Modeling the First Magnetized NIF Hohlraum Implosions

D. J. Strozzi, G. B. Zimmerman, J. D Moody, H. Sio, C. A. Walsh,
D. D. Ho, B. B. Pollock, C. R. Weber, G. E. Kemp

Other APS talks:
Hong Sio, Wed. 12 PM, NI2.6 (invited)
Brandon Lahmann, Wed. 10:54 AM, NO4.8
This session:
John Moody, UO4.2 – prior talk
Chris Walsh, UO4.4
Darwin Ho, UO4.6

Oral talk UO04.3
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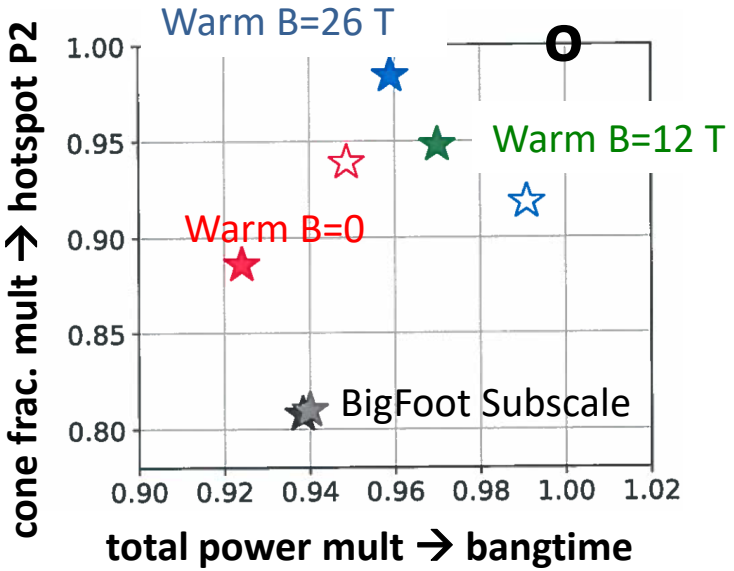
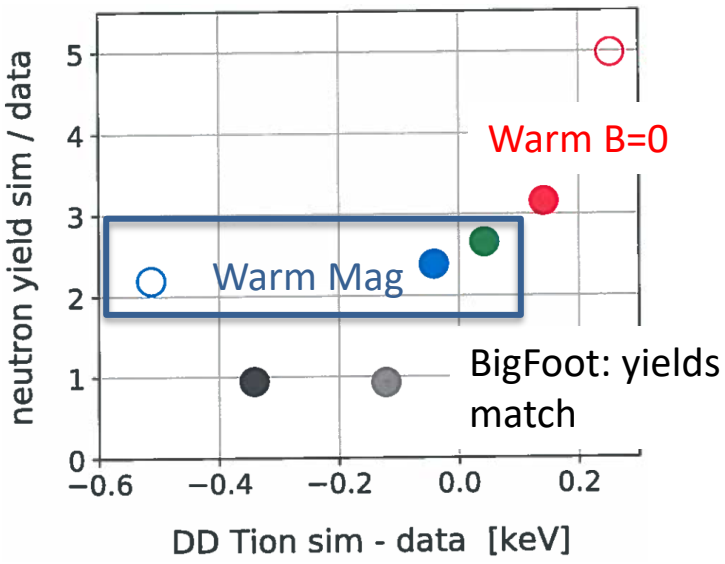
Lawrence Livermore National Laboratory

Lasnex modeling of warm magnetized and un-magnetized NIF shots: hohlraum drive OK, capsule yield too high, relative effect of B field OK

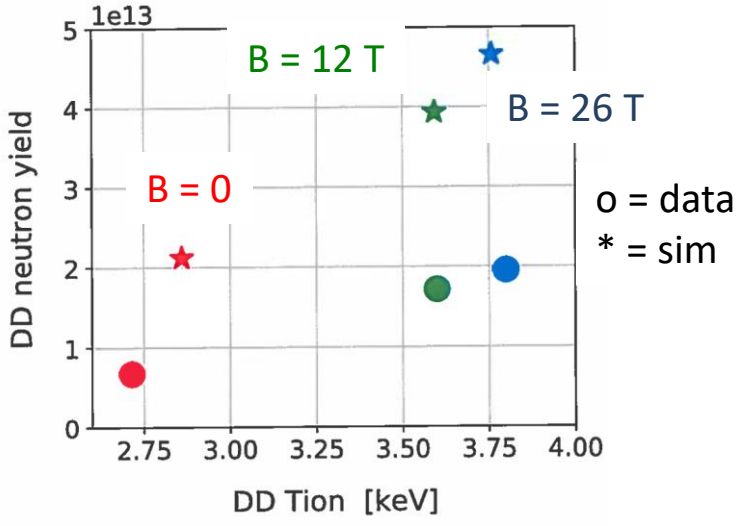
Hohlraum Inputs: laser mults to match shocks, bangtime, hotspot P2



Capsule Outputs: untuned



B = 12 T gives most of the effect of 26 T, in data and sims



o = "no mults": no change to laser power or cone fraction

Papers

J. D. Moody +, PRL accepted
J. D. Moody +, J. Fusion En. 2022
J. D. Moody +, PoP 2020

WarmMag platform designed and modeled with Lasnex and LHT (Lasnex Hohlraum Template) Common Model

Many thanks to George Zimmerman for help esp. with MHD

MHD model: full single-fluid Braginskii

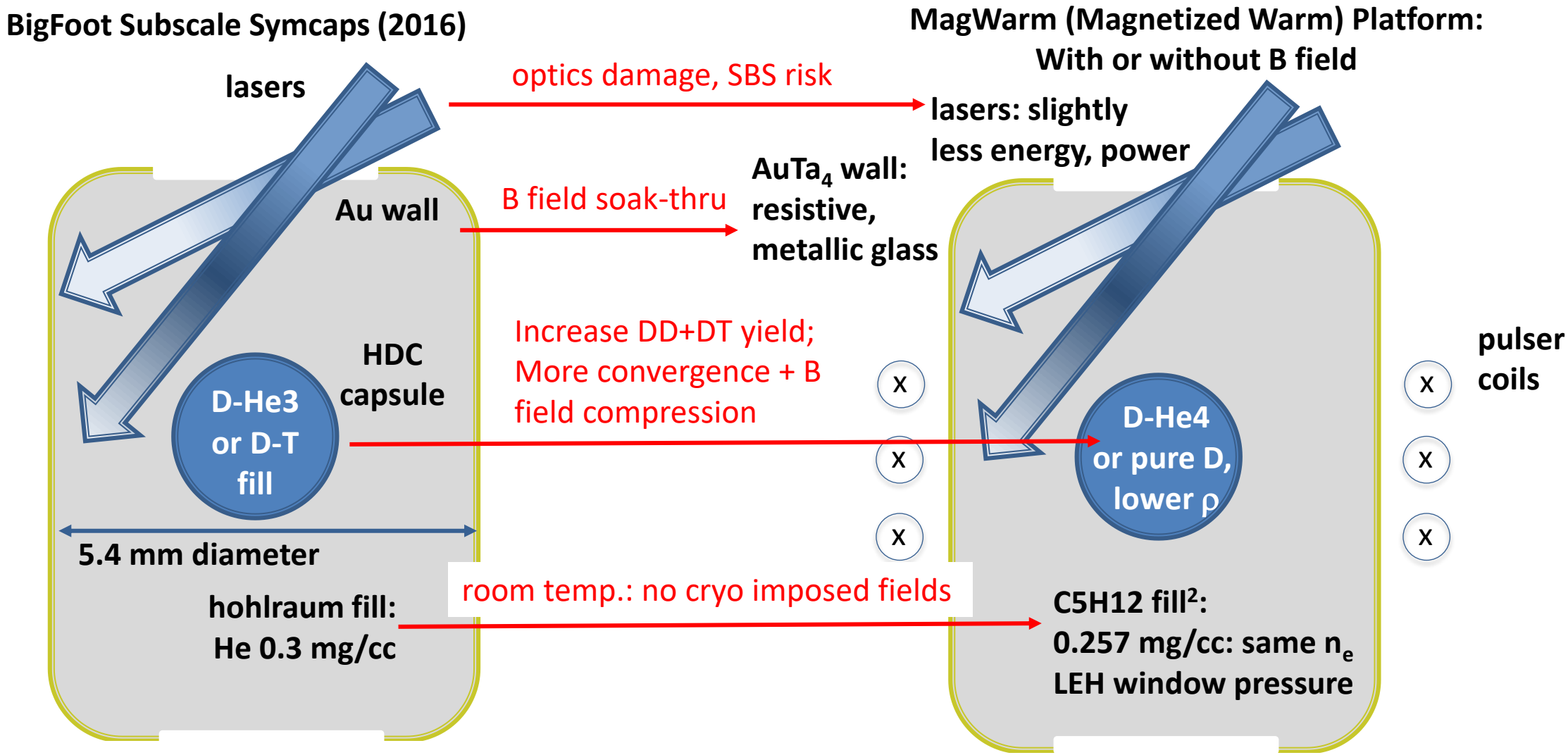
- All terms included: Biermann, Nernst, Righi-Leduc, Hall, Seebeck, …
  - Revised coefficients[1] vs. $\omega_{ce}\tau_{ei}$ and Z
  - **Nernst term multiplied by 0.1:** M. Rosen[2] Omega Au spheres and NIF dot spectroscopy; also T. Woods NIF Au bubble experiments
- Self-generated azimuthal B always included: "Biermann battery" effect
- **Imposed B:** initial B_r and B_z from analytic solution for thin, finite-length solenoid
  - B field we quote is B_z at capsule center

Lasnex + LHT model: other details

- **Inline cross-beam energy transfer (CBET)[3]** with saturation clamp $\delta n_e/n_e$ = 5E-3
  - No direct effect of B fields on CBET, just indirect via plasma conditions [Y. Shi]
- **Multi-species hydro[4]:** separate ion species densities and velocities, same temperatures
- High electron heat flux limit[5] f = 0.15, effectively local Spitzer-Harm / Braginskii
- Non-LTE: 2020 DCA models, all materials inline, except Au and Ta NLTE tables[6]
  - Big runtime savings vs. inline, esp. with two hi-Z species
- Laser Entrance Hole (LEH) hardware included
- HDC EOS 9061 – best physics at LLNL[7]

1: J. Sadler, C. Walsh, H. Li, PRL 2021
2: M. D. Rosen, APS DPP 2018
3: D. J. Strozzi, D. S. Bailey +, PRL 2017
4: D. P. Higginson, D. J. Strozzi +, PoP 2022
5: M. D. Rosen, H. A. Scott +, HEDP 2011
6: H. A. Scott, J. A. Harte +, to be submitted
7: L. X. Benedict, K. P. Driver +, PRB 2014

WarmMag Platform, with or without B: Subscale BigFoot plus constraints

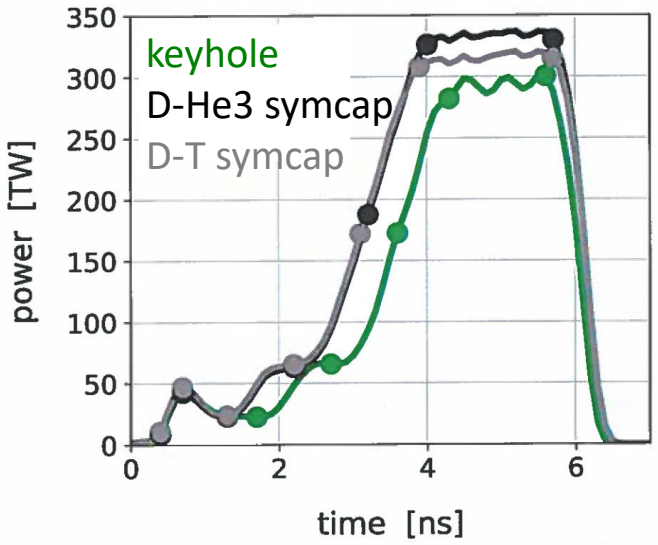


[1] C. A. Thomas +, PoP 2020; Baker +, PRL 2018

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

BigFoot shots: time-dependent laser multipliers to match shock timing, bangtime, and hotspot P2

Incident laser:
points = ANTS control times



Tuning done with ANTS (Automated NIF Tuning Suite) tool - C. Weber

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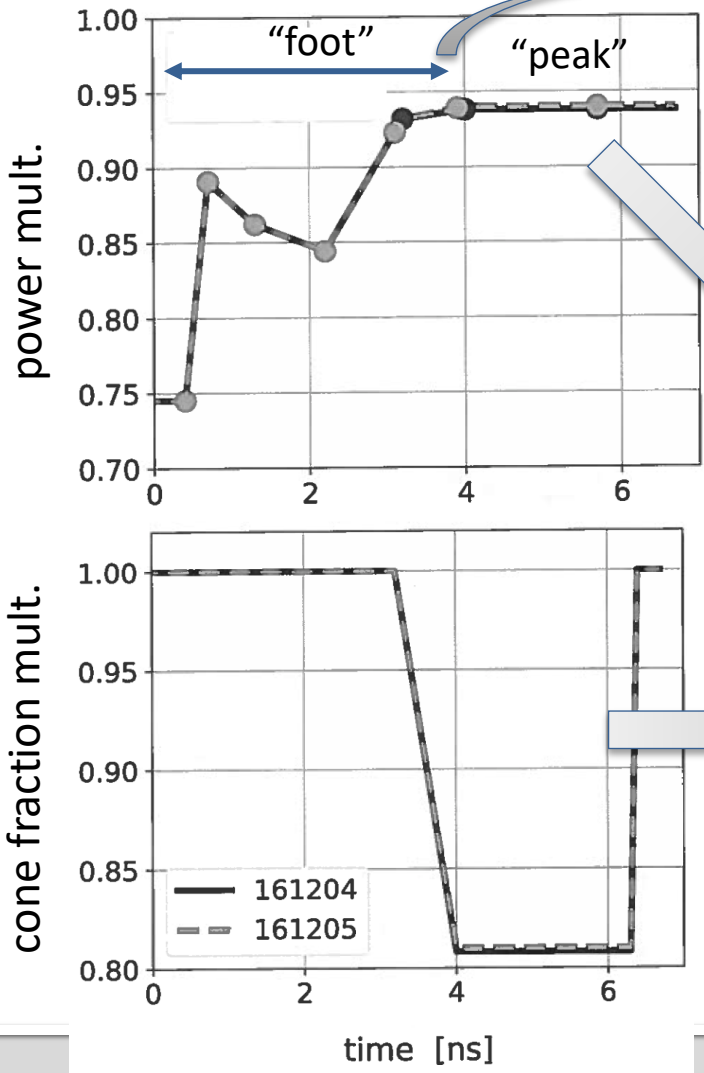
Laser multipliers



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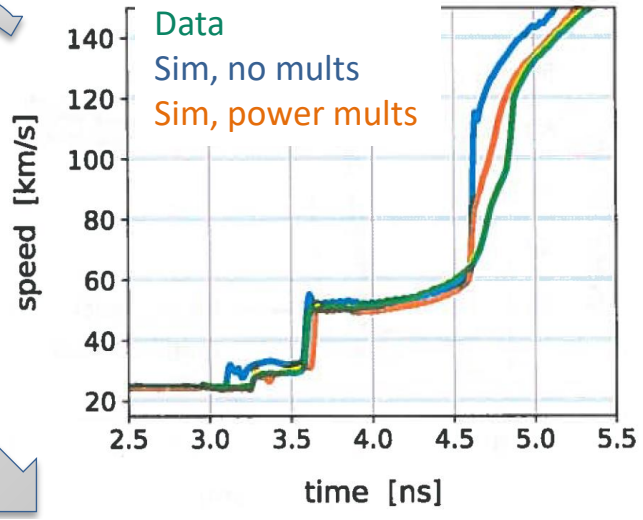
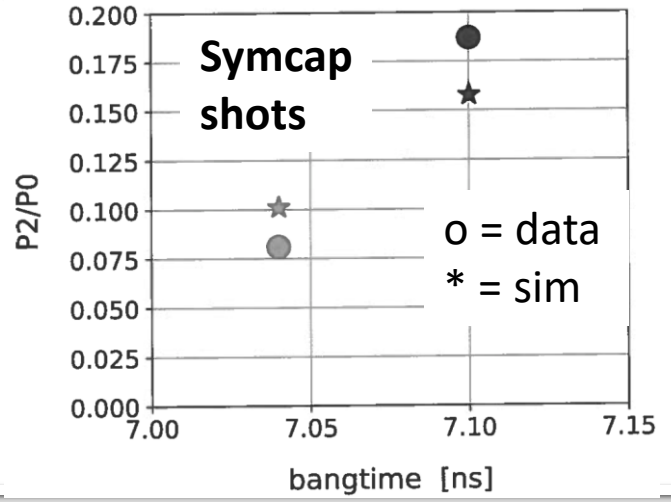
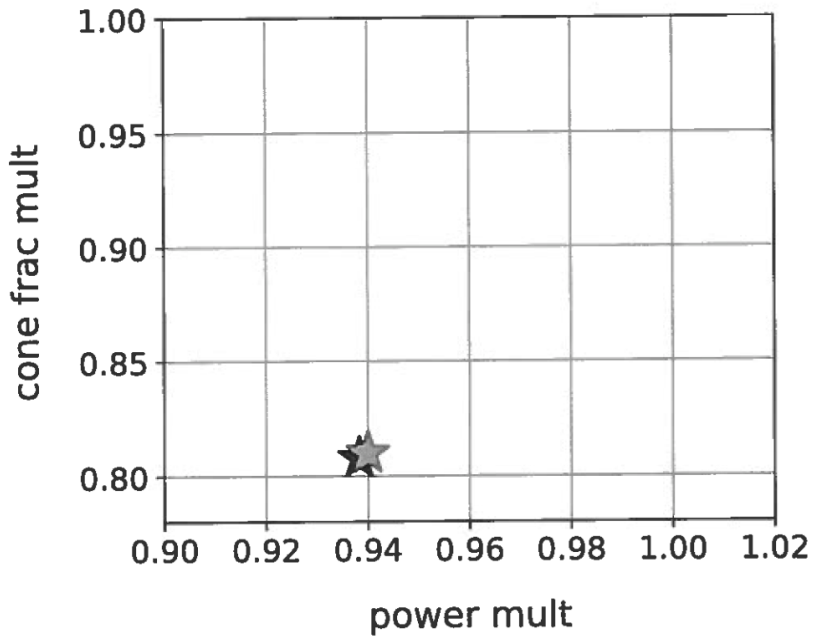
Keyhole shot: waist shock speed



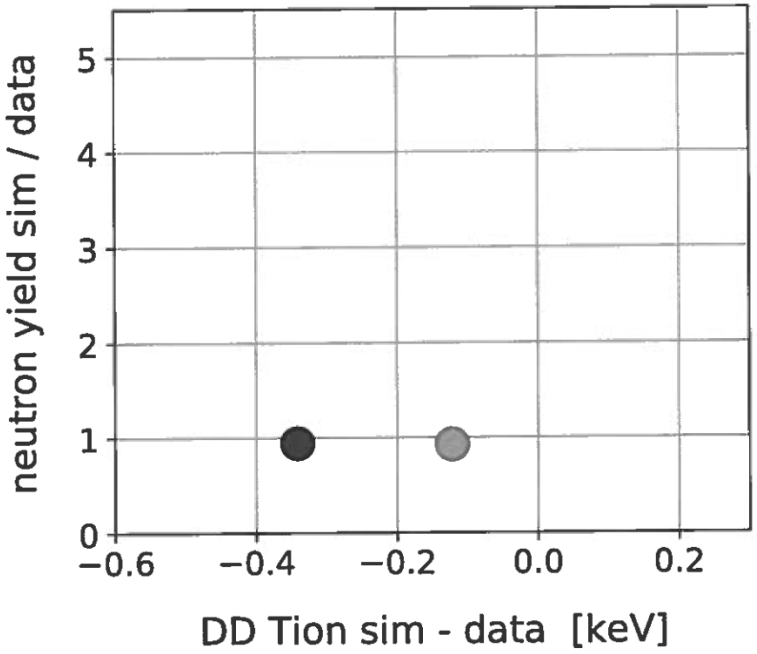


BigFoot shots: Laser multipliers give good agreement on capsule yield and T_{ion}

HOHLRAUM INPUTS:
laser power and cone frac mults.

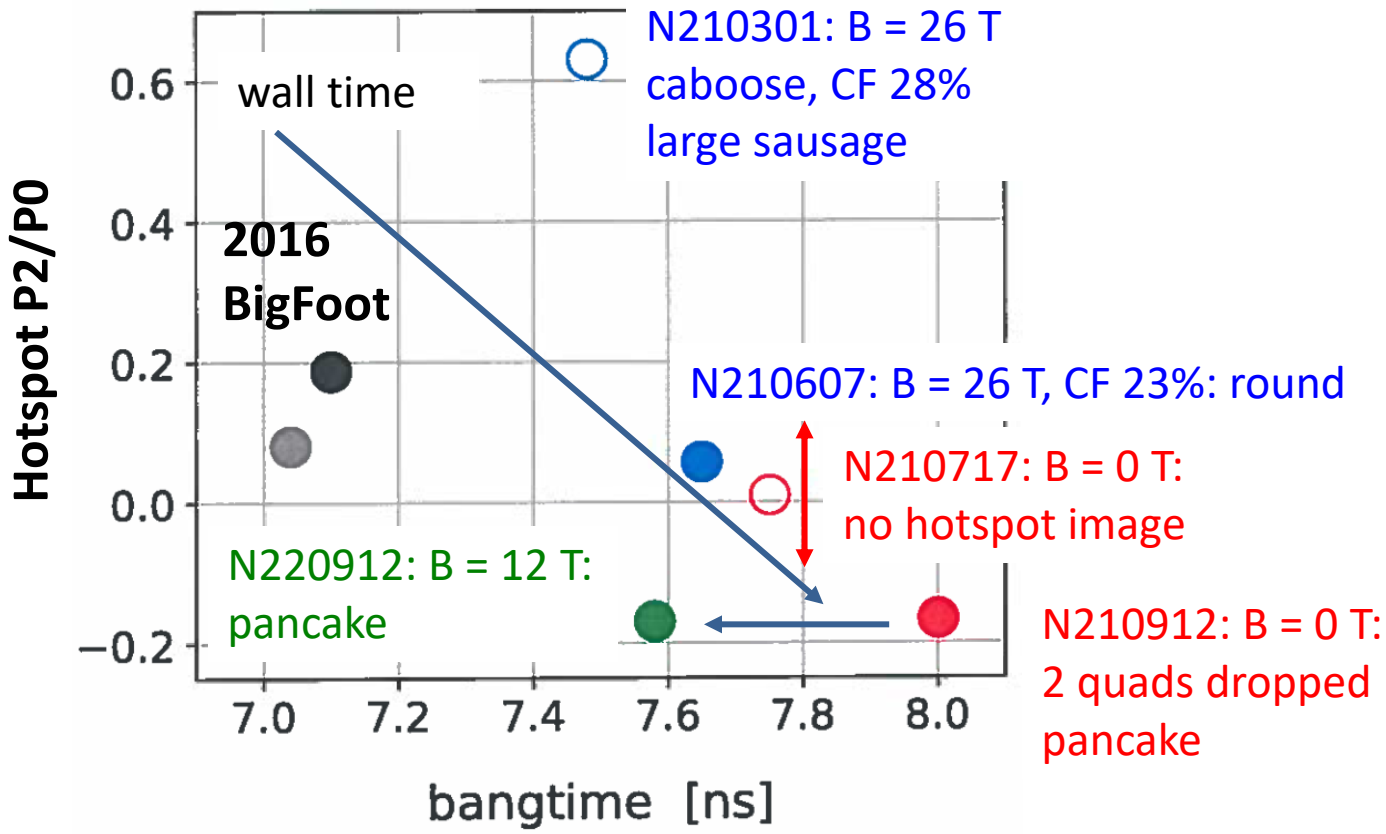


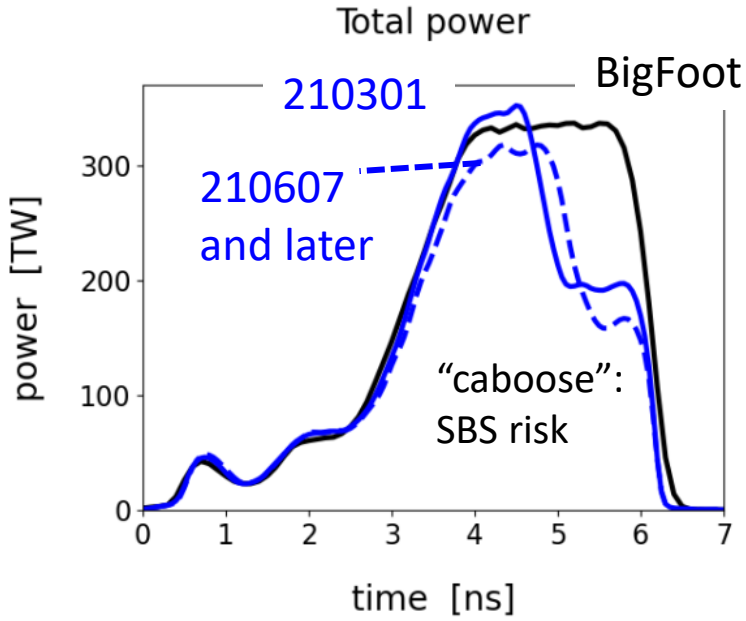
UNTUNED CAPSULE OUTPUTS:
DD Yield*, T_{ion}



Warm symcaps, B or no B: We model 5 shots with progressively less laser energy

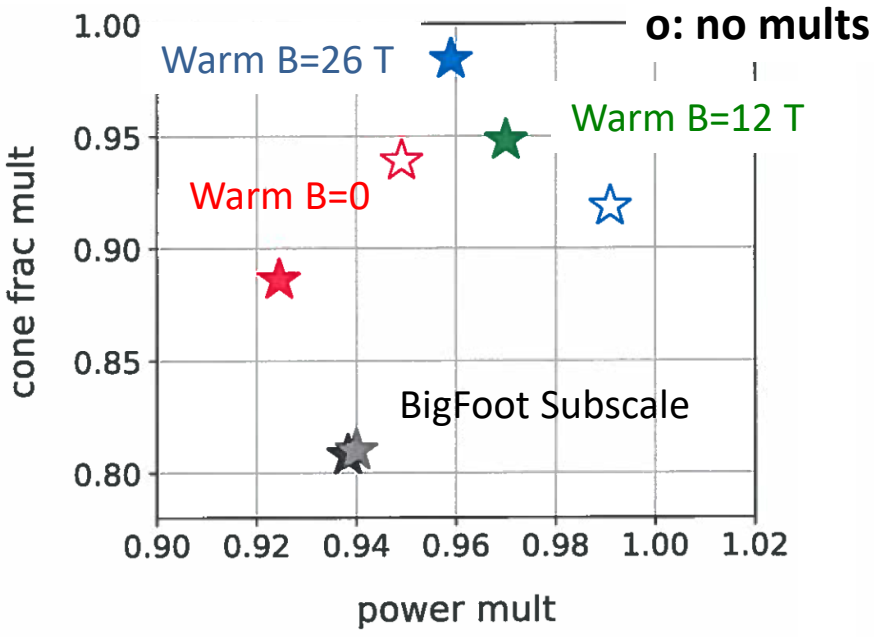
Measured data



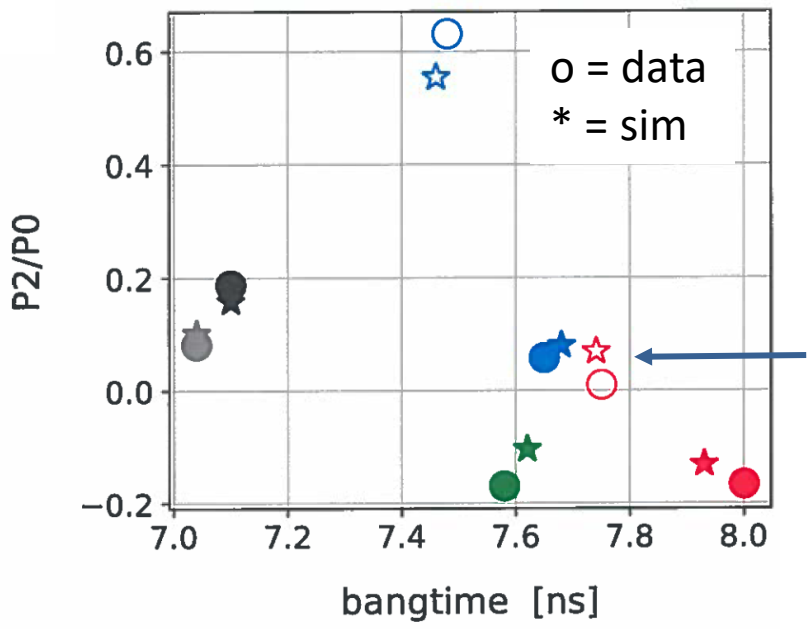


Warm shots: less laser mults needed than for BigFoot, esp. with B field

Hohlraum Inputs: laser mults. to match bangtime and hotspot P2



Hohlraum Outputs: all "close enough" to data

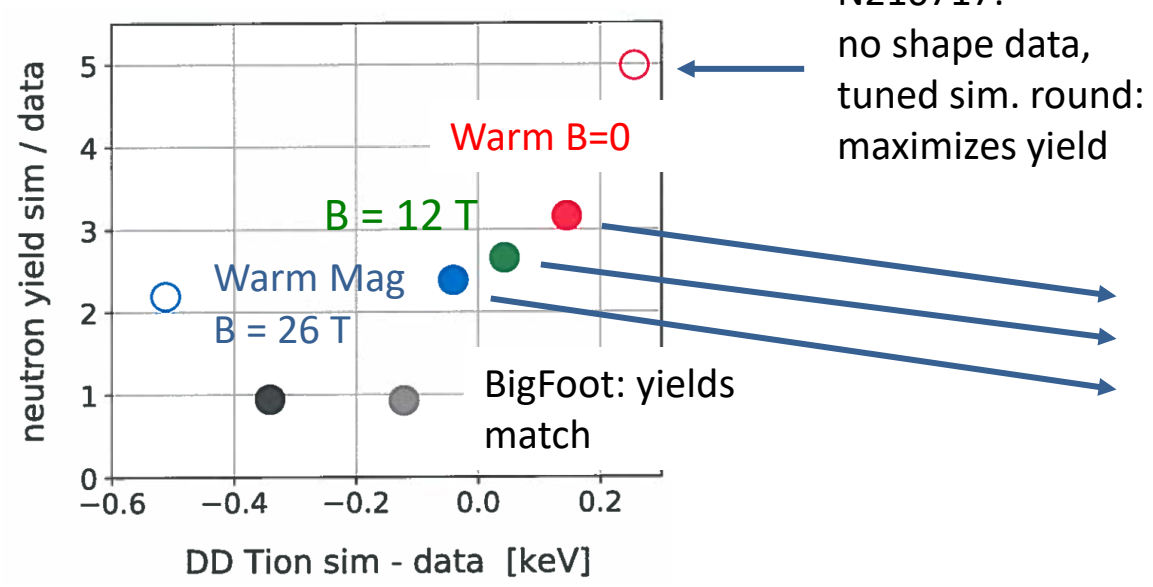


N210717: no shape data, tuned sim. round

- Warm mag. and unmag. shots have similar laser mults.
- Model is slightly less wrong (need smaller mults) for mag. than unmag. hohlraums
- Warm mults somewhat different from BigFoot: platforms differ even with B=0:
  - Au vs. AuTa4 wall, "caboose" on laser pulse, He vs. C5H12 hohlraum fill, less dense capsule fill

Model yields 2-5x data for warm shots but match for BigFoot; model matches relative effect of B field

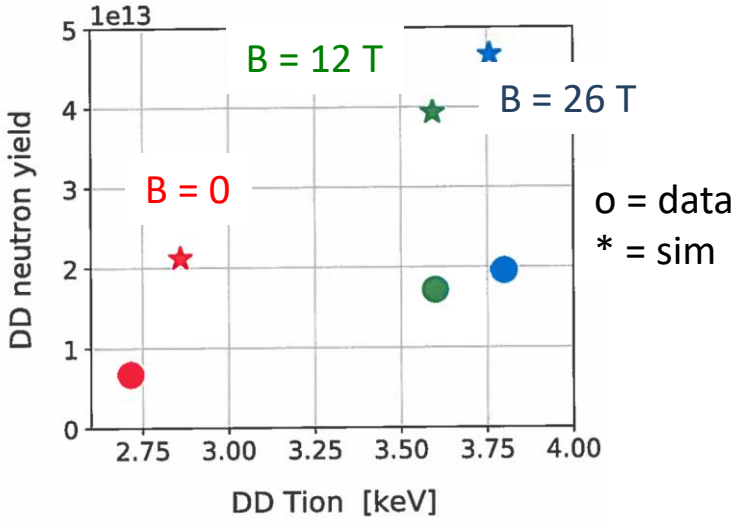
Capsule Outputs: untuned



N210717:
no shape data,
tuned sim. round:
maximizes yield

BigFoot: yields match

B = 12 T gives most of the effect of 26 T, in data and sims



o = data
* = sim

Why yields match BigFoot but not Warm?

- All sims shown here are hohlraum sims with low-resolution capsules
- No "high mode" degradation: fill tube, mix, Rayleigh-Taylor
  - High-res. capsule-only sims to be done
- *NOT due to B field – agreement less bad than no B!*
  - B field mitigates degradation?

Differences between BigFoot and Warm platform

- Less laser energy for warm → longer coast time
- Capsule: lower fill density, higher W dopant
- Foot multipliers match BigFoot shock timing
- AuTa4 vs Au wall: different h*nu > 1.8 keV spectrum?

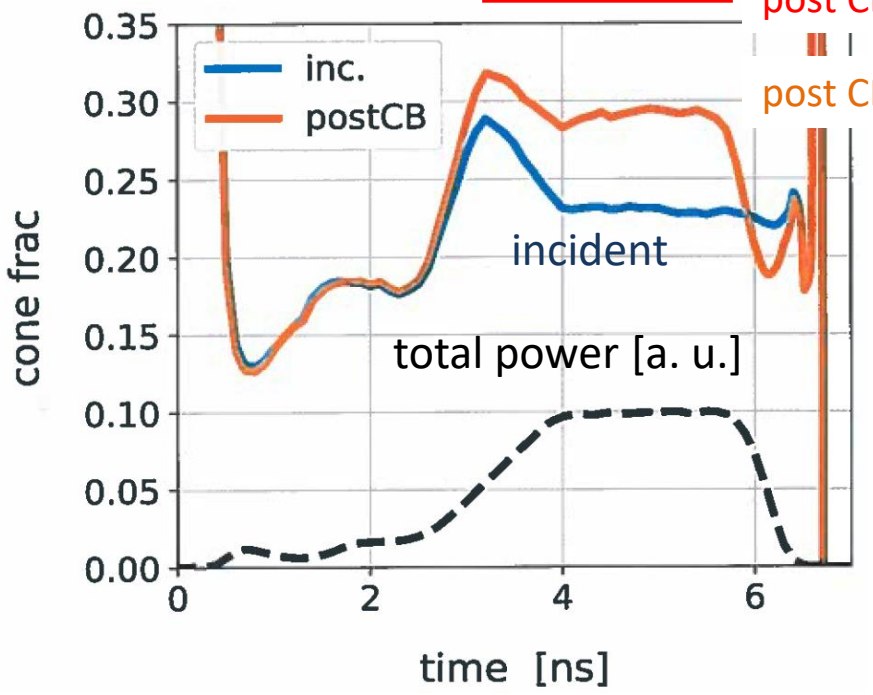
Lasnex inline CBET model: significant flow-induced transfer to inner beams – no wavelength shift

BigFoot D-He3 symcap: B = 0
cone fraction = inner / total power

post CBET, $\delta n_e/n_e$ = 1, 1 CF mult

post CBET, $\delta n_e/n_e$ = 5E-3, 1 CF mult

post CBET, $\delta n_e/n_e$ = 5E-3, 0.8 CF mult : tuned to match data



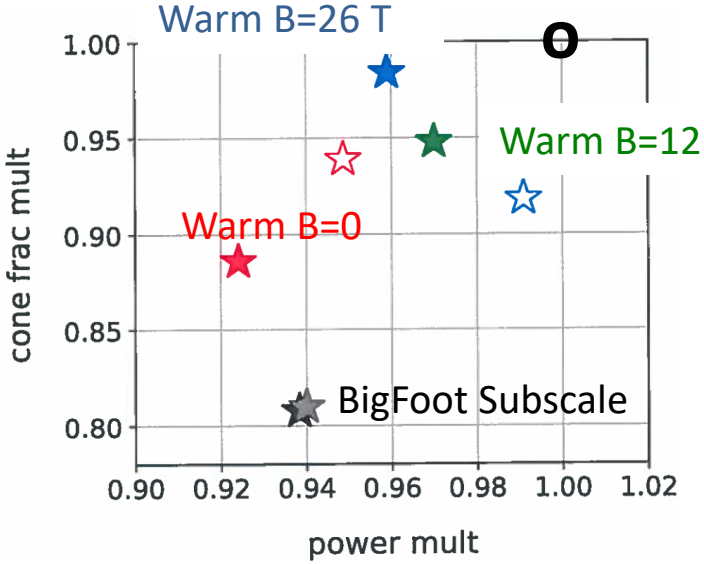
Inline CBET model[1]

- Saturation clamp $\delta n_e/n_e$ = 5E-3
  - Other NIF campaigns use ~5E-3 to 0.02
  - Could choose lower value to match data
  - But want model that allows for CBET and wavelength shifts to design future shots
- **Hypothesis:** clamp and cone fraction mult. fix errors in laser entrance hole plasma conditions – not errors in CBET model itself
- NOT due to B fields: need more cone frac. mults for BigFoot and warm B = 0 than magnetized shots

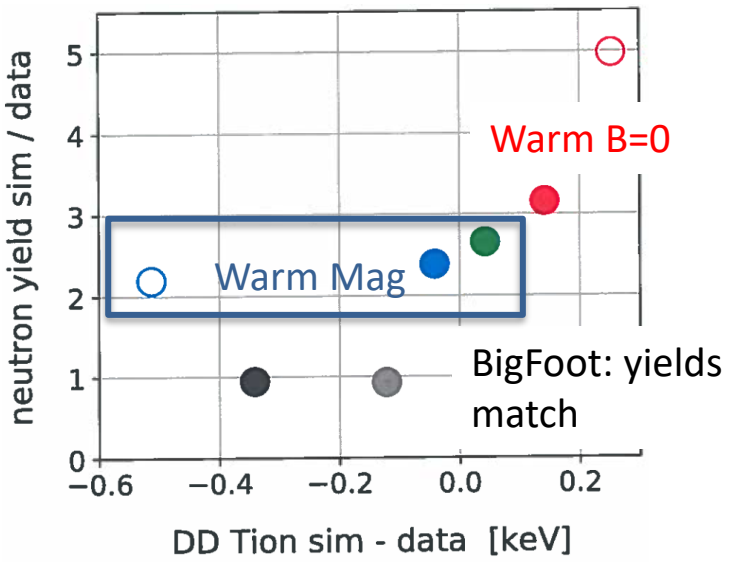
1: D. J. Strozzi, D. S. Bailey +, PRL 2017

Lasnex modeling of warm magnetized and un-magnetized NIF shots: hohlraum drive OK, yield too high, relative effect of B field OK

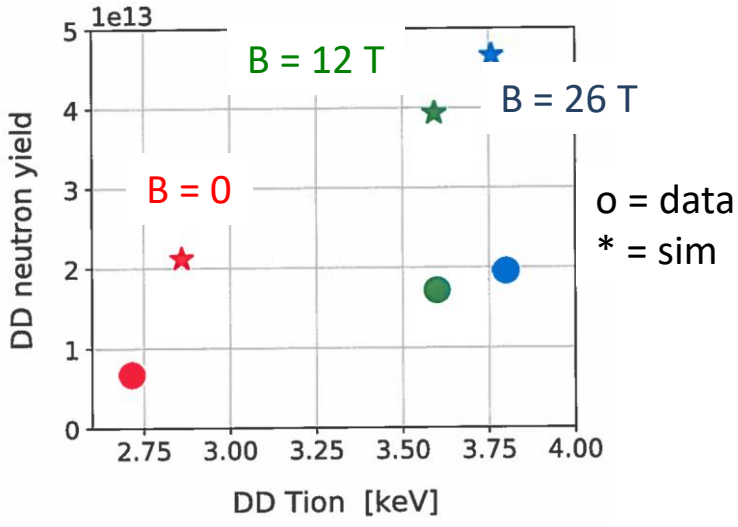
Hohlraum Inputs: laser mults to match shocks, bangtime, hotspot P2



Capsule Outputs: untuned



B = 12 T gives most of the effect of 26 T, in data and sims



We have a model that explains WarmMag data well enough to design future magnetized shots:

- **Use multipliers from warm shots**
- **Higher radiation-drive warm symcaps – upcoming over next year: magnetize more ignition relevant T_{ion}**
- **High energy cryo layered DT targets – NIF capability late 2024**

High-res. capsule-only modeling to understand yield to be done.

BACKUP BELOW

relative effect of B [Tesla]	Data	Lasnex
DD yield: B=[12, 26] / B=0	[2.54, 2.90]	[1.85, 2.19]
DD T_{ion} [keV]: B=[12, 26] – B=0	[0.88, 1.08]	[0.73, 0.89]

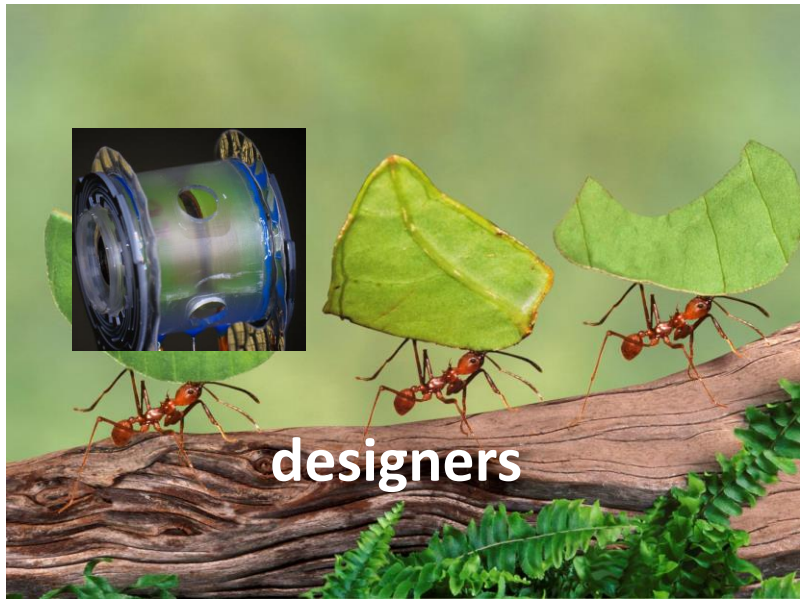
Modeling strategy: use subscale BigFoot[1] shots for power multipliers for shock timing, and baseline peak laser multipliers

	N161115-2	N161204-3	N161205-3
Shot type	Keyhole: shock timing	Symcap	Symcap
Capsule fill	liquid D2	D-He3	D-T
Capsule dopant	0.23% W	0.24% W	undoped

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

ANTS (Automated NIF Tuning Suite) tool - C. Weber

- **Power multipliers:**
  - Foot: match shock timing data: keyhole shot
  - Peak: Capsule bangtime: symcap shots
- **Cone fraction (inner cone / total power) multipliers:**
  - Foot: none
  - Peak: Hotspot x-ray self-emission P2 moment: symcap shots



Summary: Hohlraum modeling of MagWarm platform close on *relative* Tion and yield increase w/ B field, *absolute* yields too high

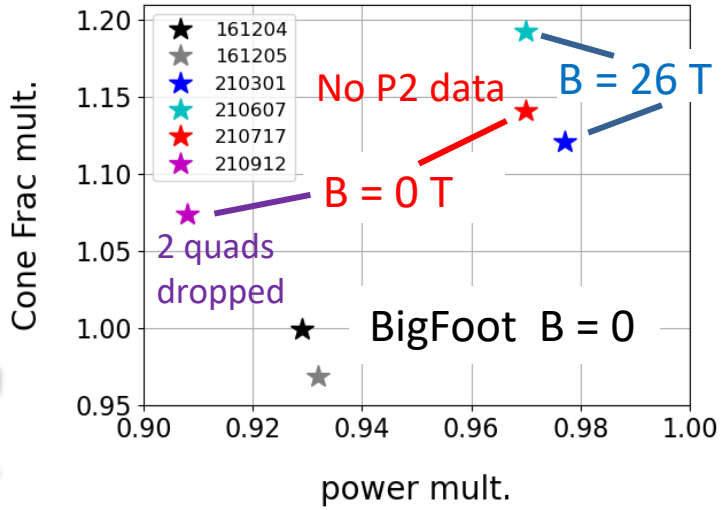
BigFoot 2016 shots: un-magnetized basis for MagWarm platform

- Small laser mults. to match bangtime and hotspot P2
- → Close on yield and Tion!

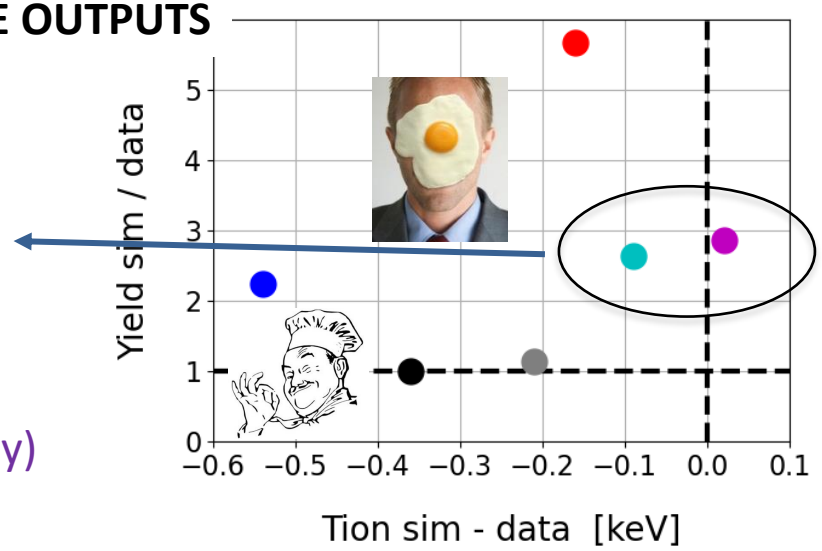
MagWarm (Magnetized Warm) platform: with or without B

- Vs. BigFoot: smaller power mults, larger cone frac mults
- CBET can replace cone fraction mults on one shot studied so far
- B vs. no-B comparison frustrated by shot issues
- Simulations vs. data: Tion close, yield several times higher
- Hohlraum dynamics similar with B or no B, in data and modeling

INPUTS



FREE OUTPUTS



Lasnex captures relative effect of B field pretty well

relative effect of B	Data	Lasnex
DD yield: B / no B	2.90	2.67
T_{ion} [keV]: B – no B	1.08	0.97

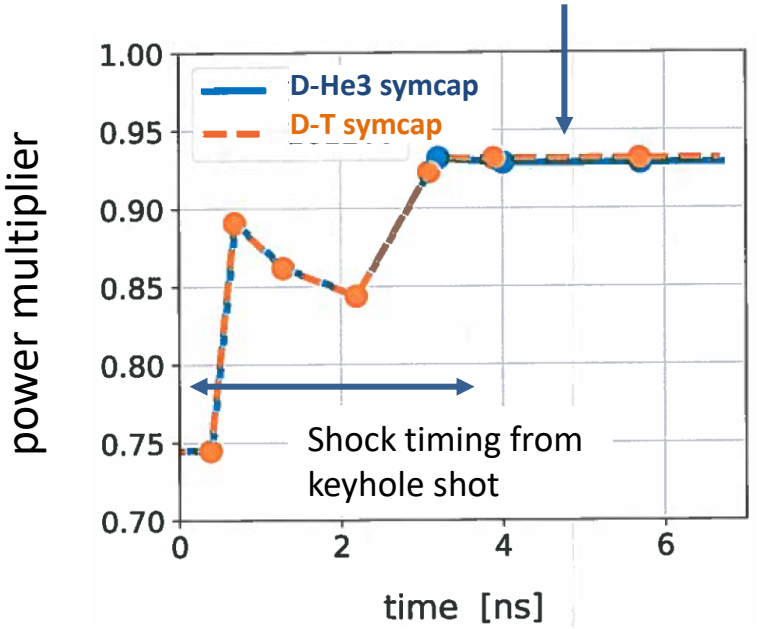
N210607: B = 26 T N210912: B = 0 (less laser energy)

BigFoot 2016 symcaps: ANTS: small laser power and cone fraction multipliers to match bangtime and P2

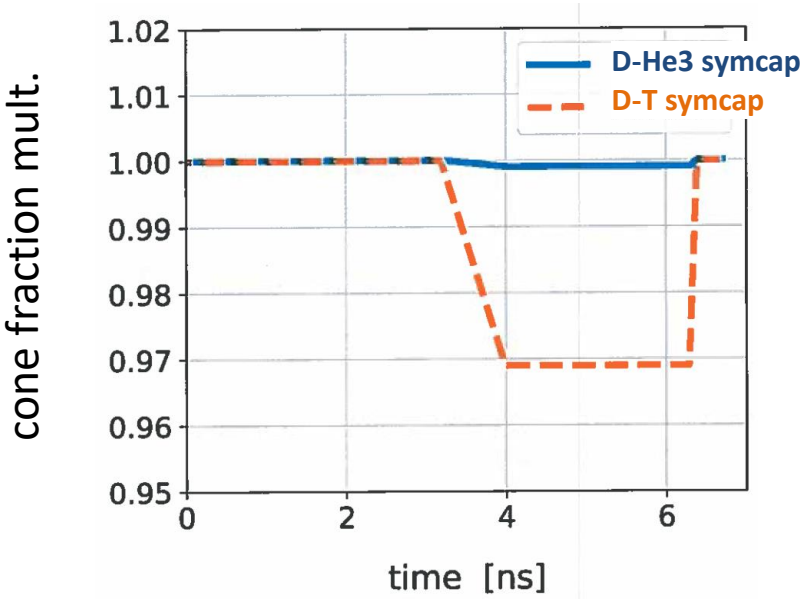
Incident laser:
points = ANTS control times

keyhole
D-He3 symcap
D-T symcap

Symcap bangtimes →
peak power mult. = 0.93



Symcap hotspot P2 →
Cone fraction mult. = 0.97 – 1.0



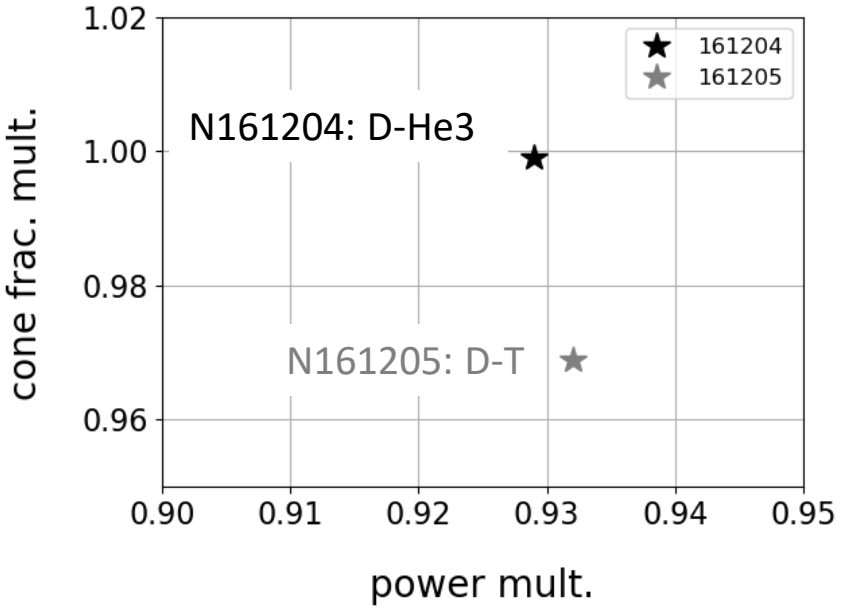
N161204-3: D-He3 W-doped symcap
N161205-3: D-T undoped symcap

Power mults "smaller" (closer to unity) than typical current full-energy NIF shot: 0.85 – 0.9

Cone fraction = inner / total power
0.97 multiplier small: CF decreased from 0.28 to 0.97*0.28 = 0.272

Bigfoot 2016 symcaps: laser multipliers to match bangtime and P2 → good agreement on yield and Tion

HOHLRAUM INPUTS:
laser power and cone frac mults.



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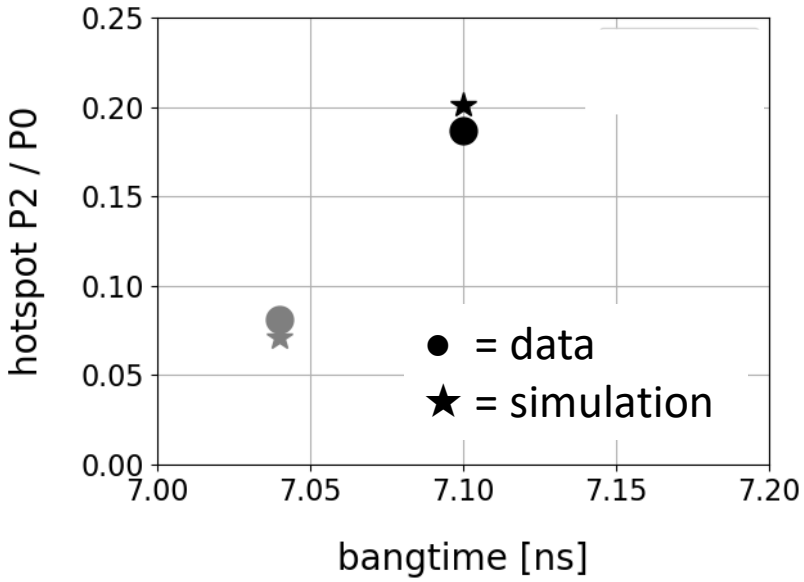
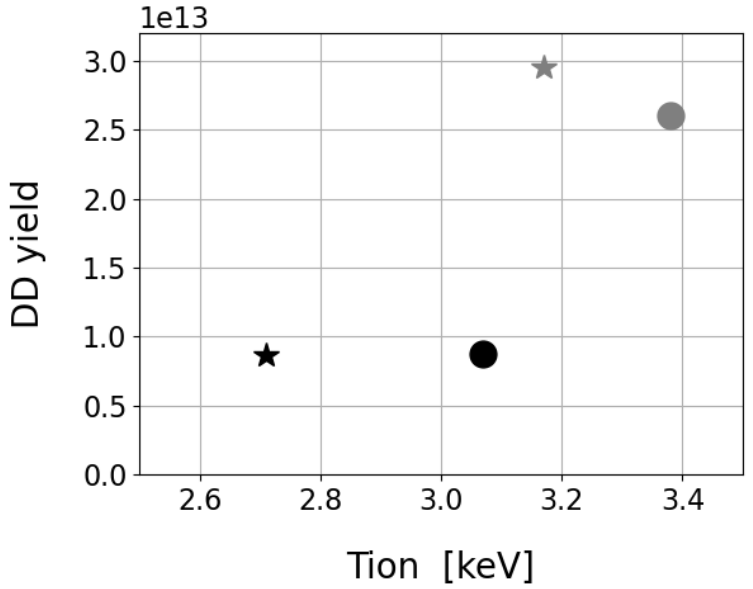
TUNED CAPSULE OUTPUTS:
Bangtime, x-ray P2



?

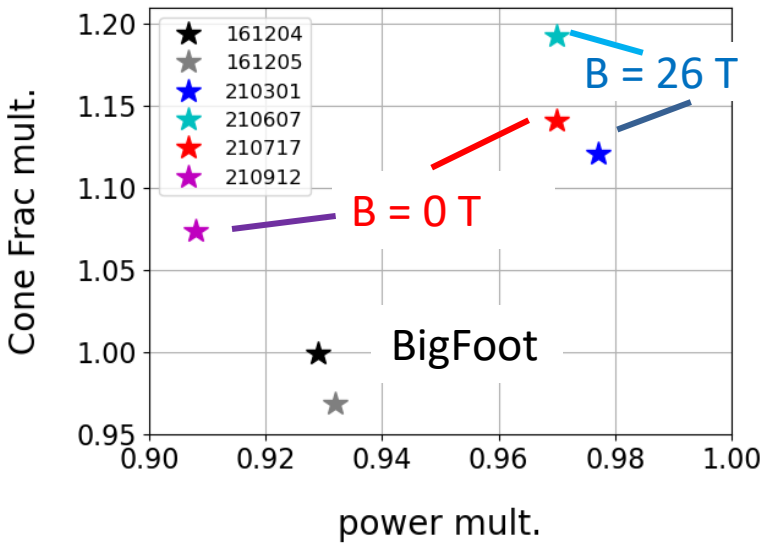
UNTUNED CAPSULE OUTPUTS:
DD Yield*, T_{ion}



* shots with not pure D capsule fill yields *10

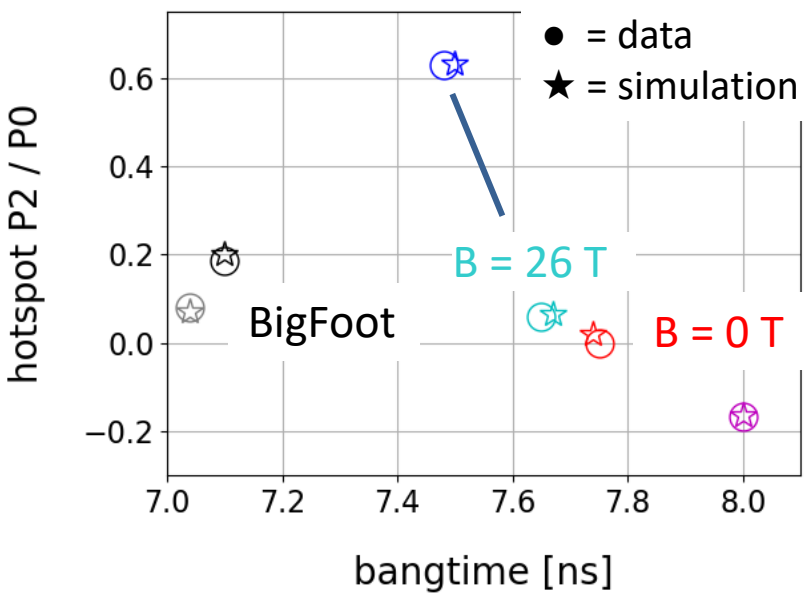
MagWarm symcaps: laser multipliers: 3 similar shots and one oddball, no clear difference for B vs. no B

INPUTS:
laser power and cone frac mults.



BigFoot D-3He
BigFoot D-T
MagWarm B = 26 T, sausage
MagWarm B = 26 T, round
MagWarm B = 0 T, no shape data, sim. tuned round
MagWarm B = 0 T, 2 quads dropped, pancake

MATCHED OUTPUTS:
Bangtime, x-ray P2

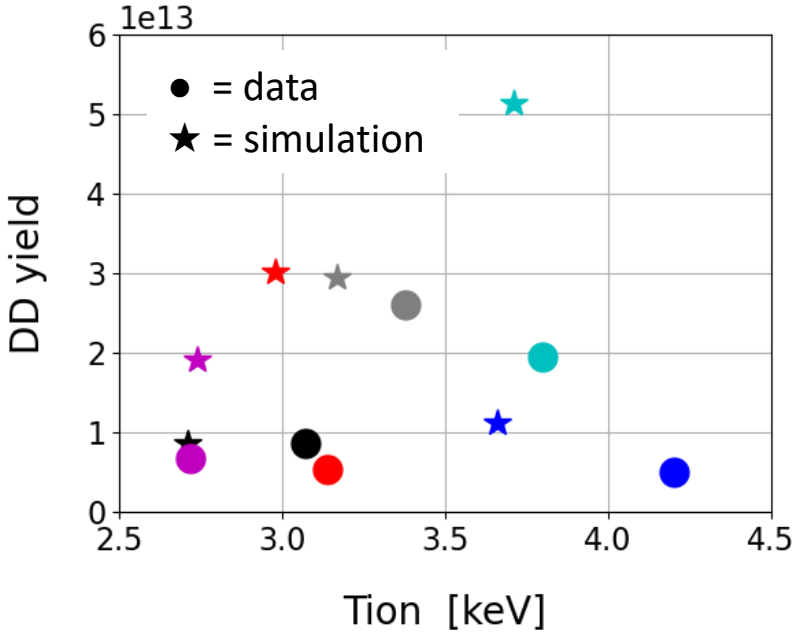


3 similar shots: 2 with B, 1 no B
- Small power mults! Less than BF
- Cone fraction mults. more than BF: CBET could be at play and different from BF

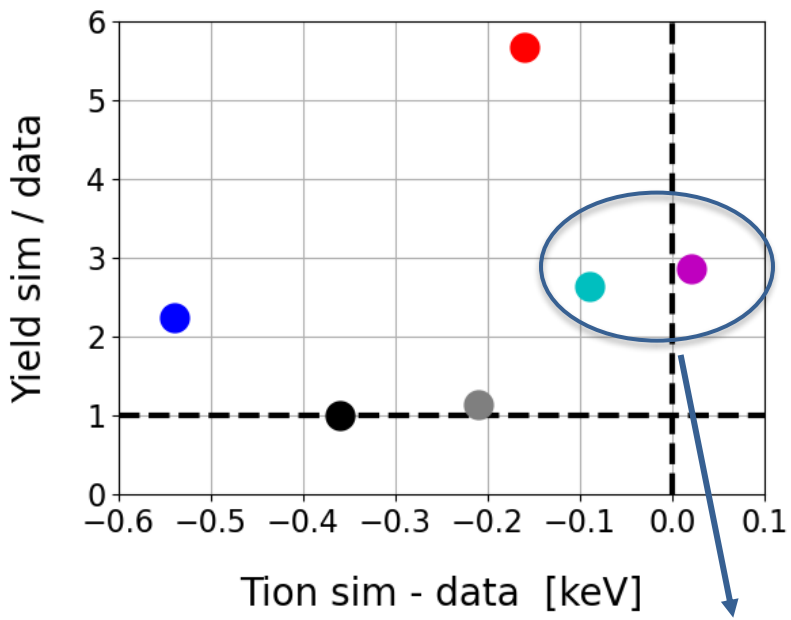
1 oddball shot (no B): 2 laser quads dropped, different cones:
- Up-down asymmetry, long "coast time"
- Power mult. more than other 3 shots
- Cone fraction mult. b/t BF and other 3

MagWarm symcaps: Simulated yield > 2x data – unlike BigFoot

FREE OUTPUTS:
DD Yield, T_{ion}



Sim vs. data:
Yield ratio and Tion difference



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* shots with not pure D capsule fill yields *10

Lasnex captures relative effect of B field pretty well

relative effect of B	Data	Lasnex
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T_{ion} [keV]: B – no B	1.08	0.97

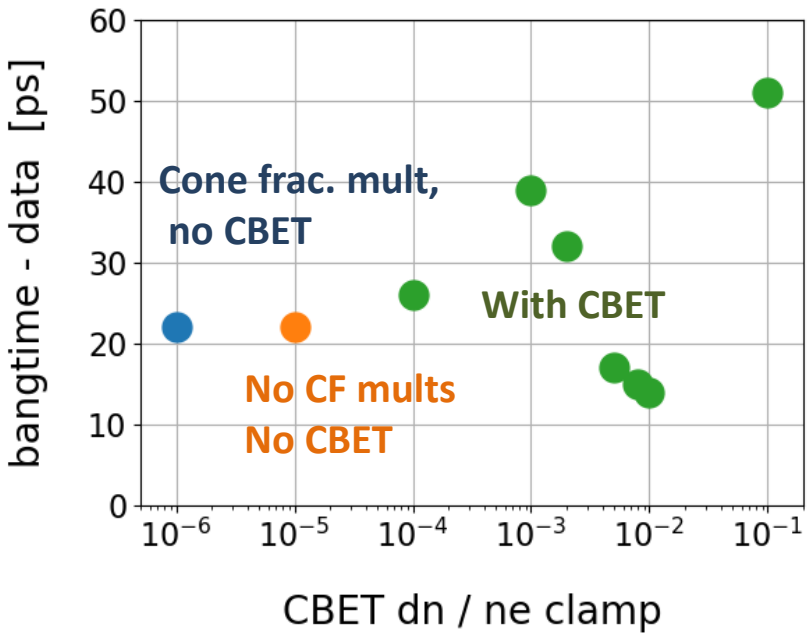
N210607: B = 26 T N210912: B = 0 (less laser energy)

MagWarm symcaps: Inline CBET: model moves power to inner beams, can explain shape data with clamp

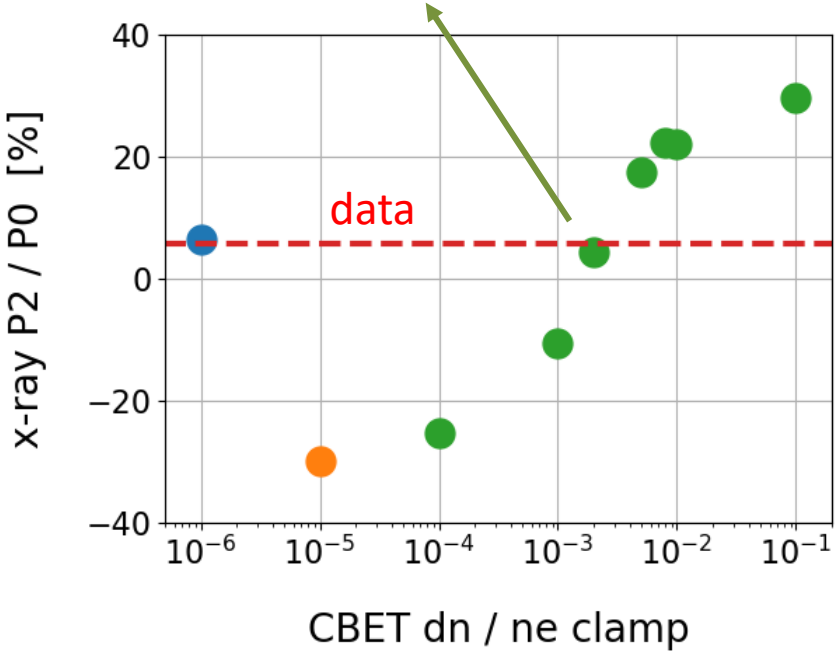
Runs of N210607: B = 26 T, round hotspot

- All use power mults. from run with cone fraction mult. tuned to match data
- No cone fraction mult.

CBET and cone fraction mult. have little effect on bangtime



Inline CBET with clamp $\delta n/n_e$ $2*10^{-3}$ matches data

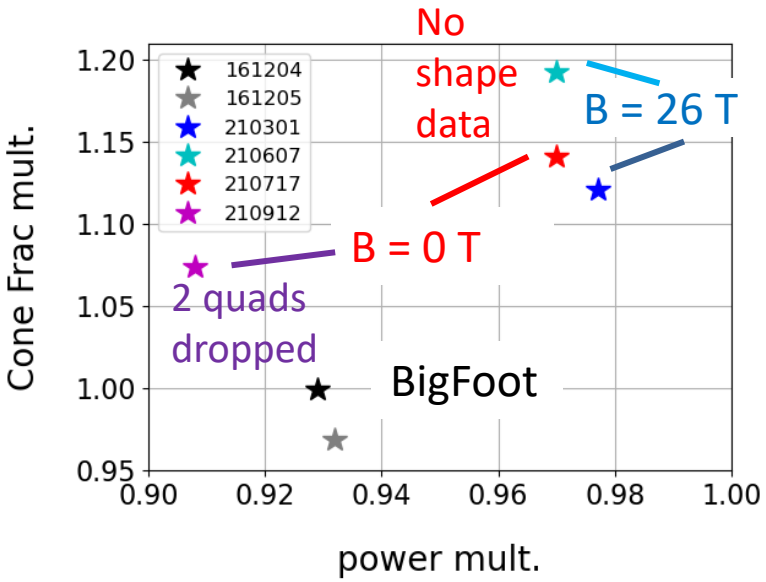


Other shots being studied: Bigfoot, MagWarm B = 0

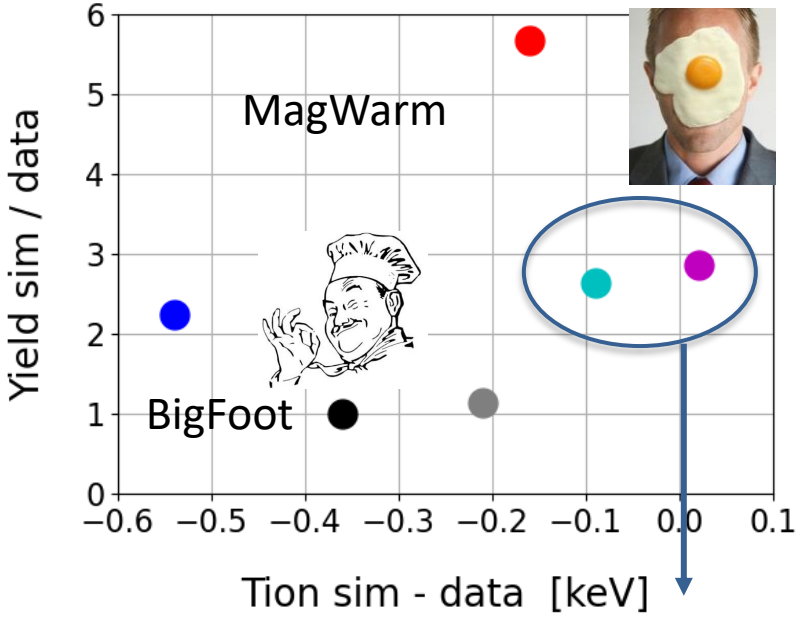
CBET modeling of several current NIF campaigns agrees with data for smaller clamps $\delta n/n_e \sim 10^{-2}$

Conclusions: Lasnex hohlraum modeling of BigFoot and MagWarm platforms

Laser multipliers aren't clearly different with B vs. no B

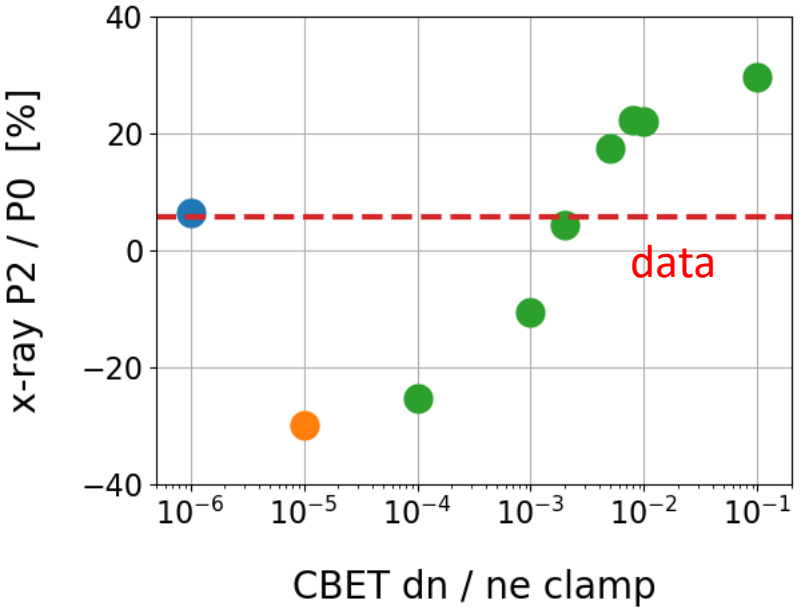


Lasnex modeling captures relative effect of B field pretty well, absolute yields > 2x data



relative effect of B	Data	Lasnex
DD yield: B / no B	2.90	2.67
T_{ion} [keV]: B – no B	1.08	0.97

Inline CBET with clamp $\delta n/n_e$ $2*10^{-3}$ matches data: B = 26 T, round hotspot shot



Future work on modeling MagWarm: open questions

Why is modeled yield near data for BigFoot but high for MagWarm?

- ***Not*** due to B field: larger difference for B = 0 MagWarm shots
- Need high-resolution capsule-only modeling for hydro instabilities, fill tube, mix, etc.
  - Maybe that explains it
- "Caboose" / longer coast time
- Lower capsule fill density
- Shock timing: tuned for BigFoot not MagWarm
- AuTa4 hohlraum spectrum

Magnetized LPI

- CBET
  - Indirect effect: B field changes plasma conditions
  - Direct effect: magnetized CBET coupling: Yuan Shi, John Palastro; potential Omega expt's
- Backscatter very low on all MagWarm shots: any B field effect small

Good collaboration opportunities

Goal is model that explains MagWarm data well enough to design magnetized, high energy, cryo layered DT targets

MagWarm platform: 4 symcaps modeled

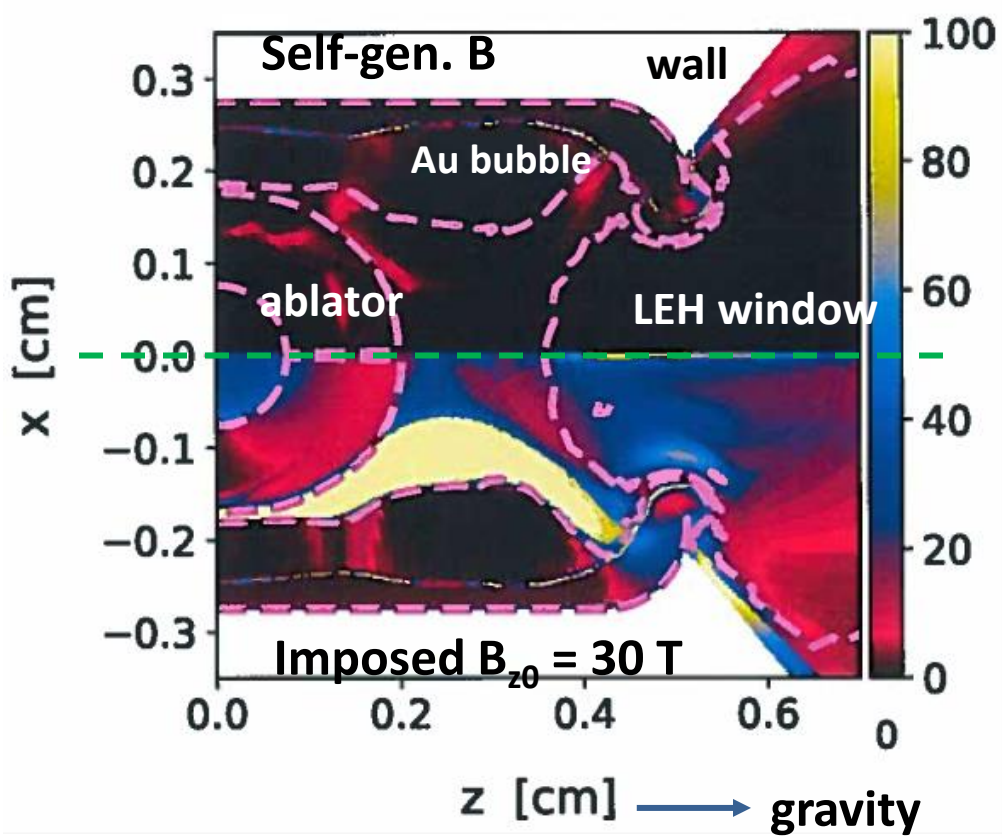
Shot	Platform	B field [T]	capsule fill [mg/cc]	peak cone frac	Laser energy [kJ]	Comment
N161204-3	BigFoot	0	D3 ^{3}He7	28	1091	
N161205-3	BigFoot	0	D T	28	1064	
N210301-1	MagWarm	26	D3 ^{4}He7	28	926	Hotspot very sausaged
N210607-2	MagWarm	26	D	23	883	Lower CF + energy, hotspot round
N210717-1	MagWarm	0	D	23	875	No shape data, sim. tuned round
N210912-1	MagWarm	0	D	23	840	2 quads dropped, pancaked

- N201228-1 and N210620-1 did not return useful capsule data
- N220110-1 had capsule leak: very low hohlraum fill 0.01 mg/cc of D2, hard to model

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

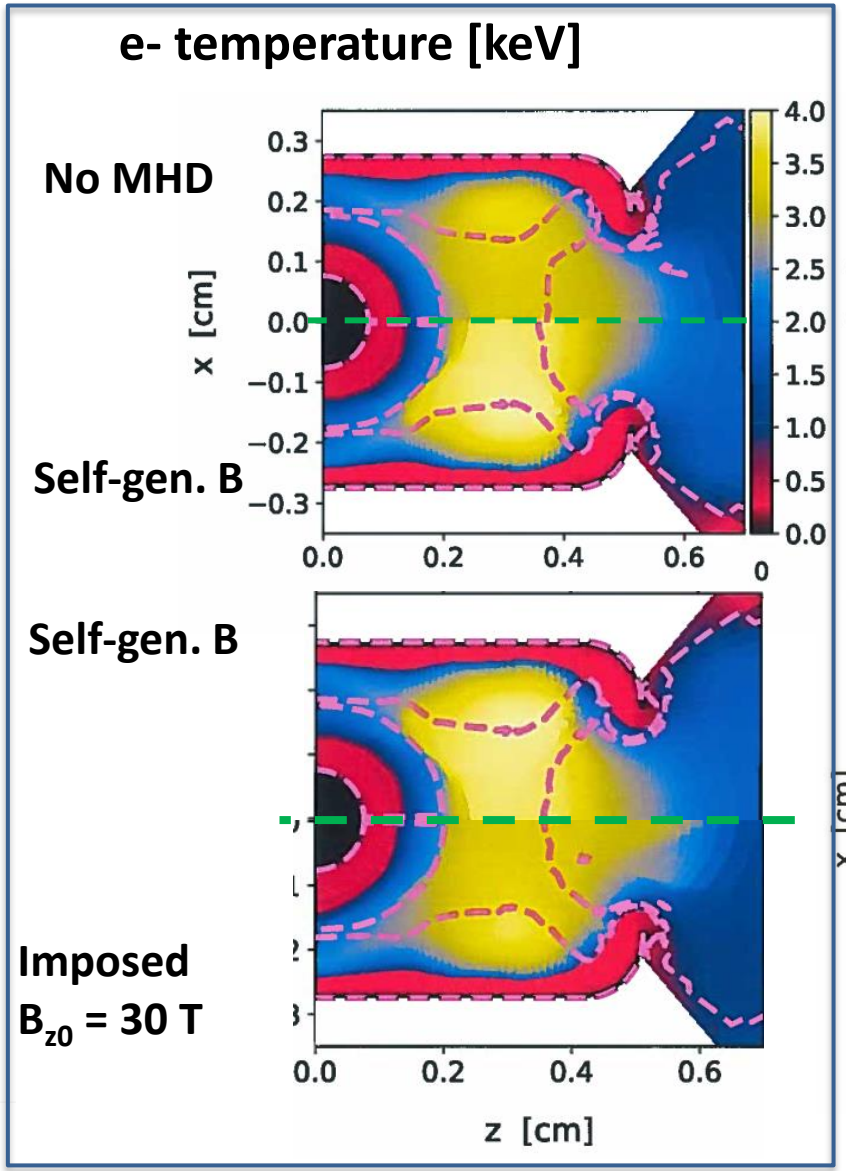
4.5 ns: early peak power

| Magnetic field | [T]

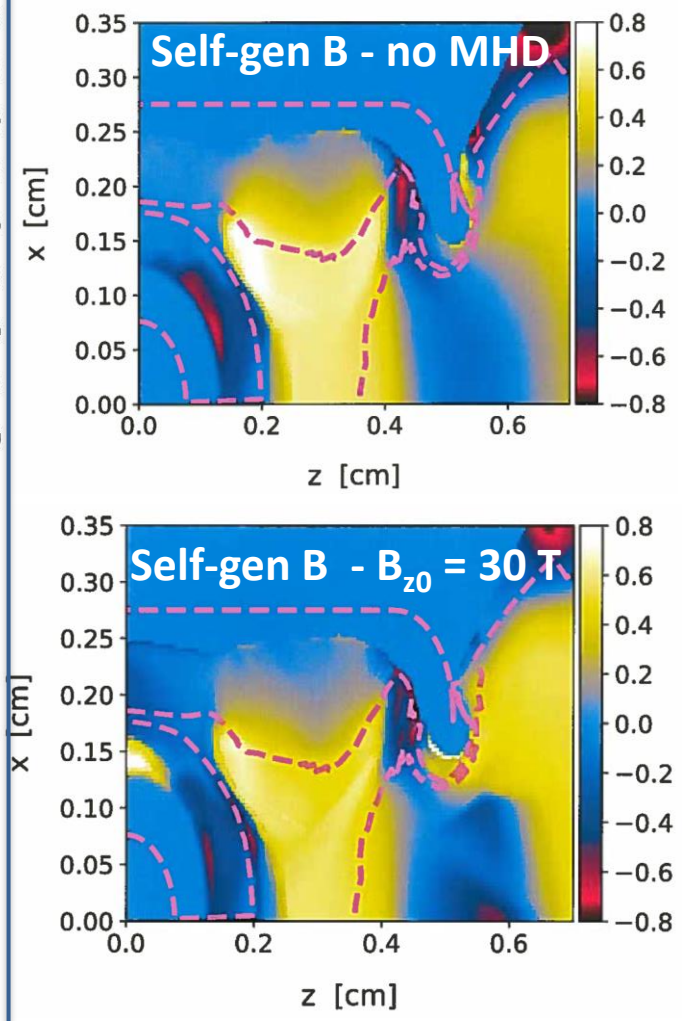


BigFoot Symcap

e- temperature [keV]



T_e difference [keV]



T_e [keV] Movie: hotter in LEH w/ imposed B, not in rest of fill