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Modeling Laser-Plasma Interaction over a Suite of NIF Experiments

D. J. Strozzi, R. L. Berger, O. S. Jones, T. Chapman, L. Divol, S. A. MacLaren, P. Michel, L. Divol

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Anomalous Absorption
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Modeling Laser-Plasma Interaction over a Suite of NIF Experiments

Anomalous Absorption Conference

D. J. Strozzi, R. L. Berger, O. S. Jones, T. Chapman, D. T. Woods, S. A. MacLaren, P. Michel, L. Divol

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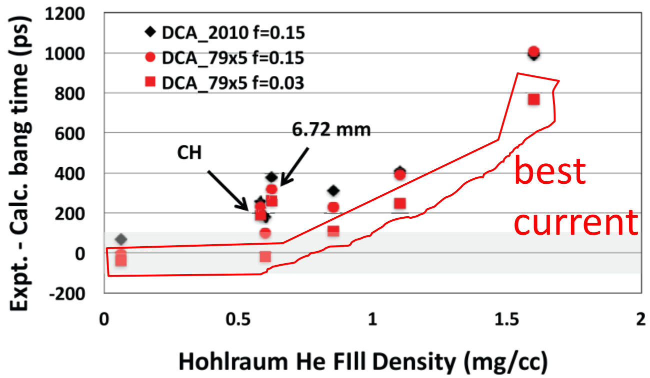
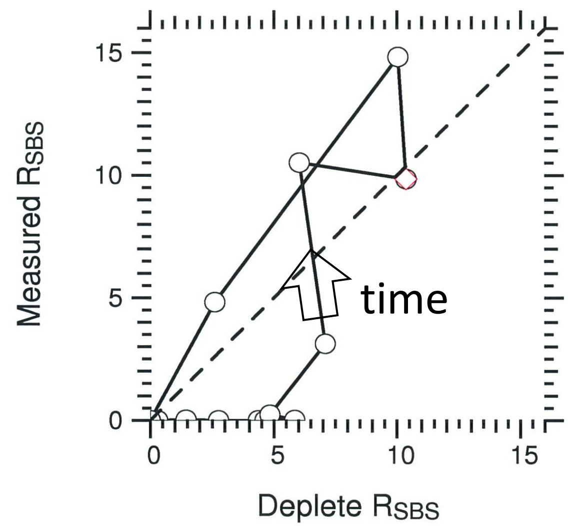
Summary: towards predictive rad-hydro + laser-plasma modeling

- **Same "best current" rad-hydro for all shots[1]**
  - O. Jones et al., Phys. Plasmas 2017
  - No per-shot multipliers
  - DCA model
  - Electron flux limit 0.03
  - Cross-beam energy xfer clamp $\delta n_e/n_e$=0.01
- **New in this work: backscatter**
  - **DEPLETE:** ray-based extension of linear gain
  - **pF3D:** paraxial-envelope code: speckles, polarization smoothing, SSD, etc.
- **NIF "bigfoot" shot**
  - CBET (calculated) to outer cones
  - Outer-cone SBS: 10-15% end of pulse
  - Deplete and pF3D: less increase vs. time
  - Both codes: SBS from gold bubble

Continued improvement in both rad-hydro and LPI modeling

Simulations: too much x-ray drive, esp. for long pulses, high fill density

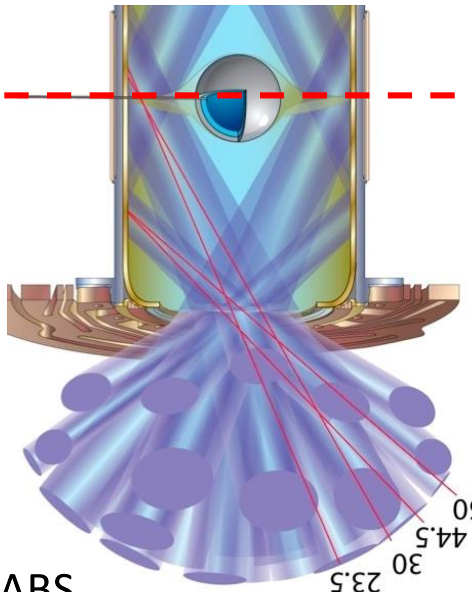




Rad-hydro model: "best current" physics in Lasnex[1]

- **Opacity + EOS**
  - LTE tables for $T_e < T_{crit}$, non-LTE DCA for $T_e > T_{crit}$
  - T_{crit} = 300 eV in wall, 50 eV elsewhere
  - DCA models: March 2014
  - Gold: dca_79x5 – improved gold bubble physics
  - Bug: over-emits x-rays with radiation field: H. Scott
- **Laser**
  - Escaping backscatter power removed from incident laser – no inline SRS/SBS
  - Inverse brem. absorption + Langdon effect
  - Inline CBET: unpolarized quads, saturation $\delta n_e/n_e = 0.01$
  - Ponderomotive force: needed for CBET momentum deposition
- **Electron heat conduction**
  - Heat flux $q = \min(q_{SH}, f\, n_e T_e v_{Te})$
  - q_{SH} = Spitzer-Harm + Lee-More corrections
  - flux limit f = 0.03 everywhere
  - No MHD, nonlocal, ion turbulence models

2D RZ axisymmetric
Only bottom half:
BS diagnostics there



FABS,
NBI detectors

[1]O. Jones et al., Phys. Plasmas 2017

Rad-hydro model: numerics / logistics

- No ad-hoc / per-shot multipliers: power, cone fraction, …
- LHT (Lasnex Hohlraum Template) version-controlled input deck
  - Needed to handle multiple shots + multiple designers
  - Based on deck from Cliff Thomas, from Richard Town, Peter Amendt, etc.
- Same Lasnex version: 13 April 2017

- **Numerical resolution:** O. Jones' "hi-res" settings from convergence study[1]
  - Capsule: 72 angular zones in 90° → $\Delta\theta = 1.25°$
  - Wall: innermost zone Δr=4 nm, Δr increases by 1.03x
  - 180 radiation energy groups
  - 10 zones across LEH window thickness

- **Mesh:** "As Lagrangian As Reasonably Achievable"*
  - ALE (Arbitrary Lagrangian-Eulerian) mesh management: R. Tipton
  - Hohlraum: ALE from t=0, may freeze mesh after laser is off
  - Capsule: ALE from user-determined t>0, mesh not frozen

- **Laser:** 600 rays per quad, CBET iteration options

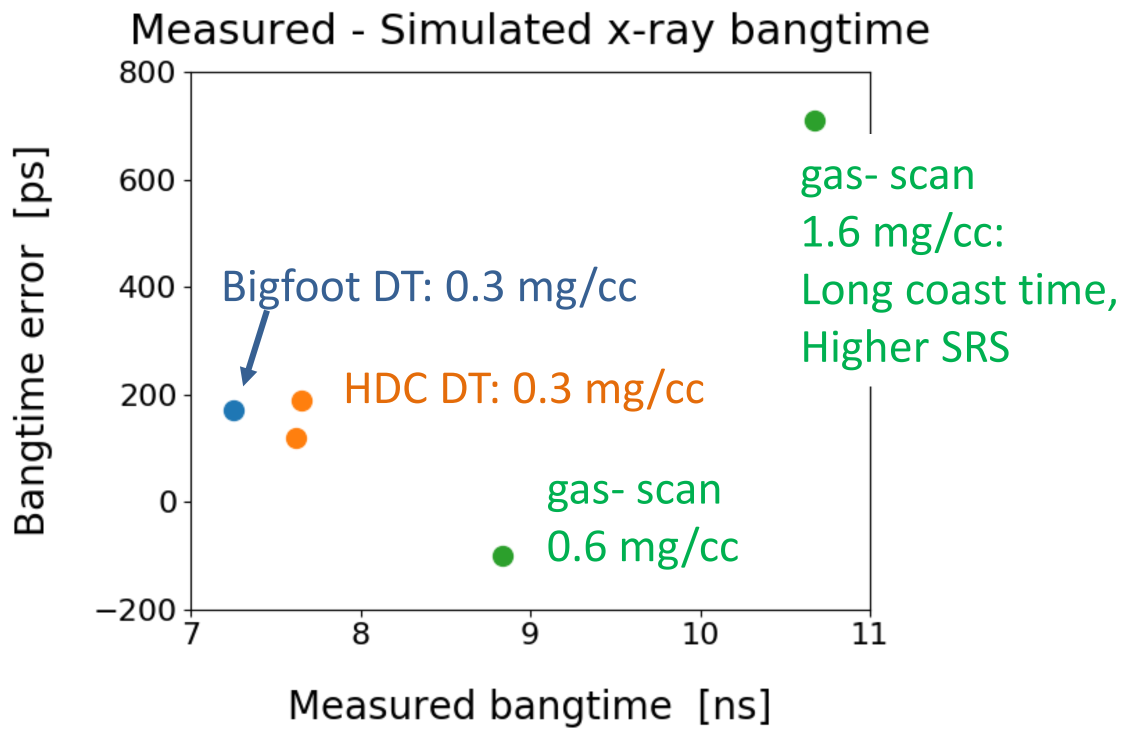
[1]O. Jones et al., Phys. Plasmas 2017

*N. Meezan, private communication (2007)

Energetics across a set of NIF shots

Drive deficit:

- Rad-hydro codes over-predict x-ray drive in NIF hohlraums
- Long-standing issue
- Especially for long pulses, high gas fill density, and high backscatter

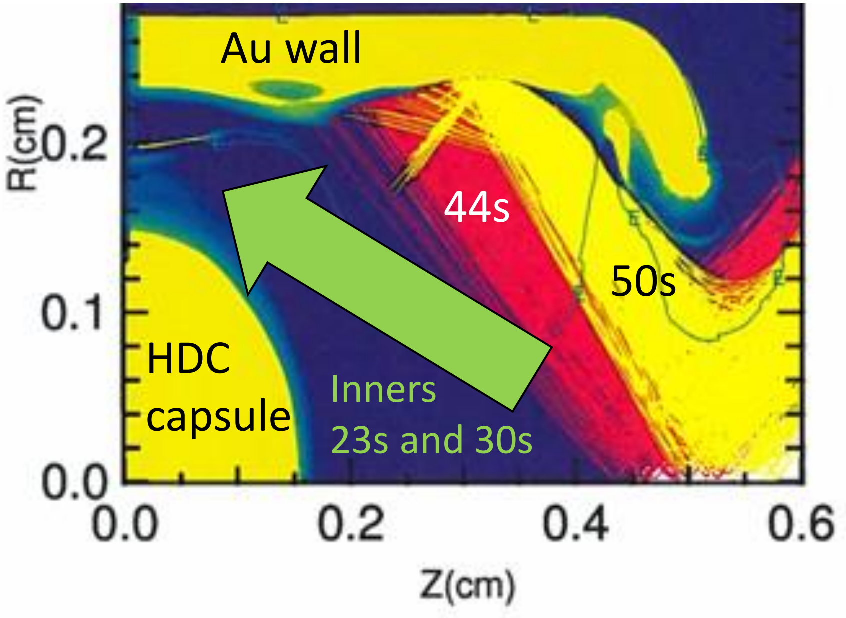


"Bigfoot"[1] shot N170109

Bigfoot

- 1st and 2nd shocks overtake in ablator, before reaching DT fuel
- "Robust" hostspot: high adiabat, lower convergence, high rho*R
- Less prone to hydro instabilities (e.g. Rayleigh-Taylor) and loss mechanisms
- At price of lower 1D gain

$\Delta\lambda$ = 0: CBET due to plasma flow only



"Quad splitting":

- Spread out outer beam spots on wall
- 4 beams in an outer quad split in azimuth
- 44's and 50's separated in Z

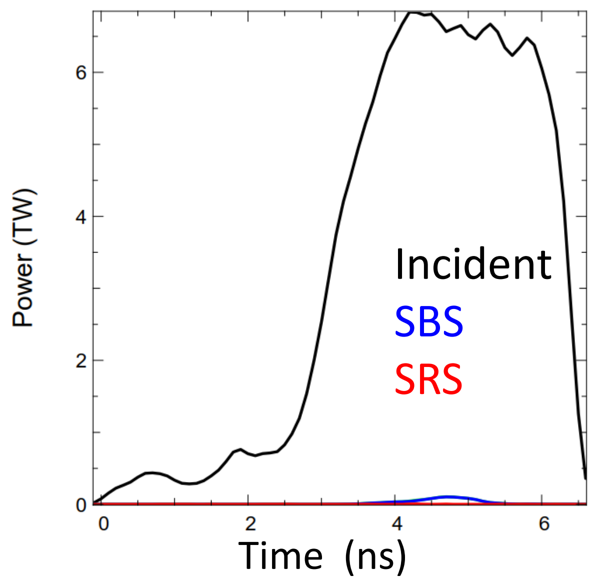
Benefits:

- Less azimuthal variation
- Lower intensity → lower SBS
- Less M-band x-rays
- Less wall / bubble motion

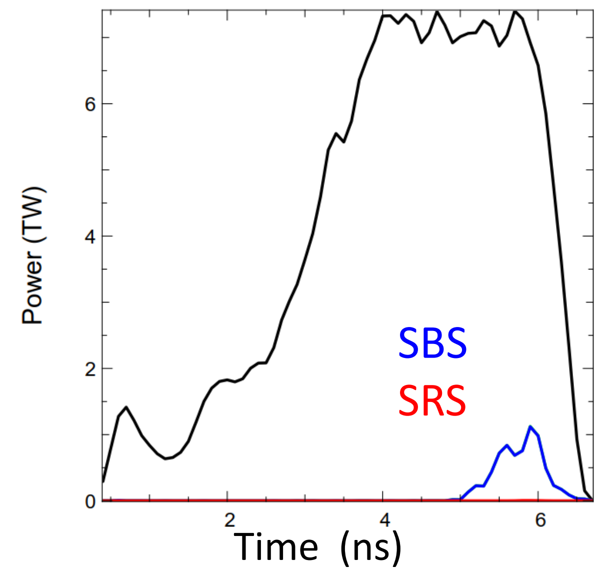
[1]C. A. Thomas, APS DPP 2016 invited talk

Bigfoot shot N170109: SBS late in time on cone 50

Q31B FABS: quad on cone 30



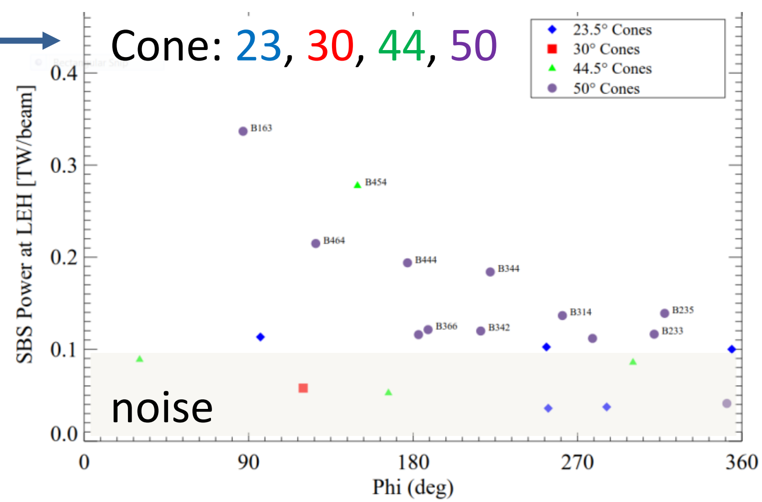
Q36B FABS: quad on cone 50



Drive diagnostic sensors

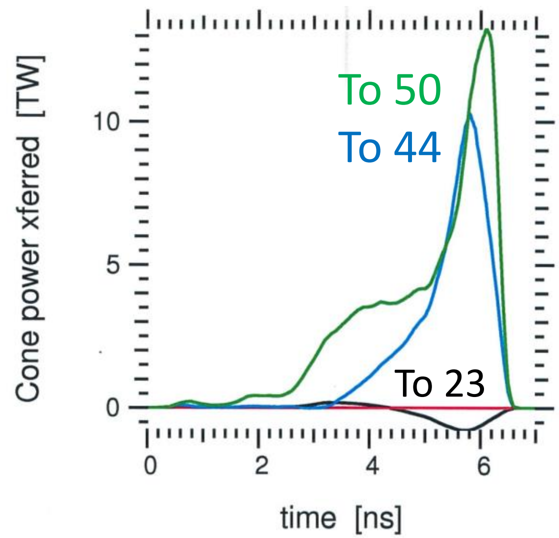
SBS in >= one beam on every quad:

- More SBS on cone 50 than 44

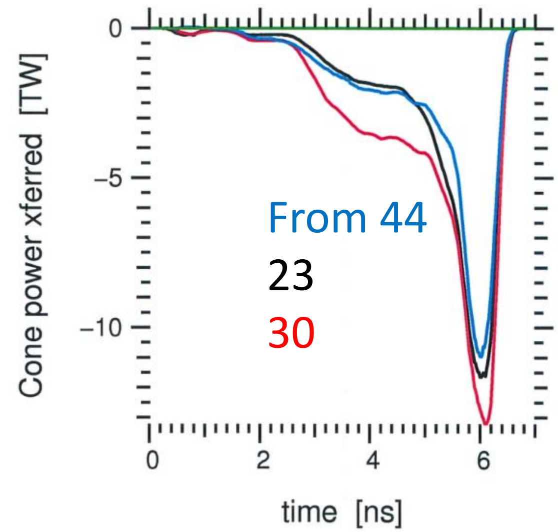


Bigfoot: calculated CBET to outers, especially 50's

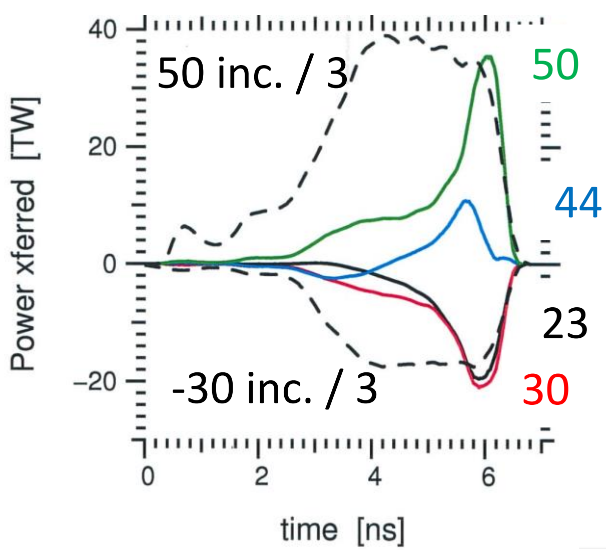
From cone 30: transfer TO 44's and 50's



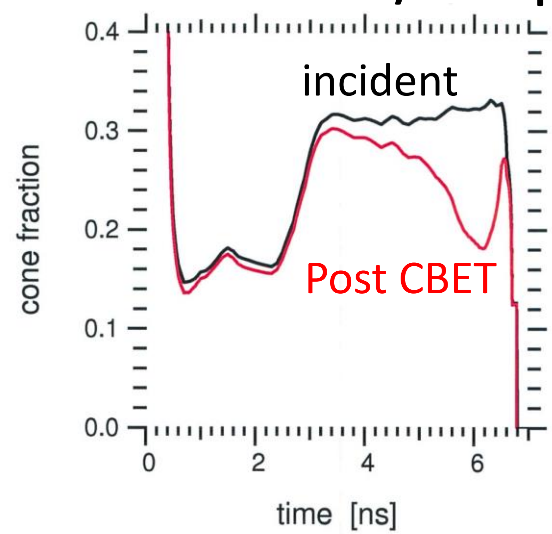
From cone 50: transfer FROM all other cones



Net transfer to each cone



Cone fraction = Inner / Total power



NIF Shot
N170109

DEPLETE[1]: ray-based, steady-state backscatter calculations, extension of linear gain

$$\frac{d}{dz}I_0(z) = -\kappa_0 I_0 \qquad - I_0 \int d\omega_1 \frac{\omega_0}{\omega_1}(\tau_1 + \Gamma_1 i_1)$$

$$-\frac{\partial}{\partial z} i_1(z,\omega_1) = -\kappa_1 i_1 \quad - \quad \Sigma_1 \quad - I_0(\tau_1 \quad + \quad \Gamma_1 i_1)$$

inv. brem. damping	brem. noise	Thomson scattering	SBS/SRS coupling

DEPLETE gain:

$$G = \ln \frac{i_1(\omega, z_0)}{i_1^{brem}(\omega, z_0)}$$

noise level without laser = scattered light with just brem. emission + absorption

Features of DEPLETE:

- Uses 1-D plasma conditions from 3-D ray-trace
- Spectrum of scattered frequencies
- Strong damping limit for plasma waves
- Pump depletion of laser
- Thomson scatter/bremsstrahlung noise sources
- Inverse-bremsstrahlung light wave damping
- Linear kinetic coupling coefficients
- Collisional plasma-wave damping

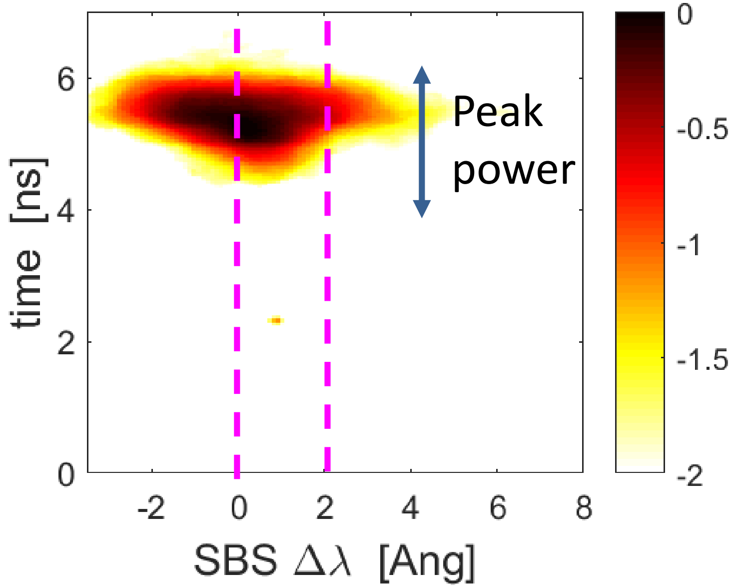
DEPLETE lacks:

- Temporal effects
- Laser speckles
- PS, SSD
- Dewandre effect
- Multi-D effects, e.g. refractive intensification

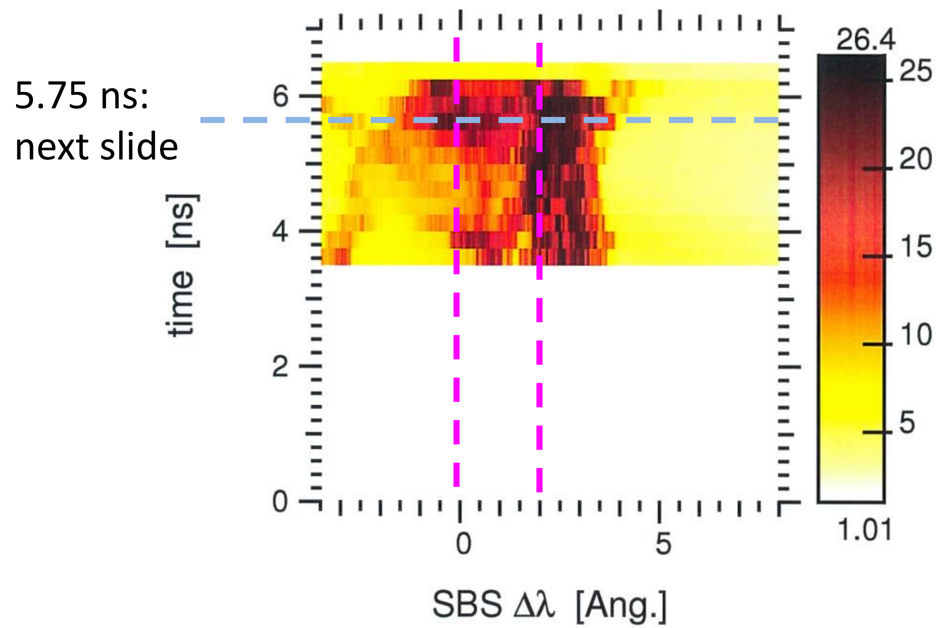
[1]D. J. Strozzi, E. A. Williams, D. E. Hinkel, D. H. Froula, R. A. London, D. A. Callahan, Phys. Plasmas 2008

Bigfoot: Cone 50 SBS spectrum vs. DEPLETE[1]

Measured SBS spectrum: Shot N161204 (Symcap)



Ray-averaged DEPLETE gain spectrum: Shot N170109 (layered DT)



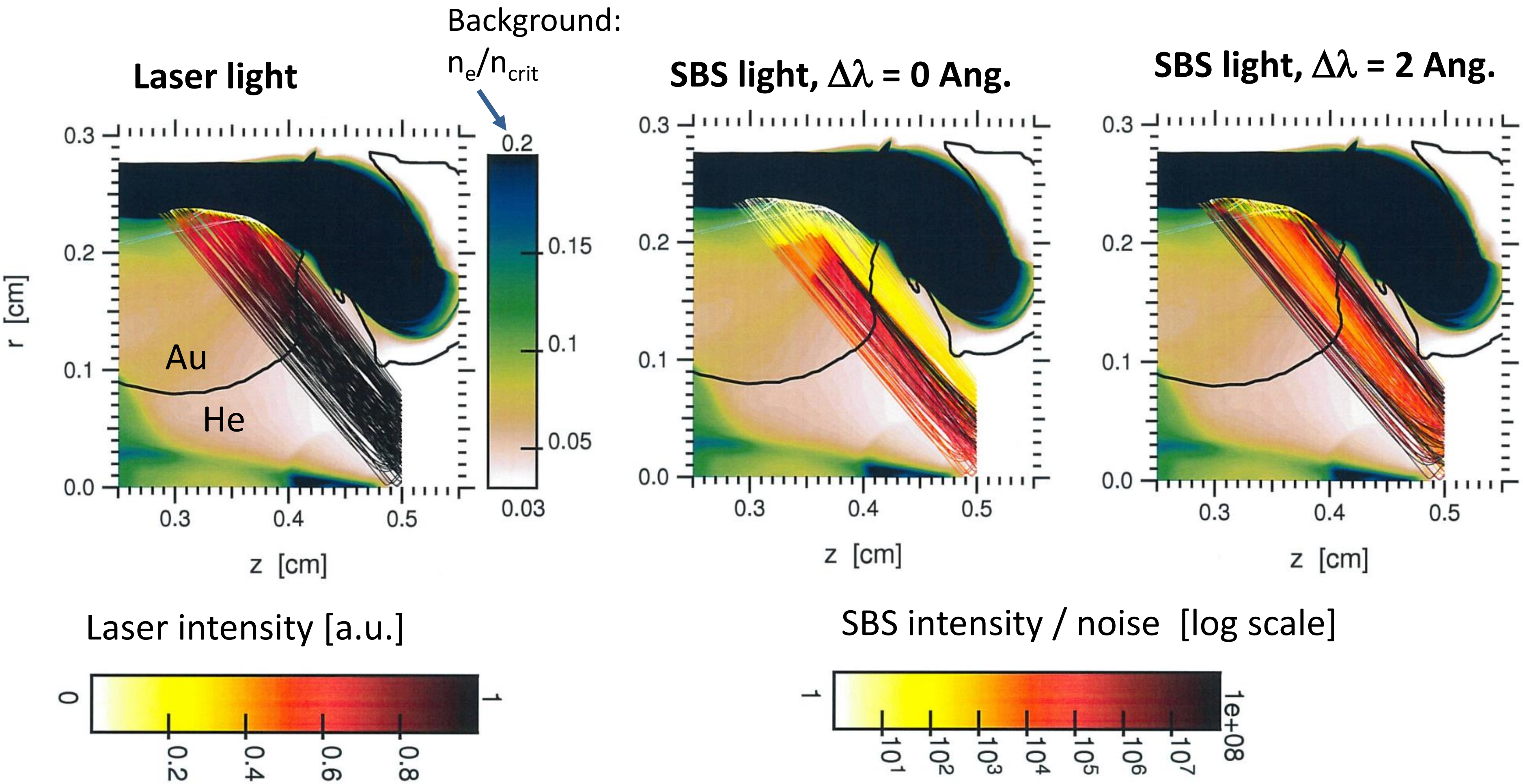
- DEPLETE spectrum redshifted by ~ 2 Ang. vs data
- Neglects SSD bandwidth, "Dewandre effect" (wavelength shift due to time-dependent electron density)

Shot N161204 – symcap, has SBS spectrum, analog of DT shot N170109 – no SBS spectrum

[1]D. J. Strozzi, E. A. Williams, D. E. Hinkel, D. H. Froula, R. A. London, D. A. Callahan, Phys. Plasmas 2008

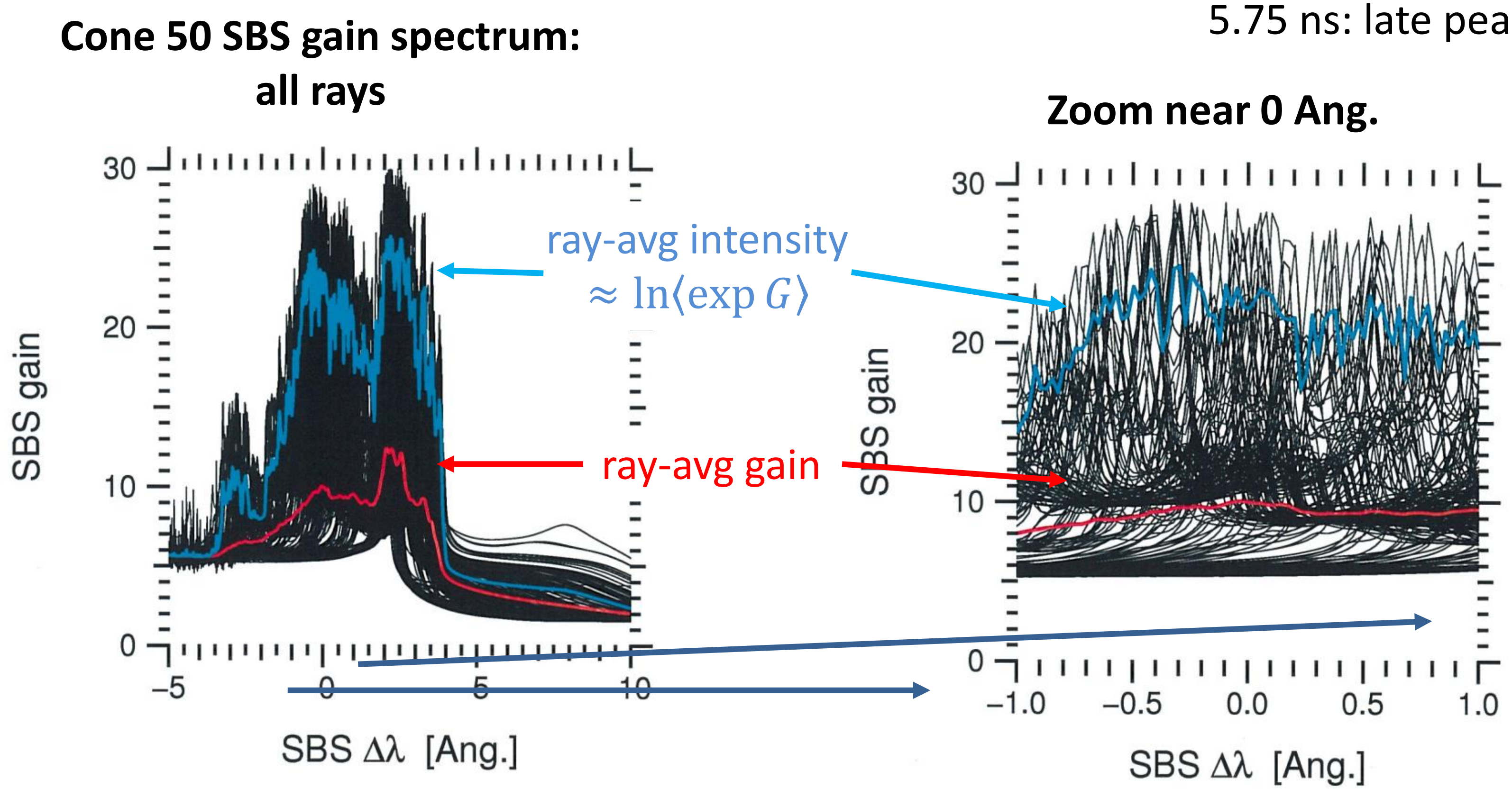
DEPLETE: Cone 50 SBS develops in gold bubble

N170109
5.75 ns: late peak power



Each ray has narrow SBS resonance at different wavelength[1]

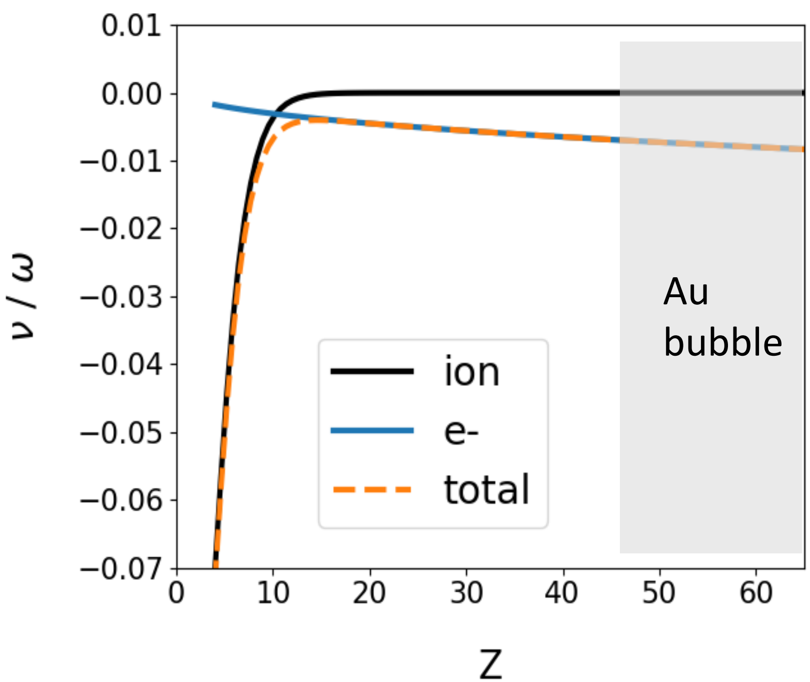
N170109
5.75 ns: late peak power



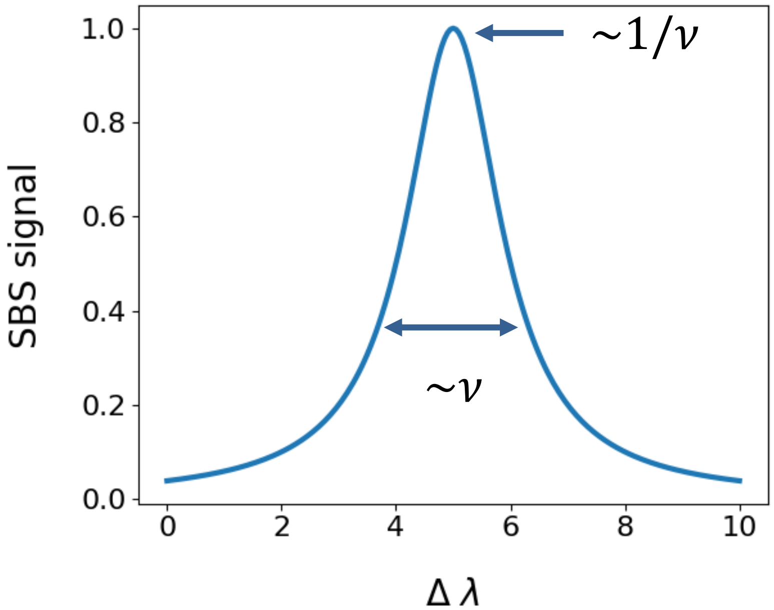
[1]L. Tolstoy, *Anna Karenina* (1878)

Ion waves weakly damped for $ZT_e/T_i >> 1$: e.g. gold

IAW Landau damping rate: gold
$T_e = 2T_i$, $k\lambda_{De} = 0.6$



SBS spectrum

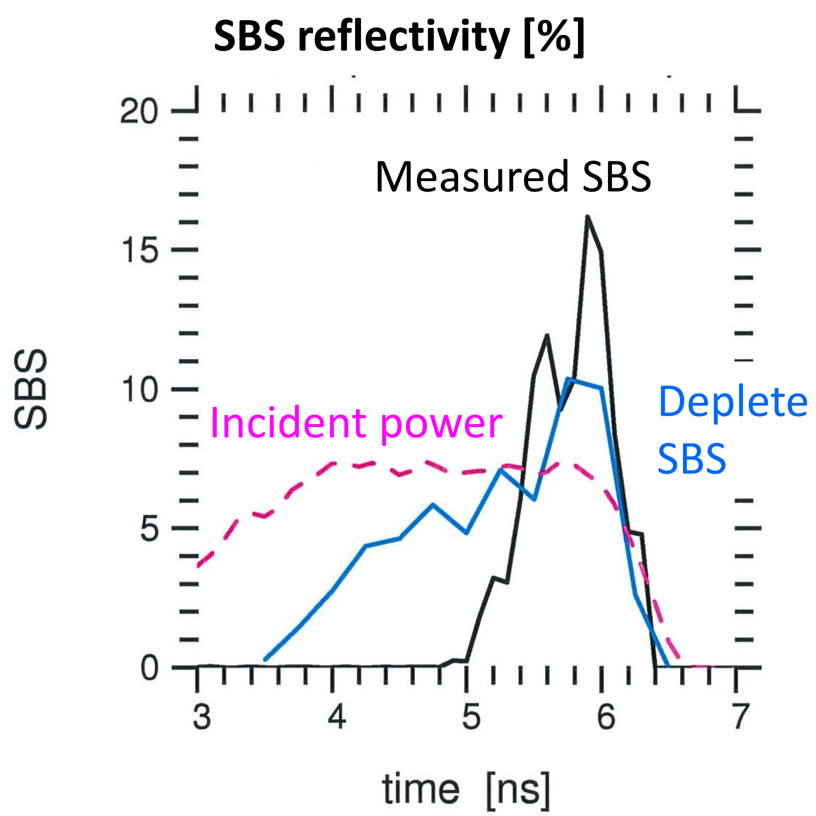


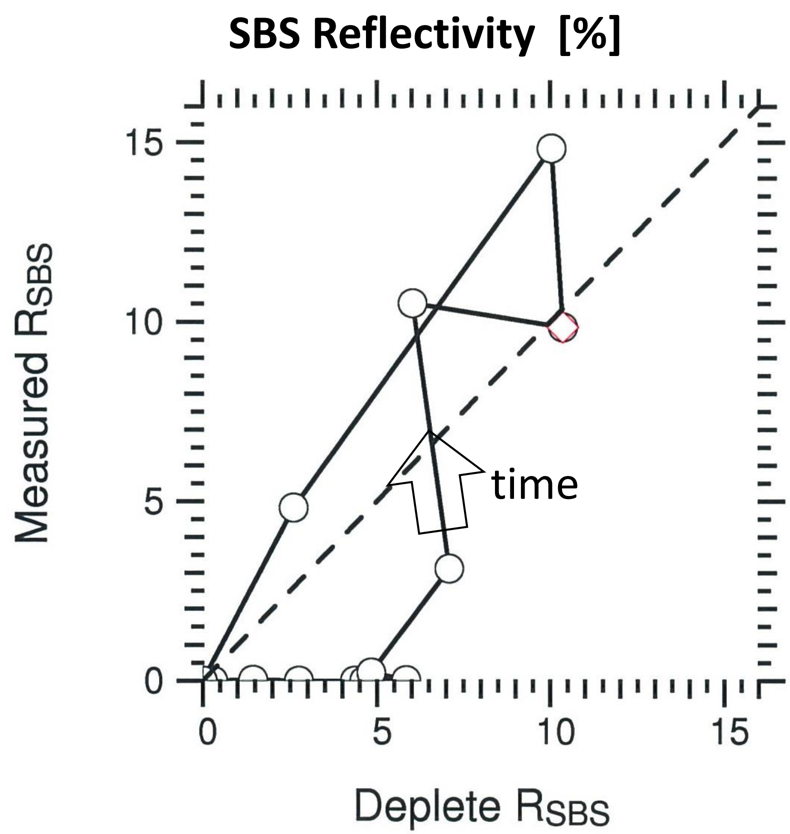
Electrons **Ions**

$$\frac{\nu}{\omega} \propto \left(\frac{Zm_e}{m_i}\right)^{\frac{1}{2}} \exp\left[-\frac{Zm_e}{2m_i}\right] + \frac{1}{2}\left(\frac{ZT_e}{T_i}\right)^{\frac{3}{2}} \exp\left[-\frac{ZT_e}{2T_i}\right]$$

Cone 50 SBS: Measured and Deplete reflectivities qualitatively track vs time

NIF Shot N170109

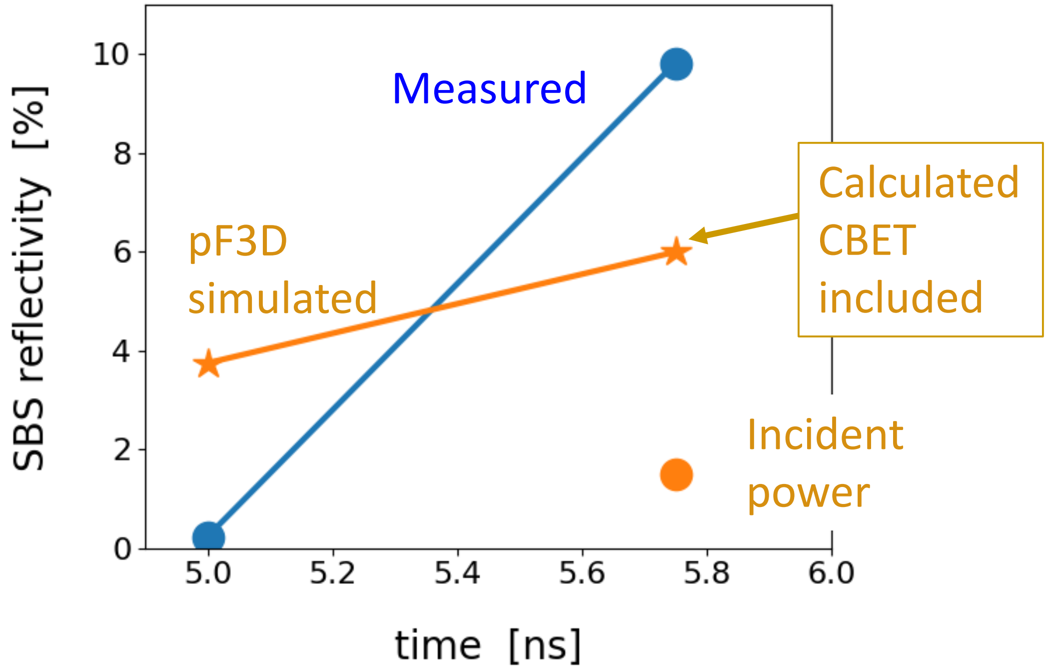




Deplete reflectivity: sum over rays of wavelength-integrated SBS intensity

Cone 50 SBS: pF3D[2] simulations close to measured reflectivity, when CBET included

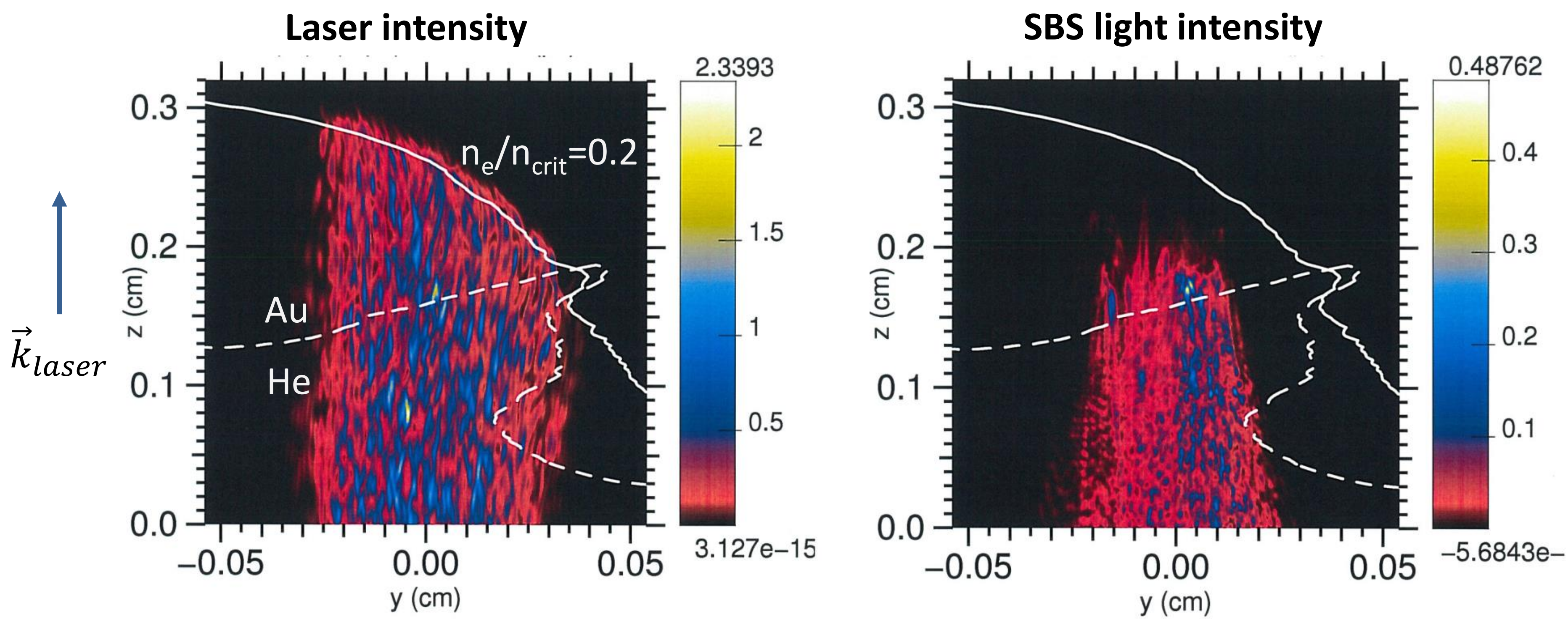
NIF Shot
N170109



pF3D simulations by R. L. Berger

[2]R. L. Berger, C. H. Still, E. A. Williams, A. B. Langdon, Phys. Plasmas 1998

pF3D: outer SBS growth localized in gold bubble



- pF3D run includes one 48° and one 52° beam – each orthogonally polarized
- 50° quad has two other beams: spatially separated at wall due to "quad splitting"
- Plots in pF3D coordinates: laser propagates in z

Conclusions and future work

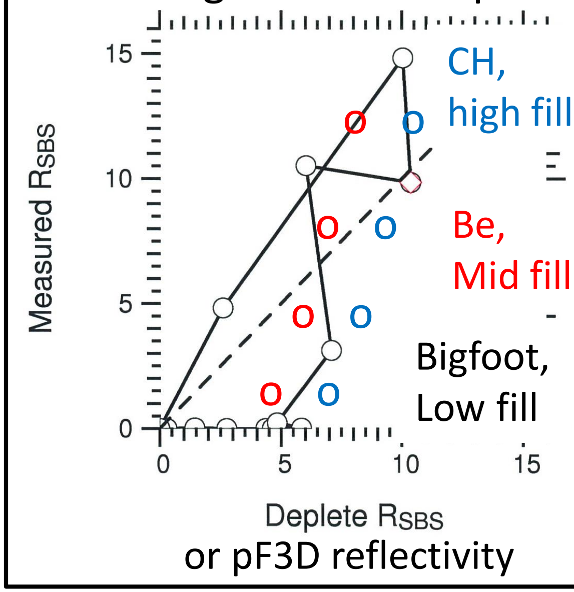
"Best current" rad-hydro model in Lasnex

- DCA 2014 + 79x5 model for gold
- Electron flux limit 0.03
- Inline CBET: saturation clamp $\delta n_e/n_e = 0.01$
- Simulated x-ray flux too high, bangtime early

"Bigfoot" shot N170109

- CBET modeling: CBET to outers, increases in time
- Backscatter: mostly cone 50 SBS, peaks late in time
- Cone 50 SBS modeling: DEPLETE and pF3D
  - Similar reflectivity to data, when CBET included
  - Increase with time less than data

Nirvana: generic "fruit plot"



Future work

- Apply to more shots, more LPI data – inner SRS, SBS in beams within quad
- Suggest rad-hydro modeling improvements, e.g. gold bubble
- Use improved rad-hydro models as available

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