U.S. NAVAL RESEARCH LABORATORY

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Simulations of an argon Z-pinch implosion with time-dependent non-LTE population kinetics*

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Abstract

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Three argon gas-puff implosions were performed on the Z-machine at Sandia National Laboratories. These three loads had the same density profile from an 8 cm diameter nozzle, mass of 1 mg/cm, and had a 2.5 cm length. The experiments produced similar K-shell radiative power pulses and K-shell yields >300 kJ [1]. The 2-D Radiation MHD code Mach2 was used to assess the current flow and plasma conditions. The simulation was able to reproduce the experimental K-shell powers, yields, and emission region. It was also shown that the ratio of the argon Lyα to Heα plus intercombination line from the simulation had good agreement to the experiments after peak K-shell power. However, at times prior to peak K-shell power, the simulation had a higher ratio than the experiments. The authors attribute the difference to 3-D effects or on the implicit assumption of steady-state population kinetics [2]. This presentation will illustrate the effect of time-dependent level populations on the K-shell radiation from simulations using the NRL DZAPP code. DZAPP is a coupled 1-D MHD, detailed non-LTE atomic physics with radiation transport, incorporating a transmission line circuit. The argon Lyα to Heα plus intercombination line ratio and K-shell radiative power pulse from the steady-state populations and time-dependent populations will be presented and compared with experiment.

[1] B.M. Jones et al. Physics of Plasmas 22, 020706 (2015)

[2] J.W. Thornhill et al. IEEE Transactions on Plasma Science 43, 2480 (2015)

Argon gas puff experiments on the Z machine have produced 330 kJ ± 9% above 3 keV photon energies

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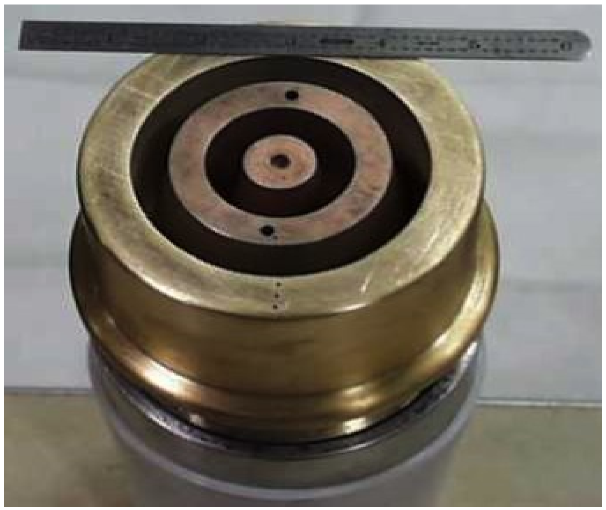

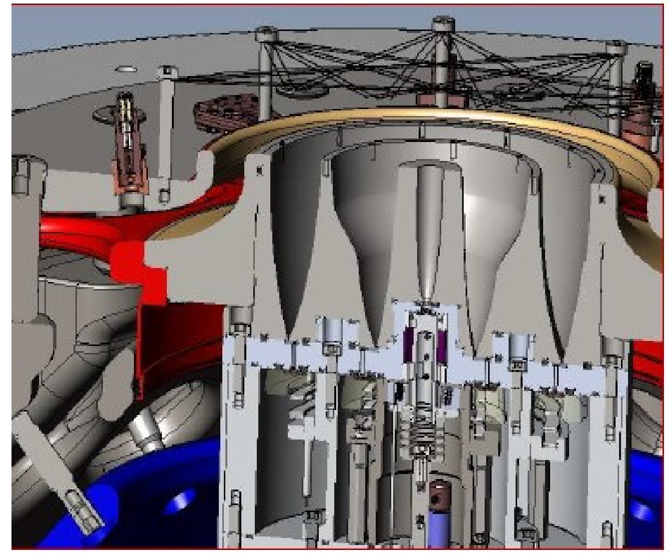

An 8 cm diameter double-shell gas nozzle was used.
The mass of the argon gas was 1 mg/cm.
The inner- to outer-shell mass ratio was 1.6:1.
The length was 2.5 cm.

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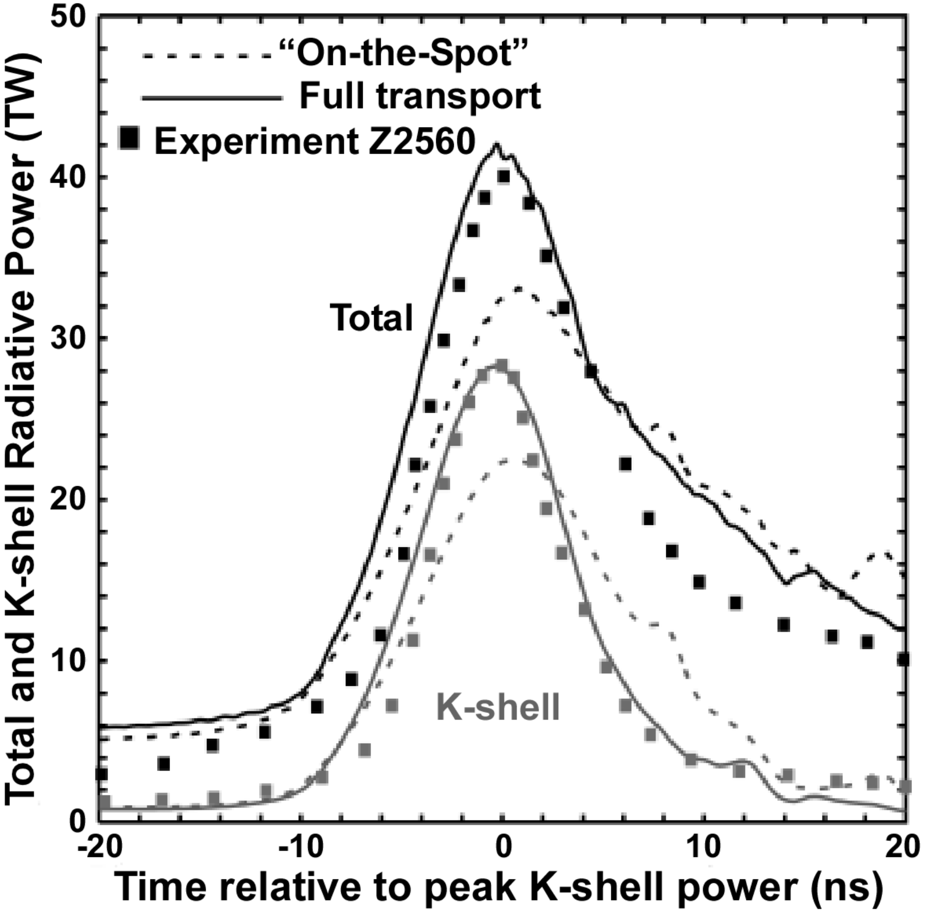
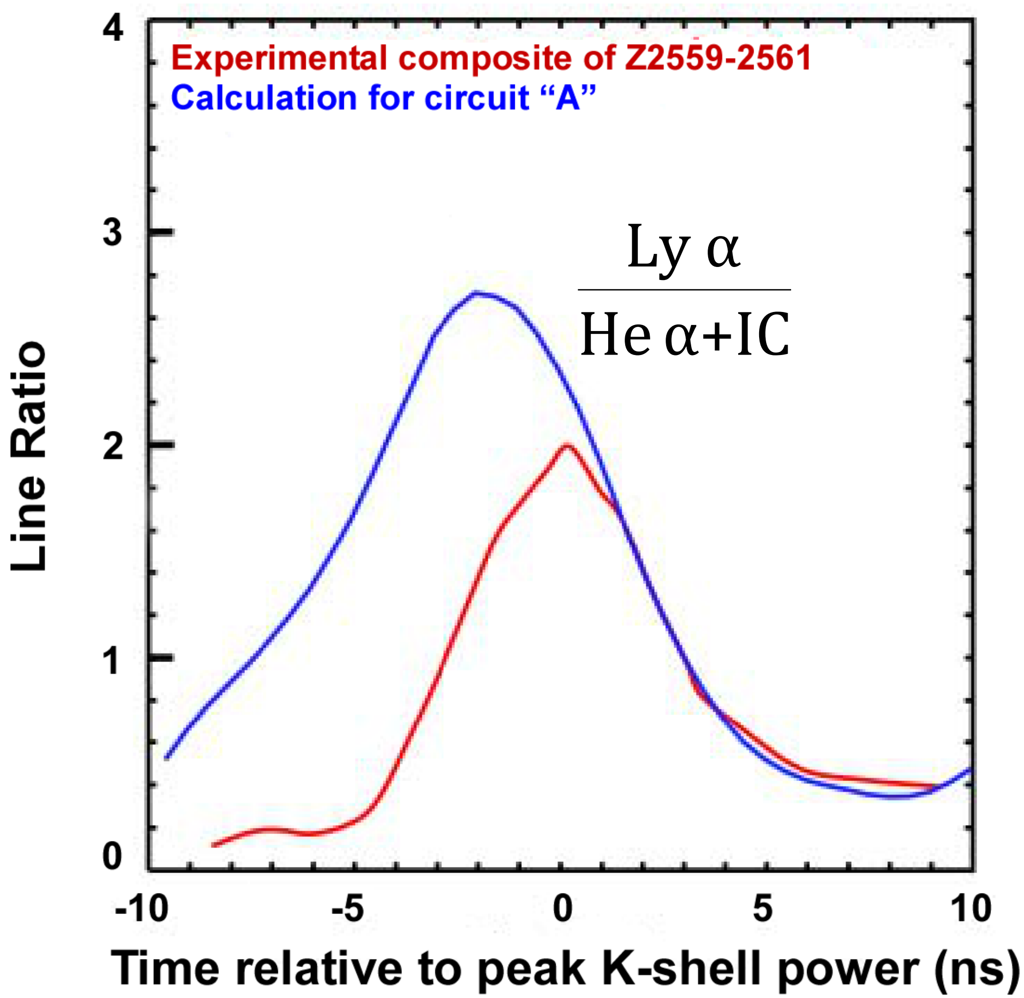
B.M. Jones et al. Physics of Plasmas 22, 020706 (2015)

Simulations using Mach2-TCRE was able to reproduce the radiative powers and yield from shot Z2560



J.W. Thornhill et al. IEEE TPS 43, 2480 (2015)

The simulation's line ratio had good agreement after peak power, but was higher prior to peak power.



Thornhill *et al* attributed this discrepancy prior to peak power to:

1. **3-D effects**
2. **Implicit assumption of steady-state populations in the TCRE table.**

This presentation will explore the effect of time-dependent level population kinetics on the line ratio.

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J.W. Thornhill et al. IEEE TPS 43, 2480 (2015)

The NRL DZAPP code was used to assess the effect of time-dependent and steady-state level kinetics

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DZAPP is a coupled 1-D MHD, detailed non-LTE atomic physics with radiation transport, incorporating a transmission line circuit for the driving generator.

The non-LTE population dynamics and radiation transport are time-split from the MHD.

Population of atomic level i in zone k

For steady-state populations the time derivative is set to zero

$$\frac{\partial f_{ik}}{\partial t} = \sum_j \left(W_{jik} f_{jk} - W_{ijk} f_{ik} \right)$$

Net rate describing a transitions from j to I

All physical processes in our collisional-radiative modeling are driven by non-LTE atomic kinetics

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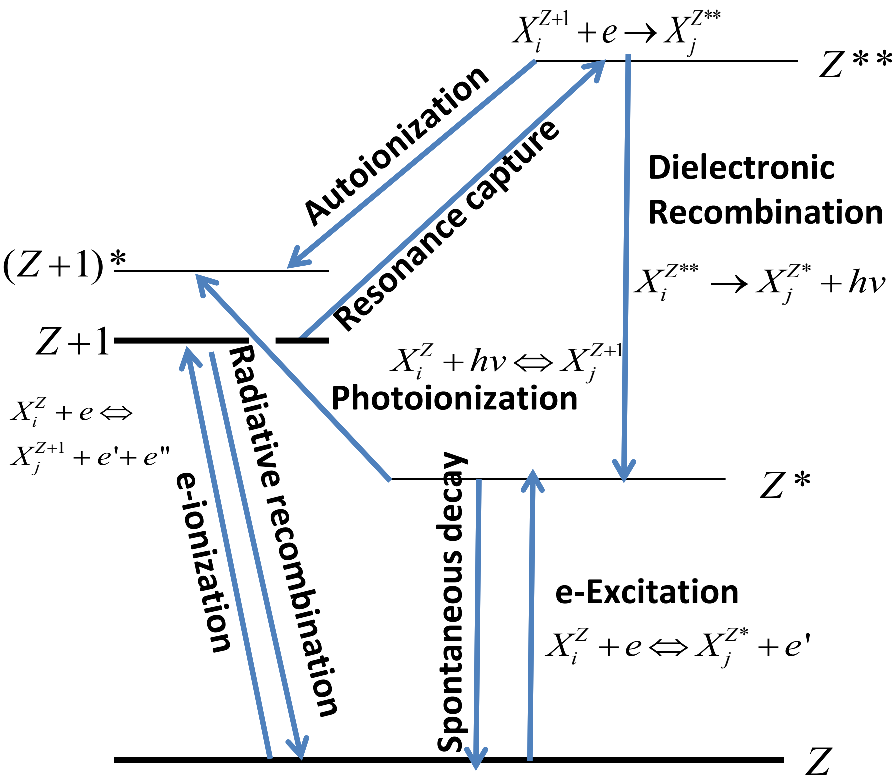
The plasma electrons, ions, and photons interact and in doing so transfer energy from one to another.



Spontaneous decay/Resonant photoabsorption

$X_j^{Z*} \Leftrightarrow X_i^{Z} + h\nu$

Electron impact ionization/3-body recombination

$X_i^{Z} + e \Leftrightarrow X_j^{Z+1} + e' + e''$

Electron impact excitation/deexcitation

$X_i^{Z} + e \Leftrightarrow X_j^{Z*} + e'$

Photoionization/radiative recombination

$X_i^{Z} + h\nu \Leftrightarrow X_j^{Z+1} + e$

Autoionization/resonant capture

$X_i^{Z+1} + e \rightarrow X_j^{Z**}$

Bremsstrahlung/inverse bremsstrahlung

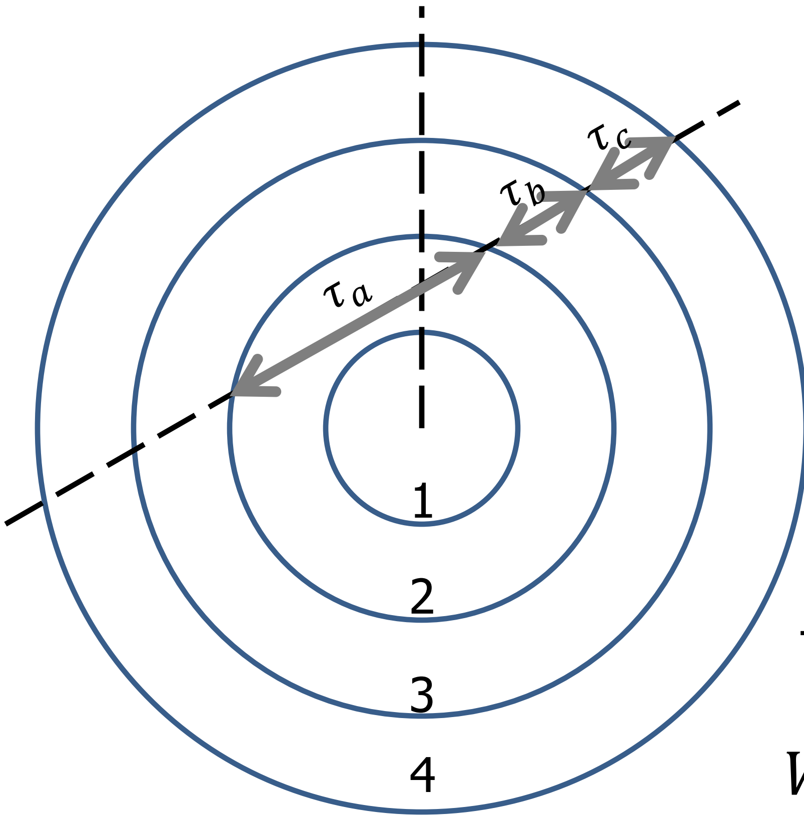
$X_i^{Z} + e \rightarrow X_i^{Z} + e + h\nu$

Dielectronic recombination

$X_i^{Z+1} + e \rightarrow X_j^{Z**}$

$X_j^{Z**} \rightarrow X_i^{Z} + h\nu$ and/or $X_j^{Z**} \rightarrow X_i^{Z+1} + e$

Multi-zone radiation transport via the coupling constant formulism



Multi-zone radiation transport is necessary because photons are more likely to escape near the edge

$$C_{24} = \frac{1}{\tau_a}\int_0^{\tau_a} \left[P_e(\tau_b + \tau) - P_e(\tau_b + \tau_c + \tau)\right] d\tau$$

Reciprocity relation:

$$C_{42} = C_{24}\frac{N_2}{N_4}$$

Ratio of number of absorbers

The photo-excitation rate for i'–i:

$$W_{ii'k} = 4\pi \sum_{k' \neq k} C_{k'k}^{ii'} j_{k'}^{ii'} \frac{V_{k'}}{N_k f_{ik} E_{ii'} V_k}$$

J.P. Apruzese, J. Davis, D. Duston, and K. G. Whitney. JQSRT 23, pp. 479-487 (1980)
J.P. Apruzese. JQSRT 25, pp. 419-425 (1981)
J.P. Apruzese. JQSRT 34, pp. 447-452 (1985)

Results from DZAPP with shows electron temperatures of up to 3 keV (steady-state populations)

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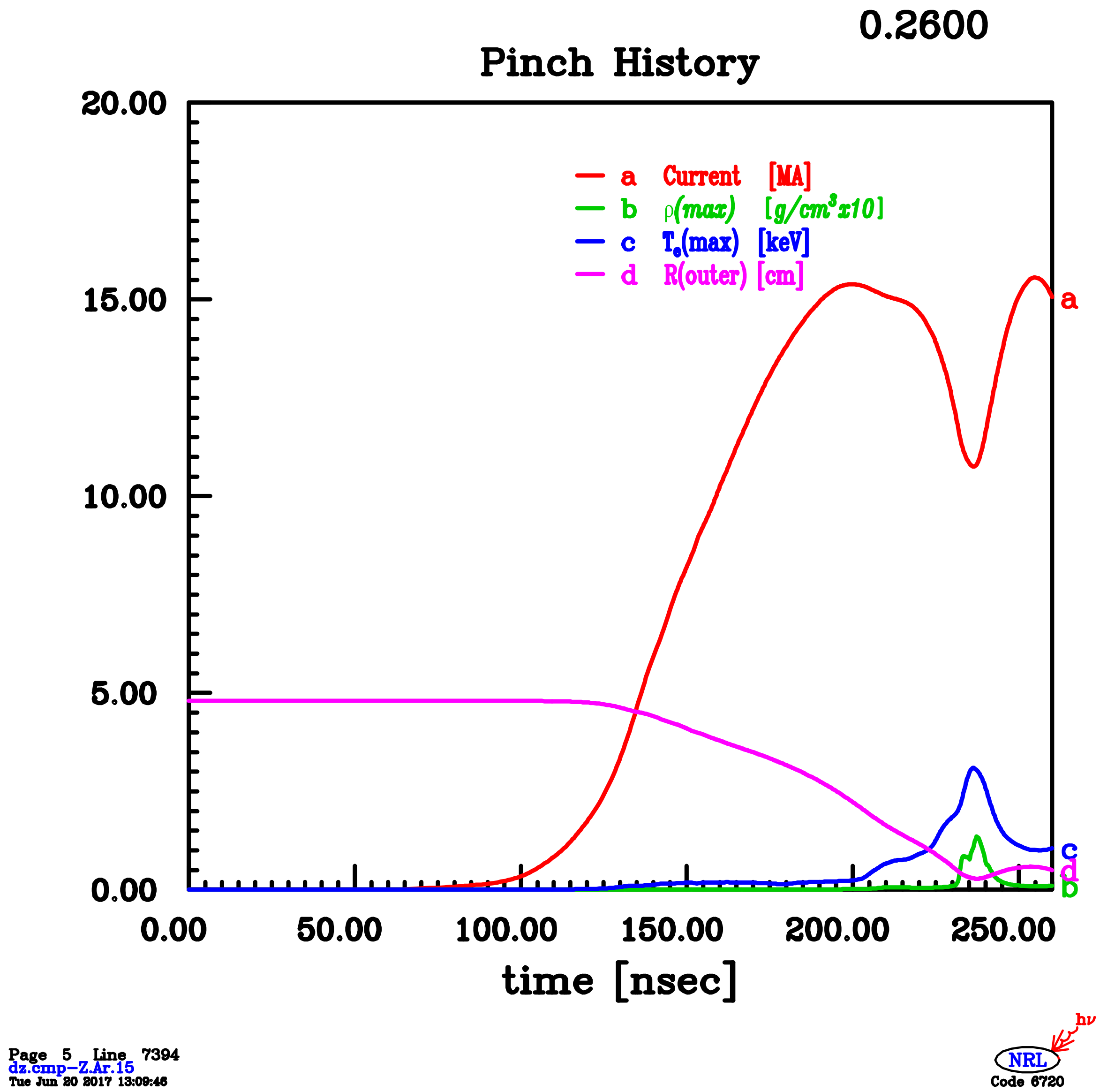
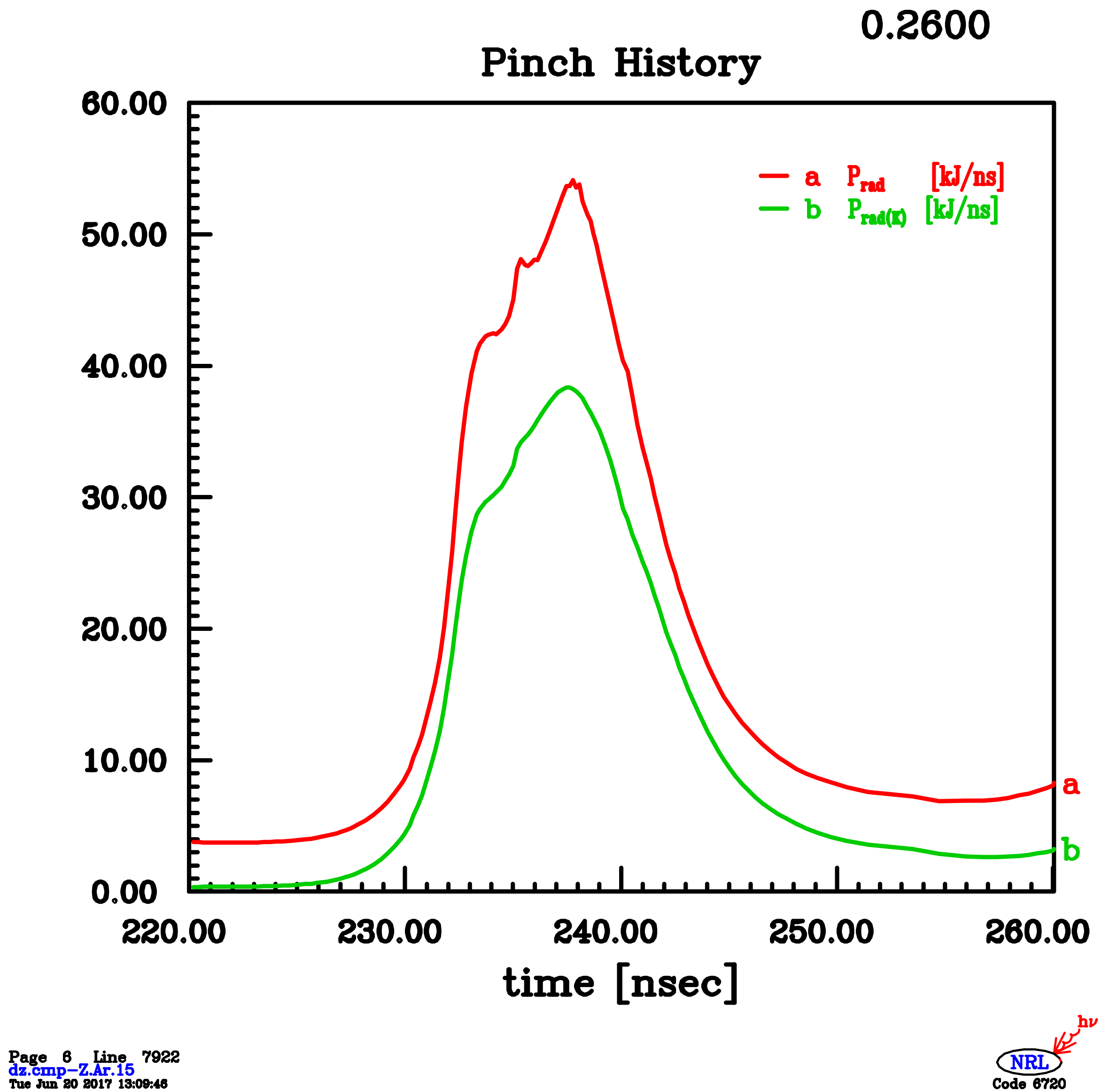
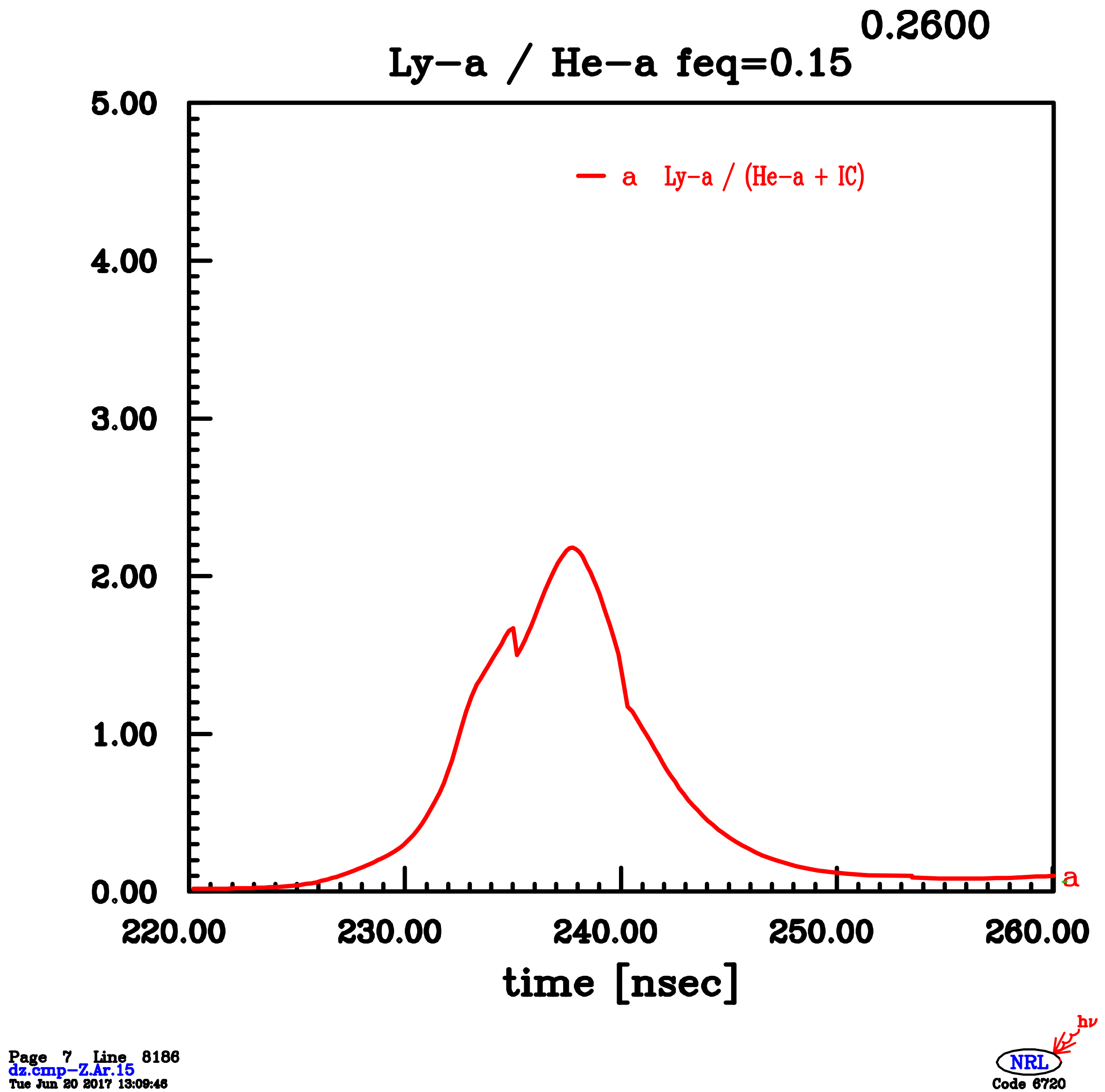


Total and K-shell radiative power pulses are higher and broader than experiment (steady-state populations)

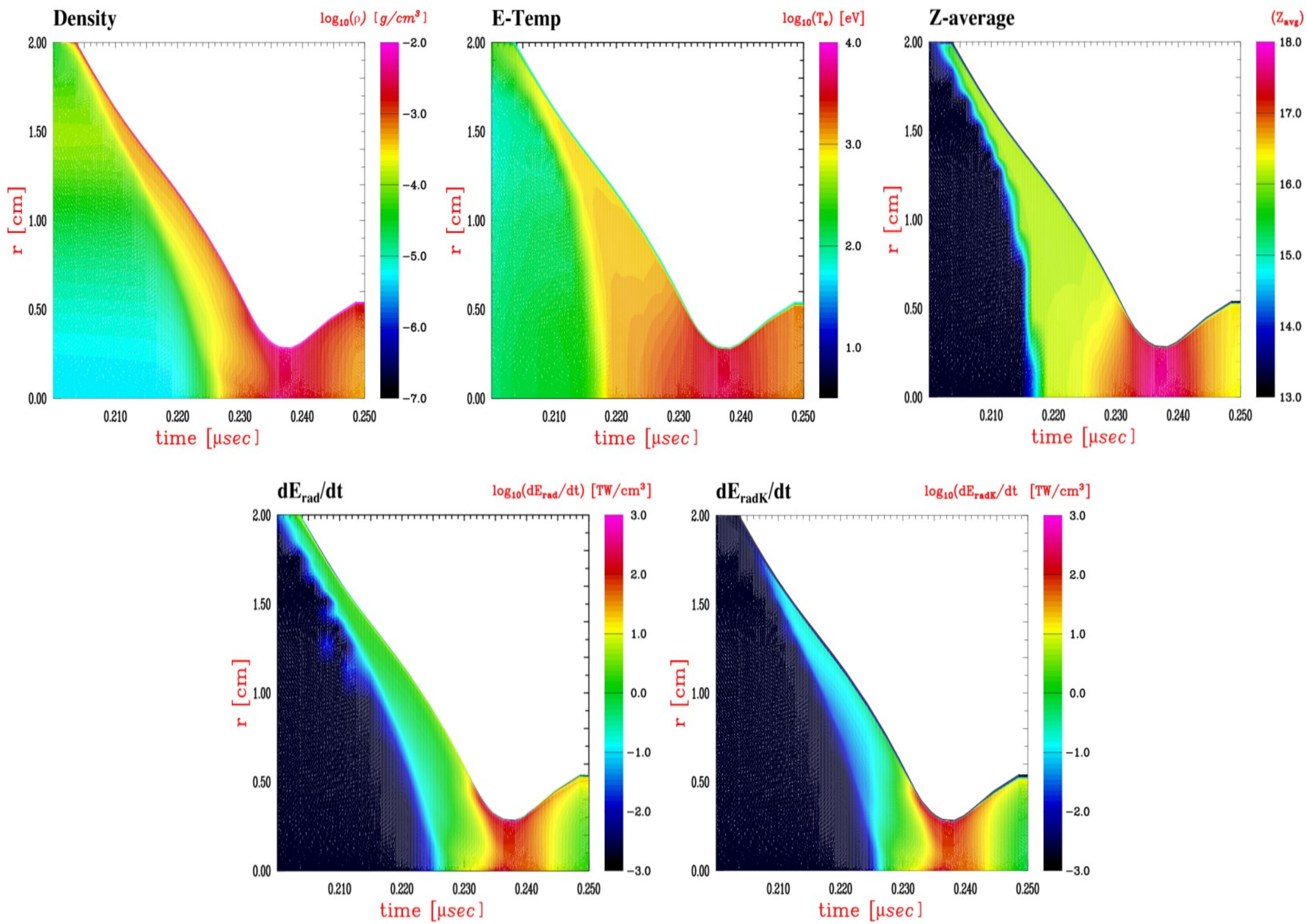


The peak line ratio is similar experiment, but the shape is broader (steady-state populations)

NRL PPD

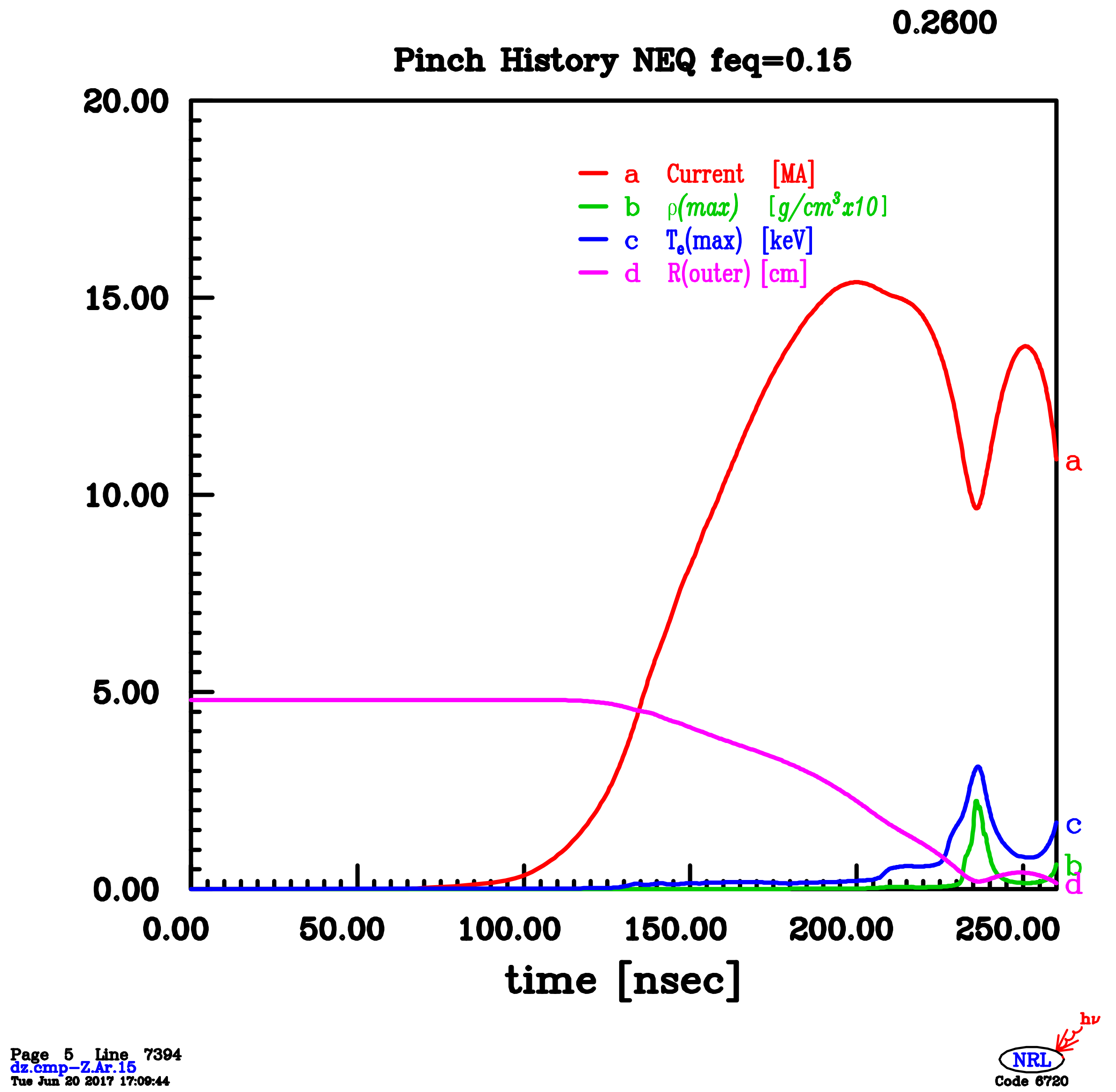


The 1-D simulation with steady-state population show that the plasma is nearly fully ionized around stagnation



Results from DZAPP with shows electron temperatures of up to 3 keV (time-dependent ground populations)

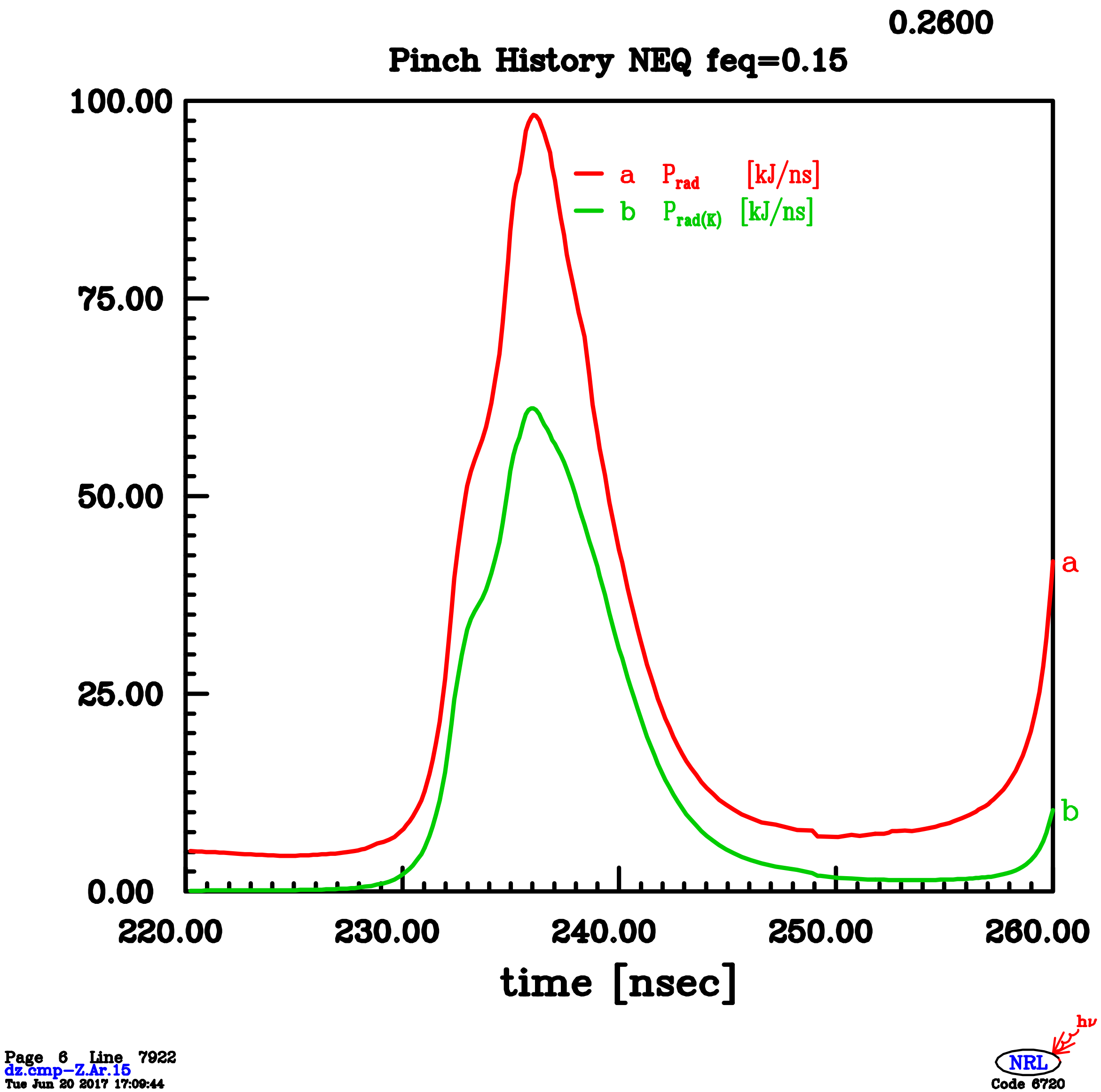
NRL PPD



The plasma was compressed more in the time-dependent case than the steady-state case

Total and K-shell radiative power pulses are higher than experiment (time-dependent ground populations)

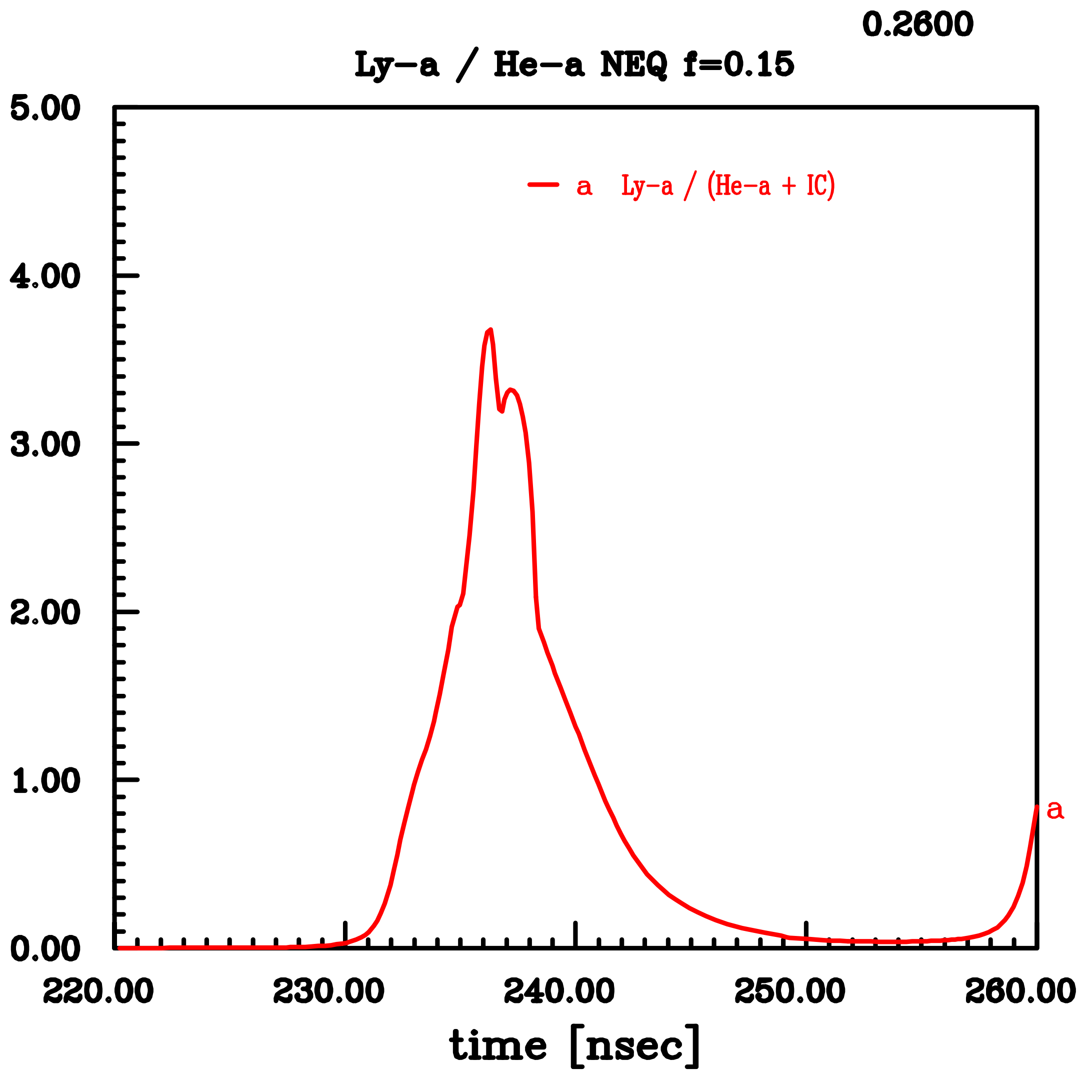
NRL PPD



The pinch was compressed to a smaller diameter leading to larger densities and powers

The peak line ratio is much higher than in experiments (time-dependent ground populations)

NRL PPD



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The dynamics of the pinch has changed with time-dependent ground populations

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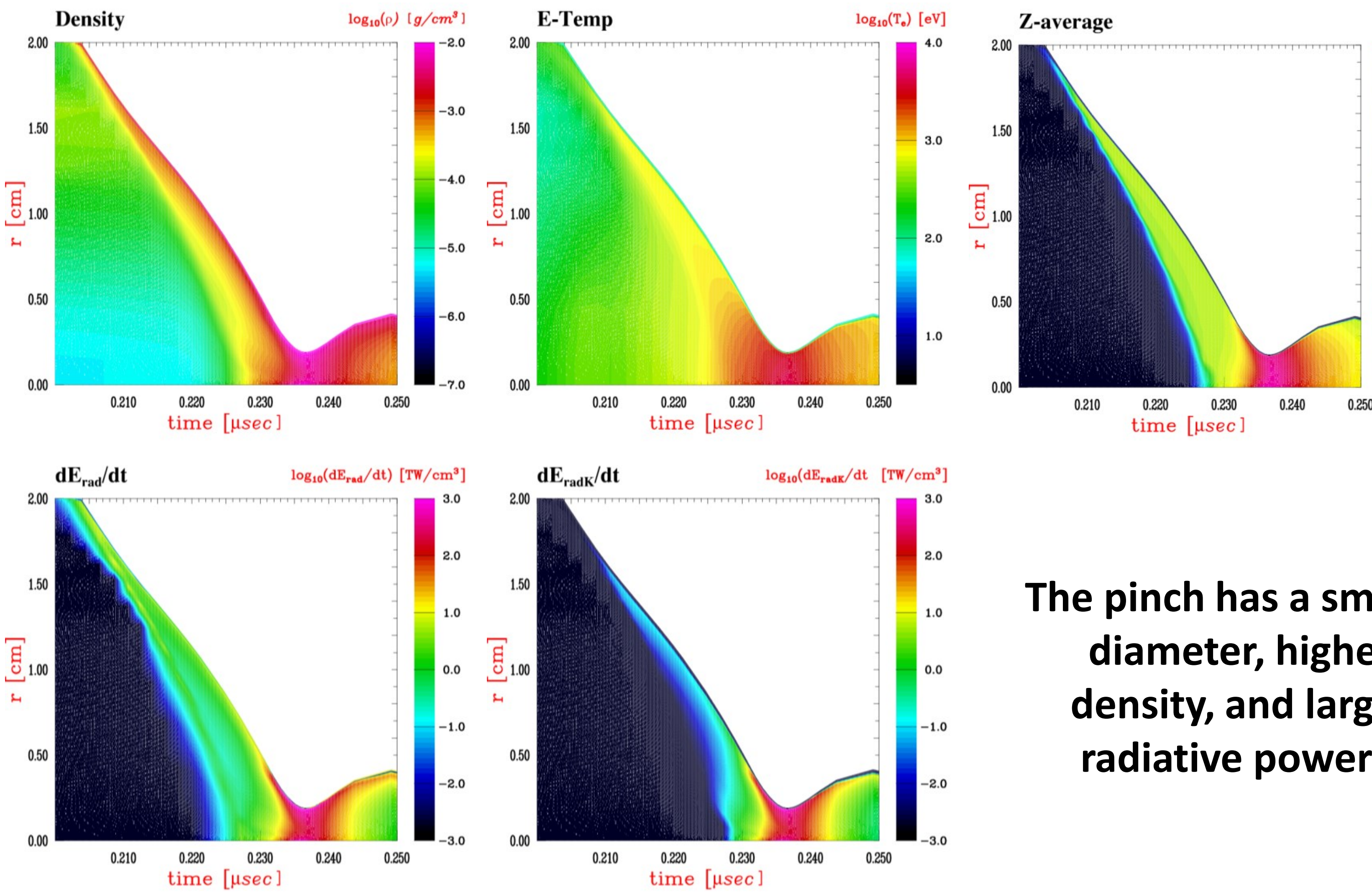

The pinch has a smaller diameter, higher density, and larger radiative powers.

Summary and Future Work

- Simulations with the NRL DZAPP code were done for two cases:
    1. Assume steady-state populations for the non-LTE kinetics
    2. Assume the ground state populations are time-dependent
- Results show the time-dependent populations changes the plasma dynamics.
- Future work will compare the steady-state to time-dependent populations while keeping the plasma dynamics the same.