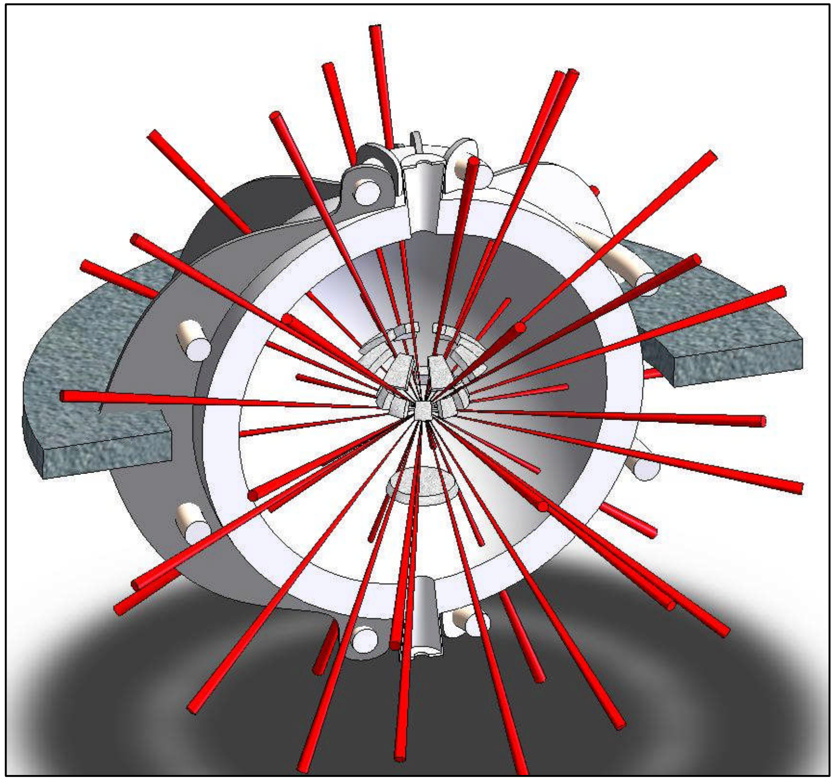
A Fusion Test Facility for Inertial Fusion

The Fusion Test Facility would be part of an integrated IFE program where the essential elements are developed and implemented as systems in progressively more capable IFE oriented facilities.



Fusion Test Facility (FTF)

- Direct laser drive
- Sub-megaJoule laser energy
- Goal of ~150 MW fusion power
- High flux neutron source
- Development path to a power plant

Presented by Stephen Obenschain
U.S. Naval Research Laboratory
September 27 2006
Fusion Power Associates Meeting

Introduction

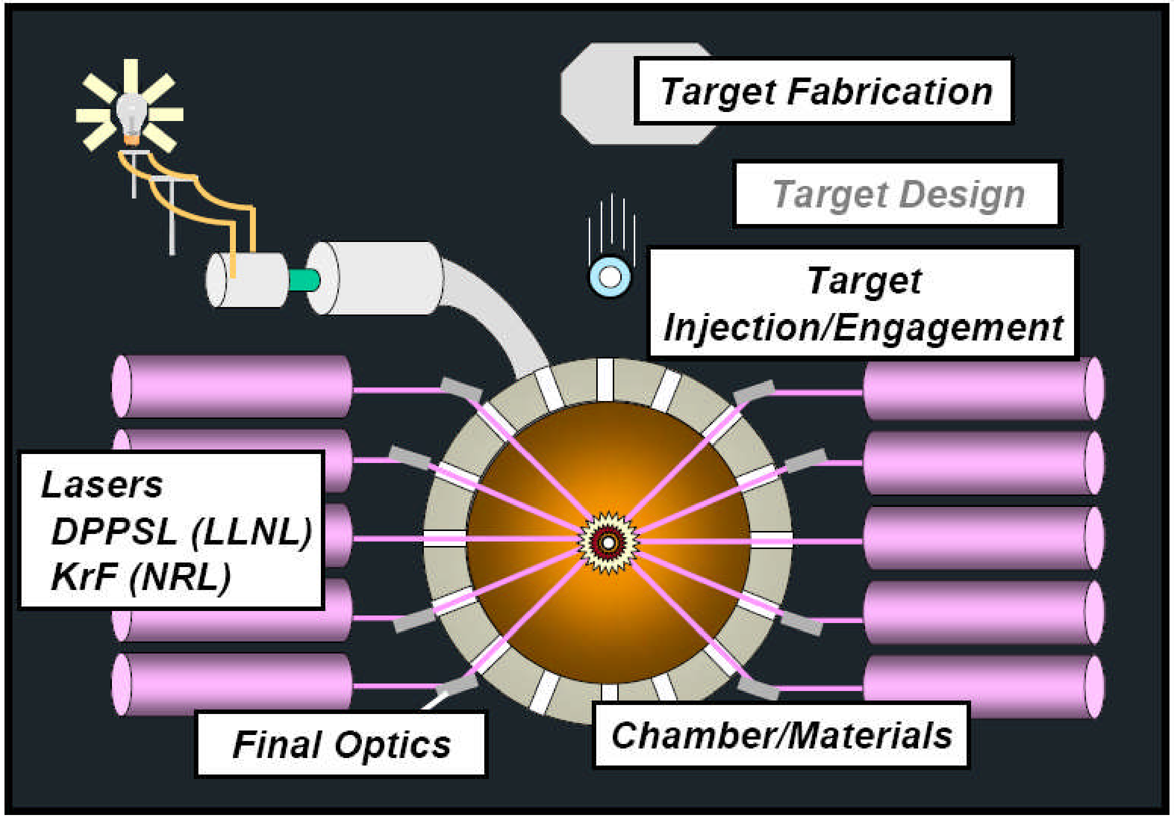
The scientific underpinnings for ICF has and is being developed via large single shot facilities.

The IFE application, while greatly benefiting from this effort, requires a different and broader perspective.

- Development of sufficiently efficient and durable high repetition rate drivers.
- High gain target designs consistent with the energy application.
- Development of economical mass production techniques for targets.
- Precision target injection, tracking & laser beam steering.
- Reaction chamber design and materials for a harsh environment.
- Operating procedures (synchronizing a complex high duty cycle operation)
- Overall economics, development time and costs.

Individual IFE elements have conflicts in their optimization, and have to be developed in concert with their own purpose-built facilities.

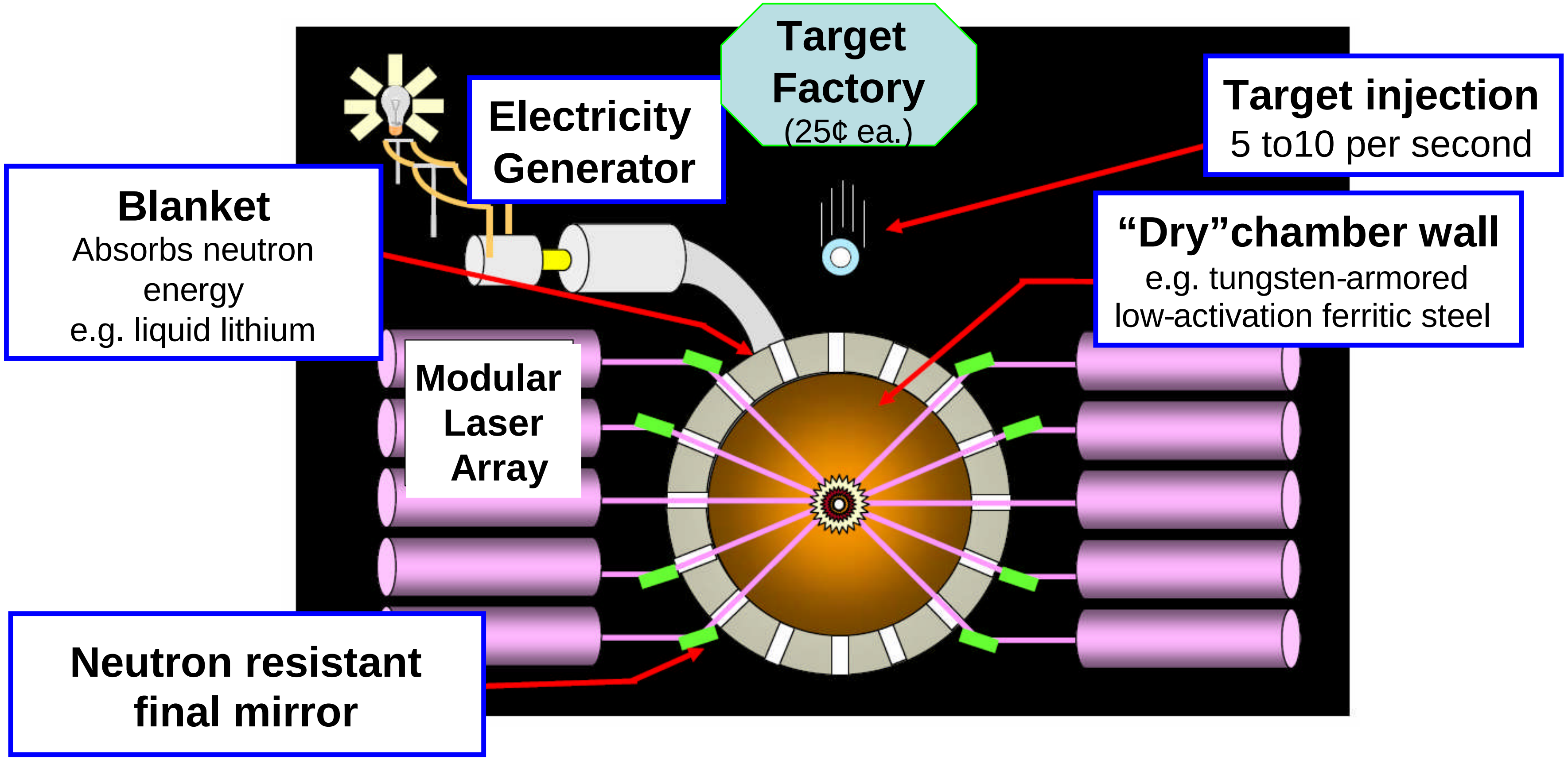
The HAPL Program: Developing the science & technologies needed for laser fusion energy



HAPL= $25M/yr High Average Power Laser program administered by NNSA

See presentations by John Sethian and John Caird this afternoon.

Typical GW (electrical)designs have >3 MJ laser drivers @ 5-10 Hz



Target Factory
(25¢ ea.)

Electricity Generator

Target injection
5 to10 per second

Blanket
Absorbs neutron energy
e.g. liquid lithium

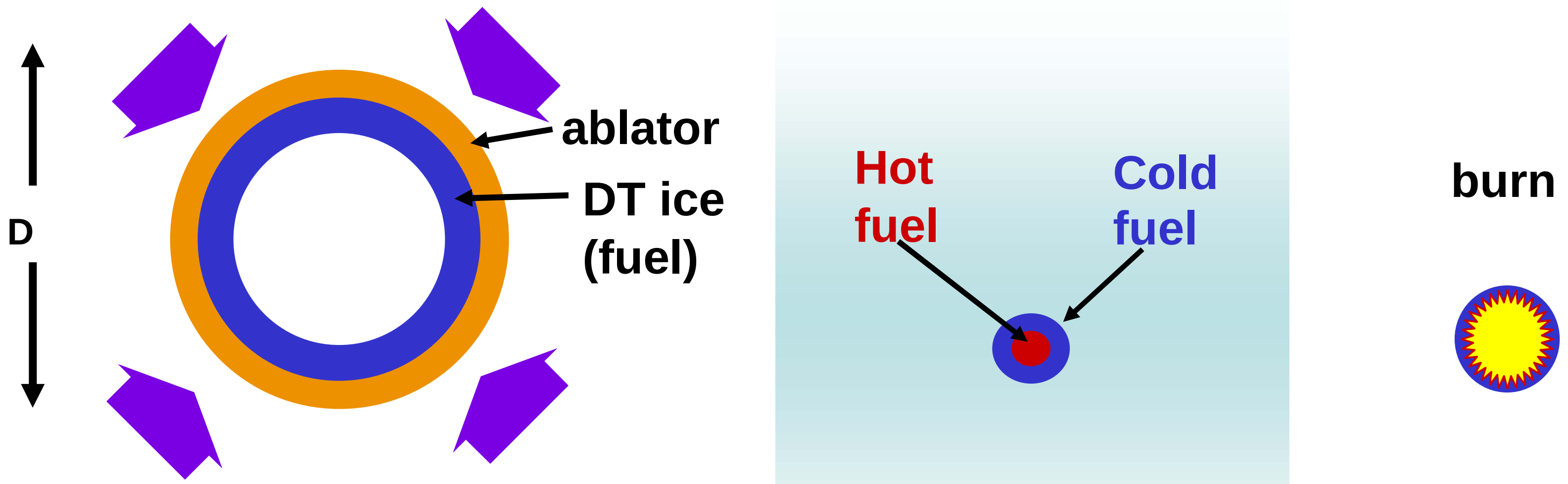
“Dry”chamber wall
e.g. tungsten-armored
low-activation ferritic steel

Modular Laser Array

Neutron resistant final mirror

Can we construct a facility that provides the needed information to design a power plant with a substantially smaller laser driver?

How to reduce substantially laser energy with direct laser drive



Pellet shell imploded by laser ablation to v ≅ 300 km/sec for >MJ designs

- 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
- Use deep UV light and large $\Delta\omega$

Deep UV laser should allow increased ablation pressure and robust pellet designs at reduced energy

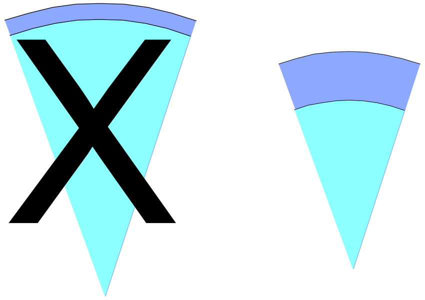
Laser plasma instability limits peak $I\lambda^2$

P scales approximately as $I^{7/9}\lambda^{-2/9}$

→ P_{MAX} scales as $\lambda^{-16/9}$

Factor of $(351/248)^{-16/9} = 1.85$ advantage for KrF's deeper UV over frequency-tripled Nd-glass

High ablation pressure (>200 MB) available with KrF allows one to achieve the high implosion velocity with low aspect ratio targets that are more resistant to hydrodynamic instability



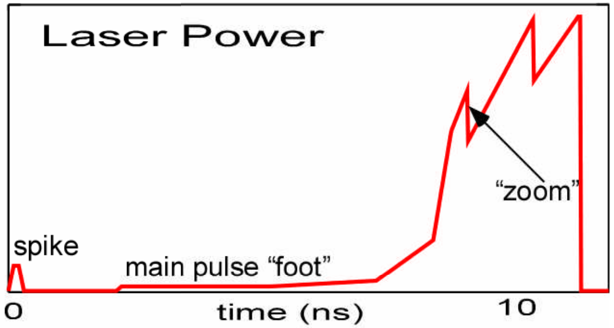
RT exponential growth $\propto$ **(2kd) ½**

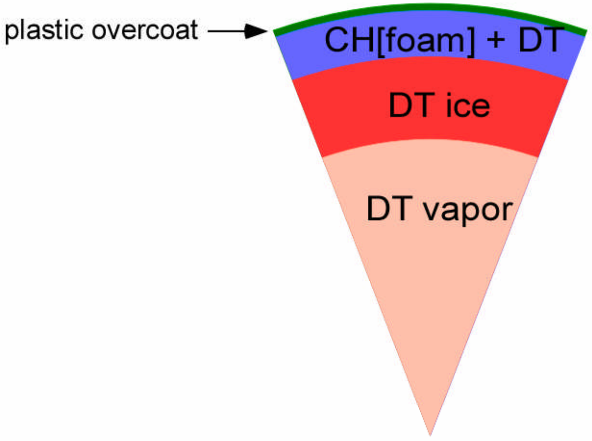
where d is the distance traveled.

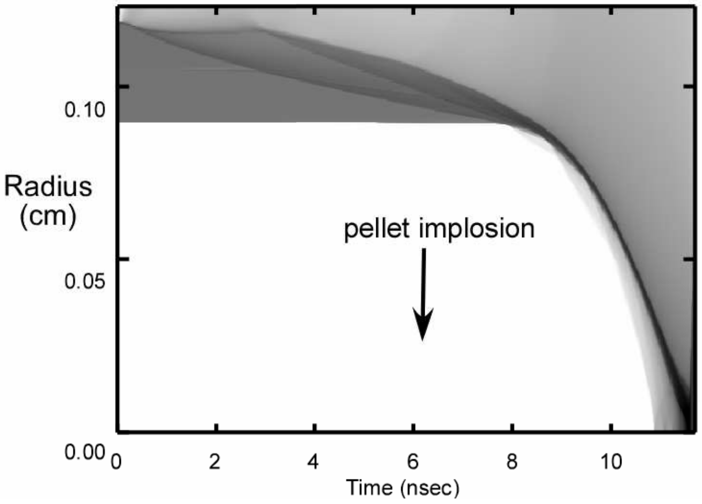
We are exploring the parameter space for stable designs that require reduced laser energy

Sample 1-dimensional calculation shows substantial gain (79) with a 460 kJ KrF laser

Max Laser Intensity	**2.4×10^{15} W/cm^2**
Implosion Velocity	**400 km/sec**
Gain	**79**

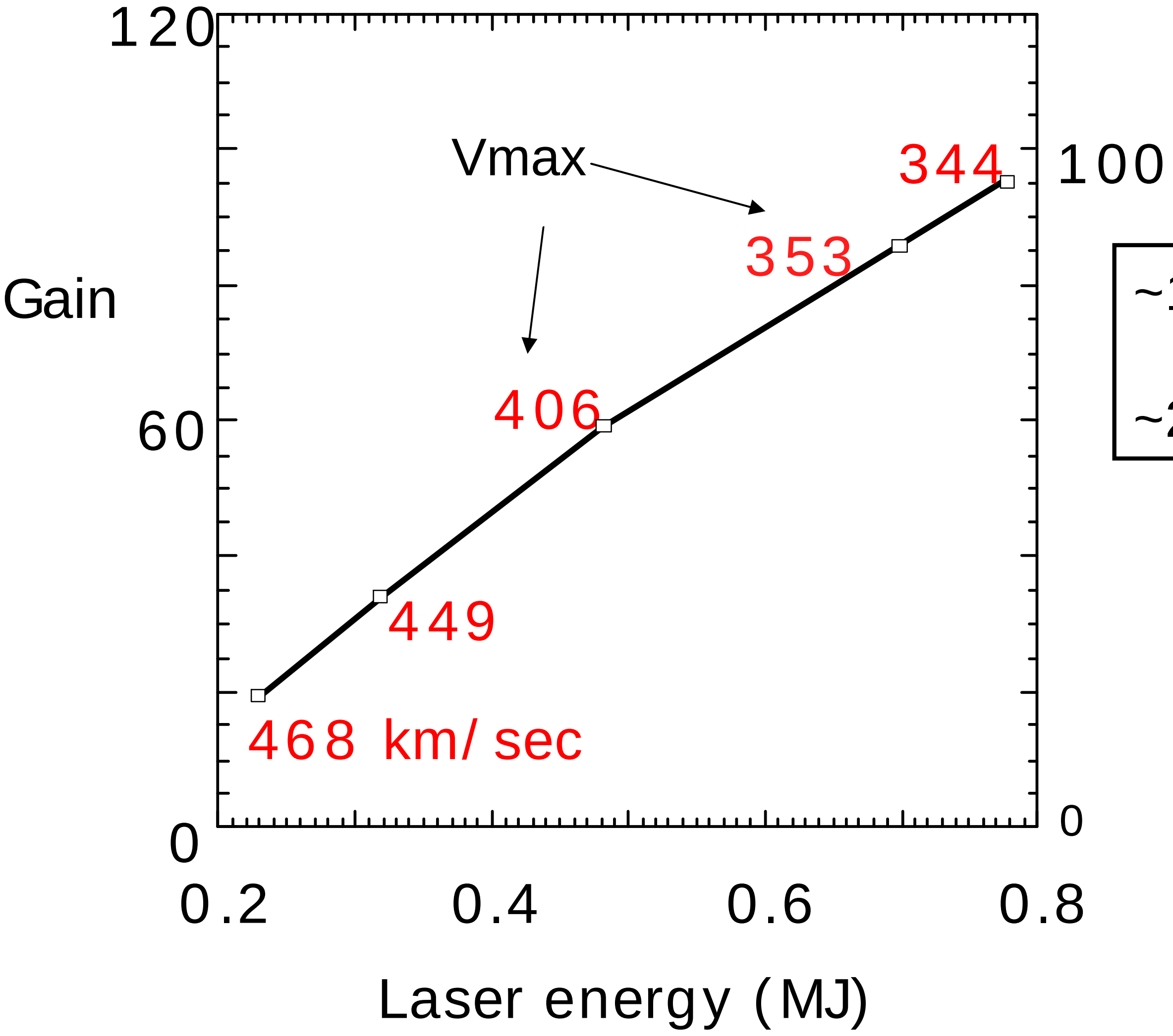






Gain increases and optimum implosion velocity decreases with laser energy

1-D gains with conventional (no spike) pulse shape

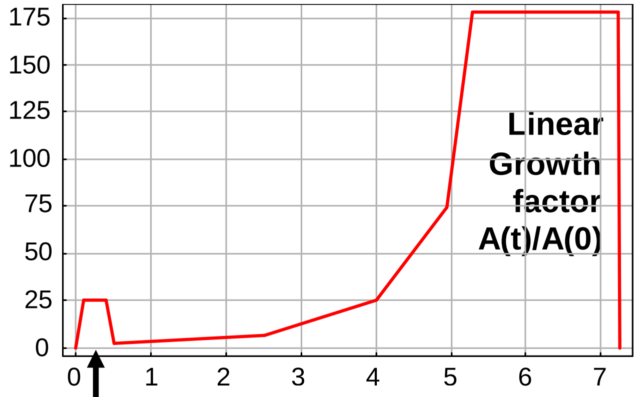


~17 TW/cm^2 foot

~2.5x10^{15} W/cm^2 Imax

LASNEX 1D/2D simulations agree that this is a promising regime

(High velocity direct-drive implosion with KrF laser)



Laser pulse

Integral Performance	
1-D Clean Yield	24.4MJ
E_drive (incident energy)	0.480MJ
Gain	51.0
IFAR at 2/3 R_0	22.4
Conv ratio	36.3

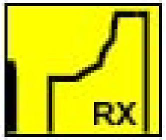
Maximum (linear) hydro-instability growth <1000x

Spike pre-prepulse can tailor the adiabat (hot ablator and cold compressed fuel) that to help hydro-stability.

Thanks to J. Perkins, LLNL

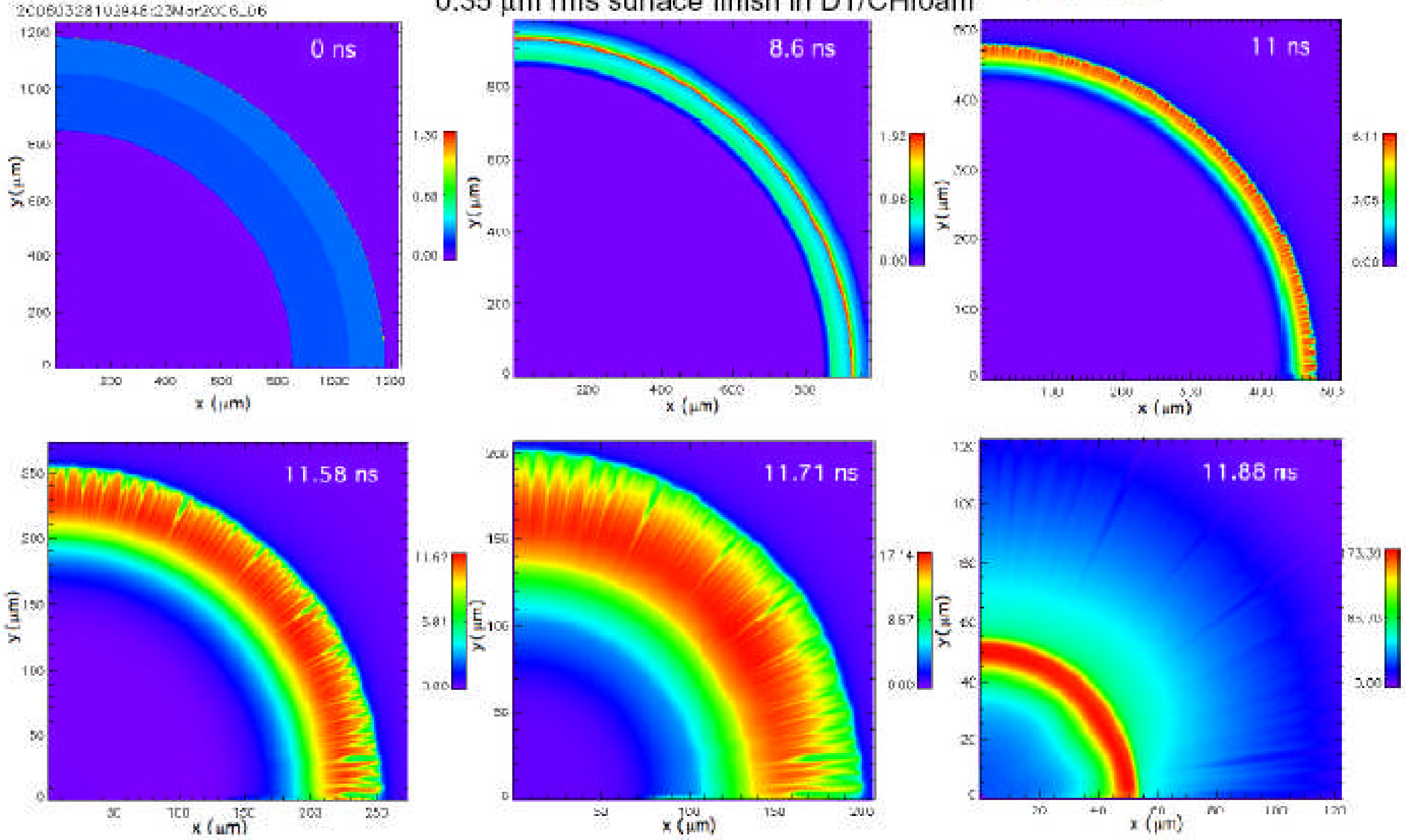
Multimode high-res 2D simulation with 460 kJ KrF

Result: With 75% NIF-spec. equivalent outer surface finish, the RX pulse gives a yield of 11 MJ, about 60% of clean-1D yield



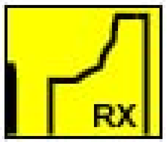
“Betti-like” laser pulse

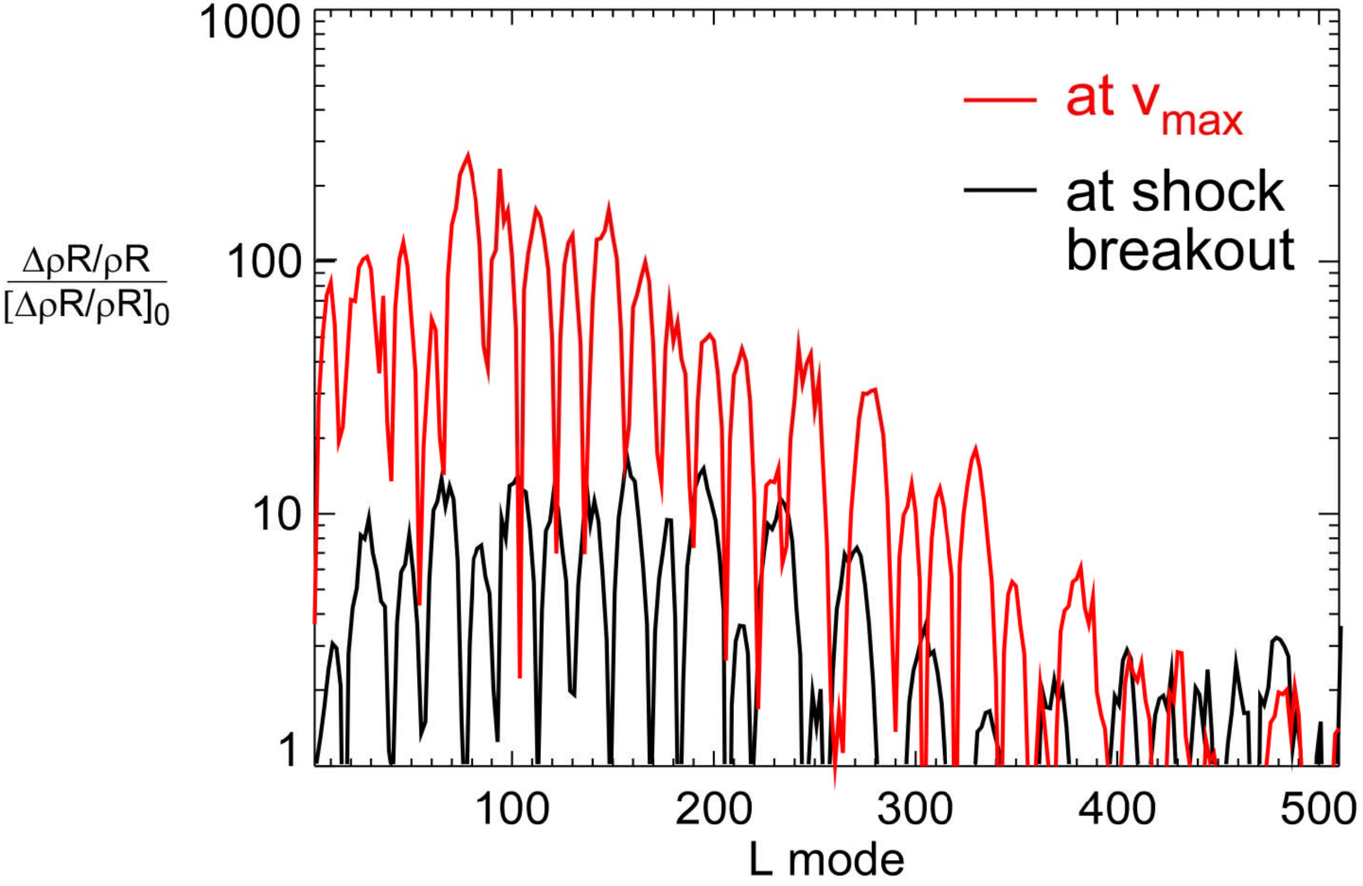
0.35 μm rms surface finish in DT/CHfoam



High resolution 2-D simulation with FASTRAD3D code

With pulse shaping the growth of instability can be small, comparable to those projected for indirect drive – but the hydro-physics is complex and challenging for the simulations.

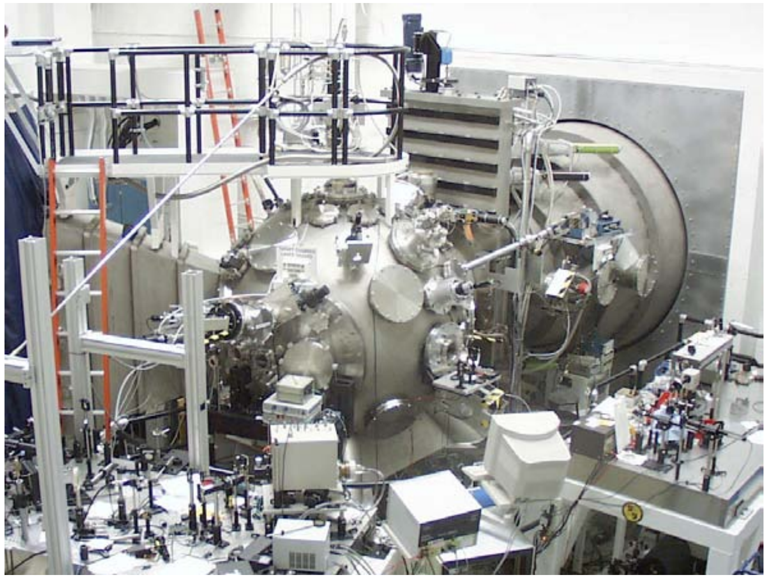


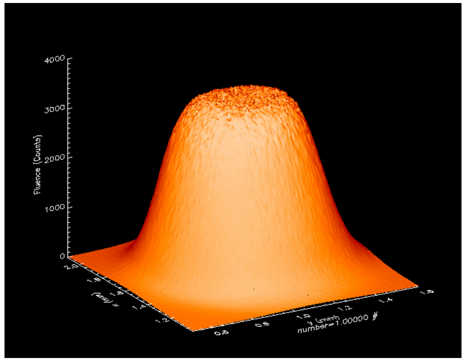

Growth of relative areal mass perturbations

Krypton-fluoride laser facilities at NRL

Electra: goal of 700 J @ 5 Hz

Nike: 56-beam 5-kJ low-rep laser-target facility (shot/30 min)



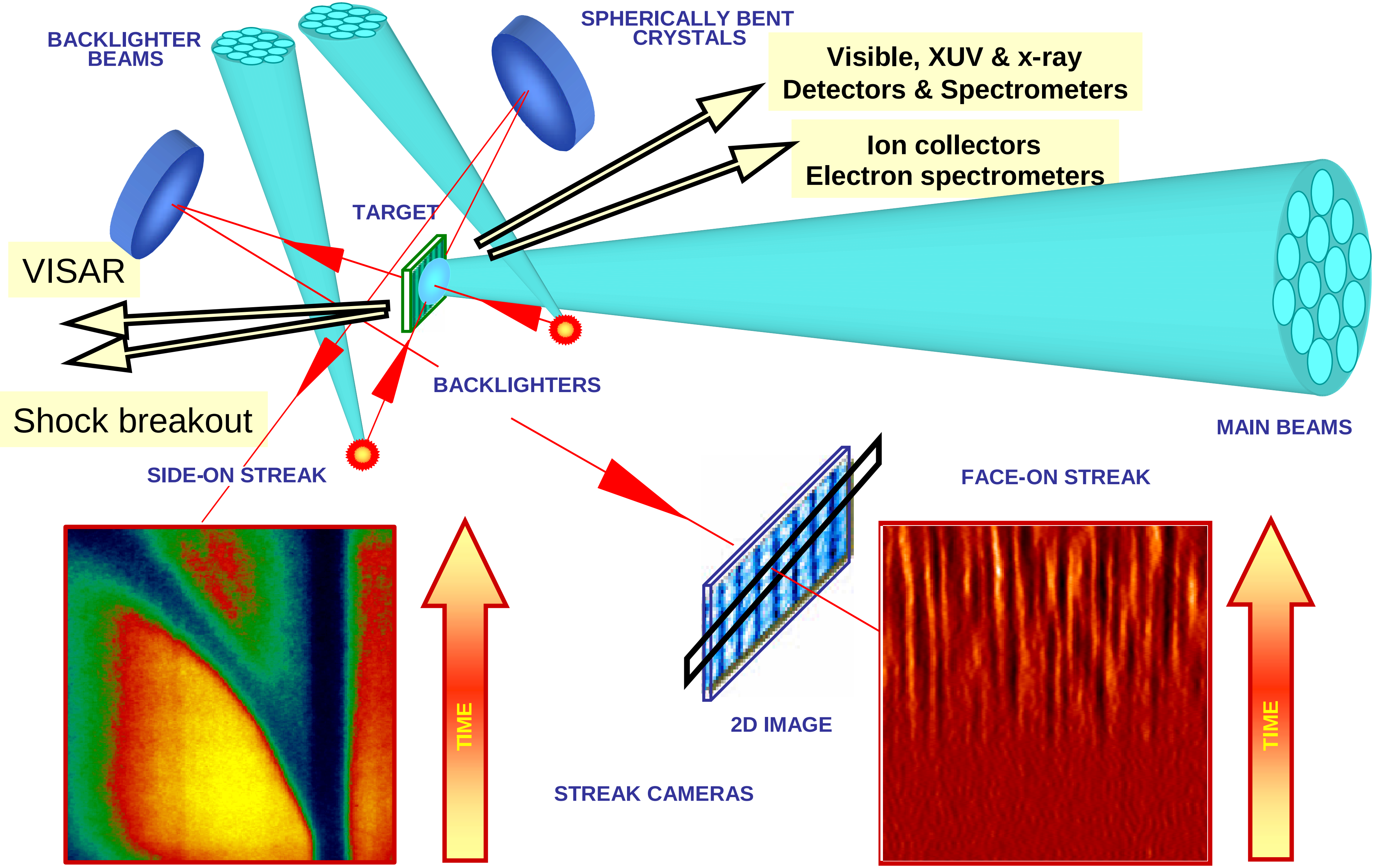


Nike laser provides highly uniform target illumination (best by far in the business)

&

deepest UV

Nike is used to study laser-accelerated planar targets



BACKLIGHTER BEAMS

SPHERICALLY BENT CRYSTALS

Visible, XUV & x-ray
Detectors & Spectrometers

Ion collectors
Electron spectrometers

TARGET

VISAR

Shock breakout

BACKLIGHTERS

MAIN BEAMS

SIDE-ON STREAK

FACE-ON STREAK

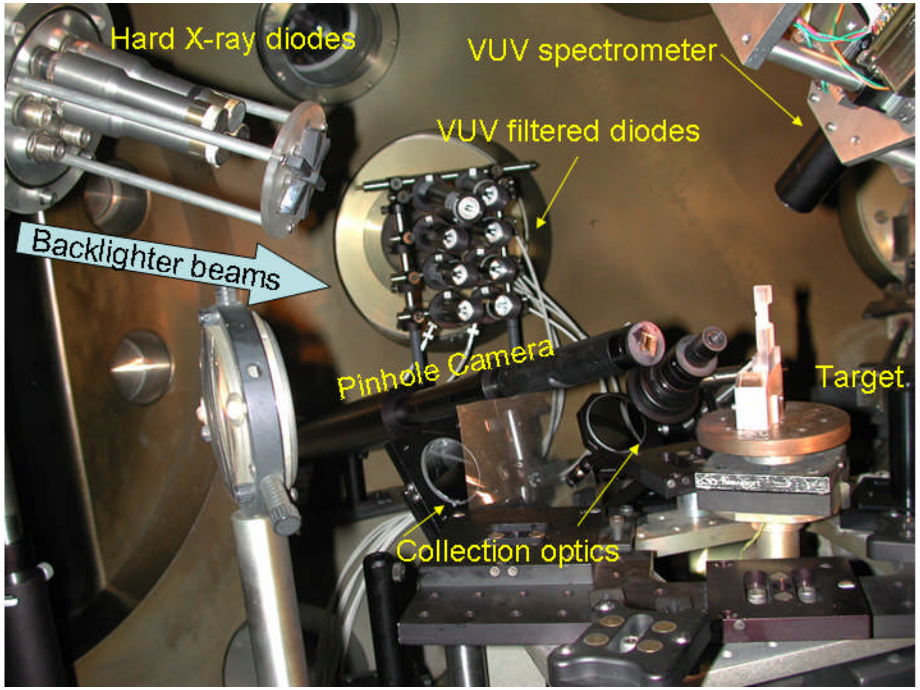
TIME

2D IMAGE

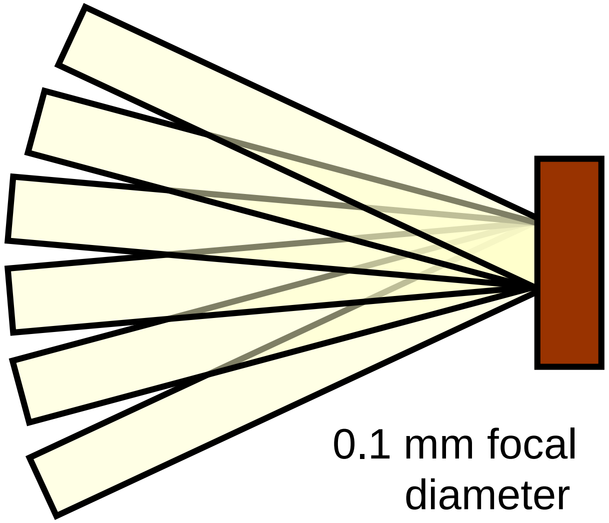
STREAK CAMERAS

TIME

Initial Nike laser plasma experiments show no evidence for parametric instability @ 2-3x10^{15} W/cm^2



12 overlapped 300 ps Nike "backlighter" beams

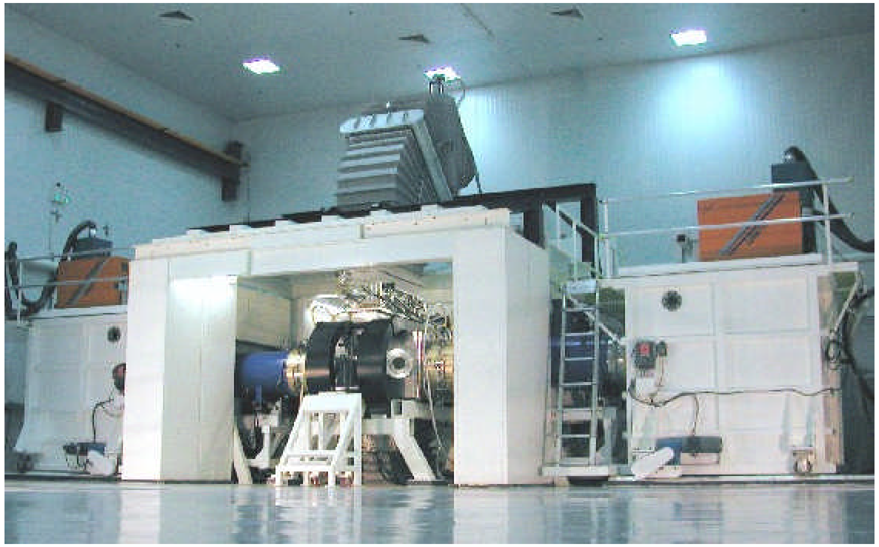


- So far no hard x-rays, no Raman scatter, no 3/2 omega
- Need more energy to simulate FTF-scale plasma (e.g. with proposed 25 kJ "NexStar" KrF facility)
- Laser plasma instability will limit max usable intensity.

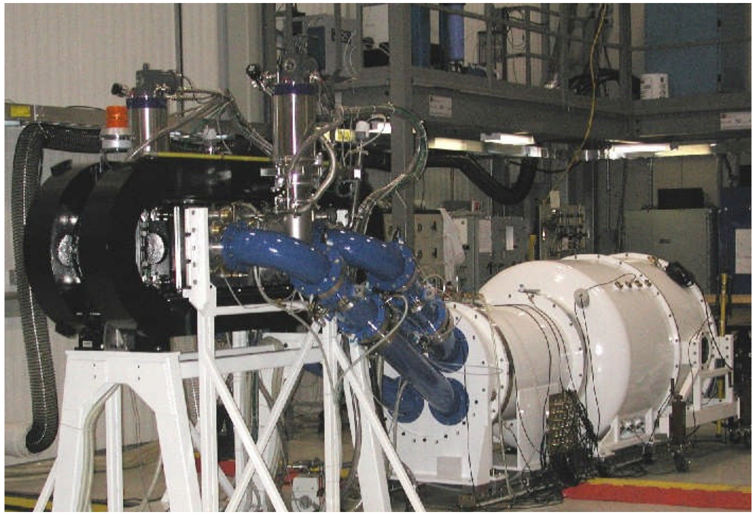
Electra high-rep rate KrF laser system

Development is guided by simulation codes

pre-amp 10 cm x 10 cm

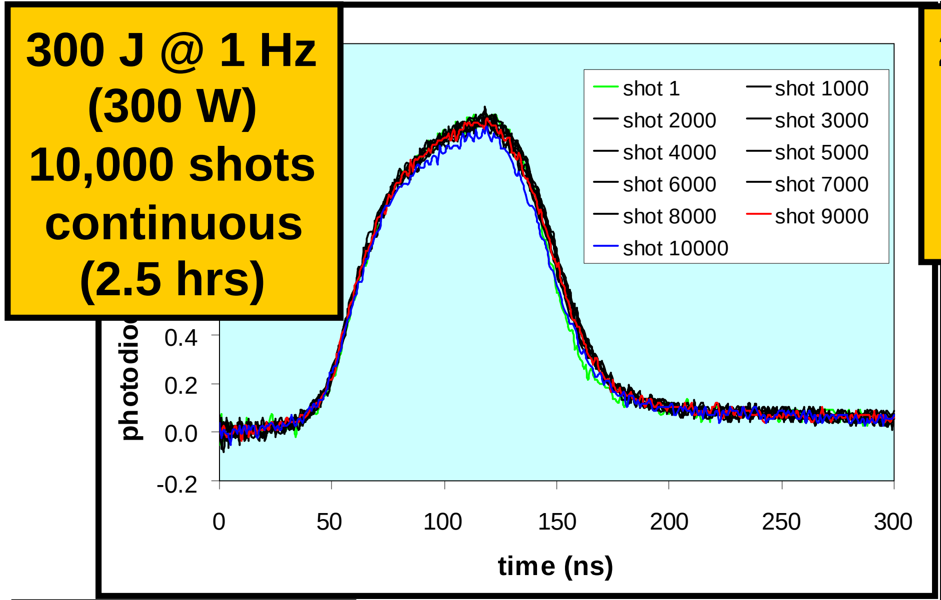


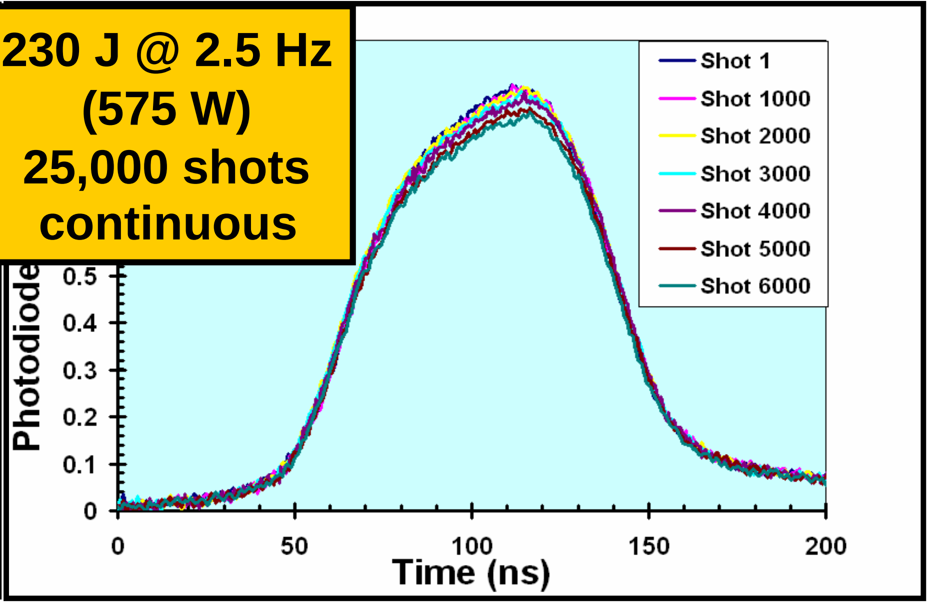
main amp 30 cm x 30 cm aperture

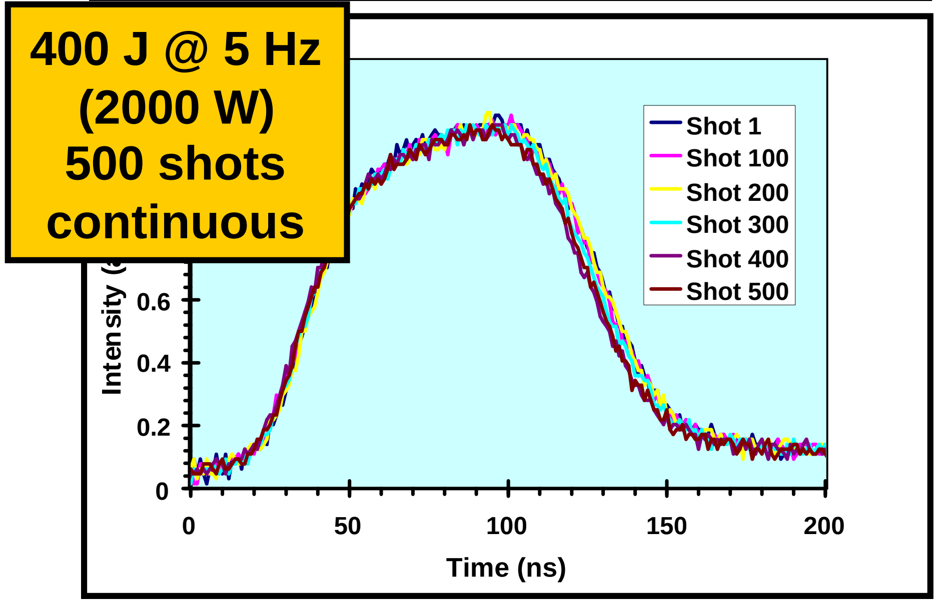


Pre-amp is upgradeable to
all-solid-state HV switching

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


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


230 J @ 2.5 Hz (575 W) 25,000 shots continuous


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

Notable results:

250 J @ 5 Hz (1,250 W)
7700 shots
In four segmented run

Monolithic Cathodes

Anticipate that within next 18 months we will have > 20,000 shots @ 5 Hz.

Based on our research an IFE sized system is projected to have a wall plug efficiency >7%.

KrF	Based on Electra expt's	12%
Pulsed Power	*Advanced Switch*	*85%*
Hibachi Structure	*No Anode, Pattern Beam*	*80%*
Optical train to target	Estimate	95%
Ancillaries	Pumps, recirculator	95%
Global efficiency		7.4%

High-Average-Power-Laser (HAPL) Program: develops S&T for inertial fusion energy via directly-driven targets with lasers

HAPL meeting #14, Oak Ridge National Lab, March 2006

Government Labs

1. NRL
2. LLNL
3. SNL
4. LANL
5. ORNL
6. PPPL
7. INEL
8. SRNL/SRS

Universities

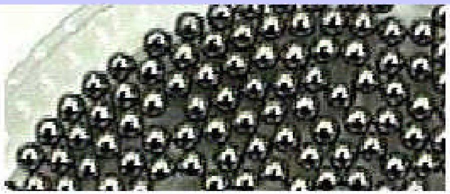
1. UC San Diego
2. Wisconsin
3. Georgia Tech
4. UCLA
5. U Rochester, LLE
6. UC Santa Barbara
7. UC Berkeley
8. U North Carolina
9. Penn State Electro-optics

Private Industry

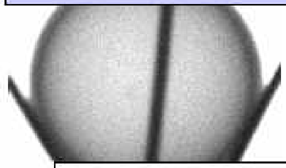
1. General Atomics
2. L-3/PSD
3. Schafer Corp
4. SAIC
5. Commonwealth Tech
6. Coherent
7. Onyx
8. DEI
9. Voss Scientific
10. Northrup
11. Ultramet, Inc
12. Plasma Processes, Inc
13. Optiswitch Technology
14. Research Scientific Inst

IFE requires techniques for mass production of targets

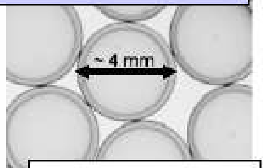
Au/Pd Overcoated shells



100 mg/cc foam shell

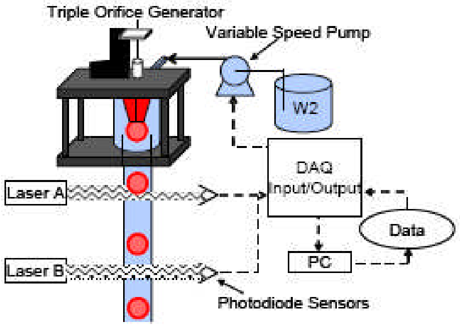


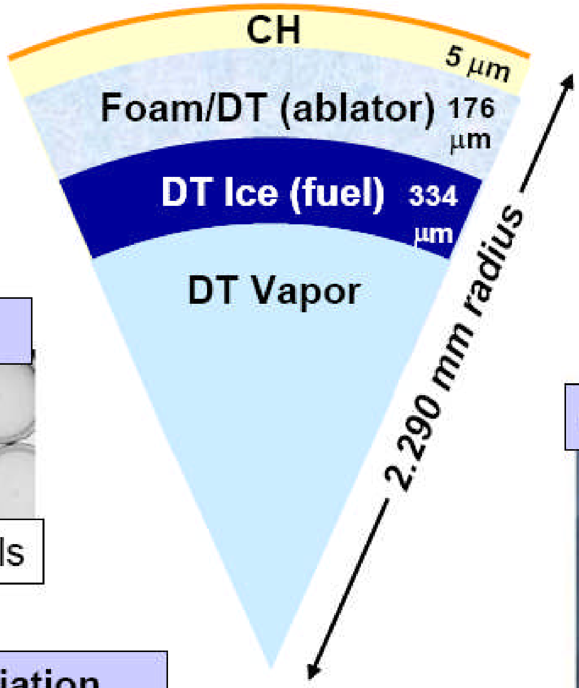
x-ray picture



"wet" shells

22 shells/min, < 1% variation

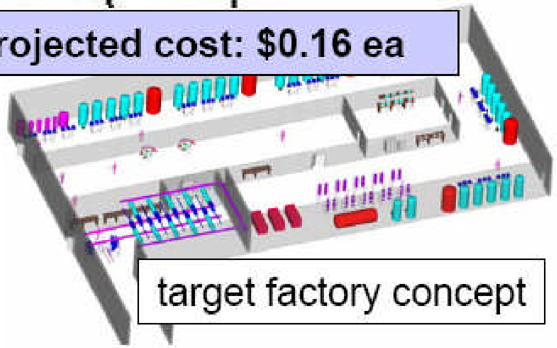




Smooth D-T ice over foam

Cryogenic fluidized bed

Target projected cost: $0.16 ea



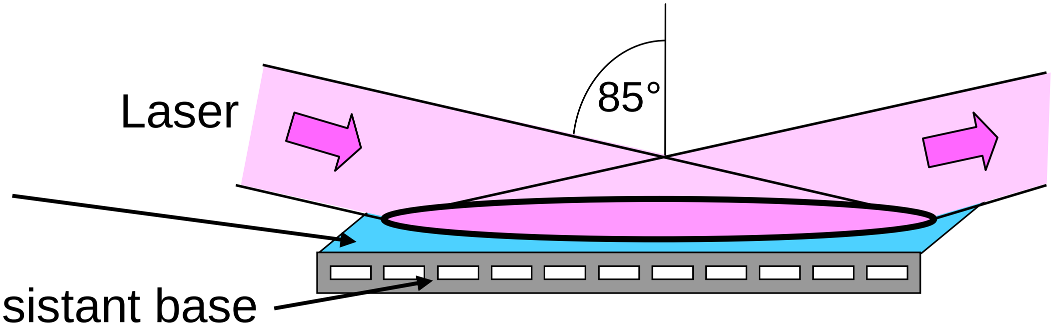
target factory concept

General Atomics
Los Alamos
Schaffer Corp

Final Optics: Aluminum Grazing Incidence Metal Mirror

1) Reflectivity (>99% @ 85°)
2) Laser damage threshold (need 3.5 J/cm²)
3) Expected to be resistant to neutron damage

Concept

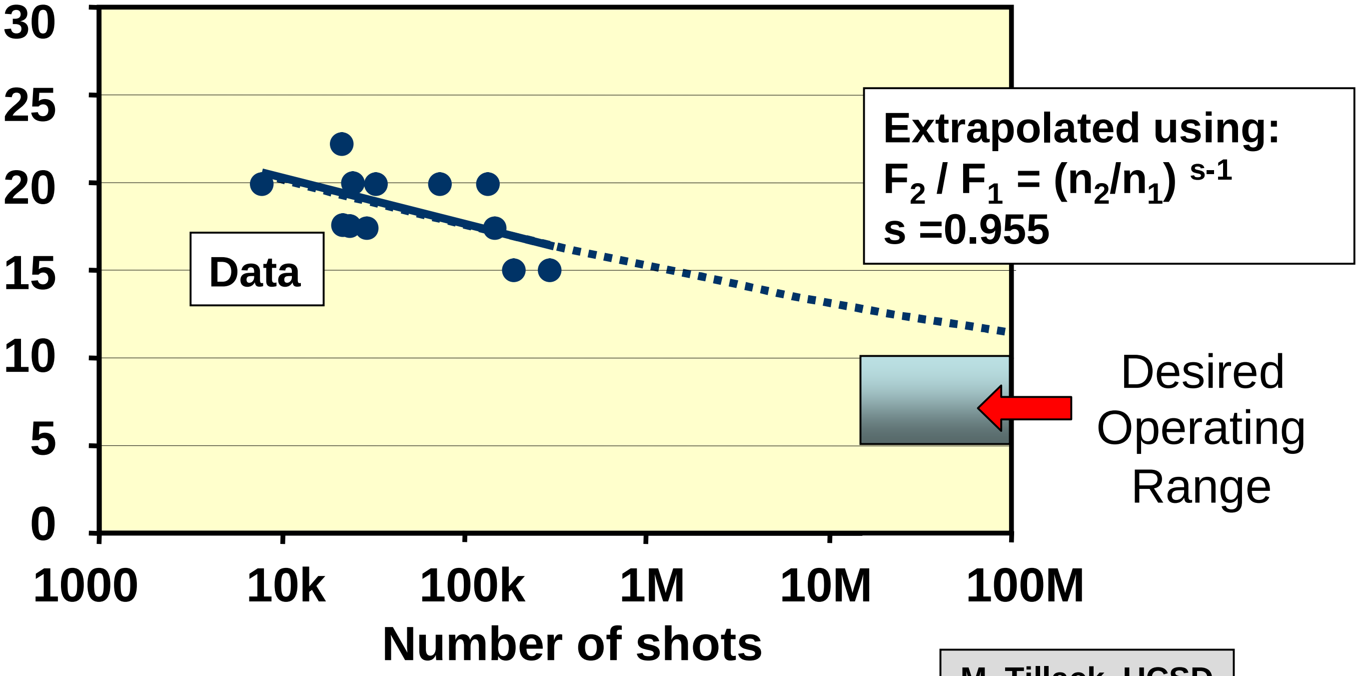


Electroplated aluminum mirror

Stiff, lightweight, neutron resistant base

Results

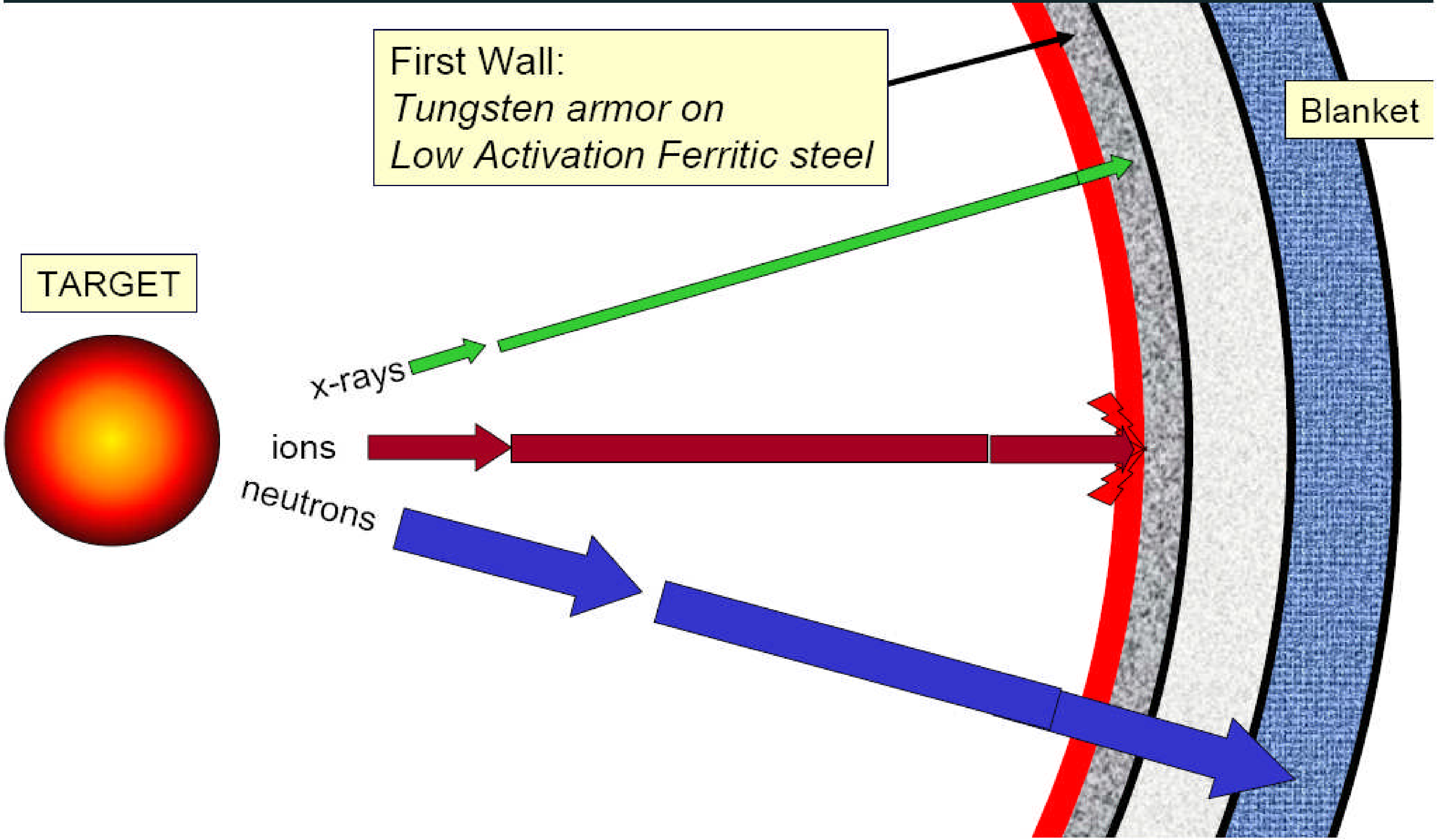
Laser Damage Threshold J/cm² (data for 20 ns pulse divide by 2.8 for 2.5 ns pulse)



Extrapolated using:
$F_2 / F_1 = (n_2/n_1)^{s-1}$
s =0.955

M. Tillack, UCSD

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



Development Plan for Laser Fusion Energy and the FTF

Stage I
2008-2013

Develop full-size components

- **25 kJ 5 Hz laser beam line**
- ***(first step is 1 kJ laser beam line)***
- **Target fabrication /injection**
- **Power plant & FTF design**

Target physics validation

- Calibrated 3D simulations
- Hydro and LPI experiments
- Nike enhanced performance, or **NexStar**, OMEGA, NIF, Z

Stage II
2014-2022
operating ~2019

Fusion Test Facility (FTF or PulseStar)

- 0.5 MJ laser-driven implosions @ 5 Hz
- Pellet gains ~60
- ~150 MW of fusion thermal power
- Target physics
- Develop chamber materials & components.

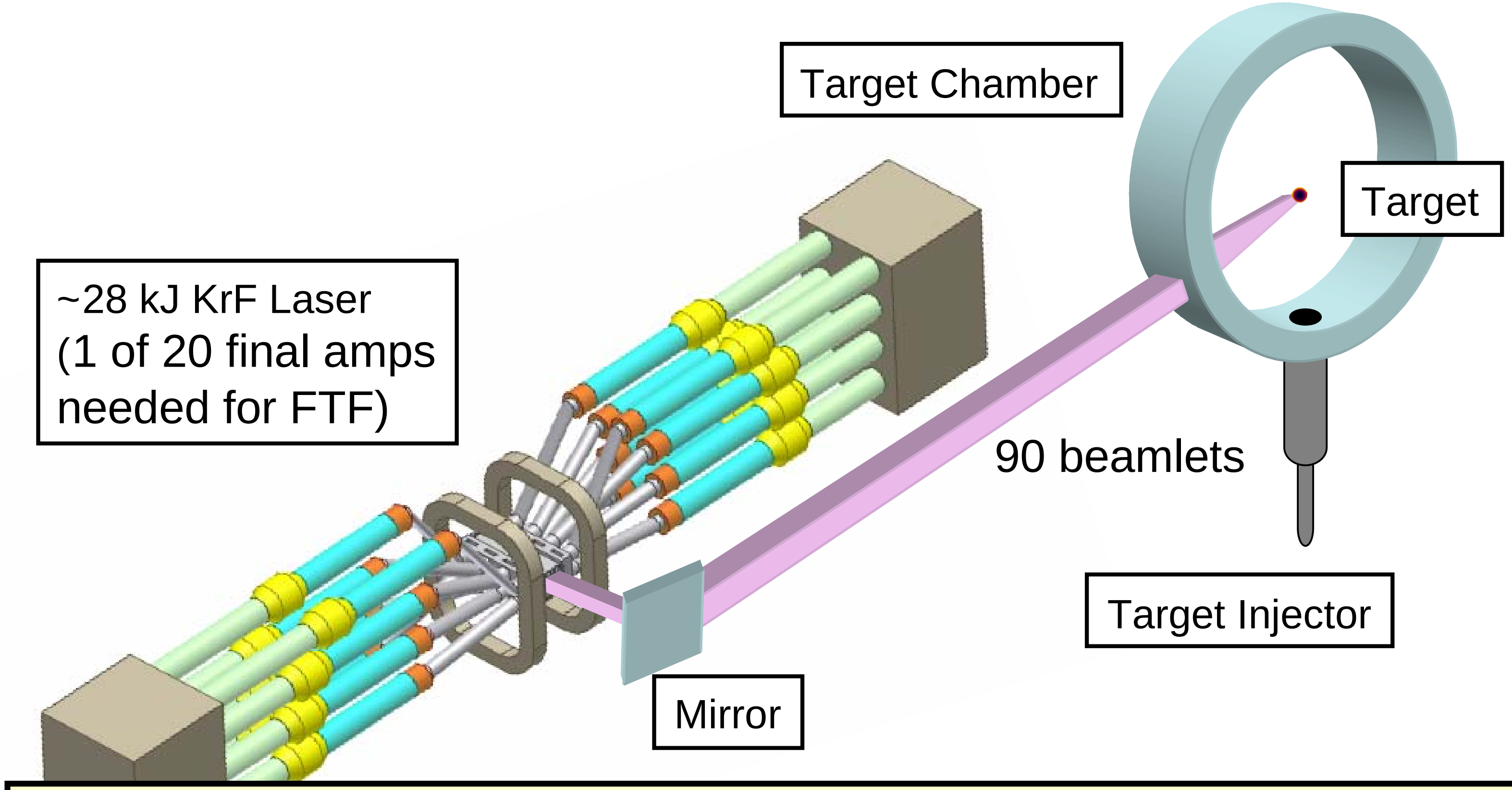
Stage III
2023-2031

Prototype Power Plants (PowerStars)

- Power generation
- Operating experience
- Establish technical and economic viability

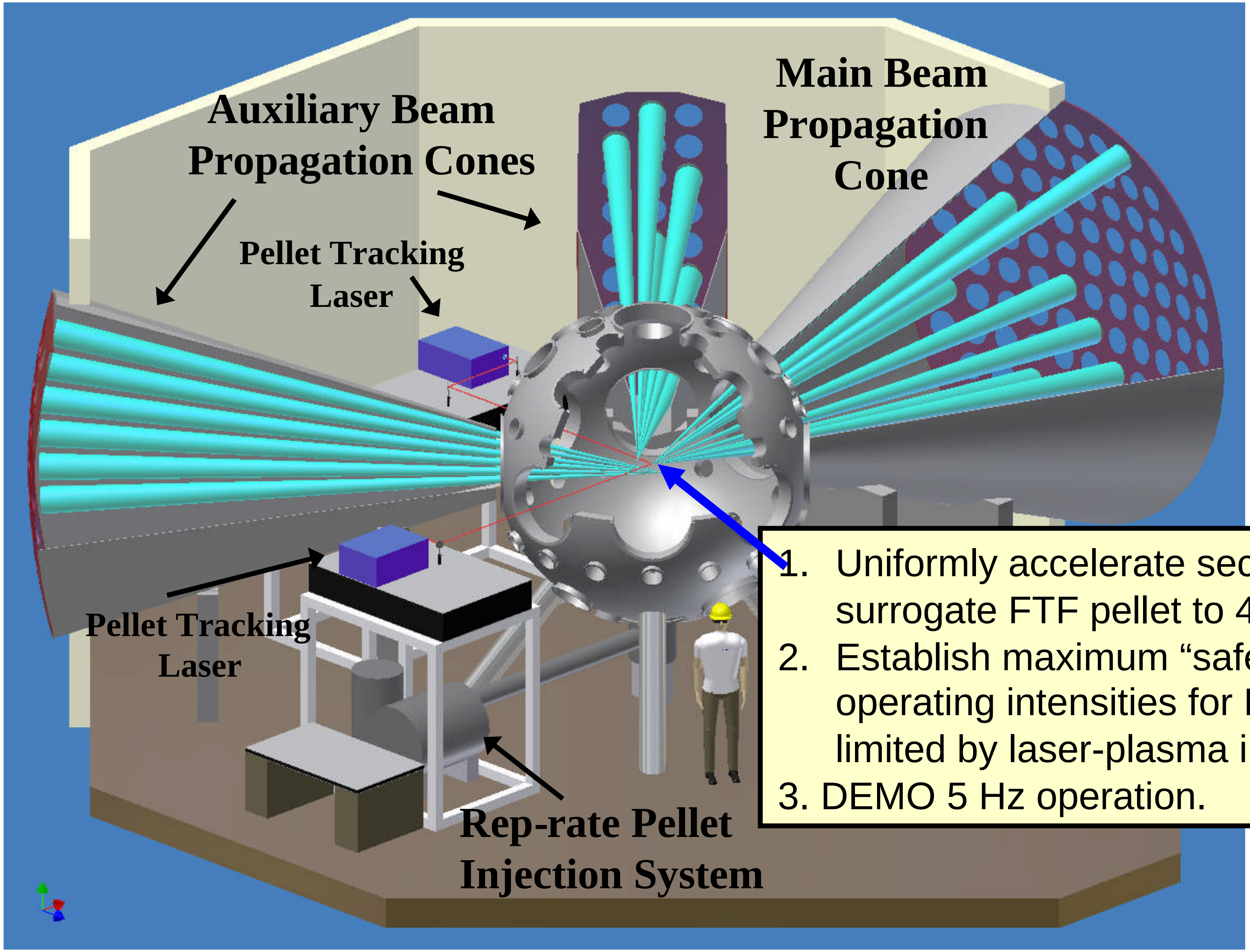
STAGE I is a single laser module of the FTF coupled with a smaller target chamber

Laser energy on target:	25 kJ
Rep Rate:	5 Hz (but may allow for higher rep-rate bursts)
Chamber radius	1.5 m



- Develop and demonstrate full size beamline for FTF
- Explore & demonstrate target physics underpinnings for the FTF

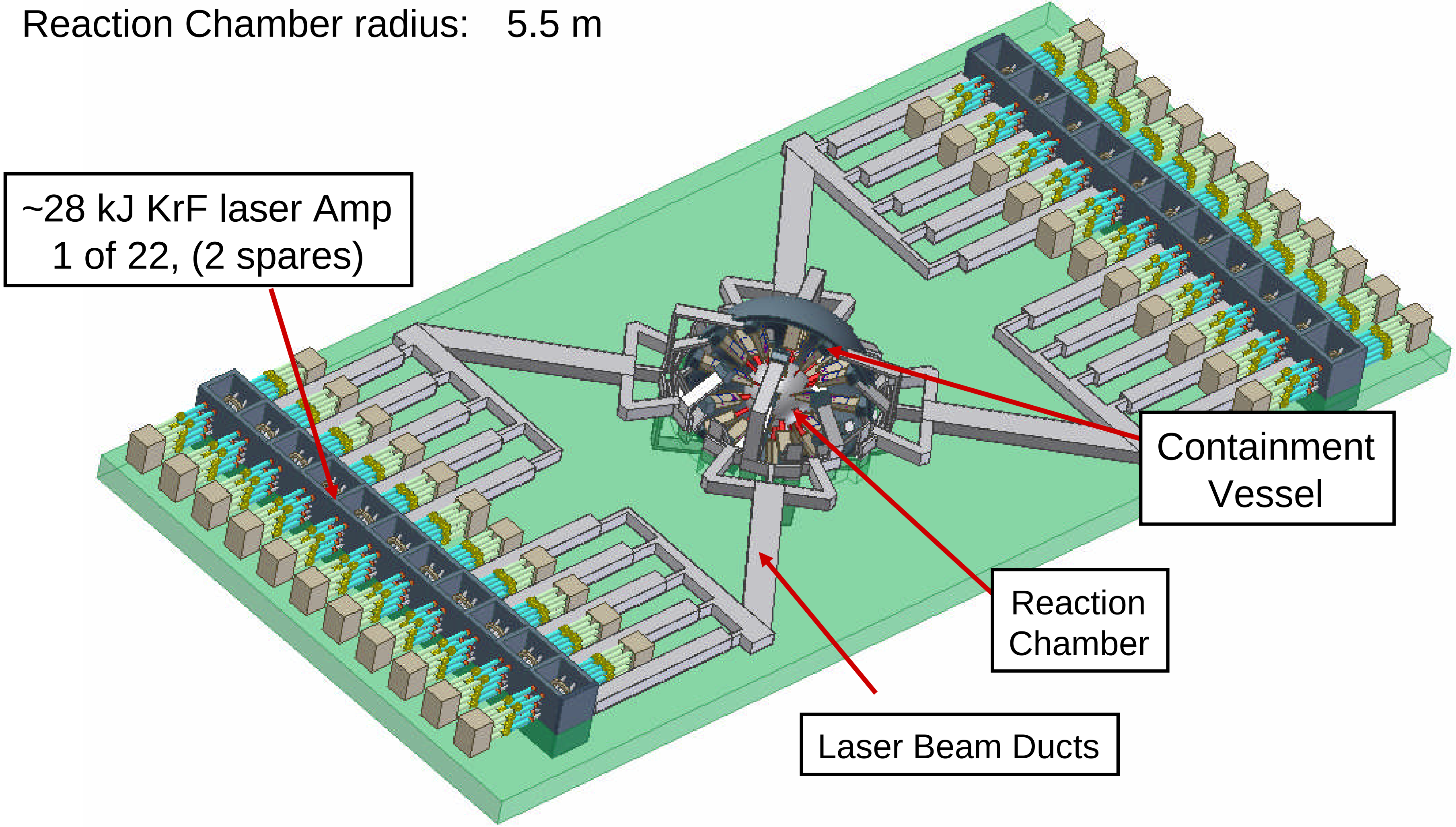
DOE-NRL "NexStar" 25 kJ 5 Hz KrF "planar" target facility



1. Uniformly accelerate section of surrogate FTF pellet to 400 km/sec
2. Establish maximum "safe" operating intensities for FTF as limited by laser-plasma instability.
3. DEMO 5 Hz operation.

The Fusion Test Facility (STAGE II)

Laser energy on target:	250 - 500 kJ
Fusion power:	30 -150 MW
Rep Rate:	5 Hz (but allow for higher rep-rate bursts)
Reaction Chamber radius:	5.5 m



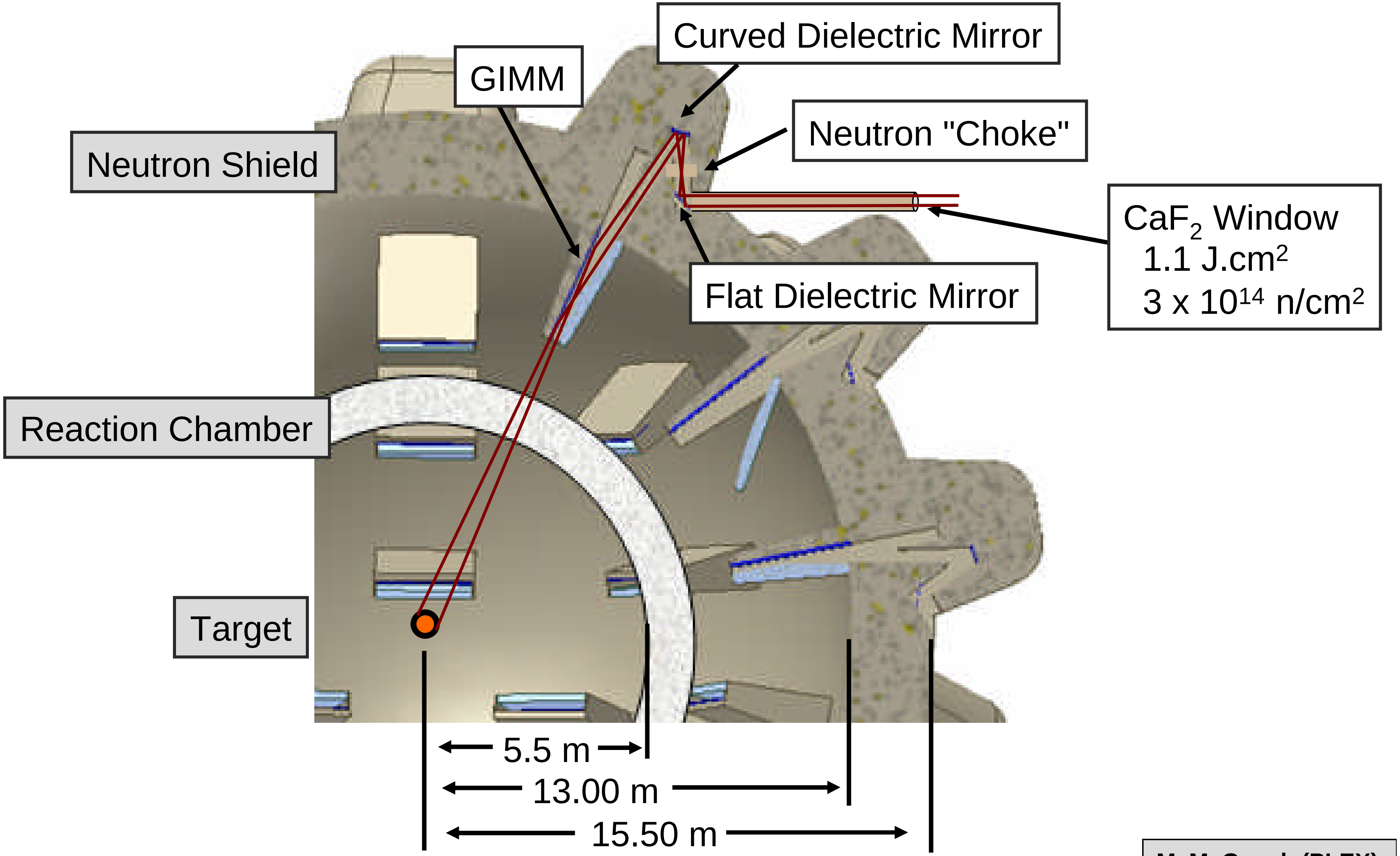
~28 kJ KrF laser Amp
1 of 22, (2 spares)

Containment Vessel

Reaction Chamber

Laser Beam Ducts

Optical train with GIMM Final Optic



Curved Dielectric Mirror

GIMM

Neutron "Choke"

Neutron Shield

CaF$_2$ Window
1.1 J.cm^2
3 x 10^{14} n/cm^2

Flat Dielectric Mirror

Reaction Chamber

Target

5.5 m

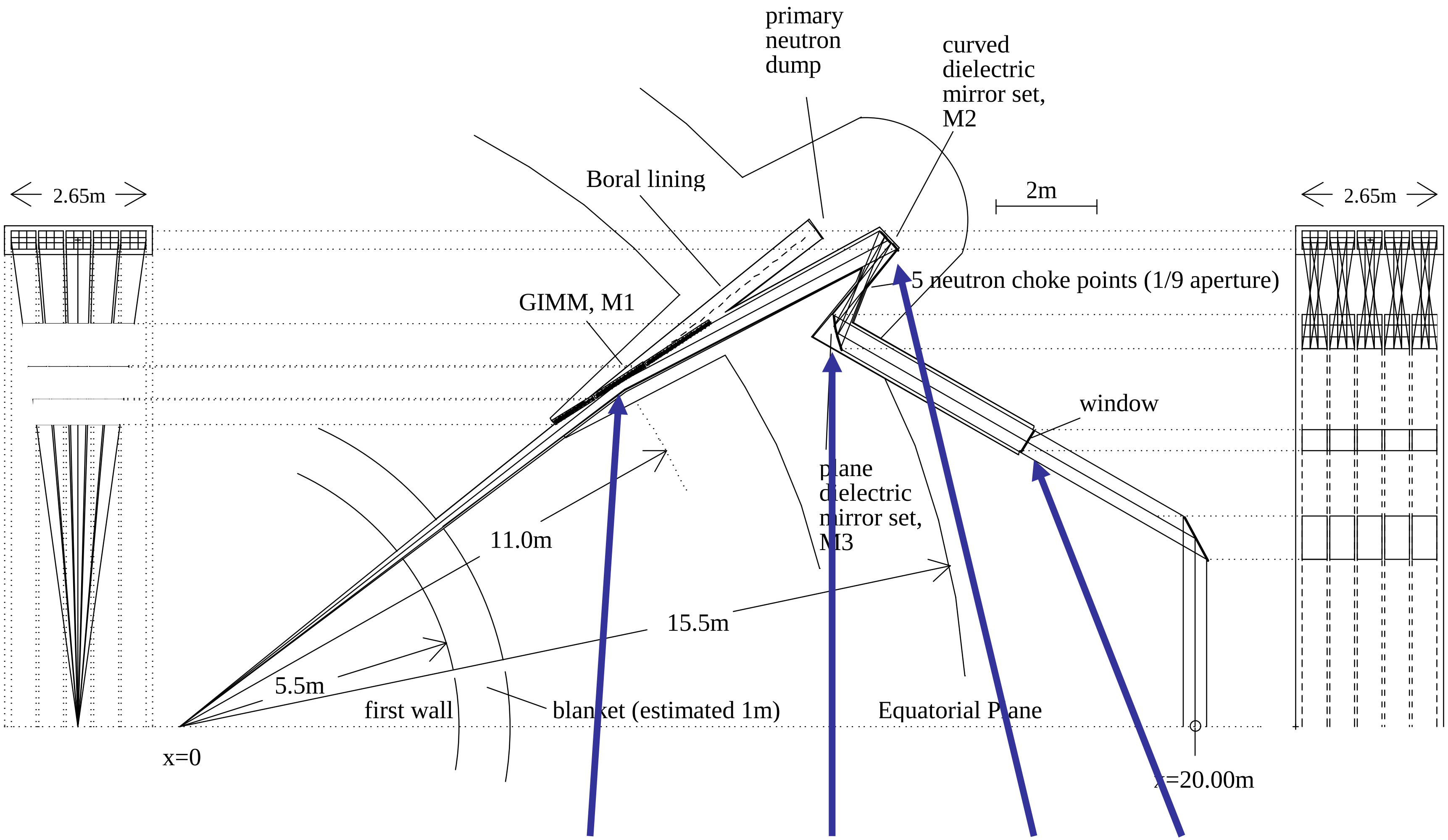
13.00 m

15.50 m

Also evaluating Dielectric Mirror in place of GIMM

M. McGeoch (PLEX)
M. Sawan (Wisc)
L. Snead (ORNL)

Total neutron fluxes on FTF final mirror optics at 150MW



70%n, 12 MeV$_{ave}$
=> 5.5x10^{19} s^{-1}
at source

1.2x10^{20} per FPY

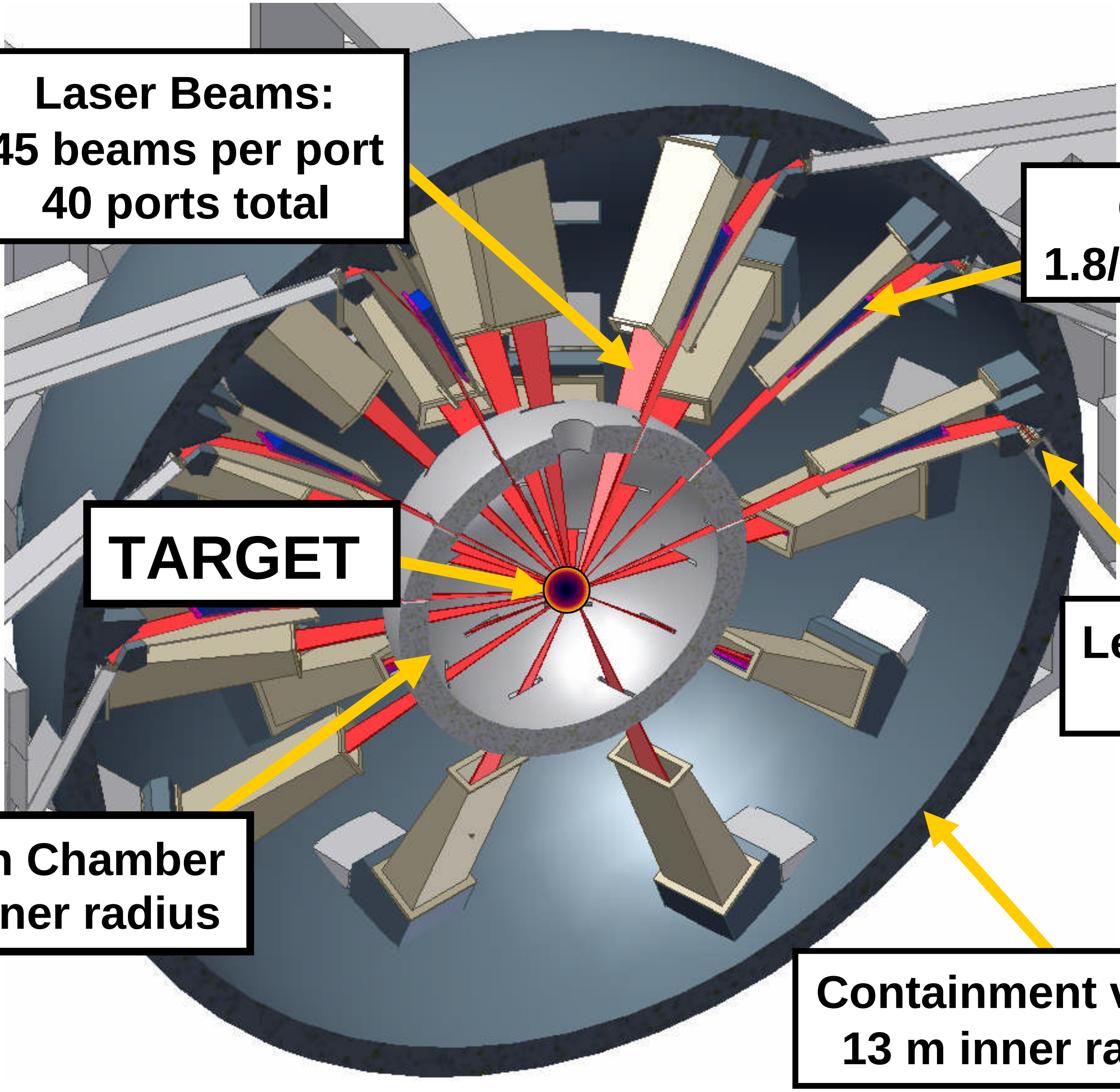
2x10^{17} per FPY

3x10^{18} per FPY

3x10^{15} cm^{-2} per FPY

Calculations from M. Sawan, U. Wisconsin

The FTF Chamber (conceptual)



Laser Beams:
45 beams per port
40 ports total

GIMM
1.8/3.4 J/cm^2

TARGET

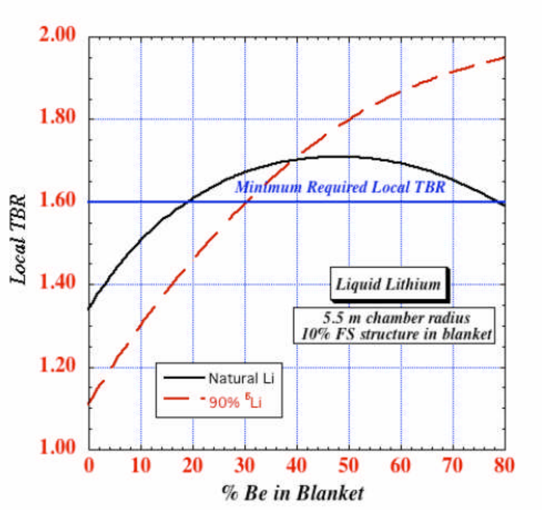
Lens/window
1.0 J/cm^2

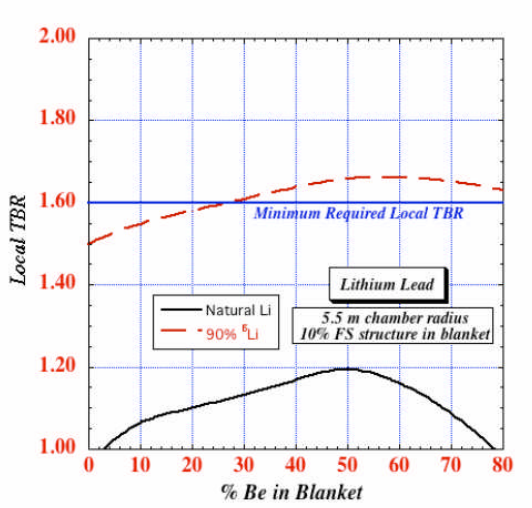
Reaction Chamber
5.5 m inner radius

Containment vessel
13 m inner radius

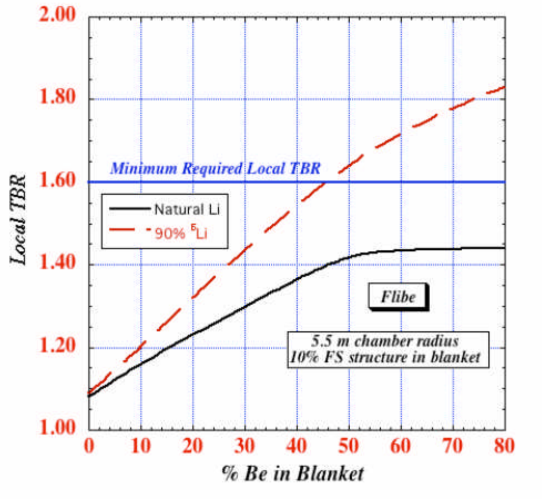
We would like the FTF to breed its own tritium despite loss in solid angle from experiments

Could a Local TBR >1.6 be Achieved?



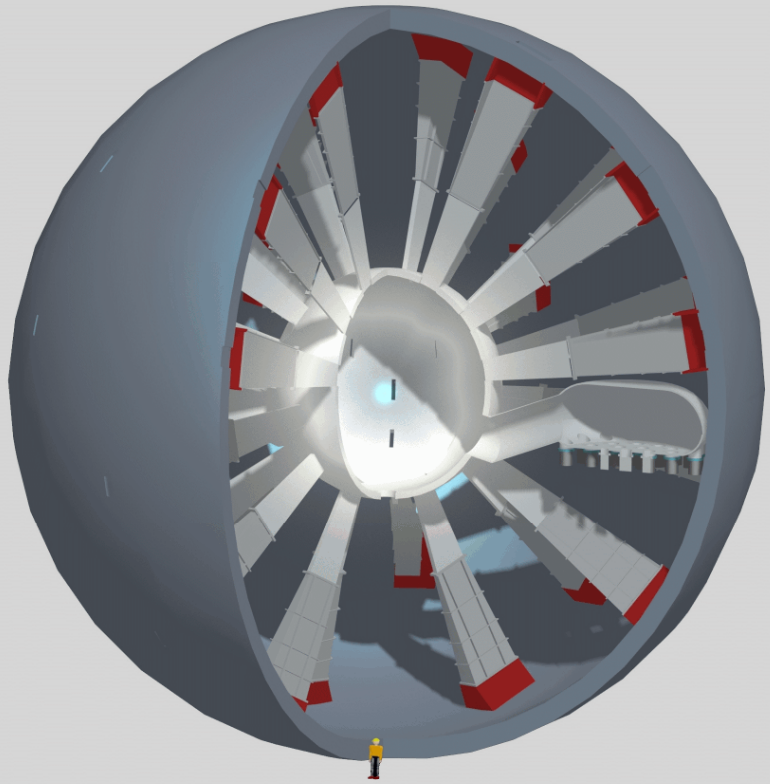


1 m thick blanket
with W armor on
FS first wall



- Local TBR >1.6 can be achieved by adding Be in blanket (with conservative 10% structure content)
- Li has the highest breeding potential. > 20% Be needed for nat. Li and >30% Be required for enriched Li. Local TBR ~1.95 can be achieved with 80% Be and enriched Li allowing for more testing
- The Li in LiPb and Flibe should be enriched. >30% Be needed for LiPb and >50% Be required for Flibe

Target Chamber Tritium Recovery, Reprocessing, Purification



HAPL 15
General Atomics, San Diego, CA
August 8th-9th, 2006

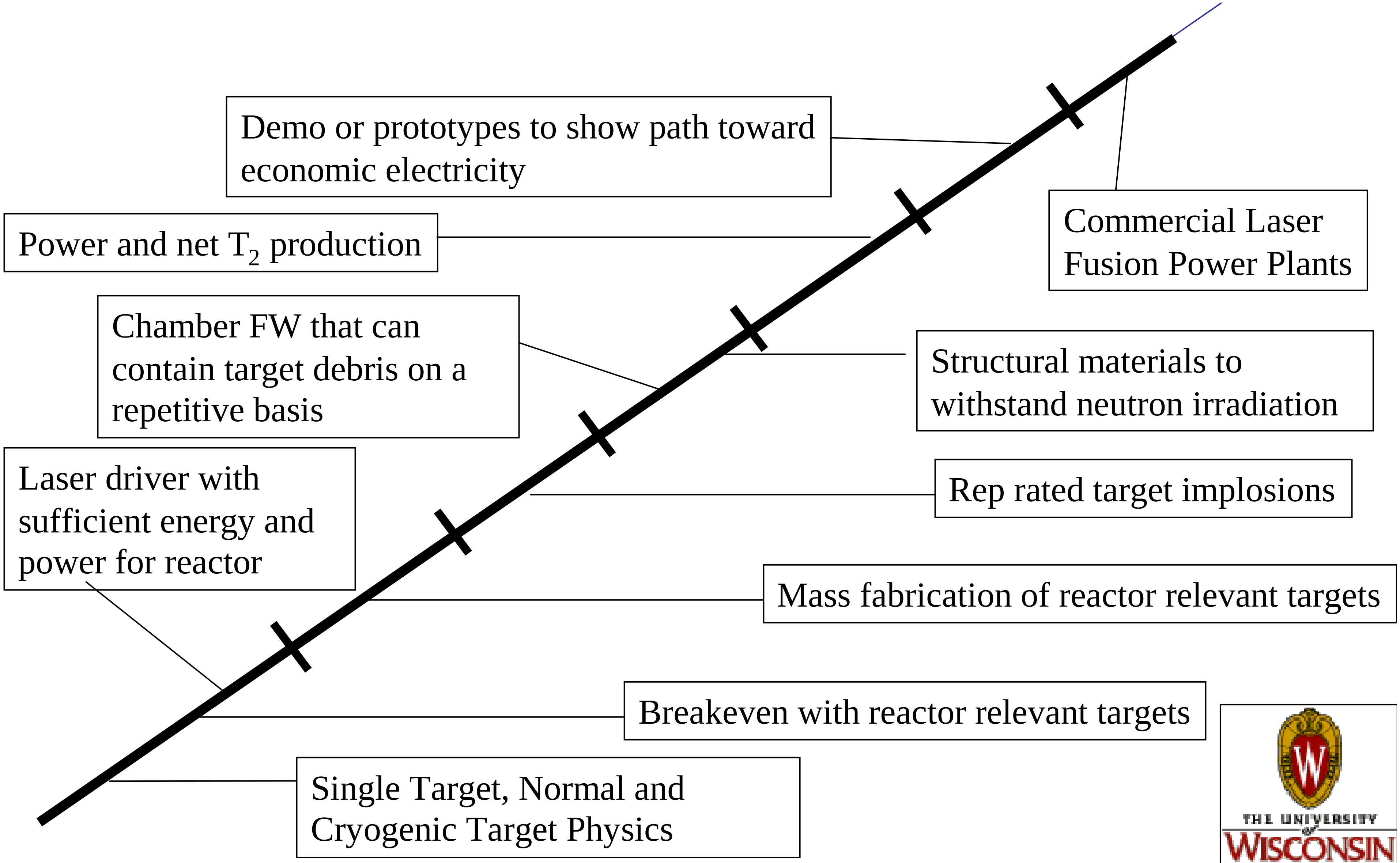
C. Gentile, C. Priniski, T. Kozub, S. Langish, J. Sethian, K. Sessions, B. Paul, L. Ciebiera

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

SRNL
SAVANNAH RIVER NATIONAL LABORATORY
We Put Science To Work™

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

What Needs to be Done on the Path to a Commercial Laser Fusion Reactor?



Demo or prototypes to show path toward economic electricity

Commercial Laser Fusion Power Plants

Power and net T_2 production

Chamber FW that can contain target debris on a repetitive basis

Structural materials to withstand neutron irradiation

Laser driver with sufficient energy and power for reactor

Rep rated target implosions

Mass fabrication of reactor relevant targets

Breakeven with reactor relevant targets

Single Target, Normal and Cryogenic Target Physics

THE UNIVERSITY of WISCONSIN MADISON

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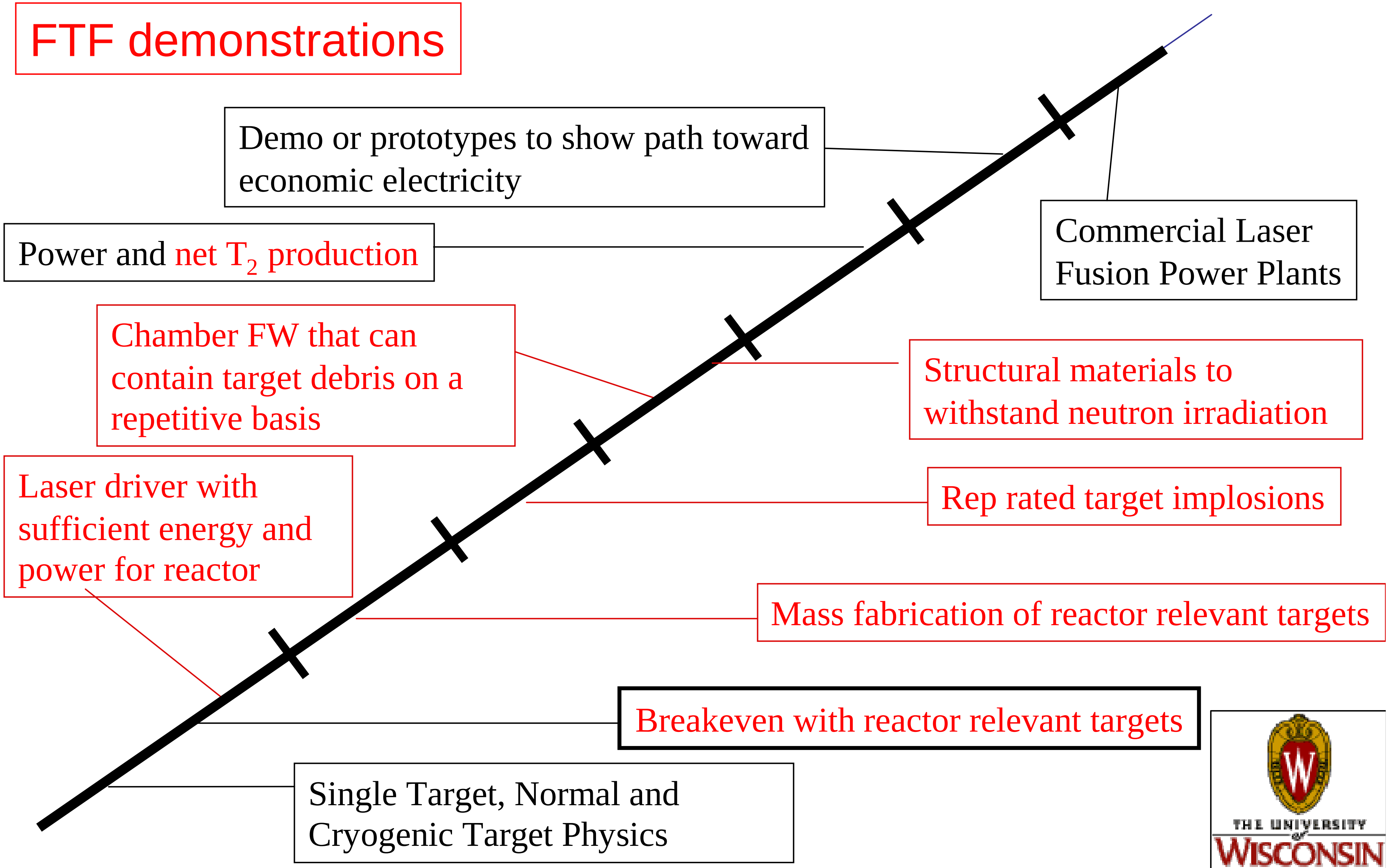

FTF demonstrations

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Conclusions

- The construction of a “FTF” facility is absolutely critical to the development of a Laser IFE power plant
- The proposed FTF will integrate reactor relevant targets, with a high energy/power rep rated laser in a chamber that will contain target debris and allow radiation resistant structural and first wall materials to be developed.