Lawrence Livermore National Laboratory

Hohlraum Mesh Design and Mesh Motion Strategies in KULL

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Introduction

Hohlraums are laser-driven x-ray ovens that are central to studies of high energy density (HED) physics and inertial confinement fusion (ICF) phenomena. The design of hohlraum-driven experiments is guided by finite-element, radiation-hydrodynamics simulations which must provide an accurate and converged model of expected physical behavior. In relevant HED-ICF codes, the initial meshing of the hohlraum and its interior, typically a fill gas and/or target, must be optimized to resolve the appropriate level of physics and accurately determine all of the integrated values, such as the laser-wall interaction that produces the x-ray drive. In this work, we use an Arbitrary Lagrangian-Eulerian (ALE) multiphysics code, KULL, to perform convergence studies of the mesh resolution for laser-driven hohlraums in both one- and two-dimensions. Additionally, we investigate the accuracy and efficiency of ALE mesh motion strategies for coarser meshes relative to highly-resolved pure-Lagrangian and Eulerian meshes.

Approach

- Determine the mesh requirements to have simulations within the convergence regime. This was determined by calculating the Least Absolute Deviations, pointwise L1 Norm.
- In the initial mesh, there were 3 parameters that we focused on: the number of zones in the fill gas and in the hohlraum wall, and the width of the first ablation zone.
- Conduct pure-Lagrangian simulations by decreasing the width of the first zone until the integrated results begin to converge.
- Systematically increase the number of zones in the hohlraum wall to find when the results begin to converge. Repeat with the zones in the fill gas.
- Select the highest resolution case to be used as an reference case and then select a moderate case to which mesh motion relaxers are applied.
- In the two-dimensional simulations, in addition to pure-Lagrangian simulations, we also investigated the same quantities using an Eulerian ALE scheme.

Grid Convergence

The order of grid convergence can be calculated through the following equation:

$$E = f(h) - f_{exact} = C \cdot h^p + \text{Higher Order Terms}$$

where h is the grid spacing, E is the error, C is a constant, and p is the order of convergence. Since an exact solution is not available, we treated our highest resolution case as the exact solution. This equation is equivalent to:

$$\log(E) = p \cdot \log(h) + \log(C)$$

where the higher order terms are disregarded.

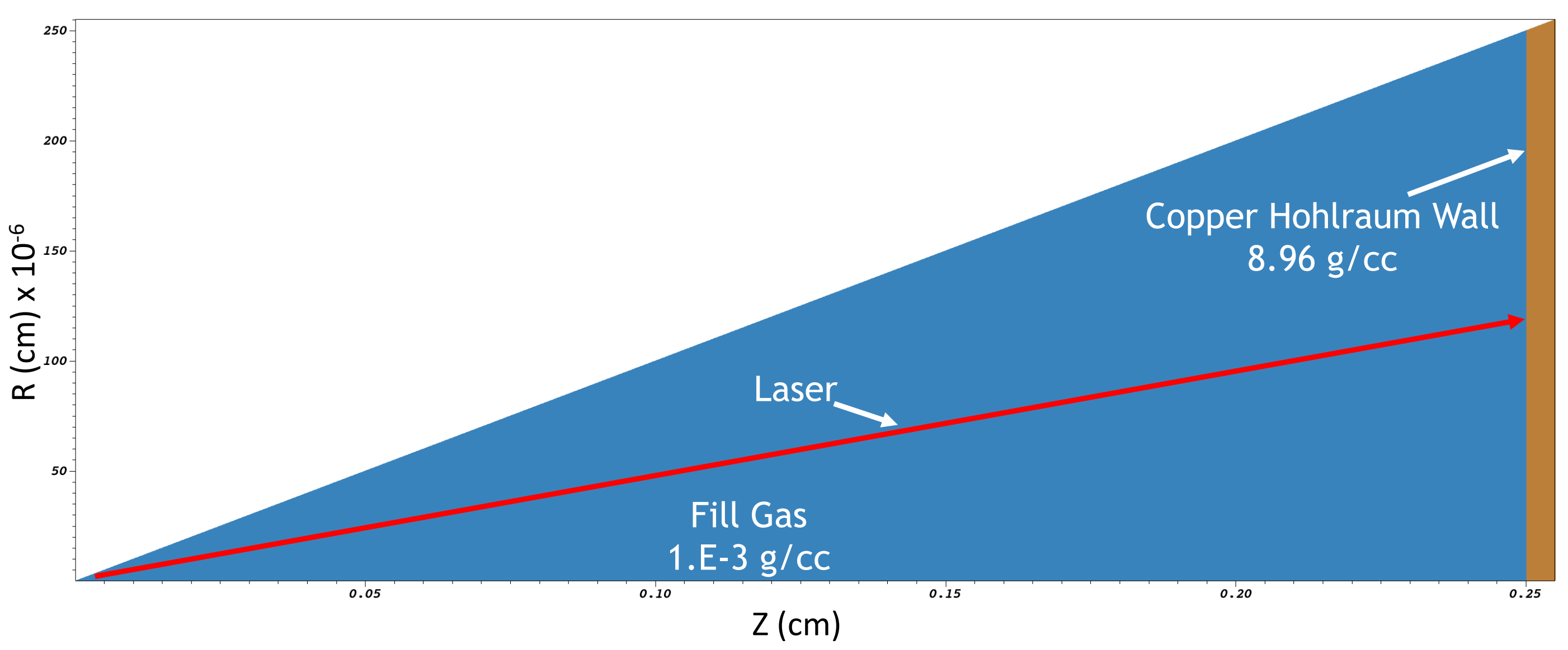
L1 Error

To use the statistical measurement of the L1 Error, calculate the pointwise difference between the reference case and the test case, sum all of the values and find the mean: $\frac{\sum_{i=0} |f(h) - f_{reference}|}{N}$

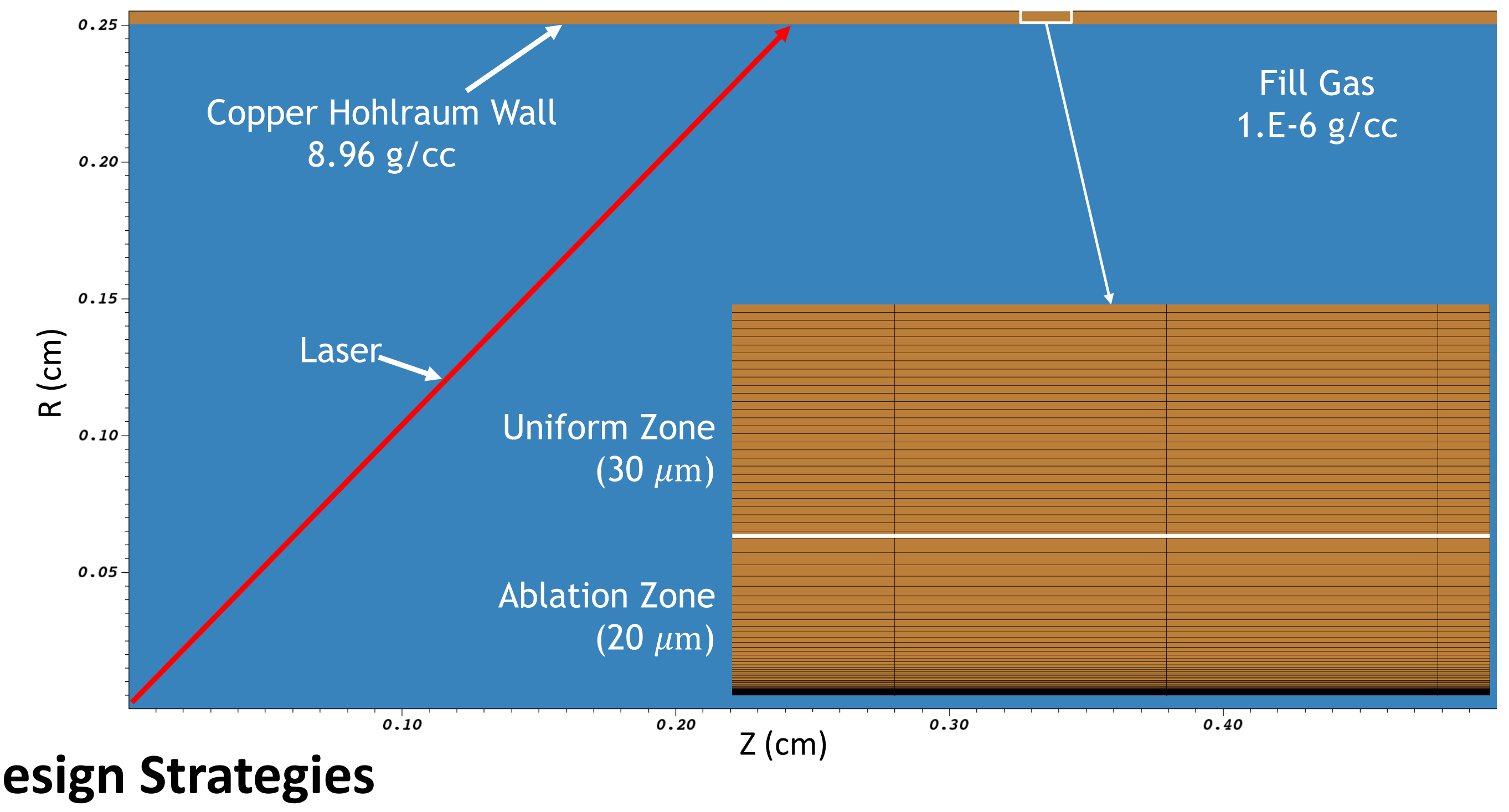
where N is the number of points.

Problem Setup

1-Dimension

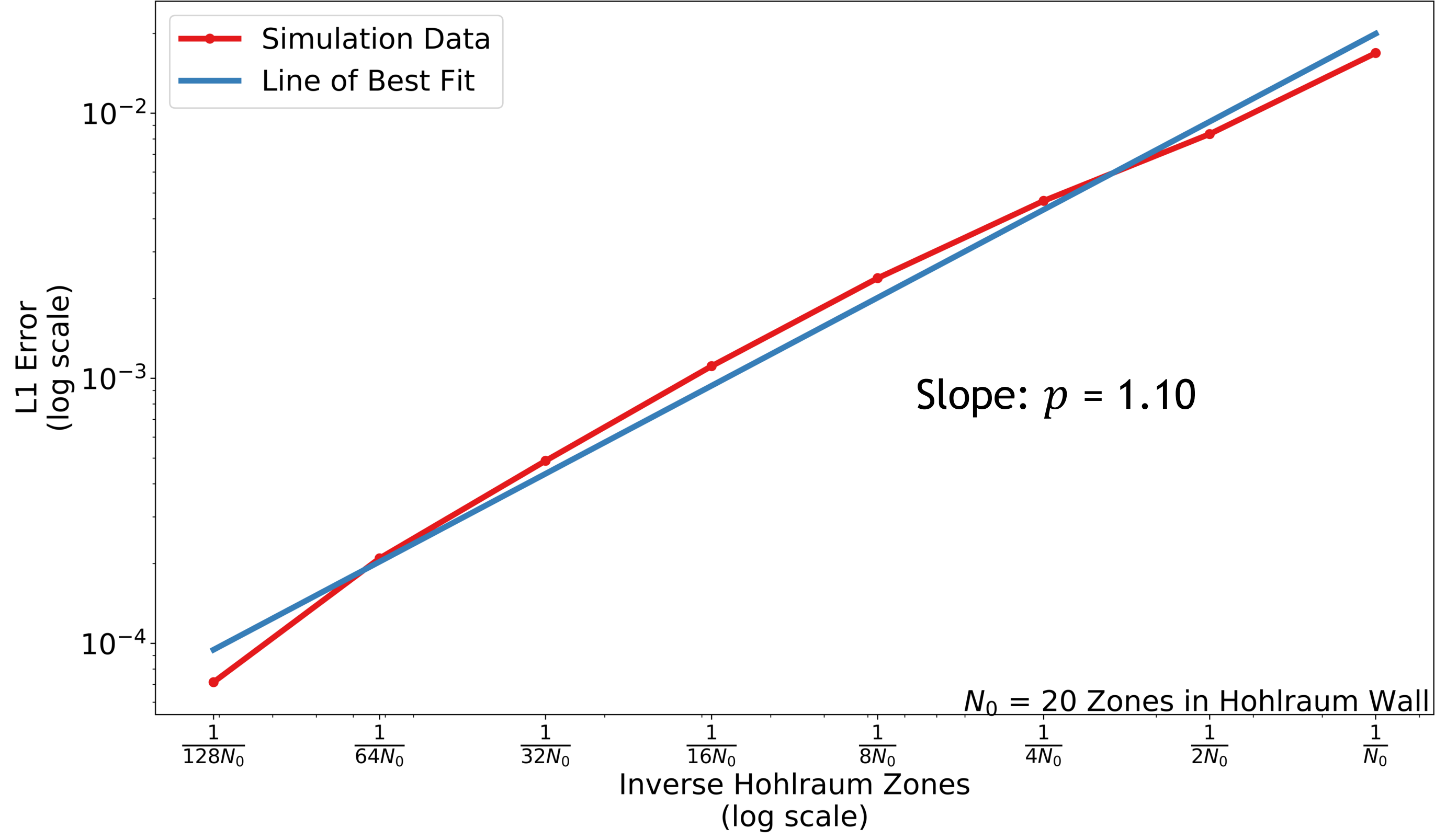


2-Dimensions

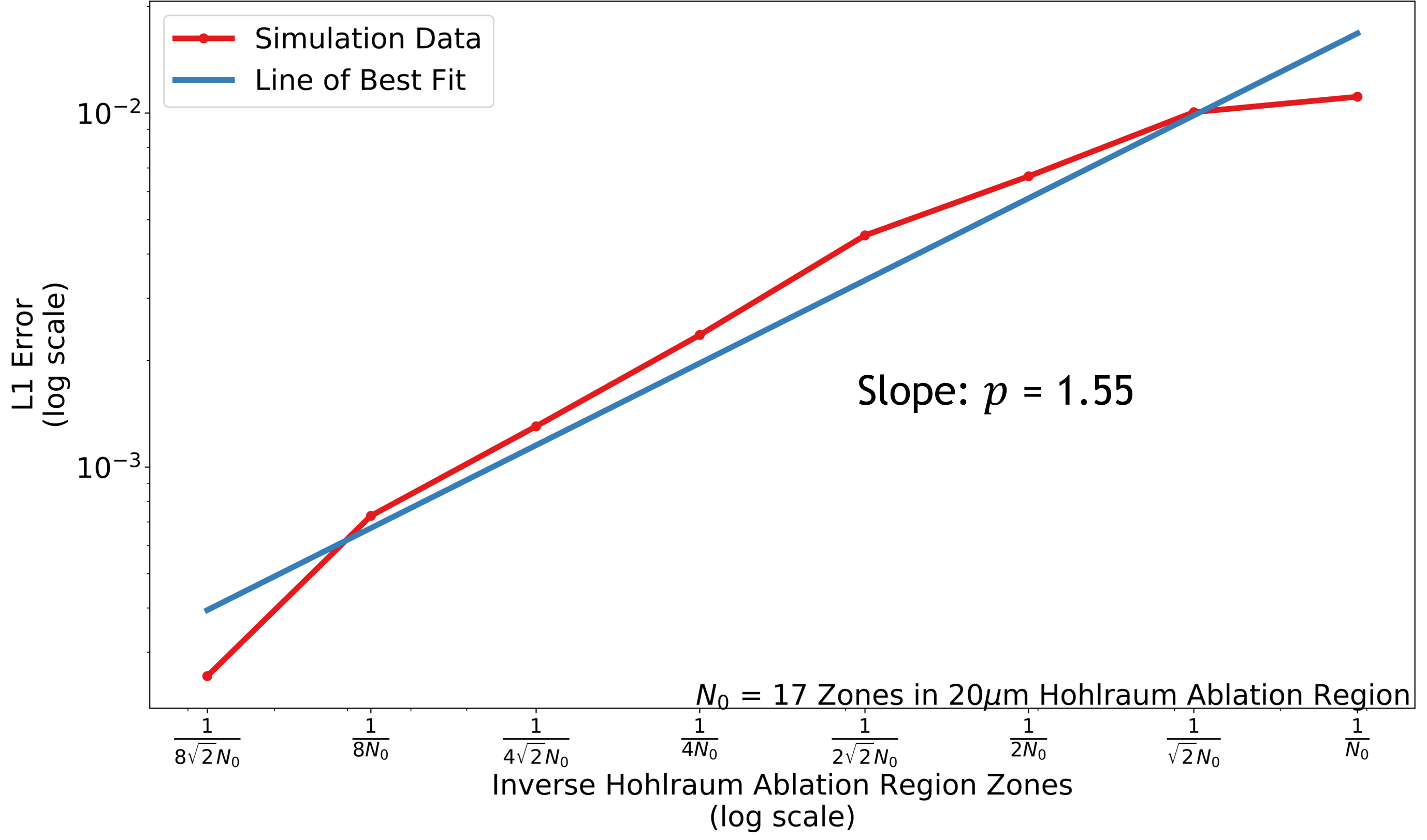


Results – Mesh Design Strategies

L1 Error of the Average Density in 1-Dimension

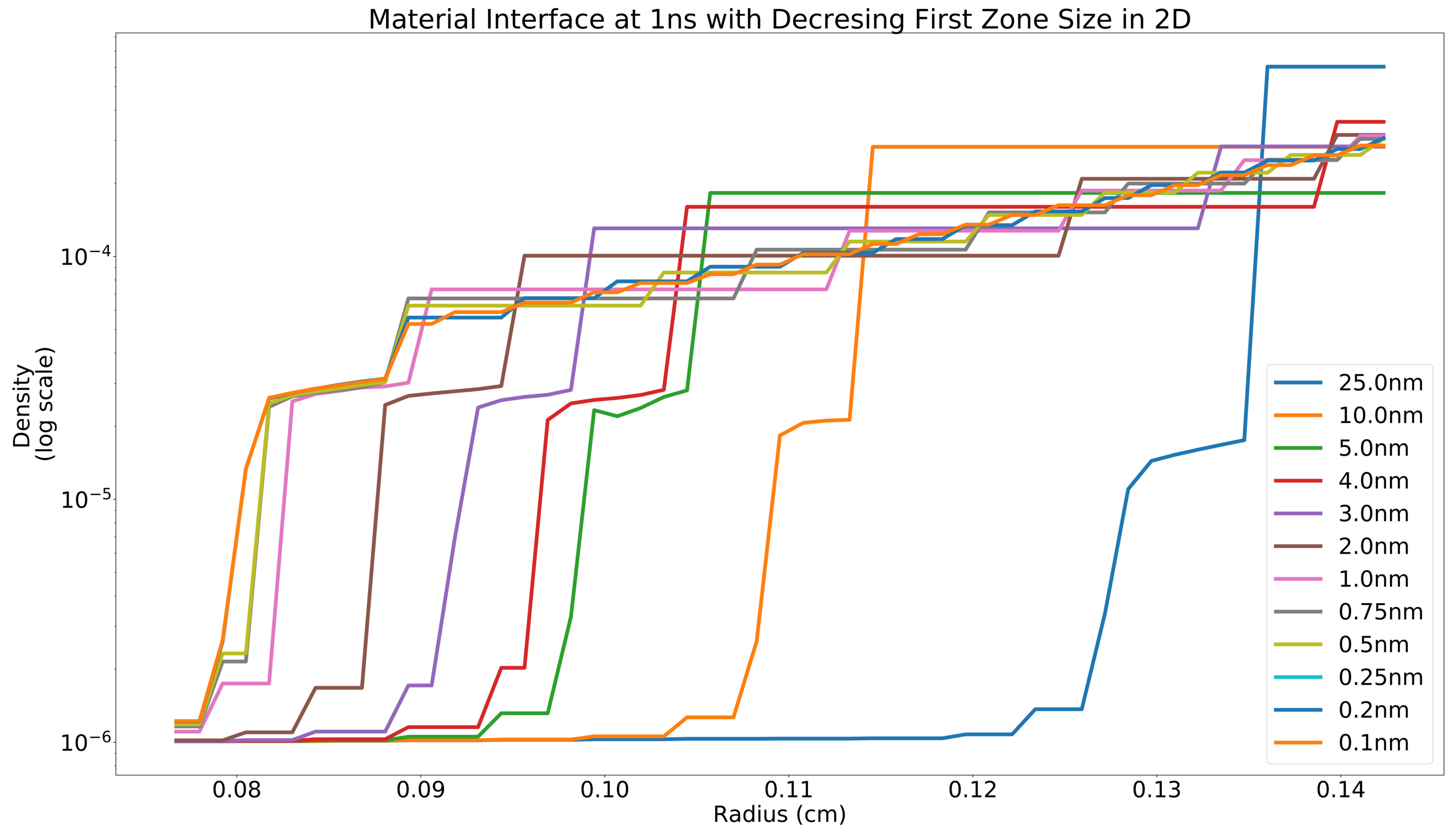


L1 Error of the Radiation Temperature in 2-Dimensions

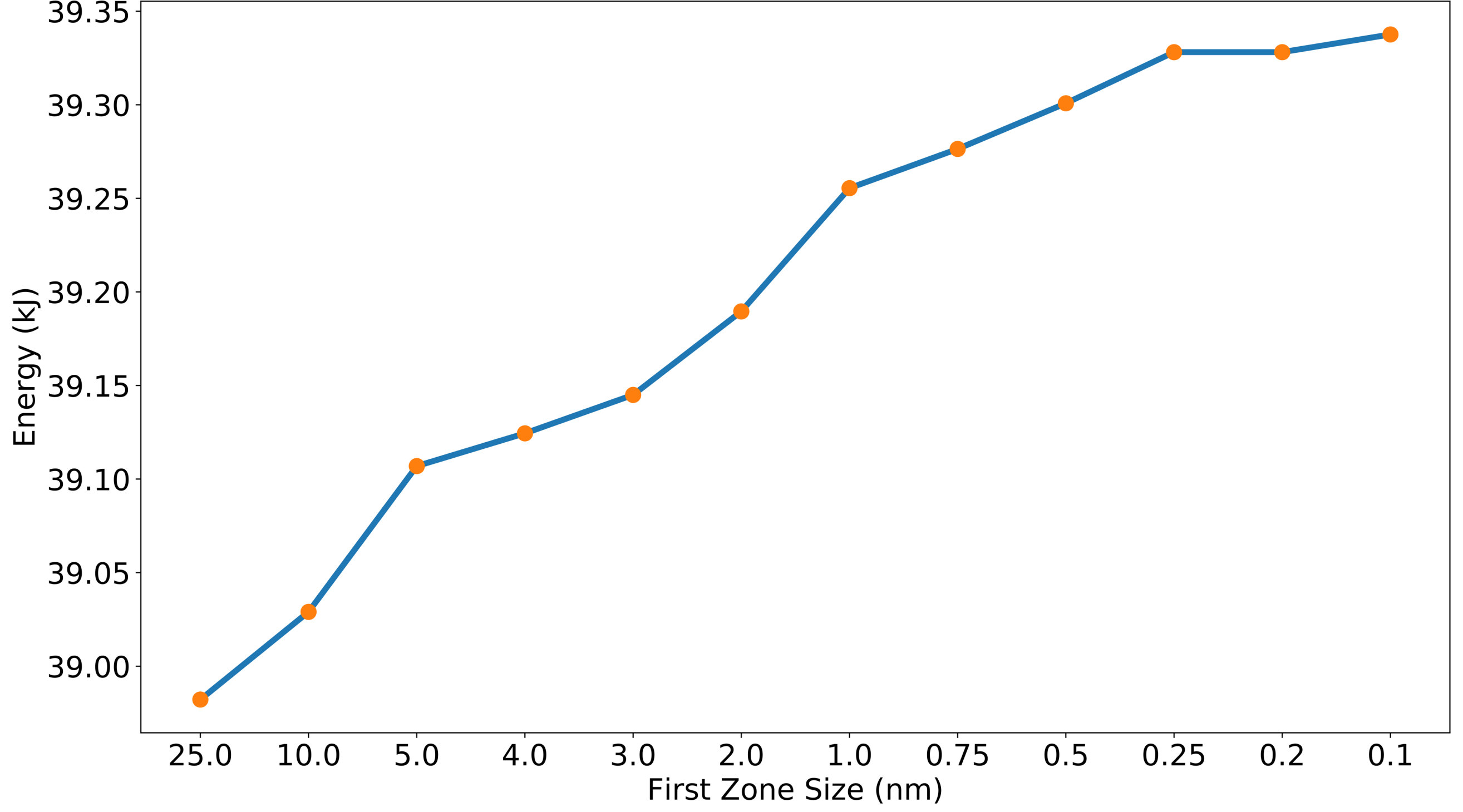


By using the Grid Convergence equation, in 1D, the order of convergence for the density was **1.10** and, in 2D, the order of convergence for the radiation temperature was **1.55**. Since the orders of convergence are greater than 1.0, these simulations are within the convergence regime.

Material Interface at 1ns with Decresing First Zone Size in 2D



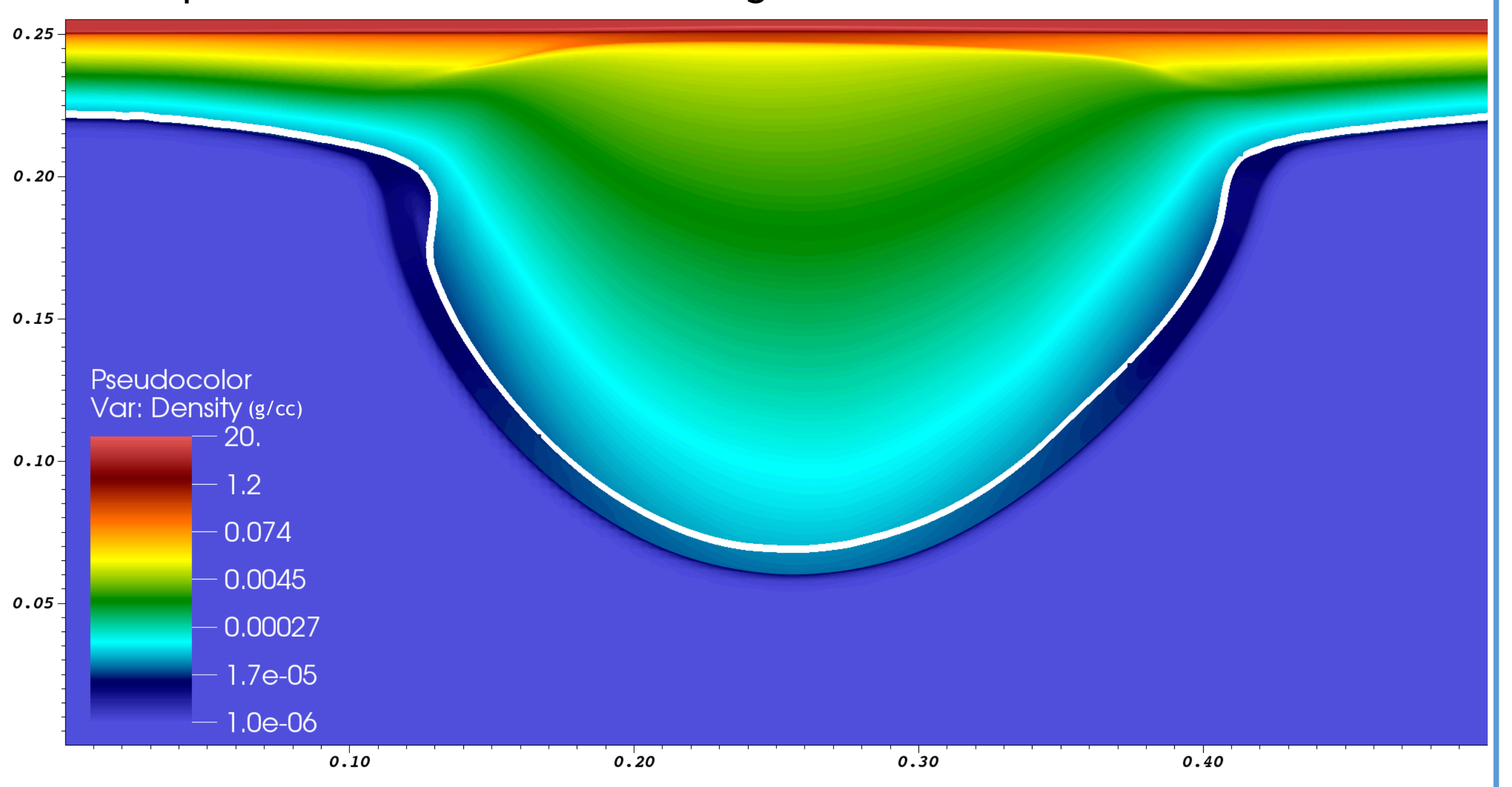
Total Beam Energy Deposited at 1ns



Using tracers, the expansion of the hohlraum wall can be mapped. By decreasing the width of the first zone while maintaining the consecutive zone width ratio at 10%, the expansion of the bubble increases until the first zone has a width of 0.5nm. The total laser energy deposited by the laser also increases with smaller first zone width.

Results – Mesh Motion Strategies

Log scale plot of density at 1ns for the moderate resolution case that is used as a comparison for mesh motion strategies in 2D.



Comparison between the reference case, a moderate resolution Lagrangian case, and the same moderate resolution with ALE mesh relaxation.

Quantity	Simulation	L1 Error
Density	Lagrangian	1.32E-04
	ALE Mesh Relaxation	4.73E-04
Pressure	Lagrangian	1.26E-06
	ALE Mesh Relaxation	4.45E-06
Radiation Temperature	Lagrangian	1.49E-03
	ALE Mesh Relaxation	5.70E-03
Electron Temperature	Lagrangian	3.47E-02
	ALE Mesh Relaxation	8.81E-02

Conclusions

- In 1D, it was determined that the most consistent results were provide by the pure-Lagrangian mesh motion simulations. The application of ALE mesh motion strategies decreased the accuracy of the results overall.
- Regarding laser energy deposition and bubble expansion, a small width for the first zone in the hohlraum wall is necessary for more accurate results. The required first zone width depends on the fill gas density. We found 2nm as optimal for 1 mg/cc in 1D and 0.5nm for 1 μg/cc in 2D.

Ongoing Work

- A comparison between Eulerian and Lagrangian simulations will be made.
- ALE mesh motion strategies using metric tests will be explored in 2D simulations to gauge efficiency and accuracy at moderate resolutions.

References

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KULL: LLNL's ASCI Inertial Confinement Fusion Simulation Code
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