The ytterbium parity-violation experiment: 'Under the hood'

library.duke.edu

Anne Fabricant
for the Budker Group in Mainz
25.05.2016

JGU
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

HIM
Helmholtz-Institut Mainz

The big picture

- Atomic parity violation (APV) as a gateway to low-energy nuclear physics
- Tool: Weak interaction between electrons and nucleons

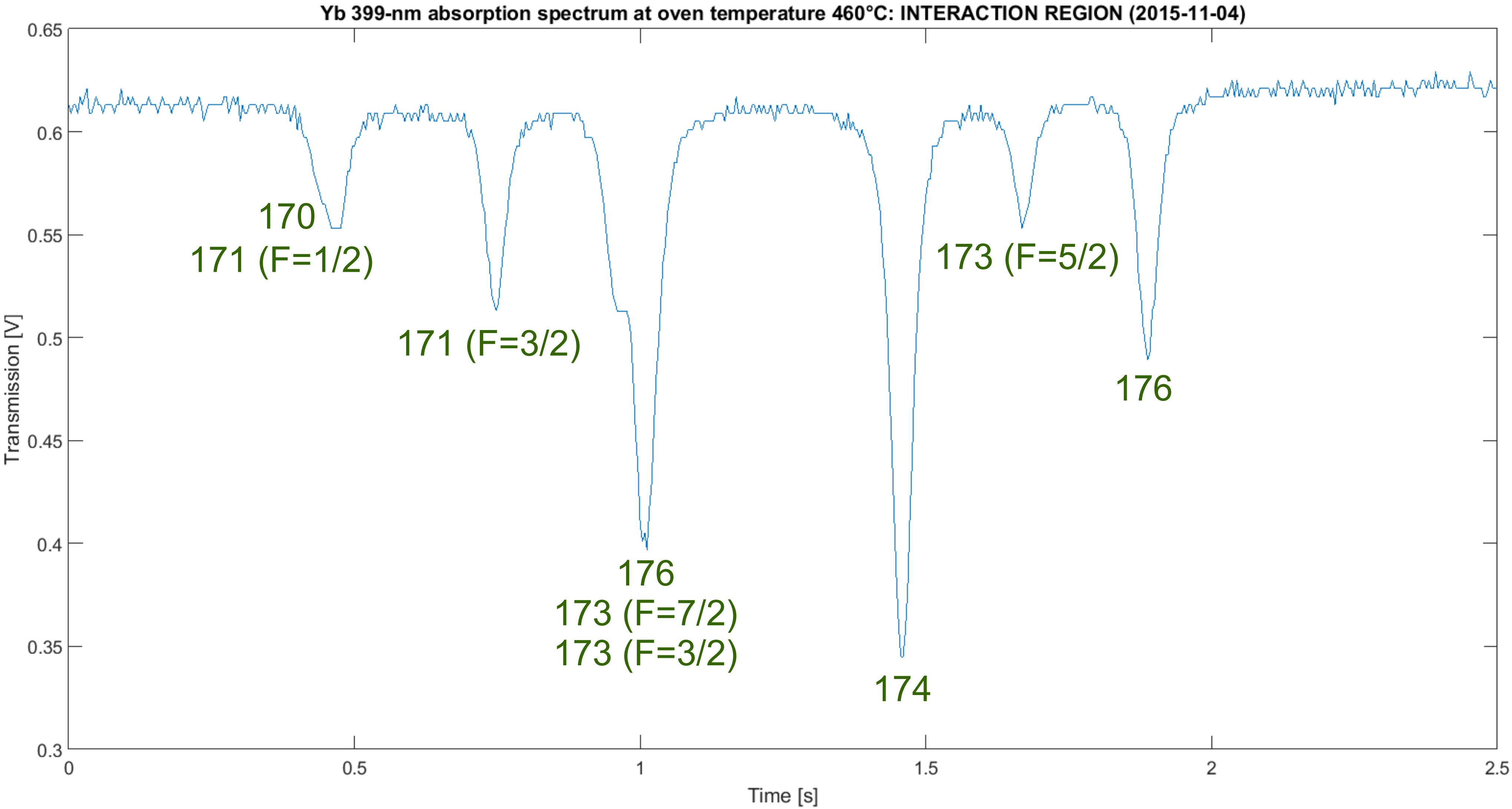
Our goals

- Investigate neutron distributions in the nucleus (the **neutron skin**) by comparing the strength of APV effects in **different Yb isotopes**
- Investigate **anapole moments** arising from weak interactions between nucleons, by comparing the strength of APV effects within **a single Yb isotope**

Yb isotopes

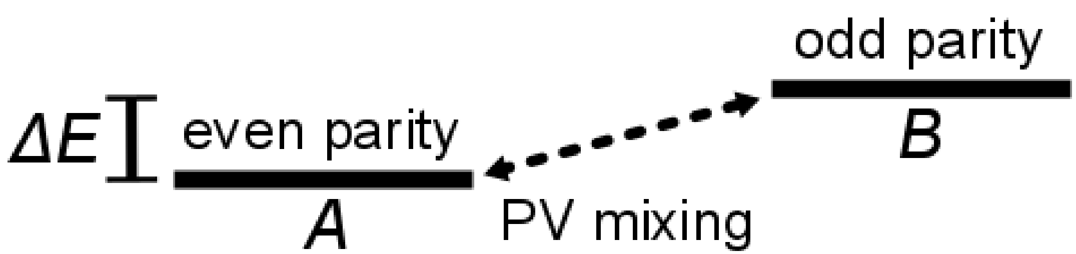
Mass number	Natural abundance [%]	Nuclear spin
168	0.13	0
170	3.04	0
171	14.28	1/2
173	16.13	5/2
174	31.83	0
176	12.76	0

Zero-field splitting



Why Yb?

- Opposite-parity states close in energy
- Configuration mixing enhances PV effect
- Large atomic number (*Z*=70)
- Seven stable isotopes

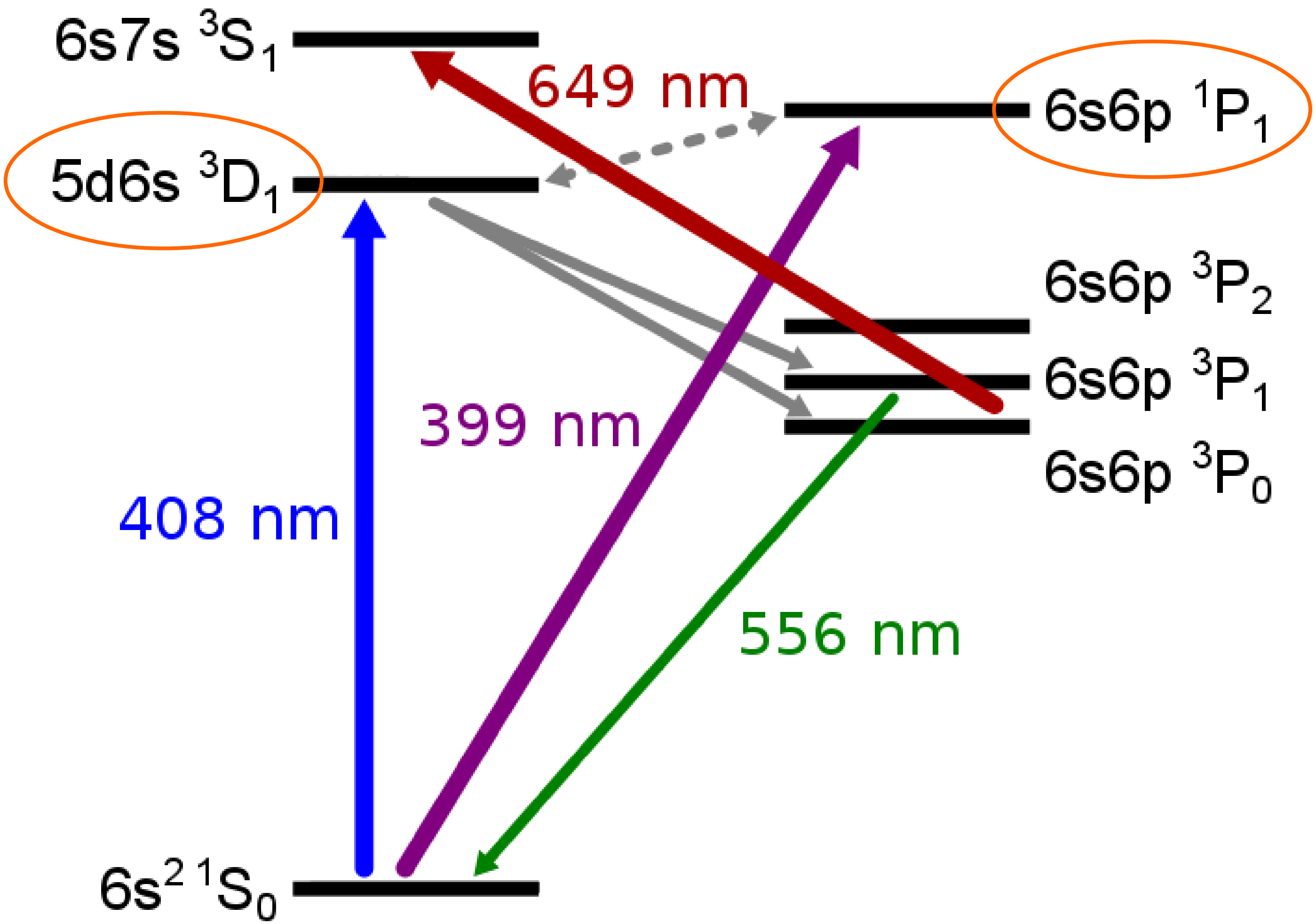


$$|A\rangle \rightarrow |A\rangle + i\zeta\,|B\rangle$$

$$|B\rangle \rightarrow |B\rangle + i\zeta\,|A\rangle$$

$$\zeta \propto \frac{Z^3}{\Delta E}$$

Energy levels



Stark-PNC interference technique

Rate of the 408-nm transition:

$A_w/A_{St} \sim 10^{-4}$

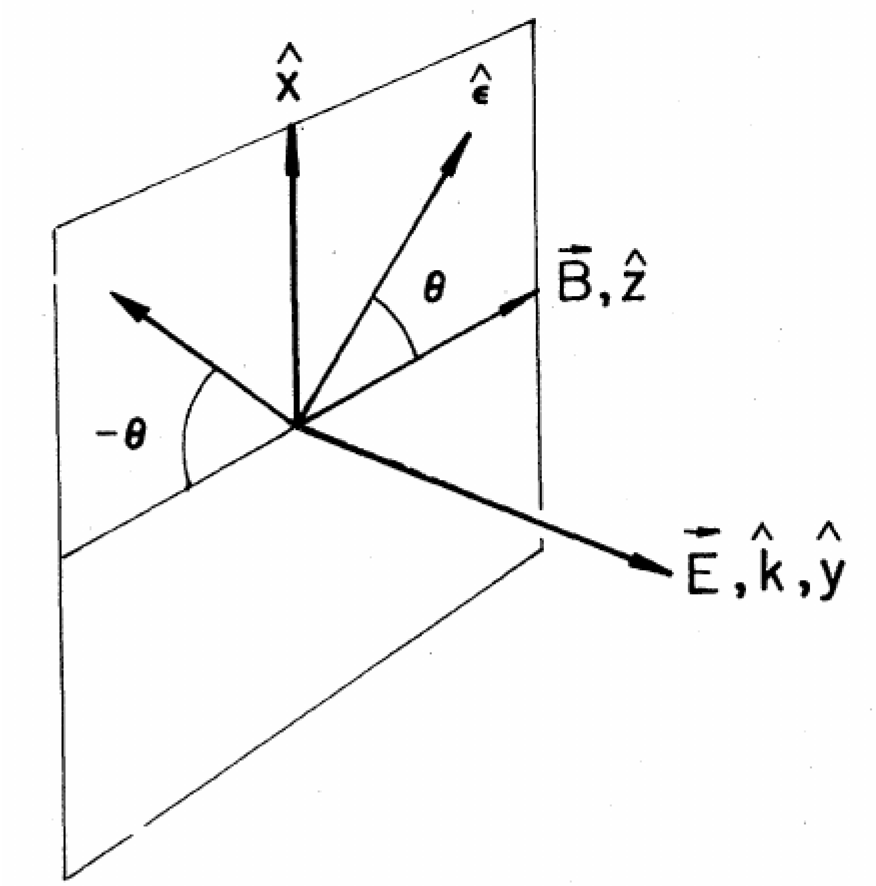
$$R = |A_{St} + A_w|^2 = |A_{St}|^2 \pm 2A_{St} \cdot A_w + |A_w|^2$$

Stark amplitude

PV amplitude

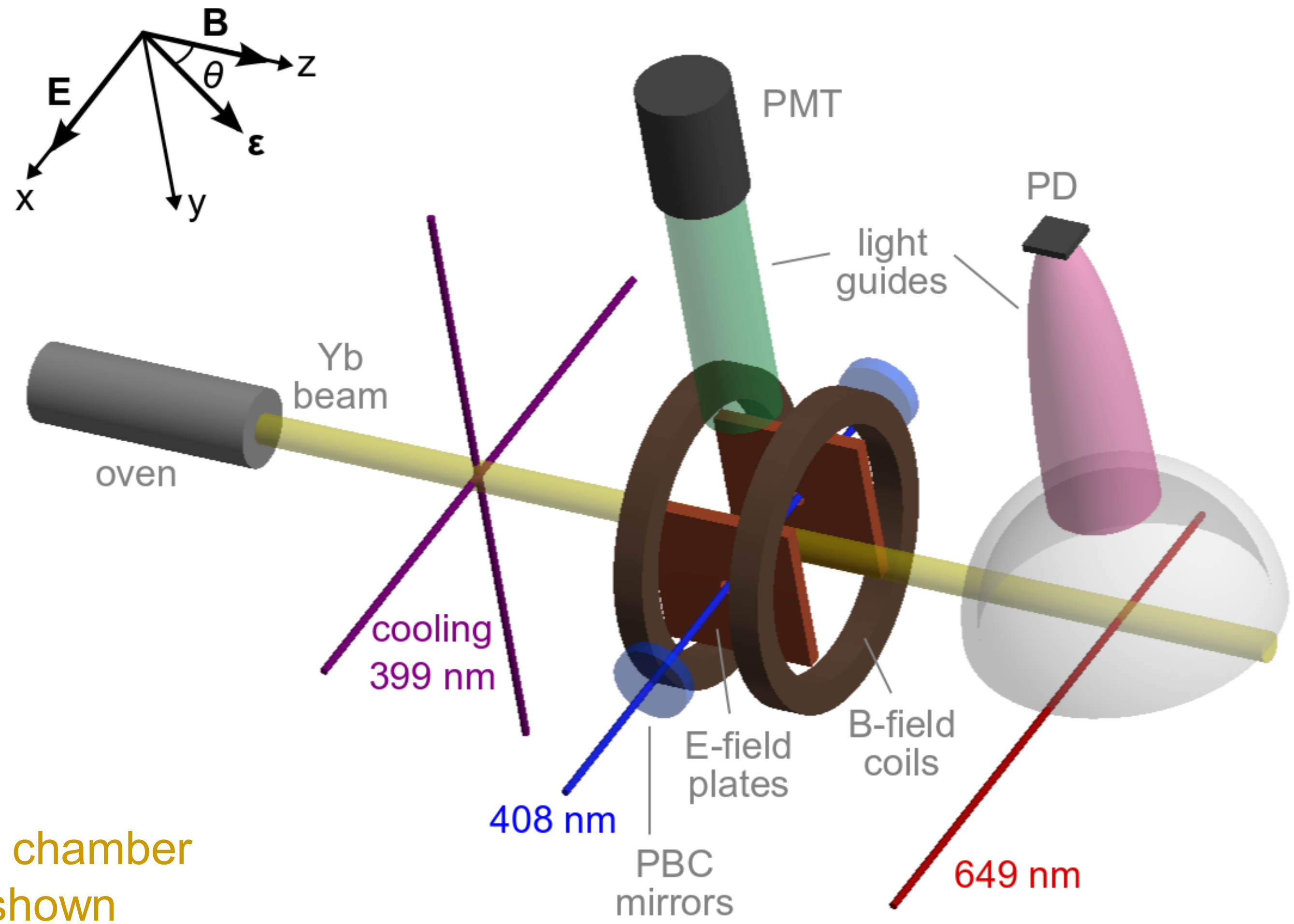
Field geometry

Drell & Commins
PRA 1985



Rotational invariant: **(ε·B)[(E×ε)·B]**

Experimental setup

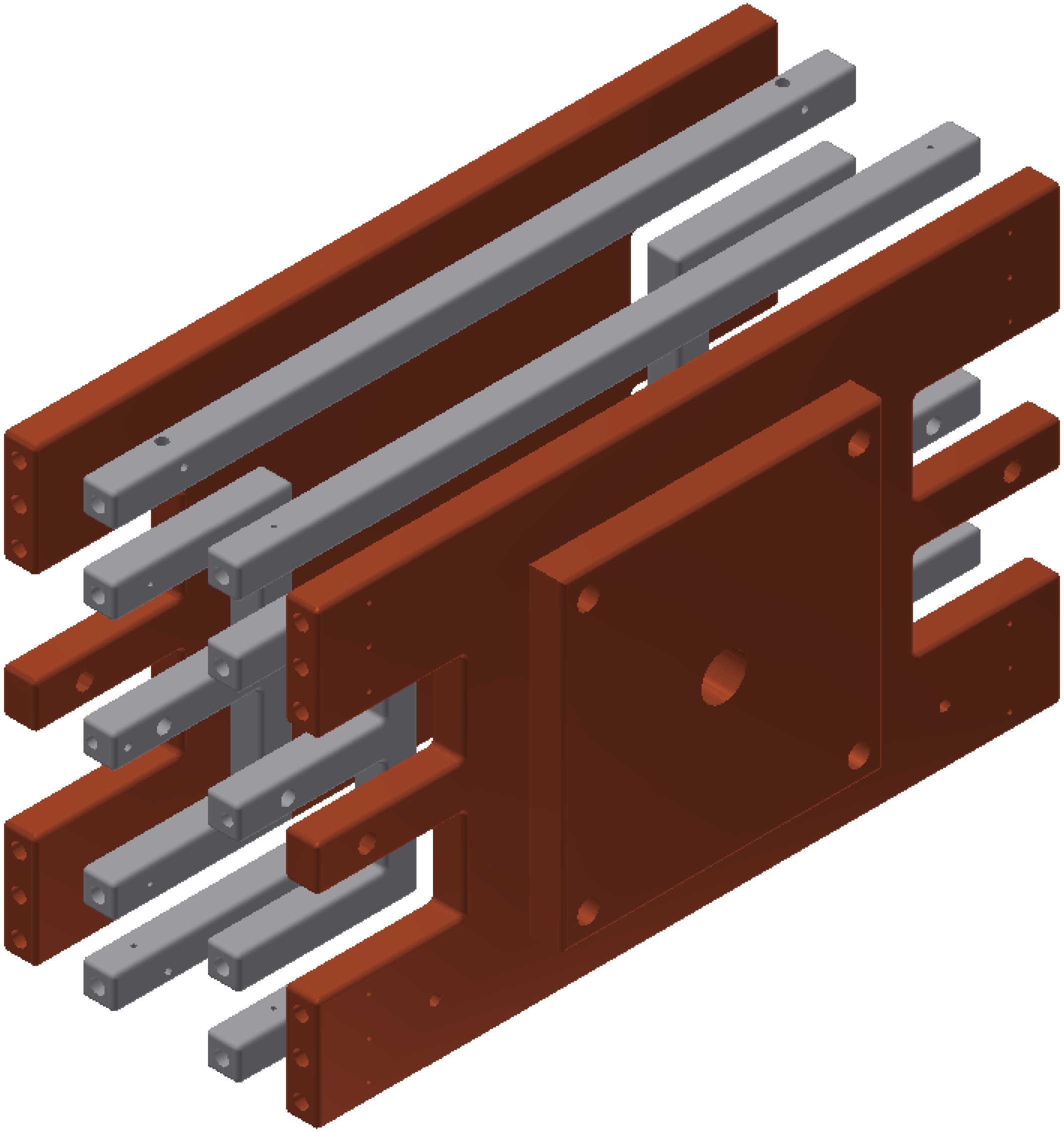


Vacuum chamber
not shown

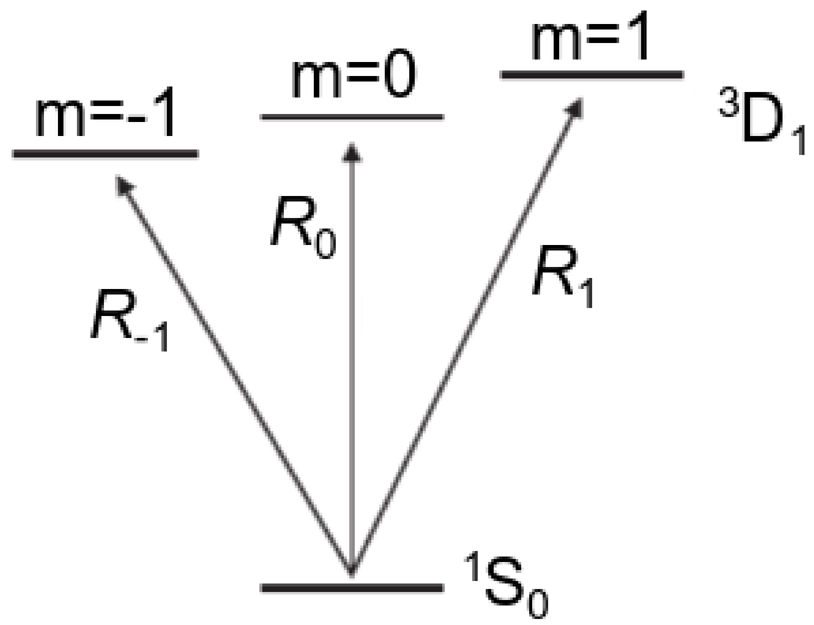
What's new in Mainz

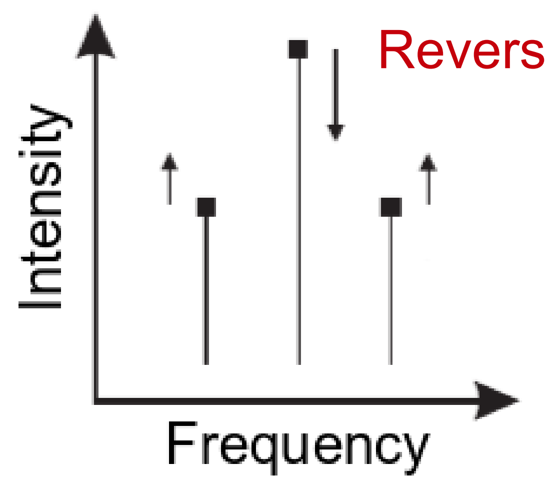
- 100× more powerful **408-nm laser system**
  - Frequency-doubled Ti:Sapph (M Squared)
  - Stabilized using wavelength meter (HighFinesse)
- Improved **vacuum chamber**: 10^{-6} Torr
- Newly designed **electric-field plates**

E-field plates



PV signature: Even isotopes (I=0)

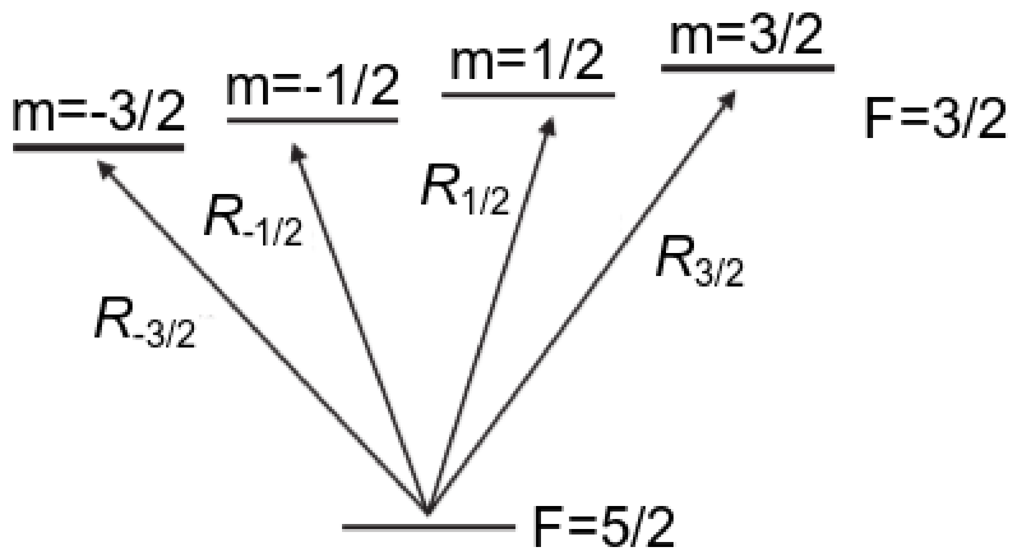


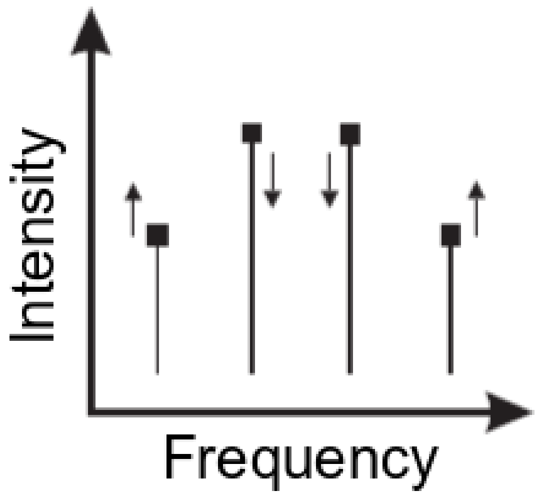


$$R_0 \propto \beta^2 E^2 \sin^2\theta + 2E\beta\zeta\cos\theta\sin\theta$$

$$R_{\pm1} \propto \frac{1}{2}\beta^2 E^2 \cos^2\theta - E\beta\zeta\cos\theta\sin\theta$$

PV signature: Odd isotopes

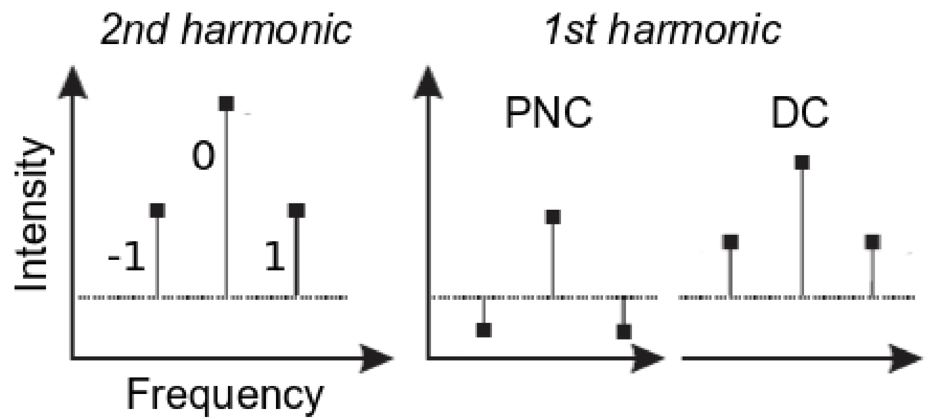




Yb-173

Extracting the PV signal

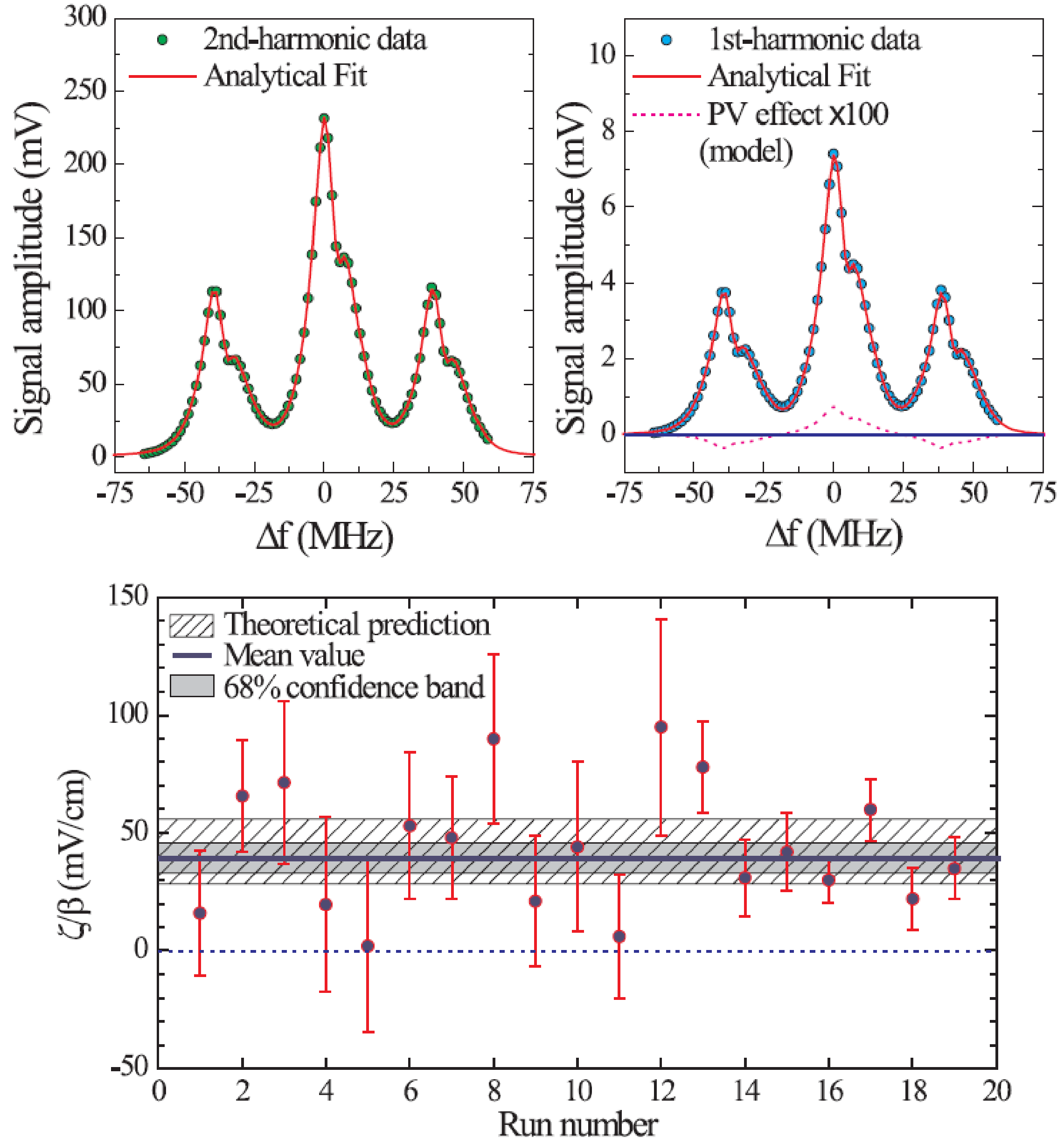
- Modulate applied E-field: $E = E_{\mathrm{DC}} + E_0 \cos \omega t$



- Compute PV-asymmetry parameter:

$$\mathcal{K} \equiv \frac{R^{(1)}_{-1}}{R^{(2)}_{-1}} + \frac{R^{(1)}_{+1}}{R^{(2)}_{+1}} - 2\frac{R^{(1)}_{0}}{R^{(2)}_{0}} = \mp \frac{16\zeta}{\beta E_0}$$

2009 results (Berkeley)



Tsigutkin *et al.*
PRL 2009

Systematics

- Want to minimize PV-mimicking effects
- Apparatus imperfections
  - Misalignment of the applied fields
  - Stray electric fields
  - Ellipticity of light polarization
  - Residual M1 effects

Experimental protocol

- Lock to each Zeeman peak and record signal
- Take data for all combinations of **B**, θ

$$\begin{bmatrix} \mathcal{K}_1 \\ \mathcal{K}_2 \\ \mathcal{K}_3 \\ \mathcal{K}_4 \end{bmatrix} = \frac{1}{4} \begin{bmatrix} -1 & -1 & +1 & +1 \\ -1 & +1 & +1 & -1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & +1 & +1 \end{bmatrix} \cdot \begin{bmatrix} \mathcal{K}(+B, +\theta) \\ \mathcal{K}(-B, +\theta) \\ \mathcal{K}(+B, -\theta) \\ \mathcal{K}(-B, -\theta) \end{bmatrix}$$

$\mathcal{K}_1$	$\mathcal{K}_2$	$\mathcal{K}_3$
$\frac{8(\tilde{e}_y e_z + \tilde{e}_z e_y)}{\tilde{E}_0^2} + \frac{16\tilde{b}_x e_y}{B\tilde{E}_0} + \frac{16\zeta}{\beta\tilde{E}_0}$	$\frac{16b'_x e_y}{B\tilde{E}_0}$	$\frac{16b'_x e_z}{B\tilde{E}_0}$

Investigating E-field systematics

- New field plates to be installed next week!
- Apply transverse fields to artificially exaggerate both DC and AC imperfections

$\mathcal{K}_1$
$\frac{8(\tilde{e}_y e_z + \tilde{e}_z e_y)}{\tilde{E}_0^2} + \frac{16\tilde{b}_x e_y}{B\tilde{E}_0} + \frac{16\zeta}{\beta\tilde{E}_0}$

Status of statistics

- Current signal-to-noise ratio: 0.5 in 1 sec
- Goal SNR: 2 in 1 sec
- Need to minimize technical laser noise

Roadmap

- Characterize systematics
- Optimize signal-to-noise ratio
- Verify expected scaling of weak charge with neutron number (0.5% measurement)
- Conduct measurements in different hyperfine levels of Yb-173 (anapole moment)
- Conduct neutron-skin measurements in chain of spin-0 isotopes (0.1% measurement)

Thanks!

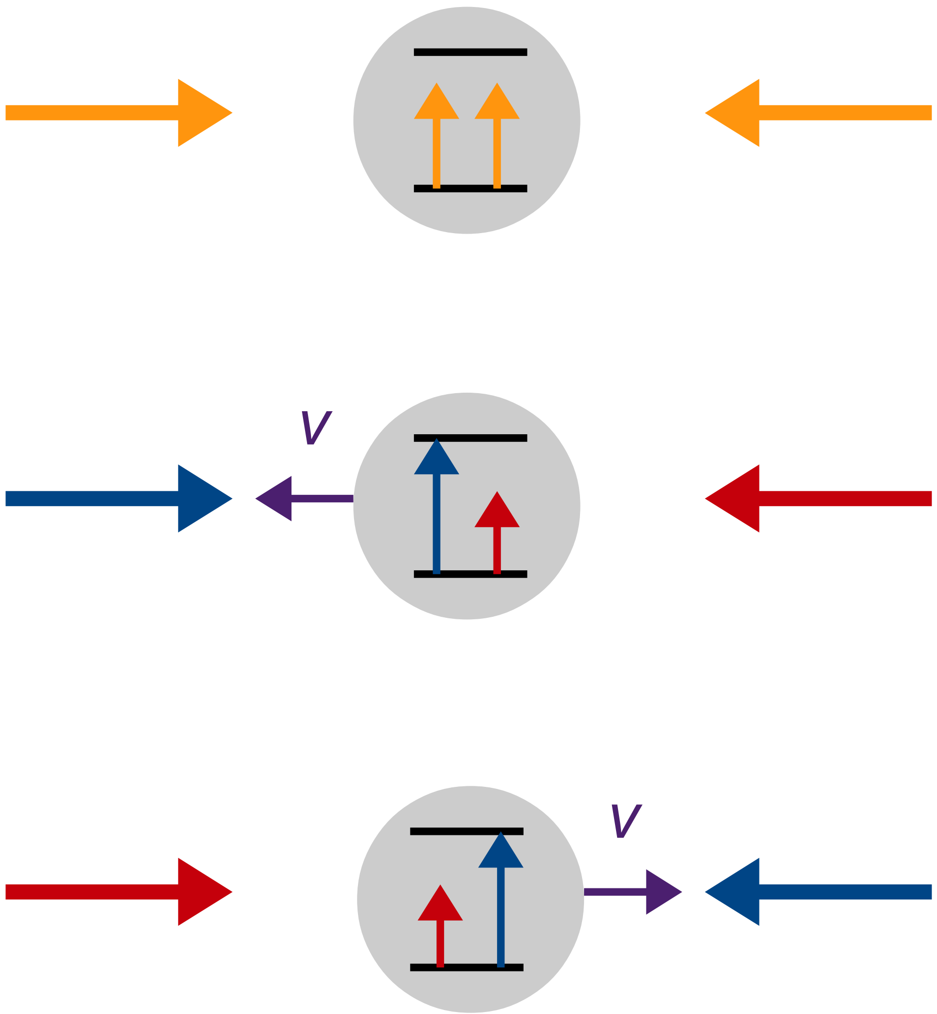
Learn more: budker.berkeley.edu/PubList.html

Prof. Dmitry Budker

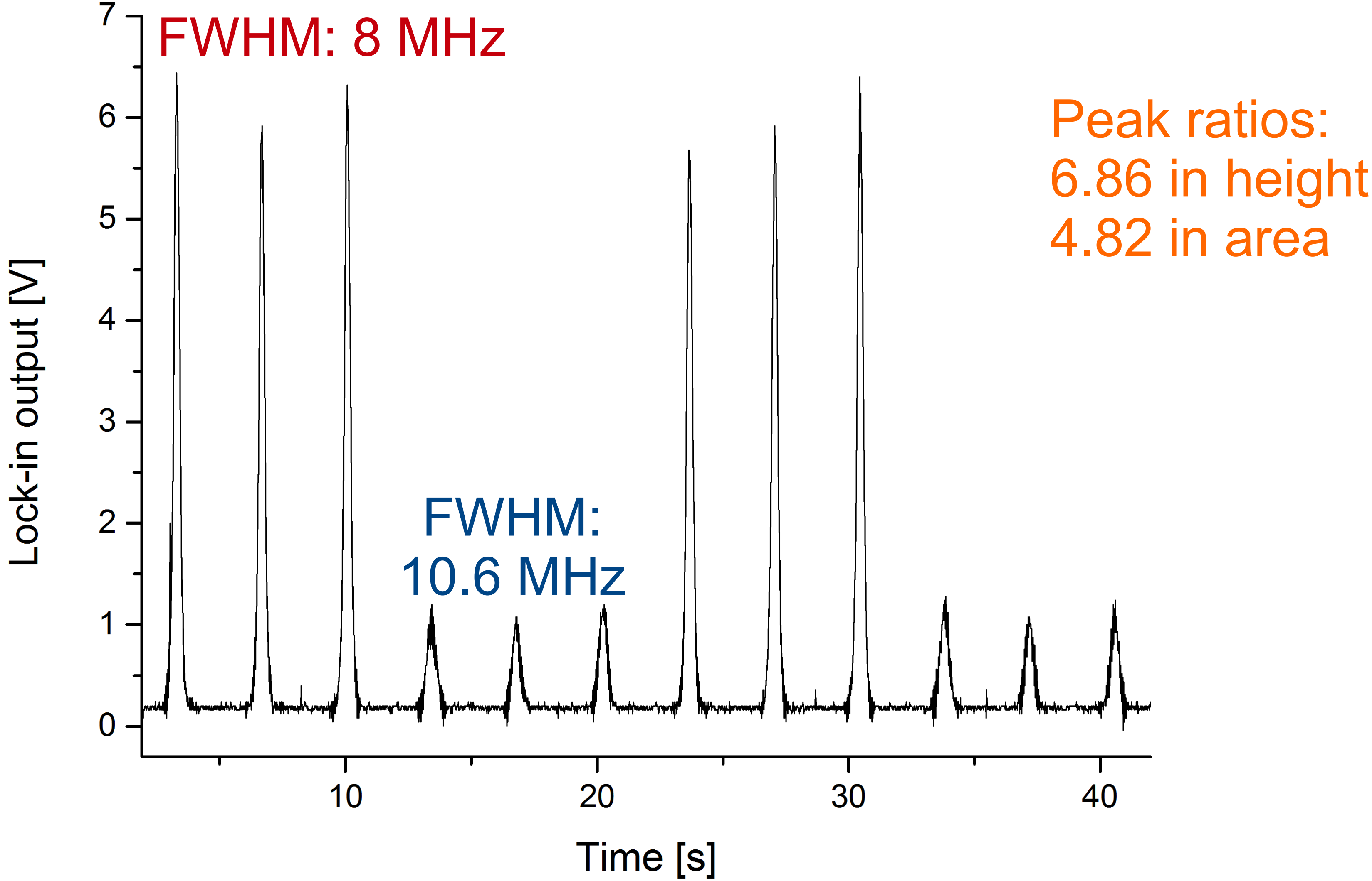
Dr. Dionysis Antypas

Dr. Konstantin Tsigutkin

Introduction to transverse laser cooling (2D Optical Molasses)



649 fluorescence signal with and without cooling at oven temp 450°C



Scan 408 laser 100 MHz in 3.4 s, lock-in time constant 3 ms

Signal v. temperature