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Two-Dimensional Radiation MHD Model Assessment of Designs for Initial Argon Gas Distributions to be Imploded on the Z machine*

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NRL

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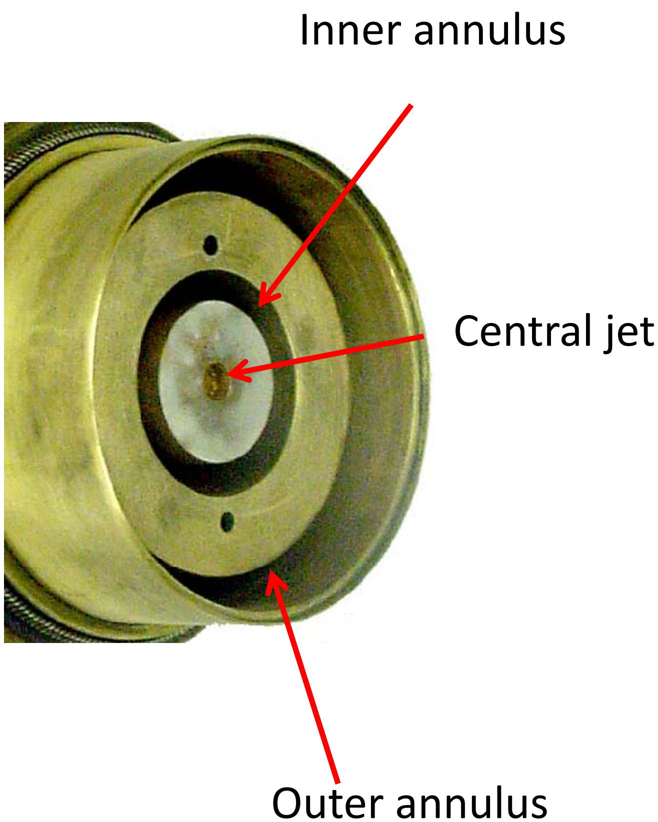
Outline

In the near future scientists at Sandia National Laboratories will be performing, for the first time, argon gas puff experiments on the refurbished Z machine. As part of the effort to determine the initial argon loads to be deployed, we theoretically assess the K-shell emission and stability properties of the gas distributions generated by the new Alameda Applied Sciences (*AASC*) 8 cm diameter double-annulus nozzle with a central jet that was recently constructed for these experiments .

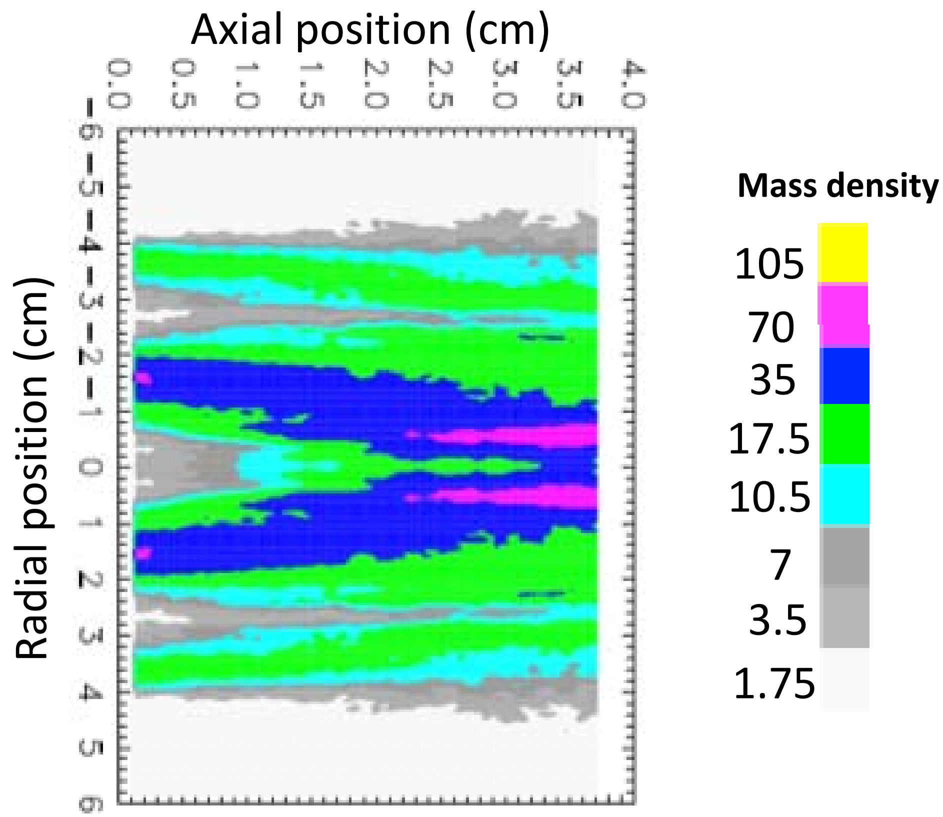
- Review past performance of pre- refurbished Z argon experiments and their implications for future ZR argon experiments.
- Employ 2D rad-MHD model to compare the stability and K-shell emission properties of gas distributions generated by the new nozzle with the distribution used in the pre-refurbished Z experiments (Titan1234 nozzle).
- Use 2D rad-MHD model to determine optimal K-shell producing *AASC* nozzle gas distribution.
- Summarize results of this argon gas puff assessment for ZR

Summary of pre-refurbished Z argon experiments

The pre-refurbished Z argon experimental results are well described in [H. Sze, P. L. Coleman, *et. al*., Physics of Plasmas *Letters*, 8, 3135 (2001).]

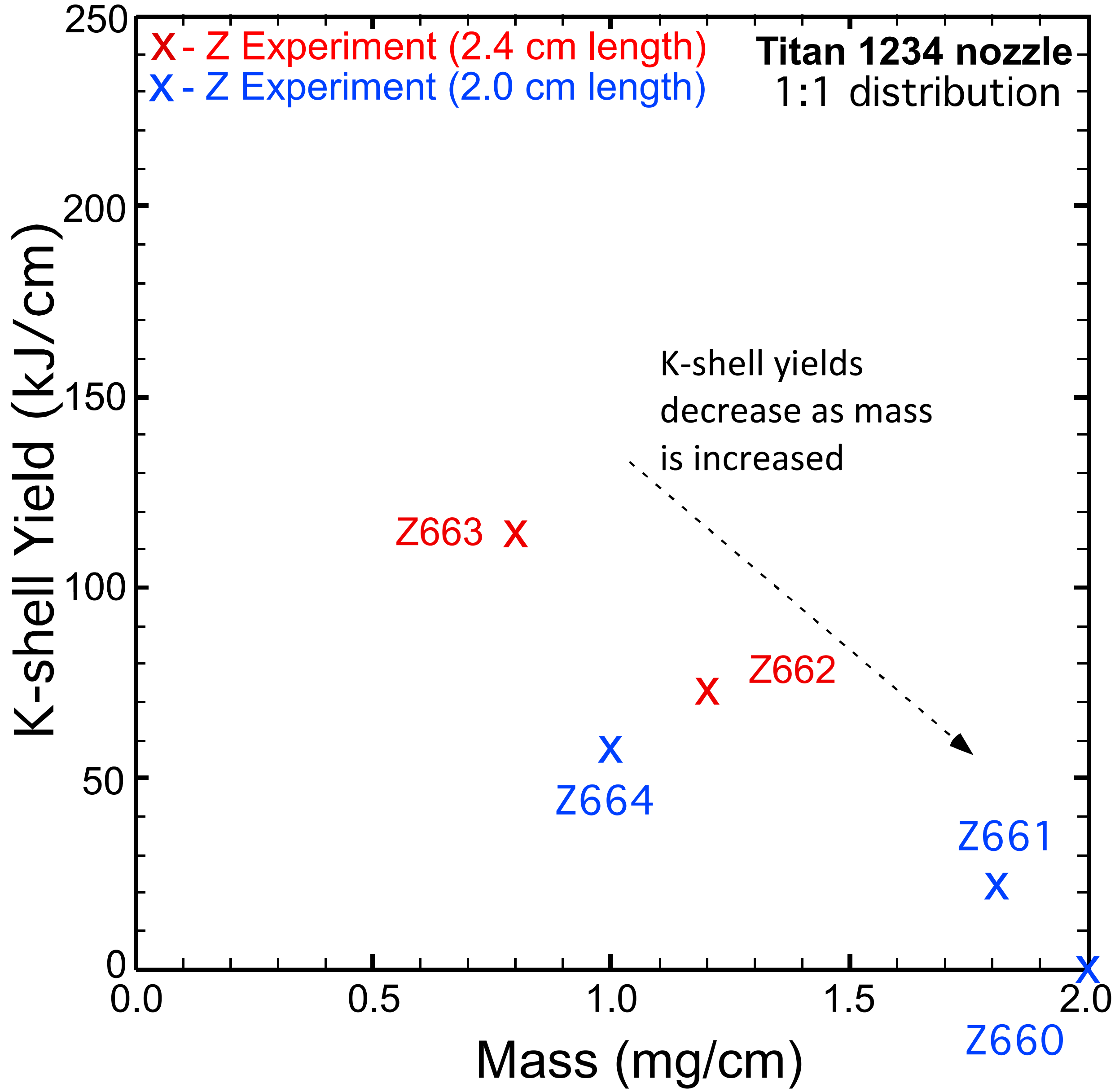


Generic 8 cm diameter multiple shell nozzle



8 cm diameter, Titan 1234 Nozzle - 1:1 gas distribution

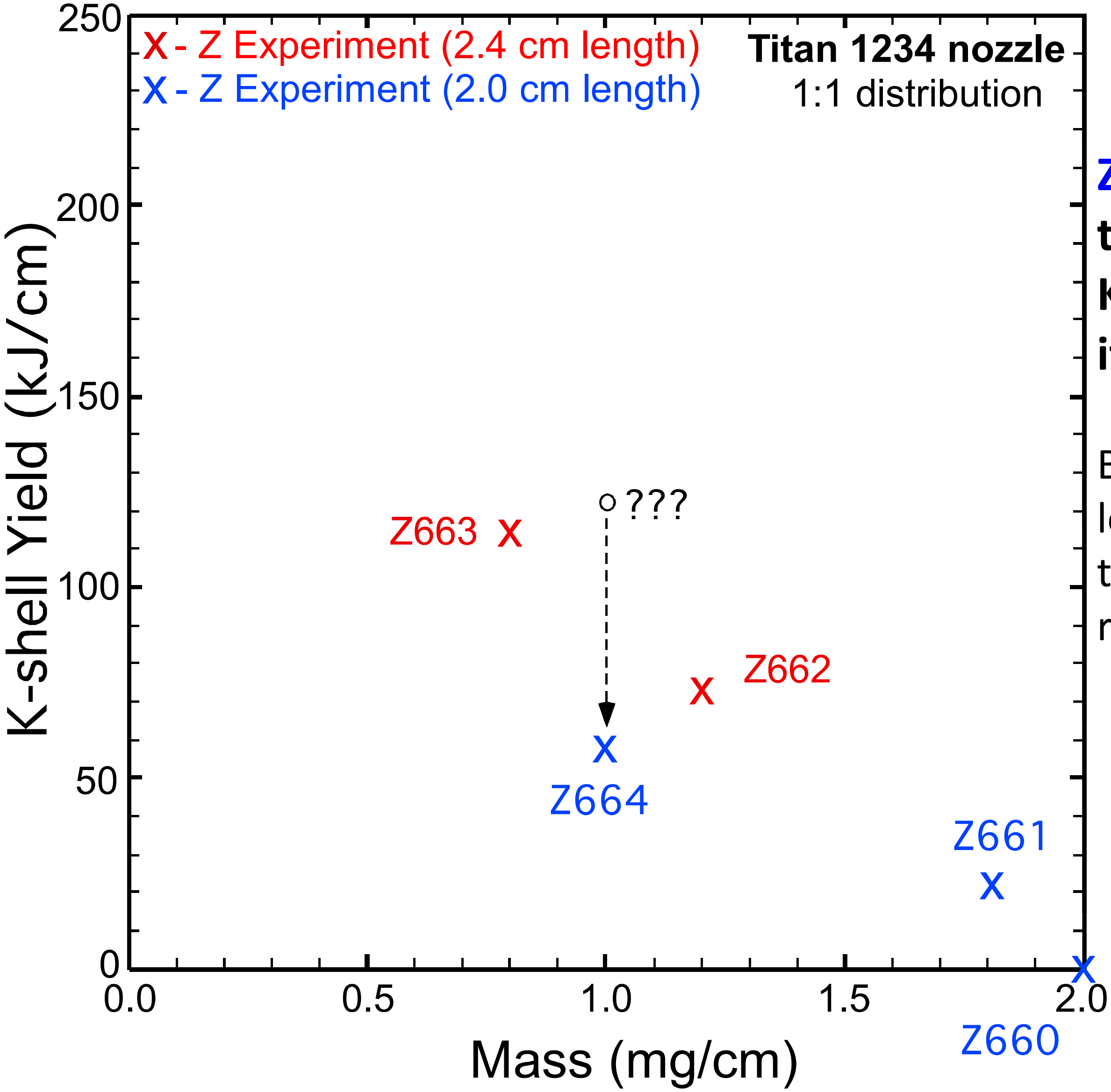
Summary of pre-refurbished Z argon experiments



Current loss was observed in most of these experiments, especially for Z660 the most massive load.

H. Sze's speculation – current loss due to UV light from implosion illuminating the convolute power feed

Load Instability likely played a role in pre-refurbished Z experiments



Z664 had more energy/cm than Z662, why was K-yield/cm less? H. Sze suspects it is due to axial non-uniformity.

By using a reduced pinch length for Z664 they eliminated the region of the pinch that had radiated best in Z662 (near anode)

Based on earlier Z argon experiments one expects for ZR:

1) **Current loss could be an issue, especially at large mass.**

2) **K-shell yields of ~274 kJ obtained on pre-refurbished Z were in I^2 scaling regime, well designed loads on ZR should also be in this regime. (Estimate ~35% more energy into a ZR load than for Z, which is ~ 370 kJ of K-shell emission).**

3) **Load instability likely played a role in earlier Z experiments and is likely to do so on ZR.**

4) **Since the AASC nozzle is new and never been tested, we don't know its stability and K-shell behavior.**

Modeling the K-shell emission and stability properties of the AASC nozzle gas distributions

- To theoretically model the non-linear growth of instabilities and multi-dimensional plasma motion that is present in gas puff implosions we employ *Numerex's* Mach2 – two dimensional magneto-hydrodynamics code.

- To account for the non-LTE kinetics, opacity , and non-local transport of radiation that affect the atomic populations of these high temperature K-shell emitting plasmas we incorporated into the Mach2 code a self-consistent EOS calculation that models this physics. It is called the tabular collisional radiative equilibrium model -TCRE

Mach2 reference – R. E. Peterkin, M. H. Frese, and C. Sovienc, J. Comput. Phys. **140**,148 (1998).
TCRE reference – J. W. Thornhill, J. P. Apruzese , *et. al*., Phys. Plasmas **8**, 3480 (2001).

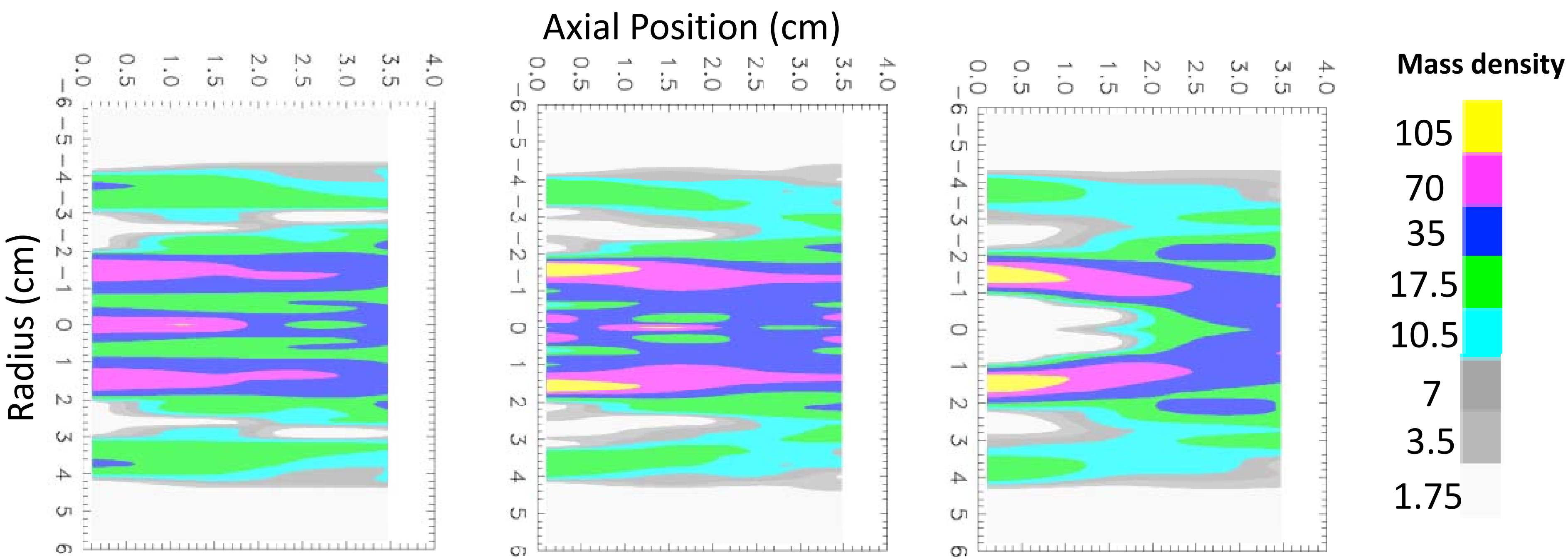
Modeling the K-shell emission and stability properties of the AASC nozzle gas distributions

There are three measured gas distributions analyzed to characterize the stability and K-shell emission properties of the AASC nozzle

1) AASC **[31_30_250]**
2) AASC **[22_30_250]**
3) AASC **[31_58_0]** --------No central jet

Pressure (psi) in **outer** annulus	Pressure (psi) in **inner** annulus	Pressure in **central jet**

Modeling the K-shell emission and stability properties of the AASC nozzle gas distributions



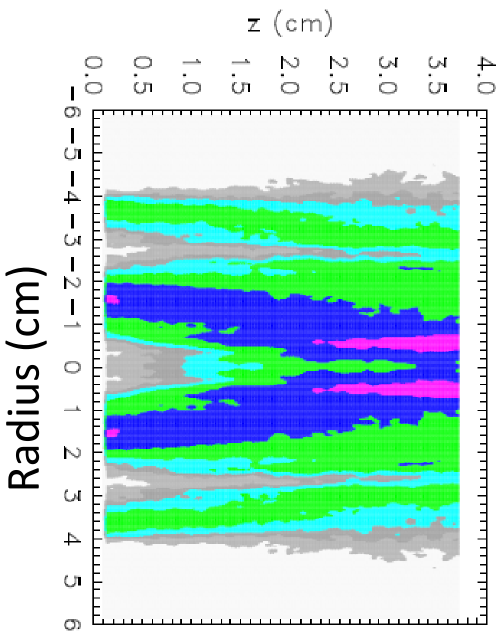
AASC [31_30_250] "1:1"

AASC [22_30_250] "1:1.4"

AASC [31_58_0] "1:2"

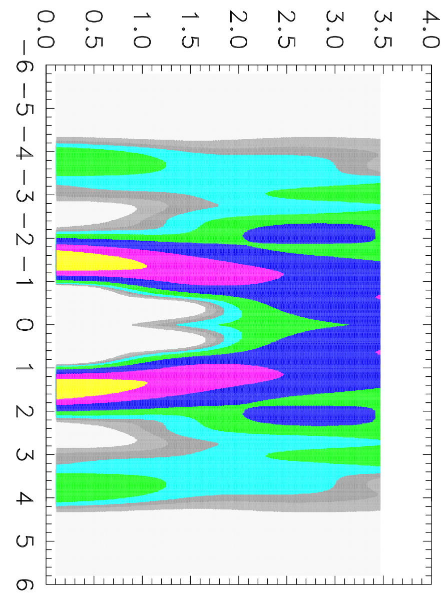
- Distributions measured using **F**iber **O**ptic **I**nterferometry
- Measurements taken along 4 axial slices (0.5,1.5,2.5 and 3.5 cm) @ ~20 radial positions
- Bicubic spline used to interpolate between data points
- The load mass is varied in the calculations by renormalizing each of the above three distributions to the mass of interest.

Comparison of the Titan 1234 and AASC gas distribution's K-shell and stability properties



Titan 1:1

Laser induced fluorescence
(120 axial x 540 radial)



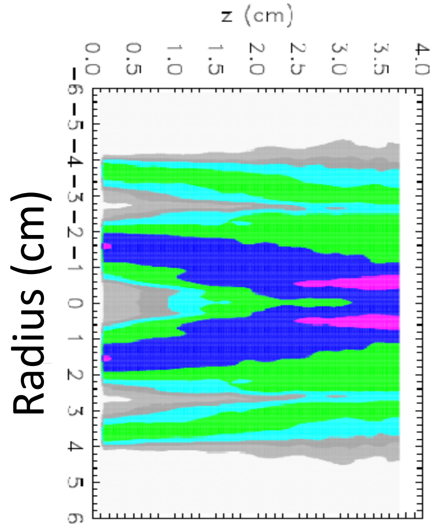
AASC 1:2

Fiber optic interferometry
(4 axial x 20 radial)

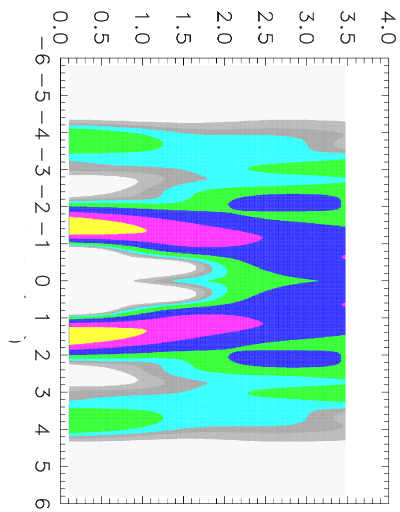
The AASC gas distribution is inherently "smoothed" due to bicubic spline interpolation of data

Comparison of the Titan 1234 and AASC gas distribution's K-shell and stability properties

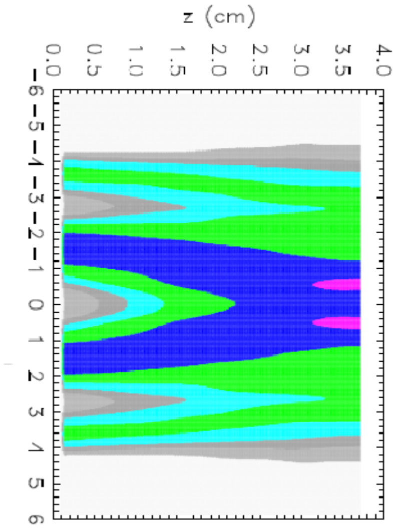
To make for a "fair" comparison with the inherently "smoothed" AASC distributions, the Titan gas distribution is "smoothed" by averaging over nearest neighbor data points successive times. Calculations are performed using a **10x** and **100x** Titan gas distribution.



Titan 1:1 (**10x**)

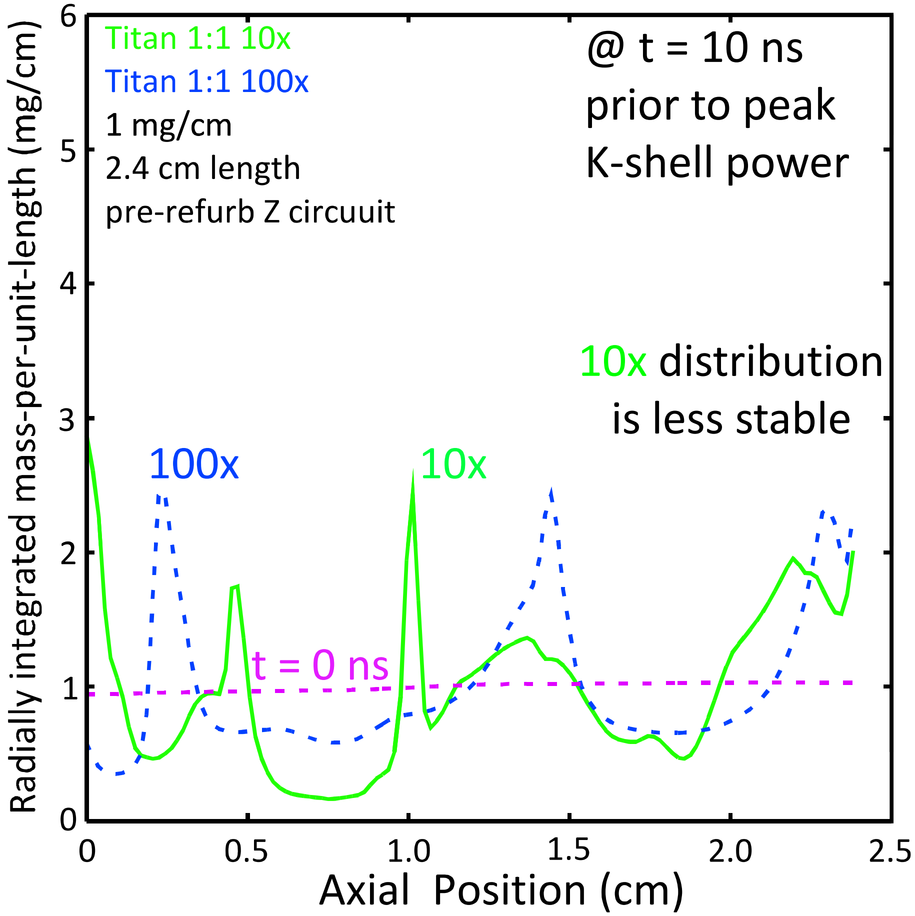


AASC 1:2

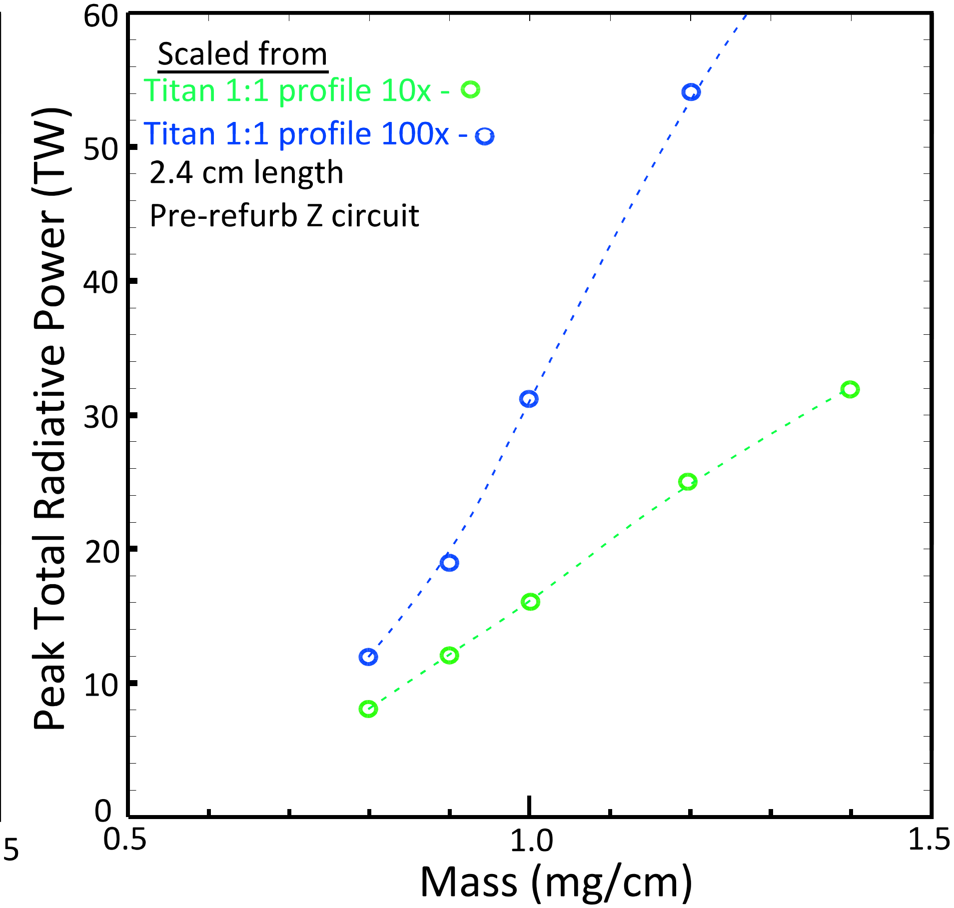


Titan 1:1 (**100x**)

Greater stability of Titan 100x distribution gives rise to higher radiative powers than 10x distribution

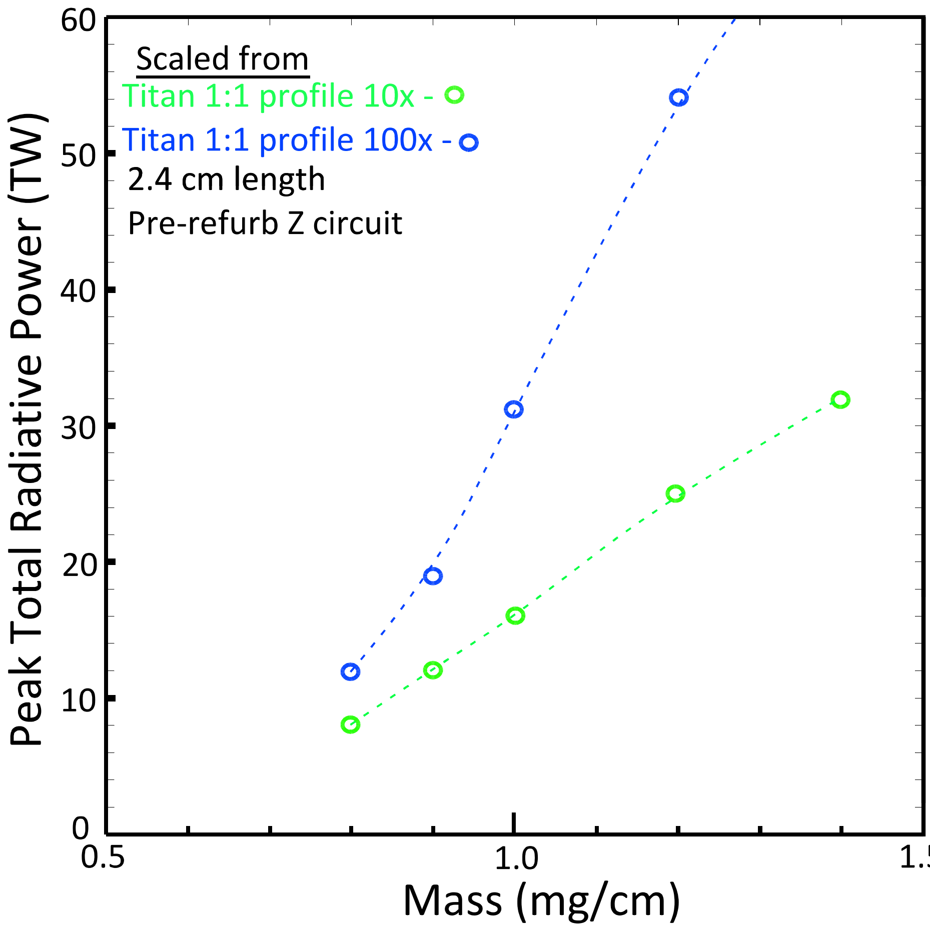


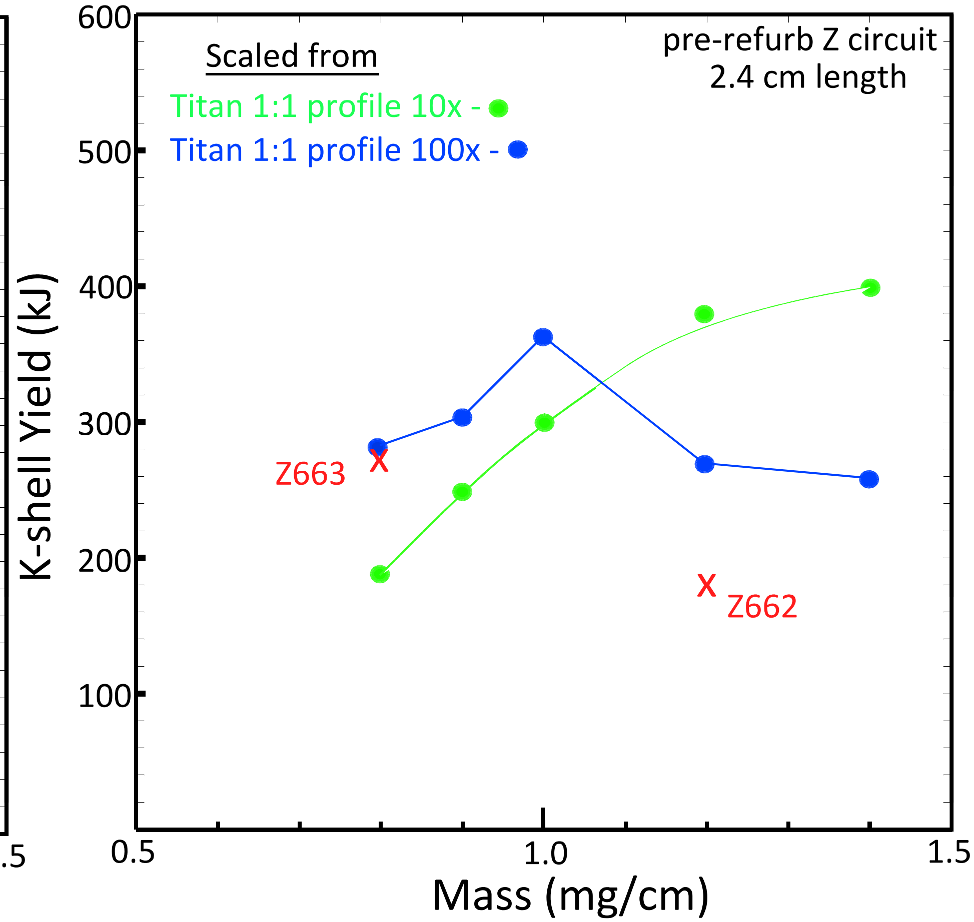
At each axial location, the mass is radially integrated. Large fluctuations denote an unstable implosion.



Lower powers of 10 x distribution are due to increased axial non-uniformity

2D Calculated K-yields and total radiative powers for Titan 1234 10x and 100x smoothed gas distribution :Pre-refurbished Z circuit

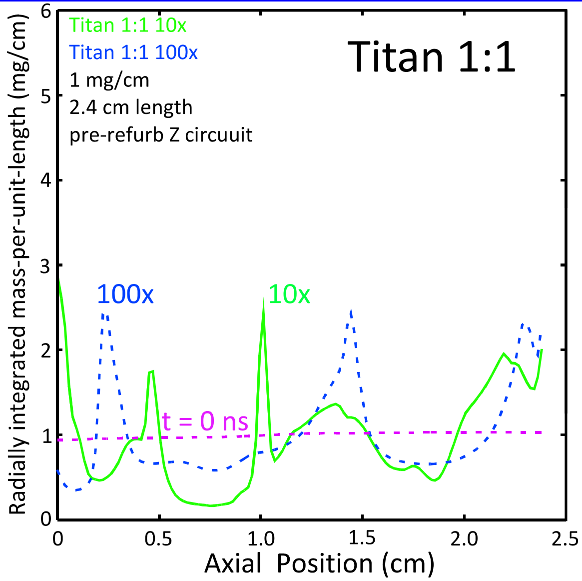


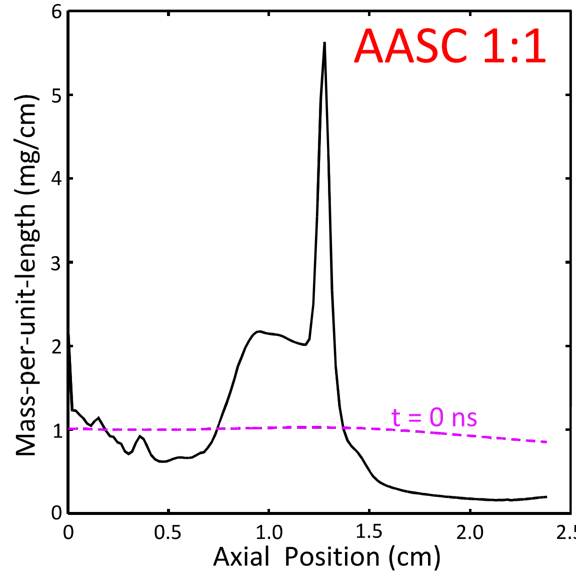


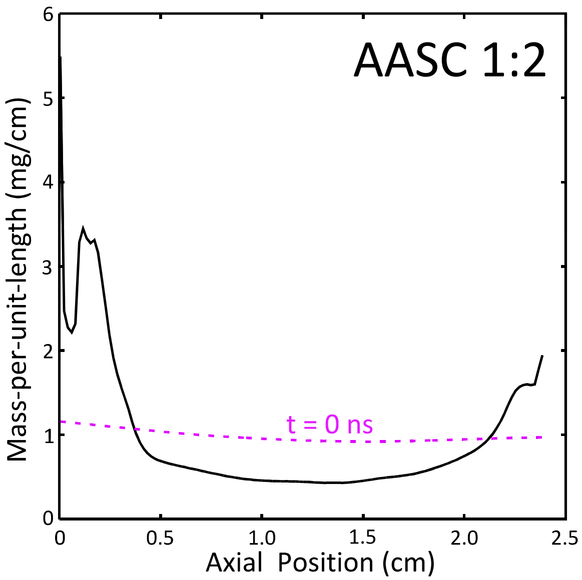
K-shell yield curve turns over when total power is sufficiently large that the plasma cools too rapidly to sustain K-shell emission

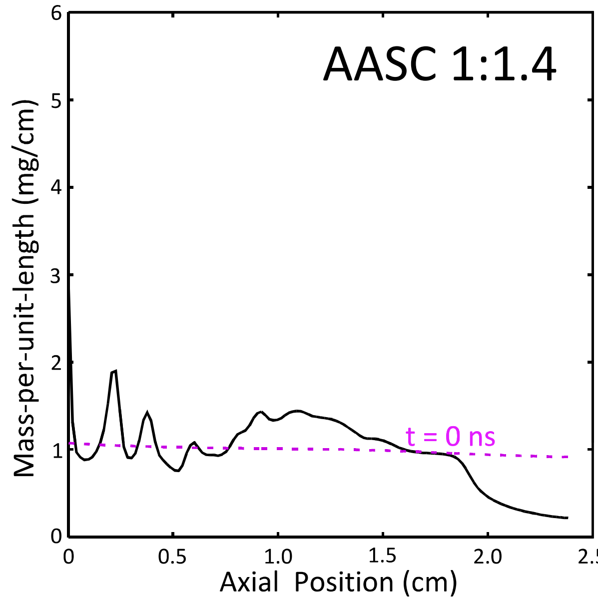
- 100 x profile best matches pre-refurbished Z experiments.
- 10 x profile has higher yield at large mass because of less radiative cooling.

The AASC 1:1 gas distribution is the least stable



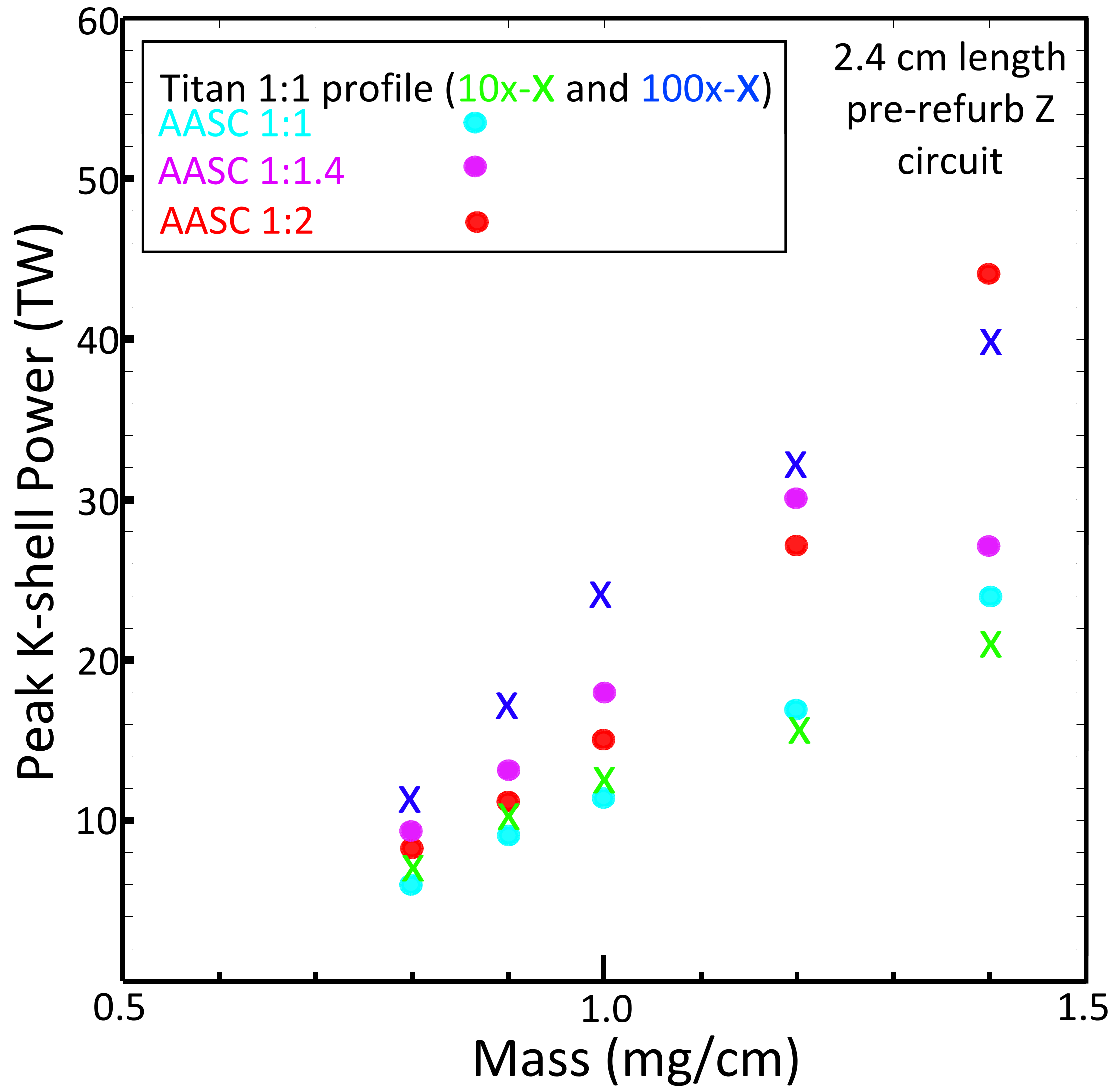






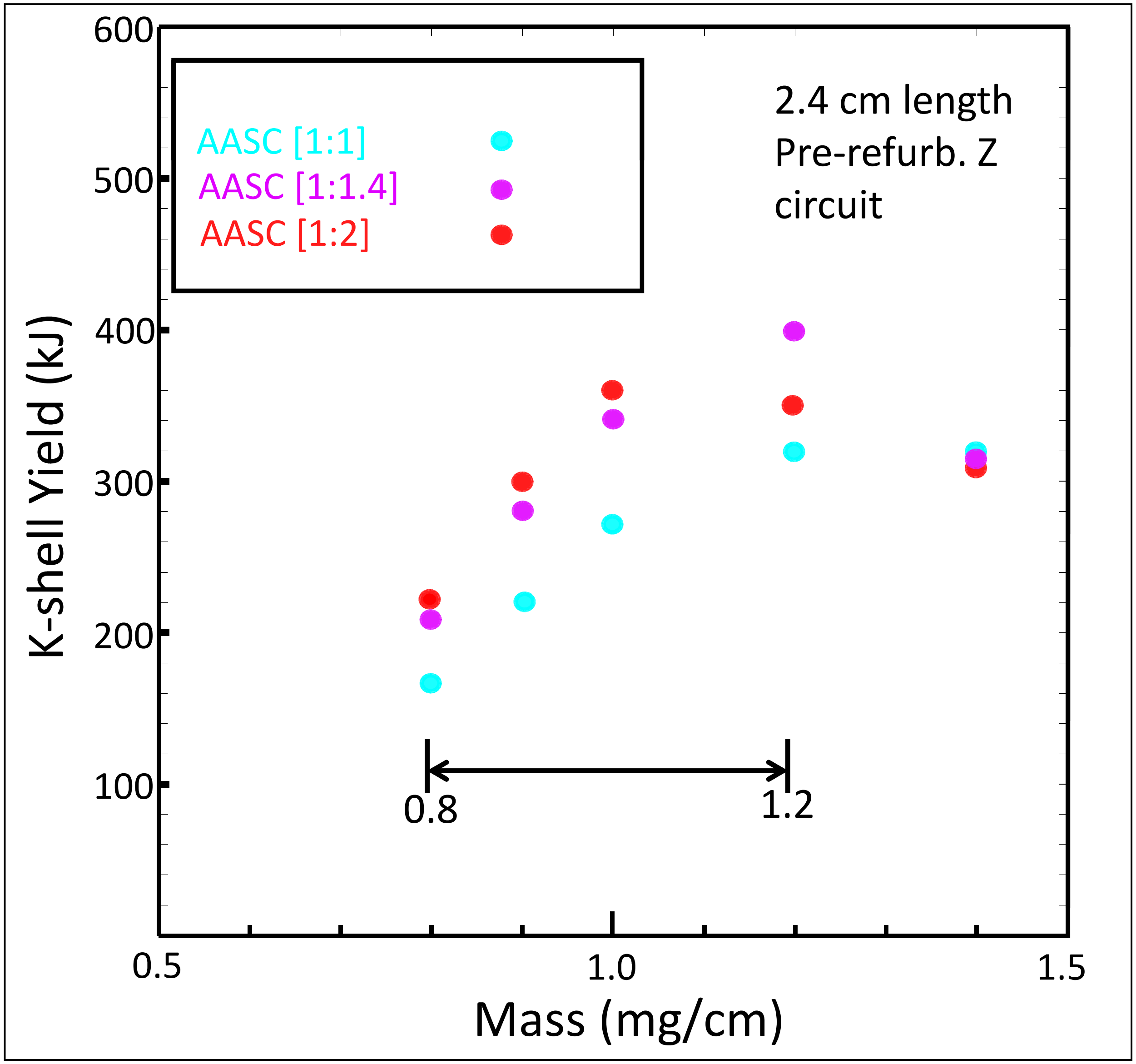
The radially integrated mass-per- unit-length as a function of axial position – 10 ns prior to stagnation. large fluctuations denote an unstable implosion. These calculations were for a 2.4 cm length, 1 mg/cm load driven by the pre-refurbished Z circuit.

2D Calculated K-shell Power for Titan 1234 and AASC Nozzles on Pre-refurbished Z



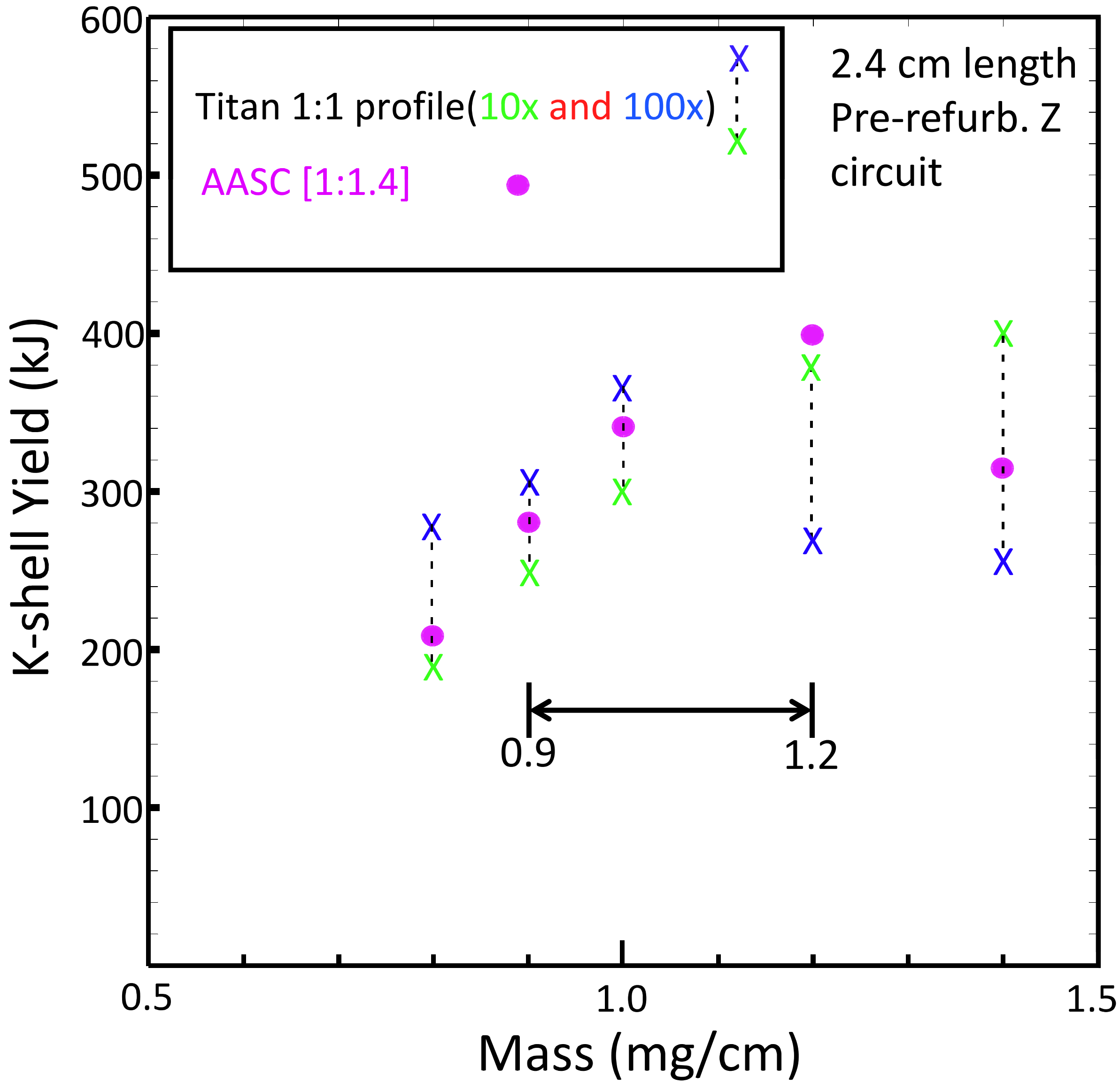
The Titan 100x, and AASC 1:1.4 and 1:2 distributions are the most stable and they have the highest K-shell and total powers.

2D Calculated K-yields for Titan 1234 and AASC Nozzles on Pre-refurbished Z



The AASC 1:1.4 and 1:2 loads outperform the 1:1 load – especially in the range **0.8 – 1.2 mg/cm**, where ZR experiments will likely take place.

2D Calculated K-yields for Titan 1234 and AASC Nozzles on Pre-refurbished Z



The AASC 1:1.4 and 1.2 loads perform as well as the Titan load in the range **0.9 – 1.2** mg/cm.

Summary

The issue of severe current losses due to UV irradiance of the convolute power feed is still under investigation.

Stability properties of the AASC 1:1 profile were the worst, resulting in lower calculated K-shell yields and powers than obtained with the AASC 1:1.4, 1:2, and Titan distributions.

The "True" AASC gas distributions are probably not as stable as the modeled bicubic spline Interpolated ("smoothed") AASC gas distributions analyzed here – would lead to lower calculated yields than shown in this analysis.

Modeled stability of the AASC 1:1.4 and 1.2 distributions was as good as that of the modeled Titan distribution – instabilities no more of a limiting factor of K-yield than they were in the pre-refurbished Z experiments with the Titan nozzle. Therefore, expect $\boldsymbol{I^2}$ K-shell scaling to be valid for AASC 1:1.4 and AASC 1:2 loads (~ 370 kJ of K-shell emission for ~ 1 mg/cm load).