Multi-Objective Optimization Approach to ILC Damping Ring Design

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May 31, 2005

Main Parameter Optimization

- Several design styles and values for circumference of damping ring are being considered
- Circumference (and others?) requirement is not fixed at the moment
- Automated procedure to generate an optimized lattice of magnets would be useful
- Completed for one style of damping ring (circular with FODO cell arcs).

Where to Start

- Ring definition is very detailed but can be characterized by a few independent quantities
- Make list of design choices (e.g. arc cell length), specifications (e.g. emittance), and quantities to minimize (e.g. sextupole strength)
- Expect trade-offs between the quantities to minimize, i.e. no set of design choices will minimize all quantities at the same time.
- Approach that sums all penalty functions with weights is the traditional way to optimize,
- But we can do something different

Multi-objective Optimizer

- Multi-objective evolutionary optimizer* was downloaded from KanGAL, India, and implemented to visualize the trade-offs of best possible solutions.
- Involves list of variables and limits, list of user-supplied constraint functions and objective functions
- Bazarov (Cornell) with others used such method on ILC main parameters and ERL source.**

*"A Fast and Elitist Multi-objective Genetic Algorithm: NSGA-II" K. Deb, 2002
**"Multivariate Optimization of a High-brightness dc gun PhotoInjector" Bazarov, PRST-AB 2005

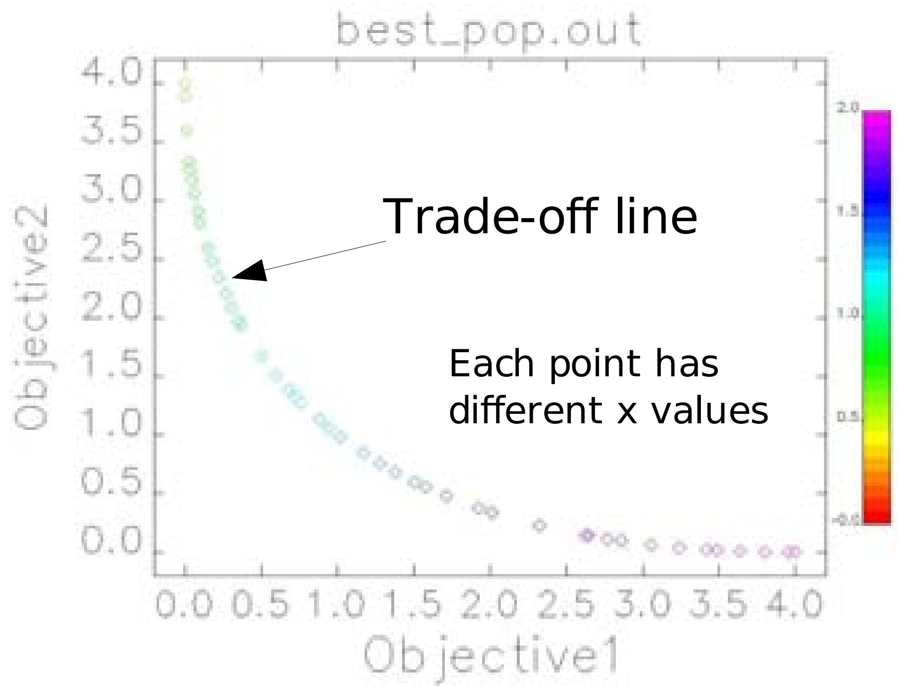
Multi-objective Optimizer Basic Function

- Initialize a population of, say, 100 sets of variables, randomly selected
- User-supplied script or function calculates values for constraint violation and objectives
- Select best subset of variables for mutation and crossing. Throw away worst subsets.
- Evaluate new population and repeat
- Selection method depends on particular algorithm
- There are genetic optimizers that work on single objectives, BTW

Multi-objective Optimizer Output

- Final result is a distribution of best objective values lying on a multi-dimensional surface, from which the user can select a solution.

- Example: Solution for objectives $f1(x) = x^2$ $f2(x) = (x-2)^2$
- 1 variable, 2 objectives



Other Comments

- Method suited to cluster computing
- Full-magnet lattice from a set of variables and simple objective functions takes 3 minutes (mostly from matching the section between the arcs and wigglers)
- Formula model available for the FODO cell-based arc, which takes milliseconds to compute, and is useful for tweaking the settings of the optimizer

Possible Variables for Damping Ring

- Number of arc cells and their length
- Number of wiggler cells and their length
- Filling factor of dipole in FODO cell
- Wiggler period
- Wiggler length in each wiggler cell
- Wiggler field
- rf gap voltage (an objective as well)

Constraints

- Emittance
- Damping time
- Circumference
- Bunch length (optional, but not really)
- Constraints effectively reduce the number of variables available to minimize the objectives.
- Some of these constraints have a close relation to variables, such as damping time and wiggler length
- Perhaps apertures should be constrained

Possible Objectives

- In general: performance vs cost
- Nonlinear kick (e.g. DA)
- Total wiggler length (e.g. cost)
- Magnet count (e.g. cost)
- Wiggler gap as calculated from scaling model (physical aperture)
- Wiggler nonlinearity (strength*period)^2
- rf gap voltage (cost)
- One can have an objective that is also a variable

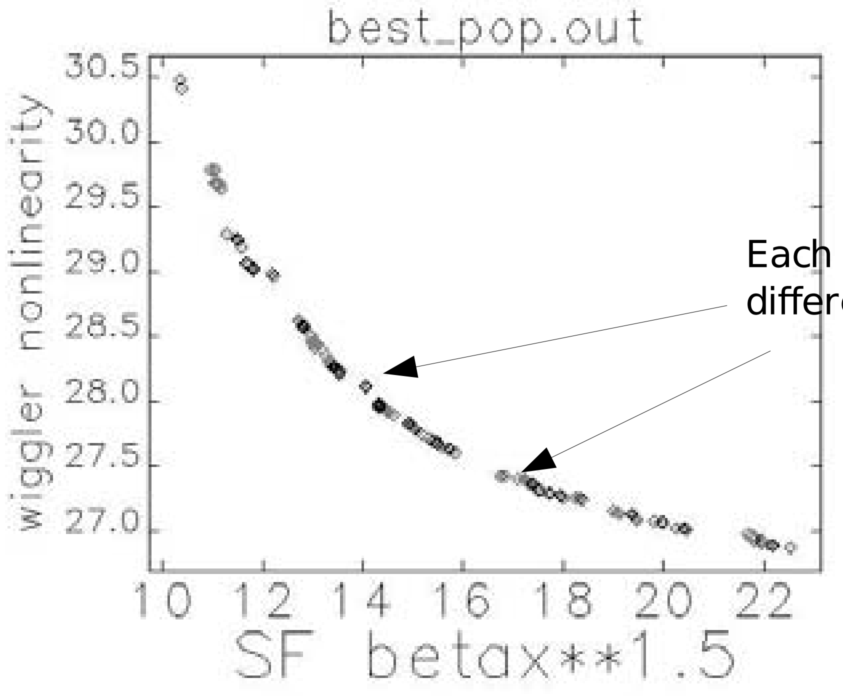
Simplified Application to a 6 km FODO cell ring

- Formula model with reduced set of variables constraints and objectives. Fix some variables.
- 4 variables, 3 constraints, 2 objectives
  - arc cells, arc length, wiggler period, wiggler cells
  - emittance, damping time, circumference
  - nonlinear kick (pushes for fewer arc cells) and wiggler nonlinearity (pushes for longer periods)
- Both objectives tend to increase quantum excitation which is constrained by emittance
- 400 sample population and 400 generations.

Simplified Application to a 6 km FODO cell ring

- Trade-off visible between objectives.
- Example of decision: select variables corresponding to sextupole strength of 10:

92 arc cell
arc cell length 58 m,
6 wiggler cells,
10 m wiggler cell (fixed),
0.36 m wiggler period

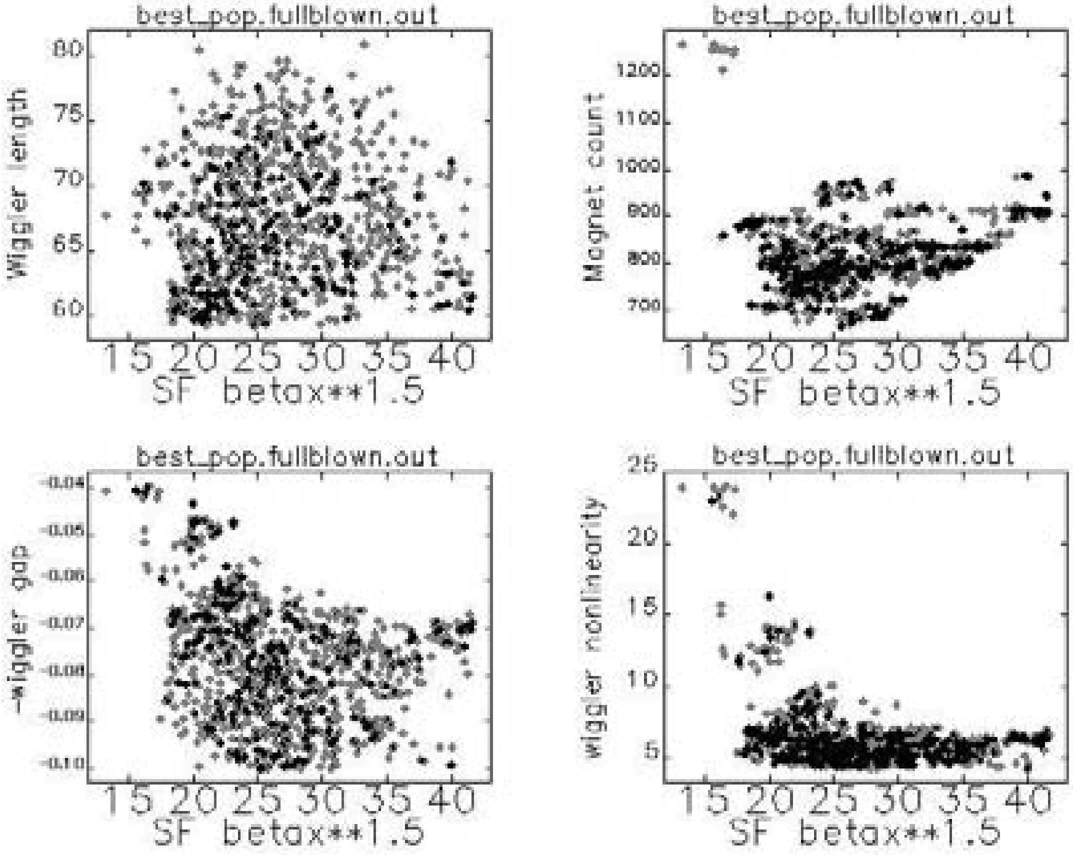


Full Application to a 6 km FODO cell ring

- Formula model with full set of variables, constraints and objectives
- 9 variables, 5 constraints, 7 objectives
  - Some objectives are not really independent
- Requires higher sample population and generations for convergence
- Expect further trade-offs amongst 21 pairs of objectives.
- Includes an additional constraint required to limit objective on wiggler gap.

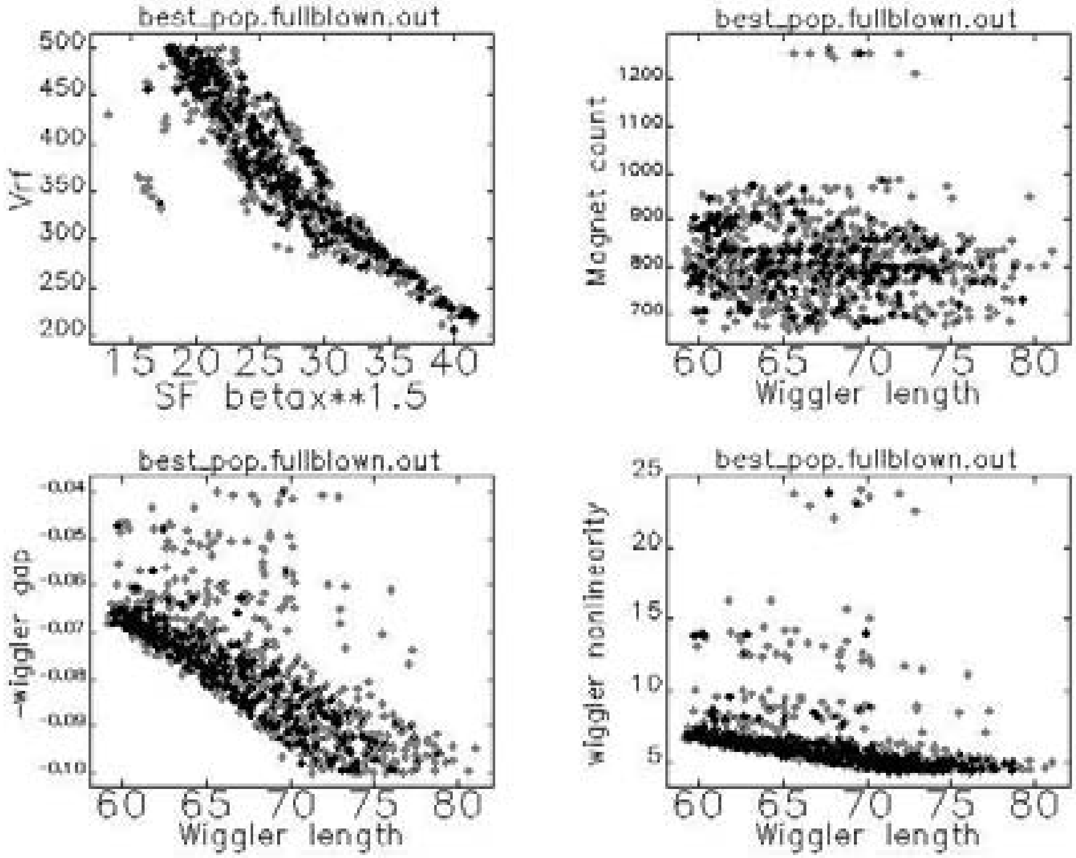
Objectives Plots

- Trade-off curves not completely formed after 2000 iterations with 1000 populations.



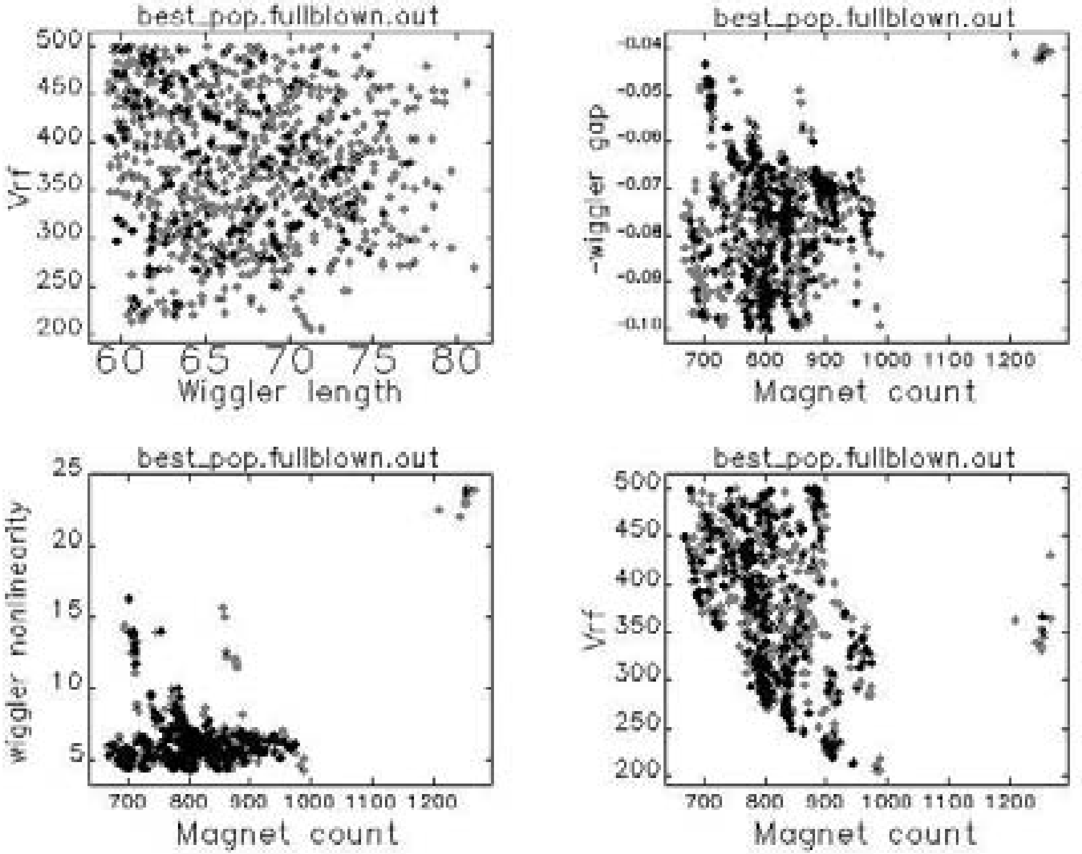
Objectives Plots

- Curve that are discernable may be interpreted.



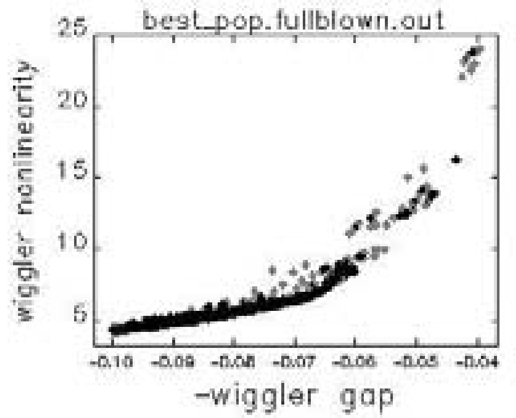
Objectives Plots

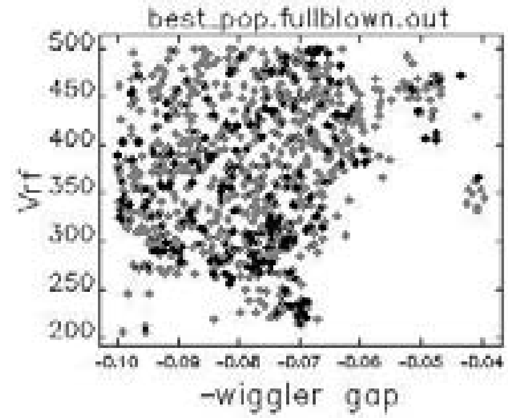
- A change in constraint (e.g. bunch length) can complete change the appearance (not shown)

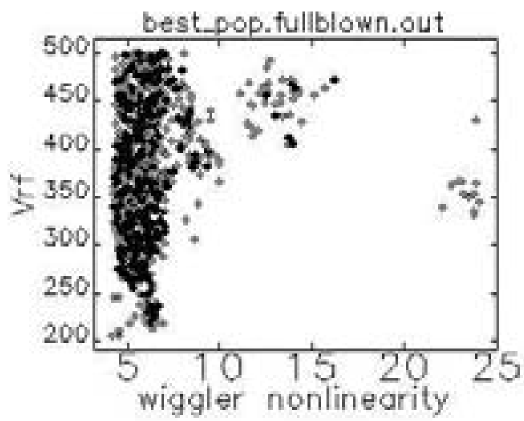


Objectives Plots

- Objectives can be plotted against each variable as well (not shown)







Conclusion for Parameter Optimization

- Software tools (algorithm, full lattice generator) have been implemented
- For large dimensions, some tweaking of optimizer setting (iterations, population) is required.
- A reduced set may be useful to analyze for actual design decisions, but we haven't looked into this yet.
- Computation time issue
  - Full lattice model feasible only in runs that require 100-200 iterations and 100 population.
  - For large dimensions, only formula model seems practical