Linear Resonances with Intense Space Charge at the University of Maryland Electron Ring (UMER)

Chao Wu, Eyad Abed, Santiago Bernal, Brian Beaudoin, Max Cornacchia, Irving Haber, Rami Kishek, Christos Papadopoulos, David Sutter, Martin Reiser, J.C.T. Thangaraj, Patrick O'Shea

Department of Electrical and Computer Engineering
and Institute for Research in Electronics and Applied Physics

University of Maryland, College Park, MD, 20742

Wednesday, August 27, 2008

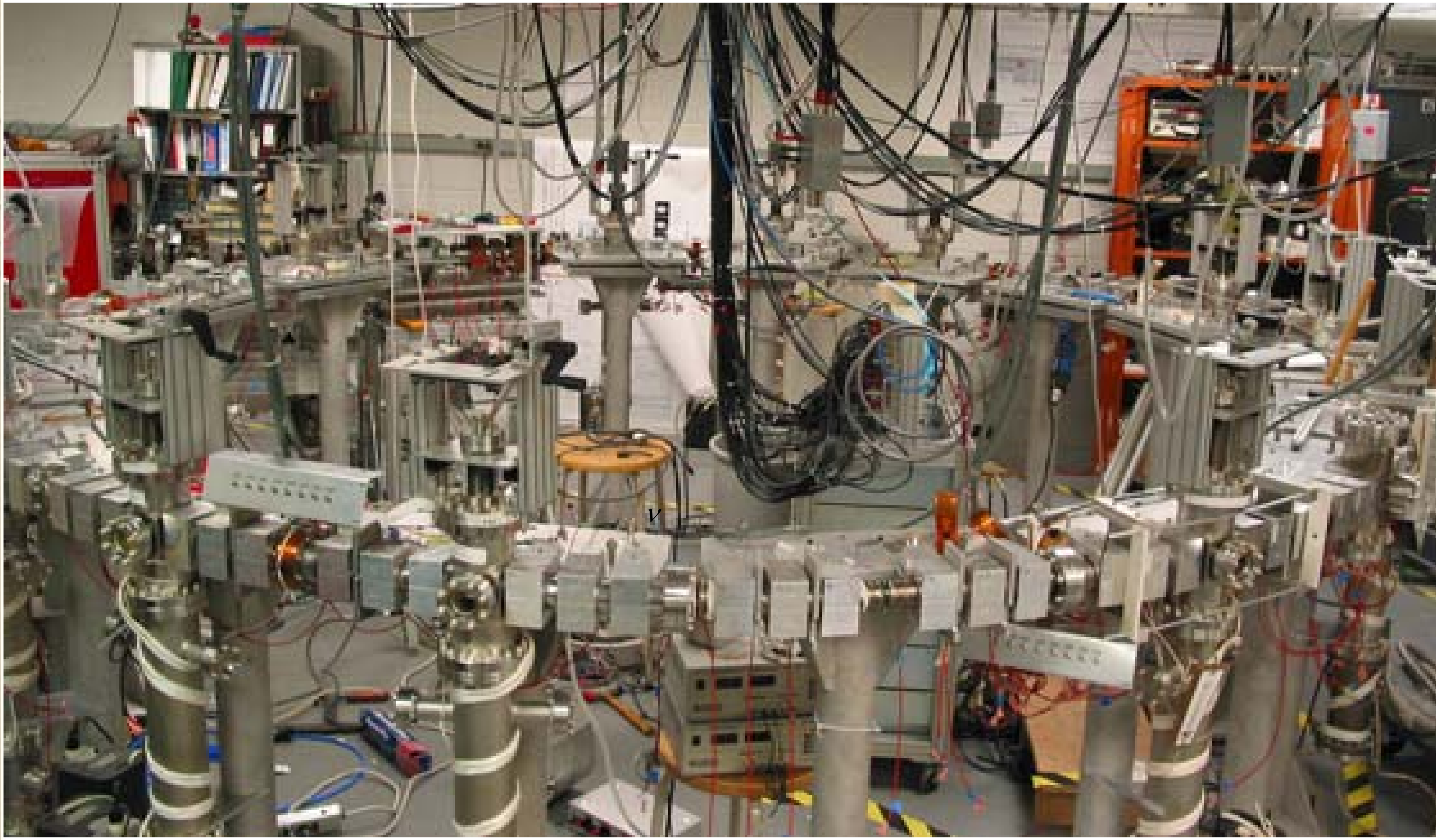
Outline

- Motivation
- Experimental results at UMER
- Simulation approach and results
  - Integer resonance
  - Half-integer resonance
- Summary

Motivation

- Issues:
  - Operating point and beam losses
  - Space charge effects: tune shifts
  - Discrepancies between measured and calculated/simulated betatron tunes
  - Effects of lattice errors and mismatch
- General Goals:
  - 100 turns at low current, 10 turns at high current w/o beam losses and $\varepsilon_f / \varepsilon_o < 4$
  - Benchmarking of codes (WARP, ELEGANT, WinAgile)

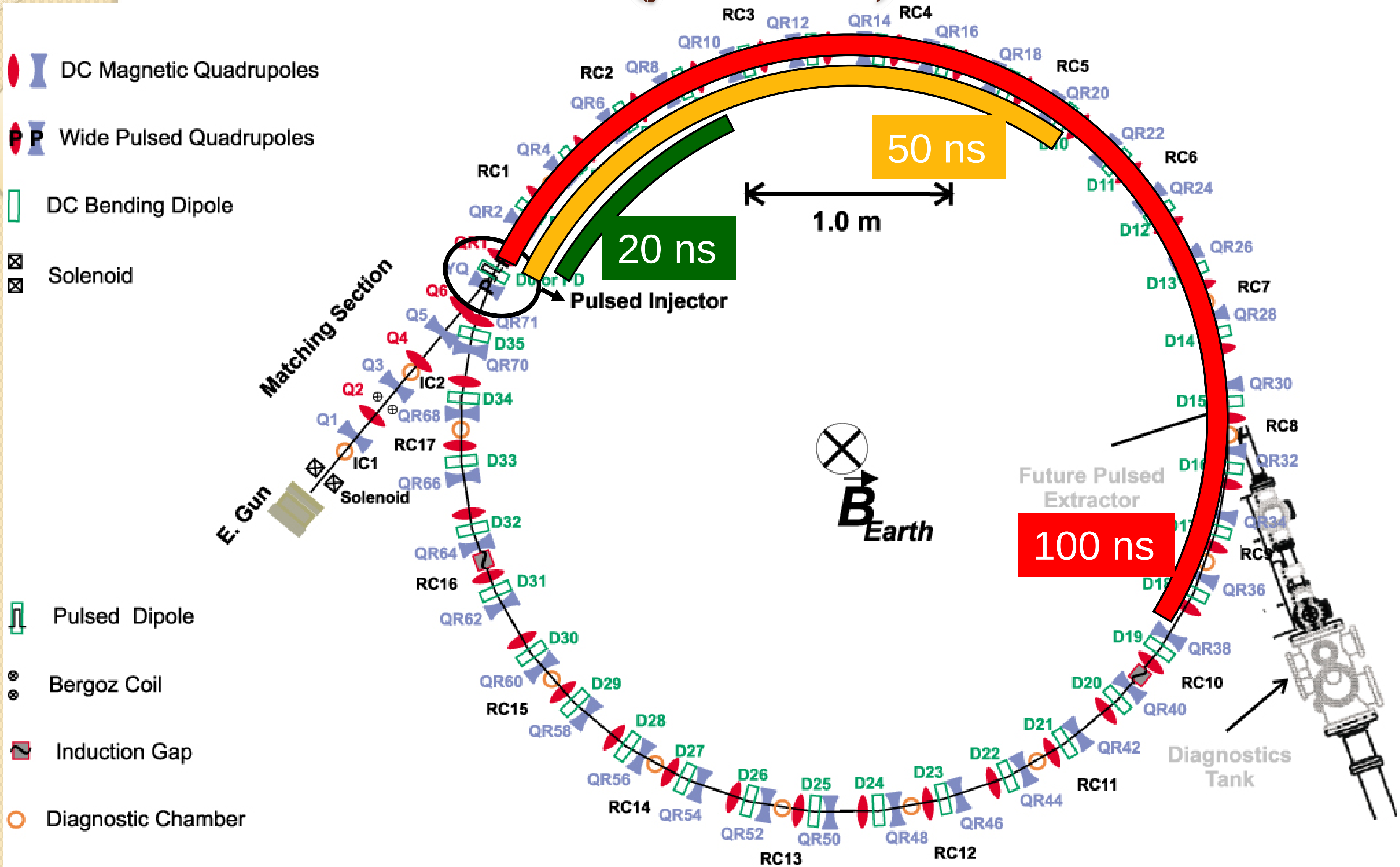
University of Maryland Electron Ring



Energy	10 keV
Current Range	0.7-100 mA

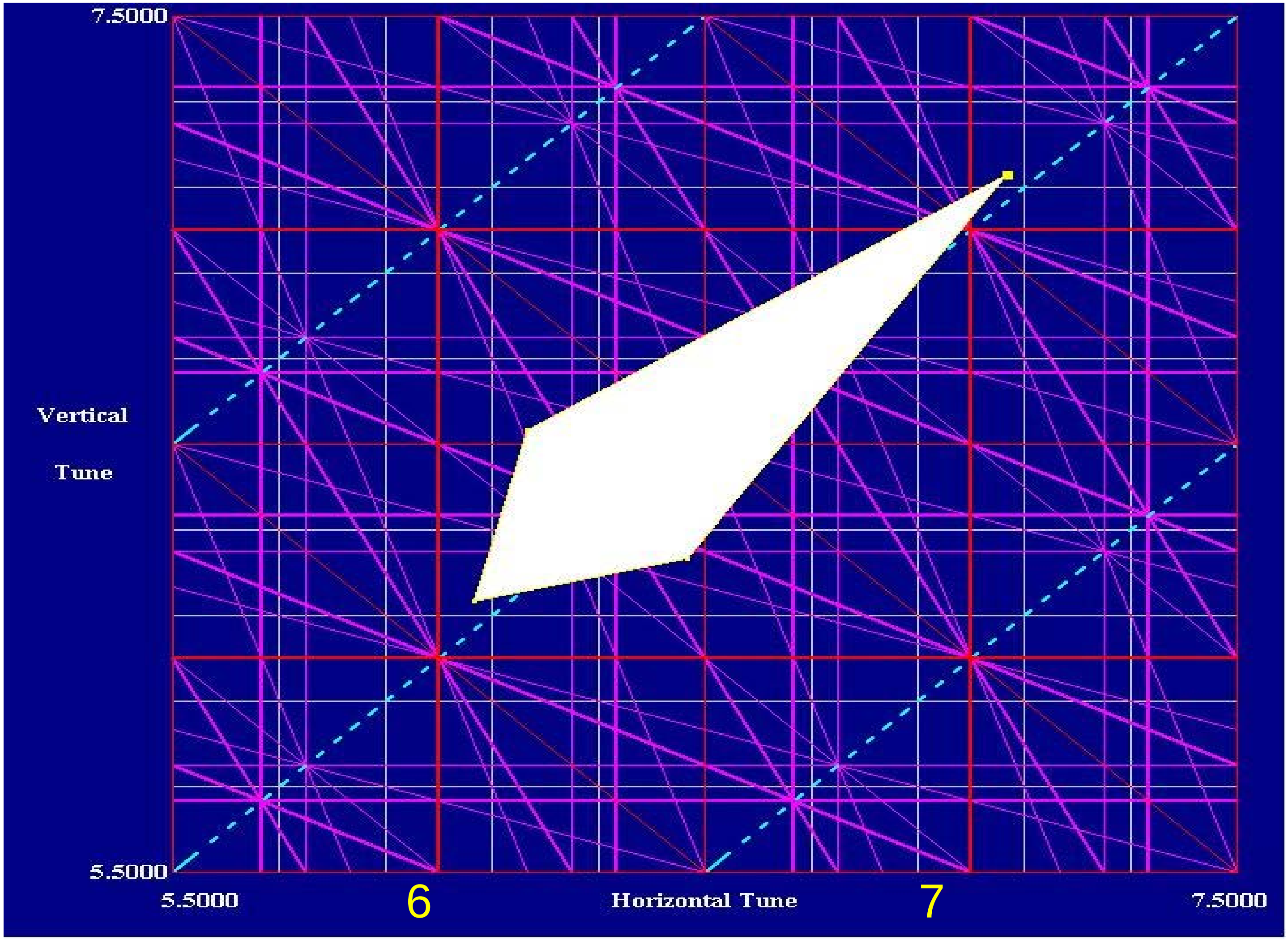
Beam current	0.7mA	7mA	23mA
ν/ν_0 At 61.7^o	0.82	0.56	0.34

UMER: 10 keV ($\beta = 0.2$)



5

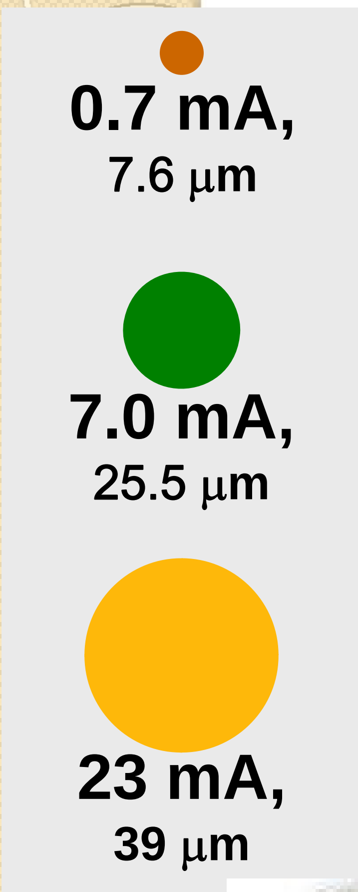
UMER lowest beam current: very large inc. $\Delta\nu$



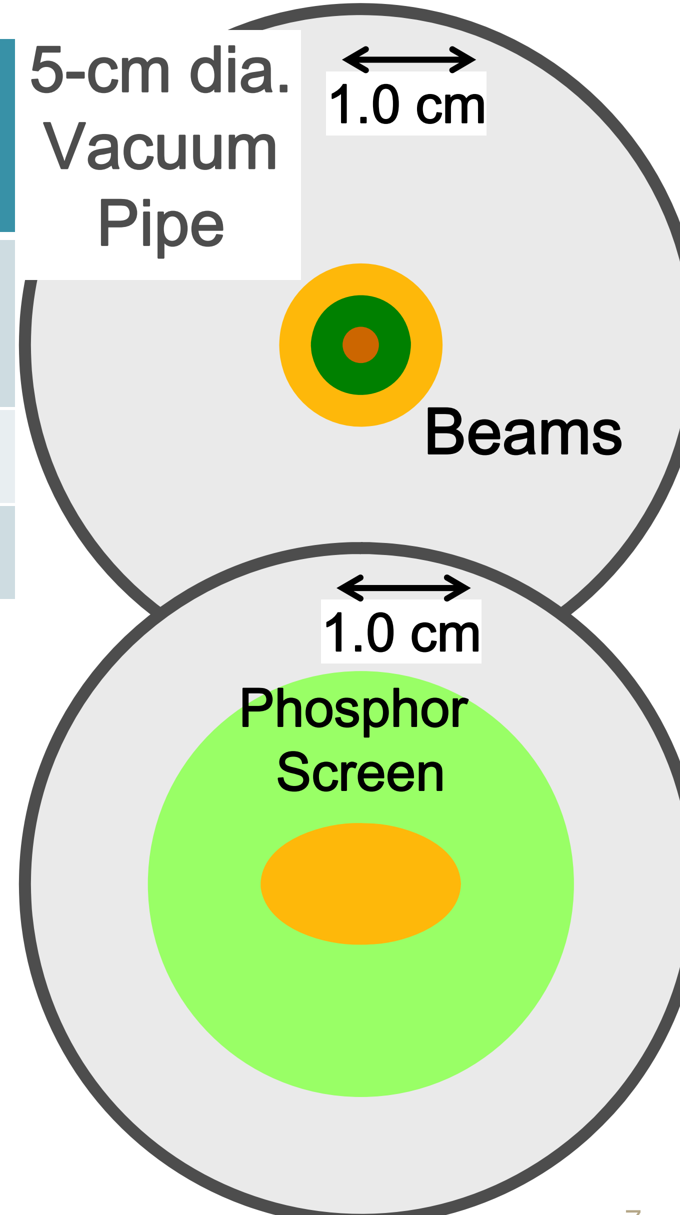
Laslett Tune shift limit: $\Delta\nu < 0.25$

Credits: Santiago Bernal, output of WinAgile code

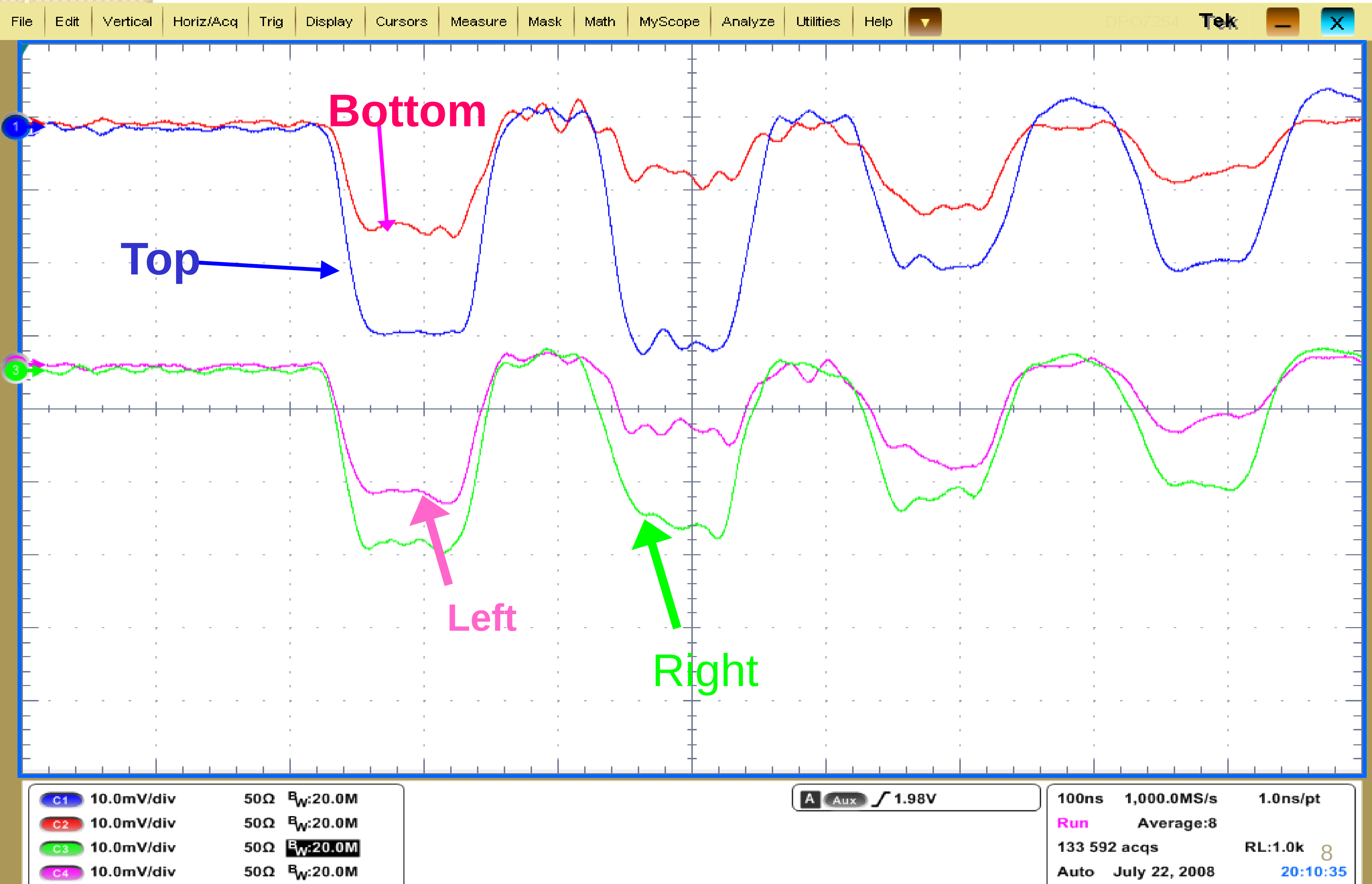
Three 10 keV Electron Beams



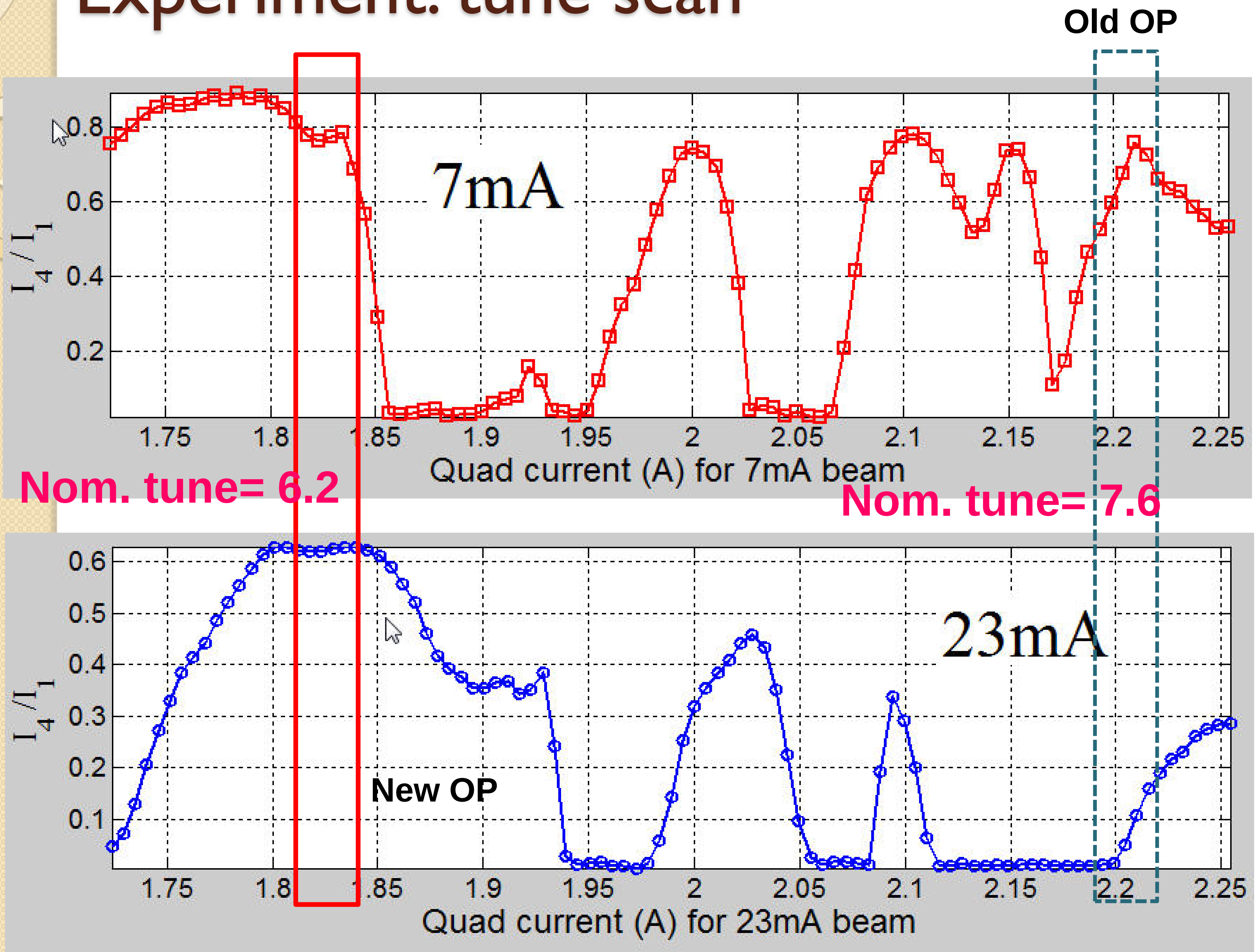
	0.7 mA	7.0 mA	23.0 mA
Nom. tune	6.17	6.17	6.17
$\Delta\nu$_inc	1.1	2.7	4.1
$\Delta\nu$_coh	0.02	0.08	0.20



Experiment: BPM RC11 signal



Experiment: tune scan



Simulation model (1)

- Particle-in-cell code WARP*,

- Initial Semi-Gaussian distribution,
- Constant earth field, By=0.4 Gauss,
- Ignore the injection,
- Magnets include full fringe fields and nonlinearities,
- Particle number np=20,000, grid nx=ny=256, ds=0.002m,

- Use 4-turn measurement approach to obtain fractional tune and equilibrium orbit**
- * Ref: D. Grote, et.al, Fus. Eng. & Des. 32-33, 193-200 (1996); A. Friedman, *et al.*, Nuclear Instruments and Methods A 544 (2005).
- ** Ref: J. Koutchouk, Frontiers of Particle Beams: Observation, Diagnosis and Correction, Proceedings, Anacapri, Isola di Capri, Italy, 1988 (Lectures Notes in Physics 343, M. Month, S. Turner –Eds-) p 46.

Fractional tune and closed orbit calculation

Let's assume that the beam has small oscillations around a closed orbit ***X***. At turn n, the beam position is

$$x_n = X + [\cos(n\mu) + \alpha \sin(n\mu)]x_0 + \beta x_0^{'} \sin(n\mu)$$

where α, β are the Courant-Snyder parameters, $x_0 , x_0^{'}$ and are the unknown initial conditions. With some manipulations, we have

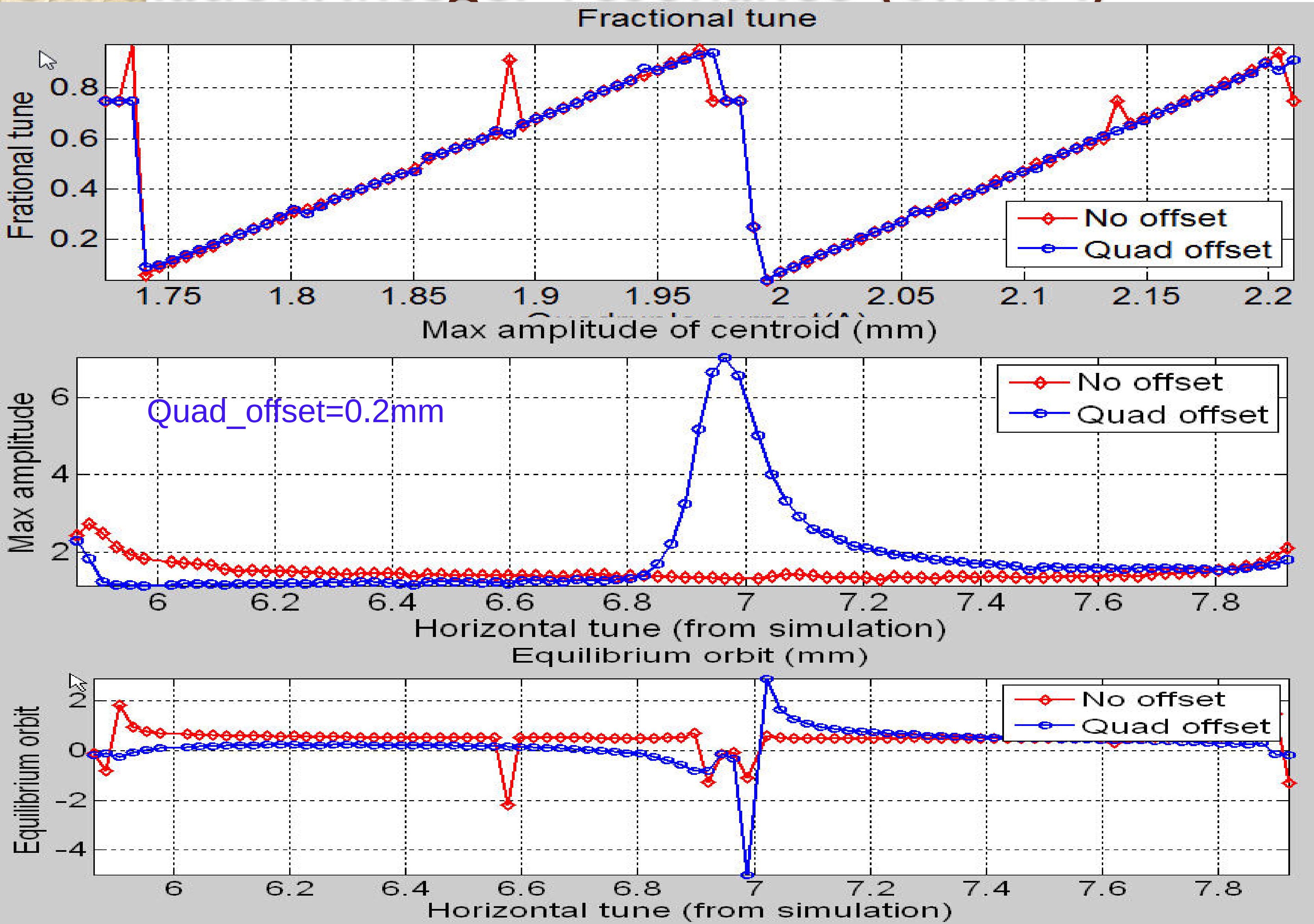
$$\cos 2\pi\mu = \frac{x_n - x_{n+1} + x_{n+2} - x_{n+3}}{2\left(x_{n+1} - x_{n+2}\right)}$$

$$x_{co} = \frac{x_{n+1}^2 - x_{n+2}^2 + x_{n+1}x_{n+3} - x_{n+2}x_n}{3\left(x_{n+1} - x_{n+2}\right) + x_{n+3} - x_n}$$

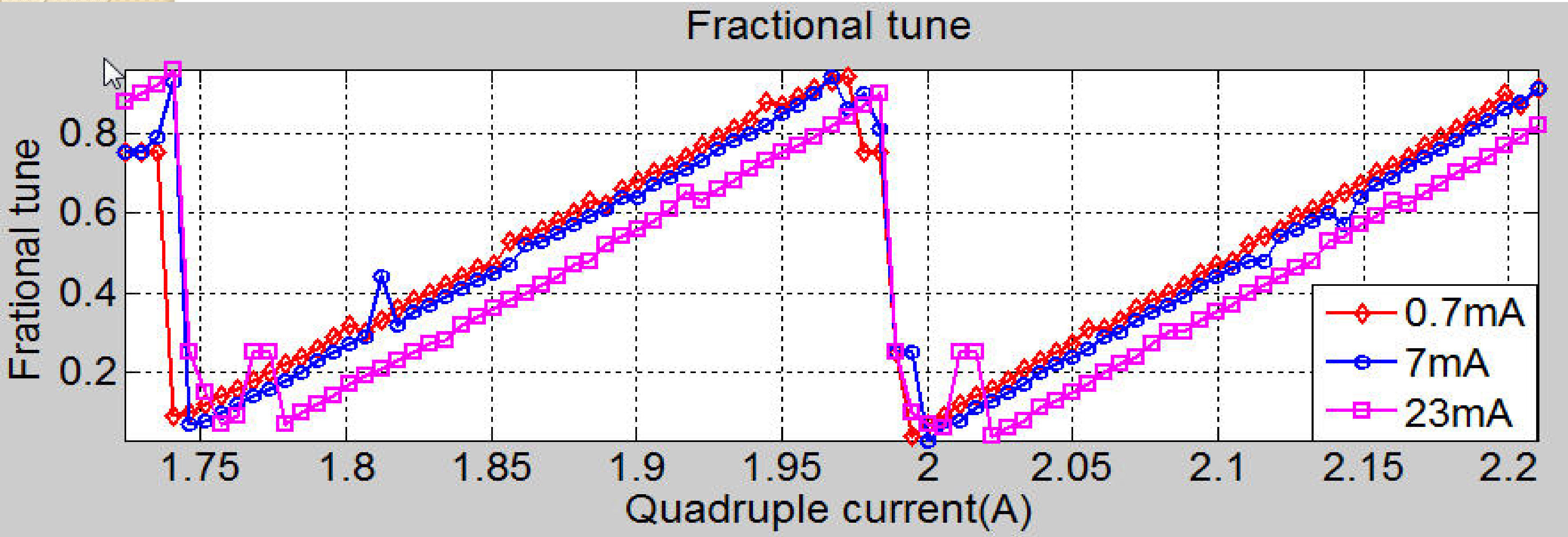
Simulation model (2)

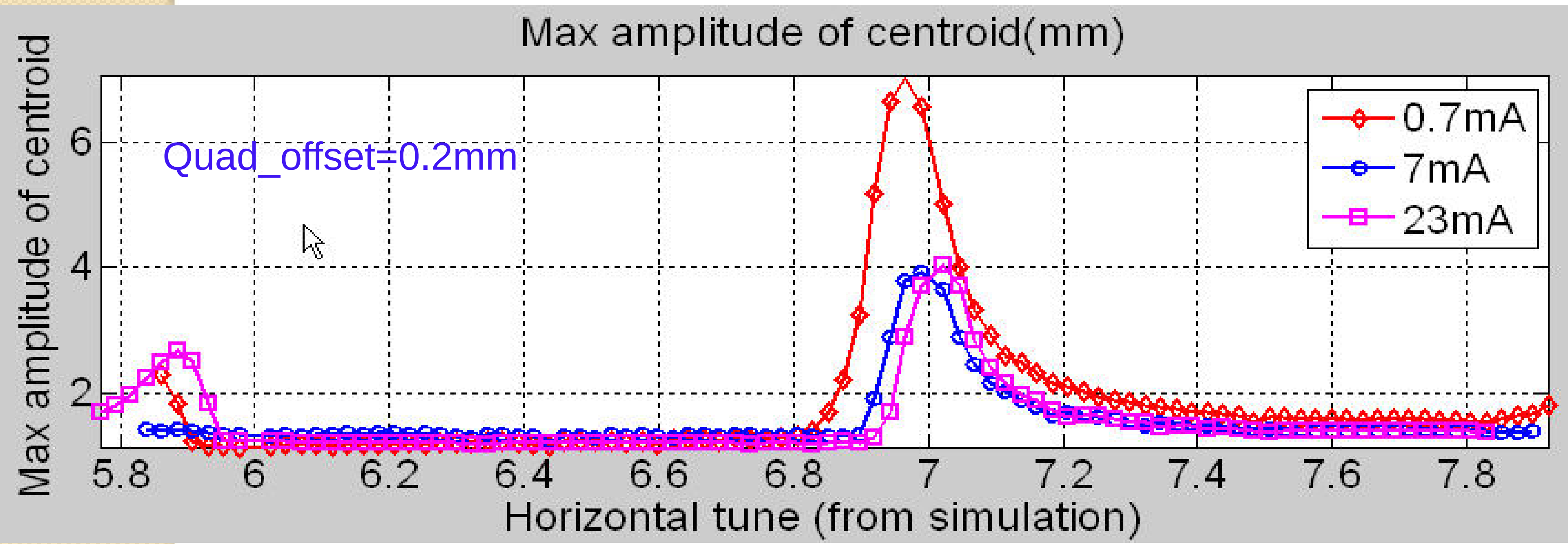
- Case 1: no quadrupole alignment errors
- Case 2: random quadrupole alignment errors in horizontal plane
  - Uniformly distributed, $\sigma = 0.0539$ mm
- Case 3: random quadrupole strength error
  - Uniformly distributed, $\sigma = 0.0366$

Simulation: integer resonance (0.7mA)

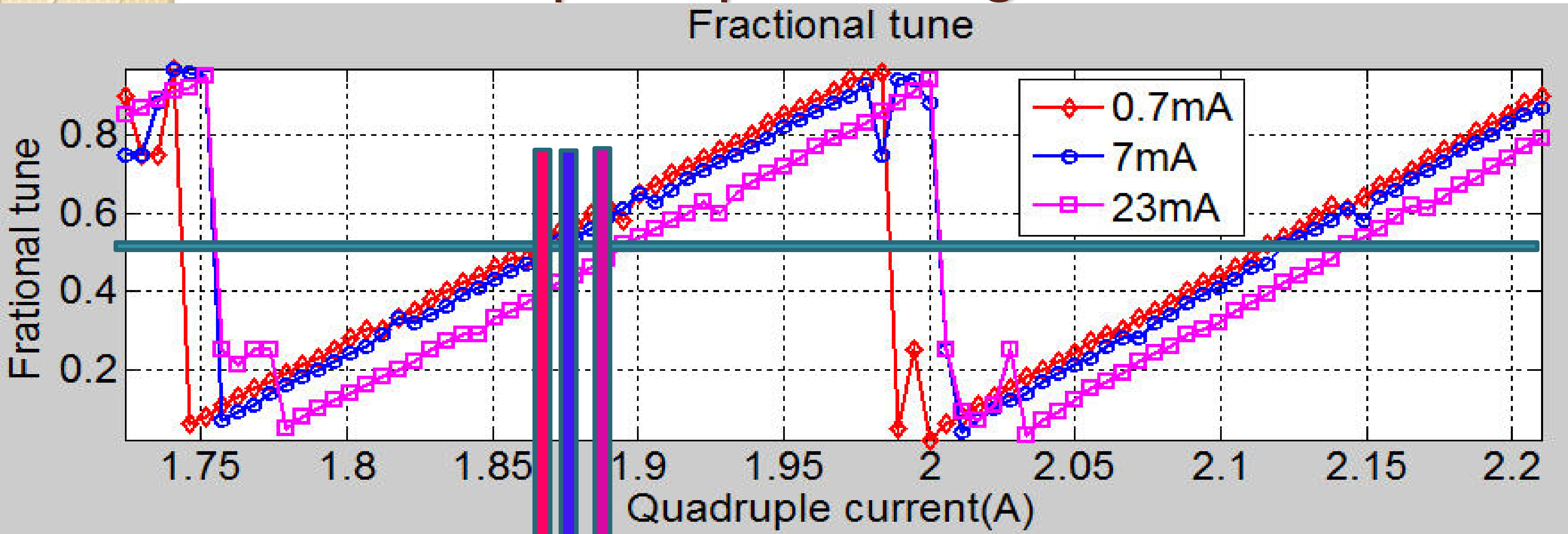


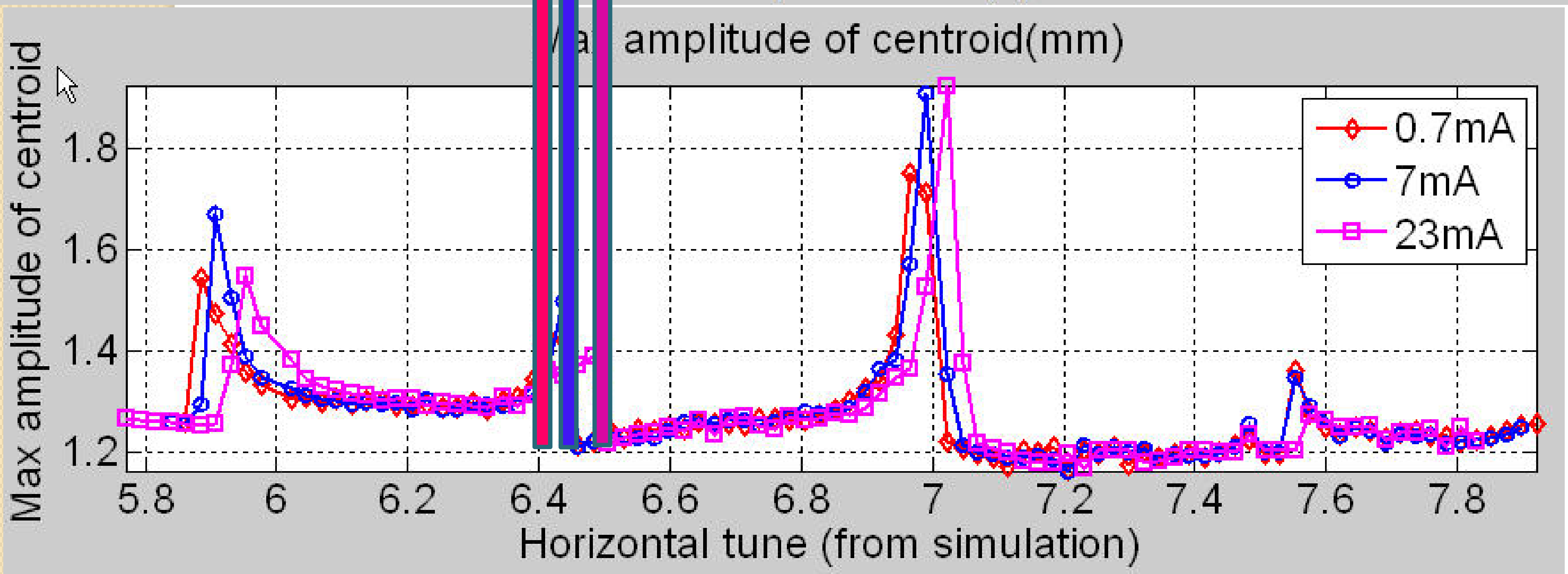
Simulation: integer resonance, quad alignment error





Case 3: Pure quadrupole strength error





Summary

- UMER operates in a regime of extreme space charge,
- A preliminary study of linear resonances in UMER was undertaken both in experiments and simulations,
- The integer resonance for low current appears to be much stronger than for high current for which space charge plays a “detuning” effect,
- Coherent effects from space charge clearly shift the ½-integer resonance points,
- Future work will include higher harmonic errors, injection/recirculation, beam losses, detailed rms envelope matching, and incoherent space charge effects.