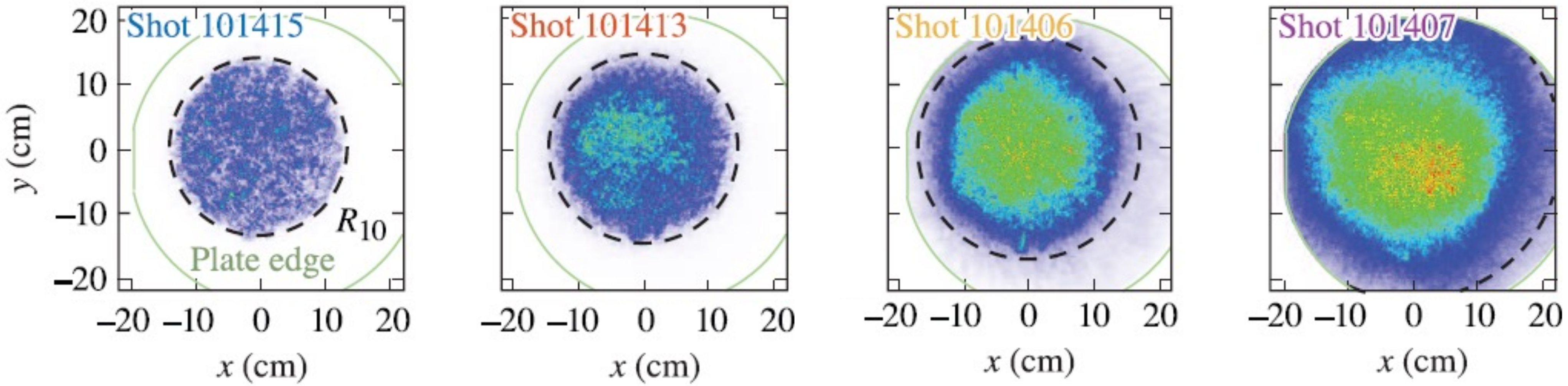
Beam Spray Thresholds in ICF-Relevant Plasmas



University of Rochester
Laboratory for Laser Energetics

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Collaborators

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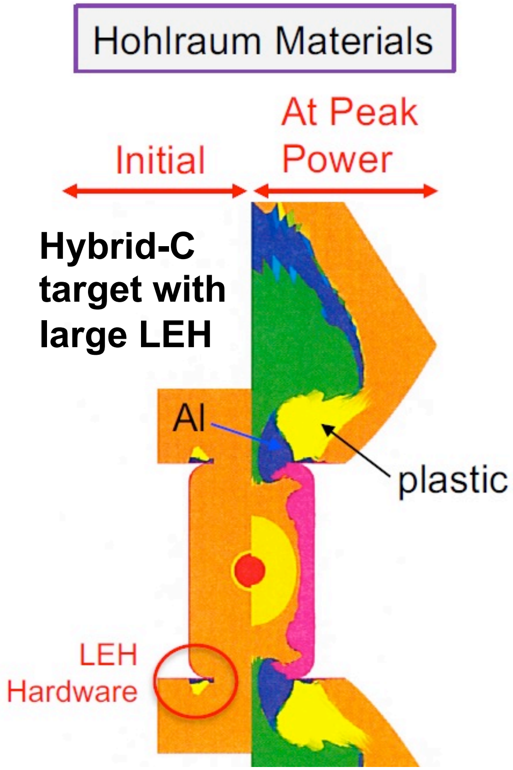
Summary

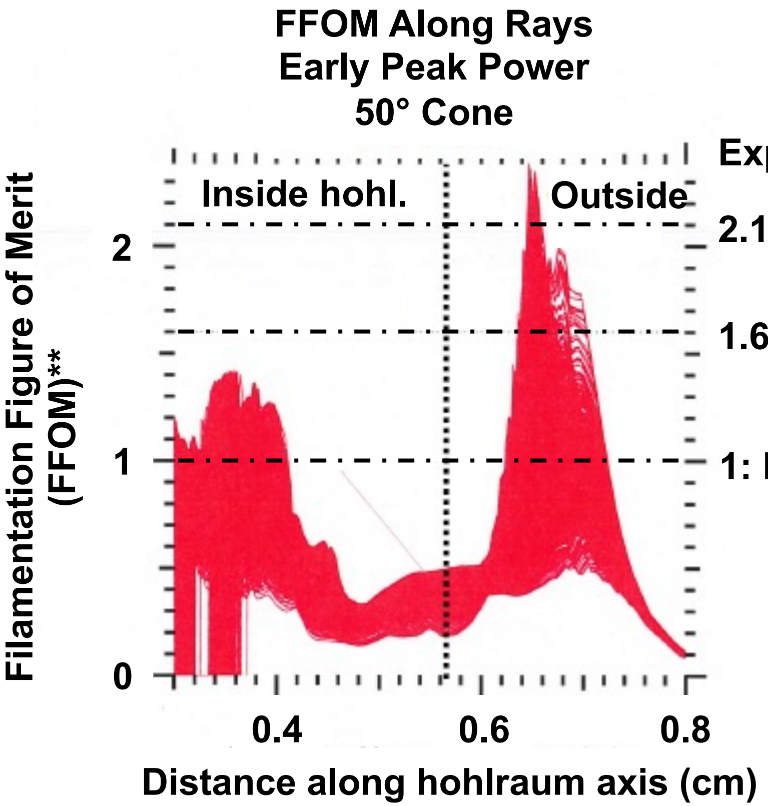
Beam spray measurements indicate thresholds ~2 to 15x less than expected based on the "filamentation figure of merit"*

- **Questions raised during the 2020 ICF workshop hohlraum physics working group motivated a renewed look at filamentation/beam spray for possible impacts on indirect-drive ICF symmetry and drive**
- **Low thresholds were observed in OMEGA experiments, attributed to forward stimulated Brillouin scattering**
  - **The onset of beam spray was consistent in all cases with thresholds proposed by Grech *et al*., with both weak ion-acoustic wave damping and thermally enhanced excitation of ion-acoustic waves contributing to the low thresholds****
- **Frequency shifts were quantified and found to be comparable to those impacting implosion symmetry—a key concern if beam spray occurs outside the hohlraum laser entrance holes**

* D. Turnbull *et al.*, submitted to Physical Review Letters.
** M. Grech *et al.*, Phys. Rev. Lett. 102, 155001 (2009).

Questions were recently raised about the possible influence of "filamentation", or beam spray, in certain hohlraum platforms*





Expected thresholds**:

2.1: DPP + PS + Smoothing by Spectral Dispersion (SSD)

1.6: DPP + Polarization smoothing (PS)

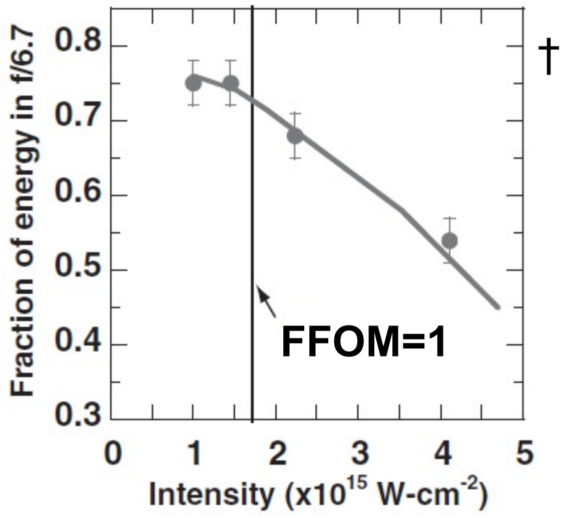
1: Distributed Phase Plate (DPP) only

Q: How is the beam impacted when in proximity to the FFOM threshold?

* Hinkel, MacLaren, Rosen *et al.*, Hohlraum Physics Working Group, 2020 ICF Workshop.
** E. L. Dewald *et al.*, PPCF 44, B405 (2005).

Various figures of merit have been proposed for predicting the onset of beam spray

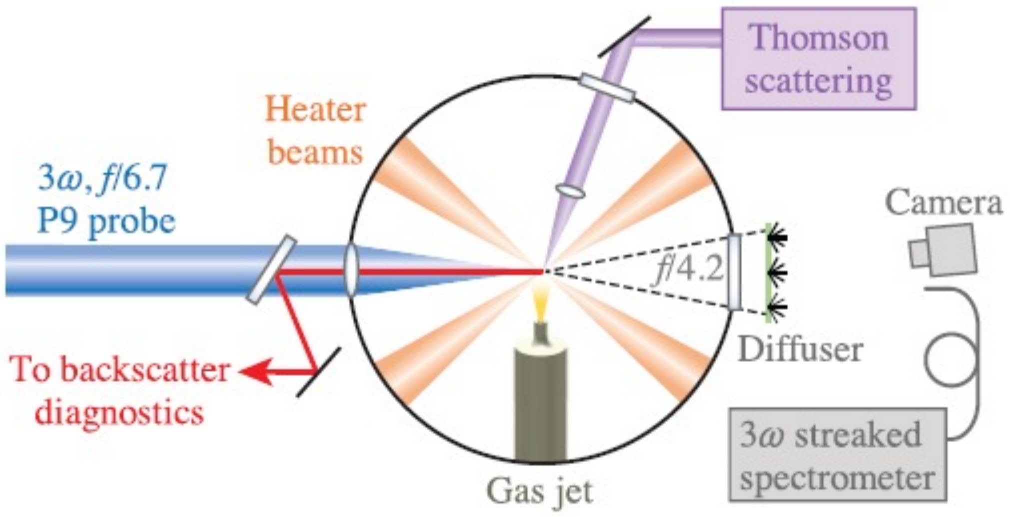
- The filamentation figure of merit (FFOM) was determined from pF3D* simulations accounting for ponderomotive filamentation**
  - $FFOM = I_{13}\lambda^2 \frac{n_e}{n_c}\frac{3}{T_e}\left(\frac{f\#}{8}\right)^2 > 1$ (DPP only)
  - Claimed to have been validated experimentally† →
- The generalized, or Grech, figure of merit (GFOM), was based on a statistical model of forward stimulated Brillouin scattering (FSBS)‡
  - $GFOM = 0.1\gamma_T\left(\frac{\omega}{\nu}\right)_{IAW} I_{13}\lambda^2 \frac{n_e}{n_c}\frac{3}{T_e}\left(\frac{f\#}{8}\right)^2 > 1$, with thermal enhancement factor $\gamma_T = 1 + 1.76 Z_{eff}^{5/7}(\rho_0/\lambda_{ei})$, ρ_0 the transverse speckle width, and λ_{ei} the e-i m.f.p.
  - *Also* claimed consistency with experiment† using $\gamma_T = 1.6$ and $\left(\frac{\nu}{\omega}\right)_{IAW} = 0.15$
  - FSBS as dominant mechanism was consistent with other prior literature^



Experiments had not been performed to break the degeneracy between the FFOM and GFOM

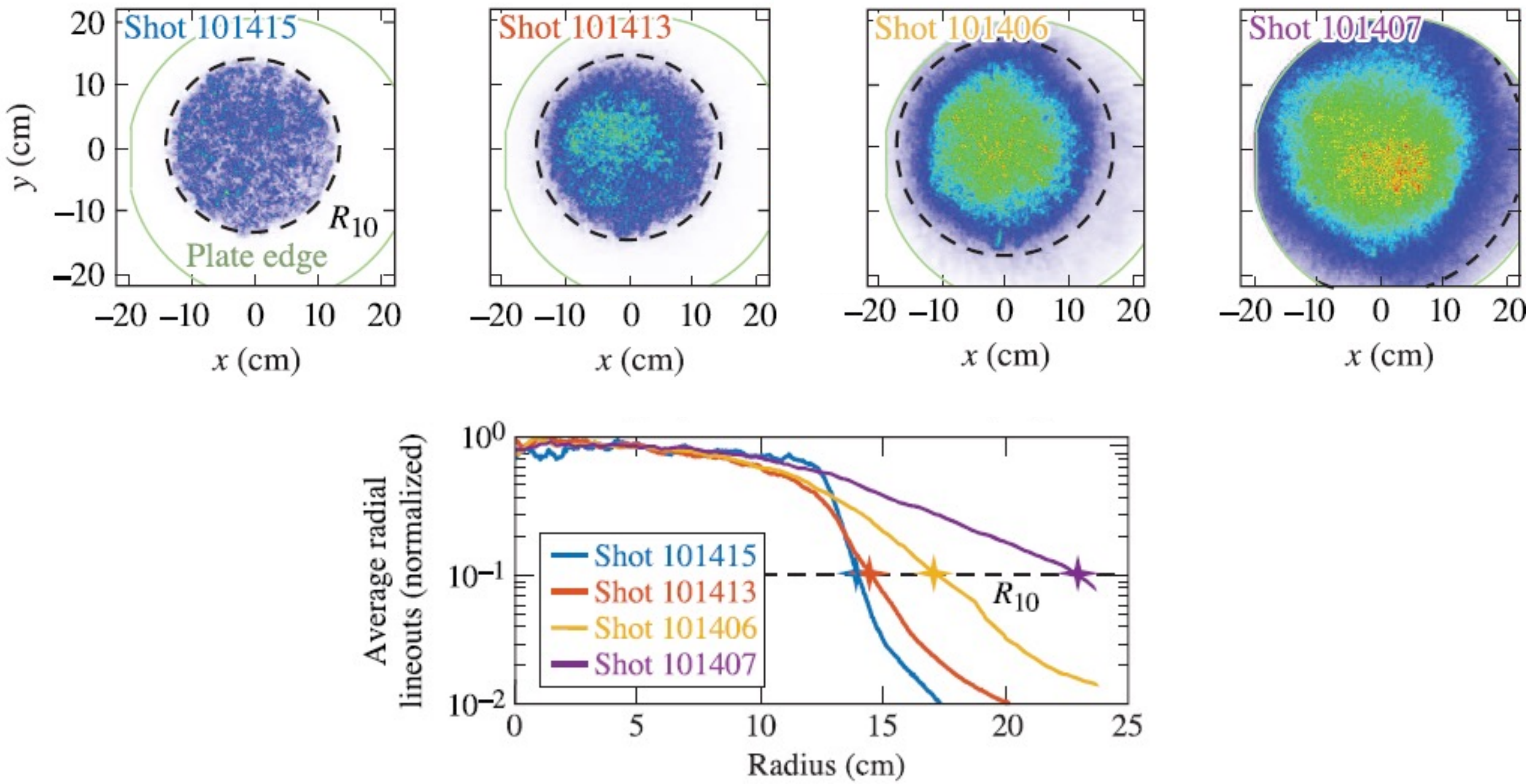
* R. L. Berger *et al.*, Phys. Fluids B 5, 2243 (1993).
** E. L. Dewald *et al.*, Plas. Phys. & Cont. Fus. 44, B405 (2005);
† D. H. Froula *et al.*, Phys. Rev. Lett. 98, 085001 (2007).
‡ M. Grech *et al.*, Phys. Rev. Lett. 102, 155001 (2009).
^ V. V. Elisseev *et al.*, Phys. Plasmas 4, 4333(1997);
A. J. Schmitt & B. B. Afeyan, Phys. Plasmas 5, 503 (1998);
A. V. Maximov *et al.*, Phys. Plasmas 8, 1319 (2001).

Experiments were performed using the LPI platform at OMEGA to study beam spray in more detail



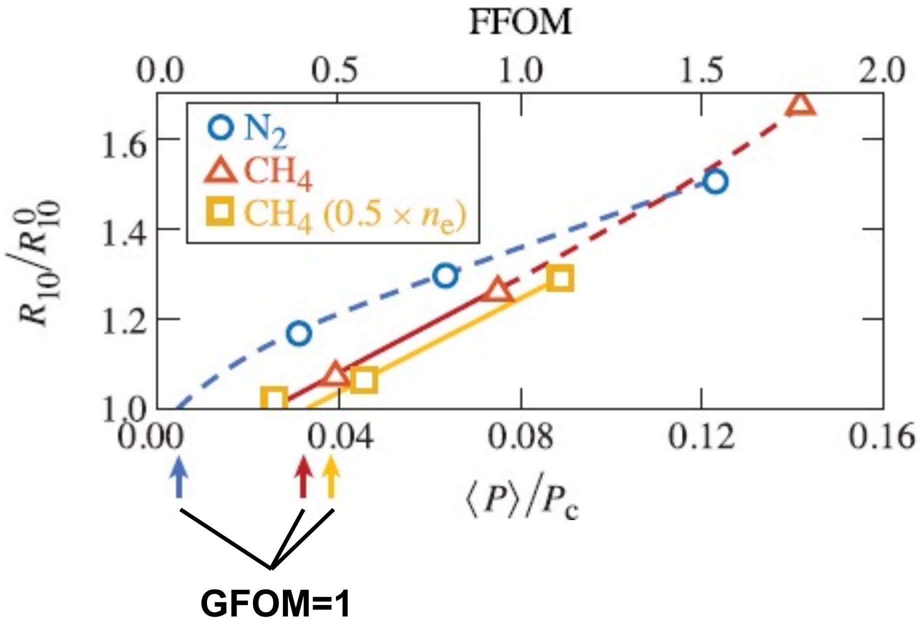
Ω#	Gas	$\langle I_{14} \rangle$	n_e (10^{20} cm^{-3})	T_e (keV)	Trans. (%)	SBS (%)	SRS (%)	Abs. (%)	Total (%)
101402	N_2	8.1	3.91	1.13	55.4	21.7	0.0	15.1	92.2
101403	N_2	17	3.98	1.23	40.1	37.2	0.0	12.9	90.2
101404	N_2	3.9	3.96	1.13	66.6	4.3	0.0	16.9	87.9
101406	CH_4	7.8	4.04	0.95	65.1	1.0	2.8	12.9	81.9
101407	CH_4	16	3.86	1.01	56.0	5.3	4.5	10.0	75.8
101408	CH_4	3.8	4.15	0.92	74.6	0.7	0.1	15.2	90.7
101413	CH_4	7.7	2.05	0.79	95.7	< 0.2	0.0	4.2	100.2
101414	CH_4	17	2.02	0.89	93.1	3.1	0.8	3.2	100.2
101415	CH_4	3.8	2.26	0.75	93.6	< 0.2	0.0	5.9	99.7

Beam spray was quantified by finding the radial location with signal nearest 10% of a central value from an average radial lineout



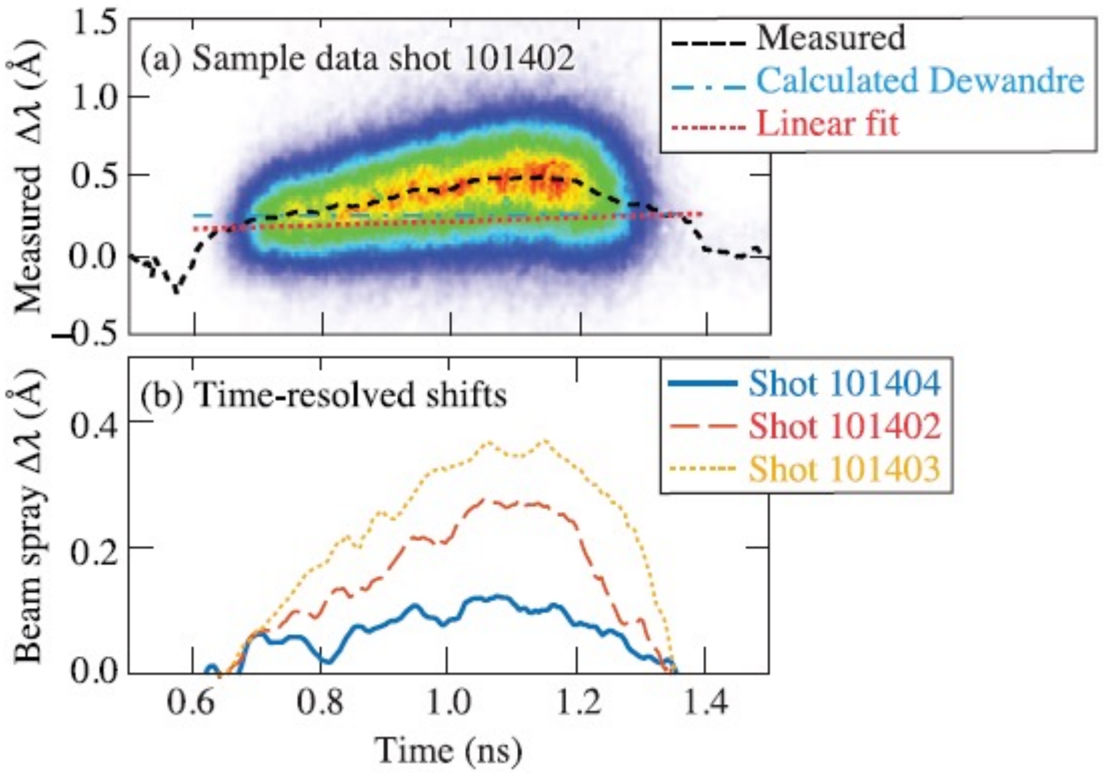
The data are consistent with thresholds predicted by the GFOM, which are ~2 to 15x lower than would be expected from the FFOM

- **Lower threshold in N_2 compared to CH_4, primarily due to weak ion-acoustic wave damping ($\frac{\nu}{\omega} = 0.02$) but also larger thermal enhancement factor ($\gamma_T = 3.1$)**
  - **Concavity suggests saturation from pump depletion**
- **Beam spray in CH turns on at higher intensity ($\frac{\nu}{\omega} \approx 0.1$)**
- **~10% difference between CH datasets is consistent with their thermal enhancement factors ($\gamma_T = 2.3$ versus 2.1)**



Transmitted-beam spectra were redshifted, confirming that FSBS is the dominant beam-spray mechanism

- Redshifts resulted from both the "Dewandre" shift* (dn/dt) and the classical FSBS shift
- Isolating the FSBS shift, the time-resolved data indicate that beam spray grows for ~100s of ps**
  - SBS expected to reach steady state in $\boldsymbol{\tau} \approx \frac{\mathbf{1}}{\nu_{IAW}}$, and $\nu_{IAW} \propto \boldsymbol{\omega_{IAW}} \approx \boldsymbol{kc_s}$, so large $\boldsymbol{\tau}$ implies small k (scattering angles <1°)
  - In turn, the total spray must result from multiple FSBS events †



* T. Dewandre *et al.*, Phys. Fluids 24, 528 (1981).
** A. V. Maximov *et al.*, Phys. Plasmas 8, 1319 (2001); M. Grech *et al.*, Phys. Rev. Lett. 102, 155001 (2009).
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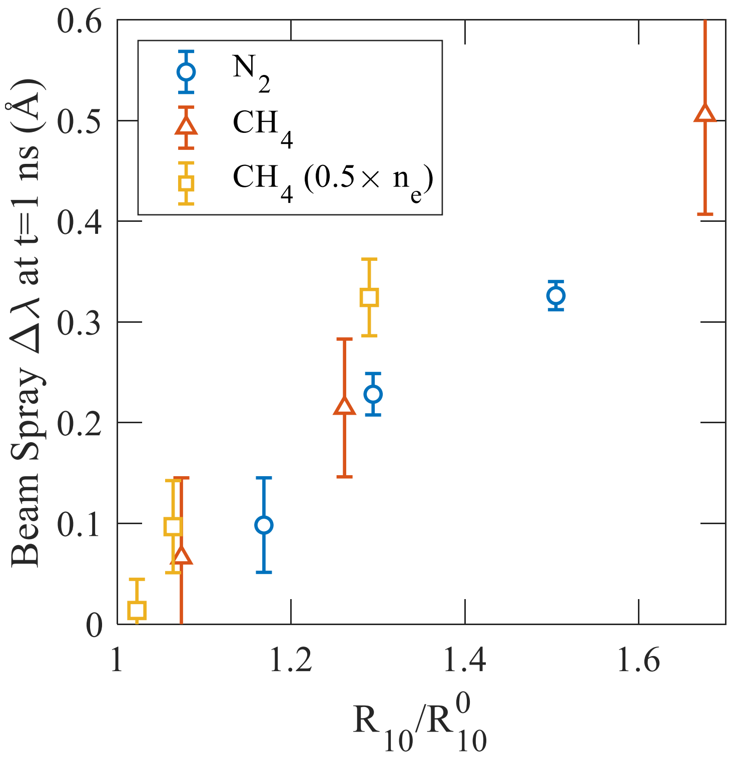
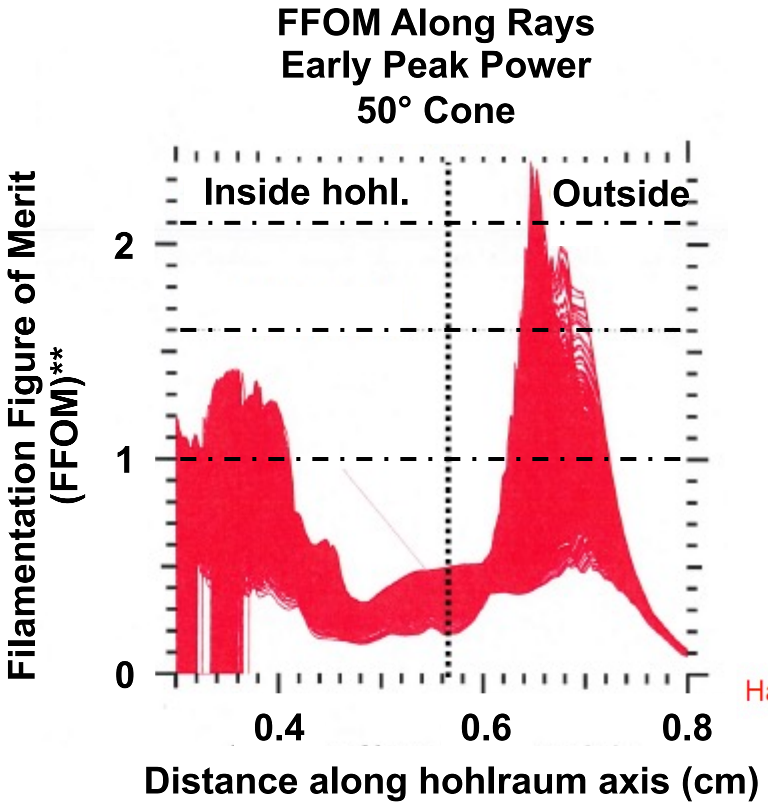
The FSBS frequency shifts scale with the amount of spray, as expected

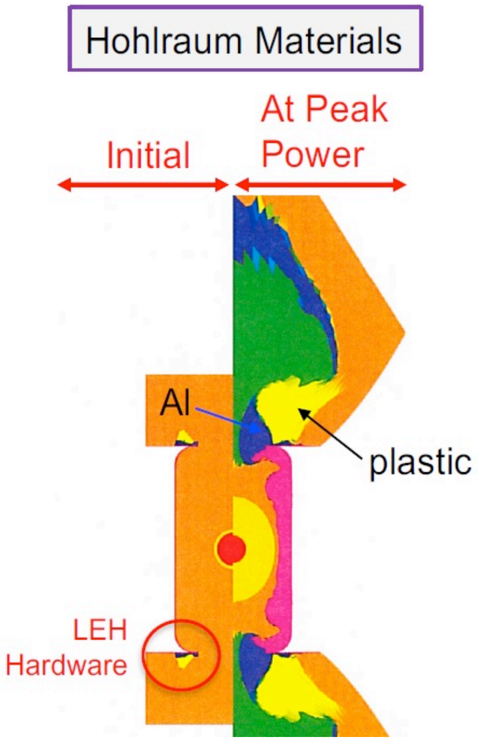
- As the amount of spray increased, so too did the FSBS frequency shifts, further confirming the mechanism
- Note there appears to be more to the story, with frequency shifts separately depending on composition and likely density at least
  - Data too sparse to identify all dependent variables affecting $\Delta\lambda$



Returning to the motivation*, beam spray could affect propagation, but the frequency shifts may be most concerning in terms of impacting symmetry

- **For high-Z, the beam spray threshold *is* very low; however, spray is not explosive around FFOM~1**
- **However, the frequency shifts are substantial (~0.5 Å at 3ω, or ~1.5 Å at 1ω), and modern hohlraums are very sensitive to wavelength detuning (~20 to 50 μm-P2/Å at 1ω)****
  - **Loss of symmetry control due to interplay with crossed-beam energy transfer may be greatest risk**





* Hinkel, MacLaren, Rosen *et al.*, Hohlraum Physics Working Group, 2020 ICF Workshop.
** A. L. Kritcher *et al.*, Phys. Rev. E 98, 053206 (2018);
L. A. Pickworth *et al.*, Phys. Plasmas 27, 102702 (2020);
A. L. Kritcher *et al.*, Phys. Plasmas 28, 072706 (2021);
A. B. Zylstra *et al.*, Phys. Rev. Lett. 126, 025001 (2021);
J. S. Ross *et al.*, arXiv:2111.04640 (2021).

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