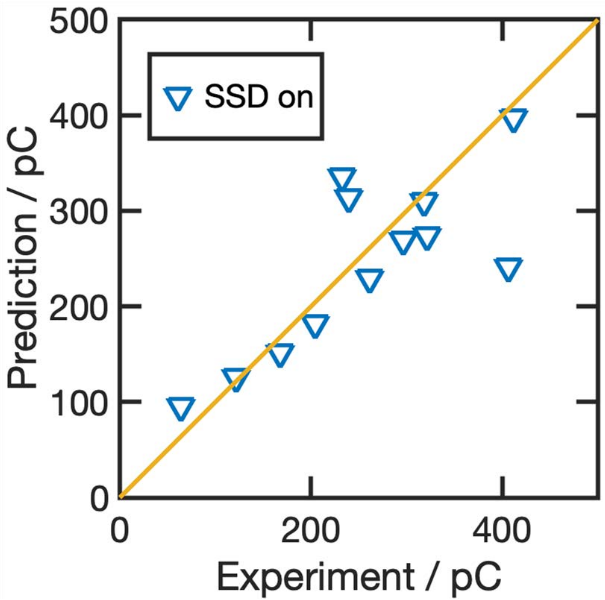
Predicting Hot Electron Generation in Inertial Confinement Fusion with Particle-in-Cell Simulations

Predicted charge of hot electrons



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Collaborators

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Hot electron generation in direct drive can be predicted by PIC simulations

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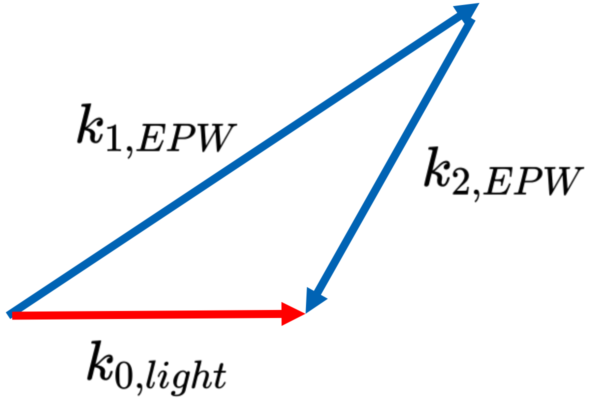
2. Using this scaling and conditions from LILAC simulations, whole-pulse hot electron generation can be predicted

3. After taking laser smoothing effects into account, the predicted hard X-ray signals agreed with Omega warm target experiments, showing the promise of this approach

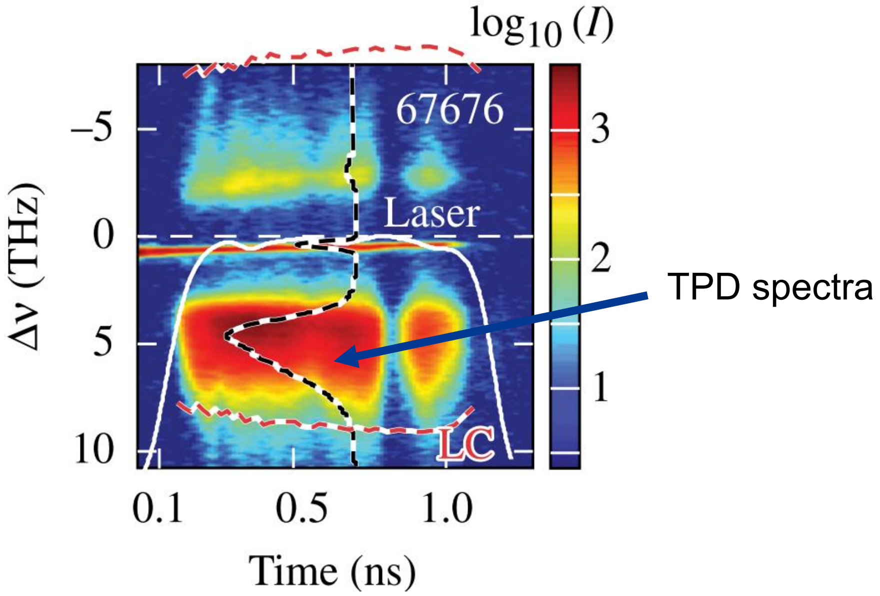
Laser plasma instabilities in the OMEGA experiments were shown to be dominated by Two-Plasmon Decay (TPD) [1]

Mode structure of TPD



$$\eta \equiv \frac{L_{\mu m} I_{14}}{233 T_{e,keV}}$$ [1]

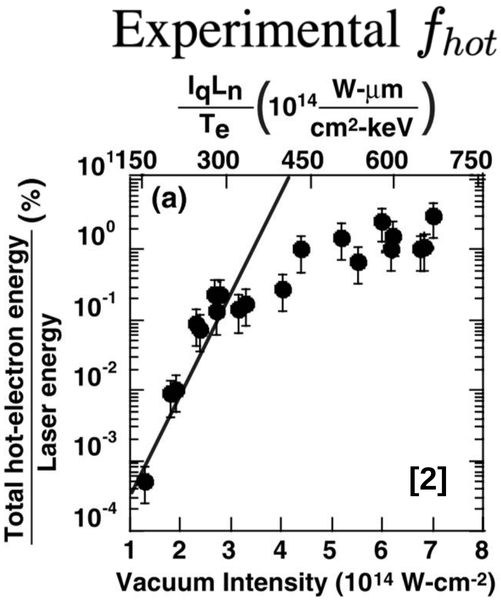
Time-resolved ω/2 spectra [2]



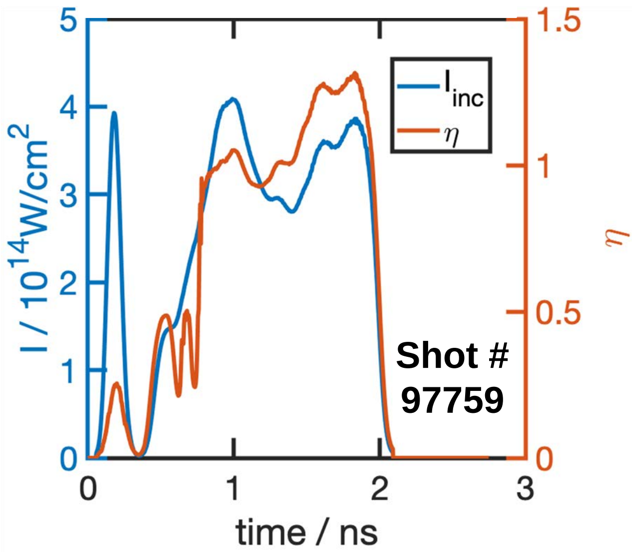
A predictive hot-electron capability is required for direct ICF design

[1] Simon, A., et al. "On the inhomogeneous two-plasmon instability." *The Physics of fluids* 26.10 (1983): 3107-3118.
[2] Seka, W., et al. "Nonuniformly driven two-plasmon-decay instability in direct-drive implosions." *Physical review letters* 112.14 (2014): 145001.

Previous efforts for hot electron scaling focused on dependency of η [1-3]



Plasma conditions from LILAC [4]



η changes in the whole pulse

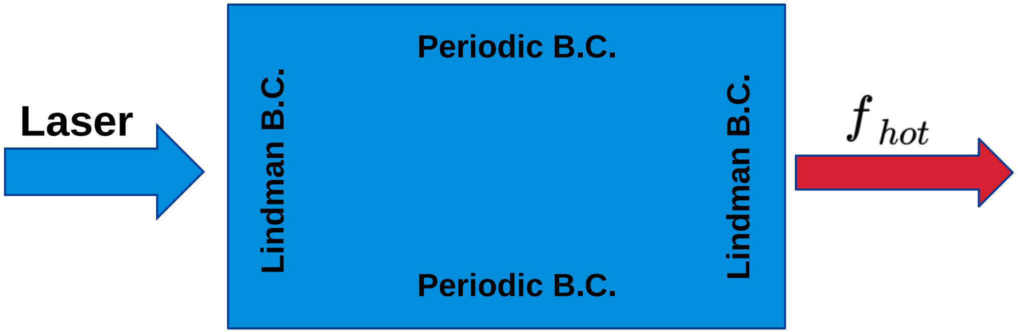
[1] Stoeckl, C., et al. "Multibeam effects on fast-electron generation from two-plasmon-decay instability." *Physical review letters* 90.23 (2003): 235002.
[2] Froula, D. H., et al. "Saturation of the two-plasmon decay instability in long-scale-length plasmas relevant to direct-drive inertial confinement fusion." *Physical review letters* 108.16 (2012): 165003.
[3] Turnbull, David, et al. "Impact of spatiotemporal smoothing on the two-plasmon–decay instability." *Physics of Plasmas* 27.10 (2020): 102710.
[4] Delettrez, J., et al. "Effect of laser illumination nonuniformity on the analysis of time-resolved x-ray measurements in uv spherical transport experiments." *Physical Review A* 36.8 (1987): 3926.

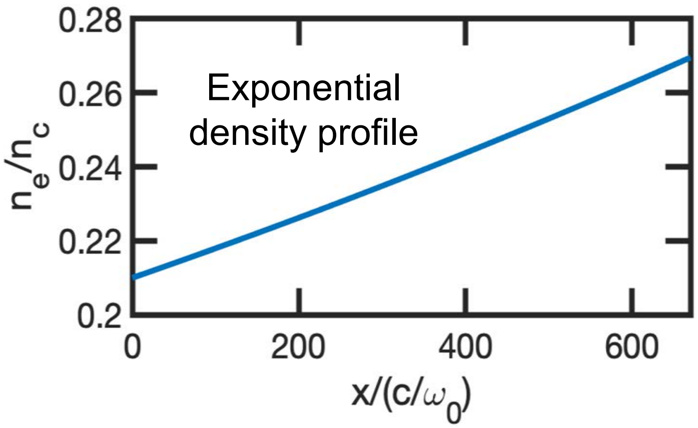
We used 2D OSIRIS simulations* to study hot electron scaling

59 simulations to scan laser plasma conditions

$$100 < L_{\mu m} < 200$$
$$1.5 < T_{e,keV} < 4.0$$
$$1.5 < T_{i,keV} < 3.5$$
$$4 \times 10^{14} < I_{W/cm^2} < 10^{15}$$

Each simulation represents one speckle in a realistic laser beam

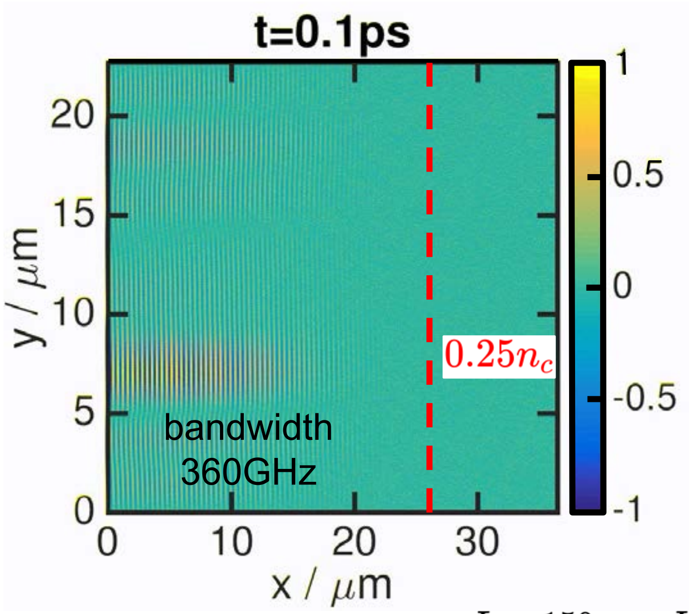




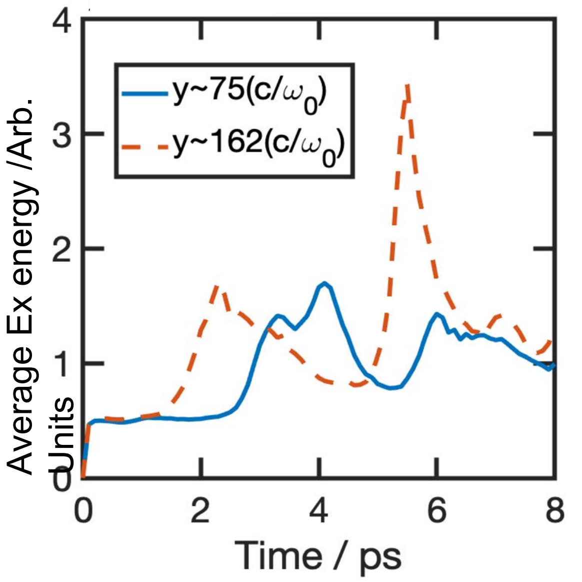
* Fonseca, Ricardo A., et al. "OSIRIS: A three-dimensional, fully relativistic particle in cell code for modeling plasma based accelerators." *International Conference on Computational Science*. Springer, Berlin, Heidelberg, 2002.

Smoothing by spectral dispersion (SSD) [1] induces intermittent speckles on a time scale of 3 ps

Laser Ey with SSD



Average Ex energy



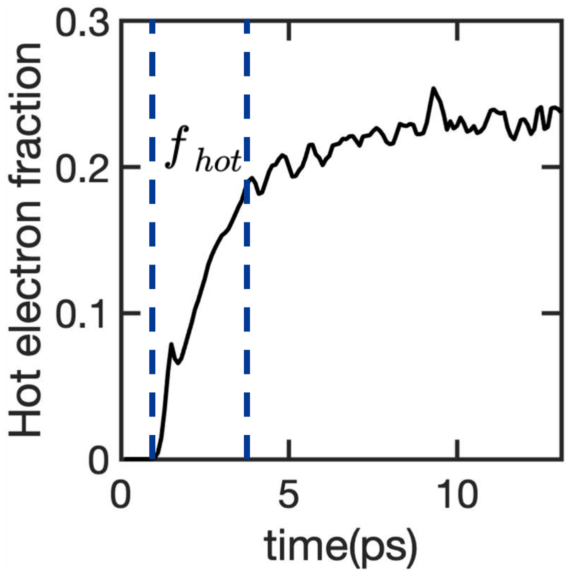
$$L = 150\mu m,\ I = 2.0 \times 10^{14} W/cm^2$$

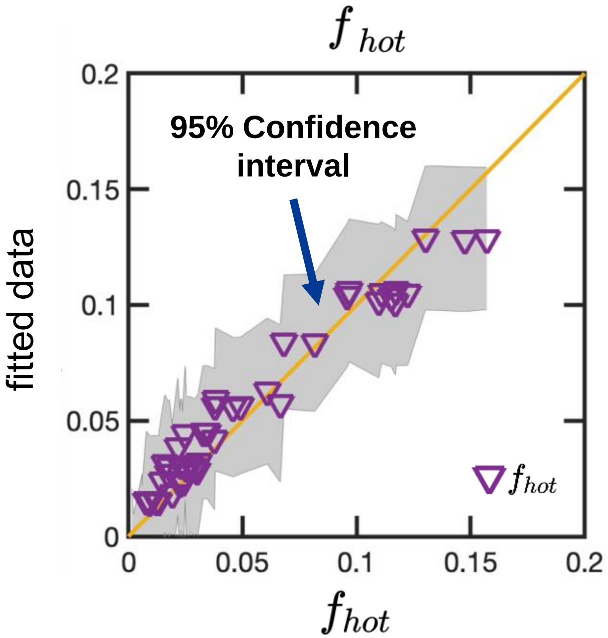
$$T_e = 2.5keV,\ T_i = 1.5keV$$

[1] Skupsky, S., et al. "Improved laser-beam uniformity using the angular dispersion of frequency-modulated light." *Journal of Applied Physics* 66.8 (1989): 3456-3462.

The obtained scaling law depends on η as well as Te

Time history of fhot

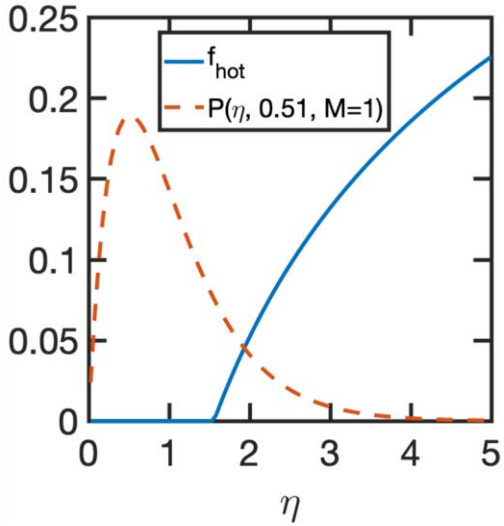




$$f_{hot} \sim \{1.9 - 0.64L^{0.19}T_e^{-0.09}(\frac{T_i}{T_e})^{0.08}\eta^{-0.16} - 2.0L^{-0.25}T_e^{-0.18}(\frac{T_i}{T_e})^{-0.23}\eta^{0.002}\}$$

Laser smoothing effects need to be considered

Speckle intensity distribution* and hot electron fraction



$$P[\eta, \bar{\eta}, M] = \eta^M exp[-M\eta/\bar{\eta}]$$

$$L = 150\mu m,\ I = 2.0 \times 10^{14} W/cm^2$$

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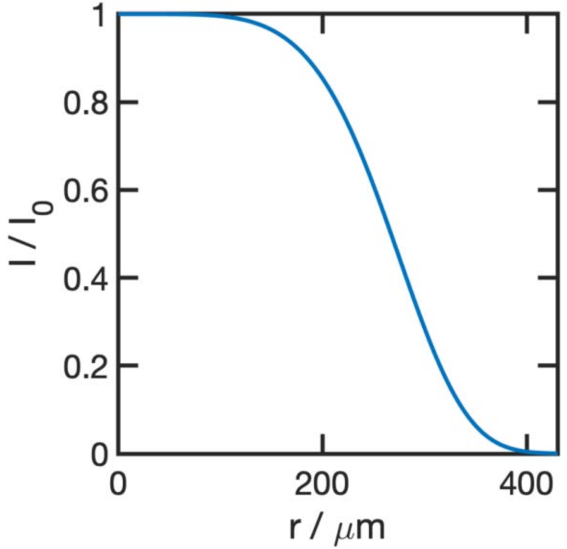
Far field intensity distributions of beams from R75 phase plate**



$$I(r) = I_0 exp[-(\frac{r}{287})^{5.11}]$$

$$\bar{f}_{hot} = \frac{\int_0^\infty f_{hot} * P d\eta}{\int_0^\infty P d\eta}$$

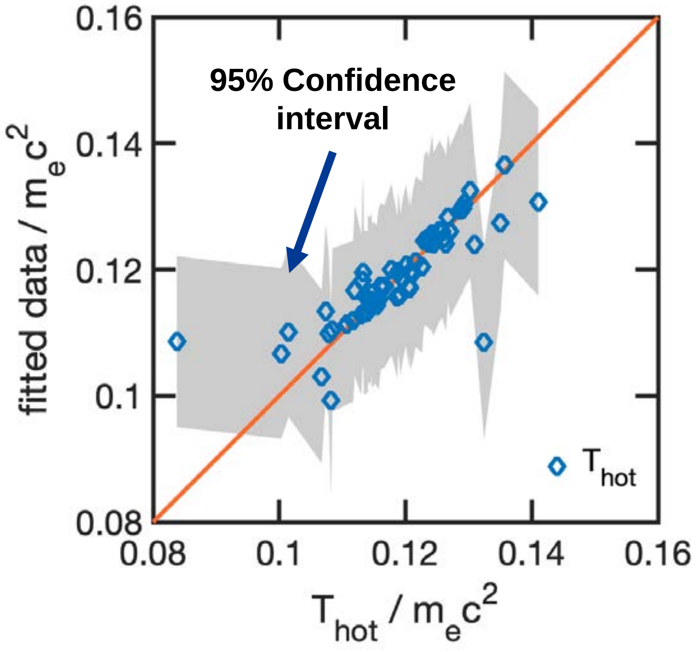
$$F_{hot} = \frac{\int_0^\infty \bar{f}_{hot} * 2\pi r I dr}{\int_0^\infty 2\pi r I dr}$$

*Dainty, J. Christopher, ed. *Laser speckle and related phenomena*. Vol. 9. Springer science & business Media, 2013.

**http://prism-cs.com/Manuals/VisRad/power_sources/phase_plate_params.html

HXRD2 can be predicted by Thot

Hot electron temperature scaling



$$E_{hot} = F_{hot} * I_0 * 4\pi r^2_{LILAC}$$

$$E_{hot} = HXRD2 \,/(-1.12 + 0.066T_{hot} + 0.0097T^2_{hot})$$

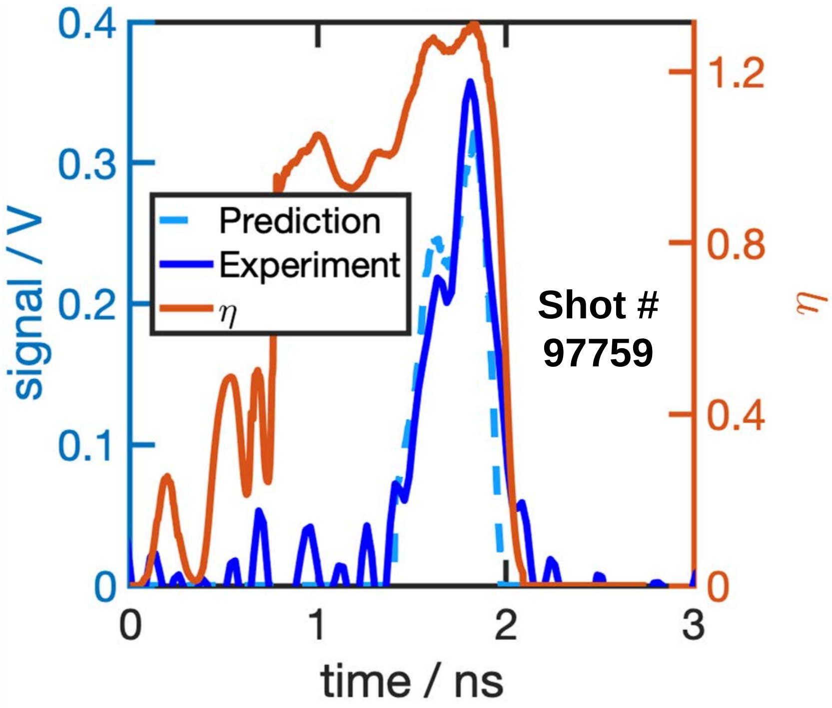
[1-2]

$$T_{hot} \sim \{0.0966 + 481L^{-0.804}Te^{0.115}(\frac{T_i}{T_e})^{0.0712}\eta^{0.674} + 64.9L^{-0.120}Te^{0.281}(\frac{T_i}{T_e})^{-0.0196}\eta^{-0.00866}\}$$

[1] Turnbull, David, et al. "Impact of spatiotemporal smoothing on the two-plasmon–decay instability." *Physics of Plasmas* 27.10 (2020): 102710.
[2] Christopherson, Alison. *Effects of Charged Particle Heating on the Hydrodynamics of Intertially Confined Plasmas*. University of Rochester, 2020.

The predicted hard X-ray signals were found to agree with Omega warm target shots

Predicted HXRD2 signal



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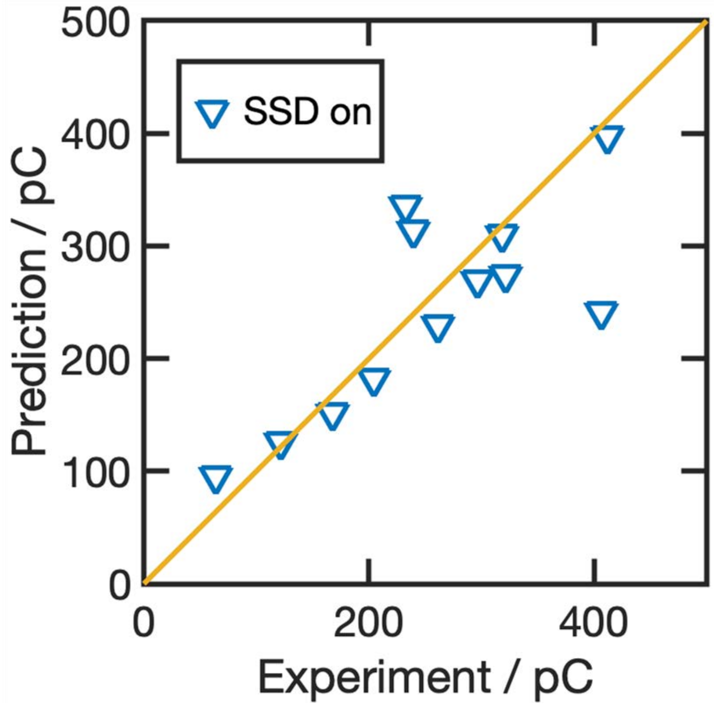

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