Laser Fusion Energy and The High Average Power Program

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Dec 13, 2004

Warning!!!

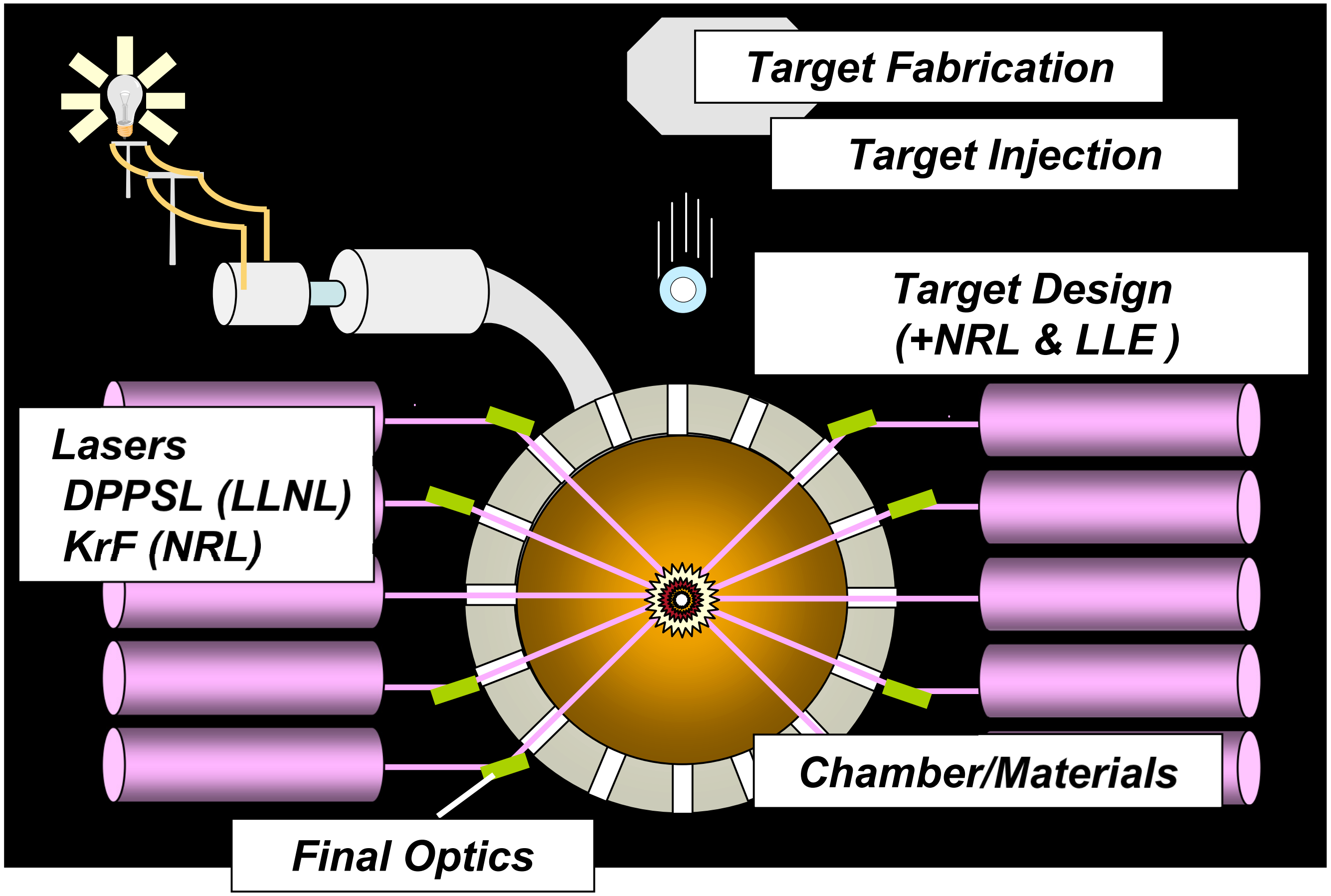
This talk is free of perspectives, promises, plans, and paths

HAPL Results vs Phase I Goals drafted at Snowmass 2002

(highlighting what's new 2004)

The HAPL Program is developing the science and technology for Inertial Fusion Energy *with lasers, direct drive targets and solid wall chambers*

6 Government labs, 9 Universities, 13 Industries



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. PPPL
7. UC Santa Barbara
8. UNC

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

HAPL meeting at Princeton, Oct 2004: 67 participants, 34 talks, 10 posters

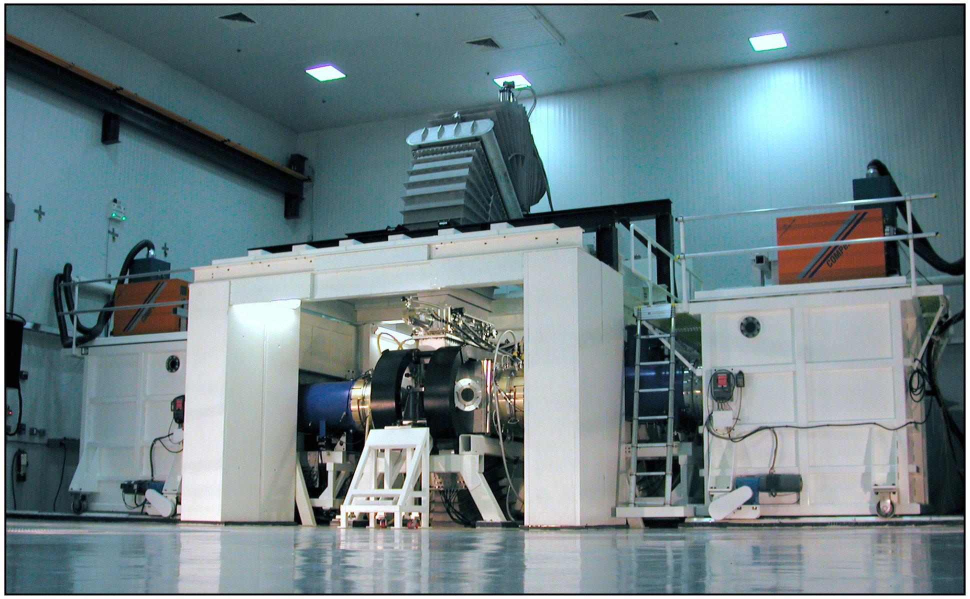
Laser(s) Goals

1. Develop technologies that can meet the fusion energy requirements for:
   1. Efficiency (> 6% total)
   2. Repetition rate (5-10 Hz)
   3. Durability (Phase I goal > 100,000 shots continuous)
   4. Wavelength
   5. Laser beam quality
   6. Pulse shaping

2. Laser technologies must:
   1. Scale to reactor size laser modules
   2. Project to have attractive costs for commercial fusion energy.

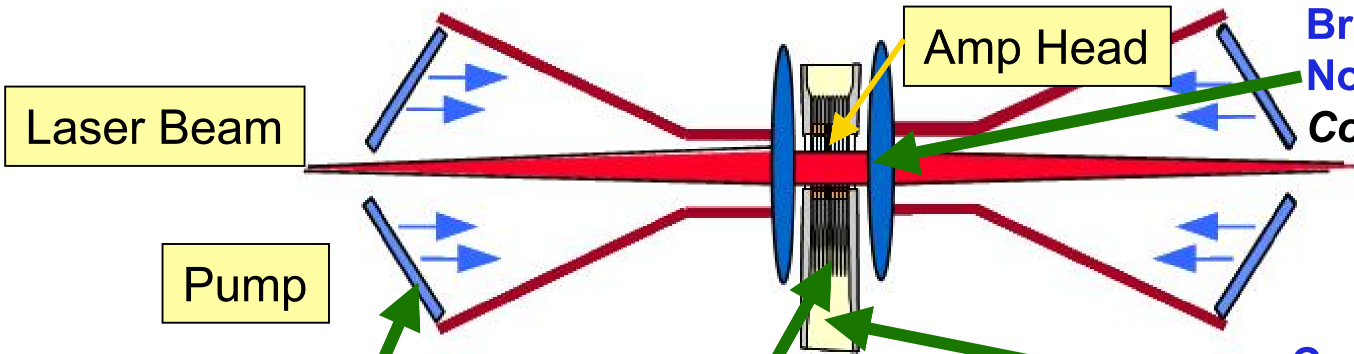
The HAPL Program is developing two types of Lasers

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



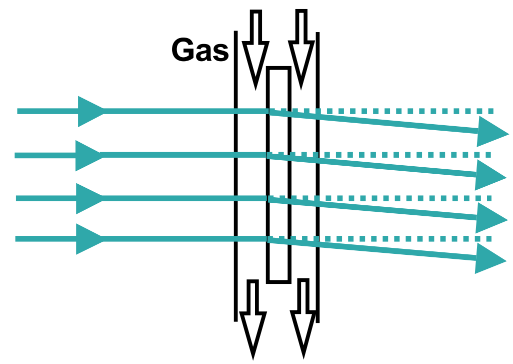
DPSSL (Mercury-LLNL)
Diode pumped solid state laser

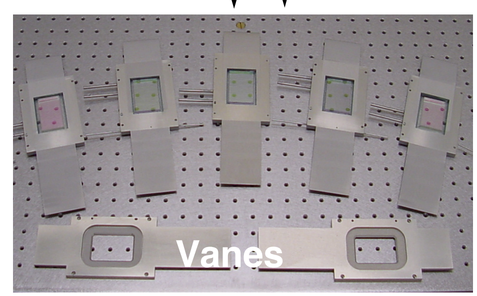
LLNL has developed four major components needed to develop a DPPSL laser for IFE



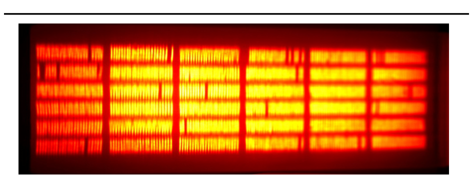
Brewster's angle → Normal incidence
Compact arrangement

Convective cooling → Forced gas
Allows 10 Hz operation

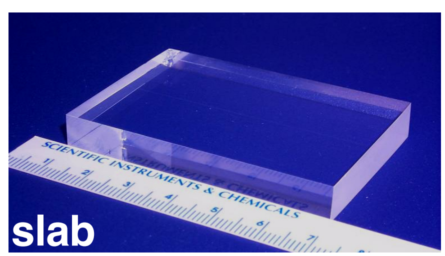




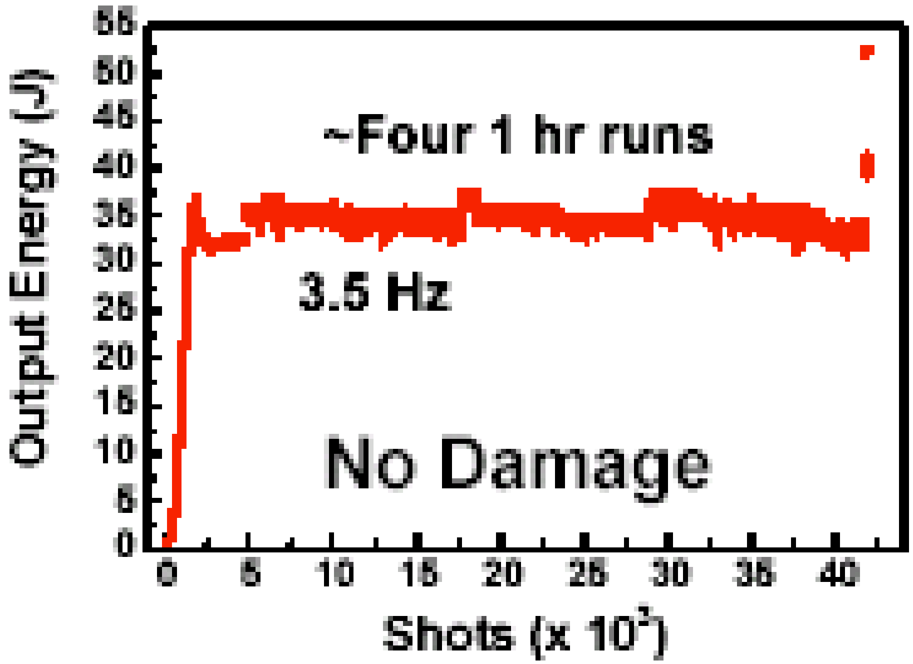
Flash lamps → Laser diodes
Higher efficiency and reliability



Nd:glass → Yb:crystals
Increased energy storage and efficiency



Mercury has produced up 34 J per pulse at 3.5 Hz (120 W) in several hour long runs

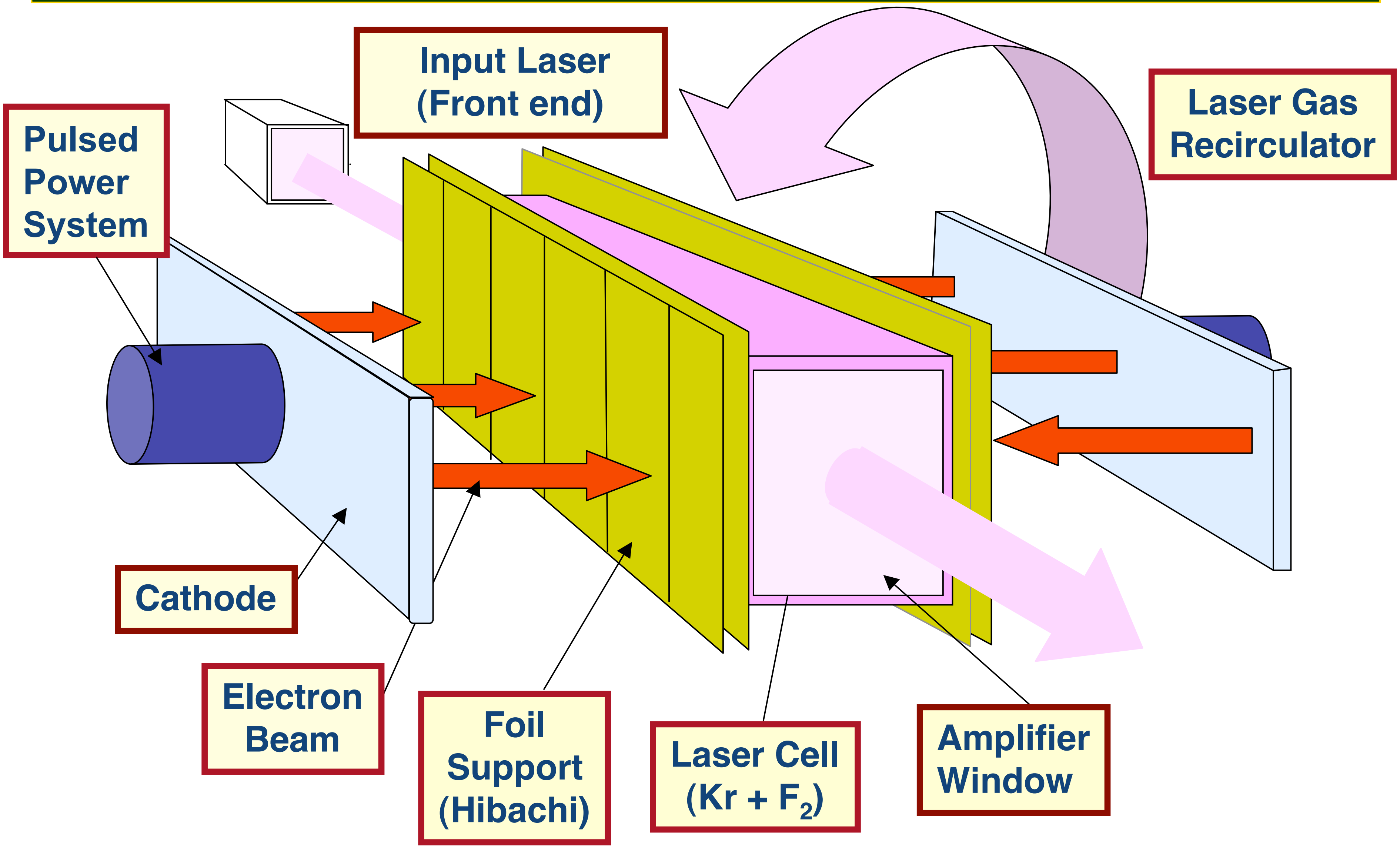


Goals for Mercury

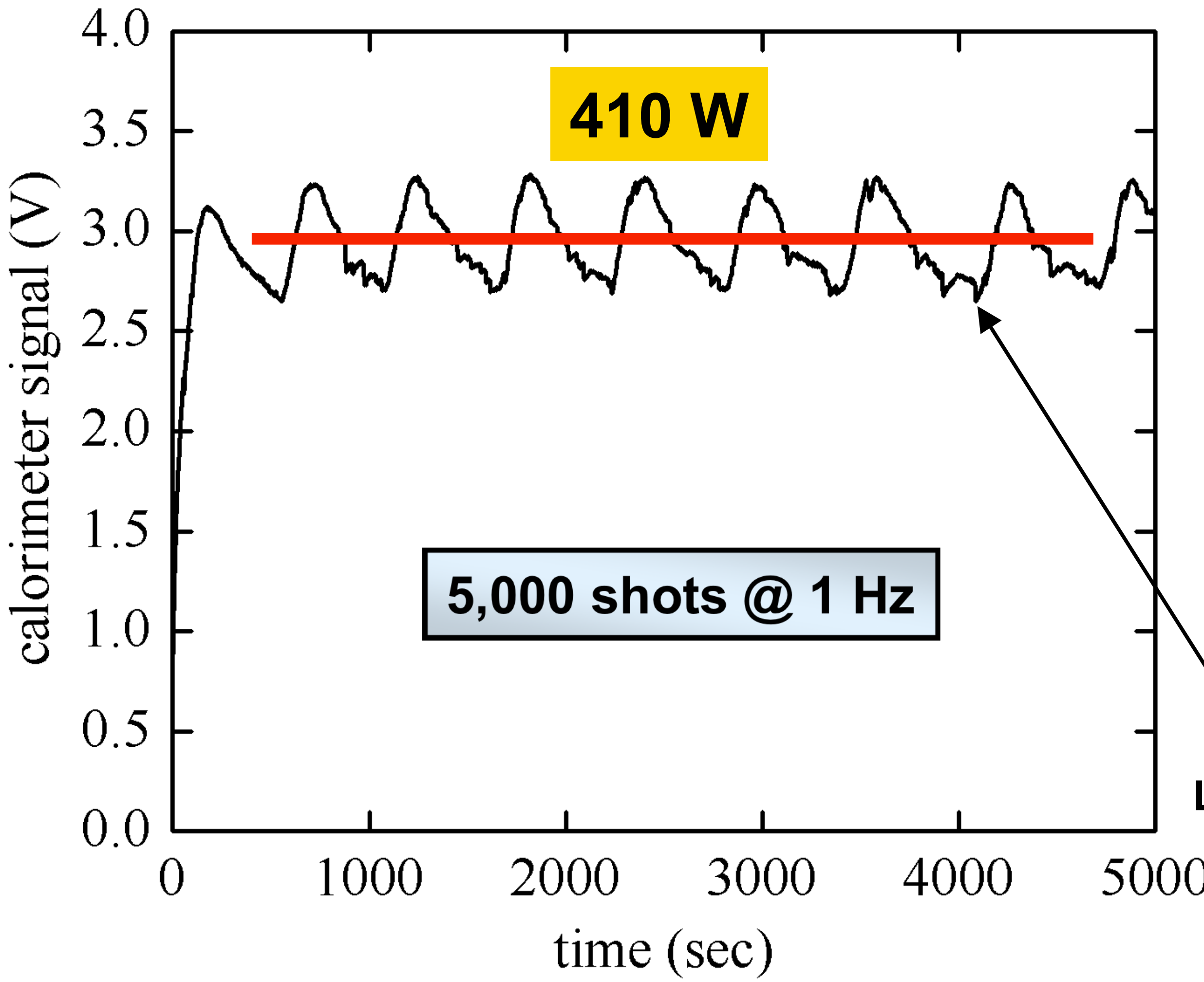
- 100 J at 1ω (λ = 1.053 μm)
- 10 Hz
- 10% efficiency at 1 ω
- 3 ns
- 5x diffraction-limited

Notes:
Results at fundamental wavelength λ = 1.053 micron
Expect 85% conversion efficiency at 2 ω
Expect 75% conversion efficiency at 3 ω

Key Components of an electron-beam pumped KrF Laser (λ = 248 nm)



Electra's main oscillator has produced > 400J/shot @ 1 Hz continuously for 5000 shots (more than 1 hour)



Laser energy constant
Fluctuation due to calorimeter cooling system

Electra progress on Phase I goals--

- **BEAM UNIFORMITY: Demonstrated 1.2% (not yet rep-rated)**

- **REP RATE: 400 - 700 J/pulse @ 1 Hz and 5 Hz**

- **EFFICIENCY: Predict > 7% wall plug, based on:**
  - **Observed KrF intrinsic efficiency (> 12%)**
  - **Newly developed high efficiency hibachi (> 80% e-beam into gas)**
  - **New advanced solid state switch (pulsed power > 85% efficient)**

- **COST**
  - **Pulsed power system using new switch (< $10.00/e-beam Joule)**
  - **Working on high confidence costing for entire system**

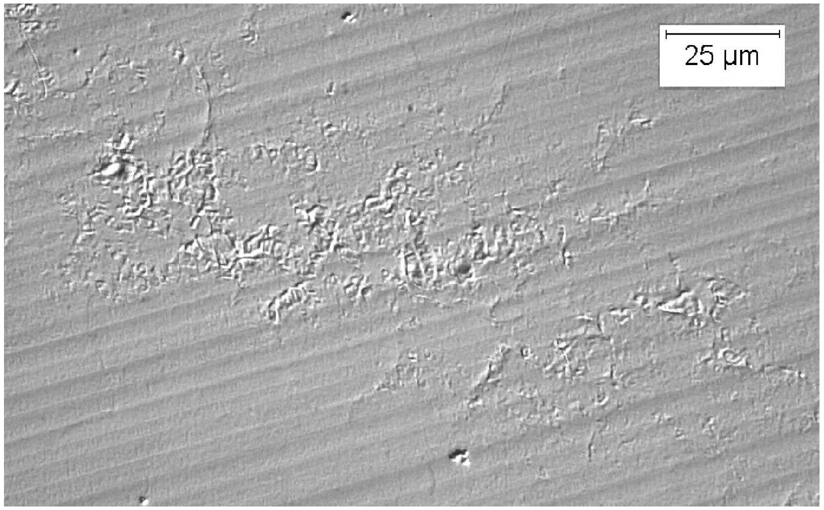
- **DURABILITY:**
  - **New advanced switch leads to an all solid state electrical system**
  - **Remaining major challenge: Hibachi foil lifetime @ 5 Hz**
    - ***Deflecting laser gas or mist cooling promising***

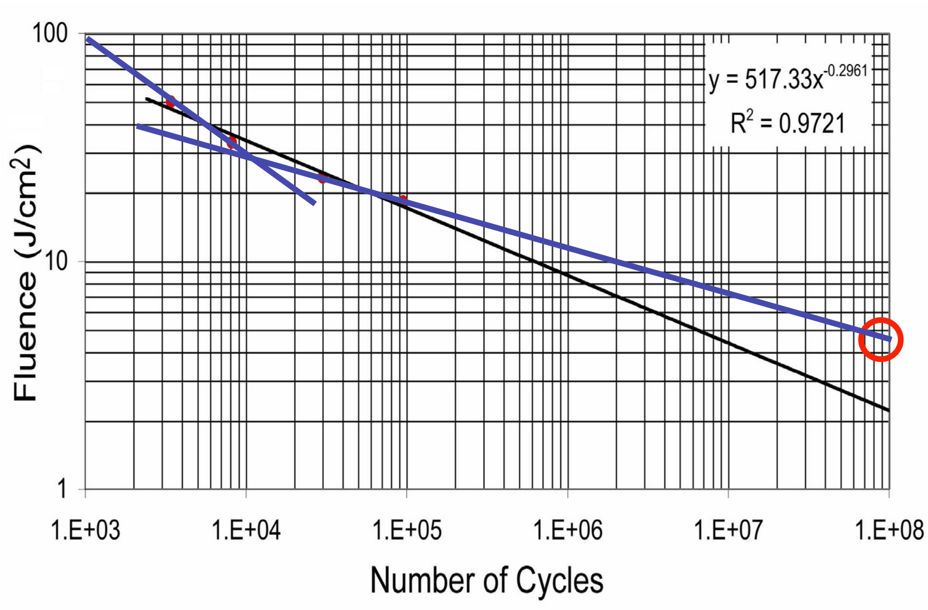
Final Optics Goals

1. Meet Laser induced damage threshold (LIDT) requirements of more than 5 Joules/cm^2, in large area optics

2. Develop a credible final optics design that is resistant to degradation from
   1. X-rays
   2. Energetic ions
   3. Debris
   4. Contamination
   5. Neutrons

Diamond-turned, electroplated mirrors survived 10^5 shots at 18 J/cm^2 on a small scale (mm^2)





What's left

- **verify with larger spot sizes**
- **Improve high-cycle fatigue behavior**
- **validate fabrication**

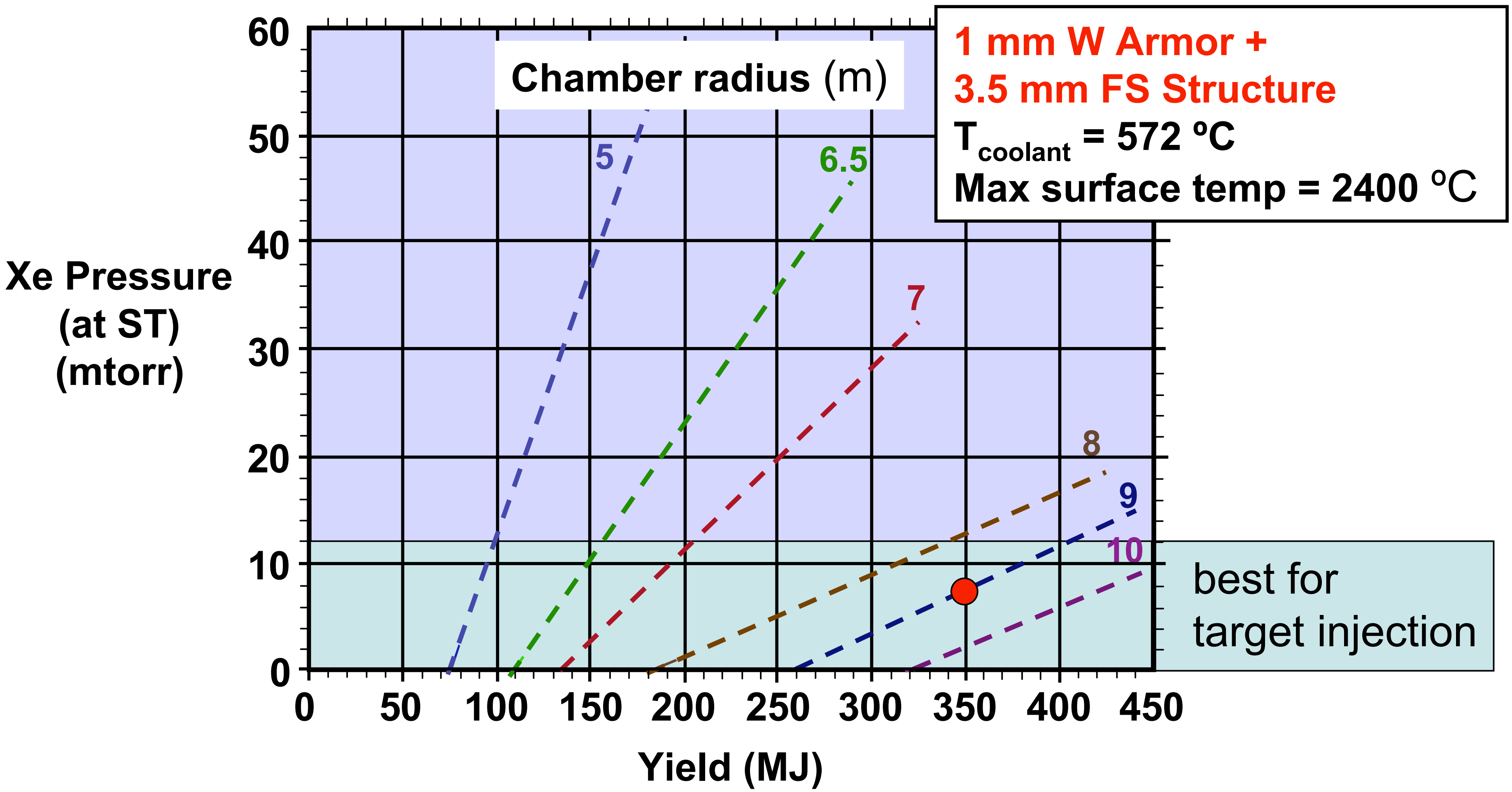
M. Tillack (UCSD)

Chamber Goals

1. Develop a viable first wall concept for a fusion power plant

2. Produce a viable "point design" for a fusion power plant

Chamber operating window that meets requirements for short term wall survival (> 1000's shots) and target injection



R. Raffray (UCSD)

What's left in establishing a viable chamber concept?

1) Chamber clearing: SPARTAN (UCSD)

2) Settle Chamber/Blanket interface: (UCSD/WISC team)
   Self cooled Li: ~ 46%
   Ceramic breeder: 36%
   Dual coolant: He + Pb/Li: 40-45% (in progress)

3) Long Term Wall Survival (ORNL/SNL/LLNL/WISC)

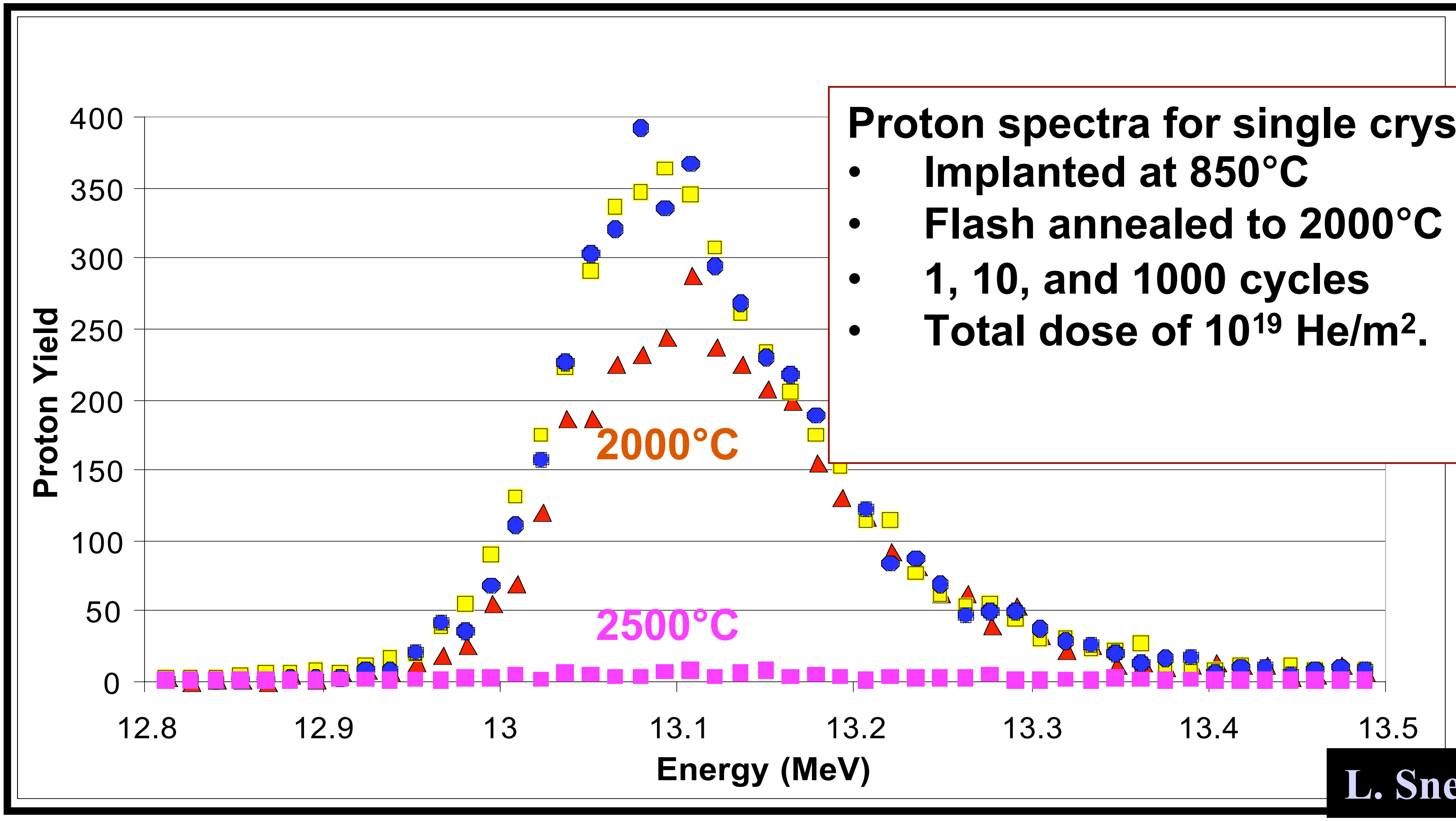
   a) Helium retention
   b) Bonding W to Steel base
   c) Thermo-mechanical Fatigue

Helium Retention: Experiments indicate He not a problem at IFE Conditions

Amount of retained helium is lowered significantly when:

Dose is spread out over large number of cycles

Sample is flash annealed to prototypical temperatures

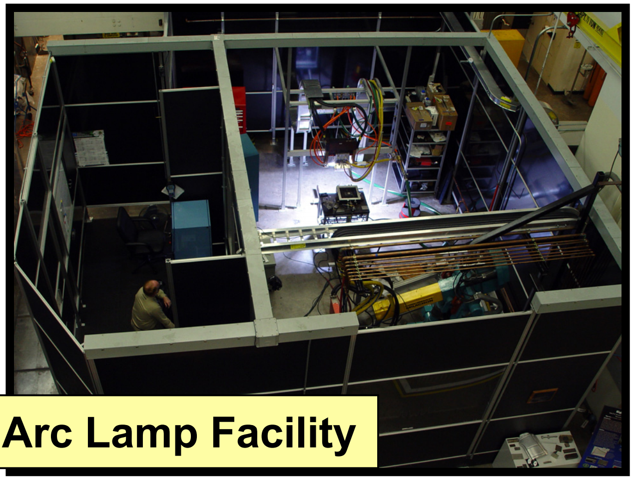


Proton spectra for single crystal tungsten

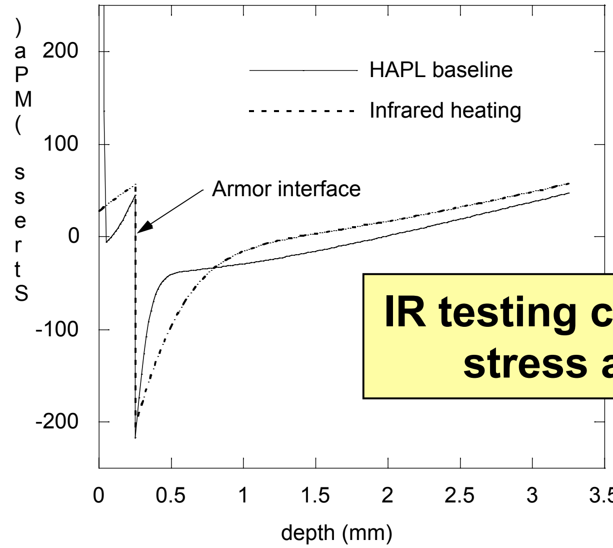
- **Implanted at 850°C**
- **Flash annealed to 2000°C (or 2500 °C)**
- **1, 10, and 1000 cycles**
- **Total dose of 10^{19} He/m^2.**

L. Snead (ORNL)

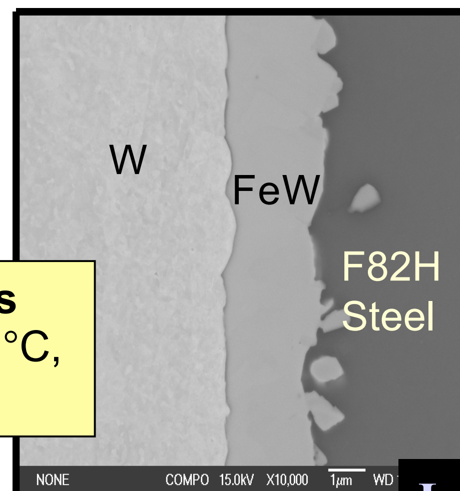
Bond strength: Preliminary results encouraging, based on "simulation" experiments with Oak Ridge High Intensity Infrared Arc Lamp



Arc Lamp Facility



IR testing closely matches stress at interface.



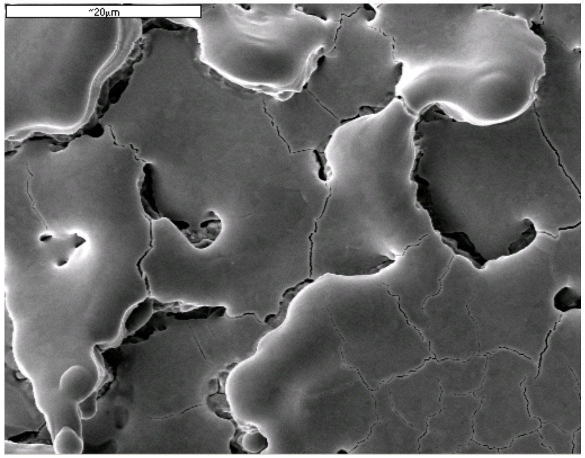
No degradation of bond after 10,000 cycles
(note interface temperature was too high at 900 °C, indicating lamp too intense)

L. Snead (ORNL)

Thermo-mechanical fatigue still unresolved

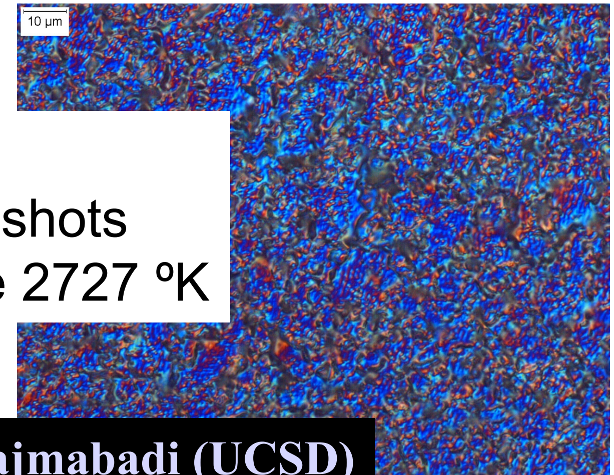
Cracks seen in surface of Tungsten after multiple exposures

ions
1,600 shots
1.5 J/cm^2



T. Renk (Sandia)

laser
10,000 shots
Surface 2727 ºK



F. Najmabadi (UCSD)

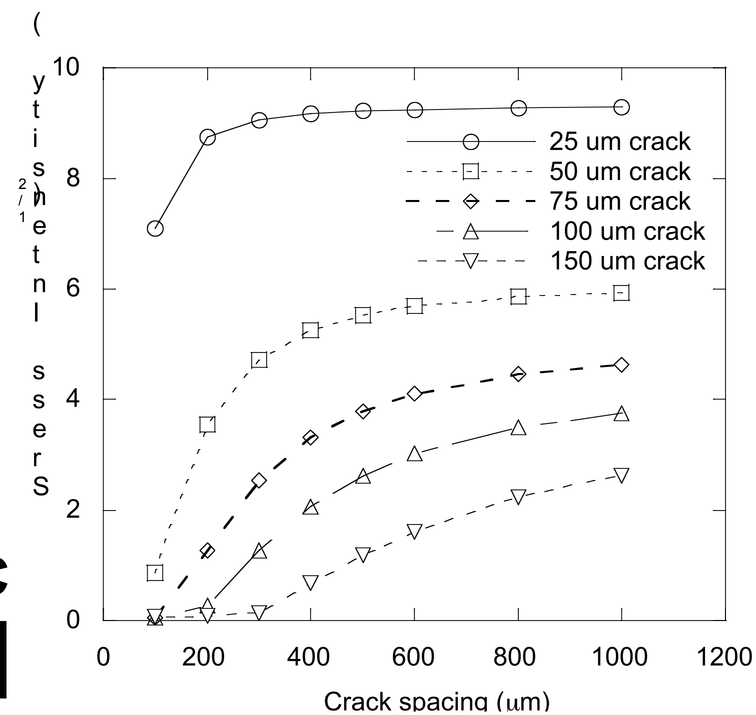
But,

a) cracks should stop before they get to substrate

b) pre "castellating" surface arrests cracks at a shallower depth

c) FW surface temp lowered to 2400 ºC

J. Blanchard (Wisc)

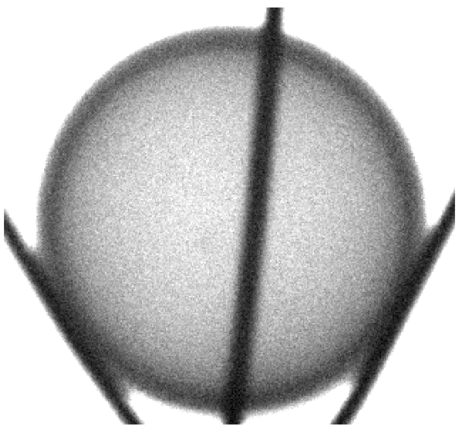


Target Fabrication Goals

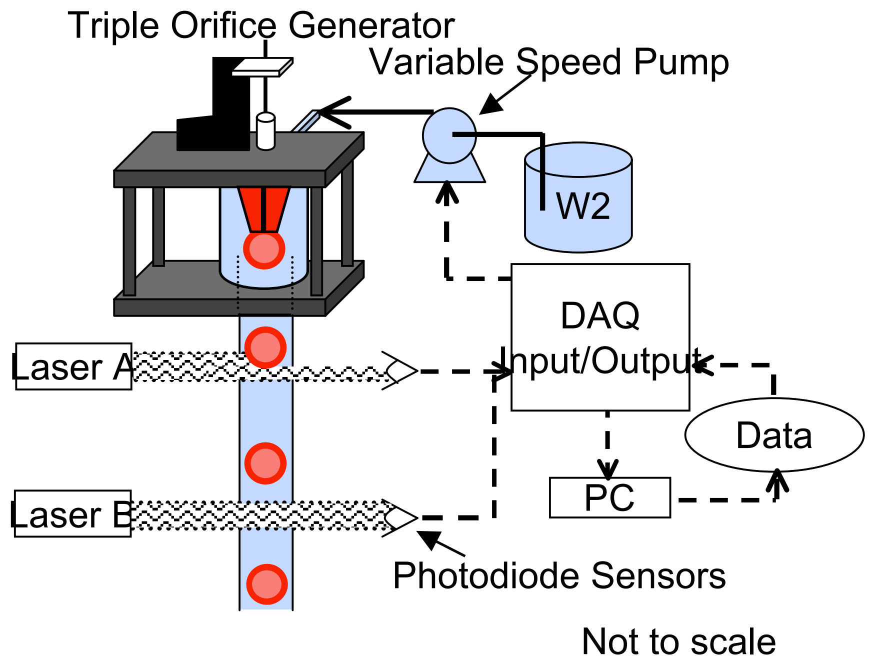
1. Develop mass production methods to fabricate cryogenic DT targets that meet the requirements of the target design codes and chamber design.   Includes characterization.

2. Combine these methods with established mass production costing models to project targets cost will be less than $0.25.

Produced 22 shells/min, 5 mm diameter, +/- 40 um (< 1 %)
Automatic feedback process controls shell diameter



X-Ray picture of batch produced foam shell 4 mm dia, 400 μ wall



Big issue non concentricity-- currently < 5%, but need better

B. Vermillion (GA) & D. Schroen and J, Streit (Schaffer)

Target Injection & Tracking Goals

1. Build an injector that can place targets at chamber center (r = 6 - 9 m) in 25 milliseconds or less (400 m/sec). *(time determined by target survival and chamber clearing considerations)*

2. Demonstrate target tracking with sufficient accuracy for a power plant (*estimated to be +/- ~~20~~ 100 microns*).

Light gas gun target injector at General Atomics

Achieved required velocity (400 m/sec)
Demonstrated separable sabot
Placement accuracy of +/- 20 mm
Jitter 0.5 msec
NOW BEING USED TO DEVELOP TRACKING SYSTEMS

R. Petzoldt (GA)

Target Design Goals

(in conjunction with NRL and LLE ICF Programs)

1. Develop credible target designs, using 2D and 3D modeling, that have sufficient gain (> 100) and stability for fusion energy.

2. Benchmark underlying codes with experiments on Nike & Omega.

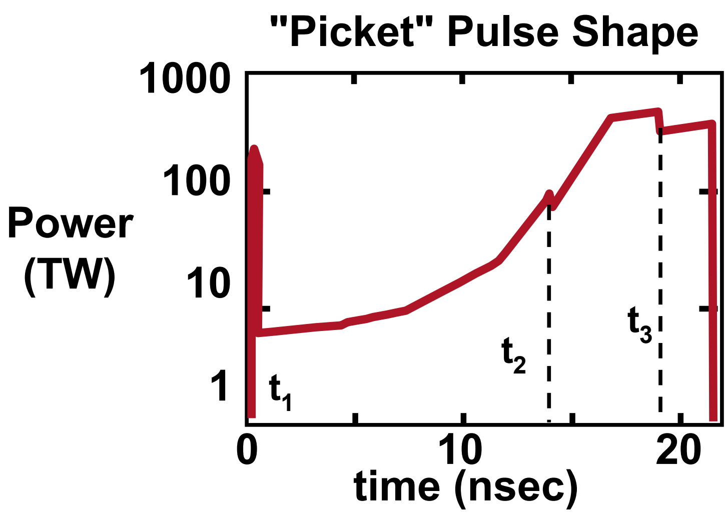
3. Integrate design into needs of target fabrication, injection, and chamber.

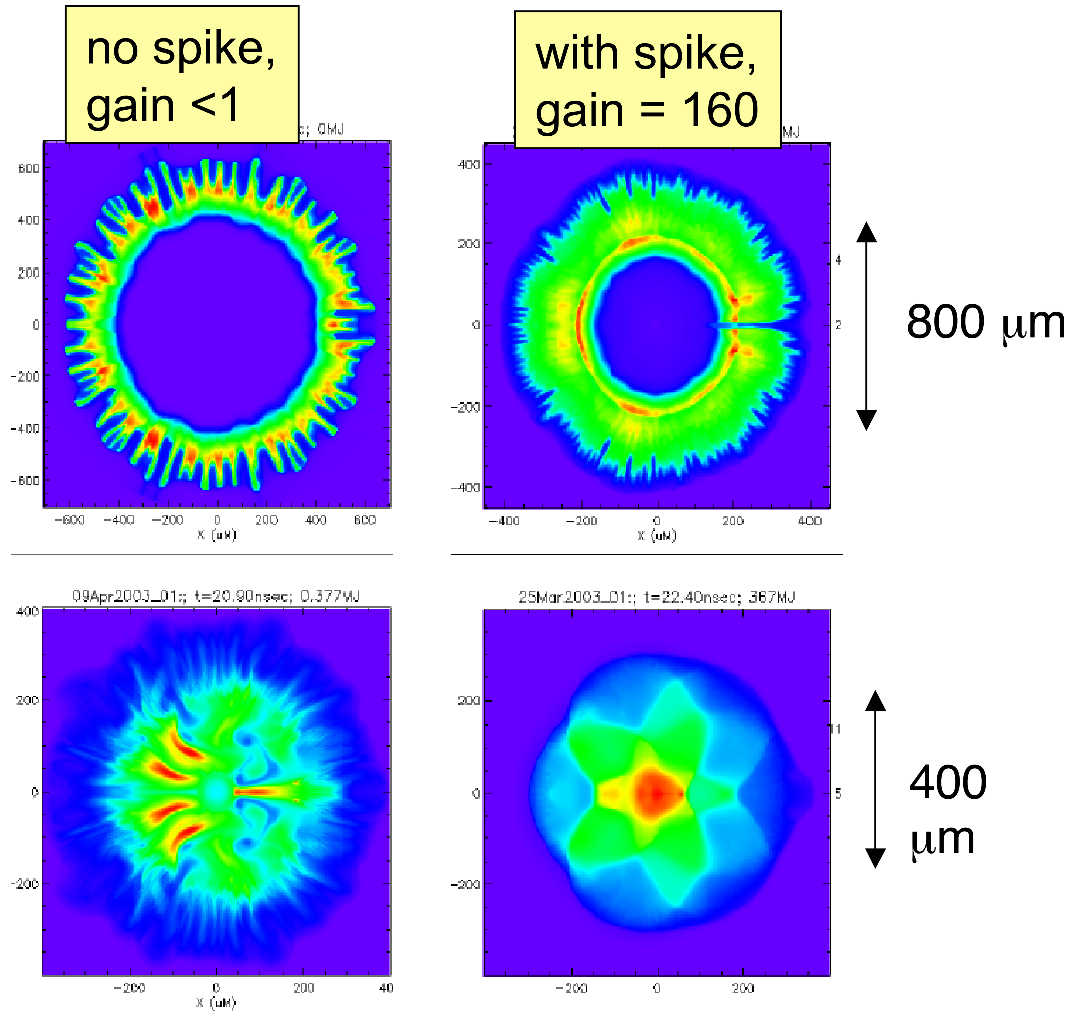
Current designs (LLE, LLNL & NRL) have gains > 100 (~2D). All use DT+ foam ablator, and prepulse spike for adiabat control / imprint reduction

NRL FAST Code (Benchmarked with experiments on Nike)

High resolution 2D calculations that account for both laser and target non-uniformity

Laser 2.5 MJ

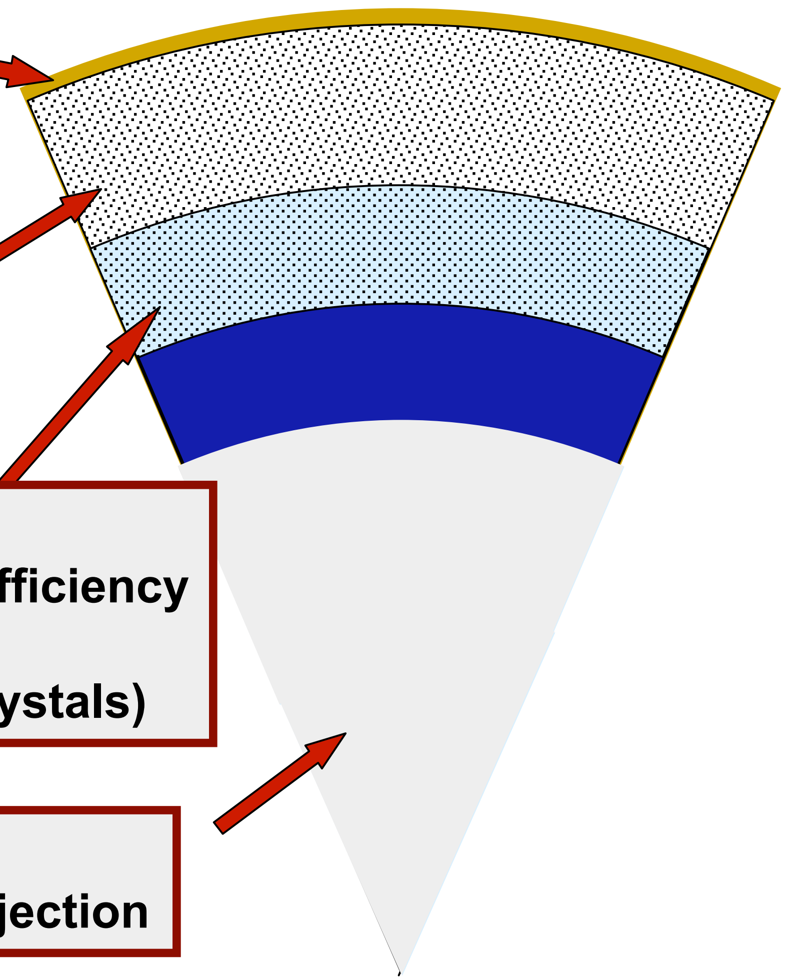




The design has sufficient flexibility to optimize the target physics along with the IFE requirements:

High Z (gold) outer layer
- Reduces laser imprint-NRL exp't
- Reflects IR during injection

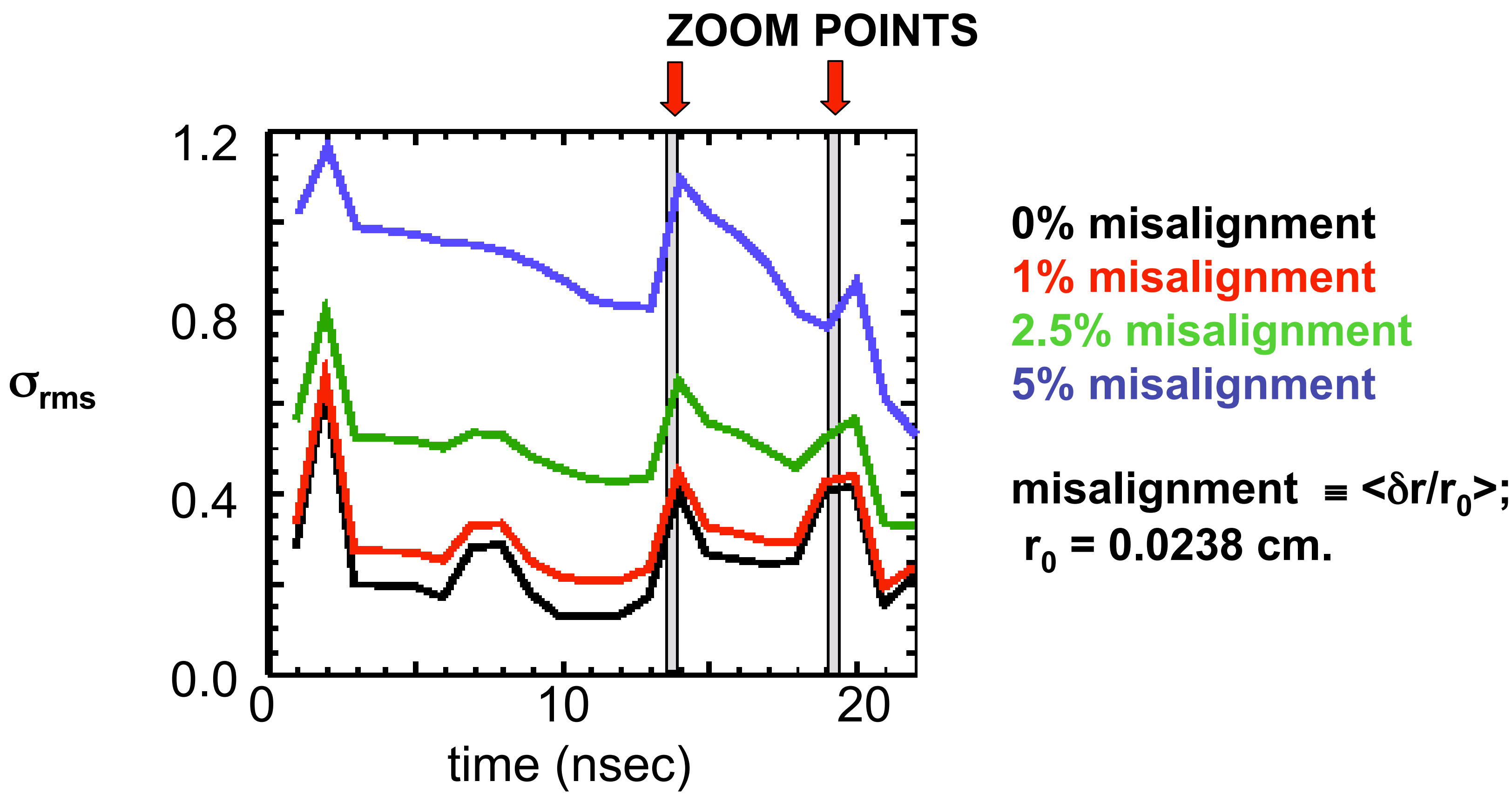
Empty foam outer layer:
- Insulates target during injection



DT + Foam ablator
- Increased absorption and implosion efficiency
- Mechanically stronger target
- Improves inner ice surface (smaller crystals)

Colder DT Ice fuel layer
- Helps survival during injection

We have developed a low-noise ray tracing module to evaluate gain sensitivity to laser-target misalignments



For 60 beam geometry, typical results indicate pointing accuracy should be better than ~100µm in order to keep _rms < 1 %.

A full 3D beam ray tracing module is under development [*D. Eimerl, et al.*],

We are nearing the goals for the Basic Science and Technology Phase of the Program to Develop laser Fusion Energy

HAPL PROGRAM

IFE components

- Krypton fluoride laser
- Diode pumped solid state laser
- Target fabrication & injection
- Final optics
- Chambers materials
- Chamber design

ICF PROGRAM

Target Design & Physics

2D/3D simulations

- Laser-target expts