Design of magnetized, gas-filled capsule experiments for NIF

Meeting on Magnetic Fields in Laser Plasmas

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Magnetic fields in hohlraums and capsules: MHD Hydra simulations

Main effect of B field: reduced e- heat conduction perpendicular to B: $\omega_{ce}\tau_{ei} > 1$
Magnetic pressure << matter pressure: $\beta >> 1$

New in this talk:

- Hohlraum sims of "bigfoot" NIF design
- Imposed axial field, "Biermann battery" fields and Nernst advection

No imposed B field: similar to W. Farmer, 2017[1]

- Biermann fields → hotter hohlraum fill
- Nernst advection reduces effect of B field
- Modest effect on implosion
- Small fields in capsule: < 50 T

1 W. A. Farmer et al., Phys. Plasmas 2017
2 D. J. Strozzi et al., J. Plasma Phys. 2015
3 L. J. Perkins et al., LLNL LDRD final report

Imposed axial field: similar to D. Strozzi, 2015[2,3]

- Frozen-in law holds: B field compressed or rarified with plasma
- ***Slightly*** hotter hohlraum fill
- Improved inner-beam propagation: hotter, less-dense equator channel
- Capsule fields ~ 2 kT
- Gas-filled capsule yields increase up to 2x

"Bigfoot"[1] platform: starting point for warm magnetized design

"Bigfoot" campaign on NIF

- Robust hotspot: High rho*R, high velocity, high adiabat, lower convergence
- Shock overtaking in ablator
- Simple hohlraum: low gas fill, short laser pulse, low LPI
- HDC capsule: short laser pulse, smooth capsules
- Tied for highest yield on NIF

1 C. Thomas, APS-DPP invited talk, 2016

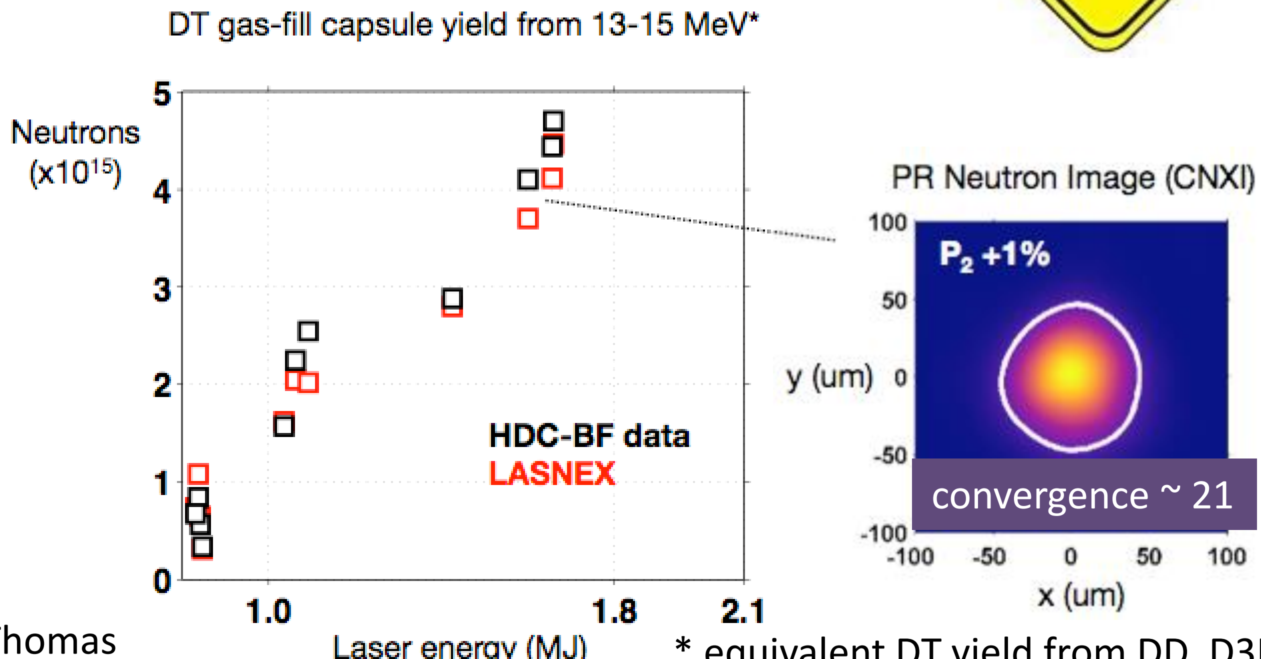


Figure courtesy C. Thomas

* equivalent DT yield from DD, D3He, …

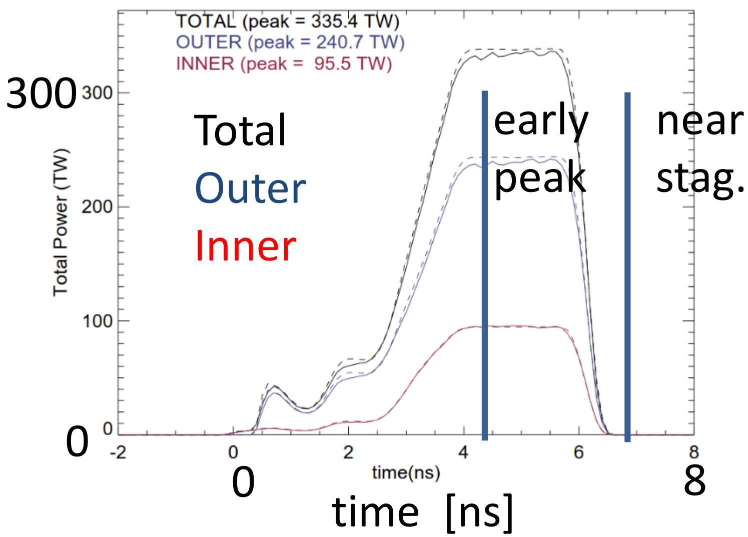
Why Bigfoot for warm magnetized design?

- Don't re-invent the wheel
- "Nice" features → predictable, easy to tune
  - Low LPI, low convergence
- But not so "nice" to be irrelevant!
  - Enough convergence to amplify B field, reduce e- conduction
  - Connection to existing, high-performance cryo platform

N161204: bigfoot NIF shot

- "Subscale" target: less taxing on laser:
  - 1.1 MJ, 340 TW
- Symcap: gas-filled capsule: D[30%]-He3[70%]
  - 5.5 mg/cc
  - no DT ice layer
- HDC capsule, W dopant
- Au hohlraum
- Low hohlraum gas fill density: 0.3 mg/cc He4

Laser power [TW]



HYDRA MHD model: Single-fluid Braginskii

Bulk momentum:

$$\rho \frac{D\vec{v}}{Dt} = -\nabla p + \vec{J} \times \vec{B}$$

Magnetic pressure:

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

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* — collisional

- Plus analogs in electron energy equation
- Full Braginskii available in HYDRA
- No nonlocal limiting of Nernst: Brodrick, Sherlock

Just Nernst advection (draw B to lower T_e)
No Righi-Leduc in energy eq.

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

→HYDRA Simulations: no imposed field

HYDRA Simulations: imposed axial field

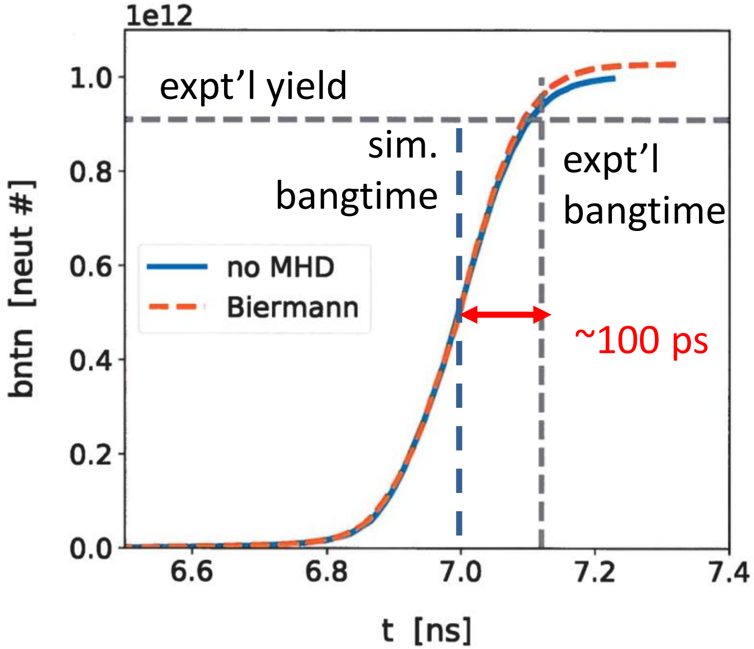
N161204 "post-shot" sims: no imposed B field: Close on bangtime and yield

HYDRA methodology
- R-Z axisymmetric
- "HyPyD": Pythonic framework:
  J. Koning, J. Salmonson
- DCA non-LTE: Sept. 2017 model: H. Scott
- Electron heat flux limit f = 0.15 (high)
- X-rays on capsule artificially symmetrized

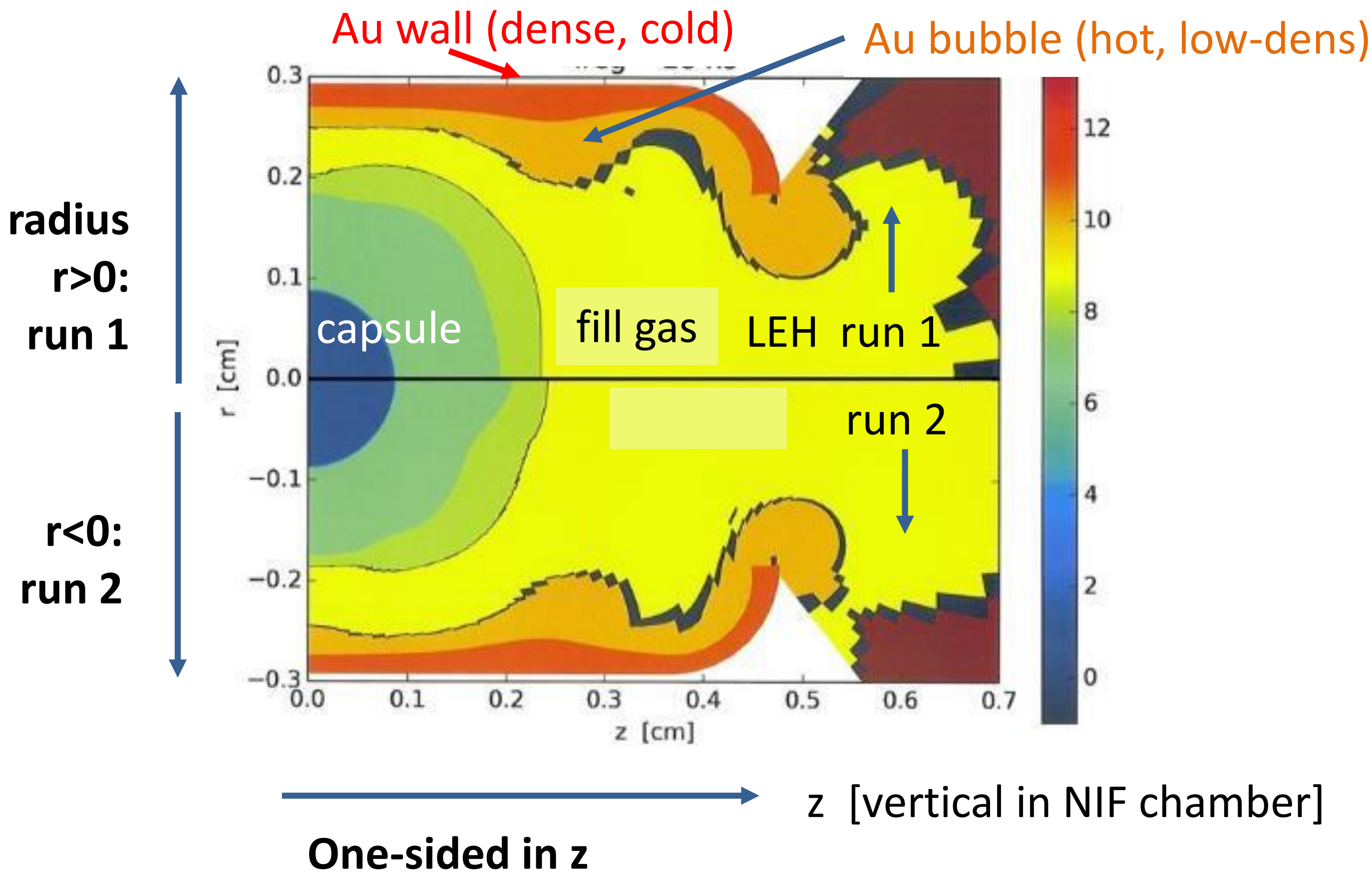
Ohm's law: this slide
$$\vec{E} = -\vec{v} \times \vec{B} - \frac{\nabla p_e}{n_e e} + \eta \vec{J}$$

Without any hand tuning
- Sims' bangtime slightly early ~ 100 ps
- Sims 10% above measured yield
- Biermann fields have little effect

neutron yield



Hohlraum map legend



N161204: Biermann fields increase T_e, Nernst advection reduces the effect

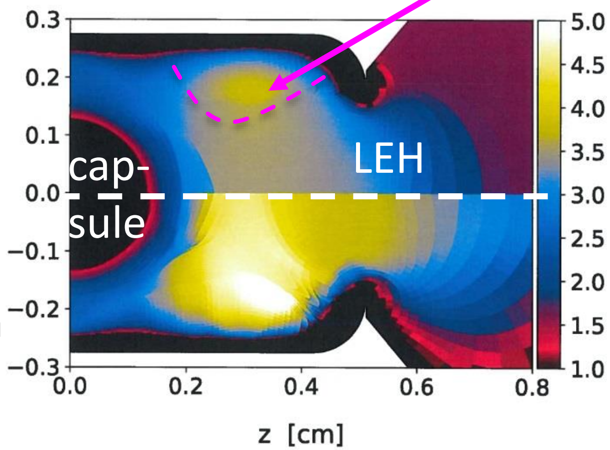
Same story as Farmer 2017

Plots at 4.25 ns: early peak power

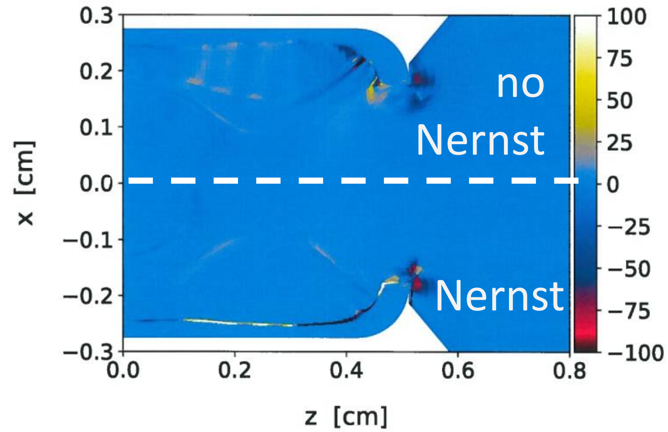
T_e [keV]

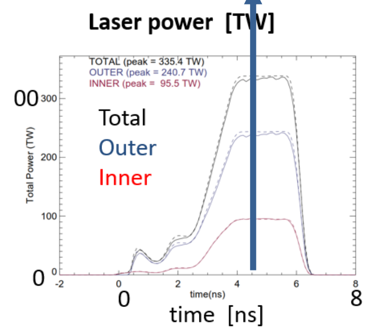
no MHD

Biermann



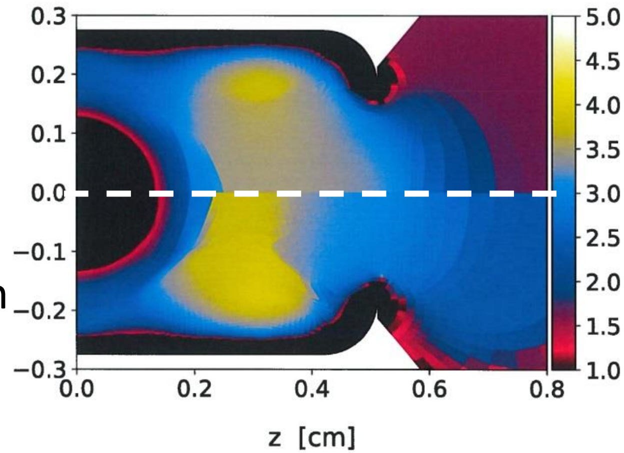
Azimuthal B [T]



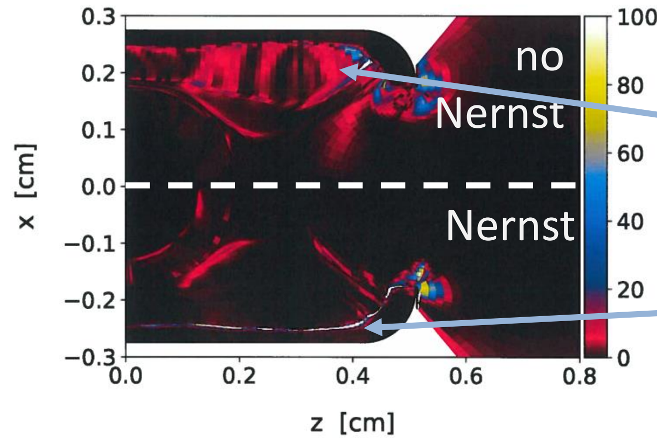


no MHD

Biermann + Nernst



|B| [T] linear scale



* Nernst advection “erases” much of Biermann field

* Draws field deeper in to cold Au wall

Hohlraums, no imposed field: Farmer PoP 2017

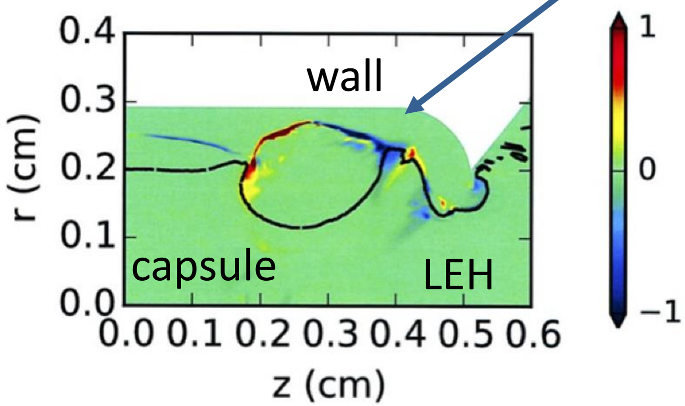
NIF shot N151122
HDC capsule
0.3 mg/cc hohlraum gas fill

MHD: Biermann + Nernst

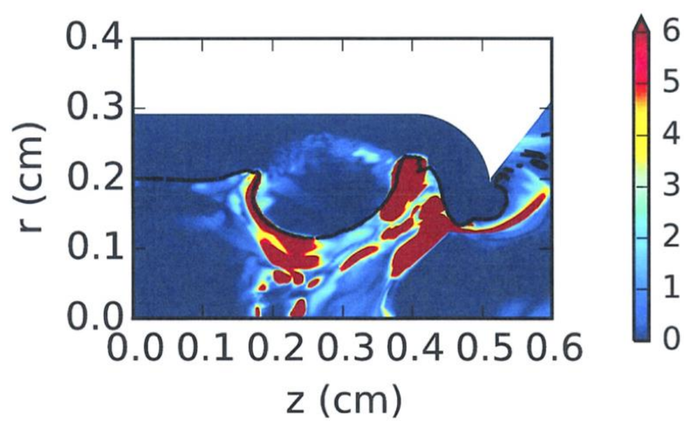
Farmer '17

Highly localized
~ 100 T fields

azimuthal B [MG]



Hall parameter $\omega_{ce}\tau_{ei}$

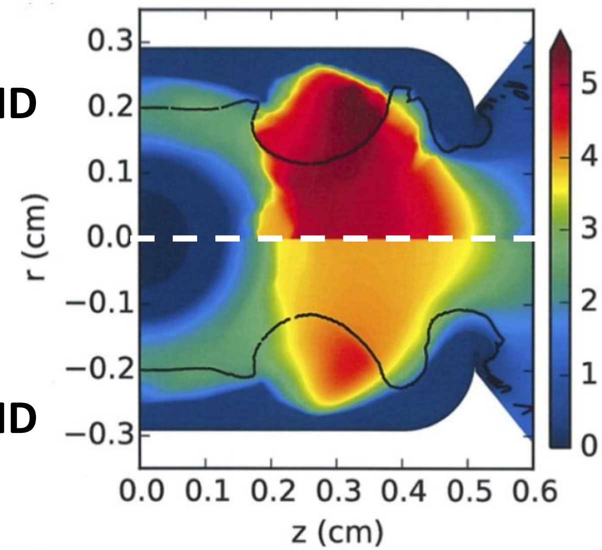


Plots at 5 ns:
late peak power

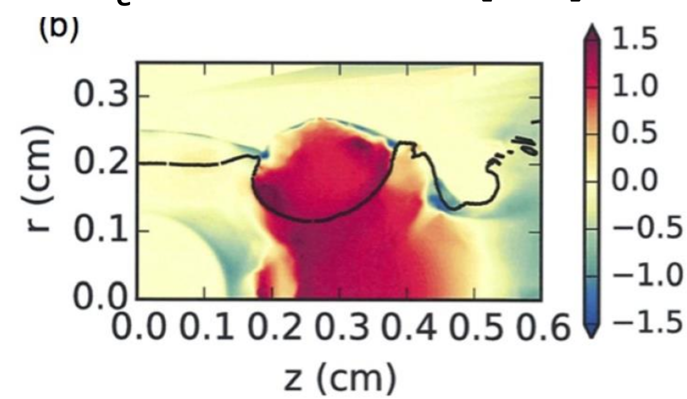
T_e [keV]

MHD

No MHD



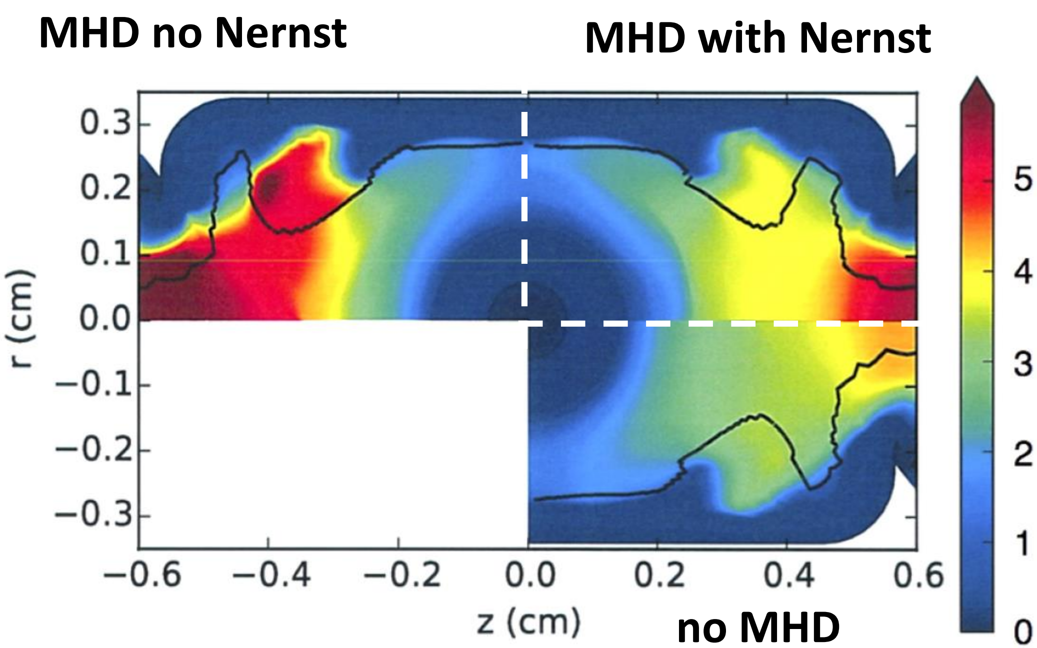
T_e MHD – no MHD [keV]

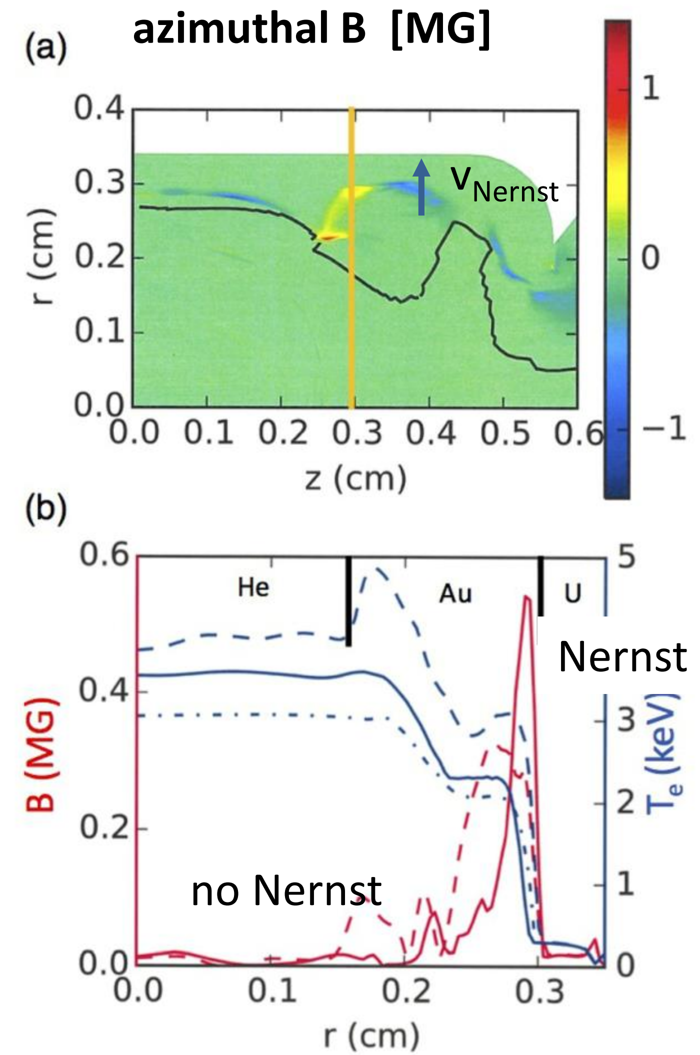


Hohlraums, no imposed B: Nernst advection reduces effect of B field

Farmer '17

"High foot" design
CH capsule
0.6 mg/cc hohlraum gas fill





"What Biermann giveth, Nernst taketh away"
– M. D. Rosen

HYDRA Simulations: no imposed field

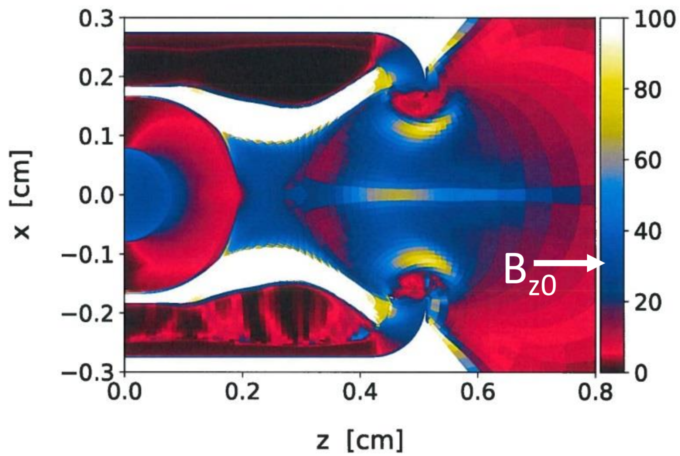
→HYDRA Simulations: imposed axial field

N161204: Imposed B_{z0} = 30 T: field "adds" with Biermann in bubble / LEH

|B| [T]: same colormap

Plots at 4.25 ns: early peak power

B_{z0} = 30 T
E = vxB + eta*J

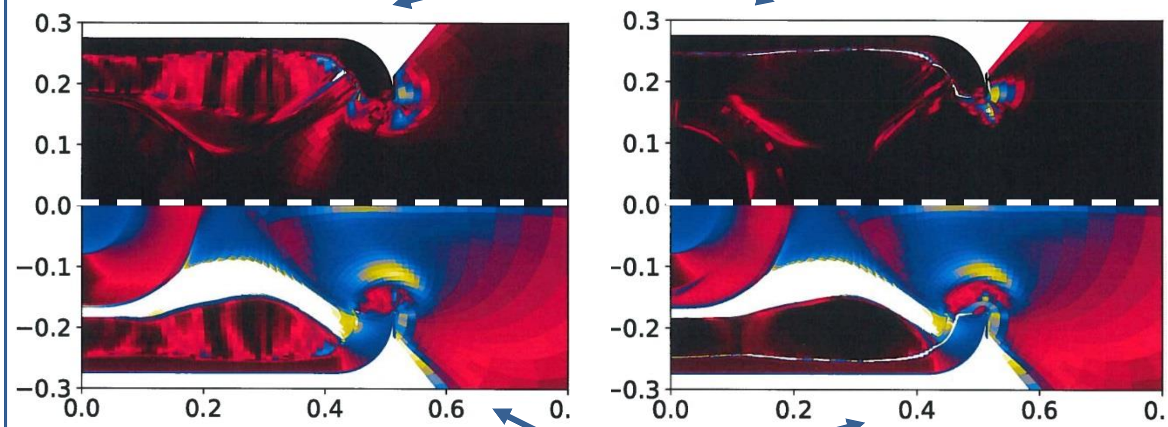


B_{z0} = 30 T
E += Biermann

E += Biermann

E += Biermann + Nernst

no B_{z0}



B_{z0} = 30 T

- Imposed-field dynamics unchanged by Biermann or Nernst
- Biermann fields unchanged by imposed – at least by eye

N161204: Imposed B_{z0} = 30 T: little effect on hohlraum fill vs. Biermann

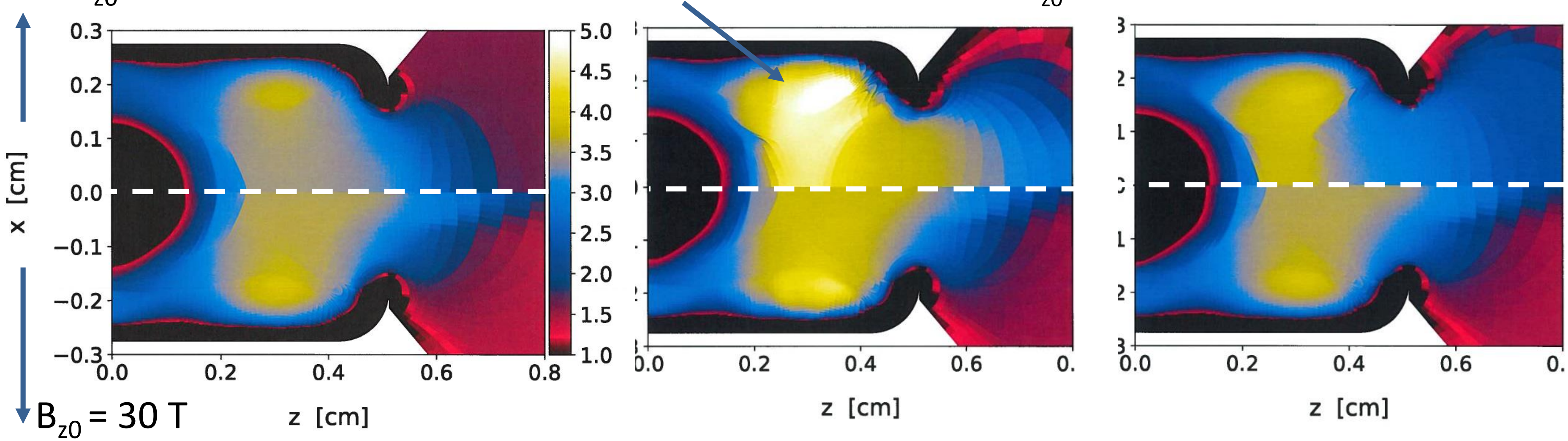
T_e [keV]: same colormap

Plots at 4.25 ns: early peak power

E = vxB + eta*J | E += Biermann | E += Biermann + Nernst

no B_{z0}

Au bubble *hotter* without B_{z0}!



Why small effect from B_{z0}?

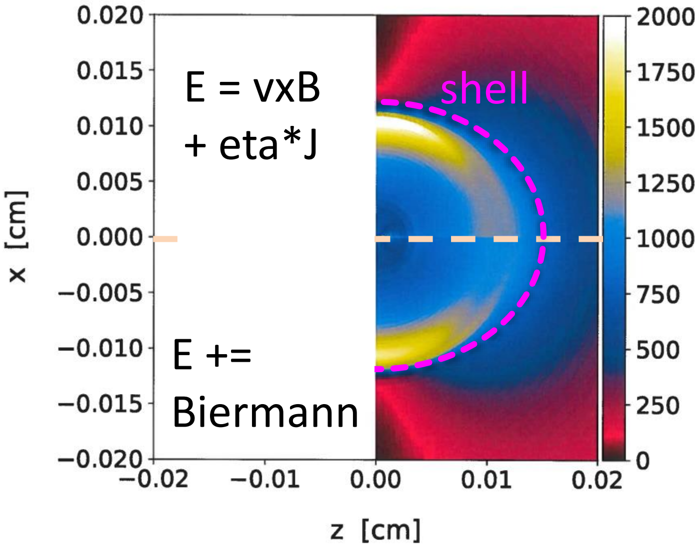
- Hall parameter > 1 in He gas fill with imposed field – not a "small field"
- imposed B reduced in Au bubble due to expansion: Frozen-in law
- Axial imposed field → B in r-z plane: heat flow only reduced in 1 meaningful direction
- Biermann azimuthal field → 2 directions reduced
- Seems we need B inside Au to increase T_e: Biermann does, imposed doesn't

N161204: Imposed B_{z0} = 30 T: capsule B field ~ 2 kT; Biermann fields small

|B| [T]: same colormap

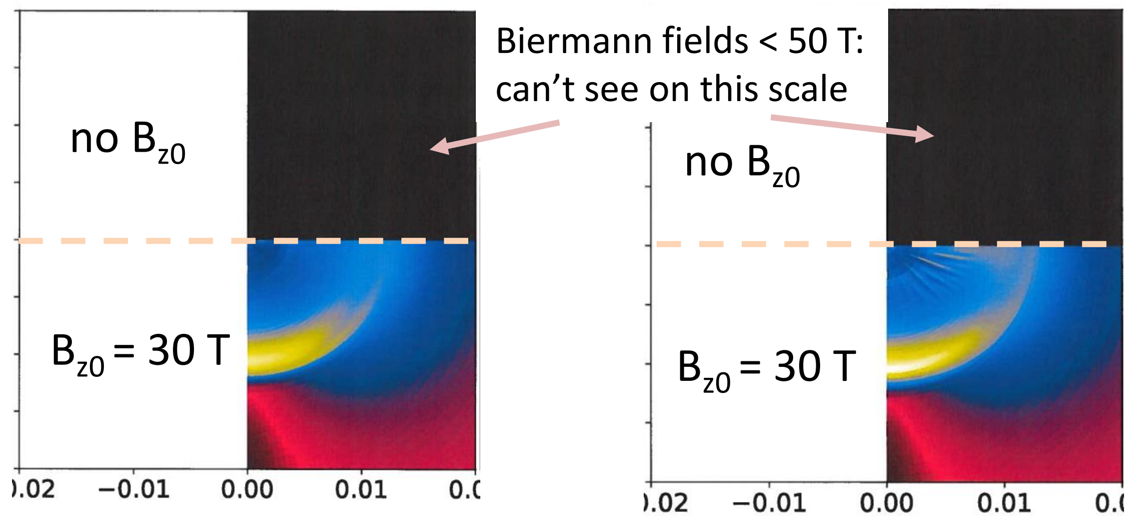
Plots at 6.75 ns: 0.25 ns before bangtime
x-ray flux on capsule artificially symmetrized

B_{z0} = 30 T



E += Biermann

E += Biermann + Nernst



Frozen-in estimate of field increase

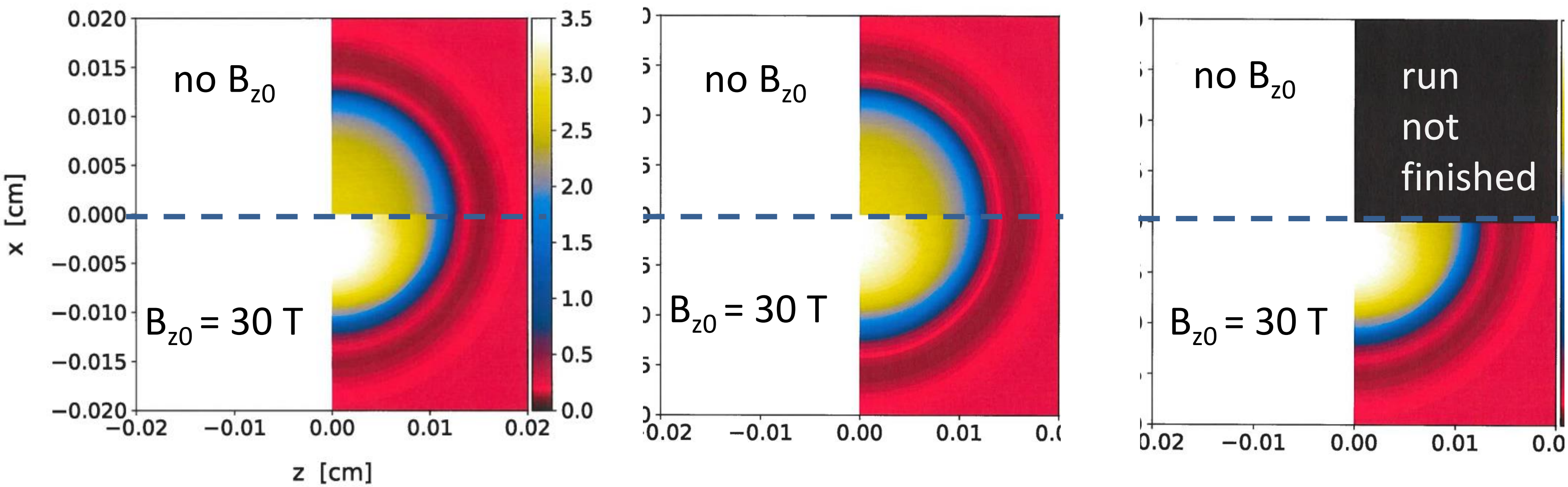
- Capsule initial radius 908 um
- Radius at this time ~ 100 um
- B increase ~ (R_initial / R_final)^2 = 81x : 30 T → 2400 T

N161204: Imposed B_{z0} = 30 T: capsule hotter for all MHD models

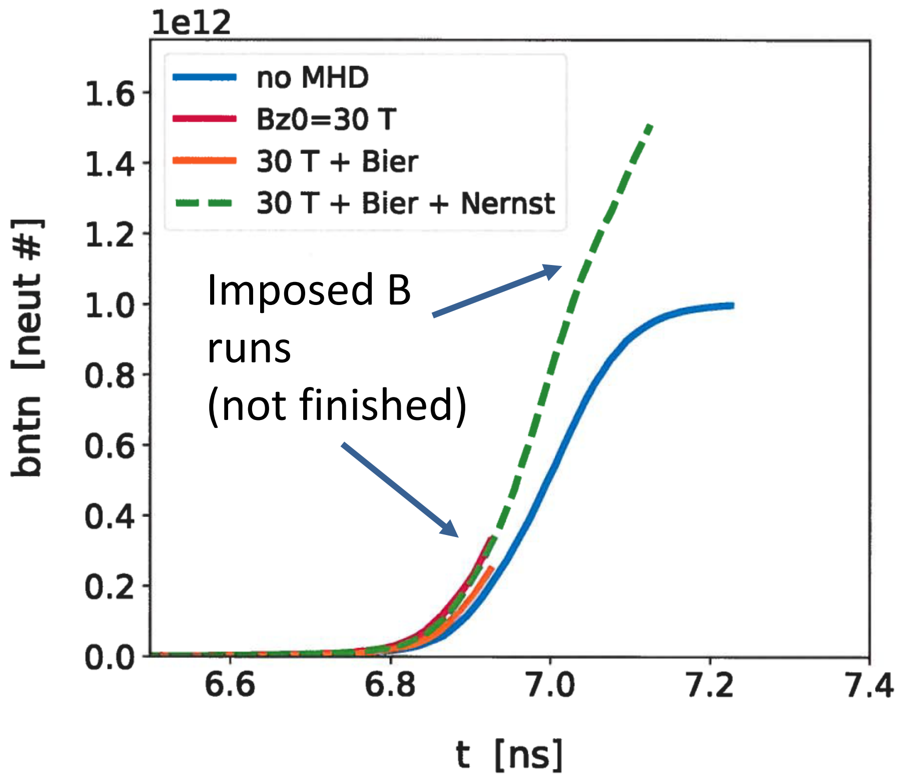
T_e [keV]: same colormap

Plots at 6.75 ns: 0.25 ns before bangtime
x-ray flux on capsule artificially symmetrized

E = vxB + eta*J | E += Biermann | E += Biermann + Nernst



N161204: Imposed B_{z0} = 30 T: bangtimes slightly earlier; yields higher



Imposed axial field (70 T) *slightly* raises T_e, improves inner-beam propagation

Strozzi '15
B_{z0} = 70 T

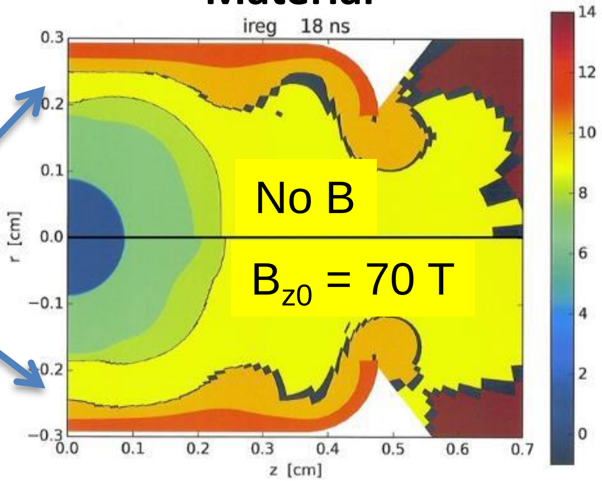
"Low-foot" shot N120321
CH capsule
18 ns: early peak power

D J Strozzi, L J Perkins, et al., *J. Plasma Phys.* (2015)

Each figure: hohlraum quadrants with initial B_{z0} = 70 T (top), and without MHD (bottom)

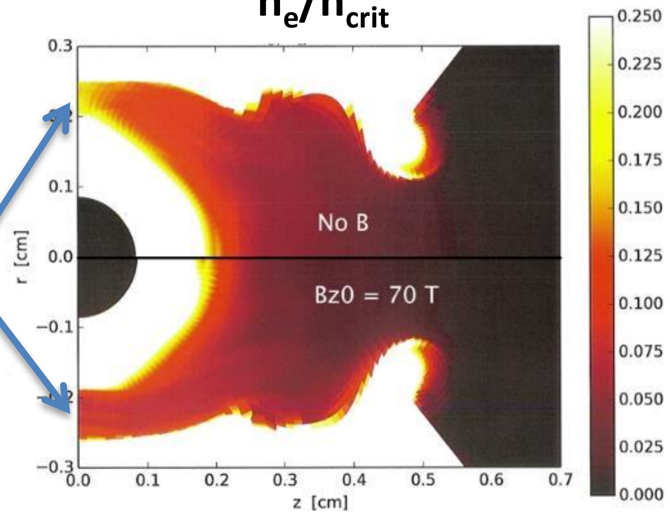
Wider equator channel with B

Material



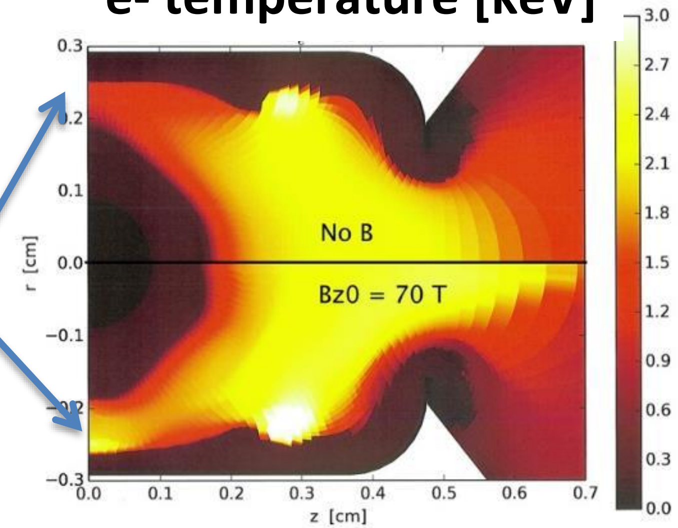
Less n_e w/ B

n_e/n_{crit}



Higher T_e w/ B, esp. on equator

e- temperature [keV]



Imposed B field: 10 T similar effect in hohlraum as 70 T

Strozzi ’15
B_{z0} = 10 T

High-foot shot N121130
B_{z0} = 10 T
15.2 ns: peak power

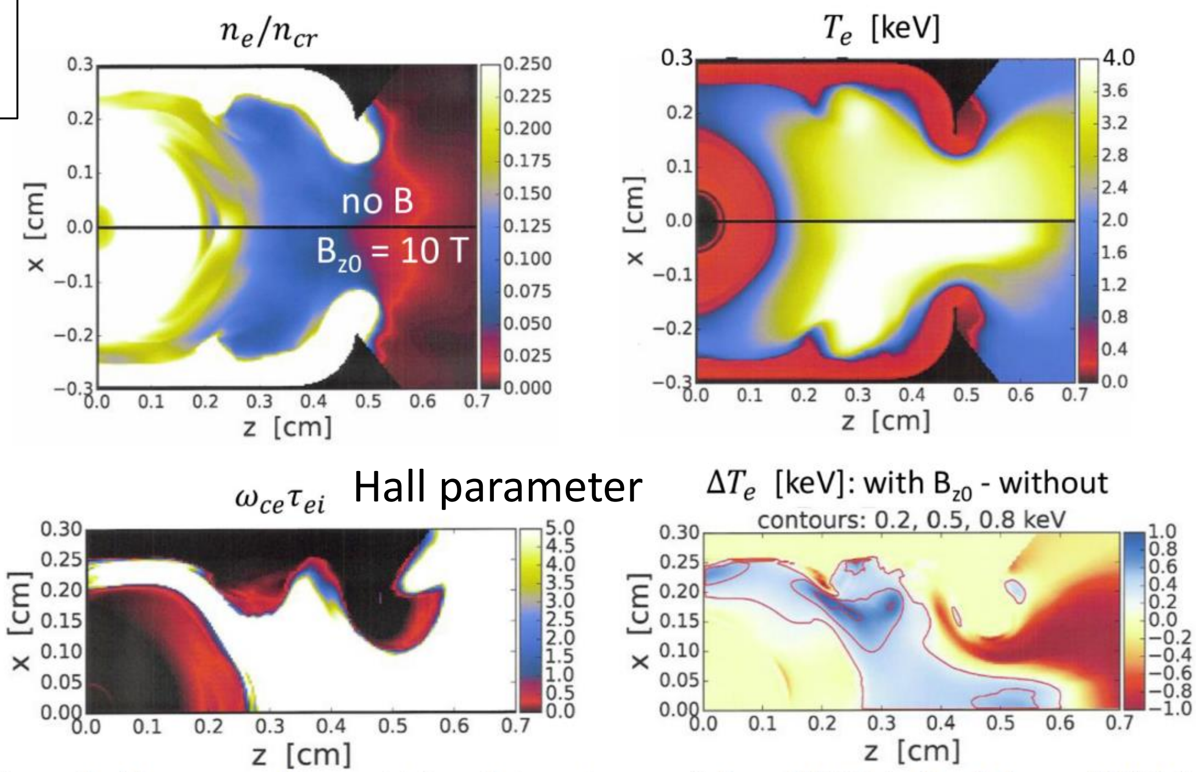


Figure 5. Plasma conditions at 14 ns (late peak power) from HYDRA simulations of NIF shot N121130. For n_e and T_e plots, top half (x>0) has no field, and bottom half (x<0) has B_{z0}=10 T. The Hall parameter $\omega_{ce}\tau_{ei}$ is capped at 5 for clarity.

L. J. Perkins et al., LDRD final report

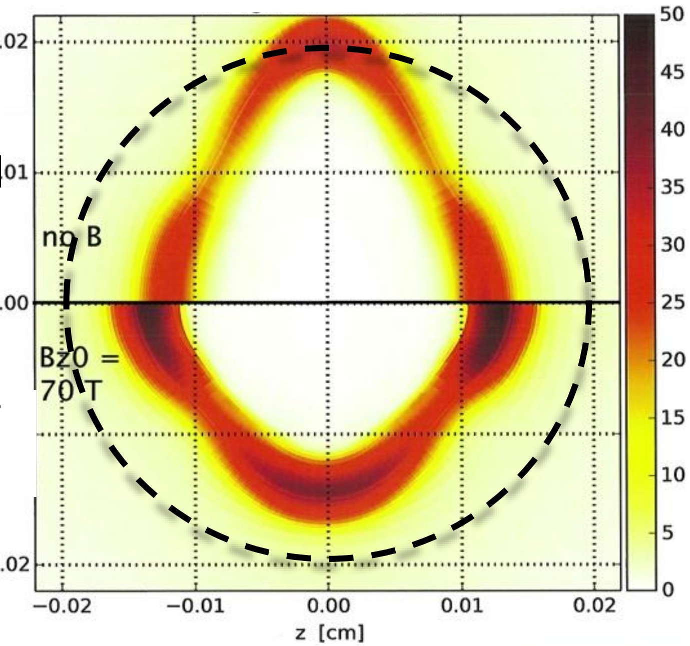
Imposed B: improved inner beam propagation, less pancaked implosion

Strozzi ’15
B_{z0} = 10, 70 T

Low-foot shot N120321[1]
B_{z0} = 70 T
21.5 ns: end of pulse

Capsule density [g/cc]

No B:
pancaked



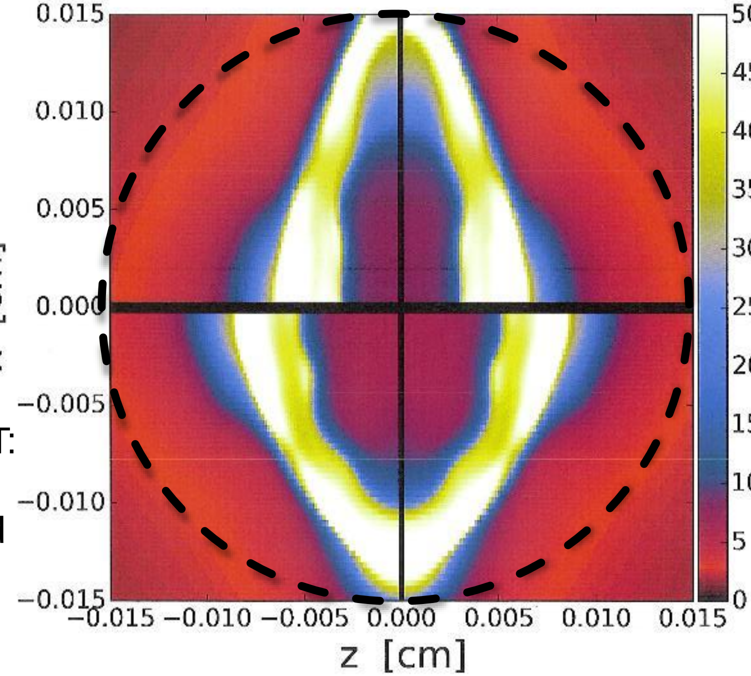
B_{z0} = 70 T
~ round

High-foot shot N121130[2]
B_{z0} = 10 T
15.2 ns: peak power

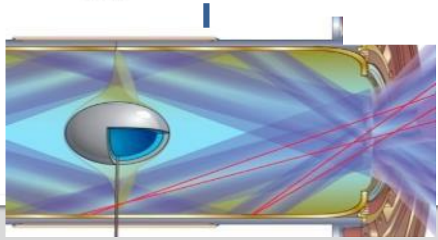
Capsule density [g/cc]

Top:
No B

Bottom:
B_{z0} = 10 T:
less
pancaked



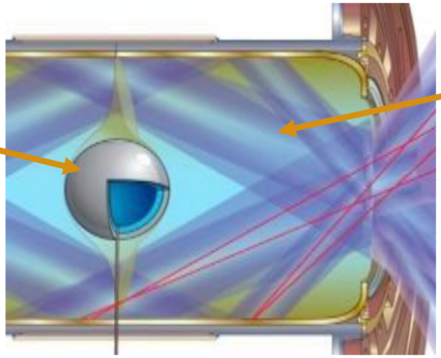
[1]D. J. Strozzi, L. J. Perkins, et al., *J. Plasma Phys.* (2015)



[2]L. J. Perkins et al., LDRD final report

Magnetized "warm" (293 K) gas-filled capsules: established NIF process for cryo analogs

HDC capsule fill
cryo: 5.5 mg/cc D-He3
warm: pure D or D-He3
Magnetized shots from TANDM, can't easily handle T



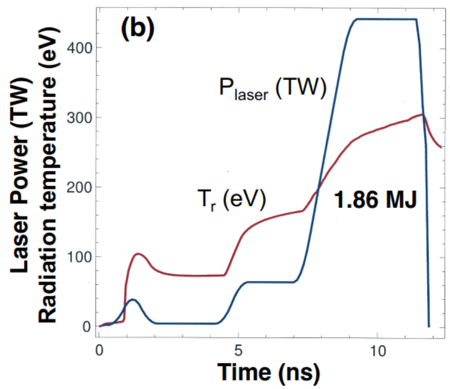
Hohlraum fill
cryo: 0.3 mg/cc He4
warm: C5H12, ~ same e- density
He4 → too much pressure on window

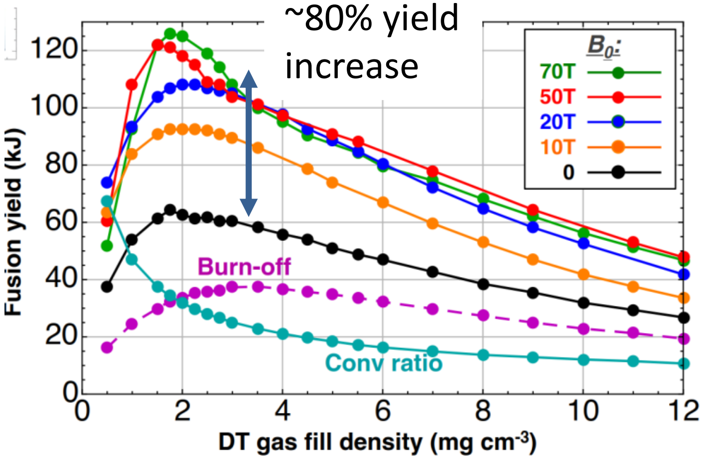
J. E. Ralph, D. J. Strozzi, et al., Phys. Plasmas 2016

- Warm analogs of "low-foot" CH implosions
- Backscatter, x-ray drive, implosion shape similar
- Capsule gas: C3D8 – light species (H, D, …) diffuse through CH –could aluminize
- HDC capsules should hold light species

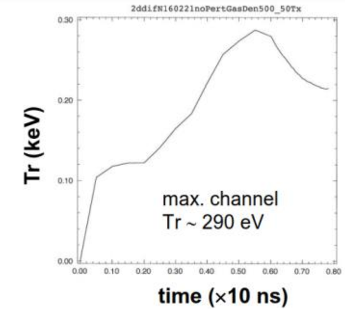
Magnetized gas-filled capsules: up to 2x yield increase with imposed B field

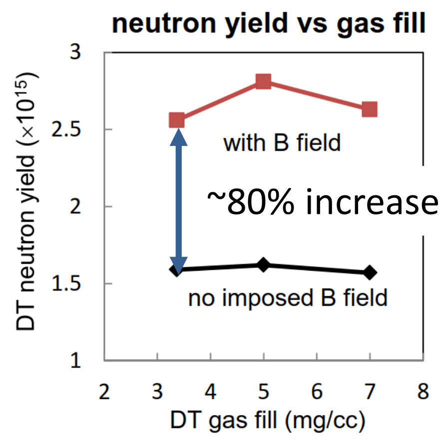
L. J. Perkins [unpublished]: HDC capsule, low adiabat

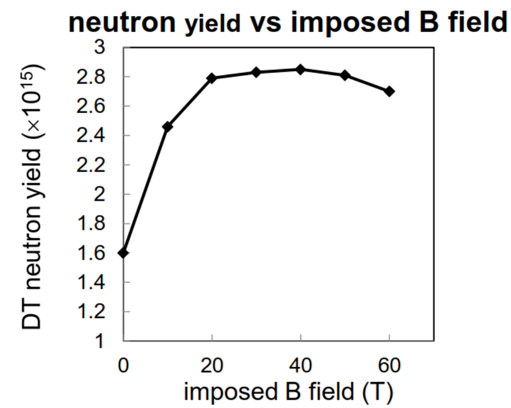




D. D. Ho [APS DPP 2016]: HDC capsule, high adiabat







DT vs. DHe3 gas capsules

- Yield increased mainly by reduced e- conduction
- Not enough alpha's to matter
- Warm shots: D-He3 fill: e- conduction reduction should have similar effect

BACKUP BELOW

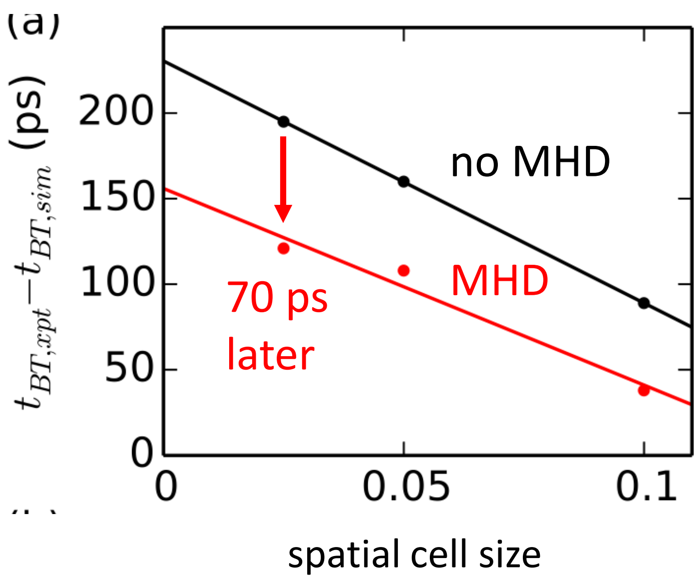
Hohlraums, no imposed field: MHD slightly reduces "drive deficit", implosion less oblate

Farmer '17

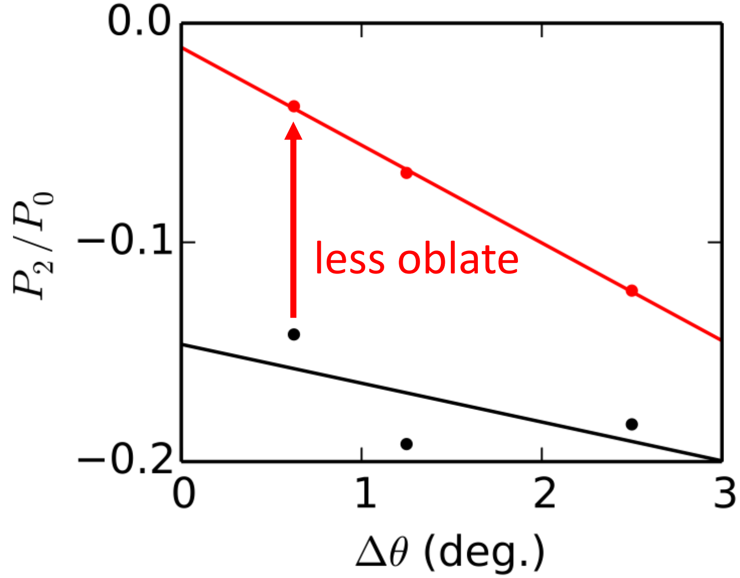
NIF shot N151122
HDC capsule
0.3 mg/cc hohlraum gas fill

W. A. Farmer, J. M. Koning, et al., Phys. Plasmas 2017

Bangtime: measured – simulated reflects total x-ray drive

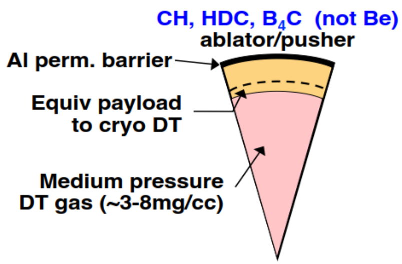


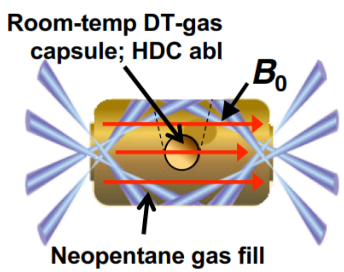
P_2/P_0: hotspot emission shape



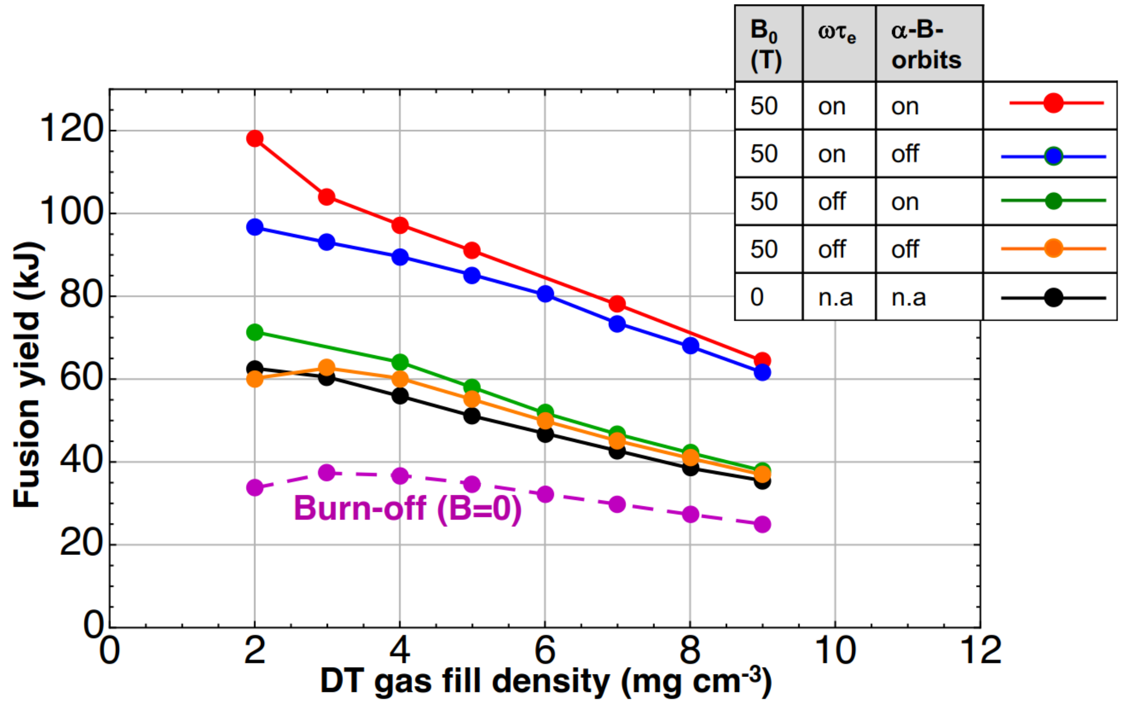
Slide courtesy L. J. Perkins

Room-temperature gas target performance, HDC shell – What's the most important role of the B-field?





Most important effect of B for (non-metal) gas targets is on electron heat conduction as there's few alphas.
⇒ Can get interesting results at low imposed B-fields (~20T) because $\omega\tau_e$ is still very high



B_0 (T)	$\omega\tau_e$	α-B-orbits	
50	on	on	red
50	on	off	blue
50	off	on	green
50	off	off	orange
0	n.a	n.a	black