New H-state lifetime measurement for the ACME electron EDM search

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DAMOP 2020
June 3, 2020

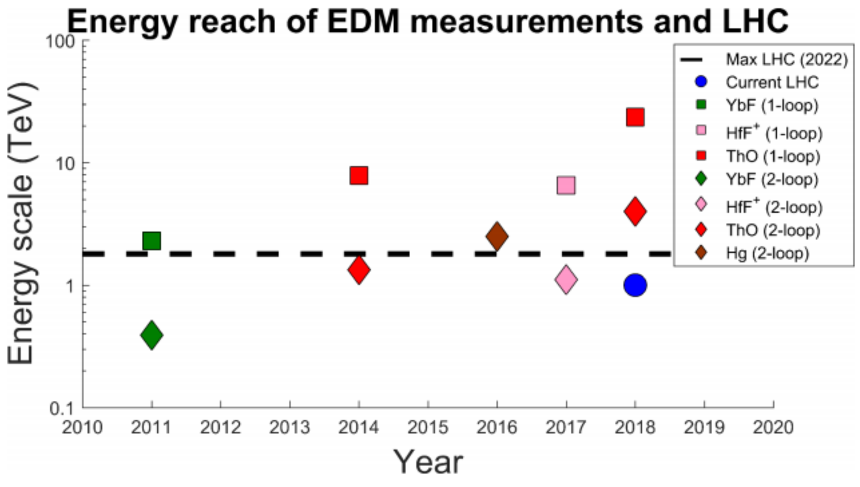
Theoretical motivations

- A non-zero electron EDM would be evidence of physics beyond the Standard Model
- Most stringent measurement of electron EDM (ACME II, 2018):

$$d_e = (-4.3 \pm 4.0) \times 10^{-30}\ \mathrm{e} \cdot \mathrm{cm}$$

$$|d_e| < 1.1 \times 10^{-29}\ \mathrm{e} \cdot \mathrm{cm}$$

- How can we improve this further?



Key EDM results since 2010. Two-loop sensitivity from Nakai & Reece (2017). One-loop sensitivity from Feng (2013). LHC scale gives stop mass sensitivity.

ACME experimental method

- Cryogenic buffer gas beam (CBGB) source of thorium monoxide (ThO)
- Transfer molecules from ground electronic state to EDM-sensitive (H, J=1) metastable state using optical pumping and STIRAP
- Prepare initial spin state, perform spin precession while applying electric and magnetic fields in the interaction region

$$\frac{1}{\sqrt{2}}(|-1\rangle + |+1\rangle) \longrightarrow \frac{1}{\sqrt{2}}(e^{i\phi}|-1\rangle + e^{-i\phi}|+1\rangle)$$

$$\frac{\phi}{\tau} = -(\tilde{\mathcal{B}} g_1 \mu_B \mathcal{B}_z + \tilde{\mathcal{N}} \tilde{\mathcal{E}} d_e \mathcal{E}_{eff})$$

- Measure phase by projecting spin-precessed state to a rapidly decaying excited state and detecting the decaying fluorescence

Significance of H-state lifetime

$$\delta d_e \propto \frac{1}{\tau E_{\text{eff}}\sqrt{\dot{n}T}}$$

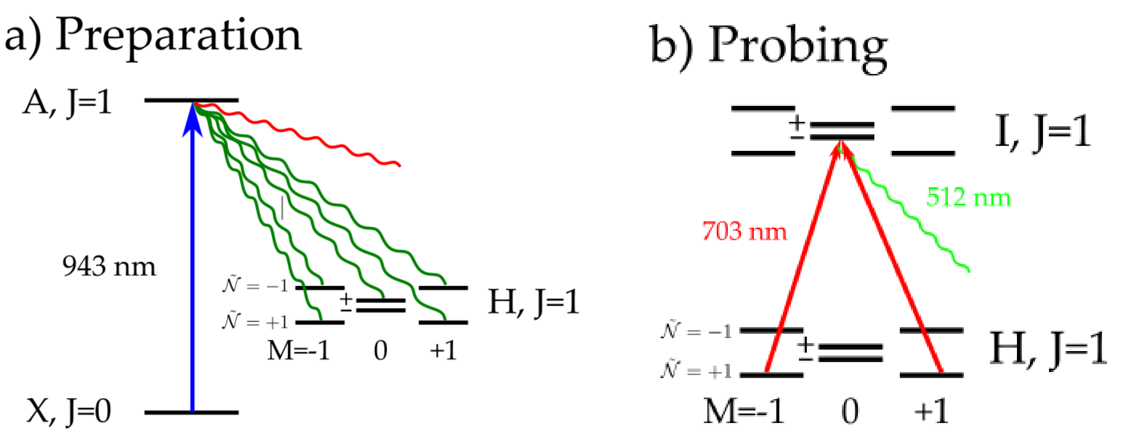
τ: precession time
E_{eff}: magnitude of effective electric field
$\dot{n}$: molecular flux
T: integration time

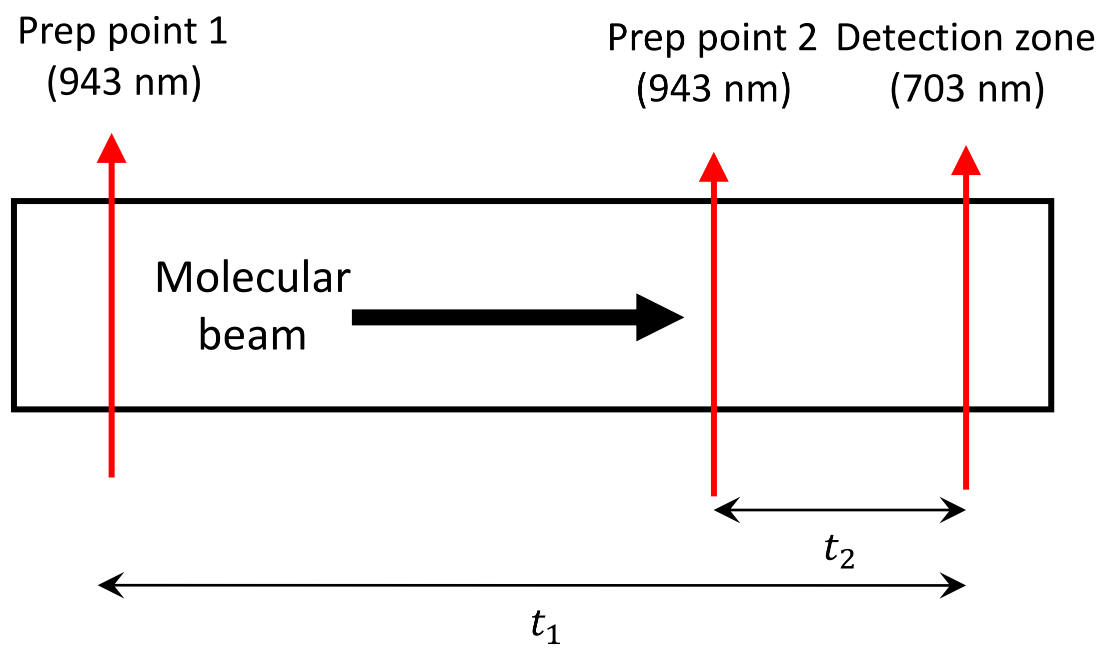
- τ is limited by the radiative decay from the H-state, which depends on its lifetime τ_H
- In ACME I and II, $\tau \approx 1\ \mathrm{ms}$ (20 cm precession region).
- Previous measurement of H-state lifetime (Vutha et al. 2009):
  $$\tau_H \geq 1.8\ \mathrm{ms}$$
- Goal: make more precise measurement to determine optimum τ

Measurement method

Basic principle:

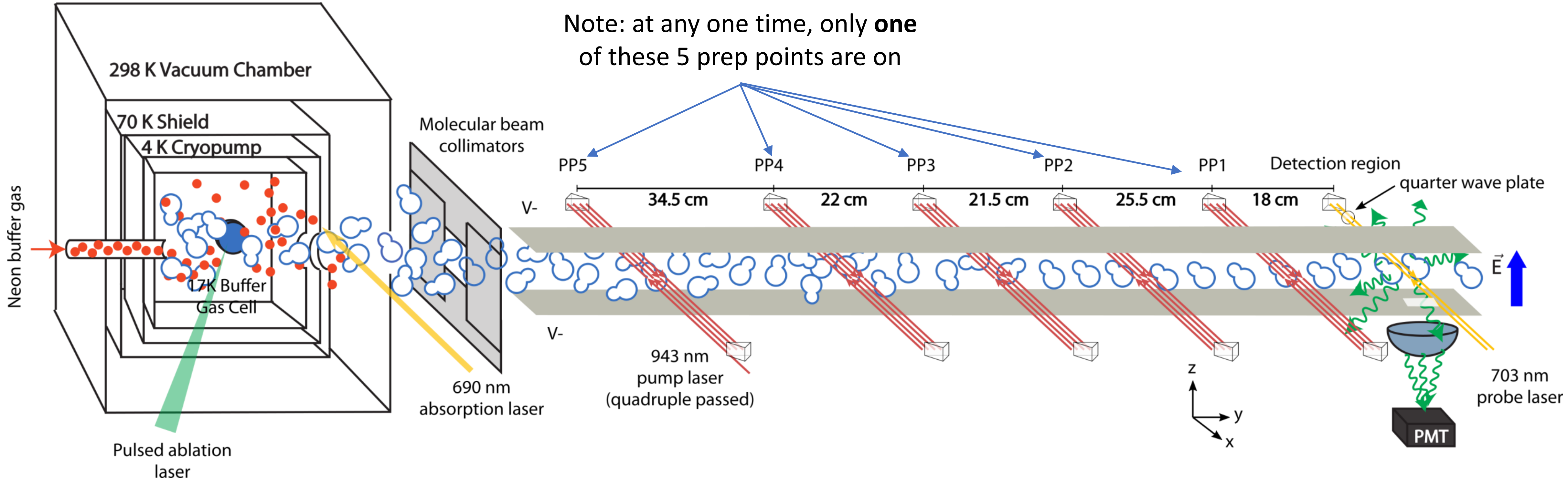
- Produce ThO molecules mostly in the ground (X, J=0) state.
- Transfer molecules into H-state via optical pumping at Prep 1
- Probe amount of remaining molecules at detection region, measure t_1
- Repeat with transfer at Prep 2
- Calculate ratio of signals and beam velocity
- Calculate lifetime τ





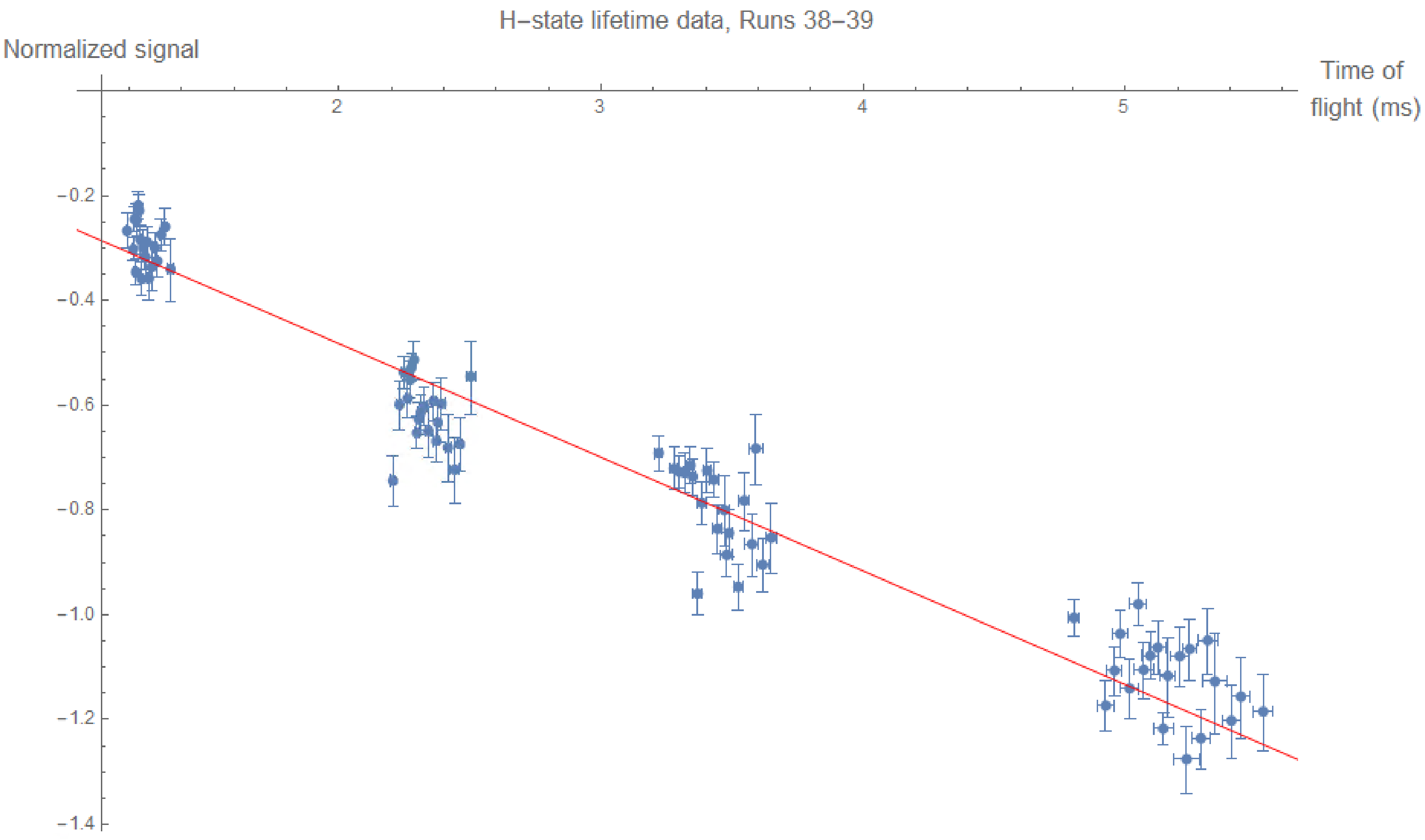
Measurement method

- Full setup: use 5 prep points, apply electric field throughout
- Quadruple passing of 943 nm laser to improve saturation



Results

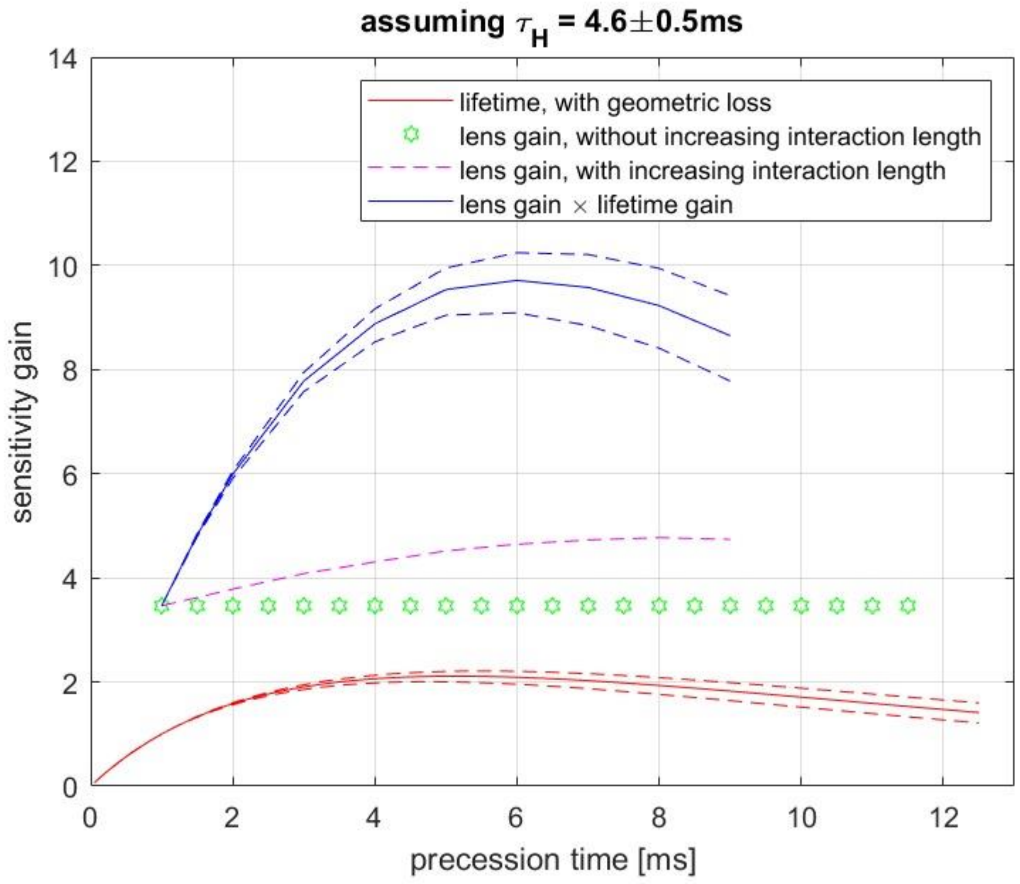
- Fitted lifetime: $\tau = 4.60(9)\ \mathrm{ms}$
- Main systematic error comes from **differences between prep points**, such as:
  - Differences in laser beam shape and size
  - Differences in laser alignment → different prep laser detunings
- These may affect saturation and thus signal size at each prep point



- No significant shifts from changing normalization scheme, using different sub-levels of H-state, etc.
- Planning experimentally quantify systematic errors more thoroughly
- Estimate of systematic error is around $\pm 0.5\ \mathrm{ms}$

Implications for the next generation of ACME

- $\tau_H \approx 4.6$ ms allows increase in precession time τ from 1 ms
  - Increase is limited by geometry and radiative decay
- However, an electric molecular lens is planned, which will allow a total of 10x EDM sensitivity gain
- See poster by X. Wu, **K01.00142:** Upgrading the ACME electron EDM search with a molecular lens



Summary & Conclusion

- Performed a new measurement of the EDM-sensitive H-state of ThO in a molecular beam, and obtained $\tau_H \approx 4.6\ \mathrm{ms}$
- Combined with molecular lens, this gives a projected 10x gain in EDM sensitivity
- Other improvements (SiPM detectors, timing jitter noise reduction) give further projected ~2.5x gain
- Clear path for order of magnitude improvement in measuring the electron EDM
- Currently designing and testing new interaction region with 5x longer precession region and other improvements to reduce systematic uncertainties

Thank you!

ACME collaboration

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Thanks to our funders:
National Science Foundation, Gordon & Betty Moore Foundation, Alfred P. Sloan Foundation