Multi-Objective Optimization of Dynamic Aperture

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Outline

- Dynamic aperture optimization
- Multi-Objective Optimization as a complimentary method
- Some results of preliminary work
- Continuing and future work
- Conclusions

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Johan Bengtsson, Weiming Guo, Sam Krinsky, Yongjun Li

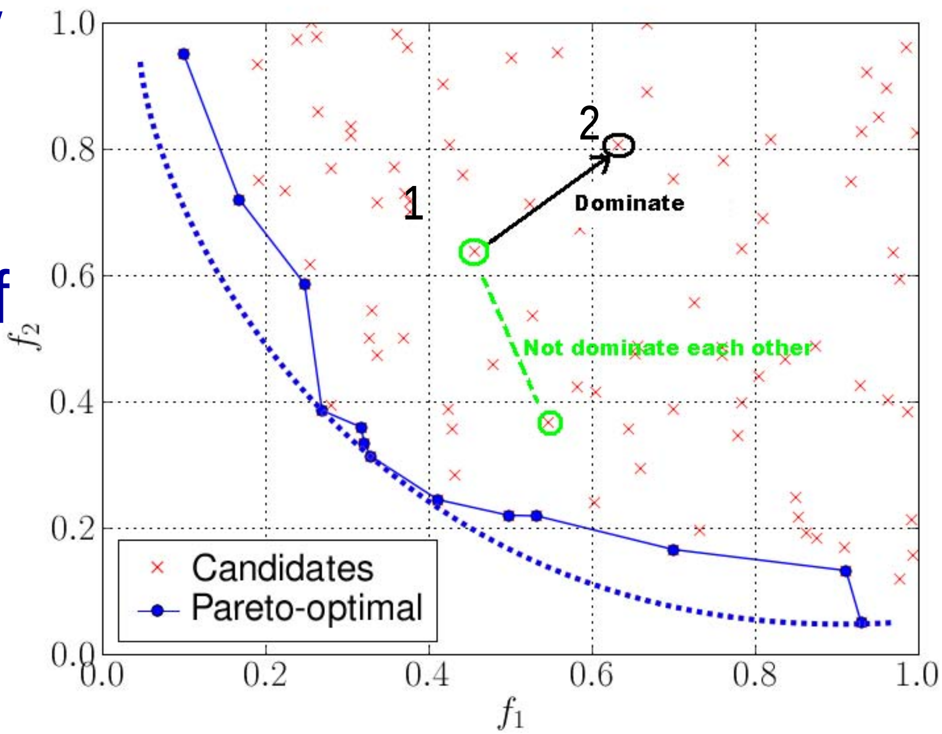
Dynamic Aperture Optimization

- Traditional approach of optimizing DA uses weighted sum of driving terms, tune with amplitude, nonlinear chromaticity, …
- DA optimization is a problem with many objective functions and constraints: on momentum, off momentum, 2D area, … (A born multi-objective optimization problem)
- Multi-Objective Optimization has been applied in many fields including economics, engineering, and accelerator physics for linear dynamics [M. Borland, L. Emery, L. Yang] and photo-injector studies [I. Bazarov].
- We are exploring the use of this method as a complimentary method to optimize the DA for NSLS-II

Pareto Optimal Set (for two properties)

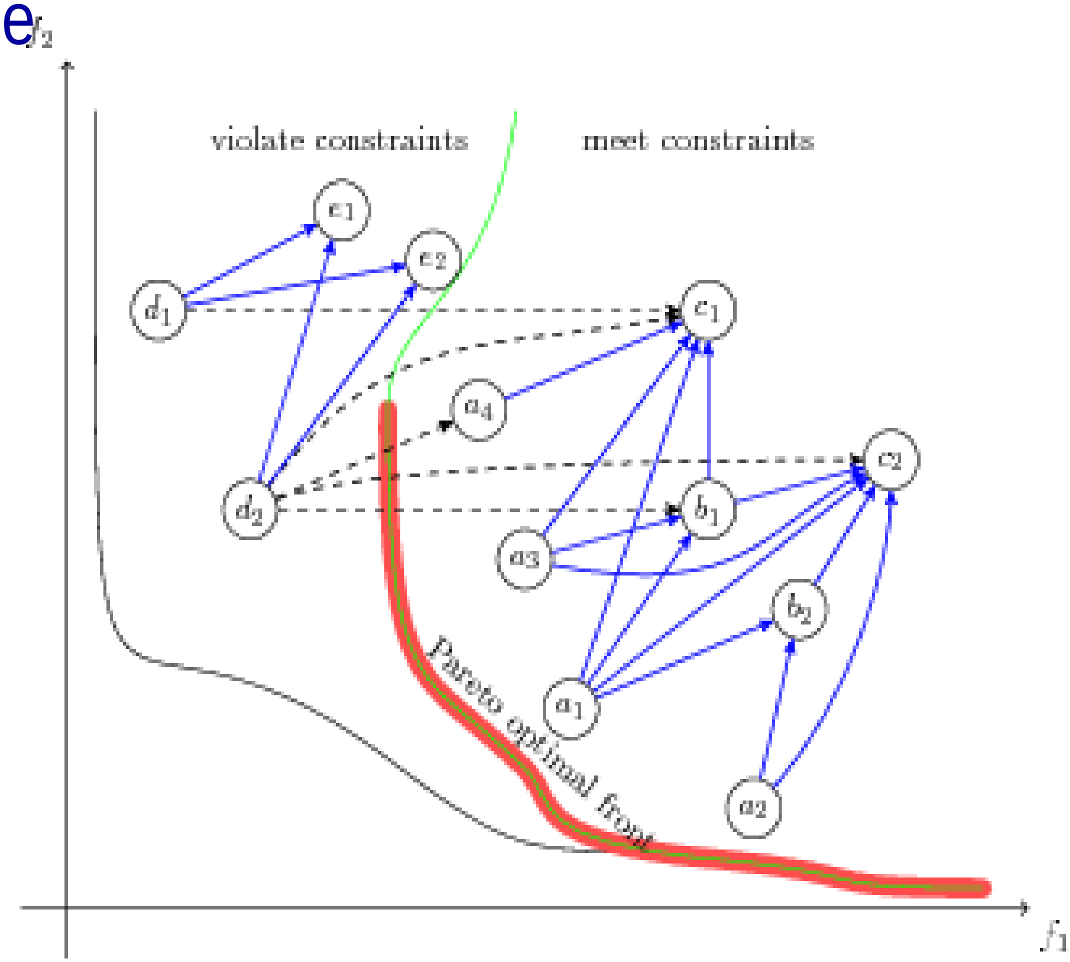
- Trial 1 dominates 2 if better in properties f1 and f2
- If trial 1 has better f1 but worse f2, then neither dominates.

- Dominating means "definitely better" in comparing two vectors.
- Pareto Optimal Set is a set of trials which are not dominated by any others
- For a set of solutions in MO, the best solution(s) are in general a set (Pareto Optimal)



Multi-Obj. Optimization with Constraints

- Constraints can change the "dominance"
- But, do not change the algorithm
- From iteration to iteration, the new trials are close to non-dominated set.
- Searching is always converging, since from iteration to iteration only trials which dominate so-far-best solutions are kept



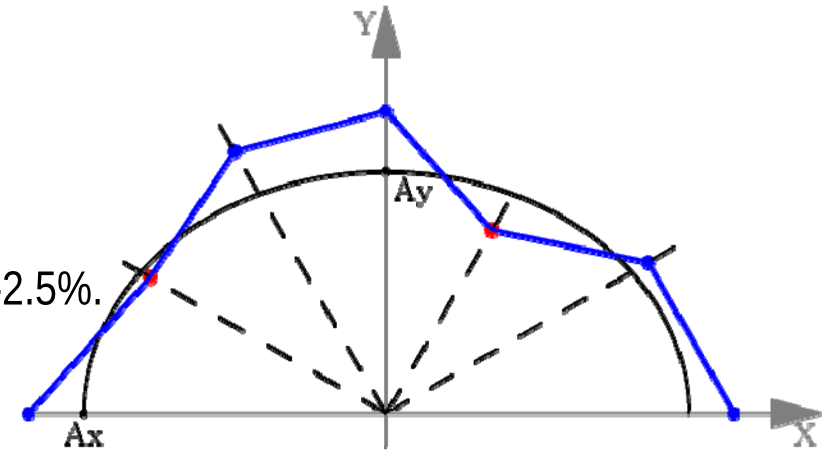
Structure of Multi-Obj. Optimization

- Create a random set of parameters x, (trials)
- Evaluate objective functions and constraints for the trials.
- “Sort” the trials, keep the best half.
- Perturb their parameters using evolutionary algorithm
- Iterate “evaluate”, “sort” and “perturb” processes, until maximum iteration or stable trials have been achieved.

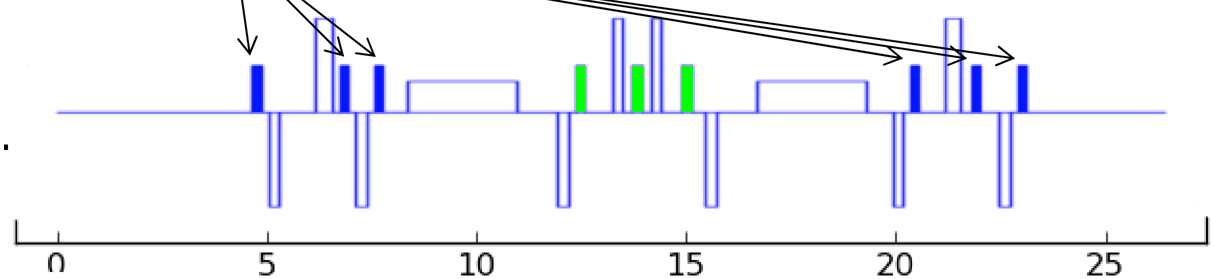
- The solution is a set of candidates (non-dominated/Pareto Set).
- Trade-off between Pareto optimal solutions requires human intelligence.

Optimization Setup

- Optimize:
  - DA of on momentum
  - Average DA of off momentum dp/p0=+2.5% and -2.5%.

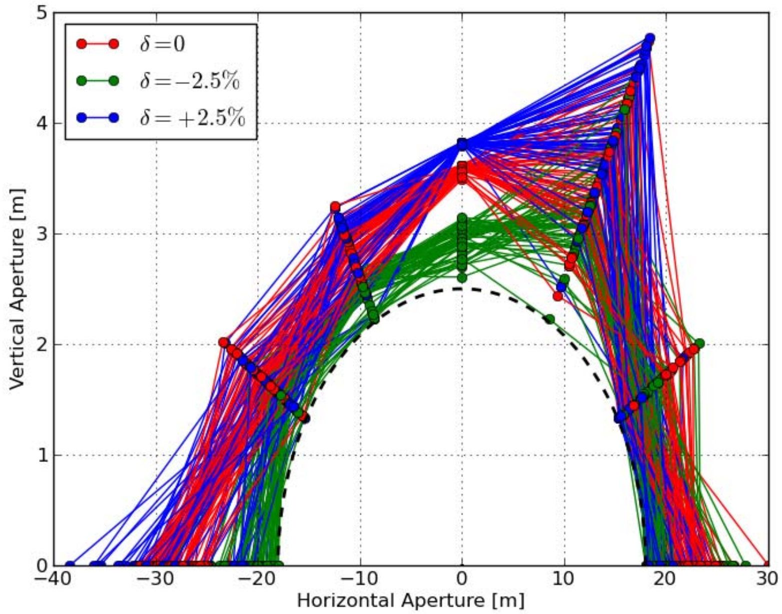


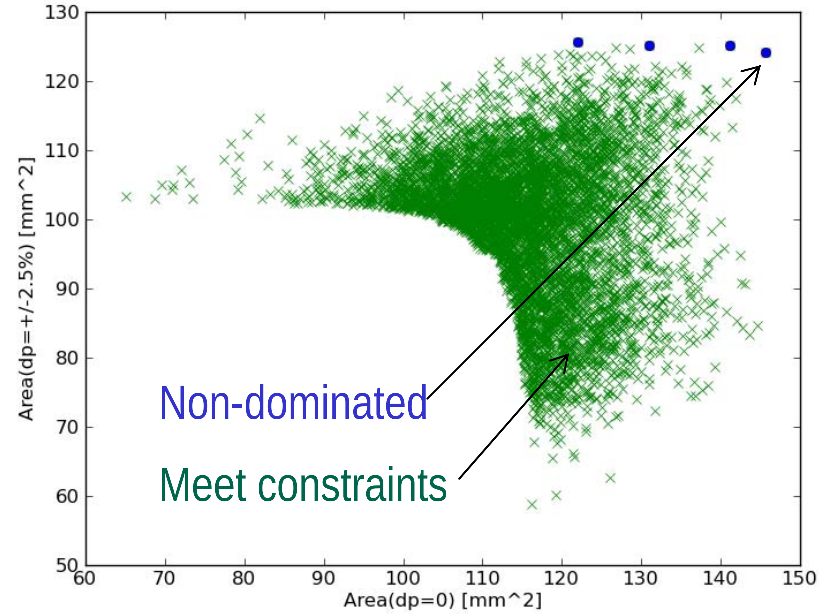
- Parameters:
  - Strength of 6 sextupoles at zero dispersion, K2 in [-40,40]



- Constraints:
  - DA fully covers an ellipse.
- Remarks:
  - Tune is fixed (33.43, 16.35), as given by Weiming Guo.
  - Linear chromaticity is fixed (1.44, 0.15), as given. (3 chromatic sextupoles are fixed)

Preliminary Results (1)





- The optimization converges.
- Several solutions are available, but need more analysis: FMA, misalignment error, multipole error, …

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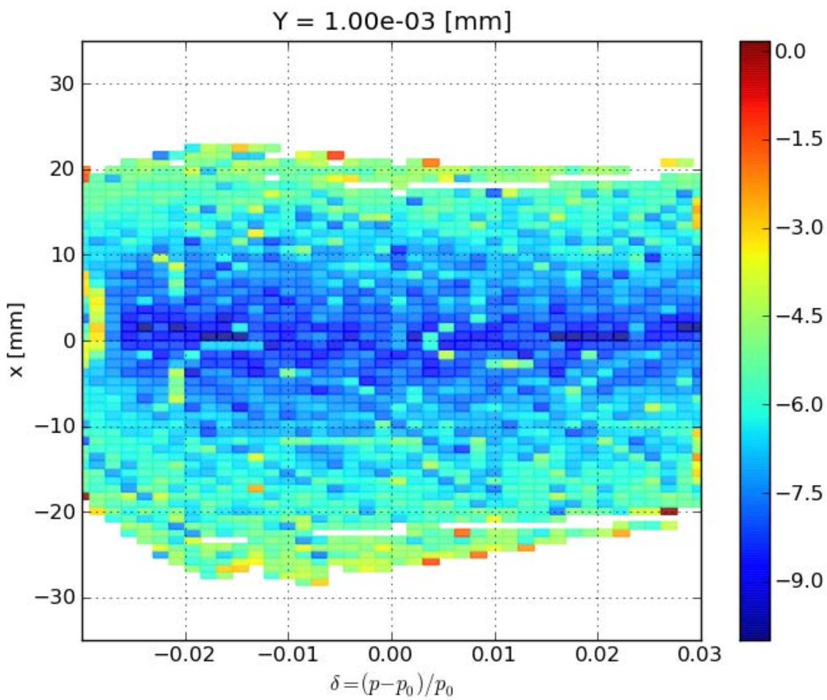
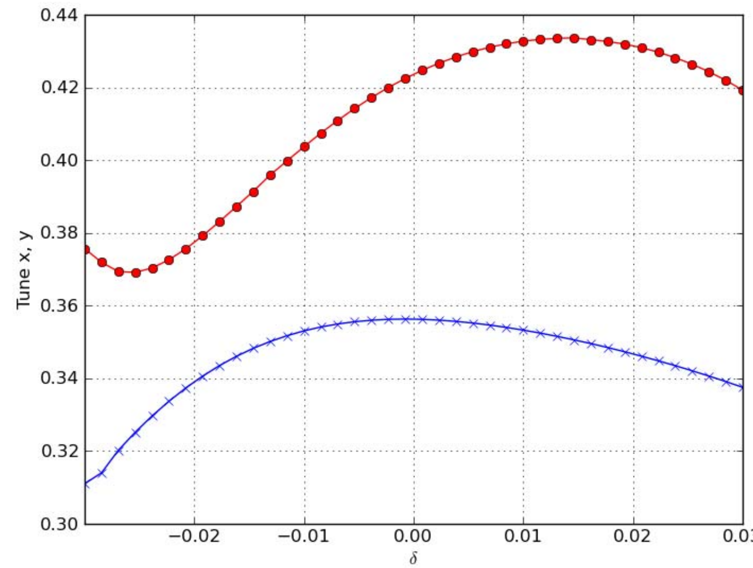
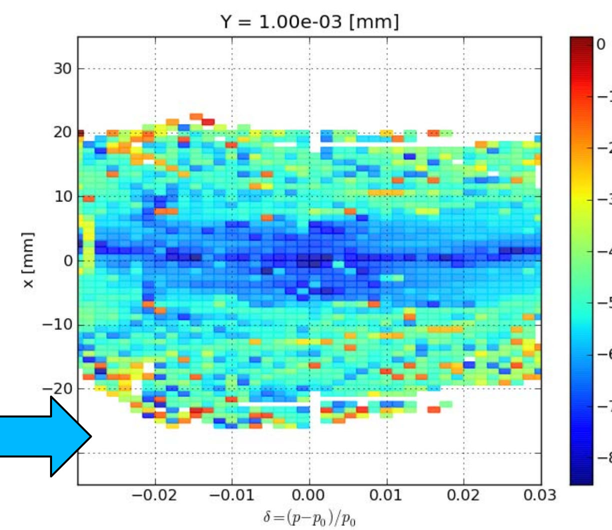
Preliminary Results (2)

- After getting a set of candidates, we then analyze the other effects, e.g. the tolerance of misalignment errors.

- One example is as following:







Sextupoles with 30um X/Y,0.5mrad alignment errors

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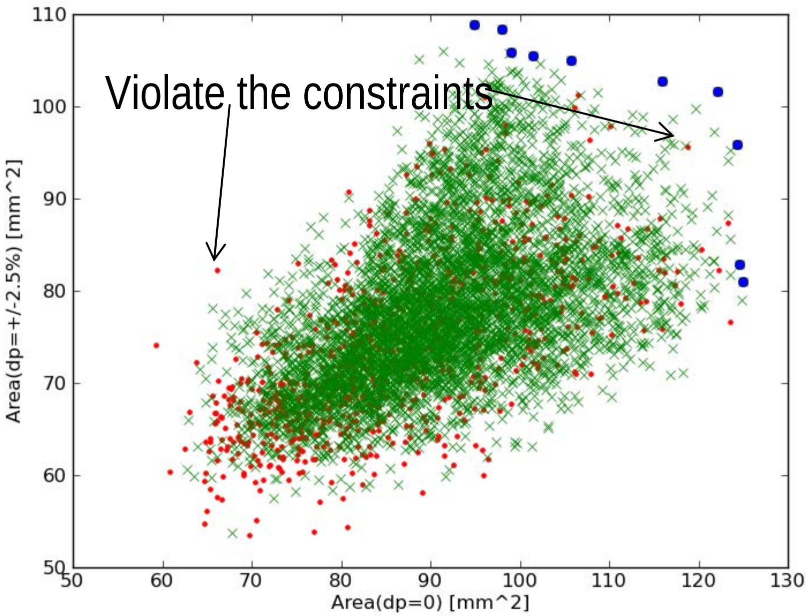
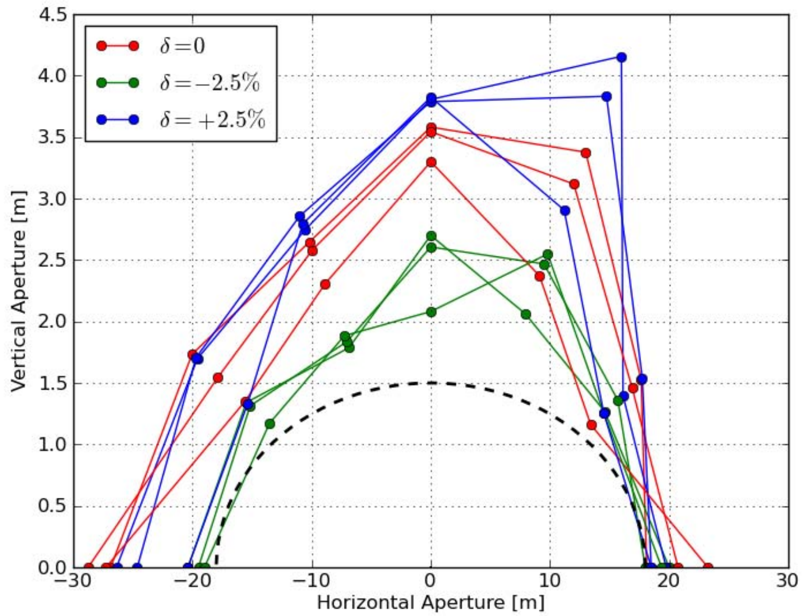
Preliminary Results (3)

- First order chromaticity is adjusted to (+2,+2) by tuning two sextupoles in dispersive region.
- Same tuning knobs as for chromaticity (~0,~0)





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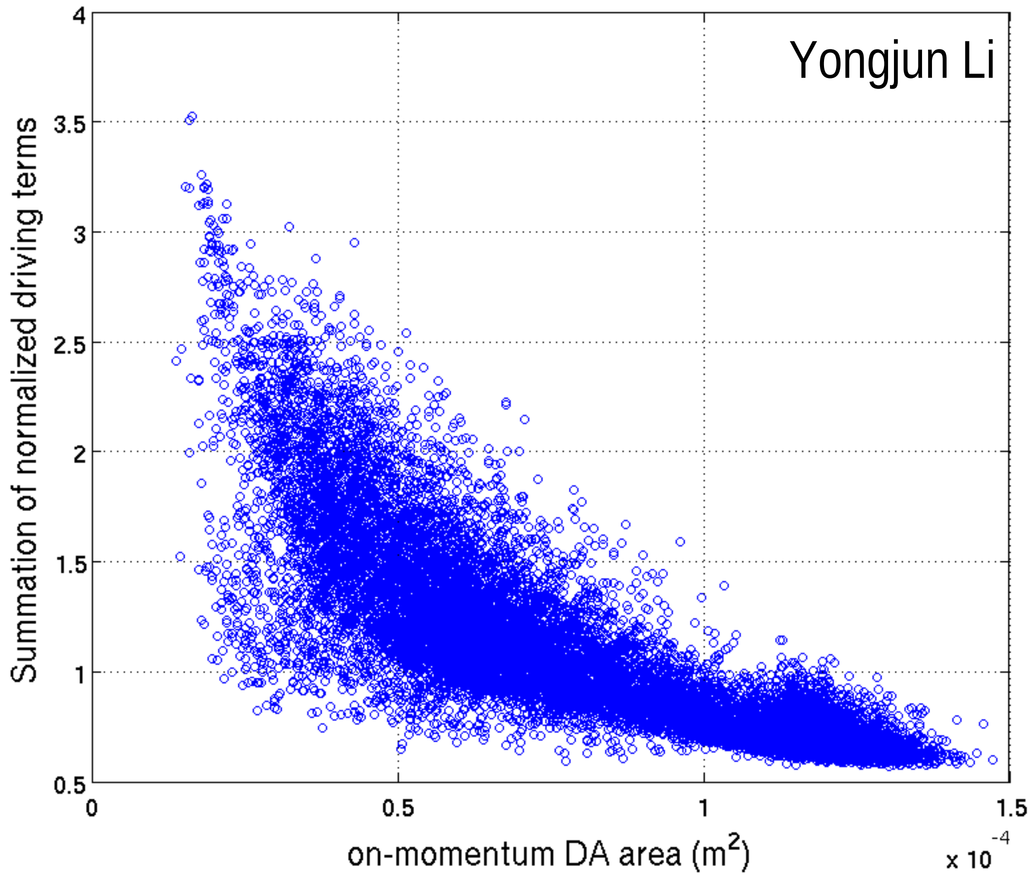
Preliminary Results (4)

- We saw strong correlation between our results and some of the traditional objective functions, e.g. tune with amplitude and driving terms.

- The larger DA from direct tracking tends having smaller driving terms and tune shift with amplitude.

- The iteration of maximizing DA area correlates with minimize the driving terms and tune shift with amplitude.



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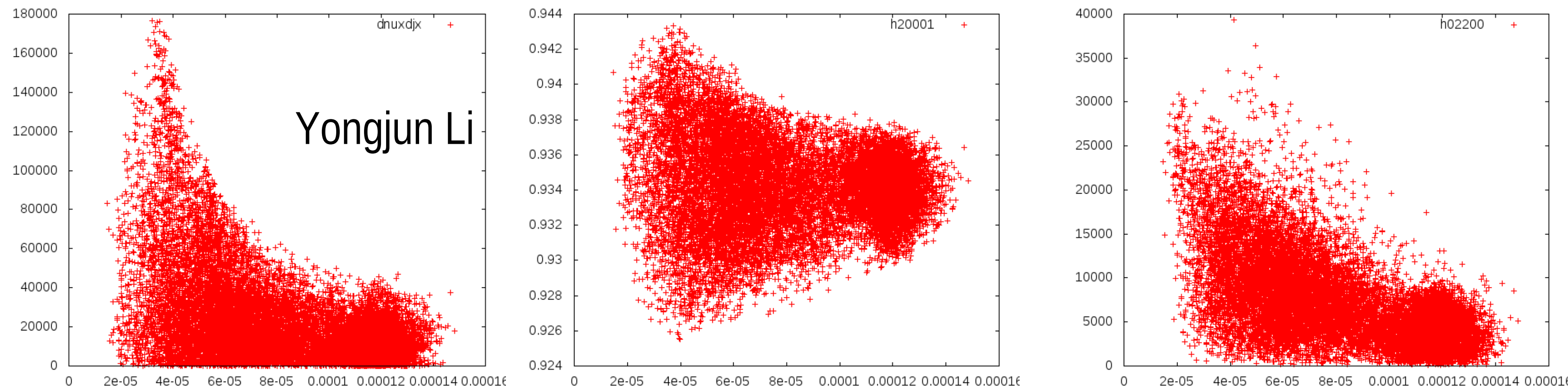
Preliminary Results (5)



- We have looked at 24 driving terms (Yongjun Li)
- Some of them show strong correlation, some show weak.
- We may use Multi-Objective optimization to show which is important (may depend on tune).
- Use these driving terms to facilitate the efficiency of MO optimizer.

Future Work

- Our goal is to develop an approach using multi-objective optimization incorporating simulation results together with analytical estimates of nonlinear optical properties, such as higher order tune shift with amplitude, nonlinear chromaticities, driving terms.
- Different working point and chromaticity will be explored
- Allowing small variations of quadrupole strength can be studied, thus comparing working points within a few hundredths of a tune unit.
- The results of optimization will be tested for robustness in the presence of magnet field errors, magnet misalignment, etc.

Conclusion

- Good nonlinear lattice has been achieved by our group members, and MO optimization comes as an interesting complimentary method.
- An early optimization of DA, with fixed tune and chromaticity showed the convergence of MO
- MO narrowed our analysis space, and can focus on lattice with nice DA from direct tracking.
- Work of combining analytical method and direct tracking is ongoing.
- More analysis on optimal solutions will be carried out.