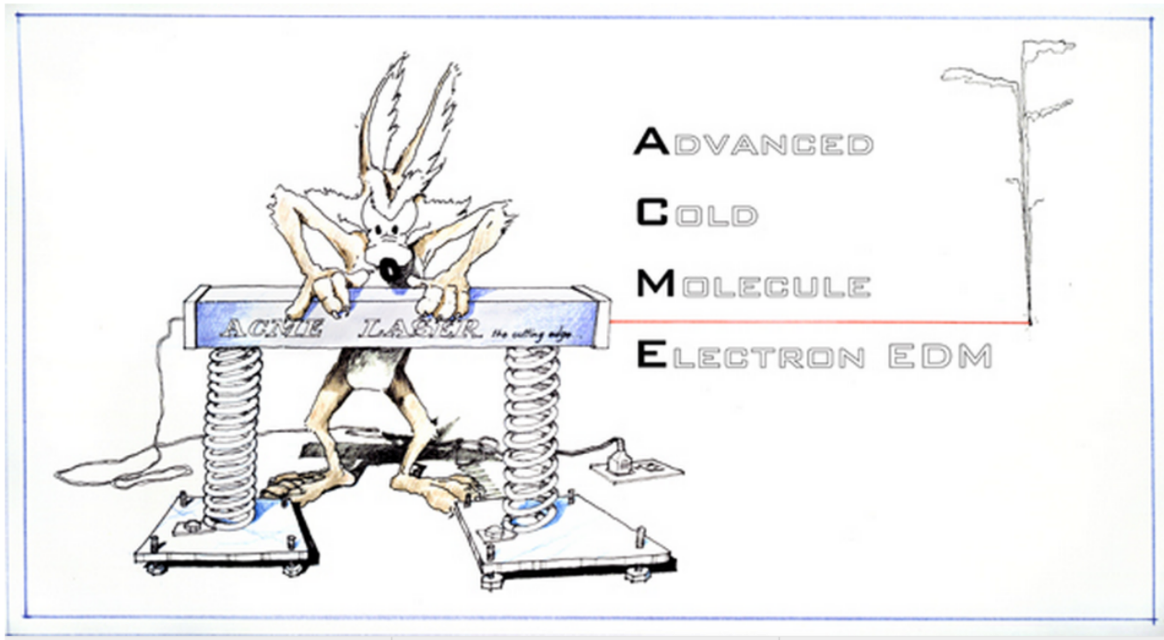

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COLE MEISENHELDER

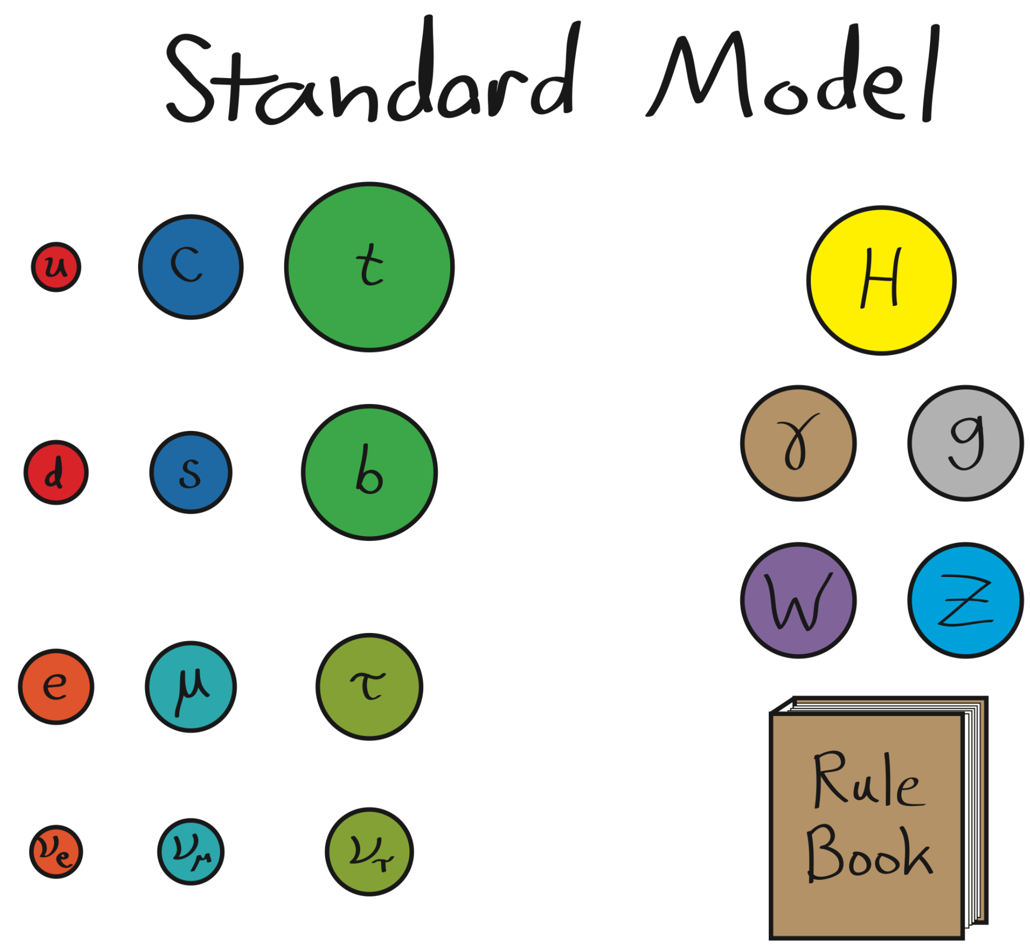
DAMOP 2020

THE ADVANCED ACME SEARCH FOR THE ELECTRON ELECTRIC DIPOLE MOMENT

SECTION I: WHY ARE EDMS INTERESTING?

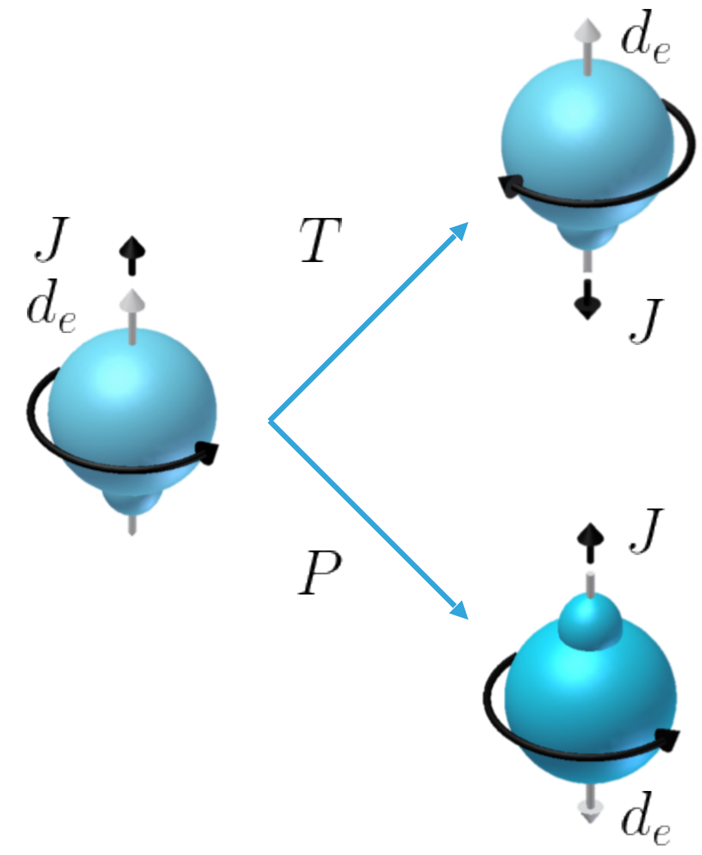
MOTIVATION

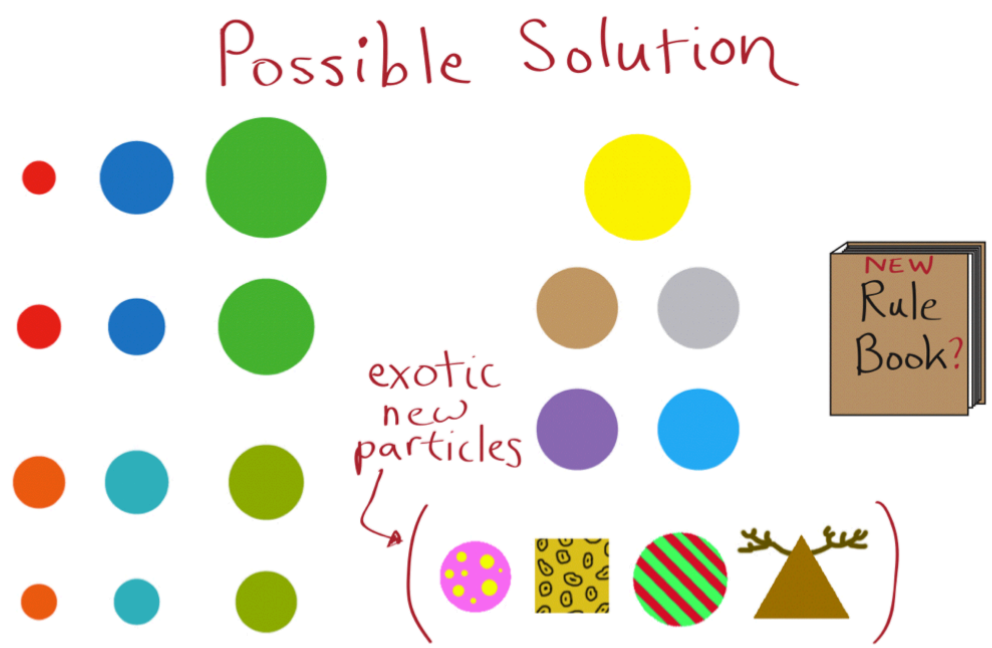
- The Standard Model cannot answer all questions
- Matter-Antimatter Asymmetry Problem
- Sakharov conditions allow for baryon asymmetry



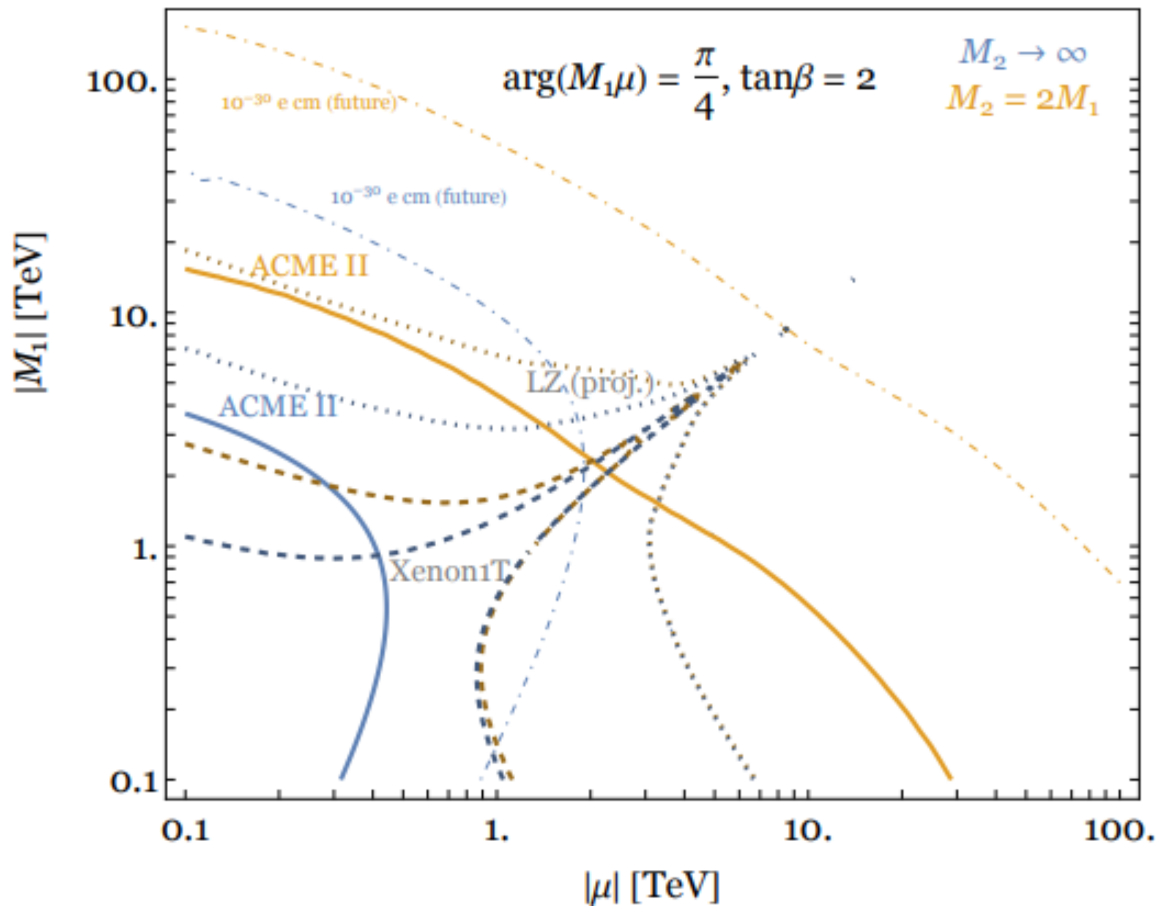
EDMS AND CP VIOLATION

- Standard Model does not account for the observed asymmetry
- Permanent EDMs inherently violate P and T
- Standard Model predicts electron EDM $< 10^{-38}\ e \cdot cm$
- Current limit: $|d_e| < 1.1 \times 10^{-29} e\ \mathrm{cm}$
- Many BSM theories predict nonzero eEDMs near our sensitivity

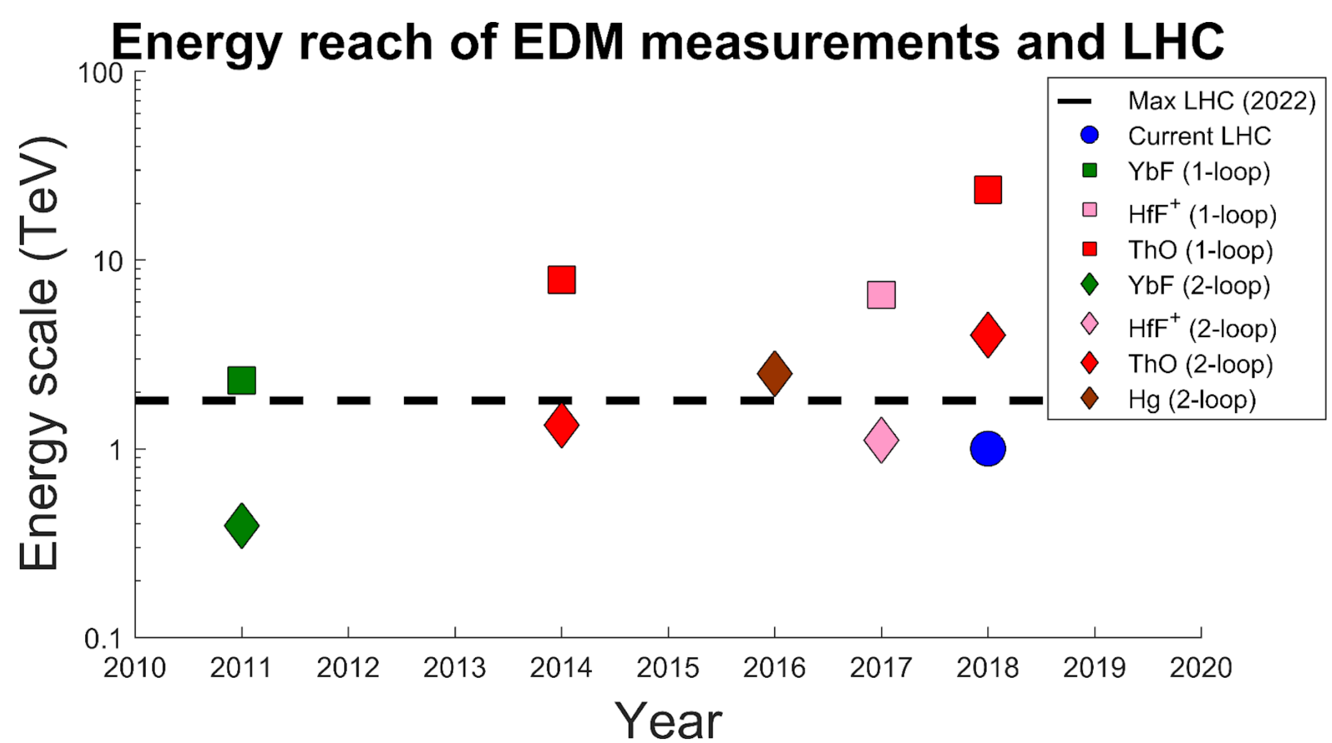




PLACING LIMITS ON NEW PHYSICS



SUSY particle bounds from the ACME II result. Fig. from Matt Reece (unpublished). Advanced ACME projection (~10^{-30} e cm) dashed.

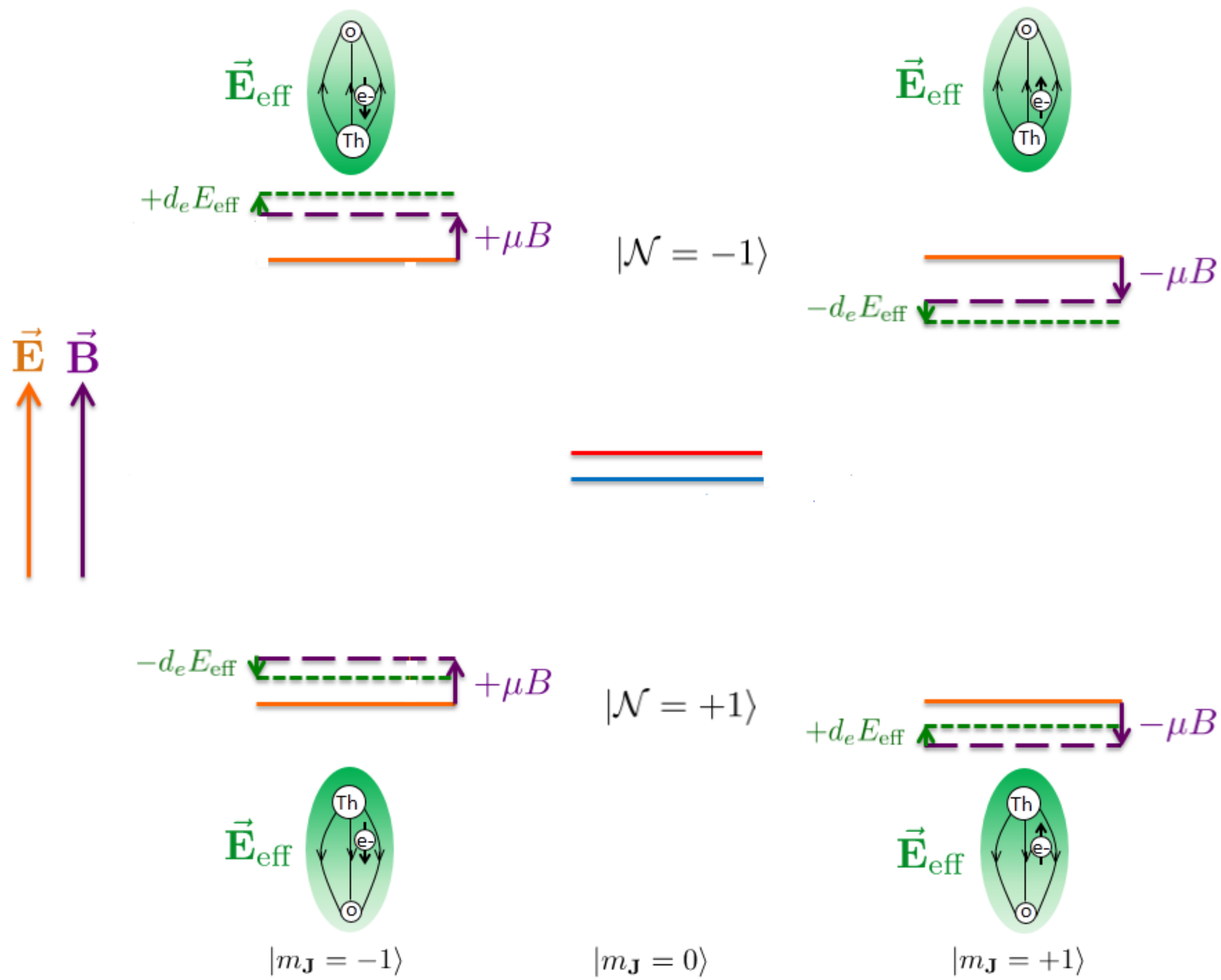


Key EDM results since 2010. Two-loop sensitivity from Nakai & Reece (2017). One-loop sensitivity from Feng (2013). LHC scale gives stop mass sensitivity.

SECTION II: HOW CAN WE MEASURE AN ELECTRON EDM?

AN EDM IN THO

- Molecules can provide strong internal electric fields
  - ThO has E_{eff} ~ 80 GV/cm
- We can flip this electric field by probing different states
  - Powerful method for eliminating systematic errors
  - ThO only requires a small applied field



EXPERIMENTAL SENSITIVITY

- For a shot noise limited measurement we

$$\delta\omega \propto \frac{1}{\tau\sqrt{\dot{N}T}}$$

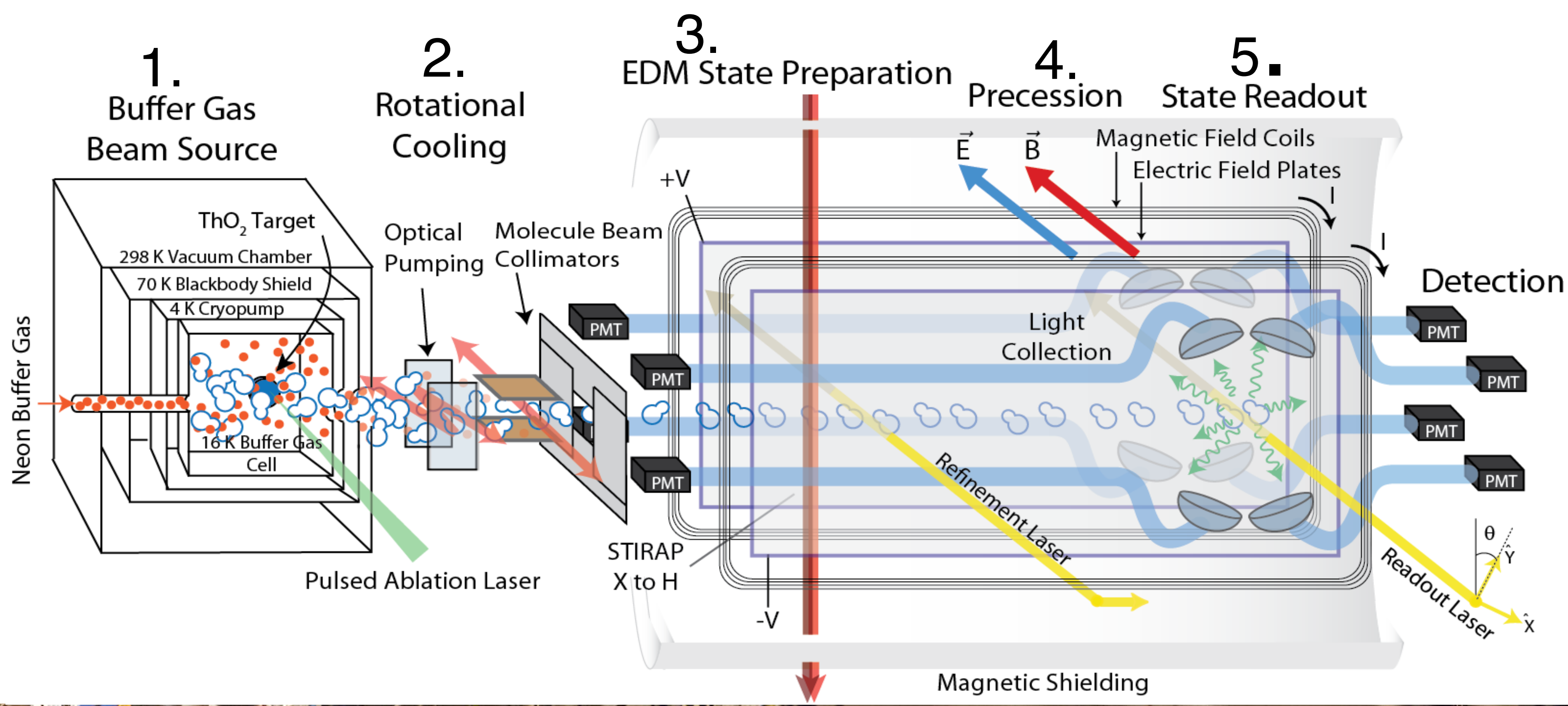
$$\tau = \text{Coherence time}$$
$$\dot{N} = \text{Count rate}$$
$$T = \text{Averaging time}$$

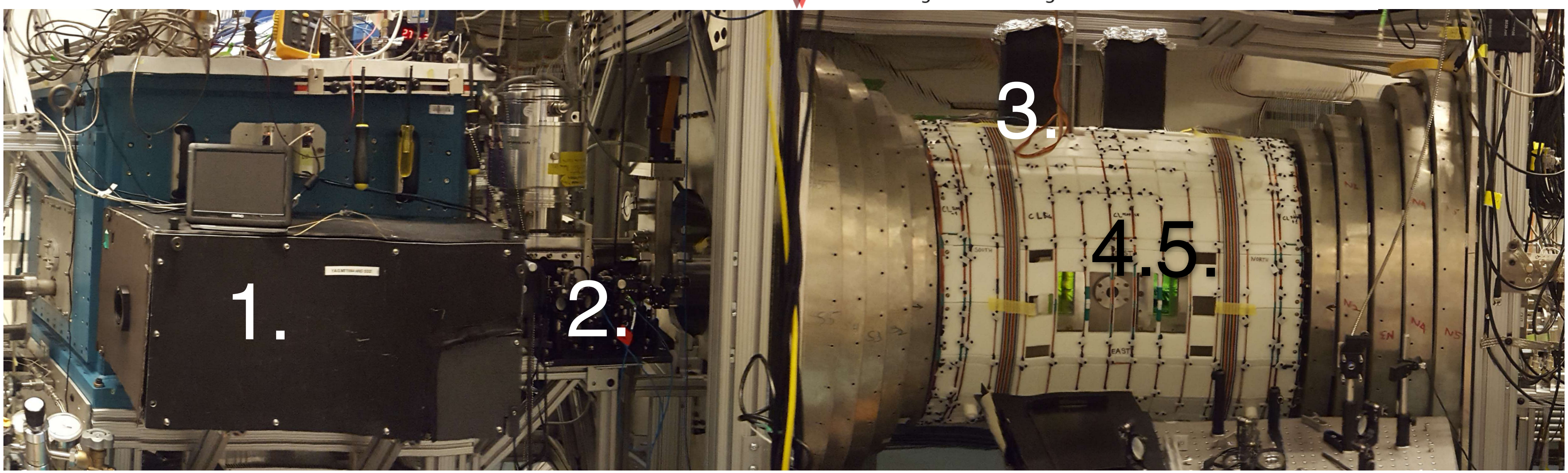
- For our experiment we have $\mathcal{H}_{EDM} = -\vec{d_e} \cdot \vec{\mathcal{E}_{eff}}$

$$\delta d_e \propto \frac{1}{\mathcal{E}_{eff}\tau\sqrt{\dot{N}T}}$$

$$\mathcal{E}_{eff} = \text{Electric field}$$

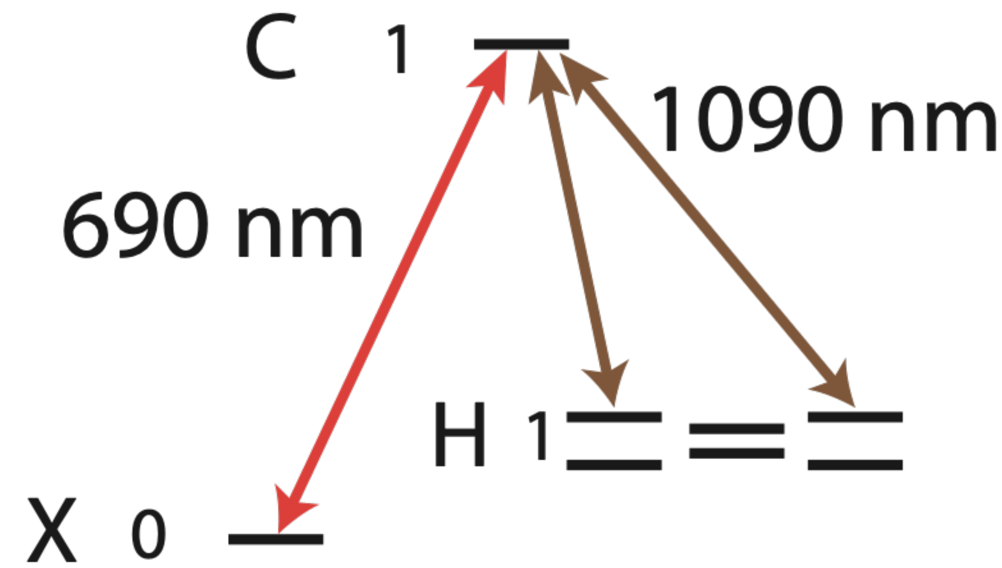
EXPERIMENT STRUCTURE

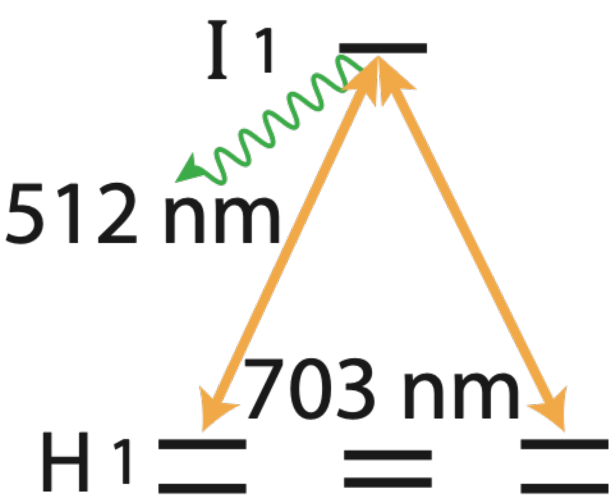


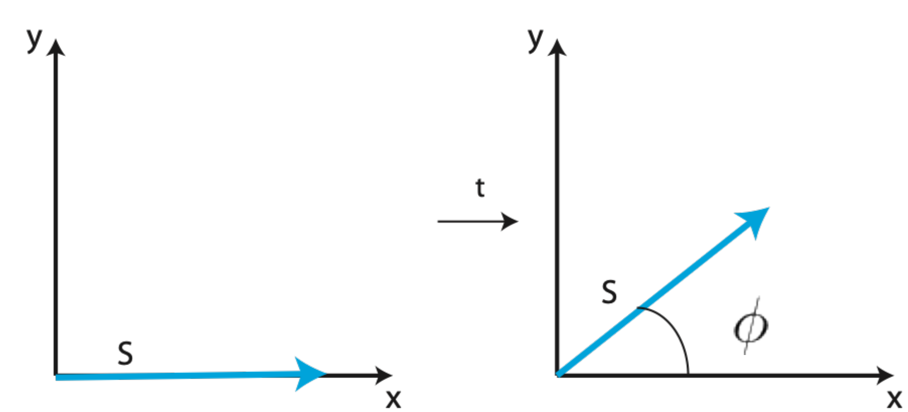


STATE PREPARATION

- Stimulated Raman Adiabatic Passage (STIRAP)
  - Coherent population transfer from X to H
  - ~75% transfer efficiency
- State Refinement
  - Optically pump into dark state with desired polarization
  - Suppress residual STIRAP phases

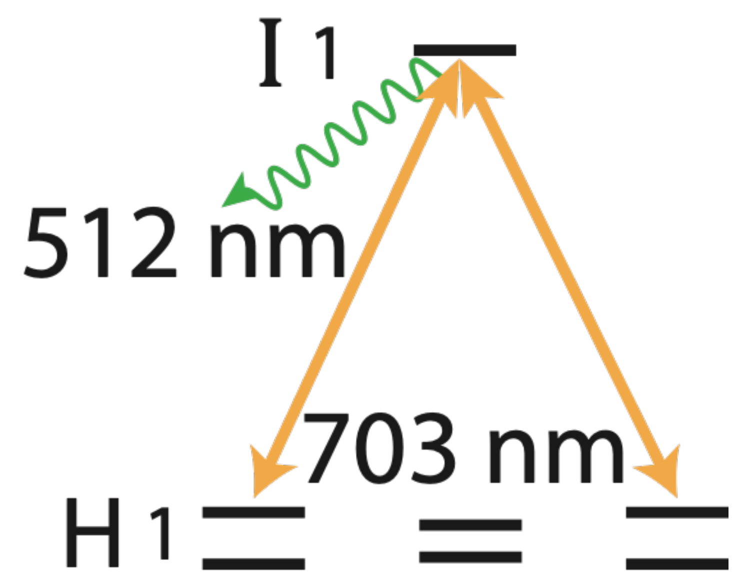


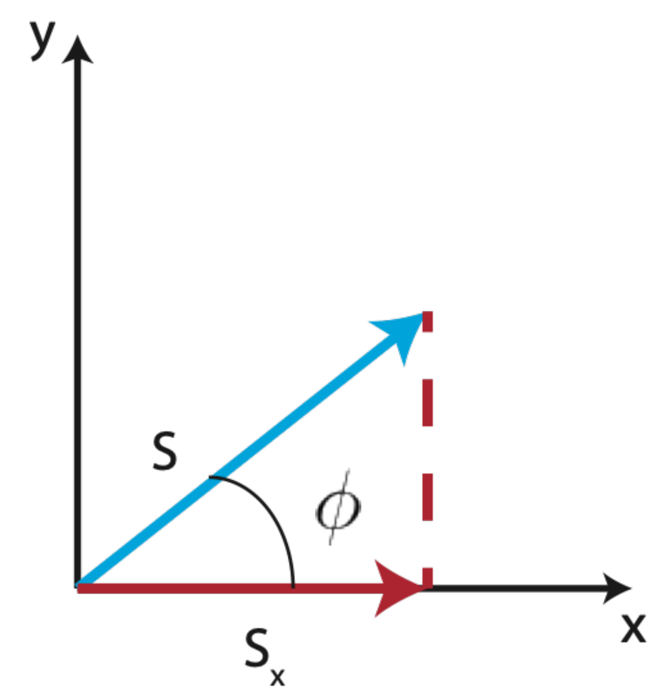


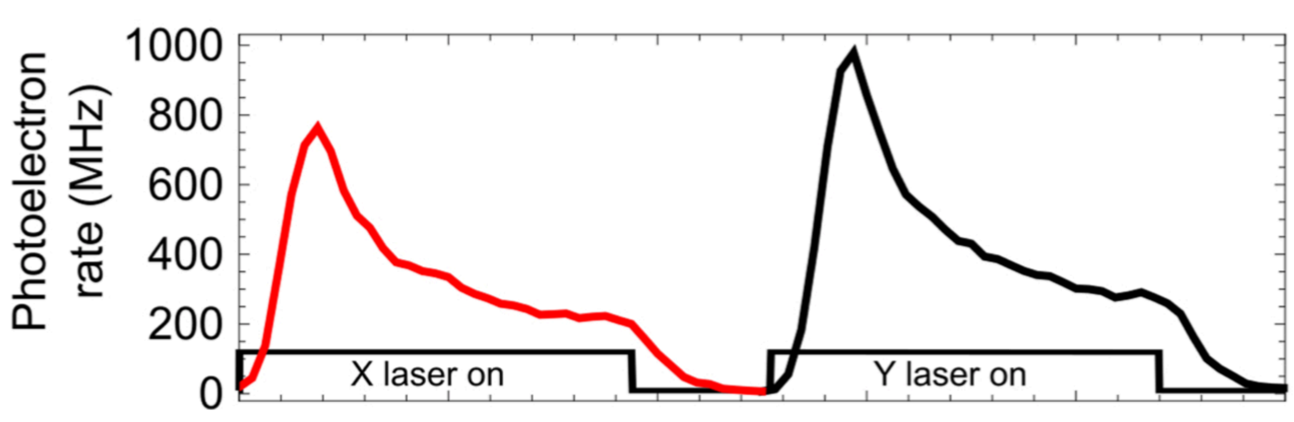


STATE READOUT

- Project phase onto orthogonal polarizations
- Rapidly switch polarization at 200 kHz
    - AOMs allow rapid switching
- Detect fluorescence with 8 PMTs







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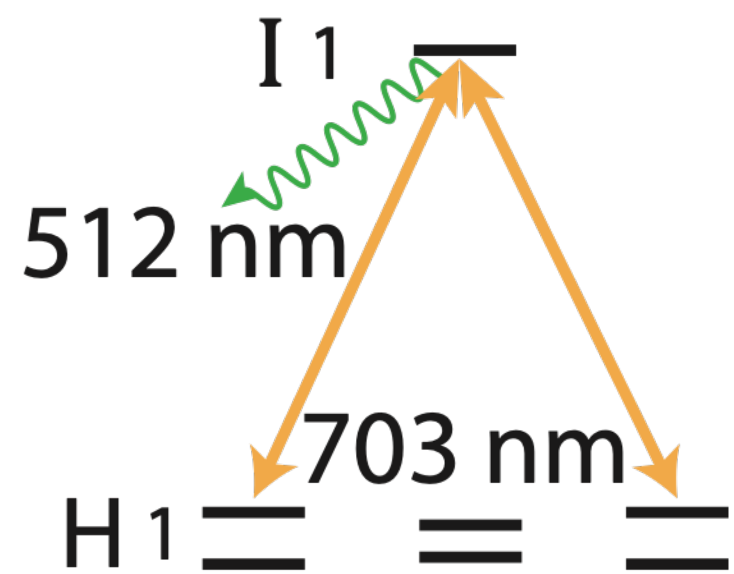

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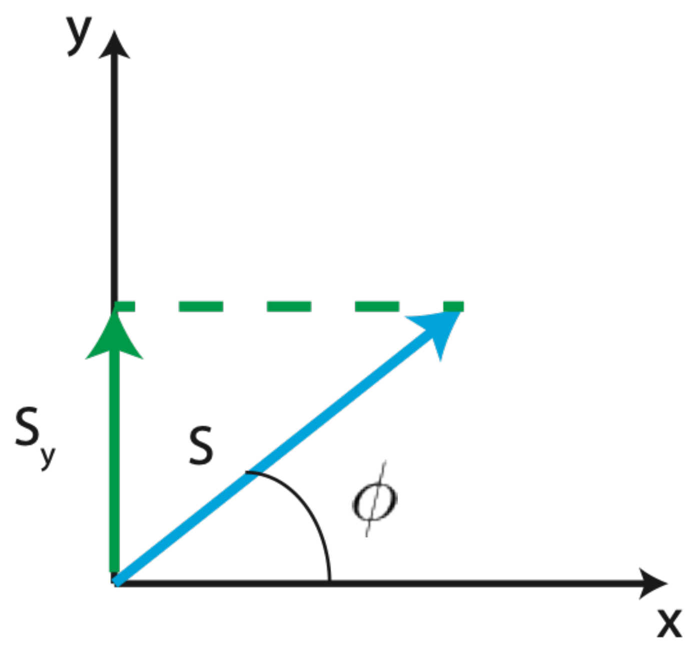
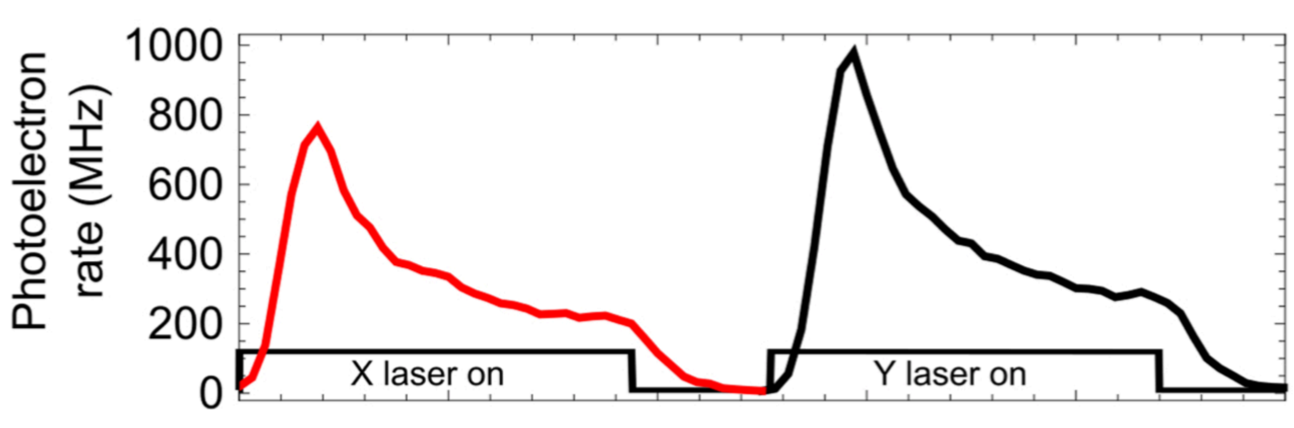
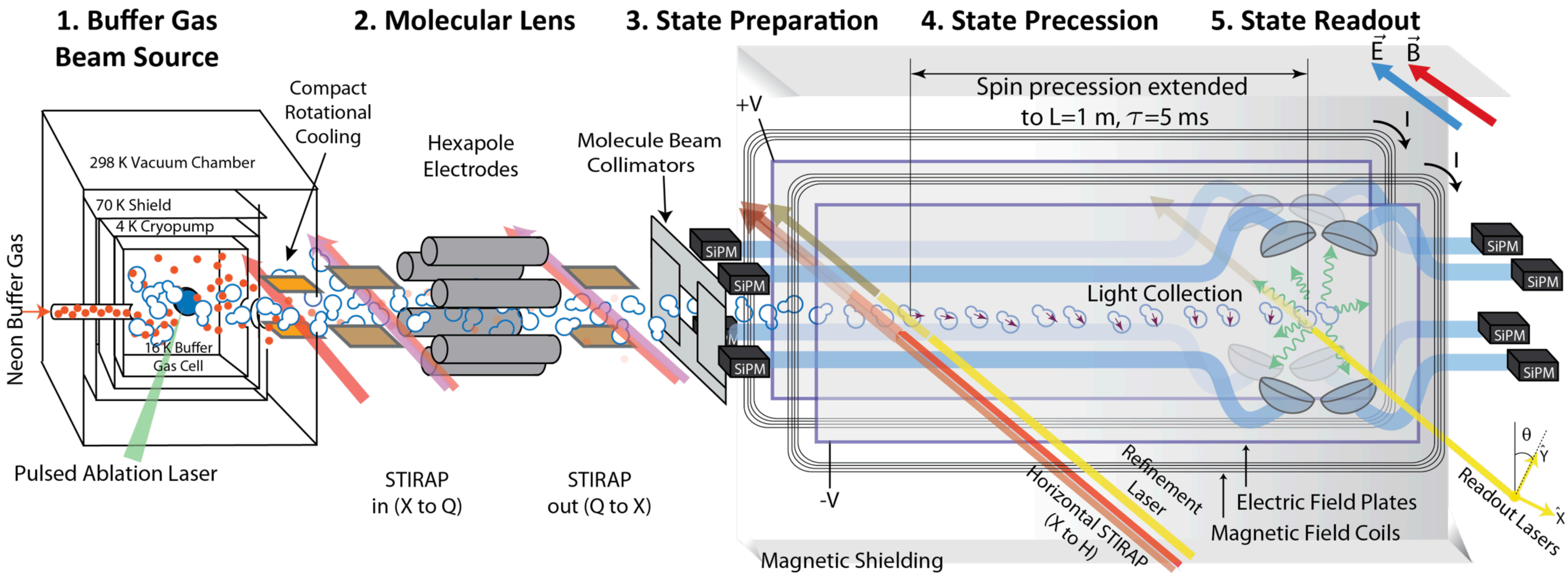




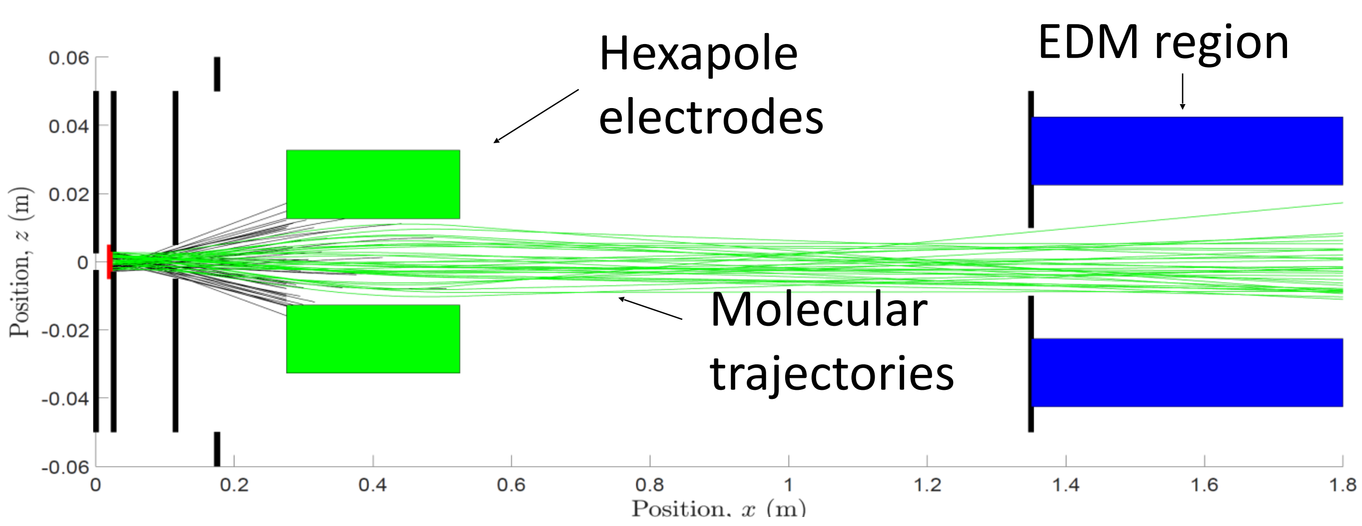
SECTION III: THE ADVANCED ACME EXPERIMENT

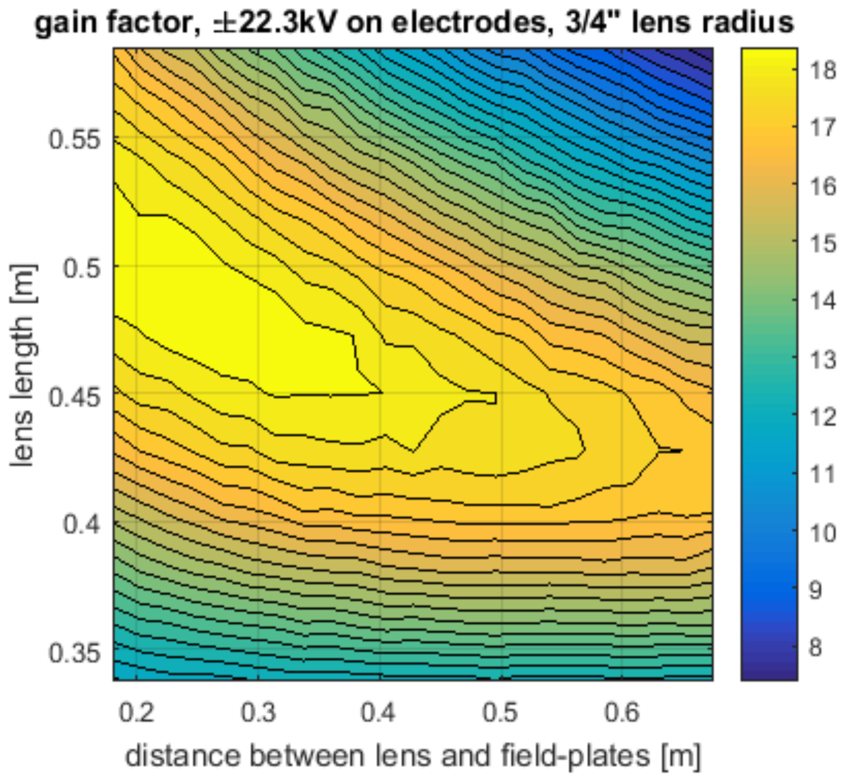
ADVANCED ACME OVERVIEW



ELECTROSTATIC LENS FOR THO MOLECULES

- Without a lens, fewer than .04% of molecules reach the detector
- Electrostatic lens focuses molecules into the EDM region, giving **~20x** gain in signal (including the efficiency of double-STIRAP)
- Efficient STIRAP into the Q state allows for strong focusing



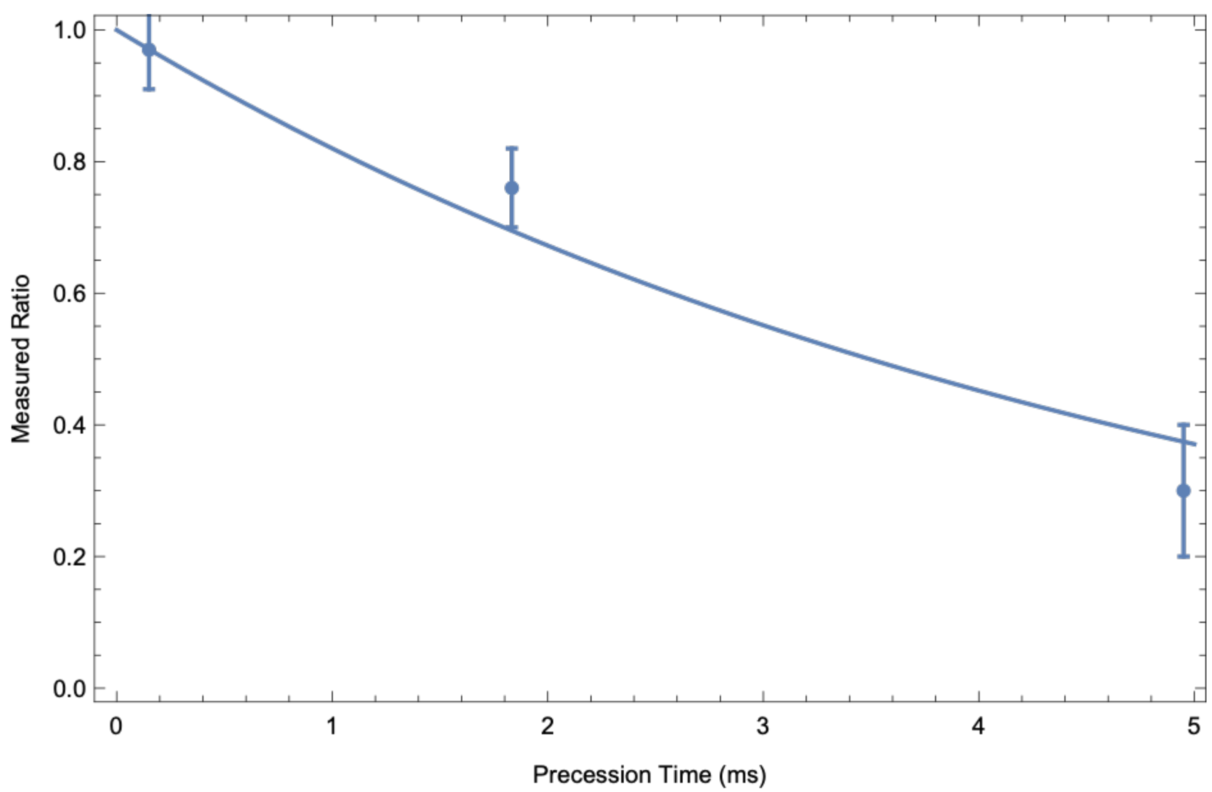


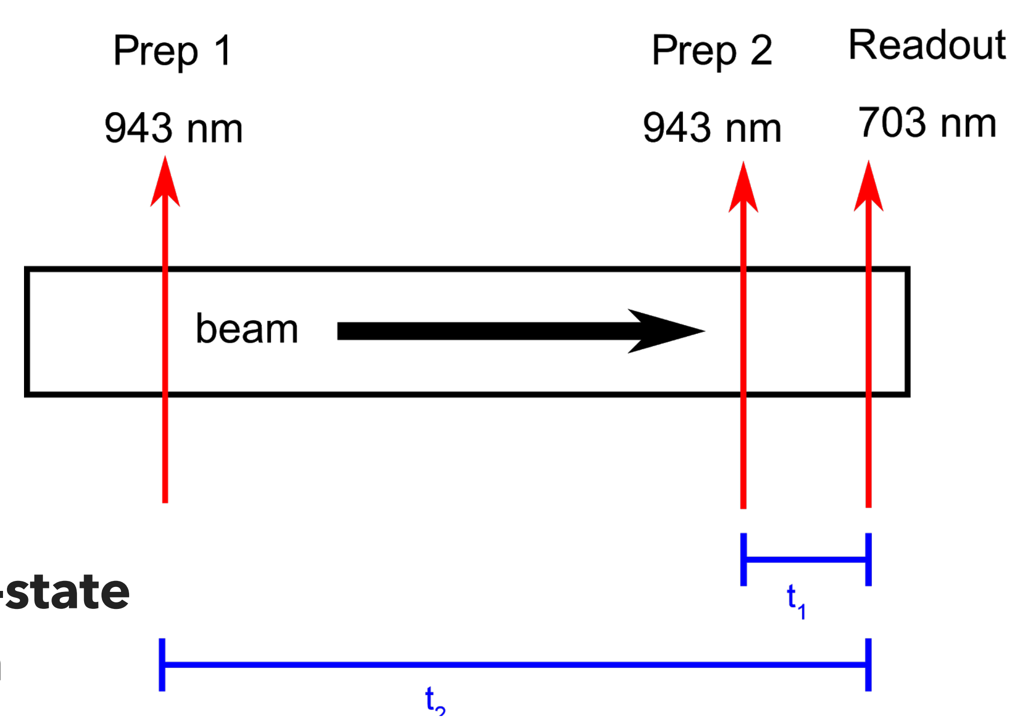
See Poster K01.00142 : Upgrading the ACME electron EDM search with a molecular lens

See: X. Wu et al., The metastable Q 3 Δ 2 state of ThO: a new resource for the ACME electron EDM search, *New J. Phys* (2020).

INCREASED H-STATE LIFETIME

- Last lifetime measurement showed a lower bound of just 1.8 ms
- ACME II used only 1 ms (20 cm) precession time
- Recent measurements suggest a lifetime of approximately **5 ms**
- Currently working on measurement to reduce uncertainty of H-state lifetime

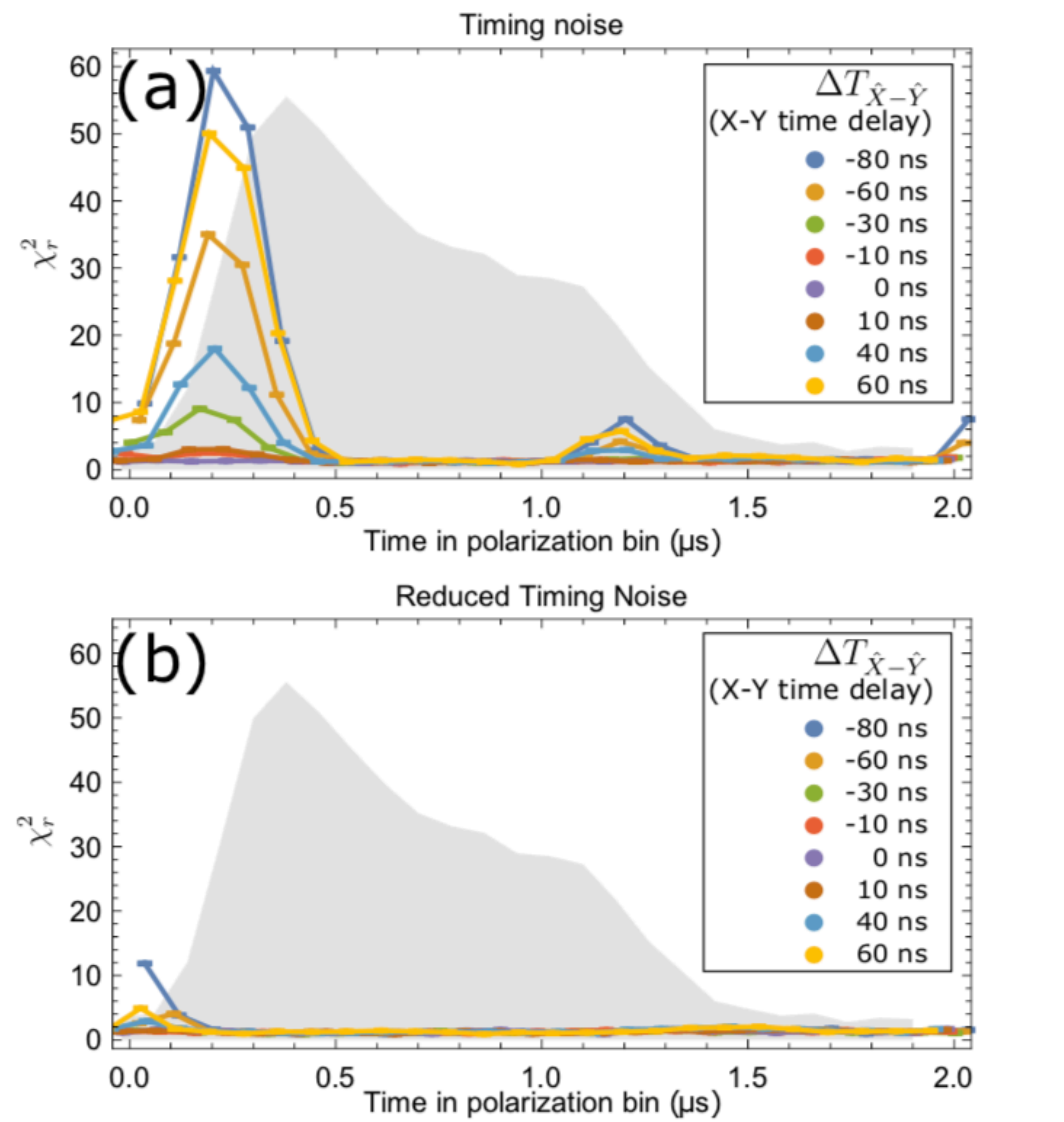




See the immediately following talk: H07.00002 : New H-state lifetime measurement for the ACME electron EDM search

CONTROLLING EXCESS NOISE FOR ADVANCED ACME

- ACME II had 1.7 times more noise than expected from the shot noise limit
- Noise came from 2 effects:
    - Large scale timing jitter
    - Timing offset between X and Y polarization bins
    - We can now control both parameters to reduce this noise



See: C. Panda et al., Attaining the shot-noise-limit in the ACME measurement of the electron electric dipole moment, *J. Phys. B* (2019).

DETECTION UPGRADES

- SiPMs provide a significant gain over the PMTs used in ACME II
- Dark count rate has been controlled in prototype tests

	Requirement	Measured	Comment
Photon detection efficiency	~ 50%	PMT × 2.5	Absolute value is unknown.
Dark count rate	< 10 Mcps	< 10 Mcps	Cooled down to -10°C
Cross talk & After pulse	< 25%	~ 20%	Array type package.
3dB Bandwidth	5 MHz	8.5 MHz	w/ Pole-Zero Cancellation
Electrical noise	< 10 nV/√Hz	< 10 nV/√Hz	

See Poster E01.00160 : Development of a silicon photomultiplier module for ACME III

SYSTEMATIC ERROR CONTROL

- Working to control systematic errors observed in ACME II
- Improved magnetic field control
  - New magnetic shielding
  - Also reduces noise from beam velocity dispersion
- Reducing stress induced birefringence in field plates

Table 1 | Systematic shifts for $\omega^{\mathcal{N}\mathcal{E}}$ and their statistical uncertainties

Parameter	Shift	Uncertainty
$\partial\mathcal{B}_z/\partial z$ and $\partial\mathcal{B}_z/\partial y$	7	59
$\omega_{ST}^{\mathcal{N}\mathcal{E}}$ (via θ_{ST}^{H-C})	0	1
$P_{ref}^{\mathcal{N}\mathcal{E}}$	–	109
$\mathcal{E}^{nr}$	−56	140
$\mathcal{C}\|^{\mathcal{N}\mathcal{E}}$ and $\|\mathcal{C}\|^{\mathcal{N}\mathcal{E}\mathcal{B}}$	77	125
$\omega^{\mathcal{E}}$ (via $\mathcal{B}_z^{\mathcal{E}}$)	1	1
Other magnetic-field gradients (4)	–	134
Non-reversing magnetic field, $\mathcal{B}_z^{nr}$	–	106
Transverse magnetic fields, $\mathcal{B}_x^{nr}$, $\mathcal{B}_y^{nr}$	–	92
Refinement- and readout-laser detunings	–	76
$\tilde{\mathcal{N}}$-correlated laser detuning, $\Delta^{\mathcal{N}}$	–	48
Total systematic	29	310
Statistical uncertainty		373
Total uncertainty		486

Values are shown in μrad s^{-1}. All uncertainties are added in quadrature. For $\mathcal{E}_{eff} = 78$ GV cm^{-1}, $d_e = 10^{-30}e$ cm corresponds to $|\omega^{\mathcal{N}\mathcal{E}}| = \mathcal{E}_{eff} d_e/\hbar = 119$ μrad s^{-1}.

Table from: ACME Collaboration et al., Improved Limit on the Electric Dipole Moment of the Electron, *Nature* (2018).

ADVANCED ACME PROPOSED GAINS

$$\delta d_e = \frac{1}{2T\mathcal{E}_{eff}\sqrt{N}}$$

Improvement	Signal Gain	EDM Sensitivity Gain
Increased Precession Time	0.20	2.3
Electrostatic Lens	20.5	4.5
SiPM Detector Upgrade	2.3	1.5
Timing Jitter Noise Reduction	1	1.7
Total	**9.4**	**26.4**

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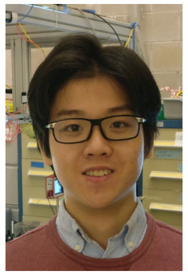
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