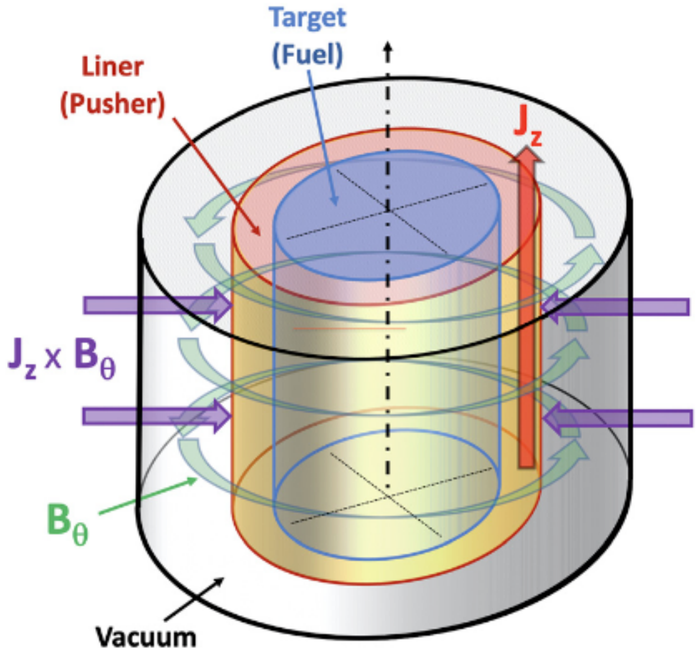
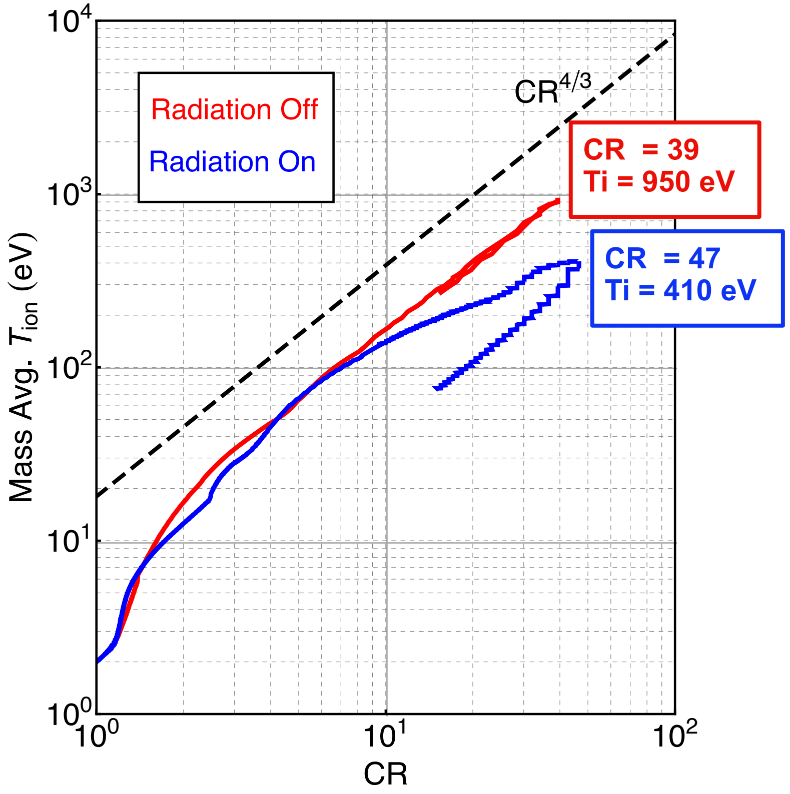
# Assessing the Validity of the Staged Z-Pinch with *FLASH*: Preliminary Simulations





**F. García-Rubio**
**Laboratory for Laser Energetics**
**Flash Center for Computational Science**
**University of Rochester**



**64th Annual Meeting of the APS**
**Division of Plasma Physics**
**Spokane, Washington**
**October 19th, 2022**

# As a first step of validating the Staged Z-Pinch (SZP) concept, we have performed *FLASH* simulations of SZP with a silver liner and ideal physics

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- Successful *FLASH* simulations require imposing a high value of the magnetic resistivity and applying temperature ceilings in the vacuum

- Simulations show a mass-averaged fuel ion temperature at stagnation of 410 eV with ideal physics

- The high-Z liner allows for significant diffusion of B field that can play an important role in the pinch stability

# Collaborators

**E. C. Hansen, K. Moczulski**
Flash Center for Computational Science
University of Rochester

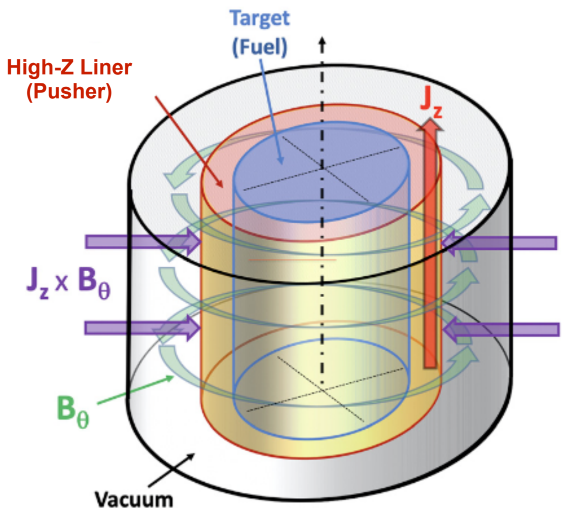
**P. Tzeferacos**
Flash Center for Computational Science
University of Rochester
Laboratory for Laser Energetics

**P. Ney, E. Ruskov, and H. U. Rahman**
Magneto-Inertial Fusion Technology, Inc. (MIFTI)

The Flash Center for Computational Science acknowledges support by the U.S DOE NNSA under Award DE-NA0003842, Subcontracts 536203 and 630138 with LANL and B632670 with LLNL. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856 through the Horton Fellowship Program at the Laboratory for Laser Energetics. Support from the U.S. DOE ARPA-E under Award DE-AR0001272 and U.S. DOE Office of Science, Fusion Energy Sciences under Award DE-SC0021990 is also acknowledged.

# The Staged Z-Pinch (SZP) concept emerged as a potential high-gain fusion energy source

## Schematic




| | SZP1* | SZP2** | SZP3† |
|---|---|---|---|
| Liner material | Xenon | Silver | Silver |
| Liner inner radius (mm) | 3 | 2 | 2.9 |
| Fuel mass density (mg/cc) | 3.4 | 9.8 | 8 |
| Simulated Gain | 42 | 5 | 20 |

## Advantages of SZP

- **No external magnetization**: the **high-Z** liner allows for B field diffusion into the target, eventually
  - Isolating target thermally
  - Improving pinch stability
- **No external preheat**: a **shock front** at the liner-target interface forms, enhancing target-plasma preheating


* Rahman *et al*. Plasma Pays. 75, 749 (2009)
** Wessel *et al*. IEEE Trans. Plasma Sci. 43, 2463 (2015)
† Wessel *et al*. AIP Conf. Proc. 1721, 060002 (2016)

# The viability of the SZP concept has been questioned recently

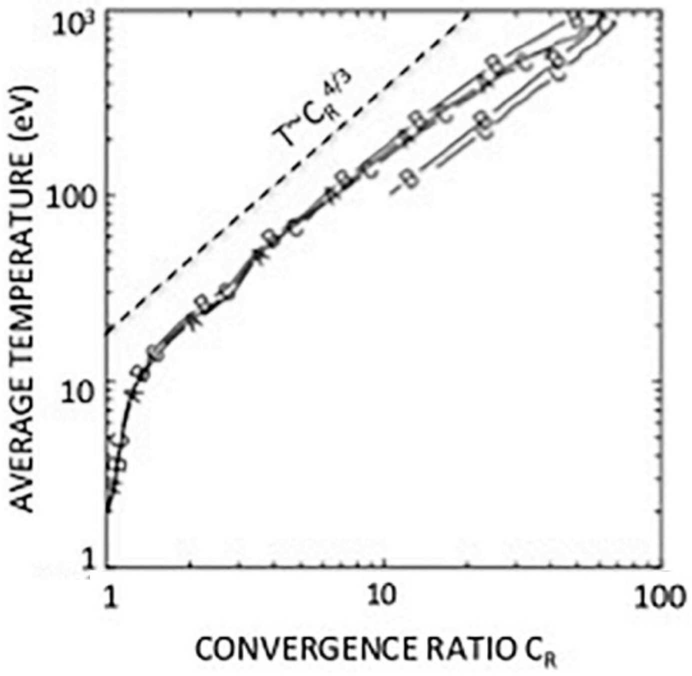
**Review from Lindemuth *et al.****

- Lagrangian simulations using *Hydra*, *Raven* and *MHRDR*
- Sceptic about shock preheating
- Not enough fuel magnetization

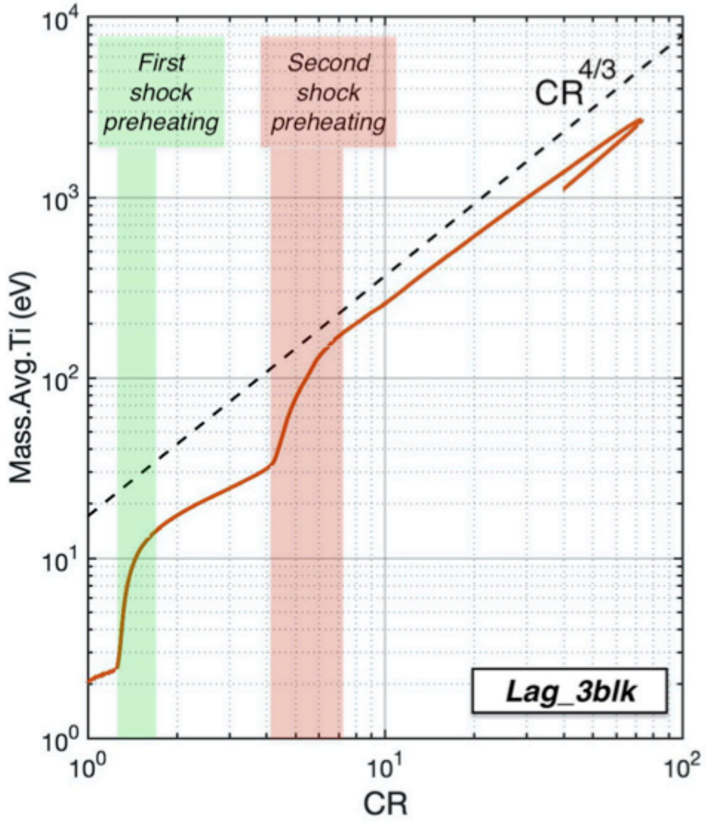
**Response from Ruskov *et al.* (MIFTI)†**

- Lagrangian and Eulerian simulations using *MACH2*
- Necessary to include the vacuum in the computational domain

**Lindemuth***




**Ruskov† (MIFTI)**

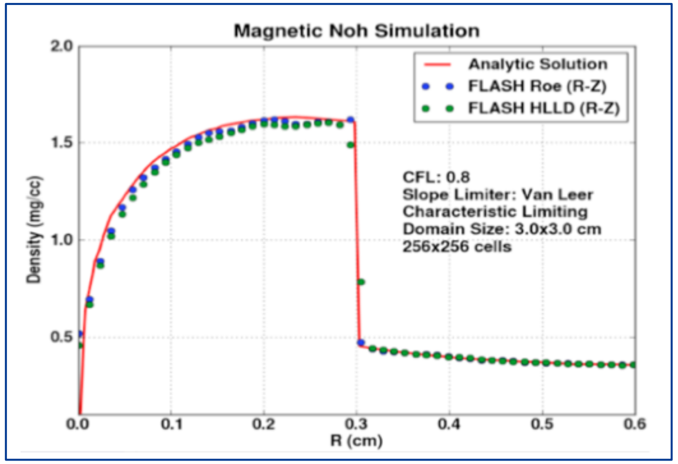



* Lindemuth *et al.* Phys. Plasmas 25, 102707 (2018)
† Ruskov *et al.* Phys. Plasmas 27, 042709 (2020)

# What can *FLASH* contribute to this discussion?*

## Analytical Tests

- Magnetized Noh Problem (Z-Pinch) **




## SZP2 - Ideal Physics

- *FLASH* capabilities:
  - ✓ Resistive 3T HD & MHD
  - ✓ Heat Exchange
  - ✓ Implicit diffusion solvers (implemented by E. C. Hansen)
  - ✓ Current drive circuit model† (implemented by K. Moczulski)
- Combined with ideal physics:
  - ✓ Gamma-law EOS
  - ✓ Gray opacities: Bremsstrahlung coefficients†† (implemented by M. Lee)

## SZP1 - Full Physics

E. C. Hansen Talk:

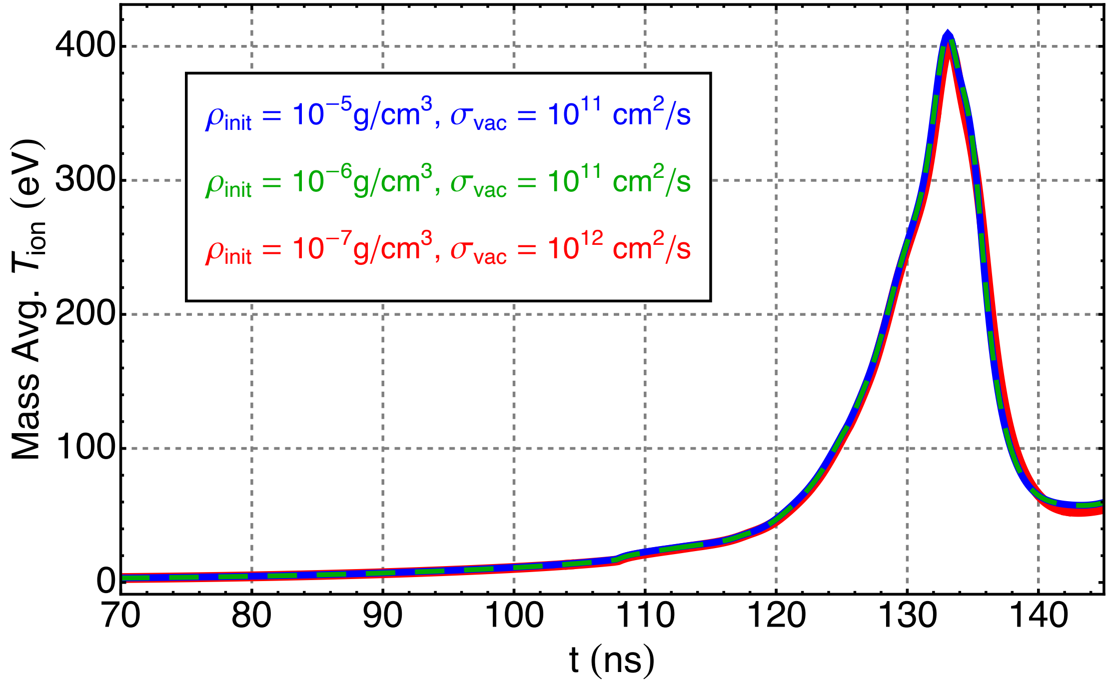
*One-dimensional FLASH Simulations of a Gas-Puff Staged Z-Pinch.*

Session YO004, Friday 10:06 AM

* Supported by the U.S. DOE ARPA-E under Award DE-AR0001272
** Velikovich *et al.* 19, 012707 (2012)
† McBride *et al.* Phys. Rev. ST Accel. Beams 13, 120401 (2010)
†† Zeldovich and Raizer - Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena

# Proper treatment of the vacuum is required for Eulerian codes (*FLASH*)

- **The vacuum region is modeled as a low-density fluid that transfers the B field from the boundary condition to the liner**
- **No currents can be supported in the vacuum:**
  - **We impose artificially high magnetic resistivity values** $\rightarrow B \propto 1/r$
- **Thermal pressure needs to be low to not affect the pinch dynamics**
  - **Temperature ceilings were applied in the vacuum**




***FLASH* simulations are robust to changes in parameters modeling the vacuum.**

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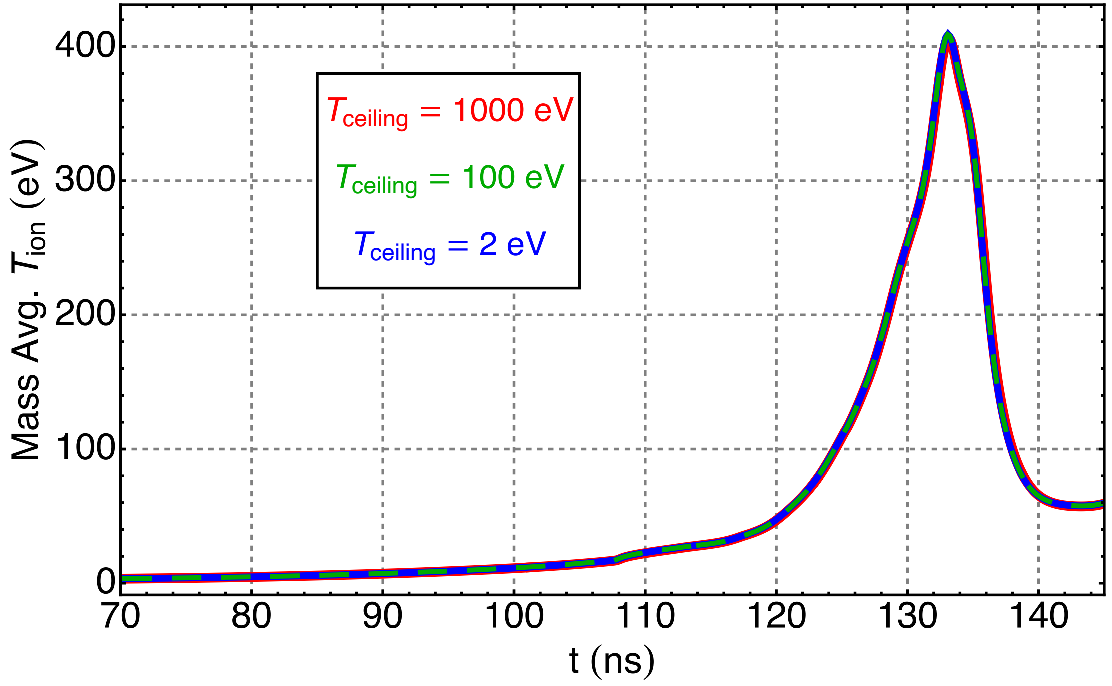
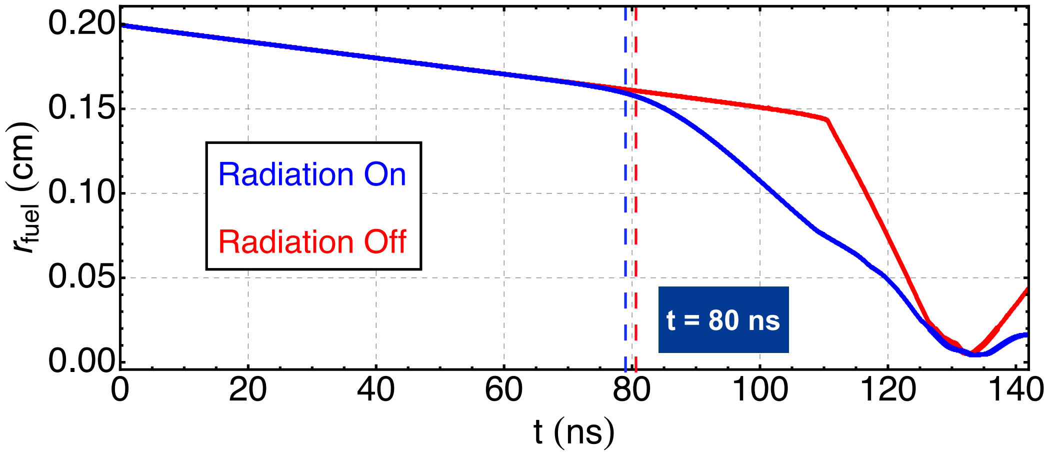


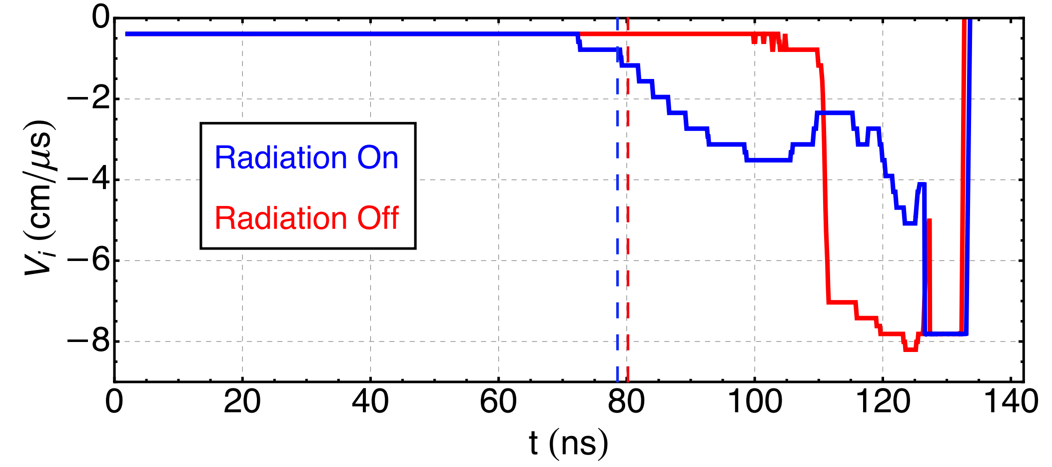

***FLASH*** **simulations are robust to changes in parameters modeling the vacuum.**

# Analysis of the trajectory of SZP2 *FLASH* simulations with ideal physics









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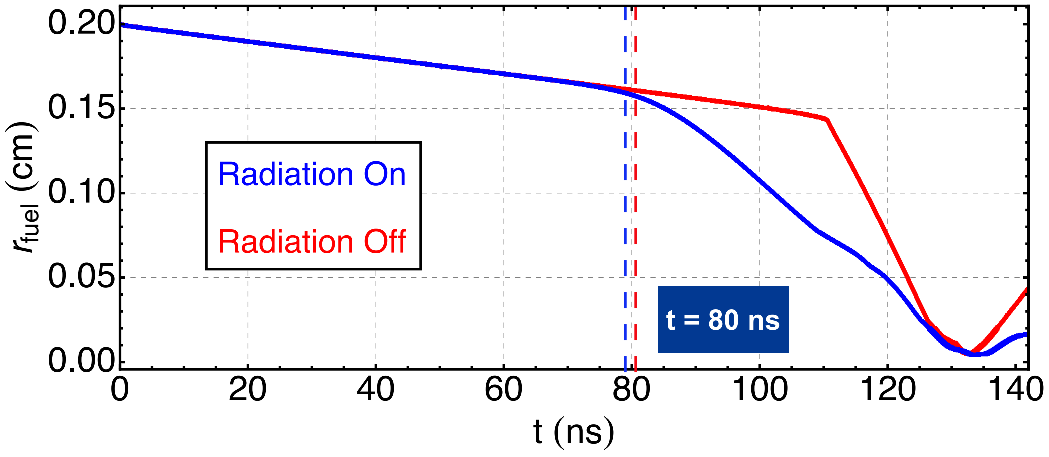


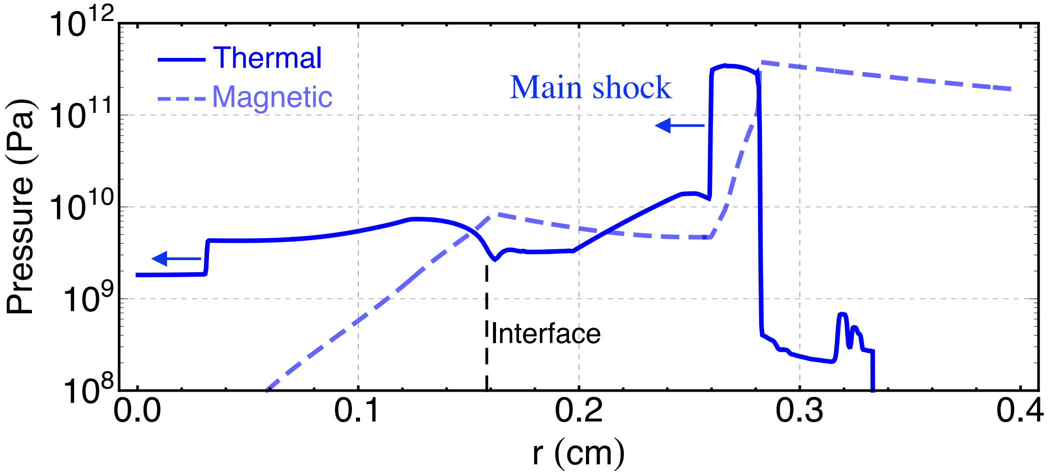


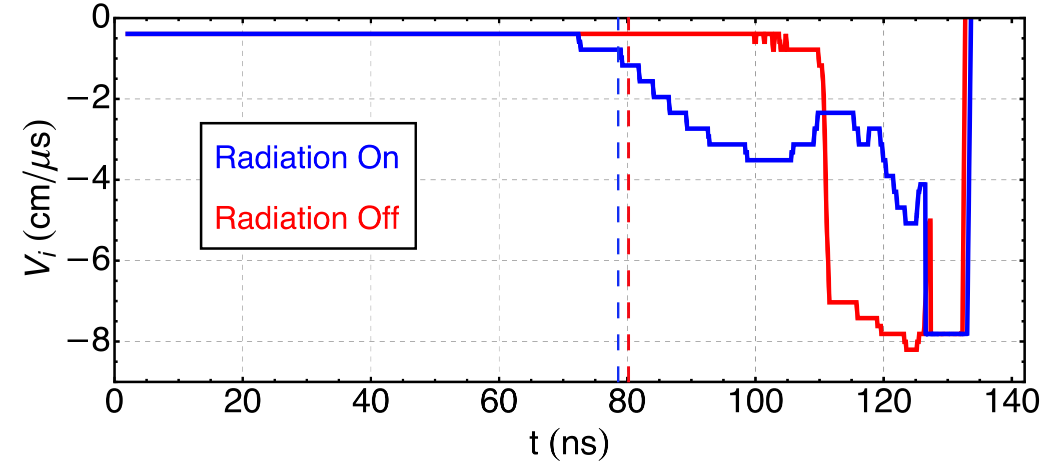


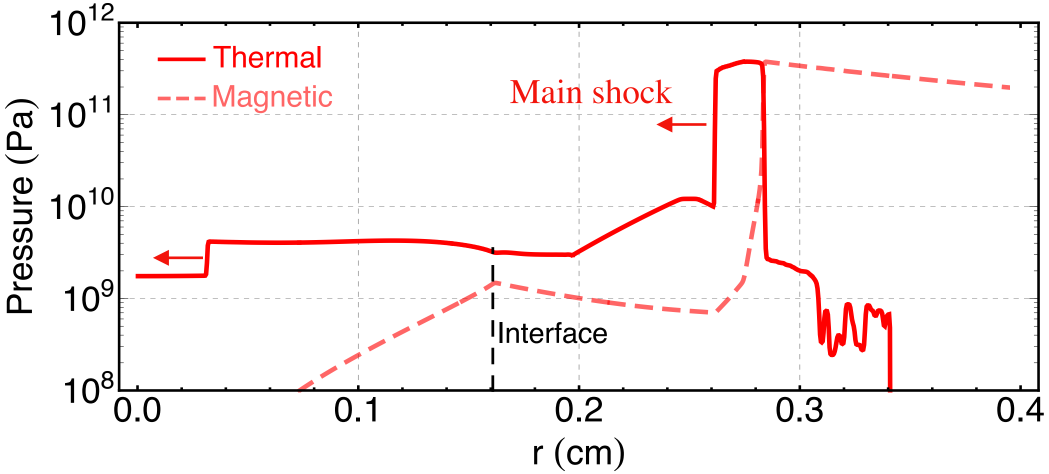

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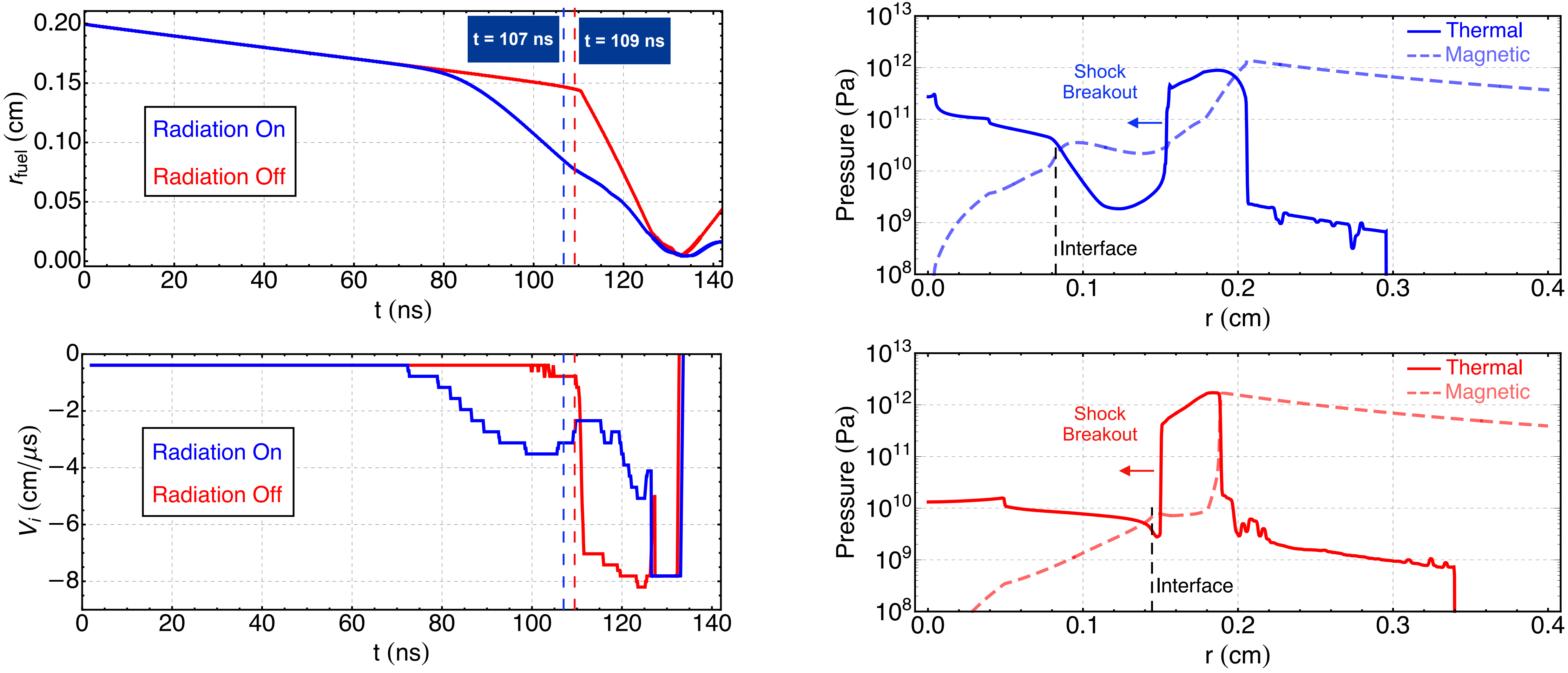

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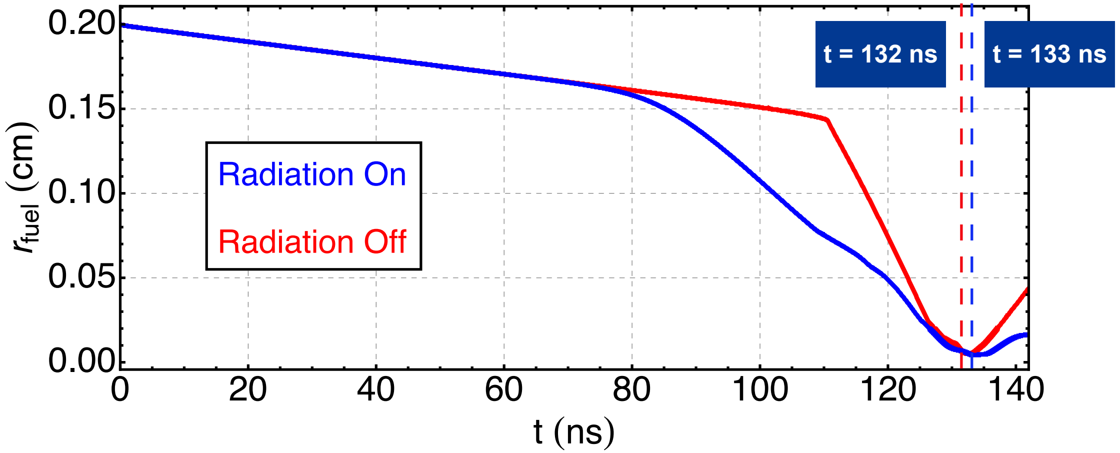
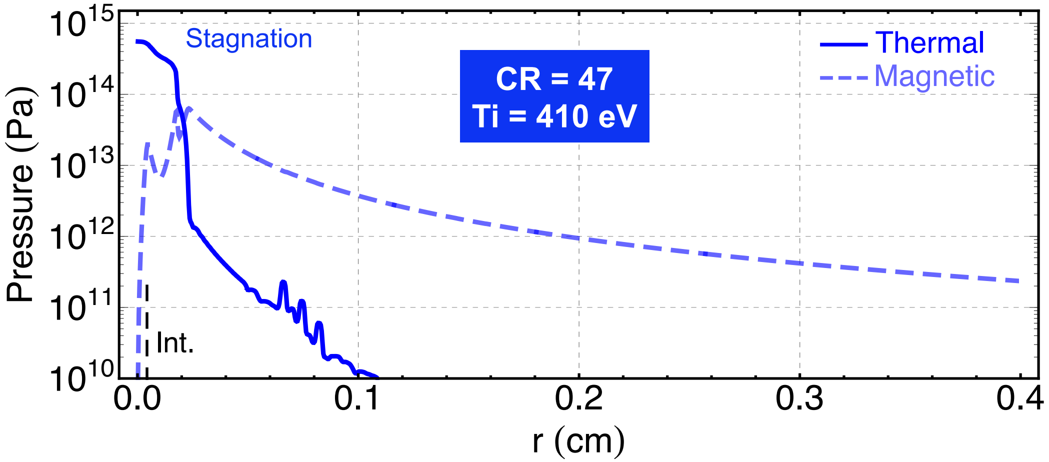
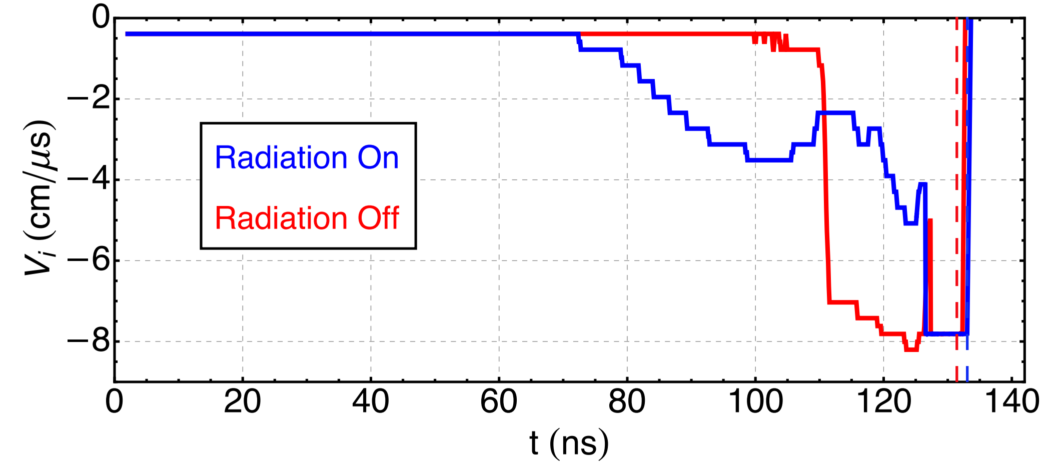
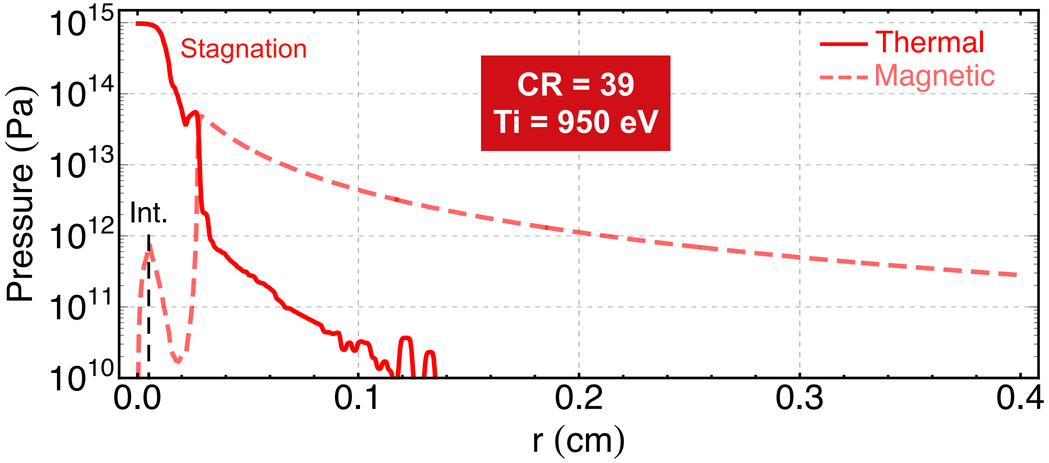


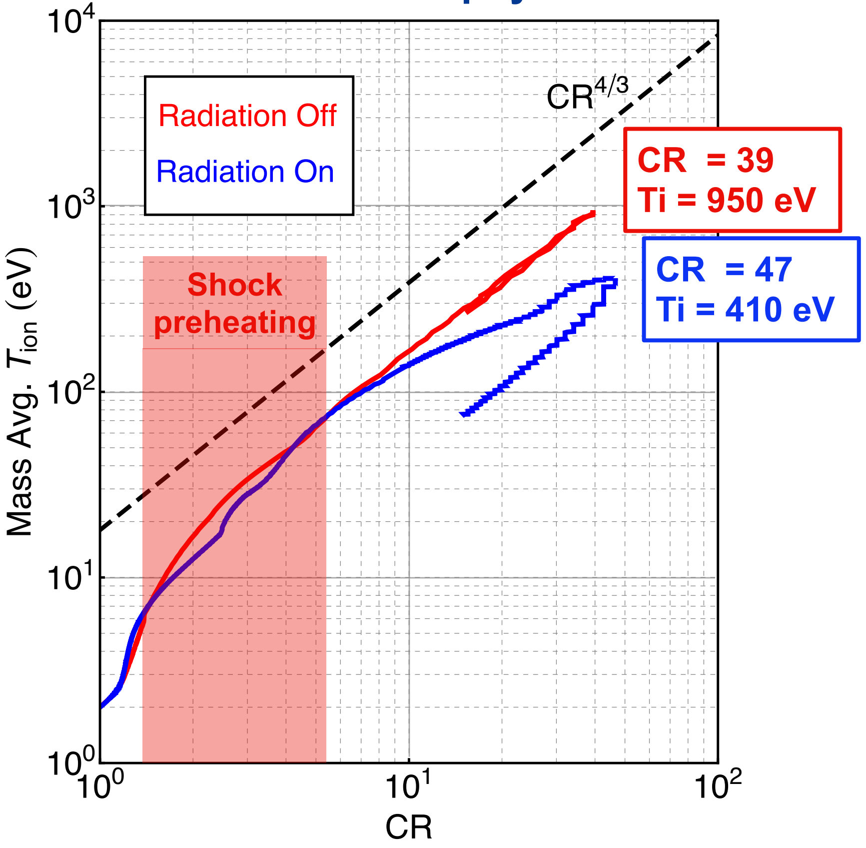



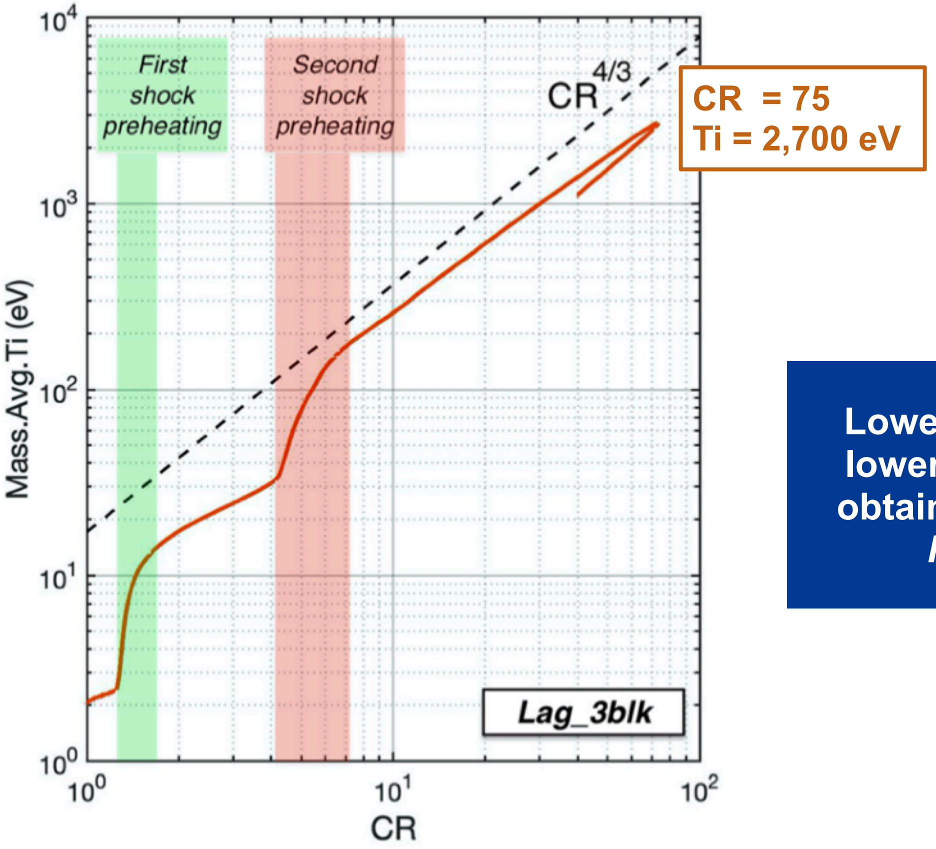



# Shock preheating is not as significant in ideal-physics *FLASH* simulations

## *FLASH* - Ideal physics




## *MACH2** - SESAME




**Lower ion temperatures at a lower convergence ratio are obtained in the ideal-physics *FLASH* simulation.**

* Ruskov *et al.* Phys. Plasmas 27, 042709 (2020).

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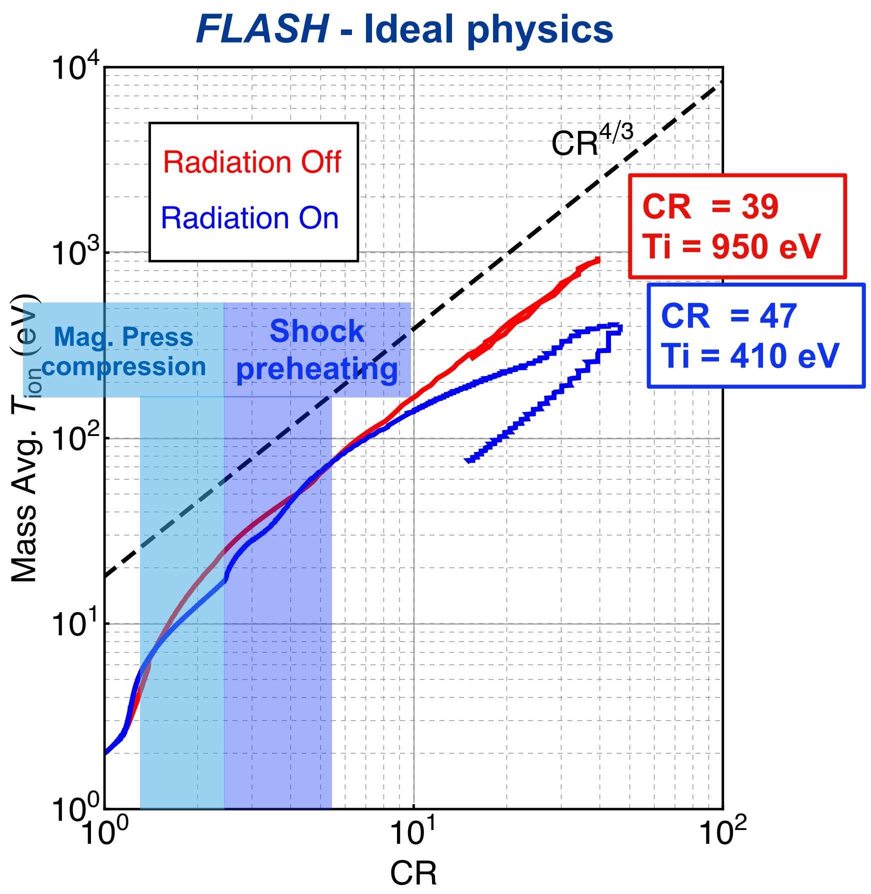


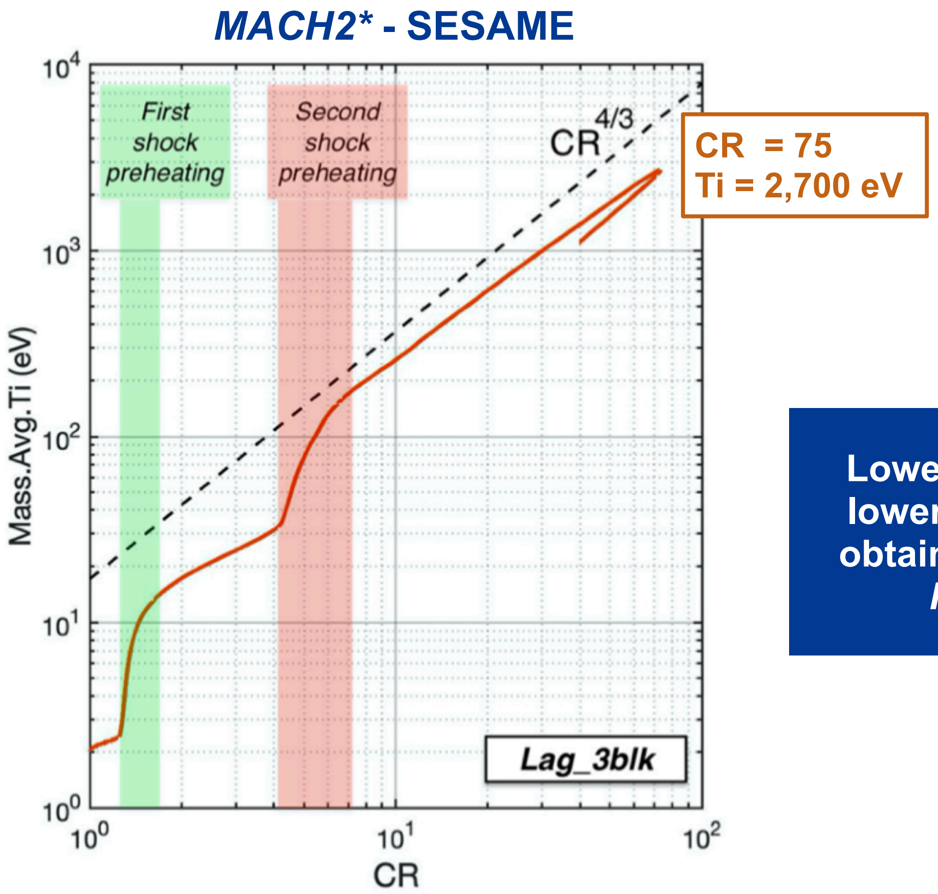


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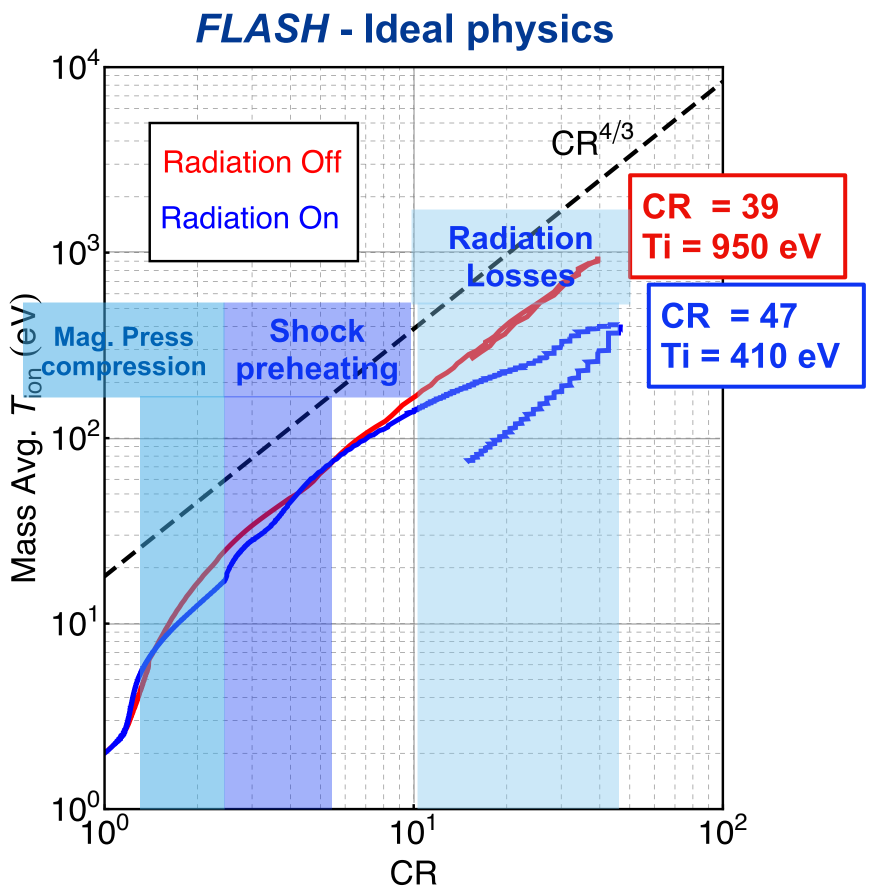


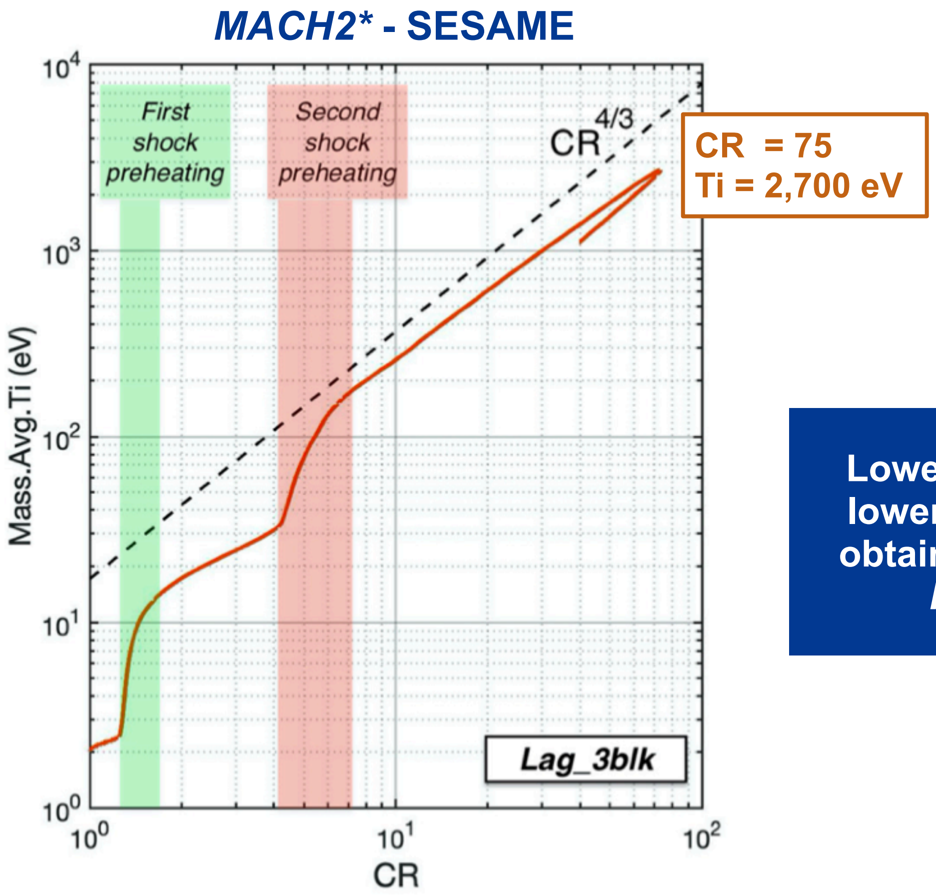


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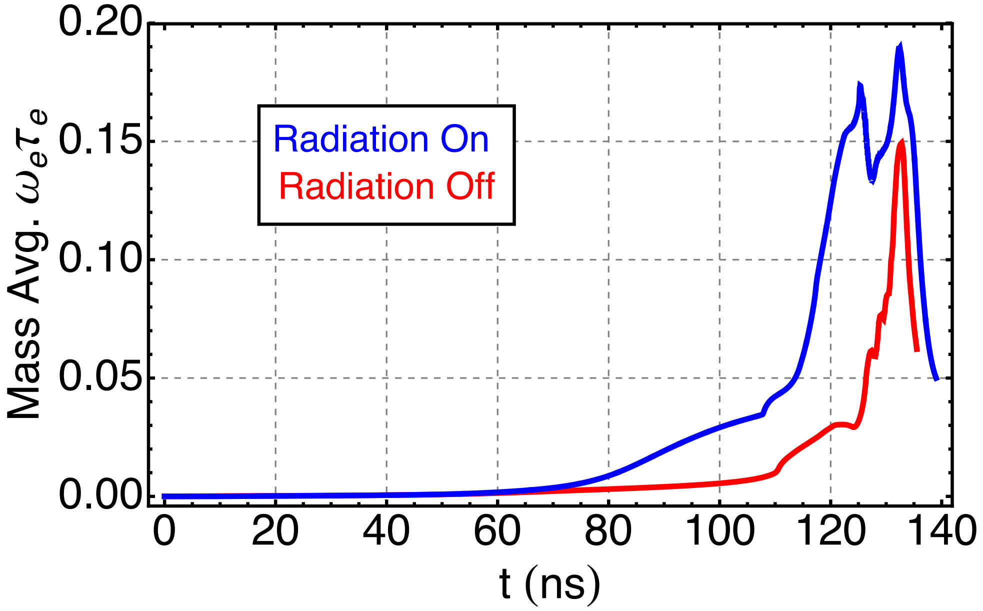
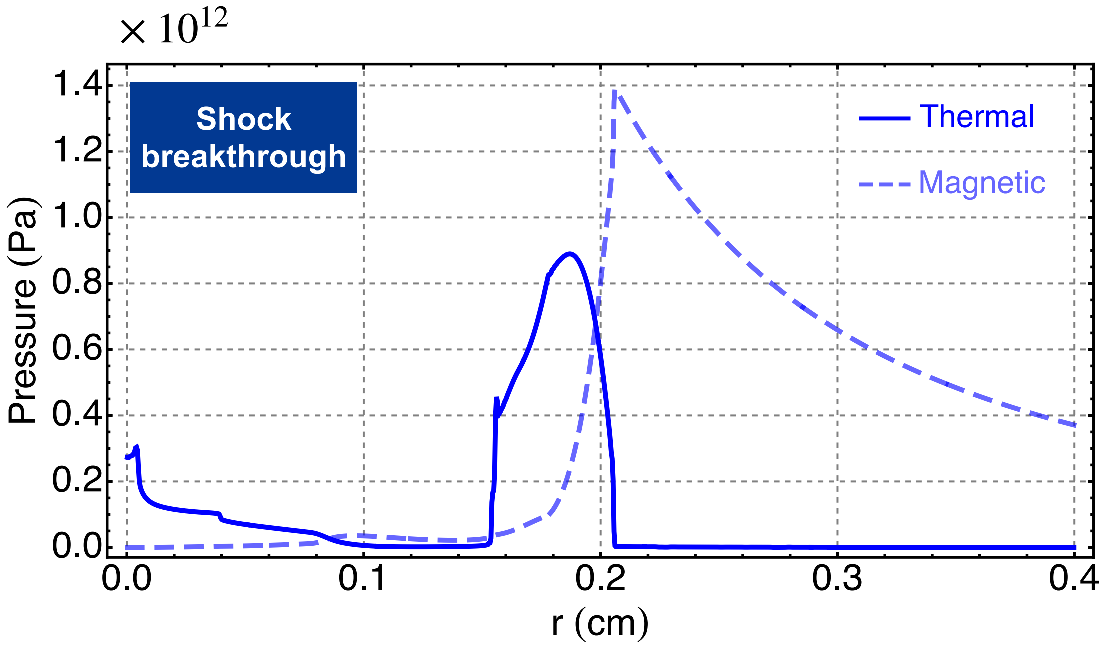
# What is the role of the diffused B field?




- **Thermal conductivity is reduced by a 12% for** $\omega_e\tau_e = 0.2$.

**The diffused B field barely ensures thermal insulation of the fuel but could enhance the stability of the pinch.**

Summary/Conclusions

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Thank you, any questions?