The IFE Target Theory and Modeling Program

John Lindl
Fusion Energy Program Leader

University of California
Lawrence Livermore
National Laboratory

Presented at:

OFES Budget Planning Meeting
Washington, DC

March 16-17, 2004

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

Goal: Aggressively exploit NNSA and International facilities and Advanced Modeling tools to explore physics issues central to IFE targets and other HEDP

- Radiation Symmetry in HIF Targets:
  - –Z-Machine (SNL)
- Ion stopping in warm dense matter:
  - –JanISP laser (LLNL)
- Non-linear hydrodynamic instability in converging geometry:
  - –Hydra 3D ASCI code
- Fast Ignition implosions and intense beam transport:
  - – Cone Focus experiments: Omega and OmegaEP(LLE), GEKKO (ILE), Vulcan(Rutherford), Z-Beamlet (SNL), and NIF (LLNL)
  - –LSP code for high current (giga-amp) fast electron transport

The IFE Target Theory and Modeling Group Has Been Active in High Energy Density Physics

Target design innovations

Cone focus fast ignition

Adiabat shaping to control Rayleigh-Taylor instabilities in directly driven laser targets

Z-pinch driven ICF target

Heavy ion targets
- Pressure balanced hohlraum
- Shims
- Close coupled designs

Tradeoff in implosion capsule design
- Stability vs. implosion velocity

Basic science studies

Pair plasmas produced by short pulse lasers

Capsule ignition model

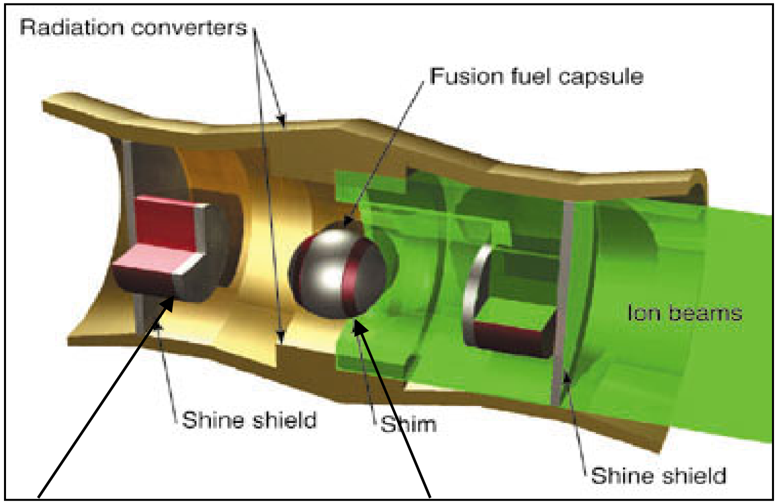
Discovery of fast proton generation in short pulse laser experiments

Analytic model for saturated state of convergent Rayleigh-Taylor instability

Transport of giga-ampere currents of relativistic electrons through dense plasmas

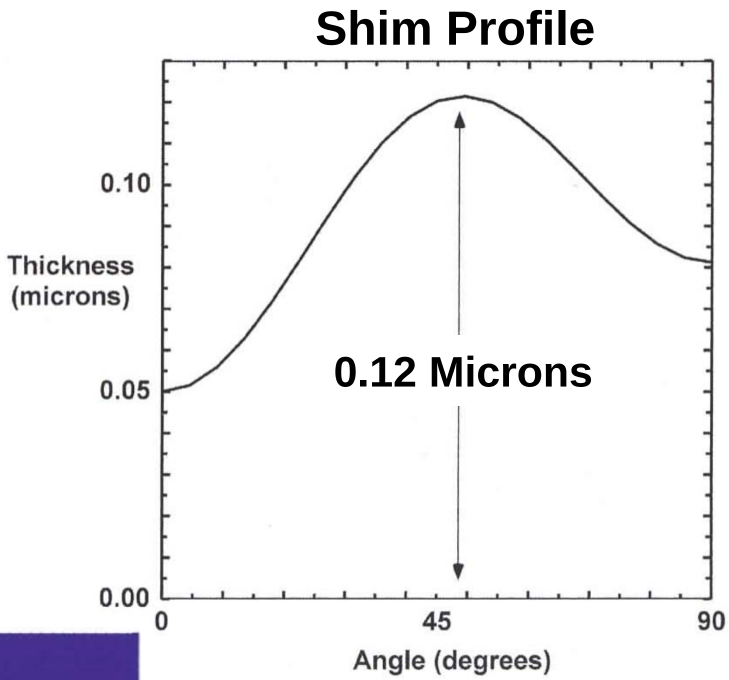
Publications 2003: 28 papers as first author or co-author

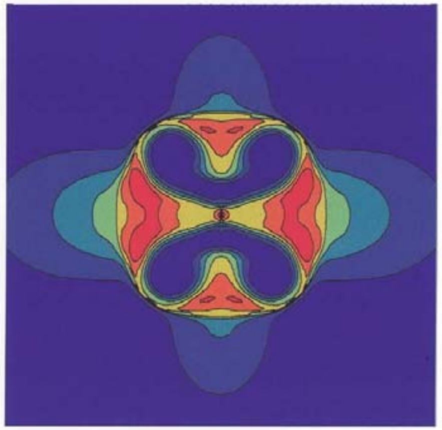
Accommodating large ion beam spots led to a target with "shimmed" radiation transport



Shine shield to control P_2

Shim to control early time P_4





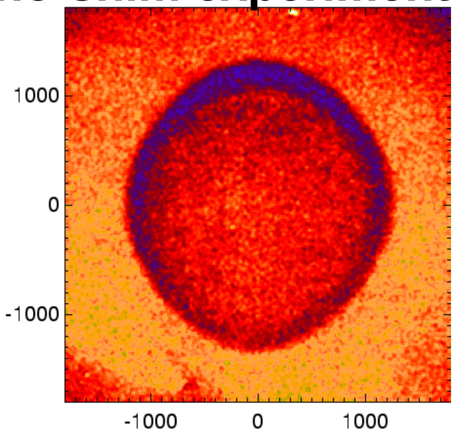
No shim

With a shim

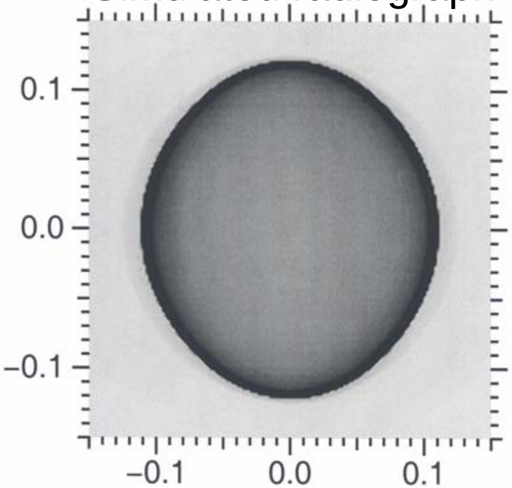
This concept will be tested at the Z-machine at SNLA

A collaboration of LLNL,SNL, and GA will begin testing radiation transport “shims” on Z in April

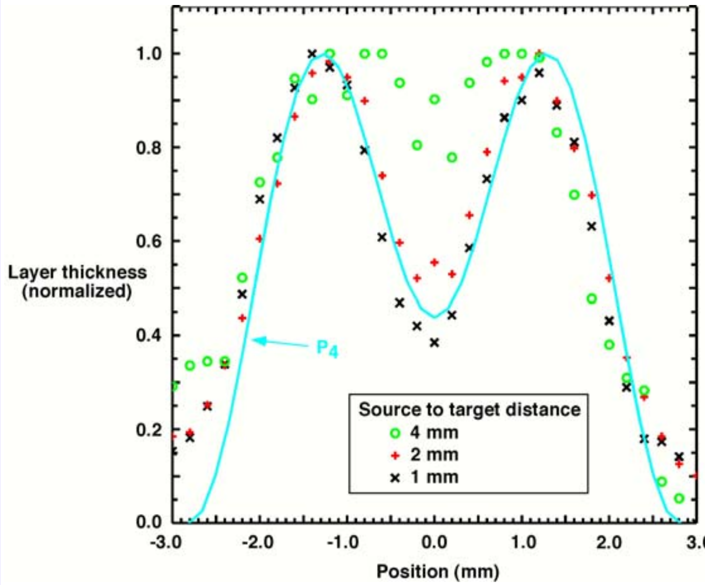
Modeling describes no-shim experiments



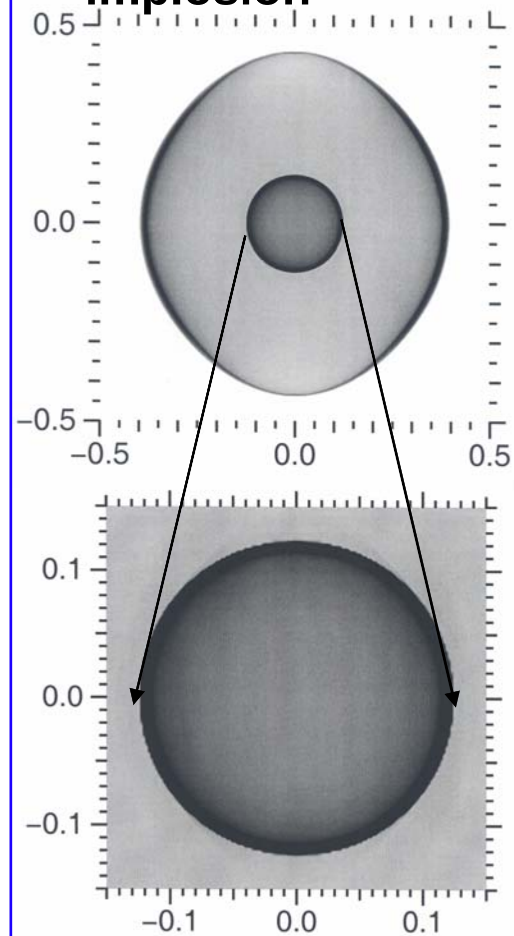
Simulated radiograph



Au deposition through masks can produce required shim structure

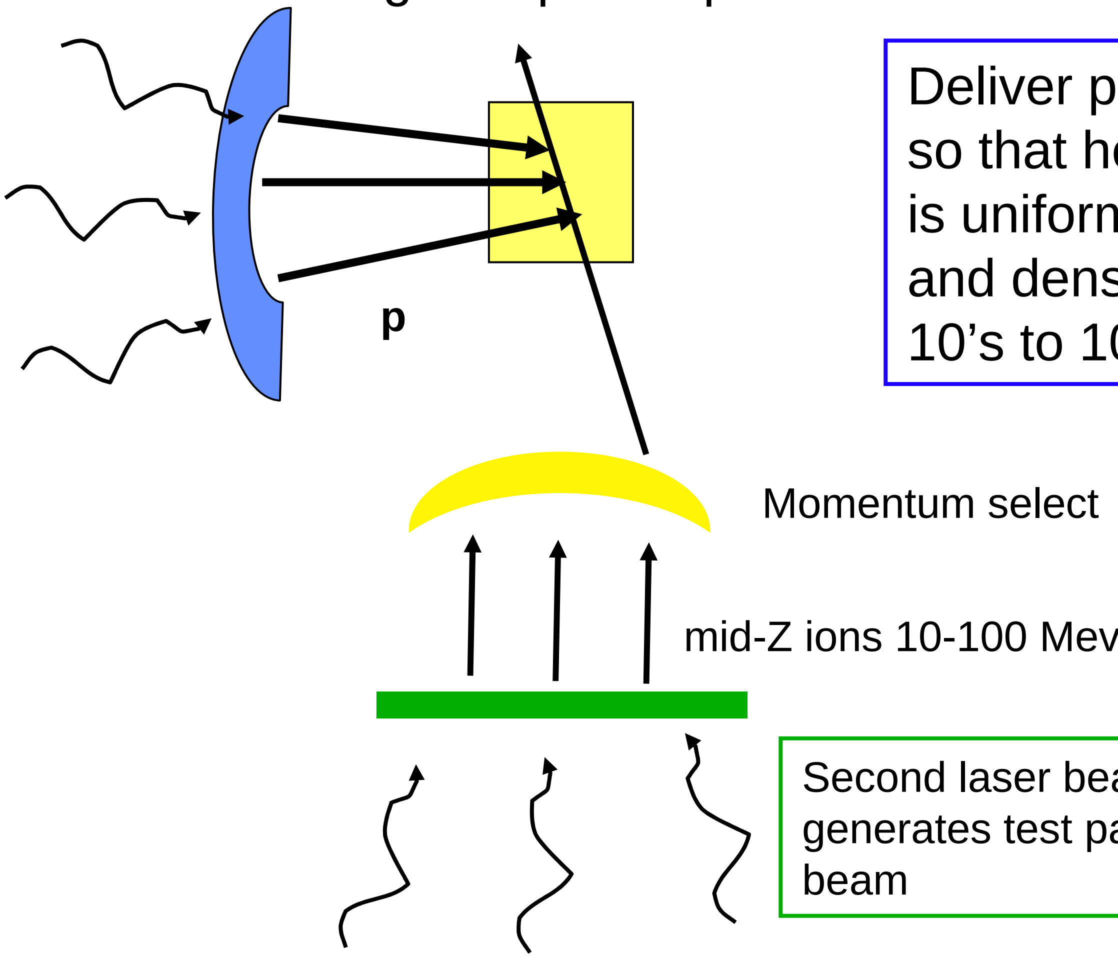


Shim symmetrizes implosion



Short pulse produced ion beams at 2 beam LLNL JanISP laser can be used to measure the stopping power of ions in dense hot plasmas

Isochoric heating with proton plasmoid

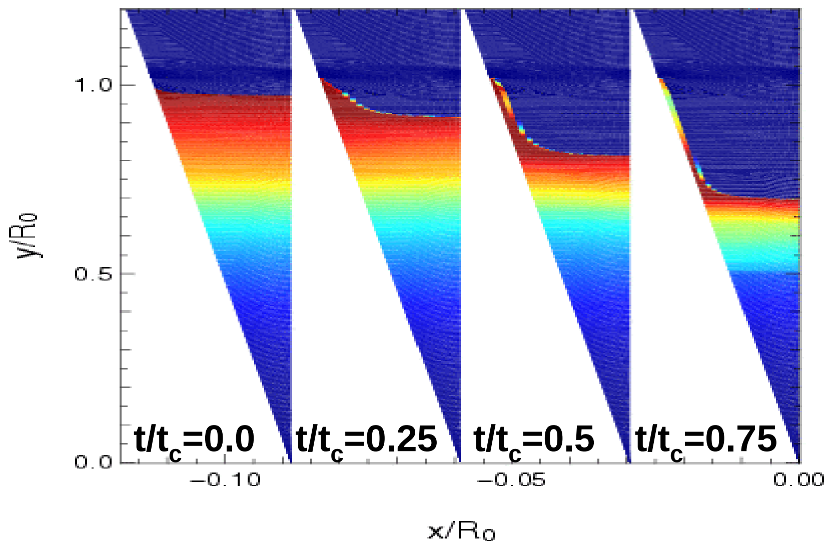


Deliver proton plasmoid so that heated material is uniform in temperature and density
10’s to 100’s eV expected

Second laser beam generates test particle beam

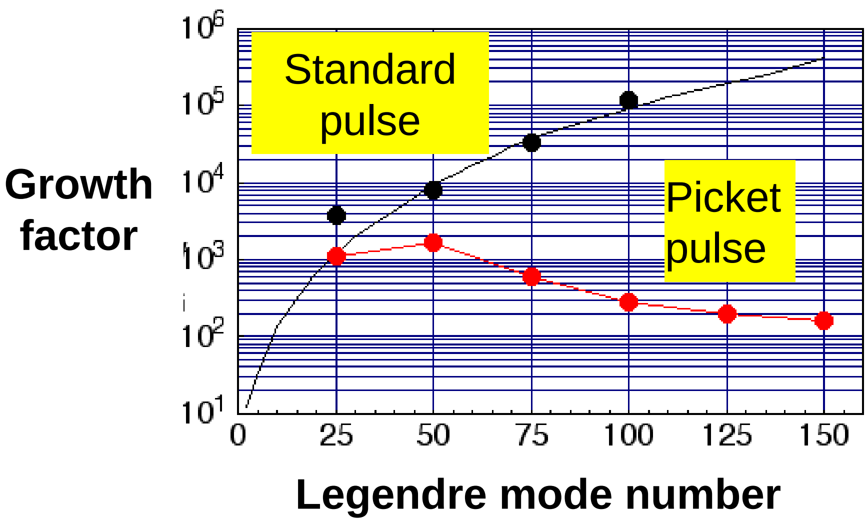
Design experiment in 2006 for execution in 2007

We are developing methods to benchmark and improve hydrodynamic calculations



The nonlinear saturated phase of the Rayleigh-Taylor instability may occur in both acceleration and deceleration phases of inertial fusion implosions

We are developing analytic techniques to model this regime in converging geometry

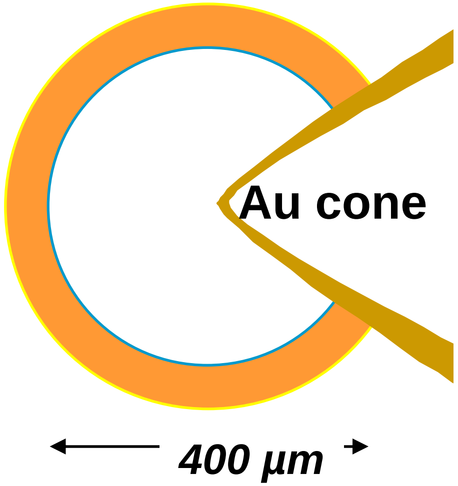


Linear growth calculations fail between l=100 and 150
Nonlinear calculations fail at l=60

We are studying the interaction of shocks with grid irregularities as the source of noise

Joint GA/LLNL experiments have tested cone focus targets on the Omega laser

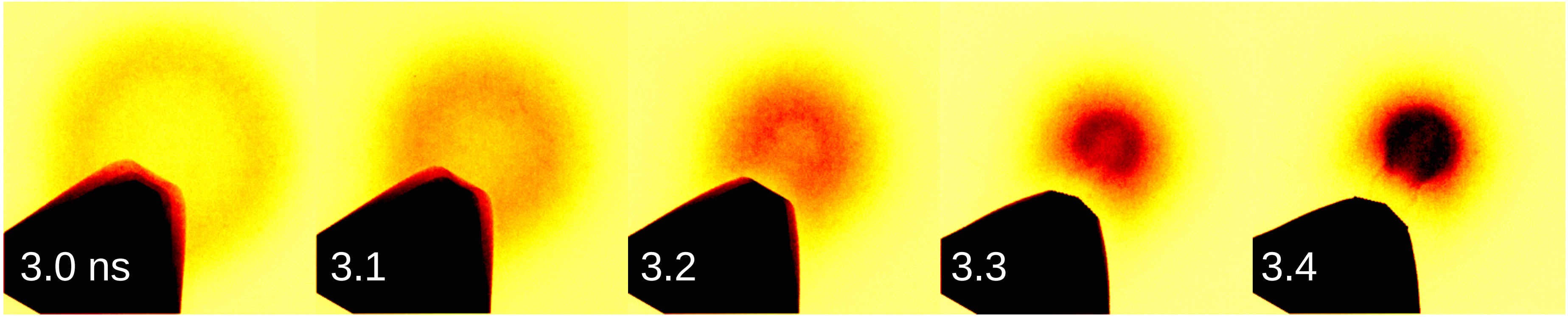
New opportunities for experiments on NNSA and International facilities will require sophisticated modelling



Cone target at Omega

QuickTime™ and a Motion JPEG B decompressor are needed to see this picture.

Radiograph

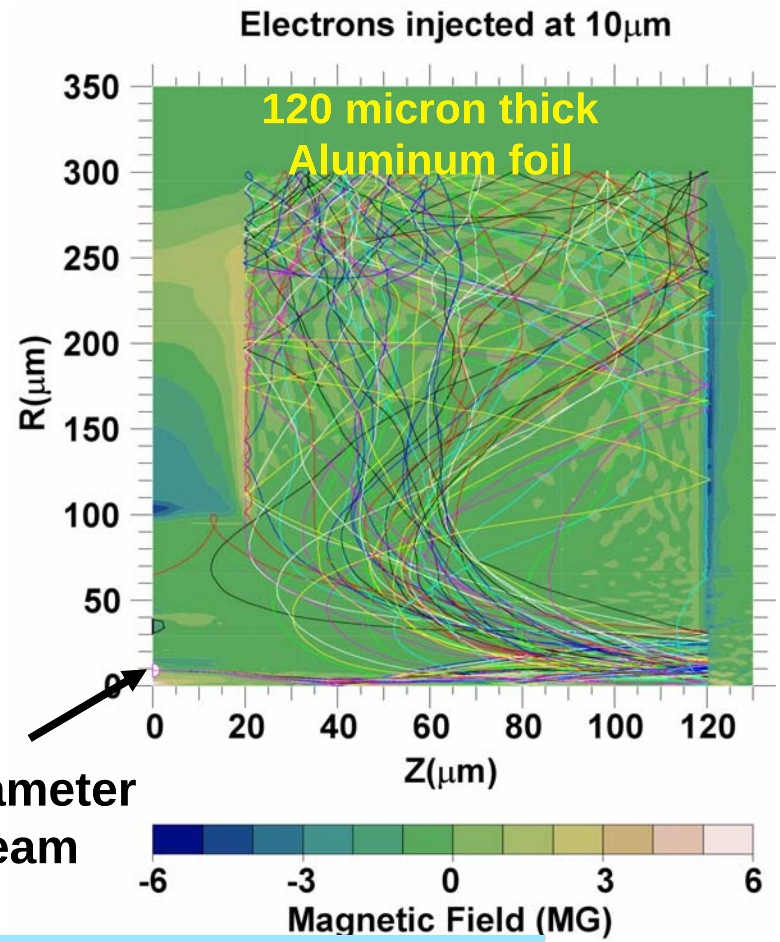


Simulated sequence of radiographs at Omega

We are using the LSP hybrid PIC code to model transport of energetic charged particles through dense matter for Fast Ignition and HEDP

- **LSP uses the direct implicit algorithm to exceed limitations set by the plasma frequency and the Debye length in warm dense matter**

- **Use of the MRC code LSP for short pulse physics was funded with OFES target design funds.**



10 micron diameter Injected Beam

Planned Improvements include QEOS, Lee-More conductivity and realistic proton and relativistic electron stopping power through very dense plasmas

At the FY06 guidance budget, the OFES target theory effort will continue to address a spectrum of critical issues for IFE and HEDP but at a reduced effort level

	FY 2004	FY 2005	FY 2006
Staffing (FTE)	3.	2.85	2.7
Operating Expense ($K)	1020	1020	1020

- **FY06 deliverables under guidance case**
  - **— Continue experiments on NNSA facilities to test unique HIF target features**
  - **— Continue use of 3D NNSA ASCI rad-hydro codes to understand symmetry and stability of IFE targets**
  - **— Continue to study and improve numerical techniques to model hydrodynamic instabilities**
  - **— Further development of Fast Ignition physics models and high efficiency implosions and participate in experiments on NNSA and International facilities**

The FY06 request case budget will allow an expansion in IFE target theory with emphasis on short pulse laser driven physics

The increase in effort for FY06 to 6 FTE's and $2050K will be directed toward:

a) **Study effect of hydrodynamic instabilities on Fast Ignition assembly**

b) **Develop integrated tools to model hydro/burn and electron/proton transport/generation for short pulse applications**

c) **Design experiments driven with short pulse lasers to measure transport and stopping power of ion beams**

d) **Developed improved models of light propagation through perturbed coronal plasmas for laser-driven IFE targets**

e) **Assess the effect of asymmetry generated B-fields on IFE targets**

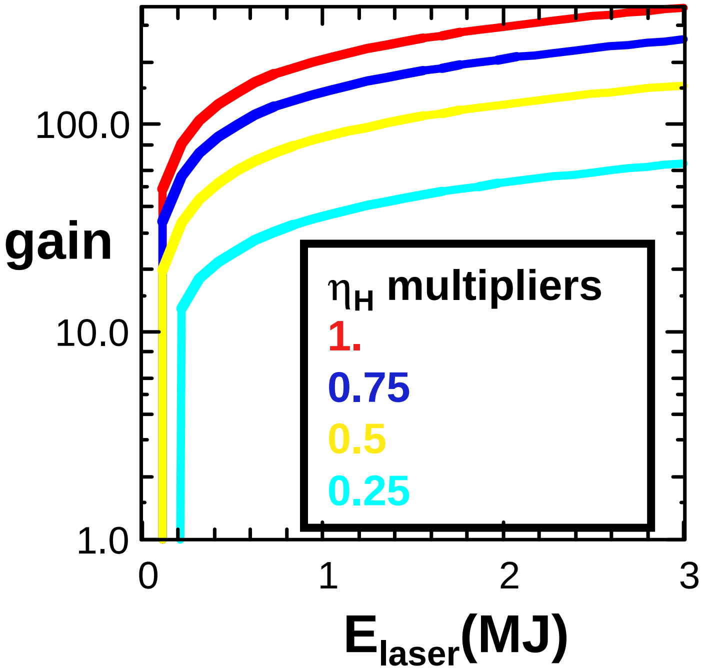
Extras

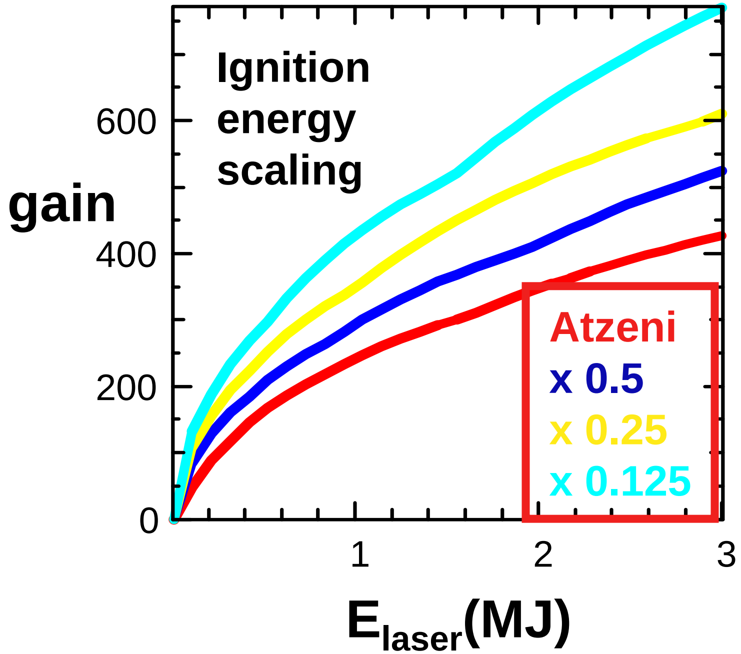
IFE and NNSA target designs have similar but distinct requirements

	Inertial Fusion Energy	NNSA
Gain requirement for affordable driver energy	$\eta G > 10$	G>1 Ignition Y>500-1000 MJ High yield for any E_{in}
Illumination geometry	Consistent with protection of first wall and driver optics	Whatever works for single shot
Target fabrication	Mass produce at low cost. No Be ablator	Targets are specialty items
Driver characteristics	Accommodate driver intensity, pointing and pulseshape accuracy	NIF spec'd for ignition

The additional requirements placed on IFE targets have driven design innovations and led to a focus on fundamental understanding. These have influenced the NNSA program

Significant improvements in Fast Ignition gain curves may be available





- Current designs exhaust half energy forming condensed core

- Future designs using high Z or density cores may be more efficient

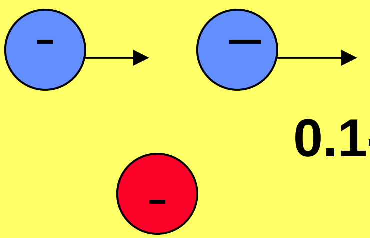
- Factor 2 reductions in ignition energy have been calculated for "cylindrical exploding pusher" ignition
- 3D has more reduction

Investigating these improvements will require advances in target fabrication

Physics at the Angstrom and micron scales may affect stopping power and transport

The Deutsch effect

When do two projectiles act coherently on a target?



0.1-1.0 nm

$\Delta E \sim (\Delta p)^2$

2 charges acting coherently in 1 plasma period lose twice the energy of 2 charges acting independently

Beam-plasma instabilities
2 stream and Weibel

$\gamma_{bp} \sim \omega_e(n_b/n_p)^{1/3} f(k) \sim 10^{15}/\text{sec}$

Peak near $\lambda = c/\omega_b \sim 1\ \mu m$

Detuned by beam and plasma temperature, collisions, gradients

Saturation may result in coherent structures or plasma turbulence
If treated as subscale effect, enhanced stopping power or resistivity