Introduction to Ion Beam Driven High Energy Density Physic Workshop and relationship to the US heavy ion fusion science program*

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** HIFS-VNL: A collaboration between Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and Princeton Plasma Physics Laboratory, USA.

The Heavy Ion Fusion Science Virtual National Laboratory welcomes you to this workshop on ion-beam-driven HEDP experiments, target chamber, diagnostics and modeling.

- **NDCX-II (1.5-3 MeV Li^+ sub-ns beam pulse, 1-3 eV target temperature) is to be available for first target experiments after beam commissioning, ~ late 2012.**

- **A new target chamber with enhanced capability for diagnostics needs to be designed for installation on NDCX-II in FY13 *e.g.* high-power lasers, cryo-targets, x-ray diagnostics-we need input on your user needs!**

Not the view from this workshop site, ..but if you sign up for collaborations!

- **Experiments planned to be in collaboration with other institutions and groups, e.g. GSI, LCLS, NIF, Japan, China, and others.**

Heavy ion beams could uniquely create matter at extreme conditions

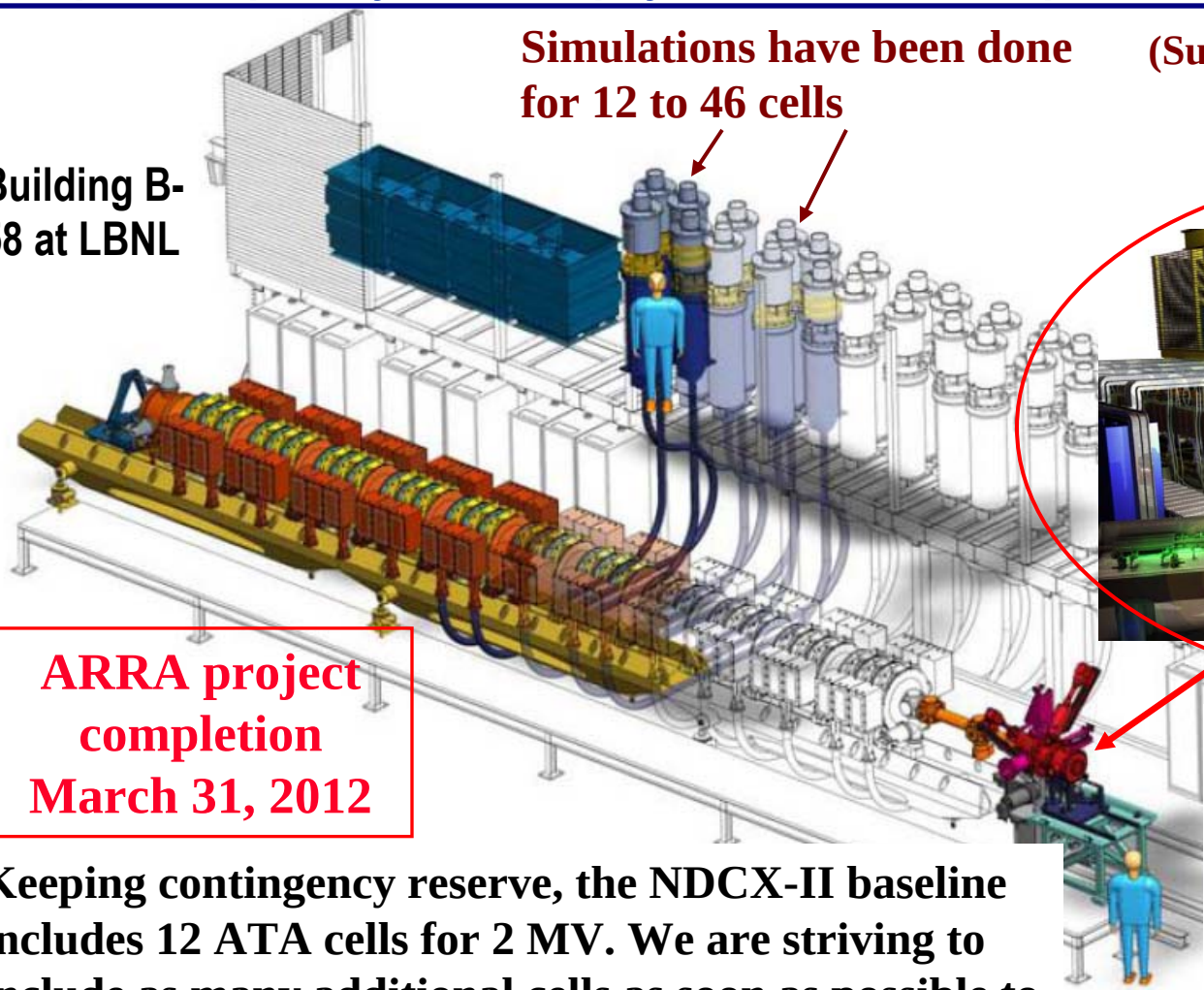
(Richard W. Lee, October 2004, LBNL)

- Emphasize the WDM part of HED regime
- Heavy ion beams have a decided advantage:
  - Relatively large sample sizes (mm^3)
  - More uniform conditions
  - Achieve high entropy at high density
  - Extreme conditions persist for long times
  - Repetition rates can be high

Dick pointed out these advantages might also be realized with x-ray drive (LCLS). We agree→ opportunity to collaborate in ion & x-ray experiments!

- In contrast, optical laser-based experiments in WDM regime have:
  - smaller volumes, larger gradients, shorter lifetimes, and lower repetition rates

July 2009: NDCX-II approved for $11M of stimulus funding as a major facility for both HEDLP and heavy ion fusion. Higher energy and sub-nanosecond pulses on targets will improve capability for WDM physics and enable experiments re: advanced HIF targets.



(Successful NDCX-II Lehman Review on January 13-14 improved project planning)

ARRA project completion March 31, 2012

A new, larger target chamber, diagnostics and student support is requested for FY11&12 OFES funding (not included in the ARRA project scope)-(See Bieniosek's talk)

Keeping contingency reserve, the NDCX-II baseline includes 12 ATA cells for 2 MV. We are striving to include as many additional cells as soon as possible to maximize capability ***(we possess 50 cells for 10 MV for quick future expansion to IB-HEDPX).***

The HIFS-VNL mission supports research areas identified in the January 2009 FESAC HEDLP and November Research Needs HEDLP Workshop:

1. **Explore Warm Dense Matter (WDM) physics with unique intense heavy ion beam techniques, extended to sub-nanosecond pulses in NDCX-II, and provide a user facility for the US HEDLP program and collaborators from GSI, ITEP, Japan, and China, who can significantly benefit from access to an operating heavy ion WDM target facility.**
2. **Provide the basis for extending and expanding the heavy-ion-driven HEDP program beyond WDM physics studies towards heavy ion inertial fusion target physics (e.g. sub-ns shocks) to be carried out in parallel with the NIF Ignition Campaign.**
3. **Provide the scientific basis for IB-HEDPX, an advanced and higher-energy heavy ion WDM/HIF user facility for the US HEDLP program in the 2015-2025 time frame.**

→HIFS-VNL interests intersect all four workshop sub-groups: 1. WDM Experiments, 2. IFE Experiments, 3. Collaborative Experiments, 4. Beam Dynamics Experiments.

The baseline ARRA project incorporates 12 active induction cells, to allow for contingency; we plan to apply any unused contingency toward an expansion of scope (Alex Friedman)

	NDCX-I (bunched beam)	NDCX-II construction project			NDCX-II 21-cell (enhanced)
		12-cell (baseline)	15-cell ("probable")	18-cell ("possible")	
Ion species	K^+ (A=39)	Li^+ (A=7)	Li^+ (A=7)	Li^+ (A=7)	Li^+ (A=7)
Total charge	15 nC	50 nC	50 nC	50 nC	50 nC
Ion kinetic energy	0.3 MeV	1.2 MeV	1.7 MeV	2.4 MeV	3.1 MeV

NDCX-II beam capability to drive targets depends on affordable # of cells

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Total charge	15 nC	50 nC	50 nC	50 nC	50 nC
Ion kinetic energy	0.3 MeV	1.2 MeV	1.7 MeV	2.4 MeV	3.1 MeV
Focal radius(50%beam)	2 mm	0.6 mm	0.6 mm	0.6 mm	0.7 mm
Duration (bi-parabolic measure = $\sqrt{2}$ FWHM)	2.8 ns	0.9 ns	0.4 ns	0.3 ns	0.4 ns
Peak current	3 A	36 A	73 A	93 A	86 A
Peak fluence (time integrated)	0.03 J/cm^2	13 J/cm^2	19 J/cm^2	14 J/cm^2	22 J/cm^2
Fluence w/in 0.1 mm diameter, w/in duration		8 J/cm^2	11 J/cm^2	10 J/cm^2	17 J/cm^2
Spec. deposition (in Al)		3 kJ/g	10 kJ/g	4 kJ/g	7 kJ/g
Max. pressure (planar-(higher w/ hollow beams)		0.07 Mbar	0.17 Mbar	0.17 Mbar	0.17 Mbar

NDCX-II commissioning starts April 1, 2012. HEDLP experiments start early FY2013.

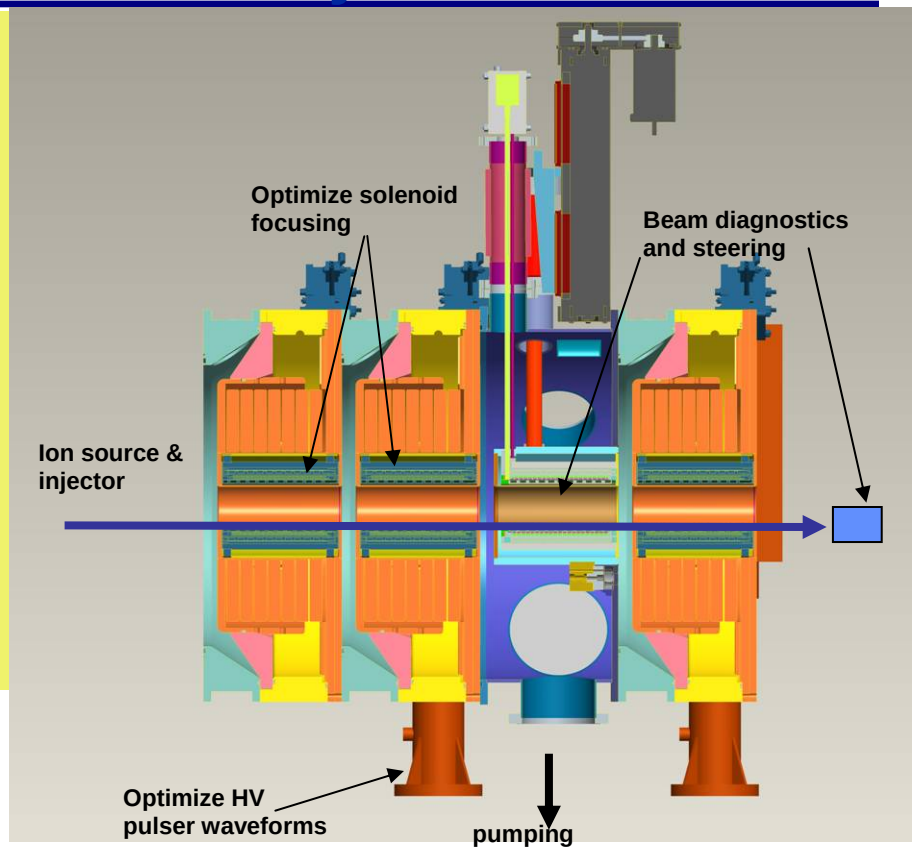
NDCX-II commissioning will start mid-FY12:

- Optimize solenoid focusing according to beam current.
- Optimize HV pulse waveforms for bunch compression.
- Beam halo control (secondary electrons) and steering corrections to improve quality of the beam bunch entering a target chamber.
- Optimize final focusing and beam neutralization to produce a beam spot on the target foil.
- Beam diagnostics to measure voltage, current, pulse length, position, and intensity profile.

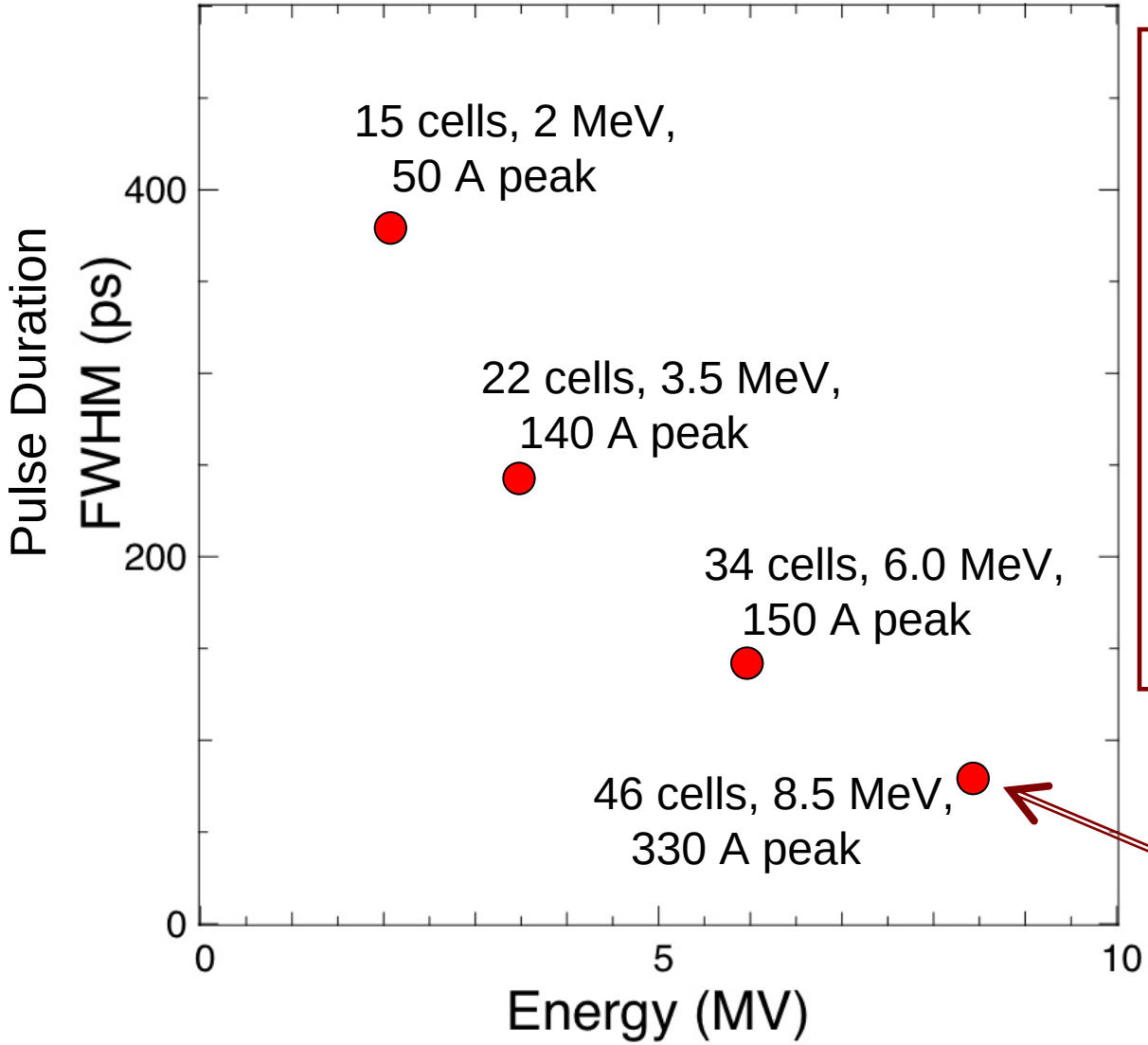
Milestone in Sep 2012 -- Characterization of initial NDCX-II beams to support NDCX-II research

HEDLP experiments will start in early FY13:

- Makes use of the initial NDCX-II beams that are already much more powerful than that in NDCX-I
- Further optimization to increase beam current and voltage to maximize beam power on target
- Further adjustment in final focusing and beam neutralization to minimize beam spot size
- Check out HEDLP target diagnostics



Future Plans: Extension of NDCX-II to the Integrated Beam-High Energy Density Physics Experiment (IB-HEDPX). Simulations show compressed pulse duration in NDCX-II varies approximately inversely with kinetic energy, assuming neutralized drift compression

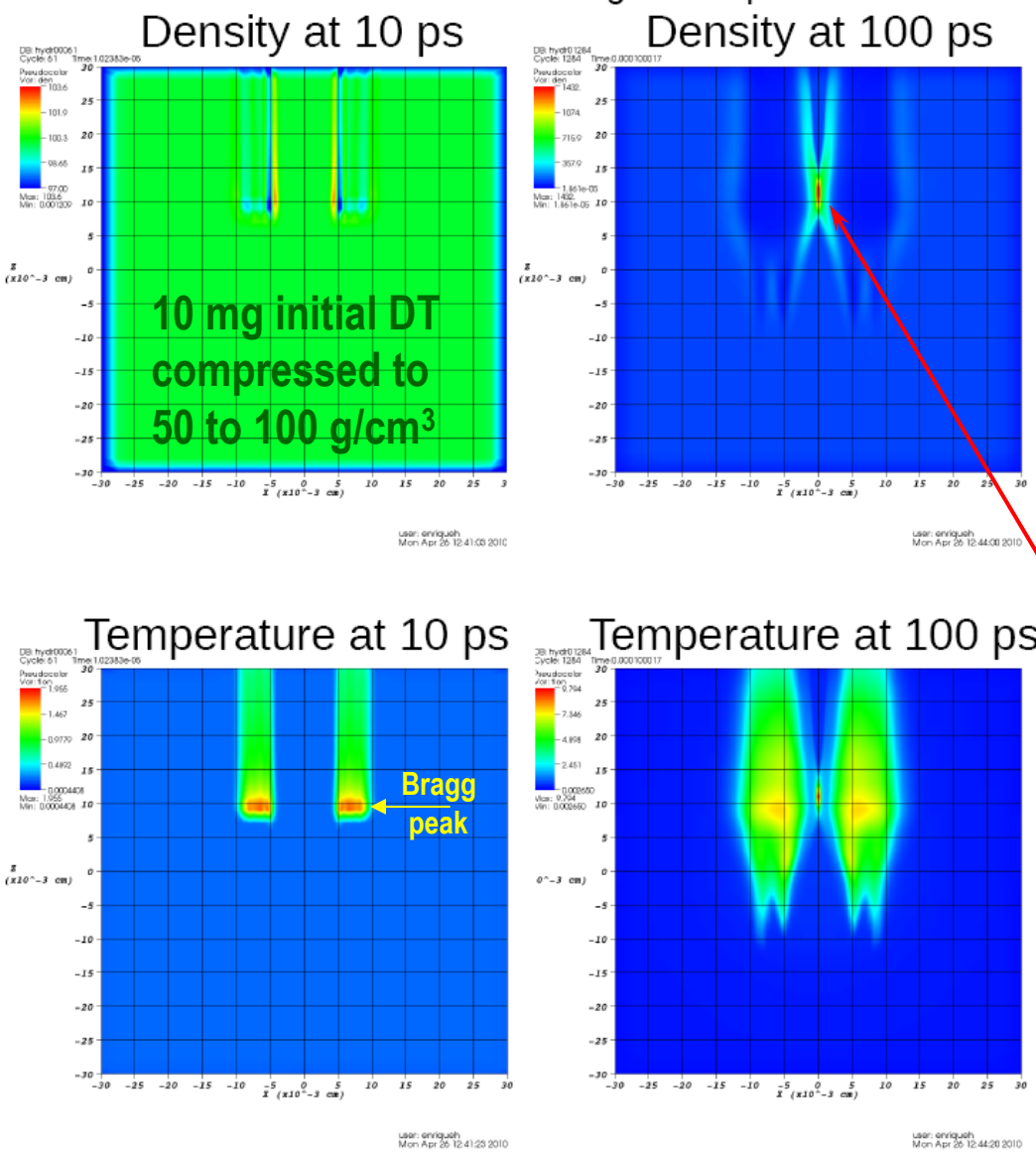


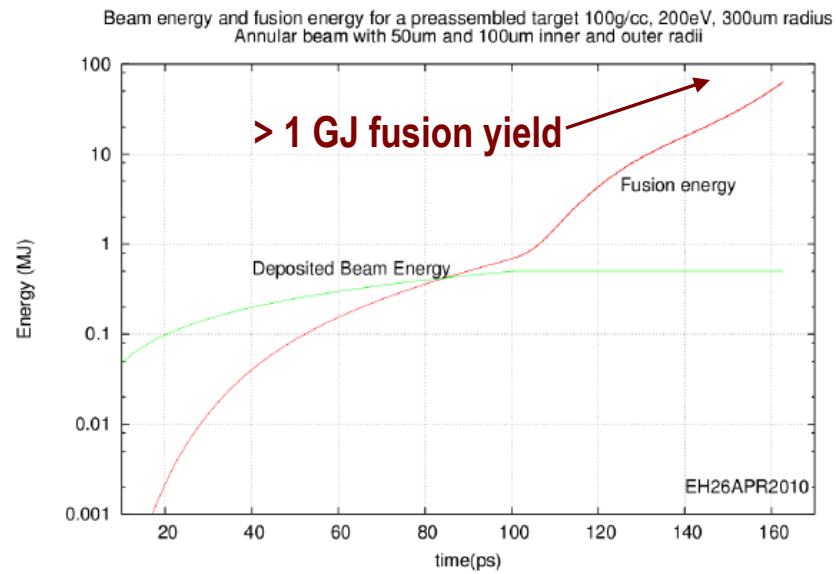
- We possess 50 ATA cells and have plans (CD0 for IB-HEDPX @ 8-10 MeV).
- The IB-HEDPX front end could also be modified to use sodium ions at higher current with more pre-bunch compression.
- Extension of IB-HEDPX could proceed during operation of NDCX-II.

IB-HEDPX

In 2005, Max Tabak and Mark Herrmann proposed heavy ion fast ignition using hollow beams: E.g., Henestroza, 4/26/10: 500 kJ, 60 GeV U, 100 ps.

The annular beam is moving from top to bottom





The density *inside* the hollow beam further compresses to >1700 g/cm³ under the Bragg peak beam deposition! The burn wave starts there, *inside* the hollow beam (*not* direct fast ignition!) Is this *shock ignition*? Can scaled experiments be done with GSI and/or NDCX-II beams made hollow with a central beam block?

What we hope from this workshop:

1. Proposed heavy-ion-beam-driven HEDP experiments that can benefit from NDCX-II (warm dense matter material properties, target physics relevant to inertial fusion energy, and intense ion beam and beam/plasma dynamics).

2. Input on NDCX-II diagnostics and experimental target chamber capabilities needed to support above proposed experiments.

3. We welcome proposals from university users (individual investigators and students to be funded by OFES solicitation programs).

4. We are seeking long term institutional collaborators in the above topics (e.g., from GSI-Germany, LCLS-Stanford, and IMP, China), in which related experiments can be jointly undertaken and cross-bench marked at several facilities.