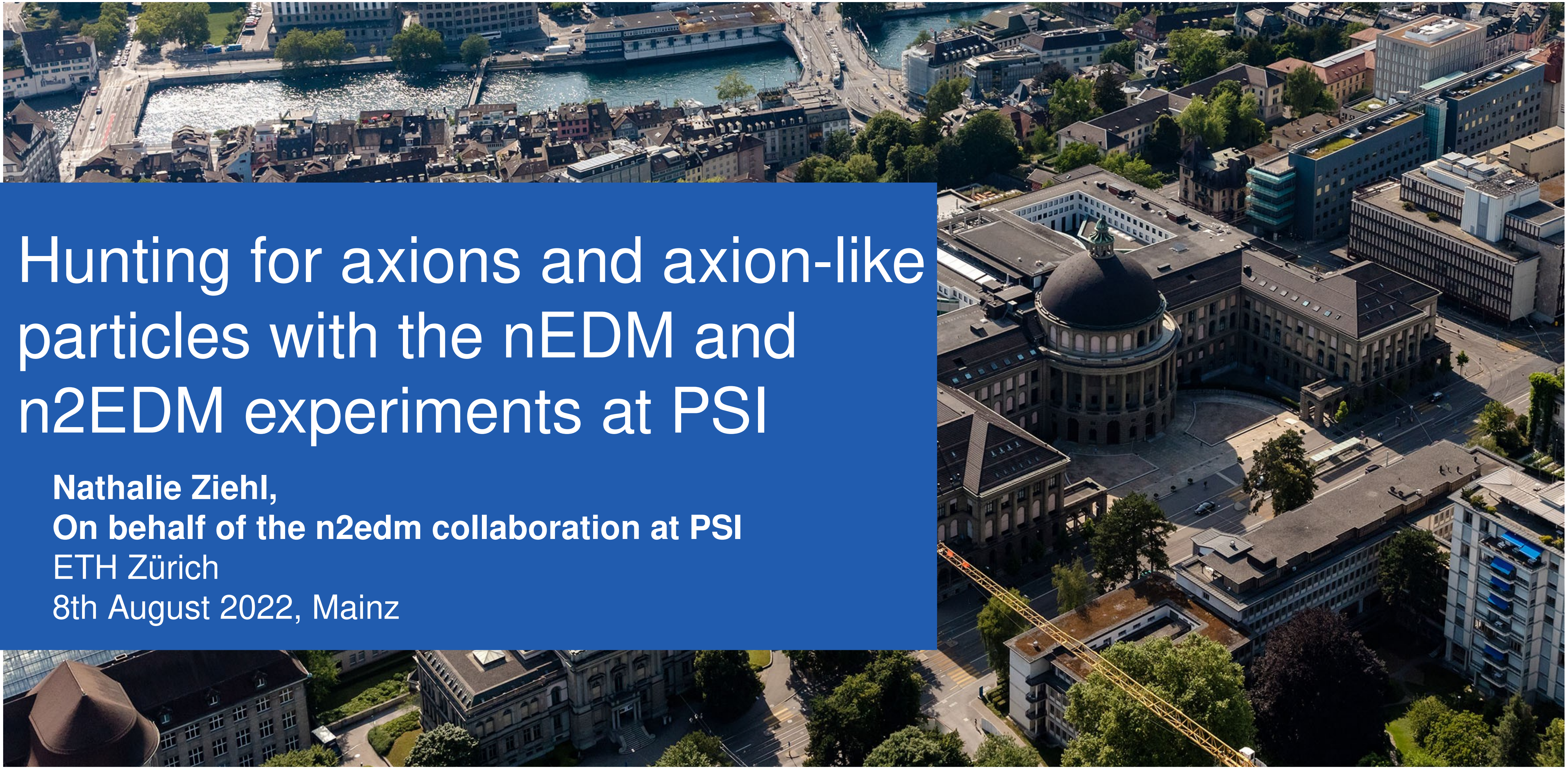
ETH zürich



Hunting for axions and axion-like particles with the nEDM and n2EDM experiments at PSI

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On behalf of the n2edm collaboration at PSI
ETH Zürich
8th August 2022, Mainz

Goal

- Ultralight axions with 10^{-22} eV < m < 10^{-17} eV
  → DM candidates

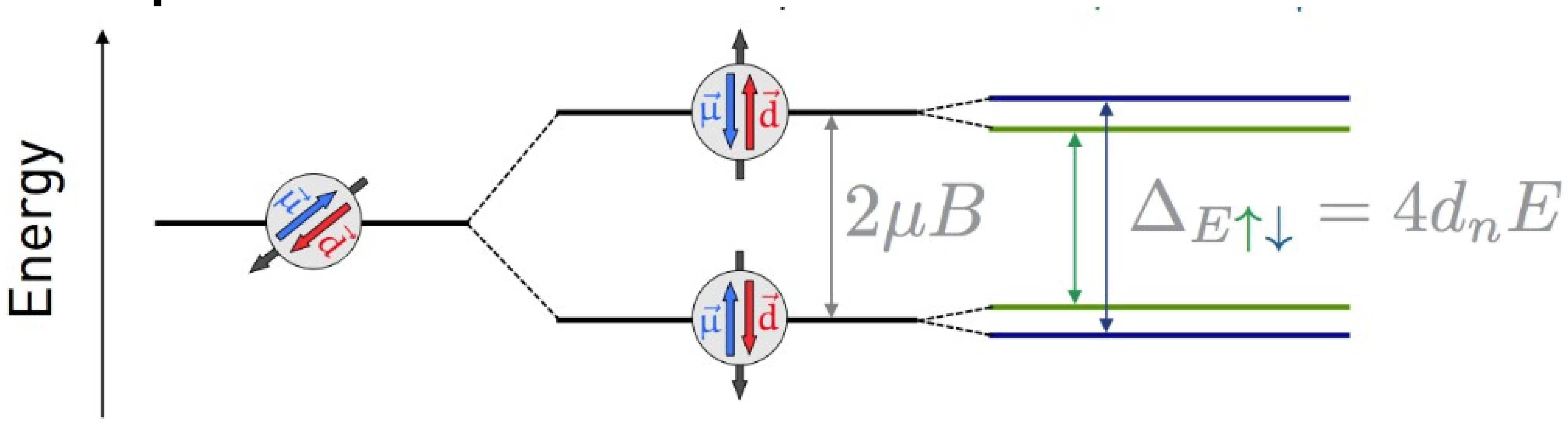
$$\mathcal{L}_{int} = \frac{C_g}{f_a}\frac{g_s^2}{32\pi^2} a G^a_{\mu\nu}\widetilde{G}^{a\mu\nu}$$

$$d_n(t) \approx +2.4 \times 10^{-16}\frac{C_g a_0}{f_a}\cos(m_a t)e\mathrm{cm},$$

Oscillating ultralight dark matter axion field → oscillating neutron EDM

Current limit of $\theta < 10^{-10}$ from nEDM measurements

nEDM Experiment



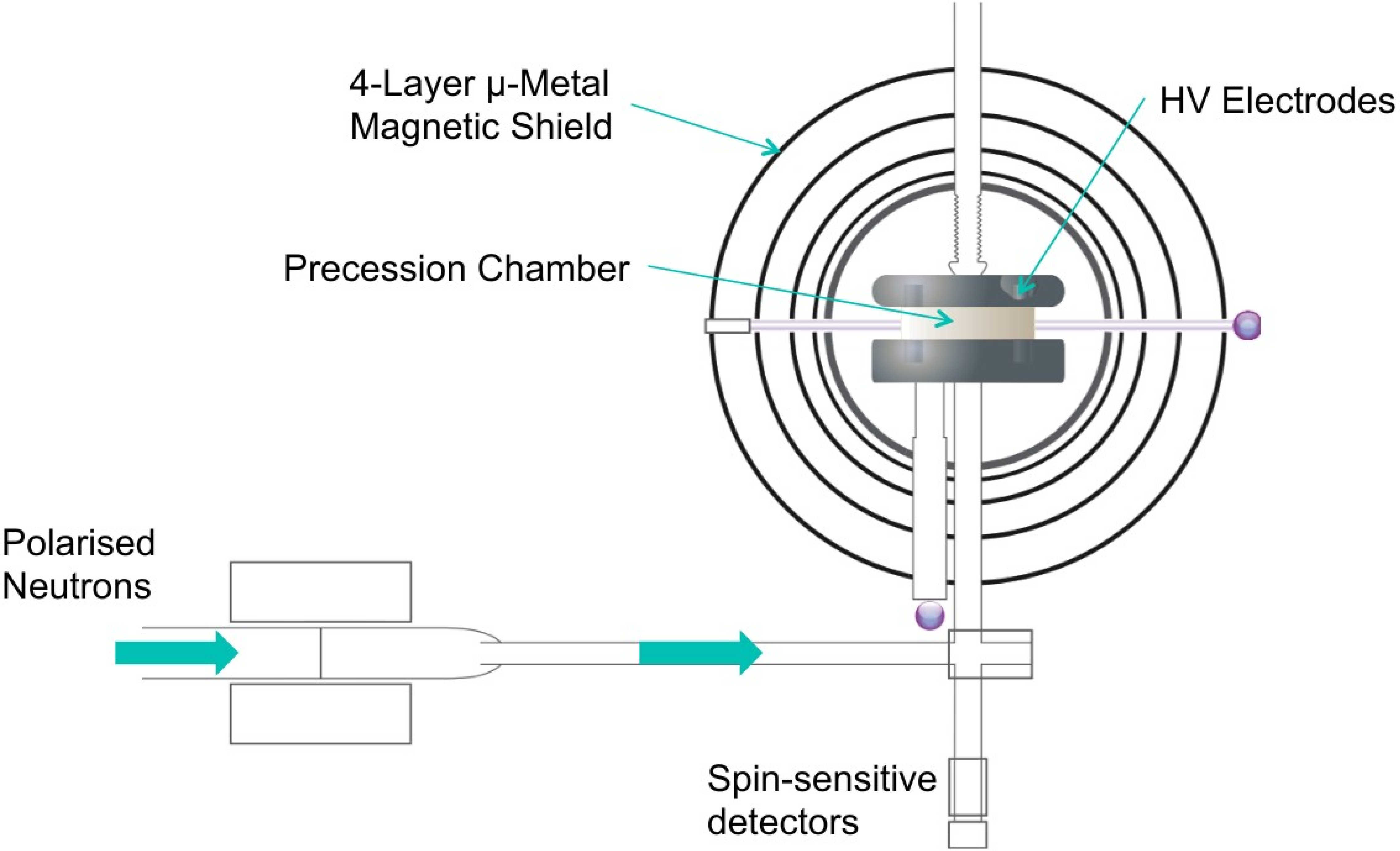
- Energy splitting between EB ↑↑ and EB↑↓
- Measure neutron Larmor frequency
  → Ramsey technique

$$d_n = \frac{\pi\hbar}{2|E|}(f_{n,\uparrow\downarrow} - f_{n,\uparrow\uparrow})$$

Ultracold neutrons (UCN)

- Free neutrons with low kinetic energy < 250-300 neV
  → gravity becomes important (100 neV → 1 m height)

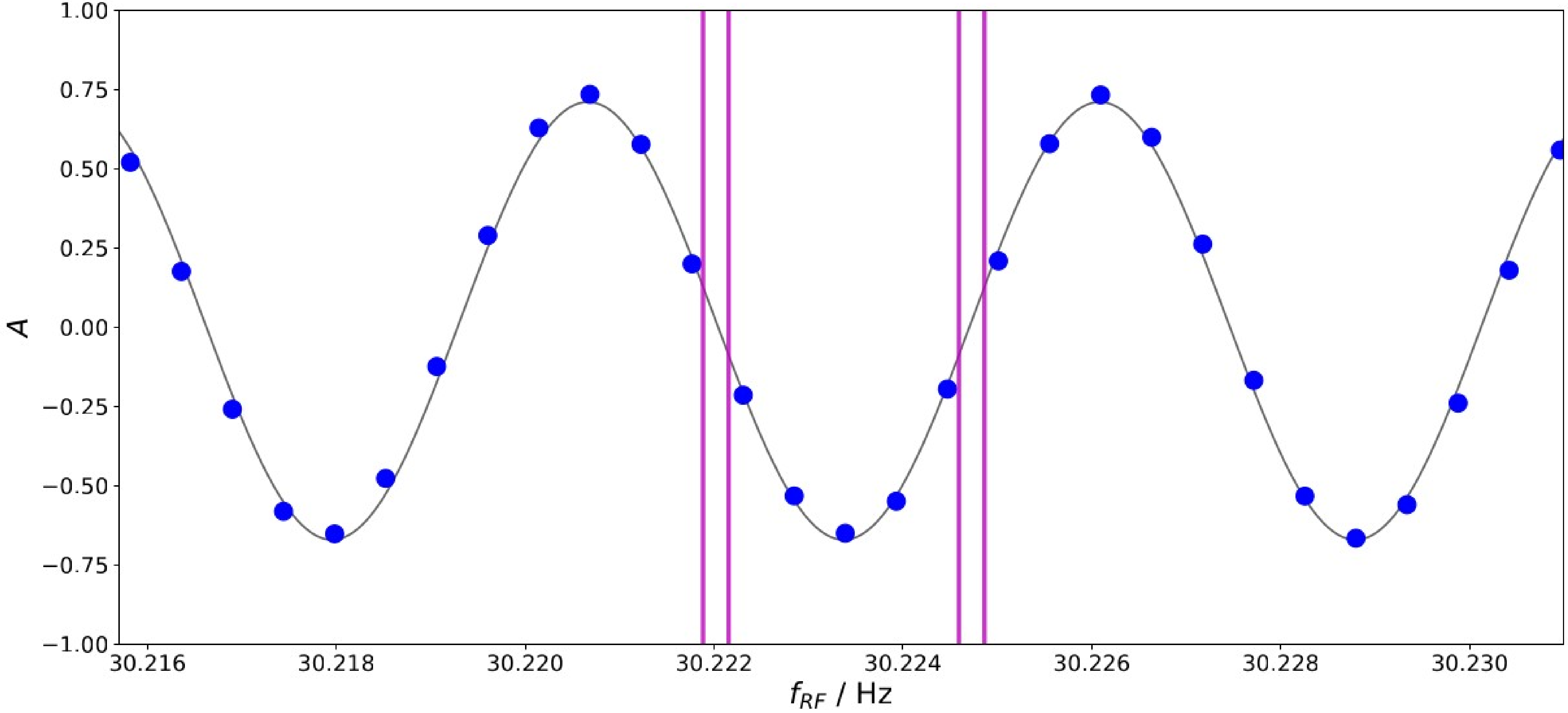
- Undergo total reflection at any angle
  → Can be stored in relatively ordinary, macroscopic containers



4-Layer μ-Metal Magnetic Shield
HV Electrodes
Precession Chamber
Polarised Neutrons
Spin-sensitive detectors

nEDM measurement

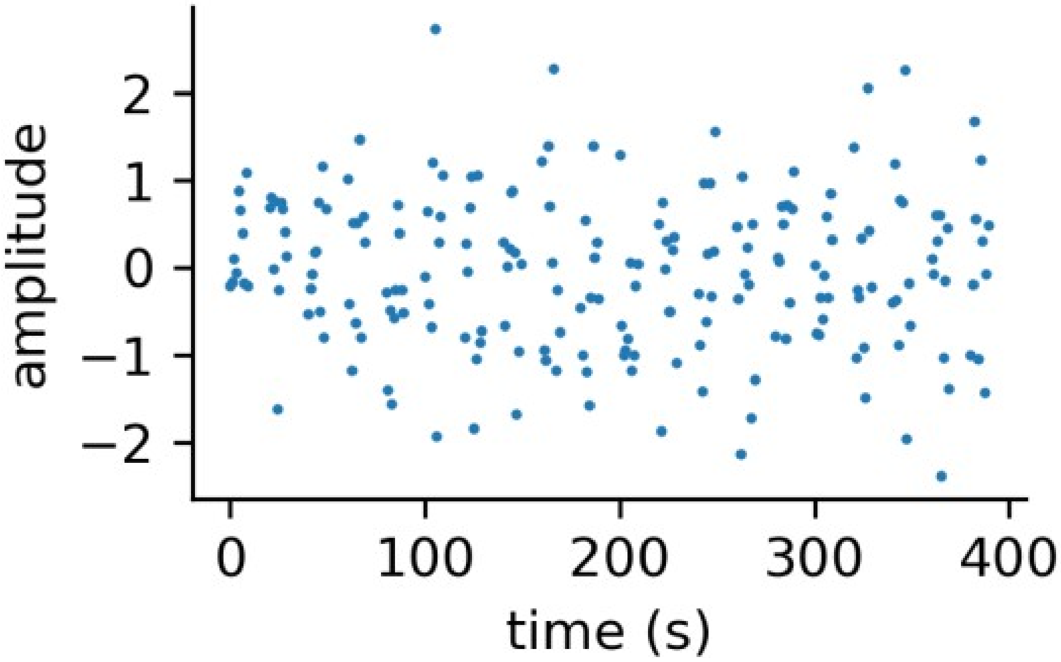
0. Polarised neutrons
1. Apply EM pulse with $f_{\mathrm{RF}} \approx |\gamma_n|/2\pi B_0$ to flip the spins
2. Let them precess for T = 180 s
3. Apply second pulse, flipping them back onto z-axis
4. Measure asymmetry $A = (N_\uparrow - N_\downarrow)/(N_\uparrow + N_\downarrow)$

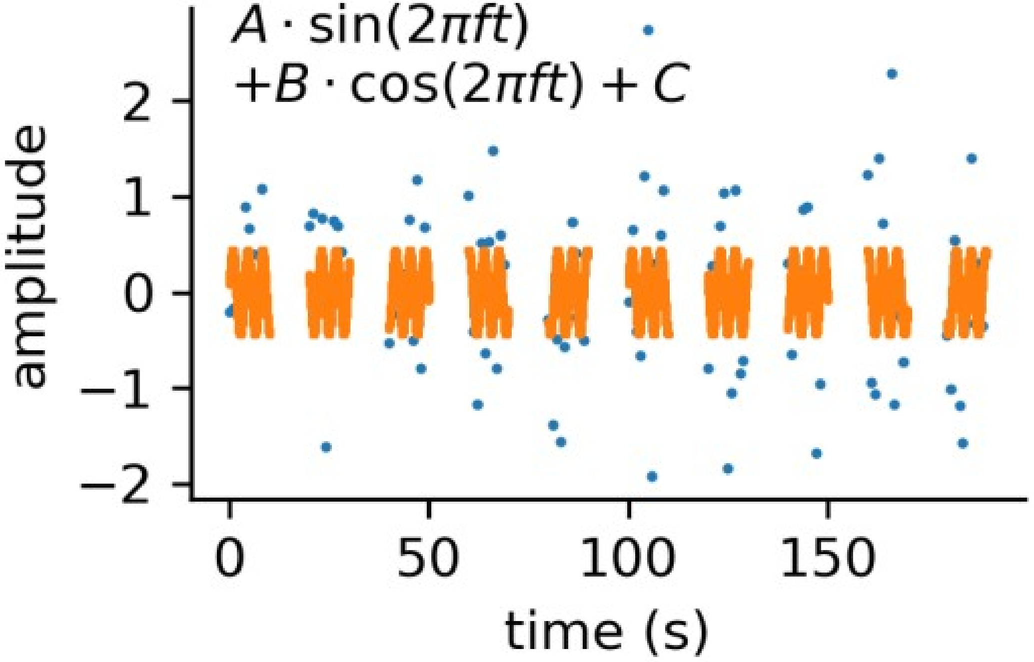


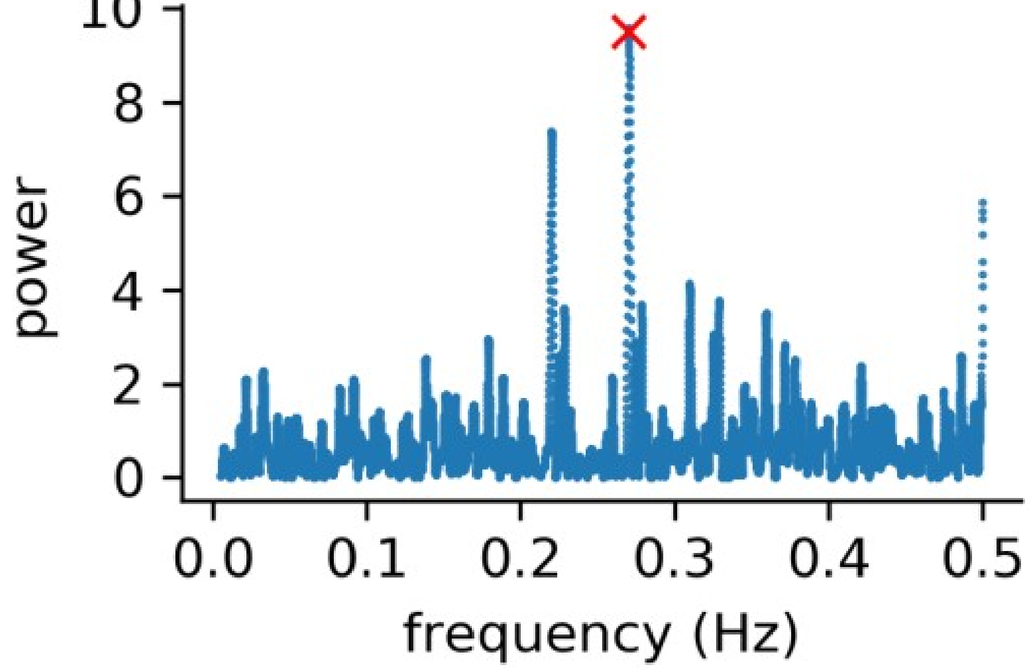
Spectral Analysis

- Normal FT not possible → unevenly spaced datapoints
- Use **LSSA** instead (least-squares spectral analysis) / (Lomb-Scargle periodogram)

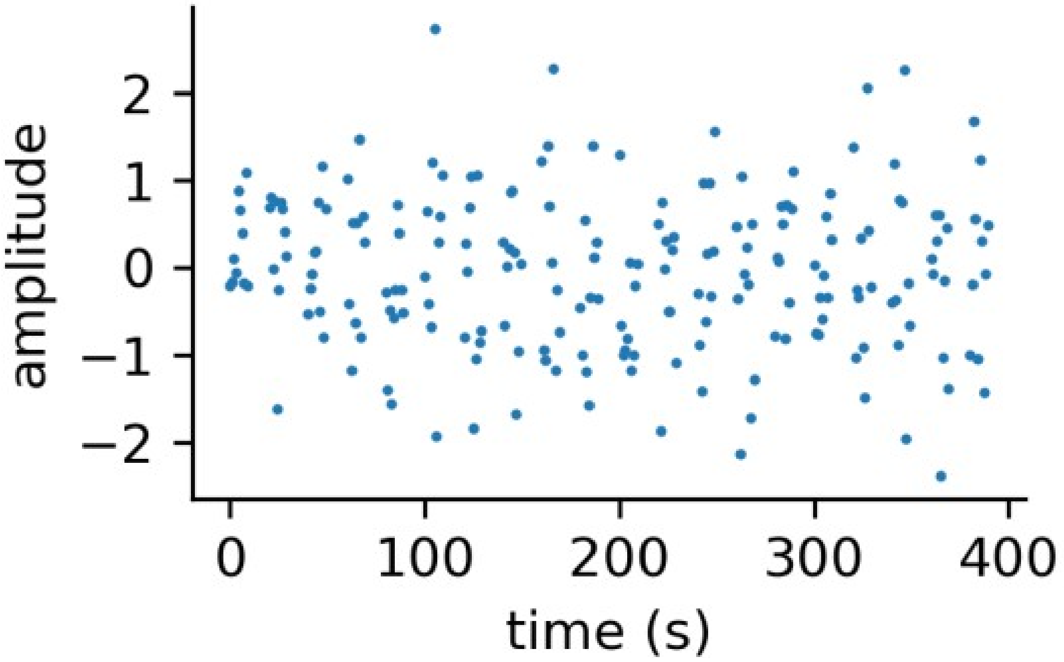
→ fit a trigonometric function to the data: $A \sin \omega t + B \cos \omega t + C$
→ obtain power spectrum from fit parameters
→ repeat for all ω

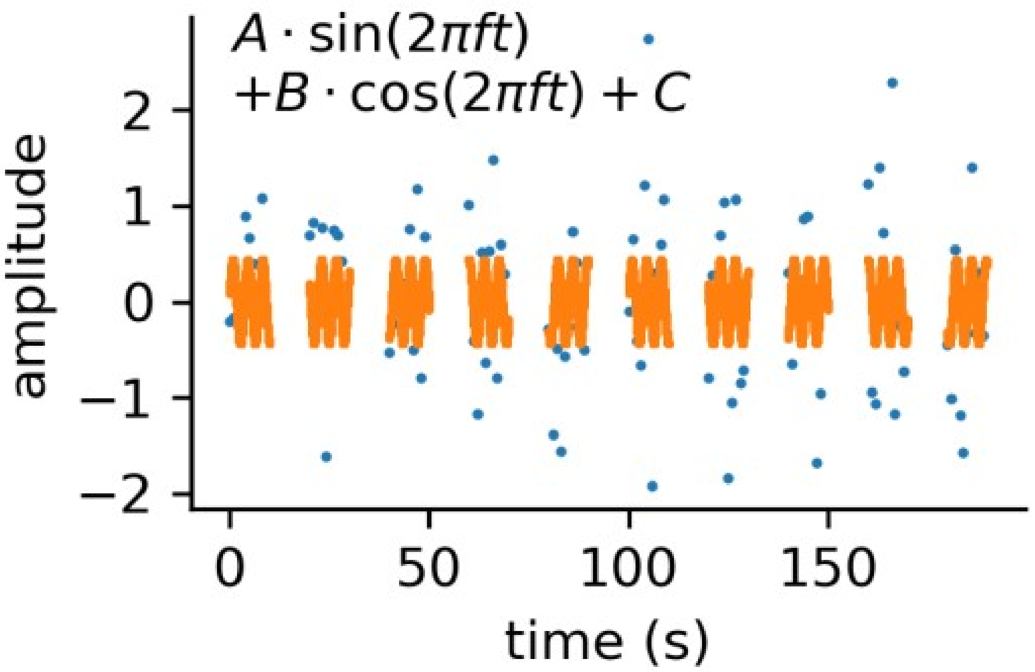


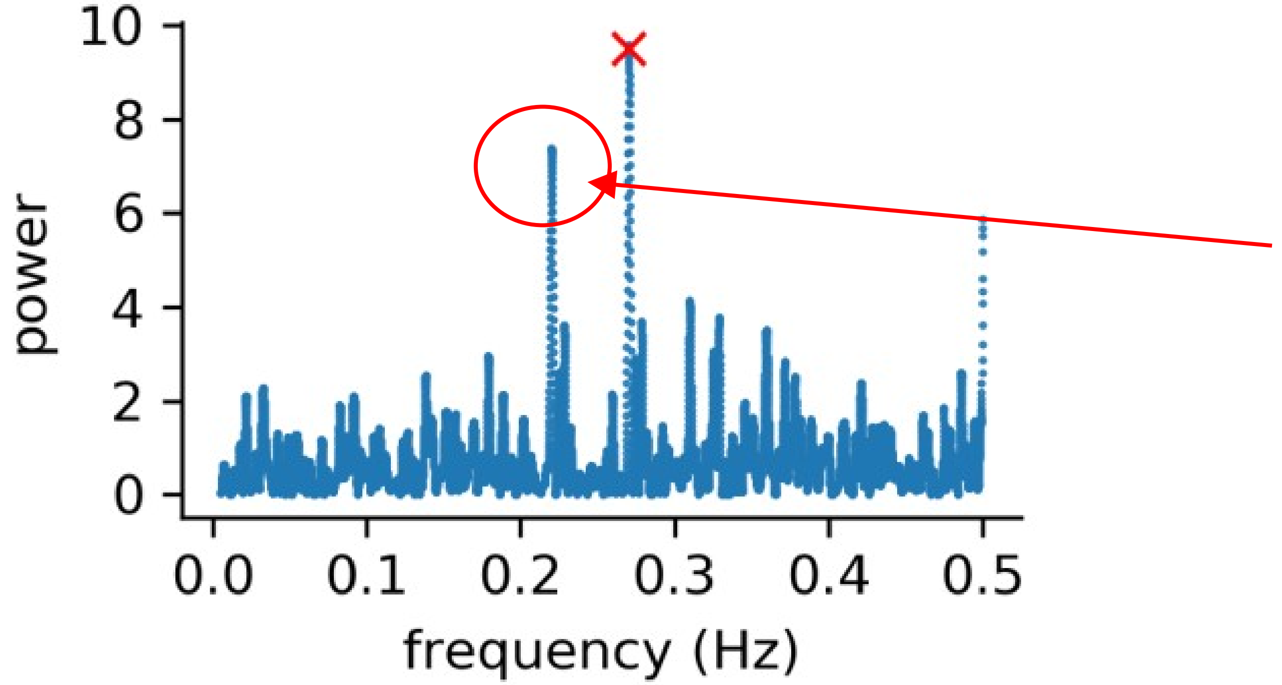




Scan ~43’000 frequencies from 10^{-9} Hz to 10^{-3} Hz







The highest peak is not necessarily a signal!

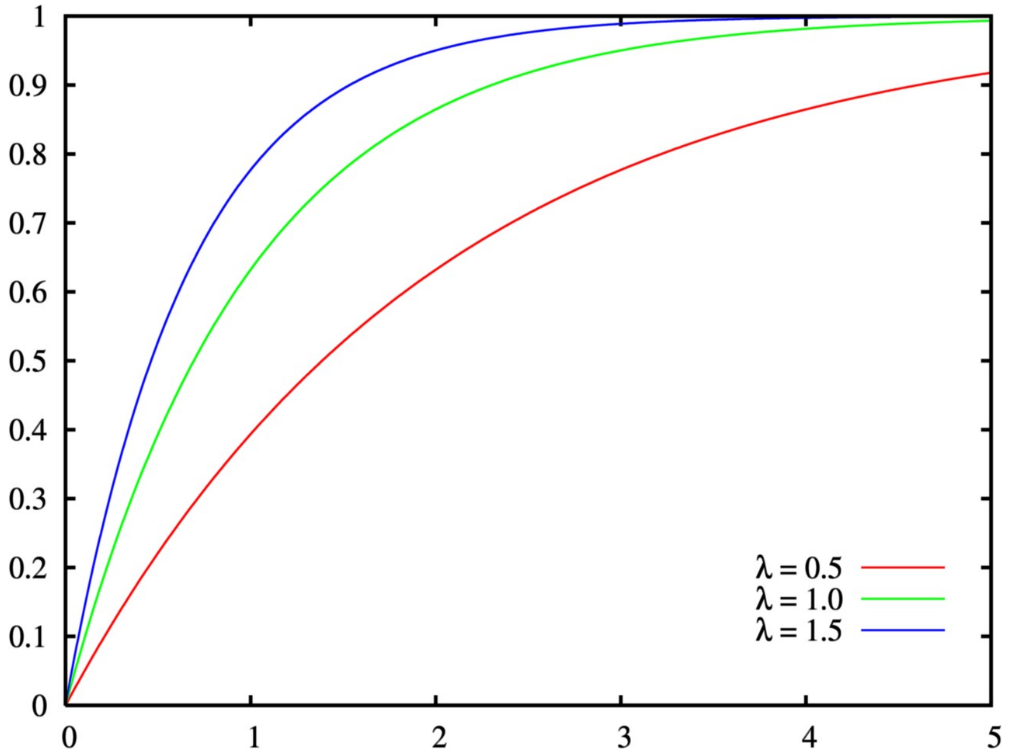
Null Hypothesis

What is the periodogram of nEDM data with no signal?

- MC simulations
- Fit CDF to the simulations
- Obtain probability for peak being just random fluctuations

CDF: cumultaive distribution function
Probability, that a random variable X at point x is smaller than or equal to x.

e.g $e^{\lambda x}$



Null Hypothesis

What is the periodogram of nEDM data with no signal?

- MC simulations
- Fit CDF to the simulations
- Obtain probability for peak being just random fluctuations

False alarm probability:
Lots of data → very rare events **will** happen.

$$p_{\text{global}} = 1 - F_Z(z)^N$$

N number of investigated events.

CDF: cumultaive distribution function
Probability, that a random variable X at point x is smaller than or equal to x.

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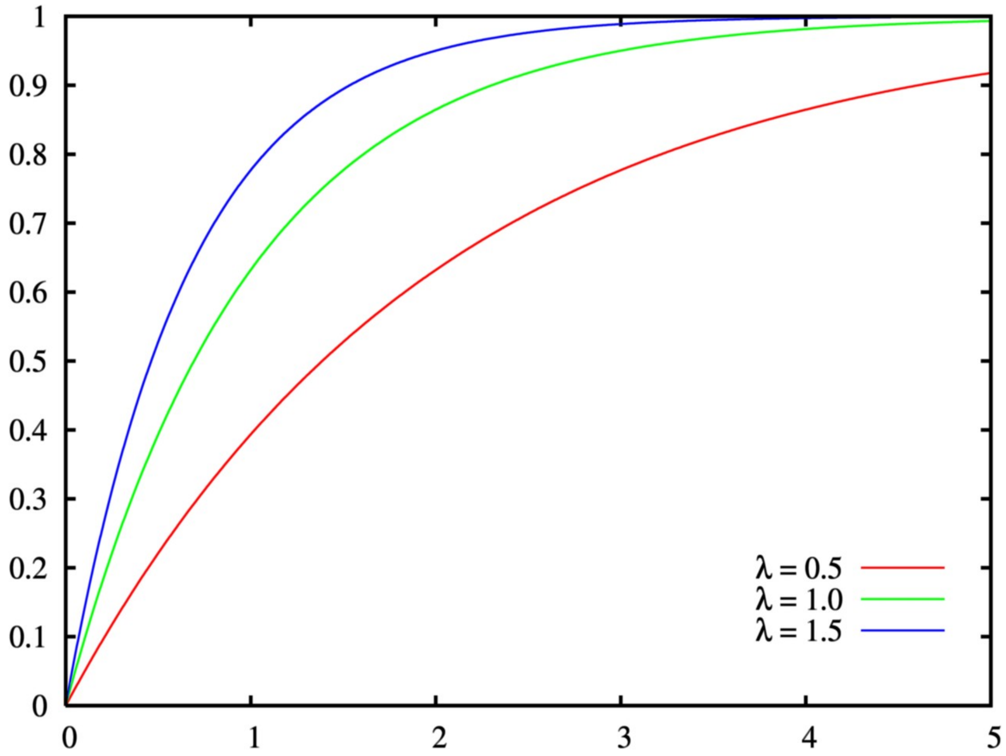


Signal Hypothesis

No statistically significant signal consistent with the hypothesis was observed.

Determine Exclusion:

1. MC simulations with axion signals with parameters (A, ω)

2. Calculate the CDF

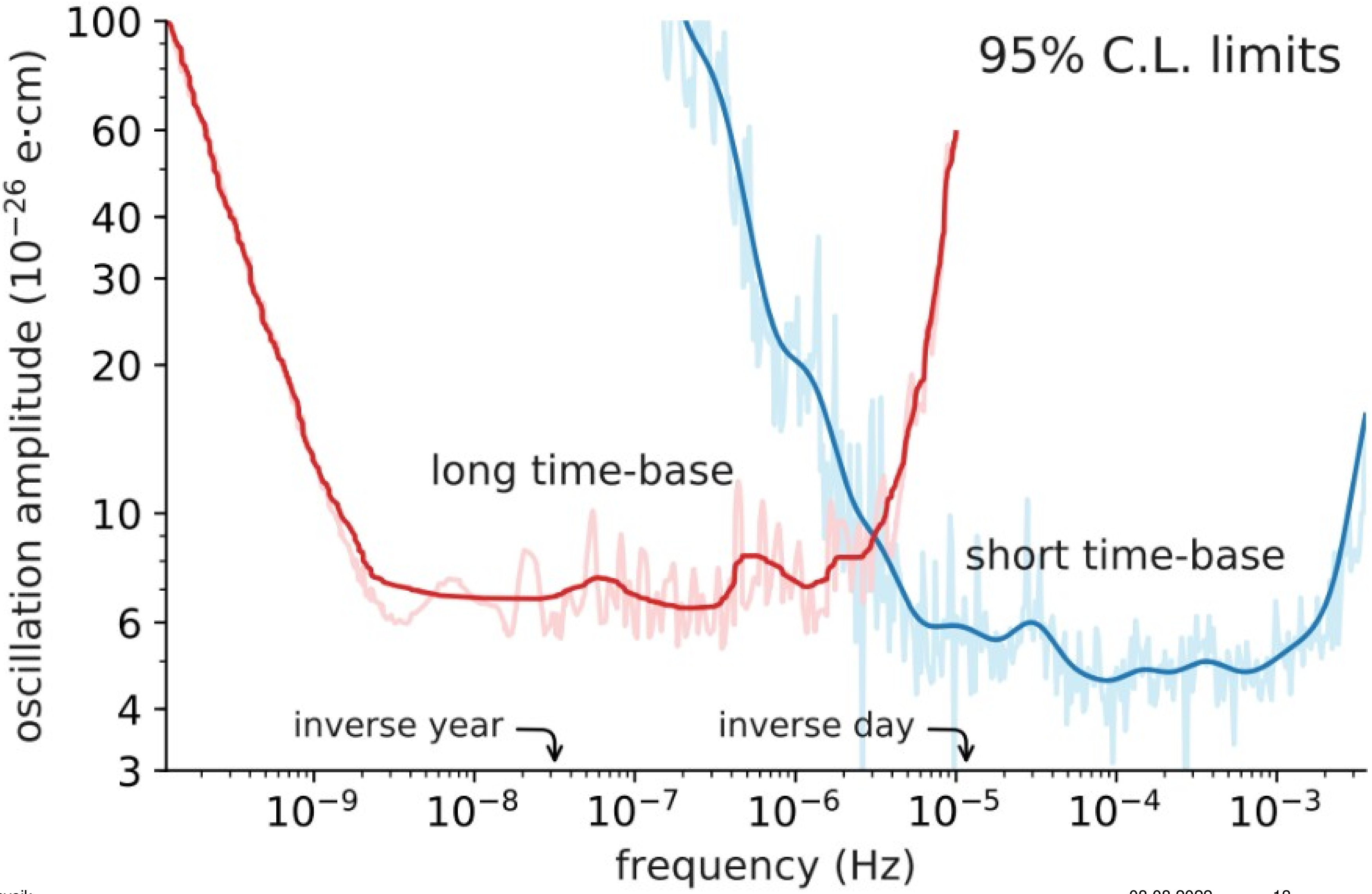
3. Obtain 2D exclusion zone

4. Use CLs method: $$\mathrm{CLs} = \frac{\Pr(P^{H(\omega,A)}(\omega) < P^{D}(\omega))}{\Pr(P^{H_0}(\omega) < P^{D}(\omega))}$$

→ correct exclusion in parameter space where the experiment is not sensitive

Results

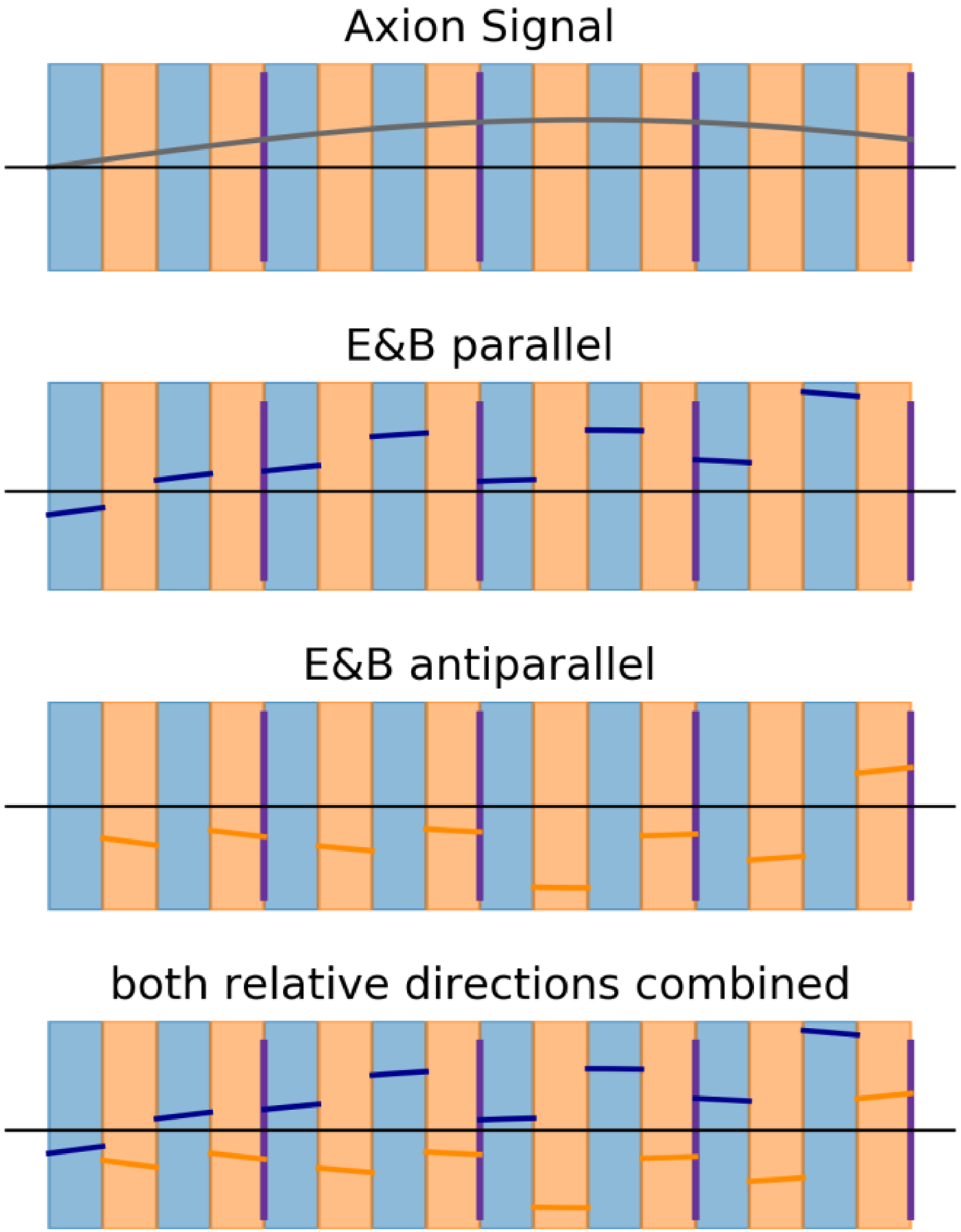
Red: Sussex-RAL-ILL (2017)
Blue: PSI (2017)



Improvements: Better fitting

- PSI 2017: EB $\uparrow\uparrow$ and EB $\uparrow\downarrow$ fitted separately
- Better: Fitting both at the same time

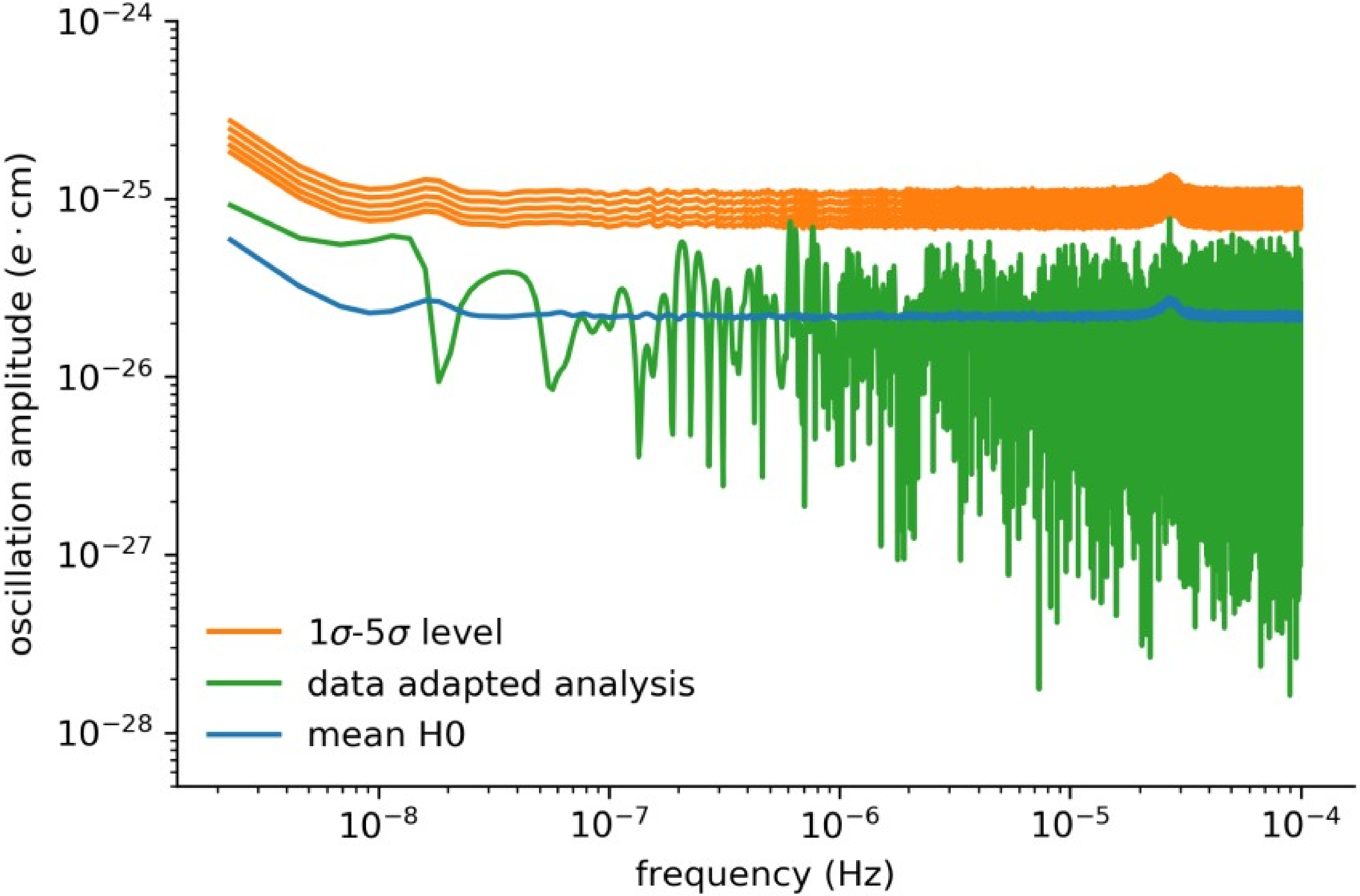
→ determine offset without loss of sensitivity
→ better exclusion at low frequencies
→ separation reveals axion signal



Improved Results

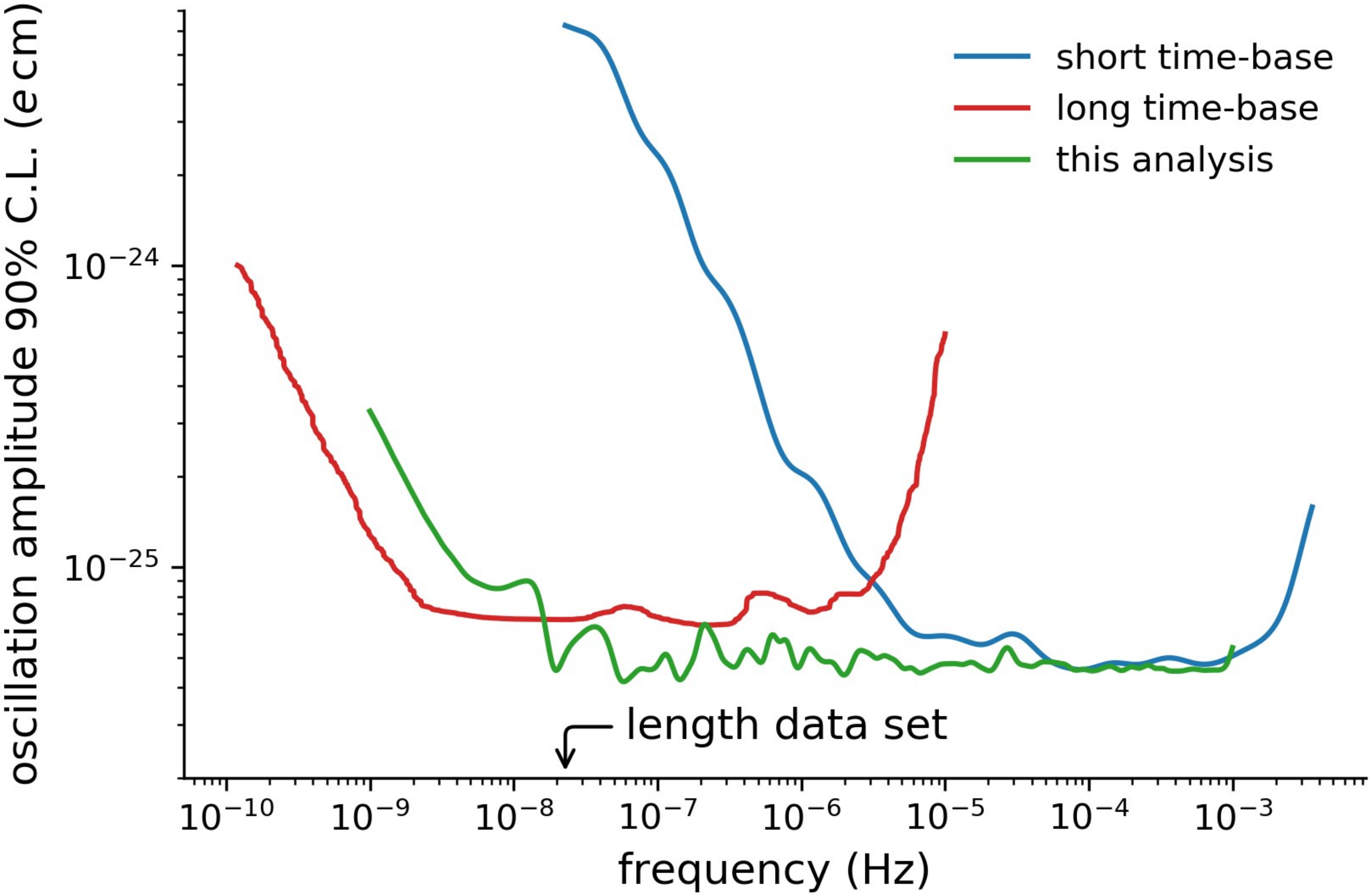
No peak above detection limit

Bump due to 112 cycle periodicity



Improved Results

Red: Sussex-RAL-ILL (2017
Blue: PSI (2017)
Green: PSI



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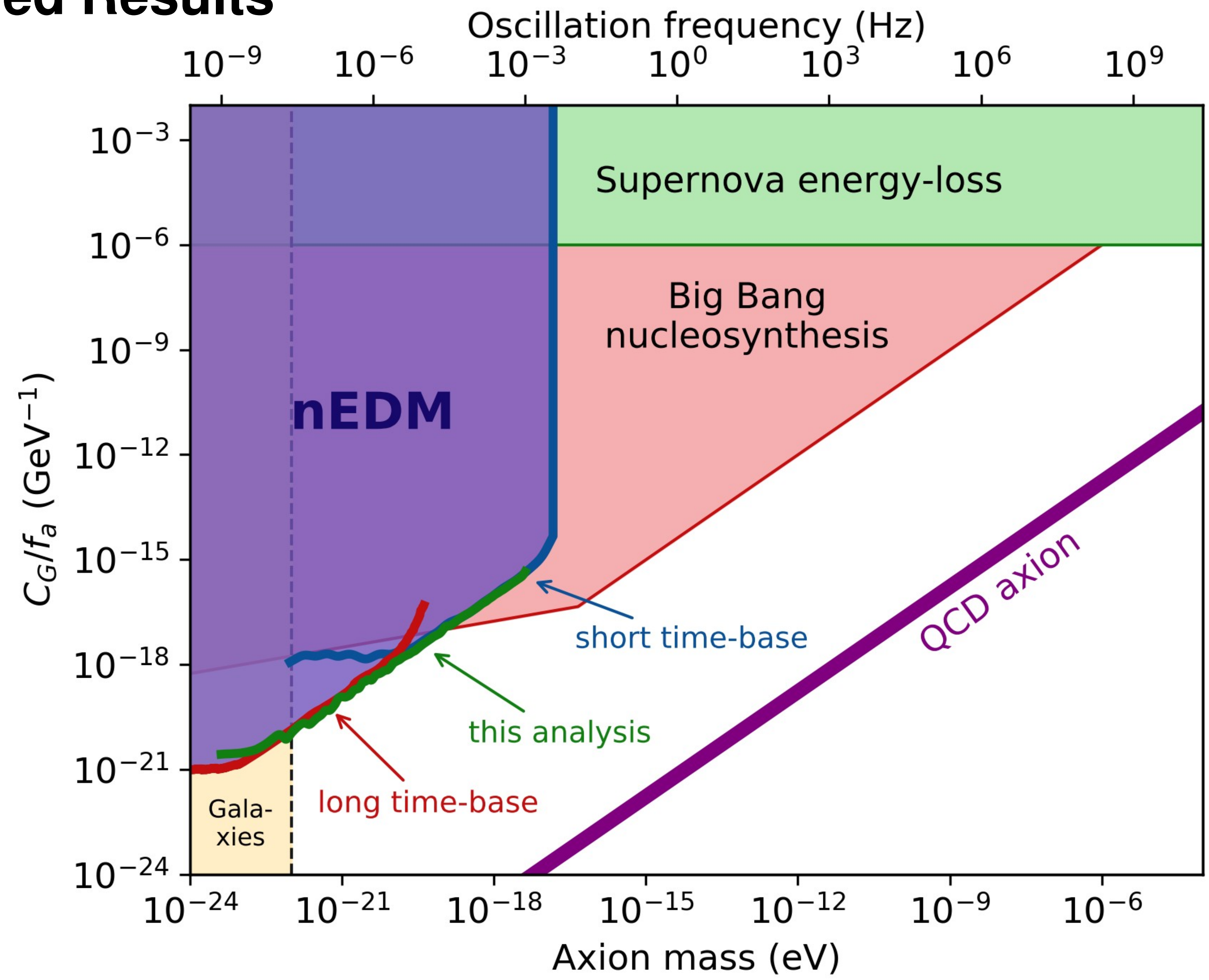
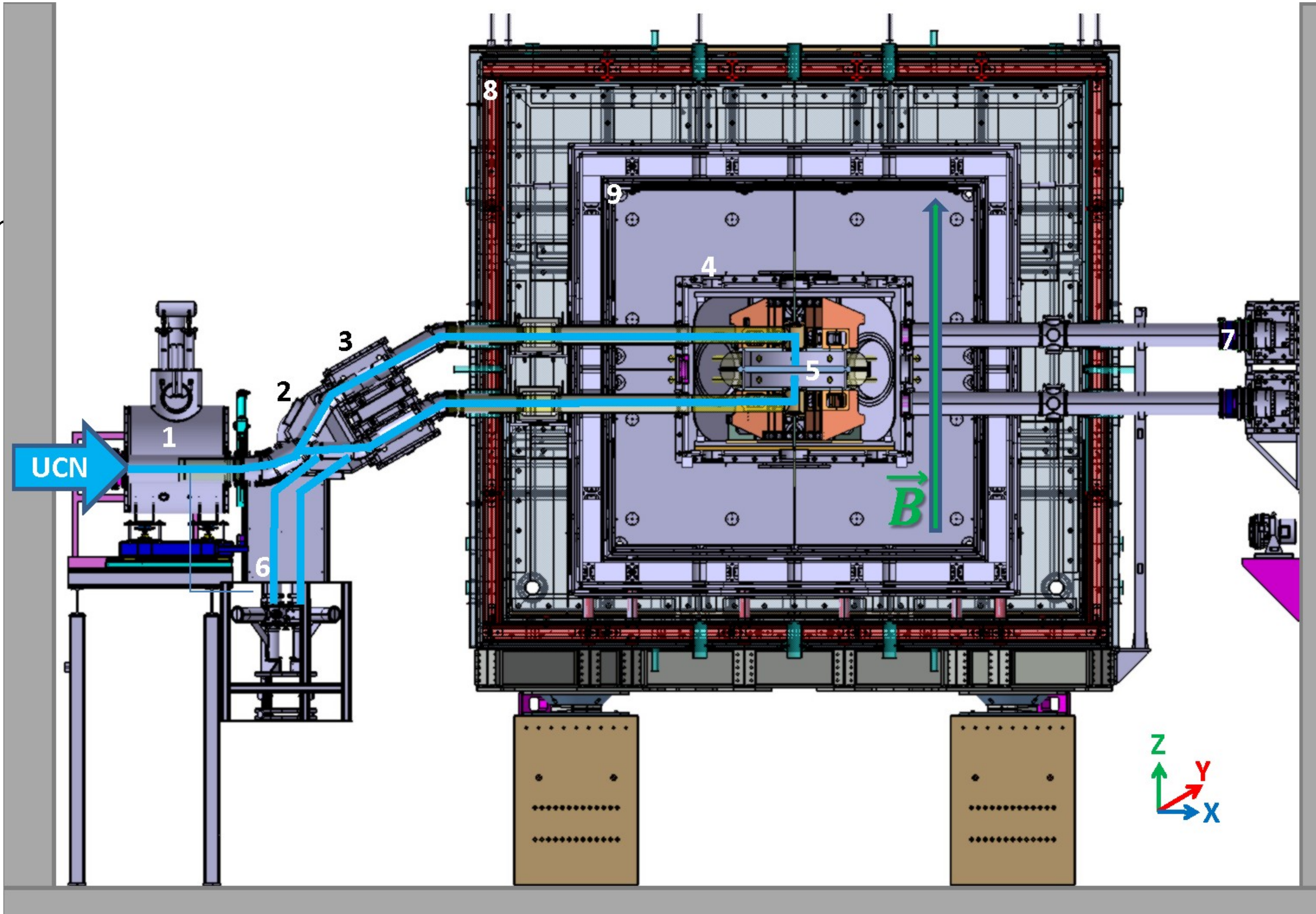


Outlook n2EDM

Apparatus improvements:

- 2 Chambers
  → EB ↑↑ and EB ↑↓ together
- Improved magnetometry

→ better gradient field measuremen



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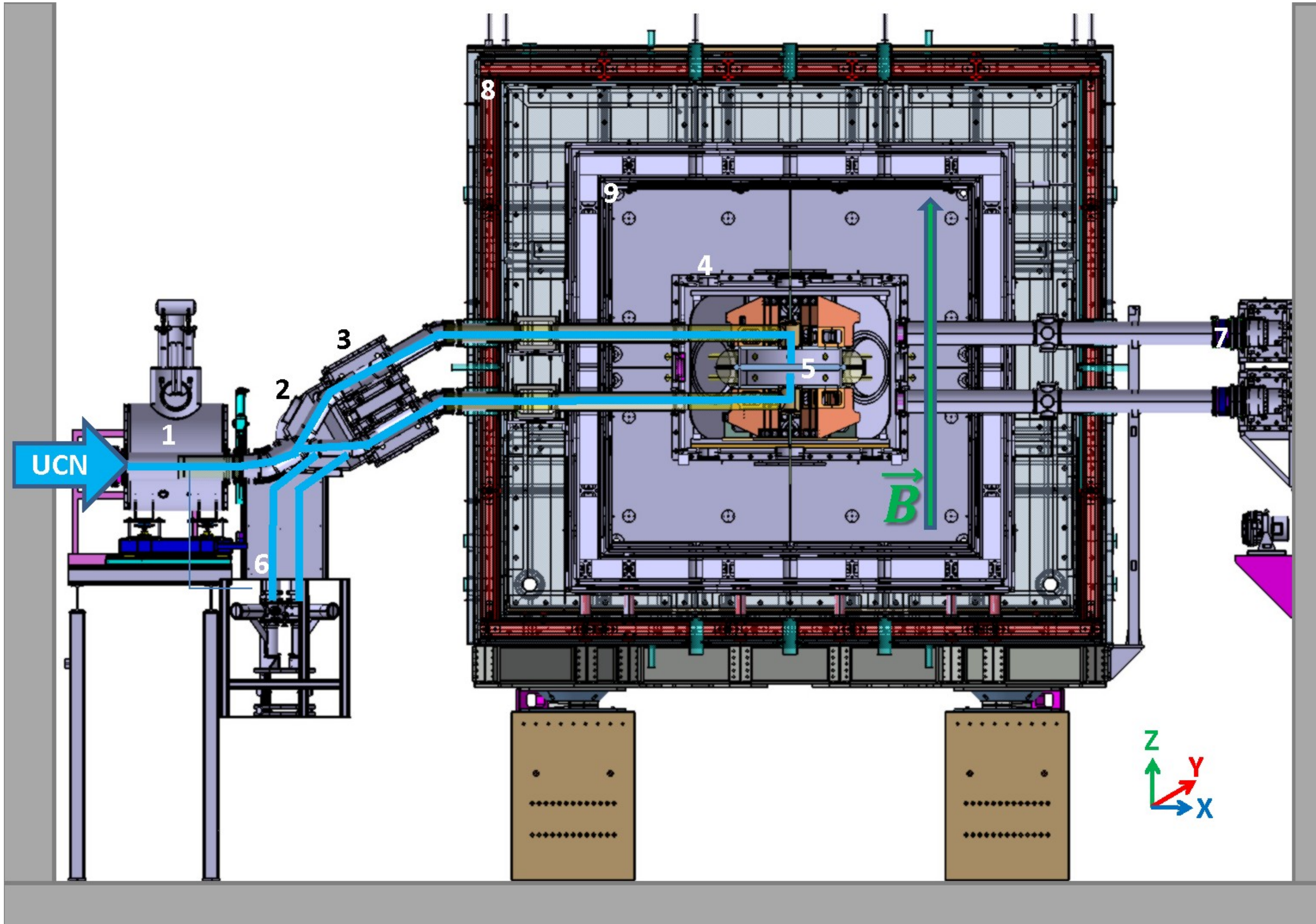
Statistical improvement:
- Bigger chambers
- Dynamic magnetic shielding
- …

Better overall nEDM sensitivity

=

Better axion sensitivity!



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Expect factor 10 overall improvement