High Resolution Two Photon Spectroscopy of the *6p←5p* transition of Xenon at 252.5 nm

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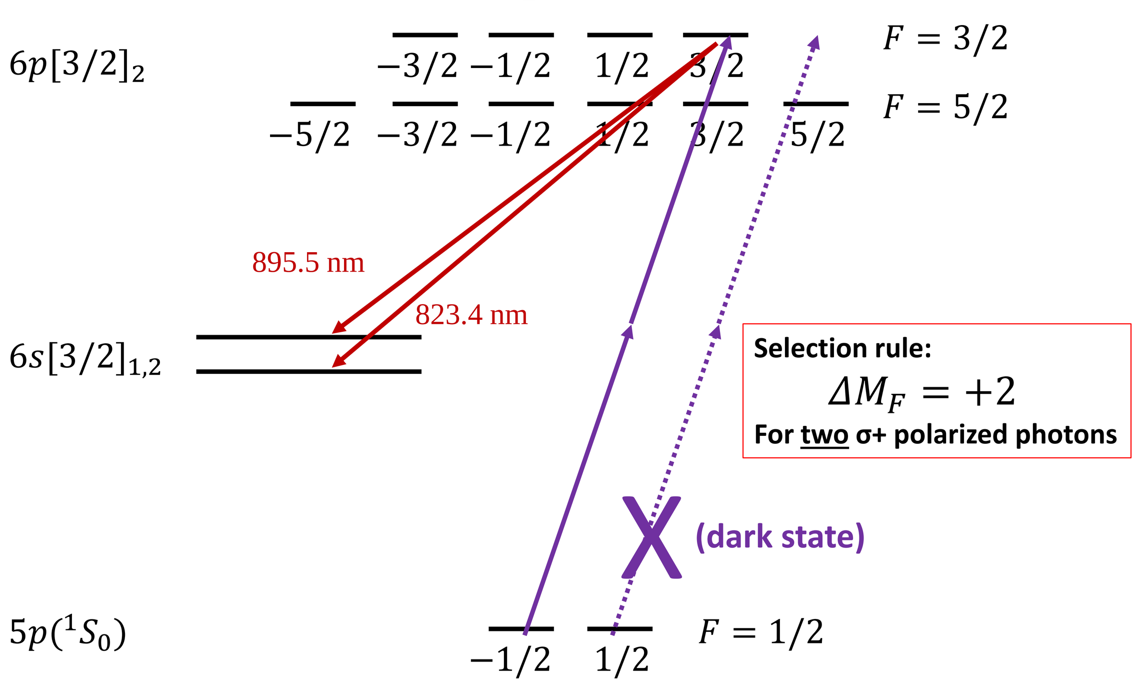
1) Motivation

The proposed dual ^{199}Hg/^{129}Xe comagnetometer for nEDM measurements at TRIUMF will measure both the magnetic field B_0 and gradient dB_0/dz. This will eliminate systematic errors due to GPE:

$$\omega_{Hg} = -\gamma_{Hg}B_{0z} - \frac{\gamma_{Hg}^2 R^2}{2c^2}\frac{\partial B_{0z}}{\partial z}E + \frac{\gamma_{Hg}^3 R^2}{2c^4}B_{0z}E^2 + \frac{3\gamma_{Hg}^3 R^4}{16\langle v_{Hg}^2\rangle}B_{0z}\left(\frac{\partial B_{0z}}{\partial z}\right)^2$$

$$\omega_{Xe} = -\gamma_{Xe}B_{0z} - \frac{\gamma_{Xe}^2 R^2}{2c^2}\frac{\partial B_{0z}}{\partial z}E + \frac{\gamma_{Xe}^3 R^2}{2c^4}B_{0z}E^2 + \frac{3\gamma_{Xe}^3 R^4}{16\langle v_{Xe}^2\rangle}B_{0z}\left(\frac{\partial B_{0z}}{\partial z}\right)^2$$

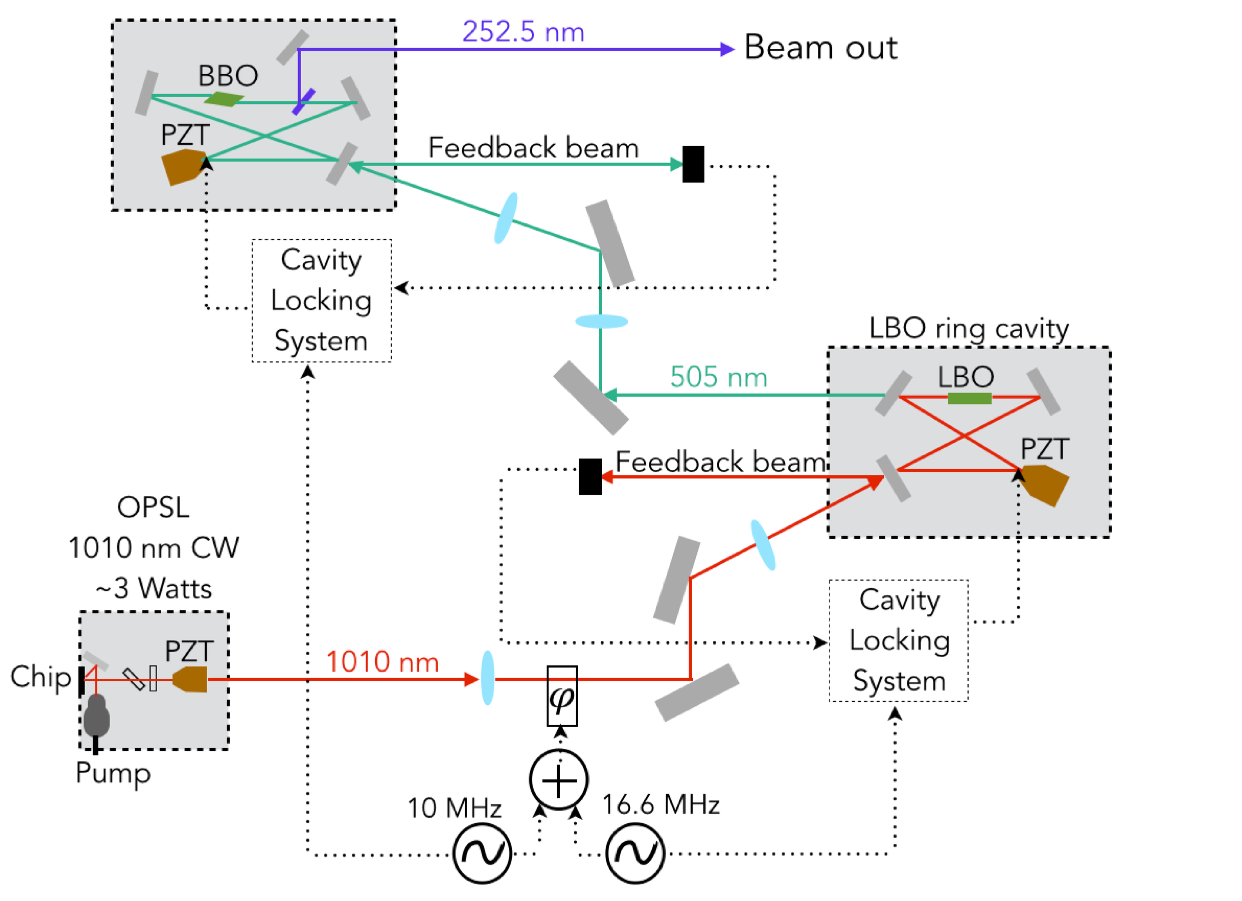
We propose optical detection of ^{129}Xe via two-photon absorption laser induced fluorescence (LIF). The transition rate to 6*p* (*J*=2, *F*=3/2) can be made sensitive to the nuclear polarization:

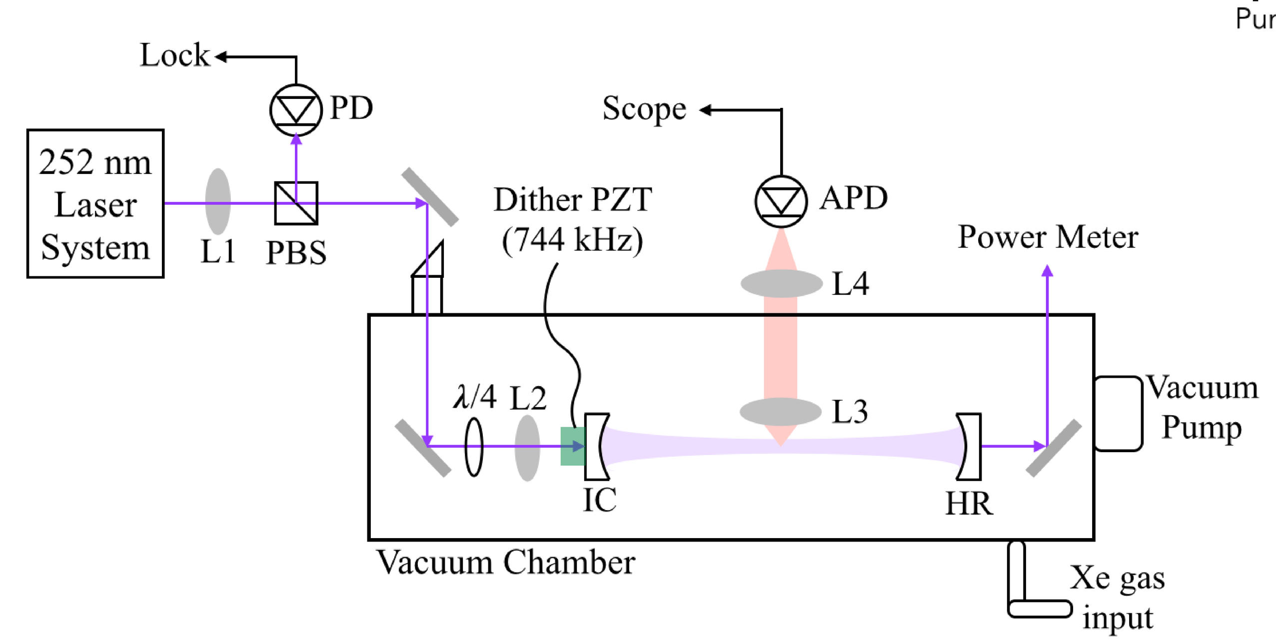


2) CW Laser and Vacuum Setup

Our group has developed a narrow-linewidth CW laser (right) to excite the transition to (*F*=3/2), based on nonlinear conversion of 1010 nm light from an OPSL using two successive doubling cavities with LBO and BBO crystals.

Wavelength: 252.5 nm
Linewidth: 174 kHz
Power: 300 mW



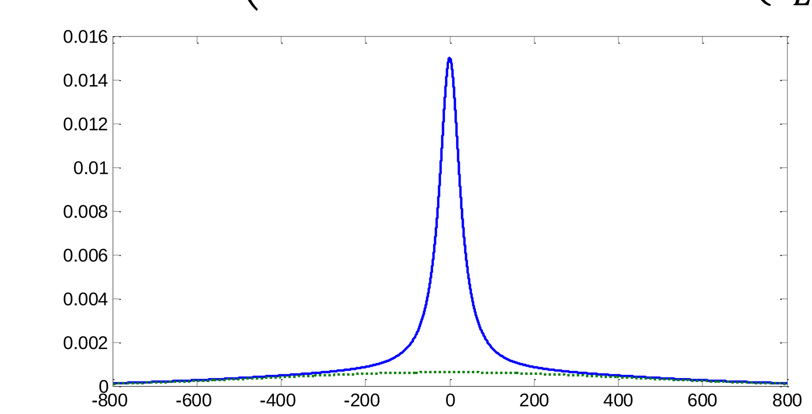


UV light is coupled into a Fabry-Perot enhancement cavity (left) under vacuum. The chamber is backfilled with 0.8 Torr of Xe (natural abundance), with 0.8 Torr of O_2 added to maintain cavity finesse. An off-axis APD detects LIF at 823 and 895 nm via lenses L3, L4.

3) Doppler-free Lineshape

Retroreflecting the UV beam enables a narrower lineshape with larger resonance excitation rate. The lineshape function is:

$$g(\omega) = \frac{2}{3\pi}\left(\frac{\sqrt{\pi}}{2kv}e^{-\Omega^2/(2kv)^2} + \frac{\Gamma_L}{\Omega^2 + (\Gamma_L/2)^2}\right)$$

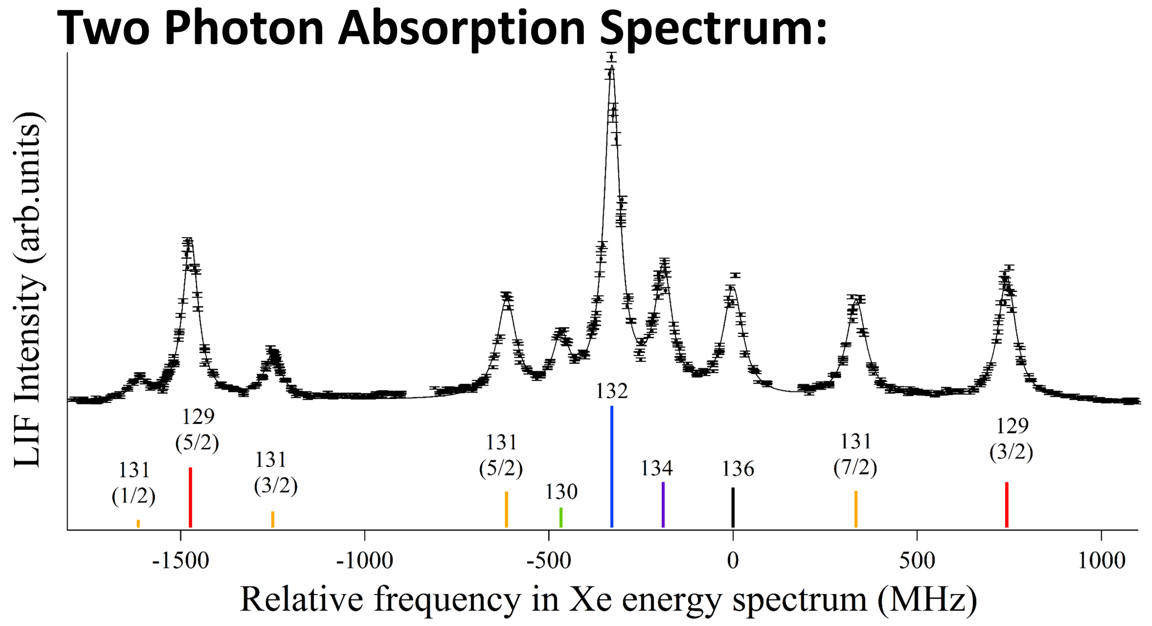


The lineshape is a Doppler-free Lorentzian superimposed on a Gaussian background. The FWHM (Γ_L = 59 MHz) is roughly consistent with pressure broadening (28.8 MHz/Torr).

Above 180 mTorr: pressure broadening dominates.
Below 180 mTorr: lifetime broadening (5 MHz) dominates.

4) Results

Two Photon Absorption Spectrum:



Hyperfine Structure:

HFS constants A_i and B_i were determined[1] from the peak centers $\nu_{0,i}$:

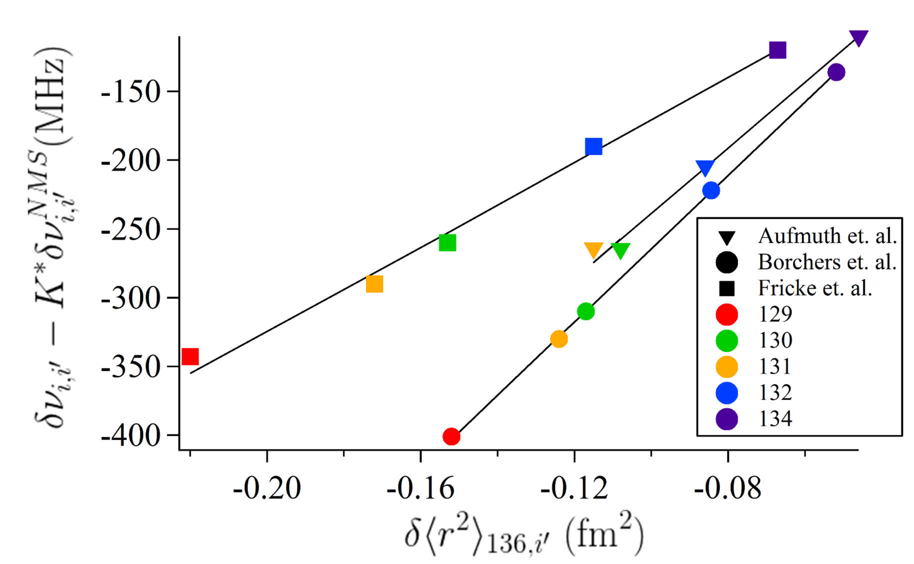
$$\nu_i(I,J,F) = \nu_{0,i} + A_i\frac{K}{2} + B_i\frac{\frac{3}{2}K(K+1) - 2I(I+1)J(J+1)}{4I(2I-1)J(2J-1)}$$

$$K = F(F+1) - I(I+1) - J(J+1)$$

HFS Constants (MHz)	
A_{129}	-886.3(2)
A_{131}	262.6(10)
B_{131}	34.8(5)

The ^{129}Xe (*F*=3/2) and (*F*=5/2) transitions are separated by 2216 MHz.

Isotope Shift and Nuclear Charge Radius:



Isotope shifts ($\delta\nu_{i,i'}$), comprised of a mass term and field term, are sensitive to nuclear parameters:

$$\delta\nu_{i,i'} = K^*\delta_{i,i'}^{NMS} + F^*\delta\langle r^2\rangle_{i,i'}$$

We fit the field shift component of $\delta\nu_{i,i'}$ against the change in squared nuclear charge radius between isotopes. The best fit is found using values of $\delta\langle r^2\rangle_{i,i'}$ from the ISOLDE experiment[2]:

$K^* = 0.36(2)$ $F^* = 2640(80)$ MHz fm^{-2}

Photon Count Rate and Detection Limit:

The photon count rate for the ^{132}Xe peak under the current conditions is **7.4x10^8 s^{-1}**. Under the assumption of isotropic LIF emission, we calculate an absorption cross section $\sigma^{(2)}$ consistent with the lower end of the range of previously published values.

The present photon counting rate predicts that the transition to ^{129}Xe (*F*=3/2) can be detected at a signal-to-noise ratio of >10 with a 10 ms measurement of isotopically pure ^{129}Xe gas at 1 mTorr.

[1] E. Altiere, E. Miller, T. Hayamizu, D. Jones, K. Madison, and T. Momose, submitted to PRD (2017).
[2] W. Borchers et. al. and the ISOLDE Collaboration, Phys. Lett. B **216**, 7 (1989).

5) Next Steps

We will obtain spectra at **lower pressure** and measure the dependence on **nuclear polarization and probe light polarization**. Low pressure is crucial for the planned nEDM measurements at TRIUMF in order to **avoid electric breakdowns** due to the applied fields.

Our lab has previously observed **emission anisotropy between off-axis and collinear detection** using a pulsed laser, as reported in the literature. Further experiments will study the threshold for the observed collinear fluorescence enhancement using CW light and allow a better estimate of $\sigma^{(2)}$.

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