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Applicability to real experiments

Modeling Power-Flow Using the PERSEUS/FLEXO and HYDRA Simulation Codes

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Motivation and outline

Modeling power-flow with high fidelity is of utmost importance for improving the performance of experiments on present and future pulsed power facilities.

- Hall MHD affects the magnetic field diffusion rates into electrode plasmas, and therefore the impact of electrode plasmas on power-flow.
- PERSEUS vs HYDRA comparison:
  - For 1-D B-field penetration into conducting slab, we verified agreement between the two codes and with analytic solution.
  - For 1-D B-field penetration into plasma layer, we verified agreement between the two codes.
  - For 2-D B-field penetration into a low-density plasma, we compared the impact of Hall physics on diffusion rates, as modeled by each code.

When does the Hall Term become important for power flow?

- When the Hall term becomes large relative to the dynamo term or resistive term in the Generalized Ohm's Law:
  - $0 = E + \boldsymbol{u} \times \boldsymbol{B} - \frac{\boldsymbol{J}}{n_e e} \times \boldsymbol{B} - \eta \boldsymbol{J}$
  - Large Hall term relative to dynamo term: small ion inertial length relative to spatial scales, i.e. low-density plasma.
  - Large Hall term relative to resistive term: strongly magnetized plasma (electron gyrofrequency large relative to collision frequency).

Simplifying assumptions to facilitate the modeling of magnetic diffusion with Hall physics:

- 2-D axisymmetric system (MITL and plasma); only J_r, J_z, and B_θ are nonzero.
- Spatially uniform resistivity and density within each material, i.e. vacuum, plasma, and electrode.
- The displacement current is negligible. This implies
  - current has negligible divergence
  - small system size compared to light propagation distance over relevant time scales
- Limited motion of plasma and electrodes.

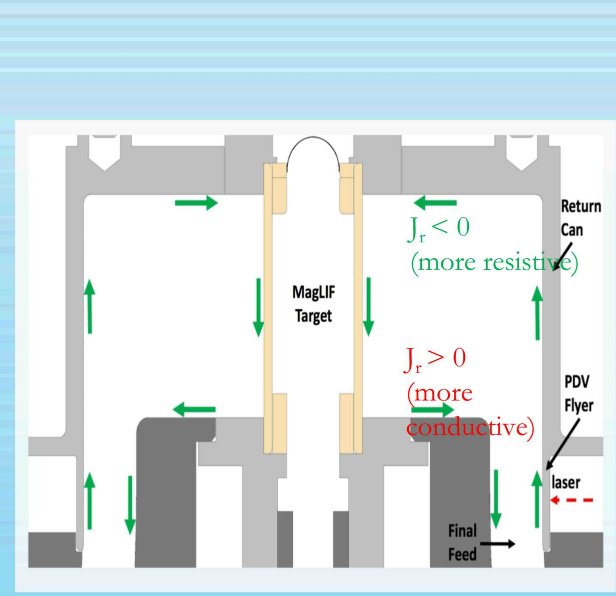
Faraday's law with Hall term:

$$-\frac{\partial \mathbf{B}}{\partial t} = \nabla \times \left[\eta \mathbf{J} - \mathbf{v} \times \mathbf{B} + \frac{\mathbf{J} \times \mathbf{B}}{ne}\right]$$

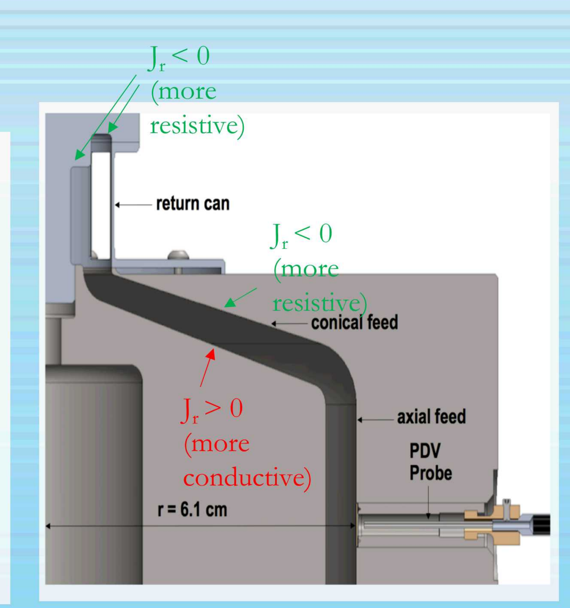
Faraday's law with Hall term and simplifying assumptions:

$$\frac{\partial (B_\theta \mathbf{e}_\theta)}{\partial t} = \eta \nabla^2 (B_\theta \mathbf{e}_\theta) - \frac{2 B_\theta J_r \mathbf{e}_\theta}{ner}$$

- The Hall term is only non-zero under these assumptions when B_θ couples to J_r (Hall term is zero in 1-D simulations where $J_r = 0$).
- $J_r < 0$: material becomes more **resistive** (**faster** B-field diffusion) than predicted by resistive MHD.
- $J_r > 0$: material becomes more **conductive** (**slower** B-field diffusion) than predicted by resistive MHD.



MagLIF Platform

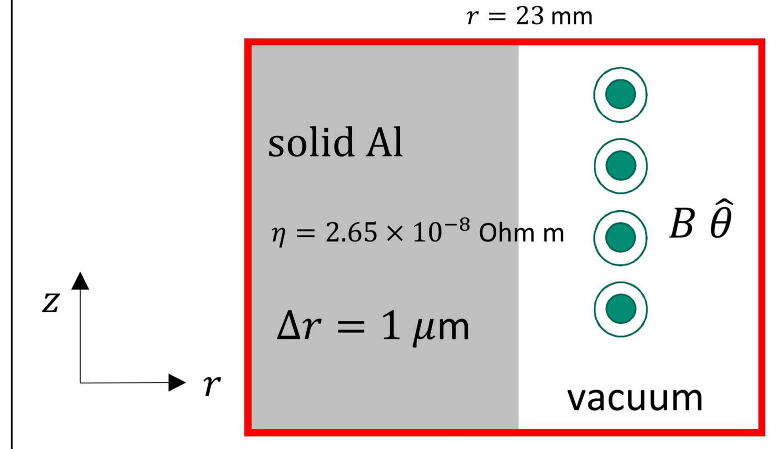


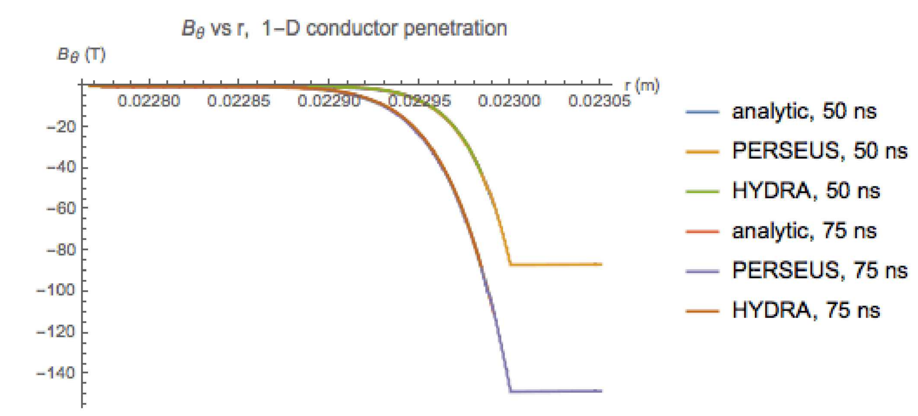
Power Flow Platform

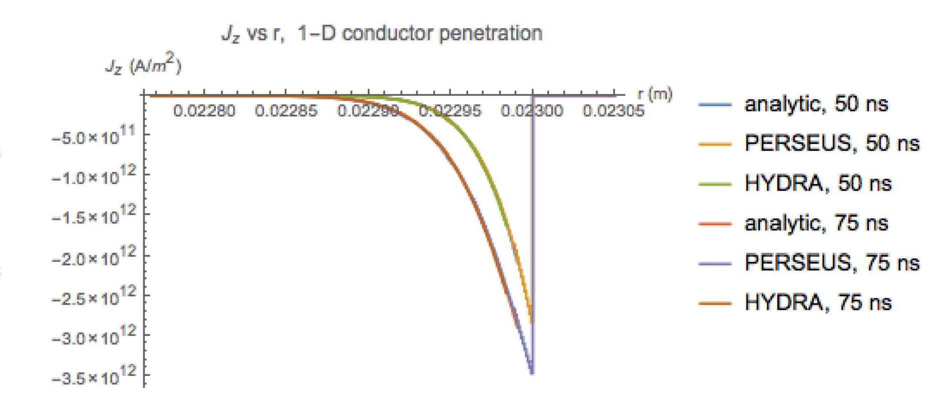
1-D magnetic diffusion:

very close agreement between PERSEUS, HYDRA, and analytic solution

System is not influenced by Hall MHD.



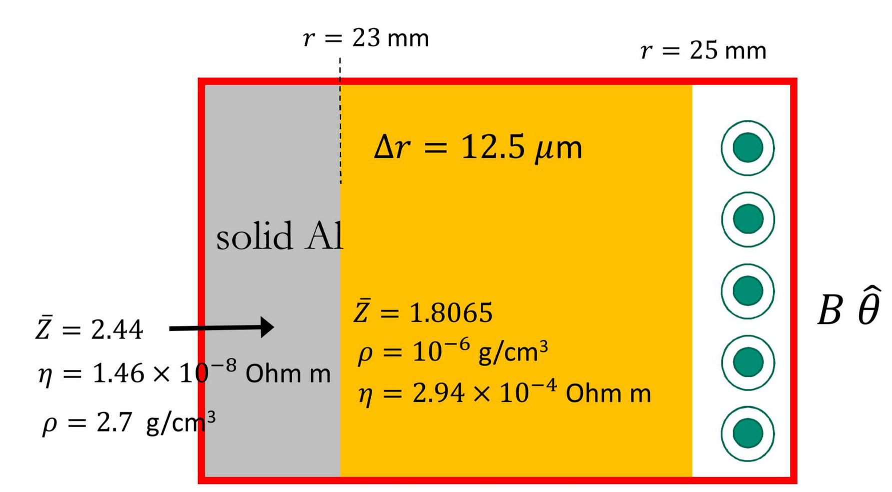


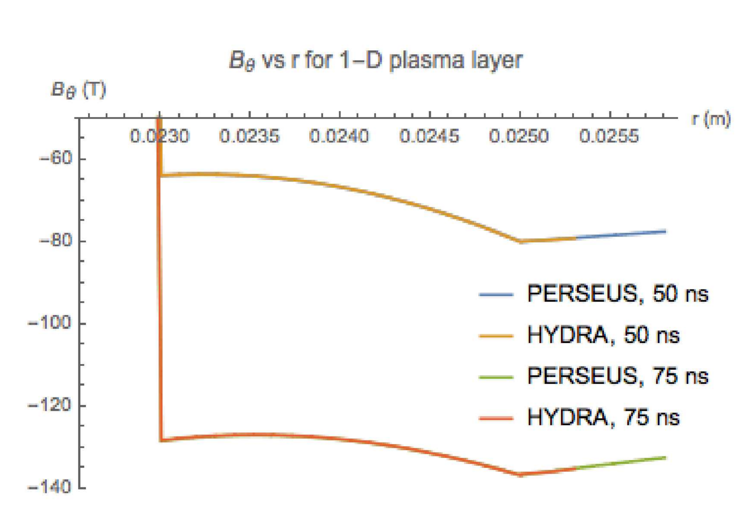


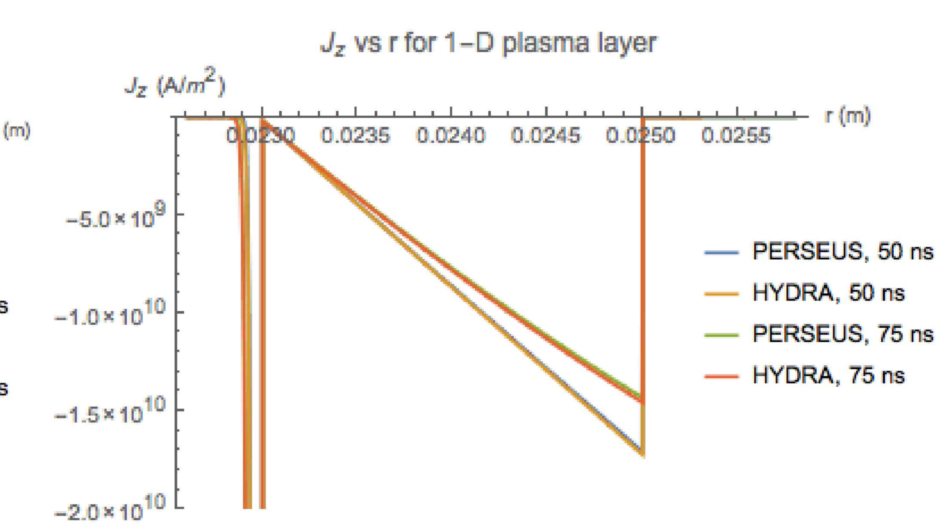
1-D magnetic diffusion into plasma

very close agreement between PERSEUS and HYDRA

System is not influenced by Hall MHD.

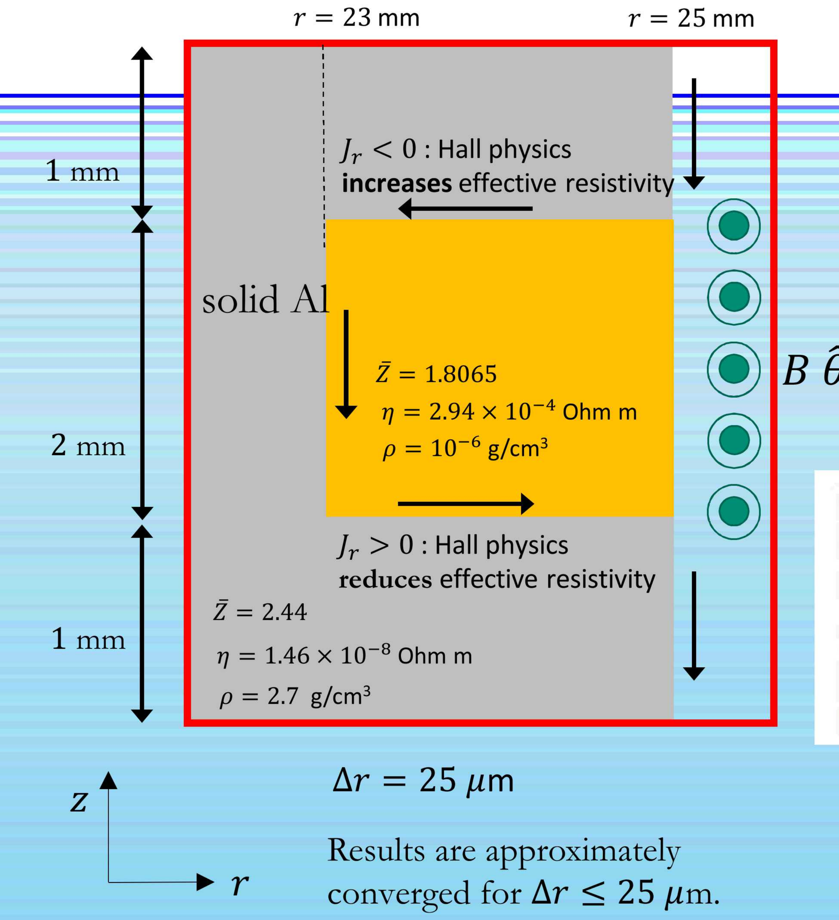






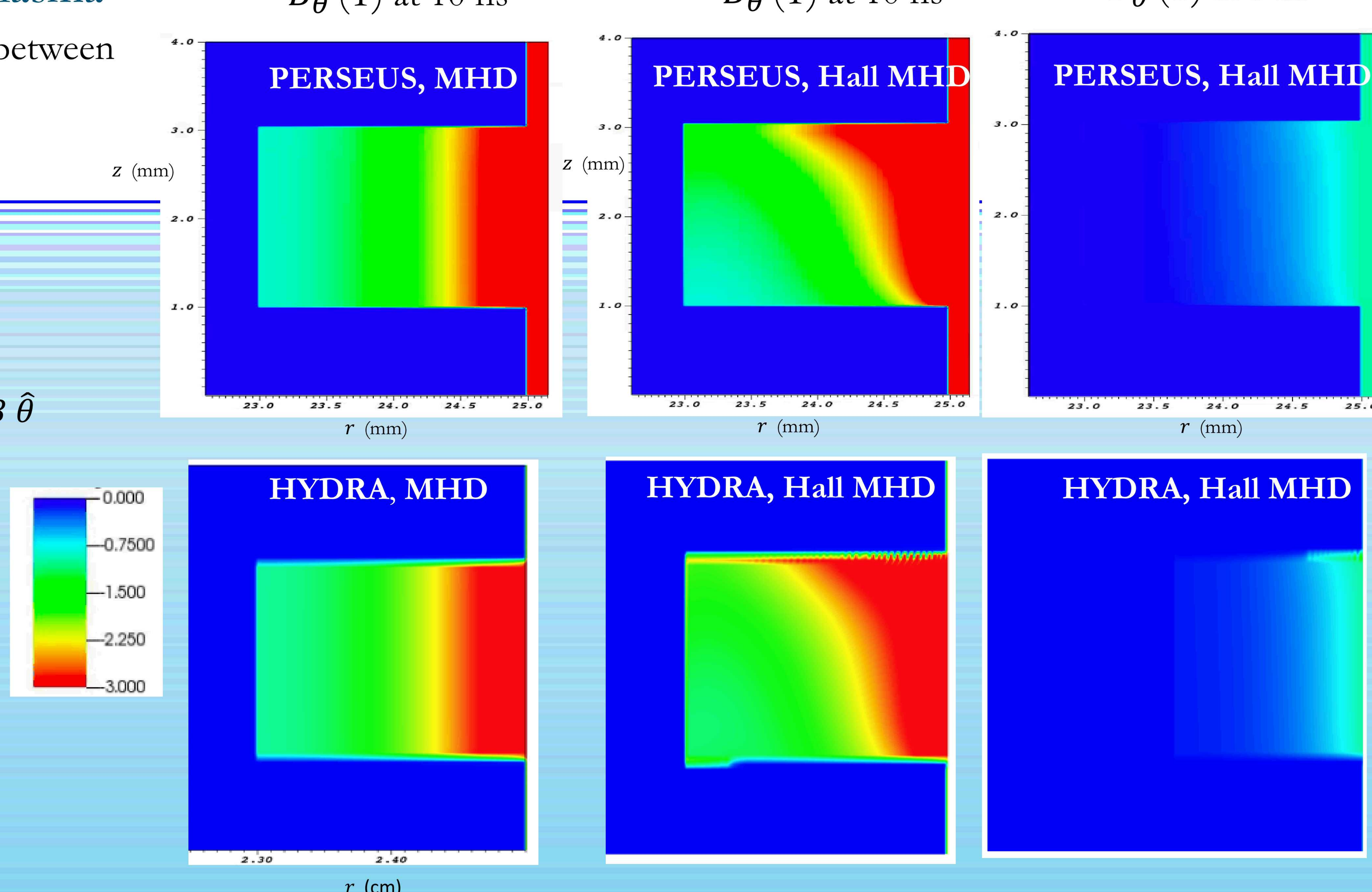
2-D magnetic diffusion into plasma

qualitative Hall MHD agreement between PERSEUS and HYDRA



$\Delta r = 25\ \mu m$

Results are approximately converged for $\Delta r \leq 25\ \mu m$.



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