Laser Fusion Energy: Progress in HAPL *-and-* Introducing The Fusion Test Facility

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Fusion Power Associated Annual Meeting
Washington DC Oct 12, 2005

Our co-authors come from 29 different institutions

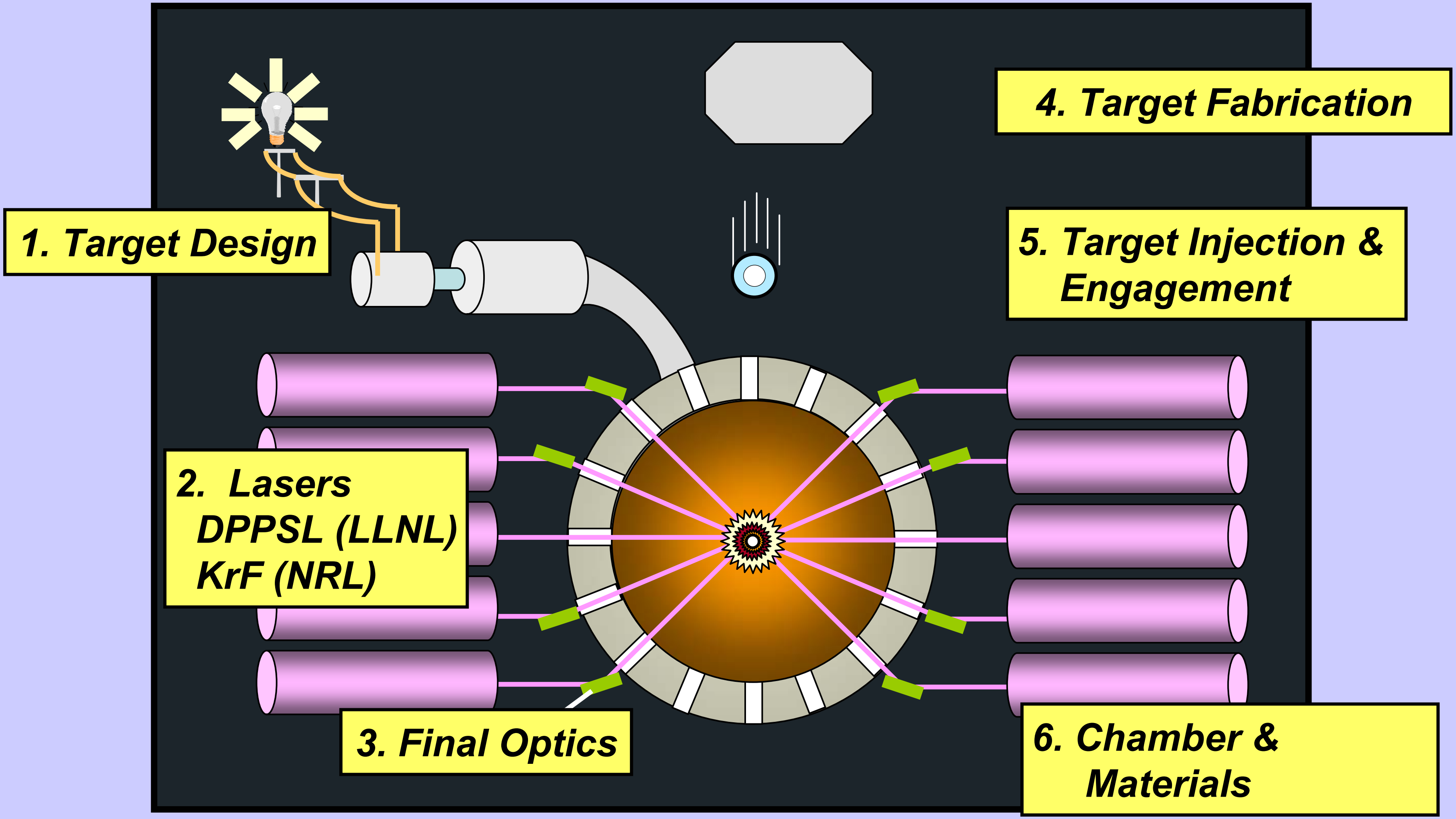
HAPL meeting #12, LLNL June 2005

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

Universities
1. UCSD
2. Wisconsin
3. Georgia Tech
4. UCLA
5. U Rochester, LLE
6. UC Santa Barbara
7. UC Berkeley
8. UNC
9. Penn State Electro-optics

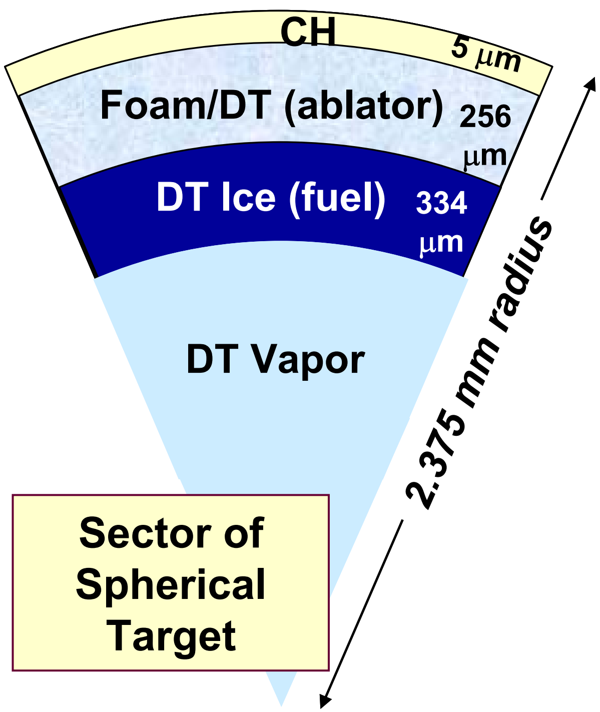
Industry
1. General Atomics
2. Titan/PSD
3. Schafer Corp
4. SAIC
5. Commonwealth Tech
6. Coherent
7. Onyx
8. DEI
9. Mission Research Corp
10. Northrup
11. Ultramet, Inc
12. Plasma Processes, Inc
13. Optiswitch Technology
14. Research Scientific Inst

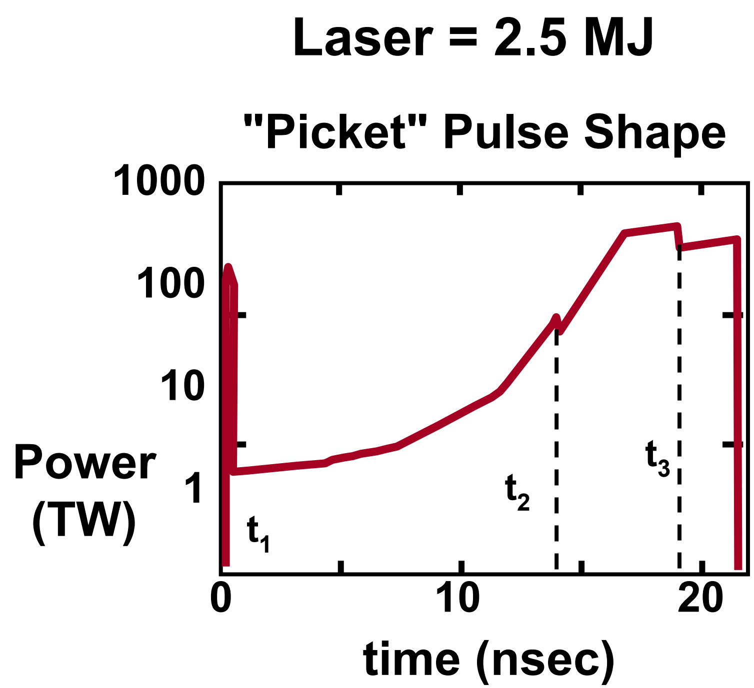
We are developing the science & technologies for laser fusion energy with direct drive targets

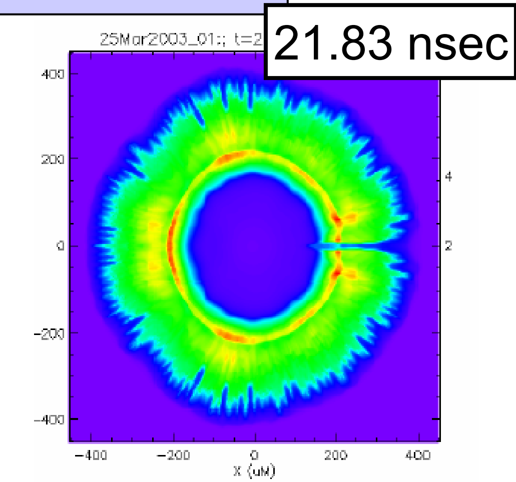


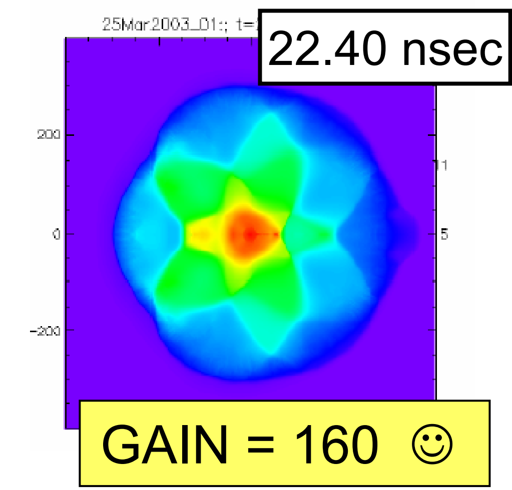
We need gains > 100 for energy application....
2 D computer simulations predict target gains > 160.

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





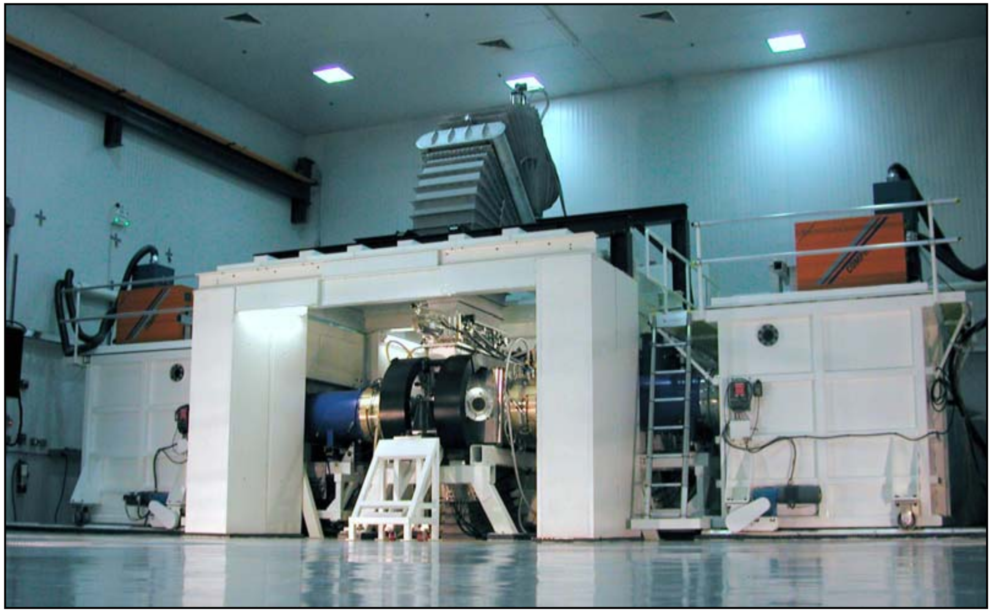




Similar results (1D) from L.J. Perkins LLNL

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



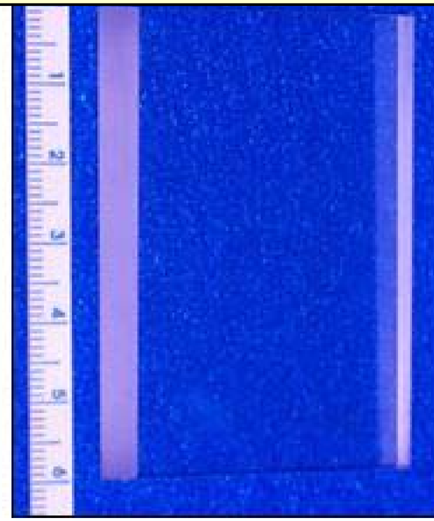
DPSSL (Mercury-LLNL)
Diode pumped solid state laser

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

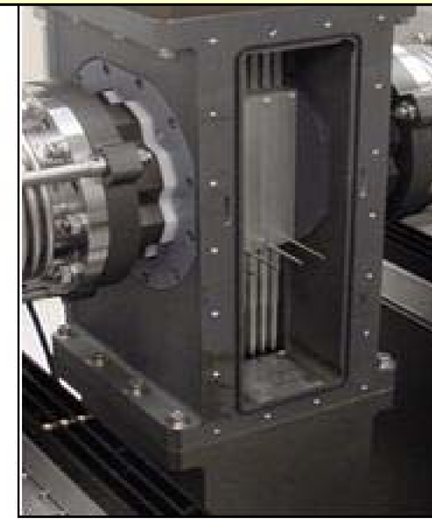
The Mercury Laser Team has developed six new technologies

Diode pump arrays

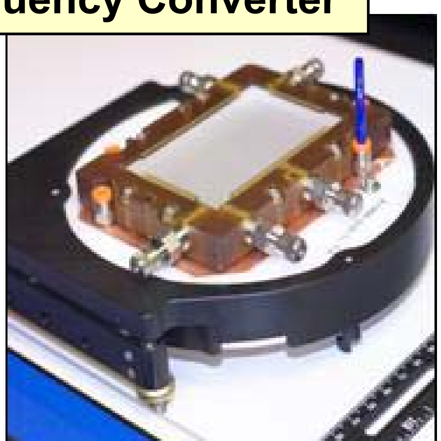
Crystalline amplifiers



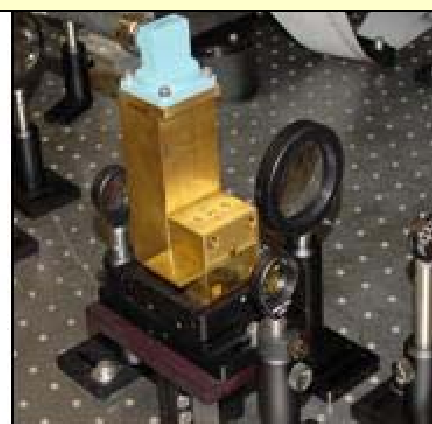
Helium gas cooling



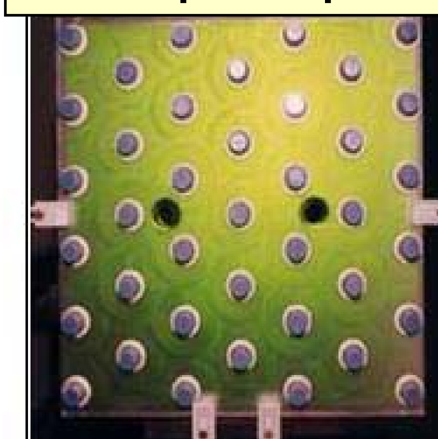
Frequency Converter



Bandwidth



Adaptive Optic

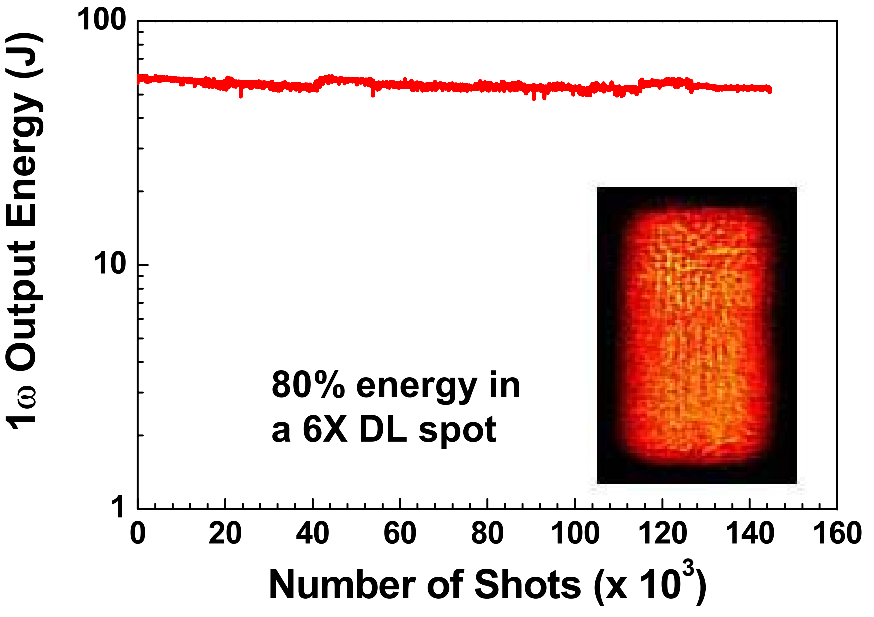


The Mercury laser was operated at an average power of 550 W for >105 shots at 1 mm and at 227 W for >104 shots at 0.5 mm

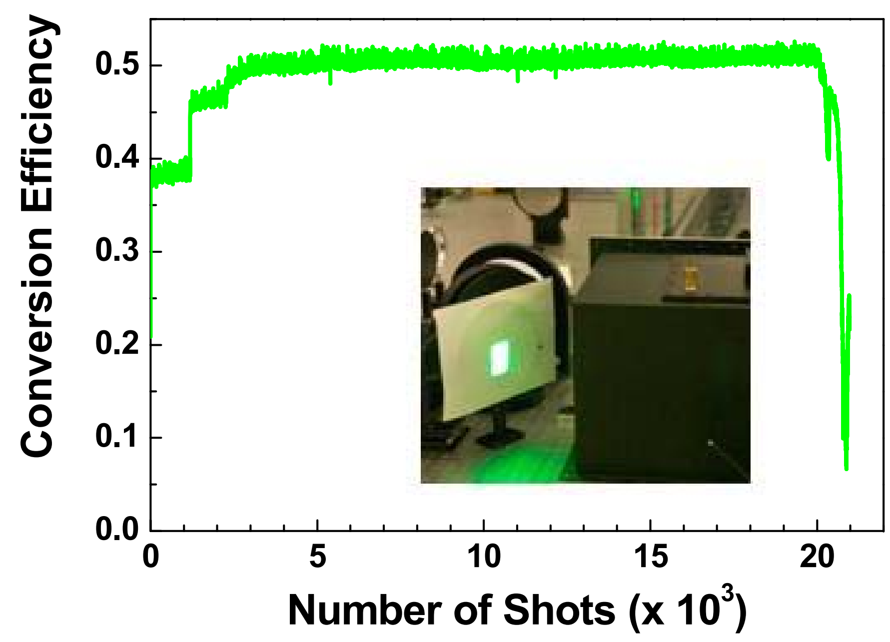
55 J/pulse at 1 μm

22.7 J/pulse at 0.5 μm

1 μm Average Power (Four 1 hr runs)

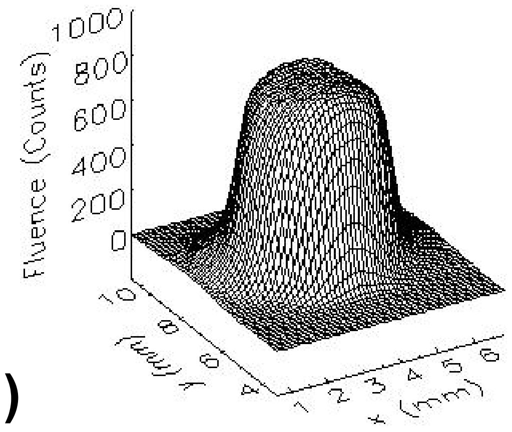


0.5 μm Efficiency (14 ns pulse)



KrF Laser Achievements

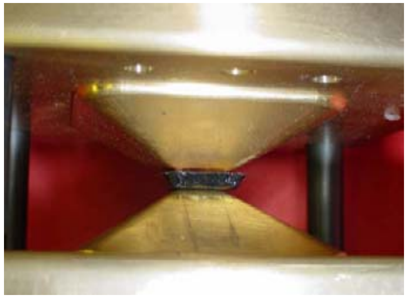
Demonstrated very uniform laser beam (Single shot):
minimizes hydrodynamic instabilities



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

Demonstrated 300-710 J/pulse in repetitive operation at 1-5 Hz
No degradation in laser output

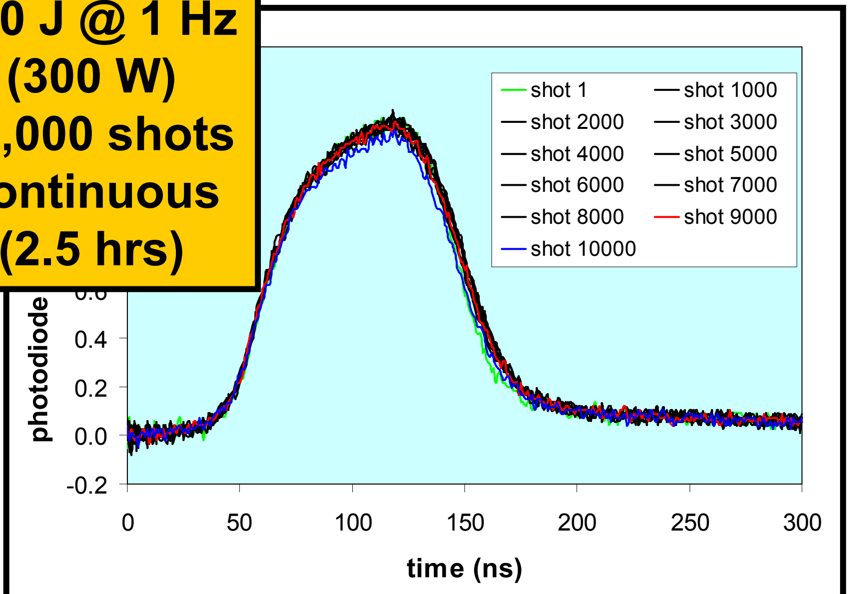
Developed solid state switch,
Basis for efficient, durable, inexpensive pulsed power



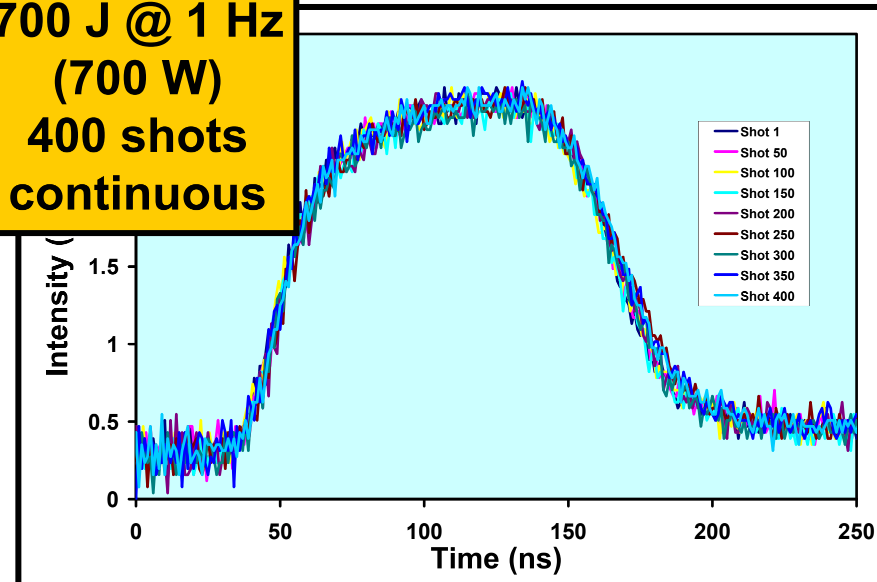
Predict Overall efficiency of IFE size system ~ 7% (meets goal)
Based on Electra R & D of the individual components

The last major hurdle is foil durability. We are getting closer

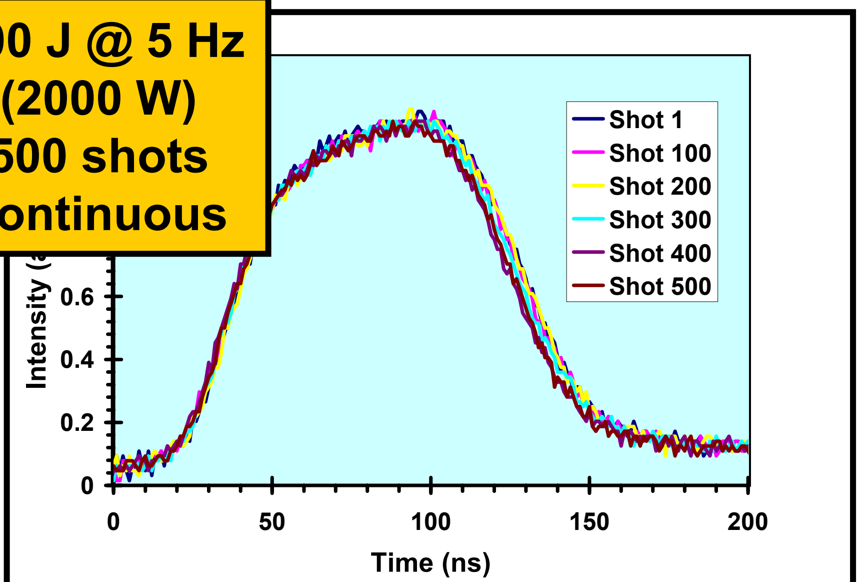
300 J @ 1 Hz (300 W) 10,000 shots continuous (2.5 hrs)



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



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



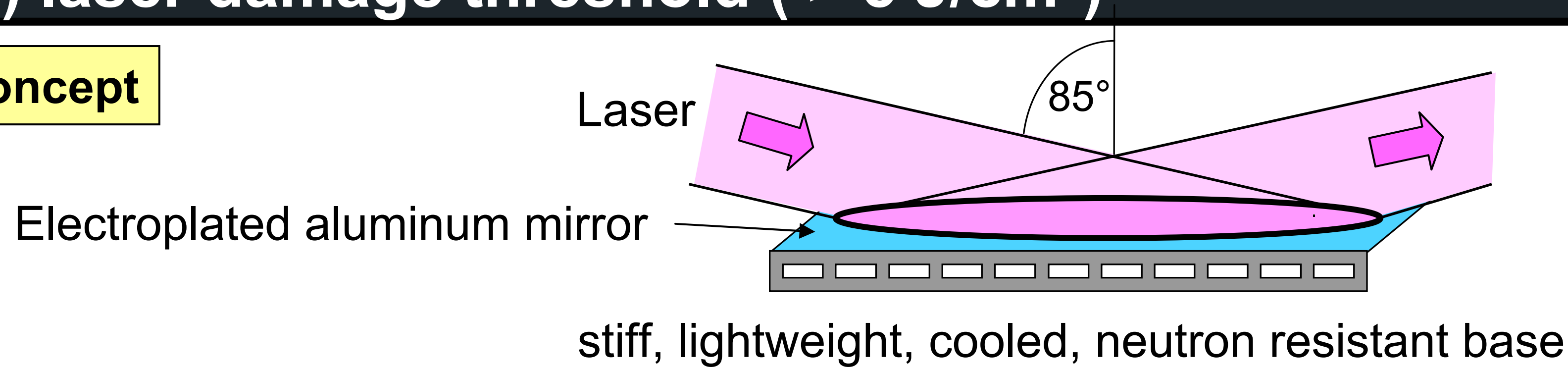
cons

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

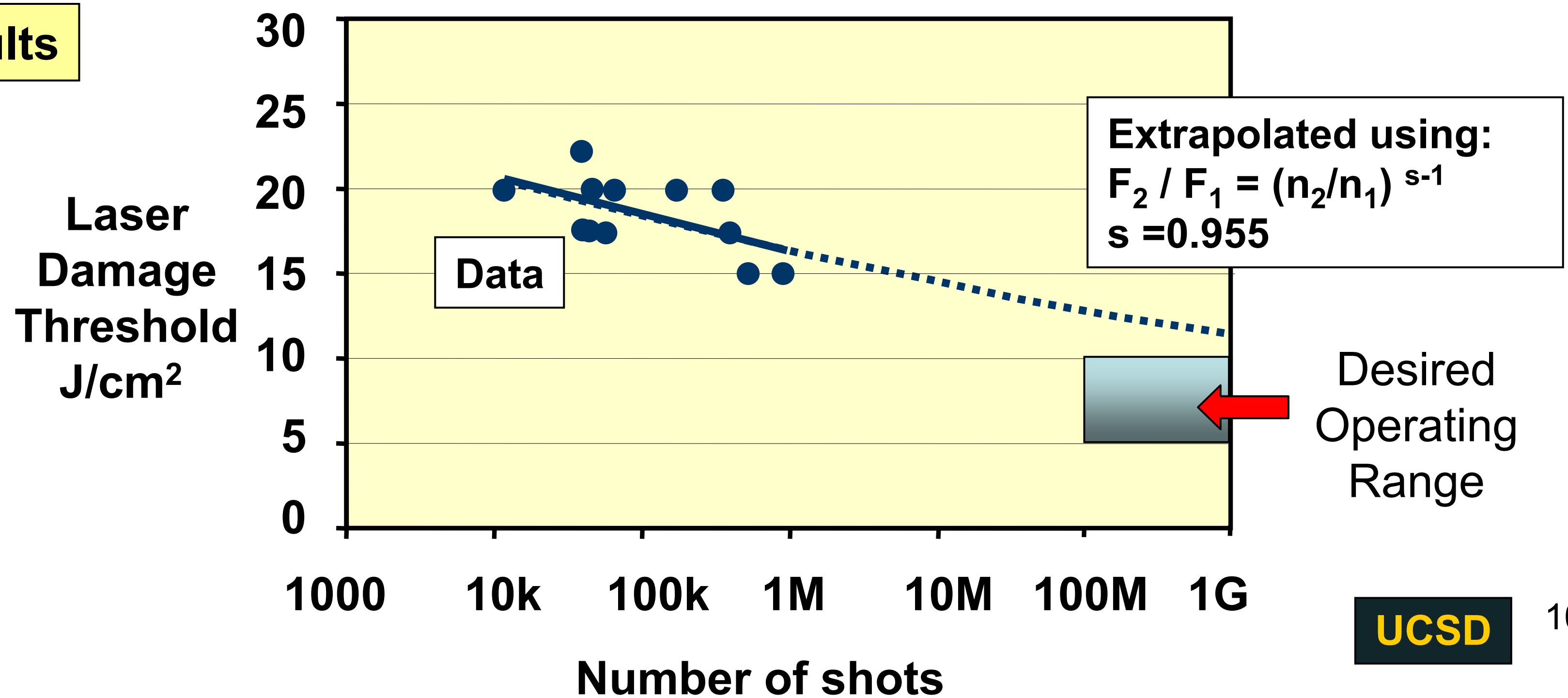
Final Optics:

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

Concept



Results

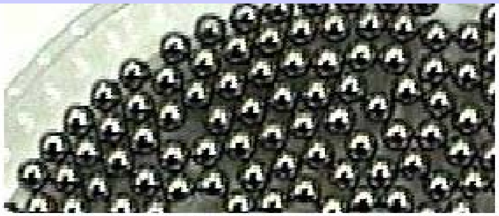


UCSD

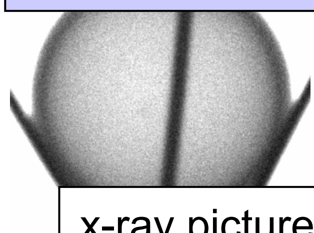
Target Fabrication:

The technologies for target fabrication are understood and either established or under development

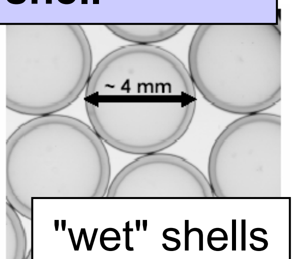
Au/Pd Overcoated shells



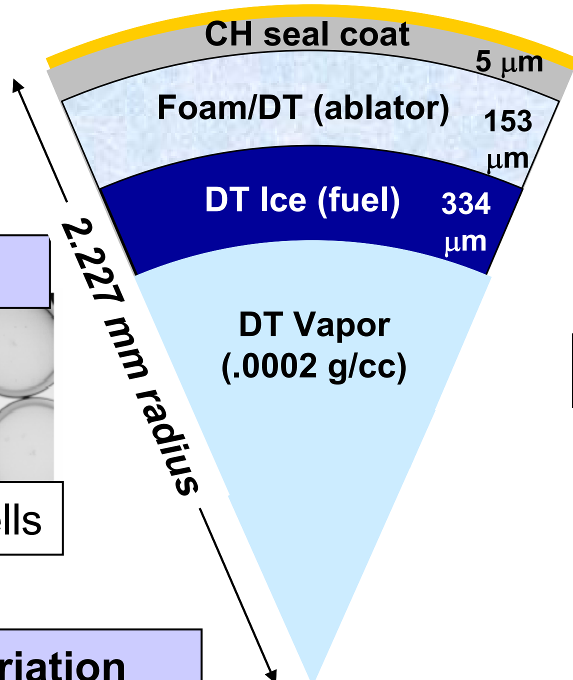
100 mg/cc foam shell



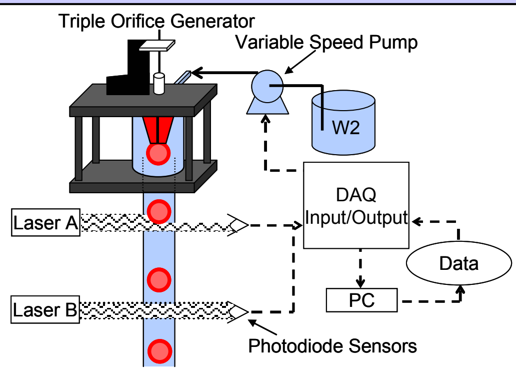
x-ray picture



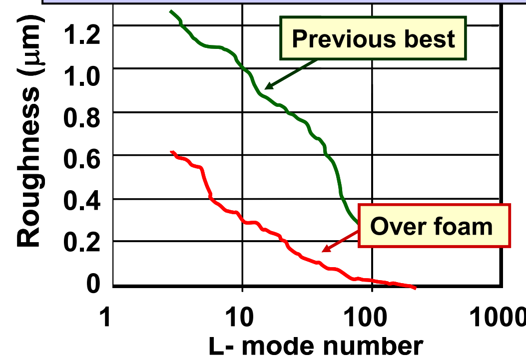
"wet" shells



22 shells/min, < 1% variation

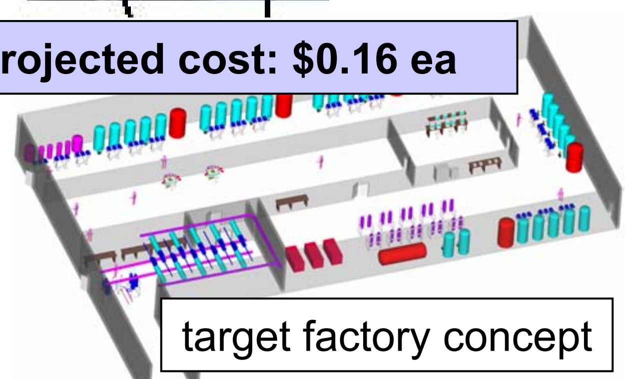


Smooth D-T ice over foam



Cryogenic fluidized bed

Target projected cost: $0.16 ea



target factory concept

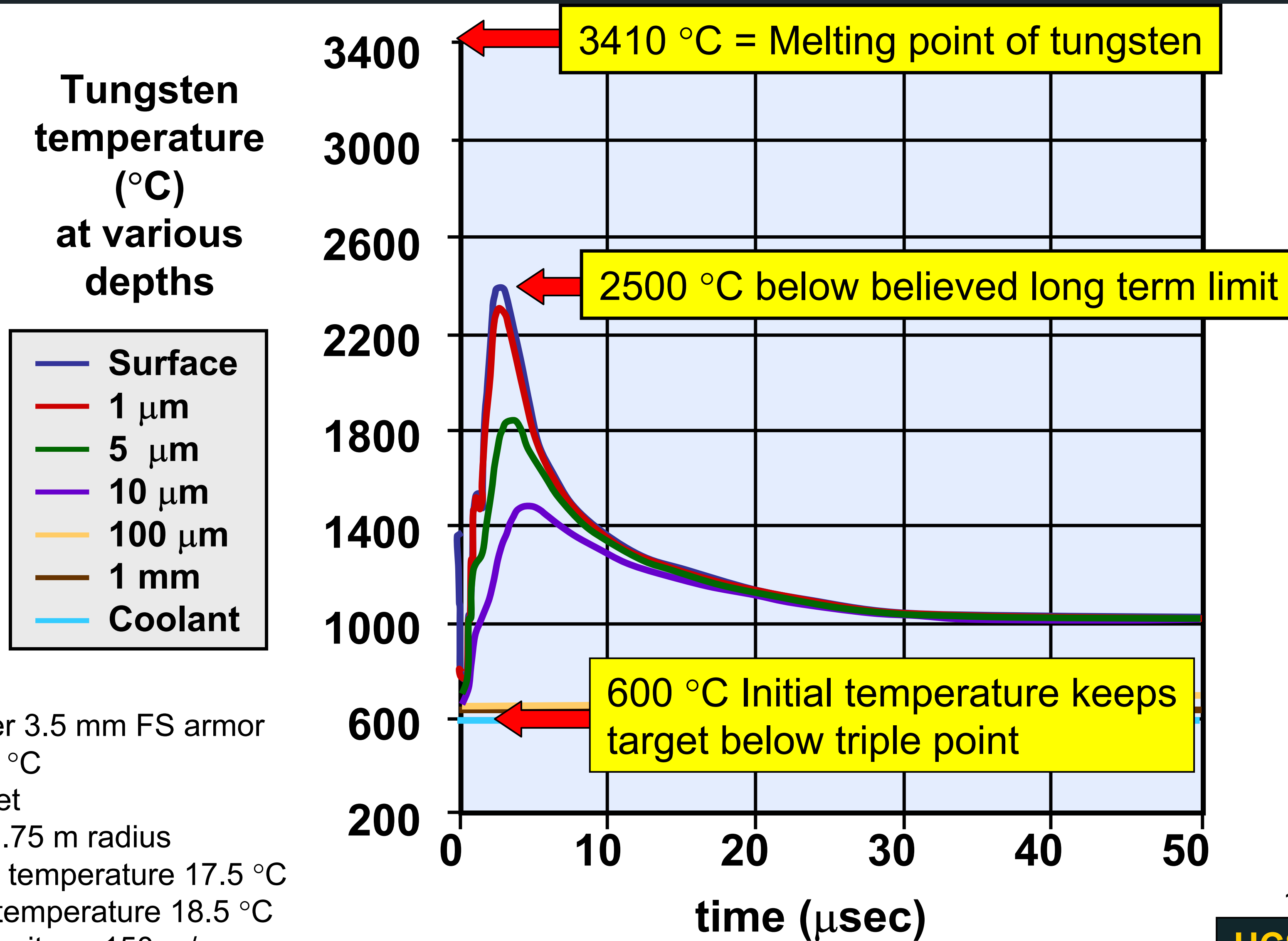
General Atomics
Los Alamos
Schaffer Corp

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** ΔT=1380	**1900°C** ΔT =1820 saturates 2 μm RMS	**3100°C** ΔT = 3090 saturates 4 um RMS
X-rays: *XAPPER* (LLNL) 	90-130 eV 50 nsec 10 Hz	10^6	**2500 °C** ΔT=1900		
Laser: *Dragonfire* (UCSD) 	1 μm YAG 8 nsec 10 Hz	10^5		**1800 °C** (ΔT= 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

Next Steps to Develop Laser Fusion Energy

- Full scale Laser Beam Line (25 kJ), plus chamber can address:
  - Laser
  - Final optics (laser effects)
  - Target fabrication (mass production methods), injection, & engagement
  - Some target physics

- 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 chamber, materials, and components

- Solution: The Fusion Test Facility
  - Smaller, less expensive facility
  - Capitalizes on newest version of NRL direct drive target

The Fusion Test Facility (FTF):

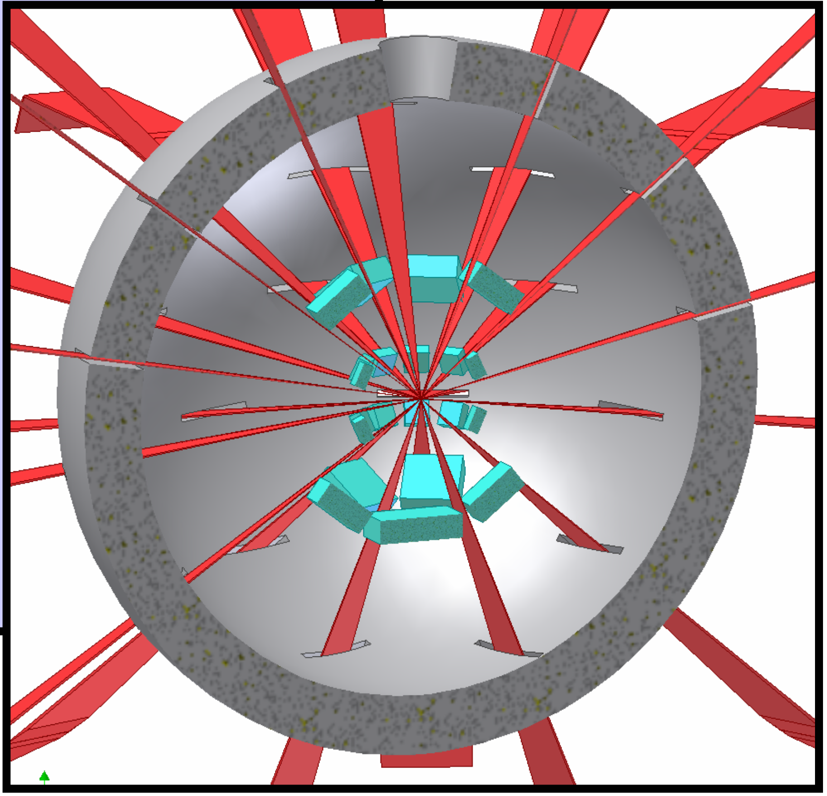
1) A lower cost, high rep rate path to fusion ignition
   ....and beyond

2) Ability to test fusion materials and components
   ....*for both IFE and MFE*

3) Based on Direct Drive with lasers

4) Fusion power ~ 150 MW

5) Prototypical power plant neutrons
   (flux and spectrum)



The prescription to the reduce the laser energy and still have sufficient gain for the mission of the FTF

- Reduce pellet mass while increasing implosion velocity (to ≥400 km/sec)
- Increase peak drive irradiance and concomitant ablation pressure (~2x)
- Use advanced pellet designs that are resistant to hydro-instability
- Exploit KrF laser's deep UV light and large bandwidth ($\Delta\omega$)

	Laser Energy kJ	1D Gain	Yield MJ	**Fusion Power (MW@ 5 Hz)**
Spike, *plus* + 100:1 contrast Main Pulse (tuned for gain)	250	30	7.5	**38**
	460	79	36	**181**
	650	90	59	**292**
Spike, *plus* 50:1 contrast Main Pulse (tuned for stability)	500	56	28	**140**
	650	76	49	**247**

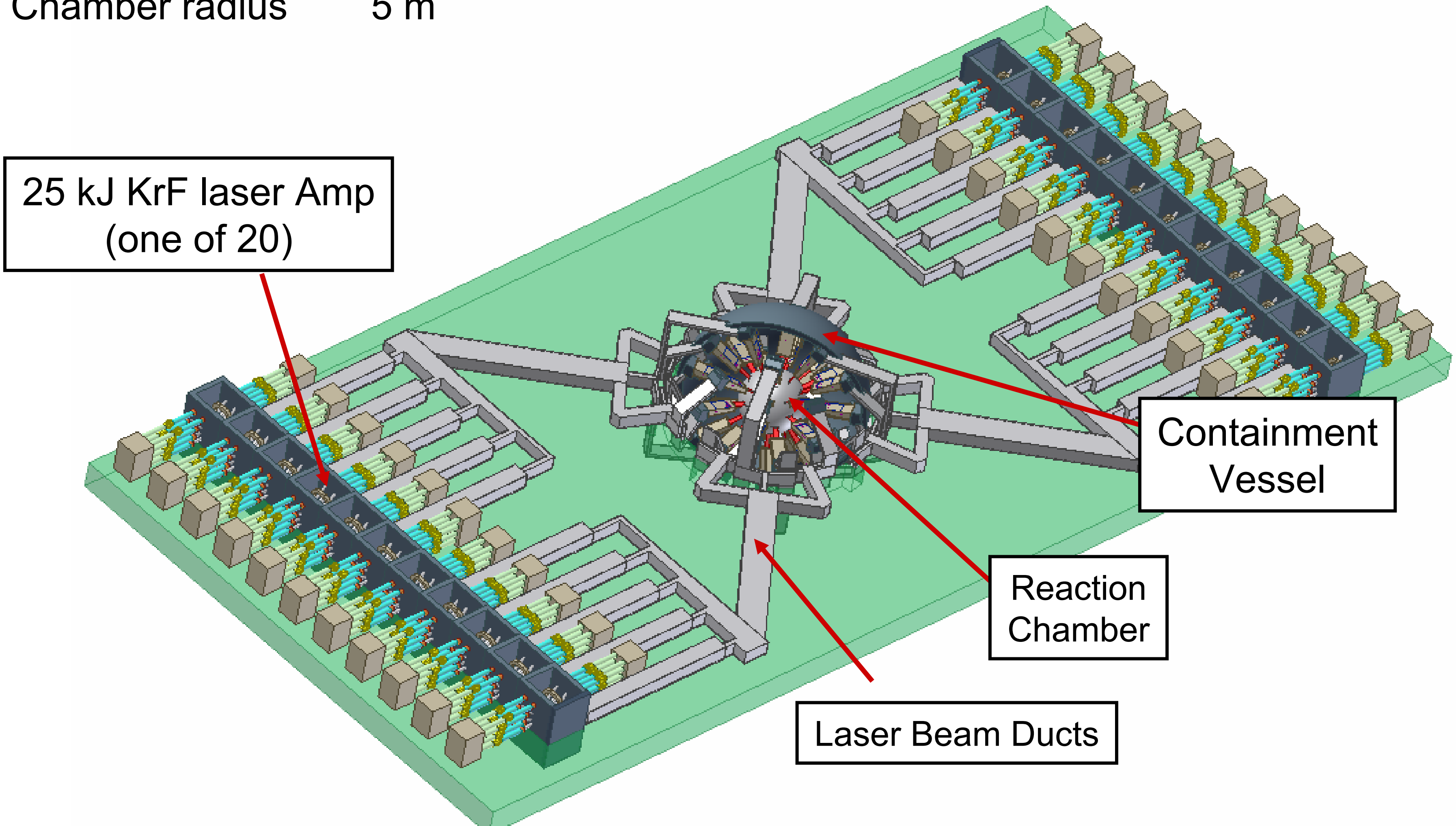
See talk by S. Obenschain at APS/DPP meeting for details

"baseline:" 500 kJ laser facility with 150 MW of fusion power

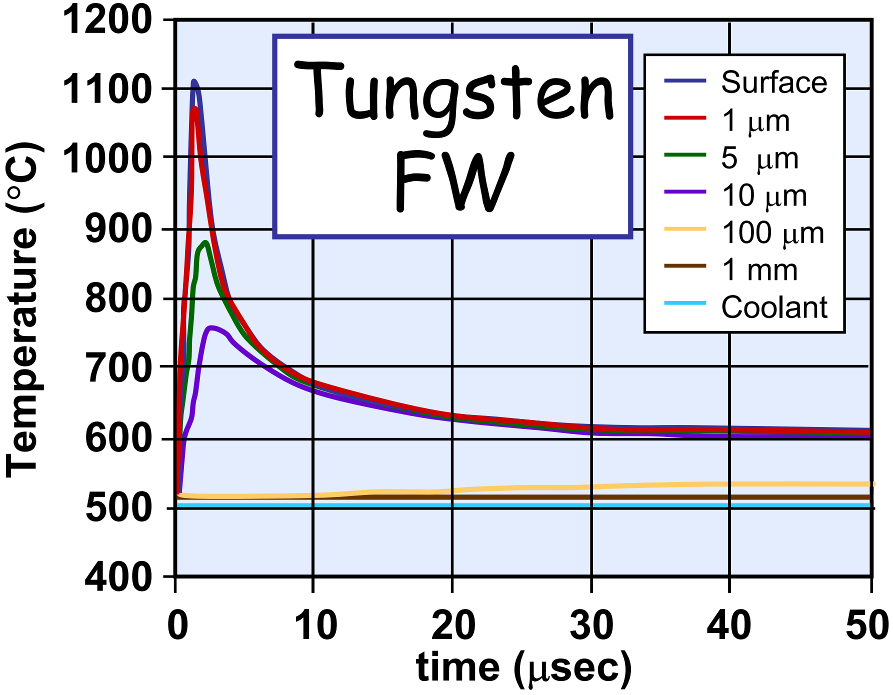
Calculations from Colombant and A.J. Schmitt

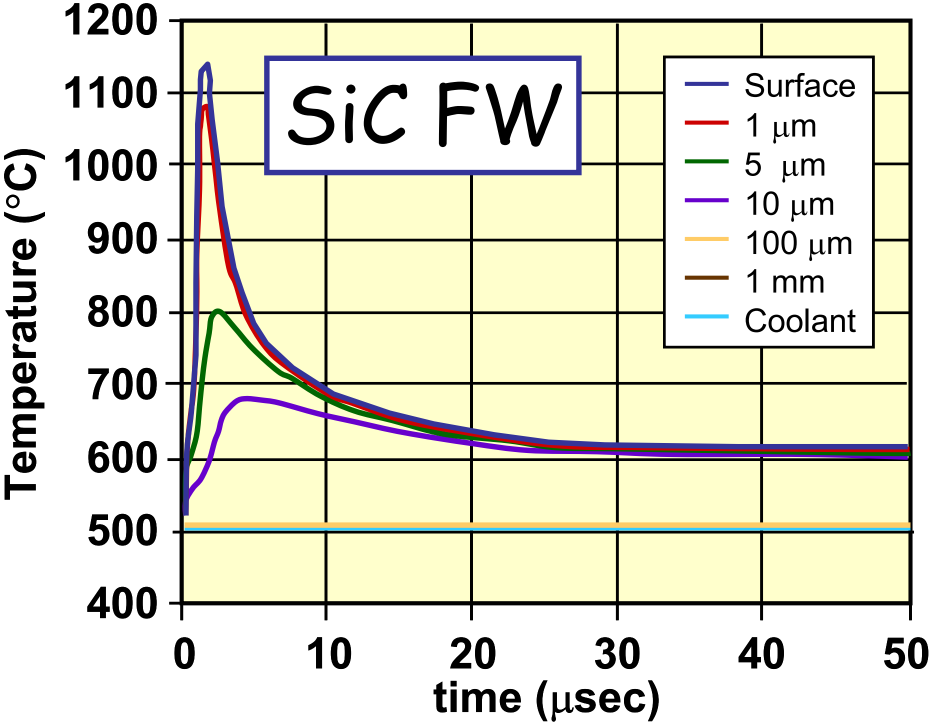
The Fusion Test Facility (Conceptual)

Laser energy:	250 - 500 kJ
Fusion power:	30 -150 MW
Rep Rate:	5 Hz (but allow for higher rep-rate bursts)
Chamber radius	5 m



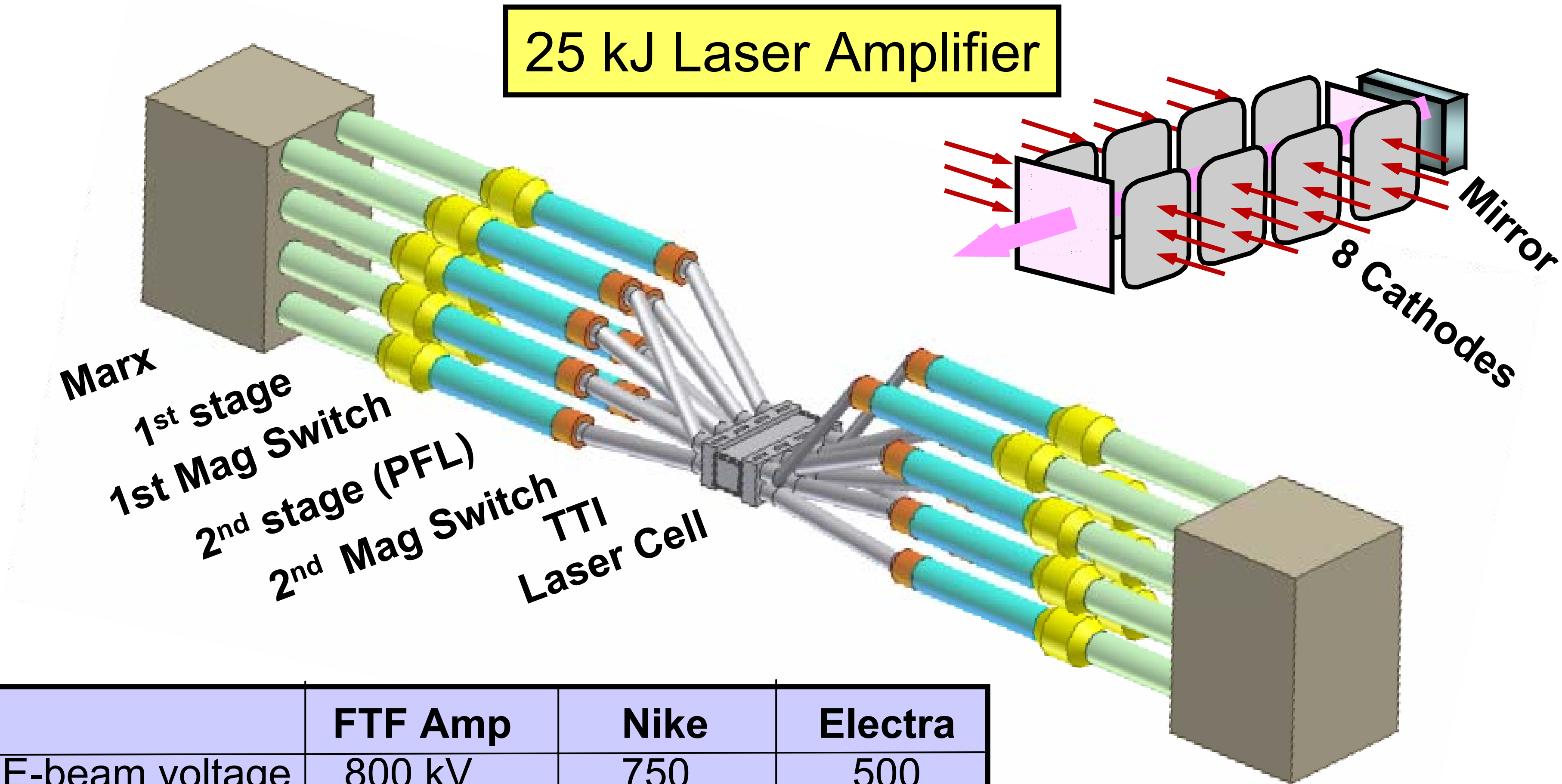
The peak temperature of the FTF first wall should be well below any thermal fatigue limit





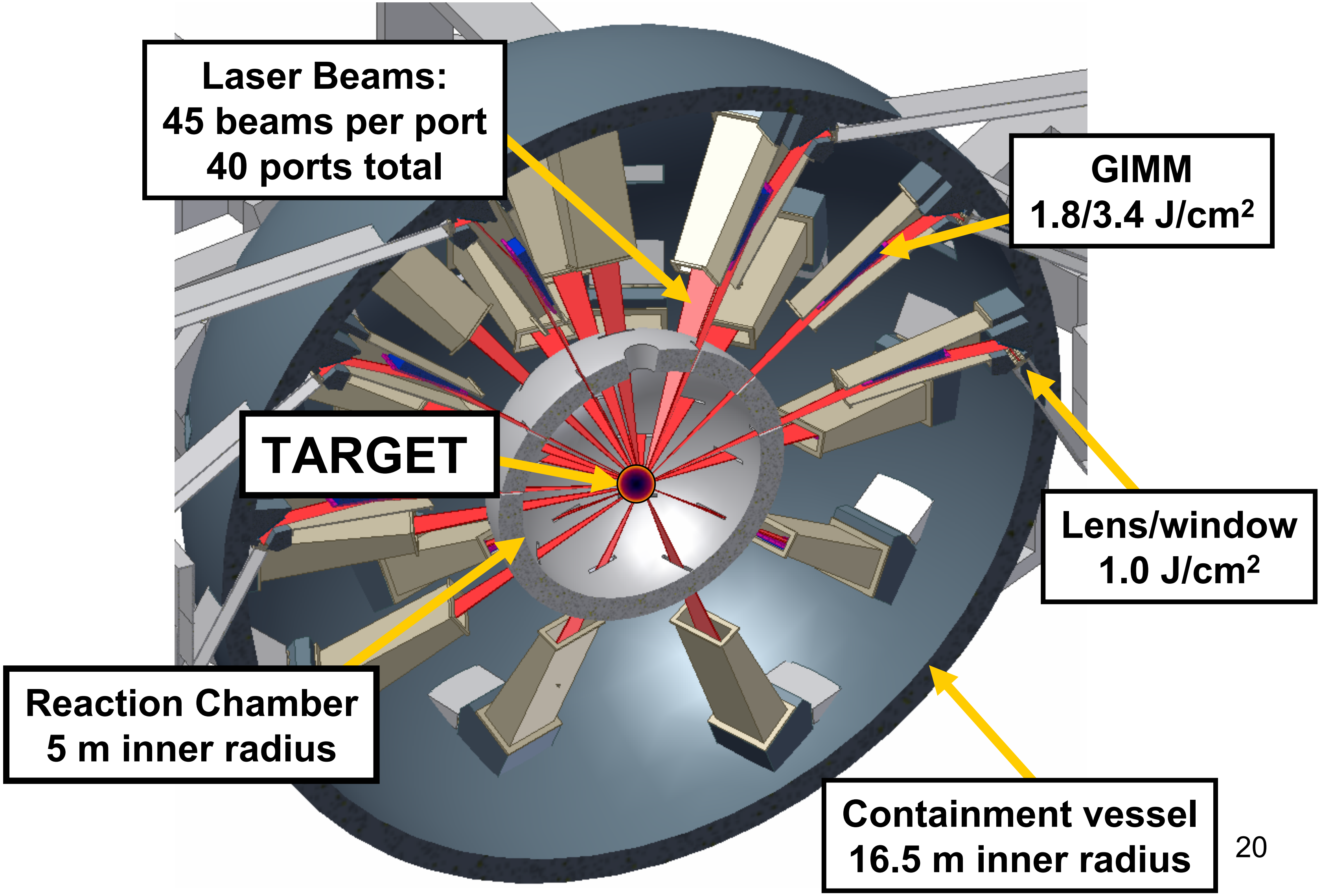
Smaller FTF targets (~ 2 mm vs ~ 4 mm) should be easier to fabricate
Lower injection velocity (~70 m/sec vs ~ 150 m/sec) helps tracking/injection

Key stresses in the FTF KrF amplifiers are within existing Electra and Nike parameters



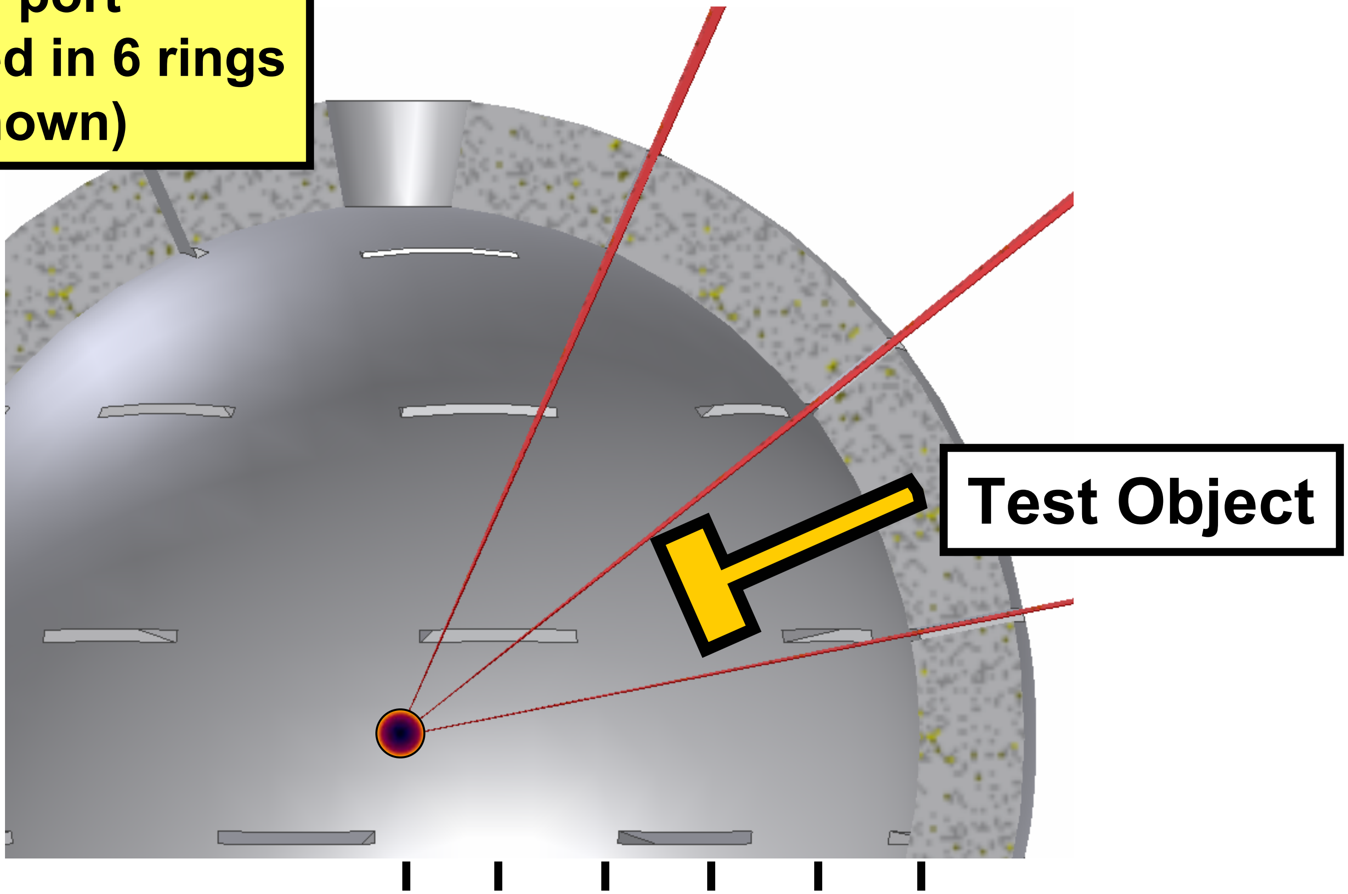
	FTF Amp	Nike	Electra
E-beam voltage	800 kV	750	500
E-beam pulse	225 nsec	225	140
Cathode size	50 x 100	60 x 200	30 x 100
Foil Load	4.1 W/cm^2	N/A	4.1
Window Load	2.5 J/cm^2	1.0	0.78

The FTF Chamber (conceptual)



There is ample room to place materials and components within the beam lines

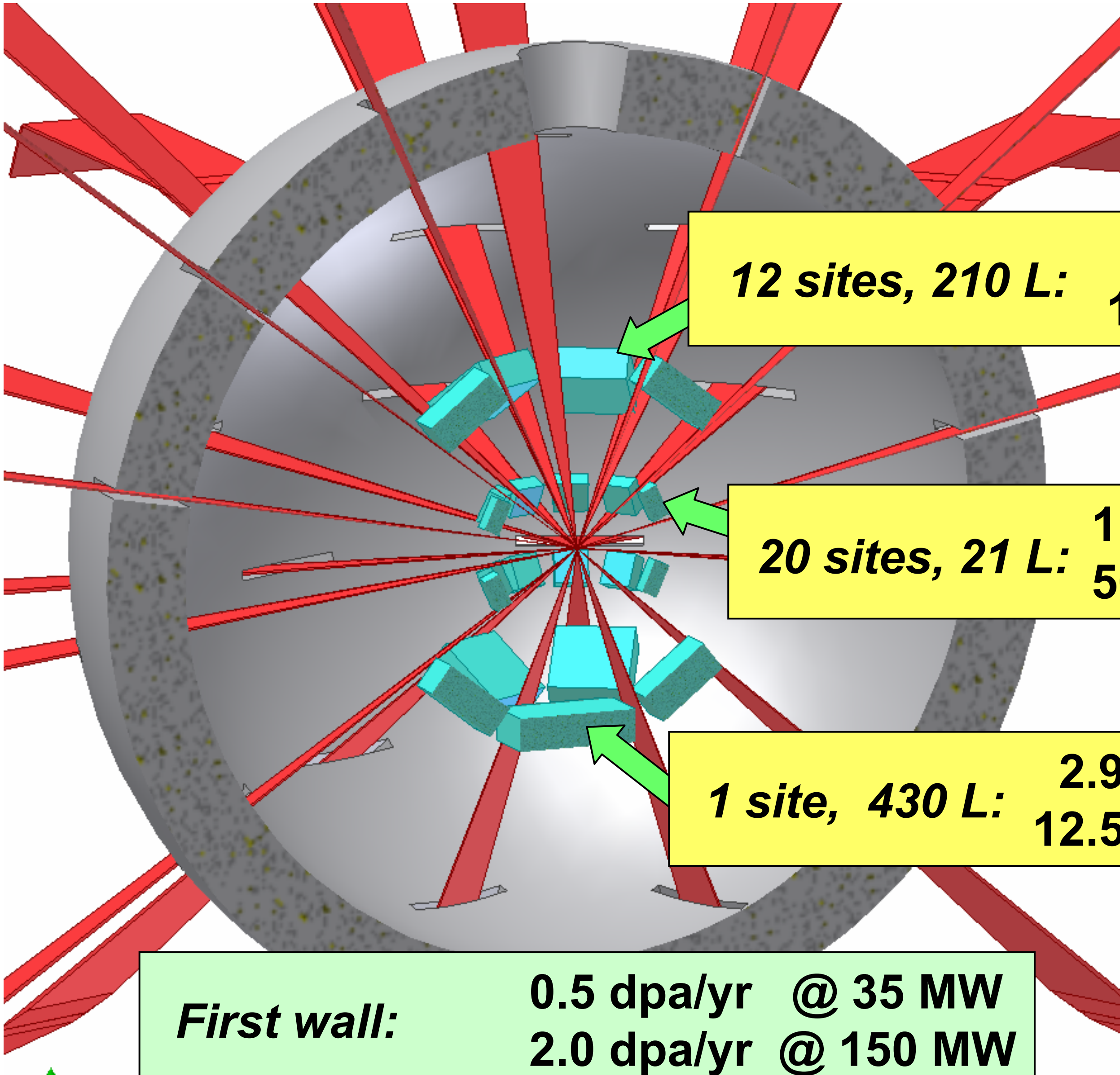
45 beams per port
Forty ports arranged in 6 rings
(only three shown)



Radius (m)	0	1	2	3	4	5
Fusion Neutron Flux (MW/m²)*		8.4	2.1	0.9	0.5	0.3

(150 MW fusion power 70% output in neutrons)

The FTF can expose materials, components, and structures to power plant level fluxes (> 10 dpa/yr)... and beyond



12 sites, 210 L: 2.9 dpa/yr @ 35 MW
12.5 dpa/yr @ 150 MW

20 sites, 21 L: 11.7 dpa//yr @ 35 MW
50.2 dpa/yr @ 150 MW

1 site, 430 L: 2.9 dpa/yr @ 35 MW
12.5 dpa/yr @ 150 MW

First wall: 0.5 dpa/yr @ 35 MW
2.0 dpa/yr @ 150 MW

(60 % availability)

The FTF can become operational by 2018

Phase I:
1999-2006

Basic laser fusion technology

- Krypton fluoride laser
- Diode-pumped solid-state laser
- Target fabrication and injection
- Chamber materials and optics

Target design & physics

- 2D/3D simulations
- 1-30 kJ laser-target exp.

Phase II
2007-2013

Develop full-size components

- Power-plant laser beamline
- Target fab/injection
- Power plant & FTF design

Ignition physics validation

- Calibrated 3D simulations
- LPI experiments

Phase III
FTF operating
~2018

Fusion Test Facility (FTF)

- 0.5 MJ laser-driven implosions @ 5 Hz
- Pellet gains ~60
- ~150 MW of fusion thermal power
- Develop chamber materials & components.
- Option to startup with 0.25 MJ laser and ~30 MW

The Fusion Test Facility concept looks attractive

On the path to develop an attractive, conceptually simple approach to fusion energy (direct drive + lasers)

Experimental validation & optimization of Laser IFE target physics.

Develop materials and components for both Laser-Based IFE and MFE