Overview of Heavy Ion Research in the U.S *

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Presented on behalf of the
Heavy Ion Fusion - Virtual National Laboratory
LBNL, LLNL and PPPL

U.S. – Japan Workshop on Heavy Ion Fusion
and High Energy Density Physics
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The US HIF-VNL is committed to the beam science common to both High Energy Density Physics (HEDP) and fusion

→The program concentrates on ion beam experiments, theory and simulations to address a top-level scientific question central to both HEDP and fusion:

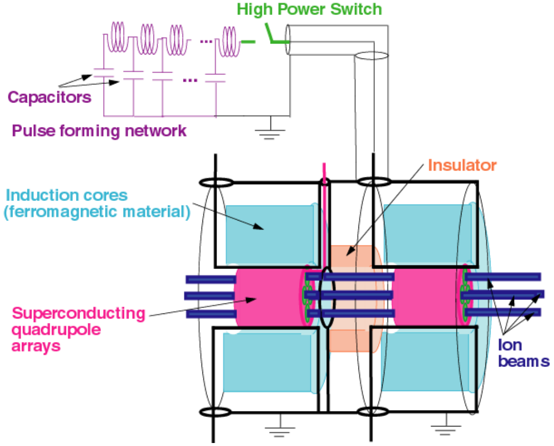
How can heavy ion beams be compressed to the high intensities required for creating high energy density matter and fusion?

Topics to be briefly discussed in this overview talk:

- New approach to accelerator driven HEDP and IFE
- Experimental advances (more to be given by Seidl)
- Theory and simulation advances (more to be given by Grote)
- A new Pulse-Line Ion Accelerator (more by Seidl and Grote)
- Warm dense matter studies (more to be given by Barnard)
- Accelerator ion-driven fast ignition prospects

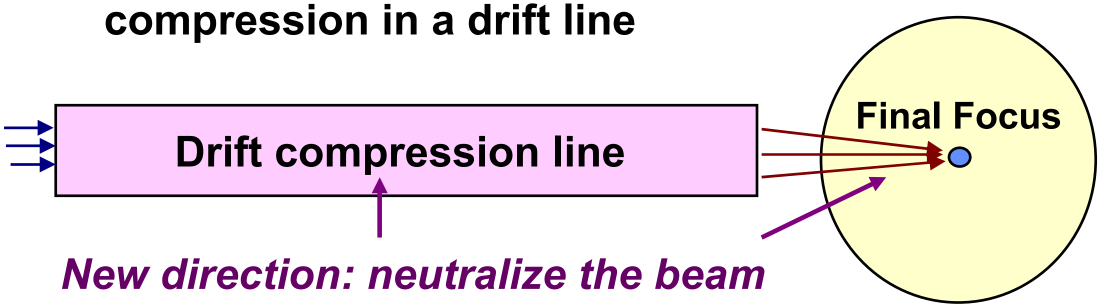
Creating warm dense matter and fusion ignition conditions requires *longitudinal* as well as *transverse* beam compression

Induction acceleration is most efficient at τ_{pulse} ~100 to 200 ns



Bunch tail has a few percent higher velocity than the head (tilt) to allow compression in a drift line

Near term High Energy Density targets require ~ 1 ns pulses; Fusion requires ~ 10 ns



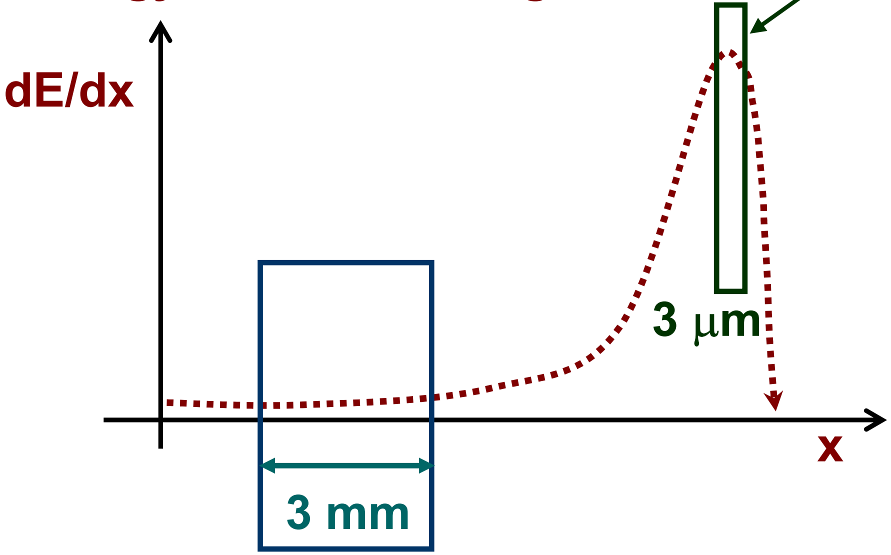
New direction: neutralize the beam space charge both in longitudinal drift compression as well as in final focus

Issues that need more study and experiments:

1. **Electron cloud effects (wherever the beam transports in vacuum)**
2. **Beam-plasma instabilities during compression.**
3. **Beam heating due to compression (conservation of longitudinal invariant)**
4. **Focal spot (chromatic effects) vs minimum pulse-width trade off with tilt**

Neutralized beam compression and focusing: unique approach to ion-driven HEDP needed for shorter ion pulses (< few ns versus a few μs)

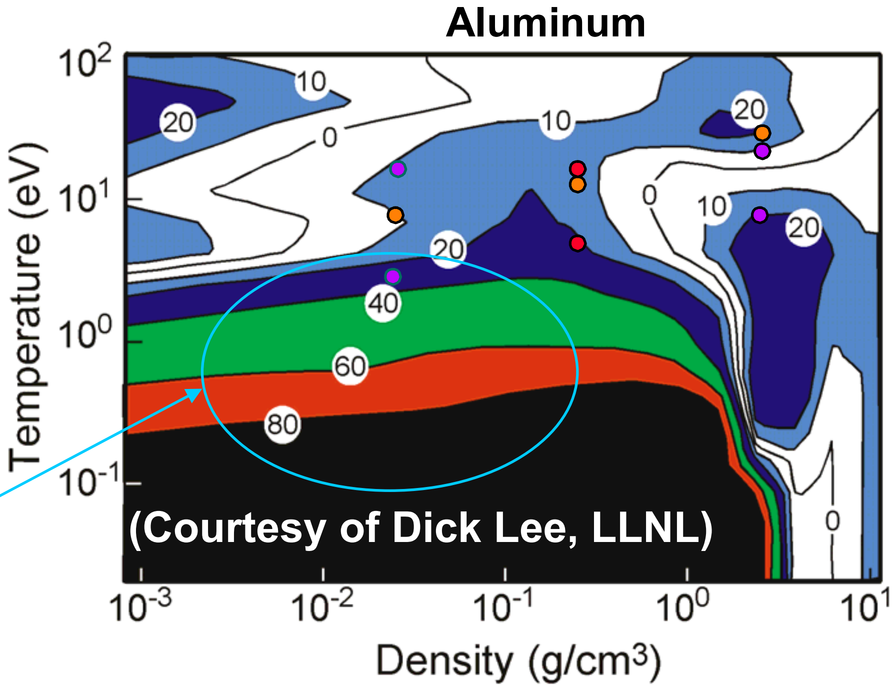
Ion energy loss rate in targets



Maximum dE/dx *and* uniform heating at Bragg peak require short (< few ns) pulses to minimize hydro motion. [L. R. Grisham, PoP, (2004)].
→Te > 10 eV @ 20J, 20 MeV
(Future US accelerator for HEDP)

GSI: 40 GeV heavy Ions→ thick targets→ Te ~ 1 eV per kJ

Dense, strongly coupled plasmas 10^{-2} to 10^{-1} *below* solid density are potentially productive areas to test EOS models (Numbers are % disagreement in EOS models where there is little or no data)



(Courtesy of Dick Lee, LLNL)

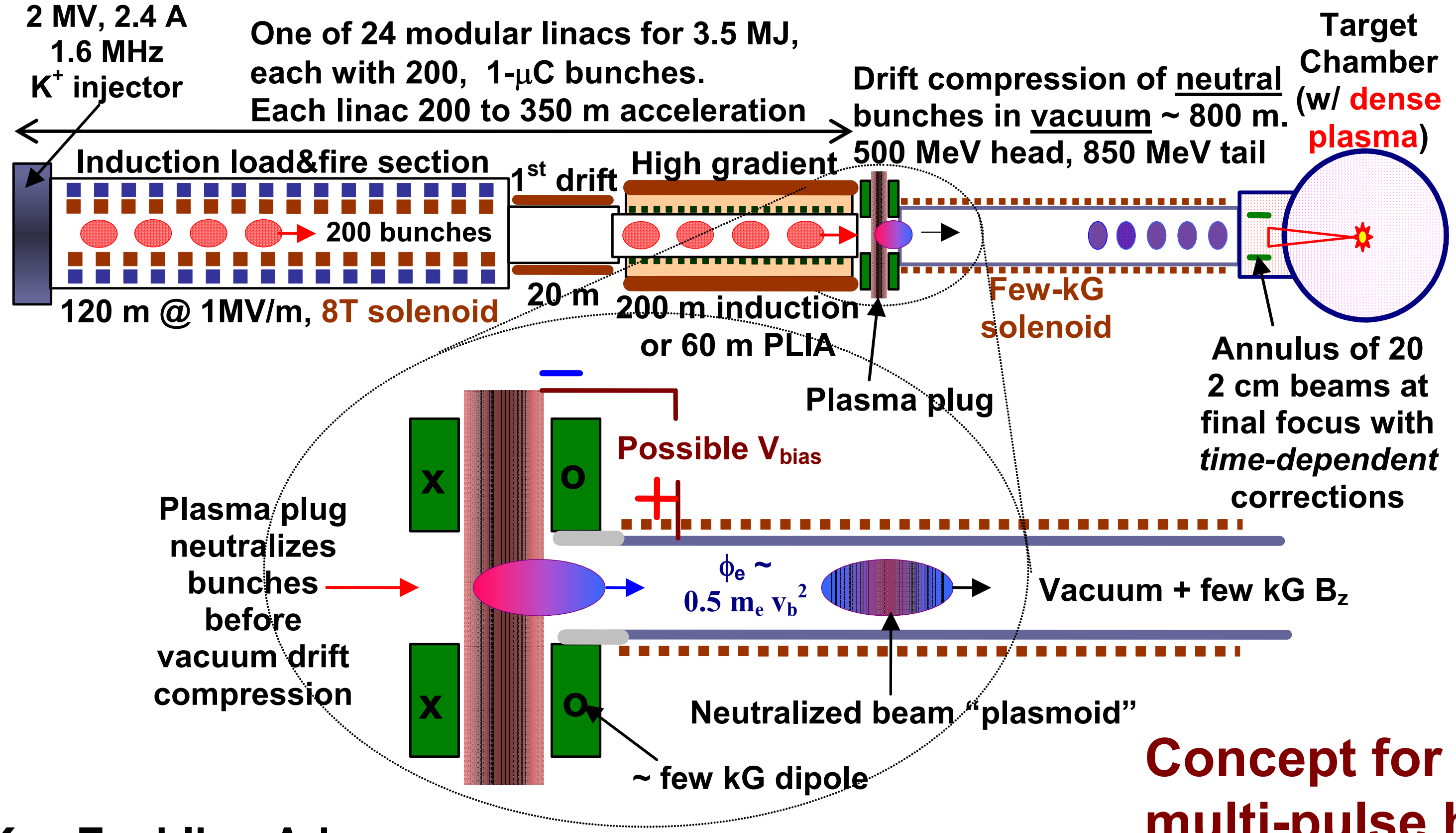
Plasma neutralization of beam space charge *upstream* of final focus is needed for HEDP targets driven by lighter ions at the peak of dE/dx.

Beam ion	1.5xEnergy (MeV) @ peak dE/dx (cold aluminum)	Range (microns) (10% solid Al)	Target Δz (microns) **for <5% T variation**	Beam energy (J)/mm^2 for 10 eV 10%ρ_o Al	τ_{hydro}= Δz/(2Cs) (@10eV) (ns)	Beam power GW per mm^2	Beam current (A) for 1 mm dia. spot	Beam perveance@ final focus
Li	2.4	30	22	3.3	0.6	6.1	1990	0.93
Na	24	60	54	8.0	1.3	6.1	200	5.4x10^{-3}
K	68	140	91	13.6	2.2	6.1	70	5.1x10^{-4}
Rb	237	250	150	22.4	3.7	6.1	20	3.3x10^{-5}
Cs	456	400	190	28.5	4.7	6.1	11	8.5x10^{-6}

These perveances are likely too high for vacuum compression, even with plasma neutralization in the target chamber
→must extend plasma neutralization upstream of final focus
→use plasma-filled solenoids, plasma lens, or assisted-pinches for final focus

Likely too expensive for US budgets

Neutralized drift compression and focusing is also key to enable a new modular driver development path to IFE



2 MV, 2.4 A
1.6 MHz
K^+ injector

One of 24 modular linacs for 3.5 MJ,
each with 200, 1-μC bunches.
Each linac 200 to 350 m acceleration

Drift compression of neutral bunches in vacuum ~ 800 m.
500 MeV head, 850 MeV tail

Target Chamber (w/ dense plasma)

Induction load&fire section

200 bunches

120 m @ 1MV/m, 8T solenoid

1st drift

20 m

High gradient

200 m induction
or 60 m PLIA

Plasma plug

Few-kG solenoid

Annulus of 20
2 cm beams at
final focus with
time-dependent
corrections

Plasma plug neutralizes bunches before vacuum drift compression

Possible V_{bias}

$\phi_e \sim 0.5\, m_e v_b^2$

Vacuum + few kG B_z

Neutralized beam "plasmoid"

~ few kG dipole

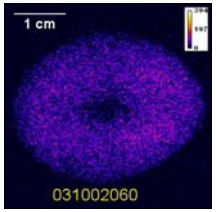
→Key Enabling Advances:

- Neutralized drift compression and focusing
- Time dependent correction for achromatic focusing
- Multi-pulse longitudinal merging and pulse shaping
- Fast agile optically-driven solid state switching

Concept for a modular multi-pulse heavy ion IFE driver (induction or PLIA)

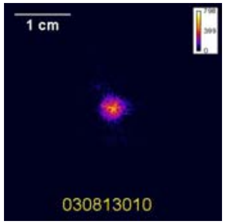
Neutralized Transport Experiment (NTX-2004) encouraged use of plasma neutralization

Non-neutralized

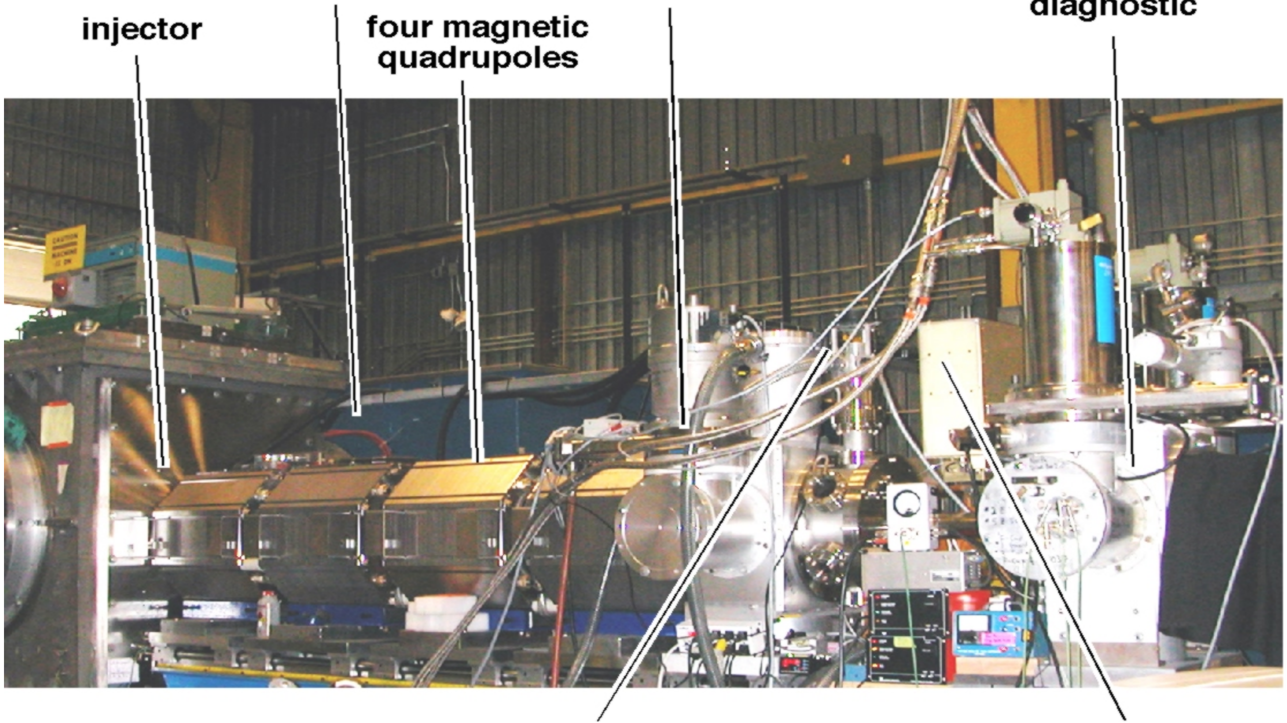


FWHM: 2.71 cm

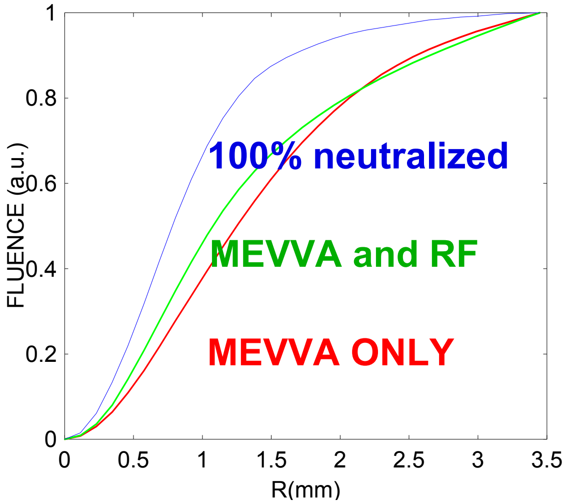
Neutralized



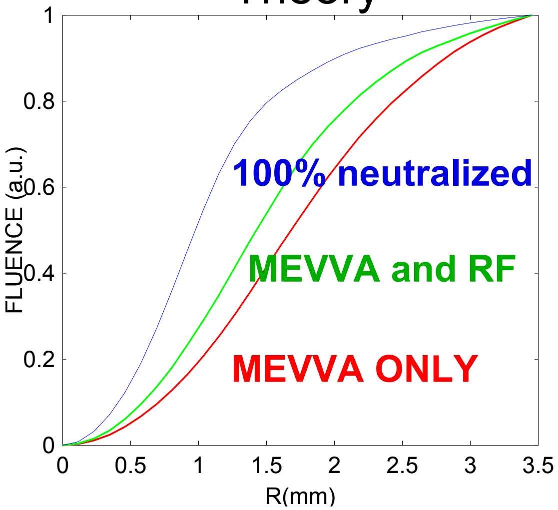
FWHM: 2.14 mm



Measurement

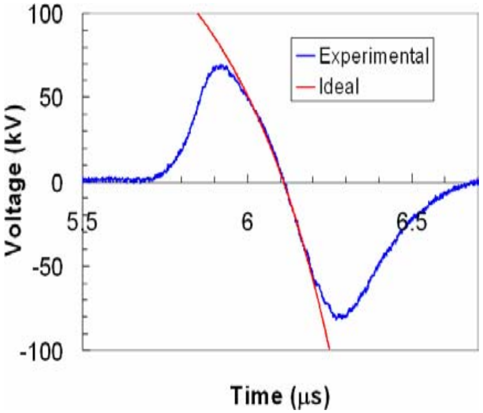


Theory

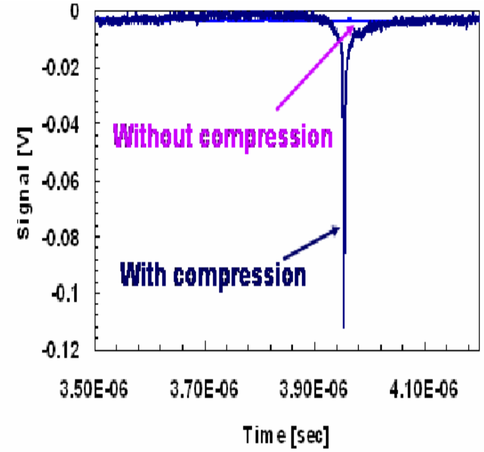


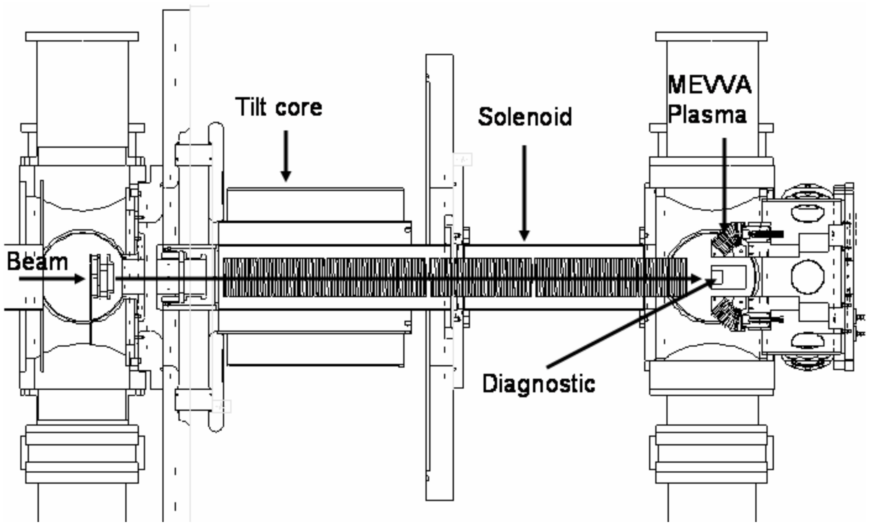
Neutralized drift compression experiment (NDCX)

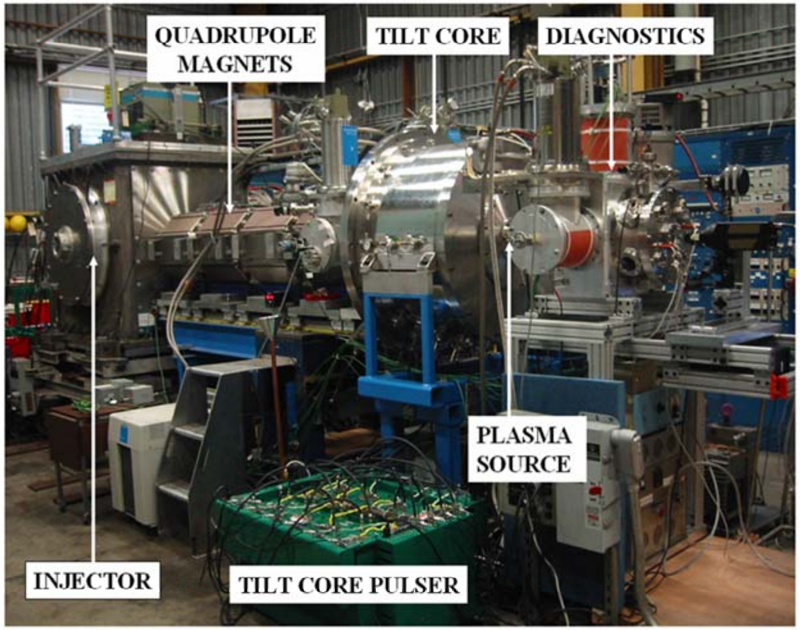
Tilt core waveform



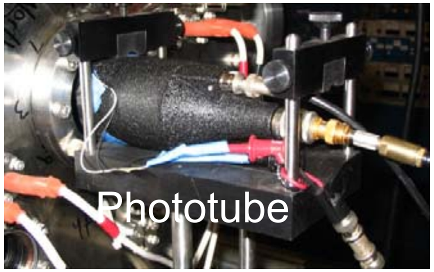
Beam current diagnostic

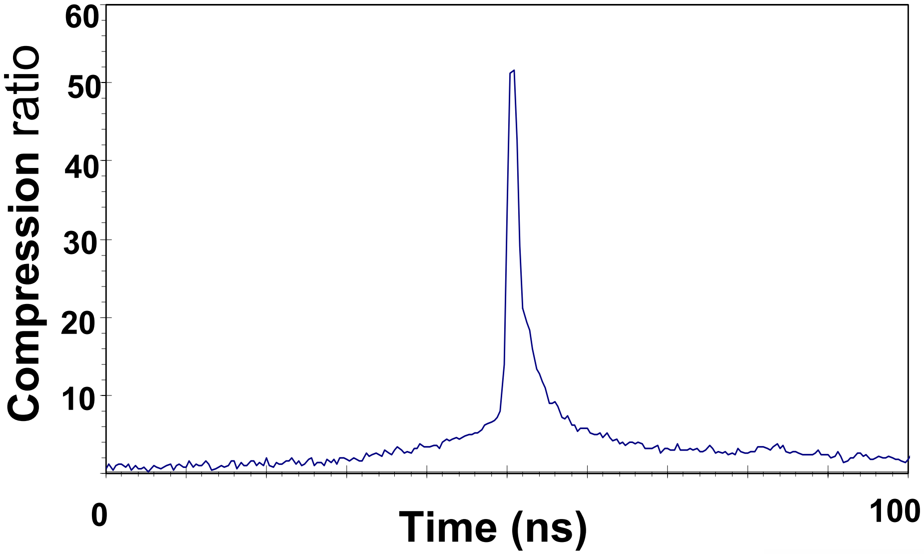


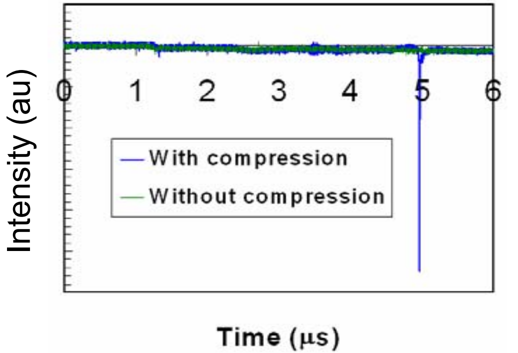




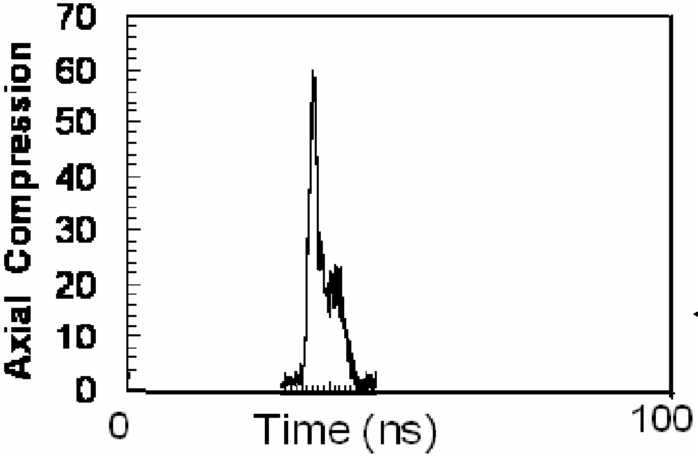
50 Fold Beam Compression achieved in neutralized drift compression experiment





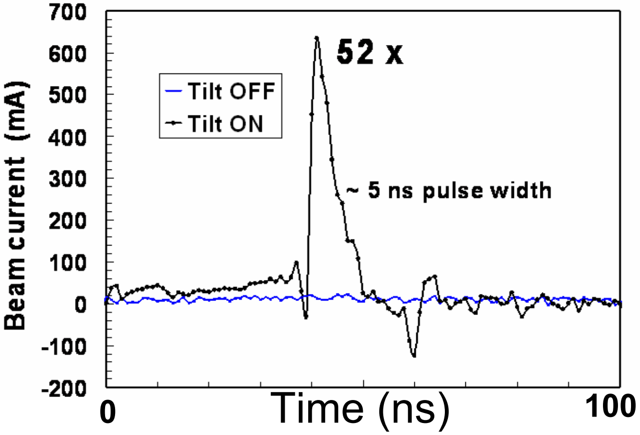


Optical data

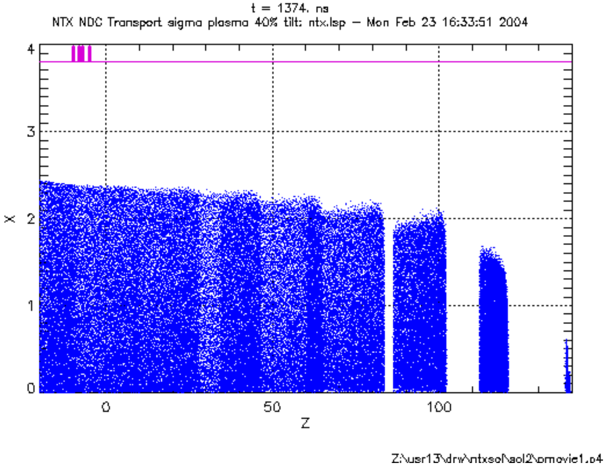


Corroborating data from Faraday cup

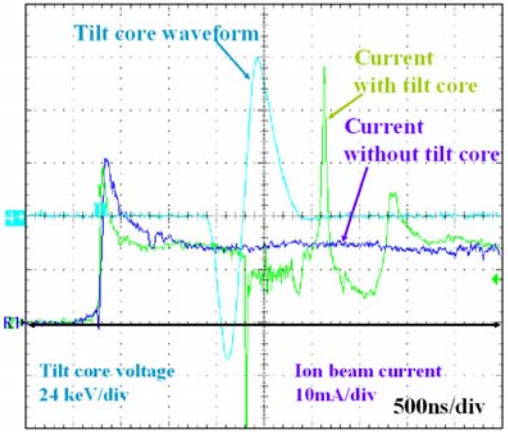
LSP simulation



Rate of progress in heavy ion beam compression in plasma points towards a revolution in high peak power ion beams

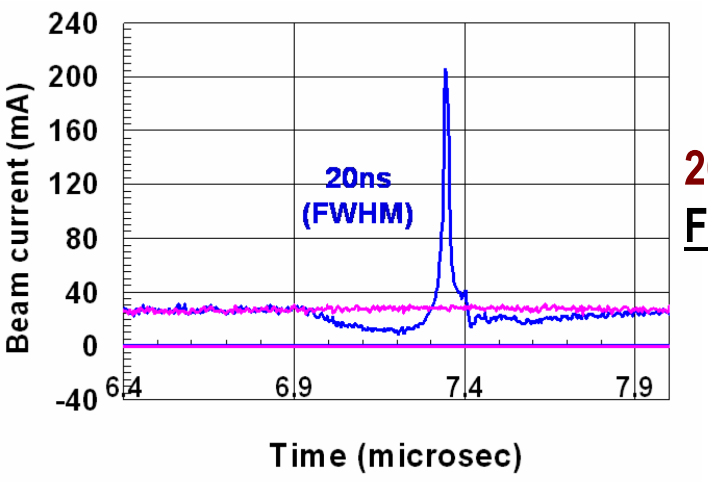


Simulation
of concept
Mar 11, 2004

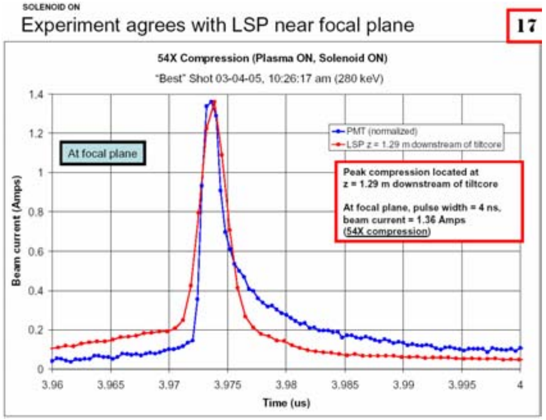


NDCX-1A
Constructed,
first data

40 ns FWHM
Dec. 9, 2004



20 ns FWHM
Feb 27, 2004


SOLENOID ON

Experiment agrees with LSP near focal plane

17

Peak compression located at z = 1.29 m downstream of tiltcore

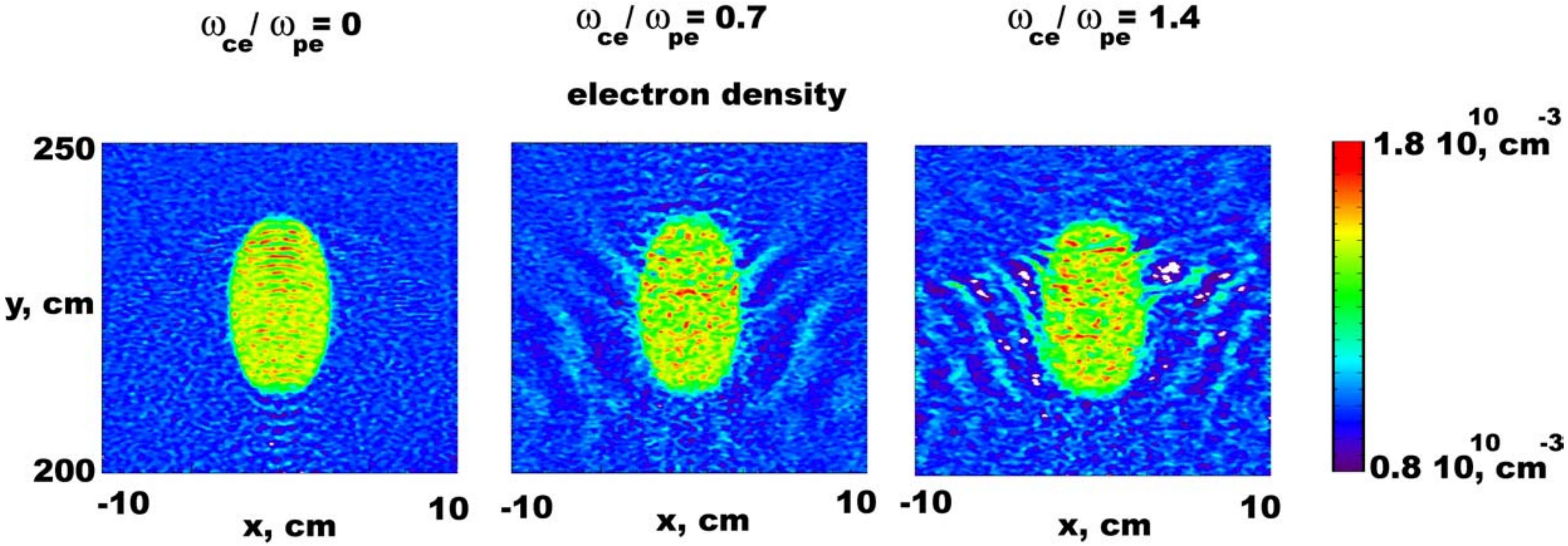
At focal plane, pulse width = 4 ns, beam current = 1.36 Amps (54X compression)

4 ns FWHM
May 2004

Simulations show that solenoidal magnetic field influences neutralizing effects of background plasma

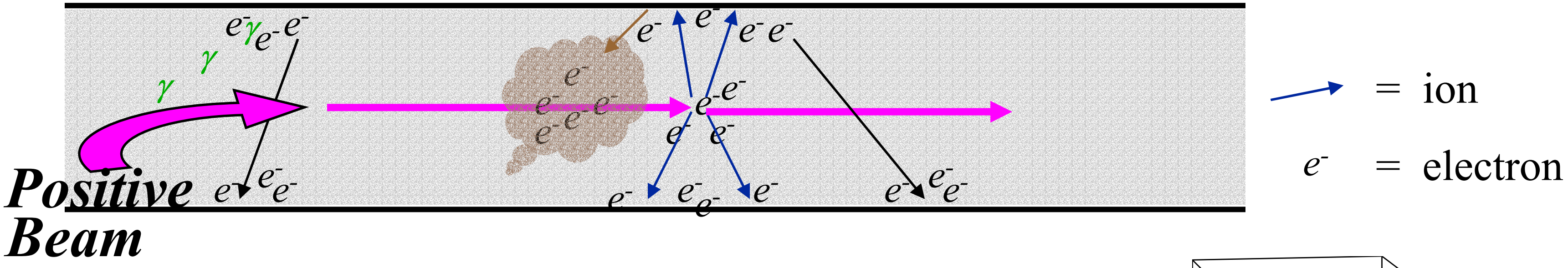
Plots of electron charge density contours in (x,y) space, calculated in 2D slab geometry using the LSP code with parameters:

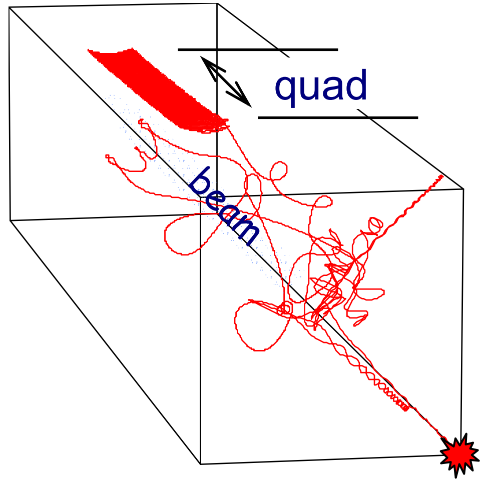
Plasma: $n_p = 10^{11}$cm^{-3}; Beam: $V_b = 0.2c$, 48.0A, r_b=2.85cm and pulse duration τ_b=4.75 ns. A solenoidal magnetic field of 1014 G corresponds to $\omega_{ce} = \omega_{pe}$.



- In the presence of a solenoidal magnetic field, whistler waves are excited, which propagate at an angle with the beam velocity and can perturb the plasma ahead of the beam pulse.

High-brightness vacuum beam transport - electron effects on intense ion beams





e^- motion in a quad

Electron cloud caused by:

Synchrotron radiation

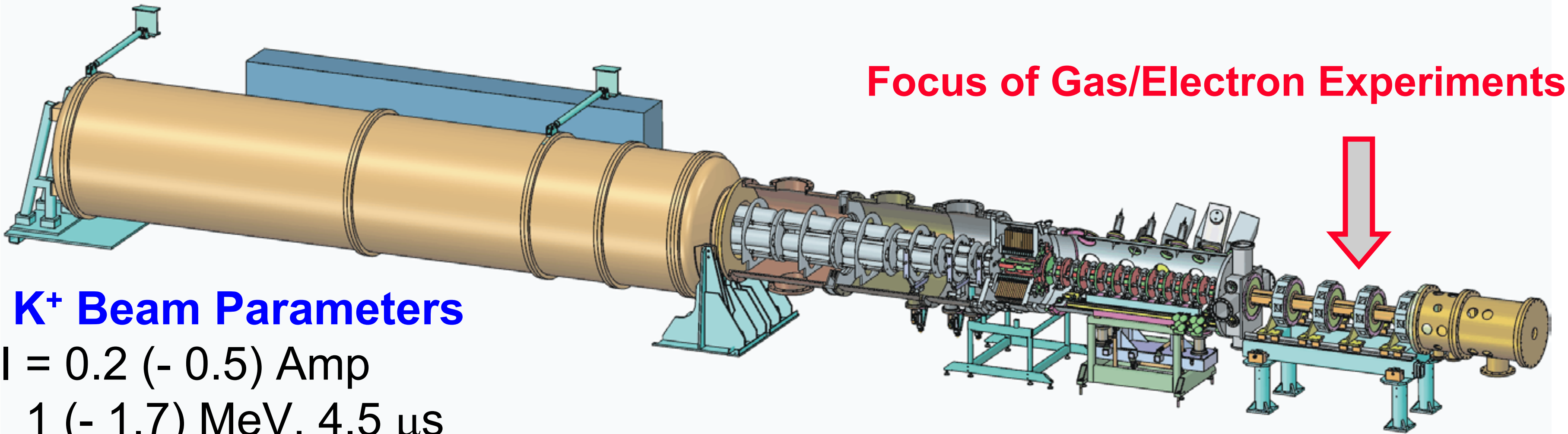
Secondary emission from e^- accelerated by beam

Beam halo scraping ⇒ e^- emission
Ionization of background gas
Expelled ions hitting vacuum wall
Ionization of desorbed gas

} **especially for HIF, HEDP**

Goal: Advance understanding of the physical processes leading to the accumulation of electrons in magnetic quadrupoles in the HCX

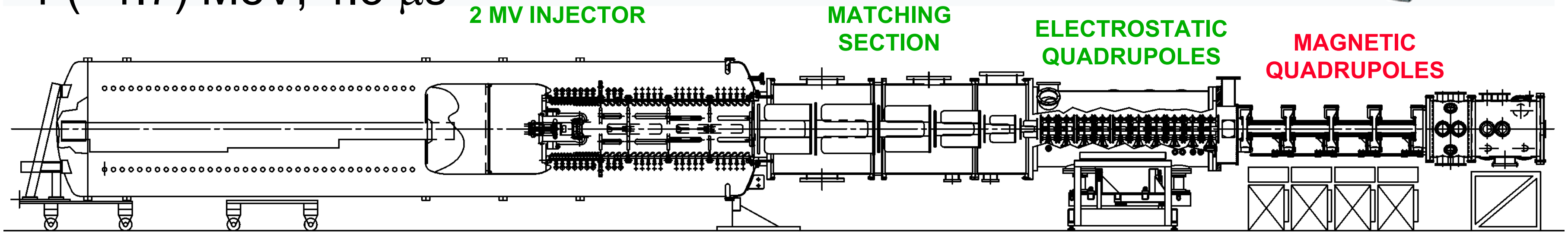
The High Current Experiment (HCX) is exploring beam transport limits



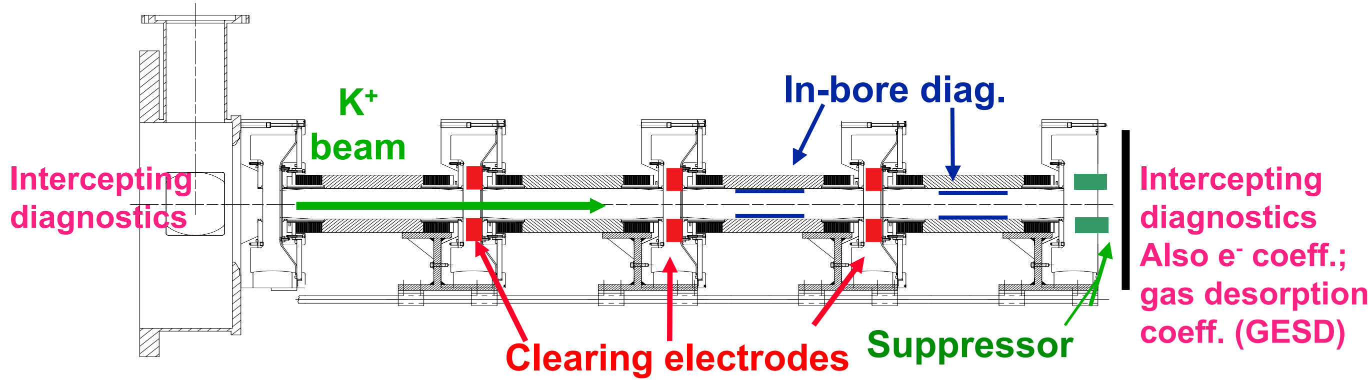
K^+ Beam Parameters

I = 0.2 (- 0.5) Amp

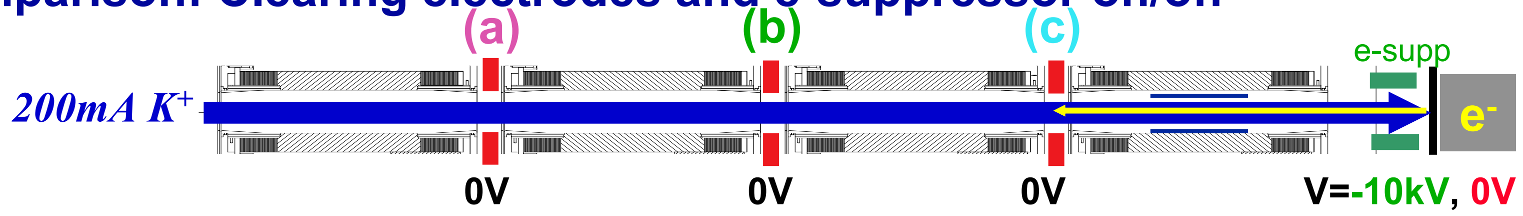
1 (- 1.7) MeV, 4.5 μs

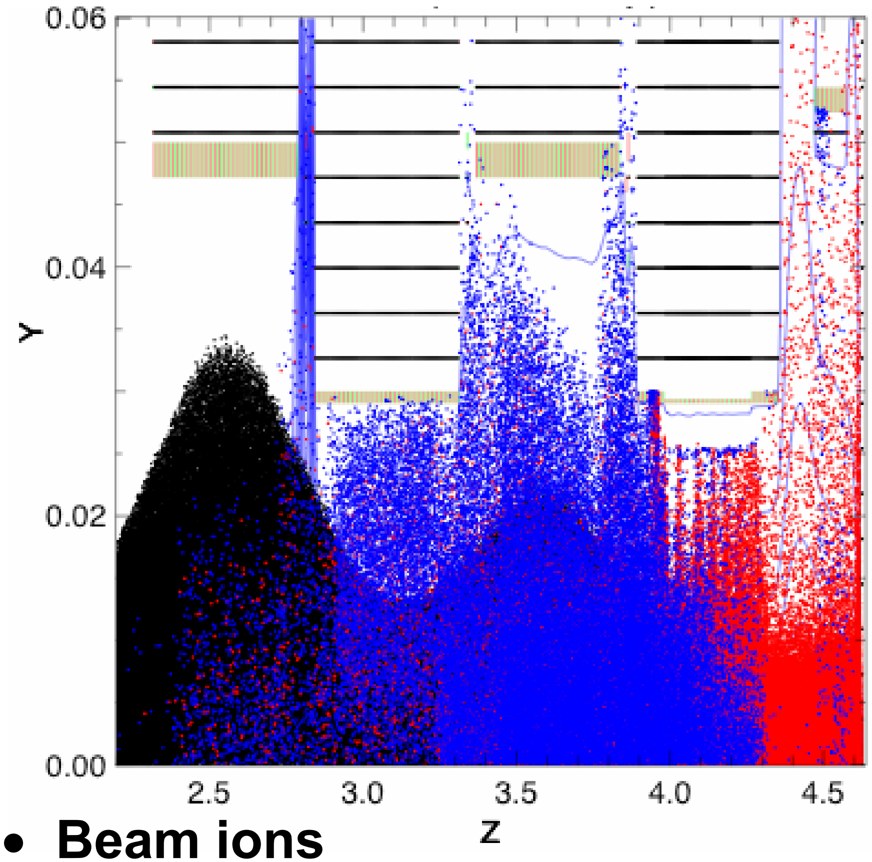


4 magnetic quadrupoles; many diagnostics

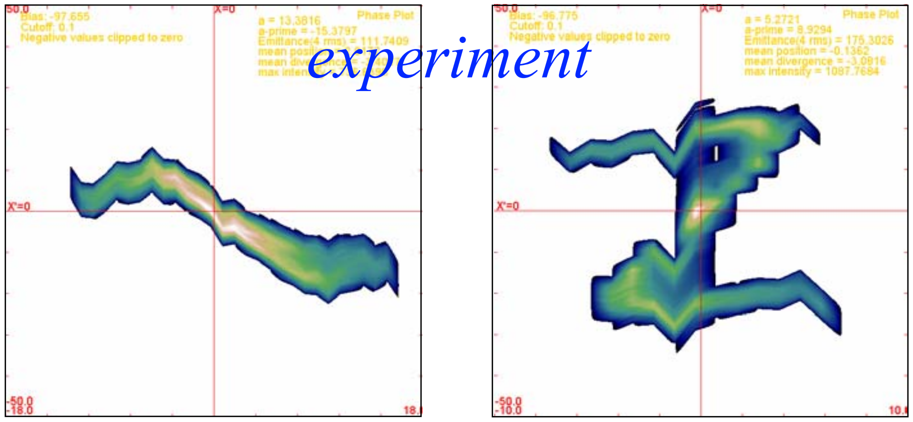


Comparison: Clearing electrodes and e-suppressor on/off



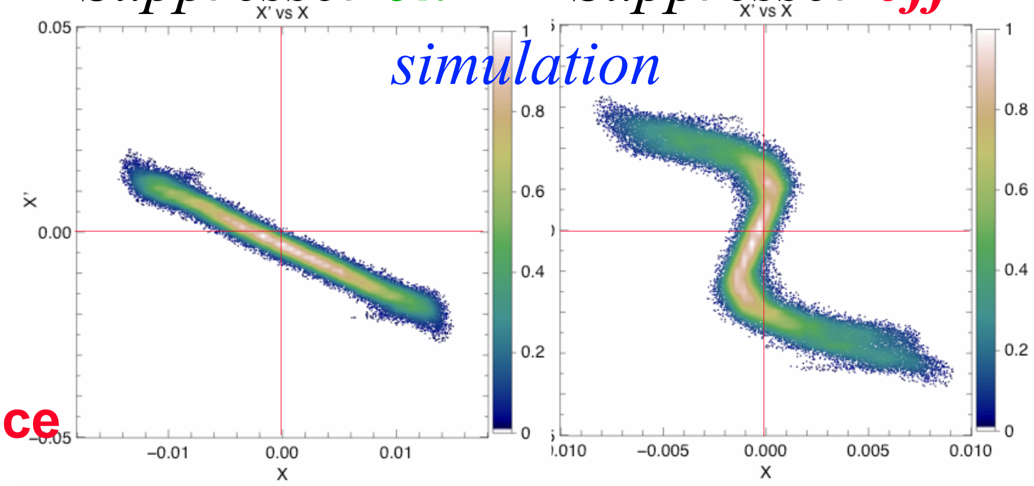


- **Beam ions**
- **Electrons from ions hitting surface**
- **Secondary electrons**



experiment

Suppressor ***on*** *Suppressor* ***off***



simulation

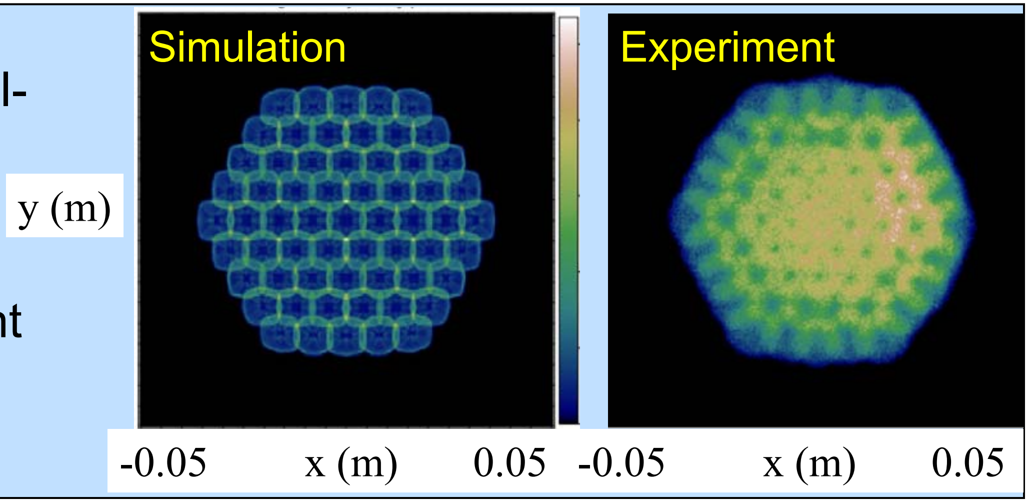
Comparison suggests semi-quantitative agreement.

Completed merging beamlet injector experiments on STS-500 validated the concept of this compact, high current source (Kwan, Westenskow)

Monolithic solid sources suffer from poor scaling vs. size at high currents

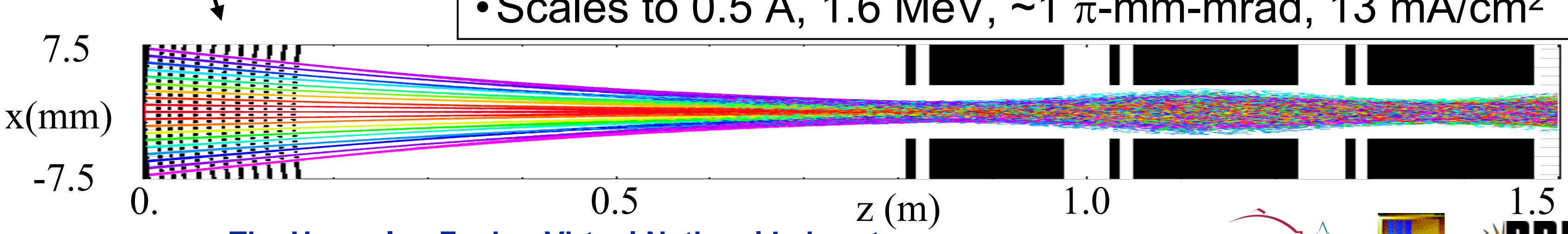
This new concept circumvents the problem via use of many small, low-current sources

From a full-gradient (parallel-beamlet) experiment



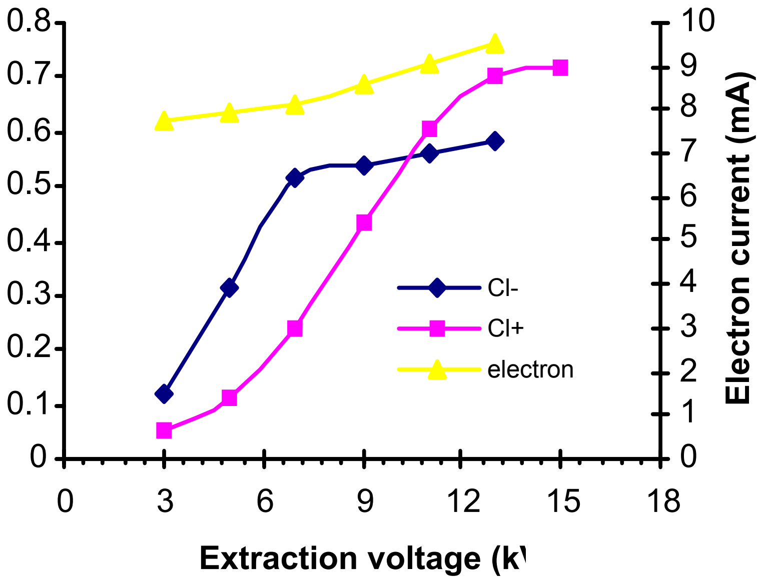
From scaled merging experiment:

- Obtained emittances comparable to simulation
- Effects of “dirty” physics (electrons, charge exchange) were minimal
- Scales to 0.5 A, 1.6 MeV, ~1 π-mm-mrad, 13 mA/cm^2



Proof-of-concept experiments demonstrate feasibility of negative halogen ions

Cl (electron affinity 3.61 eV) yields far more negative ions and far fewer electrons than O (1.46 eV affinity), confirming that greater electron affinity allows closer approach to ion-ion extractor plasma

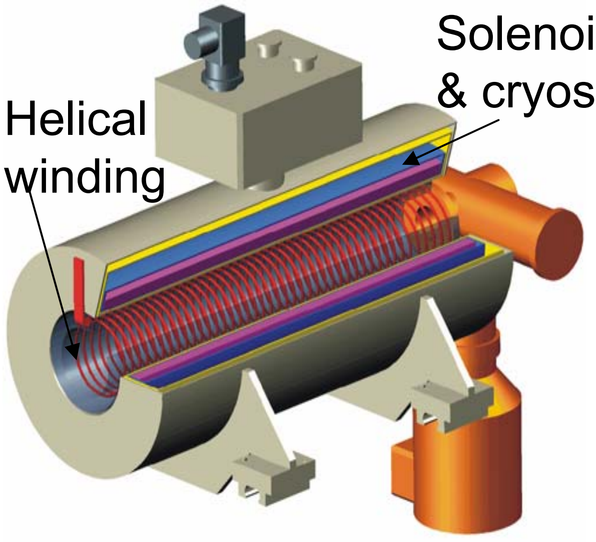


Negative ions offer potential advantages over positive ions for heavy ion fusion:

- **Will not draw electrons from surfaces.**
- **Charge exchange tails much less than for positive ions from plasma source (helps longitudinal emittance).**
- **If atomic beams desired, can be efficiently converted to neutrals by photo-detachment.**
- **Initially atomic driver beams could reduce average beam self-perveance and target spot size even if ionized en route to the target.**
- **Initial experiments suggest surprisingly low effective ion temperatures for both Cl$^-$ and Cl$^+$; if confirmed by more measurements, ions from ion-ion plasmas may offer lower emittance than from electron-ion plasmas.**

In a Pulse Line Ion Accelerator (PLIA)*, the accelerating fields are those of a "distributed transmission line"

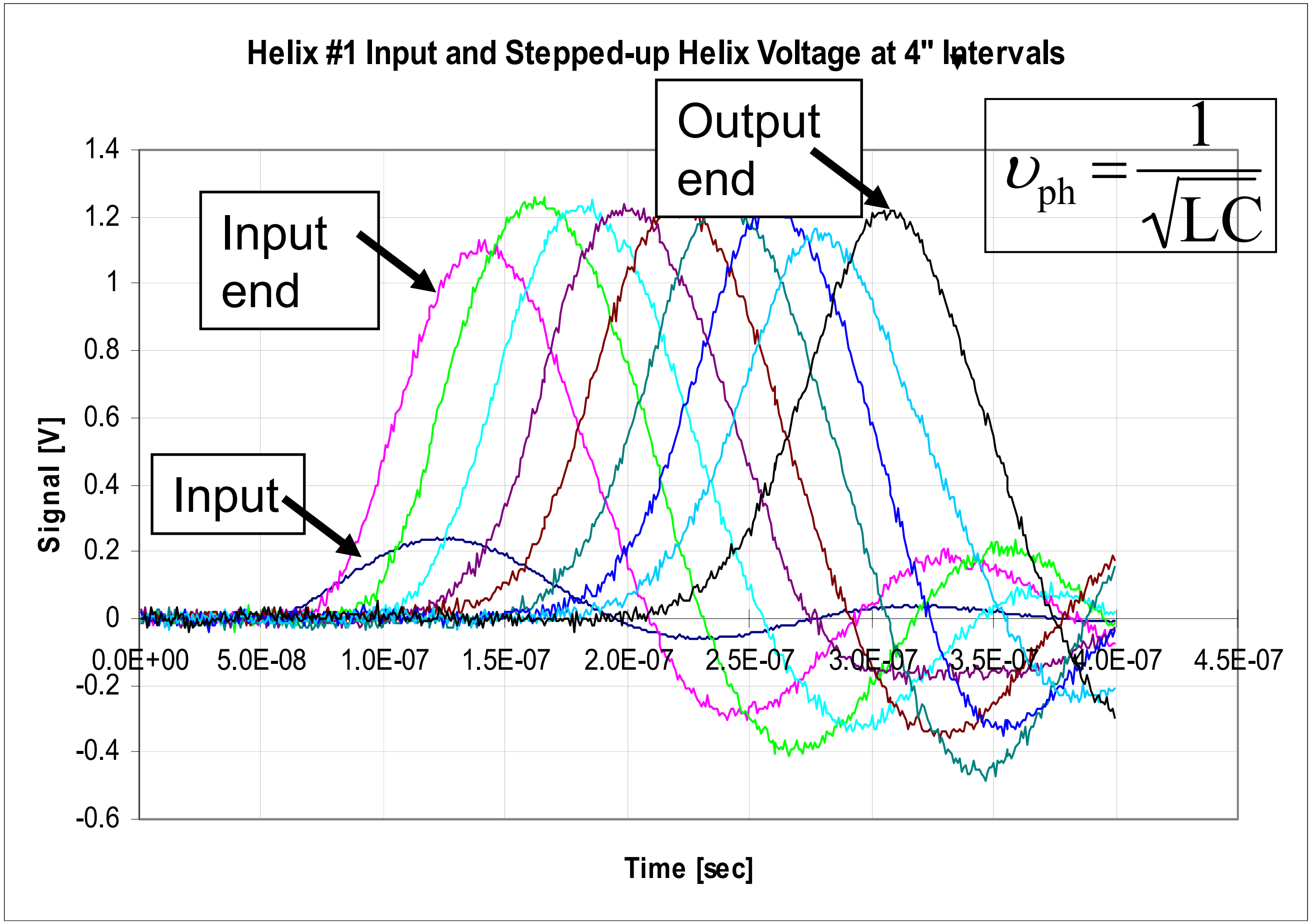
NDCX-II Accelerator Cell



Helical winding

Solenoid & cryostat

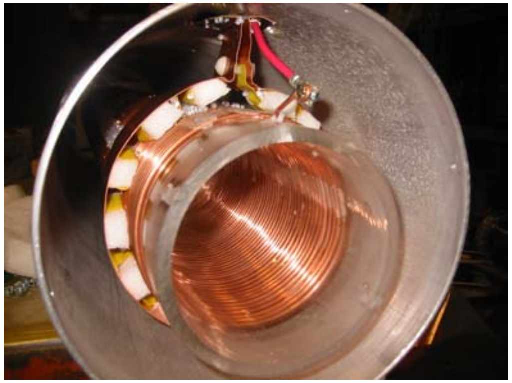
*R.J. Briggs, *et al.* - LBNL Patent, Aug 2004



Helix #1 Input and Stepped-up Helix Voltage at 4" Intervals

$$\upsilon_{\mathrm{ph}} = \frac{1}{\sqrt{LC}}$$

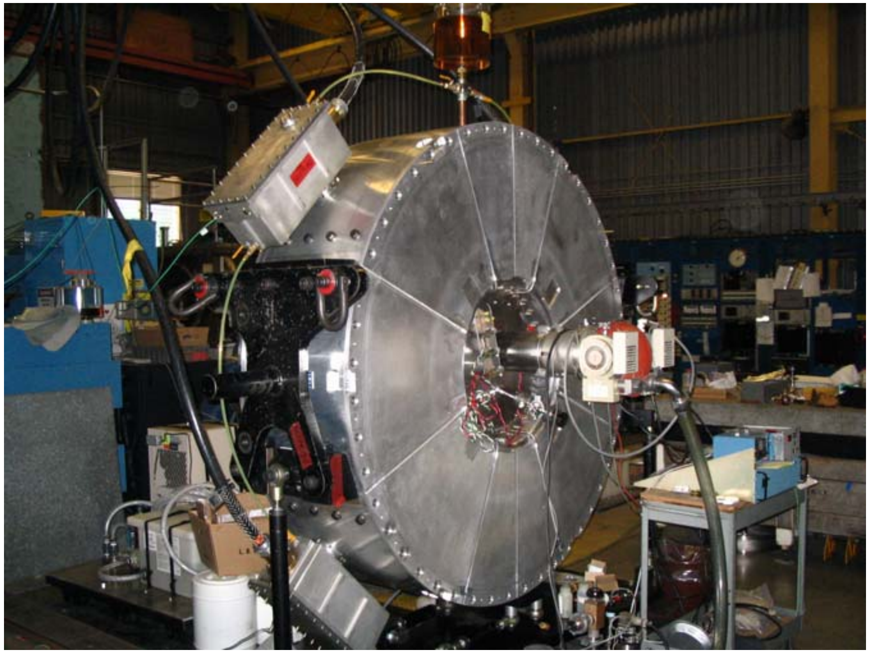
Compact transformer coupling (5:1 step-up)



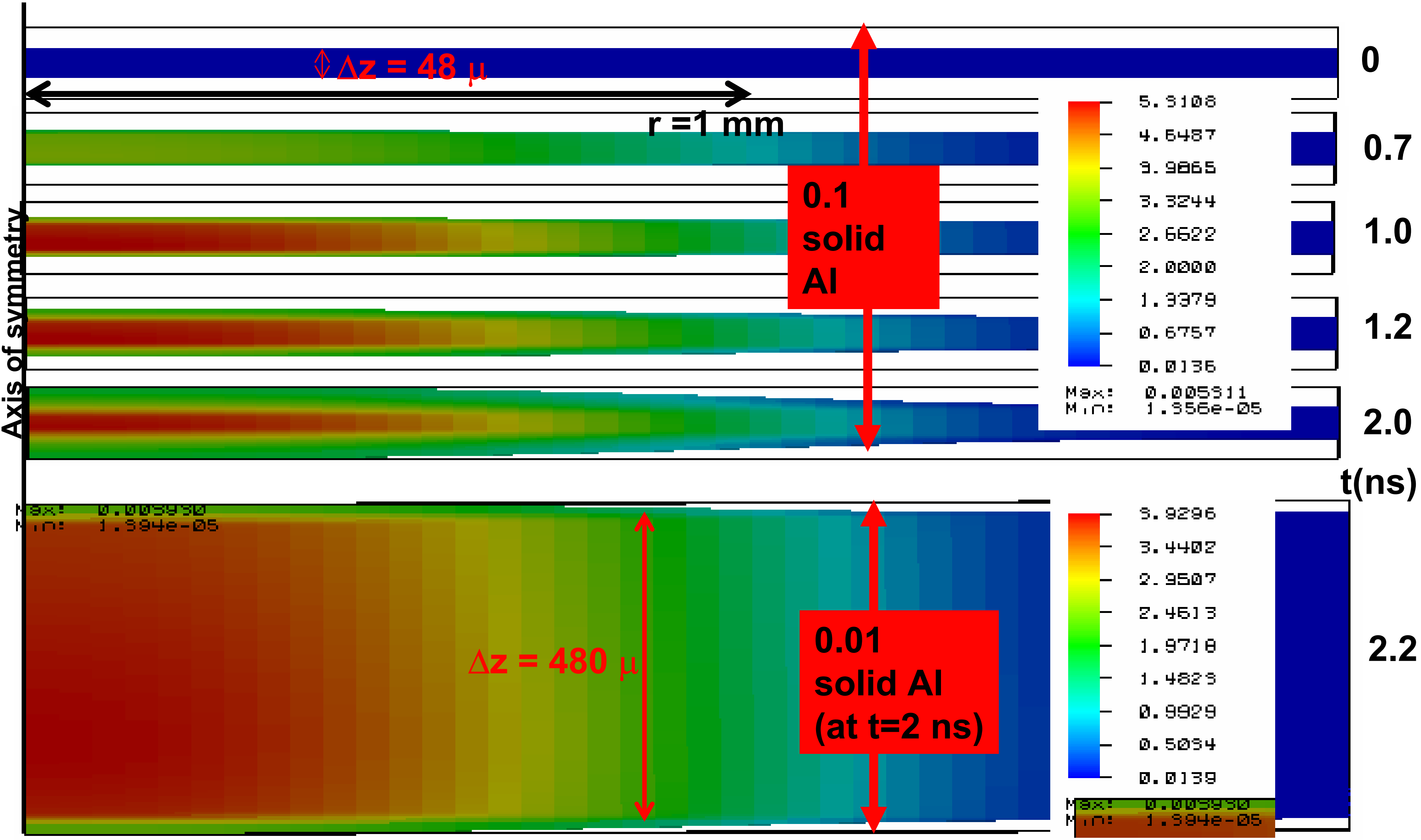
For low beta, high perveance, short ion bunches, the PLIA might reduce costs per volt by 100 X compared to induction linacs

Induction Module for the Dual-Axis Radiographic Hydrotest Facility (DARHT:
0.4 V·s (200kVx2μs)
~10,000 kg, 1 M$
(without pulser or transport magnet)

PLIA
test module results (LBNL Dec 04)
0.4 V·s (2MVx0.2μs)
~40 kg, 10 K$
(without pulser or transport magnet)



Hydra simulations confirm temperature uniformity of targets at 0.1 and 0.01 times solid density of aluminum



0.1 solid Al

0.01 solid Al (at t=2 ns)

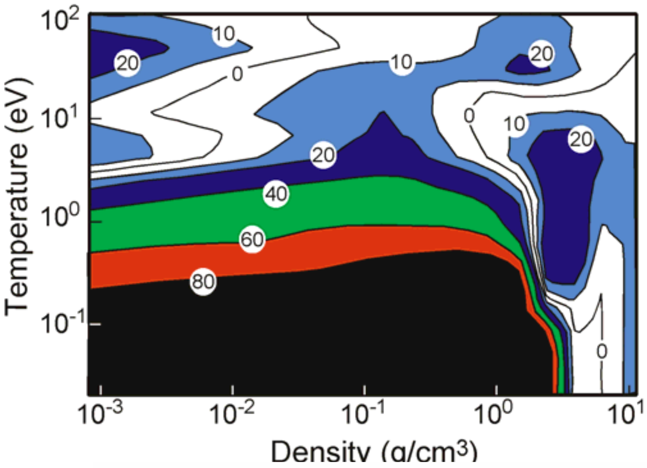
New theoretical EOS work meshes very well with the experimental capabilities we will be creating

R. More: Large uncertainties in WDM region arise in the two phase (liquid-vapor) region

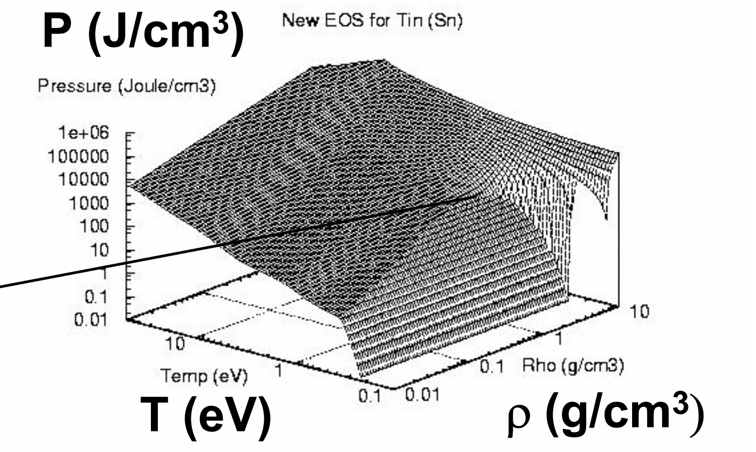
Accurate results in two-phase regime essential for WDM

R. More has recently developed new high-quality EOS for Sn.

Interesting behavior in the T~1.0 eV regime.



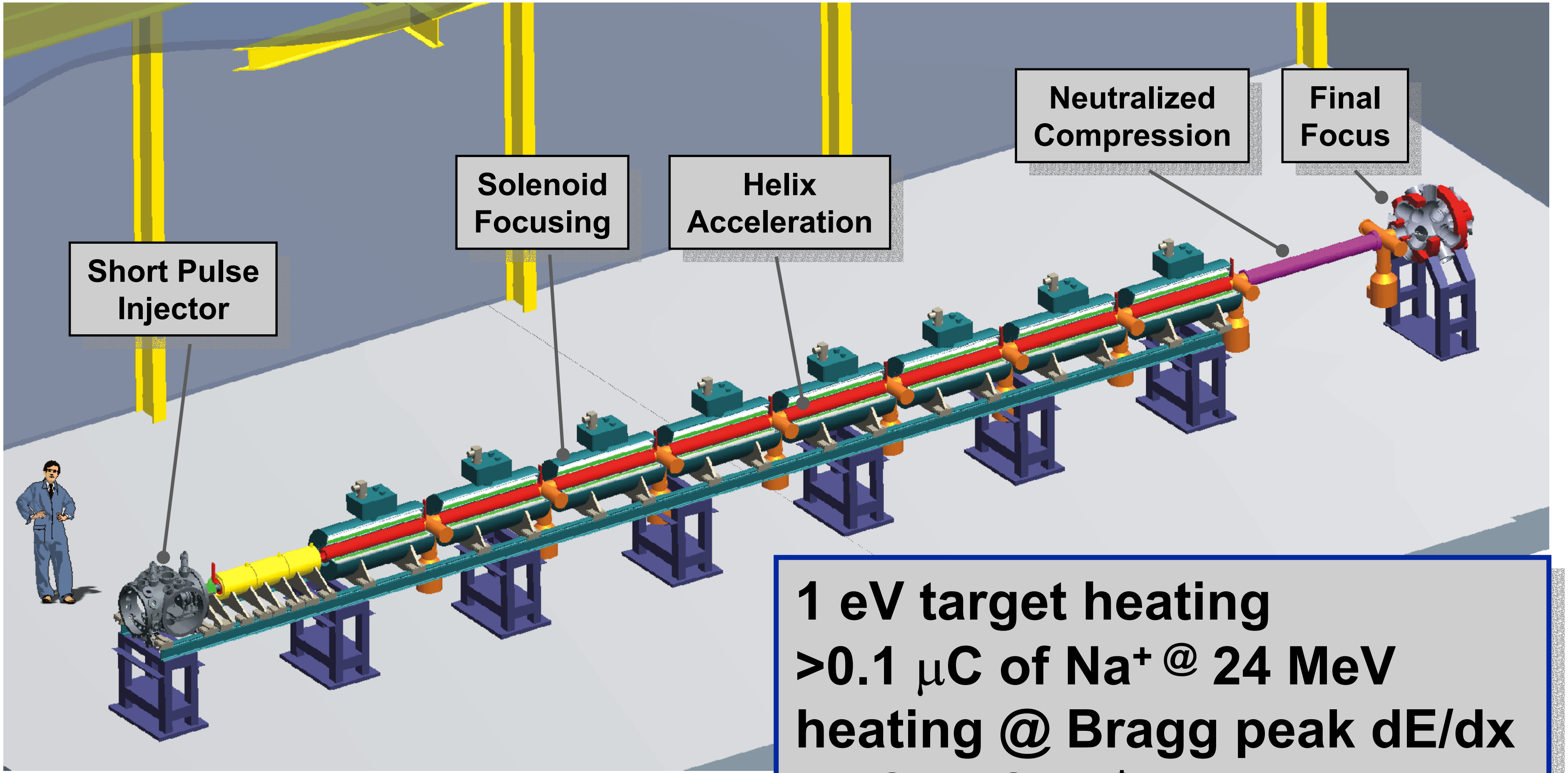
R. Lee plot of contours of fractional pressure difference for two common EOS



Critical point unknown for many metals, such as Sn

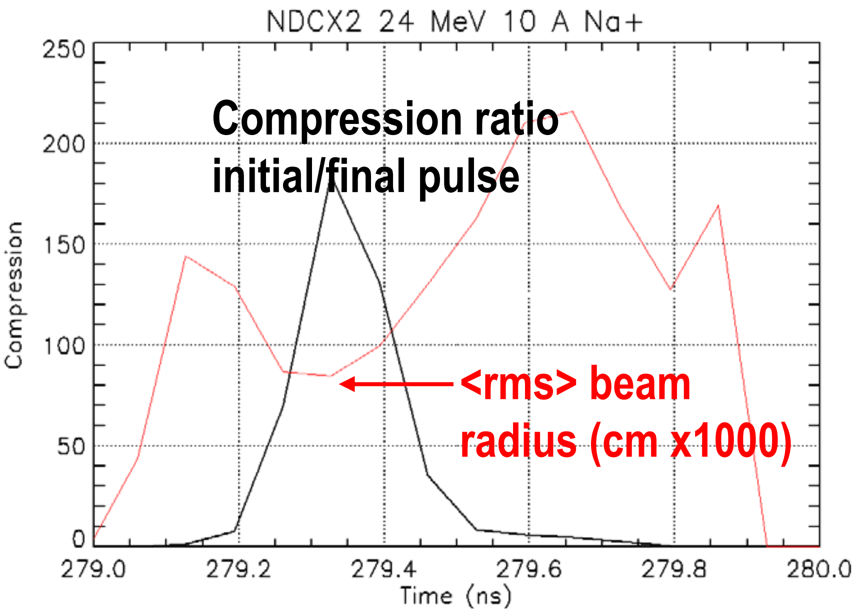
EOS tools for this temperature and density range are just now being developed.

NDCX-II vision: a short pulse high gradient accelerator for ion-driven HEDP and IFE is being evaluated



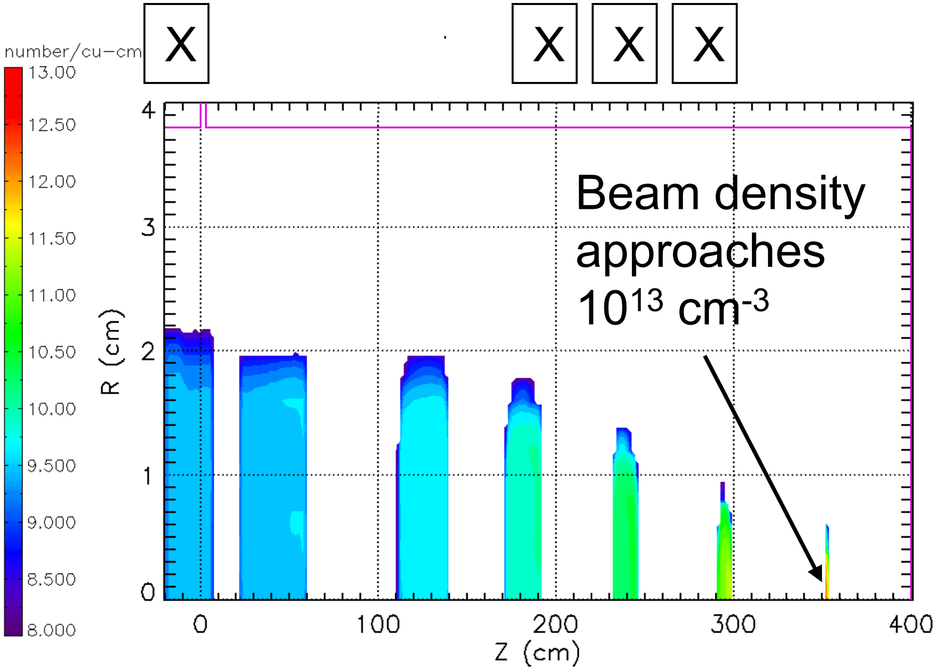
1 eV target heating
>0.1 μC of Na$^+$ @ 24 MeV
heating @ Bragg peak dE/dx
NDCX-1C + $5M hardware

LSP simulation by Dale Welch for future 24 MeV Na$^+$ NDCX-II exp. shows compression to 100 ps with 500 micron central peak focus

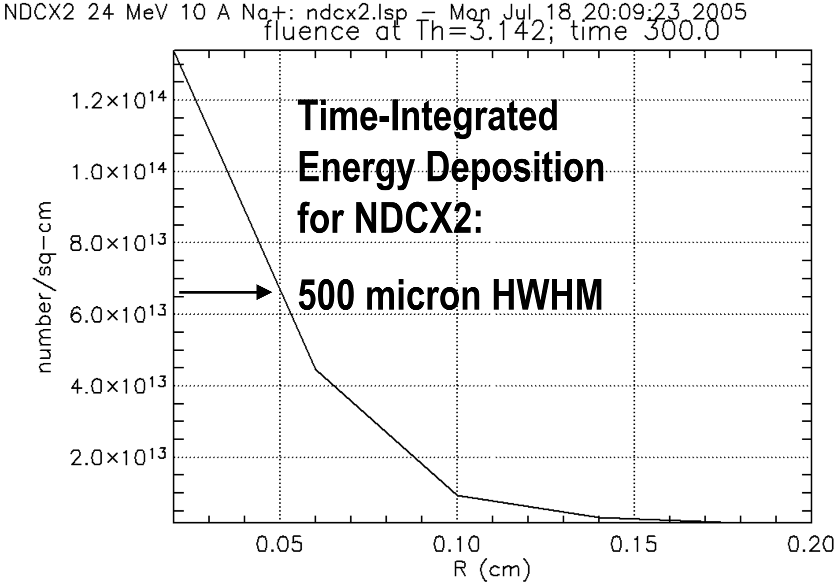


Compression ratio initial/final pulse

<rms> beam radius (cm x1000)



Beam density approaches 10^{13} cm^{-3}



Time-Integrated Energy Deposition for NDCX2:

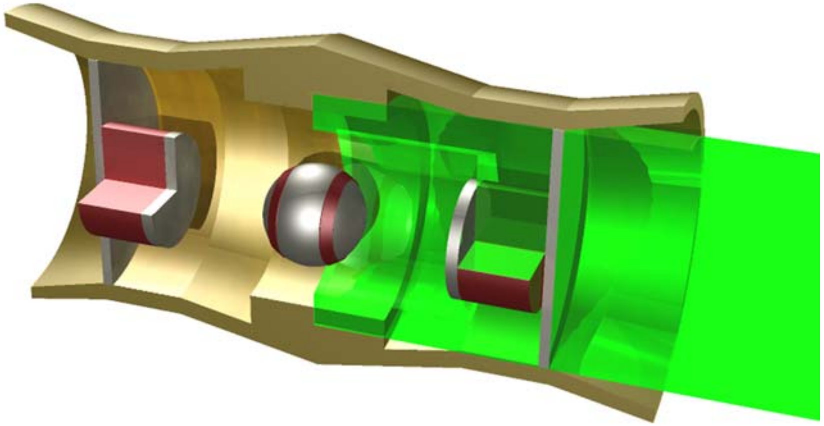
500 micron HWHM

Spot limited in simple solenoidal focusing (4T) by energy tilt (ΔE/E)

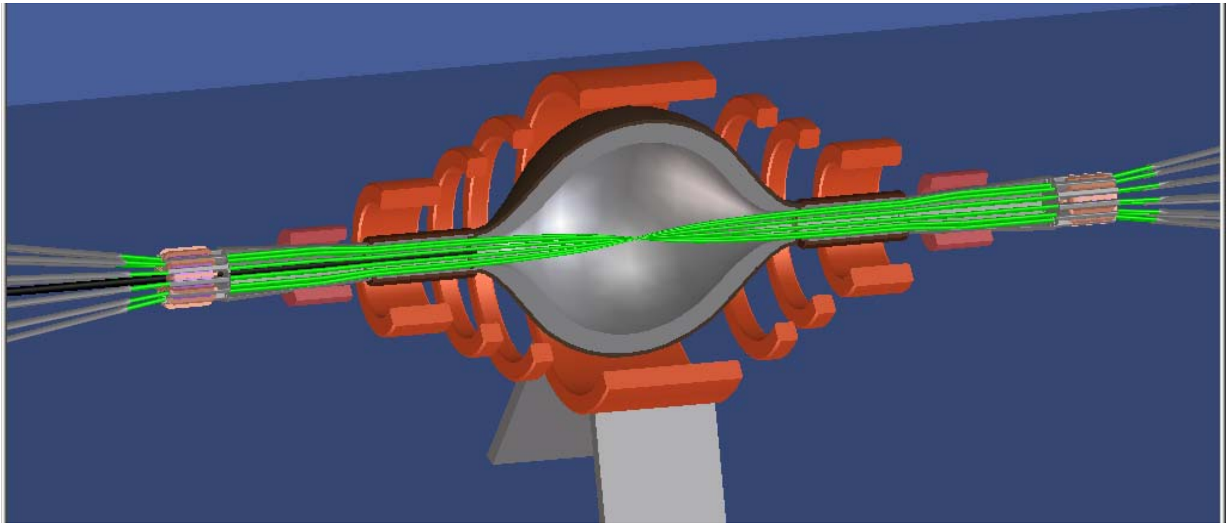
$$\frac{a_f}{a_0} \approx \frac{\pi \Delta E}{8E}$$

Smaller spot can be achieved by more aggressive focusing scheme

Research on neutralized drift compression and focusing of velocity “chirped” beams, together with larger-spot IFE target designs, may lead to improved concepts for heavy ion fusion



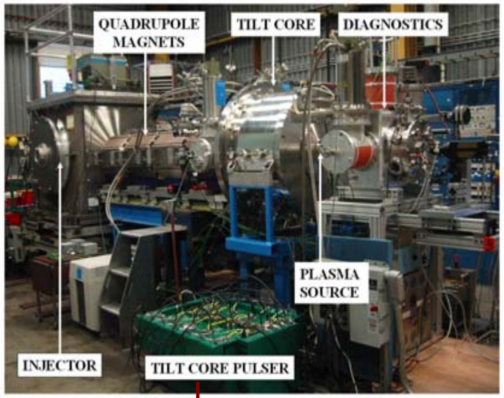
“Hybrid” target allows large 5 mm radius focal spots (D. Callahan). Uses low cost manufacturing methods for hohlraums with foam x-ray converters (D. Goodin).



Neutralized ballistic, solenoid-focused, plasma-filled liquid Flibe-wall vortex chamber concept (Ed Lee, Per Peterson)

Grand technical challenges in ten years

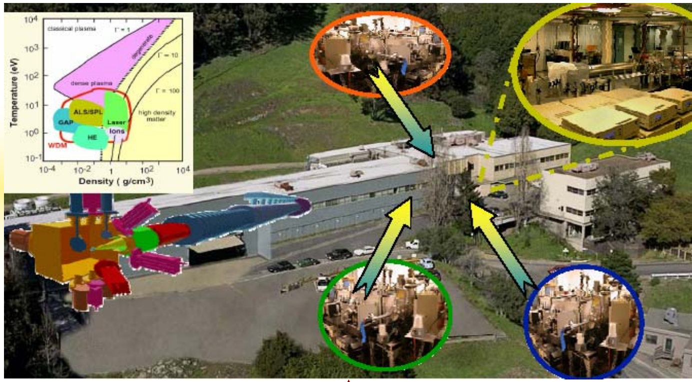
Challenge 1: Understand limits to compression of neutralized beams



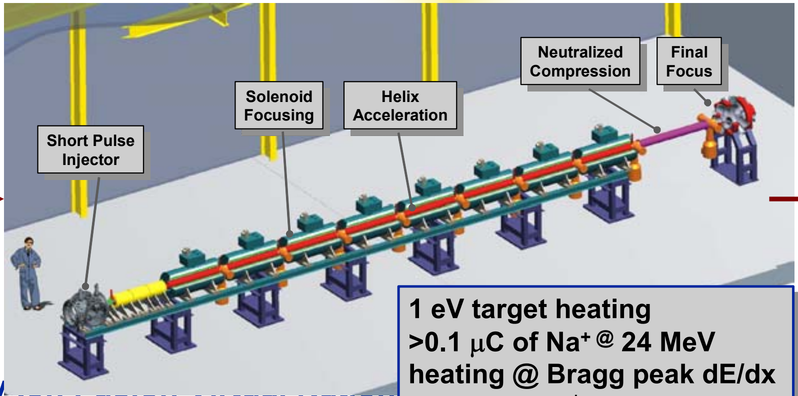
Challenge 2: Integrated compression, acceleration and focusing sufficient to reach 1 eV in targets:

0.1μC NDCX1C +PLIA +5M$=NDCXII

Challenge 3: Affordable *(<50M$)* high shot rate *(>10 Hz)* accelerator, laser, & targets for (a) HEDP user facility *(<5% EOS uncertainty)*, and for (b) prototype IFE driver module



Add acceleration



1 eV target heating
>0.1 μC of Na⁺ @ 24 MeV
heating @ Bragg peak dE/dx
NDCX 1C + $5M hardware

Add chambers, targets, HEDP diagnostics

Four reasons to include ion driven fast ignition R&D

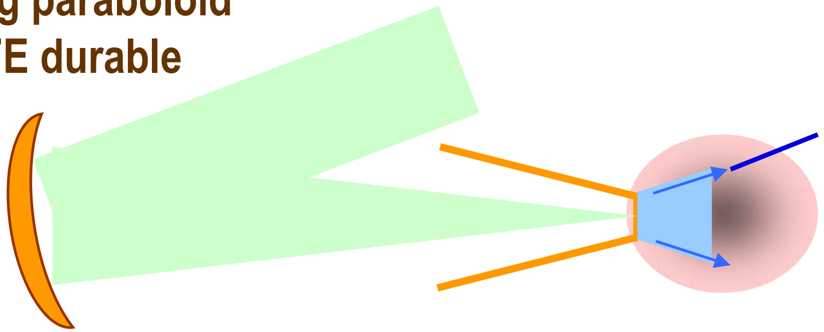
1. **The fast ignition program should explore more than one option as prudent risk management.**

2. **The heavy ion program should explore all exciting HEDP areas accessible: intense beam physics (limits to compression), warm dense matter, and fast ignition**

3. **The heavy ion program should take advantage of growing interest and opportunities for international collaboration on fast ignition.**

4. **Heavy ion-IFE should benefit from potentially-higher target gain with fast ignition, as with any driver. Some fast ignition target concepts work best with ion drive.**

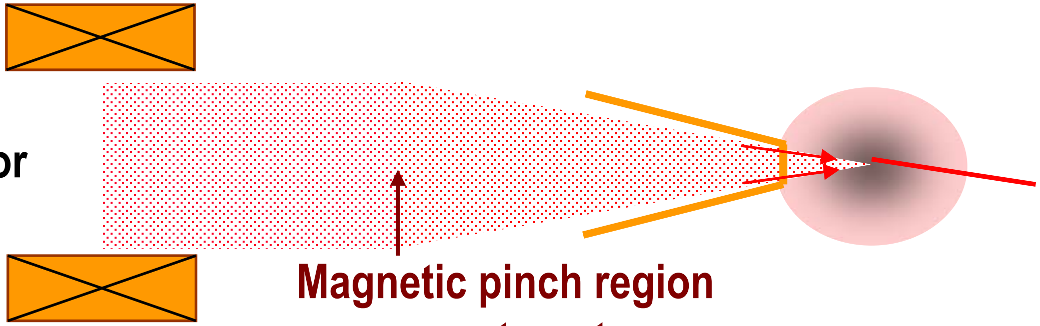
Adding accelerator ion beam R&D to exploratory fast ignition research portfolio →prudent risk management



Focusing paraboloid
not IFE durable

Petawatts of
photons are
available for
FI experiments

Unstable electron beams
may not deposit where
laser is pointing.



Petawatts of
ions await
development for
FI experiments

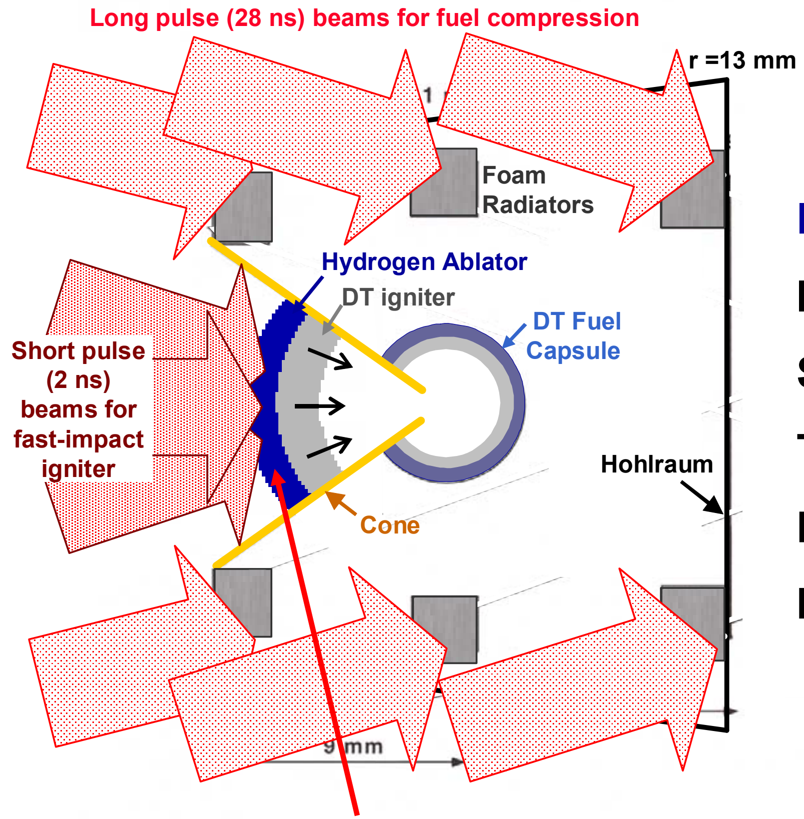
Focusing magnets
IFE durable

Magnetic pinch region
near target
may be needed

Ion beams dE/dx along
straight lines to
the Bragg peak

If neutralized drift compression and focusing of low range ions (0.001- 0.004 g/cm^2) to 1 ns, 1 mm spots can be achieved for HEDP, then ion-direct-drive-impact fast ignition* may be feasible.

Schematic of fast impact ignition target:
-ion indirect drive for fuel compression
-ion direct drive for fast impact ignitor



NDCX may study DD RT-stability in 1-D

	Ion fast igniter**	Ion direct drive impact fast igniter
Ion range	0.6 g/cm^2	0.001 to 0.004 g/cm^2
Ion energy	100 GeV (Pt)	400 MeV (Xe)
Igniter drive energy	500 kJ	250 to 500 kJ?
Focal spot radius	50 microns	1000 microns
Final pulse width	200 ps	2000 ps

** ITEP scheme

Hydrogen -best ablator for ion-direct-drive (Tabak)

Implosion velocity $V_{imp} = \chi$ Cs ln (M_H/M_{DT})

Sound speed $C_s = [(Z+1)kT_H/(Am_p]^{0.5}$

T_H=1 keV, (Z+1)/A =2 for hydrogen (=0.5 for plastic!)

M_H/M_{DT} = 5, χ ~1.5 → V_{imp} =10^6 m/s, ~250 kJ ion beam drive energy @ ~2 ns: adequate for ignition?

****M. Murakami (ILE, Osaka) described impact ignition with laser direct-drive for a cone-igniter segment at HIF04. Here we consider ion-direct drive in the cone.***

Conclusions

- There have been many exciting scientific advances and discoveries during the past two years that enable:
  - Demonstration of compression and focusing of ultra-short ion pulses in neutralizing plasma background.
  - Unique contributions to High Energy Density Physics (HEDP) and to IFE, including fast ignition.
  - Contributions to cross-cutting areas of accelerator physics and technology, e.g., electron cloud effects, Pulse Line Ion Accelerator, diagnostics.

- Heavy ion research is of fundamental importance to both HEDP in the near term and to fusion in the longer term.

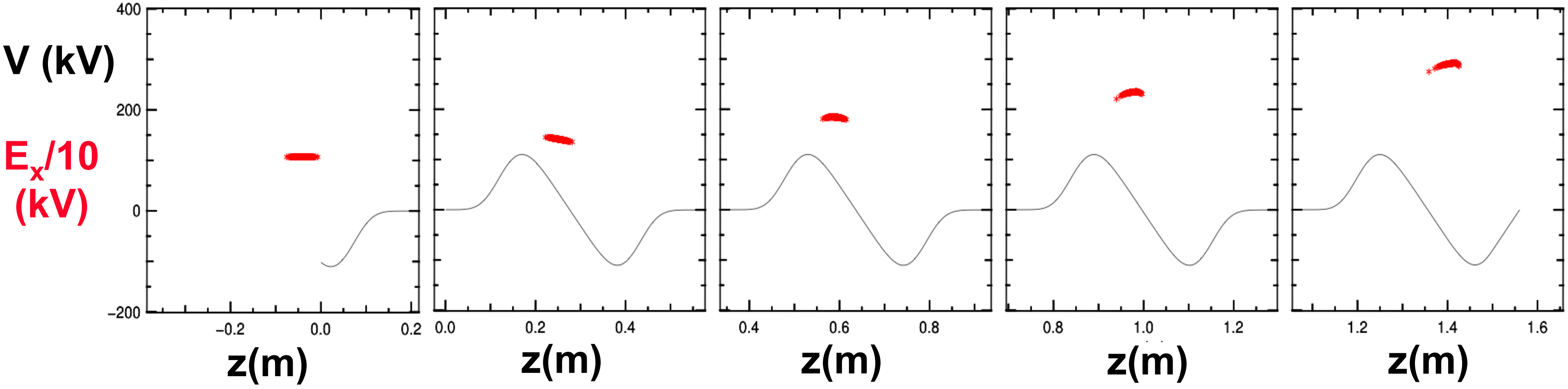
- Experiments heavily leverage existing equipment and are modest in cost.

- Theory and modeling play a key role in guiding and interpreting experiments.

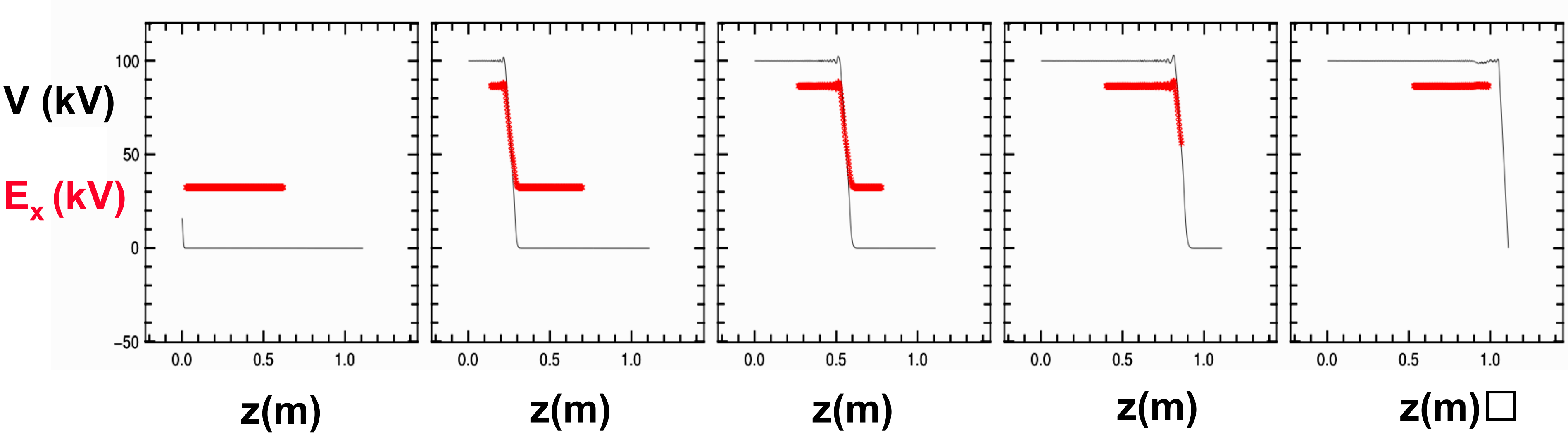
Backup Slides:
Research Highlights

PLIA can be operated in the short pulse (“surfing”) mode or the long pulse (“snowplow”) mode (Friedman)

Short beam “surfs” on traveling voltage pulse (snapshots in wave frame)

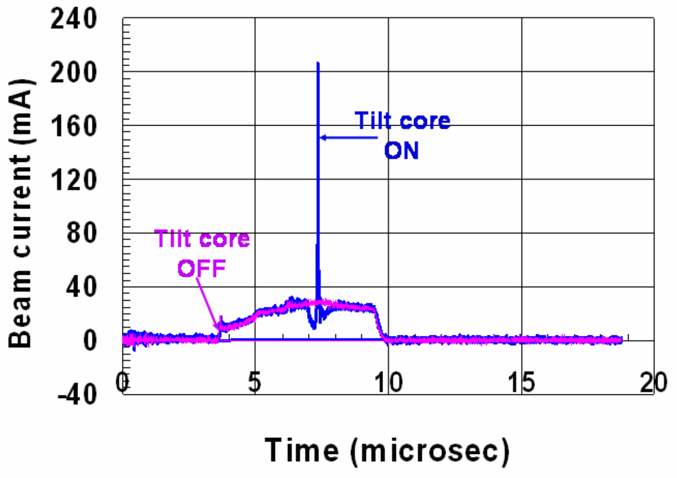


Longer beam is accelerated by “snowplow” (snapshots in lab frame)

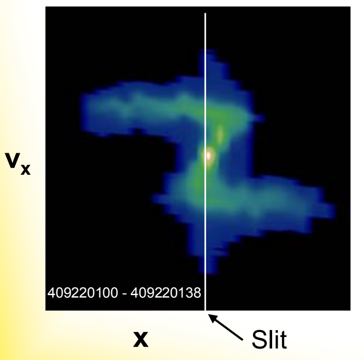


Spectacular progress towards HEDP and Fusion!

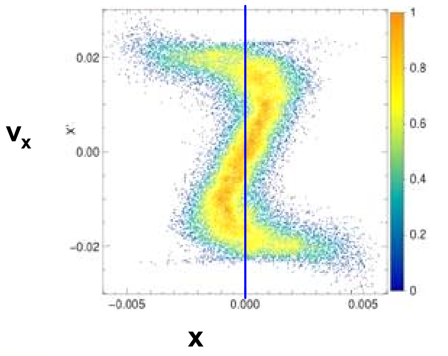
Unique ion pulse compression in plasma: From concept to simulation to 50X compression data in 12 months



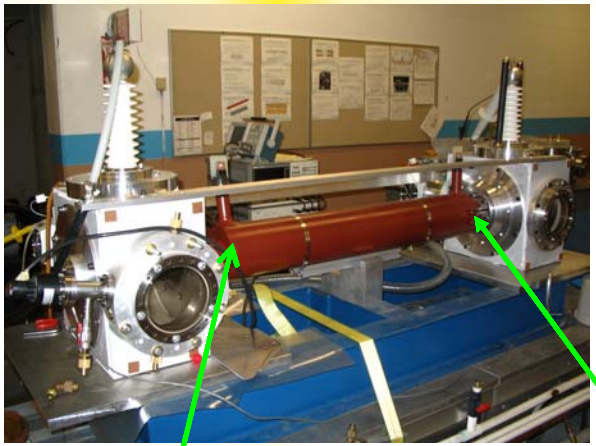
Measured v_x vs x.



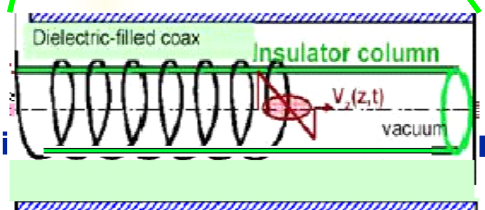
3-D simulation of electron cloud affecting ion beam v_x vs x



Unique world class capability in electron cloud physics: From transport data in four HCX quads to self-consistent simulation in 9 months



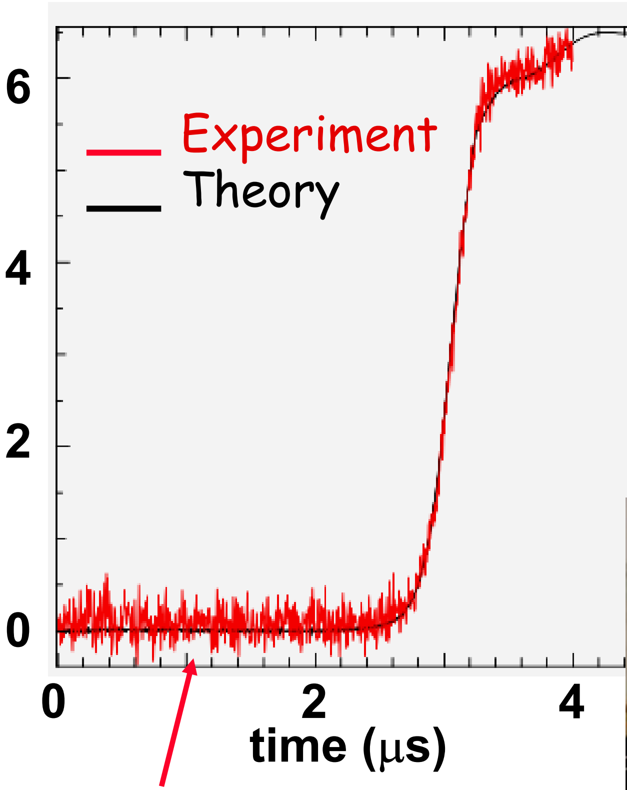
Unique accelerator concept (PLIA): From workshop to simulation to initial tests in 8 months



WARP simulations of STS-500 injector experiments clarify short-rise-time beam generation and diode optics

Rise time

Current (mA) at Faraday cup

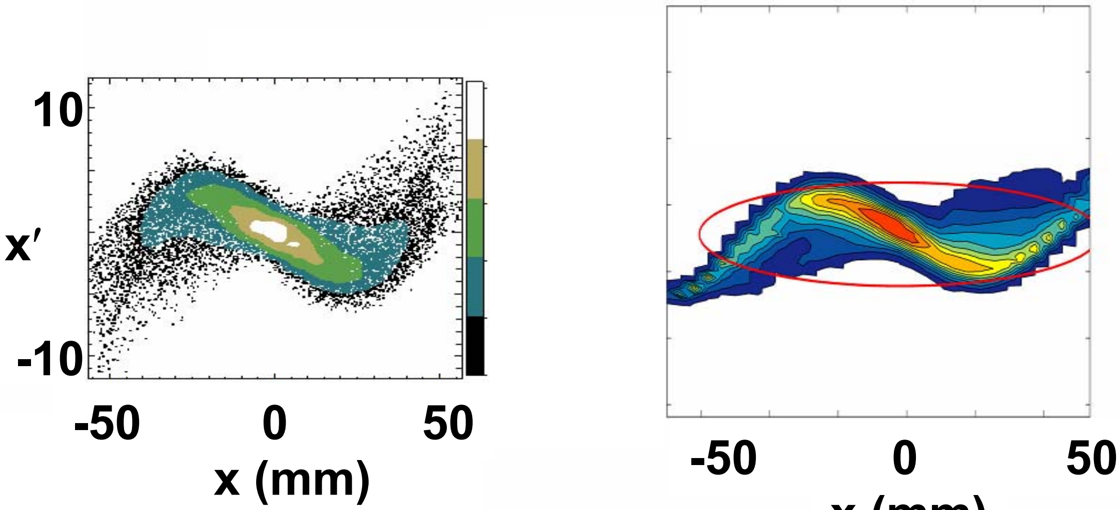


Result depends critically on mesh refinement

Phase space at end of diode

Warp simulation

Experimental data

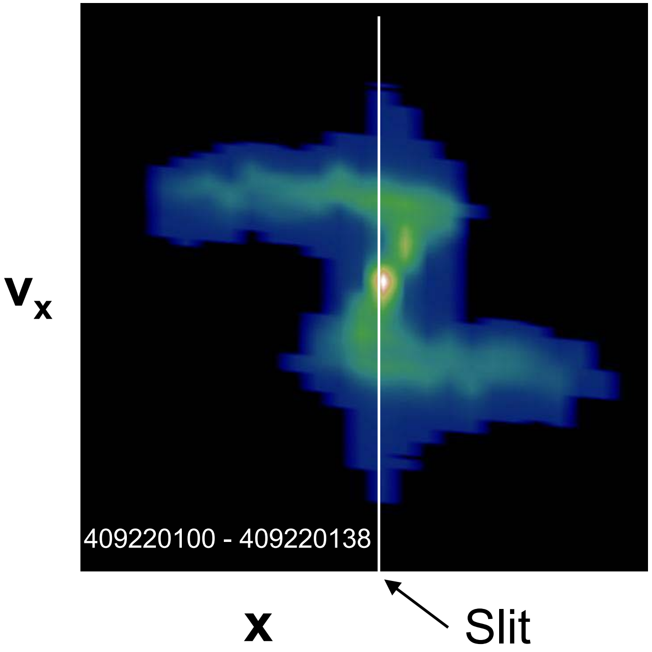


5-cm-radius K^+ alumino-silicate source

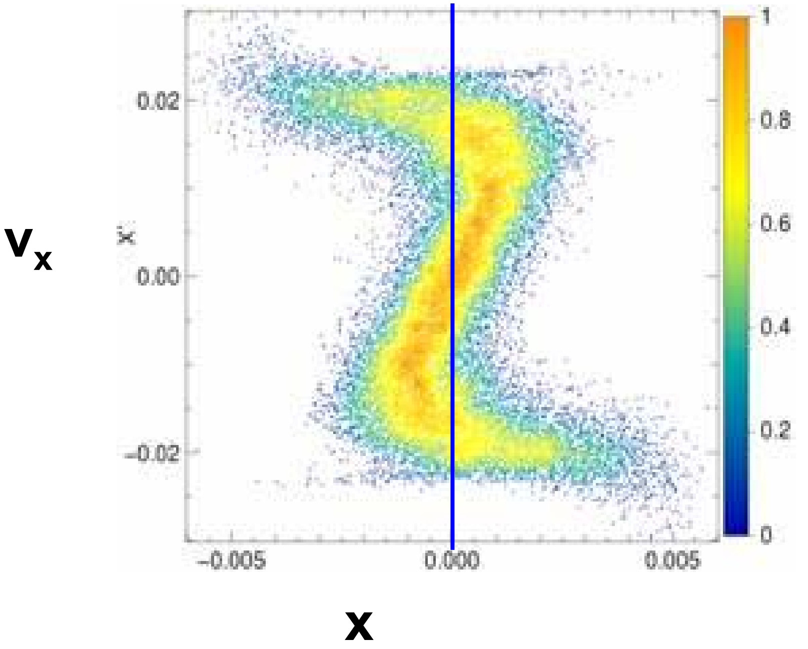
Successfully simulated electron cloud effects on ion beam dynamics in HCX using WARP in 3D with models of electron emission/reflection, and a new electron mover (Ron Cohen, et al.)

HCX conditions: 1 MeV, 0.18 A K^+ ion beam after 4 quadrupole magnets

Measured v_x vs x.



3-D simulation of electron cloud affecting ion beam v_x vs x



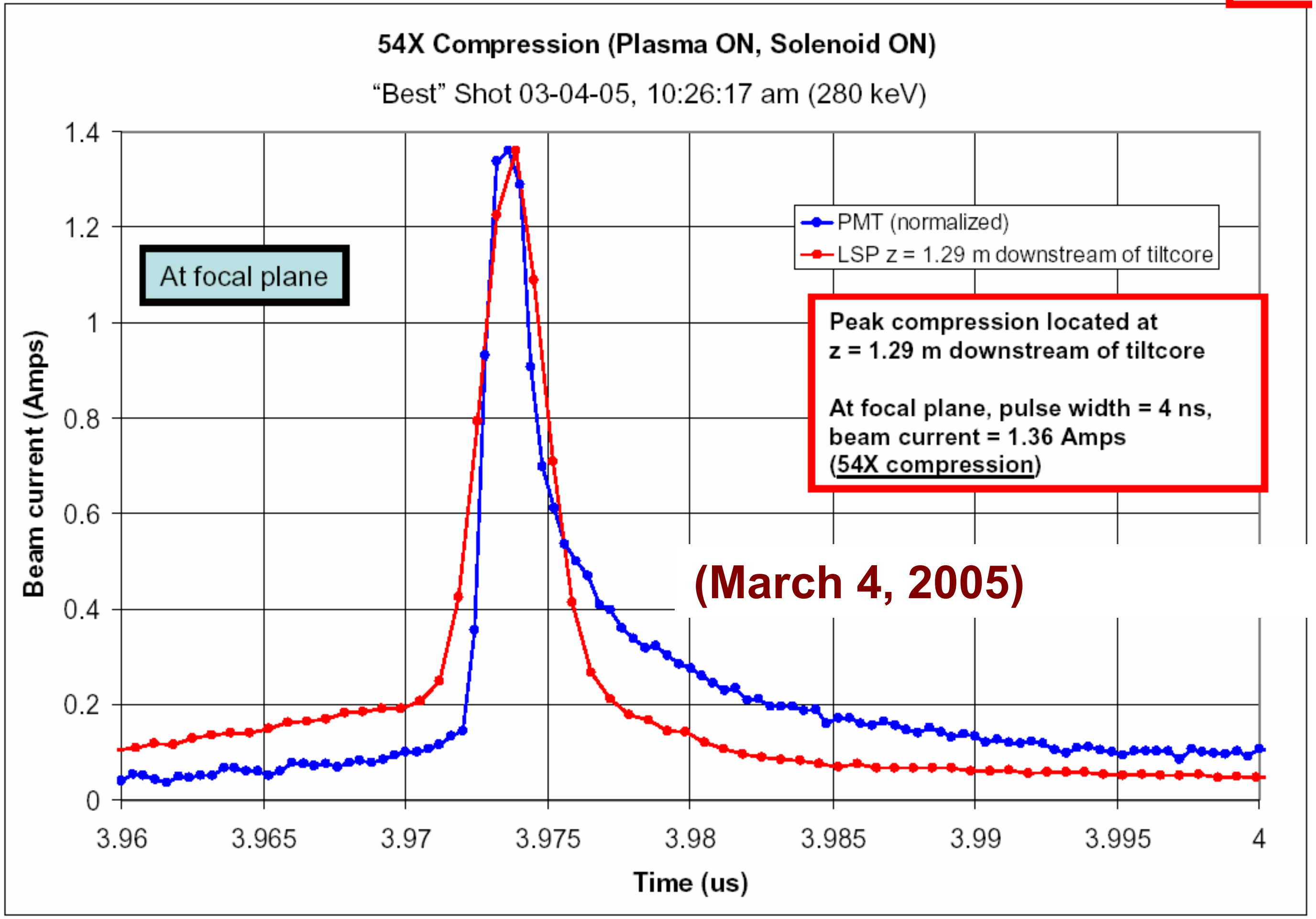
→This world-leading multi-species modeling capability is key to a predictive capability for electron cloud effects in any high intensity accelerator.

NDCX 1A data shows significant longitudinal drift compression (March, 2005; 4 ns FWHM)

SOLENOID ON

Experiment agrees with LSP near focal plane

17

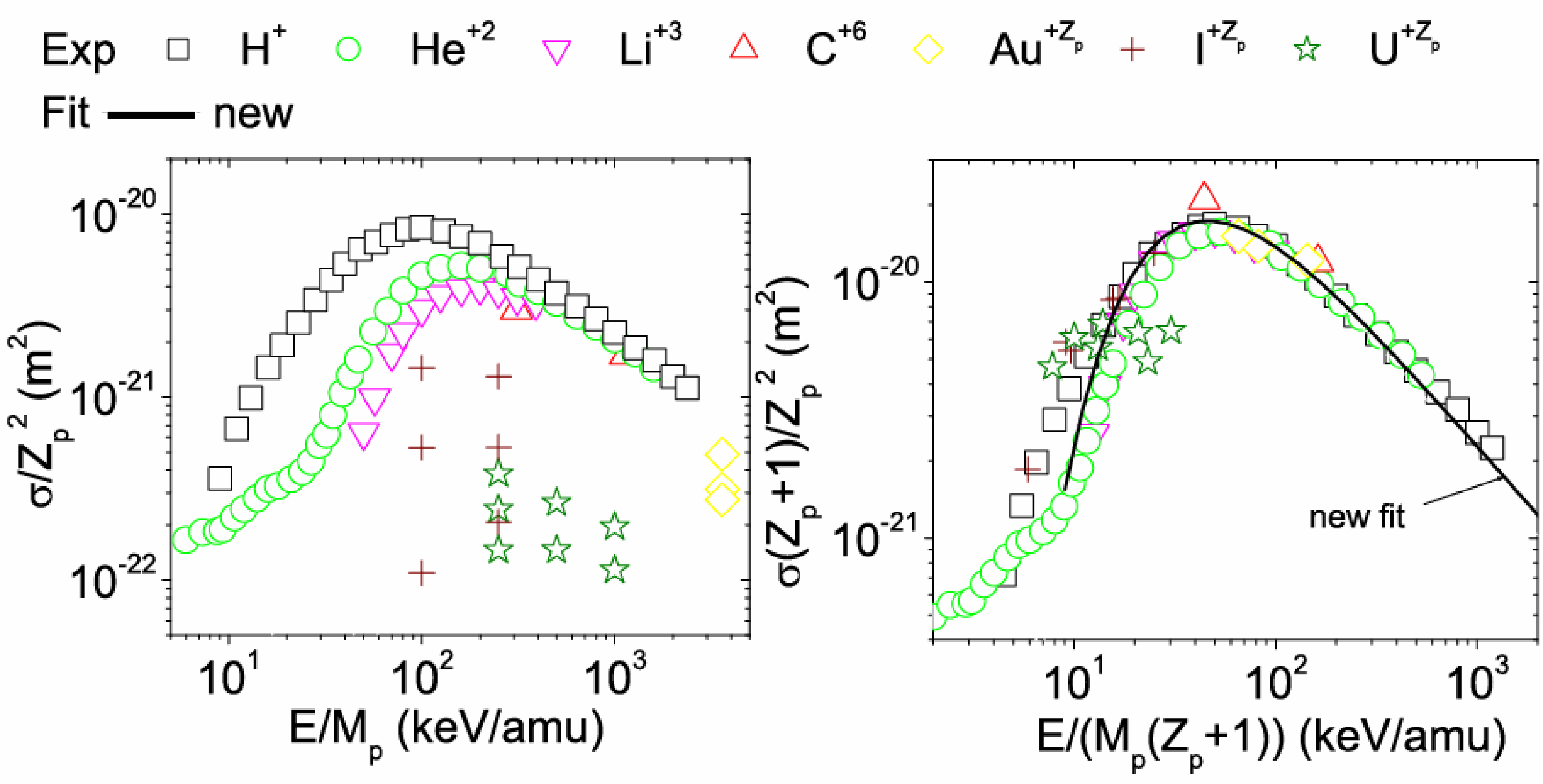


Peak compression located at z = 1.29 m downstream of tiltcore

At focal plane, pulse width = 4 ns, beam current = 1.36 Amps (54X compression)

(March 4, 2005)

A new scaling model has been developed that successfully fits the experimental data in a single plot



Ionization cross sections of He by ions with charge Z_p showing the experimental data: Left - raw data; Right - the scaled data.

See the three recent papers by I. Kaganovich, et al. at http://nonneutral.pppl.gov.

We have only begun to optimize compression - Many improvements are being explored

- Add high precision parallel energy analyzer (May 2005); measure errors in injector and tilt core waveforms which limit minimum pulse, to guide improve tilt waveform.

- Develop high precision solid state agile waveform modulators to fine tune tilt waveform and to compensate injection voltage errors.

- Redesign tilt core module to eliminate or compensate for radial variations in E_z®.

- Start with shorter pulse (<100 ns) injectors with improved precision variable-control current input $I(t)$ before tilt is applied.

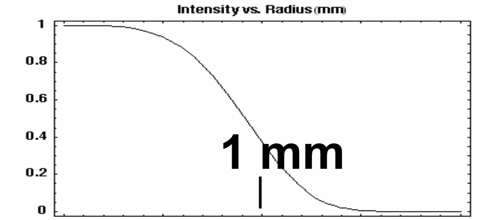
→No fundamental physics limit to pulses short enough for fast ignition (2ns for ion-drive-impact fast ignition; 0.2 ns for ion-direct fast ignition).

3D LLNL code HYDRA* has been used for ion beam - target interaction studies

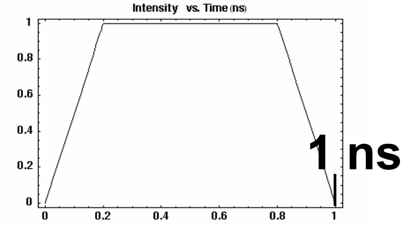
- State-of-the-art multi-physics radiation transport/ hydrodynamics code by M. Marinak and collaborators

-- Initial investigations (J. Barnard, G. Penn, J. Wurtele, P. Santhanam, A. Friedman, and M. Marinak) of ion beam interaction with foil targets

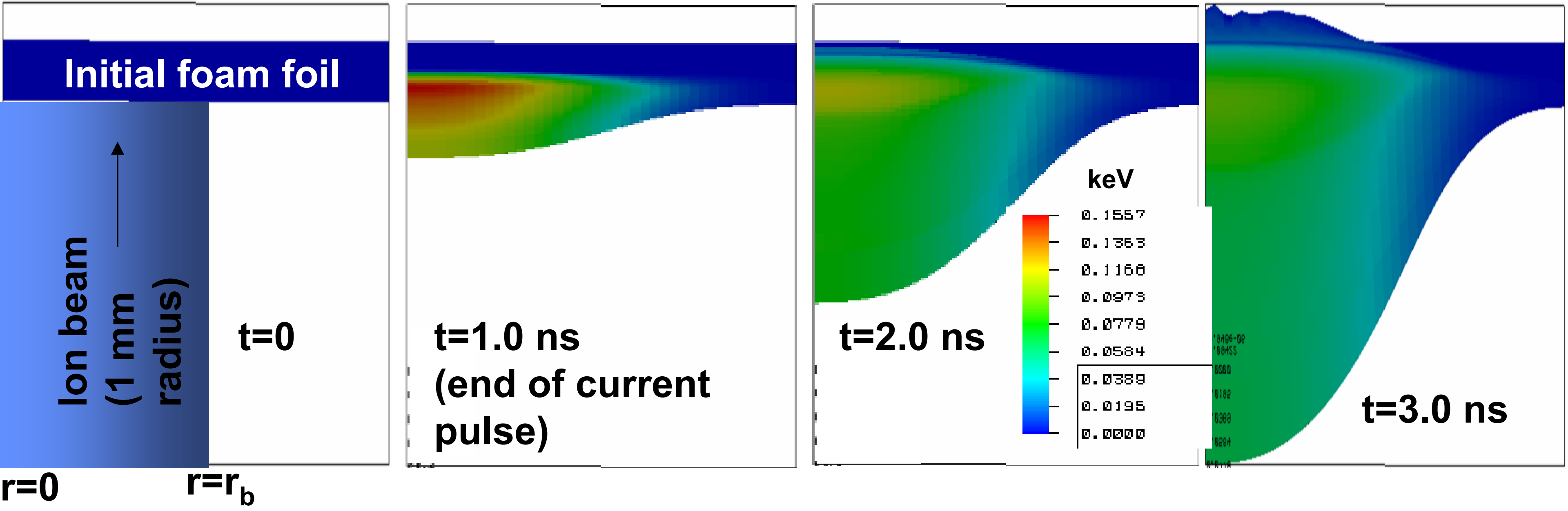
Power vs. radius:



Power vs. time:

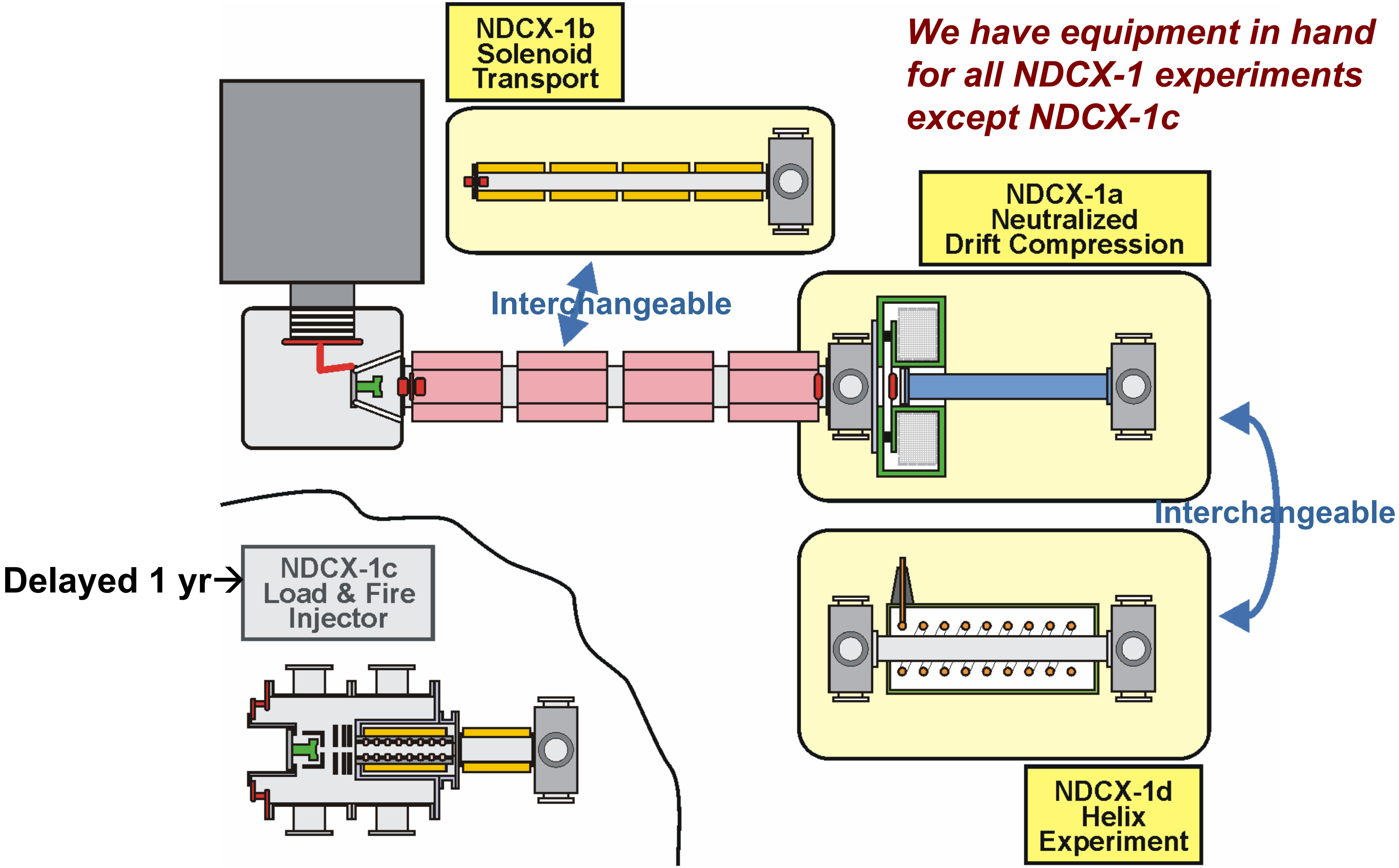


Example: Temperature contour plot for 20 MeV Ne beam hitting 10% Al foam foil



2D (r-z), time-dependent simulations; Intensity 100 X higher, foil 3 X thicker for illustration

NDCX-I: A series of experiments towards HEDP (NDCX-II)



We have equipment in hand for all NDCX-1 experiments except NDCX-1c

NDCX-1b
Solenoid
Transport

Interchangeable

NDCX-1a
Neutralized
Drift Compression

Interchangeable

NDCX-1d
Helix
Experiment

Delayed 1 yr→

NDCX-1c
Load & Fire
Injector

Timeline for next five years

Accomplishment 1
50-100 X compression
(NDCX-1A,1B) 2006-7

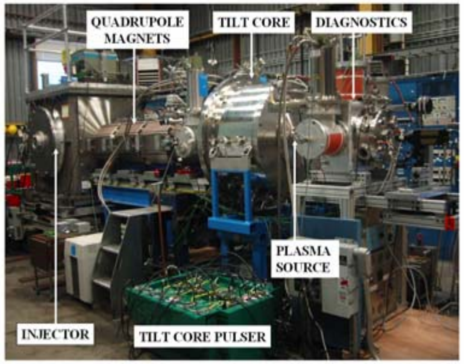
Accomplishment 2
PLIA beam acceleration
0.1 μC, 4 MeV
(NDCX-1C,1D) 2008-9

Accomplishment 3
Integrated compression, acceleration, focusing & target heating to 1 eV
(NDCX-II) 2010-11

2005

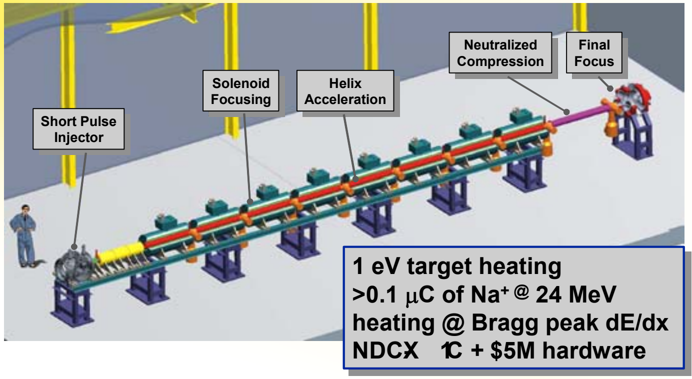
HEDP/fusion

2010



Compression

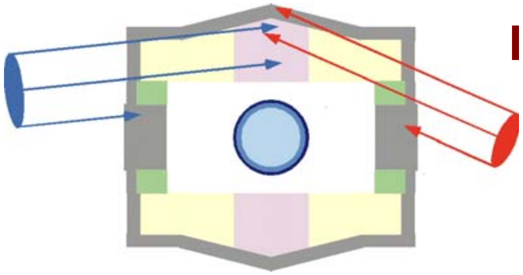
Acceleration



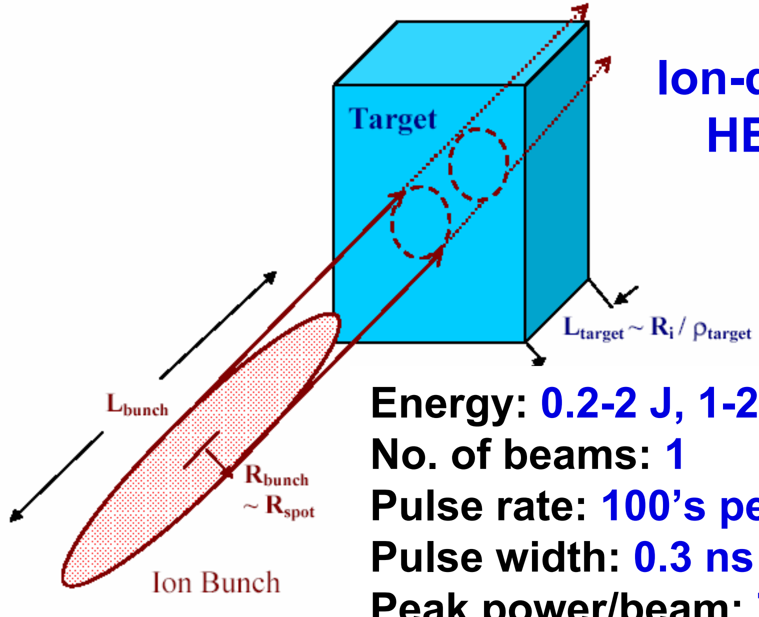
1 eV target heating
>0.1 μC of Na^+ @ 24 MeV
heating @ Bragg peak dE/dx
NDCX 1C + $5M hardware

First focus to 1 eV targets

Ion-driven targets for IFE and HEDP require common beam physics: High-brightness injection and acceleration with precision waveforms; Electron cloud control; Longitudinal bunch compression; and Beam neutralization in chamber



Ion-driven IFE



Ion-driven HEDP

Energy: 7 MJ, 4 GeV
No. of beams: 120
Pulse rate: 5 Hz
Pulse width: 8 ns
Peak power/beam: 5 TW
Focal spot radius = 2 mm
@ 6 meters focal length
Peak deposition 10^{12} J/m^3
(*per beam, into foam radiators*)

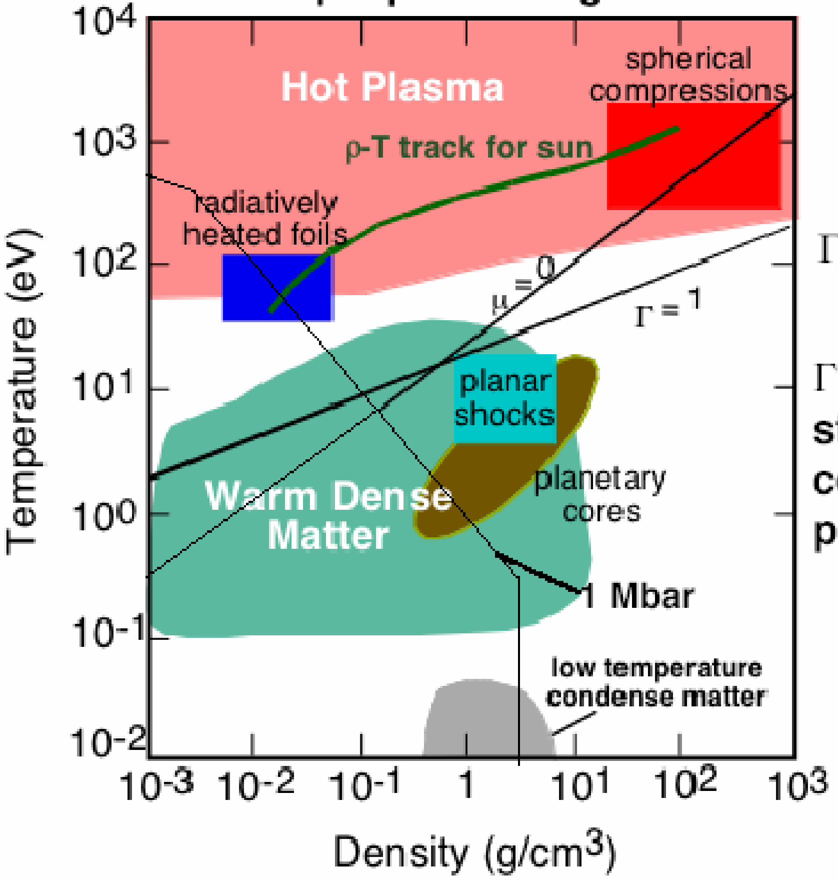
Energy: 0.2-2 J, 1-2 MeV
No. of beams: 1
Pulse rate: 100's per day
Pulse width: 0.3 ns
Peak power/beam: 7 GW
Focal spot radius: 0.5-1 mm
@ 10 cm focal length
Peak deposition 10^{11} J/m^3
(*for 1 Mbar, 1 eV, WDM*)

A key new requirement for HEDP is sub-ns pulses (needs neutralized drift compression as well as chamber neutralization).

High Energy Density matter is interesting because it occurs widely

- **Hot Dense Matter (HDM) occurs in:**
  - Supernova, stellar interiors, accretion disks
  - Plasma devices: laser produced plasmas, Z-pinches
  - Directly driven inertial fusion plasma
- **Warm Dense Matter (WDM) occurs in:**
  - Cores of large planets
  - Systems that start solid and end as a plasma
  - X-ray driven inertial fusion implosion

H ρ-T phase diagram



$$\Gamma = \frac{q^2 n^{1/3}}{kT}$$

$\Gamma > 1 \Rightarrow$ strongly coupled plasmas

HEDP definition: U> 10^{11} J/m^3; P> 1 Mbar; kT > 1eV

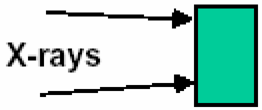
HEDP science would benefit from a variety of facilities offering different tools, shots on demand, and accessible locations for students and researchers

WDM regimes are presently accessed by heating a solid (most useful) or compressing/ shock heating a gas. Volume and uniformity set limits to accuracy of EOS measurements.

- Foils preheated by hard x-rays

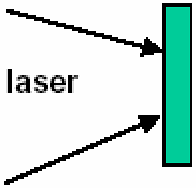
XFEL heating uniform but small volumes (10's of millijoules). High range electrons can heat < 1 mm spots –but too small for diagnostics

- Supersonically heated foams or low Z materials (thermal x-rays)



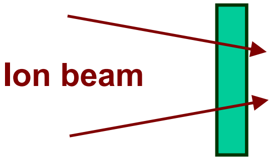
MJ of soft-x-rays available on Z but limited number of shots

- Shock compressed and heated thin foils



Lasers absorb at critical density << solid density→ large density/ pressure gradients

- Ion heated thin foils



Fast heating of a solid with penetrating ions →lower gradients→ more accurate EOS

- 100TW lasers →10-50 mJ, ps ion bunches →large energy spreads, non-uniform deposition
- GSI-SIS-100 plans 10-40 kJ of ions @100GeV,100 ns→ large volumes but limited T < 1 eV