Design of magnetized, gas-filled capsule experiments for NIF

Meeting on Magnetic Fields in Laser Plasmas

Laboratory for Laser Energetics, University of Rochester

D. J. Strozzi, J. M. Koning, J. D. Salmonson,
W. A. Farmer, J. D. Moody, L. J. Perkins, D. D. Ho

23 April 2018

LLNL-PRES-XXXXXX
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

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: β >> 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]

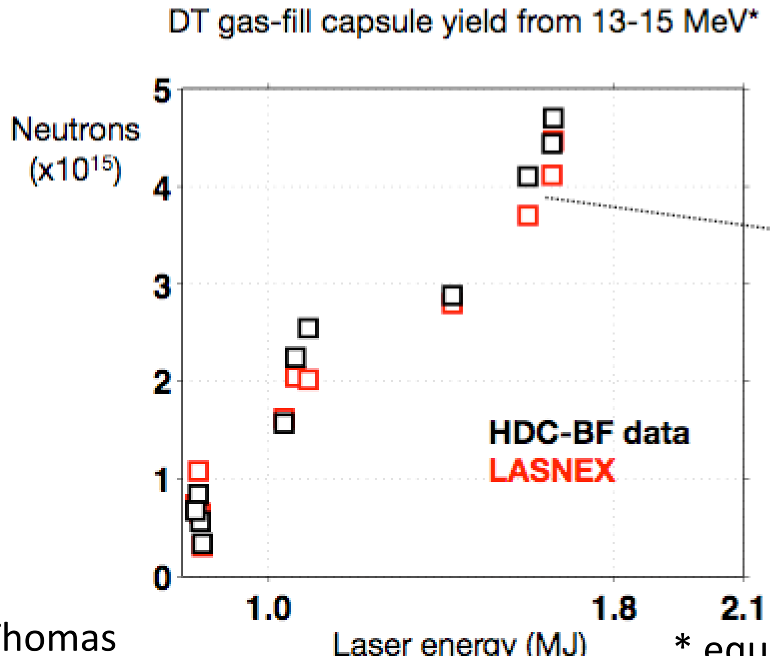
- Frozen-in law holds: B field compressed or rarified with plasma
- ***Slightly*** hotter hohlraum fill
- Improved inner-beam propagation: hotter, less-dense equator channel
- Capsule fields ~ 2 kT
- Gas-filled capsule yields increase up to 2x

"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



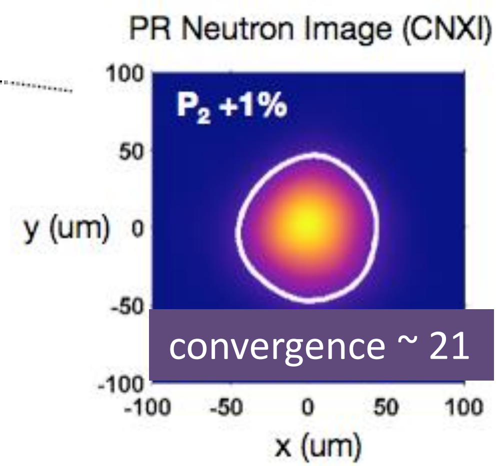


Figure courtesy C. Thomas

* equivalent DT yield from DD, D3He, …

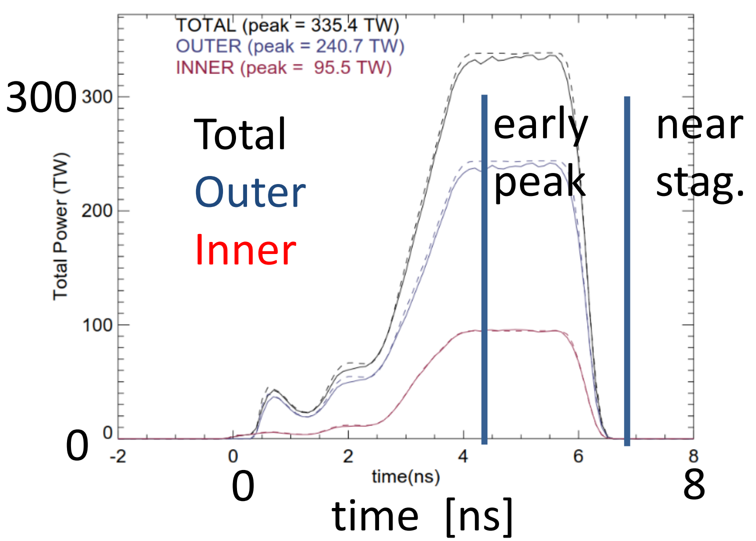
Why Bigfoot for warm magnetized design?

- 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

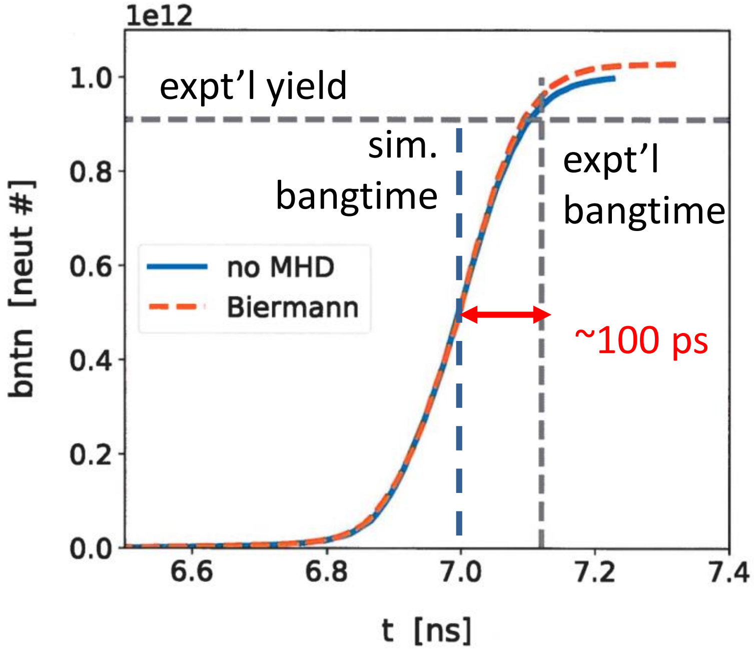
- R-Z axisymmetric
- "HyPyD": Pythonic framework:
  J. Koning, J. Salmonson
- DCA non-LTE: Sept. 2017 model: H. Scott
- Electron heat flux limit f = 0.15 (high)
- X-rays on capsule artificially symmetrized

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

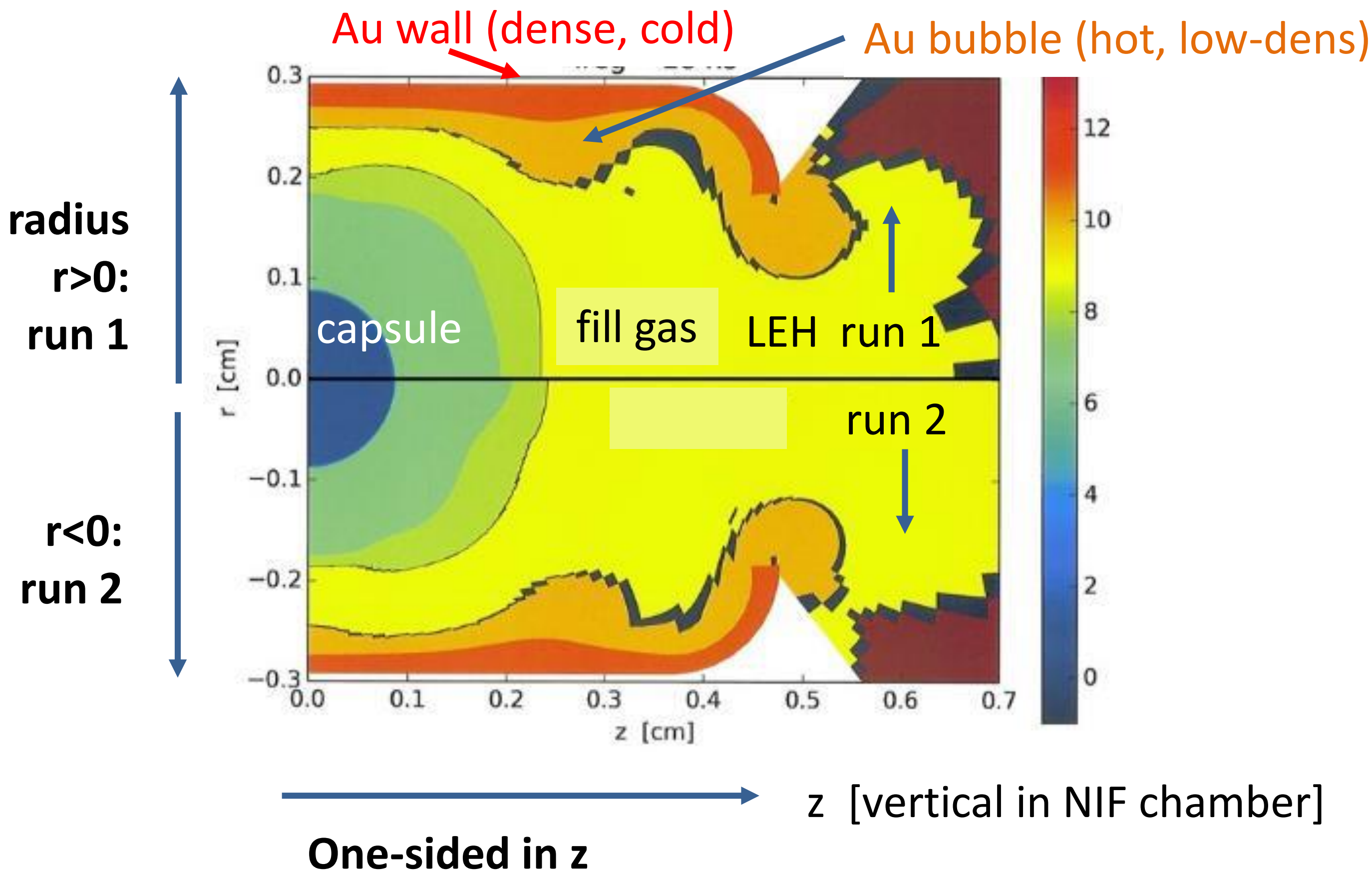
Without any hand tuning

- 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

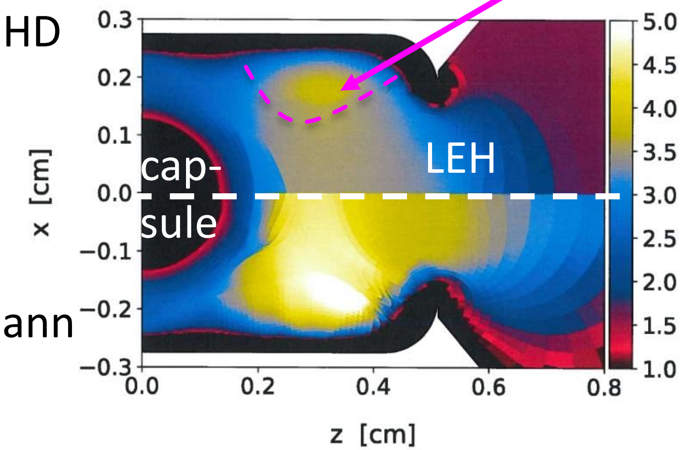
Same story as Farmer 2017

Plots at 4.25 ns: early peak power

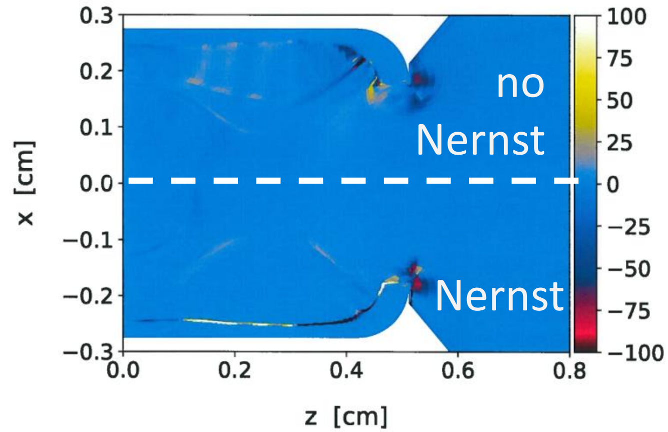
T_e [keV]

no MHD

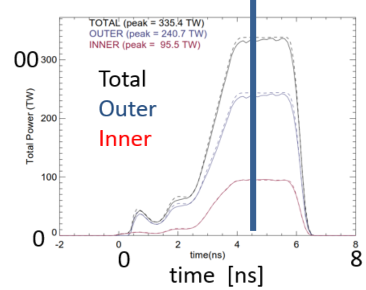
Biermann



Azimuthal B [T]

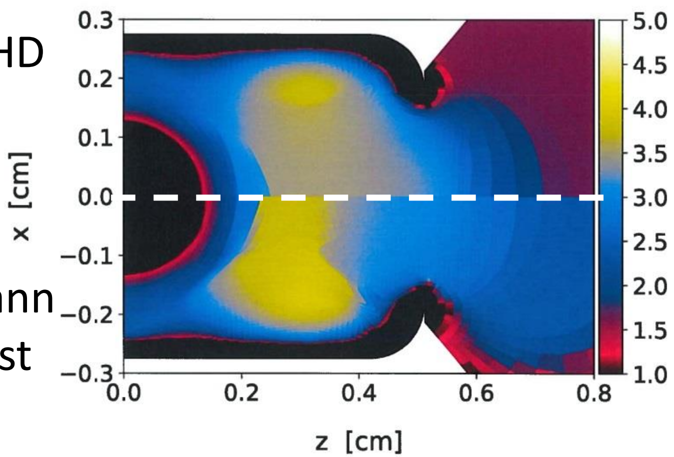


Laser power [TW]

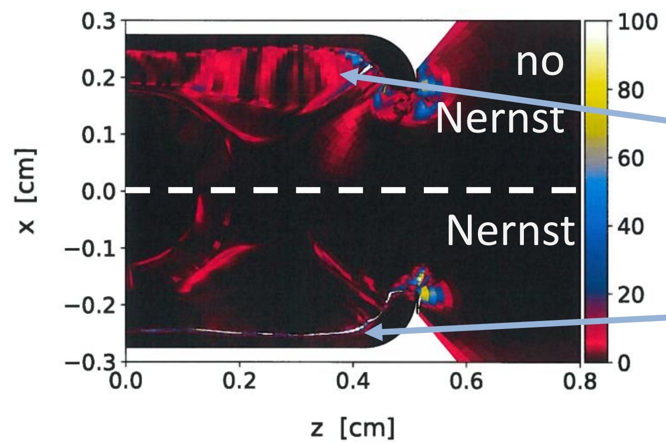


no MHD

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

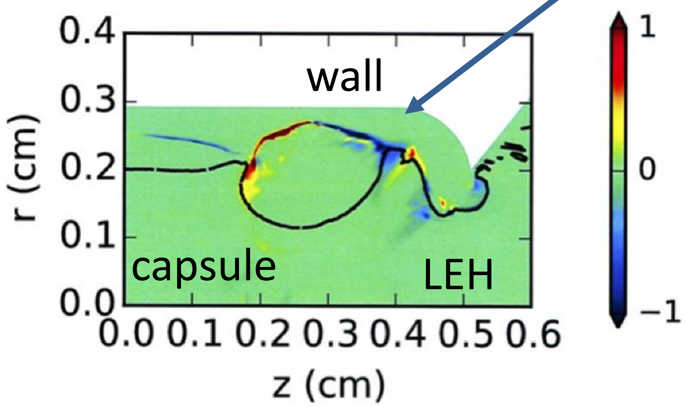
NIF shot N151122
HDC capsule
0.3 mg/cc hohlraum gas fill

MHD: Biermann + Nernst

Farmer '17

Highly localized
~ 100 T fields

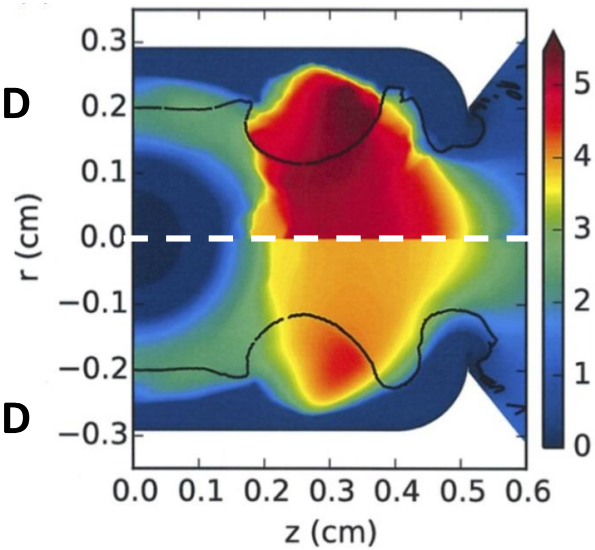
azimuthal B [MG]



T_e [keV]

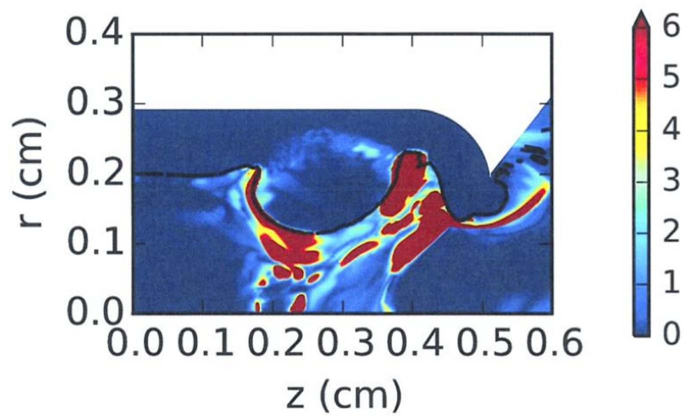
MHD

No MHD

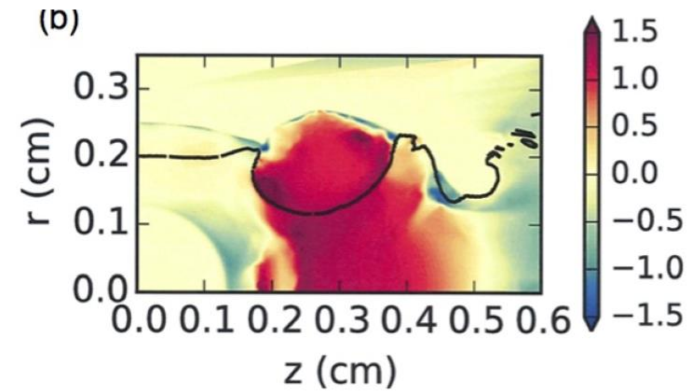


Plots at 5 ns:
late peak power

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



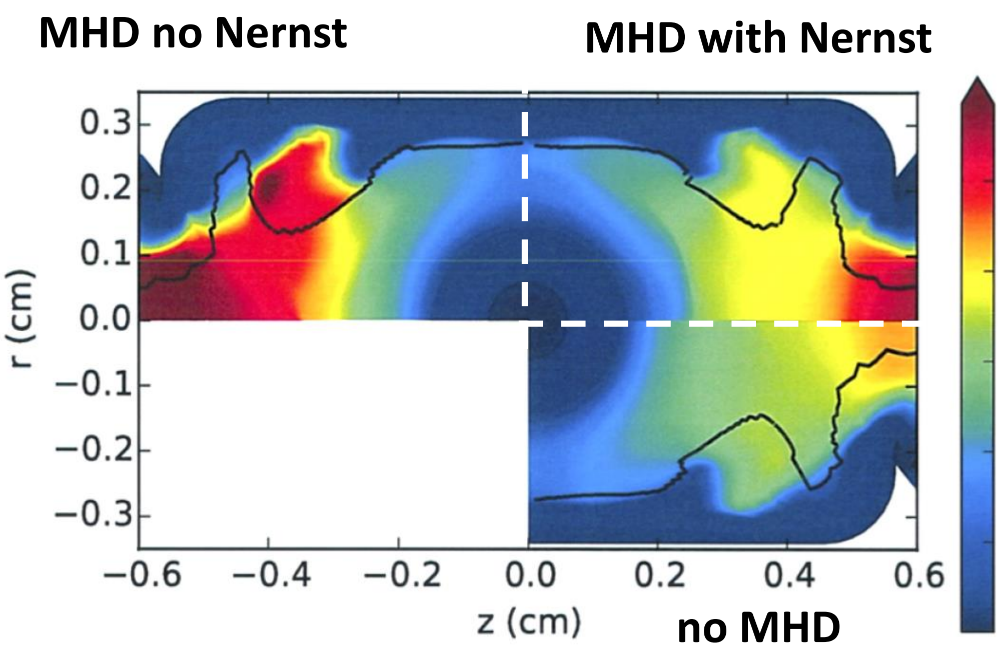
T_e MHD – no MHD [keV]

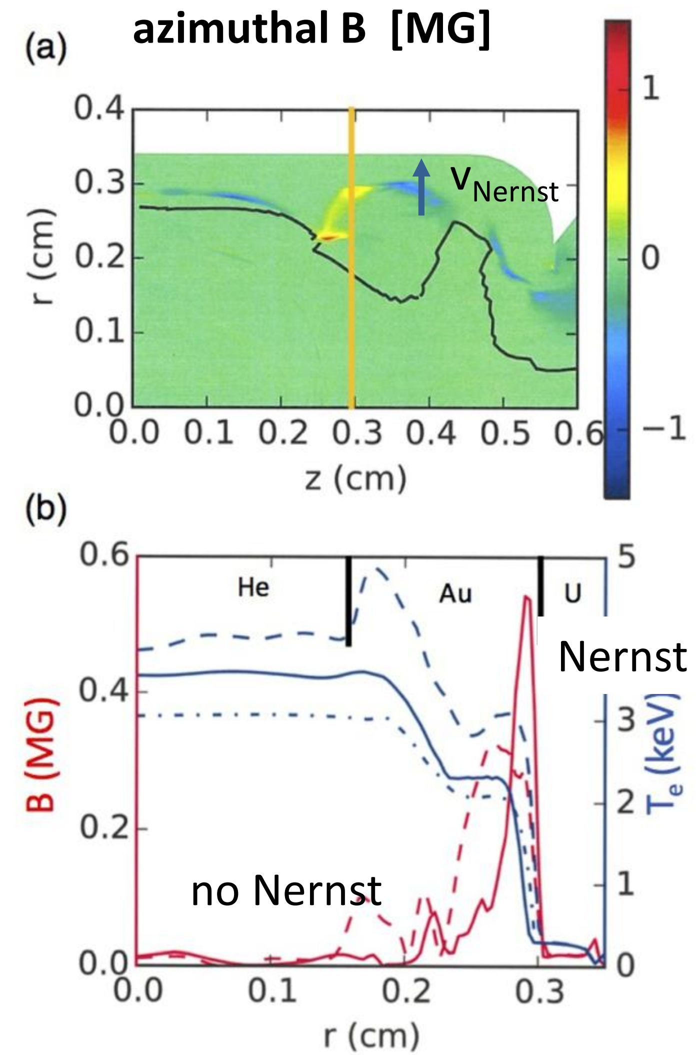


Hohlraums, no imposed B: Nernst advection reduces effect of B field

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

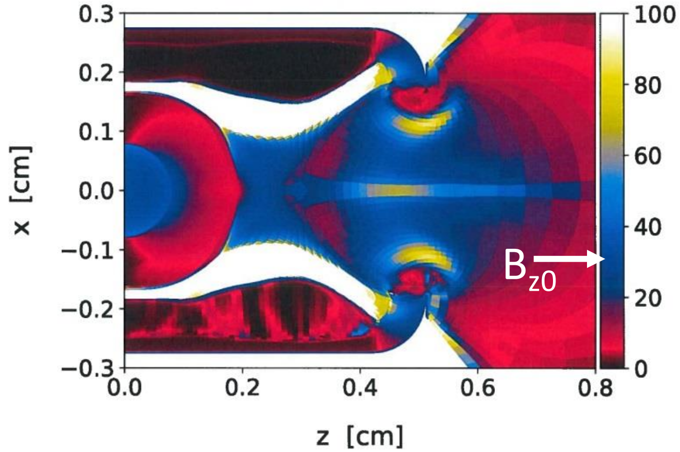
→HYDRA Simulations: imposed axial field

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

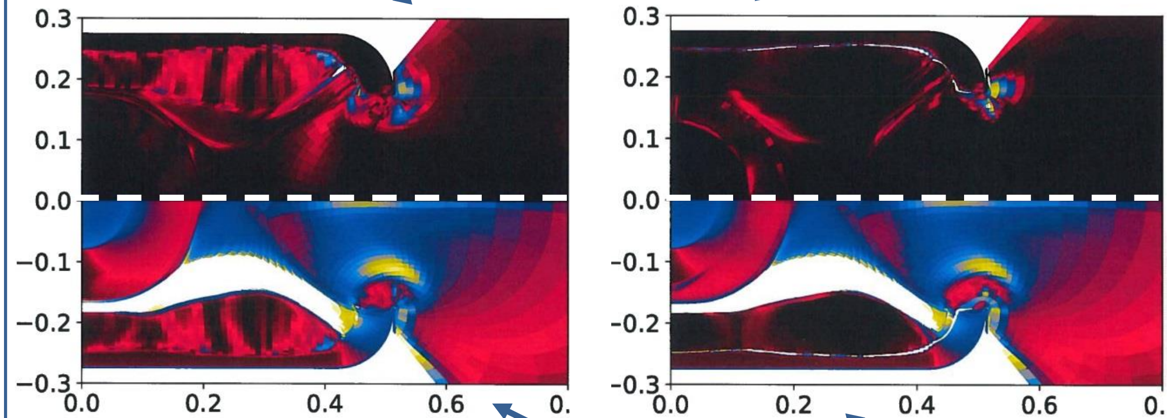


B_{z0} = 30 T
E += Biermann

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

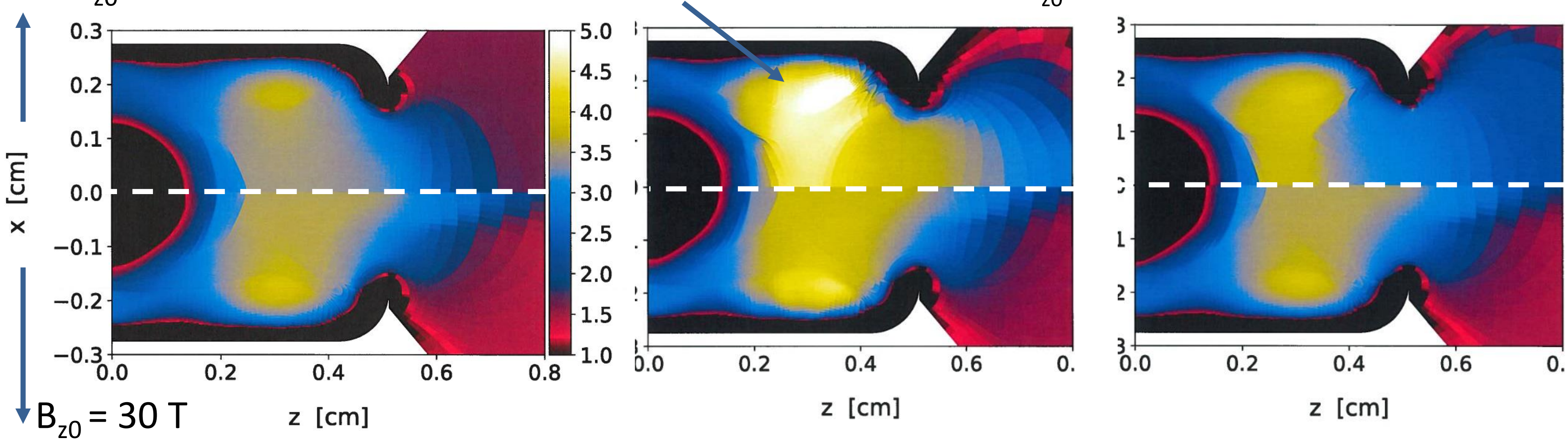
T_e [keV]: same colormap

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}?

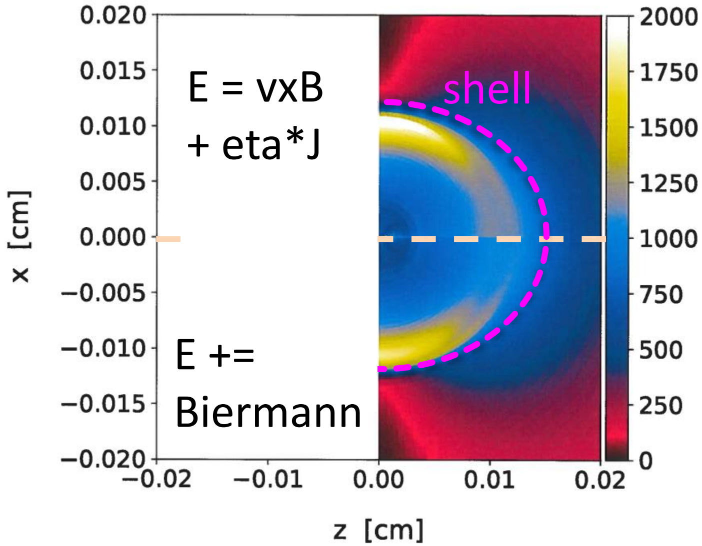
- Hall parameter > 1 in He gas fill with imposed field – not a "small field"
- imposed B reduced in Au bubble due to expansion: Frozen-in law
- Axial imposed field → B in r-z plane: heat flow only reduced in 1 meaningful direction
- Biermann azimuthal field → 2 directions reduced
- Seems we need B inside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

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

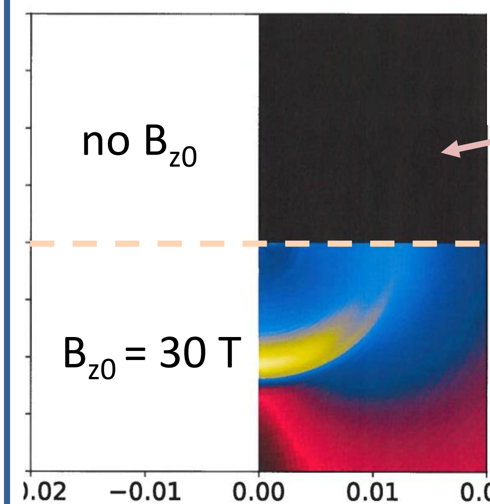
|B| [T]: same colormap

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

B_{z0} = 30 T

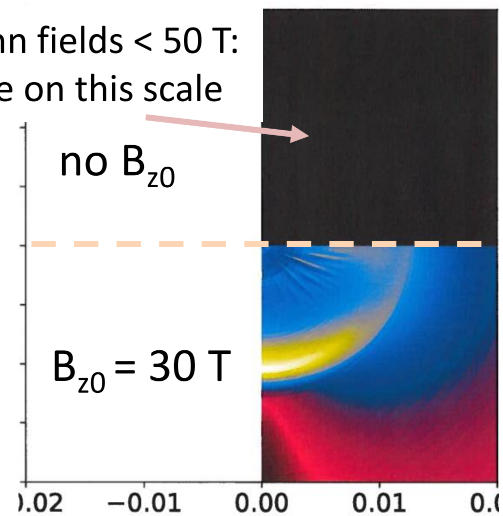


E += Biermann



Biermann fields < 50 T:
can't see on this scale

E += Biermann + Nernst



Frozen-in estimate of field increase

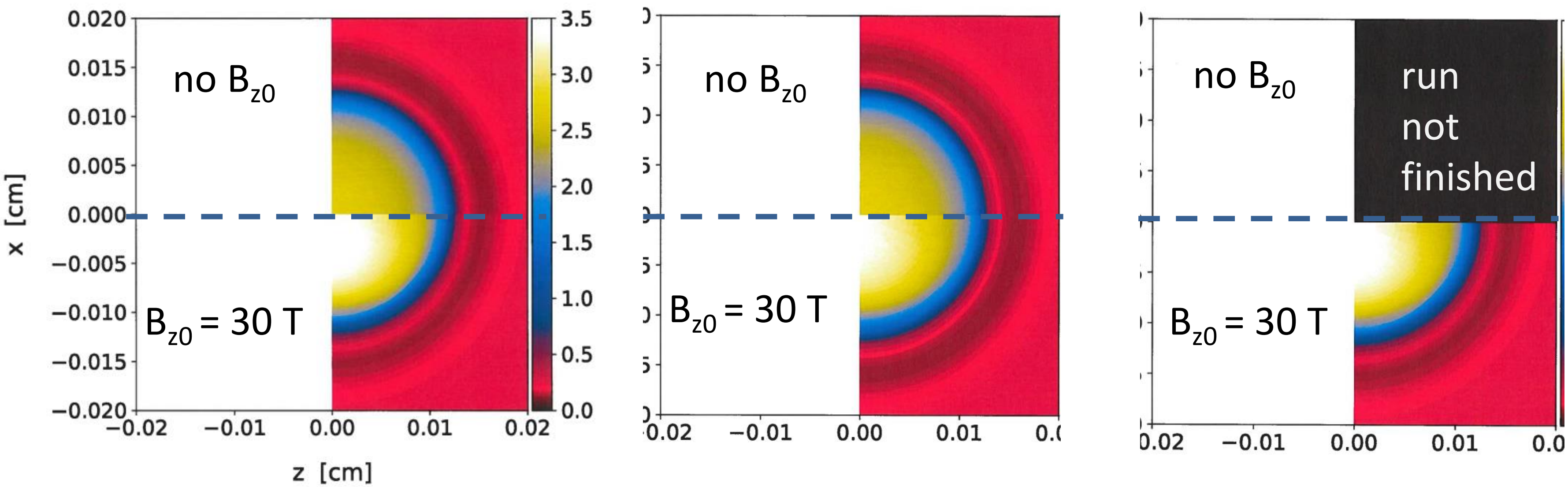
- Capsule initial radius 908 um
- Radius at this time ~ 100 um
- B increase ~ (R_initial / R_final)^2 = 81x : 30 T → 2400 T

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

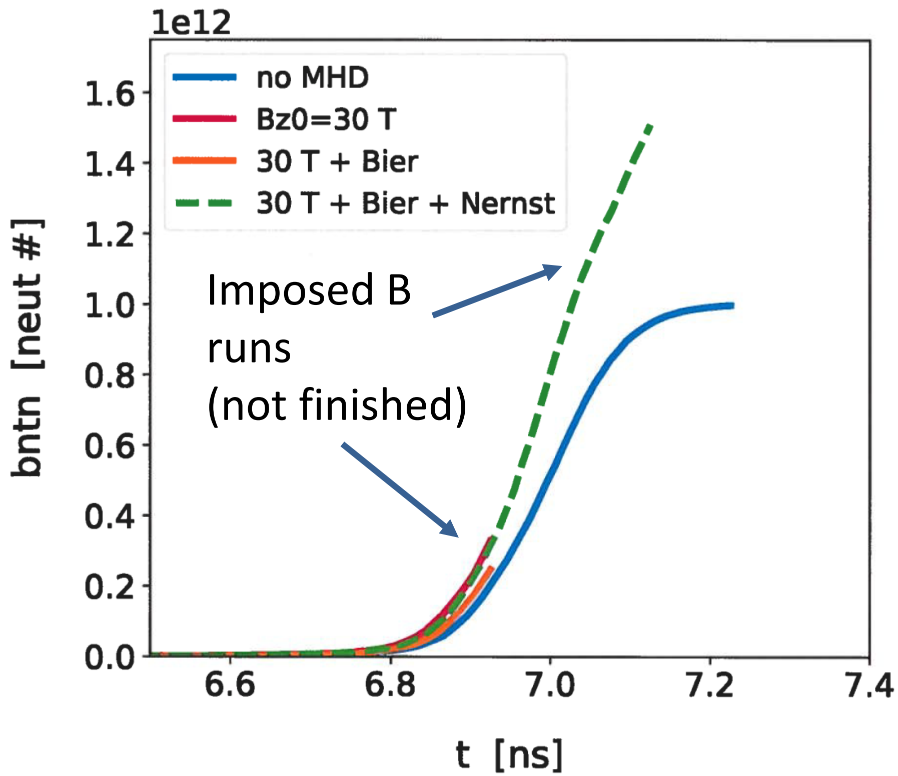
T_e [keV]: same colormap

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

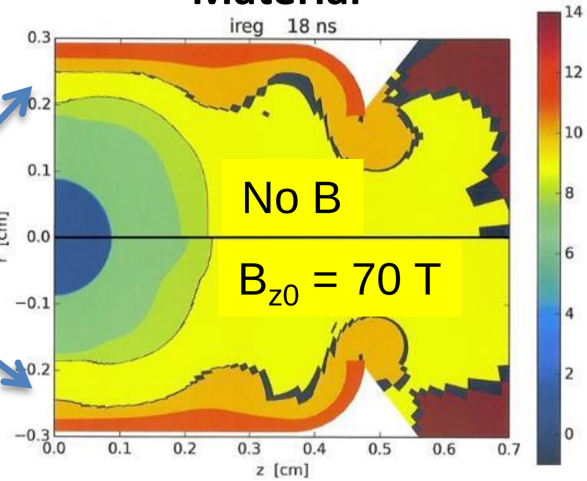
"Low-foot" shot N120321
CH capsule
18 ns: early peak power

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)

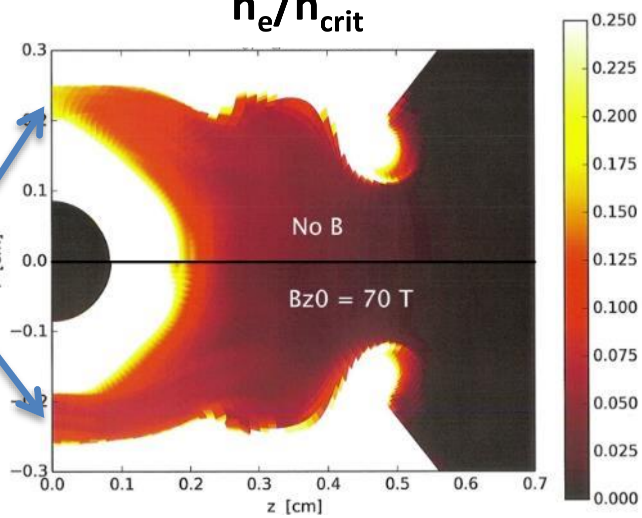
Wider equator channel with B

Material



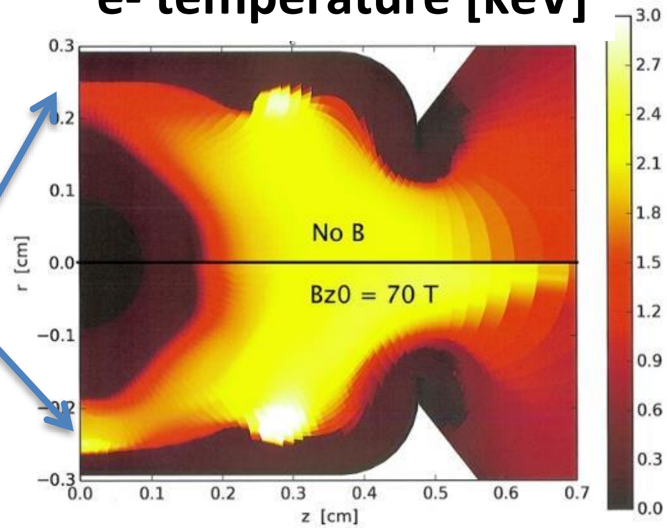
n_e/n_{crit}

Less n_e w/ B



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

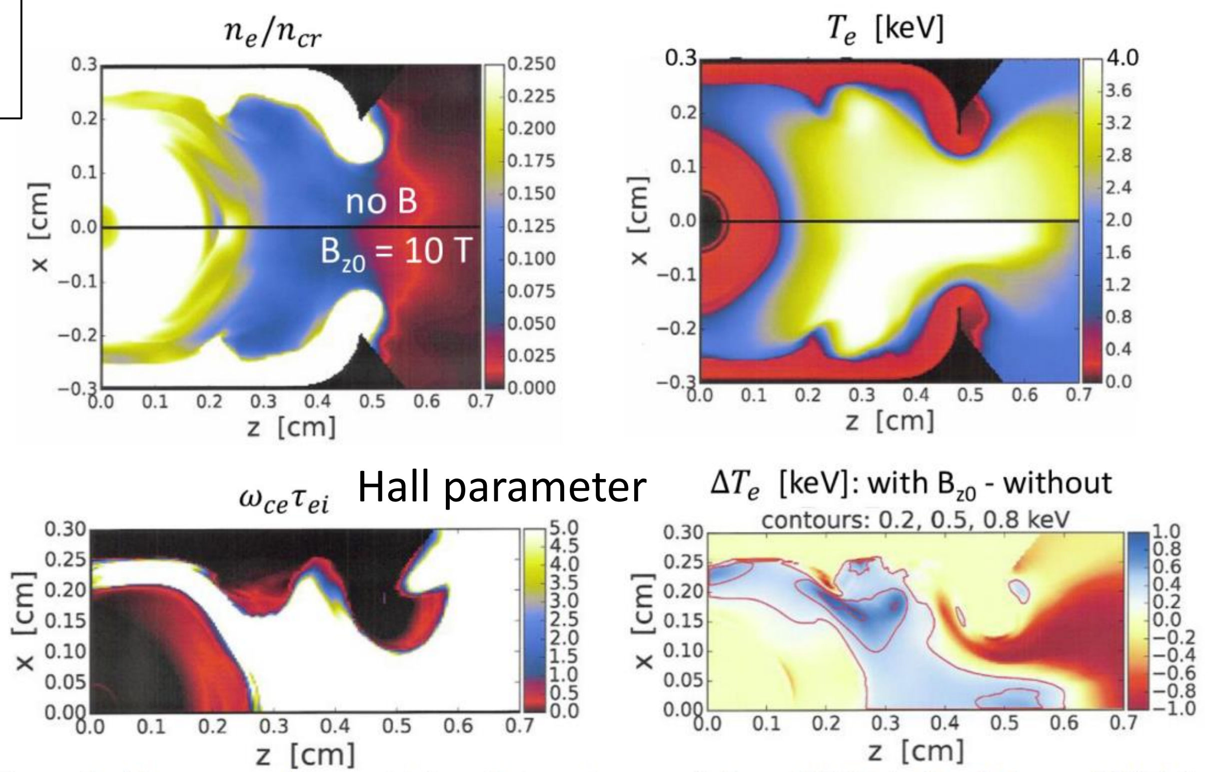


Figure 5. Plasma conditions at 14 ns (late peak power) from HYDRA simulations of NIF shot N121130. For n_e and T_e plots, top half (x>0) has no field, and bottom half (x<0) has B_{z0}=10 T. The Hall parameter $\omega_{ce}\tau_{ei}$ is capped at 5 for clarity.

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

Imposed B: improved inner beam propagation, less pancaked implosion

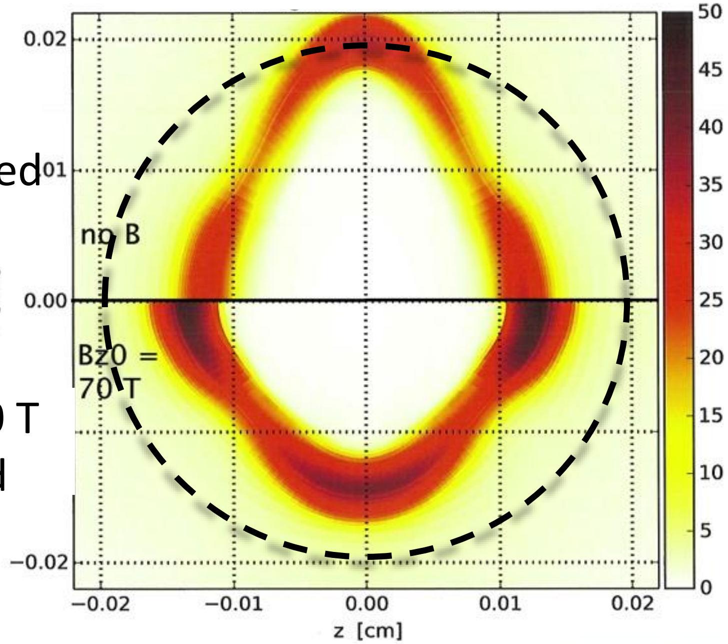
Strozzi '15
B_{z0} = 10, 70 T

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

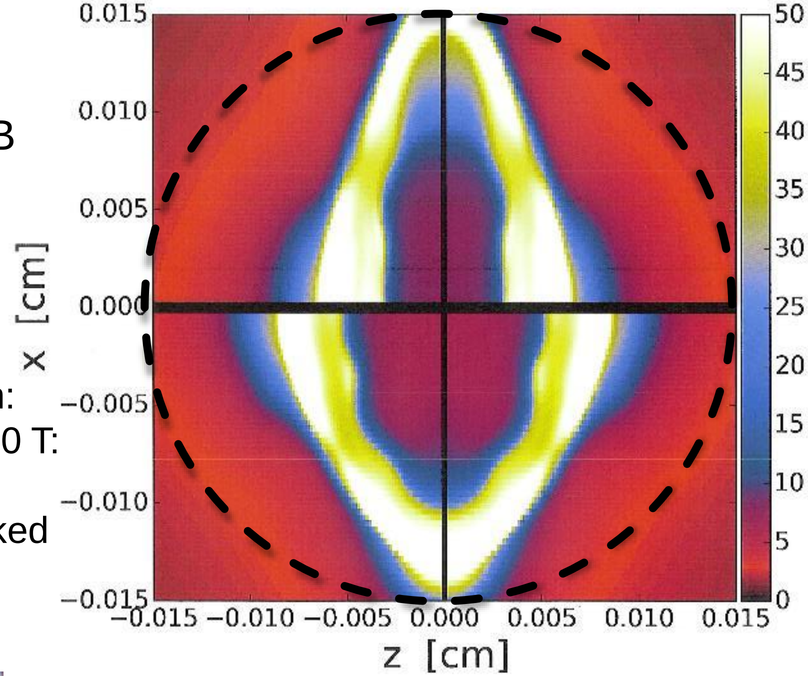


High-foot shot N121130[2]
B_{z0} = 10 T
15.2 ns: peak power

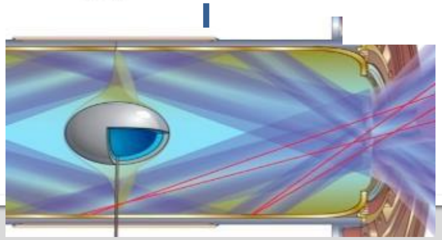
Capsule density [g/cc]

Top:
No B

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



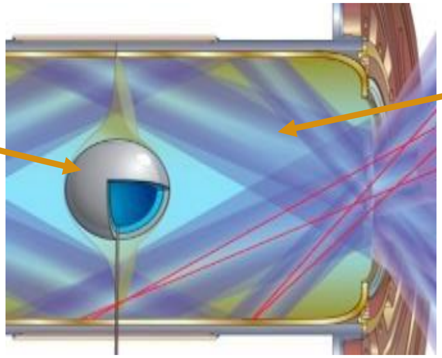
[1]D. J. Strozzi, L. J. Perkins, et al., *J. Plasma Phys.* (2015)



[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



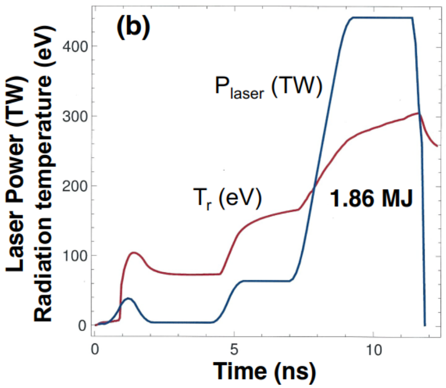
Hohlraum fill
cryo: 0.3 mg/cc He4
warm: C5H12, ~ same e- density
He4 → too much pressure on window

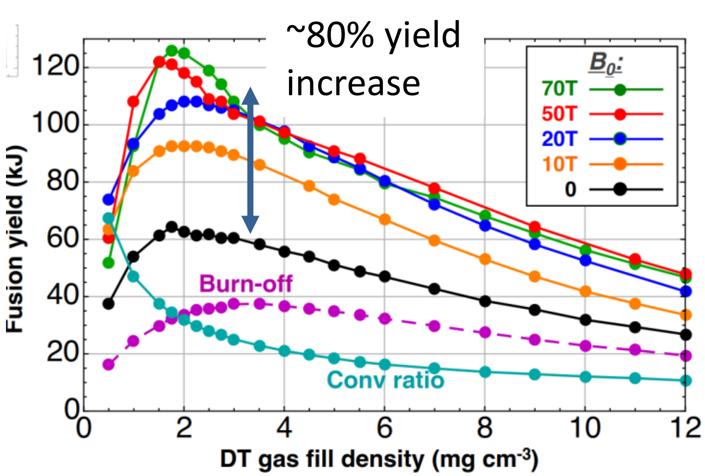
J. E. Ralph, D. J. Strozzi, et al., Phys. Plasmas 2016

- 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

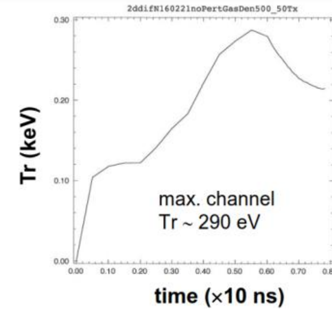
Magnetized gas-filled capsules: up to 2x yield increase with imposed B field

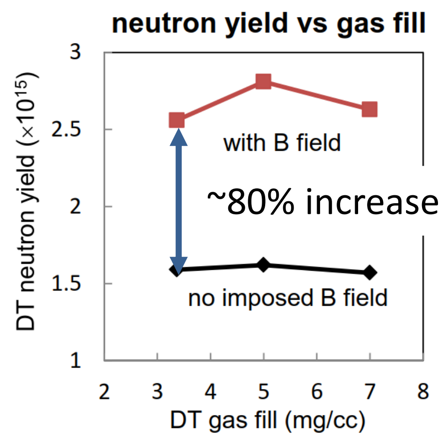
L. J. Perkins [unpublished]:
HDC capsule, low adiabat

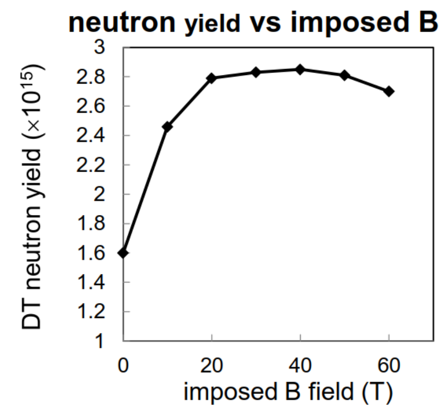




D. D. Ho [APS DPP 2016]:
HDC capsule, high adiabat







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

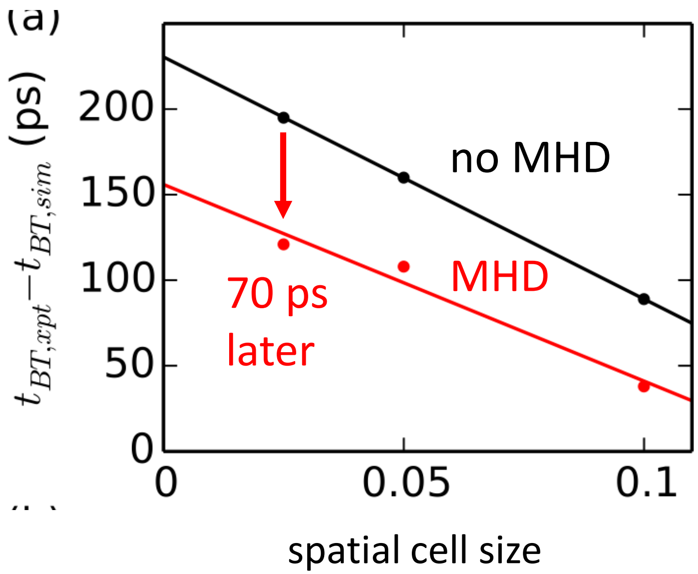
Hohlraums, no imposed field: MHD slightly reduces "drive deficit", implosion less oblate

Farmer '17

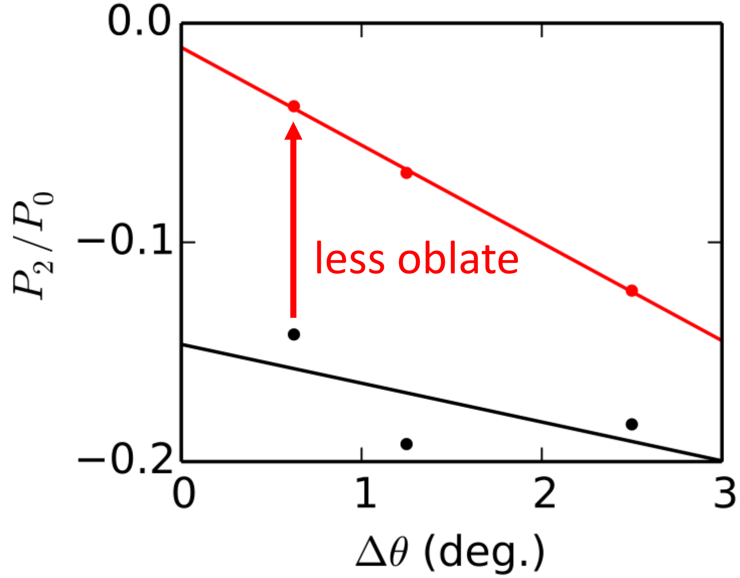
NIF shot N151122
HDC capsule
0.3 mg/cc hohlraum gas fill

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

Bangtime: measured – simulated reflects total x-ray drive

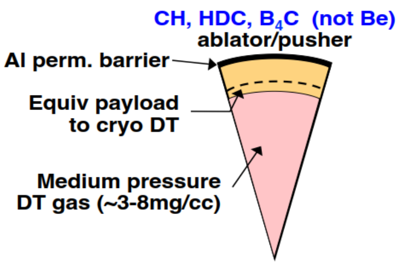


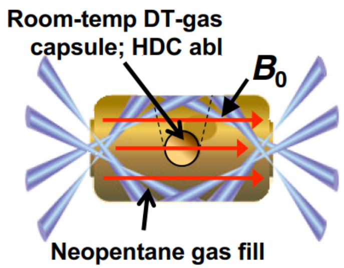
P_2/P_0: hotspot emission shape



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**