Heavy Ion Fusion Sciences Virtual National Laboratory

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HIFS News

The 2010 year in review

In 2010, the Heavy Ion Fusion Science Virtual National Laboratory made significant progress through experiments, theory and computer simulations, on the existing NDCX-I experiment, in the construction of the upcoming NDCX-II facility (see Figure), and on both Warm Dense Matter physics and target physics relevant to Inertial Fusion Energy (IFE).

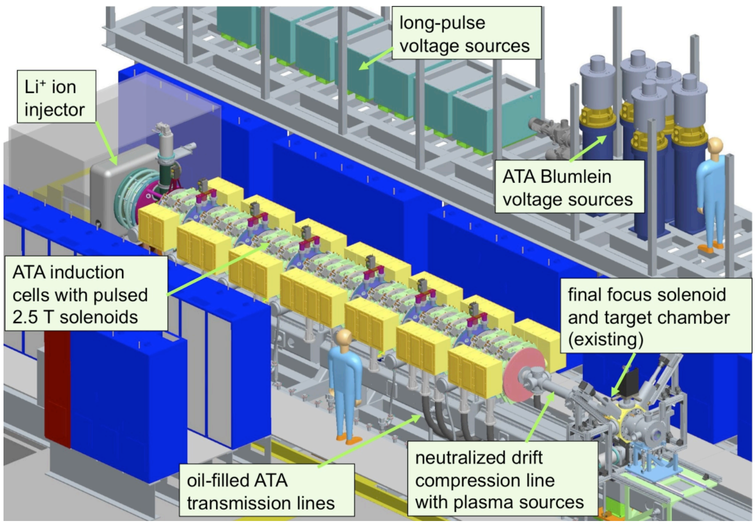

Figure. Initial NDCX-II configuration, showing key elements including 12 active accelerating cells (5 of them using Blumleins), will optimally deliver a compressed pulse of 20 nC of Lithium ions at 1.2 MeV into a sub-mm focal spot in < 1 ns.

Milestone reports submitted to the Department of Energy – During the past year, milestone reports submitted were:

- simulations of fast correction of chromatic aberrations to establish physics specifications for implementation on NDCX-I and NDCX-II (http://hifweb.lbl.gov/public/reports/FY10Q1_Report.pdf),
- develop the theory connecting pyrometer and streak camera spectrometer data to the material properties of beam heated targets and compare to the data (http://hifweb.lbl.gov/public/reports/FY10Q2_Report.pdf),
- assess the key physics that underpins high-hydro coupling-efficiency in NDCX-II experiments and high-gain heavy ion direct drive target designs using proven hydro codes like HYDRA (http://hifweb.lbl.gov/public/reports/FY10Q3_Report.pdf).

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Announcement of the 2011 Workshop on Accelerators for Heavy Ion Inertial Fusion

The workshop is to be held at Lawrence Berkeley National Laboratory May 23-26, 2011. Its purpose is to review the status of heavy ion fusion (HIF) research, and to identify the most promising areas of research by bringing together experts in:

- fusion target physics,
- ion sources RF accelerators (including linacs, synchrotrons, storage rings, cyclotrons),
- induction accelerators, superconducting magnets,
- chamber and chamber-driver interface,
- technology development (e.g.: insulators, high-voltage pulsed power, RF systems, vacuum systems, accelerator alignment and non-intercepting beam diagnostics).

The structure of the workshop will be plenary sessions to review the state of the art in Heavy Ion inertial Fusion, followed by parallel working groups, and conclude with a plenary session to review the results. This workshop would be in the spirit of the early Heavy Ion Fusion Workshops which included participants from many accelerator laboratories. A scientific report to document the results of the workshop will be produced.

The content and timing of this workshop is significant for several reasons:

- there is renewed interest in the development of energy solutions that can provide carbon-free, base-load electricity,
- the U.S. National Academies of Sciences and Engineering are sponsoring a review of the prospects for inertial confinement fusion energy systems. This will include various driver systems, including heavy-ion accelerators. Presentations are expected to commence early in 2011, (http://sites.nationalacademies.org/BPA/BPA_058425)
- the National Ignition Facility has commenced its campaign of ignition experiments. These are likely to stimulate interest in inertial fusion energy systems, (https://lasers.llnl.gov)
- the timely release of the report from the symposium "Accelerators for America's Future." It convincingly shows the potential of particle accelerators in many fields. The section on Accelerators and the Environment includes heavy ion inertial fusion. (http://www.acceleratorsamerica.org)

Workshop information (registration, accommodations, agenda) will follow in the near future.

--Peter Seidl

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NDCX-I – There were two main developments using the NDCX-I beamline in 2010:

(i) development of calorimeter diagnostic (Beam Instrumentation Workshop 2010 paper), during which a novel beam diagnostic was developed and is now routinely used on NDCX-I to assist in measuring the peak ion beam fluence at the target plane. A 3-micron tungsten foil has been inserted as a target, and the radiative light emission due to beam heating of the tungsten has been measured with both the fast gated MCP camera as well as the streak camera. The streak camera response has been absolutely calibrated against a tungsten filament source of known temperature. This calibration allows to accurately measure the temporal profile of the tungsten foil temperature and, hence, the peak beam fluence and intensity versus time. This diagnostic is used as a complement to the usual scintillator beam profile monitor. The high degree of nonlinearity in the thermal signal intensity allows usage of this tungsten foil calorimeter as a sensitive measure for peak fluence and aids in final tuning and optimization of beam transport and compression;

(ii) measurement of time-dependence of modulated beam in neutralized compression drift section. To better study the detailed dynamics and evolution of the ion beam under longitudinal compression in the neutralized transport section, a second diagnostic module was inserted into the beamline downstream of the Induction Bunching Module (IBM). This new diagnostic is located approximately halfway along the 3-m FerroElectric Plasma Source (FEPS) drift-compression section. At this location, phase-space and profile diagnostics measure the temporal variations of the un-modulated and modulated ion beams. These measurements illuminate the interaction of the ion beam with the time-varying electric fields in the IBM gap, and verify our understanding of the transition of the beam from space-charge dominated to neutralized by the background plasma. We hope to resolve discrepancies between NDCX-I target fluence measurements and particle-in-cell predictions and enable detailed particle-in-cell simulation models of greater fidelity. These studies might point to methods of mitigating the chromatic and time-varying geometric aberrations that limit peak beam fluence at the target plane. Ultimately, the goal is to more accurately design NDCX-II experiments with the highest possible fluence.

NDCX-II – The NDCX-II construction project has passed its mid-point, and is proceeding toward completion ahead of its original schedule.

During the year, a number of reviews of the NDCX-II project were carried out. Of these, the most seminal was a DOE/SC Project ("Lehman") review on Jan 13-14. The Committee heard presentations on the project's physics, engineering, and management. Although the project was fully funded via the ARRA process, the Committee applied their conventional project management criteria in making their assessment. Among the Committee's recommendations were accelerating the project where possible, identifying additional cost and scope contingency that may be invoked if costs prove higher than expected, and clarifying the acceptance criteria. These recommendations were followed and a new baseline was established. Follow-up "Lehman" reviews were held on April 9 and October 6.

The revised configuration with 12 active accelerating cells (5 of them using Blumleins) is shown in the Figure. It is intended to deliver a compressed pulse of 20 nC of Lithium ions at 1.2 MeV into a sub-mm focal spot in < 1 ns. See: http://hifweb.lbl.gov/public/slides/Friedman-APSDPP-2010 .

While the mandated project end is March, 2012, the team is aiming to finish in September, 2011. A year of commissioning (not part of the project scope) will follow.

WDM and IFE Target physics – Compressed ion beams from NDCX-I have been utilized to study interactions of intense ion beams with target foils. Measurements show beam-heated target temperature up to 0.4 eV, and indicate liquid metal droplet formation on the μs time scale. The mechanism of target heating is described by a simple model which calculates the equilibrium between energy input from the beam and energy loss from the surface of the target. We compare results with predictions of the liquid-vapor region of the target.

In these experiments, we develop techniques to generate warm dense matter (WDM) by an intense compressed ion beam pulse in a modest-size facility. Longitudinal and transverse space-charge neutralized drift compression is used to provide a hot spot on the target with compressed pulse length about 2 ns and a beam spot size of about 1 mm. Both compressed and uncompressed parts of the NDCX-I beam were used for WDM experiments.

NDCX-I provides a test bed for target physics studies, target diagnostics development, and ion beam transport and compression studies. Initial WDM experiments develop diagnostic techniques for measurement of temperature, droplet formation and other target parameters. The goal is to develop and transfer techniques for high energy density (HEDP) experiments from the NDCX-I facility to the NDCX-II facility now under construction, which will have greatly increased beam intensity on target.

A number of target designs were studied for both WDM and IFE applications. Hydrodynamic simulations of

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planar targets for WDM experiments on NDCX-II were carried out, including simulations of diagnostics at several different wavelengths. Direct drive IFE targets were simulated that quantified the effects of ion energy ramps and the number of shocks launched. A new "X-target" concept was simulated that takes advantage of volumetric ion deposition, and allows illumination from a single side, and single ion energy.

***Meetings* –** The 2010 Ion Beam Driven High Energy Density Physics (HEDP) Workshop was held in Pleasanton, California, from June 22-24, 2010. The meeting informed HEDP scientists and potential users about the beam characteristics of NDCX-I and NDCX-II, and diagnostic capabilities. There were also presentations representing other HEDP facilities including LCLS, GSI, and JLF. The workshop consisted of lectures and discussion groups. The topics of the discussion groups were: Warm dense matter theory and experiments; inertial fusion energy and shocks; beam dynamics; and a cross cutting group on collaborative experiments. The presentations and other information about the workshop may be found on the web at http://hifweb.lbl.gov/public/BeamHEDP2010.

The Heavy Ion Fusion (HIF) Symposium was held on the campus of the Technical University in Darmstadt, Germany from August 28 through September 3, 2010. Prominent accelerator-related topics covered at the symposium included reports on the Neutralized Drift Compression Experiment II (NDCX-II) under construction at Lawrence Berkeley National Laboratory and the Facility for Antiprotons and Ion Research (FAIR) project at GSI, Germany. Numerous other accelerator related topics were presented at the meeting ranging from HIF to basic accelerator physics and technology. In addition to accelerator topics, presentations were given at the symposium covering Warm Dense Matter (WDM), High Energy Density Physics (HEDP), ion stopping in matter, and HIF targets. More information is available at:
http://www.gsi.de/forschung/pp/dates/HIF2010.html.

HIFS-VNL staff also participated in a variety of major meetings and conferences sponsored by others, including the Inertial Fusion Science and Applications Conference, the International Computational Accelerator Physics conference, and the APS's Division of Plasma Physics Conference. Invited and tutorial talks were presented to the broader communities in attendance.

On December 8th and 9th, 2010, the 11th HIFS VNL Program Advisory Committee (PAC) meeting was held at LLNL; major program directions were reviewed by a panel of outside experts. There were two broad charges to the committee: a request to review and provide advice on the VNL's plans for commissioning of the Neutralized Drift Compression Experiment-II and on the balance of its planned operation in FY 2012 and FY 2013; and a request to review and provide advice on the balance and emphasis for R&D of several heavy ion fusion options that could be proposed in response to the charges for an upcoming review of Inertial Fusion Energy by the National Academy of Science. A number of talks were presented, highlighting recent progress in the VNL; these, along with a video showing a Warp simulation of the NDCX-II beam, may be downloaded from:
http://hifweb.lbl.gov/VNLPAC2010/00.TALKS/
The Committee's report is forthcoming.

***Related projects* –** The propagation distance of the University of Maryland Electron Ring (UMER) beam has recently been significantly lengthened by introducing longitudinal focusing from a single induction cell, fired approximately once every six turns. For an injected current of 0.55 mA, the tune shift due to space charge is of the order of 1.0, which is several times larger than the standard tune shift limit for storage rings. The propagation of the UMER beam for over 1000 turns, or 11.5 km, suggests the possibility of operating storage rings with significantly higher space charge intensities than previously assumed possible. For more information, visit the UMER website at http://www.umer.umd.edu/.

-- John Barnard, Alex Friedman, Joe Kwan, Steve Lidia, Peter Seidl

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