MOGA for NSLS2 DA Optimization

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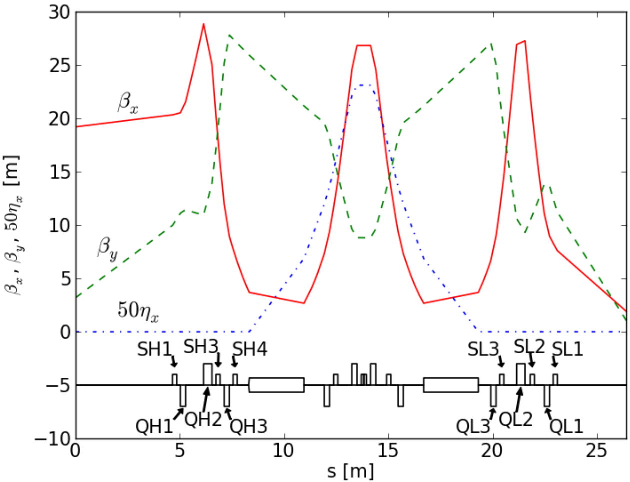
Overview

- Genetic Algorithm (GA) is an optimization algorithm which is easy to parallelize and does not need derivatives.
- We have used multiobjective genetic algorithm (MOGA) and direct tracking as an alternative method to optimize dynamic aperture (DA) for NSLS-II lattice.
- The low order nonlinear driving terms are included as objective functions and constraints.
- Recent GA based optimization of SR properties:
    - M. Borland etc: FLS 2010.
    - C. Sun etc: IPAC 2011.
    - W. Gao etc: PRST-AB 2011.
    - L. Yang etc: NIM-A 2009, FLS 2010, PRST-AB 2011.
    - ...

NSLS-II Lattice and Layout

- 30 DBA
- 15-fold symmetry.
- 6 Sext. at $\eta_x = 0$.
- 3 Sext. at $\eta_x > 0$.
- 6.6m/9.3m straight.
- 3-fold symm. with 3 DW in our simulation.



Structure of MOGA

GA mimics the evolution of nature:

1. **Crossover**: generate children from parents.
2. **Mutation**: change the children.
3. **Natural selection**: keep only certain number of population.

MOGA (Multi-Objective Genetic Algorithm)

Initialize population (first generation, random)
repeat
    crossover: 2 parents $\rightarrow$ 2 children.
    mutation: change children.
    calculate f_m, g_j, ...
    natural selection: "sorting"
until stop(reach maximum generation, find solution, ...)

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Parallel MOGA

- MOGA is easy to parallelize.

  Parallel computing is easier than ever before: Multicore Desktop (4-8 cores), Cluster, Clound Computing, (GPU, GPGPU,) ...
- Algorithm without derivatives

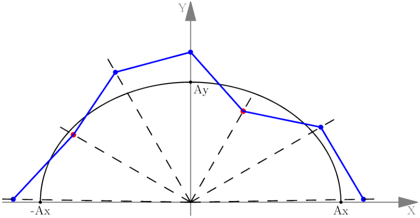
  Convenient for non-analytical quantities, e.g. DA, or non-static simulations with random errors.
- MOGA scales well

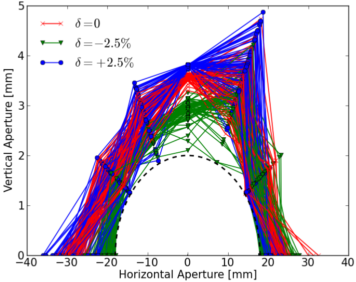
  Loosely-coupled, master-slave mode, scales well with more computing units.
- In a global sense

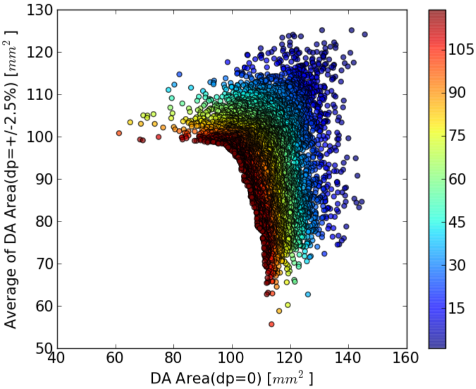
  It's an optimizer for global region
- Gives trade-offs besides the optimal solutions

  The Pareto optimal set (POS) tells trade-offs between optimal solutions

Optimizing DA Area







1. Objective func. are DA areas.
2. Constraints are fixed ellipse
3. Variables are 6 geom. sext.

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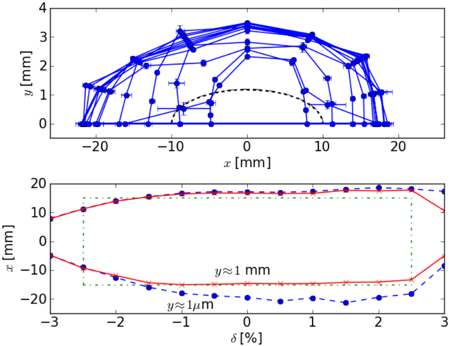
One candidate

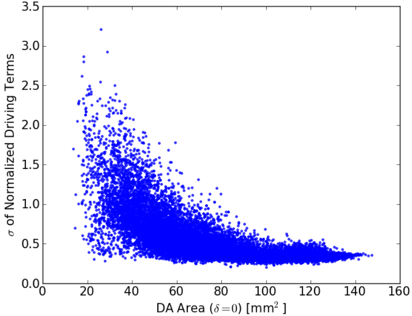
One candidate solution:



Errors	Value
Sext Shift H/V	$\sigma = 30 \mu m$
Sext Rot.	$\sigma = 5 \mu rad$
Quad Shift H/V	$\sigma = ? \mu m$
Quad Rot.	$\sigma = 5 \mu rad$
Mult. Err.	Quad.
Mult. Err.	Sext.

Quad. misalignment are added to produce 20–40μm orbit distortion and coupling.

The correlation between tunes-with-ampltude and DA area suggests:



- Each h_{ijkmn} is normalized to their average value.
- Each candidate sums up all low order normalized h^*_{ijkmn}

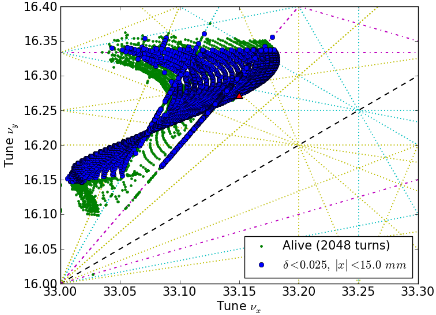
$$\begin{cases} f_1 = \sum_\delta S(\delta, y = 1\mu m) \\ f_2 = \left(\frac{\partial \nu_x}{\partial J_x}\right)^2 + \left(\frac{\partial \nu_x}{\partial J_y}\right)^2 + \left(\frac{\partial \nu_y}{\partial J_y}\right)^2 \end{cases} \quad (1)$$

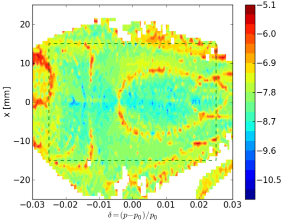
Optimization in $x - \delta$ plane ($\xi_x = 4, \xi_y = 4$)

Now we move to higher chromaticities:

7 free variables of 9 sextupoles.

- 6 geometric sext
- 2 chrometic for fixed chromaticity.
- 1 free chromatic sextupole.





- Working point ($\nu_x = 33.15, \nu_y = 16.27$), ($\xi_x = 4, \xi_y = 4$).
- Multipole errors, misalignment and rotation errors are included.
- DW is modeled by kickmap.

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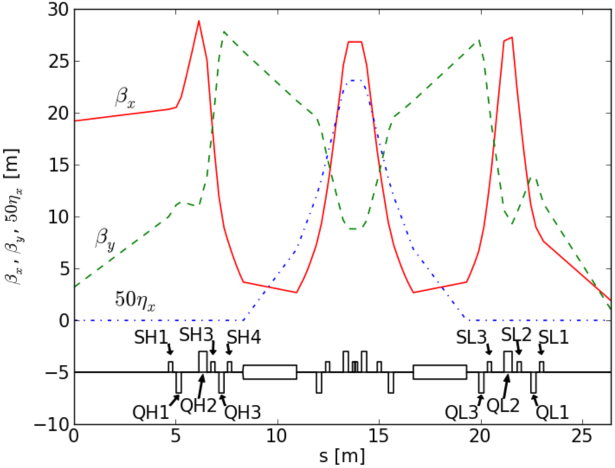
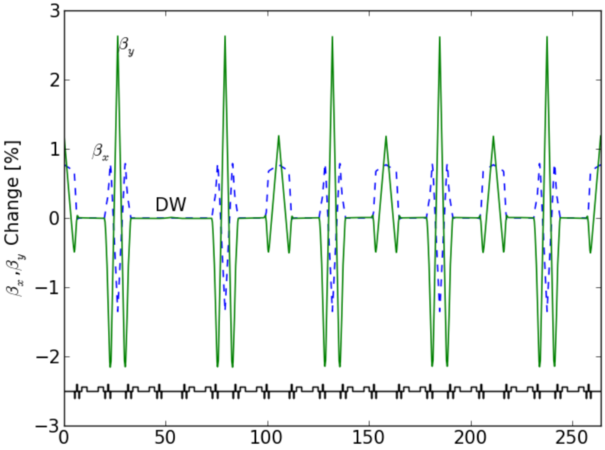
DA Optimization with Tune



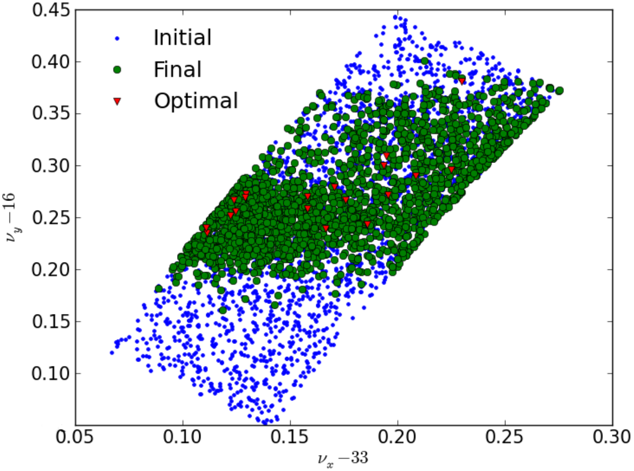
- Tune can be varied by $\beta_{x,y}$ in straight only.

DA Optimization with Tune



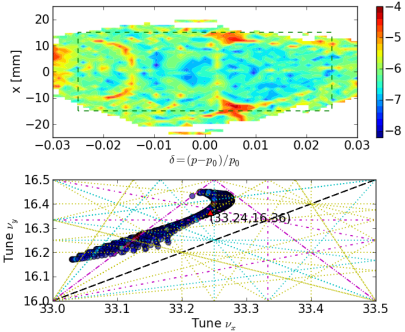
- High and low beta region can be tuned independently. DW region is fixed.

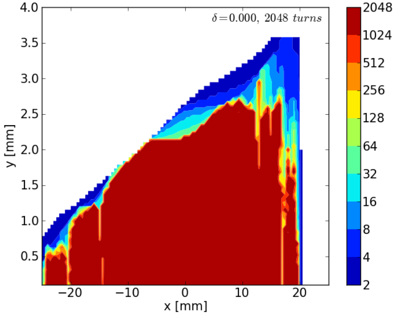
DA Optimization with Tune



- 9 Sextupoles and 6 quadrupoles are tuned in optimizer.

Optimize with Tune



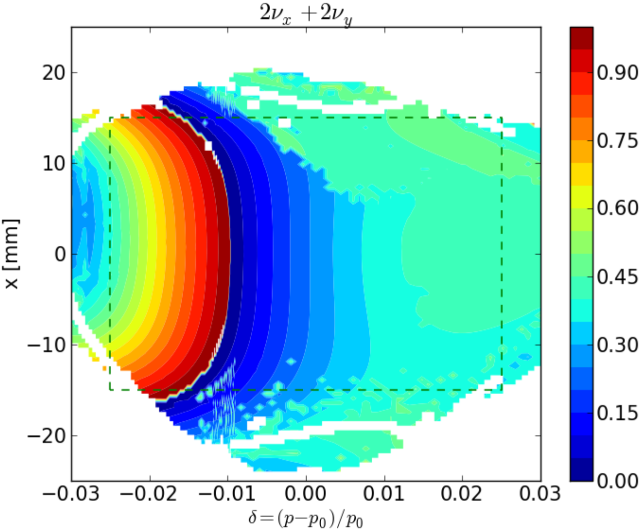


- Frequency map of a candidate lattice with tunes $(33.28, 16.35)$ and fitted chromaticity $(4.83, 4.80)$.
- The rectangle with green dashed line is the constraints. A vertical resonance line, $2\nu_x + 2\nu_y = 99$, exists around $\delta = -1\%$ in read and yellow colors.

Summary

- We have used MOGA techniques as an alternative method to optimize DA for NSLS-II.
- The nonlinear properties are based on direct particle tracking.
- Tunes-with-amplitude are used for objective functions.
- Engineering erros including misalignment and multipole errors are included.
- Tunes are varied by quadrupoles in non-dispersive straight sections.

Backup Slides



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