Longitudinal Quadrupole Instability in DAFNE Electron Ring

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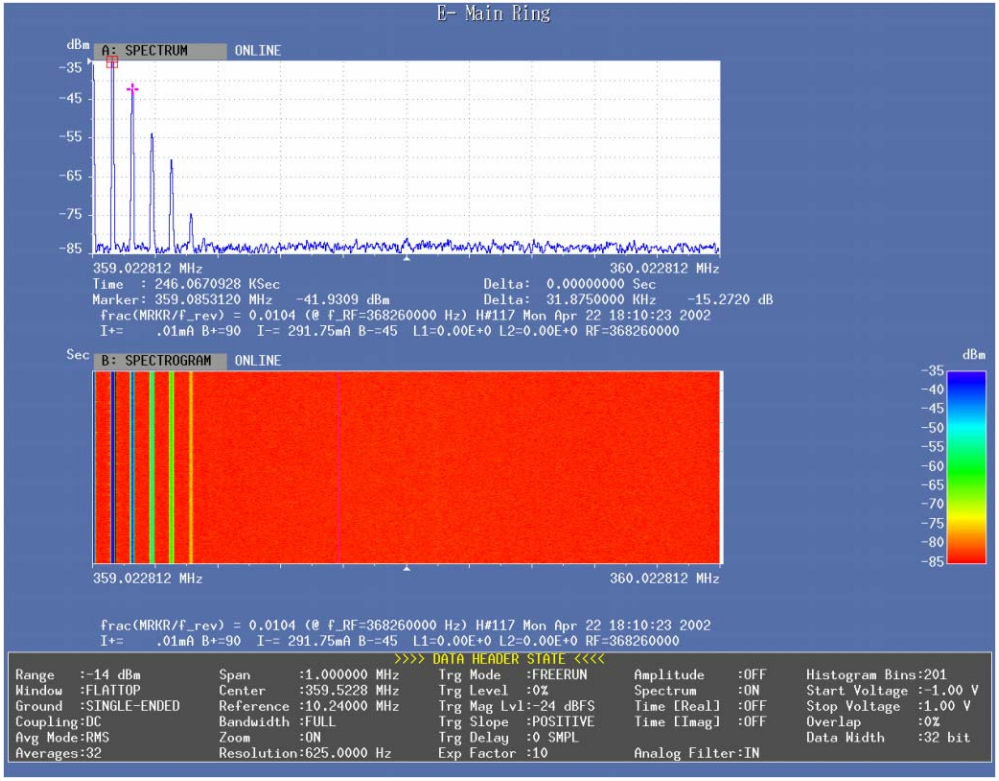
DAΦNE Parameters

- e+ / e- collider, center of mass energy 1.02 GeV
- 1 linac, 1 accumulator/damping ring, two symmetric Main Rings, two IP
- 1 RF cavity for each ring @ 368 MHz with voltage from 80 to 220 kV
- Harmonic number = 120 = max # of bunches
- Minimum bunch distance 2.7 nsec
- Max s.b. design current 44mA, [stored > 200mA]
- Typical filled pattern: ¾ of ring, each bunch followed by 1 empty bucket, ¼ of ring gap for ion clearing

Longitudinal Dynamics

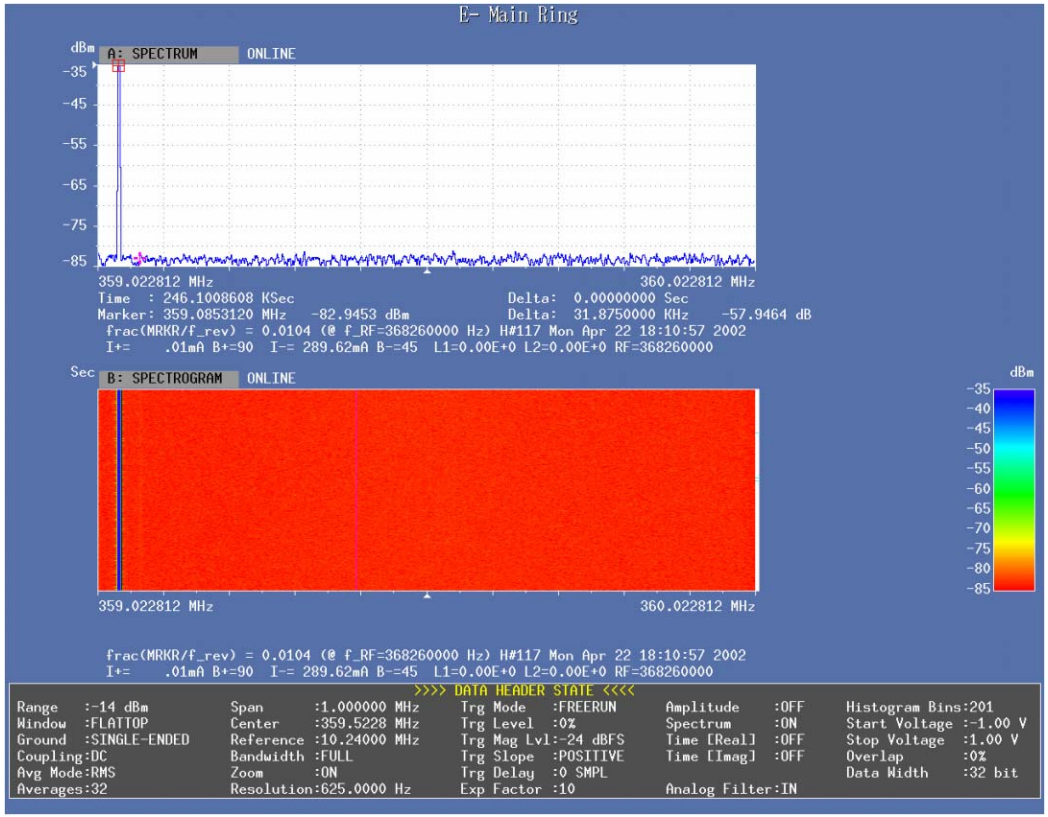
- In DAΦNE strong coupled bunch synchrotron oscillations make powerful active damping systems necessary.
- In each main ring a broadband bunch-by-bunch longitudinal feedback is operating.
- LFB has been developed in collaboration with PEP-II/SLAC and ALS/Berkeley.
- A zero-mode feedback, acting around the RF cavity and developed at Frascati, is also operating.

Multibunch Beam Spectrum With Longitudinal Feedback Off



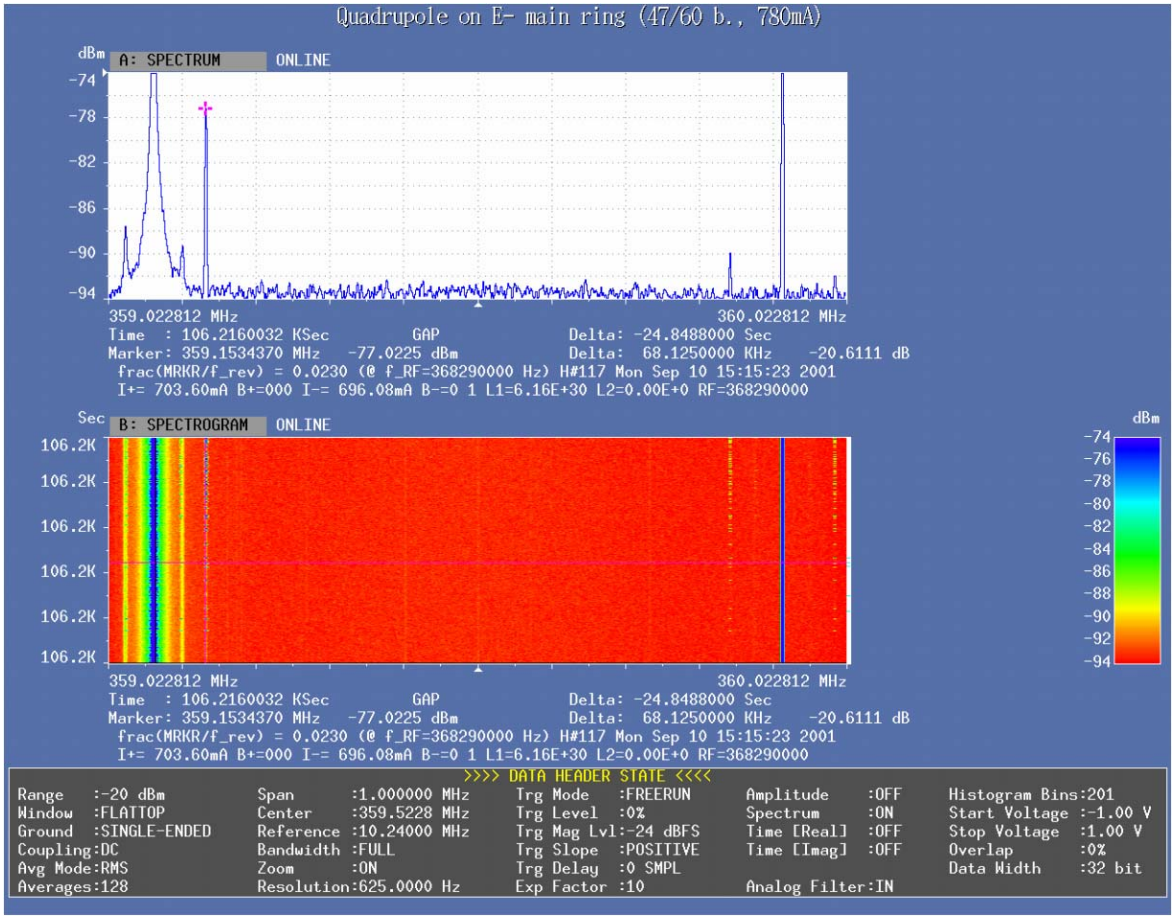
- Let's observe **as example** an e- beam with current <300mA in 45/60 bunches
- it produces several sidebands indicating large dipolar oscillations

Multibunch Beam Spectrum with Longitudinal Feedback On

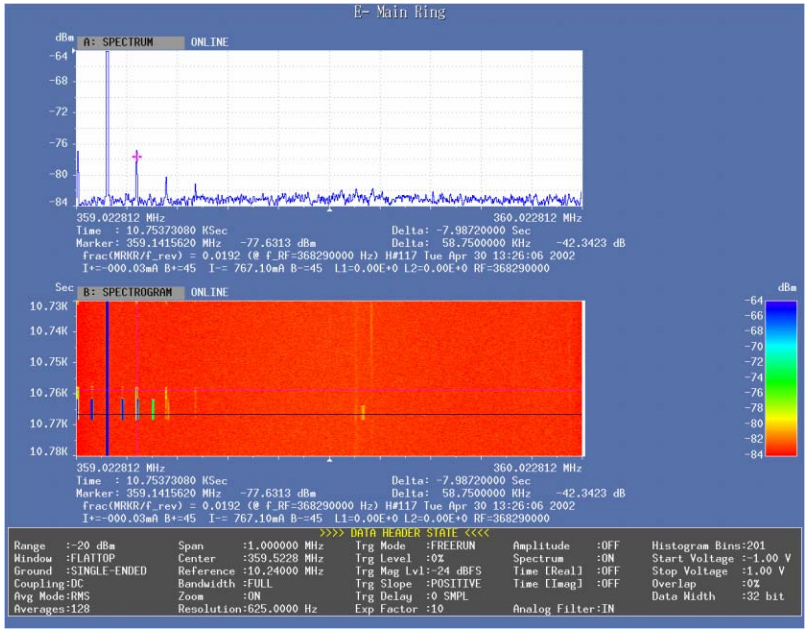


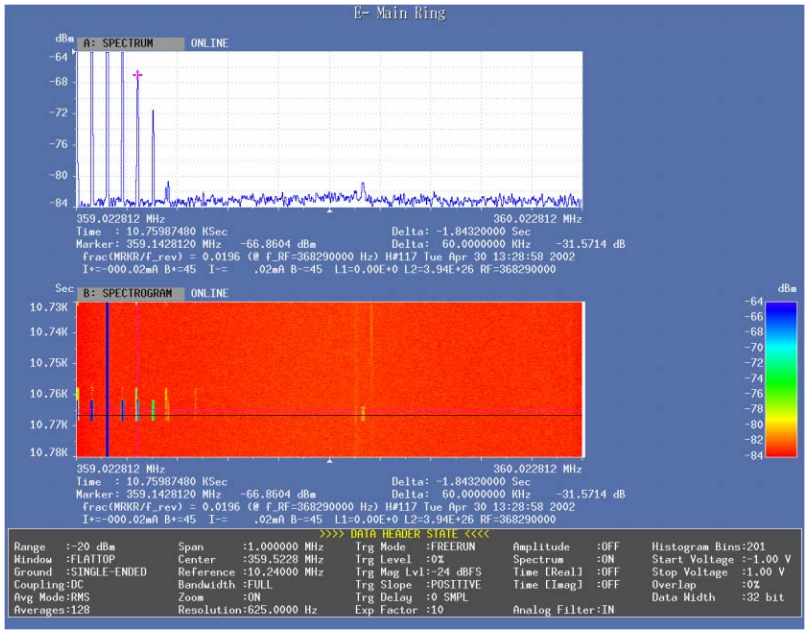
- Same beam current that the previous picture, but no sidebands around the revolution harmonic.
- Without LFB the strong longitudinal oscillations would make the beam-beam kicks in IP very destructive.

Long. Quadrupole Motion (only e- ring, at about twice F_synch)



- It appears in multibunch beam spectrum with **<u>LFB on</u>, very high currents (>600mA)** and without dipole.
- Going up with the current, it can produce loss of bunches or LFB not working properly.



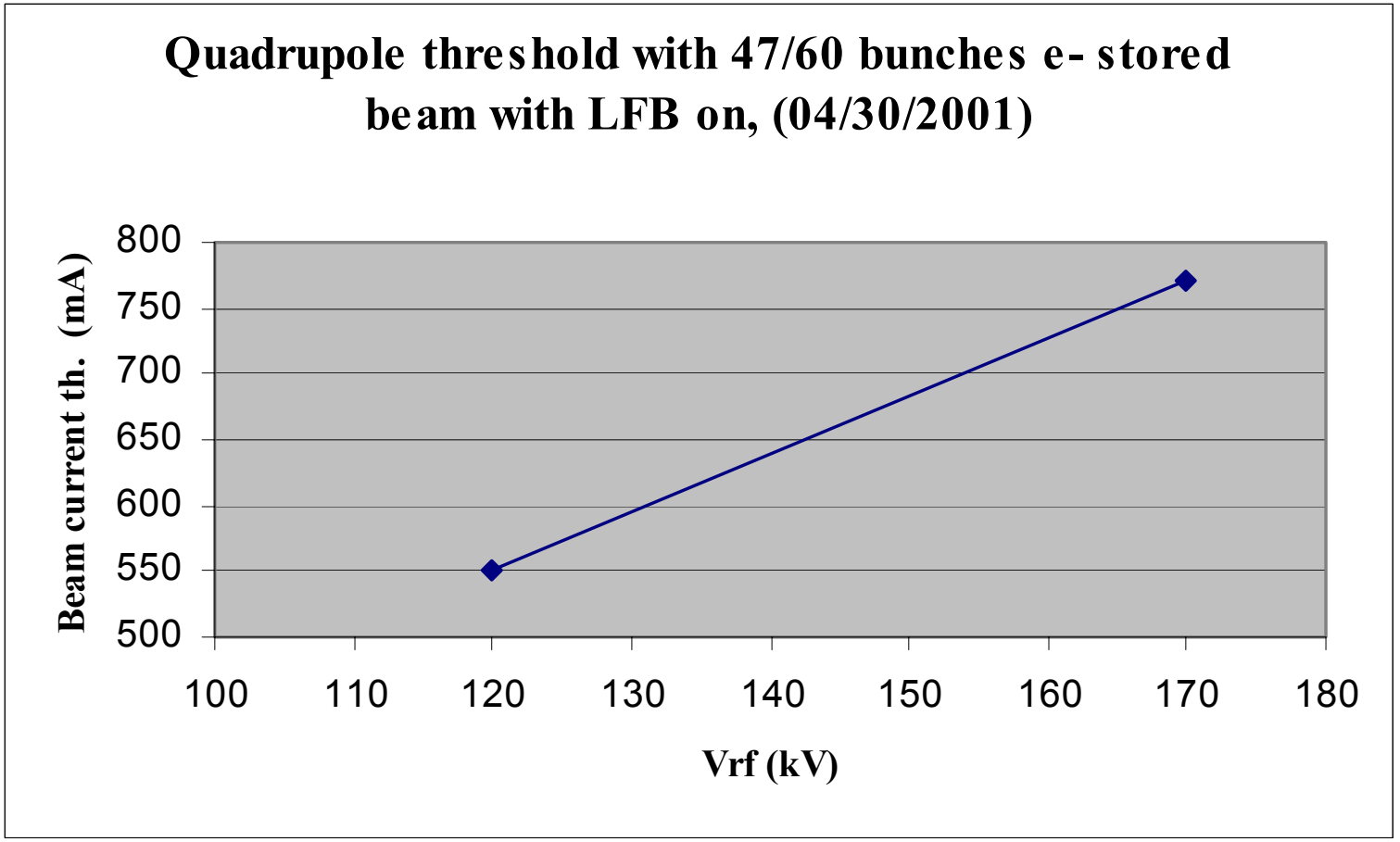


- Besides, there is another peculiar aspect: considering the multibunch case (Vrf=120kV), the quadrupole frequency (58.75KHz) has a frequency shift by -1.25 kHz relatively to the second harmonic of the synchrotron frequency (60kHz)

In order to overcome the current limit, the q-pole instability threshold has been measured as a function of the following machine parameters :

- Radiofrequency voltage
- Momentum compaction α_c
- Orbit (in the eventuality of a trapped mode)
- Injected bunch patterns
- Number of bunches
- Bunch length and LFB backend timing

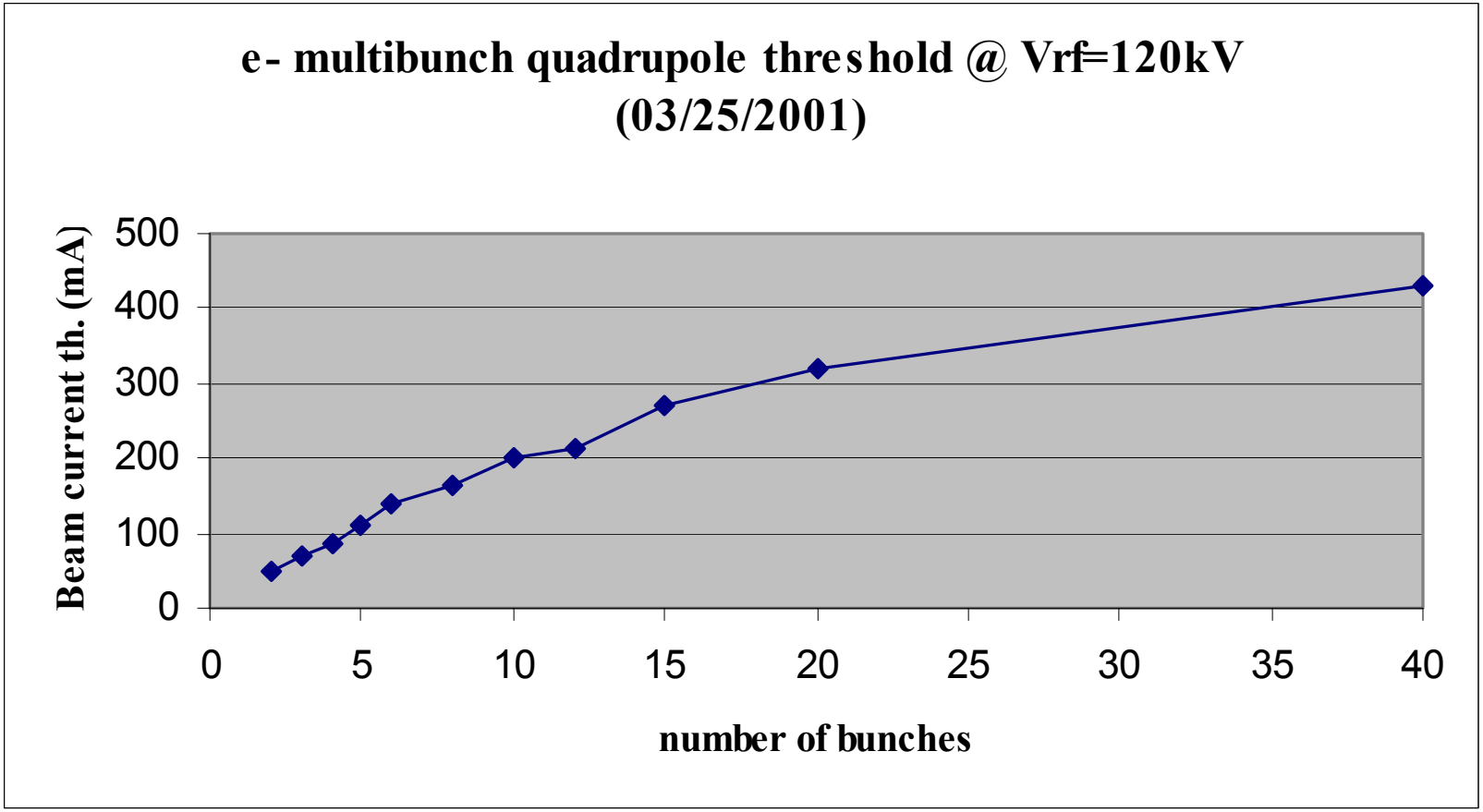
Q-pole threshold versus RF voltage



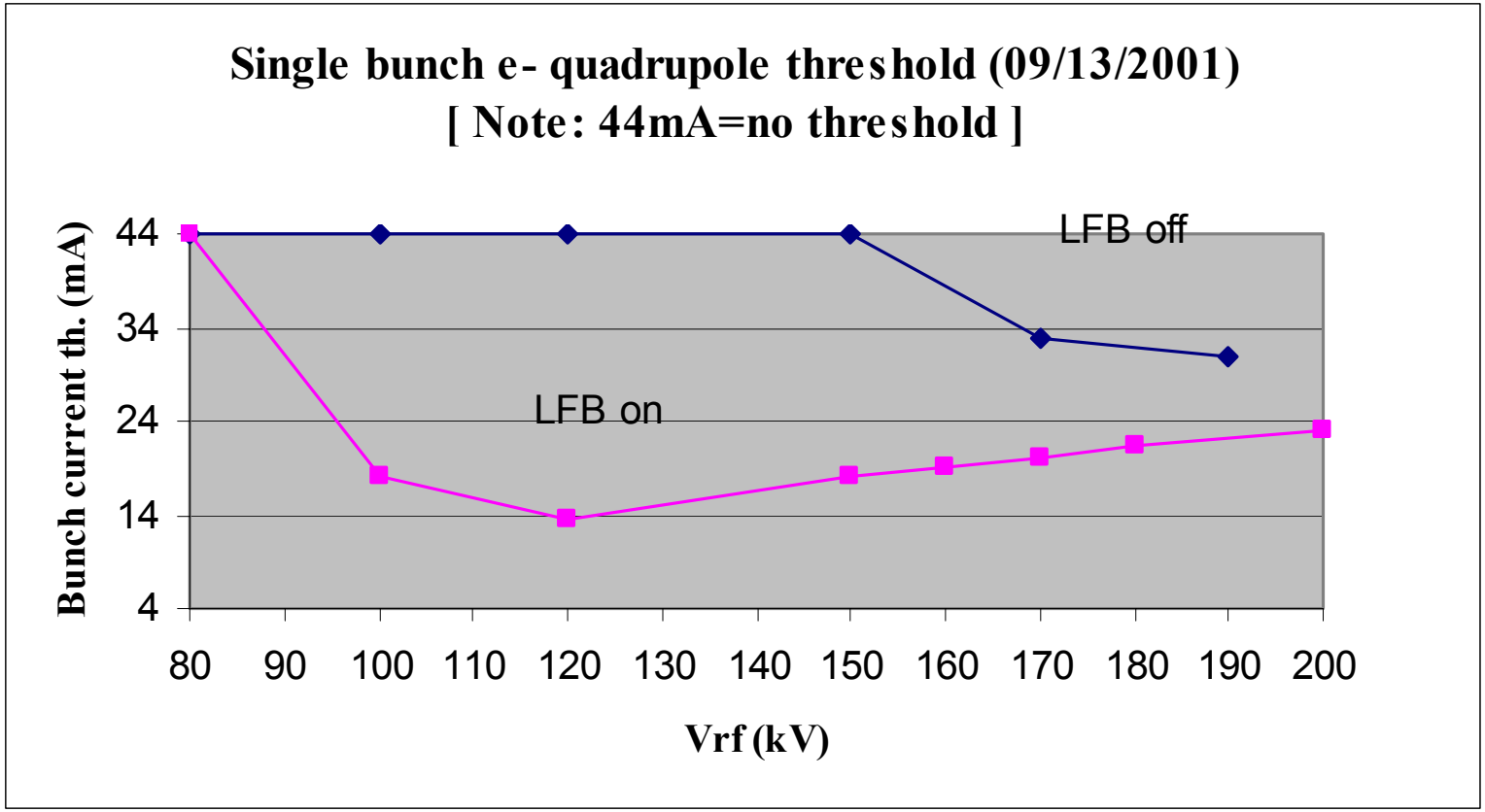
Momentum compaction

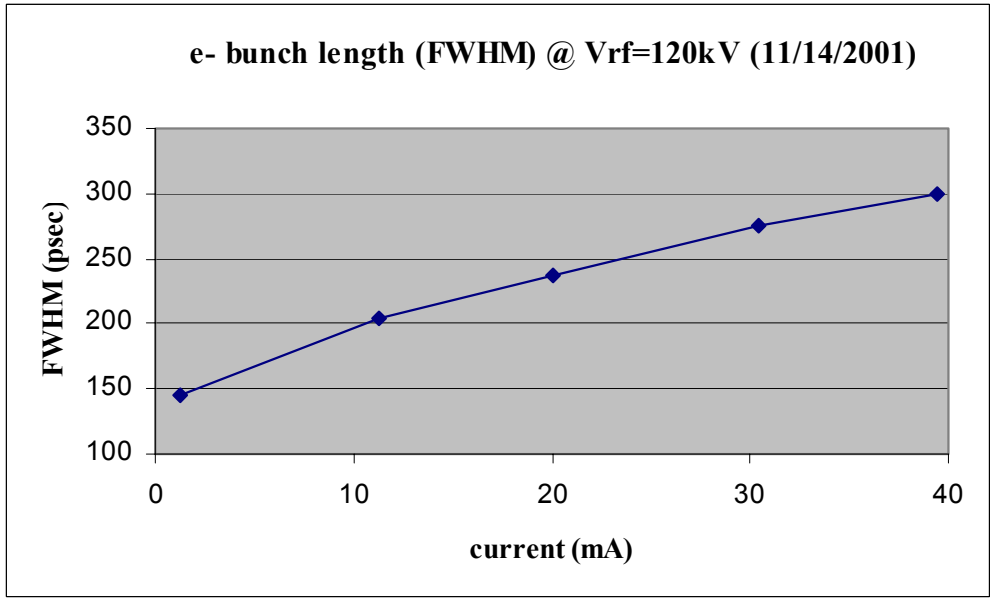
- a ~10% increase of the α_c value (from .03 to .033) allowed to increase the quadrupole threshold by ~17% (from ~750 to ~ 880mA in 47 bunches) - Oct. 2001

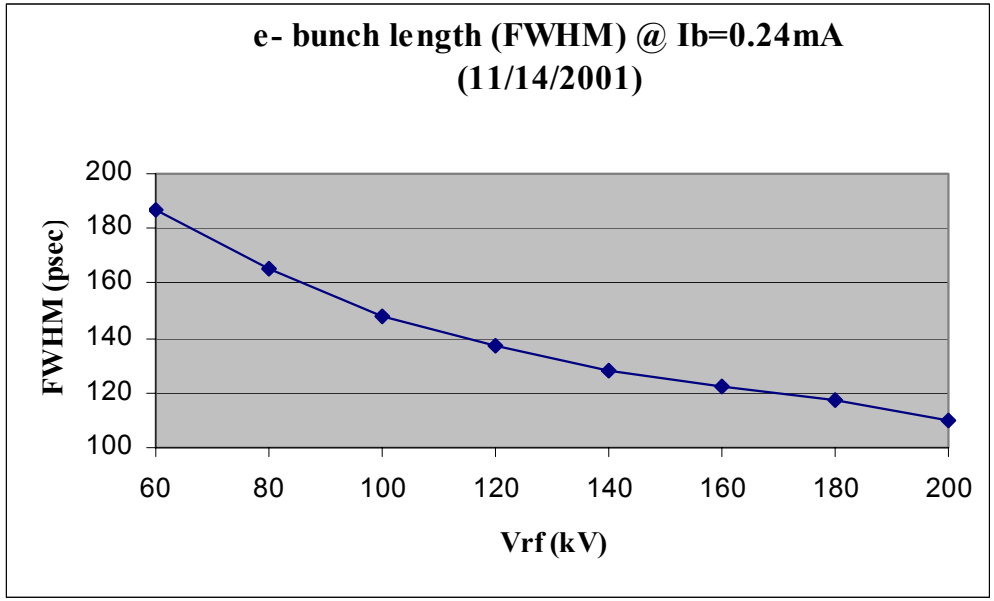
Q-pole threshold versus number of bunches:



Two different behaviours: s.b. with and without Long.feedback

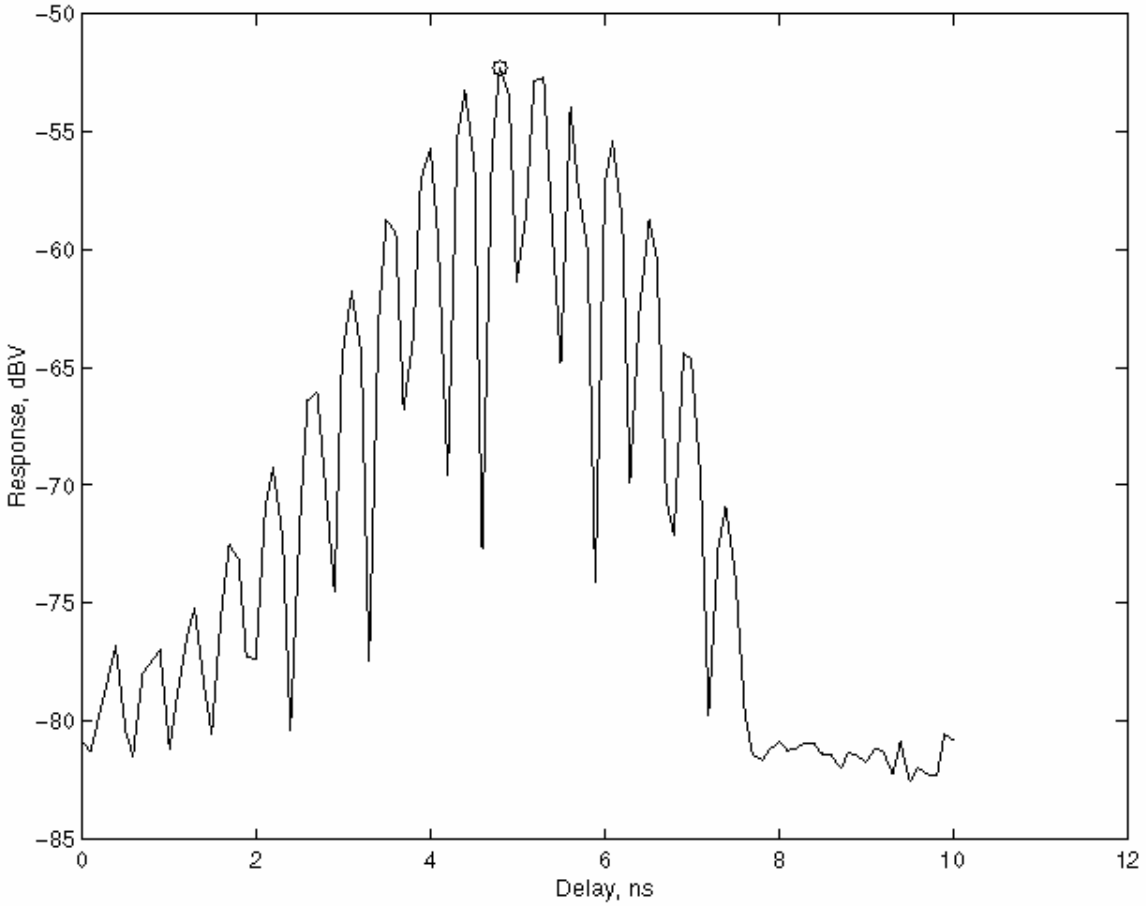






- Look at the bunch length measurements versus current:
- At high currents, the bunch longitudinal dimension (FWHM) grows up to more of 300 psec.
- On the other hand, at high Vrf, of course bunch length decreases.

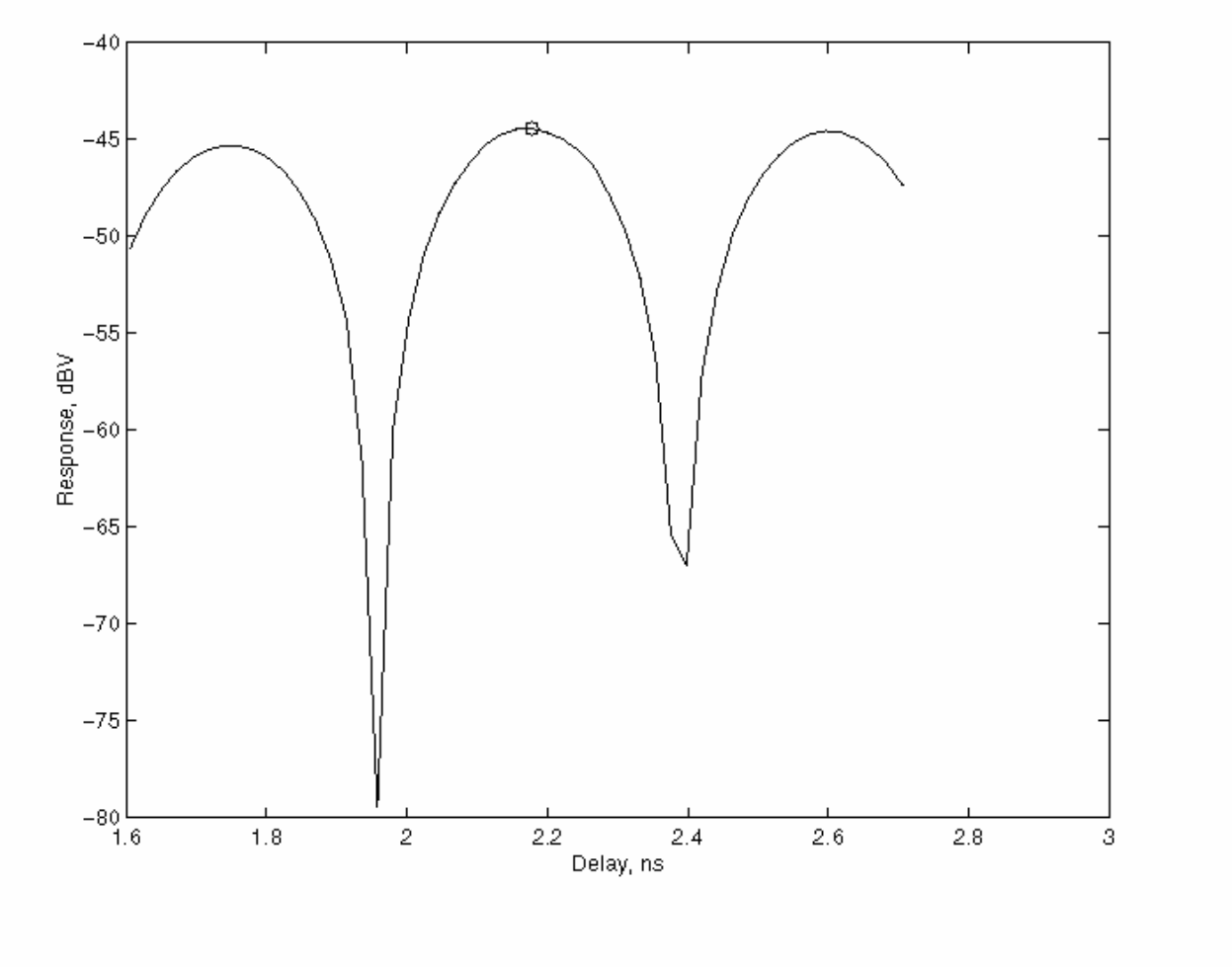
Longitudinal Feedback Back End



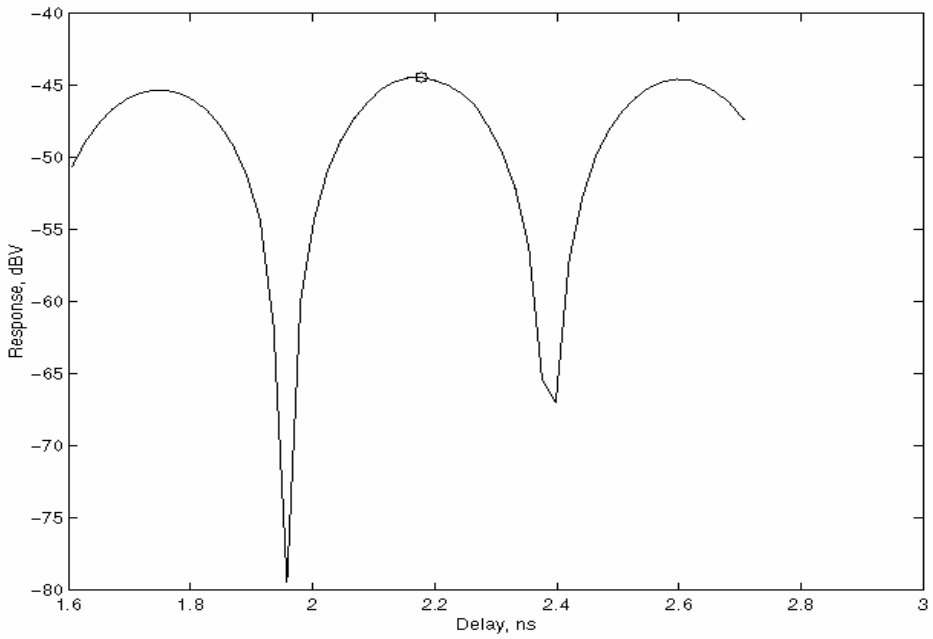
This is the longitudinal backend response versus delay;

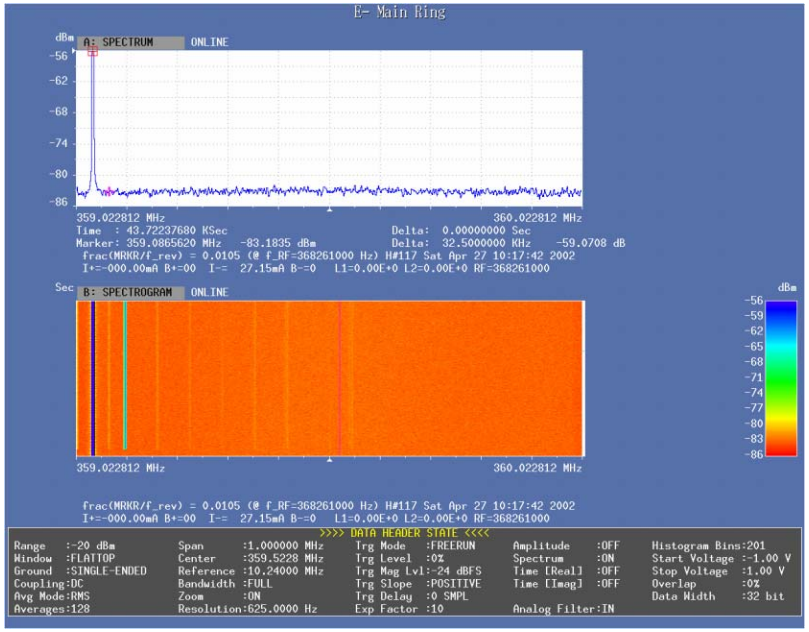
The bunch passage should be synchronized with the center of the highest lobe to exploit the most of the power.

Let's zoom: a useful period is 418 psec (note: contiguous lobes are in LFB opposite phases)



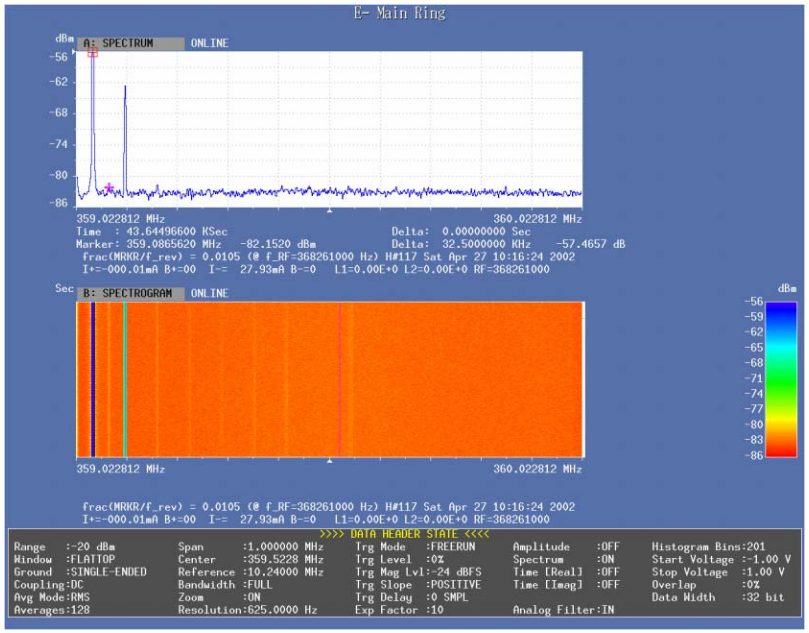
Measuring the q-pole threshold versus LFB backend delay, we discover that increasing delay (kicking bunch tail) produces higher or no thresholds and decreasing delay (kicking bunch head) lowers q-pole threshold.





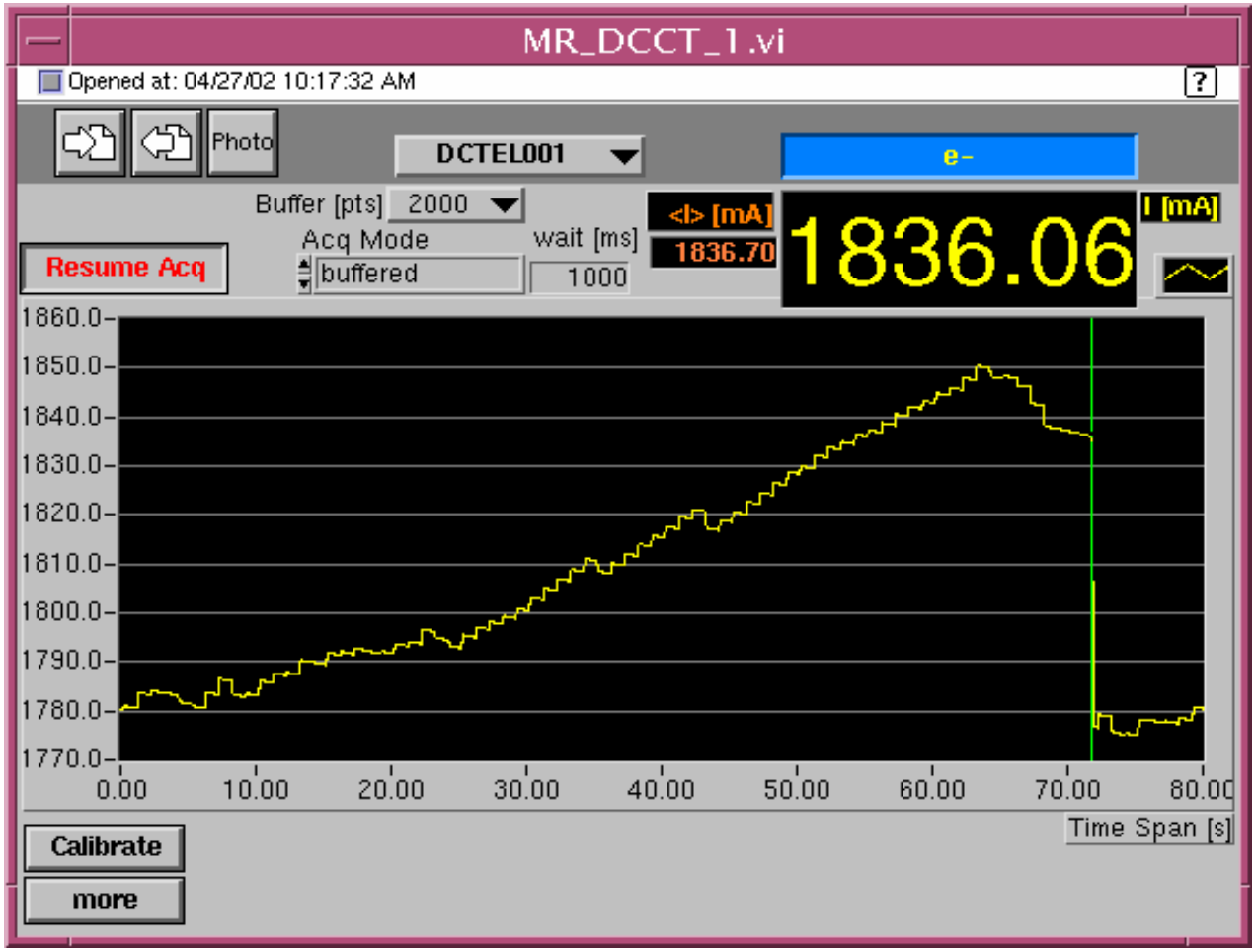
- <-BE delay=4450psec

- Still in single bunch with Vrf=120kV, and current>26mA, just decreasing by 150psec the backend delay, it is possible to excite the q-pole motion
(note that this happens also in the e+ rings at higher currents)



- <-BE delay=4300psec

1850 mA stored current with stable E-beam (90 contiguous bunches) April ’02



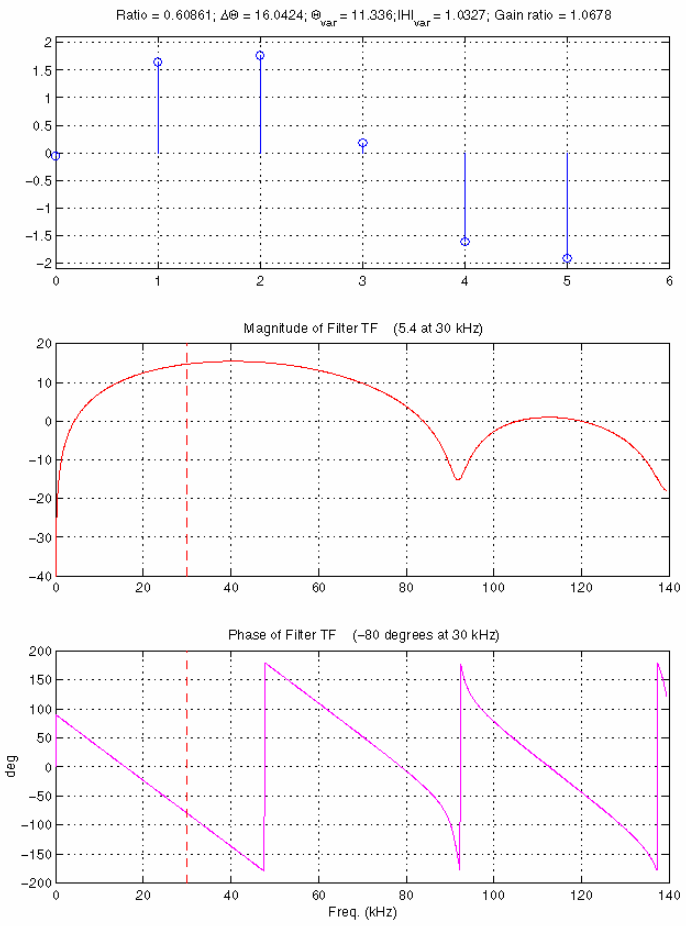
- More then 1.1 A injected and stored in collision in each ring (47 bunches, November 2001)

Further Developments

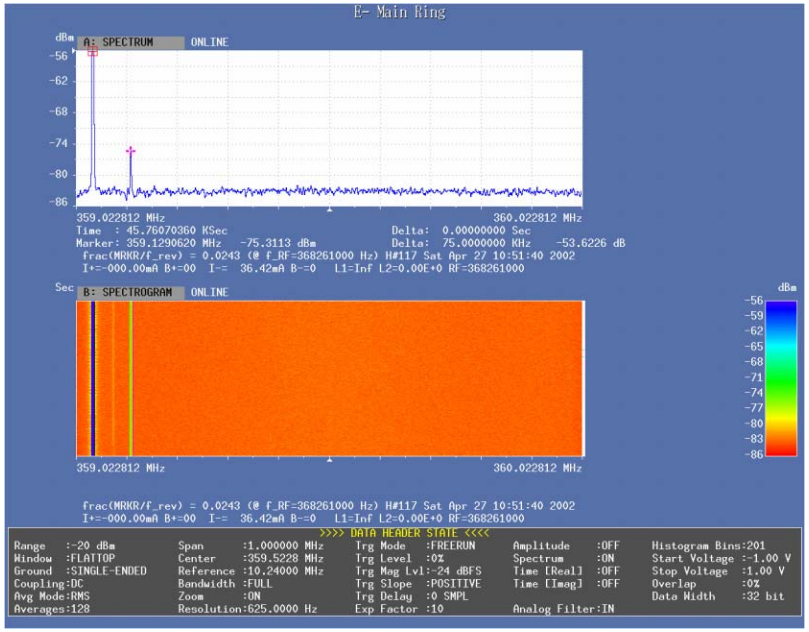
- Despite the cure found experimentally is very reliable, the underlying mechanism still has to be explained.
- In the future, it would be interesting or maybe necessary to study more deeply the phenomenon.
- To do this, some new measurements and working directions could be outlined:

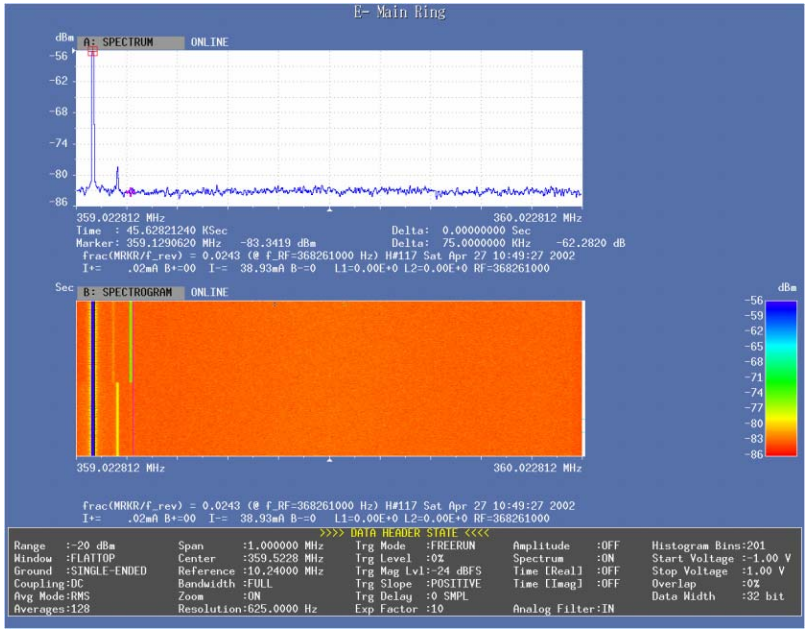
- Use a narrower LFB bandpass filter
- Try a lower frequency as LFB BE carrier. If 11/4*RF would be used in place of 13/4*RF, the backend period would be increased by 80psec (it is necessary a kicker modification)
- Study the case of q-pole with LFB off and develop a feedback setup for it
- Create numerical models and perform simulation of the instability including LFB

A purely software alternative could be to use a narrower LFB bandpass filter



- LFB uses a 40.5kHz centered FIR filter that has a -90 degree phase response at the synchrotron frequency
- It is enough convenient to damp the dipole and coexist with the mode zero oscillations
- But the filter phase response could be critical regarding to the longitudinal quadrupole
- Narrower band filters would have lower amplitude responses on the q-pole frequency
- To be verified on real cases





- This a case of quadrupole motion with LFB off, in single bunch, Vrf=190kV: it appears above 24mA
- In this case after turning on LFB, the BE delay shift does not have effect
- Still, increasing by 256 times the FB gain, the quadrupole oscillation is damped, letting at its place a shorter sideband between dipole and quadrupole frequencies
- It should be possible to think to develop a LFB setup for this case

Conclusions

- After discovering how to manage quadrupole motion, it has been possible to exceed the 800mA limit in collision
- To use correctly the LFB, the trade-off between dipole and quadrupole response have to be carefully checked
- During this year no more longitudinal quadrupole troubles or current limits
- To put in collision 2 Amperes e- beam against 2 Amperes e+ beam is the possible next development

Acknowledgements

- Thanks to A. Hoffman, J.D.Fox and D.Teytelman for an interesting even though informal meeting held in last December at SLAC.
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- Thanks to M.Serio for many discussions.