Virtual National Laboratory for Heavy Ion Fusion

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HIFSNews

Research Highlights of the U.S Heavy Ion Fusion Science Program (May 2005 to May 2006)

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A new five-year Memorandum of Agreement was signed by the LBNL, LLNL, and PPPL laboratory directors in October 2005 for the US Heavy Ion Fusion Science Virtual National Laboratory (HIFS-VNL-Fig.1), a collaboration between Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and the Princeton Plasma Physics Laboratory.

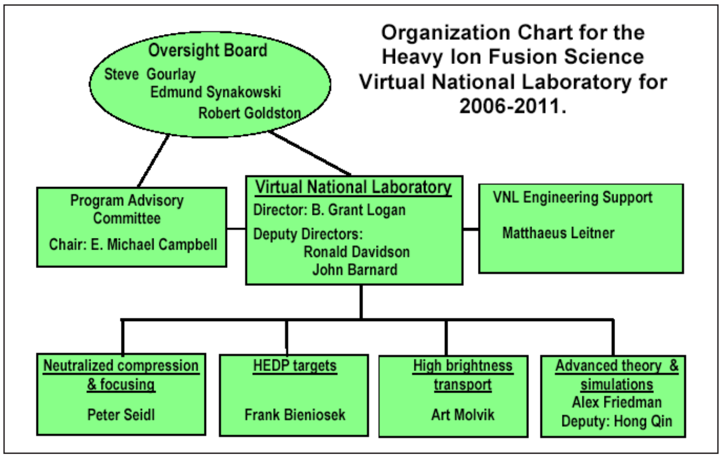

Figure 1. The Heavy-Ion Fusion Science Virtual National Laboratory organization.

Following are some of the notable accomplishments of the past year.

Neutralized drift compression

Two years ago, we calculated that heavy-ion-heated HEDP targets of a few microns' thickness (the range of our MeV ion beams) would hydro-expand in a few nanoseconds at 1 eV temperature. Therefore we needed a way to get short pulses (a few ns instead of the few μs we had previously). Longitudinal compression of an ion bunch using a velocity ramp head to tail while traveling through neutralizing plasma has provided a means of generating short ion beam pulses of a few ns, short enough to be consistent with the hydro expansion time of few-micron-thick target foils for warm dense matter physics experiments. In the Neutralized Drift Compression Experiment (NDCX), a VNL facility at LBNL, an induction core adds a velocity ramp from the head to the tail of a selected 250 to 500 ns portion of the 25 mA , 250 kV NDCX beam. The ramp is applied with a specially shaped induction drive pulse of 100 kV amplitude. The rear of the selected beam section catches up with the head particles in a 1.3-meter drift section that is pre-filled with plasma confined in a weak solenoid magnetic field. The drift compression section provides space-charge neutralization during axial compression. Using an induction core with a compressing waveform developed via detailed simulations, we achieved 60x current amplification (Fig.2) A parallel beam temperature T^z < 1.5 eV is measured with an improved-resolution electrostatic energy analyzer, which is consistent with the low longitudinal beam temperatures that simulations require to explain the large compression factors we achieve.

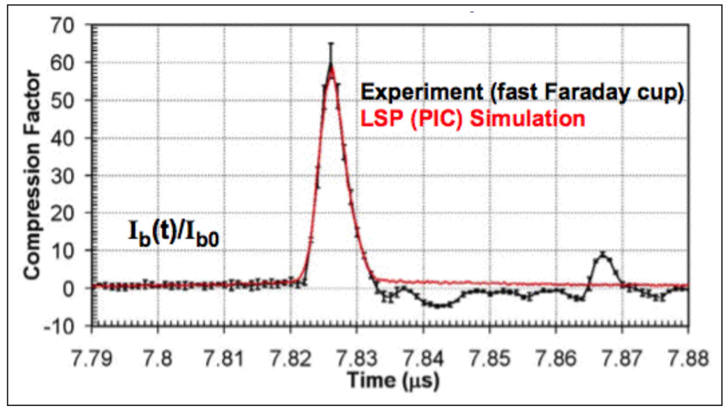

Figure 2. Comparison of fast Faraday cup current waveform with LSP PIC simulations for NDCX compression experiment. When the actual, experimentally realized waveforms were inserted in the simulations, good agreement with the data was obtained.

Design of experimental ion-beam-driven warm dense matter target experiments

Over the last year a study group was formed to propose and evaluate the best set of experiments that would allow the VNL to contribute to the science of Warm Dense Matter, (using ion beams to heat the material), as expeditiously as possible based on modest improvements to current beam facilities (NDCX and HCX) The list of experiments below is planned to yield scientifically interesting results at increasingly higher beam intensities, with concomitantly increasing target temperatures:

1. Beam induced transient emission and absorption experiments in transparent insulators (on HCX and NDCX I). The beam excites electrons to higher energy bands, resulting in holes at appropriate energy and darkening of the transparent material. The goal is to corroborate the understanding of phenomena observed at higher temperature.
2. Experiment to measure target temperature and conductivity using a beam compressed both radially and longitudinally (on NDCX 1a). Here the best focus (both longitudinally and transversely) that can be obtained on the current NDCX experiment will be used to raise the target temperature as high as possible, and begin to make hydrodynamic and conductivity experiments.

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This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48 and by Lawrence Berkeley National Laboratory under contract No. DE-AC03-76SF00098 (LBNL), and by Princeton Plasma Physics Laboratory performed under the auspices of the U.S. Department of Energy under contract No. DE-AC02-76CH-O3073. This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48 and by Lawrence Berkeley National Laboratory under contract No. DE-AC03-76SF00098 (LBNL), and by Princeton Plasma Physics Laboratory performed under the auspices of the U.S. Department of Energy under contract No. DE-AC02-76CH-O3073.

3. Positive - negative halogen ion plasma experiment (kT >~ 0.4 eV) (on NDCX, or pulse compressed HCX, either with focusing solenoid). The conductivity of a novel plasma composed primarily of positive and negative ions may have similarities to semi-conductors at high densities.
4. Two-phase liquid-vapor metal experiments (kT > 0.5 - 1 eV) (on NDCX with focusing solenoid or pulse compressed HCX with focusing solenoid or NDCX-II a new facility for WDM experiments). The exact phase transition boundary for a number of metals is unknown and the dynamics of metals passing through this phase is also not clearly understood.
5. Critical point measurements (kT > 1 eV) (possibly only on NDCX-II). The critical point occurs at the highest temperature for which a distinction between the gaseous and liquid state can be observed and is unknown for several metals.

In addition, we plan to carry out metallic foam heating experiments at GSI that will begin to explore the physics of foam targets as well as possible measurements of dE/dX in metallic foam. Ion stopping may be different when the time between collisions is less than the relaxation timescale of the ion in the excited state.

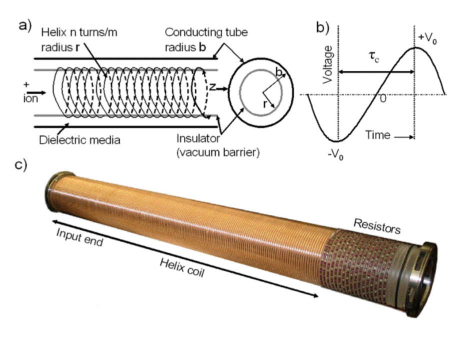

Figure 3. A schematic of the helical pulse line structure. The helical pulse line of radius r is located inside a conducting cylinder of radius b, and a dielectric media of permittivity e is located in the region outside the helix. b) schematic of a drive voltage waveform applied at the helix input. c) one-meter-long helix constructed for the PLIA experiments

Pulse Line Ion Accelerator (PLIA)

The acceleration of non-relativistic K+ ion bunches with a helical slow wave structure immersed in a dielectric (Fig.3) has been demonstrated. Due to the traveling wave that provides the accelerating field, significant energy amplification has been achieved with modest voltage pulses. Depending on the phase of ions with respect to the traveling wave, a beam energy modulation of -80 keV to +150 keV on the NDCX beam was measured using a PLIA input voltage waveform of -21 kV to +12 kV. The resulting beam energy modulation was consistent with WARP simulations. We are currently studying the causes and possible remedies of a vacuum breakdown that currently limits <Ez> <150 kV/m. If we can achieve high gradients through modeling and further experimentation, the PLIA could greatly reduce the cost per volt of accelerators that reach the parameter space we need for target experiments.

High Brightness Beam Transport

We have refined electron-cloud and gas experiments with improved diagnostics and models. We find significant agreement between measured and simulated e-cloud effects on a high current ion beam transported through four quadrupole magnets in the High Current Experiment (HCX), another VNL facility at LBNL. The HIFS-VNL has continued to make progress on multi-species simulation codes to model intense heavy ion beams interacting with electrons, gas, and plasmas. As in the beam compression experiments in NDCX discussed above, advanced simulations also closely support the e-cloud experiments in HCX. Fig. 4 below shows a snapshot of electron density in a simulation of the HCX beam being substantially neutralized in the last magnet from secondary electrons drifting in from the end wall on the right. These simulations are made possible by a large time-step particle mover that allows us to simulate complex electron drifts in 3-D magnetic fields. Fig. 4 exhibits large amplitude (~ beam space charge density level) oscillations in the electron cloud at 6 MHz, consistent in frequency and amplitude to those measured.

We plan to test these e-cloud models in upcoming solenoid experiments in NDCX, so that we can compare e-cloud effects in solenoids as well as in quadrupoles. A predictive e-cloud capability is important to design future heavy-ion-beam facilities such as NDCX-II and the Integrated Beam-High Energy Density Physics Experiment (IB-HEDP). DOE provided a Mission Need (CD-0) for IB-HEDPX December 1, 2005.

Advanced Theory and Simulation Tools

Our simulation tools for intense ion beams have seen considerable development over the past several years. This progress has enabled studies of the new regimes required for high energy density physics and warm dense matter studies. The tools and numerical techniques are also proving very useful for a broad range of accelerator physics and particle trap applications. Our simulation tools have general applicability, and we have begun to apply them outside the Fusion program, such as modeling of Large Hadron Collider (LHC) bunch trains.

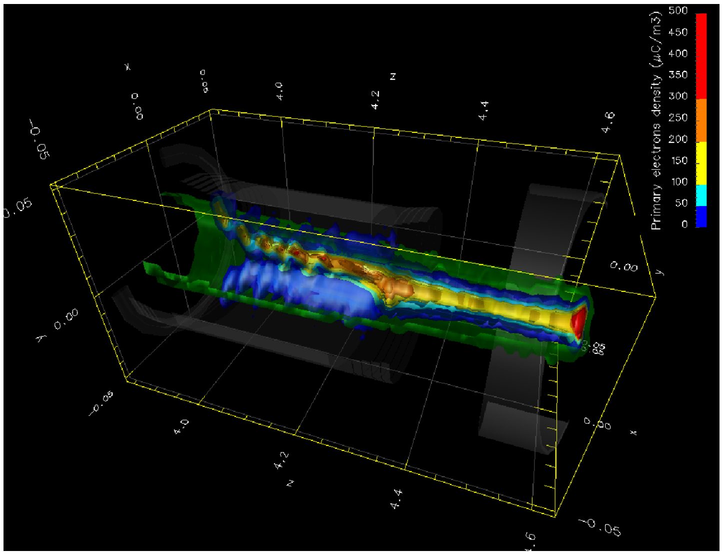

Figure 4. The charge density of primary electrons (color coded) are simulated from emission off the beam hitting the end wall on the right, and extending from through the last magnet to the clearing electrode between the last two magnets.