CeNTREX: Cold molecule Nuclear Time Reversal Experiment

D. DeMille[1], D. Kawall[2], E. Norrgard[1], K. Wenz[3], T. Zelevinsky[3]

[1]Yale University, [2]University of Massachusetts Amherst, [3]Columbia University

Motivation: Solve a deep mystery about the origin of matter

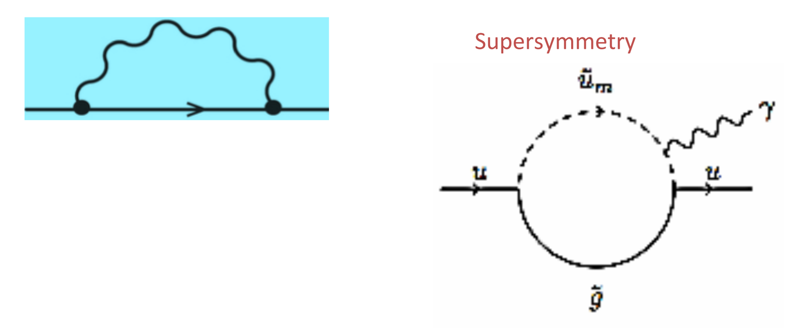
Why is the Universe made exclusively of matter? At its inception, matter and anti-matter were created in equal amounts. The Standard Model of particle physics is incomplete, and cannot explain this most fundamental problem.

New theories of physics can explain resolve the puzzle, but require the existence of fundamentally new particles and forces. In many of these theories, other new phenomena result and also lead to tiny but detectable deformation of the nuclear electric charge distribution, a Schiff Moment (SM), that violates time and parity reversal symmetries.

A new cold molecular beam experiment is under development to search for time- and parity-violating interactions in the ^{205}Tl nucleus in the diatomic molecule TlF. A first-generation experiment promises improvement in sensitivity to certain T-odd nuclear forces, including 100-fold improvement in the θ parameter of QCD, and significant improvement on the limits on the proton permanent electric dipole moment (EDM) by a factor of 30.

New physics at the TeV scale is accompanied by new *CP*-violating phases, naturally leading to EDMs and Schiff moments near current experimental limits. Searching for EDMs and SMs is a window into new physics at the TeV scale.

Charge asymmetry comes from new particles and forces. Effects largest from simpler virtual processes with fewest quantum loops and lightest new particles.

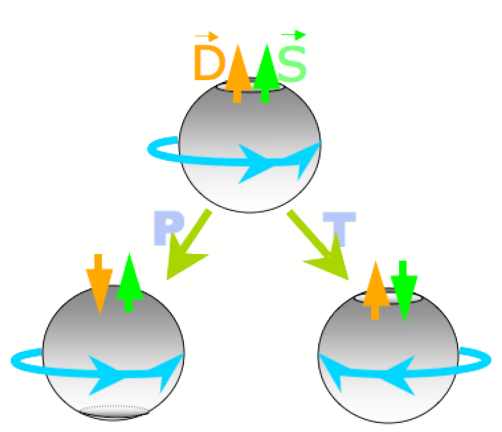


New Experiment: Three New Methods to dramatically improved sensitivity to new particle and forces

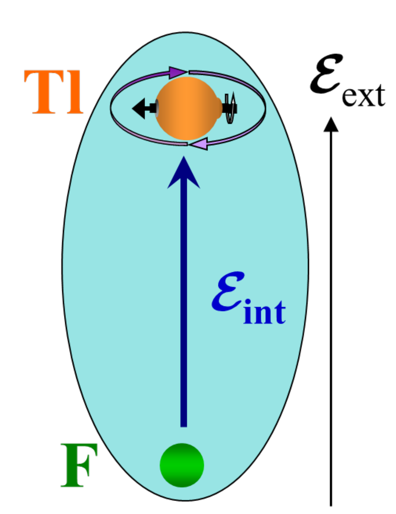
The signature of a nuclear Schiff moment (SM) is the precession of the nuclear spin vector I about a strong electric field E. The spin precession angular frequency ν is proportional to the spin-dependent energy shift $\delta E = h\nu \propto I{\cdot}E$. In our experiment the electric field E at the ^{205}Tl nucleus is a field internal to a polar molecule that has been polarized by an external laboratory field E_{lab}. Our approach uses diatomic molecules rather than atoms to search for a SM because the large polarizability of molecules leads to observable energy shifts that are 10^4 times larger than in atoms such as ^{199}Hg.

Sensitivity to the energy shift is proportional to the nuclear spin coherence time τ and to $N^{1/2}$ where N is the detection rate. New developments in cryogenic molecular beam sources produce much greater numbers of molecules N at lower velocity, permitting longer observation time τ. L. Hunter and D. DeMille identified a nearly-closed optical cycling transition that will permit high-efficiency state-preparation and detection, rotational cooling, and laser cooling to increase the statistical sensitivity significantly.

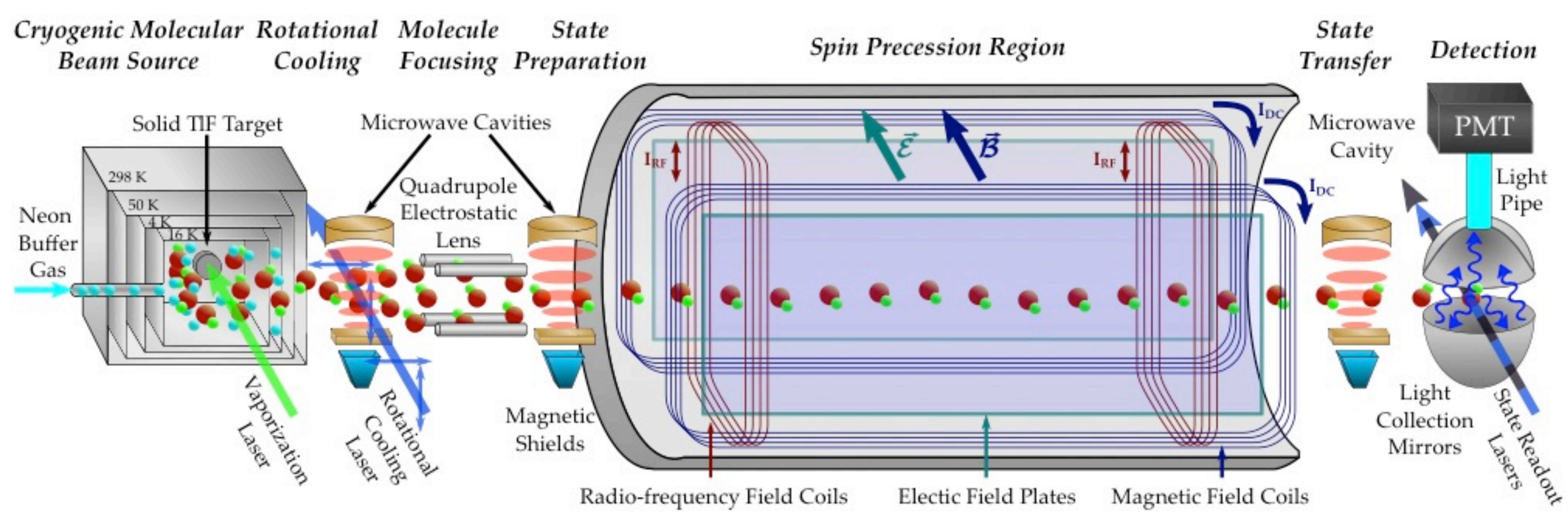
Using the source of ^{205}TlF molecules, a classic Ramsey separated-oscillatory fields measurement of the nuclear spin precession is performed with the molecules polarized by a strong electric field. We hope to achieve a frequency sensitivity of $\delta\nu \sim 0.2\mu$Hz in 300 hours of integration time in a first generation experiment.



Charge asymmetry along particle's spin axis violates time-reversal asymmetry and parity asymmetry, In most quantum field theories, *T*-violation is equivalent to *CP*-violation, the symmetry at the heart of the matter-antimatter imbalance



Torque from large intra-molecular E-field maximizes sensitivity to nuclear spin precession in an electric field from a Schiff moment.



TlF molecules from a cryogenic buffer gas beam source traverse a region of rotational cooling (using microwaves and lasers) to enhance the population in a single rotational/hyperfine sublevel. The molecules are focused and collimated by an electrostatic quadrupole lens then enter a magnetically-shielded spin-precession region with homogeneous electric and magnetic fields after being prepared in the desired spin state by a RF and microwave fields. After free flight through the roughly 2.5 m interaction region, a second set of microwave and RF coils projects the final spin state onto two spectroscopically-resolved rotational levels. The spin precession angle is read out by alternately exciting the rotational levels optically and collecting the laser-induced fluorescence. A nuclear spin precession angle that depends on the electric field direction is the signature of a nuclear Schiff moment or nuclear EDM.

Project Timeline

- Phase 1 (3 years): Design, fabricate, assemble, and test new system. Analyze potential systematic errors, design procedures to suppress errors
- Phase 2 (2 years): Take a few weeks of data, take 10x more in auxiliary data for systematics tests
- Projected sensitivity 100x better than current limits to some types of *T*-violating forces (*CP*-violating forces).
- Phase 3: (after 5 years) Strong potential for further 100x additional gain using slower and brighter molecular beam from transverse laser cooling, ultimately trapping of ultra cold TlF

Particle Physics Relevance and Impact

- Discovery of charge asymmetry would mean new particles exist, and they mediate new *CP*-violating forces. Could explain matter-antimatter imbalance
- Sensitivity to new physics can surpass the LHC in many models, not just SUSY
- One of the few known ways to be sensitive to anticipated new particle with masses in the 1-20 TeV range

HEISING-SIMONS FOUNDATION

Amherst Center for Fundamental Interactions
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

John Templeton Foundation