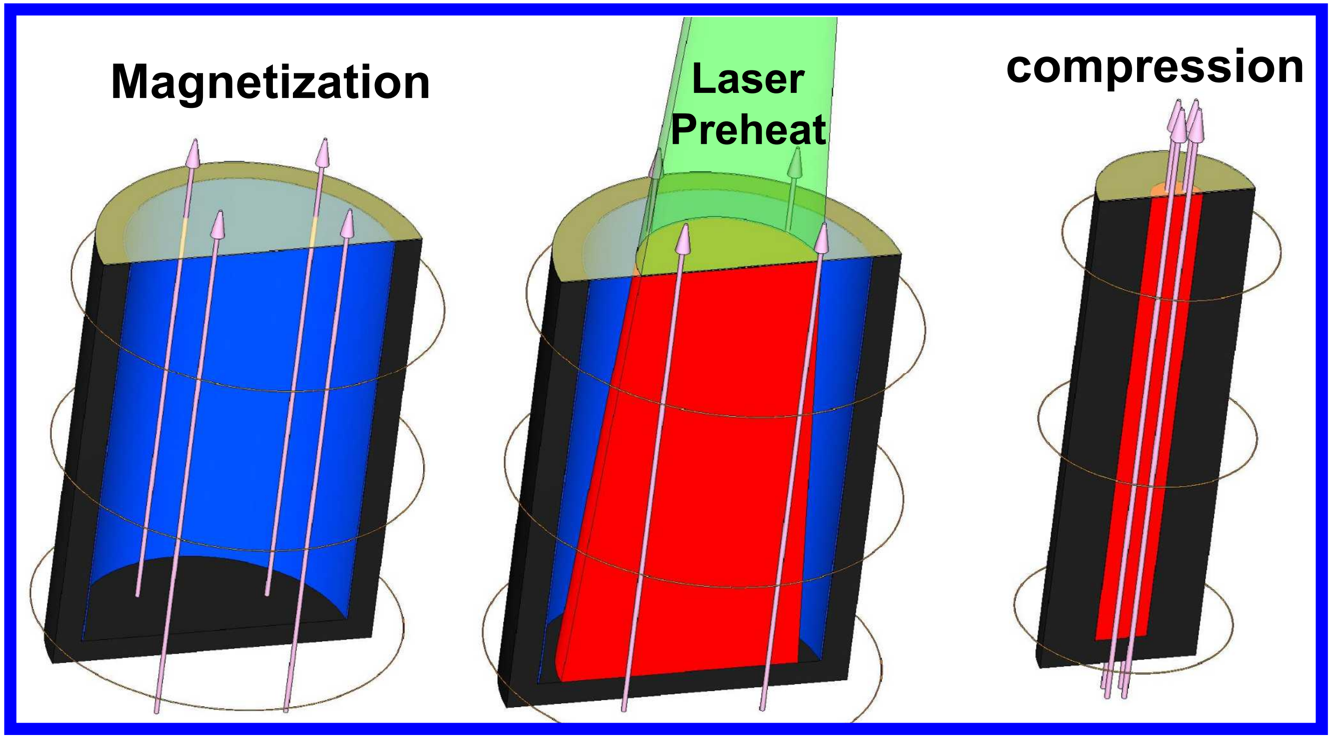
Challenges for scaling laser heating of MagLIF targets to high yields



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S. A. Slutz, A. B. Sefkow, R. A. Vesey

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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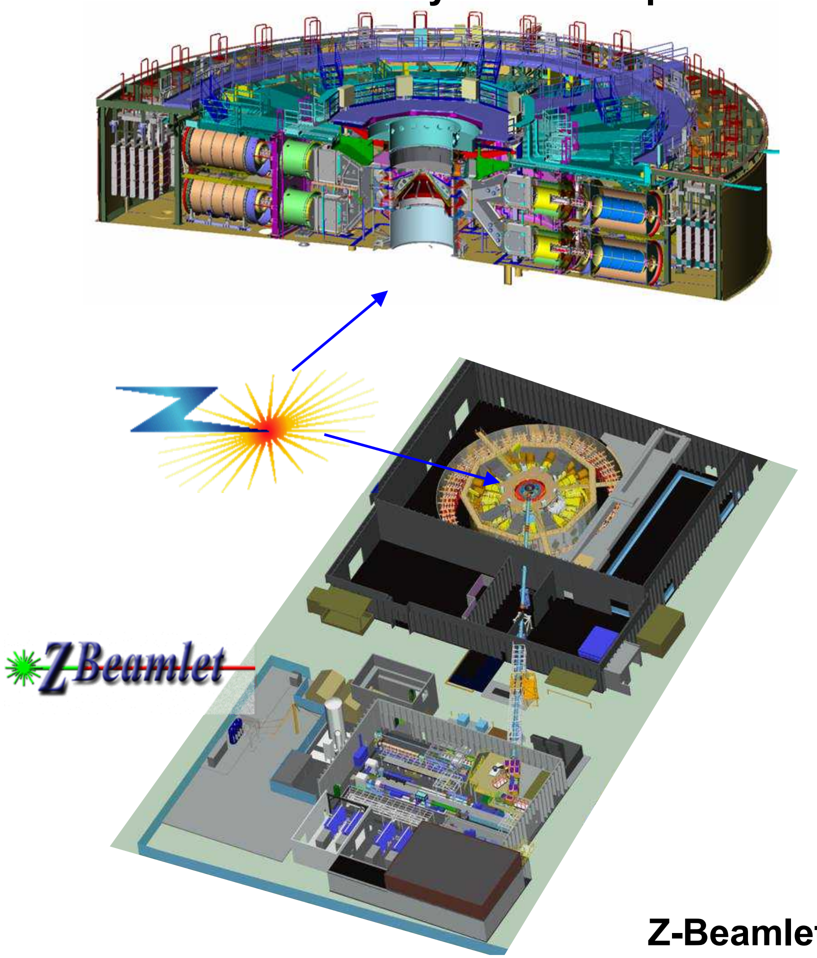
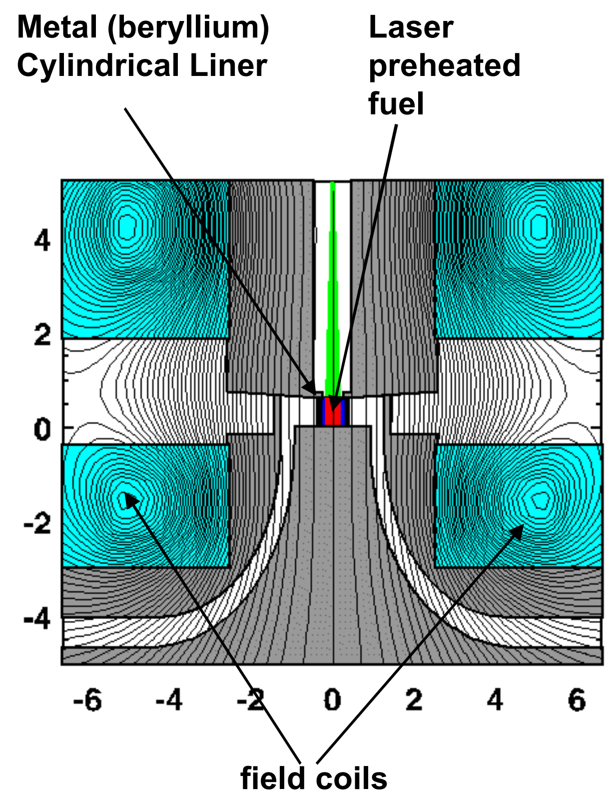
The Z facility, *which combines the worlds largest pulsed power machine with a high power laser*, enables MagLIF[1]

Z can generate high magnetic pressures to drive cylindrical implosions

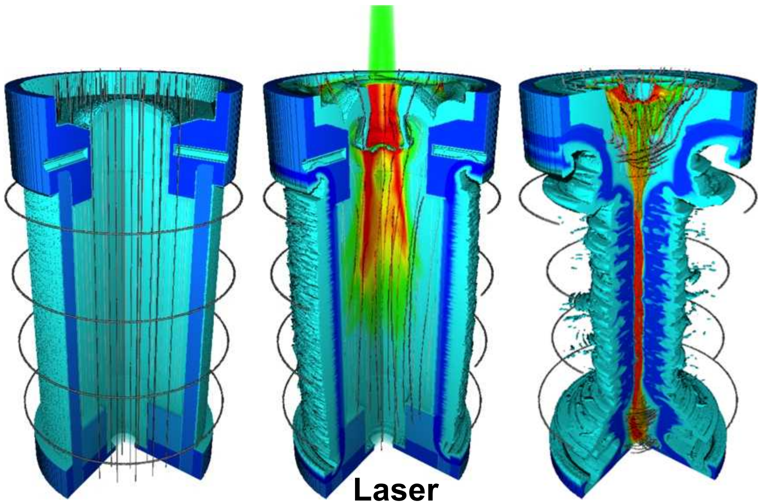




Z-Beamlet provides fuel preheat

1 *S.A. Slutz et al. Physics of Plasmas 17, 056303 (2010)*

MagLIF combines three complementary design elements



- Key target design elements
  - Magnetization
  - Laser heating
  - Liner compression

2D simulations indicate MagLIF could produce 100 kJ on Z at full Marx charge

- 30 Tesla initial magnetic field
- Laser heating of ~ 2 mg/cm^3 fuel produces initial ~250 eV plasma
- Thick ($AR=R_0/\Delta R=6$) Be liner with R_0=2.7, h=10 mm, peak velocity ~100 km/s for a 27 MA peak current drive

At stagnation:

- Efuel ~ 120 kJ
- Ti ~ 8 keV
- density is ~ 0.5 g/cm^3
- Bz > 100 MG

Similar predictions are obtained using multiple codes

Detailed designs in A.B. Sefkow, S.A. Slutz et al., Phys. Plasmas 21, 072711 (2014).

We have obtained promising initial experimental results[1] with MagLIF

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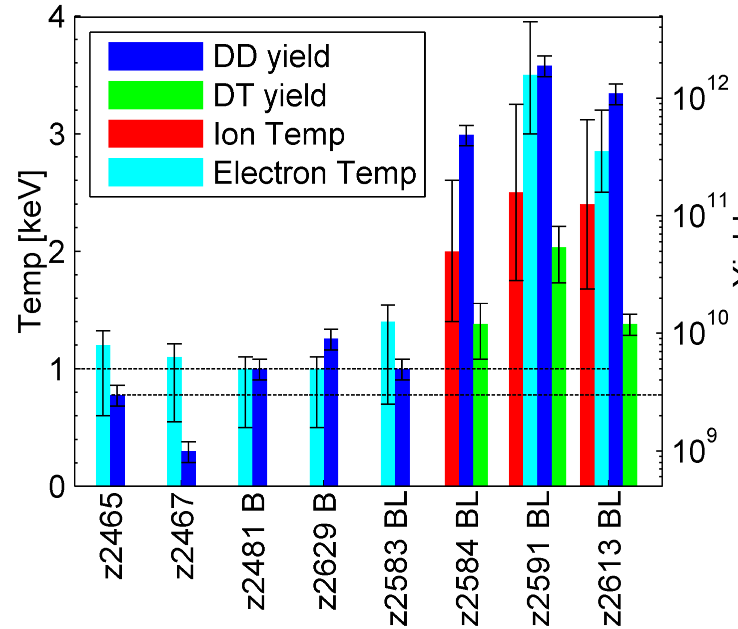
Data were collected that show a <150 μm diameter, ~3 keV, highly magnetized plasma

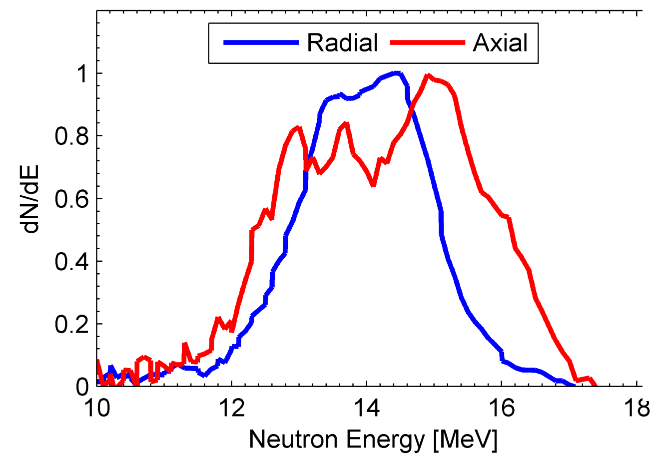
We achieved DD yields up to 2×10^{12} in our first integrated tests

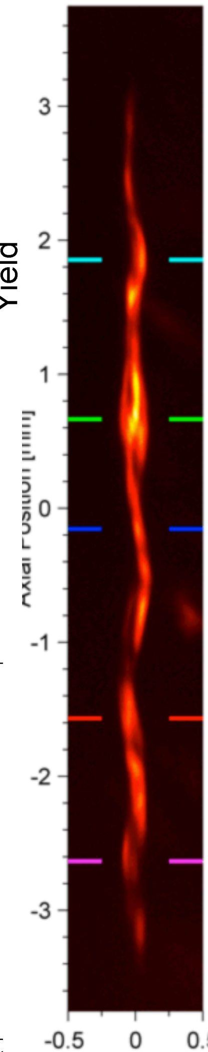
- **at less than maximum current (I < 20 MA)**
- **low preheat energy (< 1kJ)**

We are continuing to build on these results with a balanced combination of focused and integrated experiments

In parallel we are working toward improved understanding of MagLIF performance scaling with increasing drive parameters







MagLIF could in principle provide high yield and gain[1] on future accelerators

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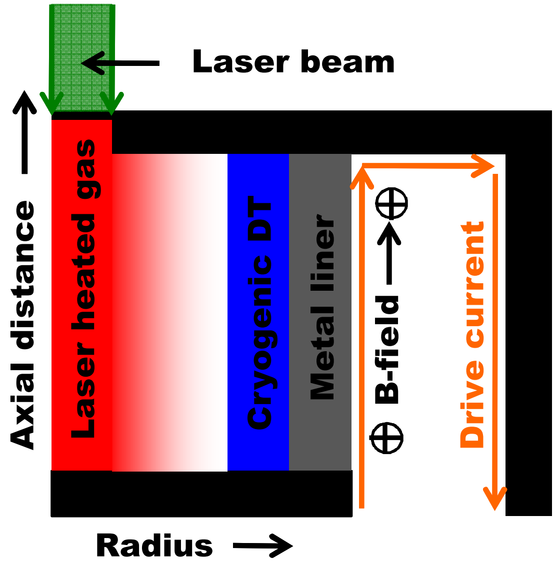


A 2D integrated Hydra simulation[2] produced ~ 6 GJ

L_{liner} = 10 mm

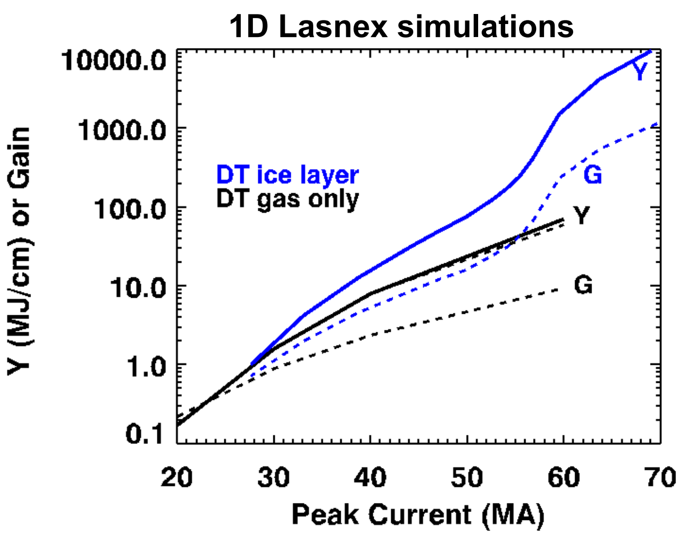
AR_{liner} = 6

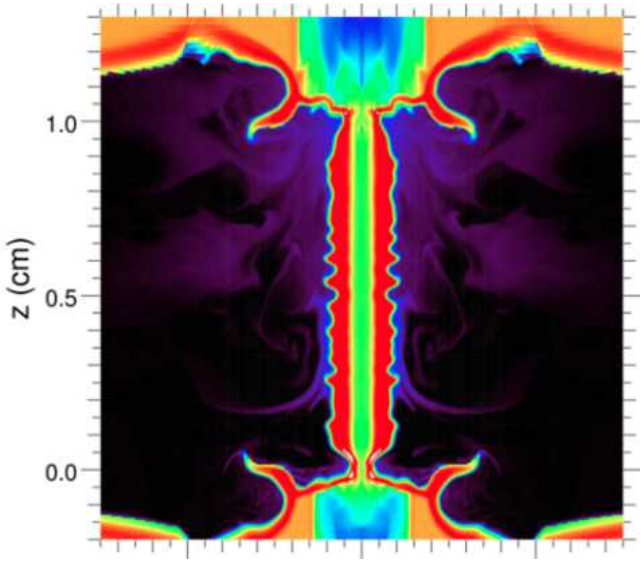
ρ_{gas} = 5 mg cm^{-3}

B_z^0 = 8T

E_{laser} = 25 kJ

Peak drive current = 70 MA





1 Slutz and Vesey PRL 108, 025003 (2012)
2 Sefkow, Slutz, Koning et al. PoP 21, 072711 (2014

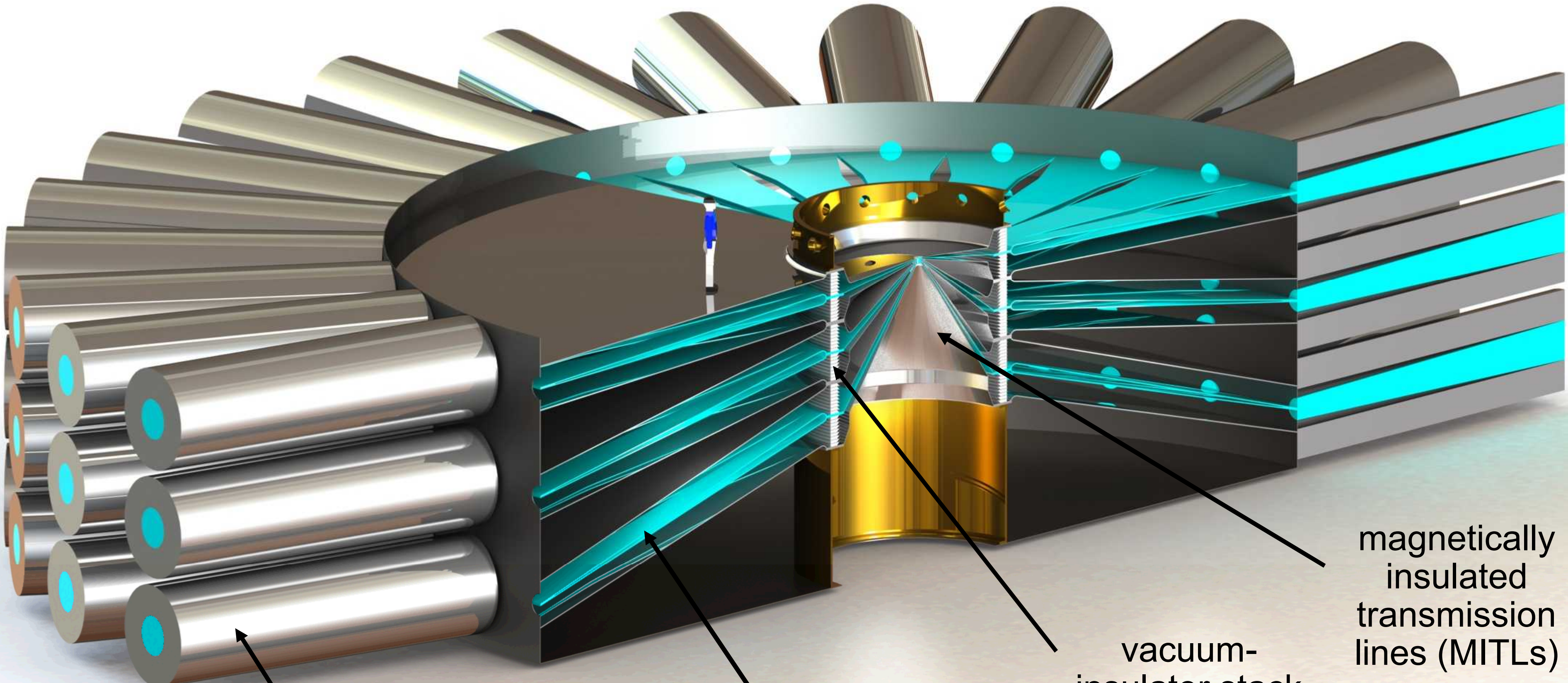
Advanced machines could deliver large currents to MagLIF e.g. conceptual designs[1] Z300 and Z800

P_{LTDs} = 315-870 TW
E_{LTDs} = 47-130 MJ

V_{stack} = 7.6-16 MV
L_{vacuum} = 16-25 nH

I_{load} = 47-61 MA
$\tau_{implosion}$ = 133 ns

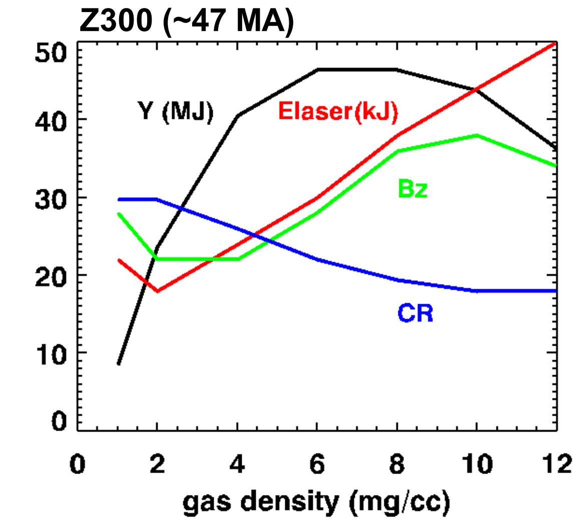
diameter = 35-55 m

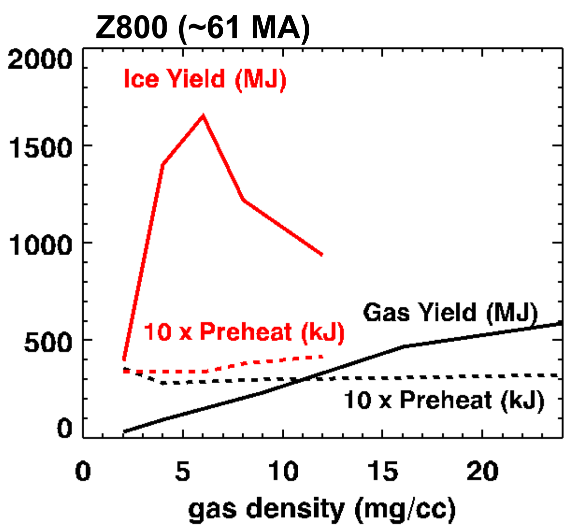


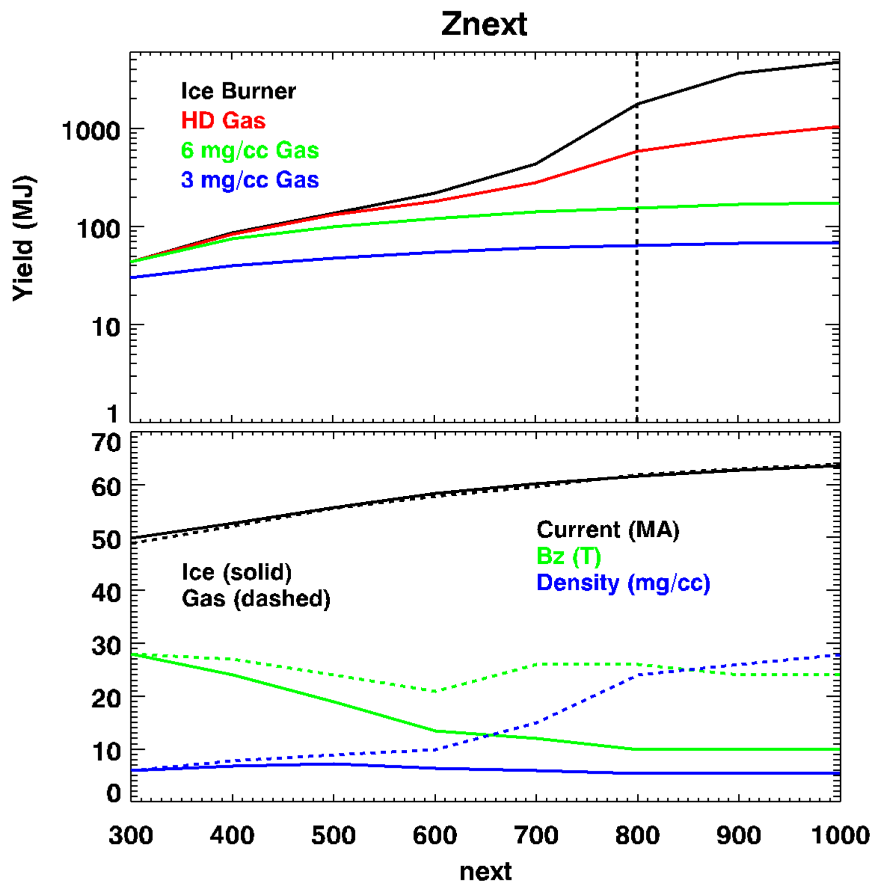
1. W. Stygar (Manuscript in preparation)

Large preheat energies (~ 30 kJ) are needed for high yield MagLIF targets

- Optimal initial fuel densities >= 6 mg/cc
- $E_{preheat}$ ~ 30 kJ near optimal for 1D
- Optimal $E_{preheat}$ increases in 2D due to end losses







Simple analytic theory predicts the laser penetration can be controlled by the beam radius and laser wavelength

The laser energy needs to be deposited into the fuel in roughly z_f = 1 cm

Laser absorption coefficient dominated by inverse Bremsstrahlung

$$C_V \frac{d\theta}{dt} = \frac{dI}{dz} = -kI \qquad k = \frac{\nu_{ei}\omega_p^2}{c\omega_L^2}\left(1-\frac{\omega_p^2}{\omega_L^2}\right)^{-1/2} = \frac{k_0}{\theta^{3/2}} \qquad k_0 \approx 1.23x10^6\left(\rho\lambda_L Z_b\right)^2\left(1-227\rho Z_b\lambda_L^2\right)^{-1/2}$$

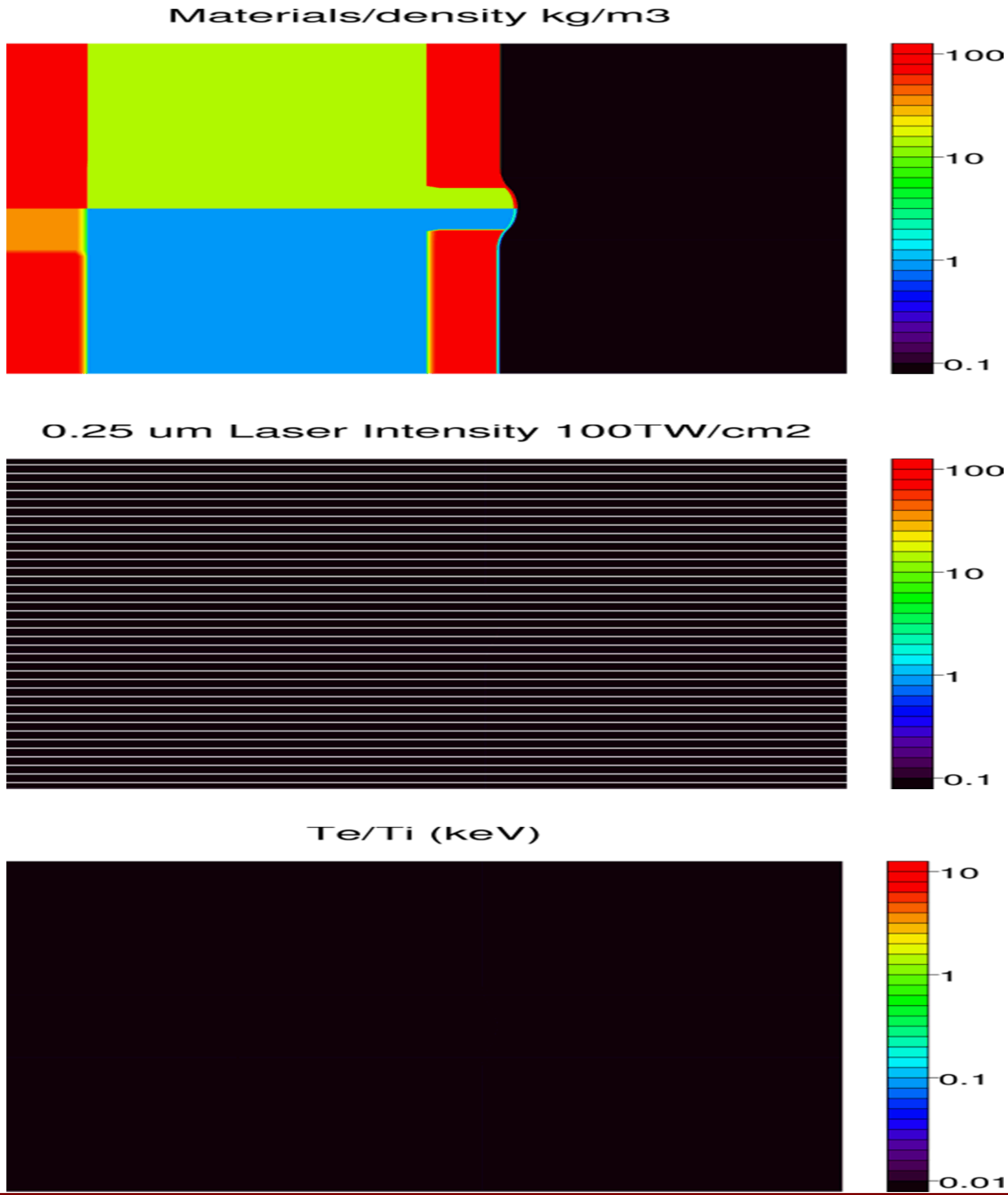
$$I = I_0\left(1-\frac{z}{z_f}\right)^{2/3} \qquad z_f = \frac{5}{3}\left(\frac{2}{5k_0}\right)^{2/5}\left(\frac{I_0 t}{2C_V\rho}\right)^{3/5} \qquad R_{laser} = 5.4x10^{-7} E_{laser}^{1/2}\lambda_L^{-.67}\rho^{-1.17}z_f^{-.83}\left(1-227\rho\lambda_L^2\right)^{.17}$$

Hydrodynamics, refraction and LPI make this process more complicated

A short wavelength laser (λ ~ 0.25-0.33 μ) could be used to penetrate the initially high density DT without excessive LPI, thus forming a low density channel

A second pulse of longer wavelength light (λ = 0.5-1 μ) could then propagate down this channel and efficiently deposit its energy

Simulation of a laser heating experiment depositing 30 kJ in 1 cm of DT at 12 mg/cc



Hole boring phase:
3 kJ of 0.25 um light

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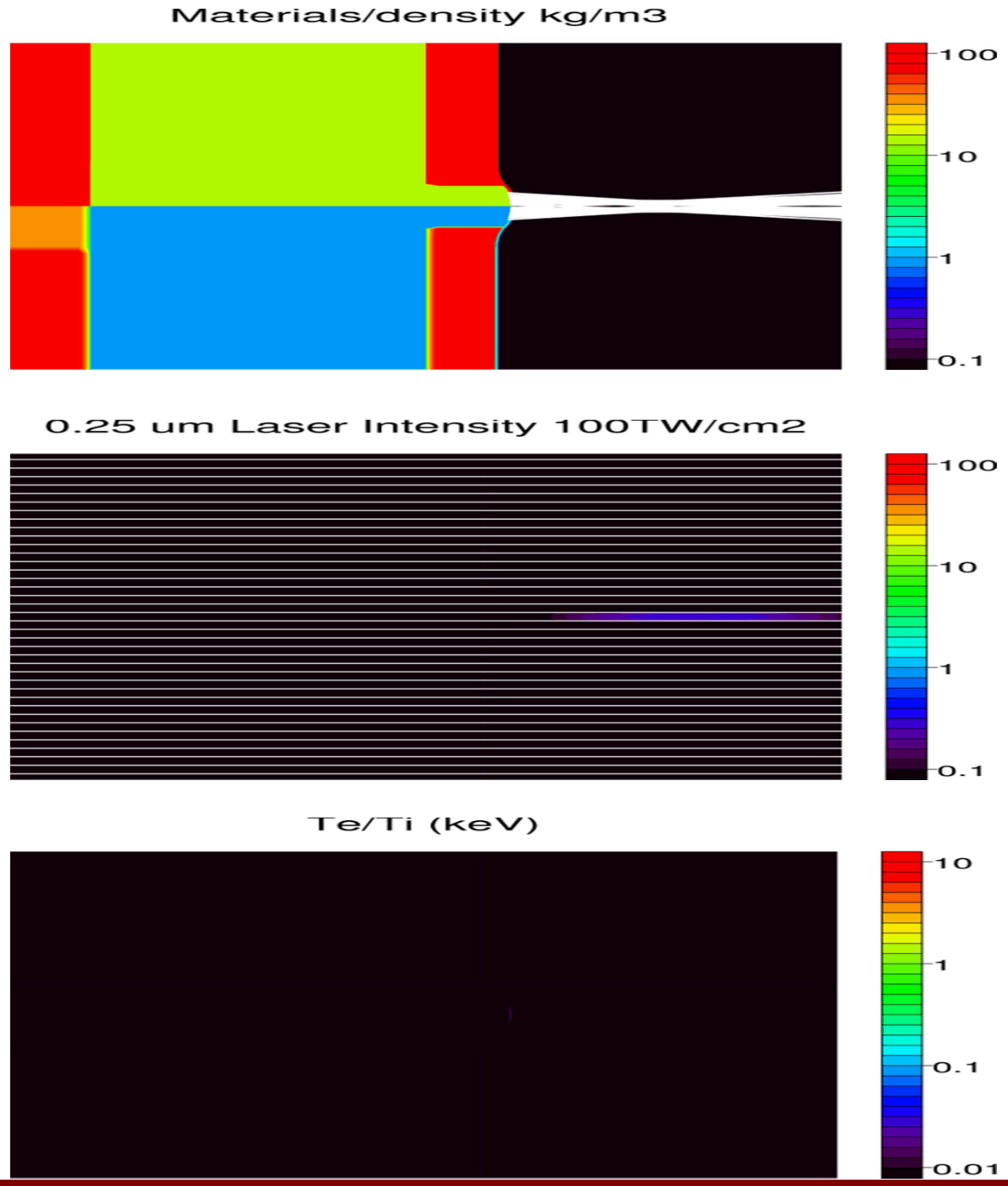

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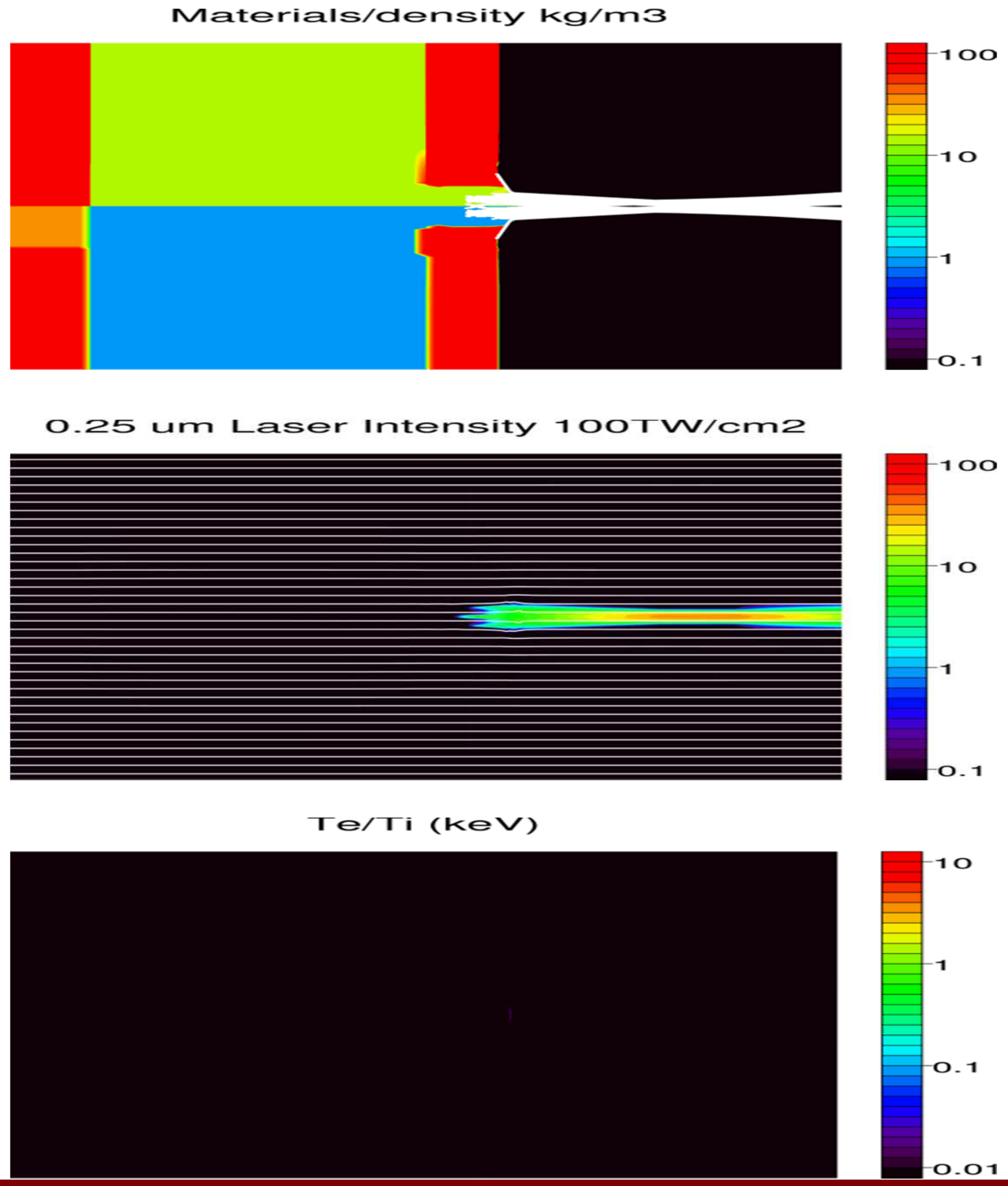

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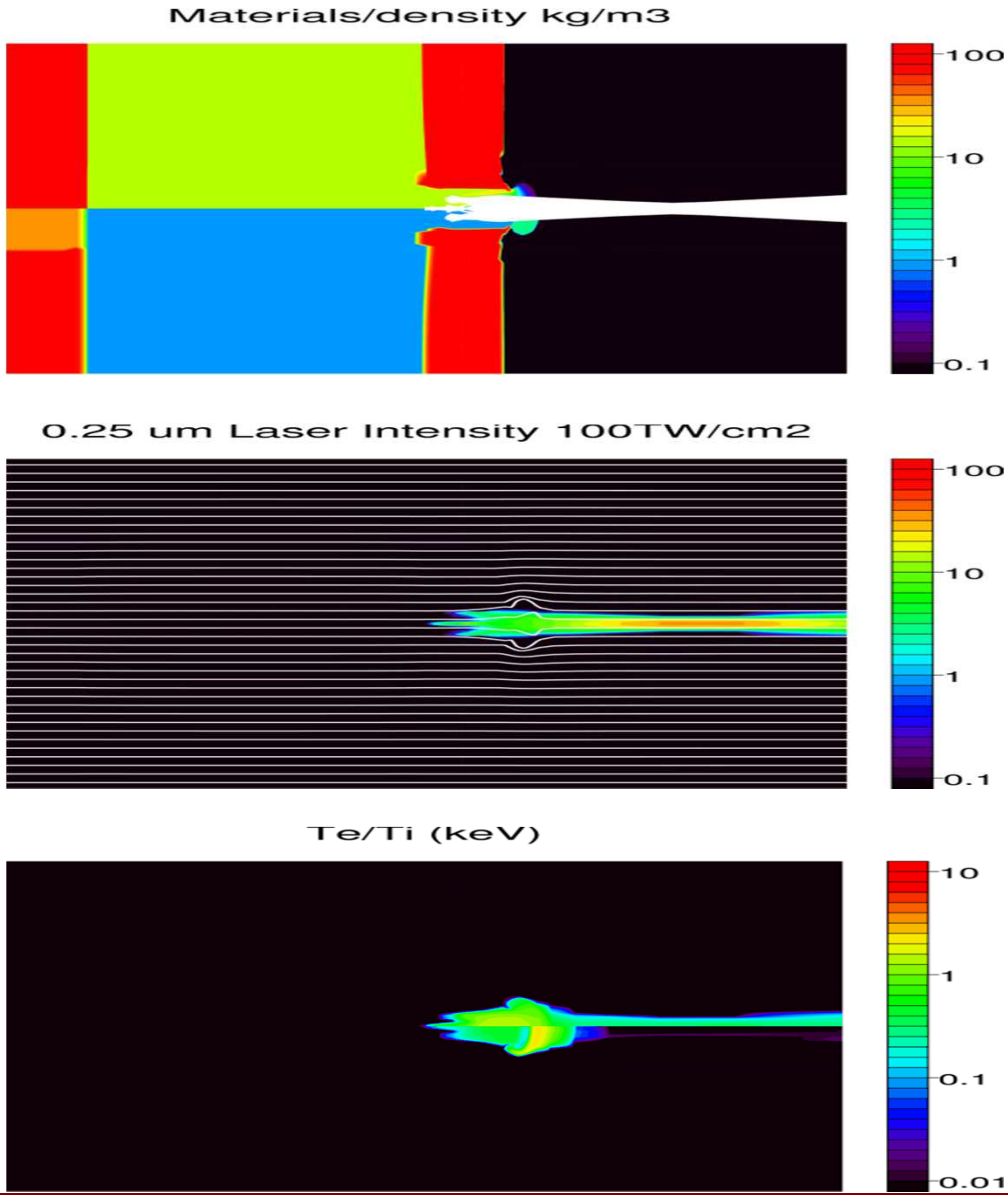

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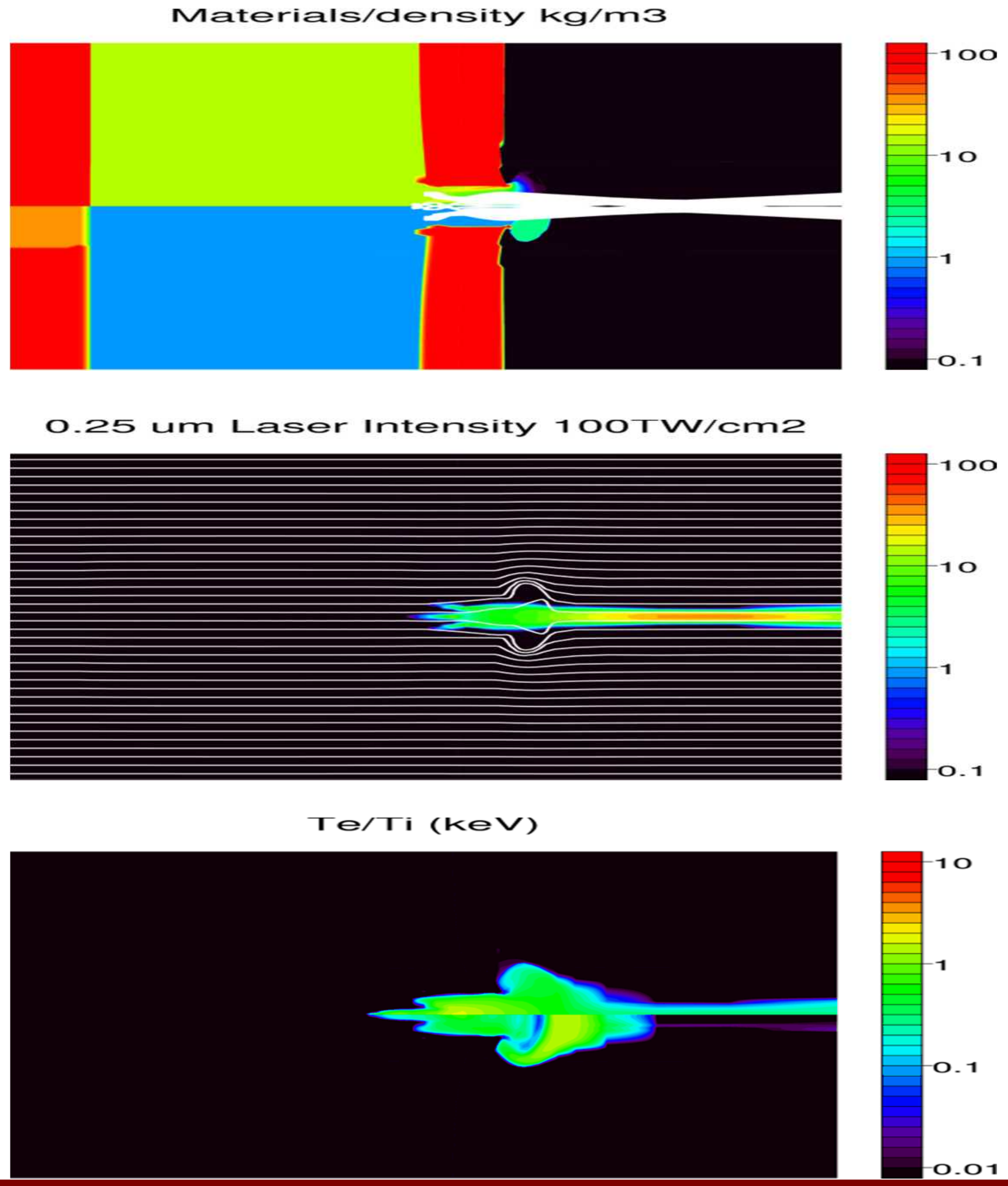

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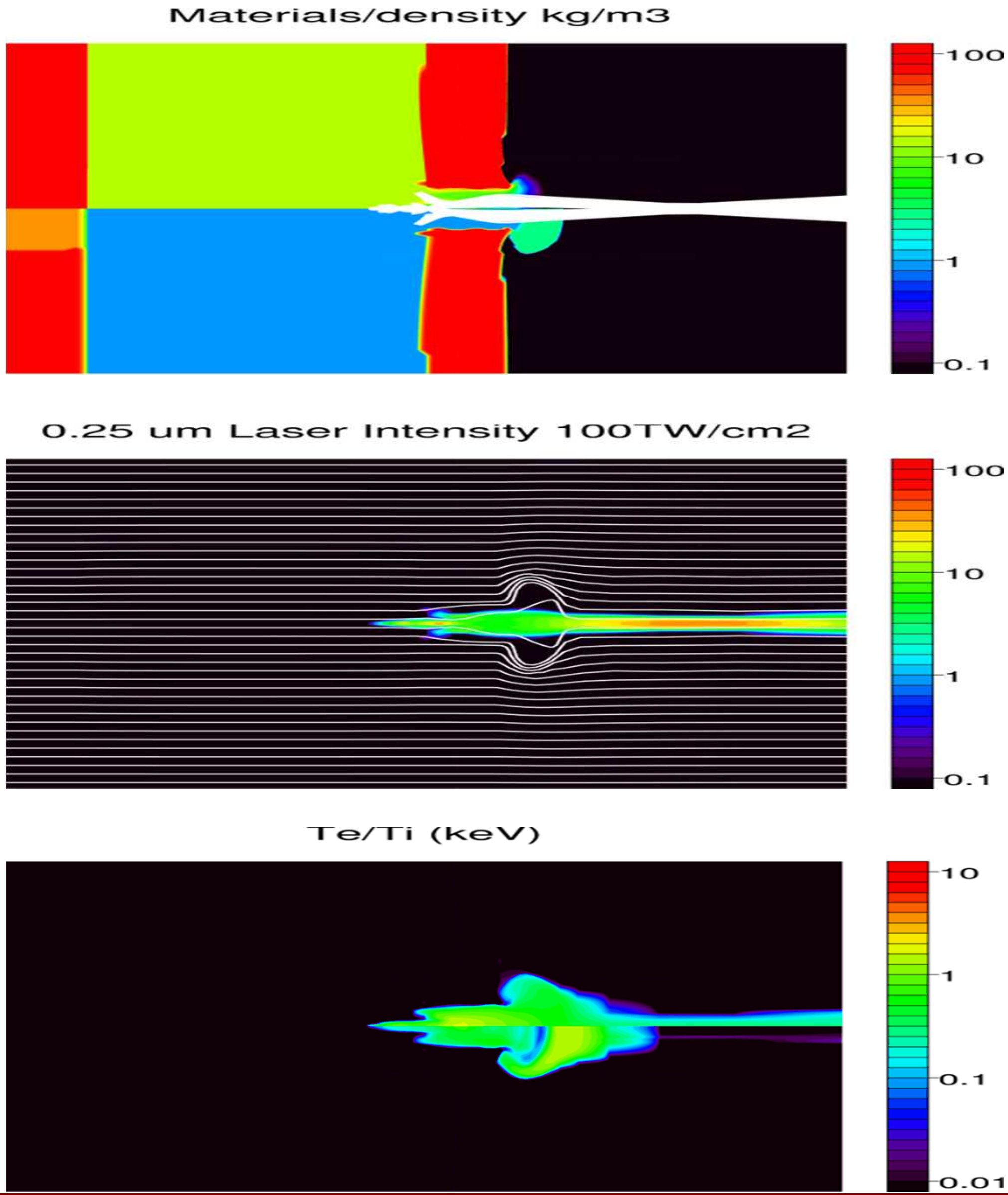

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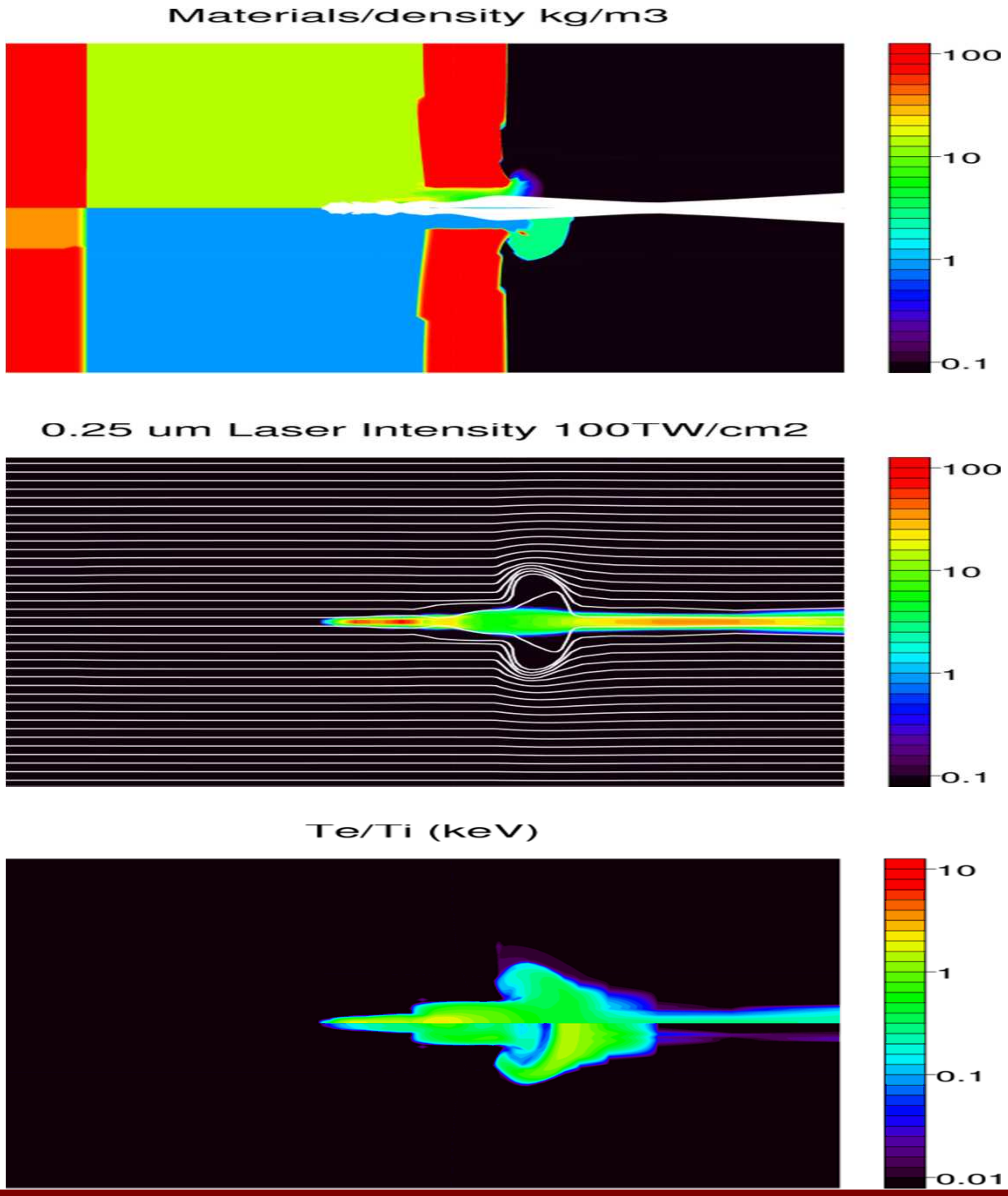

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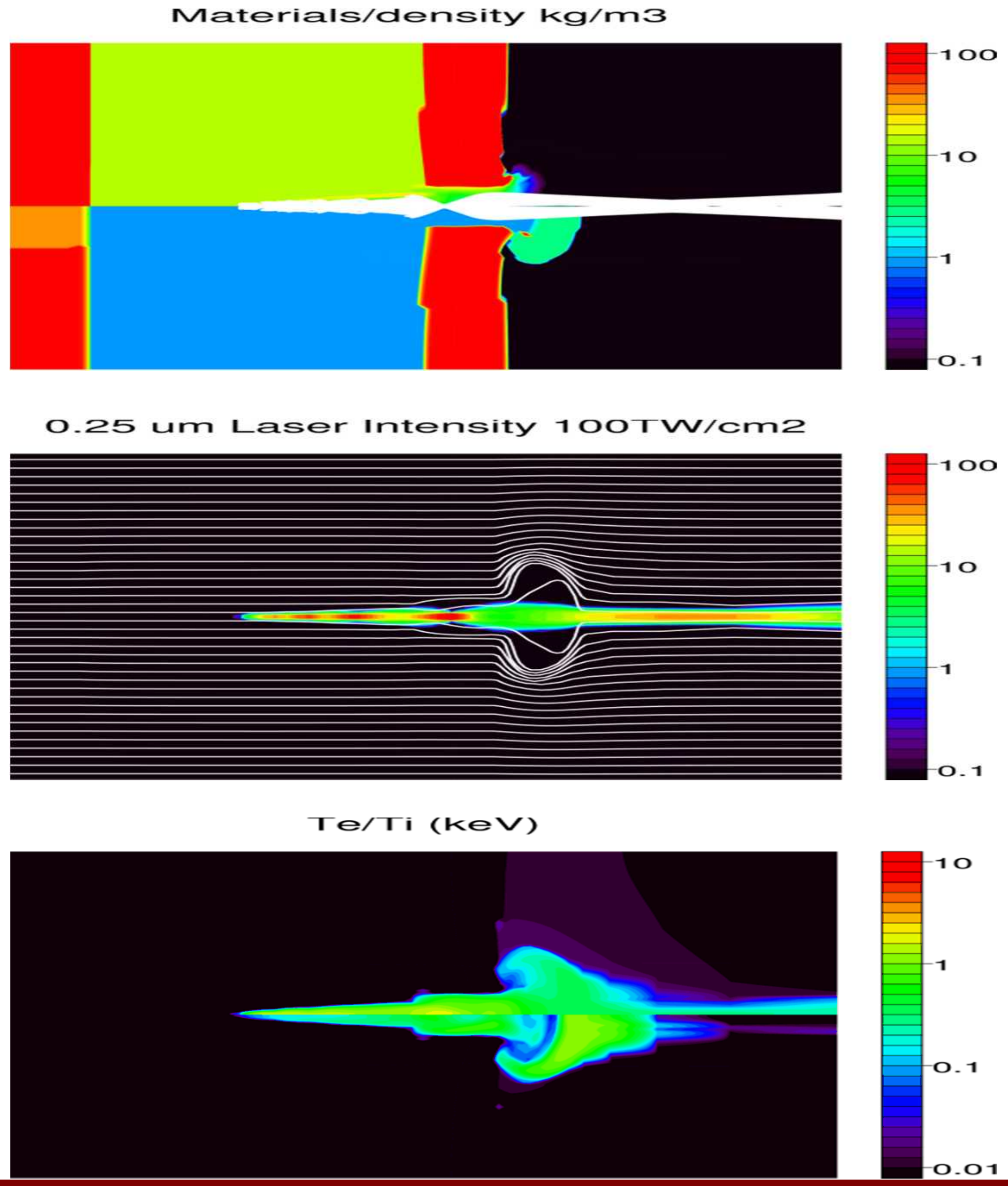

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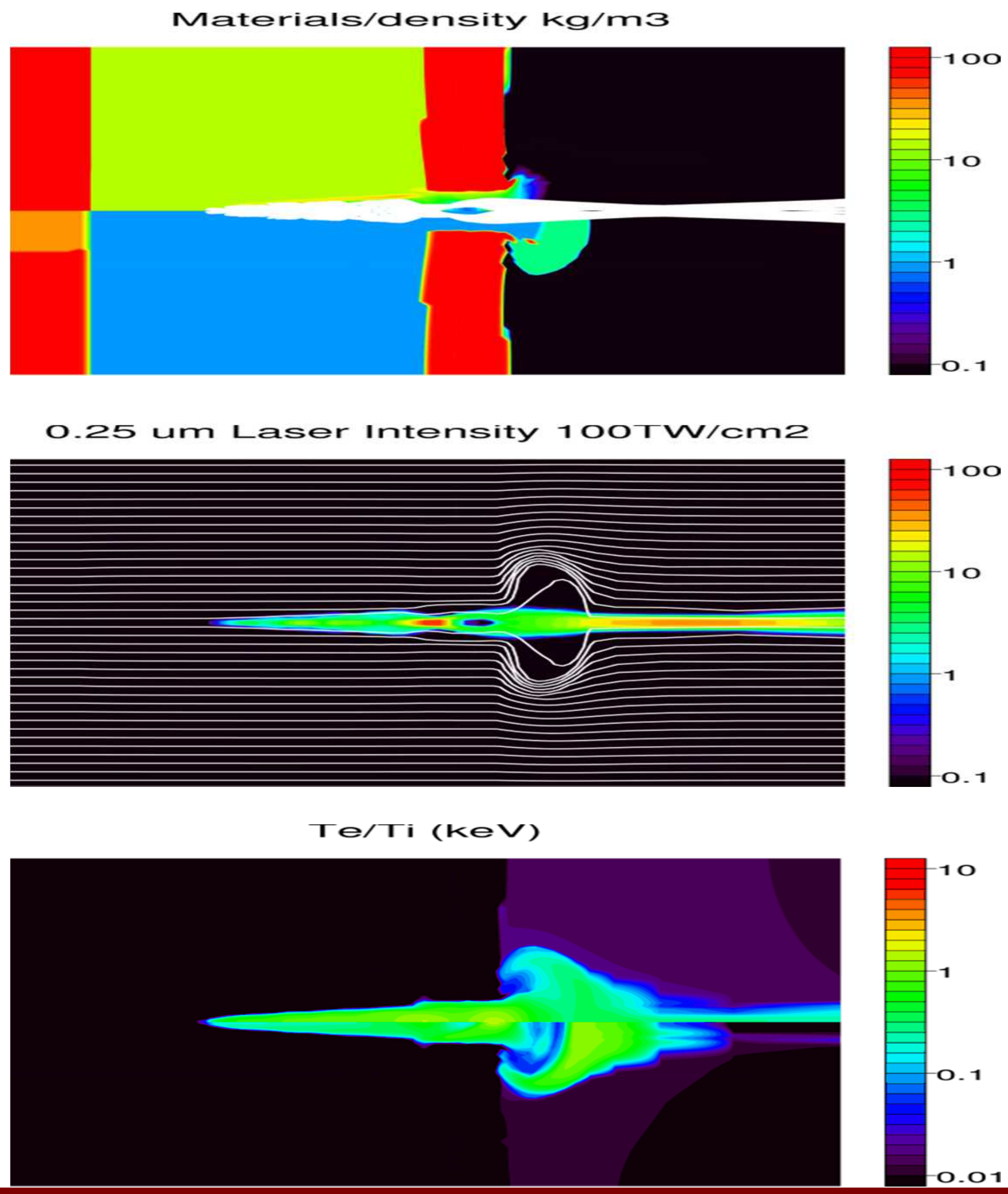

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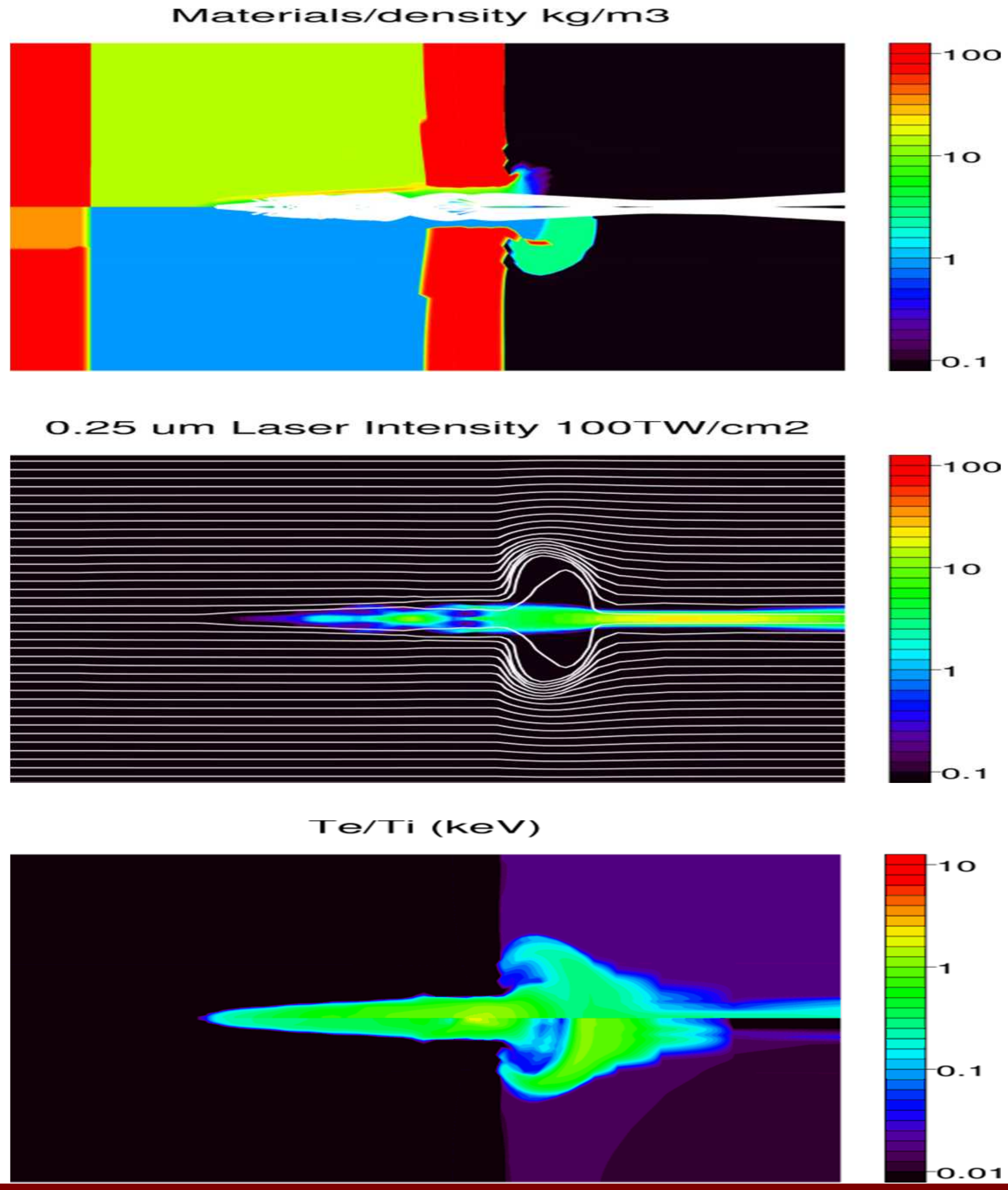

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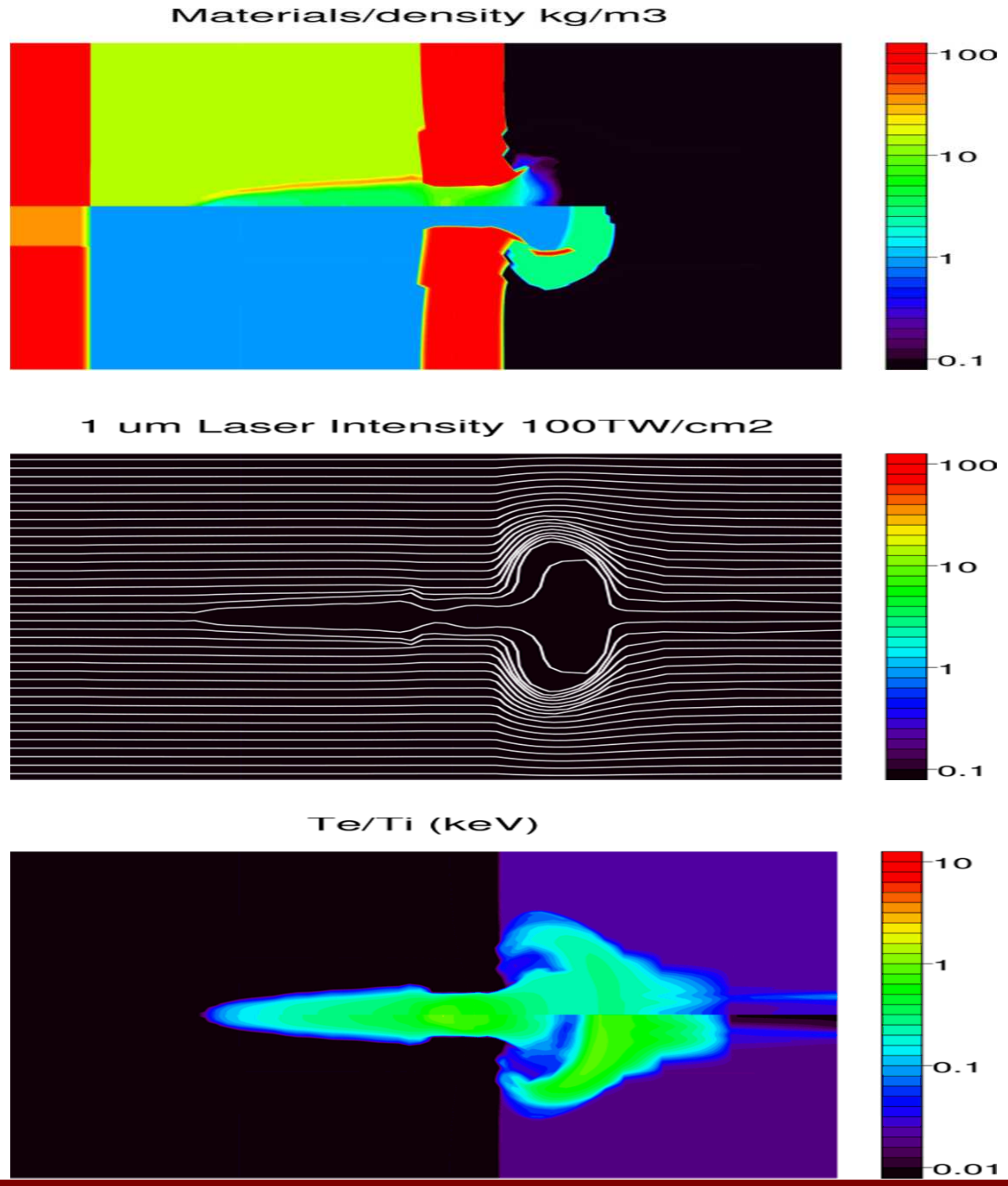
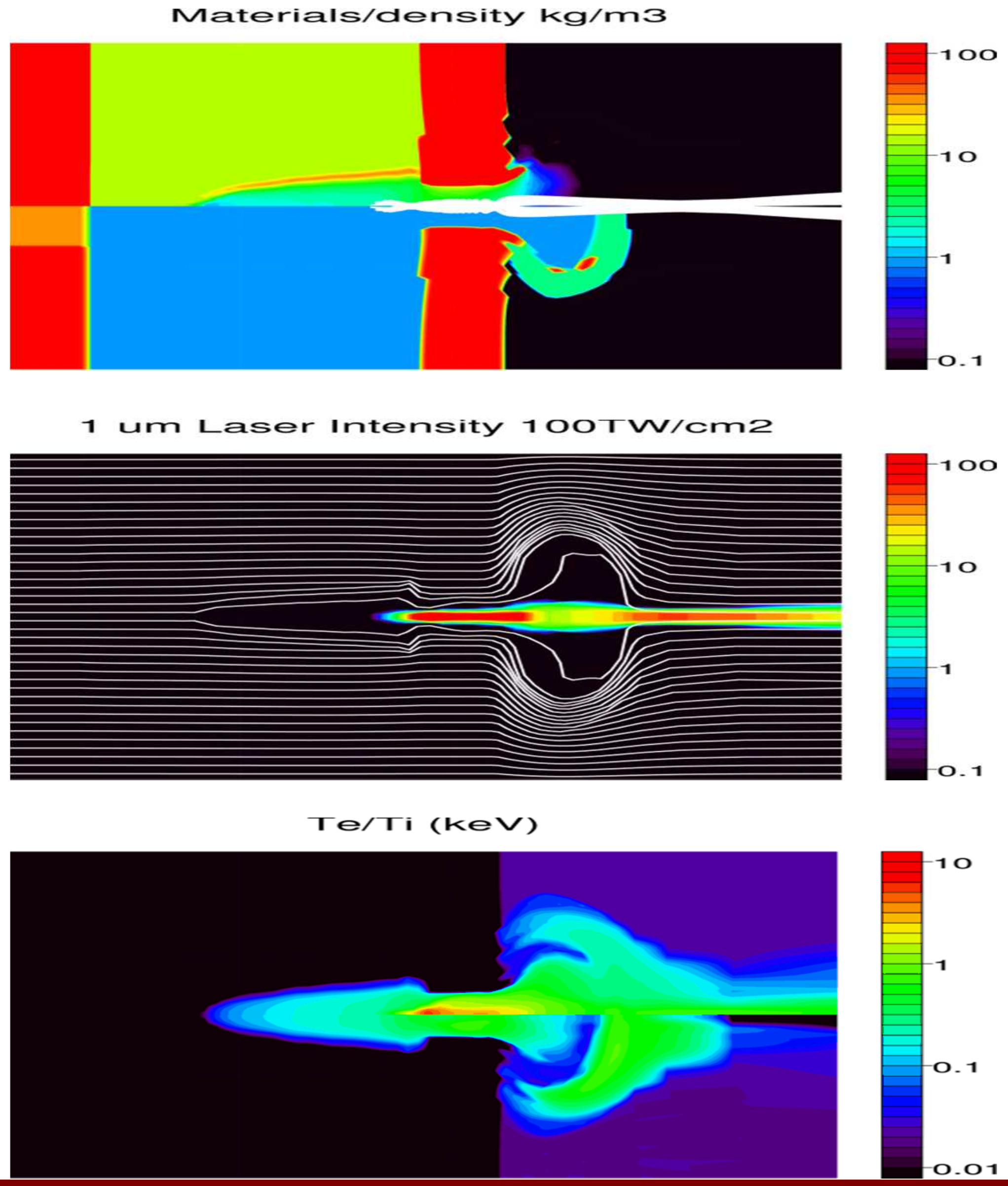


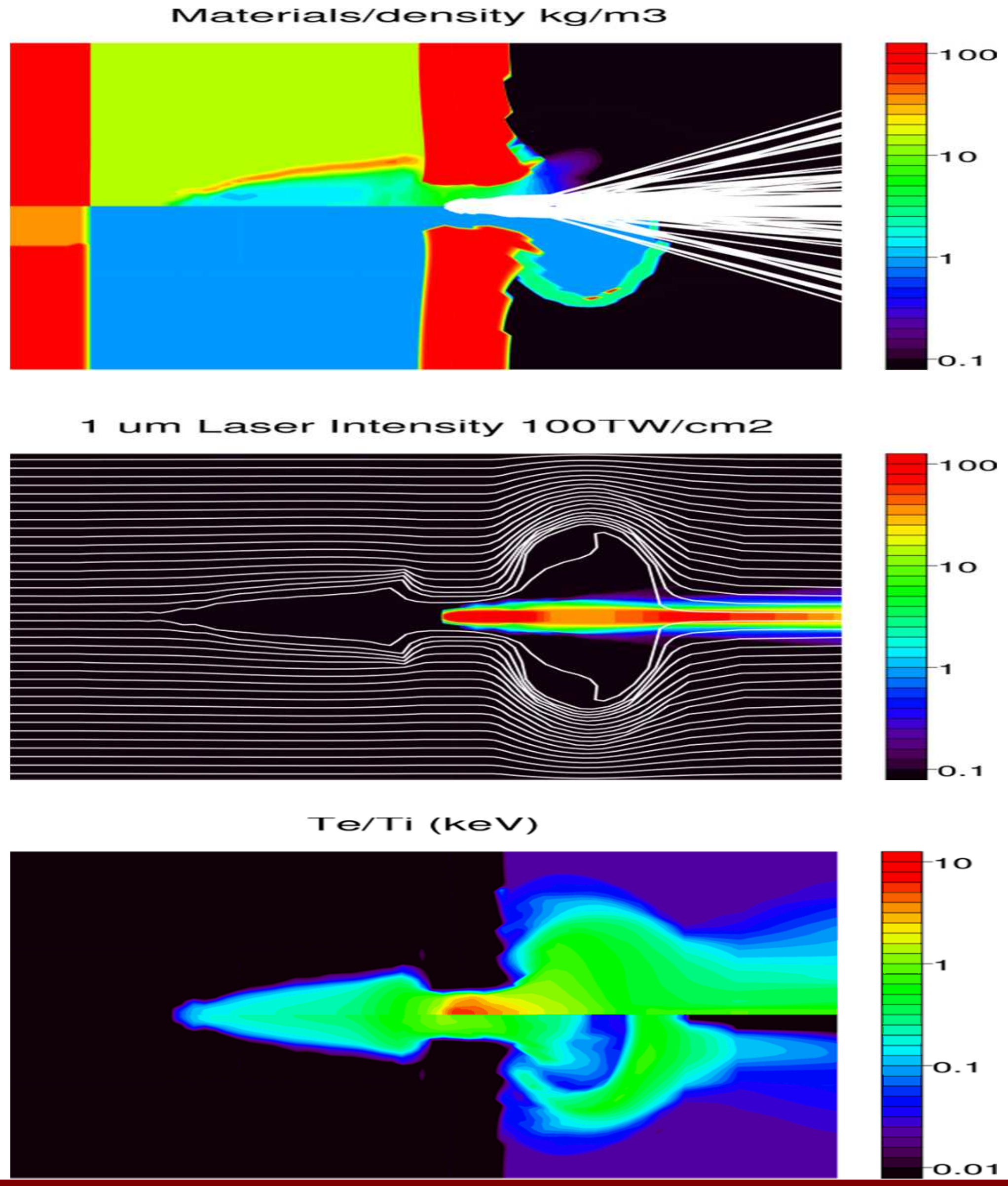
Laser off for 1 ns

Simulation of a laser heating experiment depositing 30 kJ in 1 cm of DT at 12 mg/cc



Energy deposition phase:
30 kJ of 1.0 um light

Simulation of a laser heating experiment depositing 30 kJ in 1 cm of DT at 12 mg/cc



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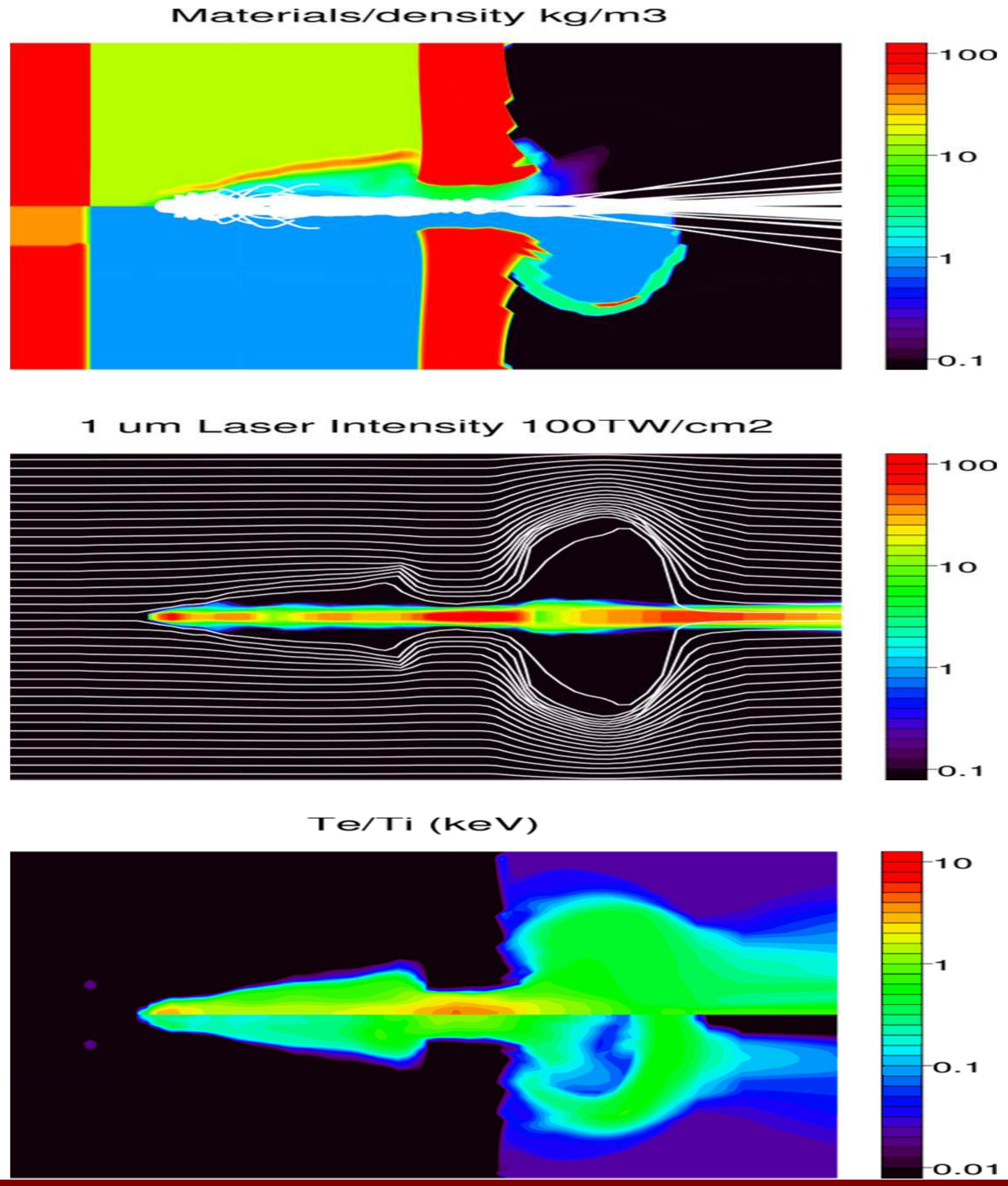

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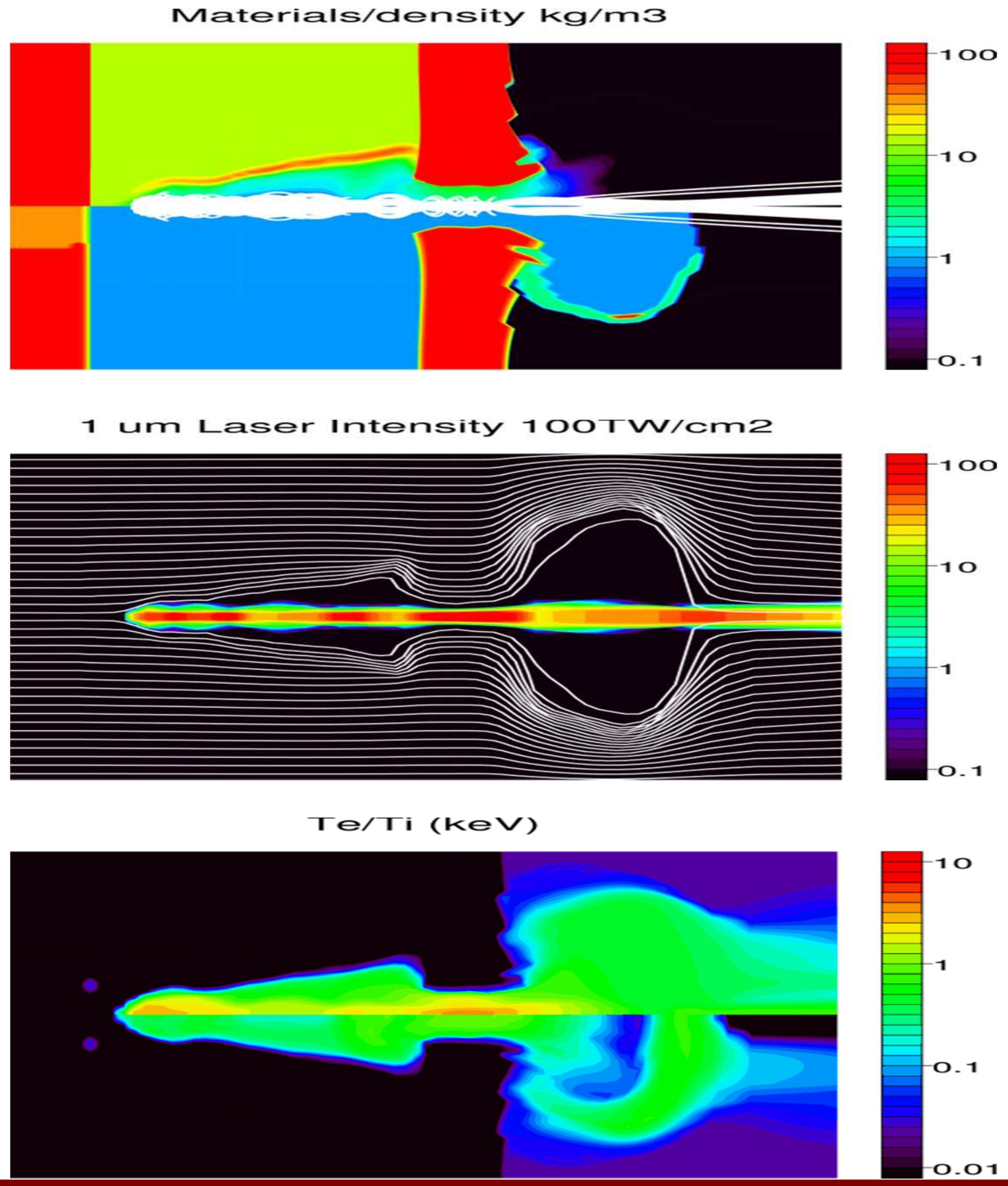

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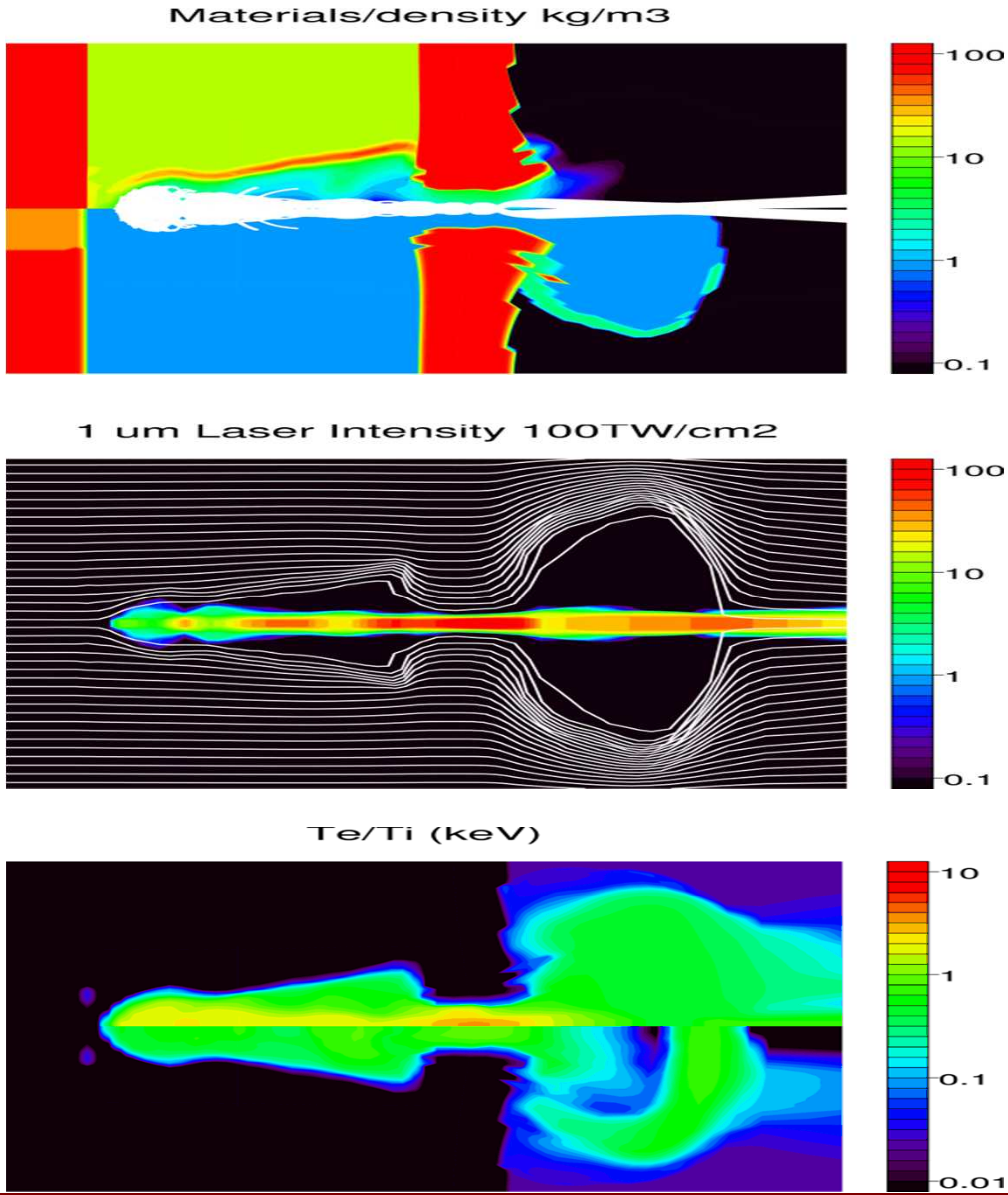

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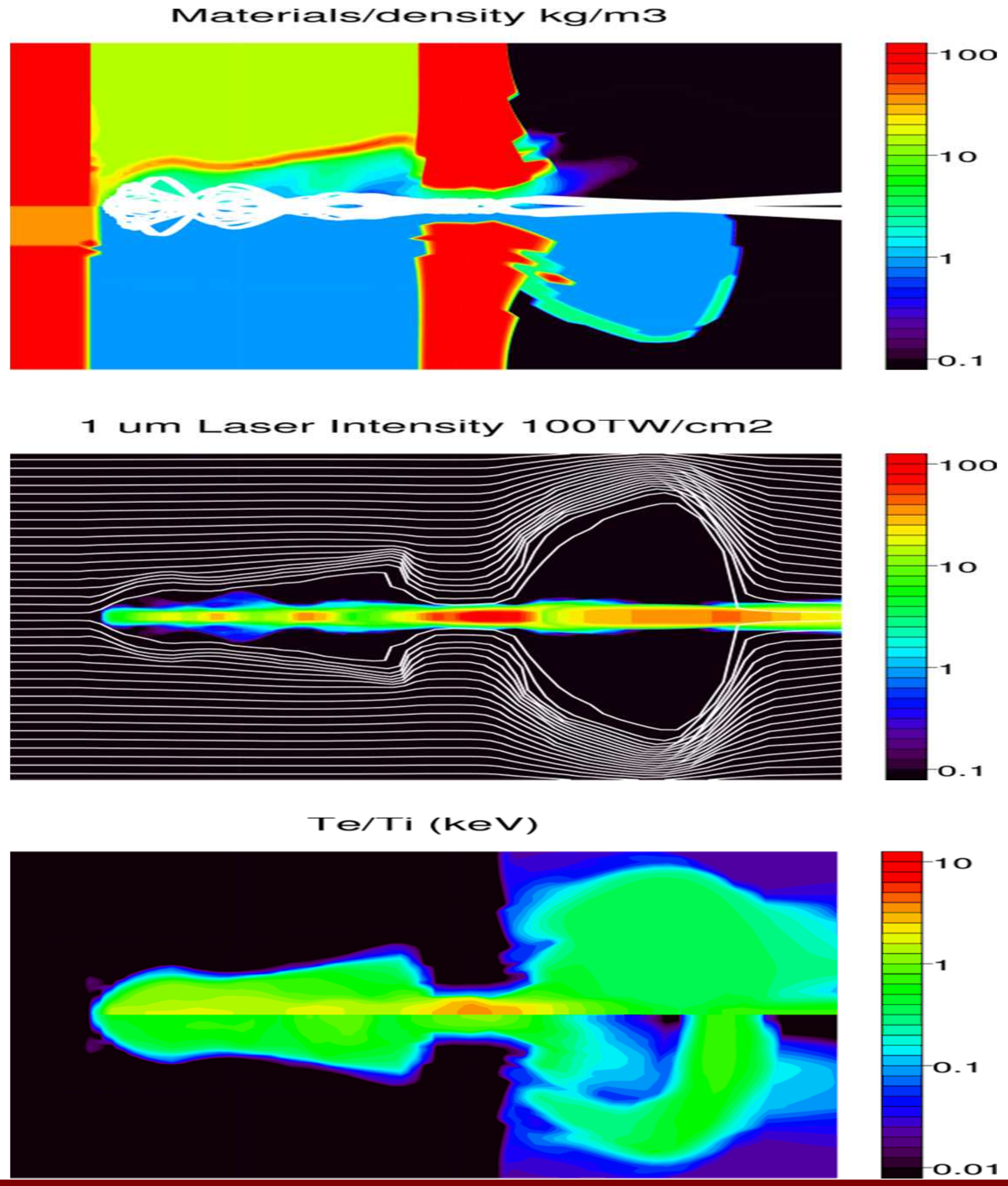

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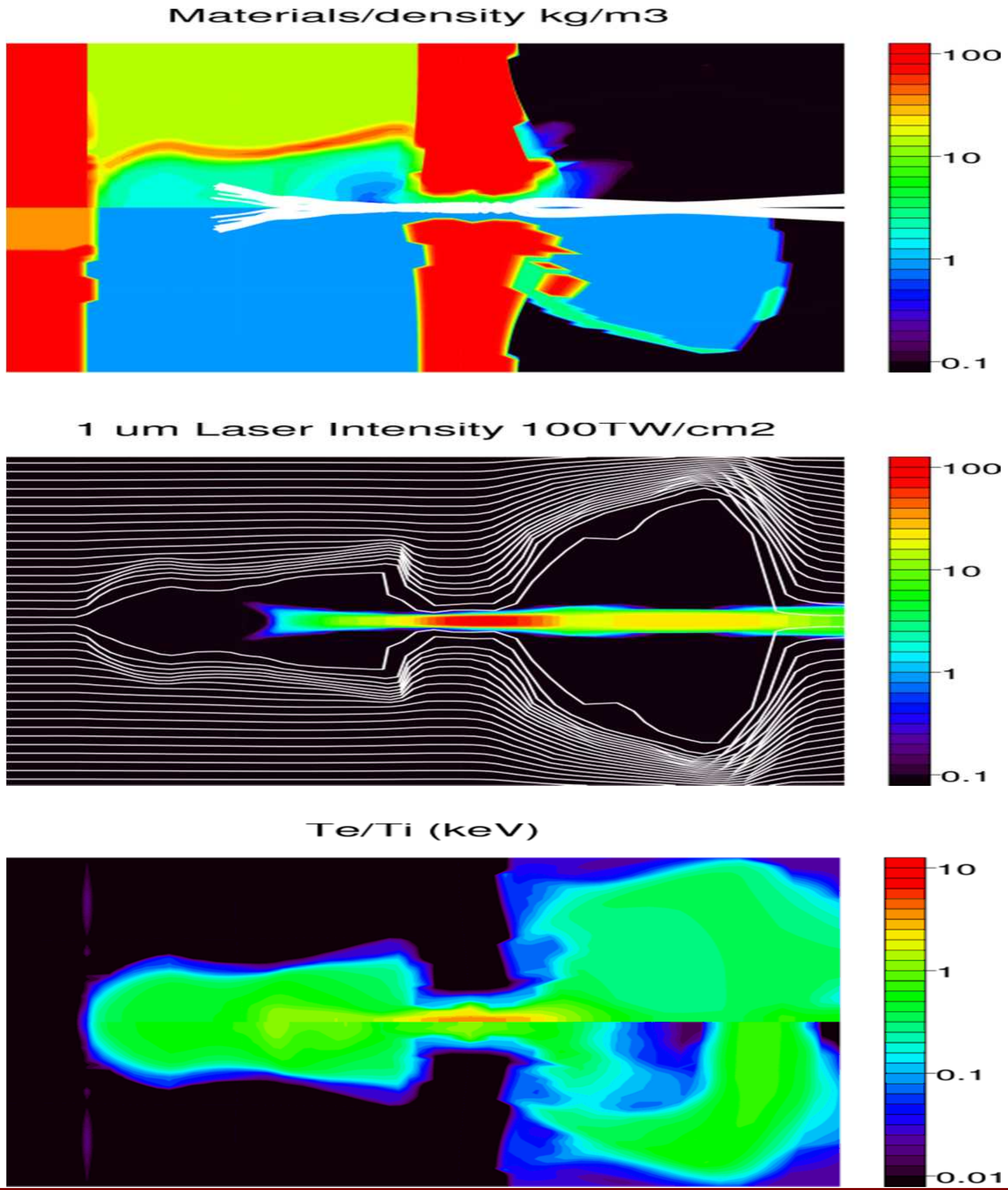

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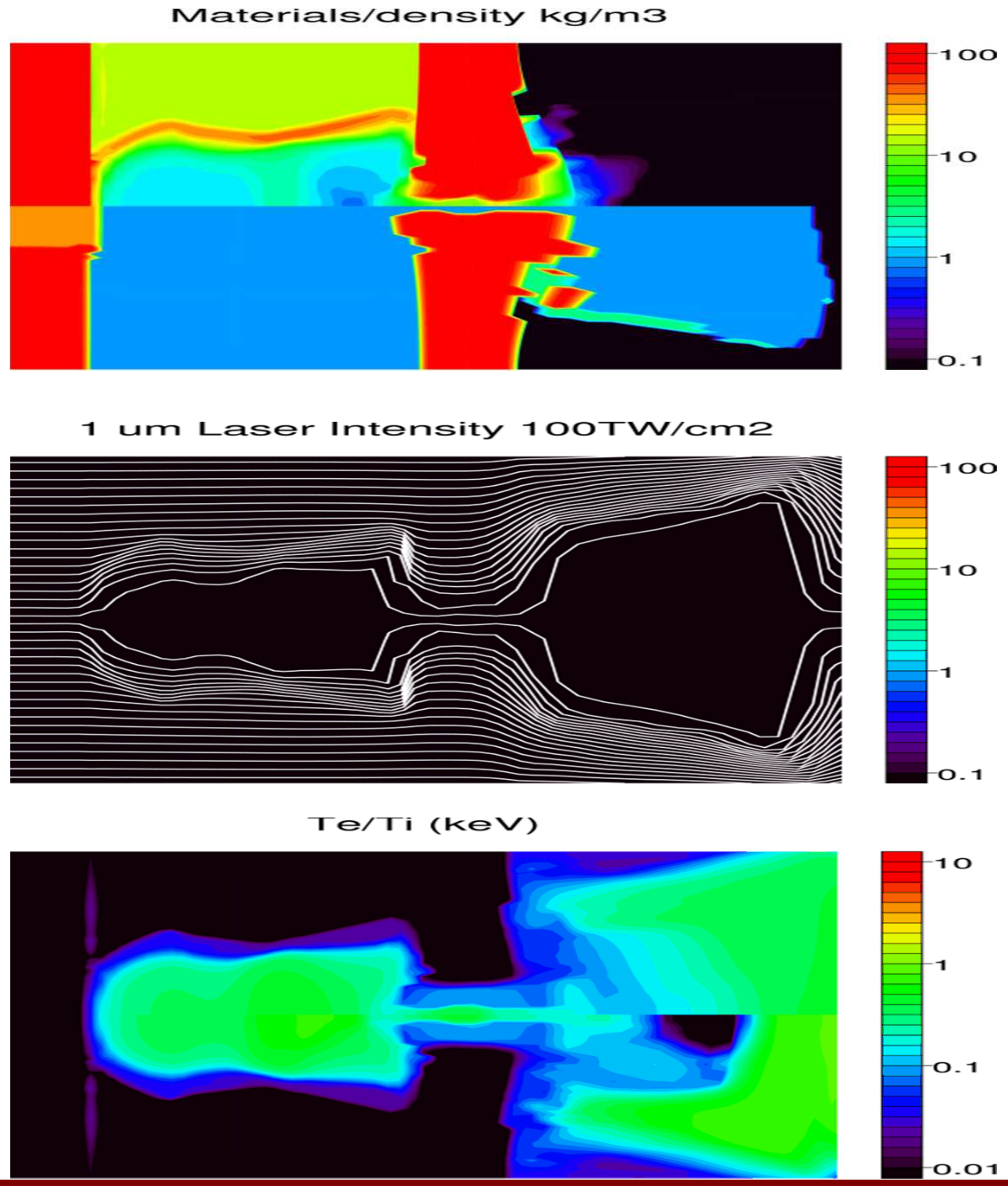

Energy deposition phase:
30 kJ of 1.0 um light

Large laser preheat energies (~30 kJ) are desirable for future MagLIF

Lasnex and Hydra simulations indicate that high gain and yields may be possible with MagLIF on a future accelerator, but substantial preheat energies are required

Analytic theory and simulations indicate that 30 kJ of laser light can be efficiently deposited within 1 cm of DT at densities appropriate for high yield MagLIF

Refraction, filamentation and LPI could pose problems. Consequently:

- We are now studying laser preheating with both Z Beamlet and Omega
- Before a future pulsed power machine is seriously considered, full scale laser deposition experiments could be performed using one quad of the NIF