Frequency Map Experiments at the Advanced Light Source

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Advanced Light Source

work done in collaboration with

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Outline

Calibrating the linear model

On-energy frequency map measurement

Beam lifetime dependence on the momentum aperture

- RF Momentum Aperture
- Physical Momentum Aperture
- Dynamic Momentum Aperture

Measurements of the momentum aperture

- RF Scans

Measurements of the dynamic momentum aperture

- Pinger Scans
- Effect of small vertical gaps

Conclusion

Tools and Techniques for Understanding the Dynamics

Linear lattice

- Quadrupole variation
- Response Matrix Analysis
- Turn-by-turn phase advance and coupling measurements
- Tunescans

Nonlinear lattice

- Scraper scans
- RF scans
- Resonance and beam loss scans
- Dynamic aperture studies
- Frequency Map Analysis

Tools and Techniques

The nonlinear dynamics in the ALS is determined by the sextupoles and the linear transport between them

- ***Other effects such as fringe fields, high order multipoles are not critical in obtaining a good model of the dynamics***

Tools and techniques

- **Response matrix analysis (LOCO)**
  - **Calibrate the linear model**
- **Symplectic integration and Frequency Map Analysis**
  - **Simulate the nonlinear dynamics and to get a global view of the dynamics**
- **Single turn kickers and BPMs, DCCT and RF scans**
  - **Test the model predictions**
  - **Model independent determination of the dynamics**

Calibrating and correcting the linear model

Response Matrix Analysis

Corbett, Lee and Ziemann (PAC,1993) and Safranek, (Nucl. Inst. and Meth, 1997)

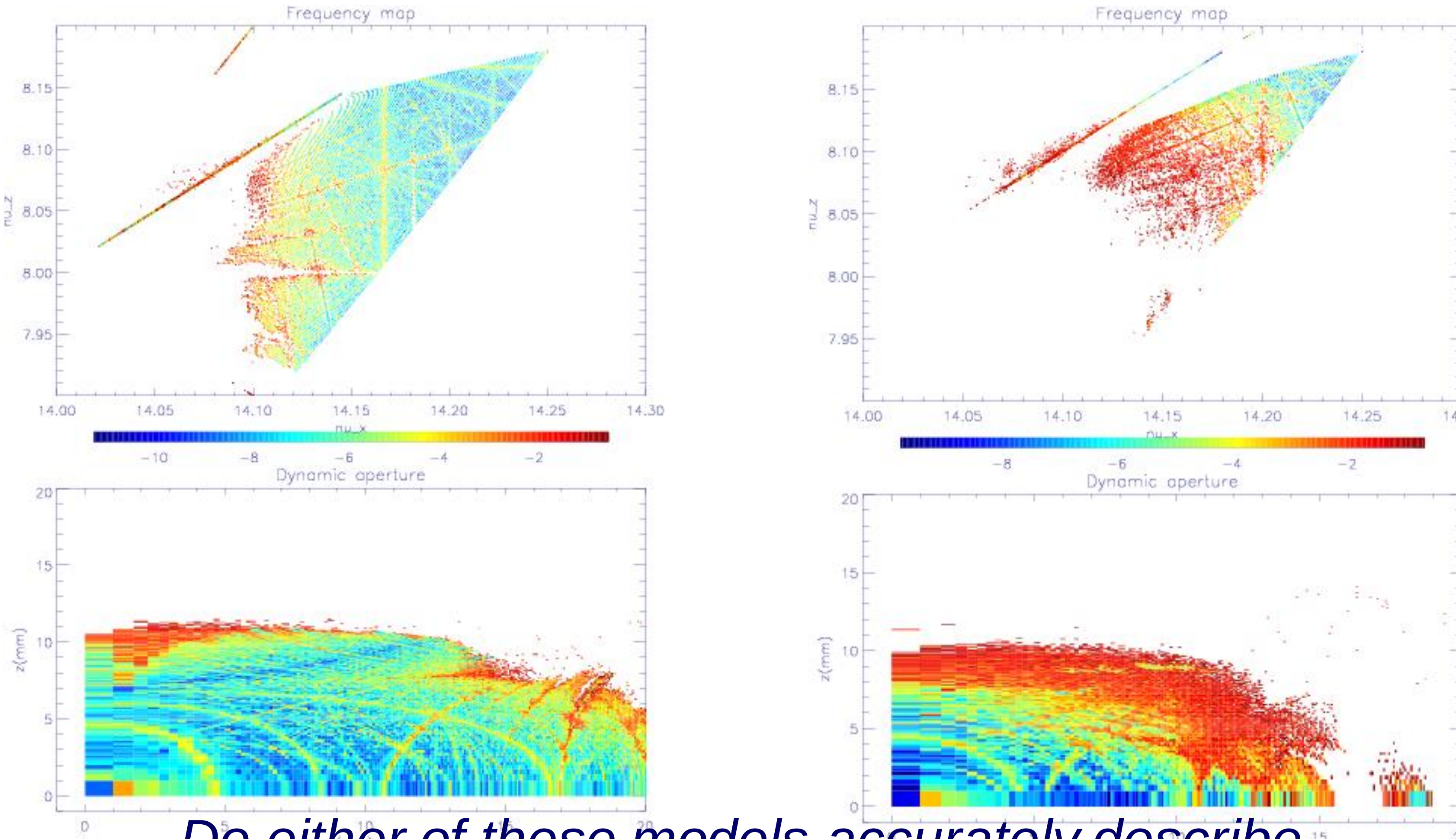
By measuring and modeling orbit response matrix data one can fit the machine model to minimize the difference in the two response matrices

Response Matrix Analysis (LOCO) is routinely used at the ALS

- Calibrate the fully coupled model
- Adjust individual quadrupole gradients to restore the lattice periodicity
  - After correction the rms β–beating is less than 1%

Robin, Decking, and Safranek, (Phys. Rev. ST Accel., 1999)

ALS : Ideal Lattice versus Calibrated Model

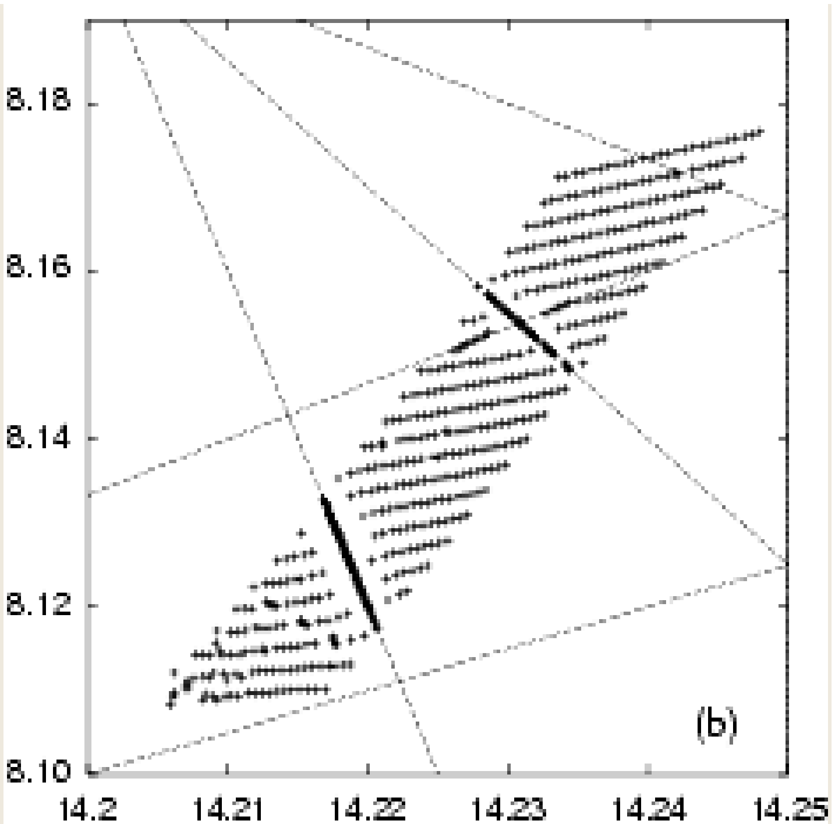


Do either of these models accurately describe the dynamics in the real ring? =>

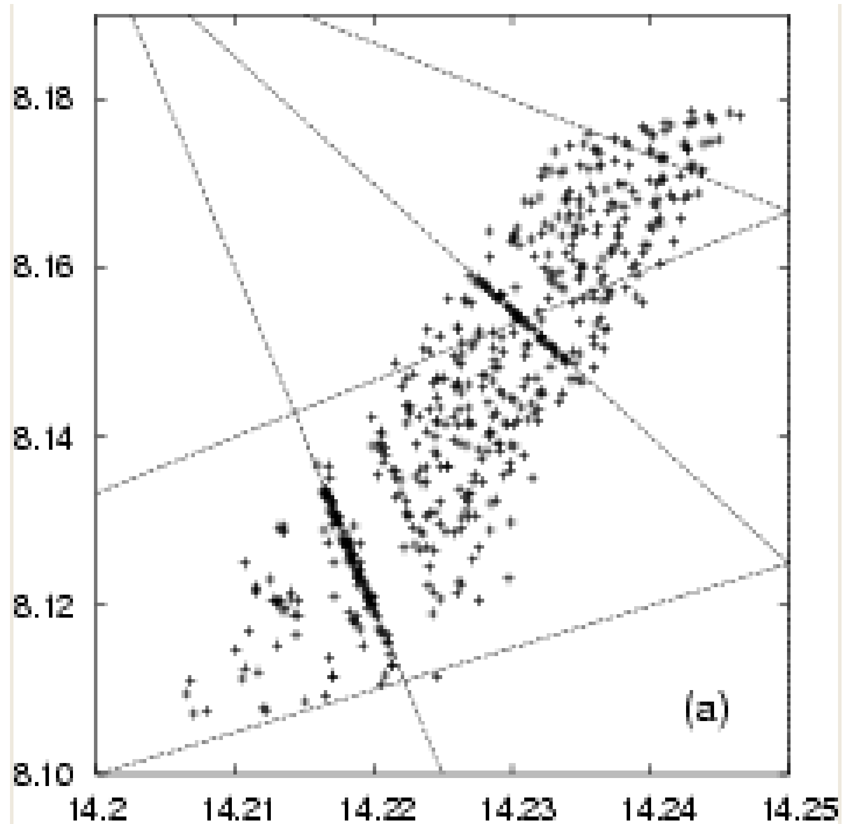
Can test models with Measured Frequency Maps

Measured versus Calculated Frequency Map

Modeled



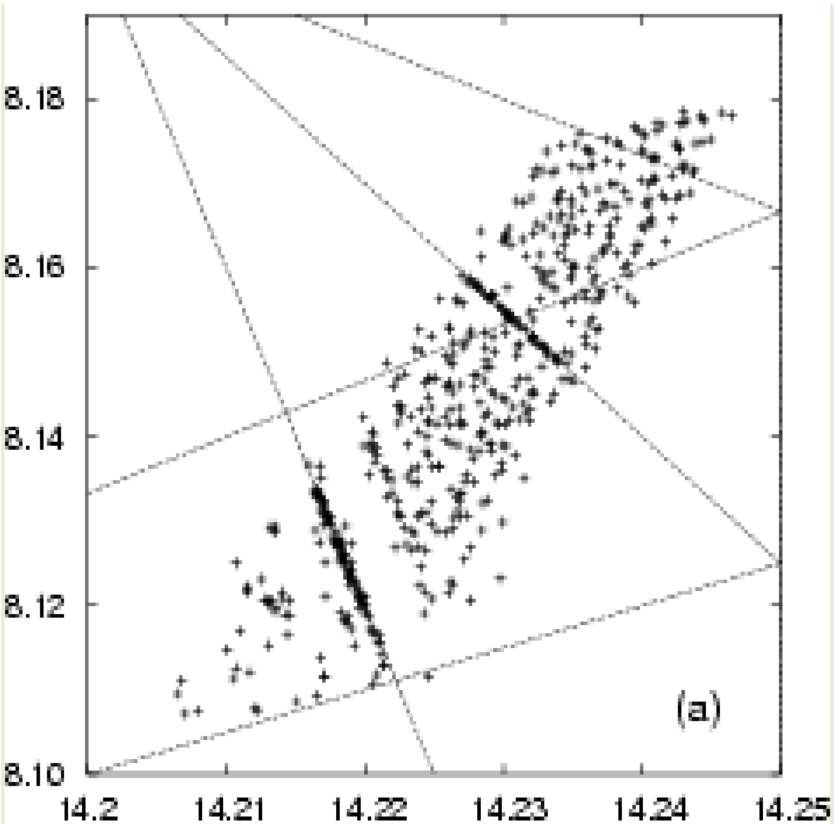
Measured

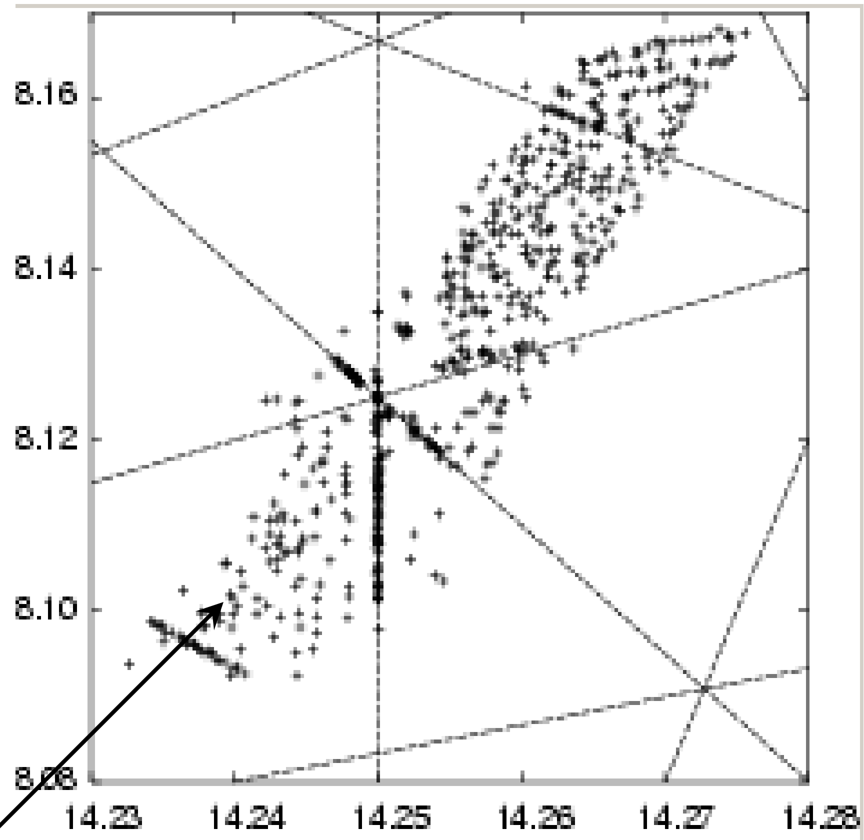


See resonance excitation of unallowed 5th order resonances

No strong beam loss ➔ isolated resonances are benign

Frequency Maps at Different Working Points





Region of strong beam loss

Dangerous intersection of excited resonances

Momentum Aperture

Momentum Aperture, ε:

The maximum momentum that a particle can gain or loose and still remain in the ring

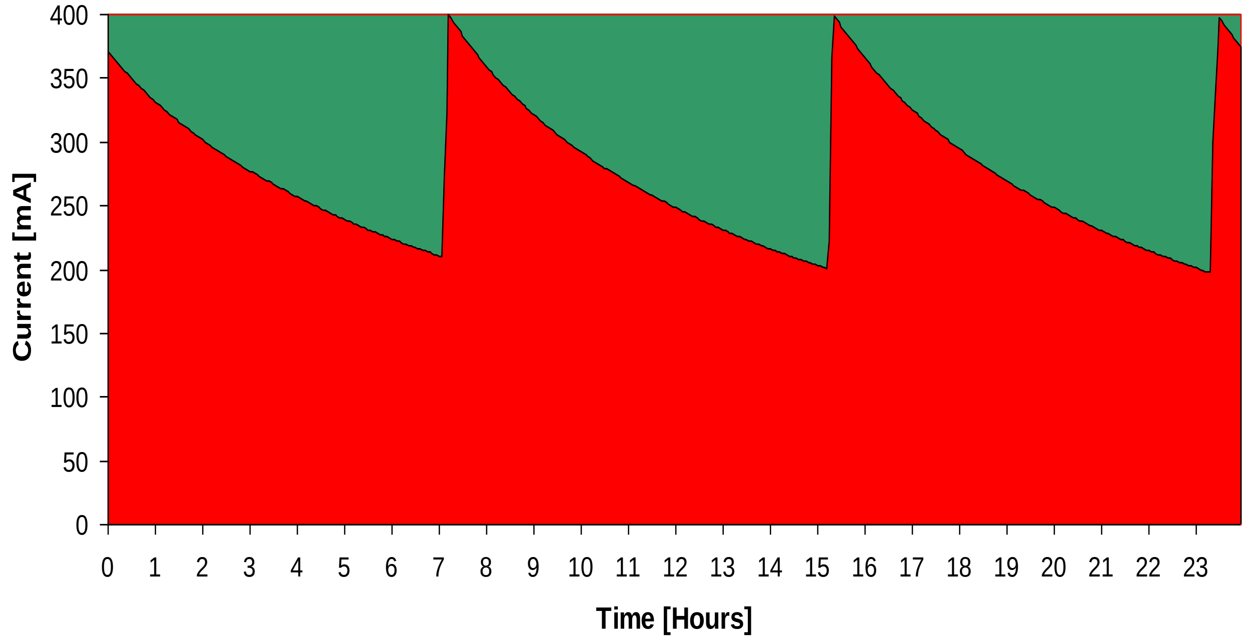
- **Beam lifetime is a strongly dependent upon the momentum aperture – larger than quadratic**
- **Design goal for future light sources (Soleil, Diamond) is to achieve large momentum apertures (> 5%)**
- **Existing third generation light sources have not realized such large apertures (1 – 3%)**

Like to understand the limitation in existing light sources in order to:

1. **Improve their performance**
2. **Accurately predict the performance of upgrades and future sources**

ALS parameters and lifetime contributions

The ALS is filled 3 times daily to 400mA and decays down to 200mA in 8 hours (with time averaged current of 250mA)

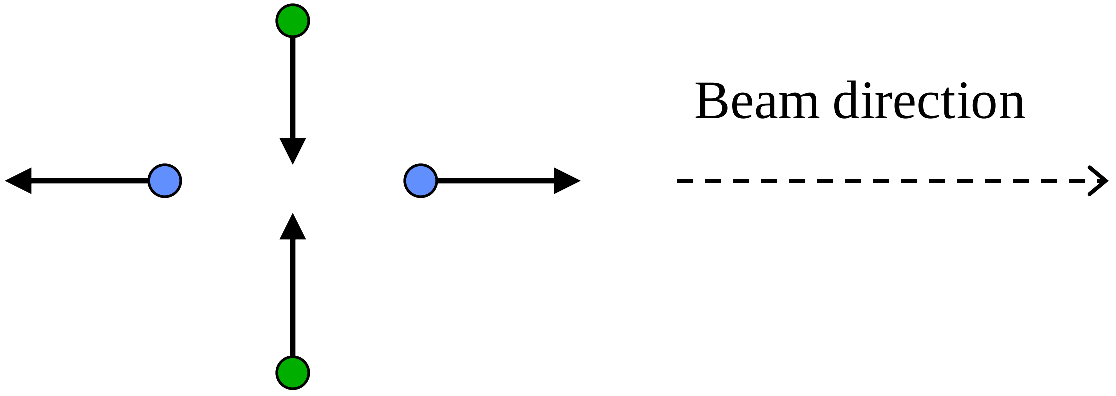


Parameters before Superbends

Beam Energy		1.5 – 1.9 GeV
Coupling		3.5%
Bunch Current		1.5 mA/bunch (at 400 mA)
Vacuum Lifetime		60 hours
Touschek Lifetime		**9 hours**
Total Lifetime		8 hours

Touschek Lifetime

Particles inside a bunch perform transverse betatron oscillations around the closed orbit. If two particles scatter they can transform their transverse momenta into longitudinal momenta.



If the new momentum of the two particles are outside the momentum aperture, ε, the particles are lost. The lifetime is proportional to the square of ε

$$\frac{1}{\tau_{tou}} \propto \frac{1}{E^3} \frac{I_{bunch}}{V_{bunch}\sigma_x^{'}} \frac{1}{\varepsilon^2} f\left(\varepsilon, \sigma_x^{'}, E\right)$$

What determines the momentum aperture, ε?

The Momentum Aperture

Momentum aperture, ε, is determined by one or more of the following things:

- ***RF Momentum Aperture:***

$$\varepsilon_{RF} \propto \pm\sqrt{\frac{V_{RF}}{\alpha h E}}$$

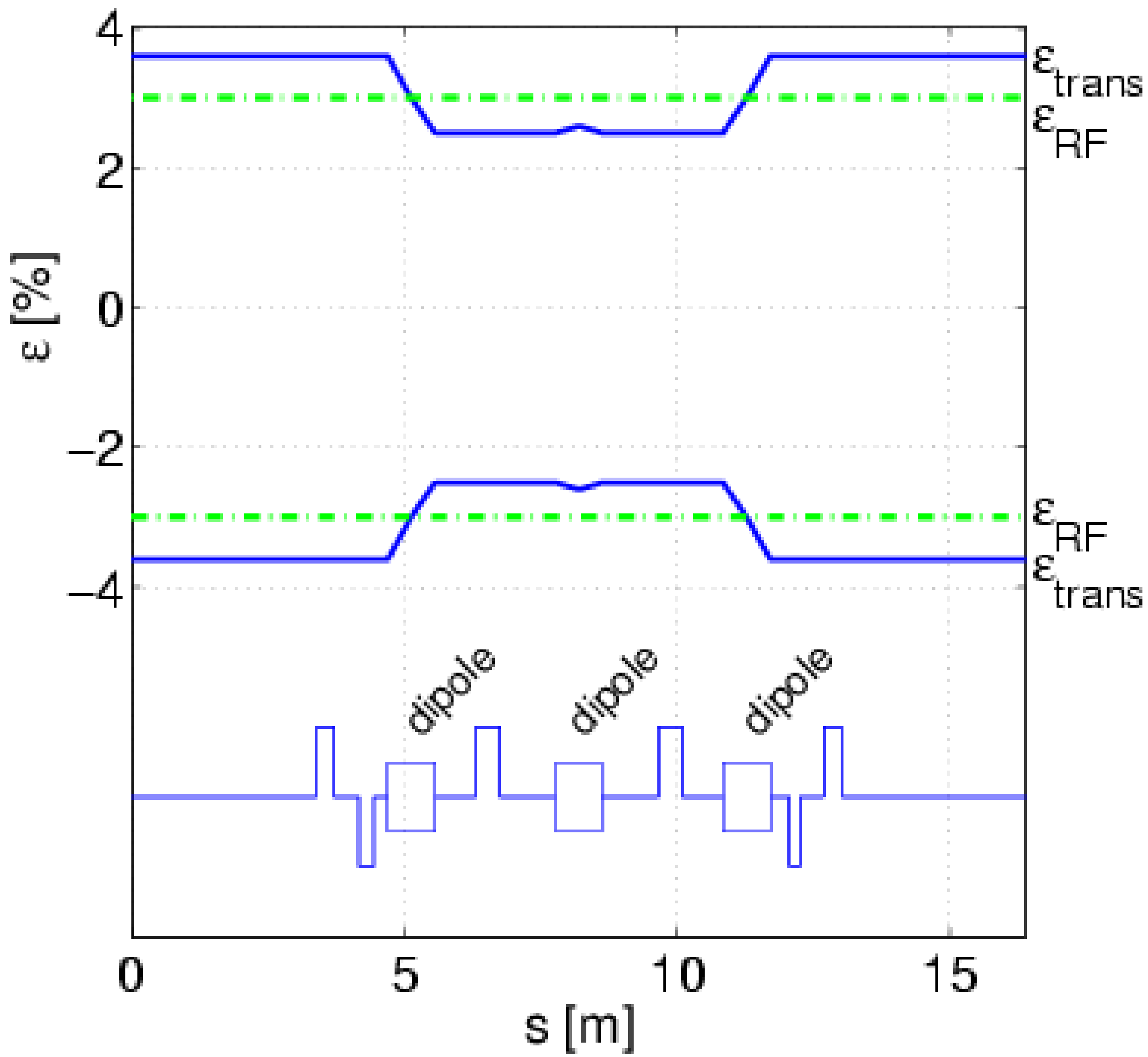
- ***Physical Momentum Aperture:***

$$A_{phys,x}(\delta) = \min\left(s \in [0,L]\right)\frac{\left(x_{vc.}(s) - (\eta(s)\delta + \ldots)\right)^2}{\beta_x(s)}$$

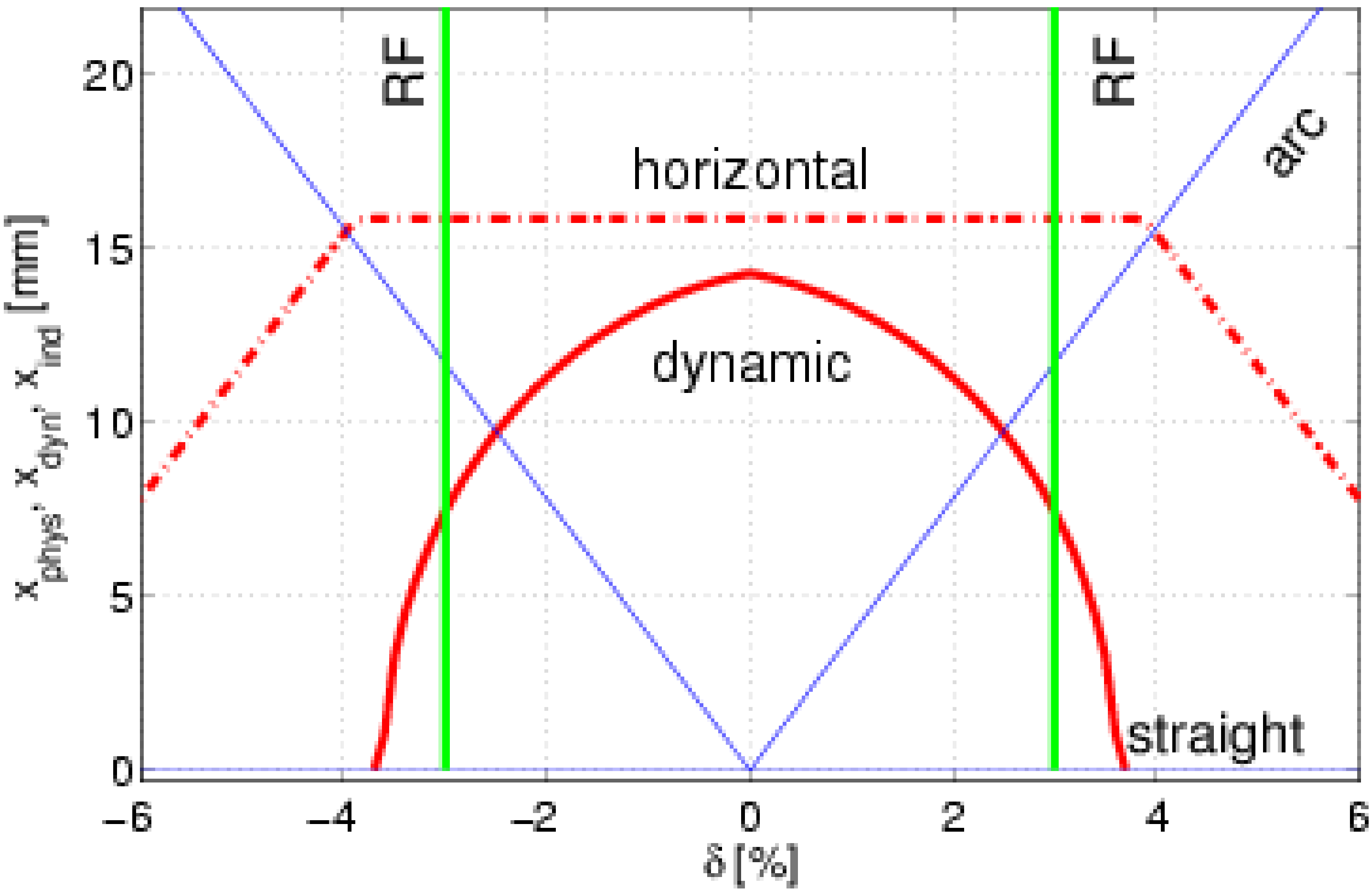
- ***Dynamic Momentum Aperture:*** $A_{dyn,x}(\delta)$

What limits ε(s) may be different in different parts of the ring

Position Dependent Momentum Aperture



Contributions to the momentum aperture



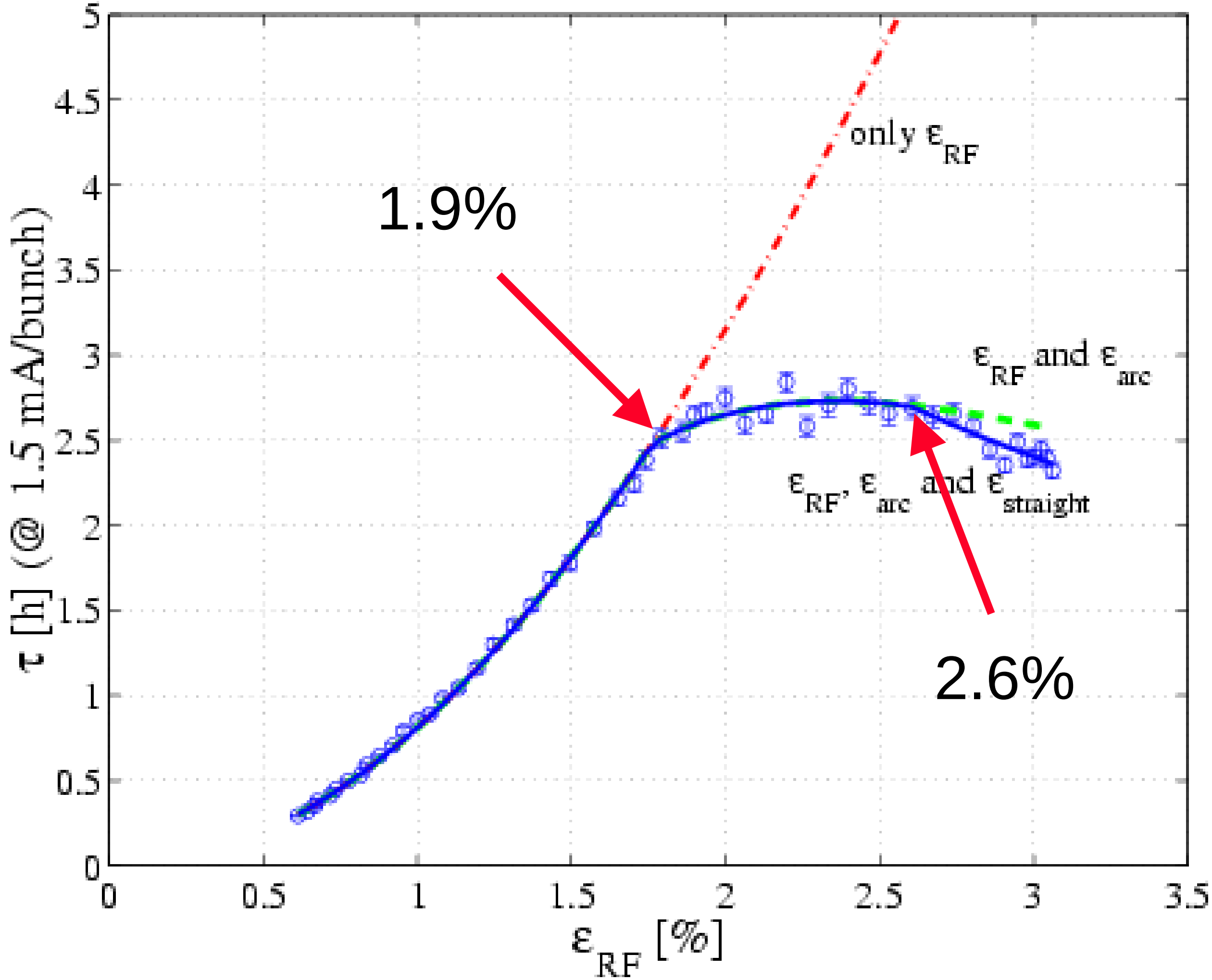
Measurements of Momentum Aperture

- Measure Touschek lifetime as a function of RF-voltage

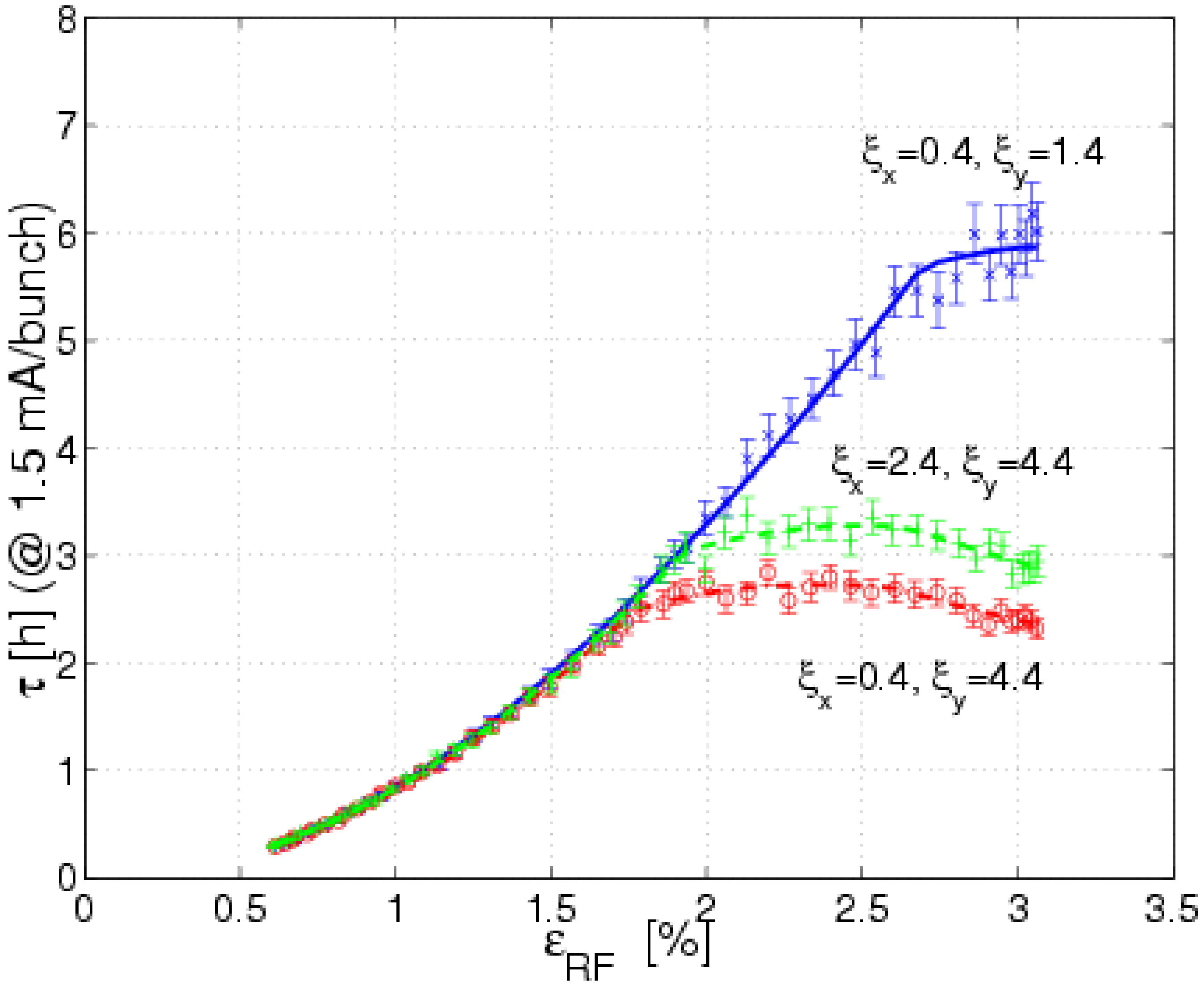
$$\frac{1}{\tau_{tou}} \propto \frac{1}{E^3}\frac{I_{bunch}}{V_{bunch}\sigma_x^{'}}\frac{1}{\varepsilon^2} f\left(\varepsilon,\sigma_x^{'},E\right)$$

- Fit Measured Data with:
  - a correction for the change of bunch length with RF
  - the momentum apertures in the arc and straight section

Dependency of Lifetime on Longitudinal Aperture



RF-Acceptance at different chromaticities



Momentum aperture at different chromaticities

Chromaticity	ε_{trans}(arc)	ε_{trans}(straight)
Horizontal = 0.4 Vertical = 1.4	2.65%	> 3%
Horizontal = 0.4 Vertical = 4.4	1.75%	2.6%
Horizontal = 2.4 Vertical = 4.4	1.9%	2.6%

Operating Condition : 1.4 mA/Bunch, 1.5 GeV, 7% Coupling, Wiggler Open

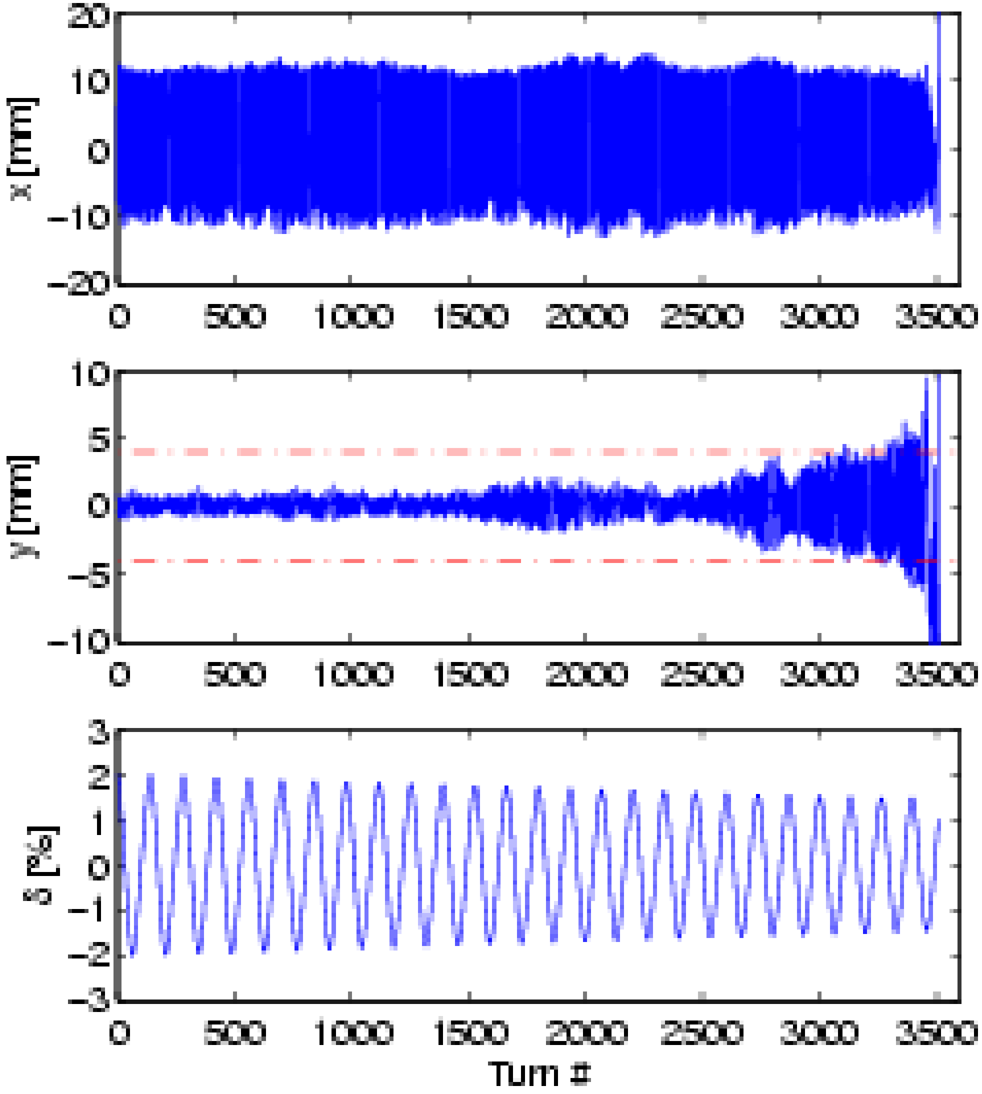
Momentum aperture at different chromaticities

What do we know?

- Dynamic momentum aperture reduces beam lifetime
- Particles get lost on the narrow gap **vertical** chamber
  - Locations with highest radiation levels

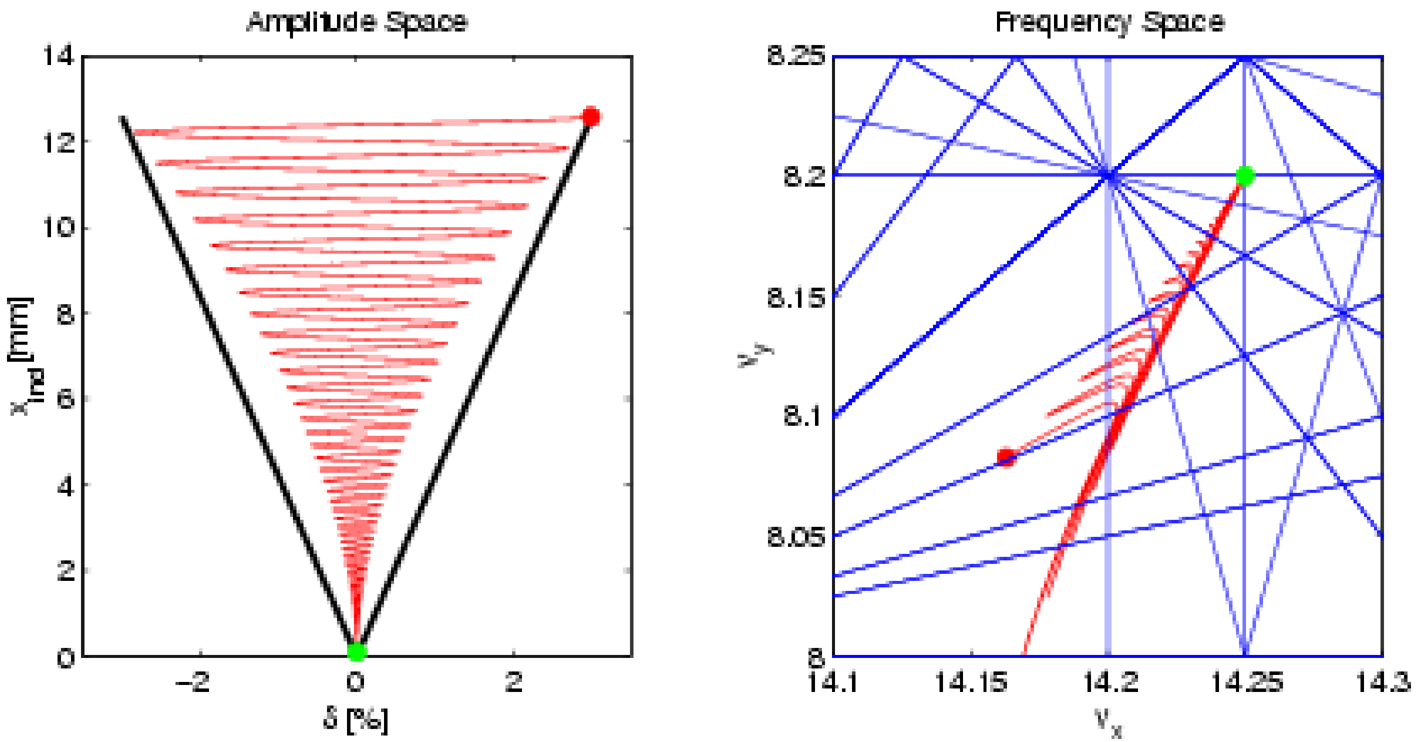
Like to have a better understanding of the dynamic momentum aperture

Particle loss after Touschek scattering.



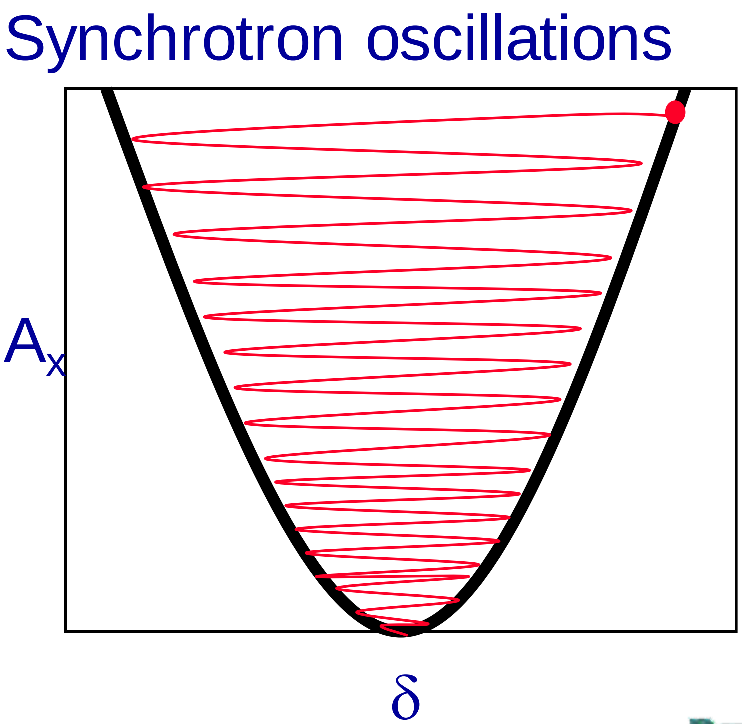
Tuneshift and particle loss

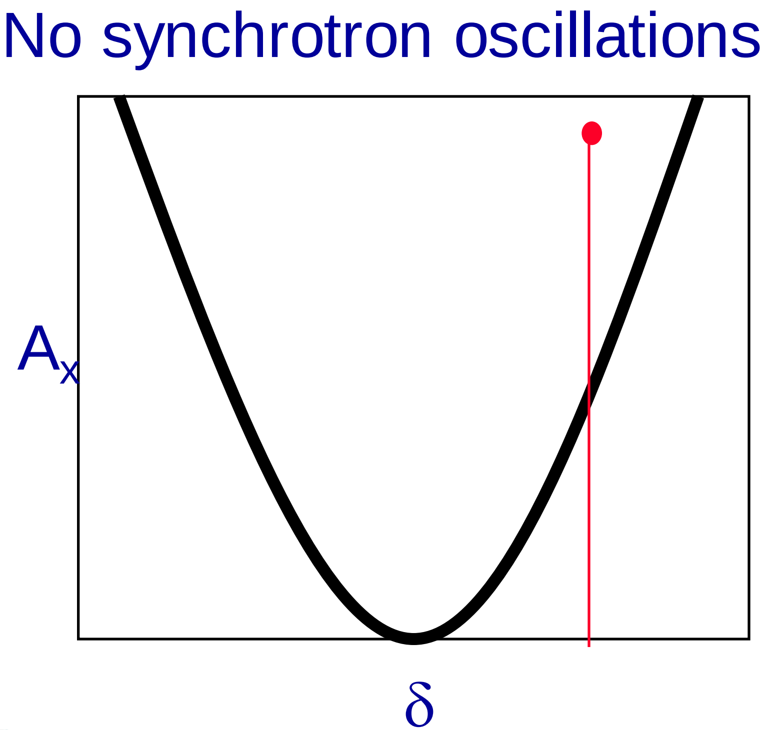
- Change in the particle's betatron tune
  - synchrotron oscillations (modulation of δ)
  - radiation damping (A_x and δ)
- In certain regions the particle motion can become resonantly excited or chaotic leading to beam loss



Dynamic momentum acceptance measurement

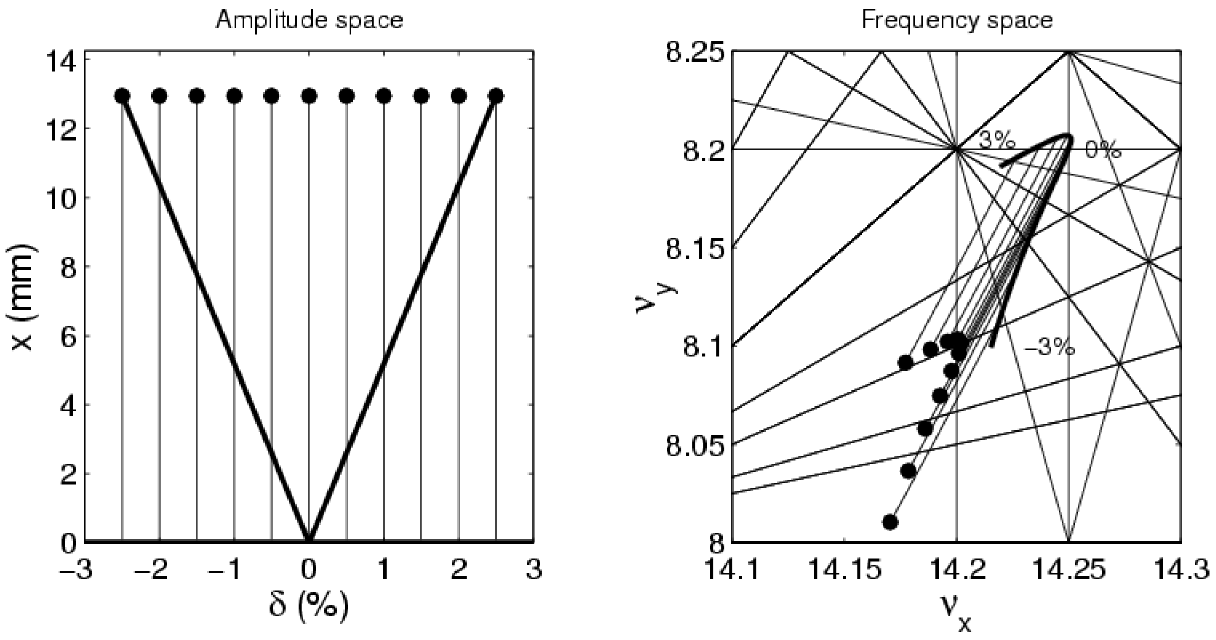
- To simulate a Touschek scattering - simultaneous single turn kick in energy and amplitude – *Difficult*
- It is possible to change the nominal machine energy (by changing the RF frequency) and then deliver a single turn amplitude kick



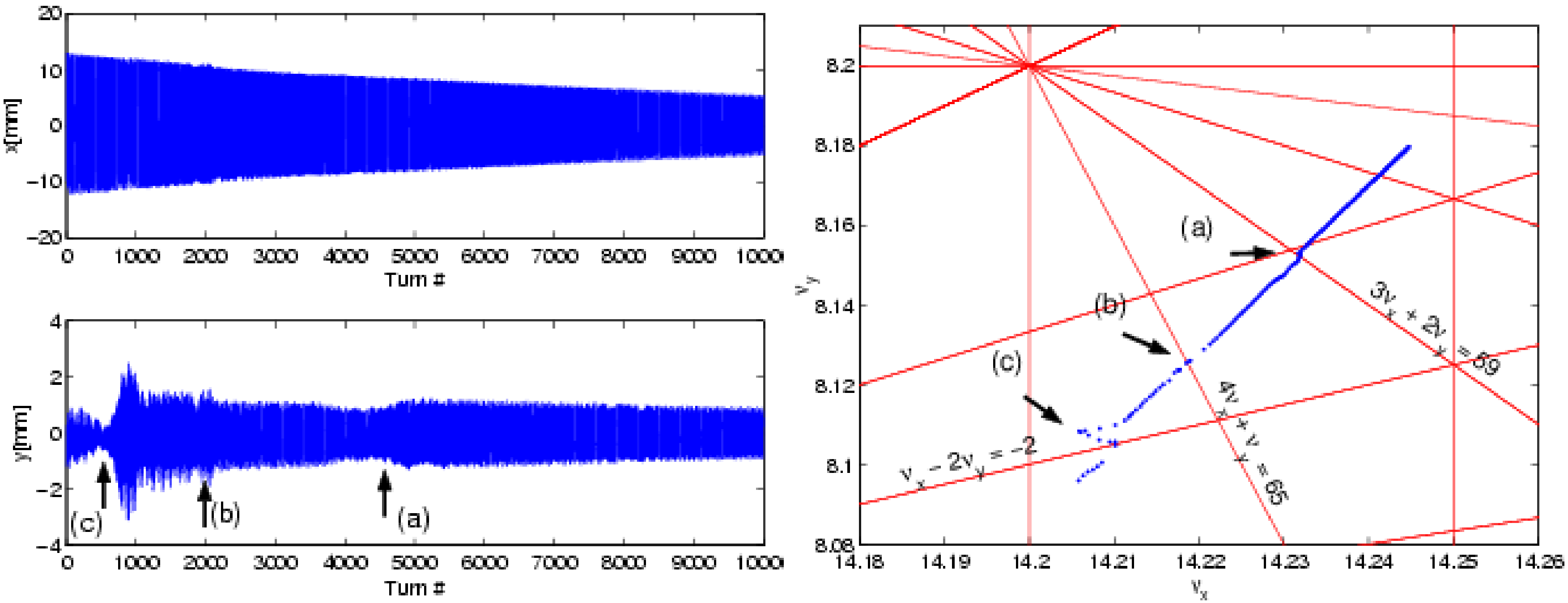


Off energy study (without synchrotron oscillations)

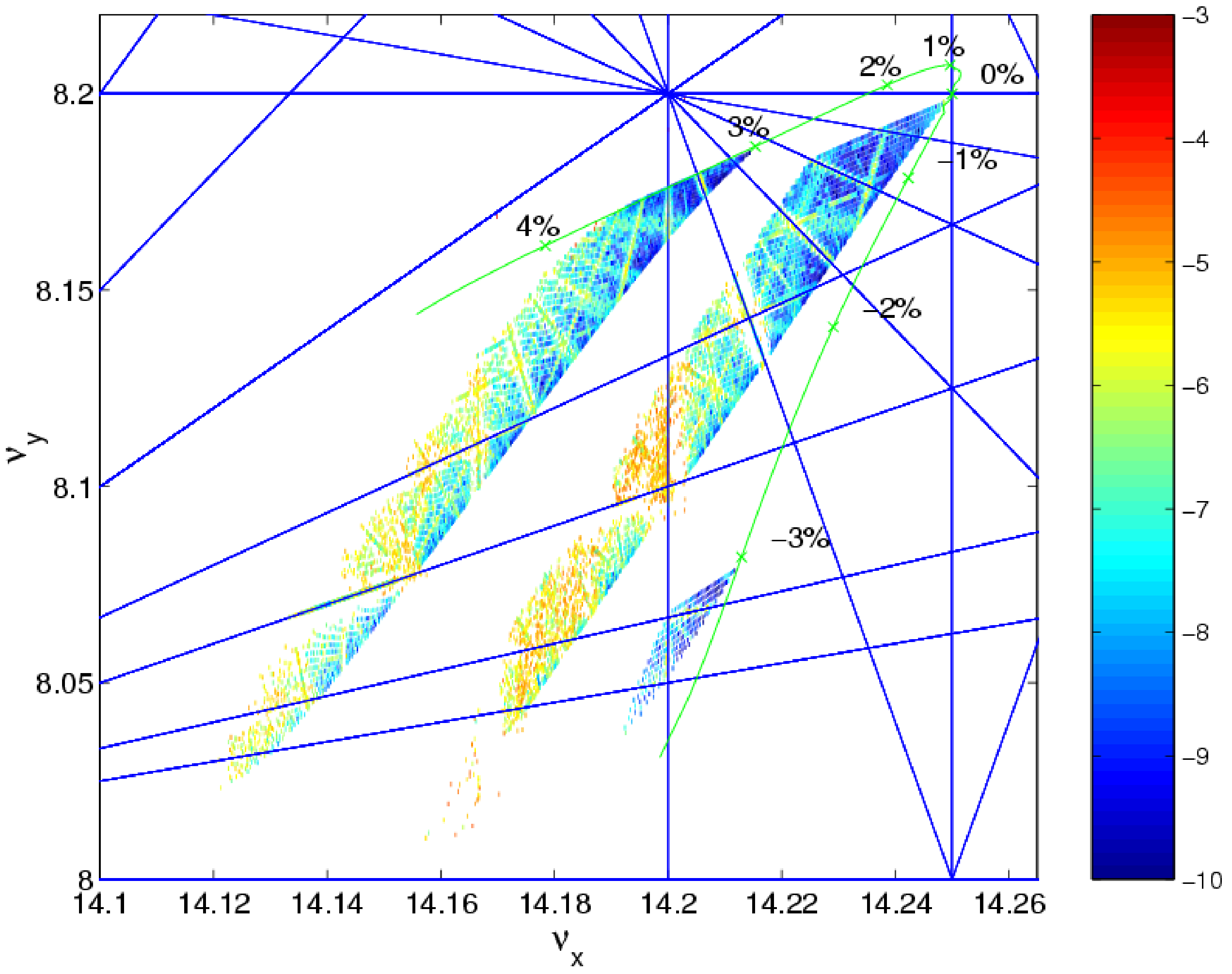
- Can still locate loss regions



Particle tracking and frequency analysis
Identifying excited resonances and diffussion



Frequency Map Analysis at 3 different energies



Aperture measurements with Pinger Magnet

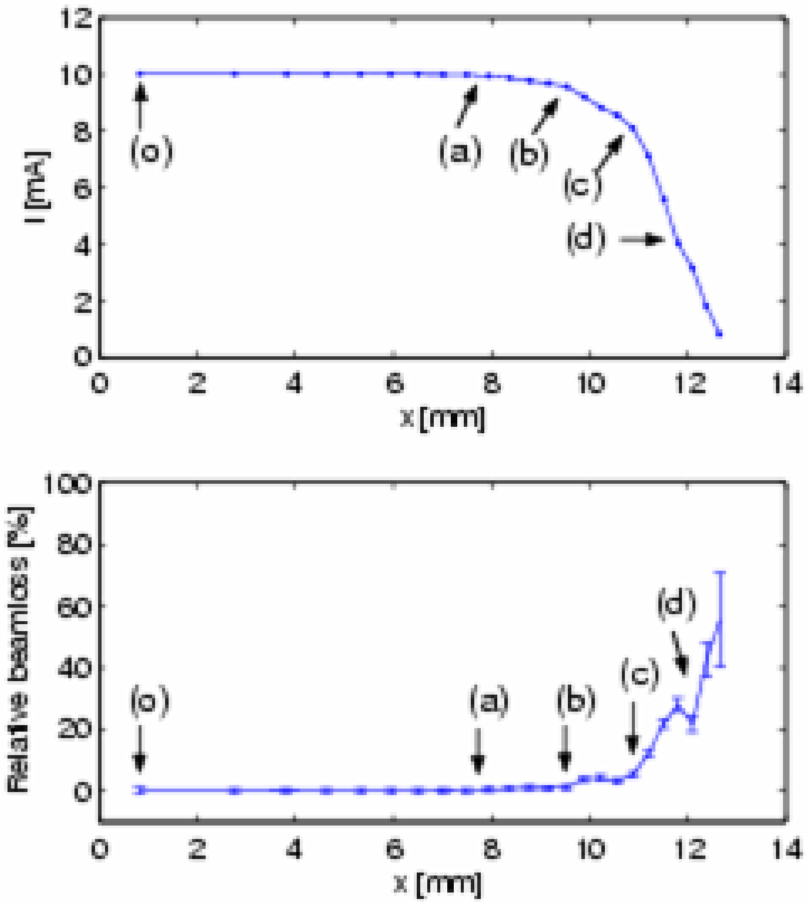
Measurement apparatus

1. Single turn horizontal and vertical pinger magnets
2. Current monitor (DCCT)
3. Single turn beam position monitor – synched to the kicker

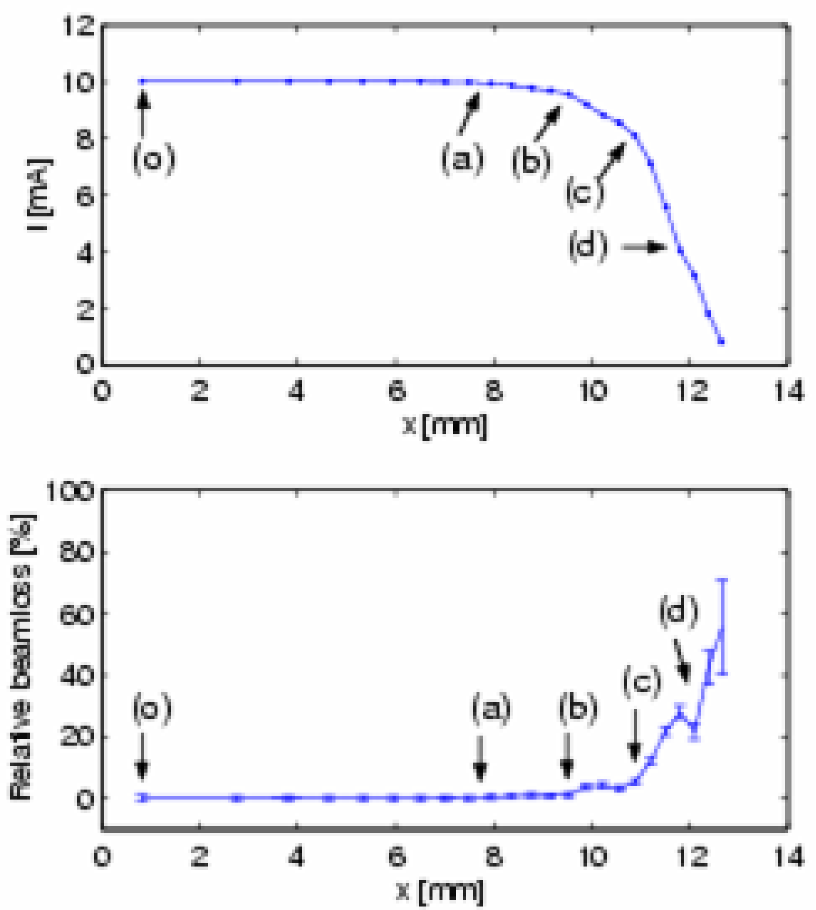
Procedure

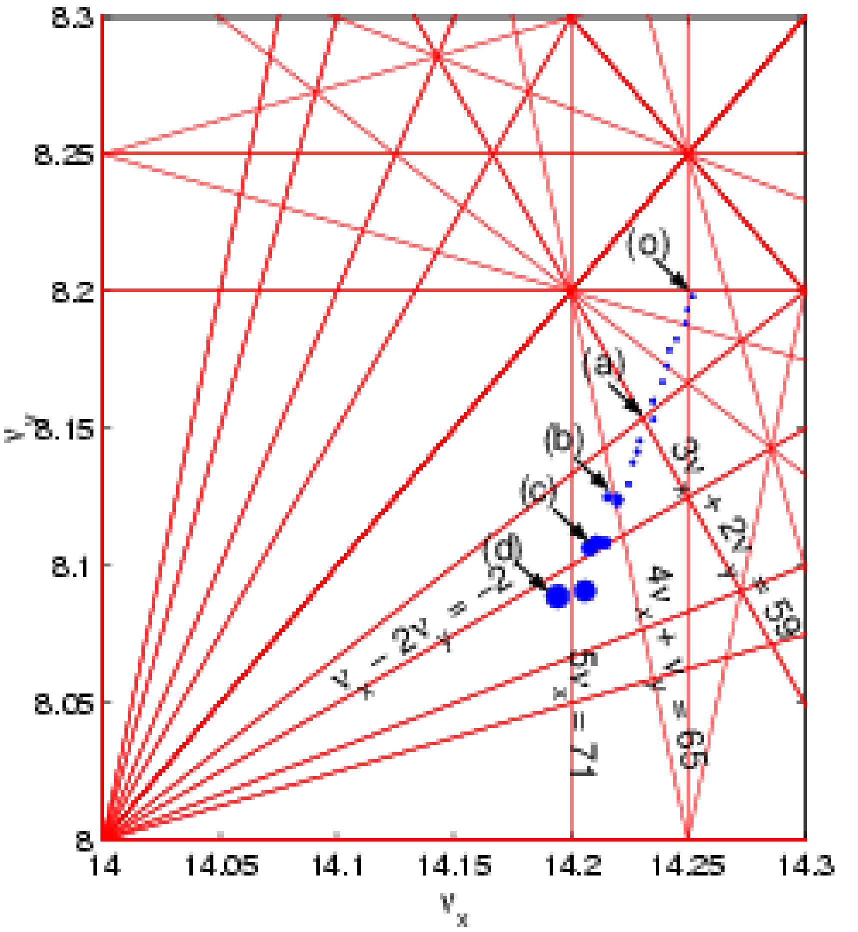
1. Fill a small bunch train with current
2. Choose energy by adjusting the RF frequency
3. Set horizontal and vertical kick strengths
4. Kick beam simultaneously in horizontal and vertical plane
    1. Record beam current before and after kick
    2. Record beam position each turn for 1024 turns
5. Repeat with increasing horizontal kick amplitudes until beam is completely lost
6. Repeat steps 1 – 5 with several different RF frequencies

Current versus kick



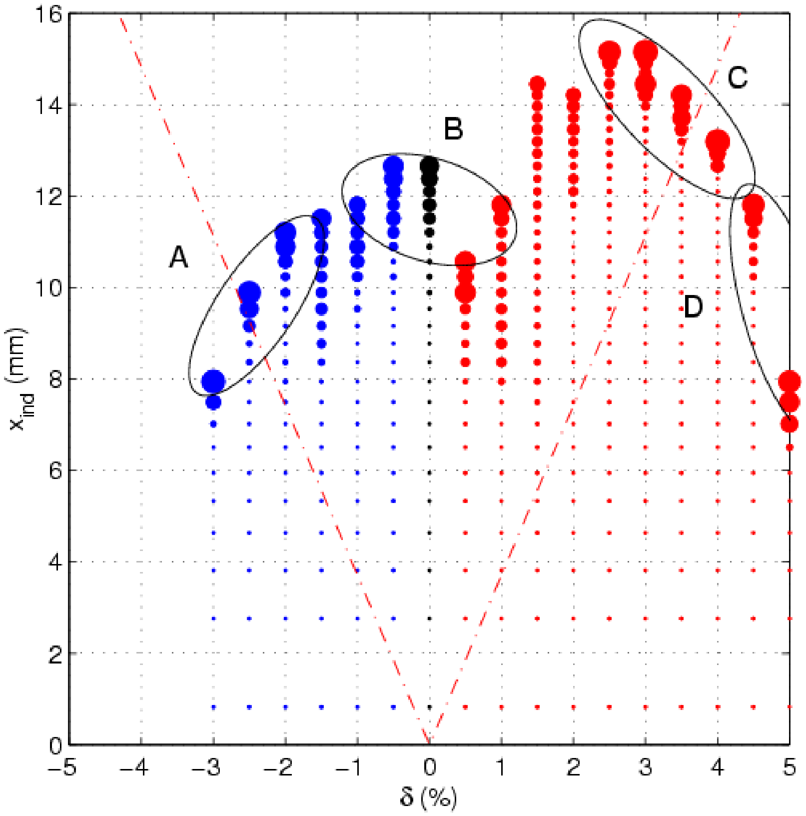
Loss versus frequency



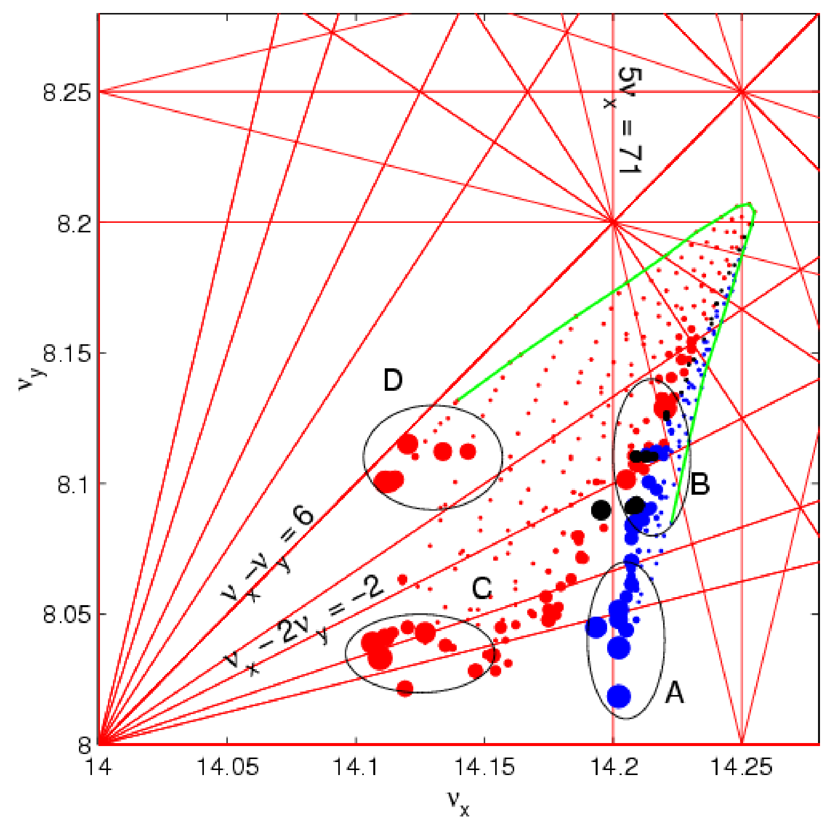


Small chromaticity case

Amplitude space

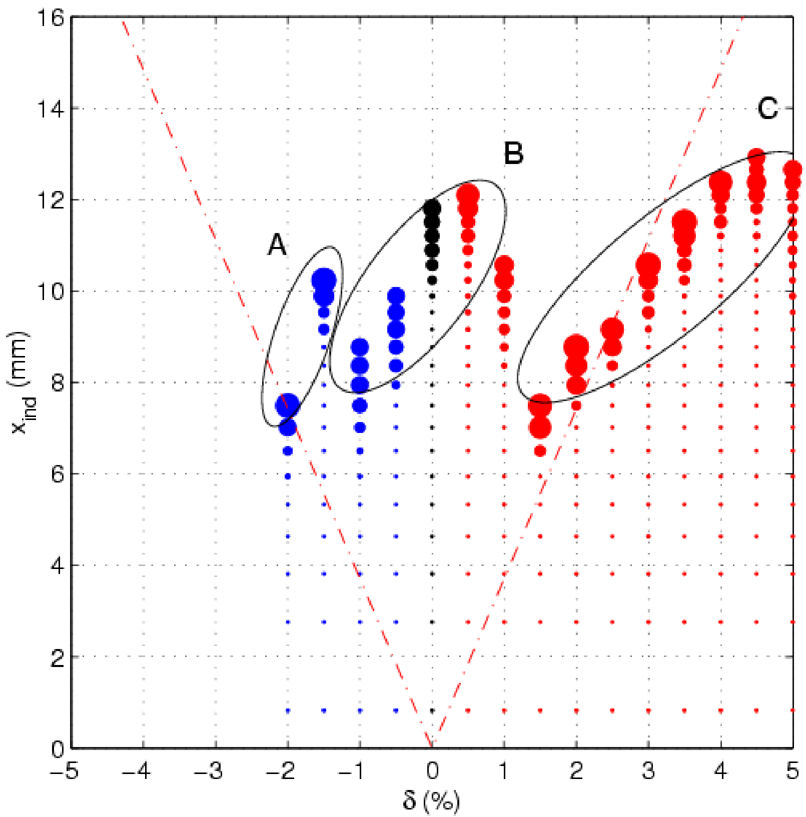


Frequency space

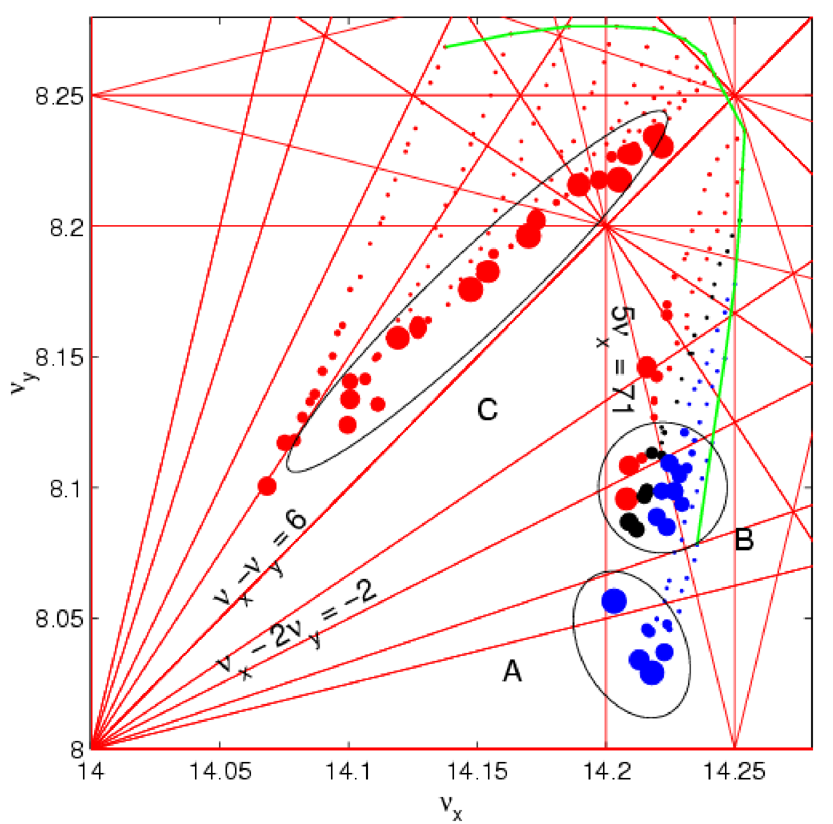


Large Vertical Chromaticity

Amplitude space

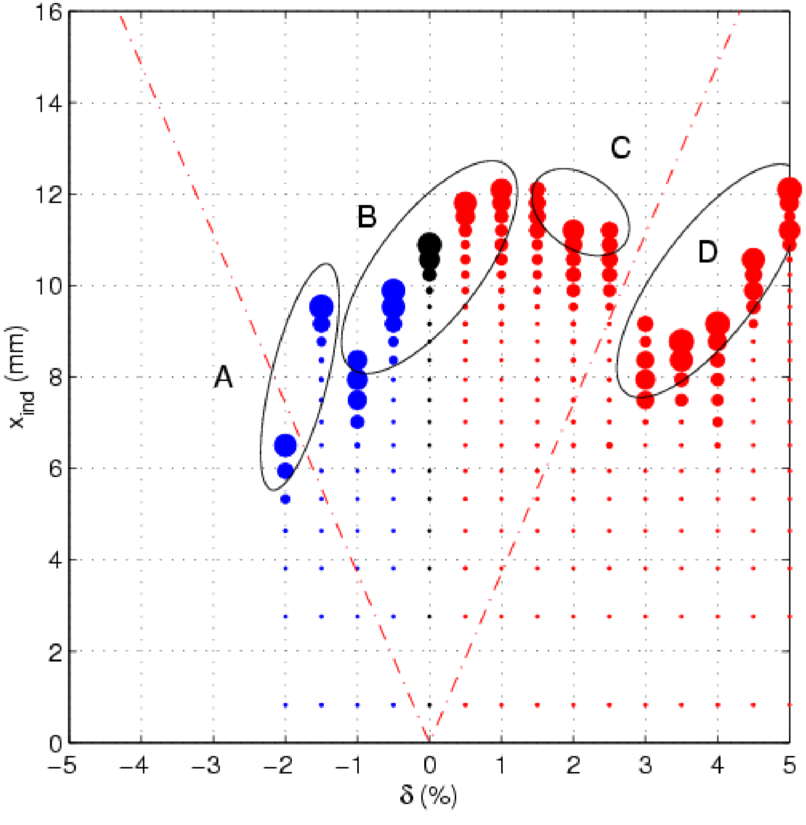


Frequency space

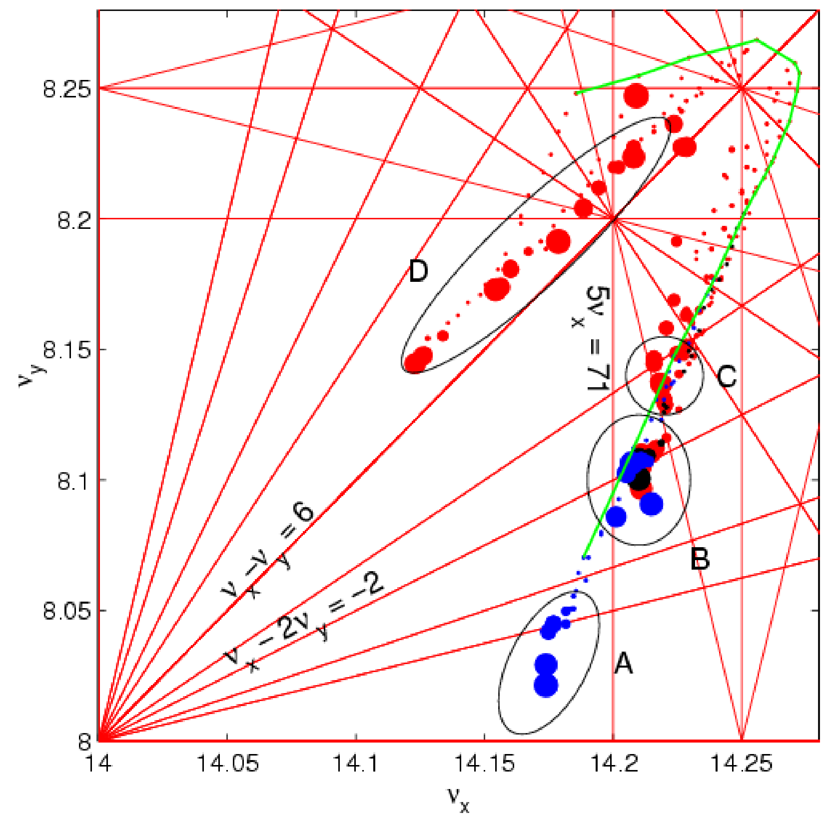


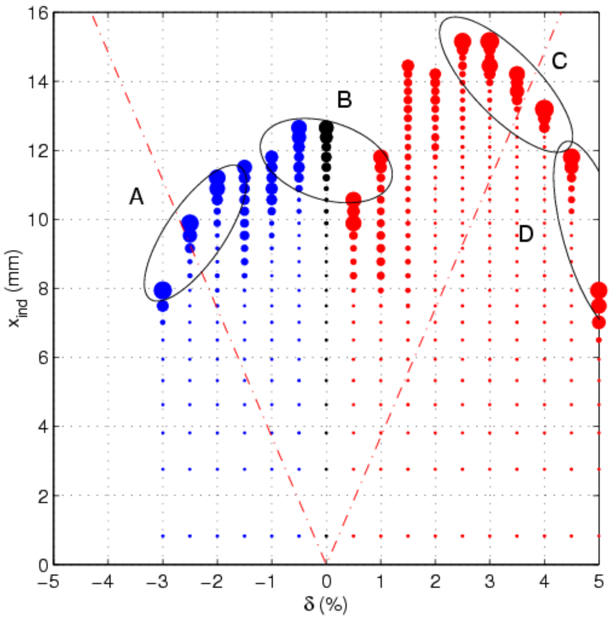
Large vertical and horizontal chromaticity

Amplitude space

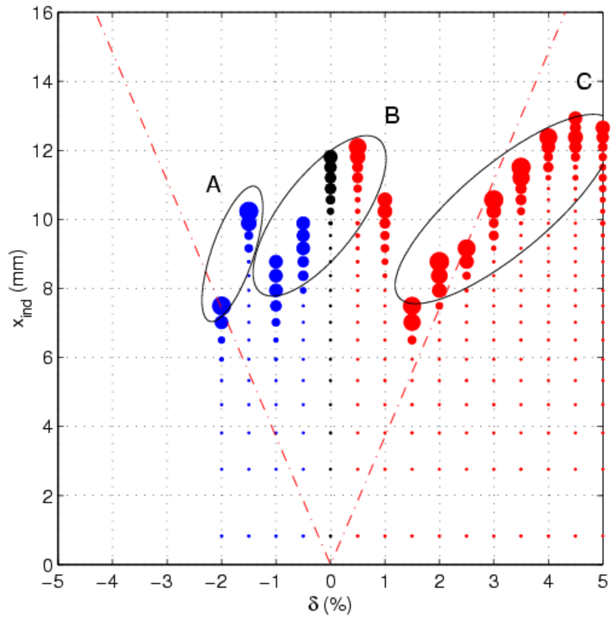


Frequency space

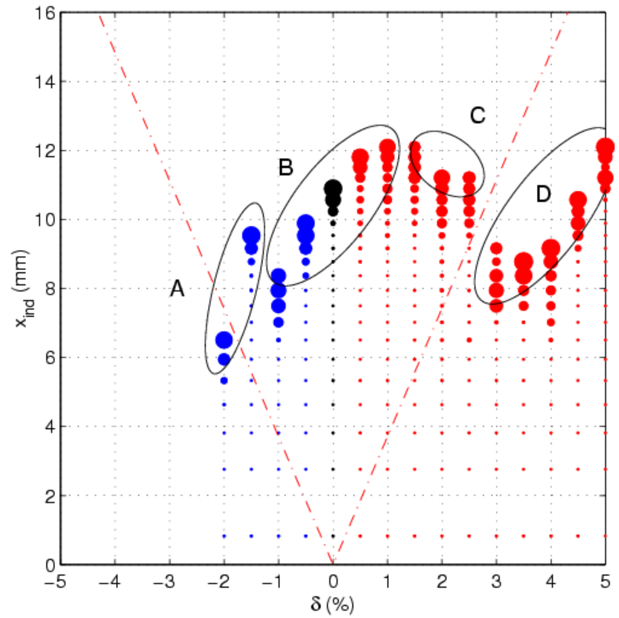




2.65%



1.75%



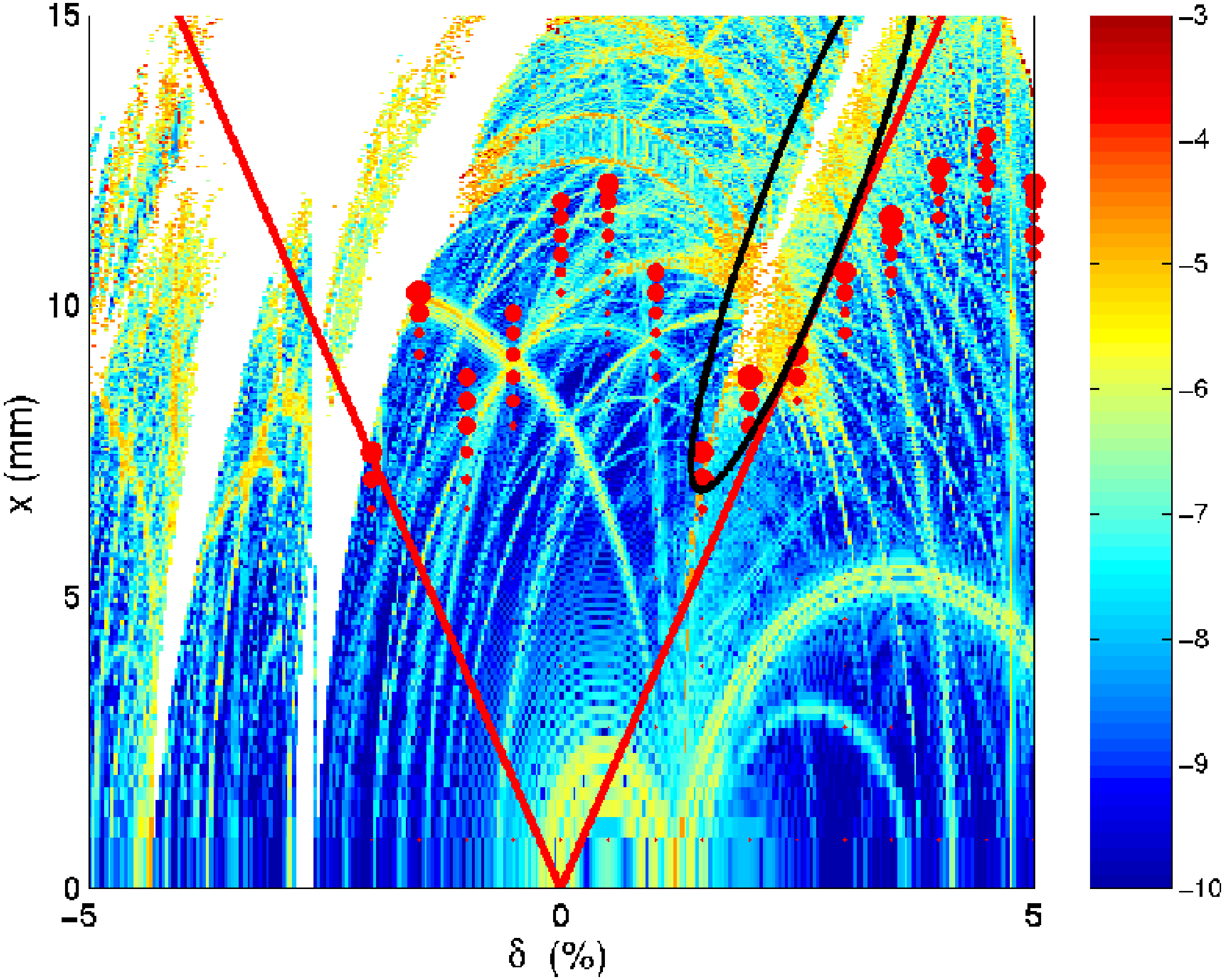
1.9%

Interpretation of results

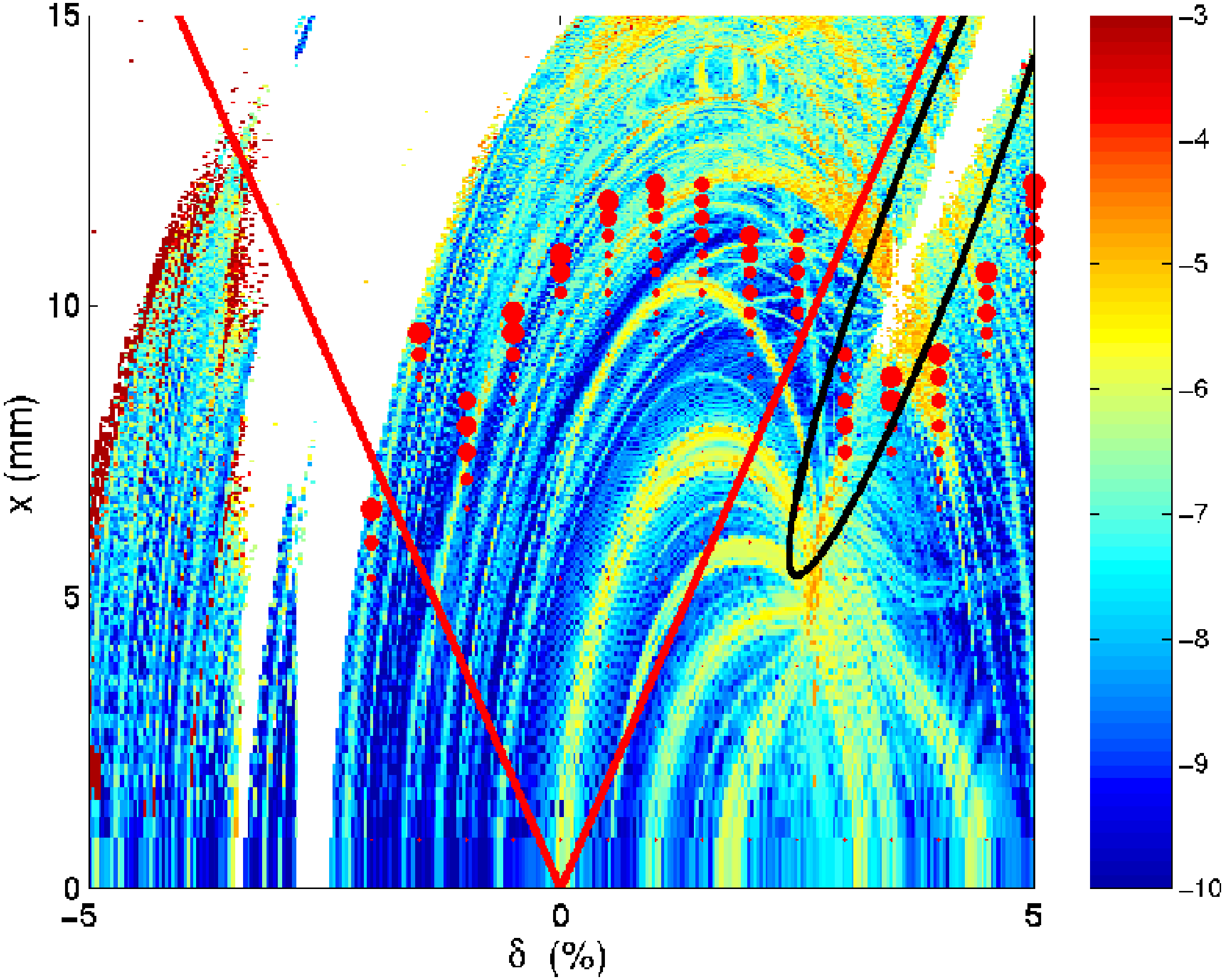
- Pinger scans tell us under which conditions the beam gets lost
  - Which amplitude and energy
  - Which resonance

- Off-Energy Frequency Map
  - Measure frequency map and loss verses different initial horizontal and energy amplitudes

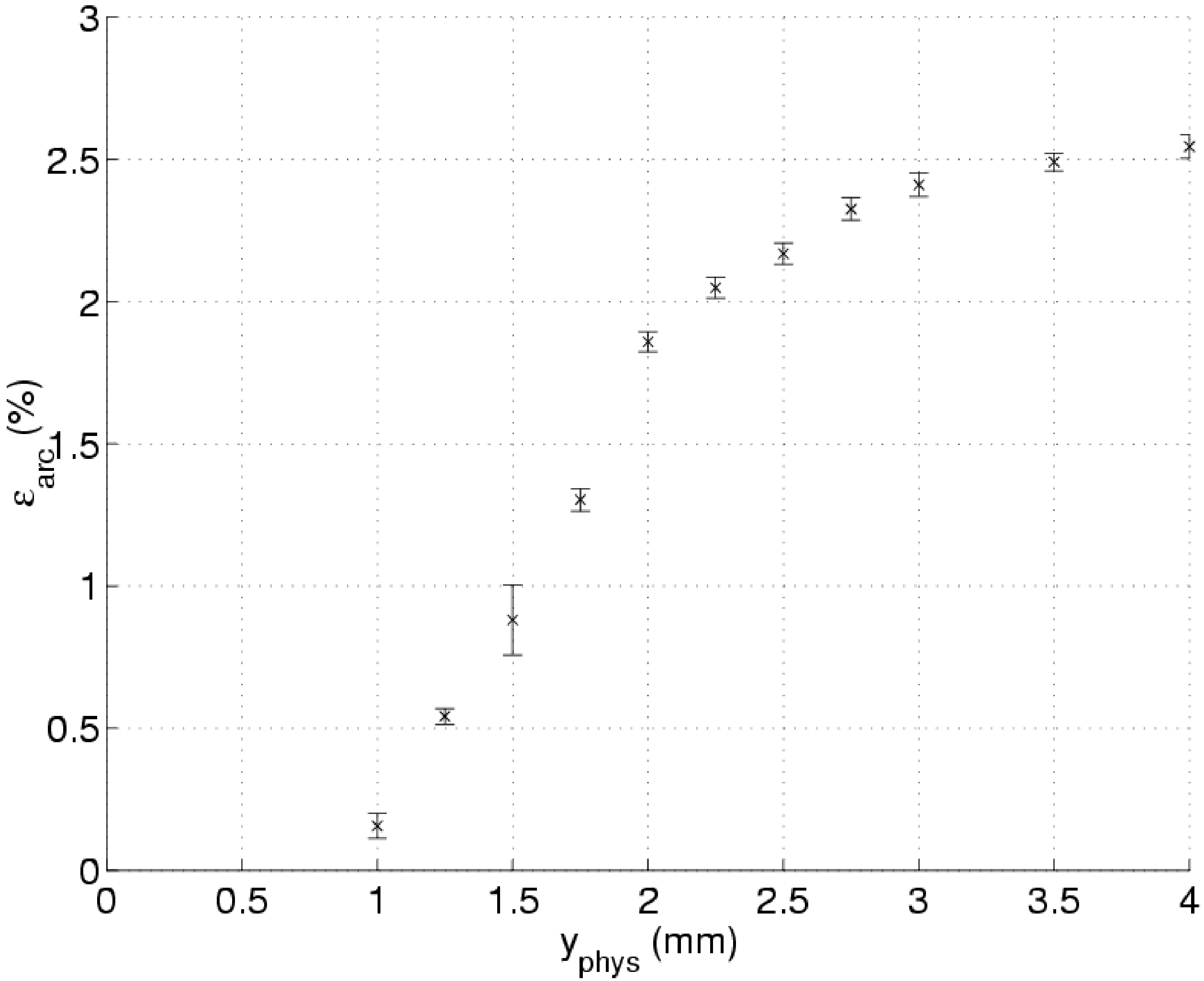
Large vertical chromaticity



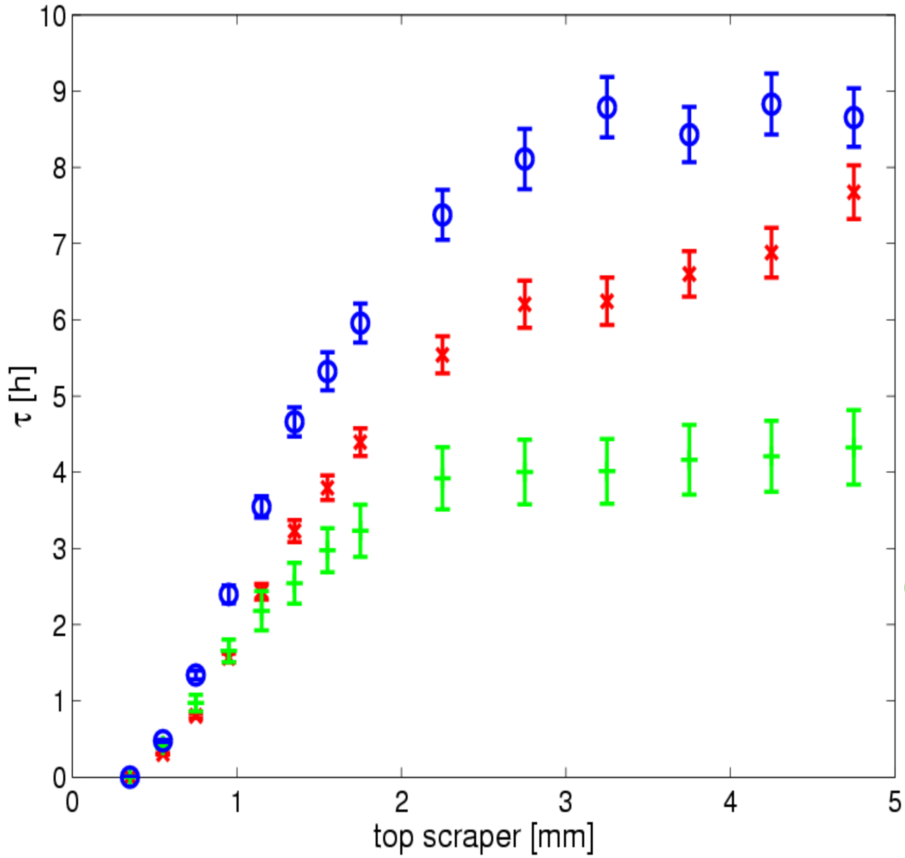
Large vertical and horizontal chromaticity



Momentum aperture versus vertical gap



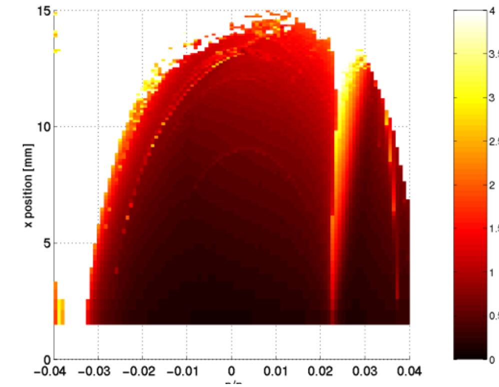
Lifetime versus Insertion Device Gaps

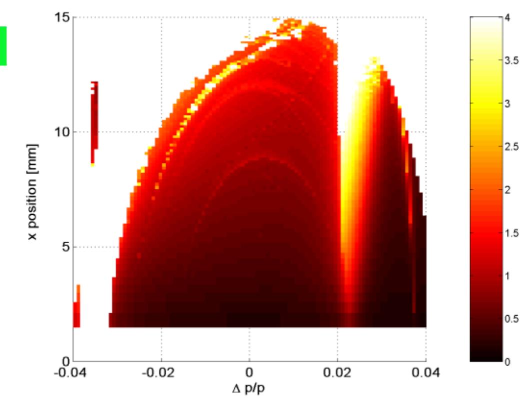


New method

Old method

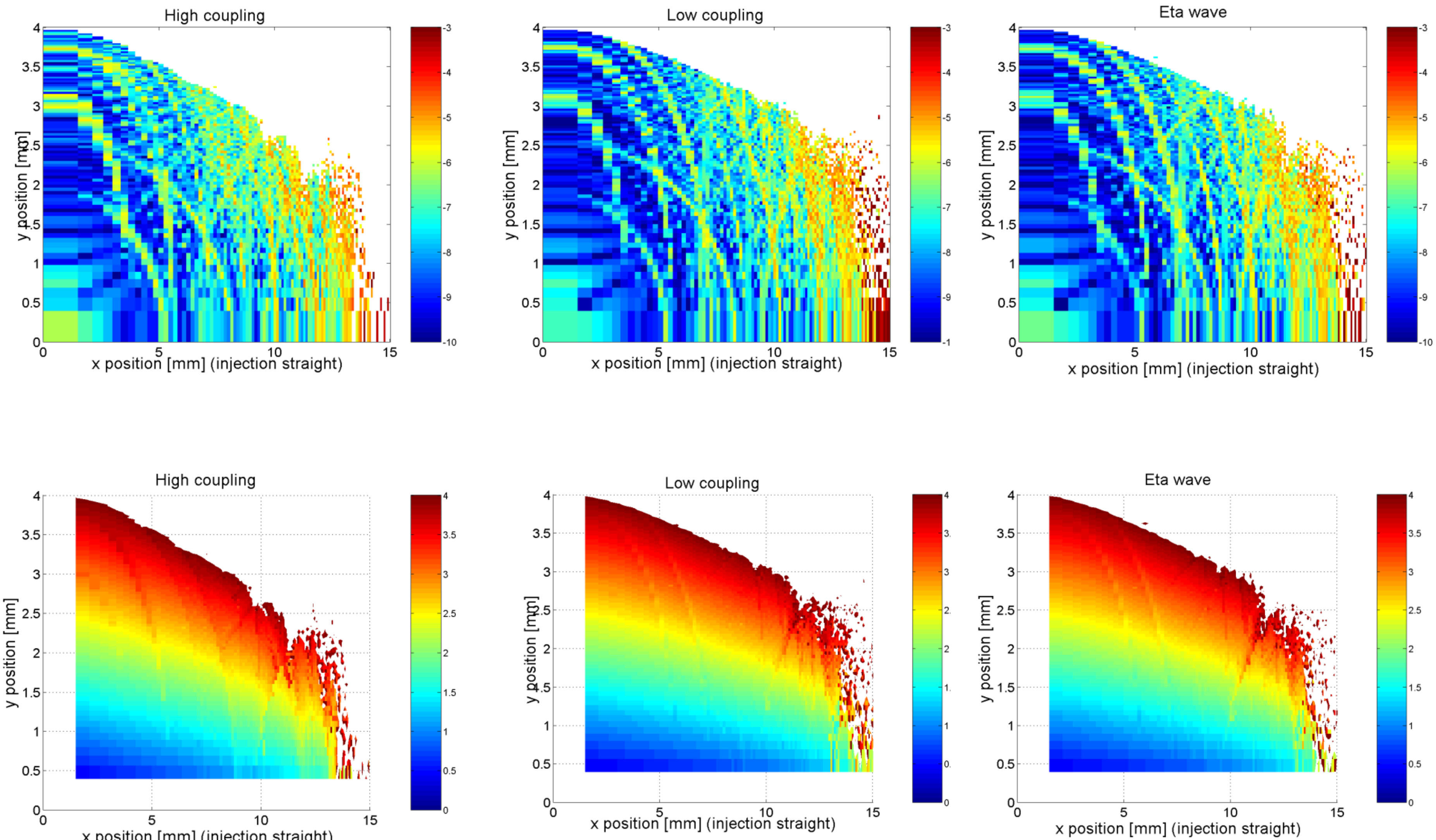
New method (small coupling)



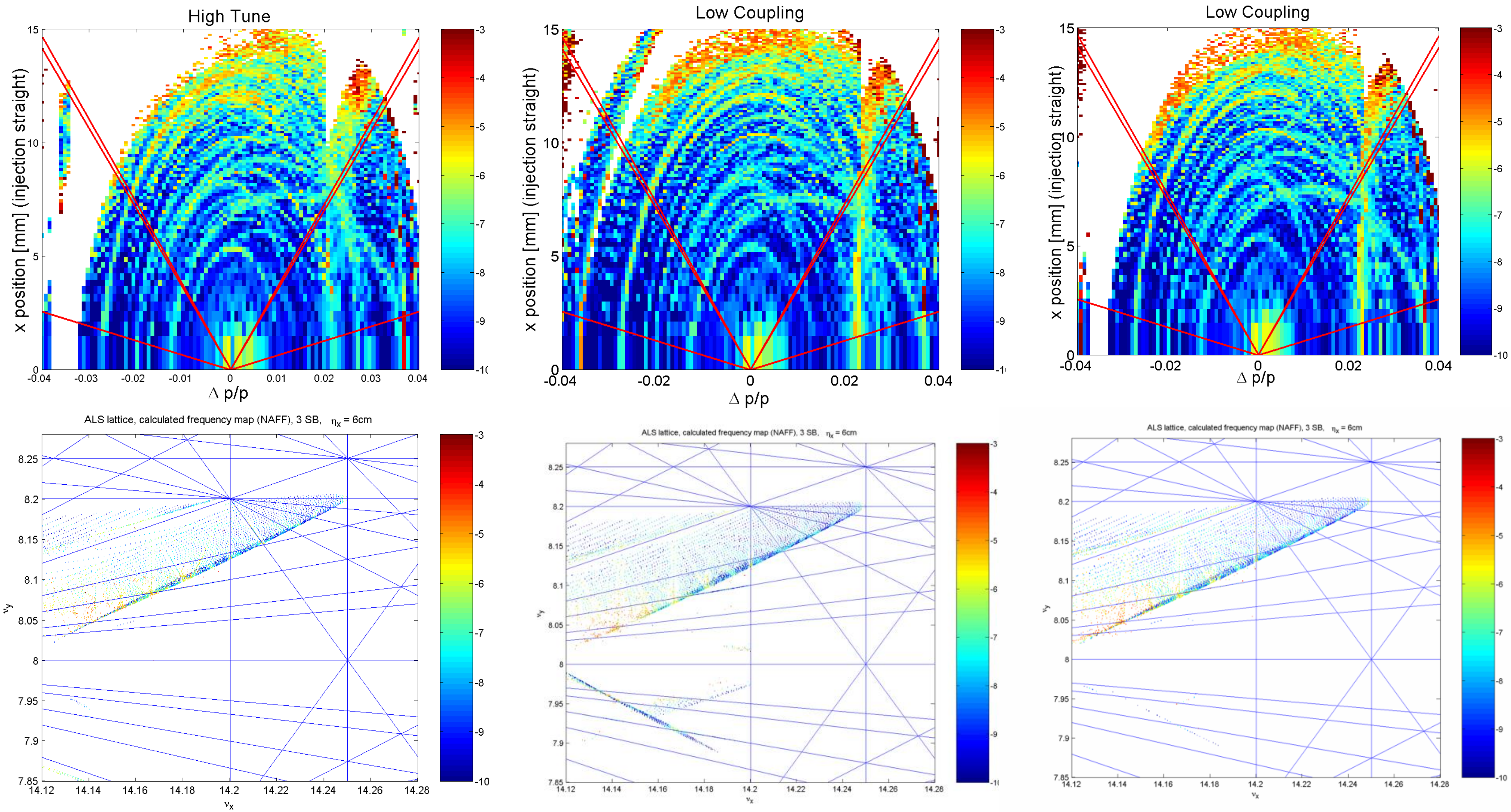


We have been able to reduce the impact of narrow gap IDs on the performance of the ALS (Pinger, simulations, coupling and scraper measurements).

On-energy dynamic aperture - frequency map (top) and effect of vertical aperture (bottom)

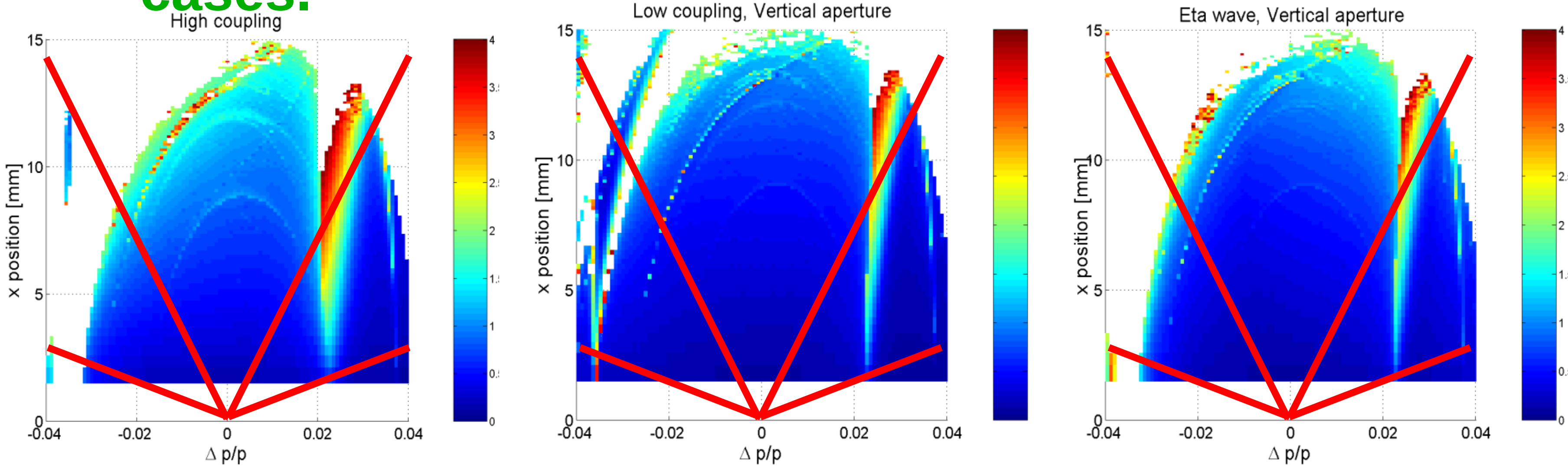


Off-energy frequency map in amplitude space (top) and frequency space (bottom)

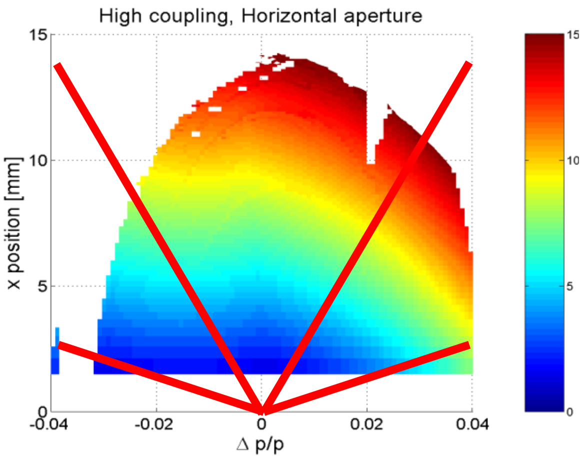


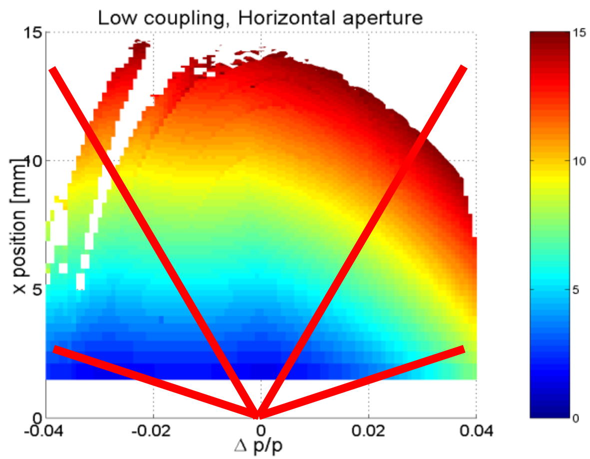
Effect of vertical aperture on the off-energy dynamic aperture

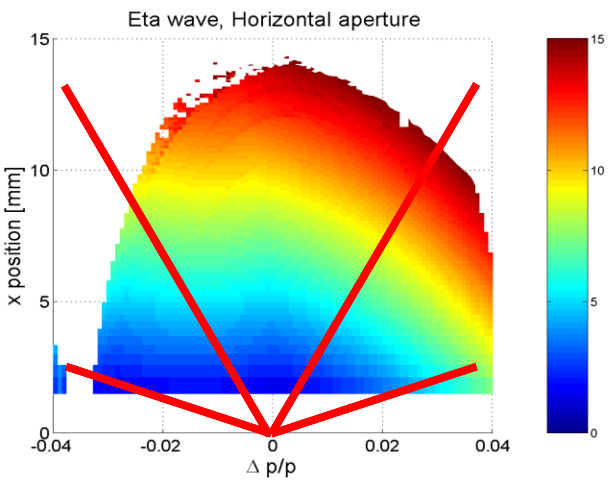
The red lines indicate the induced amplitudes for a particle scatter in arcs (lines with steep angle w/r/t the horizontal) and those scattered in the straights (lines with smaller angles). Note that the high coupling case is much more sensitive to gap than the low coupling cases.



Effect of horizontal aperture on the off-energy dynamic aperture







Conclusion

- Momentum aperture is limited by the dynamic momentum aperture

- Particle loss is primarily occurs in the narrow gap chamber
  - Suspect horizontal motion diffuses or is resonantly coupled to the vertical plane

- Pinger scans provide insight into limitations of the aperture and give guidance towards improvement
  - Simple empirical technique
  - Dynamic aperture is not a hard boundary but one with lossy regions

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