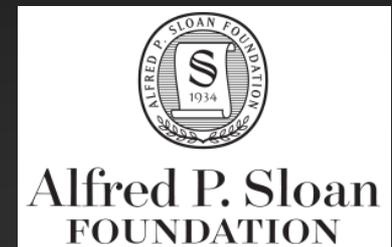


# Search for Axion Dark Matter with Cosmic Axion Spin Precession Experiment (CASPER)



July 2019  
Deniz Aybas



# Ultralight axion

- Spin = 0
- Charge = 0
- Mass = ?
- Its particle field can be expressed as an oscillating field

$$a(t) \sim a_0 \cos(\omega_a t) \quad \omega_a = \frac{m_a c^2}{\hbar}$$

- Energy density stored in the oscillations can be **dark matter**

$$\rho_{DM} \sim m_a^2 a_0^2$$

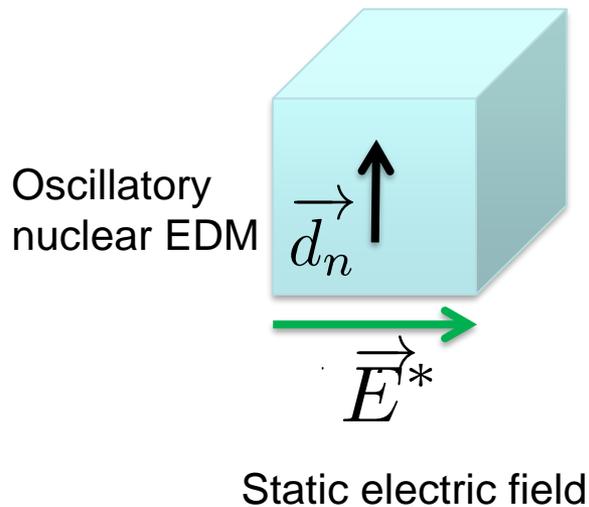
- CASPEr-Electric searching for Axion-Gluon coupling

$$H \sim a \vec{\sigma} \cdot \vec{E}$$

# Search for Axion with CASPEr

$$H \sim a \vec{\sigma} \cdot \vec{E}^*$$

$$\text{Torque} \sim \vec{d}_n \times \vec{E}^*$$

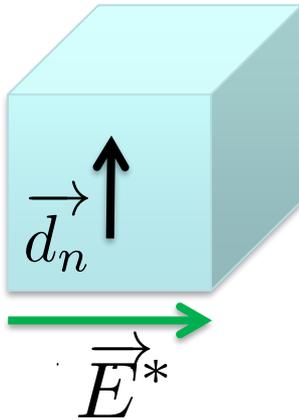


# Search for Axion with CASPER

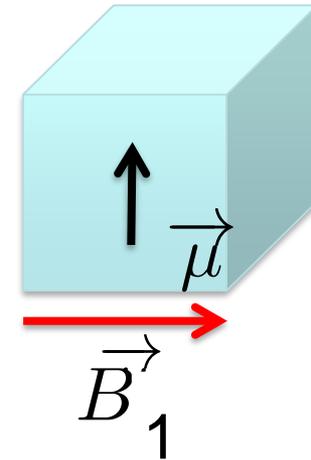
$$H \sim a \vec{\sigma} \cdot \vec{E}^*$$

Torque  $\rightarrow \sim \vec{d}_n \times \vec{E}^*$   
 $\sim \vec{\mu} \times \vec{B}_1$

Oscillatory  
nuclear EDM



Static electric field



Static  
magnetic  
moment

Oscillatory magnetic field

# Search for Axion with CASPER

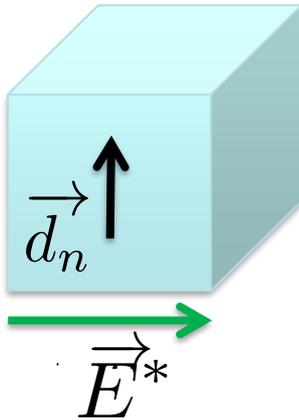
$$H \sim a \vec{\sigma} \cdot \vec{E}^*$$

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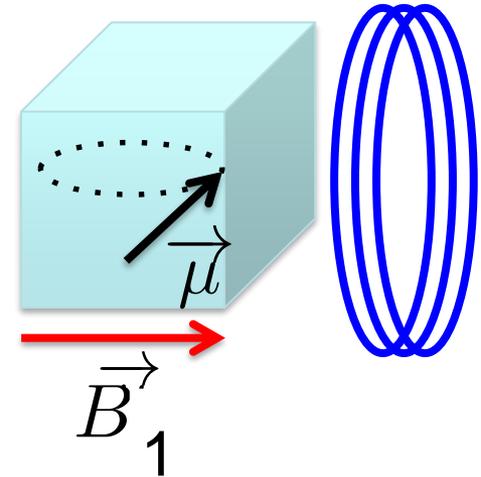
$$\sim \vec{\mu} \times \vec{B}_1$$

Nuclear  
Magnetic Resonance

Oscillatory  
nuclear EDM



Static electric field



Oscillatory magnetic field

# Search for Axion with CASPER

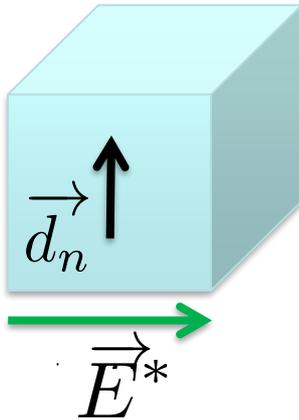
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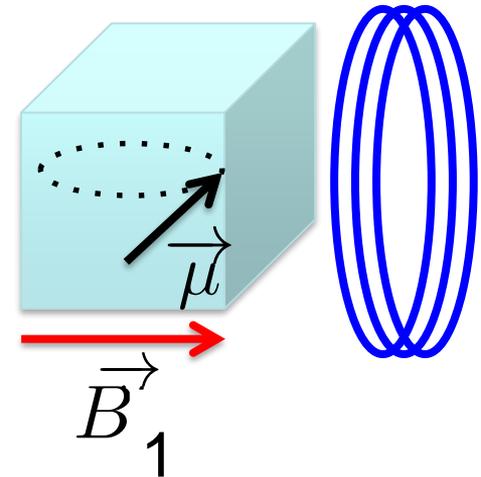
$$\sim \vec{\mu} \times \vec{B}_1$$

Nuclear  
Magnetic Resonance

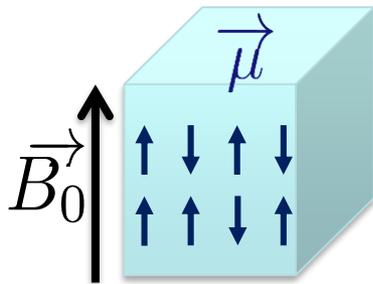
Oscillatory  
nuclear EDM



Static electric field



Oscillatory magnetic field



Static magnetic field

Spin precession at Larmor

$$\Omega_L = \gamma_n B_0$$

Thermal spin polarization

$$p \sim \frac{\mu B_0}{k_B T}$$

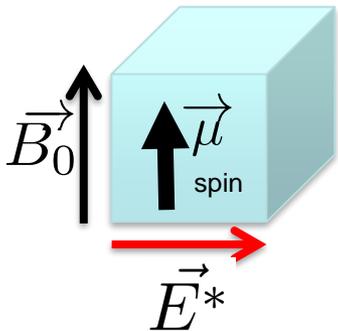
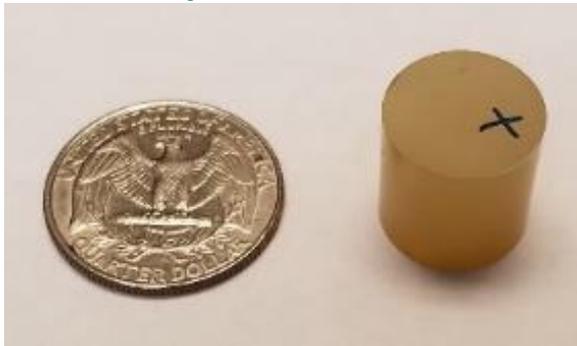
# Sample for CASPER

$$H \sim a \vec{\sigma} \cdot \vec{E}^*$$

lead magnesium niobate - lead titanate

(PMN-PT)

$^{207}\text{Pb}$  Spin  $\frac{1}{2}$

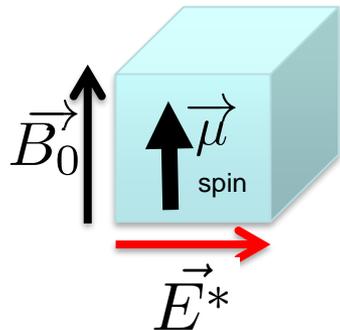
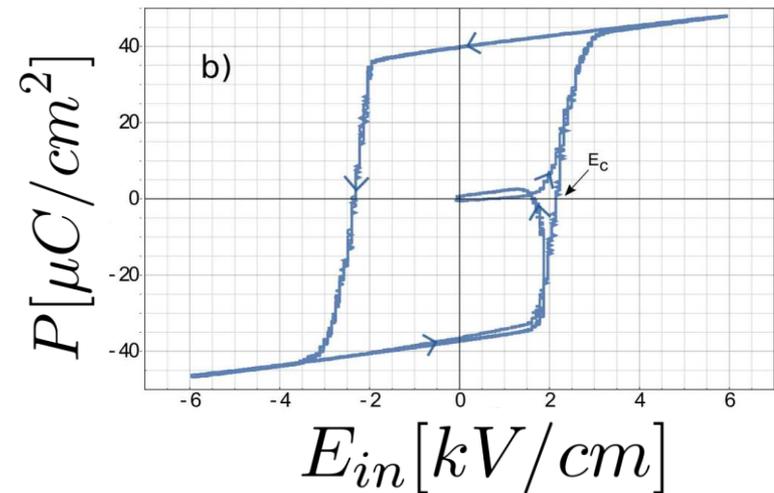
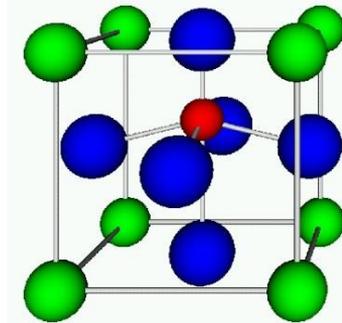


# Sample for CASPER

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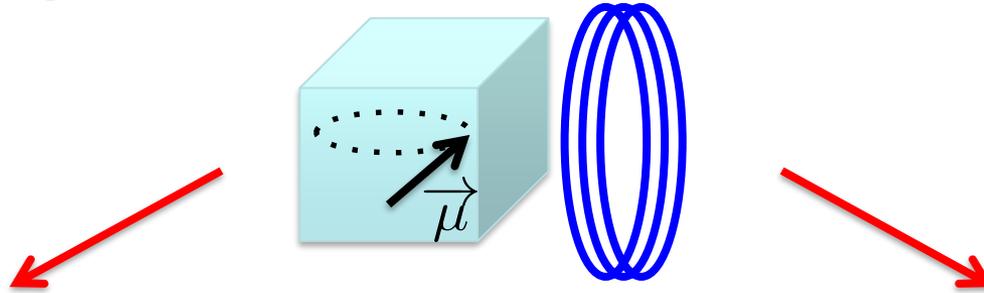
spontaneous polarization  $\vec{P}$



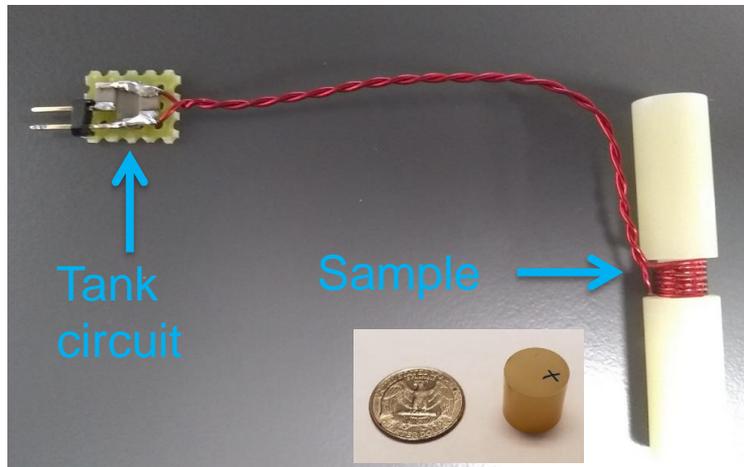
internal effective electric field

$$E^* \approx 10^8 \text{ V/cm}$$

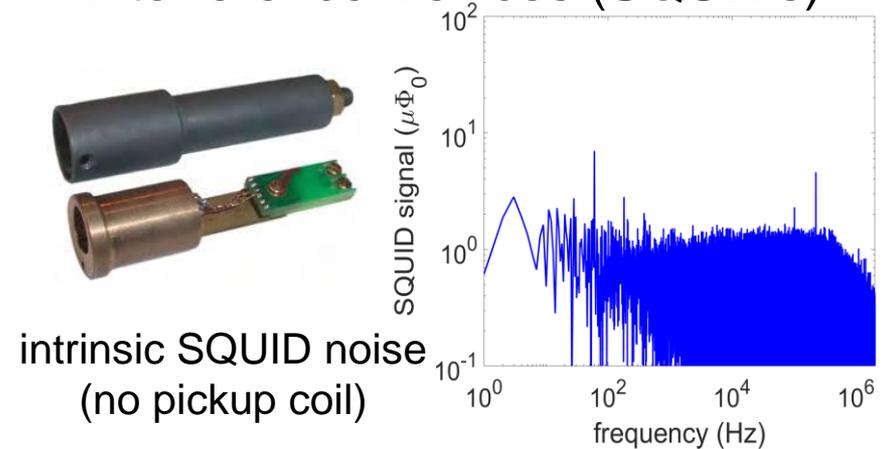
# Signal acquisition in CASPEr



Low Noise Amplifier



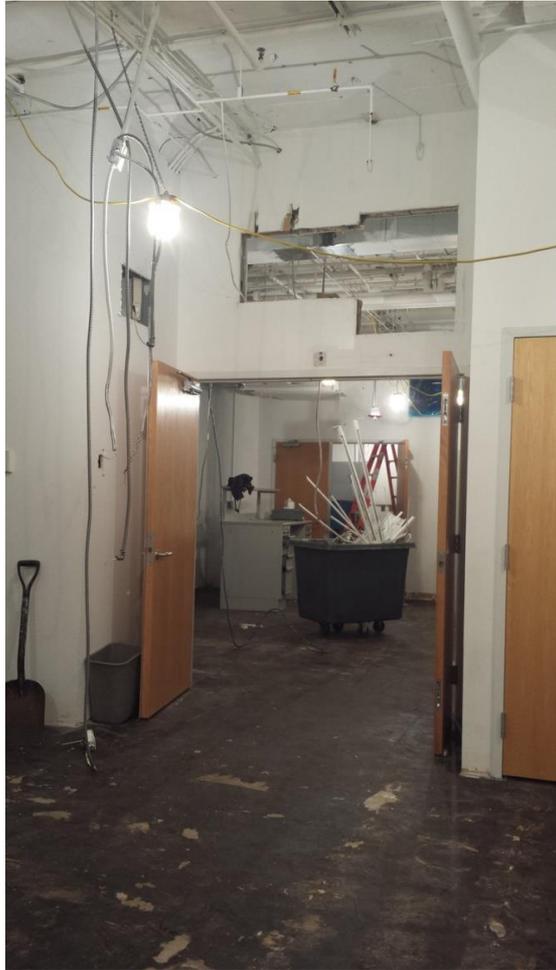
Superconducting Quantum Interference Devices (SQUIDs)



- Tuned probes
- Low noise amplifiers at 300K and 4K

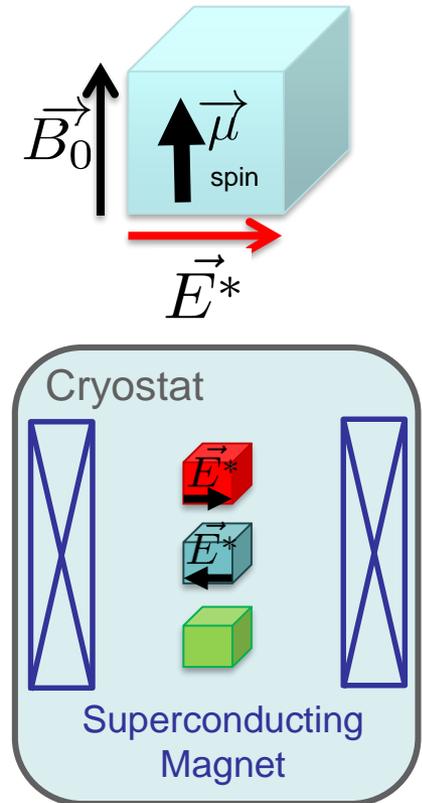
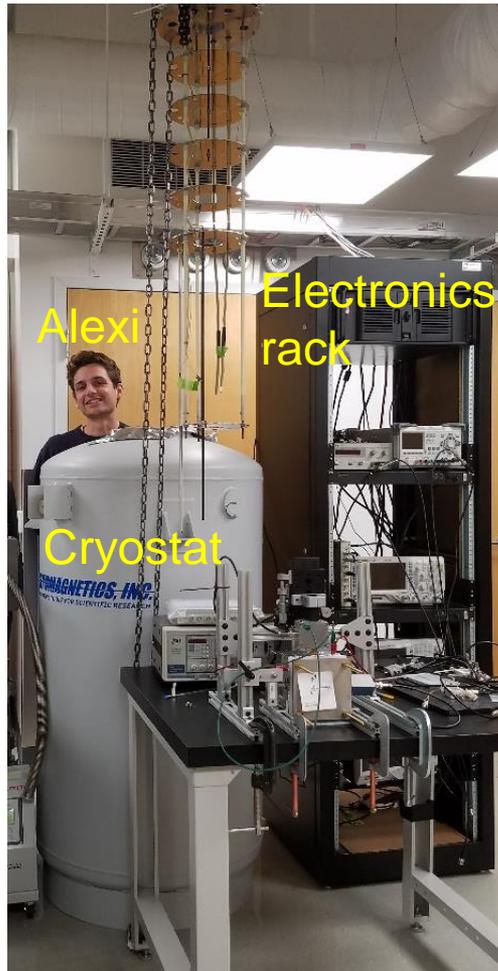
- Measured noise level on order of  $\mu\Phi_0/\sqrt{\text{Hz}}$
- Broadband

# CASPEr-now setup

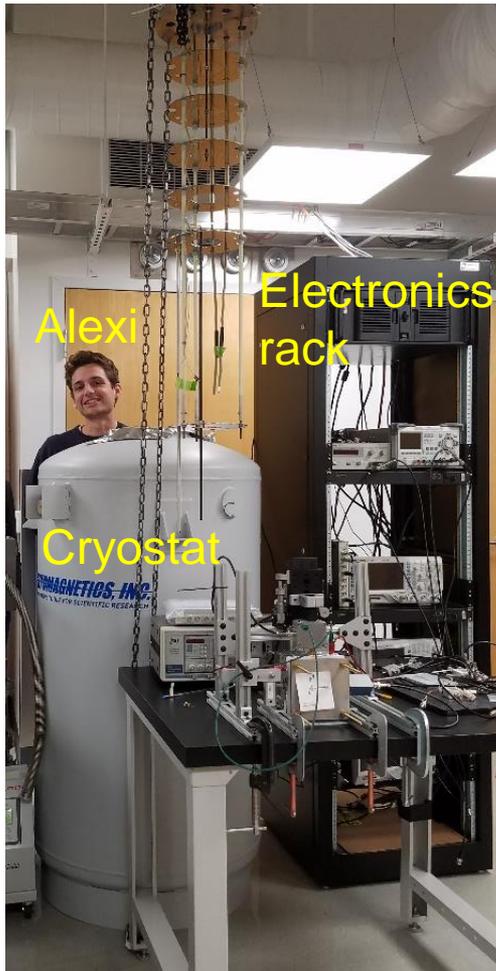


← Our lab back in 2016

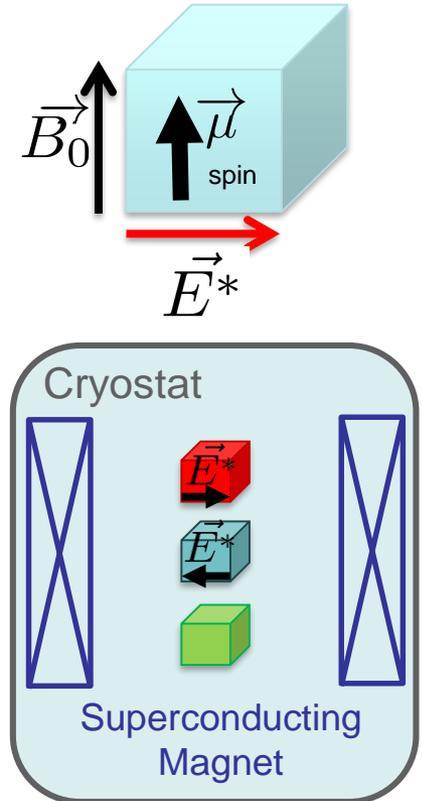
# CASPEr-now setup



# CASPEr-now setup

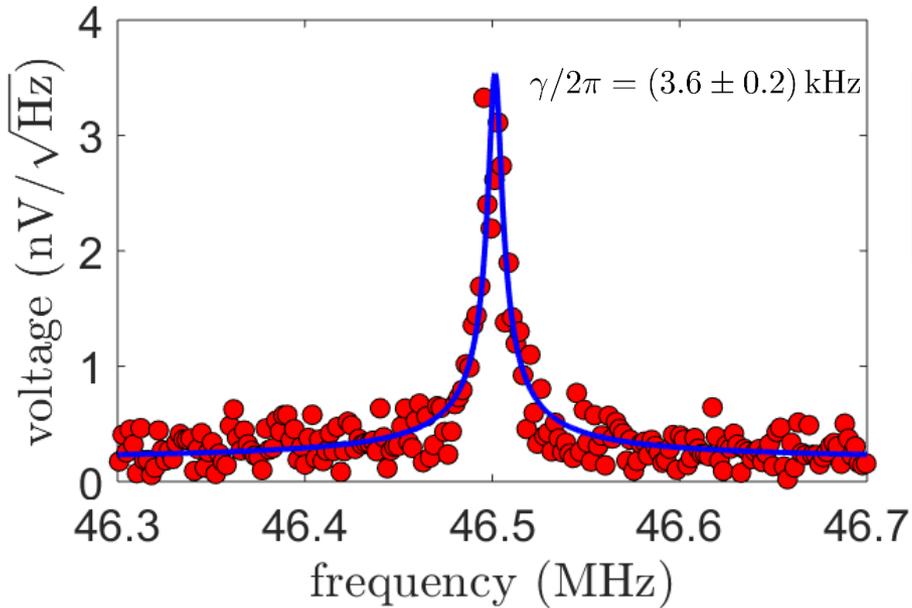


Upgrade to cryogenic amplifier with lower input noise



# CASPER-now measurements

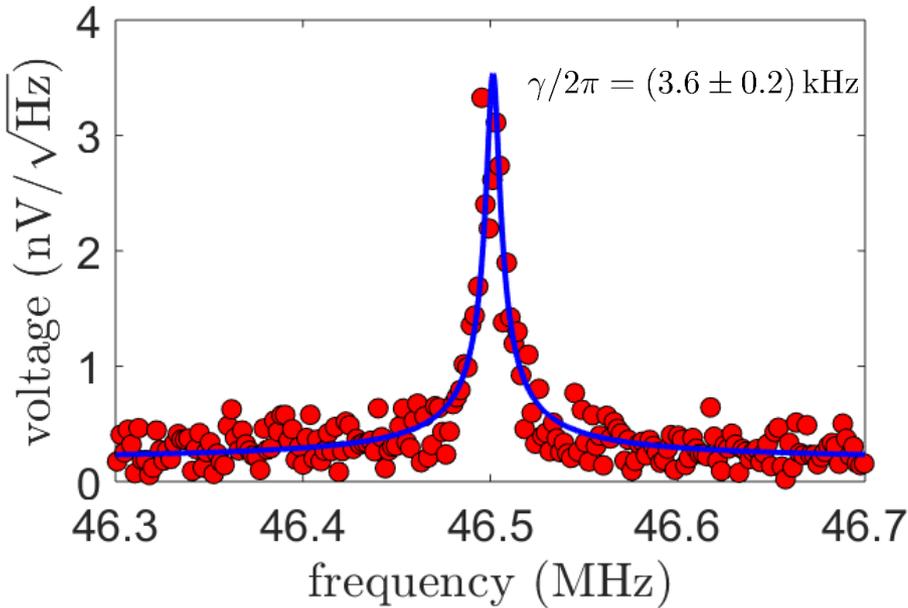
Measurement of  
Pb207 NMR at 5T  
in PMN-PT  
from pulsed NMR



NMR signal gives the  
Axion frequency we  
are sensitive to

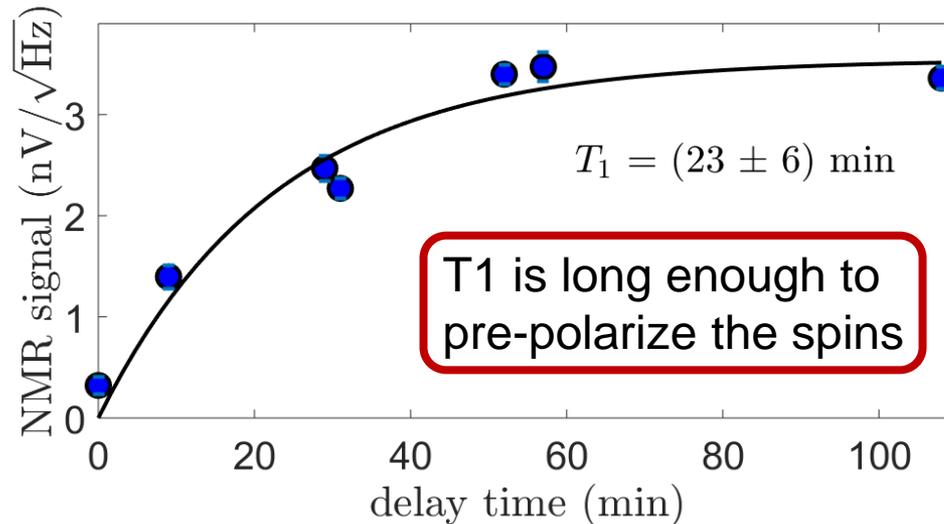
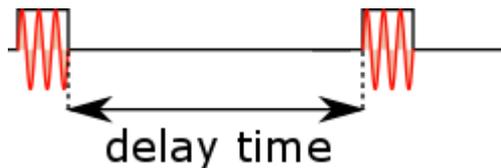
# CASPER-now measurements

Measurement of  
Pb207 NMR at 5T  
in PMN-PT  
from pulsed NMR



NMR signal gives the  
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are sensitive to

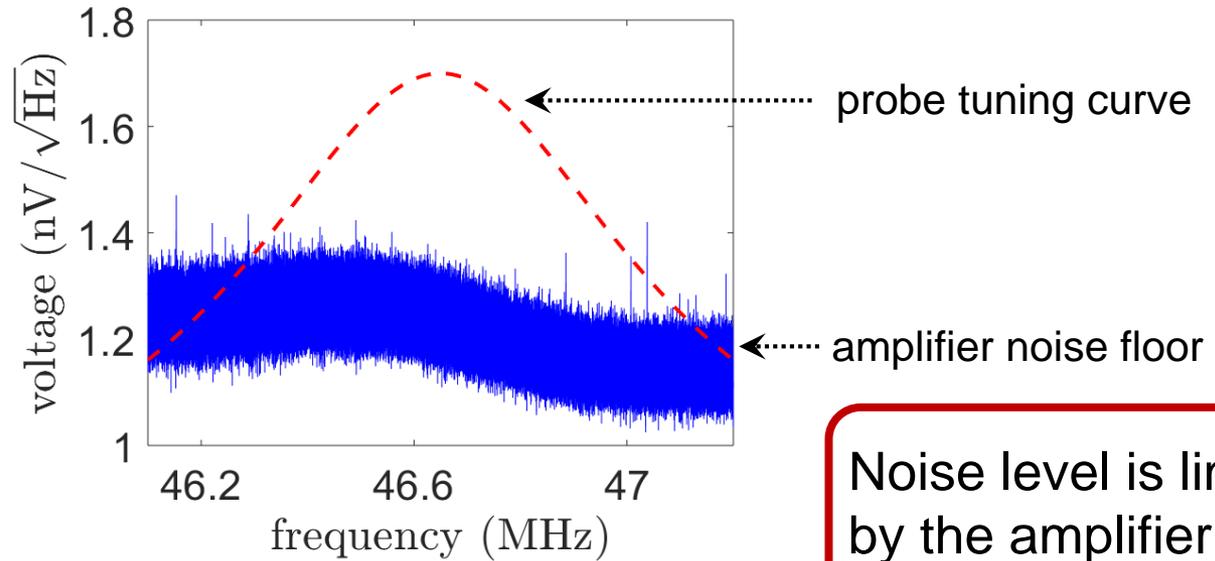
Pb207 T1 spin relaxation  
time measurement  
in PMN-PT  
with Saturation Recovery



T1 is long enough to  
pre-polarize the spins

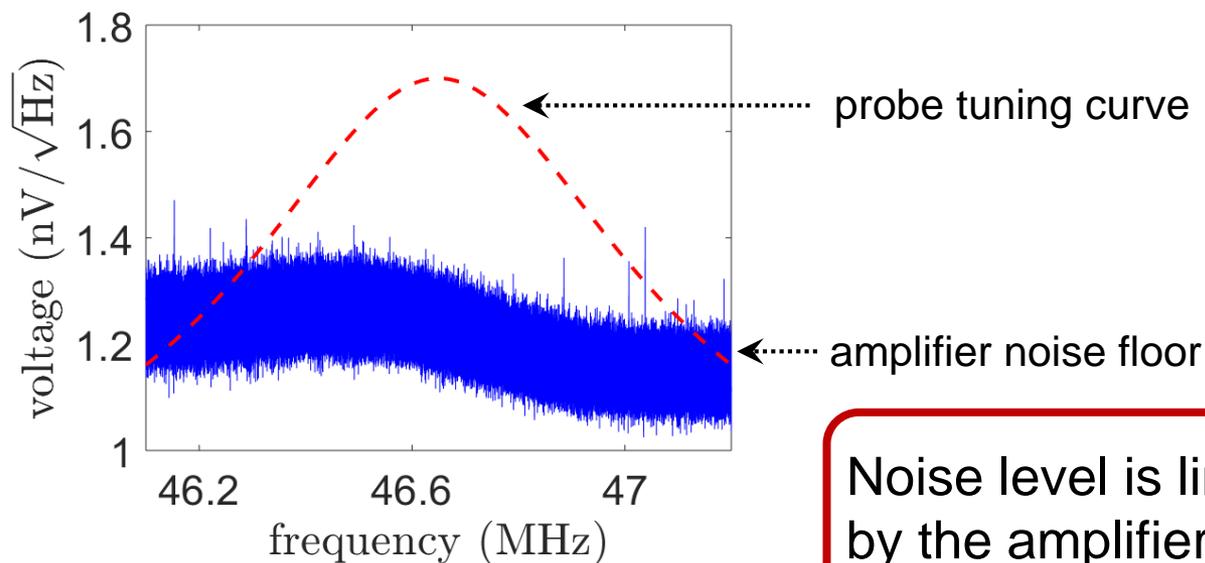
# CASPEr-now measurements

Axion search



# CASPER-now measurements

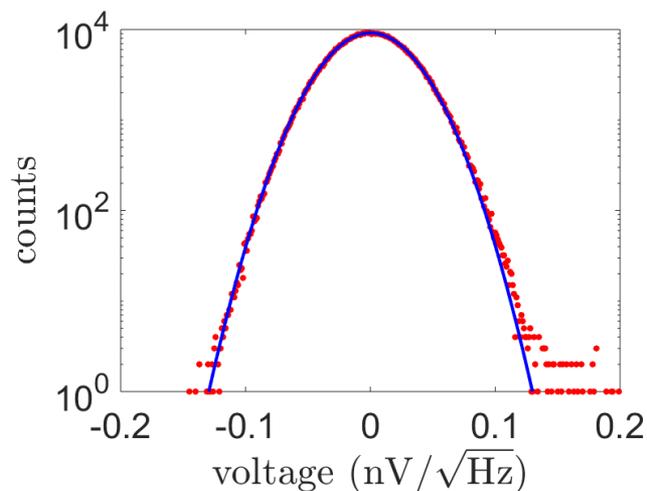
## Axion search



Noise level is limited by the amplifier input

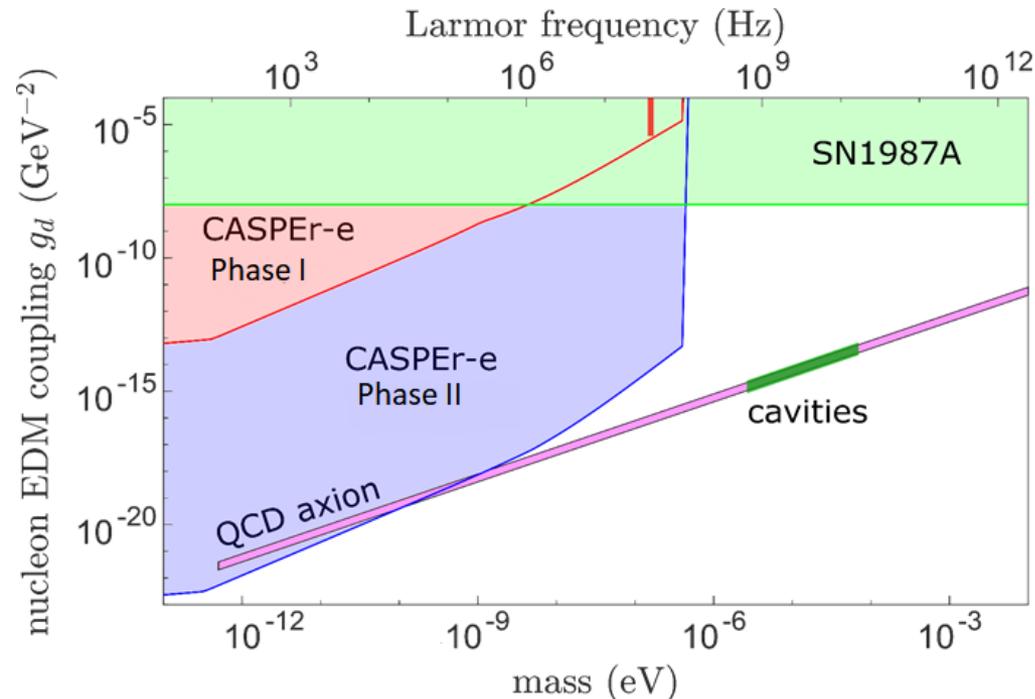
## Noise distribution

Noise is nearly Gaussian distributed after 30 min of averaging



Stay tuned for our first Axion search results!

# Sensitivity of CASPEr



## CASPEr phase I:

- thermal spin polarization,
- 0.5 cm sample size,
- 9T magnet, homogeneity 1000 ppm
- Tuned Tank circuits for detection
- Soon: broadband SQUID detection

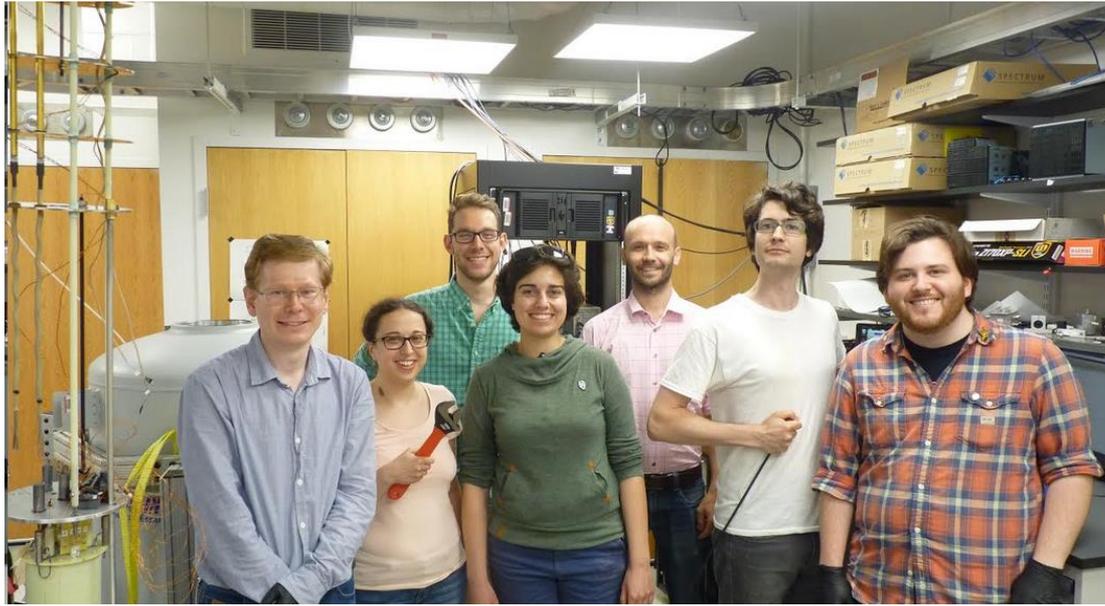
## CASPEr phase II:

- hyperpolarization by optical pumping
- 5 cm sample size,
- 14T magnet, homogeneity 100 ppm
- tuned SQUID circuit?

We are planning to search for axion in several orders of magnitude range of mass.

[PRX 4, 021030, (2014)]

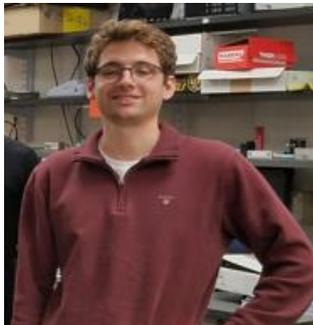
# Thank you!



Sushkov Lab @ BU:

**Sasha Gramolin, Deniz Aybas, Eric Boyers, Kristine Rezai,  
Alex Sushkov, Jack Stropko, and Dorian Johnson**

Not in photo: **Alexi Wilzewski, Janos Adam, and Annalies Kleyheeg**



JOHANNES GUTENBERG  
UNIVERSITÄT MAINZ



Helmholtz-Institut Mainz

# CASPEr Collaboration

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 Annalies Kleyheeg (Boston University)  
 Arne Wickenbrock (Mainz)  
 John Blanchard (Mainz)  
 Gary Centers (Mainz)  
 Nataniel Figueroa (Mainz)  
 Marina Gil Sendra (Mainz)  
 Tao Wang (UC Berkeley)  
 Alfredo Ferella (Stockholm)  
 Matthew Lawson (Stockholm)



Alex Sushkov (Boston University)  
 Dmitry Budker (UC Berkeley & Mainz)  
 Derek Kimball (CSUEB)  
 Surjeet Rajendran (UC Berkeley),  
 Peter Graham (Stanford)  
 Jan Conrad (Stockholm)



**Boston University:**  
 CASPEr-electric using  
 spins in solids



Alfred P. Sloan  
 FOUNDATION

SIMONS  
 FOUNDATION



HEISING - SIMONS  
 FOUNDATION



**Mainz:**  
 CASPEr-wind using  
 liquid Xenon

**Stanford, Berkeley, CSUEB, Stockholm:**

