Overview of `TriForce`: Projects, Progress, and Plans

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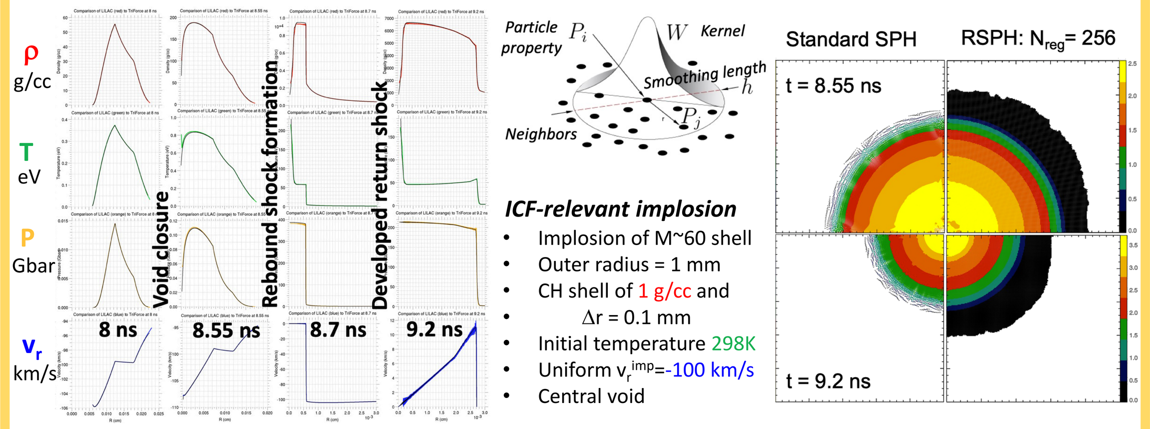
The TriForce Center for Multiphysics Modeling, *a collaboration between the Departments of Mechanical Engineering, Physics, Computer Science, and the Laboratory for Laser Energetics at the University of Rochester*

Summary

- `TriForce` is a modular C++ framework for parallel GPU-accelerated particle-based hybrid fluid-kinetic 3D simulations
- The code recovers results from both radiation magnetohydrodynamic and fully kinetic codes in those asymptotic limits, and will operate in between where both descriptions may co-exist and interact
- The hybrid method enables capabilities beyond either of the individual modeling methods alone, and is being used to investigate a range of topics such as controlled nuclear fusion, astrophysics, high-energy-density physics, and high-intensity lasers.
- The goal is to provide better predictive capability and access to advanced models for the benefit of the academic community.
- Student involvement: high school, undergraduate, and graduate

Particle-based meshless fluid algorithms



Material constitutive models

- Equation of state
  Analytic, tabular (FPEOS, LEOS, SESAME)
- Opacity and <Z>
  Analytic, tabular (Astrophys., FPEOS, Prism)
- Electrical resistivity
  Spitzer, tabular (QLMD)
- Viscosity
  Real and artificial
- Surface tension
- Stress-strain and material strength
  Elastic-plastic, Steinberg-Guinan/-Lund

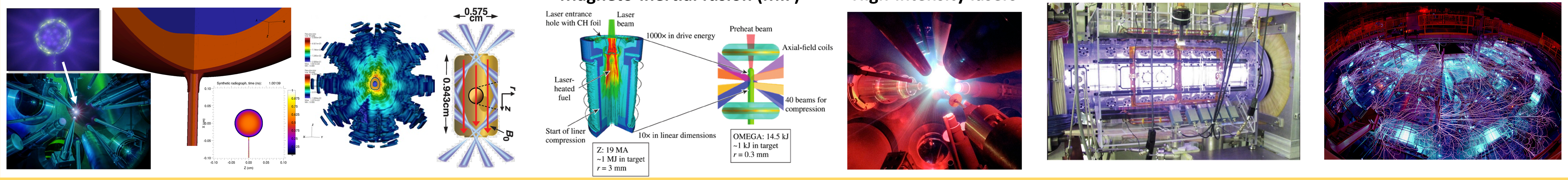
Other models

- Explicit or implicit PIC particles
- Explicit or implicit EM fields
- Adaptive particles and mesh
- Charged particle beams
- Nonlocal thermal conduction
- Nuclear fusion and α transport*
- Neutron transport*
- Photon transport*
- Circuit model
- MHD
- Gravity

* *Diffusion and Monte Carlo*

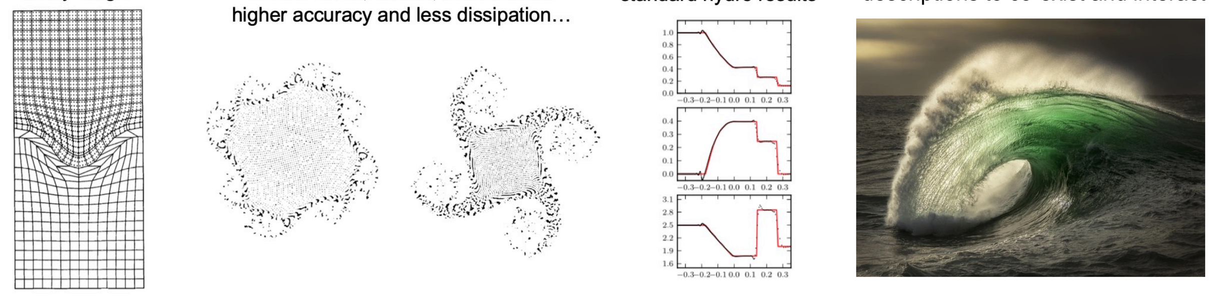
Scientific motivation

Direct and indirect inertial confinement fusion (ICF) | Magneto-inertial fusion (MIF) | High-intensity lasers | Field-reversed configuration (FRC) | Pulsed power science



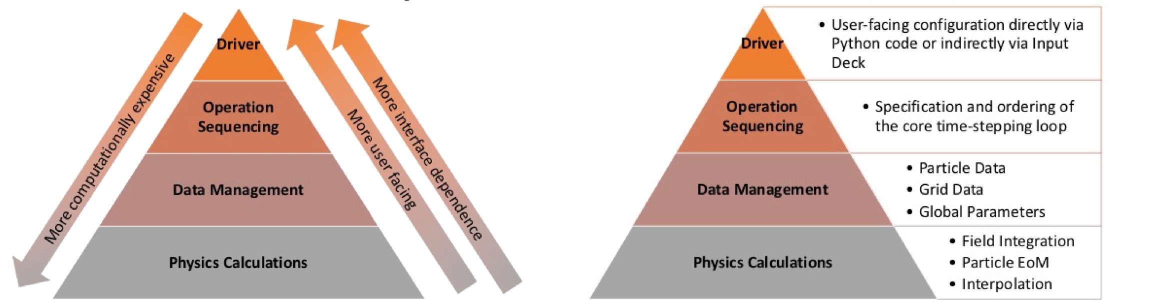
Why particles?

ALE meshes easily tangle | Particle and mesh-free approaches handle shear, eddies, and mix with higher accuracy and less dissipation… | … while reproducing standard hydro results | … and allowing fluid and kinetic descriptions to co-exist and interact



Modular multiphysics simulations

Architectural hierarchy | Implementation (e.g. PIC)



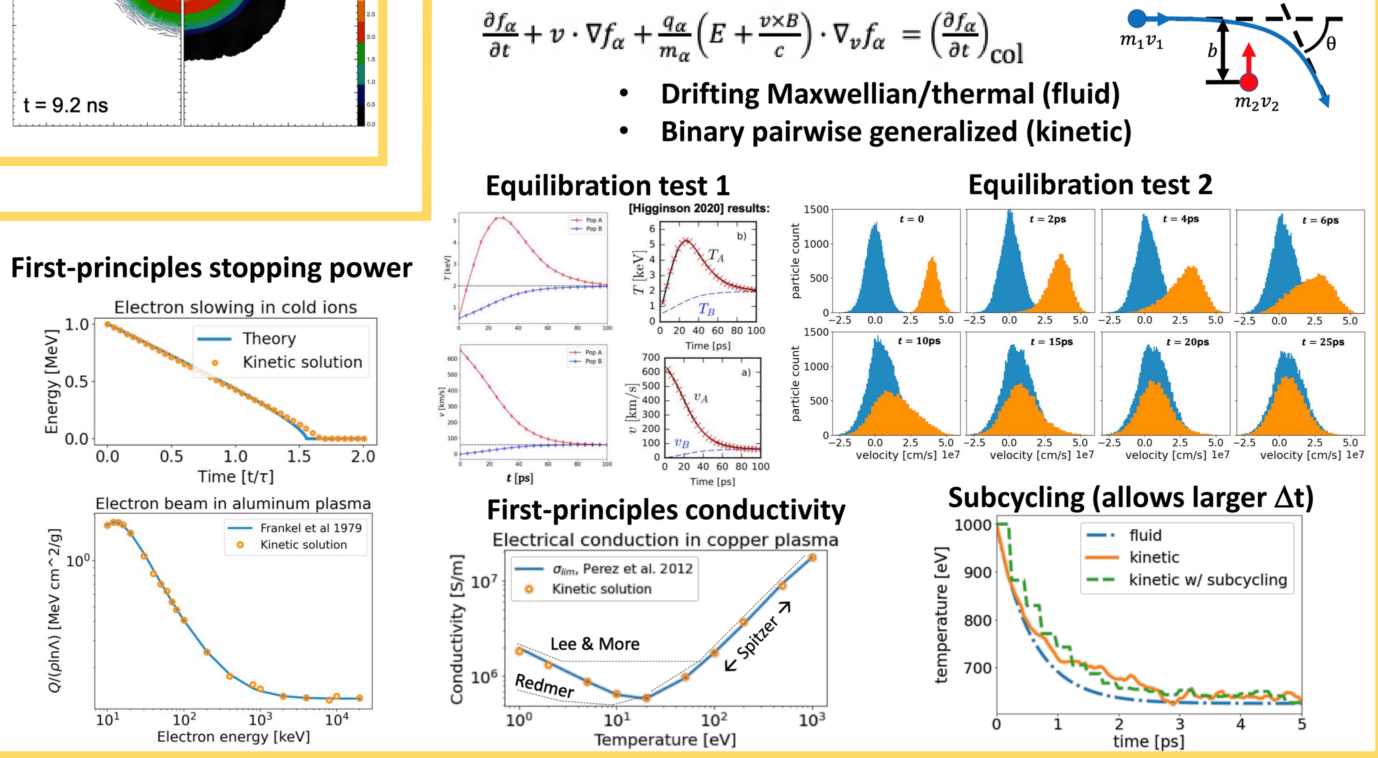
The software is being designed for
- development by multiple people
- use of abstract base classes
- modularity and extensibility
- compartmentalization of tasks
- alteration of simulation archetype
- rapid prototyping
- running in serial or parallel
- computing on CPUs or GPUs

Coulomb collision models

$$\frac{\partial f_\alpha}{\partial t} + v\cdot\nabla f_\alpha + \frac{q_\alpha}{m_\alpha}\left(E + \frac{v\times B}{c}\right)\cdot\nabla_v f_\alpha = \left(\frac{\partial f_\alpha}{\partial t}\right)_{col}$$

- Drifting Maxwellian/thermal (fluid)
- Binary pairwise generalized (kinetic)

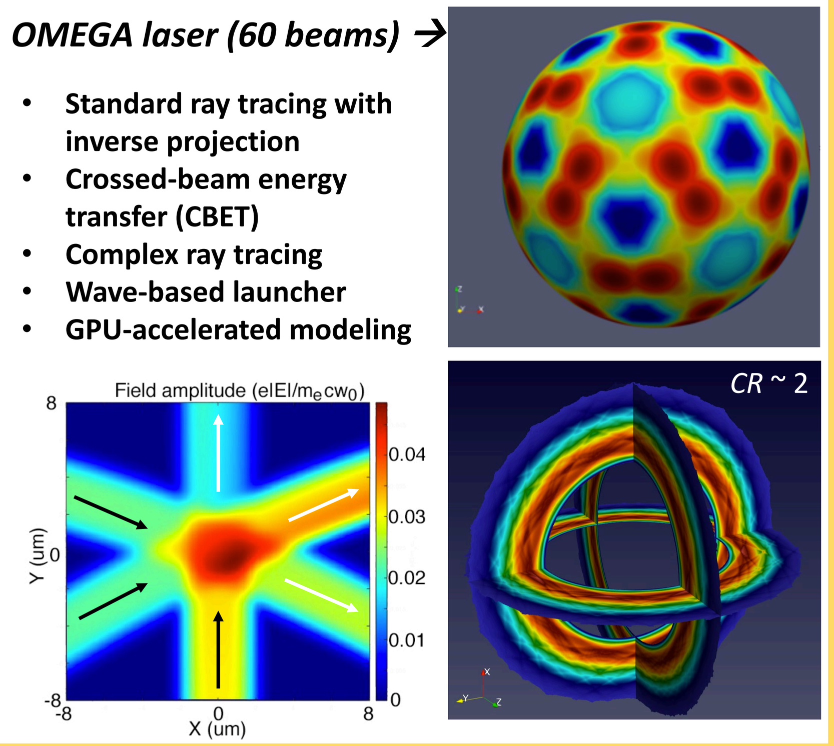
First-principles stopping power | Equilibration test 1 | Equilibration test 2 | First-principles conductivity | Subcycling (allows larger Δt)



Laser propagation and absorption

OMEGA laser (60 beams)

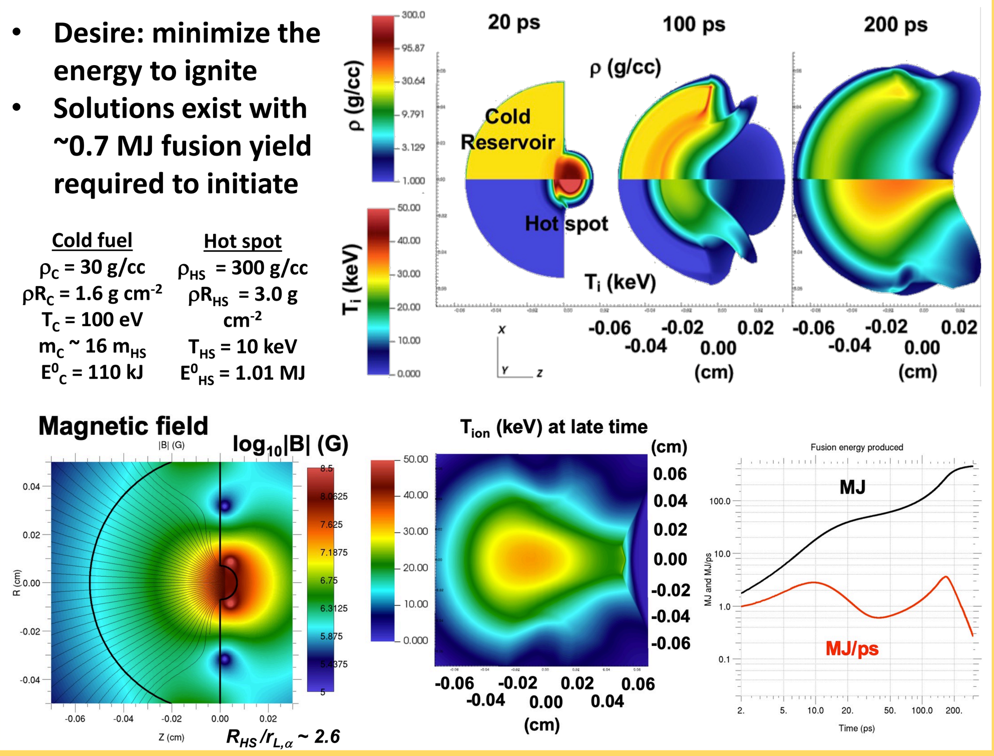
- Standard ray tracing with inverse projection
- Crossed-beam energy transfer (CBET)
- Complex ray tracing
- Wave-based launcher
- GPU-accelerated modeling



High-gain inertial fusion energy targets

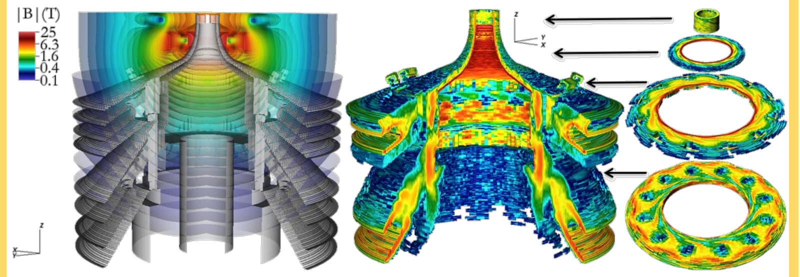
- Desire: minimize the energy to ignite
- Solutions exist with ~0.7 MJ fusion yield required to initiate

Cold fuel	Hot spot
ρ_c = 30 g/cc	ρ_{HS} = 300 g/cc
ρR_c = 1.6 g cm^{-2}	ρR_{HS} = 3.0 g cm^{-2}
T_c = 100 eV	T_{HS} = 10 keV
m_c ~ 16 m_{HS}	
E^P_C = 110 kJ	E^P_{HS} = 1.01 MJ

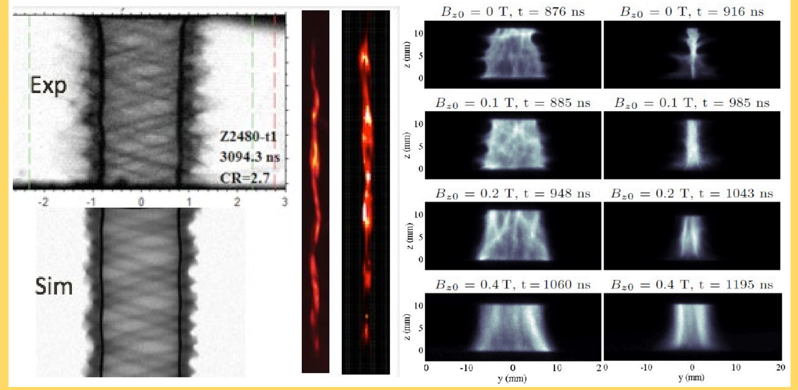


Magnetized plasma physics

Plasma flow in pulsed-power transmission lines

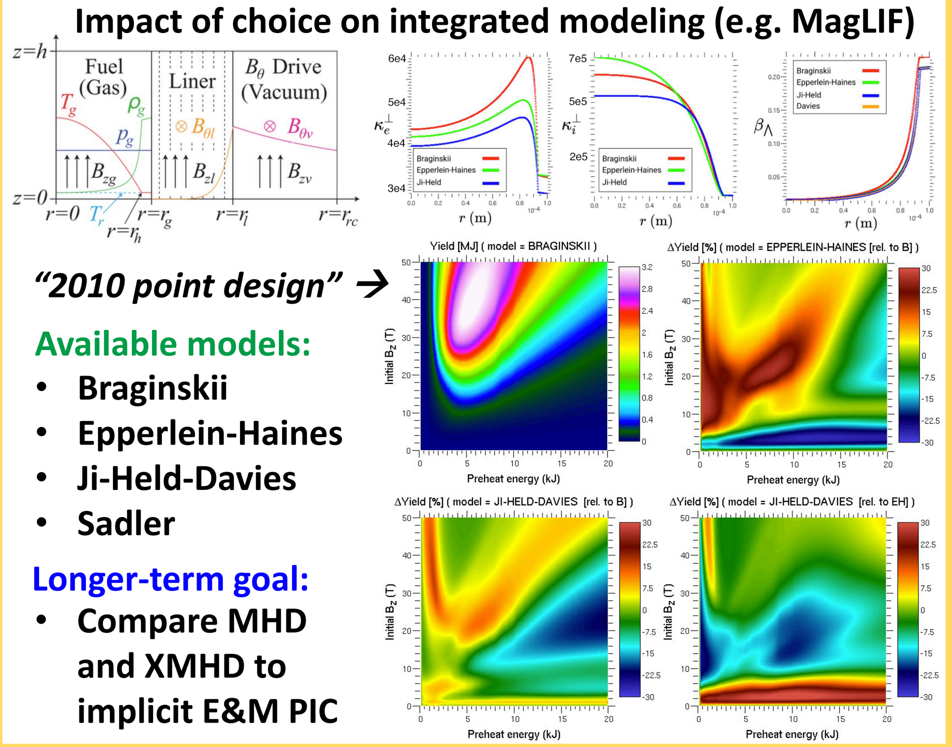


Magnetized liner inertial fusion (MagLIF) | Magnetized plasma jets and gas puff z-pinches



MHD transport coefficients

Impact of choice on integrated modeling (e.g. MagLIF)



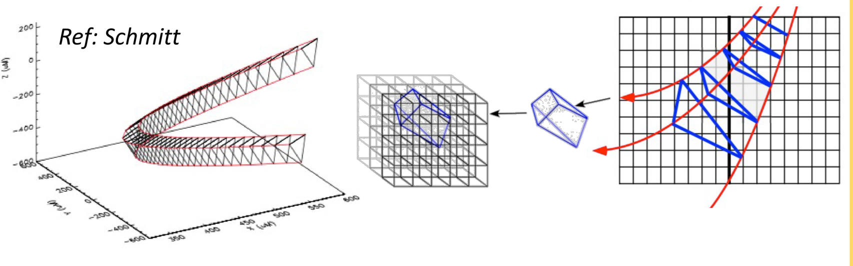
"2010 point design"

Available models:
- Braginskii
- Epperlein-Haines
- Ji-Held-Davies
- Sadler

Longer-term goal:
- Compare MHD and XMHD to implicit E&M PIC

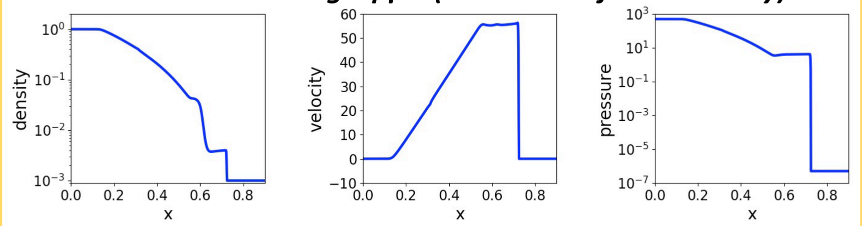
Low-noise "quiet" methods

Rays example: Smooth bundles (uses interpolation)

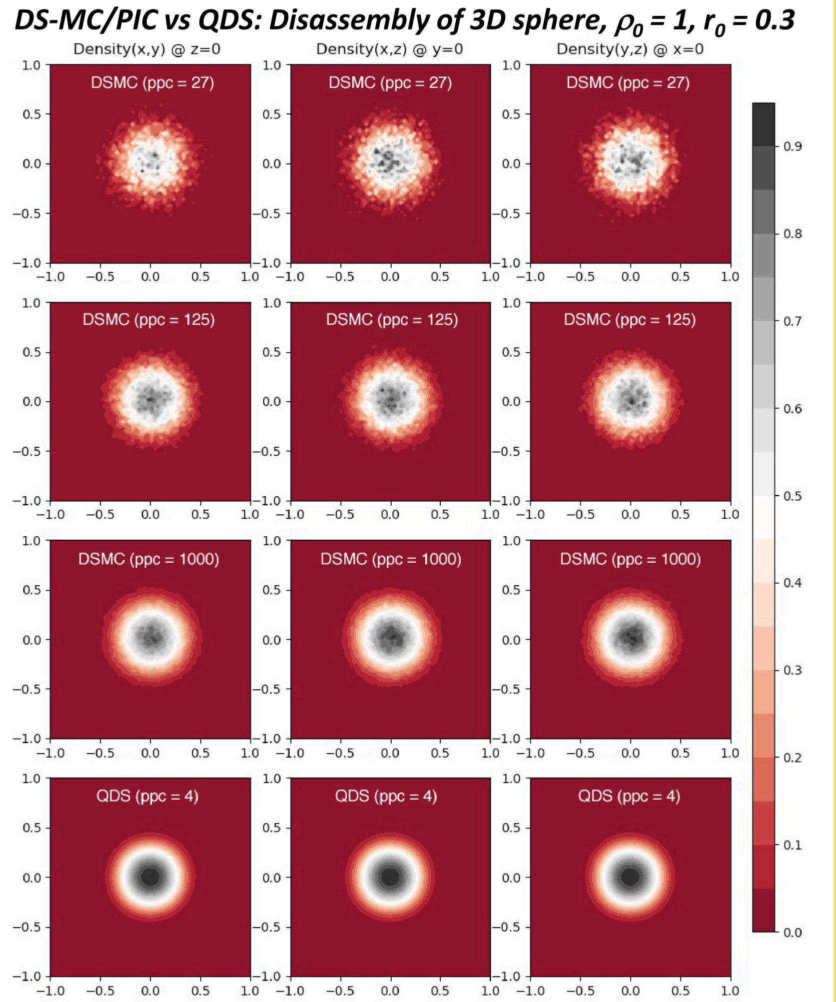


Particles examples: "quiet direct simulation" (QDS)

Sod shock tube using 4 ppc. (without artificial viscosity)



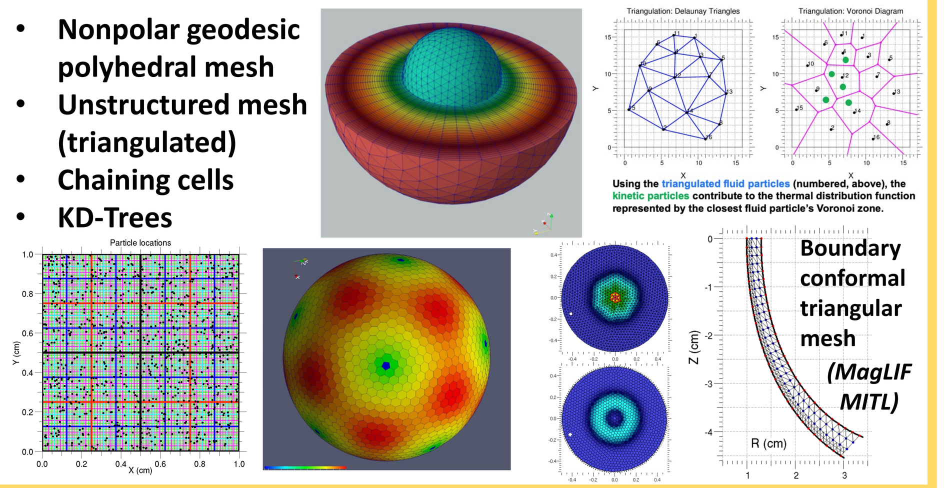
DS-MC/PIC vs QDS: Disassembly of 3D sphere, ρ_0 = 1, r_0 = 0.3



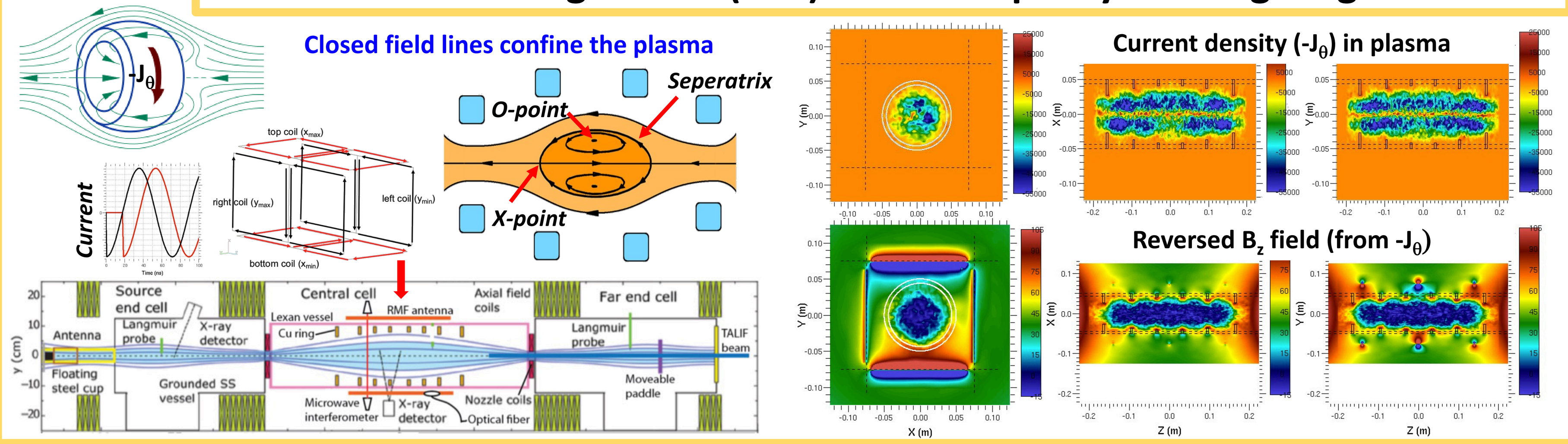
- QDS: Fewer particles, low noise, high dynamic range

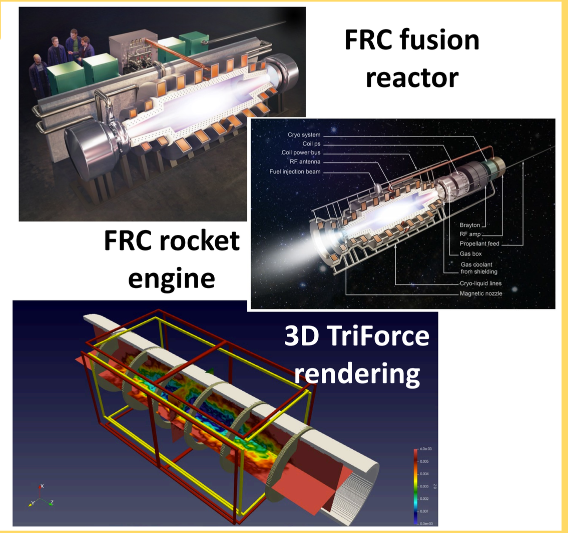
Integration of advanced structures

- Nonpolar geodesic polyhedral mesh
- Unstructured mesh (triangulated)
- Chaining cells
- KD-Trees



Field-reversed configuration (FRC) from odd-parity rotating magnetic fields





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Acknowledgements

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