Atomic parity violation in Yb

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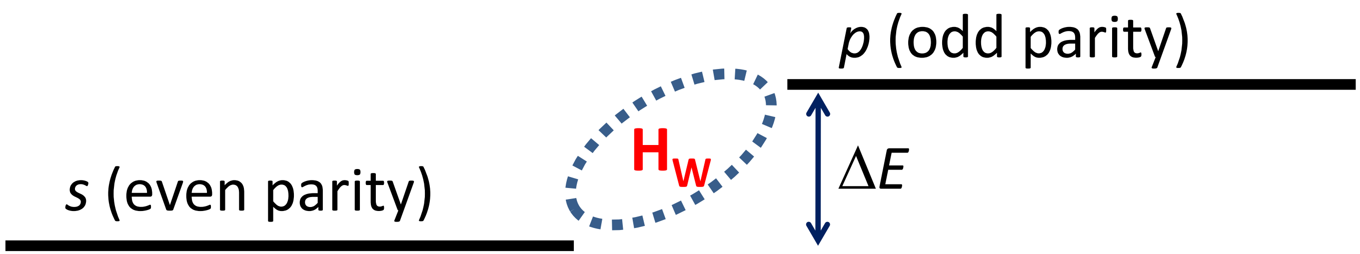
Outline

- Background
- Motivations
- Yb experiment, new results & future

The weak interaction mixes atomic states of opposite nominal parity (s & p)



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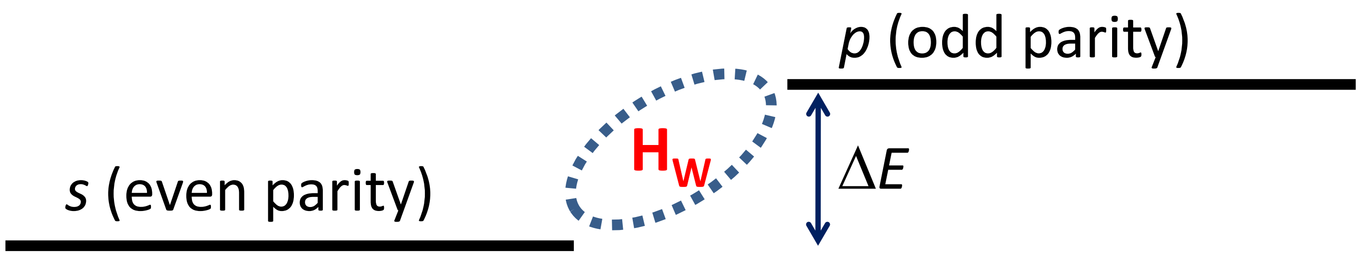


$$s \rightarrow s + i\varepsilon p;\ p \rightarrow p + i\varepsilon s$$

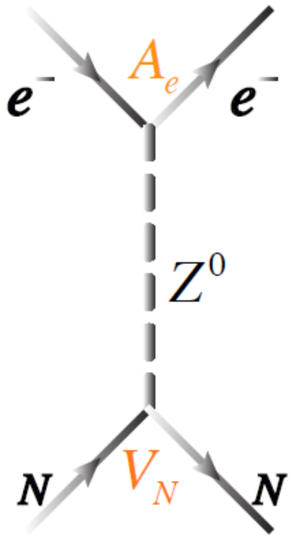
$$\varepsilon = \frac{\langle s | H_W | p \rangle}{\Delta E} \sim \frac{Z^3}{\Delta E}$$ - the Bouchiat Law

Atomic Parity Violation Enhancement:

- Heavy atoms (high Z)
- Small ΔE

Atomic Parity Violation: Main processes

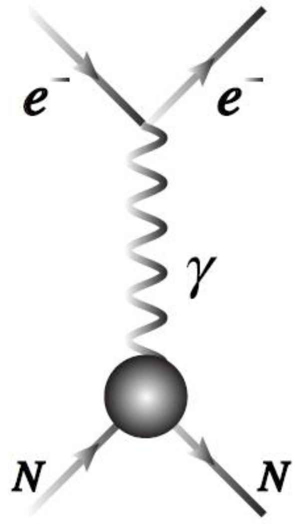
Nuclear-Spin Independent process



$$Q_W \approx -N + Z \cdot (1 - 4\sin^2\theta_W)$$

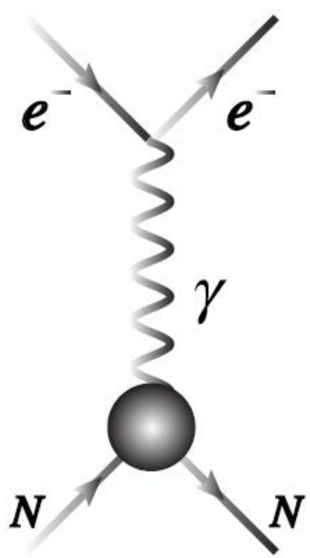
- Probe of the Standard model parameter θ_W
- Test of SM and constraints on physics beyond SM, including various "dark sector" scenarios

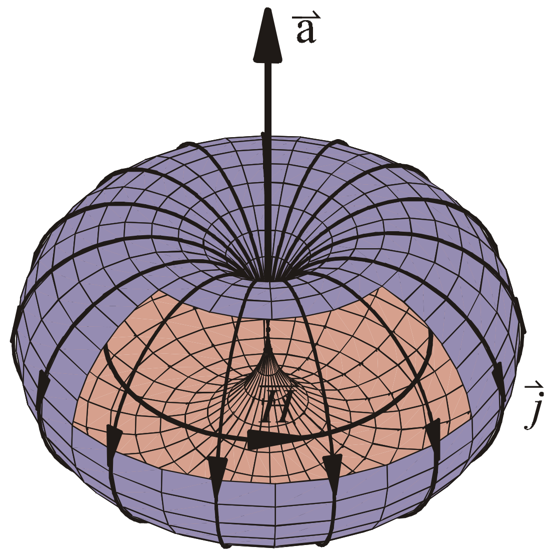
Main Nuclear-Spin Dependent process

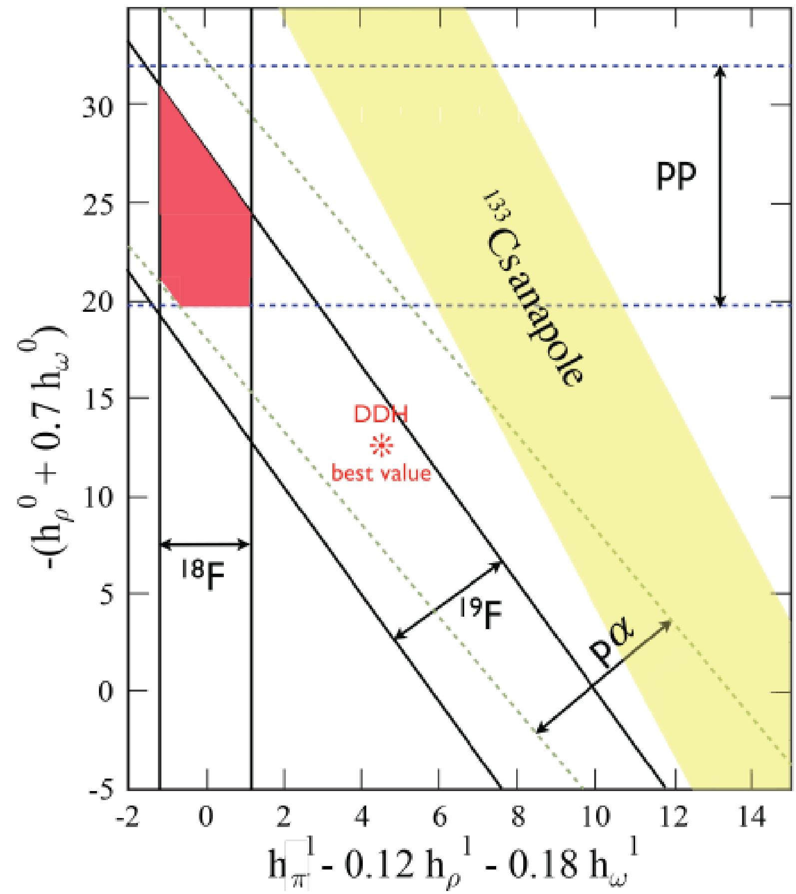


Anapole moment-hadronic PV

Yb motivation I: anapole moment







Safranova et al. arXiv:1710.01833

Anapole moment:

- P-odd E/M moment from intranuclear PV
- Probe of weak meson-nucleon couplings (hadronic PV)

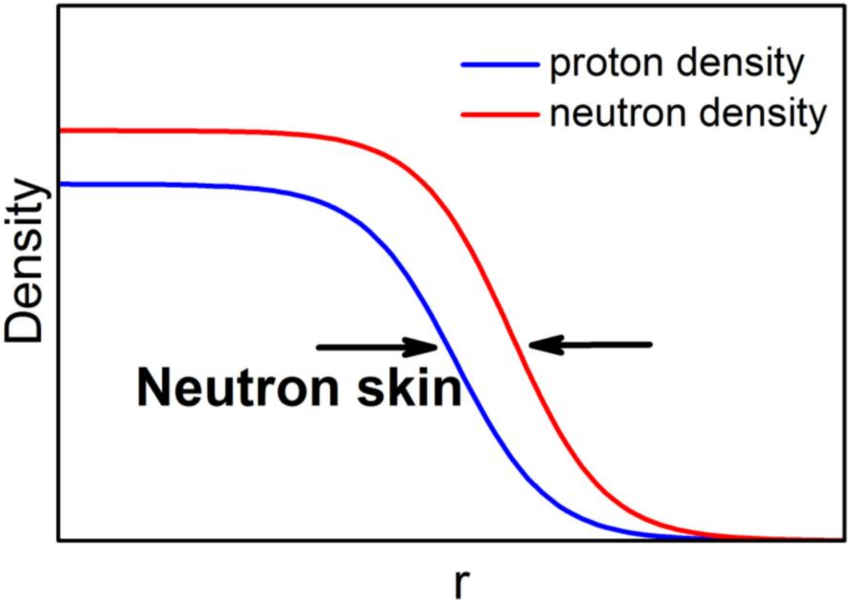
Yb motivation II: neutron skins

Weak charge: $Q_W = -N + Z\cdot(1 - 4\sin^2\theta_W)$

What is probed however is:

$Q'_W = -N\cdot\boldsymbol{q_n} + Z\cdot\boldsymbol{q_p}(1 - 4\sin^2\theta_W)$

$$q_{n(p)} = \int f(r)\rho_{n(p)}(r)\,dr$$



Neutron skin contribution between ^{170}Yb - ^{176}Yb isotopes:

$\Delta Q_W / Q_W \sim 0.1\%$

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

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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 distributions

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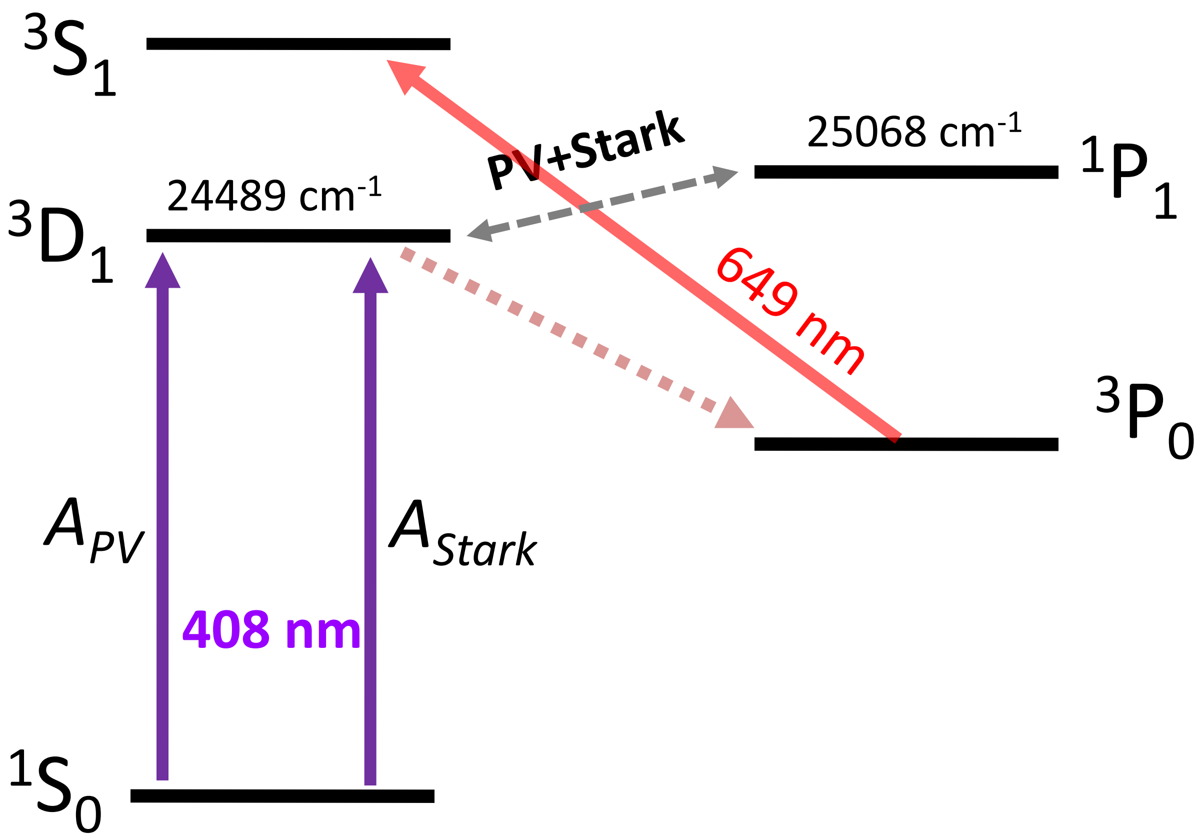
- PNC on chain of isotopes → neutron distributions
- Two isotopes with nuclear spin → anapole moment

The Yb PV experiment

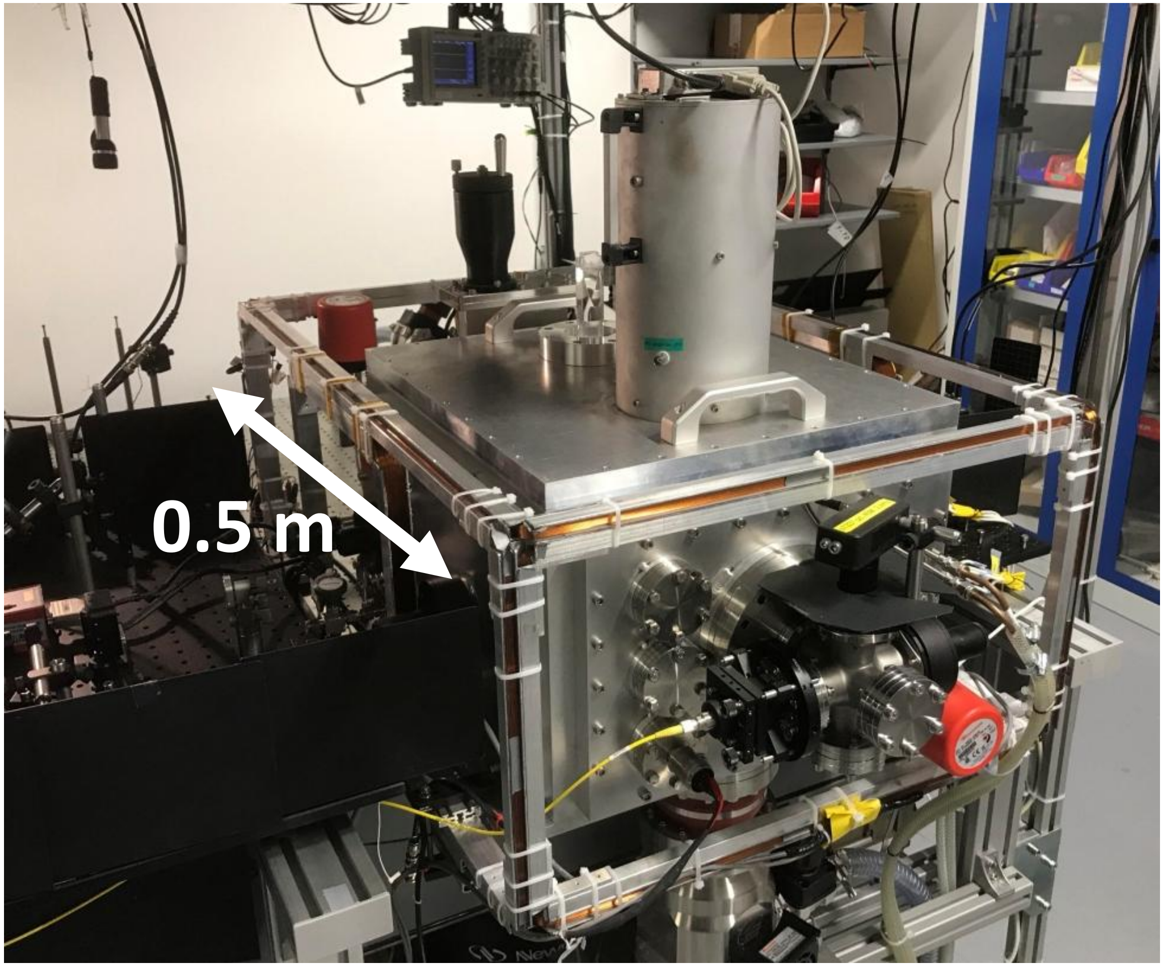


Stark-PV interference

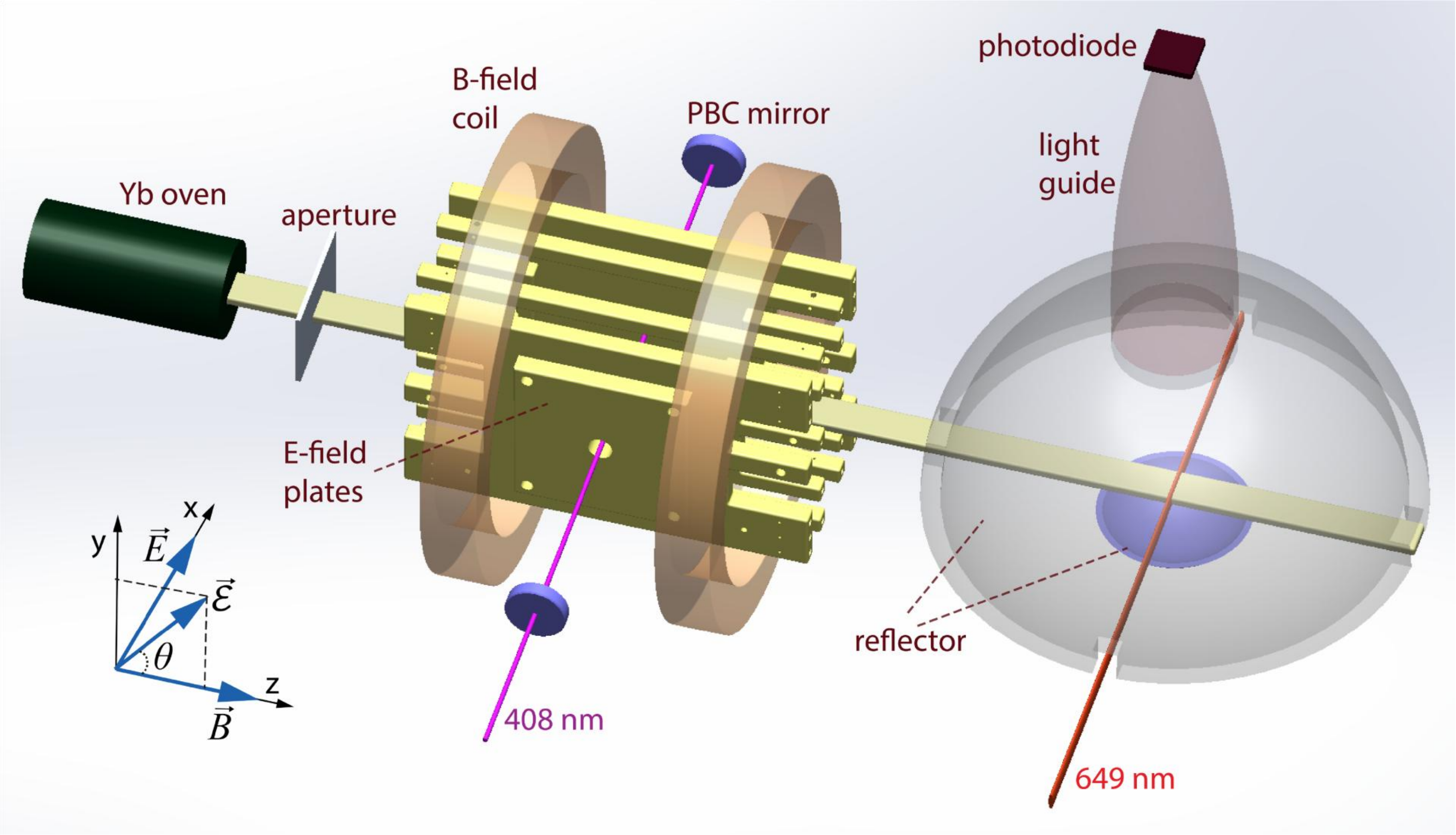
$$R \propto \left| A_{Stark} + A_{PV} \right|^2 \approx \beta^2 E^2 \sin^2\theta + 2E1_{PV}\,\beta E \cos\theta \sin\theta$$

Reverse E, θ and measure $E1_{PV}/\beta$

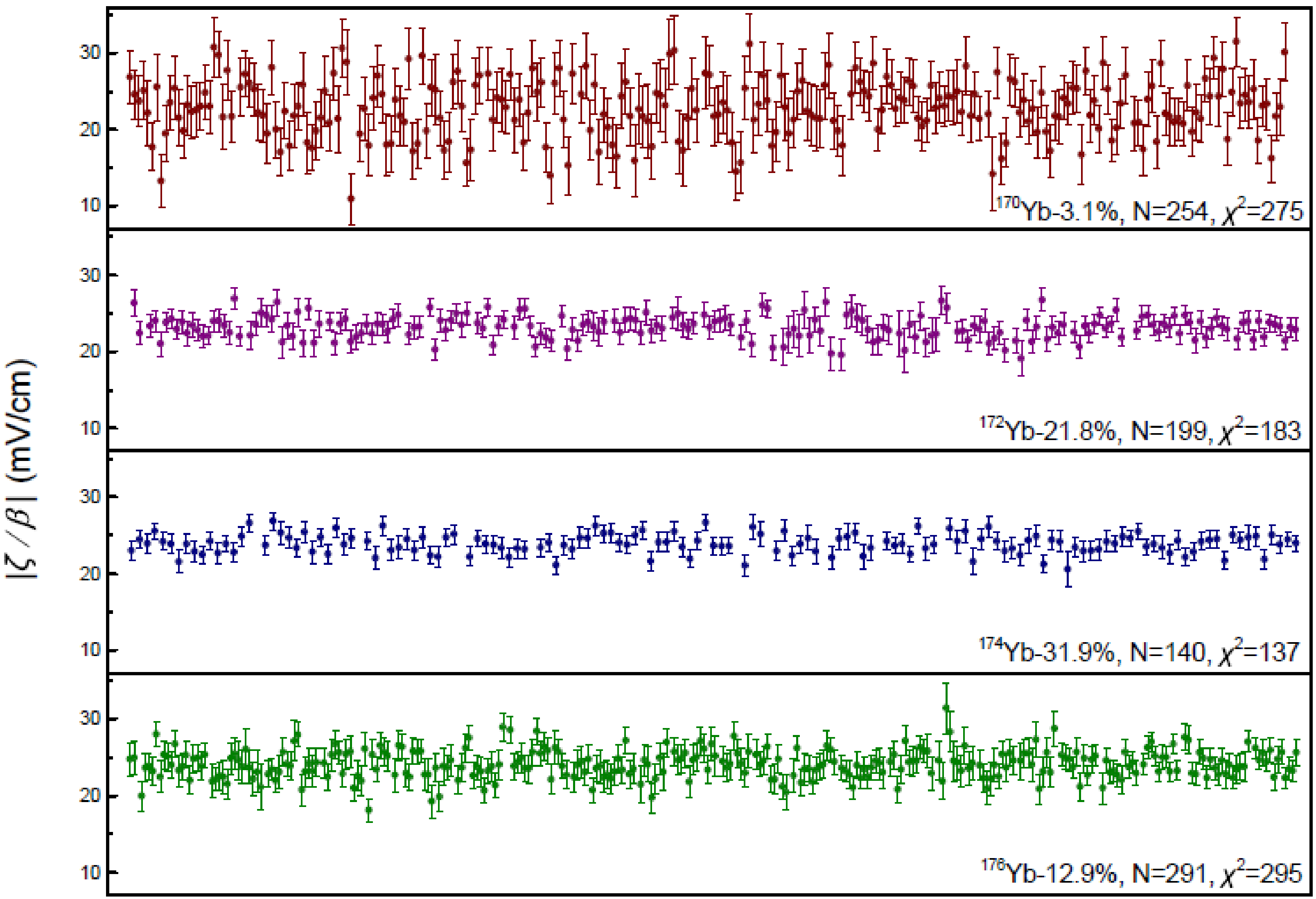
Yb apparatus



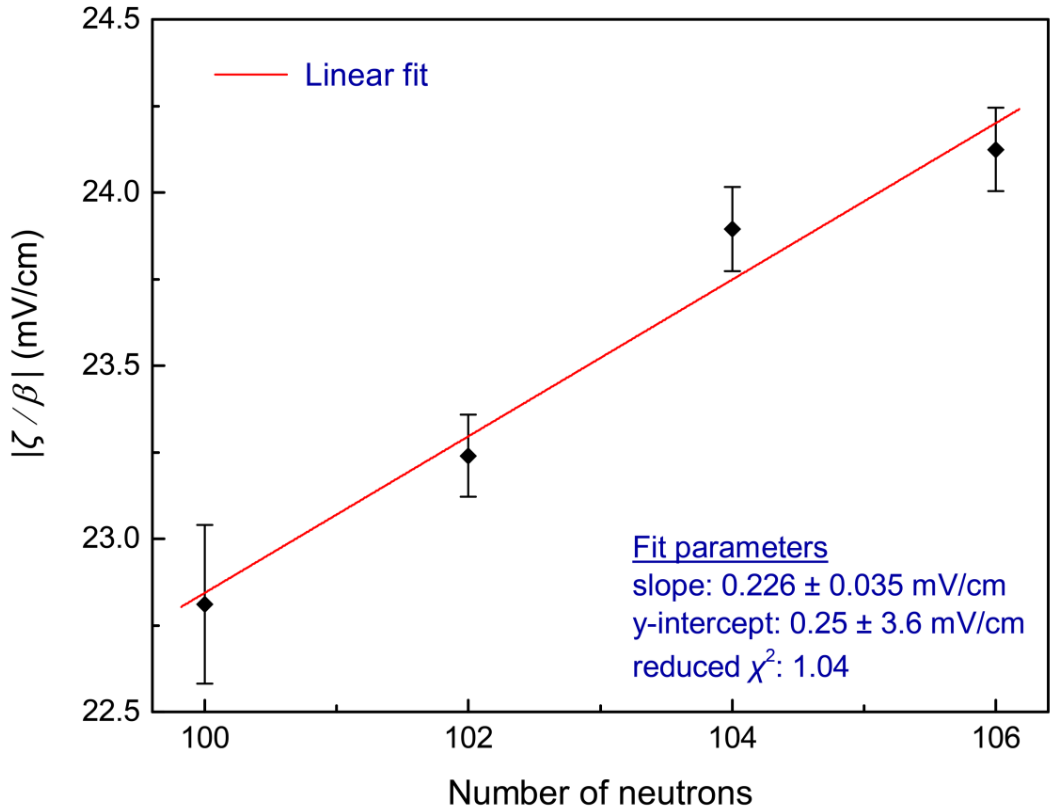
Apparatus schematic



Early 2018 run in 4 spin-zero isotopes



First observation of isotopic variation of atomic PV



0.5% single isotope accuracy

arXiv:1804.05747

SM: $Q_W \approx -N+Z(1-4\sin^2\theta_W)$ → 1% change per neutron around N=103

Observation: 0.96(15) % change per neutron

Single isotope measurement uncertainties

Systematic uncertainties	Error (%)
Harmonics ratio calibration	0.22
Polarization angle	0.1
High-voltage measurements	0.06
Transition saturation correction	0.05 (0.09 for ^{170}Yb)
Field-plate spacing	0.04
Photodetector response calibration	0.02
Stray fields & field-misalignments	0.02
Total systematic	**0.26**
Statistical uncertainty	**0. 42 (0.9 for ^{170}Yb)**
Total uncertainty	**0.5 (0.9 for ^{170}Yb)**

False-PV Related → Stray fields & field-misalignments

Effect comparison **bonus**:
decreased sensitivity to systematics

Next: anapole moment

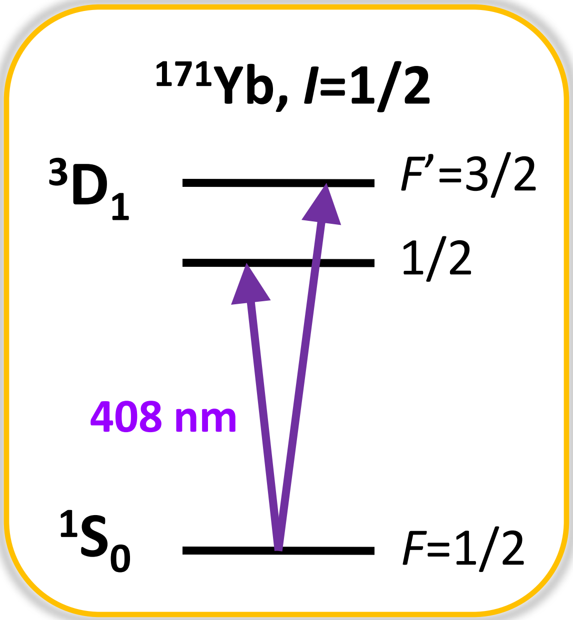


Table 1
Nuclear spin-dependent P-odd amplitudes $E1_{SD}$ are in units of ($\kappa e a_0 \times 10^{-11}$), A is the number of nucleons in the nucleus.

Isotope	Transition	$F' \to F$	$E1_{SD}$
$A = 171$	$^1S_0 \to {}^3D_1$	$1/2 \to 1/2$	-2.75
$I = 1/2$	$^1S_0 \to {}^3D_1$	$1/2 \to 3/2$	-1.94
	$^1S_0 \to {}^3D_2$	$1/2 \to 3/2$	9.13
$A = 173$	$^1S_0 \to {}^3D_1$	$5/2 \to 3/2$	2.82
$I = 5/2$	$^1S_0 \to {}^3D_1$	$5/2 \to 5/2$	-0.99
	$^1S_0 \to {}^3D_1$	$5/2 \to 7/2$	-2.85
	$^1S_0 \to {}^3D_2$	$5/2 \to 3/2$	3.89
	$^1S_0 \to {}^3D_2$	$5/2 \to 5/2$	-6.79
	$^1S_0 \to {}^3D_2$	$5/2 \to 7/2$	-8.05

S.G. Porsev et al. Hyperfine Interactions **127,** 395 (2000)

"Best guess" PV difference between ^{171}Yb *F'*=3/2 and F'=1/2 ~ 0.1%

Need to boost SNR!

Yb sensitivity improvements

Need x10 sensitivity enhancement for anapole, neutron skins

- Boost the Yb oven flux (x7 signal increase)
- Increase interaction region width (x2)
- Power build-up cavity mirrors upgrade (x2)
- Integrate longer…

Acknowledgements

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