Precision Spectroscopy of Trapped Radium Ions

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TRIμP Program
Trapped Radioactive Isotopes: μ-laboratories for fundamental Physics
Kernfysisch Versneller Instituut (KVI)
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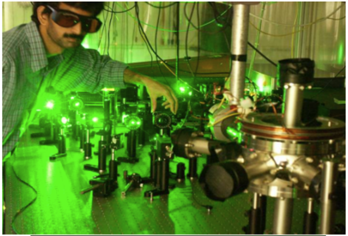
KVI FOM NWO Netherlands Organisation for Scientific Research university of groningen

Outline

Low Energy Tests of The Standard Model

The Standard Model (SM) of particle physics is incomplete
Searches for physics beyond the SM at two, complementary, fronts:

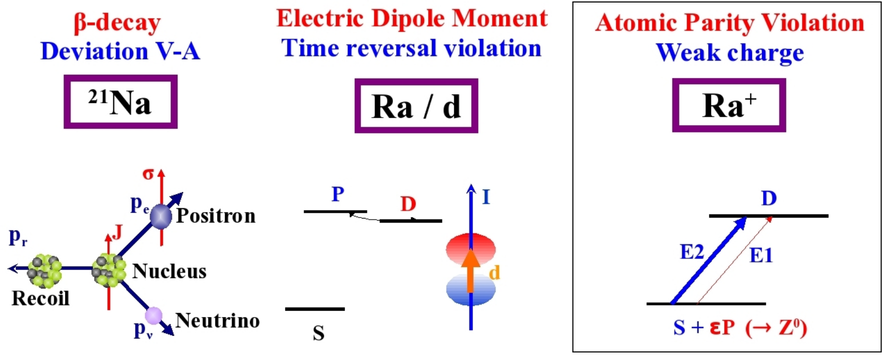
LHC @ CERN



TRIμP @ KVI

Motivation of TRIμP Programme

Violation of discrete symmetry - *Physics beyond Standard Model*



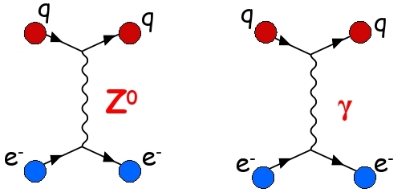
Weak Interaction In Atom

Weak Interaction (Violates Parity Symmetry):

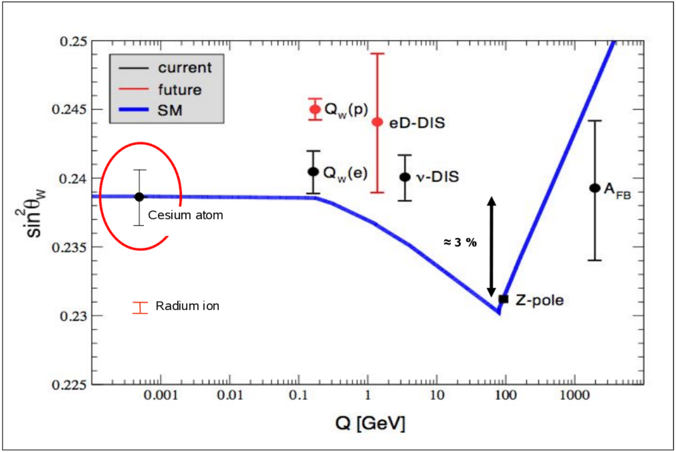
- Short range, mediated by massive ($m \approx 90 \frac{GeV}{c^2}$) Z^0 boson
- Strength of Atomic Parity Violation effects $\sim Z^3$
- Nucleus gets a weak charge Q_w

$$Q_w = -N + (1-4\sin^2\theta_w)Z + \text{Radiative Corr.} + \text{New Physics}$$

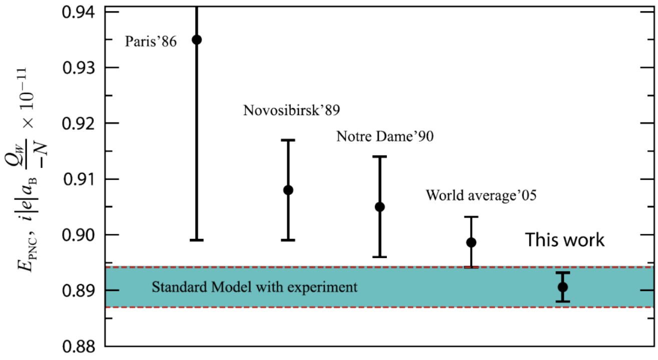
θ_w: *Weinberg angle* or *weak mixing angle*.



Running of Weinberg Angle



Running of Weinberg Angle



Precise extraction of Weinberg angle:

- Accuracy of atomic theory is indispensable
- Atomic theory needs experimental input

Figure: Adapted from A. Derevianko et al

Ra$^+$: An Ideal Candidate

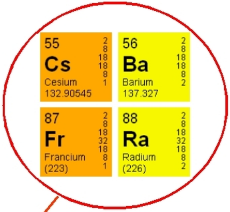
General Advantages

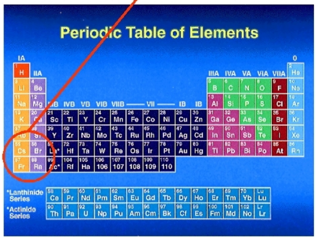
- Heavy: APV signal $\sim Z^3$
- Atomic theory is tractable
- Easy lasers (semiconductor diodes)
- Different isotopes available @ TRIμP

Single Ion Technique

- Ions are easy to manipulate
- Superior control of systematics
- Novel frequency measurement: Light Shifts (Fortson 1993)

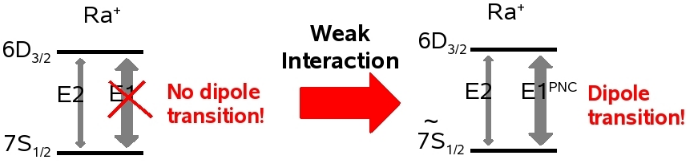
S-S	S-D
Cs 0.9	Ba$^+$ 2.2
Fr 14.2	Ra$^+$ 46.4





APV in Ra^+

Weak interaction mixes states of opposite parity

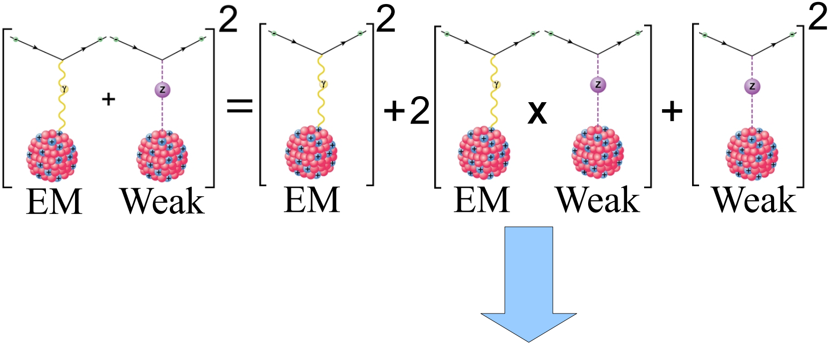


$$| 7S_{1/2}\rangle \rightarrow | 7\tilde{S}_{1/2}\rangle = | 7S_{1/2}\rangle + \varepsilon \mid nP_{1/2}\rangle$$

$$E1_{PNC} = \langle 6D_{3/2} \mid D \mid 7\tilde{S}_{1/2}\rangle = Q_w k \rightsquigarrow \text{Theory@KVI}$$

Experiment@TRIμP

Interference of Weak and EM Interaction

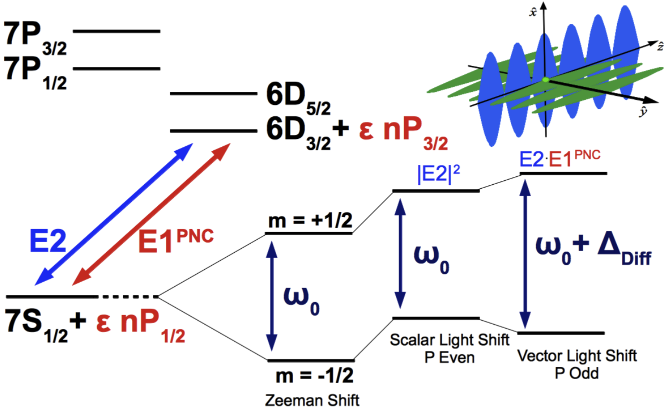


We aim to have sub - 1% accuracy

Figure: K. Jungmann, Physics 2, 68 (2009)

Measurement of Light Shift in Ra^+

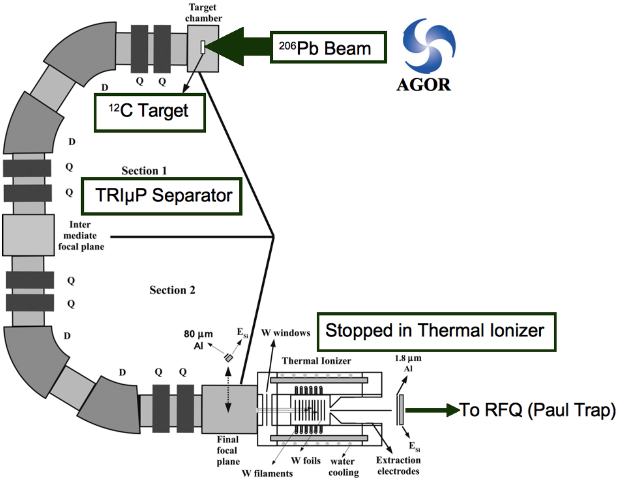
Differential Light Shift :: Interference of E2 and $E1^{PNC}$



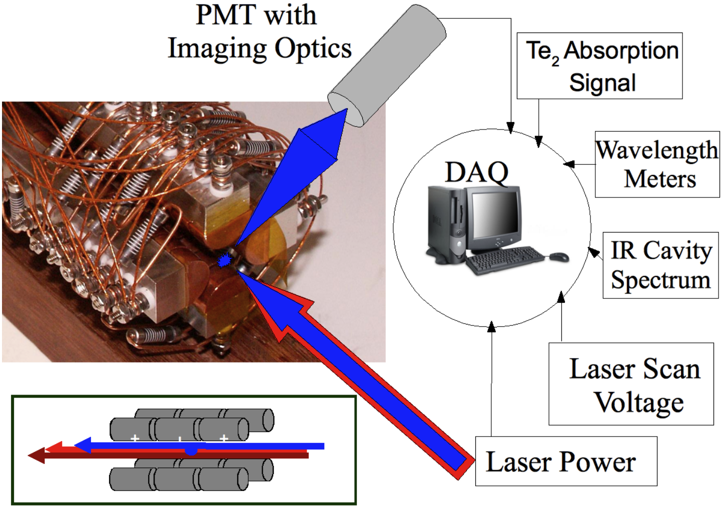
$$|\Omega|^2 = |\Omega^{E2}_{m'm} + \Omega^{PNC}_{m'm}|^2 \sim |\Omega^{E2}_{m'm}|^2 + 2Re|\Omega^{PNC}_{m'm}\Omega^{E2}_{m'm}|$$

Schematics of Experiment :: Production

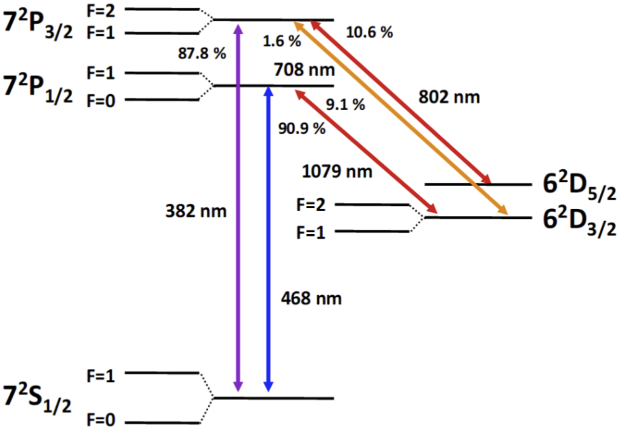
$$^{206}\text{Pb}+^{12}\text{C}\rightarrow^{218}\text{Ra}*\rightarrow^{A}\text{Ra}+(218\text{-A})\text{n}$$



Schematics of Experiment :: Trapping and Spectroscopy



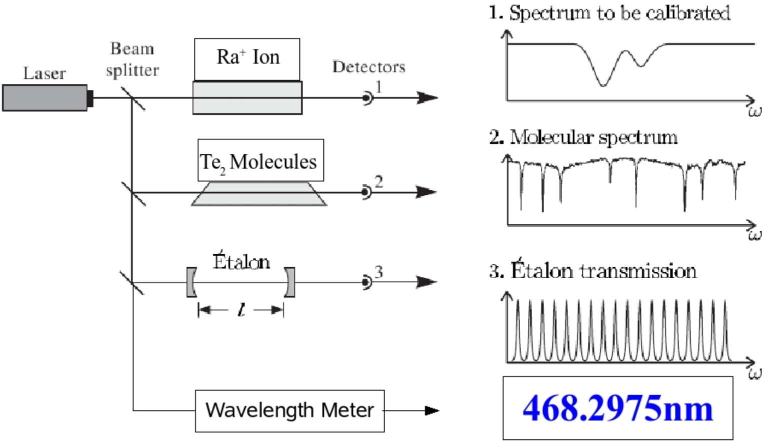
Level Structure of Radium Ion



Theoretical branching ratios and life times: B. K. Sahoo et al., Phys. Rev. A 76, 040504(R) (2007)

Experimental wavelengths: E. Rasmussen, Z. Phys. 86, 24 (1933)

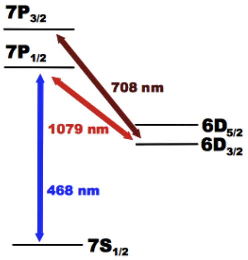
Absolute Frequency Calibration



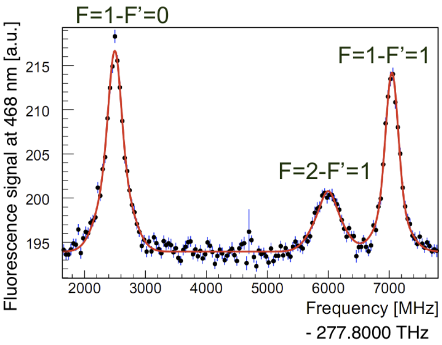
Original Figure: C.J. Foot, Atomic Physics, Oxford University Press

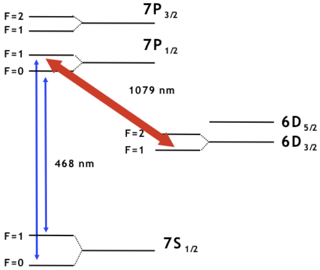
Results From Recent Measurements

- Production of a series of Radium isotopes.
- Excited state laser spectroscopy on trapped ions
  - $6^2D_{3/2}$ hyperfine structure in $^{213}Ra^+$
  - Isotope shift of $6^2D_{3/2}$ - $7^2P_{1/2}$ in $^{212,213,214}Ra^+$
  - Isotope shift of $6^2D_{3/2}$ - $7^2P_{3/2}$ in $^{212,213,214}Ra^+$
  - Lifetime of the $6^2D_{5/2}$ state



Hyperfine Structure Splitting: $6D_{3/2}$ state of ^{213}Ra

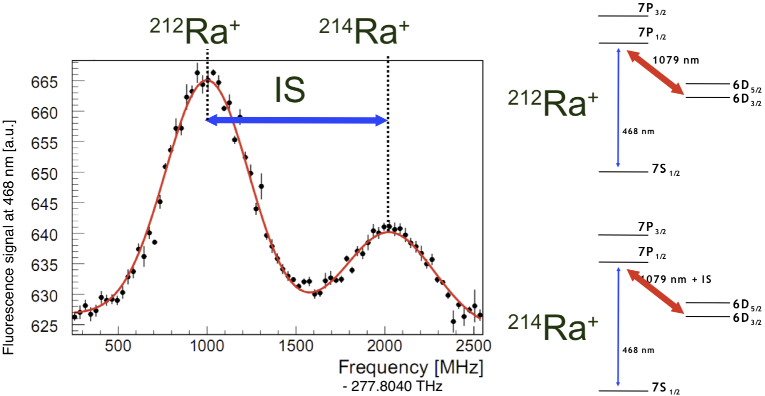




Experiment[1]	Theory[2]	Theory[3]
1054(9) MHz	1082 MHz	1086 MHz

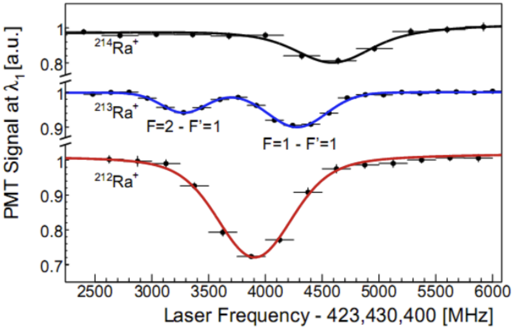
[1] O.O. Versolato, G.S. Giri et al. arXiv:1003.5580
[2] R. Pal et al., Phys. Rev. A 79 (2009)
[3] L.W. Wansbeek et al., Phys. Rev. A 78 (2008)

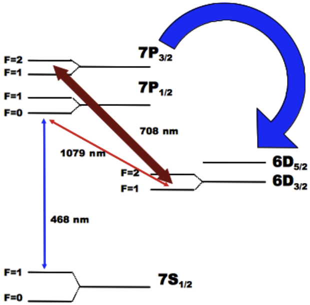
Isotope Shift: $6D_{3/2}$-$7P_{1/2}$ transition in $^{212,213,214}Ra$



^{214}Ra - ^{212}Ra	^{213}Ra - ^{212}Ra	^{214}Ra - ^{213}Ra
1032(5) MHz	318(11) MHz	714(12) MHz

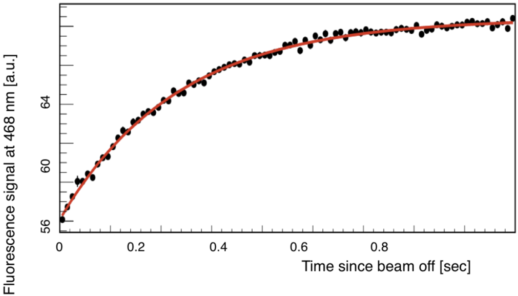
Isotope Shift: $6D_{3/2}$-$7P_{3/2}$ transition in ^{212,213,214}Ra

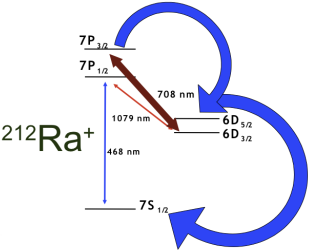




^{214}Ra - ^{212}Ra	^{213}Ra - ^{212}Ra	^{214}Ra - ^{213}Ra
701(50) MHz	248(50) MHz	453(34) MHz

Lifetime of $D_{5/2}$ State in ^{212}Ra





Experiment[1]	Theory[2]	Theory[3]
232(4) ms	297(4) ms	303(4) ms

[1] O.O. Versolato, G.S. Giri et al. arXiv:1003.5580
[2] B. K. Sahoo et al., Phys. Rev. A 76, 040504(R) (2007)
[3] R. Pal et al., Phys. Rev. A 79, 062505 (2009)

Conclusions

Summary

- Production of short lived Radium isotopes
- Buffer gas cooling and trapping of ions
- Excited state laser spectroscopy on trapped ions
  - HFS
  - IS
  - Lifetime
- Measured values provide a test of atomic theory

Outlook

- Laser cooling of trapped radium ions
- Trapping of few ions
- Measurement of APV induced light shift in a single Ra^{+}

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Experiment

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- Klaus Jungmann

Theory

- Lotje Wansbeek
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- Rob Timmermans

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Thank You !