

Experimental study of resonance crossing

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Non scaling FFAG

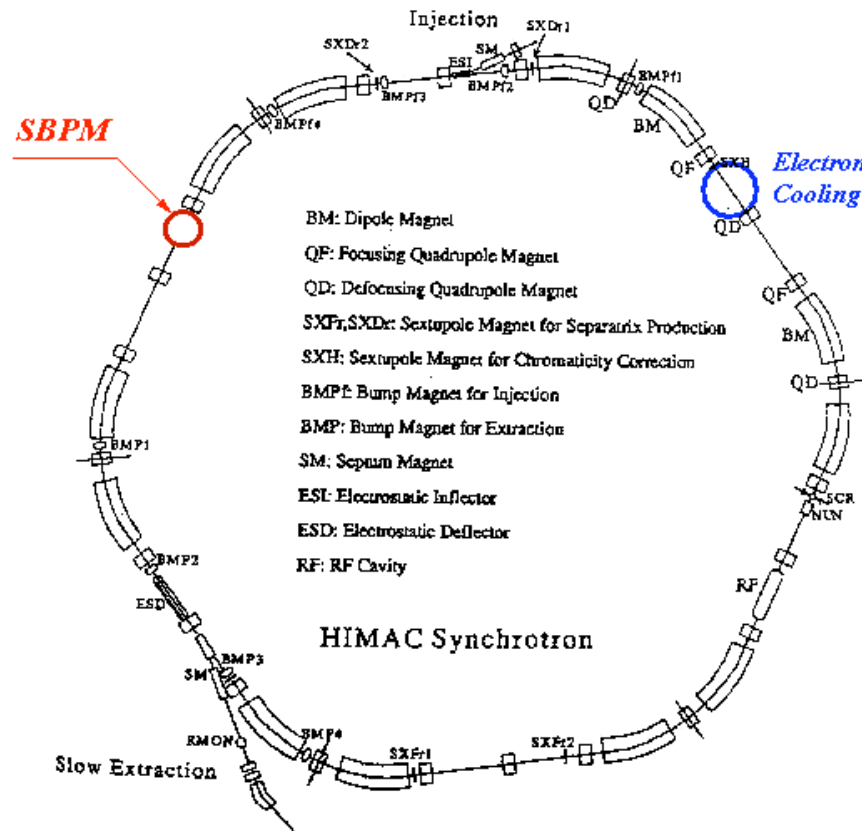
- Lattice consists of Quads and Bends just like an ordinary storage ring or synchrotron.
- Because of no chromaticity control, transverse tune changes a lot
 - For example, phase advance per cell is 140 degree at lower end and 40 degree at higher one.
- There are two issues.
 - Acceleration outside of a bucket
 - Resonance crossing during acceleration

HIMAC as non scaling FFAG

- Adequate horizontal aperture
 - Maximum dispersion is ~ 3 m.
 - Horizontal aperture ~ 0.2 m.
 - dp/p can be shifted with a few percent.
 - Initial emittance is controlled by the number of injection.
- Fancy diagnostics
 - Direct measurement of real space profile.

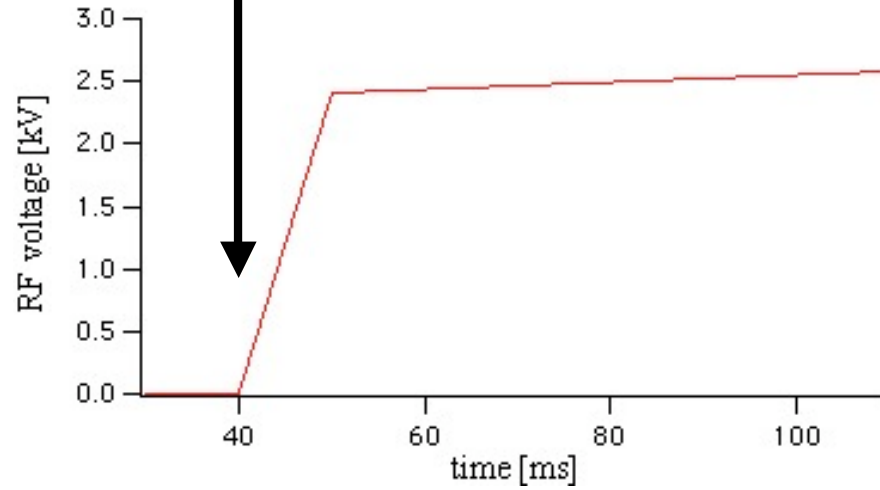
Experimental study of resonance crossing

- Fix the strength of magnet.
- Change RF frequency.
- Initial tune is just above a half integer resonance

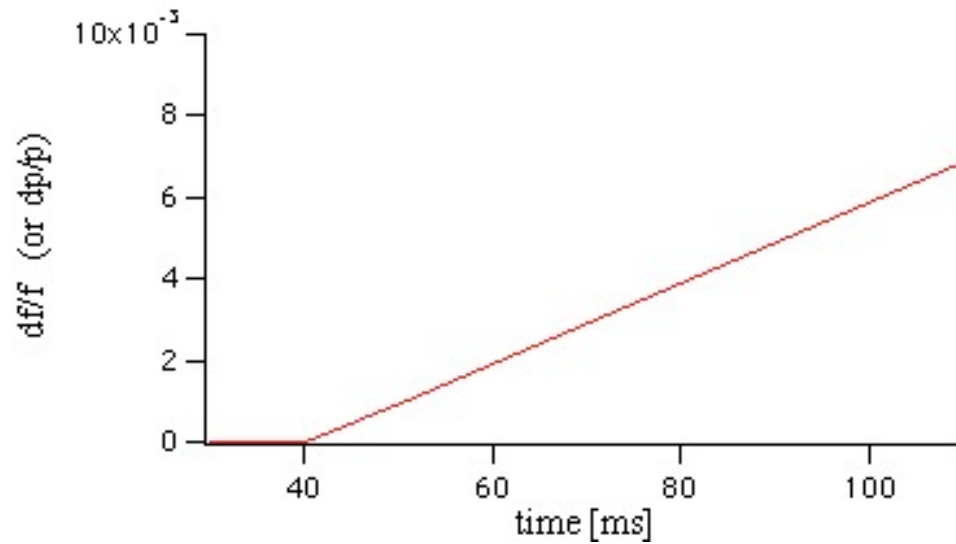


RF pattern

injection



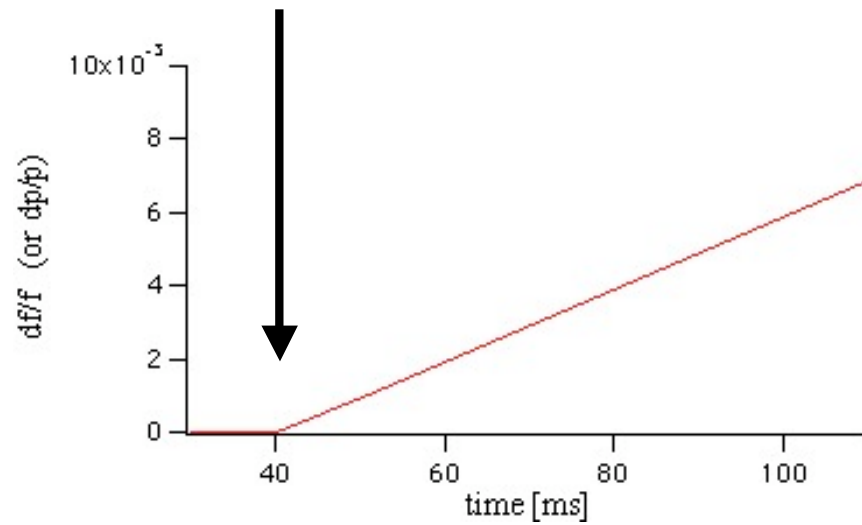
RF voltage



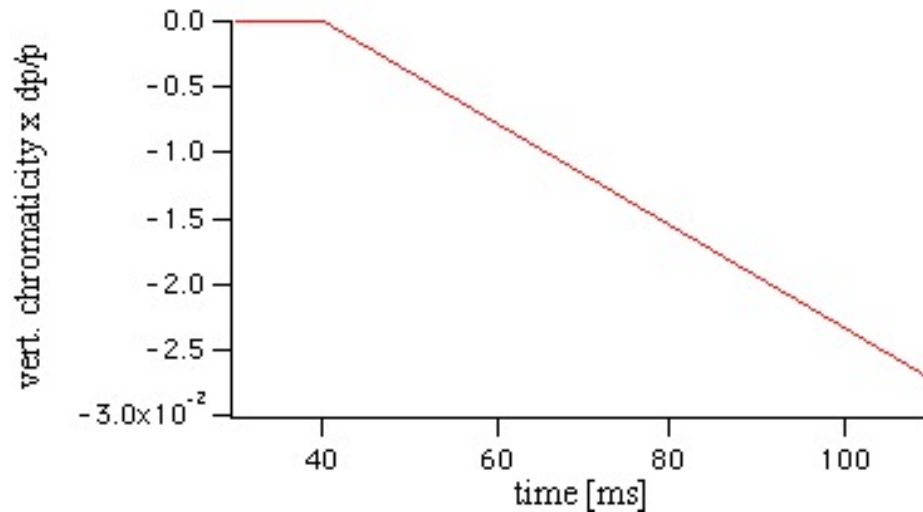
RF frequency

Beam response

injection



dp/p
($df/dt=26$ kHz/s)



← 0.

change of tune

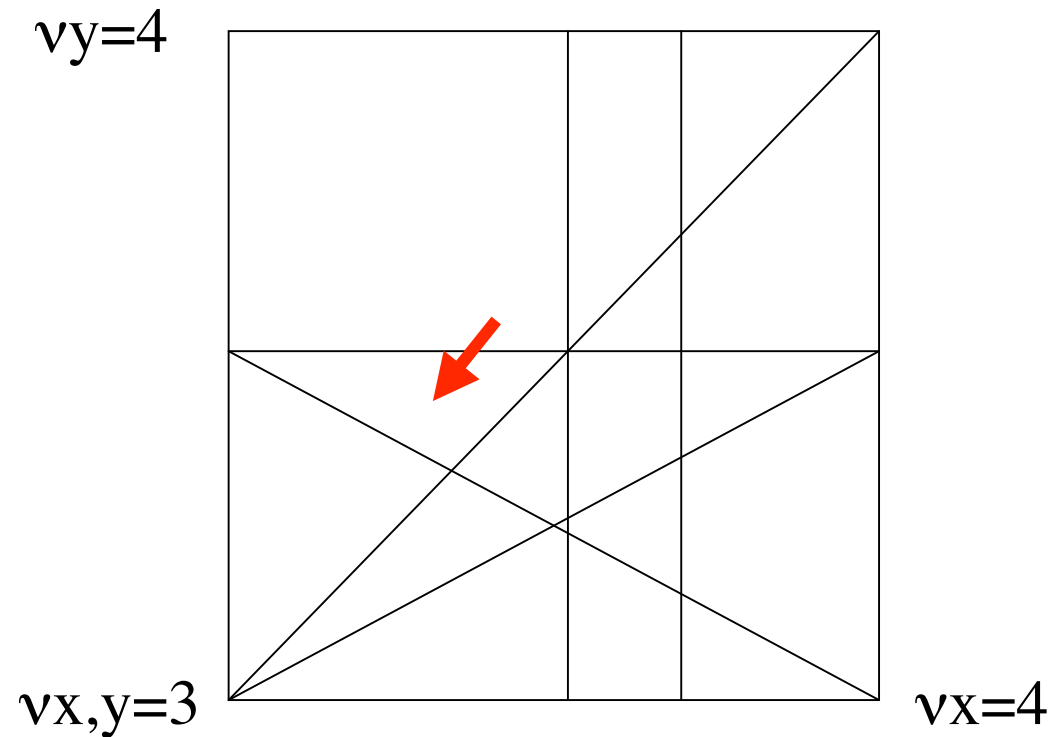
← -0.02

← -0.03

($\Delta\nu/dt=-0.0005/ms$)

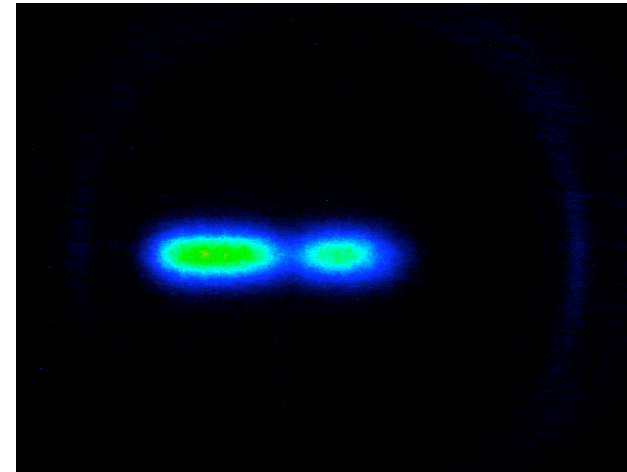
Tune diagram

Half resonance crossing with RF acceleration.

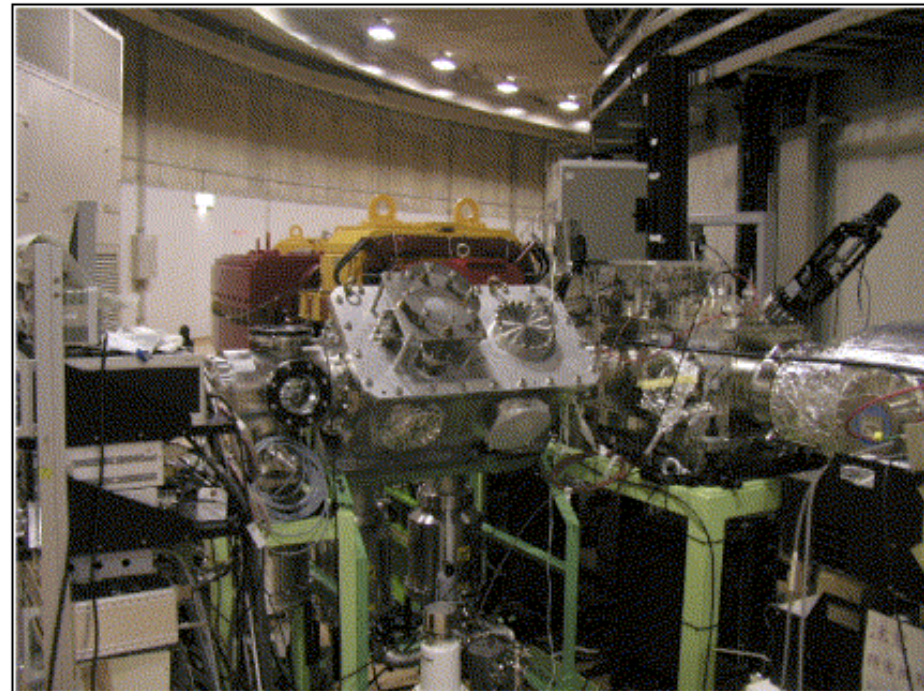
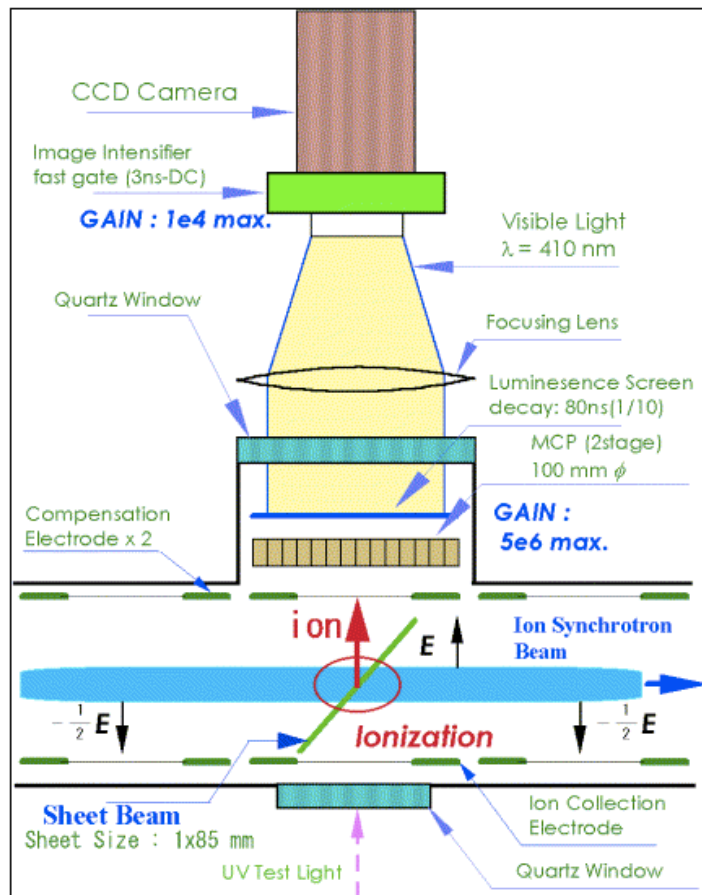


Diagnostics (1)

- Sheet beam profile monitor

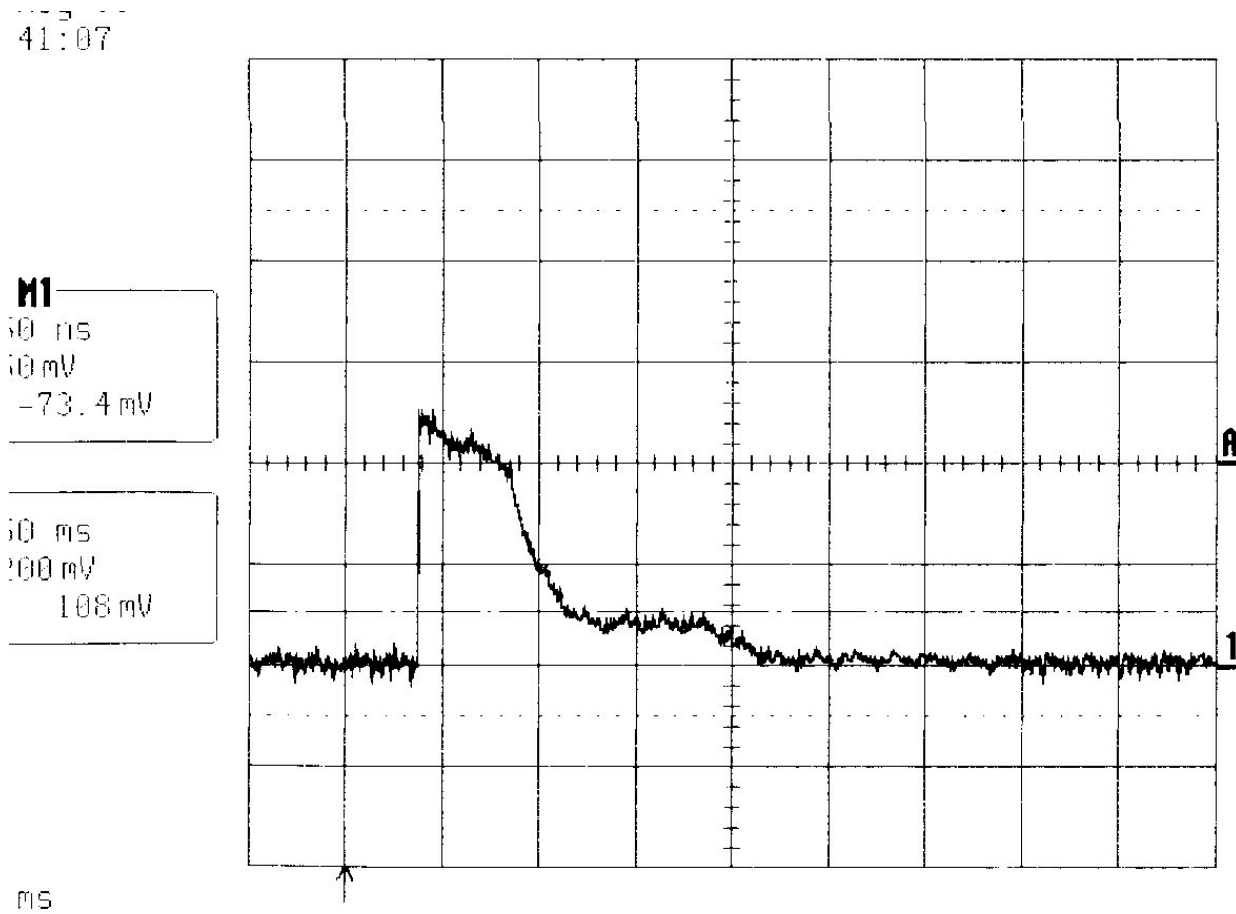


Dip at the center is due to less sensitive CCD channel.

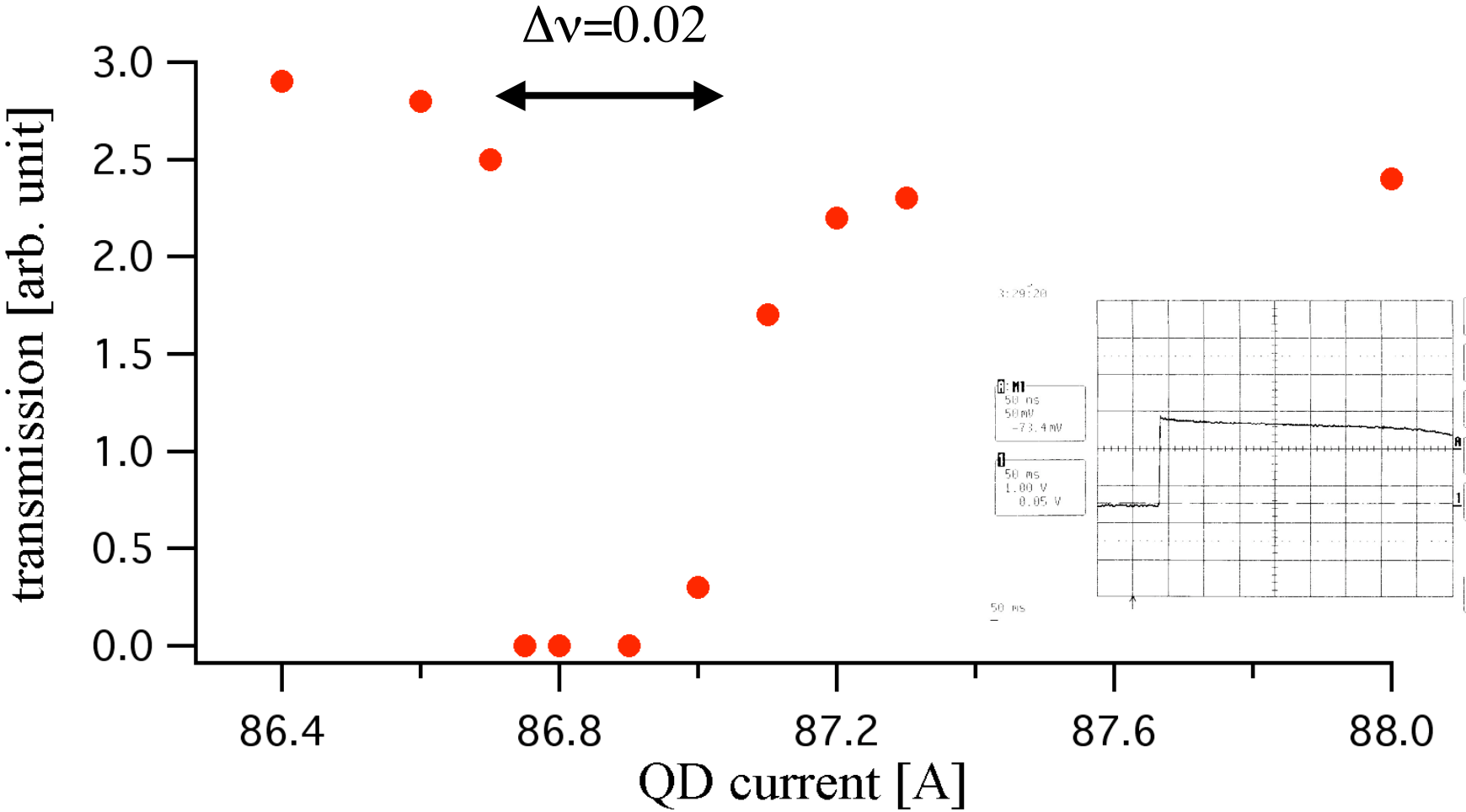


Diagnostics (2)

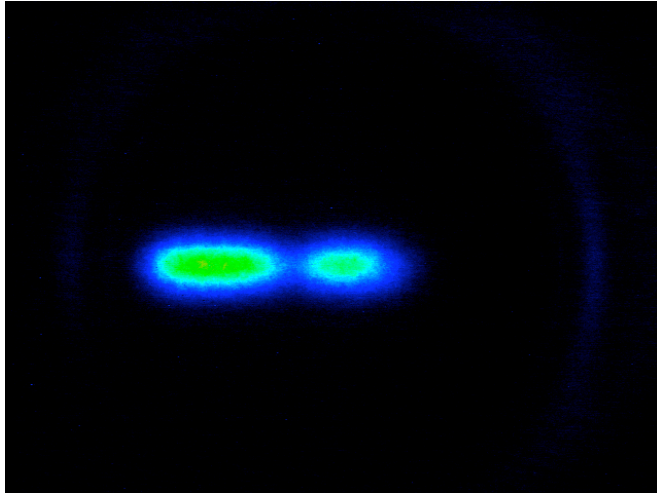
- Current transformer (DCCT)



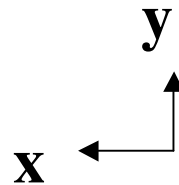
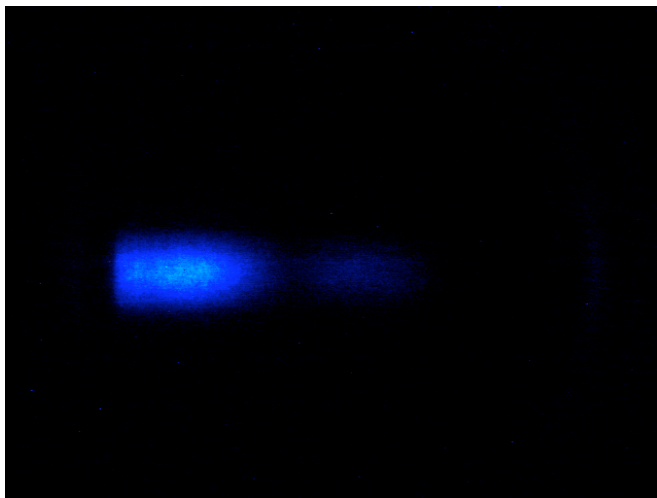
Resonance width (measured)



Orbit shift

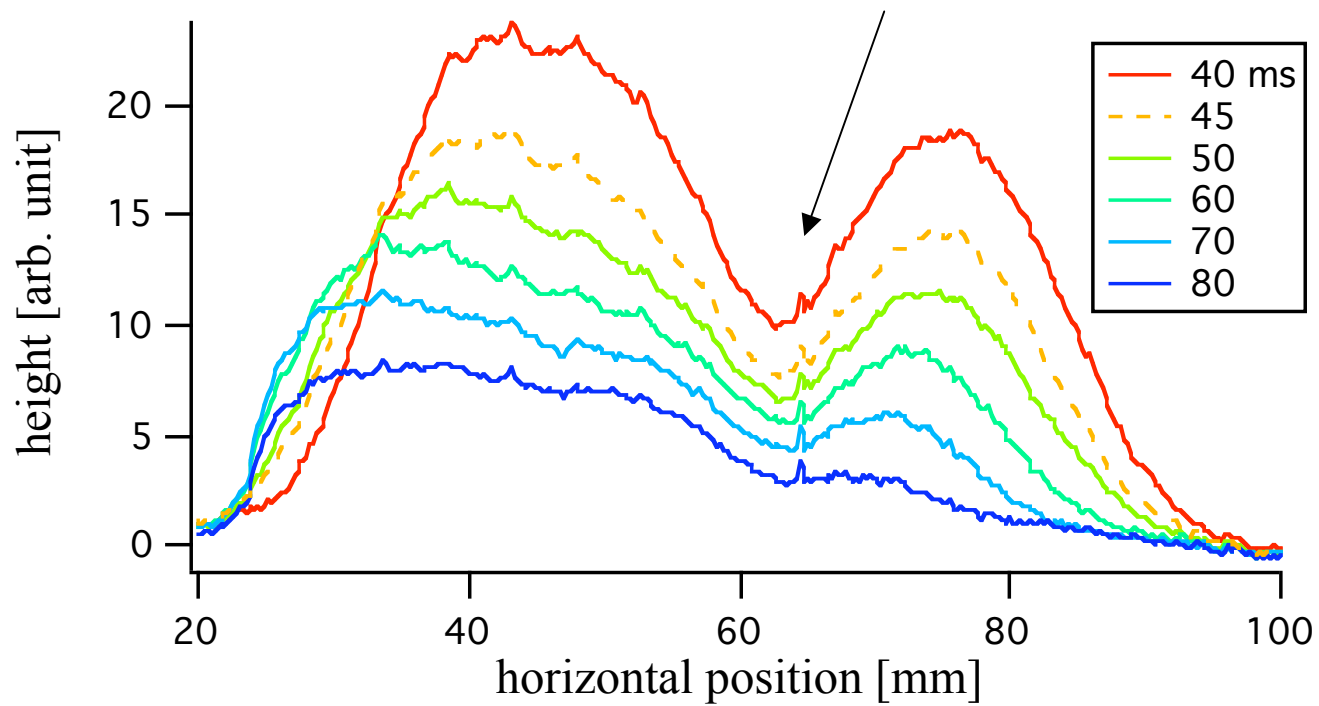


When RF frequency is increased orbit shifts outward due to positive dispersion.



Projection in horizontal plane

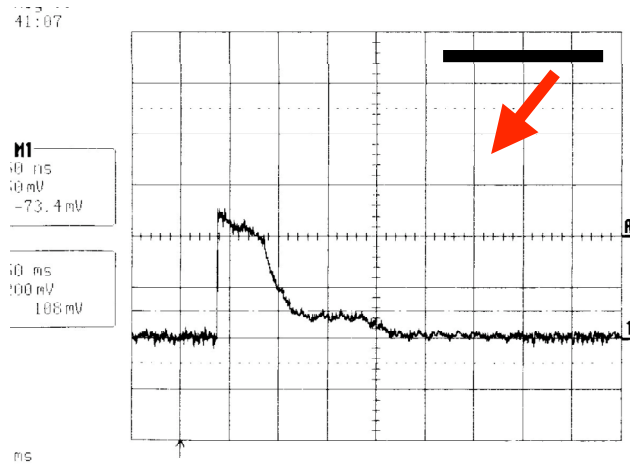
Dip at the center is due to less sensitive CCD channel.



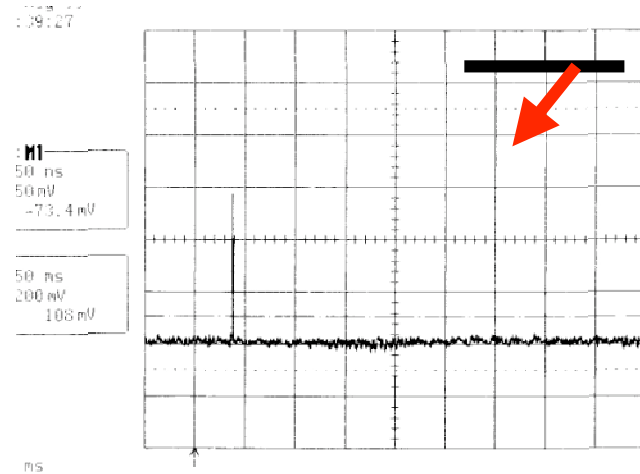
↔
Shift of 10 mm in 40 ms.

Beam loss pattern

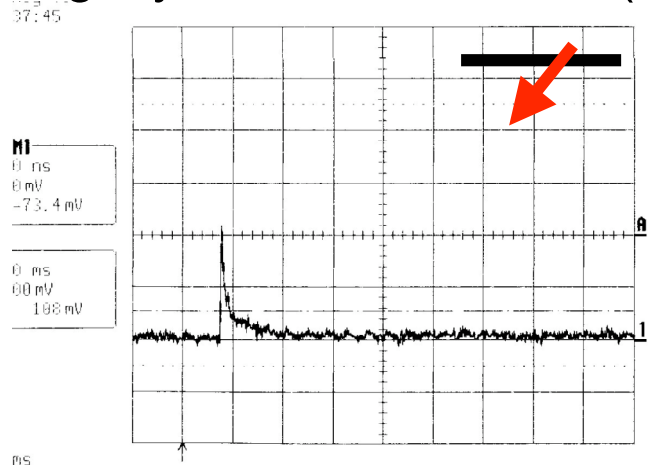
Tune at the beginning is below resonance (0).



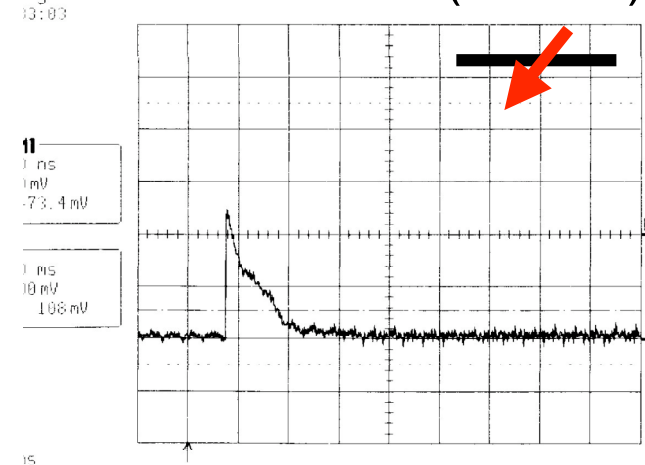
Tune at the beginning is on resonance (+0.011).



Tune at the beginning is slightly above resonance (+0.022).

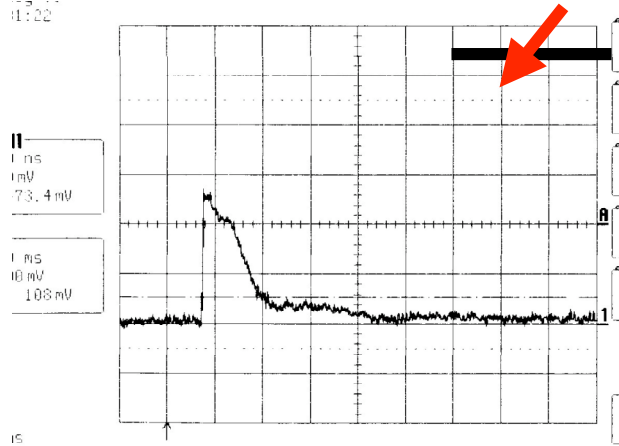


Tune at the beginning is above resonance (+0.033).

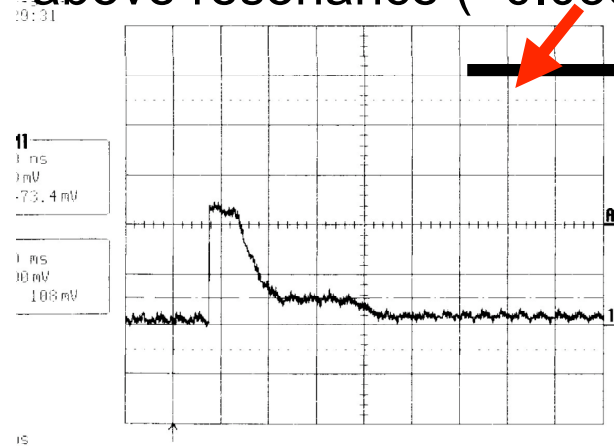


Beam loss pattern (cont.)

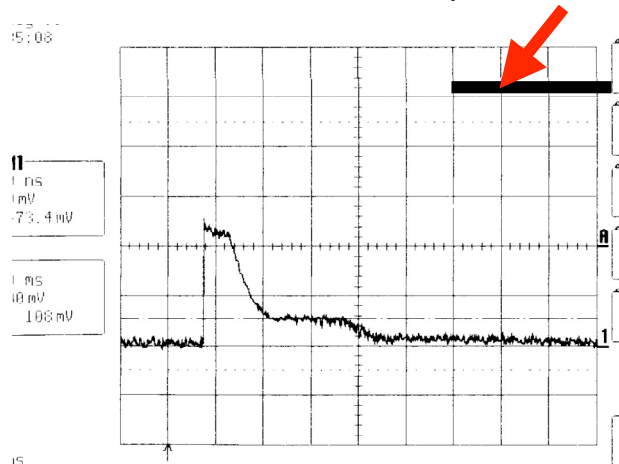
Tune at the beginning is above resonance (+0.044).



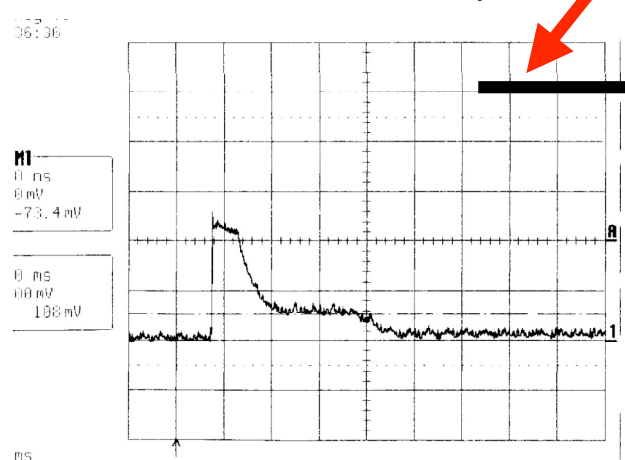
Tune at the beginning is above resonance (+0.055).



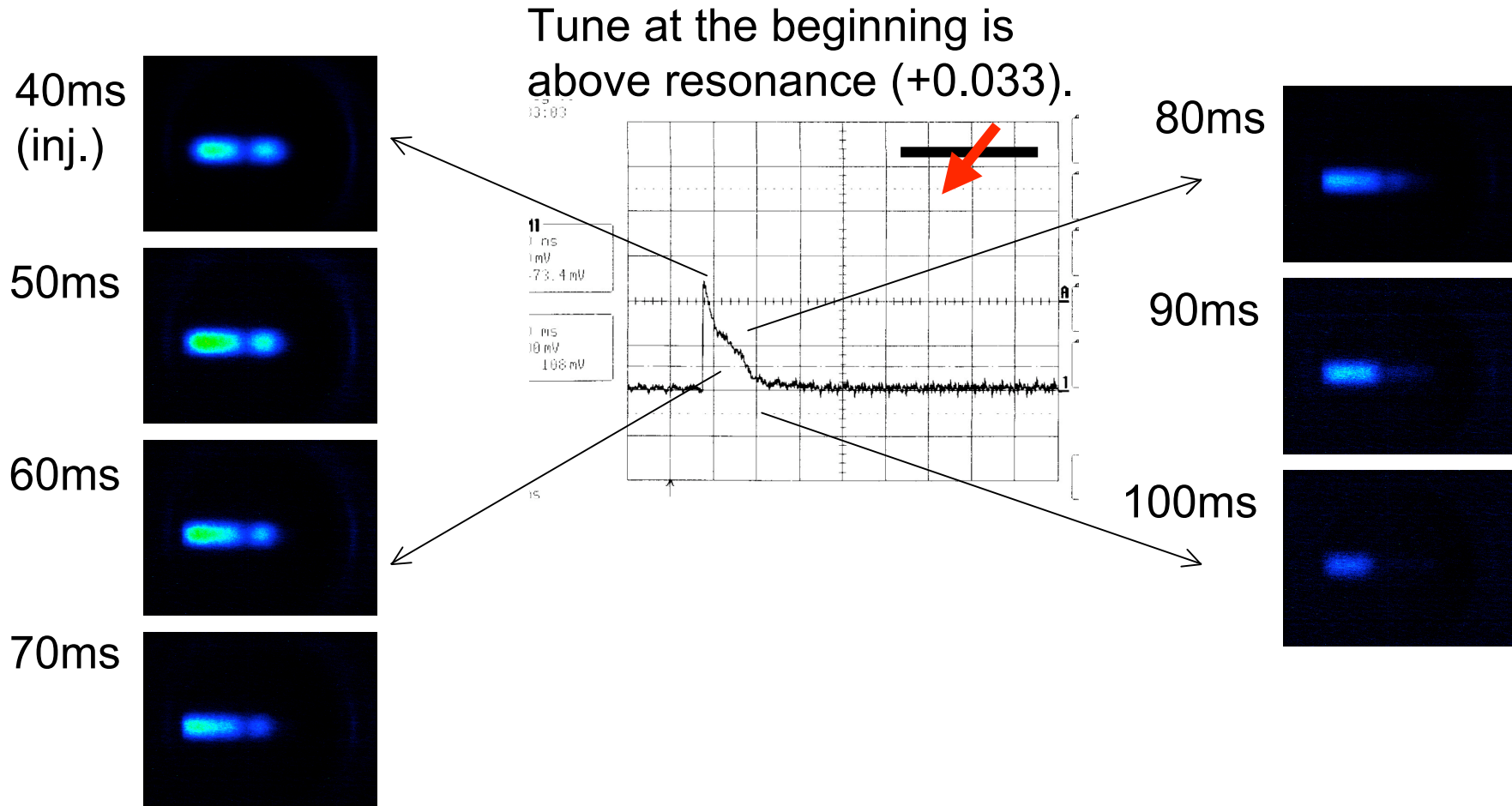
Tune at the beginning is above resonance (+0.066).



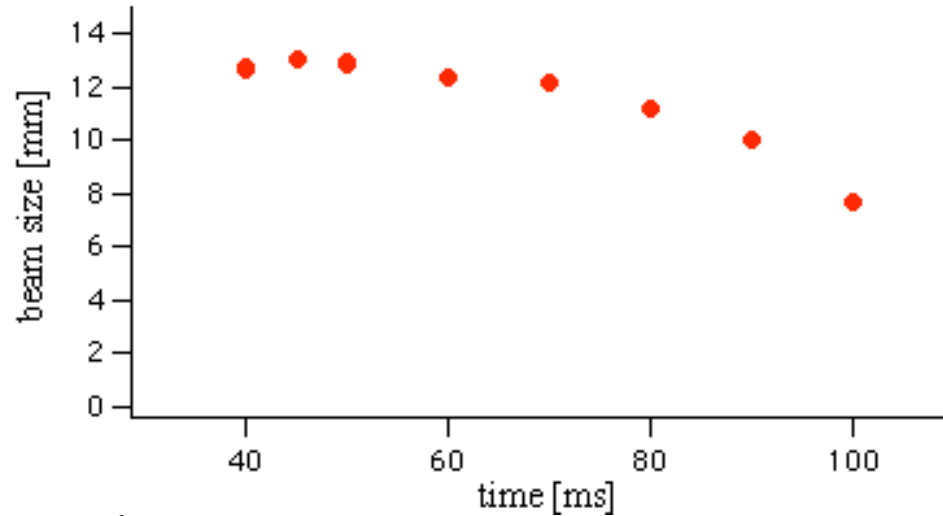
Tune at the beginning is above resonance (+0.077).



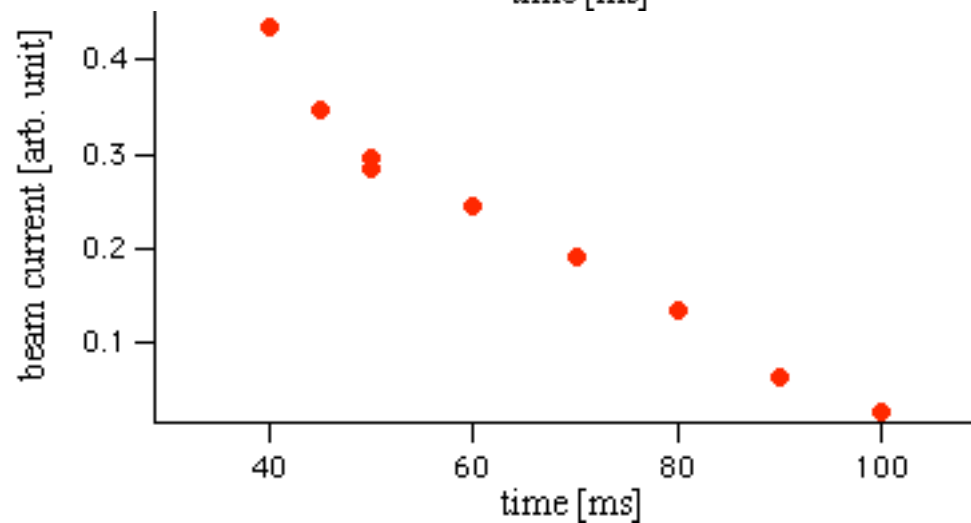
Beam profile evolution



Vertical beam size and beam current



Vertical beam size

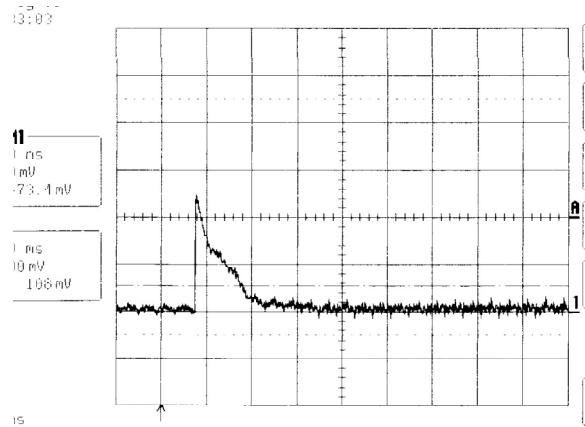


Beam current

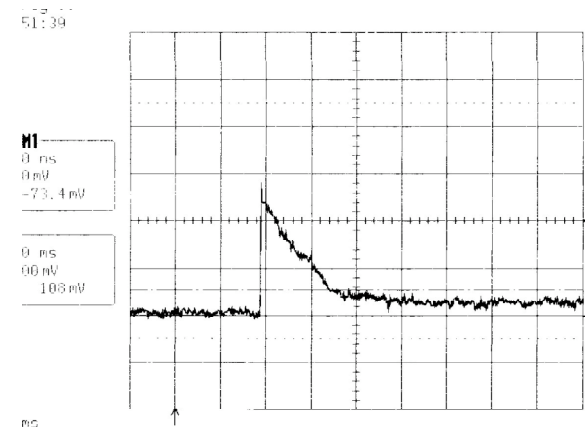
A little increase of vertical beam size and beam loss afterwards. Particles do not survive.

Increase of accelerating rate

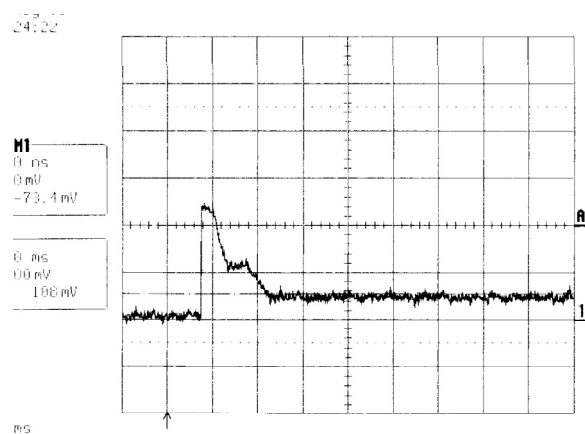
$df/dt = 26 \text{ kHz/s}$



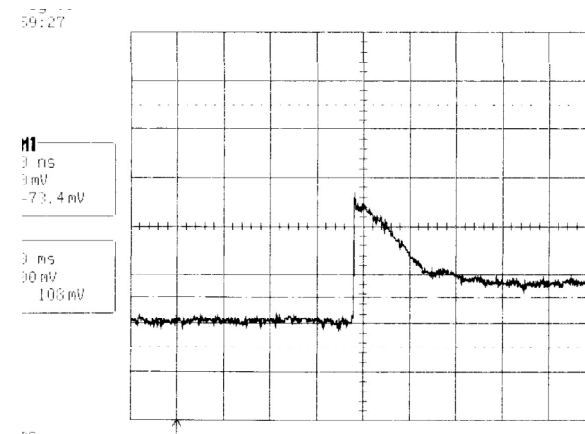
$df/dt = 52 \text{ kHz/s}$



$df/dt = 65 \text{ kHz/s}$

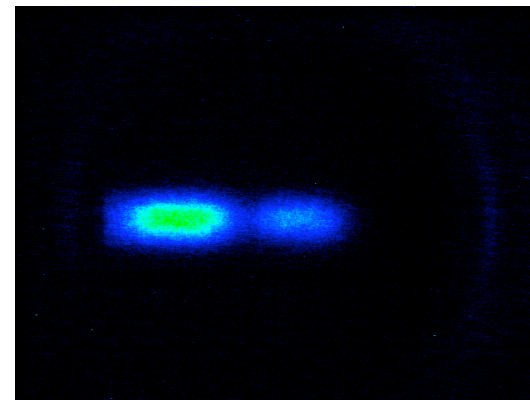
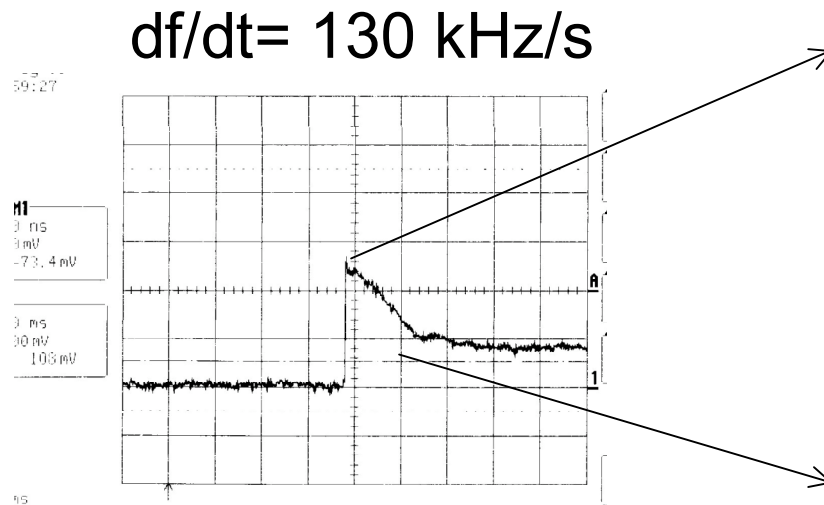


$df/dt = 130 \text{ kHz/s}$

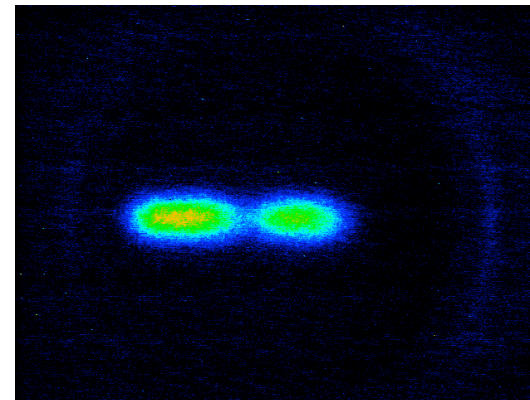


When df/dt is increased,

Particles are not captured because RF voltage is not enough.



50ms



100ms

Summary

- Fixing magnetic field of HIMAC, non-scaling FFAG was simulated.
- Particles are lost at half-integer.
 - Crossing speed $\Delta v/dt = -0.0005/\text{ms}$
 - Resonance width ~ 0.02
- When df/dt is increased, particles are not trapped because RF voltage is not enough.
- We will try again next month with
 - Correction of resonance to reduce width.
 - Optimization of RF voltage and pattern.
- Similar experiments should be possible in other synchrotron (before construction of e-model).