Heavy ion beam driven warm dense matter experiments

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Introduction

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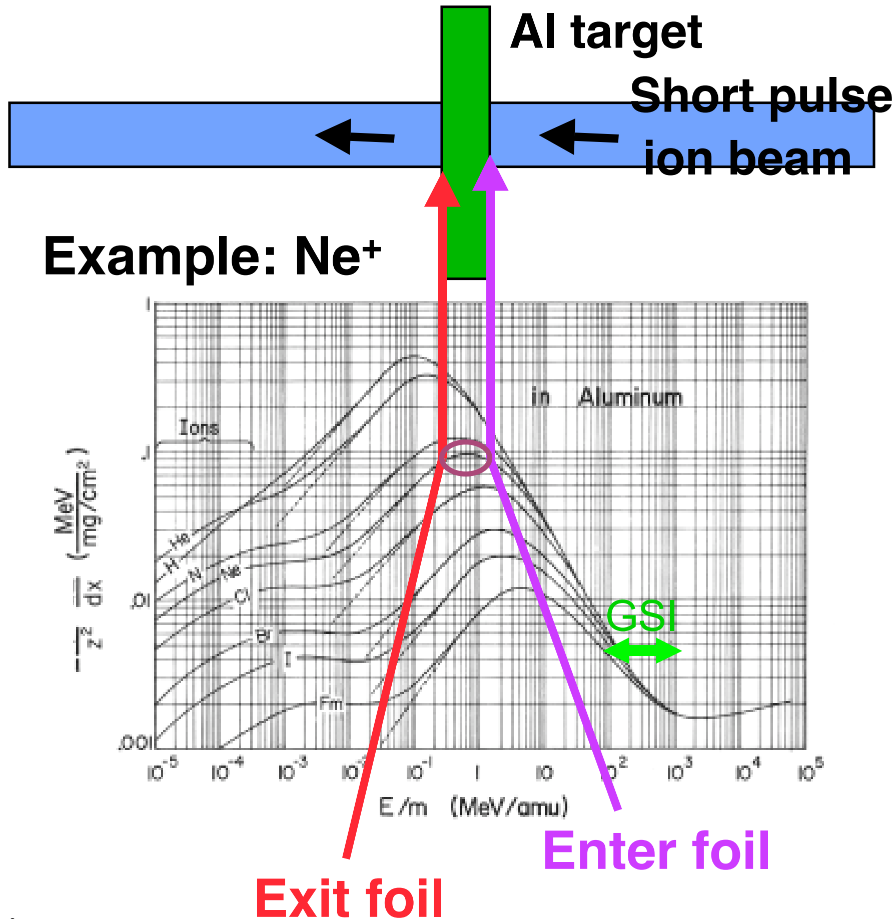
- Planned WDM experiments and diagnostics
- Target concepts for WDM experiments at LBNL, including transient darkening at HCX
  - New WDM diagnostics and target chamber
- Porous target WDM experiments at GSI, Dec. 11-17, 2006

Workshop on Accelerator-Driven Warm Dense Matter Physics, Pleasanton CA, Feb. 22-24, 2006. http://ilsa.llnl.gov/wdm/.

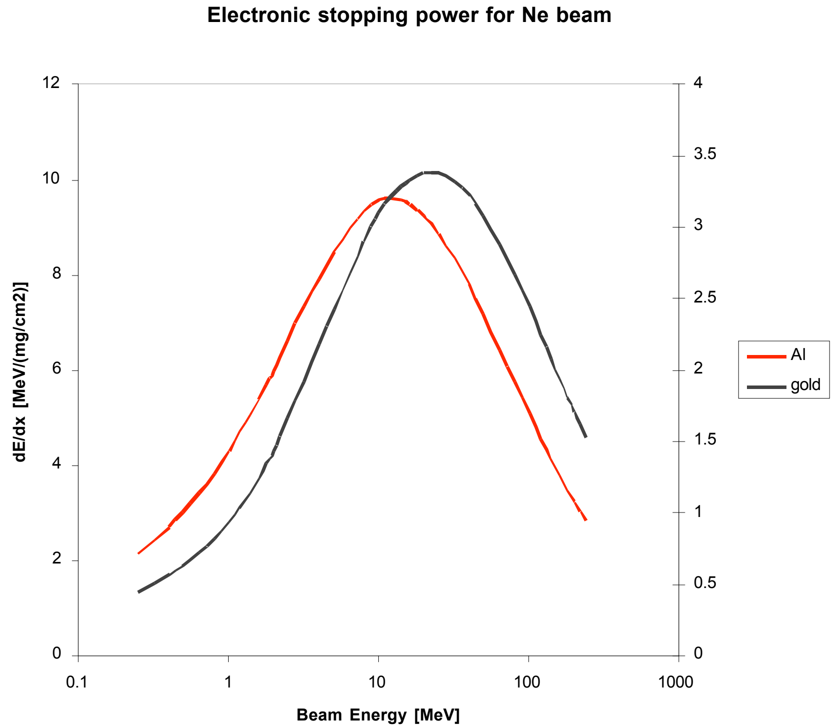
Ion beams provide an excellent tool to generate homogeneous, volumetric warm density matter.

- 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



Region of Bragg peak overlaps for various materials.

- Peak dE/dx is 2.6 MeV/micron in Al, 6.5 MeV/micron in Au
- Energy deposition and target heating are stronger with a heavy target.
  - For a given incident beam (20 MeV Ne+), instantaneous temperature rise in gold is greater than in aluminum by factor ~2.5
  - Al: 10.3 °C/(nC/cm2)
  - Au: 25.4 °C/(nC/cm2)



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

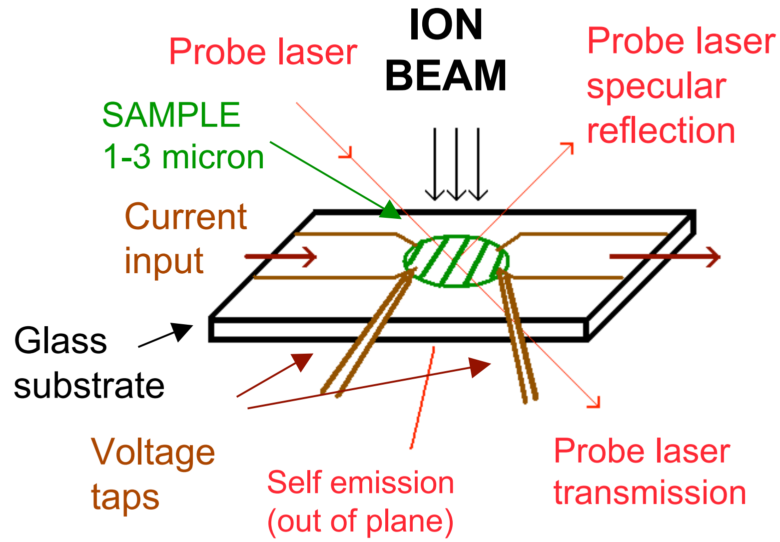
Initial diagnostics will be simple or extensions of existing capabilities

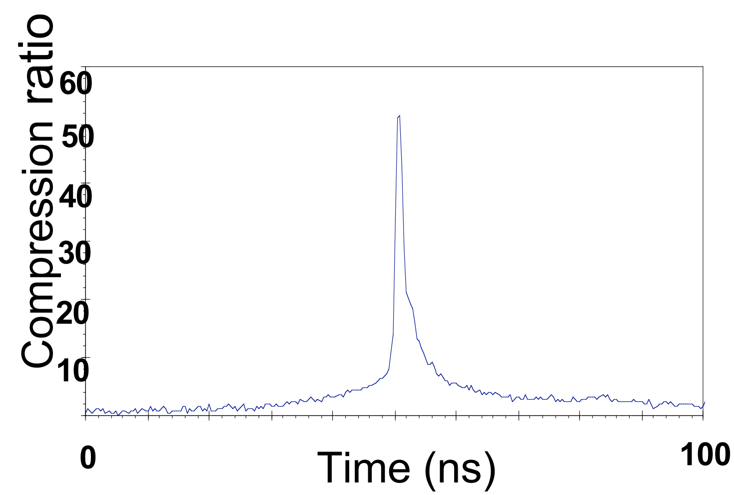
Beam diagnostics:

- beam size, current density
- energy analyzer (energy loss, charge state)

Target diagnostics:

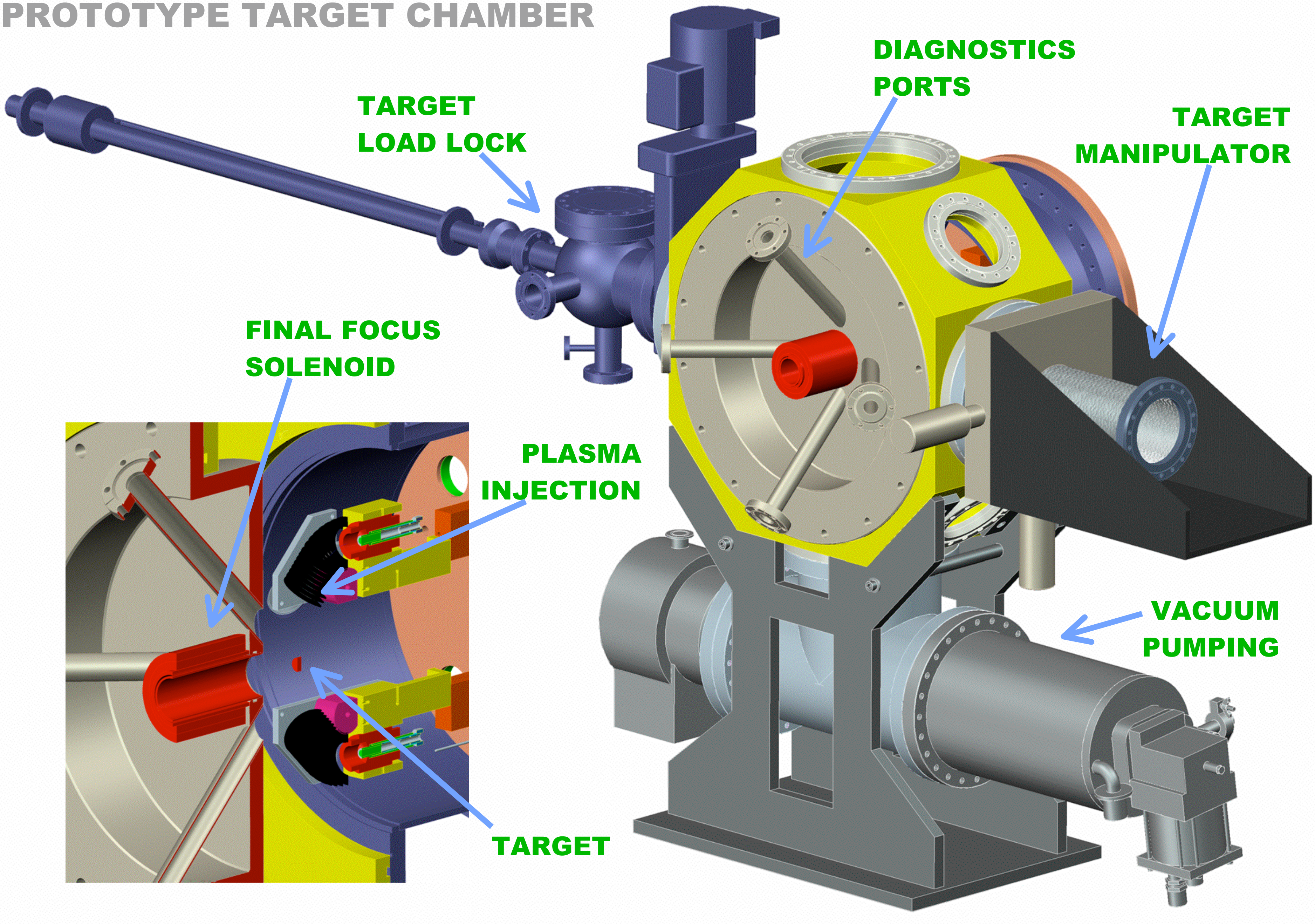
- Electrical resistivity, optical absorption (target temperature and phase transitions)
- Stopping power
- Visible light emission





Compressed NDCX beam pulse

WARM DENSE MATTER EXPERIMENTS
PROTOTYPE TARGET CHAMBER



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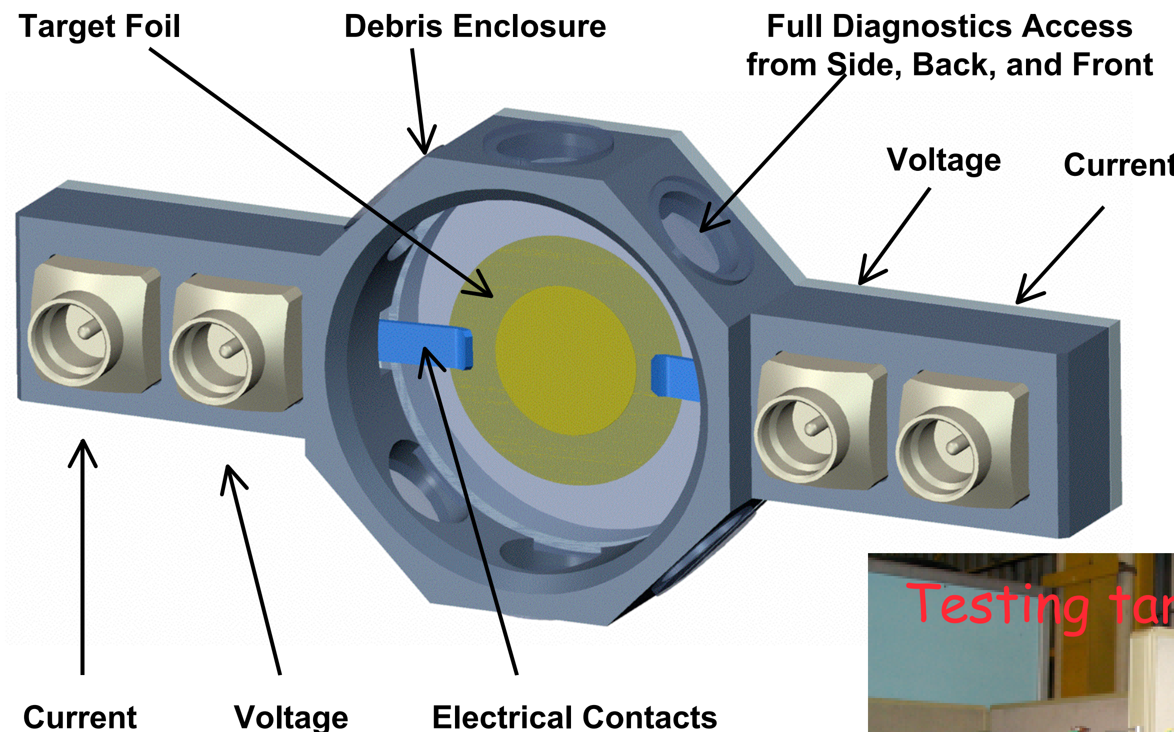
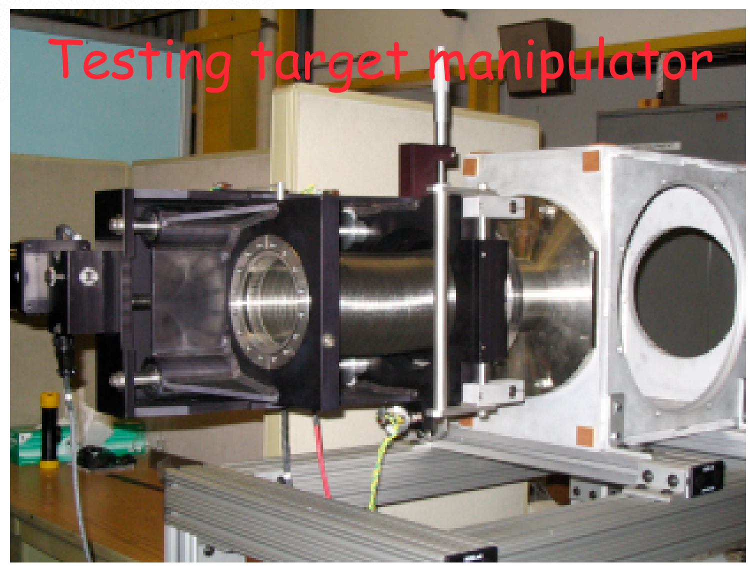
HIFS-VNL PROTOTYPE WDM TARGET MODULE

(Size: 5.66 cm wide, 2.29 cm high)





Limitations and issues with respect to prototype target chamber:

- **Load lock system required to load additional target modules**
- **Diagnostic access**
- **Compatibility with diagnostics, target manipulator**
- **Effect of target debris on chamber components**

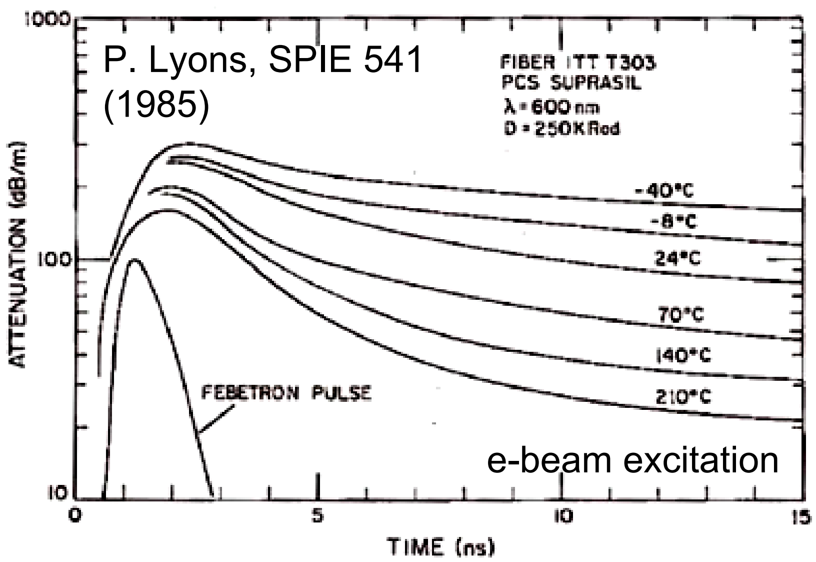
- **Issues to explore with prototype chamber:**
  - **Electrical circuit and connections using target module**
  - **Motion issues with target manipulator. How to pick up target module from target rack and how to position it.**
  - **Refine module design**
  - **Interface with beam and target diagnostics**
  - **Influence of pulsed magnet and plasma source**

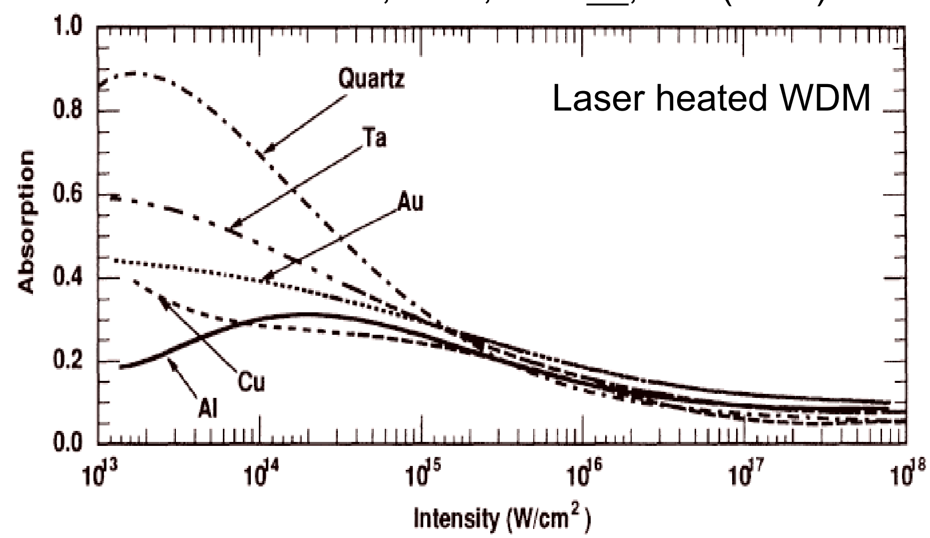
What WDM experiments can we do in the next 5 years?

	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 ↓

1. Check WDM atomic models using transient darkening of glass at low temperature to use in future work.

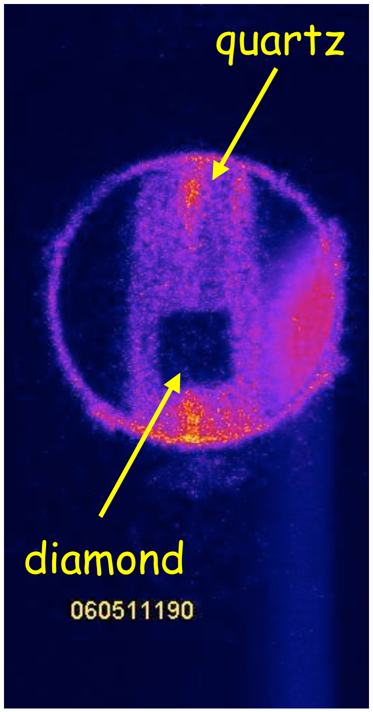


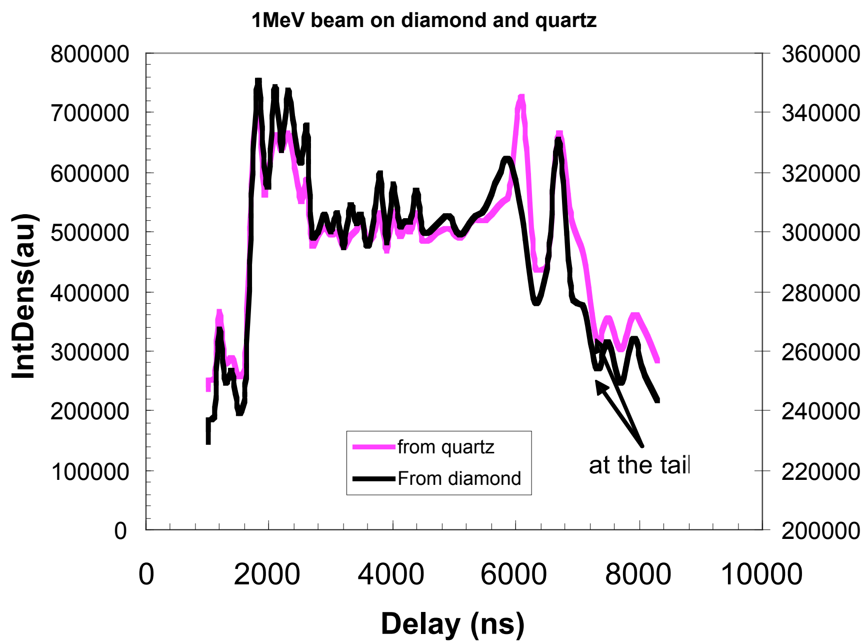


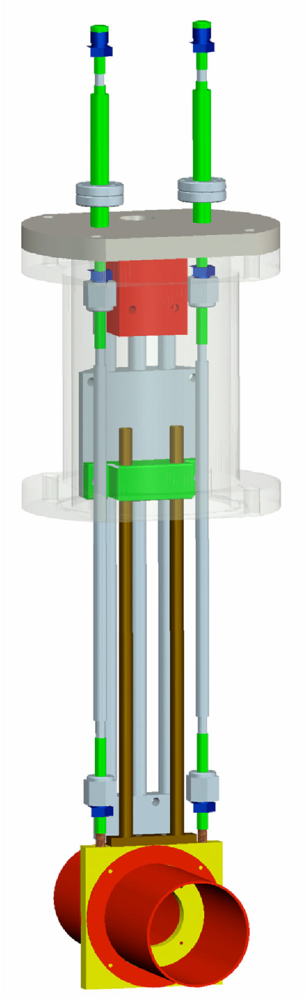
In quartz, electrons excited from 2s, 2p (ground state) to 3s leave holes in ground state to absorb photons in both cases. Measure decay rate of excited electrons by studying decay of absorption and emission rates.

Significance: interpret WDM data, possible temperature measurement, fast switching of optical properties

Initial measurements on HCX of optical emission, optical absorption for transient darkening experiment.







Optical emission: image and time response in liquid nitrogen cooled target

Transmission experiments under way (Yoneda) using quartz fiber

2-3. Develop diagnostic techniques in parallel with improving beam capability.

- Thin foil target interaction experiments can be done using NDCX beam compressed longitudinally and transversely.
  - Collect transmitted beam downstream of target in a Faraday cup
  - Use energy analyzer, time-of-flight to measure energy distribution
  - Use scintillator to measure beam scattering in foil

Significance: ion scattering near Bragg peak of theoretical interest at cold and warm temperatures.

C. Deutsch, G. Maynard. Low velocity ion stopping of relevance to the US beam-target program, Hirschegg Workshop, Jan. 2006

M. Murillo, et.al., Determining dE/dx in warm dense matter using nonequilibrium molecular dynamics, WDM Workshop, Pleasanton, Feb. 2006

- Example of diagnostic development: several ways to measure temperature
  - Hydrodynamic release: x-rays, lasers, optical imaging, streak camera
  - Electrical conductivity
  - Optical emission: fast optical pyrometer

4. As target temperatures reach T=0.4 eV or higher, new WDM regimes become accessible.

- Positive-negative ion halogen experiment (T > 0.4 eV) [see L.R. Grisham, et.al., HIF 2006 Symposium]
  - This experiment explores the expected unique properties of a dense electron-free positive-negative ion halogen plasma
  - Diagnostics include beam energy loss, target temperature, etc.
  - Electronegativity of gold: 2.54 eV, is close to halogens: 3.98 (fluorine) to 2.66 eV (bromine) ➔ initial experiments can be in gold foils

Significance: novel state of matter, unusual conductivity properties

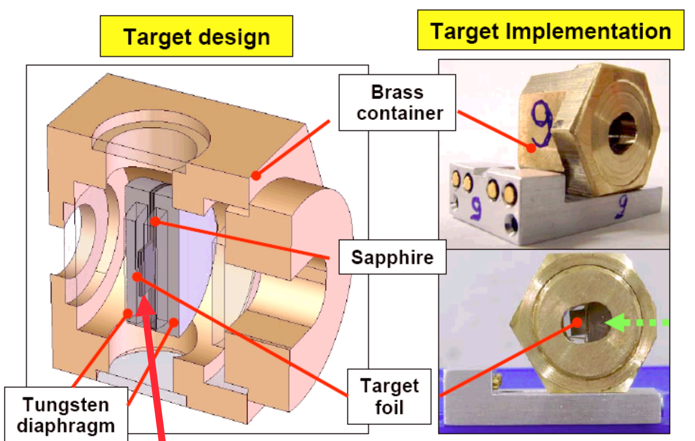
- Target temperatures surpassing 1 eV open up further WDM regimes
  - Liquid-vapor metal experiments
  - Critical point measurements

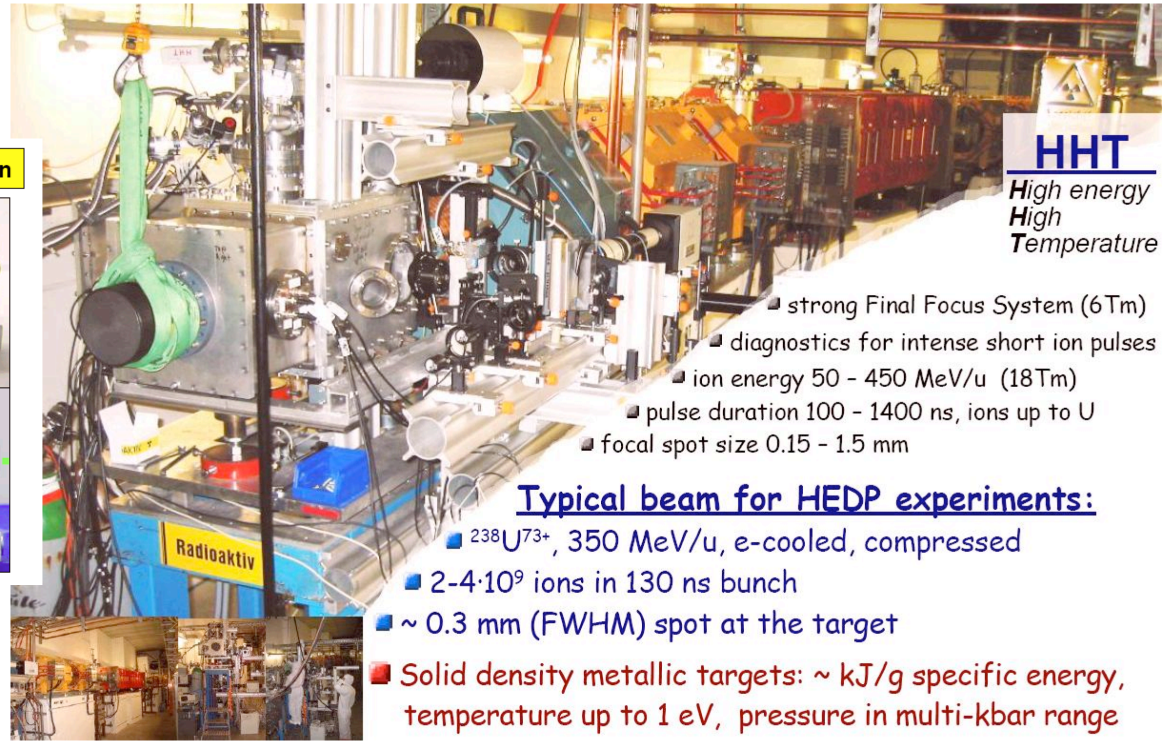
We have initiated joint experiment in Dec. 2006 at GSI (Darmstadt, Germany) to study heating of porous targets.

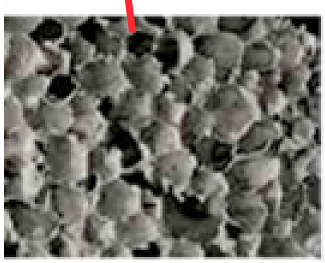
- Motivation:
  - Porous media are of great interest to HEDP/WDM and have important practical applications.
  - Short range of low-energy beams forces short pulse (1 ns) and fast diagnostics – low density porous targets reduce need for very fast pulse by increasing hydro expansion time of target.

- Modeling support effort connects experimental measurements to physics of porous target – e.g. HYDRA (LLNL); other codes under development (e.g. DPC).

Measurements performed at GSI HHT target station using ~2e9 intensity uranium beam at 300 MeV/u.

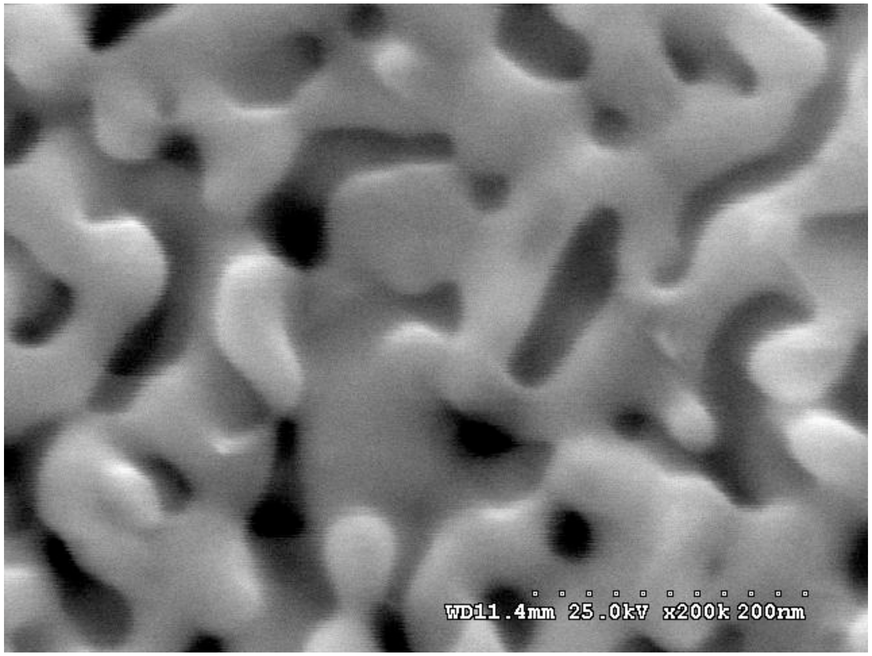




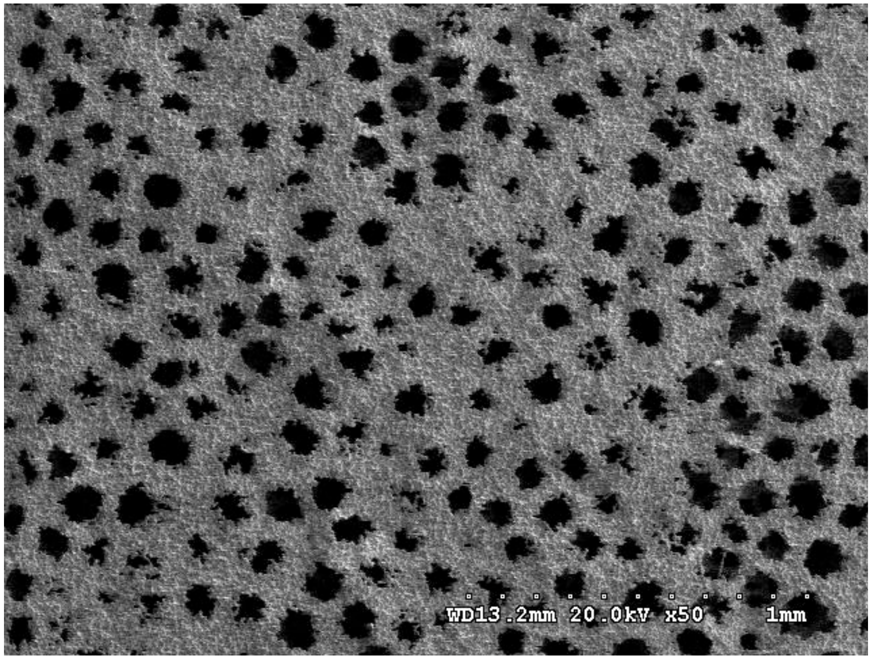


- Replace target foil with porous material.
- Study effect of pore size on target behavior using existing diagnostics.
- Sample targets: LLNL (Au, 50 nm), Mitsubishi (Cu, 50 micron).

Porous targets tested in GSI beam and compared with solid targets.



Porous gold target, 35% solid density, 50-nm pore size (Alex Hamza, LLNL)



Porous copper target, ~25% solid density, 50-micron pore size (Mitsubishi)

Preliminary results from GSI experiments, Dec. 11-17, 2006

- Tested all 4 US target styles: gold, copper, solid porous, in vacuum and gas (0.5 bar He). Uranium beam intensity 1.5 – 2.5e9. Beam energy 300 MeV/AMU.
- Gold targets heated to about 6000 K (T-boil = 2435 K). Solid and porous gold targets show similar behavior (temp, rapid expansion).
- Copper targets heated to about 3000 K (T-boil = 3200 K). Porous copper broke up into droplets; slow overall expansion.
- Detailed data files from all diagnostics to be made available from GSI shortly.
- Other experiments include: diagnostic tests (VISAR, conductivity, imaging of beam in gas), lead, tantalum targets, LiF window

Conclusion

- Ion beams provide an excellent tool to generate homogeneous, volumetric WDM.
- Development plan uses existing accelerators and pulse compression technique developed in HIFS-VNL. We are designing a target chamber, and acquiring target diagnostics.
- Initial experiments have been specified; path forward identified; measurements underway at LBNL and at GSI.