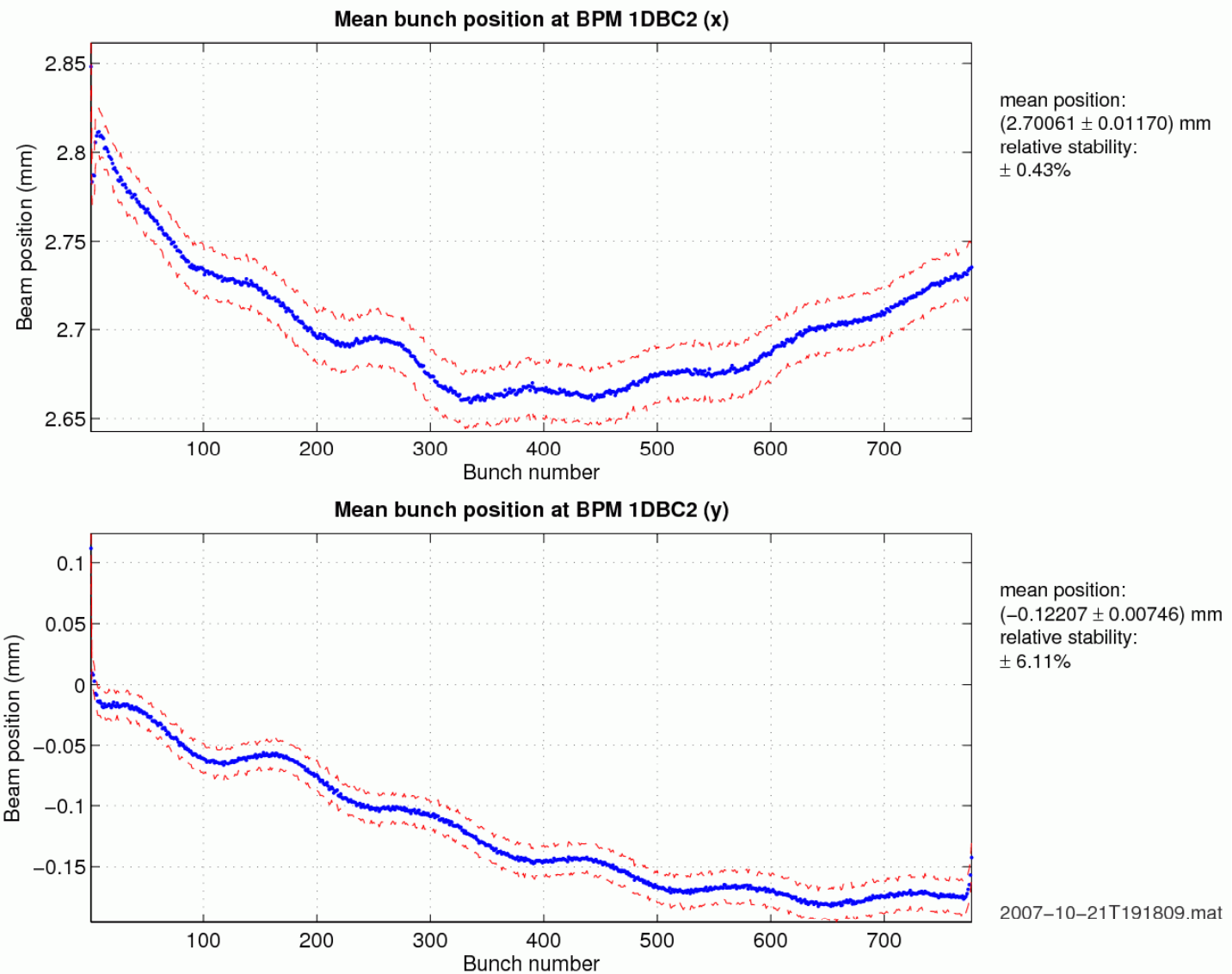
BPM 1GUN


Mean bunch position at BPM 1GUN (x)
Beam position (mm)
−0.75
−0.8
−0.85
−0.9
100
200
300
400
500
600
700
Bunch number
mean position:
(−0.76806 ± 0.01917) mm
relative stability:
± 2.50%
oscillation: ~8 kHz
Mean bunch position at BPM 1GUN (y)
Beam position (mm)
0.5
0.45
0.4
0.35
0.3
100
200
300
400
500
600
700
Bunch number
mean position:
(0.37889 ± 0.03986) mm
relative stability:
± 10.52%
2007−10−21T191809.mat

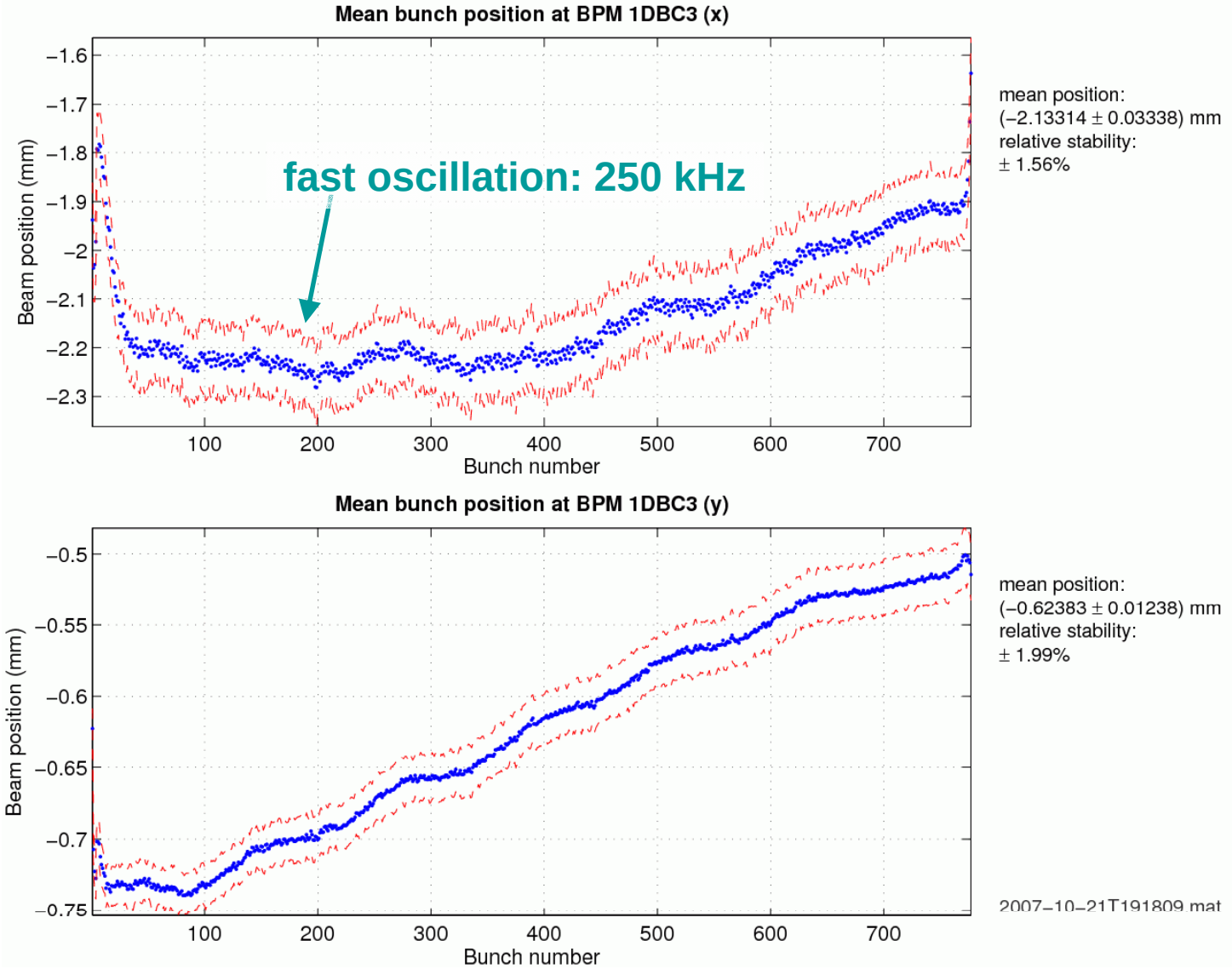
BPM 2UBC2


Mean bunch position at BPM 2UBC2 (x)
Beam position (mm)
Bunch number
mean position:
(0.05522 ± 0.01625) mm
relative stability:
± 29.42%
Mean bunch position at BPM 2UBC2 (y)
Beam position (mm)
Bunch number
mean position:
(−0.70717 ± 0.01938) mm
relative stability:
± 2.74%
2007−10−21T191809.mat

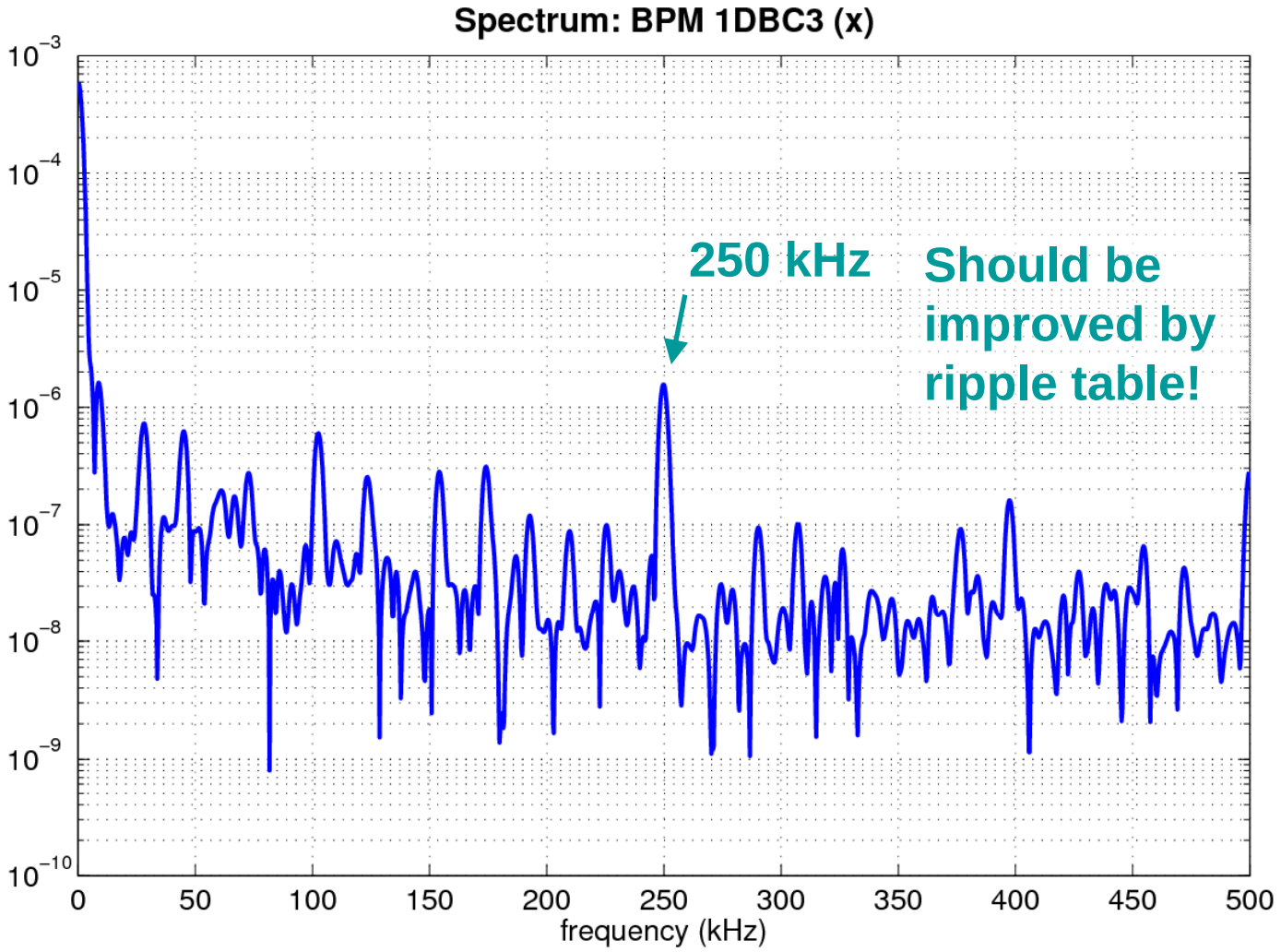
BPM 1DBC2


Mean bunch position at BPM 1DBC2 (x)
Beam position (mm)
Bunch number
mean position:
(2.70061 ± 0.01170) mm
relative stability:
± 0.43%
Mean bunch position at BPM 1DBC2 (y)
Beam position (mm)
Bunch number
mean position:
(–0.12207 ± 0.00746) mm
relative stability:
± 6.11%
2007–10–21T191809.mat

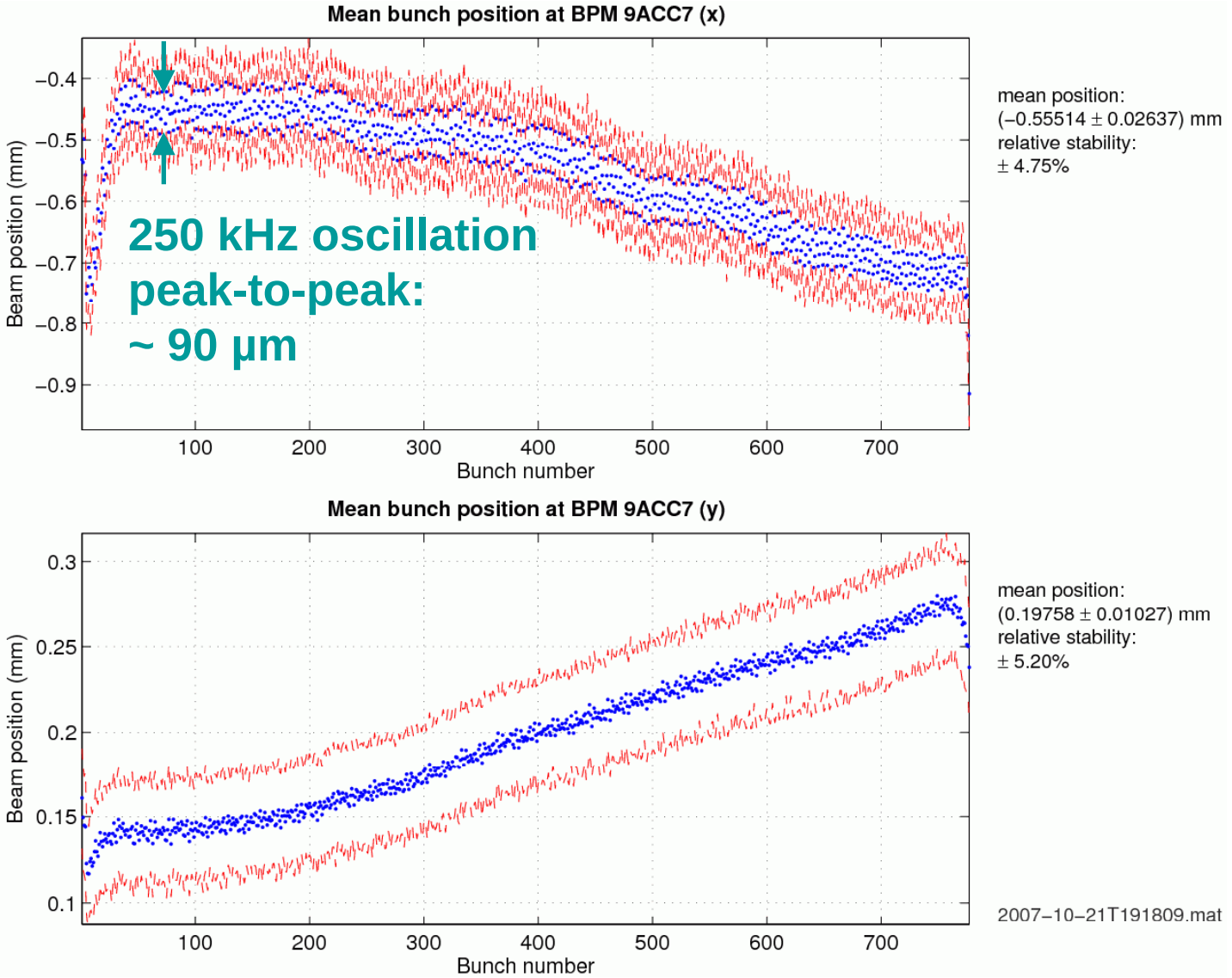
BPM 1DBC3


Mean bunch position at BPM 1DBC3 (x)
fast oscillation: 250 kHz
Beam position (mm)
Bunch number
mean position:
(−2.13314 ± 0.03338) mm
relative stability:
± 1.56%
Mean bunch position at BPM 1DBC3 (y)
Beam position (mm)
Bunch number
mean position:
(−0.62383 ± 0.01238) mm
relative stability:
± 1.99%
2007−10−21T191809.mat

Orbit Oscillations

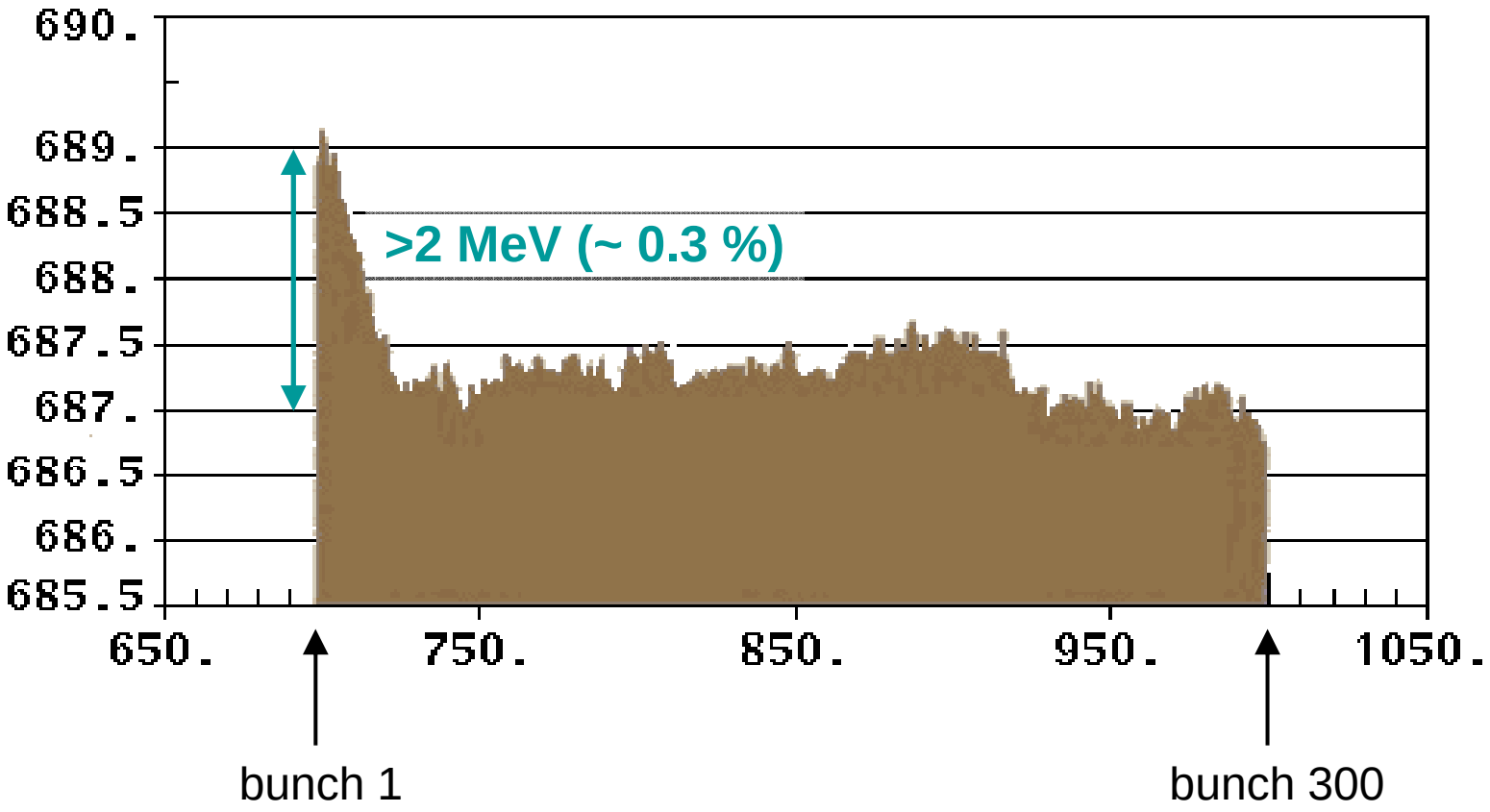


BPM 9ACC7


Mean bunch position at BPM 9ACC7 (x)
Beam position (mm)
Bunch number
250 kHz oscillation
peak-to-peak:
~ 90 µm
mean position:
(−0.55514 ± 0.02637) mm
relative stability:
± 4.75%
Mean bunch position at BPM 9ACC7 (y)
Beam position (mm)
Bunch number
mean position:
(0.19758 ± 0.01027) mm
relative stability:
± 5.20%
2007−10−21T191809.mat

Energy

bunch energy
(MeV/particle)

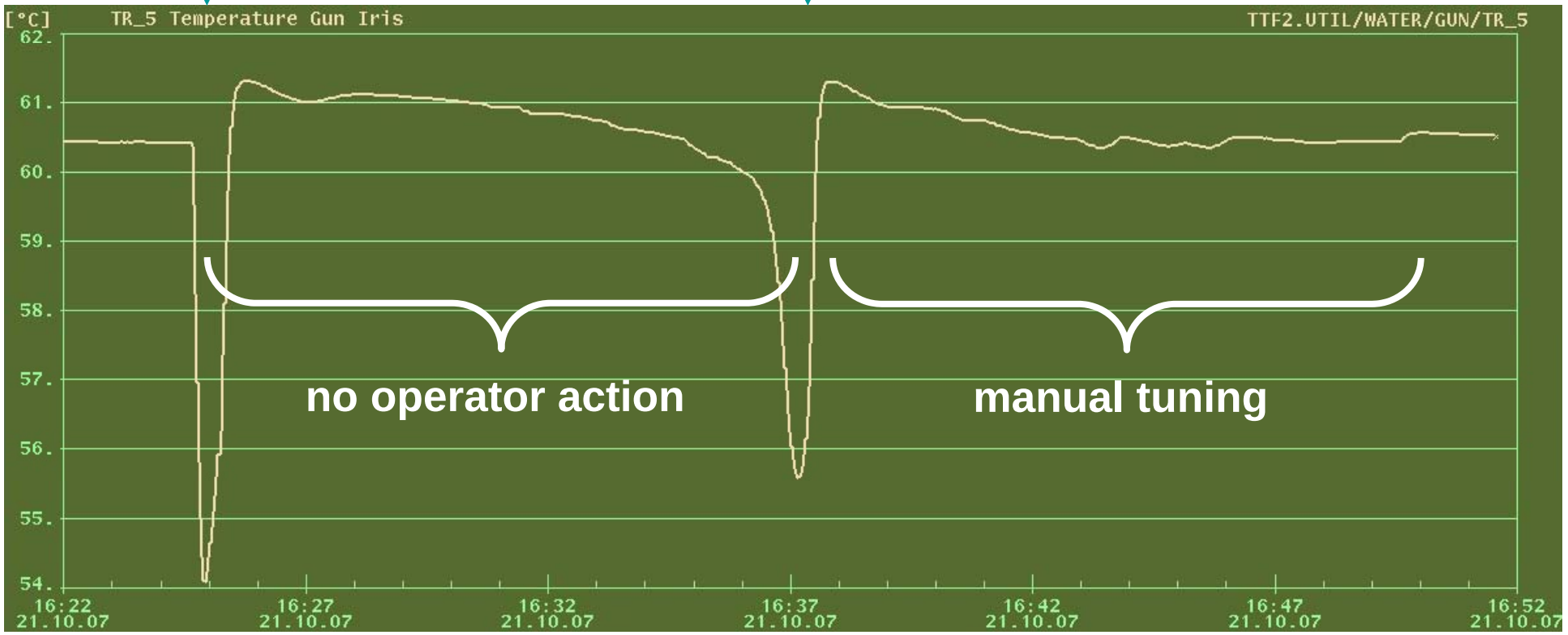


Problems & Improvements

Gun Temperature Regulation

At 850 µs gun flat top, the temperature is not stabilized anymore.

reflected power interlock **reflected power interlock**



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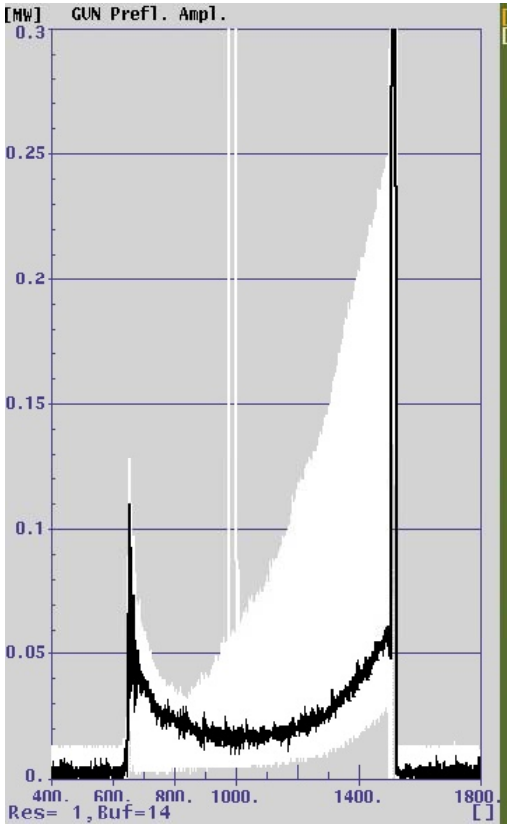
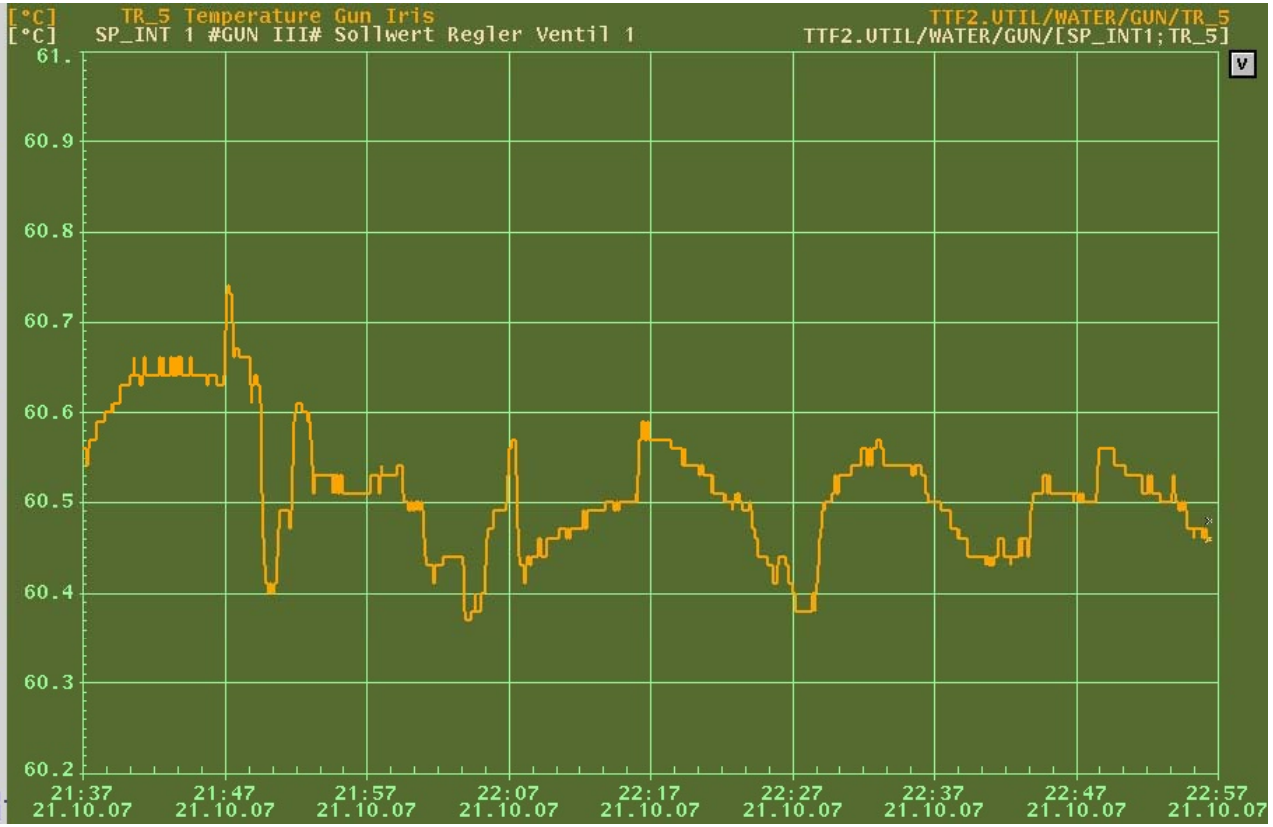
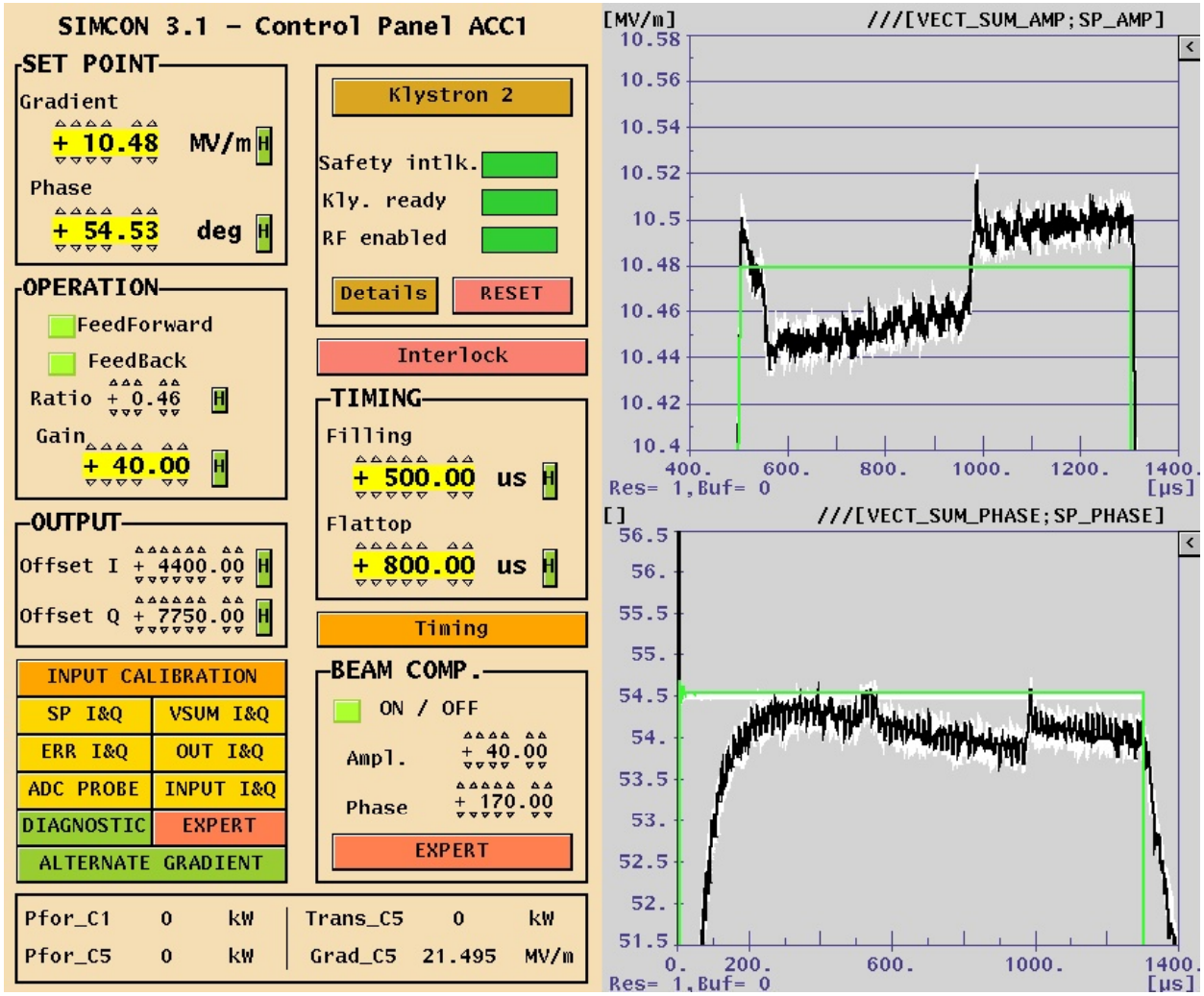




Beam Loading Compensation



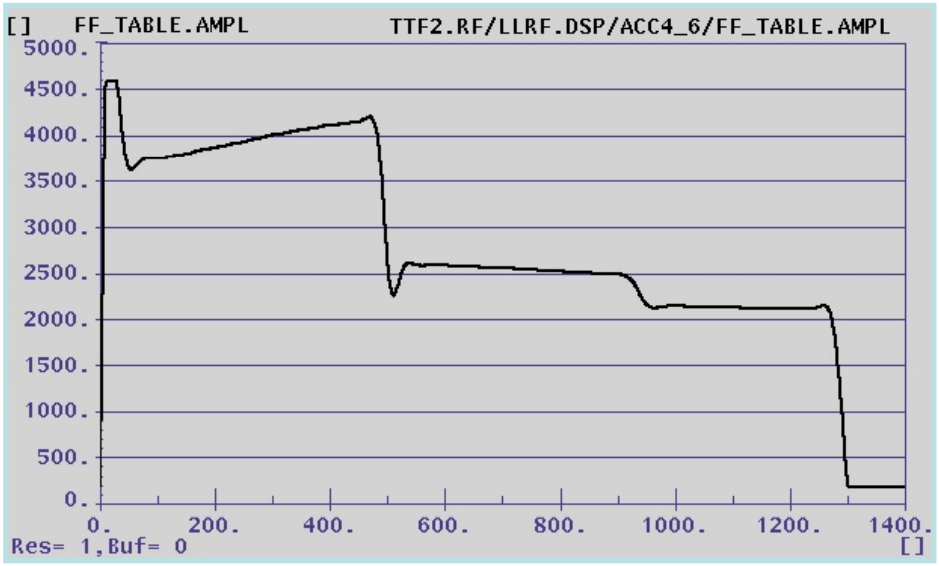
ACC1 toroid-based beam loading compensation

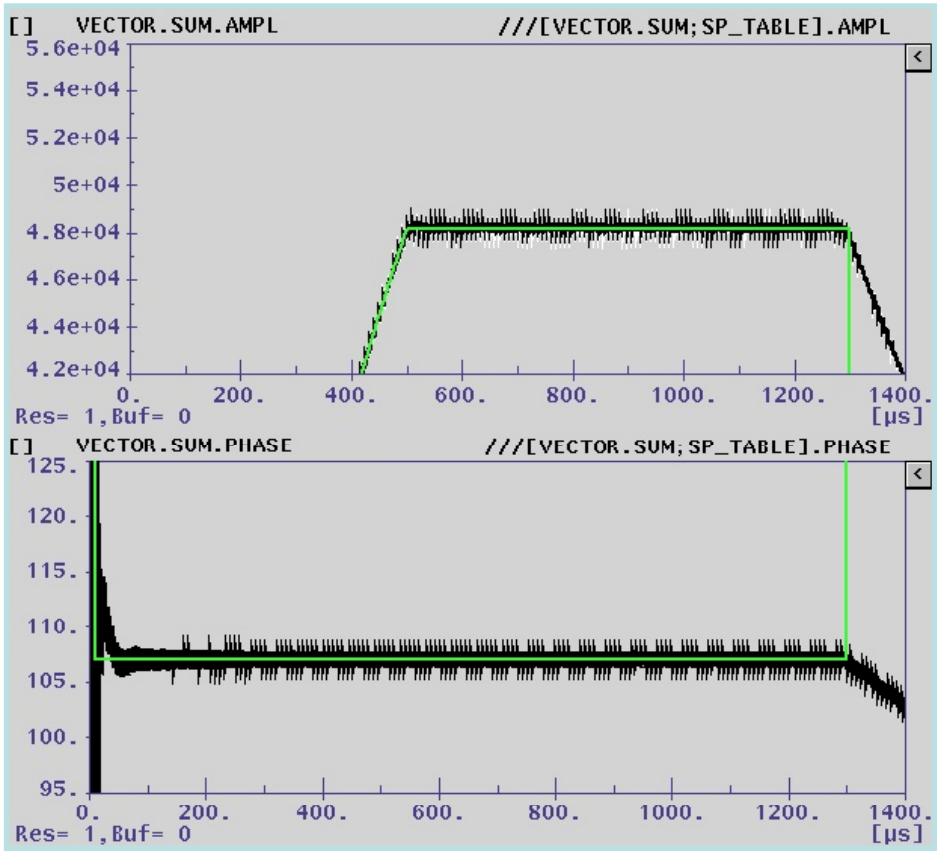
+ immediately adapts to number of bunches
– have to tune amplitude, phase, start time
– does not get the vector sum right

Adaptive Feedforward

Adaptation of feedforward tables by state machine (A. Brandt)

– slow (30–60 seconds to adapt to changed number of bunches)
+ almost foolproof (no tuning of parameters required)
+ flat vector sum except high frequency disturbances





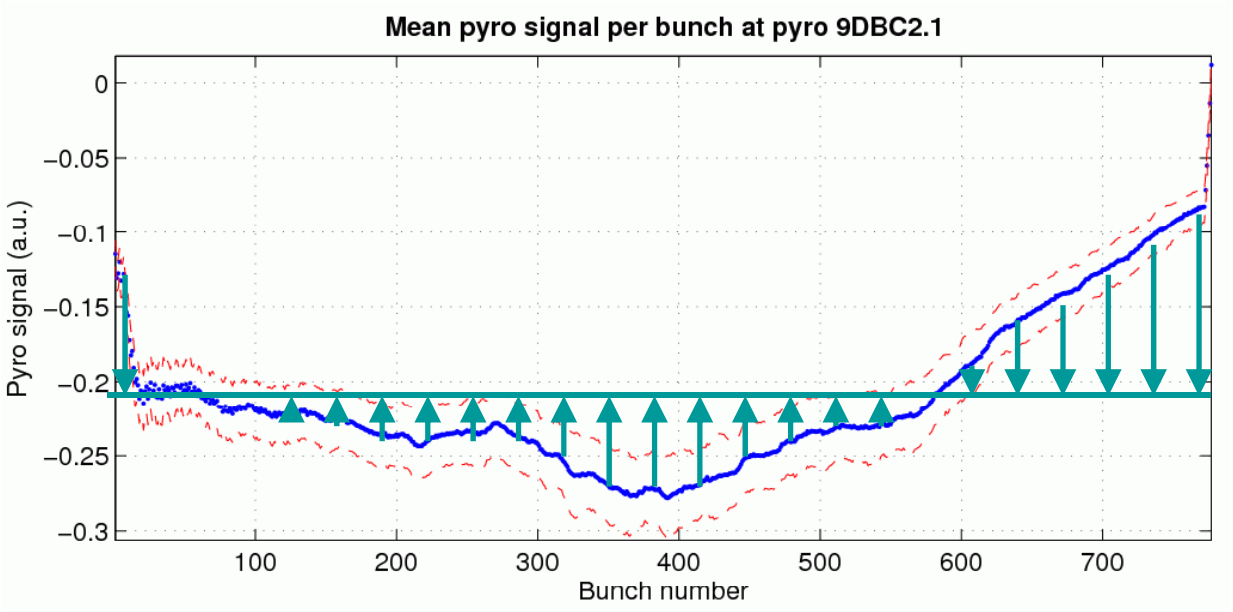
ACC1 Phase Feedback

- regulates ACC1 phase based on pyro signal of
  - single bunch, **or**
  - average of all bunches

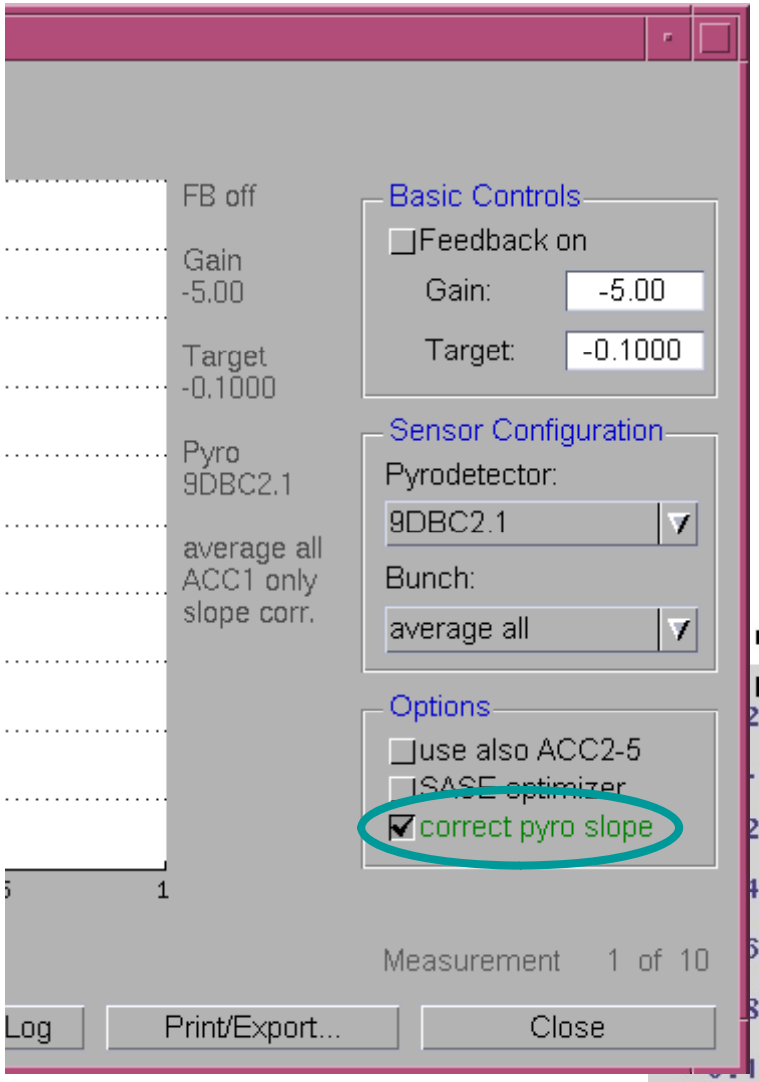
inhomogeneous compression along macropulse remains

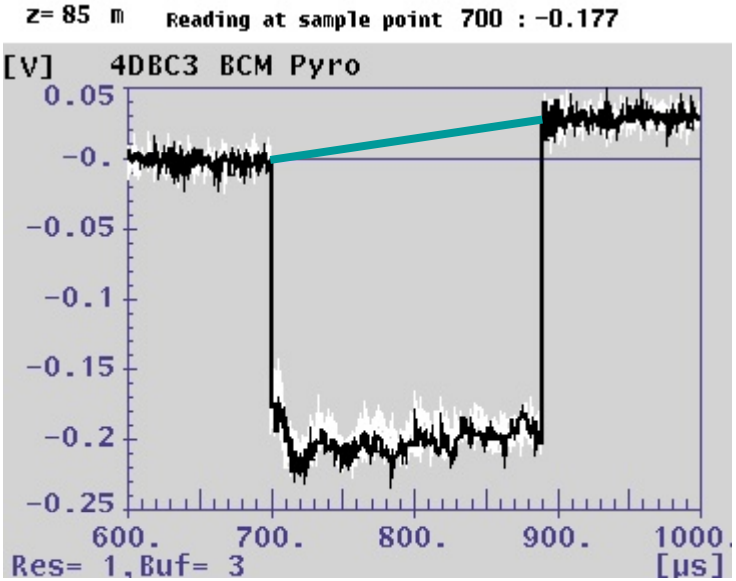
Solution:
feedback on each single bunch

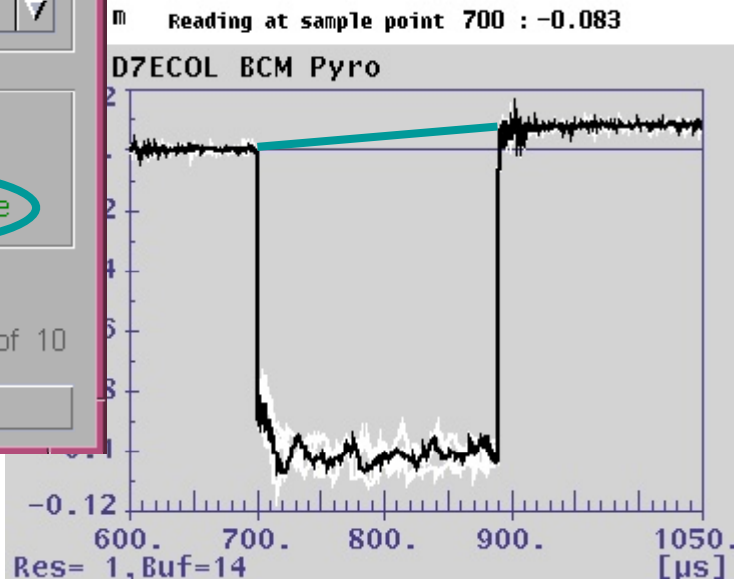
(manipulation of feedforward and setpoint tables)



Pyrodetector Baseline Shift







Conclusion

Conclusion

We reached that milestone, but...

We cannot provide 800 bunches during user run.

- Gun temperature regulation unstable at full RF pulse length
- Gun: reflected power interlocks

We need too long to switch to long pulses.

- Bad gun conditioning (sparks)
- Too high module gradients, especially in ACC1 (quenches+instabilities)
- Typically operating with high losses

Do conditioning in advance.

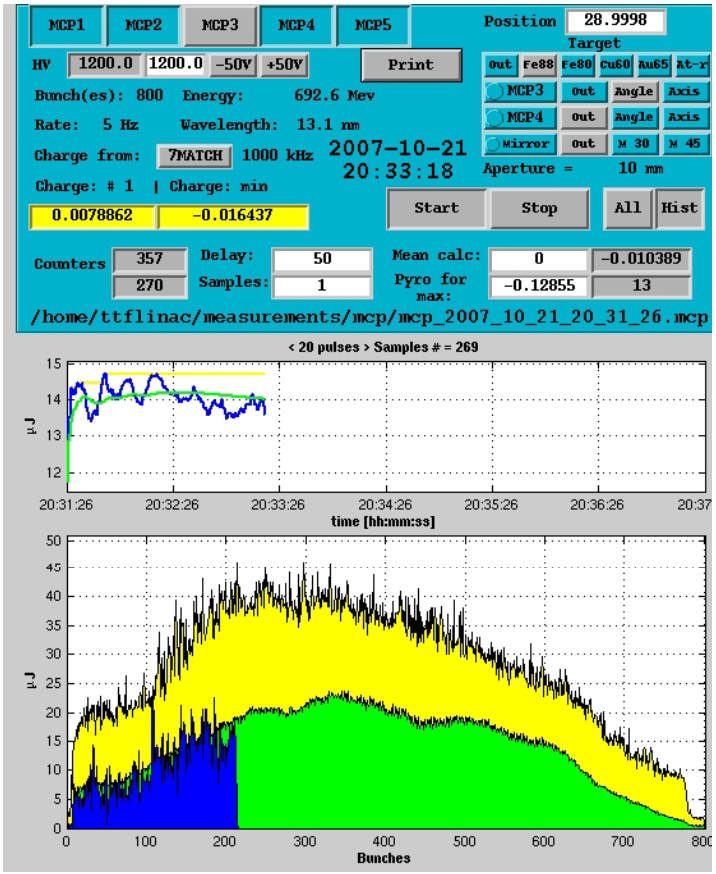
Why not run modules at full pulse length all the time?

Keep losses low even in short pulse mode.

Conclusion

Inhomogeneous lasing

- Mainly caused upstream BC2: energy/phase of laser, gun, ACC1
- 250 kHz ripple from ACC2–6



- **Reliable adaptive feedforward for all modules + gun**
- **Ripple correction table for ACC2–6**
- **ACC1 phase feedback for single bunches**
- **Fast orbit feedback**

Acknowledgements

Gevorg Petrosyan

Vladimir Balandin

Nina Golubeva

Bart Faatz

Valeri Ayvazyan

Michael Seebach

Evgeny Schneidmiller

Annette Brenger

Vitali Kocharyan

Lyudvig Petrosyan

Marion Kuhlmann

Mikhail Yurkov