Exploring Axial and Other Imposed Magnetic Fields to Improve Layered Hohlraum-Driven Implosions

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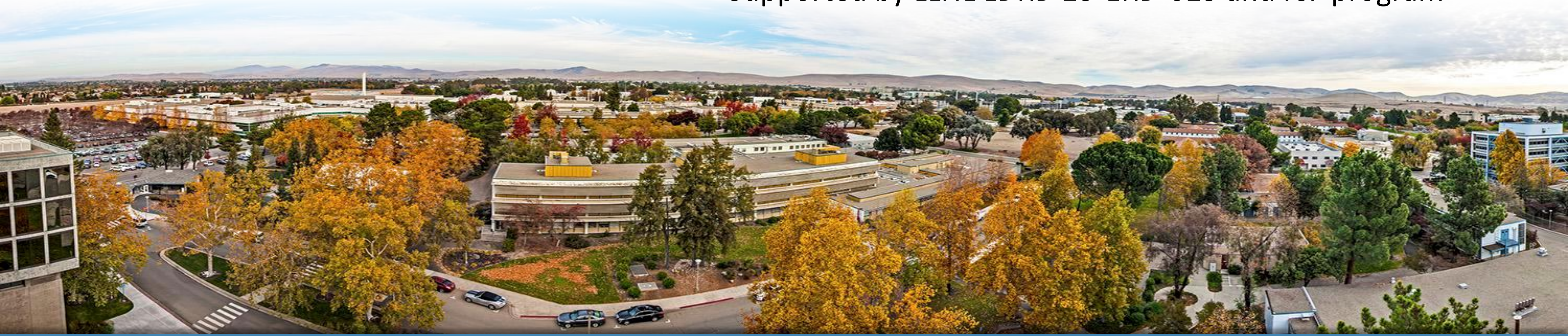

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Summary: Magnetized Ignition at LLNL: we continue room-temp. gas capsule shots, cryogenic capability delayed

Main benefits of B field:

- **Reduced electron thermal conduction and alpha particle loss perp. to B in hotspot**
- **→ Relaxed Lawson criterion for ignition**
- **May also reduce hydro instabilities / mix**

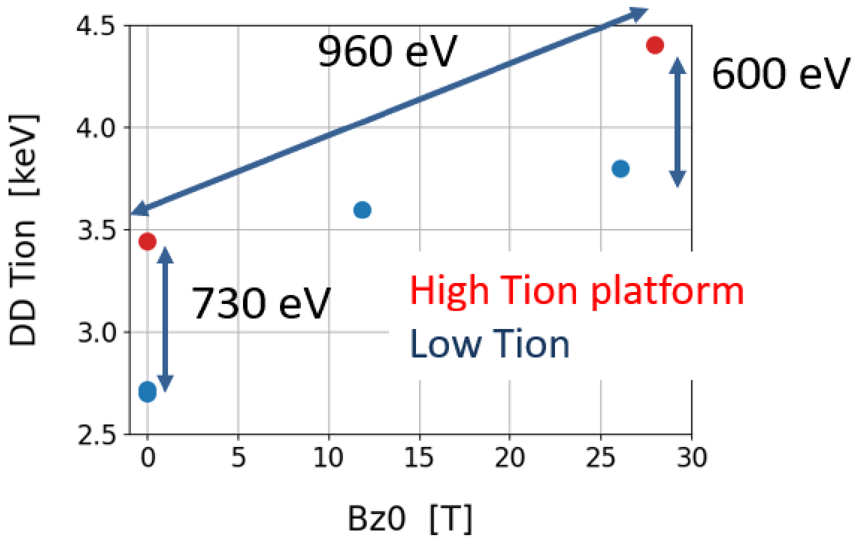
FY23 NIF gas capsule shots:

- High Tion platform: Tion = 4.4 keV with B = 28 T vs. 3.44 keV with no B
- Dual CBI (crystal backlit imager) shots planned
  - Assess role of B field on gas – shell mix

Magnetized cryogenic target system delayed two years

- Work to restart summer 2025, shots in 2027
- Only room-temp. magnetized shots until then

NIF magnetized gas capsule shots

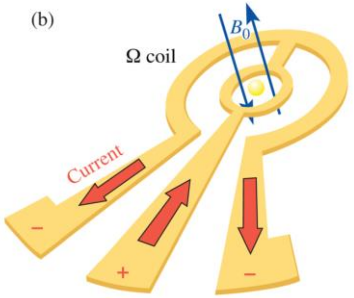


J. D. Moody et al, PRL 2022
H. Sio et al, PoP 2023 (submitted)

Summary: modeling of magnetized layered targets has started, mirror field could be better than purely axial

Axial B field: main approach, what we've shot to date
- Subscale BigFoot DT shot N190721 [D. Strozzi] – highest yield at 1.3 MJ laser energy, proposed platform for initial shots
- Ignition THD analog shot N220220 [B. Djordjevic] – "burn-off" companion to ignition DT shot N210808, low-D fuel

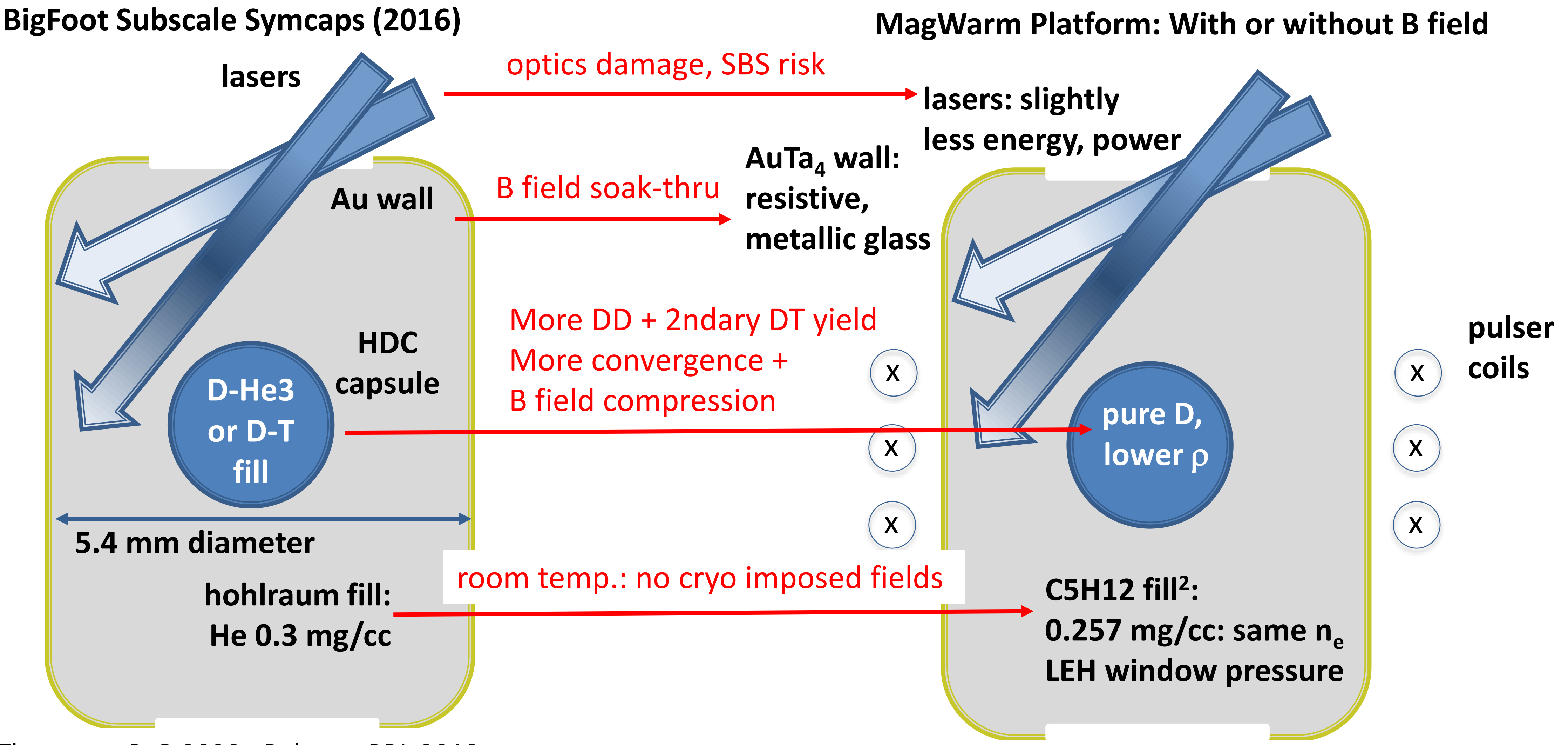
Non-axial B field [C. Walsh]
- **Mirror:** larger field on poles could reduce heat loss, field lines more conformal to hotspot on equator
- **Closed, azimuthal field lines:** no free heat flow out of hotspot
  - Very high Te, ions don't equilibrate – need a wire through the capsule!
- **"Omega" coil** [Hohenberger 2012]:
  - Sheared B field → closed field lines in implosion due to magnetic reconnection
  - Estimated seed B field in capsule ~ 0.2 T given NIF hardware – too small? [A. Povilus]



Burn-avg. T_{ion} [keV]: Increases in all cases with B, b/t 0.6 and 2.1 keV

	System	$B_0 = 0$	B_0 = 20 – 40 T	B – no B
NIF data	High Tion gas capsules – data	3.44	4.4	0.96
Lasnex sims	High Tion gas capsules (preshot)	3.5	4.6	1.1
Lasnex sims	N190721 – subscale bigfoot DT	5.2	6.5	1.3
Lasnex sims	N220220 – THD ignition analog	4.3	5.2	0.6
Gorgon sims	N170601 – first > 1e16 yield shot	3.9	5.5	1.6
Gorgon sims	N170601 – mirror field (f = 0.4)	3.9	6.0	2.1

MagWarm (Magnetized Room-Temp.) Platform, with or without B: Subscale BigFoot plus constraints



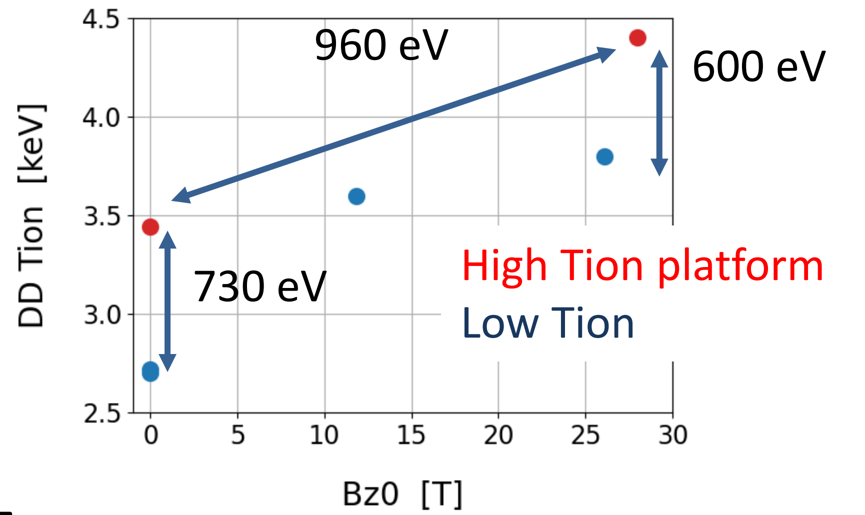
[1] C. A. Thomas +, PoP 2020; Baker +, PRL 2018

[2] J. E. Ralph, D. J. Strozzi +, PoP 2016

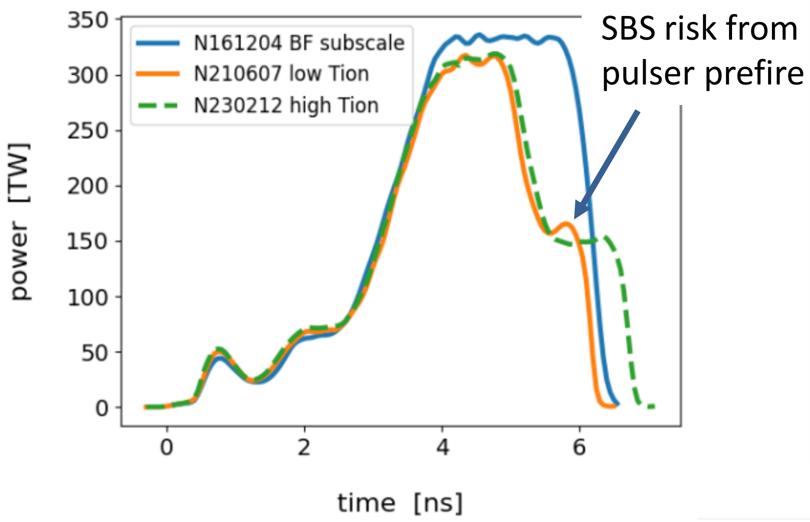
FY23 NIF magnetized gas capsules: higher Tion platform

Platform / comment	Laser energy [kJ]	LEH diam-eter [mm]	capsule fill [mg/cc]
BigFoot subscale	1091	3.45	$D_3\,{}^3He_7$ @ 6.7
Low Tion FY21-22	883	3.45	D @ 4
High Tion FY23	989	3.13	D @ 3
Purpose	More x-ray drive	More x-ray drive	More compression

High Tion platform: Tion up with and without B



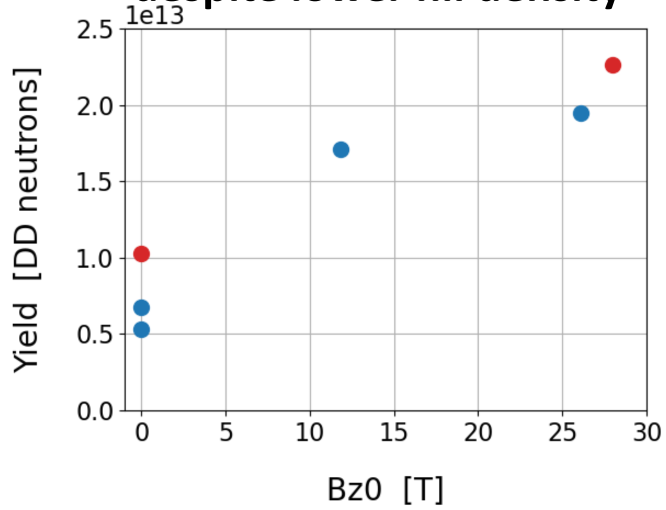
Laser power



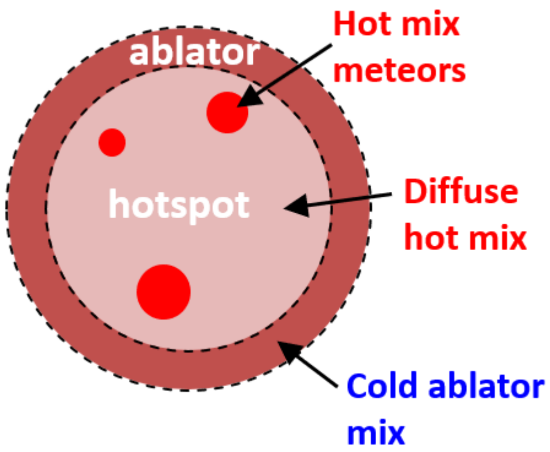
Lasnex modeling captures relative effect of B field on high Tion platform

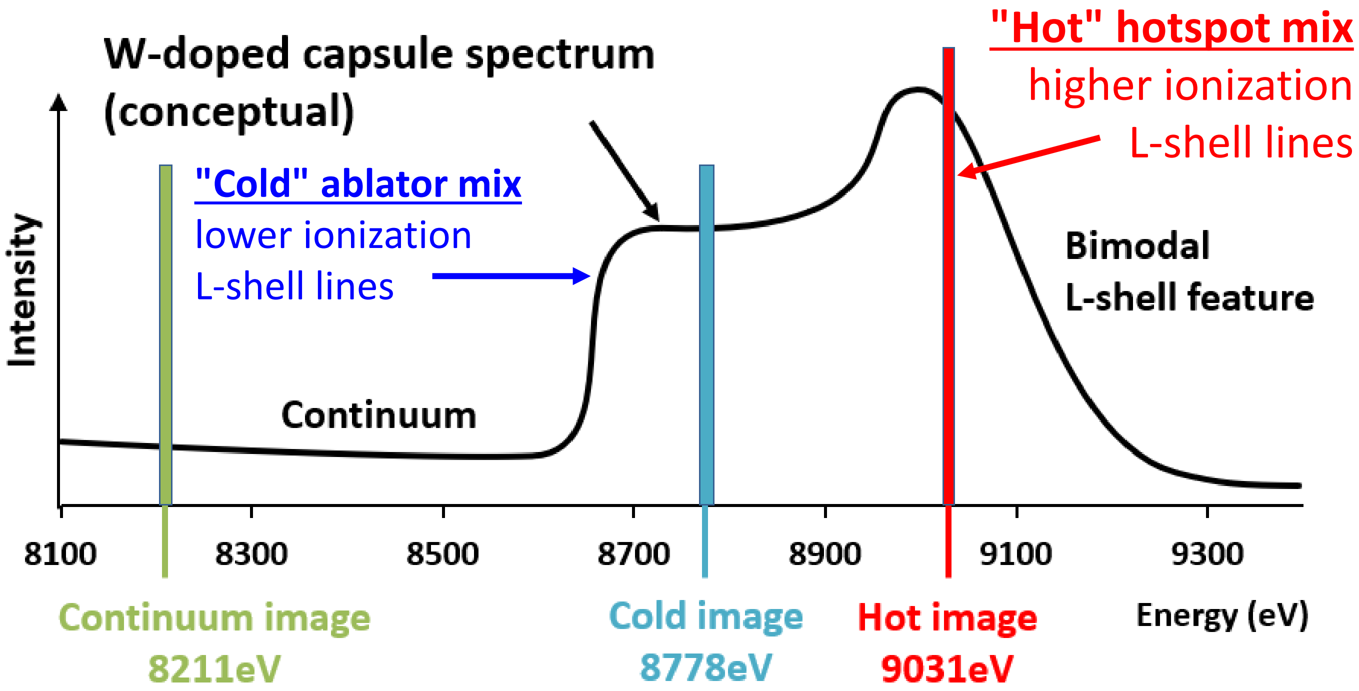
DD Tion [keV]	Data	Pre-shot Sim
B = 0	3.44	3.5
B = 28 T	4.4	4.6
28 T / 0 T	1.28x	1.31x

High Tion platform: yield up despite lower fill density



Upcoming NIF MagWarm shots: Dual CBI (crystal backlit imager) to study magnetized capsule mix





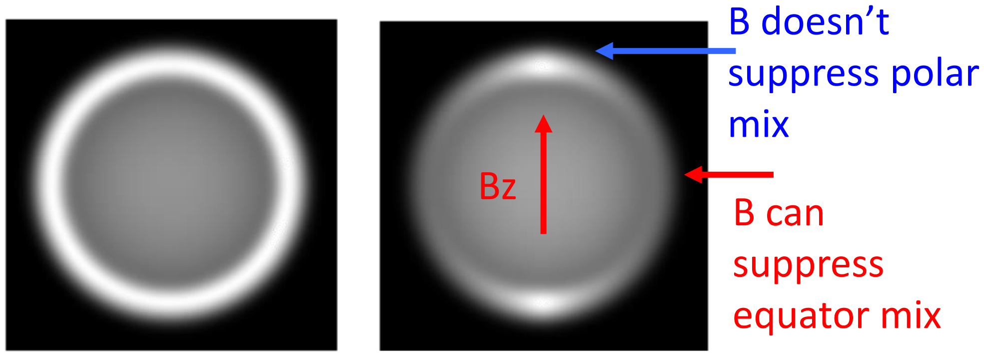
Hot mix image = Hot image – Continuum image

Cold mix image = Cold image – Continuum image

B = 0 and 26 T hot mix shots planned in our high Tion platform

Possible B-field effect on mix layer from linear magnetized Rayleigh-Taylor theory[1] (conceptual)

B = 0 **B = 26 T**



Chris Walsh – Gorgon sims

[1]C. Walsh, PRE 2022

G. Hall, B. Bachmann, T. Ebert, E. Marley …

Very early modeling of magnetizing layered DT NIF shot N190721

N190721 = subscale BigFoot[1] layered DT shot

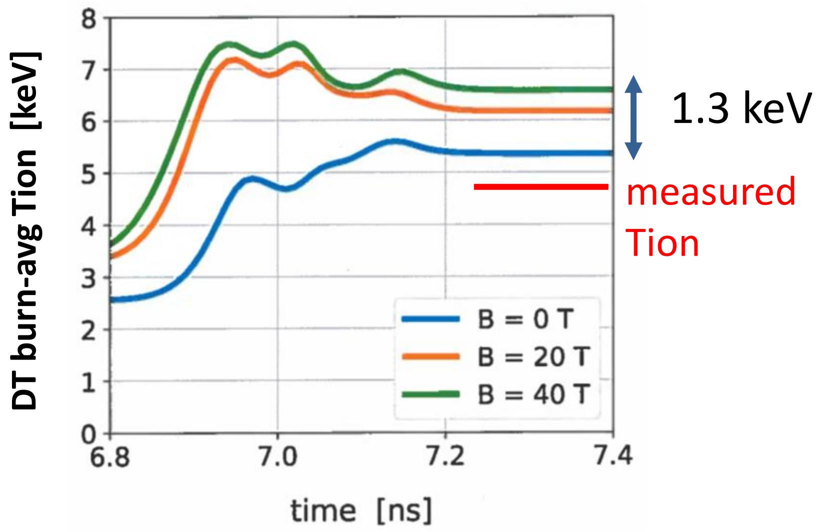
- Part of alpha heating campaign[2]
- Subscale: E_laser = 1.3 MJ
- Highest yield to date at this E_laser
- Less optics damage, SBS risk
- BigFoot is a fairly robust, reproducible platform
- Walk before you run

Lasnex Hohlraum Template (LHT) ICF common model used

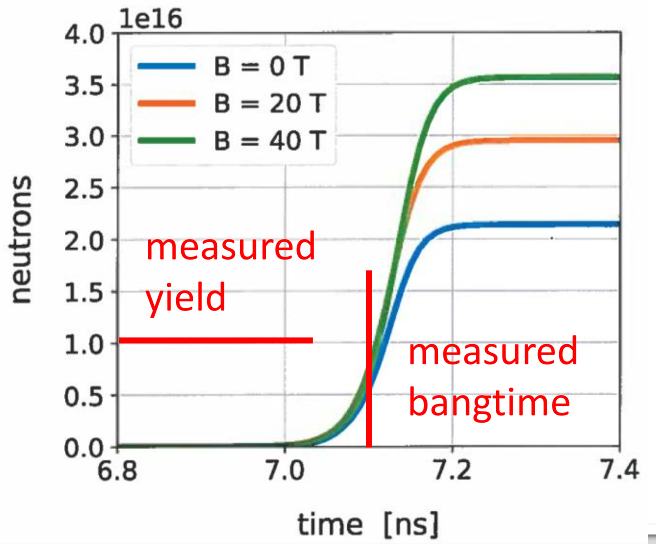
- 2D hohlraum runs: low-res. capsule, no mix
- MHD, multi-species hydro, no inline CBET
- Runs not tuned to match data yet
- Constant laser power multiplier of 0.85
- X-ray deposition in capsule symmetrized
- B field affects electron and alpha transport

B field = raw ingredient for hotter hotspot.
Need to fold into full design: tune shocks, shape, capsule thickness, …

Tion: ~ 1 keV increase with B



Neutron yield: 66% increase with B = 40 T



[1] C. A. Thomas et al, PoP 2020; K. L. Baker et al, PRL 2018
[2] K. L. Baker et al, PRE 2023

Very early modeling of magnetizing layered THD NIF shot N220220: similar to the ignition Hybrid-E platform

Runs by Blagoje Djordjevic

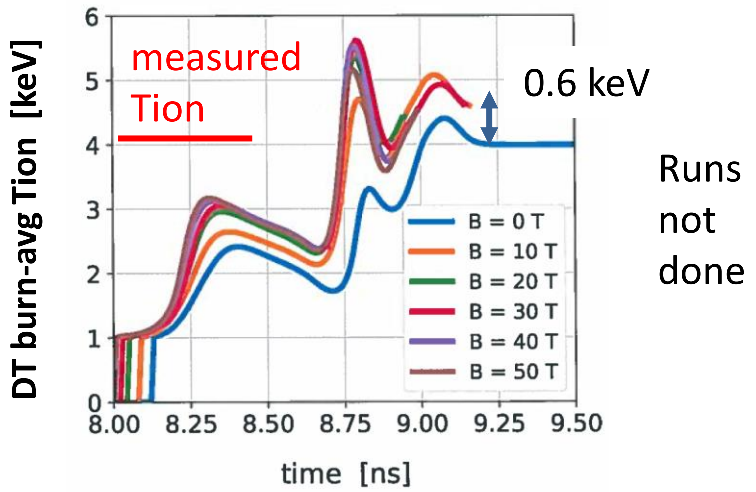
N220220: Hybrid-E THD shot

- Full scale: E_laser = 1.9 MJ
- Ice layer composition: (H, D, T) = (23.8, 1.7, 74.5)% at.
- Fuel dudded: low D, little alpha heating
- "Burn-off" analog of DT ignition shot N210808
- B field affects electron transport
  - Alphas affected but little self-heating regardless

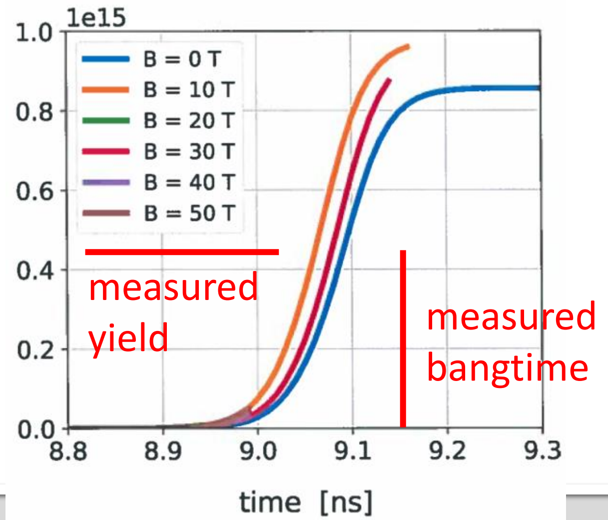
Lasnex LHT modeling: same as for N190721 except:

- Runs tuned with ANTS [C. Weber] to VISAR shock data from N221106
- Peak laser power multiplier of 0.85 starting at 5.25 ns
- Inline CBET (but capsule x-ray deposition symmetrized)

Tion: ~ 0.6 keV increase with B >= 10 T



Neutron yield coming in higher with B



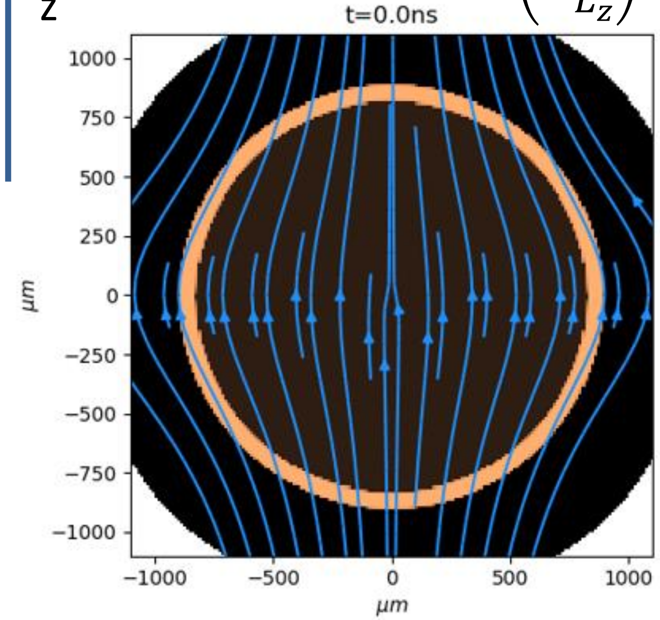
- Tion ~ 0.6 keV higher with B, yield up too – runs not complete
- Benefit saturates for B >= 20 T: electron transport suppressed
- Targets with alpha heating should have larger benefits, saturate at larger B

Non-axial B field: Mirror: motivated by reduced polar heat flow due to conserved magnetic moment

Work by Chris Walsh

Initial B field

$$B_z \propto (1-f) - f\cos\left(\pi \frac{z}{L_z}\right)$$



Gorgon sims of DT shot N170601

- First NIF shot with yield > 1e16
- No alpha heating in sim

At bangtime

Axial field (f = 0)

B_0(z=2mm) = 30T

B_0(z=0mm) = 30T

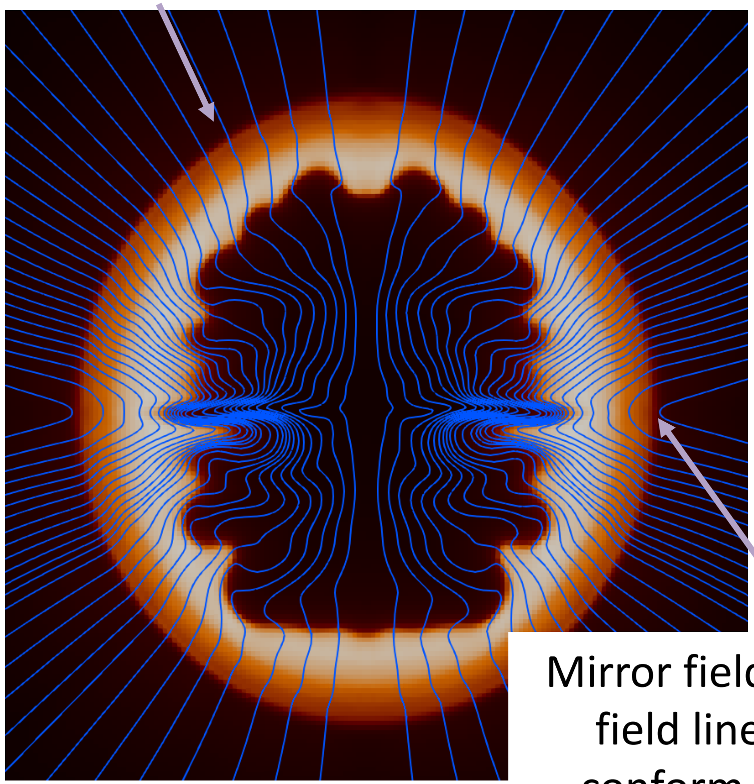
Mirror field (f = 0.4)

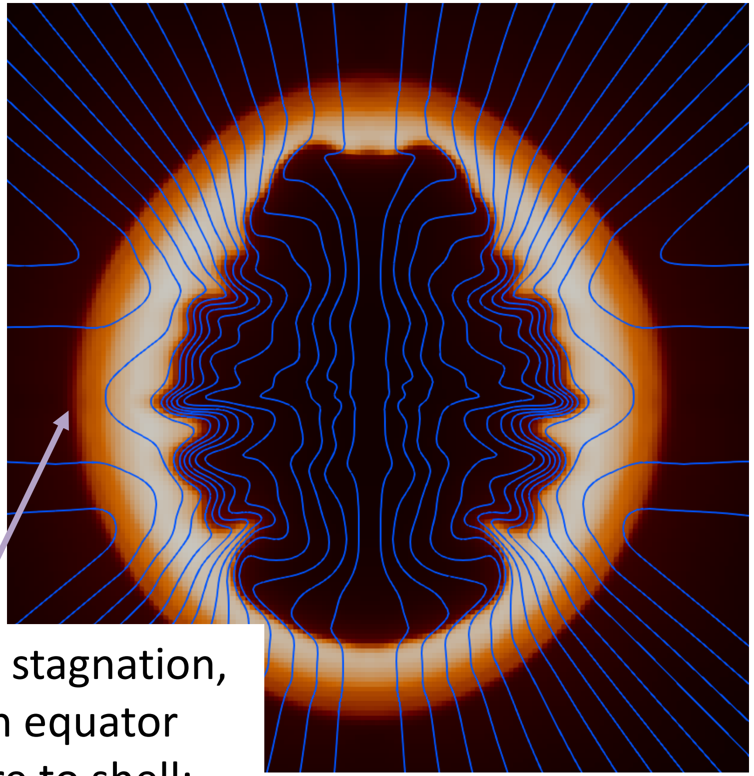
B_0(z=2mm) = 30T

B_0(z=0mm) = 6T

capsule density

Blue = field lines





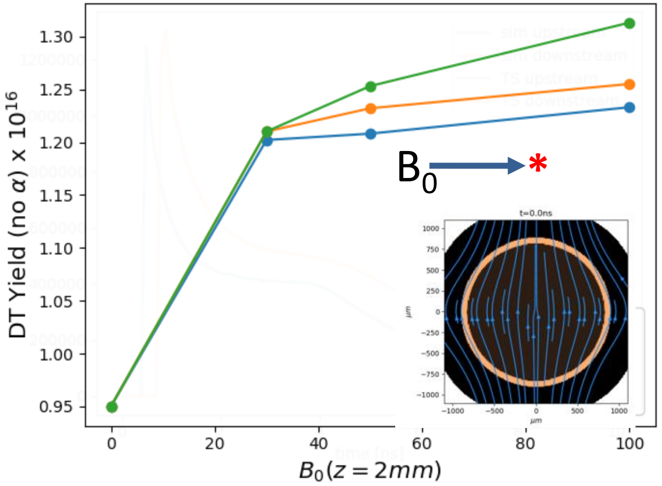
Mirror field: at stagnation, field lines on equator conform more to shell: less orthogonal

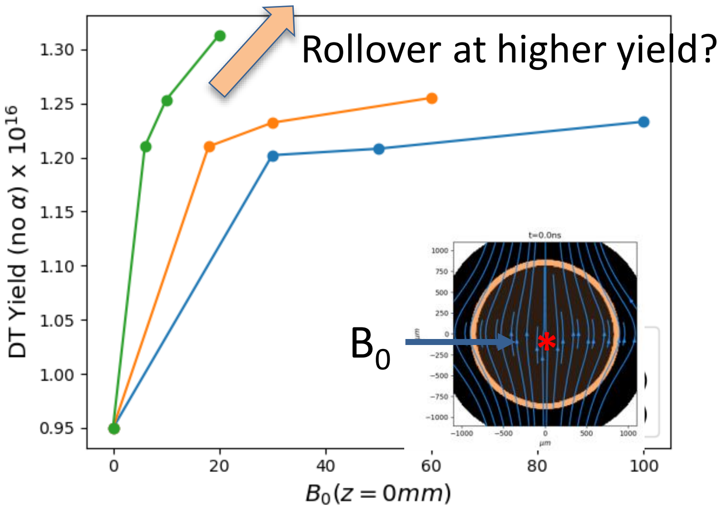
Mirror Field: Larger Tion and yield increase than axial field – unclear how to compare field strength between them

X-axis: $B_0(z = 2\text{ mm})$
B outside capsule

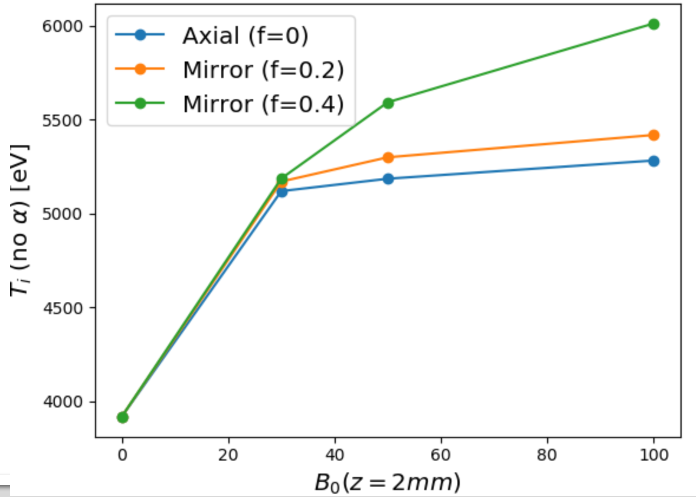
X-axis: $B_0(z = 0\text{ mm})$
B at center

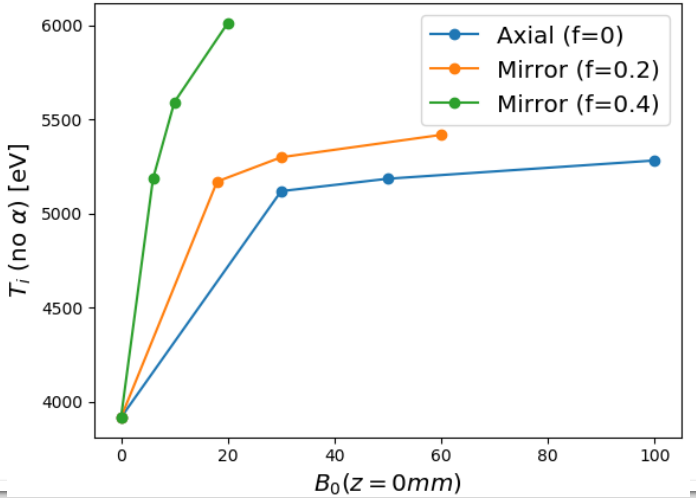
Yield





Tion





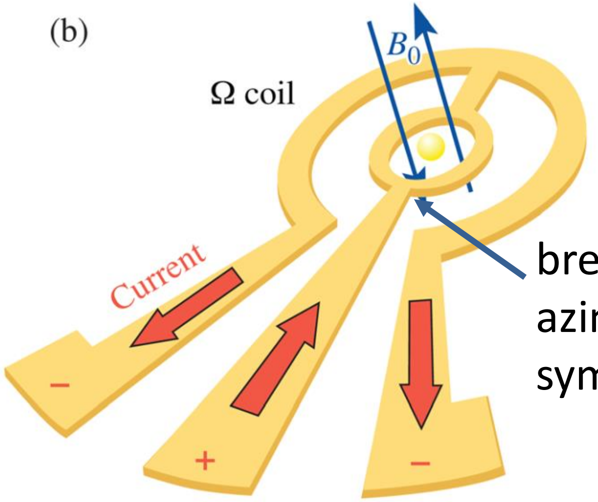
With mirror field, enhancement due to field isn't yet rolling over as it does with axial field.

Fair comparison of axial to mirror field may be what a given pulsed-power system on NIF can do.

"Omega coil:" sheared B field → closed field lines in implosions due to magnetic reconnection

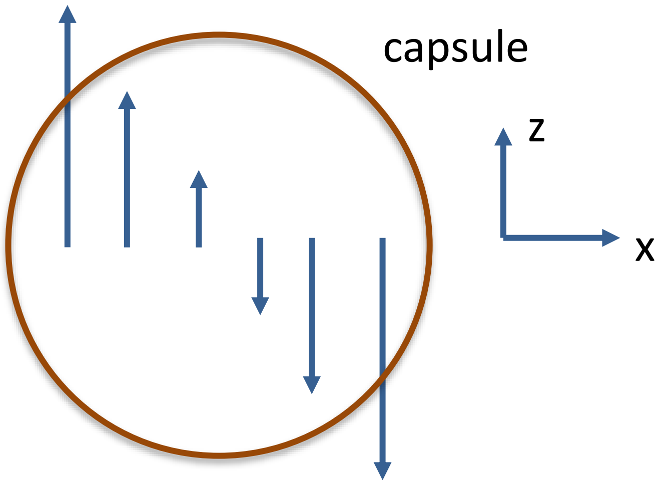
Can we create closed, azimuthal field lines without running a wire through the capsule?

- "Omega coil" is one proposal – from M. Hohenberger et al, PoP 2012
- We are not aware of this ever being shot, just a notion

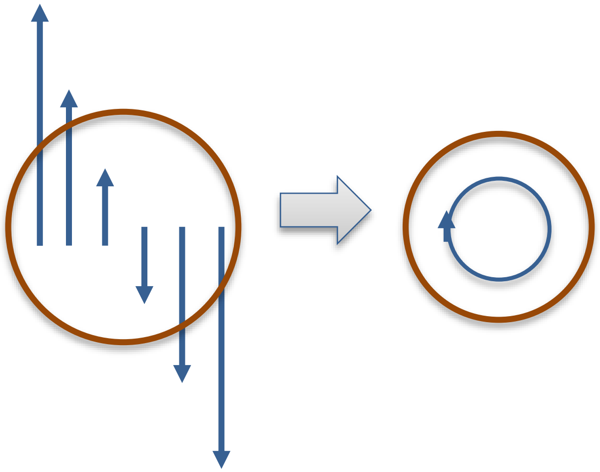


breaks azimuthal symmetry

Initial Bz of alternating sign, varies mainly in x (not y!)



Field reconnects in implosion → closed azimuthal field

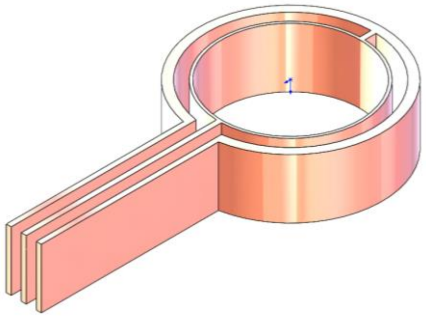


Magnetic reconnection in a dense HED plasma is an interesting basic science question!
Problem is intrinsically 3D: Bz[x] not Bz[r]!

“Omega coil” vs. ring shear coil for NIF pulser

Work by Alex Povilus

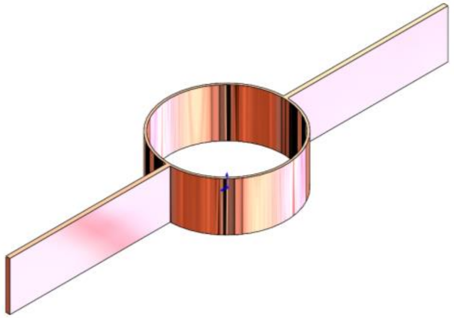
Omega coil:
Hohenberger et al.



dBz/dx = 0.05 T/mm

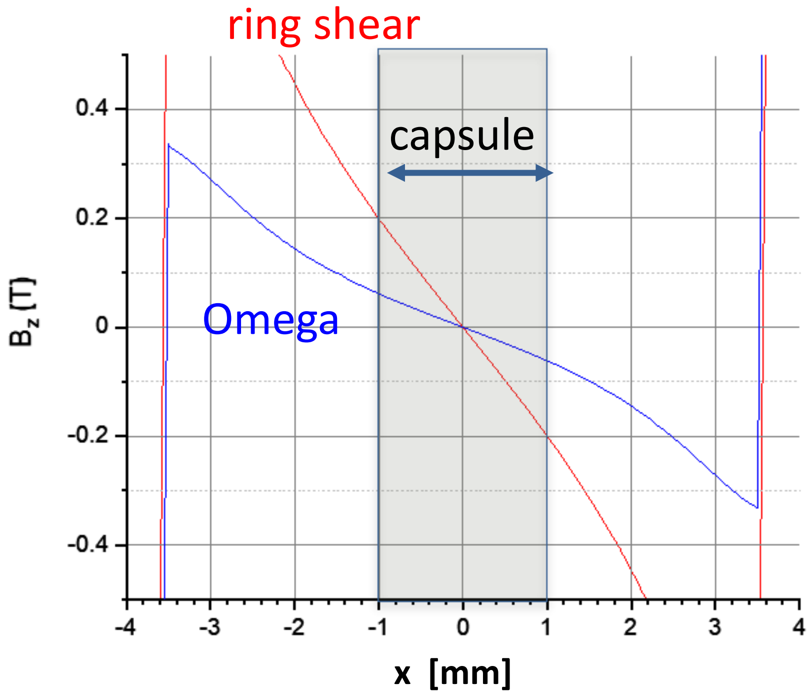
inductance = 1.2nH

Ring shear coil:
A. Povilus
higher B and inductance



dBz/dx = 0.2T/mm

inductance = 6.6nH



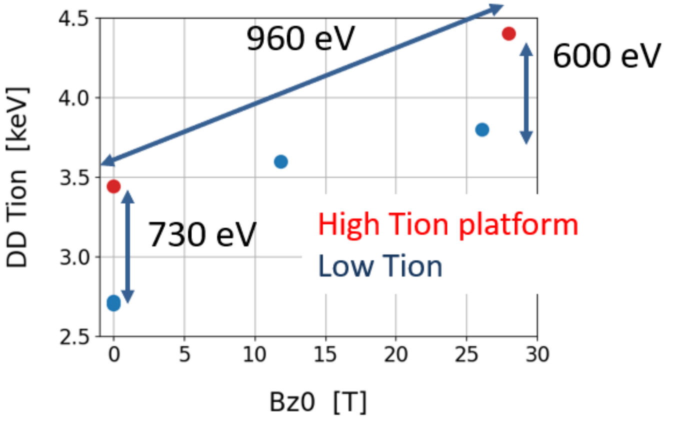
Same driver for both: 3mm strip, coil drive @ 10kA current

- Omega coil is lower inductance and can use a lower capacitance driver. Likely not an issue on NIF.
- Ring shear coil has ~ 4x more B field for same current
- Initial B < 1 T in capsule – pretty small! Even if closed field lines form, will they be too small?

Conclusions and future work

High Tion MagWarm (room temp.) NIF gas capsules:

- Tion up with and without B
- Dual CBI (crystal backlit imager) shots to measure magnetized capsule mix upcoming



Burn-avg. T_{ion} [keV]: Increases in all cases with B, b/t 0.6 and 2.1 keV

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Lasnex sims [Strozzi, Djordjevic]	High Tion gas capsules (preshot)	3.5	4.6	1.1
	N190721 – subscale bigfoot DT	5.2	6.5	1.3
	N220220 – THD ignition analog	4.3	5.2	0.6
Gorgon sims [Walsh]	N170601 – first > 1e16 yield shot	3.9	5.5	1.6
	N170601 – mirror field (f = 0.4)	3.9	6.0	2.1 winner!?

Goal: field setups or target designs with largest B field effect, e.g. ignition vs. not.

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