Dynamic Aperture Optimization Using Genetic Algorithms

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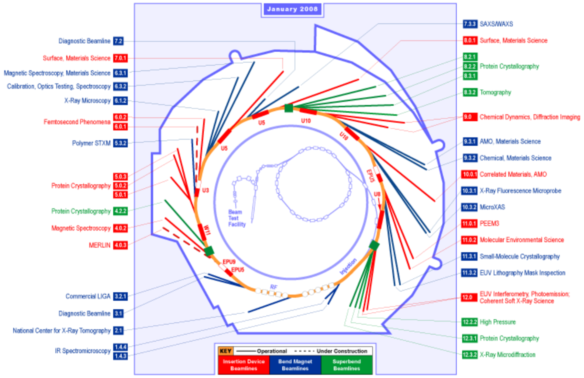

Outline of the Talk

- Three Methods to optimize dynamic aperture
- Dynamic aperture optimization using Genetic Algorithms(GA)
- Simultaneous linear and nonlinear lattice optimization using GA

Methods to Optimize Dynamic Aperture

- Resonance Driving Terms Minimization

By properly choosing the sextupole strength, the resonance driving terms can be minimized, thus nonlinear effects will be reduced.

✔ Pros: Fast

✗ Cons: Based on the perturbation theory; weight factors of driving terms must be carefully chosen, based upon experiences or even by guessing.

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- Brute Force Scans

  This technique scans all the sextupole settings, and keep the setting with the largest dynamic aperture.

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- Genetic Algorithms (GA)

  It is a method to generate optimum solutions using techniques inspired by natural evolution, such as inheritance, mutation, selection and crossover.

  ✔ Pros: Address the limitation of above methods

  ✗ Cons: Algorithm is not easily implemented

Genetic Algorithms (GA)

- A typical GA is describe as follows:

  1: Randomly generate the first generation (the first trial lattice solutions)
  2: Evaluate the first generation
  3: Sort the first generation
  4: Repeat
  5: select parent to generate child (cross over)
  6: mutate child
  7: evaluate child
  8: merge the parent and child
  9: sort the mixed population
  10: select the first half of the mixed populations
  11: Until reach maximum generation

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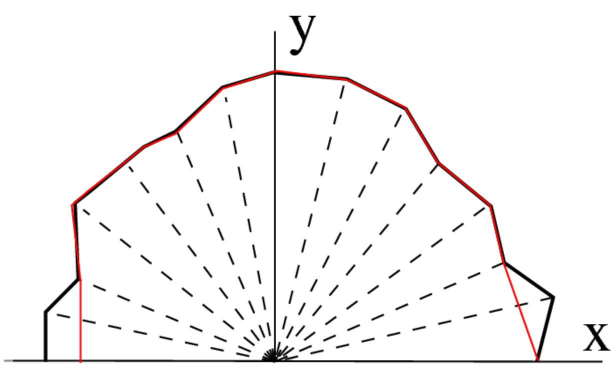
- GAs have been widely used to solve multi-objective optimization problems in many fields.

  In the field of accelerator physics, it has been used to optimize superconducting magnet, beam transfer line, photoinjector, and storage ring linear lattice and dynamic aperture.

Optimization Objectives

- Dynamics aperture area *[M. Borland, Elegant V 23.1]*
  - 21 line, and 11 steps for each line
  - 4 interval splitting to refine the boundary
  - 512 turns
  - Boundary is clipped to avoid the island



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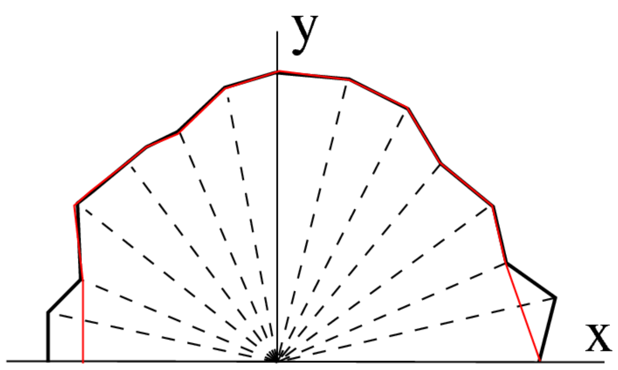
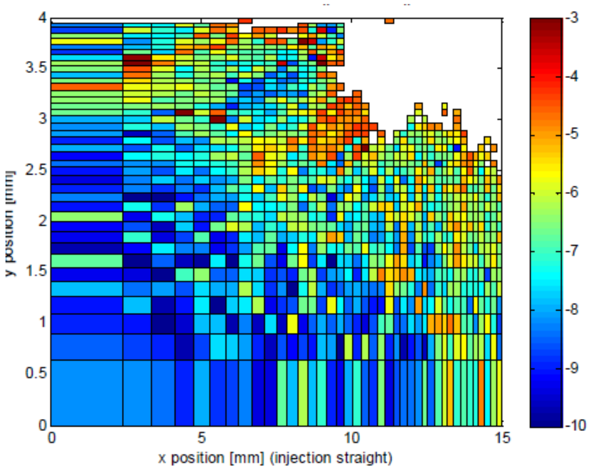


- Total diffusion rate *[C. Steier and W. Wan, IPAC 2010]*
  - Frequency Map Analysis
  - 21 by 21 non-uniform grid search
  - 512 turns for each grid.
  - Diffusion rate is calculated according to

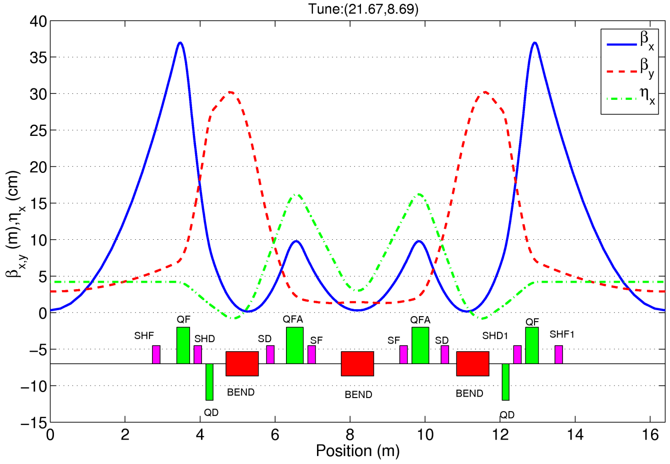
$$d = \log\left(\frac{\sqrt{(\nu_{x,1}-\nu_{x,2})^2+(\nu_{y,1}-\nu_{y,2})^2}}{N}\right)$$

  - Diffusion rate is assigned to -3 for lost particle
  - Boundary is clipped to avoid the island

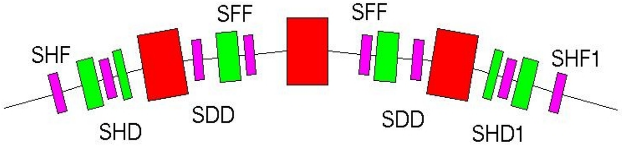


Dynamics Aperture Optimization

- ALS "ultimate" upgrade lattice is used as an example. It is a Triple Bend Achromat (TBA), consisting of 12 sectors, and 6 sextupole families.



- 6 parameters: (2 chromatic + 4 harmonic sextupoles)

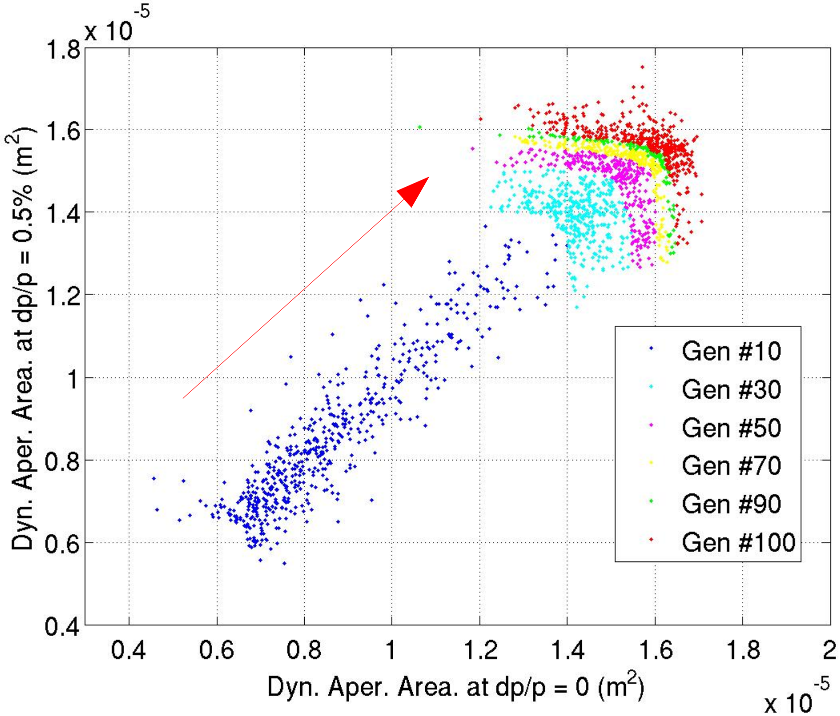


The chromatic sextupole strength are given by chromaticities fitting

- Objectives:
  - Dynamics aperture area for dp/p = 0 and dp/p = 0.5%, or
  - Total diffusion rates for dp/p = 0 and dp/p = 0.5%

Solutions at Different Generation

The lattice errors: 0.03% quad field gradient and 0.05% coupling.



Dynamics aperture area

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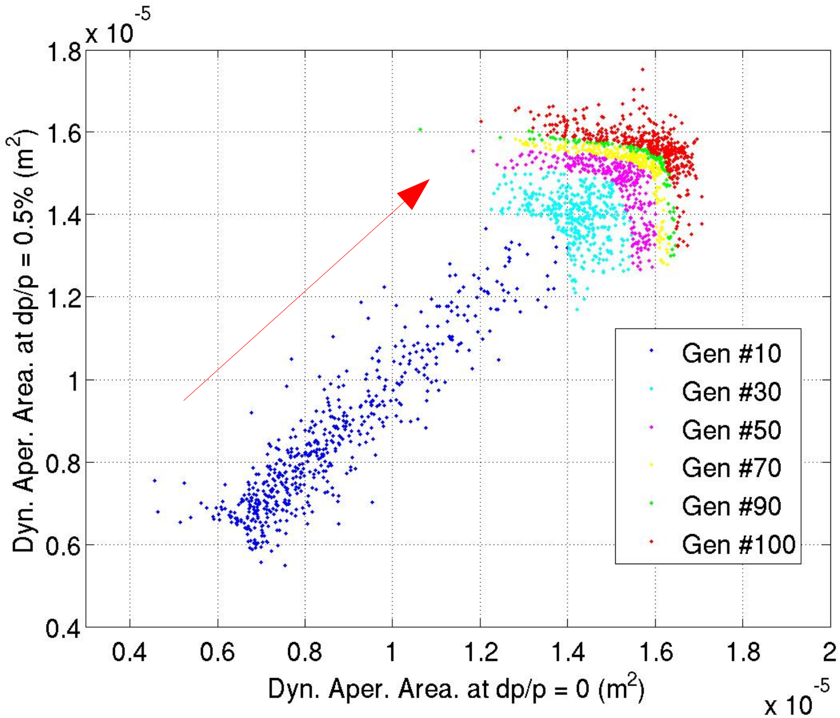
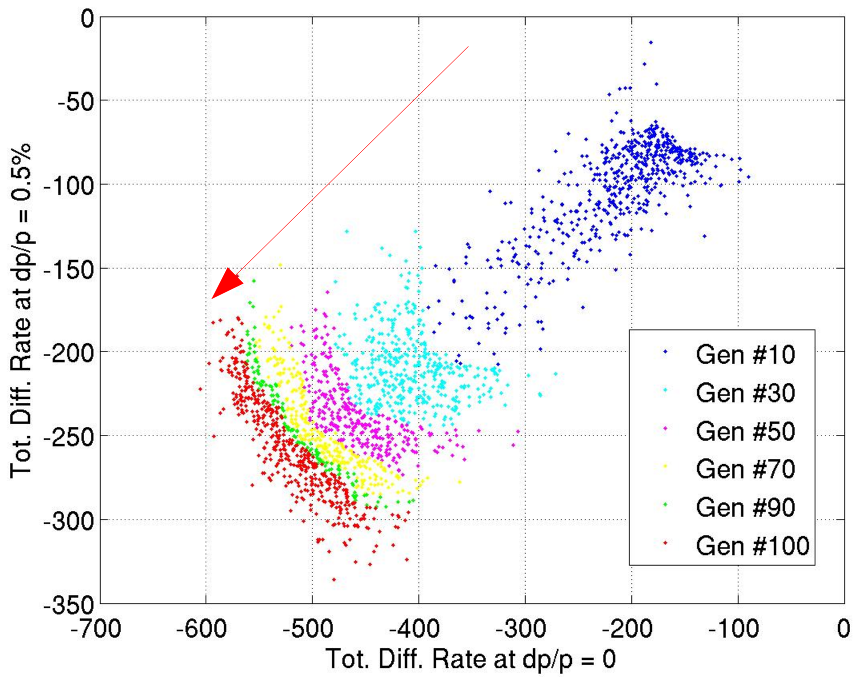
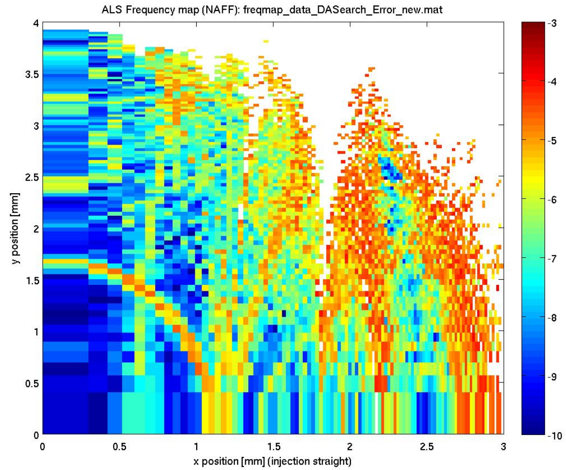


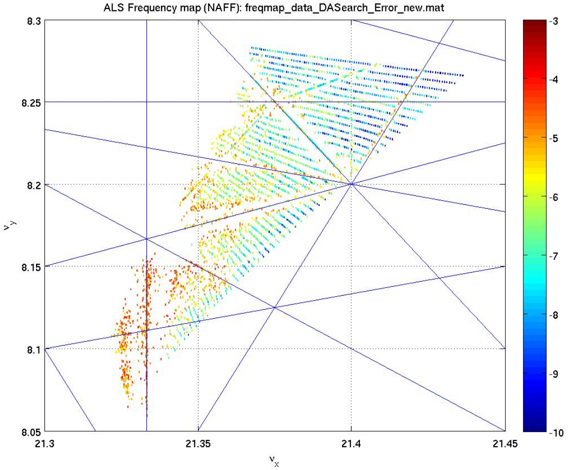
Dynamics aperture area



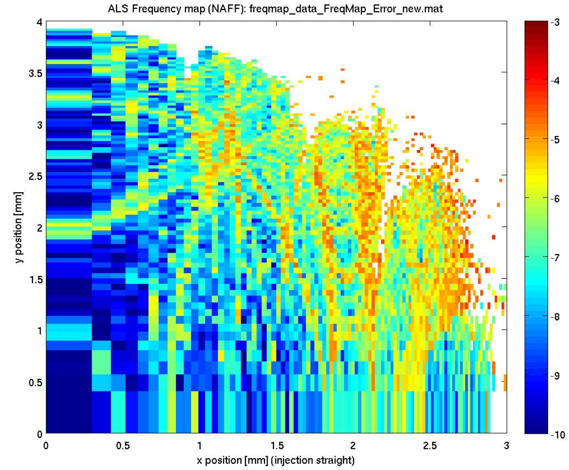
Total Diffusion Rate

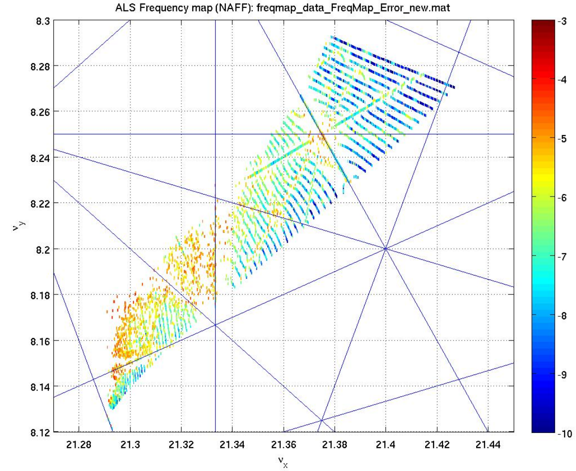
Freq Map of the Solutions Optimized Using GA





Dyna. Ape. Area





Tot. Diff. Rate

The optimization using diffusion rate as objective has a better performance!

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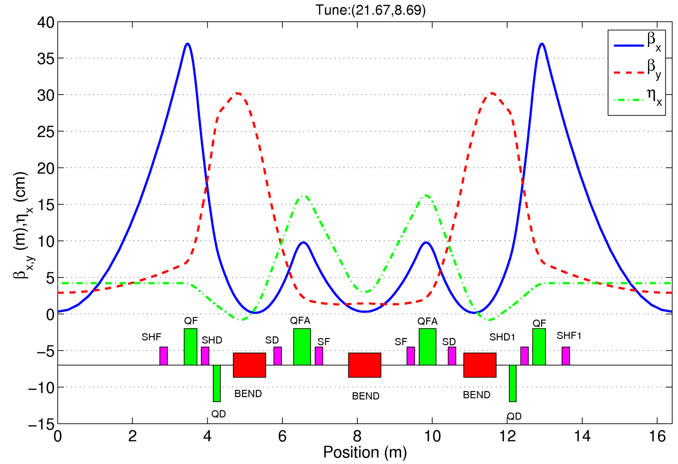
Typical Two stages of Lattice Optimization

- Storage ring lattice design typically proceeds in two steps:
  1. The first step is to design a linear lattice
  2. The second step is to optimize the nonlinear properties of the lattice
- These two steps are well separated. However, without a consideration of the suppression of nonlinear effects at the first step, the subsequent optimization in the second step might not succeed.
- In this case, the linear solution found in the first step needs revisit by changing the working tunes to ensure the best overall optimization.
- Such a strategy (known as *Dynamic Aperture Tune Scan*) has been widely used to find a best working point in many facilities.
- There are also many successful example of using the first step to mitigate the strong nonlinear effects by canceling geometric driving terms.

Simultaneous Linear and Nonlinear Optimization

ALS ultimate lattice is used as an example:

- 7 parameters: 3 Quads + 6 Sextupoles
- constraints: stability, positive partition number, reasonable optics functions
- 3 objectives: emittance, betax and dynamics aperture



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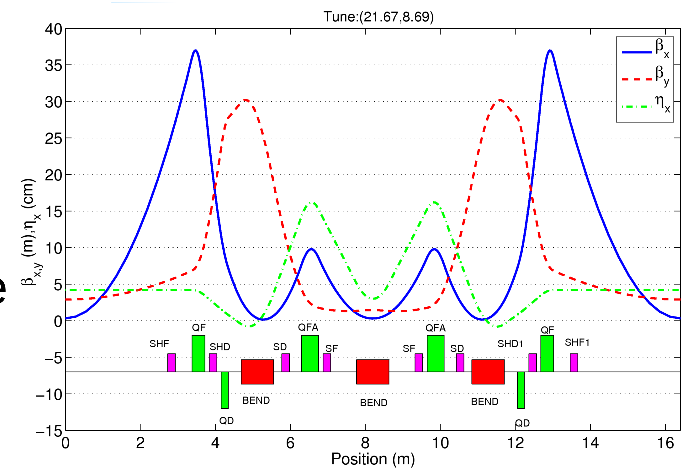

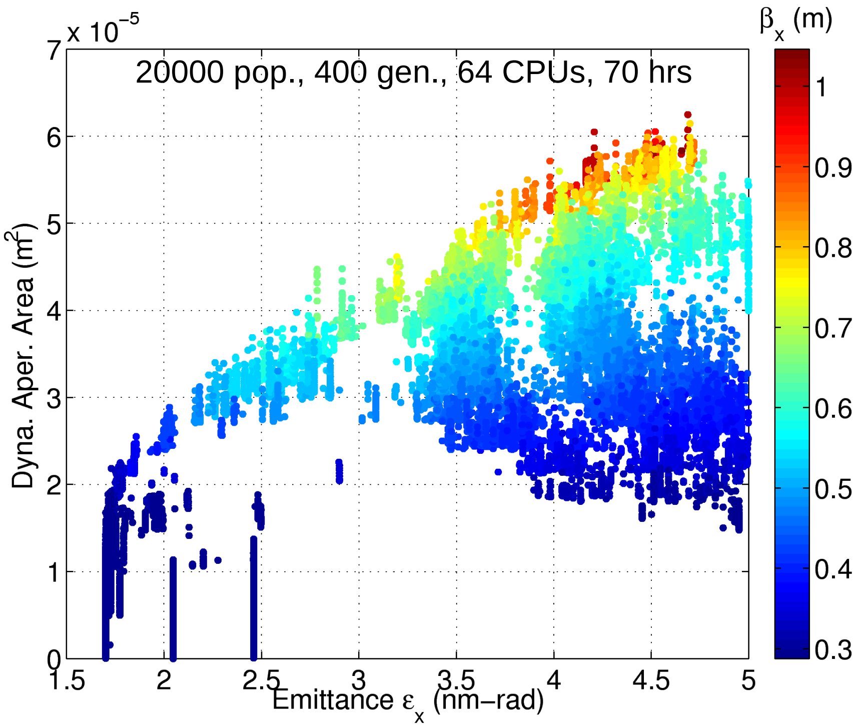

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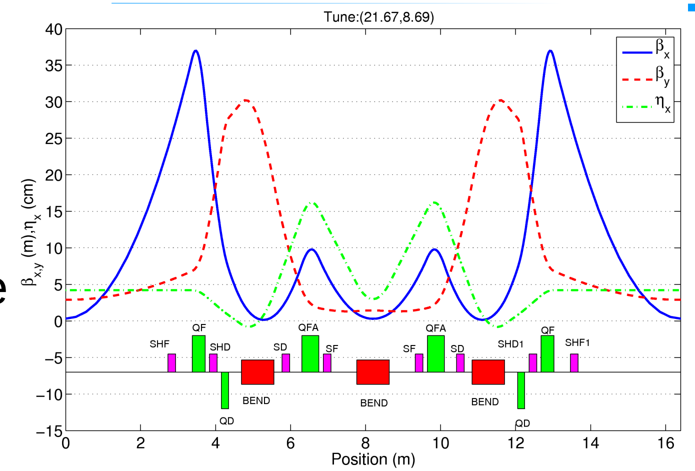
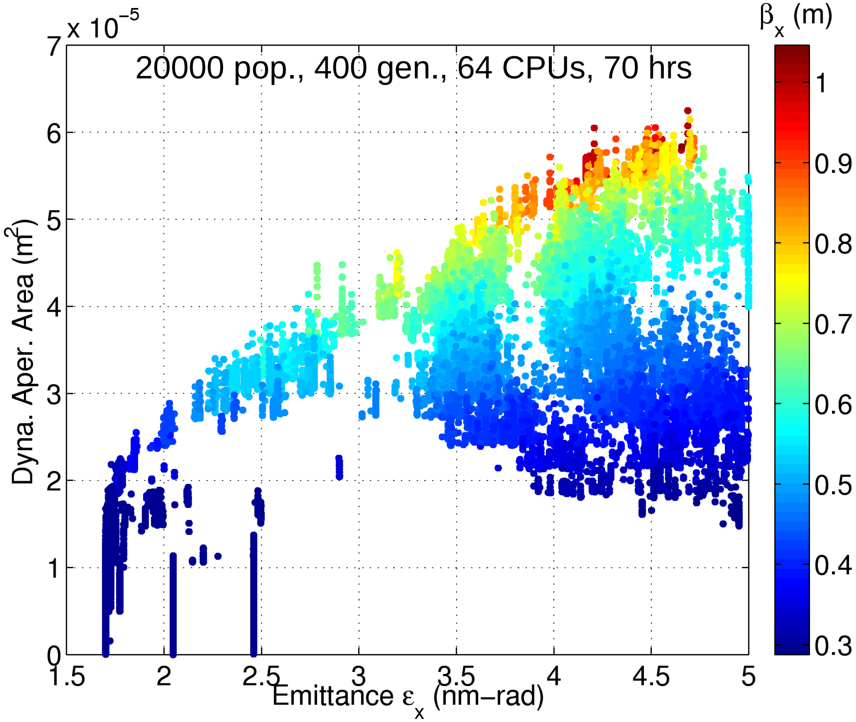
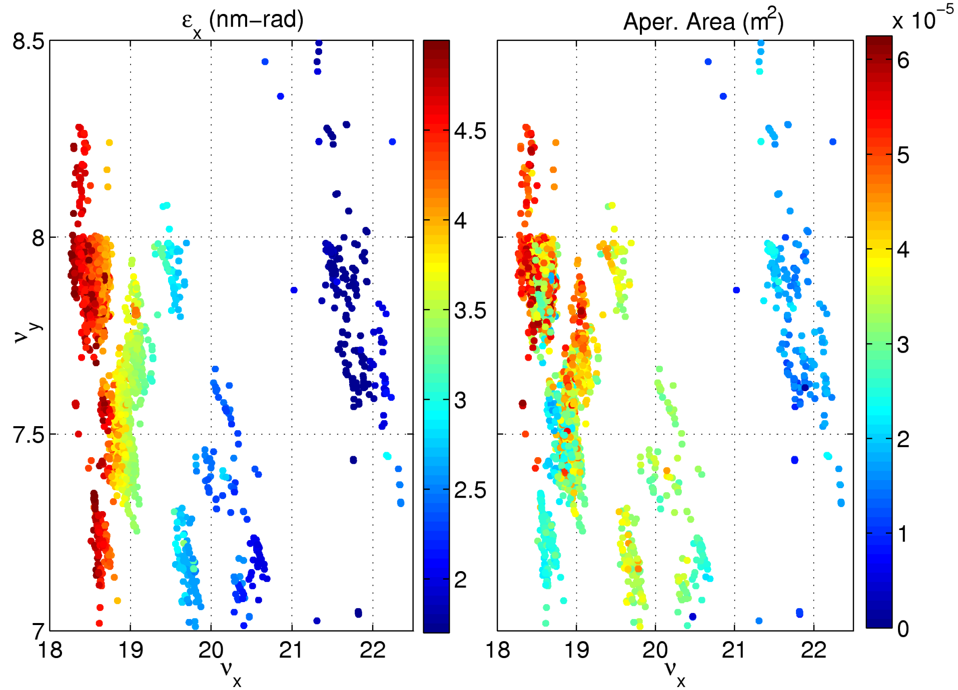
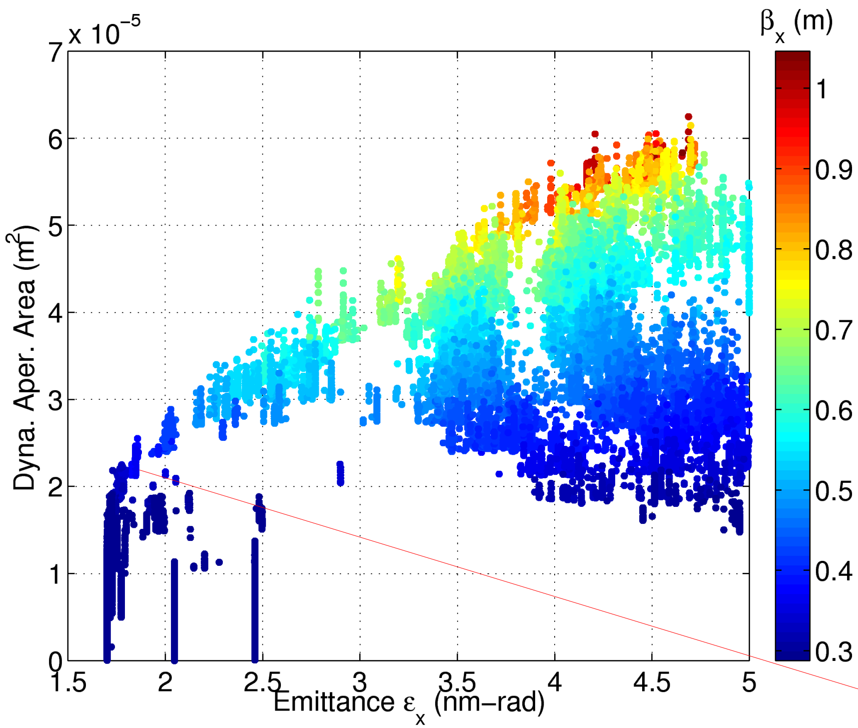
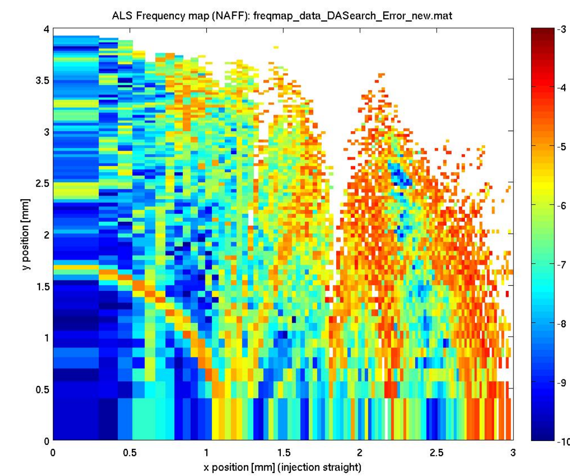






Trade-offs





Trade-off among the low emittance, small beta and large dynamic aperture are found!!!

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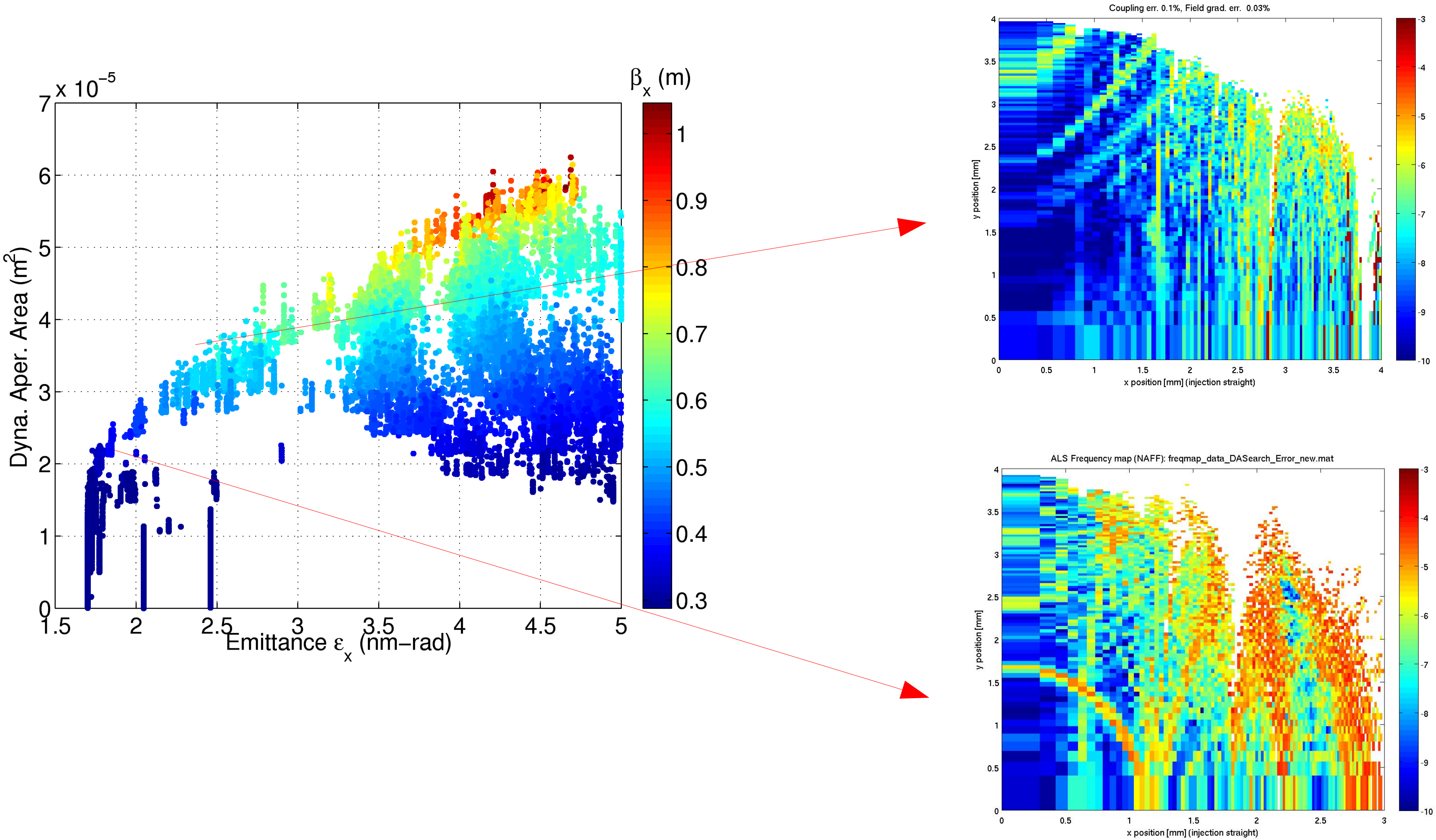

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Summary

- We successfully apply Genetic Algorithms to optimize dynamics aperture of a storage ring
- It is demonstrated that the optimization using total diffusion rate have a better performance than the optimization using dynamics aperture area.
- The linear and nonlinear properties lattice are optimized simultaneously, and trade-offs are found among the small emittance, low beta function and large dynamic aperture.