LLNL-PRES-513461

# The NDCX-II accelerator facility for Heavy Ion Fusion Science*

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*Salt Lake City, November 15, 2011*

Fusion Energy Sciences

The Heavy Ion Fusion Science Virtual National Laboratory

BERKELEY LAB PPPL

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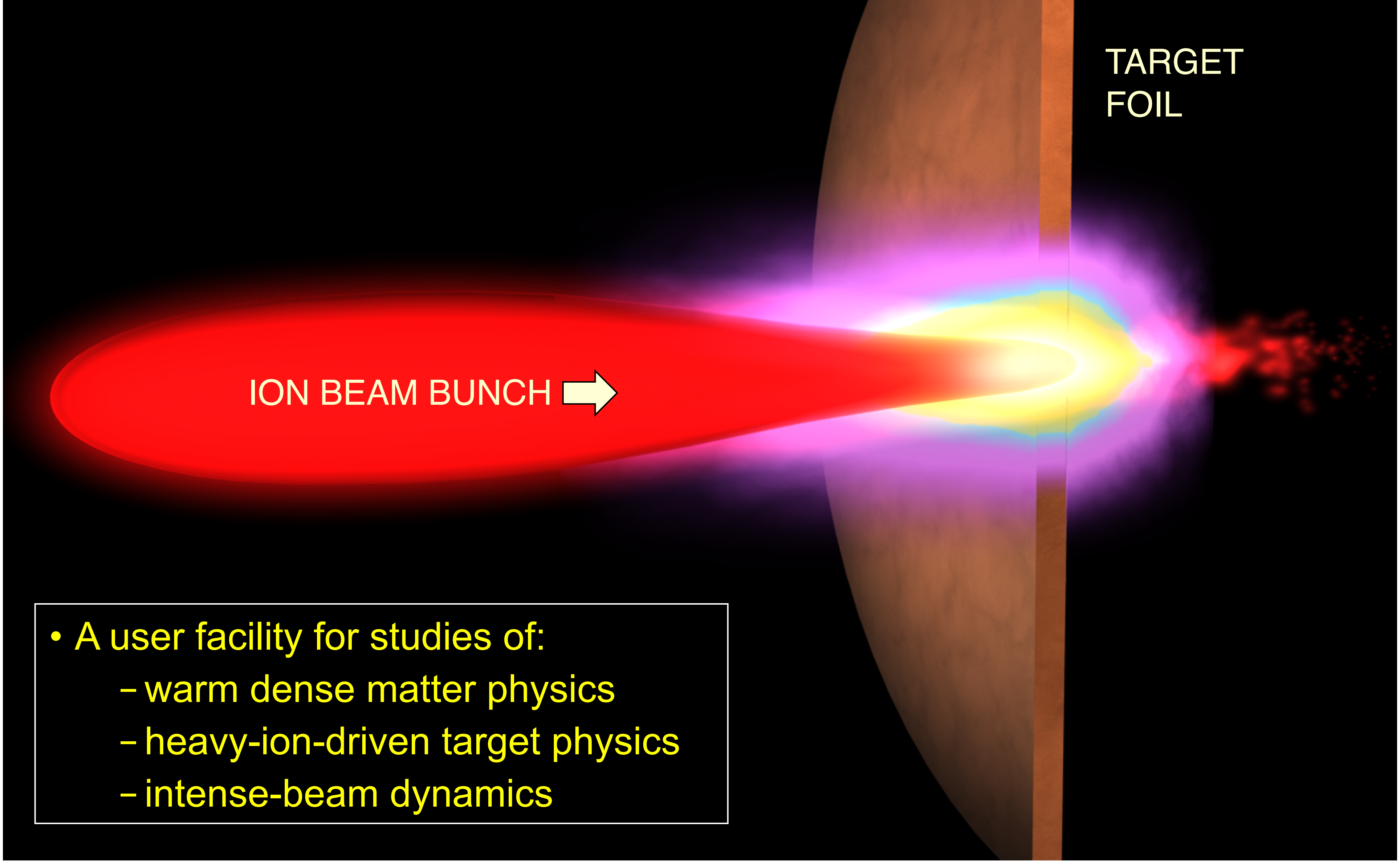
# Neutralized Drift Compression Experiment-II (NDCX-II)




- A user facility for studies of:
  - warm dense matter physics
  - heavy-ion-driven target physics
  - intense-beam dynamics

# The drift compression process is used to shorten an ion bunch

- Induction cells impart a head-to-tail velocity gradient ("tilt") to the beam
- The beam shortens as it "drifts" down the beam line

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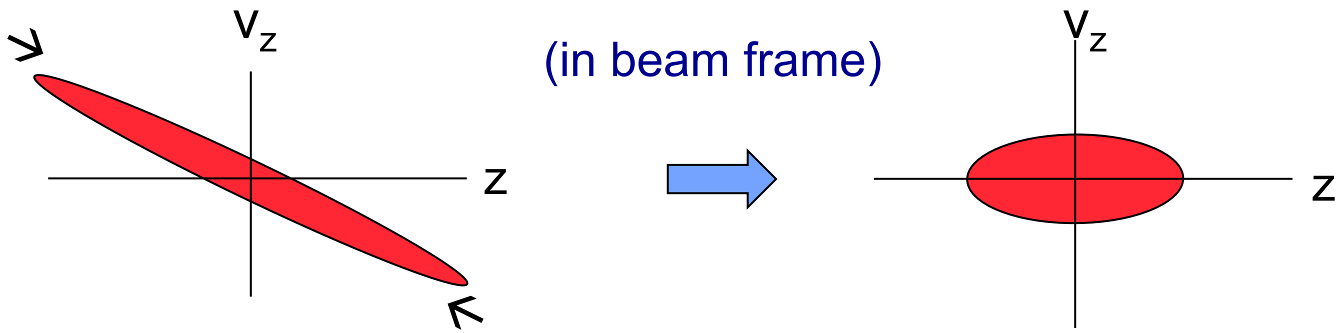
- In non-neutral drift compression, the space charge force opposes ("stagnates") the inward flow, leading to a nearly mono-energetic compressed pulse:

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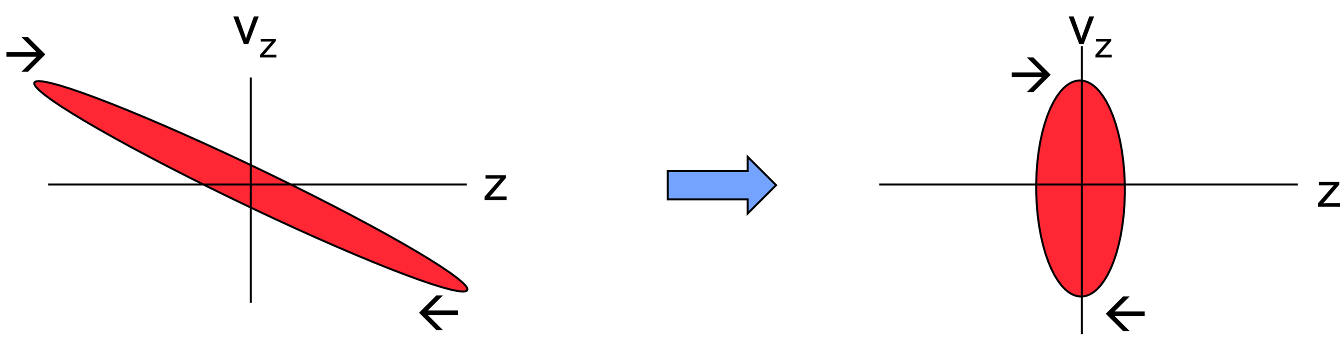
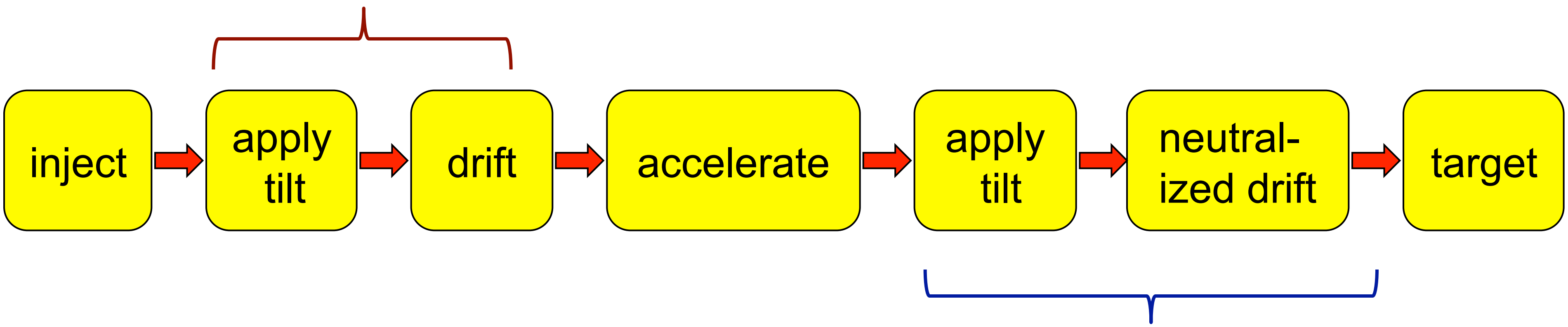
- In neutralized drift compression, the space charge force is eliminated, resulting in a shorter pulse but a larger velocity spread:



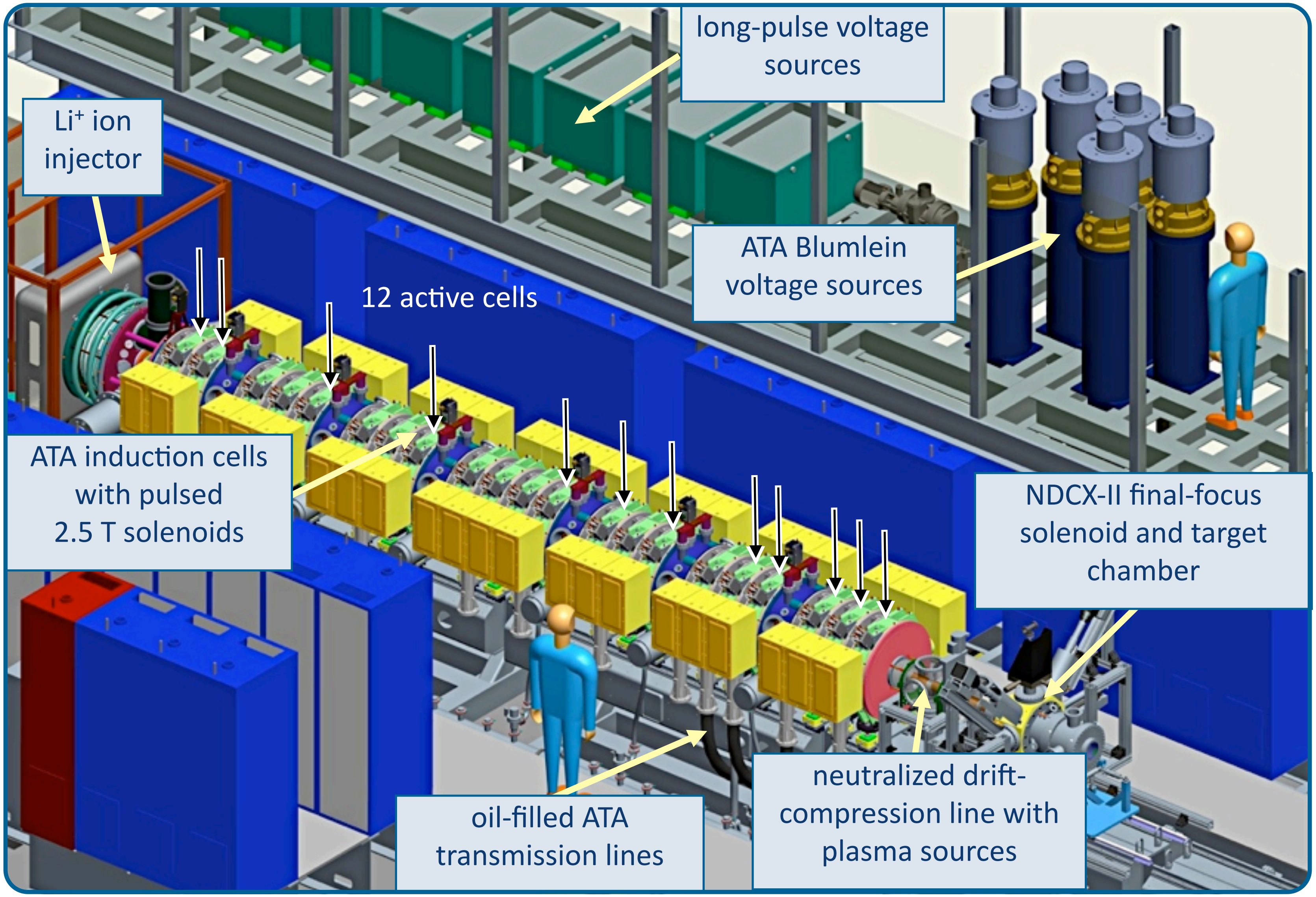
# Drift compression is used twice in NDCX-II

Initial non-neutral pre-bunching for early use of 70-ns 250-kV Blumlein power supplies from ATA

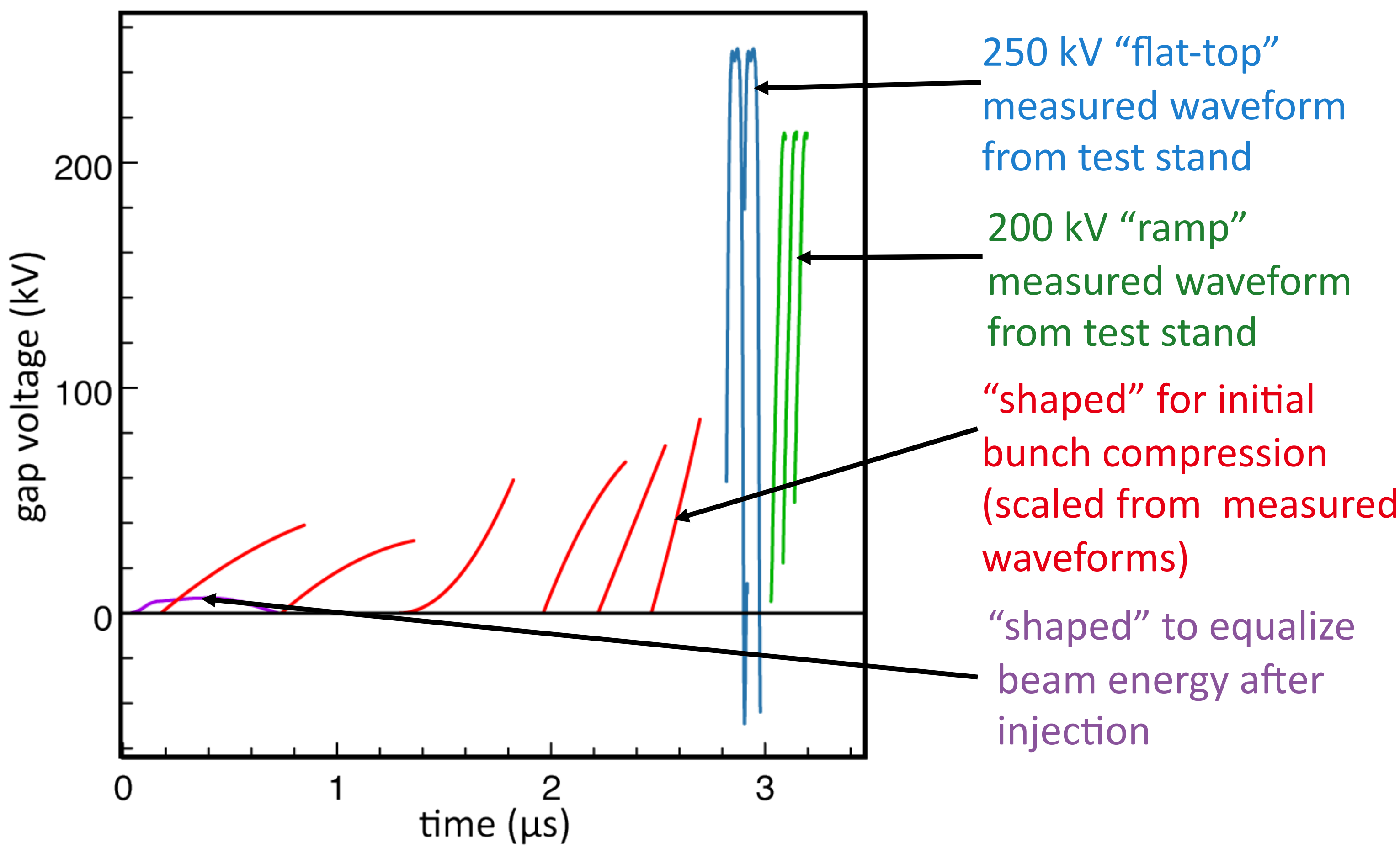



Final neutralized drift compression onto the target

# 12-cell NDCX-II baseline layout



# Accelerating waveforms are either long-pulse moderate-voltage or short-pulse high-voltage (Blumleins)

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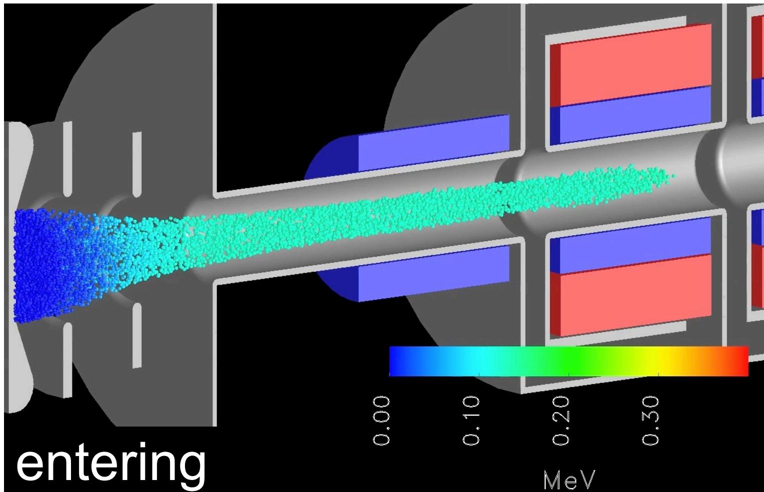
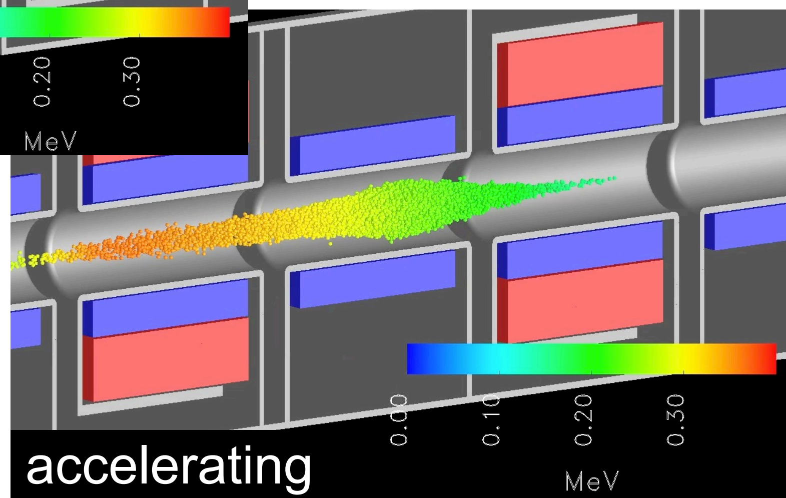
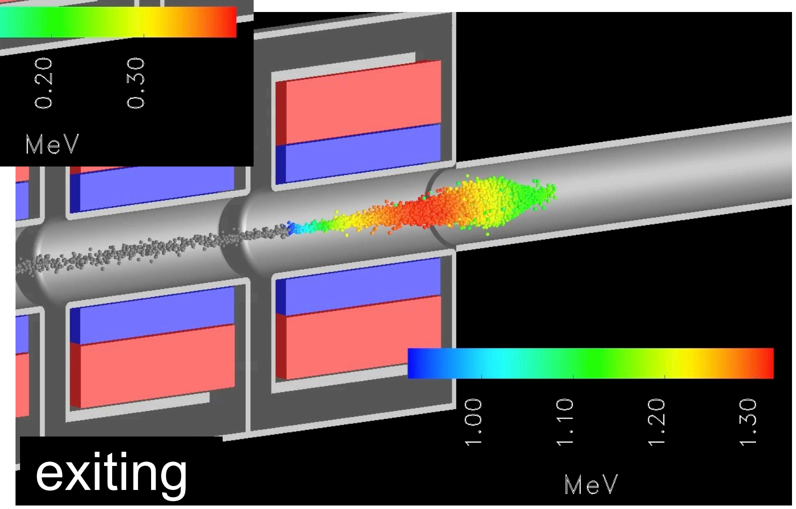
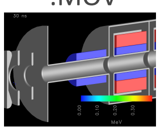
# 3-D Warp simulation with perfectly aligned solenoids (close-up)



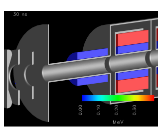




.MOV



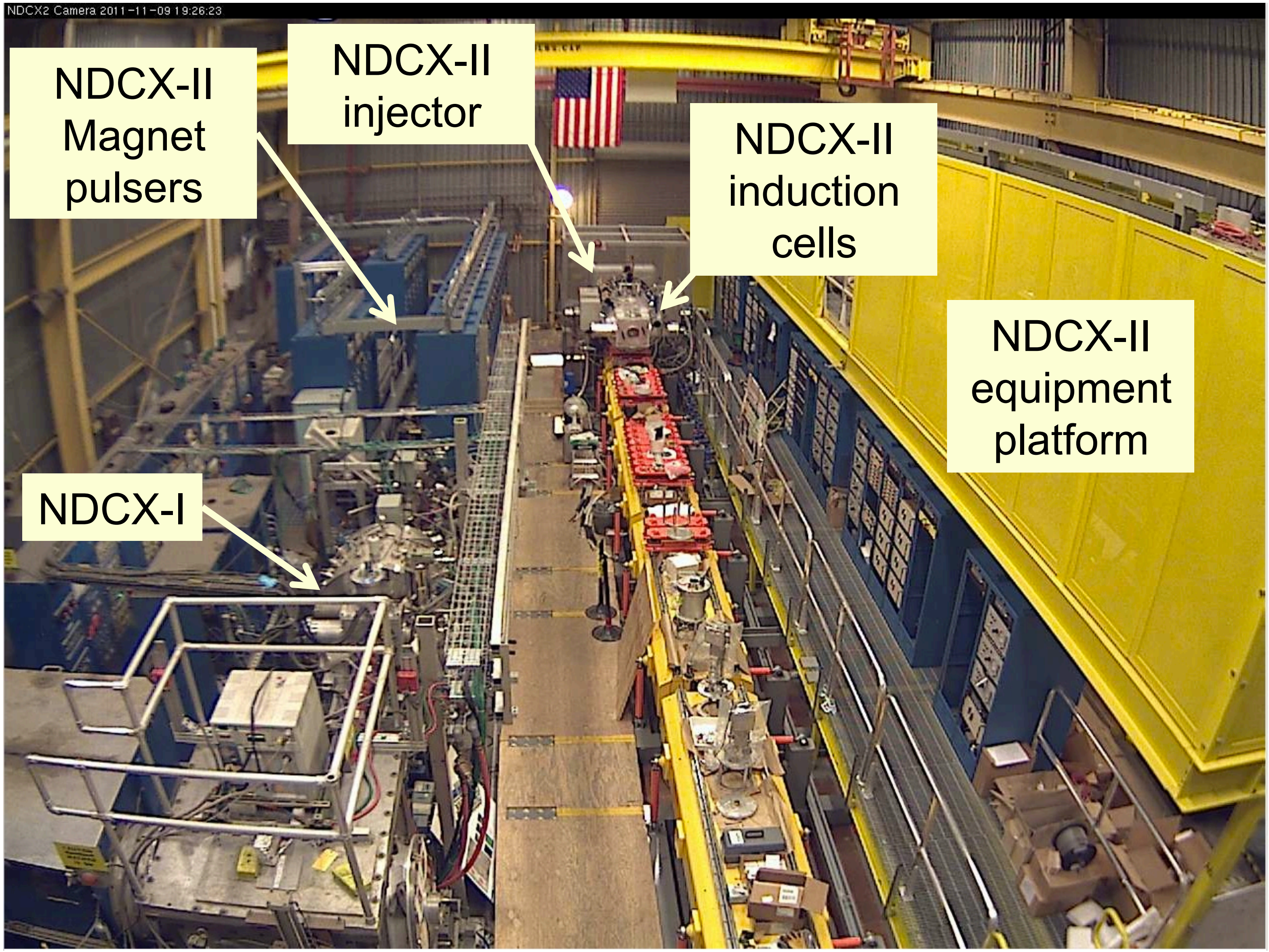
ndcx49c2_016_1280res_zoom.mov

.WMV

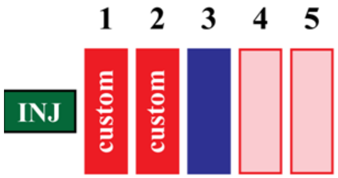


ndcx49c2_016_1280res_zoom.wmv

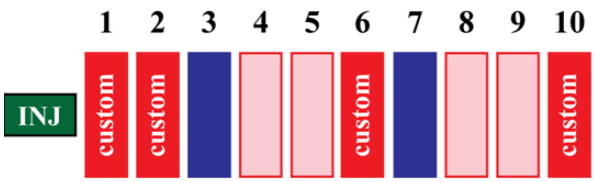
# LBNL B58 on 11/9/11, showing injector and initial induction cells



# Construction of NDCX-II began July, 2009, with $11M of ARRA funds and many ATA parts

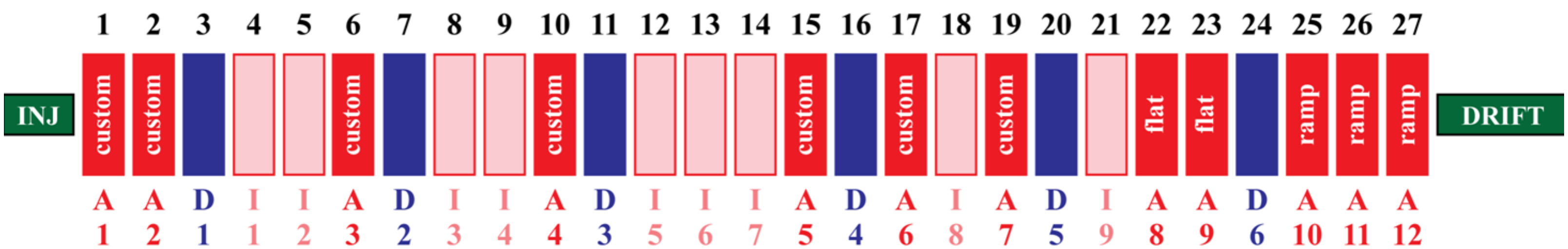



Acceptance-test configuration (Nov. 2011)




Configuration at end of ARRA funding (Dec. 2011)

We plan to spend an additional ~$500 k to achieve a 27-lattice-period, 12-active cell, 1.2 MeV configuration by the end of March, 2012:

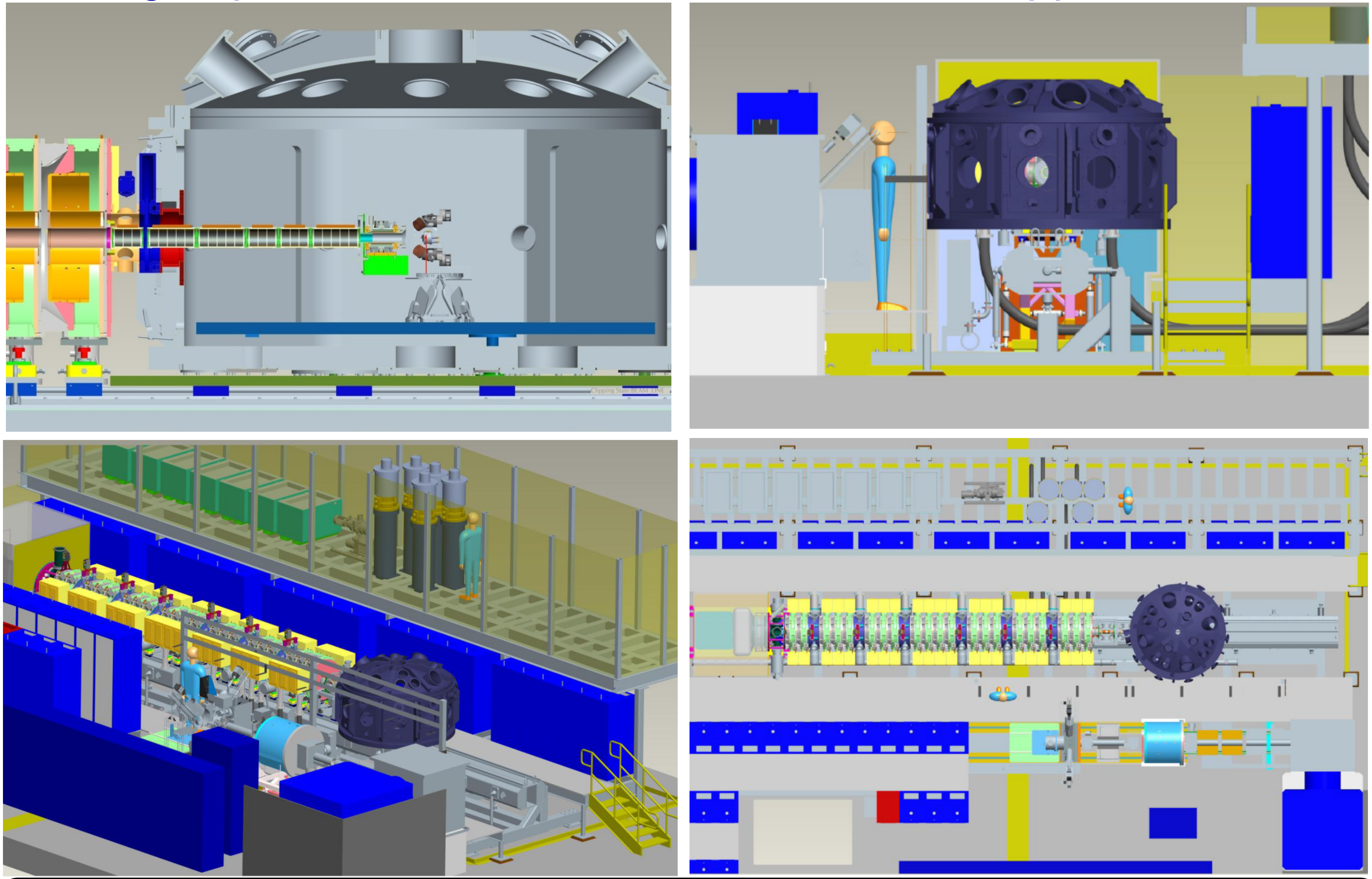



# We expect a steady increase in beam parameters as the machine and our experience mature

September 2011 HEDLP call for proposals required the HIFS-VNL to provide a timeline of estimated performance for early users of the facility:

| Li+, 12 active cells, 1.2 MeV final ion energy<br>600 ns initial pulse duration | | | | |
|---|---|---|---|---|
| Date | $I_{source}$ | $\tau_{target}$ | $r_{target}$ | $F_{target}$ |
| | Source current (mA) | Pulse duration at target (ns) biparabolic equivalent full width | Beam radius at target (mm) containing 50% of the beam current | Fluence ($J/cm^2$) avg'd. over $r_{target}$ and within $\tau_{target}$ |
| March, 2012 | 30 | 4 | 3 | 0.1 |
| June, 2012 | 60 | 3.5 | 2 | 0.3 |
| Sept, 2012 | 90 | 2.5 | 1.5 | 0.9 |
| Dec, 2012 | 90 | 1.5 | 1 | 2.1 |
| Sept, 2013 | 90 | 0.85 | 0.55 | 6.8 |

# Target chamber will resemble those of Titan/Trident/LCLS MECI; funding to procure the chamber shell has been approved



# NDCX-II can be extended to 3.1 MeV straightforwardly

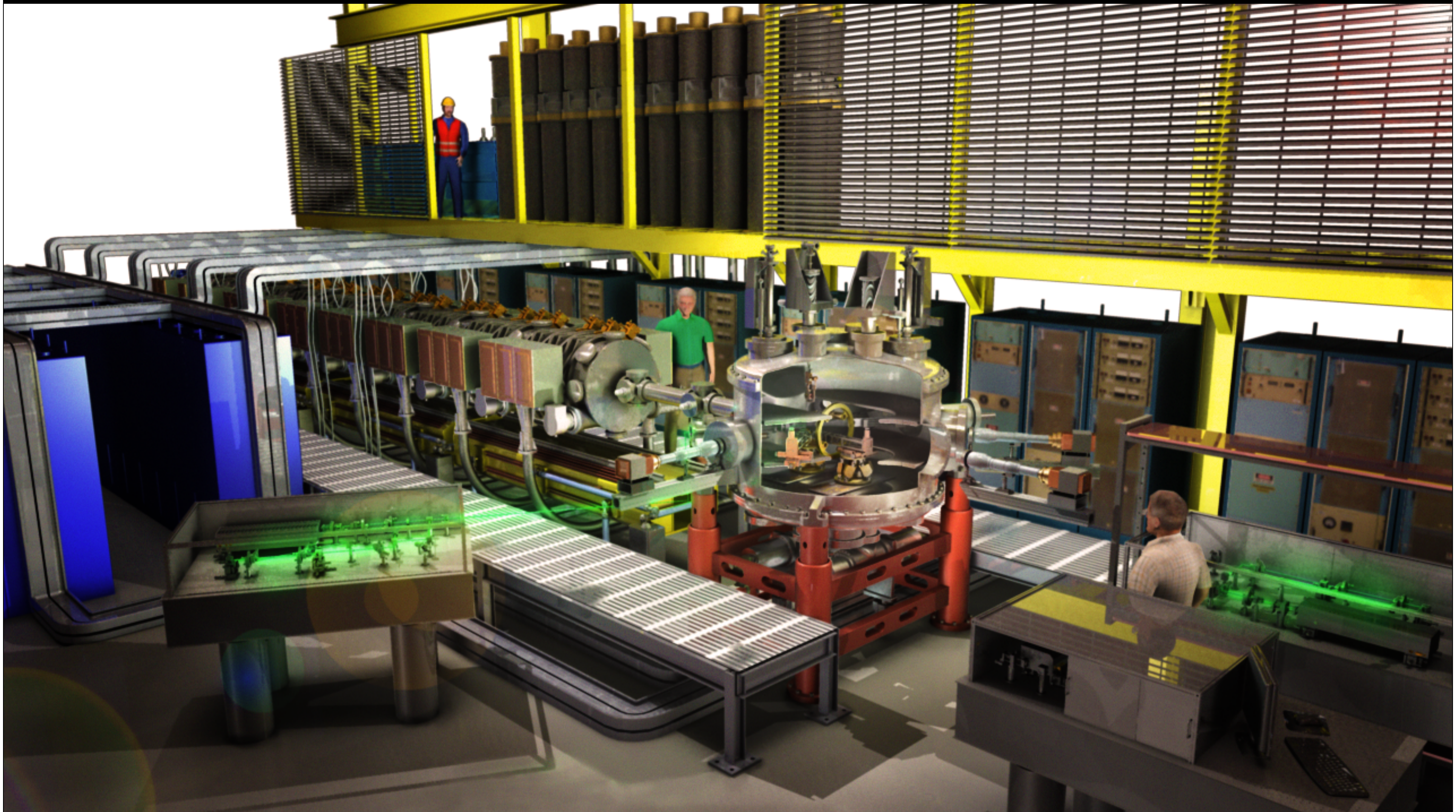
- 27 periods (12 active cells) baseline offers 1.2 MeV
- 37 periods can yield 3.1 Mev (!)
- We need only append 10 lattice periods
  - 9 active Blumlein-powered cells:
    6 more 250 kV "flat-top" (total of 8)
    3 more final 0-200 kV "ramps" (total of 6)
  - 1 diagnostic / pumping cell
- Incremental cost of ~ $1.5 M

# NDCX-II performance for typical cases in 12-21 cell configurations

| | NDCX-I (bunched beam) | NDCX-II | |
|---|---|---|---|
| | | 12-cell | 21-cell |
| Ion species | $K^+$ (A=39) | $Li^+$ (A=7) | $Li^+$ (A=7) |
| Charge | 15 nC | 50 nC total<br>25 2xFWHM | 50 nC total<br>30 2xFWHM |
| Ion kinetic energy | **0.3 MeV** | **1.2 MeV** | **3.1 MeV** |
| Focal radius (50% of beam) | **2 mm** | **0.6 mm** | **0.7 mm** |
| Duration (bi-parabolic measure = $\sqrt{2}$ FWHM) | **2.8 ns** | **0.9 ns** | **0.4 ns** |
| Peak current | **3 A** | **36 A** | **86 A** |
| Peak fluence (time integrated) | 0.03 J/cm$^2$ | 13 J/cm$^2$ | 22 J/cm$^2$ |
| Fluence w/in 0.1 mm diameter, w/in duration | | 8 J/cm$^2$ | 17 J/cm$^2$ |
| Max. central pressure in Al target | | 0.07 Mbar | 0.23 Mbar |
| Max. central pressure in Au target | | 0.18 Mbar | 0.64 Mbar |

NDCX-II estimates are from (r,z) Warp runs (no misalignments), and assume uniform 1 mA/cm$^2$ emission, high-fidelity acceleration pulses and solenoid excitation, perfect neutralization in the drift line, and an 8-T final-focus solenoid; they also employ no fine energy correction (e.g., tuning the final tilt waveforms)

# NDCX-II will be a unique user facility for warm dense matter, IFE target physics, and intense-beam physics.



Heavy Ion Fusion Science Virtual National Laboratory

# Related presentations

## This session, talks 2-7

G07.2: Prabir Roy, NDCX-II injector with a 10.9 cm diameter $Li^+$ ion source

G07.3: Joe Kwan, Completion of NDCX-II facility and initial tests

G07.4: Peter Seidl, Beam Phase Space of an intense ion beam in a neutralizing plasma

G07.5: Igor Kaganovich, Review of methods for neutralization of intense high-energy ion beam pulses by electrons

G07.6: Jean-Luc Vay, Novel Simulation Methods in the Particle-In-Cell Framework Warp

G07.7: A. Andronov, Secondary electron emission in the limit of low energy and its effect on high energy physics accelerators

## Today at 4:24 in Ballroom I:

JO8.13: Matt Terry, Directly driven, tamped heavy ion ICF targets

## Wednesday at 3:30 in Ballroom AC:

PI3.4 : Mikhail Dorf, Enhanced collective focusing of intense neutralized ion beam pulses in the presence of weak solenoidal magnetic fields

## Wednesday PM posters in Session PP9, nos. 78, 81, 82:

PP9.78: Albert Yuen, Rarefaction Waves in Van der Waals Fluids

PP9.81: John Barnard, Modeling of EOS and Ion Coupling Experiments on NDCX-II*

PP9.82: Wangyi (Bobby) Liu, Modeling droplet breakup effects with diffuse interface methods in ALE-AMR code with application in modeling NDCX-II experiments

## Friday posters in session YP9, nos. 17 - 25:

YP9.17: Bill Sharp, Alternate operating scenarios for NDCX-II

YP9.18: Dave Grote, Characterization of the NDCX-II accelerator via simulation

YP9.19: Gilles Maynard, Multiple scattering of slow Ions in a partially degenerate electron fluid

YP9.20: Sagar Vijay, Prompt gas desorption due to ion impact on accelerator structures

YP9.21: Nikolas Logan, Thermodynamic bounds on nonlinear electrostatic fluctuations in intense charged particle beams

YP9.22: Edward Startsev, Nonlinear effects of beam-plasma instabilities on neutralized propagation of intense ion beams in background plasma

YP9.23: Hua Wang, Direct and beat-wave excitation of collective beam modes in the Paul Trap Simulator Experiment

YP9.24: A. Stepanov, Beam-plasma interaction experiments on the Princeton Advanced Test Stand

YP9.25: E. Gilson, Collective mode excitation by asymmetric fields in alinear Paul trap to study beam stability

# Abstract

**The NDCX-II accelerator facility for Heavy Ion Fusion Science***

A. FRIEDMAN, J. J. BARNARD, R. H. COHEN, M. DORF, D. P. GROTE, S. M. LUND, W. M. SHARP, *LLNL*; D. ARBELAEZ, A. FALTENS, J. GALVIN, W. GREENWAY, E. HENESTROZA, J.-Y. JUNG, J. W. KWAN, E. P. LEE, B. G. LOGAN, L. L. REGINATO, P. K. ROY, P. A. SEIDL, J. TAKAKUWA, J.-L. VAY, W. L. WALDRON, *LBNL*; R. C. DAVIDSON, E. P. GILSON, I. D. KAGANOVICH, *PPPL*---

The Neutralized Drift Compression Experiment-II (NDCX-II) will generate ion beams for studies of Warm Dense Matter, target physics for heavy-ion-driven Inertial Fusion Energy, and intense-beam dynamics. NDCX-II will accelerate a 20-50 nC Li pulse to 1.2-3 MeV, compress it to sub-ns duration in a neutralizing plasma, and focus it onto a target. Construction of the induction accelerator and compression line at LBNL is approaching completion. We briefly describe the NDCX-II "physics design" [A. Friedman, *et al.*, *Phys. Plasmas* **17**, 056704 (2010)], the simulation studies that enabled it, variations (e.g., for other ions), plans for commissioning over the next year, and some possible experiments using the machine itself and extensions.

*Work performed under auspices of U.S. DoE by LLNL, LBNL, & PPPL under Contracts DE-AC52-07NA27344, DE-AC02-05CH1123, & DEFG0295ER40919.