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Axion-Dark-Matter Search Using Cold Neutrons

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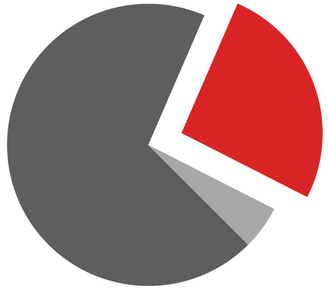
EXA online conference 2021

Motivation & Theory

Dark Matter Problem:



dark energy (69%)

dark matter (26%)

ordinary matter (5%)

possible solution

➔ axions / axion-like particles (ALPs):

- originally suggested to solve the strong CP problem [1]
- ultra-light pseudoscalar particle
- coherent oscillating field

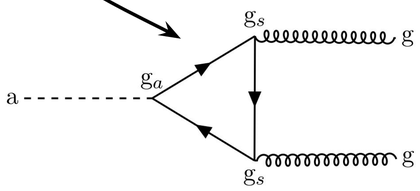
Axion Lagrangian:

$$\mathcal{L}_{\text{Axion}} = \underbrace{-\frac{1}{2}\partial_\mu a \partial^\mu a}_{\mathcal{L}_{\text{kin}}} + \underbrace{C_G \frac{a}{f_a} \frac{g^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}^{\mu\nu}_a}_{-V_{\text{eff}}} + \mathcal{L}_{\text{int}}\left[\frac{\partial_\mu a}{f_a}; \psi\right]$$

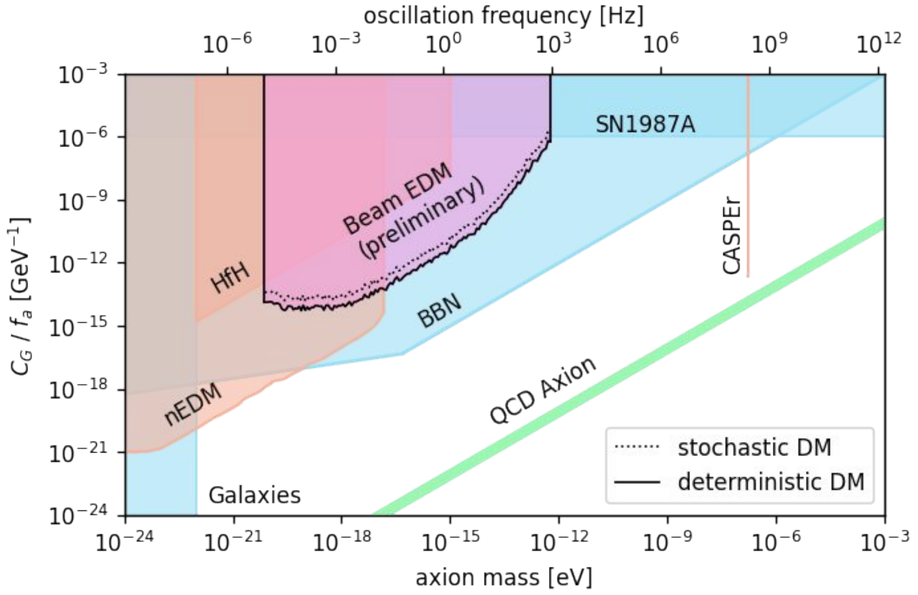
[2]

$$d_n(t) \approx \frac{C_G\ a_0}{f_a} \cos(m_a t)\ 2.4 \times 10^{-16}\ e \cdot \text{cm}$$

KSVZ: new exotic heavy quark
DFSZ: SM fermions



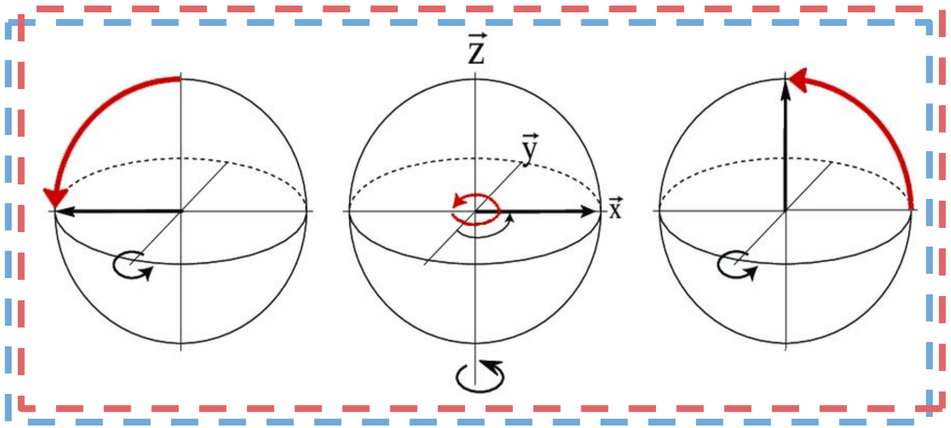
Axion Parameter Space:

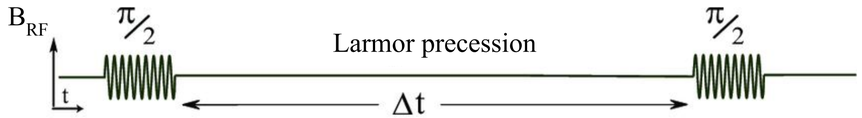


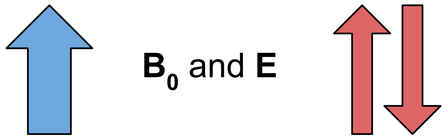
- model independent interaction
- big parameter space not covered by lab experiments
- complementary to nEDM lab experiment [3]
- higher frequency range than nEDM and HfH experiments
- benefits from existing Beam EDM apparatus

Experimental Setup

Ramsey's Technique [4]:



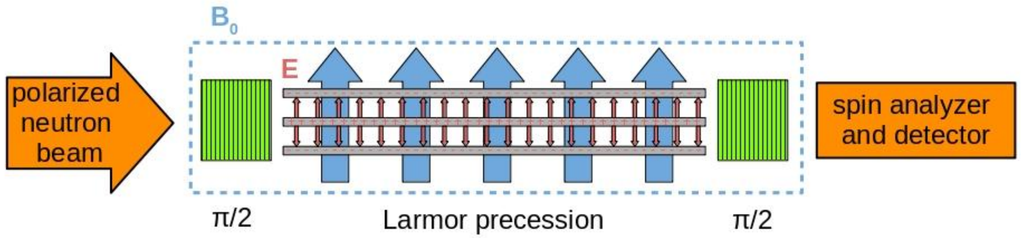


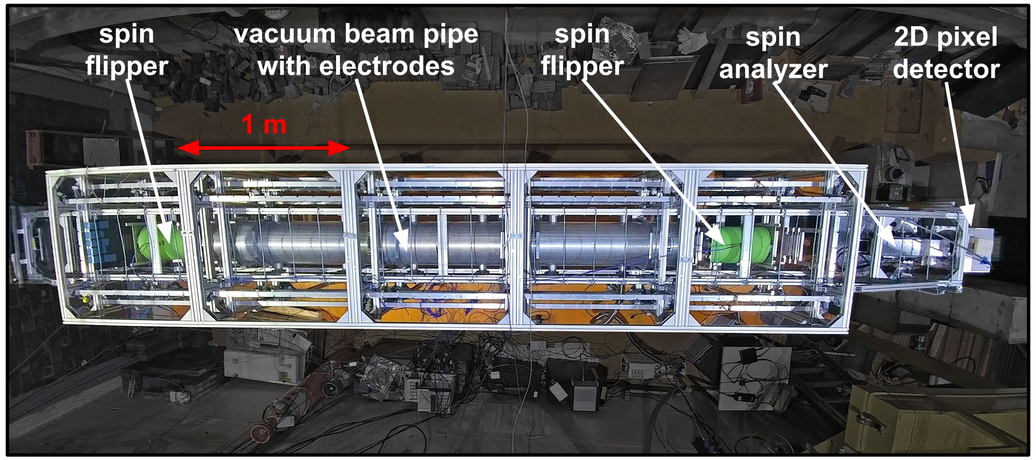


B_0 and **E**

$$\hbar\omega = 2\mu_n B_0 \pm 2d_n E$$

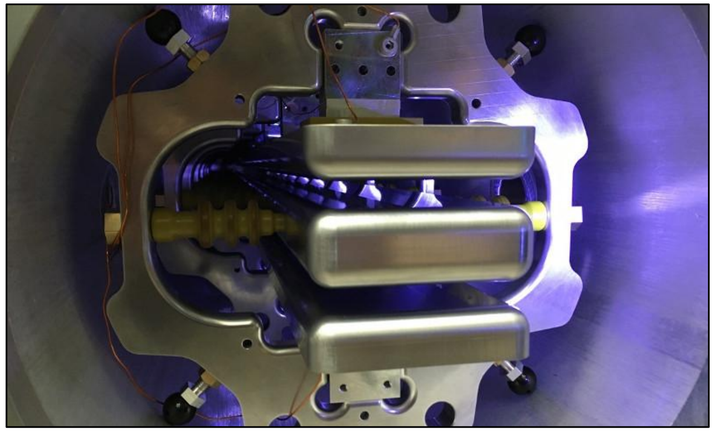
Beam Line:





Auxiliary Measurements

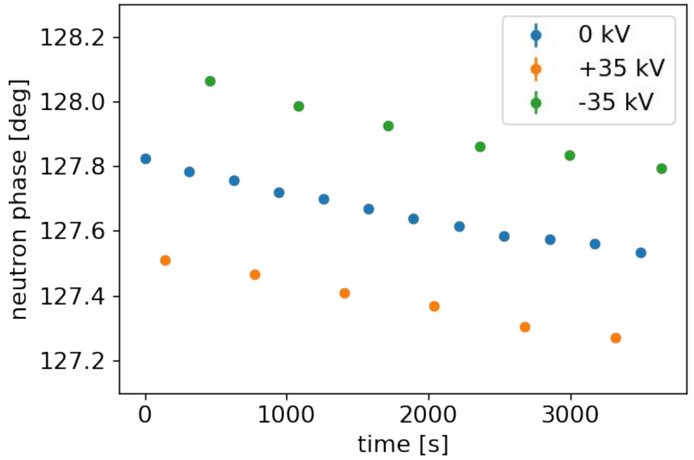
Electric Field Measurement:

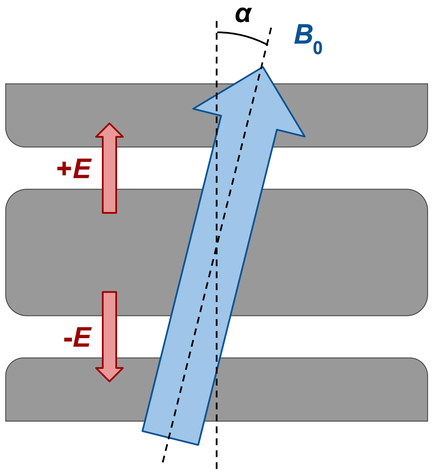


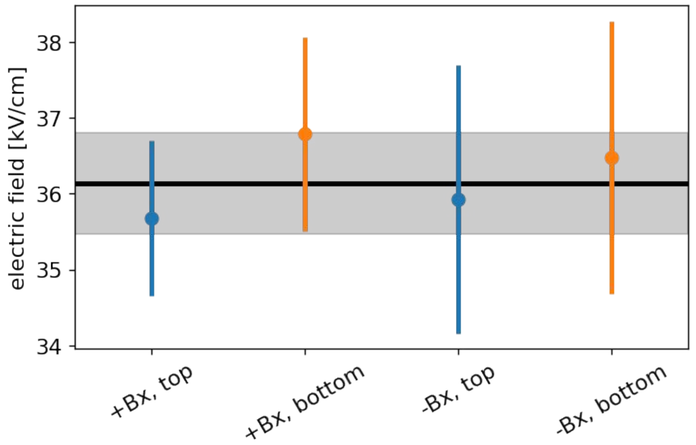
relativistic v x E effect:

$$\vec{B}_{v\times E} = -\gamma \frac{\vec{v}\times\vec{E}}{c^2}$$

$$\Delta E = \Delta\varphi \frac{c^2 d}{\gamma_n L \sin(\alpha)}$$



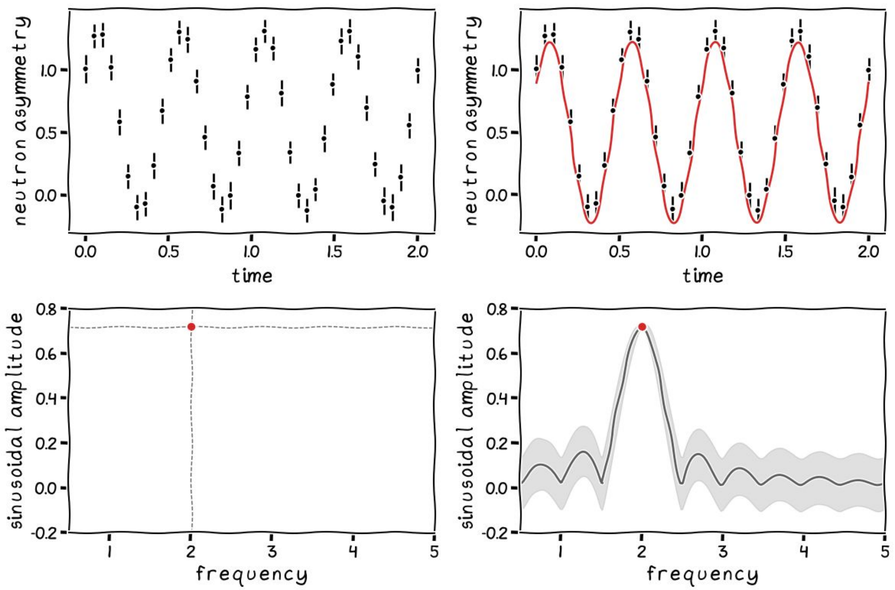




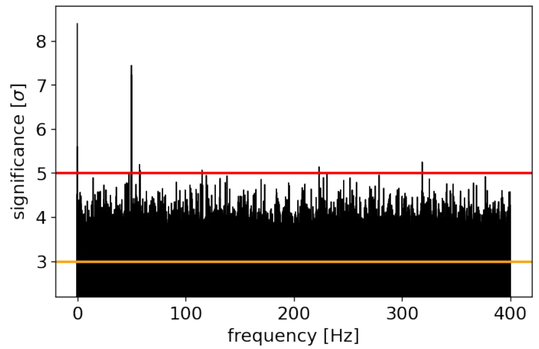
- electric field cycles: 0 / + / 0 / - / 0 / + / ….
  ➔ 0 kV measurements used for drift correction
- four measurements in agreement
- non-invasive tool to check electric field

Analysis & Results

Least-Squares Spectral Analysis:

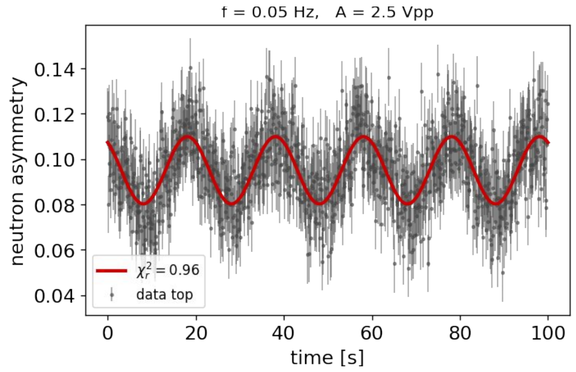


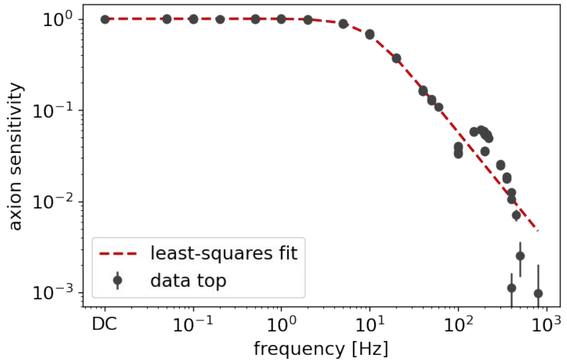
- fit a sinusoidal with a fixed frequency
- plot the amplitude of the fit
- scan a discrete frequency spectrum
- calculate coupling from amplitude



Artificial Axion Signal via Magnetic Interaction:

$$\underbrace{\gamma_n \times B_a \sin(\omega_a t)}_{\text{time dependent field}} \propto \underbrace{\frac{C_G}{f_a} a_0 \cos(\omega_a t) \times E}_{\text{time dependent moment}}$$





conclusion

- frequency dependent sensitivity
- so far no axion signal found
- final analysis ongoing

[1] Peccei, R. D. & Quinn, H. R. CP Conservation in the Presence of Pseudoparticles. *Phys. Rev. Lett.* **38**, 1440–1443 (1977).
[2] Stadnik, Y. V. & Flambaum, V. V. Axion-induced effects in atoms, molecules, and nuclei: Parity nonconservation, anapole moments, electric dipole moments, and spin-gravity and spin-axion momentum couplings. *Phys. Rev. D* **89**, 043522 (2014).
[3] Abel, C. *et al.* Search for axion-like dark matter through nuclear spin precession in electric and magnetic fields. *Phys. Rev. X* **7**, (2017).
[4] Ramsey, N. F. A Molecular Beam Resonance Method with Separated Oscillating Fields. *Phys. Rev.* **78**, 695–699 (1950).