NIF Hohlraum Modeling for Magnetically-Assisted Ignition

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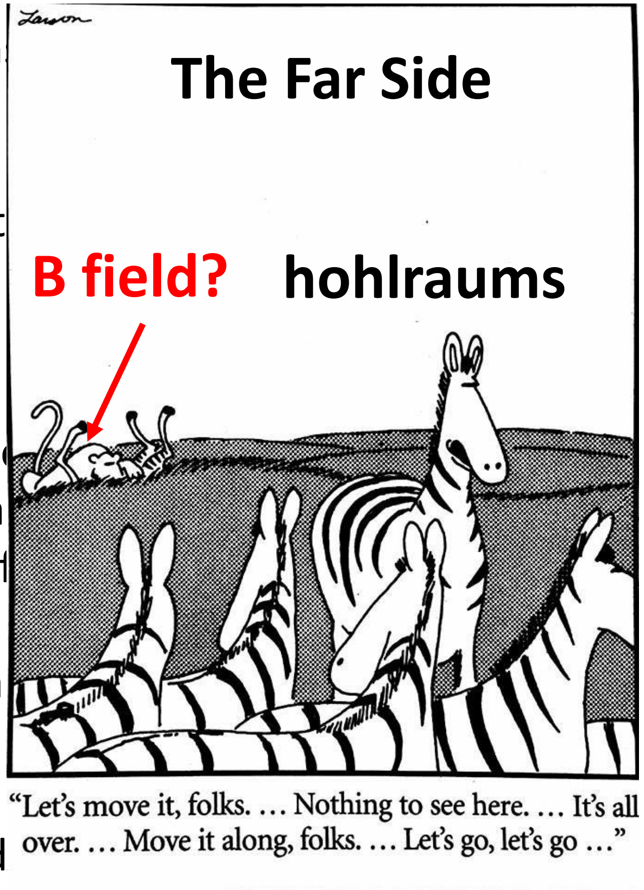
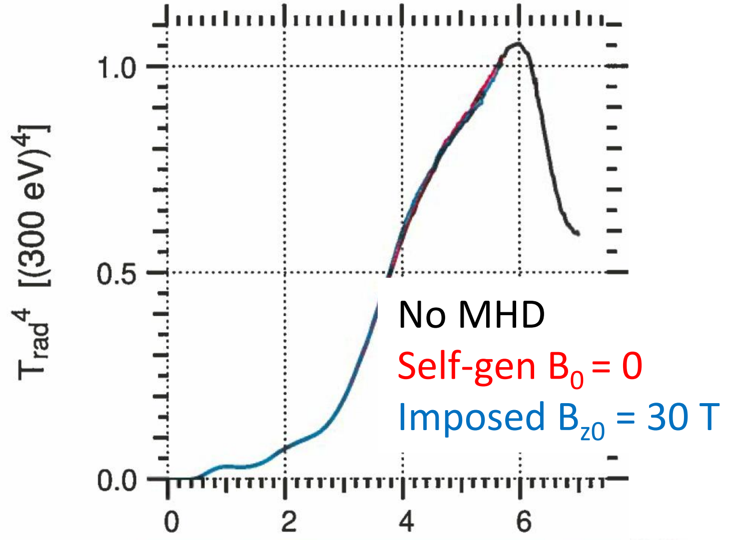
Self-generated and imposed magnetic fields: simulated to have minor effect on NIF-scale hohlraums

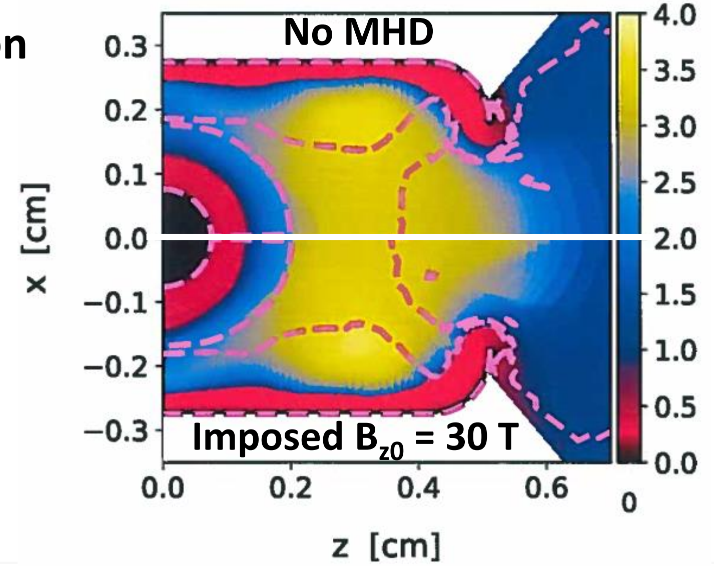
- **HYDRA MHD model:**
  - Full single-fluid Braginskii equation
  - Partial set used here for numerical
- **BigFoot subscale symcap:** starting point
- **Hohlraum dynamics:**
  - B field follows frozen-in law
  - e- Hall parameter >> 1 in fill: magn
  - Plasma pressure >> magnetic: beta
  - Temperature change: small with B f
- **X-ray flux:** small effect of B field on tota
- **Wall material:**
  - High resistivity Au+Ta alloy for field
  - X-ray drive slightly ***higher*** for Au1Ta1: “cocktail effect[1]”



Total x-ray flux



Electron temp. [keV]



[1] O. Jones, J. Schein, M. D. Rosen +, PoP 2007

HYDRA MHD Model: Full Single-Fluid Braginskii Implemented

Bulk momentum

$$\rho(\partial_t + \vec{V}\cdot\nabla)\vec{V} = -\nabla p + \vec{J}\times\vec{B}$$

Magnetic force: pressure + tension

$$\vec{J}\times\vec{B} = (\hat{\mathrm{b}}\hat{\mathrm{b}} - 1)\cdot\nabla\left(\frac{B^2}{2\mu_0}\right) + \frac{B^2}{\mu_0}\hat{\mathrm{b}}\cdot\nabla\hat{\mathrm{b}}$$

Maxwell

$$\partial\vec{B}/\partial t = -\nabla\times\vec{E}$$
$$\vec{J} = \mu_0^{-1}\nabla\times\vec{B}$$

Generalized Ohm's law

$$\vec{E} = -\vec{v}\times\vec{B} + \frac{1}{n_e e}\vec{J}\times\vec{B} - \frac{\nabla p_e}{n_e e} + \overleftrightarrow{\eta}\cdot\vec{J} - e^{-1}\overleftrightarrow{\beta}\cdot\nabla T_e$$

- advection / induction term; Hall term; Biermann battery — collisionless
- resistivity; thermal force e.g. Nernst — collisional

Electron heat equation

$$C_V(\partial_t + \vec{v}_e\cdot\nabla)T_e = \xi_{ei}(T_i - T_e) - \nabla\cdot\vec{q}_e + W_e - p_e\nabla\cdot\vec{v}_e + \cdots$$

$$\vec{q}_e = -e^{-1}T_e\overleftrightarrow{\beta}\cdot\vec{J} - \overleftrightarrow{\kappa}\cdot\nabla T_e$$ heat flux

$$W_e = \vec{J}\cdot\overleftrightarrow{\eta}\cdot\vec{J} - e^{-1}\vec{J}\cdot\overleftrightarrow{\beta}\cdot\nabla T_e$$ frictional heating

Simplifications in this work:
due to numerical issues

- No Seebeck physics: $\beta_{||} = \beta_{\perp} = 0$
- Scalar resistivity η
- No Hall term in Ohm's law
- No Righi-Leduc heat flow: $\kappa_{\wedge} = 0$

BigFoot[1] platform: starting point for magnetized design

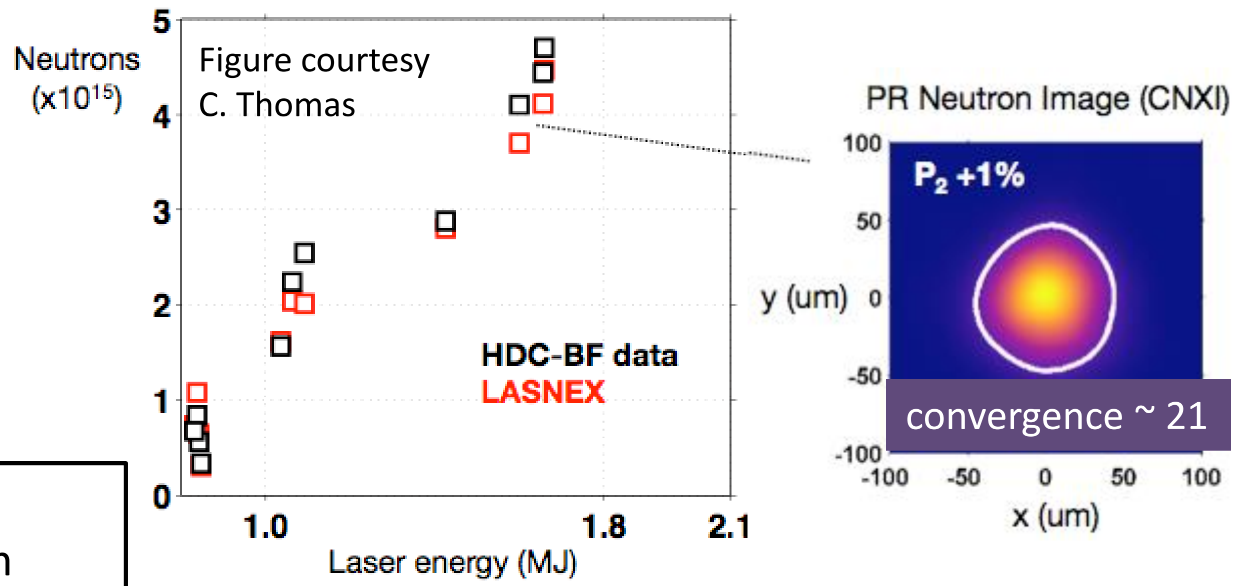
"Bigfoot" campaign on NIF

- Robust hotspot: High rho*R, high velocity
  - Price: high adiabat, lower convergence
- Shocks 1 and 2 overtake in ablator
- HDC capsule: short pulse, smooth capsules
- Simple hohlraum:
  - Low gas fill density: 0.3 mg/cc He
  - Low LPI: CBET + backscatter
  - Au: low flakes / meteors vs. DU
- Highest yield on NIF

Why BigFoot?

- Don't re-invent wheel: use existing high-yield cryo platform
- Nice features: predictable, tunable, low LPI
- "Goldilocks convergence":
  - Enough to amplify B field, reduce hotspot e- conduction
  - Not so much for significant hydro instabilities or mix

BigFoot gas-filled capsules:
Equivalent DT yield: agrees with Lasnex
13-15 MeV neutrons from DD, D3He, …



1 C. Thomas, APS-DPP invited talk, 2016; K. Baker+, PRL 2018

We model BigFoot NIF shot N161204: subscale gas-filled capsule

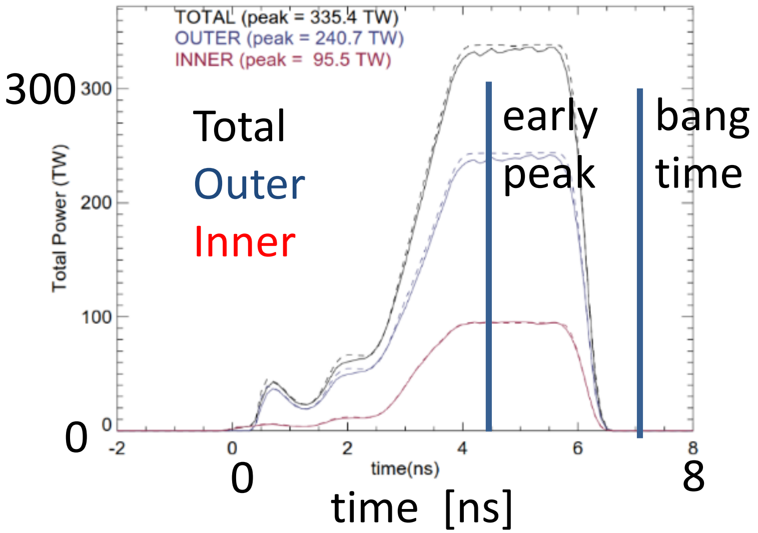
N161204: BigFoot subscale gas-filled capsule

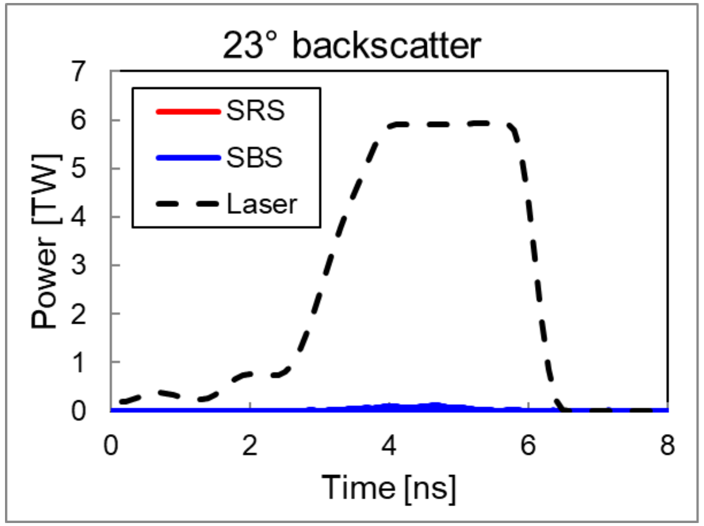
- Less taxing on laser and optics:
  - 1.1 MJ, 340 TW
- Capsule fill: D[30%] + He3[70%]
  - 6.5 mg/cc
  - Symcap: no DT ice layer

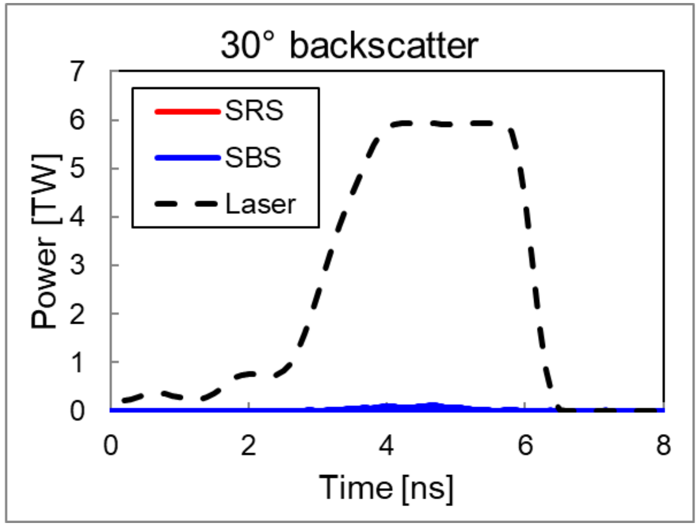
Low backscatter

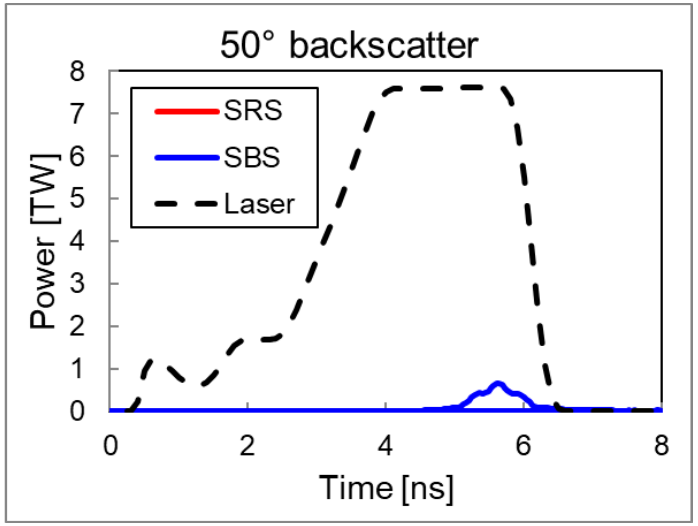
- Coupling 98.8%
- SBS on cone 50 late in time

Laser power [TW]





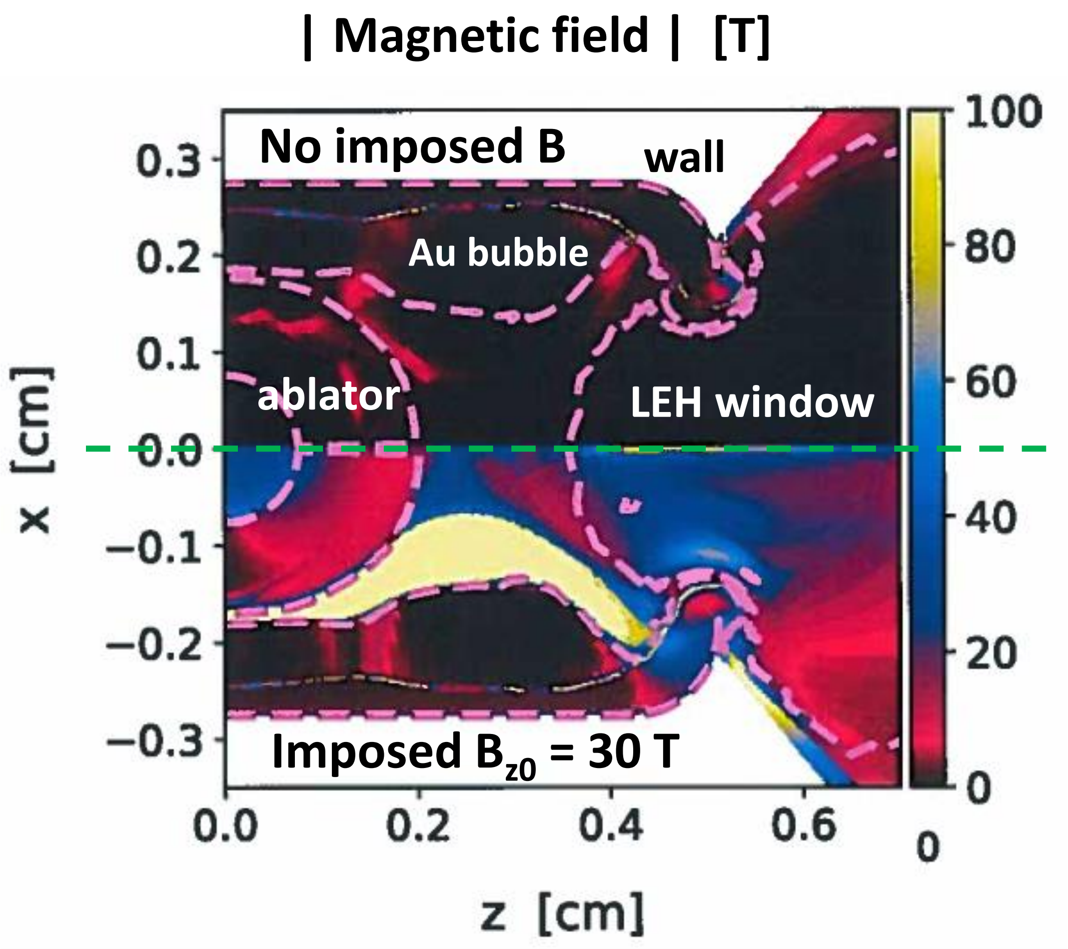


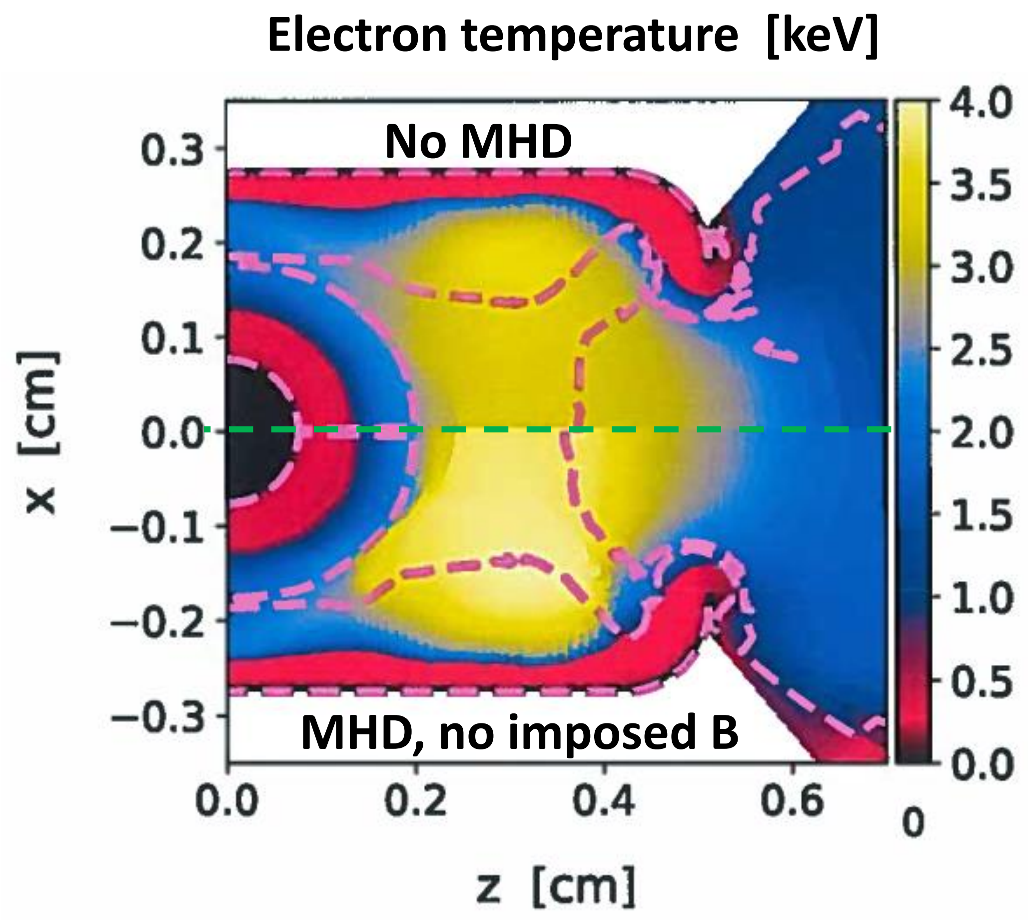


Hohlraum dynamics: frozen-in B field, small temperature change from self-generated B

4.5 ns: early peak power

BigFoot Symcap





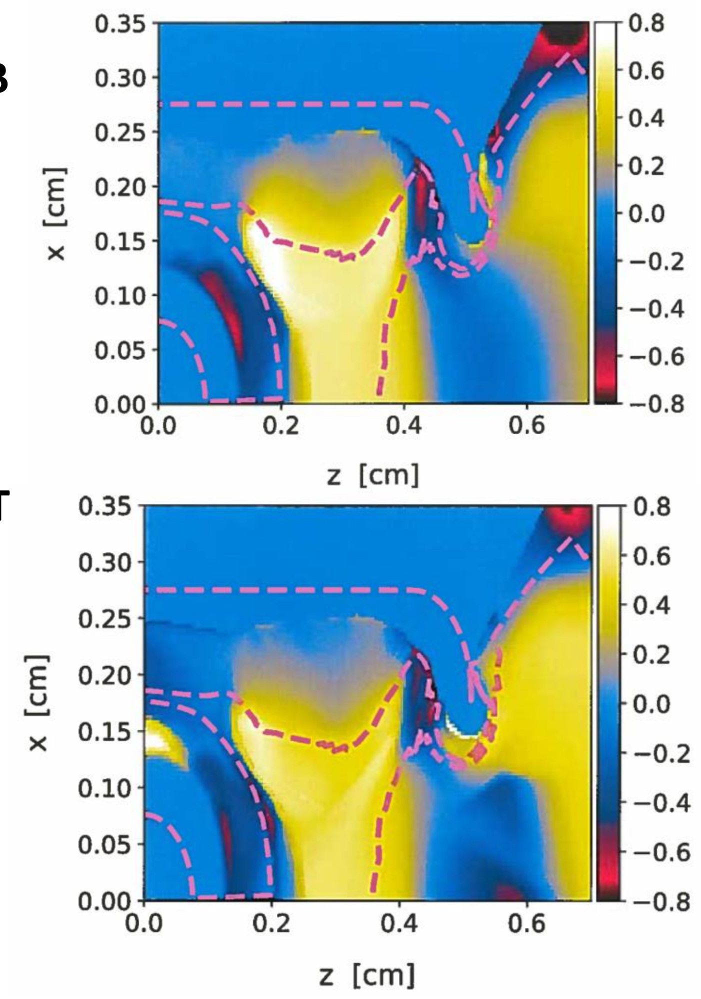
Hohlraum dynamics: small temperature change from imposed 30 T B_z field

T_e difference [keV]

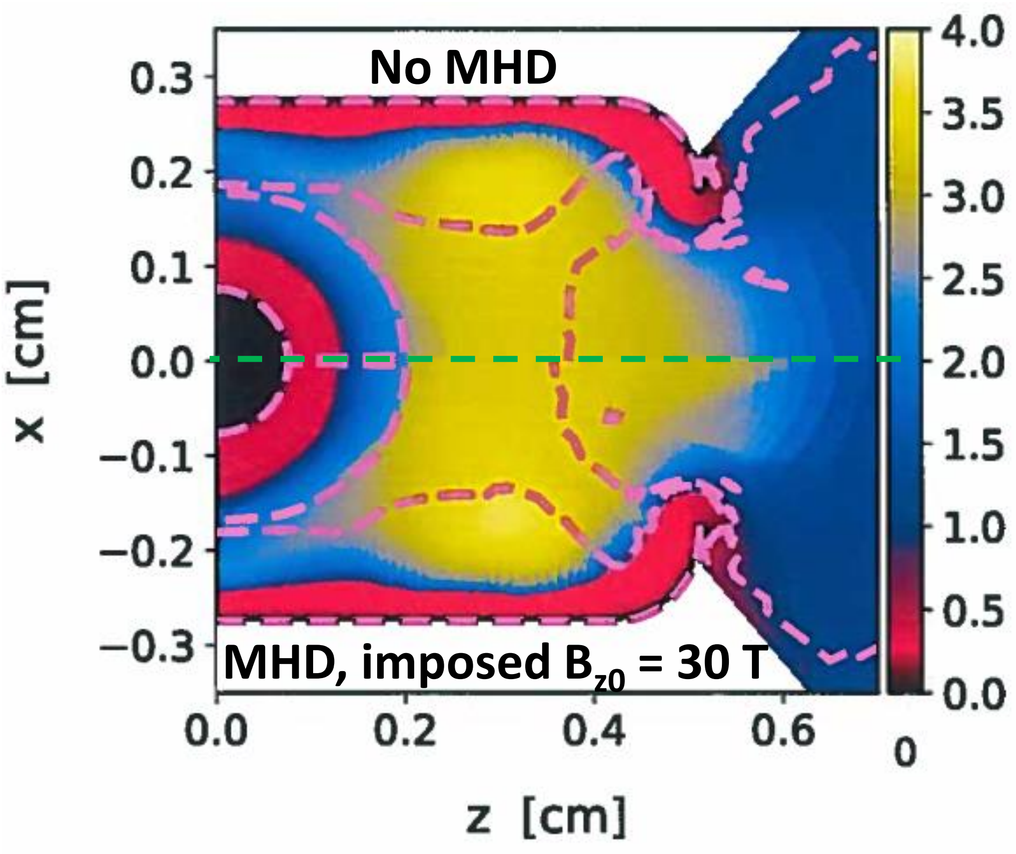
BigFoot Symcap

Self-gen B
- no MHD

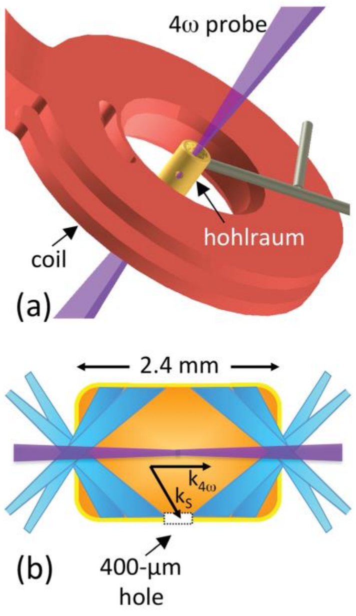
Self-gen B
- B_{z0} = 30 T



Electron temperature [keV]



Higher T_e seen in magnetized hohlraum experiments on Omega: Montgomery et al., 2015



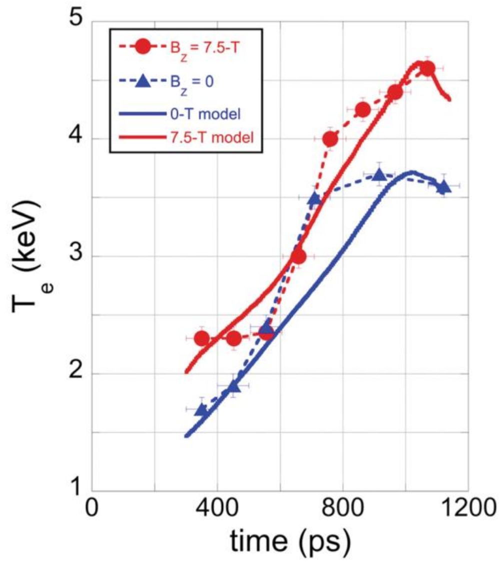


FIG. 3. Measured electron temperature versus time for B = 0 (blue triangles) and B = 7.5-T (red circles). Over-plotted as solid lines are the 2-D HYDRA model for B = 0 (blue) and B = 7.5-T (red).

Comparison with Montgomery+ PoP 2015

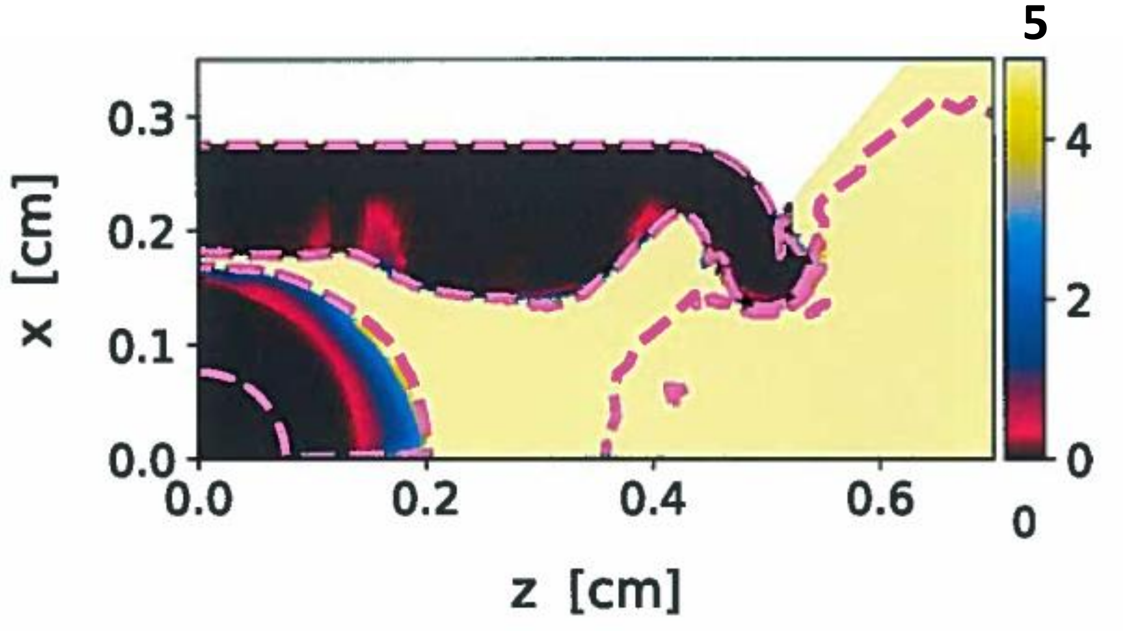
- Omega+MIFEDS hohlraum expt's
  - B_{z0} = 7.5 T, gas-filled, no capsule
- NIF hohlraums: much different scale:
  - Larger, 50x laser energy, 6-7x longer pulse
  - More time to reach quasi-equilibrium

Hohlraum dynamics with imposed B_z = 30 T:
e- Hall parameter large in fill, magnetic pressure unimportant

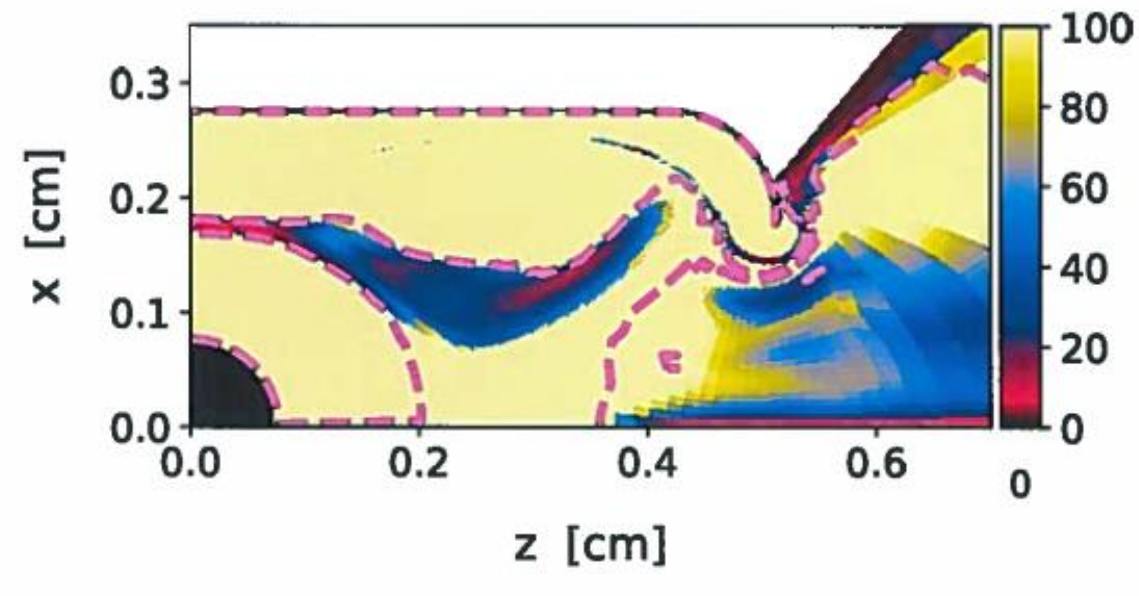
4.5 ns: early peak power

BigFoot Symcap

e- Hall parameter: $\omega_{ce}\tau_{ei}$



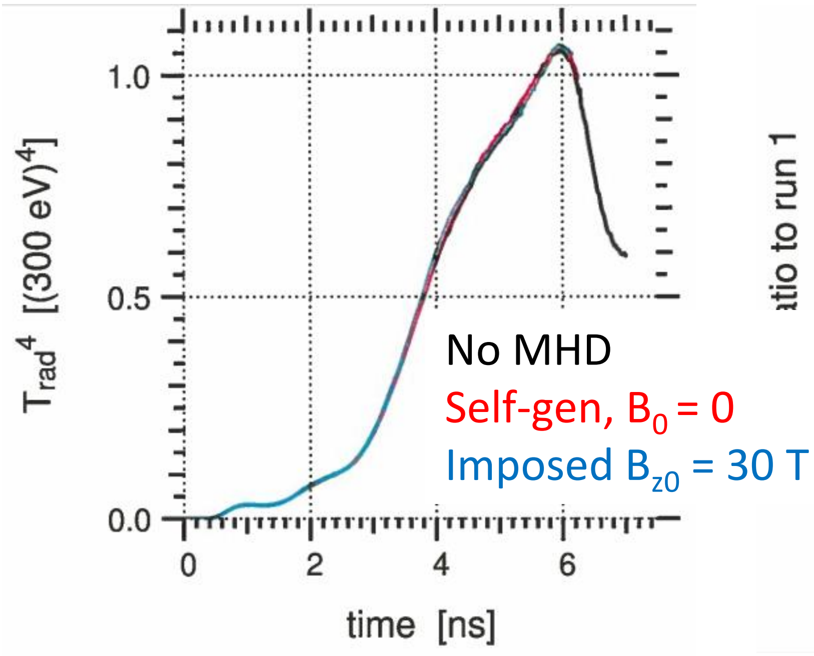
beta: plasma / magnetic pressure



Prior work on MHD in hohlraums
- D. Strozzi+, JPP 2015 – imposed B_z in high-gas-fill hohlraum
- W. Farmer+, PoP 2017 – self-generated B

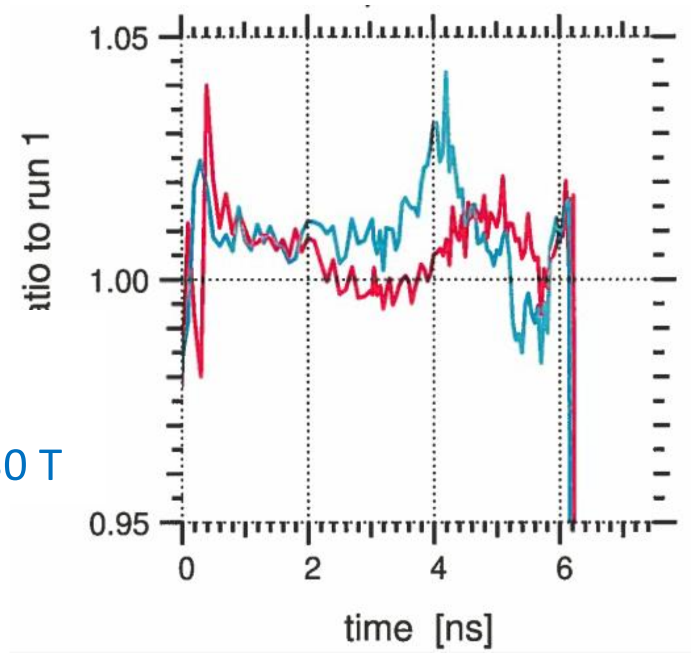
X-ray flux on capsule: small effect of B fields on drive or symmetry

Drive: total x-ray flux

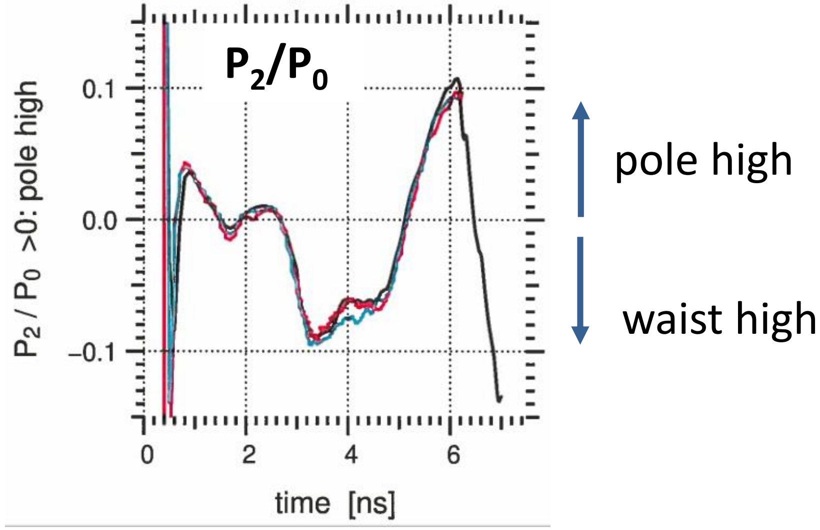


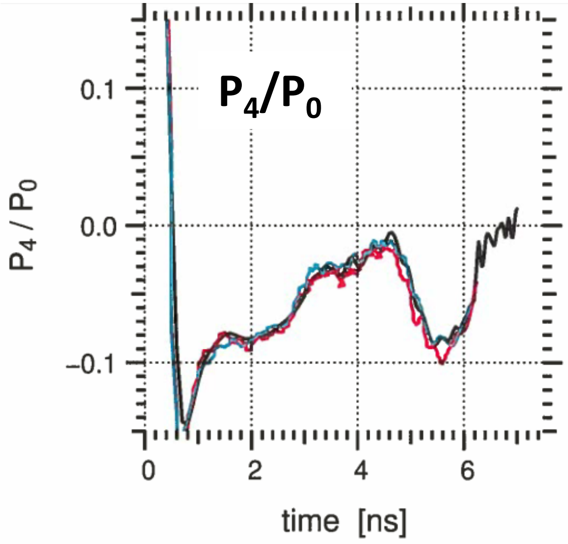
Yes, there are 3 curves

Flux ratio to no-MHD run



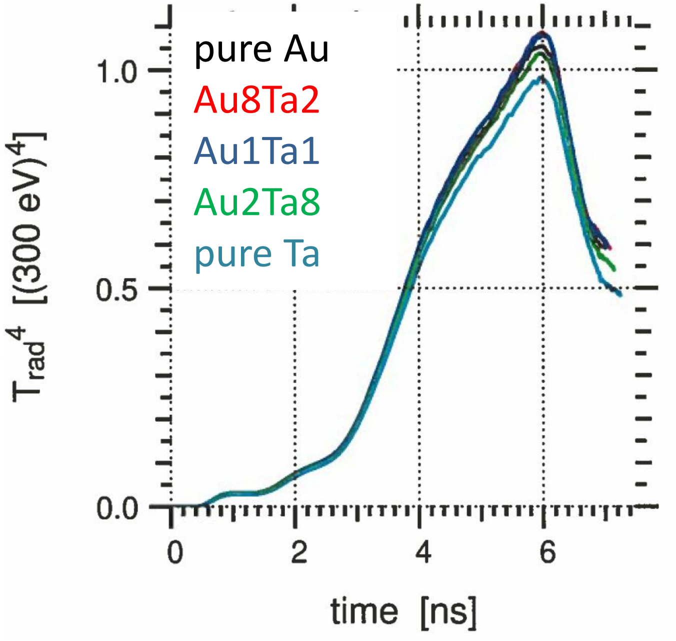
Flux asymmetries





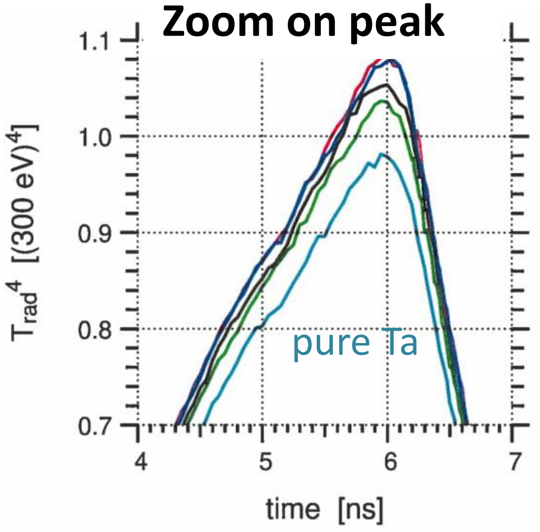
Au+Ta alloys: more resistive than Au, small effect on x-ray drive

x-ray flux on capsule

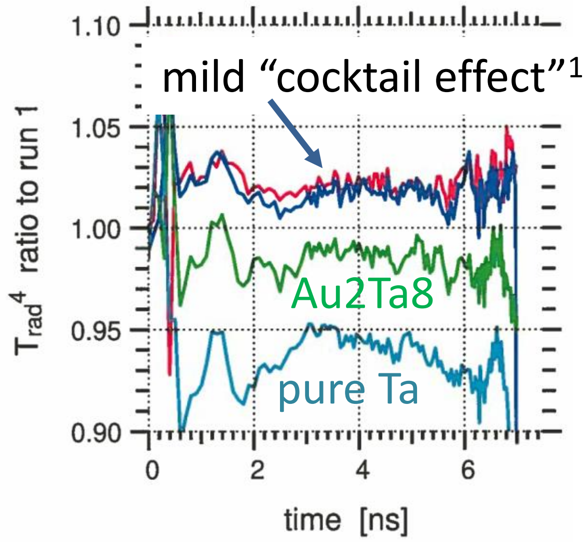


Same atom density as pure Au

Zoom on peak

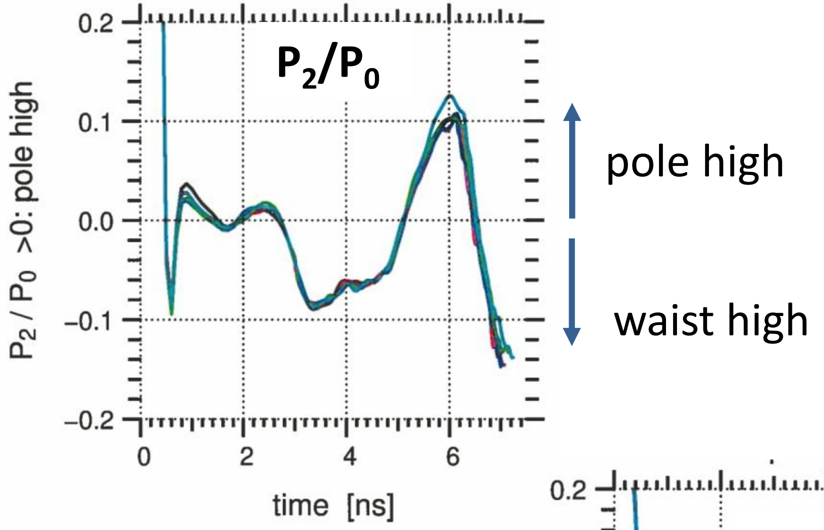


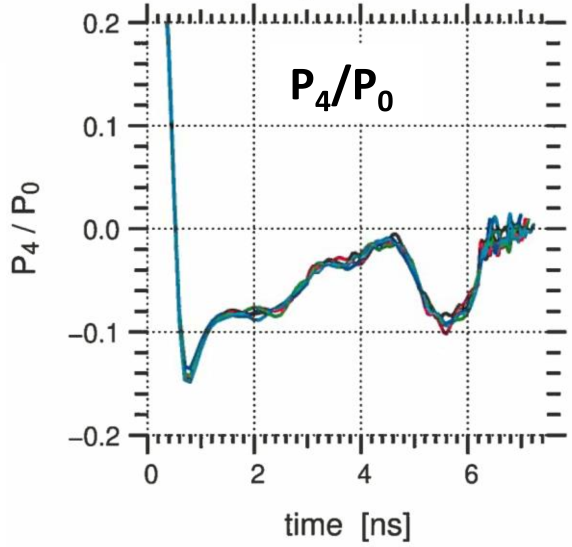
Ratio to pure Au



[1] O. Jones, J. Schein, M. D. Rosen +, PoP 2007

Flux asymmetries: small effect from wall material





Magnetized hohlraums: path forward

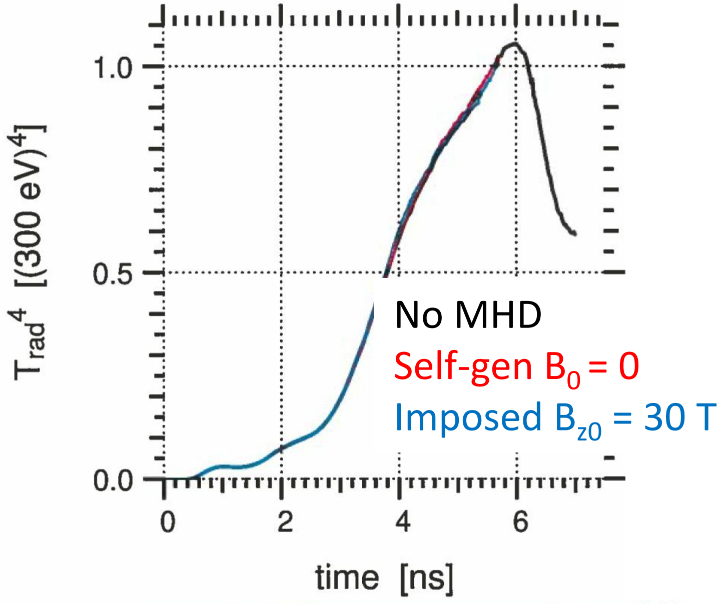
Summary

- BigFoot subscale symcap: starting point for magnetized design
- Hohlraum dynamics:
  - B field follows frozen-in law
  - e- Hall parameter >> 1 in fill: magnetized e- heat flow
  - Plasma pressure >> magnetic: beta >> 1
  - Temperature change: small with B field
- X-ray flux: small effect of B field on total drive and asymmetry
- Wall material:
  - High resistivity Au+Ta alloy for field soak-thru
  - X-ray drive slightly ***higher*** for Au1Ta1: "cocktail effect"

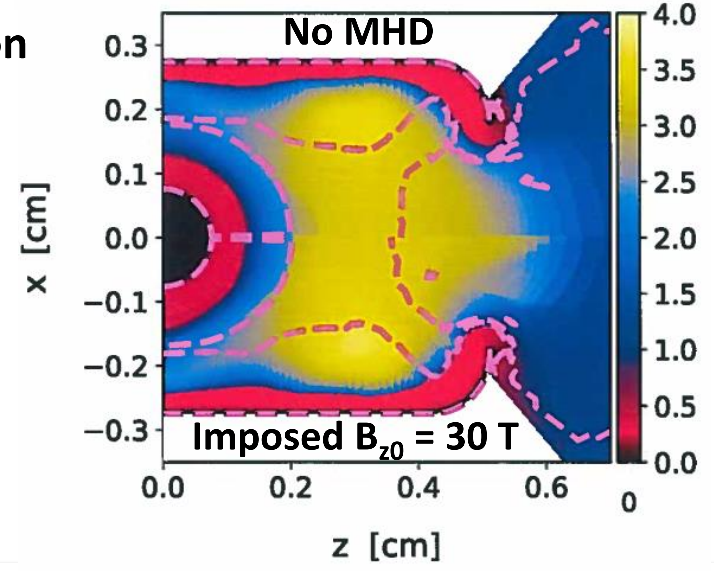
Future Work

- Room-temperature magnetized design for FY20 NIF shots
  - C5H12 hohlraum fill gas
  - High-resistivity wall
- Include full Braginskii MHD
- Nonlocality in e- transport and MHD

Total x-ray flux

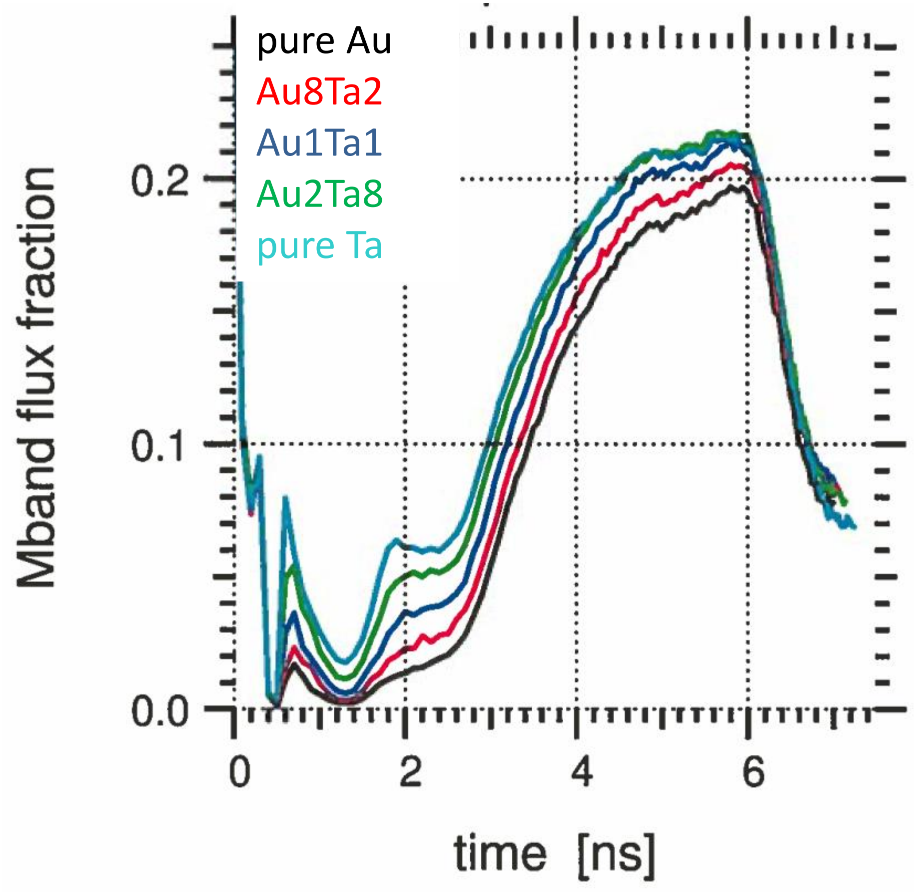


Electron temp. [keV]



BACKUP BELOW

M-band fraction increases w/ Tantalum fraction



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