Next measurement of the neutron's electric dipole moment: n2EDM at PSI

Efrain Segarra

ETH Zurich

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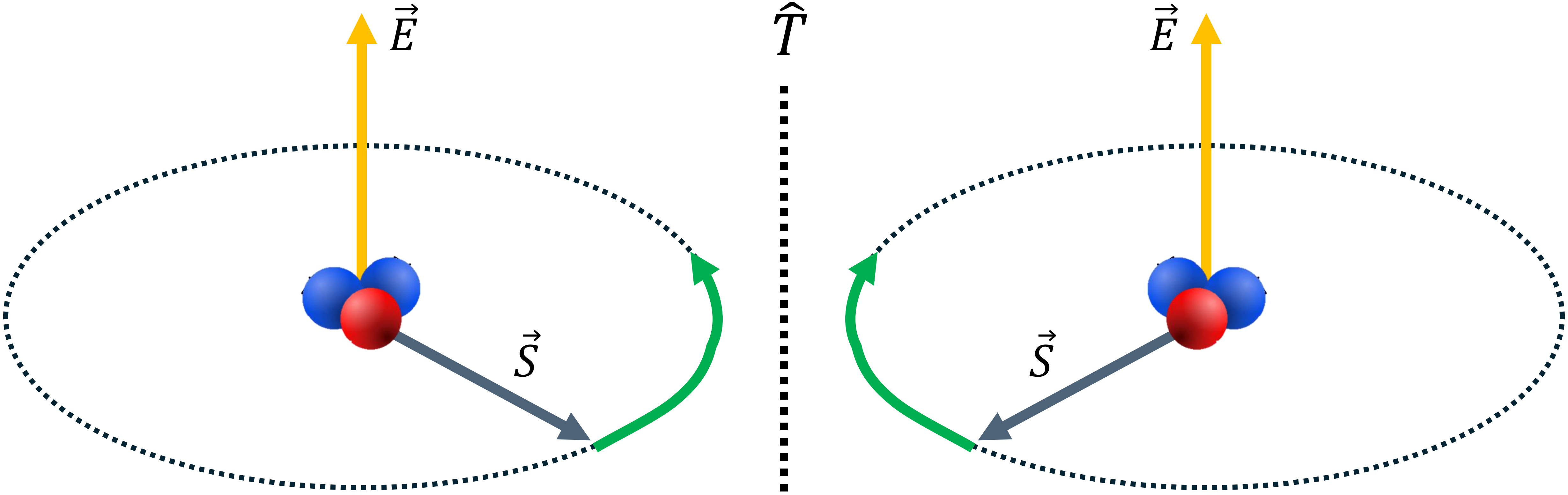
EDM ($\vec{S}$ and $\vec{E}$ coupling) violates **CP** symmetry



$$\hat{H} = -d\,\frac{\vec{S}}{S}\cdot\vec{E}$$

(T- and P-odd)

Neutron EDM tackles strong-CP problem and BSM

$|d_n^{\text{meas.}}| < 1.8 \cdot 10^{-26}\ e\ \text{cm} \quad [90\%\ \text{C. L.}]$

	$d_n^{\text{theory}}\ (e\ \text{cm})$
Electroweak	$\sim 10^{-30}$
QCD	$\bar{\theta}_{\text{QCD}}\ 10^{-16}$
BSM	$10^{-26} - 10^{-30}$

Look at many systems to disentangle “BSM”

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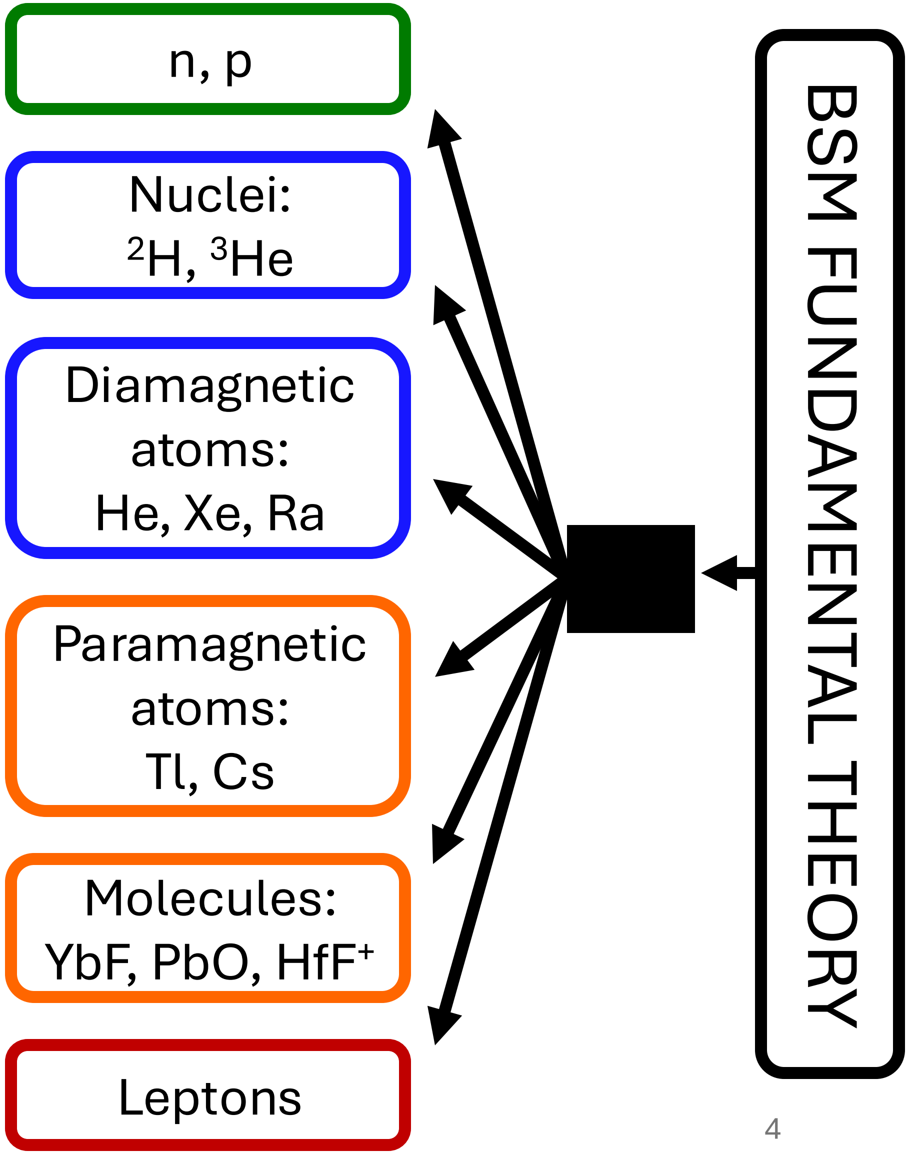
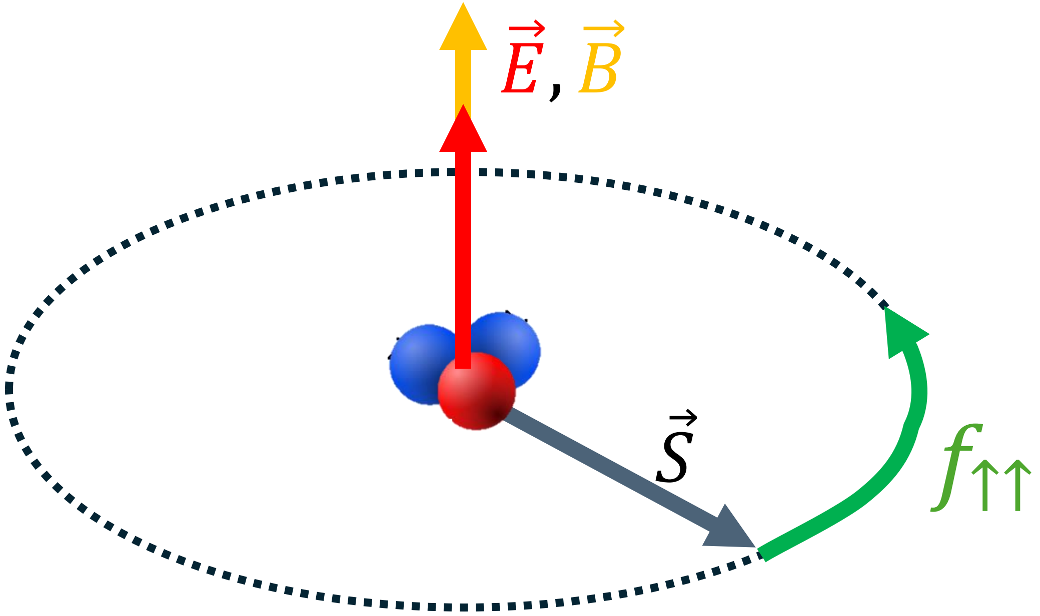


Measure the **difference** in resonance frequency



$$hf_{\uparrow\uparrow} = 2(\mu_n B + d_n E)$$

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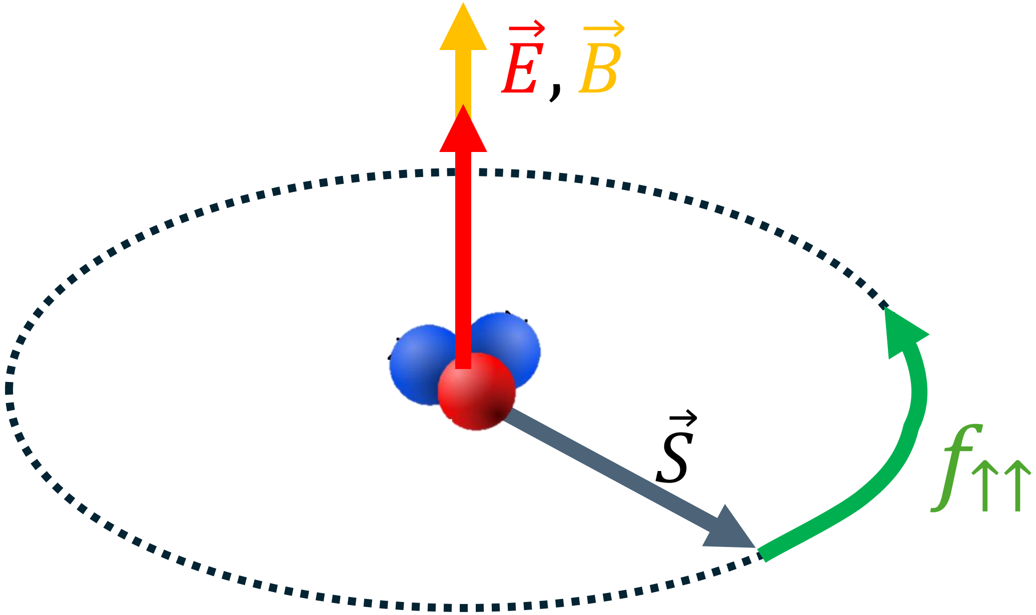
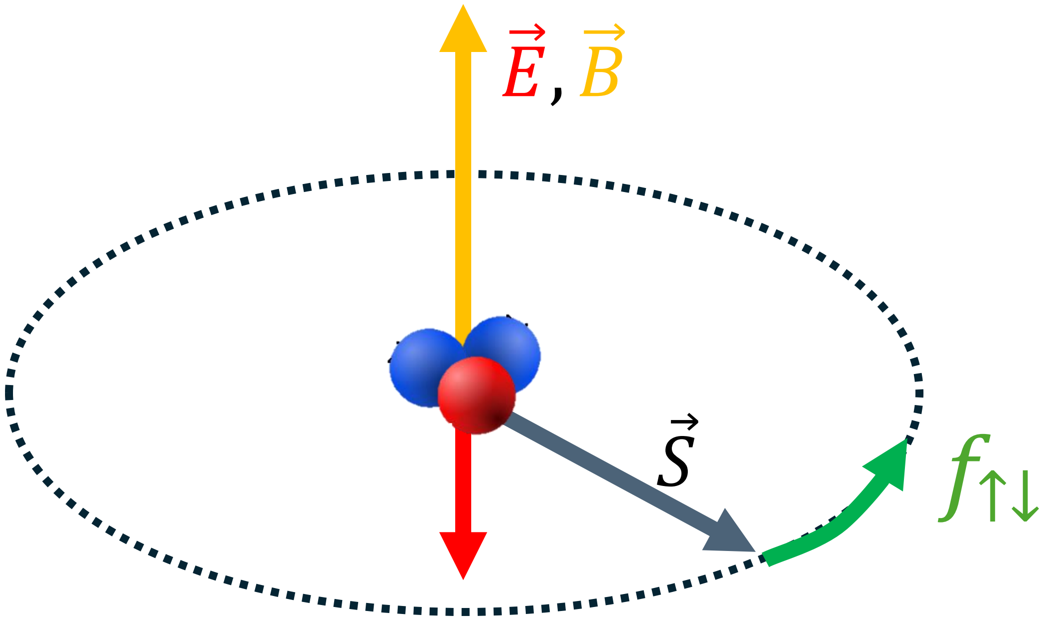


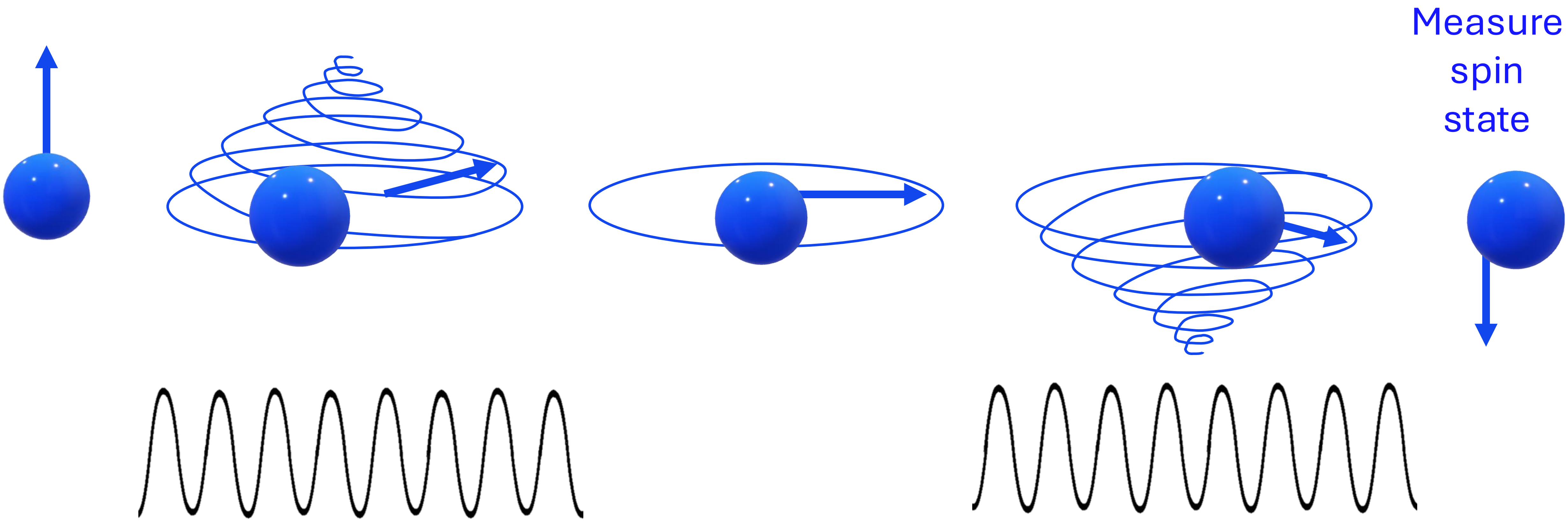


$$hf_{\uparrow\uparrow} = 2(\mu_n B + d_n E)$$

$$hf_{\uparrow\downarrow} = 2(\mu_n B - d_n E)$$

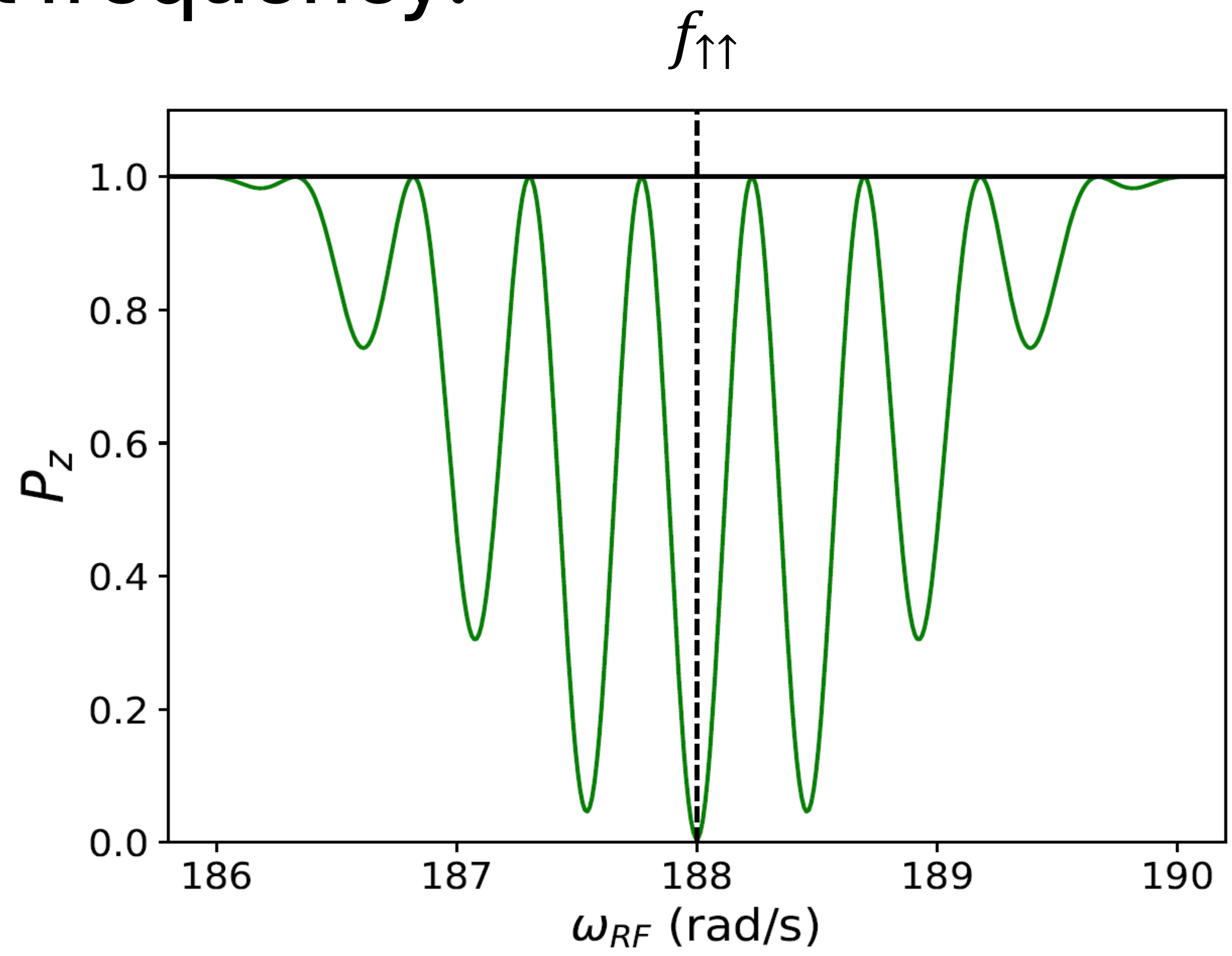
$$d_n = \frac{h}{4E}\Delta f$$

Using “Ramsey” method to extract resonance frequency

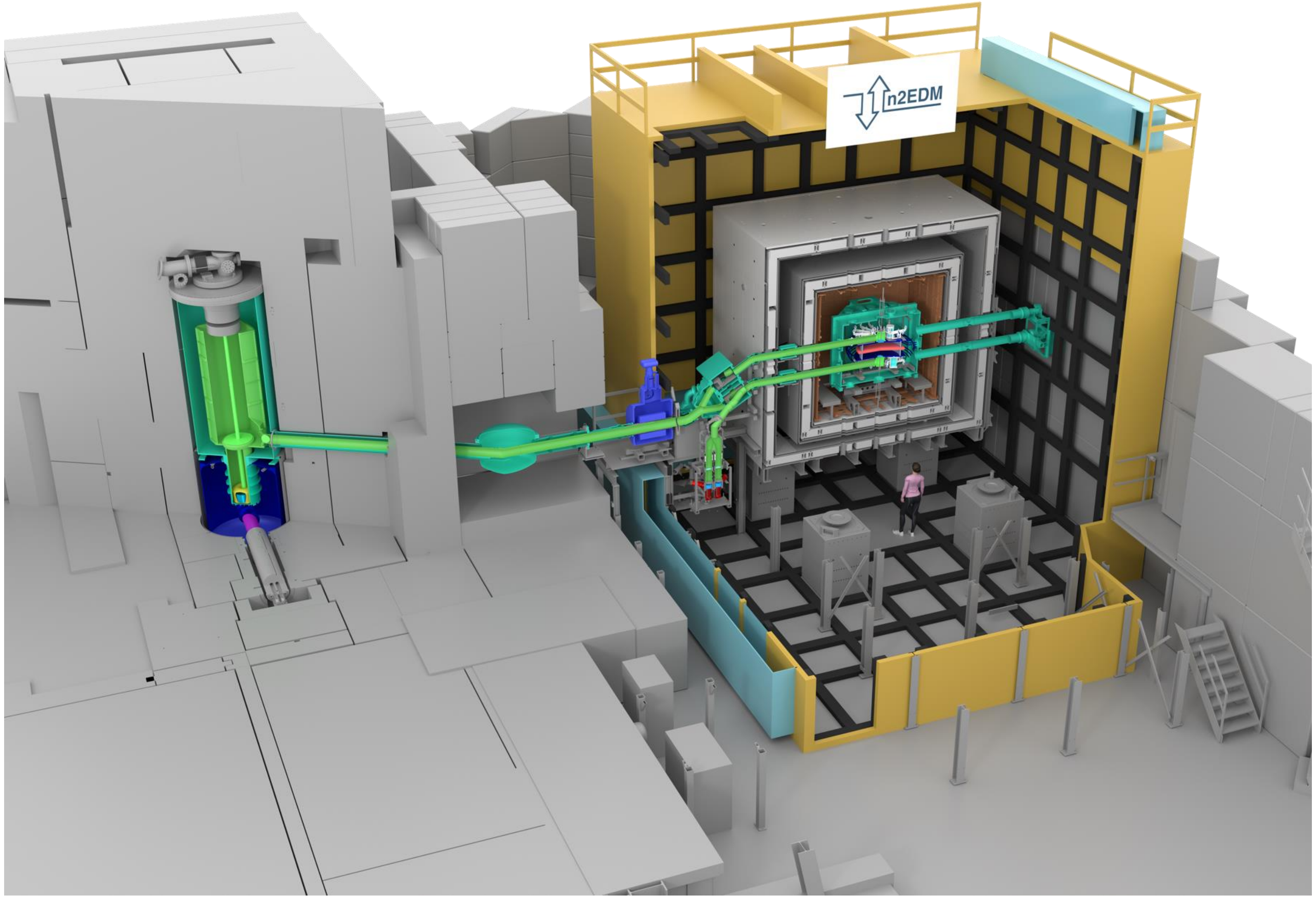


$B_\perp$ field

Frequency of spin-flip pulse is sensitive to resonant frequency!



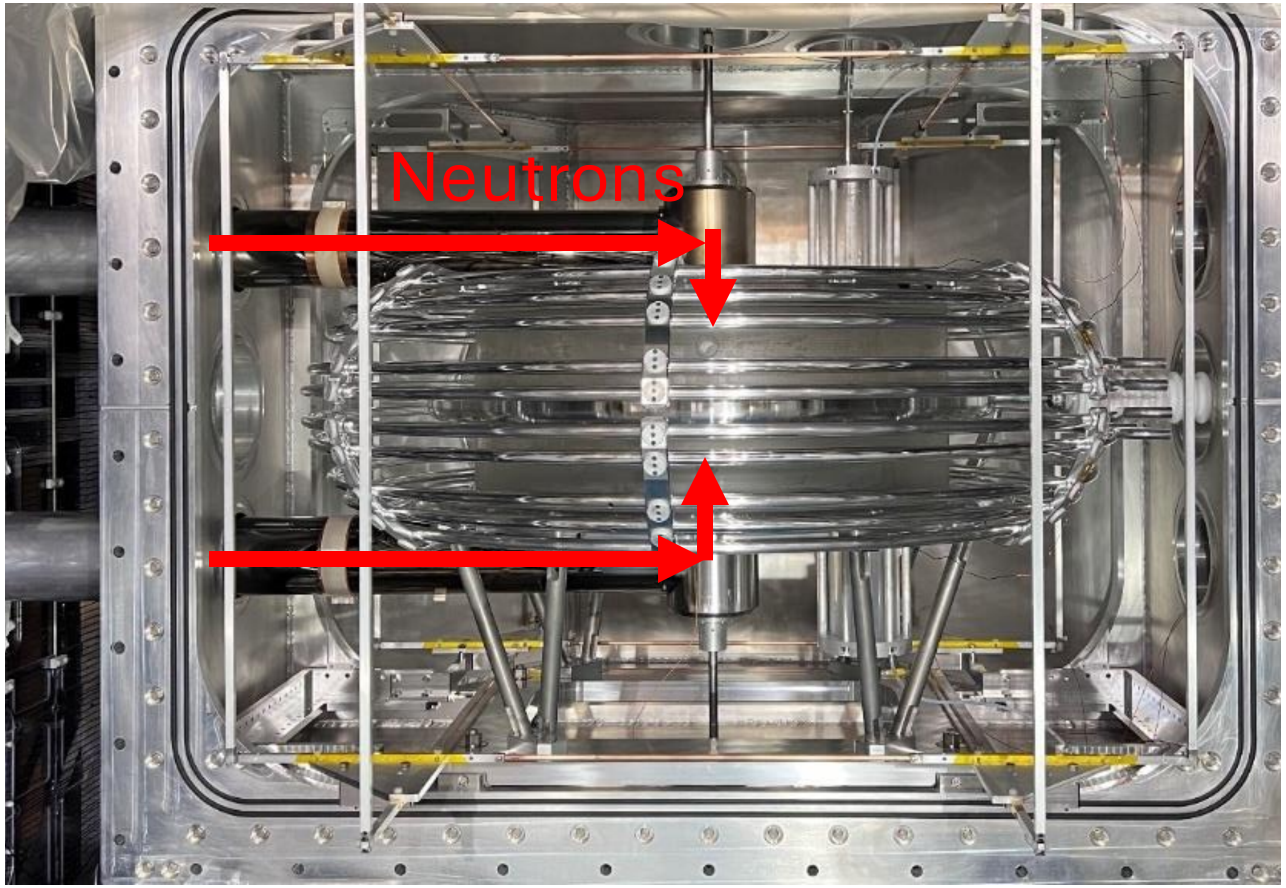
n2EDM Experiment at PSI

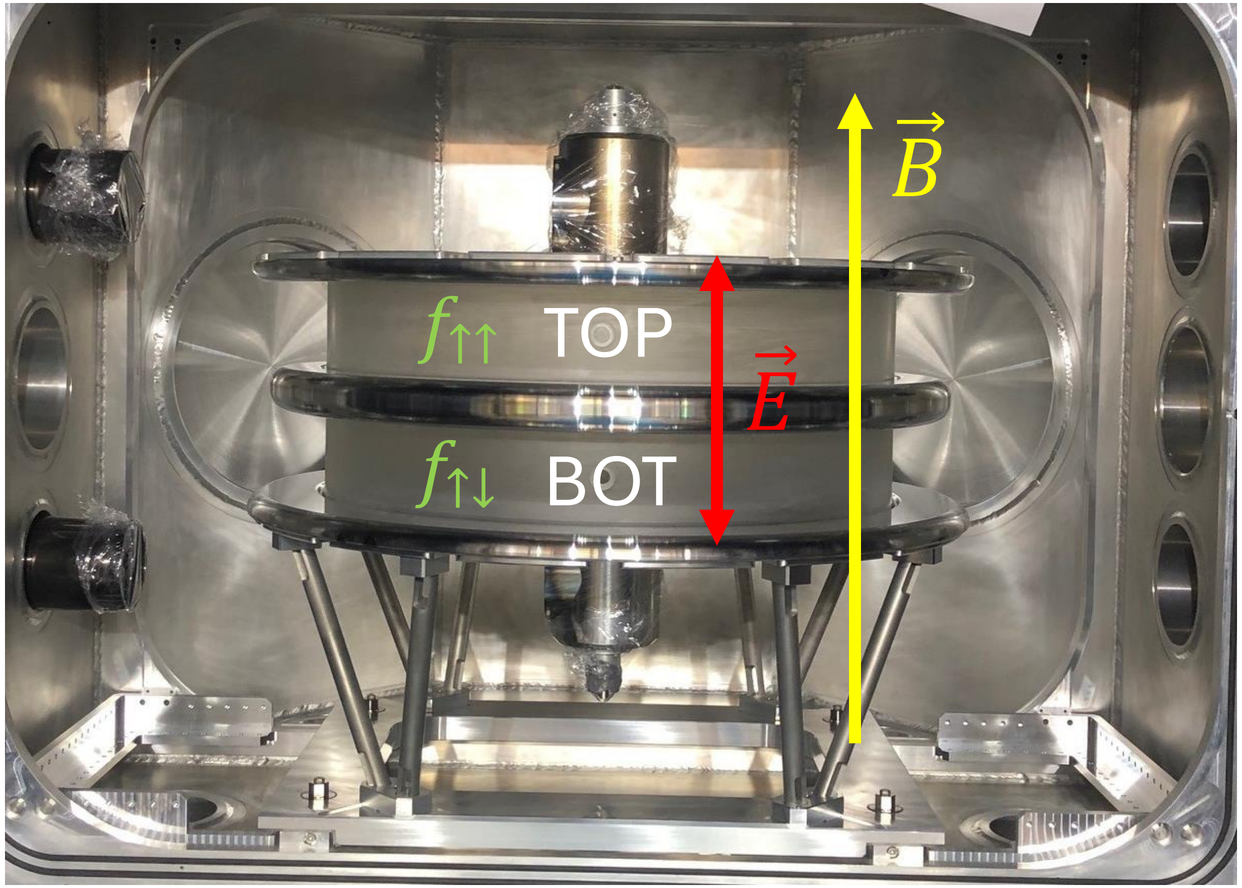


n2EDM Measurement Scheme

- Polarize *ultracold* neutrons (UCNs) → $\sim 300\text{neV}$
- Fill into storage chamber with $\vec{E}, \vec{B}$
- Perform a "***Ramsey cycle***"
- Measure spin state to extract $f_n^{\uparrow\uparrow}, f_n^{\uparrow\downarrow}$
- Repeat for years (statistics)! $\sigma(d_n) = \frac{\hbar}{2\,\alpha\,E\,T\,\sqrt{N_\uparrow + N_\downarrow}}$

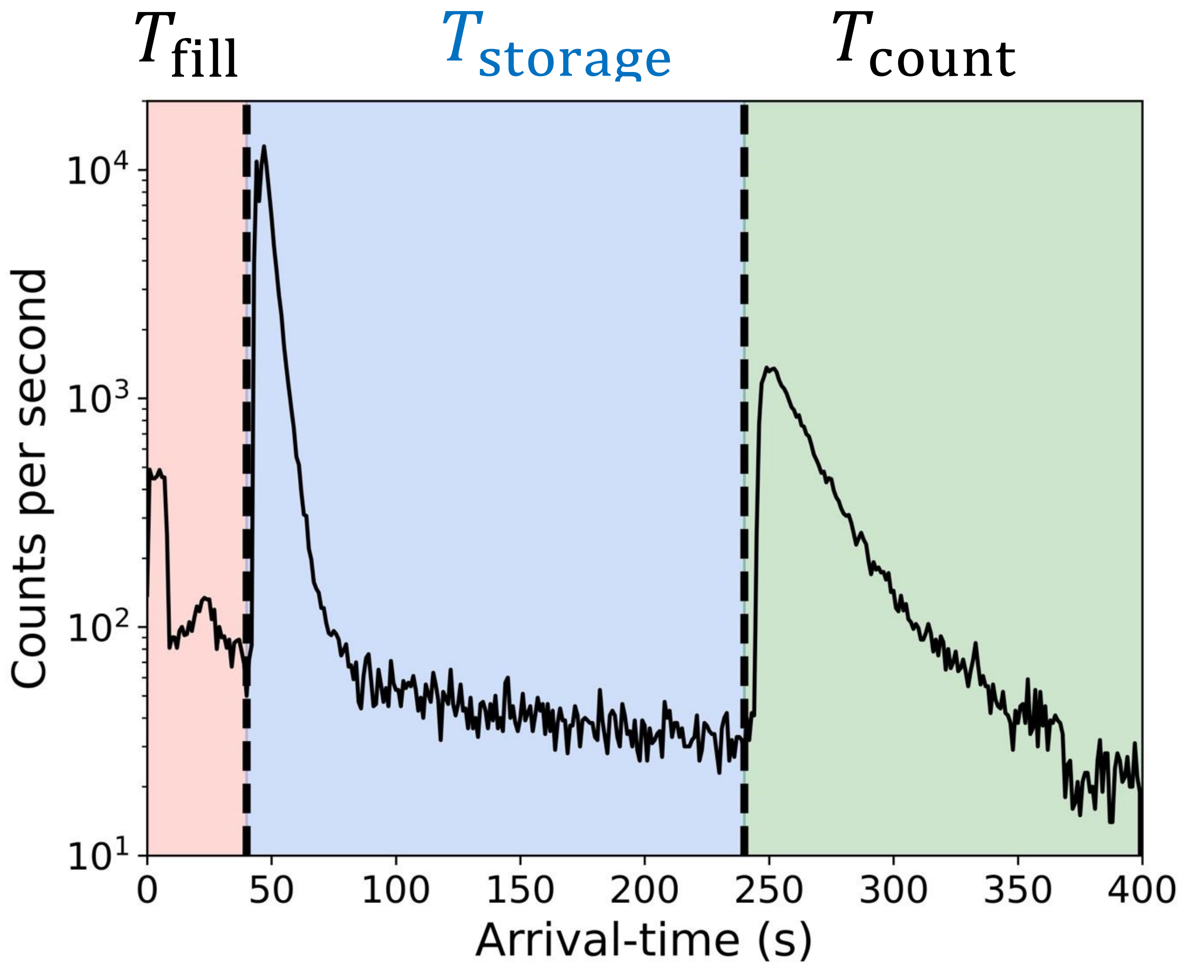
n2EDM Experiment: simultaneous f extraction



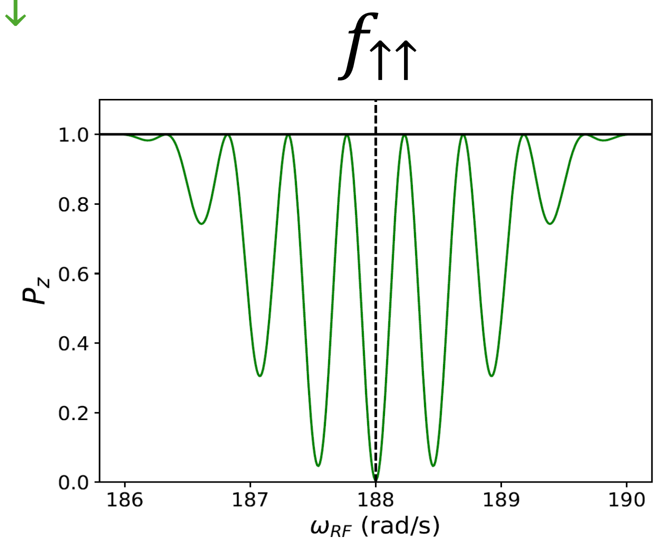


$$d_n = \frac{h}{4E}\Delta f \rightarrow \text{goal to improve sensitivity by 10x}$$

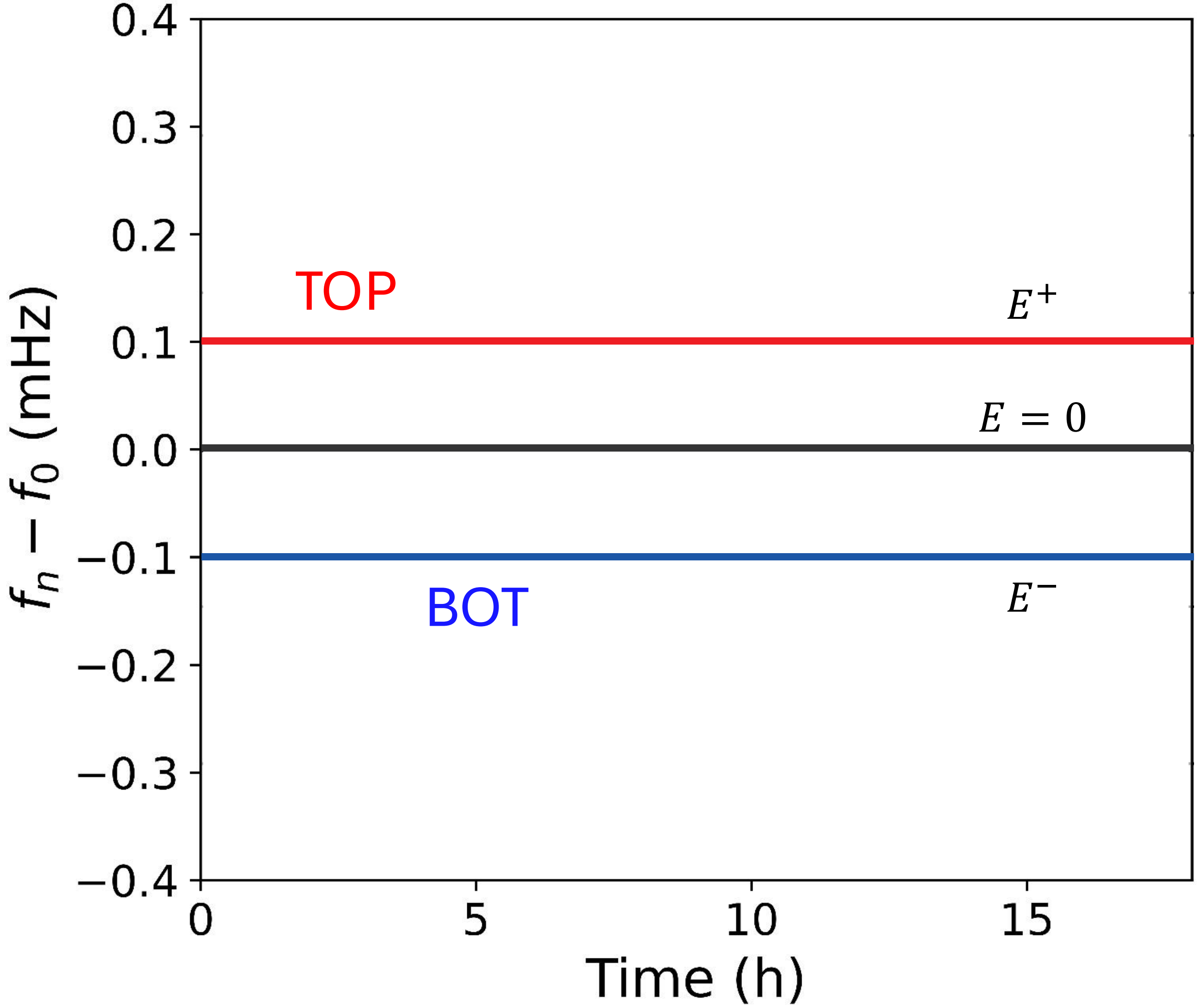
Typical measurement cycle of one spin-state



- Measure integral in green region
- Calculate spin-asymmetry
- Extract $f_n^{\uparrow\uparrow}, f_n^{\uparrow\downarrow}$
- Repeat!

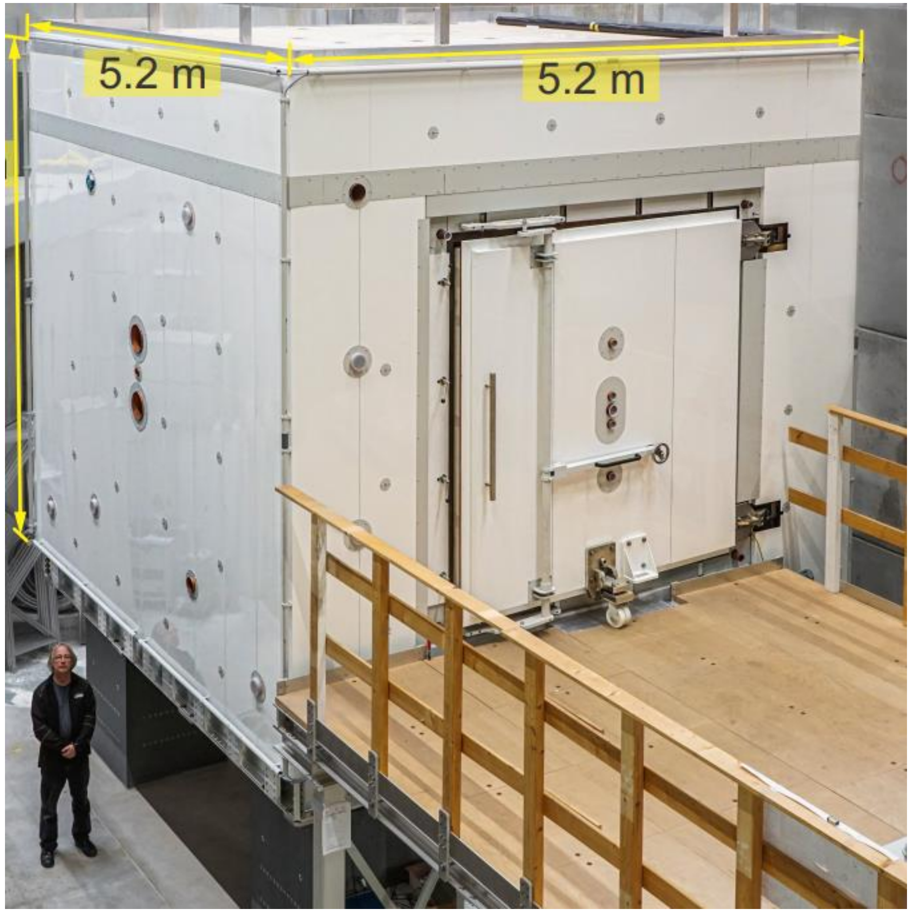


Extracting frequency over many cycles



$$f^{i} = \frac{2\mu_n}{h} B^{i} \pm \frac{2d_n}{h} E^{i}$$

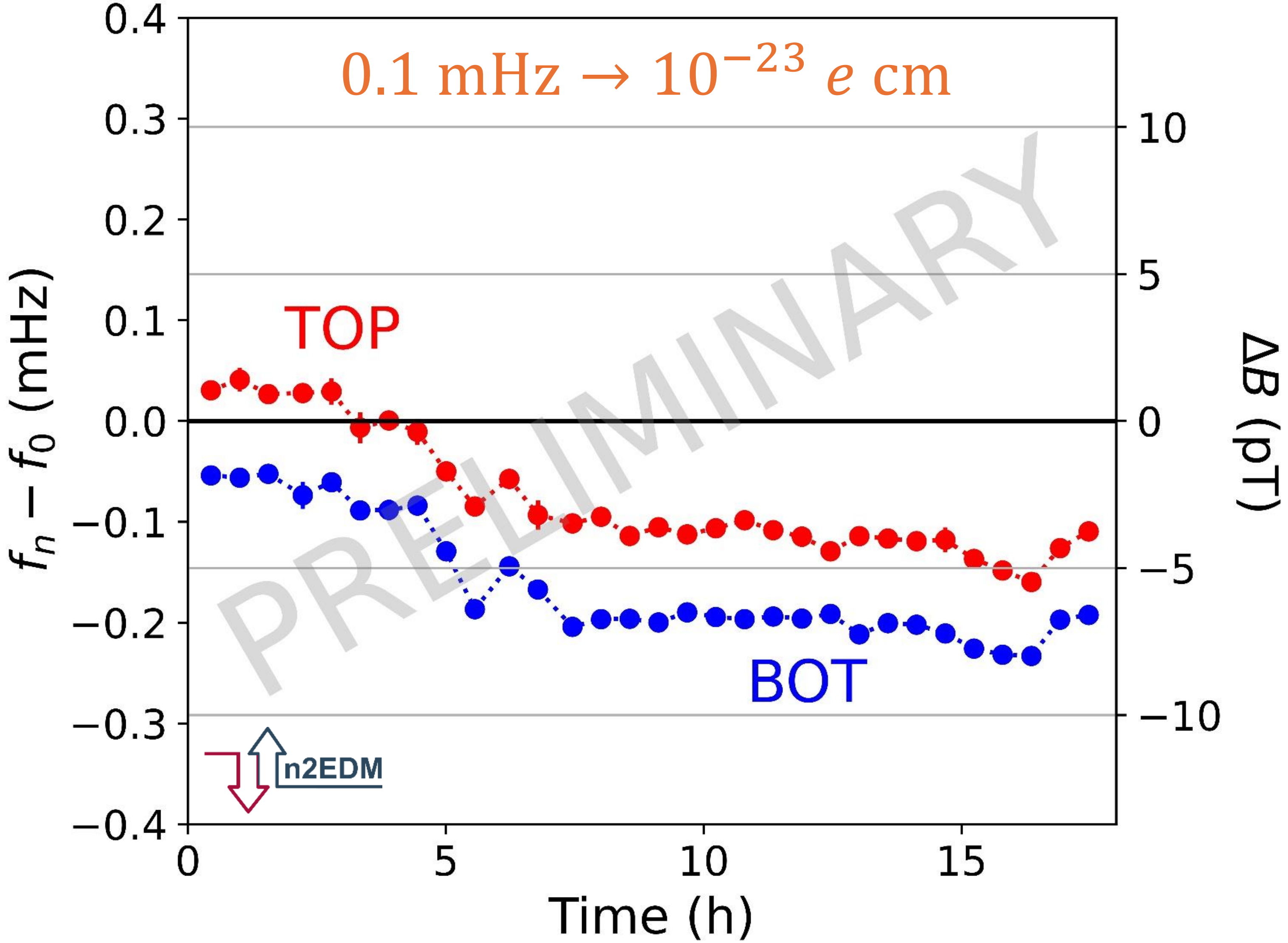
Controlling field drifts: active & passive shielding



Magnetically shielded room
$10^6 - 10^9$ shielding > 0.1 Hz

Active magnetic shield system
55km wire, kW power, mHz shielding

Despite best efforts, still see magnetic-field drifts



Instead of just using neutrons, we can sample the magnetic field with a **co-magnetometer**

$$R \equiv \frac{f}{f_{\mathrm{Hg}}} = \frac{\mu_n}{\mu_{\mathrm{Hg}}} \pm \frac{2E}{hf_{\mathrm{Hg}}} d_n$$

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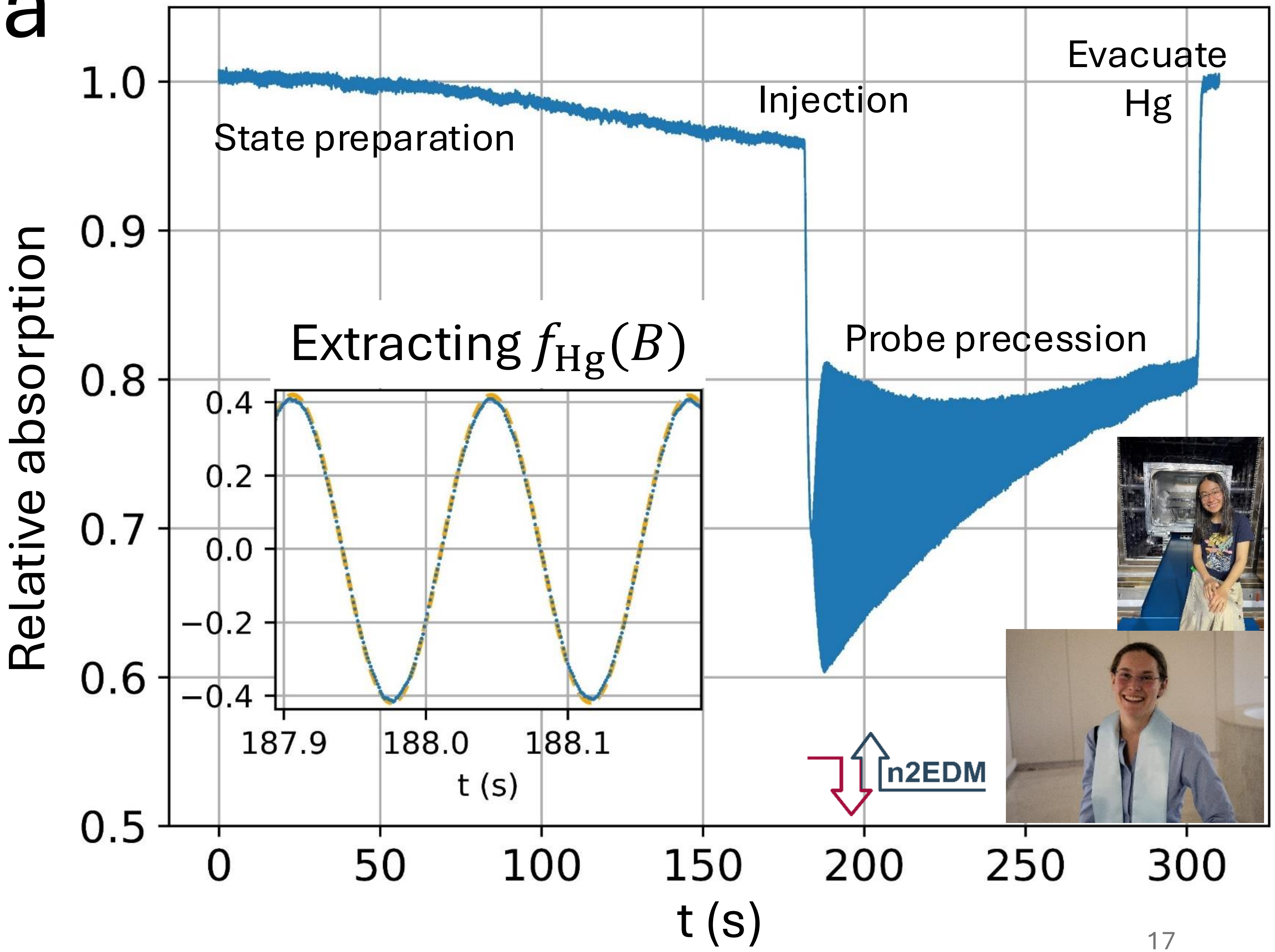


Status of n2EDM and getting to 10^{-27} e cm

Statistical requirements

Simultaneous measurement	$\lvert G_{1,0} \rvert < 0.6 \frac{\text{pT}}{\text{cm}}$
Depolarization	$\sigma(B_z) < 170$ pT
Precision of Hg	< 30 fT

Systematic requirements

Dipole (magnetic) contamination	< 5pT close to chamber
…	

Rev. Sci. Instrum. 1 September 2022; 93 (9): 095105. https://doi.org/10.1063/5.0101391

Eur. Phys. J. C **83**, 1061 (2023). https://doi.org/10.1140/epjc/s10052-023-12225-z

Eur. Phys. J. C **84**, 18 (2024). https://doi.org/10.1140/epjc/s10052-023-12351-8

Eur. Phys. J. C **85**, 202 (2025). https://doi.org/10.1140/epjc/s10052-025-13902-x

Statistical sensitivity achieved last year

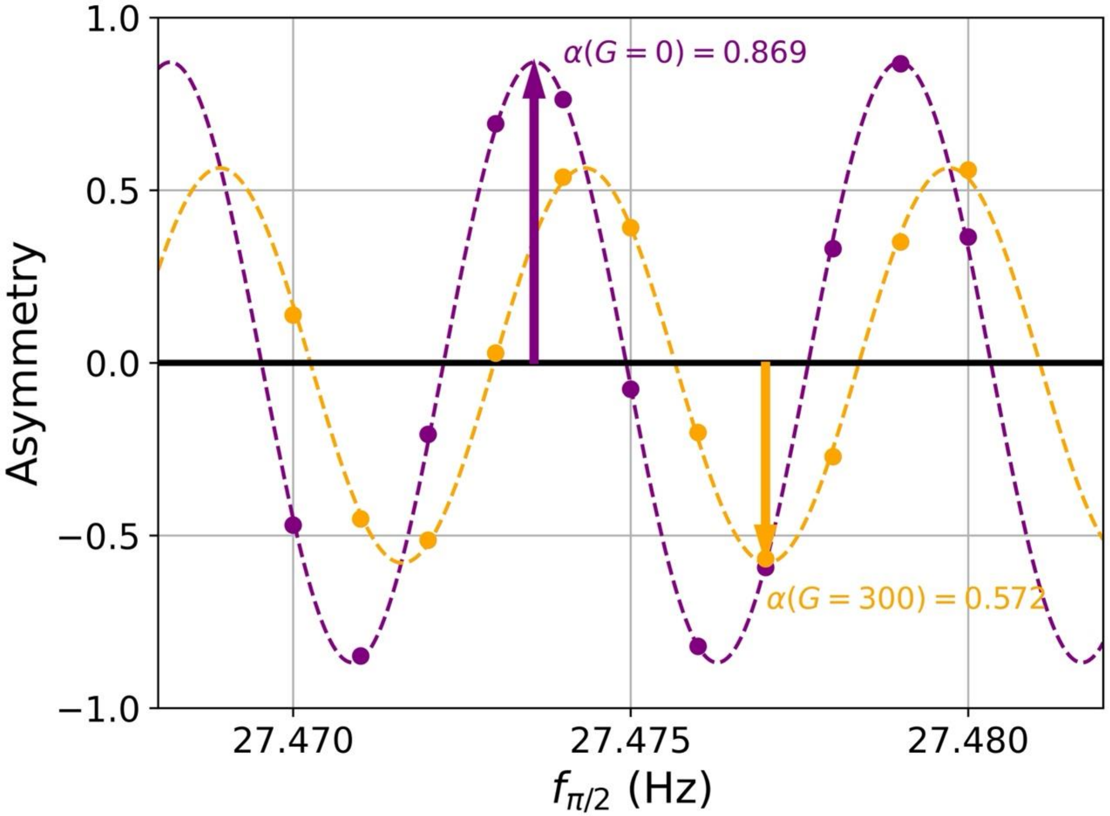
Achieved	Design
$\sigma_{\text{day}} = 4.4 \times 10^{-26}\ e\ \text{cm}$	$\sigma_{\text{day}} = 2.6 \times 10^{-26}\ e\ \text{cm}$
$E = 12.5\ \text{kV/cm}$	$E = 15\ \text{kV/cm}$
$\alpha = 0.84$	$\alpha = 0.80$
$N(T = 180) = 62\text{k}$	$N(T = 180) = 120k$

!!!

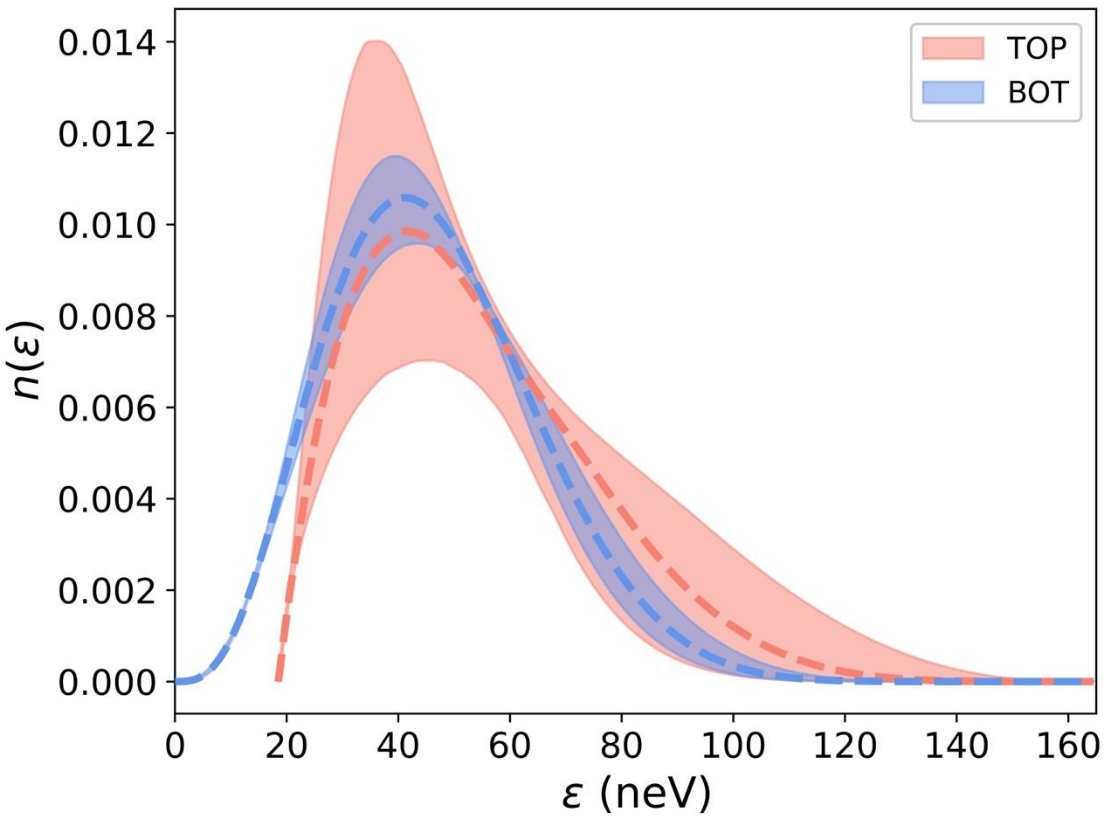
$$\sigma(d_n) = \frac{\hbar}{2\,\alpha\,E\,T\sqrt{N_\uparrow + N_\downarrow}}$$

New technique we just developed for systematics

Spin depolarization

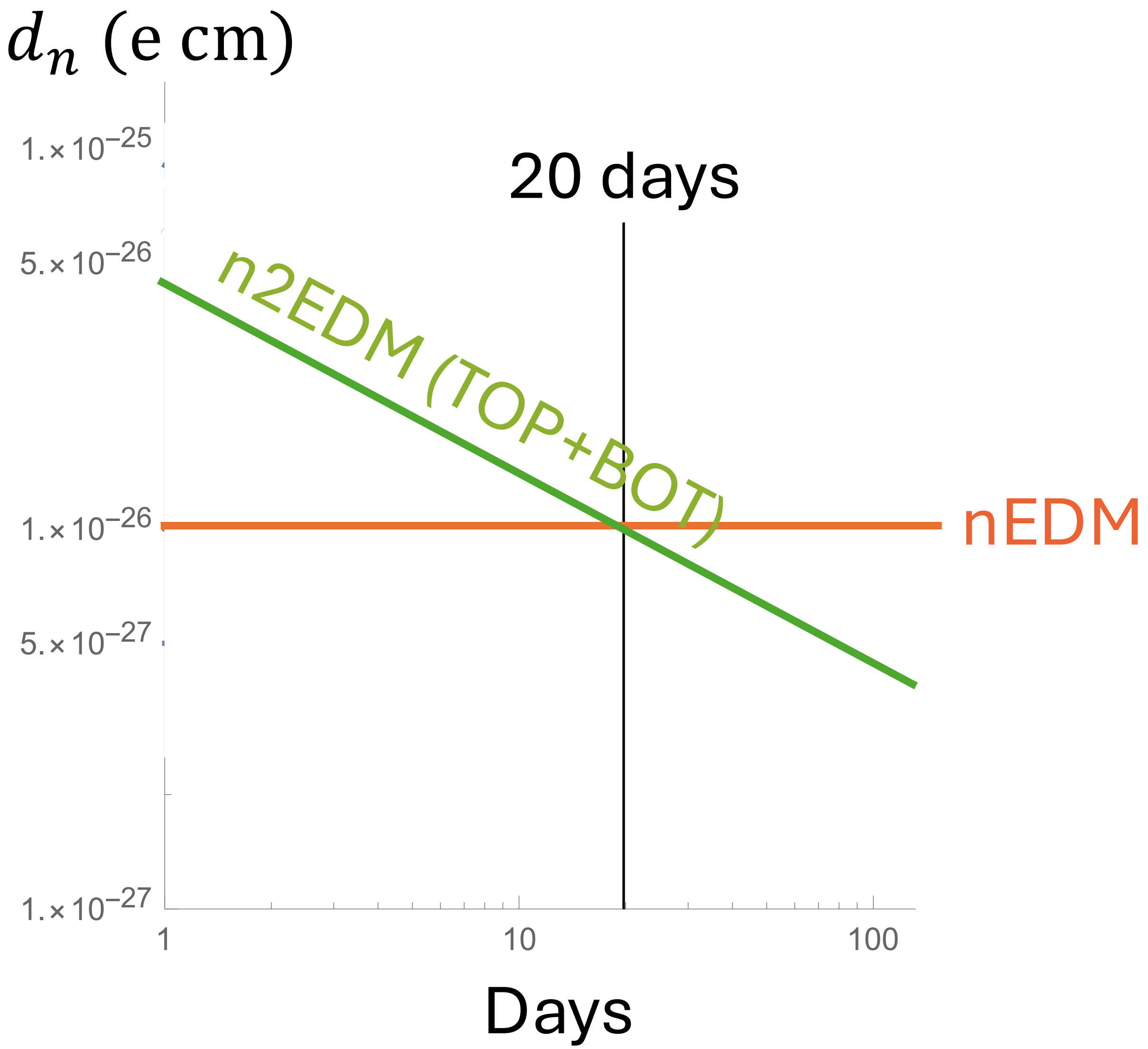


Neutron energy spectrum



Under collaboration review to submit to PRL

nEDM measurement starting soon!



<u>This year</u>: measure unblinded for 30 days for a first result with the new system with a statistical sensitivity $\sim 10^{-26}\ e\ \mathrm{cm}$

Thanks!

(on behalf of nEDM collaboration at PSI)

Efrain Segarra
ETH Zurich
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