Pulling it all together: a preferred path forward

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Heavy Ion Fusion Science Virtual National laboratory
8th Program Advisory Committee Review
Lawrence Berkeley National Laboratory
February 22, 2007

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Berkeley and Lawrence Livermore National Laboratories under Contract Numbers DE-AC02-05CH1123 and W-7405-Eng-48, and by the Princeton Plasma Physics Laboratory under Contract Number DE-AC02-76CH03073.

Opportunities and resource limits define the path forward

→*NDCX-I (WDM Option 1) has to remain the current workhorse to maintain VNL science productivity for the next several years (as per our 08-09 FWPs)*

-- The NDCX-I modular sections on rails have proven flexibility for continued quick modifications and improvements

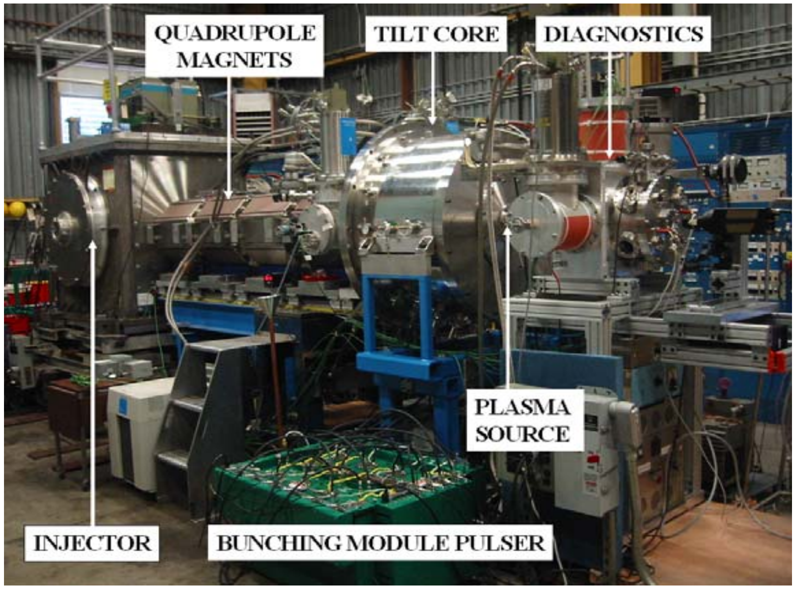
-- Transfer of equipment from NDCX-I to HCX would force a significant down time without VNL experiments, delaying some FY08/09 milestones.

-- We need more time to study option 2. It costs us nothing (no space taxes) to keep HCX available for either further e-cloud experiments (if new funding comes), or later conversion to a higher beam power WDM driver (option 2).

→With 30 cells (6 MV worth) of ATA modules donated by LLNL, we now have a very low cost path forward for NDCX-II [< $1.5 M added hardware cost needed. See preliminary design for short pulses and short double pulses that enables both WDM and later-on direct drive hydro experiments (Henestroza, Westenskow, Leitner, Waldron)]

→A short pulse NDCX-II provides a pathway to both an IBX-HEDX user facility and to an IRE-scale direct drive facility in the new 20 year plan

Preferred path (near-term): option 1: *maintain NDCX-I productivity* (for now). Continue to study possible switching later to HCX (option 2).

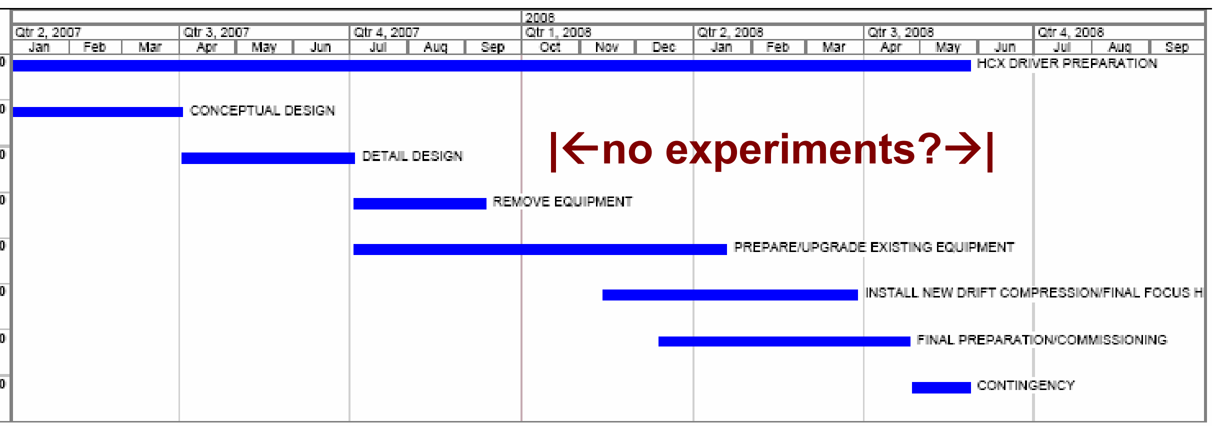


←We have recently achieved 2 ns pulses! A new improved tilt core and final focus magnet are being constructed this year.

Lets keep this goose laying golden eggs!

Transfer of equipment from NDCX-I to HCX would delay FY08 and FY09 FWP milestones at the guidance (President's FY07) funding level

ID	Task Name	Cost
1	HCX DRIVER PREPARATION	$138,000
2	CONCEPTUAL DESIGN	$0
5	DETAIL DESIGN	$0
7	REMOVE EQUIPMENT	$7,500
23	PREPARE/UPGRADE EXISTING EQUIPMENT	$36,500
39	INSTALL NEW DRIFT COMPRESSION/FINAL FOCUS HARDWARE	$63,000
53	FINAL PREPARATION/COMMISSIONING	$11,000
58	CONTINGENCY	$20,000



Proposed FY08-09 Milestones (FY09=FY08=President's 07 budget)

Fiscal Year 2008

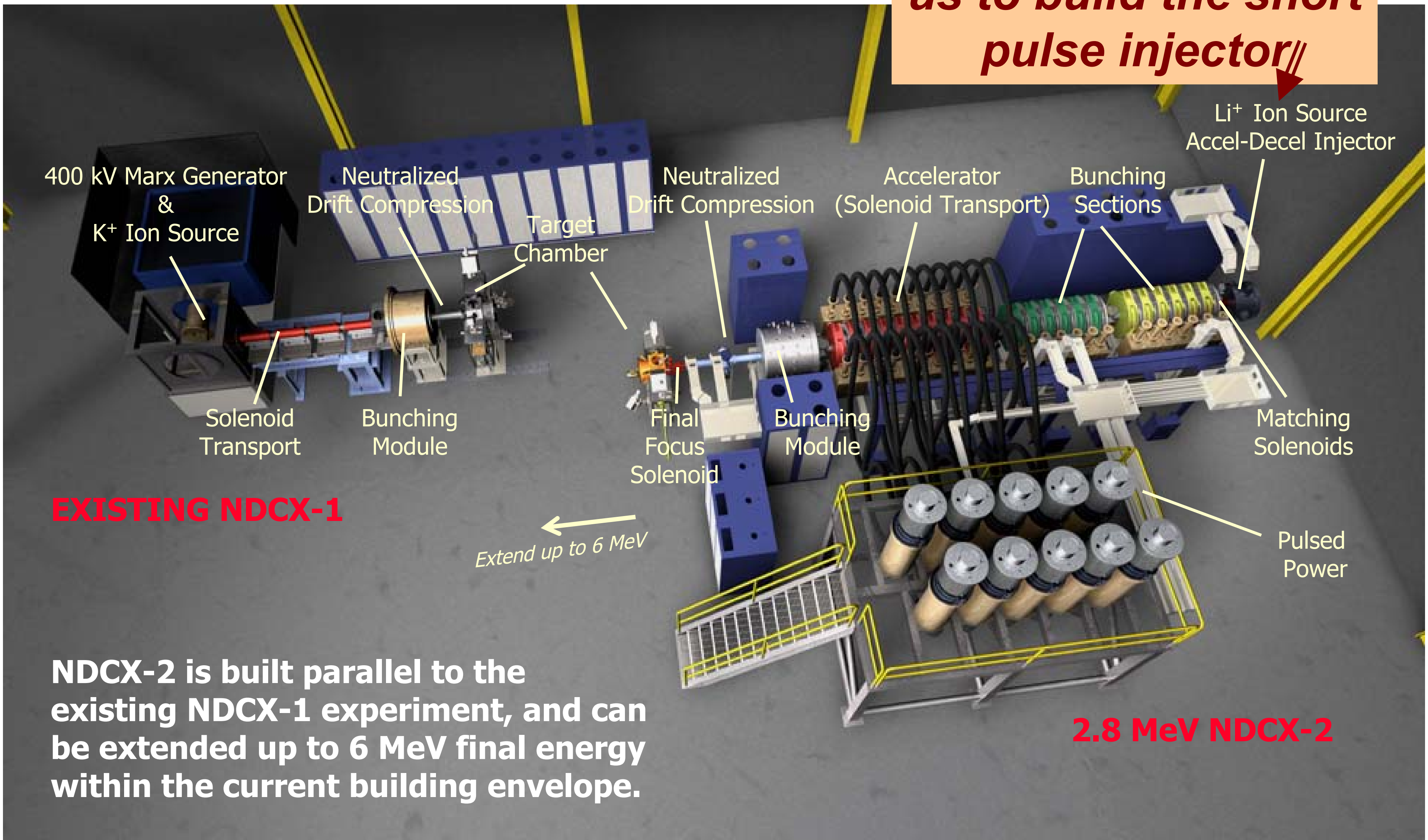
- **Q1: Report initial work on developing plasma modeling capability in WARP for NDCX experiments.**
- **Q2: Improve NDCX-I aperture size/e-traps, and bunching module gap geometry to optimize planned initial NDCX-I target experiments.**
- **Q3: Complete fabrication of target experiment chamber and implement initial target diagnostics to be used for first target experiments in NDCX-I.**
- **Q4: Carry out initial target experiment in the new target chamber, using beams compressed and focused by an improved bunching waveform and a final focus solenoid.**

Fiscal Year 2009

- **Q1: Compare theory/simulation and initial measurements of focal spot reductions using upstream time-dependent corrections of chromatic aberrations.**
- **Q2: Simulate beam neutralization near target focus using reconfigured plasma sources.**
- **Q3: Upgrade plasma source configuration and carry out initial experiments. Characterize improvements in focal spot beam intensity.**
- **Q4: Measure and simulate target temperature and hydrodynamic expansion response in best possible NDCX-I configurations with initial diagnostics suite.**

Medium-term path forward: as funding permits, begin assembly of NDCX-II (see Leitner talk) *while continuing to operate NDCX-I*

First ~200 K allows us to build the short pulse injector



NDCX-2 is built parallel to the existing NDCX-1 experiment, and can be extended up to 6 MeV final energy within the current building envelope.

Backup slides

Justification of Mission Need CD-0 for the Integrated Beam High Energy Density Physics Experiment (IB-HEDPX)

The overall IB-HEDPX program addresses a critical issue for high energy density physics in the near term, and inertial fusion energy in the long term, namely, the integration of the generation, injection, acceleration, transport, compression, and focusing of an ion beam of sufficient intensity for creating high energy density matter and fusion ignition conditions. The heavy ion beams required are very intense yet virtually collisionless, so that the beam distribution retains a long memory of effects from each region the beam passes through. Thus, the beam distribution that heats the target depends on the evolution of the beam distribution in all of the upstream regions. An integrated beam experiment IB-HEDPX is therefore essential for testing integrated beam models, and for accurate prediction of the beam energy deposition in target physics experiments. A secondary, but equally important, objective of the program is to create a critically needed user facility for experimental research in warm dense matter. Such a facility is lacking at present.

NDCX-II, requiring approximately $5 M hardware as an upgrade of the present NDCX-1 facility in Year 1 and 2, is necessary R&D to assess the performance requirements of injection, acceleration and focusing of short pulses needed for the IB-HEDPX .

APPROVAL

This Justification of Mission Need for the IB-HEDPX Project is satisfactory and Critical Decision 0 (CD-0) is approved and the Project is authorized to proceed with Conceptual Design activities.

Submitted by:

Francis Thio 12/1/2005

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Program Manager
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Approved by:

12/1/05

N. Anne Davies — Date
Associate Director for Fusion Energy Sciences
Office of Science

Reminder: NDCX-II is a prerequisite for IB-HEDPX

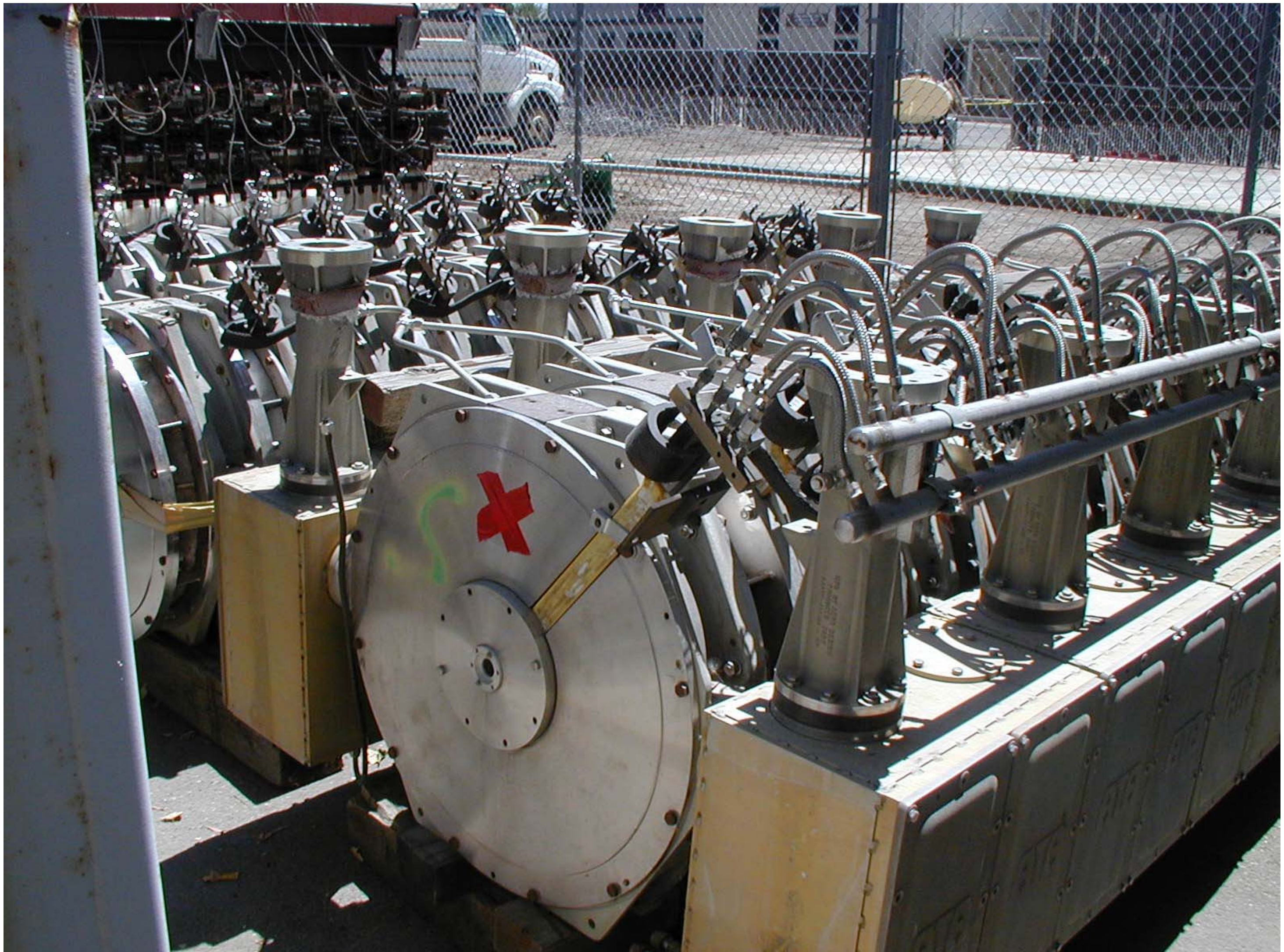
At the 6th VNL-PAC (PPPL) we identified a 2-3 MeV induction option for NDCX-II

NDCX-II $4 to 6 M hardware	Ion	Tf MeV	Q (μC)	Shot rate	Linac Output (before NDC)	NDC	τ	E_{beam} P_{beam}	L_{focus} r_{spot}	Te max (eV)
Induction	Li+	2 (Bragg peak)	0.3	0.1 Hz	K~10^{-3} 1.5A 200 ns	100 X	2 ns	0.6 J 300 MW	0.12 m, 0.5 mm	1-1.5
PLIA	Na+	24 (Bragg peak)	0.1	0.1 Hz	K~2×10^{-5} 1 A 100 ns	100 X	1 ns	2.4 J 2.4 GW	0.7 m 1 mm	2-3

IBX-NDC* ($TPC, inc. NDCXII MIE)	Ion	Tf MeV	Q (μC)	Shot rate	Linac Output (before NDC)	NDC	τ	E_{beam} P_{beam}	L_{focus} r_{spot}	Te max (eV)
Induction $ 50 M	Li+	3 (1.5x Bragg peak)	0.6	1 Hz	K~10^{-3} 3.6 A 170 ns	100 X	1.7 ns	1.8 J 1 GW	0.12 m, 0.5 mm	3-5
PLIA $ 40 M	Na+	24 (Bragg peak)	0.3	1 Hz	K~8×10^{-5} 3 A 100 ns	100 X	1 ns	7.2 J 22 GW	0.7 m 1 mm	6-10

*Includes $ 5 m for target diagnostics and three experimental chambers for users.

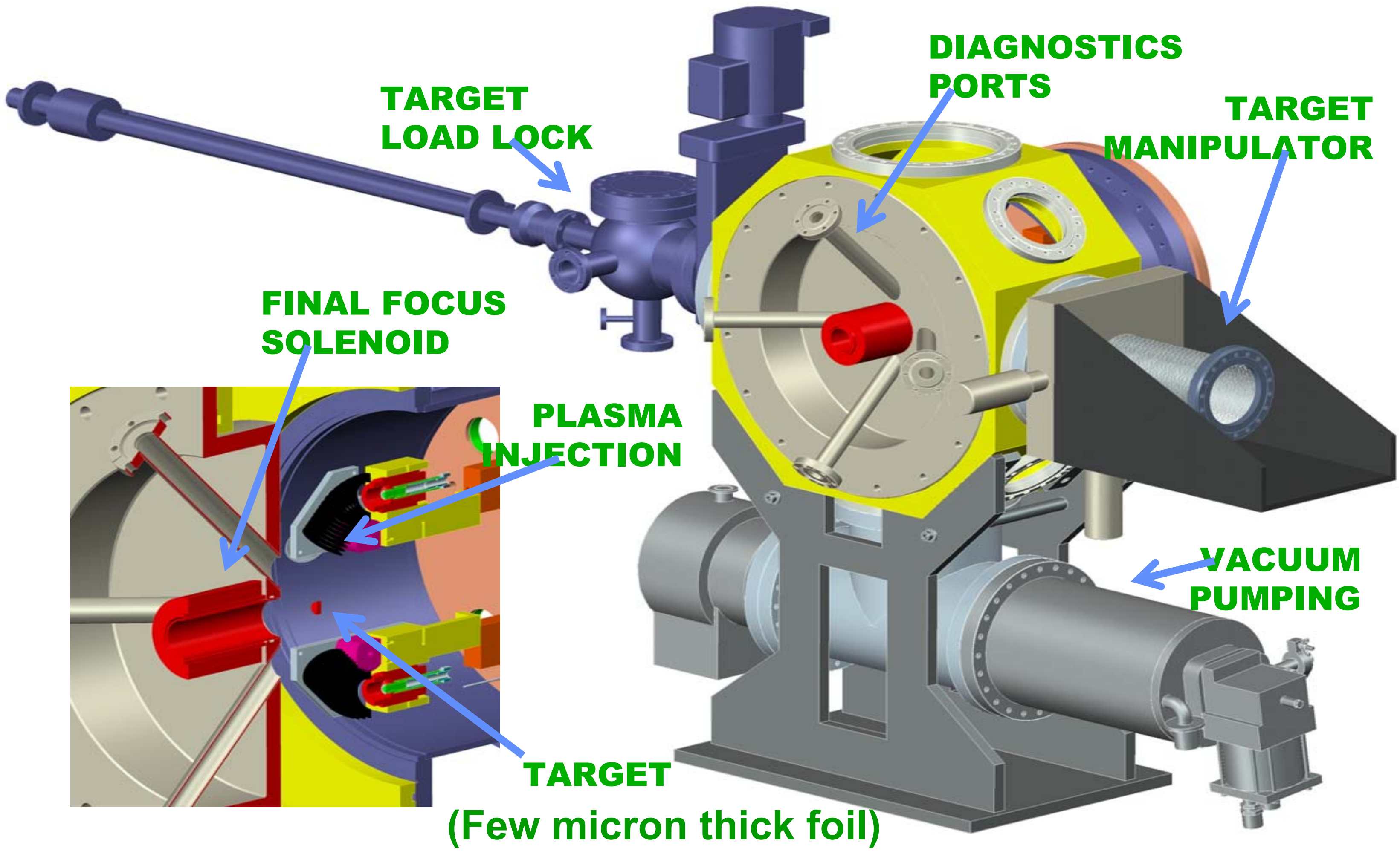
ATA Cells



Plan to utilize the ATA hardware

- Get one cell to LBNL and replace the low field DC solenoid with a 1-2T pulsed solenoid and thin the beam tube
- Get one Blumlein with cables and switch chassis to LBNL and inspect the spark gap, Blumlein ID, and insulators
- Set up one complete system at LBNL with a modified cell and pulsed power system and start running
- Only modifications to ATA pulsed power system
  - Simplified charging system (1kHz burst not required) with DC charging of the switch chassis
  - Trigger system to provide each Blumlein with a separate trigger to accommodate the ion beam transit time through the cells

We plan to build a target chamber and diagnostics, and to be doing target experiments within 2 years.



Prototype target chamber is under design

We are starting on a sequence of WDM experiments, beginning at low beam intensities and target temperatures

	Target temp.	NDCX-1 or HCX	NDCX-2
Transient darkening emission and absorption experiment to investigate previous observations in the WDM regime	**Low (0-0.4 eV)**	√	
Thin target dE/dx, energy distribution, charge state, and scattering in a heated target	**Low**	√	
Measure target temperature using a beam compressed both radially and longitudinally.	**Low**	√	
Positive - negative halogen ion plasma experiment	**>0.4 eV**	√	
Two-phase liquid-vapor metal experiments	**0.5-1.0**	√	√
Critical point measurements	**>1.0**	**?**	√

time ↓

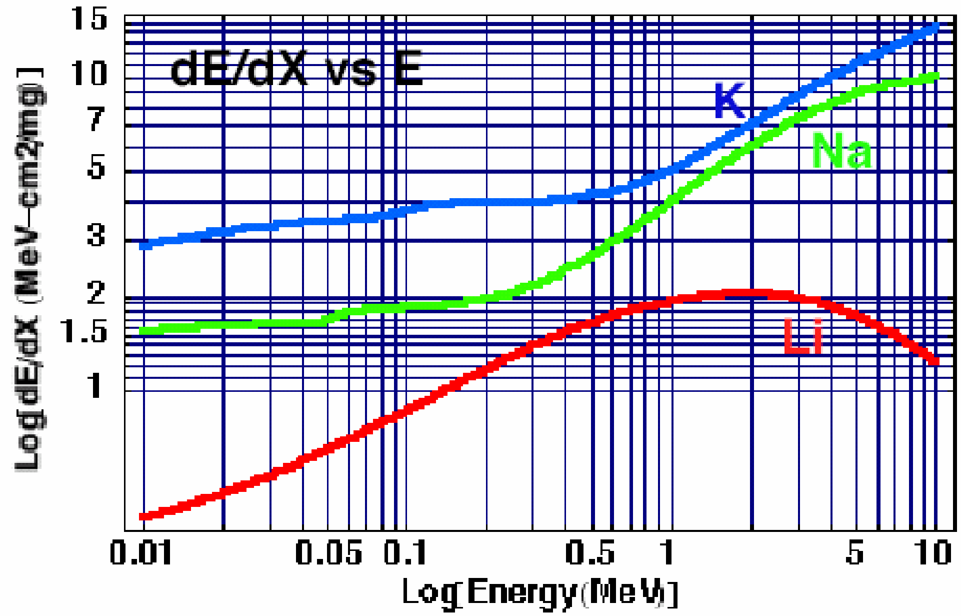
We are also discussing near-term collaborative experiments with GSI, Sandia, and others.

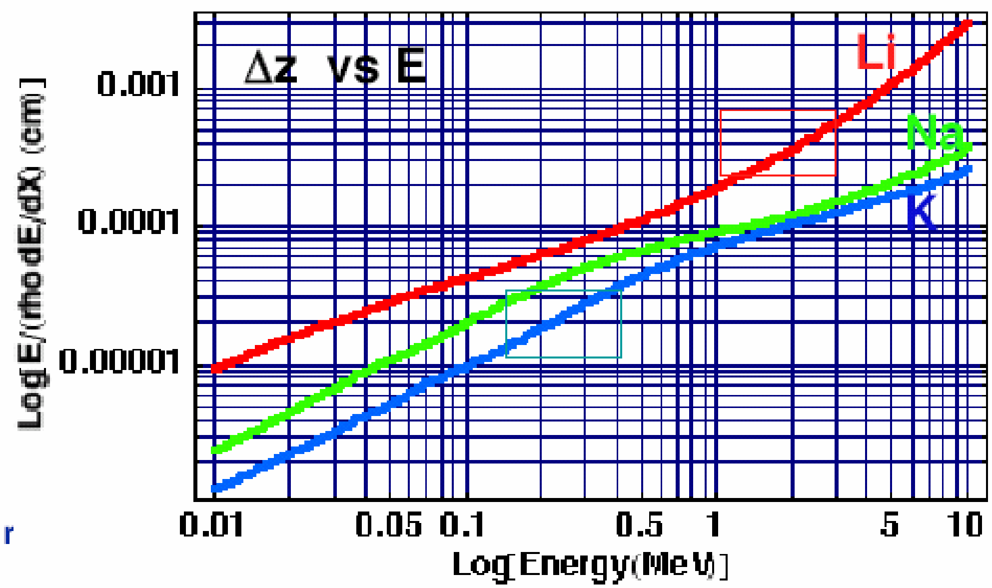
Why lithium? (J. Barnard, May 2006)

SRIM code results (provided by Igor Kaganovich) gives dE/dX for three ions of interest (K, Na, and Li).

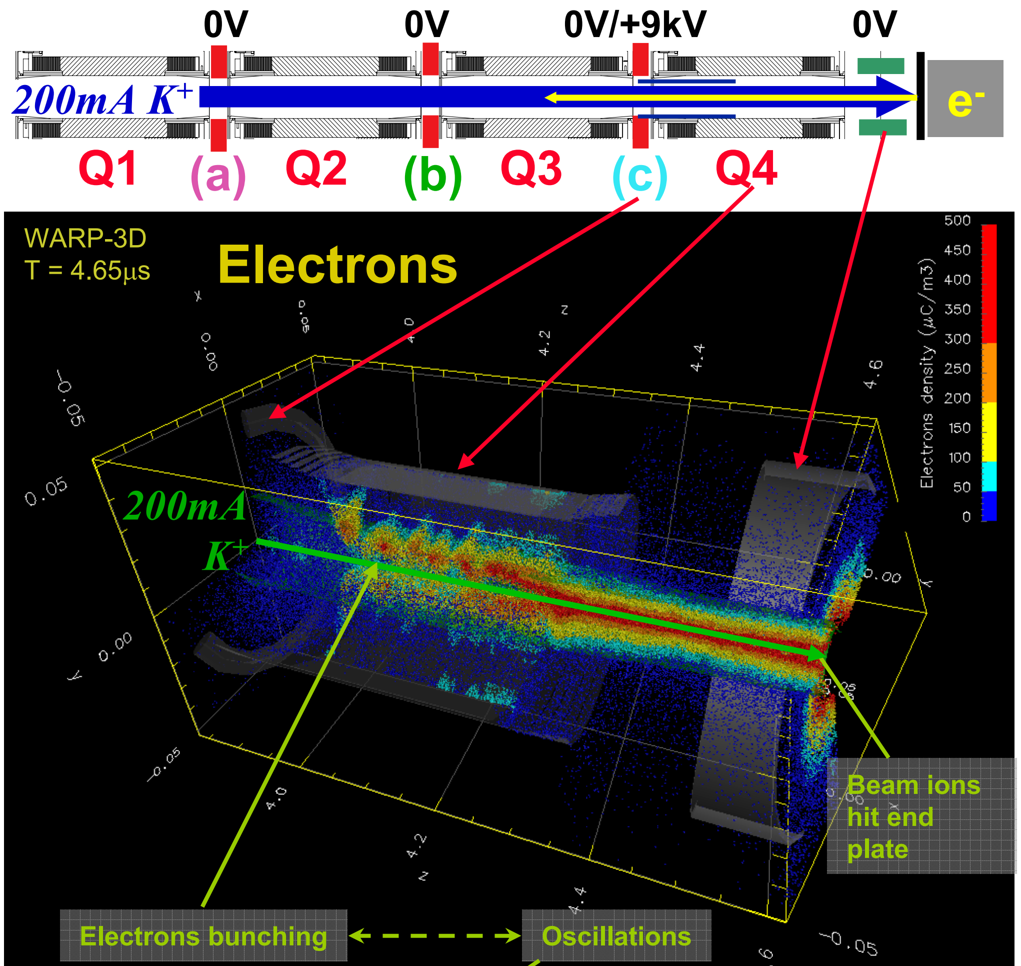
Li ions at ~ 1.8 MeV are at Bragg peak (although K ions at 200 - 400 keV are near inflection point)

Also range of Li ions at ~ 1.8 MeV is ~ 3 μ (a factor of 10 times longer than 400 keV K ions) so hydro time is factor of 10 longer

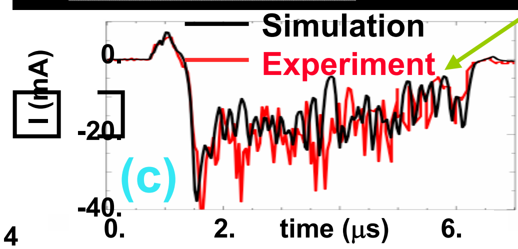




High Current Experiment (HCX) benchmarks models for unique modeling capability for electron/gas cloud effects



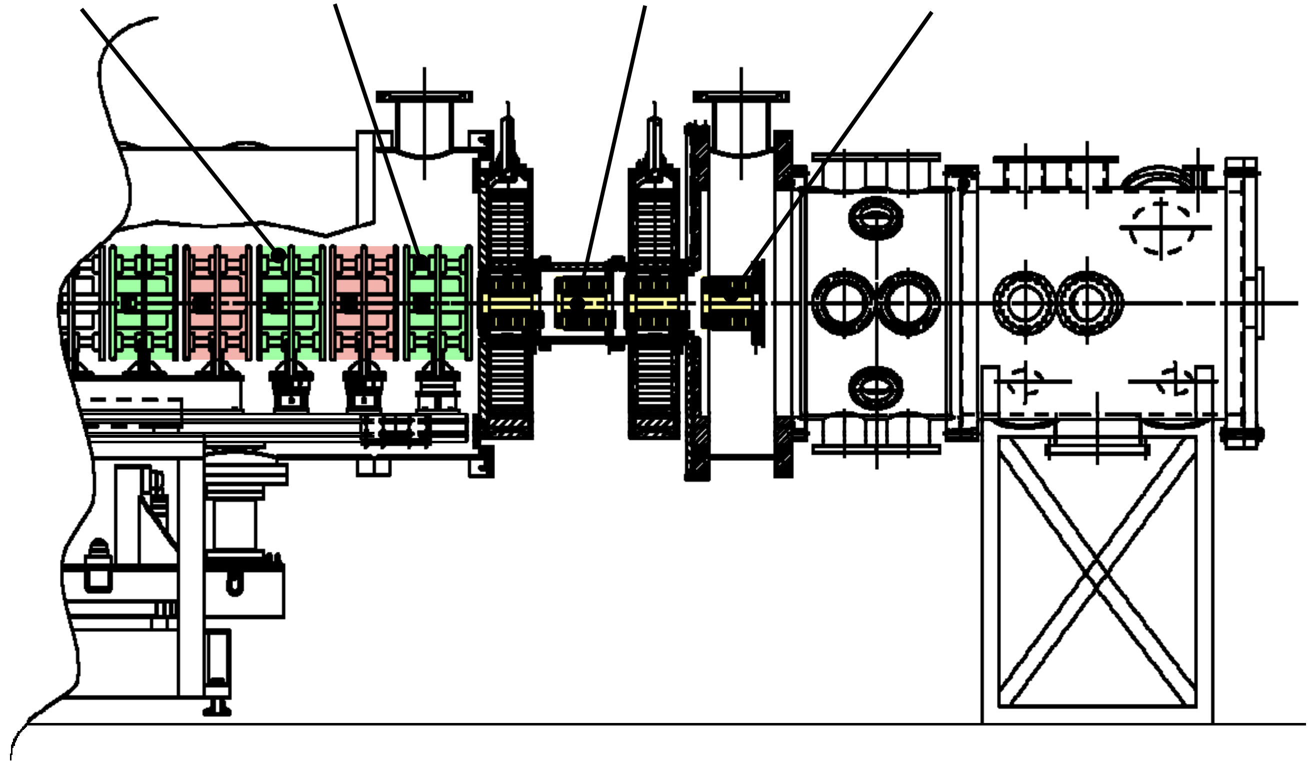
←Four HCX magnetic quadrupoles



6 MHz oscillations in (C) in simulation AND experiment

Electron and gas cloud modeling critical to all high current accelerators, including HEP: LHC, ILC …and future HEDP/fusion drivers: NDCX-II, IB-HEDPX . (See talks by Art Molvik, Ron Cohen, Jean Lu-Vay)

Upgraded HCX Transport Magnet Line



Benefits:

- Better alignment
- Better match to existing lattice
- Better engineering for improved experimental control
- Extendable to longer lattice
- Interfaces with different induction cells
- Improves diagnostics access
- UHV compatible
- Cold bore compatible

Simplified and optimized magnet transport line design can provide a scalable foundation for future quadrupole experiments and UHV gas/electron experiments.