Electron EDM measurements in a beam of ThO:
Demonstrated and planned upgrades

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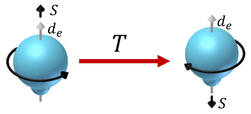
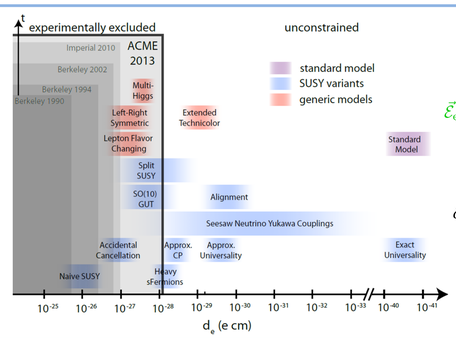
Motivation

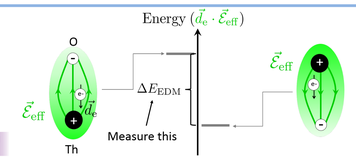
$$H_d = -\vec{d}_e \cdot \vec{\mathcal{E}}$$



Permanent EDMs violate T-symmetry

Many theories beyond the Standard Model predict T violation and EDMs at current experimental precision





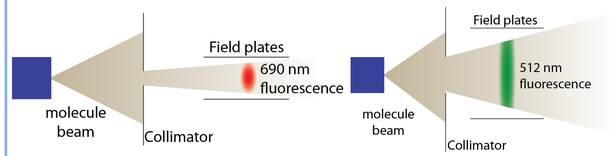
$$\delta d_e = \frac{\hbar}{2\mathcal{C}\tau\mathcal{E}_{\rm eff}\sqrt{\dot{n}T}}$$

$\mathcal{C}$ = measurement contrast
τ = coherence time
$\mathcal{E}_{\rm eff}$ = effective electric field
$\dot{n}$ = molecule flux
T = integration time

Large $\mathcal{E}_{eff}$ inside ThO molecule

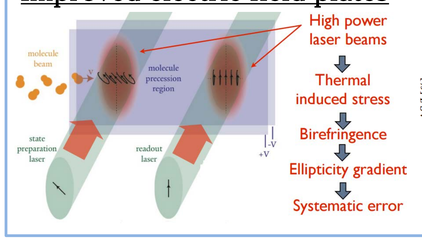
ACME II: Increase usable molecule flux ~100 ×
Reduces δd_e by ~10 ×

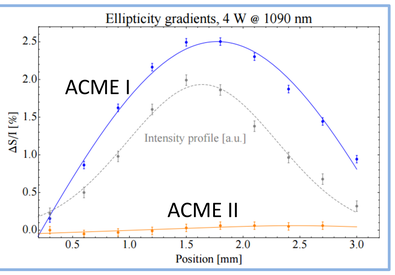
Solid angle enhancement



Shorter beamline and wider collimator spacing give **higher acceptance by ~8 ×**

Improved electric field plates



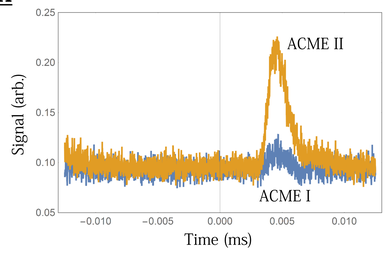


State Preparation

Preparation of spin precession state previously performed via optical pumping with ~6% efficiency

Coherent state preparation via STIRAP has ~75% demonstrated efficiency

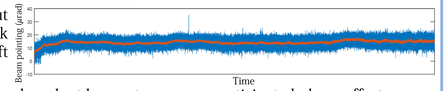
STIRAP gives ~12 × gain in state preparation



See poster "Twelve-fold increase in the number of usable ThO molecules for the ACME electron electric dipole measurement through STIRAP," Panda *et al.*

Refinement and readout beam control

Monitor and feed back on preparation and readout beam pointing to suppress anticipated Stark interference phase offset and relative Doppler shift between two readout beams



Also monitor and correct ellipticity in preparation and readout beams to suppress anticipated phase offset:

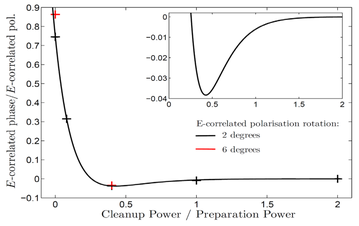
$$\Phi = \phi + \lambda\left(d\theta_{prep} - \frac{d\theta_X + d\theta_Y}{2}\right) - \lambda^2\bar{P}_{prep}\bar{P}_{read}d\Theta_{prep}(d\Theta_X - d\Theta_Y) + O(\lambda^3)$$

Measured phase — Desired phase — Linear polarization offsets — Prep/Read coupling via ellipticity

Refinement beam

STIRAP beam polarization fluctuations may lead to spurious EDM-like phase. Suppressed by "refinement" beam to re-project desired superposition state.

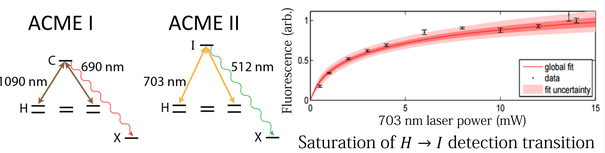
Refinement also suppresses anticipated AC Stark shift and Stark interference phases from high-intensity STIRAP lasers



Detection wavelength

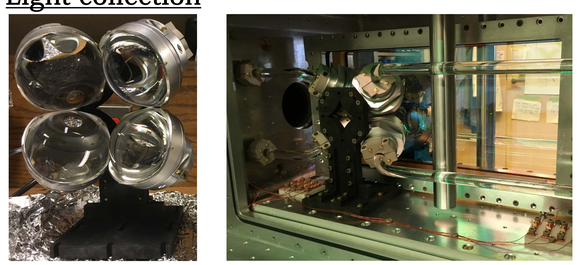
PMTs detect 512 nm with **~2.5 × efficiency** of 690 nm detection used in ACME I

Detecting 512 nm fluorescence suppresses effect of scattered light from 690 nm STIRAP laser



Saturation of $H \rightarrow I$ detection transition

Light collection



Optimized collection optics using light pipes instead of fiber bundles with ~50% packing fraction increases detection by **~2.5 ×**

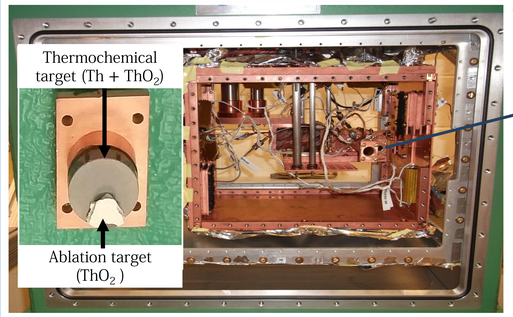
Summary of upgrades

Demonstrated upgrades	Gain
Beamline geometry	~8 ×
Fluorescence collection	~2.5 ×
STIRAP state preparation	~12 ×
Detection wavelength	~2.5 ×
Total projected statistical improvement	**300 −600 ×**

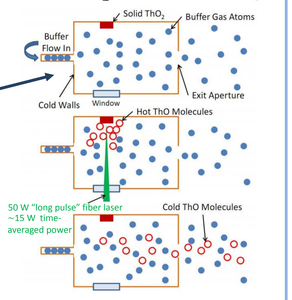
Not yet demonstrated with spin precession measurement

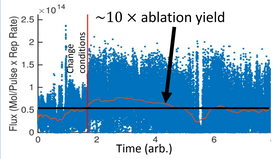
Feature	Anticipated systematic error improvement
Refinement beam	Suppress STIRAP polarization fluctuations, AC Stark shifts, AC Stark interference
Reduced field plates birefringence	Suppress ellipticity gradients
Beam pointing	Monitor and feed back to reduce Stark interference
Ellipticity control	Monitor and feed back to reduce phase offsets
Modified apparatus for magnetometry	Measure non-reversing magnetic field near spin precession region to suppress AC Stark shift phases

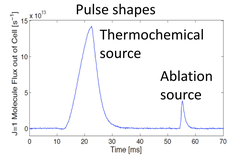
Thermochemical Beam Source

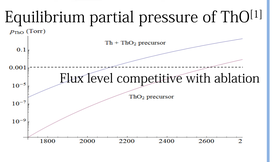


$$Th(s) + ThO_2(s) \xrightarrow{\text{Heat}} 2ThO(g)$$



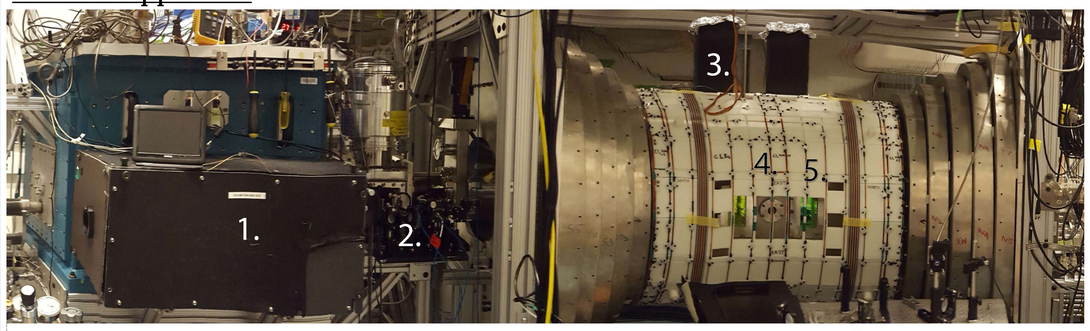


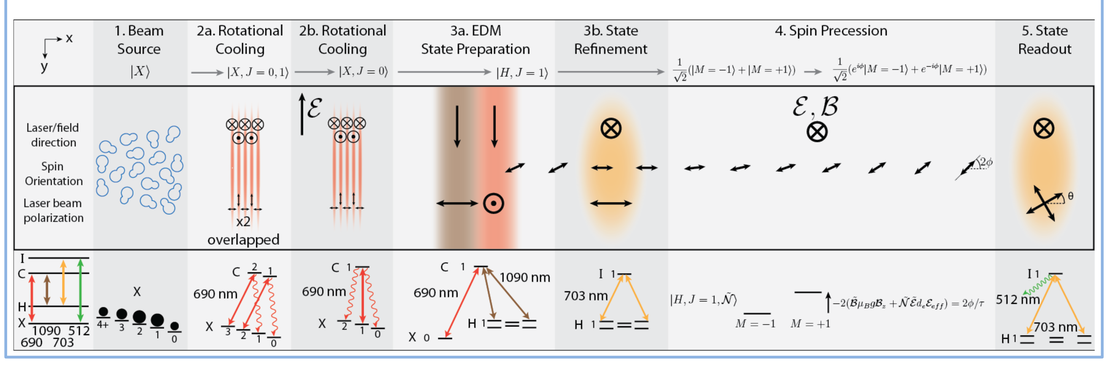




Still under development; anticipate ~10 × flux beyond ACME II

ACME II Apparatus





References

More information: www.electronedm.info

1. "A thermodynamic study of the thorium-oxygen system at high temperatures." R.J. Ackermann et al. *J. Phys. Chem.* **67(4)**, p. 762-769 (1963)

ACME I Result: "Order of magnitude smaller limit on the electric dipole moment of the electron." ACME Collaboration. *Science* **343**, p. 269-272 (2014)
State preparation: "Stimulated Raman adiabatic passage preparation of a coherent superposition of ThO $H^3\Delta_1$ states for an improved electron electric-dipole moment measurement." C.D. Panda et al. Phys. Rev. A **93**, 052110 (2016)

Previous eEDM Limit: "Improved measurement of the shape of the electron." J. J. Hudson et al. *Nature* **473**, 7348 (2011)
$E_{\rm eff}$ Calculations: "Theoretical study of ThO for the electron electric dipole moment search." L. V. Skripnikov et al. *J. Chem. Phys.* **142** 024301 (2015)
"Electron electric dipole moment and hyperfine interaction constants for ThO" T. Fleig et al. *J. Mol. Spec.* **300** p. 16-21 (2014)