Advances in the *Science, Technology, &* *Engineering* for Laser Fusion Energy

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Naval Research Laboratory
Washington, DC

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Knoxville, TN Sep 26-29, 2005

Our co-authors come from 29 different institutions

HAPL meeting #12, LLNL June 2005

Government Labs

1. NRL
2. LLNL
3. SNL
4. LANL
5. ORNL
6. PPPL

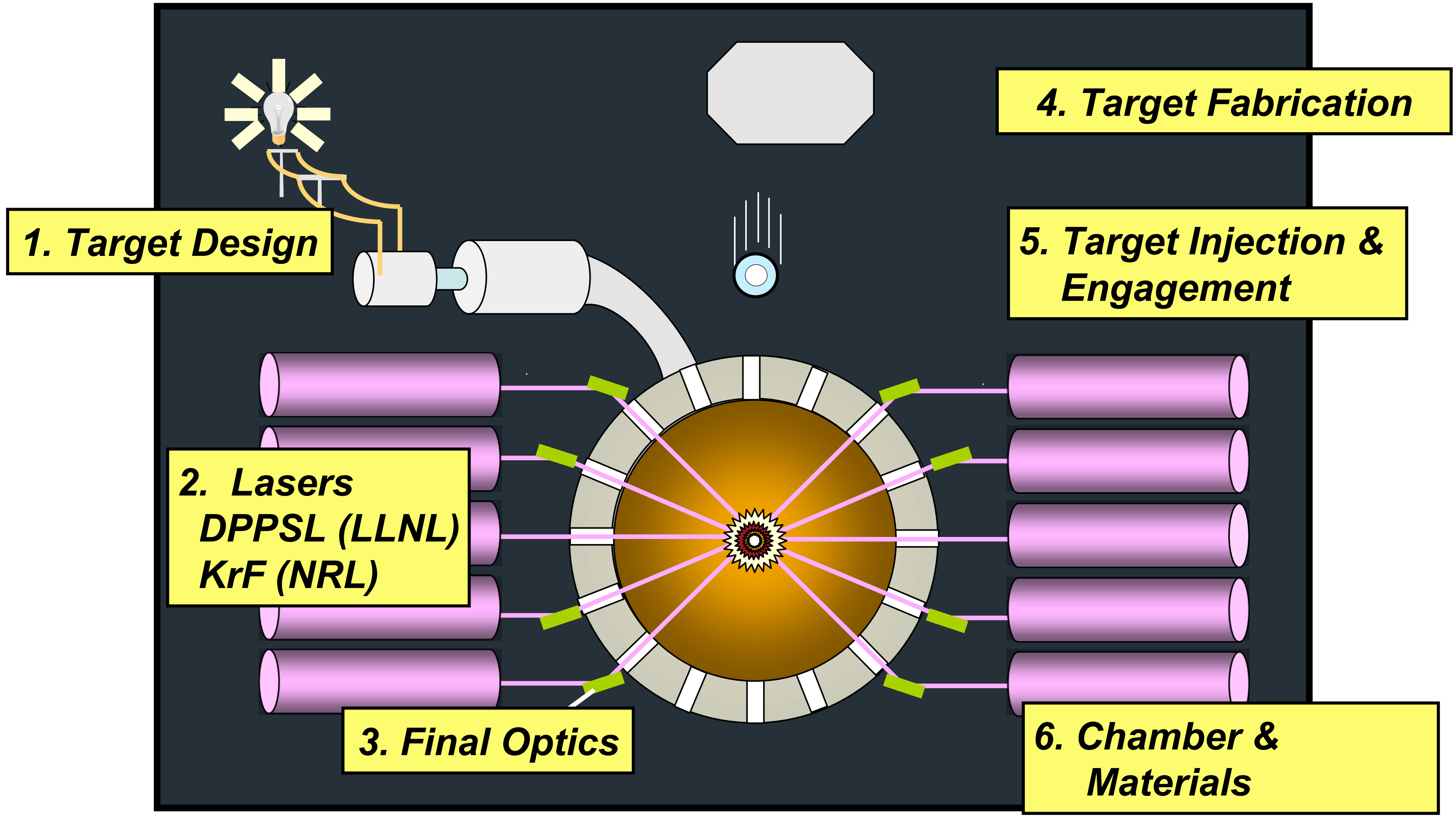
Universities

- UCSD
- Wisconsin
- Georgia Tech
- UCLA
- U Rochester, LLE
- UC Santa Barbara
- UC Berkeley
- UNC
- Penn State Electro-optics

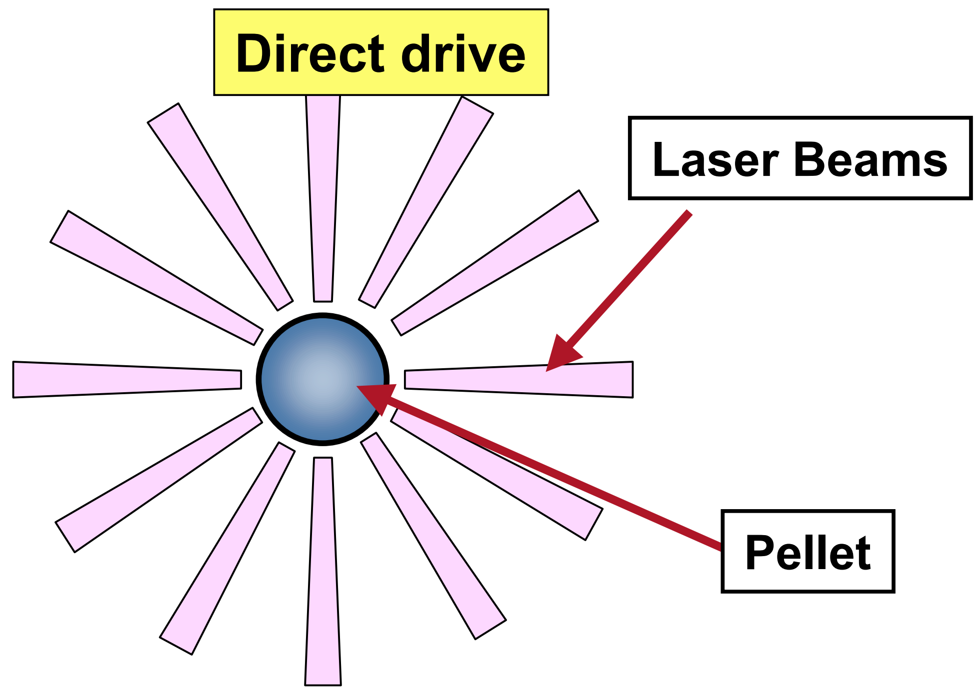
Industry

1. General Atomics
2. Titan/PSD
3. Schafer Corp
4. SAIC
5. Commonwealth Tech
6. Coherent
7. Onyx
8. DEI
9. Mission Research Corp
10. Northrup
11. Ultramet, Inc
12. Plasma Processes, Inc
13. Optiswitch Technology
14. Research Scientific Inst

We are developing the science & technologies for laser fusion energy with direct drive targets



Why we like direct drive for laser fusion



Physics is simpler --key issue is hydrodynamic stability

Higher efficiency --better coupling of laser to fuel

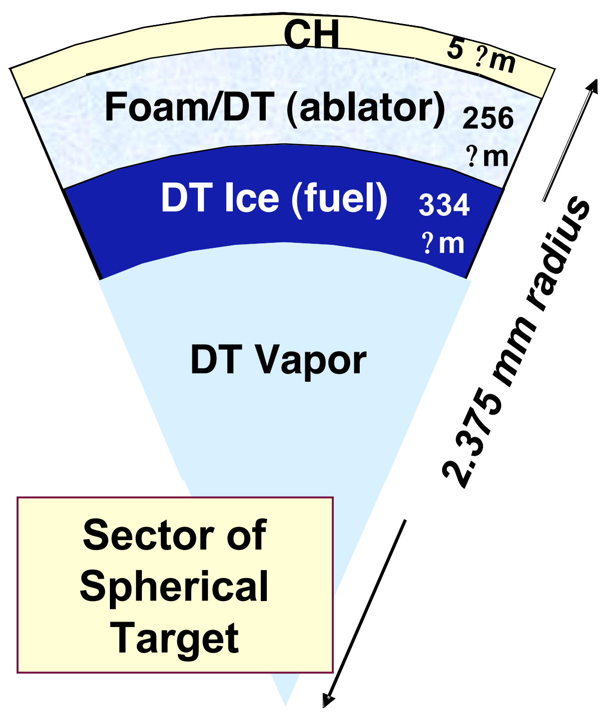
Targets relatively simple (cheap) to fabricate

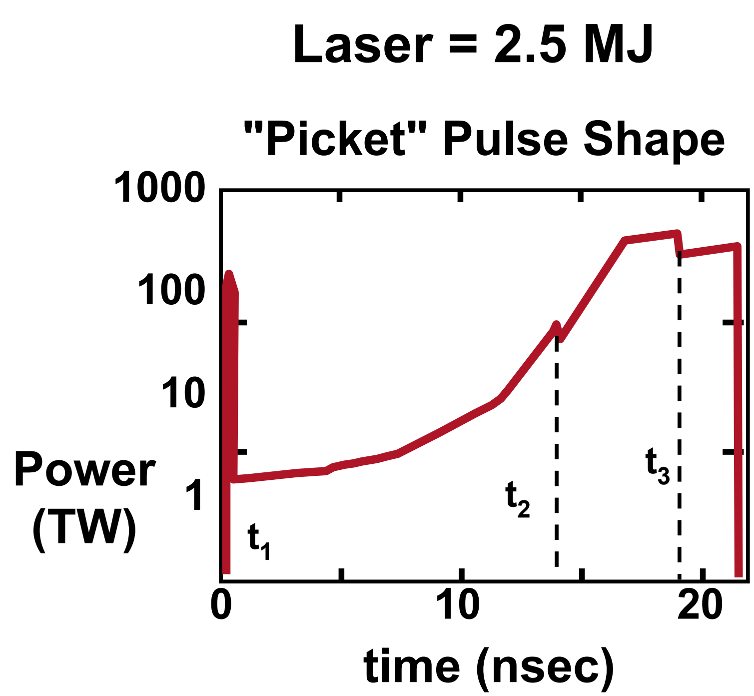
No preferred illumination direction

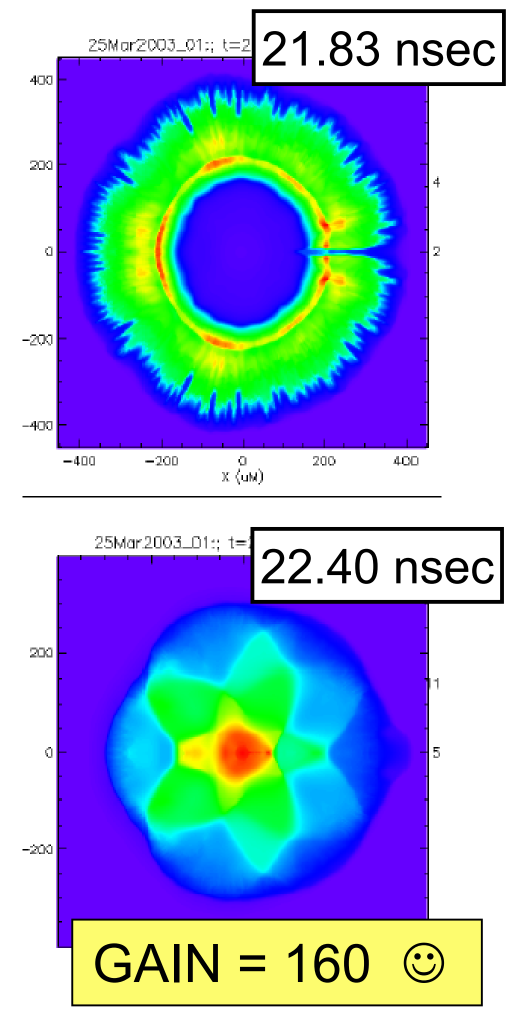
Simpler operational issues: no hohlraum debris to recycle

We need gains > 100 for energy application
2 D computer simulations predict target gains > 160.

NRL FAST CODE: high precision 2D calculations that include all relevant modes and non-uniformities in the target and laser







The baseline target revisited…. with specs that can meet requirements for gain, fabrication, & injection

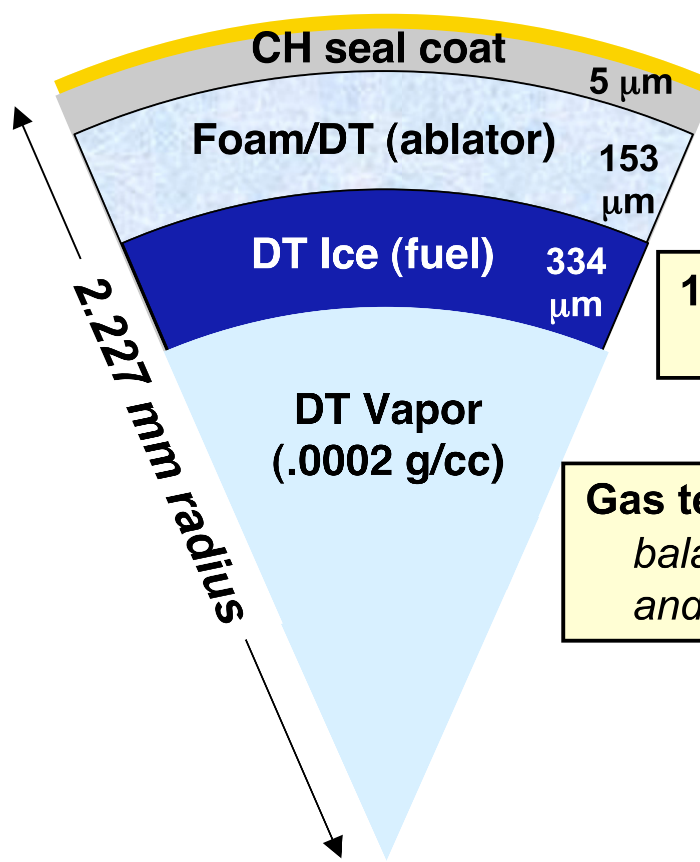
L.J. Perkins (LLNL)
1D calculation
based on NRL design

LASER:	**2.4 MJ**
YIELD:	**348.6 MJ**
GAIN:	**144.8**

(laser has picket pulse)

800 _ 50/50 Au/Pd outer layer
demonstrated:
imprint reduction,
fast DT fill
High IR reflectivity

Surface temp 18.6 °K
below DT Triple Point,
allows for warmup



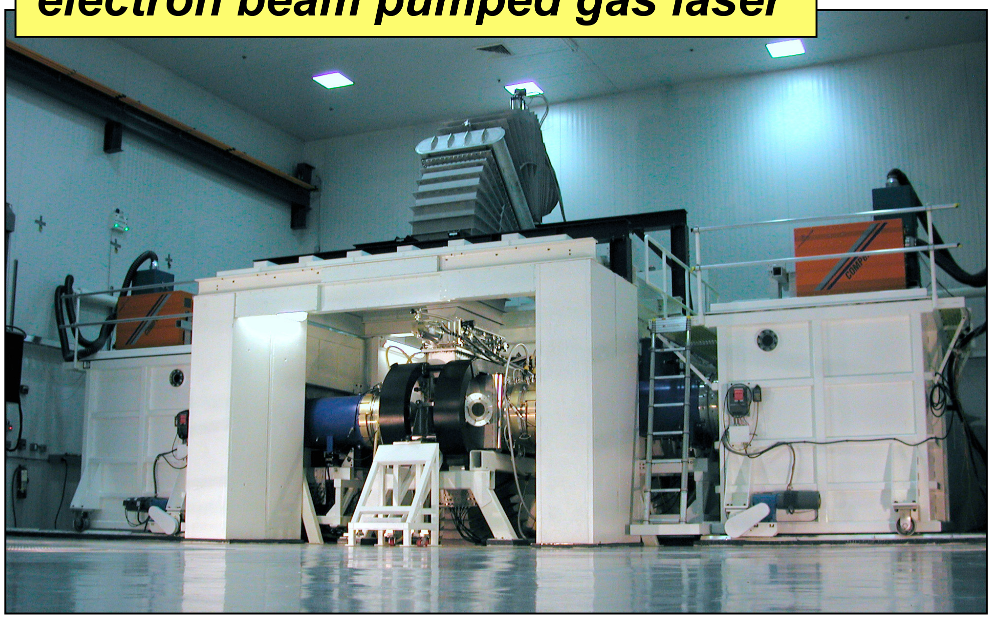
5 μm CH coating
demonstrated seal,
should get RMS < 50 nm

100 mg/cc foam
can make shells

Gas temp 17.3 °K
balances physics
and ice RMS

We are developing two types of Lasers for IFE. Both have the potential to meet the requirements for target physics, rep-rate, cost and durability.

KrF Laser (Electra-NRL)
electron beam pumped gas laser



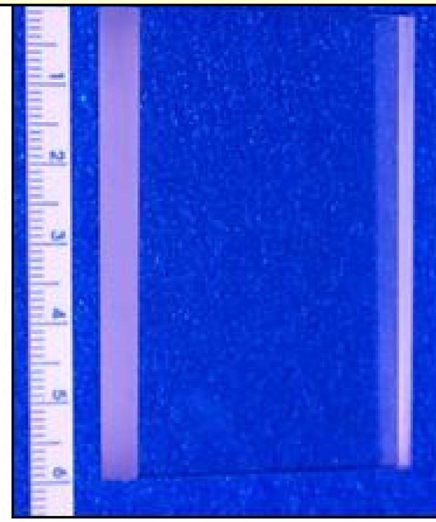
DPSSL (Mercury-LLNL)
Diode pumped solid state laser

- Needed technologies are being developed and demonstrated on large (but subscale) systems.
- Technologies developed must scale to MJ systems

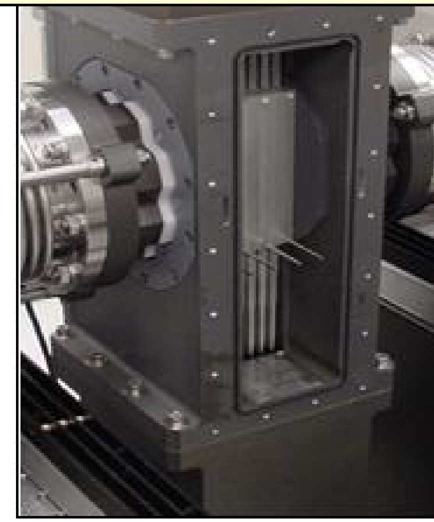
The Mercury Laser Team has developed six new technologies

Diode pump arrays

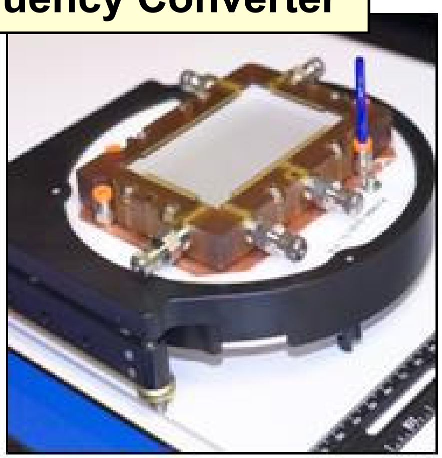
Crystalline amplifiers



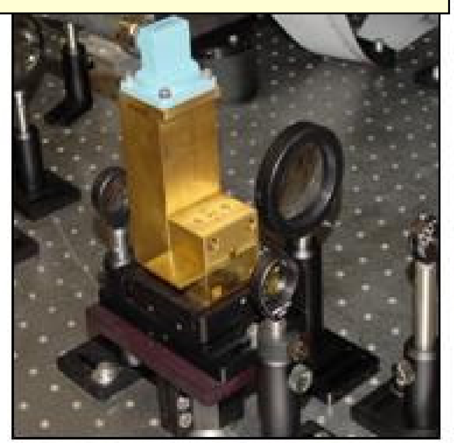
Helium gas cooling



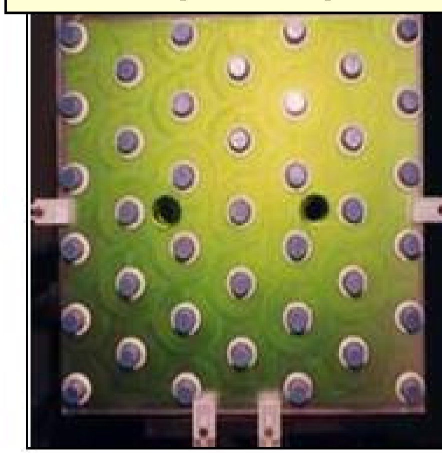
Frequency Converter



Bandwidth



Adaptive Optic

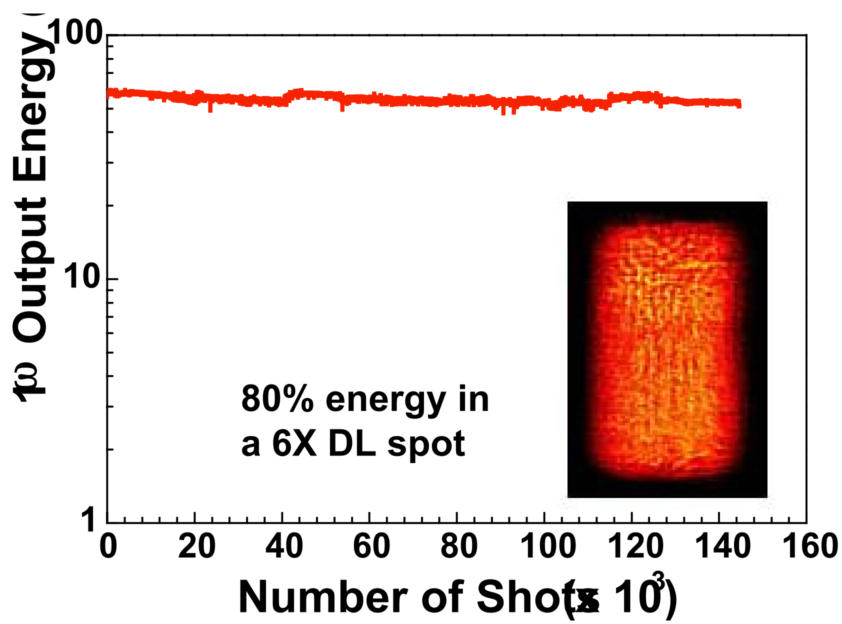


The Mercury laser was operated at an average power of 550 W for $>10^5$ shots at 1 μm and at 227 W for $>10^4$ shots at 0.5 μm

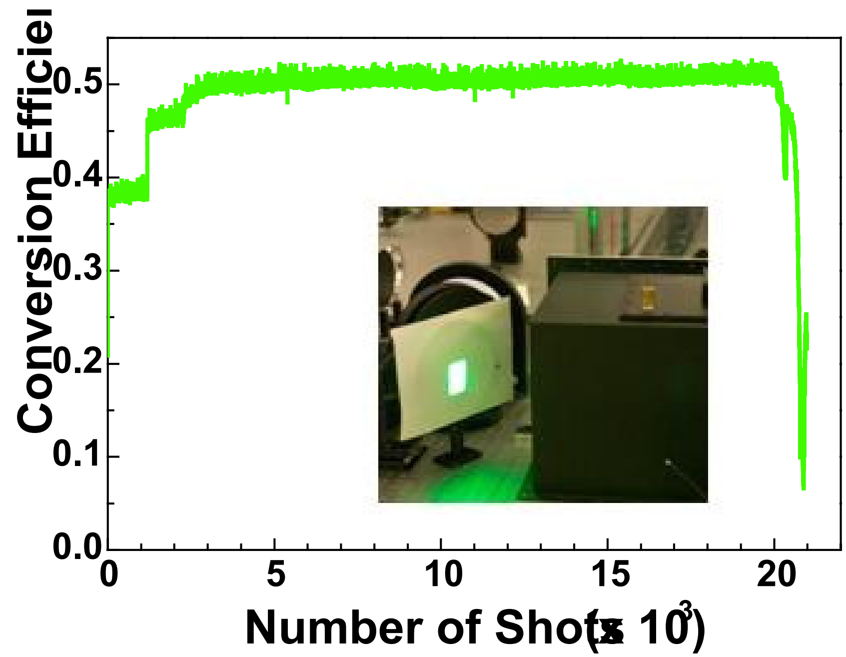
55 J/pulse at 1 μm

22.7 J/pulse at 0.5 μm

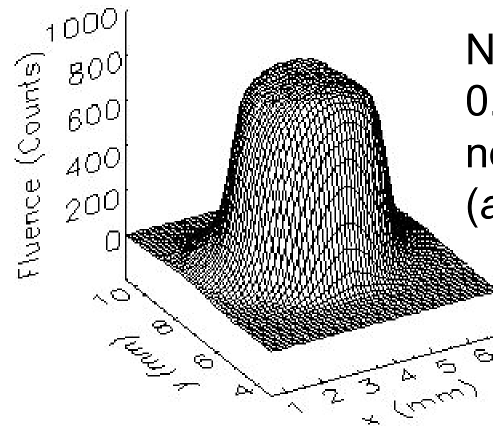
1 μm Average Power (Four 1 hr runs)



0.5 μm Efficiency (14 ns pulse)



KrF: Why use KrF lasers for inertial fusion energy



Nike Laser
0.3 - 1.3%
non-uniformity
(*all modes*)

Demonstrated very uniform laser beam:
minimizes hydrodynamic instabilities

Shortest wavelength (248 nm)
maximizes absorption & rocket efficiency
minimizes risk from Laser Plasma Instabilities

Architecture allows straight-forward "zooming"
(decrease laser spot to follow imploding pellet)

Robust, industrial architecture can scale to MJ energies

Gas medium is tough to break, easy to cool

Electra research: Overall efficiency of IFE size system ~ 7% (meets goal)

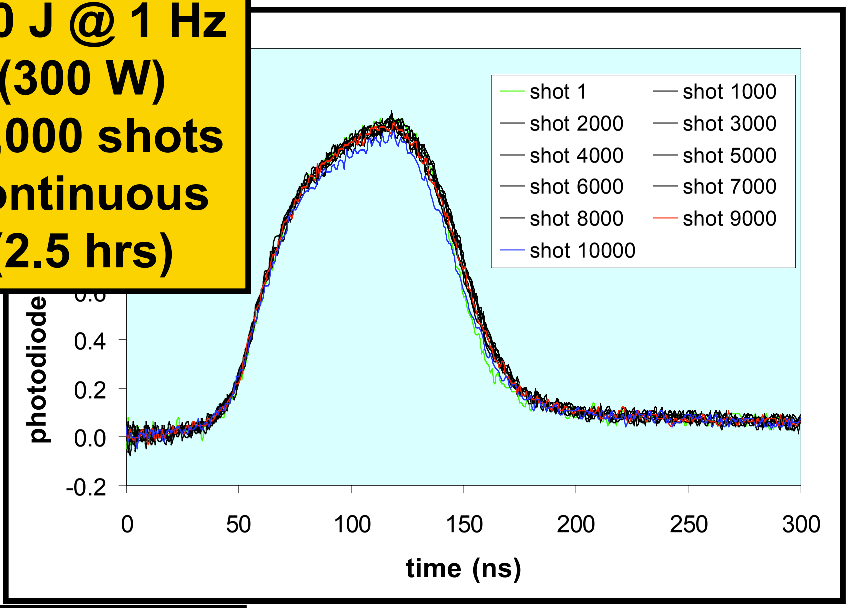
Based on our research, an IFE-sized KrF system is projected to have a wall plug efficiency of ~ 7%

	Before	After	
Pulsed Power	60%	Advanced Switch	85%
Hibachi Structure	40%	No Anode, Pattern Beam	78%
KrF	9%	Based on Electra exp'ts	12%
Optical train to target	95%	Estimate	95%
Utilities (Pumps, gas cooling)	95%	Estimate	95%
Total	1.9%		7.2%

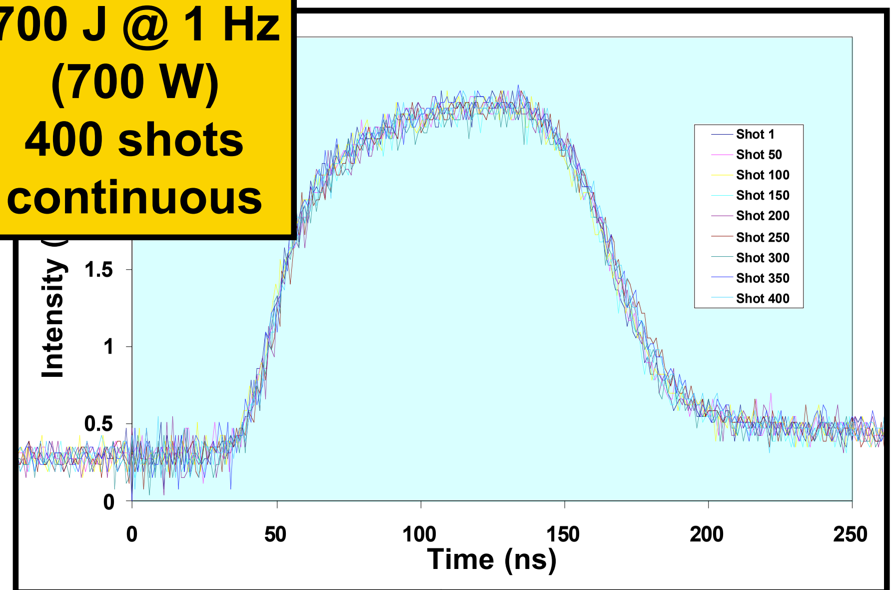
> 6 % is adequate for fusion target gains > 100...
...and latest designs have gains > 140

Electra KrF laser is very consistent in long duration, repetitively pulsed, runs

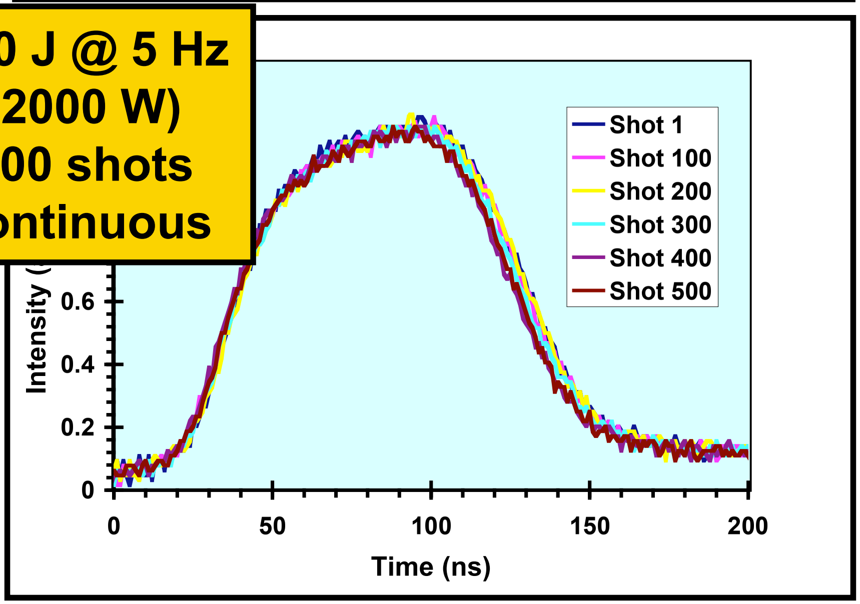
300 J @ 1 Hz (300 W) 10,000 shots continuous (2.5 hrs)



700 J @ 1 Hz (700 W) 400 shots continuous



400 J @ 5 Hz (2000 W) 500 shots continuous

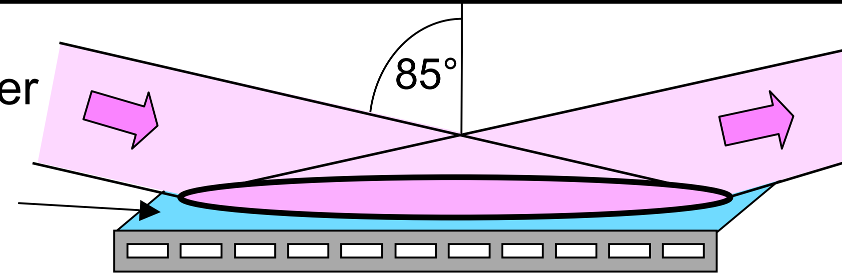


Recent results:
250 J @ 5 Hz
(1,250 W)
7700 shots
four back to back runs

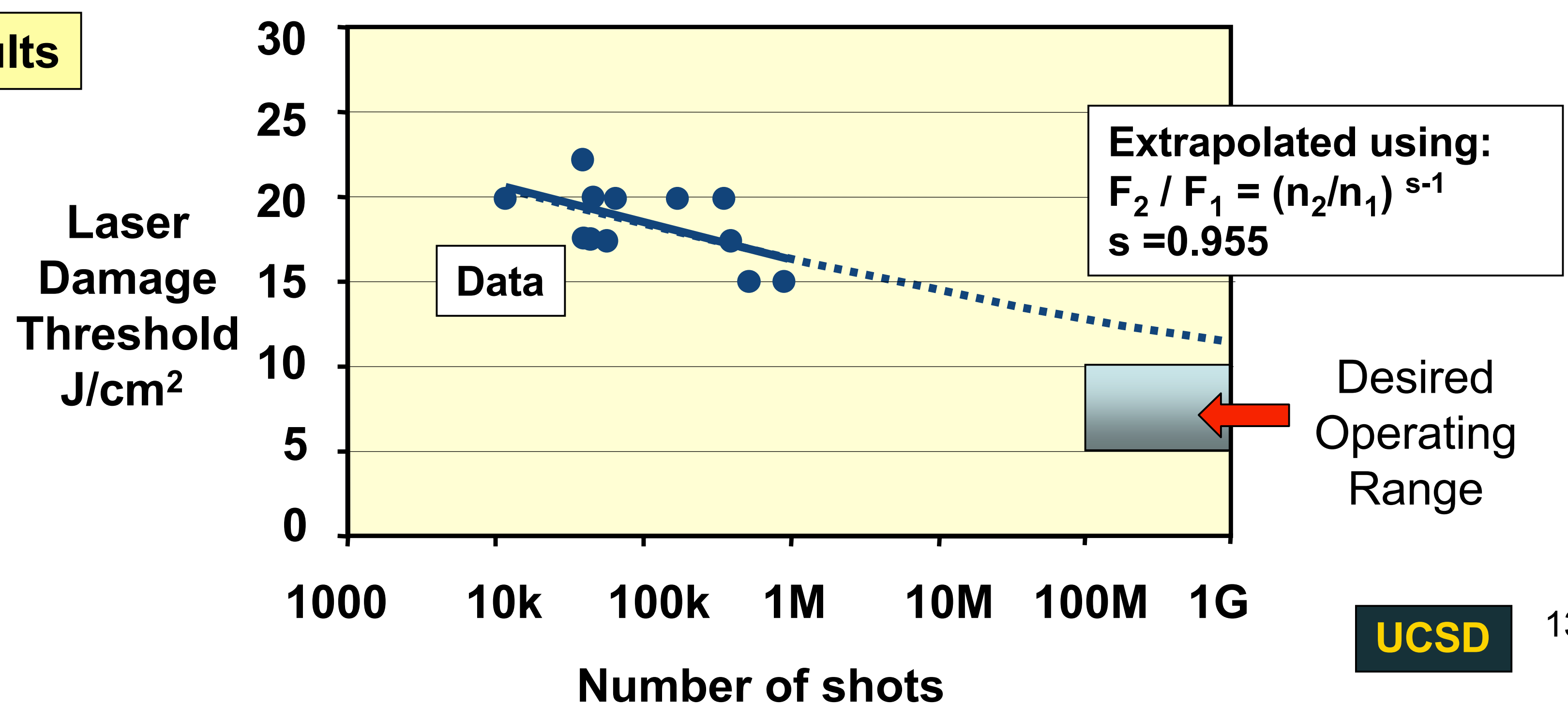
Final Optics:

Grazing Incidence Aluminum Mirror meets requirements for
1) reflectivity (>99% @ 85°)
2) laser damage threshold (> 5 J/cm²)

Concept



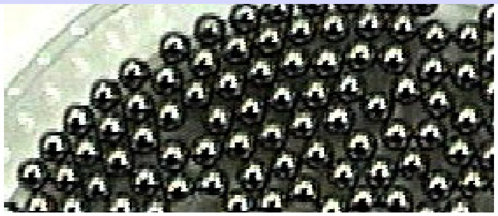
Results



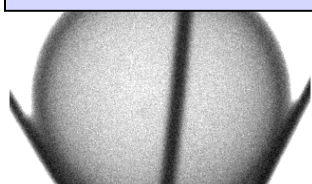
Target Fabrication:

The technologies for target fabrication are understood and under development

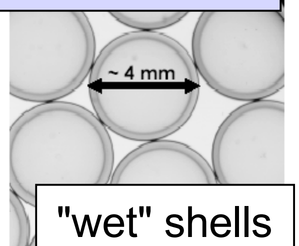
Au/Pd Overcoated shells



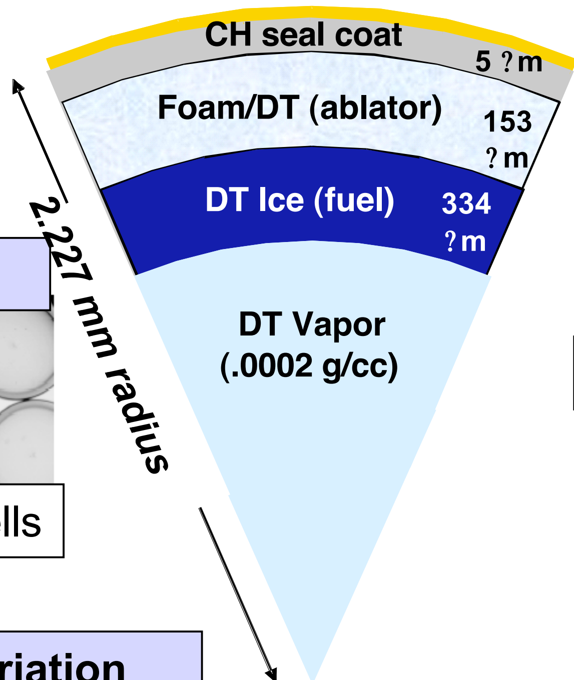
100 mg/cc foam shell



x-ray picture



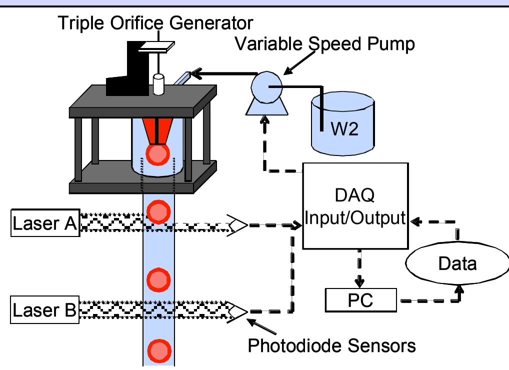
"wet" shells



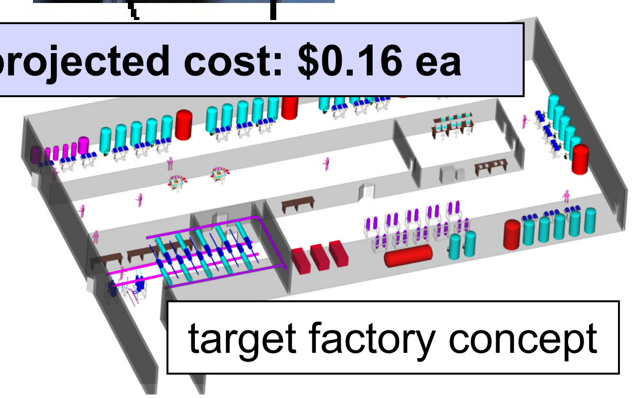
Smooth D-T ice over foam

Cryogenic fluidized bed

22 shells/min, < 1% variation



Target projected cost: $0.16 ea



target factory concept

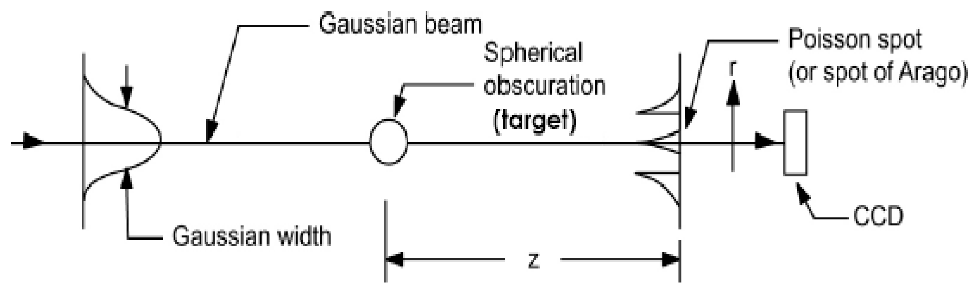
General Atomics
Los Alamos
Schaffer Corp

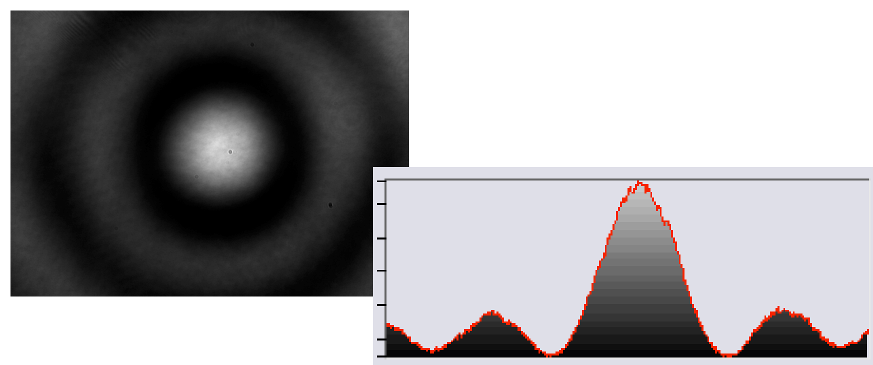
Target injection and tracking

- New injector has achieved required velocity
- Proof of principal of "Poisson Spot" tracking technique

Target Injector (gas gun)
50- 400 m/sec
+/- 10 mm aiming

Target Tracking
4.6 μm accuracy
< 0.71 msec response

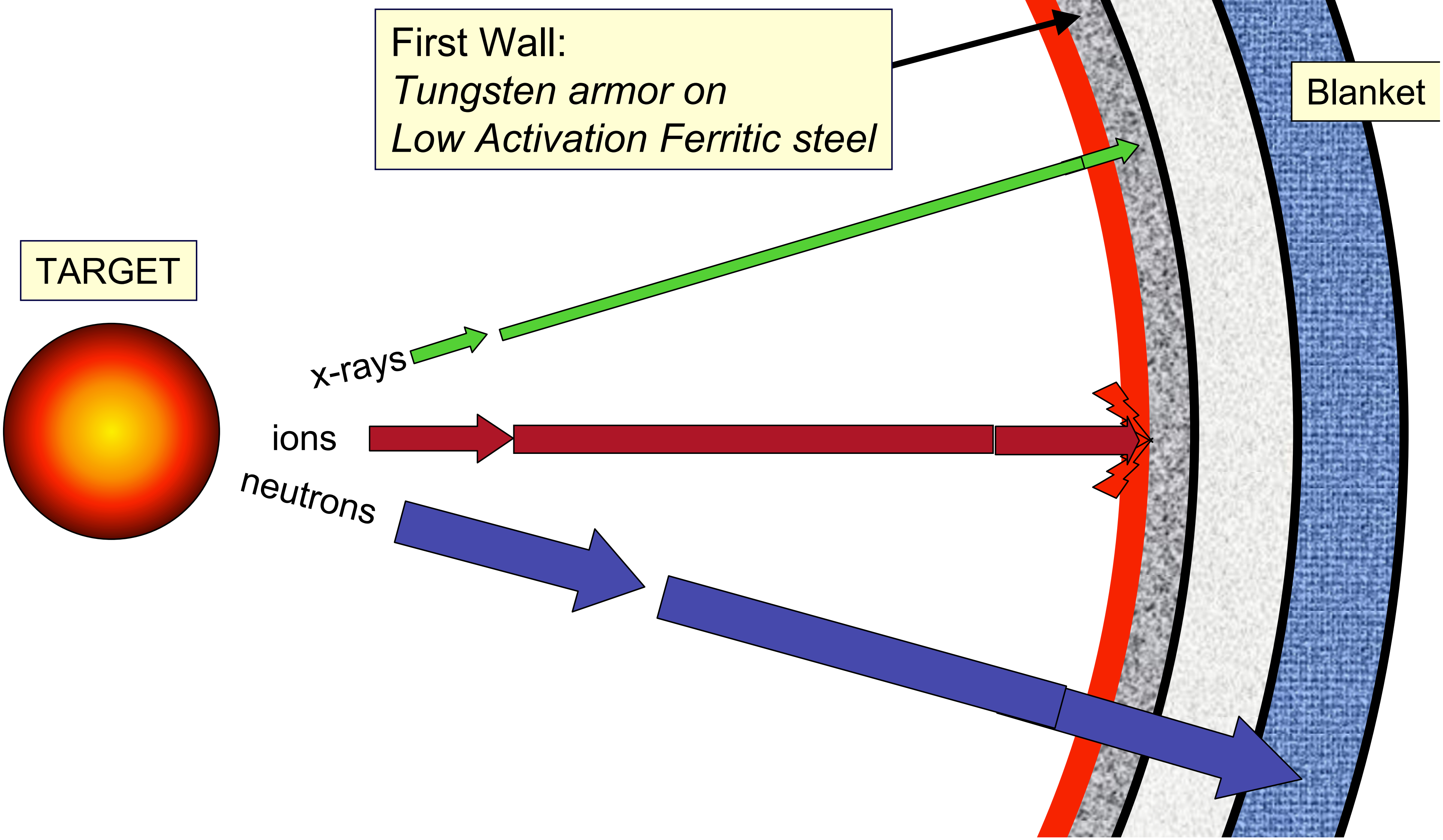




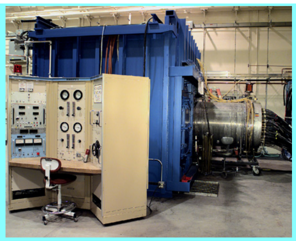
Also looking at electro magnetic based system

General Atomics
UCSD

We are developing a first wall for the chamber to withstand the steady pulses of x-rays, ions and neutrons from the target.

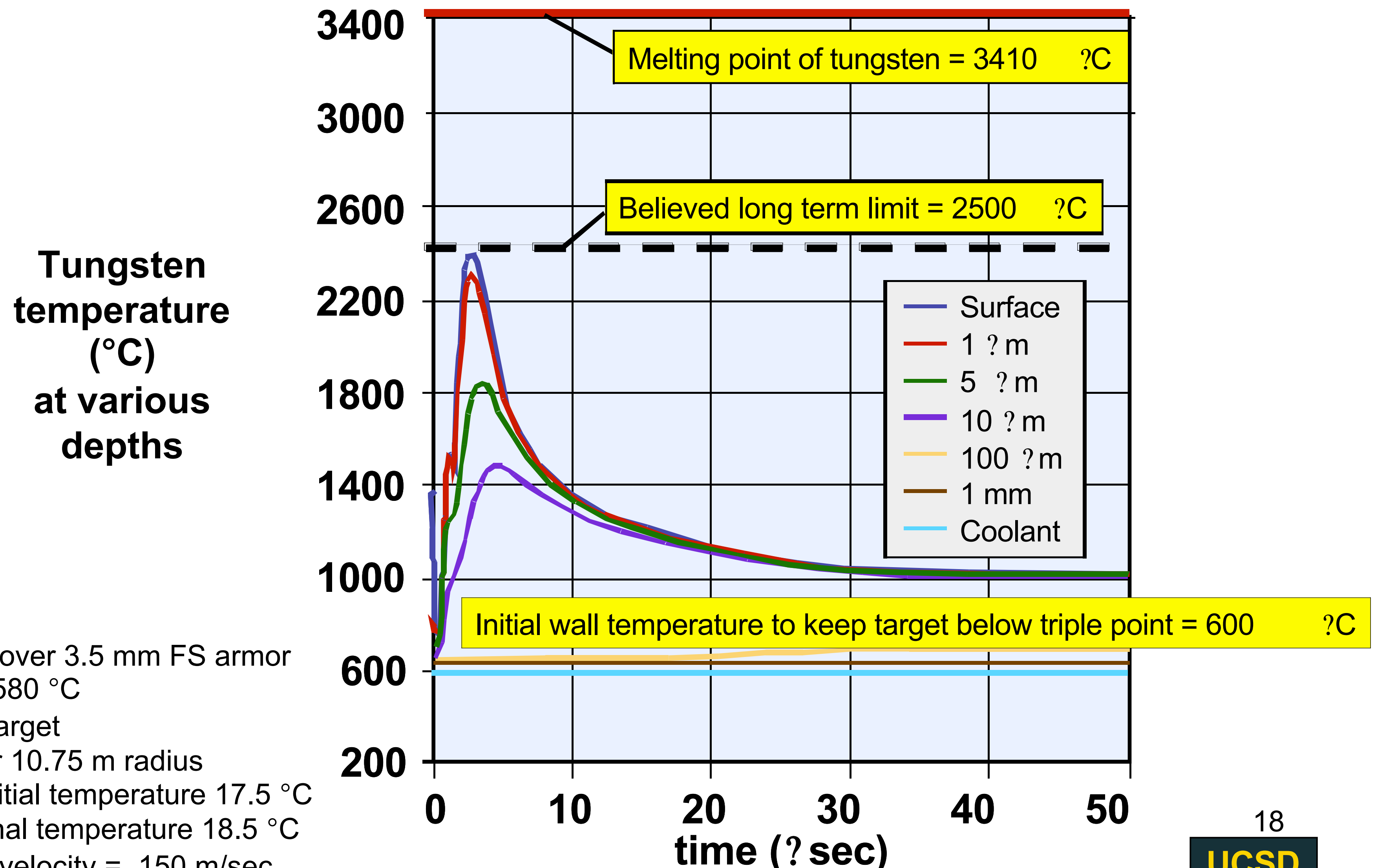


Long term exposure experiments and modeling suggest the tungsten FW should be kept < 2500 °C

	Parameters	# shots	Nothing Happens	Surface Roughens	
Ions: *RHEPP* (SNL) 	850 kV N^+ 50 nsec 0.067Hz	2000	**1400 ?C** ? T=1380	**1900 ?C** ? T =1820 saturates 2 ? m RMS	**3100 ?C** ? T = 3090 saturates 4 um RMS
X-rays: *XAPPER* (LLNL) 	90 -130 eV 50 nsec 10 Hz	10^6	**2500 ?C** ? T=1900		
Laser: *Dragonfire* (UCSD) 	1 ? m YAG 8 nsec 10 Hz	10^5		**1800 ?C** (? T= 1700) RMS vs # shots not yet quantified	
Modeling: Wisconsin,	modeling shows cracks (roughening) expected. Should stop before they get to the substrate				

Reaction Chamber Modeling:

We identified a "chamber operating" window for **long term wall survival**, target injection, and plant efficiency

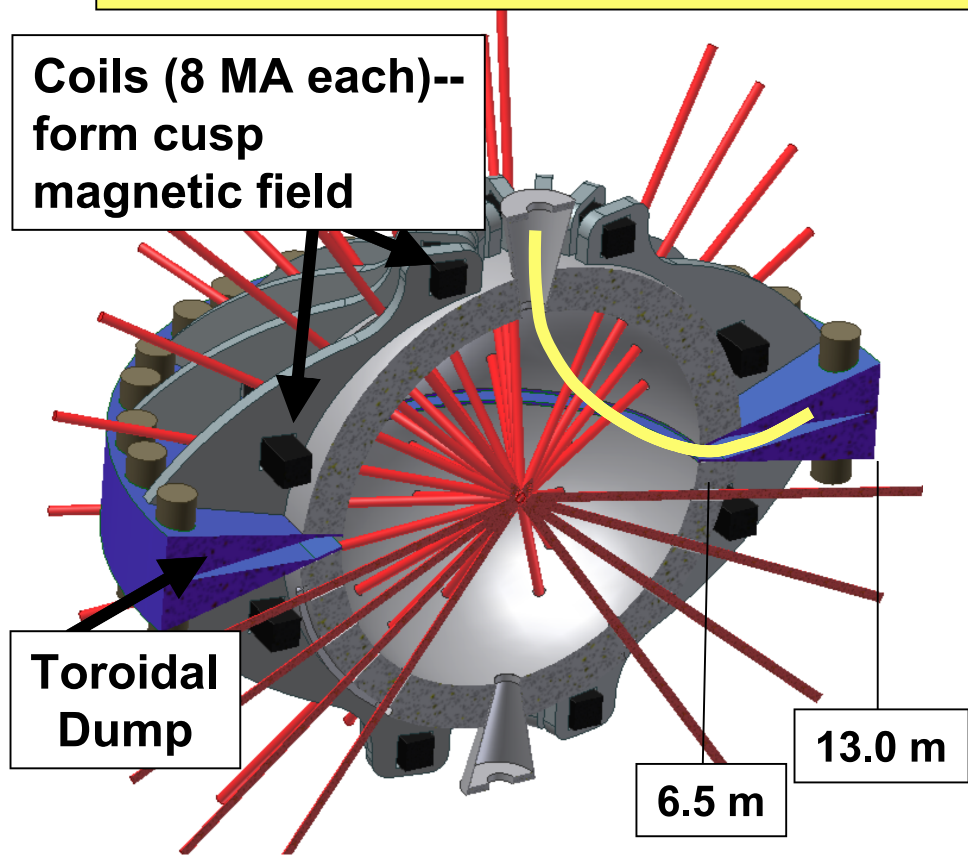


1 mm W over 3.5 mm FS armor
Coolant 580 °C
350 MJ target
Chamber 10.75 m radius
Target initial temperature 17.5 °C
Target final temperature 18.5 °C
Injection velocity = 150 m/sec

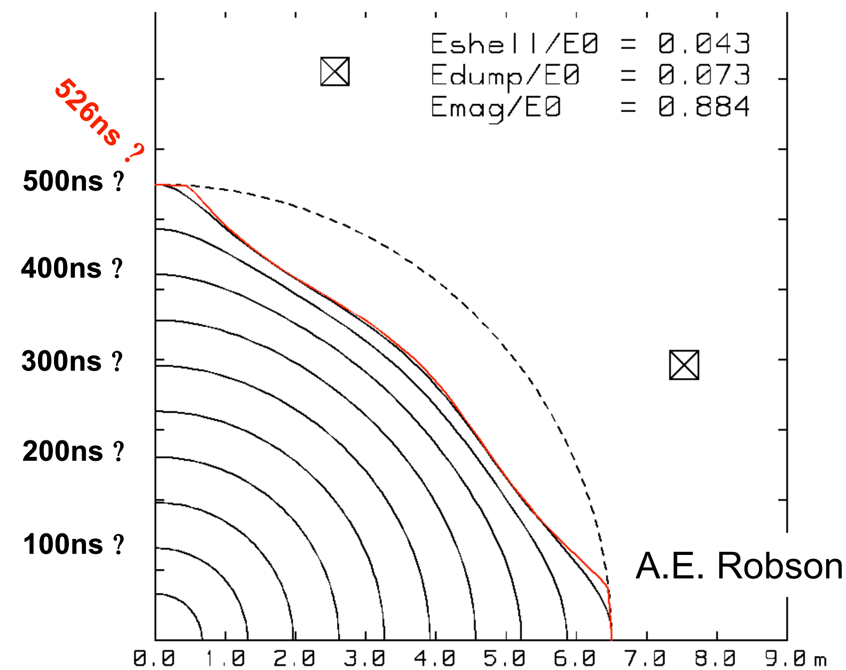
UCSD

"Magnetic Intervention" offers a way to keep the ions off the wall, possibly increase system efficiency

1. Expanding plasma compresses magnetic field against first wall
2. Ions never get to wall!
3. Field is resistively dissipated in wall
4. Ions, at reduced energy *and power*, escape through cusp poles and belt
5. Easier to absorb reduced ion power in dumps



Expansion of plasma in cusp field: 2-D shell model



Next Steps to Develop Laser Fusion Energy

- Full scale Laser Beam Line plus target chamber, can address:
  - Laser
  - Final optics (laser effects)
  - Target fabrication (mass production methods)
  - Target injection and engagement

- Full scale demo based on 350 MJ Target and 2.5 MJ laser would be expensive, and risky
  - Would like to test target physics on smaller scale
  - Need flexible facility to develop and evaluate materials and components

- Solution: The Fusion Test Facility
  - Smaller, less expensive facility
  - Capitalizes on new version of NRL direct drive target
  - See the next talk!!!