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Title: Complex Loading of CeO2 Powder

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Complex Loading of CeO_2 Powder

pRad Workshop • Wednesday, August 29, 2018

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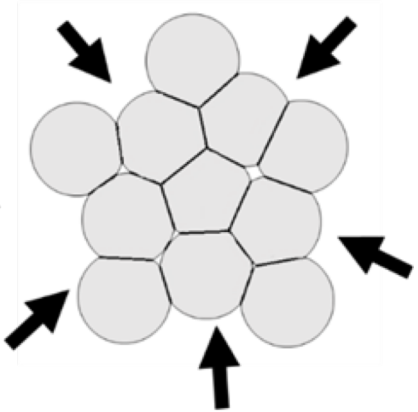
Powders are typically modeled using compaction models, which approximate pressure-density response

***P-σ_y Model* [1]**



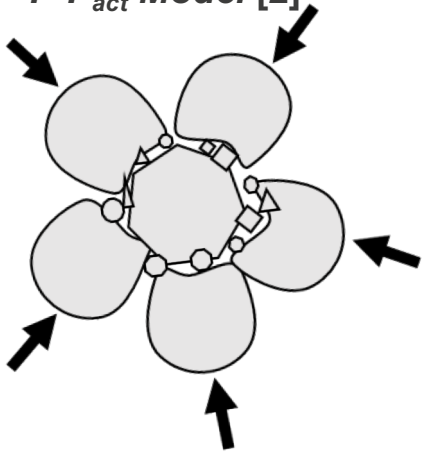
Fischmeister and Arzt (1983)

Resistance to densification is a function of increasing contact area between particles

$$P = f(\rho)$$

Scope: quasistatic, ductile

***P-P_{act} Model* [2]**



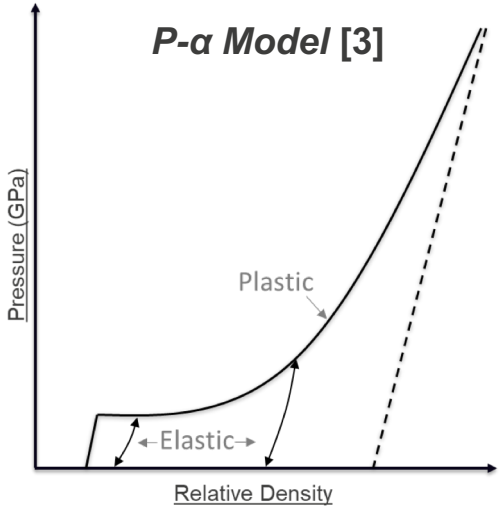
Kenkre, et al (1996)

Densification can be modeled as a particle overcoming a volume obstacle to fill a void

$$\rho = f(P)$$

Scope: quasistatic, brittle

***P-α Model* [3]**



Herrmann (1969)

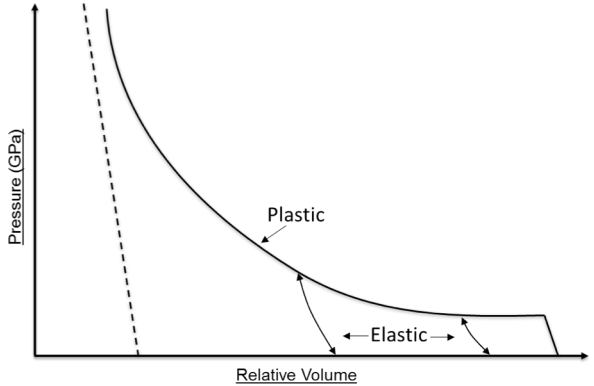
Continuum model. Separated elastic and plastic response. Introduced distention 'α'.

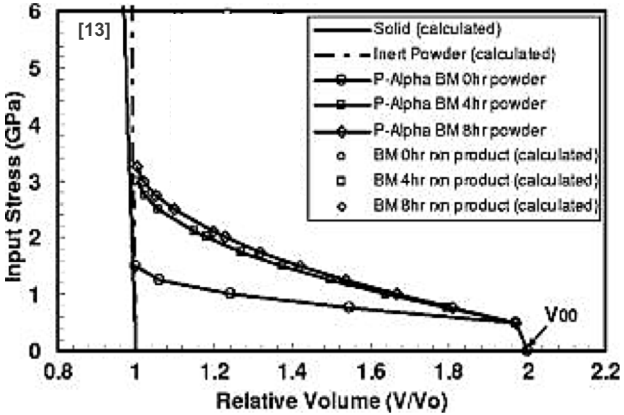
$$P = f(E, \alpha)$$

Scope: dynamic, ductile

1. H. Fischmeister and E. Arzt, *Pow. Met.* (1983) 2. V. Kenkre, et al, *JACerS* (1996) 3. W. Herrmann, *JAP* (1969)

A variety of functional forms exist for each type of compaction model, e.g., P-α; which model is best?

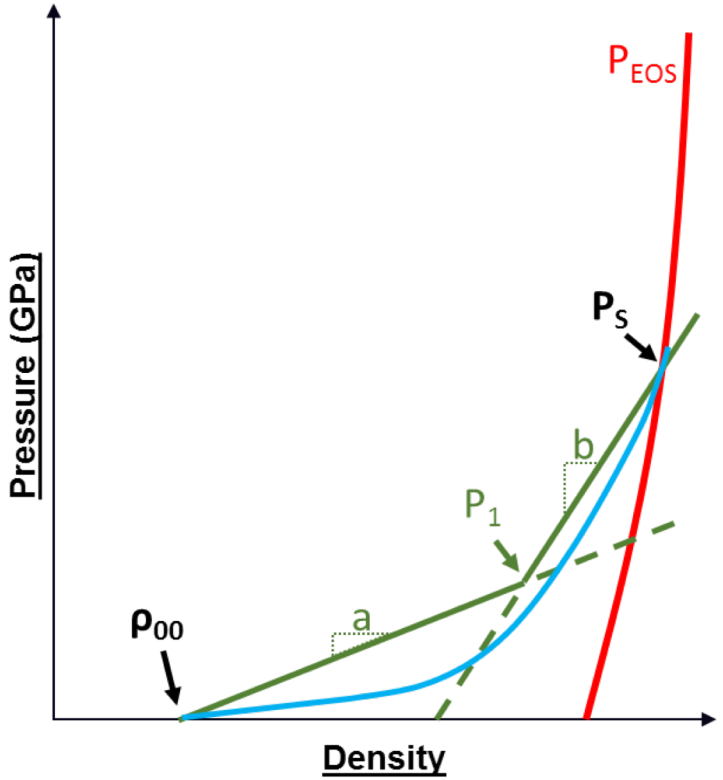




Year	Developer	Material Modeled	α Functional Form
1969	Herrmann [3]	Aluminum and iron powders	$1 + (\alpha_{00} - 1)\left(\frac{P_S - P}{P_S - P_E}\right)^2$
1969	Bucher and Karnes [4]	Iron powder	$\alpha_0 + \alpha_1 P + \alpha_2 P^2$
1970	Boade [5]	Copper powder	$1 + (\alpha_{00} - 1)\exp[-\bar{\alpha}(P_S - P_E)]$
1972	Carrol and Holt [6, 7]	Hollow sphere of ductile material	$\left[1 - \exp(-\frac{3P}{2\sigma_y})\right]^{-1}$
1999	**Menikoff and Kober [8]**	**Non-equilibrium two-phase flow**	$\left[1 - \left(1 - \frac{1}{\alpha_{00}}\right)\exp\left(-\frac{V_S P_S - V_{00} P_{00}}{V_{00} P_C}\right)\right]^{-1}$
2007	Grady [9]	Sand	$\left(\frac{P_S}{P}\right)^{\frac{1}{N}}$

3. W. Herrmann, *JAP* (1969) 4. B. Butcher and C. Karnes, *JAP* (1969) 5. R. Boade, *JAP* (1970) 6. M. Carrol and A. Holt, *JAP* (1972) 7. M. Carrol and A. Holt, *JAP* (1972)
8. R. Menikoff and E. Kober, *SCCM Conference Proceedings* (1999) 9. D. Grady, *Sandia Internal Report* 10. X. Xu and N. Thadhani, *JAP* (2004)

In the LANL hydrocode FLAG, the most prevalent compaction models are the Ramp and P-α models



P-α Models: PACXP and Menikoff-Kober

(1) $P = f(\alpha, E)$

(2) $\alpha = \frac{V}{V_{EOS}} = \frac{\rho_{EOS}}{\rho}$

(3) $\alpha_{PACXP}(P) = 1 + \sum_{i=1}^{n} \alpha_i \exp(-b_i P)$

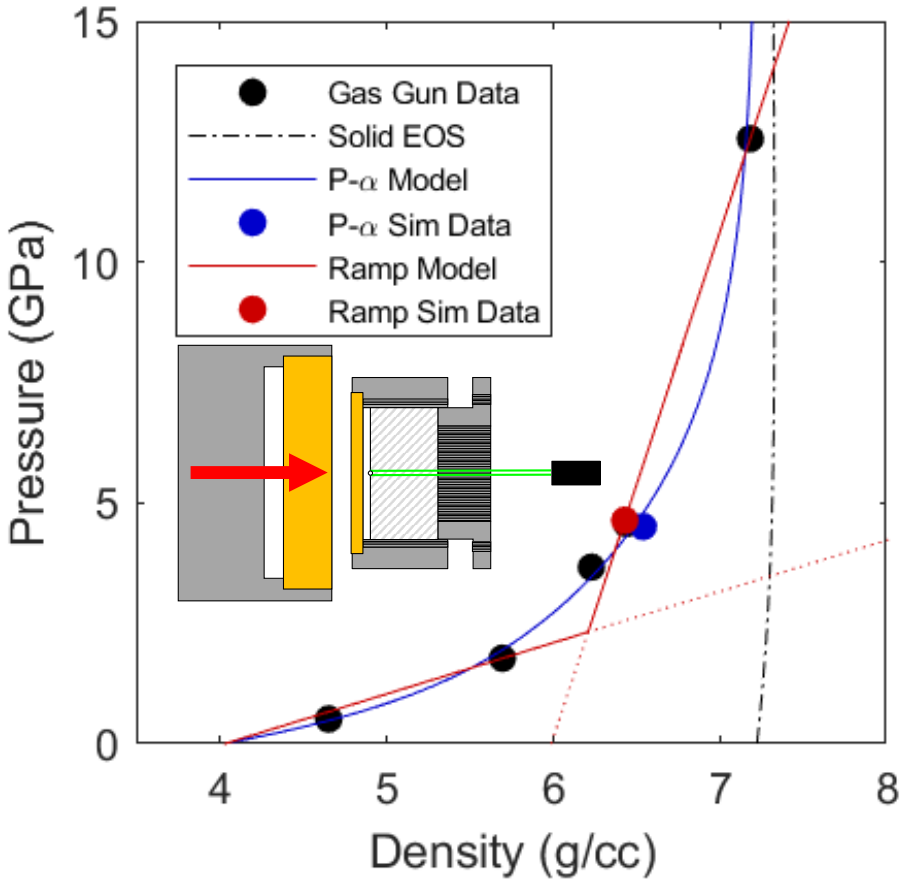
(4) $\alpha_{MenKo}(P) = \left[1 - \left(1 - \frac{1}{\alpha_{00}}\right) \exp\left(-\frac{V_S P_S - V_{00} P_{00}}{V_{00} P_C}\right)\right]^{-1}$

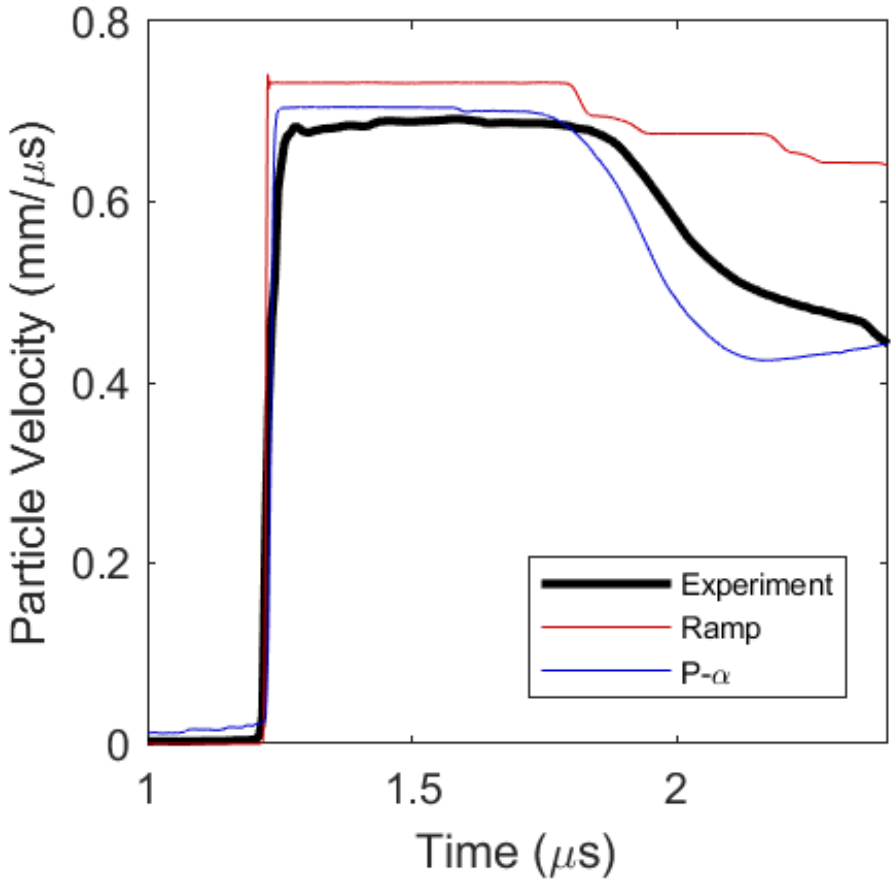
Bi-linear Ramp Model: linear transformation

(5) $P(\rho) = a\left(\frac{\rho}{\rho_{00}} - 1\right), 0 \le P \le P_1$

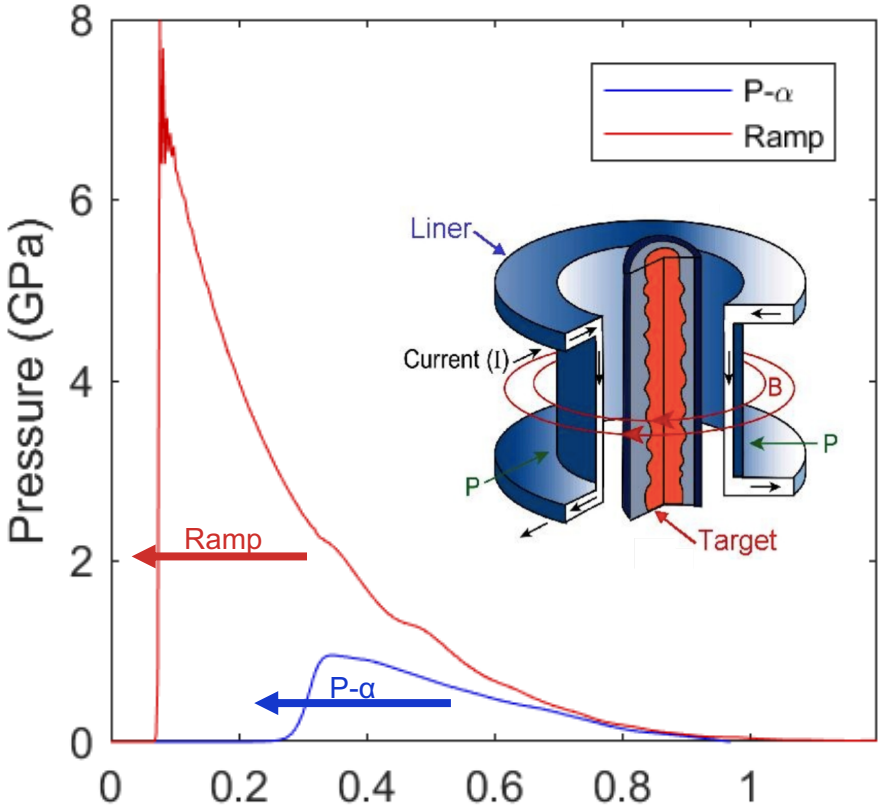
(6) $P(\rho) = b\left(\frac{\rho}{\rho_{00}} - c\right), P_1 \le P \le P_S$

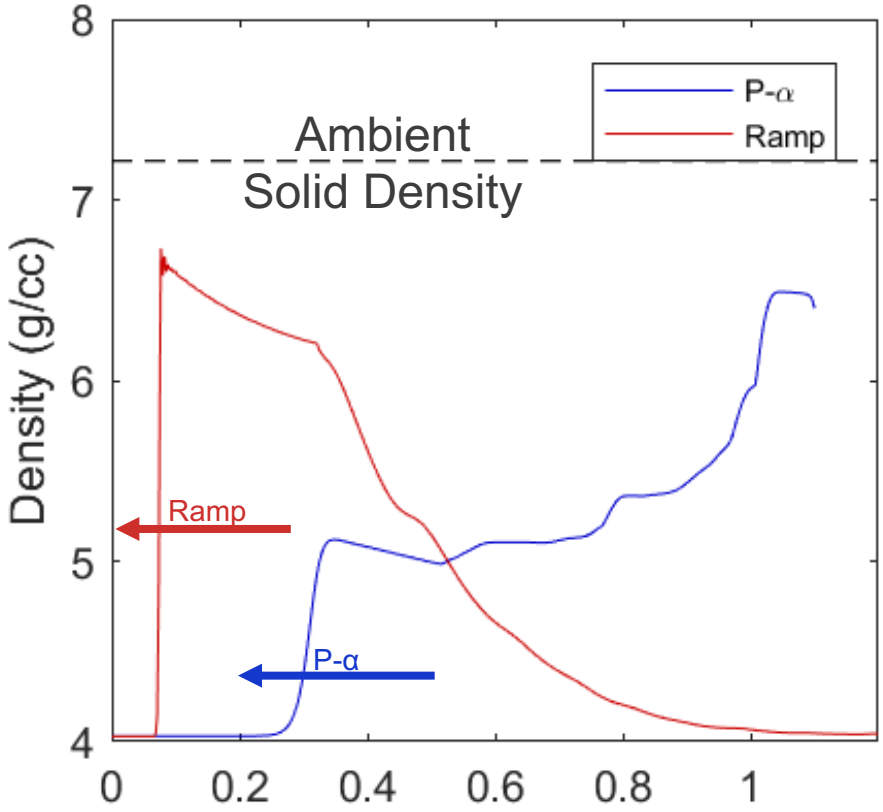
For 1D planar loading (gas gun), Ramp and P-α models reproduce P-ρ Hugoniot data and particle velocity profiles





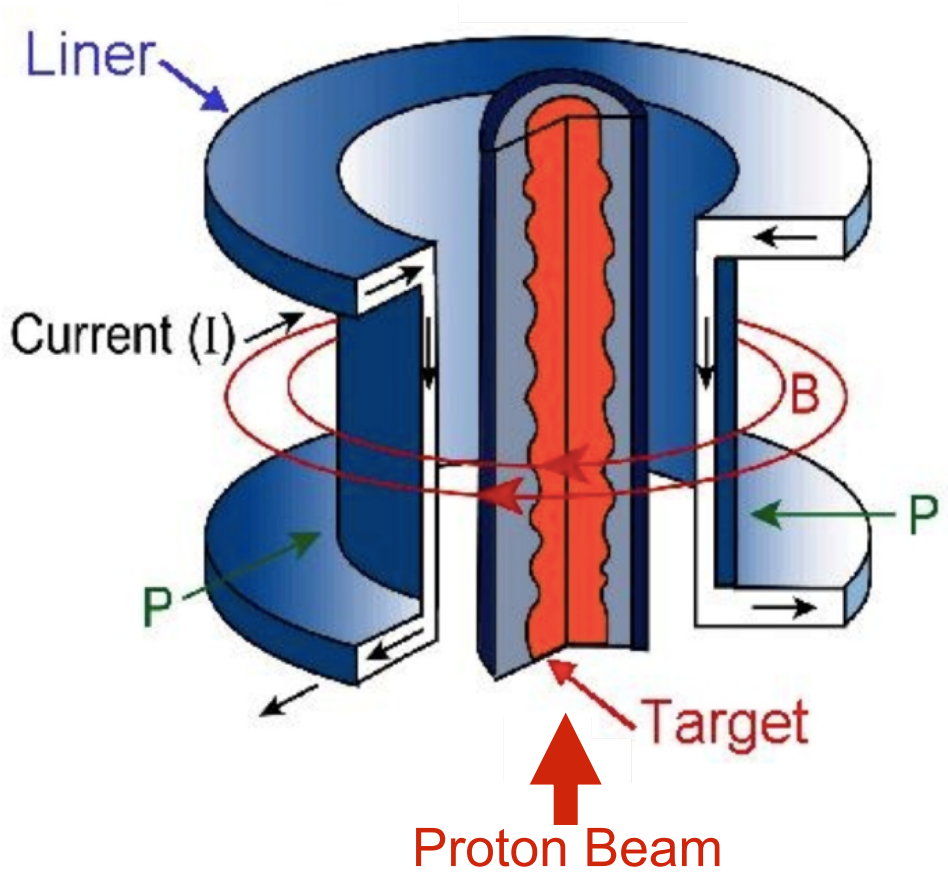
However, these models vary significantly when applied to more complex loading, e.g., 1D cylindrical





Radial Distance from Center of Powder (cm)

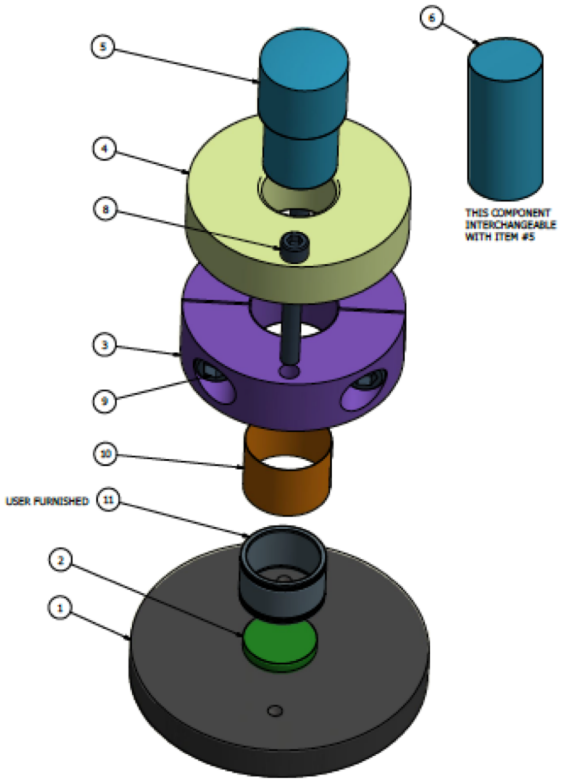
Goal of Project: Determine which of the available powder models best describe densification under complex loading

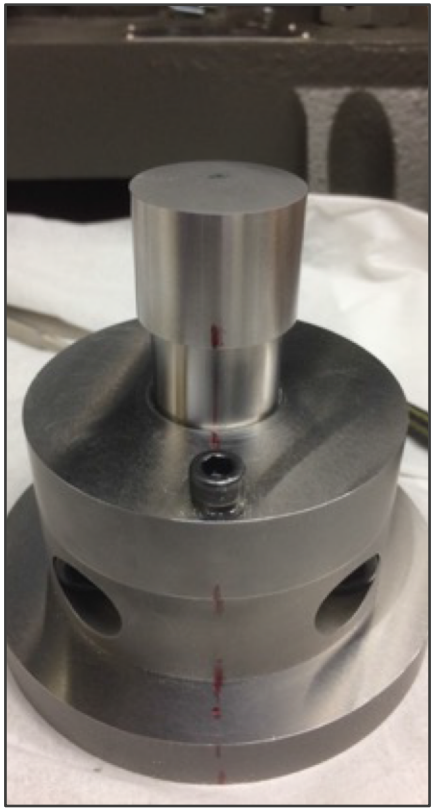


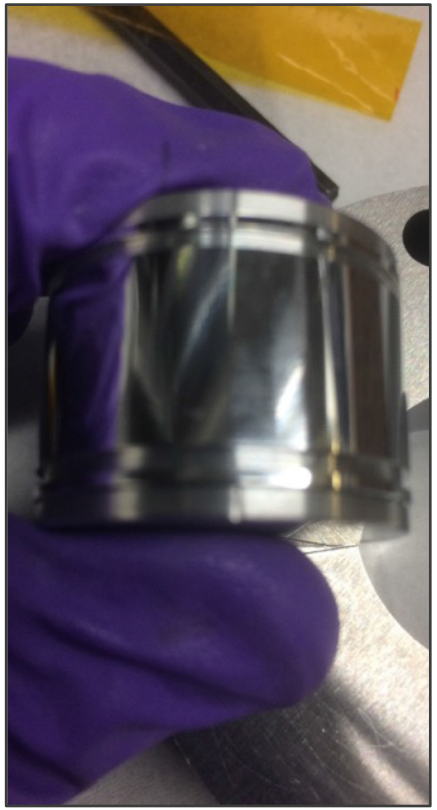
Technical Approach:

- **Design complex loading experiment**
  - Pulsed Power Driver: PHELIX
  - Measurements: Proton Radiography
- **Execute experiment**
- **Analyze data and validate models**
  - Determine opportunities for model improvements

Target Preparation: CeO_2 powder was pressed to an initial porous density of 3.95 g/cc in an Al6061-T6 cylinder

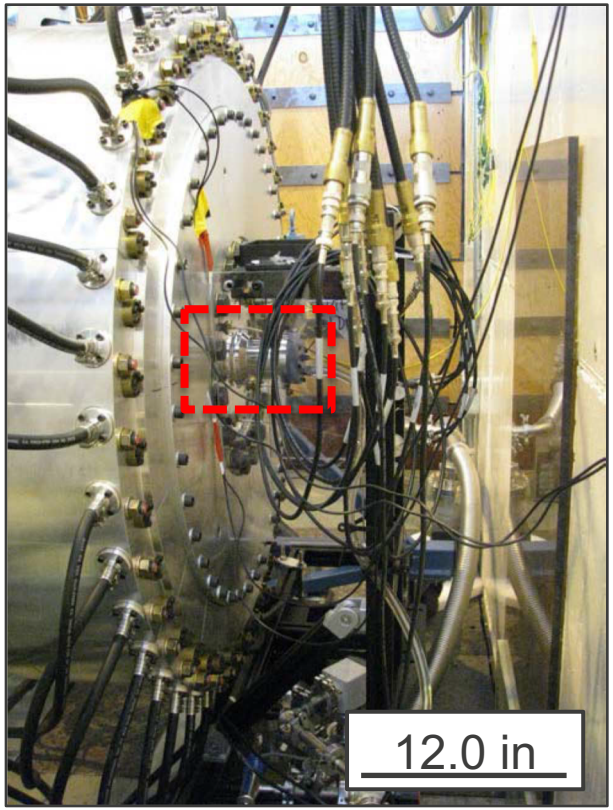


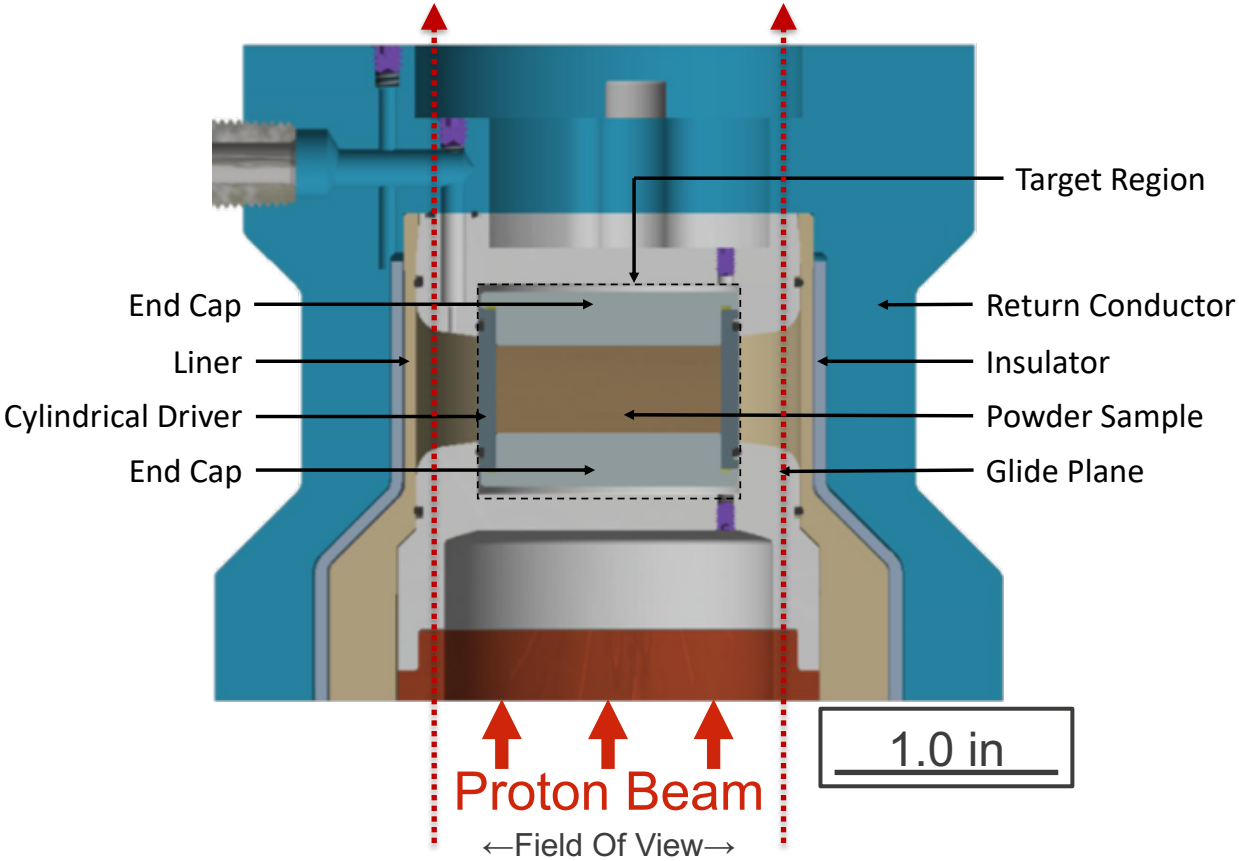




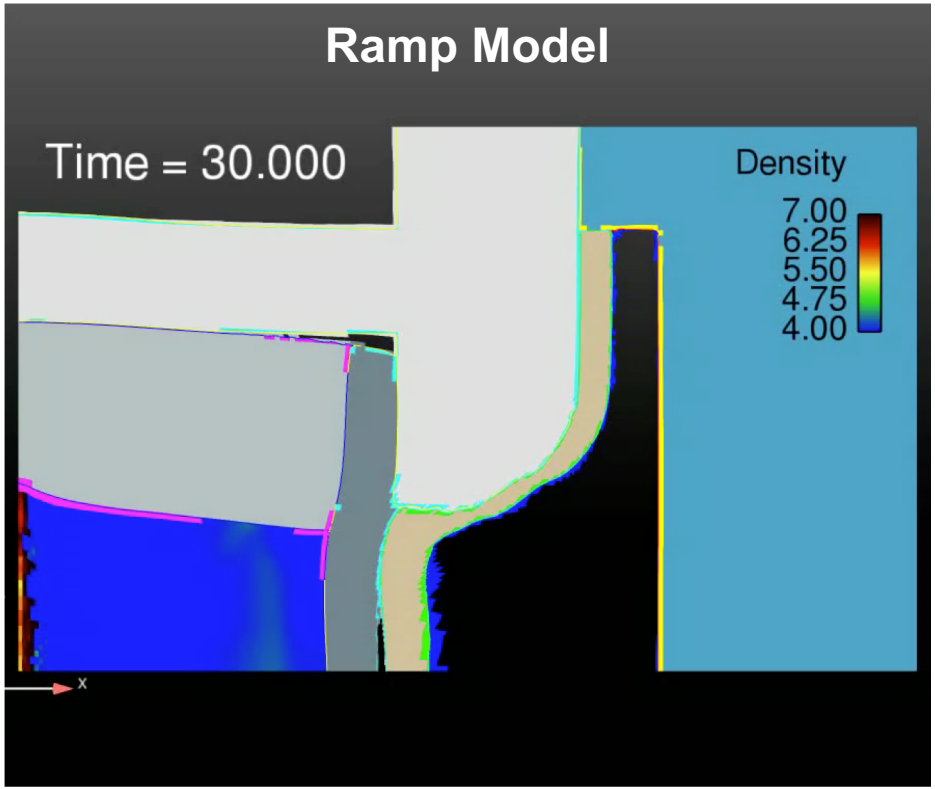
PHELIX:

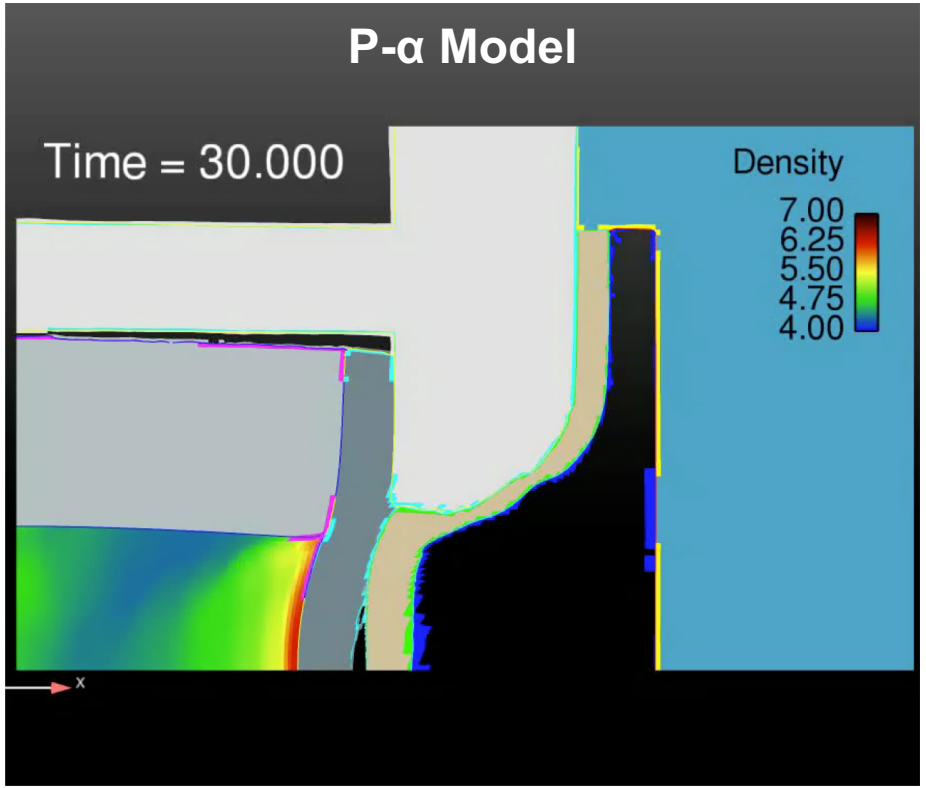
Precision High Energy-density Liner Implosion Experiment





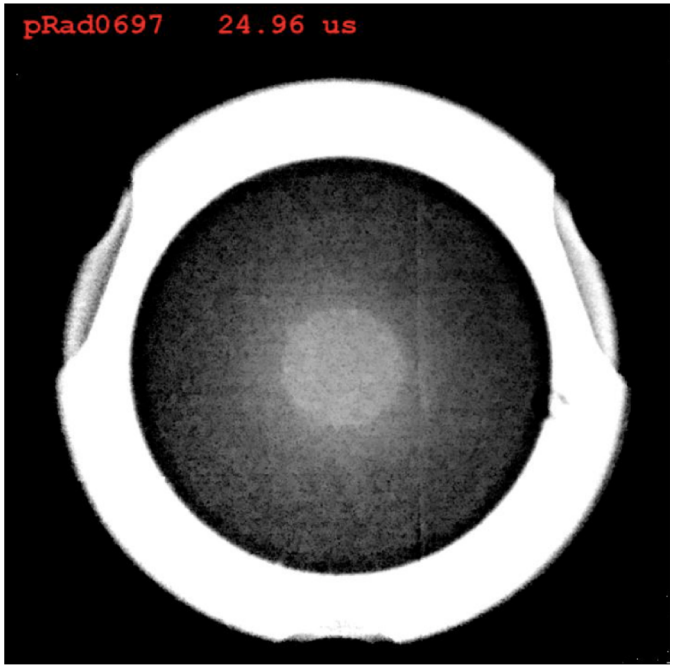
Computational Design: FLAG models the full experiment in 2D cylindrical; capsule geometry defined by CeO_2 ρ profile



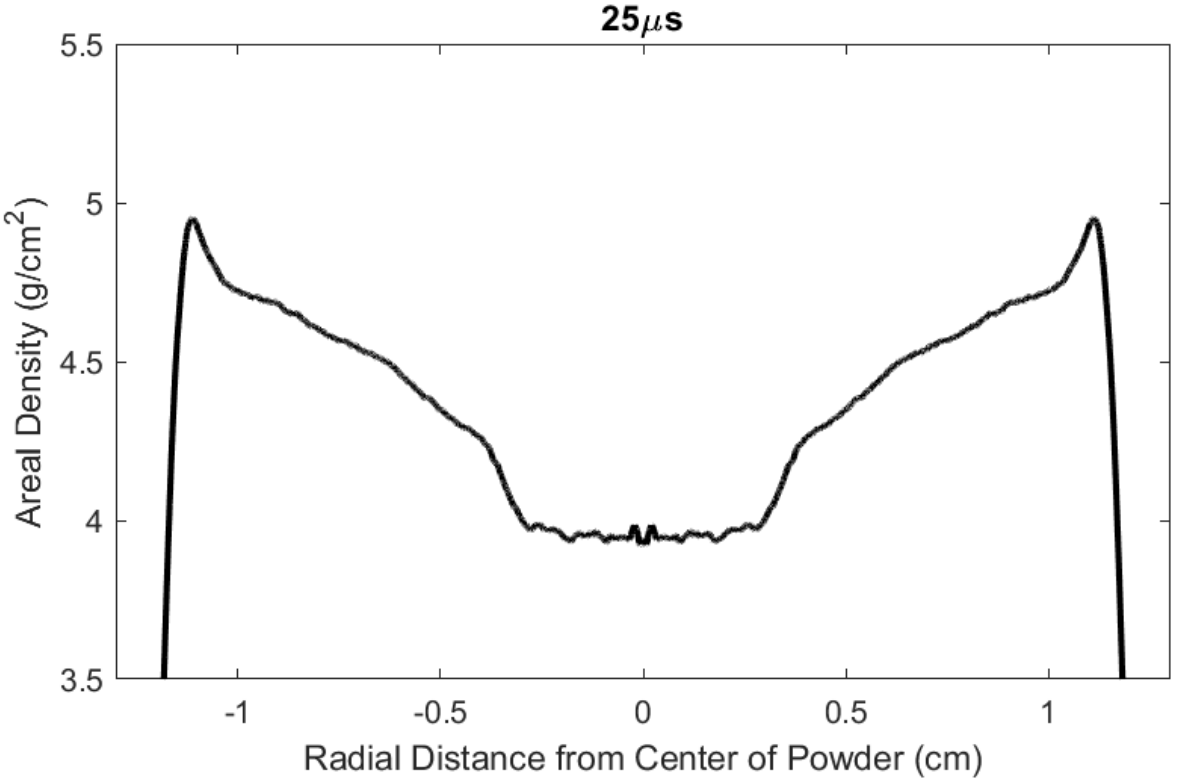


Execution: The CeO2 powder capsule was cylindrically loaded using a PHELIX capacitor charge of 85 kV

Proton Radiographs

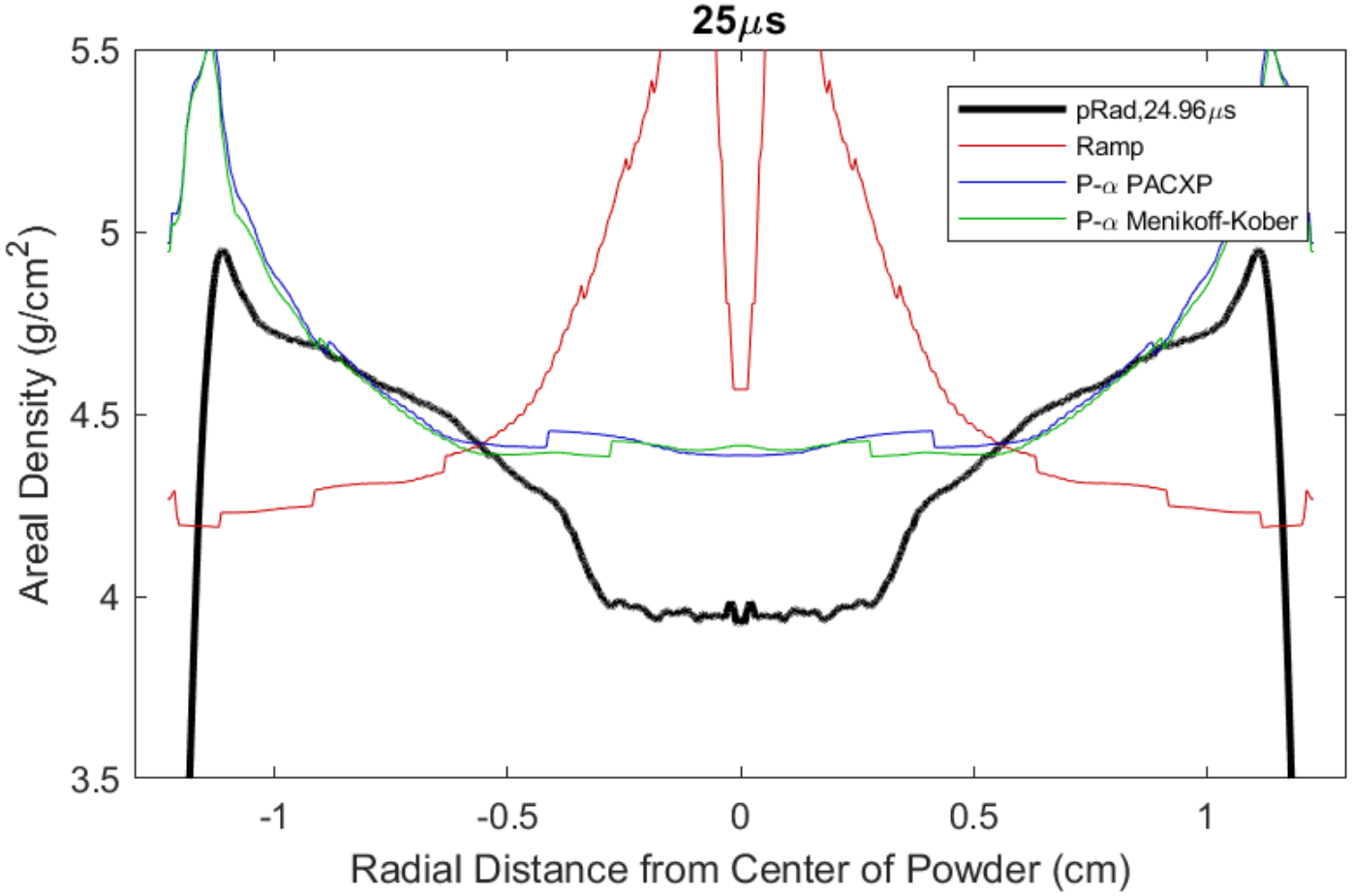


Areal Density Lineouts, Radial Average



Model Comparison: Evolution of shocked density

➢Initial analyses favor the P-α model



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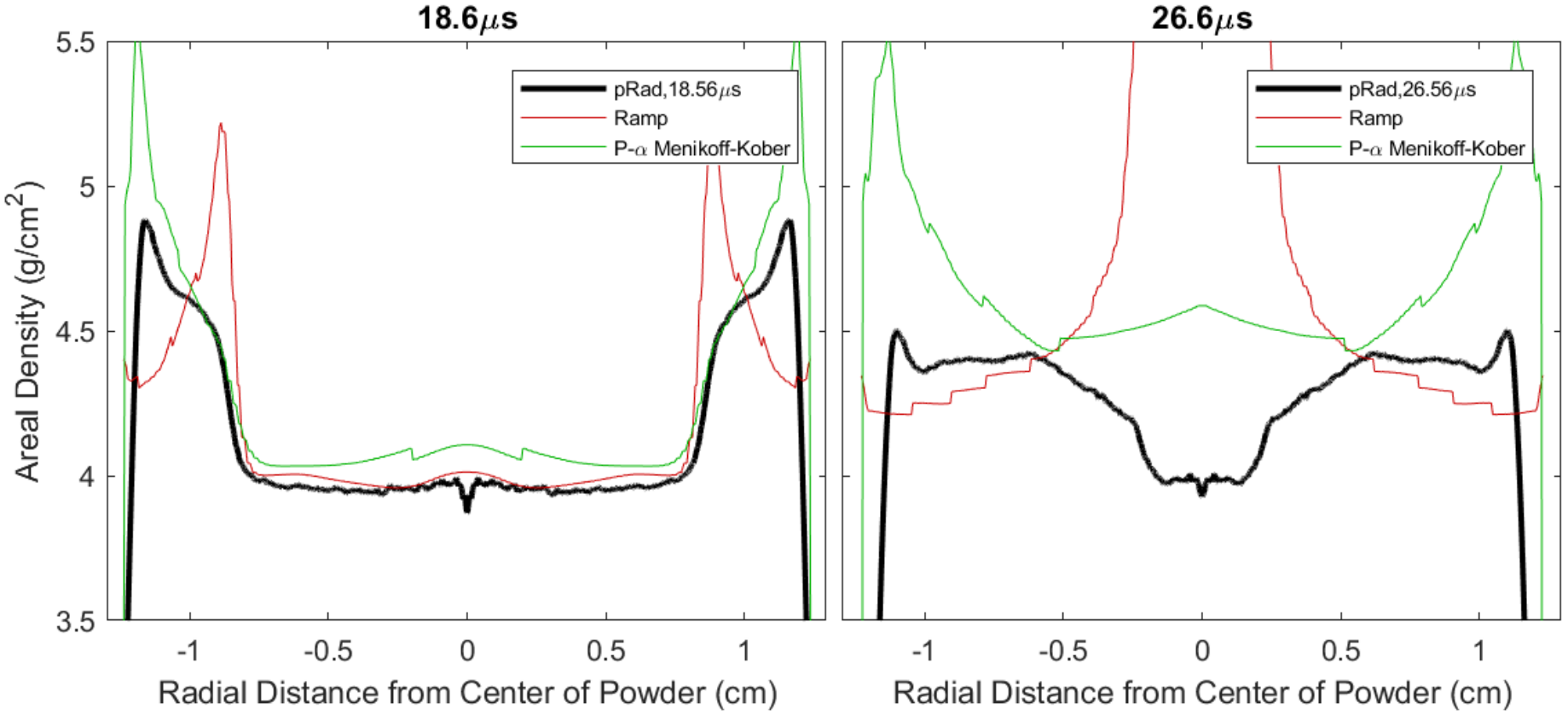

Future Work

- **Computed tomography scans of shocked powder capsule**
  - Density will be spatially resolved in 3 axes and show late time (t_∞) density
- **Calibrate a strength model for the CeO_2 powder**
  - diamond anvil cell
  - pressure-shear plate impact
- **Design an improved PHELIX experiment**
  - Compact the CeO_2 powder a greater amount
  - Impedance match (ρU_S) powder capsule end caps to powder
- **Incorporate this research into my thesis and defend**

Thank you!

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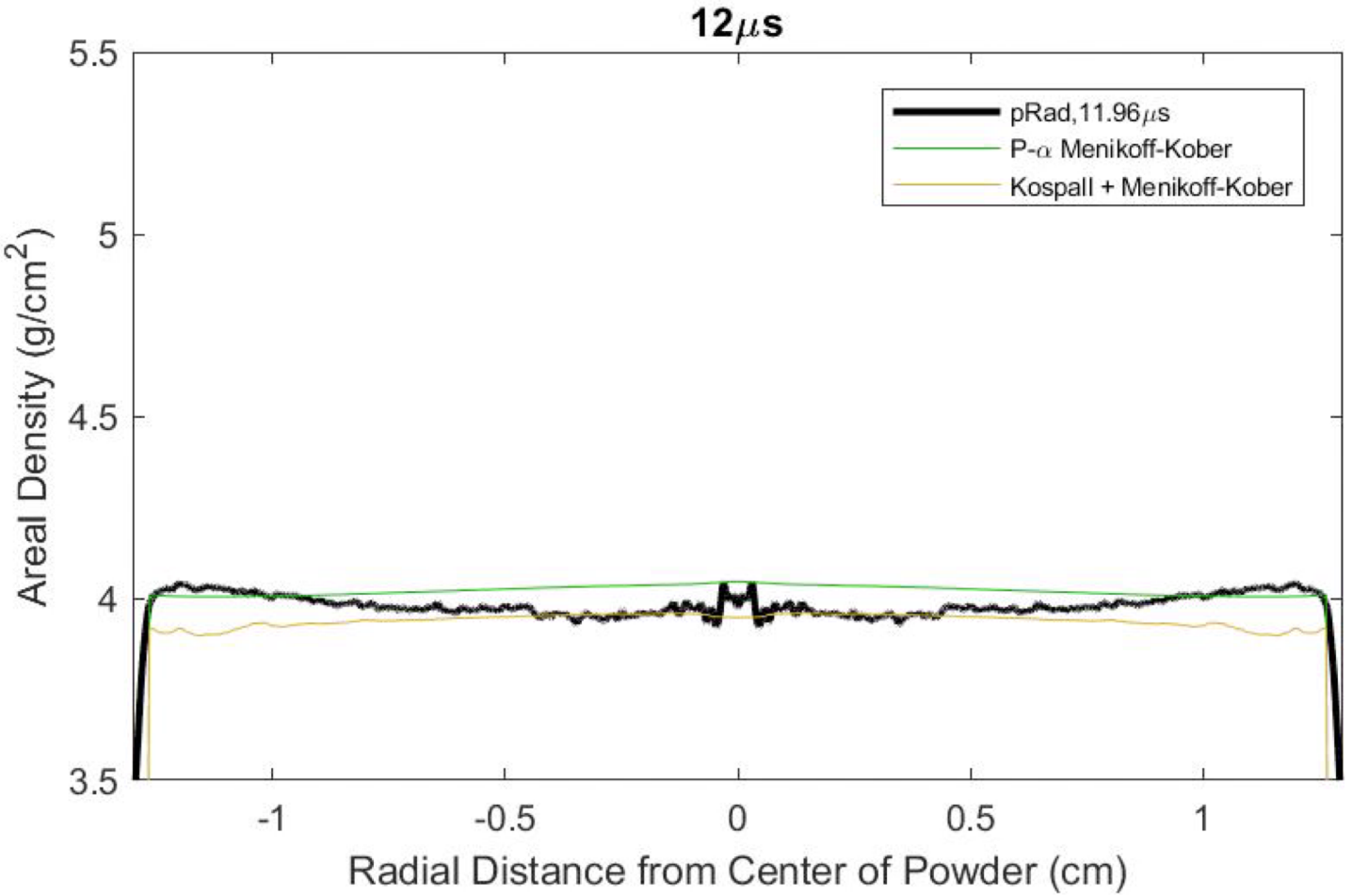
Addition of a strength model improves convergence



The field behind PHELIX's liner throws away protons