Automated synchrotron lattice design and optimisation using a multi-objective genetic algorithm

THE UNIVERSITY OF MELBOURNE

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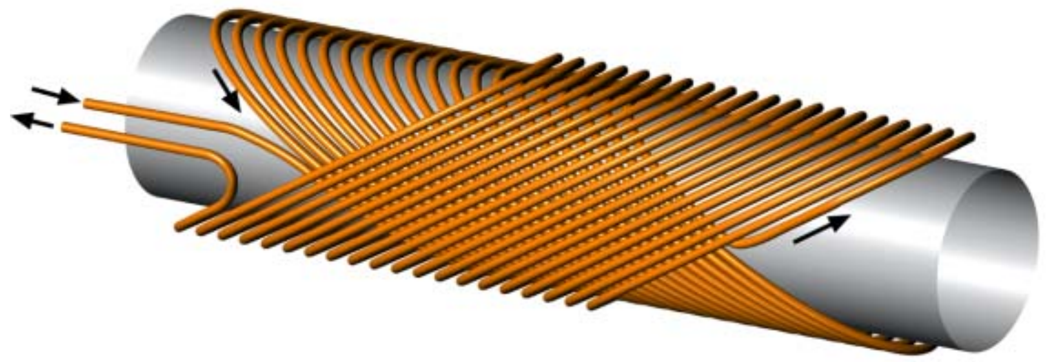
Motivation

Next Ion Medical Machine Study (NIMMS)

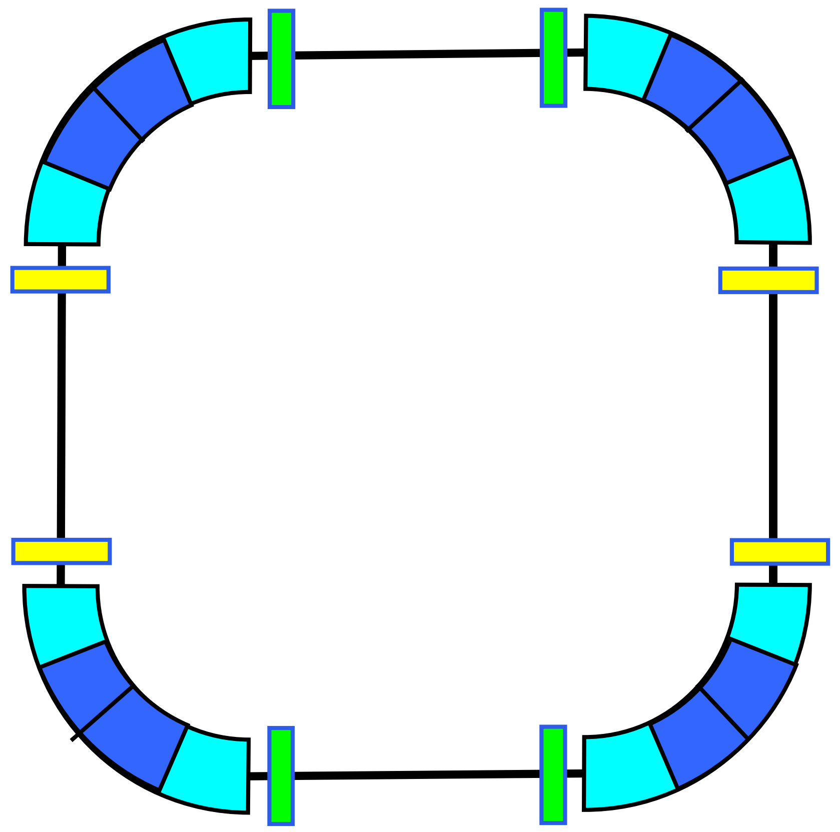
Design a compact ion synchrotron for cancer therapy and research.

Key technology: **Alternating Gradient Canted Cosine-Theta** magnets

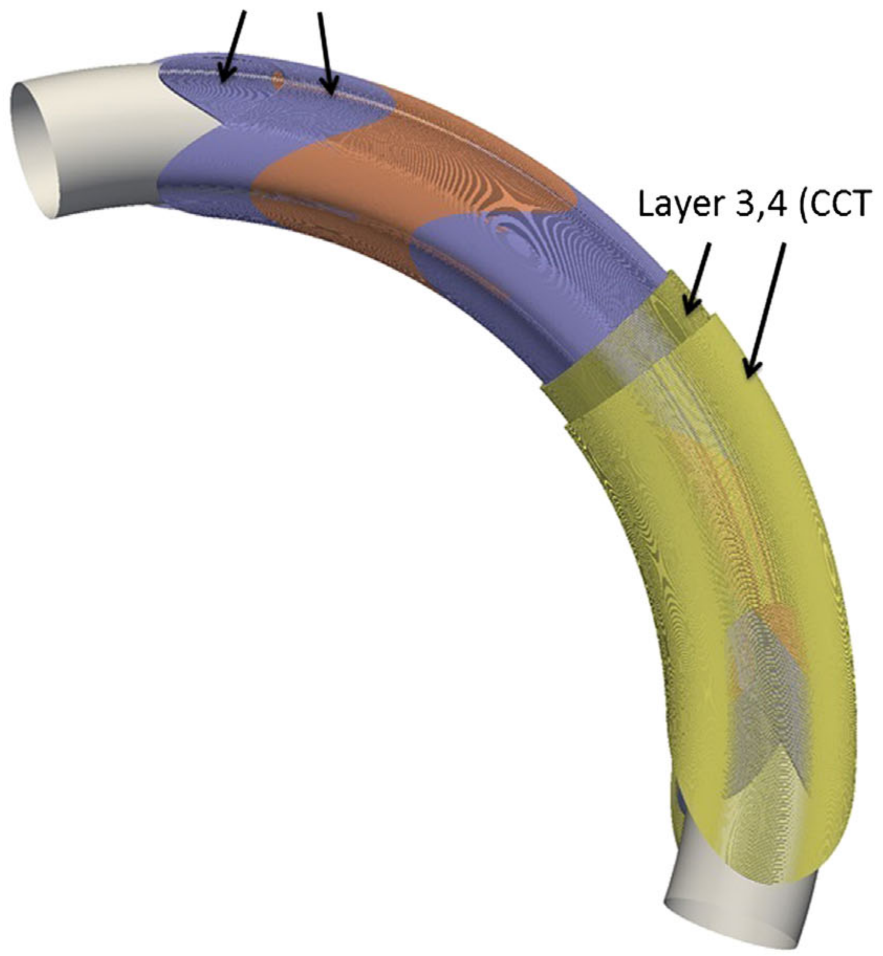
- Nested helical coils made from superconductor material.
- Strong combined function fields.
- Capabilities sensitive to tech development.



R. Meinke (AML)

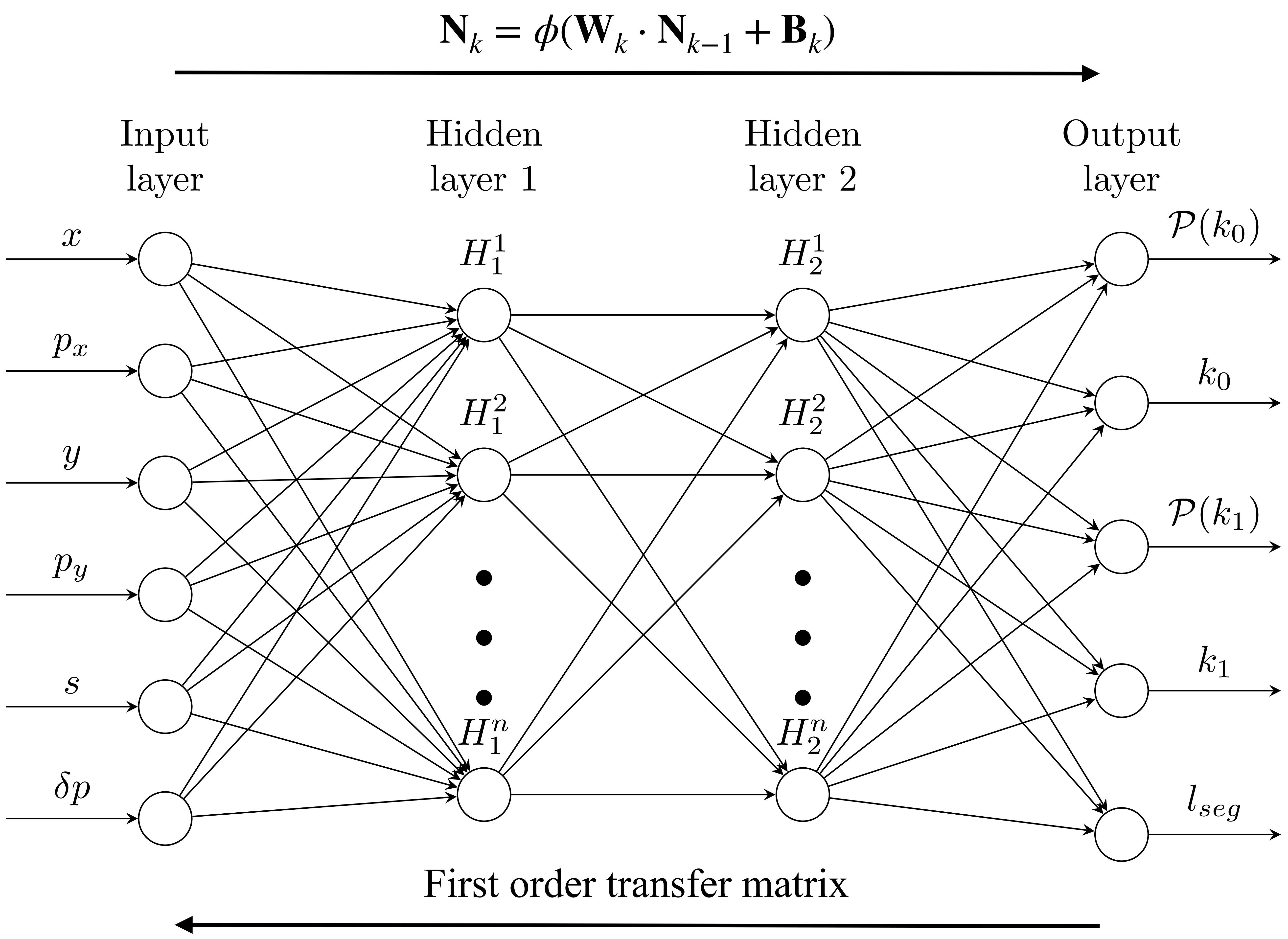


Compact synchrotron design
E. Benedetto



What is the optimum structure of the next-generation hadron therapy machine?

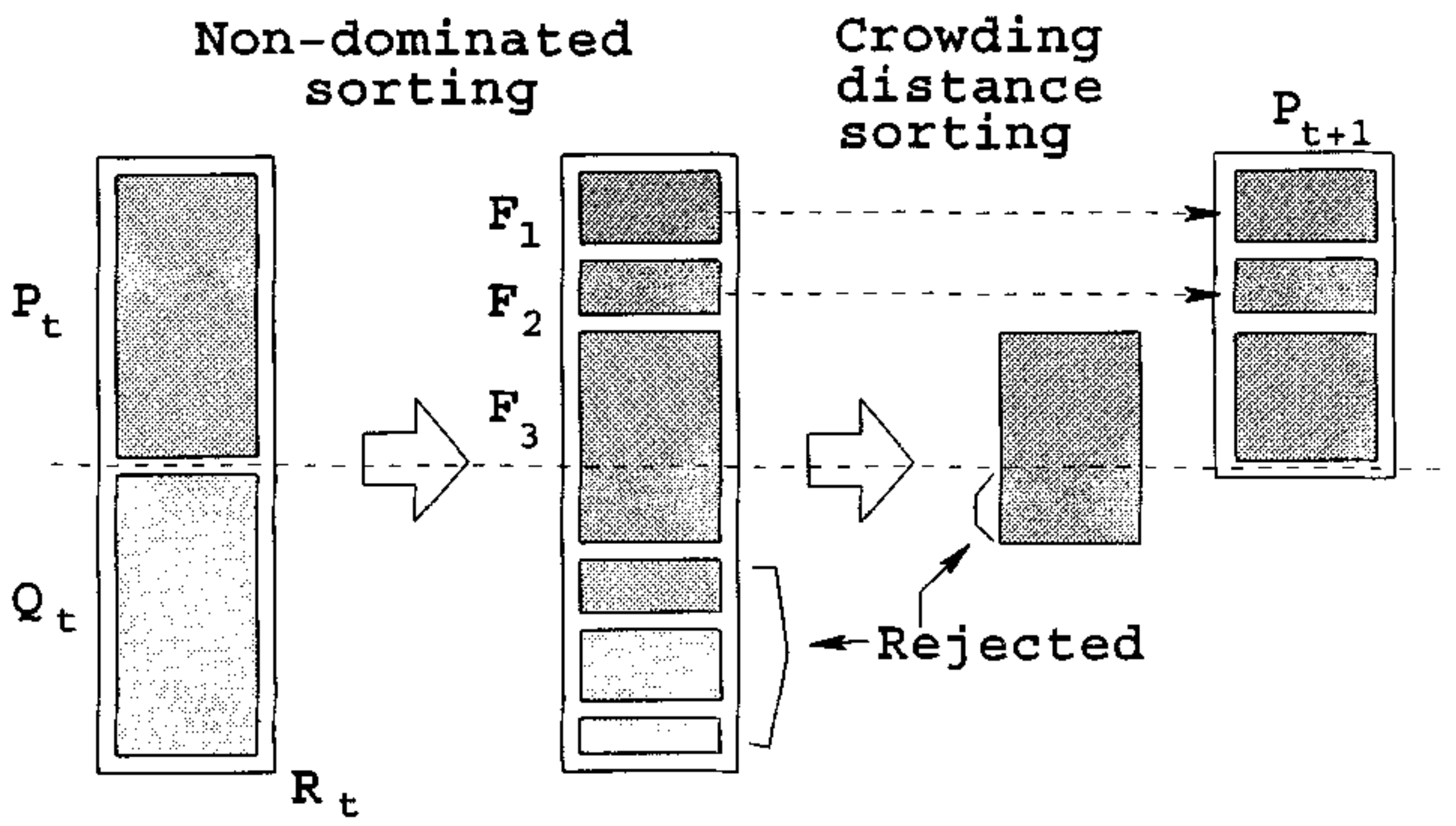
Automated lattice generation

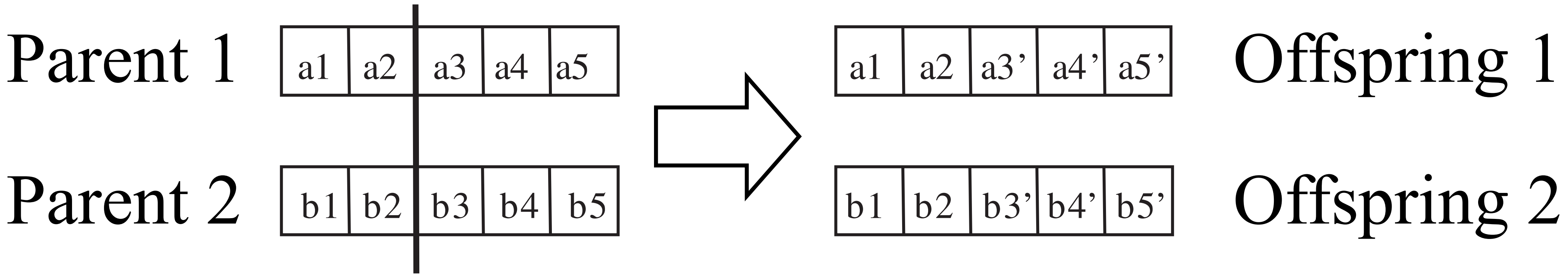


Each neural network has a set of unique transformation weights $\mathbf{W}_k$

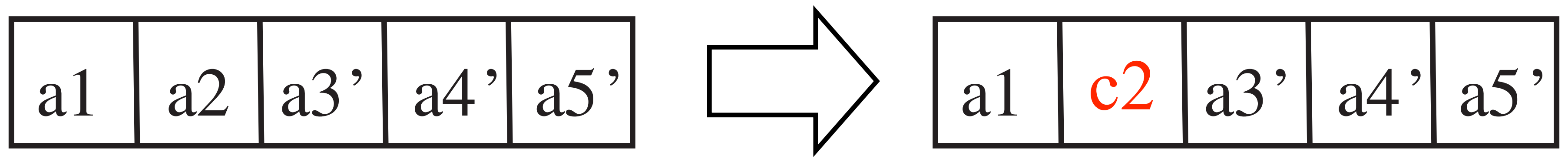
1. Neural network responds to changes in test particle position and create new lattice segments.
2. Output layer contains information about how to deflect the test particle.
3. Propagate the test particle using transfer matrices.
4. Repeat until the desired length is achieved.

Multi-objective genetic algorithm





One point cross-over



Random mutation

1. Randomly initialise a population of neural networks
2. Build the associated lattices by propagating a test particle through each neural network.
3. Evaluate the optical functions of each lattice.
4. Rank the performance of the networks using constrained-dominated sorting.
5. Pick candidates to produce new offsprings.
6. Introduce random mutations.
7. Sort combined population and pick top candidates for next iteration.

Preliminary results

Constraints:

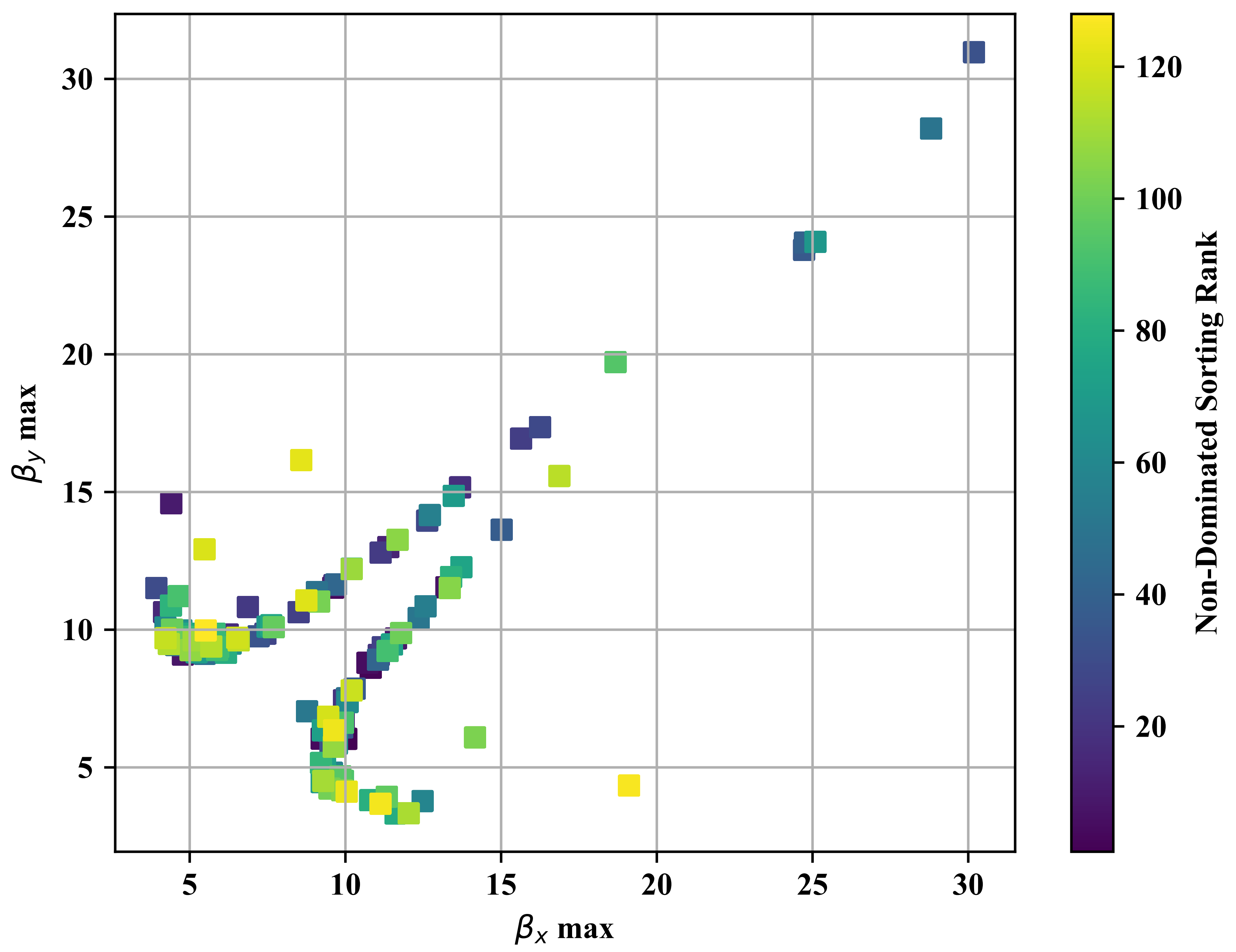
1. Stability criterion, $\mathbf{Tr}(\mathcal{M}_{\text{one-turn}}) < 2$.
2. Horizontal tune, $Q1 = 0.1672$.
3. Vertical tune, $Q2 = 0.172$.
4. Total bending angle, $B_{\text{arc}} = 20°$.
5. Initial$(\beta_x, \alpha_x, \beta_y, \alpha_y)$ = Final$(\beta_x, \alpha_x, \beta_y, \alpha_y)$.

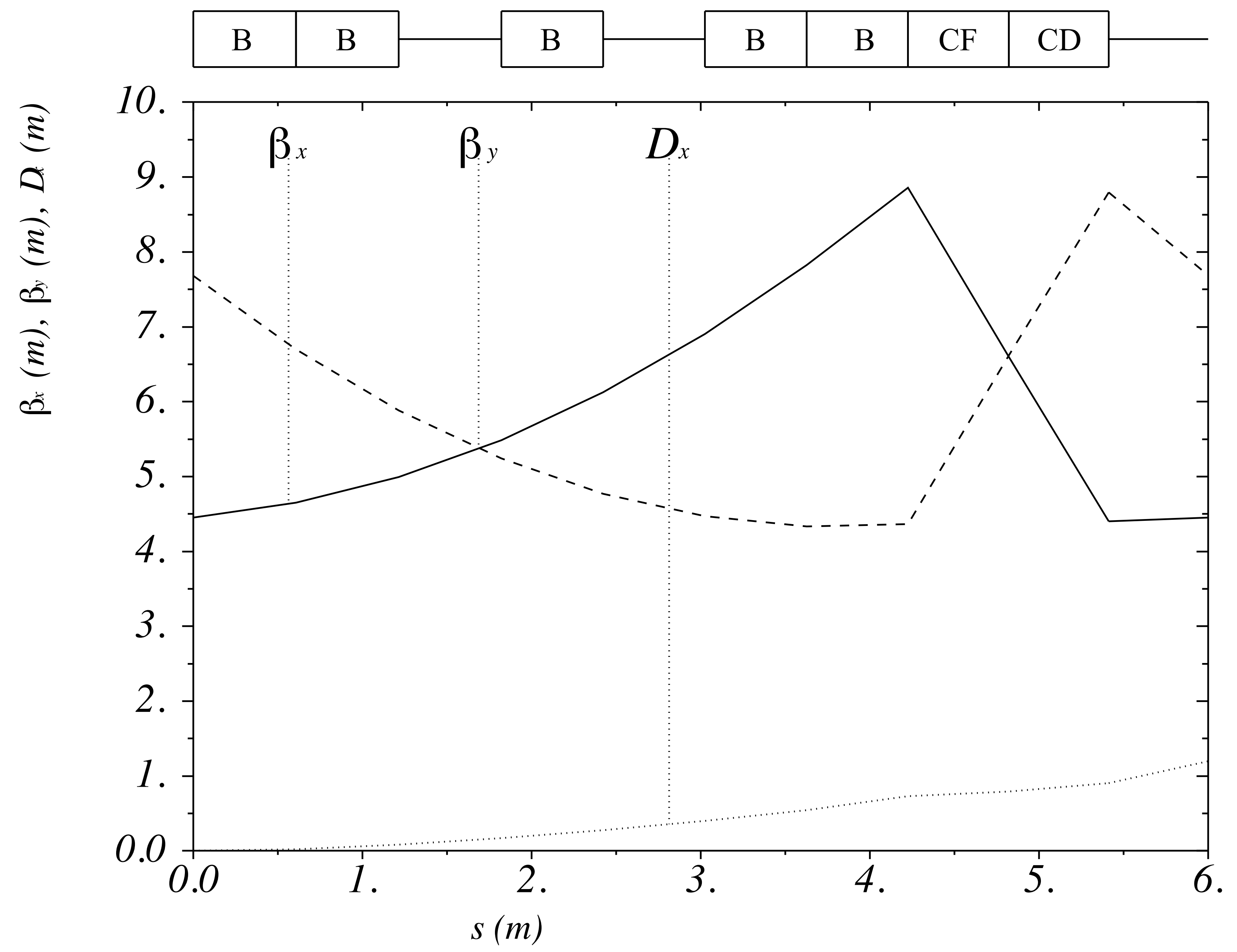
Objectives:

- f_1: Minimise max(β_x).
- f_2: Minimise max(β_y).
- f_3: Minimise number of segments.

Hyper-parameters:

- Neural networks with 2 hidden layers and 10 nodes per hidden layer.
- Population size 1000, evolved for 100 iterations.





Conclusion

- Novel automated lattice generation and optimisation algorithm
  - Capable of producing convergent and sensible lattice layouts.
  - Probe the boundary of feasible designs.

- Future works
  - Create closed ring lattices as per NIMMS compact synchrotron requirements.
  - Add constraints from slow extraction and magnet aperture.

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Thank you!

CERN

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