Heavy Ion Fusion Sciences Virtual National Laboratory

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HIFS News

The year in review

In 2009, the Heavy Ion Fusion Science Virtual National Laboratory made significant progress through experiments, theory and computer simulations, on the existing NDCX-I experiment, and in preparing for the upcoming NDCX-II facility and the proposed STS-100 test stand.

NDCX-I - Highly compressed beams were obtained with the new bunching module, which were neutralized in the longer drift compression section by the new ferro-electric plasma sources. The peak uncompressed beam intensity (≈500 kW/cm^2) is higher than in previous years measurements, and the bunched beam current profiles are ≈2ns (FWHM). The induction bunching module (IBM) was successfully operated in both the nominal bipolar mode, as well as in a unipolar mode. In the latter case, both pulse compression and ~90keV acceleration were achieved. Compressed pulse studies have demonstrated techniques that move the compressed pulse to earlier arrival times at the target plane than the uncompressed background current, eliminating a source of target pre-heating. A large increase in the experimental data acquisition rate was reached for target heating experiments [1].

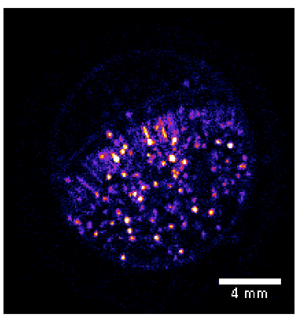

Figure 1. Shower of droplets 500 µs after the pulse.

Measurements and simulations of beam intensities and the compressed pulse fluence on the target with a modified NDCX beamline allowed for more complete coverage and higher densities of neutralizing plasma. Early and contemporaneous simulations indicate a 2X improvement in compressed beam pulse fluence with a shorter longitudinal gap between the FEPS exit and the final focus solenoid [2].

Rapid bulk heating of target foils to temperatures up to ~4500 K (0.4 eV) has been demonstrated using NDCX-I beams. Target heating is described by a simple equilibrium model that balances energy input from the beam and energy loss from the surface of the target due to mechanisms such as vaporization. Development of techniques for heating and diagnosing targets opens up the field of bulk heating of WDM targets in the laboratory using ion beam heating. The NDCX-I environment is now conducive to frequent target experiments for detailed study of target behavior under various conditions and using multiple diagnostics. Using the new remote-controlled target positioning system, the repetition rate between target shots has been as little as 2 minutes, with up to 40 target shots per day.

Evidence for the formation of liquid metal droplets (Figure 1) on the µs time scale was obtained, and compared with predictions. The liquid-vapor transition region, and the formation of droplets is a matter of interest in WDM equation of state studies. Our experiments are expected to shed light on droplet formation in metal targets under WDM conditions and on the properties of the subsequent debris shower. These results could find wide application, e.g., using ion beam volumetric heating to simulate intense volumetric neutron heating of target chamber components such as target support structures in inertial confinement fusion experiments, or optimizing applied concepts that are based on liquid metal droplets [3].

NDCX-II - LBNL has received American Recovery and Reinvestment Act (ARRA) funding to construct a new accelerator at Lawrence Berkeley National Laboratory (LBNL) to significantly increase the energy on target, which will allow both the Heavy Ion Fusion (HIF) and Warm Dense Matter (WDM) research communities to explore scientific conditions that have not been available in any other device. The NDCX-II induction linear accelerator (linac) will produce nano-second long ion beam bunches to hit thin foil targets. For Lithium ions (7 atomic mass units), useful kinetic energies range from 1.5 to 5 or more MeV. The expected beam charge in the 1 ns (or shorter) pulse is 20 nanoCoulombs or more. The pulse repetition rate will be about once or twice per minute.

Detailed engineering design and testing were carried out, related to the induction cells that are the basic building blocks of the machine. NDCX-II will reuse modified accelerator hardware from the previous ATA experiment at LLNL. Modeling calculations and test data obtained from a mock-up magnetic solenoid confirmed that the solenoids' stray

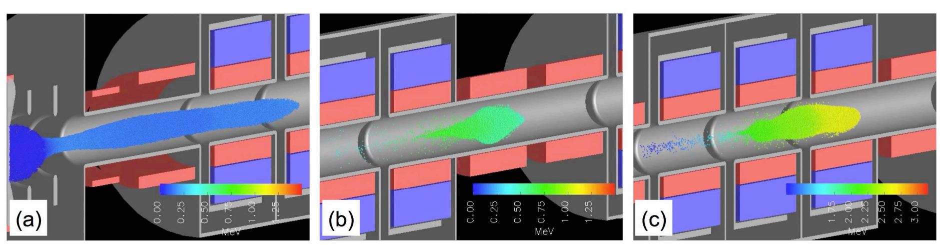

Figure 2. Images from a video depicting the beam in a 3-D Warp simulation of NDCX-II; colored bars denote ion kinetic energy. The red shapes denote the volumes occupied by the solenoids and their flux return channels. The system is assumed to be misaligned with 2 mm maximum random transverse offsets of solenoid, and the beam is shown (a) emerging from the injector; (b) after gap 8; and (c) passing through gap 16.

magnetic field must be kept away from the induction cores. An improved induction cell design has been developed to address this. The accelerator beam-line layout was finalized and a preliminary structural design of the elevated platform for mounting the pulsed power system was produced.

Computer simulations showed that a nominal solenoid alignment tolerance of ±0.5 mm allows beam transport and acceleration (Figure 2) without significant particle loss or beam degradation. Magnetic measurements to ensure the quality of the finished products are being conducted. To correct for errors, the machine is designed to allow periodic beam sensing and steering, at roughly every fourth lattice period. Using computer simulations, the accelerator performance was optimized for various numbers of induction cells and voltage waveforms.

A detailed WBS project plan was produced and the project's risk areas and mitigation strategies have been identified. A detailed Baseline Plan cost estimate was made, consistent with cost and schedule constraints. A Lehman Review is scheduled for January 2010. More information concerning the NDCX-II project is available in [4-6].

STS-100 - A proposal was submitted by PPPL requesting funds to operate a 100 kV test stand, the STS-100, acquired from LBNL, in which advanced plasma sources will be developed and ion-ion plasmas will be studied.

For effective space-charge neutralization in planned experiments at LBNL, plasma densities of 10^{15} cm^{-3} in a region one cm across and several cm long near the beam's focal spot will be required without the introduction of strong electric or magnetic fields, or excessive amounts of neutral gas. Under the auspices of the proposed research, advanced, high-density, large-volume plasma sources will be developed. Candidates include: laser-ionized gas jets and metallic vapor jets, laser ablation of solids, pulsed high-voltage discharges using ceramic or plastic materials, and plasma jet methods.

Beam focusing on NDCX1 includes the use of an 8T, 10-cm-long solenoid placed near the beam's focal spot. To ensure proper beam space-charge neutralization, it is important to understand the effects of the solenoid on the plasma production and transport to the region near the beam axis. To this end, experiments will be carried out using a strong solenoid in conjunction with the developed plasma source.

Also under the auspices of the proposed research, ion-ion halogen plasmas will be produced in the test stand to study their suitability for use as either positive or negative ion beam sources. The emittances of Cl^+, Cl^-, and Ar^+ beams will be measured and compared in order to determine if halogen ion beams can be extracted that are as cold, or colder, than the Ar^+ beam extracted from ordinary electron-ion plasmas.

A negative ion beam would not accumulate electrons that would lead to emittance growth, and a negative ion beam could be space-charge neutralized via energy-efficient photodetachment. Basic studies of ion-ion plasmas will be performed with the unique approach of analyzing the properties of the negative ions, positive ions, and electrons extracted from the plasma. A variety of feedstock gasses will be used to determine the dependence of the ion-ion plasma properties on the electronegativity of the ion species. Using a combination of ion-source and beam diagnostics, the difference between ion-ion sheaths and electron-ion sheaths will be studied.

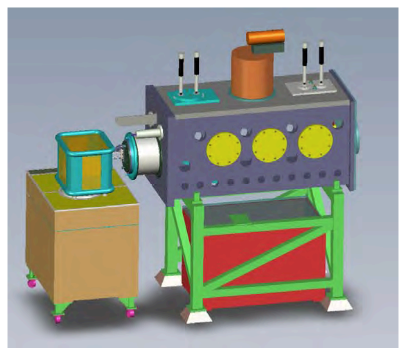

Figure 3. A drawing of the STS-100 showing the main chamber with numerous ports for diagnostics and pumping. The RF plasma source sits atop the high-voltage bias oil tank and an oil transfer tank is included.

The test stand will also be used to perform experiments on the ability to create short and bright ion beam pulses by flash-heating an aluminosilicate source with a bright pulsed radiant heat source such as a laser or a Xenon flash lamp. If such ion beam pulses can be created, their rapid rise time and short pulse length would benefit WDM and ion beam driver experiments for heavy ion fusion, and the ion source lifetime could be extended as compared to an aluminosilicate source used in a resistively heated, steady-state mode.

- Jean-Luc Vay (on behalf of the HIFS-VNL)

[1] NDCX-I Quarterly Progress Report to DOE/OFES for FY09Q2, http://hifweb.lbl.gov/public/reports/FY09Q2_Report.pdf

[2] NDCX-I Quarterly Progress Report to DOE/OFES for FY09Q3, http://hifweb.lbl.gov/public/reports/FY09Q3_Report.pdf

[3] NDCX-I Quarterly Progress Report to DOE/OFES for FY09Q4, http://hifweb.lbl.gov/public/reports/FY09Q4_Report.pdf

[4] Berkeley Lab Features
October 14, 2009 "On the Road to Fusion Energy, an Accelerator to Study Warm Dense Matter"
http://newscenter.lbl.gov/feature-stories/2009/10/14/warm-dense-matter
December 17, 2009 "Beaming in on Warm Dense Matter"
http://newscenter.lbl.gov/feature-stories/2009/12/17/ndcx-ii-animations

[5] NDCX-II Quarterly Progress Report to DOE/OFES for FY09Q4, http://hifweb.lbl.gov/public/reports/NDCX-II_FY10Q1_Report.pdf

[6] A. Friedman, HIFSNews 3, 2009

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