An Overview of Progress at First Light Fusion

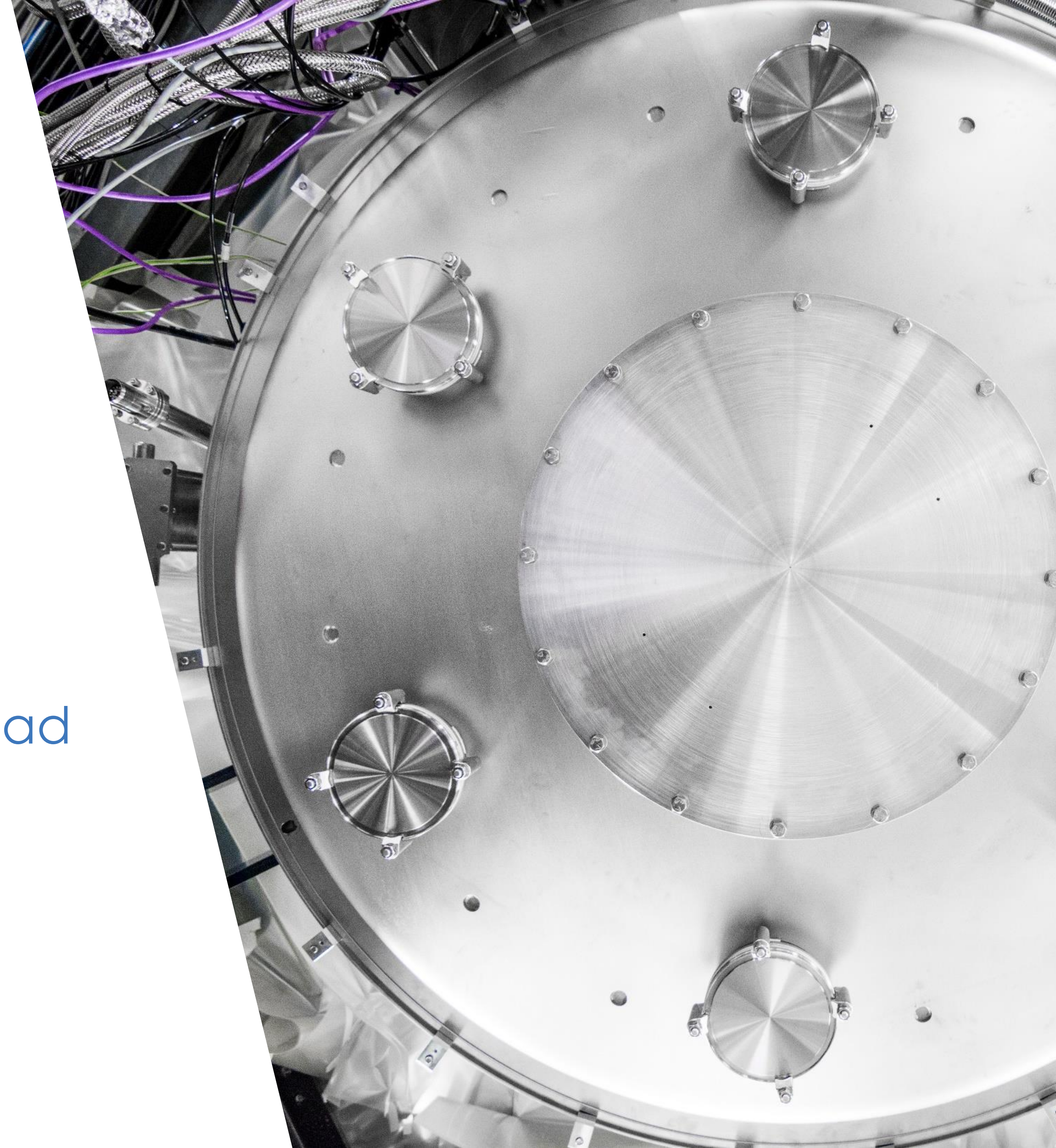
Nicholas Hawker
The First Light Fusion Team

Overview

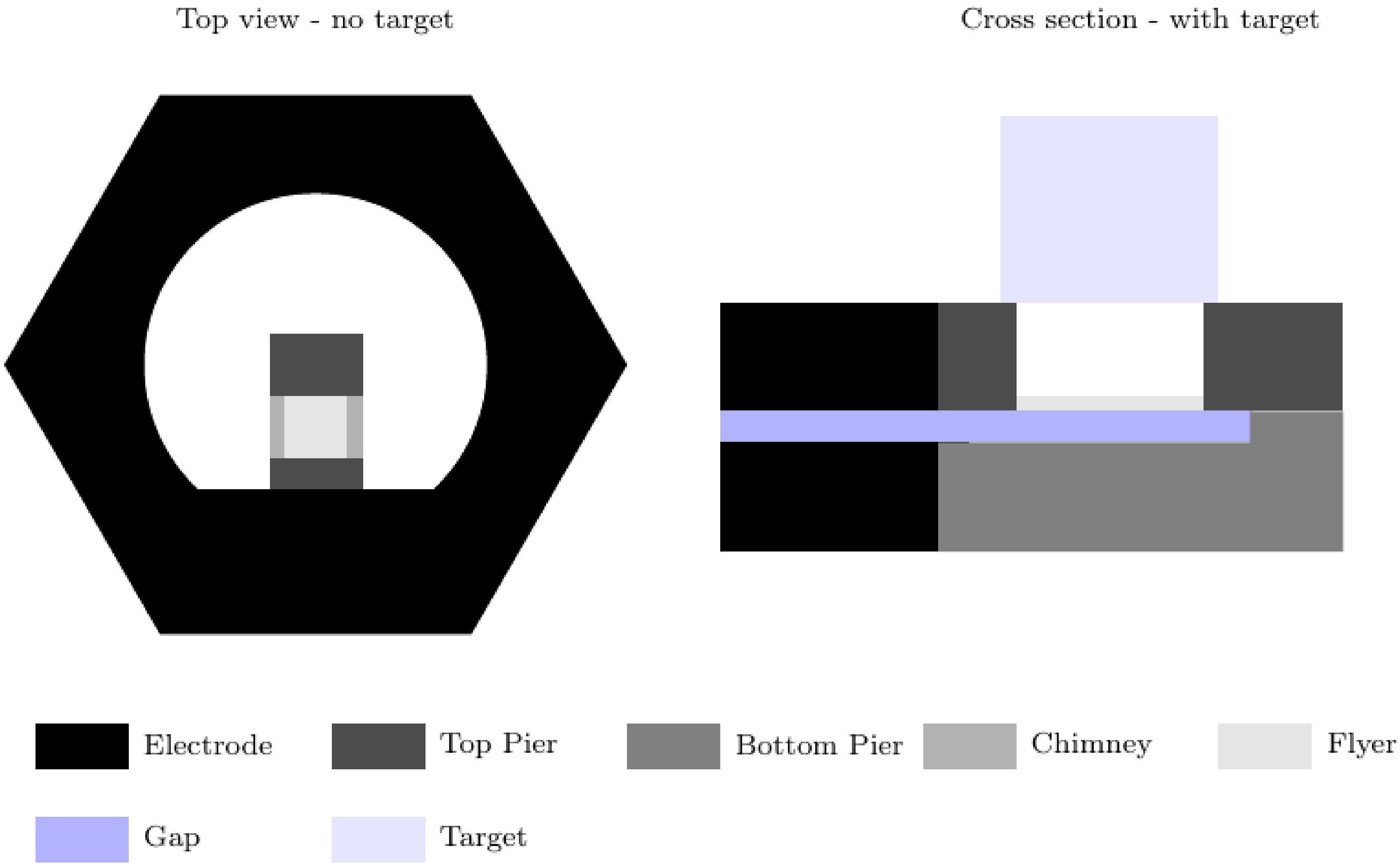
- "Projectile fusion"
  - High-velocity projectile replaces the laser
  - Target designs are key, but trade secrets
  - The targets multiply the velocity and create convergence
- 2015 – 2019: Phase Two – Demonstration of fusion
  - Machine Three commissioned
  - Experiments in progress
- 2019 – 2024: Next phase, five year plan
  - Requires new funding
  - Gain experiment and reactor design

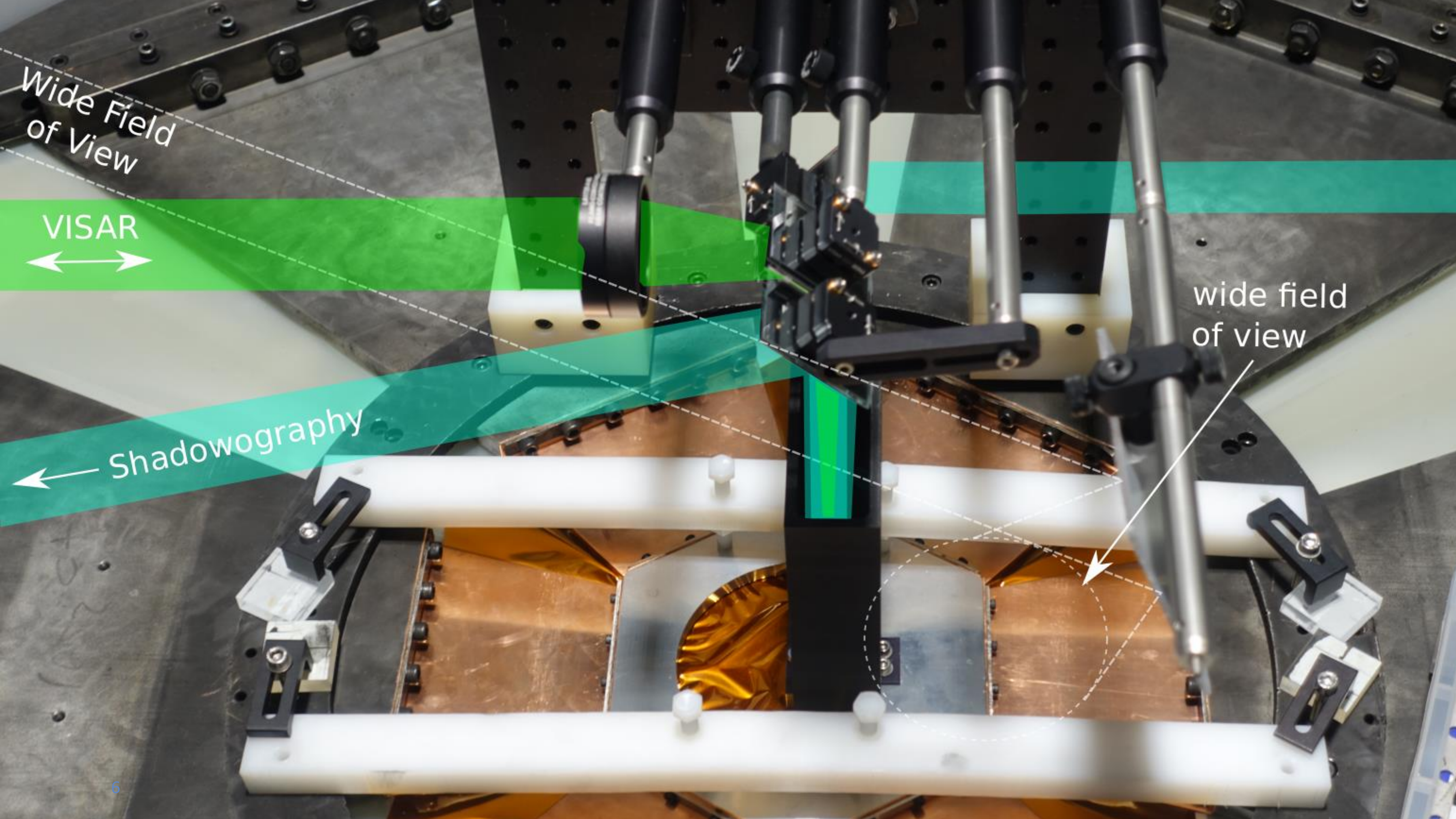
Machine Three in numbers

- 125 uF
- 12 nH, 1.5 mOhms
- ± 100 kV rated, ± 70 kV commissioned
- 70 kV → 14 MA in ~2 μs
- Current into load depends on load impedance



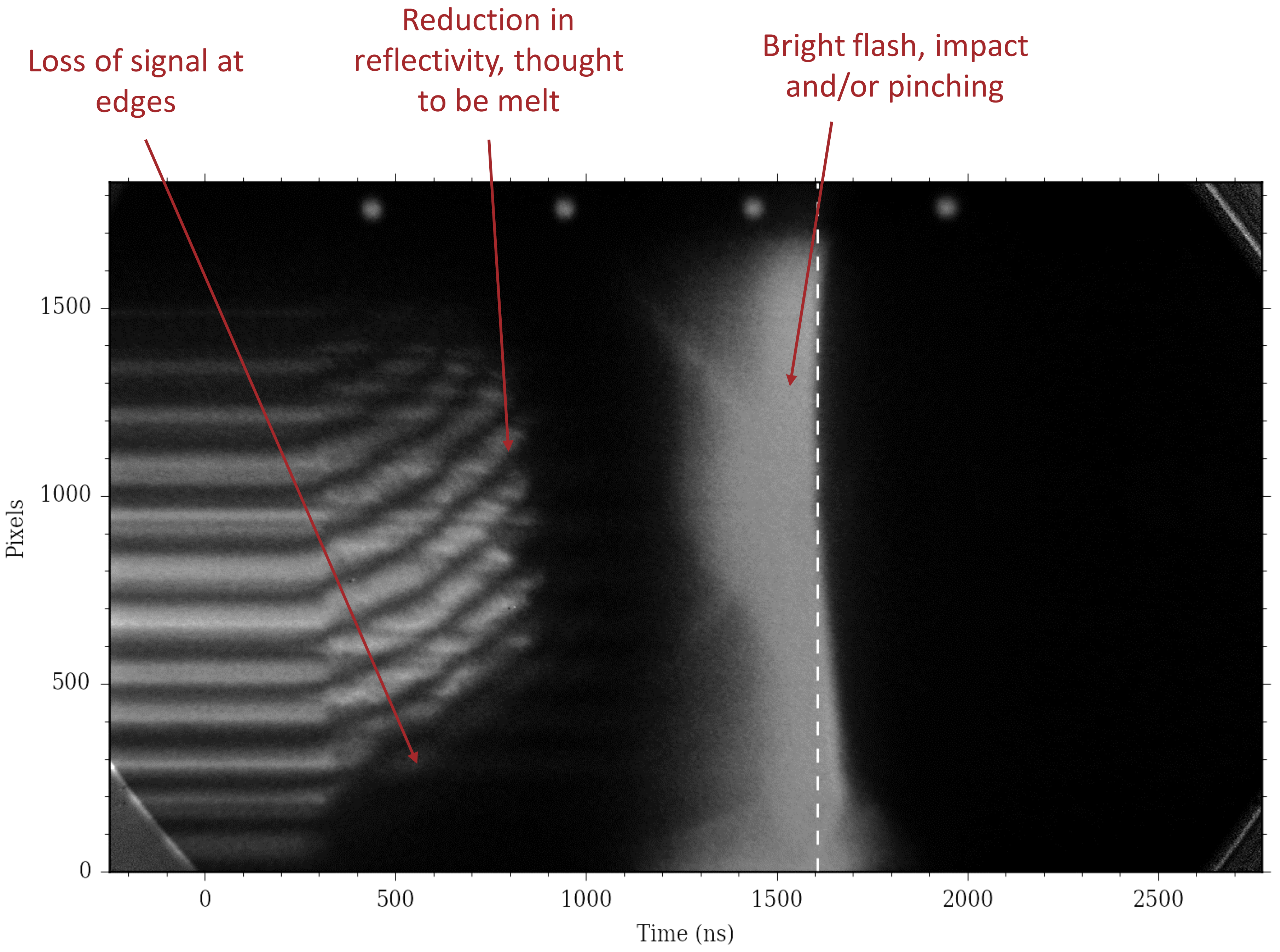
Flyer plate load schematic




Wide Field of View
VISAR
wide field of view
Shadowography

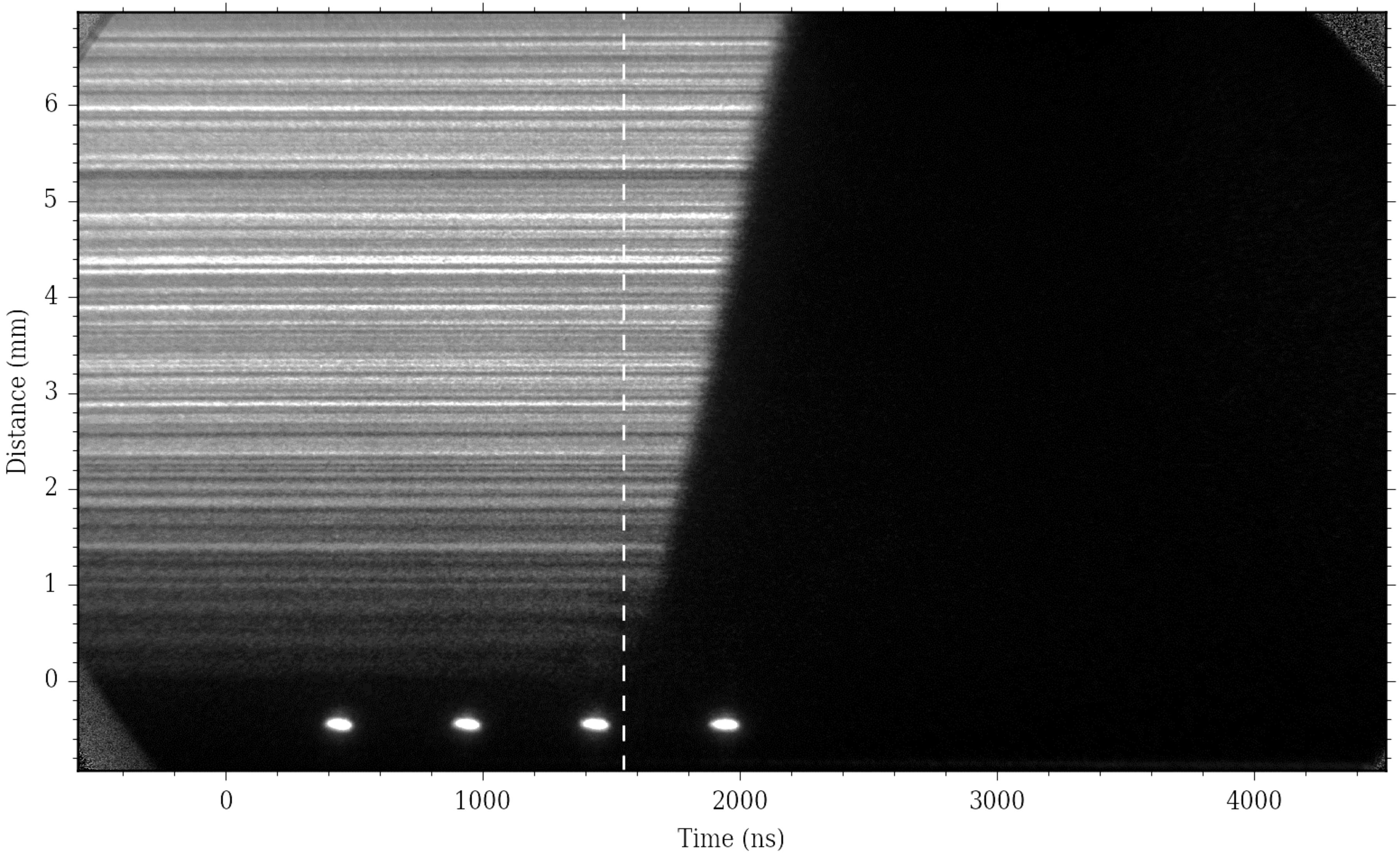
VISAR

- Shot 99
- 10x10x1 mm Al flyer plate
- VISAR velocity ~4 km/s
- Estimated velocity at impact ~14 km/s



Streaked shadowgraphy

- Shot 99
- 10x10x1 mm Al flyer plate
- Shock velocity ~12 km/s
- Pressure ~100 GPa



Present launch performance and issues

- Representative performance numbers
  - Projectile velocities ~15 km/s
  - Sustained impact pressures ~100 GPa
  - Higher pressures measured but impulsive, “blast wave” profile
- We believe we have a “power loss” issue
  - ~50% more current than expected (~9 MA vs. ~6 MA predicted)
  - Suggests a short
  - Velocity matches prediction, no interruption to acceleration

A simple ODE model for volume ignition

energy balance

$$\frac{dT}{dt} = \frac{f_\alpha W_\alpha - W_C - W_R}{(3/2)\Gamma\rho}$$

fuel depletion

$$\frac{d\rho_{DT}}{dt} = -\frac{\rho_{DT}^2 \langle\sigma v\rangle}{2m_{DT}}$$

loss of confinement

$$\frac{dr}{dt} = -\sqrt{c_{ideal}^2 + c_{fermi}^2}$$

$$W_\alpha = 5A_\alpha \rho^2 \langle\sigma v\rangle$$

$$W_R = \sigma T^4 \left(1 - e^{-r_{dirac}/l_p}\right)$$

$$W_C = \kappa \nabla T \frac{S}{V}$$

$$e = \sqrt{e_{ideal}^2 + e_{fermi}^2}$$

Developed to apply to arbitrary geometry

Monte-Carlo precalculation

$$\frac{dT}{dt} = \frac{f_\alpha W_\alpha - W_C - W_R}{(3/2)\Gamma\rho}$$

$$\frac{d\rho_{DT}}{dt} = -\frac{\rho_{DT}^2\langle\sigma v\rangle}{2m_{DT}}$$

take the shortest length

$$\frac{dr}{dt} = -\sqrt{c_{ideal}^2 + c_{fermi}^2}$$

$$W_\alpha = 5A_\alpha\rho^2\langle\sigma v\rangle$$

required if radiation trapping important

$$W_R = \sigma T^4\left(1 - e^{-r_{dirac}/l_p}\right)$$

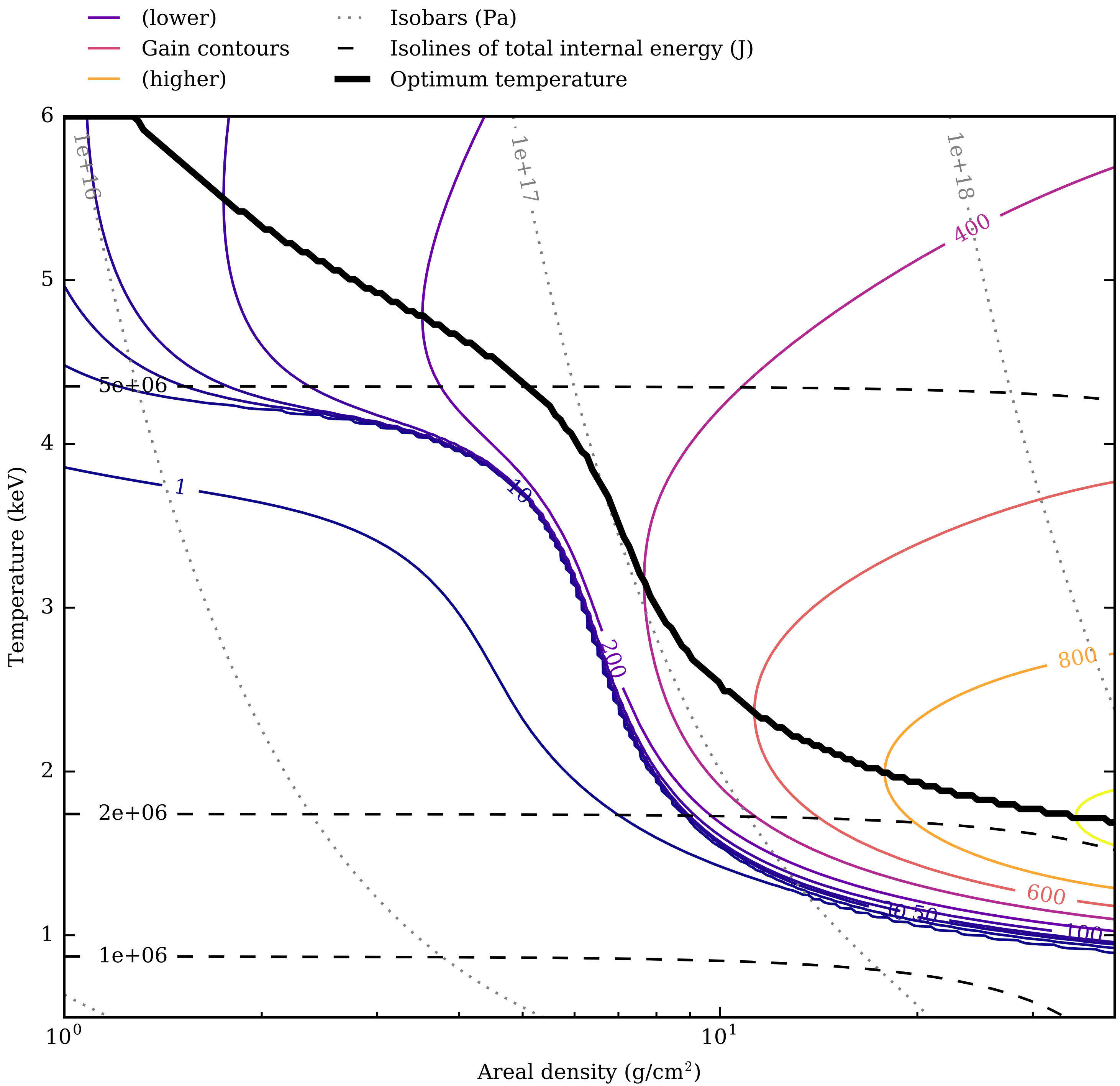
$$W_C = \kappa\nabla T\frac{S}{V}$$

take the shortest length

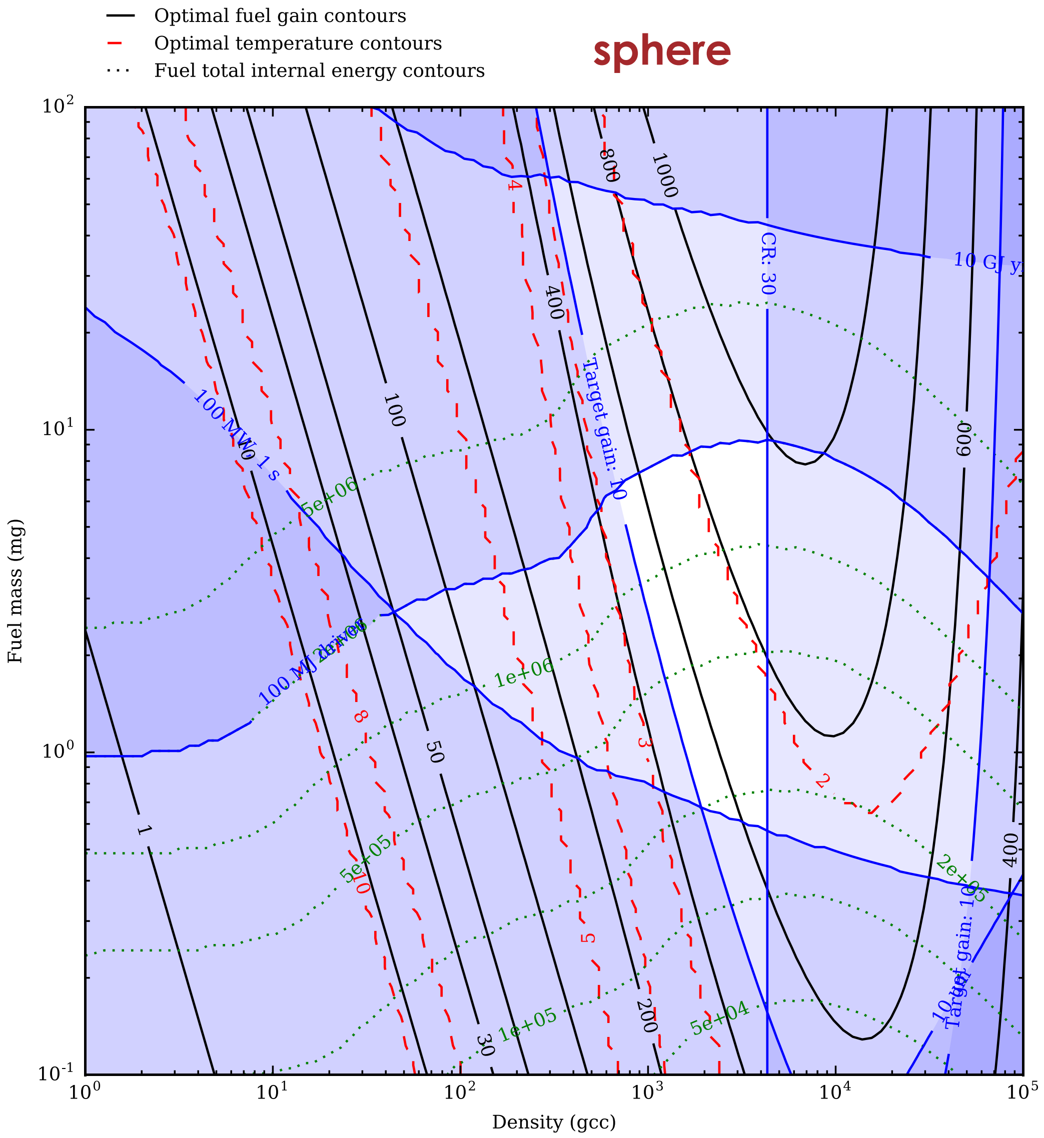
$$e = \sqrt{e_{ideal}^2 + e_{fermi}^2}$$

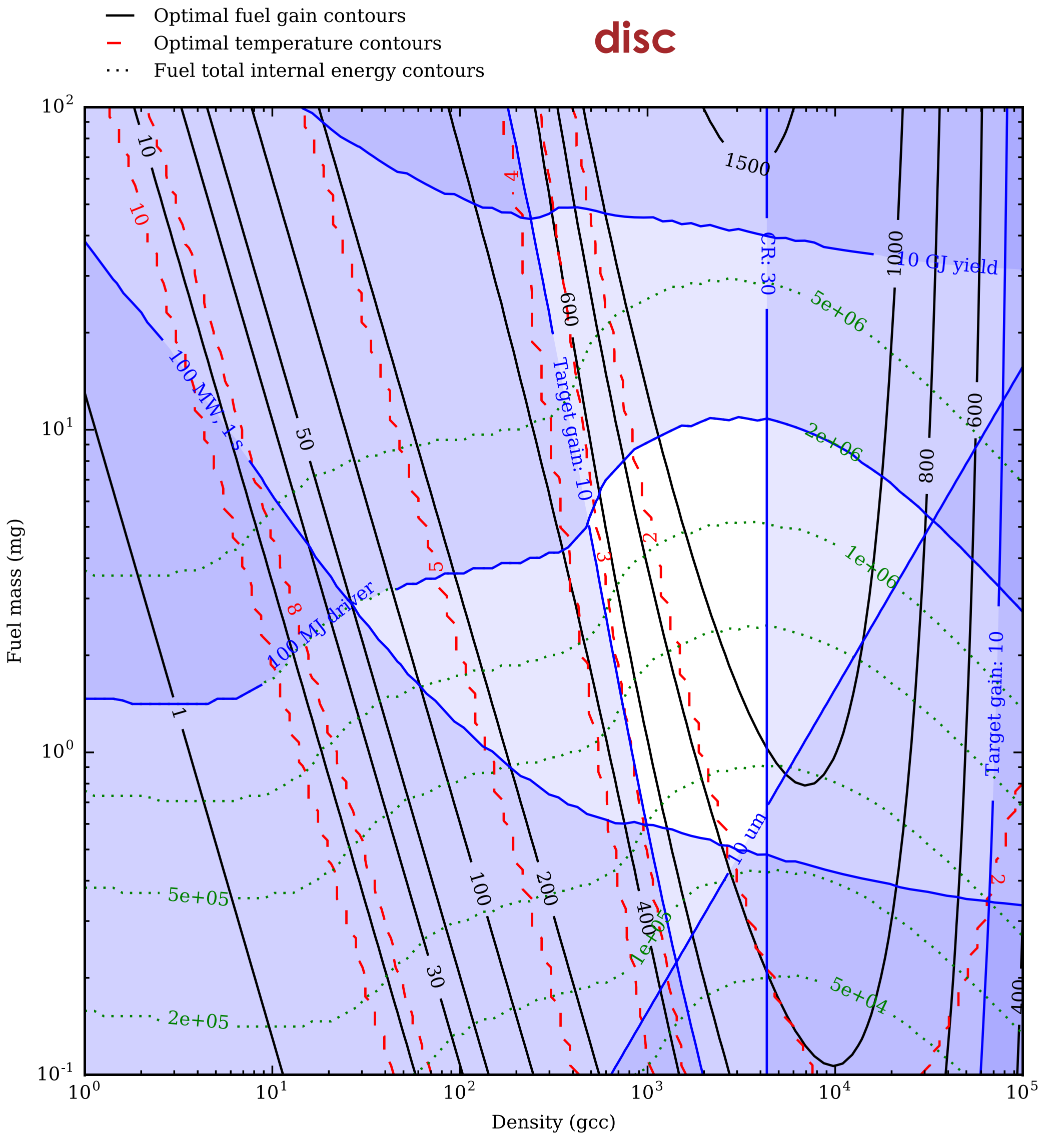
Validation

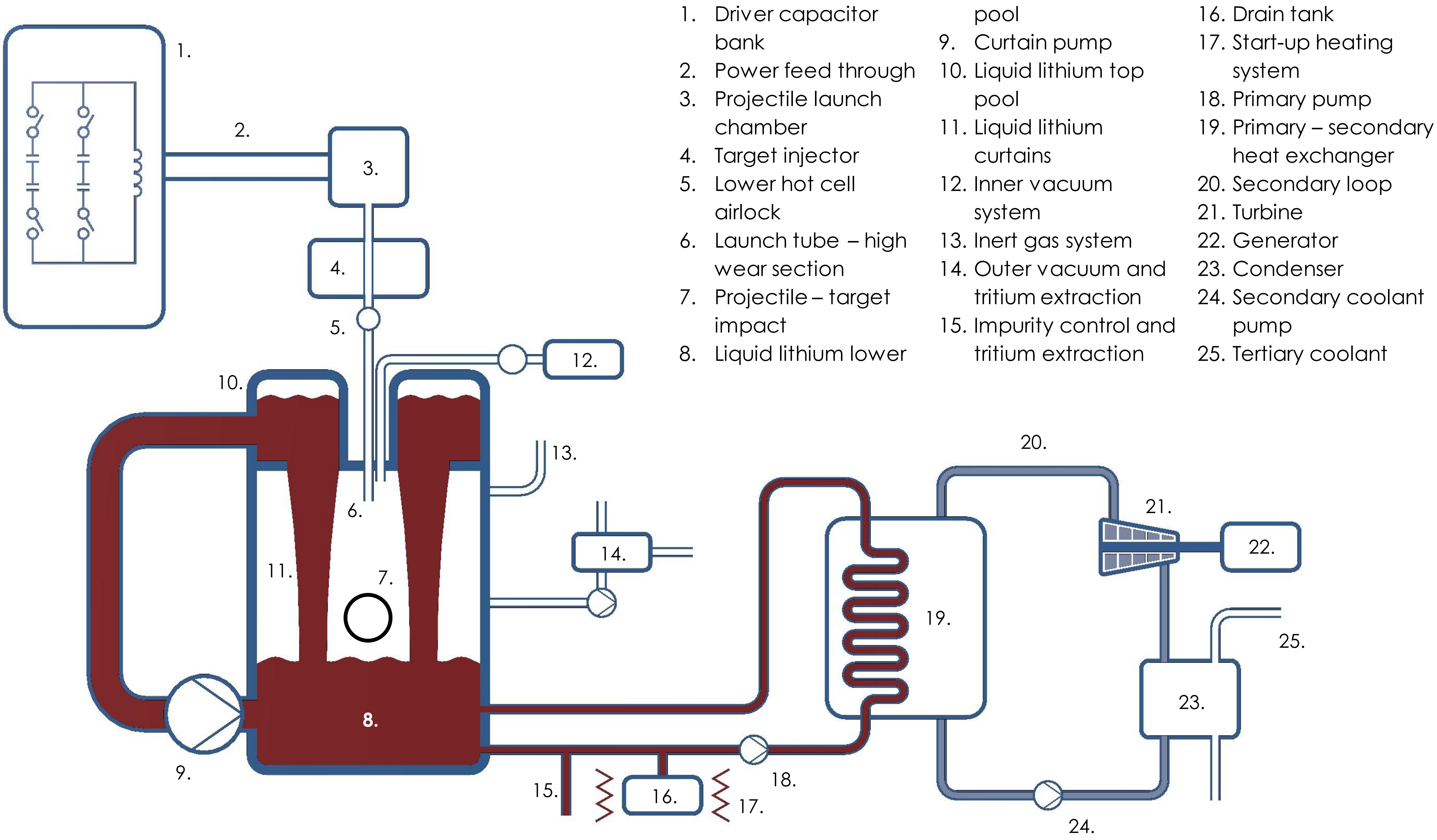
- Sphere
- Replication of Atzeni "The Physics of Inertial Fusion" figure 5.11
- Good match to integrated simulations
- Apart from gain 1 contour



When plotted in terms of density, there is little difference between geometries

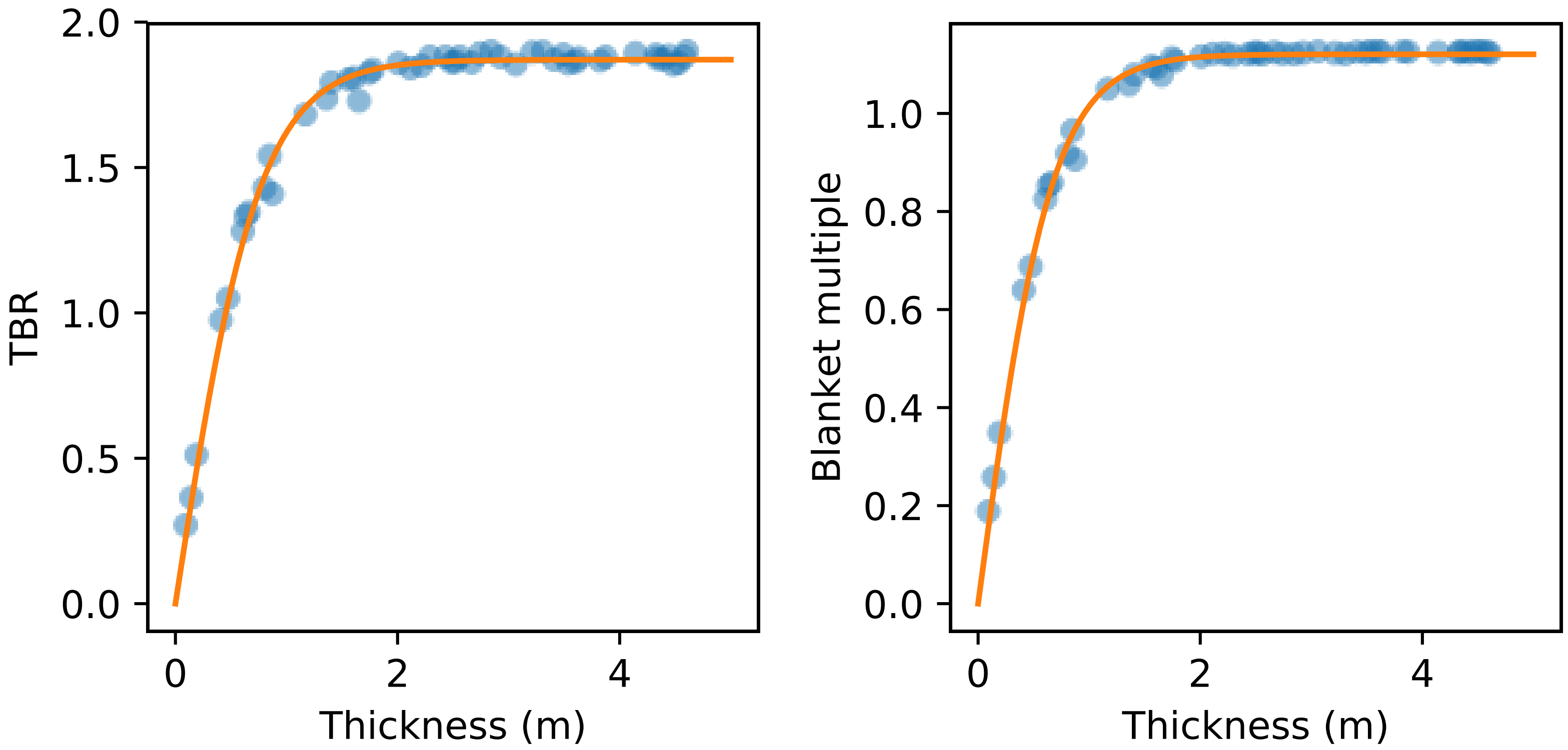





1. Driver capacitor bank
2. Power feed through
3. Projectile launch chamber
4. Target injector
5. Lower hot cell airlock
6. Launch tube – high wear section
7. Projectile – target impact
8. Liquid lithium lower pool
9. Curtain pump
10. Liquid lithium top pool
11. Liquid lithium curtains
12. Inner vacuum system
13. Inert gas system
14. Outer vacuum and tritium extraction
15. Impurity control and tritium extraction
16. Drain tank
17. Start-up heating system
18. Primary pump
19. Primary – secondary heat exchanger
20. Secondary loop
21. Turbine
22. Generator
23. Condenser
24. Secondary coolant pump
25. Tertiary coolant

Tritium breeding and energy multiplication

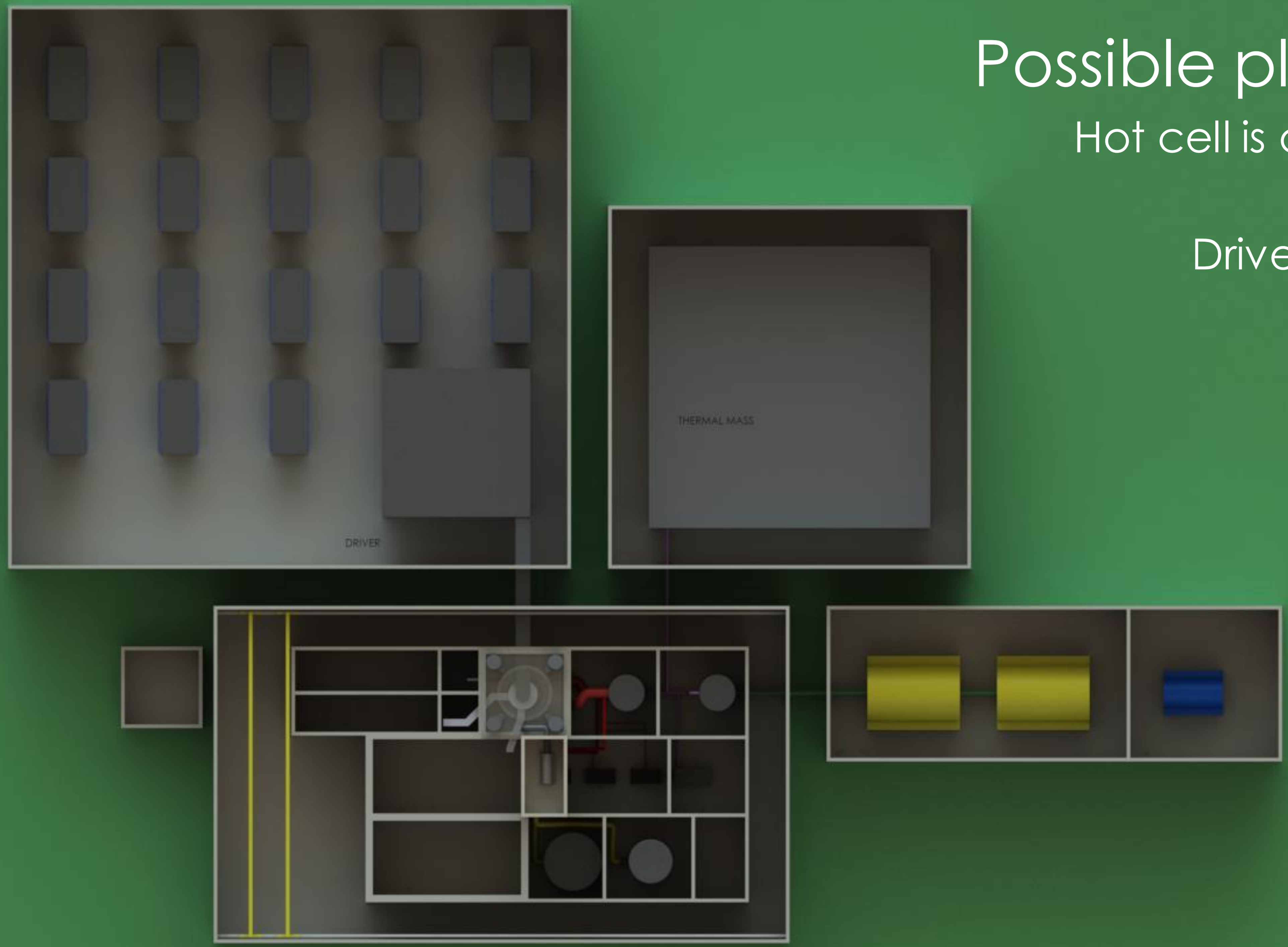
- Curtain thickness needs to be > 70 cm for TBR > 1.2
- Design can use pure, natural lithium
  - No ^{6}Li enrichment, no Be, no Pb



Possible plant layout

Hot cell is a physical small part of whole

Driver is large, in size and cost



Summary

- 2019 milestone
  - Machine Three commissioned and working well
  - Work on-going on projectile launch
  - Aiming to show fusion by end of the year
- Next steps
  - Preparation for new funding round going very well
  - Art of the possible for Machine Four being explored
  - Case for gain being built
  - Reactor vision does not seem to have an showstoppers

Other stuff from First Light @ IFSA

- "Experimental investigation of flyer plate launch on Machine 3 at First Light Fusion Ltd.", poster, Tues 3 PM, Matthew Betney
- "Towards a predictive modelling capability for Projectile-Driven ICF", talk, Thurs 2 PM, Dave Chapman
- "Simulations of the Richtmyer-Meshkov instability at First Light Fusion", poster, Thurs 3 PM, Martin Read
- "Demonstration of numerical capability at First Light Fusion", poster, Thurs 3 PM, James Pecover