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Measuring the electron's electric dipole moment using YbF: data acquisition and analysis

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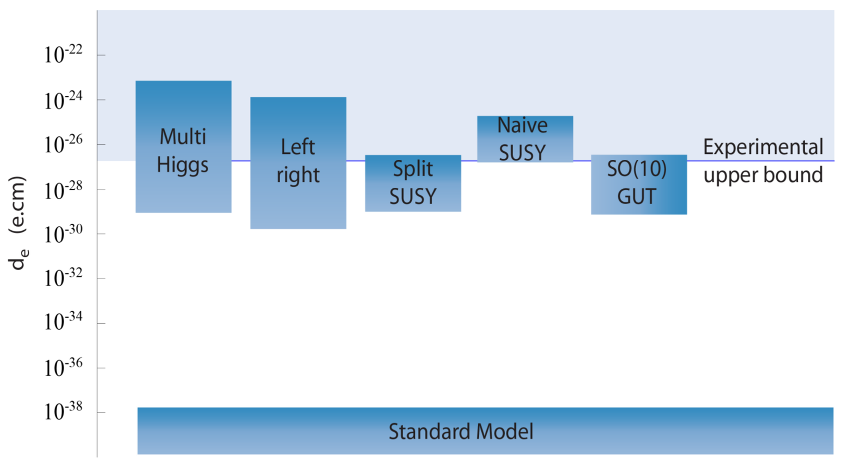
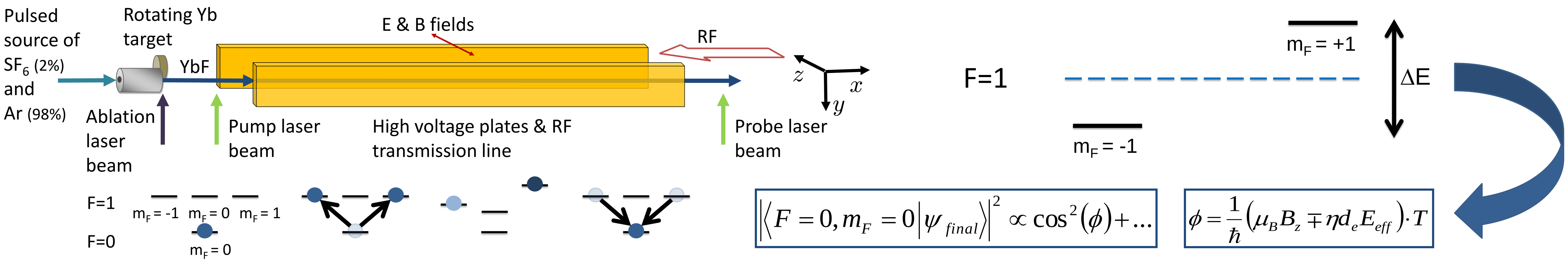
Introduction

It is well known that the existence of an electron electric dipole moment (eEDM) would violate time reversal symmetry. The Standard Model predicts an eEDM less than 10^{-38} e.cm. However, many popular extensions predict values in the range 10^{-29} – 10^{-24} e.cm. Our experiment currently has the potential to measure eEDMs down to approximately 5×10^{-28} e.cm, making it a precise test for physics beyond the Standard Model.



Experiment



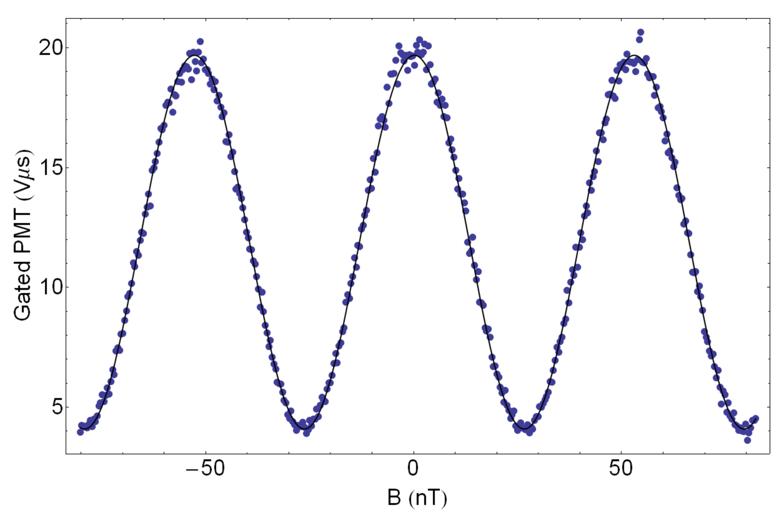
$$\left|\left\langle F=0, m_F=0 \middle| \psi_{final}\right\rangle\right|^2 \propto \cos^2(\phi)+\ldots$$

$$\phi = \frac{1}{\hbar}\left(\mu_B B_z \mp \eta d_e E_{eff}\right)\cdot T$$

Molecules are prepared in their F=0 ground state. A 18μs π-pulse of 170MHz rf drives the molecular state into an equal superposition of F=1, $m_F=\pm1$. Static E & B fields are applied to split these levels, which gain a phase difference of approximately π/4 over a 660μs evolution period. A second rf π-pulse recombines the states with a phase dependant probability. The populations before and after the rf interactions are measured through laser induced fluorescence (LIF).

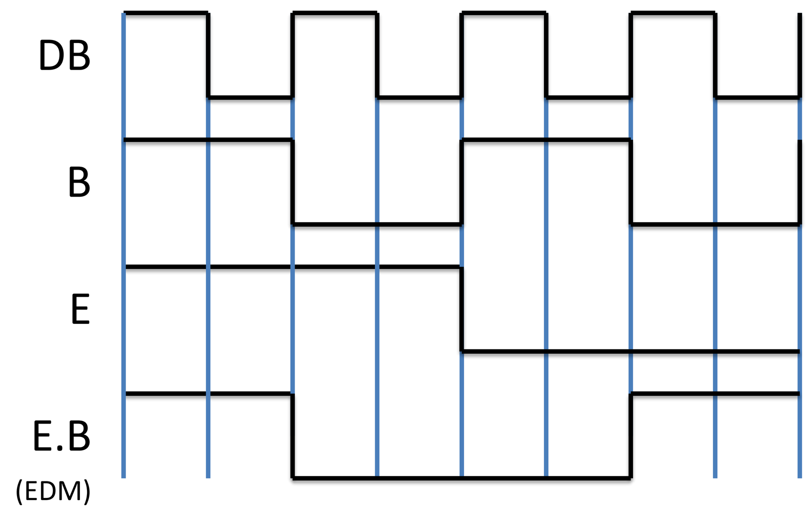
An eEDM just below the current world limit at 5×10^{-28} e.cm would induce a splitting of 2mHz. This would correspond to phase difference of 7μrad. A relatively large 12nT B-field is applied so data is acquired where we are most sensitive to this minute shift.

Scanned interference fringes



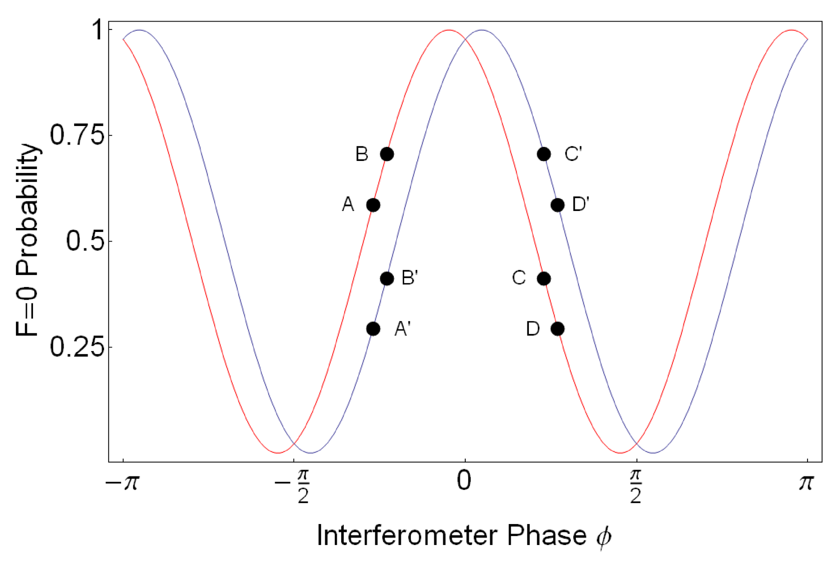
Cos² fringes scanned out by varying the magnetic field applied along z over a 160nT range.

Switching patterns



$$d_e = \frac{\mu_B dB}{2\eta E_{eff}}\frac{EDM}{CAL}$$

Corresponding measurement points



$$EDM = \frac{1}{8}\left[(A+B+C'+D')-(A'+B'+C+D)\right]$$

$$CAL = \frac{1}{8}\left[(B+C+B'+C')-(A+D+A'+D')\right]$$

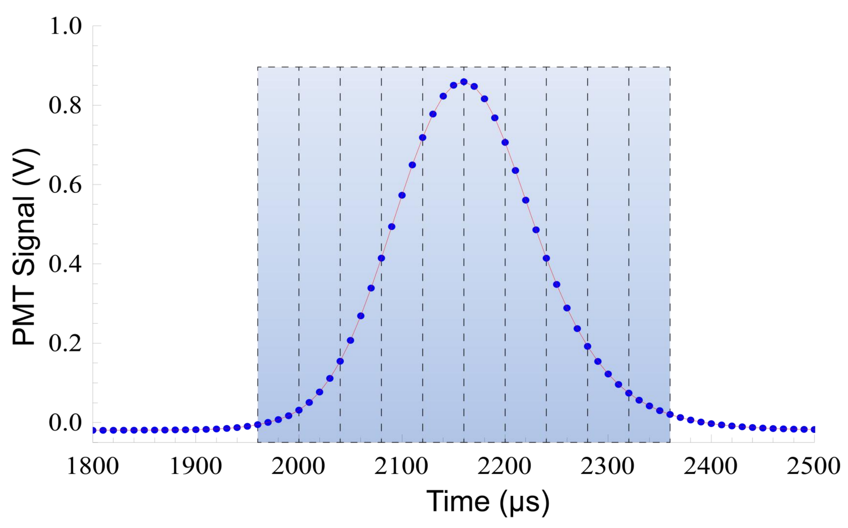
A non-zero eEDM would cause the interference fringes (shown above left) to shift left or right when the polarity of E is switched. The polarity of B is also switched, and its amplitude modulated, so that we sample 8 points with a scheme which is insensitive to fluctuations in LIF signal (above centre and right). Further to these 3 channels the laser and rf pulse parameters are switched in-between molecular pulses, forming a block of data constituting 4096 'shots'. This complex switching scheme allows parameters to be locked and measured, and reduces the impact of noise.

Tests for systematic effects

In order to probe for new unidentified systematic effects many tests are performed which include:

Channel	Description	Mean / Error	Significance
DB	Fringe contrast	203	Nothing special
SIG	Average signal	144	
LF (pump)	Signal change as pump laser frequency is stepped	166	Pump laser freq is tied to probe laser freq by an AOM. LF (probe) is zero on average but the pump laser has a detuning of 1.5MHz on average from Doppler shifts and VCO drifts
LF.DB	Contrast change as laser frequency is stepped	51.9	Fringe contrast is reduced as less molecules are pumped into their F=0 ground state
RF1F.RF2F	Correlation between rf pulse detuning	45.6	The two frequencies shift together as would be expected due to slow drifts in HV output
RF1F	Detuning of 1st rf pulse	21.8	100Hz red detunings on average, which are small compared to the 50kHz transition linewidth
RF2F.DB	Contrast change as rf frequency is stepped	5.51	
RF1F.DB		4.02	
RF1A	Signal change as rf amplitude is stepped	10.3	Slightly high due to poorly set values at the beginning of data clusters (before they locked in)
RF2A		12.4	
π.RF2A	Correlation between rf π-phase flipper and rf2 amplitude	33.6	π phase reversal is imperfect. rf phase difference is also randomised so this is not a problem
π.RF2A.DB		11	
All other channels	N/A	< 3	Great, there are no unexpected correlations!

• Checking all 512 analysis channels for a mean to error ratio larger than 3.



• Analysing the EDM and other important channels across molecular time of flight.

Also:

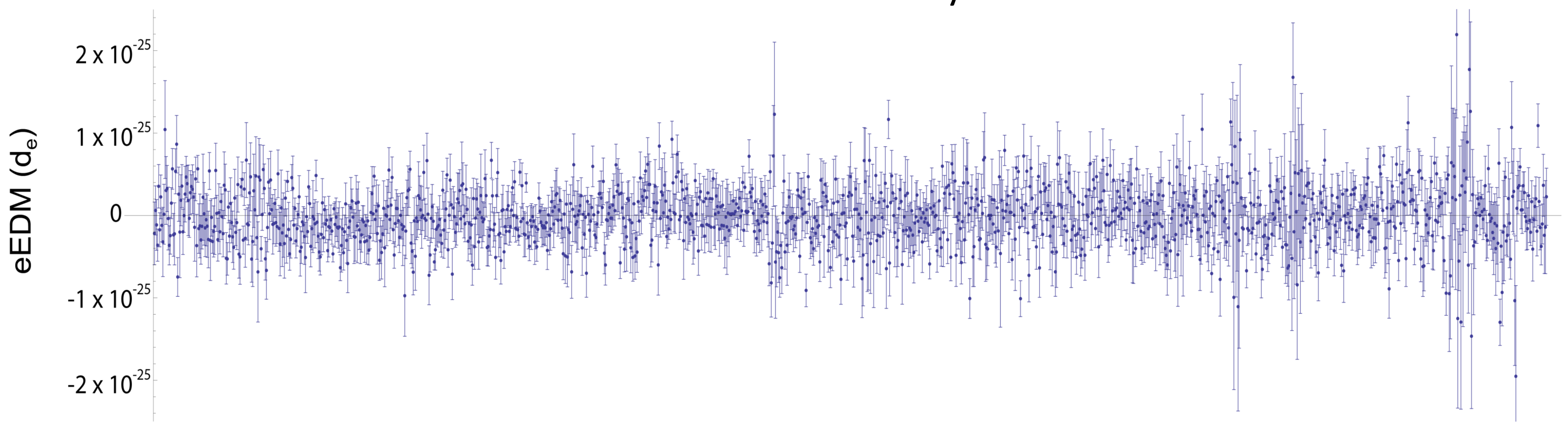
• Investigating the effects of asymmetric E-field reversals.

• Investigating the effects of offset plate voltages.

• Running with detuned laser and rf parameters.

• Running with a large applied B field in the x- & y- axes.

• Checking for a non-zero EDM across a 9V battery and a 10kΩ short.



• Taking a null data set, with no E-field reversal, which comprised 8000 blocks of data.