

# Lawrence Berkeley National Laboratory

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### **Title**

Overview of US heavy-ion fusion progress and plans

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**Overview of US heavy-ion fusion progress and plans\***  
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Significant experimental and theoretical progress has been made in the U.S. heavy ion fusion program on high-current sources, transport, final focusing, chambers and targets for inertial fusion energy (IFE) driven by induction linac accelerators seek to provide the scientific and technical basis for the Integrated Beam Experiment (IBX), an integrated source-to-target physics experiment recently included in the list of future facilities planned by the U.S. **Department of Energy. To optimize** the design of IBX and future **inertial fusion energy** drivers, current HIF-VNL research is addressing several key issues (representative, not inclusive): gas and electron cloud effects which can exacerbate beam loss at high beam perveance and magnet aperture fill **factors; ballistic** neutralized and assisted-pinch focusing of neutralized heavy ion **beams; limits** on longitudinal compression of both neutralized and un-neutralized heavy ion **bunches; and** tailoring heavy ion beams for uniform target energy deposition for high energy density physics (HEDP) studies.

Recent progress highlights: *The Source Test Stand (STS)*: High brightness beamlets of  $\text{Ar}^{+1}$  ions have been measured with current density ( $100 \text{ mA/cm}^2$  @  $5 \text{ mA}$ ) emittance ( $T_{\text{eff}} < 2 \text{ eV}$ ), charge state purity ( $> 90\%$  in  $\text{Ar}^{+1}$ ) and energy spread ( $< 0.01\%$ ) supporting future merging-beamlet injectors for **heavy ion fusion**. Sixty-one beamlets have been extracted through 4 Einzel lens arrays with good uniformity across the array. *The High Current Experiment (HCX)*: Beam loss from transport of  $180 \text{ mA}$ ,  $1 \text{ MeV K}^+$  beams over five electric-quadrupole lattice periods has been reduced **by a factor of three** by flattening the injector extraction voltage waveform [flatter  $I_b(t)$ ], improved matching (smaller envelope oscillations), and better beam centroid control. Experiments with transport through four pulsed quadrupole magnets began in May, 2003, to study gas and electron effects. Work in progress includes a variety of new diagnostics and use of electron clearing electrodes, as well as addition of small induction gaps to expel electrons. *Neutralized Transport Experiment (NTX)*: a very high brightness ion beam ( $\epsilon_n < 0.05 \text{ mm-mr}$  at  $25 \text{ mA}$ ,  $300 \text{ keV K}^+$ , supports small neutralized focal spots, RF and MEVVA plasma sources have been characterized, and initial experiments focusing high perveance ( $3 \times 10^{-4}$ ) beams show that plasma neutralization reduces focal spot radii from  $\sim 1.1 \text{ cm}$  (vacuum focus) to  **$< 0.14 \text{ cm}$**  (neutralized focus) consistent with **particle-in-cell** calculations. In addition, transport physics experiments relevant to long-path **heavy ion fusion** drivers have begun with the University of Maryland Electron Ring, and with the **Paul Trap Simulator Experiment** at PPPL. Recent theory and simulation **research** has developed 3D **time-dependent** simulations of HCX and IBX, new insights have been gained on electron cloud effects by including electron cloud models in WARP simulations, new MESH refinement capabilities in WARP result in better injector simulations, and stability limits for anisotropy and two-stream modes have been explored with the **nonlinear perturbative** BEST  $\delta f$  code.

A multi-beam induction linac driven power plant **study shows that the** detailed requirements for distributed radiator targets (spot size, power, symmetry and pulse shape) can be met with ballistic neutralized focusing of a 120 beam array over 6 meter focal lengths. Provided neutralized drift compression and focusing onto with larger spot hybrid targets can be experimentally **validated, preliminary studies** indicate modular induction linac driver systems with  $\sim 20$ -40 linacs may be cost-competitive. Methods to accommodate or correct chromatic aberrations with neutralized drift compression are being investigated in a new study. Combinations of tangential liquid injection and ejection allow controlled and flexible liquid cavity geometry, giving rise to new large vortex-liquid protected chamber concepts without oscillating jets.

The above research by the U.S **Heavy Ion Fusion Virtual National Laboratory** and supporting **heavy ion fusion** chamber and target research by the **Virtual Laboratory for Technology** supports the

scientific and technical basis for heavy **ion induction-linac-driven inertial fusion energy and high energy density physics.**

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