Low frequency axion searches with an LC circuit

ADMX SLIC
(Superconducting Lc circuit Investigating Cold axions)

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Proposal for Axion Dark Matter Detection Using an *LC* Circuit

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We show that dark matter axions cause an oscillating electric current to flow along magnetic field lines. The oscillating current induced in a strong magnetic field $\vec{B}_0$ produces a small magnetic field $\vec{B}_a$. We propose to amplify and detect $\vec{B}_a$ using a cooled *LC* circuit and a very sensitive magnetometer. This appears to be a suitable approach to searching for axion dark matter in the 10^{-7} to 10^{-9} eV mass range.

ADMX SLIC: Results from a Superconducting *LC* Circuit Investigating Cold Axions

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Axions are a promising cold dark matter candidate. Haloscopes, which use the conversion of axions to photons in the presence of a magnetic field to detect axions, are the basis of microwave cavity searches such as the Axion Dark Matter eXperiment (ADMX). To search for lighter, low frequency axions in the sub-2×10^{-7} eV (50 MHz) range, a tunable lumped-element *LC* circuit has been proposed. For the first time, through ADMX SLIC (Superconducting *LC* Circuit Investigating Cold Axions), a resonant *LC* circuit was used to probe this region of axion mass-coupling space. The detector used a superconducting *LC* circuit with piezoelectric driven capacitive tuning. The axion mass and corresponding frequency ranges $1.7498–1.7519 \times 10^{-7}$ eV (42.31–42.36 MHz), $1.7734–1.7738 \times 10^{-7}$ eV (42.88–42.89 MHz), and $1.8007–1.8015 \times 10^{-7}$ eV (43.54–43.56 MHz) were covered at magnetic fields of 4.5 T, 5.0 T, and 7.0 T, respectively. Exclusion results from the search data, for coupling below 10^{-12} GeV^{-1}, are presented.

LC circuit premise

- Axion field alters Maxwell's Equations

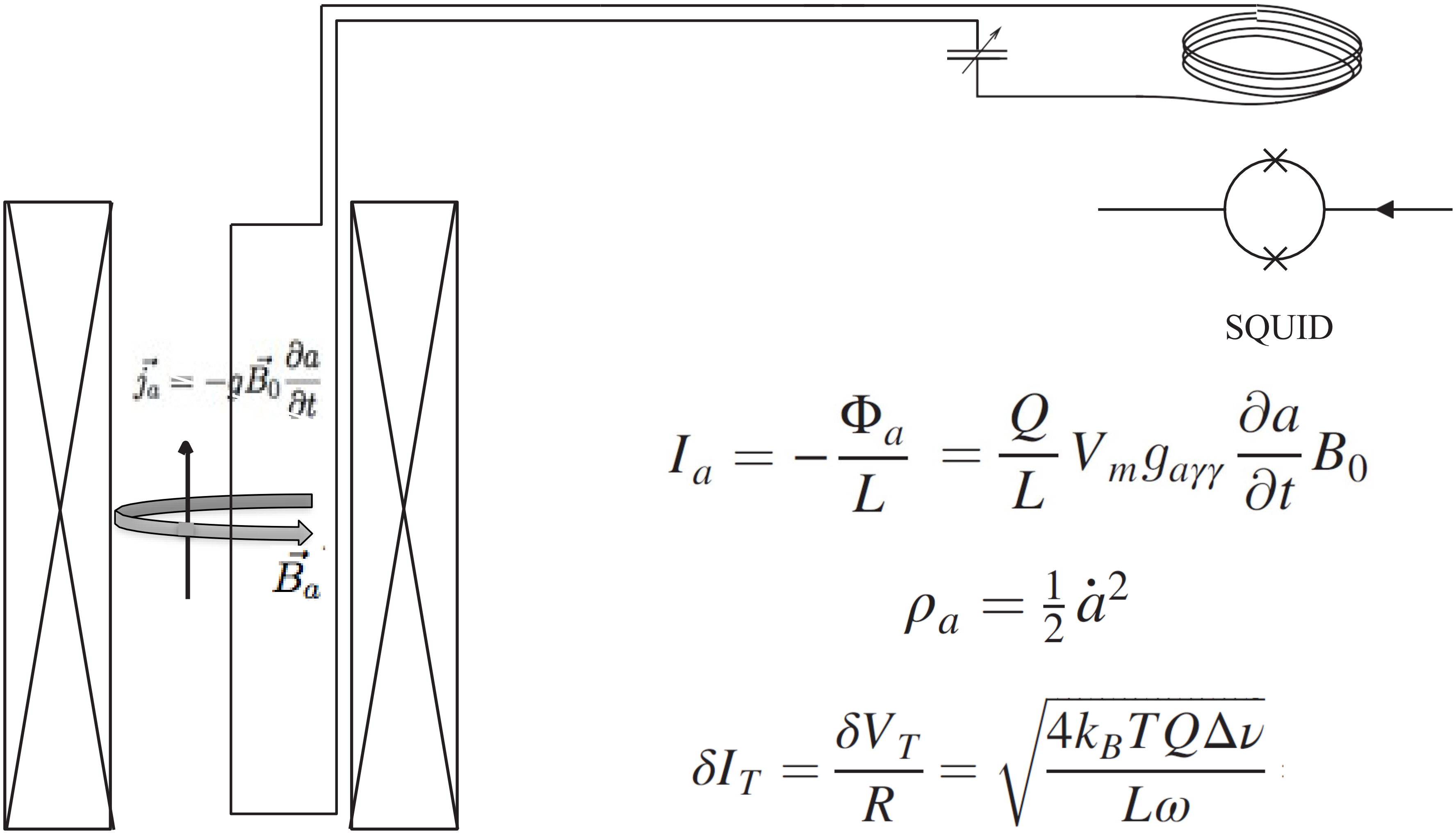
$$\nabla \cdot \vec{E} = g_{a\gamma\gamma} \vec{B} \cdot \nabla a$$

$$\vec{\nabla} \times \vec{B} - \frac{\partial \vec{E}}{\partial t} = g_{a\gamma\gamma} \left(\vec{E} \times \vec{\nabla} a - \vec{B} \frac{\partial a}{\partial t} \right)$$

- In the presence of an external magnetic field $\vec{B}_0$

$$\vec{\nabla} \times \vec{B} \cdot = \vec{j}_a = -g_{a\gamma\gamma} \vec{B}_0 \frac{\partial a}{\partial t}$$

LC Circuit Sketch



$$I_a = -\frac{\Phi_a}{L} = \frac{Q}{L} V_m g_{a\gamma\gamma} \frac{\partial a}{\partial t} B_0$$

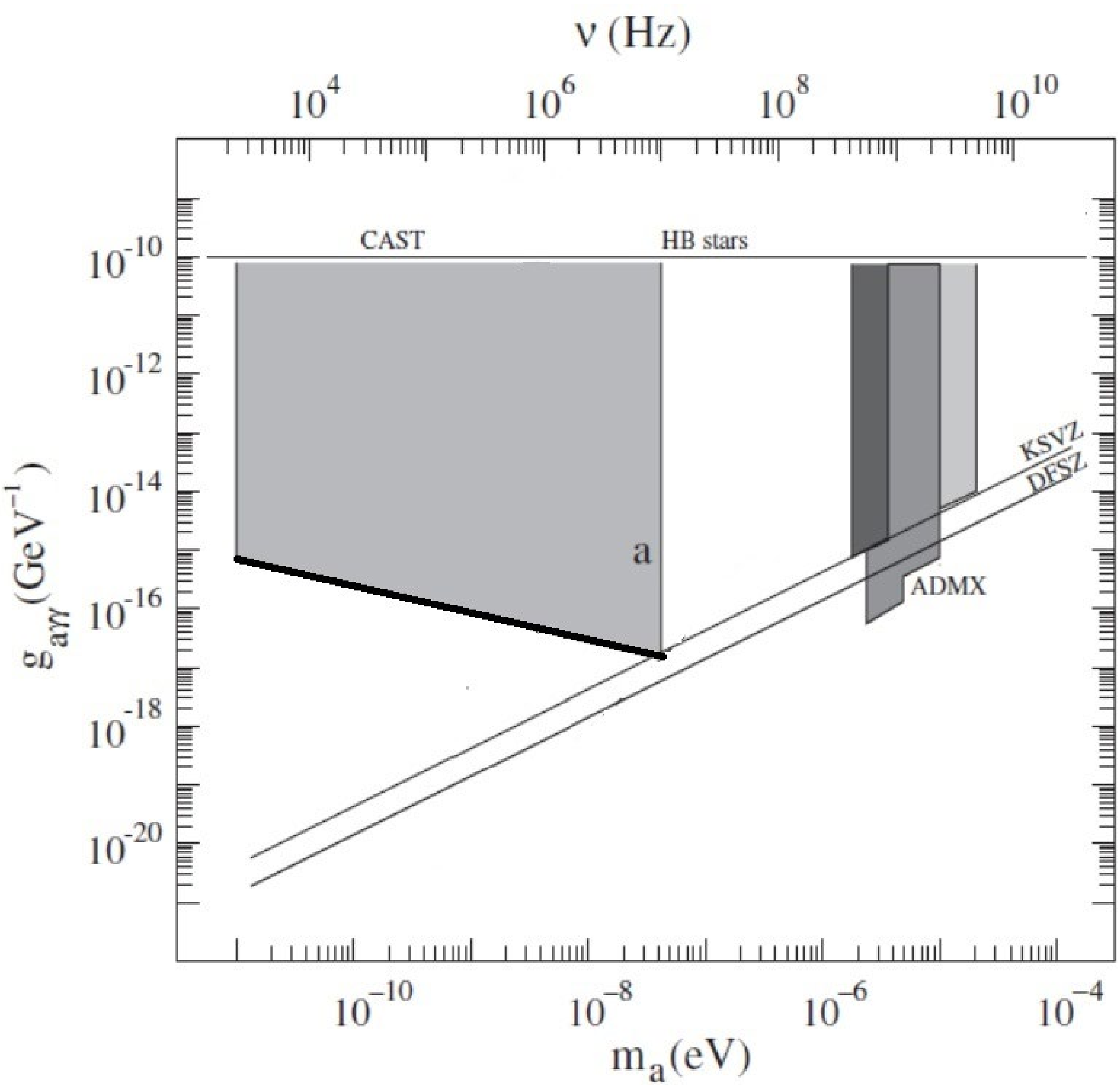
$$\rho_a = \frac{1}{2}\dot{a}^2$$

$$\delta I_T = \frac{\delta V_T}{R} = \sqrt{\frac{4k_B T Q \Delta\nu}{L\omega}}$$

LC Circuit diagram,

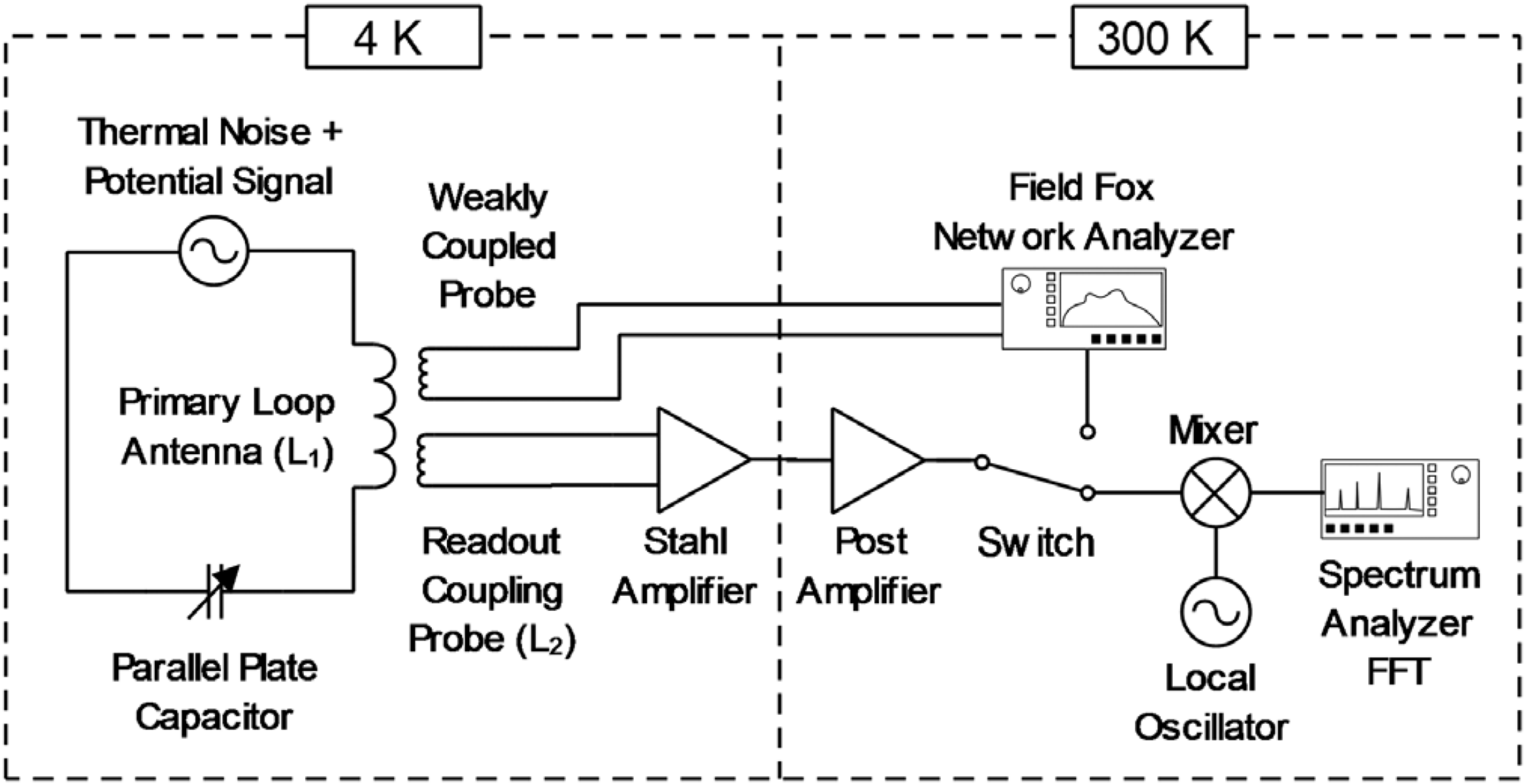
ADMX

Projected sensitivity with ADMX magnet

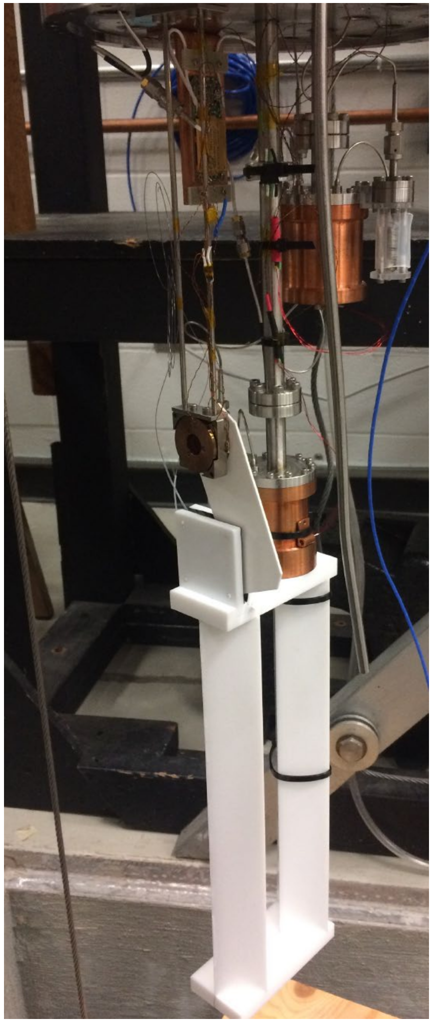


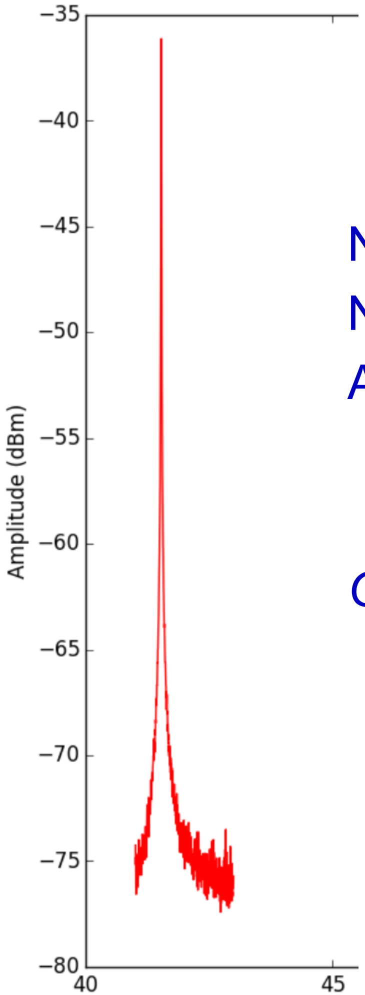
Pilot experiment

- Thesis of Nicole Crisosto. Being continued by Alex Hipp (and Neil Sullivan).
- NbTi loop, NbTi parallel plate capacitor.
- 8 T magnet, 15 cm diameter, 45 cm length.



Pilot Experiment LC loop





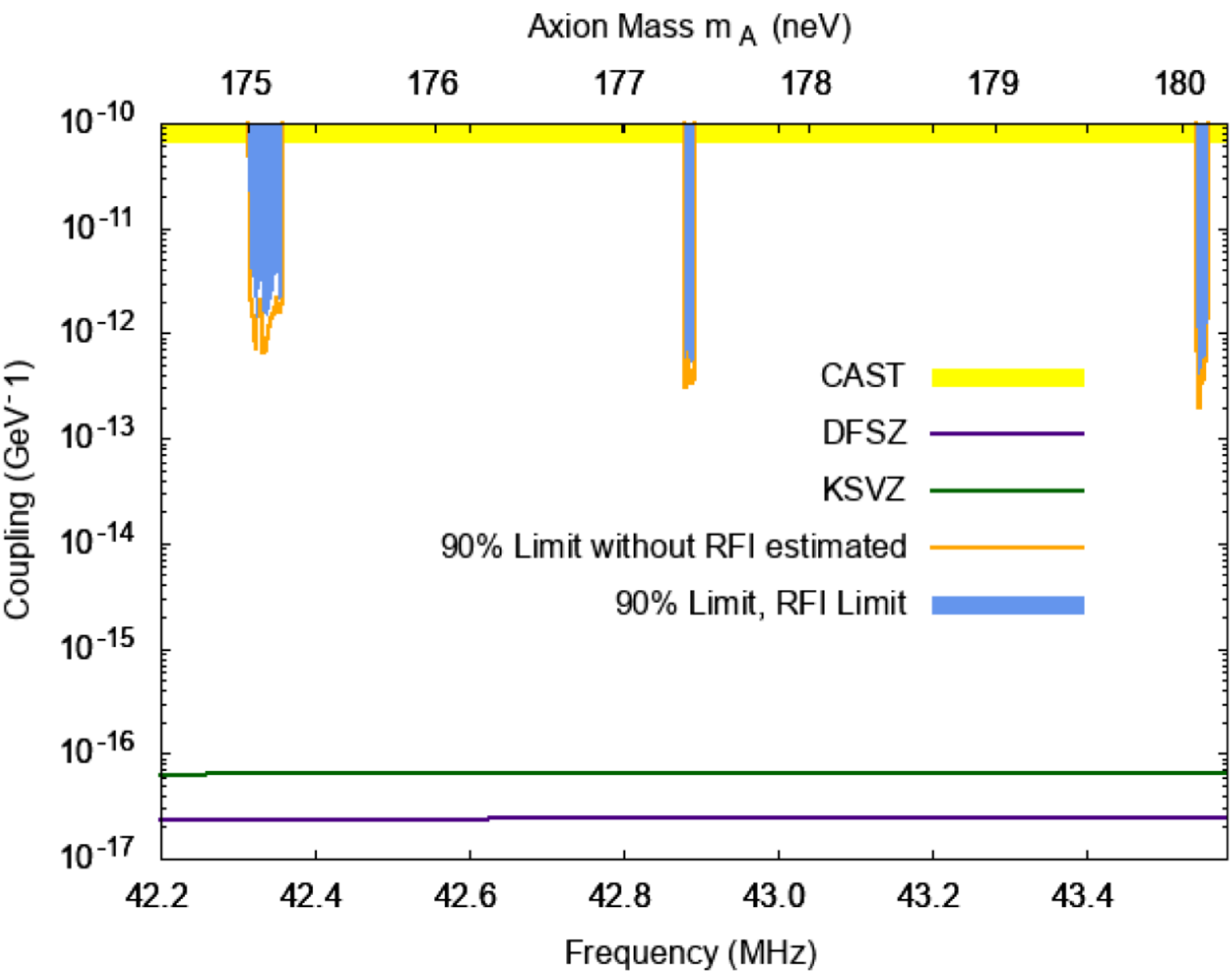
NbTi wire in *L*

NBTi foil in *C*

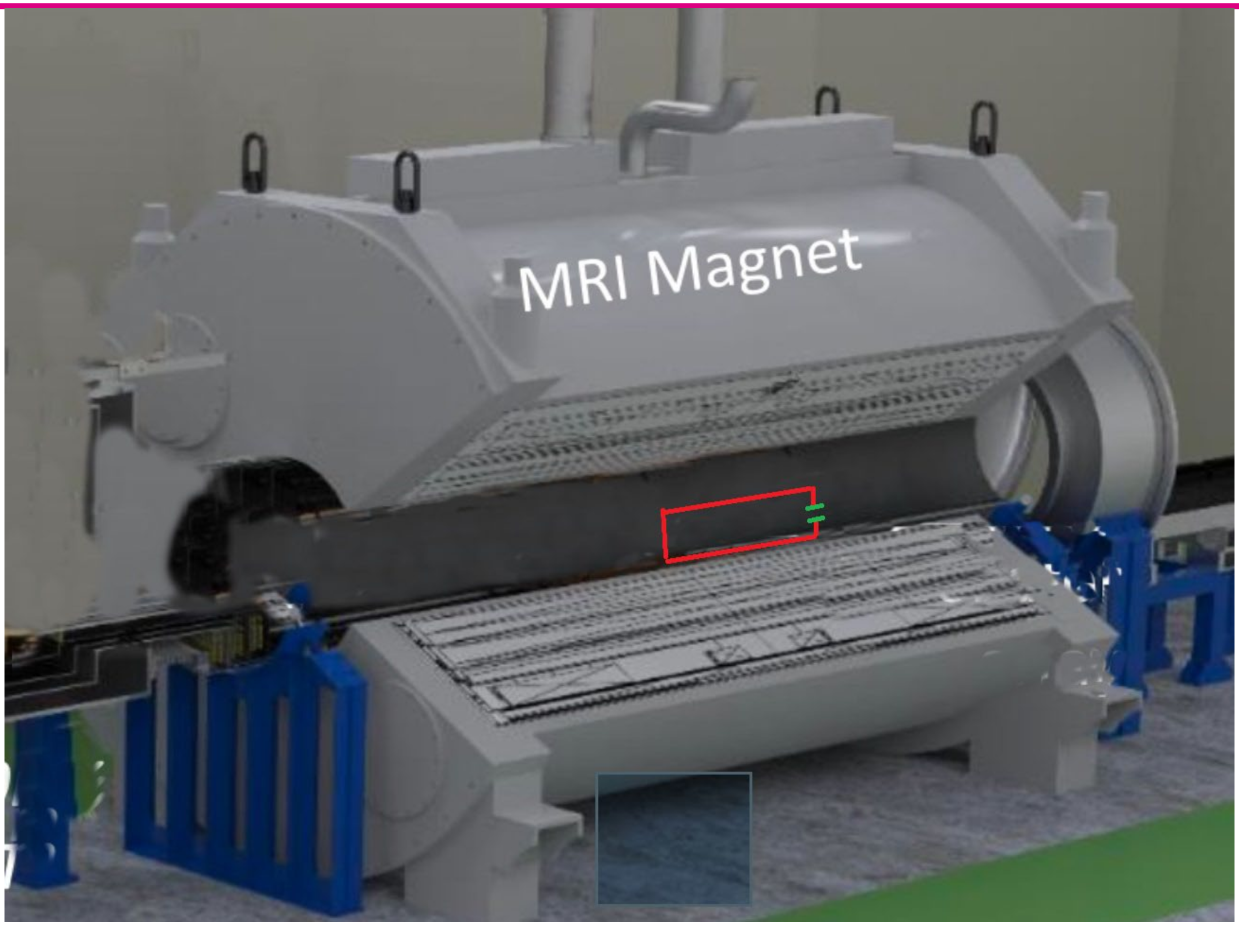
Alumina slab

Q = 12,500

Pilot sensitivity



SLIC in EFR



- Loop is 100 cm long by 40 cm high. $L \sim 3.5\ \mu H$.
- Capacitor has 50x50 mm plates, $d = 4.5$ mm. $C = 4.9$ pF.
- Second cap 25x25 mm plates. $C = 1.2$ pF
- Alumina slab, $\varepsilon = 10$. Raises C to 49 and 12 pF.

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Observing scenarios

- Tuning range:
  - 4.9 – 49 pF 38 – 12 MHz
  - 1.2 – 12 pF 77 – 24 MHz

- A: Maxwellian
  - ρ = 0.45 GeV/cm^3 and Δv = 300 km/sec
  - $\Delta f/f \sim 10^{-6}$ ($\Delta f \sim 40$ Hz @ $f = 40$ MHz)
  - Resolution time at 40 MHz is 50 ms.

- B: the big flow in the Caustic Ring model
  - ρ = 6 GeV/cm^3 and Δv = 70 m/s with v_{av} = 300 km/sec
  - $\Delta f/f \sim 2.3\text{x}10^{-10}$ ($\Delta f \sim 10$ mHz @ $f = 40$ MHz)
  - Resolution time at 40 MHz is 200 s. (Chirp is 0.3 mHz.)

SNR

$$I_a = \frac{Q}{L} V_m g_{a\gamma\gamma} \frac{\partial a}{\partial t} B_0$$

$$\delta I_T = \sqrt{\frac{4 k_B T Q \Delta\nu}{L\omega}}$$

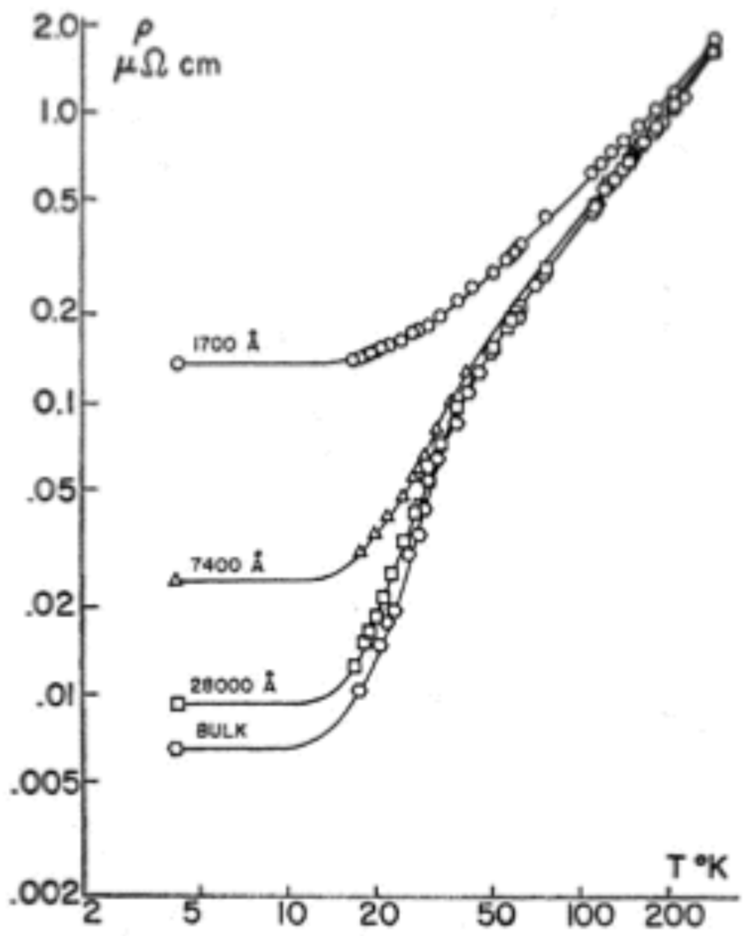
- B: Compared to estimate for ADMX
  - Volume is increased by 2.
  - Field is increased by 1.15
  - Sqrt Axion density by 2.4
  - I_a increased by 5.6

  - But sqrt Temperature increased by 72
- Overall loss in sensitivity is 13.

- Overall loss in scenario A is 200

Do not forget copper or silver

- At 40 MHz, 300 K, copper skin depth is 10 μm
- At 40 MHz and low T, with RRR = 1000, it is 0.3 μm
- So make the *L* and *C* from a tape, with thickness 0.5 μm and width 2 mm.
- R = 0.006 Ω
- Q_L = 70,000



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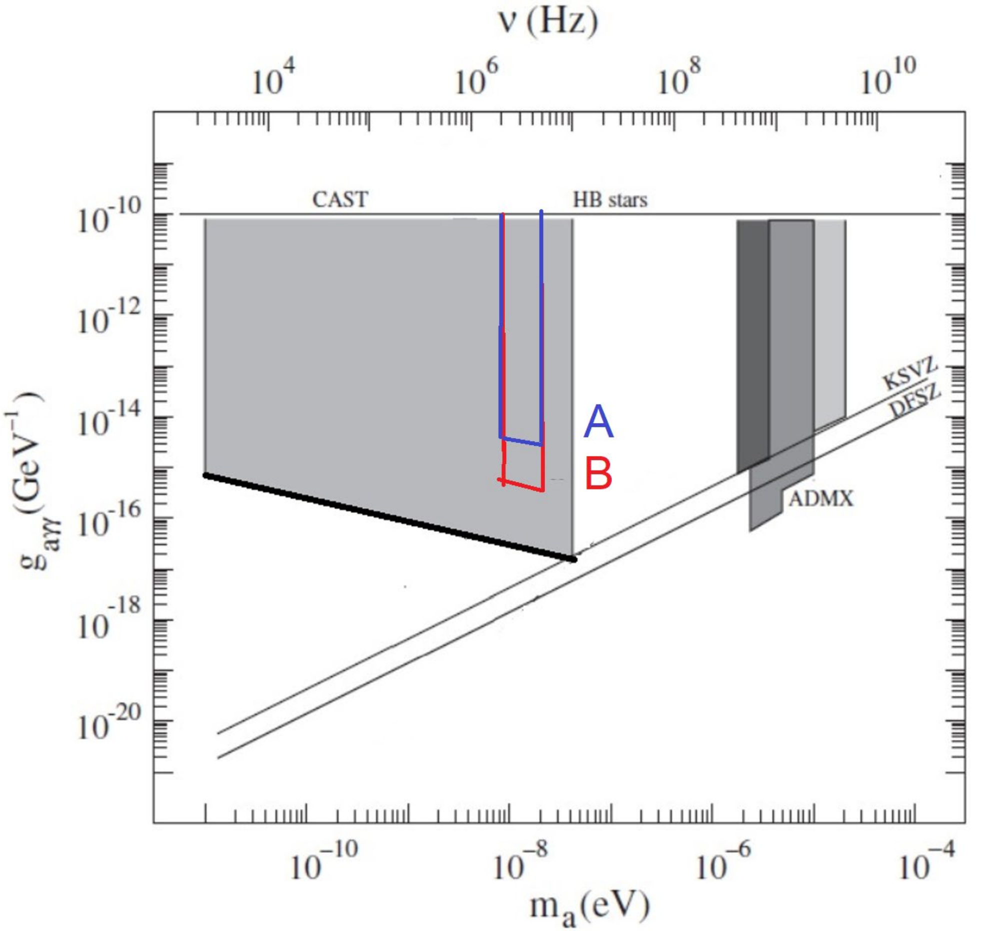
Summary and conclusions

- LC circuit can search for axions and axion-like particles ~ 100 neV.
- About 40 days live time to get these limits.
- Can extend to lower masses easily, by making *C* bigger.



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THE END