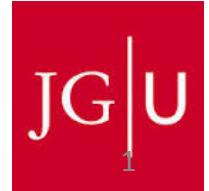


# Parity violation in Yb

Dionysis Antypas

MITP Neutron Skin Workshop



# Parity Violation in D. Budker's group

70

**Yb**

**Ytterbium**

173.04

Dionysis Antypas

Anne Fabricant

66

**Dy**

**Dysprosium**

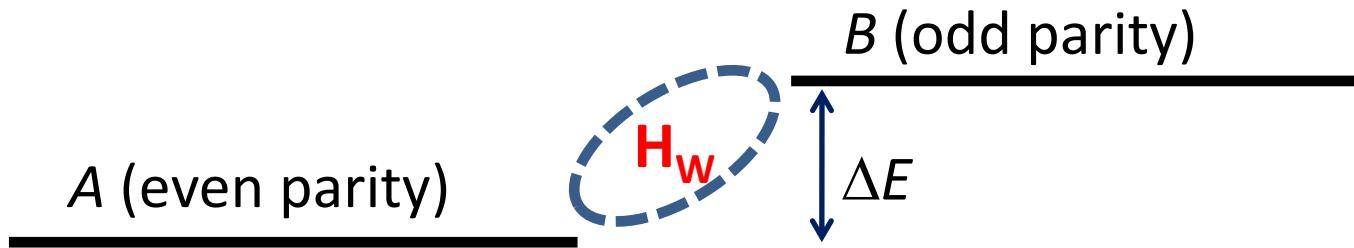
162.50

Lykourgos Bougas

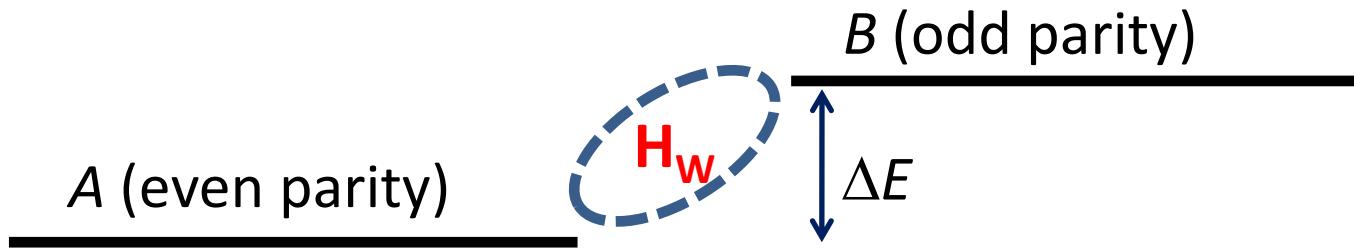
# Outline

- Background
- Scientific motivation
  - Yb experiment

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



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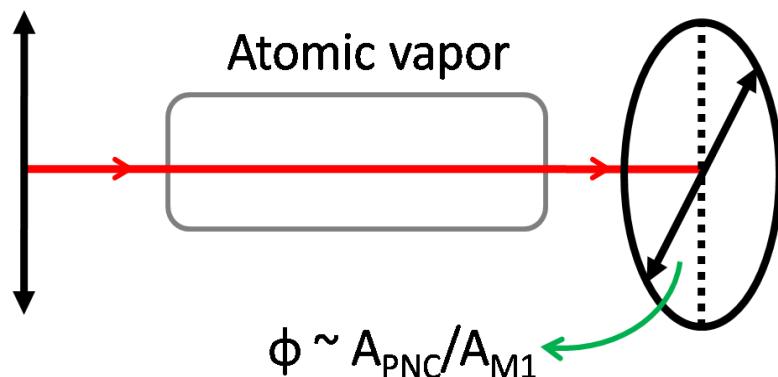
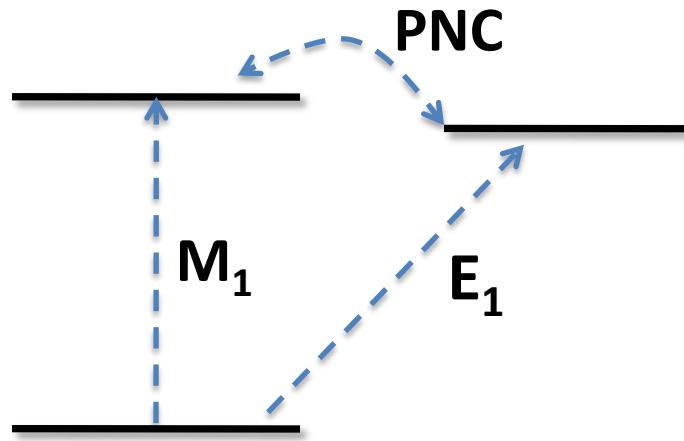
$$A \rightarrow A + i\varepsilon B; B \rightarrow B + i\varepsilon A$$

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

APV **Enhancement**:

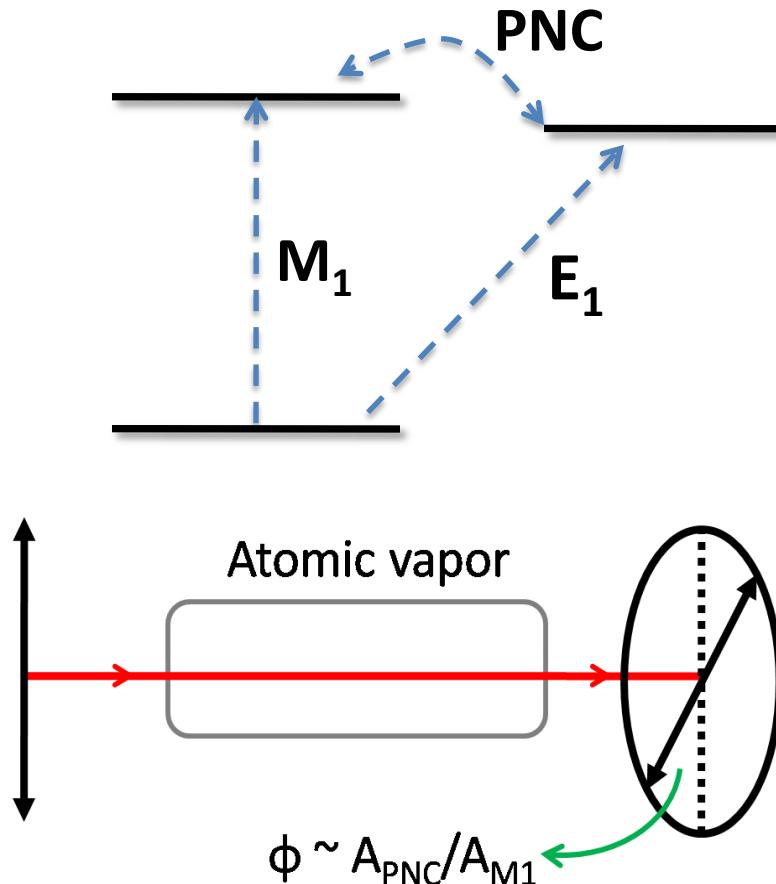
- Heavy atoms (high  $Z$ )
- Small  $\Delta E$

# Types of APV experiments

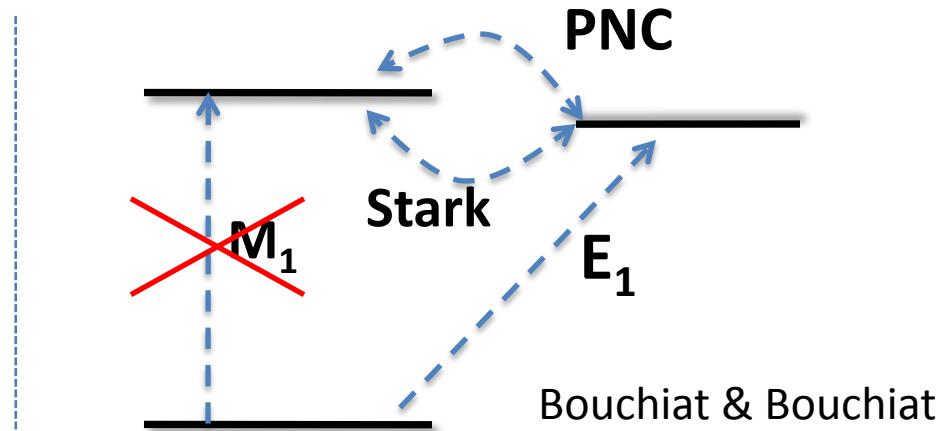


- 100% contrast (small signal)
- No reversals

# Types of APV experiments



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- No reversals



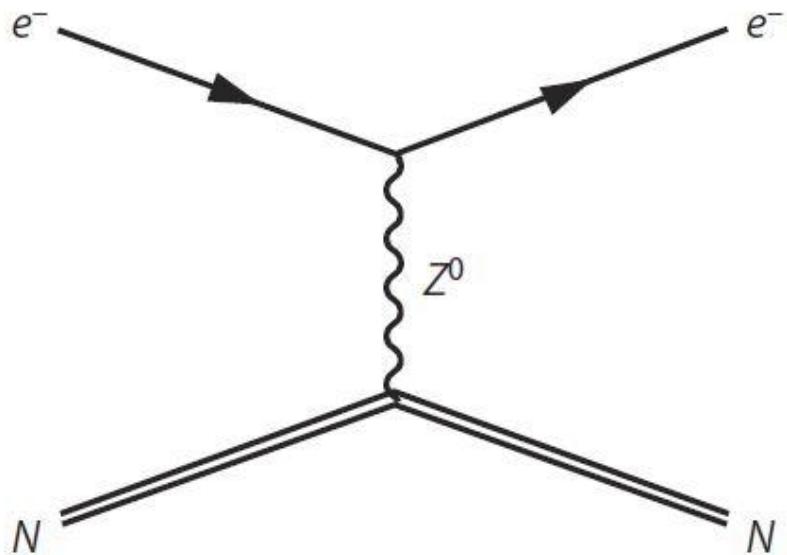
$$\begin{aligned} W_{\pm} &= |A_{PNC} + A_{Stark}|^2 \\ &\approx |A_{Stark}|^2 \pm 2A_{PNC}A_{Stark} \end{aligned}$$

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

# Experimental PNC studies

1 IA 11A		18 VIIIA 8A
1 <b>H</b> Hydrogen 1.008	2 <b>He</b> Helium 4.003	2 <b>He</b> Helium 4.003
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012	10 <b>Ne</b> Neon 20.180
11 <b>Na</b> Sodium 22.990	12 <b>Mg</b> Magnesium 24.305	13 <b>Al</b> Aluminum 26.982
19 <b>K</b> Potassium 39.098	20 <b>Ca</b> Calcium 40.078	14 <b>Si</b> Silicon 28.086
37 <b>Rb</b> Rubidium 84.468	38 <b>Sr</b> Strontium 87.62	15 <b>P</b> Phosphorus 30.974
55 <b>Cs</b> Cesium 132.905	56 <b>Ba</b> Barium 137.327	16 <b>S</b> Sulfur 32.066
87 <b>Fr</b> Francium 223.020	88 <b>Ra</b> Radium 226.025	17 <b>Cl</b> Chlorine 35.453
57-71	72 <b>Hf</b> Hafnium 178.49	32 <b>Ge</b> Germanium 74.922
73 <b>Ta</b> Tantalum 180.948	74 <b>W</b> Tungsten 183.85	33 <b>As</b> Arsenic 78.09
104 <b>Rf</b> Rutherfordium [261]	105 <b>Db</b> Dubnium [262]	34 <b>Se</b> Selenium 78.09
106 <b>Sg</b> Seaborgium [266]	107 <b>Bh</b> Bohrium [264]	35 <b>Br</b> Bromine 79.904
108 <b>Hs</b> Hassium [269]	109 <b>Mt</b> Meitnerium [268]	36 <b>Kr</b> Krypton 84.80
110 <b>Ds</b> Darmstadtium [269]	111 <b>Rg</b> Roentgenium [272]	51 <b>Sb</b> Antimony 121.760
112 <b>Cn</b> Copernicium [277]	113 <b>Uut</b> Ununtrium unknown	52 <b>Te</b> Tellurium 127.6
114 <b>Fl</b> Flerovium [289]	115 <b>Uup</b> Ununpentium unknown	53 <b>I</b> Iodine 126.904
116 <b>Lv</b> Livermorium [298]	117 <b>Uus</b> Ununseptium unknown	54 <b>Xe</b> Xenon 131.29
118 <b>Uuo</b> Ununoctium unknown		86 <b>Rn</b> Radon 222.018
Lanthanide Series		
57 <b>La</b> Lanthanum 138.906	58 <b>Ce</b> Cerium 140.115	59 <b>Pr</b> Praseodymium 140.908
60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium 144.913	62 <b>Sm</b> Samarium 150.20
63 <b>Eu</b> Europium 151.966	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.925
66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.930	68 <b>Er</b> Erbium 167.26
69 <b>Tm</b> Thulium 168.934	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967
Actinide Series		
89 <b>Ac</b> Actinium 227.028	90 <b>Th</b> Thorium 232.038	91 <b>Pa</b> Protactinium 231.036
92 <b>U</b> Uranium 238.029	93 <b>Np</b> Neptunium 237.048	94 <b>Pu</b> Plutonium 244.064
95 <b>Am</b> Americium 243.061	96 <b>Cm</b> Curium 247.070	97 <b>Bk</b> Berkelium 247.070
98 <b>Cf</b> Californium 251.080	99 <b>Es</b> Einsteinium [254]	100 <b>Fm</b> Fermium 257.095
101 <b>Md</b> Mendelevium 258.1	102 <b>No</b> Nobelium 259.101	103 <b>Lr</b> Lawrencium [262]

# Atomic Parity Violation: Main processes



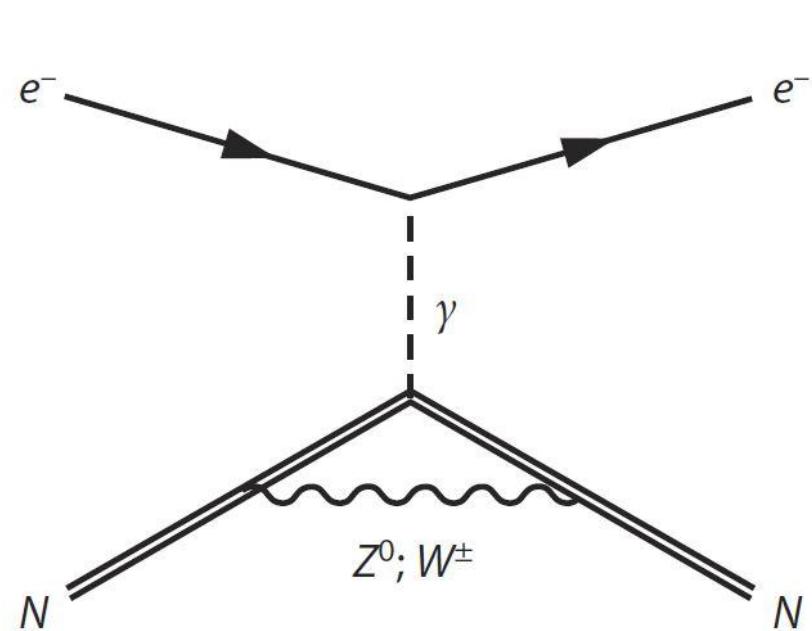
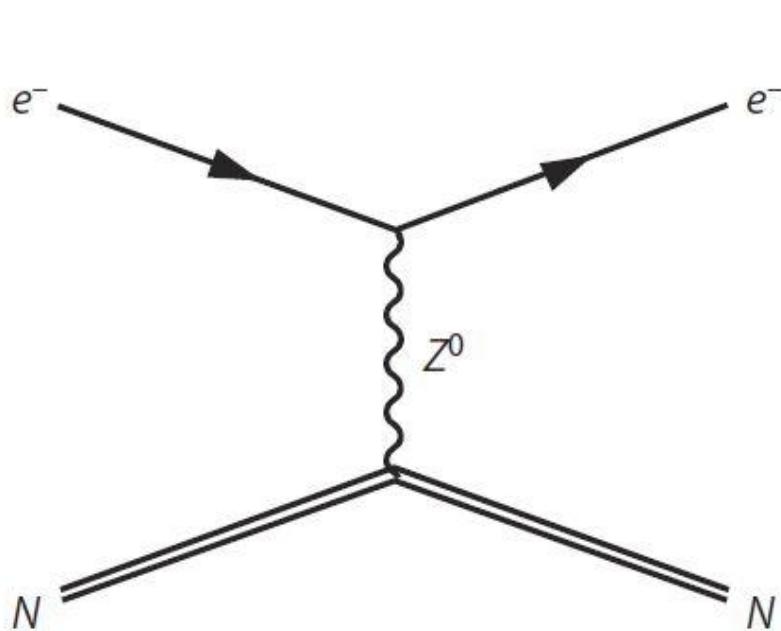
Nuclear spin independent

- 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?

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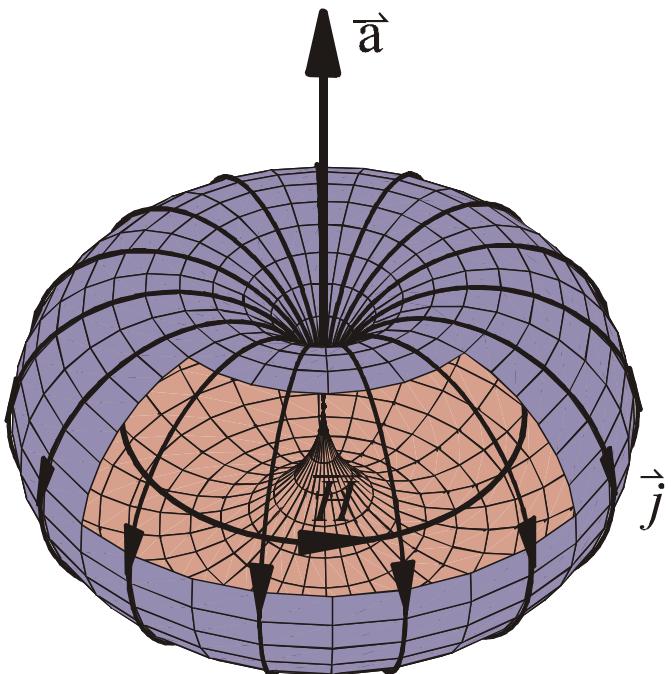
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## Nuclear spin dependent

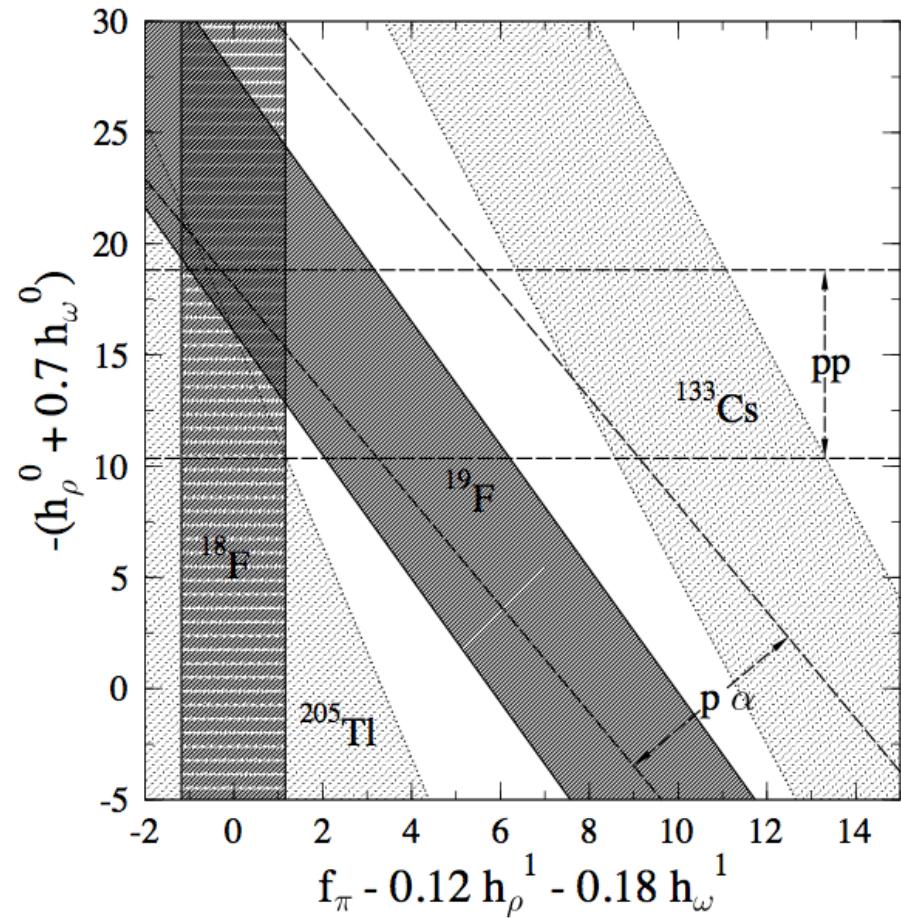
- dominant effect in heavy nuclei:  
anapole moment

# Anapole moment



P-odd E/M moment from intranuclear PV

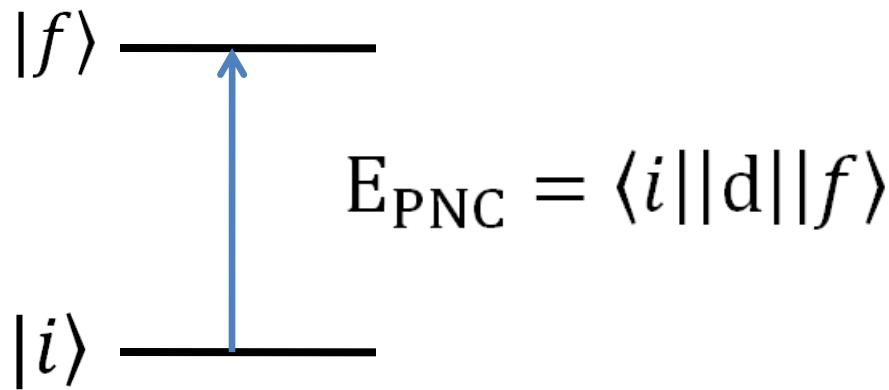
Probe of weak meson-nucleon couplings



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

# Isotopic ratios in APV

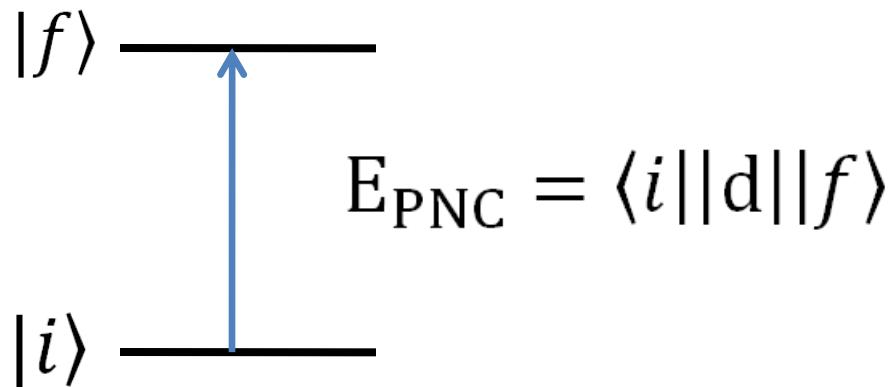
➤ APV measures:  $E_{PNC} = k \cdot \bar{Q}_W$



Element	$\delta k$
Cs	0.4 %
Yb	10 %

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Element	$\delta k$
Cs	0.4 %
Yb	10 %

➤ Atomic PV calculation errors cancel in isotopic ratios  
Dzuba, Flambaum, and Khriplovich, Z. Phys. D 1, 243 (1986)

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

# 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)

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

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- Atomic PV  $\leftrightarrow$  Neutron distributions

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

skin contribution for  $^{170}\text{Yb}$  -  $^{176}\text{Yb}$  isotopes  $\sim 0.1\%$

# Isotopic ratios and neutron skins

[PHYSICAL REVIEW C 79, 035501 (2009)]

Dispelling the curse of the neutron skin in atomic parity violation

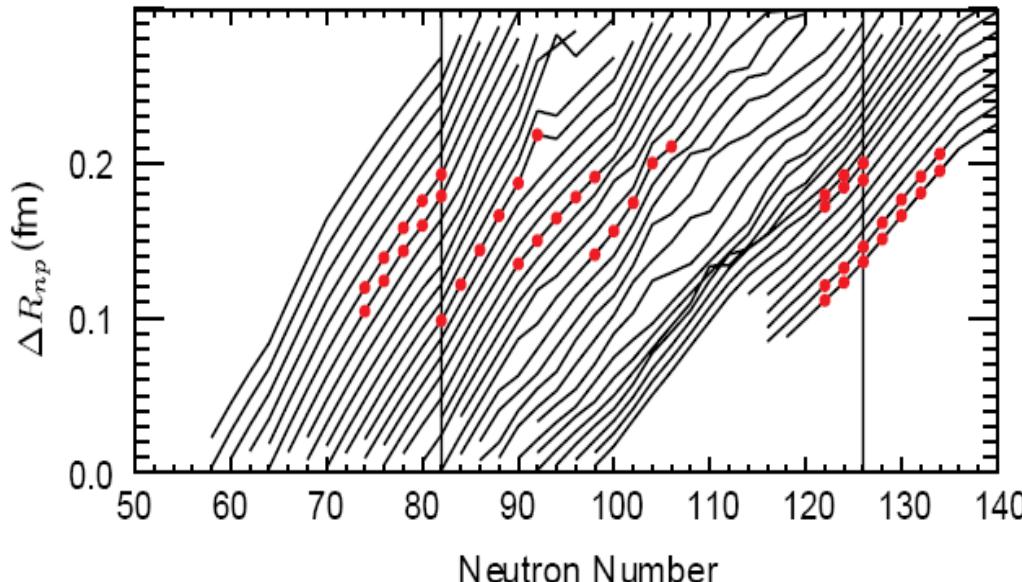
B. A. Brown,<sup>1</sup> A. Derevianko,<sup>2,3</sup> and V. V. Flambaum<sup>3</sup>

<sup>1</sup>*Department of Physics and Astronomy, and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

<sup>2</sup>*Department of Physics, University of Nevada, Reno, Nevada 89557*

<sup>3</sup>*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
$^{174}\text{Yb}$	31.8	0
$^{172}\text{Yb}$	21.8	0
$^{176}\text{Yb}$	12.8	0
$^{173}\text{Yb}$	16.1	$5/2$
$^{171}\text{Yb}$	14.3	$1/2$
$^{170}\text{Yb}$	3.04	0
$^{168}\text{Yb}$	0.13	0

PNC on chain of isotopes → neutron skins

→ New Physics?

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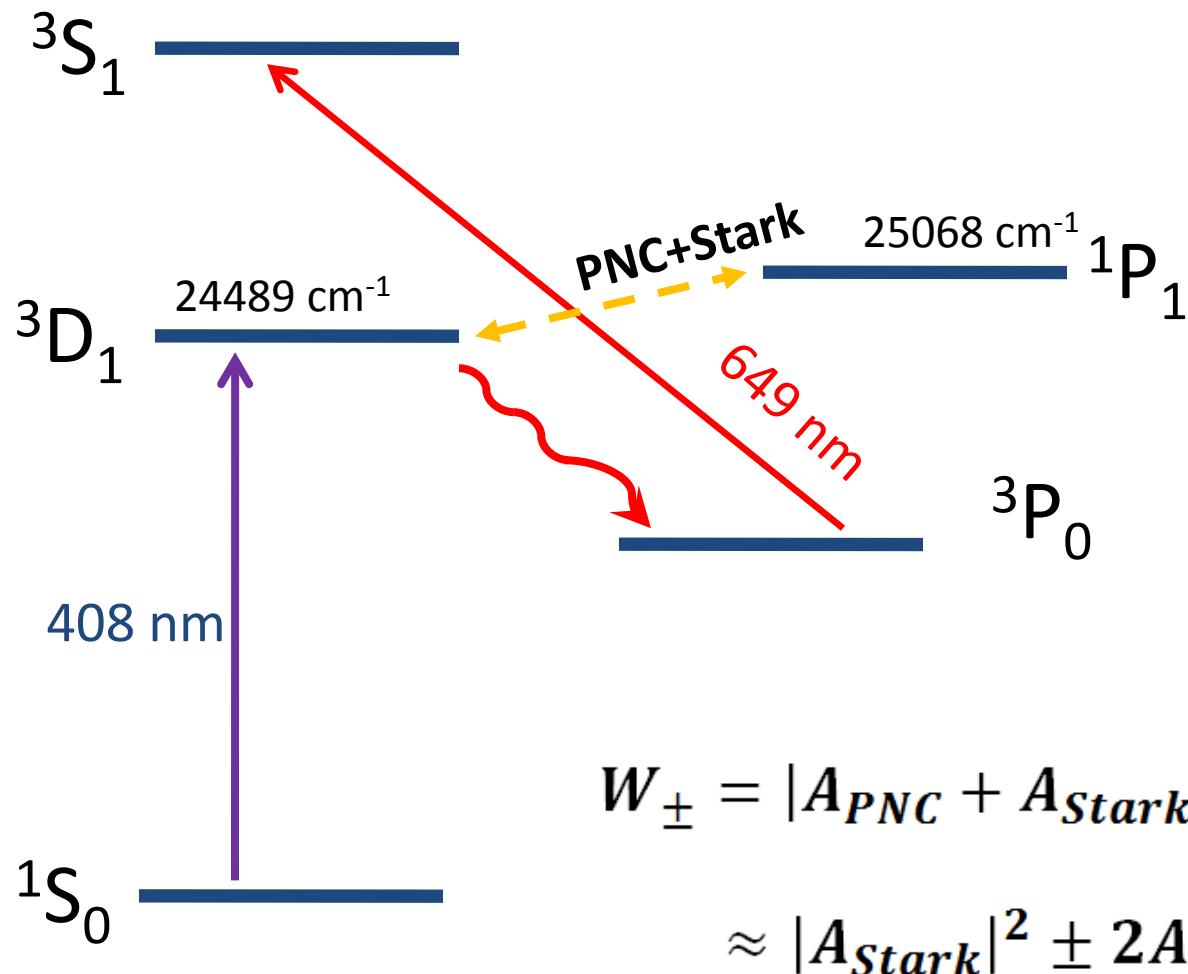
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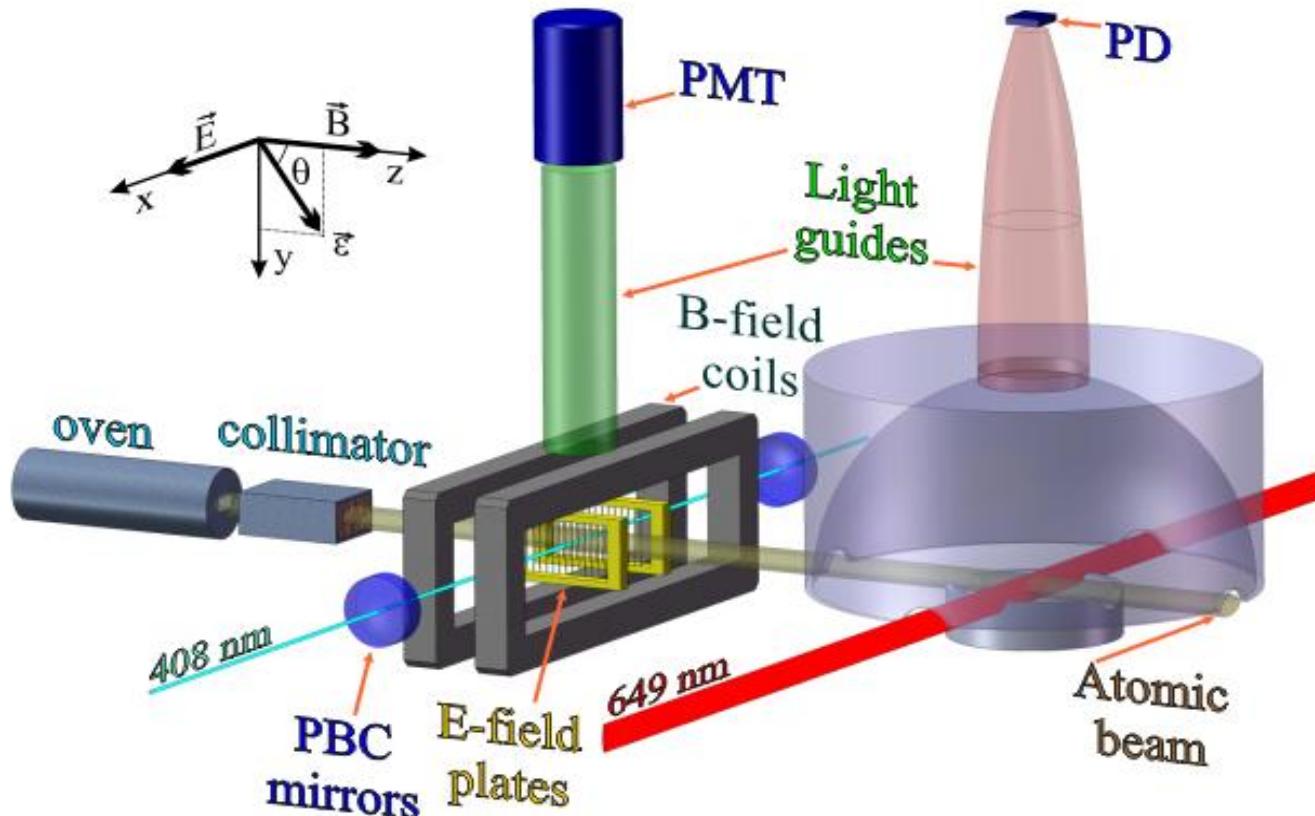
→ New Physics?

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

# The Yb PV Experiment



# The Yb PV Experiment

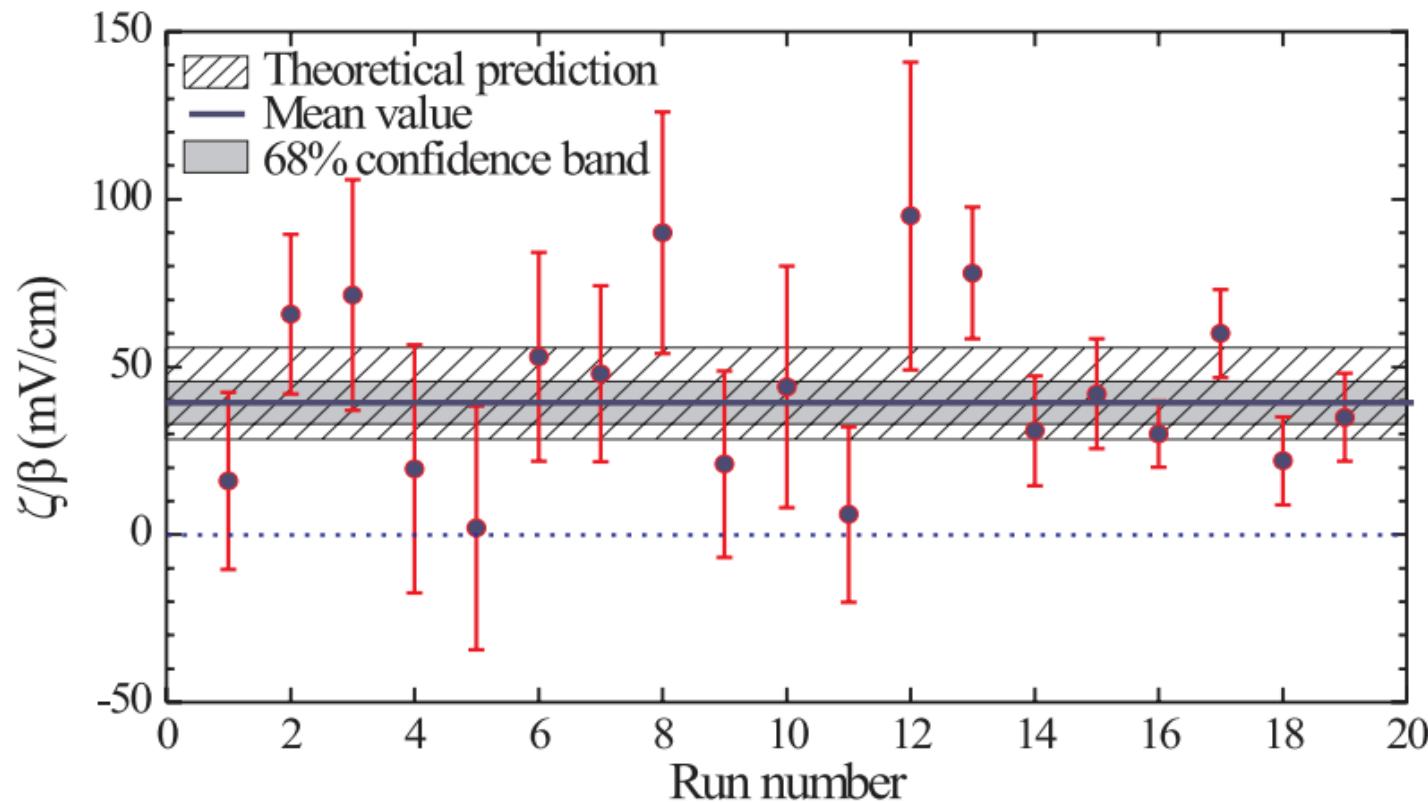


Rotational Invariant:  $(\vec{\varepsilon} \cdot \vec{B})(\vec{E} \times \vec{\varepsilon} \cdot \vec{B})$



## Observation of a Large Atomic Parity Violation Effect in Ytterbium

K. Tsigutkin,<sup>1,\*</sup> D. Dounas-Frazer,<sup>1</sup> A. Family,<sup>1</sup> J. E. Stalnaker,<sup>1,†</sup> V. V. Yashchuk,<sup>2</sup> and D. Budker<sup>1,3</sup>

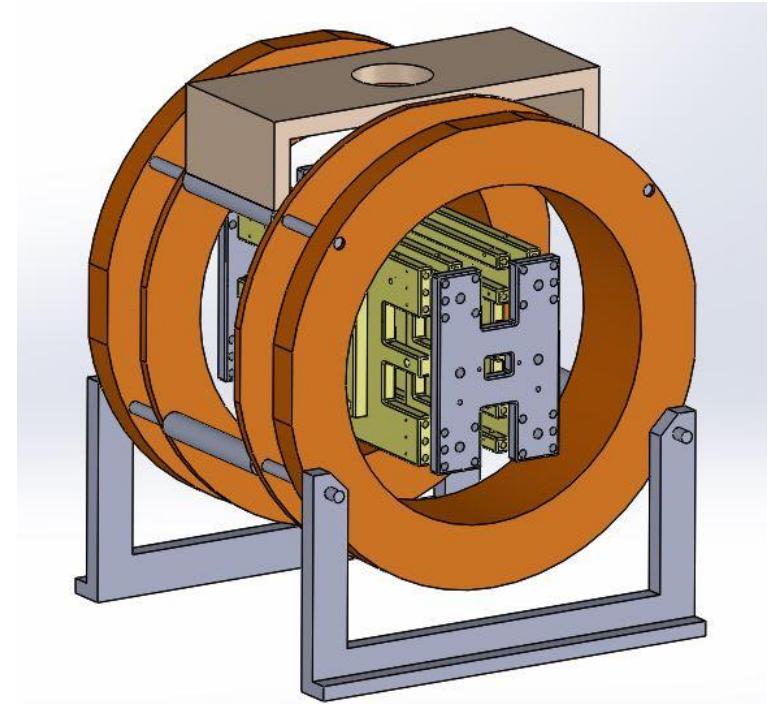


Mean value:  $39(4)_{\text{stat}}(5)_{\text{syst}}$  mV/cm,  $|\zeta| = 8.7 \pm 1.4 \times 10^{-10} ea_0$

# 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/vHz** in PNC amplitude (laser noise limited)



## Roadmap

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