Advances in IFE Targets*

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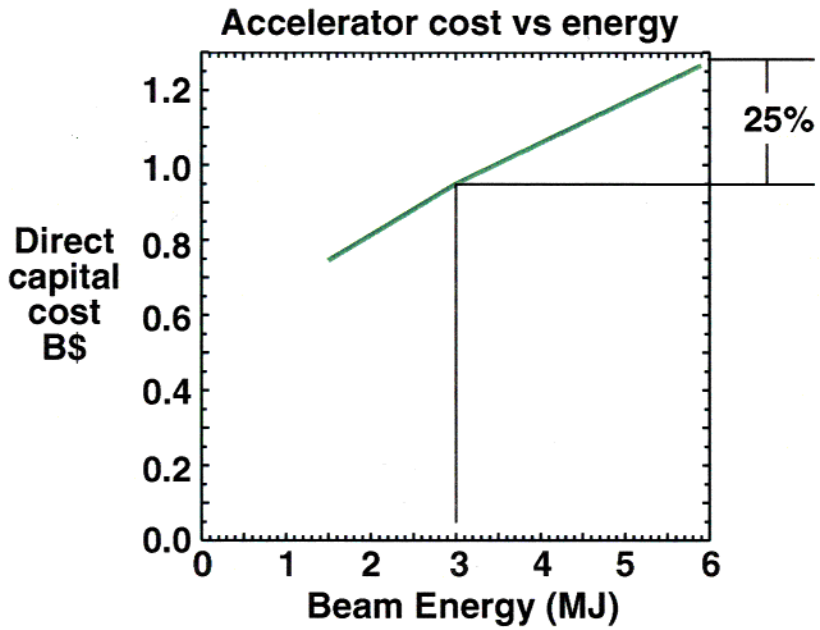
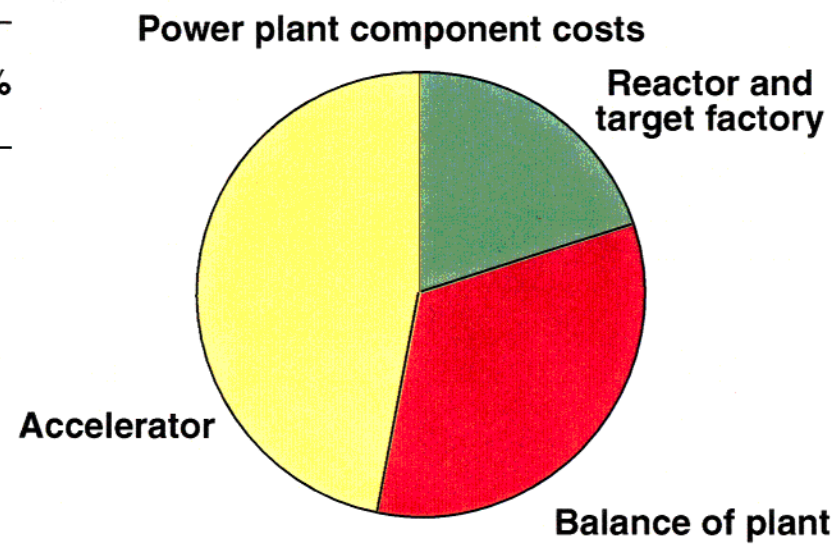
Advances in both heavy ion and laser targets may allow smaller, cheaper drivers

- A close-coupled heavy ion target may allow us to reduce the driver energy by almost a factor of two
  - Lasnex calculations predict gain 132 from 3.3 MJ of beam energy
  - This may reduce the development cost for HIF by allowing both low and high gain from a single ETF accelerator
- Heavy ion target designs that allow larger beam spots are in progress
- The new NRL direct drive laser target may allow gains as high as 135 from 1.2 MJ of laser energy
  - This gives adequate ηG (~ 10) for a 7% efficient laser at small size

A close-coupled, heavy ion target reduces the accelerator cost and the cost of electricity



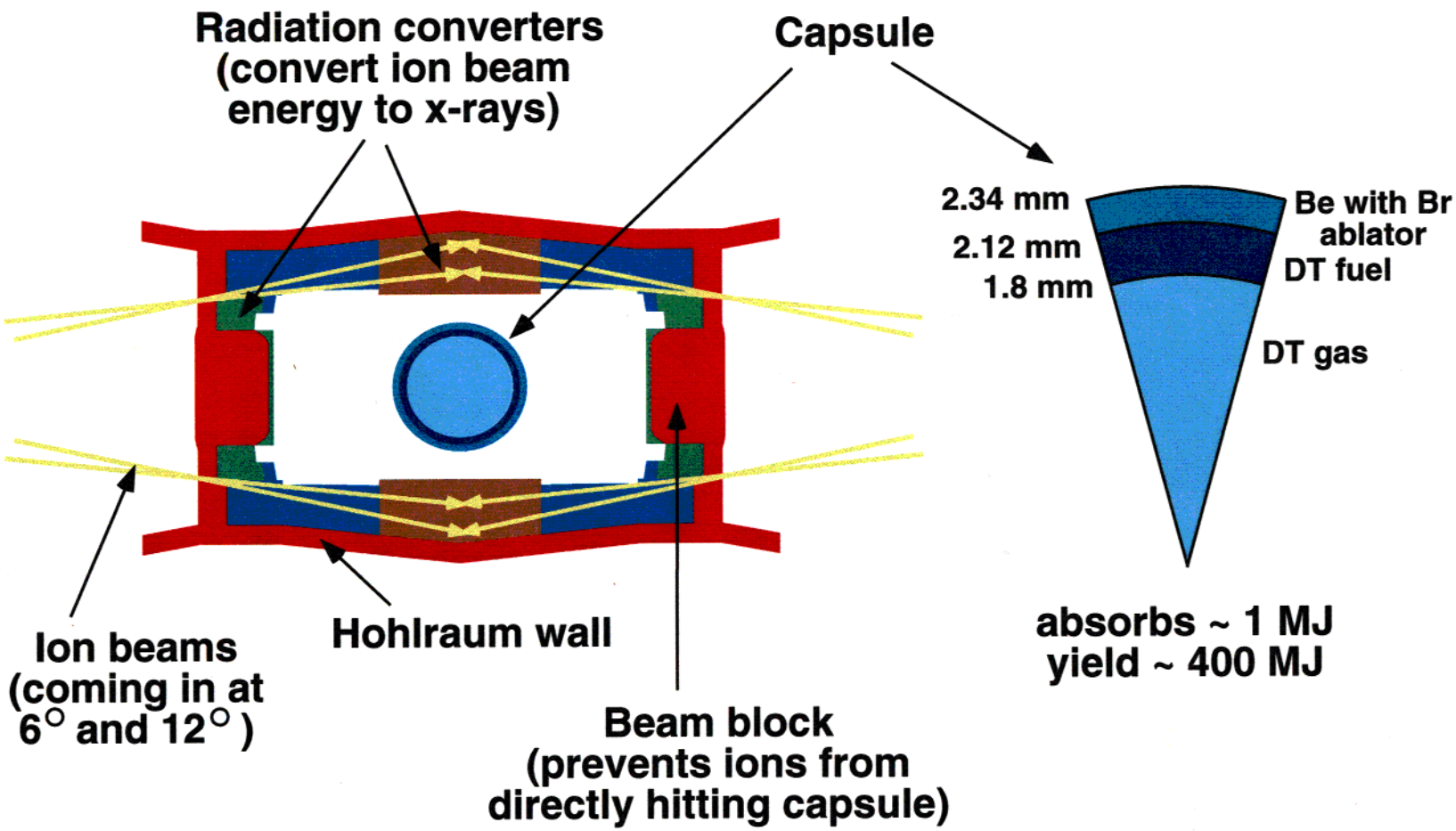


Accelerator cost is reduced by ~ 25% if beam energy is reduced from 6 MJ to 3 MJ

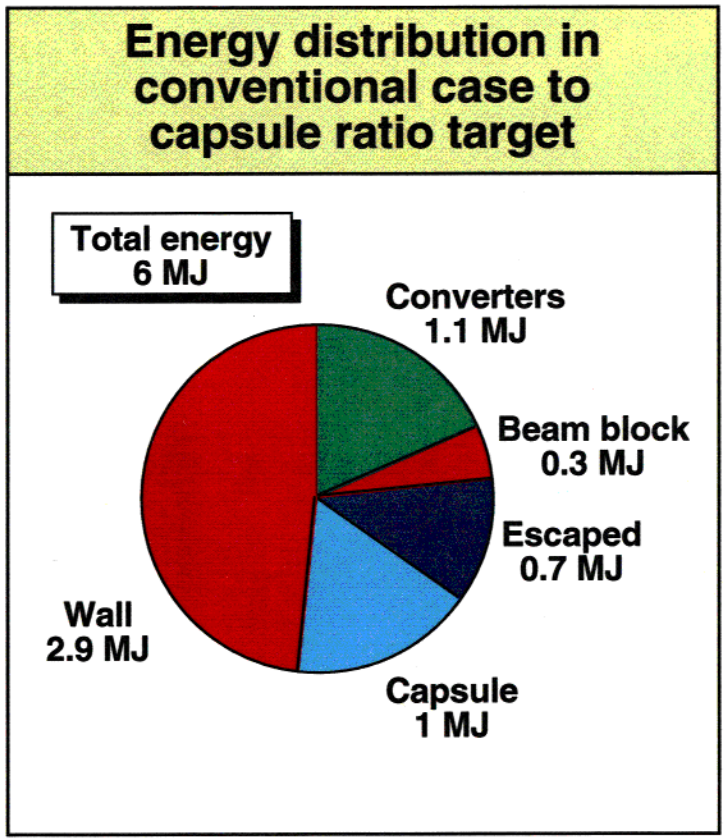
Accelerator is most expensive item → 15% decrease in COE

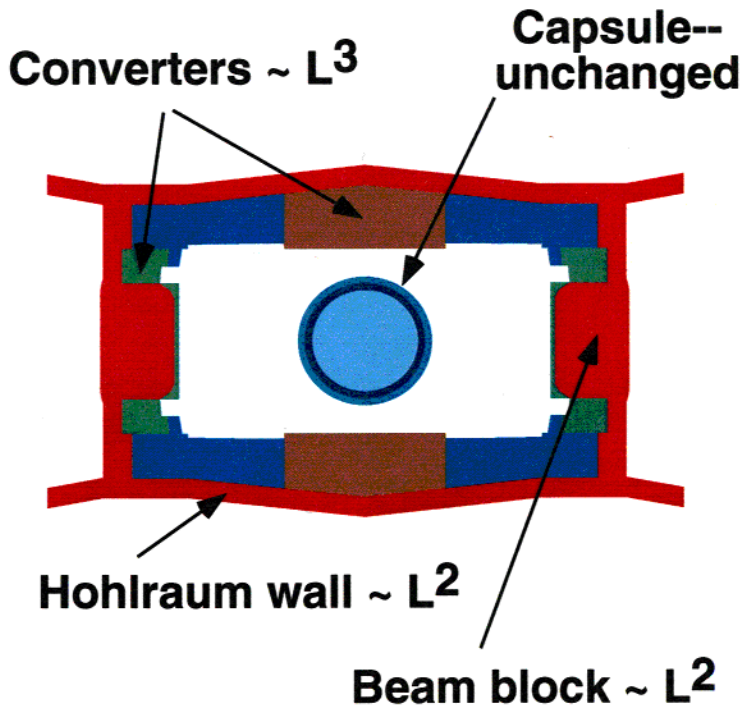
* Accelerator costs from W. Meier. Power plant costs from R. Moir (1 GWe case).

Heavy ion targets using distributed radiation converters are our current mainline

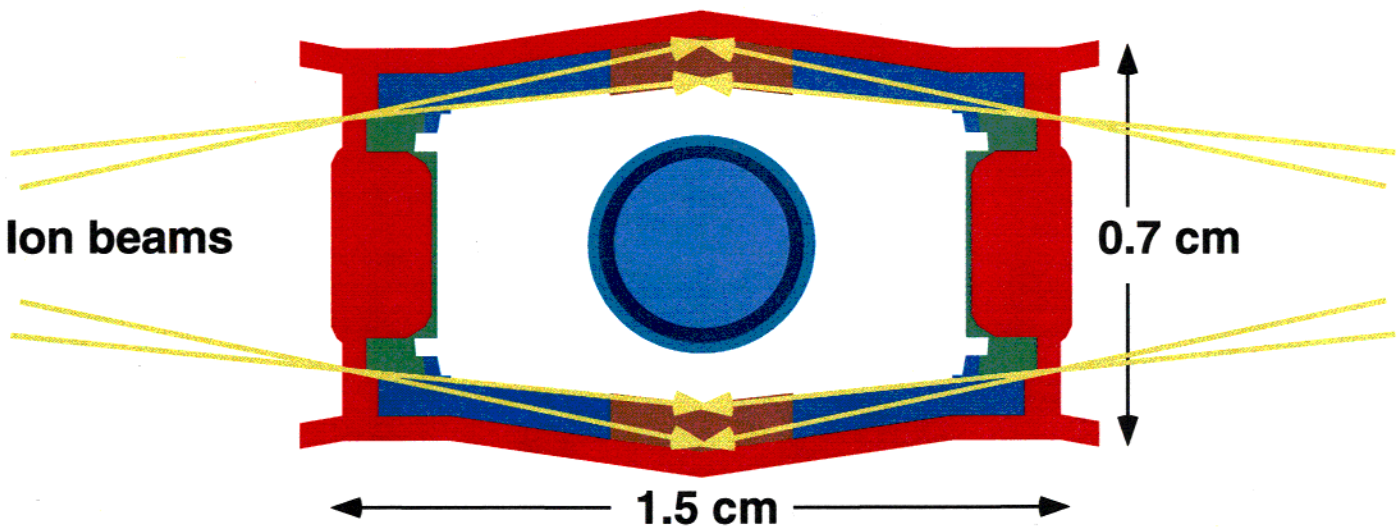


Shrinking the conventional hohlraum by 26% should reduce the drive energy from 6 MJ to 3.5 MJ



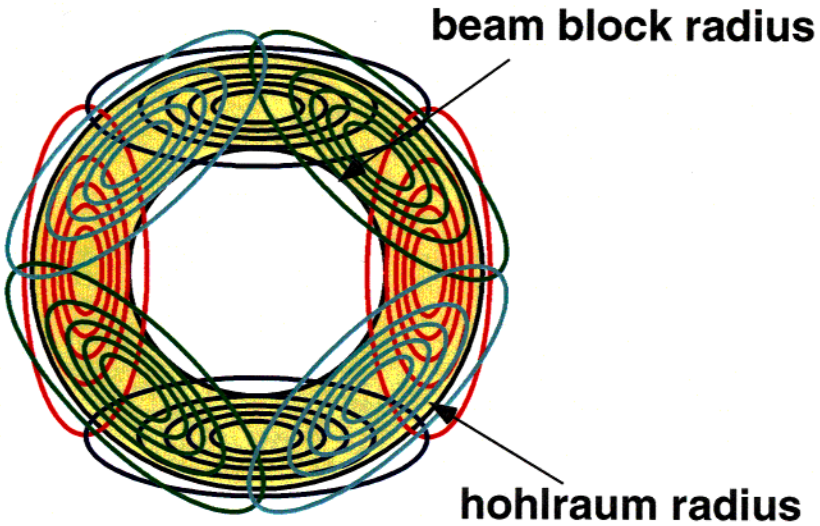


Detailed calculations confirm this scaling-- a 26% smaller hohlraum is driven by 3.3 MJ



- Foot pulse: 0.5 MJ of 2.1 GeV Pb^+ ions entering at 6 °
  Main pulse: 2.8 MJ of 3.5 GeV Pb^+ ions entering at 12 °
- Ion kinetic energy is changed to overcome range shortening which causes a swing in symmetry
- Calculation produced 435 MJ yield from 3.3 MJ of beam energy for a gain of 132. (1-D yield = 436 MJ)

Ion beams are aimed to form an annulus on the end of the target



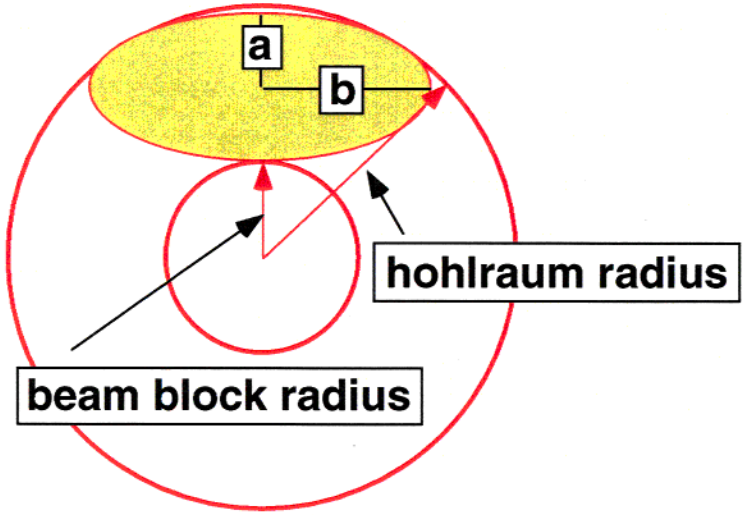
Each beam has a Gaussian distribution and is focused to an elliptical spot

Ellipse contains 95% of the beam charge

Beams are aimed to form an annulus around the beam block which prevents ions from hitting the capsule

Azimuthal asymmetry of source:
6% in m=8 for 8 beams
< 1% in m=16 for 16 beams

Beam spot size must be reduced by more than 26%

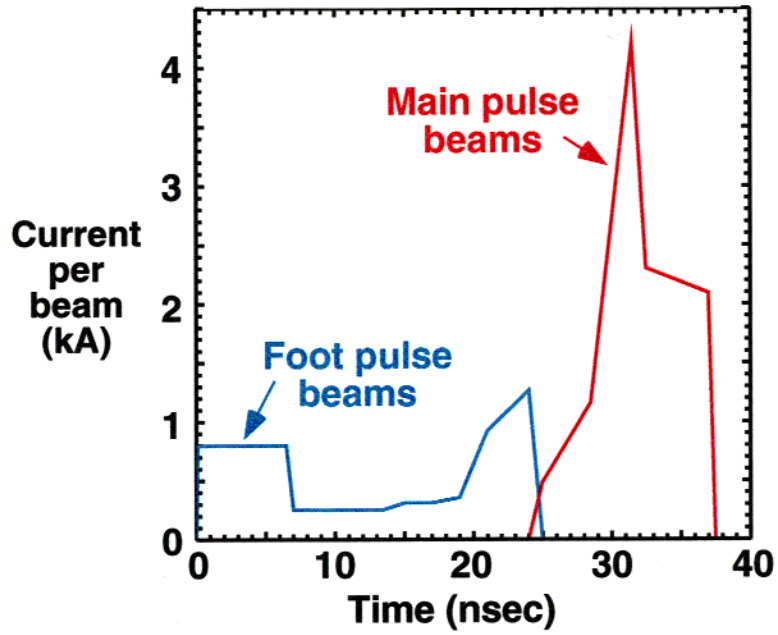


- Beam dimensions (a, b) determined by the hohlraum radius and the beam block radius
- The beam block radius is set by the capsule size and does not change when the hohlraum size is reduced

	a (mm)	b (mm)	r_{eff}=sqrt (ab)
Conventional design	4.2	1.8	2.7
Close-coupled design	2.8	1.0	1.7

37% smaller beam radius required

With 48 beams, a simple model suggests the required spot size is achievable



- 16 beams (2.1 GeV Pb^+) in the foot
  32 beams (3.5 GeV Pb^+) in the main pulse
- Simple model suggests the required spot (1.7 mm spot) is achievable with 95% neutralization and emittance of 20 π mm-mrad
- Detailed chamber calculations and experiments are needed

A scaled version of the close-coupled target could be the basis for a high-gain ETF

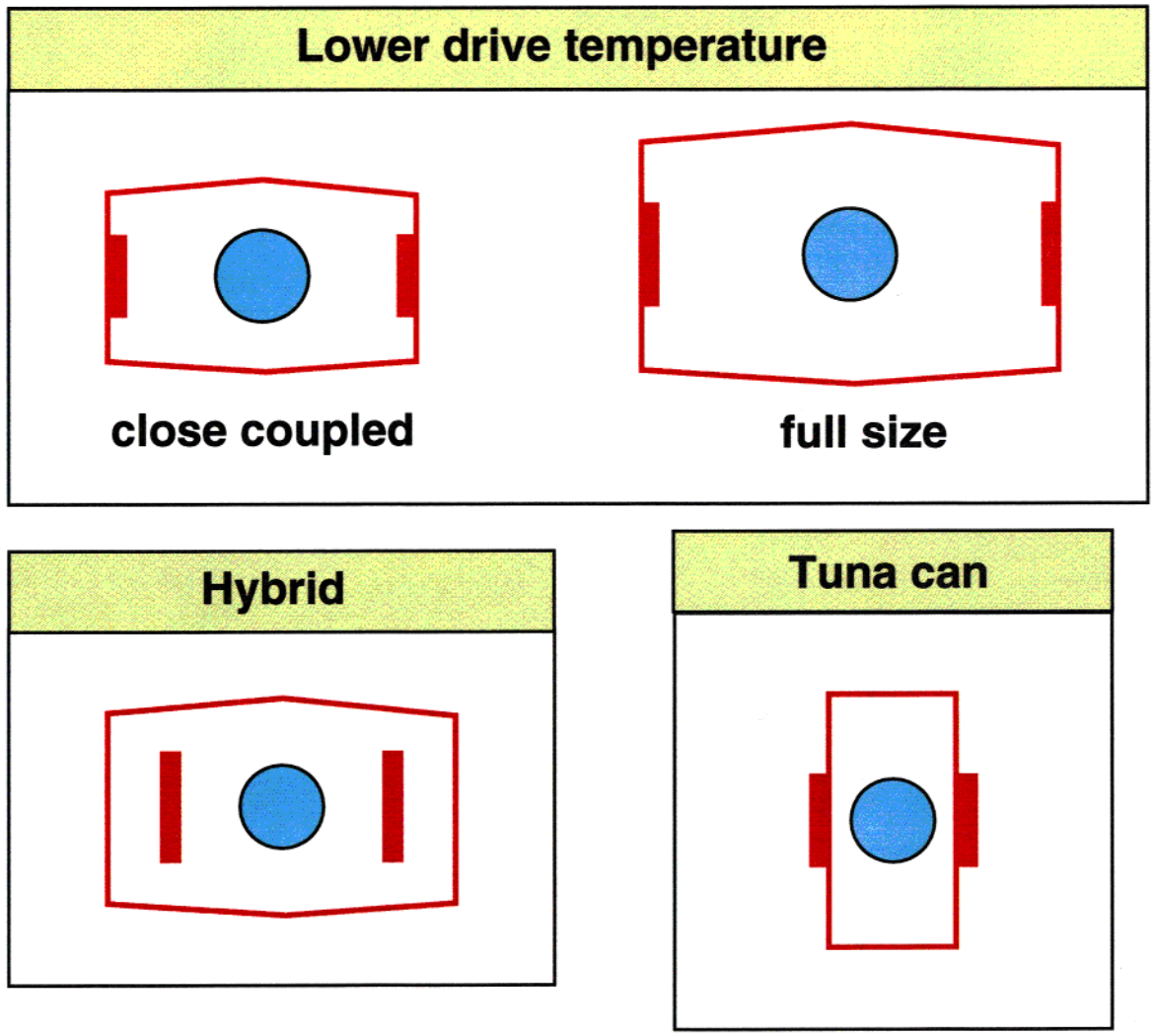
- A goal of the IFE program is to build an Engineering Test Facility (ETF) that would demonstrate all the physics and technology needed for an IFE power plant

- 2-d Lasnex calculations predict 165 MJ of yield from 1.75 MJ of beam energy (gain of 94) for a 0.77 scale close-coupled target

- The smaller target requires a smaller beam spot (1.3 mm), shorter pulse duration (6 nsec) and lower ion kinetic energy (3 GeV Pb^+)-- all of which make focusing the beam harder

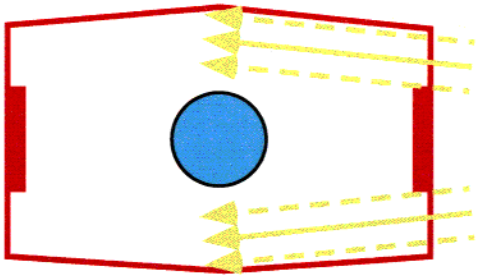
- An ETF accelerator that is able to do both low and high gain will shorten the development path to an IFE power plant
  - Given adequate repetition rate, the ETF accelerator could be upgraded to a demonstration power plant by using multiple chambers

Three types of targets that increase the spot size and/or pulse duration are under consideration



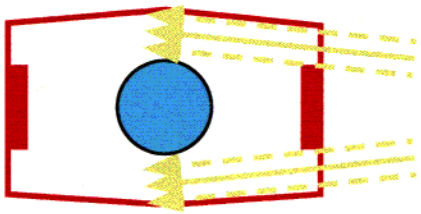
Using a lower drive temperature allows a larger hohlraum for the same drive energy

Full size



driver ~ 6 MJ
gain ~ 65
spot size ~ 3.25 mm

Close coupled



driver ~ 3.5 MJ
gain ~ 115
spot size ~ 2 mm

1-d capsule calculations predict 380-400 MJ of yield when a slightly larger capsule is driven at 210 eV (currently use 240-250 eV)

This allows a 20% larger beam spot and a 20% longer pulse duration for the same driver energy

Status:

5 MJ of yield in a 2-d integrated calculation with flat-top beams travelling parallel to the axis (old beam geometry)

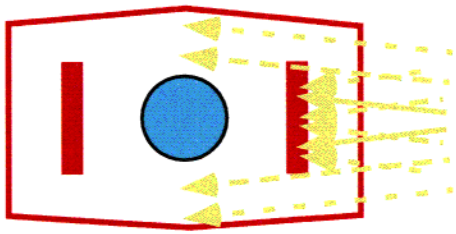
Possible problems:

Ignition margin is reduced from 30-40% for 240 eV drive to 15-20% for 210 eV drive

May need to increase temperature to 220 eV to regain margin

The hybrid target attempts to capture beam energy behind a shine shield

Hybrid



driver ~ 7-7.5 MJ
gain ~ 55-60
spot size ~ 4 mm

By using a shine shield, the beam can illuminate most of the end of the hohlraum

Design is a hybrid between the distributed radiator and the end radiator targets

Status:

2-d integrated calculations use 7.5 MJ of beam energy to drive the capsule at ~ 250 eV with a 4 mm beam spot

Symmetry is not good enough

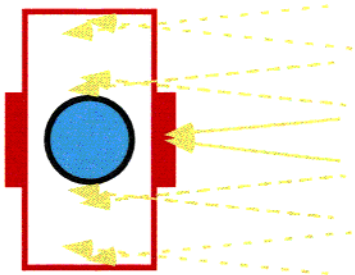
Possible problems:

Hydrodynamic motion of the converter material behind the shine shield makes symmetry control very difficult

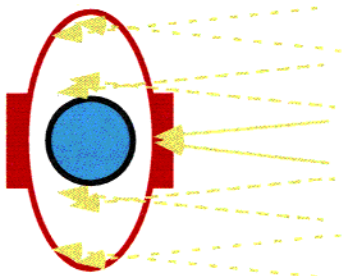
It is unlikely that a close coupled version of this target will work

Reversing the aspect ratio of the hohlraum may allow a very large beam spot

Tuna can



driver ~ 7-8 MJ
gain ~ 50-60
spot size ~ 7 mm



Clamshell

By using a hohlraum shaped like a tuna can instead of a soup can, very large beam spots are possible

Status:

Simple scaling laws predict 7-8 MJ of beam energy with up to a 7 mm spot

We plan to begin integrated calculations of this target this year

Possible problems:

Symmetry may be difficult due to the very short hohlraum

High target gain (>100) requires designs that preheat the ablator while keeping the DT fuel on low isentrope.

NRL high gain target design:

E_L ~ 1.2 MJ

Gain ~ 135
(*with laser zooming*)

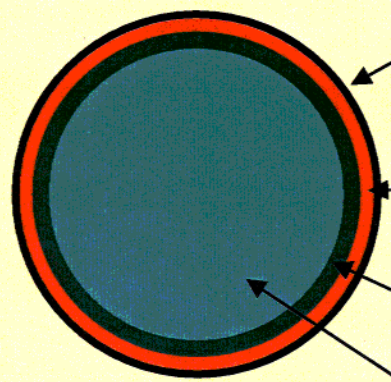
R_{spark} ~ 56 g/cc

R_{max} ~ 280 g/cc

$I_{max} = 7 \times 10^{14}$ W/cm^2

IFAR ~ 50

DMOT ~ 35



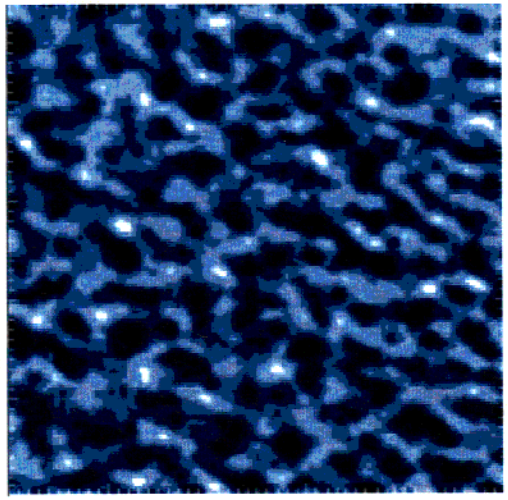
Fluid instabilities controlled by:

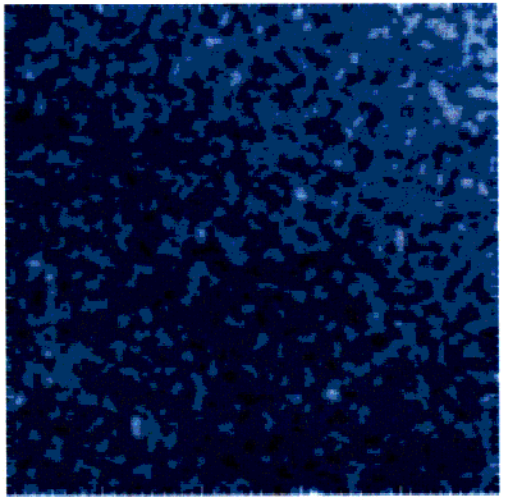
1. Preferential radiative heating of ablator by the high-Z overcoat and by the low-opacity foam
2. Reduced mass perturbations using ultra-uniform broadband laser beams.

Recent NRL foil experiments have shifted to the uses of CH foam with cryogenic DD, and to gold overcoating.

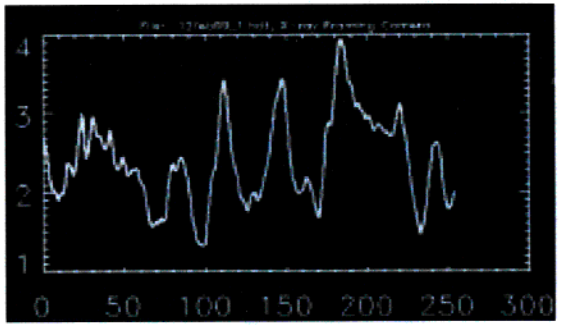
Without Au layer on solid CH | **With 400 Å Au on solid CH**

ISI laser imprint at 2.6 ns via x-radiography:

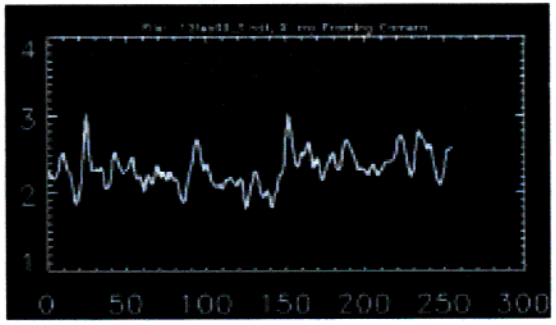




Areal mass:



Position (μm)



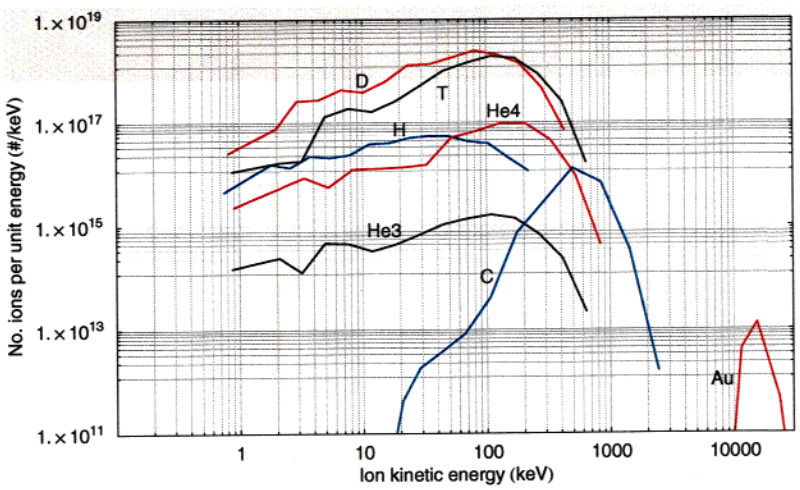
Position (μm)

We observed significant reduction in mass imprinting with a thin Au overcoat.

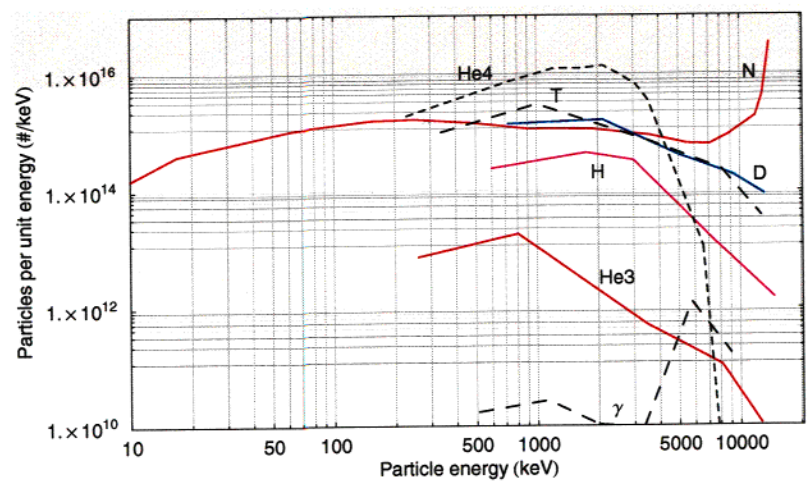
Our LASNEX Analyses Have Confirmed the Performance of the NRL Direct-Drive Target in 1-D

The Output Particles/Spectra are very Different from the Older SOMBRERO Target:

	Latest NRL Direct-Drive Target (1999)	Original SOMBRERO Direct-Drive Target (1992)
Gain	128	118
Yield (MJ)	154 (for E_{laser} = 1.2MJ)	425 (for E_{laser} = 3.6MJ)
X-Rays (MJ)	2.1	24
Neutrons (MJ)	109	317
Burn Product ions – D,T,He,… (MJ)	18.1	~0
Debris Ions – D,T,C, Au,… (MJ)	24.9 (Carbon ions = 0.7MJ)	83.2 (Carbon ions = 55MJ)



Debris KE Spectra from LASNEX



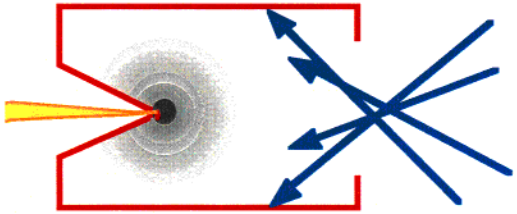
Fast Burn Product Spectra from LASNEX

Where Might We Invest Effort in Advanced Target Concepts?

- **Ion *Direct* Drive –** High gain possible at low energy (e.g G ~ 90 @ 0.6MJ). Stability is a critical issue. Also, 4π illumination geometry probably precludes liquid walls

- **Laser *Indirect* Drive –** Two-sided indirect drive may be feasible with closed-coupled, high efficiency hohlraums (*Suter*). Can then take advantage of liquid walls.

- **Fast Ignition –**
  - Laser fast ignition – Point design indicates gain ~350 for ~700kJ compression energy and ~100kJ fast ignitor
  - Cone focus geometries are under study
  - High-intensity laser-driven fast ions may be an alternative fast ignition option (*Roth, GSI*)
  - In general, fast ignition may considerably relax the constraints on timing, symmetry and target fabrication



- **Tritium Lean Targets –** Fast ignition may permit us to burn advanced fuels: D-D capsules with DT sparkplugs (1%-T, in-situ self-breeding). With 20% of the energy in fast neutrons, this might permit direct energy conversion of target output.

- **Can magnetic fields be employed?**
  - Z-pinches (either with radiation drive or directly for high density)
  - Magnetized targets – pre-emplaced B-fields may aid hot-spot through compression and suppress electron heat conduction

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