Simulations of Laser-Driven Magnetized Liner Inertial Fusion

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*Webster Schroeder High School and Summer High School Research Program

Summary

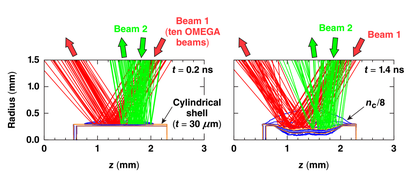
A variety of magnetized liner inertial fusion (MagLIF) experiments have been modeled

- OMEGA experiments without a preheat beam
  - the shape and speed of the imploding cylinder agrees with observations
- Sandia's Z machine experiments
  - qualitative agreement is found between simulations and experiments for various parameter variations
- Future Z-scale experiments with high-density gas and 3ω preheat beam
  - a whole-beam self-focusing channel helps to provide uniform heating
- OMEGA experiments with a preheat beam
  - a D_2 temperature of ~400 eV is predicted

TC13356

OMEGA Experiments Without a Preheat Beam

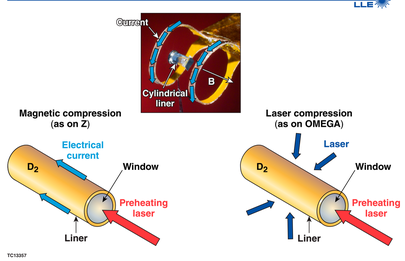
A compression-only MagLIF shot (79495) on OMEGA was modeled



- This shot used a 1.5-ns flat pulse

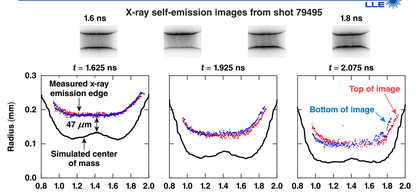
Run 1134
TC13359

Full MagLIF experiments on OMEGA include a magnetic field generated by coils



TC13357

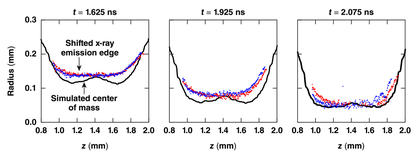
Experimental x-ray self-emission images have been compared with predictions of the shell center of mass



- Based on *Spect3D* post-processing of a *SAGE* run, the inner edge of the x-ray emission is expected to be ~47 μm from the center of mass

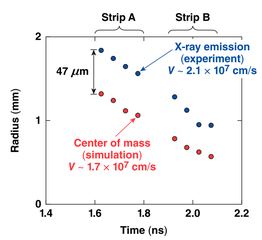
Run 1134
TC13360

When adjusted for the 47-μm separation, the experimental and simulated profiles agree closely



Run 1134
TC13361

The experimental shell implosion velocity agrees with the simulated velocity



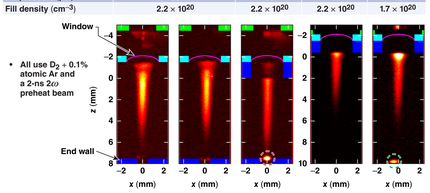
TC13362

Z-Machine Experiments

Z-machine x-ray emission images showed heating distributions for various parameters*

Shot	H39 (Reference)	H40	H41	H42	H43
Energy (kJ)	2		4	2	2
Phase-plate diameter (mm)	0.75		0.75	1.1	1.1
Fill pressure (psi)	60		60	60	45
Fill density (cm^{-3})	2.2×10^{20}		2.2×10^{20}	2.2×10^{20}	1.7×10^{20}

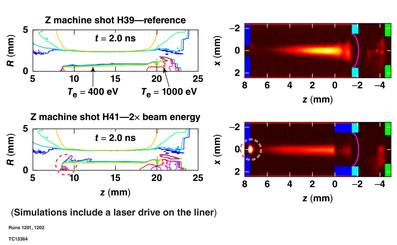
- All use D_2 + 0.1% atomic Ar and a 2-ns 2ω preheat beam



*A. Harvey-Thompson (Sandia National Laboratories).

TC13363

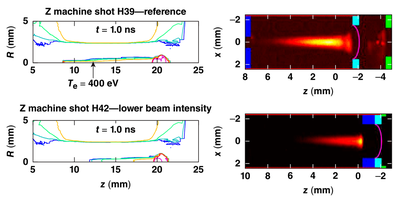
When the beam energy is doubled, the heating penetrates to the end wall and creates a hot spot



(Simulations include a laser drive on the liner)

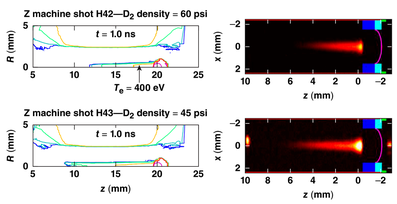
Runs 1201, 1202
TC13364

When the beam diameter increases, the x-ray emission is lower and the penetration is less



Runs 1201, 1203
TC13365

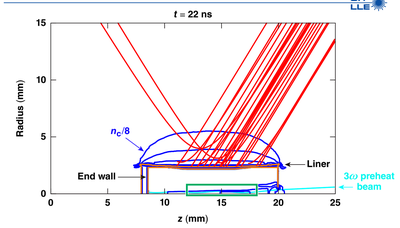
When the gas density is lowered, the heating beam penetrates farther



Runs 1203, 1204
TC13366

Future Z-Scale Experiments

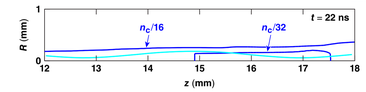
Z-scale simulations with higher-density D_2 have been performed using laser drive rather than magnetic drive



- The laser energies and pointing were optimized to give a uniform implosion with the desired speed (implosion at 80 ns)

Run 1139
TC13367

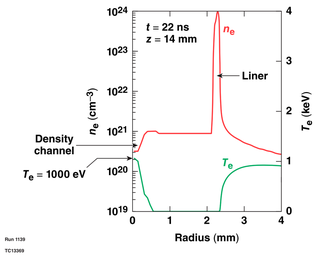
A whole-beam self-focusing density channel is created by the expansion of laser-heated deuterium away from the axis



- When a ray encounters the high density at the edge of the channel, it is refracted back toward the axis.

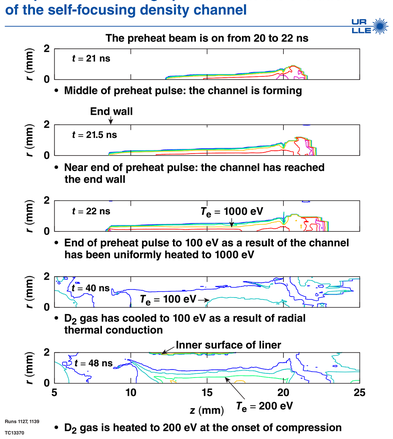
Run 1139
TC13368

A 1-D lineout in the radial direction shows a hot region confined to the density channel



Run 1139
TC13369

Temperature contour graphs illustrate the evolution of the self-focusing density channel

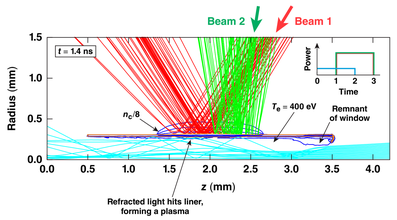


- Middle of preheat pulse: the channel is forming
- Near end of preheat pulse: the channel has reached the end wall
- End of preheat pulse to 100 eV as a result of the channel has been uniformly heated to 1000 eV
- D_2 gas has cooled to 100 eV as a result of radial thermal conduction
- D_2 gas is heated to 200 eV at the onset of compression

Runs 1122, 1139
TC13370

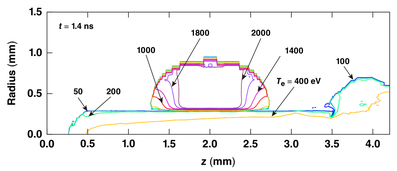
OMEGA Experiments With a Preheat Beam

SAGE has been used to model shots with the preheating beam



Run 1100
TC13371

The D_2 gas is heated to ~400 eV



Run 1100
TC13372

Abstract

In magnetized liner inertial fusion (MagLIF), a high electric current is run through a cylindrical metal shell (or liner) containing deuterium fuel, forming a strong magnetic field that causes the cylinder to implode. A preheating laser beam is fired down the axis of the cylinder to heat the deuterium so that when the cylinder implodes, compressing the deuterium, the deuterium is able to reach the high temperatures needed for fusion. Simulations using the hydrodynamics code *SAGE* were conducted to help understand the physics of MagLIF. Simulations of laser-driven MagLIF experiments on OMEGA without the preheating beam have demonstrated agreement with experimental data for the implosion of the cylinder. Simulations of preheat-only experiments with large-scale targets on the Sandia Z machine using a 0.5-μm laser beam are consistent with the experimental observations in four shots, a reference shot and three variations. Simulations of a Z-scale target with a higher deuterium density and a 0.35-μm laser beam, as may be desired for future experiments, show that near-uniform heating along the axis is achieved through the formation of a whole-beam self-focusing density channel.

TC13358

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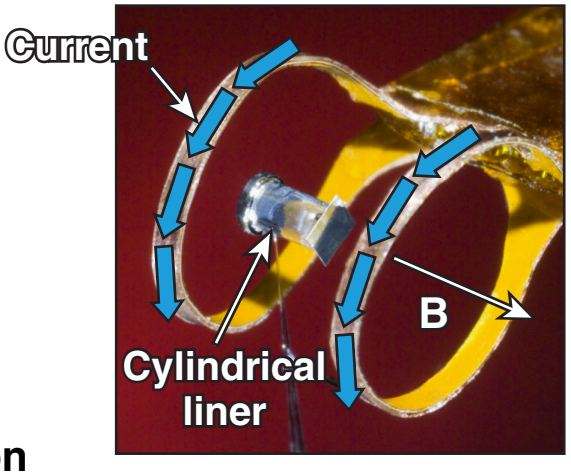
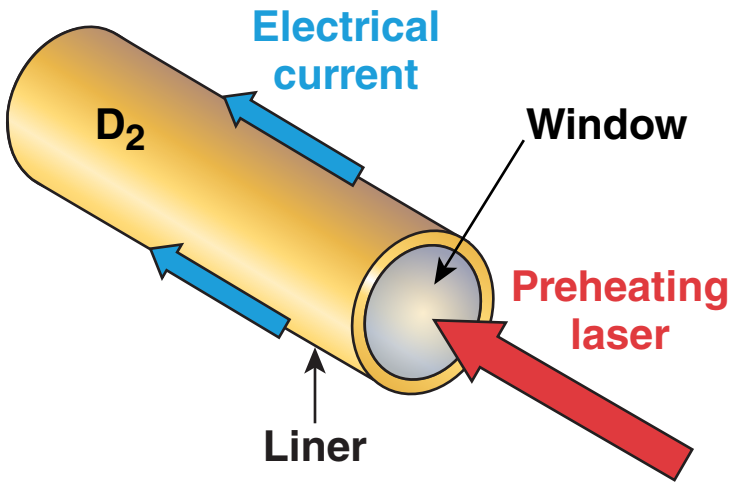
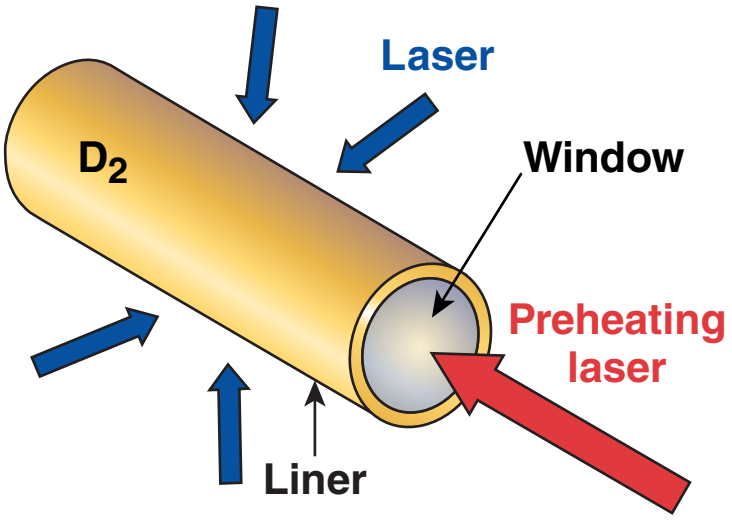


Magnetic compression (as on Z)



Laser compression (as on OMEGA)



TC13357

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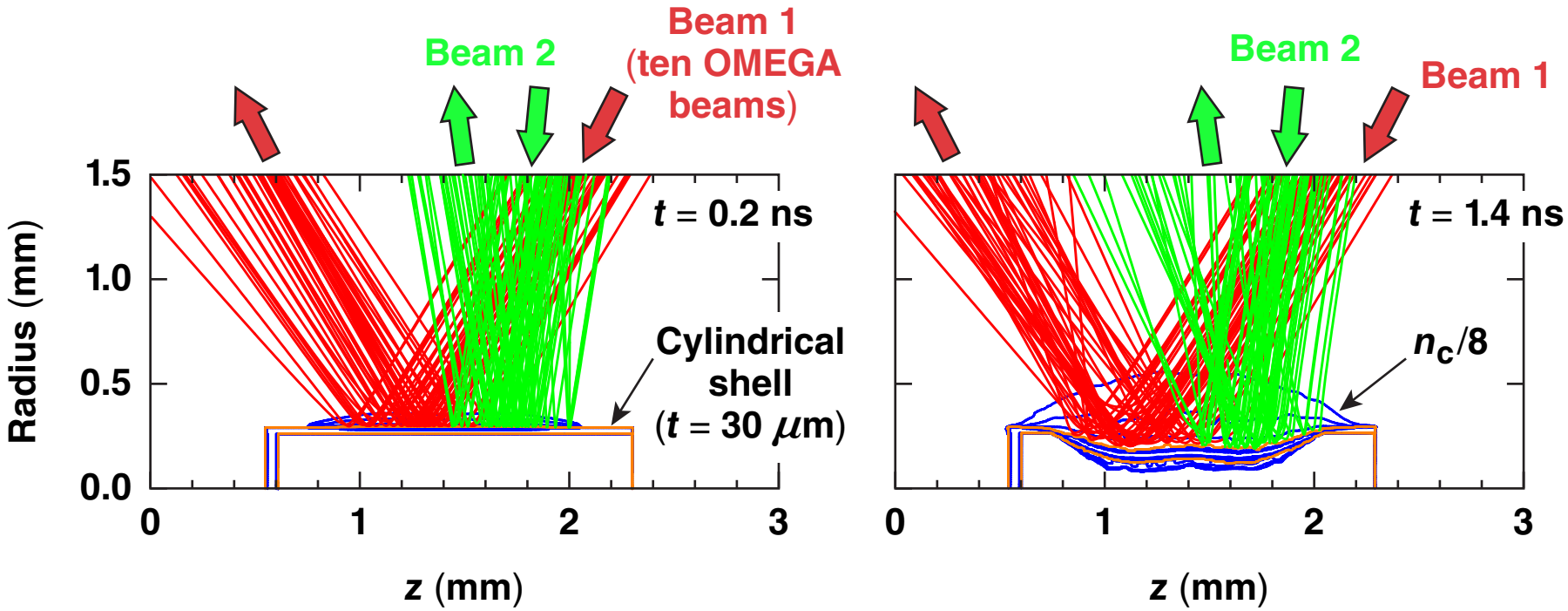

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Run 1134

TC13359

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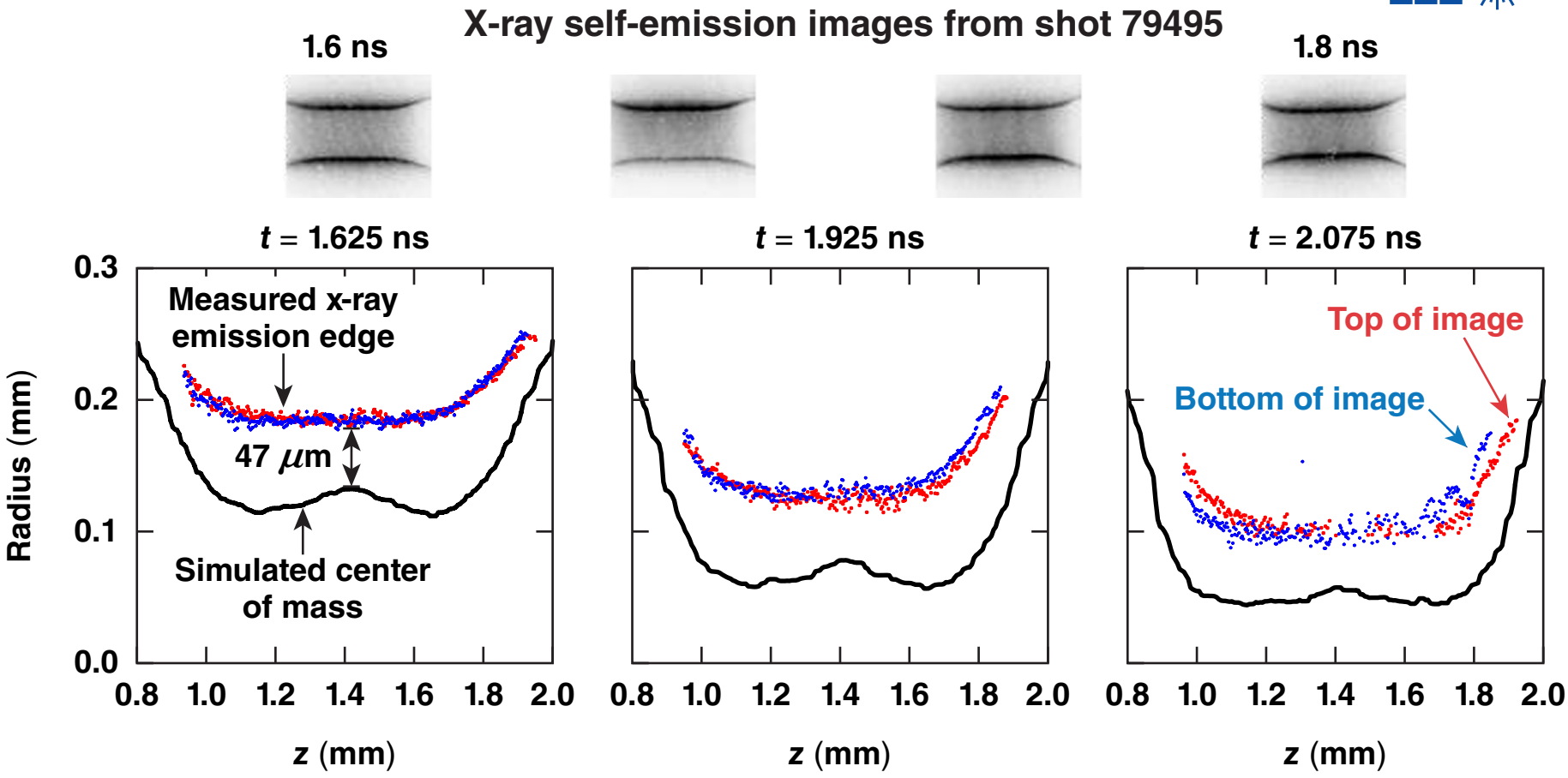

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TC13360

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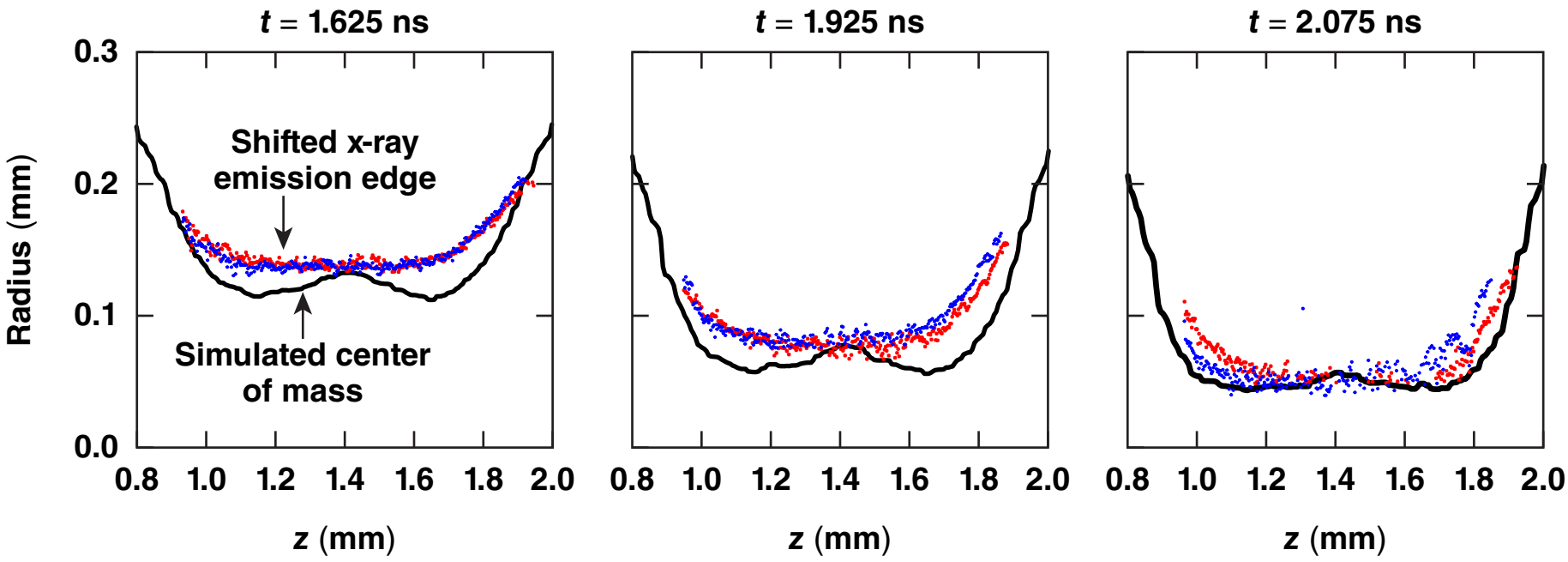

Run 1134

TC13361

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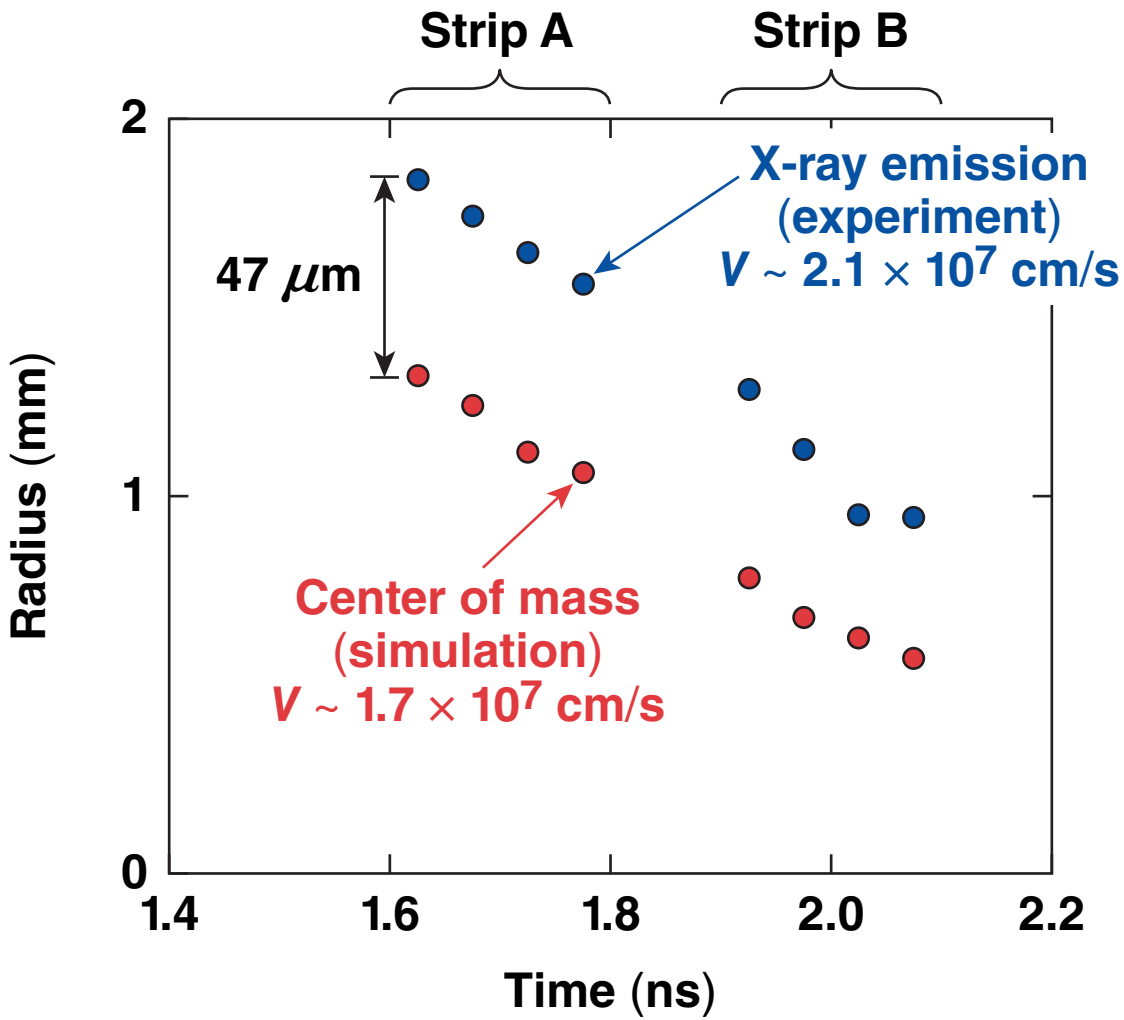

TC13362

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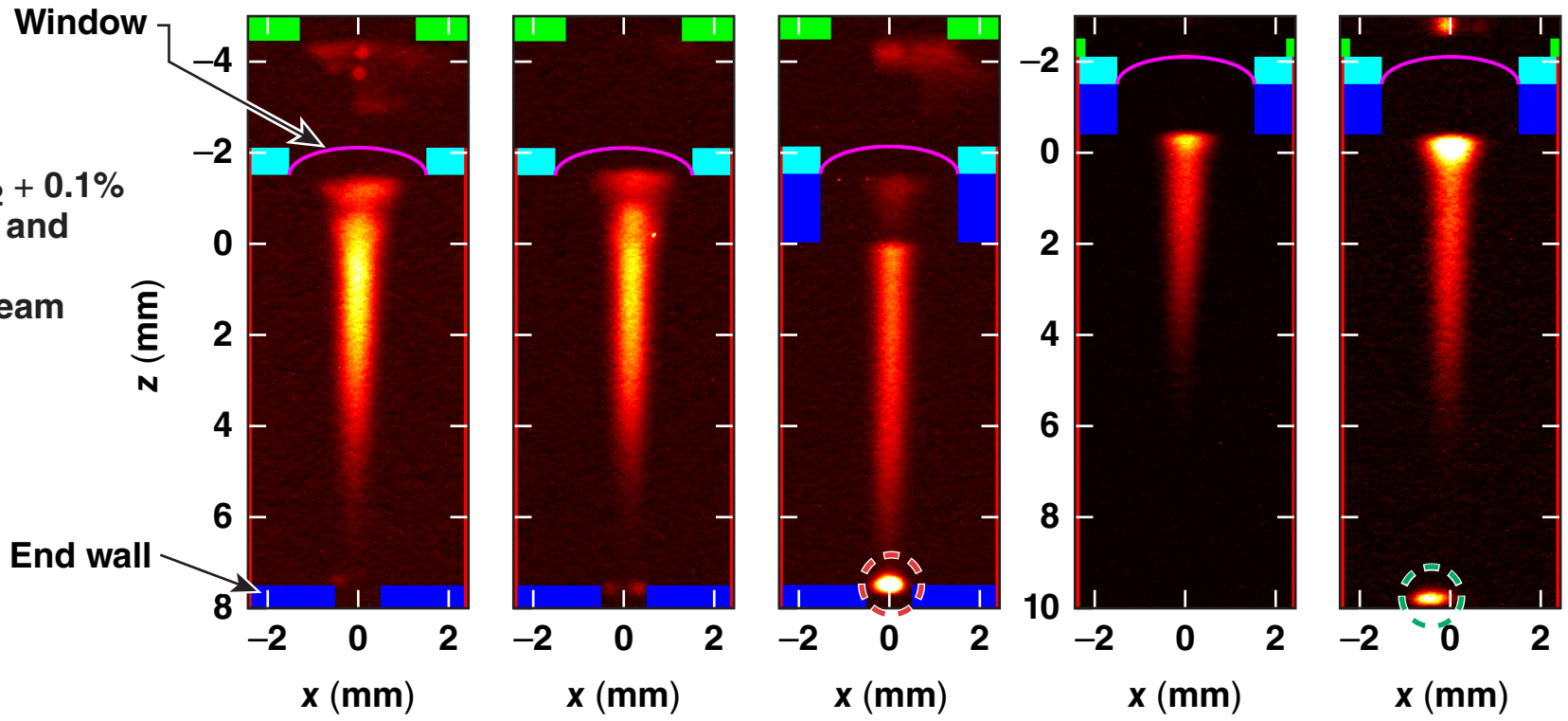

TC13363

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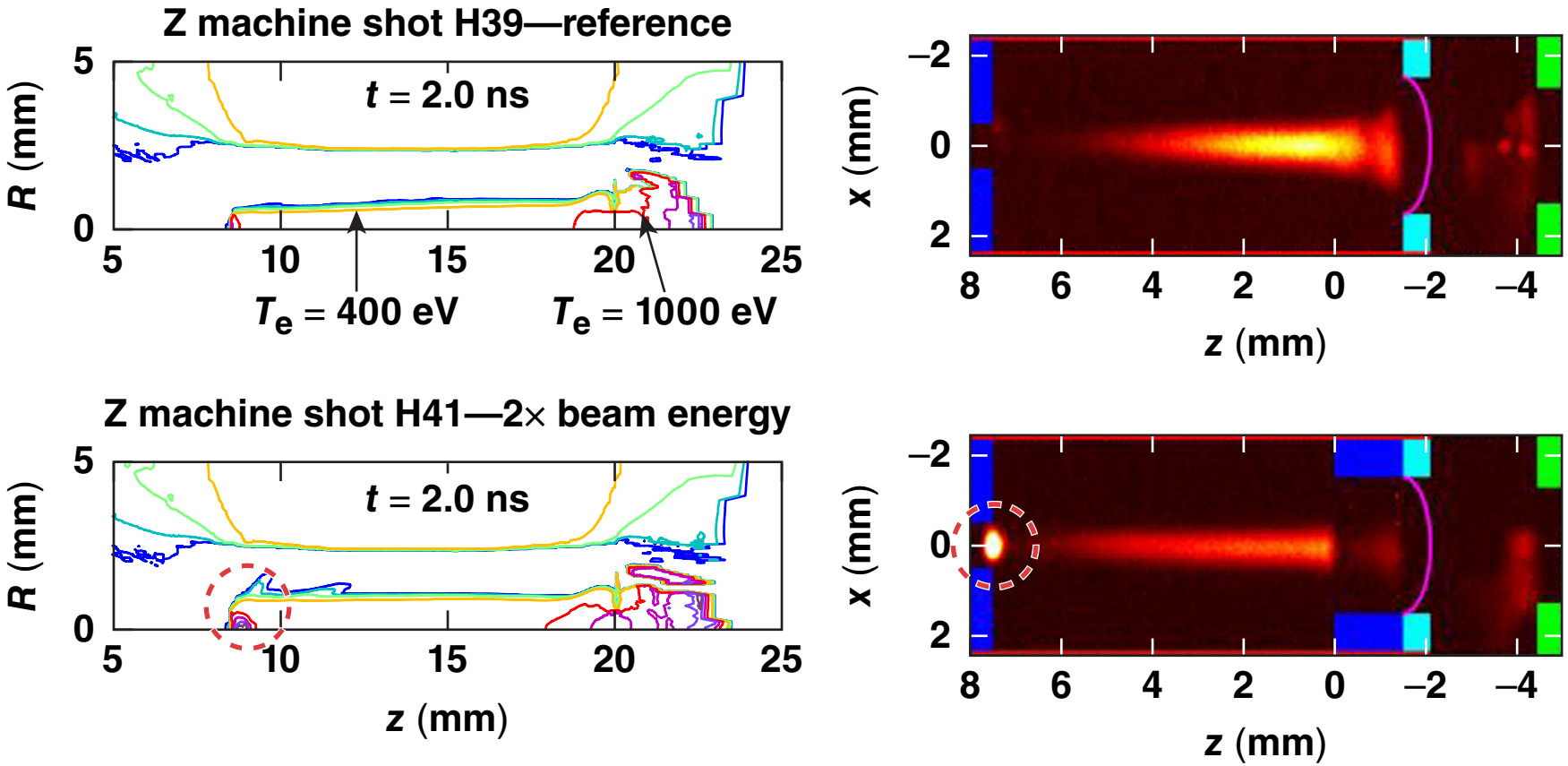

(Simulations include a laser drive on the liner)

Runs 1201, 1202

TC13364

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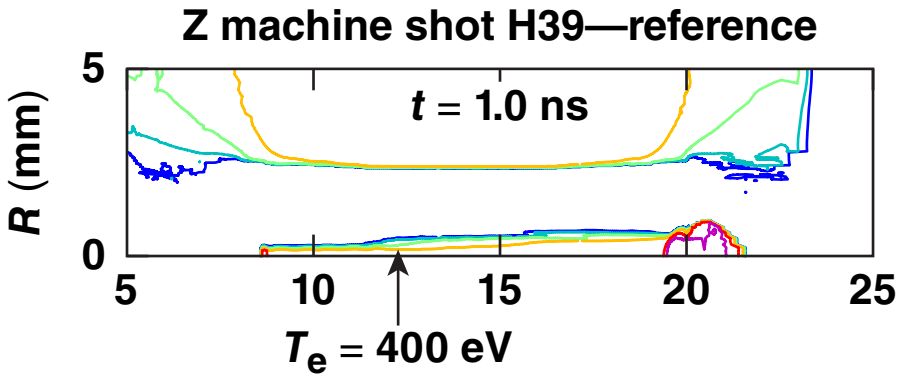
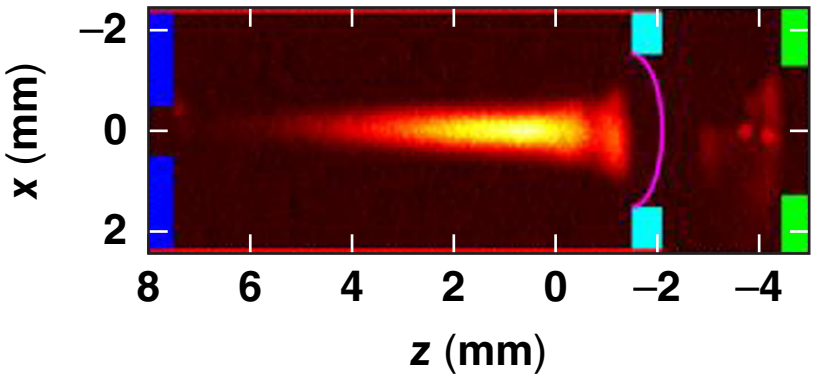
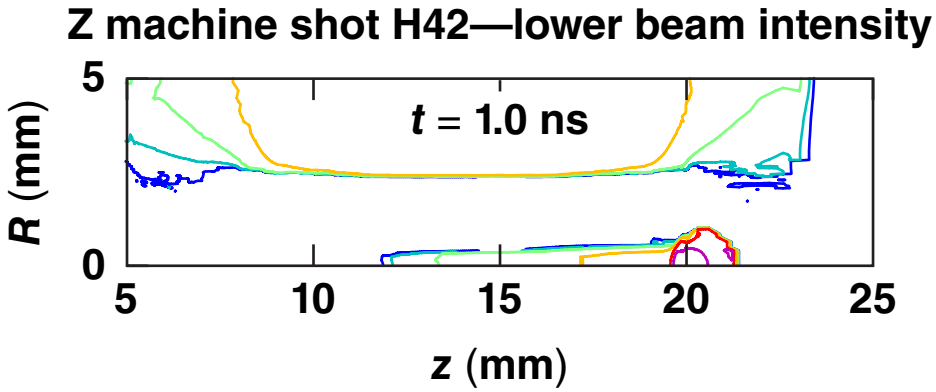
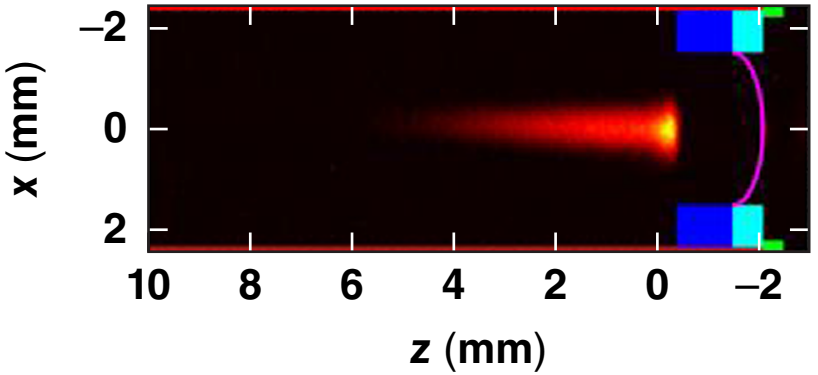




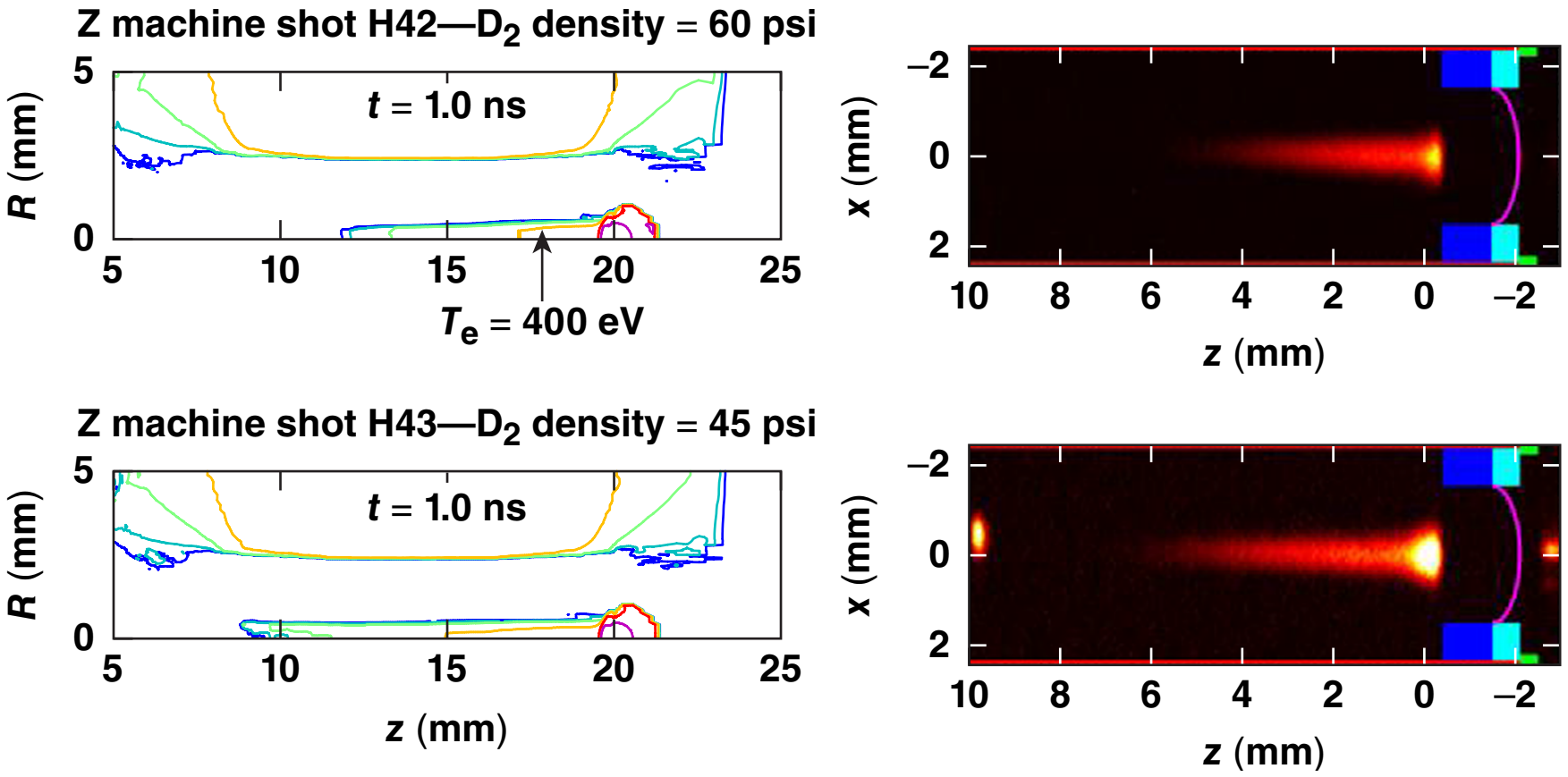




Runs 1201, 1203

TC13365

When the gas density is lowered, the heating beam penetrates farther



Runs 1203, 1204

TC13366

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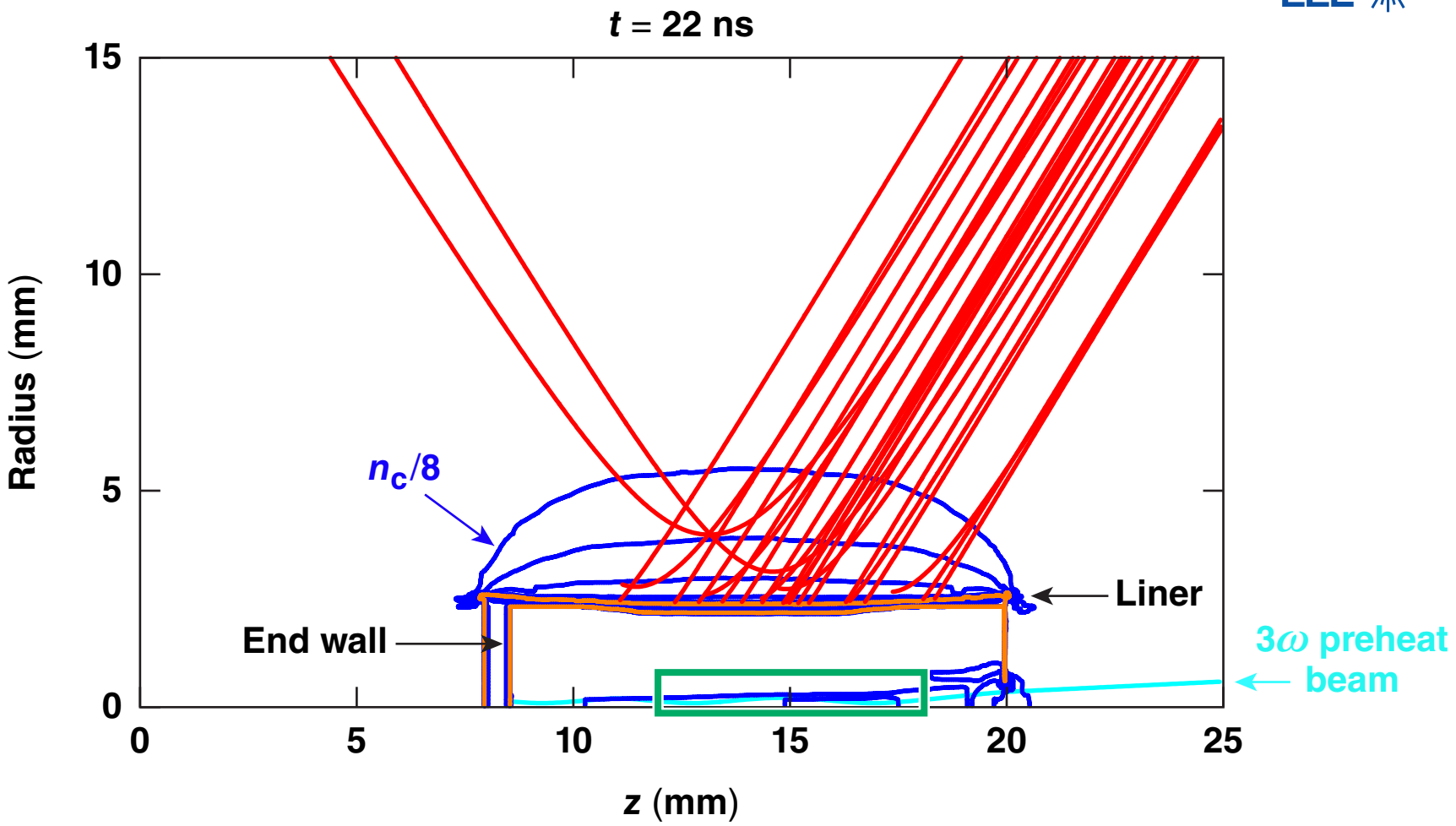

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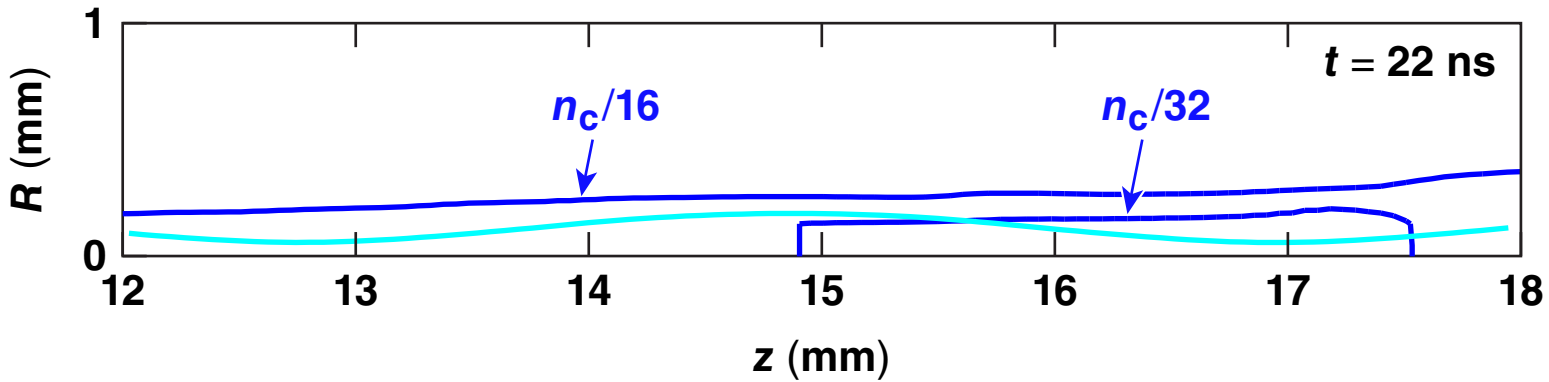
Run 1139

TC13367

A whole-beam self-focusing density channel is created by the expansion of laser-heated deuterium away from the axis



Run 1139

TC13368

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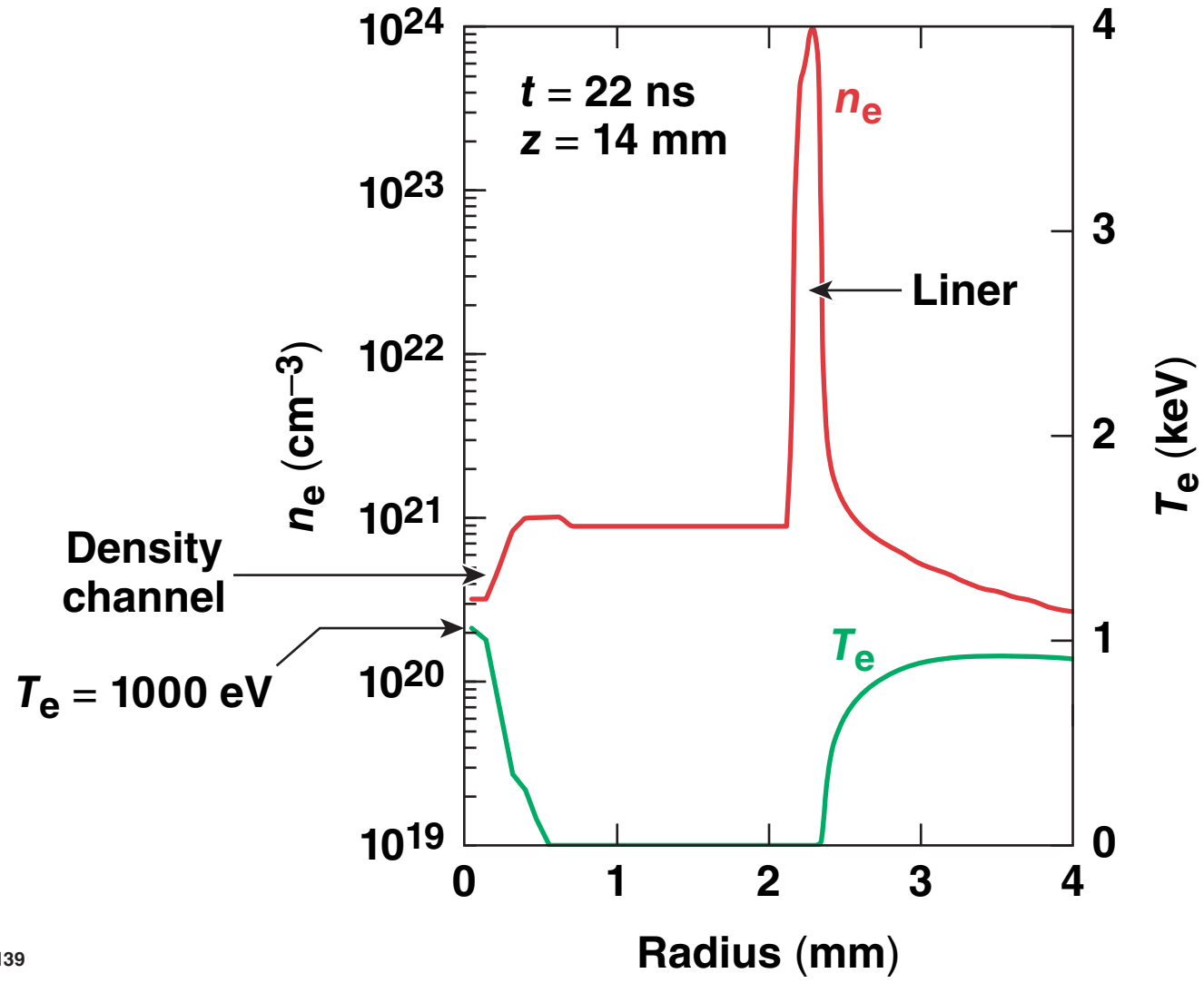
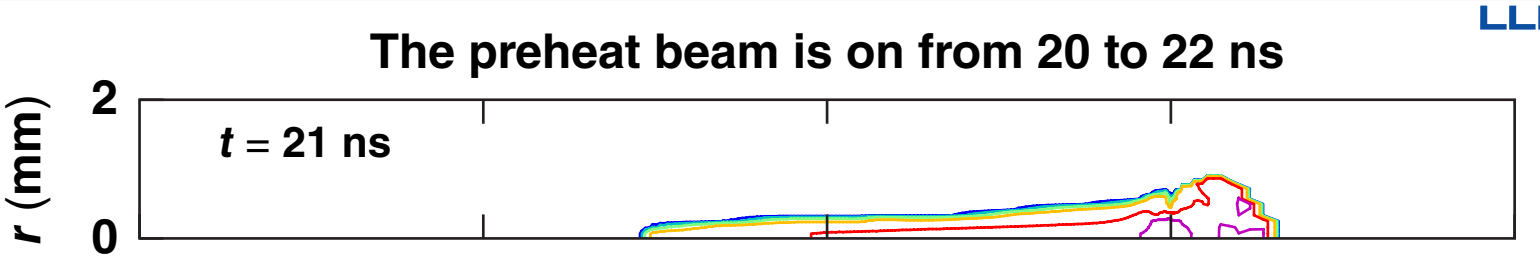
A 1-D lineout in the radial direction shows a hot region confined to the density channel



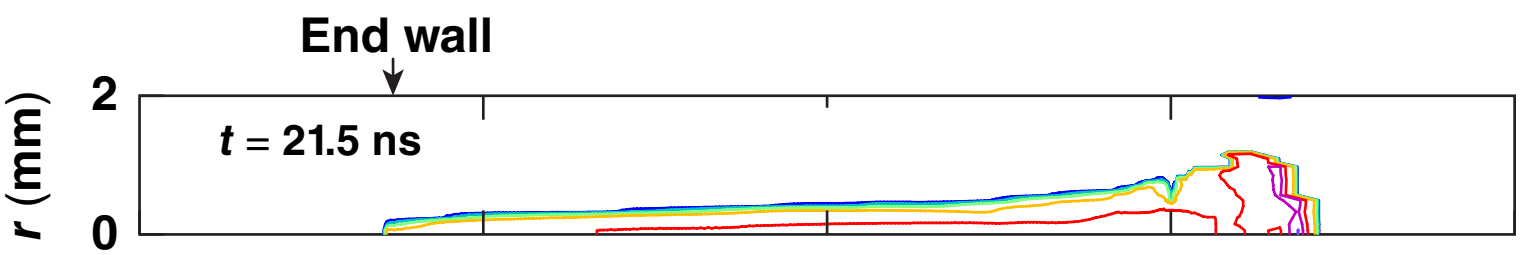
Run 1139

TC13369

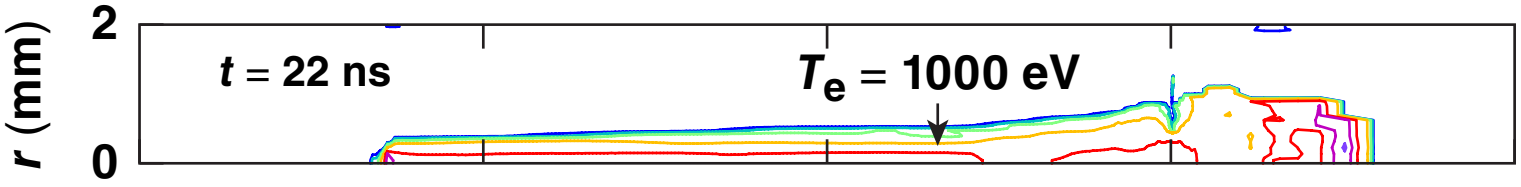
Temperature contour graphs illustrate the evolution of the self-focusing density channel



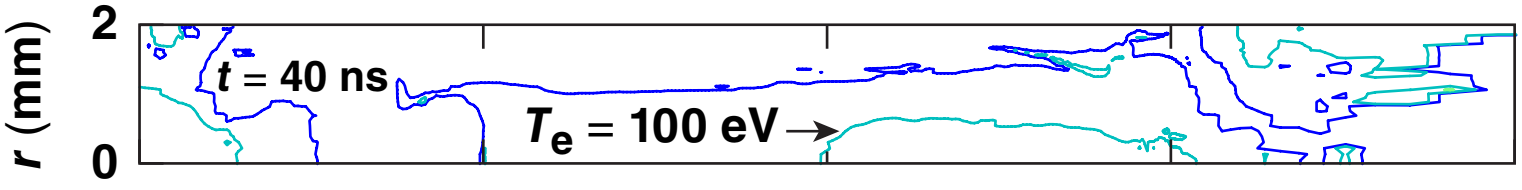
- Middle of preheat pulse: the channel is forming



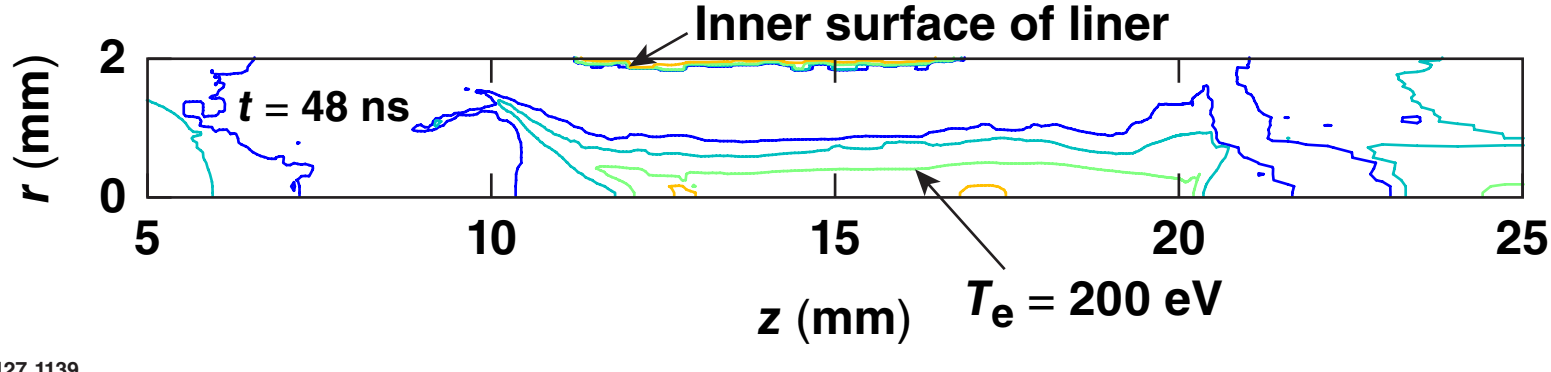
- Near end of preheat pulse: the channel has reached the end wall



- End of preheat pulse to 100 eV as a result of the channel has been uniformly heated to 1000 eV



- D_2 gas has cooled to 100 eV as a result of radial thermal conduction

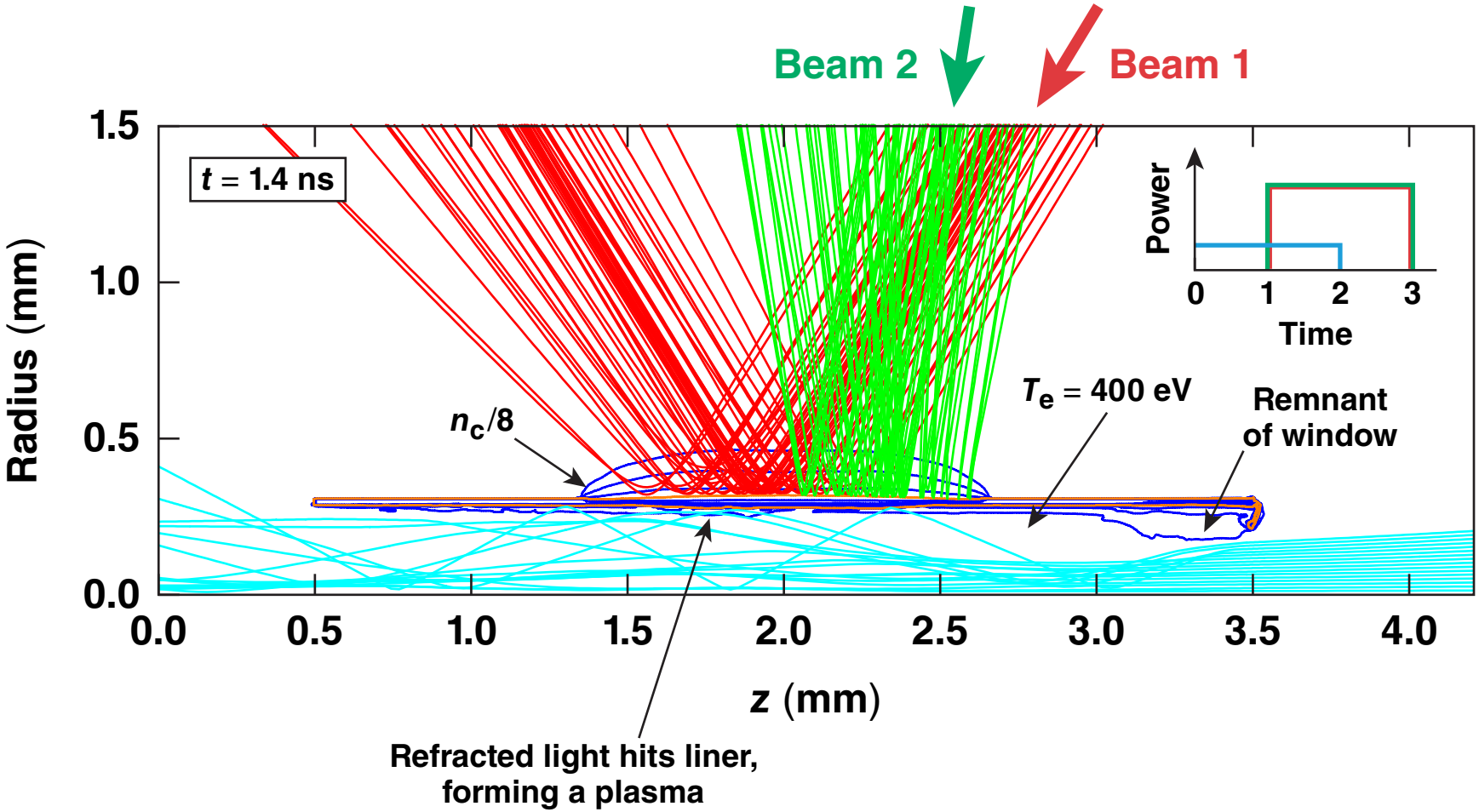


- D_2 gas is heated to 200 eV at the onset of compression

Runs 1127, 1139

TC13370

SAGE has been used to model shots with the preheating beam



Run 1100

TC13371

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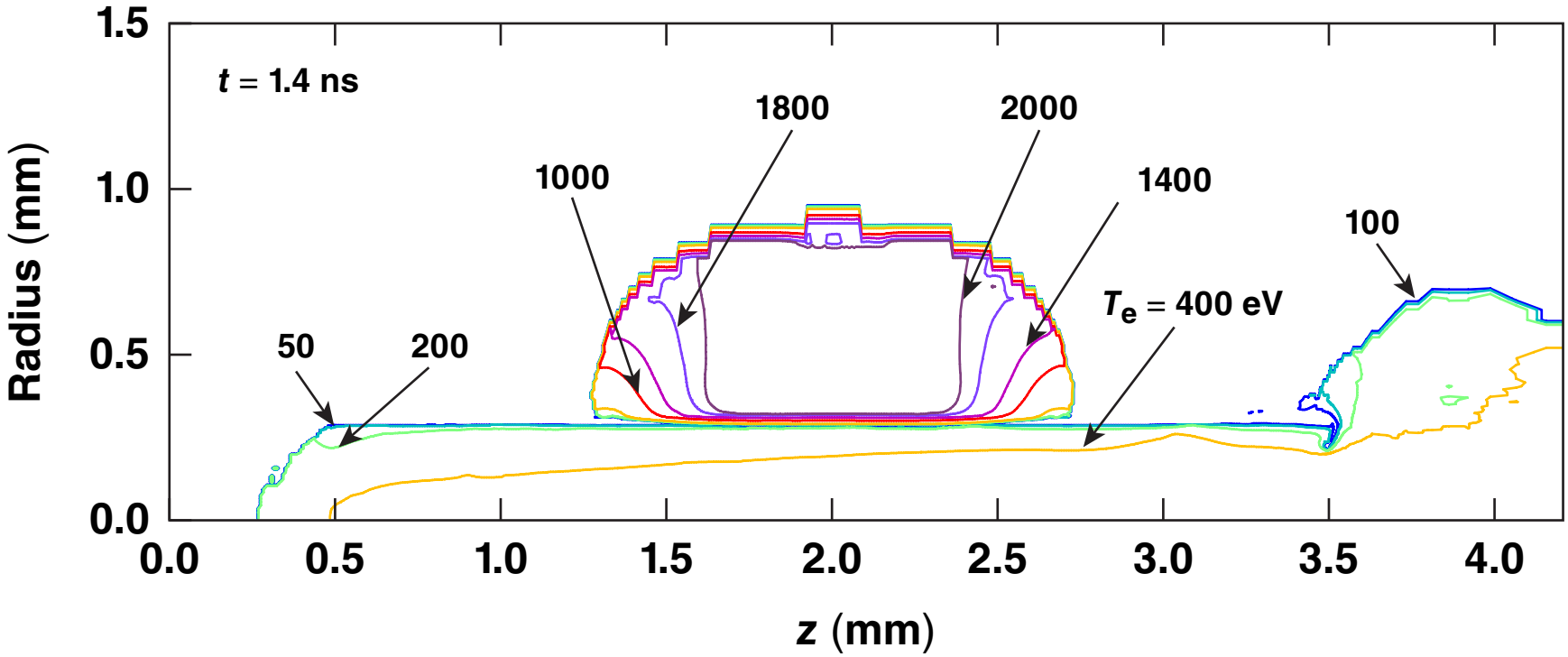

Run 1100

TC13372