Progress Towards Measurement of the Nuclear Anapole Moment of $^{137}$Ba Using BaF Molecules

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Motivation and Potential Impact

- Measure nuclear spin dependent parity violating (NPV) effects
- Strength of interactions changes
  - Weak interaction: $\lambda = \frac{G_F}{\sqrt{2}}$ (weak force strength)
  - Strong interaction: $\frac{N_c \lambda}{\sqrt{2}}$ (strong force strength)
- Two primary contributions to NPV:
  1. $Z$ Boson Coupling
  2. Nuclear Anapole Moment

What is the Nuclear Anapole Moment?

- PV electronic interactions and nuclear anapole moment
- Optical angular momentum
- Nucleus spin
- Nucleus current

Measurement Strategy

- Nuclear parity violation
- Stark Interference
- First Molecular Species: BaF

Stark Interference

- Start with only lower state populated
- Drive population to upper states with blue detuned E field
- $\lambda$ changes with R exchange
- Anapole modifies amount of population driven
- With a single cycle stimulated electric field, $E(t) \sim E_0 \sin(\omega t)$:
  - Population transfer:
    - $\Delta = \omega - \Delta E$
- Anapole experiment with $E_Z \rightarrow -E_Z$
- Subtract two runs and squared to get "symmetry" $\Delta$
- Scale for $W$ to get NPV strengths
- Shot noise uncertainty:
  - $\Delta W \approx \frac{1}{2 N W} \sqrt{2 N}$

The Experiment

- Magnet solvent
- Optical angular momentum
- Nucleus spin
- Nucleus current
- Anapole moment

Systematic errors due to combinations of imperfections

- Non-resonant field $E_R$: detuning = even asymmetry, e.g. vertical octupole $E_R$ & quadrupole $E_Q$: detuning = odd asymmetry, even symmetry

Experimental Apparatus

- Variable magnetic field
- Monochromatic laser
- Ti: sapphire laser

Result Consistent with Zero in Control bosons: $^{137}$Ba

- $W_{\text{mol}} = -0.36 \pm 0.12 \text{Hz}$
- Expected $W_{\text{mol}}$ for $^{137}$Ba is $160 \pm 0.07 \text{Hz}$

Control Over $E_R$ + AC Stark Systematic

- Detuning offset and drift in $E_R$: $\Delta \lambda = -0.3 \pm 1.3 \text{MHz using Ne-He laser reference}$
- Select optical frequency stability requires suppressing $E_R$ + AC Stark systematic
- Plan for future: Modulator Transfer Spectroscopy (MTS) signal provides reliable frequency reference with very low uncertainty, e.g. from Doppler background
- Stable transfer cavity locked to frequency stabilization via PTH scheme and $^{136}$Ba laser lock offset feedback system

Frequency Reference: Modulator Transfer Spectroscopy

- Basic Concept of MTS
- Double-sided Feynman diagram

Summary and Outlook

- Short term goal: measure NPV in $^{137}$Ba with 100s stronger and 3x shorter buffer-gas time
- Long term goal: measure NPV in variety of nuclei
- NPV effects scale differently with mass and atomic number Z
  - $\lambda \propto Z^3$
- $\lambda \propto Z^3$ exchange constant with $\propto Z$
- $\propto Z$ overall signal $\propto Z$
- Only spin-dependent effects, must measure multiple nuclei, over wide range mass

For further information on: