Retrospective of Heavy Ion Fusion Designs

Heavy Ion Fusion Symposium

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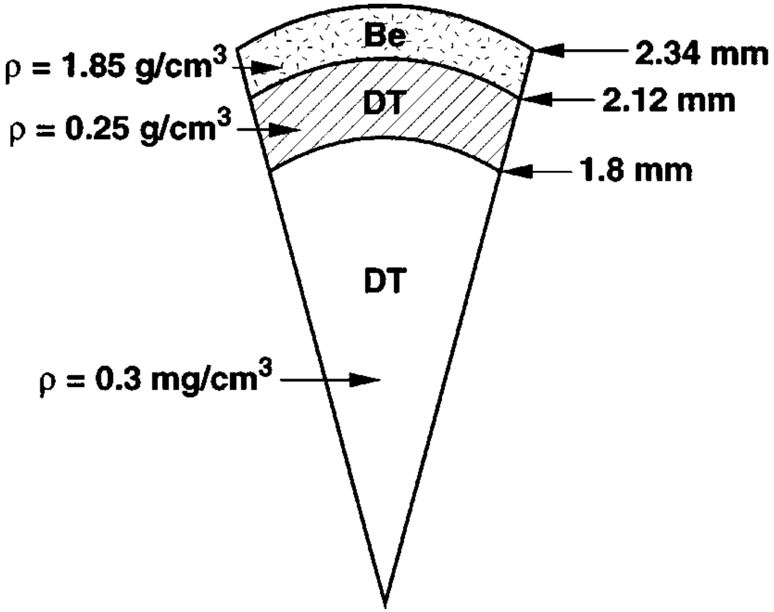
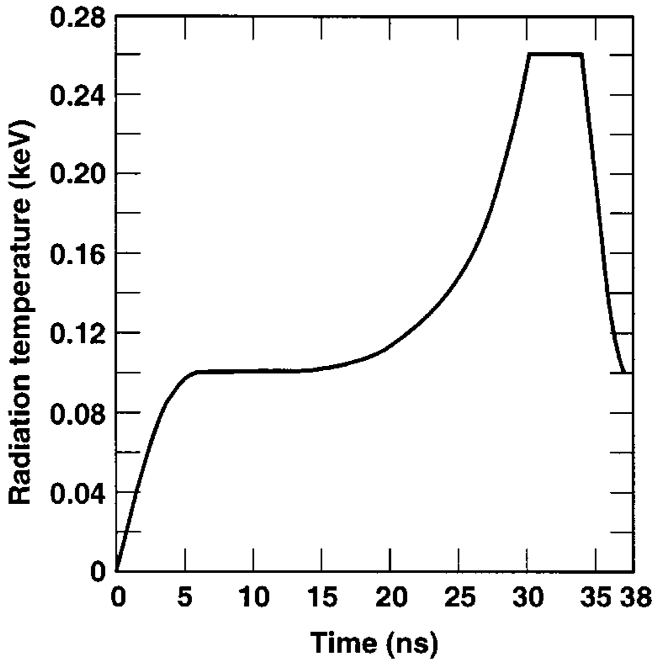
We developed a large variety of targets and target concepts for Heavy Ion Fusion

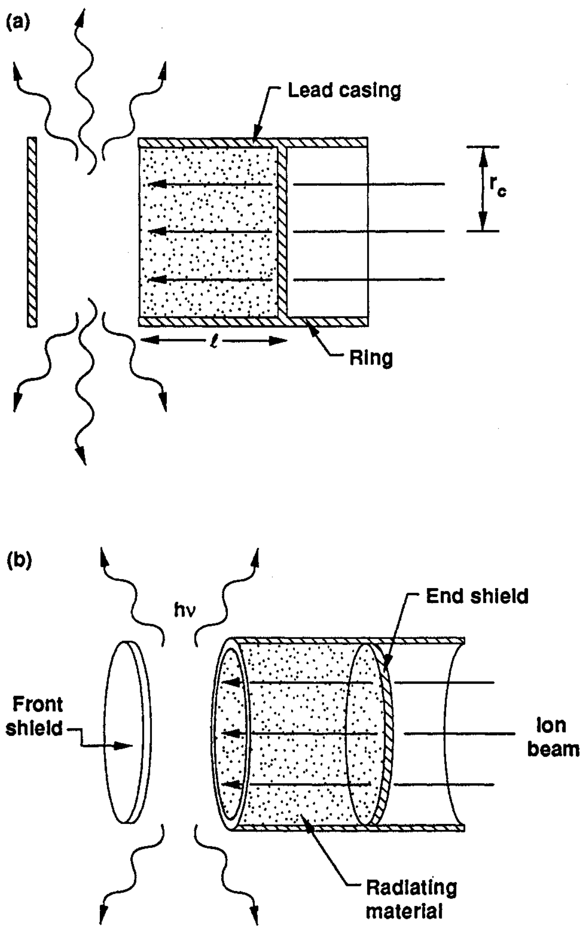
- End radiators
- Distributed radiators
- Hybrid concepts
- Close coupled targets
- Ion driven Fast Ignition

The target designs began with a capsule designed by Darwin Ho



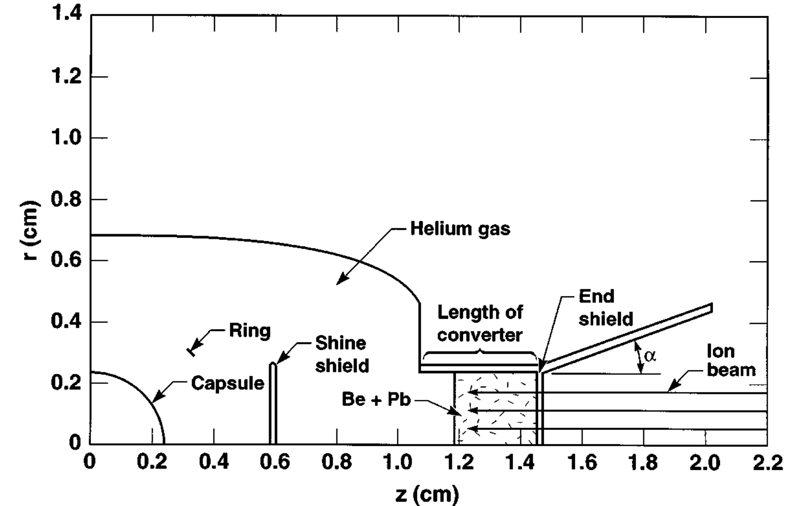


The original end radiator design began with radiators that converted ion kinetic energy into radiation with efficiency ~90%

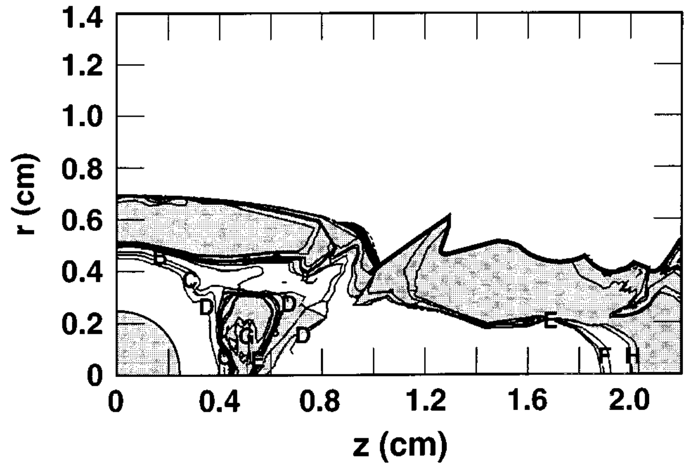


Expansion of converter material into main hohlraum cavity led to requirement for long convertors and low gain

- Material motion changed radiation symmetry during pulse
- Long converter kept material out of hohlraum but increased converter wall and transport losses
- Gain 80 -> gain 20

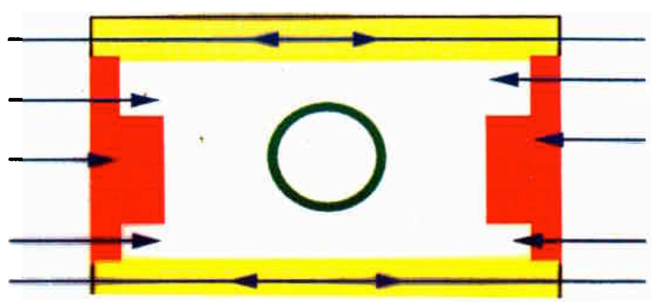


(d) t = 33 ns



2-D calculations integrating physics from ion deposition through implosion and burn demonstrate more than adequate gain for inertial fusion energy

- Reactor designs using thick liquid wall protection prefer two sided illumination geometry to 4π illumination
- Two focussing strategies have spot sizes consistent with neutralized chamber transport
- Pressure balanced cylindrical hohlraums using low density materials maintain adequate drive symmetry
- G > 65 at 6 MJ implies $\eta_D G > 16$
- We are extending the target operating range to provide more flexibility for accelerator design

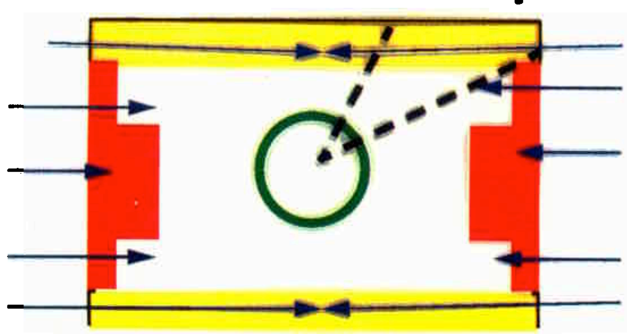


Reactors using thick liquid walls prefer two sided illumination

- Thick liquid first walls breed tritium and protect the first structural walls
- The first structural walls using 304 stainless steel in the HYLIFE design are lifetime components
  - Consistent with shallow burial at end of life
- Forming beam ports from liquids becomes increasingly difficult with number of beams
  - 2 sided illumination desired
- Background density(10^{13}/cc) in chamber is consistent with charge neutralized beam transport
- Two sided illumination eases final beam transport in accelerator

Pressure balanced hohlraums using low-Z materials maintain adequate symmetry

- Radiation asymmetries with high spatial frequency(or high Legendre mode l) are smoothed by radiation transport
- Low l modes must be cancelled by proper location of sources
  - Near zeroes of P_4 weighted to cancel P_2
- Must maintain position of sources
  - Minimize range shortening
  - Need constant density along beam path--stationary hohlraum
- Want path between source and capsule to be transparent at all times

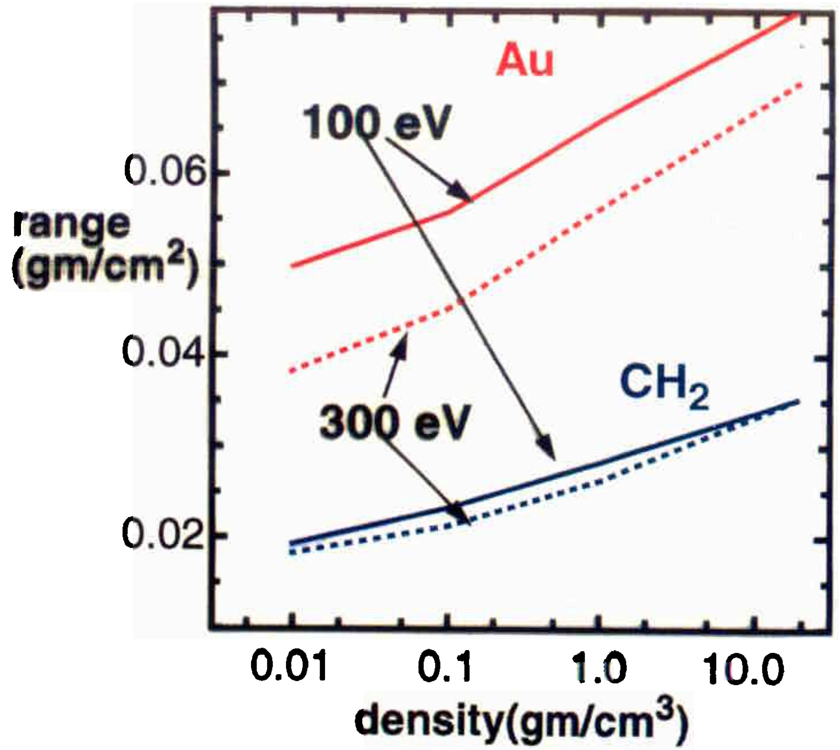


- - - - P_4=0

Range shortening due to density changes is more important than temperature driven shortening

- Dynamic range in density is much larger than in T

Beam is 3.5 GeV Pb



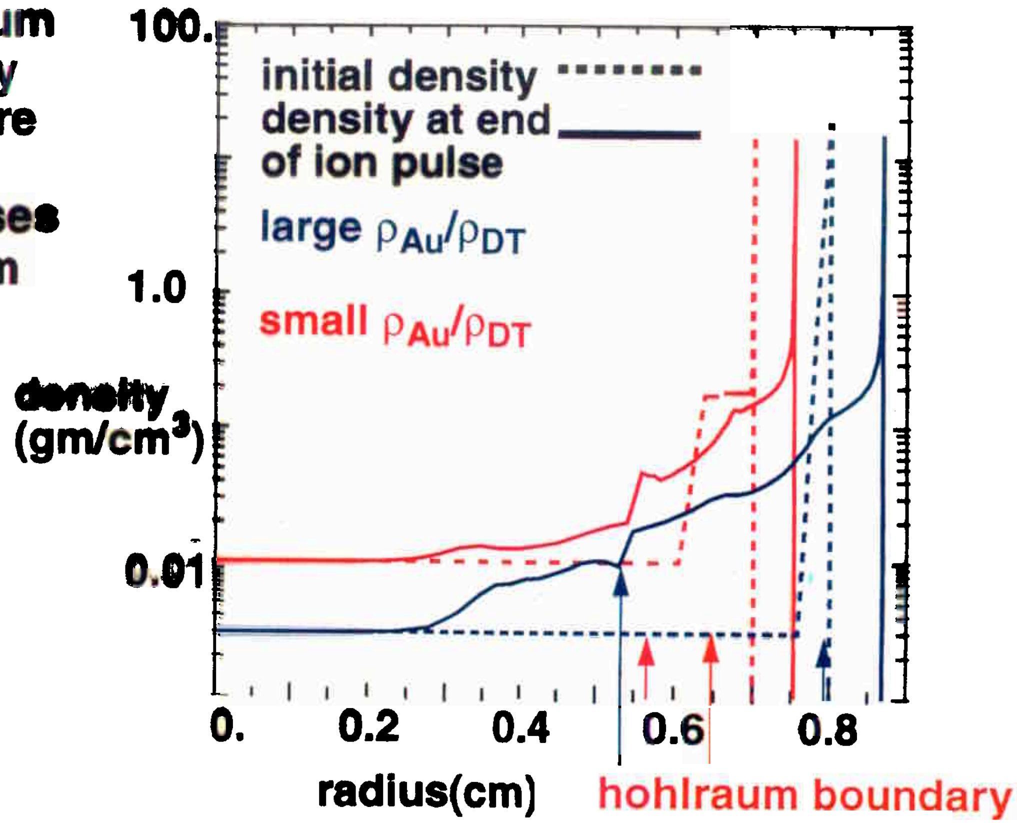
Use low density materials to minimize range shortening due to expansion

The motion of the hohlraum wall can be controlled by varying fill and wall densities with no energy penalty

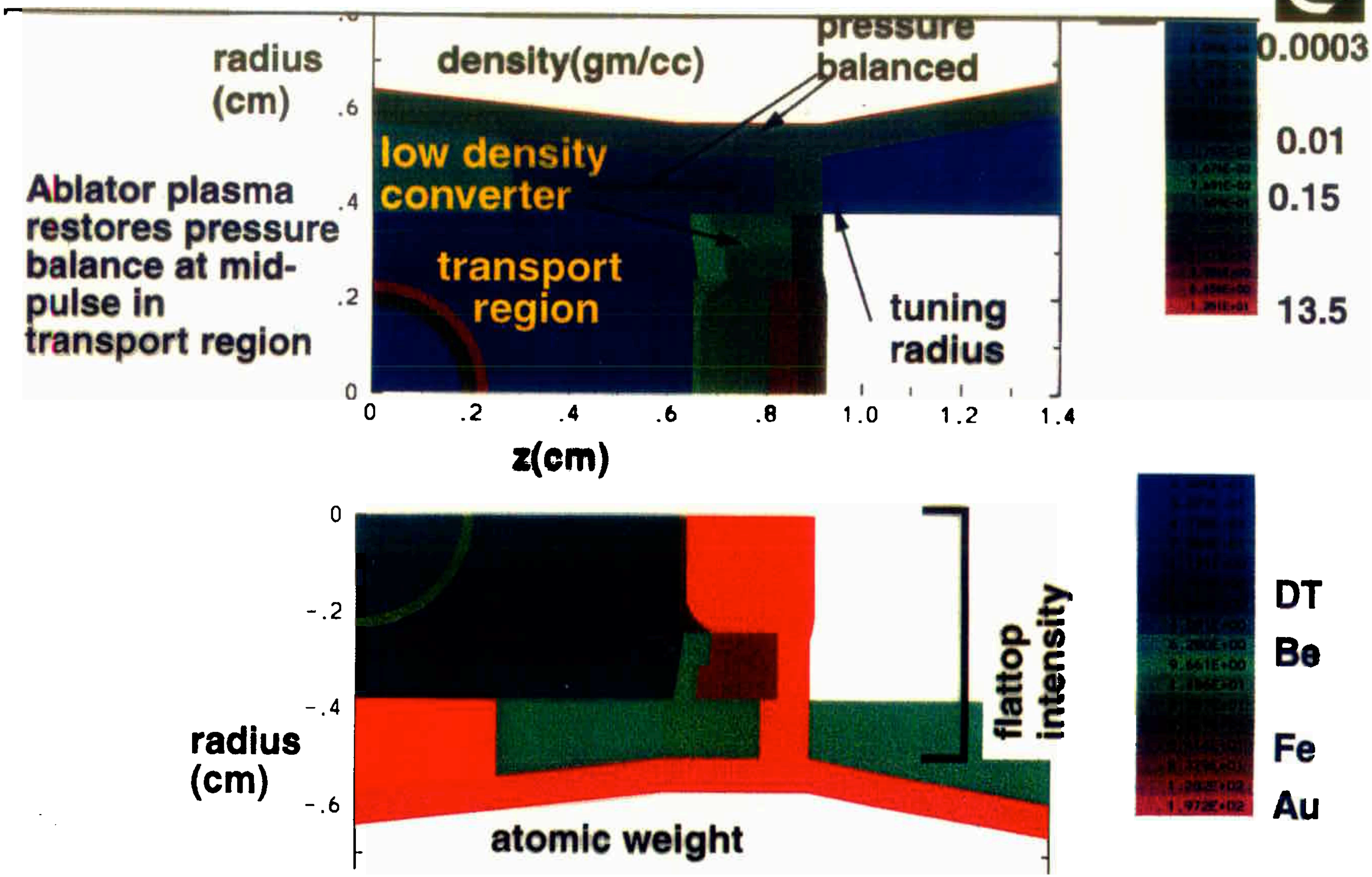
- Two gas-filled high-Z cylinders driven with the same radiation temperature profiles arrive with similar final geometries

- The tamped hohlraum used 15% less energy to sustain temperature

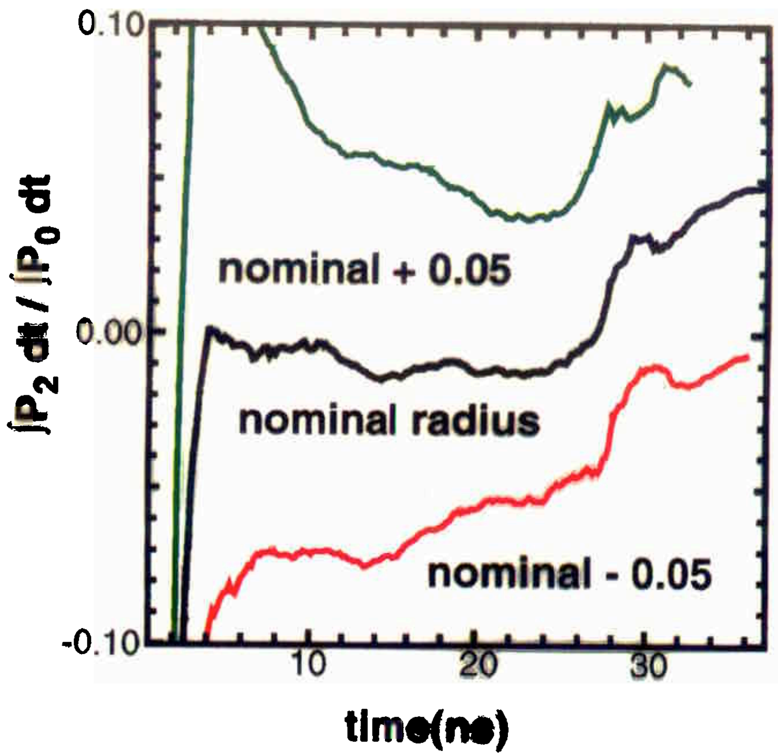
- The point design uses a stationary hohlraum wall

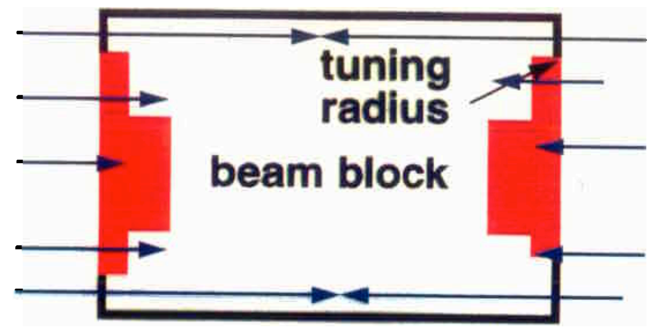


The distributed radiator target uses low density materials in approximate pressure balance



We can tune P_2 by changing the fraction of the beam energy reaching the hohlraum midplane

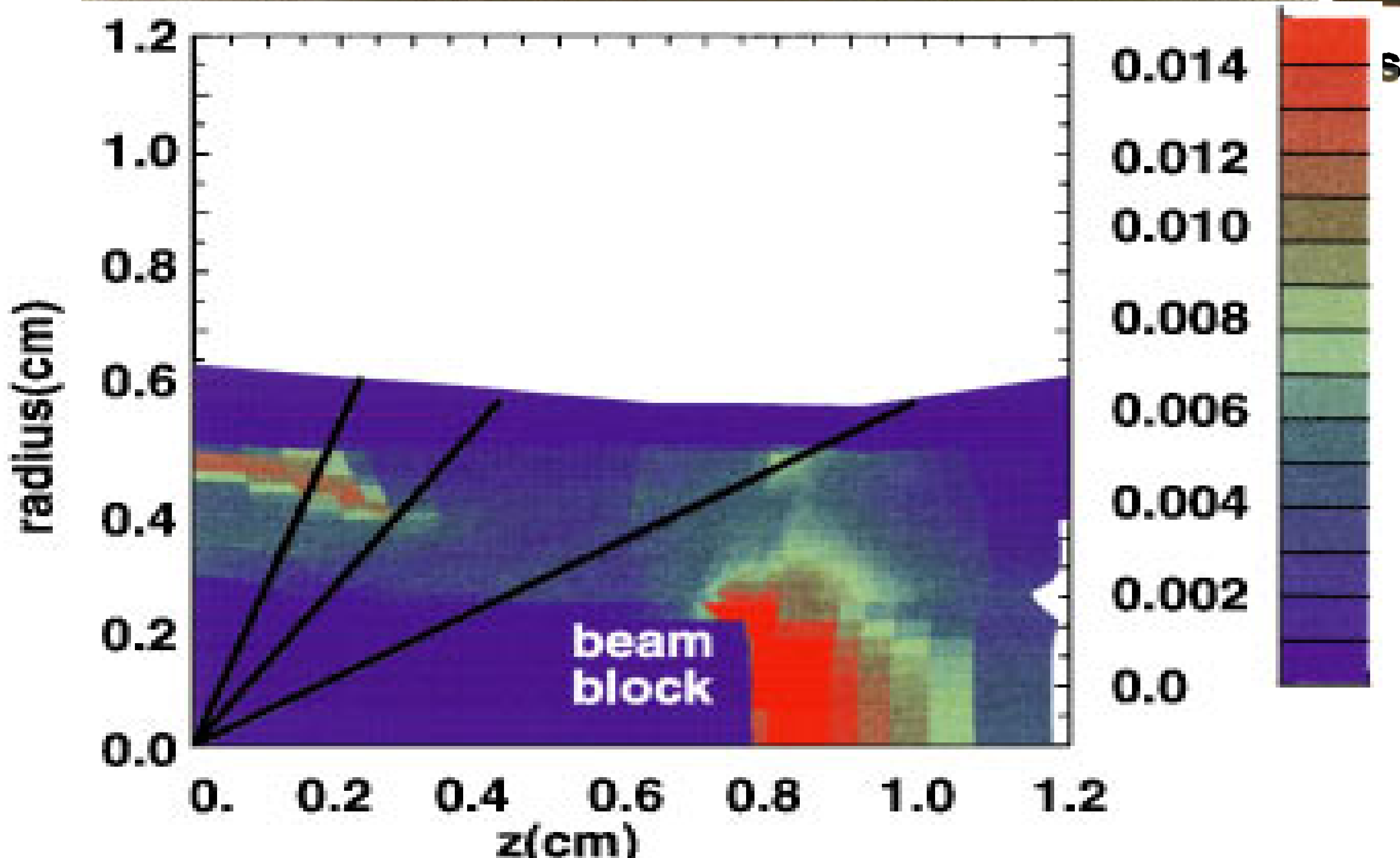




- Rise in P_2 at 30 ns due to range shortening
- Fix: increase particle energy from 3.0 to 4 GeV at 29 ns

- P_4 can be tuned by changing the hohlraum shape or by placing burnthrough foils on or near the capsule

The visible ion beam power is deposited near the zeroes of P_4

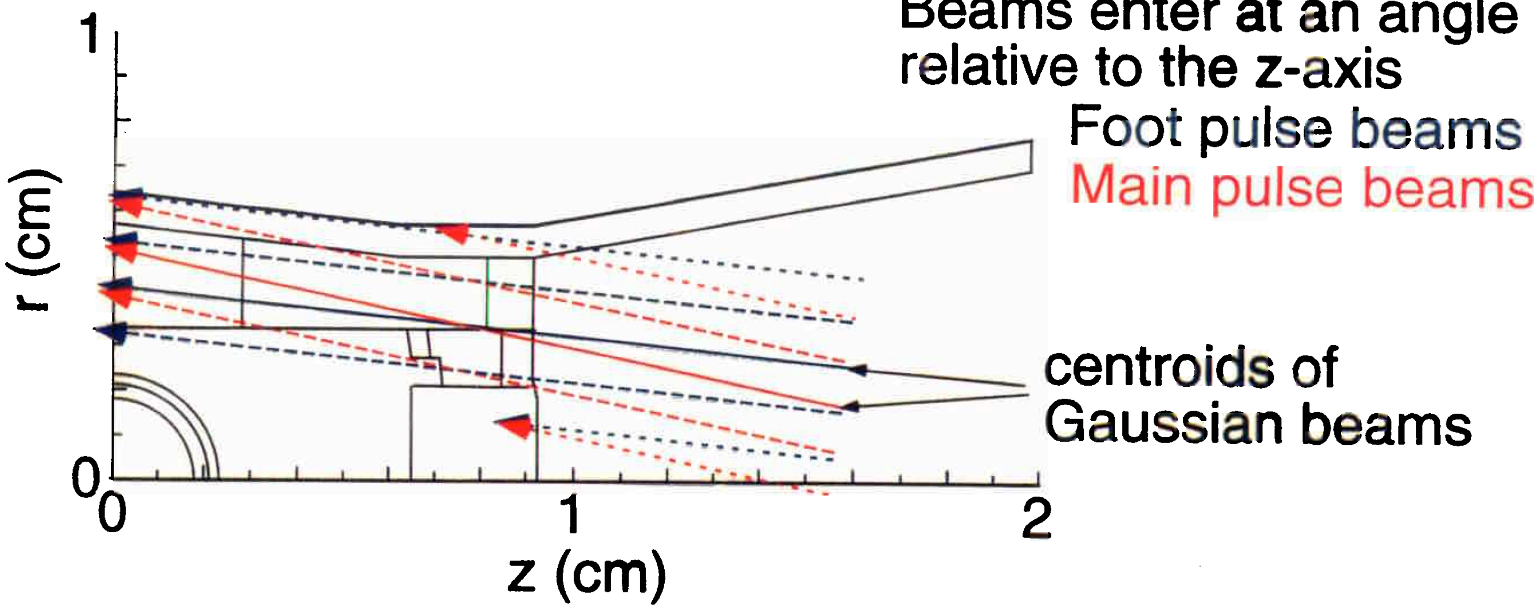


The original distributed radiator target required small opening angles for the beam and a flat beam spot

- The modified target could use Gaussian beams and obtained symmetry by aiming beams at the proper positions in the hohlraum(like laser targets)

Heavy ion target with realistic multibeam illumination produced gain > 65 in integrated Lasnex calculations.

5.87 MJ of ion energy used
(10% in the wings of the Gaussian "misses" the target)
Yields of 386-402 MJ



For more information, see D. A. Callahan's poster on Wednesday afternoon (IWepP4.08)

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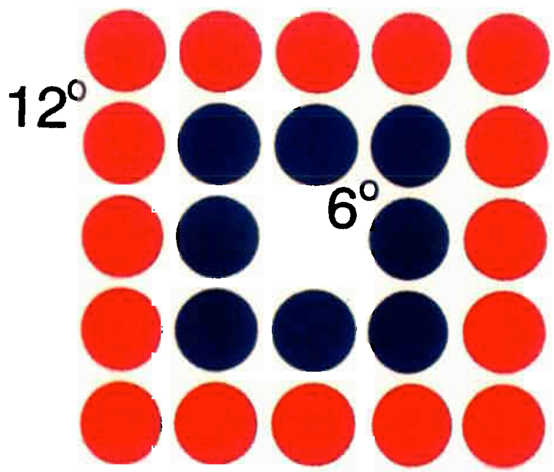
48 Gaussian, elliptical beams illuminate the target.

Foot pulse: 16 beams (8 per side), 3 GeV Pb, 1.6-2.1 MJ
Main pulse: 32 beams (16 per side), 4 GeV Pb, 3.77-4.27 MJ

Beam array at chamber entrance



Angles relative to z-axis:
- 6 degrees foot pulse (blue)
- 12 degrees main pulse (red)

Each beam has a 1 degree focusing half angle

Angles, energies, and numbers of beams are consistent with W. Meier's systems code accelerator design.

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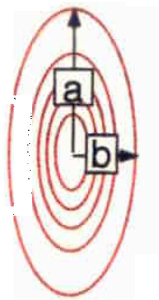
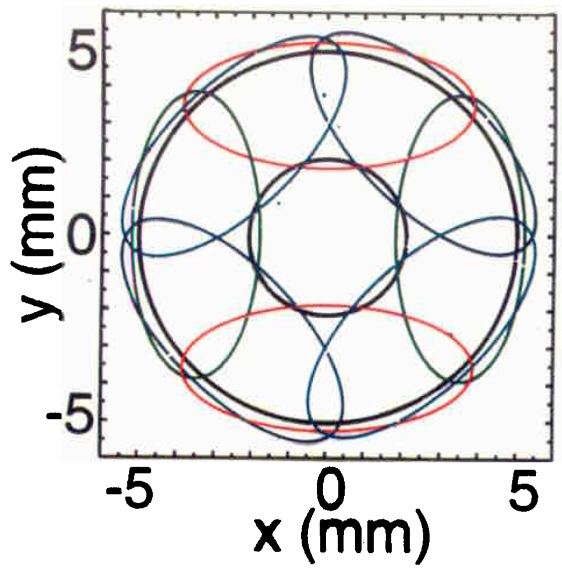
Overlapping Gaussian, elliptical beams are focused at the end of the target

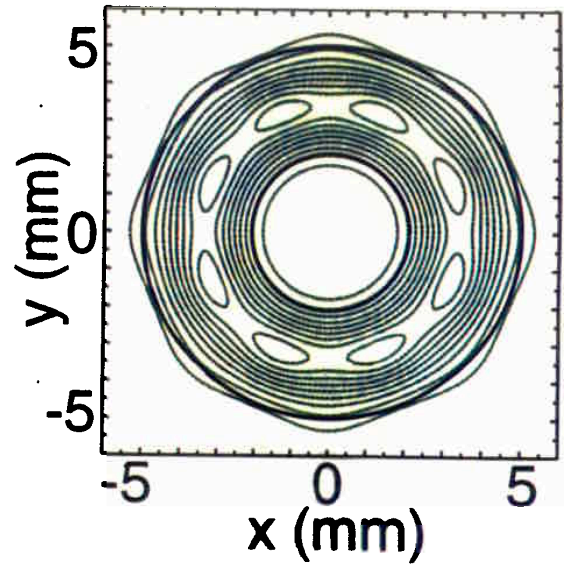
Each beam is an ellipse



8 beams overlap in the foot pulse



Sum of 8 foot pulse beams



a = 4.15 mm
b = 1.8 mm
$r_{effective} = \sqrt{ab} = 2.7$ mm
95% of charge inside

Azimuthal asymmetry:
foot pulse: -1.6% in m=8
main pulse: 0.06% in m=16

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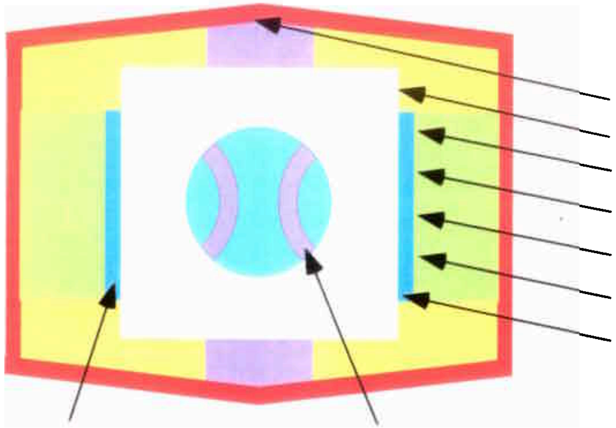
But this new target required smaller beams and stressed beam focusing more

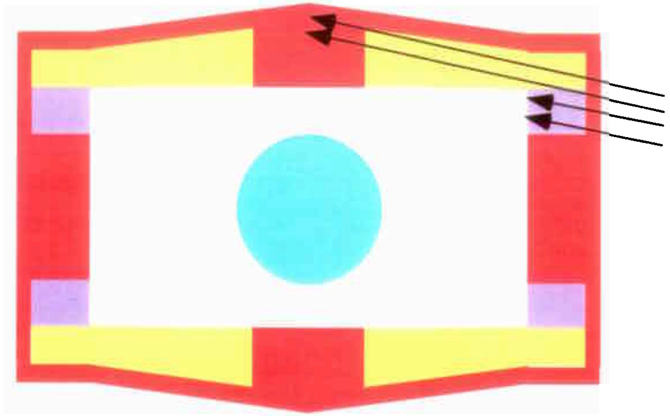
- Developed hybrid target that accepted bigger spots

We are using internal hohlraum shields to develop distributed radiator targets with larger beam spots



shine shield to control P_2

radiation shim to control early time P_4



original distributed radiator target

Beam spot: 3.8 mm x 5.4 mm
Effective radius: 4.5 mm

6.7 MJ beam energy
Gain = 58

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

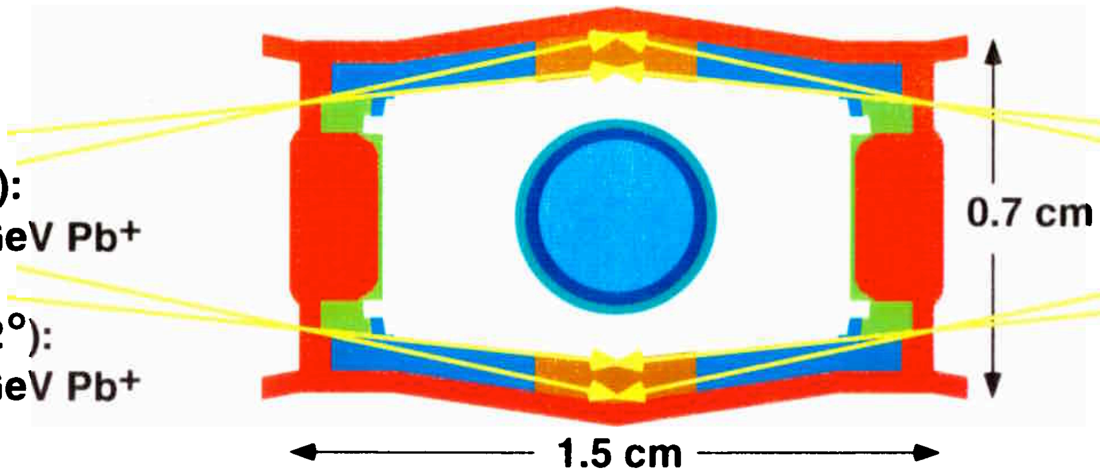
Callahan-Miller 7/00

A close-coupled, heavy ion target is predicted to get a gain of 130 from 3.3 MJ of beam energy

Ion beams

Inner cone (6°):
0.5 MJ of 2.1 GeV Pb^+

Outer cone (12°):
2.8 MJ of 3.5 GeV Pb^+

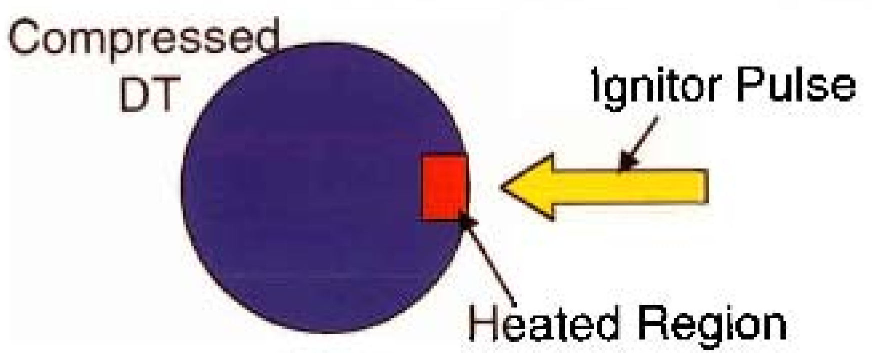


- The close-coupled target reduces the required driver energy by almost a factor of 2 from our previous targets (5.9-6.5 MJ)
- Small beam spots are required to achieve these results: beams were assumed to have elliptical spots with semi-major and semi-minor axes of 2.8 mm by 1 mm

A scaled version of this target produced gain 90 from 1.8 MJ of ion beam

At Heidelberg(1997?) Heavy Ion Symposium we proposed heavy ion driven Fast Ignition

- A point calculation ignited with a 50 GeV Pb beam, with 50kJ, in 50 ps , into 60 micron FWHM
- Focusing and pulse length requirements were stressing so D. Callahan looked at energy requirements of more relaxed irradiations



Lasnex calculations of the ignitor beam show some of the available parameter space.

fuel ρr (g/cm^2)	density (g/cc)	τ (psec)	FWHM (microns)	T_{ion} (GeV Pb)	E_{beam} (MJ)	E_{prod} (MJ)
4.3	375	35	45	50	0.056	224
3	128	234	200	60	1.3	430
3	128	117	200	60	0.87	497
3	128	2.3	200	60	0.72	576
2.5*	128	234	200	75	1.3	460
4	256	156	156	70	0.62	320
4	256	50	156	50	0.31	371
4	256	50	156	33	0.22	376

* Tamped (outer 39 microns replaced by Au in pressure balance with DT)

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