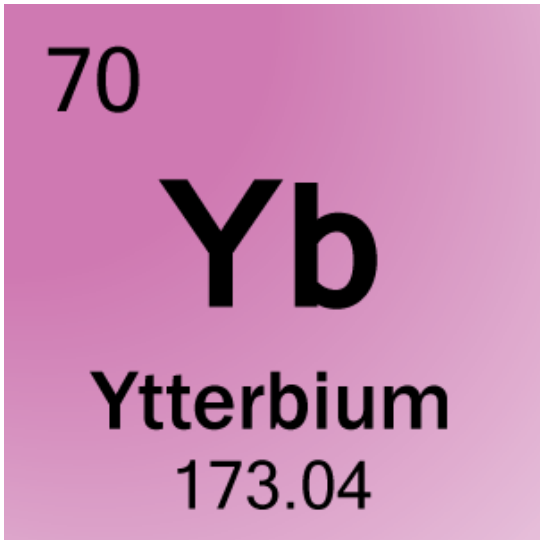
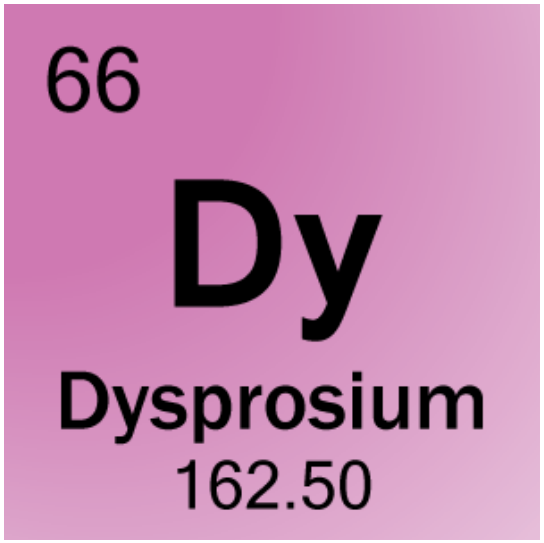
Parity violation in Yb

Dionysis Antypas

MITP Neutron Skin Workshop

Parity Violation in D. Budker's group





Dionysis Antypas

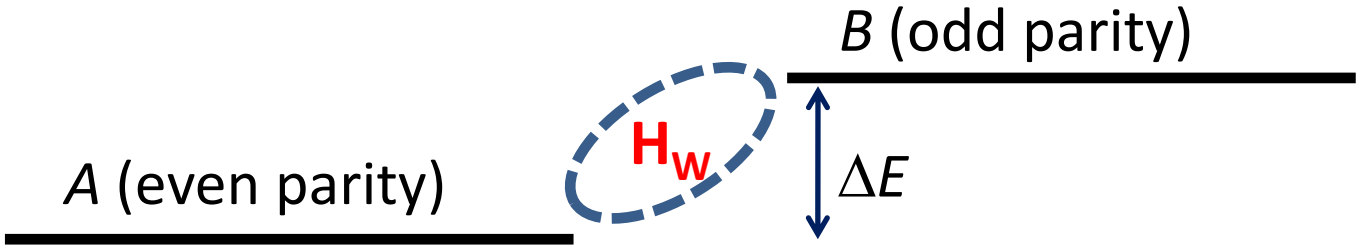
Anne Fabricant

Lykourgos Bougas

Outline

- Background
- Scientific motivation
- Yb experiment

APV: mixing of states of opposite nominal parity (PNC)



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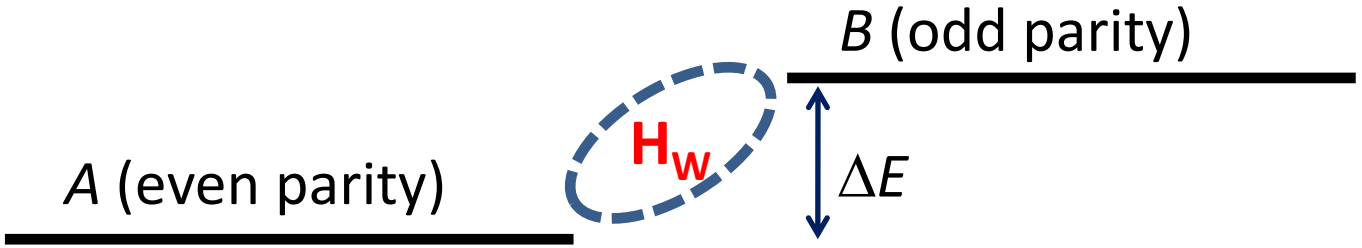


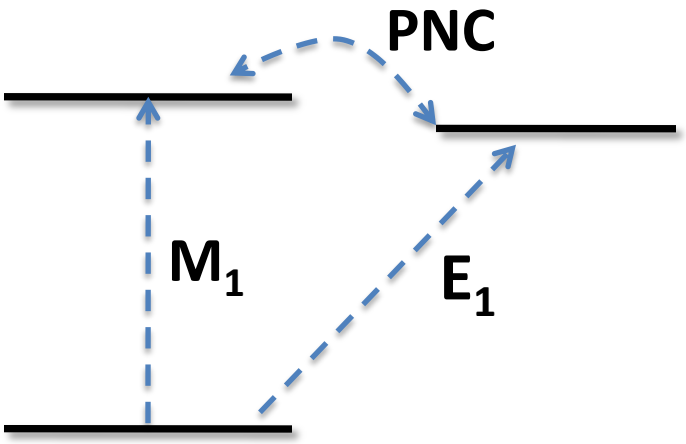
$$A \to A + i\varepsilon B;\ B \to B + i\varepsilon A$$

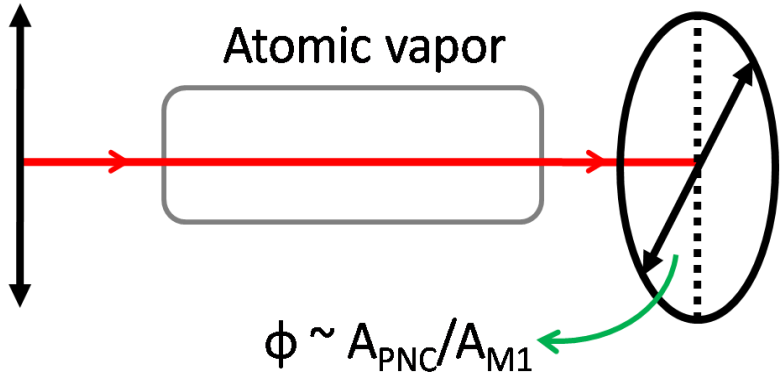
$$\varepsilon = \frac{\langle A|H_W|B\rangle}{\Delta E} \sim \frac{RZ^3}{\Delta E} \text{ - the Bouchiat Law}$$

APV **Enhancement**:

- Heavy atoms (high Z)
- Small ΔE

Types of APV experiments





- 100% contrast (small signal)
- No reversals

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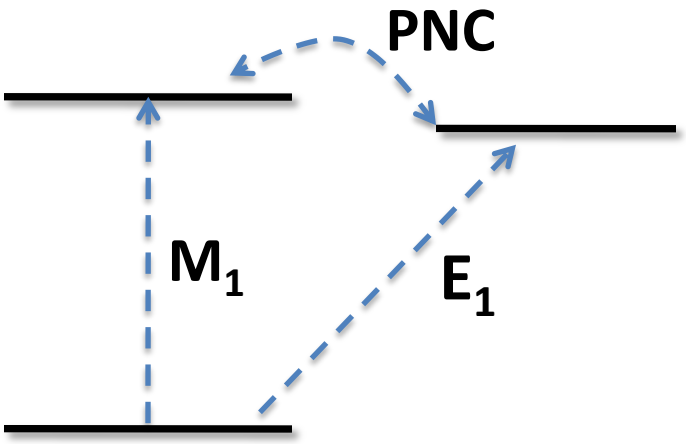

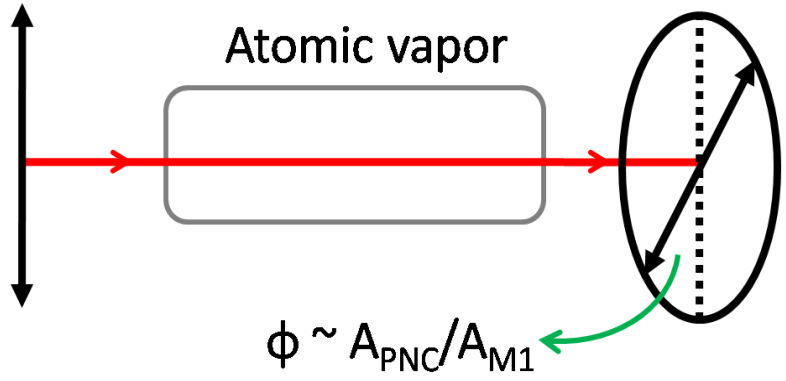

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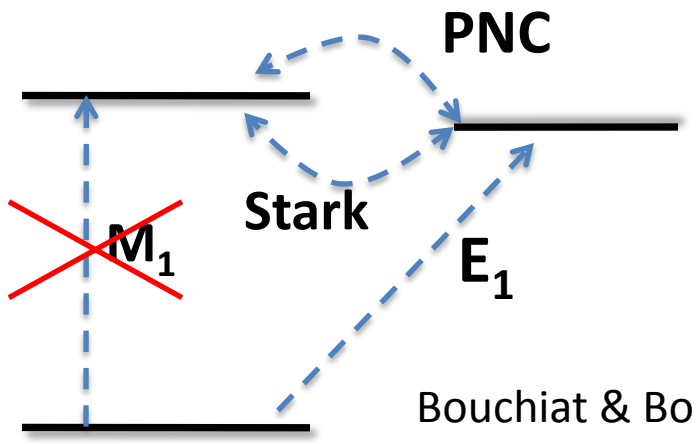


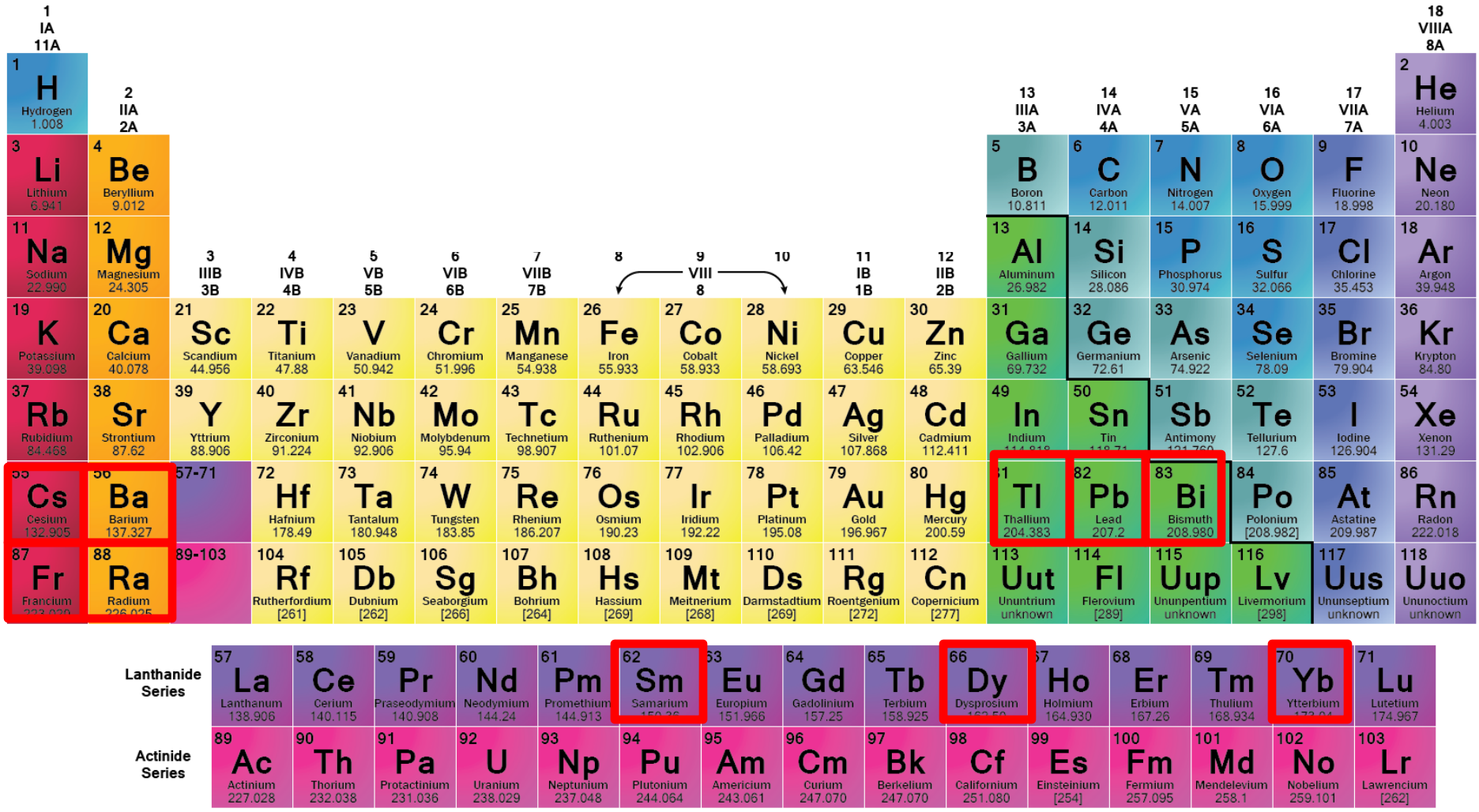
Bouchiat & Bouchiat

$$W_{\pm} = |A_{PNC} + A_{Stark}|^2$$

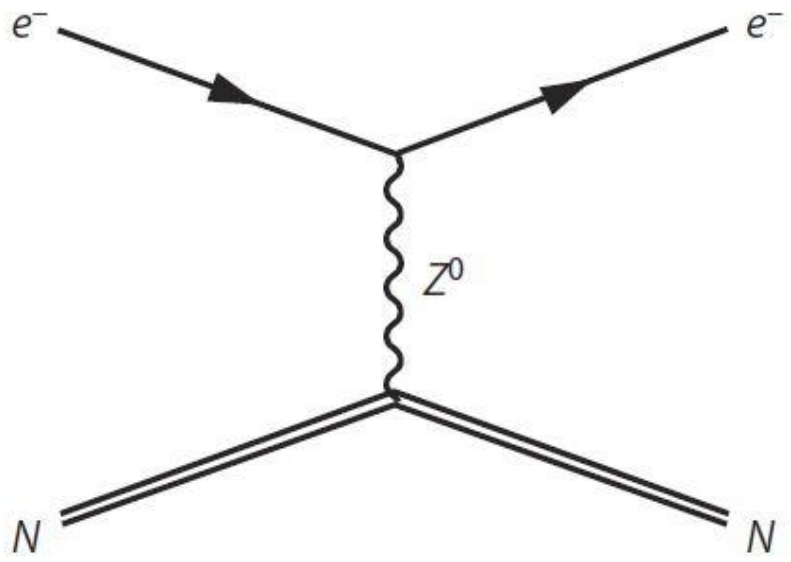
$$\approx |A_{Stark}|^2 \pm 2A_{PNC}A_{Stark}$$

- Small asymmetry on large signal
- Many reversals for checking systematics

Experimental PNC studies



Atomic Parity Violation: Main processes



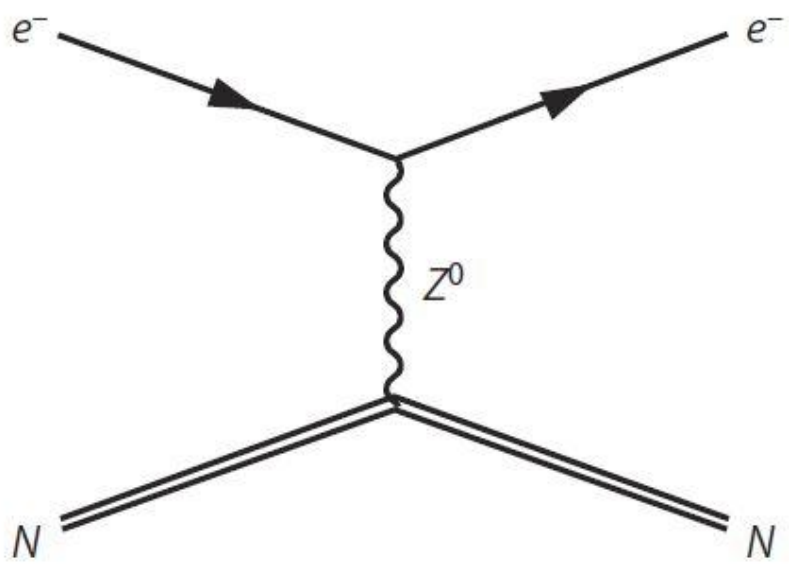
Nuclear spin independent

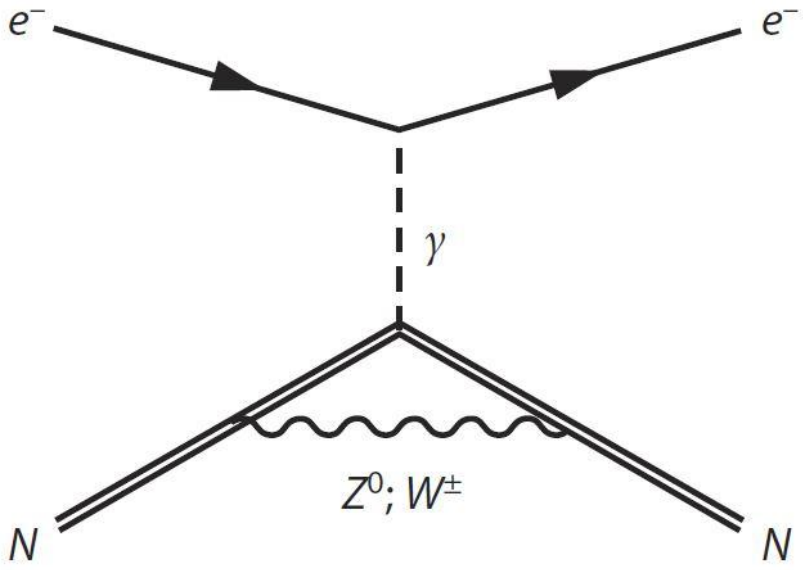
•measure of weak charge, Q_w

$$\langle j|H_W|i\rangle = \frac{G_F}{2\sqrt{2}} C_{ji} R_p^{2\gamma-2} \bar{Q}_W$$

• Lower bound on new Z' bosons
• Dark bosons?

Atomic Parity Violation: Main processes





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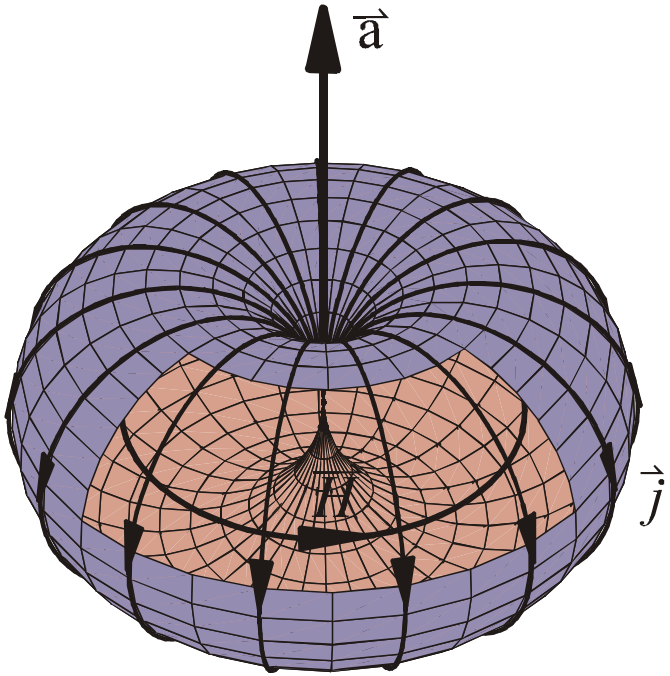
Nuclear spin dependent

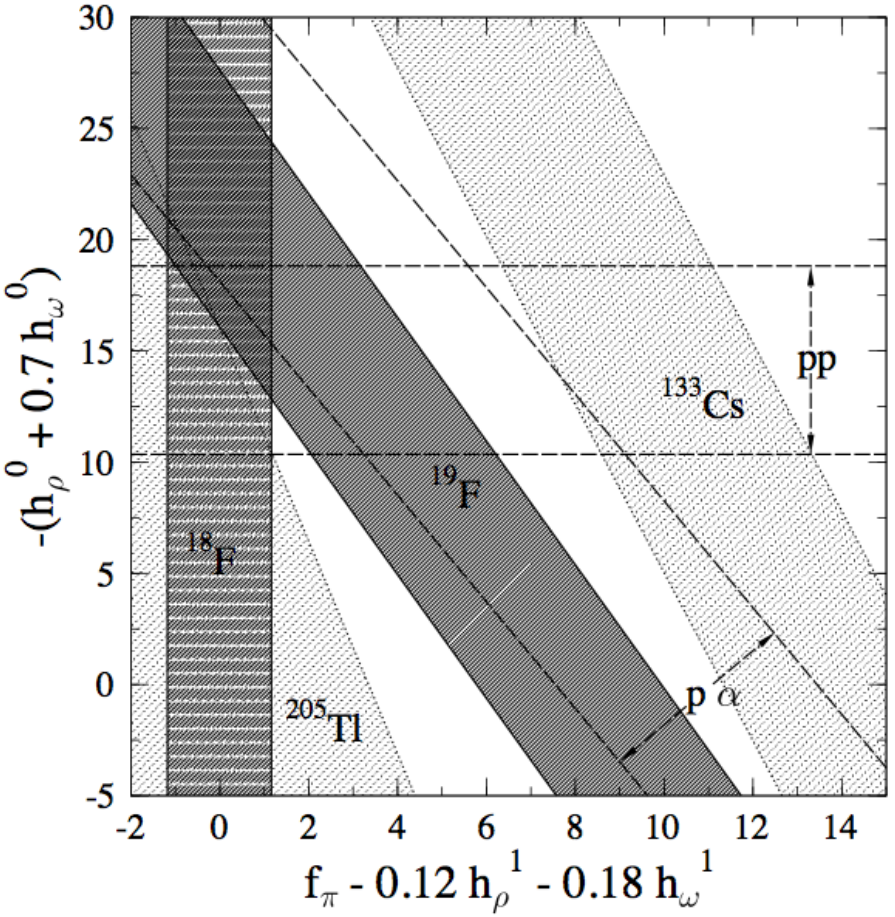
• dominant effect in heavy nuclei: anapole moment

Anapole moment



P-odd E/M moment from intranuclear PV

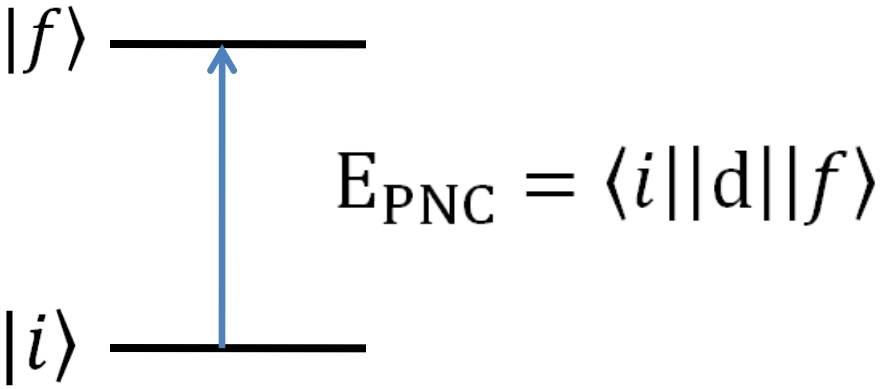
Probe of weak meson-nucleon couplings



Haxton, et. al.
PRC, VOLUME 65, 045502

Isotopic ratios in APV

- APV measures: $E_{PNC} = k \cdot \bar{Q}_W$



Element	δk
Cs	0.4 %
Yb	10 %

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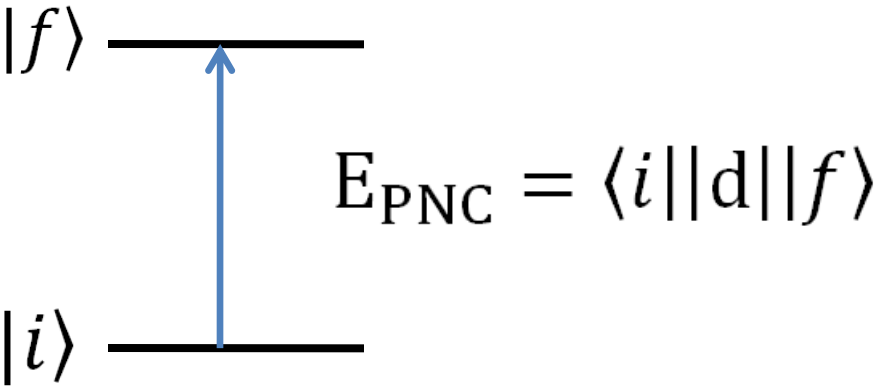

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- Atomic PV calculation errors cancel in isotopic ratios

  Dzuba, Flambaum, and Khriplovich, Z. Phys. D 1, 243 (1986)

$$R = \frac{E'_{PNC}}{E_{PNC}} = \frac{\bar{Q}'_W}{\bar{Q}_W}$$

Isotopic ratios and neutron skins

- Limitation to isotopic ratio method: enhanced sensitivity to the neutron distribution $\rho_n(r)$

  Fortson, Pang, Wilets, PRL **65**, 2857 (1990)

$$\bar{Q}_W = -Nq_n + Zq_p(1 - 4\sin^2\theta_W) + \Delta Q_{\text{new}}$$

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- Atomic PV $\leftrightarrow$ Neutron distributions

$$\frac{E_{PNC}}{E'_{PNC}} \approx 1 + \frac{\Delta N}{N} + \frac{3}{7}(\alpha Z)^2 \frac{[\Delta R'_{ns} - \Delta R_{ns}]}{R_p}$$

skin contribution for ^{170}Yb - ^{176}Yb isotopes ~ 0.1%

Isotopic ratios and neutron skins

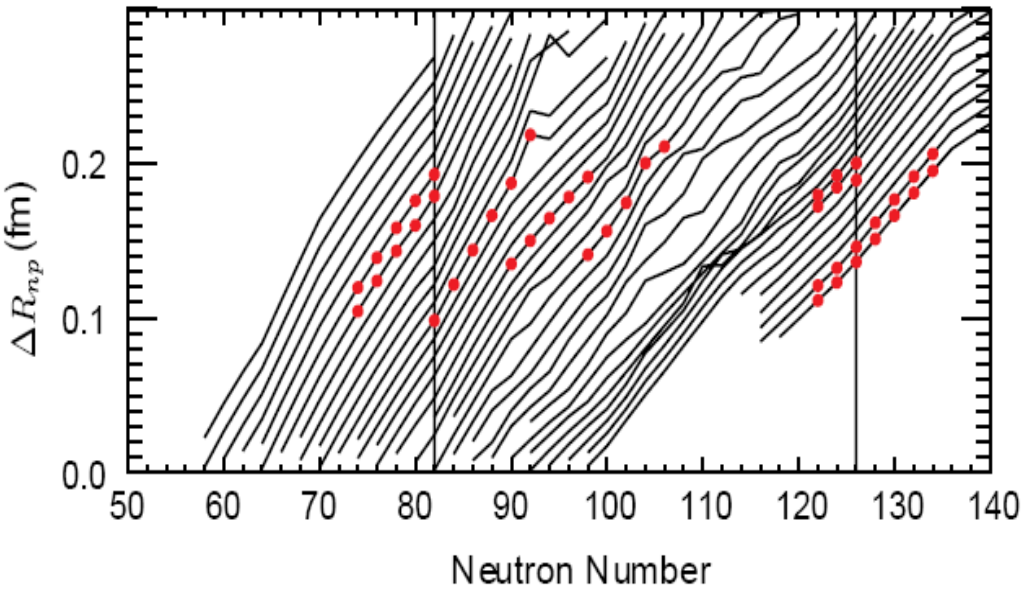
[PHYSICAL REVIEW C **79, 035501 (2009)**]

Dispelling the curse of the neutron skin in atomic parity violation

B. A. Brown,[1] A. Derevianko,[2,3] and V. V. Flambaum[3]

[1]*Department of Physics and Astronomy, and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*
[2]*Department of Physics, University of Nevada, Reno, Nevada 89557*
[3] *School of Physics, University of New South Wales, Sydney 2052, Australia*

- Neutron-skin effects in different isotopes are **correlated**



APV in ytterbium

- **Large** APV effect (DeMille *et al*, 1995 - Tsigutkin *et al,* 2009)

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- 7 stable isotopes (A=168, 170-174,176)

Isotope	NA (%)	I
^{174}Yb	31.8	0
^{172}Yb	21.8	0
^{176}Yb	12.8	0
^{173}Yb	16.1	5/2
^{171}Yb	14.3	1/2
^{170}Yb	3.04	0
^{168}Yb	0.13	0

PNC on chain of isotopes → neutron skins

→ New Physics?

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PNC on chain of isotopes → neutron skins

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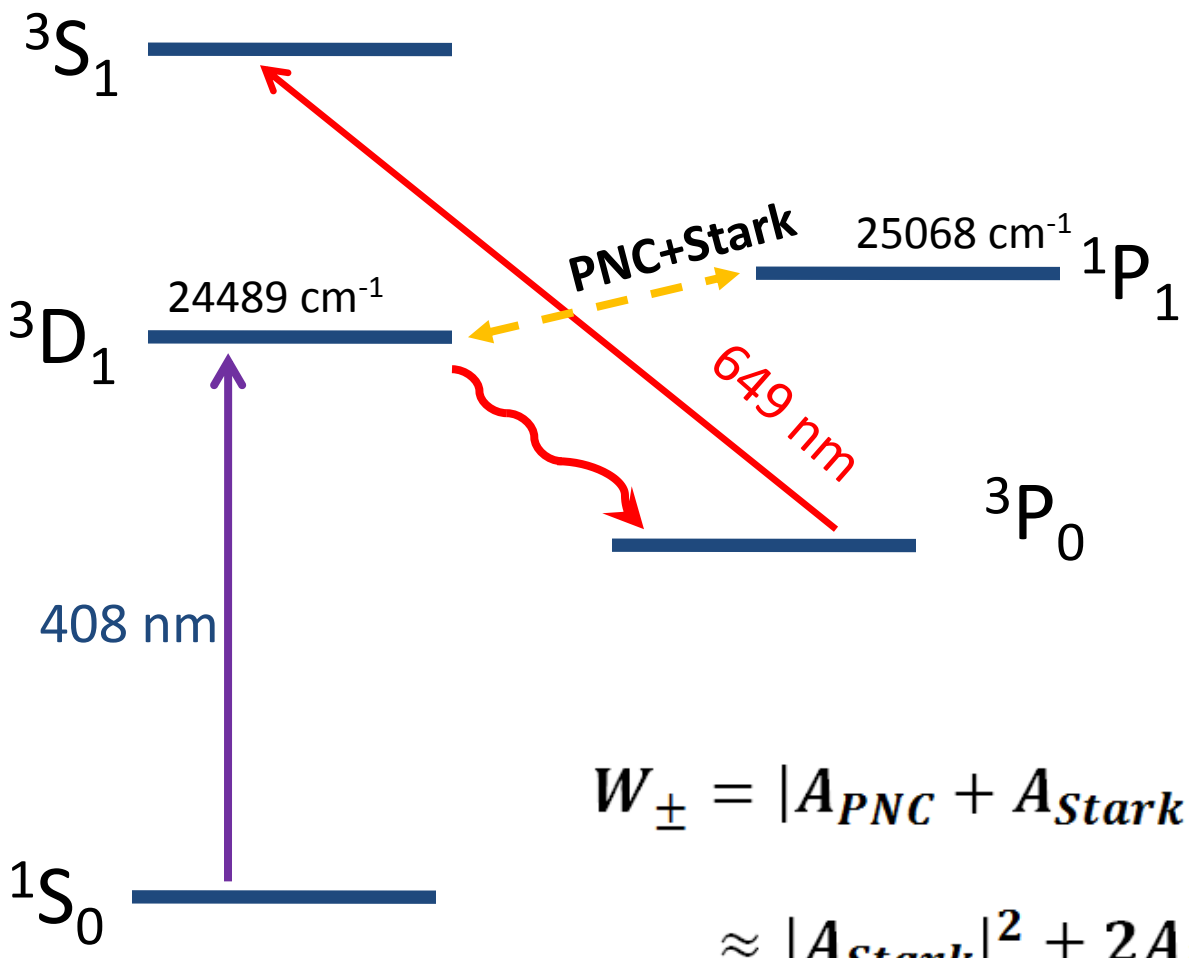
- 2 with nuclear spin (^{171}Yb → I=1/2, ^{173}Yb→ I=5/2) (anapole moment)

The Yb PV Experiment



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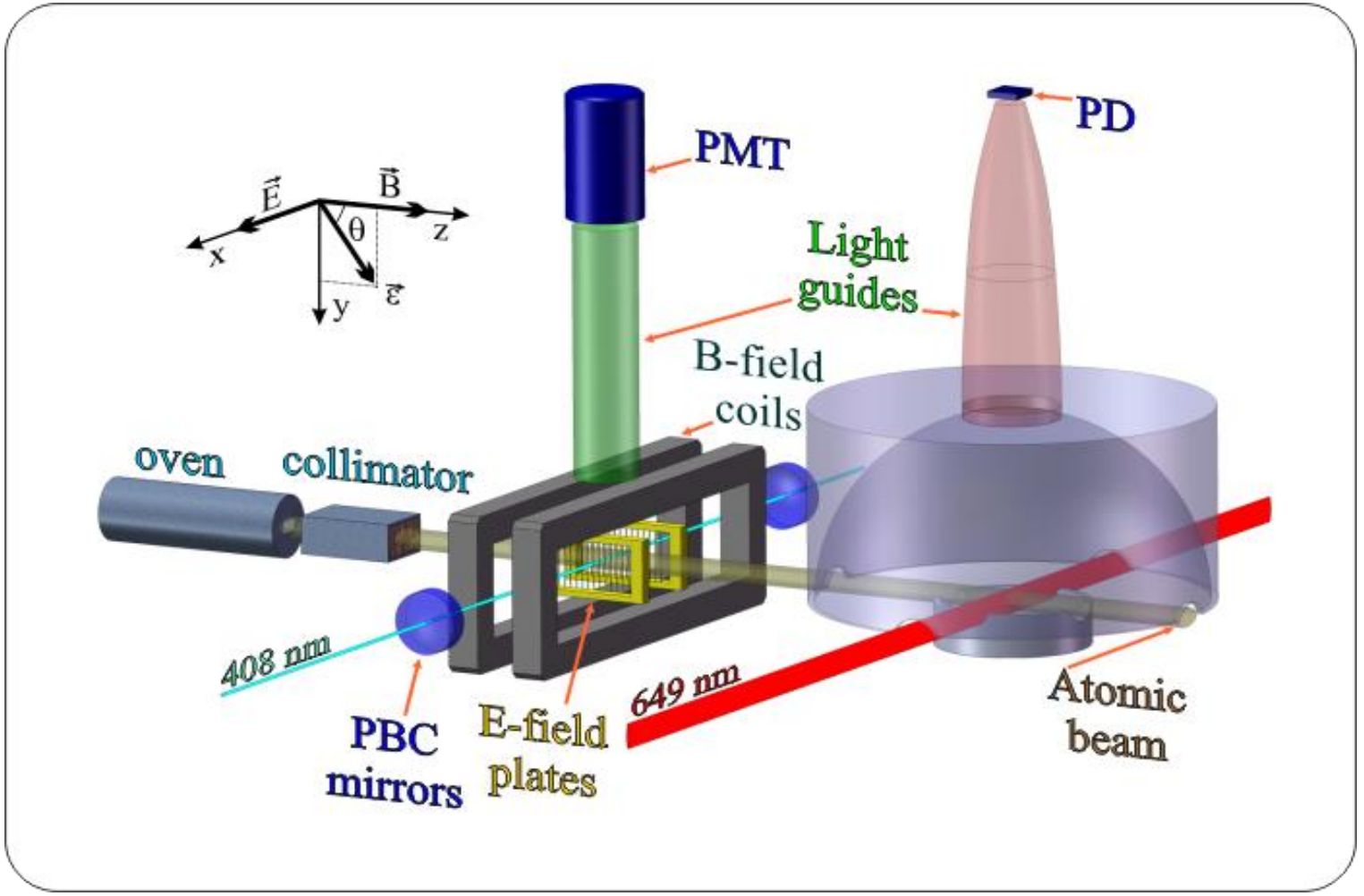
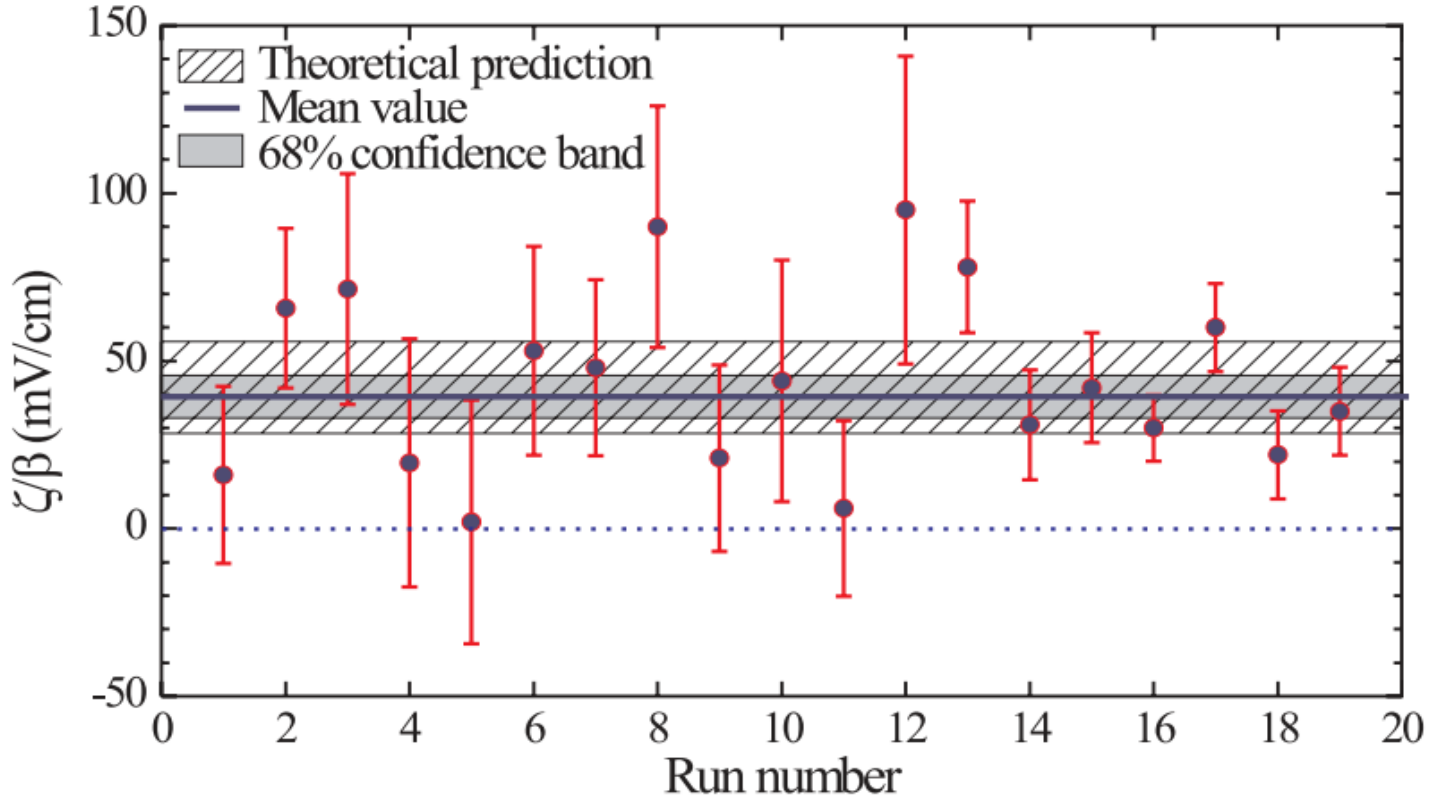


Rotational Invariant: $\left(\vec{\varepsilon}\cdot\vec{B}\right)\left(\vec{E}\times\vec{\varepsilon}\cdot\vec{B}\right)$

PRL 103, 071601 (2009) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2009

Observation of a Large Atomic Parity Violation Effect in Ytterbium

K. Tsigutkin,[1,*] D. Dounas-Frazer,[1] A. Family,[1] J. E. Stalnaker,[1,†] V. V. Yashchuk,[2] and D. Budker[1,3]

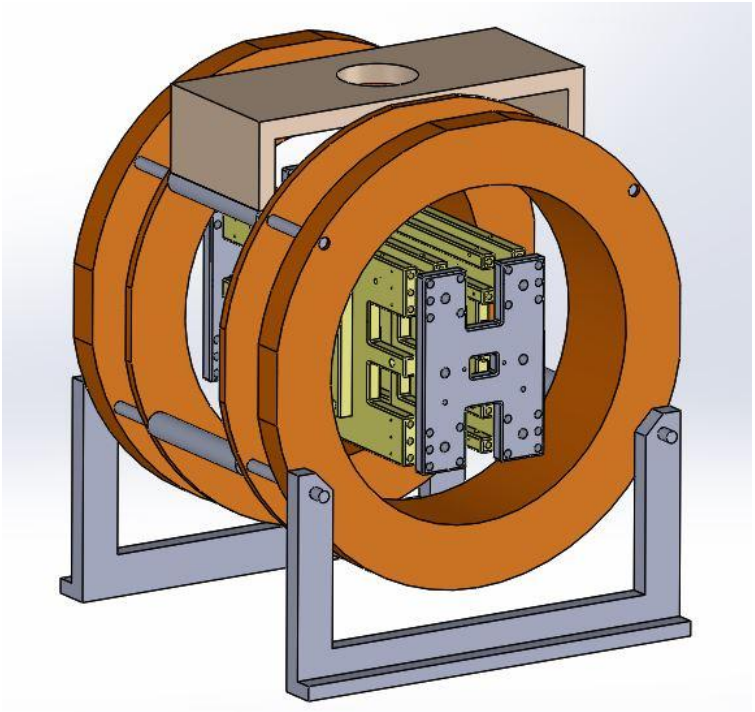


Mean value: $39(4)_{\text{stat}}(5)_{\text{syst}}$ mV/cm, $|\zeta| = 8.7 \pm 1.4 \times 10^{-10} ea_0$

Yb reincarnation in Mainz

Apparatus upgrades

- New, more **powerful** 408 nm laser
- Improved interaction region design to minimize electric field imperfections
- Currently achieving **SNR ~ 0.5/√Hz** in PNC amplitude (laser noise limited)



Roadmap

- Verify expected isotopic dependence of E_{PNC} (0.5% accuracy) - 6 months
- Probe anapole moment (~0.2 %) - (1 year)
- Neutron distributions/Standard model check (~0.1%) - 2 years