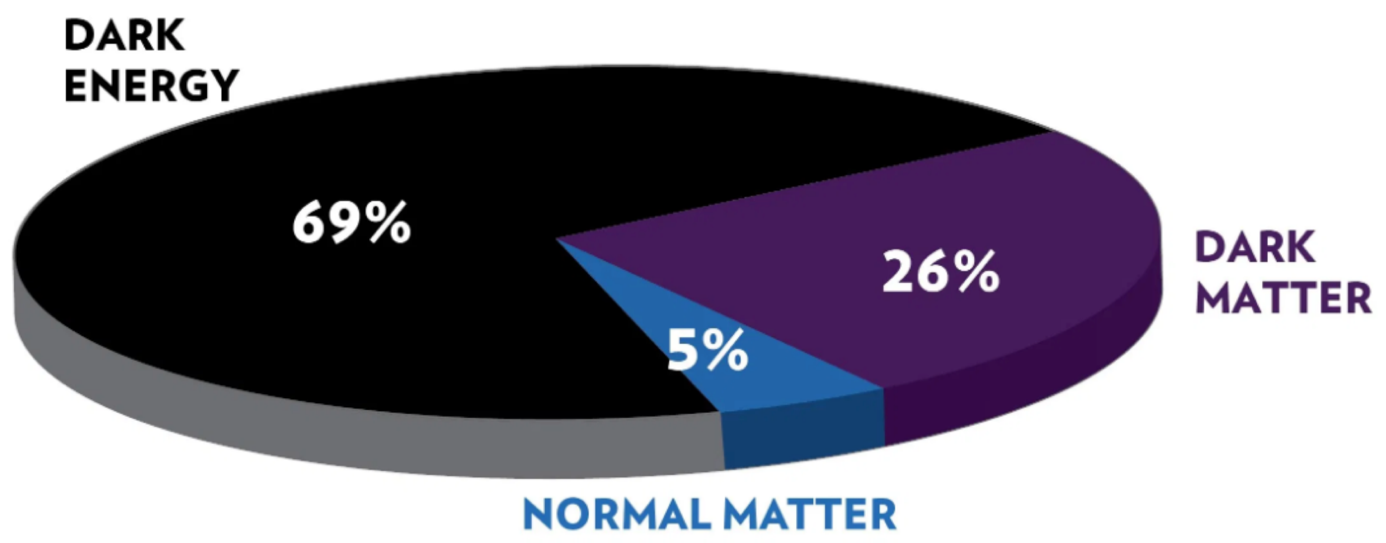
# A Tunable Plasma Axion Haloscope

*ALPHA Collaboration*

UC Berkeley, ITMO University, U of Maryland, MIT, University of Colorado Boulder - JILA, Oak Ridge National Laboratory, Oskar Klein Center, Stockholm University,

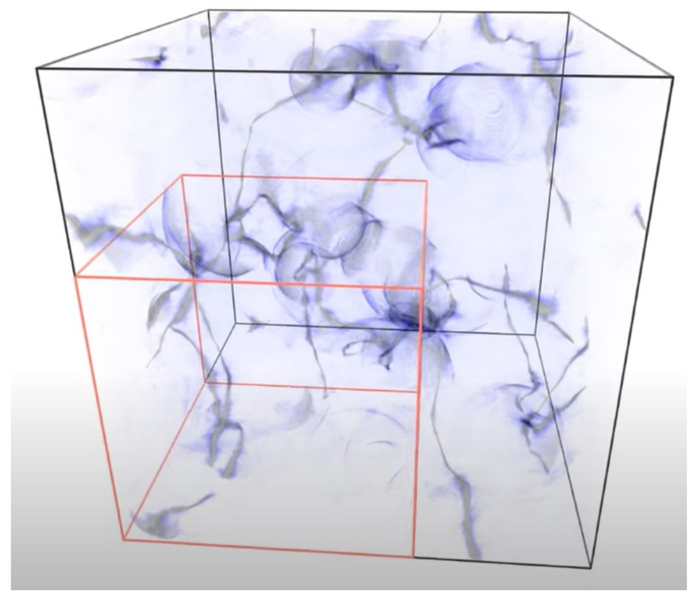
## Science Motivation



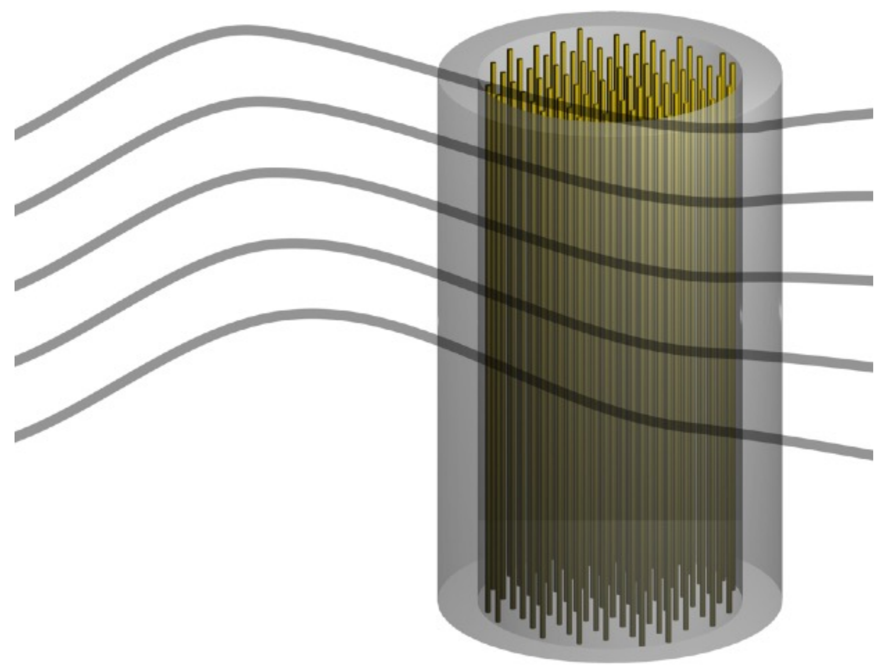

- The search for dark matter remains one of the most compelling physics goals for HEP.
- The nature of dark matter is unknown. To address this question, a broad experimental program is underway to find evidence for it using a multitude of techniques.
- The axion, in view of its roots in fundamental physics, is an especially promising dark matter candidate.

- Recent theoretical work points to a highly constrained range of axion masses that leads to the observed DM abundance, assuming conventional (non-inflationary) cosmology following the Peccei-Quinn transition.

M. Buschmann et al., Nat. Comm. 13 (2022) 1049



## Experimental approach



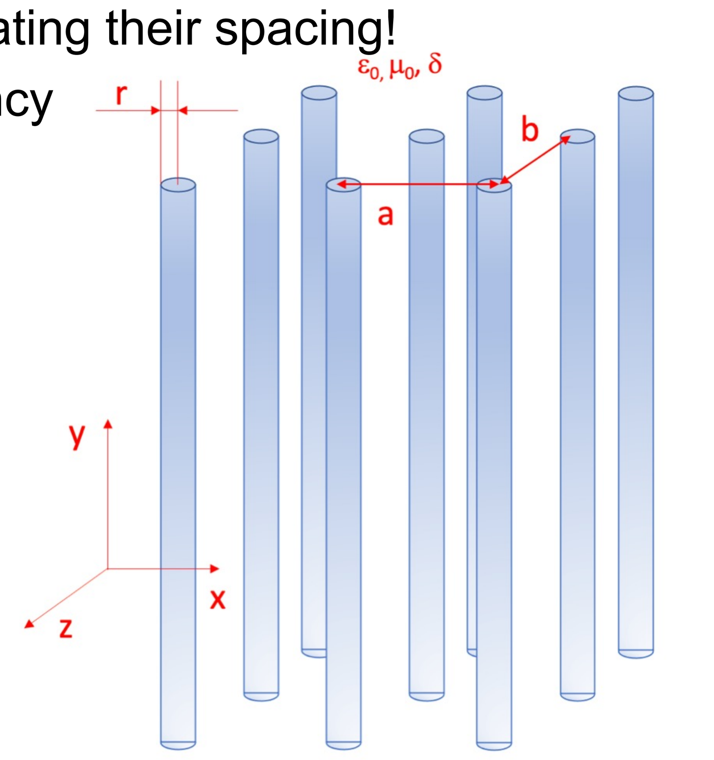
Phys Rev Lett.123.141802 by M. Lawson et al.

- Cavity haloscopes main limitation is that their size is limited by the Compton wavelength, so get too small at high axion masses, have limited tunability and long integration times, limiting the axion search mass region.
- A plasma haloscope matches axion and photon masses (plasma frequency), $m_a = \omega_{plasma}$. This ameliorates size constraints.
- The plasma frequency is given by the effective electron number density and its mass

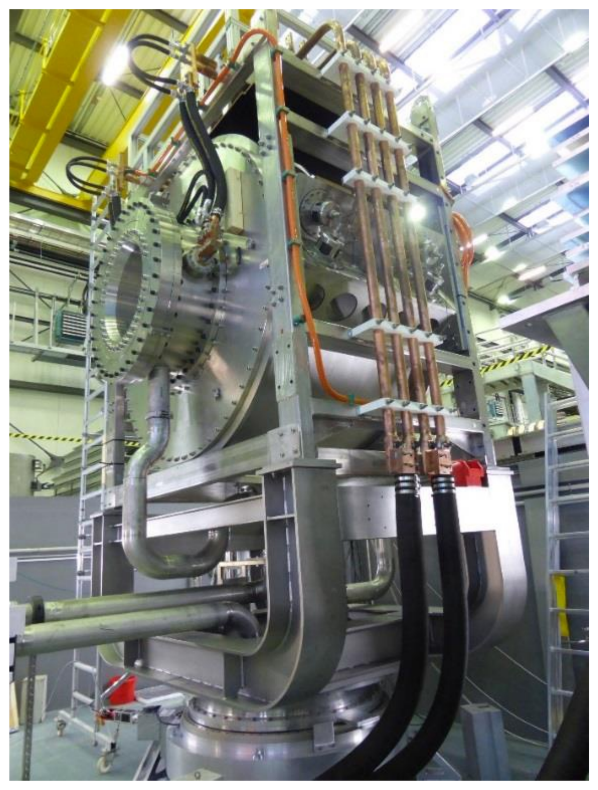
$$\omega_p^2 = \frac{n_e e^2}{m_{eff}} = \frac{2pi}{a^2 \log(a/r)}$$

- Wire array metamaterials exhibit plasmonic behavior. They can serve as resonators for a dark matter axion experiment.
- The wires mutually induct, which affects the plasma frequency.
- Thus, the array can be tuned by manipulating their spacing!
- ~cm spacing gives ~GHz plasma frequency

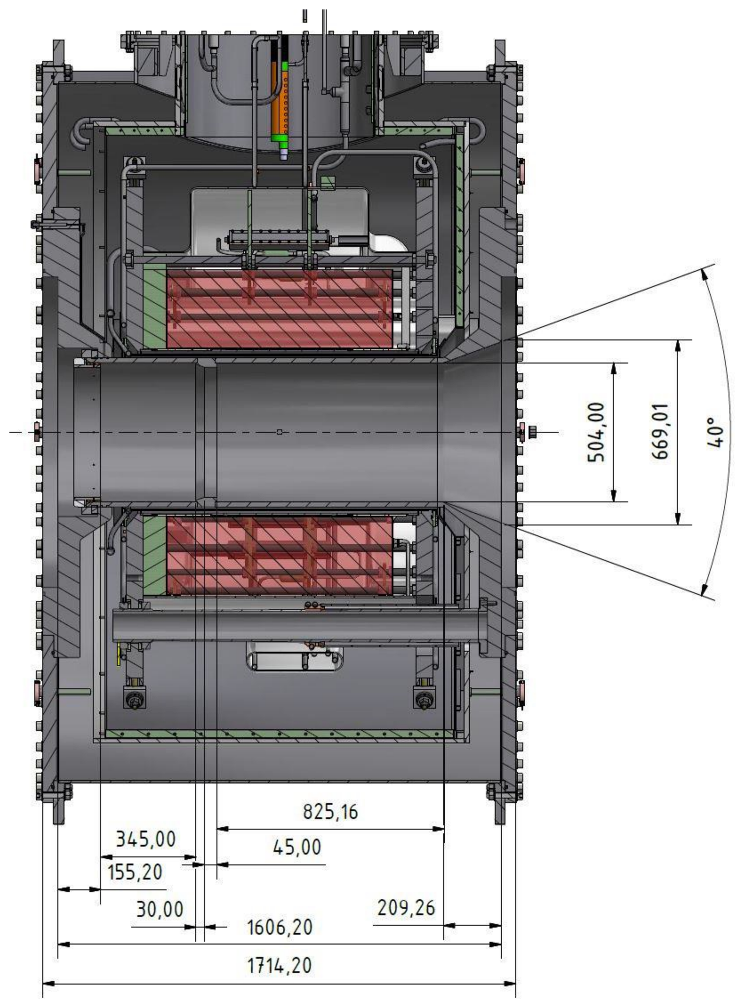
- Sensitive readout can be achieved using a squeezed-state receiver following the HAYSTAC protocol (M. Malnou et al., Phys. Rev. X 9 (2019) 021023).




## ALPHA Implementation

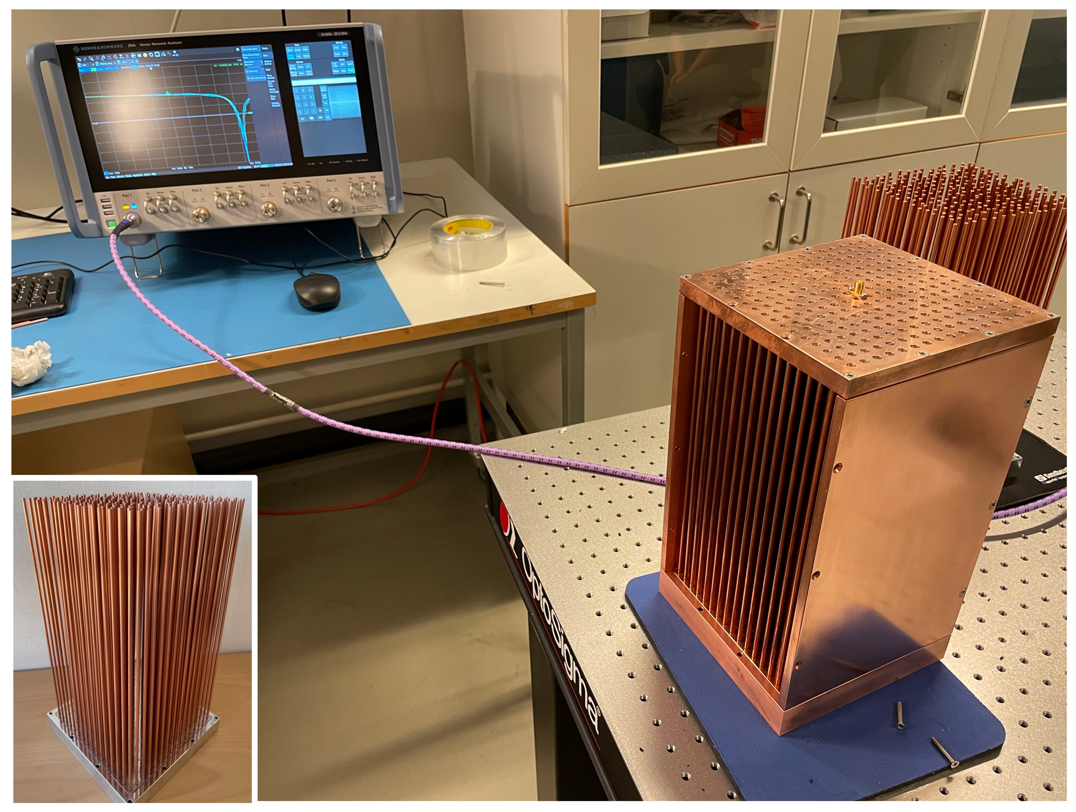


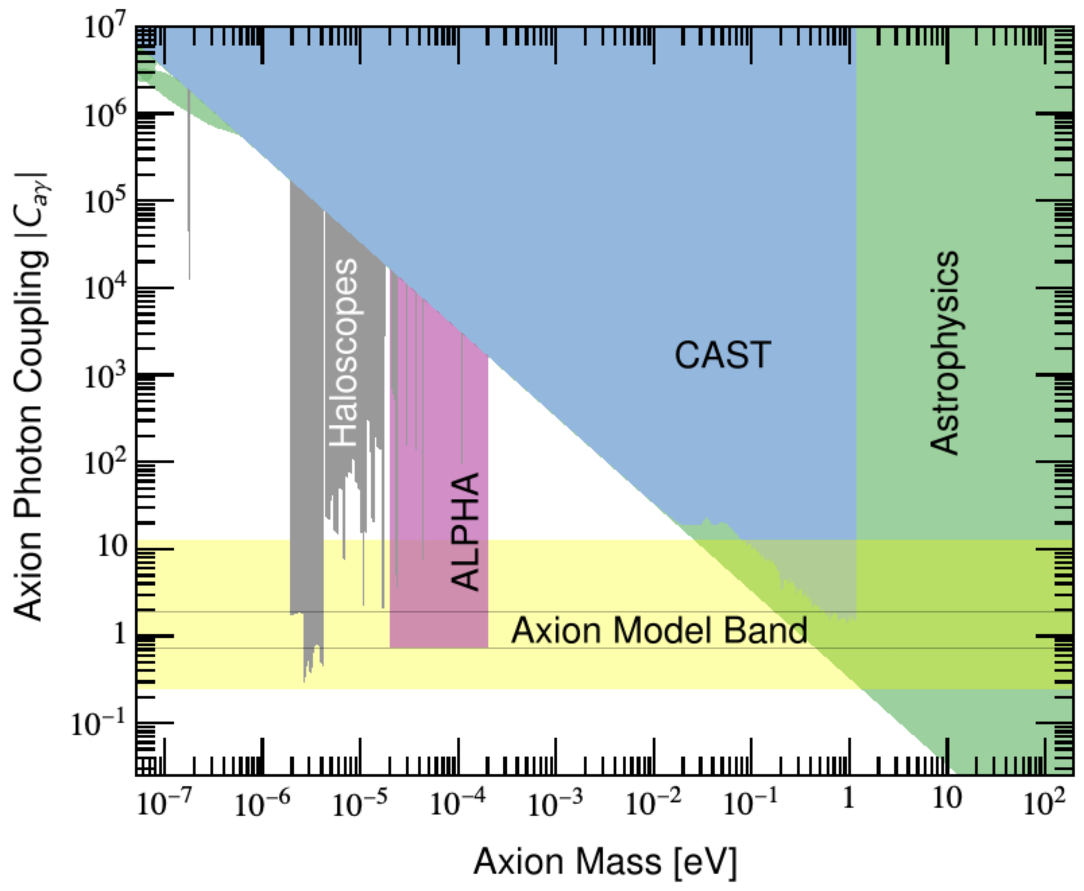
We plan to deploy an existing, 13T magnet developed at Helmholtz Zentrum Berlin at Oak Ridge National Laboratory.



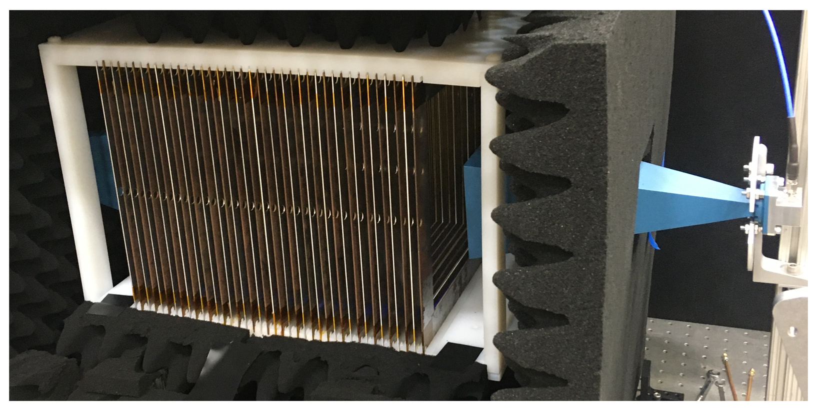

- ALPHA initial nominal resonator requirements
  - Frequency ~10 $GHz$
  - Volume ~$4\cdot10^5$ $cm^3$
  - Quality factor ~$10^4$

- Demonstrator Resonator
  - 16x16 array of 3.175 mm diameter Cu rods
  - Fixed frequency resonator to test simulations
  - Q > 2000 at room temperature

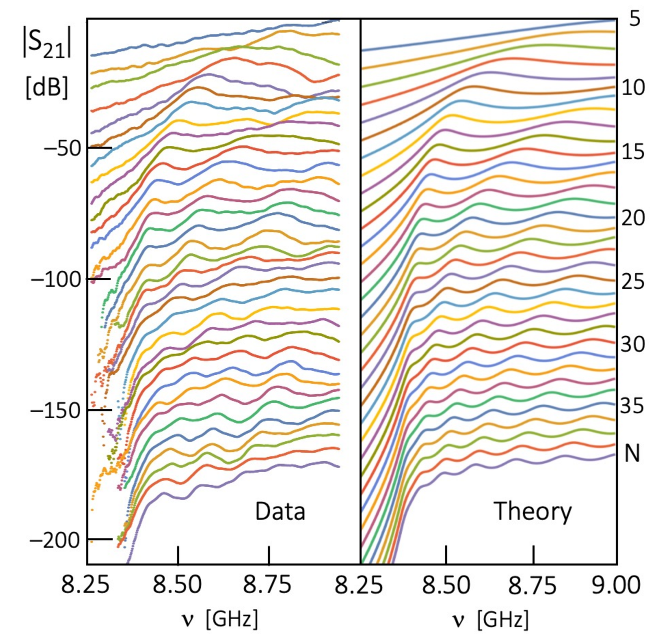





## Preliminary Results



Wire plane array compares power received at antenna 2 relative to the power input to antenna 1 (S21)




**The ALPHA tunable plasma haloscope represents a novel technique to perform a broadband axion search, avoiding persistent bottlenecks of cavity-based approaches. It can access the preferred post-inflation axion mass range.**