Axion-Dark-Matter Search Using Cold Neutrons

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photo courtesy: isa_mau (pixabay.com)

Axion-Dark-Matter Search

The Dark Matter Problem

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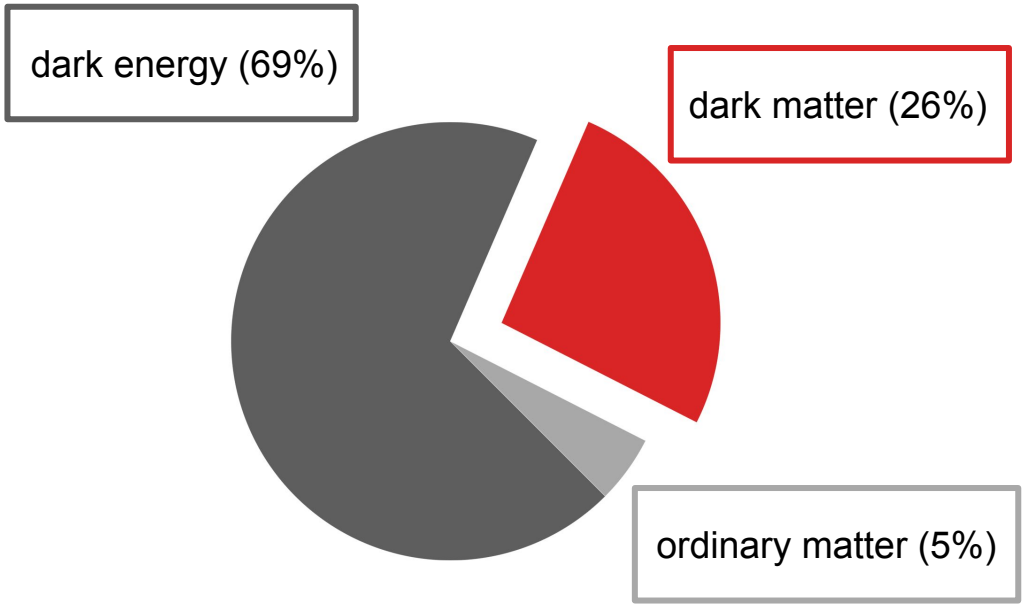

what we know:

- no interaction with photons
- gravitational interaction
- (no self-interaction)

Axion-Dark-Matter Search

Dark Matter Candidates

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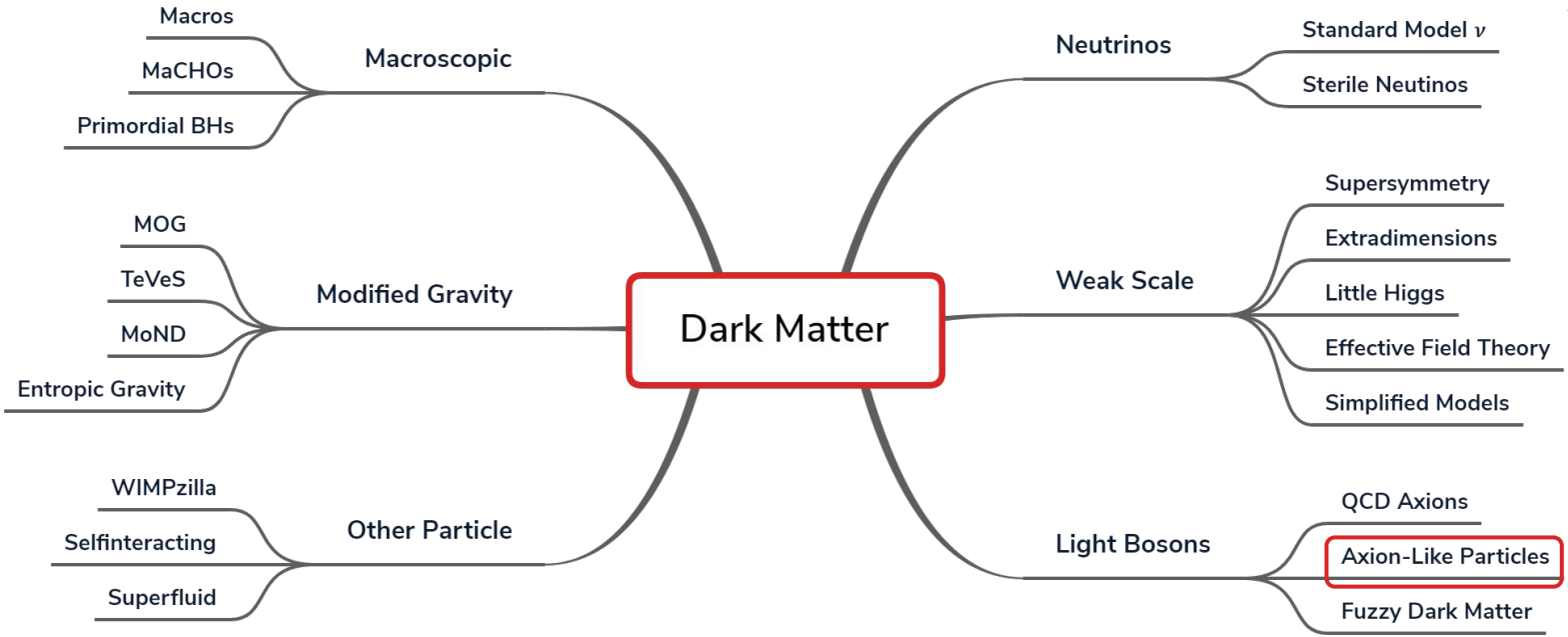

graphic adapted from:
https://phys.org/news/2018-10-era-quest-dark.html

Axion-Dark-Matter Search

Axion-Like Particles (ALPs)

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non-gravitational interaction:

$$\mathcal{L} = \frac{C_\gamma}{f_a}\frac{\alpha}{8\pi} a \mathcal{F}_{\mu\nu}\tilde{\mathcal{F}}^{\mu\nu} + \underbrace{\frac{C_G}{f_a}\frac{\alpha_s}{8\pi} a \mathcal{G}_{\mu\nu}\tilde{\mathcal{G}}^{\mu\nu}} - \sum_F \frac{C_F}{2f_a} a \bar{N}\gamma^\mu\gamma_5 N$$

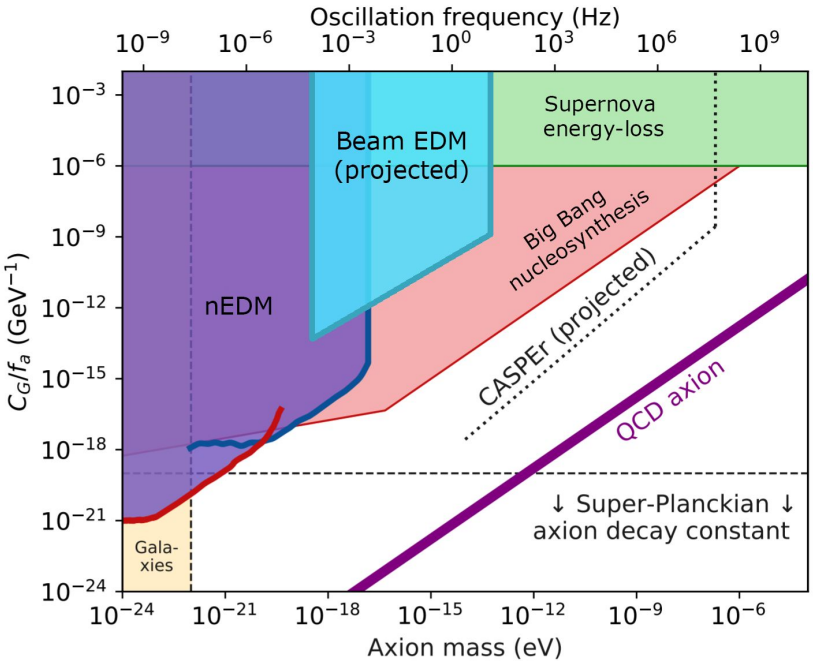
axion-gluon coupling
➔ oscillating neutron EDM

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

C: model dependent parameter
α: coupling constant
f_a: axion decay constant
a: axion field
F: electromagnetic field tensor
G: gluonic field tensor
N: nucleon field
a_0: axion field amplitude
m_a: axion mass

Axion-Dark-Matter Search

Axion-Gluon Coupling



graphic adapted from:
arXiv:1708.06367 Fig. 4

why we do this:

- many astrophysical constraints
- only one lab experiment
- higher frequency range
- benefits from existing Beam EDM apparatus

Axion-Dark-Matter Search

Beam EDM Apparatus - Ramsey Technique

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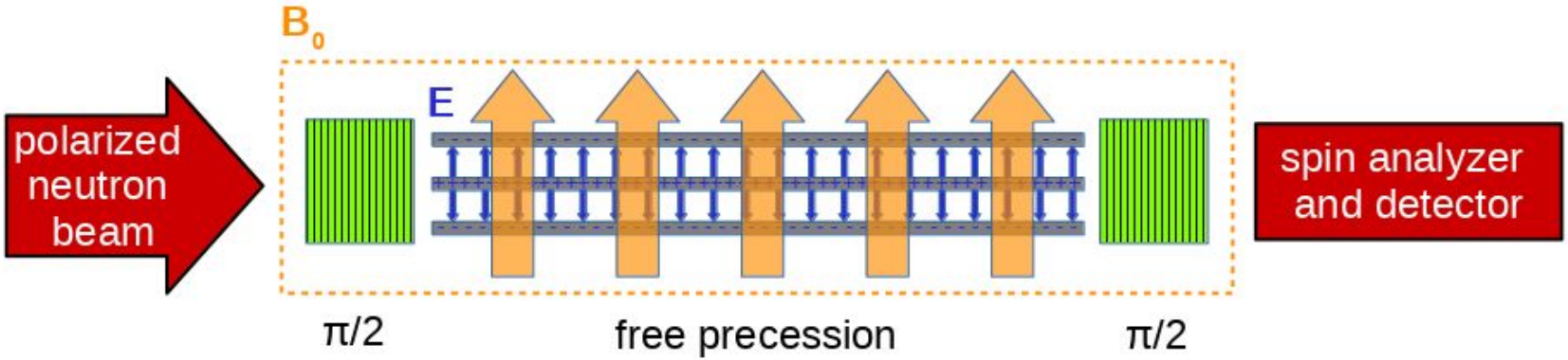

oscillation of the neutron EDM results in oscillation of the asymmetry between the two spin states

$$A(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)}$$

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Experimental Setup - Beam EDM Apparatus

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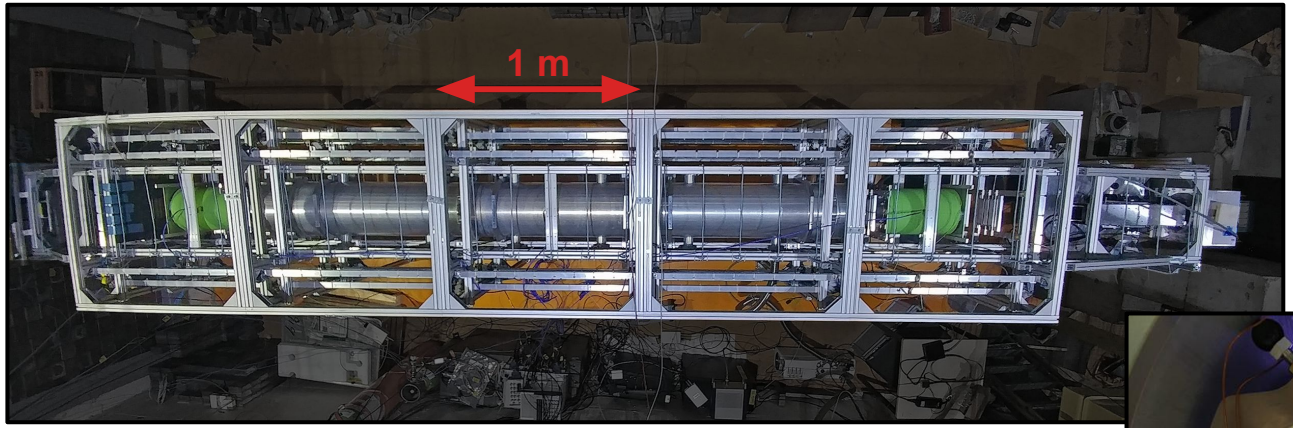

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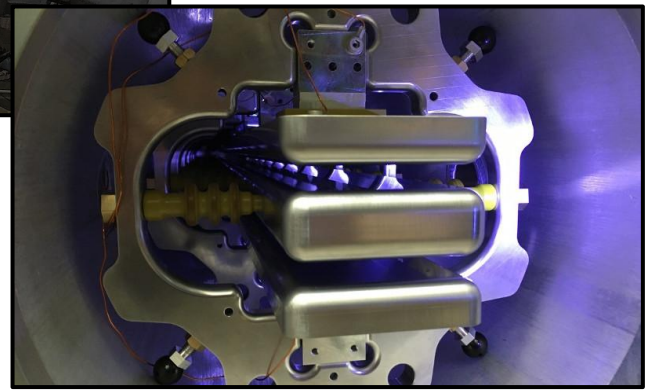

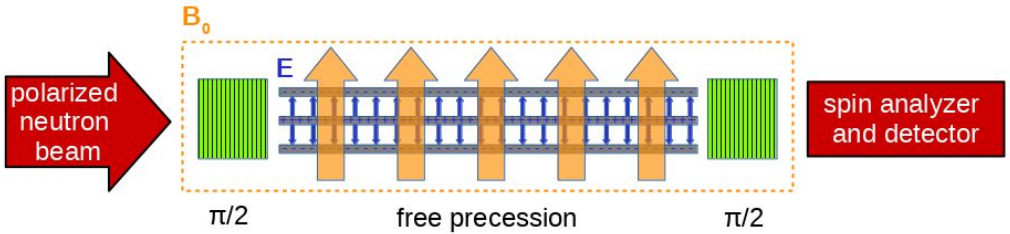

Axion-Dark-Matter Search

Analysis Method - Least Squares Spectral Analysis

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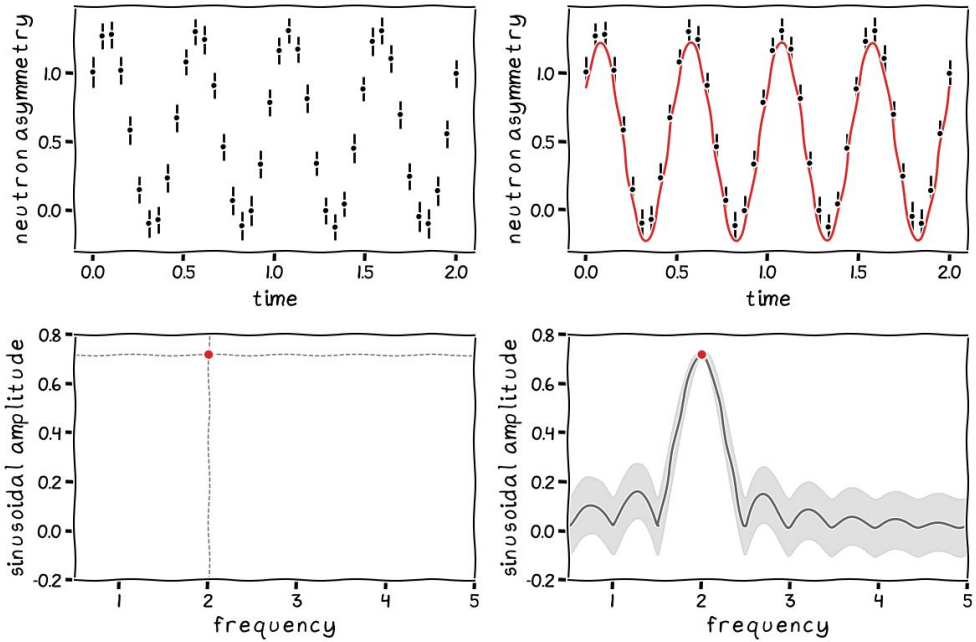

1. get data from experiment
2. fit a sinusoidal with a fixed frequency
3. plot the amplitude of the sinusoidal
4. scan a frequency grid
5. calculate coupling from amplitude

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Fake Axion Data

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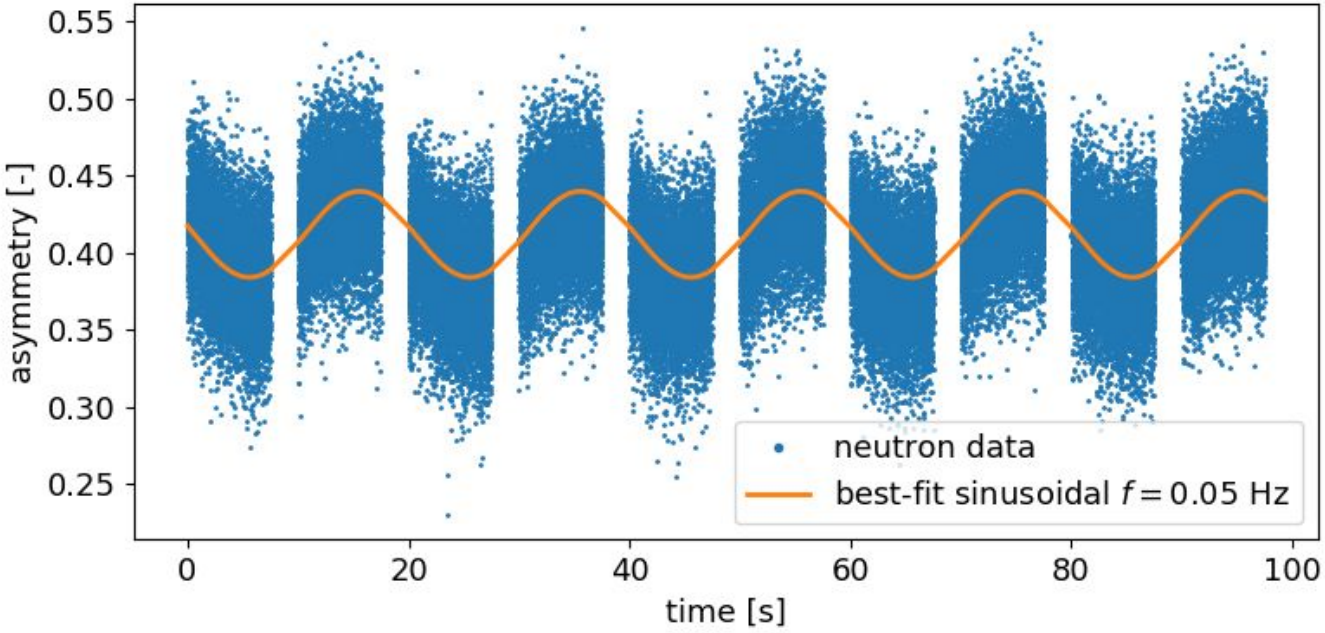
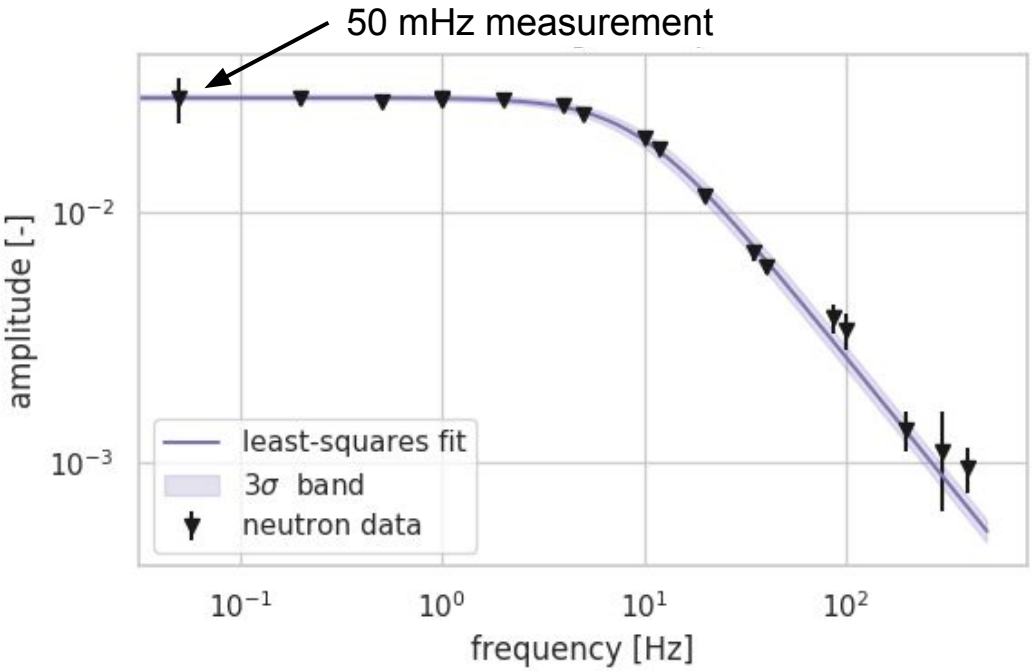


Axion-Dark-Matter Search

(Fake) Axion Sensitivity



fit function: $\dfrac{A}{\sqrt{1+(f/f_c)^2}}$

sensitivity cut-off frequency: ~10 Hz

➔ RF shielding by aluminum of fake axion field

➔ not present for “real” axions

Axion-Dark-Matter Search

Conclusion

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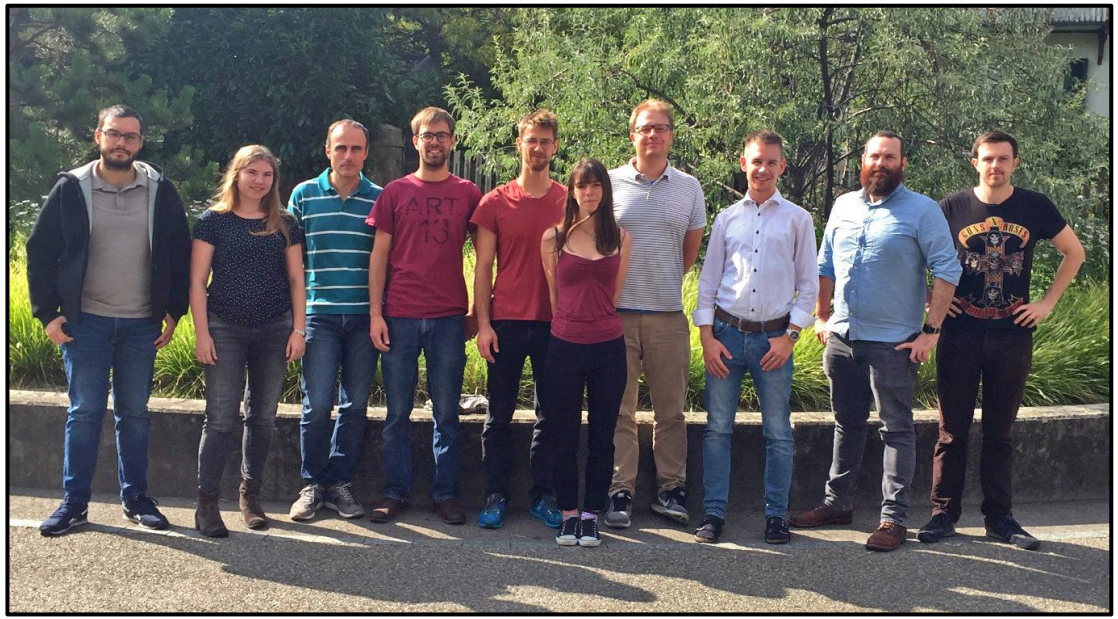
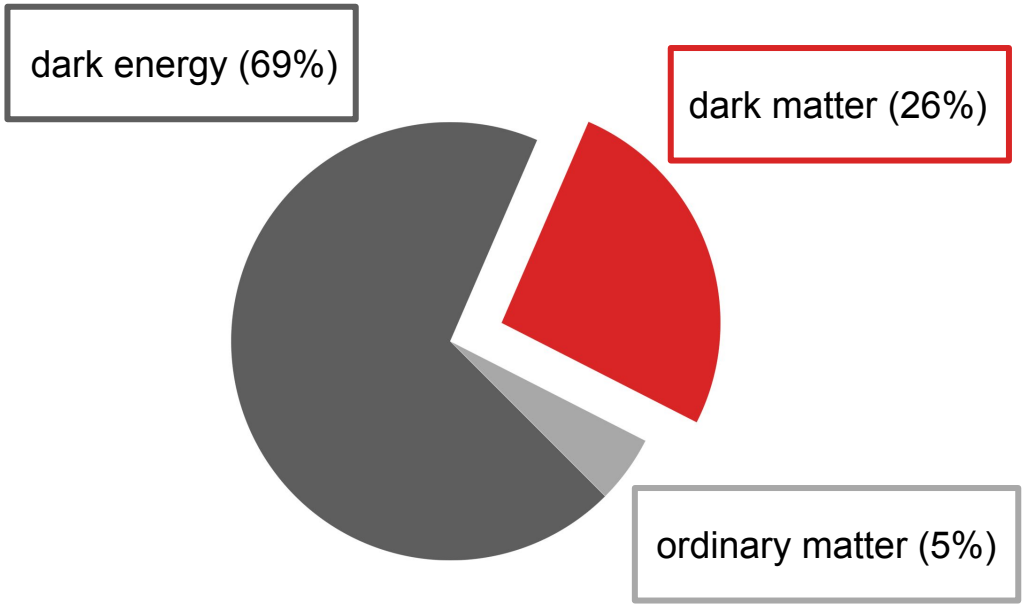


- complementary lab experiment to search for axion-gluon coupling
- proof of principle at PSI 2018 beamtime
- characterization of the apparatus sensitivity
- next measurement at ILL in 2020

Axion-Dark-Matter Search

The Dark Matter Problem

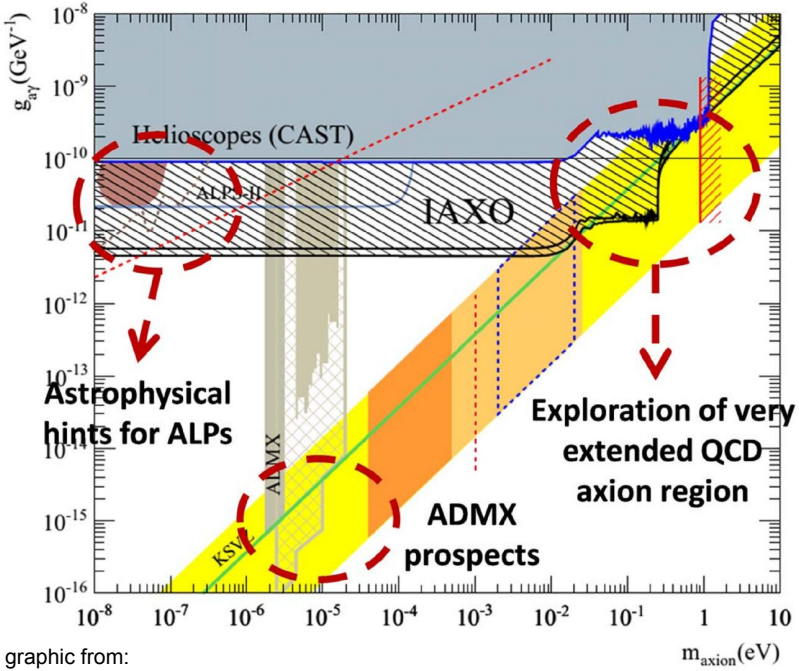


dark matter evidence:

- galaxy clusters
- galactic rotation curves
- cosmic microwave background
- the bullet cluster
- large-scale structure formation

Axion-Dark-Matter Search

Backup - Axion-Photon Coupling



graphic from:
arXiv:1501.01456 Fig. 3

experiments:

- CAST: CERN Axion Solar Telescope
- IAXO: International Axion Observatory (at CERN)
- ADMX: Axion Dark Matter eXperiment

Axion-Dark-Matter Search

Experimental Setup - Fake Axion Measurement

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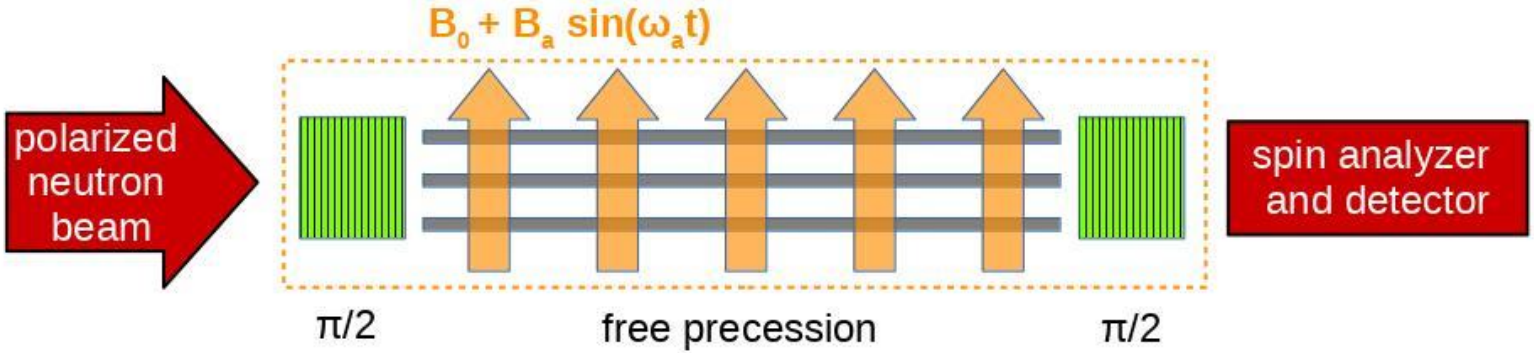

$$\underbrace{\gamma_n \times B_a \sin(\omega_a t)}_{\text{time dependent field}} \propto \underbrace{\frac{C_G}{f_a} a_0 \cos(\omega_a t)}_{\text{time dependent moment}} \times E$$

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Axion Conditions

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A. no signal for E = 0

B. peak with same amplitude for B↑↑E and B↑↓E

C. 180° phase shift for B↑↑E compared to B↑↓E