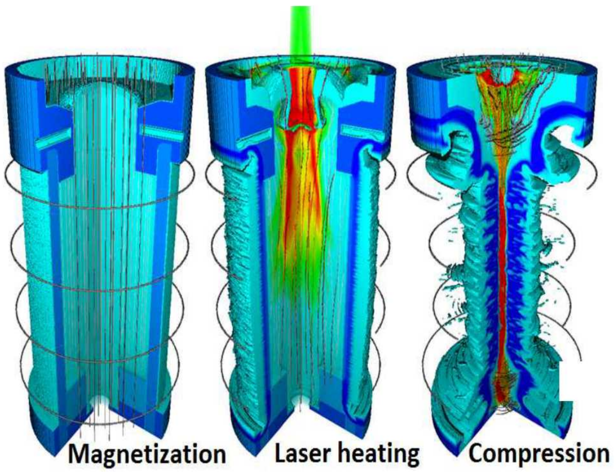
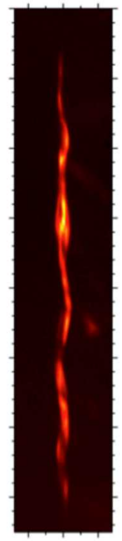
SAND2018-12518C

# Mitigating fuel mix for high performance MagLIF




X-ray image
Stagnated fuel



- experimental/simulated yield~0.5 for best shots
- Mix is the most likely cause of reduced yield
- Mitigation techniques are presented

**APS-DPP Meeting**

**Portland Oregon, November 9, 2018**

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***Sandia National Laboratories***

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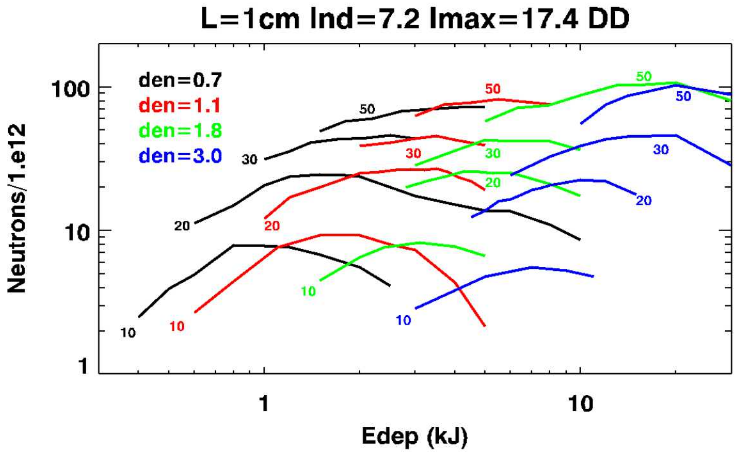
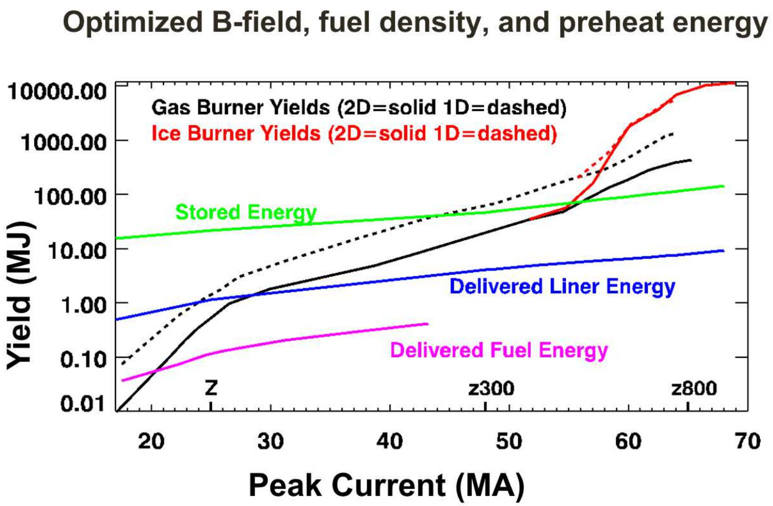
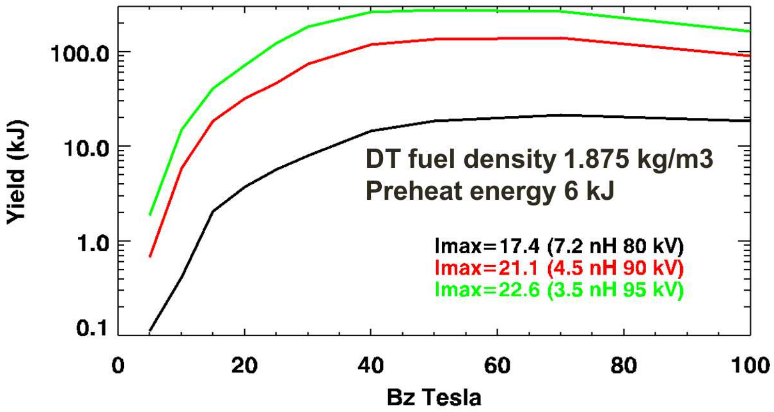
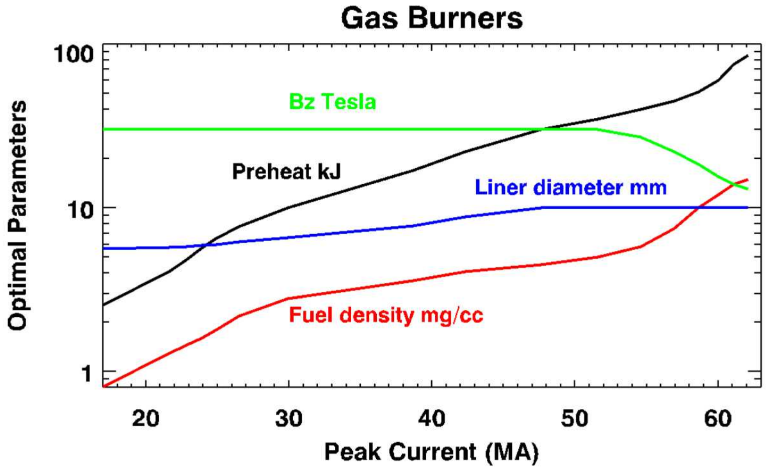
# Simulations predict favorable scaling of yield on Z and future machines[1]



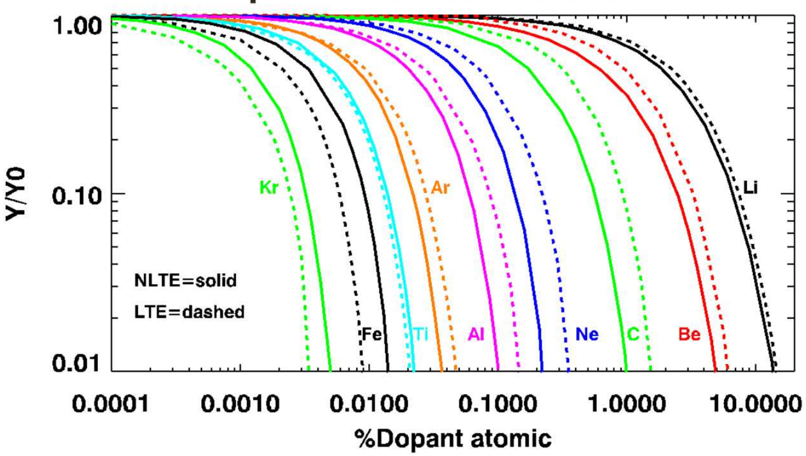



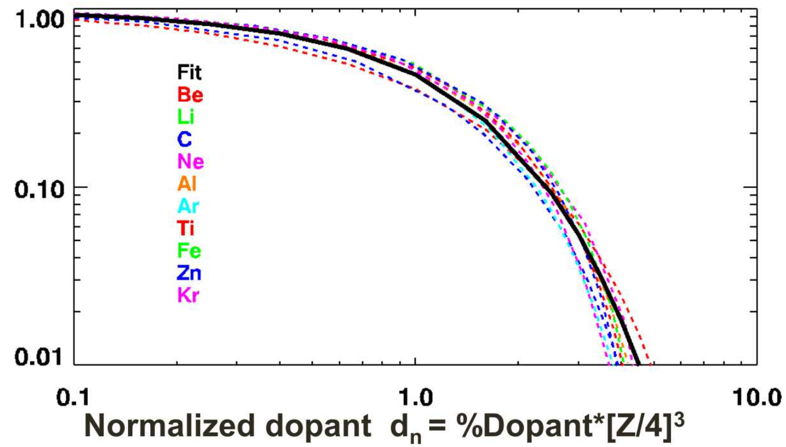

[1] S.A. Slutz et al. Phys. Plasmas 23, 022702 (2016)

# Lasnex simulations show mix can degrade MagLIF performance

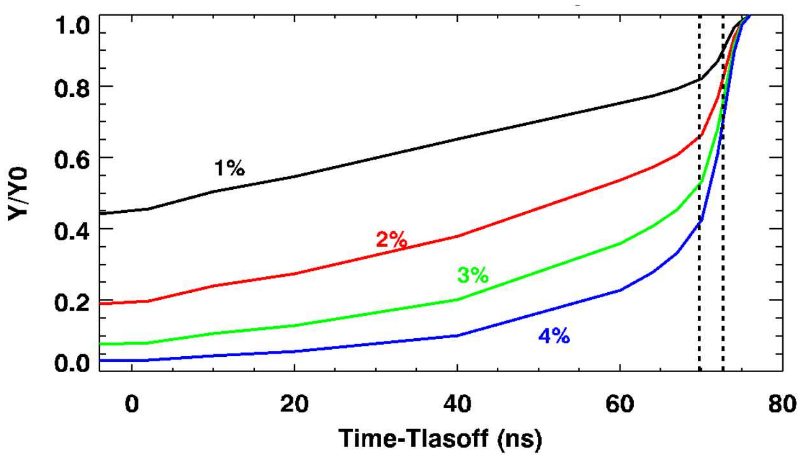
## Dopants introduced at t=0



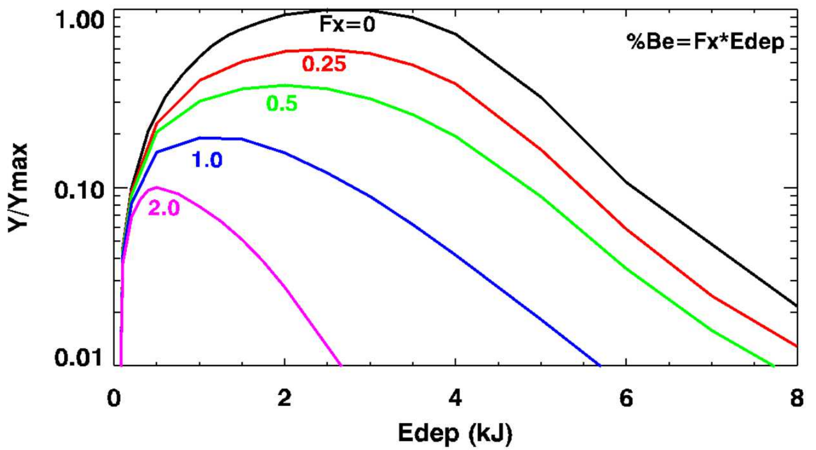

## Dopant effect scales as $Z^3$




## Effect of dopant vs when mix occurs




## Mix could depend on preheat



# Spectroscopic dopants indicate that the LEH window is pushed into the fuel

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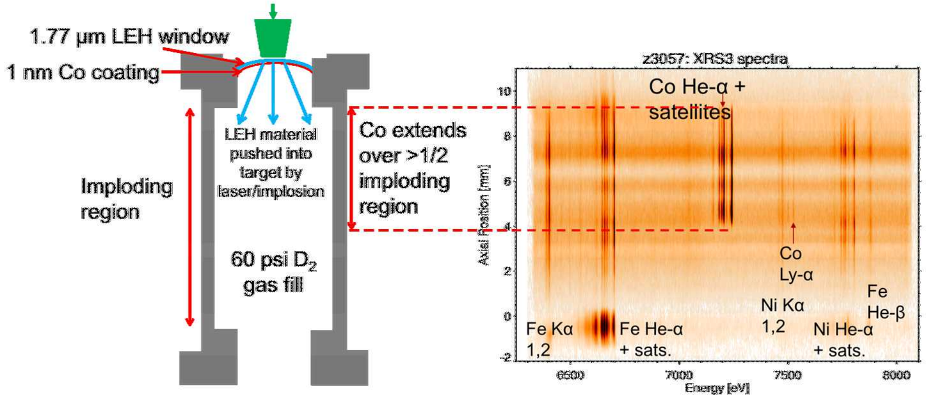
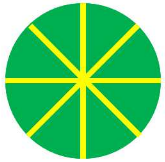



- Only observed in the upper half
- High apparent temperature indicates that it is mixed into the central fuel

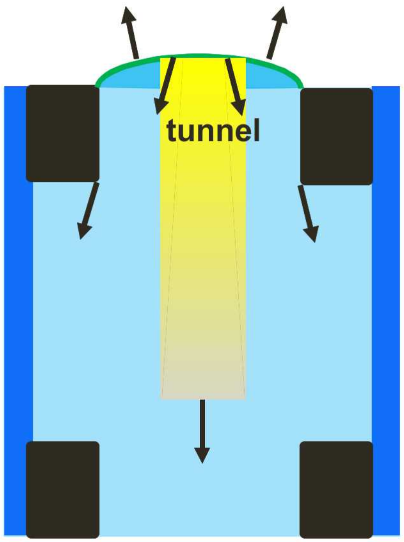
Top view

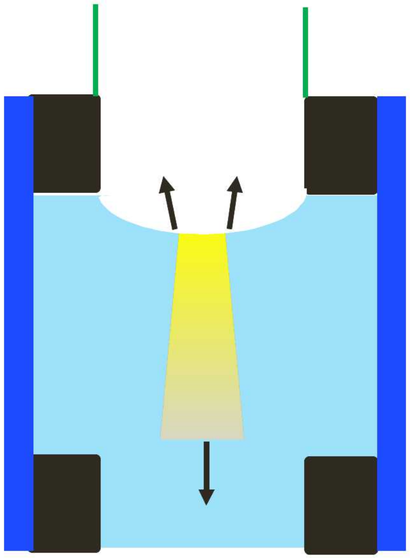


## Laser-gate could remove window and cushion mix

- LEH window foil is weaken by laser heating in an star pattern
- The fuel gas pressure breaks the foil and pushes it out of the main laser path
- A rarefaction wave propagates downward at ~1 mm/µs voiding the tunnel region.
- The laser then propagates with little absorption through the tunnel to only heat fuel within the liner

$$t = 1.810^{-6}\left(\frac{\Delta_{\mu} R_{LEH}}{\rho_{fuel}}\right)^{1/2}$$



# Experiments demonstrate that mix degrades the yield of MagLIF implosions

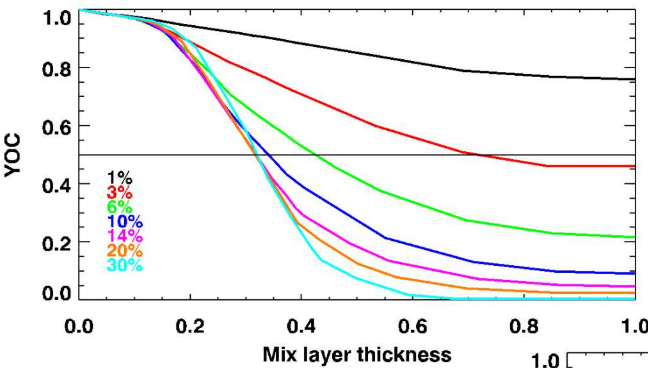
### Yields are degraded when aluminum rather than beryllium is used for the cushions

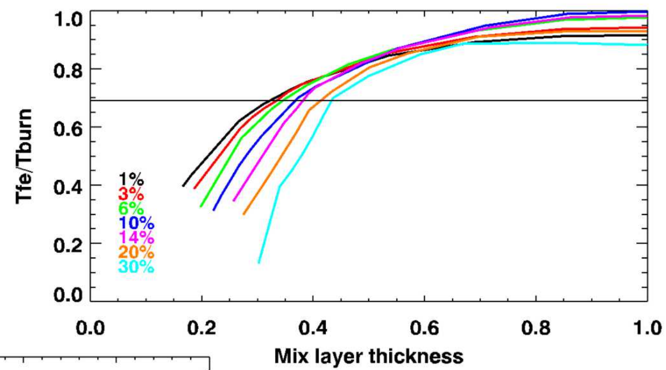
- material is being mixed into the fuel by blast wave or direct laser heating

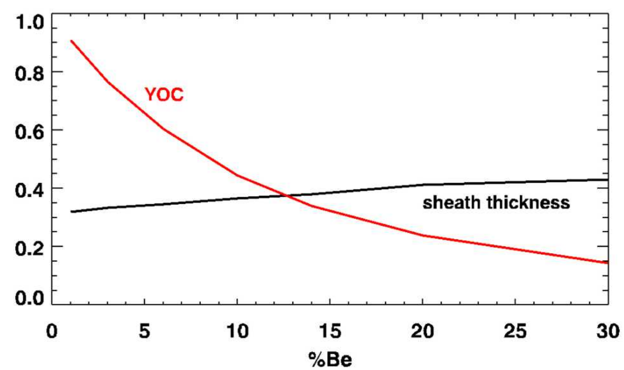
### Iron is observed spectroscopically in the stagnated fuel

- Iron is an impurity of known fraction in the liner material.
- The temperature is 70% of the burn temperature which implies it is not in the central part of the fuel
- The best experimental yields are about 50% of the simulated yields, i.e. YOC=0.5

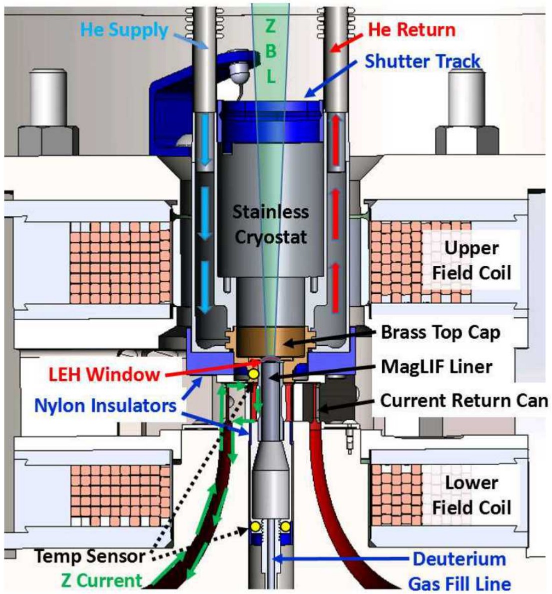
### Lasnex simulations with Be mix region ~1/3 of the fuel stagnation ratio are consistent with YOC and Fe spectra

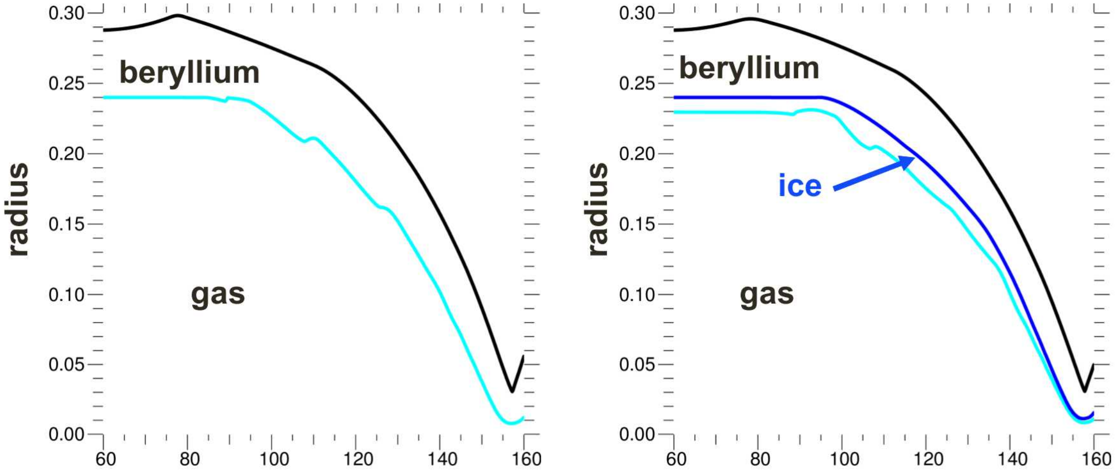


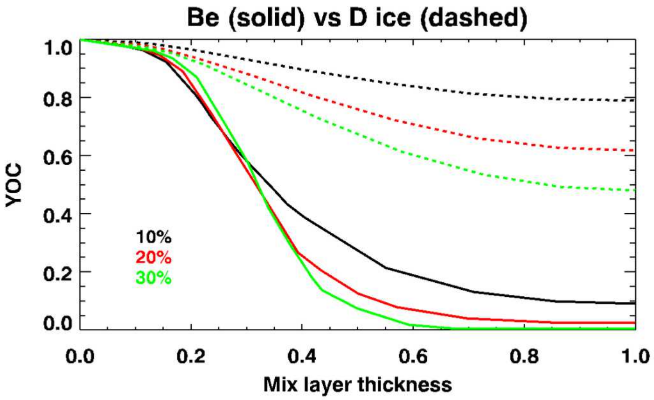



# The capability to operate MagLIF at cryogenic temperatures is being developed




- Higher fuel densities with low pressure and thin LEH window
- The inside layer of the liner and cushions could be coated with $D_2$/DT ice to mitigate mix
- Developing this capability would lead directly to high gain ice burning



# Vapor density of $D_2$/DT ice (0.3 mg/cc) is not sufficient for MagLIF operation

**Gas densities 1-10 mg/cc are required for MagLIF**

- the optimal fuel density increases with current
- the convergence ratio decreases with fuel density
- ice burning targets require ~ 5 mg/cc

**A plume of gas can be generated by laser heating an ice pond at the bottom of the target**

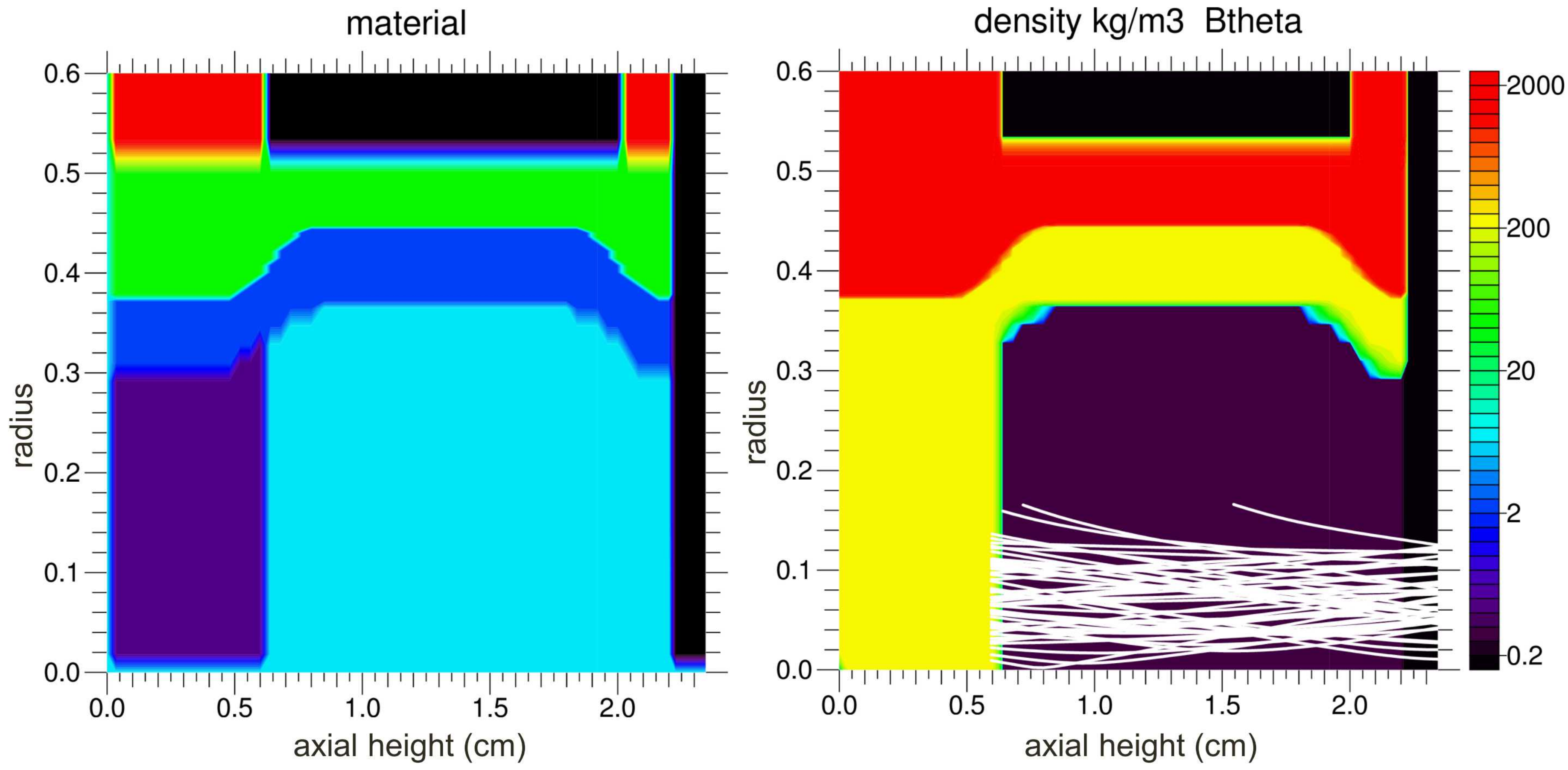
- no laser entrance hole (LEH) foil required
- gas density is nonuniform, which could disrupt implosion symmetry

**Gas can be injected from a reservoir at the bottom of the target**

- the warm gas will melt the ice layer
- due to gravity, melted ice will fall ~ 1 μm in 450 μsec
- a fast opening valve and an LEH foil are required
- an axially uniform fuel density can be produced
- nichrome wire heating ¾ perimeter of a square foil would open in ~ 10 μsec "wiregate"

# 2D simulation of ice burner MagLIF using a laser heated pond
# Elas1=1 kJ Elas2=30 kJ $I_{peak}$=64 MA Yield =4.5 GJ

time= 1 ns  end of 1st laser pulse



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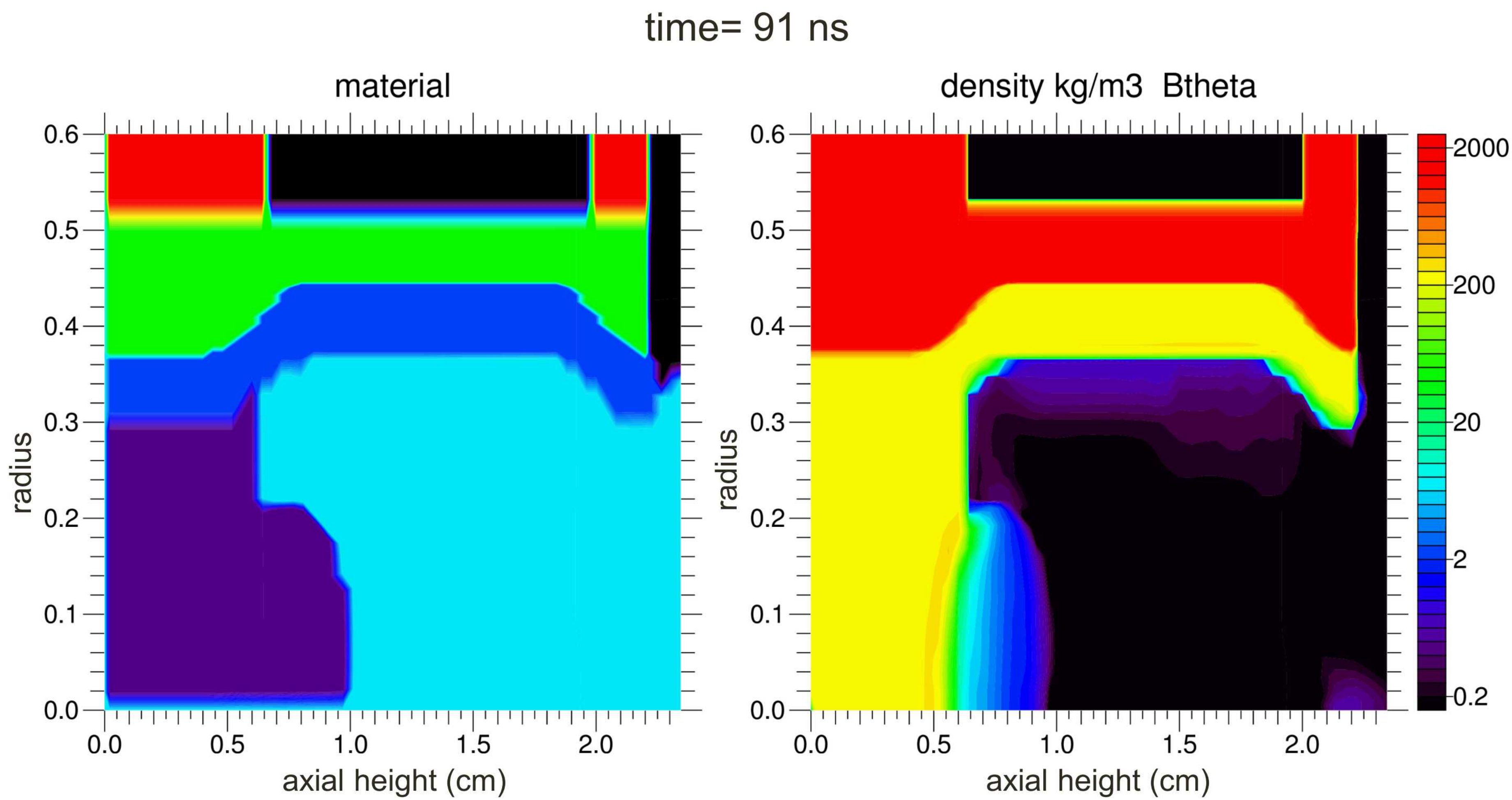

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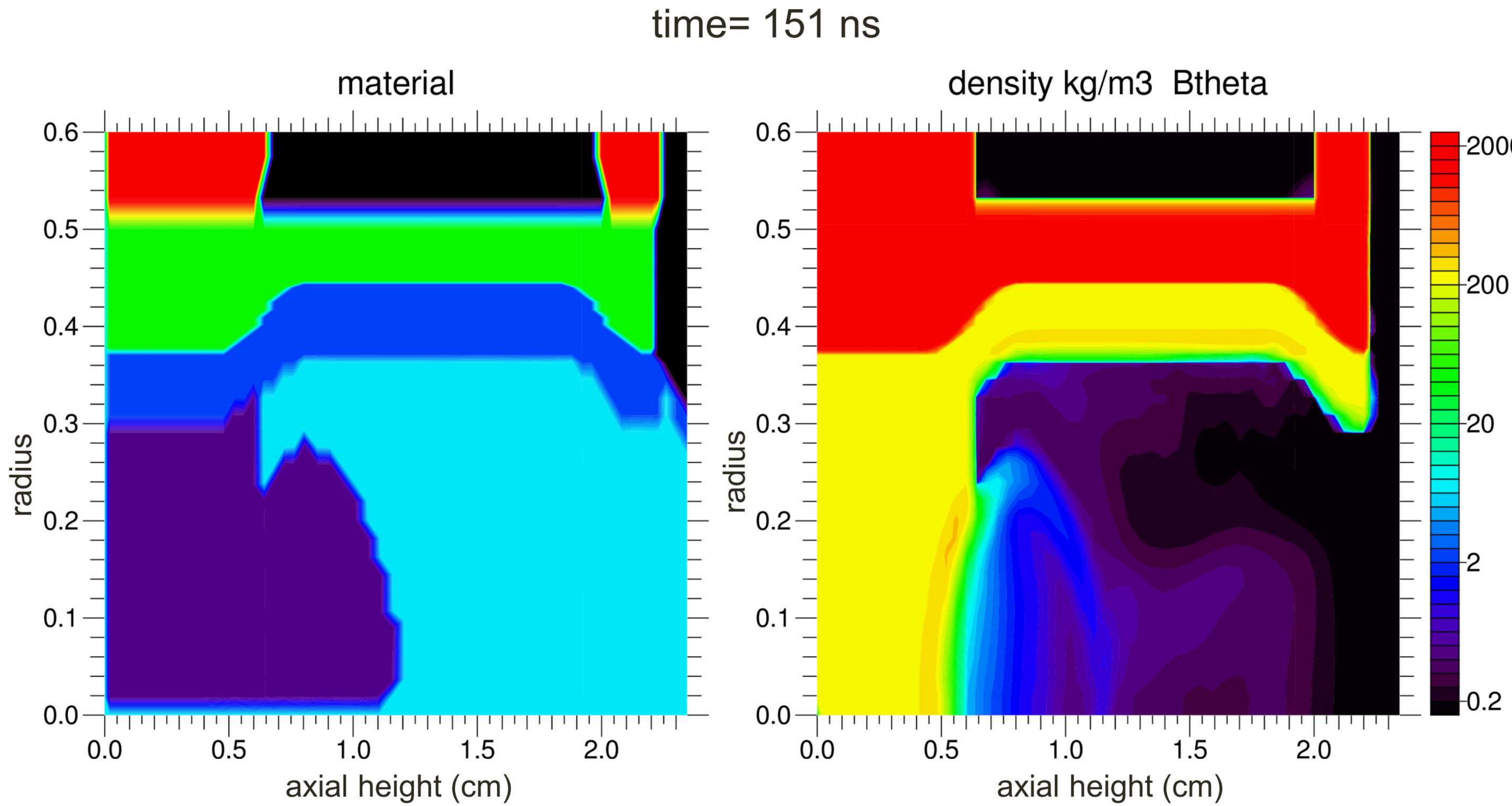
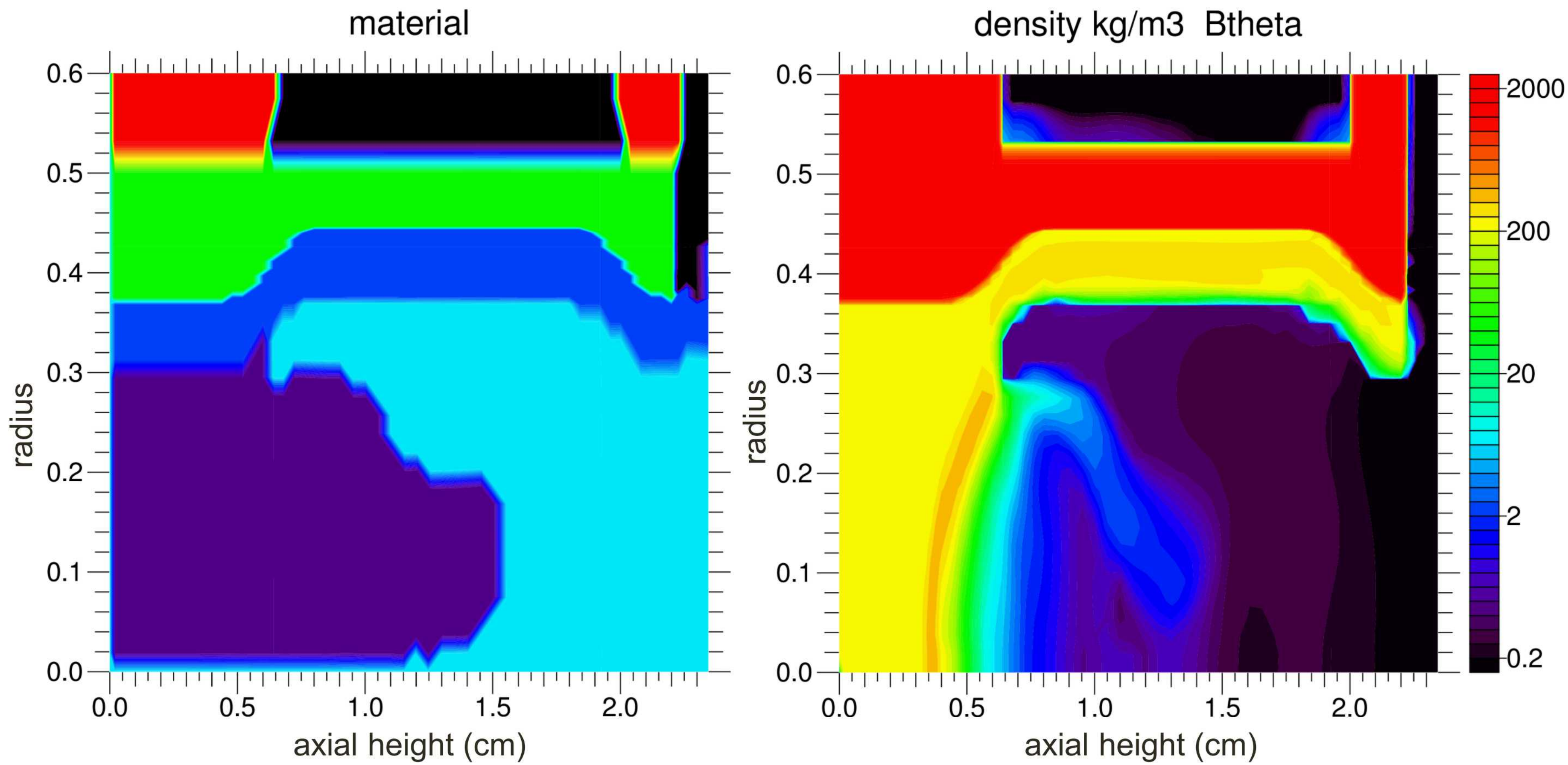


# 2D simulation of ice burner MagLIF using a laser heated pond
# Elas1=1 kJ Elas2=30 kJ $I_{peak}$=64 MA Yield =4.5 GJ

time= 348 ns



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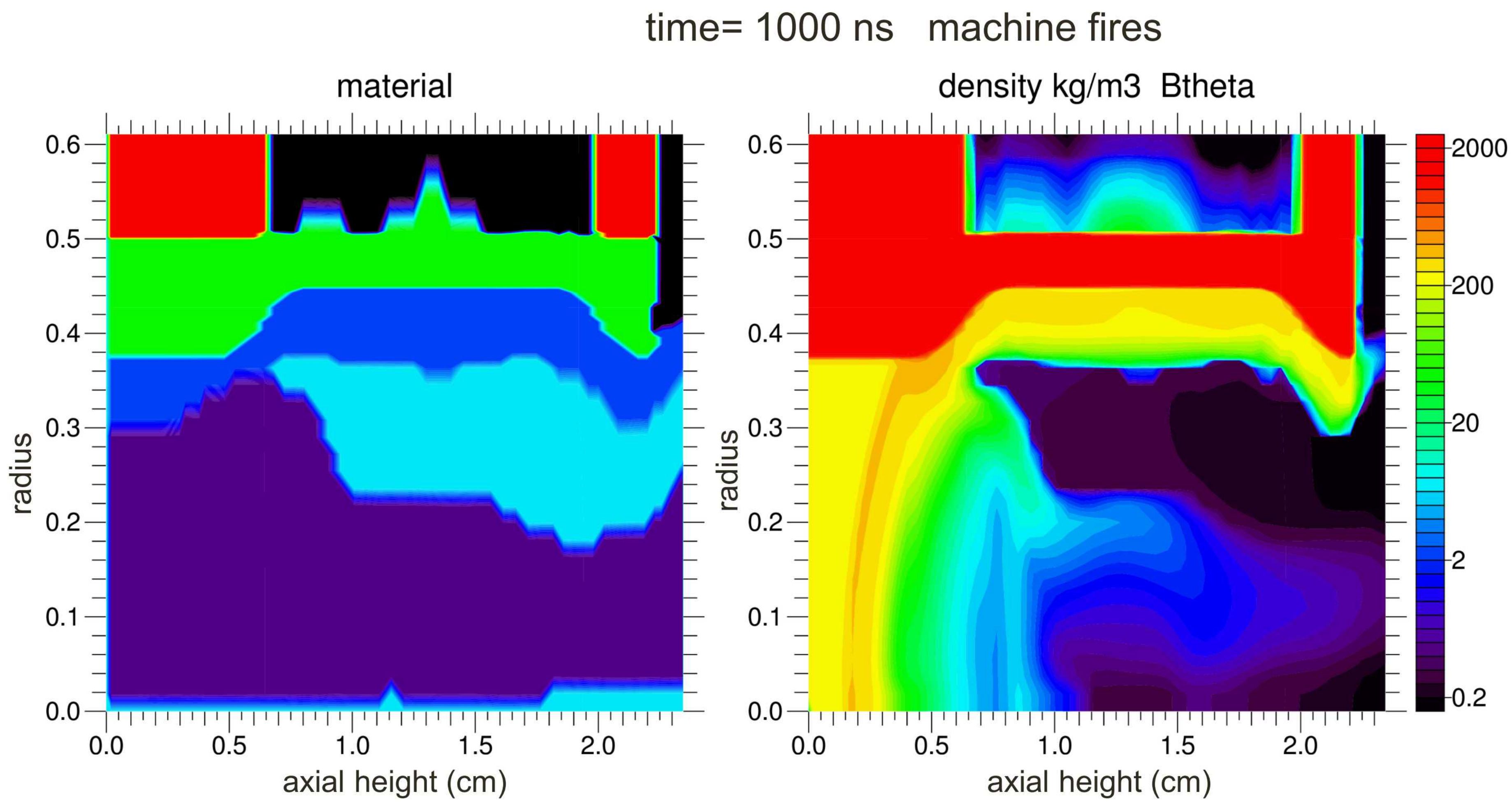

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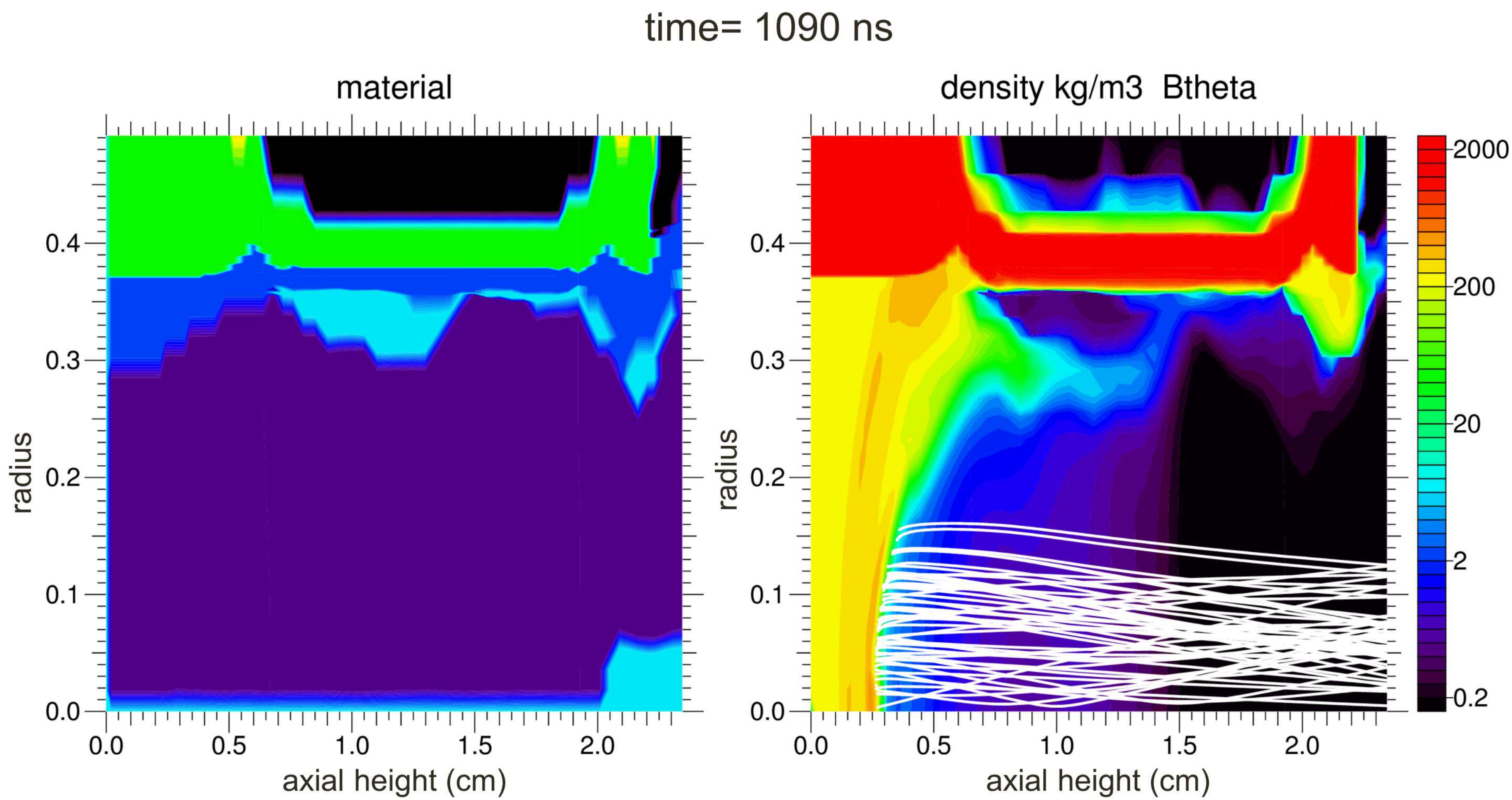

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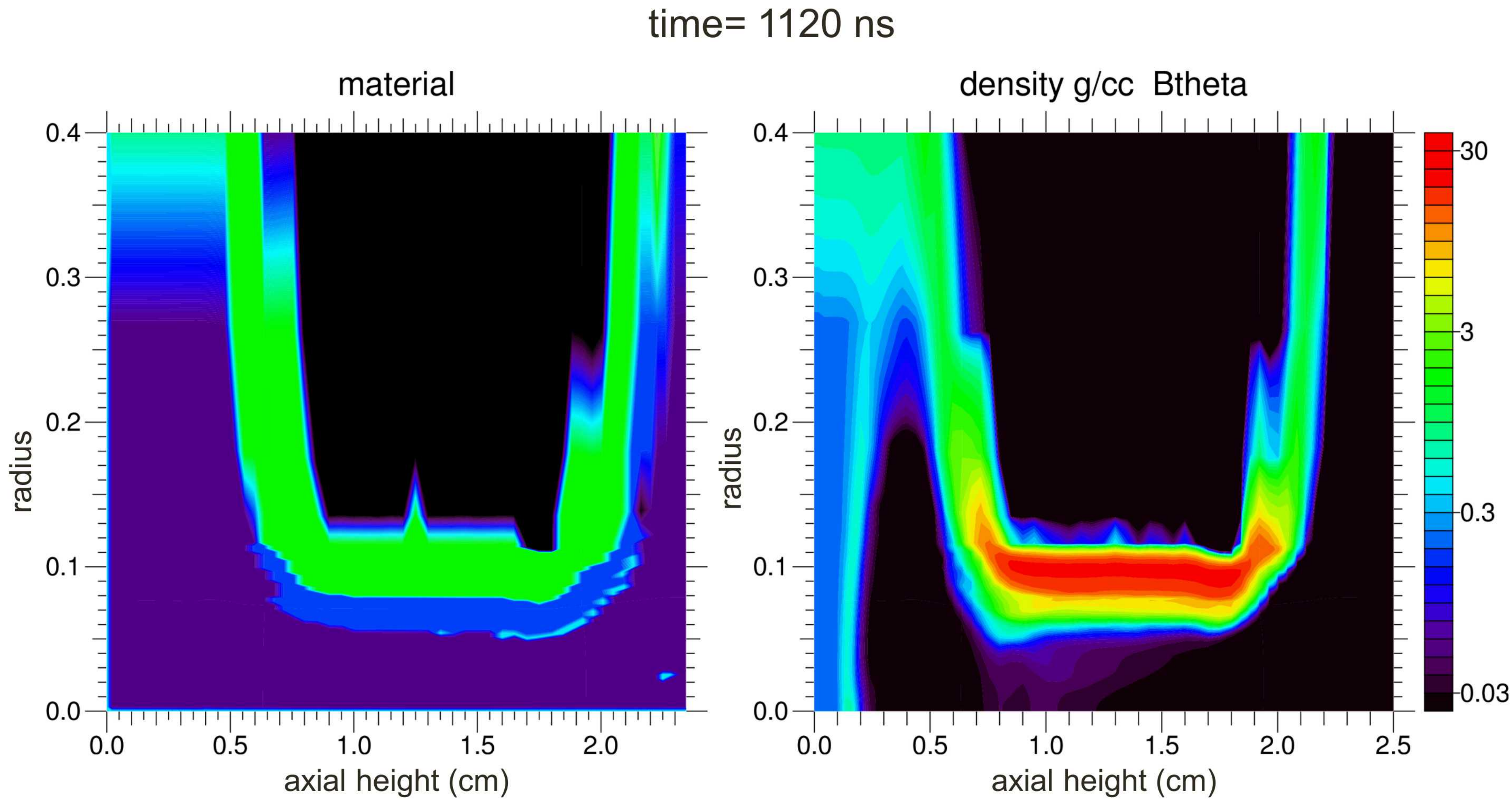

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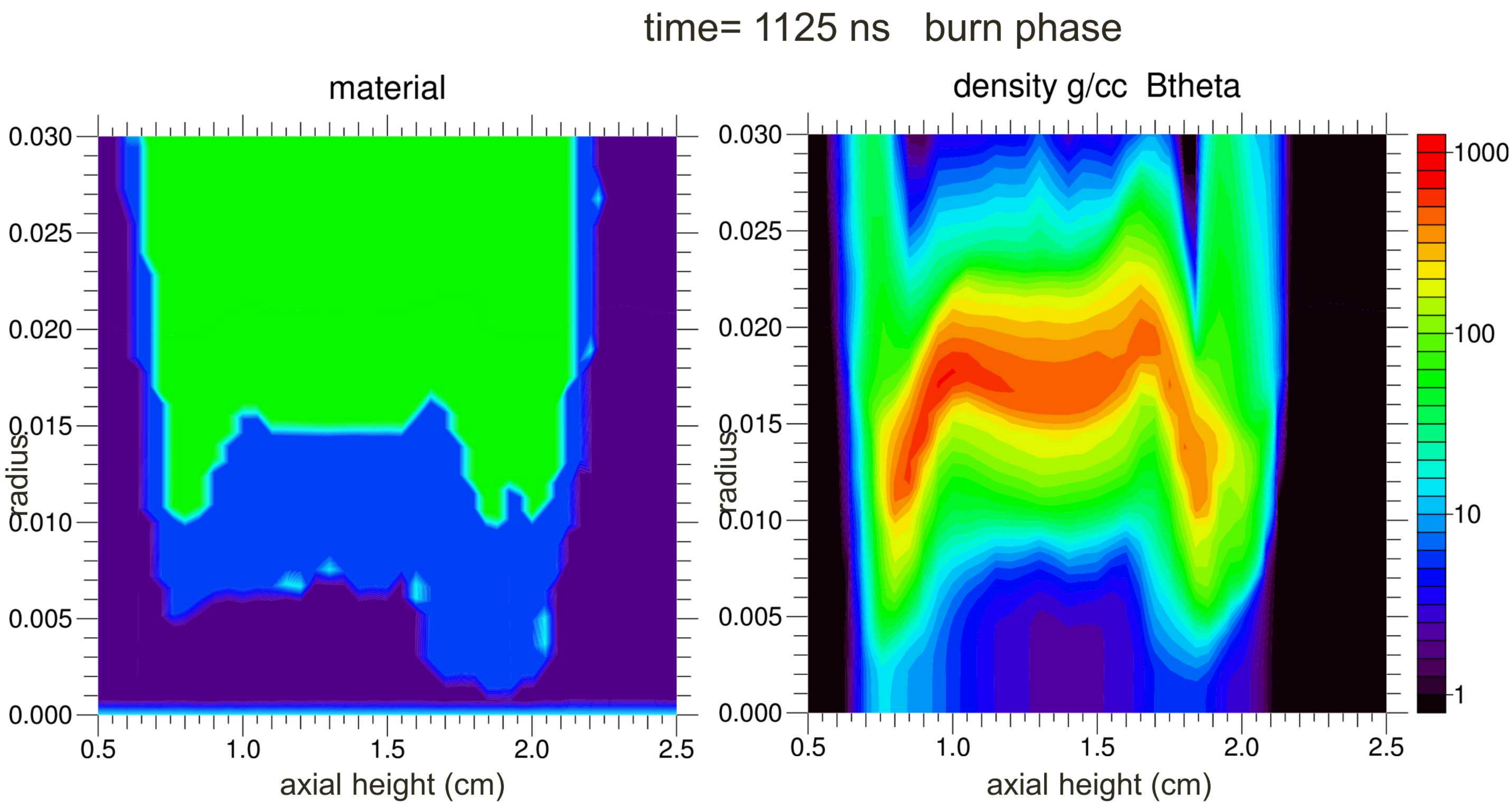

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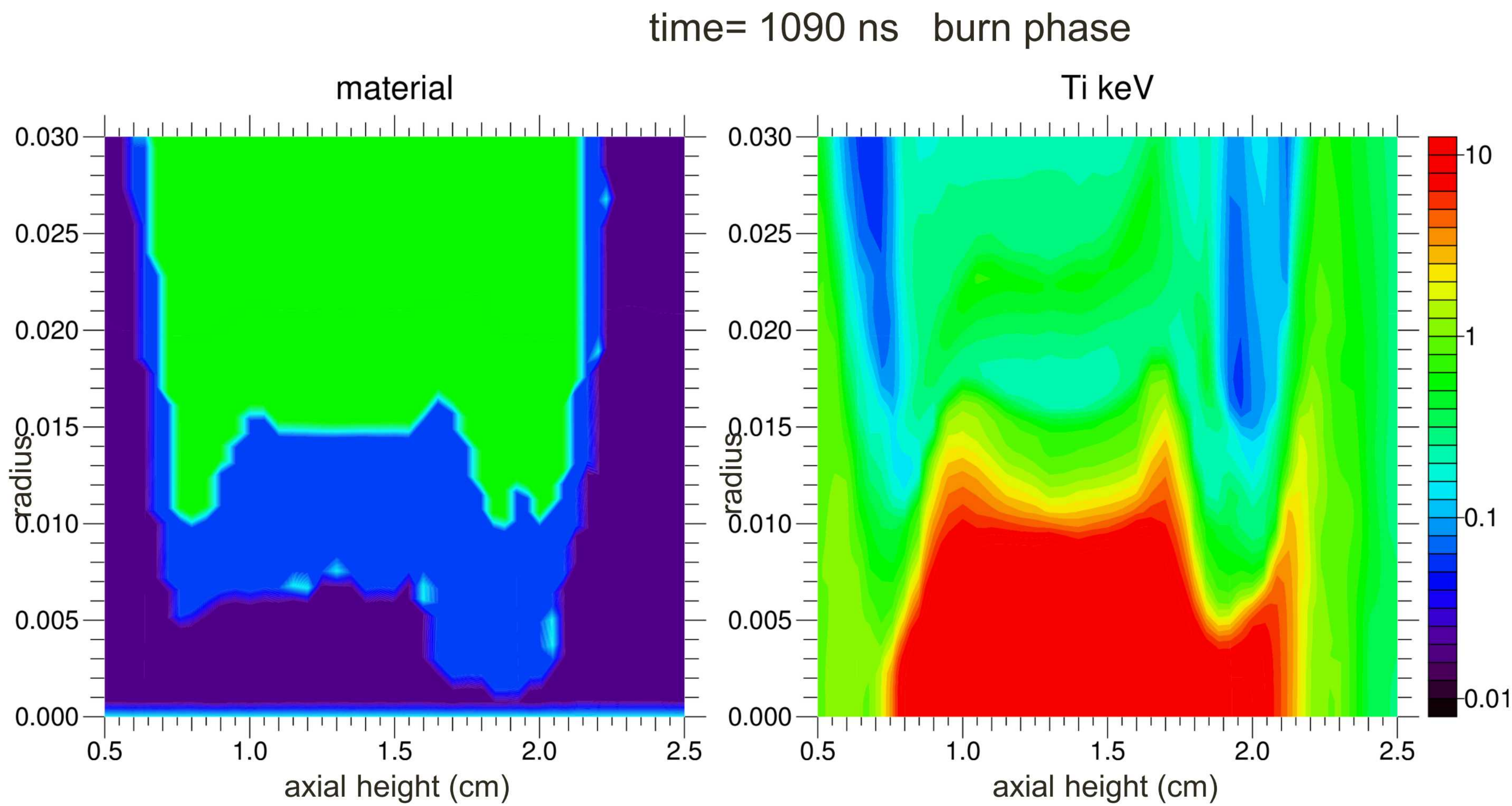



Will nature be as kind to a non-uniform stagnation as this simulation?

# Summary

**Simulations without mix indicate MagLIF yields can be substantially improved**

- Ten-fold increase on Z with increased B-field, fuel density and preheat and modest increase in drive current (18-22 MA)
- Large yields (> 1GJ) and large gains (>1000) at currents above 60 MA

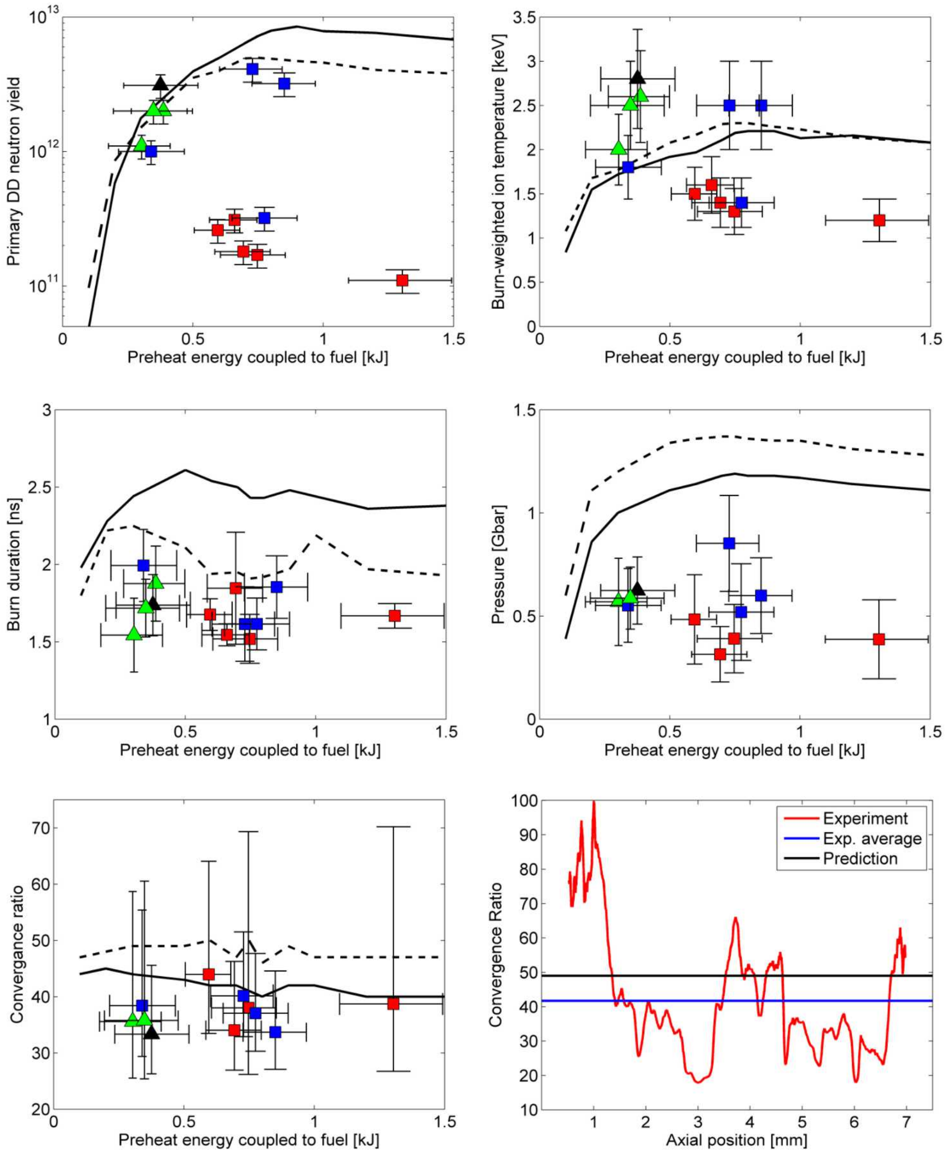
**We have strategies to mitigate the effect of mix**

- laser gate can remove mix from the LEH foil
- very thin LEH foils are possible at lower gas temperatures
- a $D_2$/DT ice layer can separate the metal liner from the fuel

**Ice layered MagLIF liners require gas fill after formation**

- laser heated ice pond
- gas injection from a reservoir

# Simulated MagLIF performance parameters are in reasonable agreement with experiments




**Z Beamlet produces 2 kJ of 0.53 mm light**

- **Only ~ 300-1400 Joules is deposited in the fuel[1]**
- **Peak current 17.4 MA**

**DD/DT=> BR~0.4 MG-cm**

- Tritons are magnetically trapped
- Tritons good surrogate for alpha particles
- Bz*r increases with convergence

**Mix can lower the yield**

- **Both window and cushion material mix have been observed spectroscopically**
- **Beryllium mix of several percent atomic inferred spectroscopically from iron impurity in liner material**
- **Unless controlled, increasing the laser preheat energy could increase mix**



[1]M. Geissel et al., Phys. Plasmas 25, 022706 (2018)