Ignition Hohlraum Simulations with Imposed Magnetic Field, and Effect on Hot Electrons

IFSA 2015

Poster Tu.Po.45

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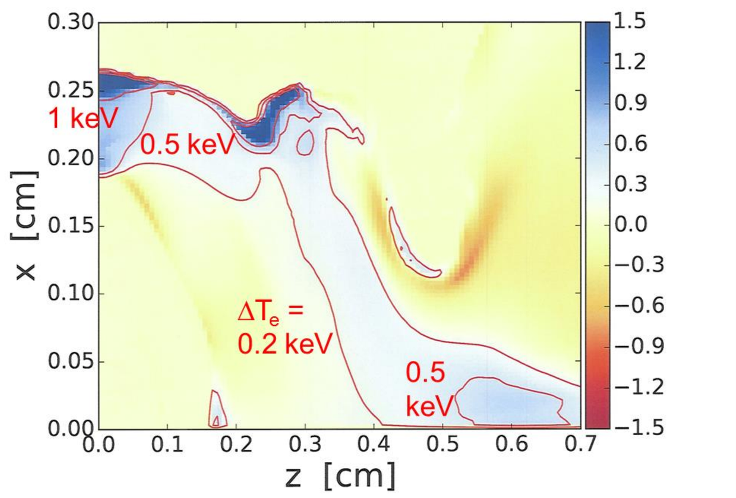
Summary: axial B field impacts hohlraum rad-hydro and hot electrons

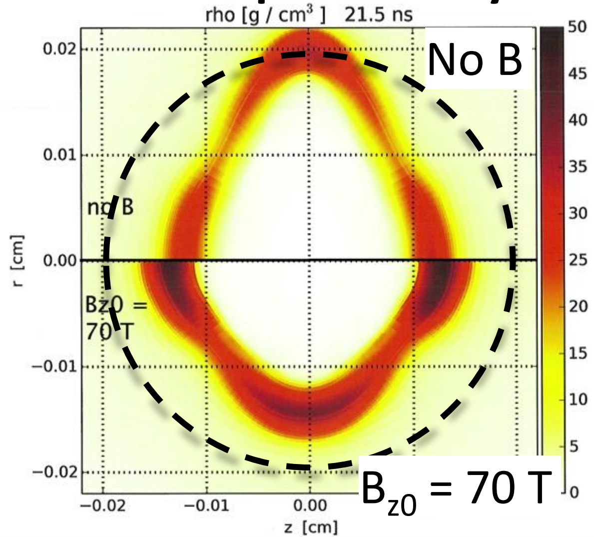
- Axial field of 70 Tesla: goal for NIF: L. J. Perkins, IFSA talk Thurs 2:50pm

Raises temperature, esp. near wall

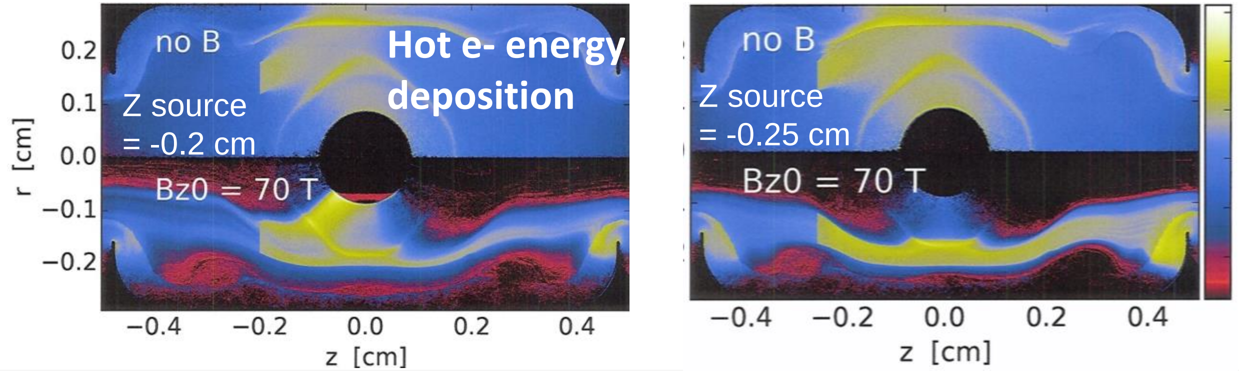
e- temperature: with B - without B [keV]



Improves inner beam propagation: Increased equator x-ray drive



Hot electrons magnetized in fill gas: guided to or away from capsule



D. J. Strozzi et al., Journ. Plasma Physics (submitted), arxiv.org/abs/1508.00803

Hydra MHD model: simple Ohm’s law, reduced heat conduction across B the main effect

Single-fluid, quasi-neutral, “Ohmic”: no e- inertia or displacement current

Blue: how MHD / B field affect matter

Faraday: $$\partial_t \vec{B} = -\nabla \times \vec{E}$$

Ampère: $$\mu_0 \vec{J} = \nabla \times \vec{B}$$

Mass continuity: $$\partial_t \rho_m + \nabla \cdot \left(\rho_m \vec{V} \right) = 0$$

JxB force / magnetic pressure

CM velocity: $$\rho_m \left(\partial_t + \vec{V} \cdot \nabla \right) \vec{V} = \rho \vec{E} + \vec{J} \times \vec{B} - \nabla p$$

0: quasi-neutral

Ohm’s law: inertia-less e- momentum equation:

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

Full Braginskii 1965

$$= -\vec{v} \times \vec{B} + \eta \bullet \vec{J}$$

Used in this work

Electron energy equation:

Reduced conduction perp. to B

Ohmic heating

$$\rho \frac{d\varepsilon}{dT_e} \partial_t T_e + p_e \nabla \cdot \vec{v} = \xi_{ei} (T_i - T_e) - \nabla \cdot \left[\left(\left(\kappa_\parallel - \kappa_\perp \right) \hat{\mathbf{b}} \hat{\mathbf{b}} + \kappa_\perp \overleftrightarrow{\mathbf{I}} \right) \nabla T_e \right] + \eta J^2 + \ldots$$

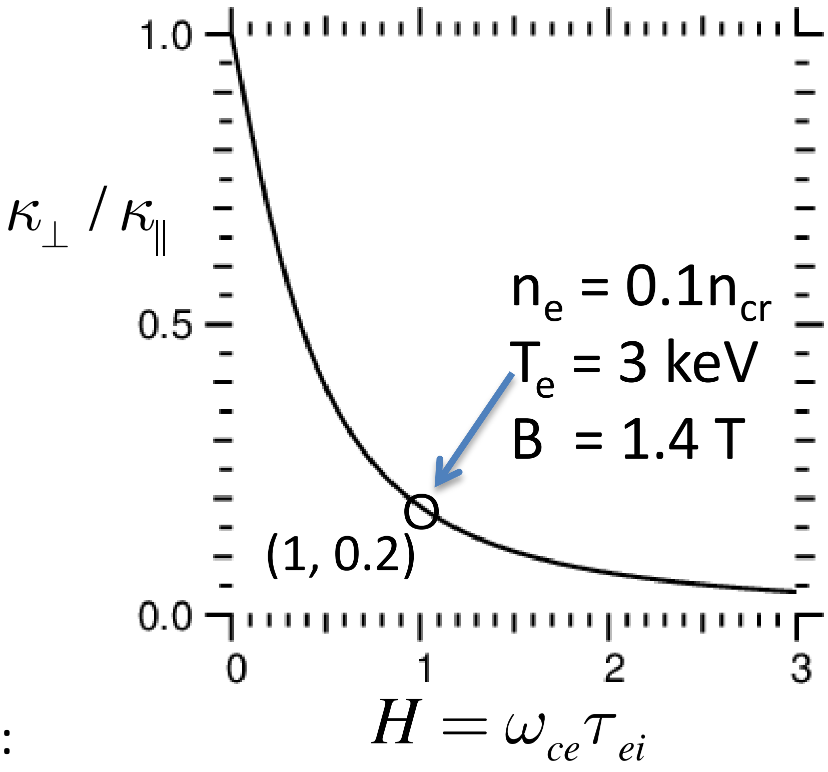
e- heat conduction perpendicular to B strongly suppressed in underdense low-Z fill for B > 1 T

$$\frac{\kappa_\perp}{\kappa_\parallel} \approx \frac{1 + p_1 H}{1 + p_2 H + p_3 H^2 + p_4 H^3}$$

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

p_i depend on Z_i

Z=2 helium



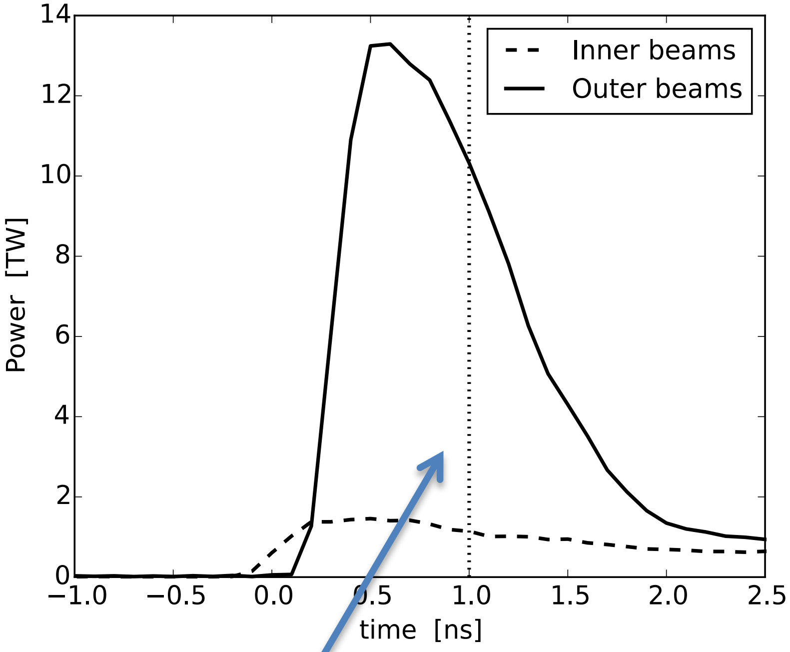
$n_e = 0.1 n_{cr}$
T_e = 3 keV
B = 1.4 T

Reduced perpendicular heat conduction:

- Increases electron temperature
- Improves inner beam propagation

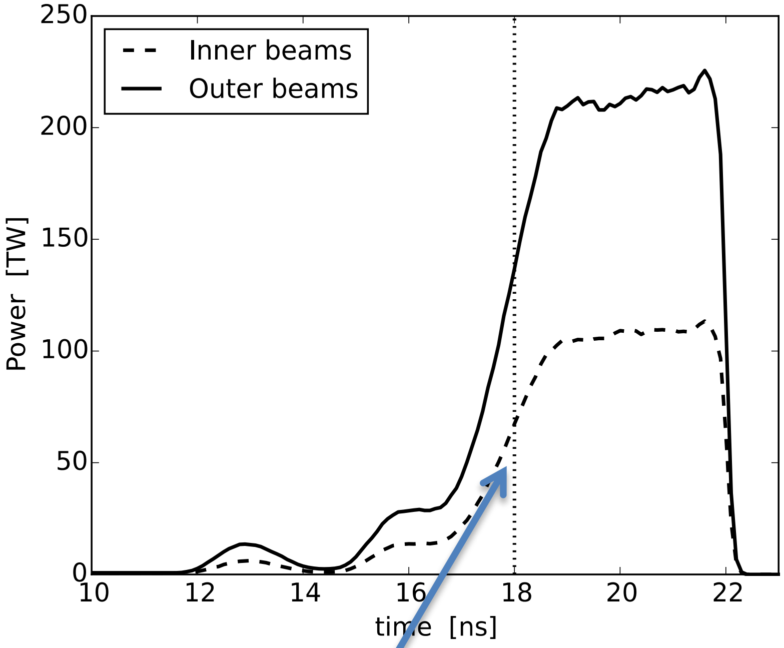
NIF shot N120321: low-foot pulse, CH ablator, DT ice layer

Picket



Time used for two-plasmon hot e- Zuma study

Peak power

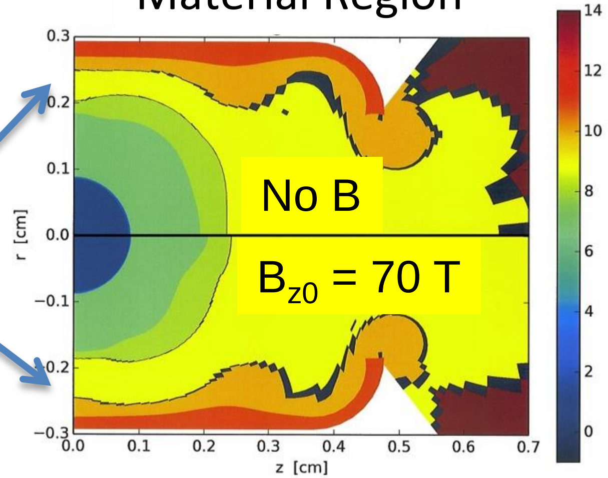


Time used for direct-on-capsule and SRS hot e- Zuma studies

Increased T_e: hotter fill and wall, less material in inner beam path near wall with 70 T axial field

NIT shot N120321
18 ns: early peak power

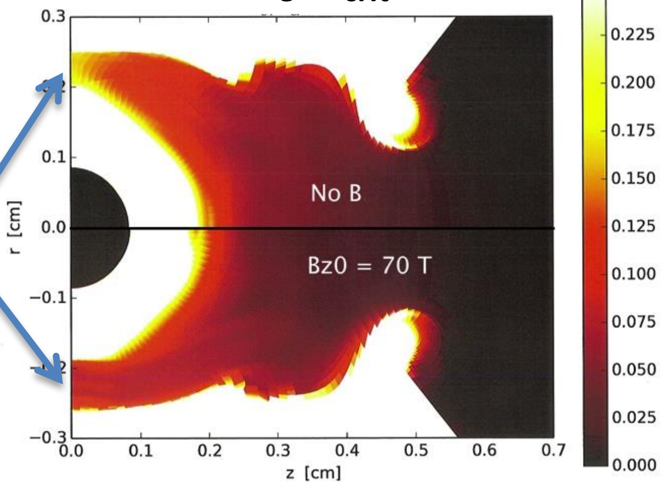
Material Region



Wider equator channel with B

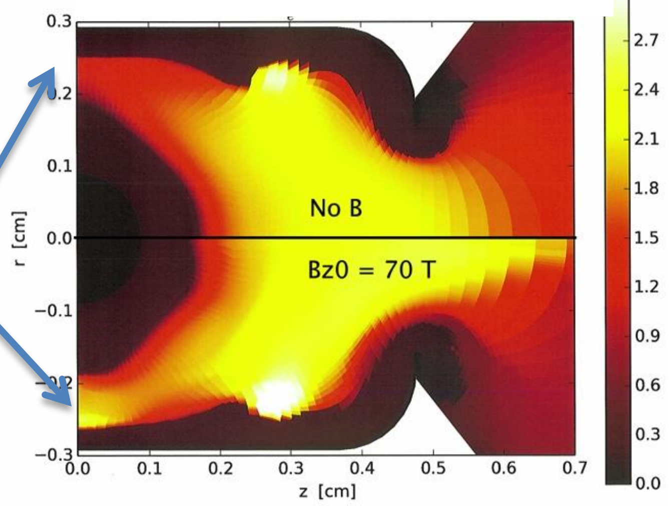
Each figure is a hohlraum quadrant with (top) and without (bottom) B field

n_e/n_{crit}



Less n_e w/ B

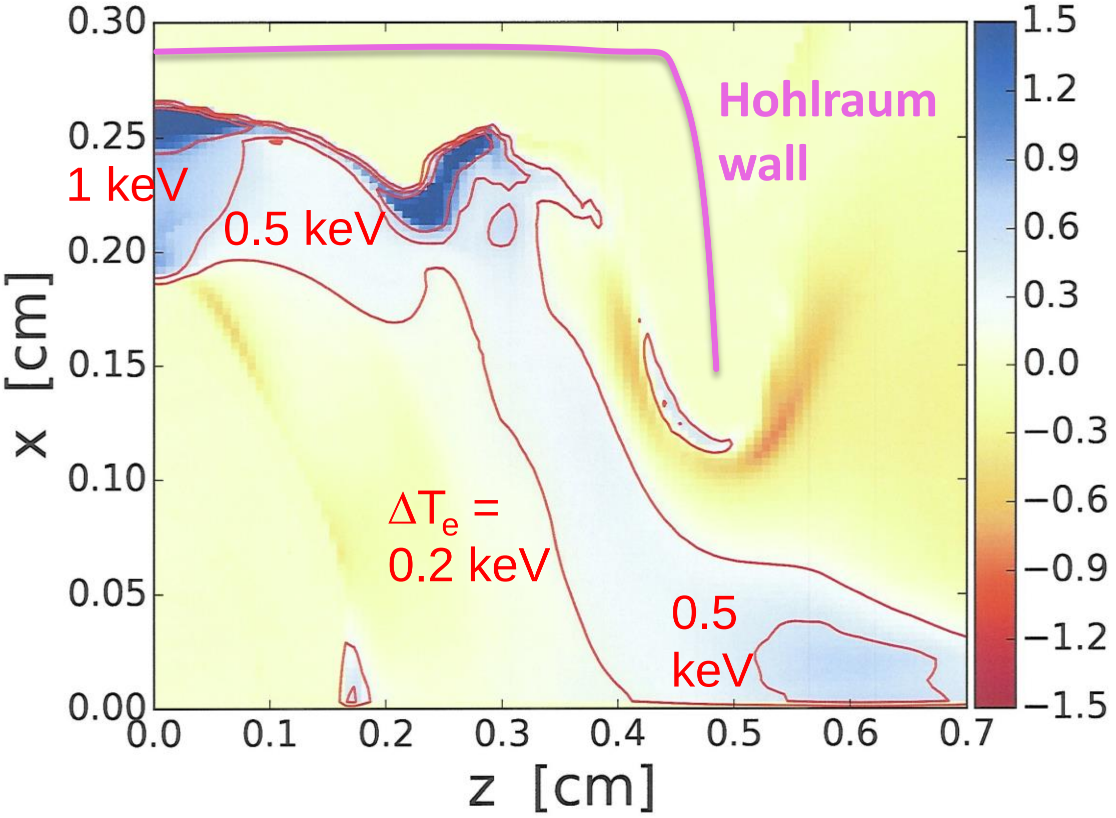
e- temperature [keV]



Higher T_e w/ B, esp. on equator

Increased T_e: with B field, T_e is 0.5 – 1.5 keV hotter near wall, < 0.5 keV in rest of fill

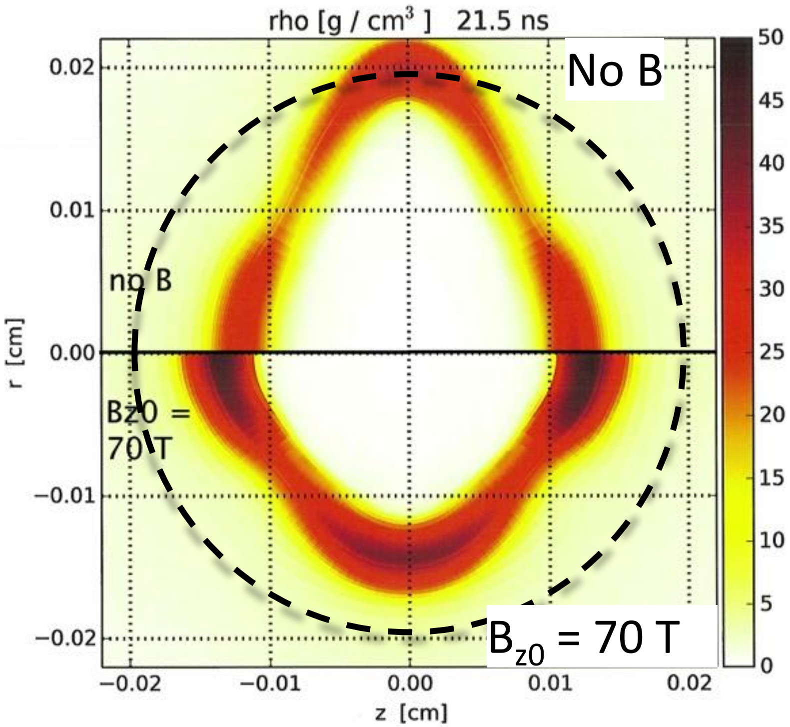
E- temperature difference at 18 ns:
With B – without B [keV]

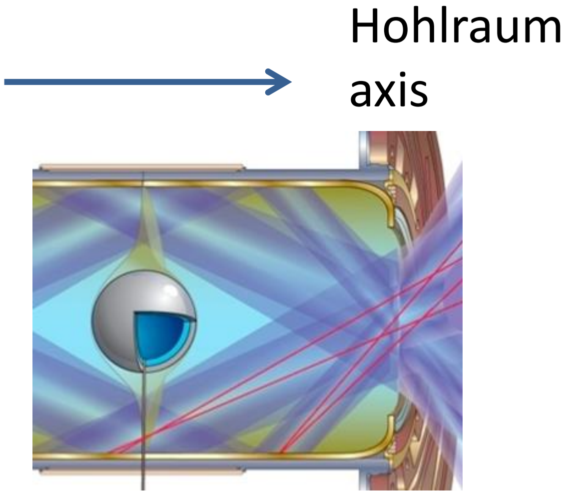


Inner beam propagation: B field reduces inner beam absorption in fill, less pancaked implosion

NIF Shot N120321: 21.5 ns: end of pulse

- Shell radius ~ 150 um
- No B: shell oblate (pancaked)
- With B: close to round, better inner-beam propagation





Hot electrons: ZUMA[1] (D. J. Larson): Hybrid PIC code: kinetic hots, dense plasma background

Run here in “Monte-Carlo” mode:

- Hot electrons undergo collisional drag and angular scatter[2]
- Lorentz force from time-independent B field; no E field

$$\frac{dE}{ds} = -\frac{C_e n_e}{m_e v^2} L_d$$

$$\approx \frac{C_e n_e}{2E} \ln\left[\frac{E}{\hbar\omega_{pe}}\right] \qquad \hbar\omega_{pe} \ll E \ll m_e c^2$$

$$L_d = \ln\left[\frac{\beta\varepsilon^{1/2}}{2^{1/2}}\frac{m_e c^2}{\hbar\omega_{pe}}\right] + \frac{9}{16} + \frac{1/8 + \ln 2}{\gamma} * \left(-1 + \frac{1}{2\gamma}\right)$$

Drag (energy loss):
~ 1/[e- energy]

$$C_e \equiv \frac{e^4}{4\pi\varepsilon_0{}^2}$$

$$\frac{d\left\langle\theta^2\right\rangle}{ds} = \frac{2C_e}{p^2 v^2}\left[L_{sI}\sum_i n_i Z_i{}^2 + n_e L_{se}\right]$$

$$\approx \frac{C_e n_e}{2E^2}\left(\frac{\left\langle Z^2\right\rangle}{\left\langle Z\right\rangle} + 1\right)\ln\frac{2(2T_e E)^{1/2}}{\hbar\omega_{pe}} \qquad E \ll m_e c^2$$

$$L_{sI} = \ln\frac{2\lambda_{De} p}{\hbar} - 0.234 - 0.659\beta^2 \qquad L_{se} = L_{sI} - \frac{1}{2}\ln\frac{\gamma + 3}{2}$$

Angular scatter:
~ 1/[e- energy]$^{3/2}$

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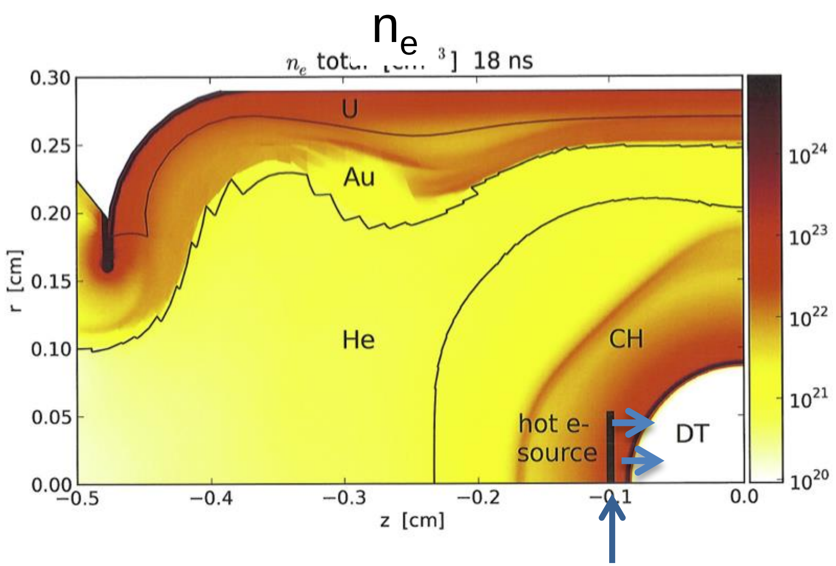
[1] D. J. Larson et al., APS-DPP 2010; D. J. Strozzi et al., Phys. Plasmas 2012

[2] A. P. L. Robinson et al., Nuclear Fusion 2014

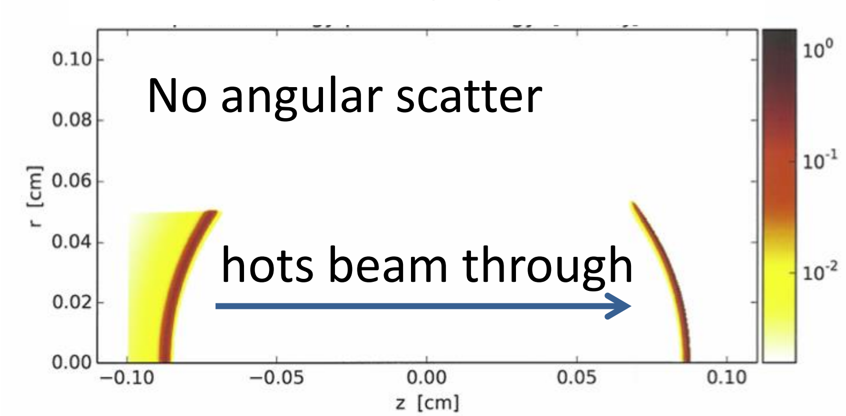
Hot electron test case: source directly incident on capsule

N120321   18 ns: early peak power



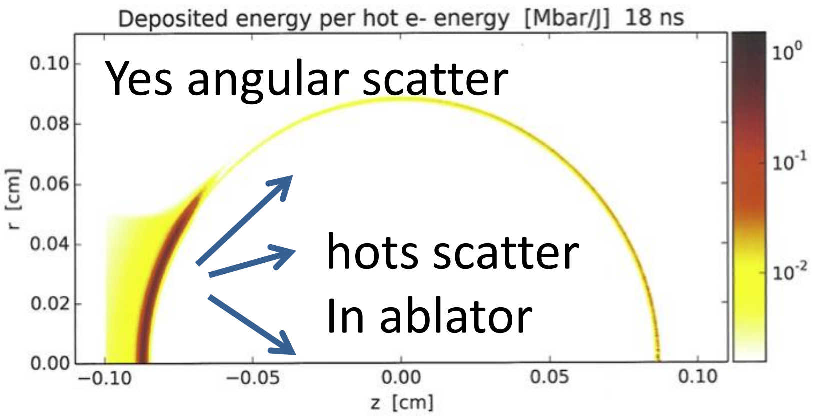
Unphysical test source:
Mono-energetic, collimated

Energy deposited per volume
E = 175 keV



No angular scatter

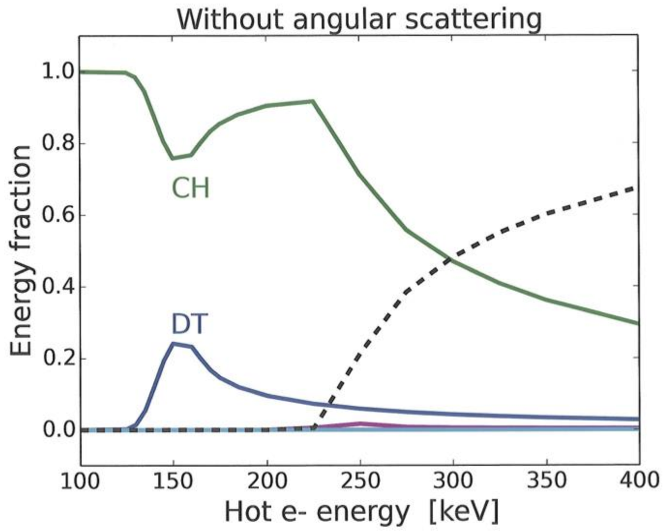
hots beam through

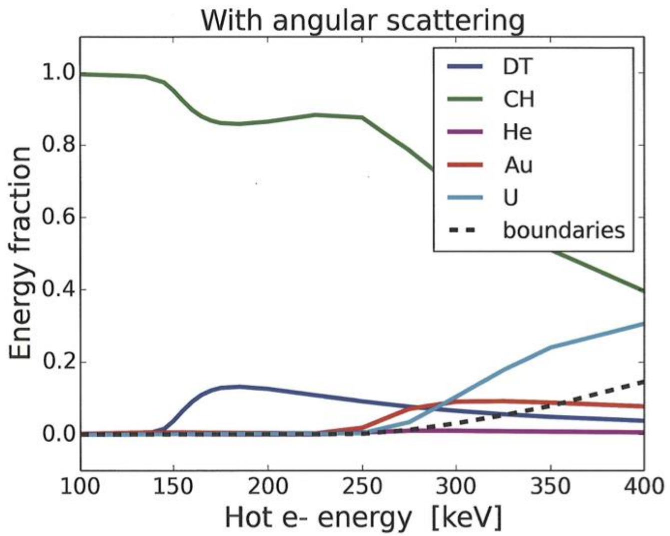


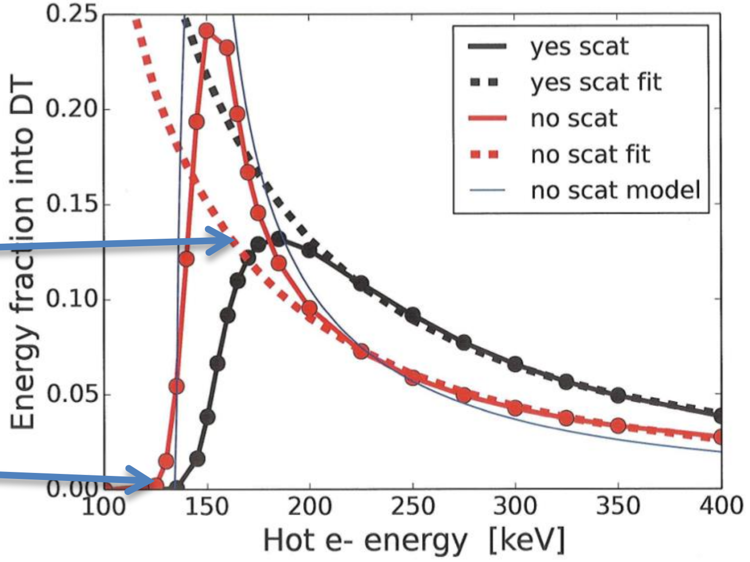
Yes angular scatter

hots scatter
In ablator

Hot electron test case: E > 130 keV to reach DT, 185 keV couple best





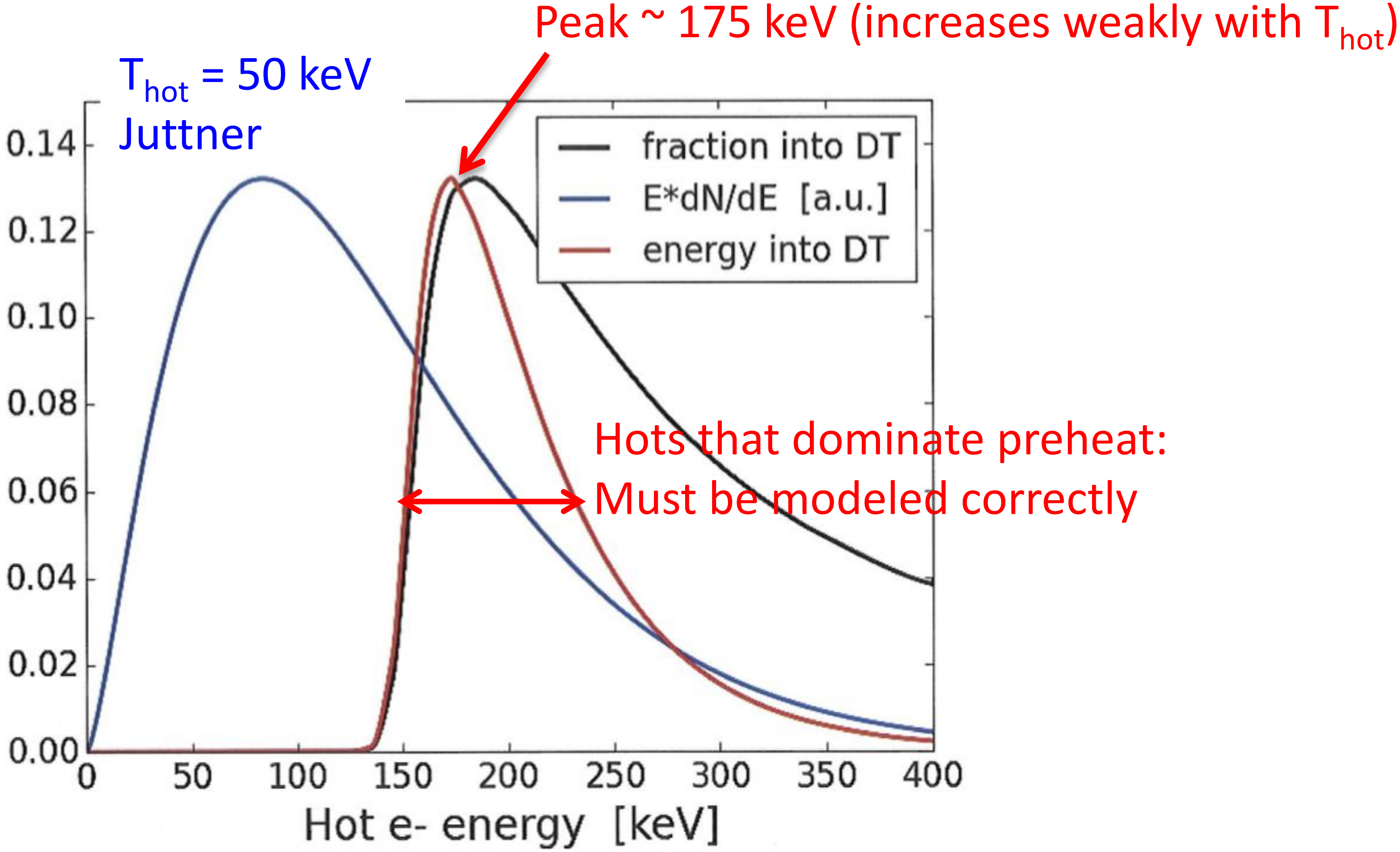


185 keV couple best to DT

130 keV to reach DT

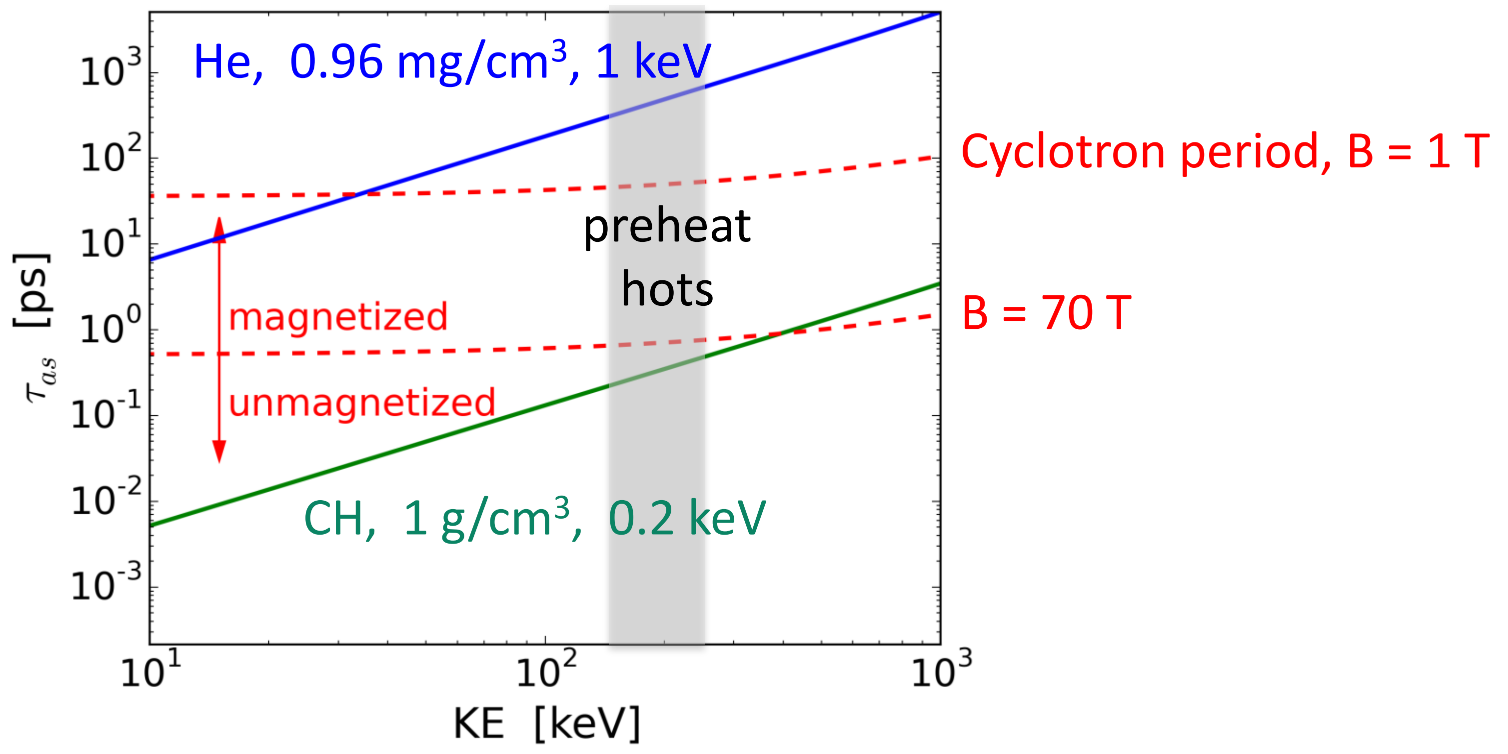
Hot electron test case: preheat given by 150 to 250 keV electrons

"Gamow peak": Energy to DT = coupling efficiency * hot e- energy spectrum



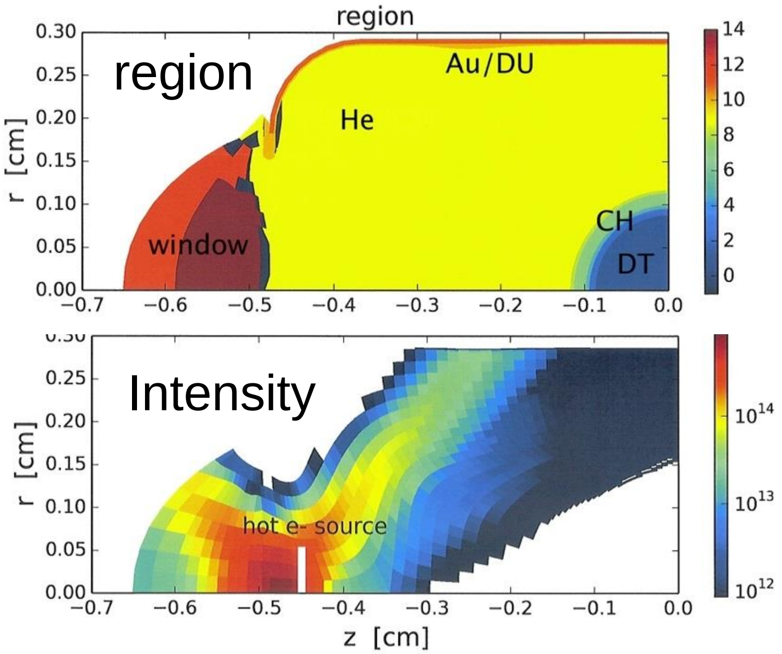
Adding 1 Tesla field strongly magnetizes hots in underdense fill, not in dense ablator

Time for r.m.s. 90 deg. angular scatter

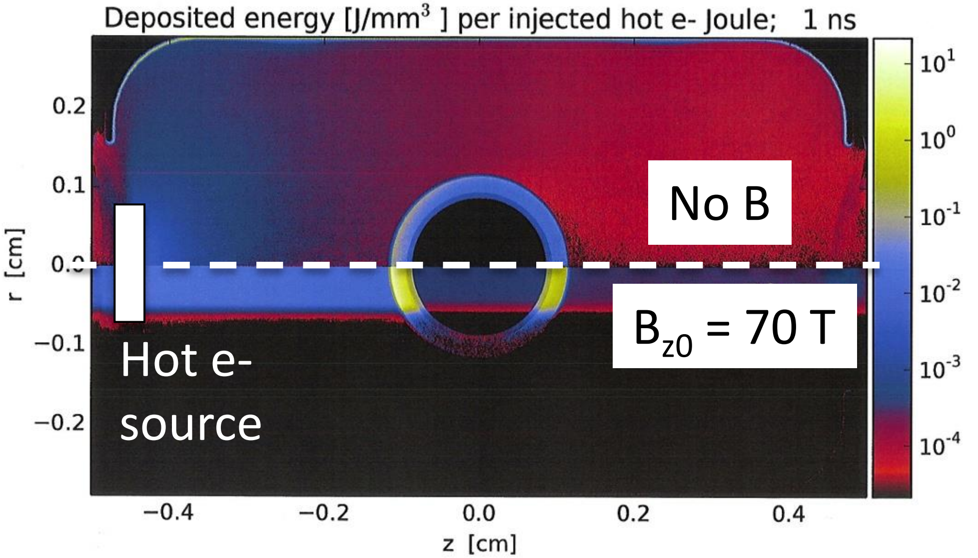


Hot electrons: Picket with two-plasmon hot e- source in window: B field guides hots to capsule

NIF shot N120321 @ 1 ns



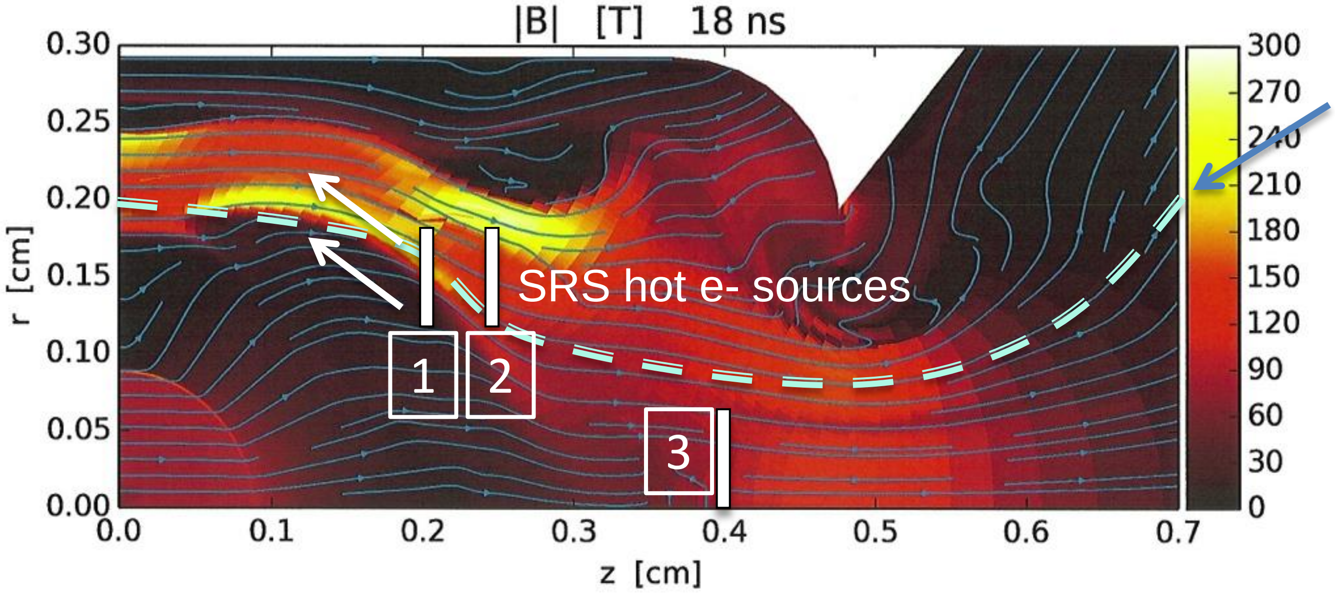
Hot electron energy deposited



- Two-plasmon decay hot e- source: T_{hot} = 80 keV, R=500 um, $dN/d\Omega$ = const. for $v_z > 0$
- B_z = 70 T (uniform): hot e-'s magnetized in fill, transported directly at capsule
- Fraction of hot e- energy deposited in DT ice: no B: $2.2*10^{-3}$, with B: 0.026 (12x higher)
    - Still only ~20 mJ so OK?
- Pre-heat concentrated along poles – may be shape issue
- Preheat depends on hot e- production, tunable by picket pulse shape (e.g. low-power "toe")

B field lines roughly follow MHD frozen-in law: advected with conducting plasma

N120321, 18 ns: early peak power



Critical field line:

- Inside lines connect to capsule
- Outside lines don’t

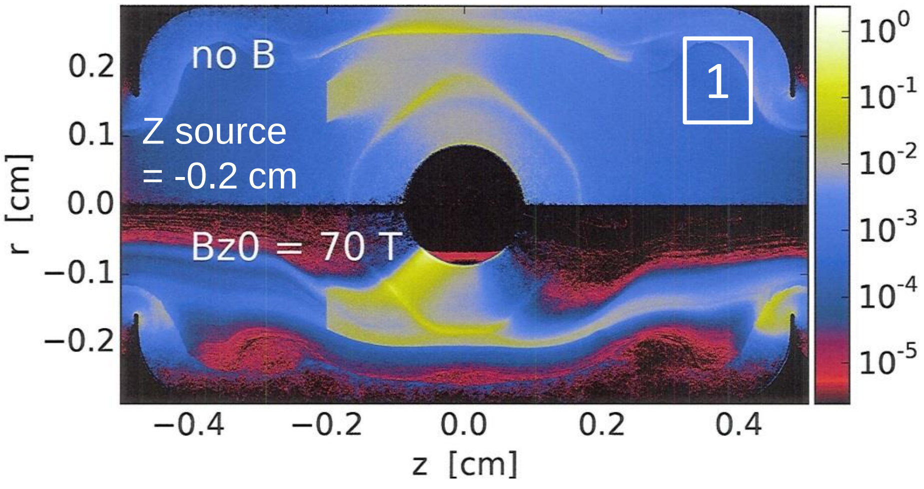
- B_{z0} = 70 T
- Field increases where compressed between ablator and wall
- Some field lines connect to capsule, some don’t

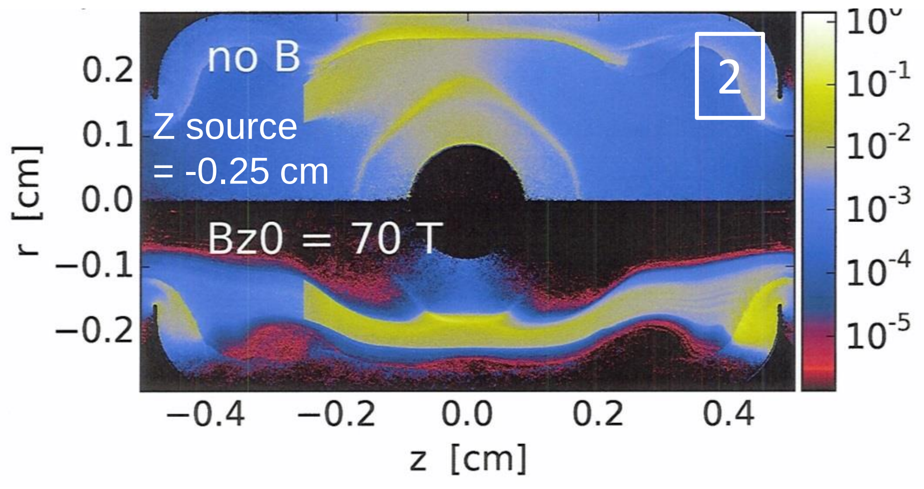
SRS source:

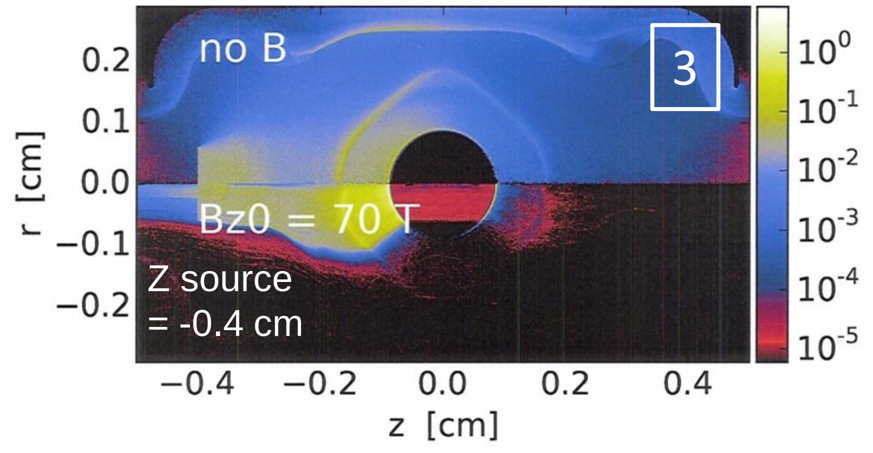
- T_{hot} = 30 keV
- Angle spectrum: $dN/d\Omega = \exp[-((\theta-27^o)/10^o)^4]$

Hot electrons: coupling to DT early in peak power is very sensitive to source location

Coupled energy [J/mm^3] per injected hot e- Joule







Fraction of hot e- energy coupled to DT ice

Source	**No B**	**B_{z0} = 70 T**	**B_{z0} / no B**
1	1.19E-4	1.26E-3	10.6
2	1.37E-4	3.44E-6	0.025
3	3.58E-4	2.89E-3	8.07

Conclusion: imposed B field may improve inner beam propagation, could help or hurt hot electron preheat

Hydra MHD simulation of low-foot shot N120321, with 70 T initial axial field:

- Cross-field electron heat conduction greatly reduced
- Leads to hotter and less dense equator, better inner-beam propagation
- May reduce inner-beam SRS

Zuma studies of hot electron propagation:

- Picket: two-plasmon source in window guided to capsule, energy coupled to DT 12x higher
- Peak power: SRS source confined to He fill, energy coupled to DT strongly depends on source location
- Story may change if hot electrons made no field lines still connected to capsule

Future work:

- Many MHD terms presently neglected in Ohm’s law and e- energy equation
- “Biermann” self-generated fields have significant effect in Hydra (D. Strozzi) and Lasnex (C. Thomas), numerics being investigated
- Nernst effect may significantly affect imposed-field dynamics (A. Joglekar, PRL 2014 and Anomalous Absorption 2015)