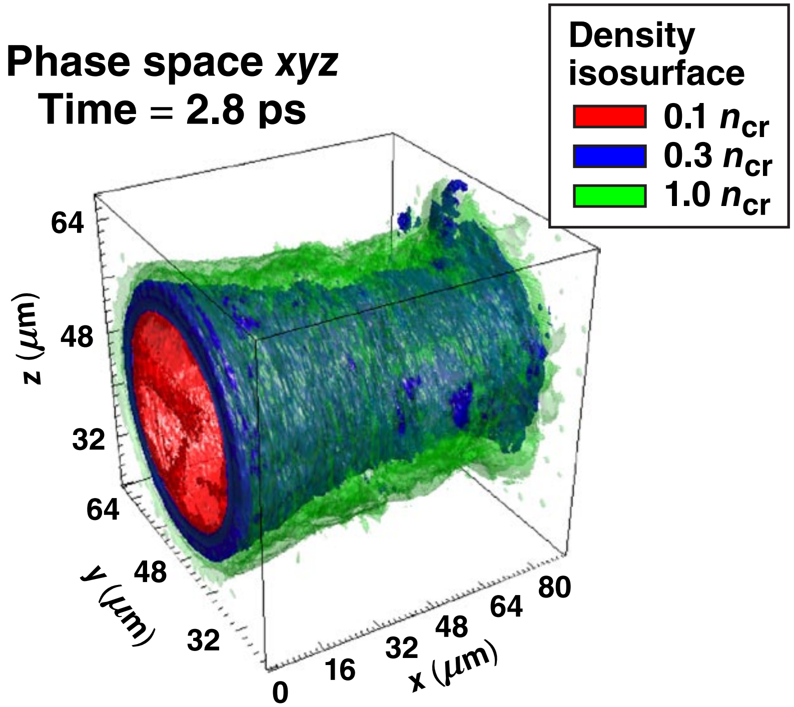
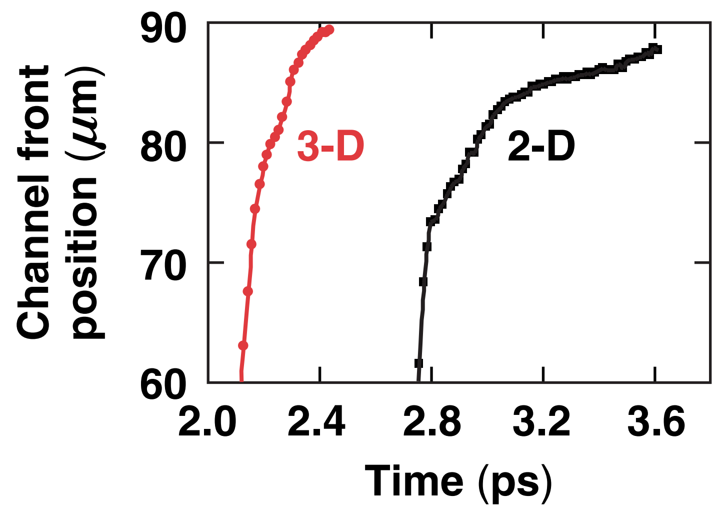
Three-Dimensional Effects in Laser Channeling in Fast-Ignition Targets





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Summary

A clean channel can be established by a high-intensity laser in the underdense plasma of fast-ignition targets

UR LLE

- Channel advancing in 3-D PIC simulations is faster than in 2-D.
- The difference of channel advancing in 2-D and 3-D is due to the difference in laser self-focusing and ponderomotive force.
- Electrons are heated to relativistic temperatures, which reduces laser-plasma coupling in the channel.
- A low-density channel significantly improves the transmission of the ignition pulse for fast ignition.

Collaborators

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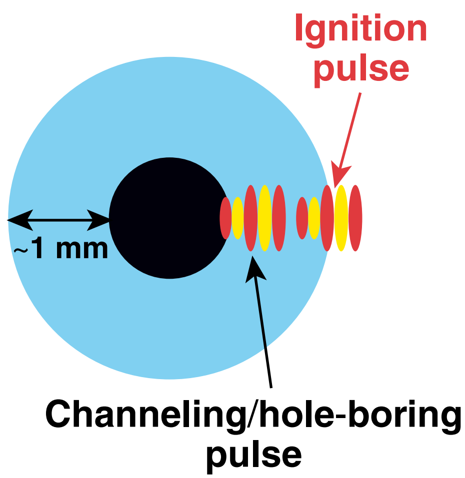
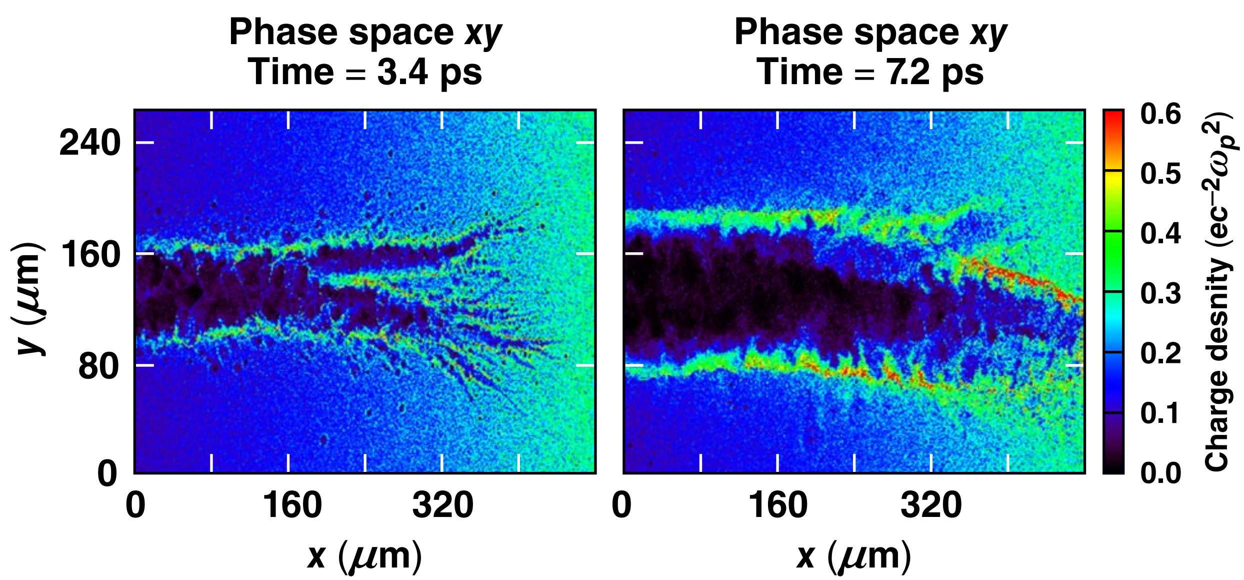
Simulations were carried out at NERSC
through a DOE INCITE grant.

Laser channeling in millimeter-scale plasmas is a highly nonlinear and dynamic process

- Full-scale 2-D slab-simulation parameters*
  - box size: 1 mm × 0.25 mm
  - grids number: 10460 × 2614
  - particles number: 5.6×10^7
  - simulation time: 20 ps
  - $n = 0.1 \sim 1.0\, n_{cr}$
- The simulations show many nonlinear phenomena
  - plasma piling up
  - laser hosing/refraction leads to channel bending
  - channel bifurcation/self-correction
- Important 3-D effects must be studied





TC8318

*G. Li *et al*., Phys. Rev. Lett. 100, 125002 (2008).

A low-density channel is established in 3-D PIC simulations

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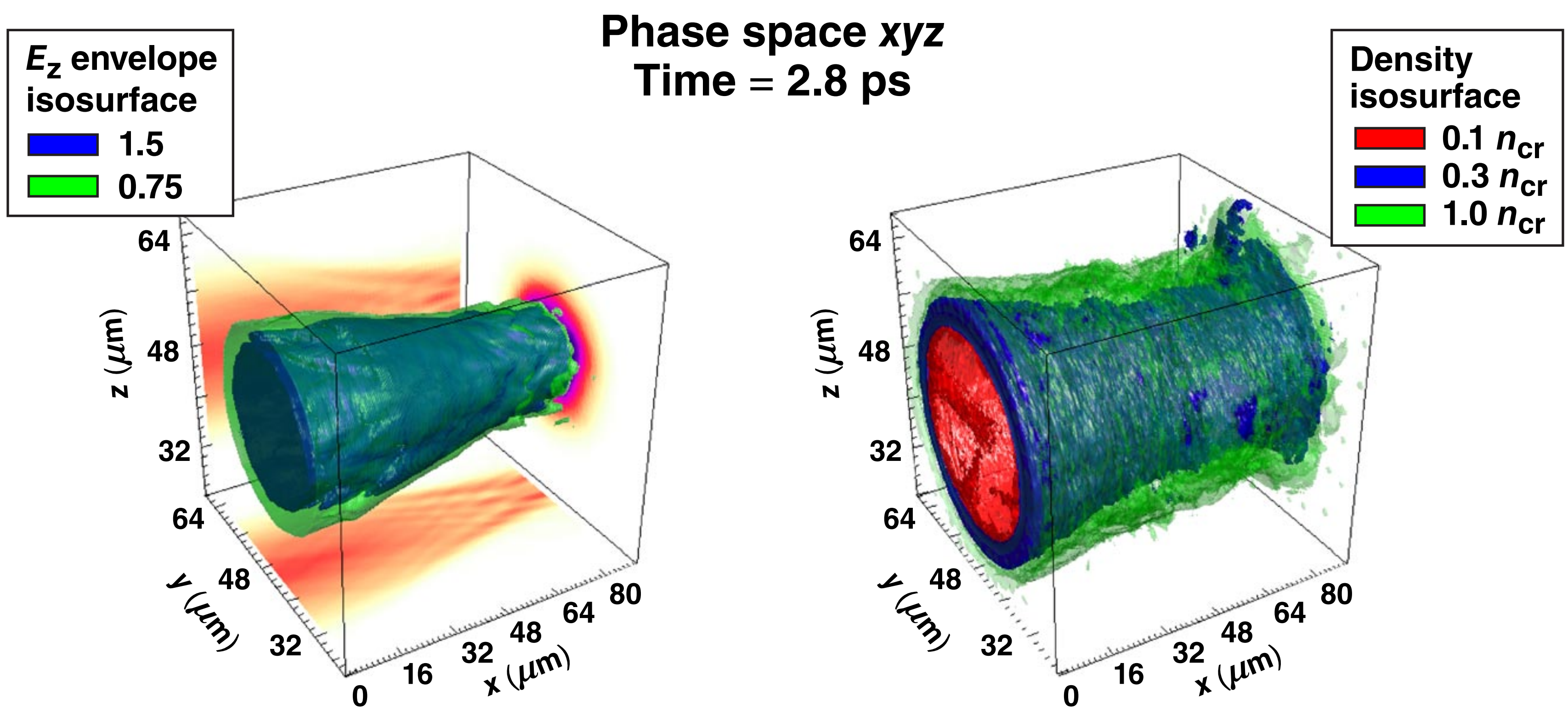
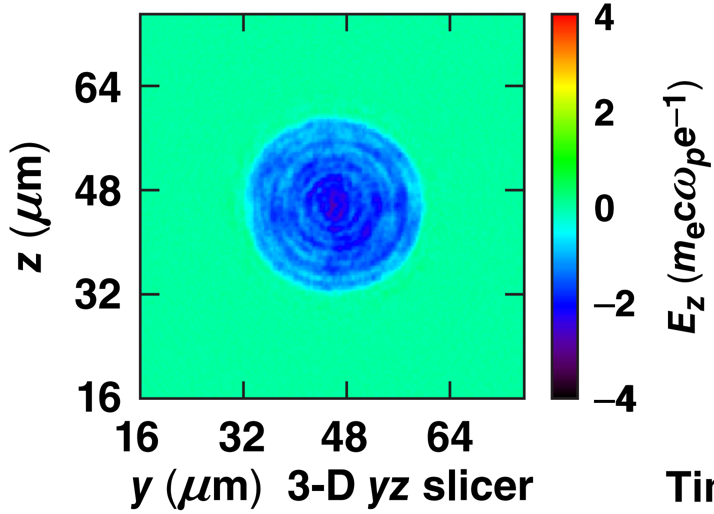


- 3-D PIC simulation parameters
  - box size: 90 × 90 × 90 μm
  - total particles number: 3.0×10^9
  - $I = 10^{19}$ W/cm^2, $n = 0.5 \sim 0.6\ n_{cr}$
  - grids number: 1728 × 916 × 916
  - simulation time: 2.8 ps

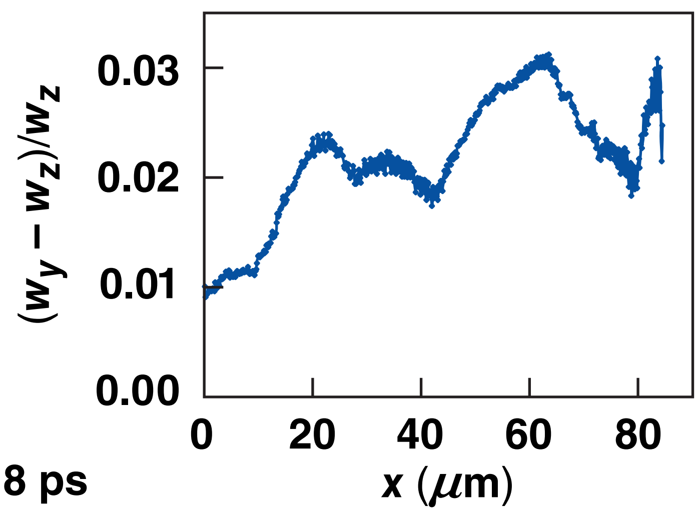
TC8319

The pulse and the channel are nearly symmetric in the transverse directions

- The 3-D pulse is nearly symmetric in the transverse directions.

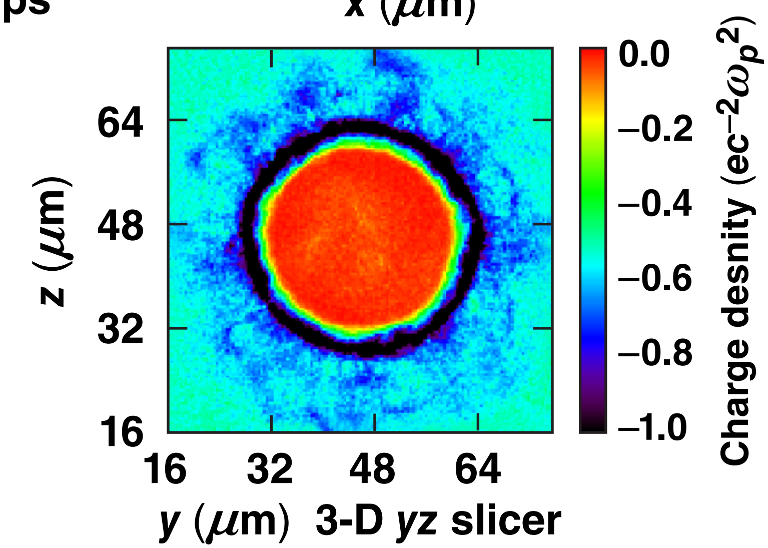


Time = 2.8 ps



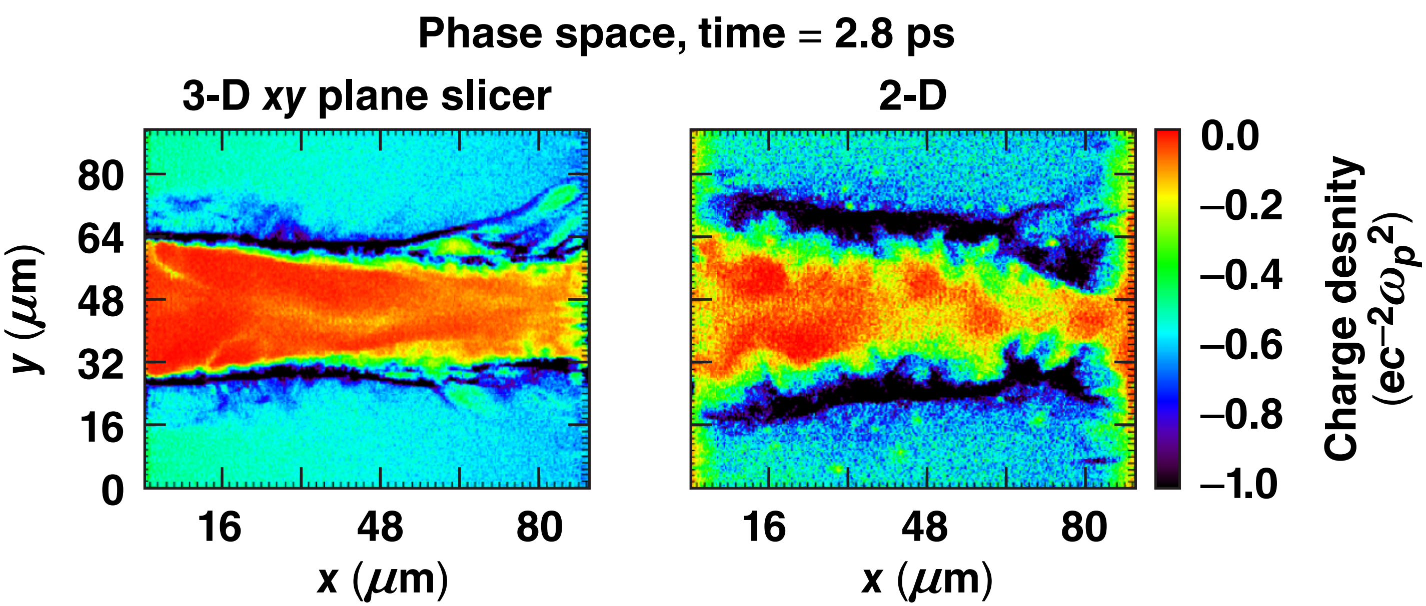
- The 3-D channel is nearly round.

- It is reasonable to assume cylindrical symmetry in 3-D.

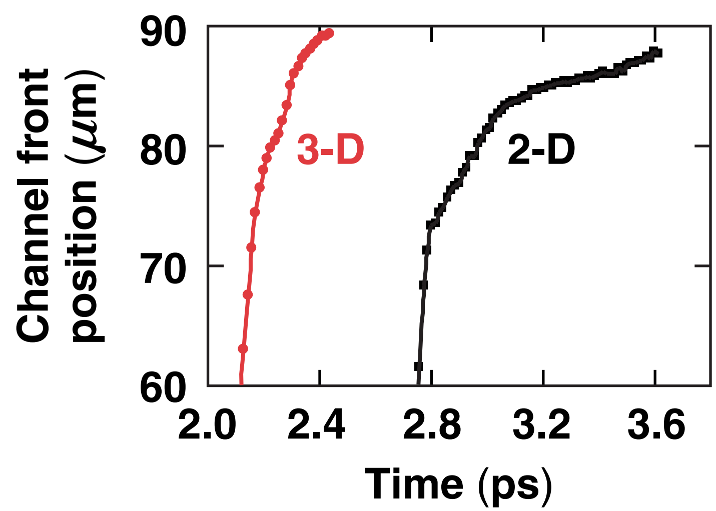


TC8320

A low-density channel is established faster in 3-D than in 2-D



- The channel in 3-D has a more regular shape.
- The average residual density in 3-D is smaller.

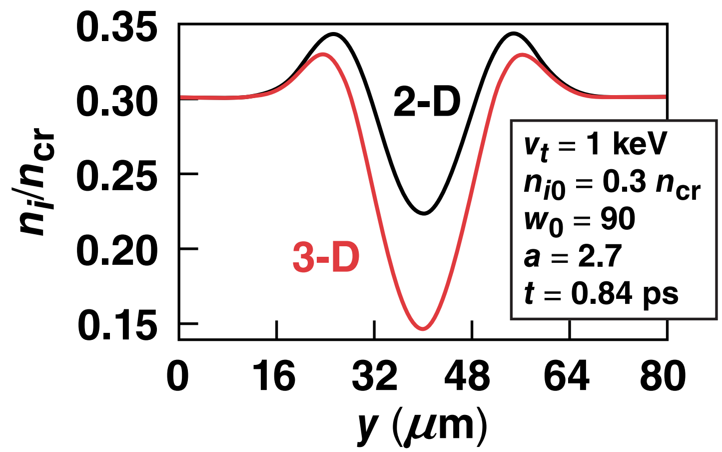


TC8321

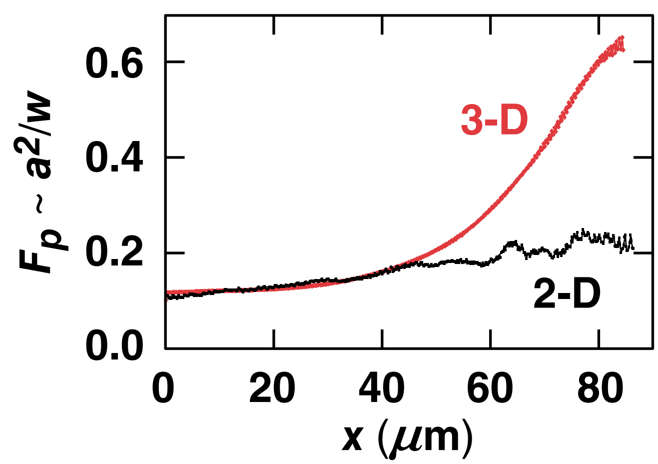
The stronger 3-D ponderomotive force allows the channel to form faster

- For the same laser ponderomotive force $F_p \sim a^2/w$, the channel is deeper in 3-D than in 2-D

$$\left(\frac{\partial^2}{\partial t^2} - c_s^2 \nabla_\perp^2\right)\frac{\delta n_i}{n_{i0}} = c^2 \frac{Zm_e}{m_i}\nabla_\perp^2 \left(1 + a^2/2\right)^{1/2}$$



- F_p is larger in 3-D than in 2-D due to self-focusing
  - 3-D: w^2a^2 = const
  - 2-D: wa^2 = const
  - $F_{p3\text{-D}}/F_{p2\text{-D}} = w_0/w_f > 1$ (if $w_{f2\text{-D}} = w_{f3\text{-D}}$)



TC8322

Relativistic T_e suppresses self-focusing and other nonlinear interactions

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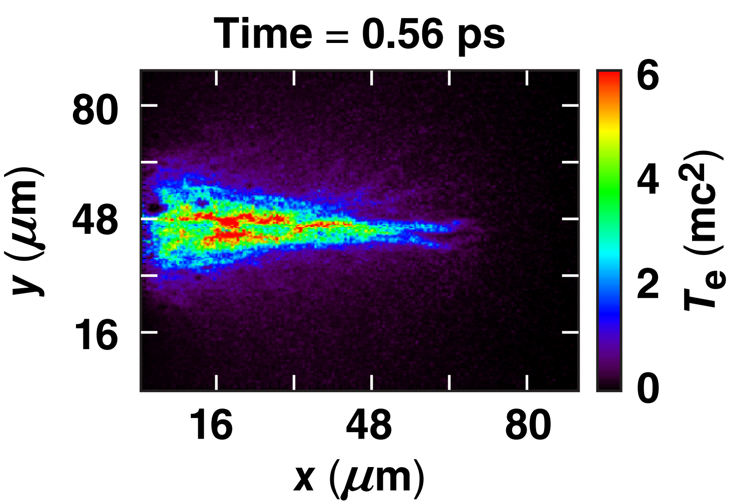
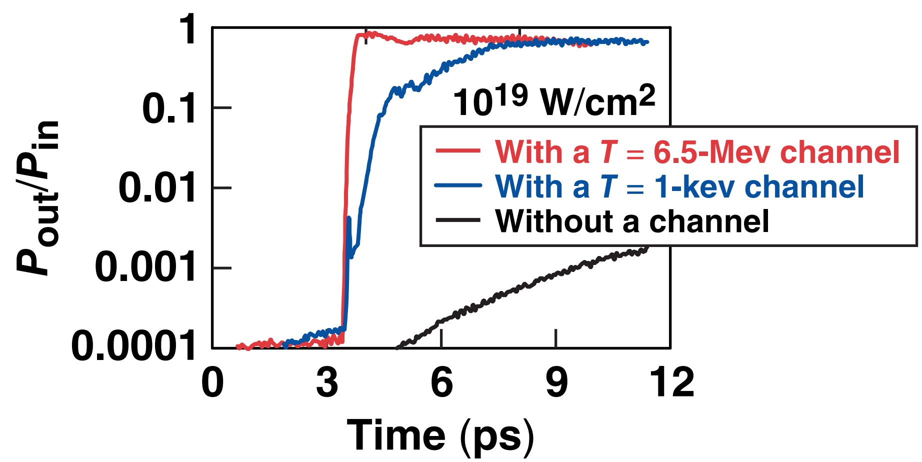
- PIC simulations show the residual electrons are quickly heated to relativistic T_e
- When T_e is relativistic, the quiver velocity v_z is reduced*

$$v_z = \frac{a/\gamma}{\left(1 + 5\,p_{th}^2\right)^{1/2}}$$

- The ponderomotive force is decreased by 14× times for $p_{th} = 6$, leading to the laser-plasma decoupling
  - w_f decreases by a factor of 2 in both 2-D and 3-D
- Decoupling at relativistic temperature increases the laser transmission





TC8323

*K. C. Tzeng *et al.*, Phys. Rev. Lett. 81, 104 (1998).

Summary/Conclusions

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