

# PRÎSMA+ Cluster of Excellence Project 8 Atom Trapping Demonstrator IIII

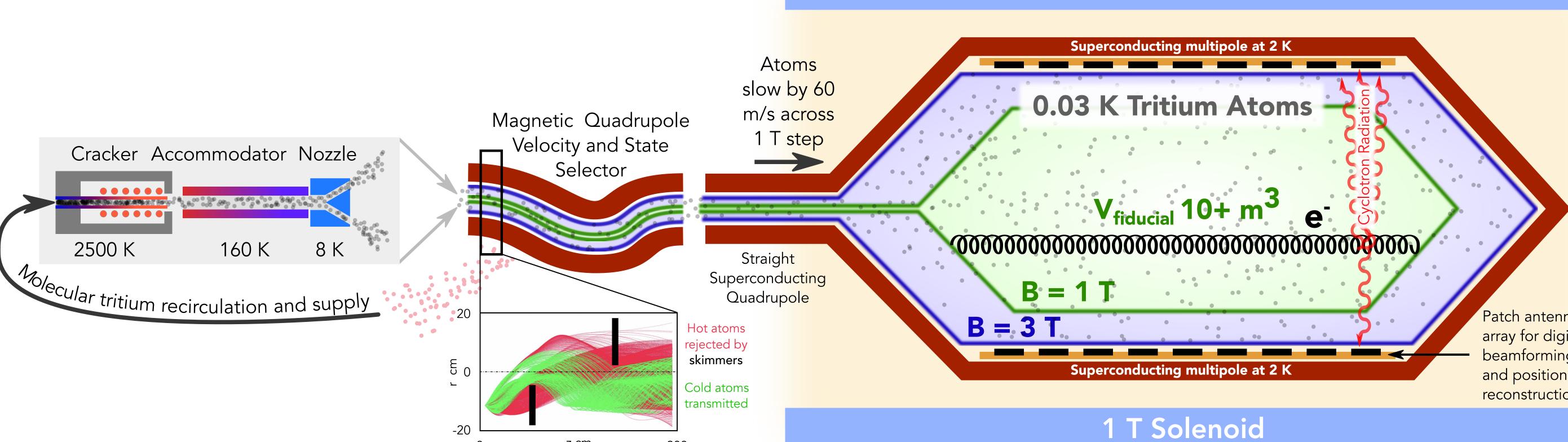
Alexi Radovinsky for the Project 8 Collaboration | Plasma Science and Fusion Center | Massachusetts Institute of Technology, Cambridge, MA | radovisnky@psfc.mit.edu





Cyclotron Radiation Emission Spectroscopy is a new method, invented by Project 8, for measuring infdividul electron energies. We use it to measure the energy spectrum in tritium beta decay, which is sensitive to the mass of the neutrino.

CRES converts the emission frequency of electrons in a uniform field back into the original electrons' energies. The signals are small, about 1 fW, but we regularly measure them and have achieved ~2 eV resolution at 17800 eV.



The energies of electrons from beta decays of molecular tritium are smeared by about 1 eV, thanks to rovibrational excitations of the molecular system. Atomci tritium has no such smearing, making it a compelling tool for precision spectroscopy.

chain to supply tritium atoms cooled to about 30-50 mK for storage in the main trap.

0.04 eV (90% CL) to the neutrino mass.

### Requirements

TO demonstrate trapping of atomic tritium for Project 8, the Atom Trapping Demonstrator magnet must provide the following:

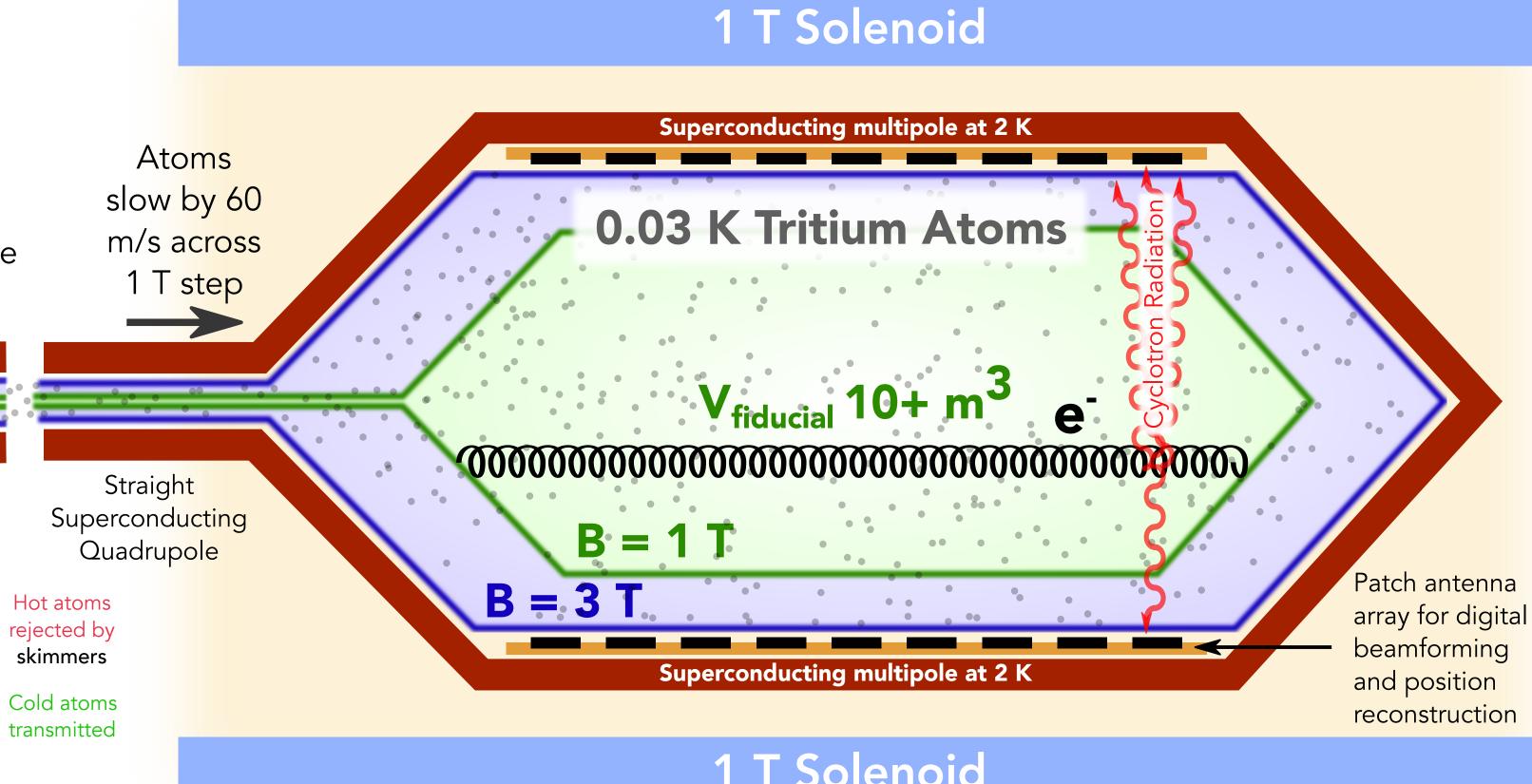
- A background 1-T solenoid
- A closed magnetic bottle at least 2 T deep
- A trap volume of at least 1 m<sup>3</sup>
- An opening for loading the atoms
- Separate coil (~4 K) and wall (2-90 K) temperatures
- Space for a tritium isolation container
- Space for the CRES antennae

The design proposed here achieves or accommodates each of these requirements.



The magnet proposed here meets the unusual requirements of Project 8. In particular, it provides a cubic-meter-scale magnetic bottle that is 2 T deep and that surrounds a volume where the field is  $< 10^{-4}$  T. Such contrast is key to Project 8, since variations in the magnetic field distort the energy reconstruction.

This design is ready for preparation of a detailed engineering design, and that process is proceeding.



### Atomic Tritium

We have designed a production, cooling, and injection

Using atomic tritium, Project 8 will have a sensitivity of

#### Four axial conductors and two pinch coils form the traditional loffe trap. However, this configuration fails

Field uniformity: any inhomogeniety in the magnetic field in the fiducial volume directly worsens our energy resolution; the quadrupole-pinch loffe trap has a strongly-varying field everywhere.

two important requirements of Project 8.

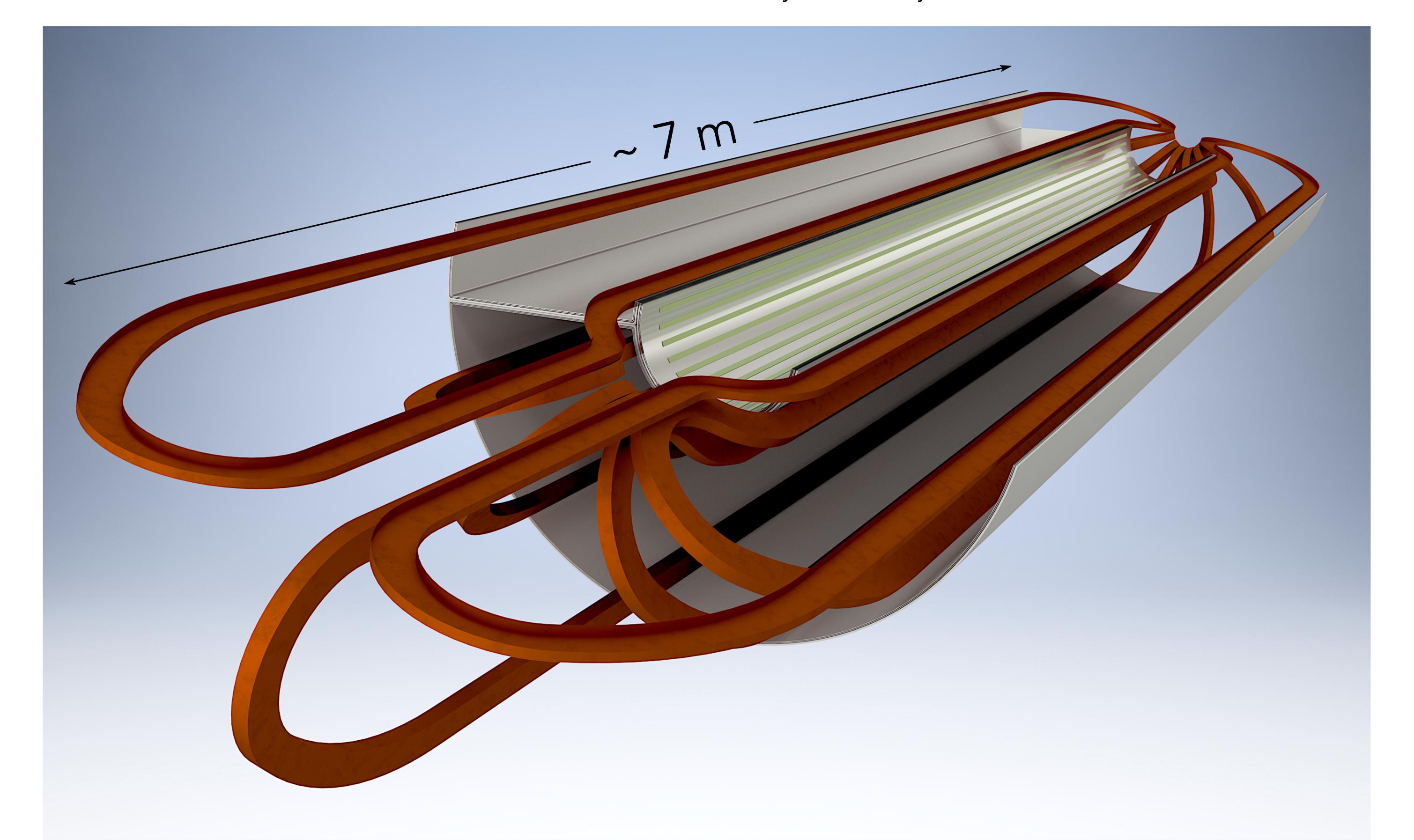
The Classic Ioffe Trap

Atomic tritium recombines to molecules on contact

with physical surfaces. Therefore, a magnetic bottle is

required to store tritium atoms for a useful length of

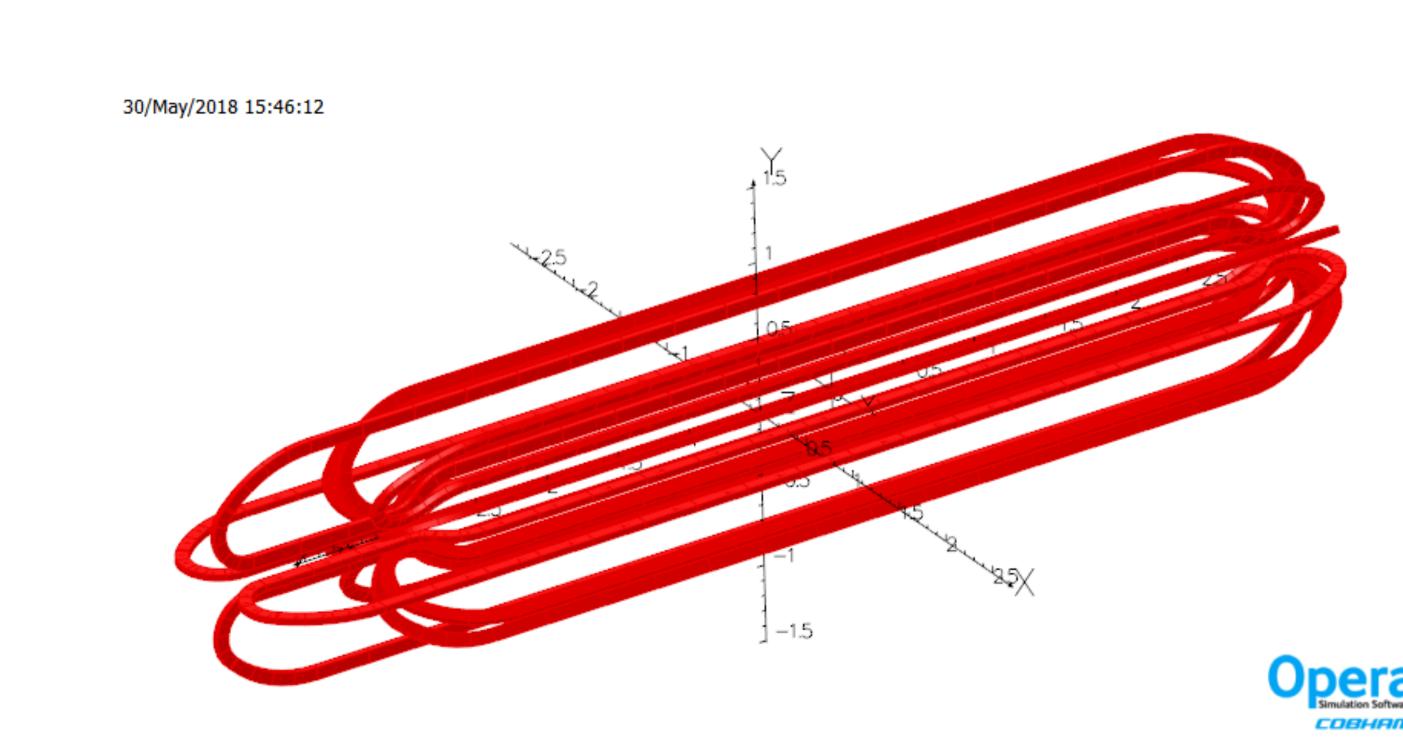
Trap volume: if the quadrupole bars are moved apart for more volume, low-field gaps will appear and atoms will escape the trap. Even loffe traps that are large by atom- or neutron-trapping standards are measured in millimeters or centimeters; Project 8 requires a meterscale trap.



The proposed manget provides a 2-T deep magnetic bottle with a loading opening for filling the trap, as well as a region of low field in the center where the energy resolutiuon of CRES is not degraded by field inhomogeniety. The coils are in brown, thermal shells as metallic, and the CRES antennae in light green. The 1-T solenoid is not shown. The cryogenic design is challenging: it is necessary to set the innermost wall at anywhere from 2 K to 90 K without disturbing the coils.

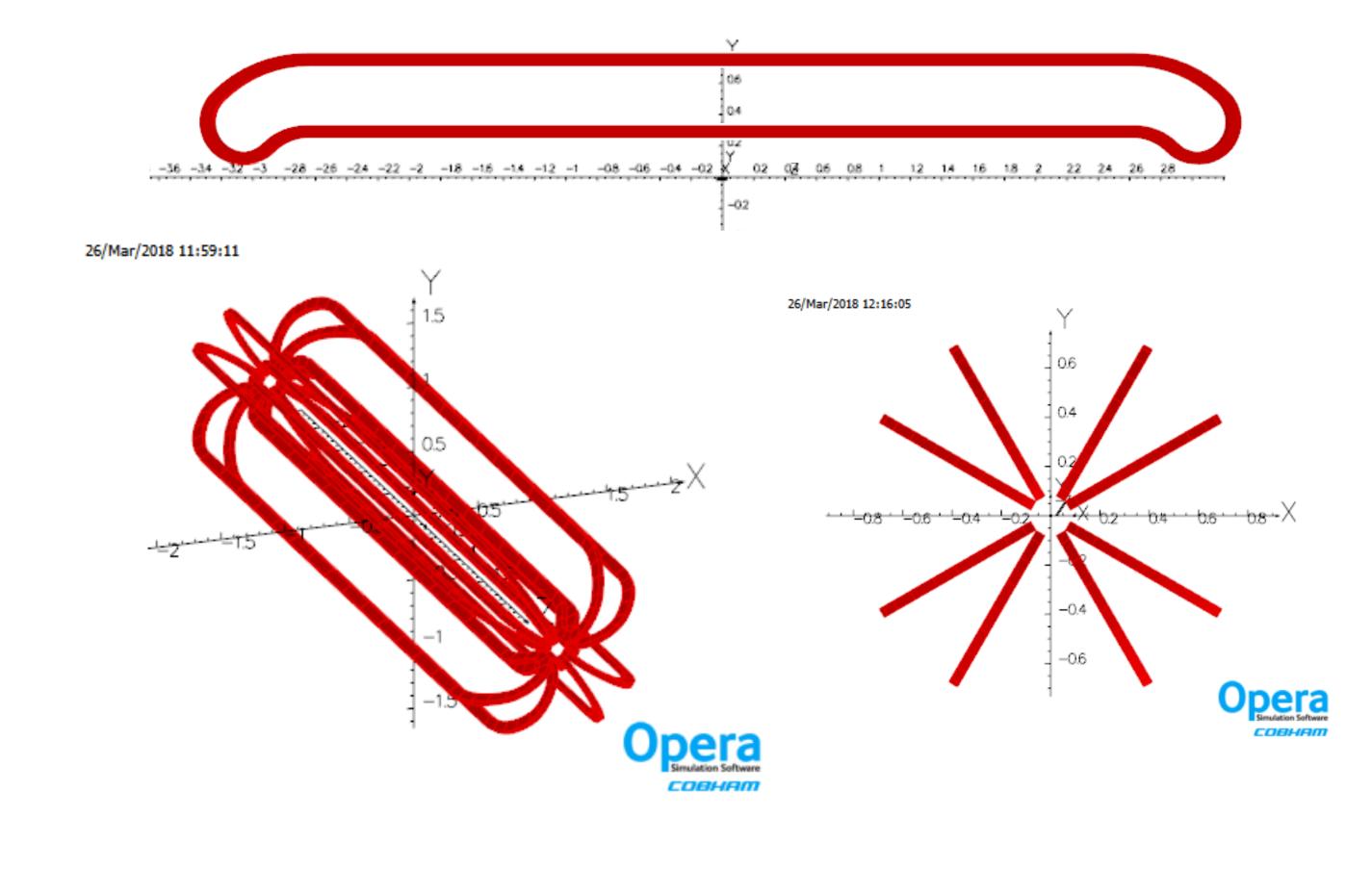
#### Coil A

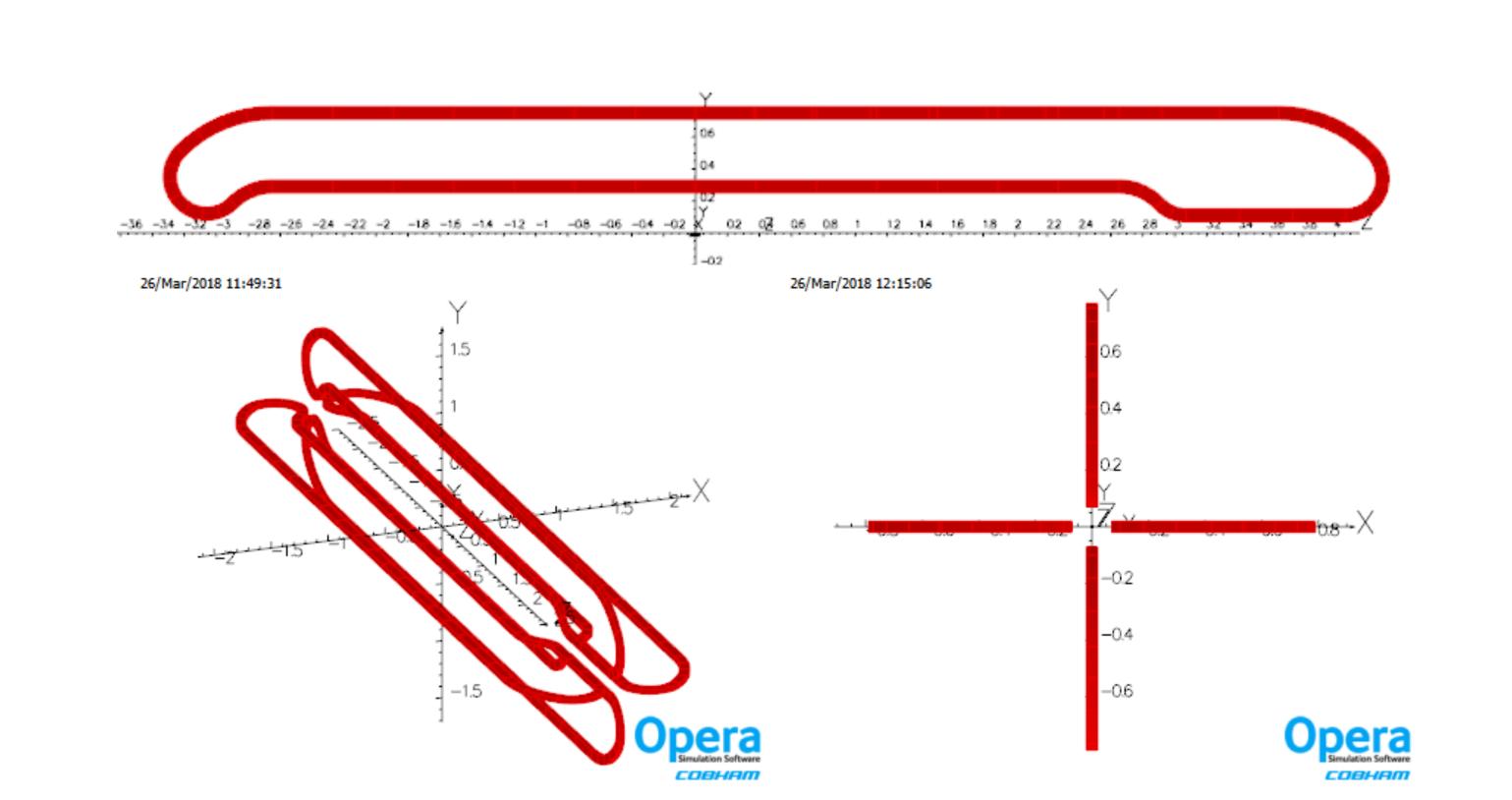
These coils fill the non-quadrupole spaces in the array. They include a straight segment, part of the main loffe trap, two curved end segments, helping close the trap, and an outer return leg to form a flat racetrack.

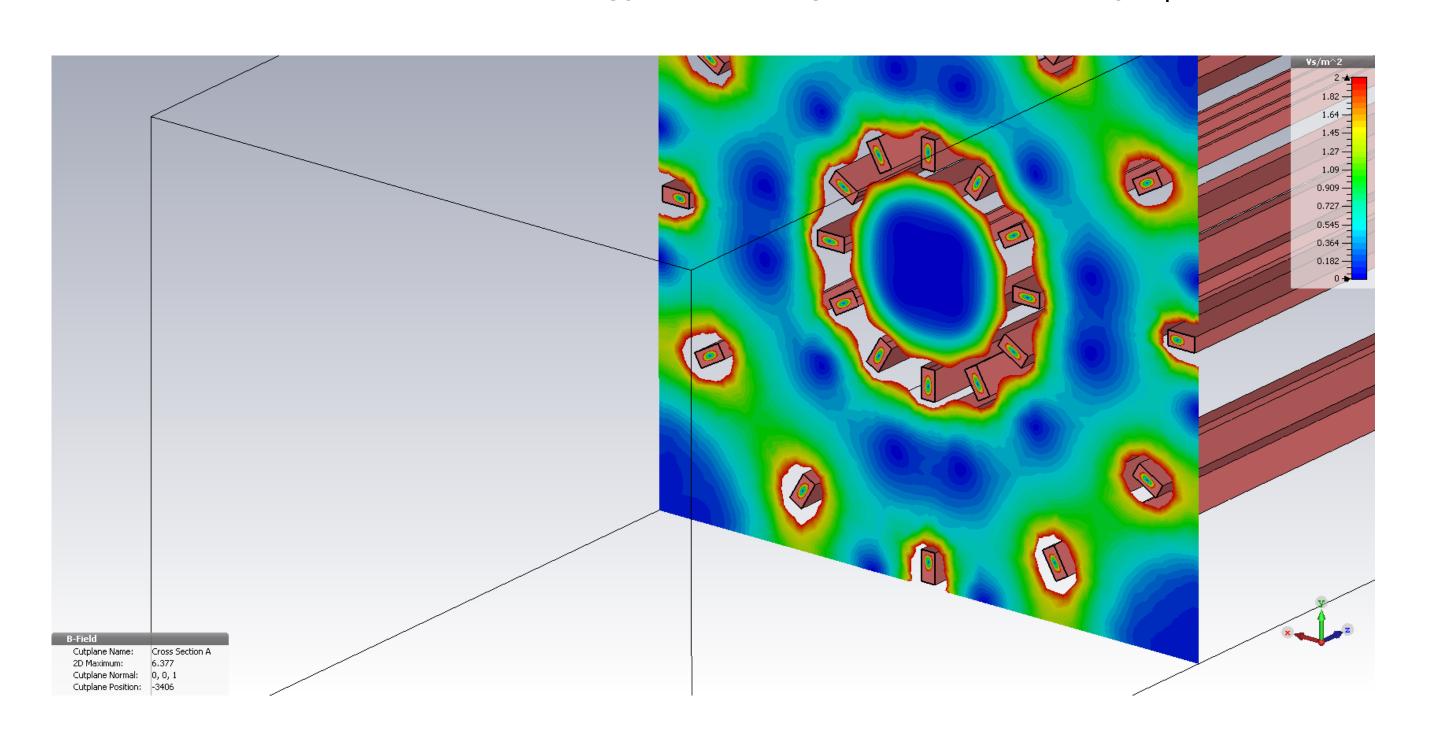


#### Coil B

These have an extended straight section that connects to the atom loading system; this straight segment is displaced radially towards the trap axis to ensure the quadrupole thus formed provides a closed trapping

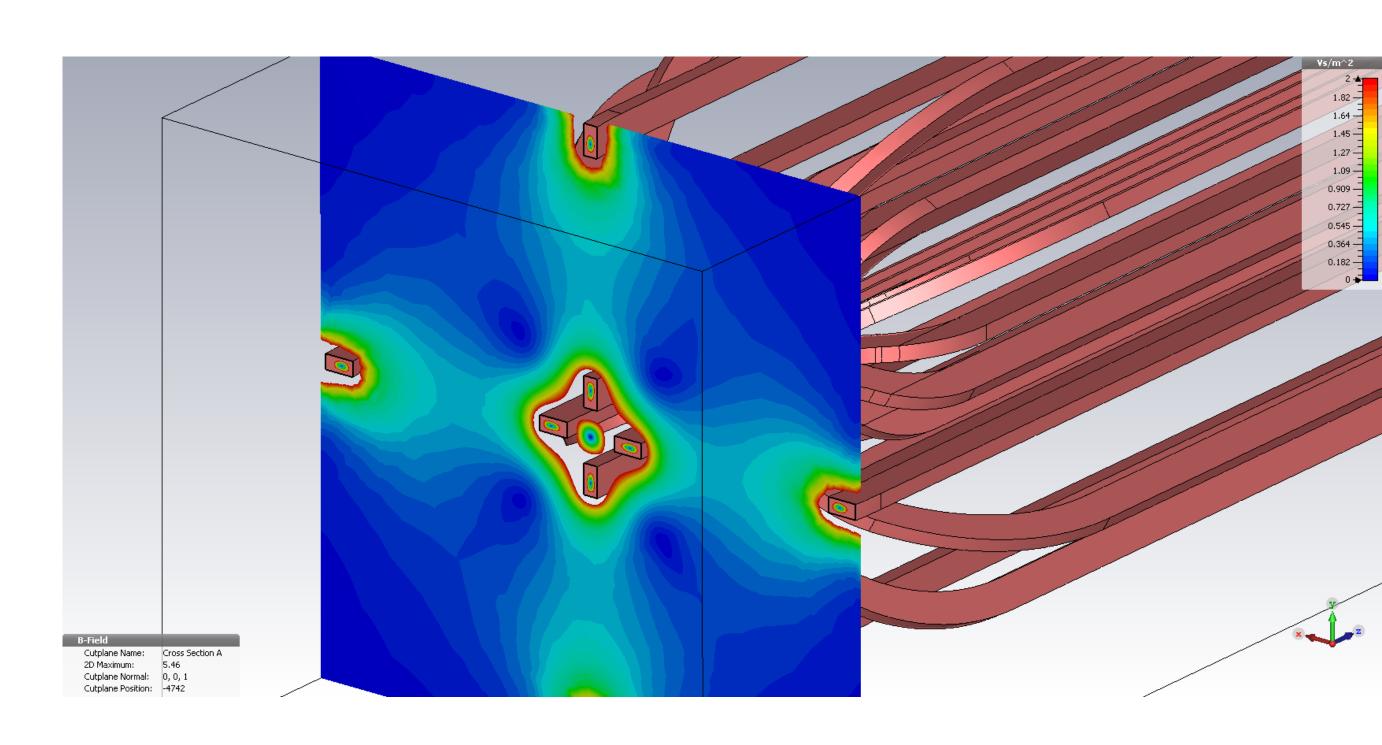






# Field Shape

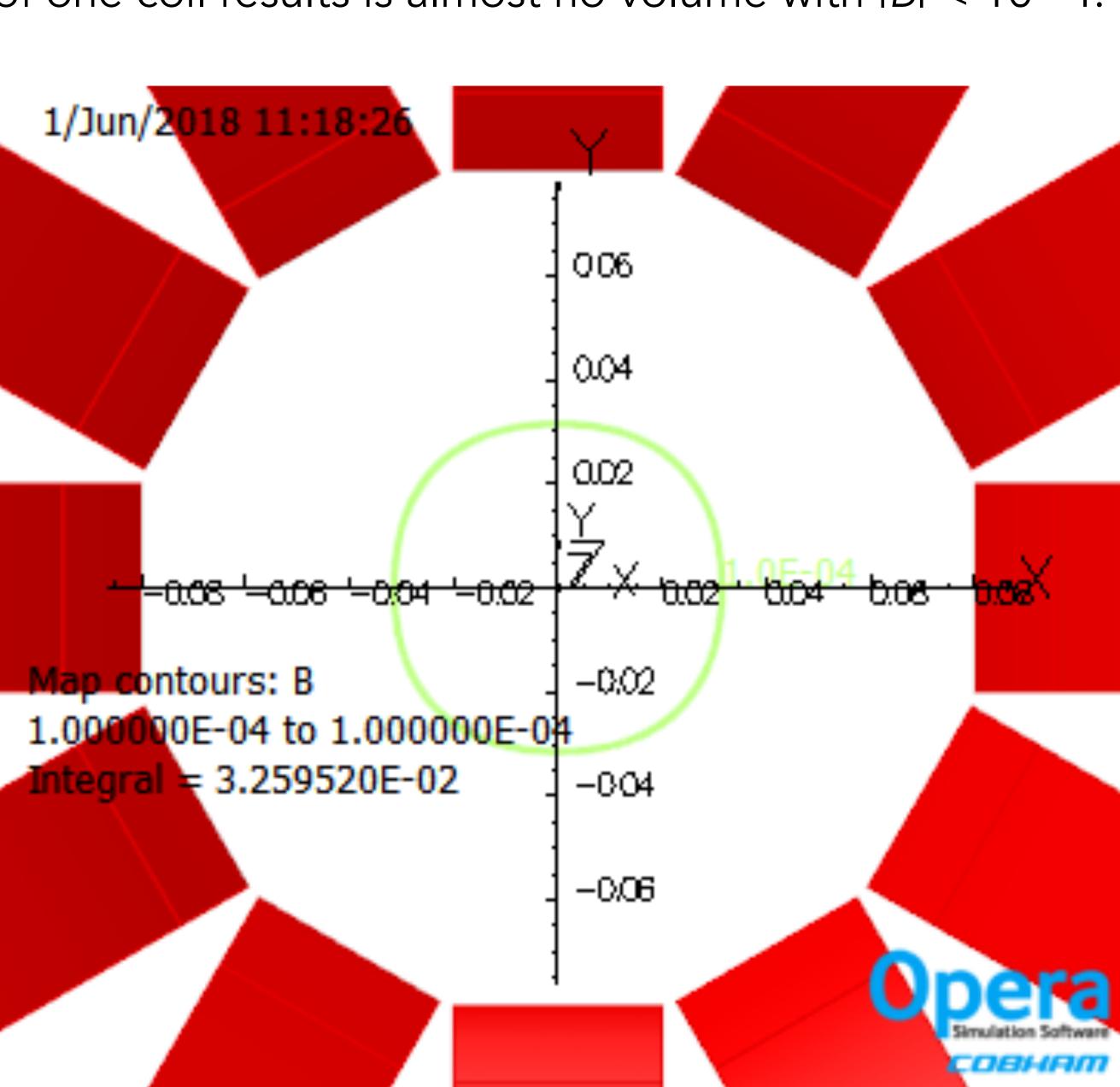
At the midplanec, above, and at the end, below, the field reaches its design magnitude away from the conductors suyrface, as desired.



# Low-Field Region

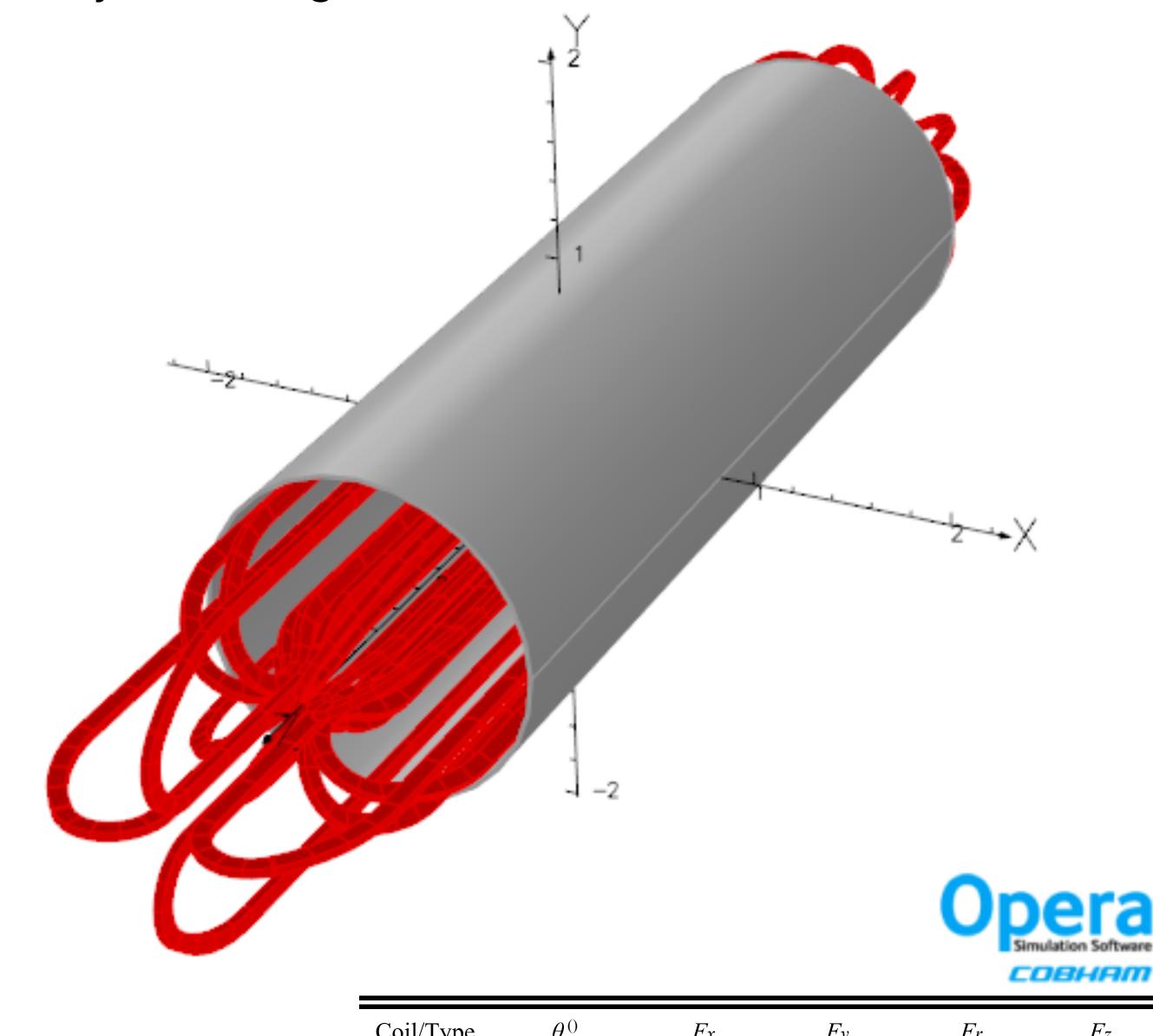
Higher-order multipoles, as planned for the full-size Project 8 atom trap, provide still-better field cancellation than this 12-pole design. Still, even this small demonstrator has a nonzero region of field below

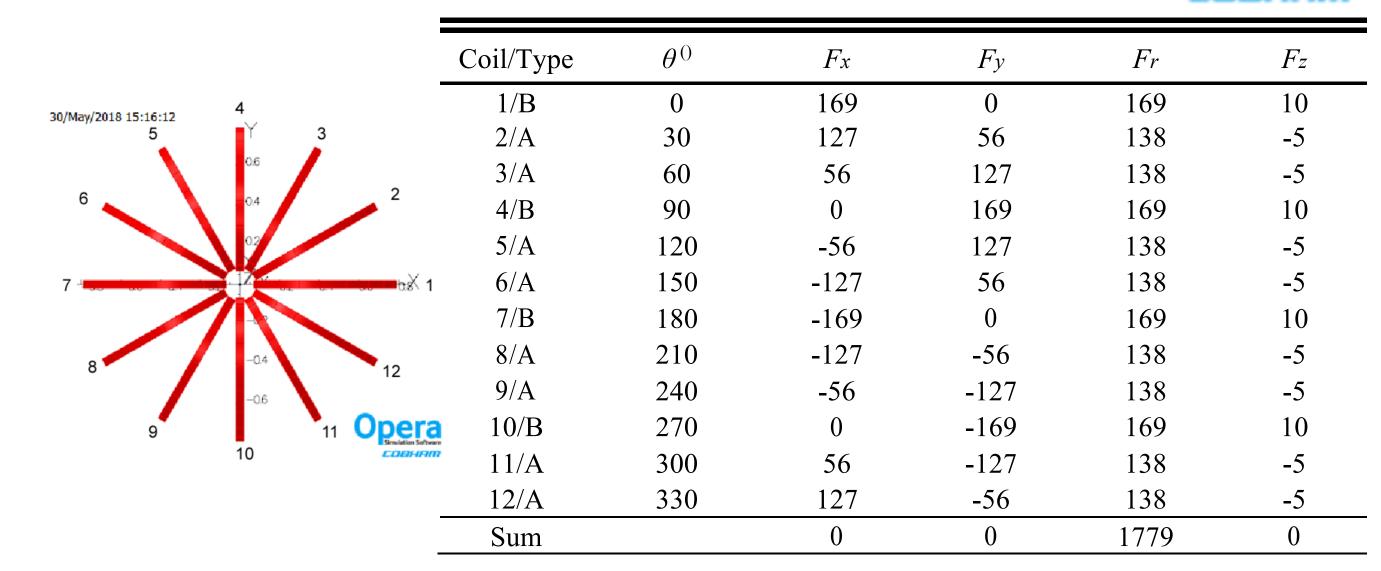
The size of the low-field region is strongly influenced by the precision with which the as-manufactured coils match their ideal positions. Even a 1-mm displacement of one coil results is almost no volume with  $|B| < 10^{-4}$  T.



## Hoop Stress

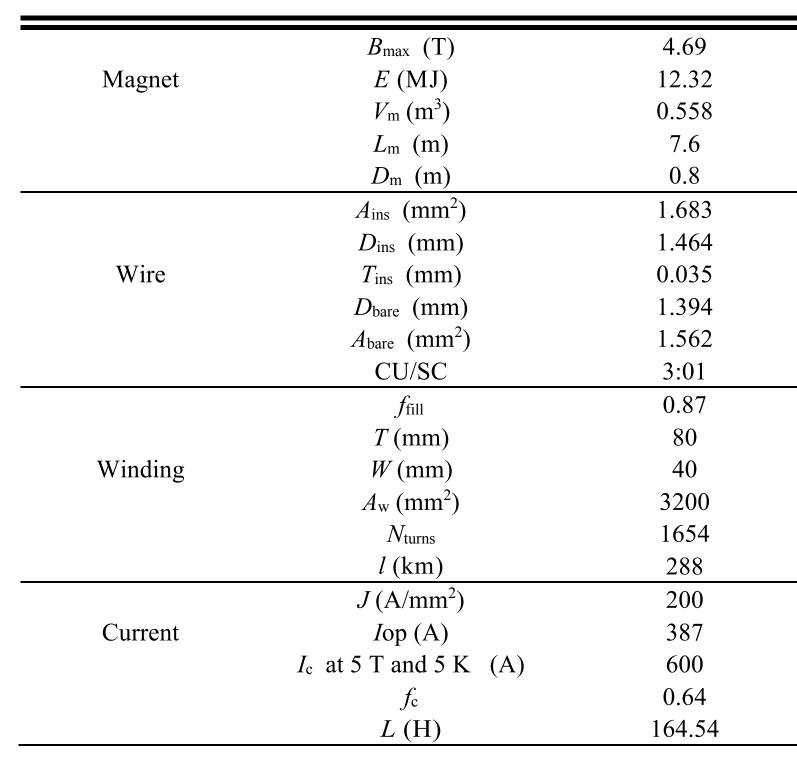
Thanks to cancellation of many force components, the expected stress in a structural hoop is about 25% of the yield strength of 6061 aluminum.





### Magnet Parameters

The table below describes the engineering choices in the proposed design. NbTi is the conductor of choice for its ease of manufacturing; the target smeared winding current density of 200 A/mm<sup>2</sup> is within NbTi's



# Next Steps

Discussions are underway with a manufacturer for a quote to produce a biddable engineering design for the Atom Trapping Demonstrator. This process will address all questions of mechanical structure, winding methods, tolerances, cryogenics, and the lifecycle of the magnet.