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U.S. NAVAL RESEARCH LABORATORY

SCALING OF EFFICIENT AR K-SHELL EMISSION FROM FAST GAS-PUFF Z-PINCHES IN THE 10 TO 100 MA CURRENT RANGE*

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Outline

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- **Results of recent simulations of argon gas-puff Z-pinch implosions using MACH2-TCRE code are presented.**
  - Overview of MACH2
  - Previously, successfully used for modeling argon gas-puff implosions with various load configuration and diagnostic dopant options on Z facility
- **In this presentation, a large set of high-current (10 MA to 100 MA) simulations spanning a wide circuit parameter space are discussed**
  - increasing the MITL current by varying the voltage profile
  - varying mass density
- **Analysis led to the confirmation of I^2 scaling of the efficient K-shell radiation yield previously established by NRL and that it is expected to be valid at high currents.**

MACH2 Can Simulate a Gas puff Z-pinch Implosion Including Radiation Emission

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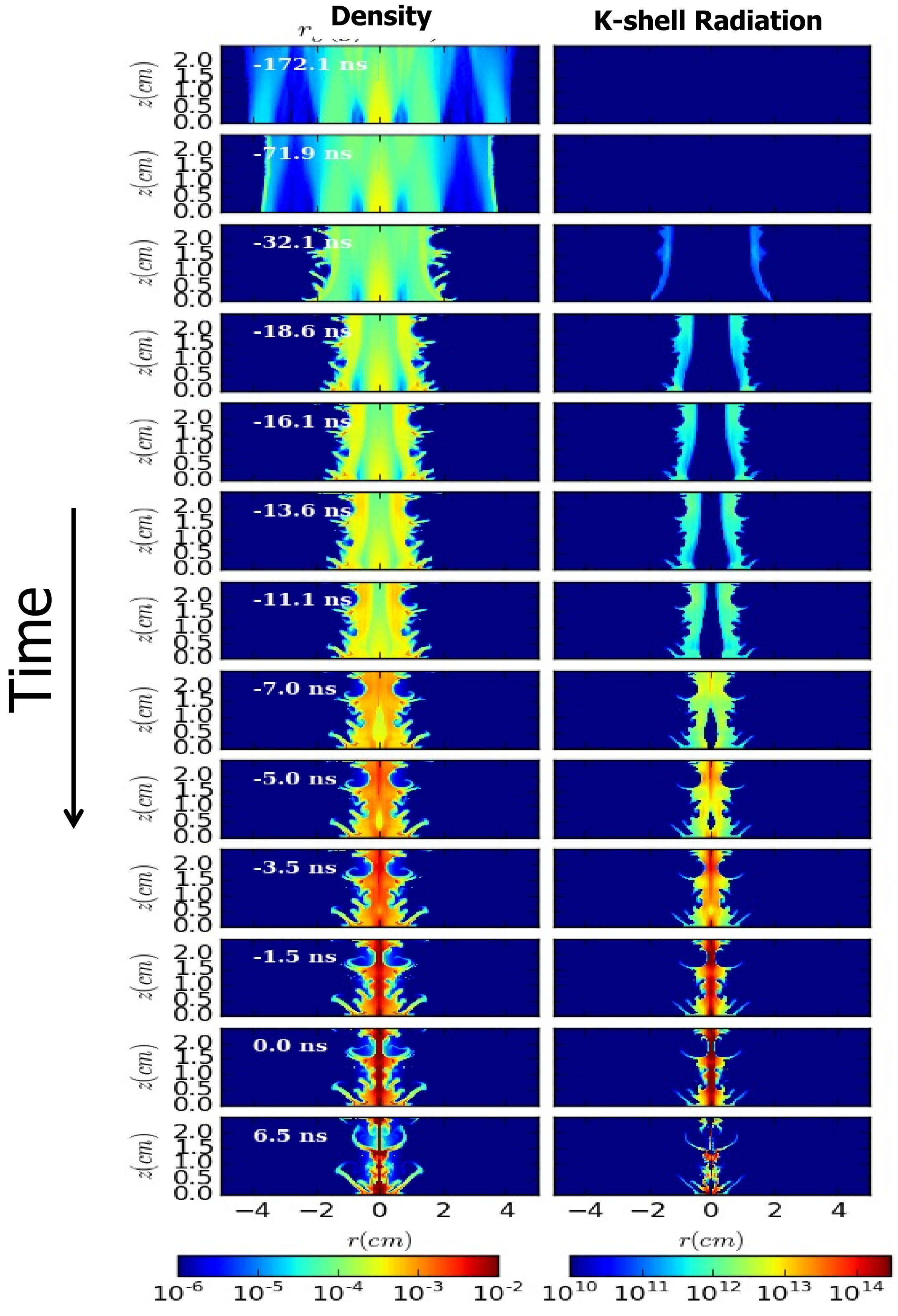

- **Simulation Tool: 2D (R-Z) MACH2**
  - R-Z cylindrical geometry with moving radial grid.
  - Arbitrary Lagrangian-Eulerian (ALE) resistive MHD code *(Peterkin, Frese, and Sovienc, J. Comput. Phys. 140,148, 1998)*
- **Radiation hydrodynamics included: TCRE**
  - Tabulated Collisional Radiative Equilibrium (TCRE) used for non-LTE ionization kinetics. *(Thornhill, Apruzese, Davis, et al., PoP, 8, 3480, 2001; Apruzese, G..)*
- **Interface tracking between Center jet and outer shells using the SLIC Algorithm**
- **Circuit model: Consistently coupled to the MHD**
- **TCRE-Mach2: Coupling improved to handle multi-materials**

Mach2 Can Handle a variety of Complex Geometries and Problems

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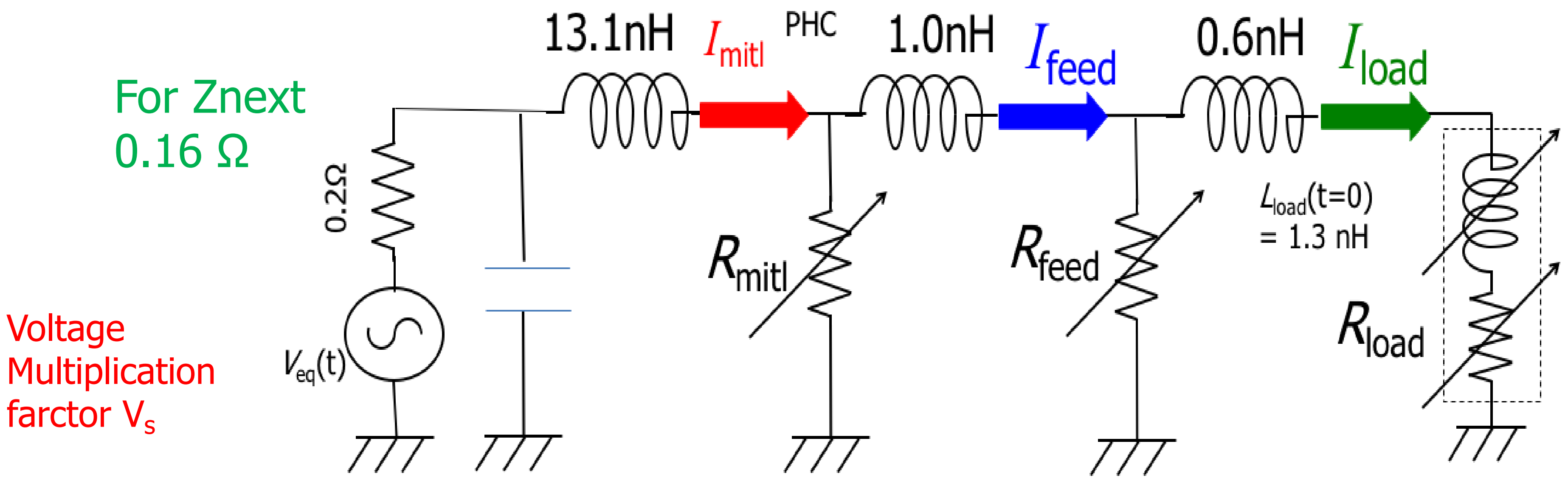
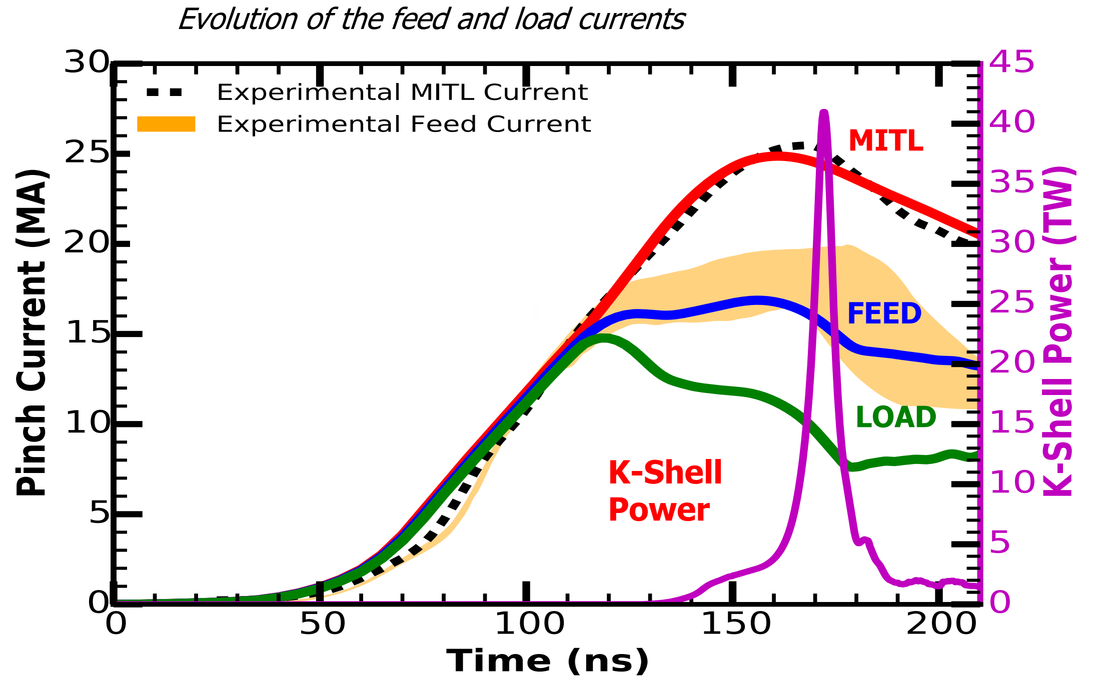


Customizable circuit



The shaded areas correspond to experimental bounds on feed currents

- **The circuit includes multiple loops that control the flow of pulsed power from the generator to the load. R_{mitl} and R_{feed} act as losses.**
  - **Loss controlled by varying the timing**
- **The circuit parameters were comprehensively investigated by Thornhill et. al.**
  - **Mach2-TCRE tuned to reproduce the measured I_{Feed} and I_{MITL} currents as well as the radiative properties of the experiments for Z2560.**
  - **Then timing was varied to investigate various loss scenarios**

$$R^A_{MITL}(\Omega) = \begin{cases} 5, & t \le t_A = 113 \text{ ns} \\ 0.2 + (5-0.2)e^{(t_A - t)/4\text{ns}}, & t > t_A \end{cases}$$

$$R^A_{feed}(\Omega) = \begin{cases} 5, & t \le t_A = 113 \text{ ns} \\ 0.3 + (5-0.3)e^{(t_A - t)/4\text{ns}}, & t > t_A \end{cases}$$

Empirical scaling of argon K-shell yield versus peak current

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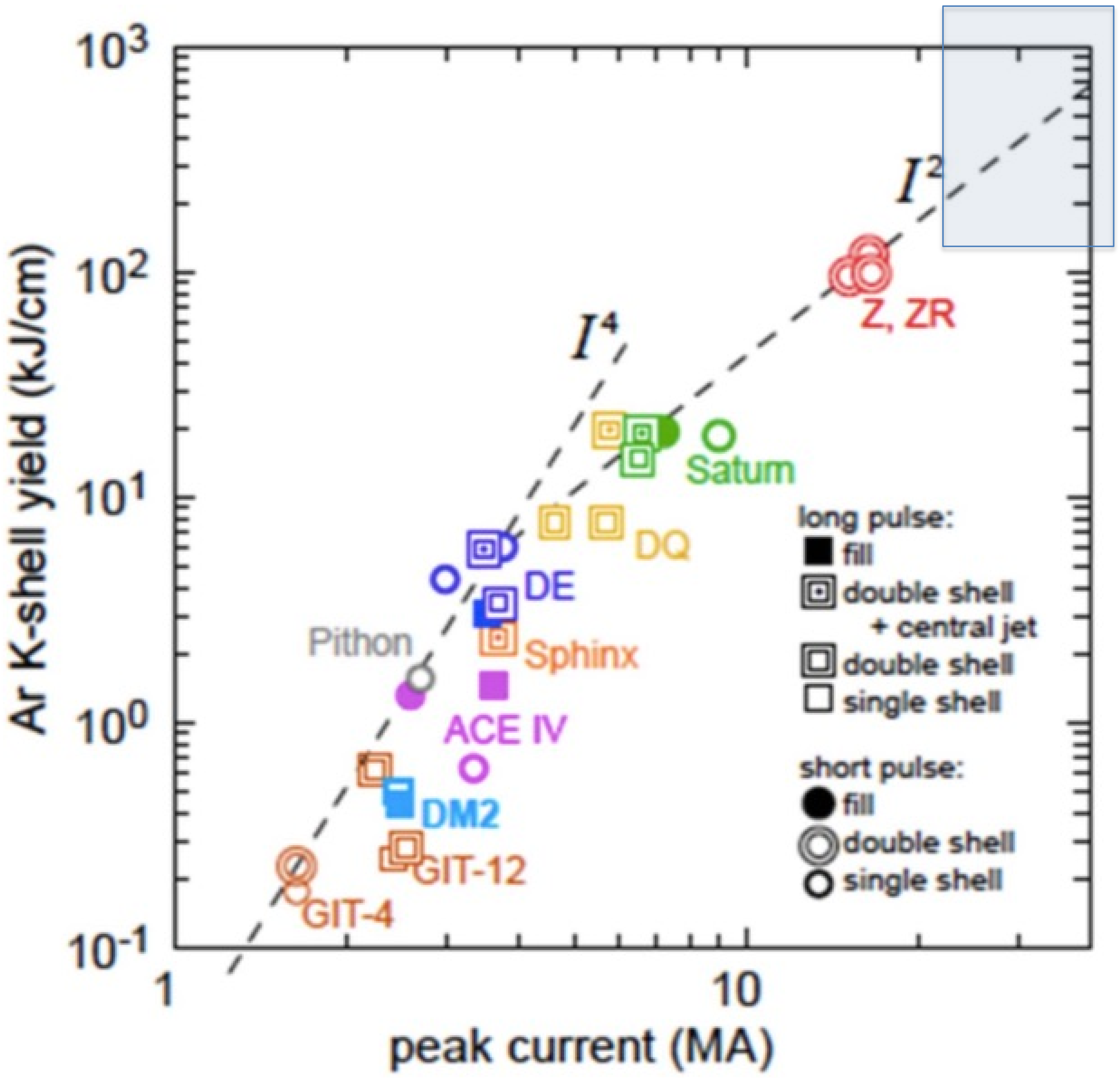

- **Ar K-shell yield is larger for generators that produce larger currents**
  - **I^2 Scaling of K-Shell Radiation Yield found at larger currents**
- **Apruzese et al. found that there is no break point if the K-shell radiation is plotted against the K-shell-emitting mass**

J. L. Giuliani; R. J. Commisso IEEE Transactions On Plasma Science, **8** 2385 (2015)

Mach2 Simulation results at 12.53 mg/cm

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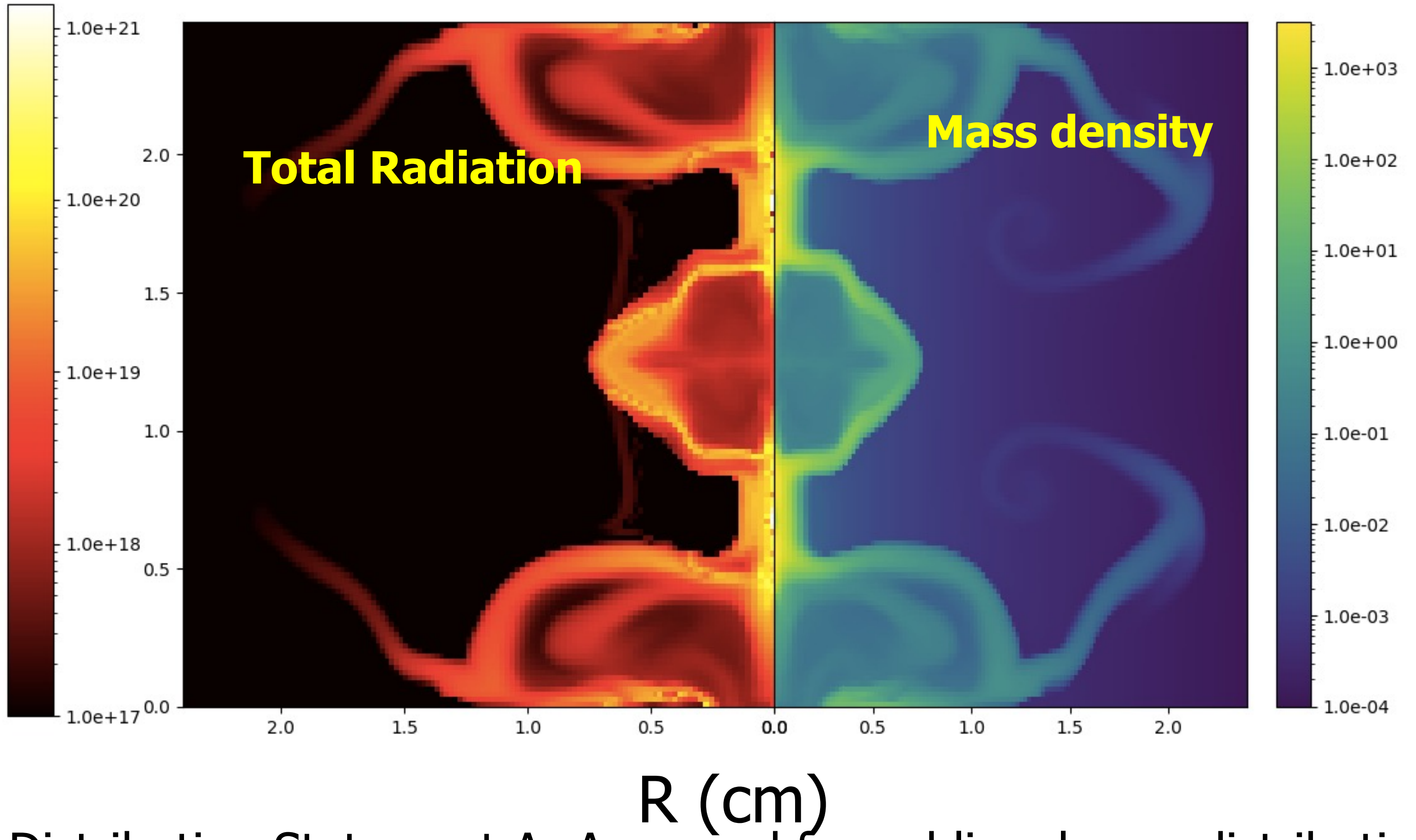
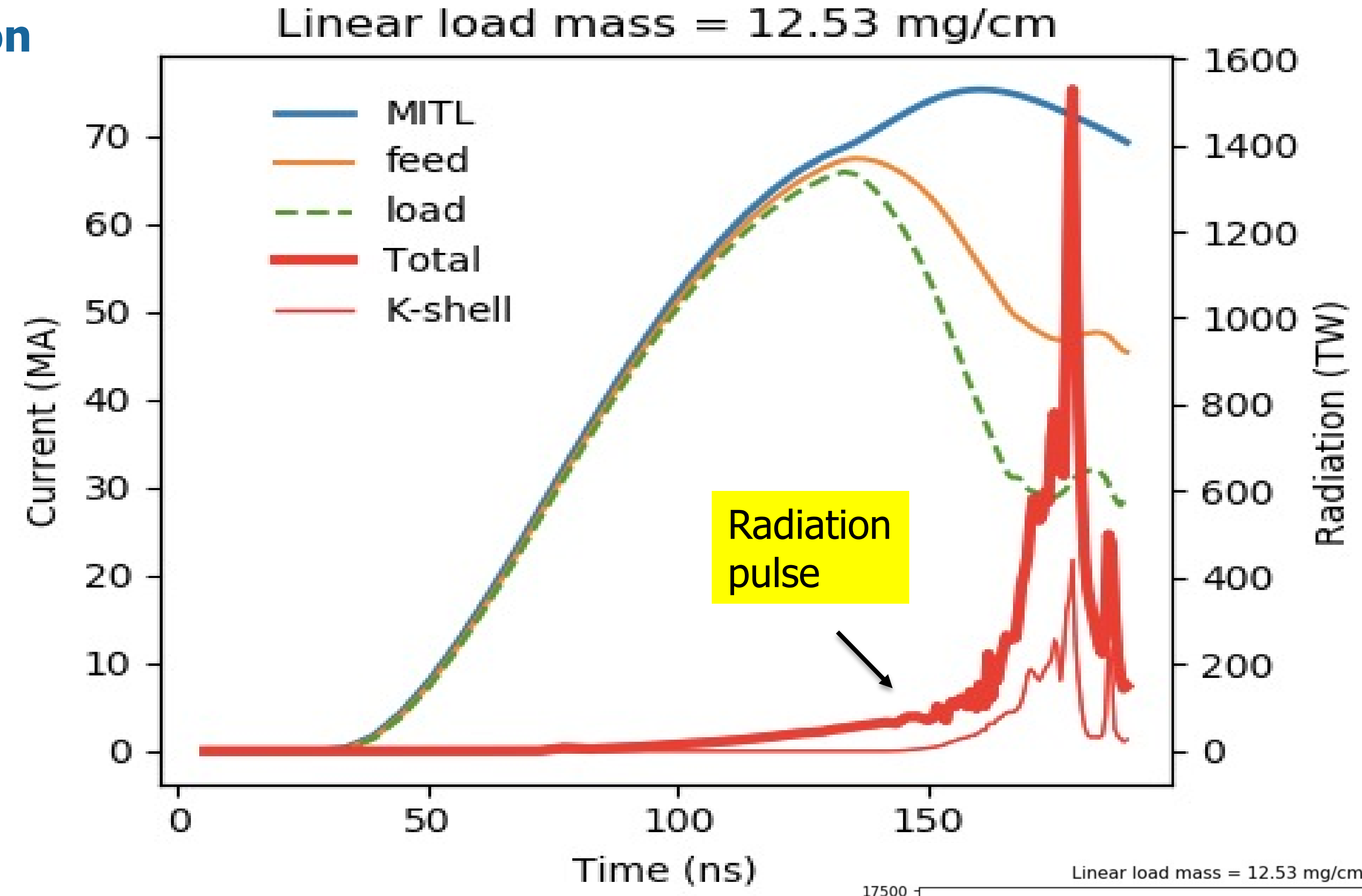
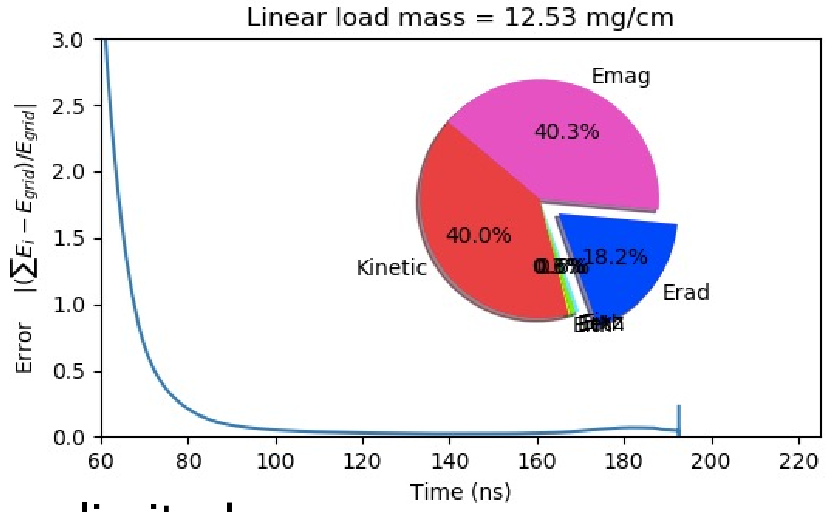
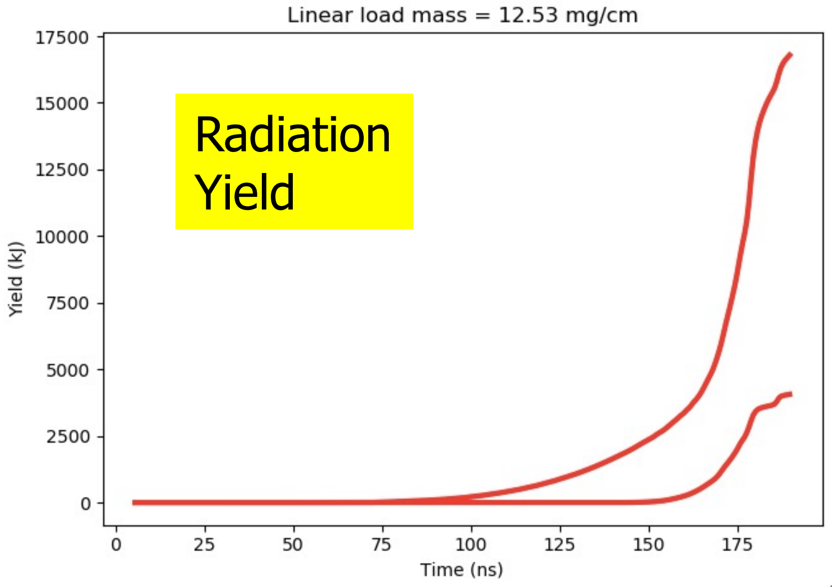
- Small fraction of mass emits for majority of the radiation
- Low density region plays a critical role
- About 1.5 Petawatt of peak total radiation emitted,
  400 TW K-Shell in about 30ns
- 15 MJ of total radiation
- 3.5 MJ of K-Shell radiation
- Prominently visible magnetic bubble
- No perturbation from added noise









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Previous Simulation Data was close to observations

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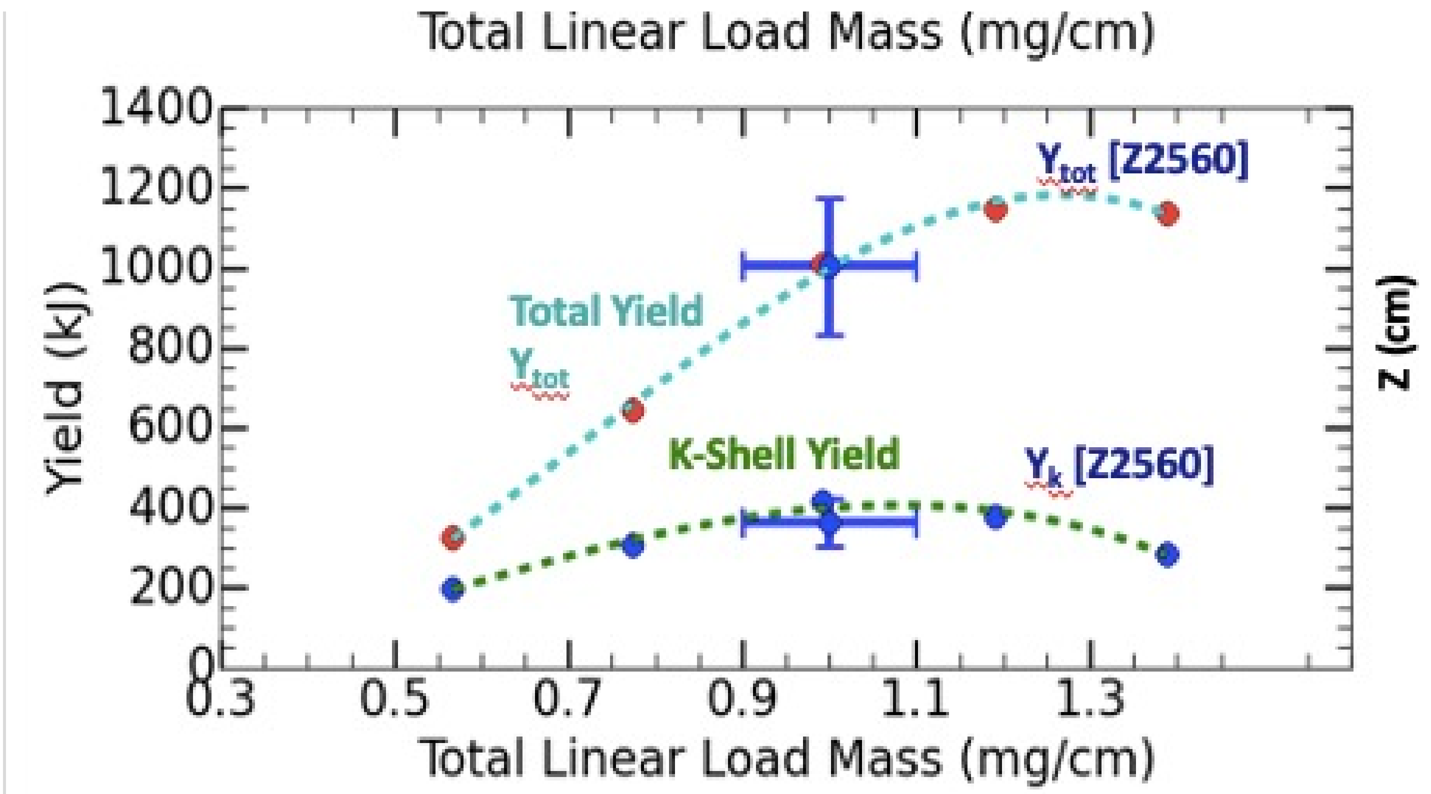

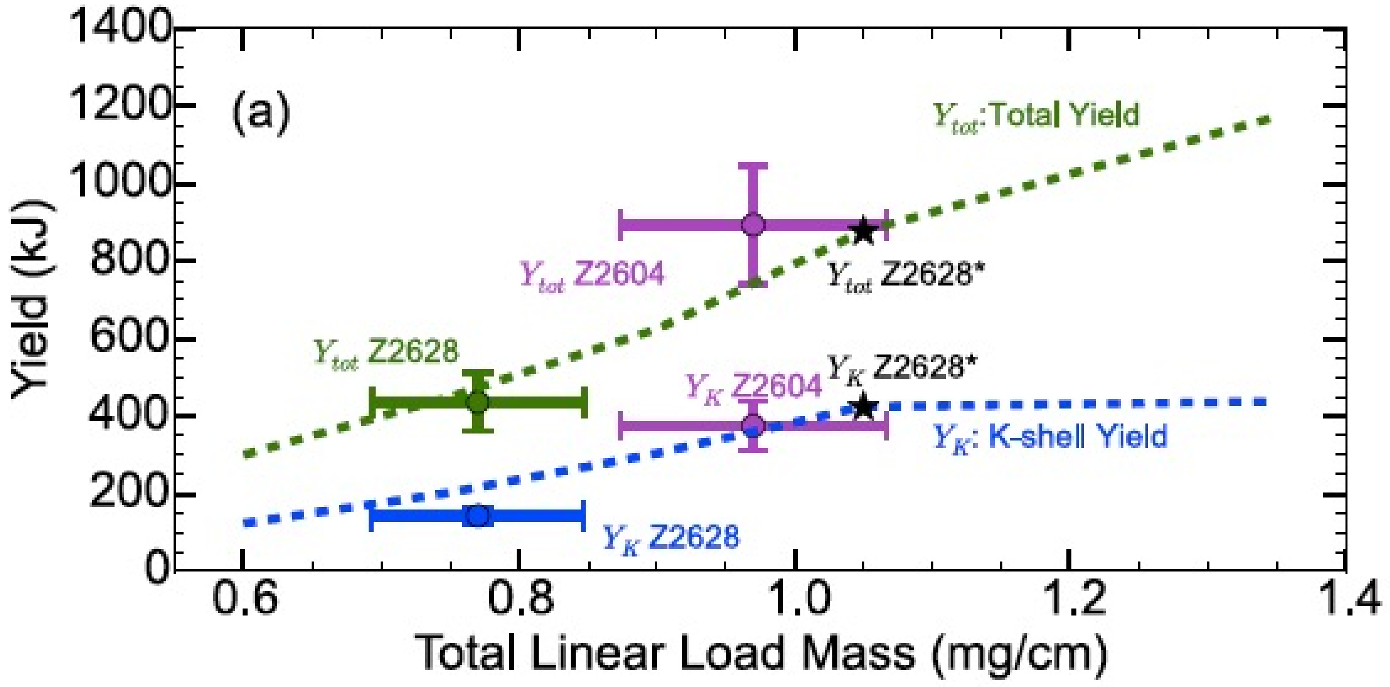

Previous result:
Tangri et. al. Phys. Plasmas 23, 101201 (2016)

- **Simulation Data close to observations**
  - –Dashed lines: MACH2 simulation estimate
  - –Circles with errorbars: Z2628 (purple), Z2604 (blue)

- **Yield from double shell at a higher load mass can match that of the double shell + center jet, but not the power**

- **Mass varied in 0.6mg/cm -1.4mg/cm range**

- **Current consistent with Z-circuit**
  - — **This presentation investigates for larger masses and currents**

I^2 Scaling of K-Shell Radiation Yield versus peak MITL Current

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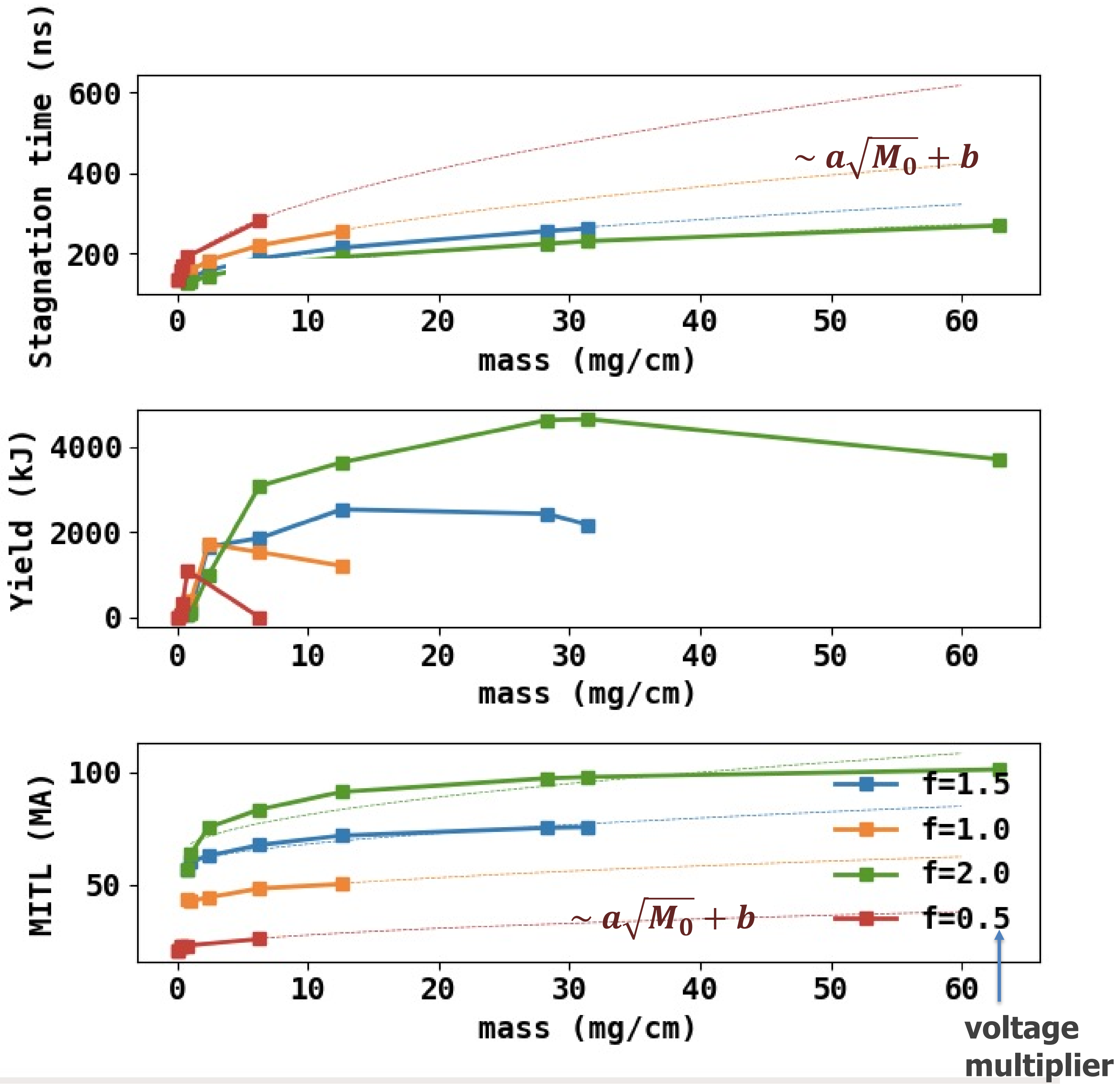


- Mass varied in 0.15mg/cm -60mg/cm range
- Current varied in 10-100MA range
  - Using a voltage multiplier to simulate larger currents (f) in figure
- Optimal mass for each current range found

- implosion time varies with the total mass M_o and the peak current I_{pk} as

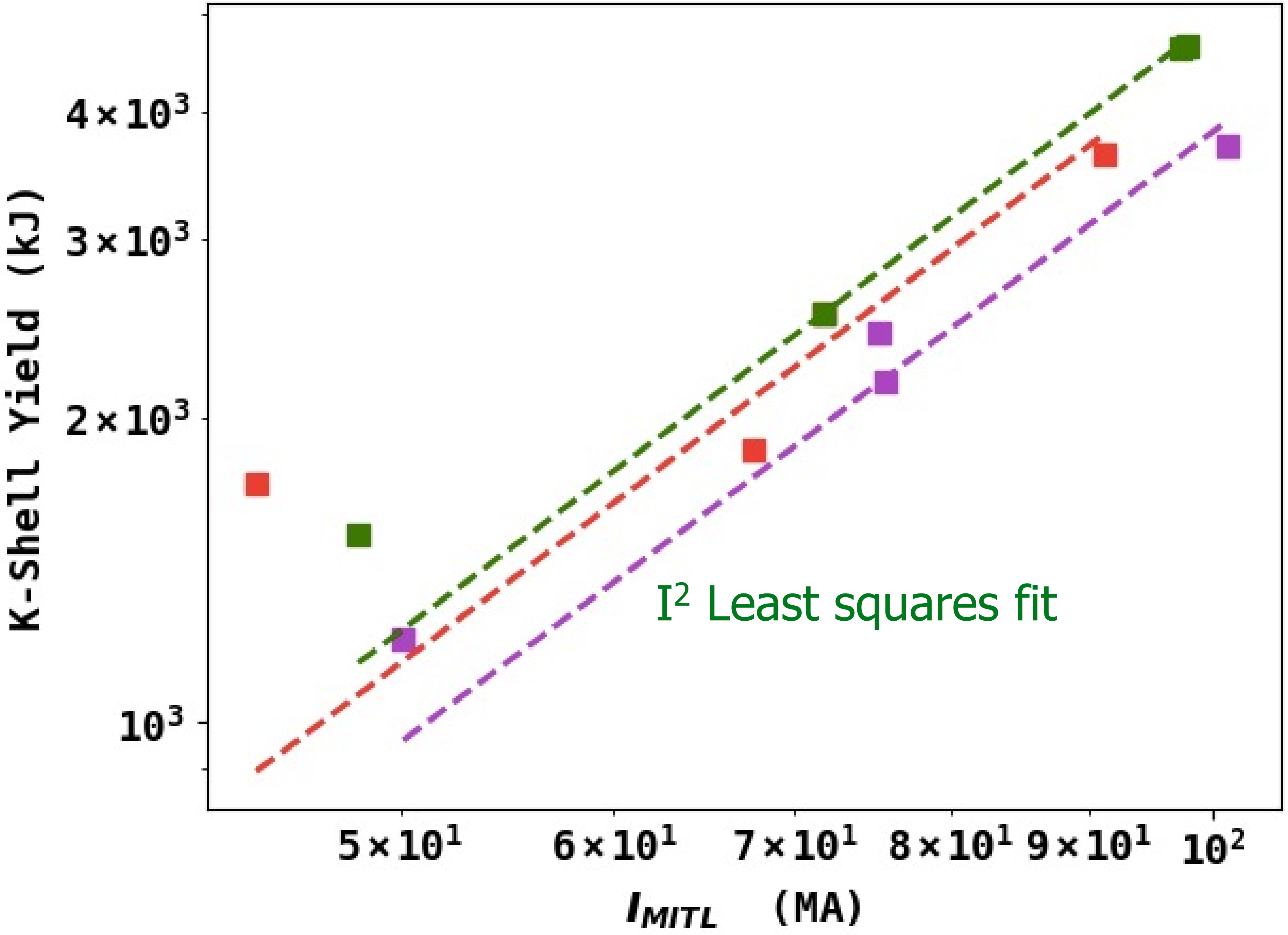
$$M_o r_o^2 \sim \frac{\ell}{c^2} I_{pk}^2 t_{imp}^2. \quad \text{(III-34)}$$

John L. Giuliani, and Robert J. Commisso, IEEE Trans. on Plasma Science, **43**, (2015)

- Both Stagnation time as well as current $\sim\sqrt{M_0}$
  - —Indicated by thin dashed line
  - —Consistent with above equation

I^2 Scaling of K-Shell Radiation Yield versus peak MITL Current

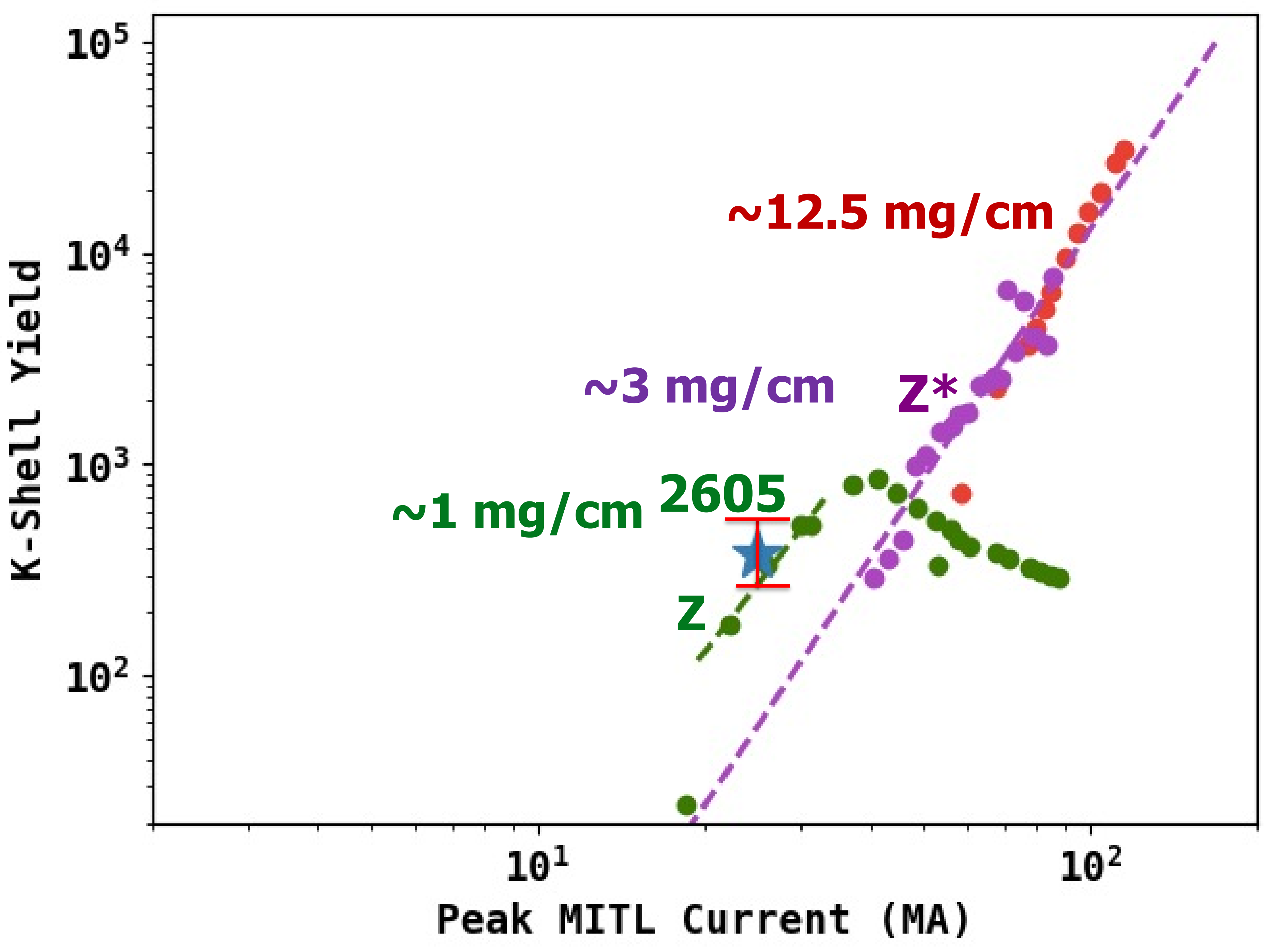
NRL PPD



- **Investigated the effect of increasing the mass as well as current on K-Shell Yield**
- **Each point in the figure is a different run**
  - **Mass varied to find optimum parameters for that range**
  - **Plotted on a log-log scale**
- **Lines connect data with similar implosion time**

I^2 Scaling of K-Shell Radiation Yield versus peak MITL Current

NRL PPD



Increasing f →

- Investigated the effect of increasing the voltage by using a multiplication factor
  - This factor varied to perform over a hundred simulations
  - One-loop circuit used
- Each point in the figure is a different run
  - Mass varied to find optimum parameters for that range
  - Plotted on a log-log scale
- Simulations for Z* (purple) have the same voltage profile as in Z(green)
  - Different mass
- The star is previous simulations for Z2605 Tangri et. al. Physics Of Plasmas 23, 101201 (2016)
- I^2 Scaling observed

Summary

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- **In this presentation, a large set of high-current (10 MA to 100 MA) simulations spanning a wide circuit parameter space was discussed**
  - —increasing the MITL current, varying the voltage profile, mass density,
  - —Parameters varied to perform over a hundred simulations

- **Analysis led to the confirmation of I^2 scaling of the efficient K-shell radiation yield previously established by NRL and that it is expected to be valid at high currents.**

- **Future work: Examine the values of K-Shell mass for these simulations. We will also examine the effects of hollow and peaked inital mass density profiles**