X-Target for Direct-Drive Heavy-Ion Fast Ignition: Design Update

Workshop on Accelerators for Heavy Ion Inertial Fusion
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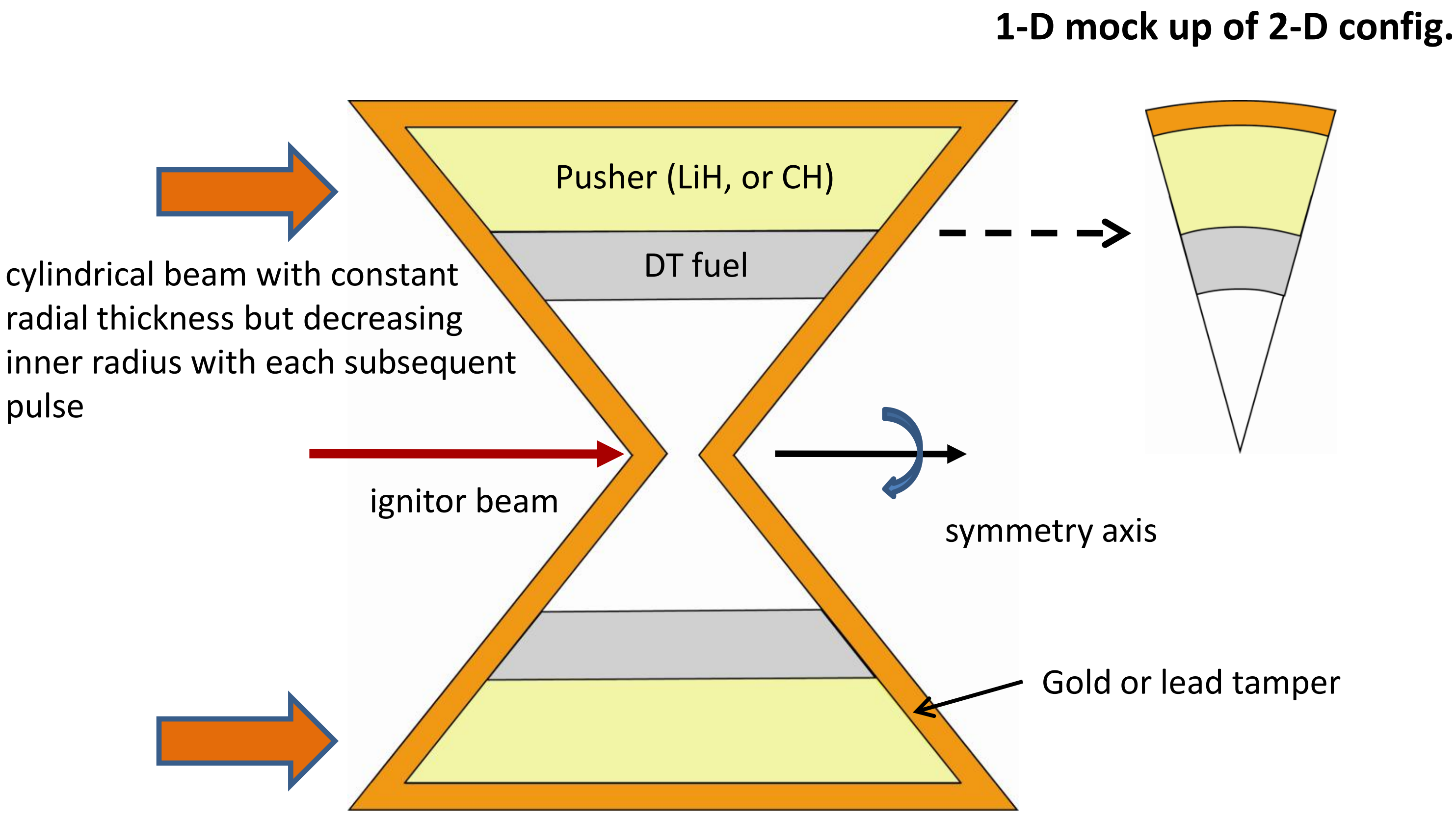
X-target design strategy

- Our fuel compression scheme is the same as that for conventional hot-spot ignition or laser fast ignition for minimizing the fuel entropy, i.e., shock timing so that the first three shocks meet at the fuel-gas interface and then followed by the fourth shock.
- Optimize beam-pusher coupling (i.e., minimizing the variation in areal density seen by the different beam pulses) by using a double-layered pusher and assuming all beam pulses have the same kinetic energy.
- In our current 1-D design, peak fuel density is limited to about 150 g/cm^3 (with a corresponding ρr of 3.5 g/cm^2) since peak density is limited by the 2-D tamper wall motion when the fuel is approaching its assembled configuration. (Peak density as high as 400 g/cm^3, with a corresponding ρr approaching 6 g/cm^2, has been achieved in our 1-D simulations.)

Single-layer pusher configuration

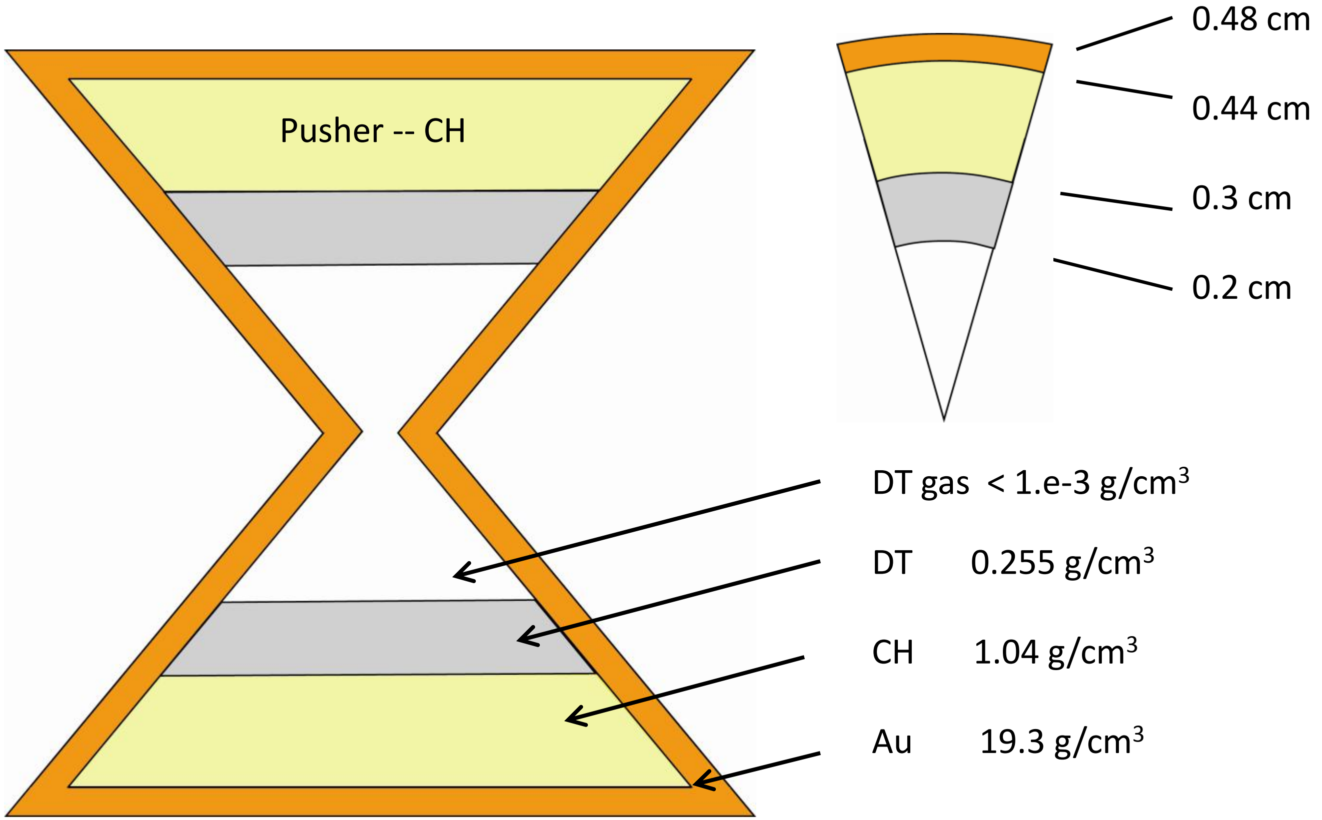
1-D simulations allow us to uncover new physics and to obtain optimization quickly before starting 2-D simulations

- Beam deposition is modeled by electron energy deposition that is proportional to density



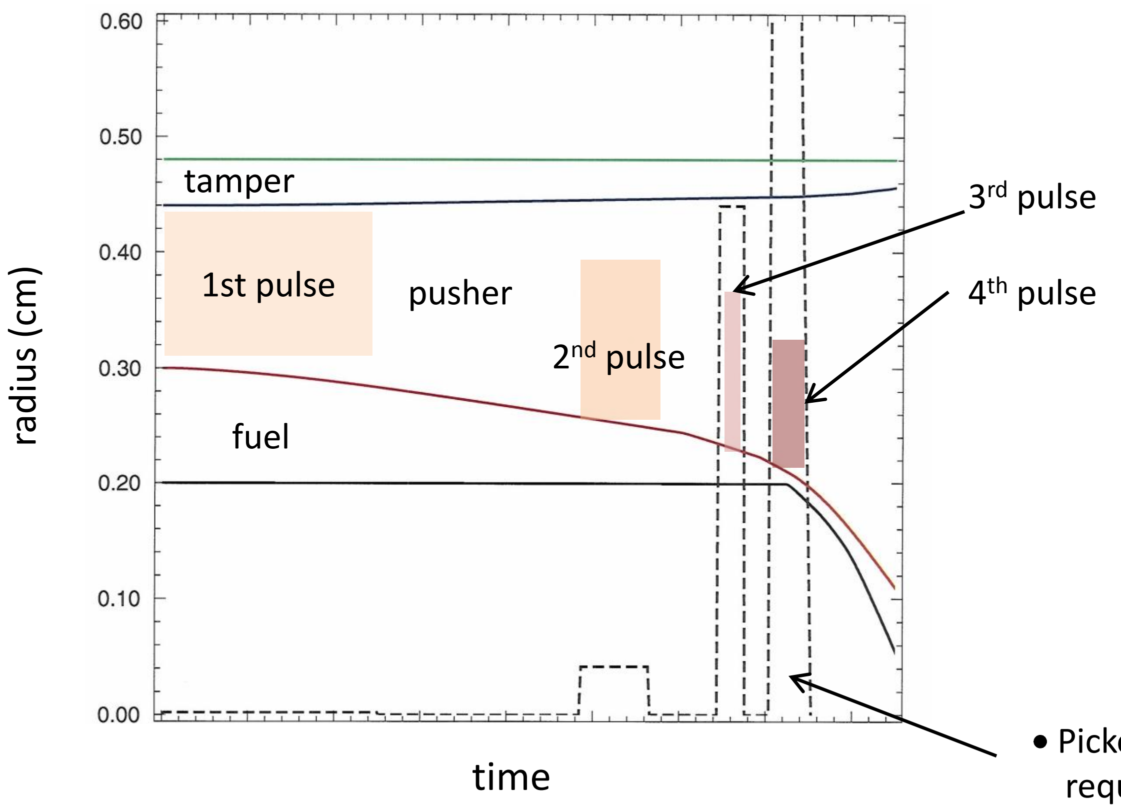
Target configuration

- Outer radius = 0.48 cm, ablator thickness = 0.14 cm, fuel thickness = 0.1 cm
- Fuel mass = 14.3 mg for a 45° X-configuration (volume ratio for fill vol./void = 0.707/0.293)
- In perspective, fuel mass for NIC ignition capsule is about 0.2 mg and for LIFE reactor capsule is about 2 mg



Inner beam radius is reduced four times during the pulse to closely following the fuel-pusher boundary

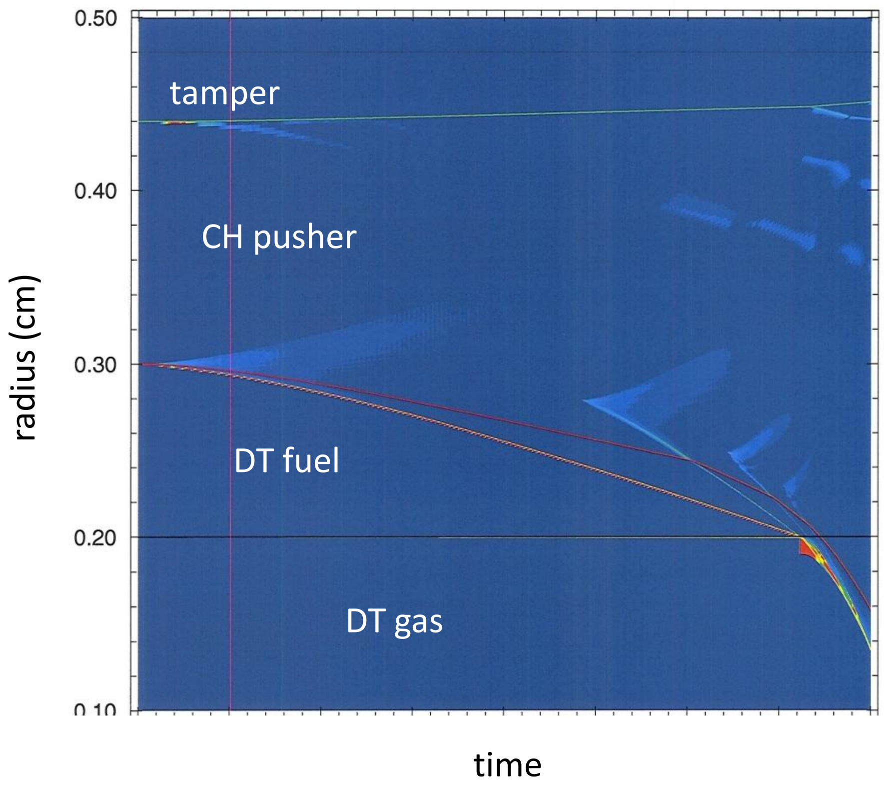
- Thick cylindrical beam (with a thickness of 0.14 cm) is used here to minimize the reduction in areal density seen by the 3rd and 4th pulses.



- Picket fence reduces required beam energy

High fuel compression is achieved by precision shock timing

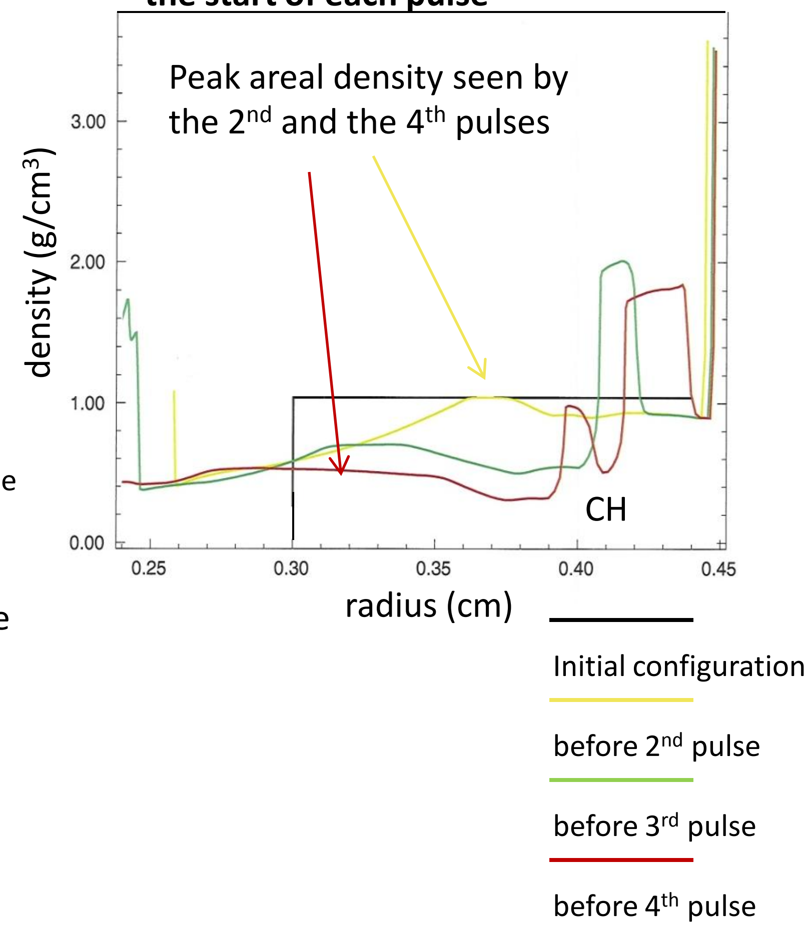
- Shock diagram shows the first three shocks meet at the fuel-gas surface.
- Each shock has a strength approximately four times the previous shock

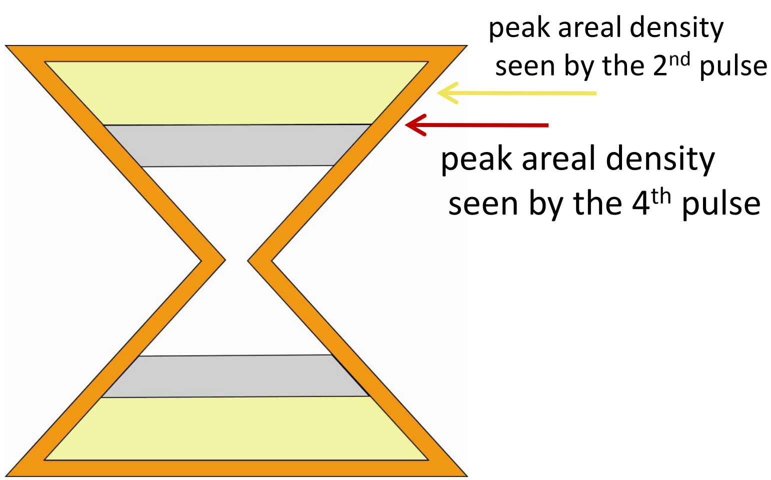


Density profiles of the pusher region at the start of each beam pulse show there is more than a factor of two variation in areal density between the first pulse and the fourth pulse

- The ratio of peak density in the pusher seen by the 2nd and the 4th pulse is 2.1 and the corresponding ratio of the areal density is about 2.3

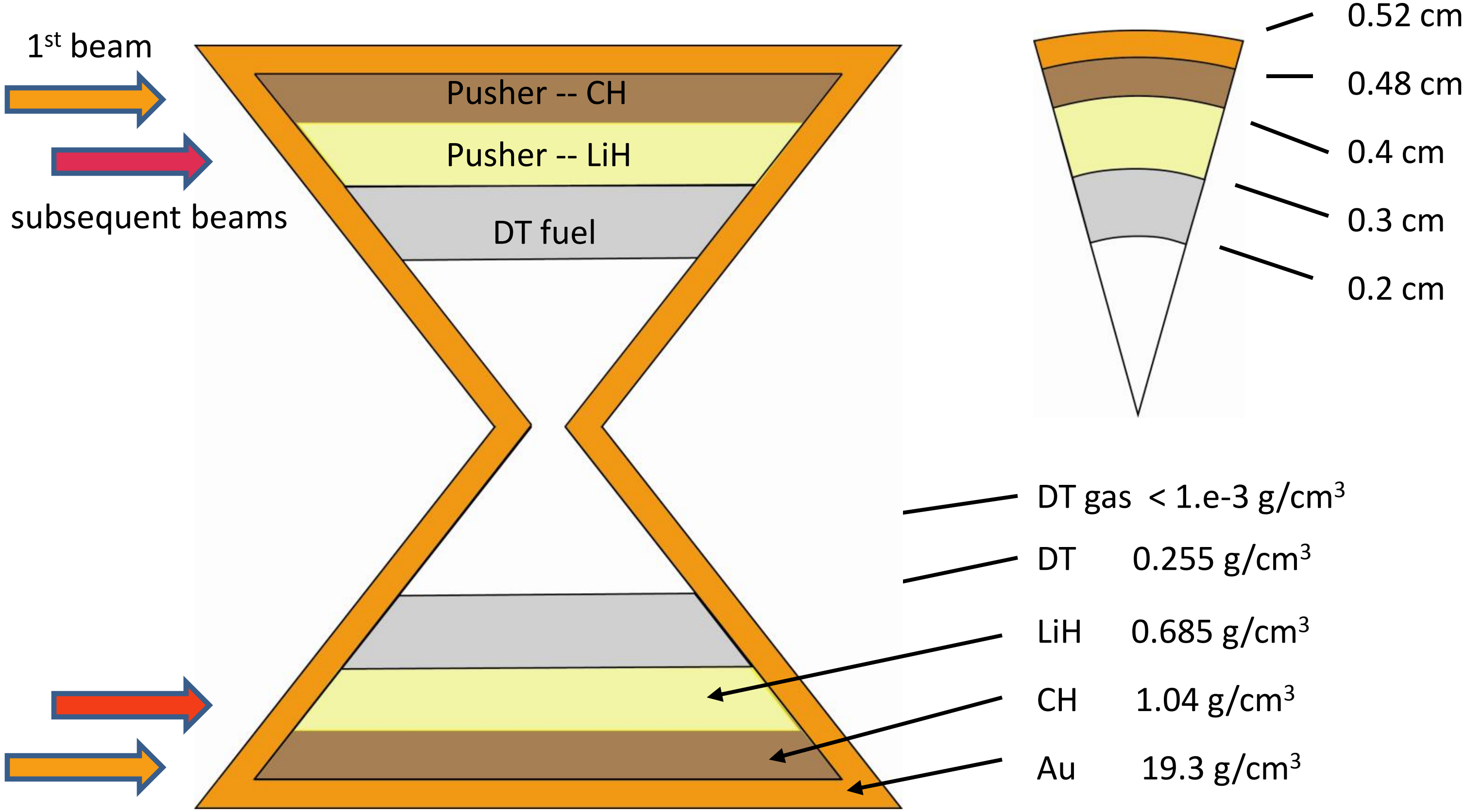
Pusher density profiles at the start of each pulse





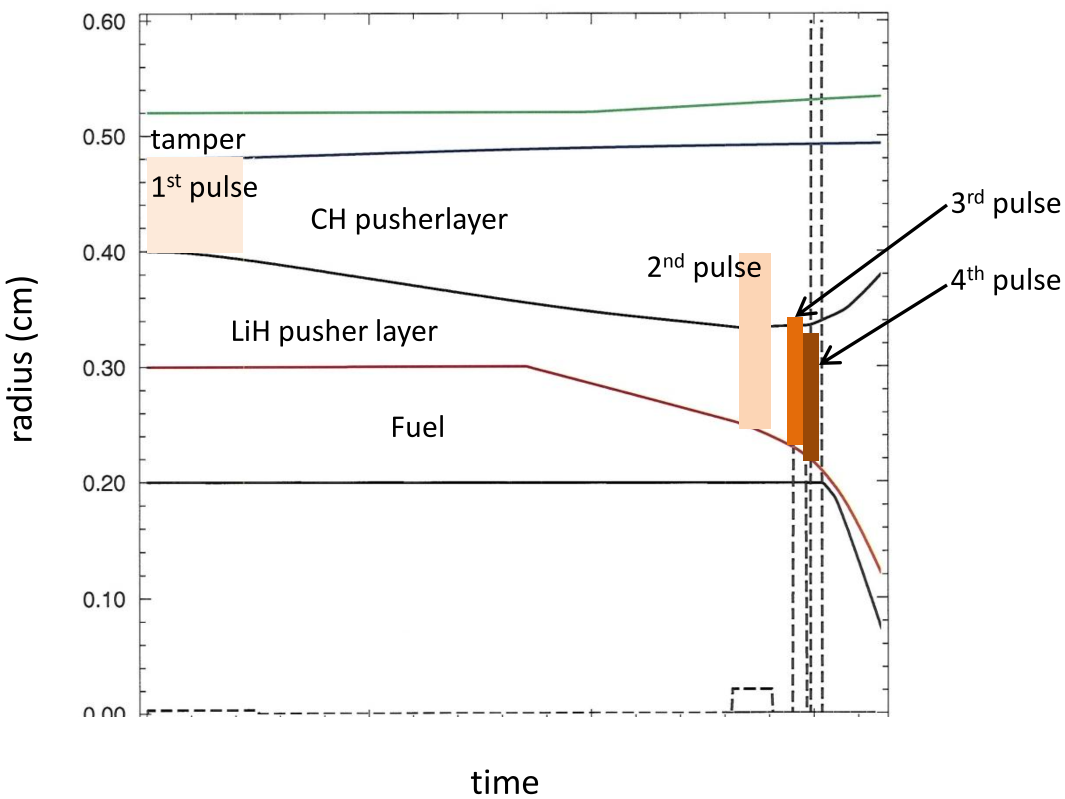
Double-layered pusher configuration

Use double-layered pusher to improve the beam-pusher coupling



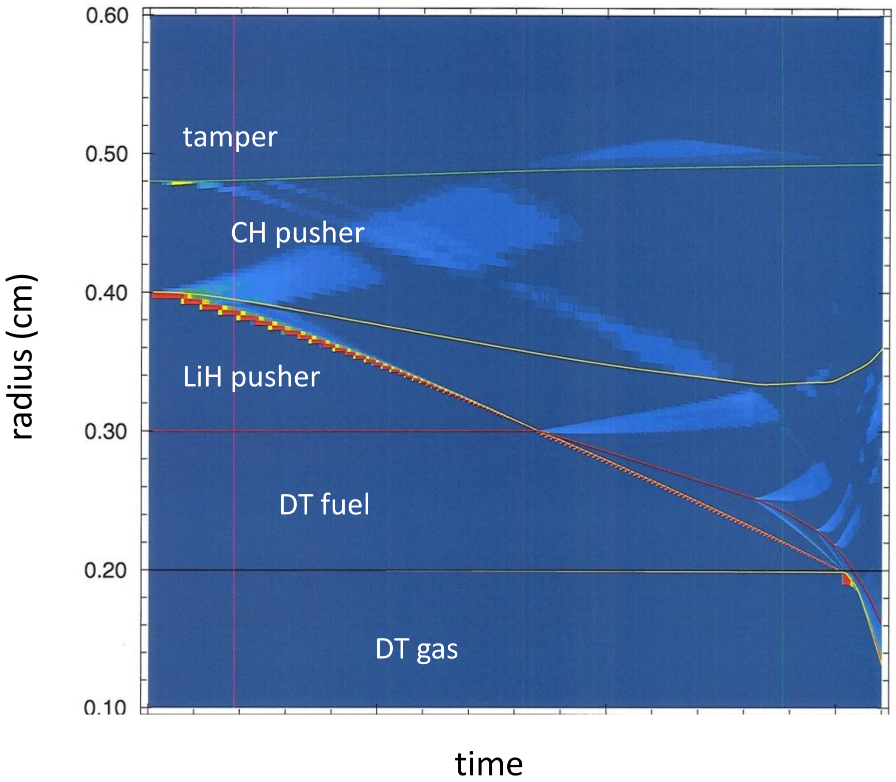
Two-layer pusher configuration can reduce the variation of areal density seen by the beam pulses

- First pulse heats up the outer CH pusher layer. Subsequent pulses heat up the inner LiH pusher layer.



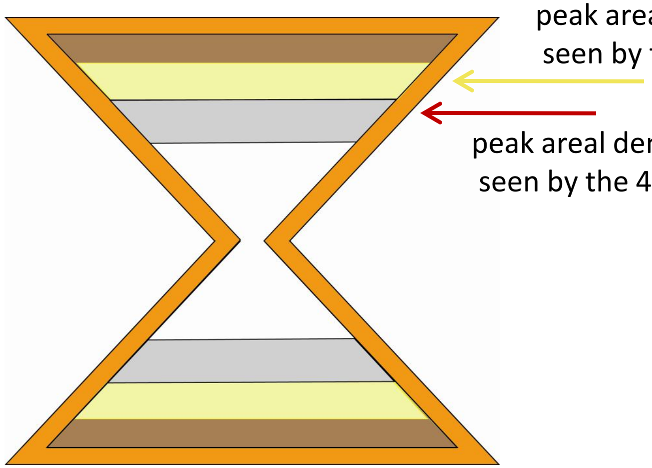
Shock diagram for the double-layer pusher configuration

- Takes longer for the first shock to arrive the fuel-gas interface because the first beam heats up only the outer CH pusher layer and the first shock has to traverse through the LiH pusher layer.

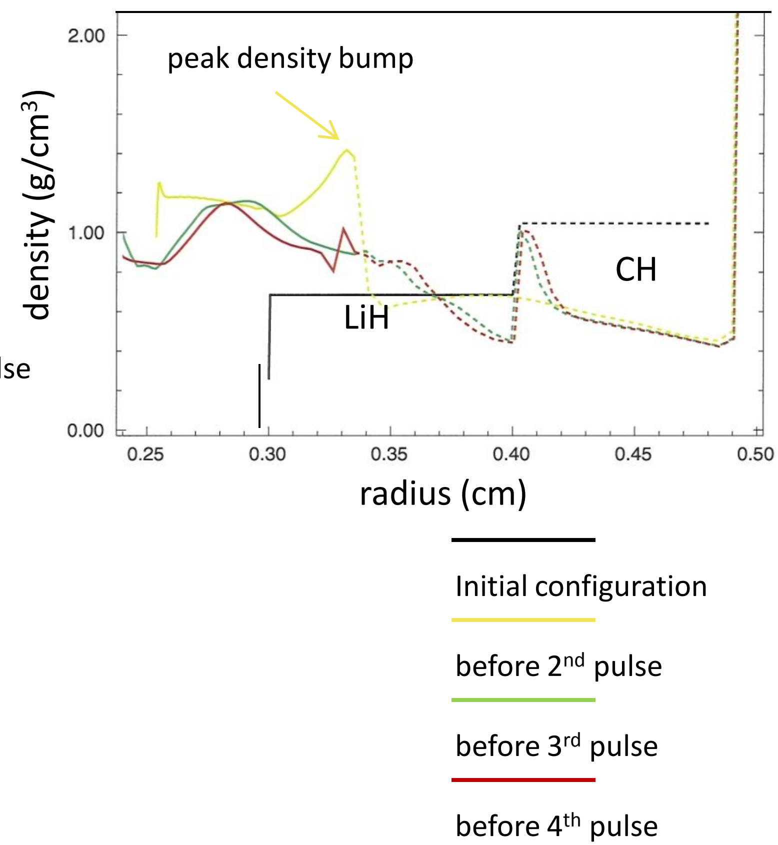


Density profiles in the pusher region at the start of each beam pulse show the variation in areal density seen by the beams is reduced

- The ratio of peak density in the pusher between the 2nd and the 4th pulse along the beam path is 1.17 and the corresponding ratio of the areal density is about 1.4
- The bump in density seen by the 2nd pulse may be eliminated by introducing a smooth density transition between CH and LiH layers and/or by other combination of pusher materials.



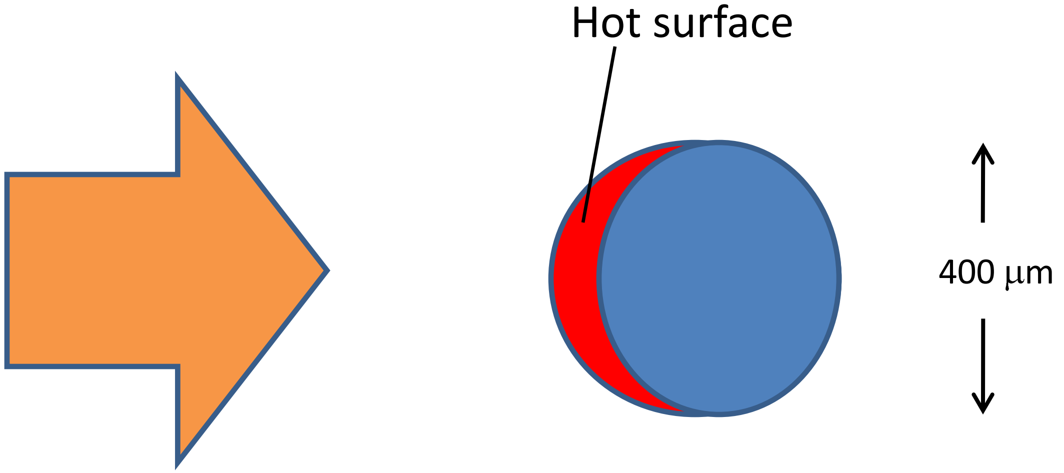
Pusher density profiles at the start of each pulse



Performance of the 3 types of ablator in terms of DT fuel compression

Pusher type	**CH**	**CH/LiH**	**CH/LIH (no 4th shock)**
peak fuel ρr (g/cm^2)	3.5	3.75	1.9
max. ave. density r = 200μm	150	150	72
fuel ρr with the above condition	3.45	3.7	1.85
Burn fraction with the above condition [ρr/(ρr + 7)]	0.33	0.346	0.21
Energy production (GJ)	1.58	1.66	1.0
Gain (compression beam has 2 – 3x of deposited energy + 2.5 MJ of ignitor beam energy)	250	486	340

Ignition by hot surface



Ignition beam with 200 μm radius

Summary and work plans

- Simulations show that beam-pusher coupling can be improved by using a double-layered pusher configuration.

- Further improvement in beam-pusher coupling (i.e., minimizing the variation in areal density seen by the beams) may be possible by introducing a more graduate change in density between the CH and LiH pusher layers and/or using different combination of pusher materials.

- 1-D simulations show high fuel compression (> 150 g/cm^3) and relatively high ρr (~ 3.5 g/cm^2) can be achieved by precision shock timing.

- 1-D gain can approach 500.

- Need to estimate the beam energy deposition by a 1-D slab model

- 2-D simulation will start very soon. Expect both the peak density and peak ρr to go down somewhat.