Ion Beam Heating and Diagnostics - I

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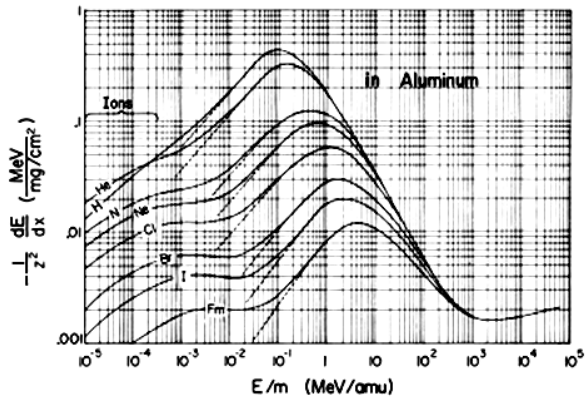
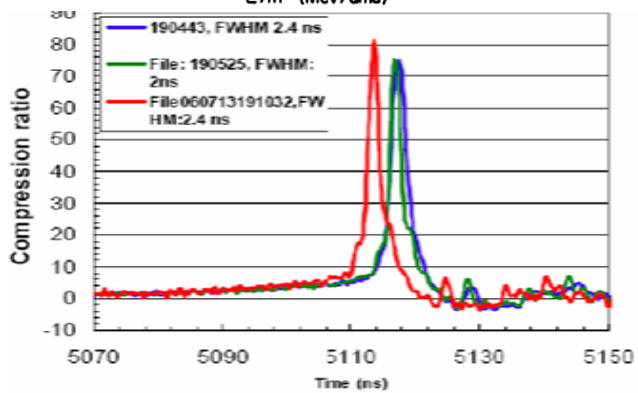
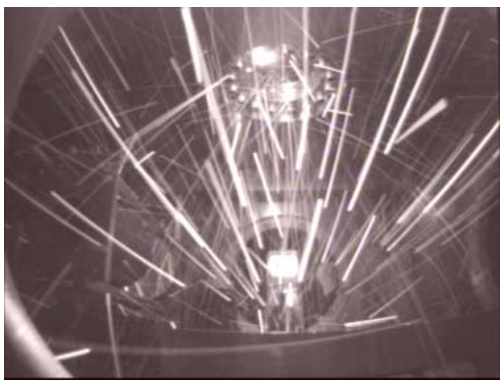
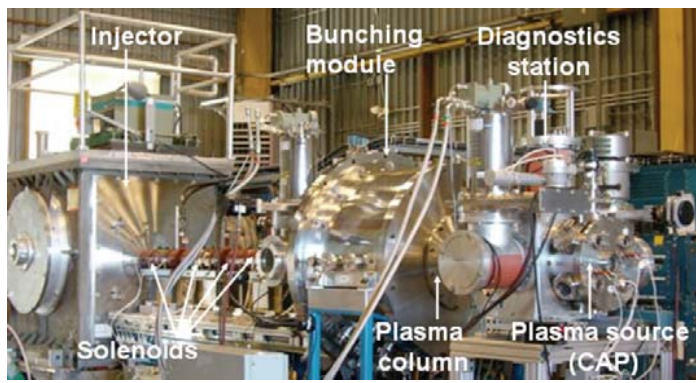
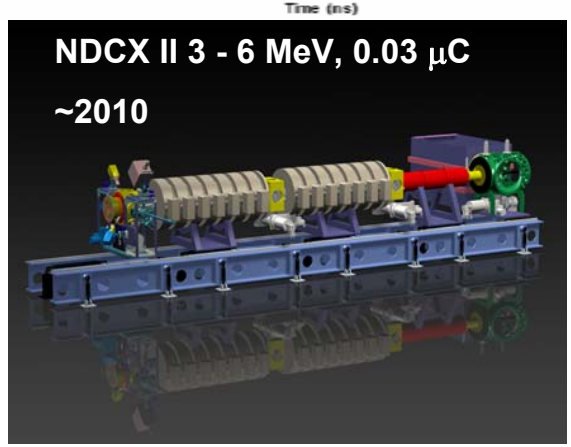










Outline of talk

Heavy Ion Fusion Science experiments:

The physics of compressing beams in space and time

-- Ion-driven WDM

-- Accelerator technology

-- Drift compression and final focus

Warm Dense Matter (WDM) experiments

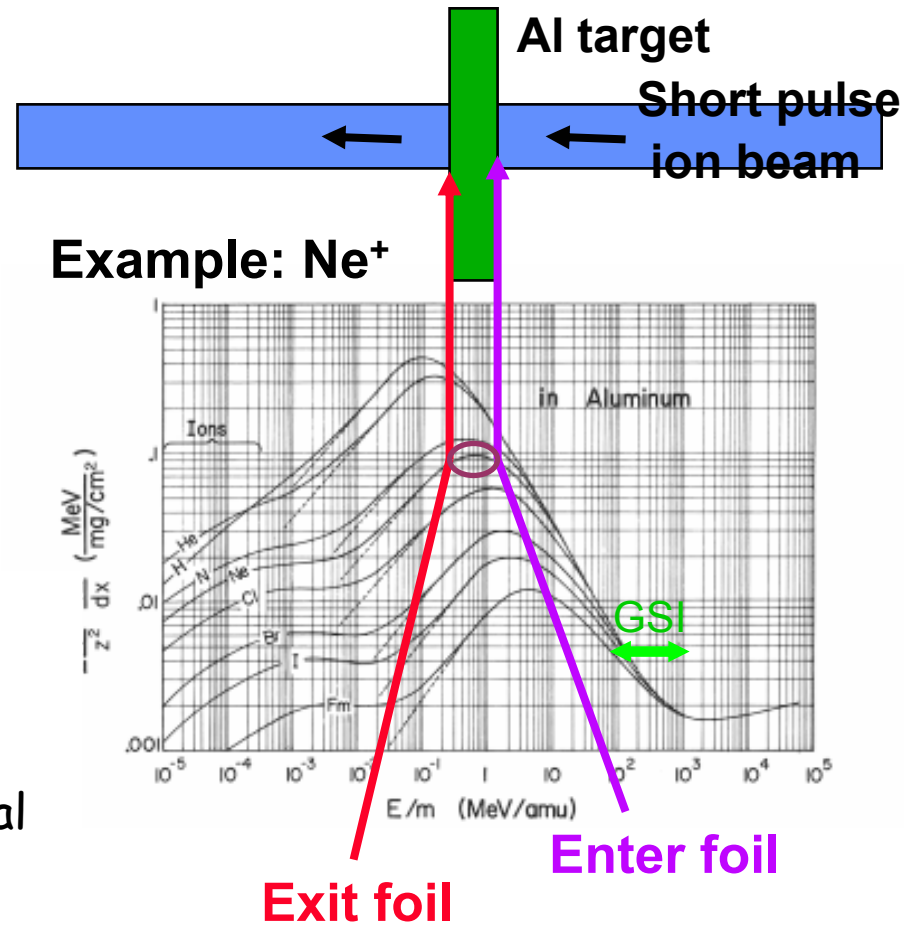
-- WDM target chamber and diagnostics

-- Experimental plan

-- GSI experiment with porous targets

Ion beams provide an excellent tool to generate homogeneous, volumetric warm density matter.

- Warm dense matter (WDM)
  - T ~ 0.1 to 10 eV
  - ρ ~ 0.01 -1 * solid density
- Techniques for generating WDM
  - High power lasers
  - Shock waves
  - Pulsed power (e.g. exploding wire)
  - Intense ion beams
- Some advantages of intense ion beams
  - Volumetric heating: uniform physical conditions
  - High rep. rate
  - Any target material



WDM strategy: maximize uniformity and the efficient use of beam energy by placing center of foil at Bragg peak.

Ion beam driven HEDP/WDM has unique characteristics.

Precise control of energy deposition

Large sample sizes compared to diagnostic resolution volumes (~ 1's to 10's μ thick by ~ 1 mm diameter)

Uniformity of energy deposition (<~ 5%)

Ability to heat all target materials (conductors and insulators, foams, powders, ...)

Pulse long enough to achieve local thermodynamic equilibrium

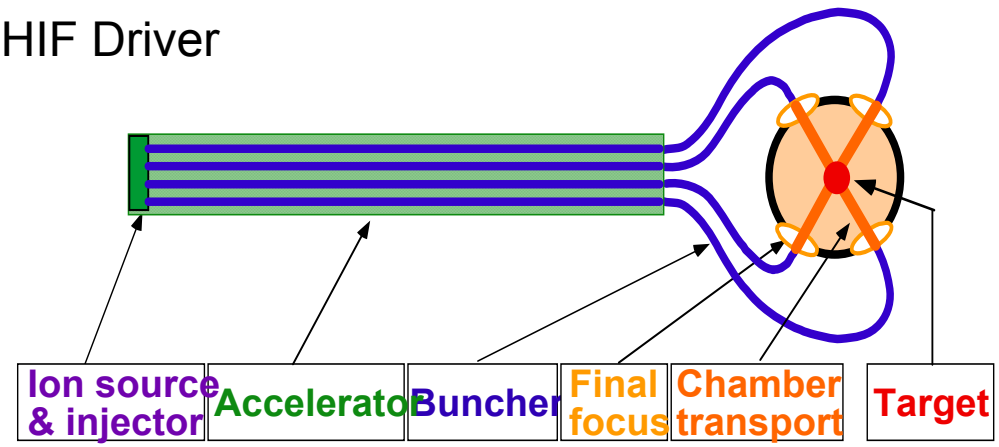
A benign environment for diagnostics

High shot rates (10/hour to 1/second)

Potential for multiple beamlines/target chambers

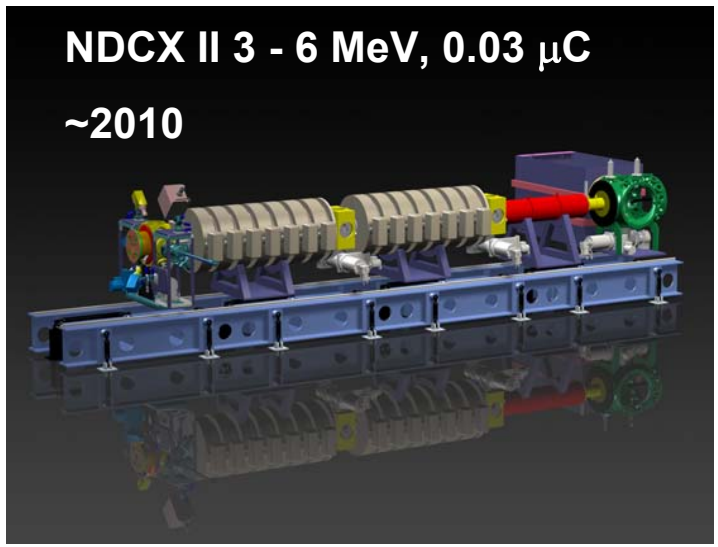
The HIF Driver/WDM experiments require beam compressions to hit mm-sized spot with ns pulse.

HIF Driver

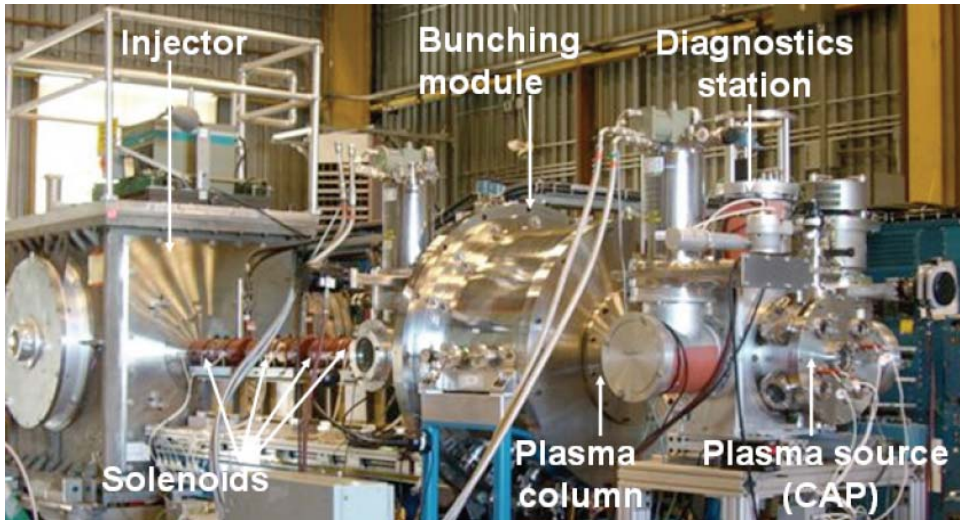


	HIF Driver	WDM
Beam	~40 kA (~4GeV)	~30A (3-6MeV)
Beam number	~120	1
Focal spot	2 mm	1 mm
Pulse length	~10 ns	~1 ns

One concept of WDM facility: NDCX-II



HIFS-VNL accelerators for WDM experiments



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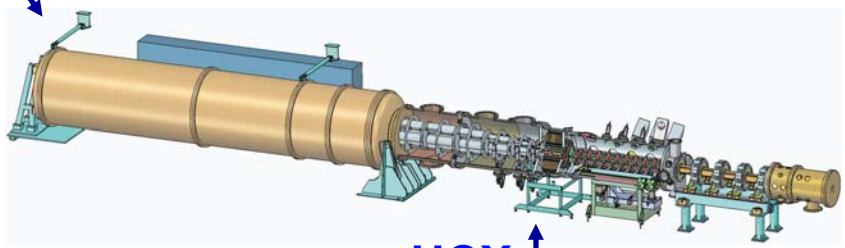


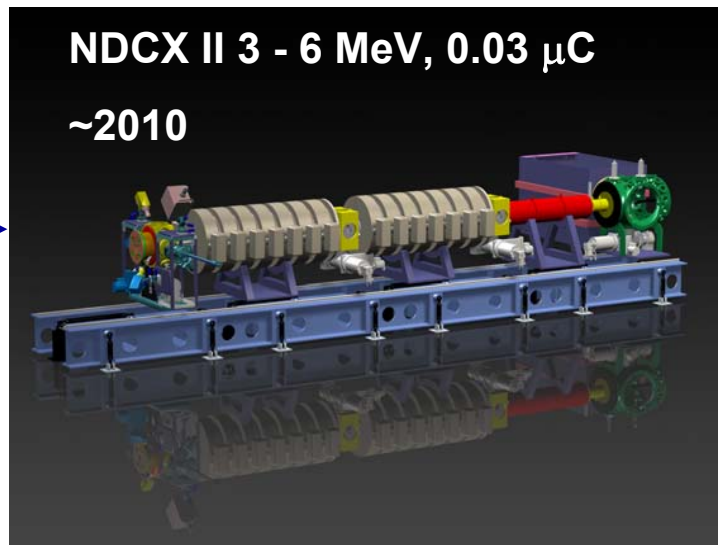
HCX

1.7 MeV, ~0.025 μC

NDCX I

0.4 MeV, 0.003 μC

Soon



Future

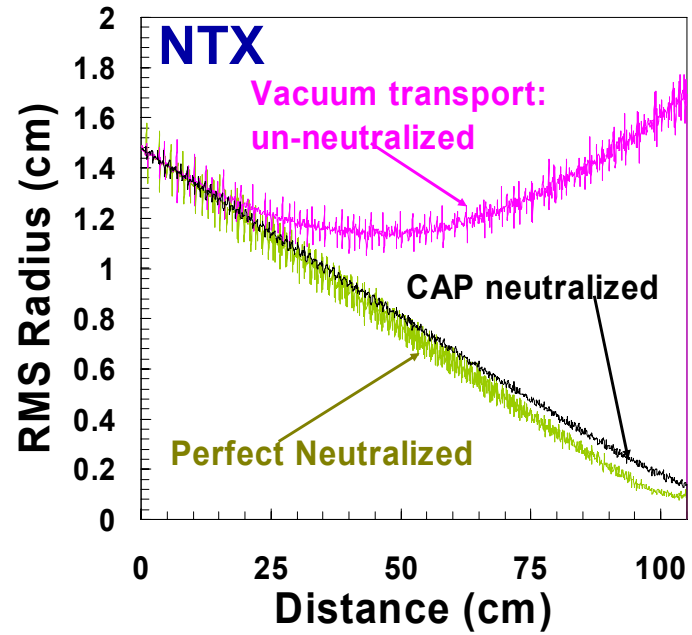
IB-HEDPX (with CD0)
5 - 15 year goal
20 - 40 MeV, 0.3 - 1.0 μC
WDM User facility

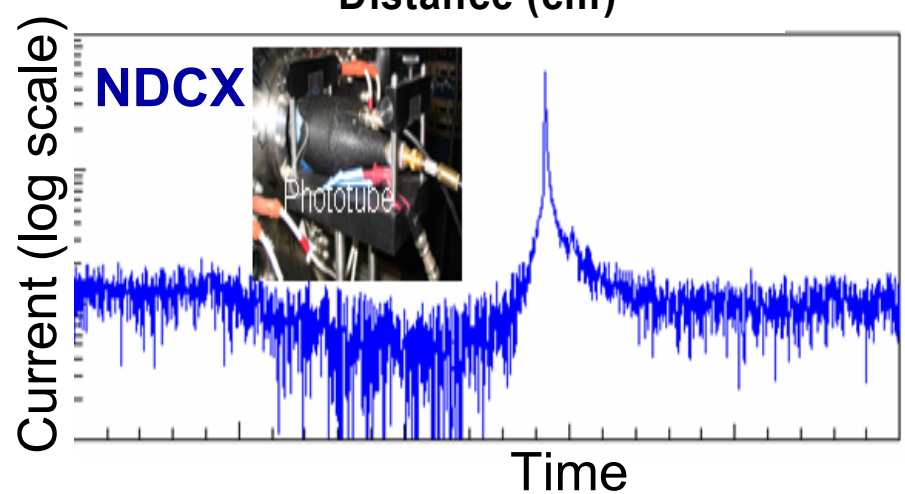
10 kJ Machine for HIF
10 - 20 year goal
Target implosion physics

Neutralized beam transport (NTX) & drift compression (NDCX) can provide ~mm spot with ~nsec pulse.

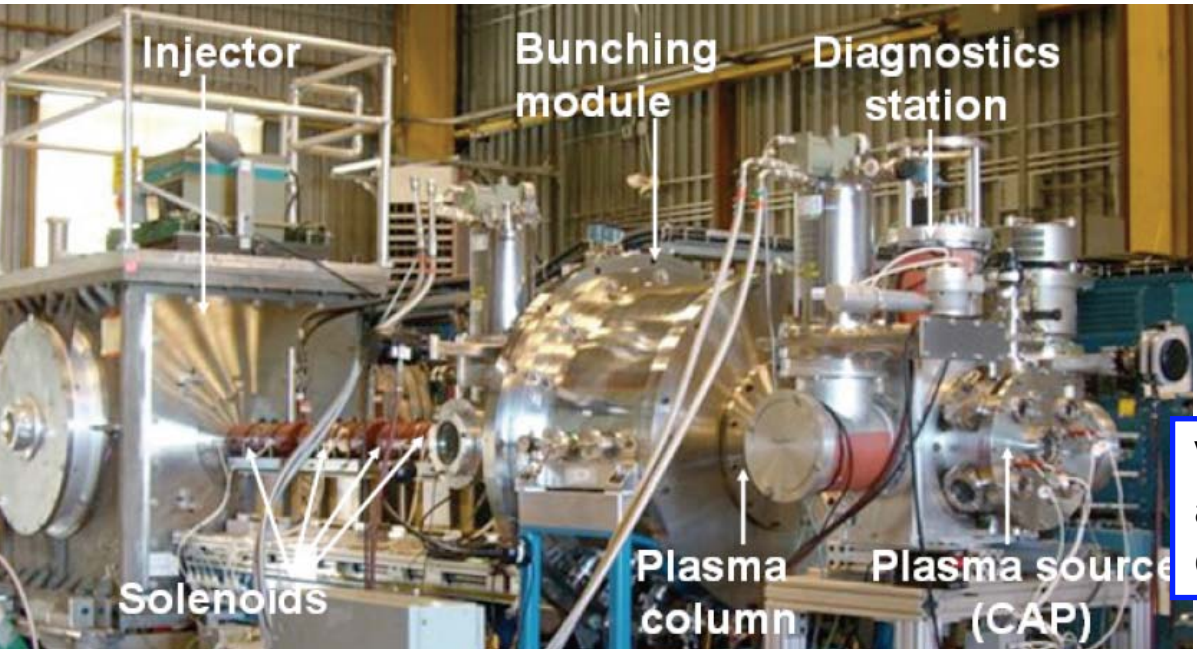
- **NTX**: In beam neutralization, electrons from a plasma or external source are entrained by the beam and neutralize the space charge sufficiently that the pulse focuses on the target in a nearly ballistic manner to a small spot.

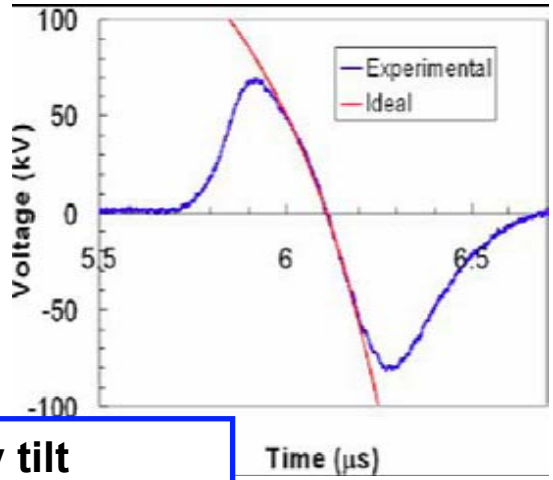
- **NDCX**: In neutralized drift compression beam is longitudinally compressed by imposing a linear head-to-tail velocity tilt to a drifting neutralized beam and producing a pulse duration of several ns.



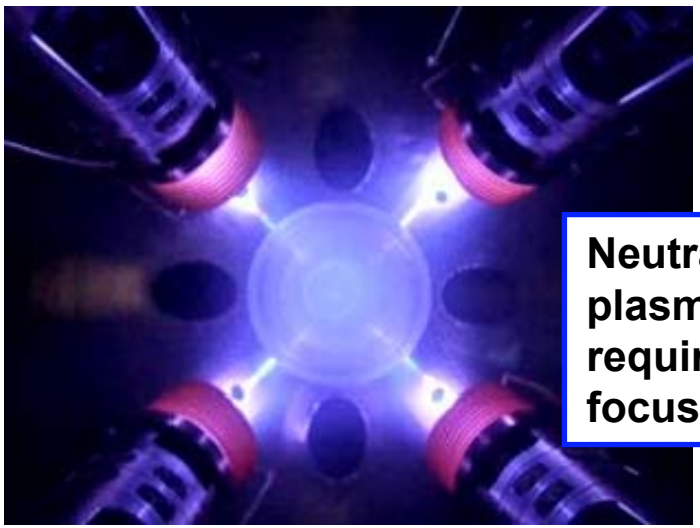


NDCX-1 has demonstrated factor ~70 pulse compression, and simultaneous transverse and longitudinal focusing

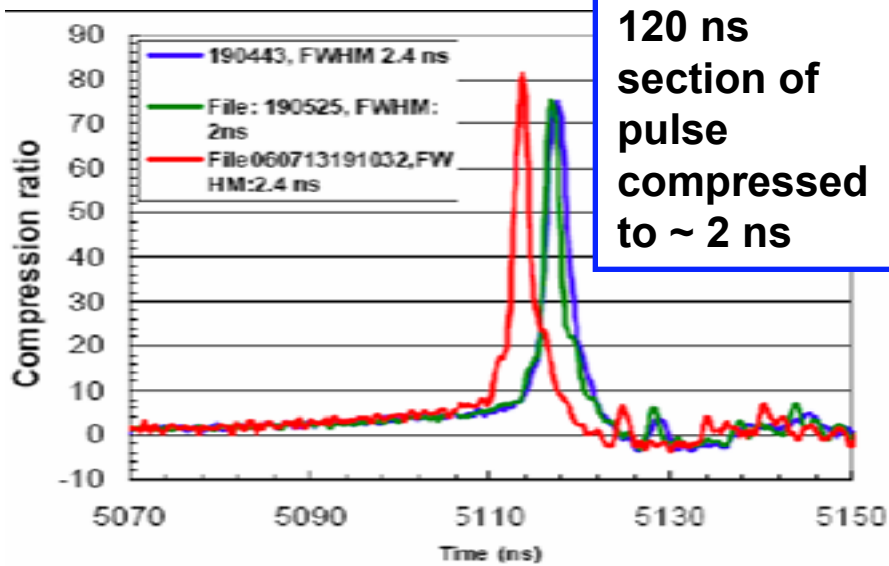




Velocity tilt accelerates tail, decelerates head

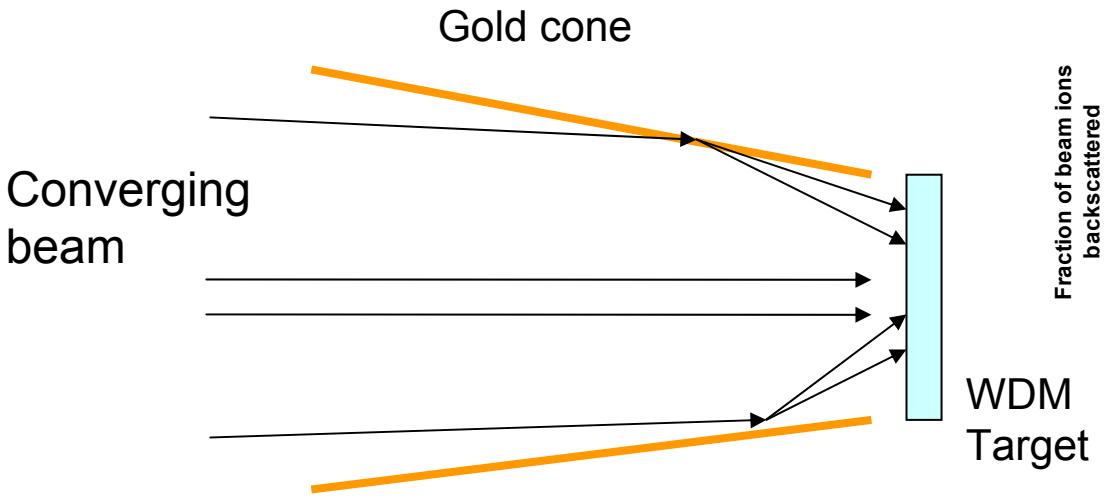


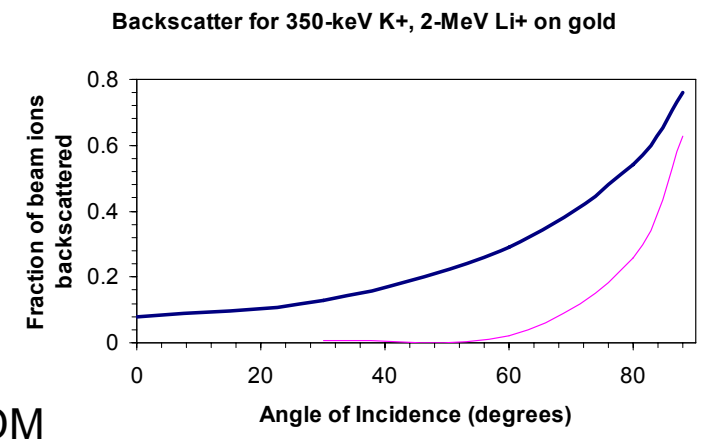
Neutralizing plasma is required for final focus



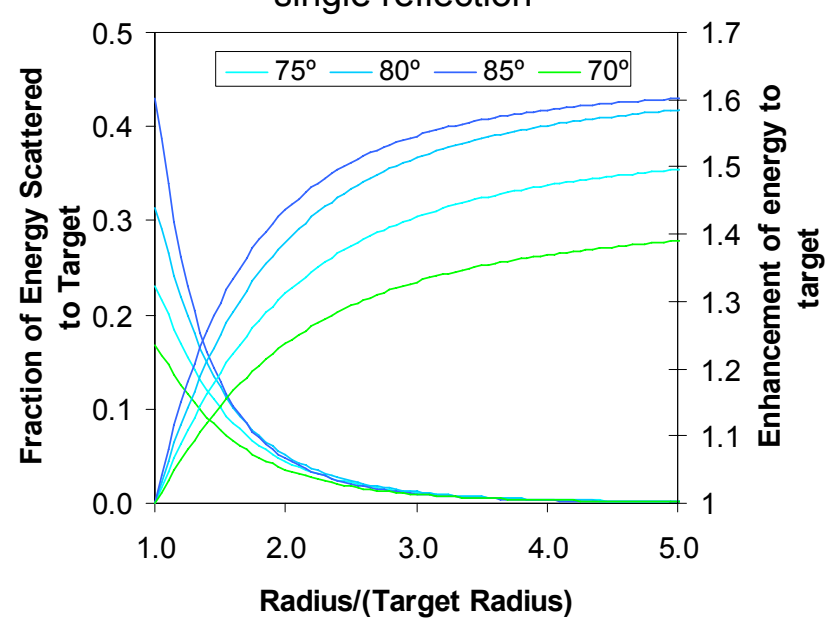
120 ns section of pulse compressed to ~ 2 ns

Concentration of ion beam using funnel (cone) provides a new path to increasing energy density on target.



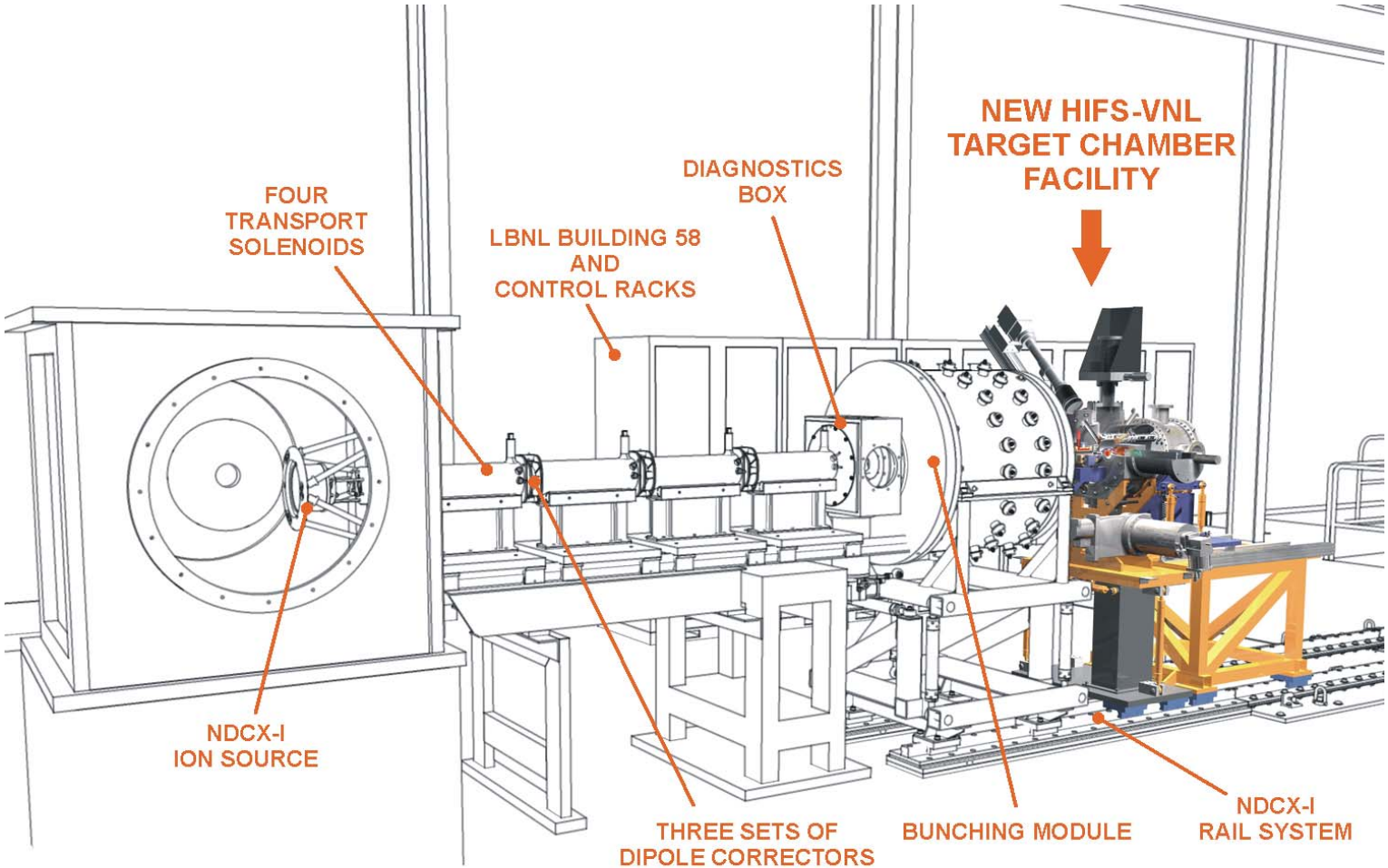


TRIM calculations for a single reflection



- **Cone acts as grazing incidence mirror. Beam particle reflection coefficient is 80% at 89° incidence.**
- **Space charge neutralization of beam electric field, electron production.**
- **40% measured increase in intensity with 200 mrad (79°) gold cone.**
- **Greatly improved beam concentration in grazing incidence and scattering geometries may be possible.**

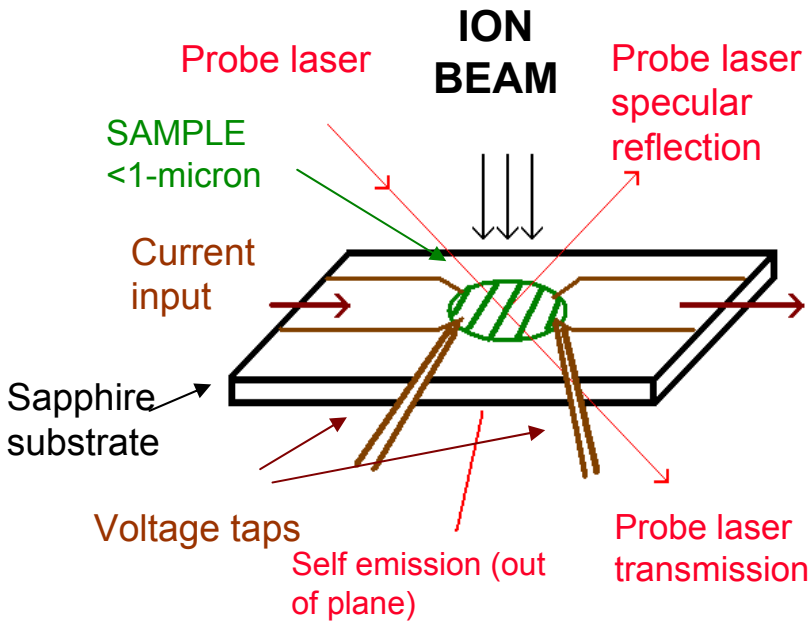
View of the new HIFS-VNL target chamber facility installed on NDCX-I.



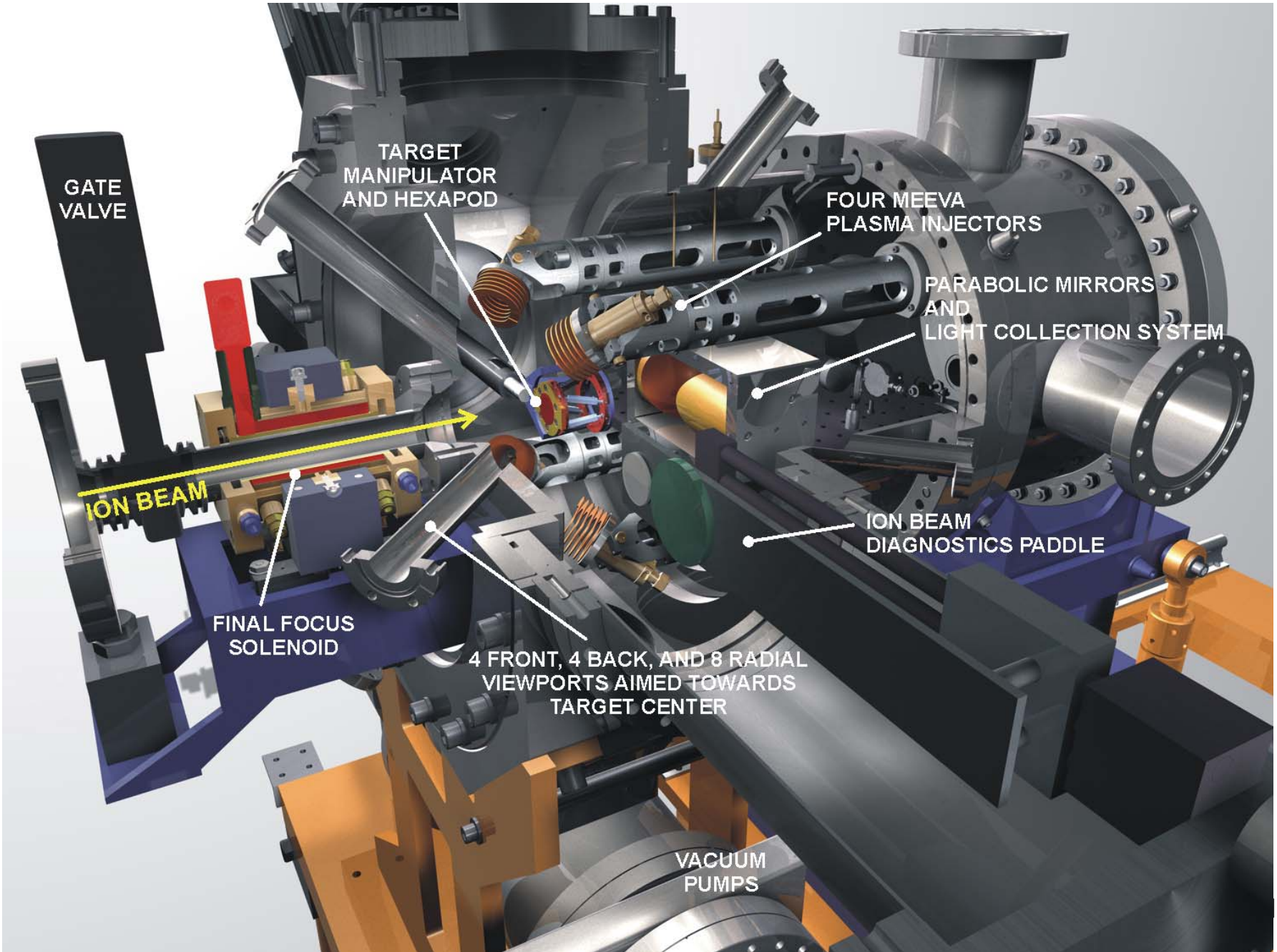
Near-term experiments provide opportunity to gain experience with diagnostics on WDM targets.

Initial diagnostics will include

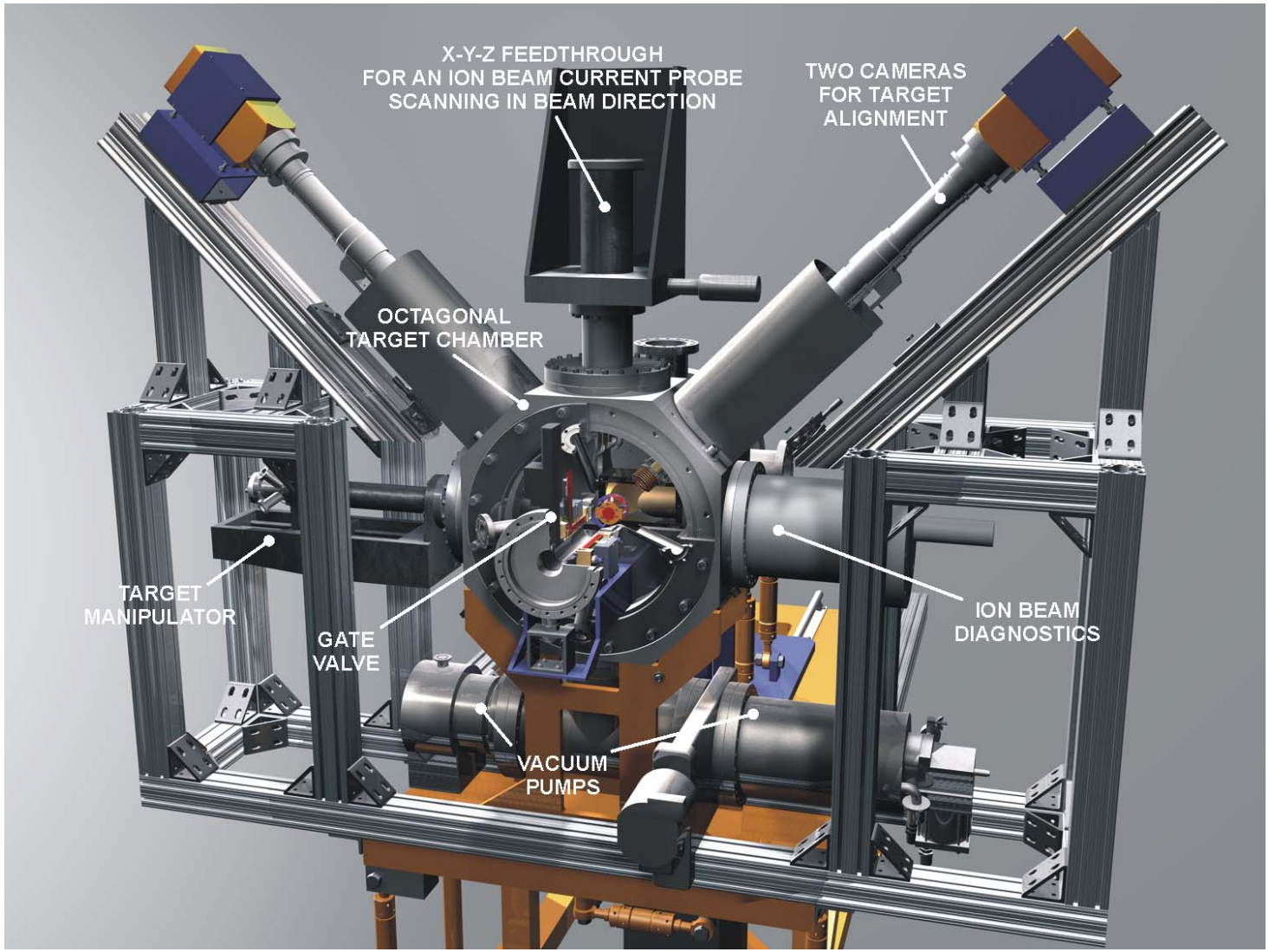
- Visible light emission, especially optical pyrometer
- Electrical conductivity, optical absorption provide information on target temperature and phase transitions
- Stopping power
- Laser, VISAR probes



WARM DENSE MATTER EXPERIMENTS TARGET CHAMBER



Front view of the octagonal shaped target chamber. The target is mounted in the exact center of the chamber with the ports aiming at the target location.

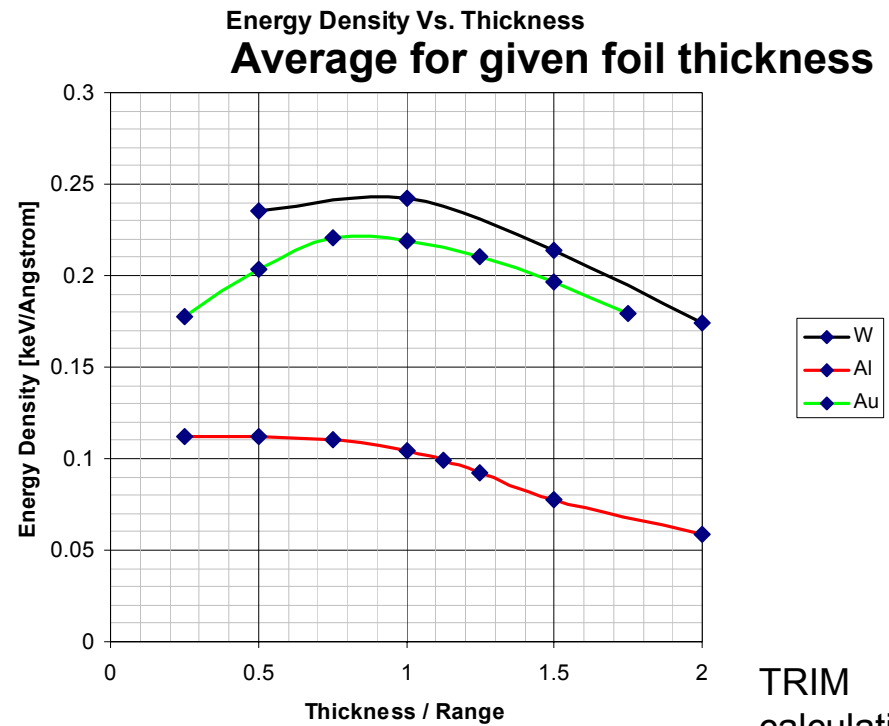


Initial set of target experiments on NDCX-1 will take place in next few months.

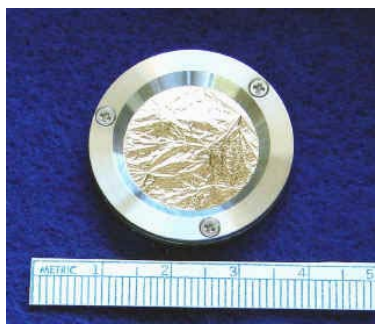
- Initial set of targets is on hand

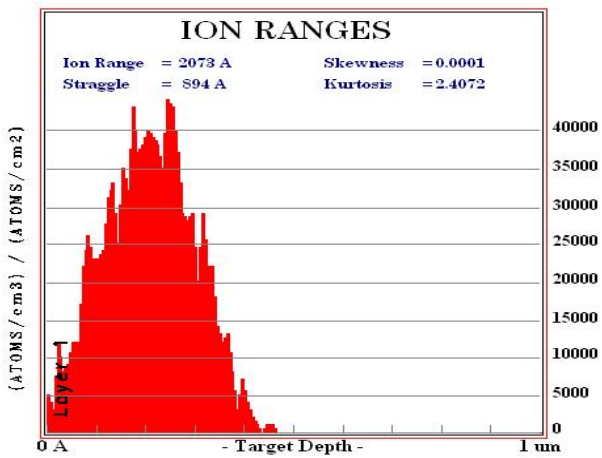
- Deposited layers on sapphire substrate
  - Al: 350 nm (1.2 x range)
  - Au: 150 nm (1.4 x range)
  - W: 150 nm (1.5 x range, for pyrometer calibration)

- Free-standing foils
  - 350-nm Al
  - 150 nm Au



TRIM calculations





HYDRA simulations of the NDCX-1 experiment

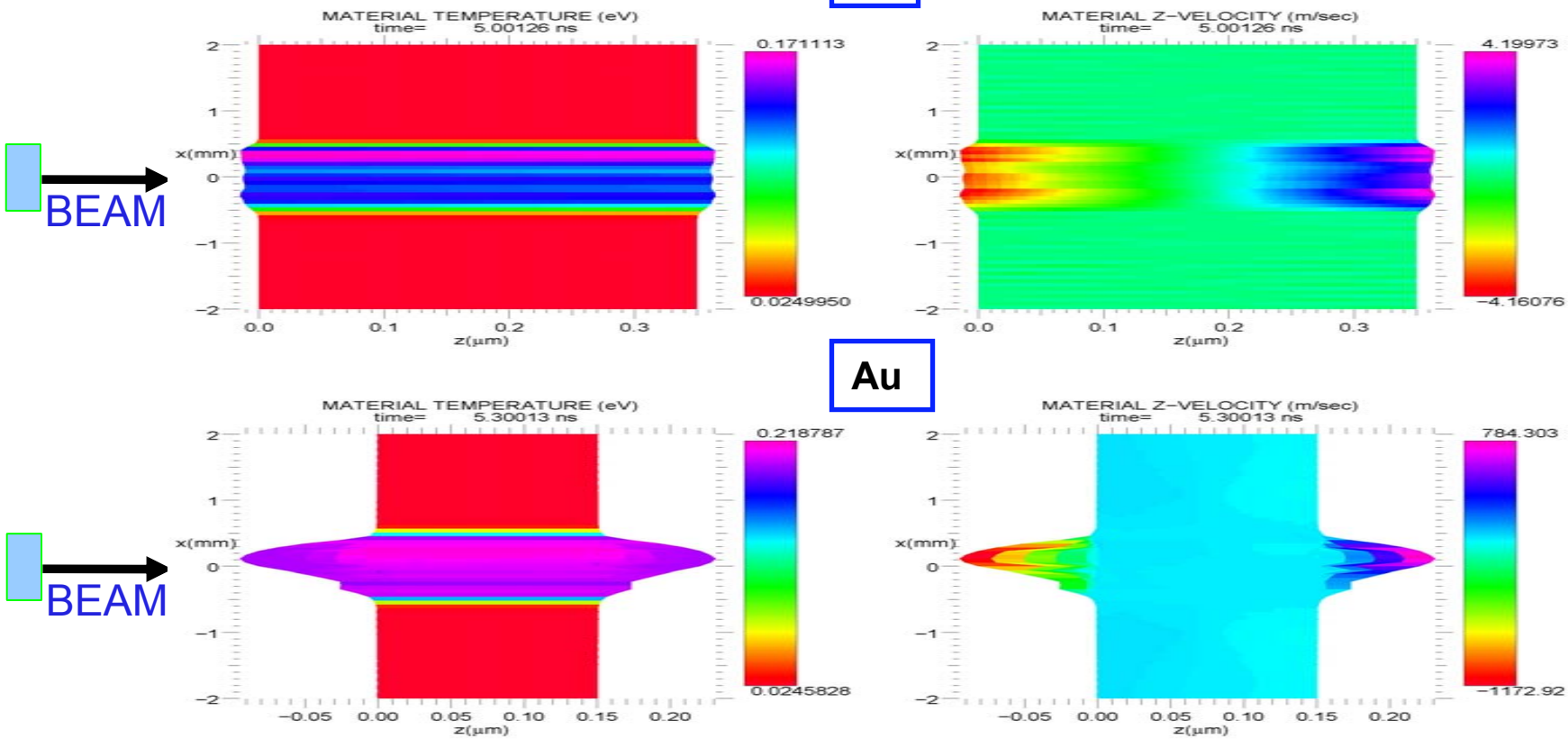
2A, 2 ns, 1 mm diameter, 350 keV K^+ beam will heat up a 350 nm solid aluminum target to ~ 0.16 eV, and a 150 nm solid gold target to ~ 0.2 eV. The simulation assumes a uniform transverse beam profile and EOS from QEOS for aluminum and SESAME tables for gold.

The (transverse) non-uniformity of the profiles is due to the small number of sampled beam rays.

Temperature profile

Al

Axial velocity profile



Au

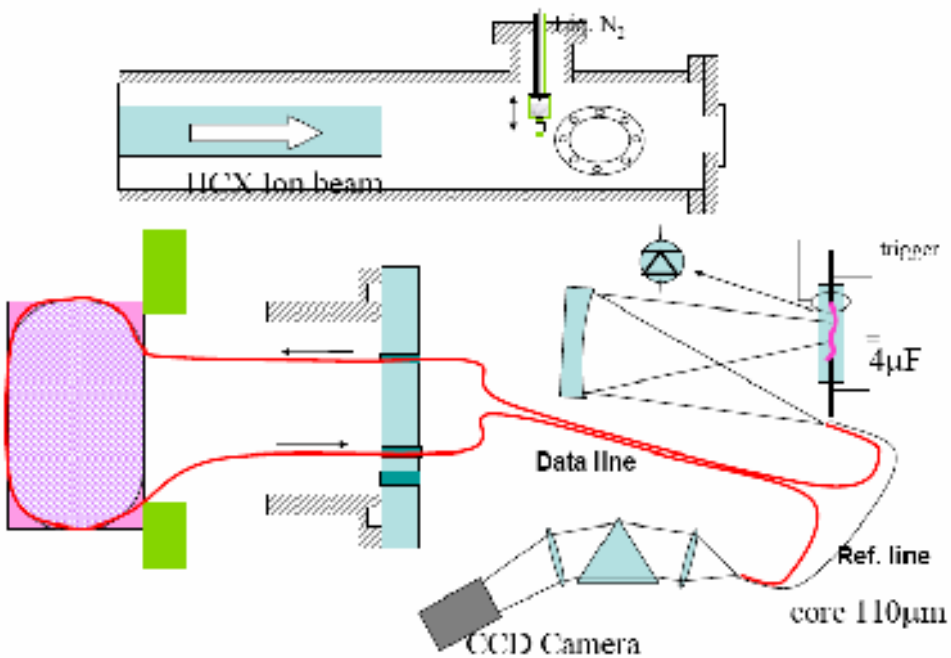
We have begun a series of warm dense matter experiments that can begin on NDCX-I at Temperature < 1 eV.

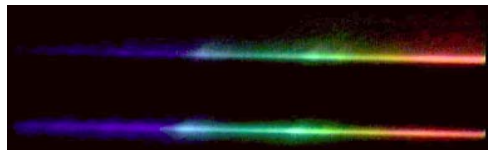
	Target temp.	NDCX-1 or HCX	NDCX-2
Transient darkening emission and absorption experiment to investigate previous observations in the WDM regime	**Low (0-0.4 eV)**	√	
Measure target temperature using a beam compressed both radially and longitudinally	**Low**	√	
Thin target dE/dx, energy distribution, charge state, and scattering	**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**		√

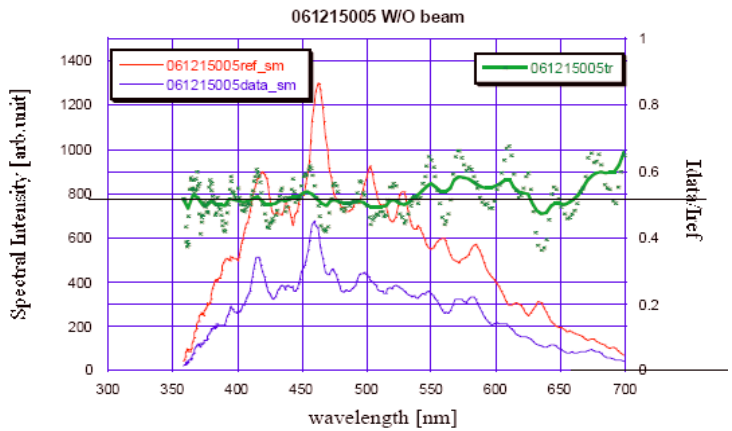
time

Also: low density porous targets, wire arrays, etc.

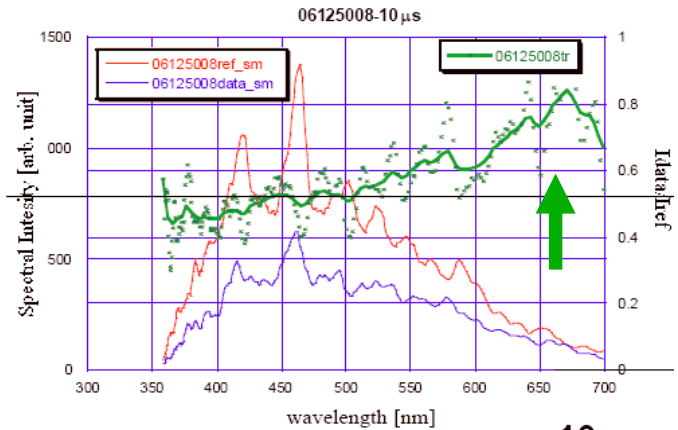
Transient optical transmission experiments in quartz fiber performed on HCX (1 MeV K^+ ion beam).







No beam

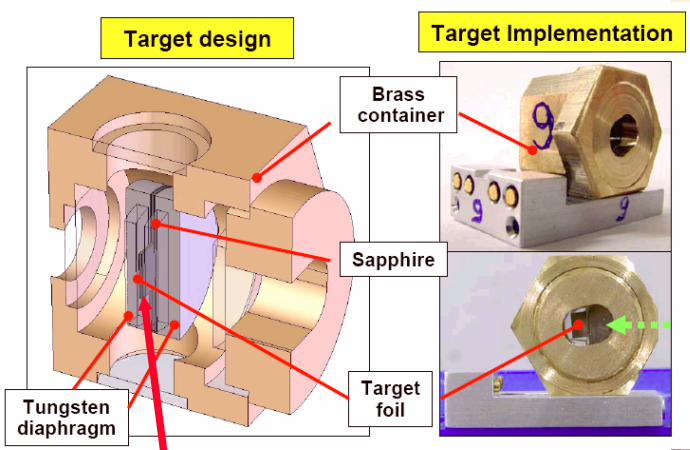


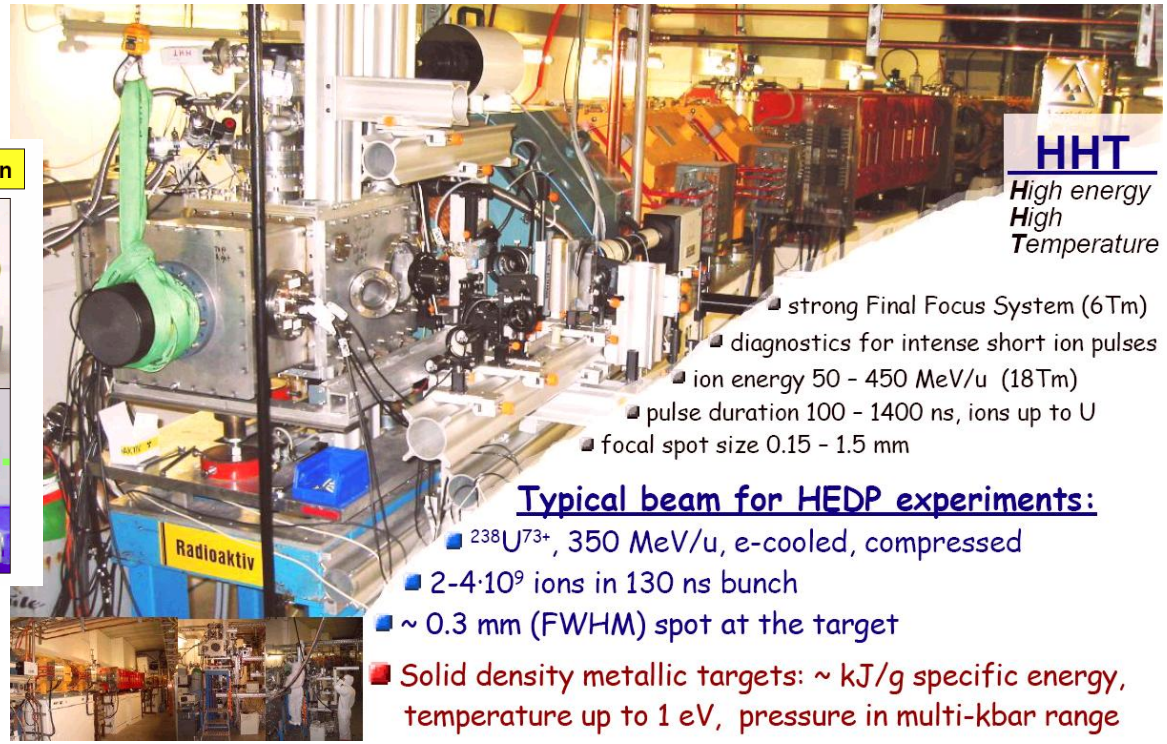
10μs

Optical transmission experiment: look for difference in fiber transmission with and without beam.

Initial experiment shows possible weak effect at 10 μs, long wavelengths ➔

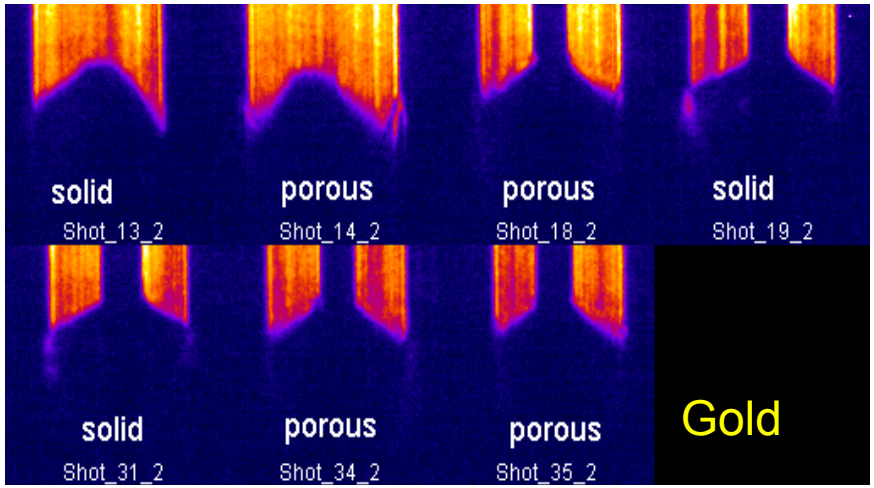
Porous target beam-driven experiment Dec. 2006 at GSI.

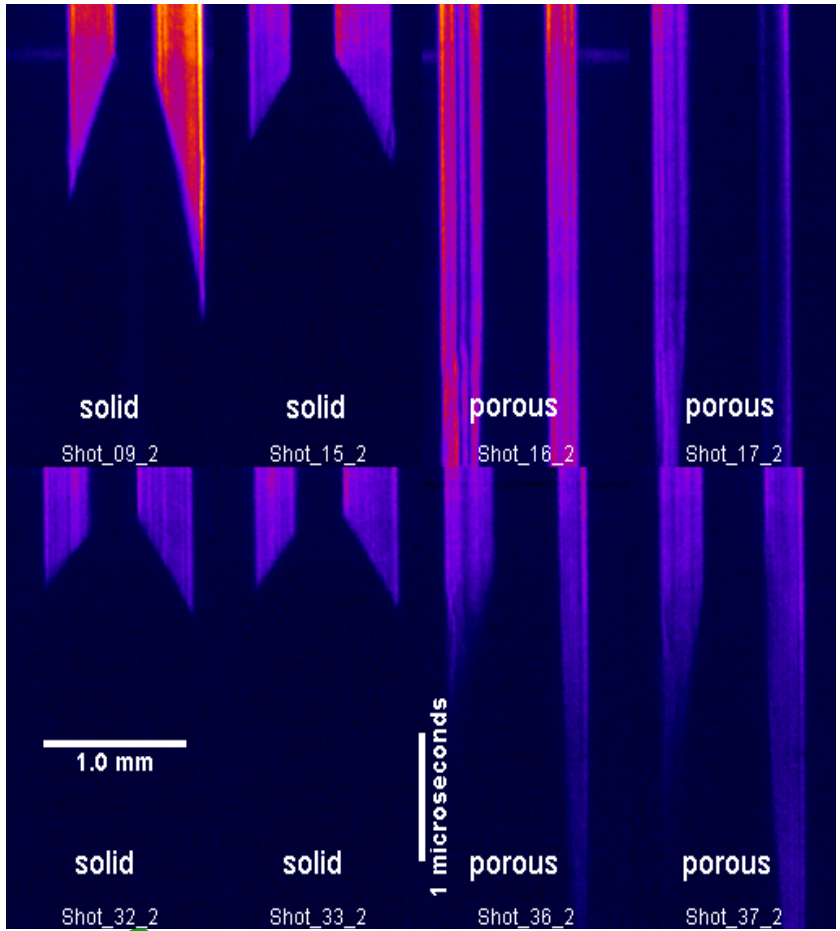




- Replace target foil with porous material.
- Study effect of pore size on target behavior using existing diagnostics.
- HIFS-VNL targets: Au, 50 nm, Cu, 50 micron.

Streak camera data shows expansion of the targets solid/porous gold and copper targets.

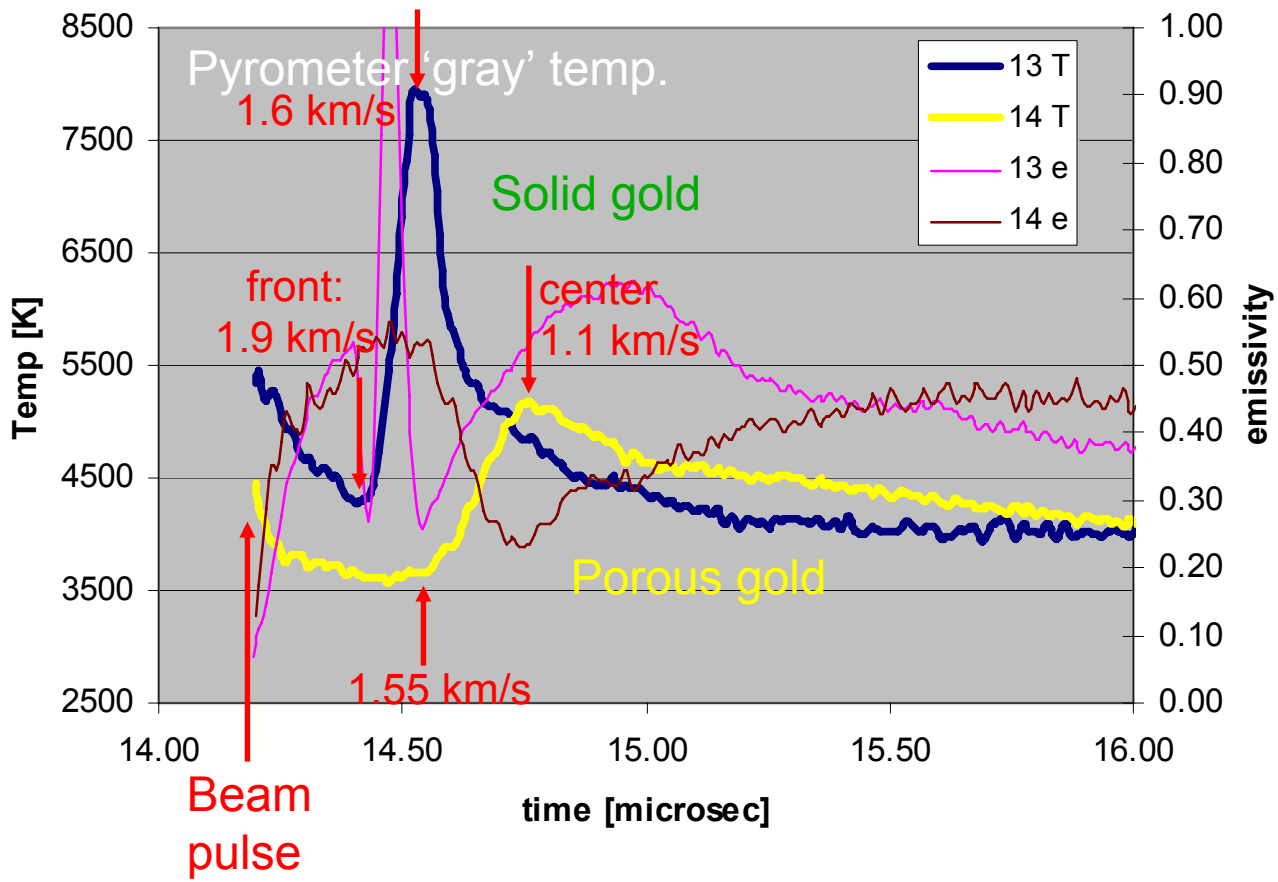




Copper

Pyrometer data for gold targets.

- Solid gold is initially heated 1000 deg. hotter than porous gold. The solid gold also expands into the sapphire window much more rapidly than the porous gold (shots 13 and 14). At late times the temperatures of the two targets come together. (T-boil = 2435 K)



Conclusion

- Ion beams provide a new tool to generate homogeneous, volumetric WDM.
- Development plan uses existing accelerators and pulse compression technique developed in HIFS-VNL. We have built a target chamber.
- We are developing and fielding target diagnostics on the target chamber (to be described by Pavel Ni).
- Initial experiments performed at GSI; experiments specified at LBNL; initial set of targets are in hand; target modeling is underway.