Virtual National Laboratory for Heavy Ion Fusion

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HIF News

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New Experiments and simulations of electron effects in magnetic quadrupoles

Electron cloud effects, which are frequently observed to limit the beam quality in high-energy physics rings and colliders, are also a concern for future high-intensity heavy-ion linear accelerators for HIF and HEDP. The High Current Experiment (HCX) is testing the influence of electrons on ion beam transport.

At 1 MeV, where we performed our experiments, the beam contains 6 x 10^{12} K^+ ions distributed over a ~5 µs pulse. In this regime, space-charge forces and the image charges induced on metallic structures of the machine aperture play an important role. The beam potential of 1-2 kV can trap electrons, and the magnetic quadrupole field restricts their axial flow.

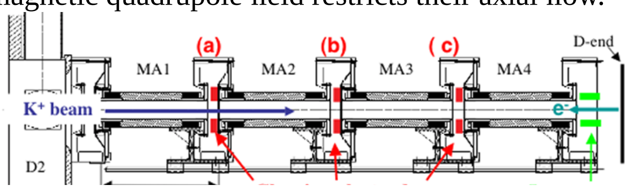

FIGURE 1. Elevation view of quadrupole magnet lattice in the HCX with clearing electrodes (red) and e^- suppressor (green).

Clearing electrode rings, biased to V = +9 kV, remove electrons from drift regions between magnets. A negatively biased electron suppressor (V = -10 kV) after the last magnet (MA4) suppresses electron production at intercepting beam diagnostics (D-end); or unbiased, allows the copious electron production to flow upstream.

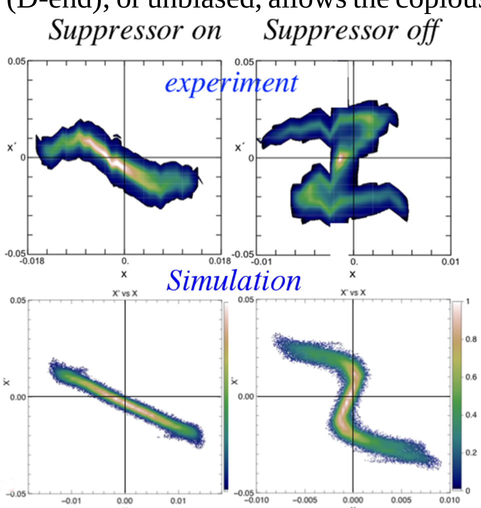

FIGURE 2. x-x´ distribution measured at D-end. Left: electron suppressor V = -10 kV. Right: electron suppressor grounded. The axis units are (m, rad).

In Fig. 2, we compare the effects on the K+ beam of minimizing electrons with the suppressor and all clearing electrodes biased (left), with the exaggerated case of admitting electrons to the magnets with the suppressor off and only the first clearing electrode (a) biased (right). Maximizing electrons significantly degrades the beam (right), compared with minimizing electrons (left). The WARP simulation is in semi quantitative agreement with the experiment, a step towards validation of the code models.

– F.M. Bieniosek, A.W. Molvik, M. Kireeff Covo, P.A. Seidl and J.-L. Vay

Interpolation algorithm for computing self-consistent electron clouds in ion beams

Contaminating clouds of electrons are a concern for most accelerators of positively charged particles, including heavy-ion accelerators for fusion and high-energy density physics. For modeling these, self-consistent electron and ion simulation is required, including a particle advance scheme, which can follow electrons in regions where electrons are strongly magnetized, weakly magnetized, and unmagnetized.

We have developed such a mover for electrons that interpolates between full electron dynamics and drift kinetics. The algorithm builds upon the observation by Parker and Birdsall that the conventional Boris particle advance scheme, when run with time steps large compared to the cyclotron period, continues to exhibit correct drift velocities, but causes particles to gyrate with a radius that is large compared to the physical gyro-orbit, and with a frequency that is lower than the physical gyro-frequency. Our interpolation scheme corrects the former deficiency, and is thus well suited for simulating electrons everywhere in an accelerator with magnetic focusing. Specifically, the instantaneous particle velocity is advanced using the standard Boris algorithm, and then the particle positions are advanced using a blend of the instantaneous velocity and the drift velocity. With a proper choice of the interpolation parameter, a physically correct gyration radius is obtained, while also preserving correct drift and parallel (to the magnetic field) velocities.

This new long-time-step electron mover enables stepping of electrons on a time scale governed by the electron bounce time in the electrostatic potential well, gaining 1-2 orders of magnitude in computational speed, see Figure.

– R. Cohen

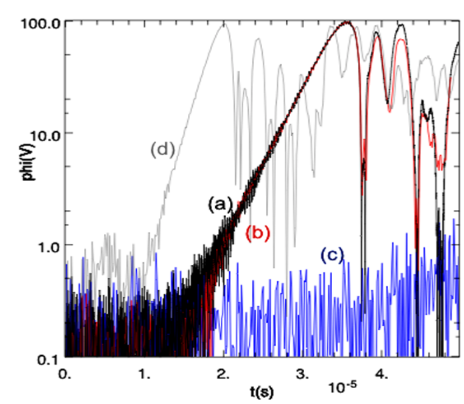

FIGURE. Instability of counter-streaming thin ion beams. Shown is history of the maximum perturbed potential for (a) a simulation that resolves the gyro frequency; (b) the interpolated mover with 20 times larger timestep; (c) standard Boris mover with the larger timestep; (d) interpolated mover with beams twice as wide

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