Frequency Map Calculation

for the Advanced Light Source

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Advanced Light Source

work done in collaboration with

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Outline

Motivation

- Beam Lifetime
- Injection Efficiency

Single Particle Beam Dynamics in the ALS

- Importance of Periodicity
- Example of Frequency Map with Lattice Errors

Frequency Map and Particle Loss

Injection

- Superbend Example

Summary

Motivation

Performance of the Advanced Light Source (ALS) is limited by the single particle electron beam dynamics

- **Injection efficiency**
- **Beam lifetime**

Continue to strive for better understanding of the beam dynamics in order to

- **Improve the performance of the ALS**
- **Accurately predict what will happen when the ALS is upgraded to include**
  - **Superbends, narrow gap insertion devices, elliptically polarizing undulators, femtoslicing modifications, …**

Dynamics of the ALS

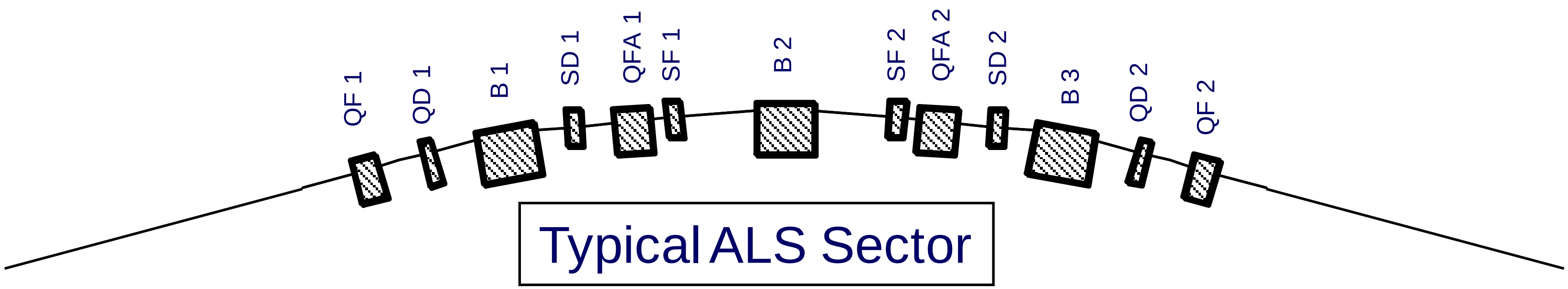
The ALS is an interesting machine for studying the particle beam dynamics:

1. Simple ➔ Simple Magnetic Lattice
2. Very Nonlinear

In terms of single particle beam dynamics, the ALS is one of the most extensively studied storage rings

1. Theoretical investigations of the ALS began in the mid 1980s (Nishimura, Forest, Ruth, Bengtsson, …)
2. The ALS was used as the first example of frequency map analysis applied to accelerators (Laskar and Dumas in 1993)

Dynamics in the ALS: Lattice



ALS consists of 12 sectors

- **12-fold periodicity ➔ *Suppression of resonances***

$$m\nu_x + n\nu_y = 12 \text{ x } q$$

where *m*, *n*, and *q*, are integers

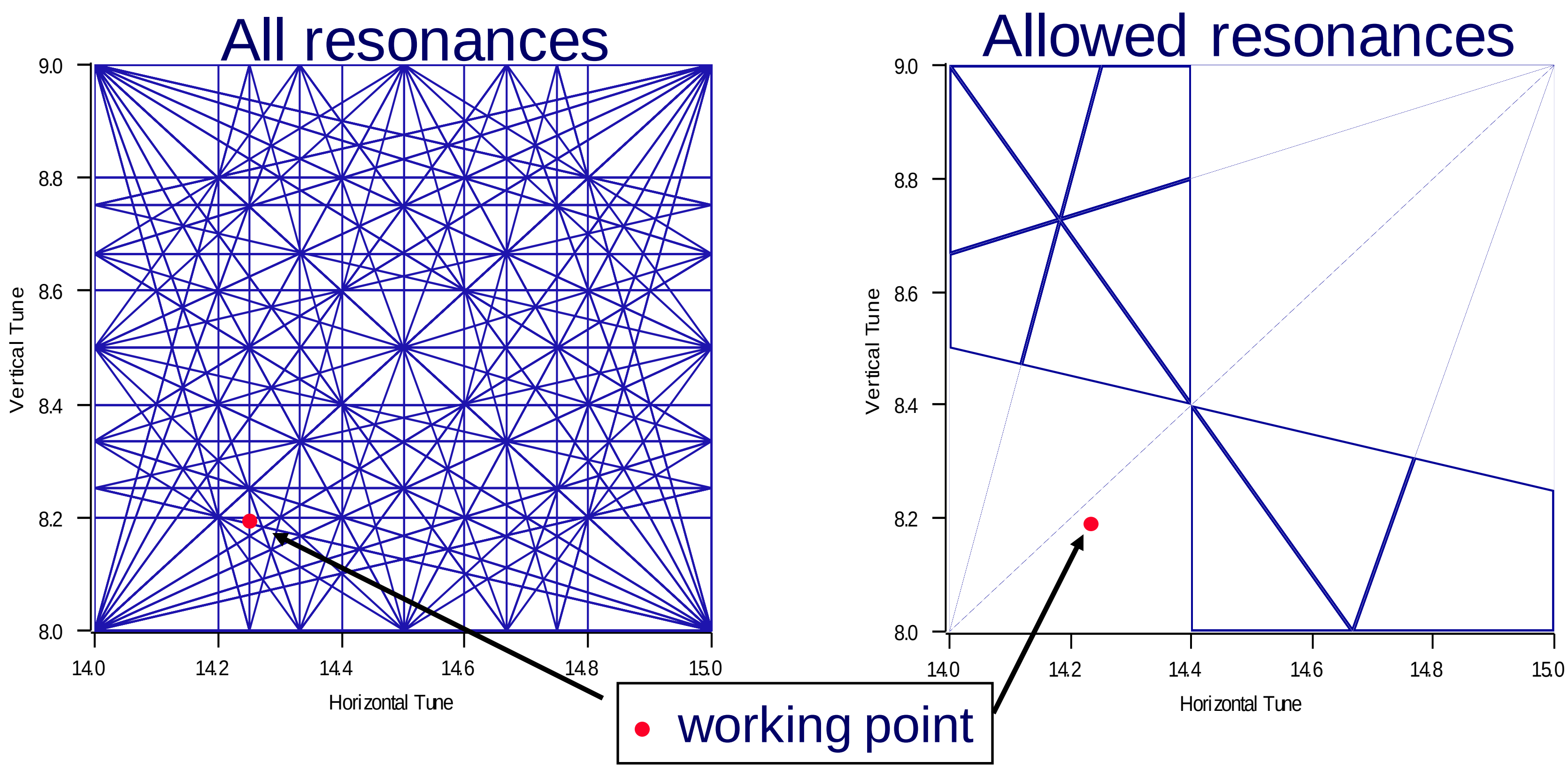
Resonance Excitation

Resonances can lead to irregular and chaotic behavior for the orbits of particles which eventually will get lost by diffusion in the outer parts of the beam.

Rule of thumb → Avoid low order resonances

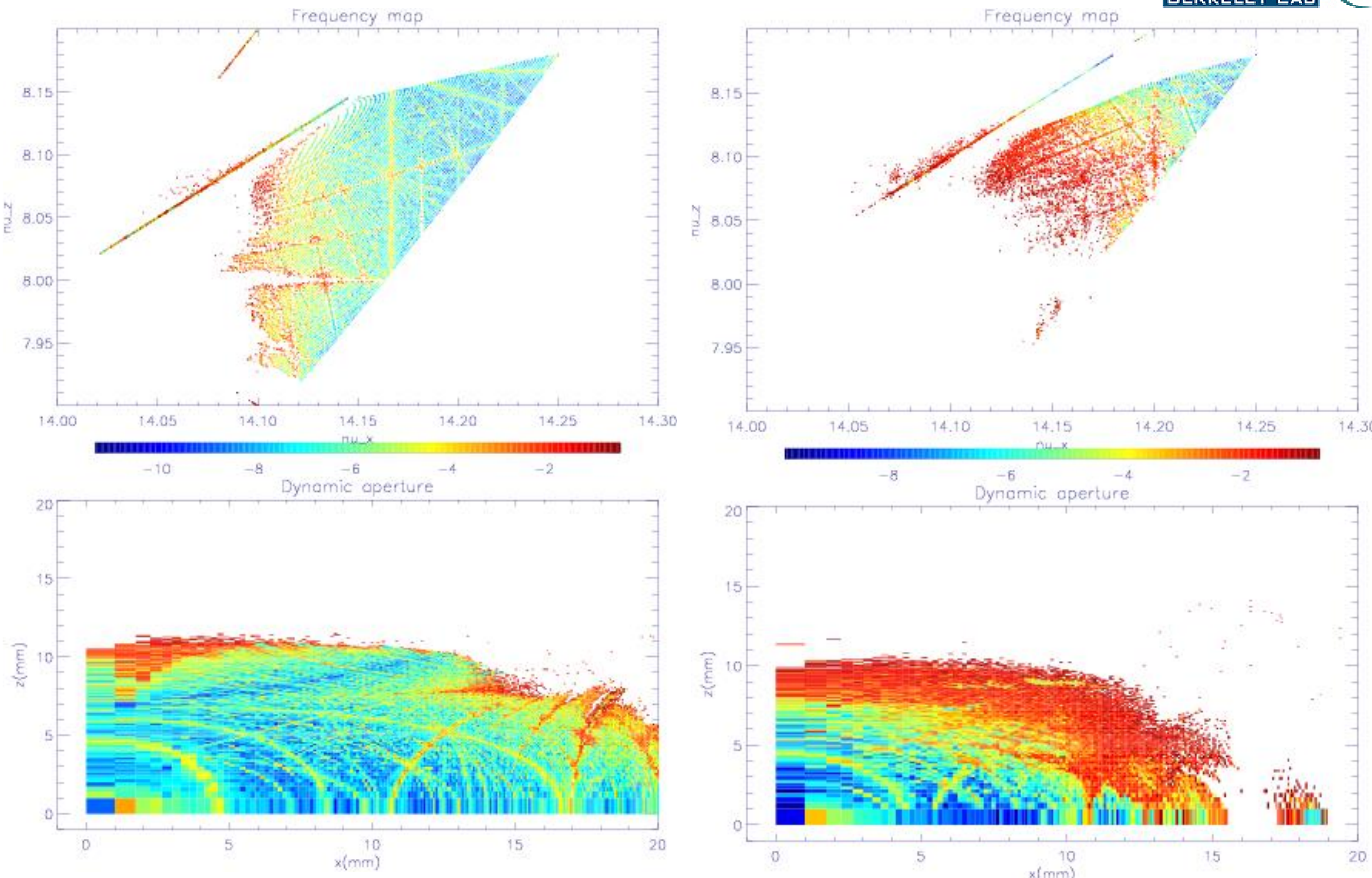
Benefits of Periodicity

Tune plane - *resonances up to 5th order*



Unfortunately there is no simple way to forecast the real strength of a resonances without a realistic model of the ring and a tracking code.

ALS : Ideal Lattice versus Calibrated Model



Ideal versus Calibrated Model

Introducing linear errors fundamentally changes the beam dynamics

Ideal ring

- The dynamic aperture is large
- Small chaotic zone at large amplitudes
- Particle loss is fast
- Particle loss is due to high order resonances

Ring with calibrated linear errors

- Dynamic aperture is smaller
- Large chaotic zone at large amplitudes
- Particle loss is slow
- Particle loss is due to lower order unallowed resonances

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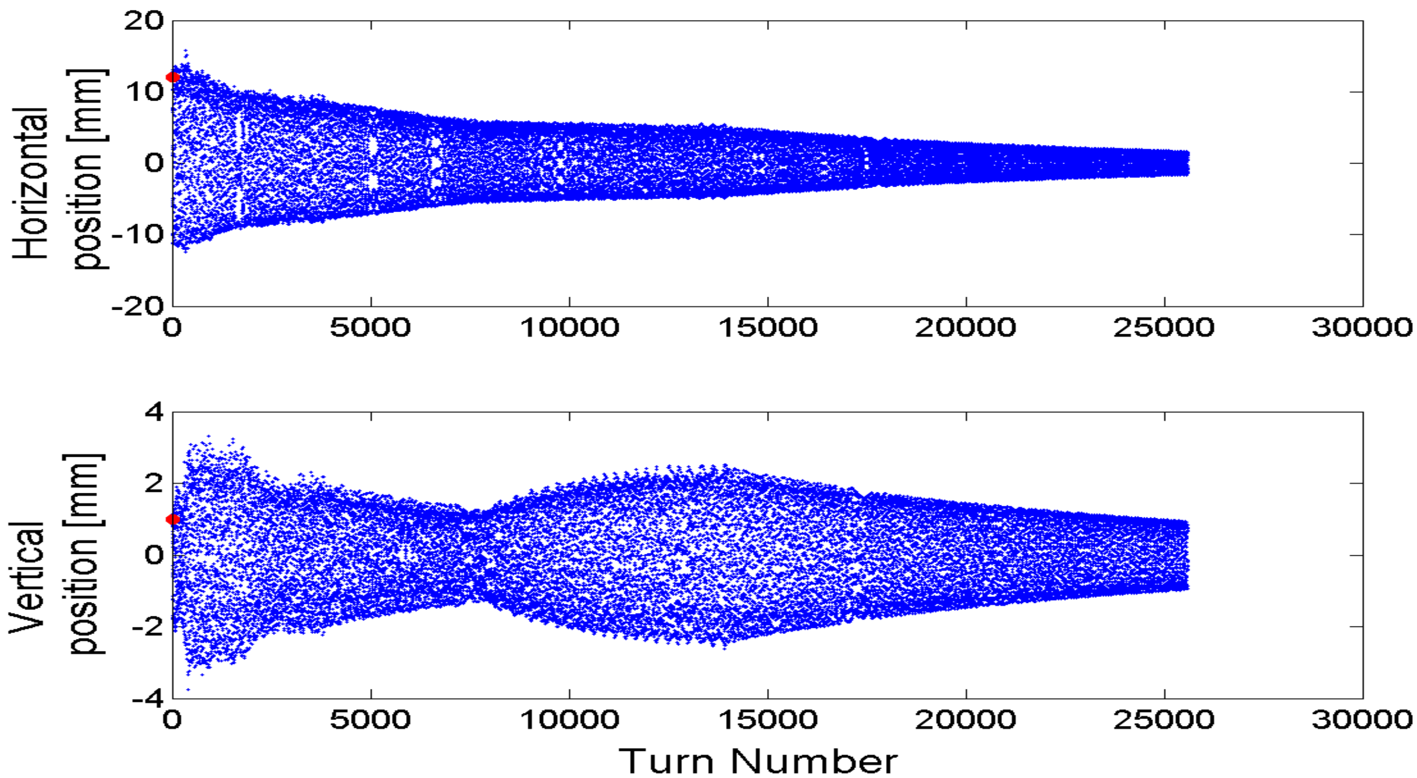
Vertical orbit diffusion – On-energy example

Particle are lost in the vertical plane

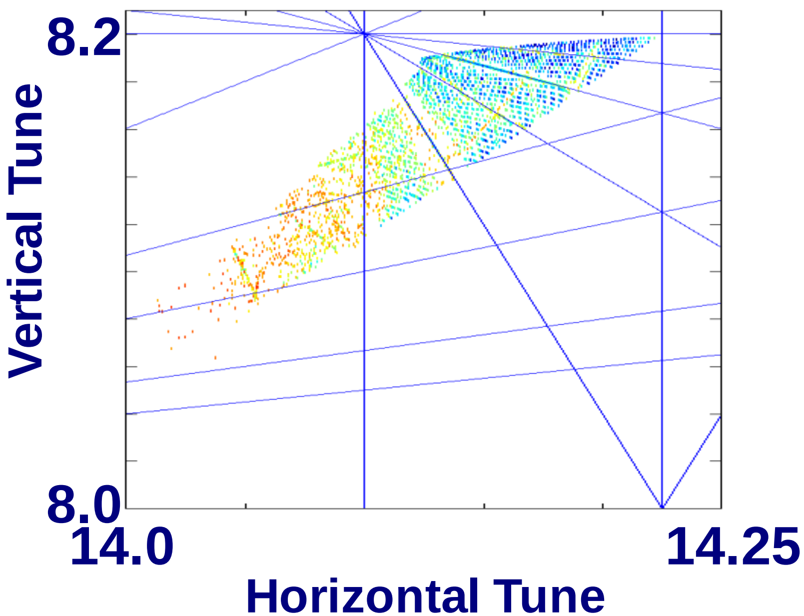
- ***via nonlinear coupling and diffusion of the trajectory.***



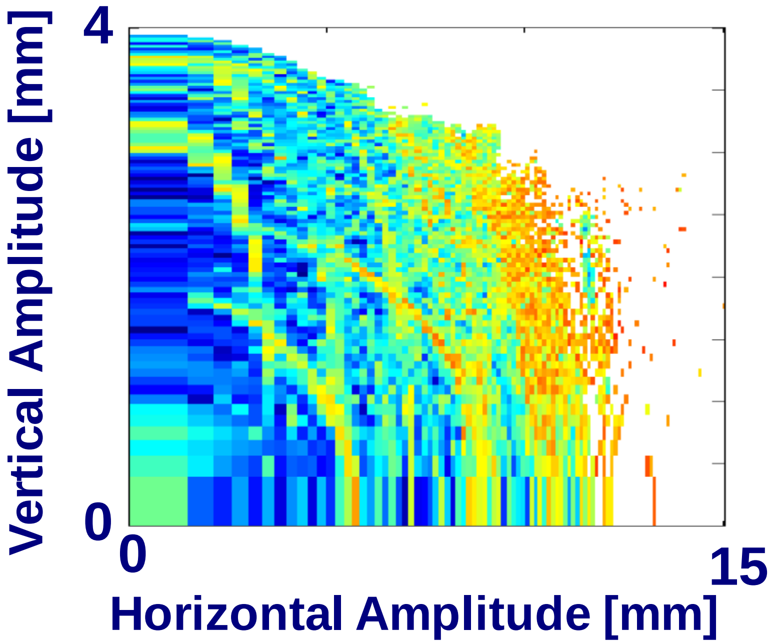
Example : Particle launched at 12 mm horizontally and 1 mm vertically and tracked with damping and synchrotron oscillations.

Frequency Map Analysis

Frequency Space

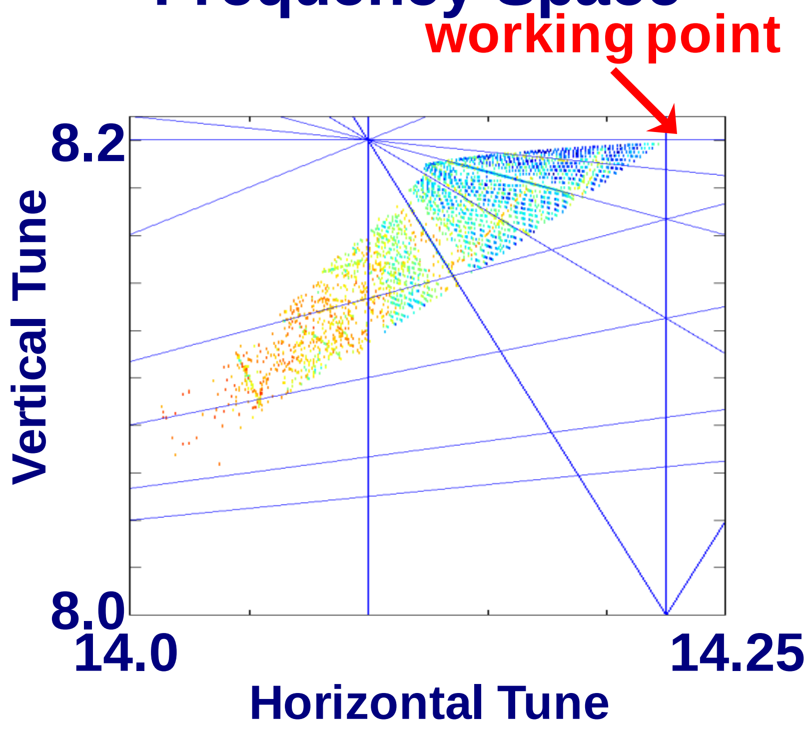


Amplitude Space

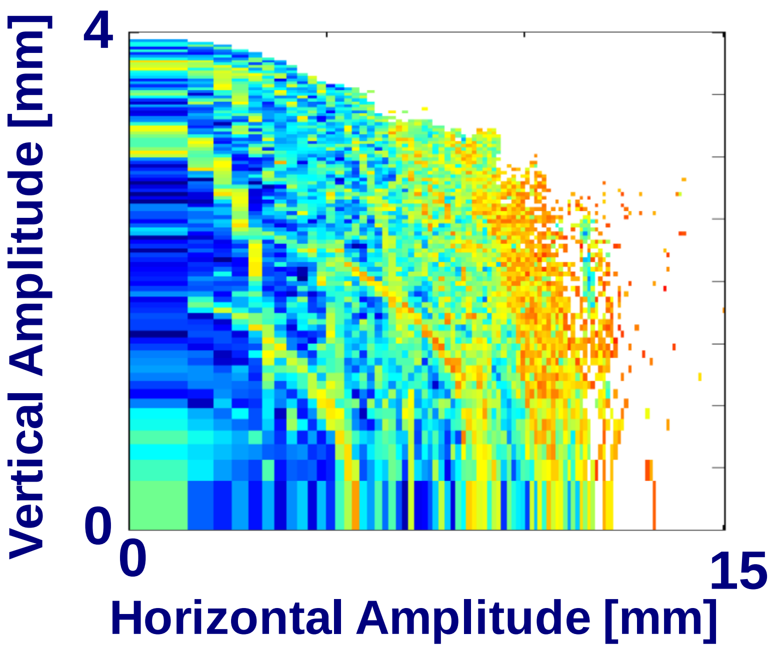


Frequency Map Analysis

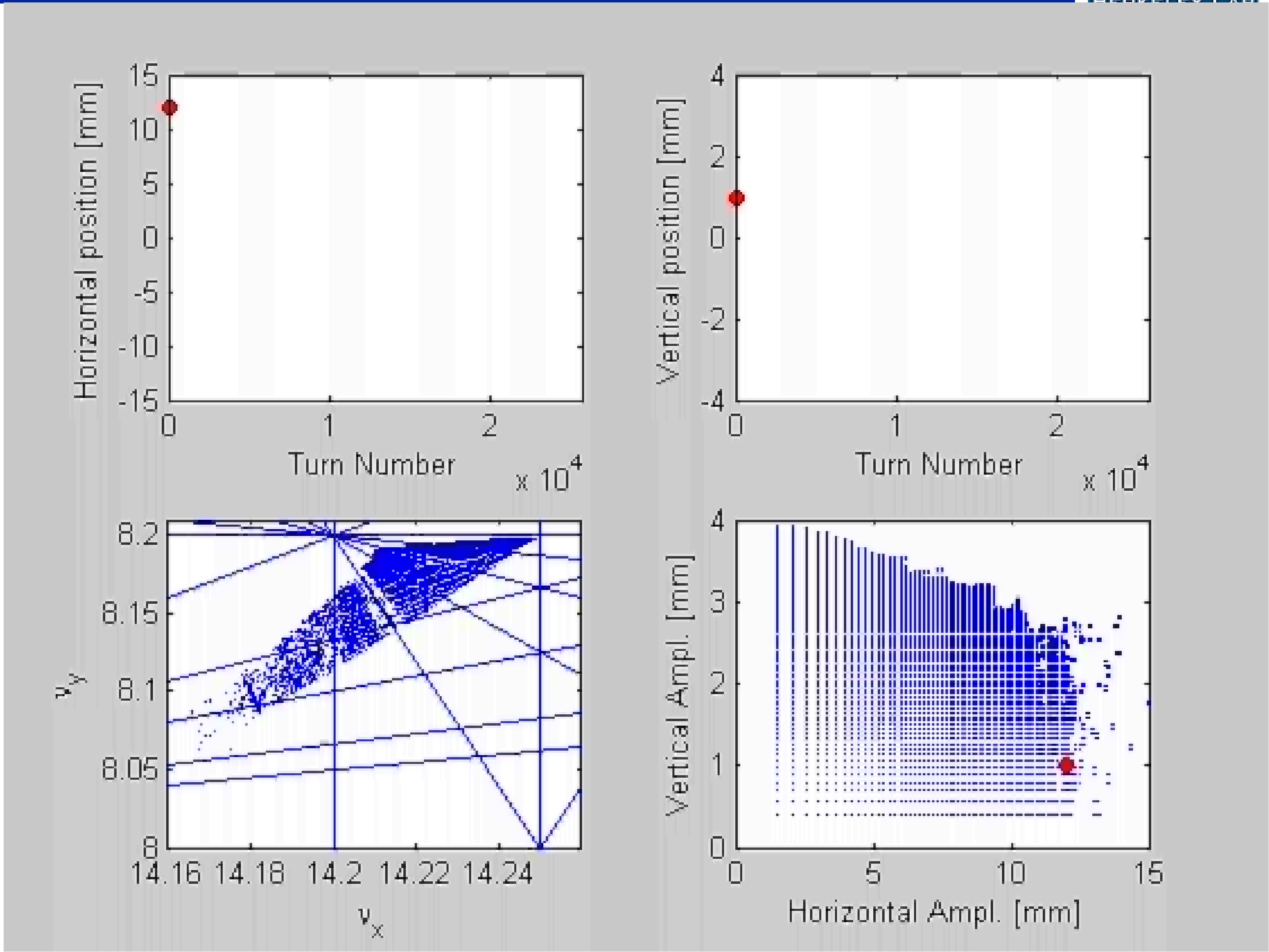
Frequency Space



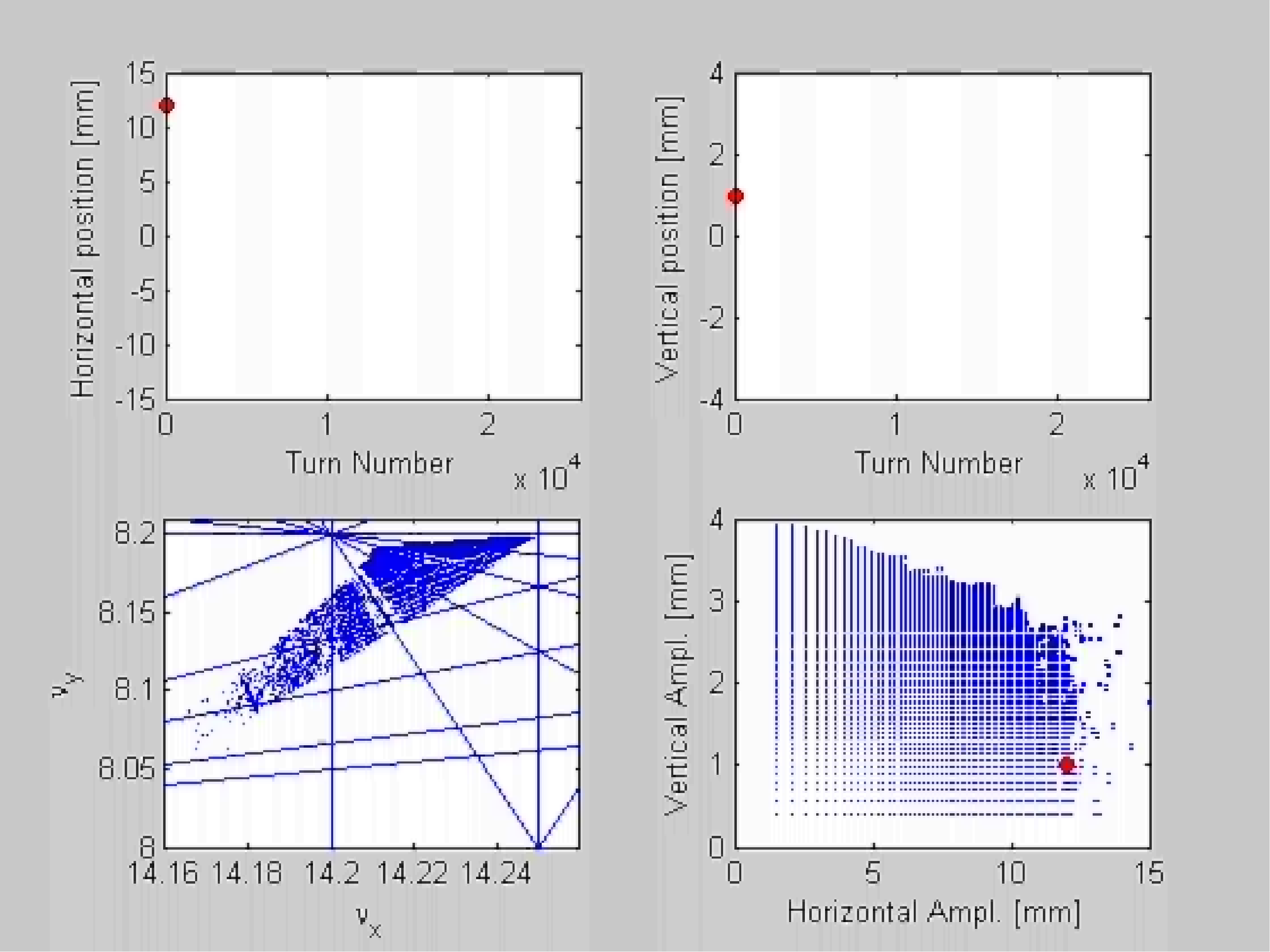
Amplitude Space



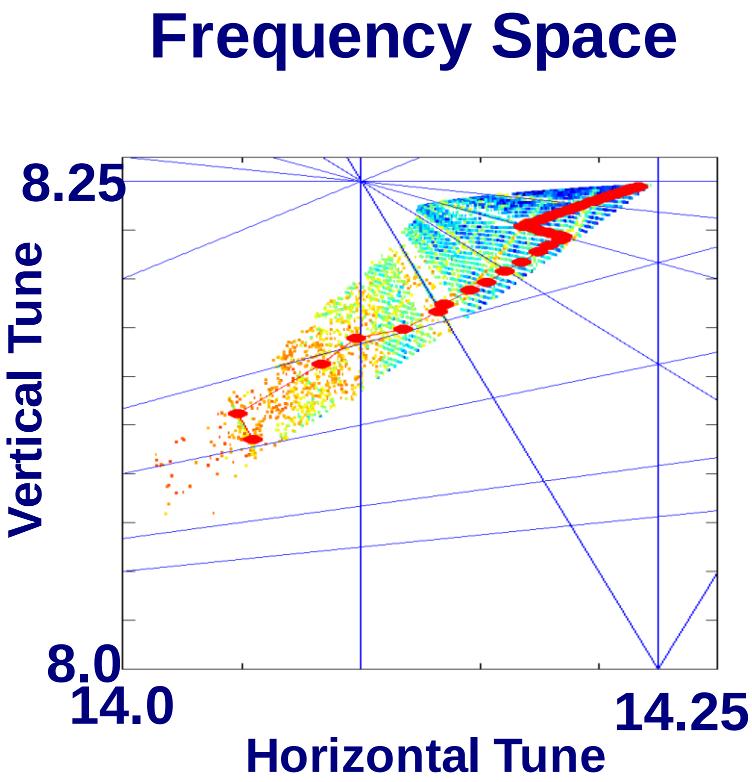
Tools and Techniques

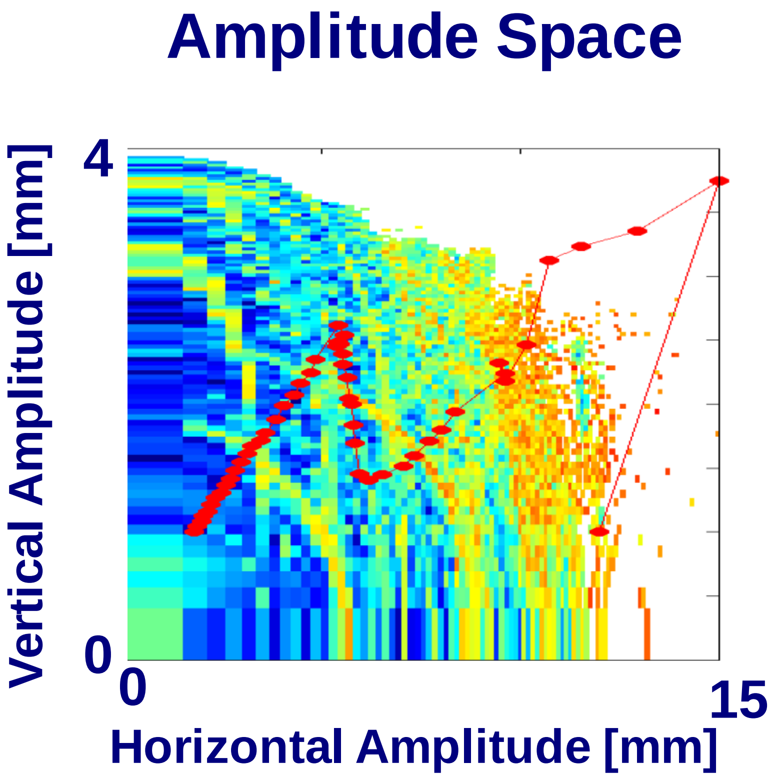


Tools and Techniques



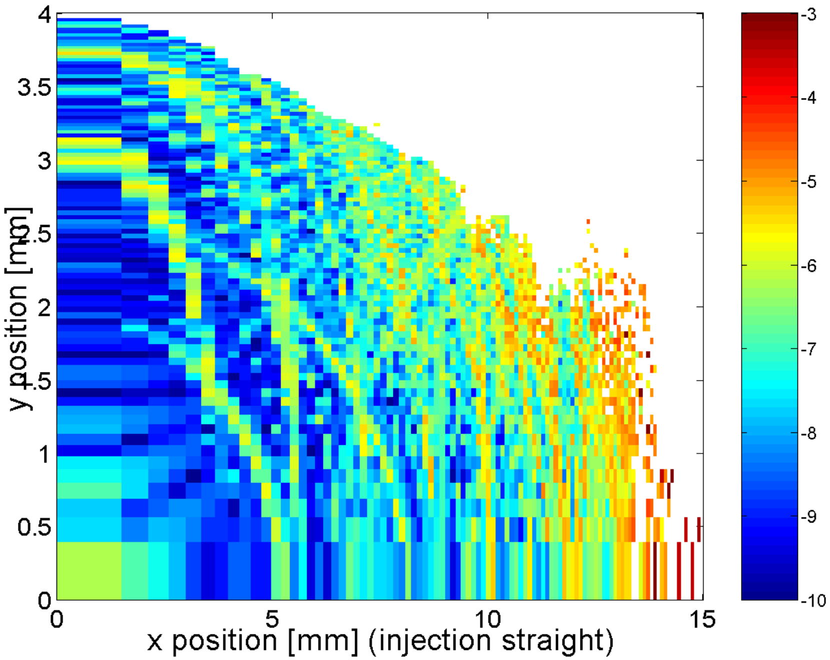
Frequency Map Analysis



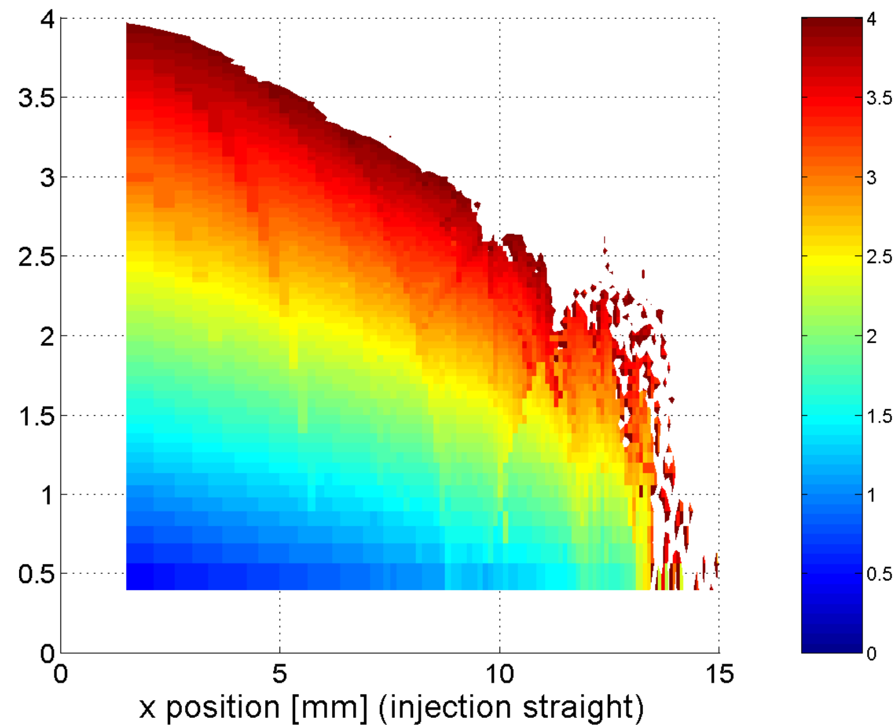


On-energy dynamic aperture - frequency map (left) versus induced amplitude (right)

Frequency Map



Induced Amplitude



Injection efficiency

- Like to have a good injection efficiency
  - Minimize fill times
  - Minimize radiation levels
    - Top-off
    - Insertion devices

- At the ALS the injected beam is horizontally offset by ~10mm from the stored beam when it enters the ring.

- The injected beam oscillates about the stored beam and slowly damps down.

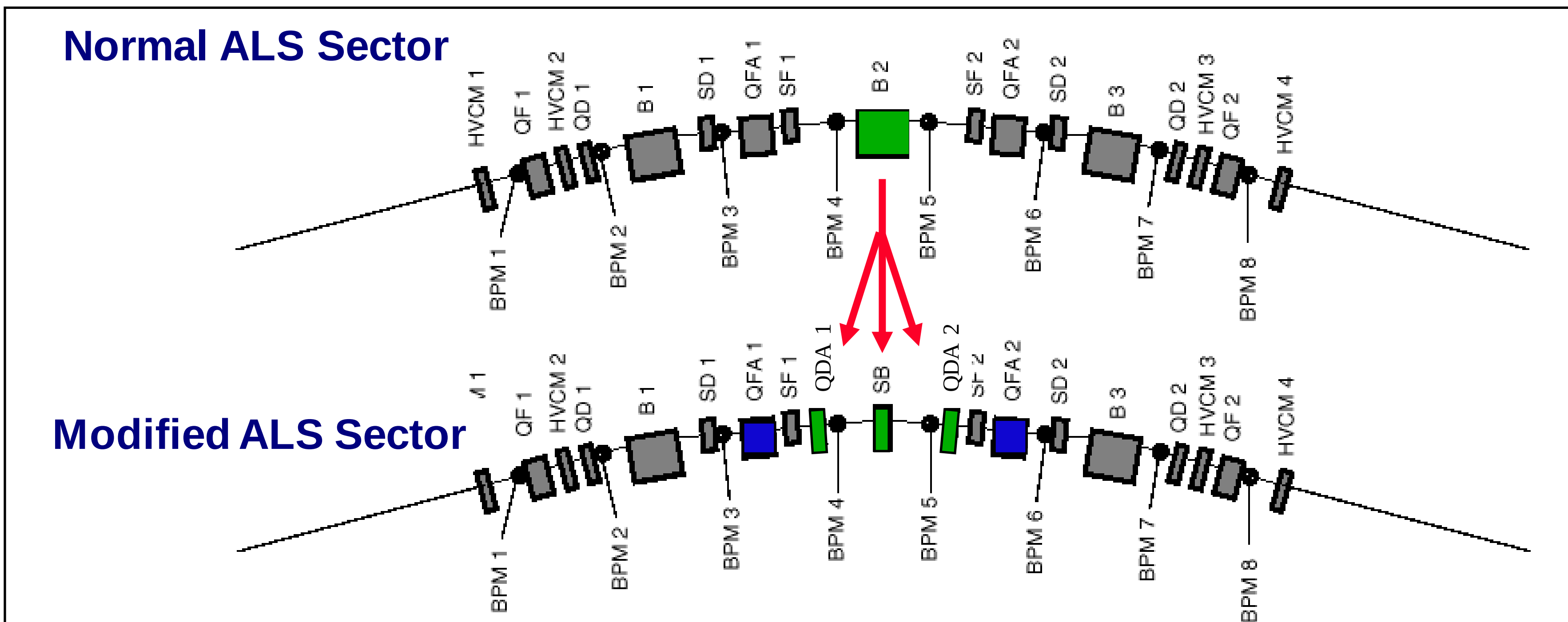
- If particles in the injected beam encounter regions of high diffusion they can be lost.

Goal is to ensure that the particle motion is stable in the region where injected particles may travel

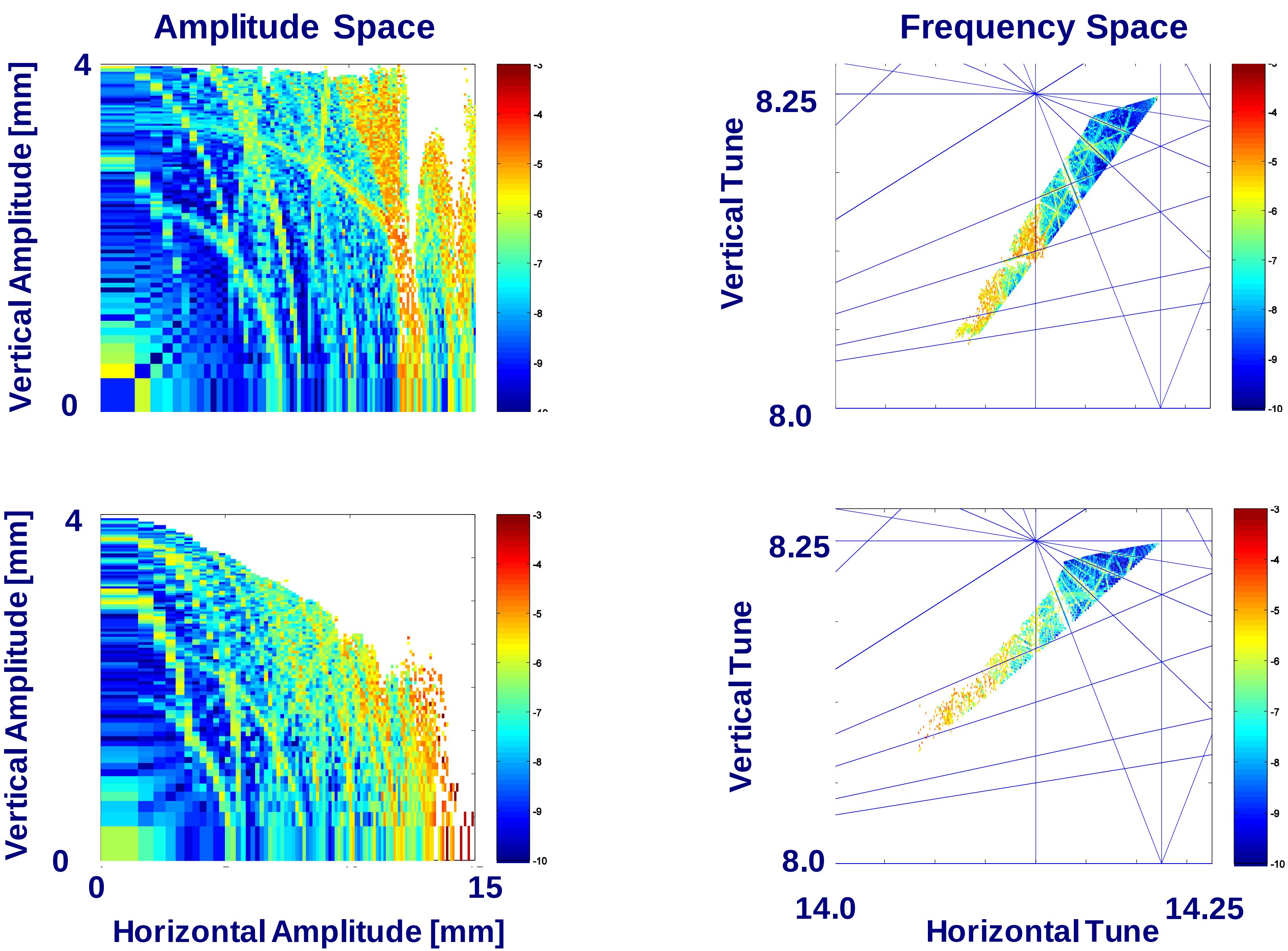
Example : Superbend Upgrade

In three of the twelve ALS Sectors

- Replaced the central combined function dipole with a Superbend and two quadrupoles



Frequency Maps without Superbends (Top) versus with Superbends (Bottom)



Momentum Aperture and Lifetime

Frequency Map Analysis has been extended to study the momentum aperture and the effect on lifetime

In the case of the Superbends the predictions agreed with the result to within 5%

The off energy frequency maps will be discussed in the next talk.

Other Results

Frequency Map Analysis has been an important technique for optimizing and predicting the performance of future upgrades

In addition to the Superbend Upgrade we have used FMA for studying

- Effect of Insertion Devices with Complicated Field Profiles
- Smaller Gap Insertion Devices
- Femtosecond Slicing Upgrade
- Higher Tune Lattice
- …

Some References

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