The IFE Program

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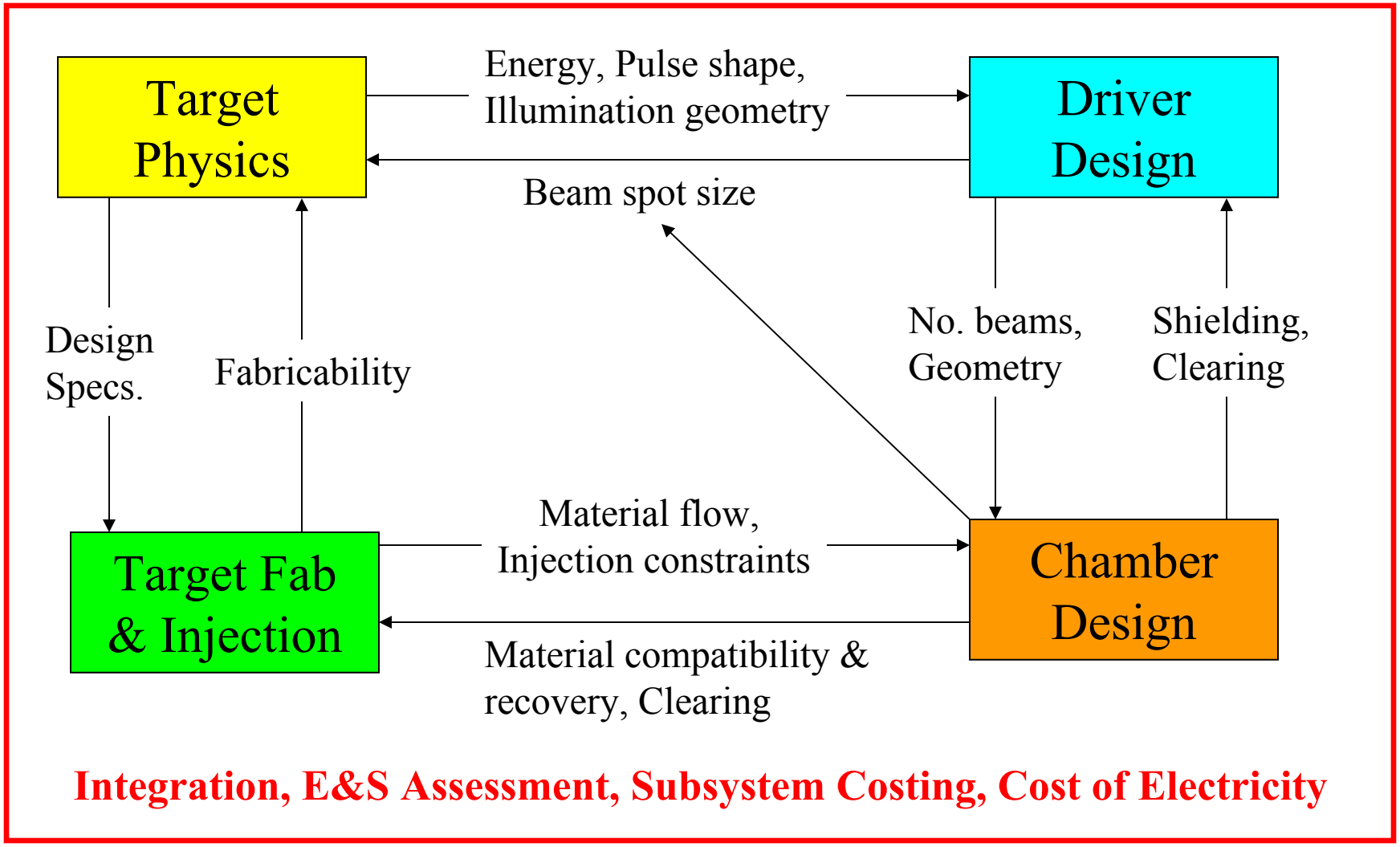
Presented at:

OFES Budget Planning Meeting
Washington, DC

March 18-19, 2003

***Work performed under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48**

A self-consistent vision for IFE requires a balanced program to address a wide range of interconnected science and technology issues



Outline

- IFE technology
- Target physics
- Fast ignition concept exploration
- HIF-VNL (Grant Logan)

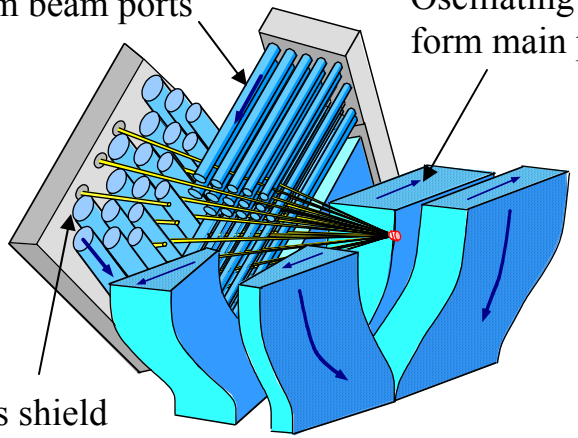
Because the issues are interconnected, work carried out within the VLT plays a crucial role for the next steps in IFE

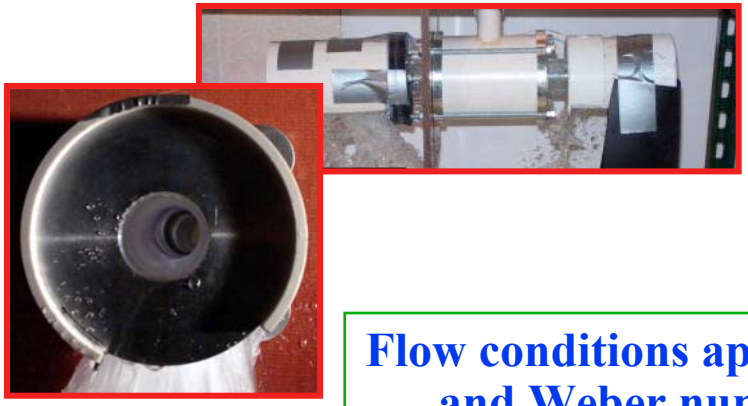
Requirements to proceed to an IRE
(Red indicates contributions by VLT funded work)

- Resolve key proof-of-principle driver issues (efficiency, reliability, focusability, cost) that are specific to each approach
- Adequate gain IFE target designs with 2-D hydrostability for plausible beam non-uniformities
- Plausible pathways for target fabrication and injection
- A chamber design concept that is self-consistent with target illumination geometry, final focus and beam propagation, chamber clearing, and adequate lifetime

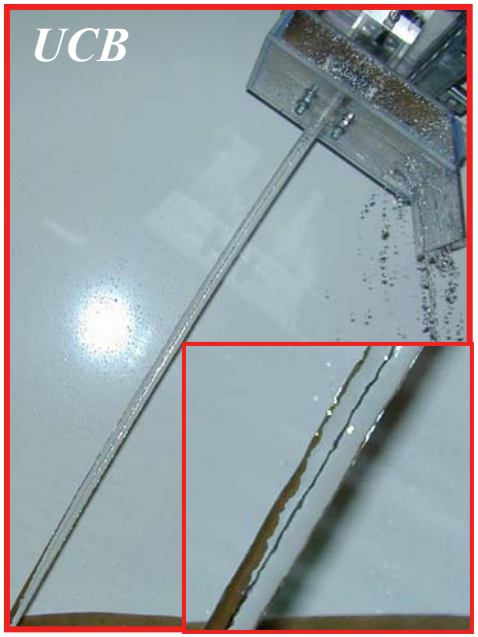
Ref.: Snowmass 2002 report

Example: Engineering Science experiments on liquid flows are essential to understanding the chamber propagation and focusing conditions for ion beams





Vortices



Highly smooth cylindrical jets

Slab jet arrays with disruptions

Flow conditions approach correct Reynolds and Weber numbers for HYLIFE-II

IFE science and technology work funded through the VLT involves a wide range of institutions and research areas

- **Chamber technology** (primarily engineering science of liquid wall chambers)
  - –UCB, UCLA, GT, UCSD, LLNL, UW, ARIES team
- **Chamber/driver interface** (final focus magnets and optics)
  - –UCB, UCSD, UCLA, LLNL, ARIES team
- **Systems modeling and integration for HI drivers and power plants**
  - –LLNL, ARIES team
- **Environmental and safety for IFE** (engineering science of hazards assessment)
  - –INEEL, LLNL, UW
- **Target fabrication** (material science and process development for IFE capsules and hohlrams) **and injection** (engineering science and technology of precise injection and tracking)
  - –GA, LANL
- **Leadership for IFE element of VLT**
  - –LLNL

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The IFE target design work includes work on the baseline approaches and more speculative advanced targets

- Heavy Ion Indirect Drive
  a) Identify tradeoffs among accelerator energy, power, particle range, focal spot size, intensity, beam geometry
  b) Optimize target materials for ES&H and manufacturability
  c) Design and analyze experiments on Omega and Z to test unique features
  d) Utilize 3D ASCI codes to evaluate inherently 3D target geometries

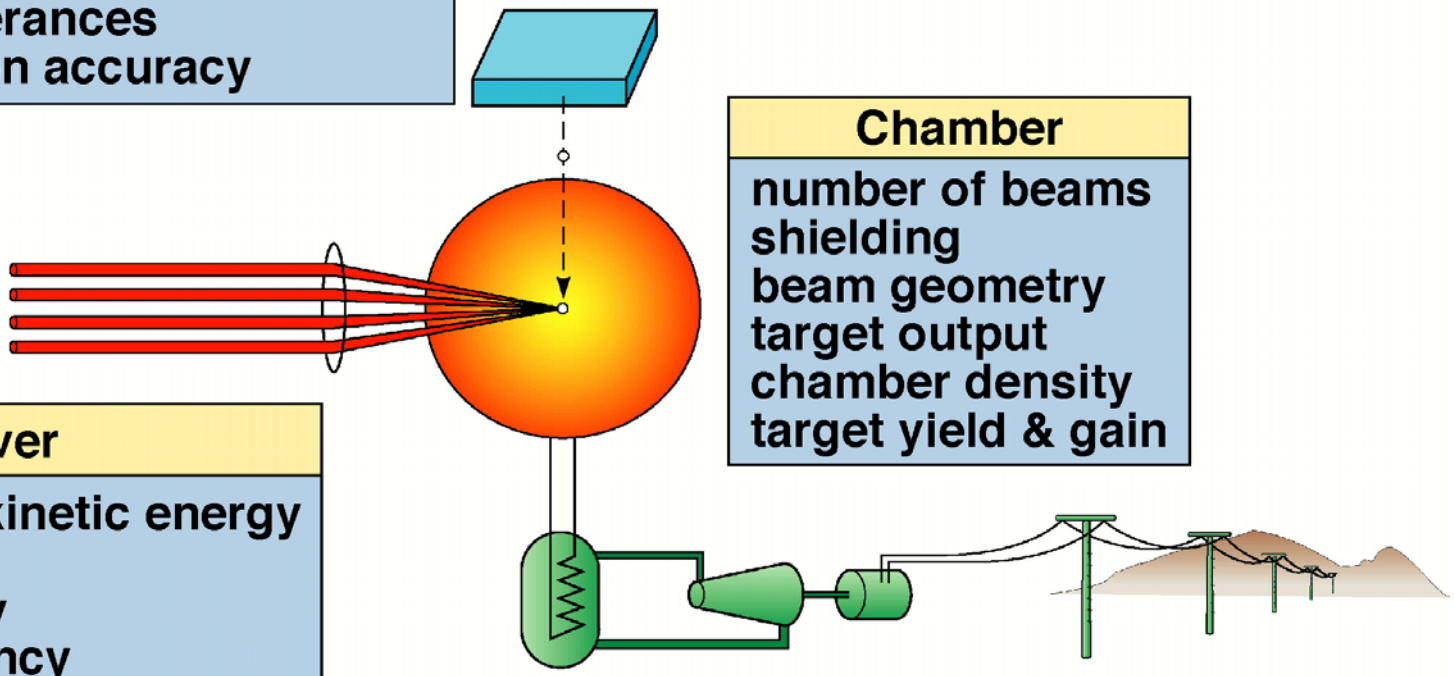
- Laser Direct Drive
  a) Optimize tradeoff between gain, stability, and imprint for IFE targets using DP ASCI codes

- Some possible advanced targets
  a) Fast ignitor targets with minimal plasma propagation path
  b) Laser driven targets compatible with liquid wall protection
  c) Direct drive ion targets

The target interfaces with all the parts of an IFE system and has to consider the trade-offs between the demands placed on the different piece

Target Fabrication and Injection

materials (ablator and hohlraum)
capsule surface finish
ice roughness and temperature
hohlraum tolerances
target injection accuracy



Chamber

number of beams
shielding
beam geometry
target output
chamber density
target yield & gain

Driver

ion species/kinetic energy
spot size
driver energy
driver efficiency
peak power
pulse shape

Example: The choice of hohlraum material impacts all parts of the IFE system

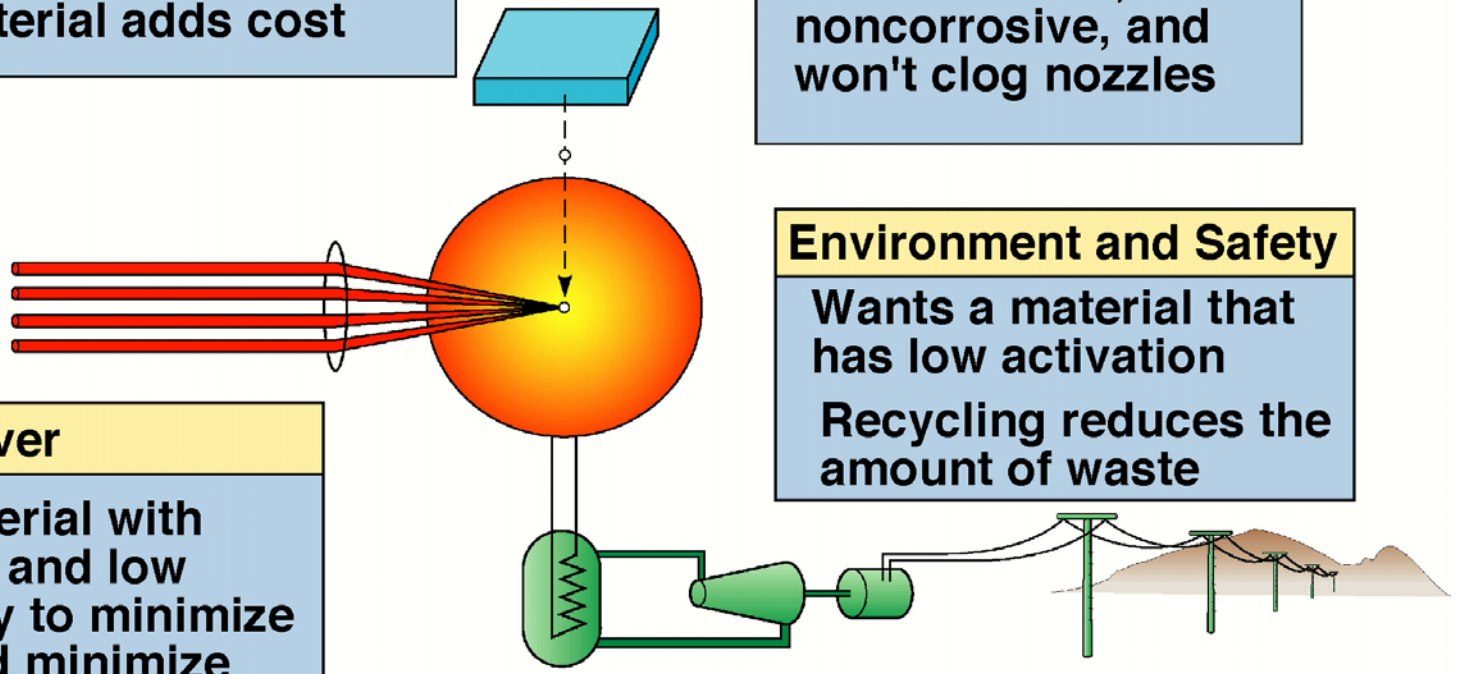
Target Fabrication and Injection

Wants a material that is easy and cheap to fabricate

Recycling material adds cost

Chamber

Wants a material that is easy to extract from chamber, noncorrosive, and won't clog nozzles



Environment and Safety

Wants a material that has low activation

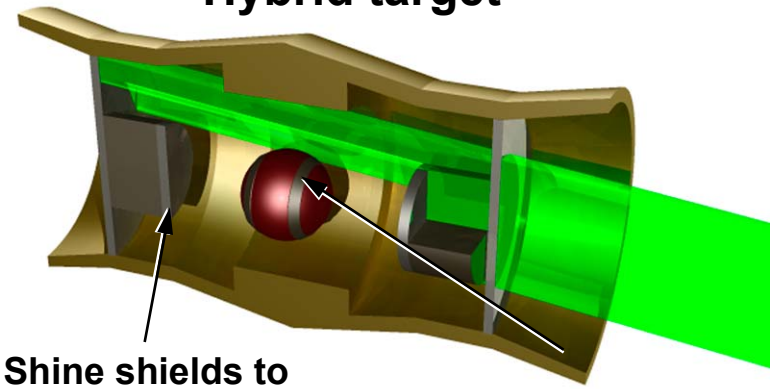
Recycling reduces the amount of waste

Driver

Wants a material with high opacity and low heat capacity to minimize wall loss and minimize driver energy

New symmetry control techniques allow target designs with larger spots for distributed radiator targets for heavy ion fusion

Hybrid target

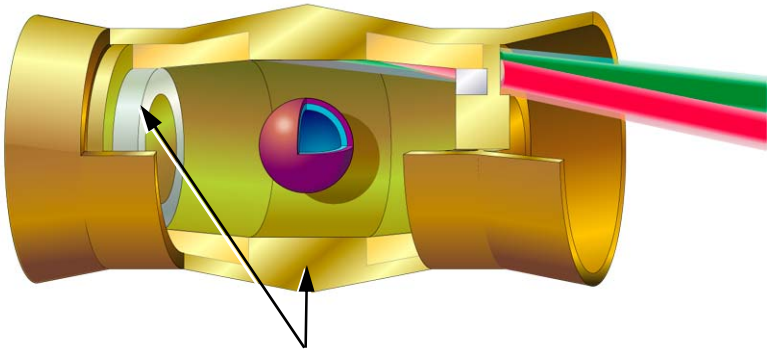


Shine shields to control Legendre mode P_2

Shim to control early time P_4

Beam spot: 3.8 mm x 5.4 mm
Effective radius: 4.5 mm
6.7 MJ beam energy
Gain = 58

Distributed radiator target



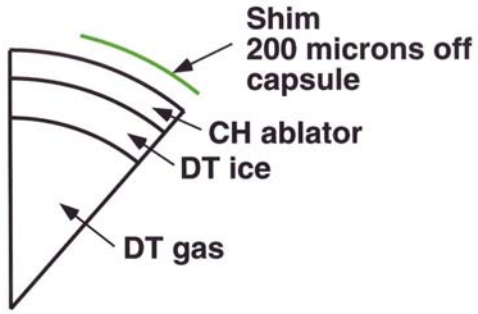
Pressure balance holds position of radiators

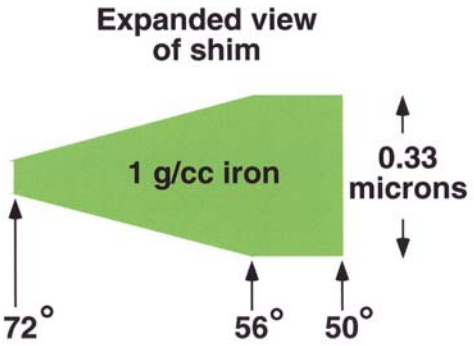
(NIF-like symmetry control)
Beam spot: 1.8 mm x 4.1 mm
Effective radius: 2.7 mm
5.9 MJ beam energy
Gain = 68

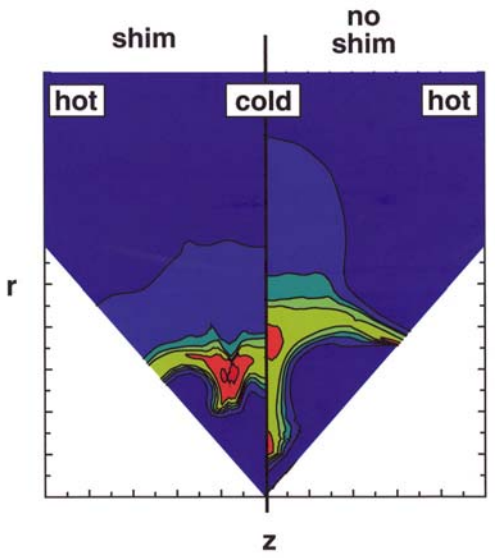
66% increase in beam radius with a 14% increase in beam energy

Initial experiments to test the utility of symmetry "shims" will be tested on the Z-machine in FY03

- Placing the layer off the ball reduces hydro-coupling
- Comparing two calculations with a 3% asymmetry in temperature in the foot with and without a shim layer



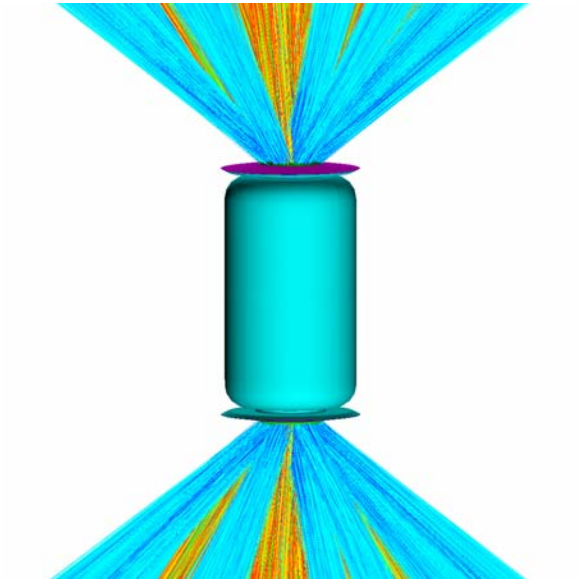


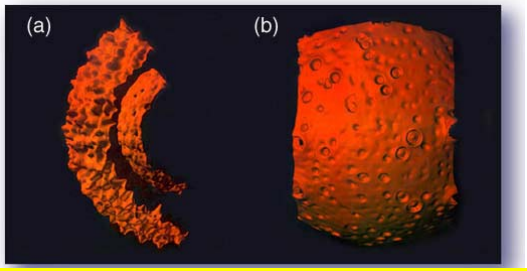


Imploded configurations

Follow-on experiments will be carried out in FY04 and FY05

We have started the analysis of HIF targets using 3-D hydrocodes





HYDRA(a parallel,3D, radiation-hydrodynamics code) has been used to model NIF hohlraum dynamics and implosion capsule stability

We now have initial results for HIF 3D capsule instability

In 2004-2005 we shall study the 3-D hydro stability of our HIF point design and carry out initial integrated hohlraum calculations

At the guidance budget, the OFES target design effort will continue to address a spectrum of critical issues for IFE but at a reduced effort level

	FY 2003	FY 2004	FY 2005
Staffing (FTE)	3.25	3.	2.85
Operating Expense ($K)	1028	1031	1031

- FY05 deliverables under guidance case
  - — Continue experiments to test unique HIF target features
  - — Continue use of 3D rad-hydro codes to understand symmetry and stability of IFE targets
  - — Further development of HIF targets which are less sensitive to beam focusing properties
  - — Study irradiation control for direct drive laser targets
  - — Further development of Fast Ignition physics models

The request case budget will allow an expansion in IFE target design consistent with the needs of the IFE development plan

	FY 2003	FY 2004	FY 2005
Staffing (FTE)	3.25	4.9	5.
Operating Expense ($K)	1051	1657	1778

The increase in effort for FY04 will be directed toward:

a) Identify the most robust strategy for HIF ~30MJ yield targets appropriate for an Engineering Test Facility - this has a major impact on the development path strategy

b) Assess the effect of asymmetry generated B-fields on laser direct-drive targets

c) Begin integrated Fast Ignition calculations

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The OFES FI team of LLNL, GA, Princeton and UC Davis has been highly successful in obtaining run time on facilities in the US, Japan and Europe

- Two separate run week on the JanUSP facility at LLNL
  - electron transport
  - ballistic focusing of a picosecond proton beam

- A six week run at the Rutherford Appleton Lab Vulcan laser with UK and Japanese scientists (an LLNL "ticket" in exchange for Nova parts)
  - proton radiography of an imploded capsule
  - Cu K-alpha transport experiment

- A collaborative experiment on the ILE Osaka Petawatt laser beamline
  - proton heating of an Al foil using a ballistically focused picosecond ion beam

The OFES concept exploration project will be able to access significant new capabilities in FY04 and FY05

- Three new 1PW lasers in Europe and Japan will support more integrated 'closer to ignition' studies of both electron and proton FI
- A US, NNSA PW laser Initiative is developing technology for High Energy Petawatt (HEPW) 2 to 5kJ, 1PW pulses which should be progressively available at major DOE lasers from FY05
- Project can transition to 'proof of principle' at DOE HEPW lasers in FY05 or FY06 via FY04 experiments at 500J , 1 PW lasers
- Must use latest hybrid PIC modeling benchmarked by experiments to predict ignition

The ILE Osaka petawatt system achieved a major step forward in demonstrating the feasibility of Fast Ignition

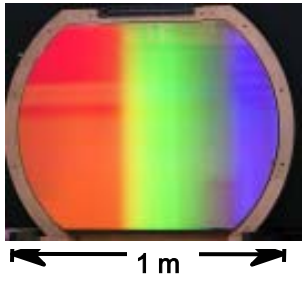
GEKKO XII is currently the only laser system in the world that can test compression followed by fast heating

Petawatt laser system (500J in 0.5 ps)

Amplifier

Pulse compressor

grating



GEKKO XII (10J in 1 ns at 0.53 μm)

Amplifier

Focusing System

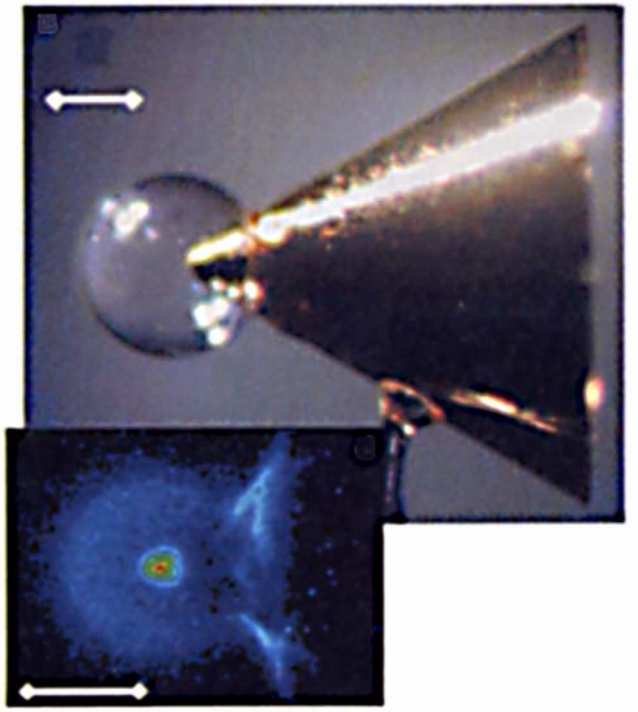
spherical symmetry irradiation

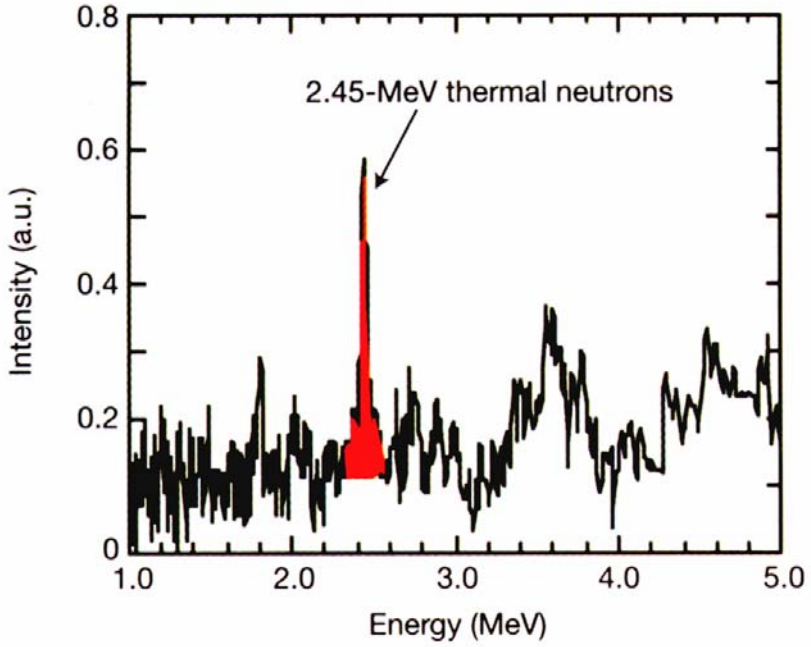
One side irradiation system

Experiments on Gekko XII have seen enhanced neutron output from fast heating of a direct drive target with a reentrant cone

ILE OSAKA

Enhanced neutron output from fast heating of deuterated direct drive shell implosion on Gekko XIII laser (Japan,UK) R. Kodama, et al., Nature 412, 798 (2001)



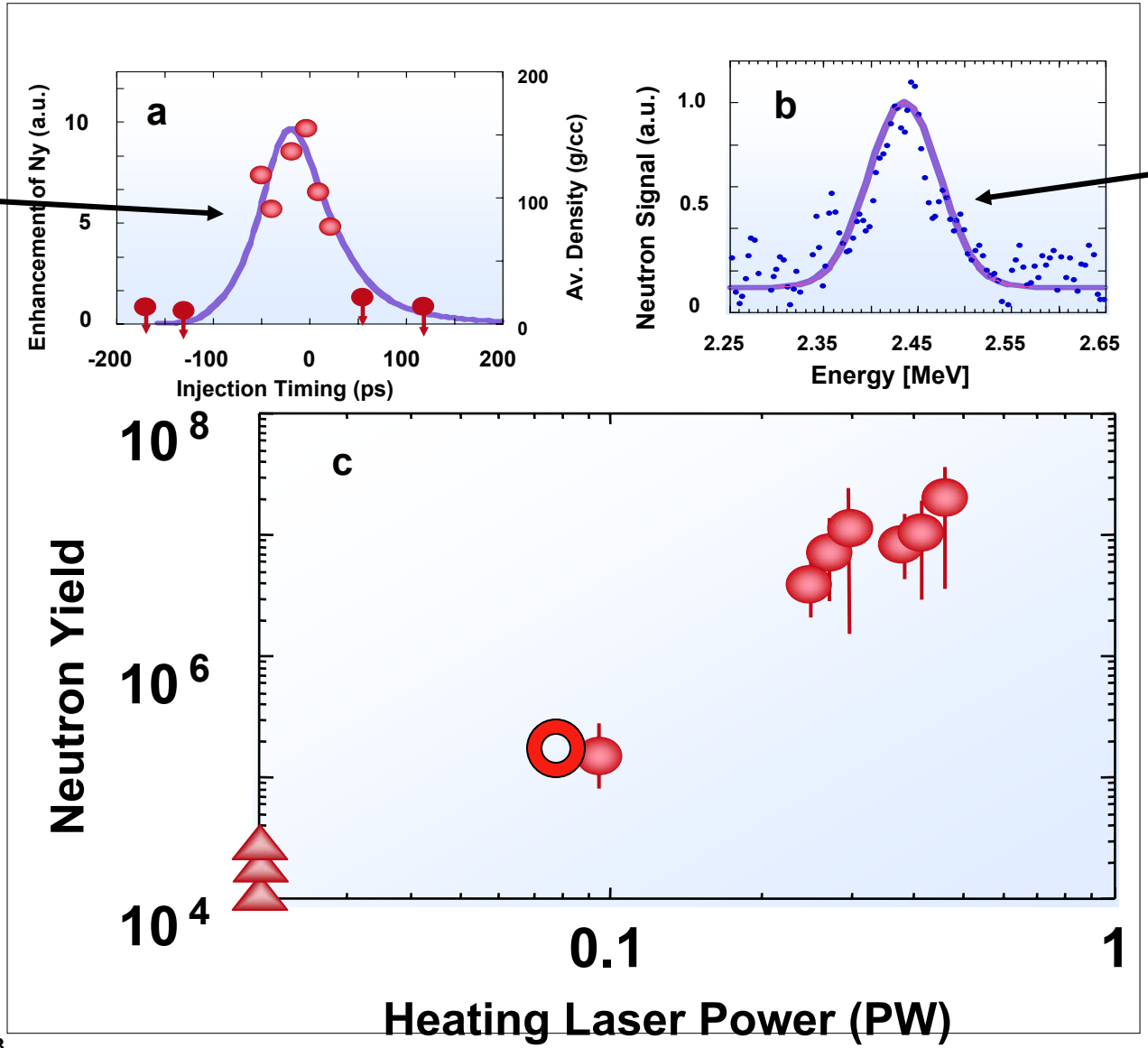


1.2 KJ compression pulse + 60 J, 100 tw fast heating pulse

Petawatt laser heating experimental results of cone guide target

ILE OSAKA

Required timing is 50ps



800keV

IF/OV1
T.Yamanaka

The first phase of the Fast Ignition Realization Experiment (FIREX) Project has been approved at ILE as part of the Japanese fusion program

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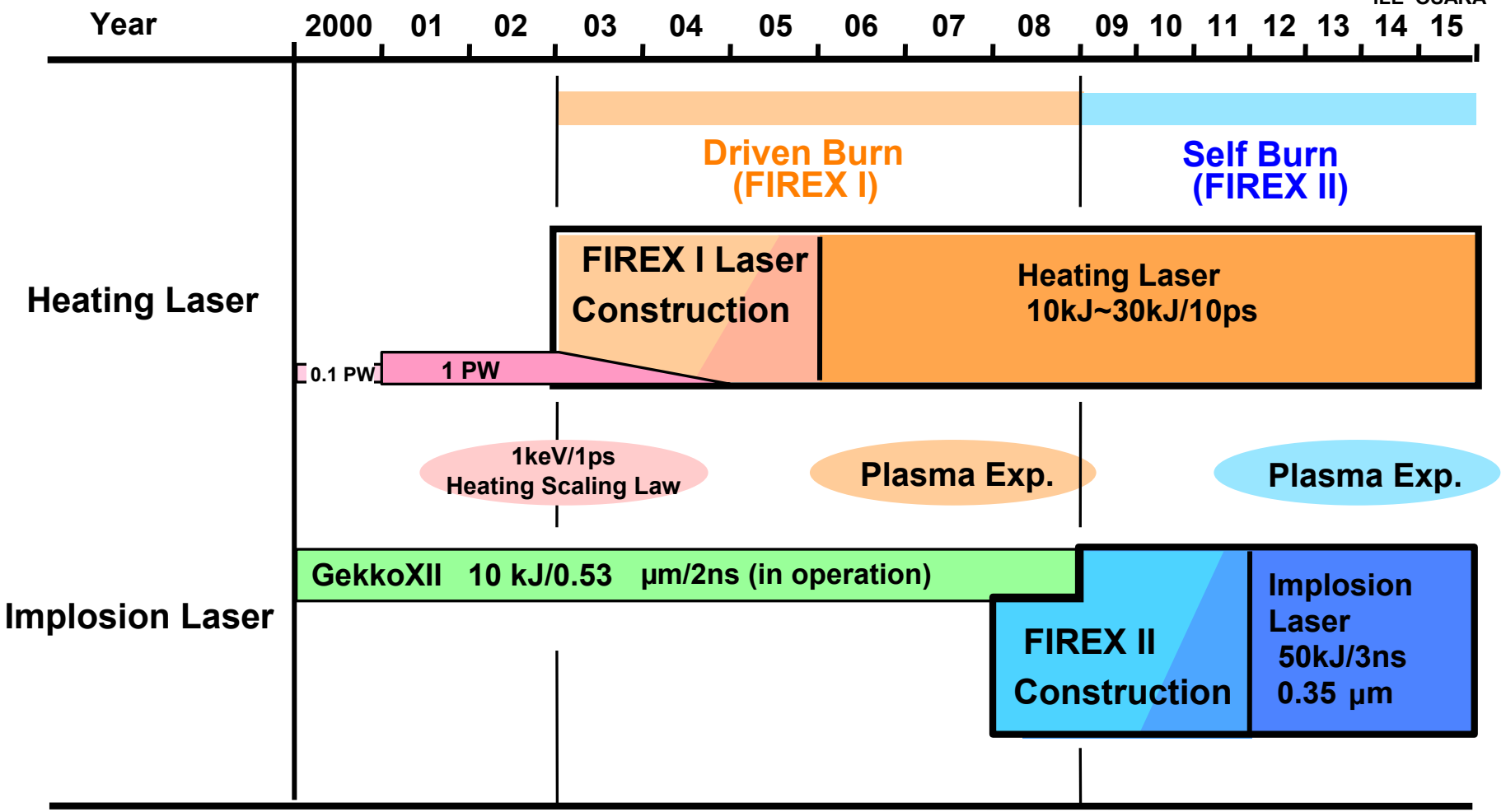
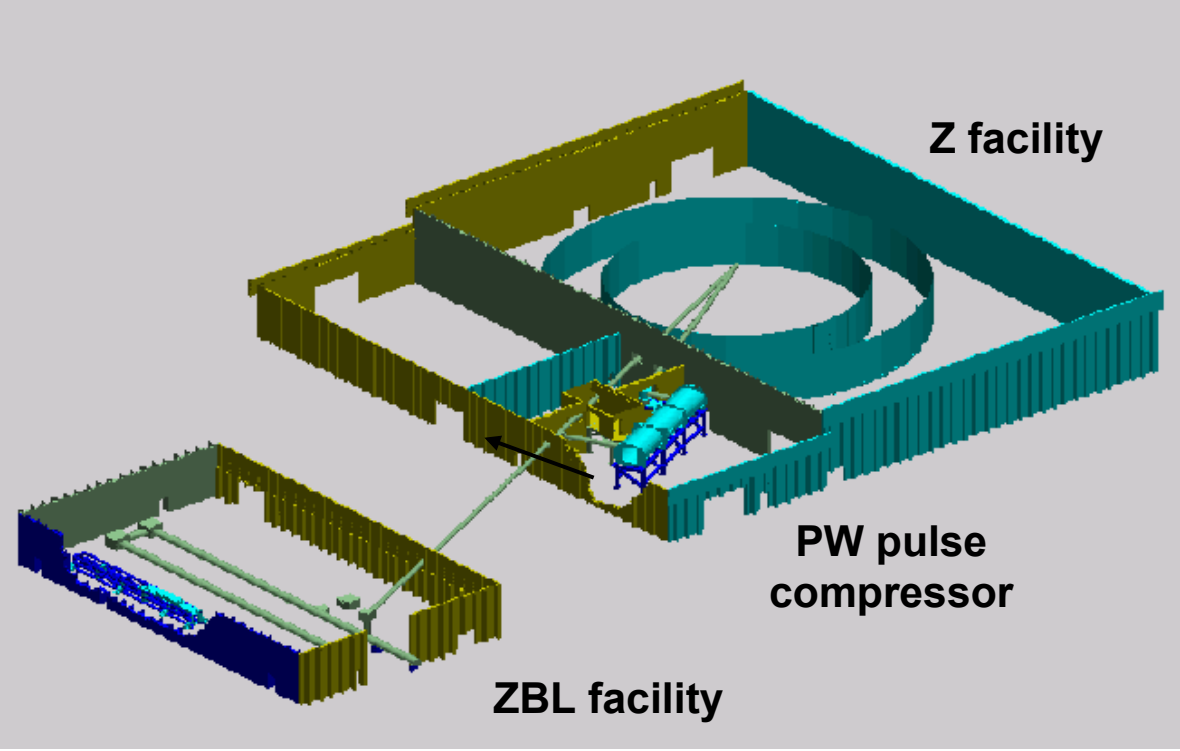


Congress appropriated $5M in FY03 for an HEPW beam line using the Z Beamlet (NIF prototype) laser at SNL

- Modification of the Z-Beamlet laser (ZBL) facility will enable fast ignition experiments on Z.



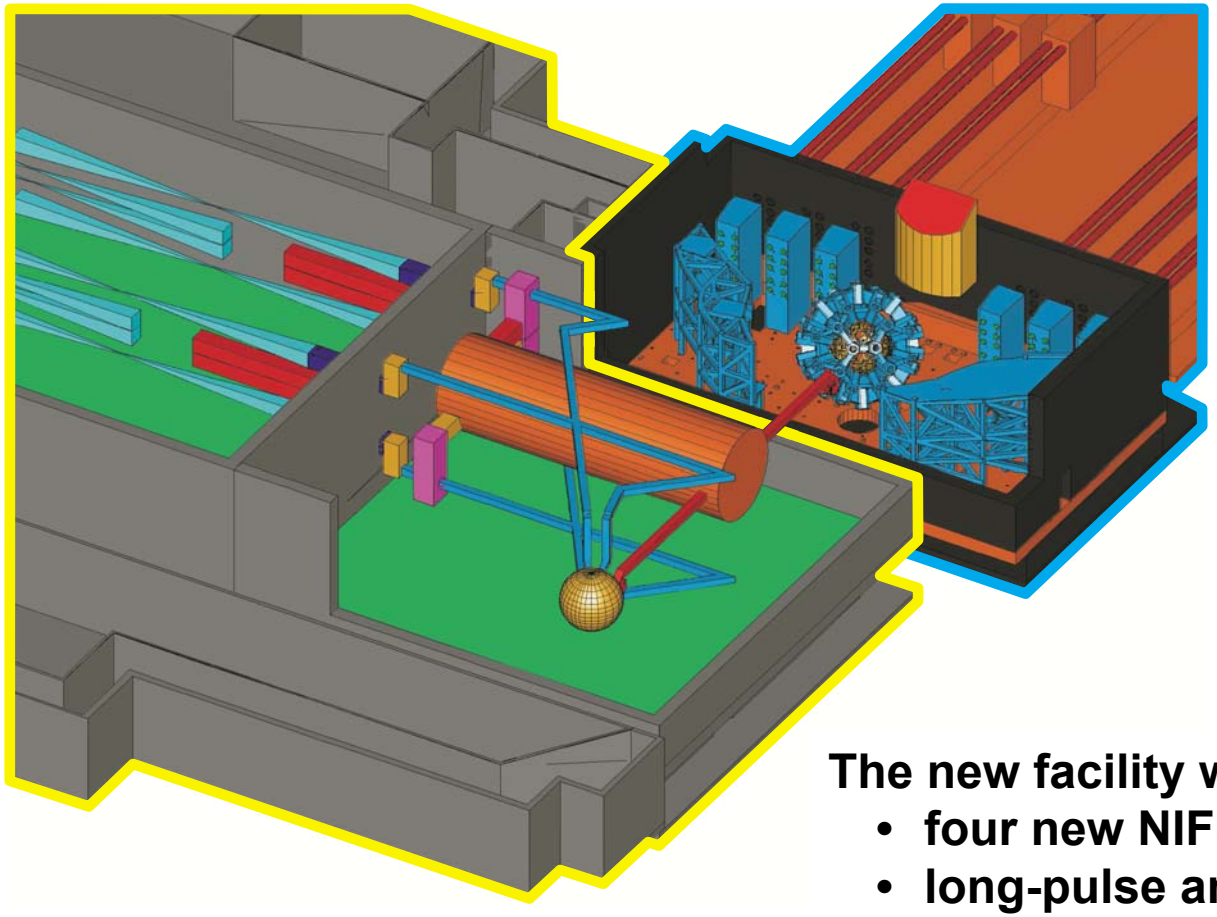
Proposed Capability

Phase I (FY04):
500 J in 0.5 ps

Phase II (FY05):
1.5 kJ in 5 ps

Phase III (FY06):
3.0 kJ in 5 ps

Congress appropriated $13M toward the construction of a versatile new facility adjacent to the existing Omega target chamber

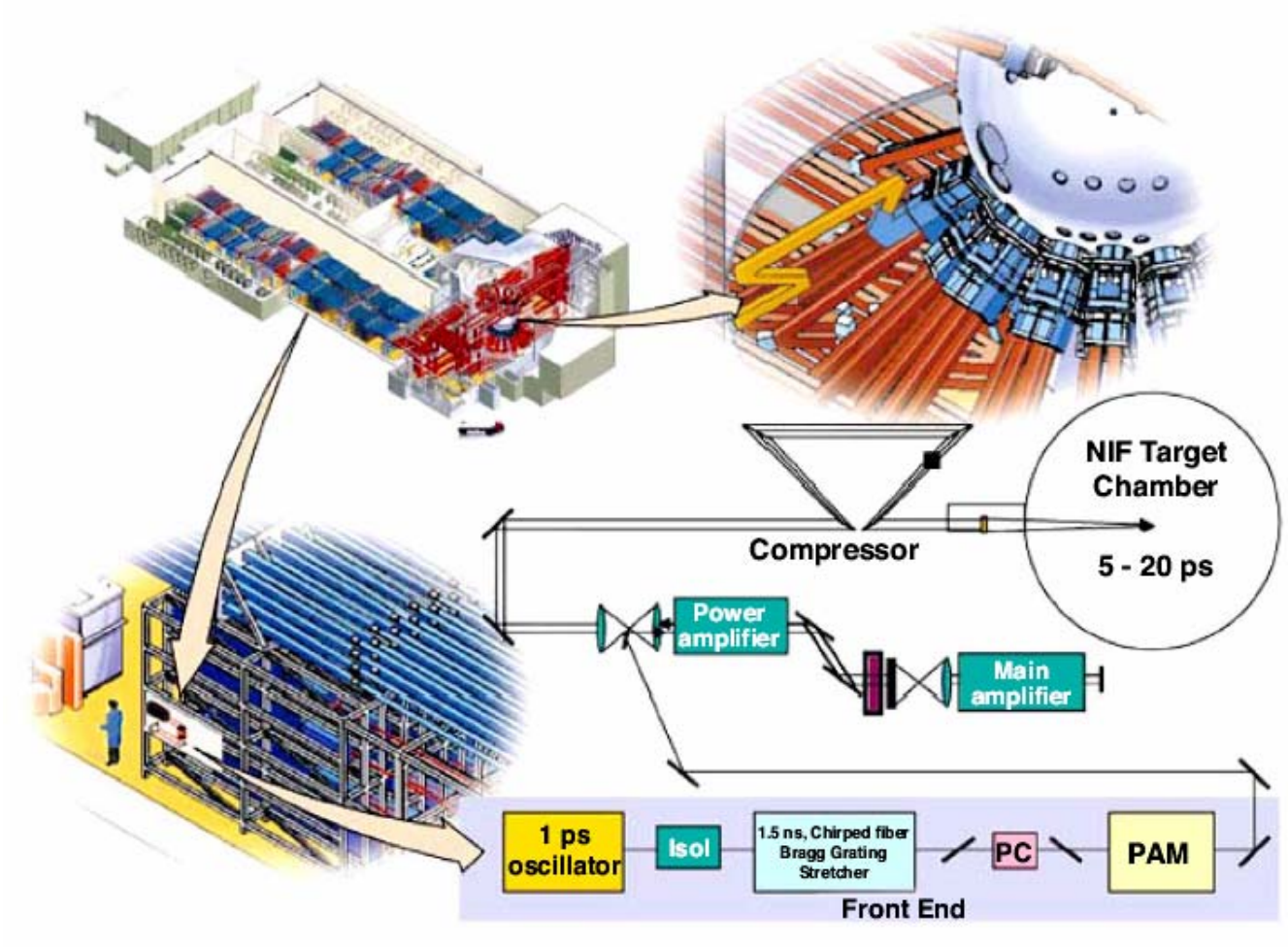


2 HEPW beams will generate 2kJ at <1 ps for fast ignition

The new facility will include:

- **four new NIF-style beamlines**
- **long-pulse and CPA capability**
- **a 61st beam injected into OMEGA**
- **an auxiliary target chamber**

Multi-HEPW beams, leading to demonstration, are compatible with existing NIF architecture



Increased FY05 funding of the joint LLNL/GA project is needed to prepare for 'proof of principle' transition

- New numerical modeling capabilities (notably hybrid PIC) must be applied to design and interpret 1PW integrated experiments and justify a transition to proof of principle (add 1.2 FTE, 350k)
- Increased manpower and new diagnostics are required to field more complex 1PW experiments at labs in Europe and Japan (add 1 grad student, 1 post doc ,0.5 FTE and procurements, 400 k)
- Increased technical effort and material costs for target fabrication at GA (add 1.0 FTE and procurements 400k)
- Total FY04 cost at GA and LLNL $2000k

	FY 2003	FY 2004	FY 2005
Staffing (FTE)	2.2	2.2	5.2
Operating Expense ($K)	760	800	2000

Unchanged FY05 funding will delay progress to 'proof of principle' level and diminish the presence of IFE science on worldwide Petawatt facilities

- New numerical modeling capabilities (notably hybrid PIC) will be available but the OFES project will lack effort to use the codes, impeding design and interpretation of expts. and extrapolation to ignition .
- Fewer new diagnostics and a cut back from 3 to 2 ,1PW experiments at labs in Europe and Japan will be required -slowing data acquisition .
- Targets for experiments will be less in number and sophistication , under-using the GA capability and the potentially available PW laser shots
- Total FY05 cost at GA and LLNL $800k

	FY 2003	FY 2004	FY 2005
Staffing (FTE)	2.2	2.2	2.2
Operating Expense ($K)	760	800	800