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Initial experiments and theory on electron and gas accumulation in a heavy-ion beam*

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Accelerators for heavy-ion inertial fusion energy (HIF) have an economic incentive to fit beam tubes tightly to beams. This places them at risk from gas desorption runaway, and from electron clouds produced by secondary electrons and ionization of gas. We have initiated an experimental and theoretical program to measure, understand, and model these effects in heavy-ion accelerators. Theory and PIC simulations suggest that the electrons will be radially trapped in the ≥1 kV ion-beam potential, and can be detrapped by drifting into an upstream acceleration gap. We are installing four quadrupole magnets on the High-Current Experiment (HCX) at LBNL in which we will characterize electron production and trapping, effects on ion beams, and mitigation techniques at 25-45 keV/amu. We have used the Gas-Electron Source Diagnostic (GESD) on the HCX to measure the flux of electrons and gas evolved from a target, whose angle to the beam can be varied between 2° and 12° from grazing incidence. We are also planning a collaboration with GSI-Darmstadt to measure gas and electron emission under bombardment by ions with energies up to the maximum of 20 MeV/amu expected in HIF power plant drivers.

We use a variety of charged particle diagnostics in quadrupole magnets: Electrodes that are flush with the beam tube wall measure the secondary electron emission. Using the electron-emission coefficient measured with the GESD, we infer beam-halo loss. Capacitive probes measure the net charge from which we can infer electron densities if they exceed a few percent of the beam density. Grids shield collectors from the 3-orders-of-magnitude larger capacitive signal enabling the measurement of the current of expelled ions from ionization of gas. This can be calibrated to determine both the time dependence of gas density in the beam, and the production rate of electrons from gas (corrected by the ratio of the ionization cross section to the sum of ionization and charge-exchange cross sections). Slit scanners and beam profile diagnostics before and after the quadrupole magnets will allow effects of electrons on the ion beam to be determined.

These data will be compared with predictions of theory and simulations. Ion-electron two-stream stability is evaluated with the BEST code. We are adding electron source and transport modules to the WARP beam-dynamics PIC code, with the goal of developing a self-consistent, experimentally-validated tool for predicting electron effects in positive-beam accelerators.

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