Millikelvin Atomic Tritium for Project 8

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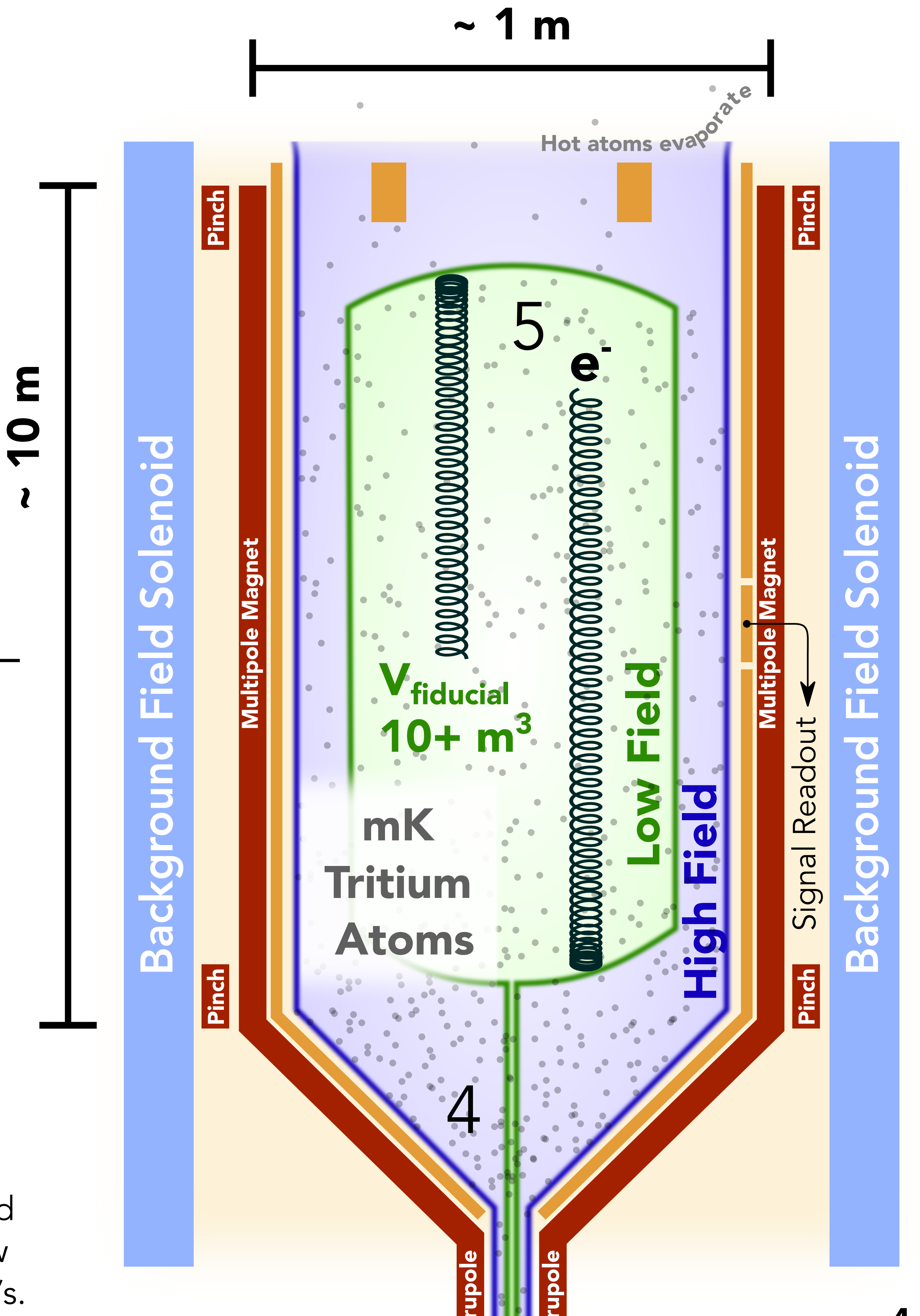
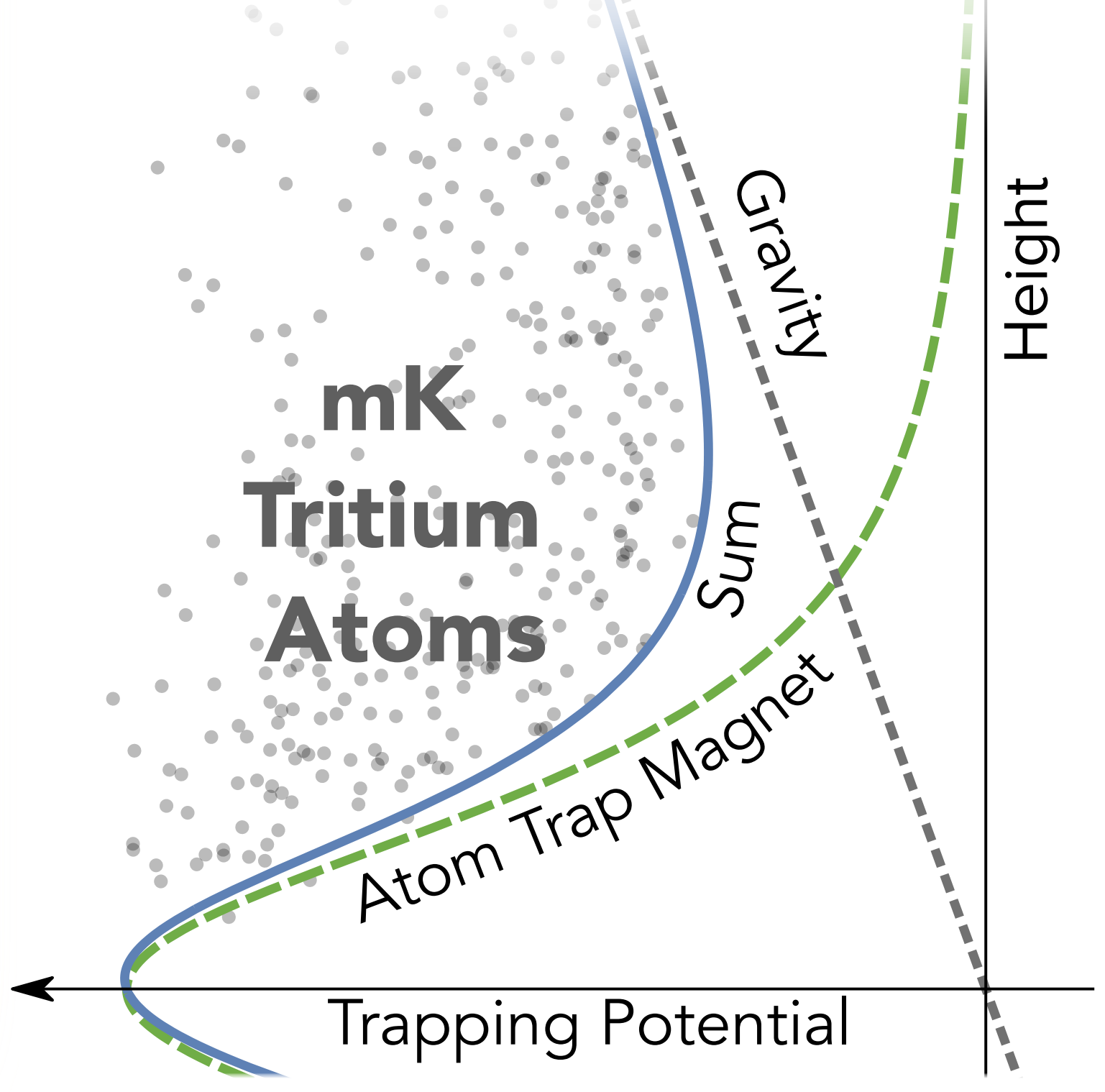
Atomic tritium is key to Project 8's unprecedented sensitivity of 40 meV. However, atomic tritium has not been produced at the required flux or trapped at the required volume. Project 8 intends to use the following steps to meet our atomic tritium needs:

1. Production of >10^{19} T atoms/s by dissociating T_2
2. Initial cooling via surface collisions to 10-30 K
3. Evaporative cooling and slowing in a magnetic guide to 1 mK internal and translational temperature
4. Loading through a small opening into a large trap
5. Storage for ≥ 1000 s in a magneto-gravitational trap designed for compatibility with CRES, Project 8's frequency-based spectroscopic technique



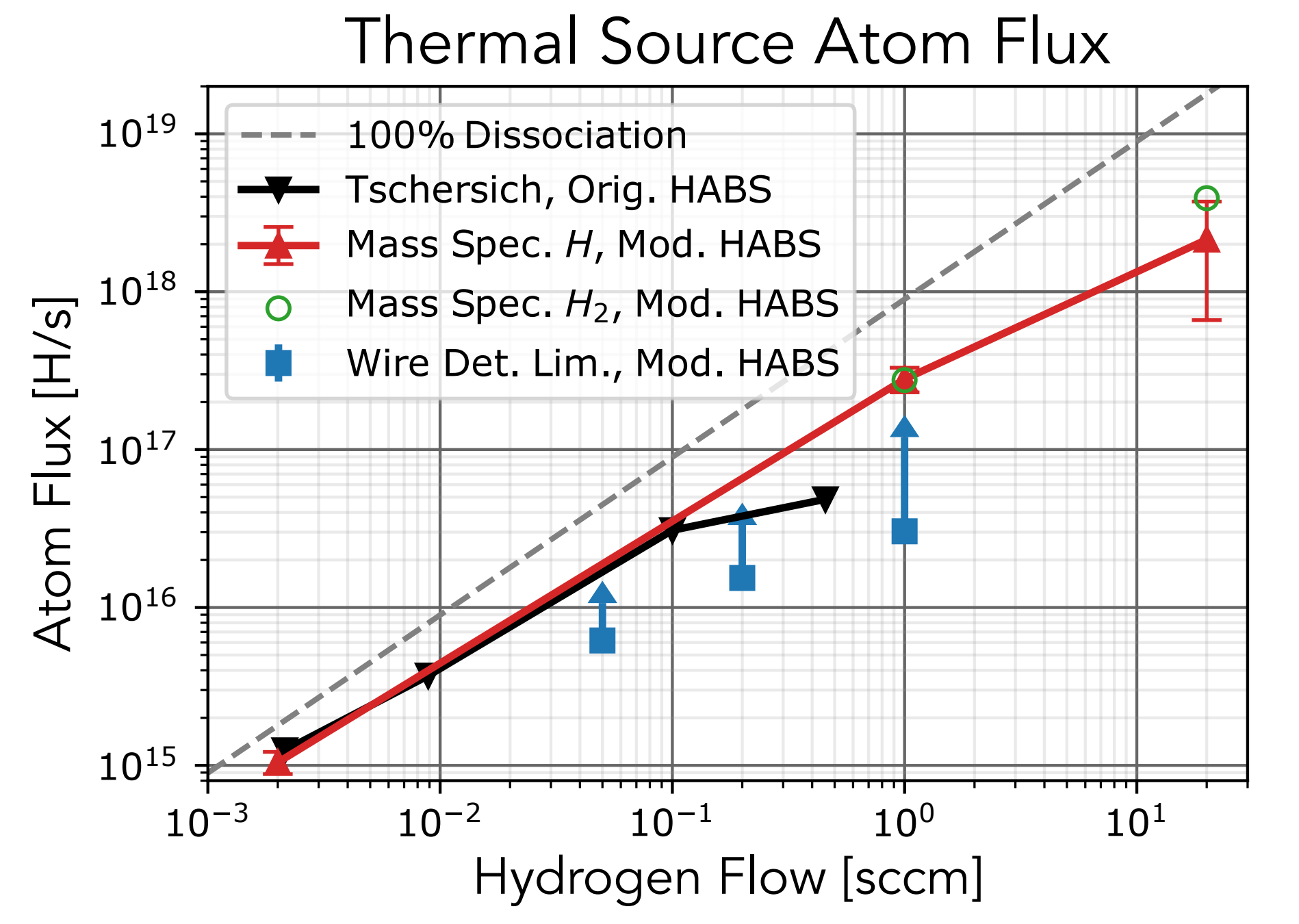
5. Magneto-Gravitational Trapping

For the best CRES performance, the main trap should hold only electrons up to a certain axial momentum. This trap depth is smaller than for the atoms, so we use gravity too.

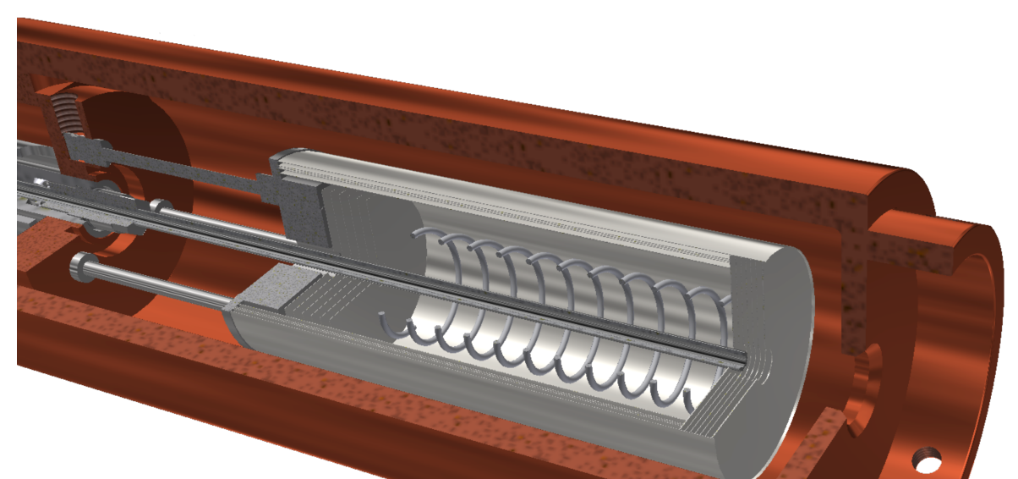


1. Making Atoms

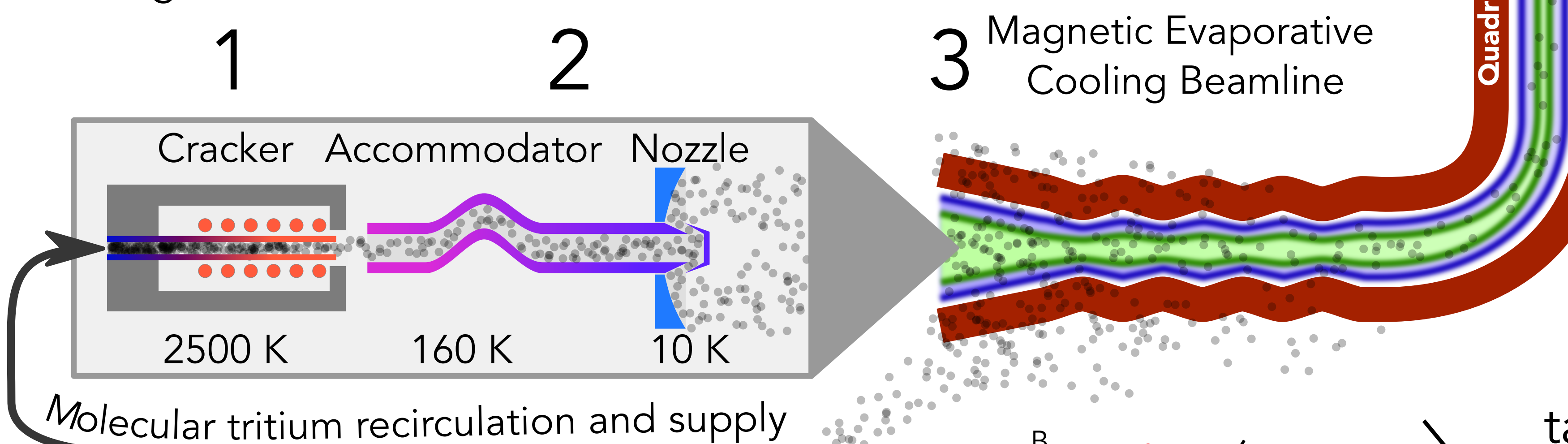
No past (tritium-compatible) atom source has made our goal of 10^{19} atoms/s. We have improved a thermal atom source by packing fine tungsten wire into its 1 mm tungsten capillary, and shown this design should reach the target. A new ECR plasma source may do the same at lower temperature.



Measurements of the original and improved thermal source at 1 mm tube size. The new design with a 3 mm tube should reach 10^{19}/s.

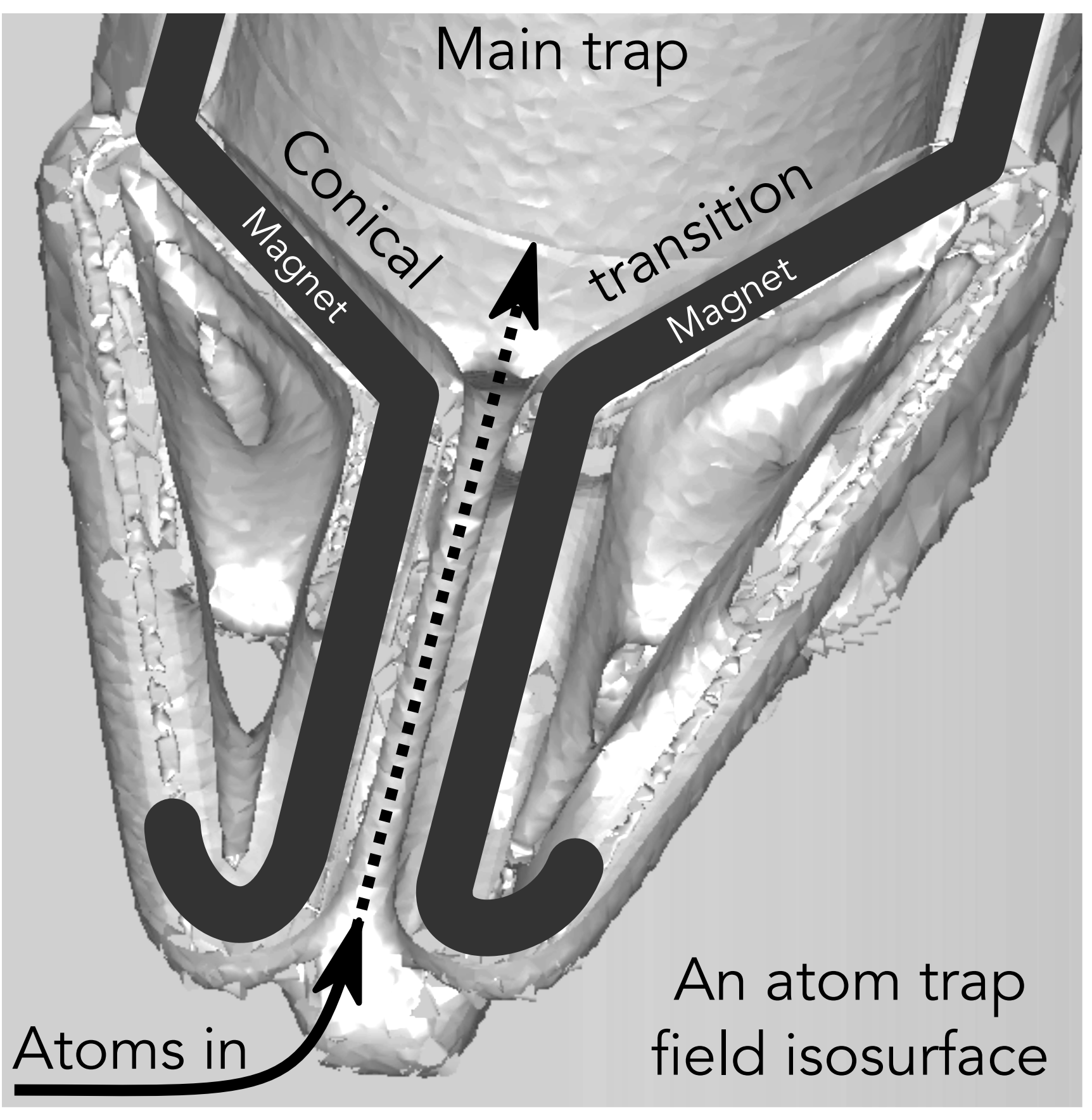


A tritium-compatible thermal atom source

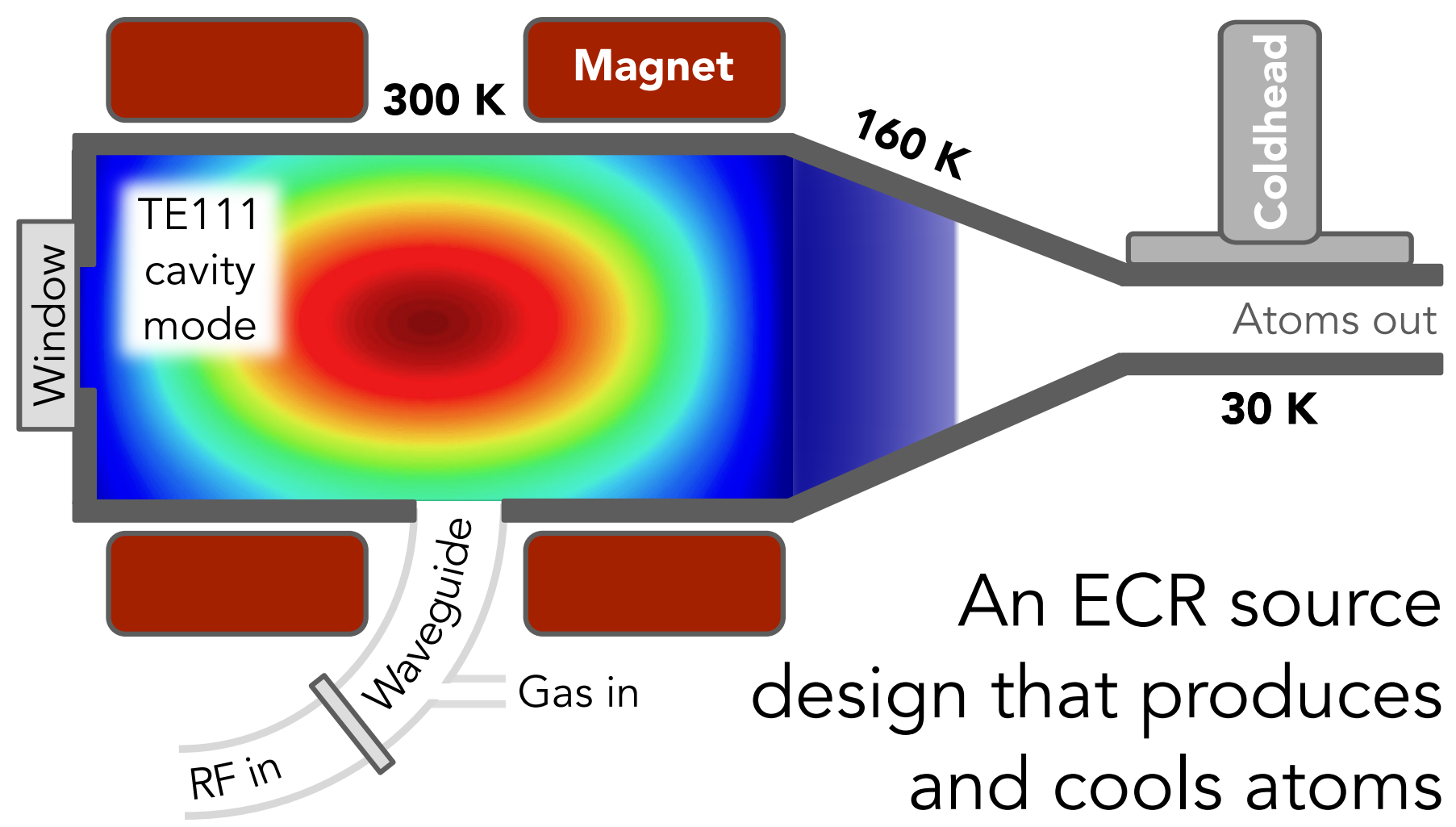


4. Loading

The cold, slow atoms must move efficiently from the cm-scale guide to the meter-scale trap. A tapered transition adds magnet poles without field zeros to link the guide and trap.



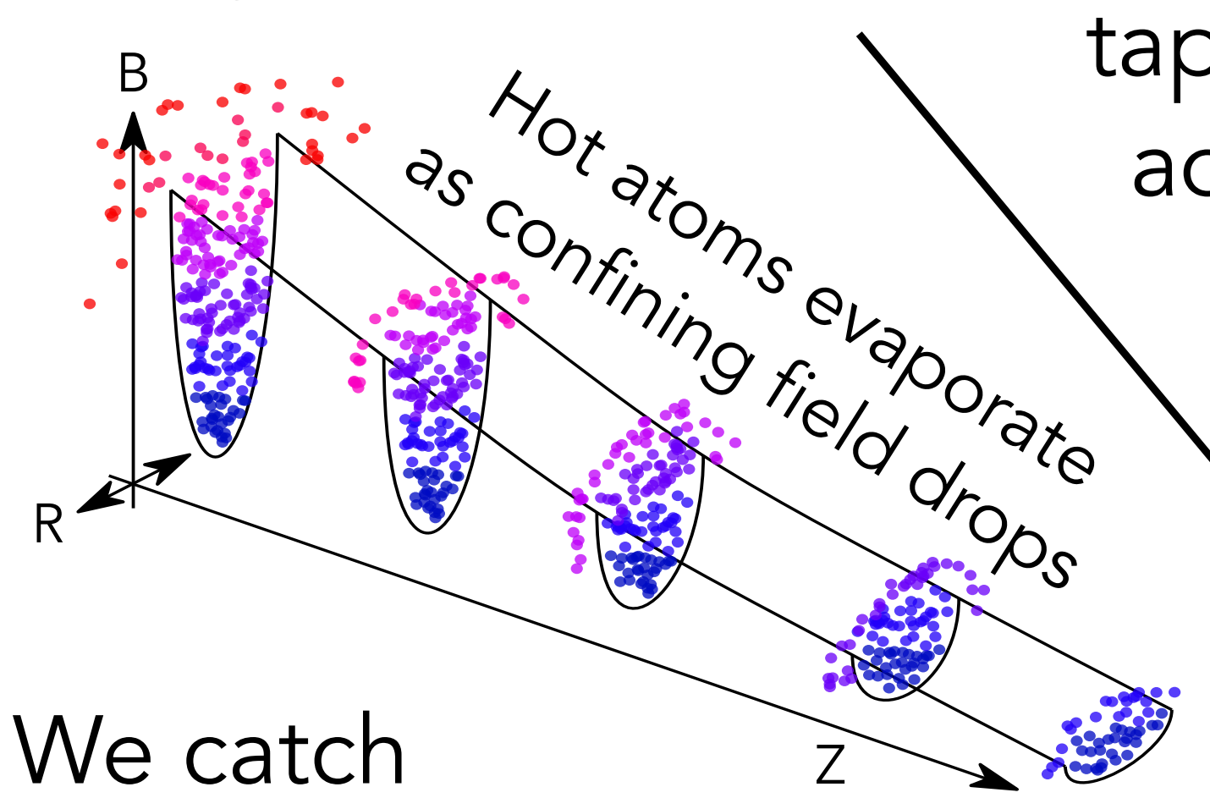
An atom trap field isosurface



An ECR source design that produces and cools atoms

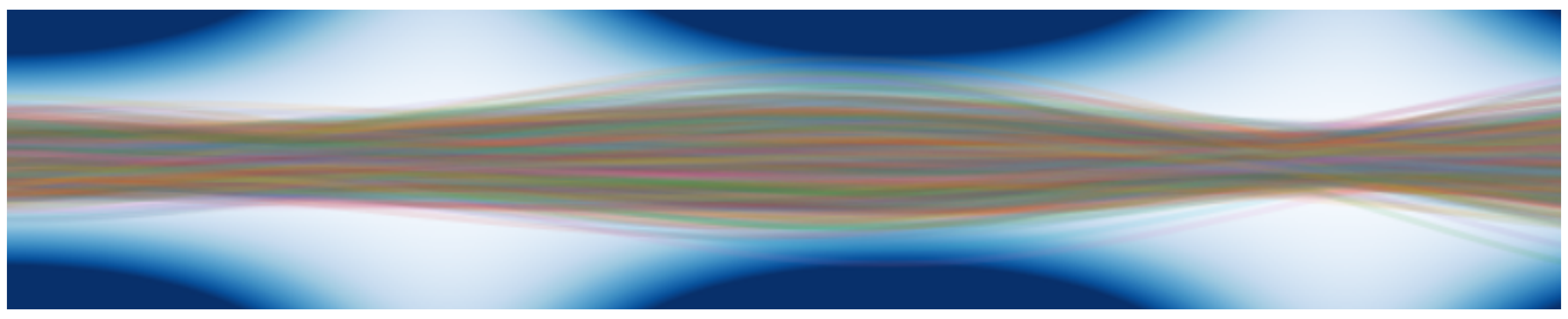
2. Surface Cooling

Hot atoms must be cooled to trap them. Atoms recombine on surfaces, but the rate is low near 160 K, so we start cooling on the wall of an Al accommodator. One bounce on a nozzle (~ 30 to 10 K) balances loss and cooling.



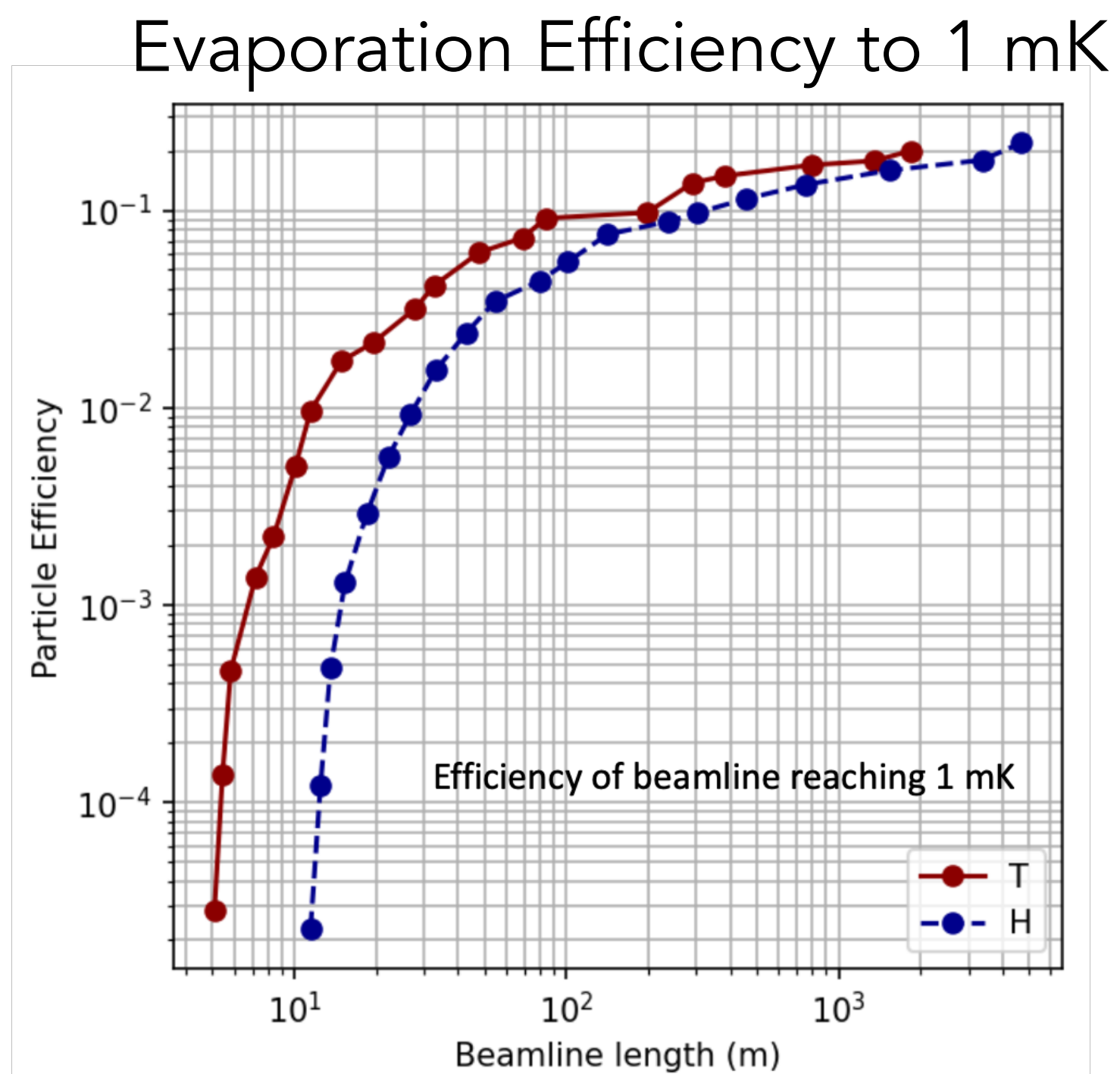
3. Magnetic Cooling & Slowing

T atoms have four spin states; magnetic minima can trap two. We catch atoms off the nozzle in a quadrupole guide. Those with large radial momenta escape. The rest collide and thermalize to a colder internal temperature. Bends or bumps in the guide convert axial momentum to radial, so evaporation cools and slows.



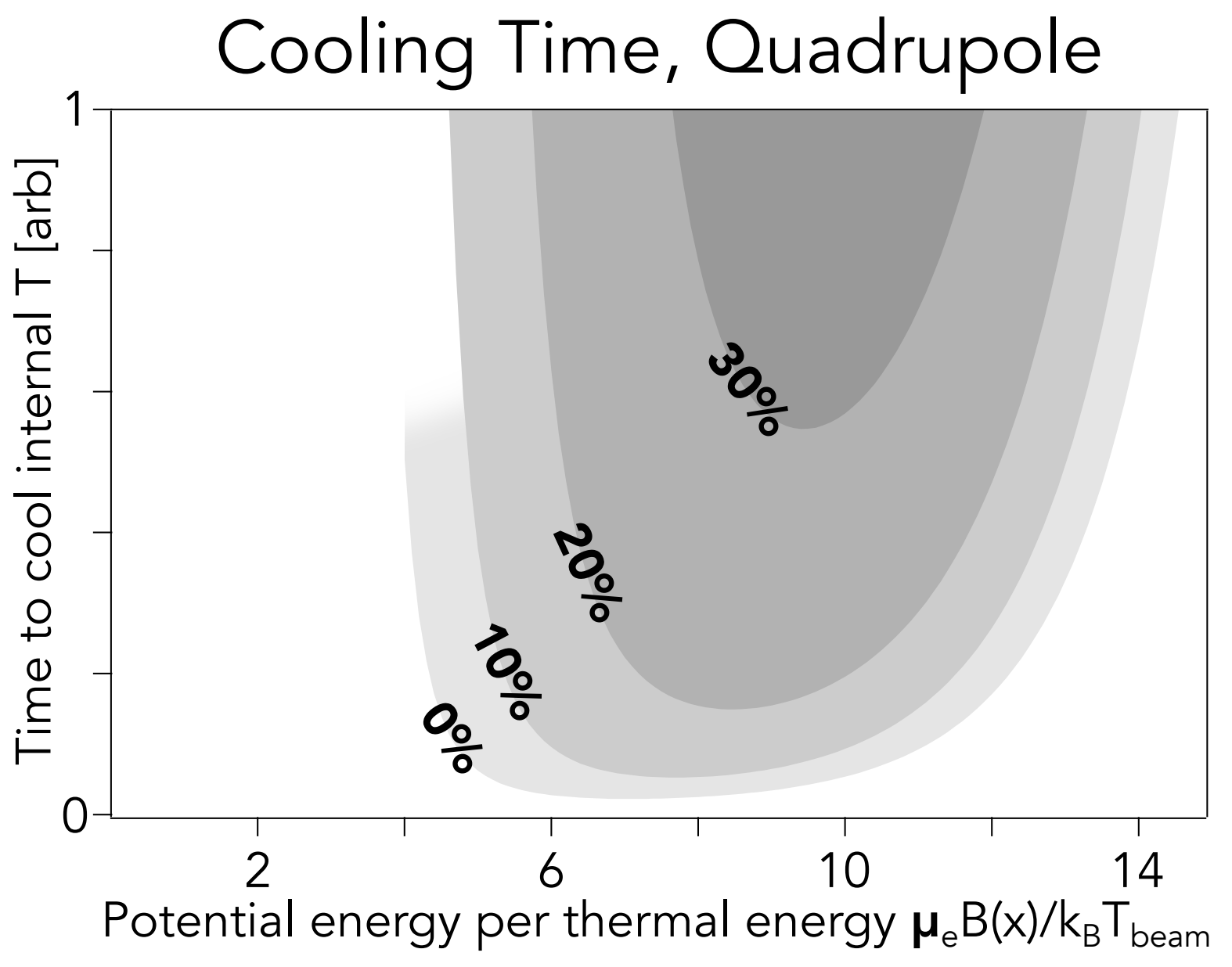
Above: atom trajectories traversing "bumps" in the magnetic guide

Project 8's combination of high flux and low atom temperature requires significant R&D.

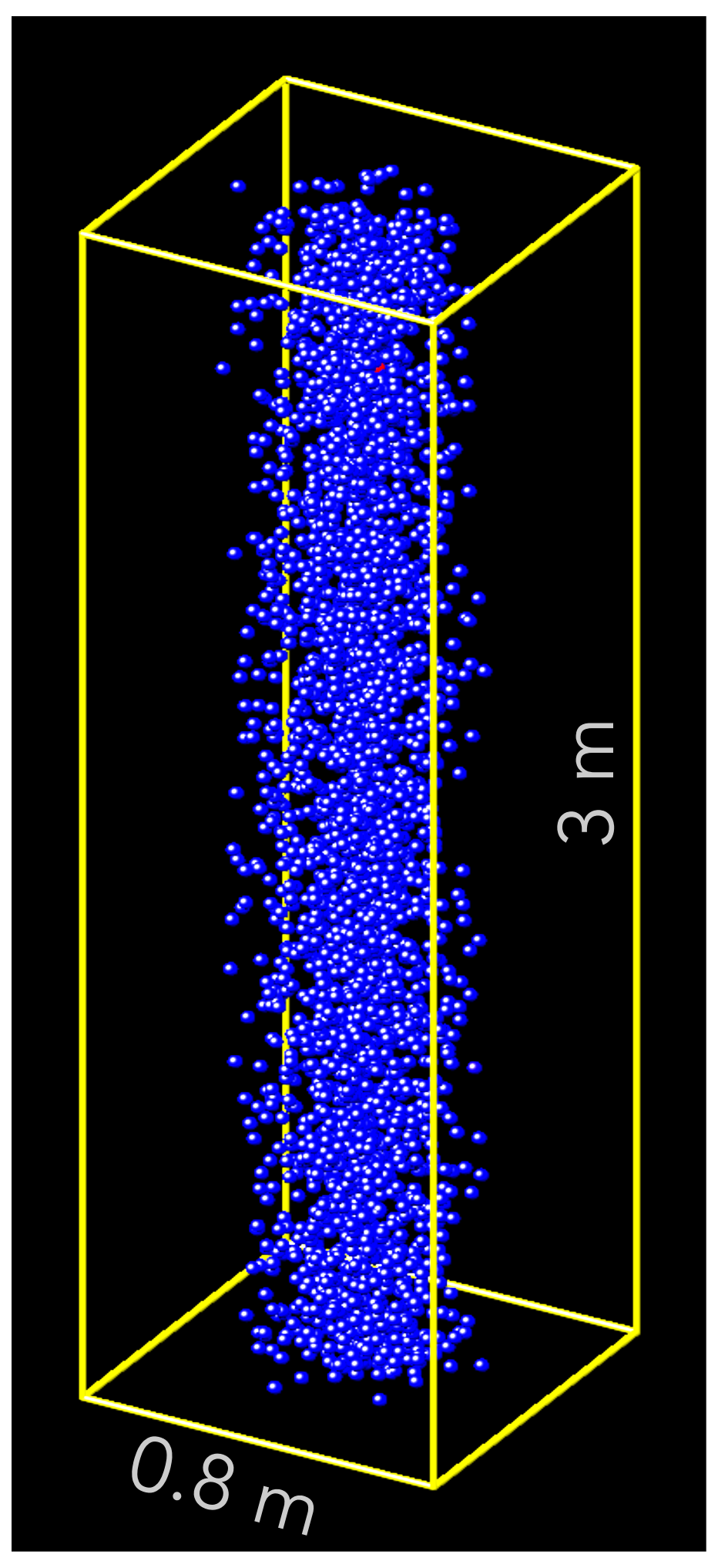


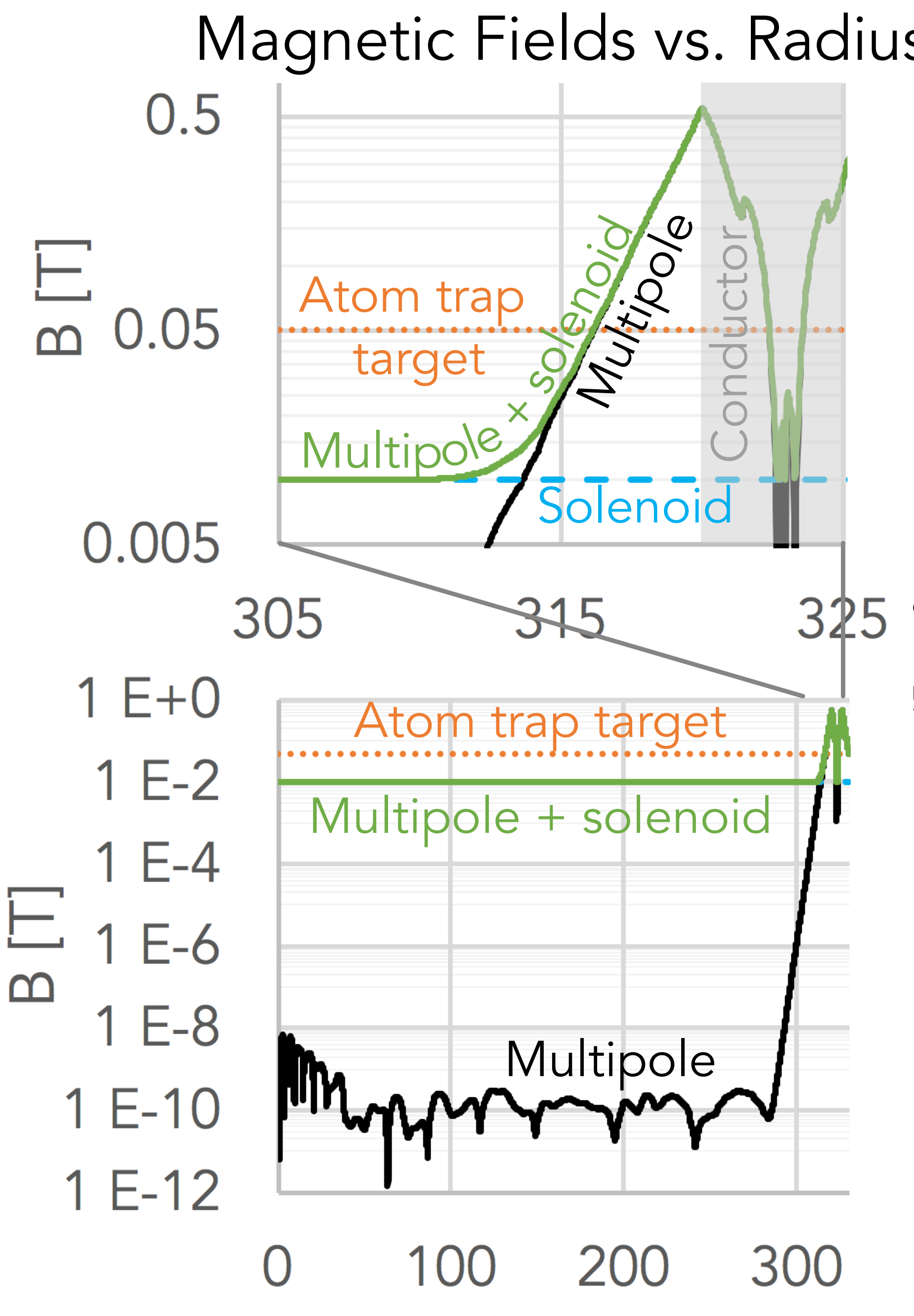
A longer magnetic guide does not need to eject atoms as harshly, allowing for higher efficiency

In addition to cross-validated models, the first stage of a ^{6}Li beam-line for validation is now running. This combines laser cooling and diagnostics with freedom from radioactivity.



Using more of the evaporation power to slow the beam (contours) delays cooling the internal temperature; this model supports our optimization work





Left: Walls holding 10^{17} m^{-3} atoms at 1 mK for 1000 s surround a highly uniform central field.

Left: a simulation of atoms in a magneto-gravitational trap with SPARTA (a DSMC code), as extended for Project 8 with 3D potentials

This work was supported by the US Department of Energy, the US National Science Foundation, the PRISMA+ Cluster of Excellence at JGU Mainz, and internal investments at all collaborating institutions.