

NDCX-II, an Induction Linac for HEDP and IFE Research

by

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The Heavy Ion Fusion Science Virtual National Laboratory in the USA is constructing a new Neutralized Drift Compression eXperiment (NDCX-II) at LBNL. This facility is being developed for high energy density physics and inertial fusion energy research.^{1,2} The 12 m long induction linac in NDCX-II will produce a Li⁺ beam pulse, at energies of 1.2 - 3 MeV, to heat target material to the warm dense matter regime (~ 1 eV). By making use of special acceleration voltage waveforms, 2.5T solenoid focusing, and neutralized drift compression, 20 - 50 nC of beam charge from the ion source will be compressed longitudinally and radially to achieve a sub-nanosecond pulse length and mm-scale target spot size.

The original Neutralized Drift Compression Experiment (NDCX-I) has successfully demonstrated simultaneous radial and longitudinal compression by imparting a velocity ramp to the ion beam, which then drifts in a neutralizing plasma to and through the final focussing solenoid and onto the target.³ At higher kinetic energy and current, NDCX-II will offer more than 100 times the peak energy fluence on target of NDCX-I.

NDCX-II makes use of many parts from the decommissioned Advanced Test Accelerator (ATA) at LLNL. It includes 27 lattice periods between the injector and the neutralized drift compression section (Figure 1). There are 12 energized induction cells, 9 inactive cells which provide drift space, and 6 diagnostic cells which provide beam diagnostics and pumping. Custom pulsed power systems generate ramped waveforms for the first 7 induction cells, so as to quickly compress the beam from 600 ns at the injector down to 70 ns. After this compression, the high voltages of the ATA Blumleins are then used to rapidly add energy to the beam. The Blumleins were designed to match the ferrite core volt-seconds with pulses up to 250 kV and a fixed FWHM of 70 ns. The machine is limited to a pulse repetition rate of once every 20 seconds due to cooling requirements.

The NDCX-II beam is highly space-charge dominated. The 1-D ASP code was used to synthesize high voltage waveform for acceleration, while the 3-D Warp particle-in-cell code was used for detailed design of the lattice.⁴

The Li⁺ ion was chosen because its Bragg Peak energy (at ~ 2 MeV) coincides with the NDCX-II beam energy. The 130 keV injector will have a 10.9 cm diameter ion source. Testing of small (0.64 cm diameter) lithium doped aluminosilicate ion sources has demonstrated the current density (~ 1 mA/cm²) used in the design, with acceptable lifetime.⁵ A 7.6 cm diameter source has been successfully produced to verify that the coating method can be applied to such a large emitting area. The ion

source will operate at ~ 1275 °C; thus a significant effort was made in the design to manage the 4 kW heating power and the associated cooling requirements.

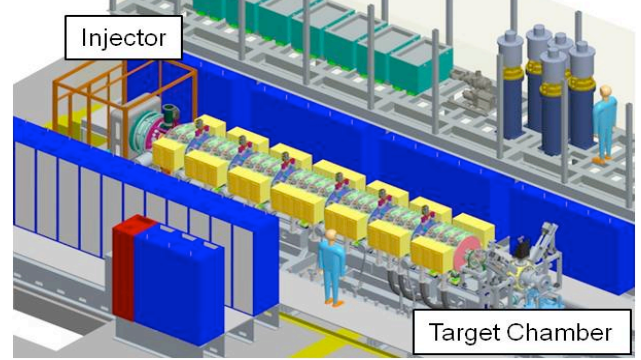


Figure 1: NDCX-II CAD Design

In modifying the ATA induction cells for NDCX-II, the low-field DC solenoids were replaced with 2.5 T pulsed solenoids. The beam pipe diameter was decreased in order to reduce the axial extent of the solenoid fringe fields and to make room for water cooling. In addition, an outer copper cylinder (water-cooled) was used to exclude the solenoid magnetic flux from the ferrite cores.

Precise alignment is essential because the beam has a large energy spread due to the rapid pulse compression, such that misalignments lead to corkscrew deformation of the beam and reduced intensity at focus. A novel pulsed-wire measurement method is used to align the pulsed solenoid magnets.⁶ Alignment accuracy has been demonstrated to within 100 μ m of the induction cell axis.

The neutralized drift compression region after the last induction cell is approximately 1.2 m long and includes ferroelectric plasma sources (FEPS) fabricated by PPPL similar to those successfully operating in NDCX-I. The 8-T final focus pulsed solenoid, filtered cathodic arc plasma sources (FCAPS), and target chamber from NDCX-I are to be relocated to NDCX-II.

The NDCX-II project started in July 2009 and is expected to complete in fall of 2011. As future funds become available, additional induction cells and pulsed power systems will be added to increase the beam energy.

- [1] J.J. Barnard, et al., Nucl. Instr. Meth. A **606**, 134 (2009).
- [2] F.M. Bieniosek, et al., J. Phys. Conf. **244**, 032028 (2010).
- [3] P.K. Roy, et al., Phys. Rev. Lett., **95**, 234801 (2005).
- [4] A. Friedman, et al., Phys. Plasmas **17**, 056704 (2010).
- [5] P.K. Roy et al., Rev. Sci. Instrum., **82**, 013304 (2011).
- [6] D. Arbelaez, Particle Accel. Conf., New York, NY (2011).

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