GA-A26008

Capsules/Foams
Multi-fill Tube Target
Aerogel Foam

Coatings
Beryllium Coatings
Cocktail Hohlraum

Characterization
Optical
SEM

Micromachining
Specialty Targets

INERTIAL CONFINEMENT FUSION

Annual Report

October 1, 2006
through
September 30, 2007

Schafer

GENERAL ATOMICS

GA–A26008

RESEARCH AND DEVELOPMENT AND FABRICATION OF INERTIAL CONFINEMENT FUSION TARGETS, COMPONENTS, AND COMPONENT TECHNOLOGY

ANNUAL REPORT TO THE U.S. DEPARTMENT OF ENERGY FOR THE PERIOD OCTOBER 1, 2006 THROUGH SEPTEMBER 30, 2007

by
PROJECT STAFF

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GENERAL ATOMICS PROJECT 30272
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GENERAL ATOMICS

1. INTRODUCTION

This report documents General Atomics' (GA) fiscal year (FY) 2007 activity for Inertial Confinement Fusion (ICF), a research and development program of the U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA). The program goals are controlled nuclear fusion at laboratory scales using large laser and pulsed power facilities in the U.S., and conducting experiments relevant to high energy density physics (HEDP) using those same facilities. GA is registered in the ISO 9001:2000 program and maintained excellent communication with the users of the targets to continually improve the performance of the team. As well as getting extensive and generally very positive feedback from its customers in FY07, the GA staff authored a number of papers in refereed journals and presented work at major international conferences. Highlights of the GA ICF technology work performed under DOE Contract No. DE-AC52-06NA27279 in FY07 comprise the subject of this report. Comments and requests for further information may be directed to the current GA Inertial Fusion Technology Program Manager, Abbas.Nikroo@gat.com (858) 455-2931.

ICF relies on inertia to confine a mixture of deuterium and tritium (DT) for the time required to create a self-sustained fusion reaction. This also requires that the DT be highly compressed (about 1000 times solid density) and heated to about 100,000,000 deg. The ICF Ignition and High Yield Campaign supports the NNSA's goal to develop laboratory capabilities to create and measure extreme conditions of temperature, pressure, and radiation density. Achieving HEDP conditions is critical to validate codes and to study high energy density conditions.

The strategy to accomplish this long-term goal is centered on four objectives:

1. Achieve ignition in the laboratory and develop it as a scientific tool.
2. Support execution of HEDP experiments necessary to provide advanced assessment capabilities.
3. Develop advanced technology capabilities that support long-term needs of NNSA.
4. Maintain robust national program infrastructure and attract scientific talent to the programs.

The ICF Campaign, which includes the National Ignition Campaign (NIC) and HEDP experiments, is presently executed at six sites: Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), the University of Rochester Laboratory for Laser Energetics (UR/LLE), the Naval Research Laboratory (NRL) and GA. General Atomics concentrates on making the targets and doing the R&D for the targets for experiments which are carried out at several laser and pulsed power facilities. In this, GA supports all four of the above strategies of NNSA's ICF Campaign.

There are three major ICF facilities: the OMEGA glass laser at UR/LLE, the Z pulsed-power facility at SNL, and the National Ignition Facility (NIF) at LLNL. This 192-beam laser is not quite 100% complete but has done preparatory experiments with a few prototype beams and will perform Early Opportunity Shots within the next year. These facilities are supplemented by LANL's Trident laser, NRL's Nike laser and other smaller lasers.

In FY07, GA continued its support of NNSA's ICF program by on time delivery of more than 4000 fully characterized target components and targets, necessary to enable experiments at the various facilities. The OMEGA laser accounted for the majority of experiments for ICF and HEDP. Each shot requires a new target and generally there is a completely different type of tightly specified and well-characterized target for each day or half day of shots. The Z facility paused operation during the summer of FY06 for a major refurbishment and came back online in the late fall of CY2007. In FY07, GA produced components for these facilities consisting of many different types (Section 2). Many of the components are novel and were made by techniques requiring significant development. As the targets are the initial conditions for the experiments, the targets and components need to be accurately measured and characterized for each shot, which destroys the target.

In Section 2 of this report, we summarize the target deliveries for these facilities. By the nature of experiments, there is always the question of specifying the target well enough in advance for complete manufacture and characterization of the target to specification. The experimentalists may delay specifying the target, pending analysis of previous experiments and computer simulations, but several months are often required for fabrication, which often requires some development and characterization. In FY07, GA worked closely with LLNL — and the other sites — to manage the rolling specification of hundreds of targets per year required for OMEGA.

In Section 3, we summarize research and development work for the ignition campaign on the NIF (NIC Target Development) and supporting current deliveries for OMEGA (NIC x-ray drive target production and NIC direct drive target production), and Z (SNL Target Development and Production). This development work has been presented to peers in the inertial fusion and HEDP community at major international conferences (e.g., Inertial Fusion Sciences and Applications, IFSA, in Kobe, Japan and the American Physical Society Division of Plasma Physics, APS/DPP, in Orlando, Florida, USA). Section 3 has selected presentations from these major meetings; also included in this technical section is closely related target work on fast ignition and inertial fusion energy funded via related contracts.

Demonstration of laboratory ignition is the highest priority and a major objective of NNSA. This work is encompassed in the NIC which is an enhanced management activity of the NNSA, managed with the rigor of a project. There is a point design for the ignition target for the NIC. Major R&D is required to produce this target for 2010 due to the demanding specification on the ignition targets, the cryogenic capability required for ignition, and the higher quality standards required for experiments on the NIF.

In FY07, GA was the major program participant in the development of the non-cryogenic components of the new NIC targets. These include fuel capsules with graded doped ablators with micron-scale fill tubes. The specifications on the surface finish, roundness, uniformity, doping fraction, fill tube fillet, etc., are demanding. The cryogenic hohlraum that contains the capsules is continuing to evolve. GA is fabricating the prototypes and pieces used in current cryogenic fuel layering experiments. An accelerated program of R&D and preparing for facilitization to produce hundreds of targets per year is ongoing to ensure the success of the NIC. GA also supports the Cryogenic Target System (CTS) for the NIF by supplying LLNL-onsite engineering and technician staff.

Development for current x-ray drive targets on OMEGA includes surrogate target components that are shot on OMEGA in preparation for NIC development work. For current direct drive targets on OMEGA, development includes novel ways of attaching fill tubes to direct drive targets, ways of making targets to achieve enhanced implosion performance and x-ray yield for backlighting. Research for SNL includes a design to create targets for Z with many fill tubes on the large Z targets enabling several experiments on one shot to help examine the way the fill tube itself perturbs an implosion.

2. DELIVERIES

GA and Schafer supplied a wide range of ICF components to LLNL, LANL, SNL, UR/LLE, and others in FY07. Tables 2-1 summarizes these deliveries by quarter.

TABLE 2-1
FY07 DELIVERIES BROKEN DOWN BY GA CENTER. BY LABORATORY, AND BY QUARTER SHIPPED

Sum of Number Shipped		Lab											
Quarter shipped	Center	LANL	LLE	LLNL	NLUF	NRL	SNL	AWE	CEA	FI consortium	ILE	U Mich	Grand Total
Q1	Capsules	73	229	9	12	0	6						329
	Micromachining	110	35	145	16		5						311
	Foams												
	Coatings												
	Development												
Q1 Total		183	264	154	28	0	11						640
Q2	Capsules	0	215	29	40	11	6						301
	Micromachining	284	181	361			6	63					895
	Foams		20	30	37					14		16	117
	Coatings			30									30
	Development												
Q2 Total		284	416	450	77	11	12	63		14		16	1343
Q3	Capsules	73	228	21	18	0	0						340
	Micromachining	298	101	210	78		2	20		71			780
	Foams		27		0			101					128
	Coatings												
	Development	12	16	14									42
Q3 Total		383	372	245	96	0	2	121		71			1290
Q4	Capsules	28	178	27	40	0	0						273
	Micromachining	110	76	133	111				12	22			464
	Foams		19		17					12	29		77
	Coatings												
	Development	4											4
Q4 Total		142	273	160	168	0	0		12	34	29		818
Grand Total		992	1325	1009	369	11	25	184	12	119	29	16	4091

3. DEVELOPMENT

3.1 Target Development and Manufacturing

This section reports monthly accomplishments and progress for the National Ignition Campaign (NIC), as described in NIC Progress Reports for FY07.

The response of a cryogenic DT ice layer to the room temperature radiation that is encountered during clamshell shroud opening was characterized. The spherical interferometer developed for full area inspection of ablator capsules is now in operation and has been used to demonstrate that full-thickness graded germanium CH (hydrocarbon) ignition capsules meet the isolated defect specification for exterior surfaces of this capsule type. A new cryogenic experiment was initiated to directly compare x-ray phase contrast characterization of a DT ice surface with optical shadowography of the ice in the same capsule at the same time. Test artifacts were developed in order to calibrate x-ray phase contrast radiography.

First article parts for the NIC Thermo-Mechanical Package (TMP), as shown in Fig. 1, were produced in FY07. We then completed the first prototype assembly of a thermal mechanical package (TMP), as shown in Fig. 2. Also in FY07, a cryogenic experiment demonstrated significant improvement in the surface quality of a DT ice layer at 18.3 K by rapidly cooling the layer from 19.5 to 18.3 K.

Ion-assisted sputtering was demonstrated to be a considerable improvement in the beryllium coating process in FY07. Adequate gas retention in full-thickness NIF Be capsules using ion-assisted sputtering was demonstrated. Two batches of shells were coated using this process, and all of the

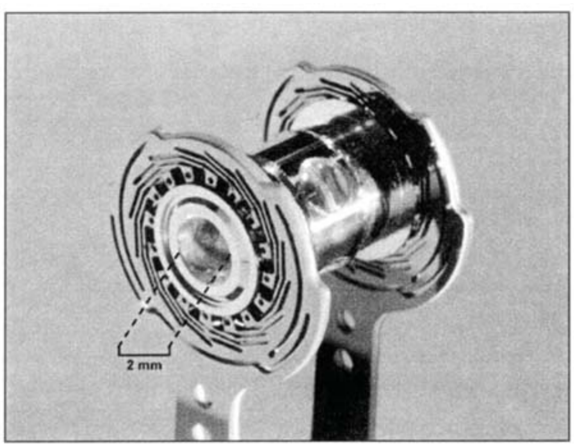

Fig. 1. First prototype assembly of a hohlraum inside of the thermal mechanical package.

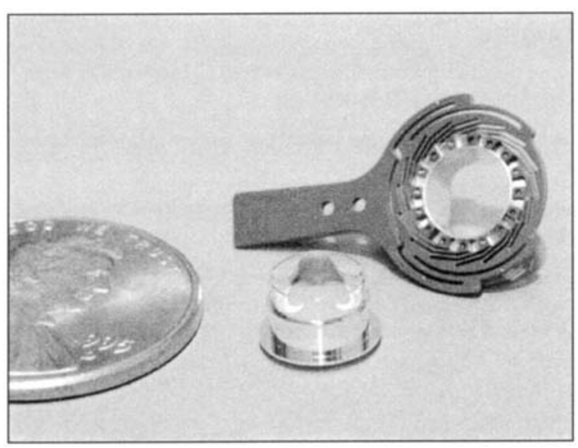
Fig. 2. Two components of the thermo-mechanical package; a silicon equalizer glued to the TMP can and a TMP can before assembly.

shells tested from these batches were proven to be leak free. In addition, the use of Be mandrels was demonstrated to reduce the uptake of oxygen in Be shells.

Ionized physical vapor deposition (IPVD) was tested on Au/U cocktails and was shown to improve the shelf life of the coating and the joint at the waist of the hohlraum. Installation was completed of a new LLNL-designed station for precise assembly of micro fill tubes onto ignition capsules. A versatile electron-beam and sputter deposition coating system was transferred from LANL to GA to improve beryllium capsule development capability.

A milestone to develop a preliminary NIF/NIC target component binning strategy that addresses target parameter variability and provides the required manufacturing and assembly flexibility to meet campaign requirements was completed. CH capsules doped with Ge that meet NIC ignition specifications and measured a batch yield of 40%–75% were manufactured. We also completed a capsule and fill tube assembly for a multi-view radiography experiment, as shown in Fig. 3. The first ignition prototype NIC target assembly was fabricated and cooled to 18 K, demonstrating cryogenic performance and completing a milestone, as shown in Fig. 4.

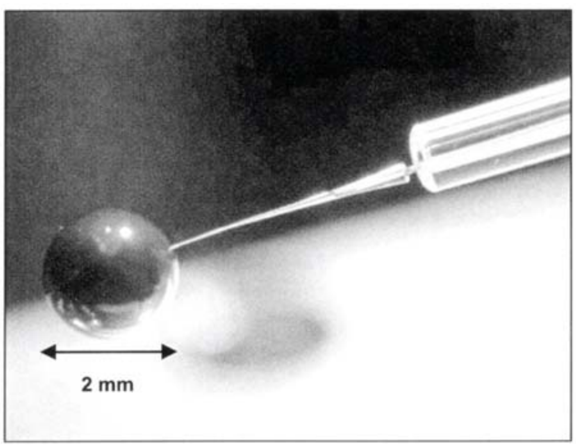

Fig. 3. A 2-mm Be capsule and fill tube assembly for a multi-view radiography experiment showing the tapered fill tube and the transition to the fill line to the reservoir.

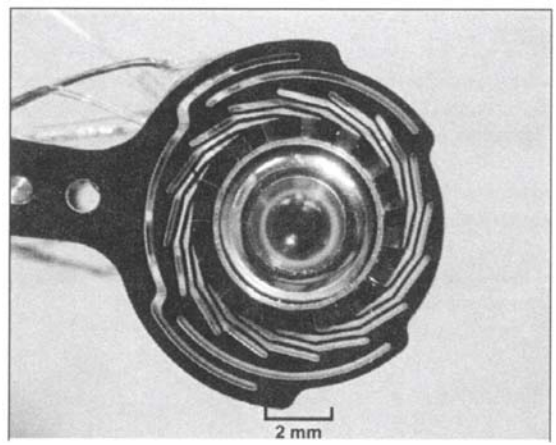

Fig. 4. Top view of the first NIC ignition prototype target assembly showing the Si cooling arms and the tented capsule.

We developed a process for bonding fill tubes to Be shells that optimizes the surface treatment of the components and the epoxy to maximize the strength of the bond by more than 10x. Pure uranium NIC-scale hohlraums, with a thin electroplated gold protective liner, were tested for lifetime and oxygen pickup for over seven weeks and met specifications.

A baseline plan for NIF target assembly flow, including sub-assembly at GA and assembly and proofing at LLNL was completed. The first gold-boron co-sputtered hohlraums for experiments at OMEGA, which successfully demonstrated reduction in wall backscatter, were delivered to UR/LLE. A milestone for the transfer of fill tube assembly technology from LLNL to GA was completed. We completed a Level 2 DOE milestone to demonstrate a scientific prototype ignition capsule with fill tube, and produced a cocktail hohlraum with the shelf life needed for ignition experiments. A plan was completed for design and fabrication of all assembly point workstations that is consistent with a start of pilot production in 2008. We demonstrated component pre-pilot production for capsules, fill tube assemblies, Au hohlraums and thermo-mechanical package (TMP) components, and completed a second station for subassembly of hohlraums and TMP components.

A batch of prototype Laser Entrance Hole (LEH) windows was received and successfully leak checked to establish the viability of this design for cryogenic NIF targets. We completed assembly of an ignition prototype target for testing with tritium in the Hohlraum Test System (HTS). A non-destructive radiography technique was developed to allow the measurement of both argon and copper content in Be capsules with a spatial resolution of 2 micrometers and a sensitivity of 0.15 atom %.

We produced the first hohlraum component with a gold-boron liner for NIF Early Opportunity Shot experiments, as shown in Fig. 5.

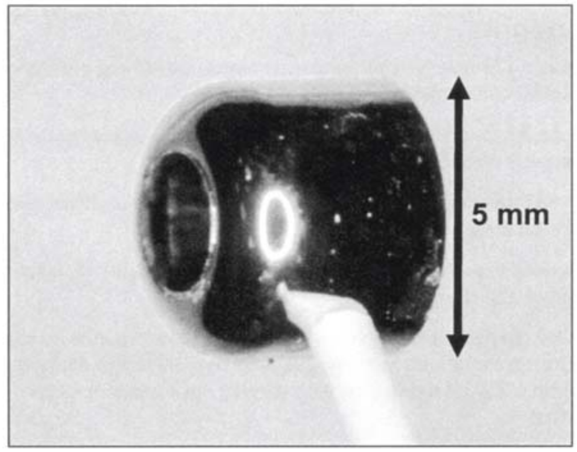

Fig. 5. Hohlraum components for NIF Early Opportunity Shot experiments.

3.2 Target Development

In this section, attachments of technical presentations summarize the research and development work, and the progress, on the NIF (NIC Target Development) and supporting current deliveries for OMEGA (NIC x-ray drive target production and NIC direct drive target production), Z (SNL Target Development and Production) and the NRL laser target development. These presentations represent work discussed at major international conferences including the 5th International Conference on Inertial Fusion Sciences and Applications in Kobe, Japan, and the 49th Annual Meeting of the APS Division of Plasma Physics in Orlando, Florida, USA. These attachments are selected presentations from these major meetings; also included in this technical section is closely related target work on fast ignition and inertial fusion energy funded via related contracts.

4. PUBLICATIONS

4.1. List of Publications

Akli, K.U., Key, M.H., Chung, H.K., Hansen, H.B., Freeman, R.R., Chen, M.H., Gregori, G., Hatchett, S., Hey, D., Izumi, N., Kign, J., Kuba, J., Noreys, P., Mackinnon, A.J., Murphy, C.D., Snavely, R., Stephens, R.B., Stoeckel, C., Theobald, W., and Zhang, B., “Temperature Sensitivity of Cu K_α Imaging Efficiency Using a Spherical Bragg Reflecting Crystal,” Phys Plasmas **14**, 023102 (2007).

Alexander, N.B., Goodin, D.T., and Stephens, R.B., “Target Mounting Systems for Rep-Rated Lasers,” Fusion Sci. Technol. **51**, 795 (2007).

Alfonso, E.L., Crippen, J.W., Nguyen, A.Q.L., “Monolithic Fill Tube Target Fabrication,” Fusion Sci. Technol. **51**, 651 (2007).

Back, C.A., Audbert, A., Baton, S.D., Bastiani-Ceccotti, S., Guillou, P., Lecherbourg, L., and Barbrel, B., Gauci, E., Koenig, M., Gemillet, L., Rousseaux, C., Giraldez, E., and Phommarine, S., “Study of Non-LTE Spectra Dependence on Target Mass in Short Pulse Laser Experiments,” AIP Conf. Proceedings **926**, 19 (2007).

Bennett, G.R., Hermann, M.C., “Fill-Tube-Induced Mass Perturbations on X-Ray-Driven, Ignition-Scale, Inertial Confinement-Fusion Capsule Shells and the Implications for Ignition Experiment,” Phys. Rev. Lett. **99**, 227207 (2007).

Bernat, T.P., Alexander, N.B., and Kaae, J.L., “Thermal and Electrical Conductivities of Electroplated Gold,” Fusion Sci. Technol. **51**, 782 (2007).

Bhandarkar, S., Letts, S.A., Buckley, S., Alford, C., Lindsey, E., Hughes, J., Youngblood, K.P., Moreno, K., Xu, H., Huang, H., and Nikroo, A., “Removal of the Mandrel from Beryllium Sputter Coated Capsules for NIF Targets,” Fusion Sci. Technol. **51**, 564 (2007).

Chen, K.C., Lee, Y.T., Huang, H., Gibson, J.P., Nikroo, A., Johnson, M.A., and Mapoles, E., “Reduction of Isolated Defects on Ge Doped CH Capsules to Below Ignition Specifications,” Fusion Sci. Technol. **51**, 593 (2007).

Chen, S.N., Gregori, G., Patel, P.K., Chung, H.-K., Evans, R.G., Freeman, R.R., Garcia Saiz, E., Glenzer, S.H., Hansen, S.B., Khattak, F.Y., King, J.A., Mackinnon, A.J., Notley, M.M., Pasley, J.R., Riley, D., Stephens, R.B., Weber, R.L., Wilks, S.C., and Beg, F.N., “Creation of Hot Dense Matter in Short-Pulse Laser-Plasma Interaction With Tamped Titanium Foils,” Phys. Plasmas **14**, 102701 (2007).

Czechowicz, D.G., Chen, C.J., Dorman, J.A., and Steinman, D.A., "Investigations to Remove Domes From Plastic Shells by Polishing," Fusion Sci. Technol. **51**, 600 (2007).

Dannenberg, K.K., Back, C.A., Frederick, C.A., Giraldez, E.M., Holt, R.R., Krych, W.J., Schroen, D.G., and Russell, C.O., "Characterization of Embedded Spheres in Opaque Foams," Fusion Sci. Technol. **51**, 673 (2007).

Eddinger, S.A., Stephens, R.B., Huang, H., Drake, T.J., Nikroo, A., Flint, G., and Bystedt, C.R., "Precisiion X-ray Optical Depth Measurements in ICF Shells," Fusion Sci. Technol. **51**, 525 (2007).

Forsman, A.C., Lundgren, E.H., Dodell, A.L., Komashko, A.M., and Armas, M.S., "SuperPulseTM: A Nanosecond Pulse Format for Improving Laser Drilling," to be published in Photonics Spectra. (2007)

Frederick, C.A., Back, C.A., Nikroo, A., and Takagi, M., "Fabrication of Multiple Fill Tube Targets for Sandia National Laboratory," Fusion Sci. Technol. **51**, 647 (2007).

Frey, D.T., Alexander, N.B., Bozek, A.S., Goodin, D.T., Stemke, R.W., Drake, T.J., Bittner, D., "Mass Production Methods for Fabrication of Inertial Fusion Targets," Fusion Sci. Technol. **51**, 786 (2007).

Fuchs, J., Sentoku, Y., d'Humières, E., Cowan, T.E., Cobble, J., Audebert, P., Kemp, A., Nikroo, A., Antici, P., Brambrink, E., Blazevic, A., Campbell, E.M., Fernandez, J.C., Gauthier, J.-C., Geissel, M., Hegelich, M., Karsch, S., Popescu, H., Renard-LeGalloudec, N., Roth, M., Schreiber, J., Stephens, R., and Pépin, H., "Comparative Spectra and Efficiencies of Ions Laser-Accelerated Forward From the Front and Rear Surfaces of Thin Solid Foils," Phys. Plasmas **14**, 053105 (2007).

Gallix, R. and Mijatovic, P., "Keeping the Cryogenic Targets Layered Until Shot Time in a Z-Pinch IFE Power Plant," Fusion Sci. Technol. **52**, 464 (2007).

Gallix, R., Crippen, J.W., Czechowicz, D.G., Forsman, A.C., Giraldez, E.M., Hund, J.R., Jaquez, J.S., Nguyen, A.Q.L., "Unitized Wire Arrays for Z-Pinch Machines: A Feasibility Study," Fusion Sci. Technol. **51**, 772 (2007).

Green, J.S., Ovchinnikov, V.M., Evans, R.G., Akli, K.U., Azechi, H., Beg, F.N., Bellei, C., Davies, J.R., Freeman, R.R., Habara, H., Heathcote, R., Key, M.H., King, J.A., Lancaster, K.L., Lopes, N.C., Ma, T., Mackinnon, A.J., Markey, K., McPhee, A., Najmudin, Z., Nilson, P., Norreys, P.A., Onofrei, R., Stephens, R.B., Takeda, K., Tanaka, K.A., Theobald, W., Tanimoto, T., Waugh, J.; VanWoerkom, L., Woosleh, N.C., Zepf, M., "Effect of Laser Intensity on Fast-Electron-Beam Divergence in Solid-Density Plasmas," Phys. Rev. Lett. **100**, 015003 (2008).

Hoppe, M.L. and Steinman, D.A., "New Developments in Glass Shells from SiGDP — Residual Gases, Gas Filling and Tailored Half-Lives," Fusion Sci. Technol. **51**, 606 (2007).

Huang, H., Koziozemski, B.J., Stephens, R.B., Nikroo A., Eddinger, S.A., Chen, K.C., Xu, H.W., Moreno, K.A., "Quantitative Radiography: Submicron Dimension Calibration and ICF Target Characterizatiaon," Fusion Sci. Technol. **51**, 519 (2007).

Huang, H., Stephens, R.B., Nikroo, A., Eddinger, S.A., Chen, K.C., Xu, H.W., Moreno, K.A., Youngblood, K.P., Skelton, M., "Quantitative Radiography: Film Model Calibration and Dopant/Impurity Measurement in IFC Ablators," Fusion Sci. Technol. **51**, 530 (2007).

Hund, J.F., Nikroo A., Frederick, C.A., Greenwood, A.L., Luo, W., McElfresh, J., "Fabrication and Characterization of Aluminum Oxide Aerogel Backlighter Targets," Fusion Sci. Technol. **51**, 701 (2007).

Jaquez, J.S., Alfonso, E.L., Nikroo, A., and Greenwood, A.L., "Al Coatings as a Deuterium Permeation Barrier on Foam Shells and the Dependence on Foam Surface Finish," Fusion Sci. Technol. **51**, 688 (2007).

Jones, O.S., Schein J., Rosen, M.D., Sutere, L.J., Wallace, R.J., Dewald, E.L., Glenzer, S.H., Campbell, K.M., Gunther, J., Bammel, B.A., Landen, O.L., Sorce, C.M., Olson, R.E., Rochau, G.A., Wilkens, H.L., Kaae, J.L., Kilkenny, J.D., and Nikroo, A., "Proof of Principle Experiments that Demonstrate Utility of Cocktail Hohlraums for Indirect Drive Ignition," Phys. Plasmas **14**, 056311 (2007).

Lancaster, K.L., Green, J.S., Hey, D.S., Akli, K.U., Davies, J.R., Clarke, R.J., Freeman, R.R., Habara, H., Key, M.H., Kodama, R., Krushelnick, K., Murphy, C.D., Nakatsutsumi, M., Simpson, P., Stephens, R.B., Stockel, C., Yabuuchi, T., Zepf, M., and Norreys, P.A., "Measurements of Energy-Transport Patterns in Petawatt Laser-Plasma Interactions at Intensities of 5×10^{20} Wcm^{-2}," Phys. Rev. Lett. **98**, 125002 (2007).

Lundgren, E.H., Forsman, A.C., Hoppe, M.L., Moreno, K.A., and Nikroo, A., "Fabrication of Pressurized 2 mm Beryllium Targets for ICF Experiments," Fusion Sci. Technol. **51**, 576 (2007).

Mauldin, M.P., Giraldez, E.M., Jaquez, J.S., Shearer Jr., C.H., Stephens, R.B., Woodhouse, D.M., "Fabrication of Targets for Proton Focus Cone Fast Ignition Experiments," Fusion Sci. Technol. **51**, 626 (2007).

Moreno, K.A., Xu, H.W., Nikroo, A., Huang, H., Fong, J., Knipping, J.E., Kaae, J.L., Giraldez, E.M., "Fabrication and Characterization of Beryllium Rayleigh-Taylor Targets for Omega Experiments," Fusion Sci. Technol. **51**, 581 (2007).

Nguyen, A.L., Alfonso, E.L., and Czechowicz, D.G., "Deterministic Fabrication and Characterization of Fill Tube Surrogate Targets for OMEGA Experiments Using a Polymer Stalk," Fusion Sci. Technol. **51**, 643 (2007).

Nikroo, A., Alford, C.S., Cook, R.C., Cooley, J.C., Letts, S.A., Moreno, K.A., Xu, H.W., and Youngblood, K.P., "Investigation of Deuterium Permeability of Sputtered Beryllium and Graded Copper Doped Beryllium Shells," Fusion Sci. Technol. **51**, 553 (2007).

Paguio, R.R., Nikroo, A., Frederick, C.A., Hund, J.F., and Thi, M., "Fabrication of Tin Loaded Resorcinol Formaldehyde Aerogel and Foam Spheres for Extreme Ultraviolet Source Emission," Mater. Res. Soc. Symp. Prov., Vol. 961 (2007).

Paguio, R.R., Takagi, M., Thi, M.A.W., Hund, J.F., Nikroo, A., Paguio, S.P., Luo, R.W., Greenwood, A.L., Acenas, O., and Chowdhury, S., "Improving the Wall Uniformity of Resorcinol Formaldehyde Foam Shells by Modifying Emulsion Components," Fusion Sci. Technol. **51**, 682 (2007).

Parks, P.B. and Cowan, T.E., "Runaway Electron Production During Intense Electron Beam Penetration in Dense Plasma," Phys. Plasmas **14**, 013102 (2007).

Pasley, J. and Stephens, R.B., "Simulations Investigating the Effect of a Deuterium-Tritium-Ice Coating on the Motion of the Gold Cone Surface in a Re-Entrant Cone-Guided Fast Ignition Inertial Confinement Fusion Capsule," Phys. Plasmas **14**, 054501 (2007).

Pasley, J., Wei, M., Shipton, E., Chen, S., Ma, T., Beg, F.N., Alexander, N.B., Stephens, R.B., MacPhee, A.G., Hey, D., Le Pape, S., Patel, P., Mackinnon, A.J., Key, M., Offermann, D., Link, A., Chowdhury, E., VanWoerkom, L., and Freeman, R.R., "Experimental Observations of Transport of Picosecond Laser Generated Electrons in a Nail-Like Target," Phys. Plasmas **14**, 120701 (2007).

Petzoldt, R.W., Alexander, N.B., Carlson, L.C., Flint, G., Goodin, D.T., Spalding, J.D., and Tillack, M.S., "A Continuous, In-Chamber Target Tracking and Engagement Approach for Laser Fusion," Fusion Sci. Technol. **52**, 454 (2007).

Petzoldt, R.W., Valmianski, E.I., Carlson, L.C., and Huynh, P., "Target Injection Placement Accuracy Improvement with Electrostatic Steering," Fusion Sci. Technol. **52**, 459 (2007).

Schroen, D.G., Back, C.A., Holt, R.R., Smith, G.E., Stamm, R.M., and Taylor, J.L., "Target Fabrication for Sandia's Z-Pinch Accelerator," Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering, Albuquerque, New Mexico (Institute of Electrical and Electronics Engineers, Inc., Piscataway, New Jersey) (2007).

Snavely, R.A., Zhang, B., Akli, K.U., Chen, Z., Freeman, R.R., Gu, P., Hatchett, S.P., Hey, D., Hill, J., Key, M.H., Izawa, Y., King, J., Kitagawa, Y., Kodama, R., Langdon, A.B., Lasinski, B.F., Lei, A., Mackinnon, A.J., Patel, P., Stephens, R.B., Tampo, M., Tanaka, K.A., Town, R., Toyama, Y., Tsutsumi, T., Wilks, S., Yabguuci, T., and Zheng, J., "Laser Generated Proton Beam Focusing and High Temperature Isochoric Heating of Solid Matter," Phys. Plasmas **14**, 092703 (2007).

Steinman, D.A., Alfonso, E.L., and Hoppe, M.L., "Improvements in Capsule Gas Fill Half-Life Determination," Fusion Sci. Technol. **51**, 544 (2007).

Stoeckl, C., Boehly, T.R., Delettrez, J.A., Hatchett, S.P., Frenje, J.A., Glebov, V.Yu., Li, C.K., Miller, J.E., Petrasso, R.D., Seguin, F.H., Smalyuk, V.A., Stephens, R.B., Theobald, W., Yaakobi, B., and Sangster, T.C., "Hydrodynamics Studies of Direct-Drive Cone-In-Shell Fast-Ignitor Targets on OMEGA," Phys. Plasmas **14**, 112702 (2007).

Takagi, M., Saito, K., and Frederick, C.A., "Investigation and Attachment of Polyimide Fill Tubes," Fusion Sci. Technol. **51**, 638 (2007).

Valmianski, E.I. and Petzoldt, R.W., "Mechanical Response of the Target Acceleration for a Laser Fusion Power Plant," Fusion Sci. Technol. **51**, 564 (2007).

Vermillion, B.A., Bousquet, J.T., Andrews, R.E., Thi, M., Hoppe, M.L., Castillo, E.R., Nikroo, A., Goodin, D.T., and Besenbruch, G.E., "Development of a GDP Coater Enabling Increased Production," Fusion Sci. Technol. **51**, 791 (2007).

Wilkens, H.L., Nikroo, A., Wall, D.R., Wall, J.R., Klingmann, J., and Dzenitis, E., "Developing Depleted Uranium and Gold Cocktail Hohlraums for the National Ignition Facility," Phys. Plasmas **14**, 056310 (2007).

Wong, B.Y., Buckingham, R.T., Brown, L.C., Russ, B.E., Besenbruch, G.E., Kaiparambil, A., Santhanakrishnan, R., and Roy, A., "Construction Materials Development in Sulfur-Iodine Thermochemical Water-Splitting Process for Hydrogen Production," J. Hydrogen Energy **32**, 497 (2007).

Xu, H.W., Alford, C.S., Cooley, J.C., Cook, R.C., Dixon, L.A., Hackenberg, R.E., Letts, S.A., Moreno, K.A., Nikroo, A., Wall, J.R., and Youngblood, K.P., "Beryllium Capsule Coating Development for NIF Targets," Fusion Sci. Technol. **51**, 547 (2007).

Youngblood, K.P., Alford, C.S., Buckley, S., Huang, H., Lee, Y.T., Letts, S.A., Moreno, K.A., and Nikroo, A., "Removal of GDP Mandrels from Sputter Coated Beryllium Capsules for NIF Targets," Fusion Sci. Technol. **51**, 570 (2007).

4.2. List of Presentations

Akli, K.U., "Laser Heating of Solid Matter by Light Pressure-Driven Shocks at Ultra-Relativistic Intensities," 49th American Physical Society DPP Meeting, Orlando, Florida, November 12–16, 2007.

Alexander, N.B., "Mass Production Layering for IFE," US/Japan Workshop, San Diego, California, March 5–6, 2007.

Alexander, N.B., “IAEA CRP on IFE,” IFE Science and Technology Strategic Planning Workshop, San Ramon, California, April 24–27, 2007.

Alexander, N.B., “Layering Methods for Inertial Fusion Targets,” IFE Science and Technology Strategic Planning Workshop, San Ramon, California, April 24–27, 2007.

Alexander, N.B., “IFE Targets General Atomics,” IFE Materials Science Workshop, Edmonton, Canada, January 23, 2007.

Alexander, N.B., “Nuclear Hydrogen at General Atomics,” General Atomics Internal Meeting, San Diego, California, 2007.

Alexander, N.B., 34th European Physical Society Conference on Plasma Physics, Warsaw, Poland, July 2–6, 2007.

Alger, E. “NIF/NIC Pilot Production Readiness,” Pilot Production Meeting, Livermore, California, July 19, 2007.

Back, C.A., “Sandia National Laboratory Liner Prototype,” Sandia National Laboratories/Lawrence Livermore National Laboratory Liner Workshop, January 25, 2007.

Back, C.A., “Study of Non-LTE Spectra Dependence on Target Mass in Short Pulse Laser Experiments,” 15th International Conference on Atomic Processes in Plasmas, Gaithersburg, Maryland, March 19, 2007.

Back, C.A., “OMEGA Ordering/Z and NLUF Targets,” US Department of Energy Target Fabrication Review, San Diego, California February 7, 2006.

Back, C.A., “Overview of GA Plans for New SNL Targets,” presentation to Sandia National Laboratories, San Diego, California, July 11, 2007.

Back, C.A., “Integrated Target Scheduling,” OMEGA FY08 Scheduling Meeting, Rochester, New York, June 27, 2007.

Back, C.A., presentation given at University of San Diego, La Jolla, California, July 31, 2007.

Back, C.A., “Current and Projected Needs for OMEGA,” VanFleet Review, San Diego, California, August 28, 2007.

Back, C.A., “Innovative Targets for Pulsed-Power Experiments,” 5th International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Blue, B.E., “Current and Projected Needs for Z,” VanFleet Review, San Diego, California, August 28, 2007.

Blue, B.E., “Astrophysical Jet Experiments on Inertial Confinement Fusion Machines,” 5th International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Brocato, B., “Review and Assessment of April 2007 Pattern Specifications,” SNRT Workshop, Livermore, California April 23,2007.

Brown, L.C., “Thermochemical Water-Splitting and the US Nuclear Hyrogen Programme,” Workshop on Sustainable Hydrogen Production: a Role for Fusion, Oxford, United Kingdom, April 11–12, 2007.

Buckingham, R.T., “Production of Hydrogen Using Nuclear Power by the Sulfur=Iodine Hydrogen Cycle,” Bi-Annual Steering Committee Meeting, Korea, May 16, 2007.

Buckingham, R.T., “A Sulfur-Iodine H2A Economic Assessment,” AlChE Conference, Salt Lake City, Utah, November 5–9, 2007.

Carlson, L., “Demonstration of an IFE Target Tracking and Engagement System,” US/Japan Workshop, San Diego, California, March 5–6, 2007.

Czechowicz, D.G., “Developments in Target Fabrication for the US ICF Program,” 3rd Moscow Workshop on Targets and Applications, Moscow, Russia, October 15–19, 2007.

Drake, T.J., “Tantalum Applications for Use in Small Scale Sulfur-Iodine Experiments,” AlChE Conference, Salt Lake City, Utah, November 5–9, 2007.

Forsman, A., “Advanced Double Pulse Format for Increasing the Speed and Quality of High Aspect Ratio Laser Micormachining,” Proceedings of 8th International Symposium on Laser Precision Microfabrication (LPM), Vienna, Austria, April 24–28, 2007.

Forsman, A., “Laser Produced Fill Holes and Starbursts,” Pilot Production Meeting, Livermore, California, April 19, 2007.

Forsman, A., “Double Pulse Laser Machining,” PhAST Conference, Baltimore, Maryland, May 2007.

Forsman, A., “Laser Drilled Counter-Bored Fill Holes in Beryllium Capsules,” 5th International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Frederick, C.A., “Fabrication of Planar Foam Targets for Rayleigh-Taylor Instability Experiments,” 49th American Physical Society DPP Meeting, Orlando, Florida, November 12–16, 2007.

Giraldez, E.M., “Machining Capability Center,” Pilot Production Meeting, San Diego, California, March 19, 2007.

Giraldez, E.M., “Machining Capability Center,” Pilot Production Meeting, Livermore, California, April 19, 2007.

Giraldez, E.M., “Machining Capability Center,” Pilot Production Meeting, San Diego, California, May 31, 2007.

Giraldez, E.M., "Machining Capability Center," Pilot Production Meeting, Livermore, California, July 19, 2007.

Goodin, D.T., "Current and Projected Needs for IFE," VanFleet Review, San Diego, California, August 28, 2007.

Goodin, D.T., "Progress in Demonstrating Feasibility of the Target Supply for Laser Fusion," 5th International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Goodin, D.T., "Mass production of Targets for Inertial Fusion Energy," 3rd Moscow Workshop on Targets and Applications, Moscow, Russia, October 15–19, 2007.

Goodin, D.T., "IFE Target Fabrication, Delivery, and Cost Estimates," 49th American Physical Society DPP Meeting, Orlando, Florida, November 12–16, 2007.

Huang, H., "Capsule Characterization Quarterly Update," ITS Quarterly Review, Lawrence Livermore National Laboratory, Livermore, California, January 18, 2007.

Huang, H., "Logic of Centers and Their Relationships," Pilot Production Meeting, San Diego, California, March 19, 2007.

Huang, H., "Metrology Development Plan," Pilot Production Meeting, Livermore, California, April 19, 2007.

Huang, H., Pilot Production Meeting, San Diego, California, May 31, 2007.

Huang, H., 22nd Symposium on Fusion Engineering, Albuquerque, New Mexico, June 17–21, 2007.

Huang, H., Pilot Production Meeting, Livermore, California, July 19, 2007.

Hund, J.F., US/Japan Workshop, San Diego, California, March 5–6, 2007.

Hund, J.F., "Target Fabrication Status for the HAPL Program," 22nd Symposium on Fusion Engineering, Albuquerque, New Mexico, June 17–21, 2007.

Hund, J.F., "Progress in Target Fabrication for Laser Fusion," IFE Science and Technology Strategic Planning Workshop, San Ramon, California, April 24–27, 2007.

Hund, J.F., "Recent Foam Shell Progress," VTC with D. Harding, August 22, 2007.

Hund, J.F., "IFE Target Fabrication Update," HAPL Meeting, Washington, DC, October 29, 2007.

Hund, J.F., "Density Uniformity and Surface Characterization of Tantalum Oxide Aerogel for Radiation Transport Experiments," 49th American Physical Society DPP Meeting, Orlando, Florida, November 12–16, 2007.

Kilkenny, J.D., US Department of Energy General Atomics Review, San Diego, California, February 7, 2007.

Kilkenny, J.D., “Making the Targets for Inertial Confinement Fusion— Fuelling a Star on Earth,” Celebrating 50 years of Fusion, San Diego, California May 15, 2007.

Kilkenny, J.D., “The GA/Shafer Target Fabrication Contract,” VanFleet Review, San Diego, California, August 28, 2007.

Miller, W.J., “Management Review of the IFE Quality System,” Management Review, San Diego, California, February, 2007.

Miller, W.J., “Management Review of the IFE Quality System,” Management Review, San Diego, California, May, 2007.

Miller, W.J., “Management Review of the IFE Quality System,” Management Review, San Diego, California, August, 2007.

Miller, W.J., “IFT ISO9001:2000,” VanFleet Review, San Diego, California, August 28, 2007.

Miller, W.J., “IFT ISO9001:2000 Orientation,” orientation training, San Diego, California, September 19, 2007.

Moreno, K.A., “Characterization Metrology,” Pilot Production Meeting, Livermore, California, April 19, 2007.

Moreno, K.A., “Characterization Metrology,” Pilot Production Meeting, San Diego, California, May 31, 2007.

Moreno, K.A., “Characterization Metrology,” Pilot Production Meeting, Livermore, California, July 19, 2007.

Nikroo, A., “Assessment,” Pilot Production Meeting, Livermore, California, April 19, 2007.

Nikroo, A., “Coating (Capsules),” Pilot Production Meeting, Livermore, California, April 19, 2007.

Nikroo, A., “Current and Projected Needs for National Ignition Campaign,” VanFleet Review, San Diego, California, August 28, 2007.

Nikroo, A., “Progress Towards Fabrication and Metrology of Ignition Design Capsules,” 5th International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Nikroo, A., “Fabrication and Metrology of Ignition Design Copper Doped Beryllium Capsules With Fill Tubes,” 49th American Physical Society DPP Meeting, Orlando, Florida, November 12–16, 2007.

Paguio, R.R., “Fabrication of Over-Coated Resorcinol Formaldehyde (R/F) Shells for IFE,” US/Japan Workshop, San Diego, California, March 5–6, 2007.

Petzoldt, R.W., “Target Injection Work in the USA,” US/Japan Workshop, San Diego, California, March 5–6, 2007.

Petzoldt, R.W., “Target Injection and Engagement,” IFE Science and Technology Strategic Planning Workshop, San Ramon, California, April 24–27, 2007.

Petzoldt, R.W., “IFE Target Positioning,” IFE Science and Technology Strategic Planning Workshop, San Ramon, California, April 24–27, 2007.

Petzoldt, R.W., “Update on Target Injection Positioning,” HAPL Meeting, Washington, DC, October 29, 2007.

Russ, B., “Status of the INERI Sulfur-Iodine Integrated-Loop Experiment,” International Conference on Advances in Nuclear Power Plants (ICAPP-2007), Nice, France, May 13–18, 20097.

Russ, B., “Status of the US Nuclear Hydrogen Initiative,” International Conference on Advances in Nuclear Power Plants (ICAPP-2007), Nice, France, May 13–18, 2007.

Russ, B., “Si Process Hi Decomposition Development and ILS Integration,” NHI Annual Review, Idaho, October 22, 2007.

Russ, B., “Status of the Sulfur-Iodine Integrated Lab Scale Experiments,” AlChE Conference, Salt Lake City, Utah, November 5–9, 2007.

Schroen, D.G., “Target Fabrication for Sandia’s Z-Pinch,” Symposium on Fusion Engineering, Albuquerque, New Mexico, June 17–21, 2007.

Schroen, D.G., “GA Performance on Target Deliveries,” VanFleet Review, San Diego, California, August 28, 2007.

Stephens, R.B., “Electron Transport in Nail-Head and Cone Wire Targets,” US/Japan Fast Ignition Workshop, Japan, January 1–9, 2007.

Stephens, R.B., “Update on Precision Radiography of Beryllium Capsules,” IET VTC with Lawrence Livermore National Laboratory, April 25, 2007.

Stephens, R.B., “OFES Fast Ignition Renewal Program,” presentation to F. Thio, US Department of Energy, Germantown, Maryland, July 17, 2007.

Stephens, R.B., “Creation of Warm Dense Matter and Transport Through It,” FSC Director’s Meeting, San Diego, California, August 4–5, 2007

Stephens, R.B., “Proton Focusing in a FI Target Compatible Configuration,” 5th International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Stephens, R.B., “Energy Injection for Fast Ignition Fusion,” 10th Annuual Directed Energy Symposium, Huntsville, Alabama, November 4–7, 2007.

Stephens, R.B., "Ultra-Intense Laser Beam Interactions in Cone Geometry for Fast Ignition," 49^{th} American Physical Society DPP Meeting, Orlando, Florida, November 12–16, 2007.

Wilkens, H.L., "Fabrication of NIF-Scale Cocktail Hohlraums," ITS Quarterly Review, Lawrence Livermore National Laboratory, Livermore, California, January 18, 2007.

Wilkens, H.L., "Holhraums — Energetics and Symmetry," IET VTC with Lawrence Livermore National Laboratory, April 21, 2007.

Wilkens, H.L., "Coating Hohlraums," Pilot Production Meeting, San Diego, California, March 19, 2007.

Wilkens, H.L., "Sputtered Depleted Uranium and Gold Multi-Layers for Applications in Inertial Confinement Fusion," Depleted Uranium User's Conference, Knoxville, Tennessee, April 23–15, 2007.

Wilkens, H.L., "Uranium and Cocktail Hohlraum Fabrication Update," IET VTC with Lawrence Livermore National Laboratory, April 5, 2007.

Wilkens, H.L., "Coating Hohlraums," Pilot Production Meeting, Livermore, California, April 19, 2007.

Wilkens, H.L., "NIF/NIC Pilot Production Readiness — Gold and Cocktail Hohlraums," Pilot Production Meeting, San Diego, California, May 31, 2007.

Wilkens, H.L., "Concept Review," Lawrence Livermore National Laboratory Meeting, Livermore, California, June 8, 2007.

Wilkens, H.L., "Uranium and Cocktail Hohlraum Fabrication Update," IET VTC with Lawrence Livermore National Laboratory, Livermore, California July 18, 2007.

Wilkens, H.L., "NIF/NIC Pilot Production Readiness — Gold and Cockktail Hohlraums," Pilot Production Meeting, Livermore, California, July 19, 2007.

Wilkens, H.L., "Recent Success in Fabrication of Depleted Uranium and Cocktail Hohlraums for the National Ignition Facility," 5^{th} International Conference on Inertial Fusion Sciences and Applications (IFSA), Kobe, Japan, September 9–14, 2007.

Wong, B., "Corrosion and Crack Growth Studies of Heat Exchanger Construction Materials for HI Decomposition in the Sulfur-Iodine Hydrogen Cycle, Annual US Department of Energy H_2 Program Review, Washington, DC, May 17, 2007.

Wong, B., "Progress Update — Cadmium Solar Hydrogen Cycle," SHGR Quarterly Meeting, Las Vegas, Nevada, April 30, 2007.

Wong, B., "Water-Splitting Thermochemical Reactions for Hydrogen Production," presentation to Ciemat, Spain, September 27, 2007.

Wong, B., "General and Stress Corrosion Behavior of Construction Materials for HI Gaseous Decomposition," AlChE Conference, Salt Lake City, Utah, November 5–9, 2007.

Zimmerer, Z., "Capsule and Fill Tube," Pilot Production Meeting, San Diego, California, March 19, 2007.

Zimmerer, Z., "Thermal Mechanical Package (TMP)," Pilot Production Meeting, San Diego, California, March 19, 2007.

Zimmerer, Z., "Thermal Mechanical Package (TMP) Sub-Assembly," Pilot Production Meeting, Livermore, California, April 19, 2007.

Zimmerer, Z., "Capsule and Fill Tube Assembly," Pilot Production Meeting, Livermore, California, April 19, 2007.

Zimmerer, Z., "Capsule and Fill Tube Subassembly," Pilot Production Meeting, San Diego, California, May 31, 2007.

Zimmerer, Z., "Thermal Mechanical Package (TMP) Subassembly," Pilot Production Meeting, San Diego, California, May 31, 2007.

Zimmerer, Z., "Capsule and Fill Tube Subassembly," Pilot Production Meeting, Livermore, California, July 19, 2007.

Zimmerer, Z., "Thermal Mechanical Package (TMP) Subassembly," Pilot Production Meeting, Livermore, California, July 19, 2007.

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ATTACHMENTS

"Recent Success in Fabrication of Depleted Uranium and Cocktail Hohlraums for the National Ignition Facility," by H. Wilkens, presented at the 5th International Conference on Inertial Fusion Sciences and Applications, Kobe, Japan, September 9-14, 2007.

"Progress Towards Fabrication and Metrology of Ignition Design Capsules," by A. Nikroo, presented at the 5th International Conference on Inertial Fusion Sciences and Applications, Kobe, Japan, September 9-14, 2007.

"Progress in Demonstrating Feasibility of the Target Supply for Laser Fusion," by J. Kilkenny, presented at the 5th International Conference on Inertial Fusion Sciences and Applications, Kobe, Japan, September 9-14, 2007.

"Astrophysical Jet Experiments on Inertial Confinement Fusion Machines," by B. Blue, presented at the 5th International Conference on Inertial Fusion Sciences and Applications, Kobe, Japan, September 9-14, 2007.

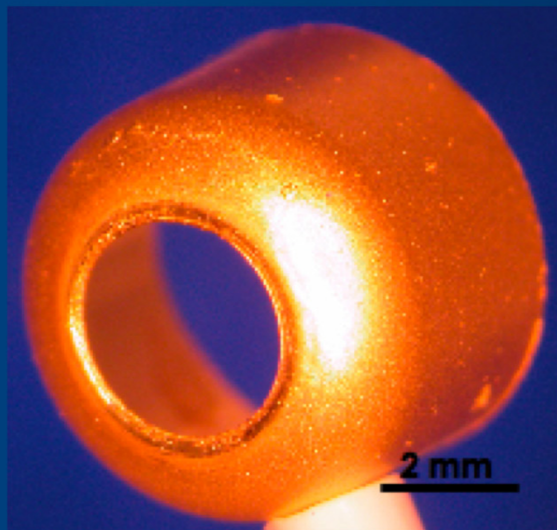
"Laser Drilled Counterbored Fill Holes in Beryllium Capsules," by A. Forsman, presented at the 49th Annual Meeting of the Division of Plasma Physics, Orlando, Florida, November 12-16, 2007.

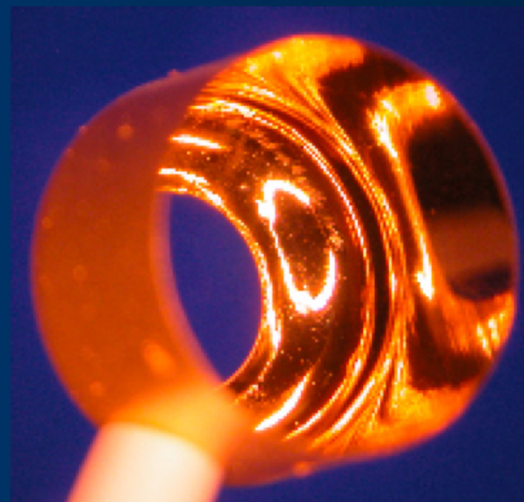
"Ultra-Intense Laser Beam Interactions in Cone Geometry for Fast Ignition," by R.B. Stephens, presented at the 49th Annual Meeting of the Division of Plasma Physics, Orlando, Florida, November 12-16, 2007.

"Laser Heating of Solid Matter by Light Pressure-Driven Shocks at Ultra-Relativistic Intensities," by K. Akli, presented at the 49th Annual Meeting of the Division of Plasma Physics, Orlando, Florida, November 12-16, 2007.

"Fabrication and Metrology of Ignition Design Copper Doped Beryllium Capsules With Fill Tubes," by A. Nikroo, presented at the 49th Annual Meeting of the Division of Plasma Physics, Orlando, Florida, November 12-16, 2007.

Recent success in fabrication of depleted uranium and cocktail hohlraums for the National Ignition Facility





Heather Wilkens
General Atomics

5th International Conference on Inertial Fusion Sciences and Applications
September 14, 2007
Kobe, Japan

GENERAL ATOMICS

Collaborators

N. Hein, J. Wall, D. Wall, and A. Nikroo
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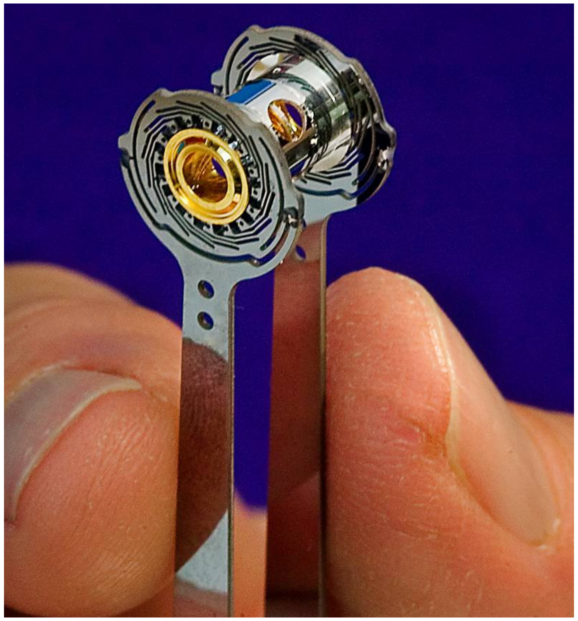
Lawrence Livermore National Laboratory

J. Cooley
Los Alamos National Laboratory

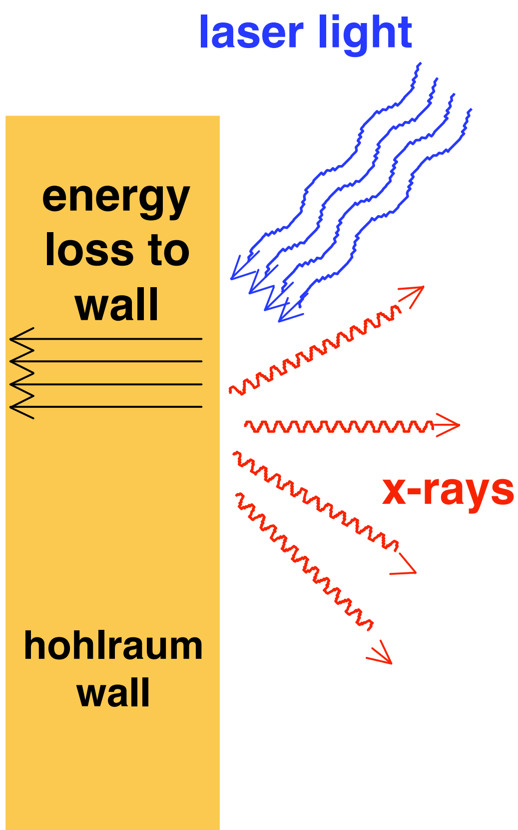
And many others…



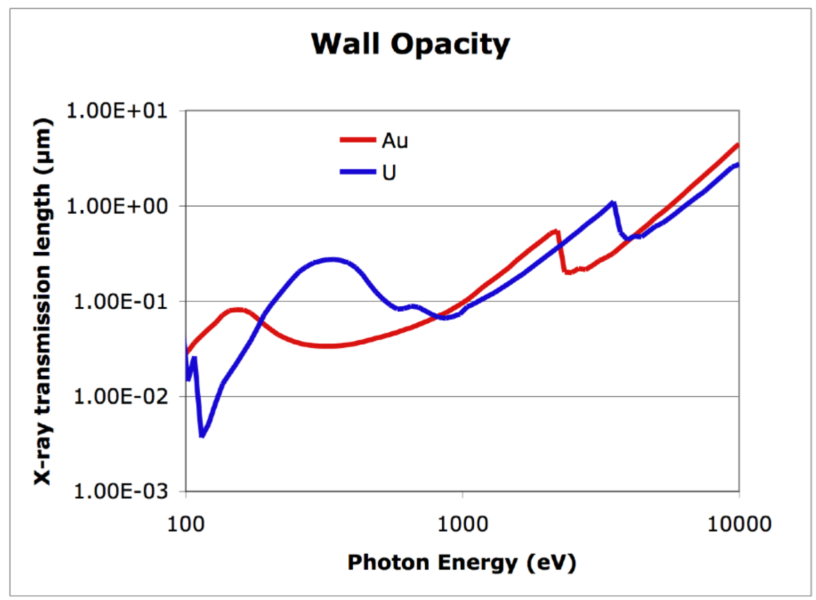
NF Los Alamos NATIONAL LABORATORY

GENERAL ATOMICS

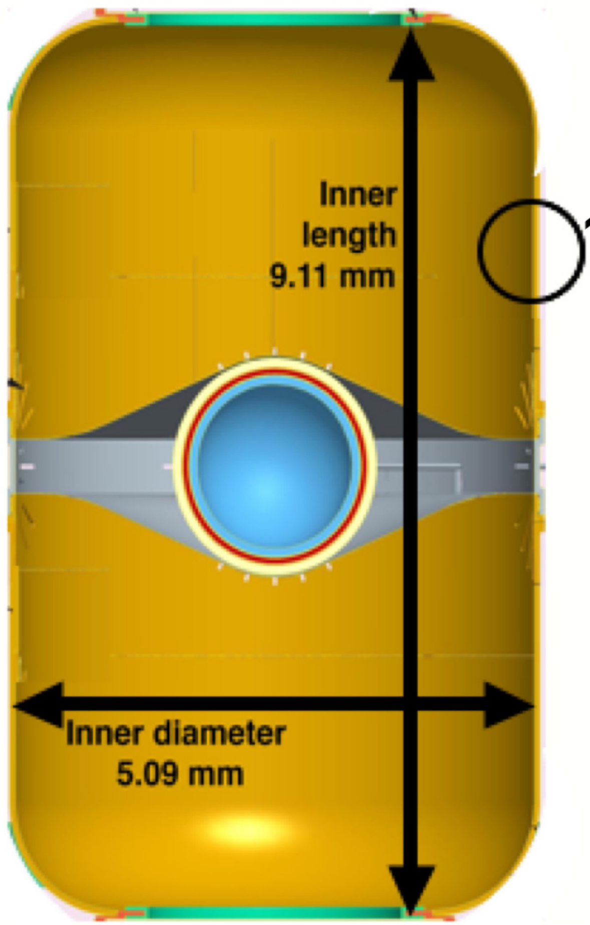
The NIF target design calls for a uranium or "cocktail" hohlraum to minimize wall losses



- **Composite has higher net opacity than constituents**
  - Higher opacity = more re-emission
  - Provides margin for ignition on NIF
- **Addition of U to Au hohlraum:**
  - Radiation losses reduced by 17%



Developments for NIF are focusing on meeting hohlraum can design specifications

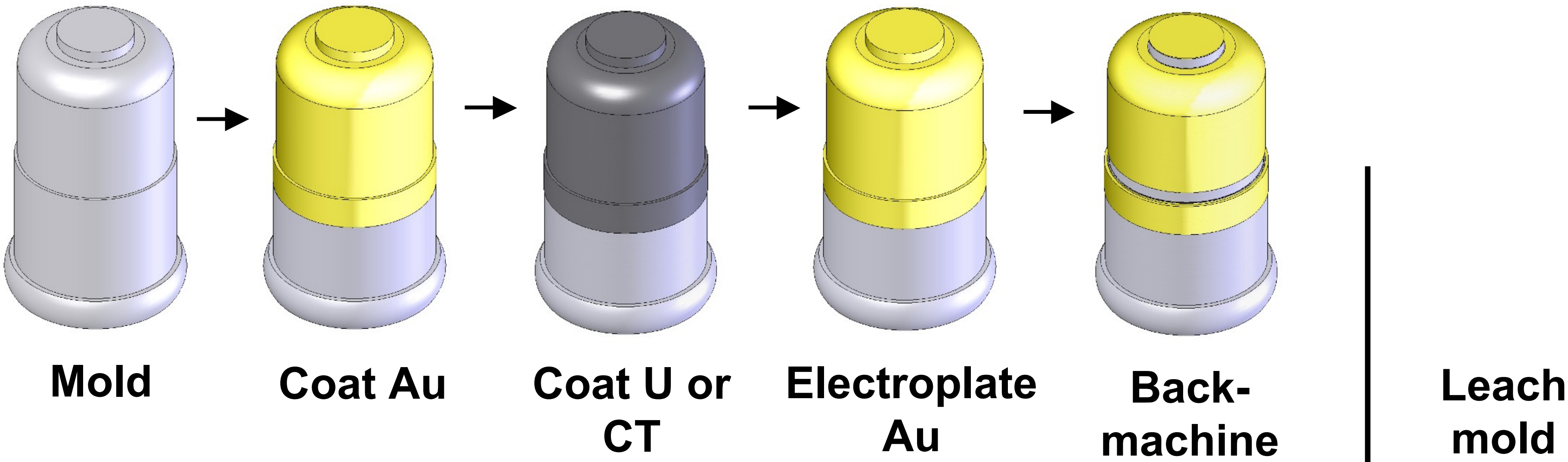


Hohlraum Can Specifications

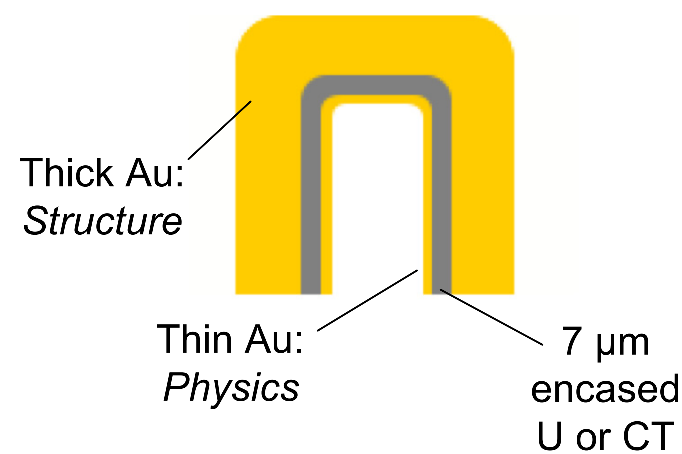
Total cocktail thickness	≥7 μm
Composition	75 at% U:25 at% Au known to <5 at%
Au inner liner	≤ 0.5 μm ± 0.01 μm
Au backing layer	≥10 μm
Bulk Oxygen content	<5 at%

Must withstand handling and a <u>minimum of 2 week exposure to air</u> for final assembly

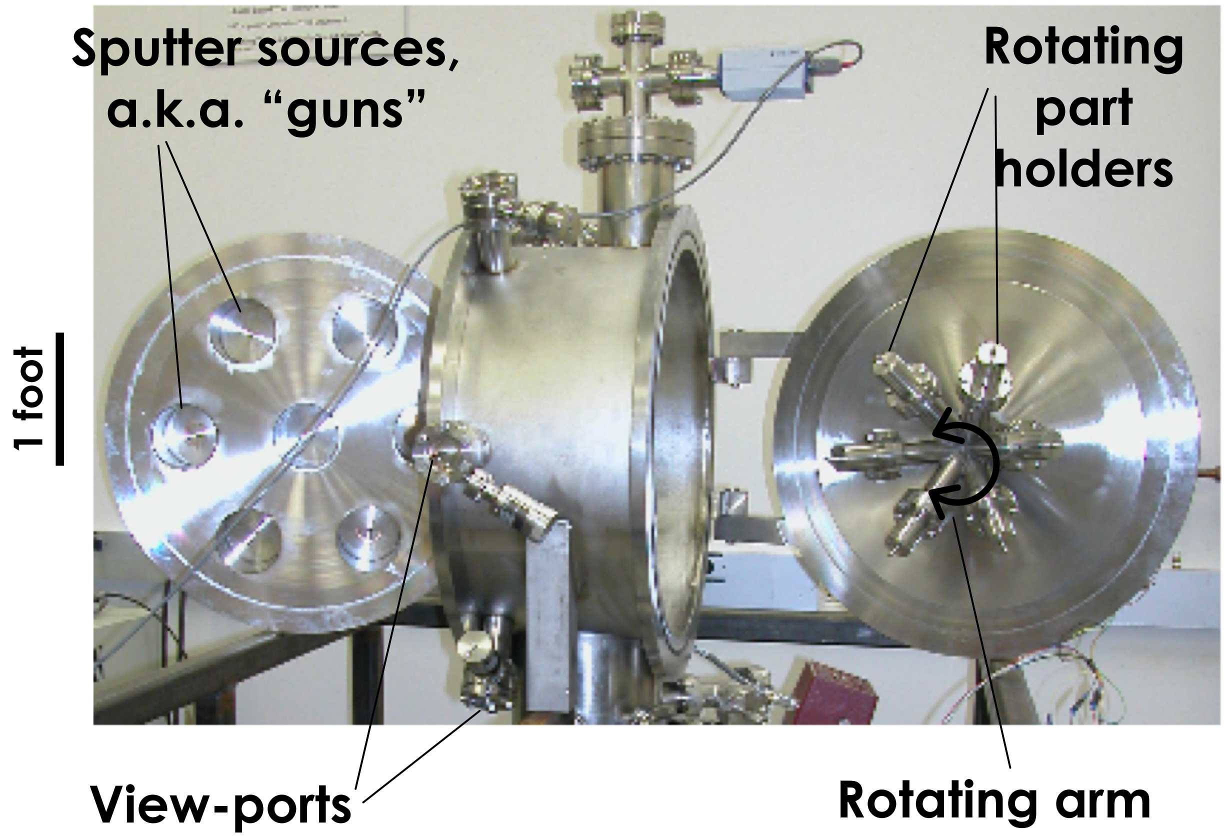
Keeping the depleted uranium from oxidizing is the greatest experimental challenge

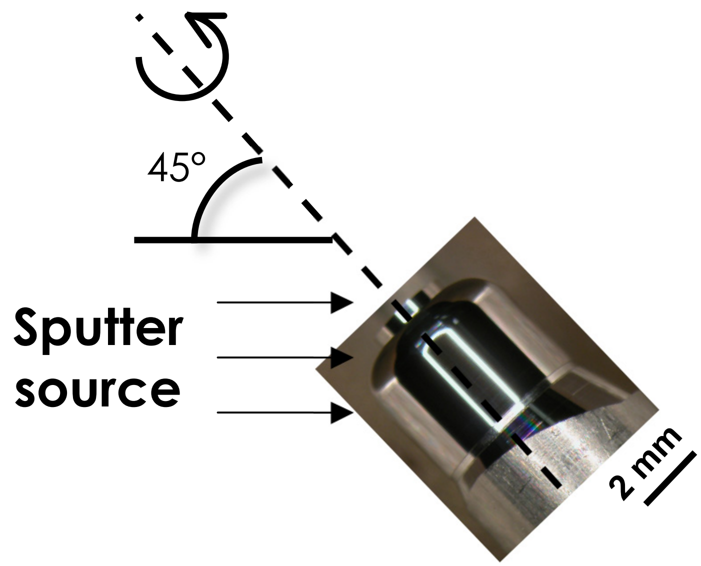


- **The presence of oxygen in the hohlraum**
  - Cancels efficiency gain
  - Results in physical failure



The multi-layers are made by rotating the substrate between separate Au and U sputter sources



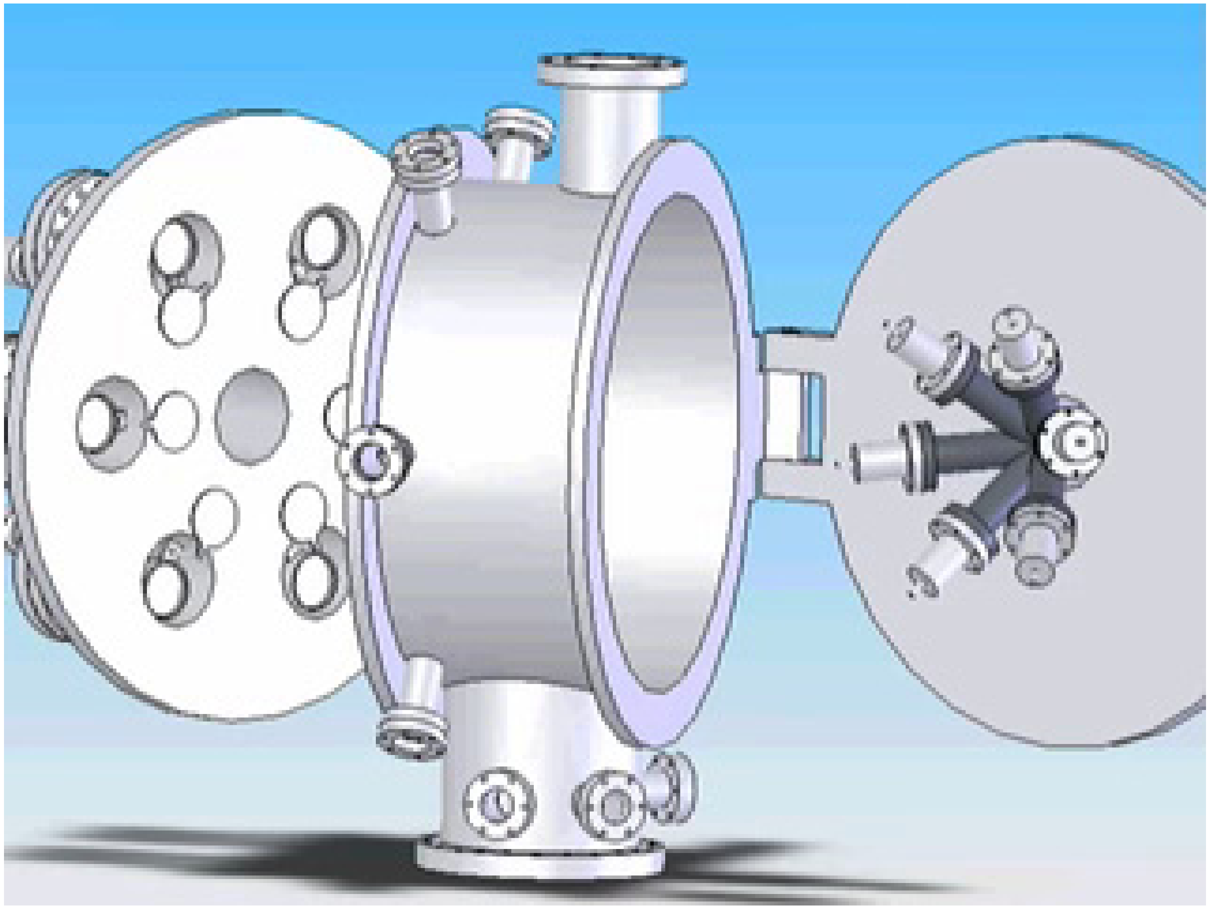


Rotating mandrel onto which material is sputtered

Oxygen mitigation:

- Base pressure - high 10^{-8} Torr
- Monitor chamber with residual gas analyzer

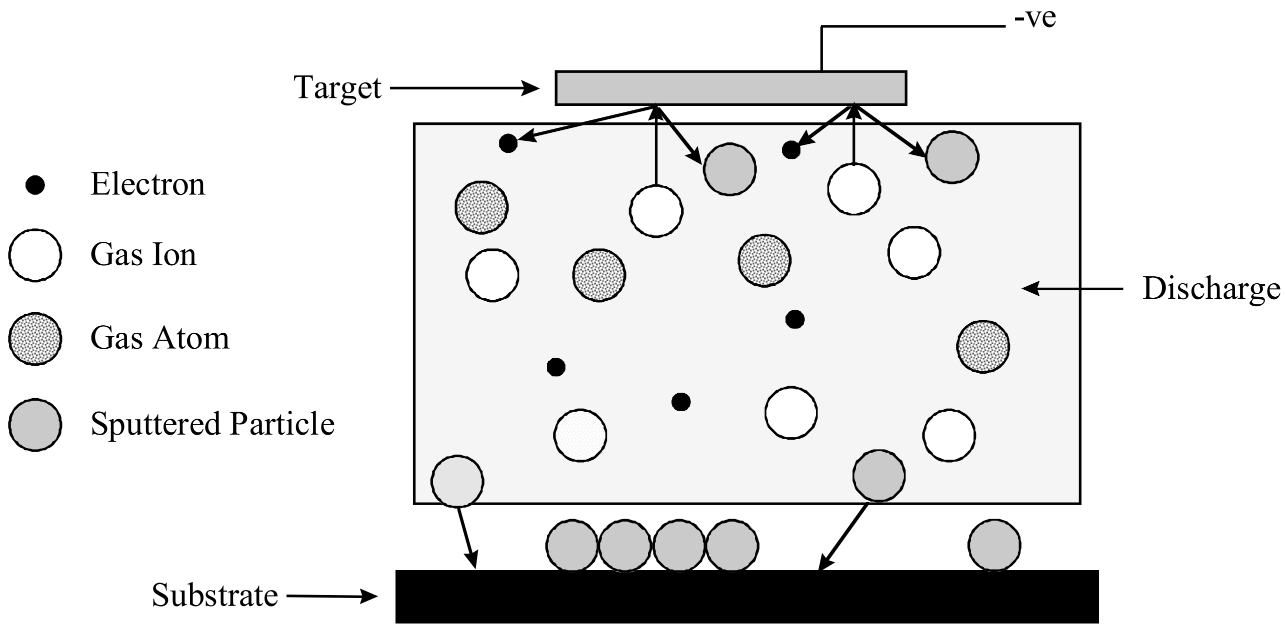
Sputter deposition system



- **Use this system to deposit cocktails or U-only hohlraums**

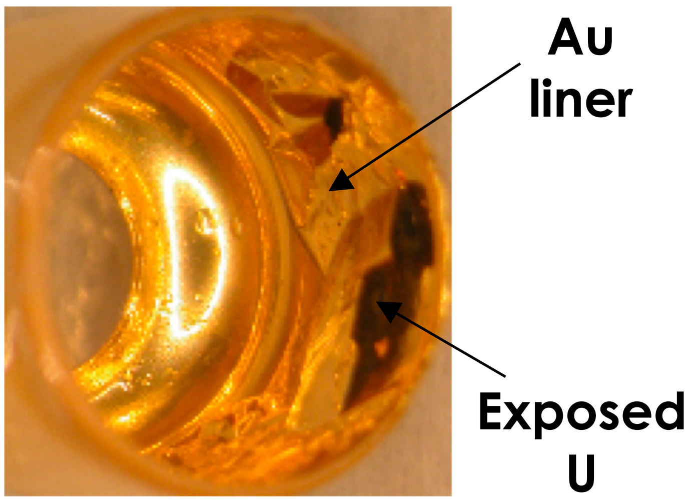
Schematic of the basic sputtering process

- **Sputter deposition is a type of physical vapor deposition**
  - Film quality dependent on the energy of the particles arriving at the substrate surface



Concerns over poor yield and shelf-life prompted change in deposition technique

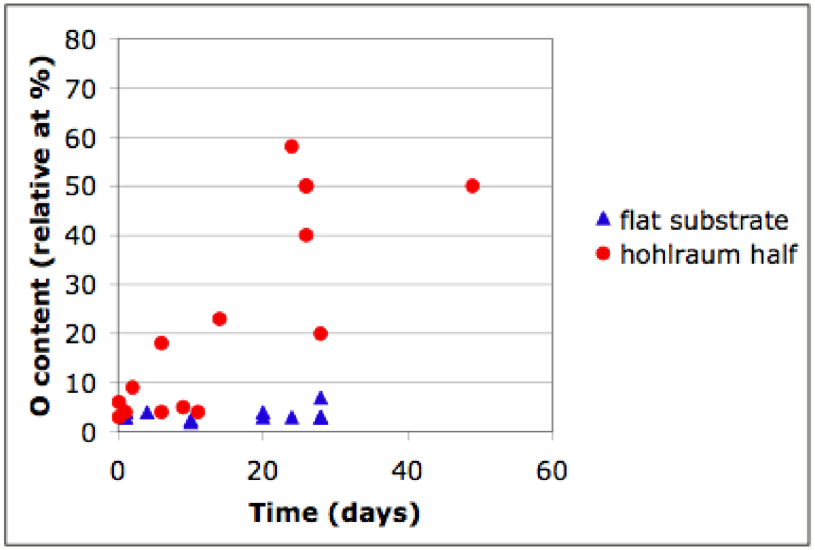
- **Yield was <40% intact post leach**
- **Shelf-life limited to 2-3 days**
- **Yield of parts with required lifetime of >2 weeks = 0%**



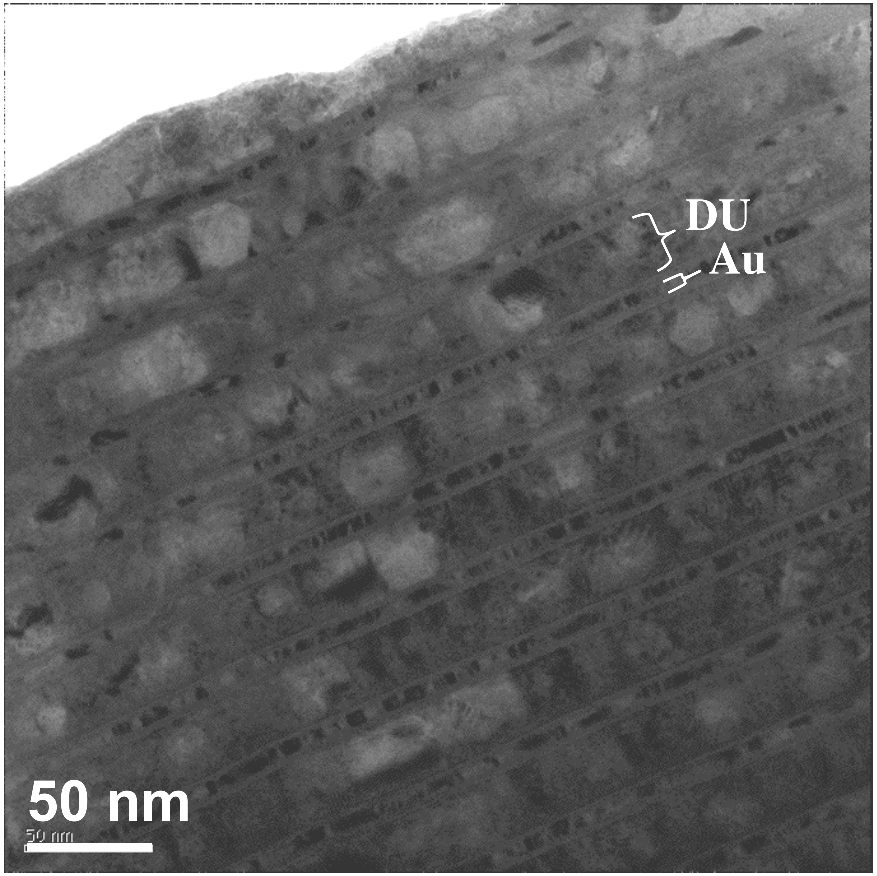
Example of failure during leach

Cocktail coatings on flat substrates fared better with time than those on mandrels

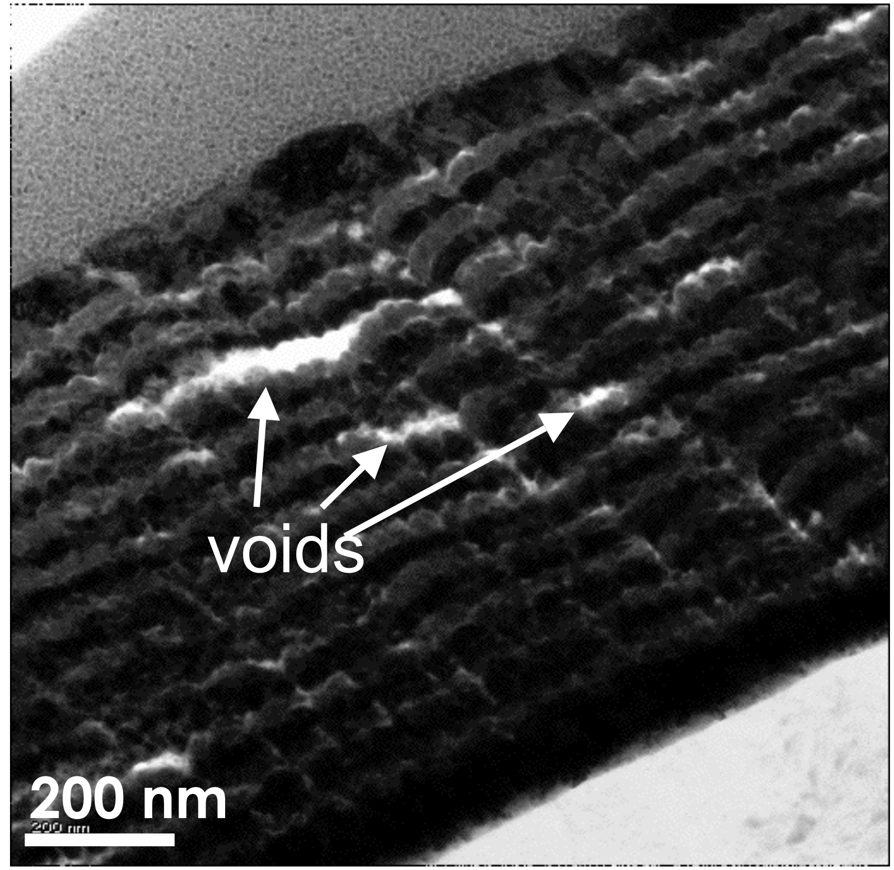
- **Microstructure is weaker along barrel**
- **Coatings on flat substrates pick up less oxygen over time than freestanding hohlraums**
- **Coating at oblique angles is known to induce self-shadowing**
  - Low density, porous films



Transmission electron microscopy images support concerns over self-shadowing



Cocktails on flat substrates are planar, uniform, & have well-defined interfaces



Growth on mandrel barrel is non-uniform, angled, and sometimes porous

Recent alterations to coating geometry result in dramatically improved yield and shelf-life

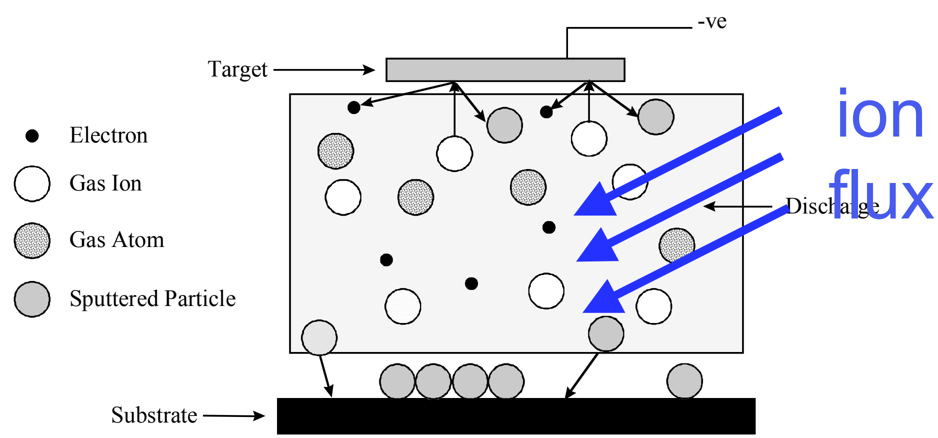
- **Ion assist promotes better mobility of adatoms**
- **Improvements in density and structural integrity has allowed:**
  - 93% yield through fabrication
  - 70% of these parts have a shelf-life of >4 weeks in air (higher % >2 weeks)
    - Minimal oxygen uptake

UPDATE #s

Produced cocktails that had shelf-lives of several weeks

Yield of intact parts increased from <40% to ~70%

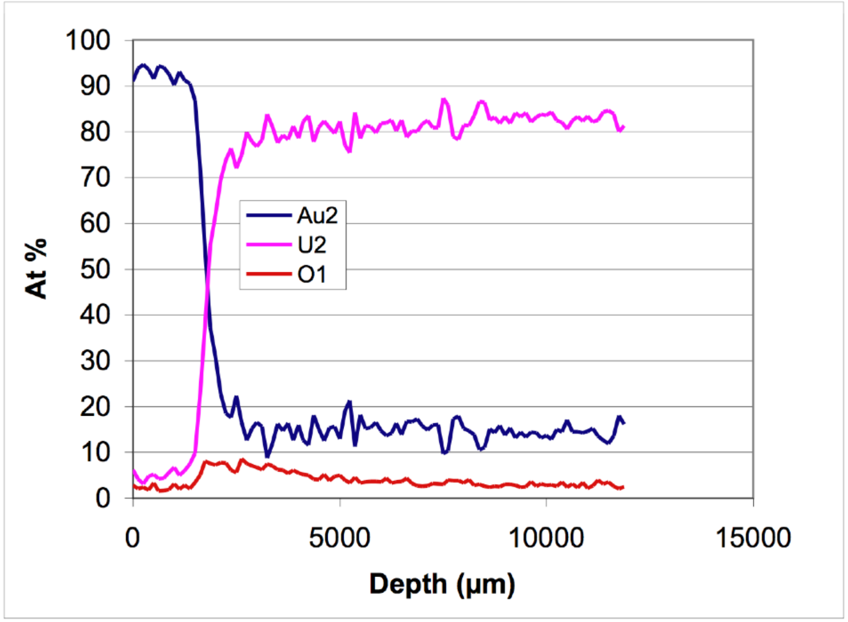
Focused on U only at the beginning of R&D effort

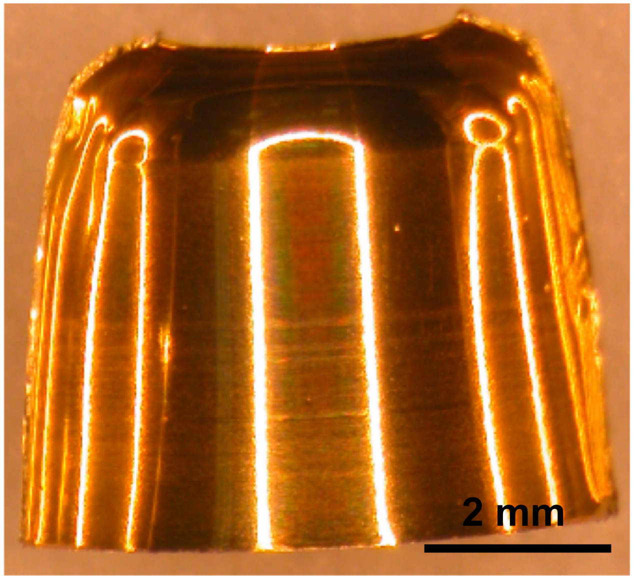


U-only design is preferable from a fabrication standpoint

- **Small hit in radiation temperature**
  - Some energetics penalty in replacing Au/U with U (U gives ~75% of the cocktail benefit)
  - U performance is relatively less sensitive to passivating layer thickness
- **Easier fabrication, higher yield**
  - Explain

Uranium-only hohlraum halves now exceed the shelf-life specification





- **Part cut for AES after 4 weeks in air**
  - 0.2 µm sputtered Au liner
  - No visible signs of degradation under microscope
- **Au appears in bulk because of overlap in secondary AES peaks**

Much progress has been made on NIF hohlraums…

- **Demonstrated ability to produce NIF-scale cocktail and uranium-only hohlraum halves**
- **U-only design preferable from fabrication standpoint**

- **NIF "early opportunity shots" begin next year**
  - Au, U and cocktail shots are planned (L. Suter talk)

Progress towards fabrication and metrology of ignition design capsules

Abbas Nikroo

IFSA 07

Sept 9-14 , Kobe Japan

Almost all of Be shell specifications have been met

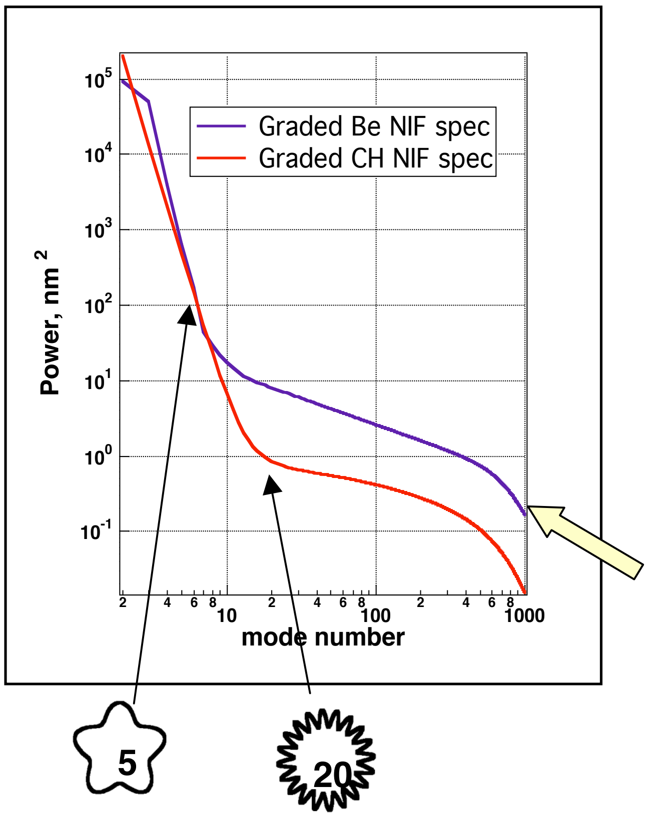
- **Fill tube details are being addressed currently**
- **Reproducibility, reliability and yield of processes is major focus currently**

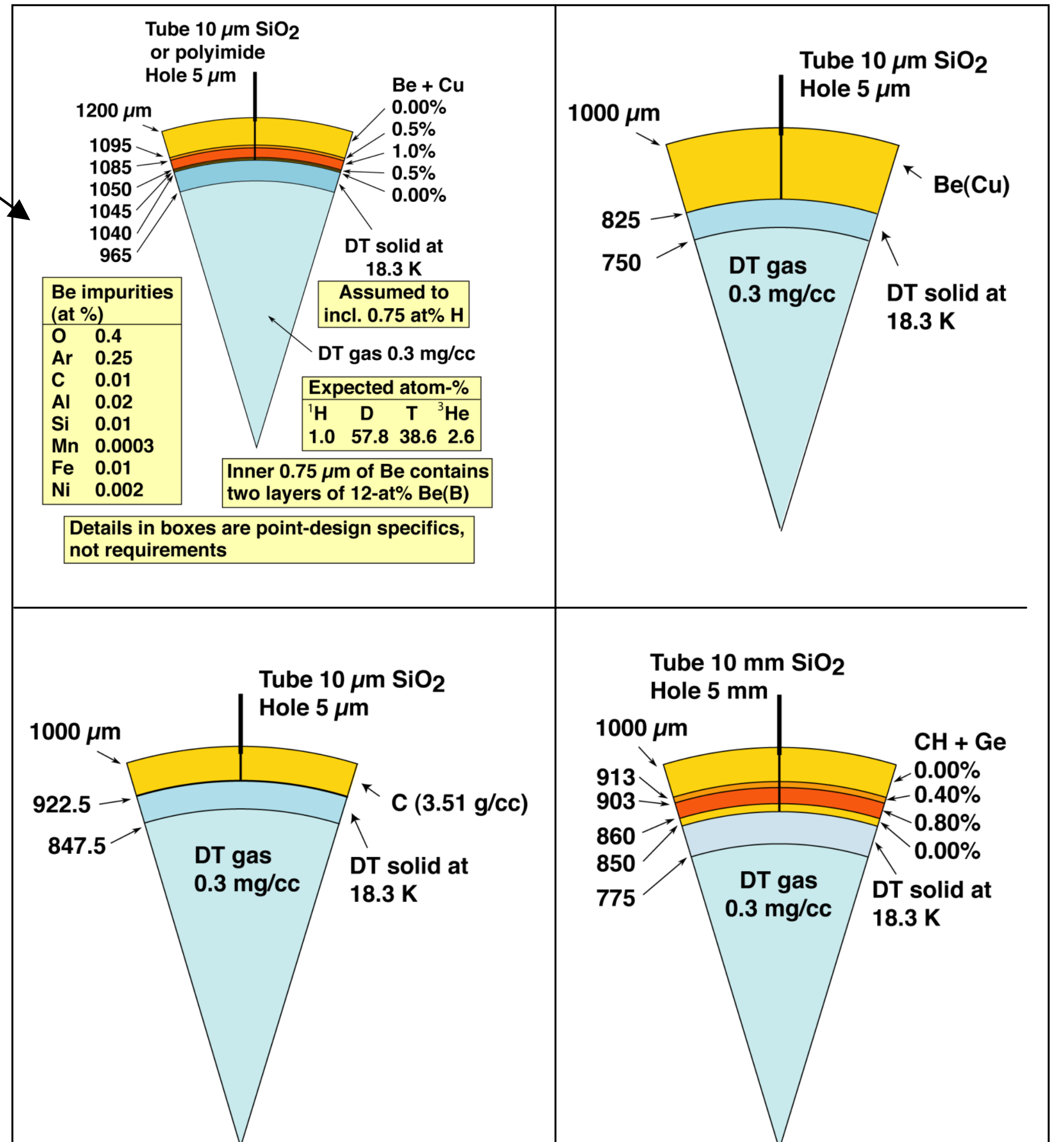
Capsule outer radius, tolerance	± 5µm
Ablator composition	Be
Ablator layer thicknesses	see table
Ablator layer dopant concentration	see table
Ablator oxide layers	
Ablator – average mass density	± 3% absolute, ± 1.5 % relative to campaign average
Ablator layer density	see table
Ablator – voids	< 3% void fract, < 0.1 µm3 void volume
Ablator – measurement of x-ray optical depth variations	accuracy <0.01%
Ablator thickness non-uniformity	see table
Ablator inner surface figure	see table
Capsule surface isolated defects	see figure
Capsule cleanliness	See isolated defects
Ablator – Low level impurities	sum(atomic fraction)*Z^2 < 0.1
Gas retention	> 7 day half life at room temp

(Legend: green = **Met spec**; yellow = **No major tech issue**; red = **Not met**. All table rows are shown green.)

Three ablator designs are being currently considered

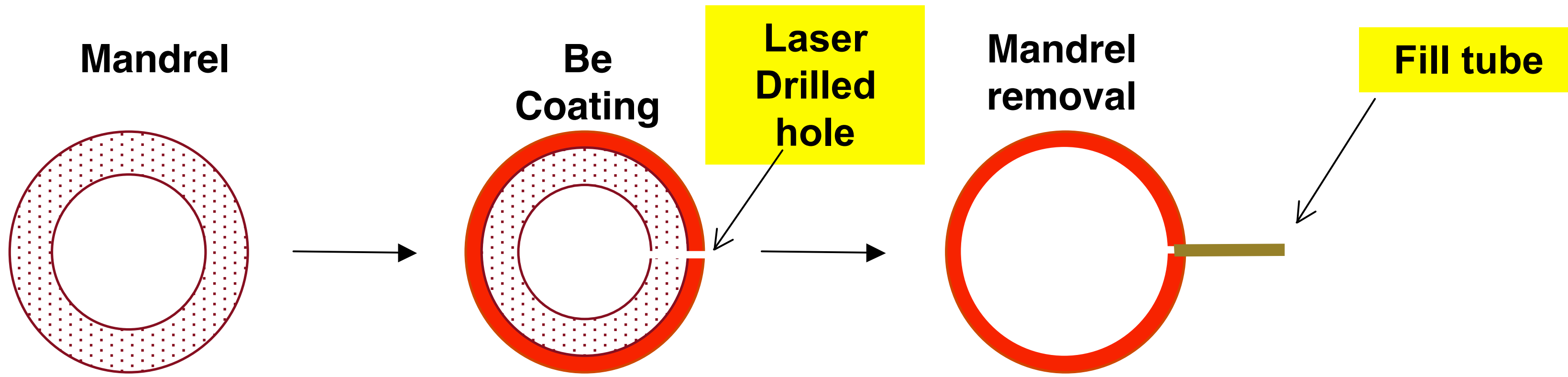
Graded Be is current baseline design



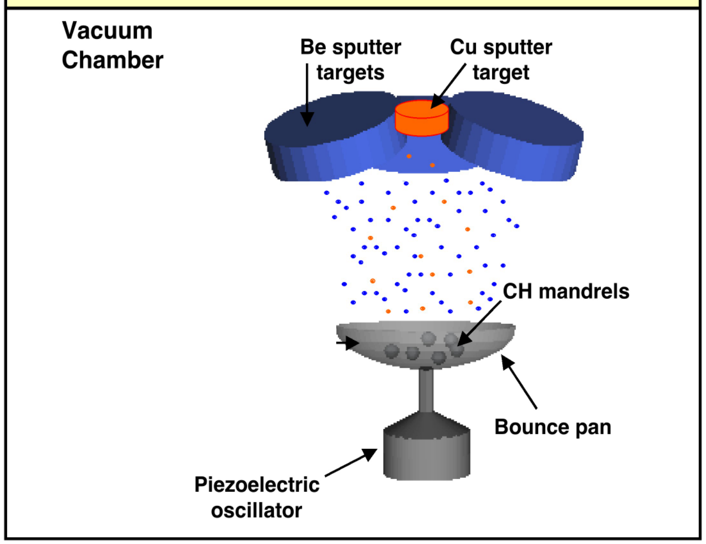


See Biener, TuO6.3

We have produced graded Cu-doped Be capsules at NIF-scale by sputter deposition



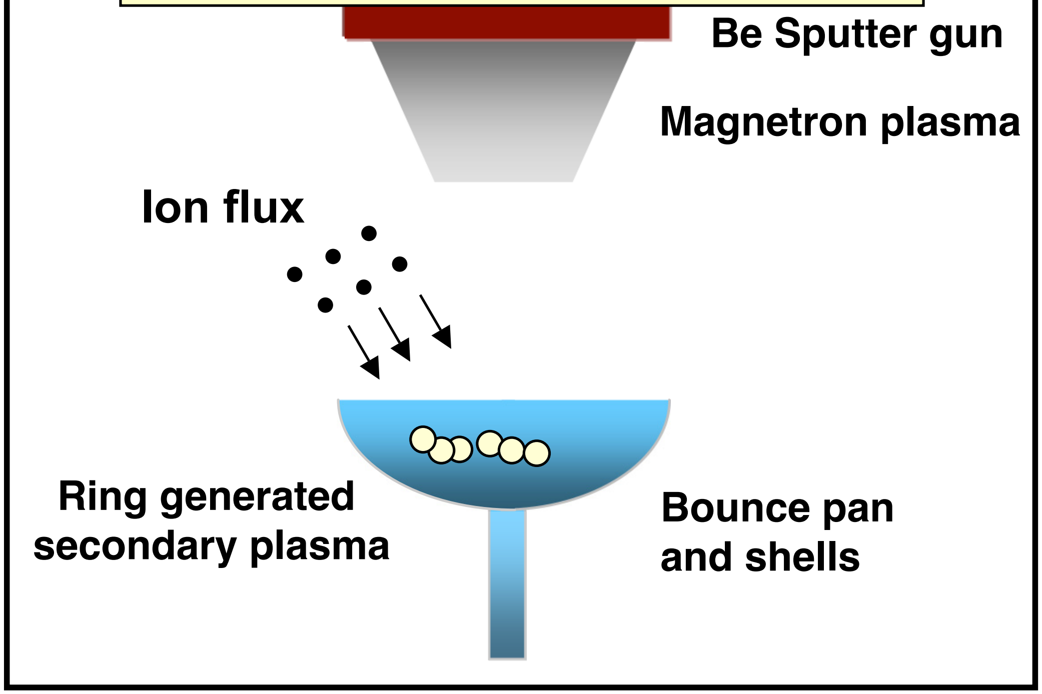
Sputter deposition on CH mandrels



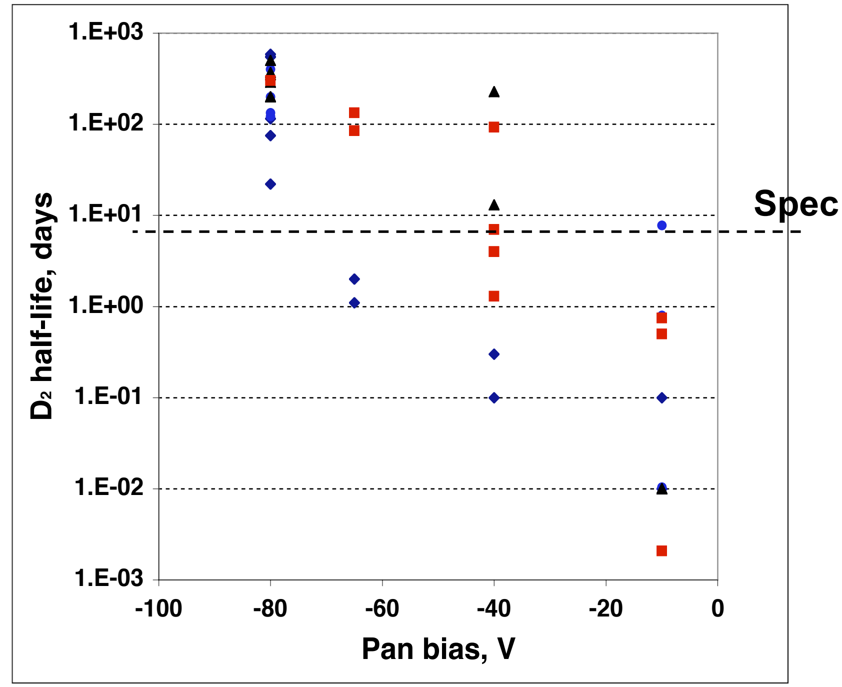
- The ablator is coated using sputter deposition
- Allows grading of dopant

Ionized physical vapor deposition was utilized to obtain gas retentive shells

Schematic of ion assisted deposition



Increased gas retention



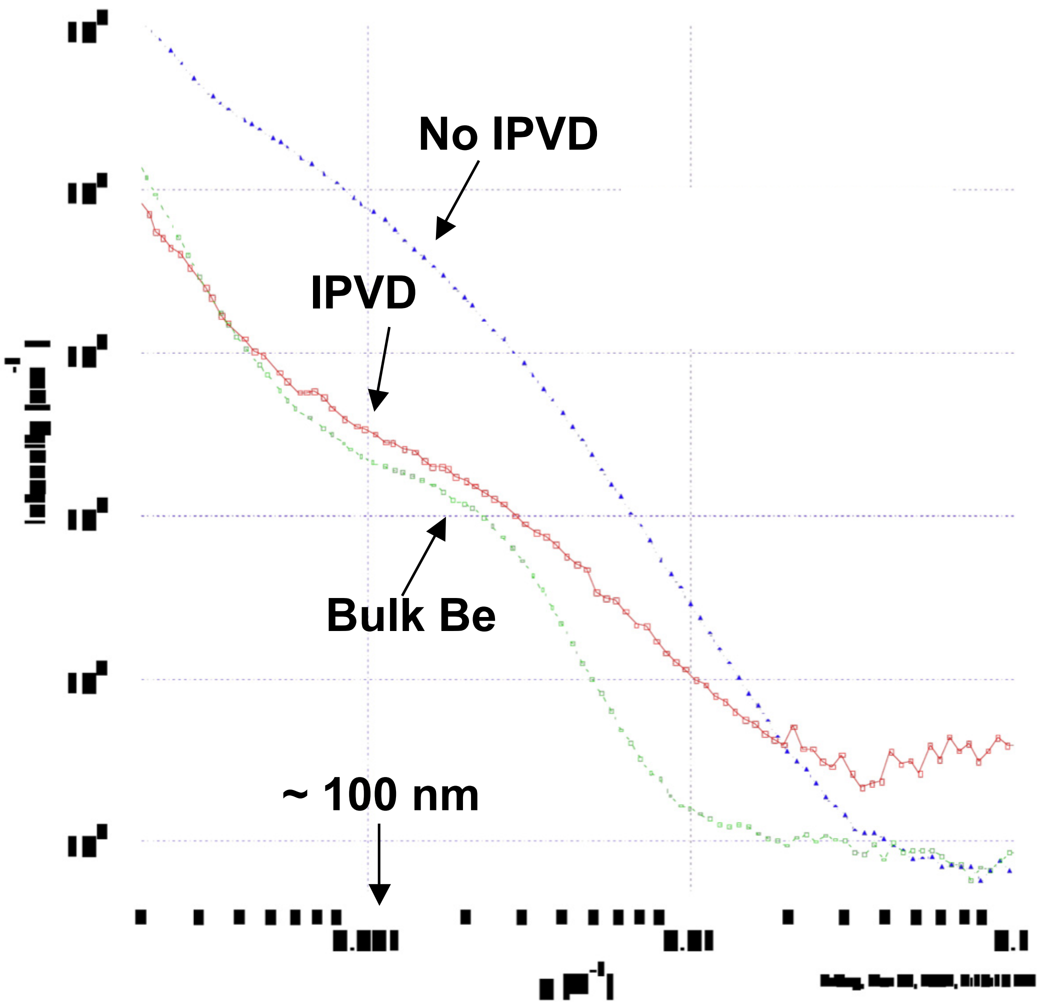
- Argon content of shells is also increased from <0.1 at% to as much as 2 at% (spec 0.25 ± 0.1 at %)

- A coater configuration identified that leads to ~ 0.25 at% Ar in gas retentive shell meeting specifications
  - Current effort focused on understanding the parameter space to extend to other coating systems

USAXS measurements indicate reduced bulk porosity using IPVD

- **USAXS shows that the pore fraction has been significantly reduced**
  - **Low scattering intensity at intermediate q implies that voids are significantly lower**

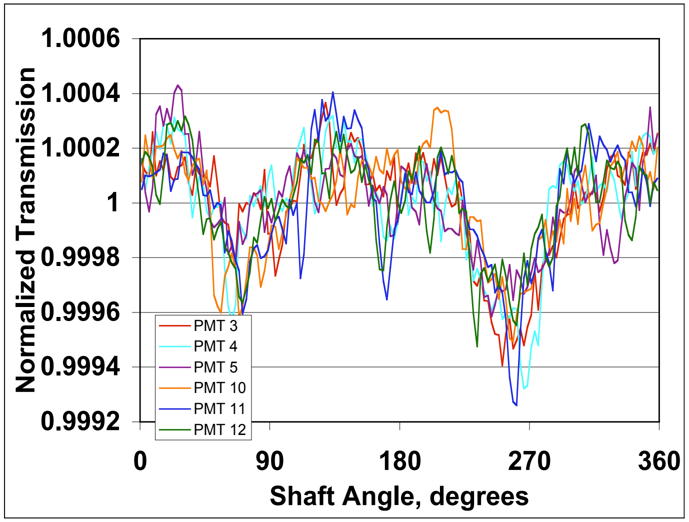
- **IPVD works by creating a dense structure by creating additional ions that are then accelerated toward the target**



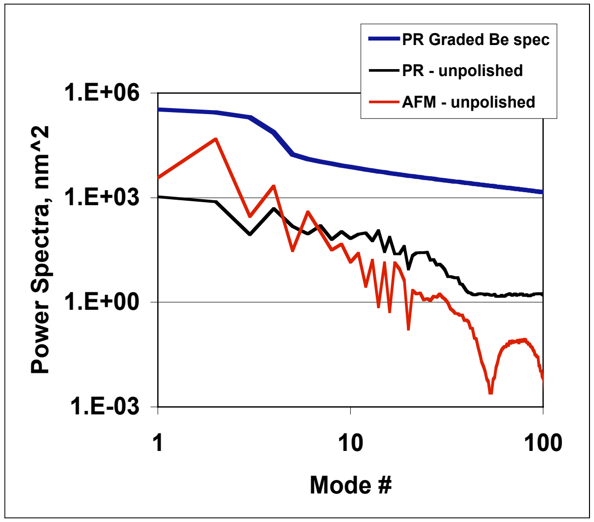
IPVD sputter deposition sharply reduces the intergranular porosity and hence permeability

Current precision radiography indicates shells meet 10^{-4} optical depth uniformity spec

- Precision radiograph examines azimuthal optical depth uniformity of the shells
- For graded Be:Cu two factors can lead to OD variations
  - Roughness at Cu doped interface
  - Void agglomeration
- Much data has been collected
  - Meet current assumed specification
- A power spectrum based specification is being developed
- Isolated features can dominate OD power spectrum



X-ray transmission vs angle



Graded doped Be:Cu shell

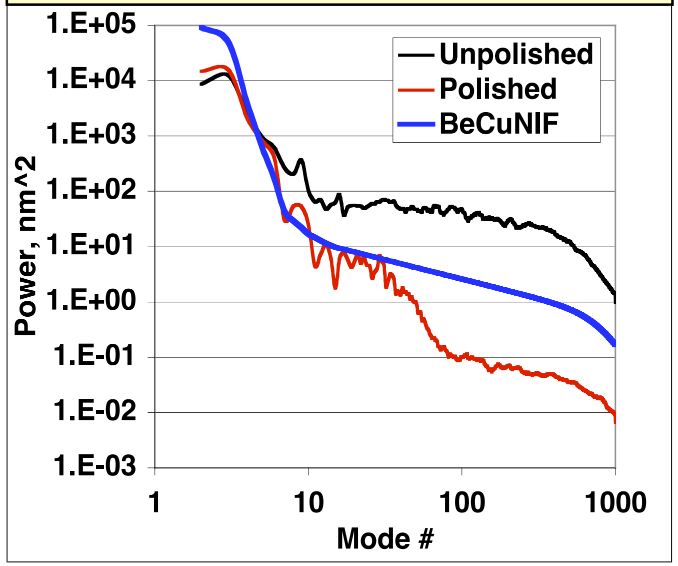
Polished Be capsules are approaching NIF ignition surface finish requirements

Unpolished and polished Be shells

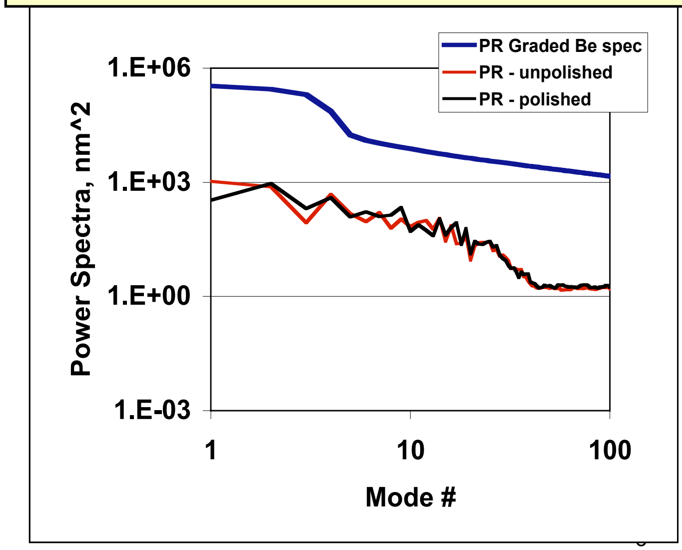
- **Polishing reduces as coated shell high mode roughness to well below spec**

- **Low mode mainly dominated by mandrel**
  - **Mandrel selection mitigates that issue**
  - **Polishing does not increase low mode**

Polished Be vs spec

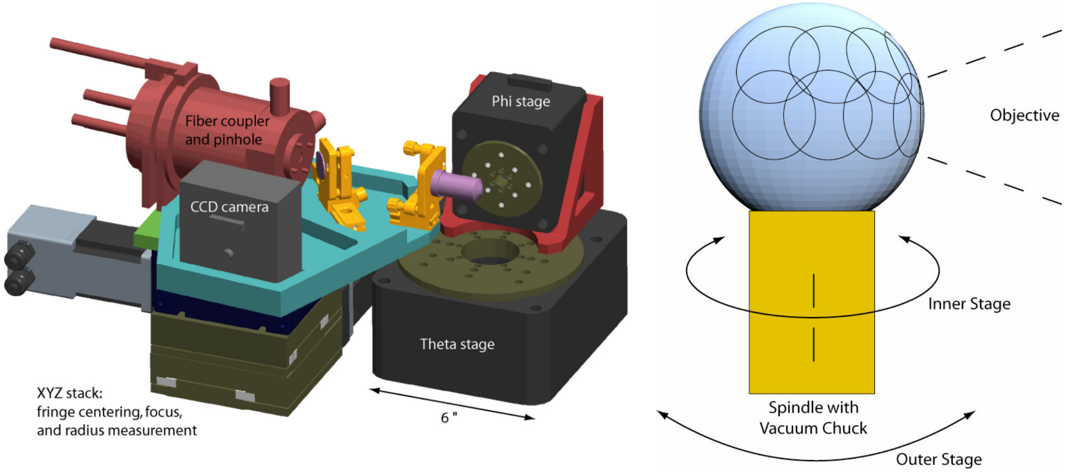


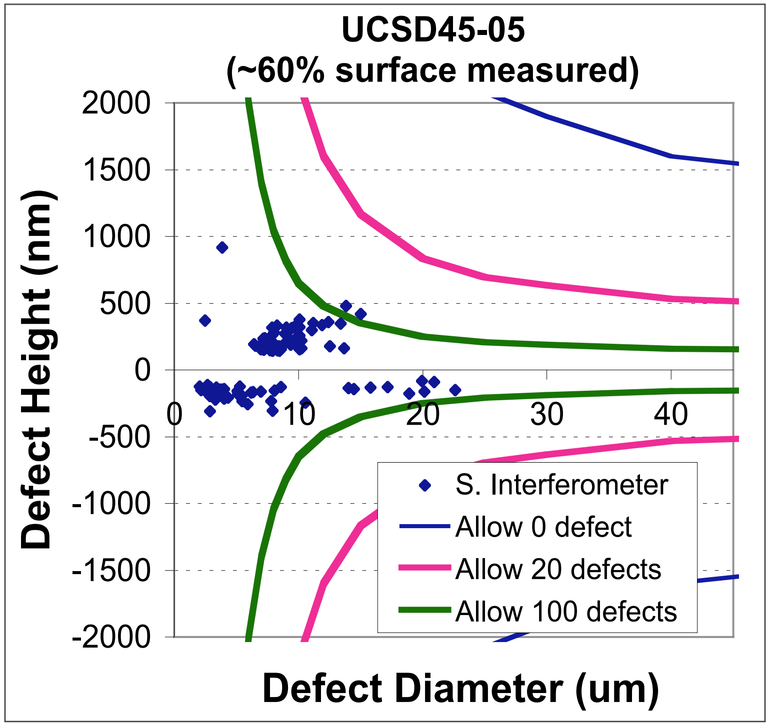
Optical depth PSD post polish



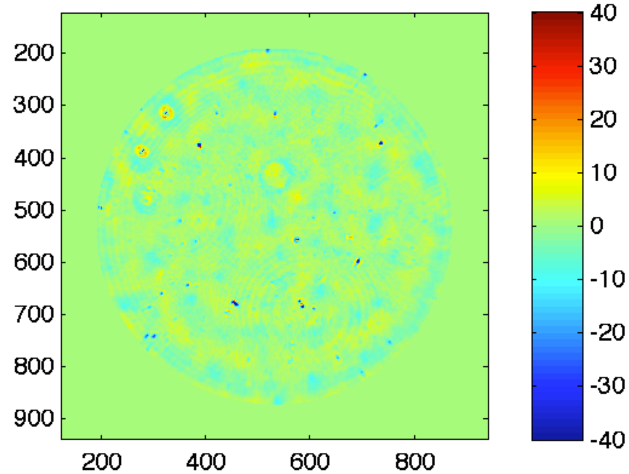
Be shells have met outer surface isolated defect feature requirement

- Shells examined by phase shift diffractive interferometer (PSDI)
- Patches taken around surface
- 60% of data analyzed
- No major features found
- RMS also below NIF curve requirement
- Need to collect more data
  – We are collecting more data on inner surface with PSDI nearly in production mode

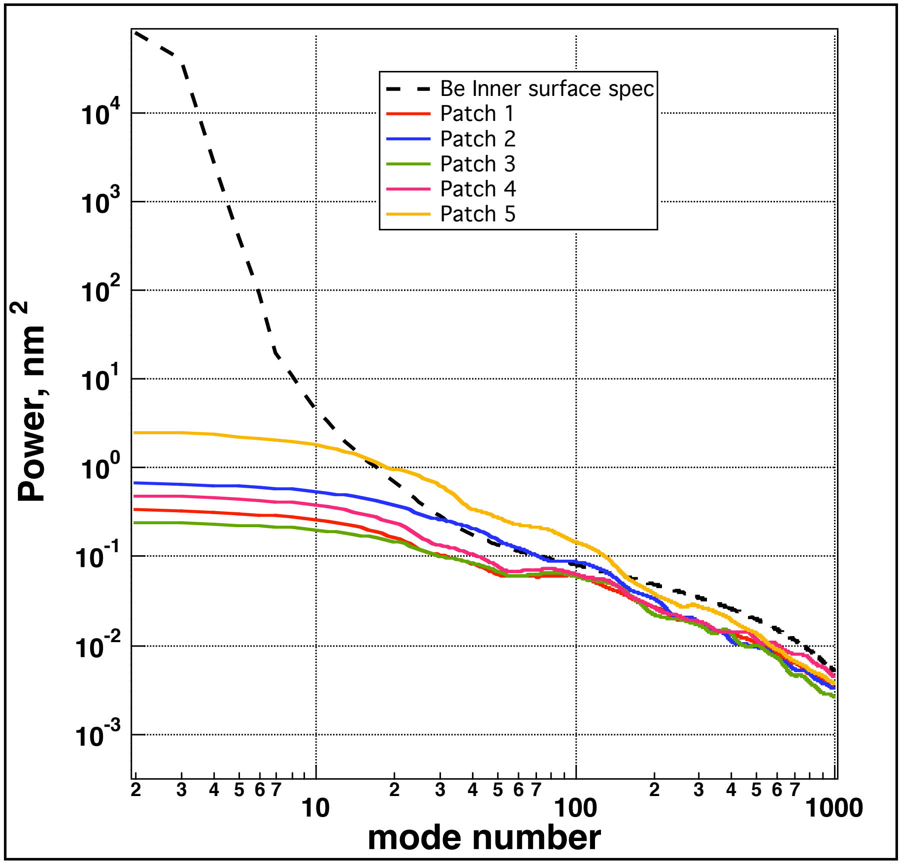




Inner surface of shells made using ion assist are below or near the NIF spec



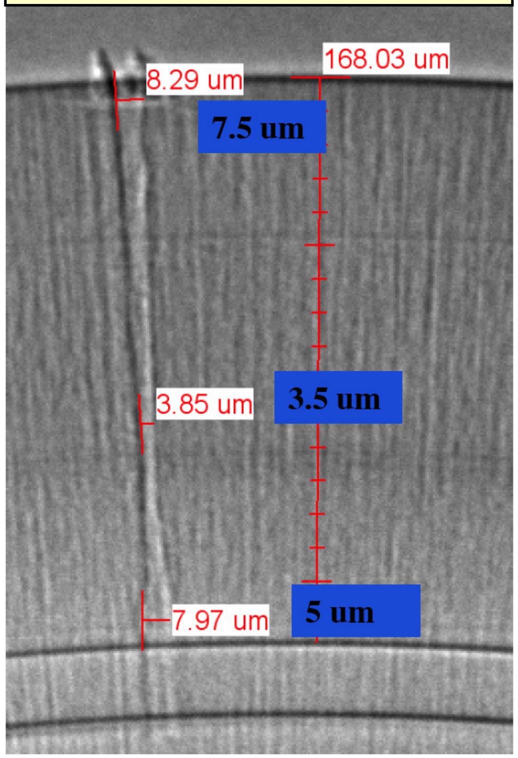
PSDI Patch scans ~ 500 μm dia



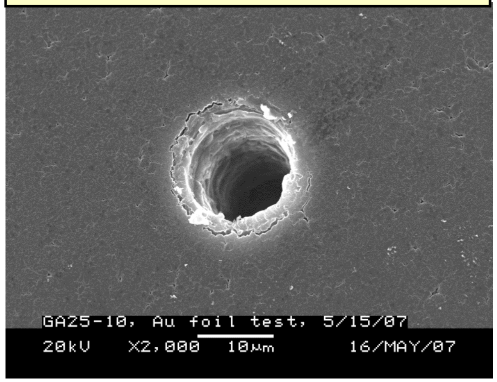
- **Destructive test**
- **Inner surface determined by mandrel and its removal process**
- **More data will be taken as unit is available in production mode**

Fill holes have been drilled to specification

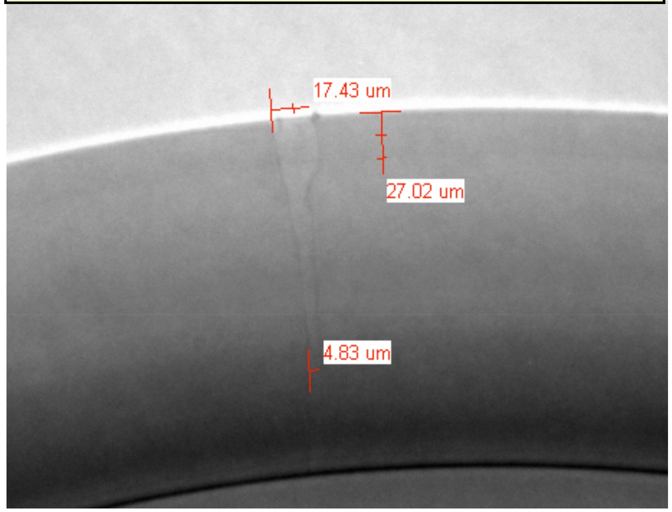
Fill hole in Be



Recast eliminated



Counterbore hole



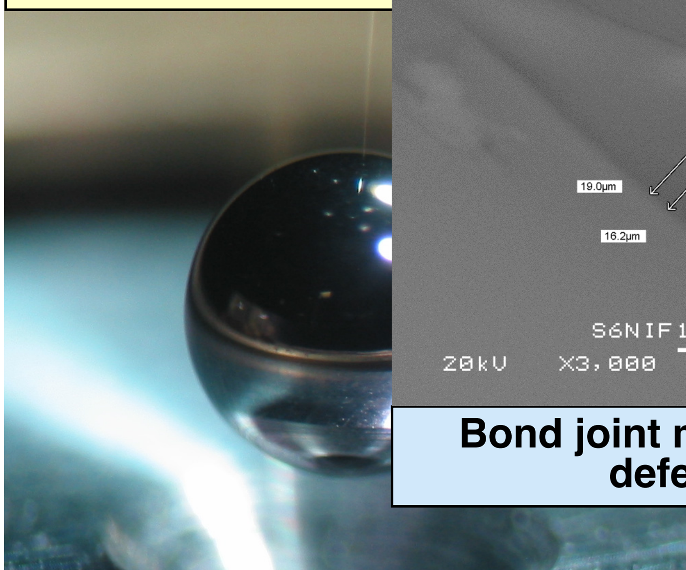
- **Hole volume/mass defect meets spec**
- **Fill hole focused on counterbore needs development**

Forsman FPo46

NIF scale fill tubes have been attached to beryllium shells

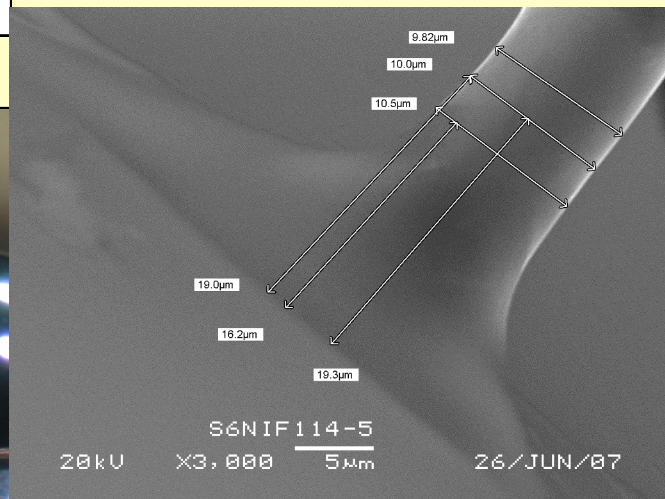
- **Multiple capsule and fill tube assemblies have been built and tested for flow, pressure, ar**

Polished Be



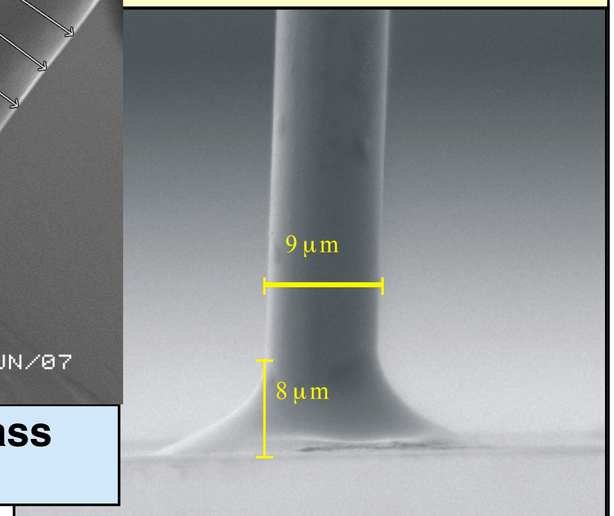
Be capsule with bonded fill tube

NIF spec fill-tube bond



Bond joint meets NIF mass defect spec

NIF fill-tube bond



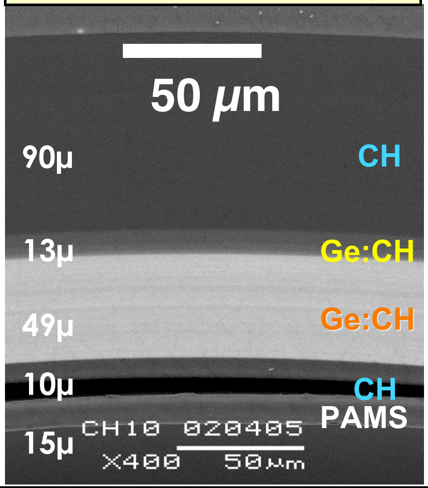
Bond joint meets NIF mass defect spec of 2.5 ng of adhesive

- **Leak, pressure and openness of tube testing integrated into process**
- **However, assemblies have failed during transport**

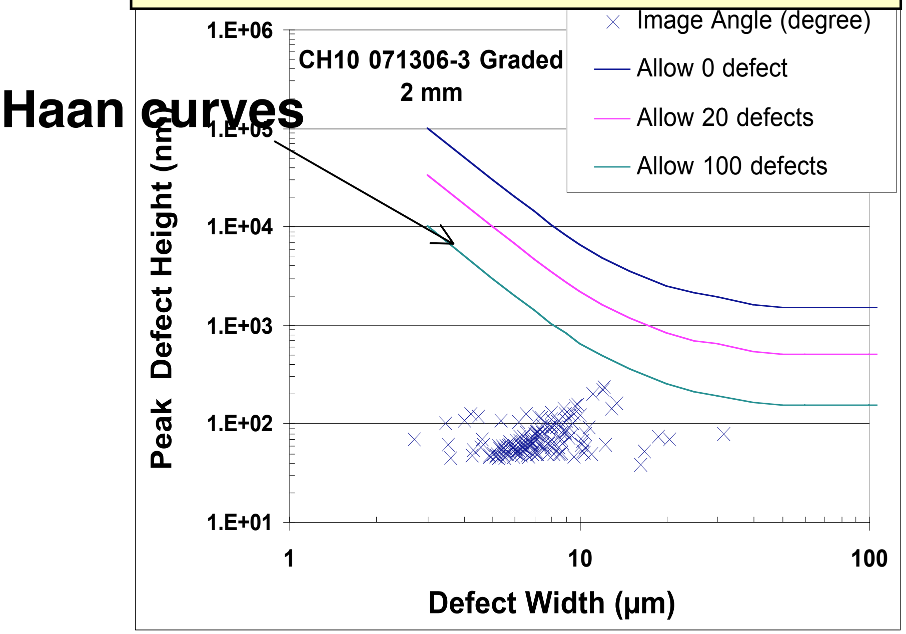
CH capsules have met all NIF specifications

- **Tens of graded CH:Ge capsules have been produced and characterized that meet all specifications including:**
  - — **NIF outer surface power spectrum**
  - — **Wall thickness uniformity**
  - — **Doping levels and layer thicknesses specifications**
  - — **Major issue with CH shells:**
    - – **Isolated defects**
      - — **Shells made in batches of ~ 9 shells meet the isolated defect specification**

SEM Image



Isolated defects in spec



Almost all of Be shell specifications have been met

- **Fill tube details are being addressed currently**
- **Reproducibility, reliability and yield of processes is major focus currently**

Capsule outer radius, tolerance	± 5µm
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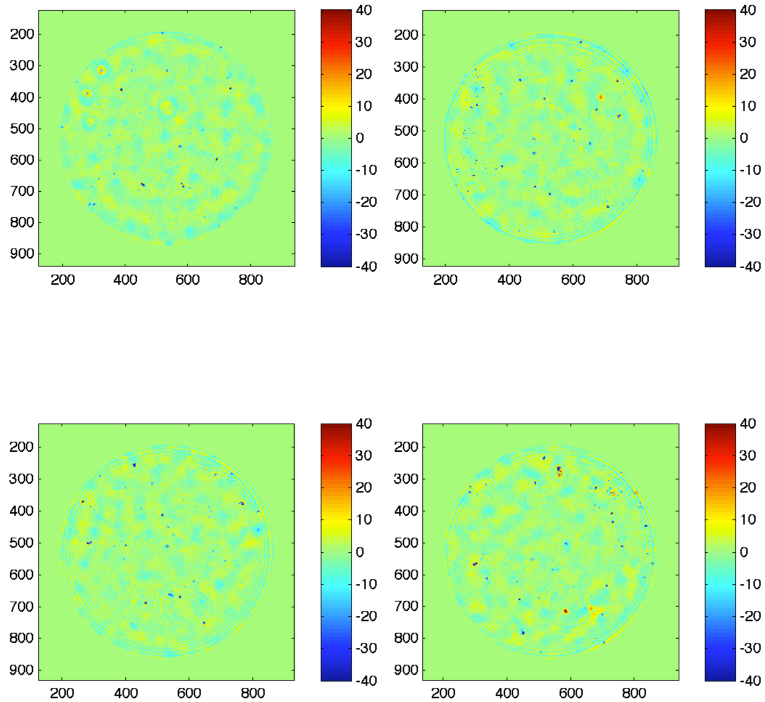
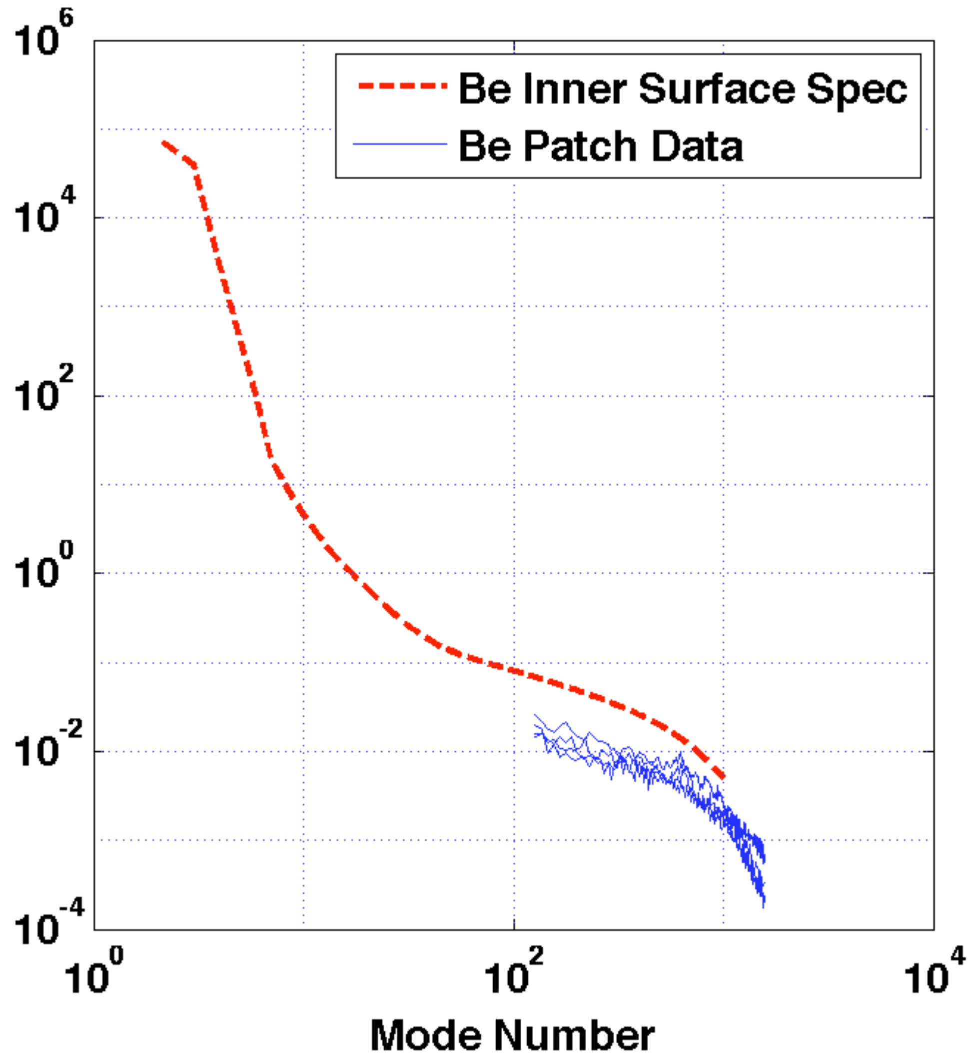
Ablator inner surface figure	see table
Capsule surface isolated defects	see figure
Capsule cleanliness	See isolated defects
Ablator – Low level impurities	sum(atomic fraction)*Z^2 < 0.1
Gas retention	> 7 day half life at room temp

Met spec (green)
No major tech issue (yellow)
Not met (red)

End Of presentation

Inner surface of full thickness shells made also meets NIF specification



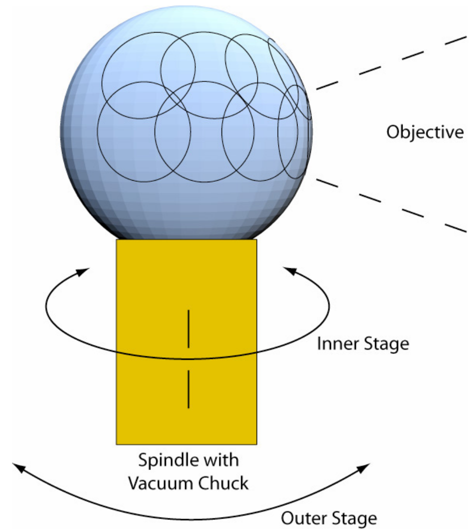


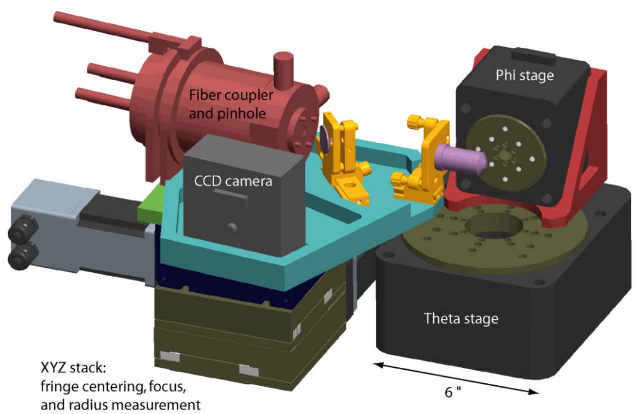
PSDI Patch scans ~ 500 μm dia

- **Destructive test**
- **Inner surface determined by mandrel and its removal process**
- **Again more data needs to be taken with PSDI now available for routine examination**

Spherical Interferometer allows mapping of the outside and inside of shells

- **Phase sensitive diffractive interferometry (PSDI) has been adapted to provide complete mapping of exterior capsules surface**
  - **Best tool to quantify isolated defects**





- **Data propagation is manual and slow**
  - **Automation in process**

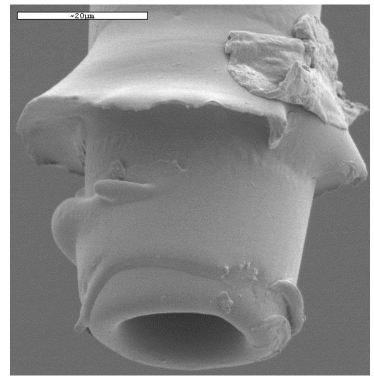
- **Shell flipper under development and construction**
  - **Automation of data acquisition**

- **Above will increase throughput**

Failure mechanism of glue joint to Be was identified and remedied

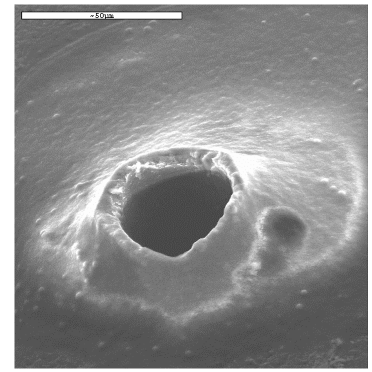
- Glue-Be joint identified as weak joint
- Glue joint strength optimized
  - Optimization of the adhesive type (Dymax)
  - Surface preparation (ultra-clean and activated)
- Allows us greater safety margin for handling 10µm scale assemblies
- Improvements observed at 20 µm fill tube dimension
  - Extending to 10 µm tubes currently
  - We have not DT filled capsule with < 20 µm fill tube yet

Before



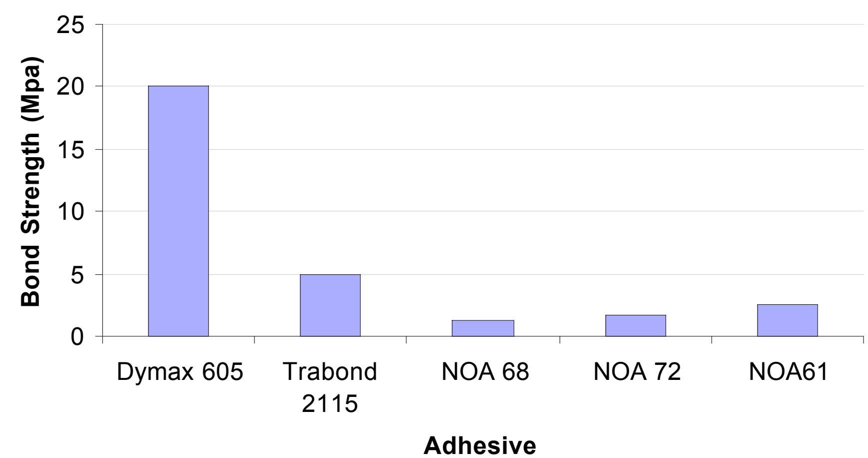
Failure at *28 mN*

Now



166mN

Optimum strength glue identified



Progress in Demonstrating Feasibility of the Target Supply for Laser Fusion

Presented by Joe Kilkenny

at the
Fifth International Conference on Inertial Fusion Sciences and Applications
Kobe, Japan
September 9-14, 2007

GENERAL ATOMICS

Acknowledgements

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UCLA - Robin Garrell

Lawrence Livermore - *John Perkins*

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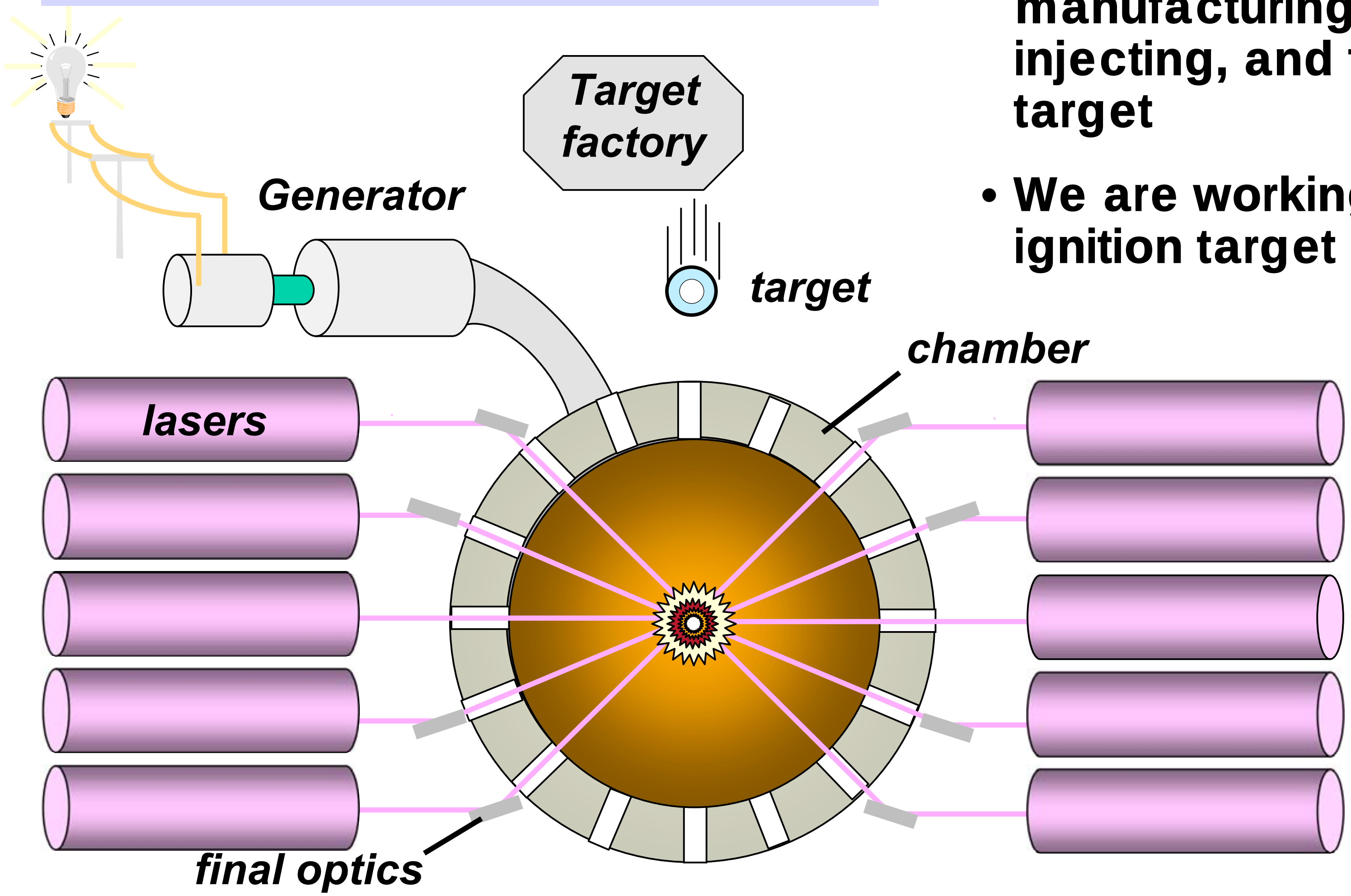
Top-level objective = show feasibility of economical target fabrication for commercial fusion

Our objective is to develop the "target factory" for HAPL

Dry wall, direct-drive, laser fusion



- **"Target factory" involves manufacturing, filling, injecting, and tracking the target**
- **We are working towards an ignition target**

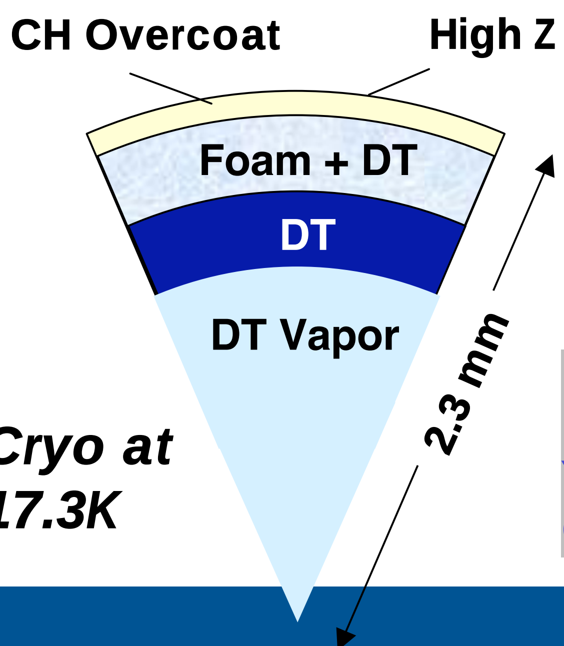
~500,000 targets/day for 1000 MW(e) power plant

IFE Ignition Targets - "Beyond the Basics"

- ***Potential manufacturing processes that are adaptable to mass-production identified***
- ***An experimental demonstration program for each process step laid out and initiated***
- ***A "baseline" target design identified and good progress made on its fabrication ....***

Basic process steps

1. ***Fab foam capsule***
2. ***Overcoat foam***
3. ***Fill/layer fusion fuel***
4. ***Inject***
5. ***Track and engage***

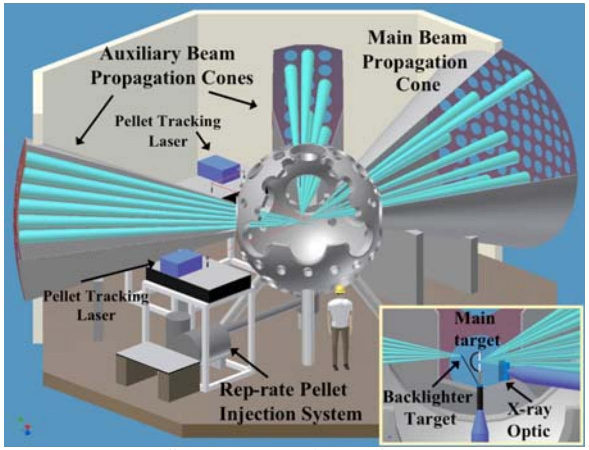


Cryo at 17.3K

IFE Reference Target

Diameter = ~4.6 mm
Foam Wall = ~176 μm
Yield = ~350 MJ
Gain = ~150

Fusion Test Facility (FTF) proposed next step



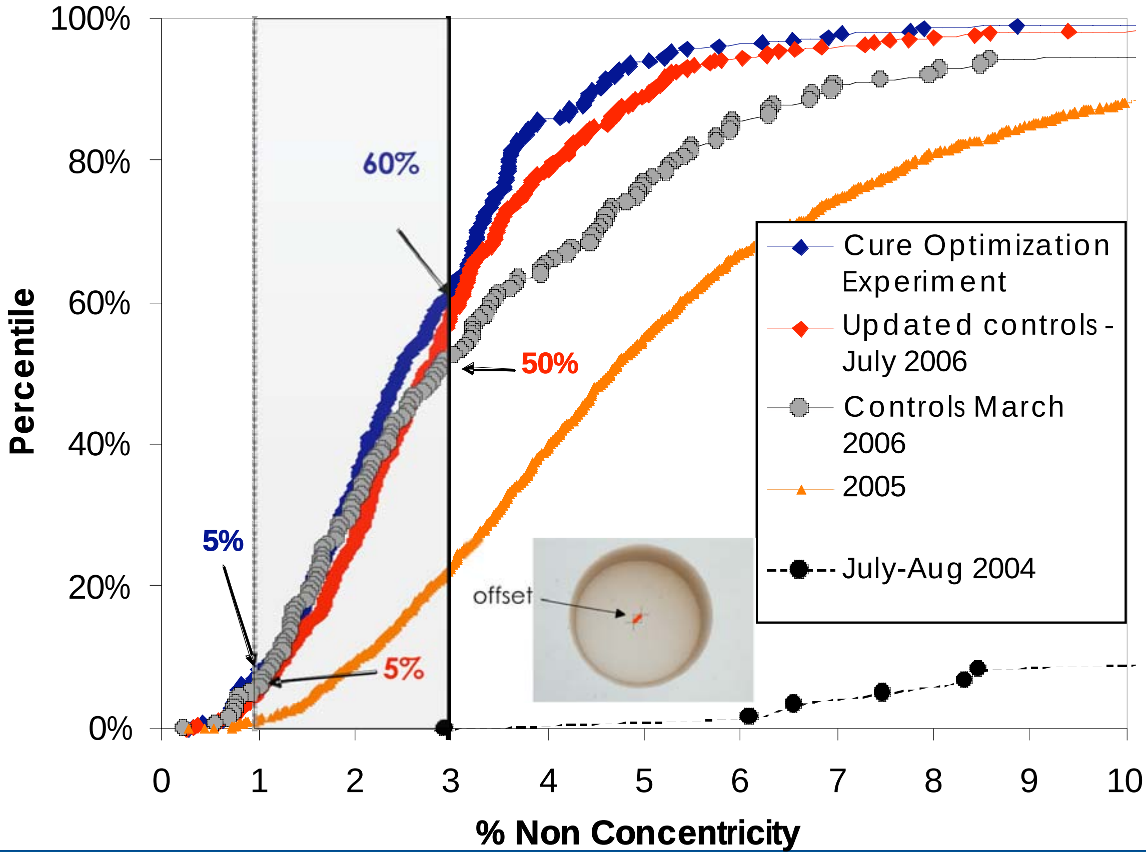
Naval Research Laboratory

"Beyond the basics" on foam capsules

IFE-sized (~4 mm OD) divinybenzene (DVB) foam capsules

FTF-sized (~2.4 mm OD) DVB foam capsules

- ***Optimization of rotobeaker "curing" to improve Non-Concentricity (NC)***
- ***Yields of DVB foam capsules at 1 to 3% NC improved dramatically***



Checklist of foam capsule progress

Attribute	Value	Tolerance	Meet?	Comments
Composition	DVB	(Low O/N)	Yes	DVB is original baseline foam
Diameter	4.6 mm	±0.2	Yes	Controlled by process flows Characterization: optical
Wall thickness	176 µm	±20	Yes	Controlled by process flows
Density	≤100 mg/cc	[25%]	Yes	Calculated, measured optically
Pore size	~1 µm	<3 µm	Yes	Qualitative by SEM - 1 to 3 µm
Out of round	<1 % of radius	--	Yes	Limited data, but never an issue
Non-concentricity	< 1-3% wall th.	--	Yes	Basic feasibility demo'd, yields 5 to 60%

So does this mean we're finished? (no…)

Overcoats for the foam capsules are a current focus!

Status - for polyvinyl phenol on DVB foam (original baseline, made by interfacial polycondensation)

Attribute	Value	Tolerance	Meet?	Comments
Composition	CH +	O/N OK	Yes	Polyvinyl phenol was “baseline”, others possible
Thickness	1 µm	±1	No	Originally 1 µm, ~10 microns may be acceptable
Surface finish	<50 nm	--	No	
Permeability	Holds DT at cryo	--	No	Low yield of overcoats,shrinkage, implosion, “microcracks” common
Strength	For filling	--	Not yet shown	

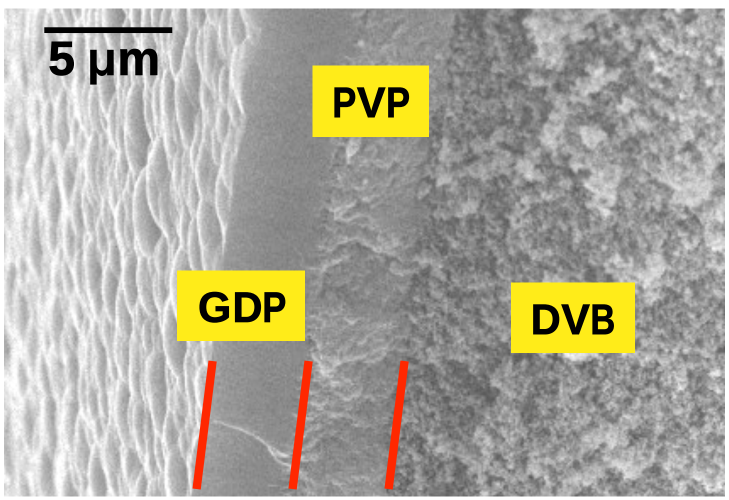
A major difficulty is overcoating (sealing) hi-aspect ratio shell at wet stage

Alternate approaches to the original, baseline method for overcoats have been evaluated

Evaluated two major approaches..

1. ***Two-step process - fill DVB pores with PVP then GDP coat***
2. ***Switch to smaller-pore foam like resorcinol formaldehyde (RF)***

PVP overcoated with GDP

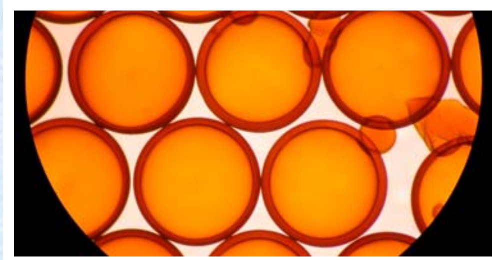


Cross section of coated DVB shell

Oxygen content of RF OK'd by designers

Successful at Omega size (~1 mm OD)

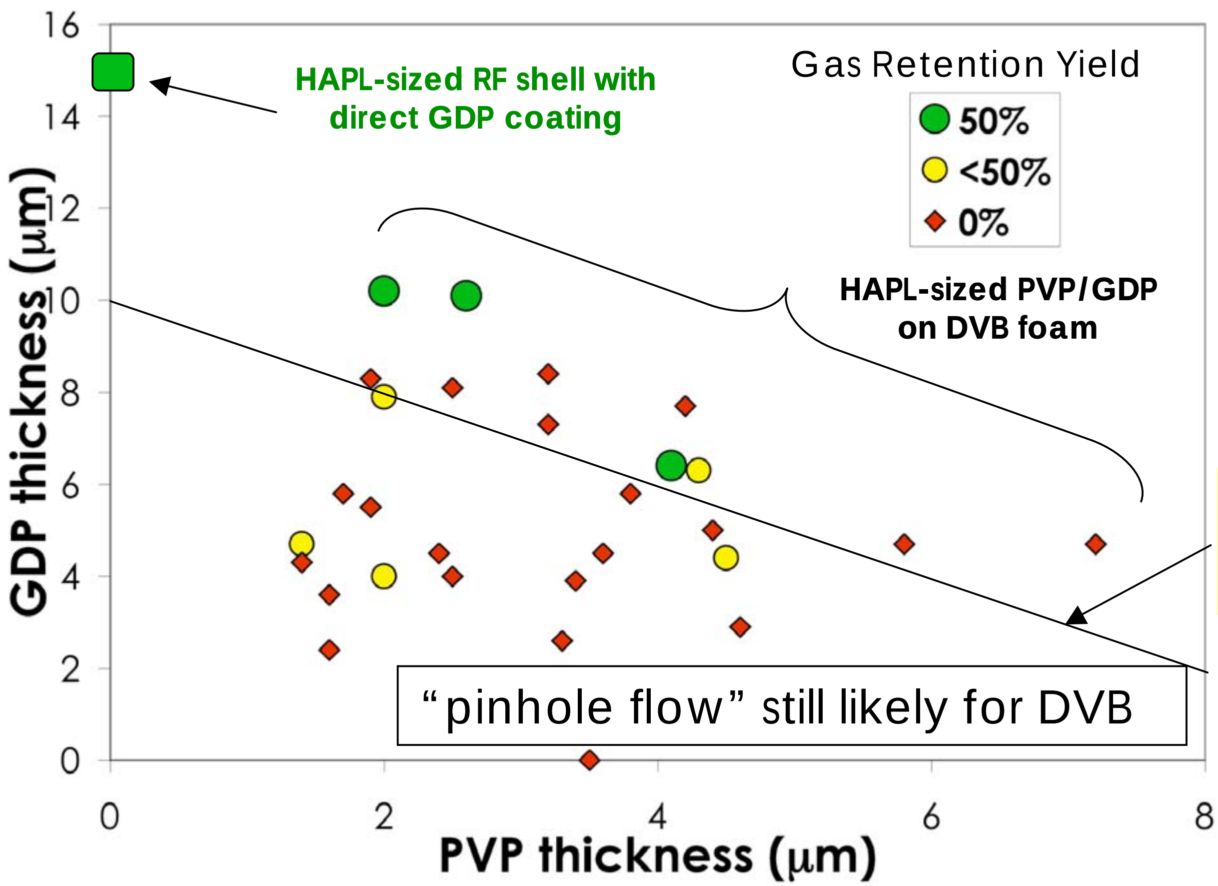
RF foam, with <0.1 μm pore size, directly overcoated with GDP



...the simpler approach turns out to be best

The first gastight HAPL-sized foam capsule - GDP on RF

- ***Half-life with deuterium testing confirms permeation flow - not "pinholes"***

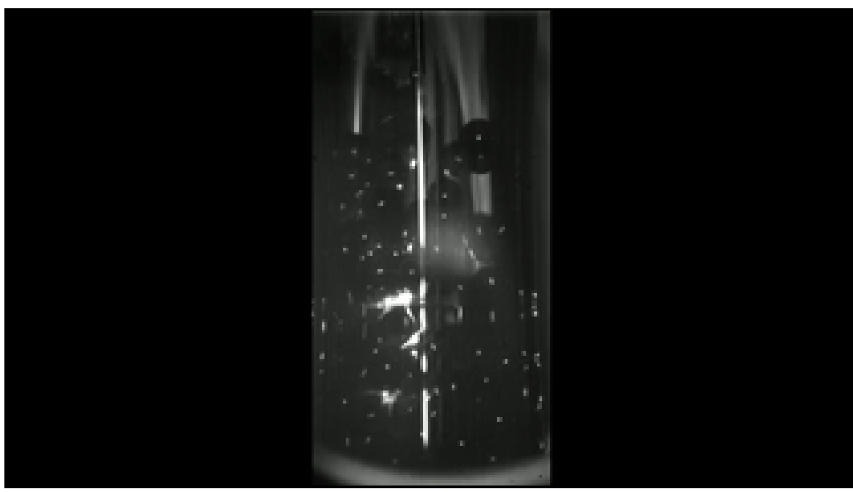


Significant work remains to perfect this high aspect ratio overcoat

Current goal of <10 μm total

A cryogenic fluidized bed has been constructed to demo mass-production layering

- *Static controlled*
- *Scoping tests show good randomization*
- *Initial cryostat cooldowns to ~ 11K*
- *Method to "grab" one shell for characterization has been done at cryogenic conditions*



Unfilled shells at 11 Kelvin

Hi-P cell (1400 bar)

UCSD

Includes filling with HD (via permeation thru overcoats)

Target injection now has several acceleration options …

Previously demonstrated:

- Velocity ≥400 m/s, time jitter 0.5 ms, 2-piece sabot separation in vacuum
- Target placement accuracy of 10 mm at 17 meters standoff (1σ)

Gas-gun with 2-piece sabot to protect target

Magnetic diversion reduces gas in chamber, reduces heating, and allows slower injection

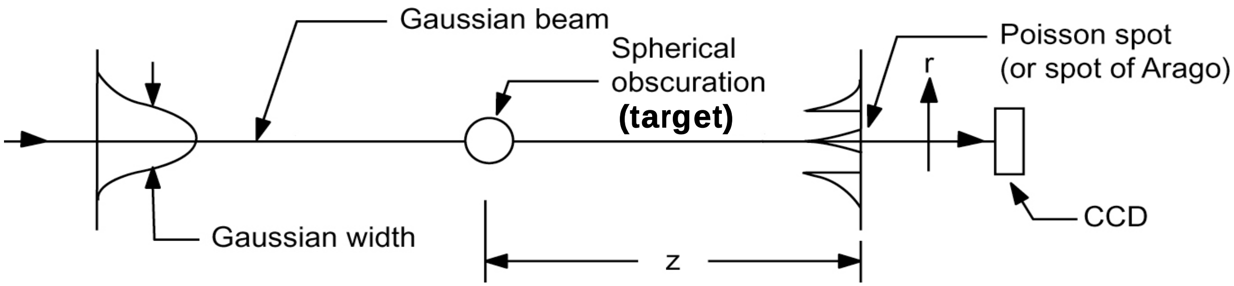
Range of options, including:

1. Gas-gun for >400 m/s
2. "EM Slingshot" concept for 50-100 m/s

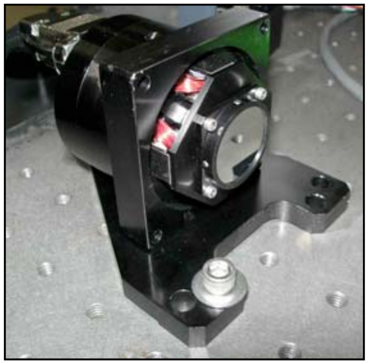
***Improved accuracy demo'd at 50 m/s (without 2-piece sabot) → 4 mm at 17 m (1σ)*, and done with ~1 mg projectiles**

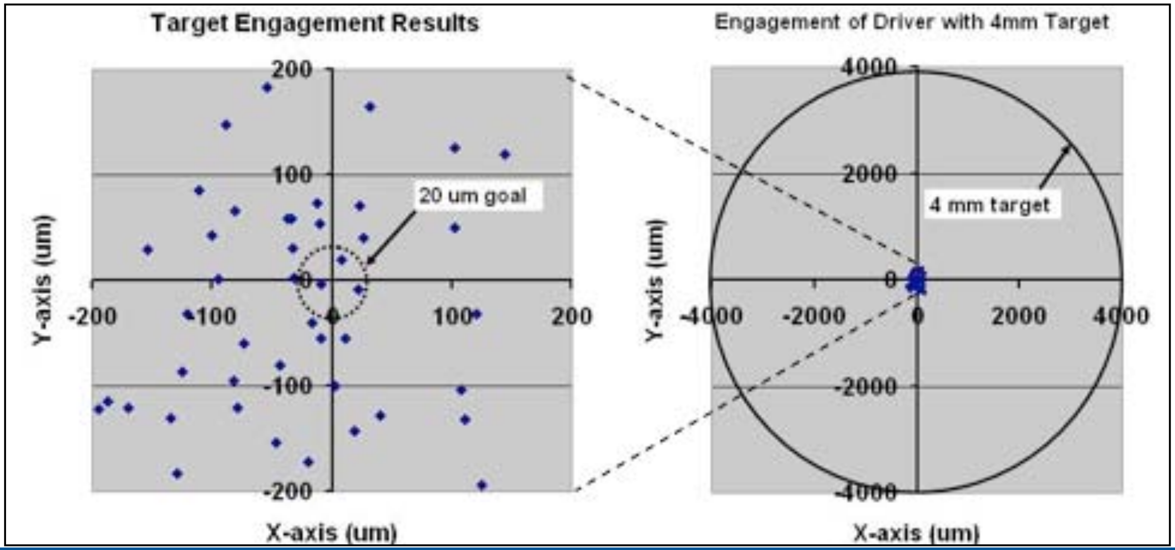
Tracking - optical table demo of “hit-on-fly” engagement

- IFE requirement is alignment of lasers and target to 20 μm
- System using lasers, optics and fast steering mirror
- Also - “glint” from target ~1 ms before the shot aligns optical train (target itself is the reference point)



Fast steering mirror for demo (commercial)





- Scaled experiment, velocity ~ 5 m/s
- Accuracy of hitting “on-the-fly” is 110-150 microns now (1σ)
- Working toward 20 micron goal for demo

UCSD

Poster ThPo 8 by Lane Carlson

Summary/Conclusions

1. Moving "beyond the basics" in demonstrating laser fusion target supply
   - Mass-production identified for each step
   - Demo programs underway with good progress
   - Advanced methods being evaluated

2. Basic foam capsules can be made
   - Focus now on yield curves and detailed specifications

3. Working to get gastight, smooth overcoats - first one made

4. Mass production demo for layering now undergoing cold checkouts

5. A range of target injection methodologies available

6. Tracking and engagement table-top demo is closing in on our goal of 20 micron alignment in a scaled experiment

Astrophysical Jet Experiments on Inertial Confinement Fusion Machines

by B. Blue

Presented at the
5th International Conference on Inertial Fusion Sciences and Applications
Kobe, Japan

September 9-14, 2007

GENERAL ATOMICS

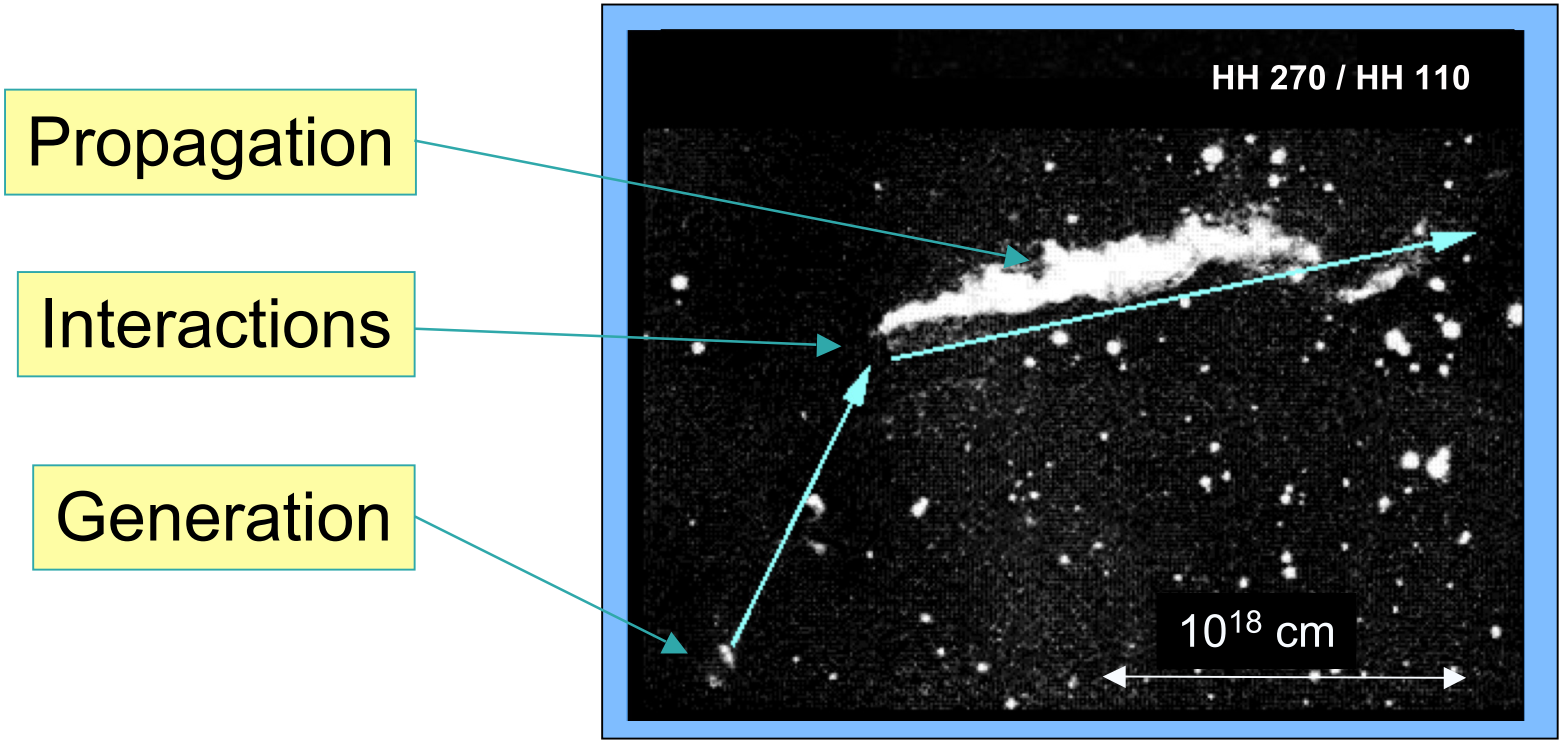
Summary

- We have developed a target platform to study high Mach number, compressible, turbulent plasma flows

- Scaled experiments allow us to study deep nonlinear dynamics relevant to astrophysical phenomena in the laboratory

- A series of experiments has been performed to study:
  - — The transition to turbulence and its effect on global hydrodynamic evolution
  - — Jet interaction dynamics
  - — Shock interactions with spherical objects

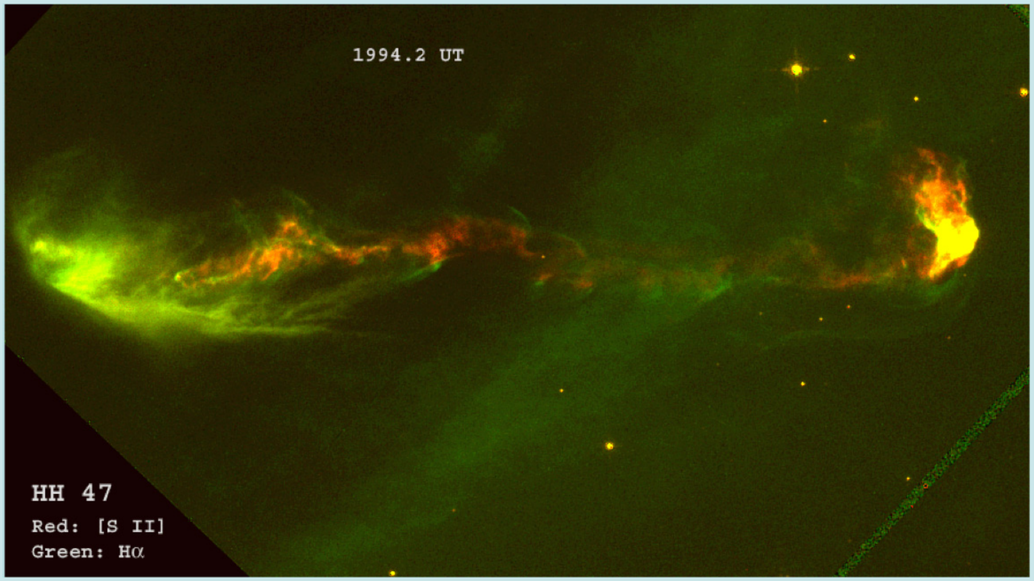
Several fundamental questions about astrophysical jets remain unanswered



We are not recreating all of the physical processes in an astrophysical jet. Rather, we are isolating specific subset of the physics and testing them via a combination of experiments and simulations.

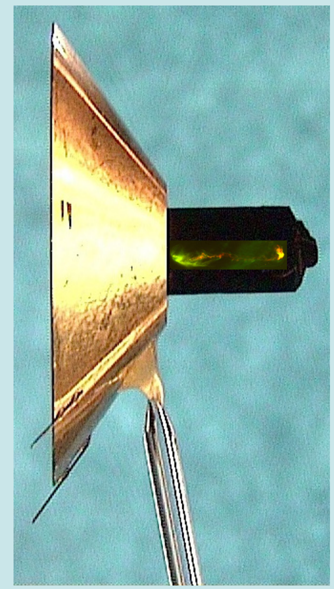
Euler scaling permits us to study astrophysical jets in the laboratory

~10^{15} m long HH-47



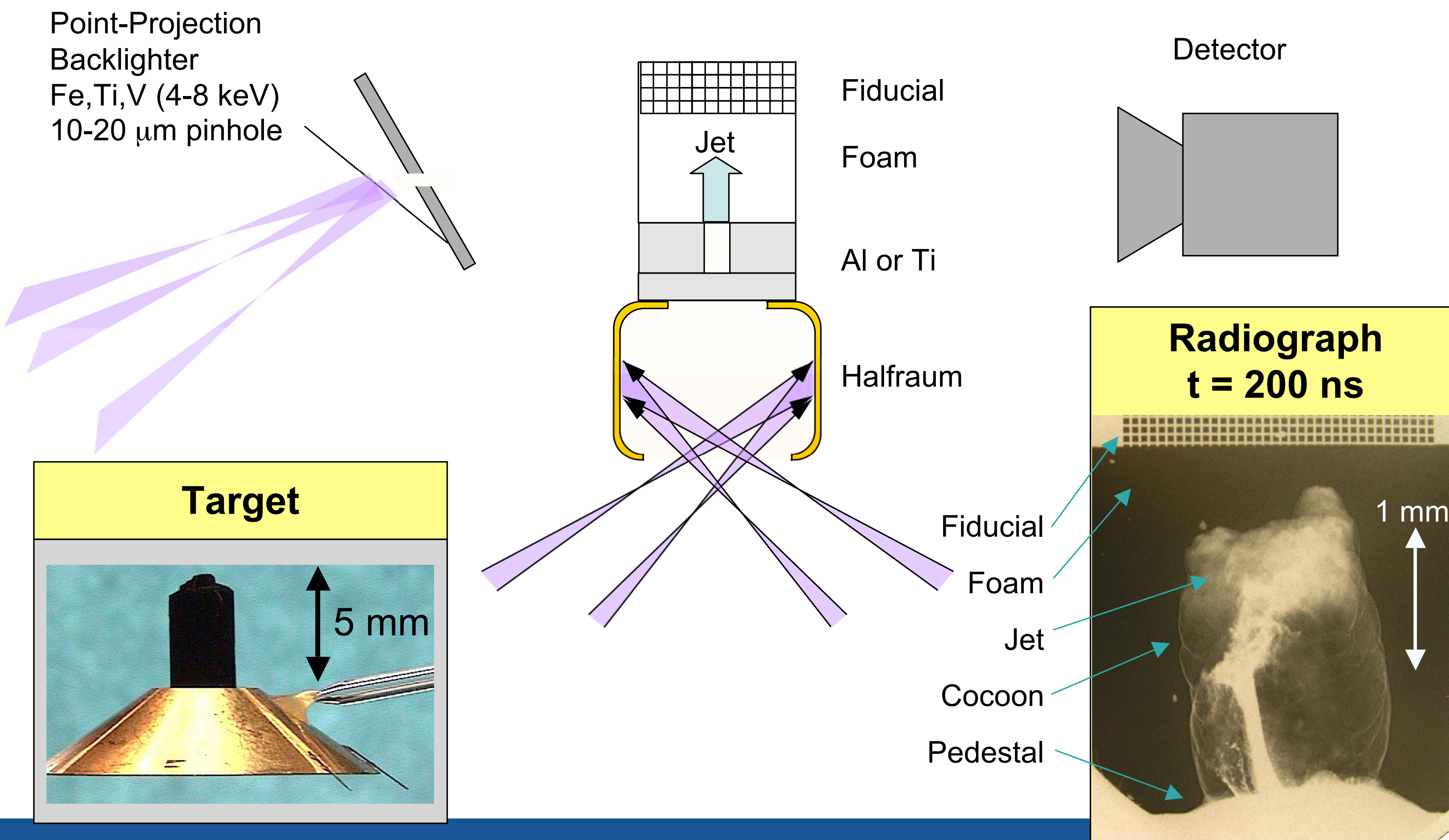
18 orders of magnitude smaller

mm-sized Target



50 ns in the laboratory corresponds to 100 years in space

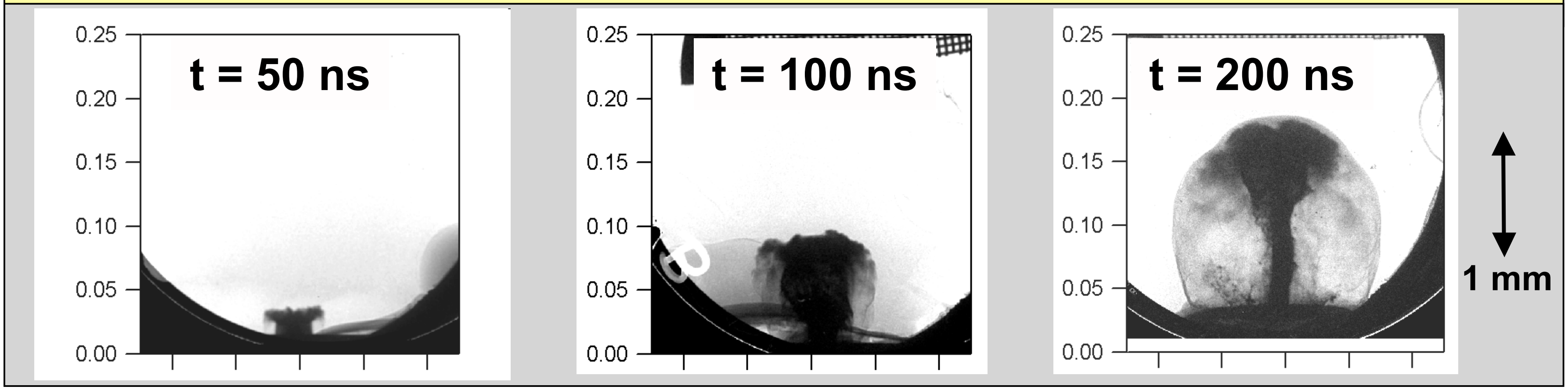
Radiography was used to diagnose the jet's temporal evolution



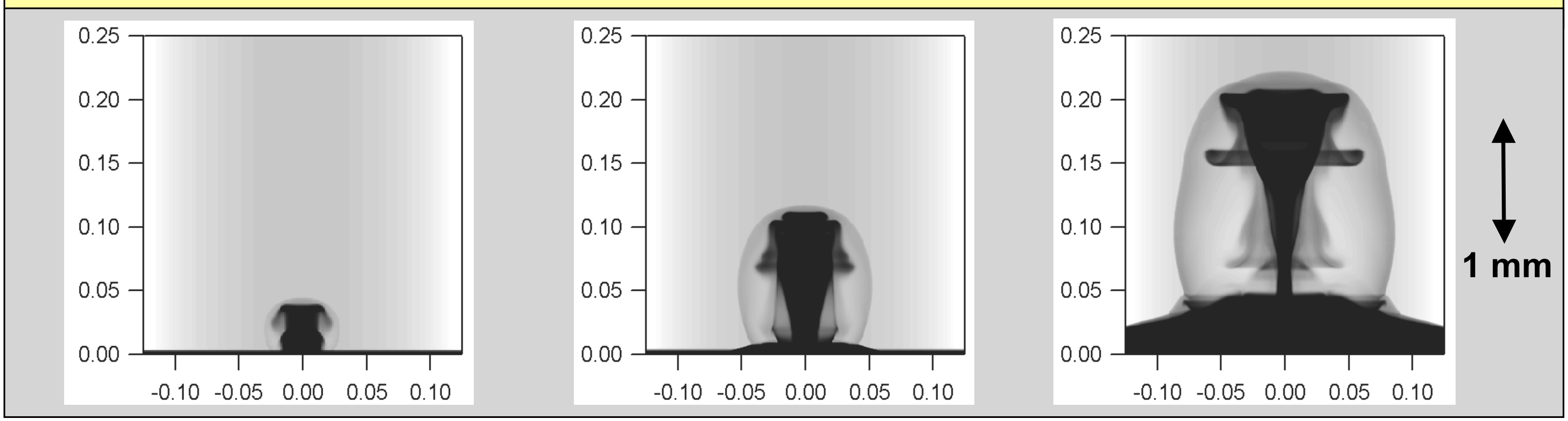
(Larger Target)

By observing the jets at different times, we can diagnose their turbulent evolution

Time series of jets on the Omega laser



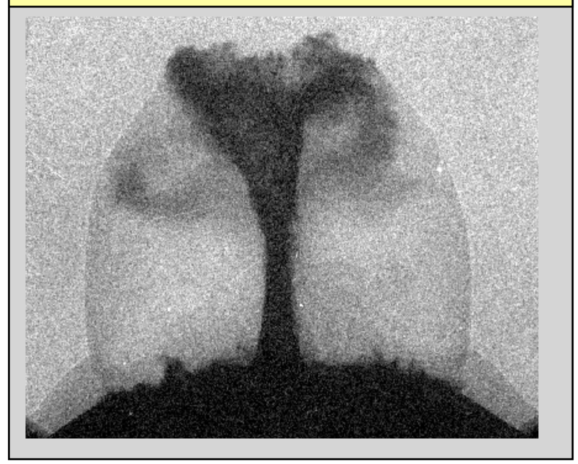
2D simulations with the AMR code RAGE reproduce the overall jet evolution well



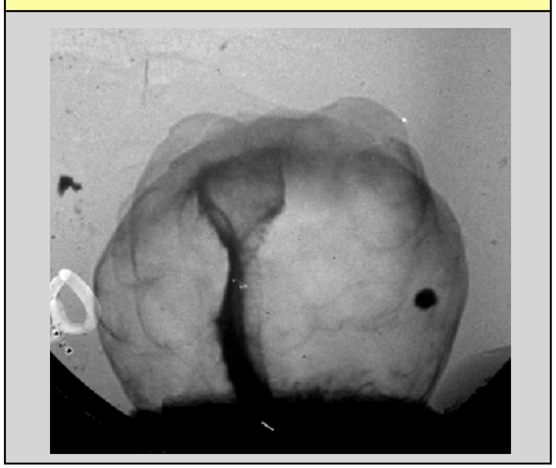
By varying target components, we were able to study different aspects of jet physics

5.2 keV V Backlighter

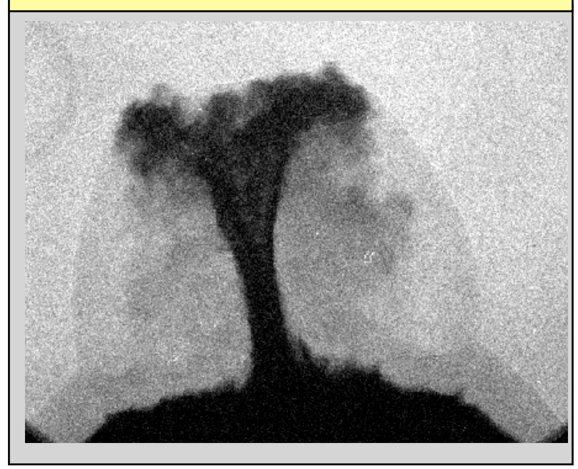
0.1 um cell size foam



4.7 keV Ti Backlighter

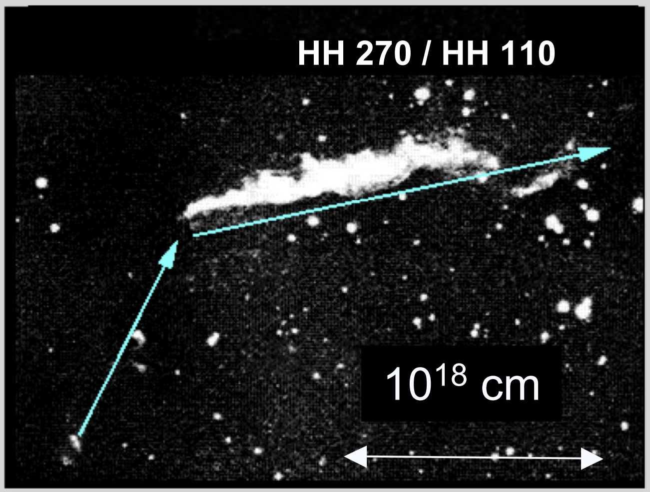


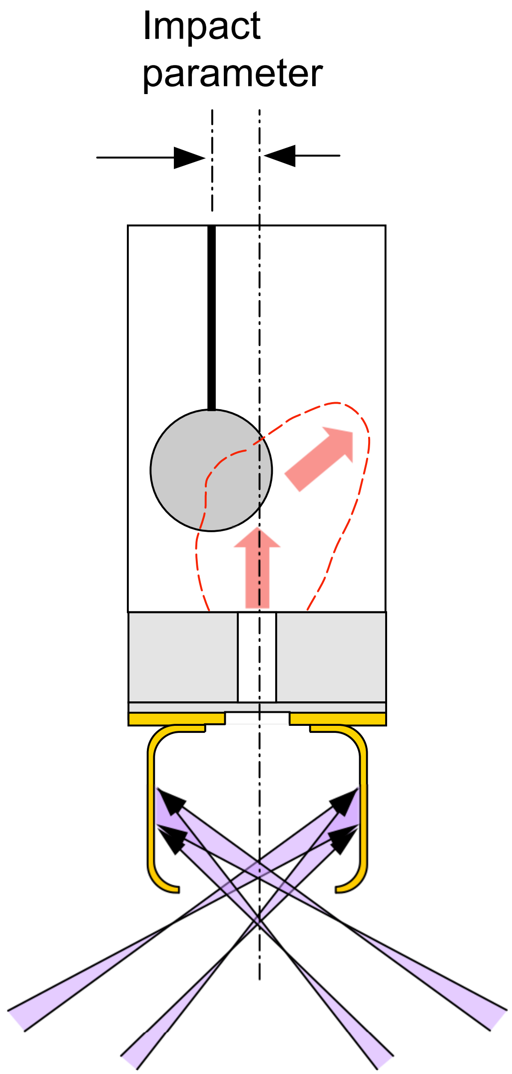
2 um cell size foam



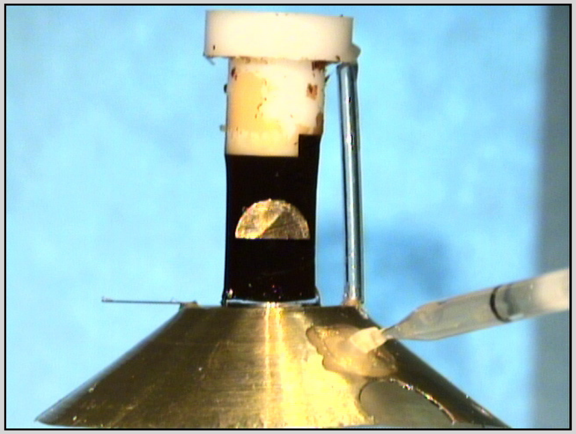
Targets were constructed to address the physics of a jet deflecting off a gas cloud

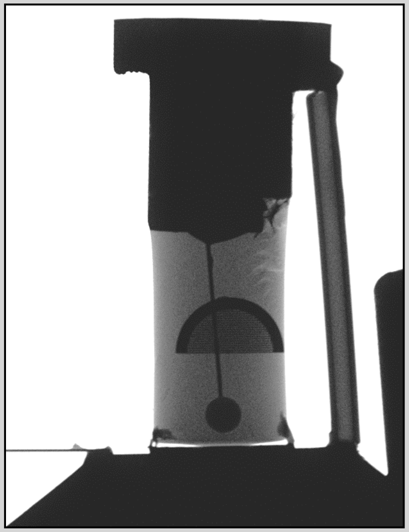
Astro Object





Target Pictures



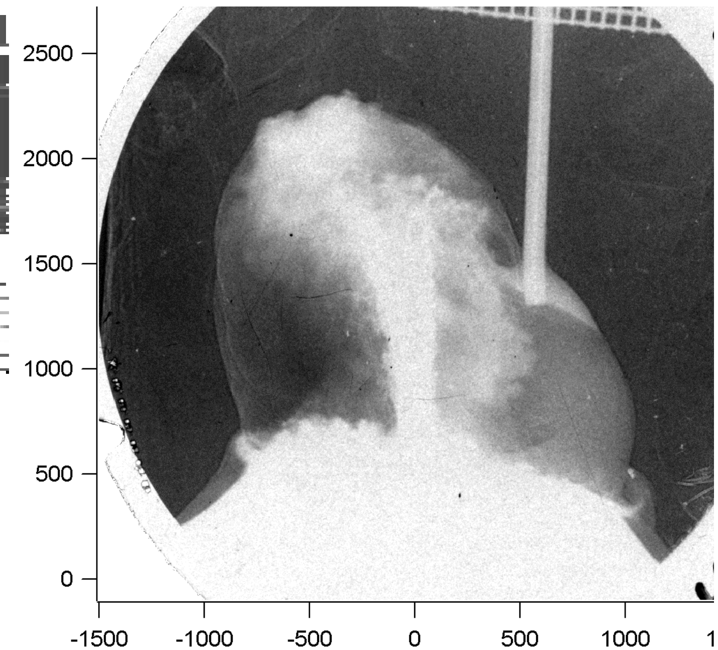


3D RAGE simulations accurately model the large scale hydrodynamic motions

RAGE simulation
Fe backlighter at 80 ns

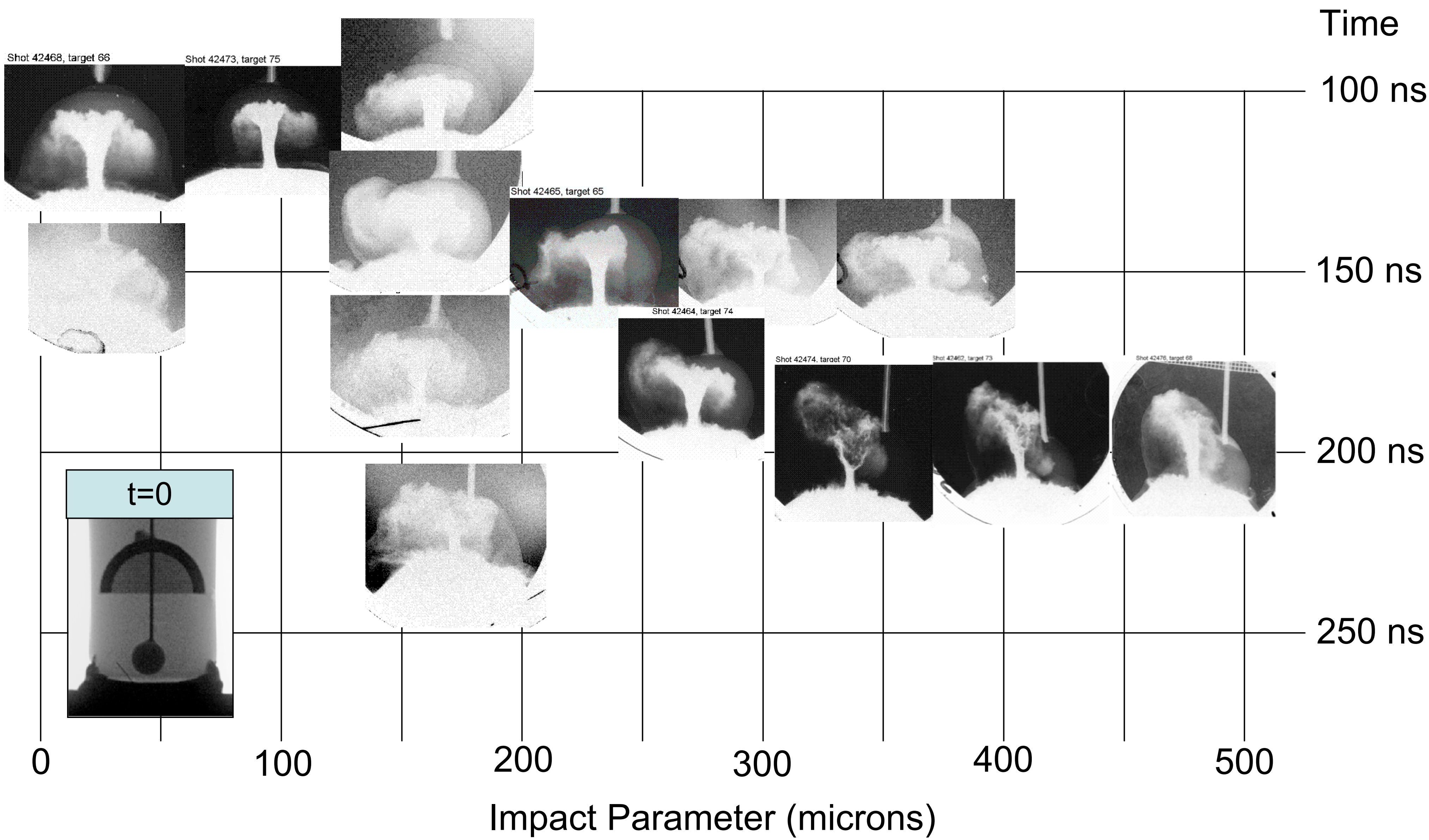
RAGE simulation
Fe backlighter at 200 ns

Data
Fe backlighter at 200 ns



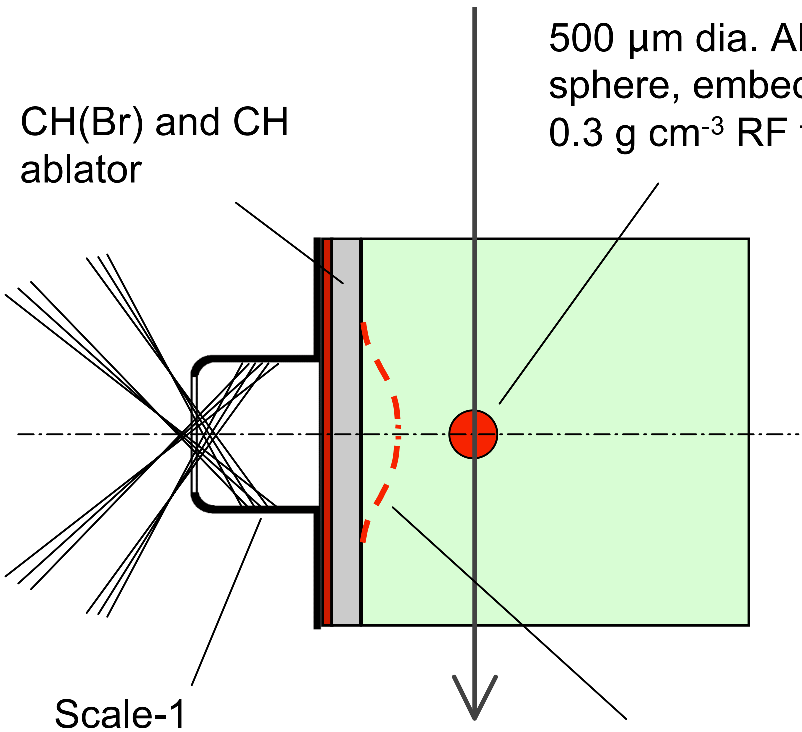
Significant target characterization is needed to constrain the simulations

A large number of well characterized targets were shot to study jet deflection physics

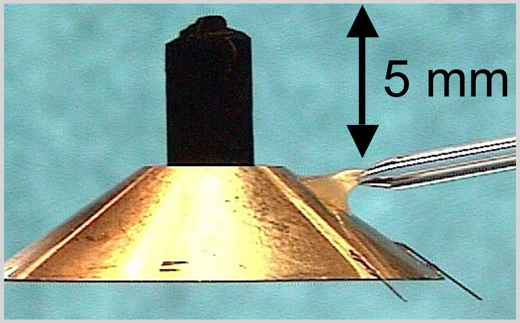


GENERAL ATOMICS

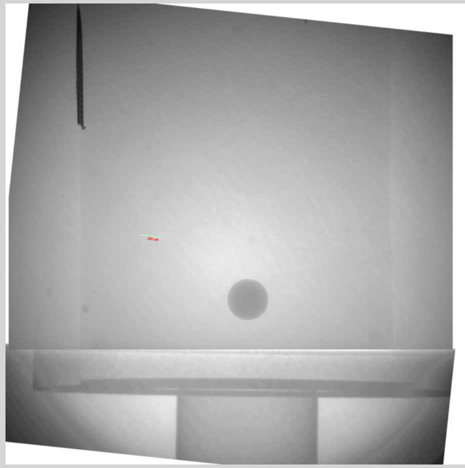
Targets were constructed to study the physics of a shock interacting with a spherical object



Target

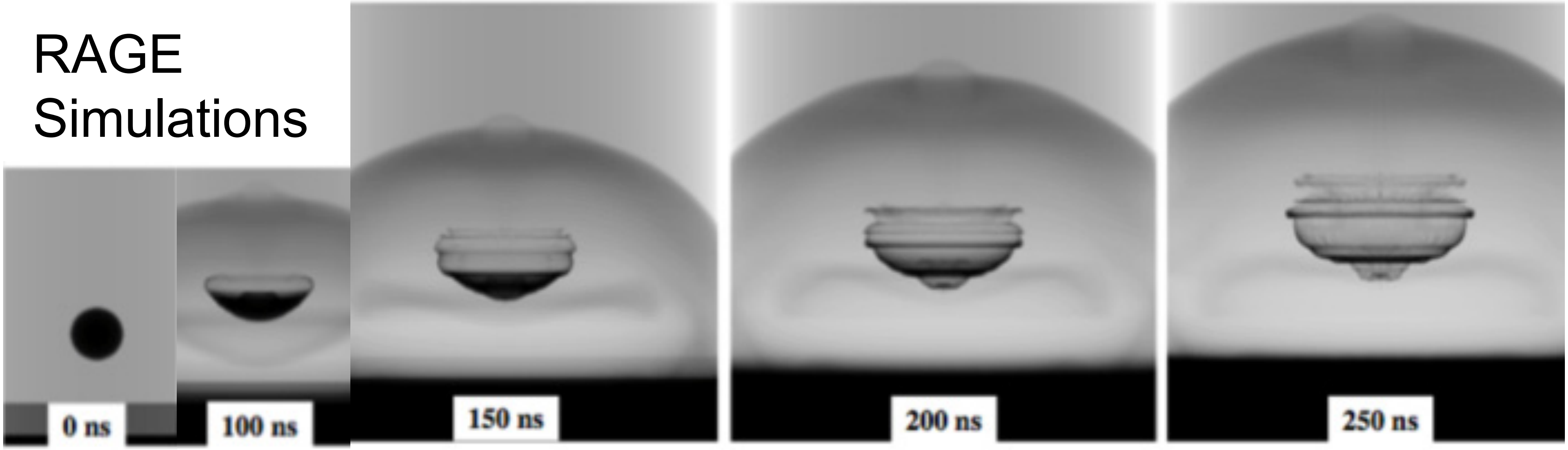


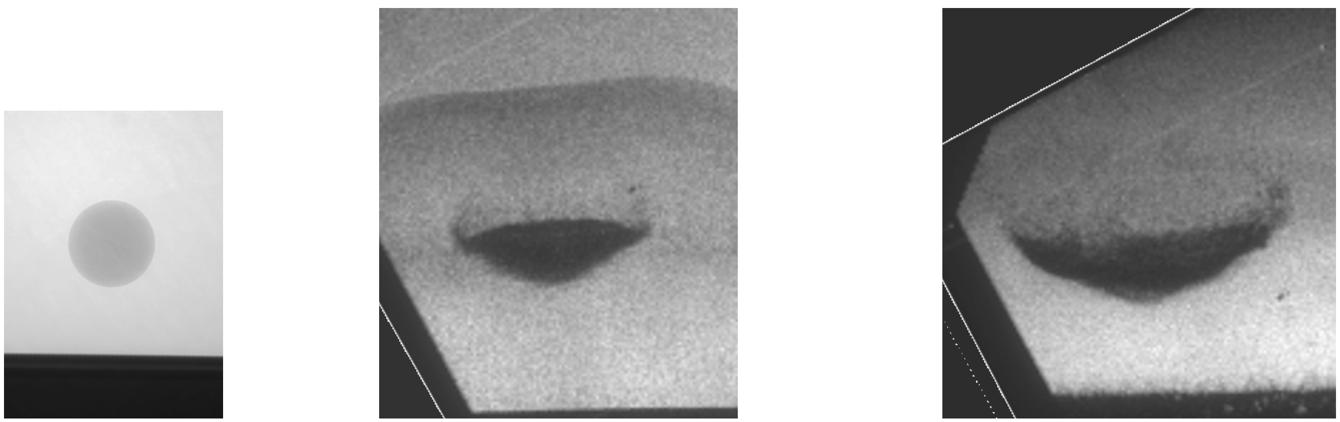
Radiograph



The experiment shows more breakup of the ball than predicted by the simulations

RAGE Simulations



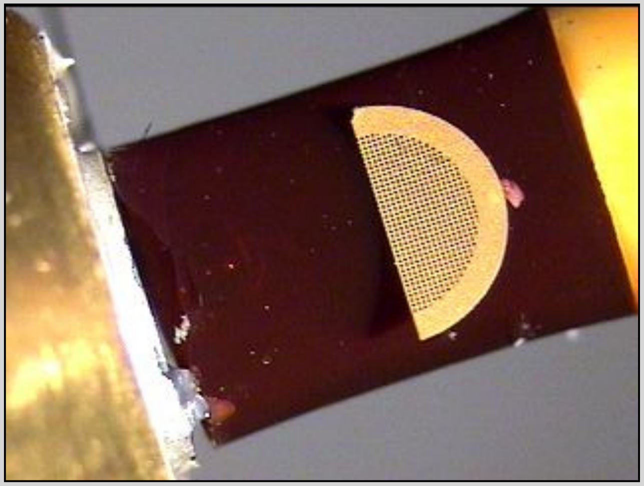


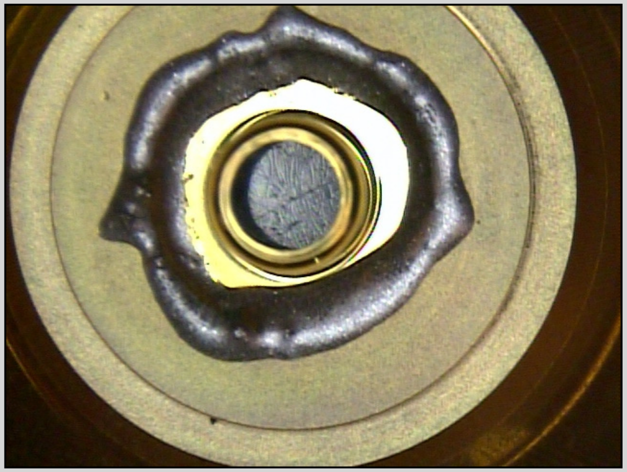
0 ns | 100 ns | 200 ns

Experimental Data

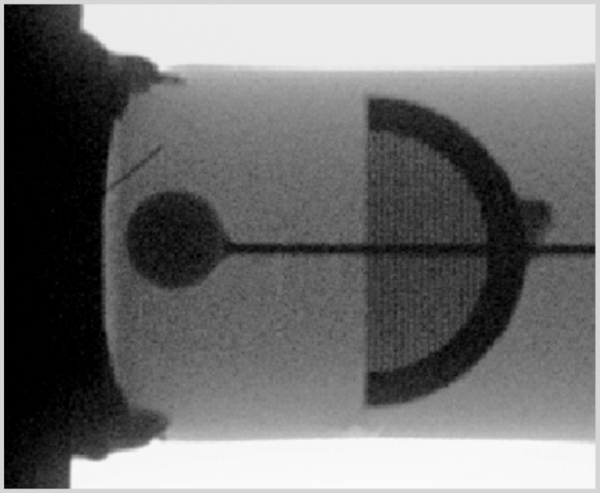
Characterization of assembled targets is necessary for interpreting experimental results

Optical





X-Ray

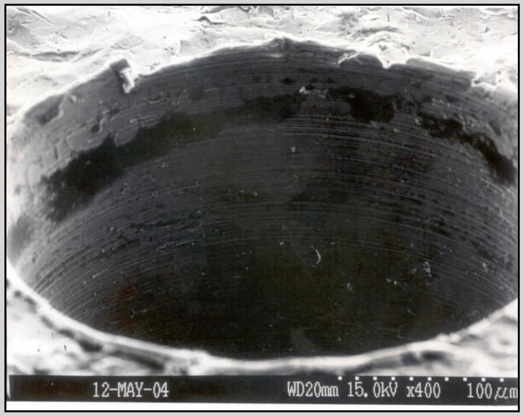


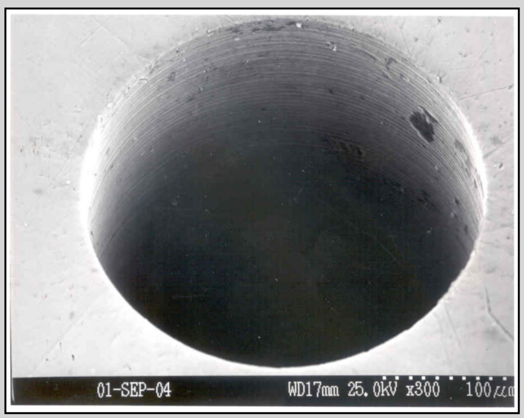
Characterization impossible after the shot - Target destroyed

GENERAL ATOMICS

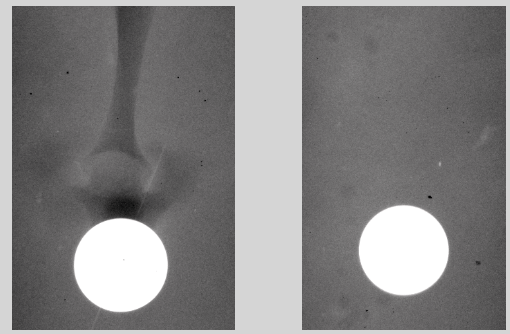
Characterization of individual target components is critical before the target has been assembled

Images of hole before and after polishing



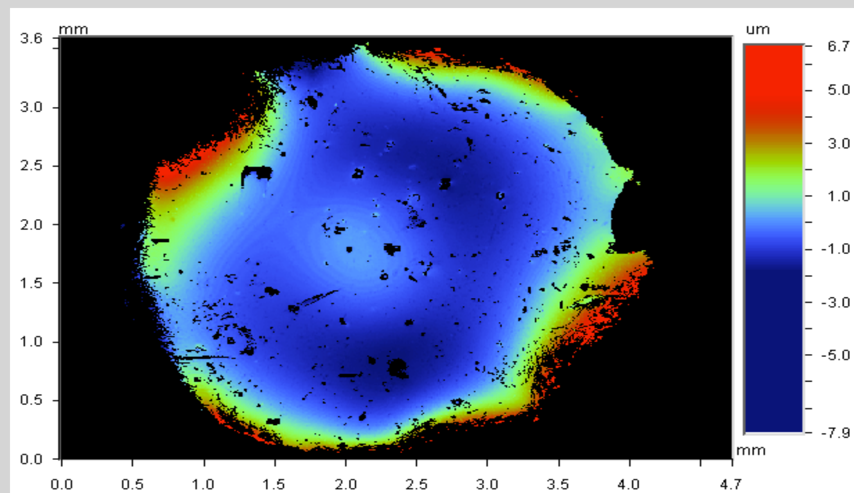


Foam Perturbations



With Without

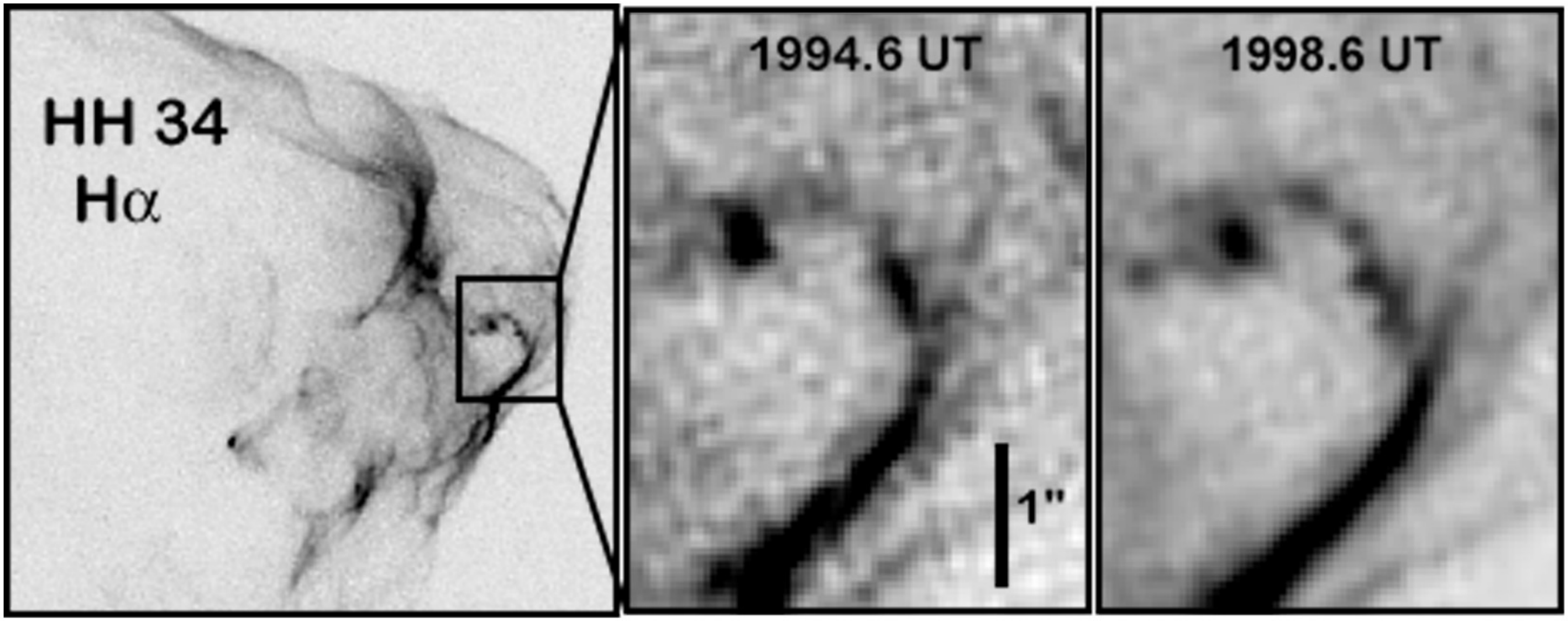
Cast foam surface finish



Characterization is necessary for high-quality targets

GENERAL ATOMICS

Our collaboration is using observation time on the Hubble Space Telescope to study jet dynamics



HST project to obtain 3rd epoch to follow instabilities, clumps, and shear

3 targets: HH 1&2, HH 34, HH47

Data to be taken August 2007 – January 2008

Summary

- We have developed a target platform to study high Mach number, compressible, turbulent plasma flows

- Scaled experiments allow us to study deep nonlinear dynamics relevant to astrophysical phenomena in the laboratory

- A series of experiments has been performed to study:
  - The transition to turbulence and its effect on global hydrodynamic evolution
  - Jet interaction dynamics
  - Shock interactions with spherical objects

Laser drilled counterbored fill holes in beryllium capsules

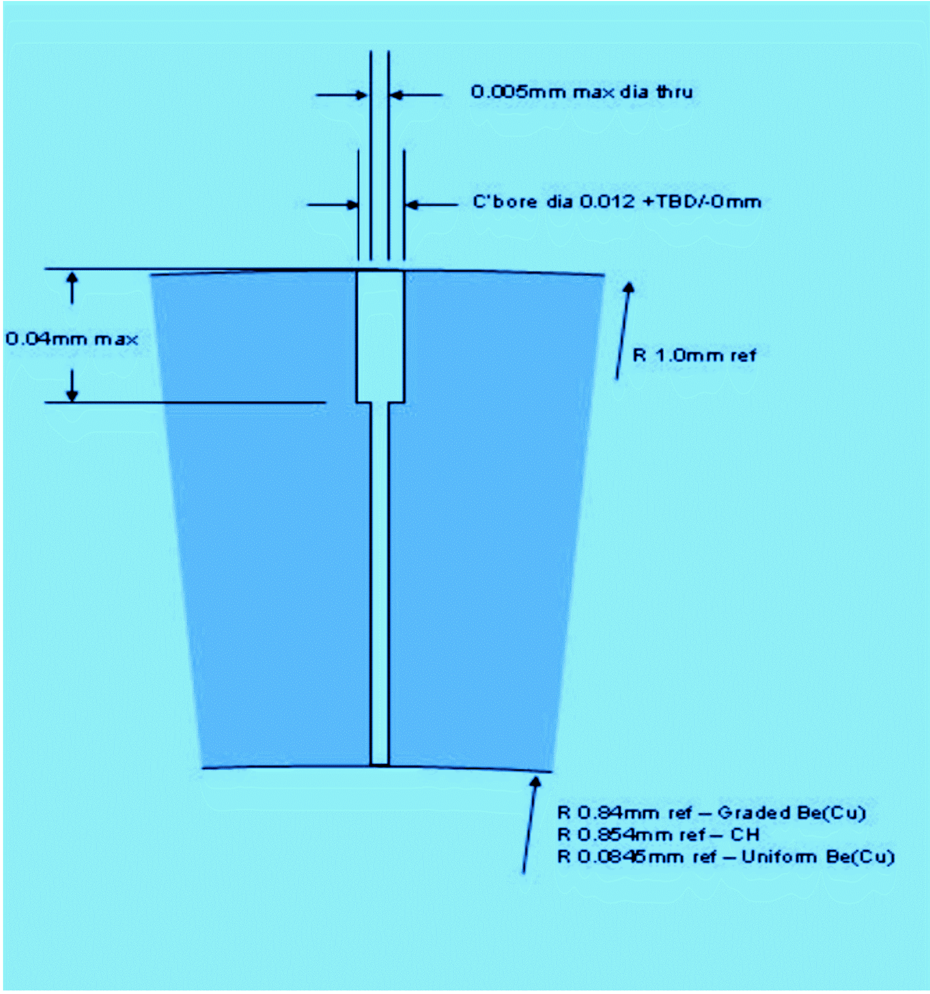
A. Forsman, E. Lundgren, A. Komashko, K. Moreno

General Atomics, San Diego, USA

GENERAL ATOMICS

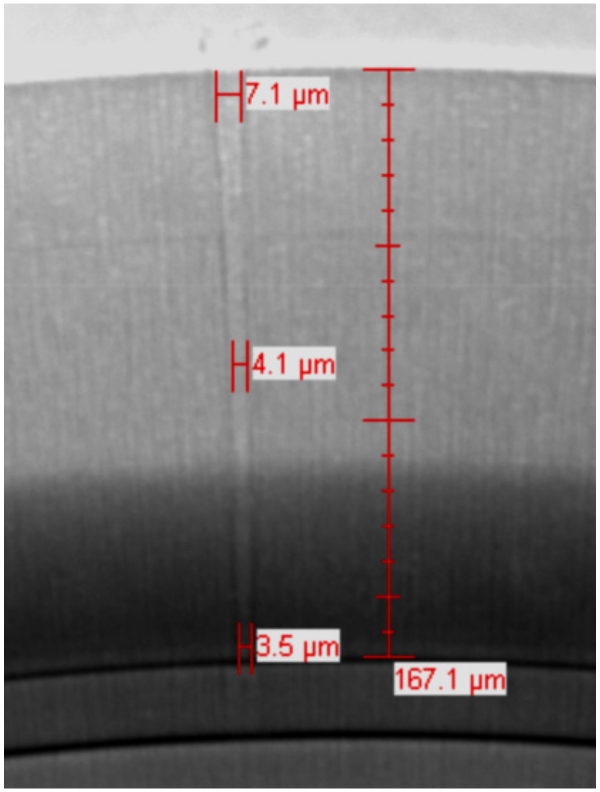
Ideal fill holes have > 30:1 depth : diameter aspect ratio.

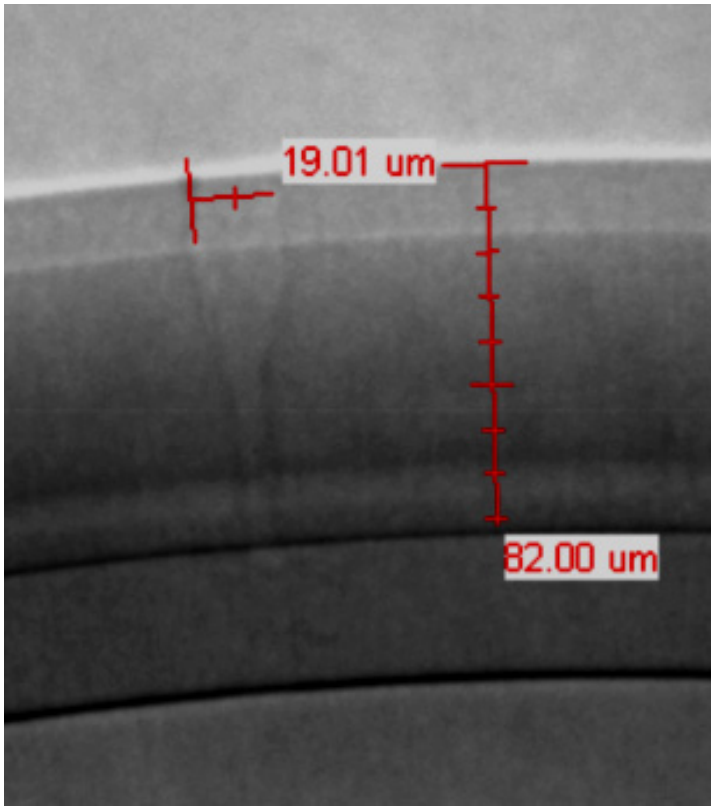
- **The holes need to be ~ 5 um in diameter.**
  - Allowed mass defect is 125% of an ideal 5 um hole.
  - Hole needs to allow for pyrolysis.
- **175 um of multilayered Be and 15 um thick GDP mandrel.**
  - The drilling process is more akin to drilling a pipe than a hole.
- **Drilling process produces a reasonable approximation to the ideal shape.**



Nanosecond lasers form the hole and the counterbore

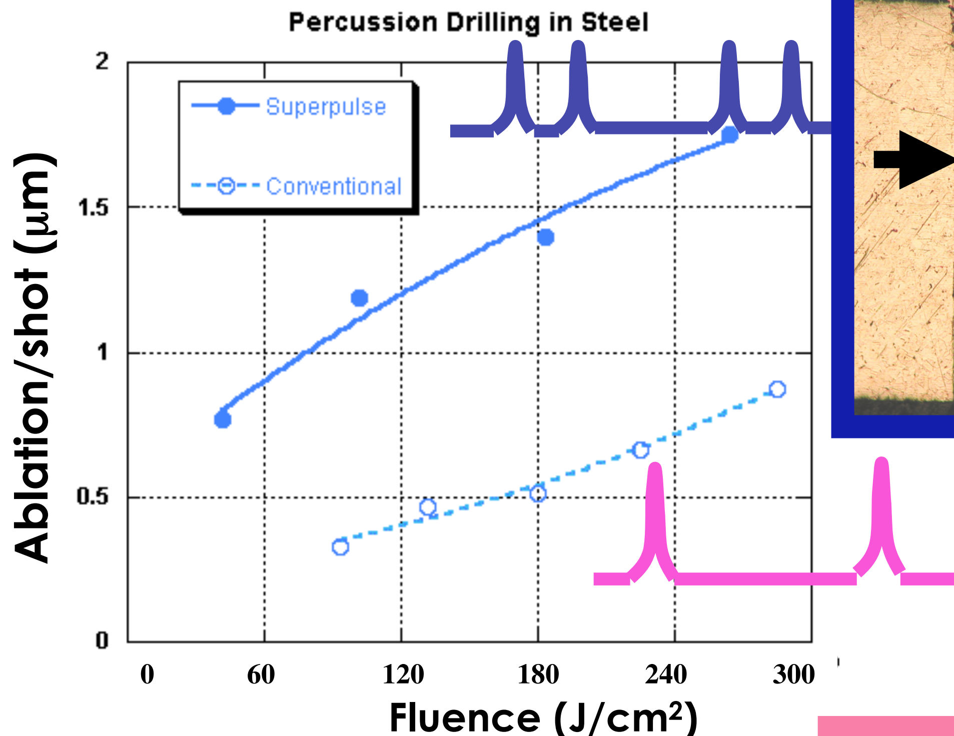
- **Technique proven for fuel injectors**
- **Nanosecond lasers (Sierra)**
  - Reliable & maintenance free
  - 532 nm, 4 ns
- **25 mm laser focusing lens**
  - Good standoff
  - Survivability & depth of focus.

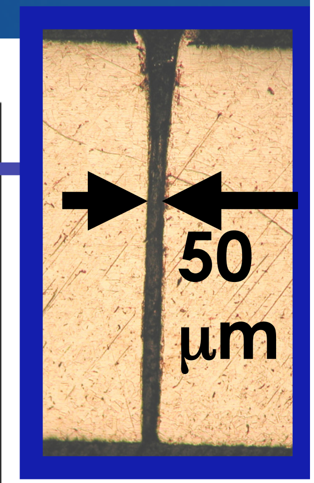


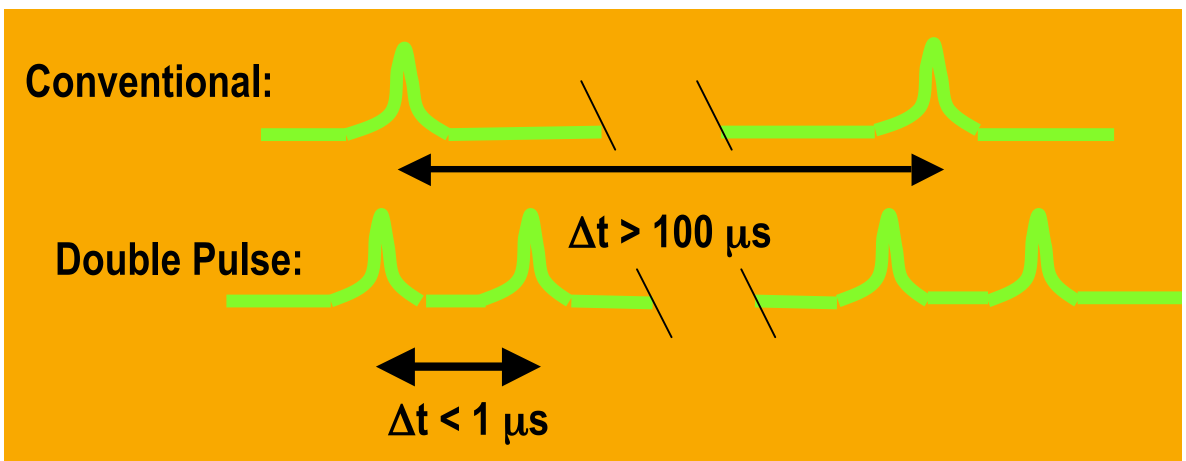


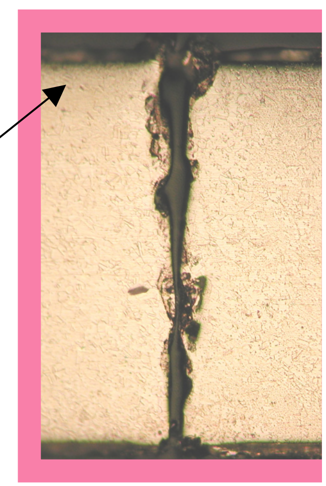
Formatted laser pulses enable the drilling of the fill holes

- **Double pulse format outperforms conventional technique**
  - Trademarked by GA as SuperPulse
  - Forsman et al., J. Appl. Phys **98** 033302-1 (2005)
- **Conventional approach reduces ablation debris**
  - Femtosecond lasers
  - Gas assist jets
- **Double pulse format uses ablation debris**
  - Increases basic material removal rate.
  - Improves ejection of ablation products.





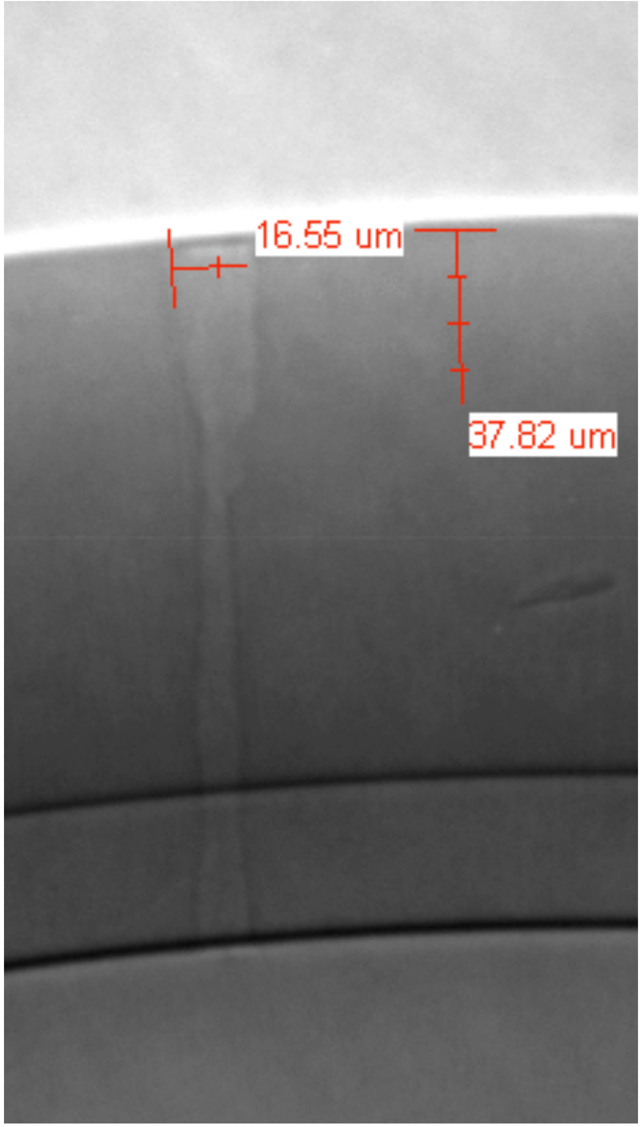




1 mm type 304 stainless steel

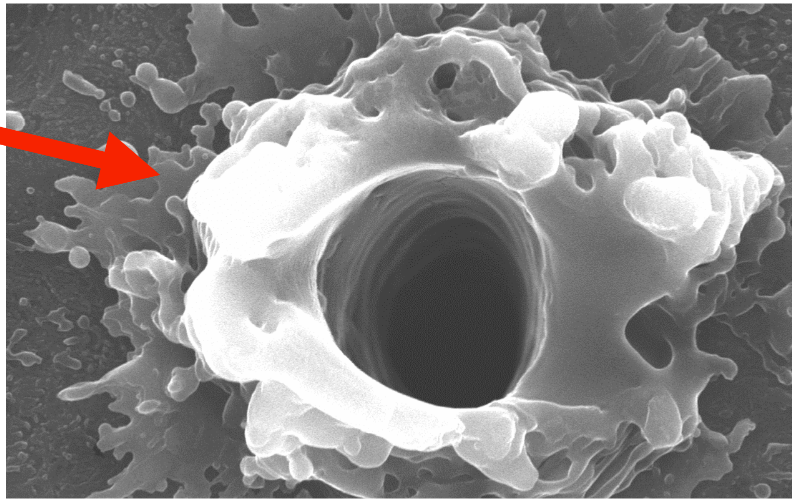
The counterbore is also drilled using the laser in situ.

- **In-situ drilling is fast and accurate**
  - Eliminates need for ultra-precise tool
- **The tapered bottom prevents the fill tube from blocking the hole**

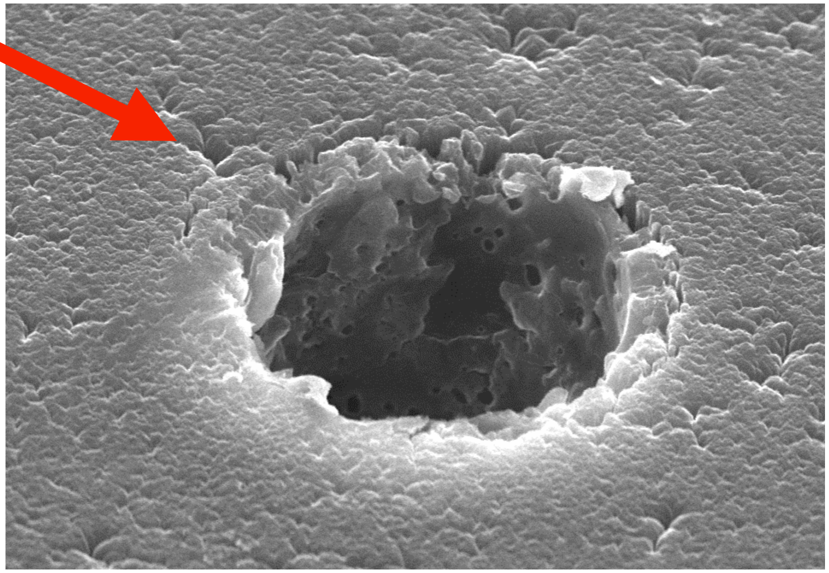


A sacrificial foil is used to control surface debris

- **Debris from ablation will normally accumulate on the surface around the hole.**
  - This is undesirable.
- **A thin foil is placed in imminent contact with the capsule at the drill site.**
  - External debris accumulates on the foil
  - The foil is removed after drilling



5 µm hole entrance



Present process development work is focused on parasitic processes that limit aspect ratio and quality

- **Parasitic processes arising due to small, high aspect ratio holes:**

- **Unwanted laser energy deposition**
  - Occurs in the bore walls of the high aspect ratio hole.
  - Can be thought of as transmission losses.
- **Unwanted plasma thermal deposition.**
  - Hot (100 000 K) plasma flows out through a small, relatively long hole.
- **Hole enlargement due to plasma**
  - Radially expanding plasma can ablate the bore walls next to the target point
- **Internal debris management**
  - How to control redeposition

Parasitic processes, continued

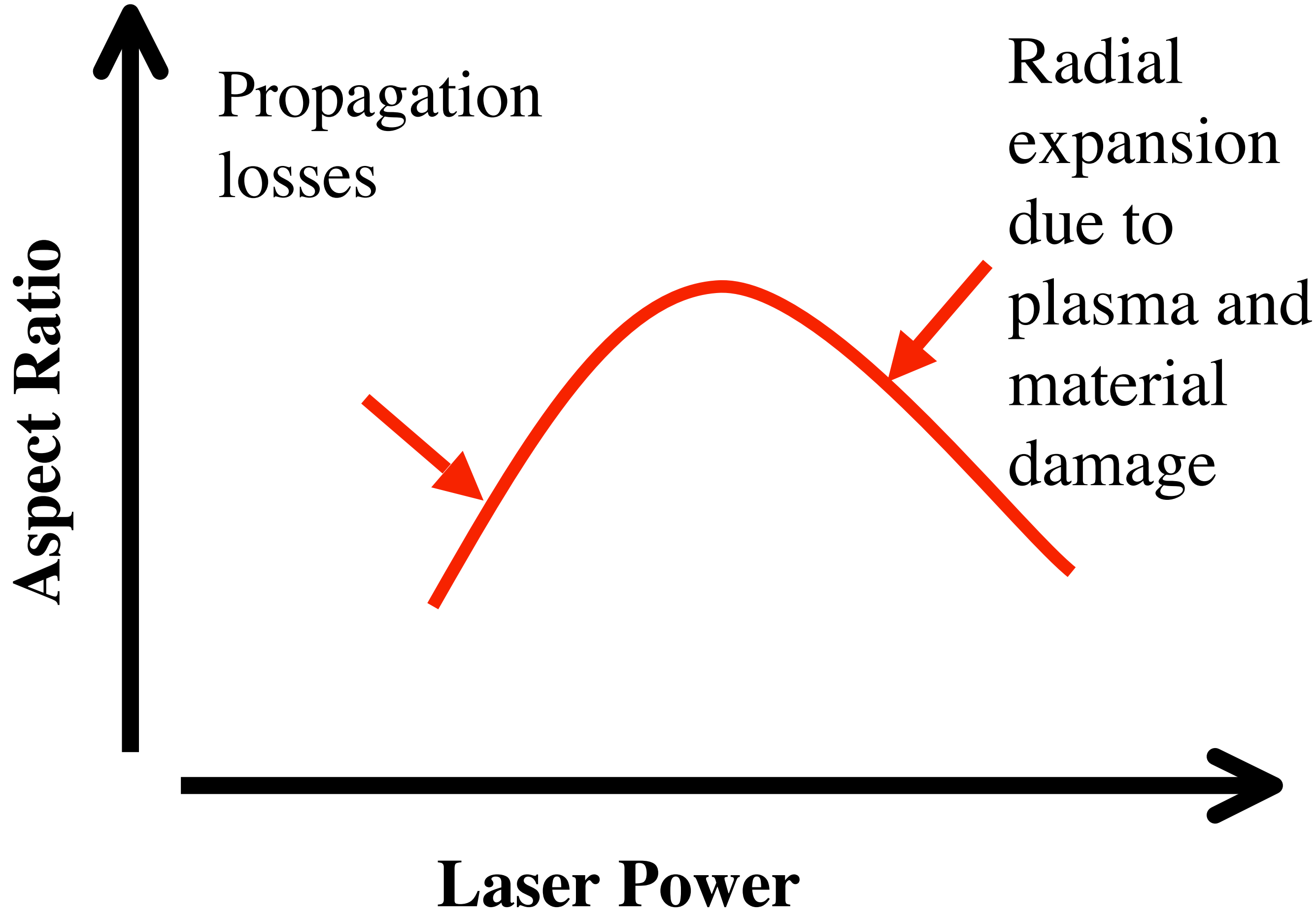
- **1st-order EM waveguide model shows that 70% transmission losses at the hole bottom should be expected.**
  - Cannot experience losses less than this for a cylindrical hole.
  - Can reduce hole taper through more energetic primary pulses.
  - Hole taper would increase unwanted laser deposition.
- **Adjusting the durations and timing of the laser pulses allows us to influence the temperatures and the durations of the ablation plasmas.**
  - Can also affect material redeposition.
- **Becomes multi-dimensional process optimization.**

The double pulse technique already mitigates these parasitic processes

- **Improved ablation rates and material ejection efficiency mean that**
  - Fewer laser shots are used → less overall energy applied..
  - Redeposition is reduced
- **Each laser pulse is less intense than it would have to be if a conventional technique was used**
  - Ablation plasmas are less energetic and hence cause less damage as they exit the hole.
  - Absolute transmission losses are smaller and thus undesirable laser energy deposition is reduced.
- **Further process optimization is underway**

A limit on the aspect ratio for small holes ?

- **30:1 or 40:1**
  - 5 μm hole
  - Beryllium & Aluminum
  - 4 ns laser pulses
  - Double pulse format
  - 532 nm



Ultra-Intense laser beam interactions in cone geometry for Fast Ignition

R.B. Stephens, General Atomics

49th Annual Meeting
of the
Division of Plasma Physics
November 12-16, 2007
Orlando, FL

This work was performed under the auspices of the U.S. Department of Energy
under contracts No.DE-FG02-05ER54834 and W-7405-Eng-48.

ACFI

GENERAL ATOMICS

Collaborators

- K. Akli[1], T. Bartal[3], F. Beg[3], S. Chawla[3], C. Chen[6], R.R. Freeman[3,5], D. Hey[4], M. H. Key[2], J.A. King[3], A. Link[5], T. Ma[3], A.J. MacKinnon[2], A. MacPhee[2], V. Ovchinnikov[5], D. Offermann[5], Y. Ping[2], L. VanWoerkom[5], Y. Tsui[7],

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[7]University of Alberta, Edmonton, Alberta T6G 2E1, Canada

Abstract

FI pulses are absorbed inside cone - complex geometry -hard to understand

- Reflect light?
- Create forward e current?

Expts at 10^{20} W/cm^2 to measure reflectivity and electron creation

- **Preliminary results show**
  - **High reflectivity at glancing incidence (~40x)**
  - **Lower electron generation at glancing incidence (~10x)**

    --> Minimal light absorption at glancing incidence
  - **No Electrons generated fluorescence forward from laser beam**

    (Escaped electrons carry insignificant energy)

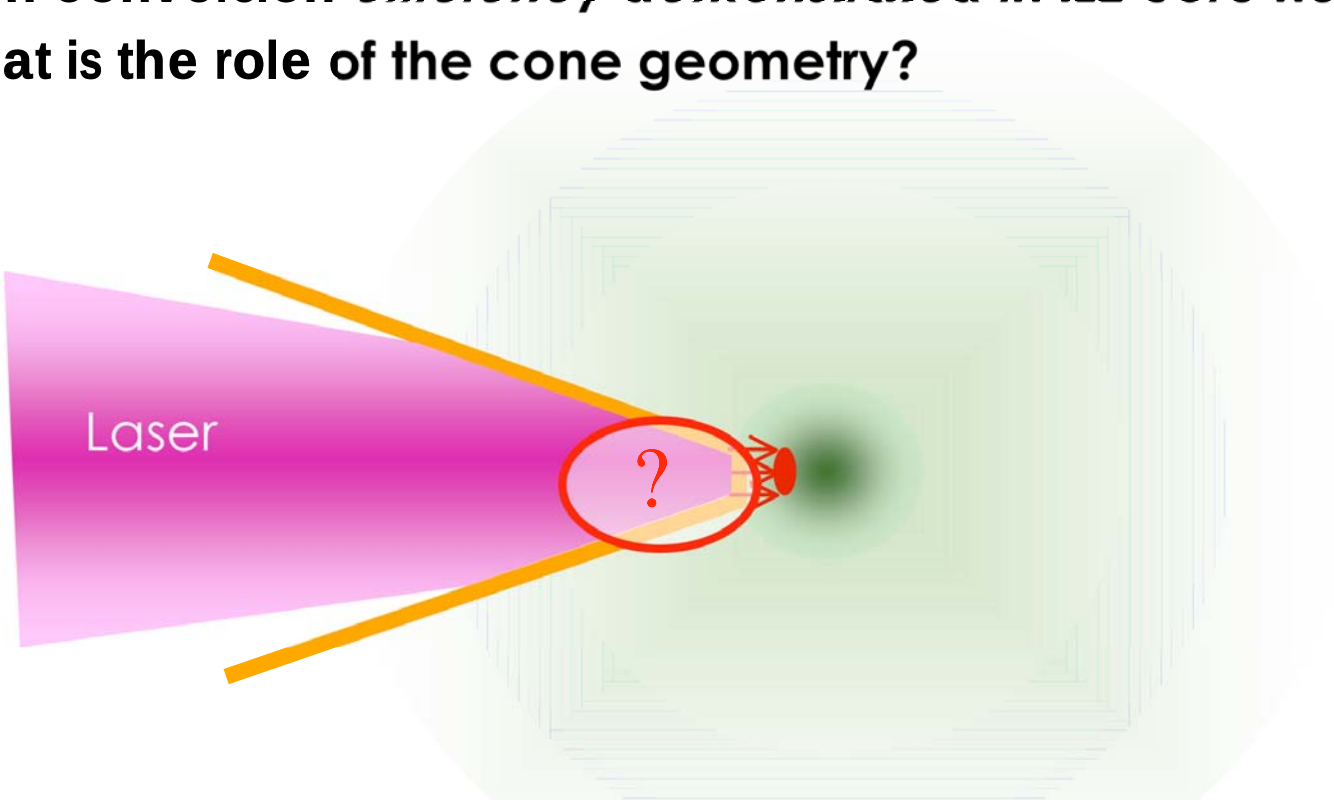
⇒ **Dominant cone effect is focusing light**

⇒ **Energy mostly absorbed on near-normal incidence**

Design cones for concentrating light in glancing incidence reflection

Ignitor pulse converted to electrons inside cone

- High conversion efficiency demonstrated in ILE core heating expt.
- What is the role of the cone geometry?

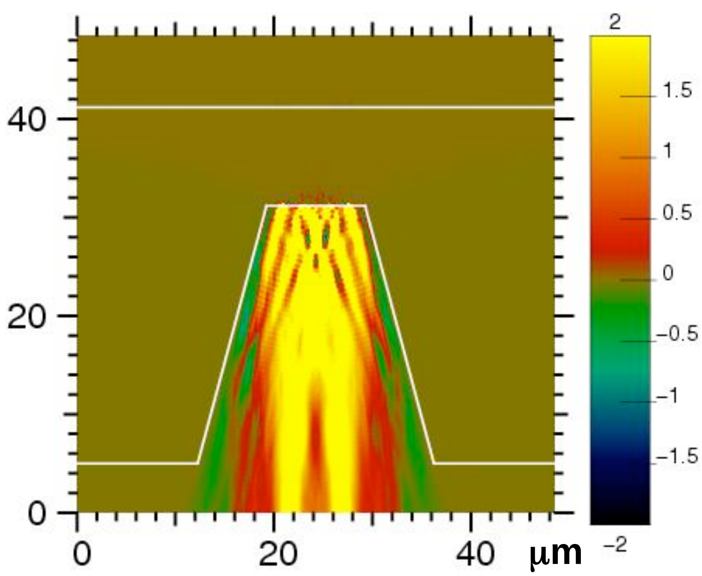


— Increase light intensity at tip?

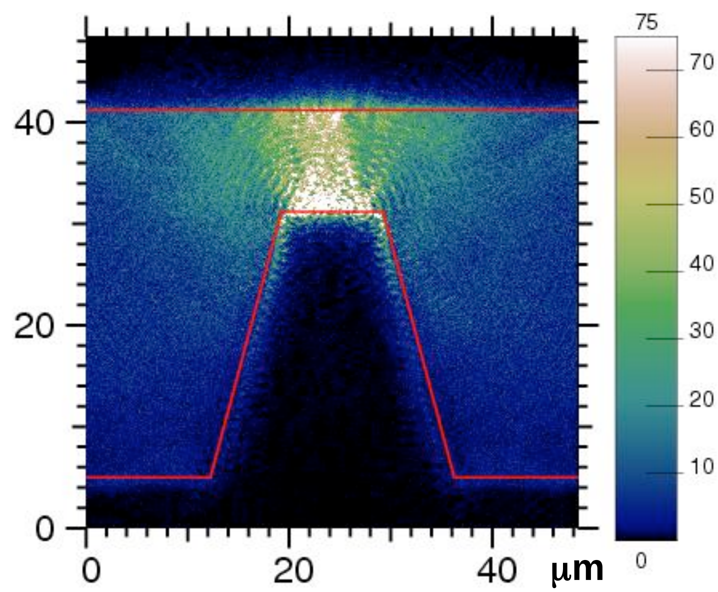
— Increase electron flow at tip?

1) Cone walls reflect and concentrate light at tip

- **Particle in cell (PIC) modeling with sharp interfaces show side wall interactions strongly reflect light at FI intensity 10^{19} to 10^{20} Wcm^{-2}**



Poynting flux



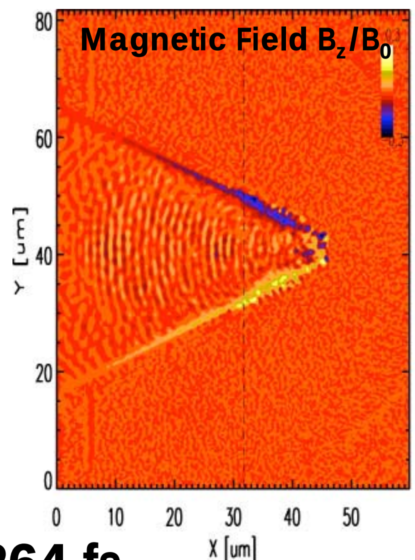
Electrons>1MeV

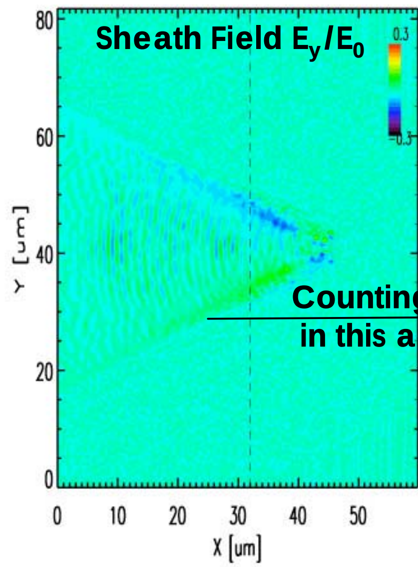
Zohar B modeling, B. Lasinski (LLNL)

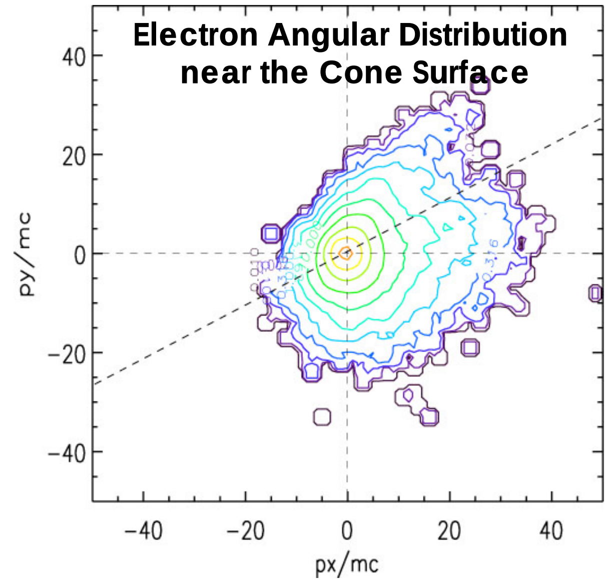
2) Electrons formed in sidewalls flow toward tip and concentrate there

Surface Magnetic Field and Sheath Field are excited on Inner Surface

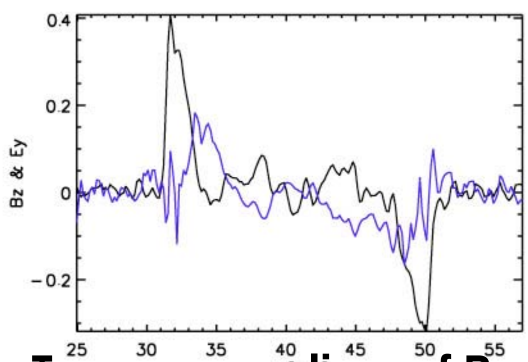
⇒Electrons are flowing toward the tip.







t=264 fs

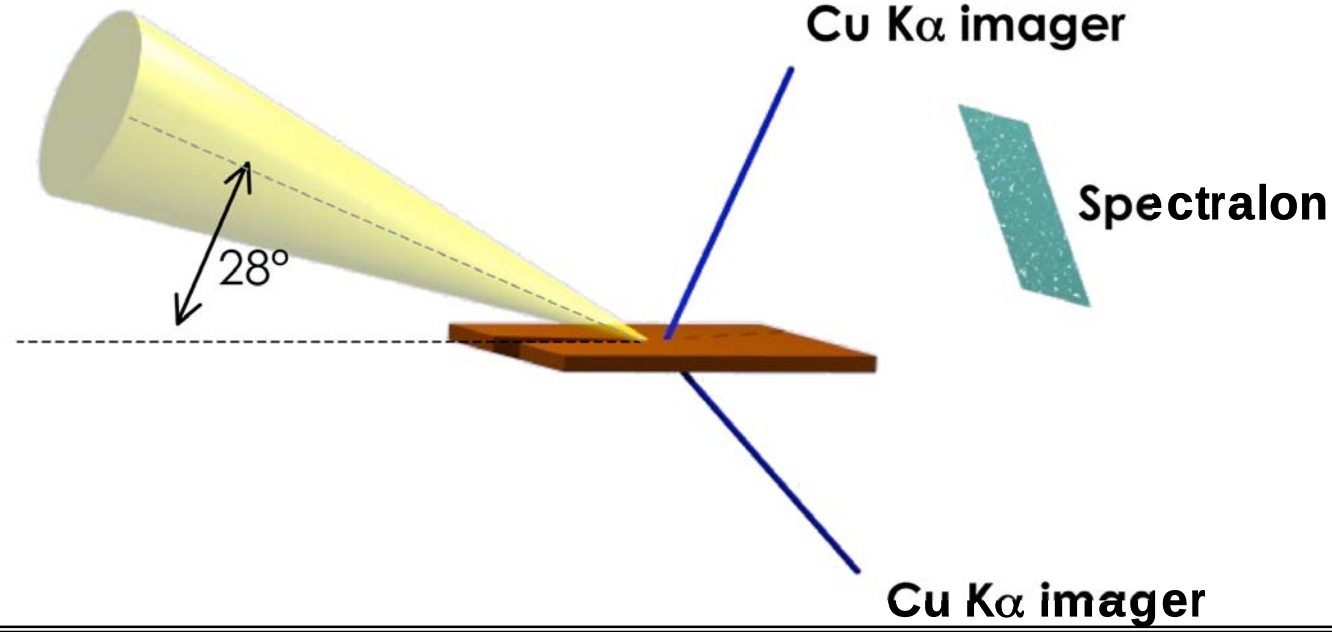


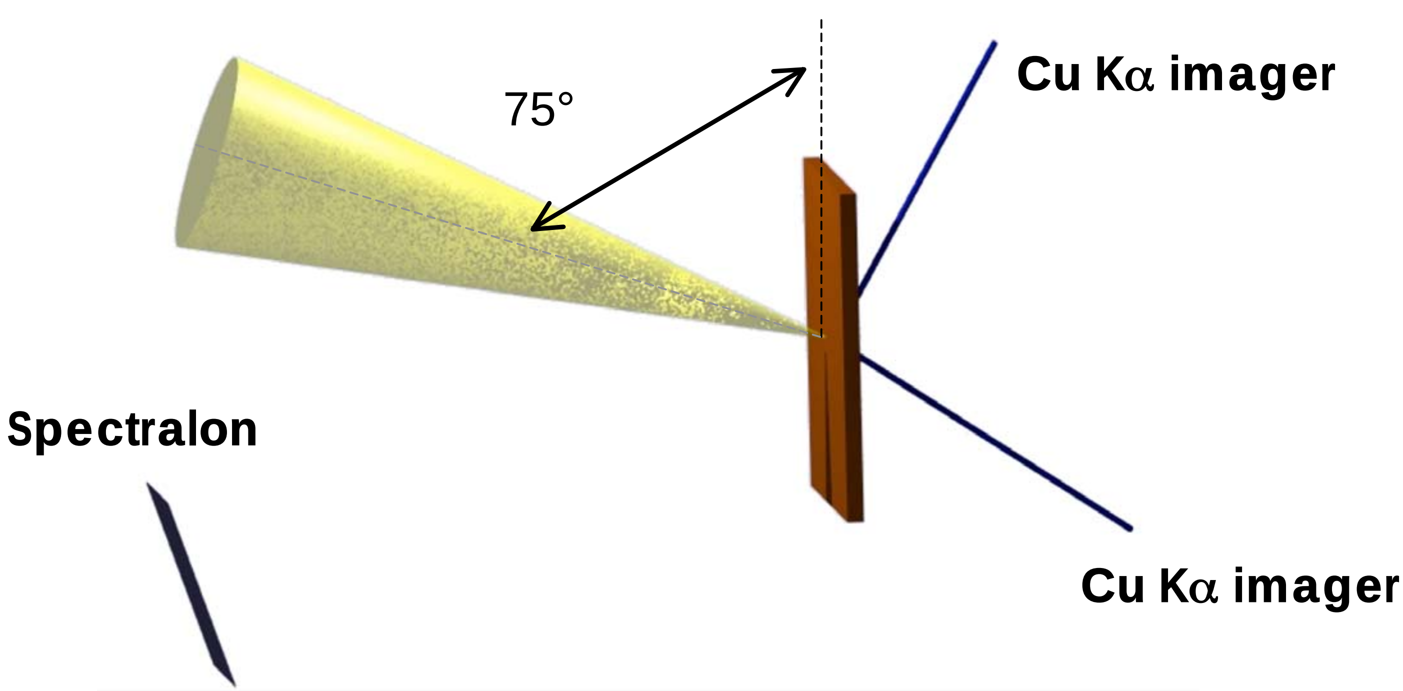
Transverse slice of B_z & E_y

PICLS modeling
Y. Sentoku (UNR)
***Phys of Plasmas* v.11**
#6 3083-3087 (2004)

Created LPI with simplified geometry to investigate effect

- Titan laser pulse f/3 10^{20} W/cm^2, 1 psec, ~150 J
- Focused *f*/3 beam to 10 μm
- Incident at 28° and 75° from surface normal - s-polarized
- Target 0.5x0.5 mm^2 x 25 μm thick
- Detect reflectance by light scattered off Spectralon™ surface
- Detect electrons using Bragg mirror to image Kα reflectance
- Count electrons with single hit ccd - (data not yet analyzed)


Cu Kα imager
Spectralon
28°
Cu Kα imager

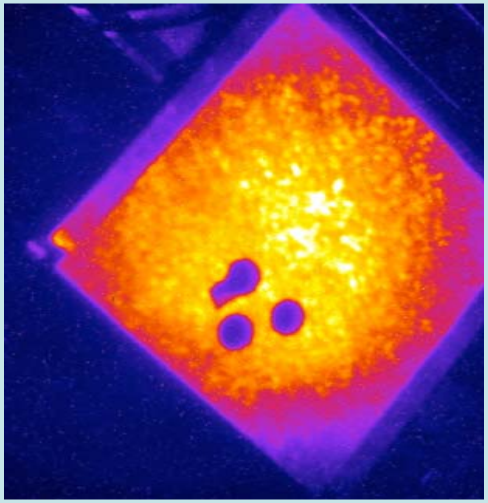

75°
Cu Kα imager
Spectralon
Cu Kα imager

Reflectance low at near normal

- **Still working on calibration**
- **Reflection ~ Independent of prepulse**

Near normal incidence

Normal Prepulse (~5mJ)



20080824 s2

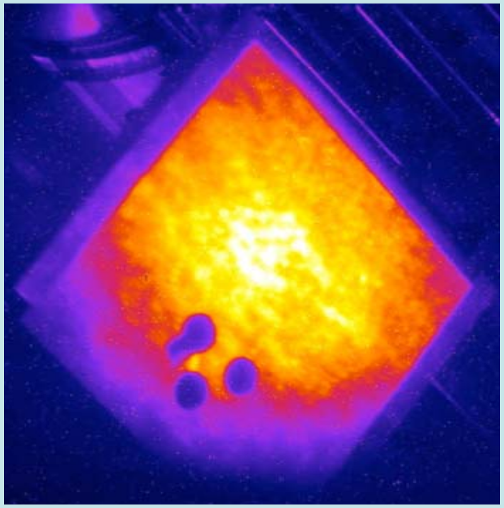
Laser ~ 140 J

Specular ~ 1.73 J

Specular: 1.24 a.u.

Near normal incidence

Large Prepulse (20x larger)



20080828 s2

Laser ~ 151 J

Specular Energy:~ 1.14J

Specular: 0.75 a.u.

Reflection at glancing incidence 20-40X larger

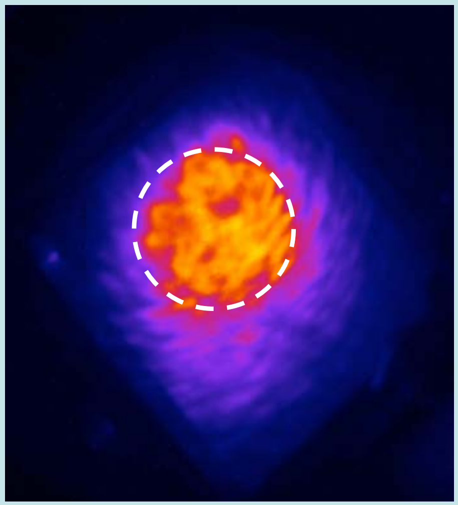
Glancing incidence - Normal Prepulse

Laser ~ 146.7 J

Specular ~ 36.6 J

Specular: 25.1 a.u.

20070830 s04

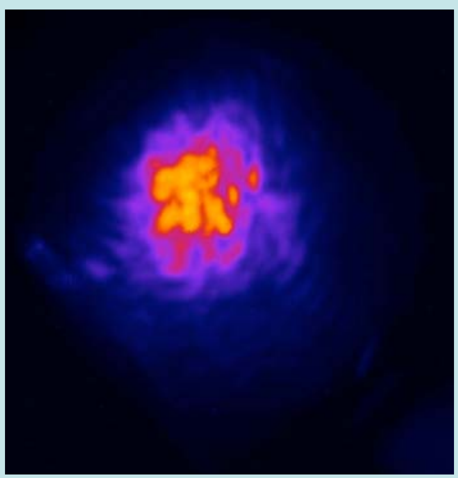


Laser ~ 32.3 J

Specular ~ 13.4 J

Specular: 38 a.u.

20070830 s02



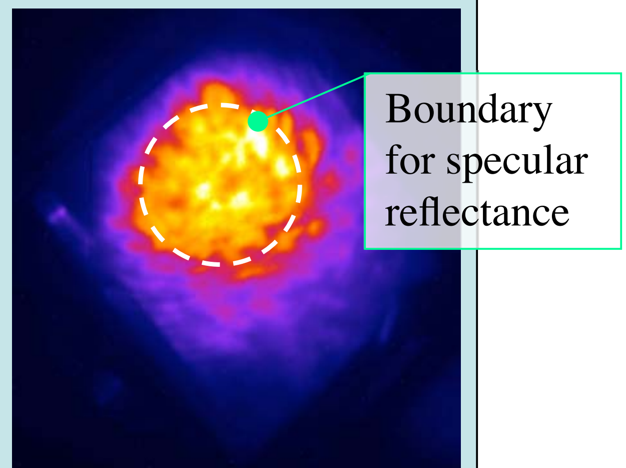
Glancing incidence - Large Prepulse

Laser ~ 134 J

Specular ~ 38.6 J

Specular: 28.8 a.u.

20070830 s03

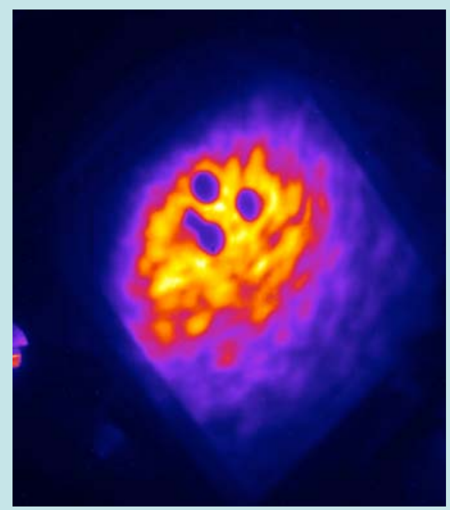


Laser ~ 129 J

Specular ~ 32.3 J

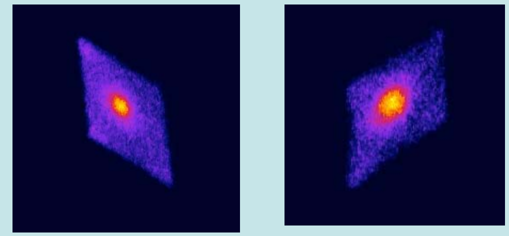
Specular: 25.0 a.u.

20070830 s01



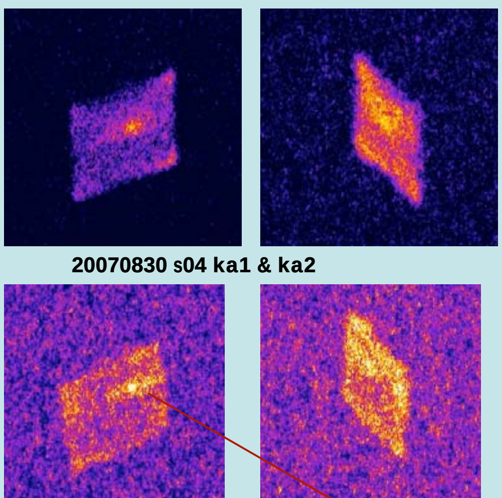
Fluorescence shows no evidence of forward directed hot electrons

- Normal incidence shows symmetric electron spread
- Glancing incidence shows no electrons forward from beam
- Effect seems independent of plasma gradient



20070827 s01 ka1 & ka2

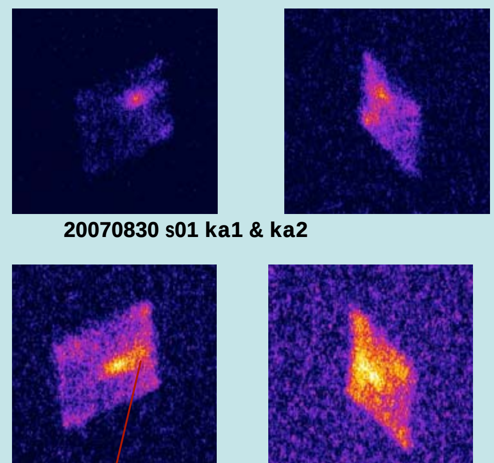
Near Normal Incidence



20070830 s04 ka1 & ka2

20070830 s02 ka1 & ka2

Glancing - Normal Prepulse



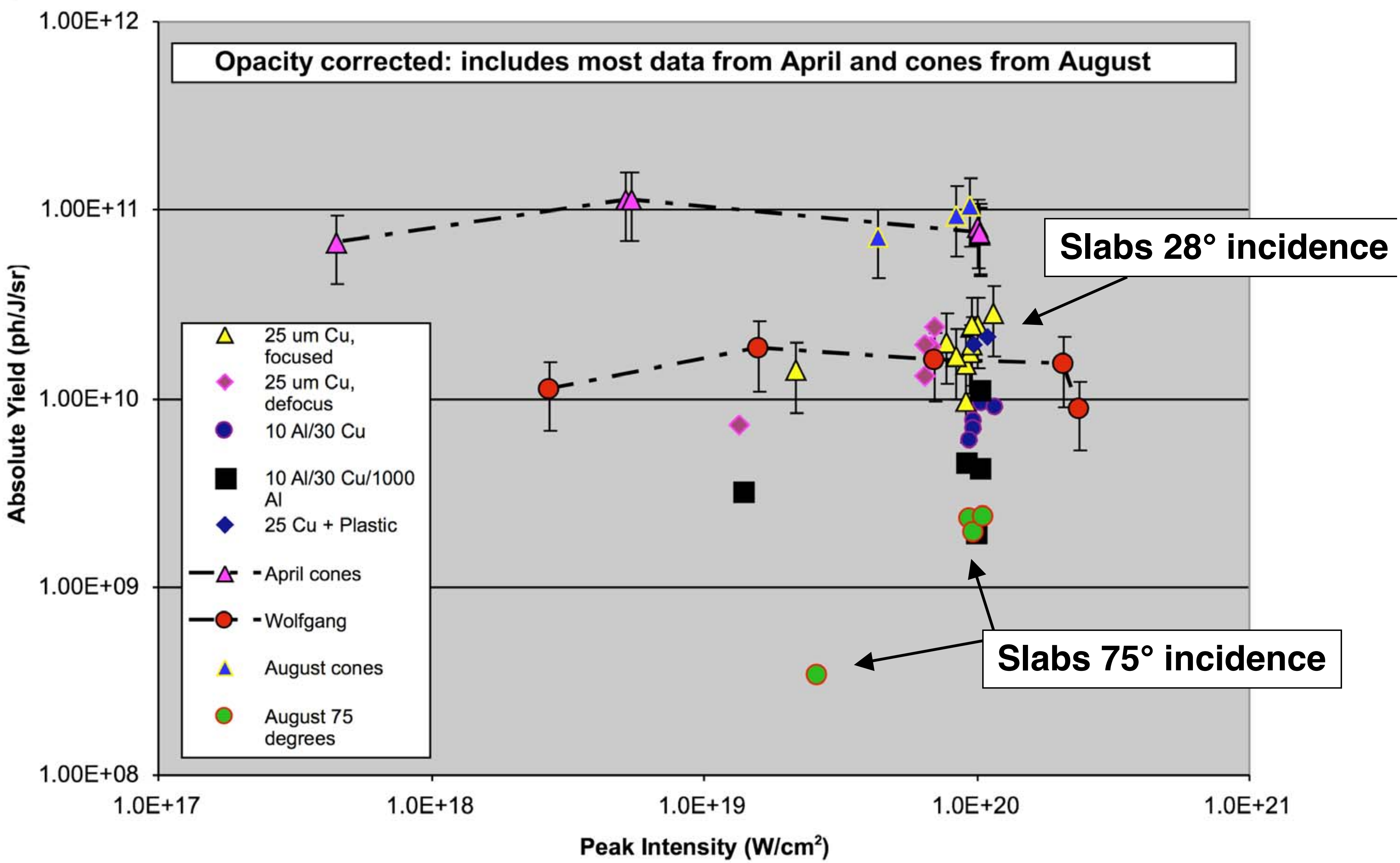
20070830 s01 ka1 & ka2

20070830 s03 ka1 & ka2

Glancing - 20X Prepulse

Streak is back along laser beam

Electron generation much lower at glancing incidence (s polarization)



Any significant electron flow would be visible

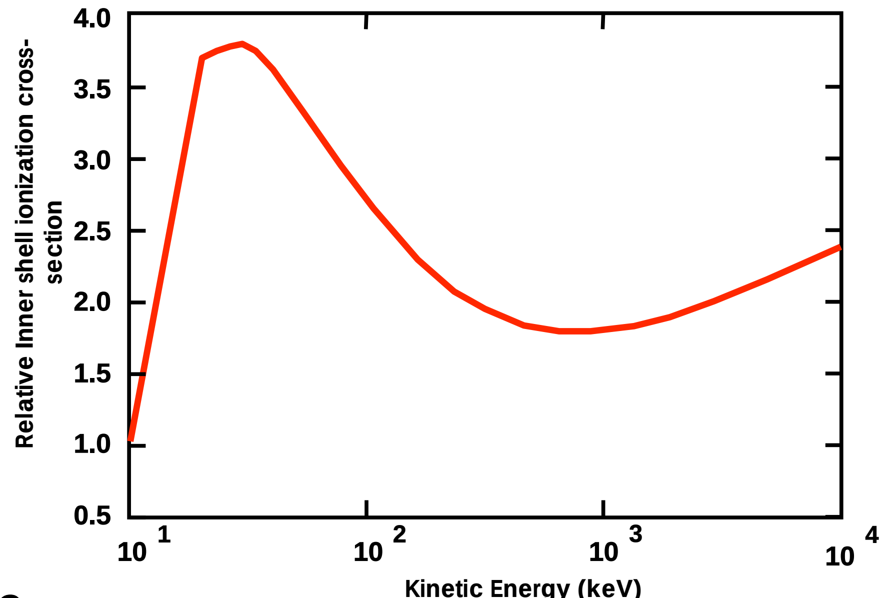
- **A few electrons can leave target without a trace**
  - Depends on target size - preplasma expansion can increase numbers.
  - Forward directed surface electrons detected with electron spectrometer.

T.Yabuuchi et al., Plasm & Fus Res 1,1 (2006)

H. Habara et al., Phys. Rev. Lett 97, 095004 (2006)

- **Most electrons are trapped on the target**
  - Losing 2×10^{11} electrons charges 1/2 mm sphere to MV
  - If all MeV electrons, loss of 30 mJ
  - Current flowing up support stalk insignificant ~10^6 electrons

- **All trapped electrons can be seen**
  - Target only 25 μm thick so
    we see all fluorescence
  - Scattering cross section
    ~ independent of energy
    down to threshold so we follow them
    through their entire lifetime



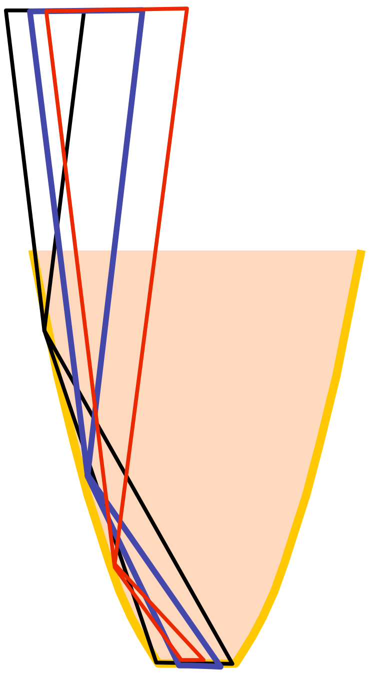
⇒ **No significant e flows along the surface**

Maximize efficiency with Winston non-imaging light concentrator

- High reflection at glancing incidence, minimal electron generation
- Low reflection at normal incidence, maximum electron generation
- No significant electron flow along surface

⇒ Maximize light intensity at tip

- Winston Collector has the right properties
  - Single bounce gets all light to the tip
  - Concentrates light proportional to f/number



See also:

QI1.00003 Linn Van Woerkom - Intense laser plasma interactions on the road to fast ignition

CO6.00012 T. Yabuuchi - Influence of sheath fields on hot electron emission from small foils irradiated by intnse laser pulses

GO6.00015 Andrew MacPhee - Short pulse laser coupling efficiency to hot electrons for fast-ignition studies

Laser heating of solid matter by light pressure-driven shocks at ultra-relativistic intensities

Kramer Akli
General Atomics

49th Annual Meeting of the Division of Plasma Physics
Orlando, Florida
November 12-16, 2007

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UCRL-POST-236420

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UNIVERSITY OF CALIFORNIA, Department of Applied Science, UCD — D. Hey

THE OHIO STATE UNIVERSITY, College of Mathematical and Physical Sciences — R.R. Freeman, L. Van Woerkom, D. Clark, K. Highbarger, R. Weber, N. Patel, A. Link, V. Ovchinnikov.

UCSD — F. N. Beg, S. Chen, T. Ma

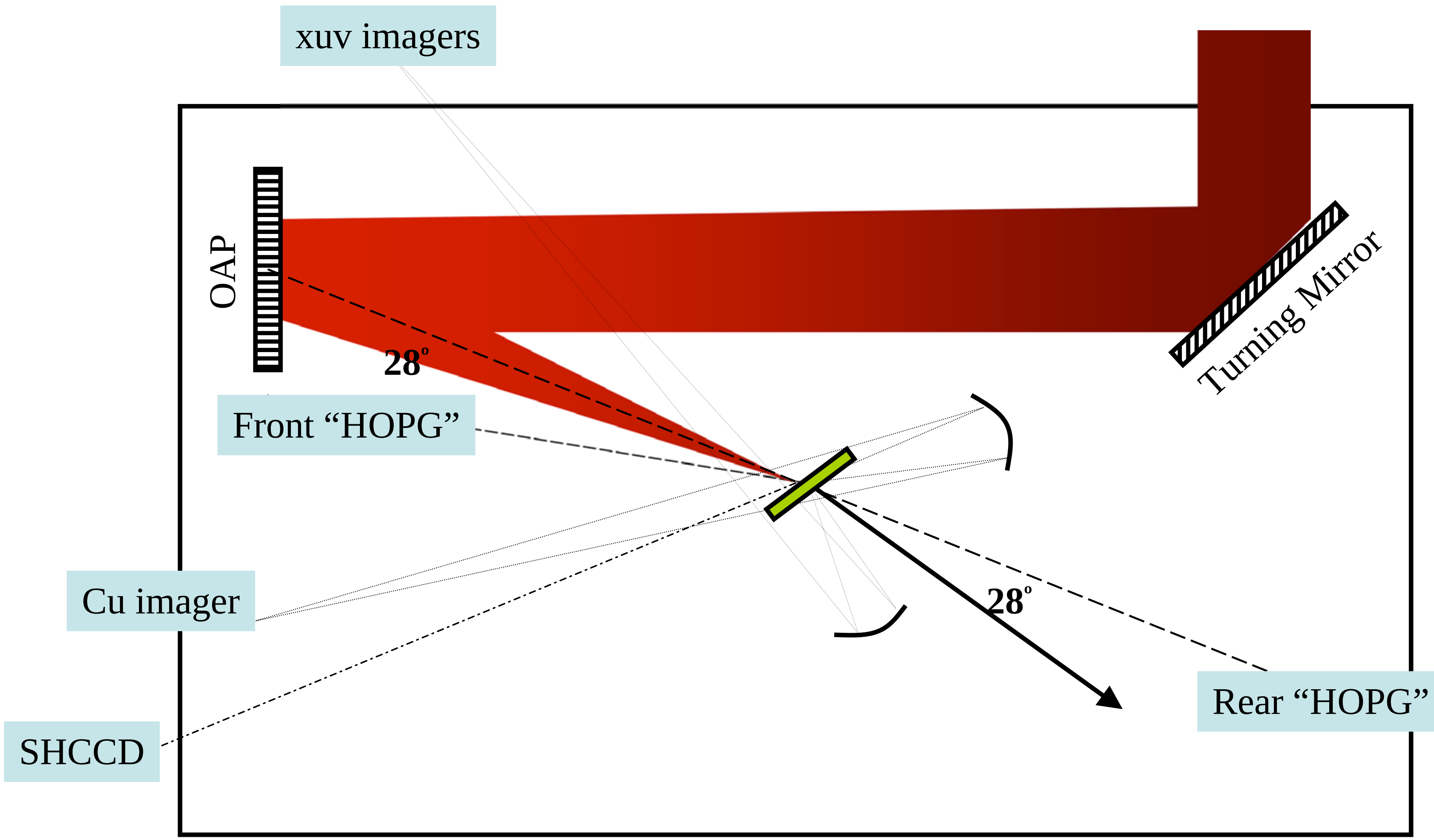
UNIVERSITY OF ROCHESTER — C. Stoeckl, W. Theobold, M. Storm.

CCLRC — P.A. Norreys, J. S. Green, K. Lancaster, C.D. Murphy G. Gregori.

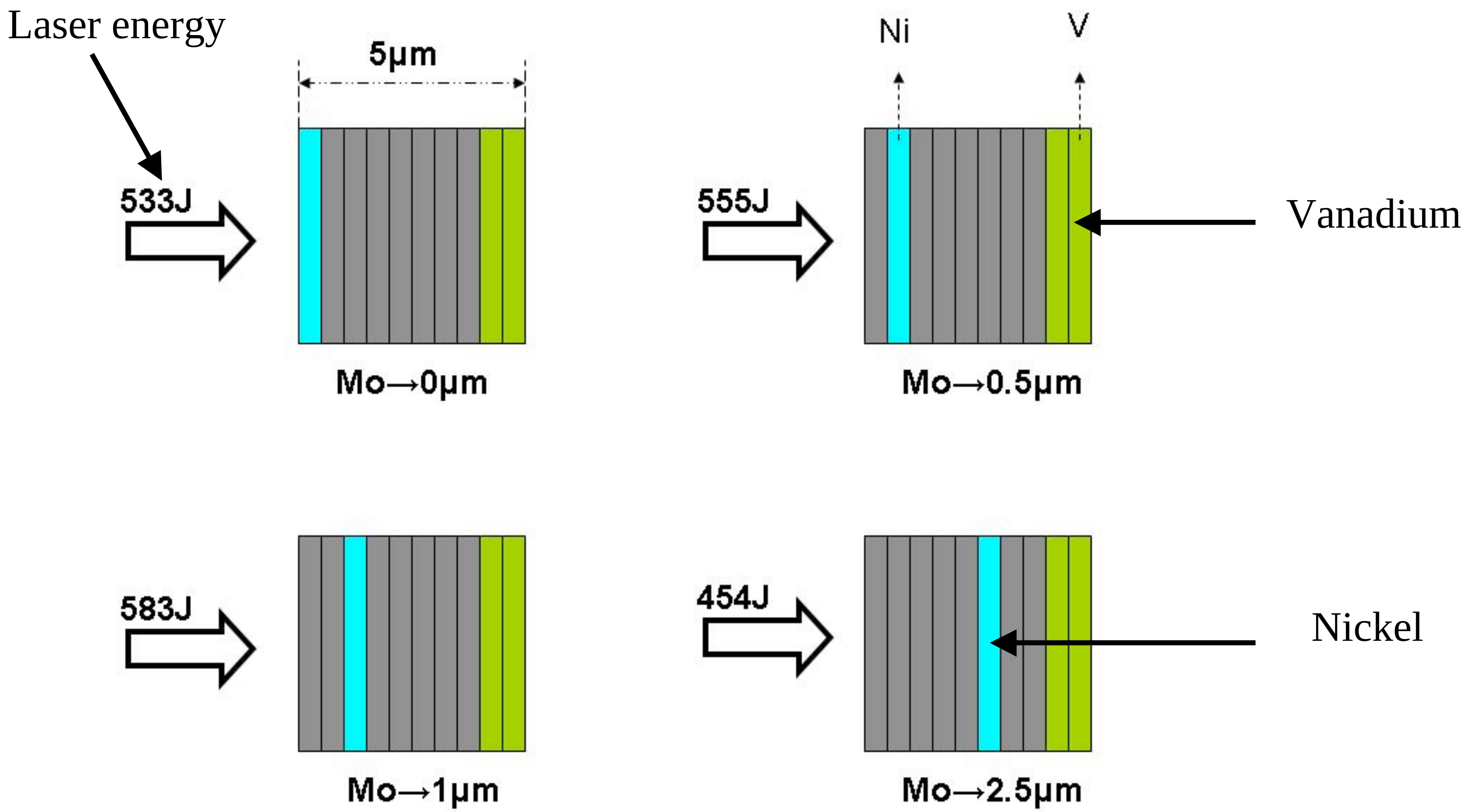
Abstract

Heating by irradiation of a solid surface in vacuum with $5 \times 10^{20}\ Wcm^{-2}$, $0.8\ ps$, $1.05\ \mu m$ wavelength laser light is studied by x-ray spectroscopy of the K-shell emission from thin layers of Ni, Mo and V. A surface layer is heated to $\sim 5\ keV$ with an axial temperature gradient of $0.6\ \mu m$ scale length. Images of Ni Ly_α show the hot region has a $\sim 25\ \mu m$ diameter. These data are consistent with collisional particle-in-cell simulations using pre-formed plasma density profiles from hydrodynamic modeling, which show that the $> 100\ Gbar$ light pressure compresses the preformed plasma and drives a shock into the solid heating a thin layer.

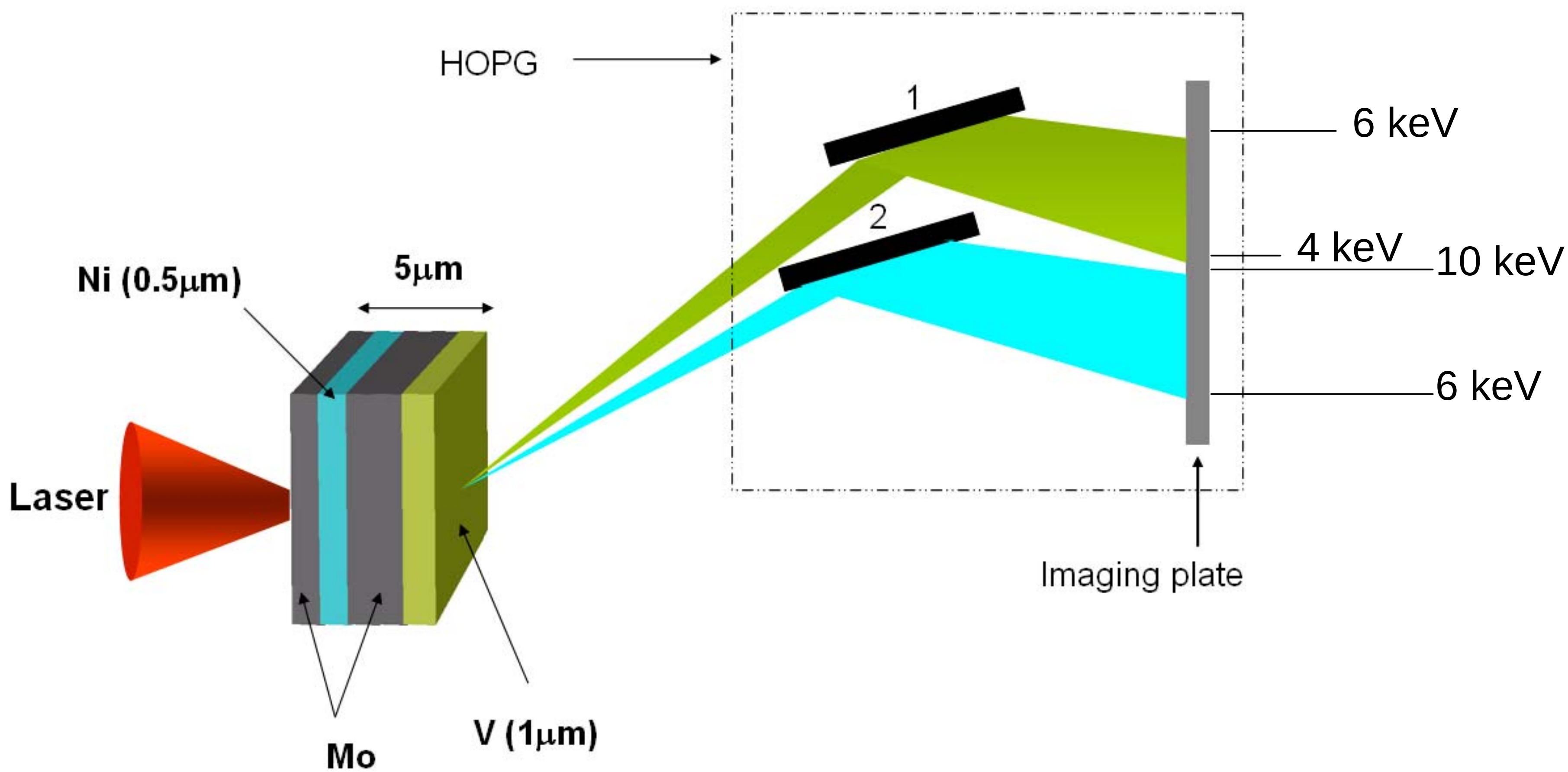
Experimental setup

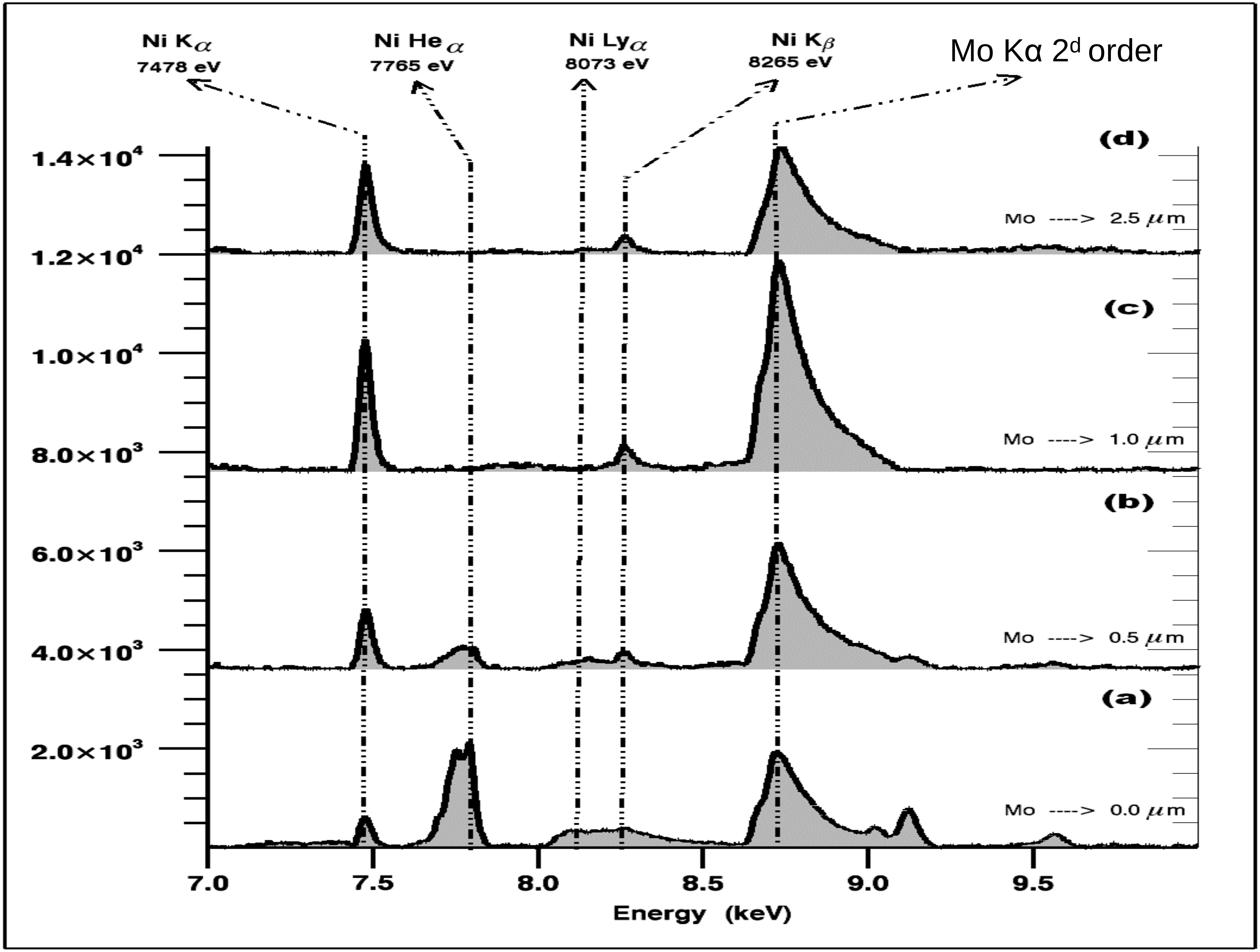


Mo/Ni/V multi-layered targets were used to study laser-generated electrons transport and the associated isochoric heating

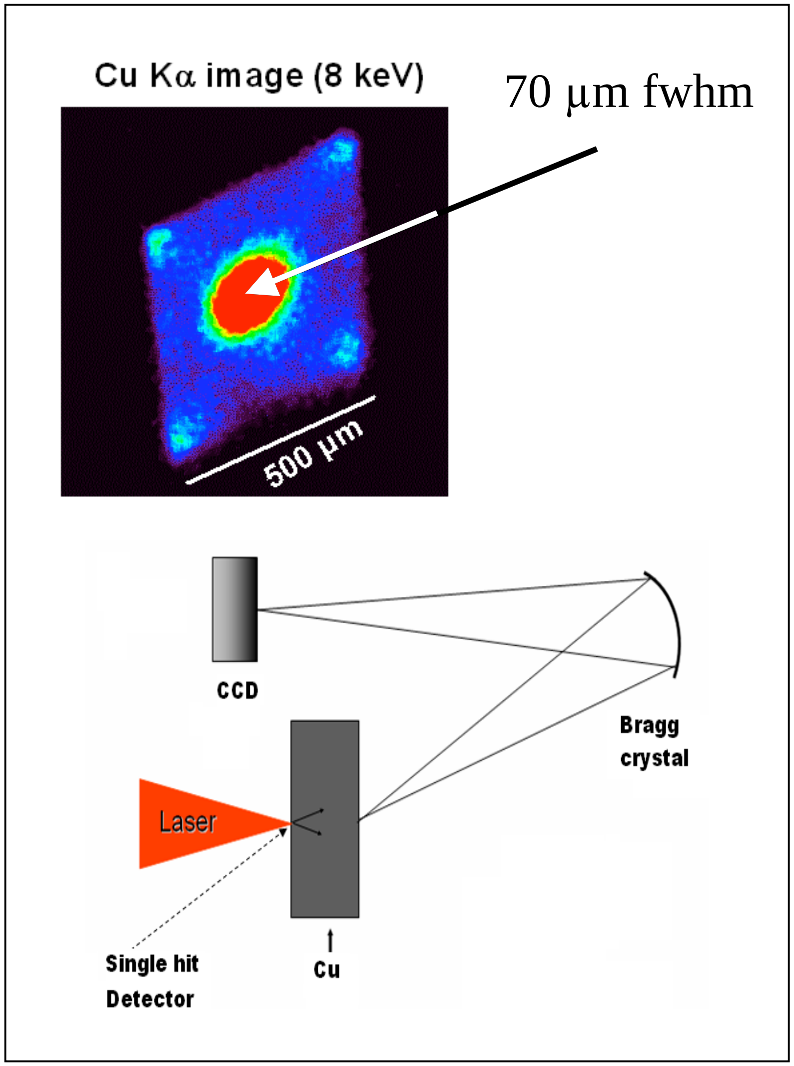


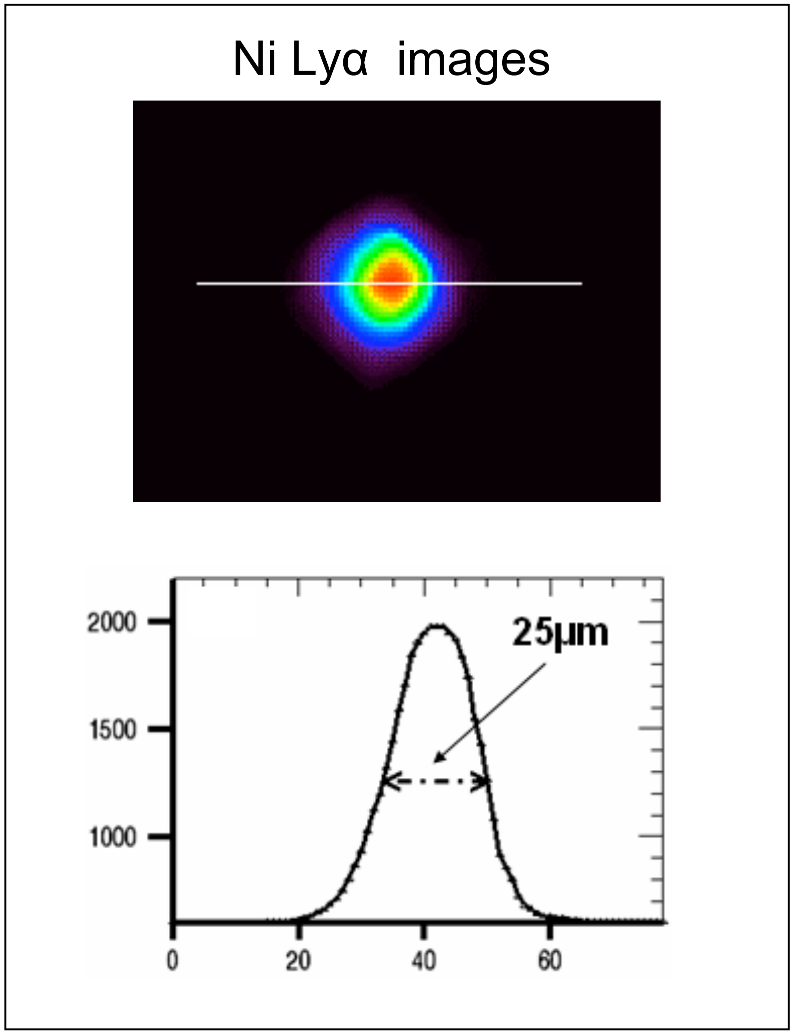
Two Highly Ordered Pyrolytic Graphite (HOPG) Crystal spectrometers were used to obtain x-ray spectra: "Rear HOPG" and "Front HOPG"




Ni Kα
7478 eV
Ni Heα
7765 eV
Ni Lyα
8073 eV
Ni Kβ
8265 eV
Mo Kα 2d order
(d)
(c)
(b)
(a)
Mo ----> 2.5 μm
Mo ----> 1.0 μm
Mo ----> 0.5 μm
Mo ----> 0.0 μm
1.4×10⁴
1.2×10⁴
1.0×10⁴
8.0×10³
6.0×10³
4.0×10³
2.0×10³
7.0
7.5
8.0
8.5
9.0
9.5
Energy (keV)

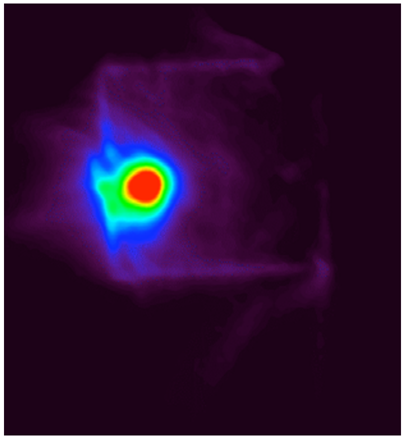
Ni Ly$_\alpha$ images indicate that the hot surface region has a 25 μm diameter (much smaller than the region of cold K$_\alpha$ emission).



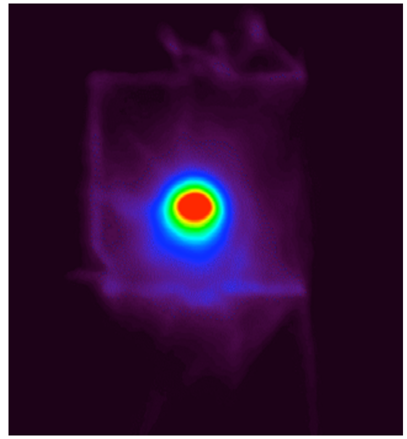


Two XUV imagers at 68 eV and 256 eV recorded spatial patterns of thermal emission from the rear surface of the targets

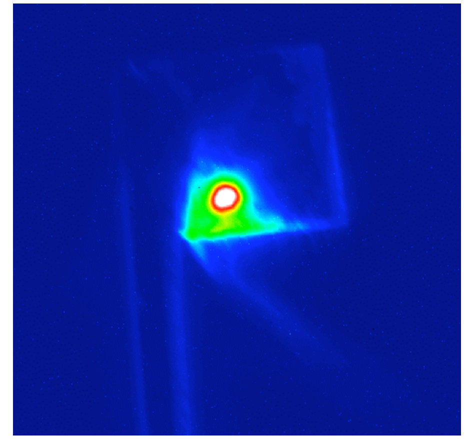
68 eV



0 μm Mo

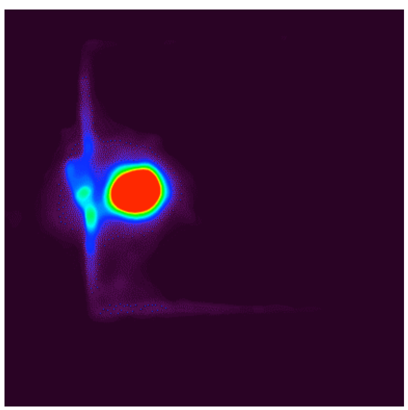


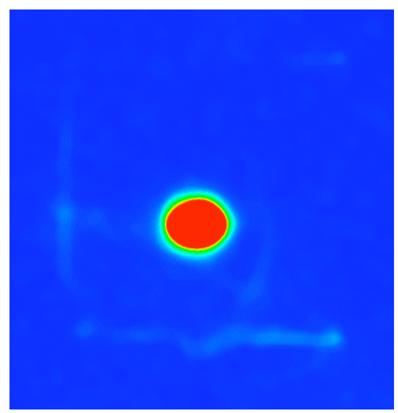
0.5 μm Mo



2.5 μm Mo

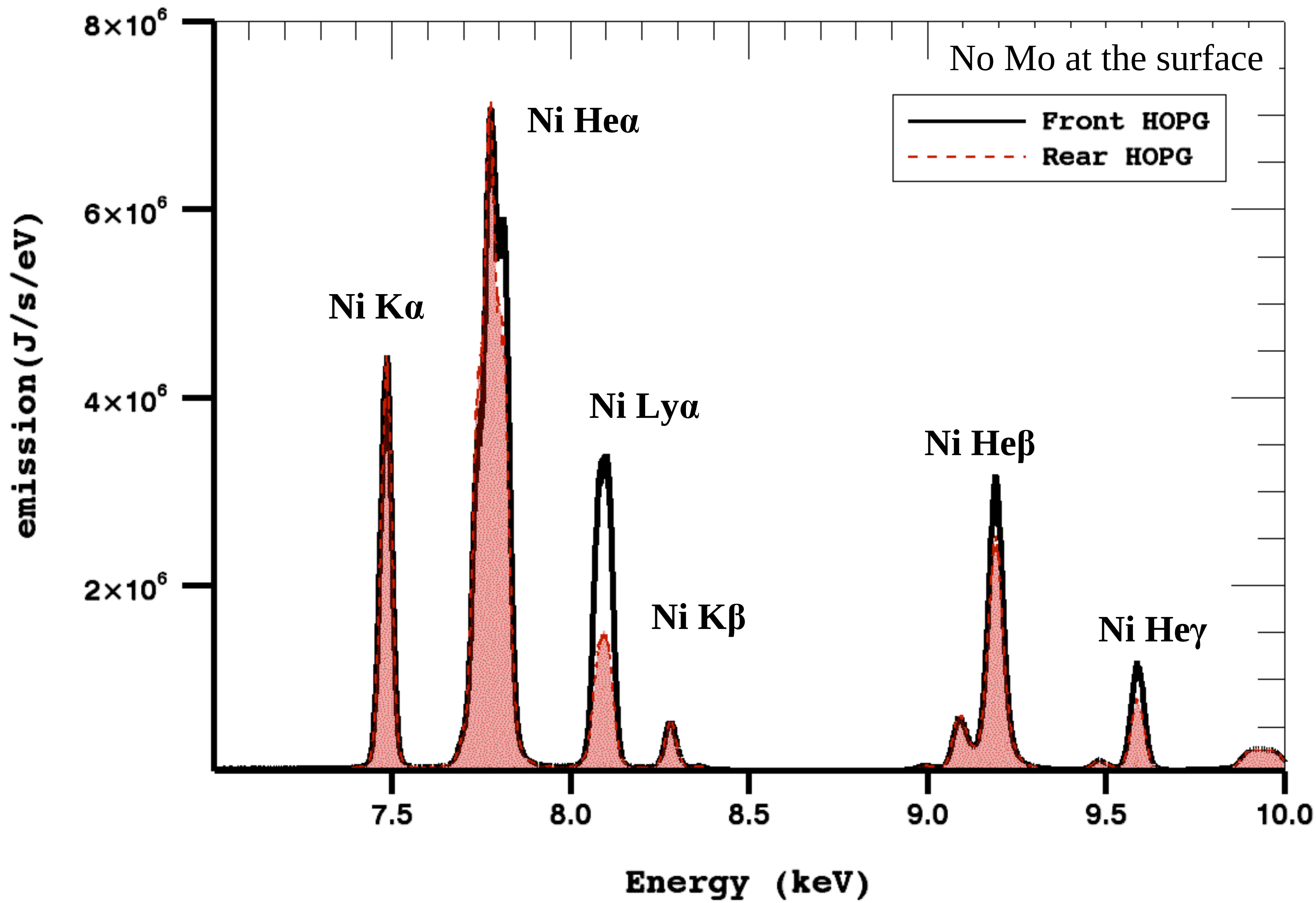
256 eV



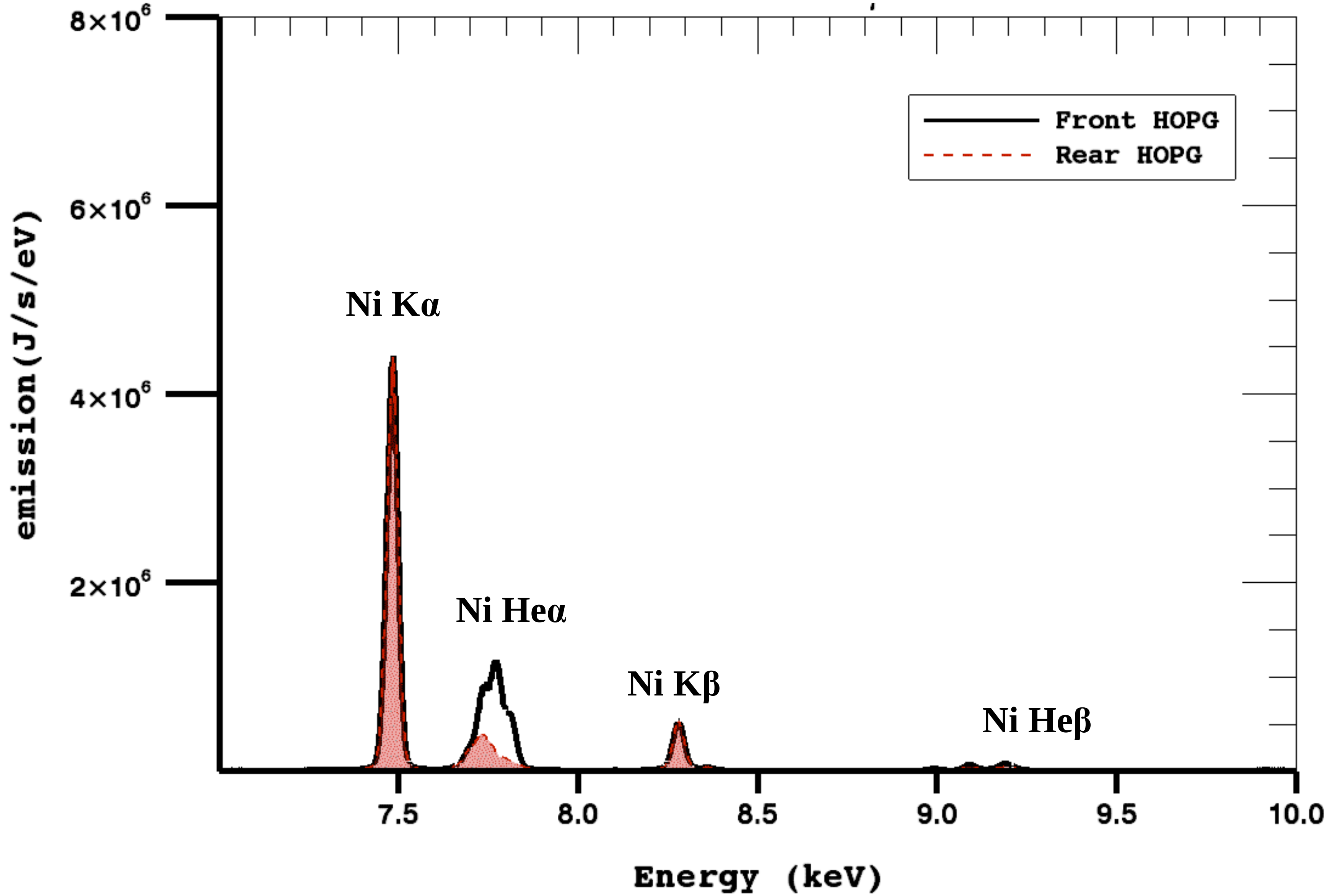


The rear surface temperature was determined to be ~ 400 eV

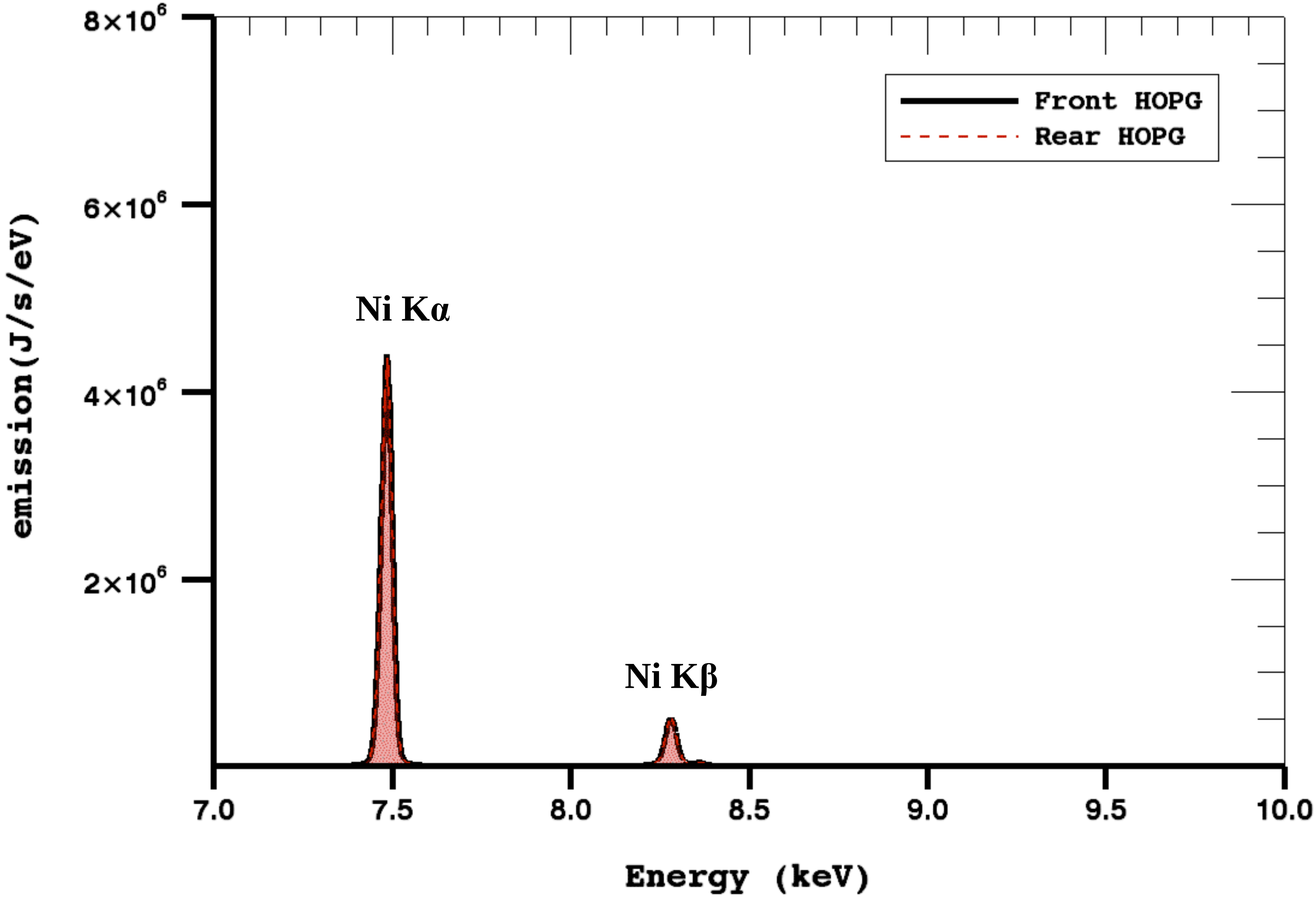
The collisional-radiative model SCRAM was used to generate Ni spectra

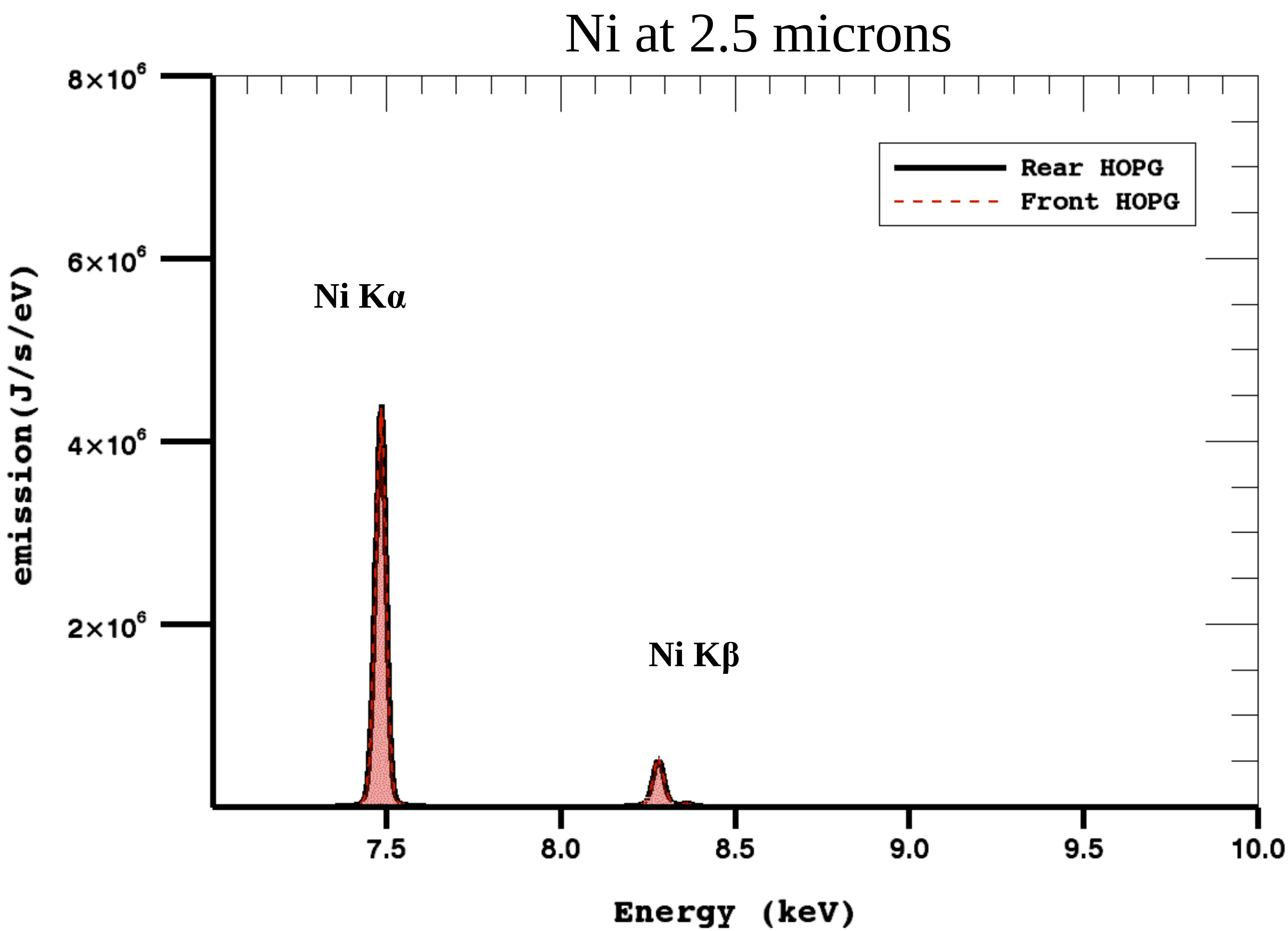


Ni at 0.5 microns



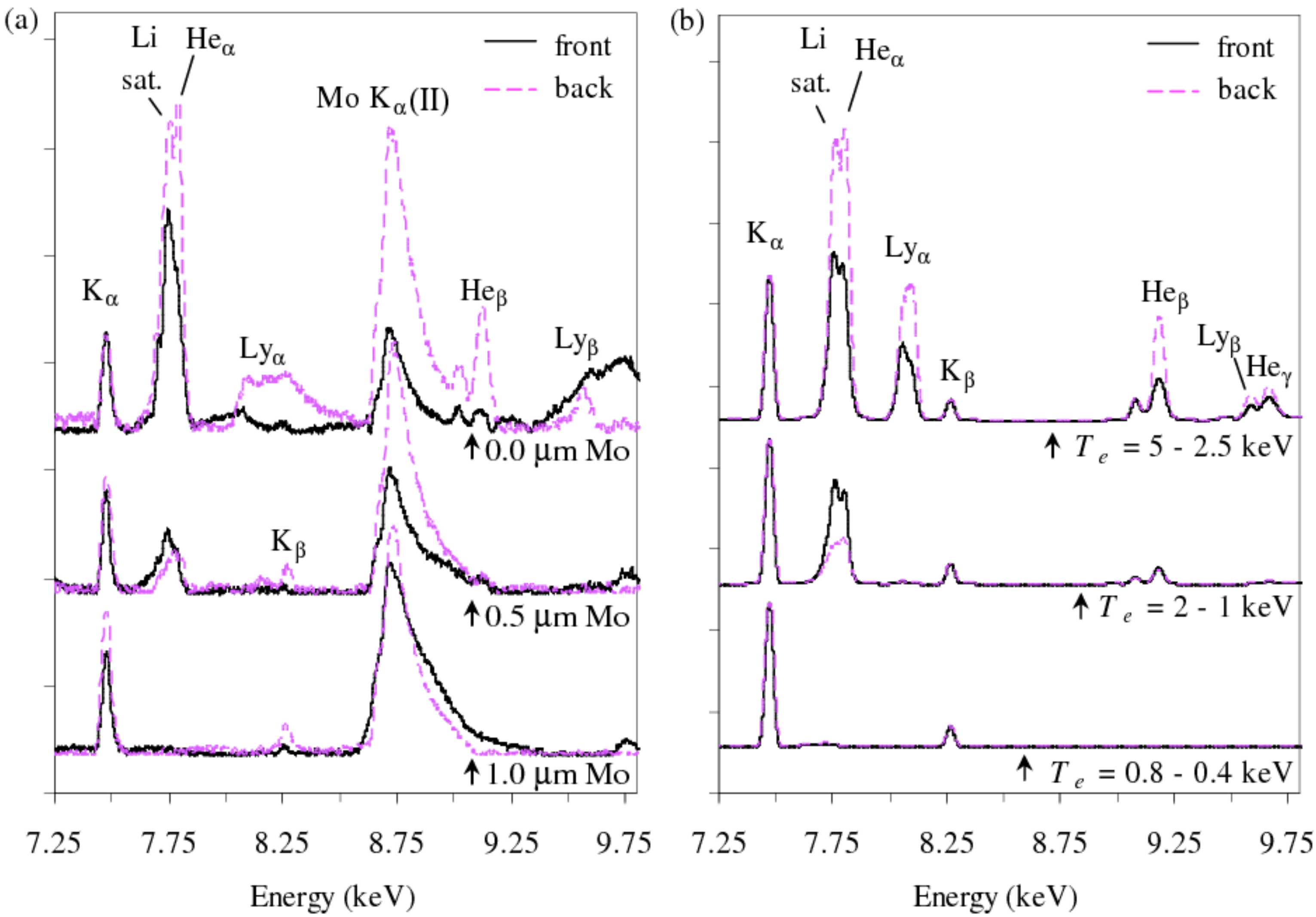
Ni at 1.0 microns



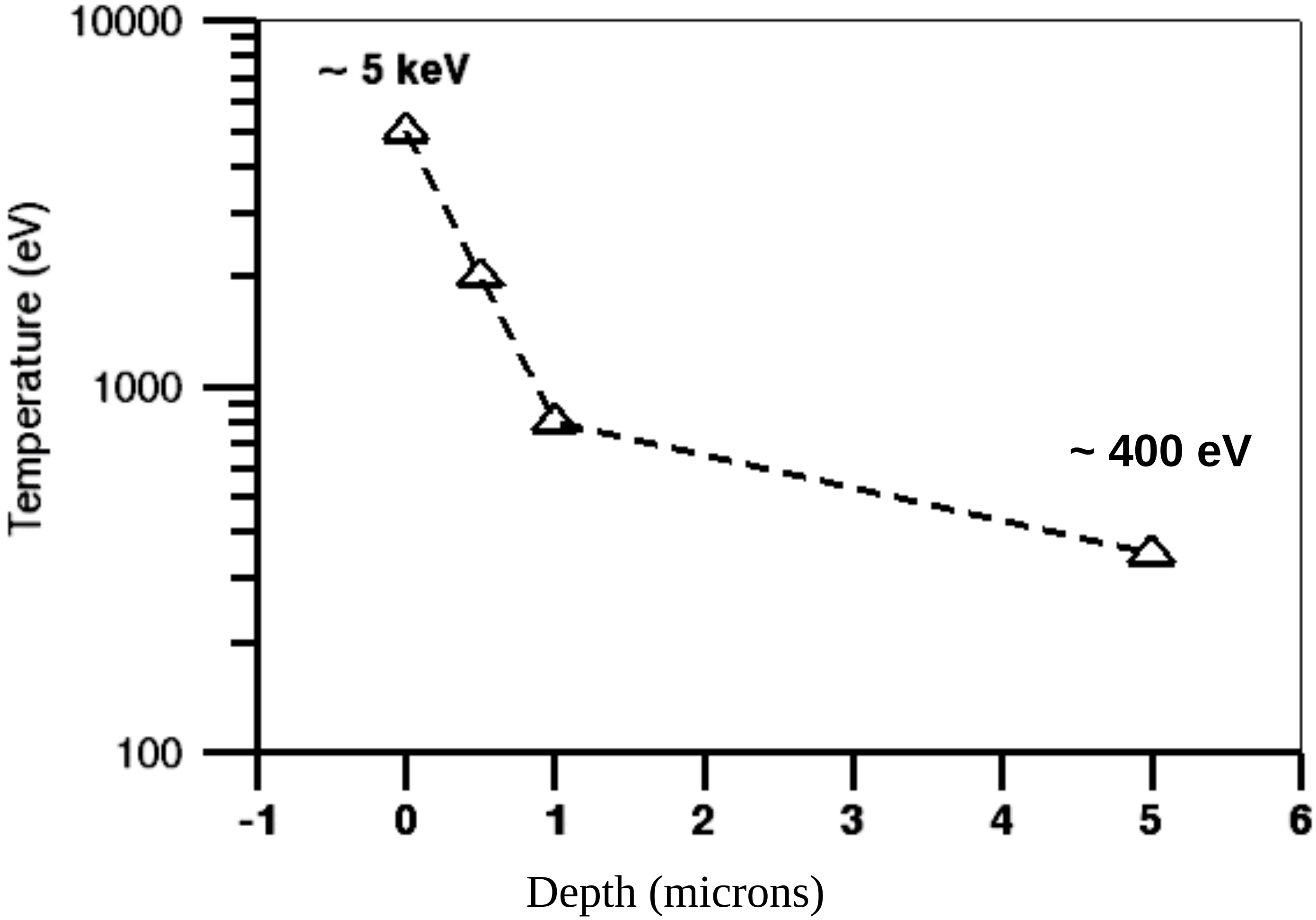


Ni at 2.5 microns
8×10^6
6×10^6
4×10^6
2×10^6
emission (J/s/eV)
Rear HOPG
Front HOPG
Ni Kα
Ni Kβ
7.5
8.0
8.5
9.0
9.5
10.0
Energy (keV)

K-shell emission spectra showing the reduction of thermal lines intensity with Mo overlay

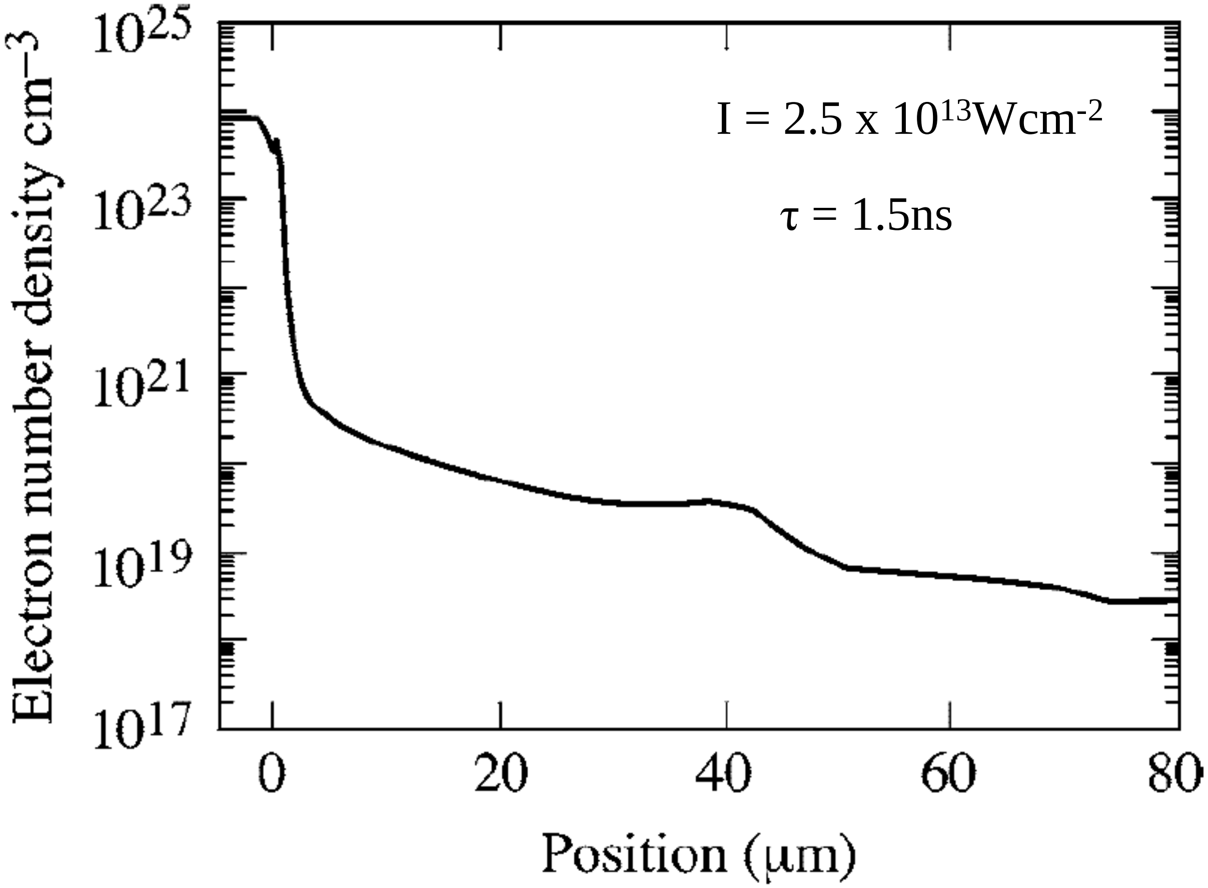


Temperature profile obtained using thermal line intensity ratio



The rear surface temperature is consistent with both spectroscopic modeling and xuv results

Hydrodynamic modeling of the Vulcan laser pre-pulse shows that the pre-plasma extends 2 – 3 μm between critical and solid density



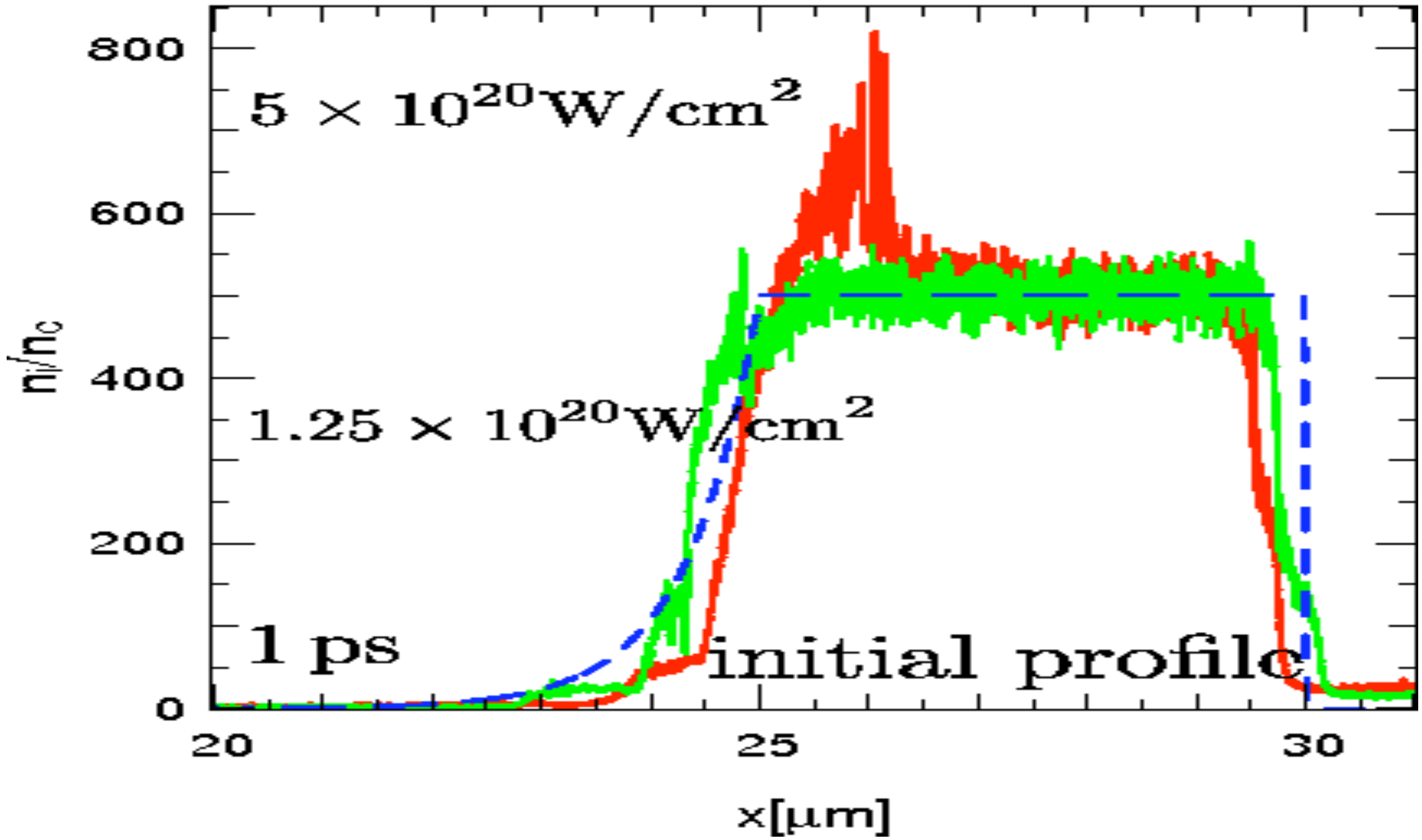
Electron density profile

obtained using the 2D

Eulerian Code POLLUX

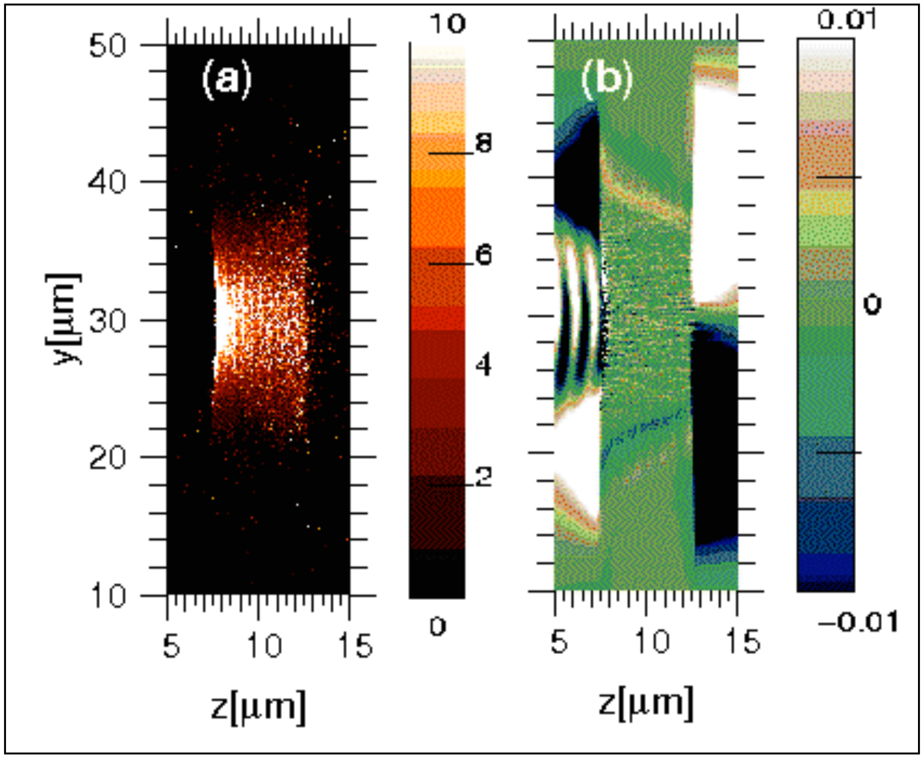
W. Theobald *et al.* Phys. Plasmas **13**, 043102 (2006)

1D PIC simulations of 5μm solid density Mo^{+5} slab target with pre-plasma at two different laser intensities



Results of 1D PIC simulation: ion density profile at time 1ps for two different laser intensities. Also shown is the intial ion density profile

2D collisional Particle-in-Cell (PIC) simulations of a 5 μm thick Molybdenum target

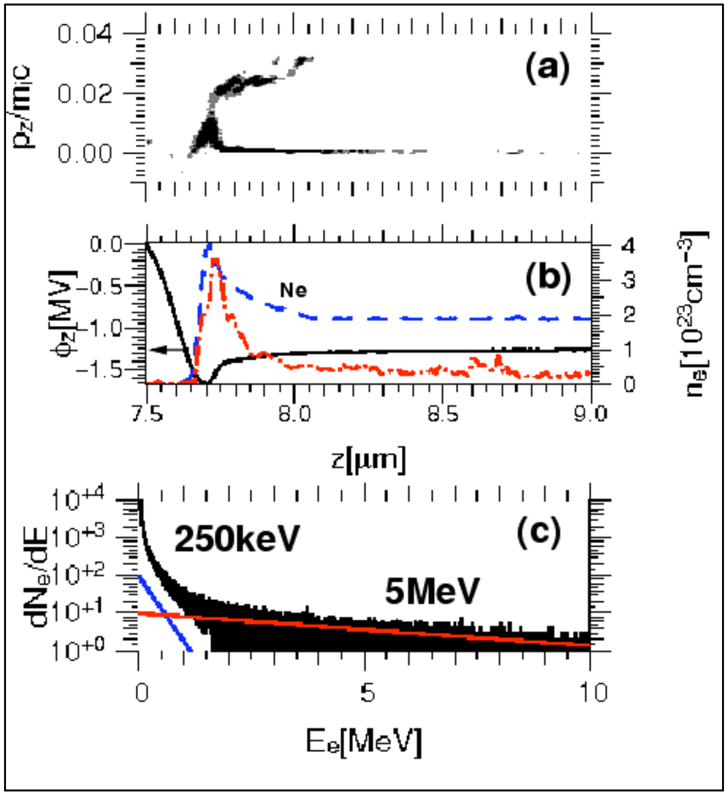


The laser pulse is modeled as Gaussian in space and top-hat in time

The simulation box has a total size of 30 μm x 60 μm at a resolution of 80 cells per μm and 10 ions plus 50 electrons per cell

Results of 2D PIC simulation:
(a) electron energy density (arbitrary units)
(b) azimuthal magnetic field in units of B0=2MG at time 100fs.

PIC simulations suggest light pressure-driven electrostatic shock as a heating mechanism



Results of 2D PIC simulation :

(a) longitudinal ion phase space.

(b) electric potential (solid), and electron density (dashed) along laser irradiation axis; average over 0.25um.

(c) energy spectrum of all electrons at time 100fs

The amount of energy in the hot surface layer is ~0.3 J which is < 1% of the laser energy.

Conclusion

- Heating of a sub micron thick layer at near solid density to ~5keV temperature by $5x10^{20}wcm^{-2}$, 0.8 ps laser irradiation is attributed to the light pressure-driven shock.

- Such shock heating is expected only when the light pressure and pulse duration are sufficient to sweep up preformed plasma.

- The heating is interesting in its own right for creation of high energy density states of matter. It is not a major drain of electron energy and therefore does not adversely affect fast ignition.

Fabrication and metrology of ignition design copper doped beryllium capsules with fill tubes

Abbas Nikroo
APS/DPP 07
Nov 12-16 , Orlando Florida

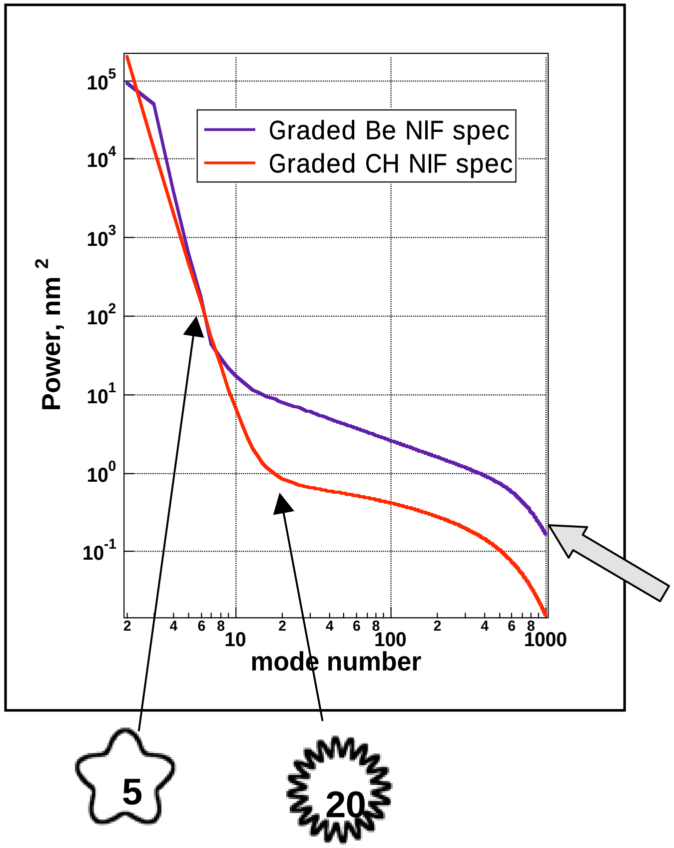
S. Eddinger, A. Forsman, H. Huang, T.Y. Lee, E. Lundgren K. Moreno, A. Nguyen, J. Wall, H. Xu, K. Youngblood

General Atomics

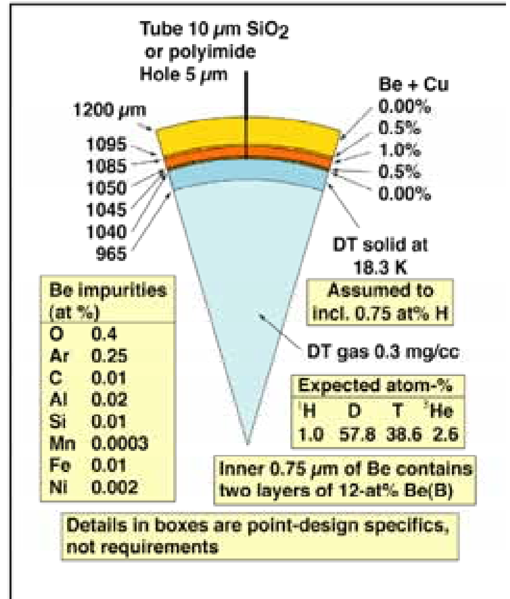
C. Alford, S. Bhandarkar, A. Hamza, J. Hughes, M. Johnson, E. Mapoles S. Letts,T. Van Buuren

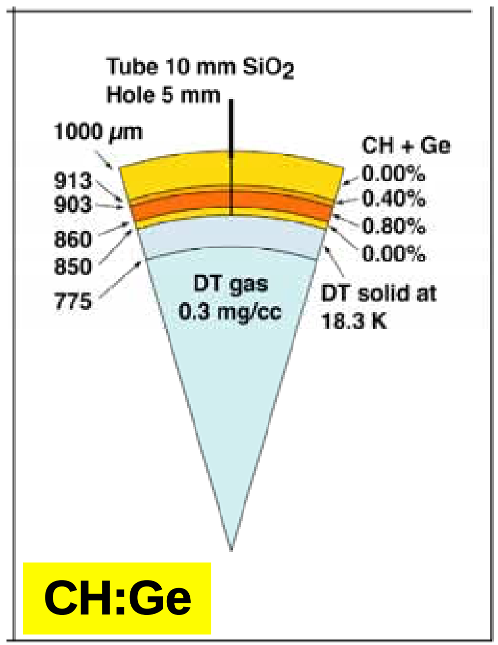
Lawrence Livermore National Laboratory

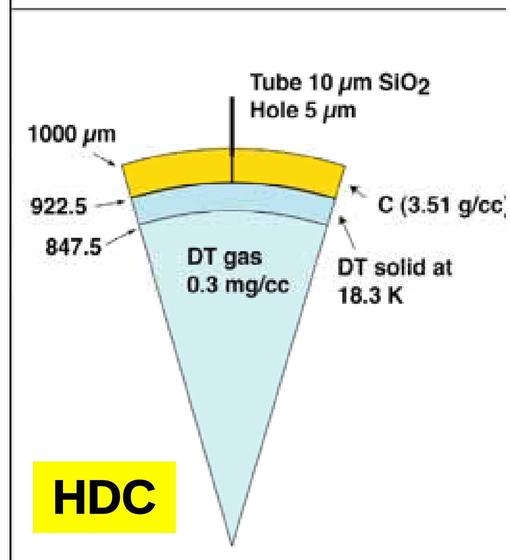
Three ablator designs are being currently considered for ignition campaign



Graded Be:Cu is current baseline design







- **Capsule specs**
- **Fill hole and tube specs**

D. Ho, TI1-3

All Be shell specifications have been demonstrated

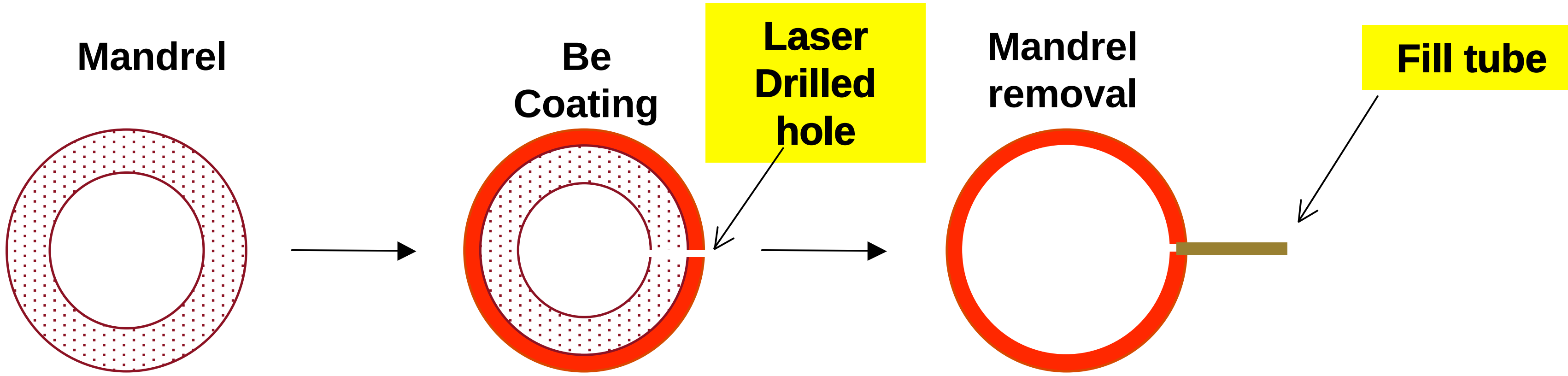
Category	Specification	Value
Dimensional and dopant	Capsule outer radius, tolerance	± 5µm
	Ablator composition	Be
	Ablator layer thicknesses	see table
	Ablator layer dopant concentration	see table
Voids and density	Ablator – average mass density	± 3% absolute, ± 1.5 % relative to campaign average
	Ablator layer density	see table
	Ablator – voids	< 3% void fract, < 0.1 µm3 void volume
	Ablator – measurement of x-ray optical depth variations	accuracy <0.01%
	Ablator thickness non-uniformity	see table
Surface	Ablator inner surface figure	see table
	Capsule surface isolated defects	see figure
	Capsule cleanliness	See isolated defects
Opacity	Ablator oxide layers	
	Ablator – Low level impurities	sum(atomic fraction)*Z^2 < 0.1
Gas retention	Gas retention	> 7 day half life at room temp

Capsule and fill tube specs have been met

← **Haan spec table**

- **Process reproducibility, reliability and yield are major focus currently as we move into pilot production**

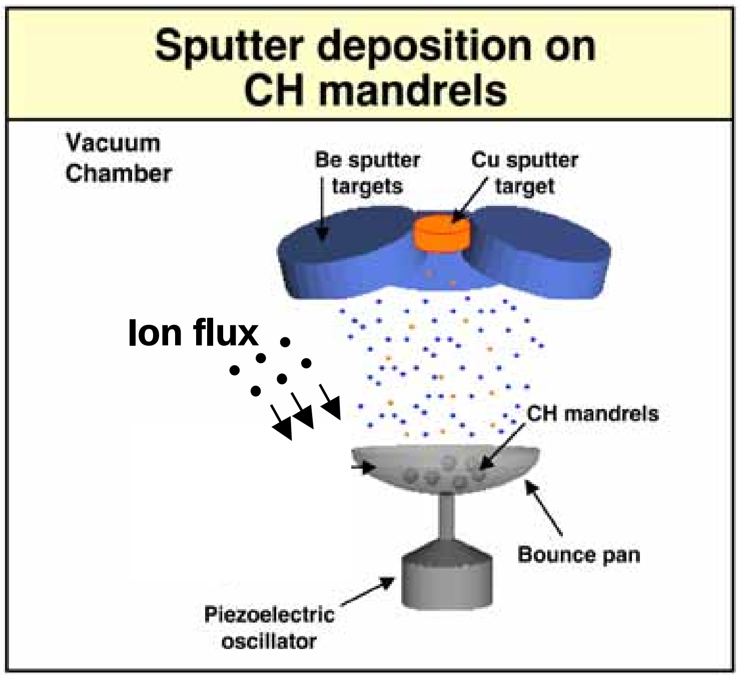
We produce graded Cu-doped Be capsules at NIF-scale by sputter deposition



- **The ablator is coated using sputter deposition**
  - **Allows grading of dopant**

- **Adequate rate for CH mandrel fabrication demonstrated**

- **Ion flux used for improved structure**

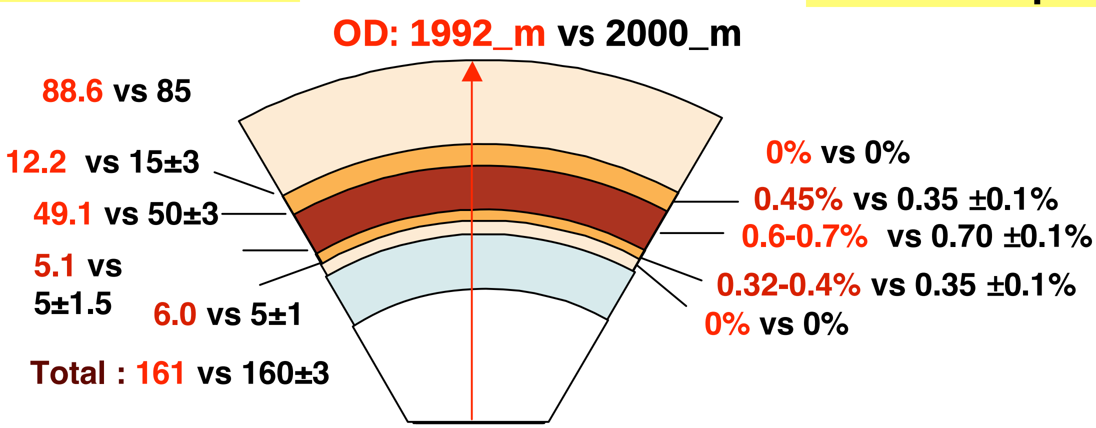


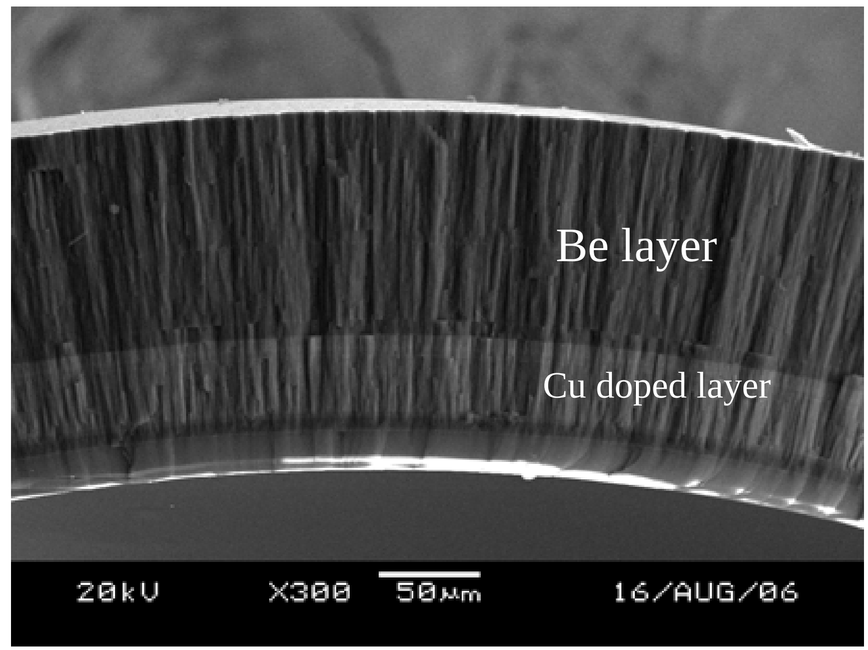
Although dimensional and dopant specs were met, previous process led to non-gas retentive Be shells

Dimensional and dopant specs demonstrated

Thickness, μm
Made vs spec

Cu dopant at %
Made vs spec

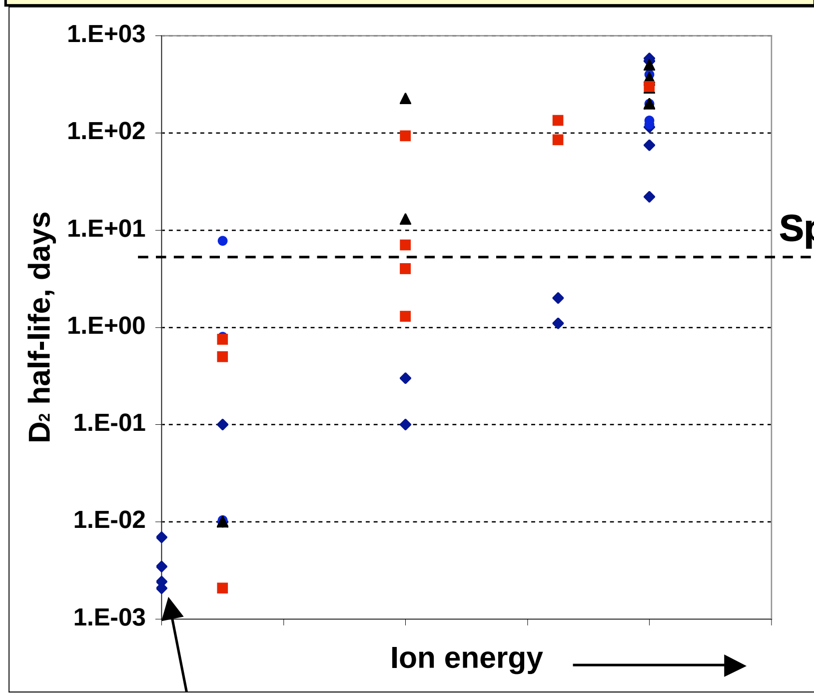




- **Weak structure and accumulated stress in coating led to nano-cracks in shells**
- **Nano-cracks led to rapid leakage of gas out of the shell**

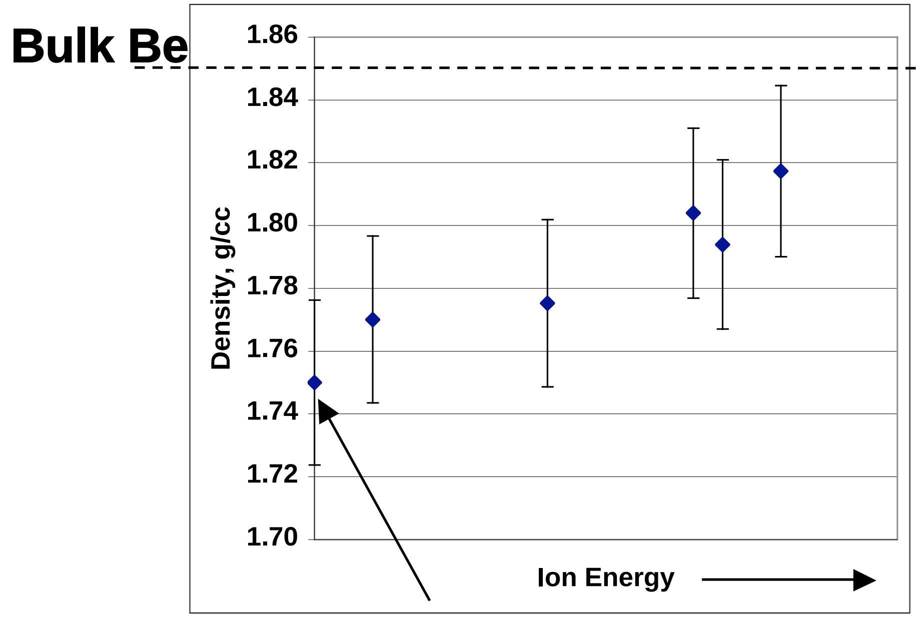
Ion assisted deposition was utilized to obtain gas retentive shells

Increased gas retention



Previous process

Increased density



Previous process

- **Density increase also observed ~ 1.82 ± 0.2 g/cc**
- **X-ray scattering confirms total void and size (<500nm) reduction**

- **Argon content of shells is also increased from <0.1 at% to as much as 2 at% (spec 0.25 ± 0.1 at %)**
- **Coater configuration used that leads to ~ 0.25 at% Ar in gas retentive shell meeting specifications**

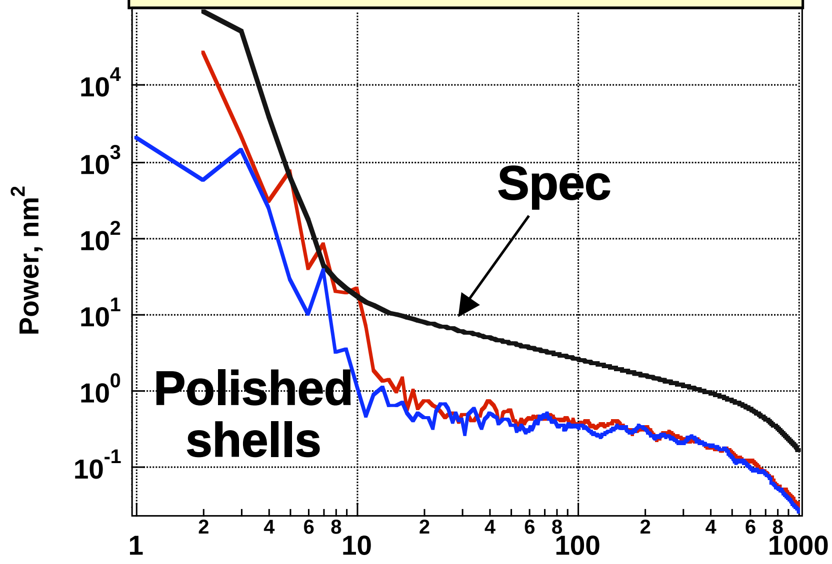
Polished Be capsules meet NIF ignition surface finish requirements

The National Ignition Campaign

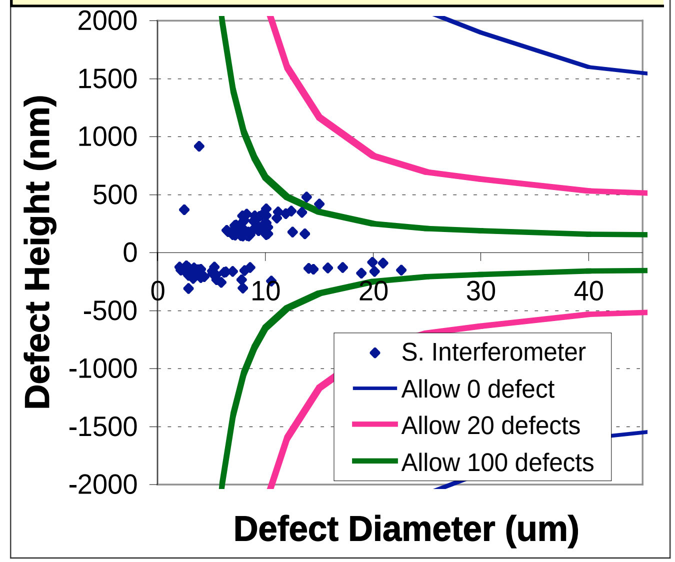
Unpolished and polished Be shells

- **Polishing reduces as coated shell high mode roughness to well below spec**
- **Low mode mainly dominated by mandrel**
  - **Mandrel selection mitigates that issue**
  - **Isolated defects within specifications**

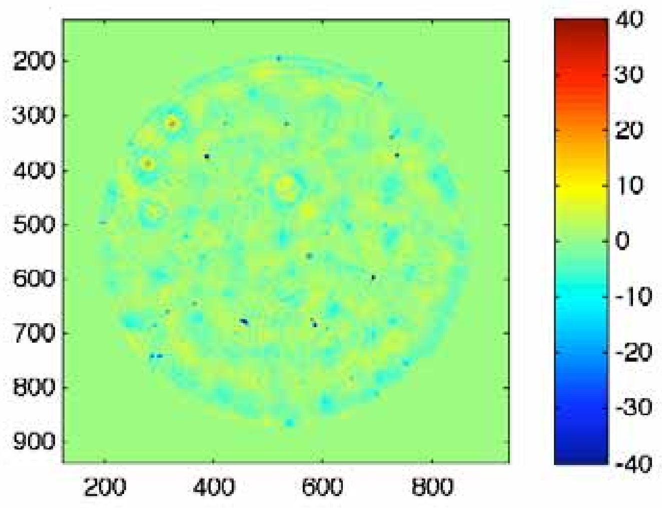
Polished Be vs spec



Isolated defects

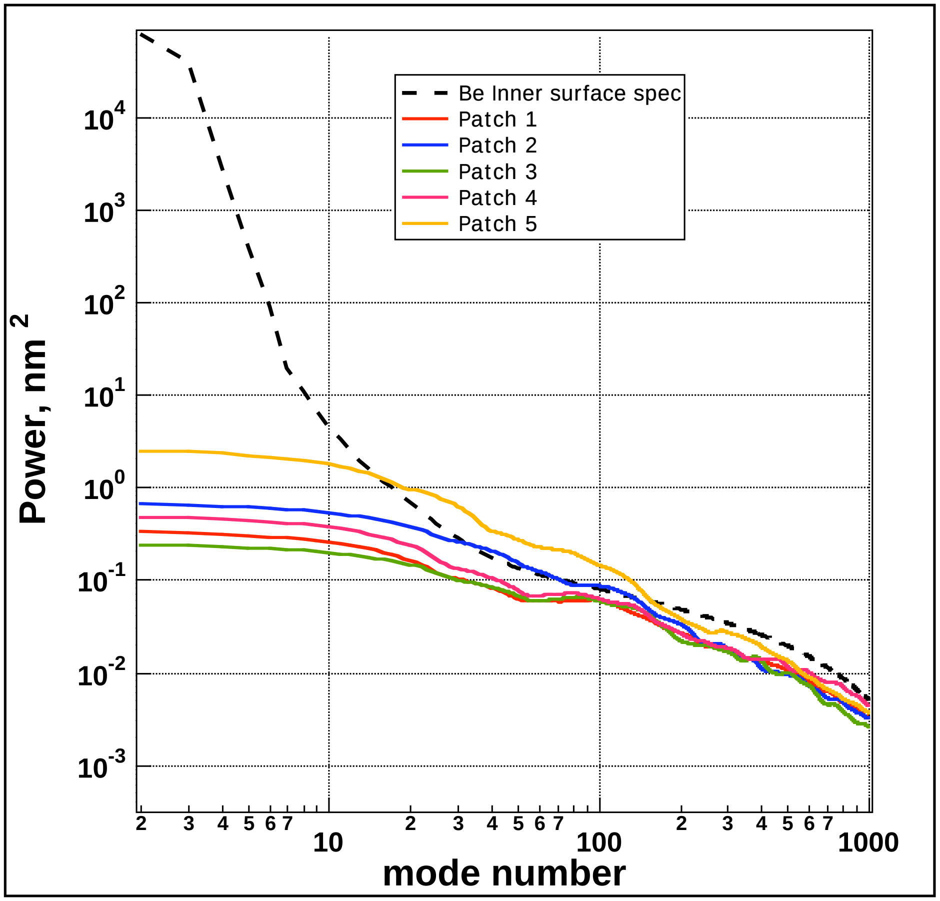


Inner surface of shells made using ion assist are below or near the NIF spec



PSDI Patch scans ~ 500 μm dia

- **Destructive test**
- **Inner surface determined by mandrel surface**
- **Blistering of inner surface has been mitigated by adjustment to removal temperature**

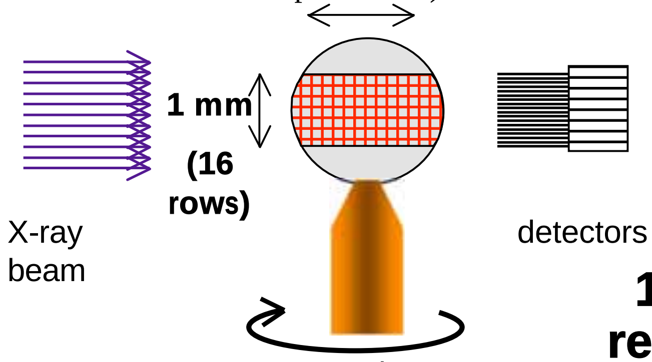


- **Effect of isolated features being modeled**

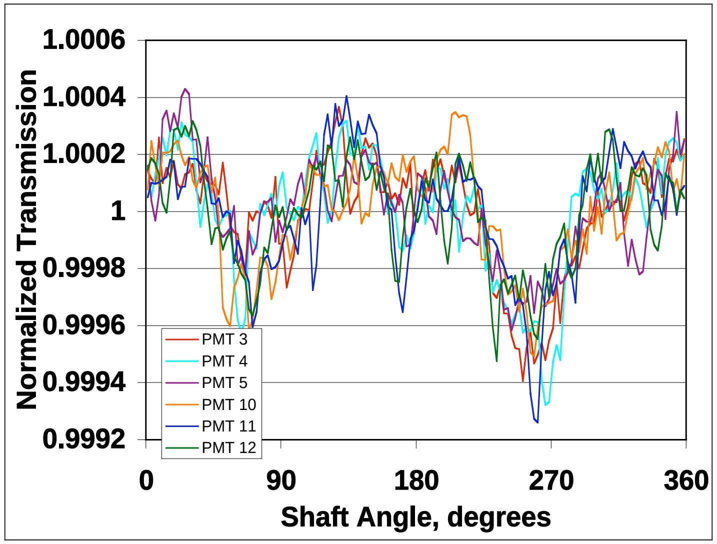
B. Hammel, PO6-3

Current precision radiography indicates shells meet 10^{-4} optical depth uniformity spec

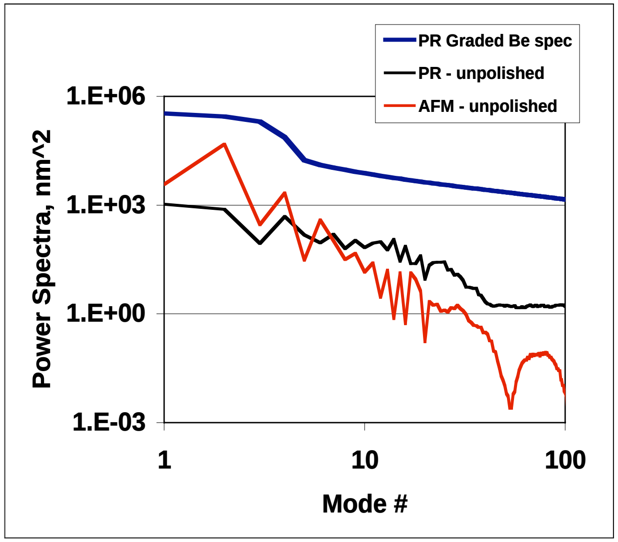
- **Precision radiograph examines azimuthal optical depth uniformity of the shells**
- **Three factors can lead to OD variations**
  - Thickness variations
  - Void agglomeration
  - Roughness at Cu doped interface
- **A more rigorous power spectrum specification is being developed**
  - Sputtered shells meet nominal spec



100 µm resolution



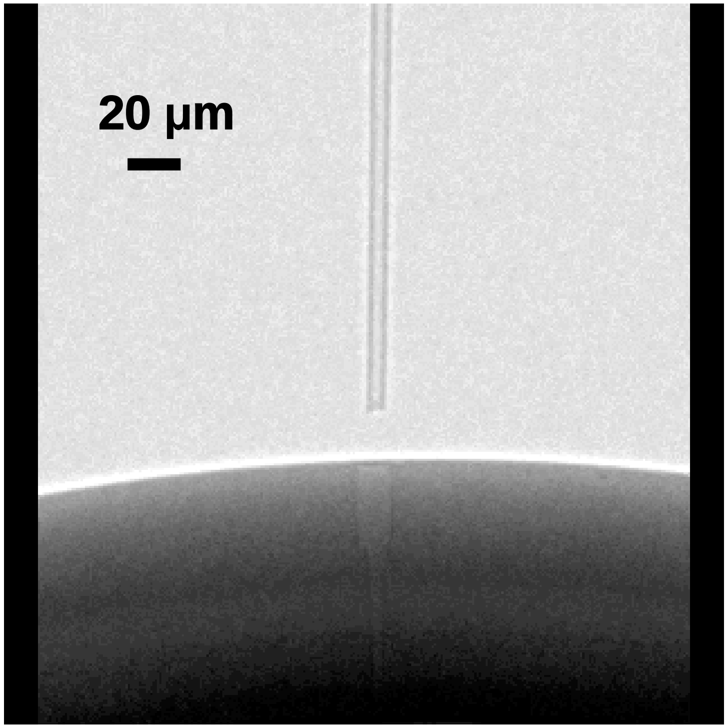
X-ray transmission vs angle



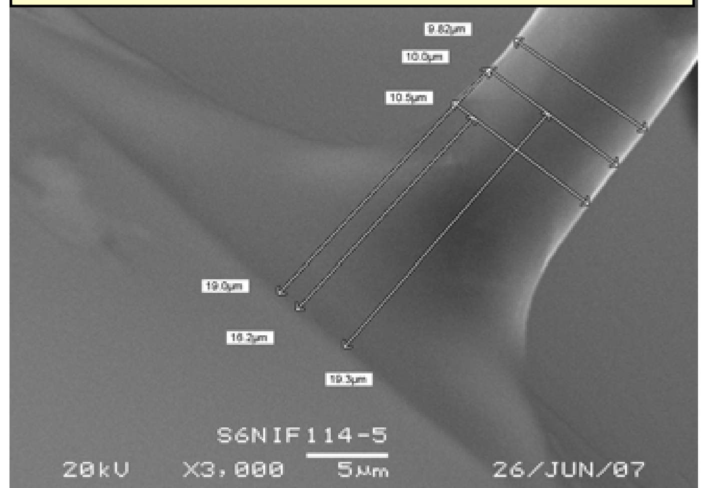
Graded doped Be:Cu shell

GENERAL ATOMICS

Fill holes have been drilled to specification



NIF spec fill-tube bond



Bond joint meets NIF mass defect spec

- **Used super pulse nano-sec laser technique**
  - **Fuel injector drilling**

- **Hole volume/mass defect meets spec**
  - **5 μm through hole**
  - **15 μm counterbore**

- **10 μm fill tube**

Be capsule with bonded fill tube

A. Forsman , YO5-9

All Be shell specifications have been demonstrated

Category	Specification	Demonstrated
Dimensional and dopant	Capsule outer radius, tolerance	± 5µm
	Ablator composition	Be
	Ablator layer thicknesses	see table
	Ablator layer dopant concentration	see table
Voids and density	Ablator – average mass density	± 3% absolute, ± 1.5 % relative to campaign average
	Ablator layer density	see table
	Ablator – voids	< 3% void fract, < 0.1 µm3 void volume
	Ablator – measurement of x-ray optical depth variations	accuracy <0.01%
	Ablator thickness non-uniformity	see table
Surface	Ablator inner surface figure	see table
	Capsule surface isolated defects	see figure
	Capsule cleanliness	See isolated defects
Opacity	Ablator oxide layers	
	Ablator – Low level impurities	sum(atomic fraction)*Z^2 < 0.1
Gas retention	Gas retention	> 7 day half life at room temp

Capsule and fill tube specs have been met

← **Haan spec table**

- **Process reproducibility, reliability and yield are major focus currently as we transition into pilot production**