

Bayesian Optimization for Constrained Beam Transport Line Design in the RAON Injector

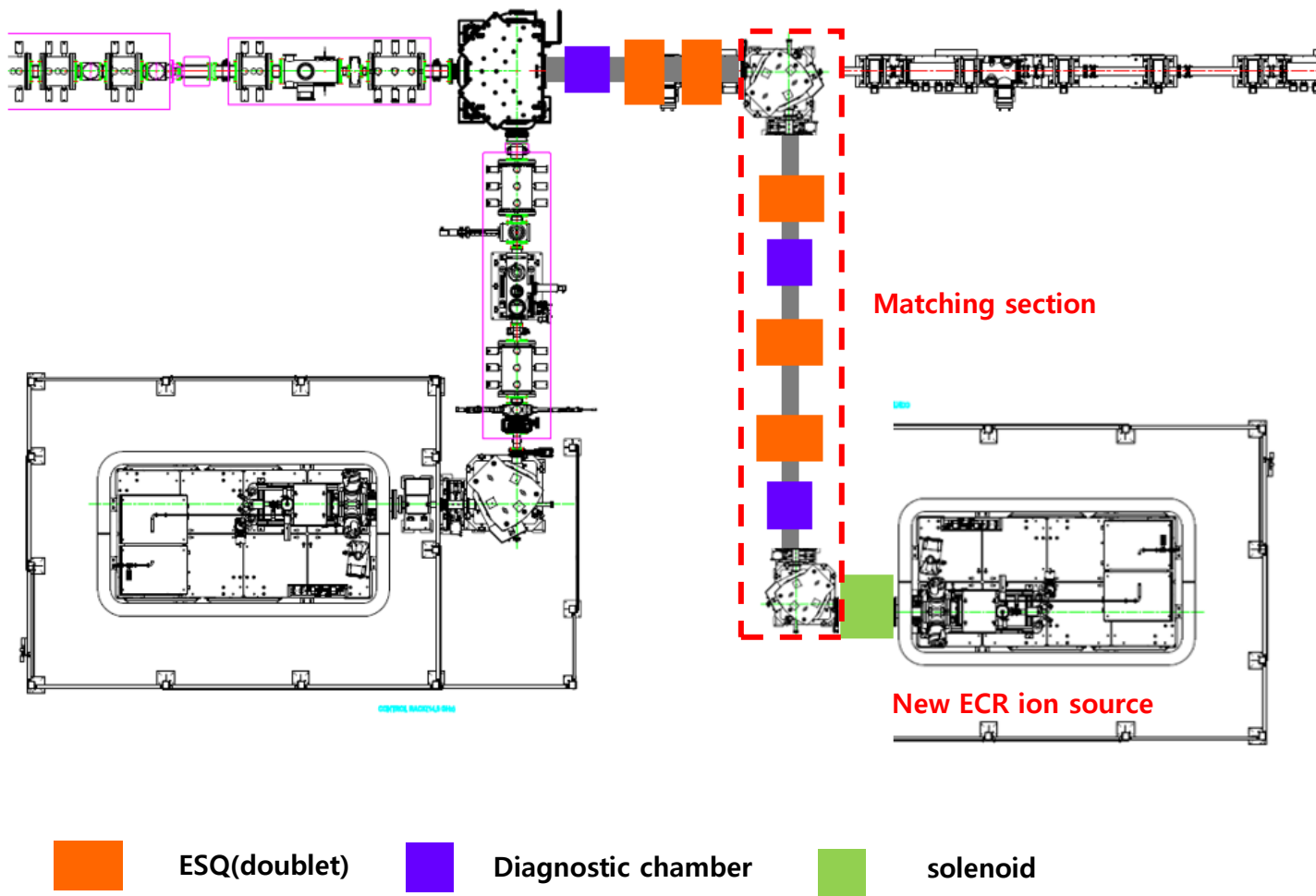
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Motivation & Design Problem

- Beam Line Design under Existing LEBT Constraints

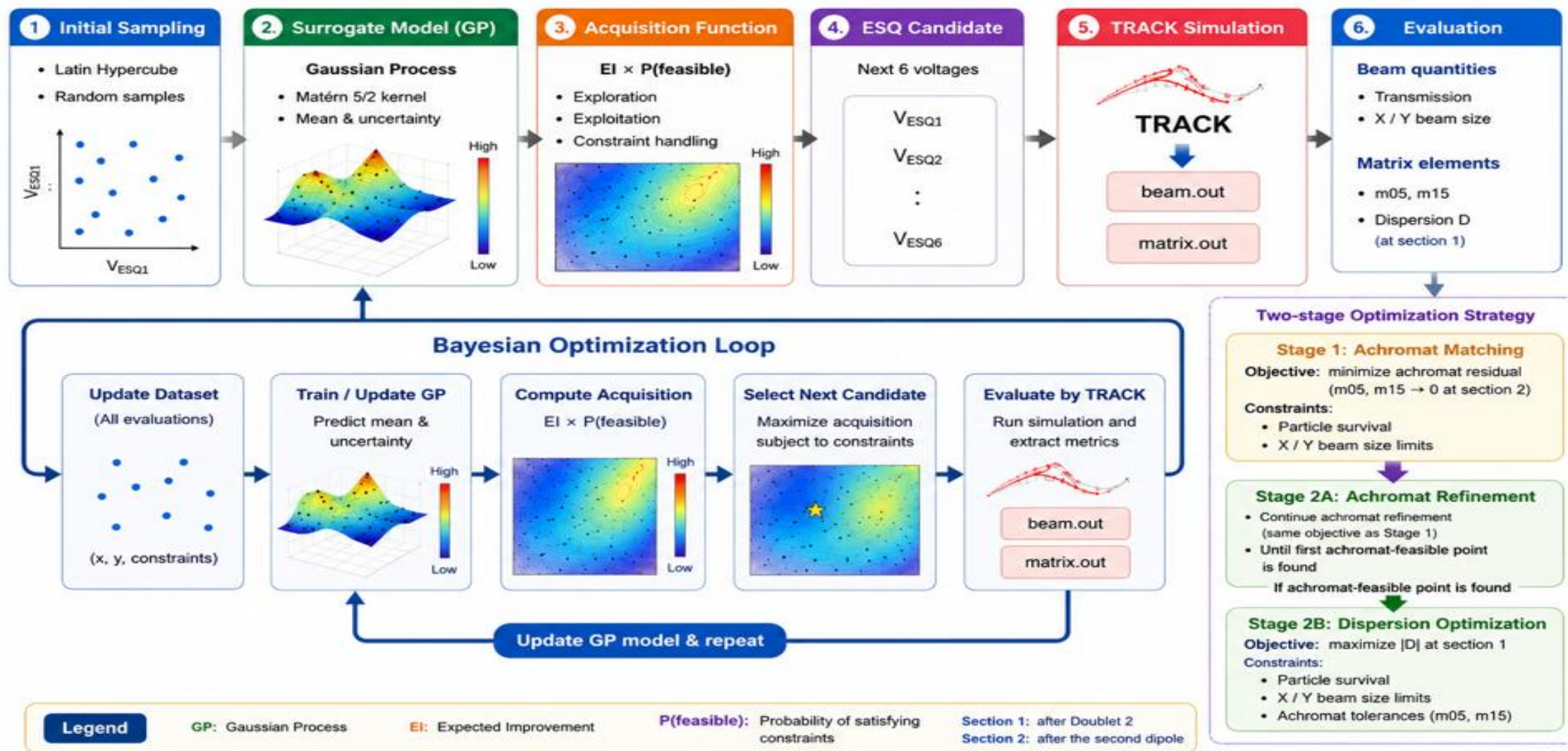


	Optimization setup
Design variables	6 ESQ voltages
Simulation	TRACK
Beam constraints	Particle survival, X/Y beam size
Objective function 1	Achromatic condition after the 2nd dipole
Objective function 2	Dispersion after Doublet 2

The present study focuses on the dipole-to-dipole section, where six ESQ voltages are optimized using TRACK simulations.

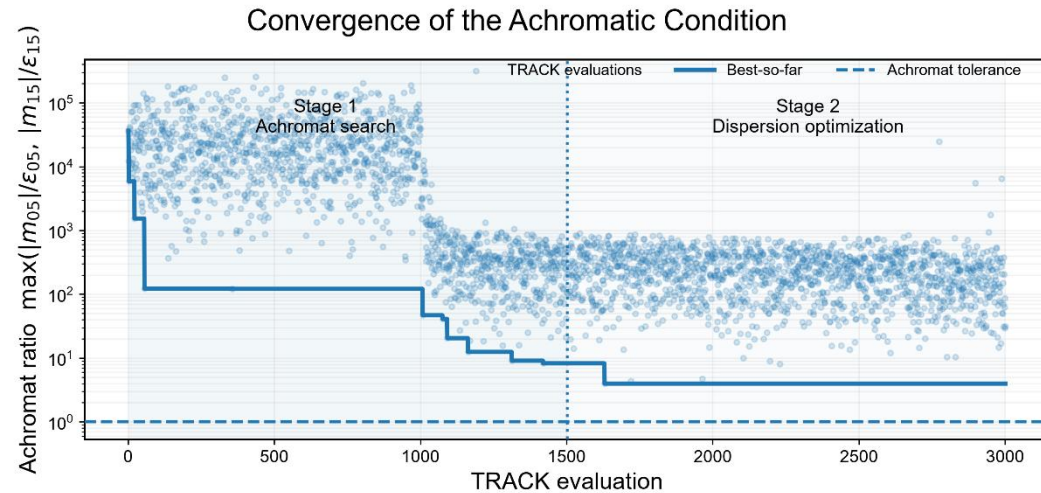
Bayesian Optimization Method

Two-stage Constrained Bayesian Optimization

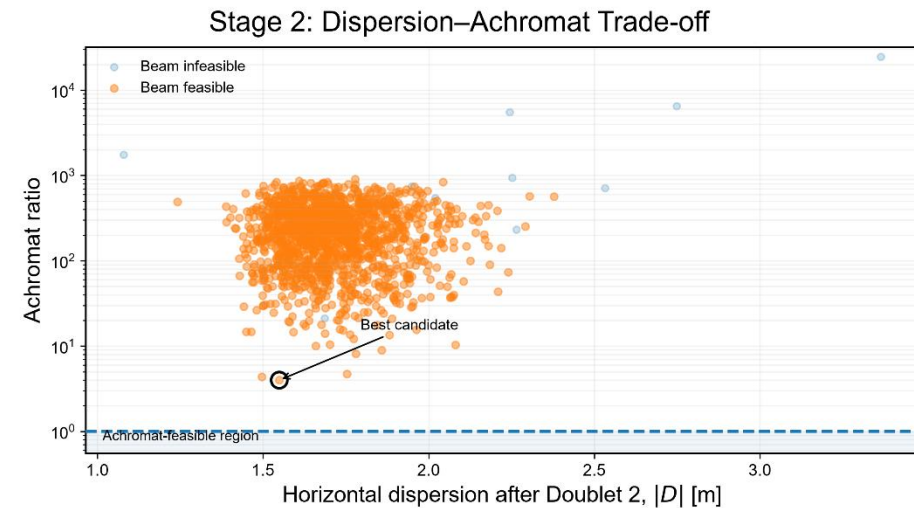
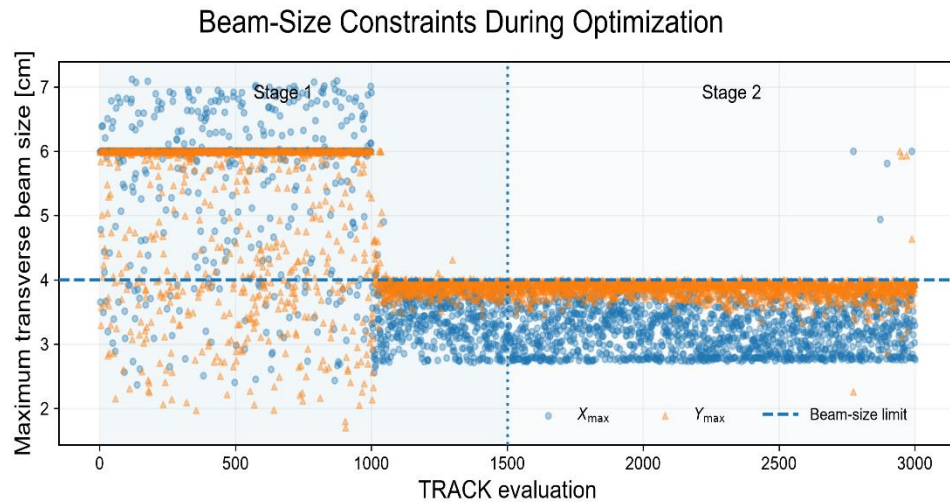


Optimization Results

■ Current Optimization Results



- 3000 TRACK simulation
- Beam-feasible configurations were successfully identified.
- The achromatic residual was progressively reduced.
- Target achromat ratio: ≤ 1
- Best achromat ratio: ≈ 3.98



Summary & Next steps



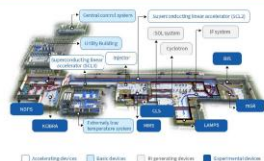
- BO identified beam-feasible configurations in the dipole-to-dipole section.
- The achromat residual was reduced to a best ratio of ~ 3.98 .
- The current lattice does not yet satisfy the achromatic tolerance.
- Next: refine magnet positions, re-run BO, maximize dispersion, and perform downstream Twiss matching.



Abstract

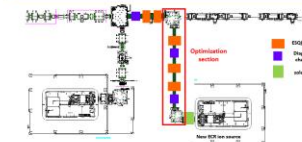
The design of low-energy beam transport (LEBT) lines involves high-dimensional optimization under multiple physical constraints, including beam size, transmission efficiency, and limited beamline geometry. In the RAON injector system, the integration of a new 14.5 GHz ECR ion source requires re-optimization of the beam transport line while maintaining compatibility with the existing injector configuration. In this study, Bayesian optimization (BO) is applied to the constrained design of a new ECR beam transport line for the RAON injector. Experimentally measured initial beam parameters from the Allison scanner are incorporated into beam dynamics simulations to reflect realistic operating conditions. A two-stage optimization strategy is employed to efficiently identify feasible solutions and improve beam matching performance within the constrained parameter space. The optimized beamline configuration satisfies the operational constraints of the RAON LEBT system while achieving improved beam matching performance. The results demonstrate that BO provides an effective approach for constrained beam transport line design problems.

Overview



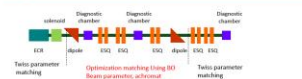
RAON (Rare Isotope Accelerator complex for ON-line experiments) is a heavy-ion accelerator facility in Korea designed to produce and study rare isotopes. It uniquely combines the ISOL and in-flight fragmentation methods to generate a wide range of exotic nuclei. The accelerator consists of an injector system and a superconducting linear accelerator, enabling acceleration of ions from protons to uranium. RAON supports fundamental research in nuclear physics, astrophysics, and applied sciences.

Design Problem and Existing LEBT Constraints



A new beam transport line is being designed to integrate the 14.5 GHz ECR ion source into the existing RAON injector. The beam line layout is constrained by the available installation space and the geometry of the existing LEBT system. Therefore, the locations of the dipoles and focusing elements must be determined considering both physical installation constraints and beam transport requirements.

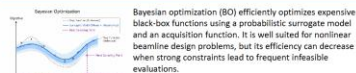
Optimization setup



Design variables	Optimization setup
Simulation	6 ECR voltages
Beam constraints	Particle survival, X/Y beam size
Evaluation point 1	Dispersion after Doublet 2
Evaluation point 2	Achromatic condition after the 2nd dipole

The present optimization focuses on the dipole-to-dipole section. Downstream magnets are reserved for later Twiss-parameter matching.

Bayesian optimization



Two stage Bayesian Optimization



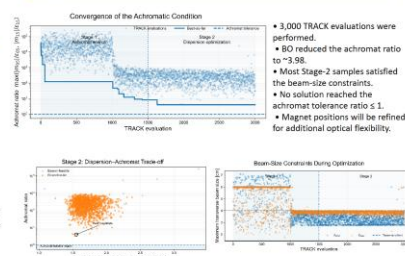
To efficiently search the highly constrained parameter space, the optimization is divided into two stages. Stage 1 searches for feasible ESQ settings satisfying the beam and achromatic conditions. Stage 2 then aims to enhance the dispersion while maintaining the feasible beam transport conditions.

BO-TRACK Optimization Framework



Gaussian-process surrogate models are iteratively updated using TRACK simulation results to efficiently explore the constrained ESQ parameter space.

Optimization Results



- 3,000 TRACK evaluations were performed.
- BO reduced the achromat ratio to ~3.98.
- Most Stage-2 samples satisfied the beam-size constraints.
- No solution reached the achromat tolerance ratio ≤ 1 .
- Magnet positions will be refined for additional optical flexibility.

Thank you.

