Virtual National Laboratory for Heavy Ion Fusion

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Multi-Aperture Injector Tested

An ion beam for HIF or HEDP driver must have high "brightness"; that is high current and low emittance temperature in order to deliver high power onto a small target spot. A first step in achieving this is to begin with the minimum possible emittance at injection. Present HIF power plant concepts require 50 - 100 A of beam current arranged in multiple beam channels of ~0.5 A each, with an injection energy of ~1.6 MV. An effective way to overcome space-charge limits is to produce these high-current beams by merging a large number of high-current-density beamlets.

To study the emittance growth of beam merging, we injected 119 beamlets into an electrostatic quadrupole (ESQ) channel. At 400 kV (1/4 full voltage) the beam current obtained was 70 mA, which scales to 0.56 A at 1.6 MV. In full voltage gradient

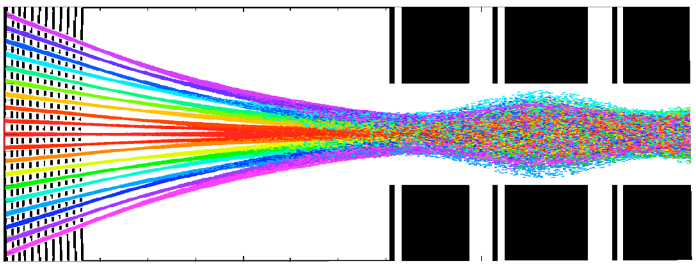
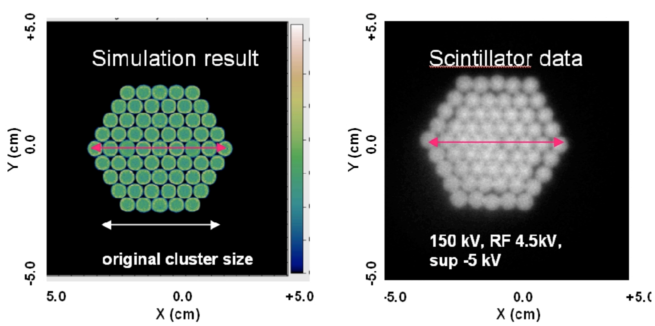


FIG. 1. Computer simulation of beamlet trajectories.

tests, we obtained argon current density > 100 mA/cm^2. Using curved electrodes in the injector, we produced an array of converging beamlets with envelope radius, convergence, and ellipticity matched to an ESQ channel, Fig. 1. Experimental results were in good quantitative agreement with simulation and demonstrated the feasibility of this concept, Figs. 2. The success of this experiment has significant economical and

Fig. 2 Simulation and measured beamlets at z=15cm



technical impact by reducing the size of injector systems for heavy ion fusion (HIF) drivers.

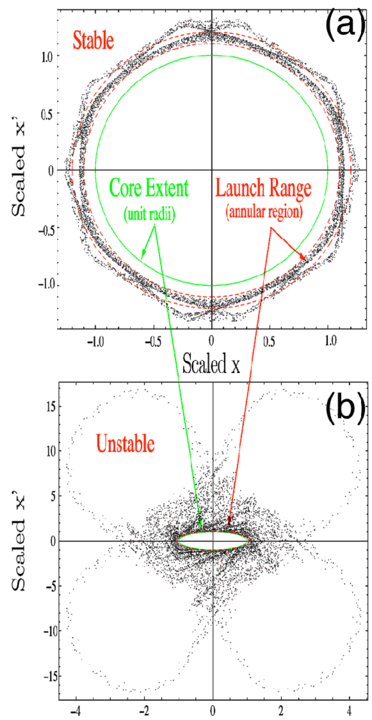
HEDP, requires similar current per channel, near-term systems will need only one to a few channels so size is less important. Short pulse duration with minimal pre-pulse is essential, and is well matched to multi-beamlet capabilities. We are planning multi-beamlet injectors using an alumino-silicate source with ion choices ranging from the traditional cesium or potassium ion beams to lighter ions such as sodium and lithium. We are therefore developing alumino-silicate sources that can produce high current density light alkaline ions.

– Joe Kwan and Glen Westenskow

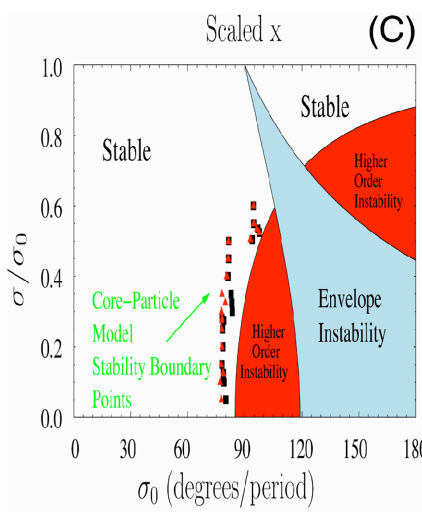
High space-charge transport limits

Experiments and particle-in-cell (PIC) simulations of space-charge-dominated ion beams in periodic quadrupole transport channels show significant emittance growth and particle loss for undepressed phase advance beyond about 85° per lattice period. This stability criterion has been employed for years in HIF without understanding its origin.

Using extensive WARP PIC simulations and core-particle models, we quantified and identified processes responsible for the limit – it results from halo particle resonances near the core of the beam. These resonances allow near-edge particles to rapidly increase in oscillation amplitude when the space-charge intensity and the flutter of the matched beam envelope are both sufficiently large. Due to a finite beam edge and/or perturbations, this mechanism can result in: large and rapid halo-driven increases in the statistical phase-space area of the beam, lost particles that can act as e-cloud precursors, and degraded transport.



The figure shows scaled Poincare phase spaces of a beam with low (stable) and high (unstable) values of phase advance and strong space-charge. Particles launched in the annular region between the red ellipses, just outside the core boundary (green ellipse), rapidly develop large oscillation amplitudes in the unstable case (b -high phase advance and strong space-charge) but only undergo small increases in the stable cases (a - lower phase advance and/or weaker space-charge).



A core-particle stability boundary derived from such analysis is shown (c). It coarsely agrees with experiment and simulations. Deviations appear related to distribution sensitivities that occur near the transition to instability. This increased understanding of intrinsic transport limits promises more optimal and robust machine design.

A manuscript has been published in NIM-A.

– Steven M. Lund (LLNL) and Sugreev R. Chawla (LBNL)