

Simulation of Burn Wave Propagation on Two Dimensional Distorted Meshes

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Abstract

Distorted meshes are often formed at the stagnation phase of direct drive ignition target simulations when using 2-D Lagrangian hydrodynamics codes. A comparison of the subsequent burn propagation through the distorted mesh using both Monte Carlo charged particle tracking and multi-group flux-limited diffusion will be presented. Diffusion theory has limitations in the accurate treatment of the long mean free path charged particle transport and the effects of mesh distortion on burn front uniformity computed using finite difference methods. Monte Carlo has limitations related to statistical noise effects on the burn front and the increasing computational cost to reduce this noise. Simulations will be compared for various L-mode perturbations in laser uniformity for a NIF polar direct drive target.



Energy Deposition in the Two Models

Diffusion:

Energy deposition rate by the mean value approximation:

$$\dot{E}_{dep}^i = A t_E \frac{N_g}{\tau_g} \frac{E_{g+1} - E_g}{E_g^{3/2} + A t_E} \quad \dot{E}_{dep}^e = \frac{N_g}{\tau_g} (E_{g+1} - E_g) - \dot{E}_{dep}^i$$

Monte Carlo:

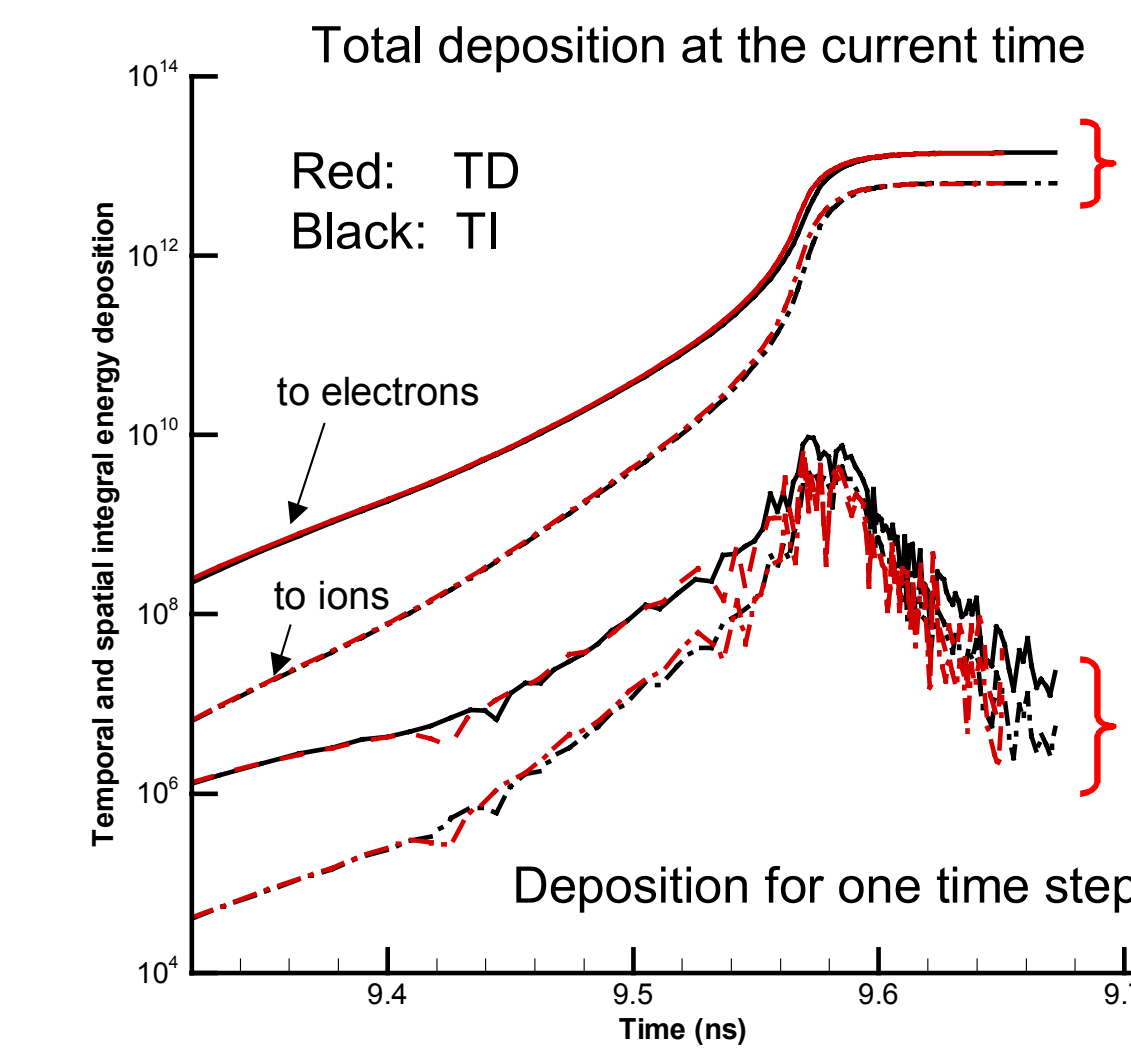
Assuming the stopping power is constant for a small traveling distance ΔS , the final energy becomes

$$E = E_i - \frac{dE}{ds} \Delta S$$

The traveling time is $\tau = \frac{2}{3} \frac{1}{v_e} \ln \frac{v_e^2 E^{3/2} + A_i}{v_e^2 E_i^{3/2} + A_i}$



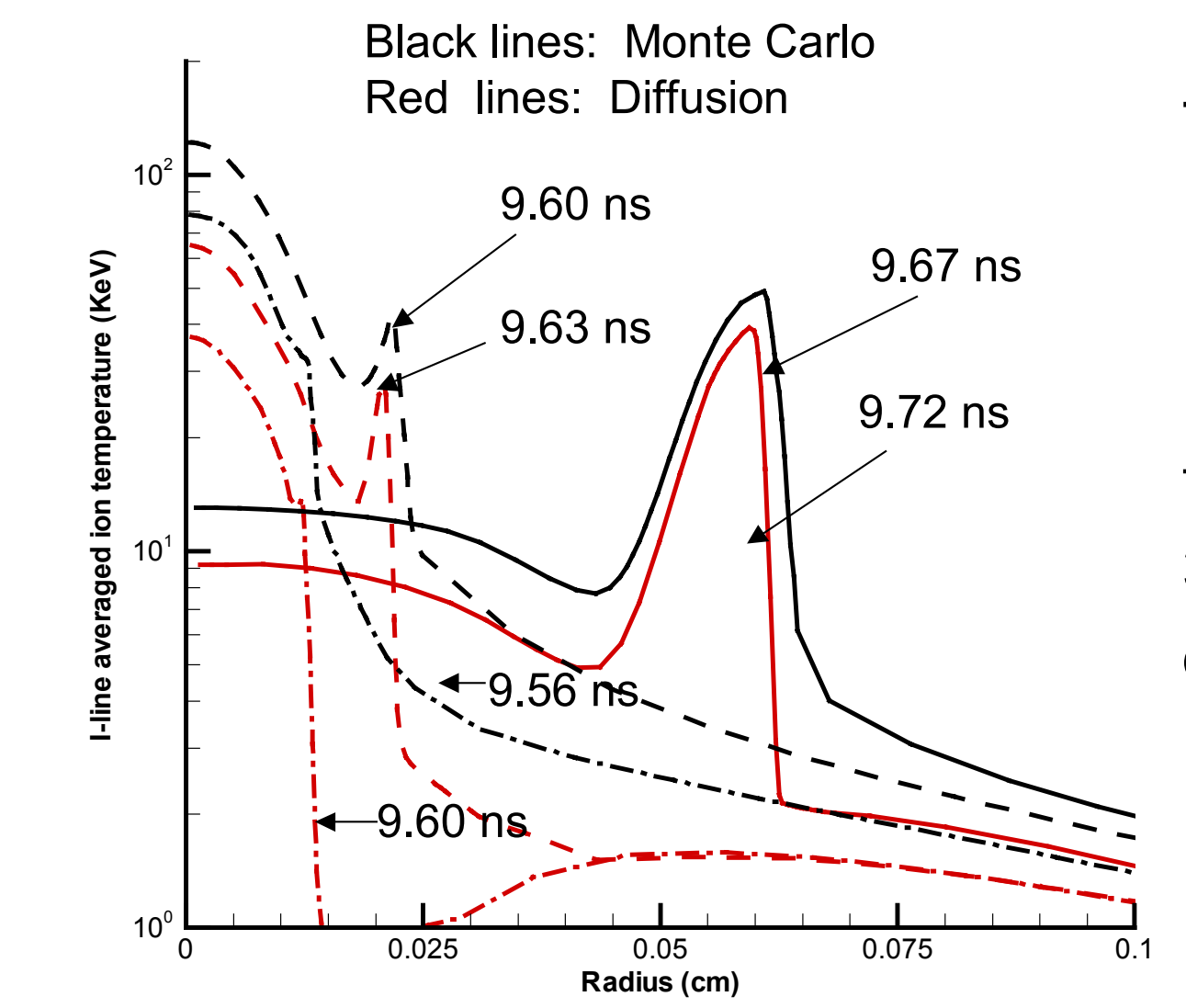
MC Time Dependent and Independent Tracking



In the hydro-time dependent method, the hydro time step acts as a clock for particles to march, while in the independent method the particles deposit all their energies in the current time interval. The results are similar.



Burn Wave Propagation Time Matching



This figure clearly illustrates that the Monte Carlo method predicts the starting time of ignition about 30 ps earlier than the diffusion method predicts.



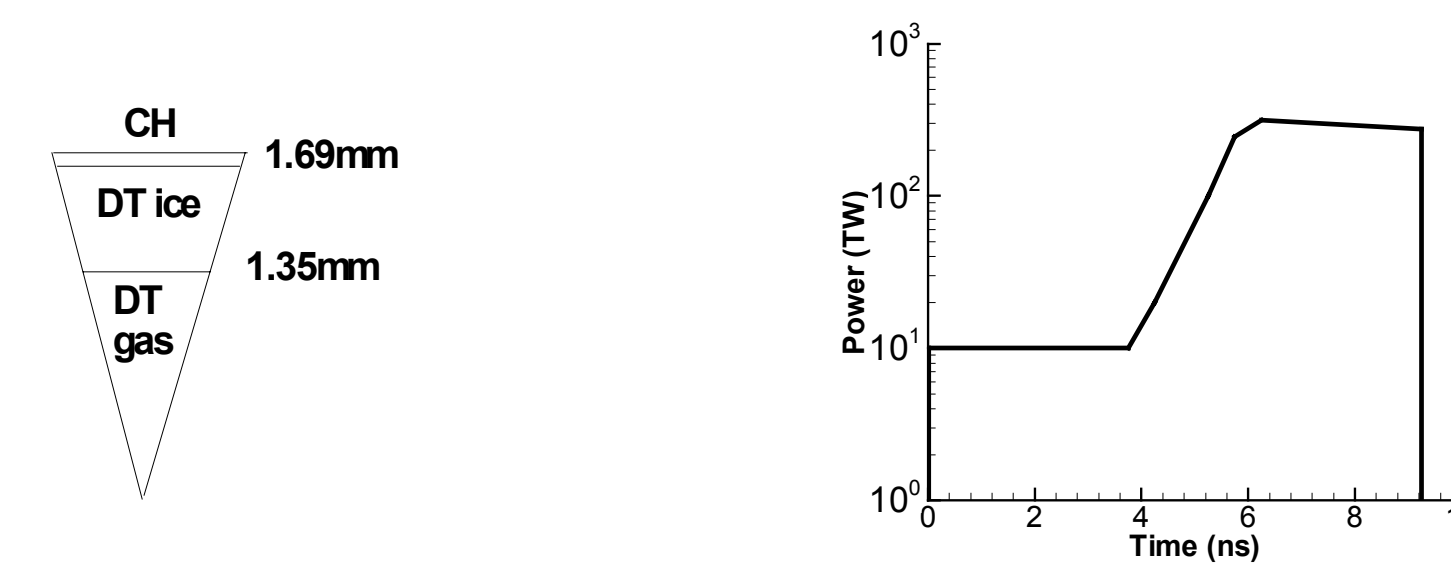
Outline

- Background of approaches for charged particle transport
 - Monte Carlo particle tracking
 - Multi-group flux-limited diffusion
- Simulation of burn wave propagation for a NIF target
 - Ion temperature and ρR contour at maximum compression
 - Time dependent and time independent tracking
 - I-line averaged energy deposition
 - Burn wave propagation and timing comparison
 - Energy gain
- Summary and future work



Baseline Direct-drive NIF Design

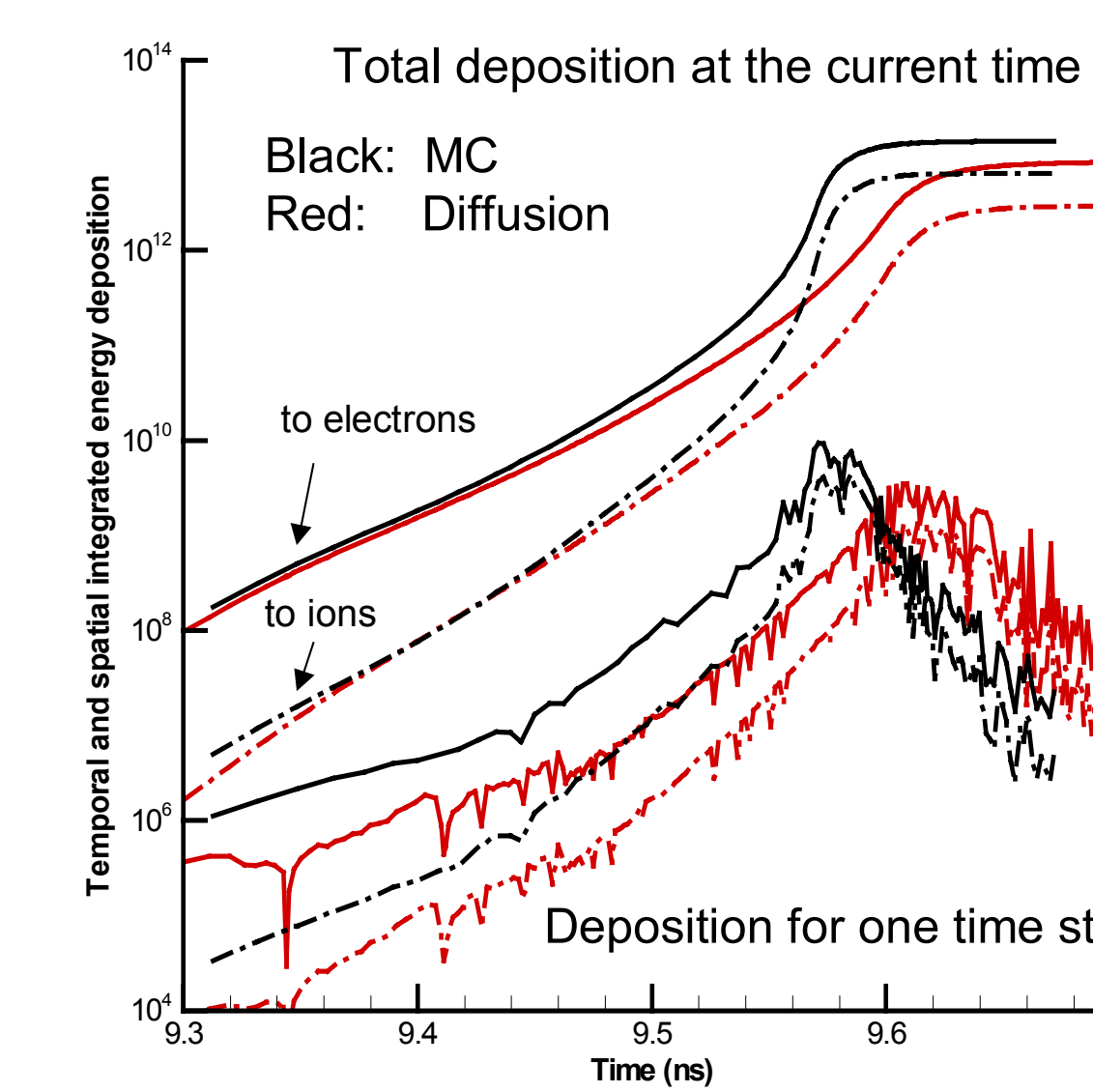
The design employs a cryogenic DT-shell target with a thin polymer ablator surrounding the DT ice shell. The isentrope of the ablation surface and the fuel is controlled by a preheat shock. In order to test the scheme with distorted meshes, a non-uniformity laser irradiation is applied at l mode equal to 6 with the amplitude of 1% variation.



P.W. McKenty, et. al., Physics of Plasmas 8, 2315 (2001)



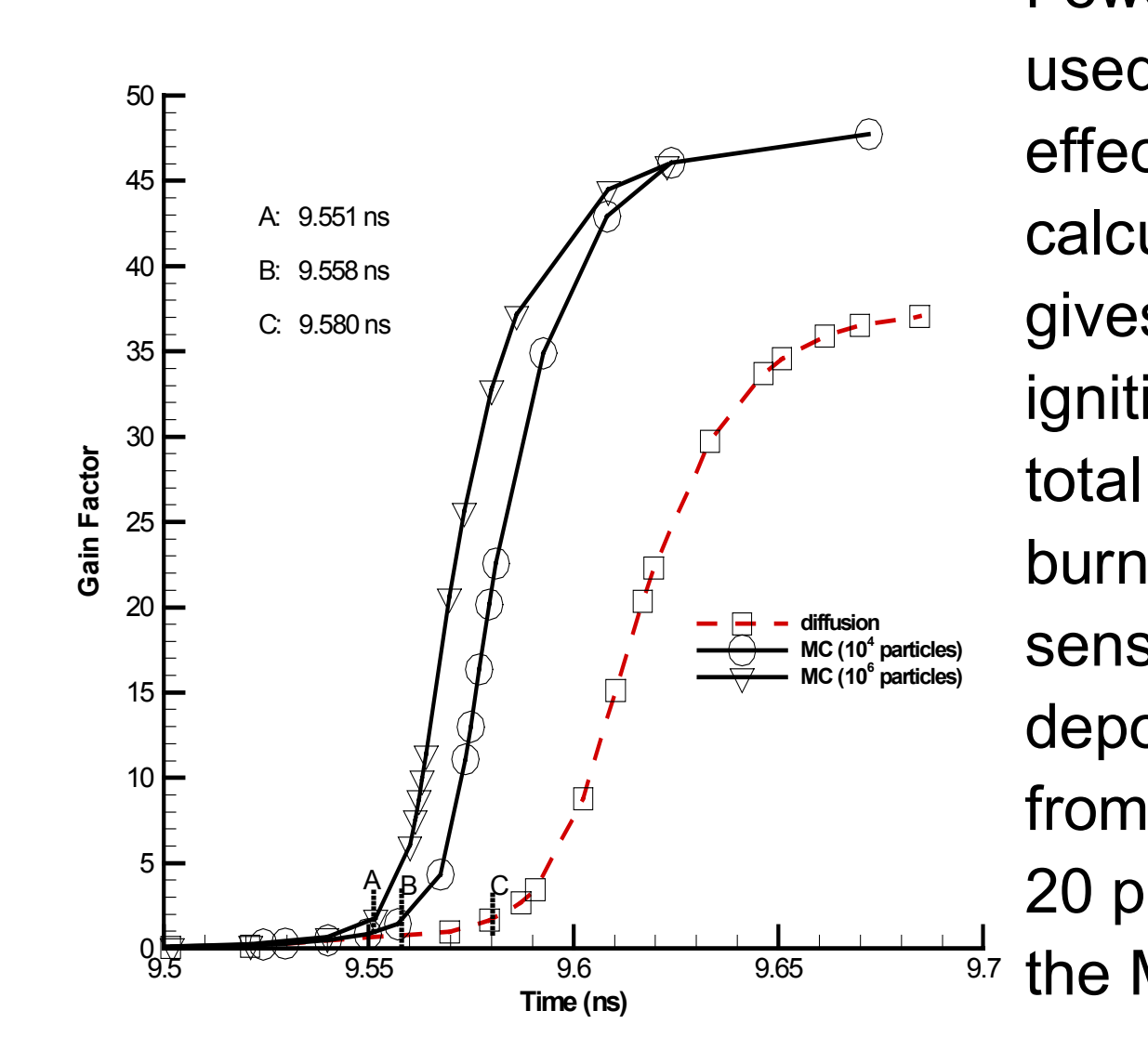
Comparison of MC and Diffusion



The energy deposition before 9.55 ns is close. After 9.55 ns, the deposition from the Monte Carlo method is significantly larger than that from the diffusion method. It lasts for 50 ps to 9.6 ns before the deposition decreases.



Gain Factor from Both Methods

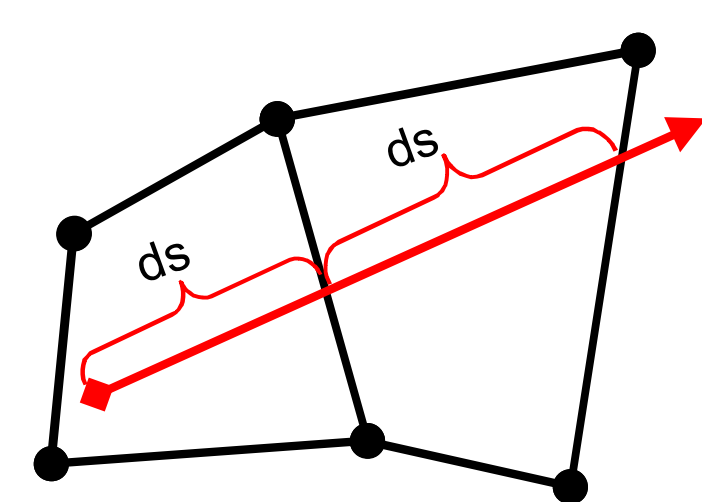


Fewer particles (10^4) are used to study the statistical effect. It can be seen that the calculation with few particles gives 7 ps delay for the ignition but generates similar total gain. It also shows the burn dynamics is very sensitive to the energy deposition. The total gain from the diffusion method is 20 percent lower than using the Monte Carlo method.



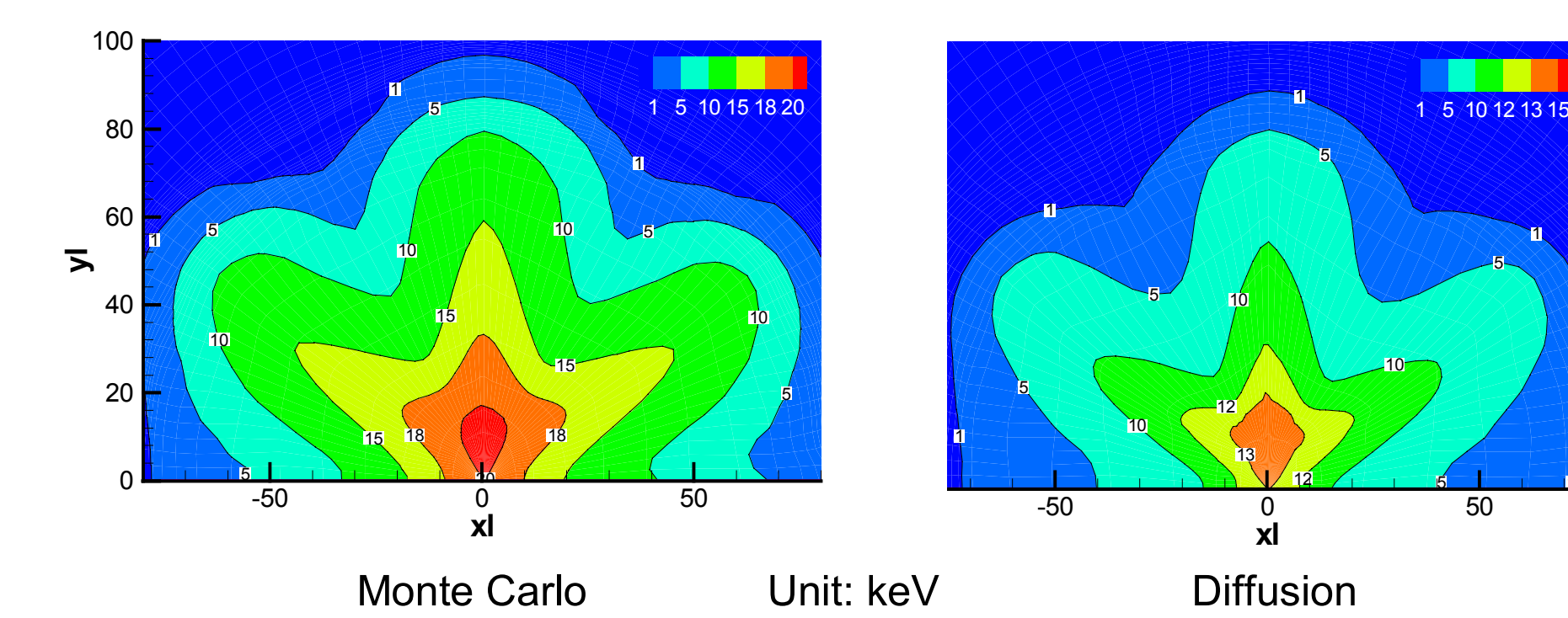
Monte Carlo Particle Tracking

In the Monte Carlo particle tracking method, a bunch of particles is followed from random generation to termination. Particle trajectories are approximated by straight lines. Energy loss to the plasma is calculated from the travel distance to each cell edge, and the amount of lost energy is governed by the stopping power.

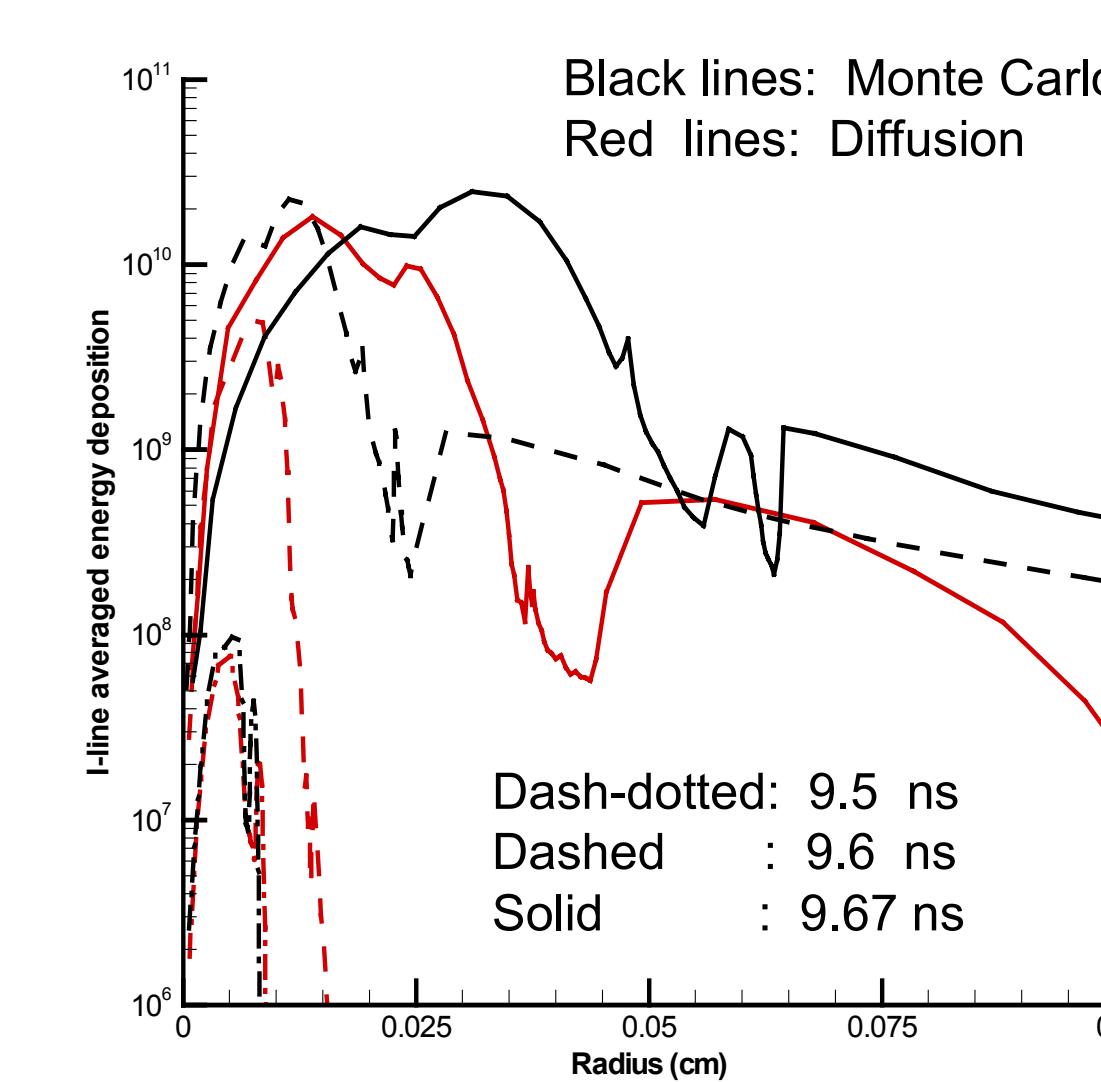


Comparison of Ion Temperature Contour

At 9.55 ns which is the time for maximum compression, the Monte Carlo method predicts higher ion temperature at the center of the hot spot, which is 20 keV in comparison with 13 keV from the diffusion method. The size of the hot spot, however, is quite similar.



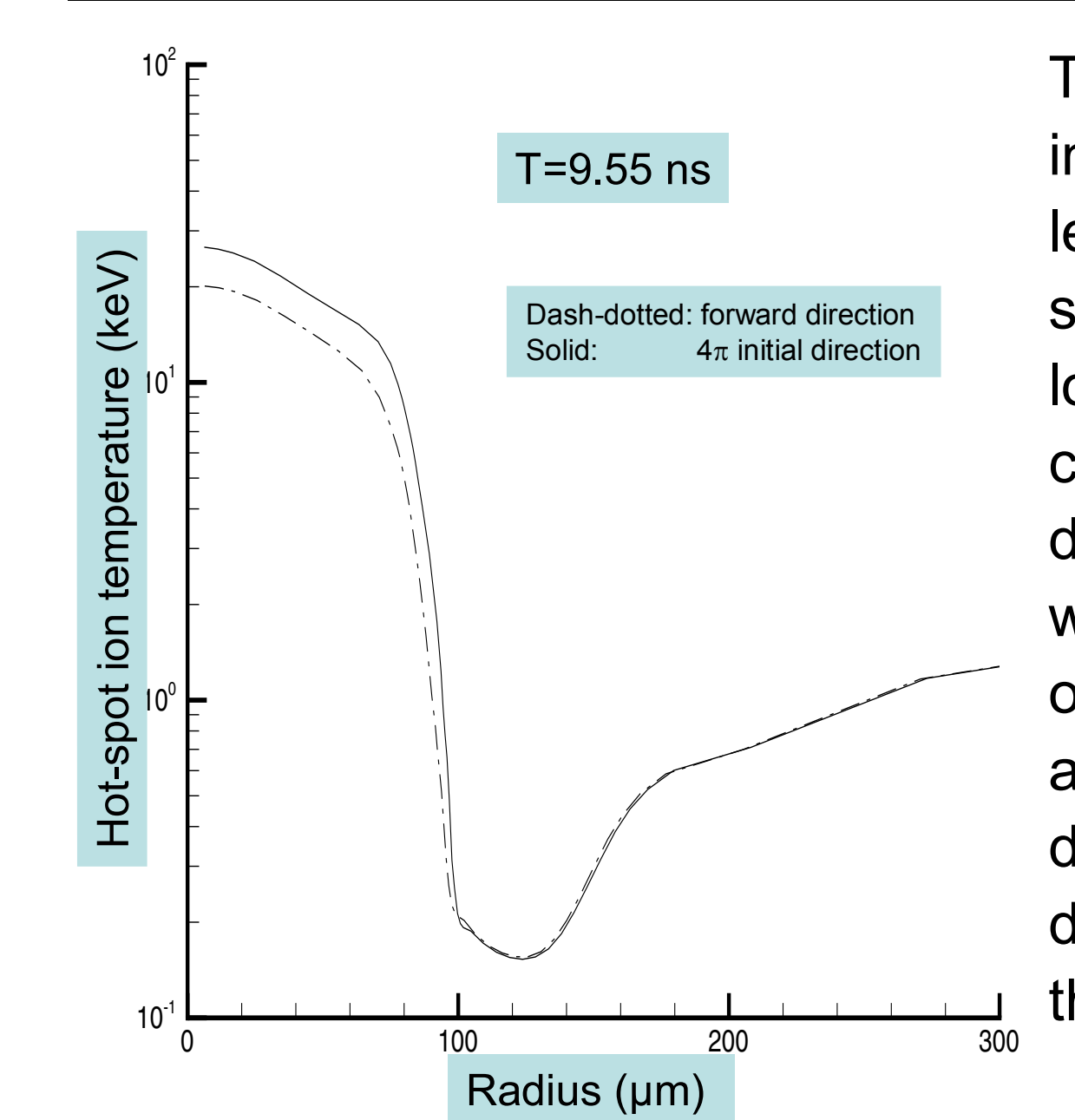
I-line Averaged Energy Deposition



At 9.5 ns, both results are similar since not much burn occurs. At 9.6 ns, a thermal burn wave is already generated in the Monte Carlo method while the alpha particles still deposit energies at the center of the hot spot in the diffusion method.



Possible Explanation for Earlier Ignition



The particles having an inward direction travel a length of the diameter of the sphere and thus more likely lose their energy at the center of the hot spot. To demonstrate this conjecture, we rerun the calculation with only the forward direction allowed. It is seen that all-direction-allowed method drives higher temperature at the hot spot.



Multi-group Charged Particle Diffusion Model

Multi-group Diffusion Equation:

$$\frac{\partial N_g}{\partial t} = \nabla \cdot D_g \nabla N_g - \frac{N_g}{\tau_g} + \frac{N_{g+1}}{\tau_{g+1}}$$

Alpha particle density in group g:

$$N_g = \int_{E_g}^{E_{g+1}} N(r, E, t) dE$$

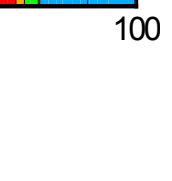
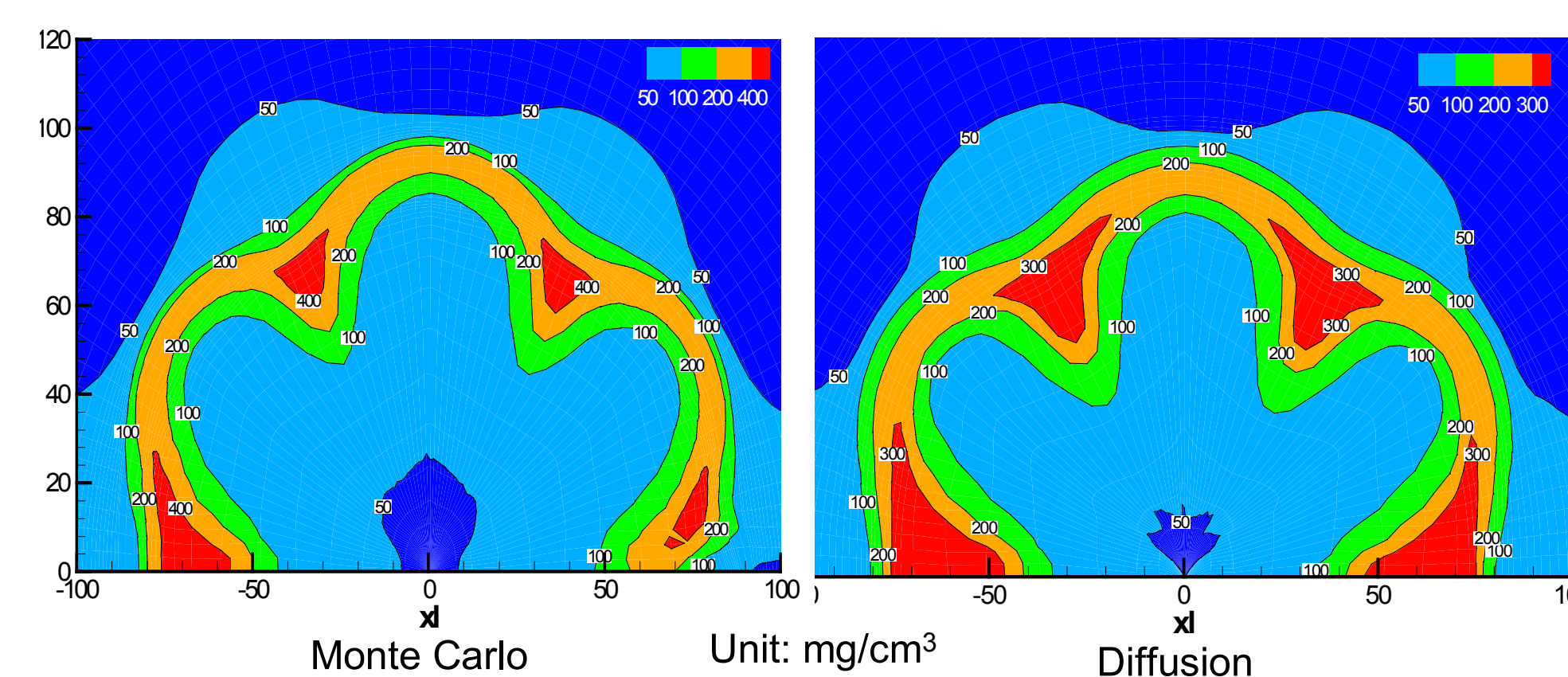
Relaxation time from upper group g+1 to lower group g:

$$\tau_g = \frac{2}{3} \frac{1}{v_e} \ln \frac{v_e^2 E_{g+1}^{3/2} + A_i}{v_e^2 E_g^{3/2} + A_i}$$

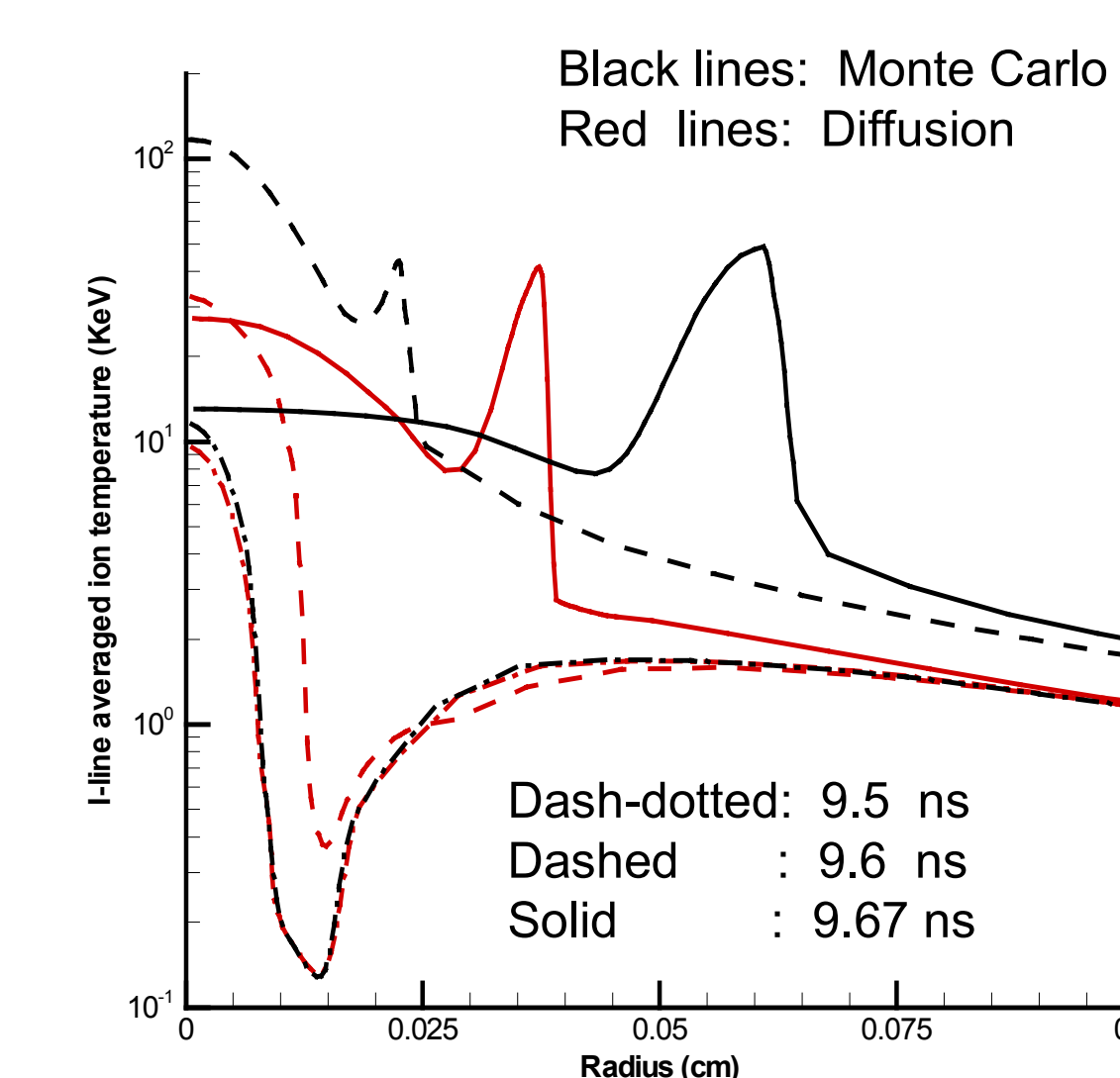


Comparison of Density Contour

At 9.55 ns, the density behind the spike tip from the Monte Carlo method is larger than that from the diffusion method, however, the area is smaller. It is very similar for other regions, and therefore, the Monte Carlo method has more effects on the perturbation layer.



Propagation of Thermal Burn Waves



The resulting burn waves from energy deposition show that the ignition predicted by the Monte Carlo method is earlier than predicted by the diffusion method.



Summary and Future Work

We have implemented a Monte Carlo particle tracking algorithm for charged particle transport into the multi-dimensional hydrodynamic code DRACO. The algorithm explicitly follows the particle trajectory cell-by-cell in three dimensional real space. Detailed comparison with the multi-group flux-limited diffusion for a NIF target shows that the Monte Carlo method predicts earlier ignition and higher gain than predicted by the diffusion method.

In the future, we will apply this tracking framework to the Implicit Monte Carlo (IMC) transport for radiation.

