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Kinetic simulations of burn propagation

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Accurate modeling of burn propagation in inertial confinement fusion plasmas is essential for advancing fusion energy research. This work presents recent enhancements to the collisional and radiative particle-in-cell code TriForce that enable 1D spherical simulations of burn propagation in advanced inertial confinement fusion targets including the aneutronic fuel proton–boron-11 ($p^{11}B$).[1] We demonstrate the numerical model accurately captures the dynamics of hot-spot expansion and burn propagation in isochoric deuterium–tritium (DT) assemblies. Consistent with theoretical models, our simulations show sensitivity to the ignition threshold; however, our kinetic results show the ignition cliff to be less steep compared to radiation-hydrodynamics modeling highlighting the importance of kinetic effects in burning plasmas. Next, we apply the model to pre-assembled $p^{11}B$ configurations to identify a burning regime capable of achieving gain. While results suggest that the hot-spot conditions necessary to achieve thermonuclear burn propagation in pure $p^{11}B$ assemblies are presently impractical, determining means to leverage aneutronic fusion will greatly enhance the viability of future inertial fusion energy power plants.[2,3]

In this study we share results for advanced mixed-fuel configurations that relax the hot-spot conditions for ignition while minimizing neutron production by using a central DT hot spot that serves as a sparkplug for igniting surrounding cold $p^{11}B$ fuel. We consider different configurations such as the case shown in Figure 1 that illustrates an isochoric mixture with a DT sparkplug and cold DT and $p^{11}B$ layers. At 20 ps while the plasma is still burning, the 0.48 MJ target (including thermal energy in the hot-spot and Fermi energy of the degenerate electrons in the cold fuel) has a fuel gain of ~50. Using the numerical tools for collisional and radiative processes advanced and demonstrated in this study, we will continue to explore advanced targets in pursuit of viable pathways towards inertial fusion energy.

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References

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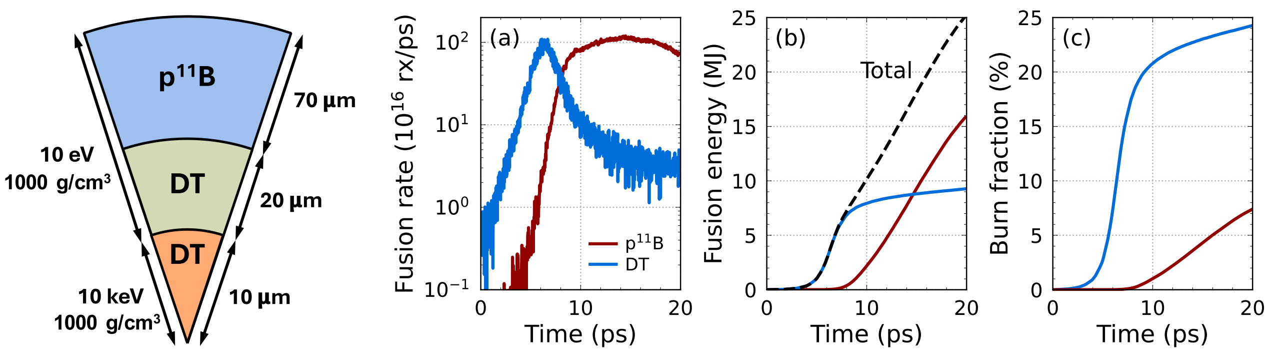

Figure 1. (Left) A schematic of a pre-assembled isochoric inertial confinement fusion target including a DT ignitor surrounded by cold layers of DT and $p^{11}B$. (Right) Energy metrics from a 1D spherical simulation of the burning target including (a) fusion rate, (b) fusion energy, and (c) burn fraction. Results predict a fuel gain greater than 50.