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Beam Line Optimization for Laser-Accelerated Ions

The rapid development of high-power laser systems in recent decades has sparked significant interest in laser-driven ion acceleration, offering promising characteristics such as high brightness, ultrashort pulse duration, and high particle energies. However, the practical use of laser-accelerated ion beams remains challenging due to their large energy spread and high angular divergence, complicating beam capture and transport.

This work presents a generalized optimization framework that combines genetic algorithms with the particle tracking code Astra to investigate and improve essential beam parameters such as transmission, emittance, and energy spread. While the optimization focuses on beamline design, the analysis includes the effects of upstream fluctuations—such as variations in laser intensity or differences between acceleration mechanisms—on beam transport performance. By studying the robustness of optimized beamlines to these input variations, the framework provides insight into the interplay between beamline design and source characteristics, and serves as a basis for investigating potential scaling laws linking laser parameters, target configurations, and the resulting beamline performance metrics.

To illustrate the capabilities and limitations of the method, a benchmark scenario was considered using typical PHELIX laser parameters and the reference energy of the UNILAC (11.4 MeV) at the GSI Helmholtz Center for Heavy Ion Research. In this case, it was found that the maximum particle yield achievable using TNSA falls short by approximately two orders of magnitude when compared to conventional acceleration methods.

Ongoing and future work aims to identify high-impact improvements for the benchmark scenario, whether at the target or beamline level, in order to reduce the performance gap between conventional and laser-accelerated ion sources.

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