E-field Plates for ACME III Electron EDM Search

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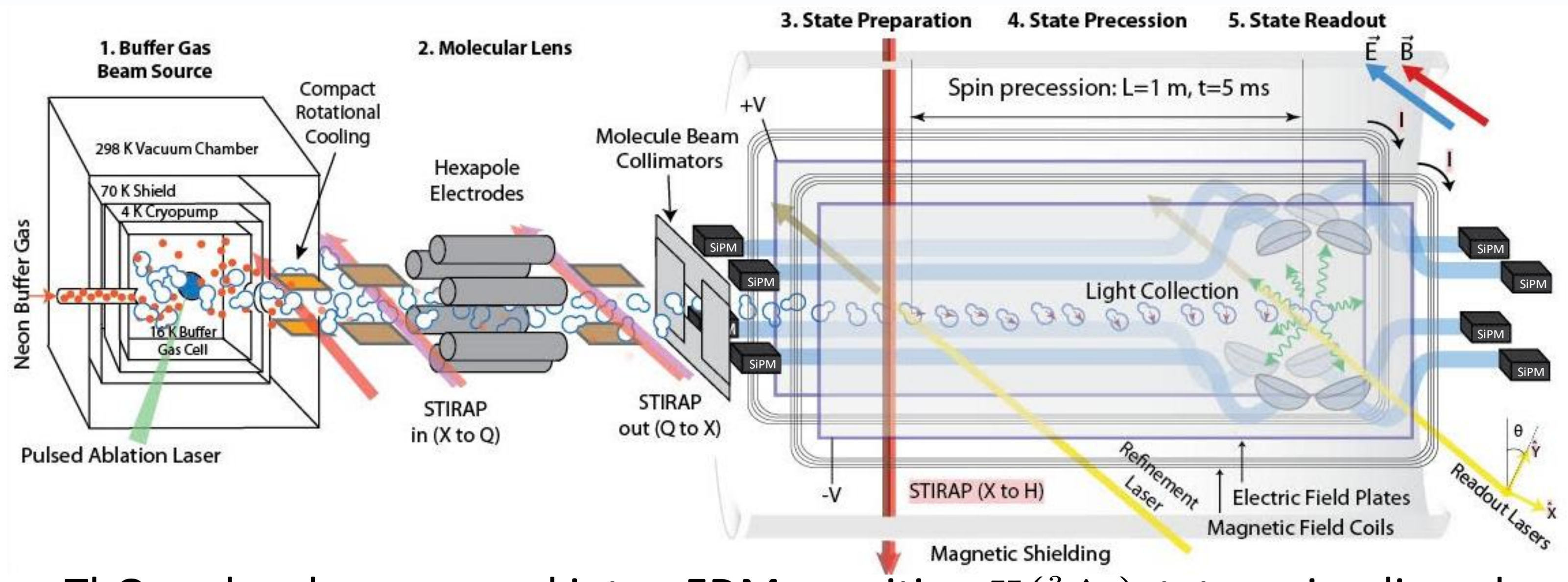
Abstract: A primary source of systematic error in the first two generations of ACME was the polarization imperfection of the state preparation and readout lasers used to detect electron spin precession state of ThO molecules. Most of this imperfection comes from stress-induced birefringence of the optical components along the laser path, including vacuum chamber windows and field plates. We report here some details of the field plate design for ACME III.

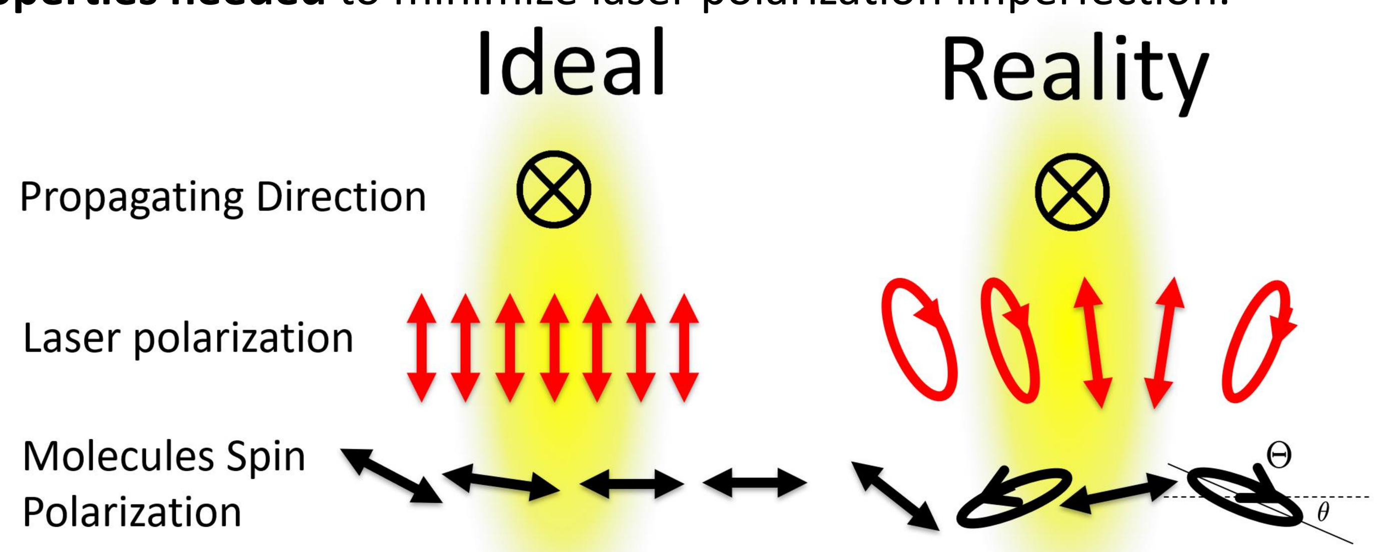
ACME eEDM experiment



- ThO molecules prepared into eEDM-sensitive $H(^3\Delta_1)$state, spin-aligned with refinement laser, precess under E and B-fields. Precession phases measured with readout laser. eEDM extracted from precession phases with different 'switches' (experimental configuration).
- ACME II eEDM result: $d_e = (-4.3 \pm 3.1_{\rm stat} \pm 2.6_{\rm syst}) \times 10^{-30}\,{\rm e \cdot cm}$.

EDM systematic error related to polarization imperfection

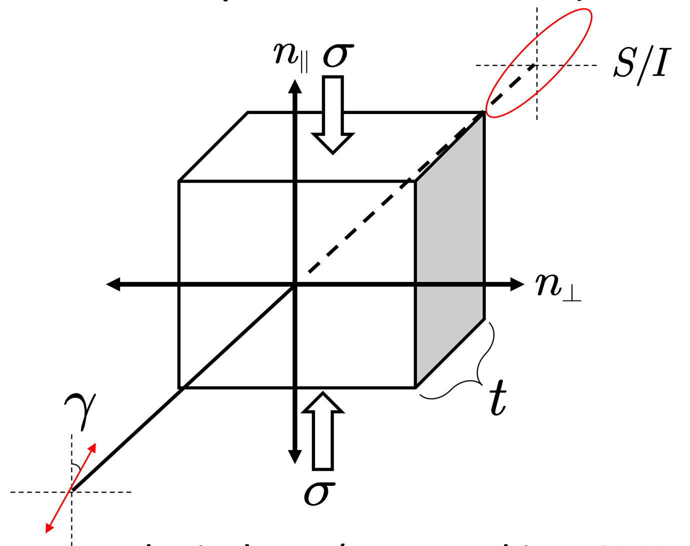
- In ACME II, biggest single uncertainty contribution from non-reversing electric field $\mathcal{E}^{\rm nr}$ related systematic, with $\sigma_{\mathcal{E}^{\rm nr}} = 1.2 \times 10^{-30}\,{\rm e \cdot cm}$
- $\mathcal{E}^{\rm nr}$ from stray electrostatic charge or patch potential on E-field plates couples with imperfect laser polarization during refinement and readout stages, contribute to EDM systematic error.
- **ACME III goal:** transparent field plates with **flat, smooth and parallel surfaces**, ITO coating for uniform and reversable electric field, and **optical properties needed** to minimize laser polarization imperfection.



Transparent E-Field plates: stress birefringence

- Polarization imperfection accumulates as laser beam passes through optical components (vacuum window, field plate, lenses, etc.) before reaching molecules.

Solids exhibit birefringence under stress as $n_\parallel - n_\perp = K\sigma$, potentially distorting linearly polarized light to be elliptically polarized as
$$S/I = \sin\left(\frac{2\pi}{\lambda} K\sigma t\right)\sin(\gamma).$$
$n_\parallel, n_\perp$ are indices of refraction, K= stress-optic coeff., σ = stress. S/I= fraction of circularly polarized component in light.



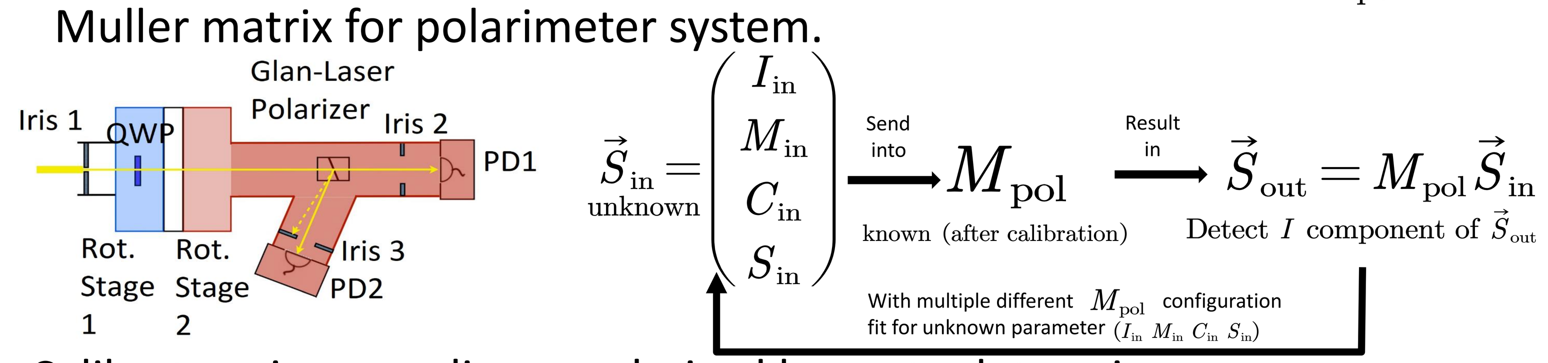
Sources for mechanical stress in field plates and windows (expected in ACME III):

External source
- Clamping
- Mounting
- Vacuum pressure (for vacuum windows)
- Differential thermal expansion

Internal source
- Laser-induced thermal stress: optics absorb laser power and build up temperature gradient and thus thermal expansion gradient, producing stress
- Residual stress from manufacturing

High Precision Polarimeter

- High precision polarimeter (developed in ACME II, V. Wirthl et al, arXiv:1703.00963) to measure polarization imperfections and birefringence in optical components for ACME III.
- Working principle: $\vec{S} = (I, M, C, S)$ as Stokes parameter of light, $M_{\rm pol}$ = Muller matrix for polarimeter system.

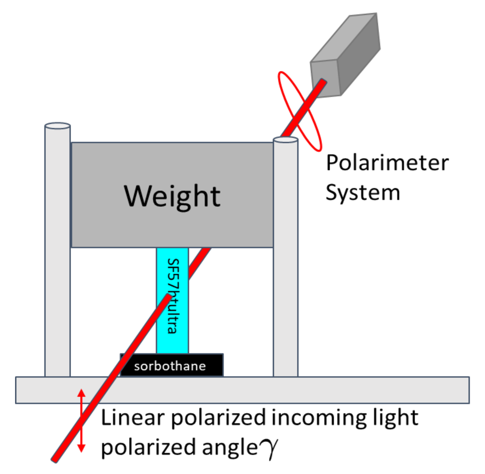


- Calibrate using pure linear polarized beam to determine $M_{\rm pol}$.
- Experimental setup: waveplate and PBS, each in rotatable stage. Two photodiodes monitor light transmitted and rejected by polarizer.
- **For circular polarization fraction S/I in light, precision $|\Delta(S/I)| < 0.1\%$ achieved.**

Glass material with low stress-optic coefficient

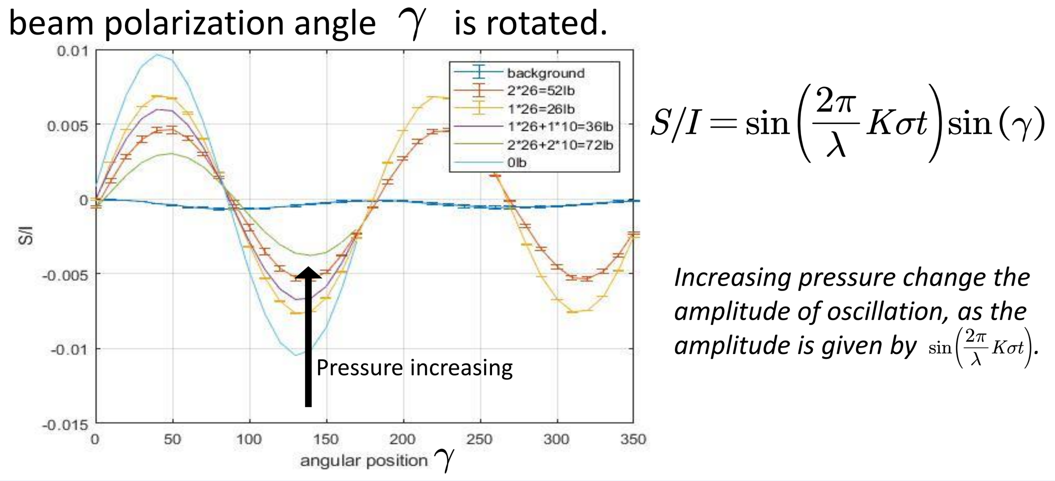
- To reduce stress-induced birefringence effect, use material with low stress-optic coefficient *K* and low laser absorption. We found Schott SF57HTUltra glass provides **~40x times smaller stress induced birefringence than standard glasses** at 703nm.

	Borosilicate (Borofloat)	N-BK7	Corning 7980 Fused silica	**SF57HTUltra**
Stress-optic coeff. $K\,[10^{-3}{\rm GPa}^{-1}]$	4.0	2.77	3.5	**0.075**



Test setup verifying low K property for SF57HTUltra

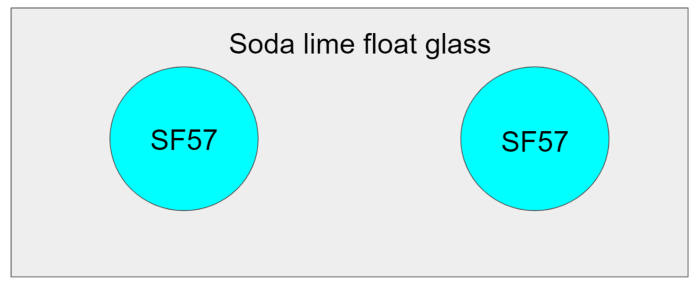
- Measured K for SF57HTUltra by applying pressure onto a test sample while sending a laser beam going through it. Incoming beam polarization angle γ is rotated.



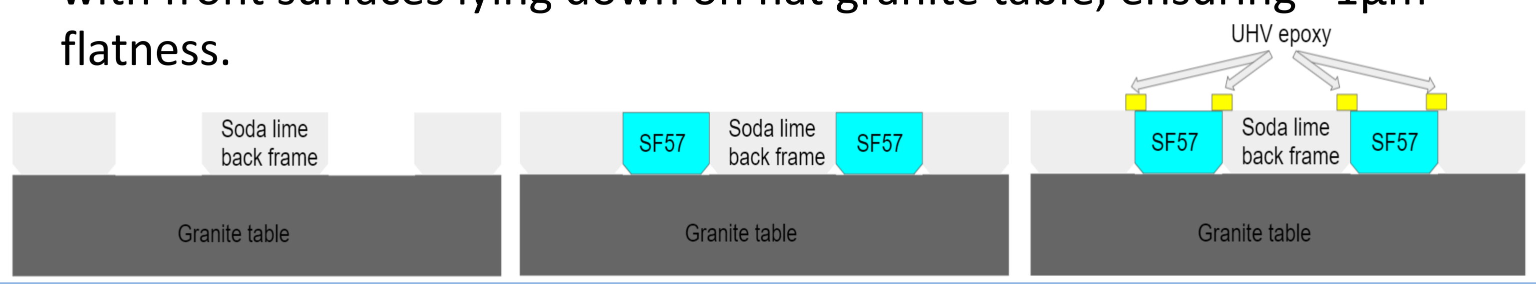
$$S/I = \sin\left(\frac{2\pi}{\lambda} K\sigma t\right)\sin(\gamma)$$

Increasing pressure change the amplitude of oscillation, as the amplitude is given by $\sin\left(\frac{2\pi}{\lambda}K\sigma t\right)$.

ACME III Field Plate Design



- Special glass SF57HTULTRA not available with dimension (>1m long) required for ACME III interaction region.
- Current plan: build composite field plate with two SF57HTULTRA disks for laser access and soda lime glass (<0.6 ppm/K thermal mismatch) support frame with holes to match disks.
- Assembly: glue disks to support frame with UHV-compatible epoxy. Glue with front surfaces lying down on flat granite table, ensuring ~1μm flatness.



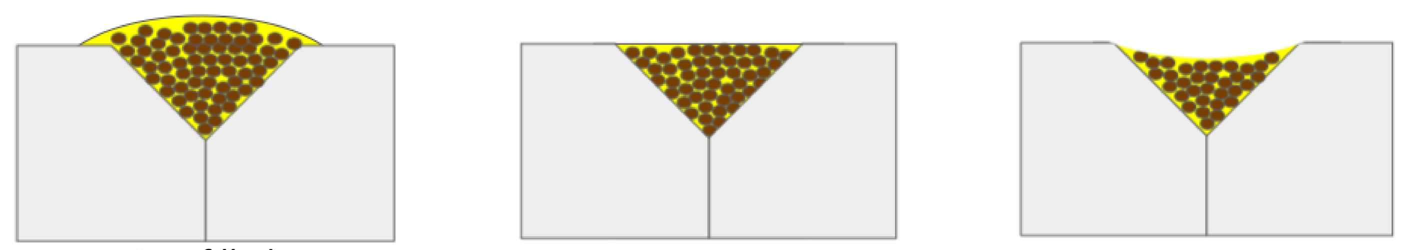
References

For more information, visit electronedm.info.

More information about topics in this poster:
1. **ACME II result:** Improved limit on the electric dipole moment of the electron, ACME Collaboration, Nature 562, 355-360 (2018).
2. **Detailed analysis on polarization imperfection related systematic (ACME I):** Methods, analysis, and the treatment of systematic errors for the electron electric dipole moment search in thorium monoxide, J Baron et al 2017 New J. Phys. 19 073029
3. **Self-calibrating polarimeter:** A self-calibrating polarimeter to measure Stokes parameters, V. Wirthl et al, arXiv:1703.00963
4. **SF57HTULTRA:** Datasheet from SCHOTT https://shop.schott.com/advanced_optics/en/Optical-Glass/SF57HTULTRA/c/optical-glass/glass-SF57HTULTRA

Flatness Across Field Plate Front Face

- Glass edges have small chamfer, must fill at epoxy joint for electrode flatness.
- After SF57 pieces securely glued at back of soda lime glass, remaining divots at front face chamfer filled with epoxy for better flatness.
- Interface region includes two chamfers with face width ~250μm. Initially, overfill divots with epoxy, then scrape off excess epoxy with razor blade before curing.
- Over-removal of epoxy mitigated by adding particulates to epoxy and repeating procedure post-cure.



Overfilled epoxy *Extra epoxy scraped* *Epoxy over-removal*

Sources of stress in the composite field plate

- Soda-lime glass chosen for thermal matching purpose (ΔCTE <0.6 ppm/K). Approximate rotational symmetry about SF57 disk reduces thermal-mismatch-induced birefringence.
- As in ACME I and II, thermal stress from laser heating present.
- Epoxy curing process can generate non-trivial stress, suppressed by carefully machining disks and holes to minimize epoxy volume.
- Data from ACME I and II suggests that clamping stress on field plate potentially large. Further investigation needed for optimal clamping design.

	S/I gradient (%/m)	Method
Epoxy	2	Experiment
Residual	4	Experiment
Clamping	3	Theory
Vacuum	1	Theory
Laser heating	0.6	Theory
Thermal mismatch	0.4	Theory
ACME III Quadrature Sum	6	Theory
ACME II overall	~100	Experiment

Sources of stress and estimated contribution to ellipticity gradients in ACME III. Theory values are conservative estimates based on modeling with known material properties.

Birefringence related systematics in ACME summary

- Model for systematics related to non-reversing E-field scales linearly with gradient of S/I across laser beam. In ACME I, ΔS/I ~1%/mm, corresponding to EDM systematic uncertainty $\Delta d_e \approx 0.5 \cdot 10^{-29}$e·cm
- In ACME II, ΔS/I ~0.1%/mm, corresponding to systematic uncertainty $\Delta d_e \approx 0.1 \cdot 10^{-29}$e·cm
- For ACME III, goal is ΔS/I ~0.01%/mm, sufficient for ACME II target sensitivity $d_e > 1 \cdot 10^{-30}$e·cm. Preliminary polarimeter data is promising and target ellipticity gradient seems within reach.