WDM experiments and plans

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Heavy Ion Fusion Science Virtual National Laboratory

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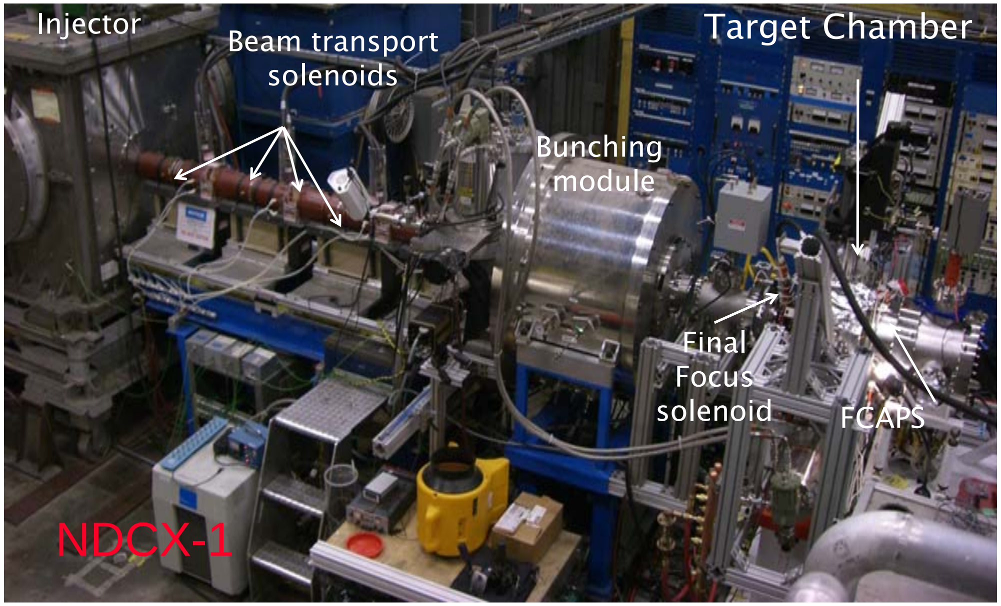

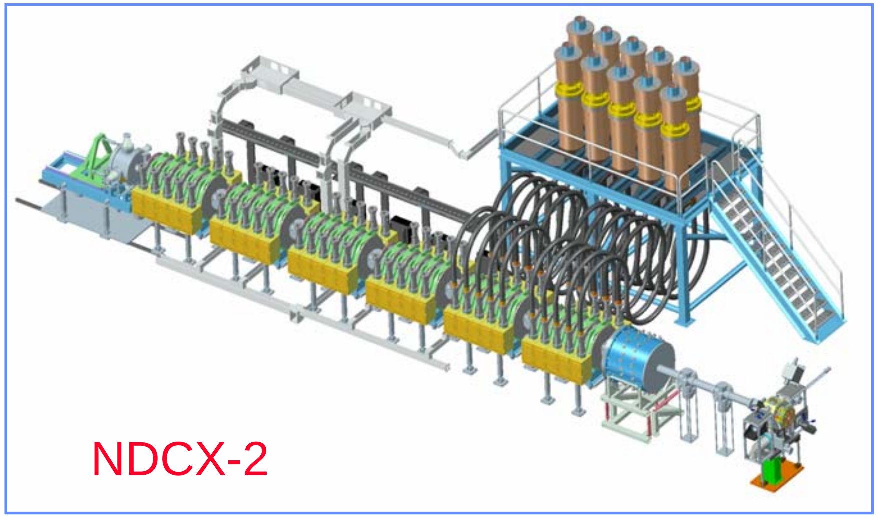

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Outline of talk

Overview

Status of experimental facility:

-- Targets, target chamber, target diagnostics installed and successfully operated

-- WDM experiment (Run 1) Aug. – Nov. 2008: 12 shots

-- Comparisons between initial experiment and models underway

Experiment plans

-- Run 2 to begin early 2009 with improved:

-beam parameters

-target manipulator for rapid shot repetition rate

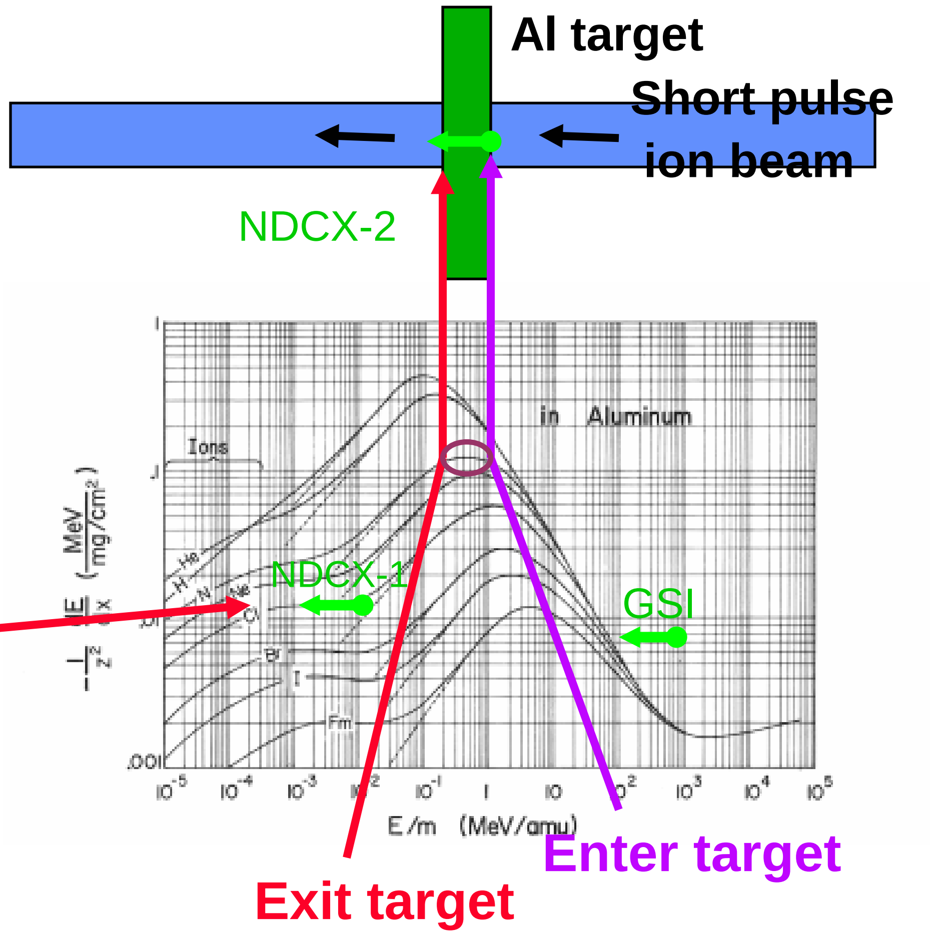
-diagnostics

-- Study liquid-gas interface (droplets) in targets

-- High electron affinity, porous targets, etc.

Ion beams provide a tool for generating homogeneous warm dense matter.

- Warm dense matter (WDM)
  - T ~ 0.1 to 10 eV
  - ρ ~ 0.01 -1 * solid density
- Strategy for uniform energy deposition: operate near flat portion of dE/dx curve
- Pedestal for heavy ions at lower beam energy (~NDCX-1)
- Place Bragg peak at center of foil (NDCX-2)



Characteristics of ion beam driven HEDP/WDM.

Precise control of energy deposition

Sample size large compared to diagnostic resolution volumes (~ 1's to 10's μ thick by ~ 1 mm diameter)

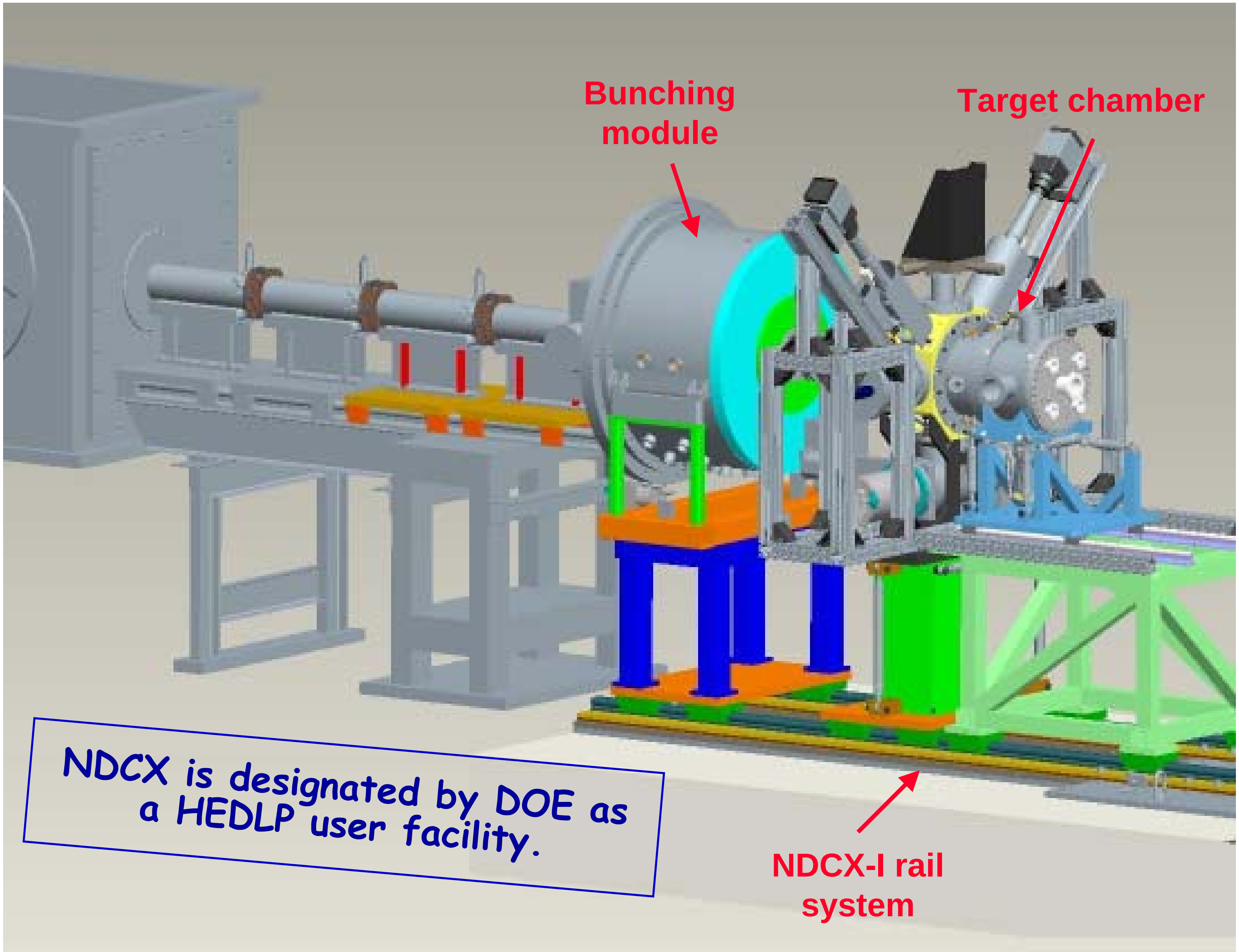
High efficiency, uniform energy deposition (<~ 5%)

Able to heat any target material (conductors, insulators, foams, powders, ...)

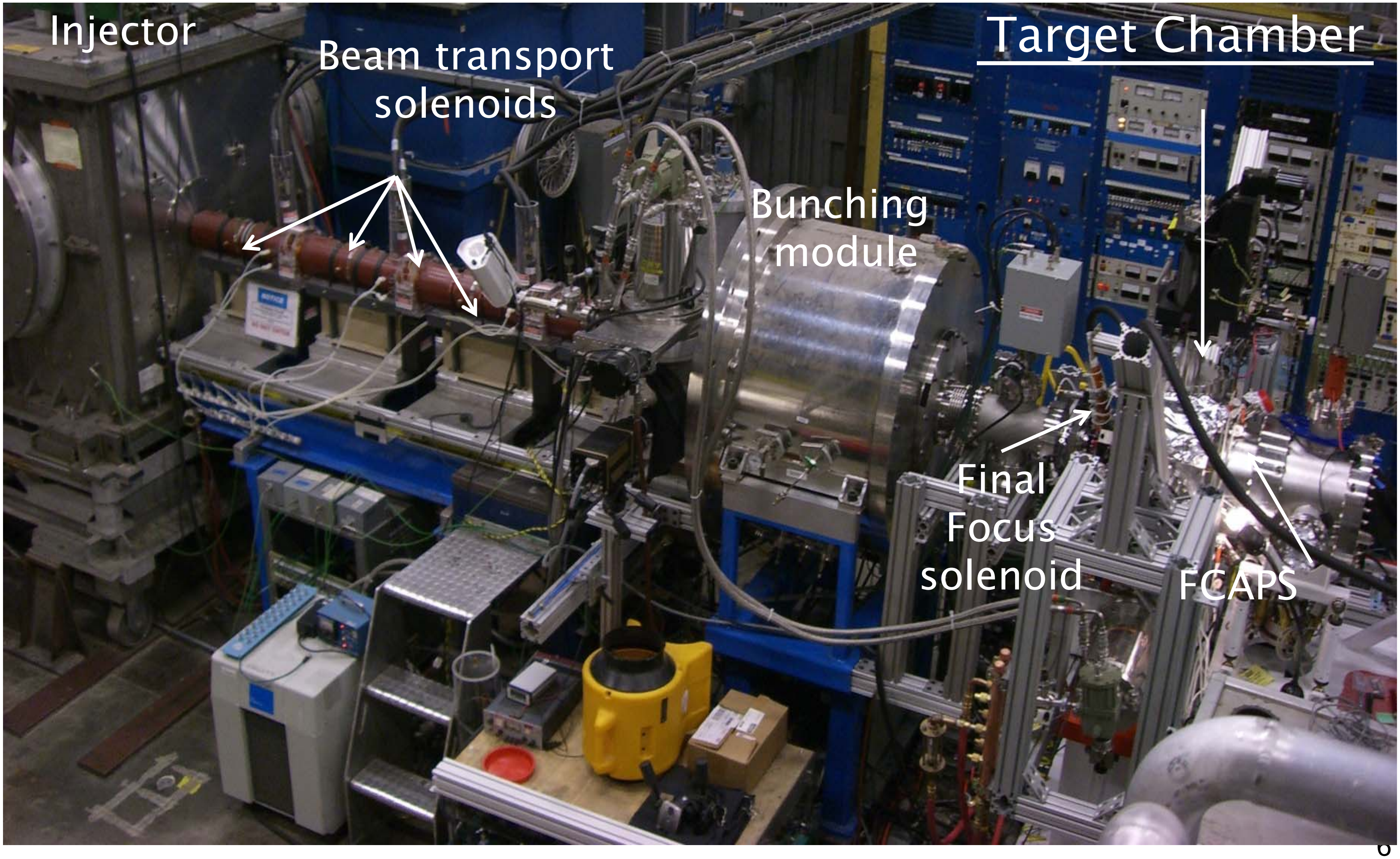
A benign environment for diagnostics

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

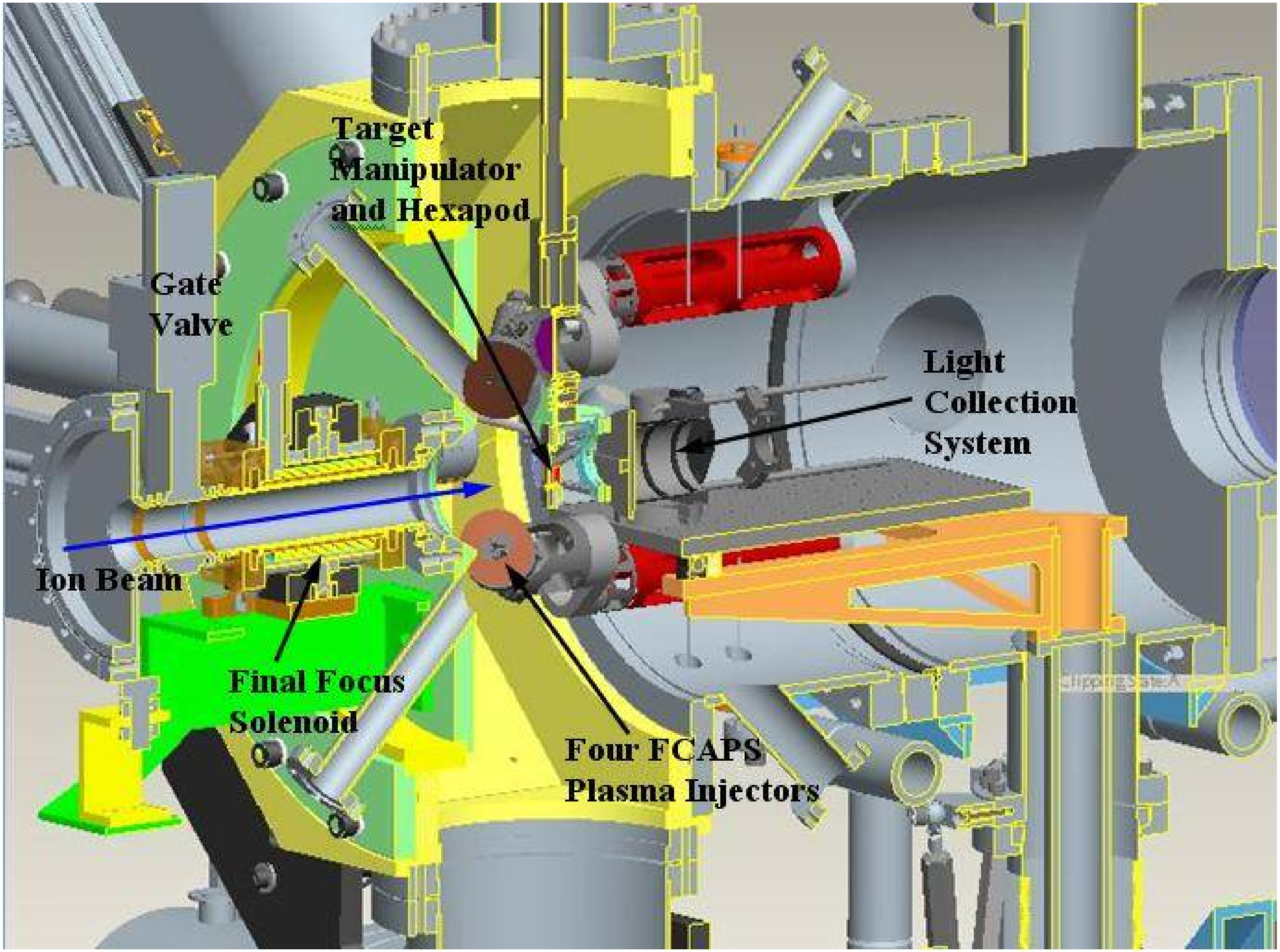
WDM target chamber is installed on NDCX-I.



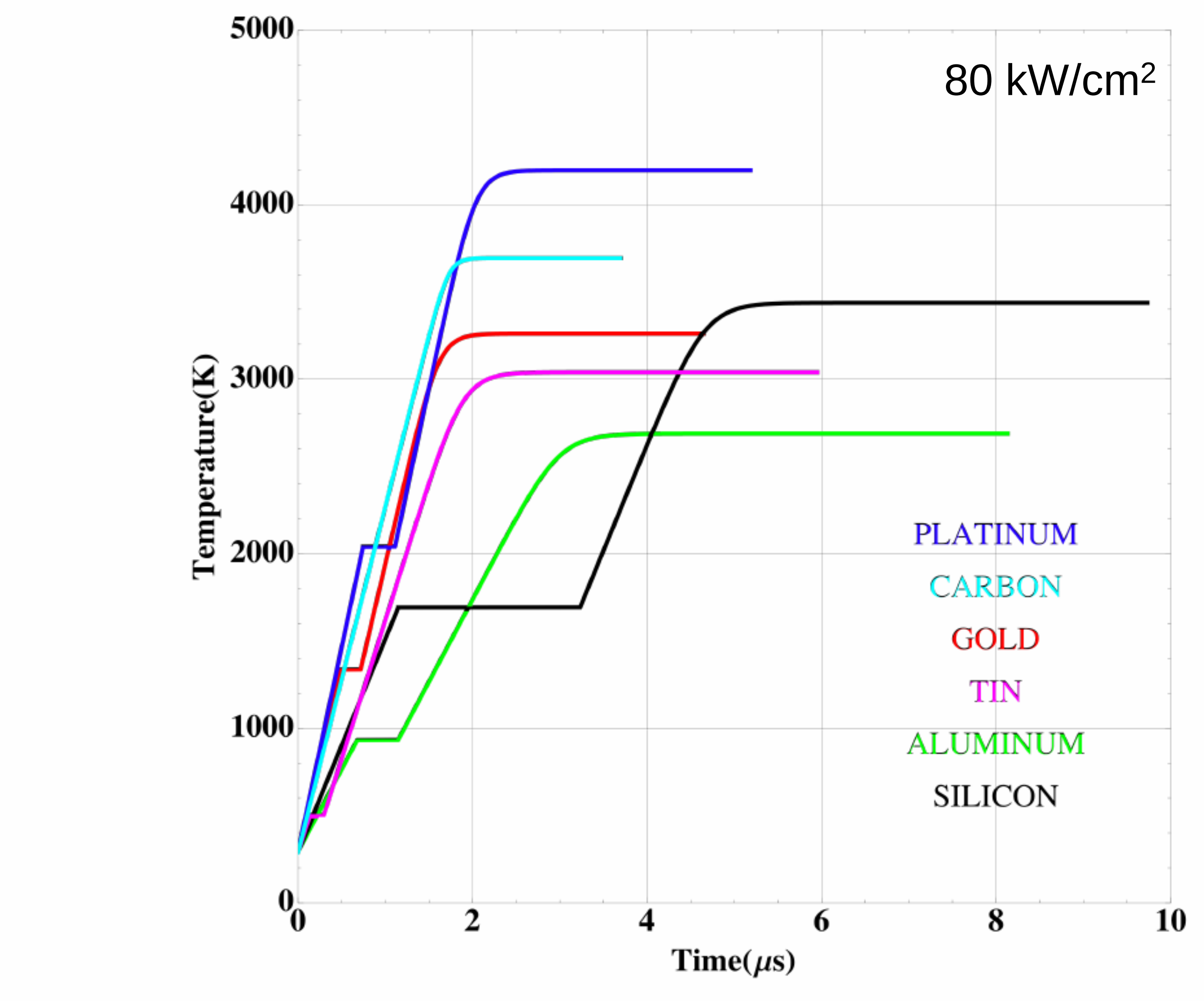
WDM target chamber is installed on NDCX-I.



WARM DENSE MATTER TARGET CHAMBER



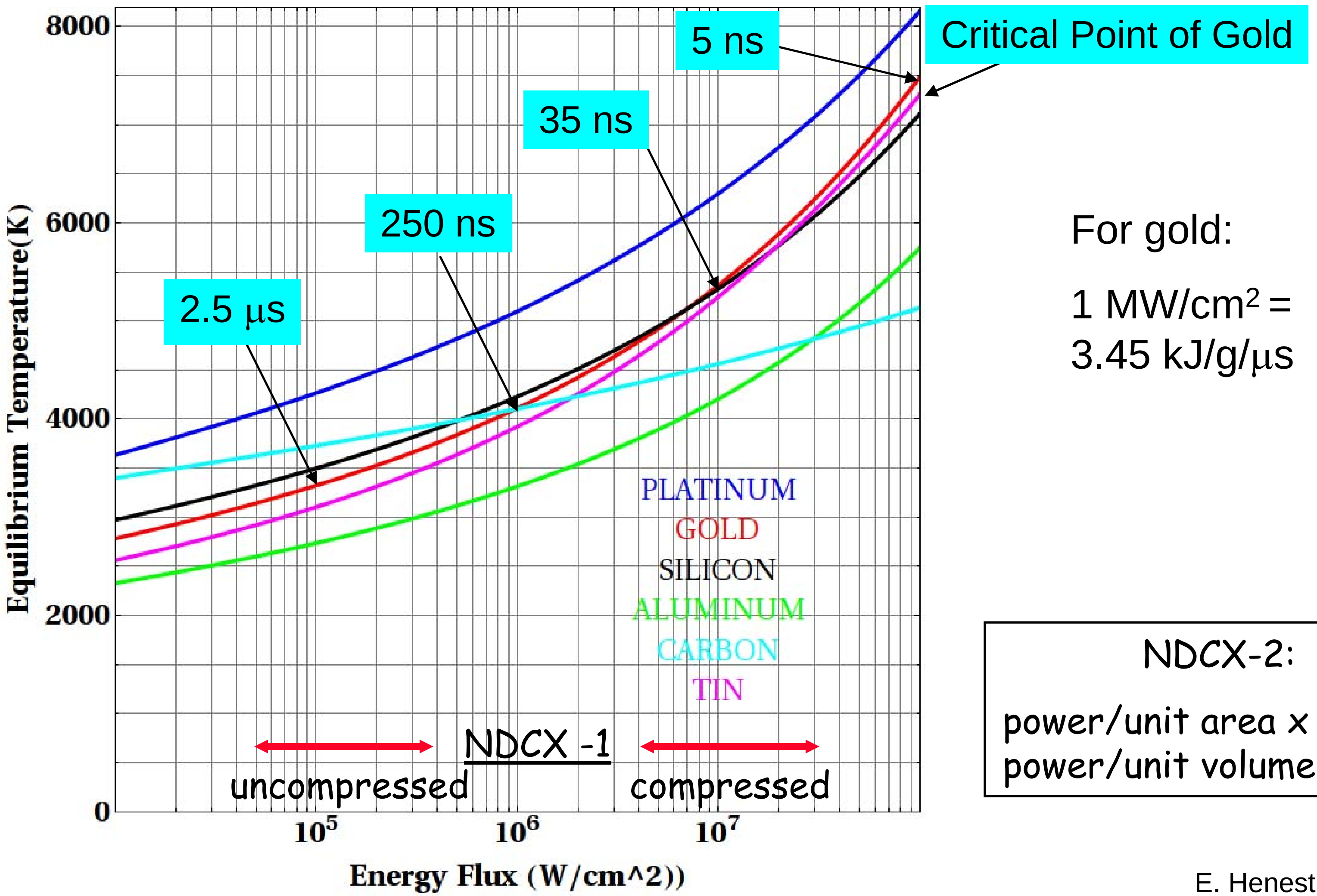
Simple model of target heating predicts T ~ 0.3 – 0.4 eV using NDCX-1 uncompressed beam.



Gold --> 150 nm
Aluminum --> 350 nm
Platinum --> 120 nm
Silicon --> 200 nm
Tin --> 300 nm
Carbon --> 300 nm

E. Henestroza

Dependence of equilibrium temperature on heating rate shows effect of increasing beam energy flux on target.



For gold:

1 MW/cm^2 = 3.45 kJ/g/μs

NDCX-2:

power/unit area x 100
power/unit volume x 10

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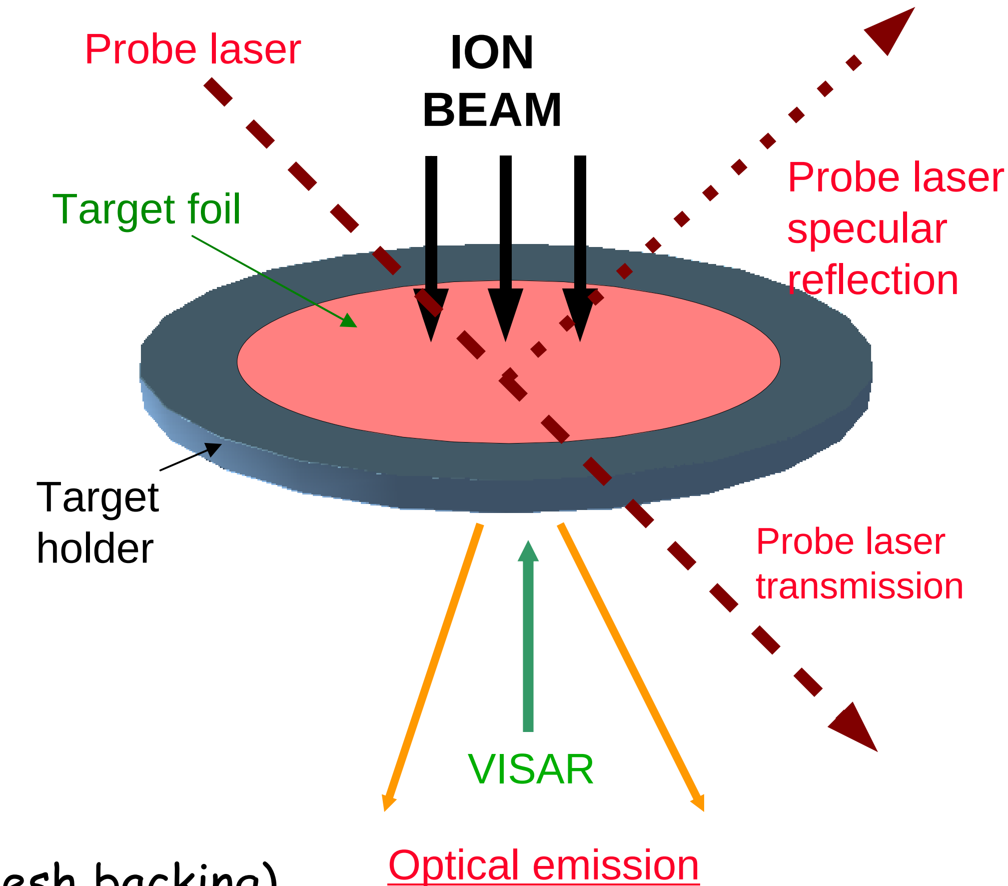
Experiments include WDM target and beam diagnostics.

Initial diagnostics include

- Optical emission, especially high speed optical pyrometer
- High speed I-CCD cameras
- Streak camera
- Optical spectrometer
- VISAR probe
- Electrostatic energy analyzer

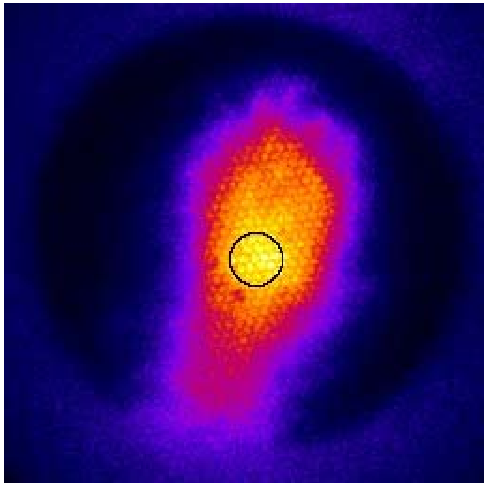
Future: beam & laser transmission, conductivity probes etc.



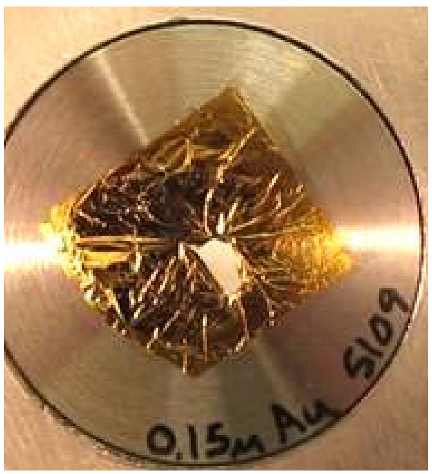
<u>Initial set of targets (foils with mesh backing)</u>

- 350-nm Al
- 150 nm Au
- 120 nm Pt
- 400 nm Si
- 350 nm C

Target assembly protects target from beam by pinhole or gold cone.



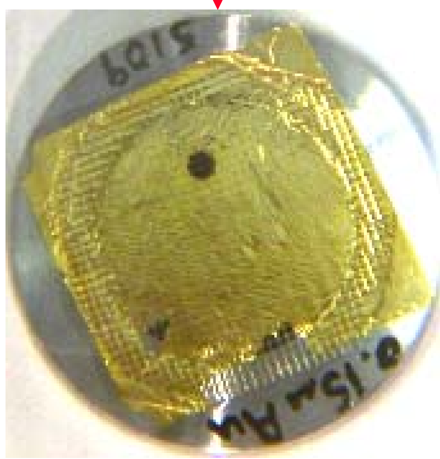
Beam imaged on target without pinhole



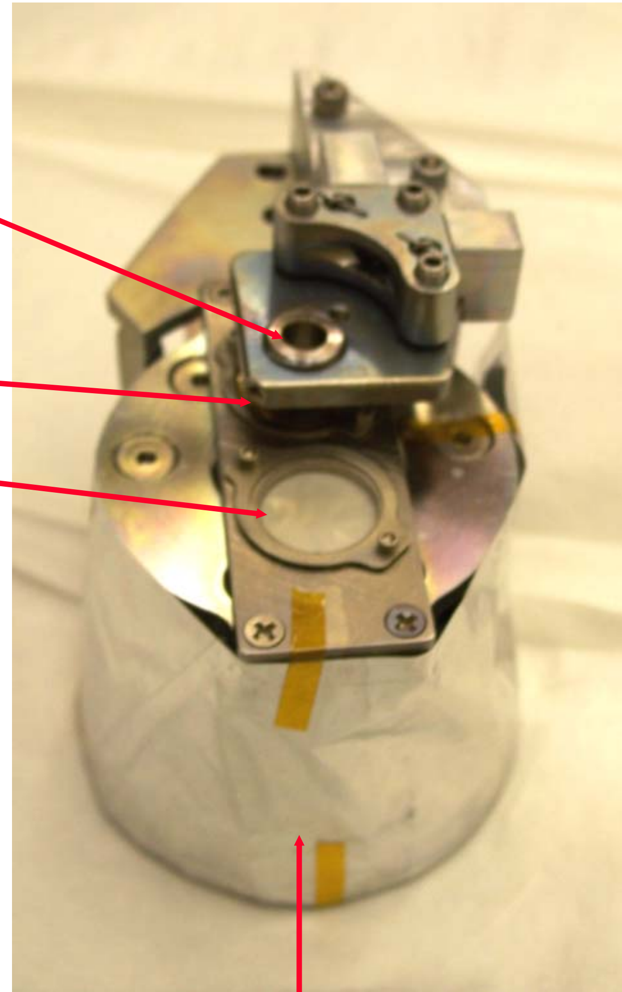
Pinhole/cone

Target foil

Scintillator

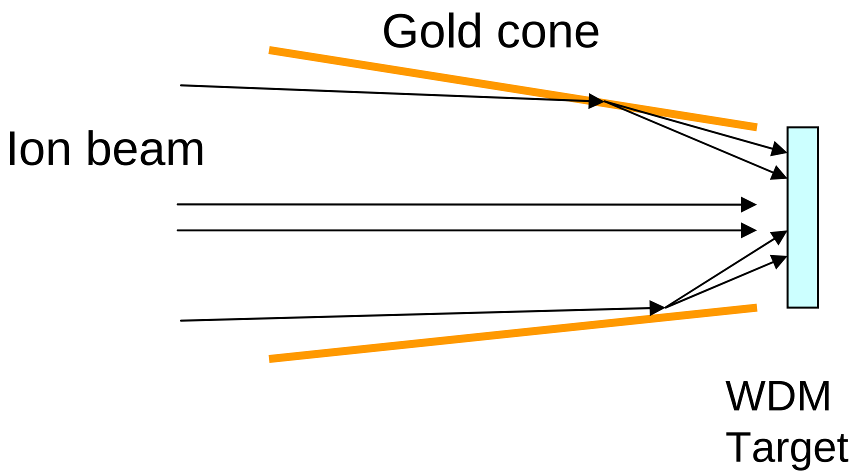


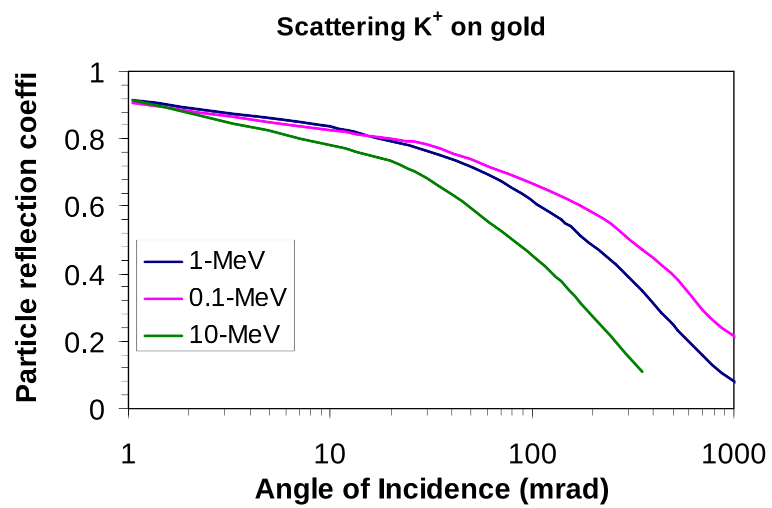
Beam spot under 1-mm pinhole



Debris catcher

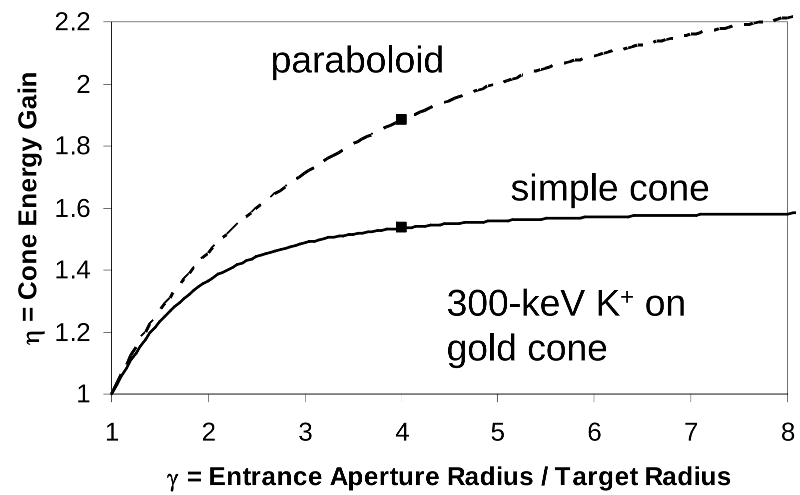
Gold cone concentrates ions on target for increased beam intensity.





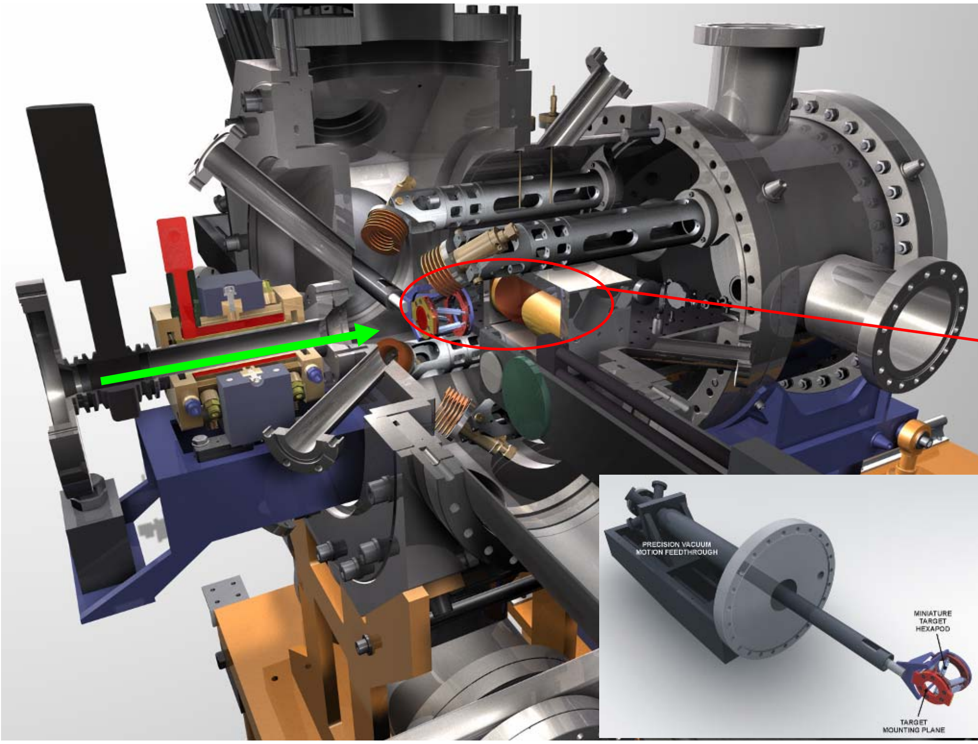
TRIM calculations for a single reflection

- **Cone acts as grazing incidence mirror. Enhanced ion intensity using cone has been demonstrated.**
- **Shields target from unwanted heating by edge of beam**
- **Produces grazing incidence secondary electrons for reduced space charge**
- **Homogenizes energy flux on target**
- **No chromatic effects**

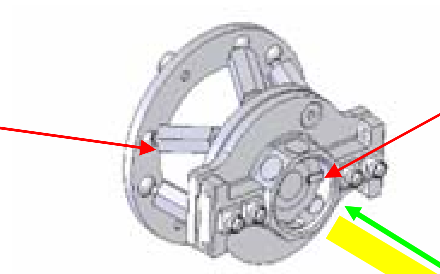


Optical probing of target

Target chamber:



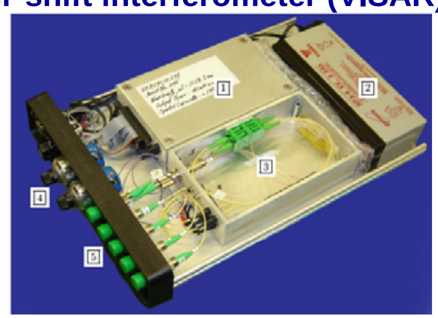
Probing of target:



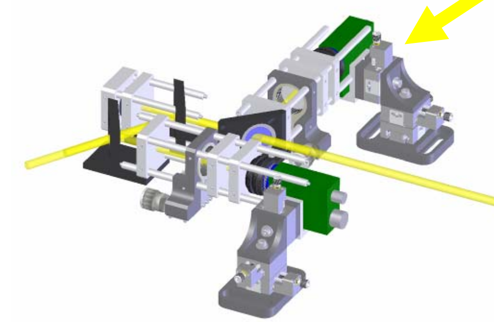
Heated sample

Fiber bundle

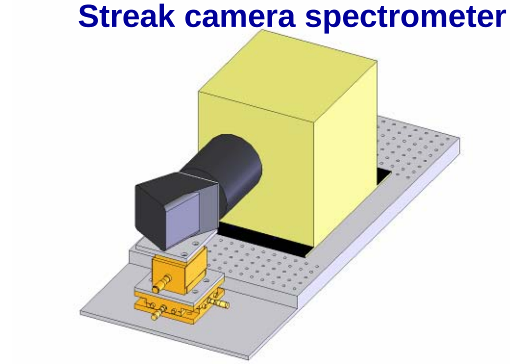
Doppler-shift interferometer (VISAR):



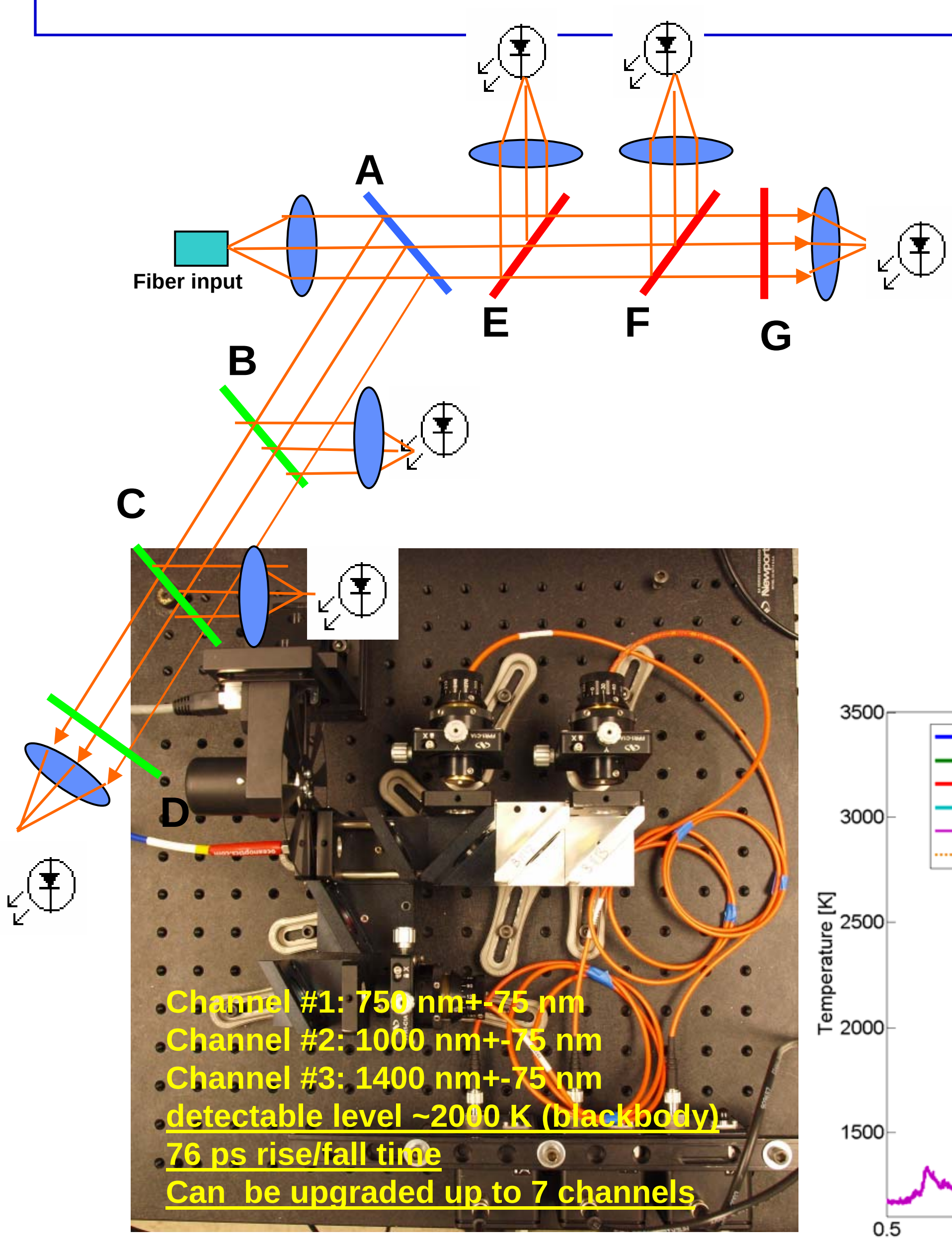
Pyrometer:



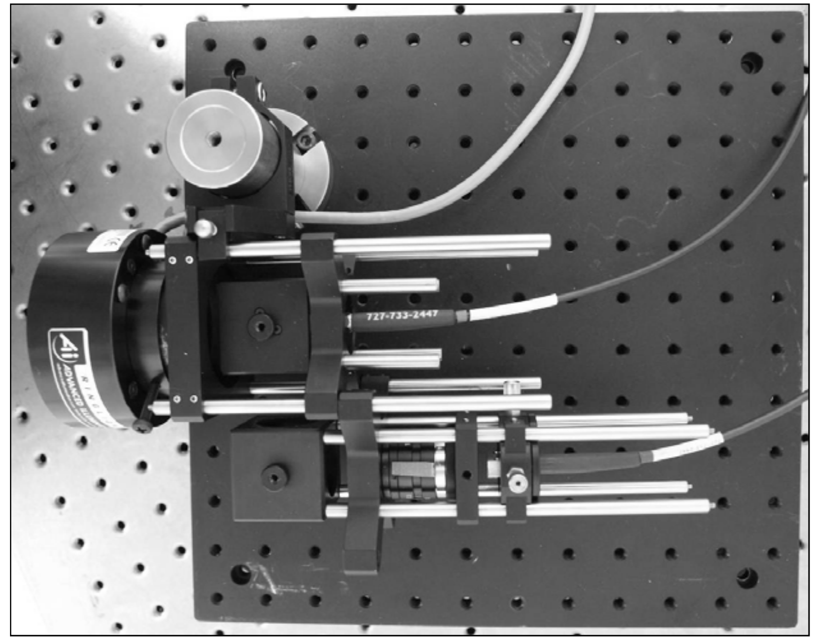
Streak camera spectrometer

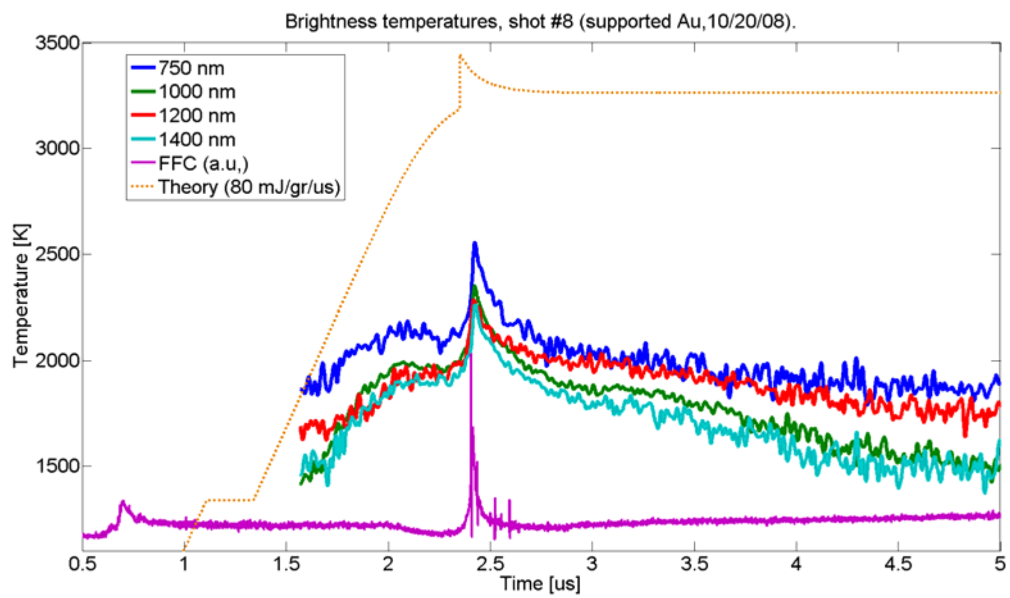


Ultra-fast optical pyrometer for experiments at NDCX

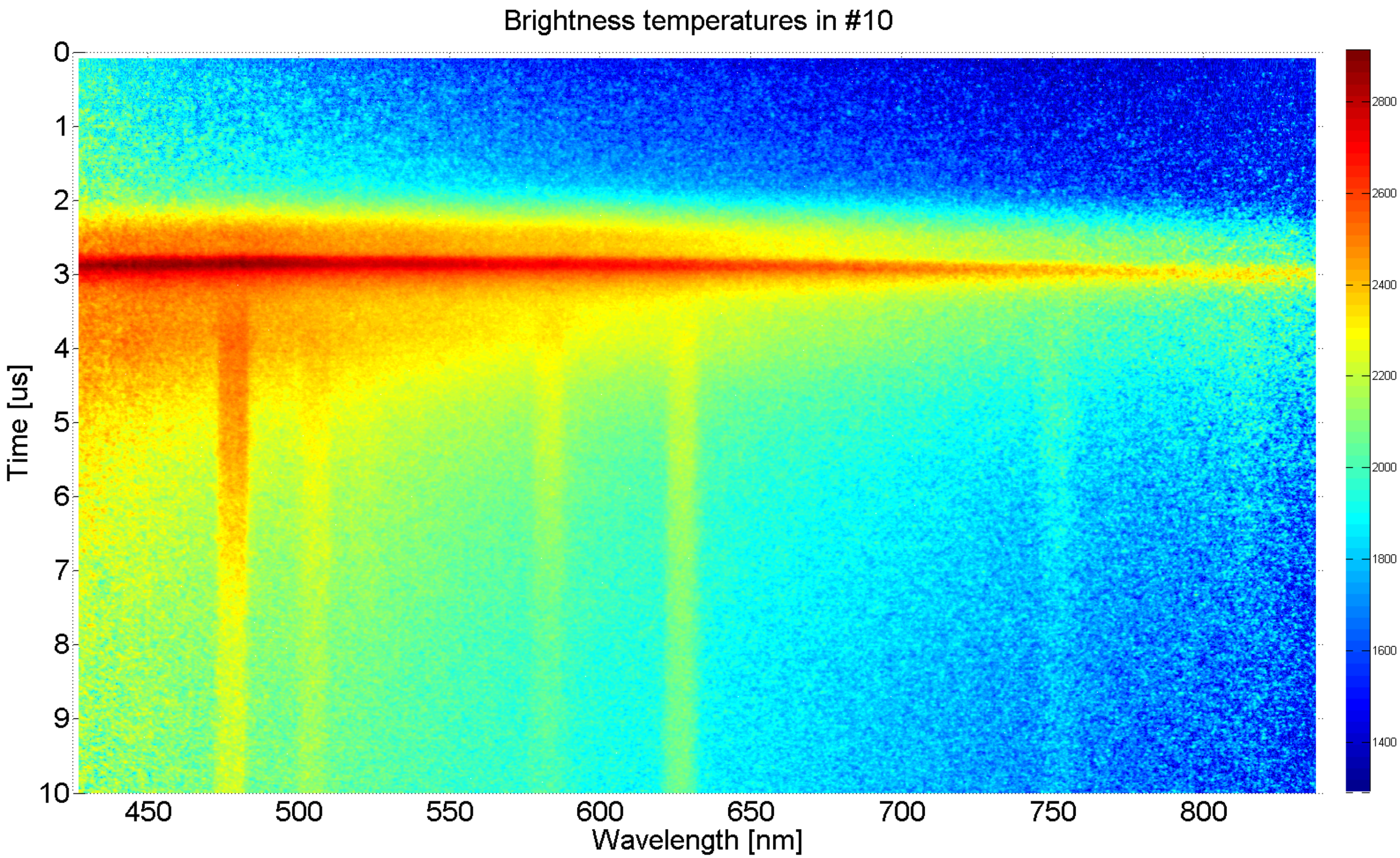


Channel #1: 750 nm+-75 nm
Channel #2: 1000 nm+-75 nm
Channel #3: 1400 nm+-75 nm
detectable level ~2000 K (blackbody)
76 ps rise/fall time
Can be upgraded up to 7 channels



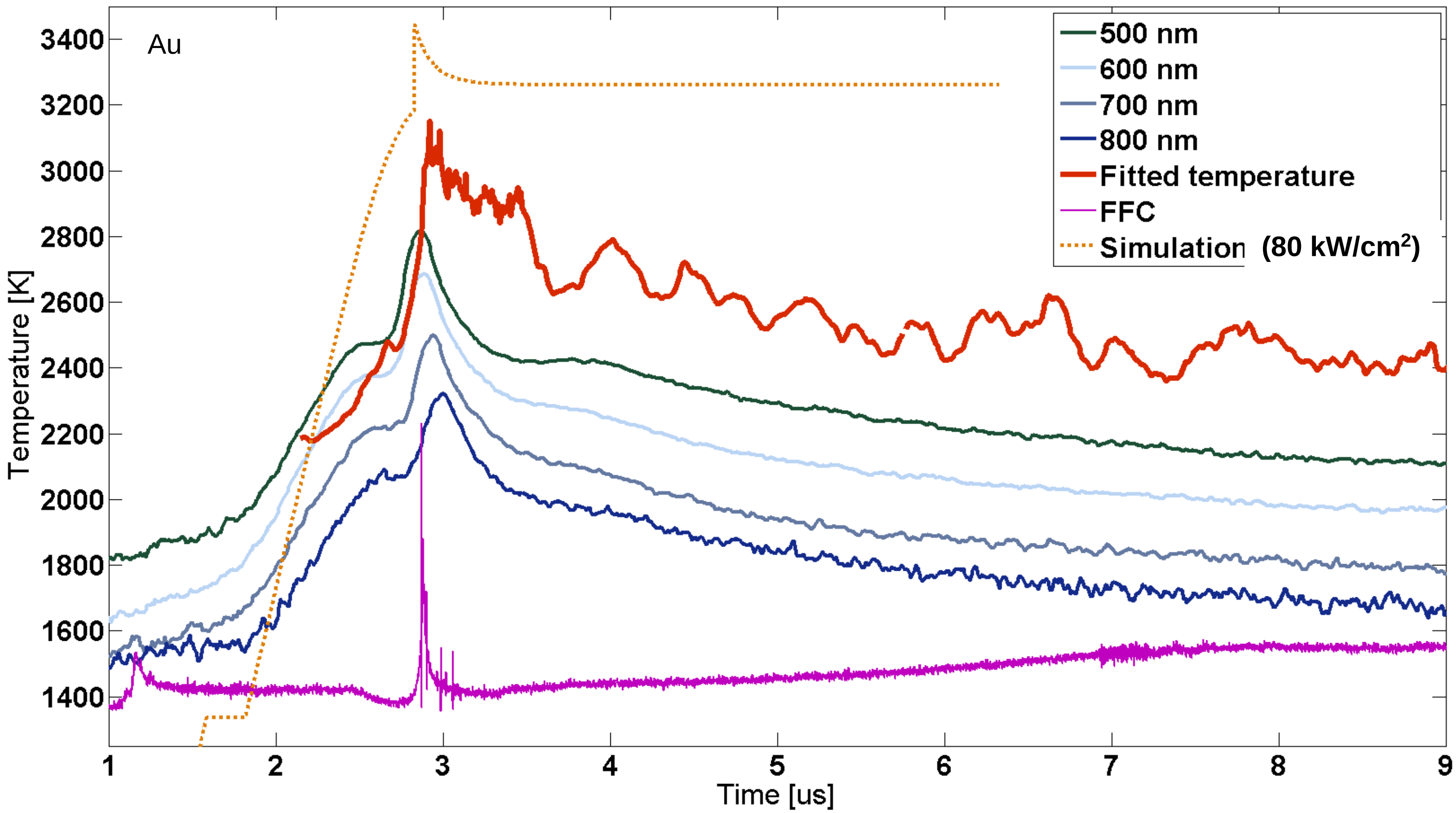


Typical data in foil targets shows heating from the prepulse and compressed pulse.



Streak - spectrometer data in Au target showing emission lines from heated gold.

Targets show drop in brightness temperature at ~3 μs (when model approaches equilibrium).



Formation of ~μm size droplets could explain temperature drop. Other possible explanations include rapid vaporization, transparency, fog (very small droplets).

We are pursuing a series of experiments in warm dense matter.

- **Porous target experiment at GSI to compare response of solid/porous targets:**
  - **Performed Dec. 2006; Analysis underway**

- **“Black glass” experiment performed on HCX: studying optical changes (e.g. insulator – conductor transition) in materials**

- **First beam-driven WDM target experiments on NDCX use uncompressed pulse to reach boiling point, then compressed pulse to explore liquid-gas phase transition (e.g. droplet, bubbles).**
  - **T > 0.3 eV, NDCX-1**

- **Well defined transition behavior (e.g. silicon, carbon) will help calibrate temperature diagnostics (carbon ➔ no liquid droplets).**

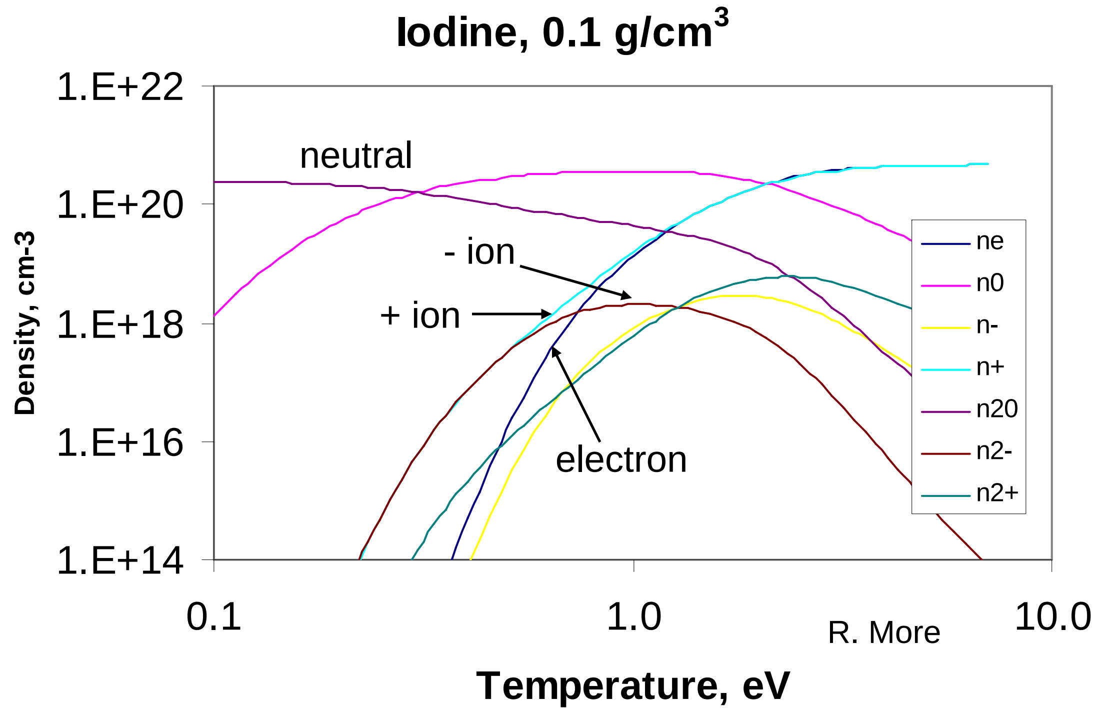
- **Low density porous target studies to lengthen target expansion time (e.g. gold black on NDCX-1)**

We are pursuing a series of experiments in warm dense matter (cont.).

- **High electron affinity WDM targets (gold, iodine)**
  - **T > 0.4 eV,   NDCX-1/NDCX-2**
- **Two-phase liquid vapor WDM targets: fragmentation, droplet formation**
  - **T ~ 0.5 – 1 eV, NDCX-1/NDCX-2**
- **Other EOS studies; critical point**
  - **T ~ 1 eV, NDCX-2**
- **Beam - shock-wave coupling in cryogenic targets (Ne, H)**
  - **NDCX-2**
- **Other:**
  - **Silicon target (NDCX and GSI); relevant to NIF damage control**
  - **Thin target dE/dx (e.g. carbon), beam scattering, charge state**
  - **Micro-implosions driven by ion beam**

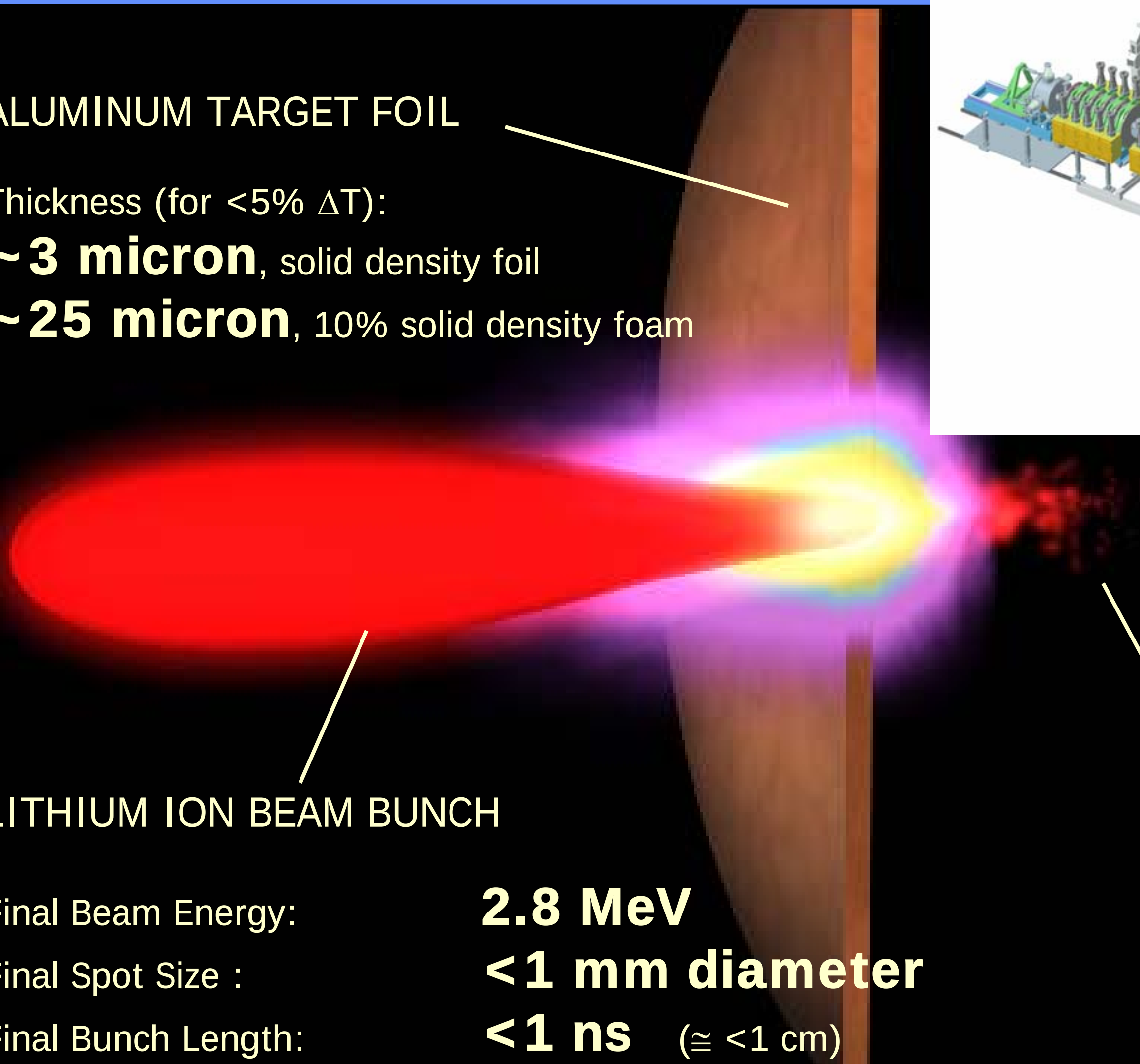
Experiment in high electron affinity targets

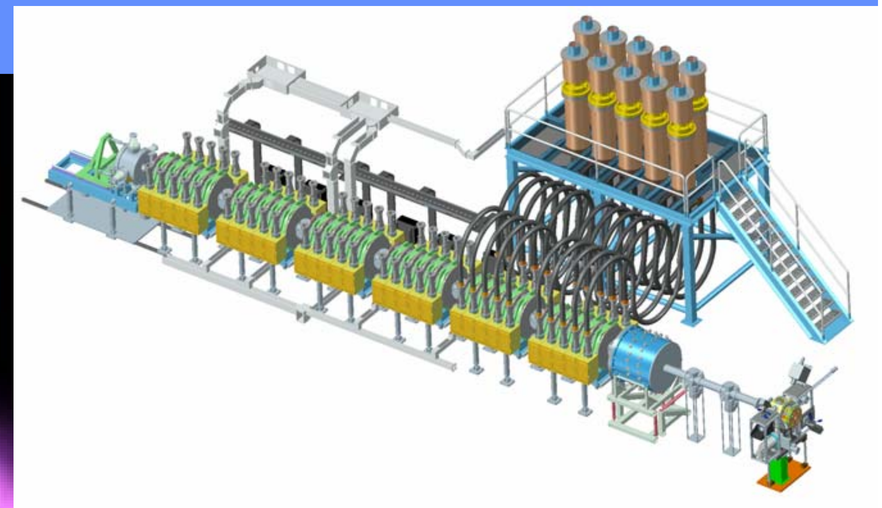
Electron affinity:	
Au	2.3 eV
I	3.1
Br	3.4



- Unusual material – dominated by +/- ions
- narrow temperature range; e.g. 0.4 to 0.7 eV for iodine at 0.1 g/cc.
- radiation from charge exchange
- expect conduction by charge transfer
- unequal mobility for electrons and holes
- Other: optical behavior, metal-insulator transition

NDCX-2 TARGET POINT DESIGN AND DRIVER REQUIREMENTS FOR >1 eV TARGET HEATING





ALUMINUM TARGET FOIL

Thickness (for <5% ΔT):

~3 micron, solid density foil

~25 micron, 10% solid density foam

LITHIUM ION BEAM BUNCH

Exiting Ion Beam Available for dE/dx Measurement

Final Beam Energy:	**2.8 MeV**
Final Spot Size :	**<1 mm diameter**
Final Bunch Length:	**<1 ns** (≅ <1 cm)
Total Charge Delivered:	**0.03 micro-Coulomb** (~ 2×10^{11} particles or I_{max} ~ 42 A)
Normalized Emittance:	**0.4 pi-mm-mrad**

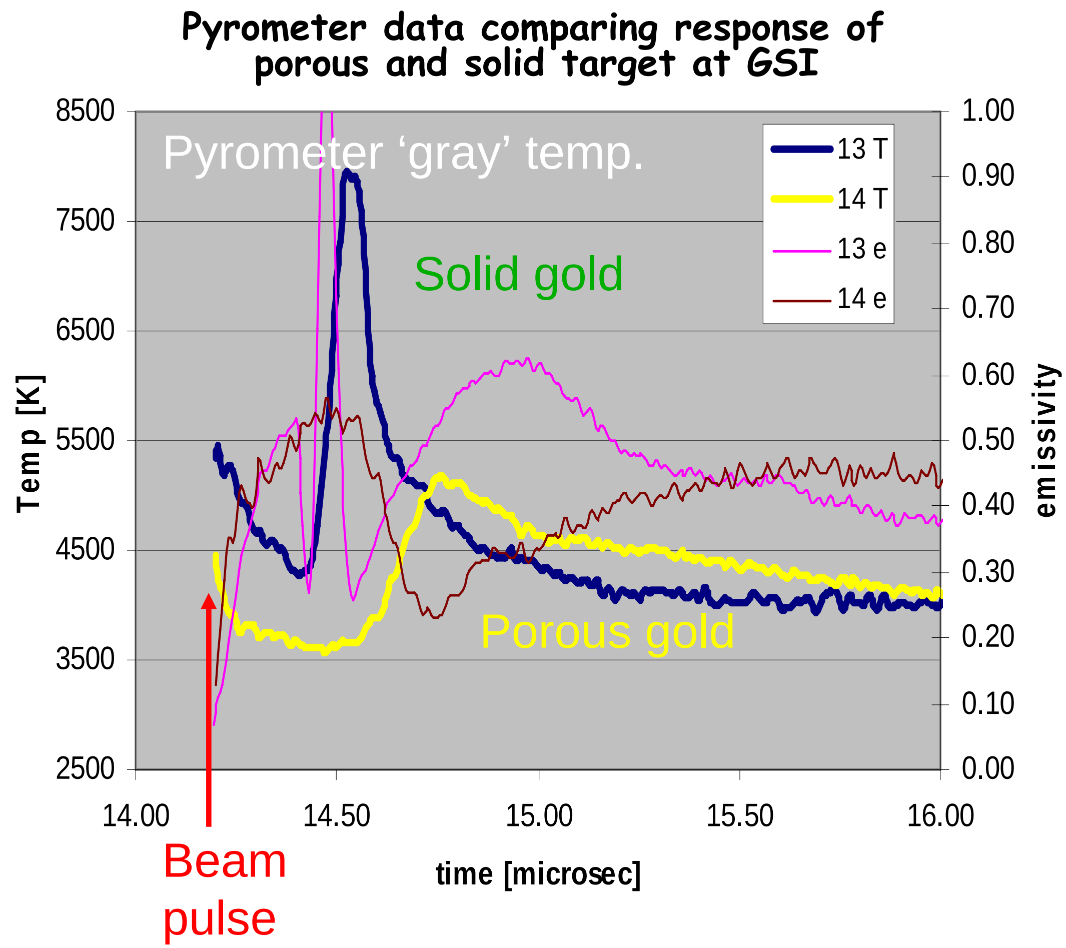
Summary

- Ion beams provide a new tool to generate homogeneous WDM.
- Pulsed accelerator NDCX and pulse compression technique have been developed as a new HEDLP user facility for studying WDM physics.
- We have developed and tested initial set of target diagnostics, built a new target chamber, and performed initial experiments.
- Initial experiments take advantage of beam pre-pulse to pre-heat foils; goal is to study liquid-gas phase transition region.
- Initial results suggest interesting physics and target modeling is going on.
- Future experiments with improved NDCX-1 and NDCX-2 will explore many aspects of WDM physics, including high electron affinity targets, porous targets, etc.

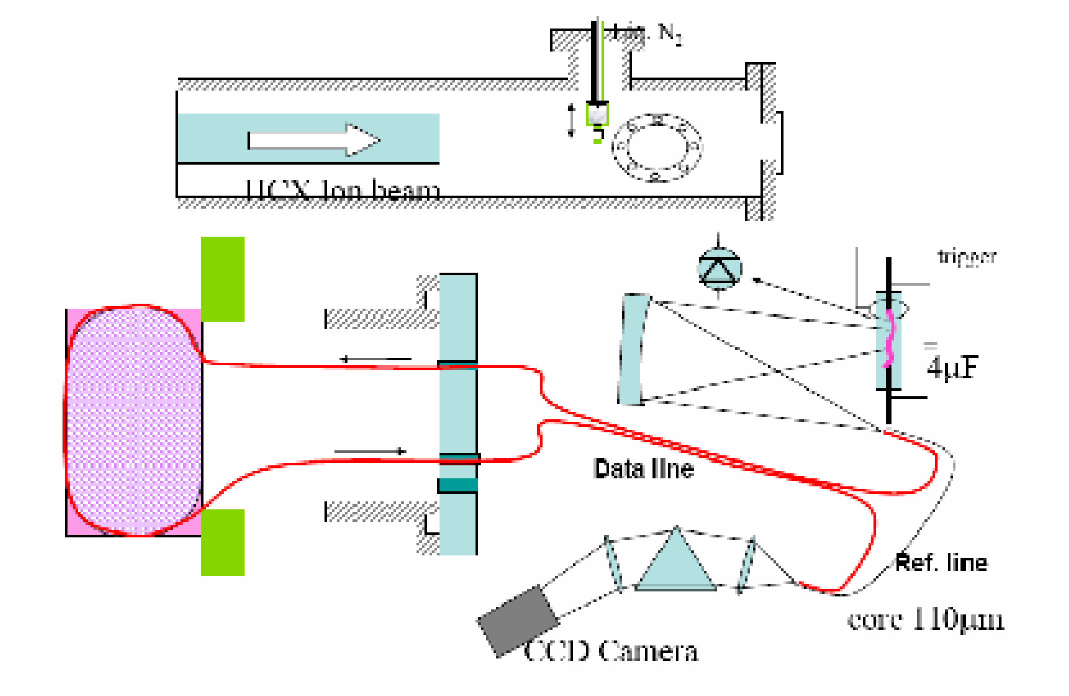
Extra slides

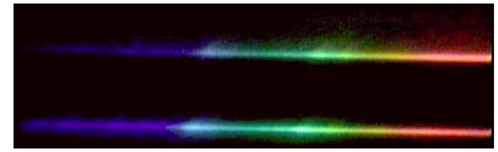
Porous target slows expansion compared to response of solid target to ion beam pulse.

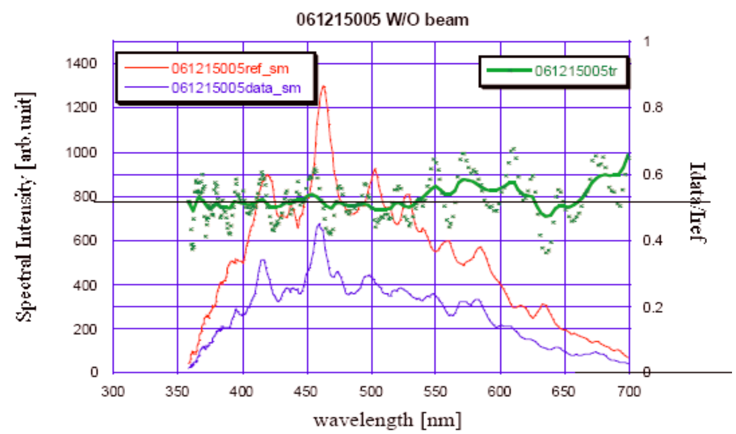
- **Beam range is longer in porous target, slowing down hydro expansion time**
- **Very low density porous targets, such as gold black, can increase expansion time by factor ~100**
- **Target expansion time can be >> compressed pulse length ~2 ns.**
- **Modeling of porous target data from GSI is underway**



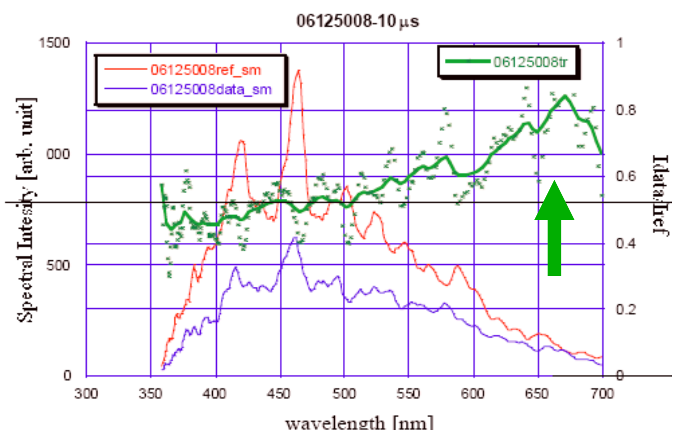
Transient optical transmission experiments in quartz fiber performed on HCX (1 MeV K^+ ion beam).







No beam



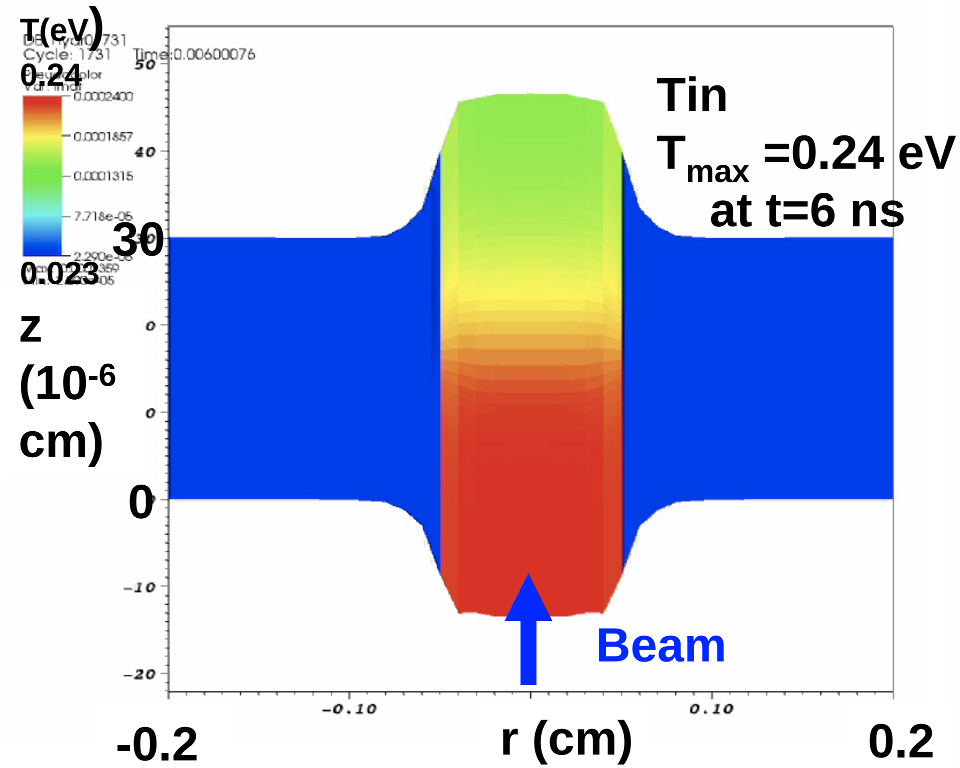
10μs

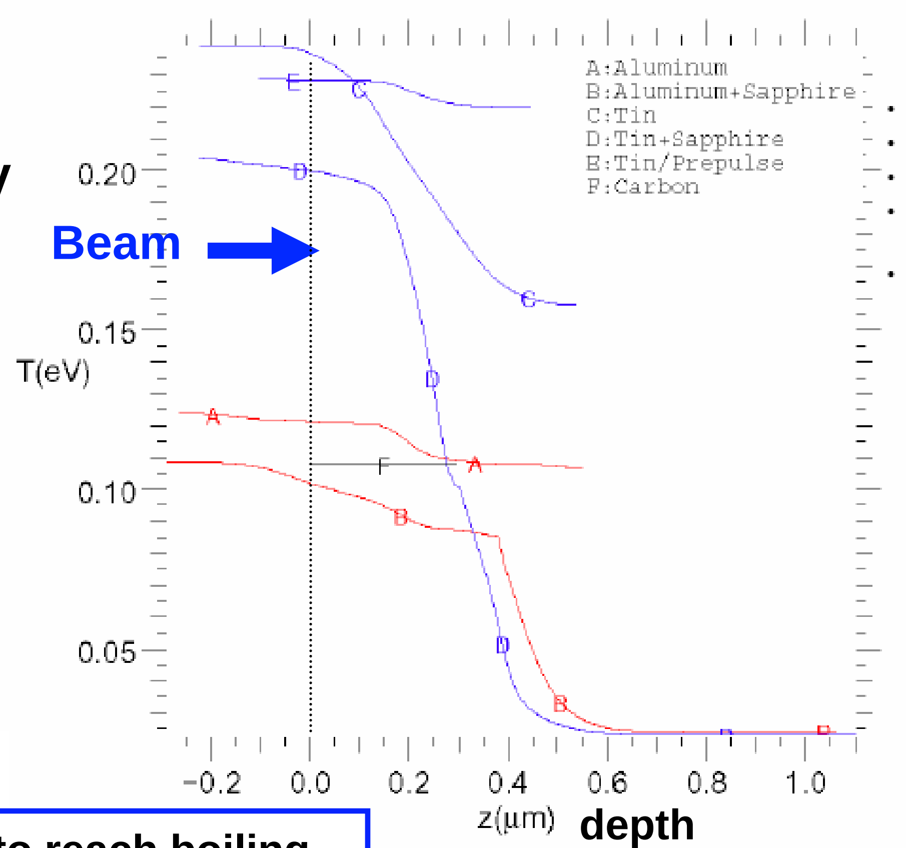
Optical transmission experiment: look for difference in fiber transmission with and without beam.

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

Simulations of NDCX-I planar targets predict temperatures of a few tenths of an eV.

**Simulation assumptions: Ion energy: 350 keV Energy fluence: 0.1 J/cm²
Spot radius: 0.5 mm Pulse duration: 2ns FWHM Total energy deposited: 0.8 mJ Peak current: 1 A (40 times compression) Total charge: 2.3 nC**





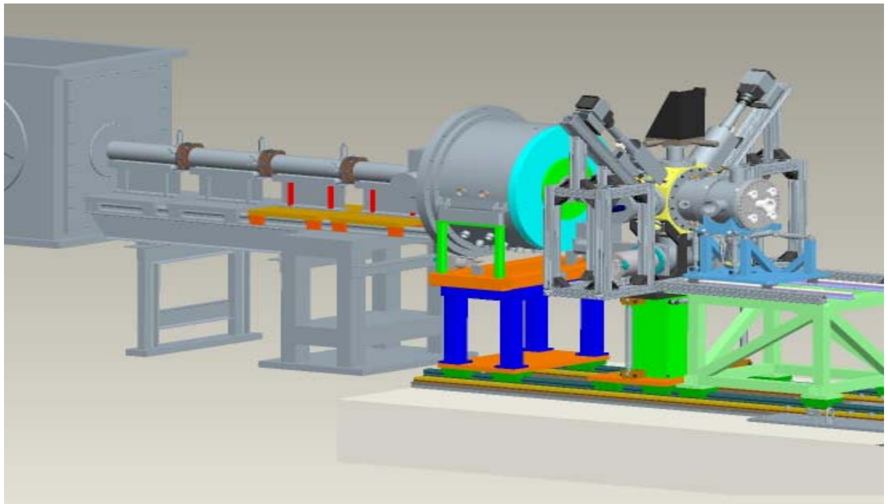
HYDRA simulations by Enrique Henestroza

Energy required to reach boiling point (J/cm²): 0.12 (Au); 0.25 (Al)

NDCX is designated by DOE as a HEDLP user facility.

Facility
First beam-target experiment: Aug. 2008
Beam ions: 300-350 keV K^+
Long pulse on target: Pulsewidth: 2-20 msec Energy: 35 mJ/μs/cm^2
Short pulse on target: Pulsewidth: 2 ns Energy: 10 mJ/cm^2 Peak Power:5 MW/cm^2
Beam Ion Range: 100-400 nm
Repetition rate: Up to 1 shot per 20 seconds
Target temperature: ~0.3 eV

Diagnostics
Optical: Fast optical pyrometer, Visible streak camera, ICCD gated cameras, Visible spectometer/ streak-spectrometer, VISAR
Other: Manipulators for Target and Diagnostic positioning
Under development: Laser transmission, Beam transmission current monitor
8 user proposals under HEDLP program announcement



General Information	
Facility POC's	Dr. Grant Logan (510-486-7206) Dr. Peter Seidl (510-486-7653) Dr. Frank Bieniosek (510-486-5456)
Web site	http://www-afrd.lbl.gov/fusion.html
Shots available for external users	Based on request
Targets	Foils; coatings on substrate