First Magnetized Hohlraum-Driven Implosions on the NIF

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LLNL

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Magnetization increases nuclear yield and hotspot temperature in hohlraum-driven, gas-filled implosions, in line with modeling

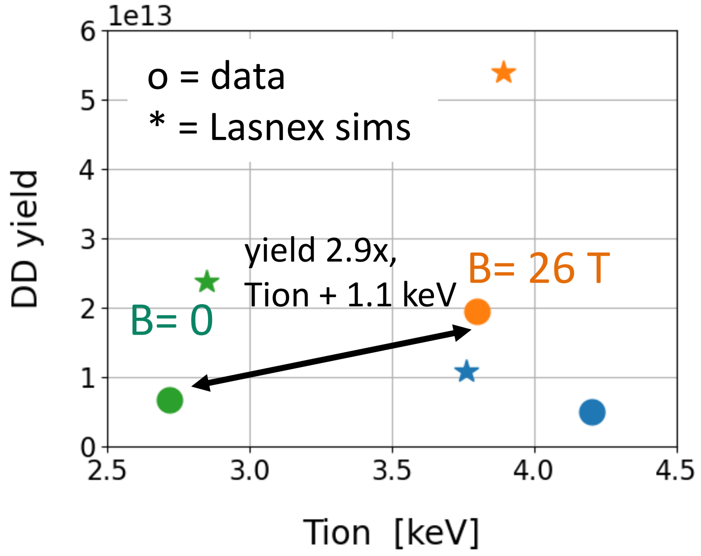
What we learned from 6 NIF shots from Dec. 2020 to present:

1. "Hohlraum energetics:"
- Electrically resistive AuTa4 alloy[1] for hohlraum wall: facilitate field soak-thru
- Good hohlraum material: efficient x-ray production, low backscatter

2. Magnetized hohlraums similar to unmagnetized:
- x-ray drive similar, backscatter low for both
- Implosion shape tunable with laser cone fraction

3. Magnetized capsules are hotter and give higher yield
- Due to reduced electron thermal loss from hotspot
- Reduced alpha loss matters for layered DT, not for these gas capsules

All rad-hydro modeling shown uses Lasnex with the LHT common model



UO4 Mag. NIF block: 1 down, 3 to go
UO4.7: John Moody: Mag. NIF overview
UO4.8: Dave Strozzi: Mag. NIF shots: this talk!
UO4.9: Hong Sio: 2ndary DT's on NIF shots
UO4.10: Darwin Ho: magnetized shocks

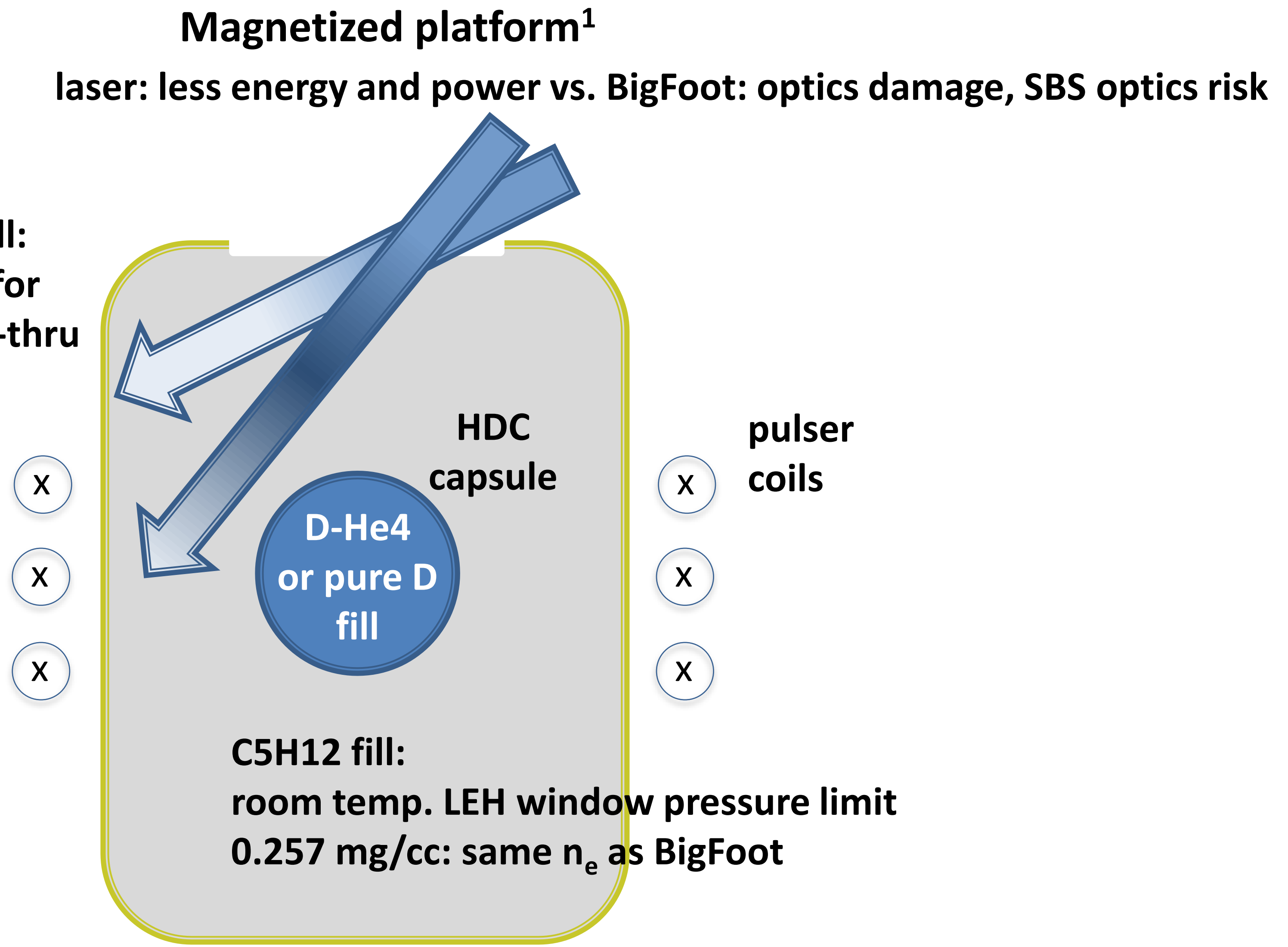
UO4.11 – 13: A. Bose, S. O'Neill, C. Walsh: more on magnetized ICF

[1] A Engwall +, US patent app. 62/928968; L B Bayu Aji +, J. Phys. D 2021; A M Engwall +, Appl. Surf. Sci. 2021; J H Bae +, J. Appl. Phys. 2021

Magnetized platform[1]: BigFoot[2] subscale platform plus constraints

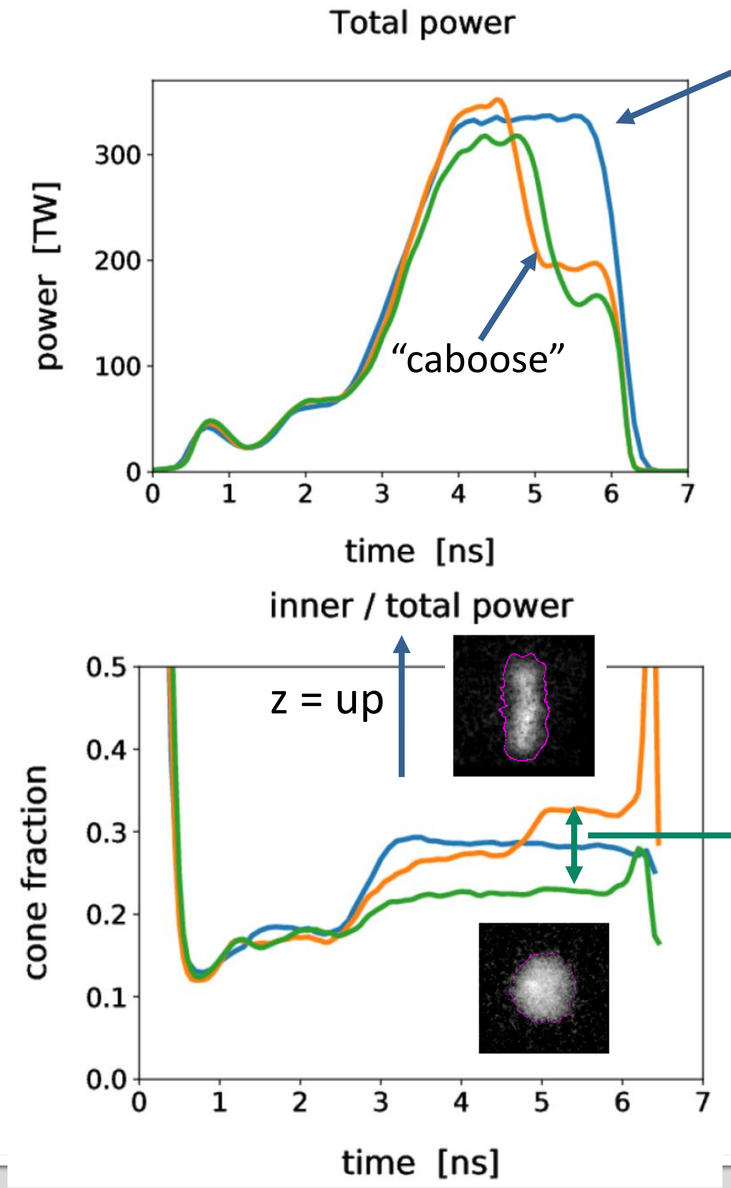
Why BigFoot? Best combo of
- High performance
- Reliability / predictability
- NIF subscale database

2 C. A. Thomas +, PoP 2020;
K. Baker +, PRL 2018



1 J. D. Moody +, PoP 2020; J. D. Moody +, J. Fusion Energy [submitted]

Laser pulse: implosion shape tunable by cone fraction even with B field



N161204: BigFoot subscale baseline:

- 28% peak cone fraction: moderately sausaged hotspot

N210301: 1st magnetized pulse: sausaged

- N161204 with energy reduced to meet SBS risk
- "Caboose": free for SBS risk due to low power
- 28% peak cone fraction → very sausaged magnetized implosion

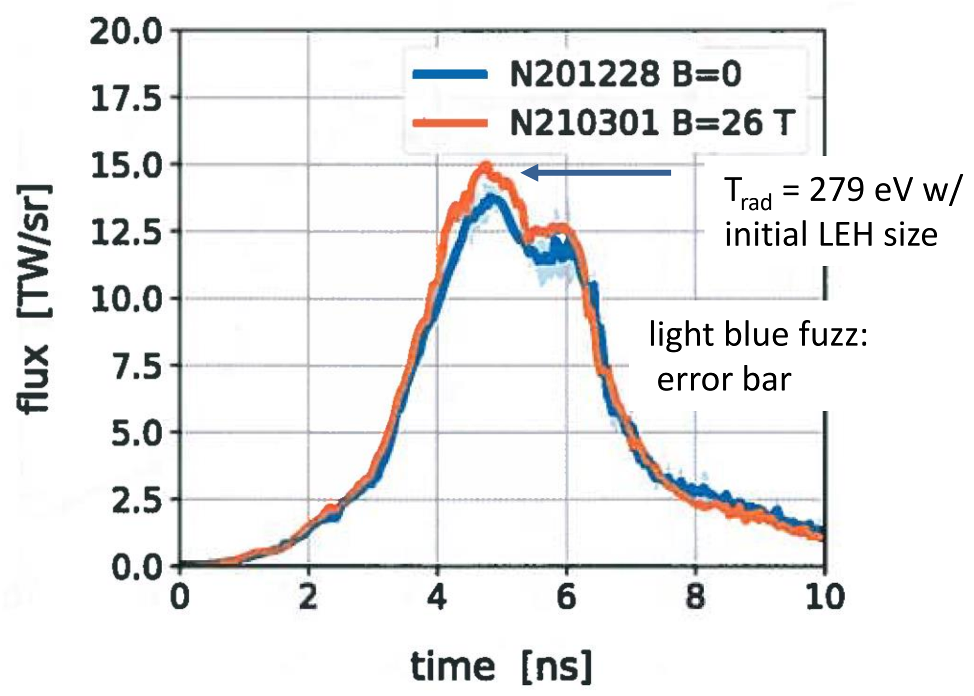
N210607: 2nd magnetized pulse: round

- Reduced 23% cone fraction for round magnetized implosion: it was!
- Total power reduced due to SBS risk:
  - Outers at max., inners set by cone fraction

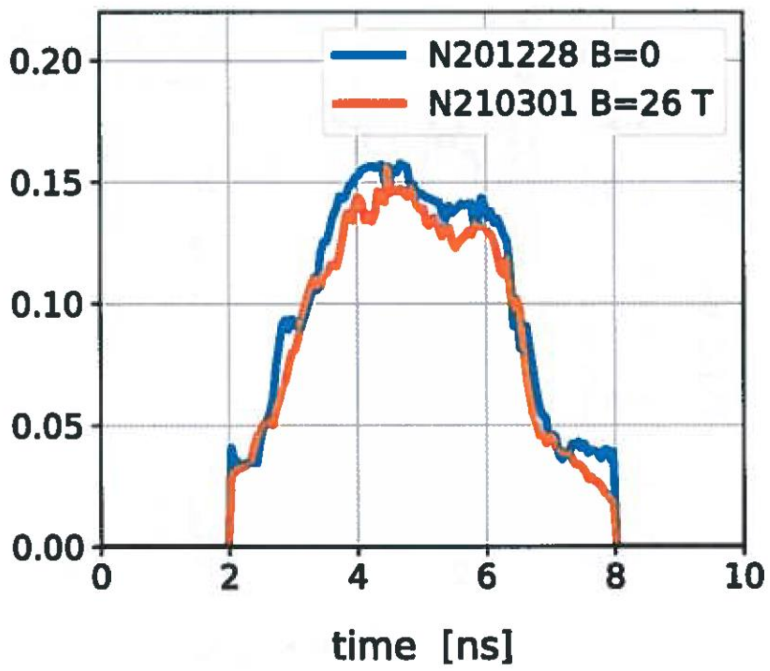
- **Only design choice for platform: lower cone fraction for 2nd magnetized pulse**
  - **It worked!**

AuTa4 hohlraum wall: x-ray drive with B and no-B comparable

Total flux measured by DANTE-1
28% cone fraction shots: B and no-B close



> 1.8 keV "M-band" flux fraction



Drive comparable to similar BigFoot shots with Au wall

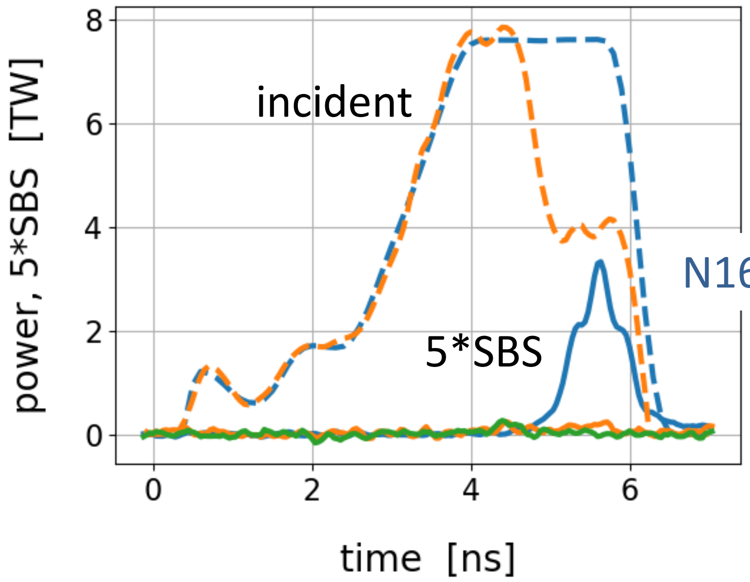
OMEGA AuTa foil experiments showed slight decrease (<5%) of total flux with increasing Ta %

DANTE data unfold by PUKA tool: Elijah Kemp +, RSI 2020

Backscatter: low on all magnetized platform AuTa4 shots, no sign of B field effect

Shot	Platform	Cone frac %	Backscatter / laser energy %	Comment
N161204	BigFoot, B = 0	28	1.2	mostly cone 50 SBS late in time, common on BigFoot
N201128	Mag, B = 0	28	0.2	All low: low-power caboose why no cone 50 SBS?
N210301	Mag, B = 26 T	28	0.1	all low, no effect of B field
N210607	Mag, B = 26 T	23	0.1	all low
N210717	Mag, B = 0	23	0.1	all low; N210912 similar

Cone 50 SBS



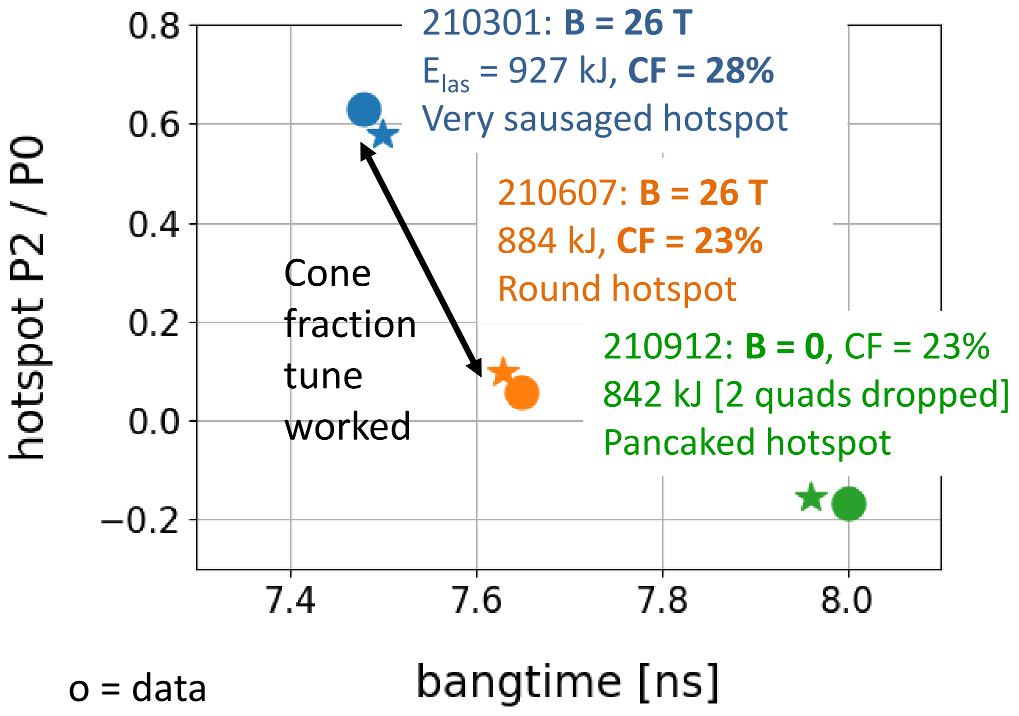
N161204: BigFoot: pure Au

N201228: Unmag, CF = 28%

N210301: Mag, CF = 28%

Lasnex modeling: cone fraction multipliers to match data different with B vs. no B

"INPUTS": Hotspot bangtime and P2

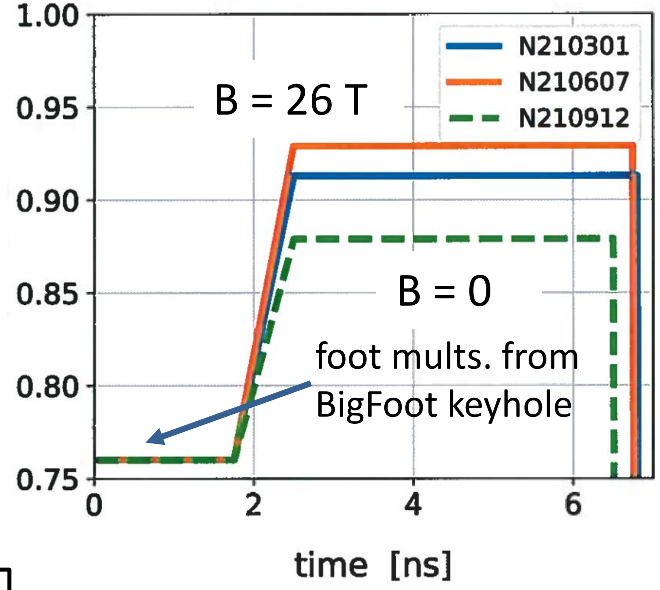


o = data
* = Lasnex sims

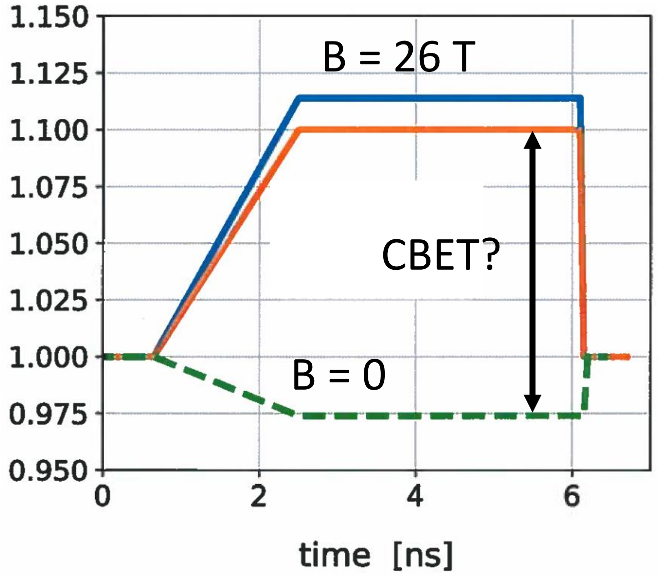
Lasnex post-shot sims: laser power and cone fraction multipliers to match bangtime and hotspot P2

Laser multipliers from ANTS (Automated NIF Tuning Suite) tool by Chris Weber

power multiplier: remove energy to match bangtime



cone fraction multiplier: drive asymmetry to match hotspot P2

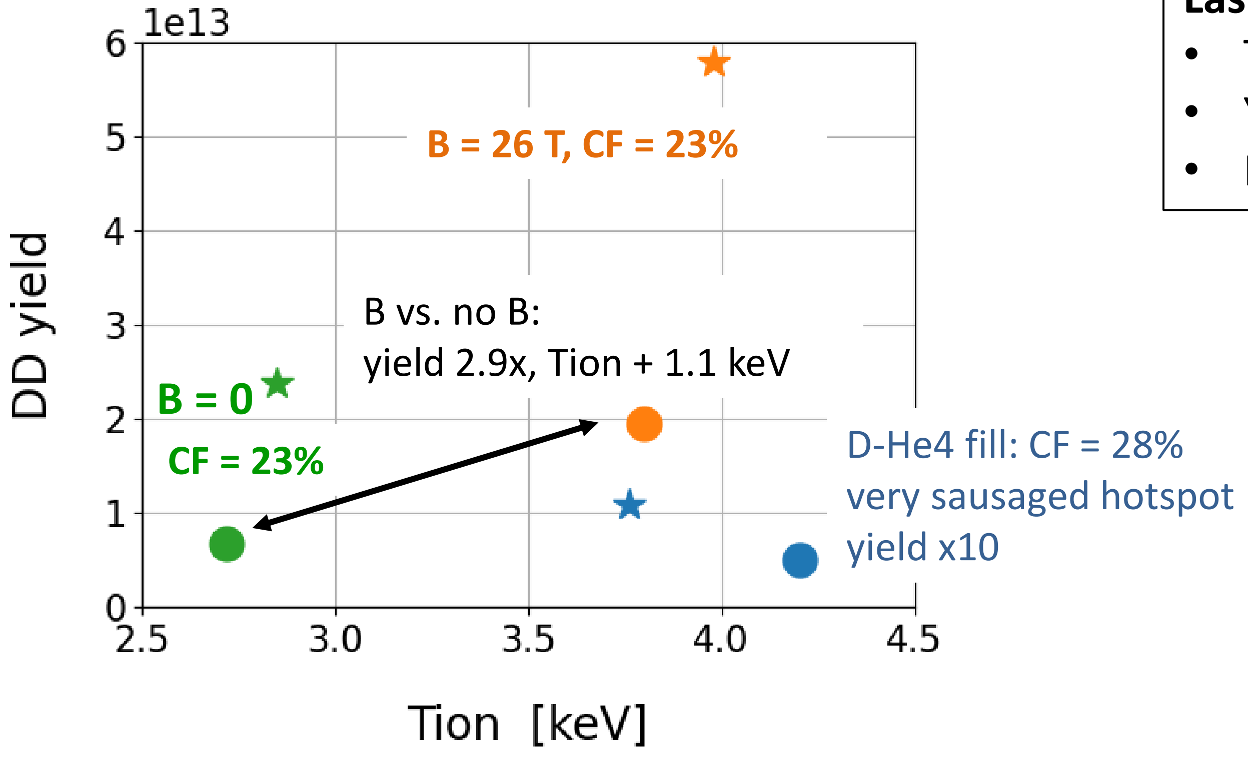


Difference in cone fraction mults. with B vs. no B due to CBET changes? CBET not included in this modeling.

B field increases nuclear yield and ion temperature, Lasnex captures trends but absolute yields too high

o = data
* = Lasnex sims

"OUTPUTS": Yield and T_{ion}



Lasnex sims

- T_{ion} close for 2 nearly-round implosions
- Yields 2-3x above data
- Possible causes: fill tube, mix, hotspot velocity

Lasnex captures relative effect of B field pretty well

CF = 23% shots	data	Lasnex
DD yield: B / no B	2.90x	2.43x
Tion [keV]: B – no B	1.08	1.13

Summary and Future Plans: Towards Magnetized Ignition

Summary: Lessons learned in 6 NIF shots:

1. "Hohlraum energetics:"

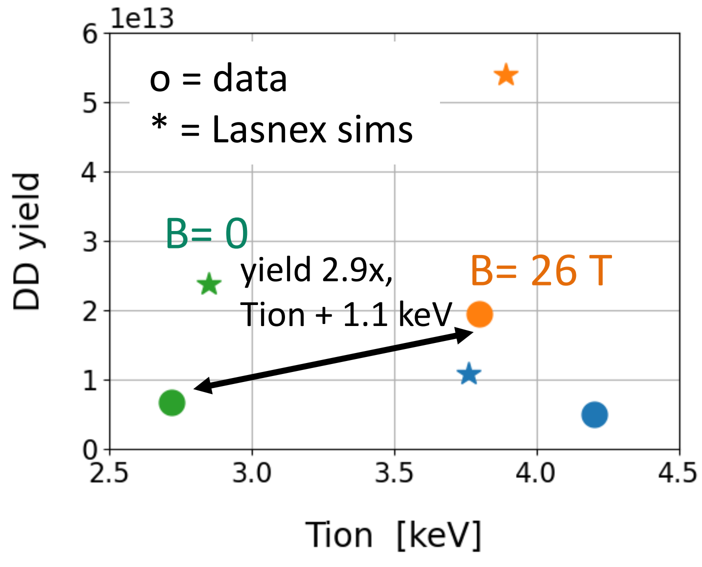
- Electrically resistive AuTa4 is good hohlraum wall material: efficient x-ray production, low backscatter

2. Magnetized hohlraums similar to unmagnetized:

- x-ray drive similar, backscatter low for both
- Implosion shape tunable with laser cone fraction, comparable to un-magnetized

3. Magnetized capsules are hotter and give higher nuclear yield

- Due to reduced electron thermal loss from hotspot
- Reduced alpha loss matters for layered DT, not for these gas capsules



The Future

- **Warm subscale NIF platform:**
  - Vary B field, capsule gas fill → convergence
  - Higher performance: higher x-ray drive from smaller hohlraum, DU wall, 1/3 cone fraction
    - B field took hotspot from 3 to 4 keV, can B take from 4 to 5 keV?
- **Modeling:**
  - Understand difference in laser multipliers with B and no B: cross-beam energy transfer (CBET)?
  - Improve agreement on yield: mix, fill tube, hotspot velocity
- **On to magnetized cryo implosions in FY24!**

BACKUP BELOW

Magnetized platform[1]: BigFoot[2] subscale platform plus constraints

Why BigFoot?

- Best combination of high performance and reliability as of 2018
- Extensive subscale experiments

Why Subscale?

- Laser energy ~ 1 MJ for optics damage, SBS risk
- Smaller hohlraum → larger B field ~ pulser current / hohlraum volume

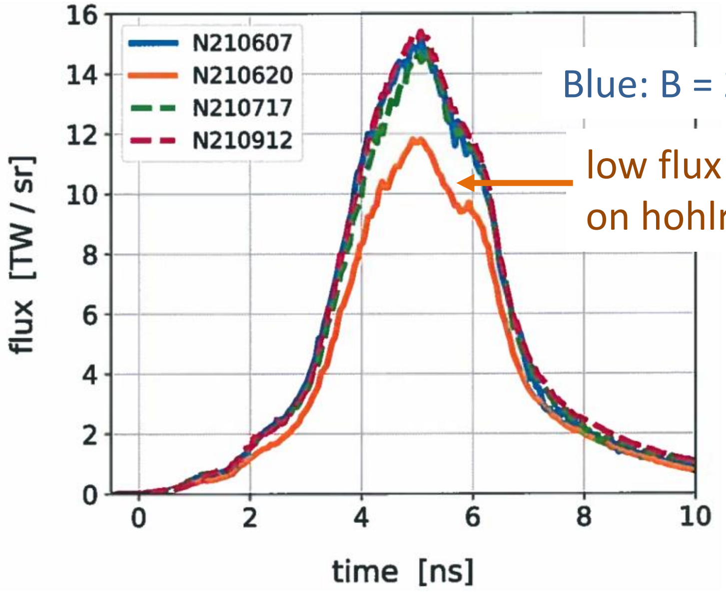
Why room temperature?

- Pulser not fielded on cryogenic target positioner yet; planned for 2024
- Gas-filled capsules: no ice layer, no keyholes

1 J. D. Moody +, PoP 2020; J. D. Moody +, J. Fusion Energy [submitted]

2 C. A. Thomas +, PoP 2020; Baker +, PRL 2018

Total DANTE flux: 4 shots, 23% cone fraction

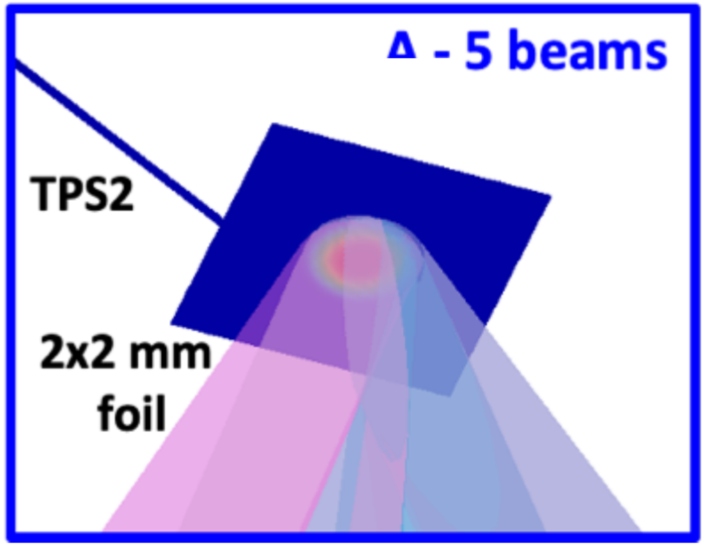


Blue: B = 26 T, rest had no B

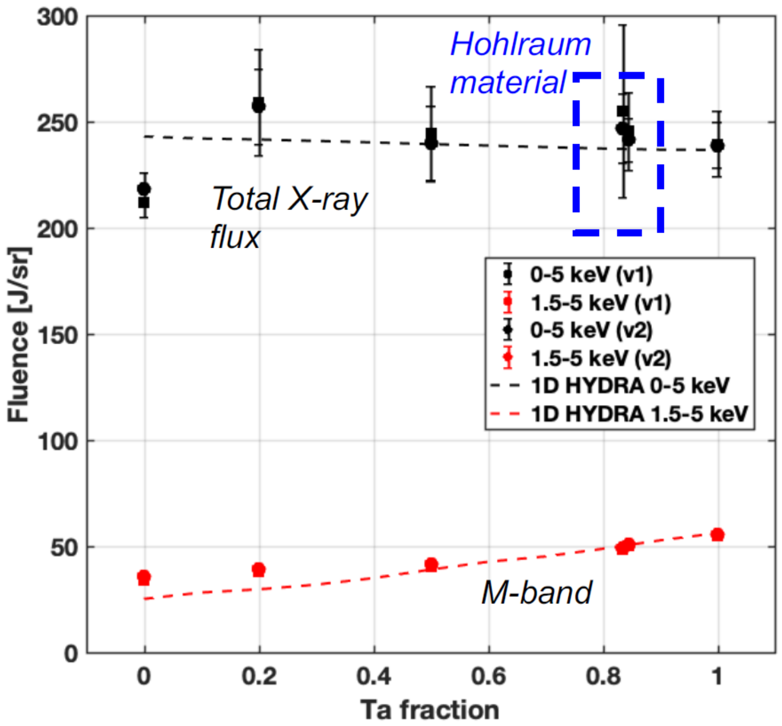
low flux may be due to low-Z liner on hohlraum – Tfab issue

Foil experiment on OMEGA demonstrated comparable total x-ray flux and M-band between Au and AuTa alloy

Target-laser configuration



Total x-ray flux and m-band



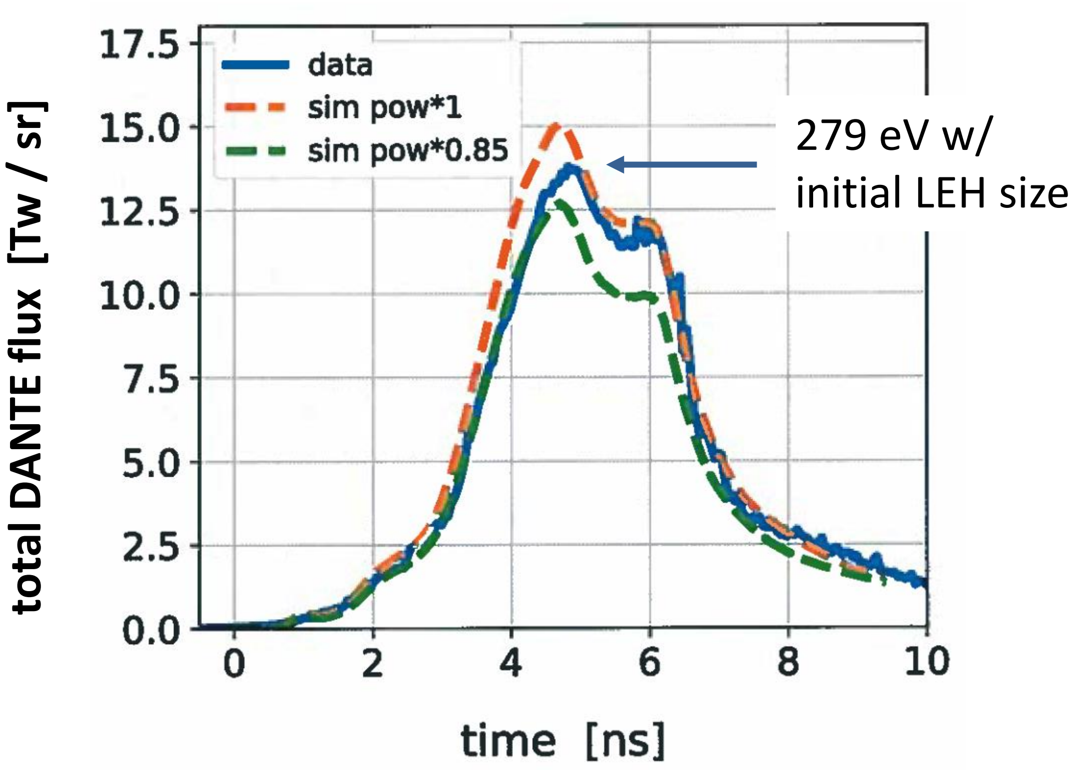
Omega DANTE instrument operated by Dan Barnak

DANTE analysis and HYDRA sims by Elijah Kemp

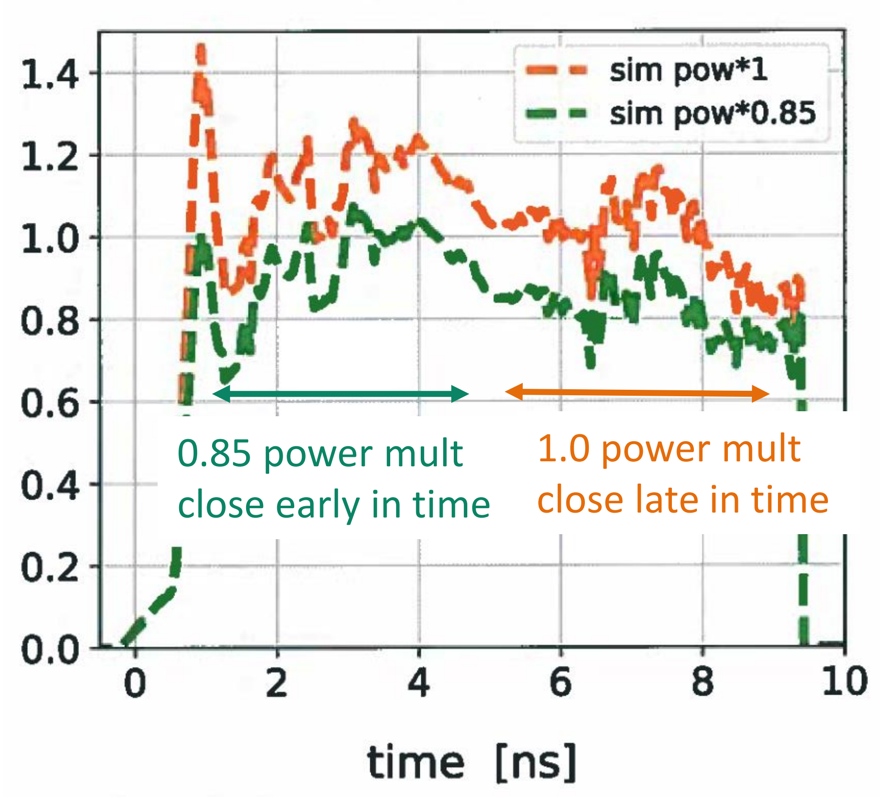
Total flux shows a slight decrease (< 5%) and M-band increase (~ 40%) with increasing Ta concentration

Lasnex modeling: need to reduce laser power by 0 – 15% to match measured DANTE flux

N201228: first mag. shot, 28% cone frac, no B field



simulated / measured flux



Shot summary, calendar order

Shot	Bz [Tesla]	Capsule fill [mg/cc]	Cone fraction [%]	DD Yield [#]	DD Tion [keV]	Hotspot P2/P0 [%]	Upshot, what we learned
N201228-1	0	None: leak	28	N/A	N/A	N/A	Hohlraum commissioning: good x-ray drive, low backscatter
N210301-1	26	4.07 D3-^{4}He7	28 ↓ Only design	5.0E11	4.2	63	First magnetized hohlraum shot: hotspot large sausage
N210607-2	26	3.99 D2	23 choice so far	2.0E13	3.8	5.7	Reduced cone frac → round implosion! Switch to pure D fill: more 2ndary DT's
N210620-1	0	3.99 D2	23	N/A	N/A	N/A	low x-ray drive, maybe due to low-Z hohlraum liner from Tfab
N210717-1	0	3.89 D2	23	5.3E12	2.7	N/A	Yield and Tion much lower than mag. shot No shape data: blocked line of sight
N210912-1	0	3.99 D2	23	6.7E12	2.7	-16.6	B = 0 repeat with shape data: Moderate pancake

Cone fraction = inner / total laser power