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Simulation of Beam Compression for Heavy-Ion Fusion*

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Intense beams for heavy-ion inertial fusion (HIF) must be compressed by a factor of more than ten both in length and in radius between an induction accelerator and the inertial-fusion target. The compression scenario favored by the US HIF program is to first impose a head-to-tail velocity increase or "tilt," so that the beam tail approaches the head in a "drift-compression" section. After this lengthwise compression, the beam is focused radially by quadrupole magnets, so it converges as it drifts to the target.

Both compression stages raise important physics questions. Before drift-compression, the beam current and velocity must be carefully tailored so that the beam longitudinal space-charge field removes the velocity tilt just as the beam enters the final-focus lattice. Transverse focusing in the drift compression section must be designed so that all parts of the beam remain approximately matched as the beam expands to the larger radius needed for final focusing. The principle physics questions posed by this section are how much the total emittance grows, whether a beam halo develops, and how these processes scale with beam and lattice parameters. Radial focusing also poses challenges both because of the high beam density required at the target and because collisional stripping by the background gas expected in the chamber further increases the beam charge. Detailed numerical simulations with no external electron sources show an acceptable focal spot only for beam currents far below the values assumed in recent HIF reactor scenarios, so much recent work has studied neutralization by low-density plasma just after final focus. Here, the main physics questions involve the degree and persistence of neutralization, the choice of optimum plasma parameters, and the effects of photoionizaton by the heated target.

Recent theoretical work to model the final longitudinal and radial compression of a HIF beam is summarized in this paper. The three-dimensional electrostatic particle-in-cell (PIC) code WARP3d is used to study beam transport in the drift-compression section, while transport in the fusion chamber is modeled in using the electromagnetic PIC code LSP. Possible low-energy near-term experiments are investigated, as well as full-scale fusion drivers, and for each accelerator category, we examine how transport and error sensitivity scale with the major beam and lattice parameters.

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