ThO Electron EDM Search: Statistics Update and Understanding Systematic Errors

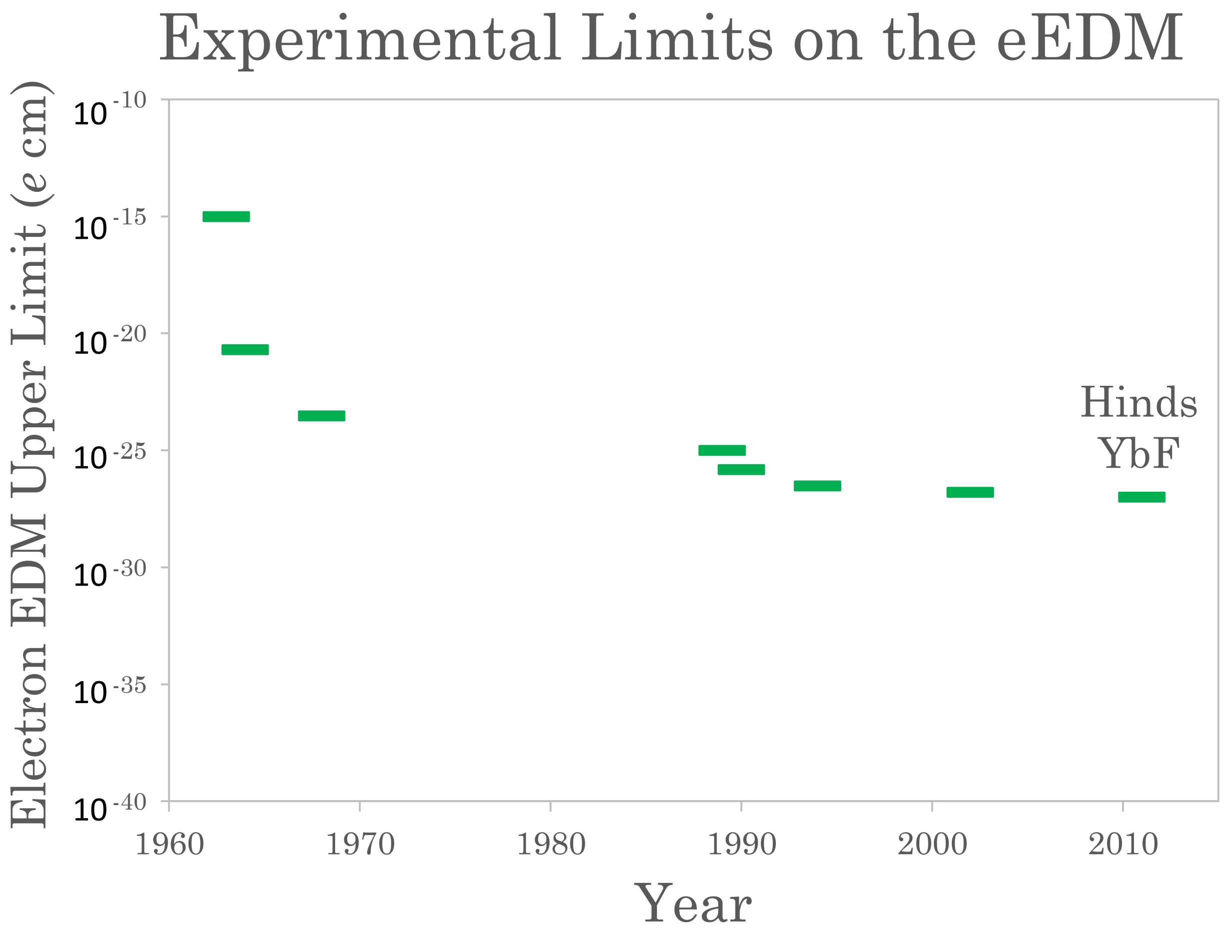
Elizabeth Petrik

Advisor: John Doyle

ACME Collaboration, Harvard University

April 23, 2013, CUA 10 minute talk

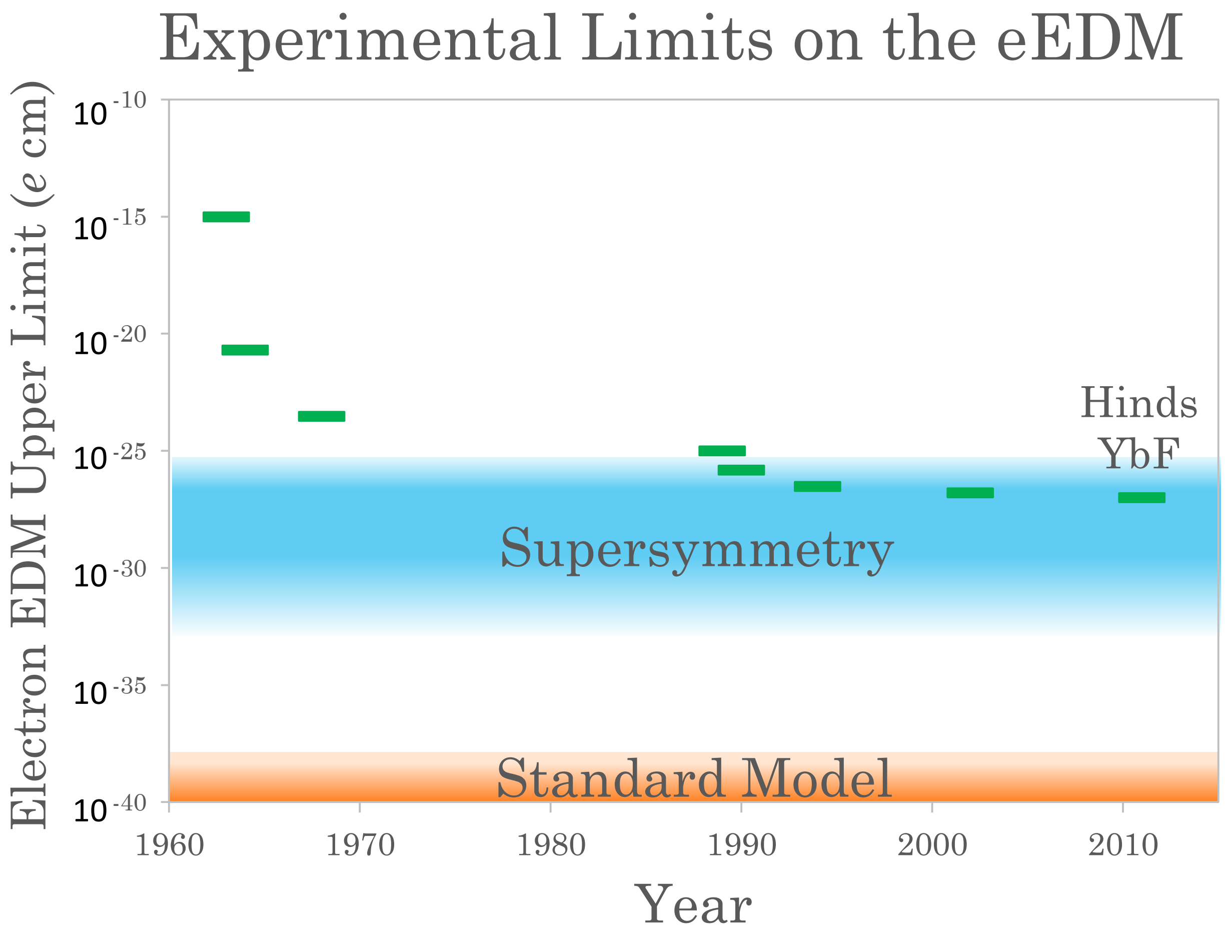
Motivation for eEDM Search



Data compiled by Amar Vutha

Motivation for eEDM Search

- Permanent EDMs violate CP



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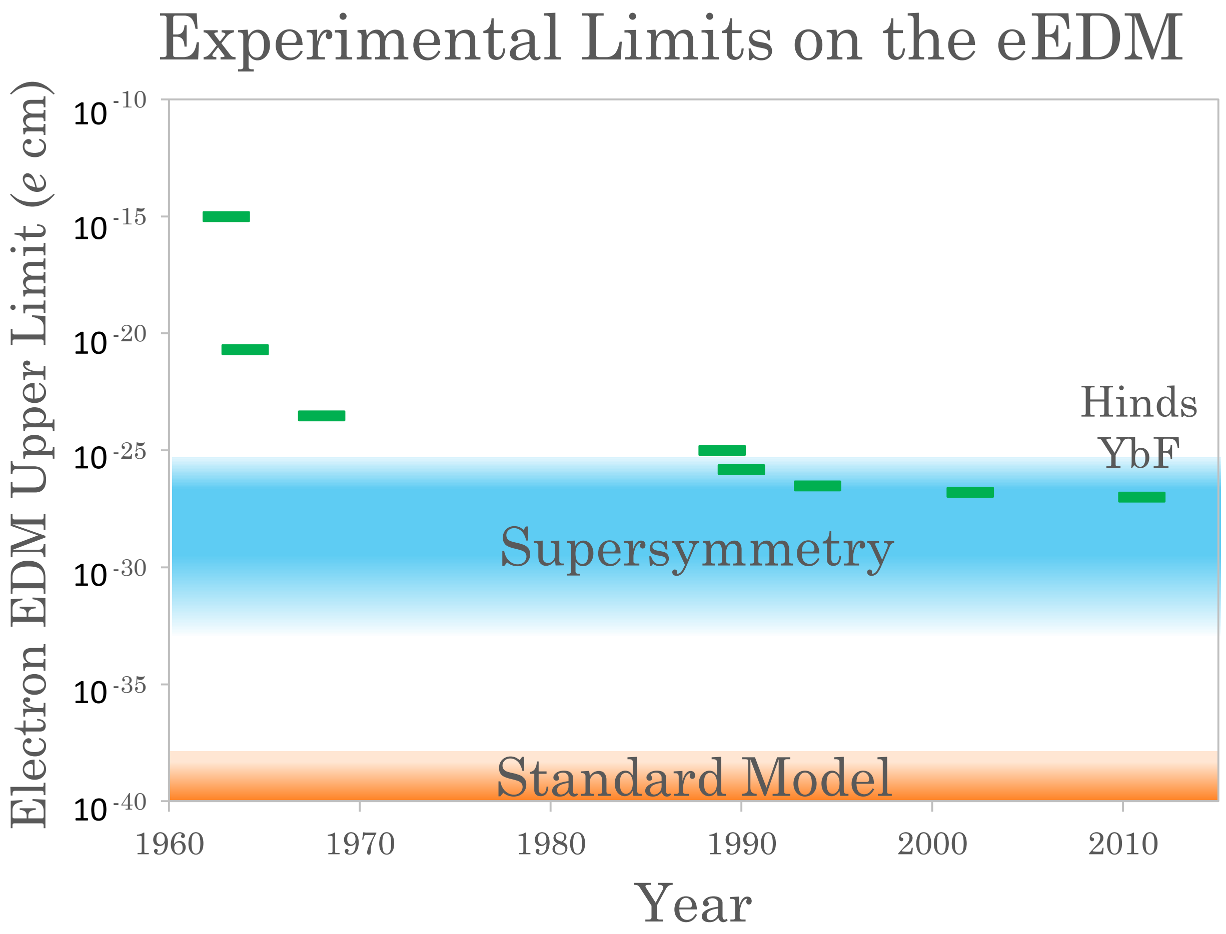
Motivation for eEDM Search

- Permanent EDMs violate CP
- Standard Model CP violation is highly suppressed for leptons → SM eEDM is unmeasurably small



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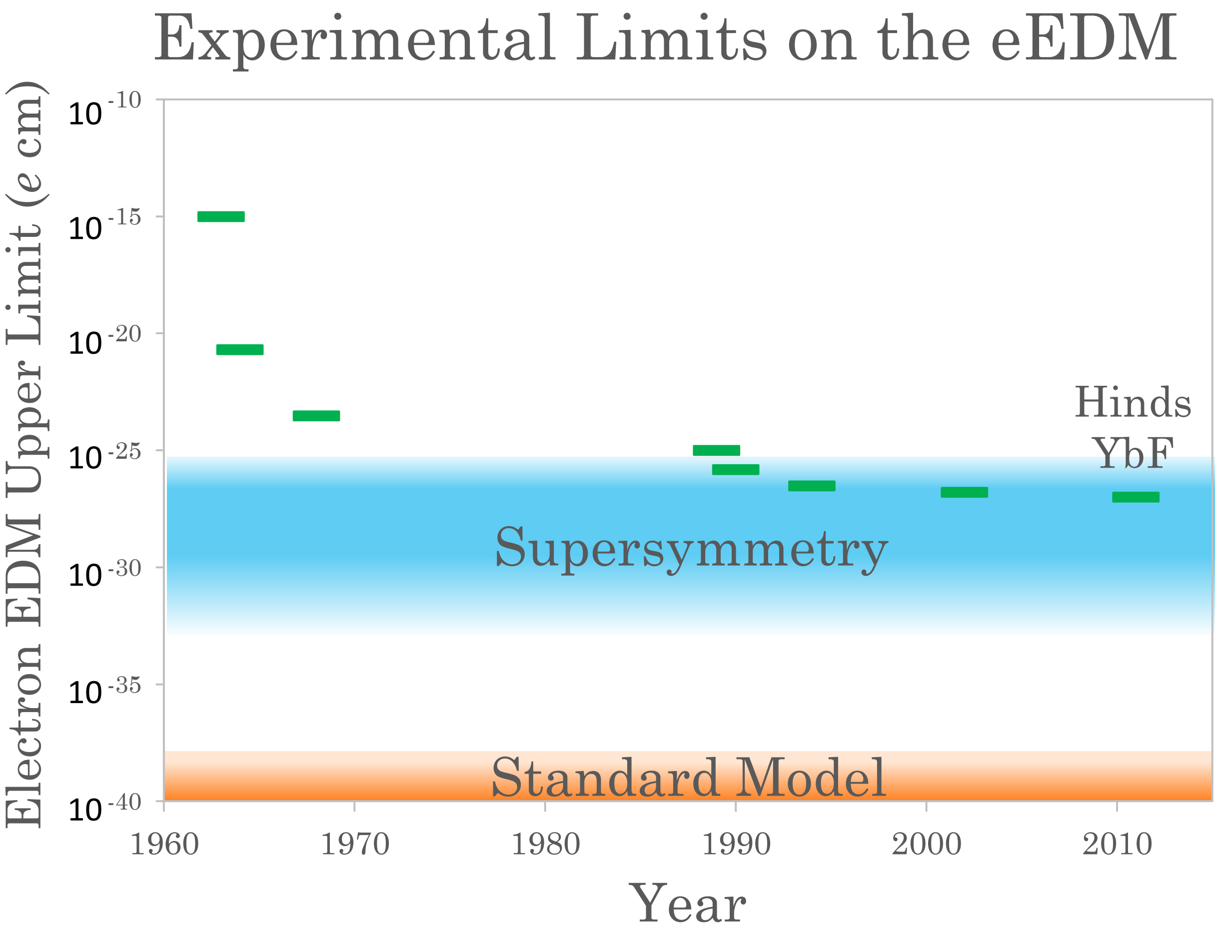
- Extensions to the SM (e.g. supersymmetry) predict eEDMs at levels accessible to present experimental techniques



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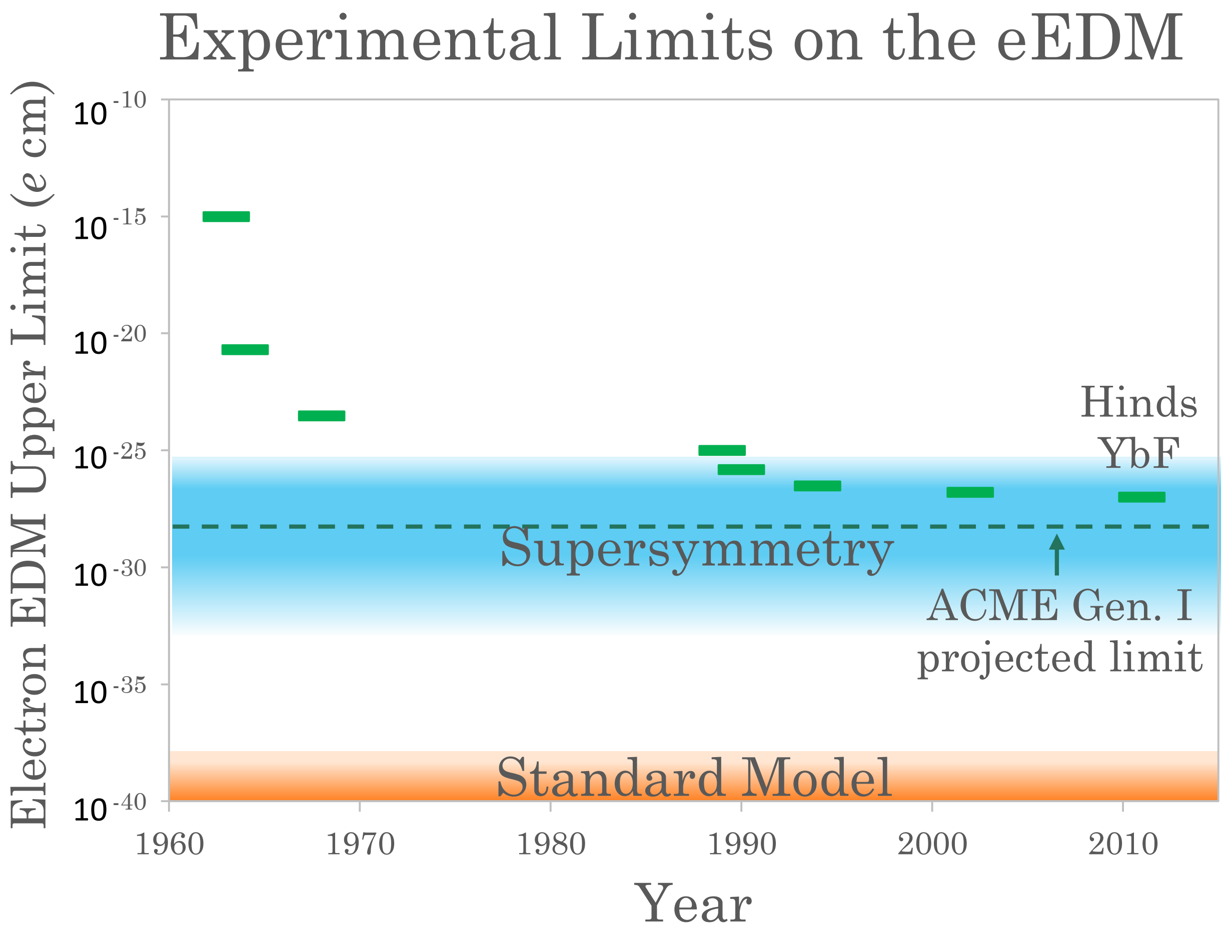
- **Observation of a nonzero eEDM → new physics**



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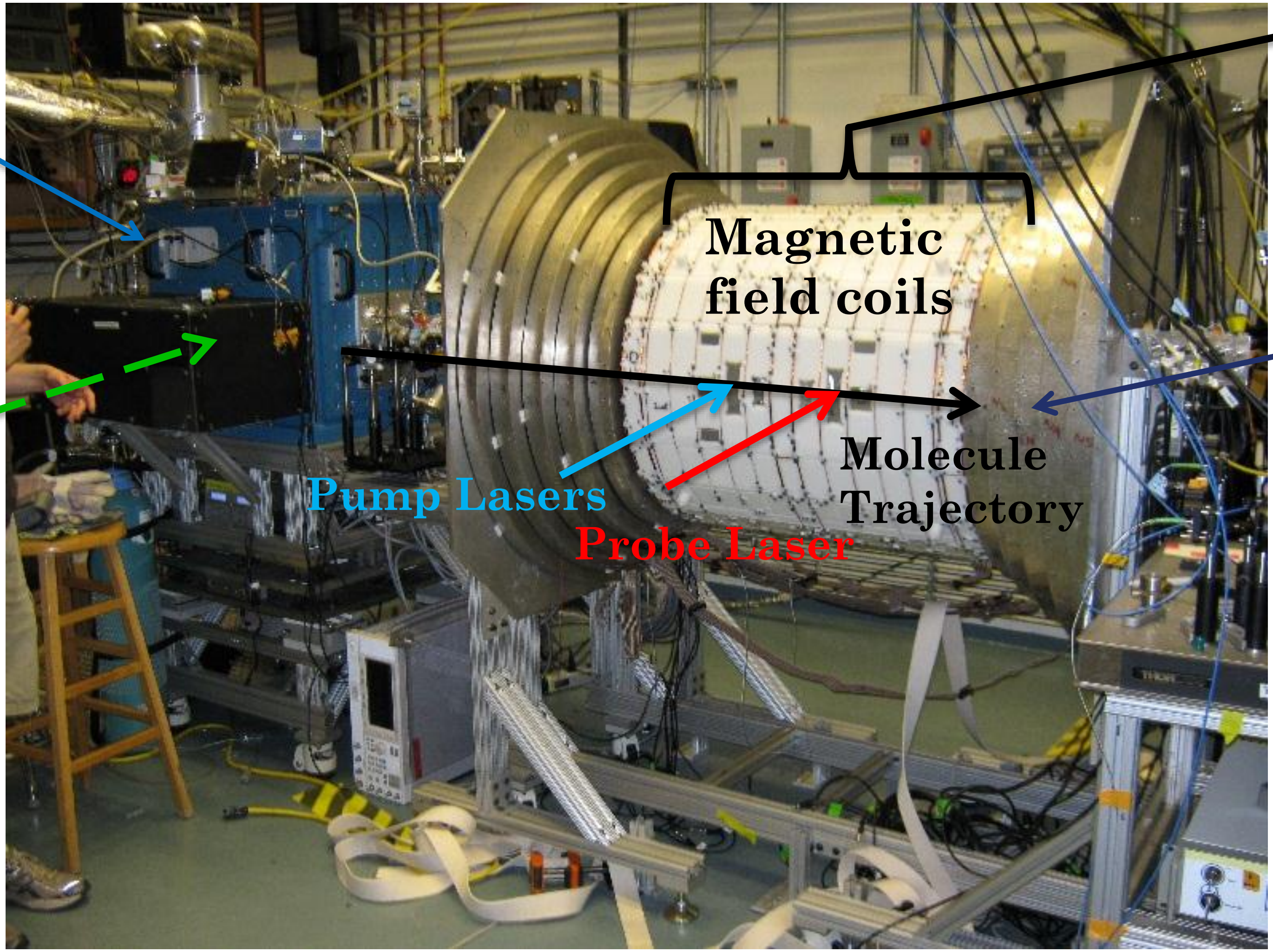
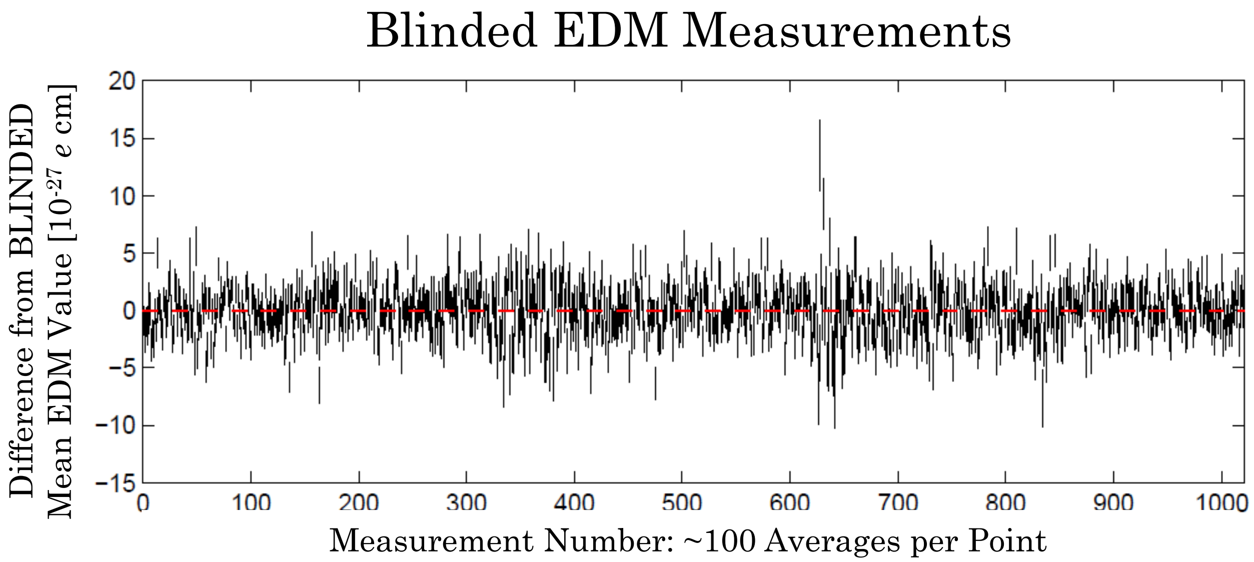
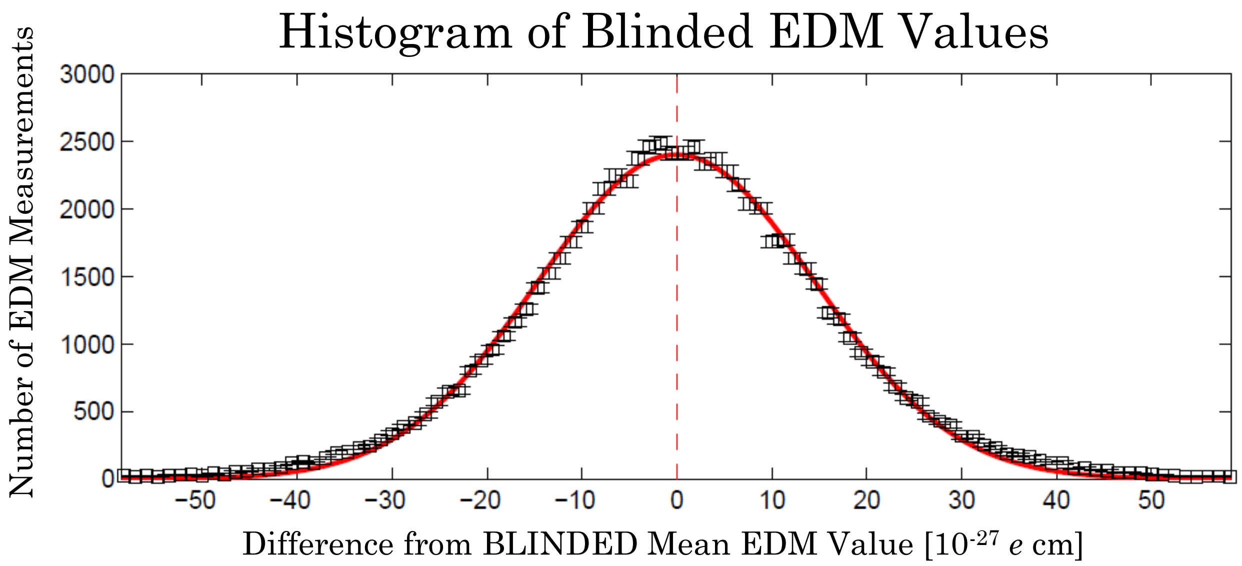
ThO eEDM Apparatus



ACME Update – Statistics





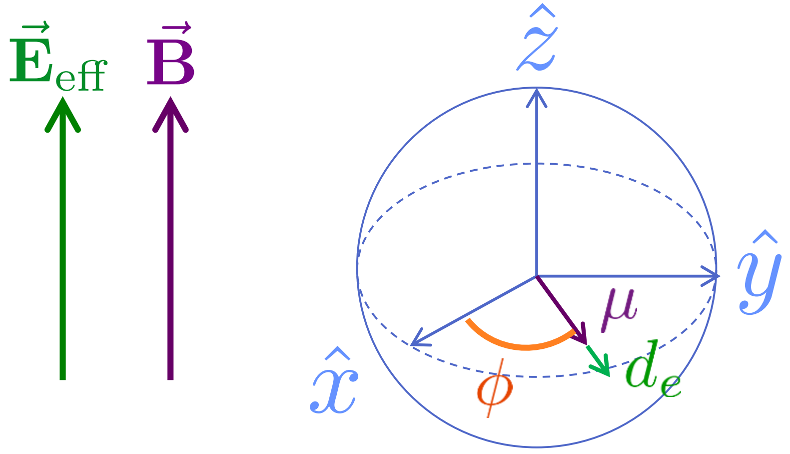
- 100 hours of data
- Blind offset added in analysis; plots show difference from blinded mean
  - No eEDM value can be derived from this data until the blind is removed
- Statistical error bar after 100 h:

$$\Delta d_e = 5 \times 10^{-29} e \cdot \mathrm{cm}$$

Plots from Nick Hutzler

Isolating eEDM Precession Phase

$$\phi(\vec{B}) = (\vec{\mu} \cdot \vec{B} + \vec{d}_e \cdot \vec{\mathcal{E}}_{\text{eff}})\tau/\hbar$$



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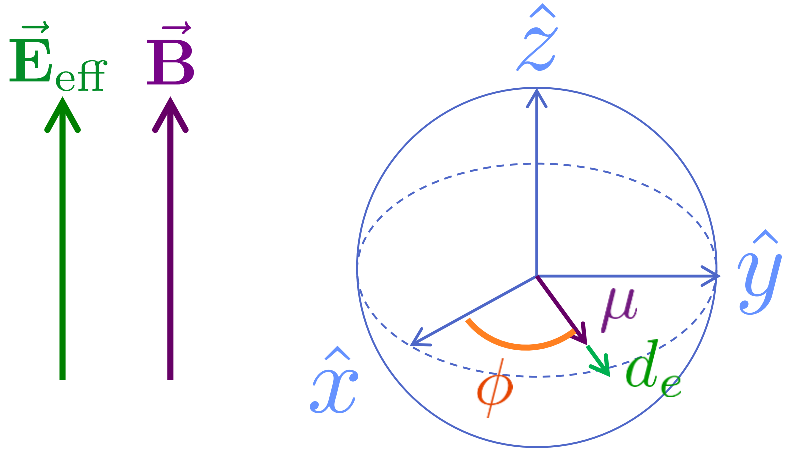

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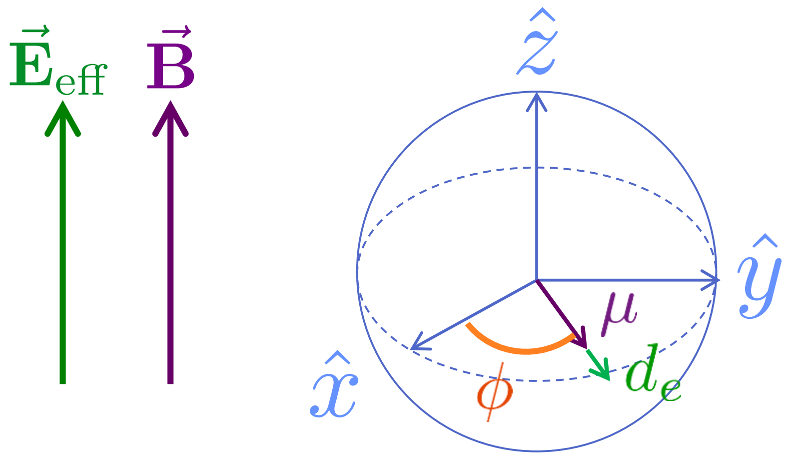

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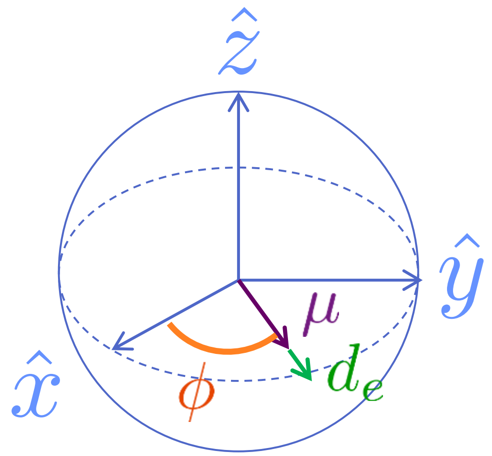

The eEDM phase can be isolated from most other phases in the experiment using the eEDM's particular symmetry under the parameter switches:

- N – orientation of the ThO molecule
- E – applied electric field
- B – applied magnetic field

$\mathcal{N}\vec{E}\vec{B}$	Terms Contributing to Phase	Physical Quantities
$+++$	$\vec{\mu}\cdot\vec{B}_{\text{nr}}\tau/\hbar$, θ	Electron spin precession in background (non-reversing) magnetic field, Pump/probe relative polarization offset
$++-$	$\vec{\mu}\cdot\vec{B}\tau/\hbar$	Electron spin precession in applied magnetic field
$+-+$	$\vec{\mu}\cdot\vec{B}_{\text{leak}}\tau/\hbar$	Leakage currents B_{leak}
$-++$	$\Delta\vec{\mu}\cdot B_{\text{nr}}\tau/\hbar$, $\Delta\vec{\mu}\cdot B_{\text{leak,nr}}\tau/\hbar$	Imperfect field reversals interacting with opposite molecule polarizations
$+--$		—
$-+-$	$\Delta\vec{\mu}\cdot\vec{B}\tau/\hbar$	Electron spin precession due to molecule polarization dependent magnetic moment
$--+$	$\vec{d}_e\cdot\mathcal{E}_{\text{eff}}\tau/\hbar$, $\Delta\vec{\mu}\cdot\vec{B}_{\text{leak}}\tau/\hbar$	**Electron EDM,** Molecule polarization dependent $\vec{\mu}$ precession in leakage magnetic field
$---$	$\Delta\vec{\mu}\cdot\vec{B}\frac{E_{\text{nr}}}{\lvert E\rvert}\tau/\hbar$	Molecule polarization difference in $\vec{\mu}$ correlated with imperfect E reversal

Isolating eEDM Precession Phase

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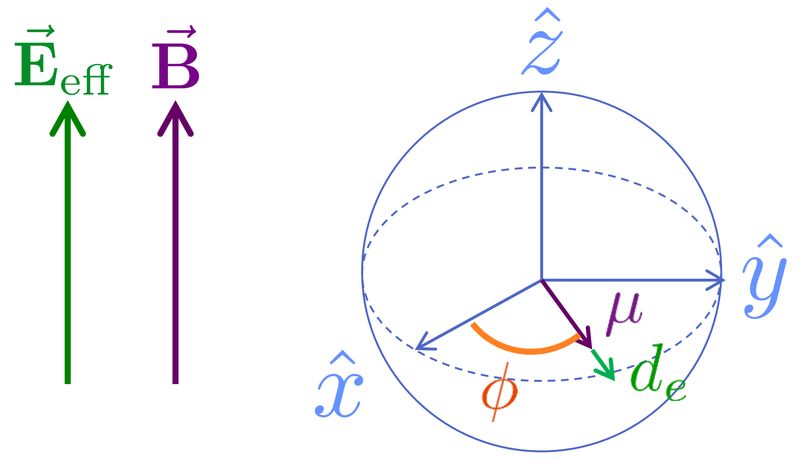

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Determining Systematic Error Bars

- Suppose systematic depends linearly on experimental imperfection X (e.g., $X = E_{nr}$):

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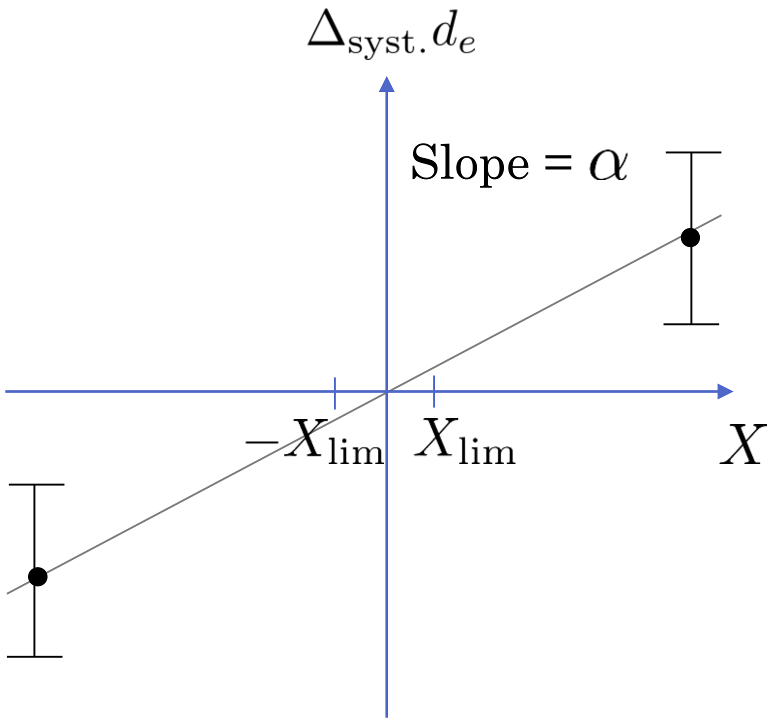
- Generate a large $X >> X_{\text{lim}}$ and measure the resulting eEDM:



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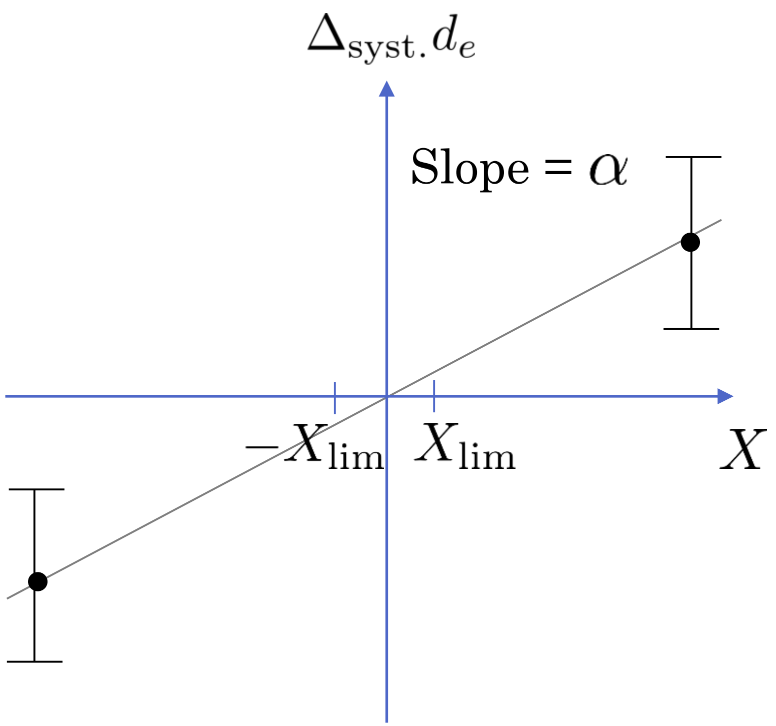
- Generate a large $X >> X_{\text{lim}}$ and measure the resulting eEDM:

- Now we can set a limit on $\Delta_{\text{syst.}} d_e$:

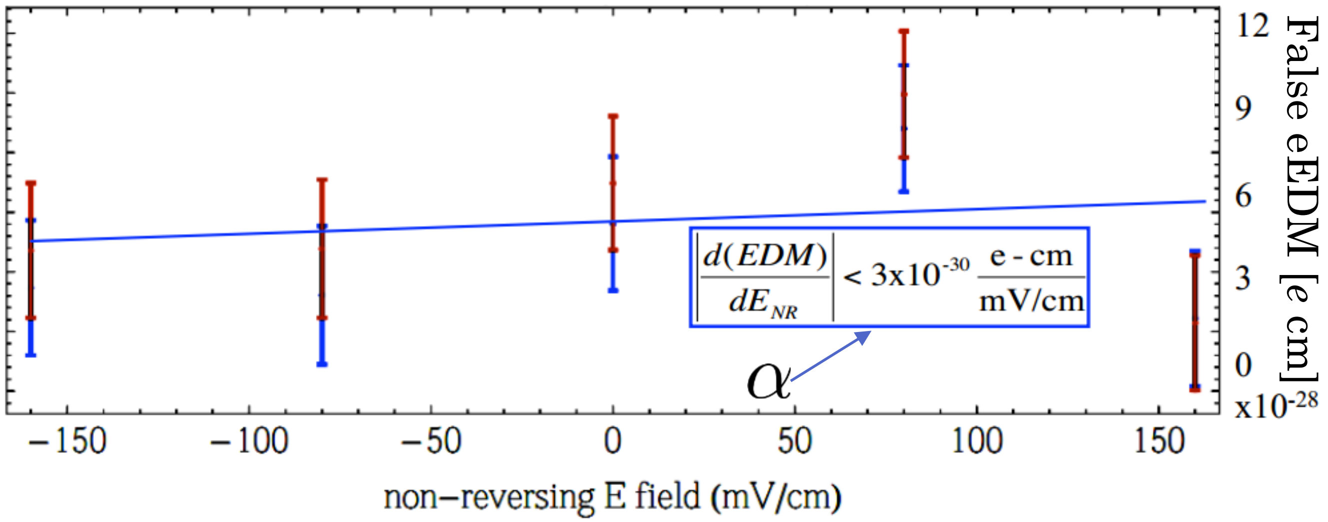
$$\Delta_{\text{syst.}} d_e < \alpha X_{\text{lim}}$$



Determining Systematic Error Bars – Example

Figure courtesy of Ben Spaun

Systematic Error Correlated with E_{nr}



$$\Delta_{\mathrm{syst.}} d_e(X_{\mathrm{lim}}) < \alpha X_{\mathrm{lim}}$$

$$\Delta_{\mathrm{syst.}} d_e(E_{\mathrm{nr}} = 5\ \mathrm{mV/cm}) \sim 10^{-29} e \cdot \mathrm{cm}$$

So far, every studied systematic error term contributes an uncertainty of:

$$\Delta_{\mathrm{syst.}} d_e \lesssim 10^{-29} e \cdot \mathrm{cm}$$

Summary and Conclusion

- The ACME collaboration is performing an eEDM measurement with a to-date statistical uncertainty of:

$$\Delta d_e = 5 \times 10^{-29} e \cdot \mathrm{cm}$$

  a factor of 20 below the current upper limit on d_e

- By switching experimental parameters *N*, *E*, and *B*, we can cancel out all contributions to the phase that have a different symmetry from the eEDM

- We put limits on the remaining systematic effects by amplifying and measuring them directly.

- Once we are finished studying our systematic effects, we can un-blind the data and report a result!

ACME Collaboration

Visit us in LISE G14!

Affiliation: Harvard / Yale

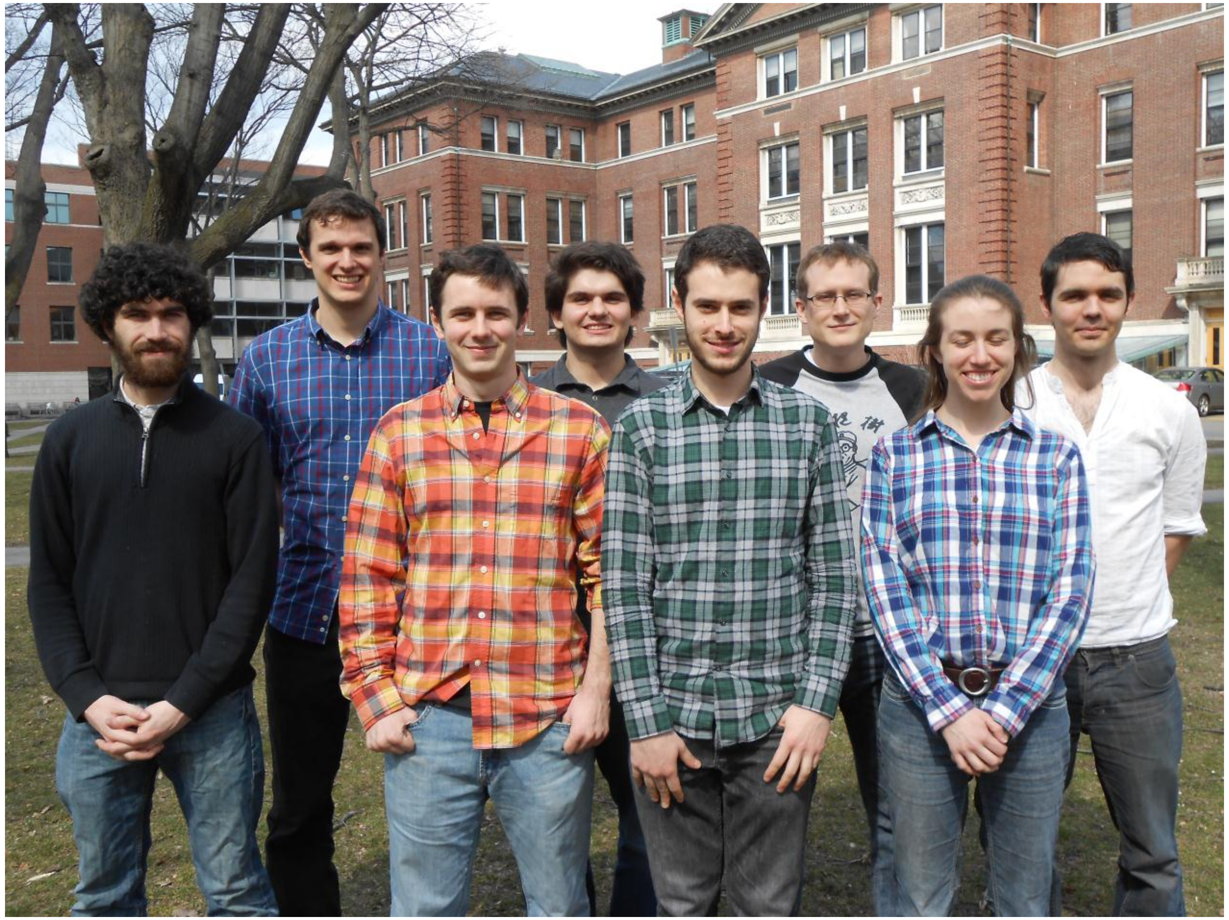
Not pictured:

PI's

- **John Doyle**
- **Gerald Gabrielse**
- **David DeMille**

Alumni

- Wesley Campbell
- Yulia Gurevich
- Emil Kirilov
- Amar Vutha



Graduate students (left to right)

- Brendon O'Leary
- Ben Spaun
- Paul Hess
- Cris Panda
- Jacob Baron
- Nick Hutzler
- Elizabeth Petrik

Postdoc (far right)

- Adam West