Laser spectroscopic studies along the Al isotopic chain and the isomer-shift of the self-conjugate nucleus ^{26}Al

H. Heylen (KU Leuven)

S. Malbrunot-Ettenauer (CERN)

COLLAPS Collaboration

Motivation

R. F. Garcia Ruiz et al., Nature Physics (2016), 10.1038/nphys3645.

N=32 ?

^{38,38m}K: np pairing

M. L. Bissell et al., Phys. Rev. Lett. 113, 052502 (2014)

charge radii beyond N=28

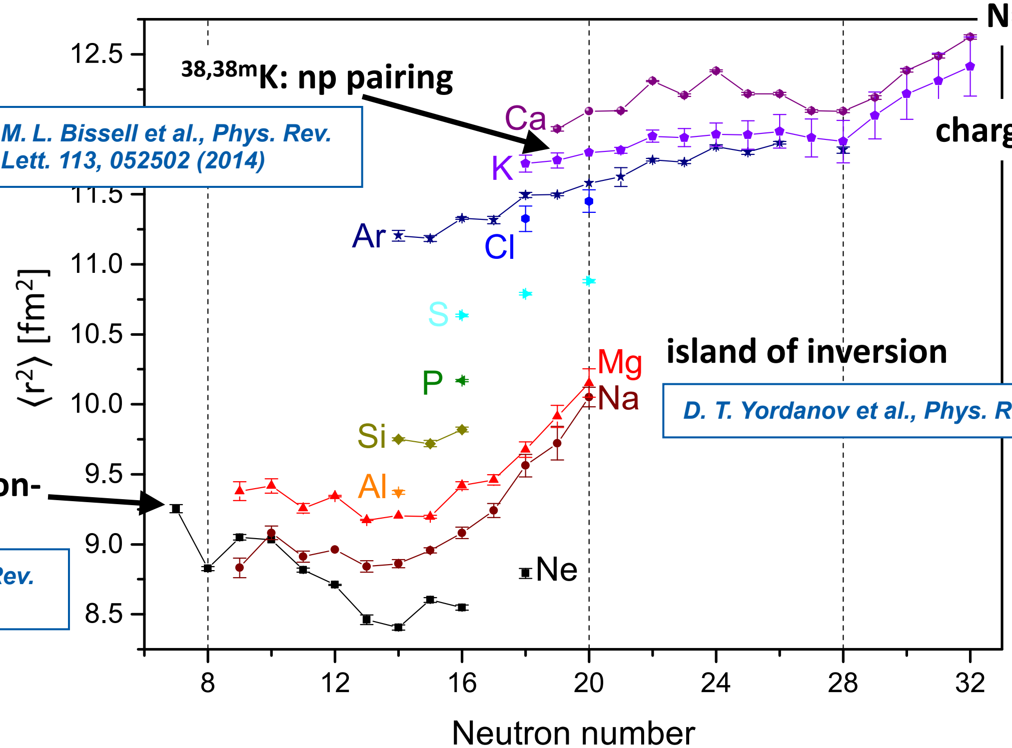
K. Kreim et al., Physics Letters B 731, 102 (2014)

island of inversion

D. T. Yordanov et al., Phys. Rev. Lett. 108, 042504 (2012)

^{17}Ne: two-proton-halo candidate

W. Geithner et al., Phys. Rev. Lett. 101, 252502 (2008)



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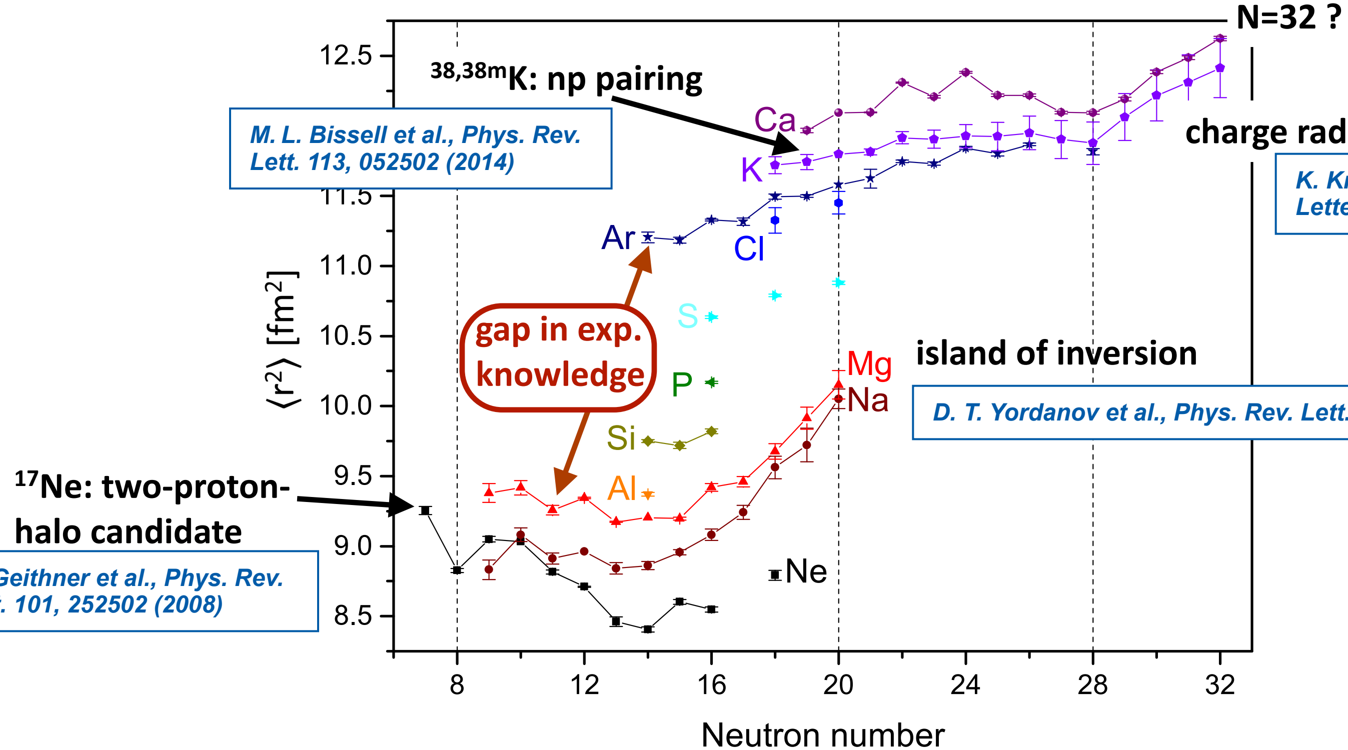

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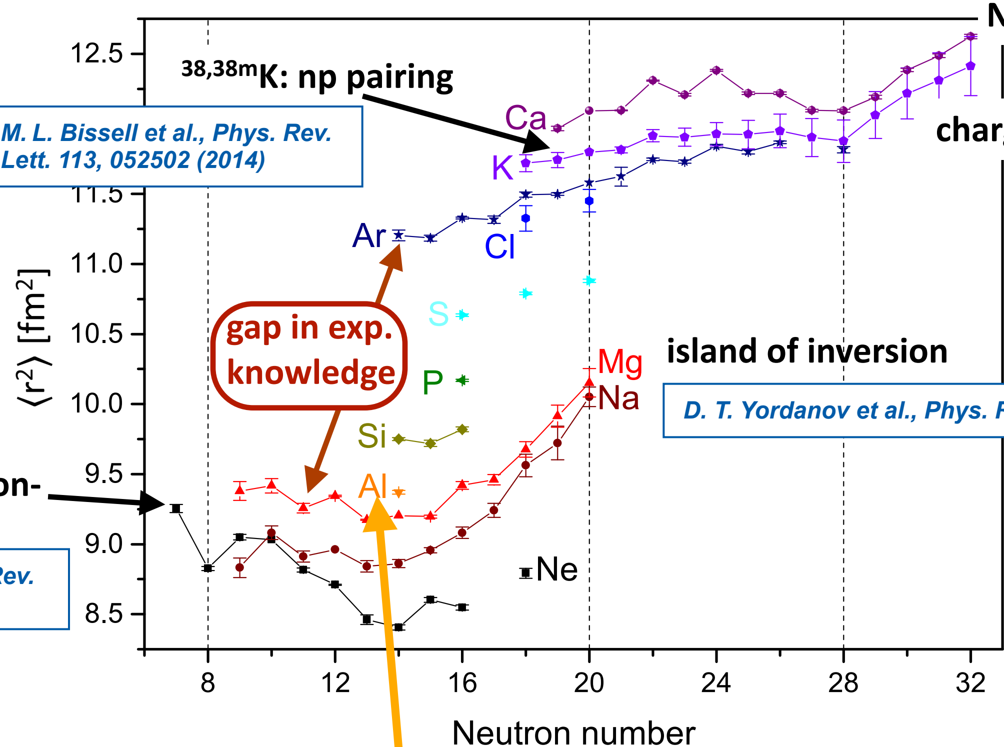

gap in exp. knowledge

island of inversion

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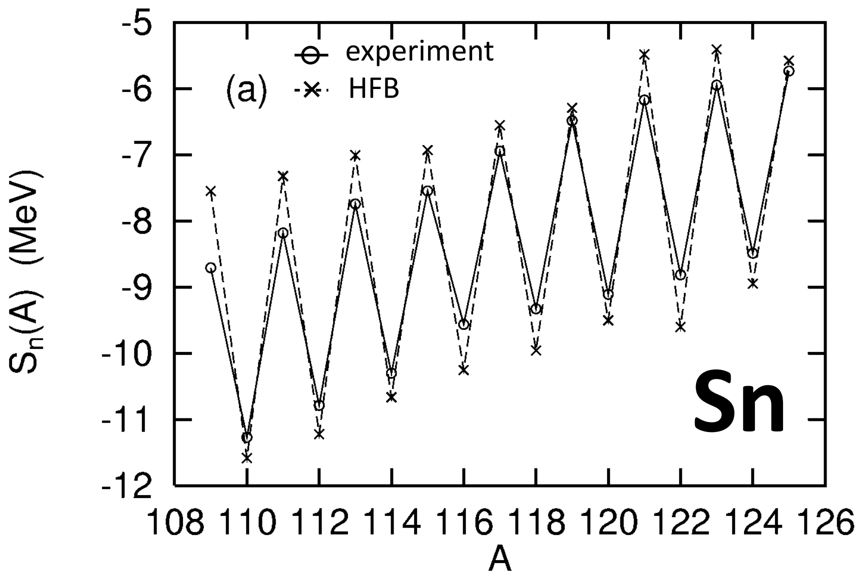
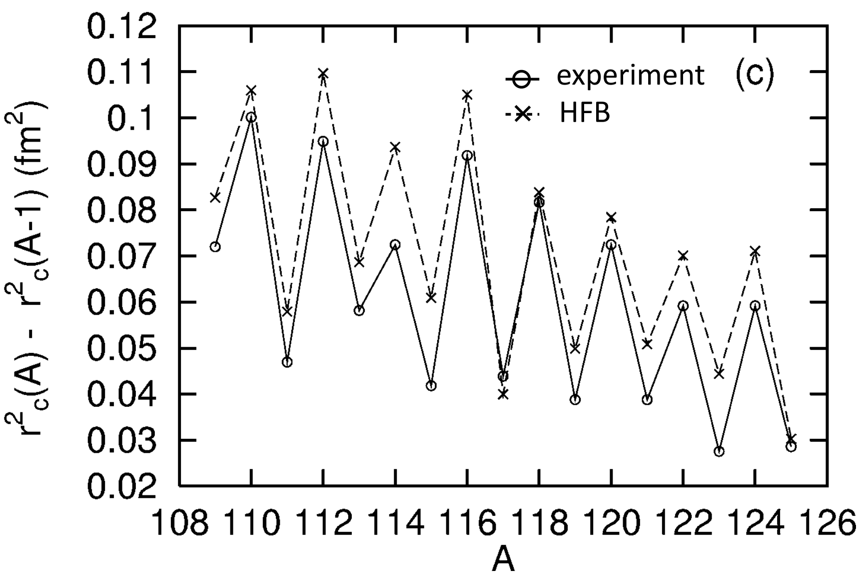
Al isotopic chain

np pairing | **superallowed β decays** | **at the border of the island of inversion**

odd even staggering in nuclear charge radii

motivation I





S. Sakakihara and Y. Tanaka, Nucl. Phys. A691, 649 (2001).

pairing plays a fundamental role

B. S. Reehal and R. A. Sorensen, Nucl. Phys. A161,385 (1971)
D. Zawischa, Phys. Lett. B 155, 309 (1985)
U. Regge and D. D. Zawischa, Phys. Rev. Lett. 61, 149 (1988)
M. Horoi, Phys. Rev. C 50, 2834 (1994).
E. Caurier et al., Phys. Lett. B 522, 240 (2001).
S. Sakakihara and Y. Tanaka, Nucl. Phys. A691, 649 (2001).

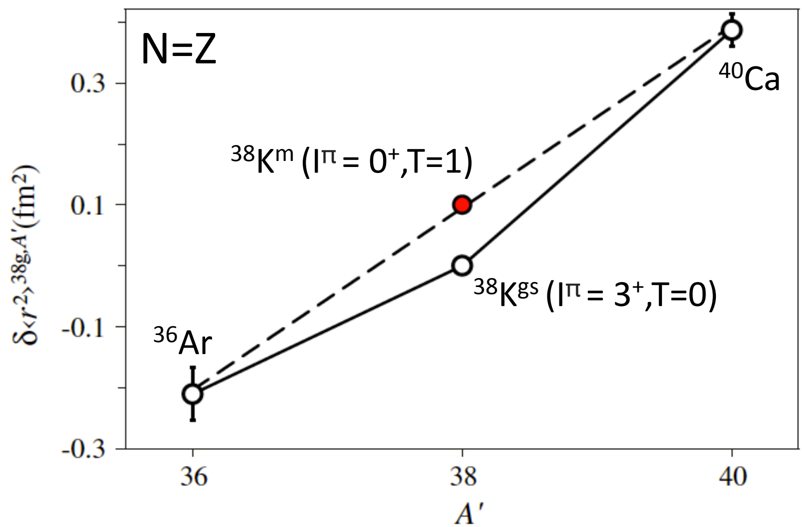
simple model:

- pair 'scatters' on the Fermi surface to many states (with larger r)
- unpaired nucleon 'blocks' scattering

$\Big\}$ $r_{\text{even N}} > r_{\text{odd N}}$

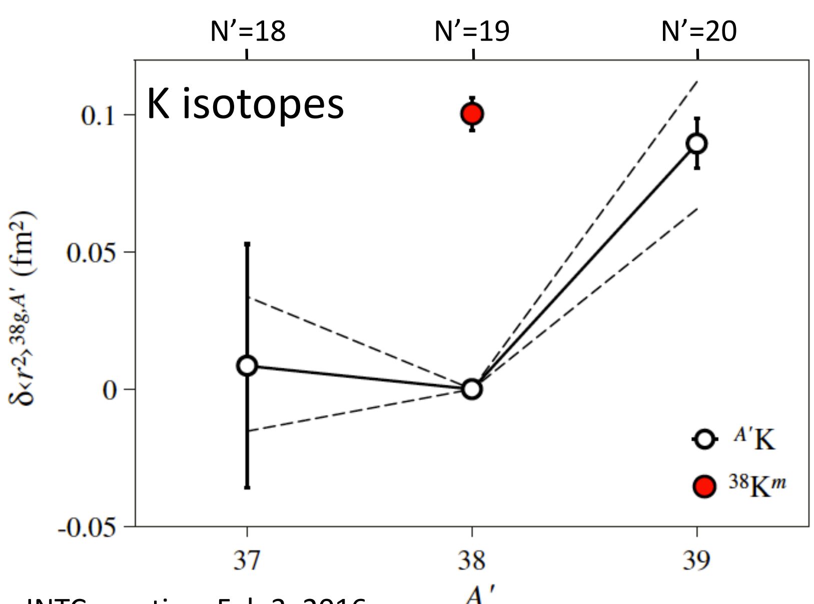
np pairing

motivation I



all T=1 pairs should behave the same
⇒ expect to see effect also for **np pair**

ideal test cases:
gs-isomer comparison in N=Z nuclides with one T=1 state



^{38,38m}K follows expectation

- T=1 isomer with larger r_c
- $\delta\langle r^2\rangle^{gs,m}$ larger than odd-even staggering (unpaired proton in ^{37,39}K)

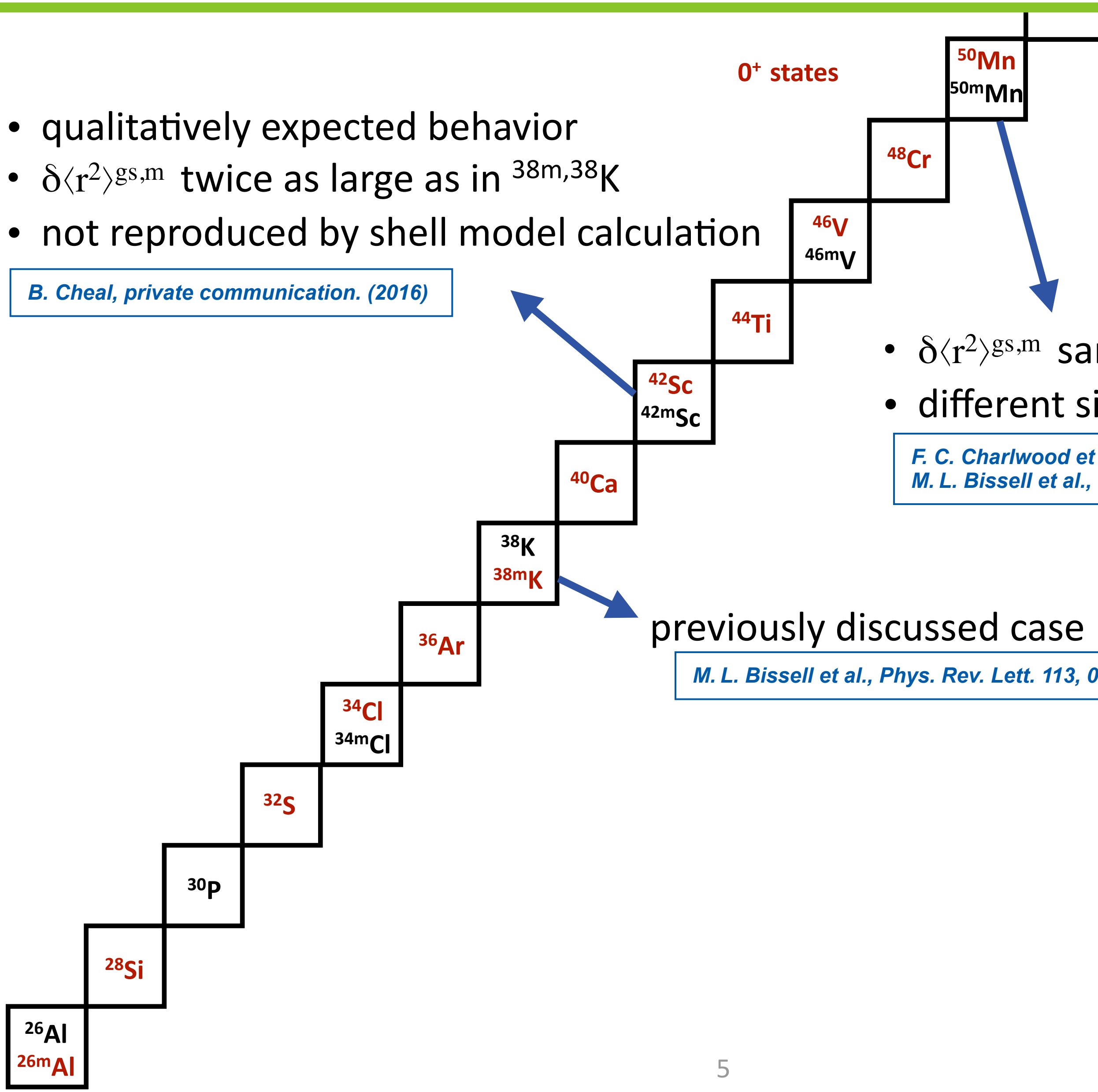
M. L. Bissell et al., Phys. Rev. Lett. 113, 052502 (2014)

motivation I

0⁺ states

- qualitatively expected behavior
- $\delta\langle r^2\rangle^{gs,m}$ twice as large as in ^{38m,38}K
- not reproduced by shell model calculation

B. Cheal, private communication. (2016)



- $\delta\langle r^2\rangle^{gs,m}$ same size as in ^{38m,38}K
- different sign (g.s. T=1 state)

F. C. Charlwood et al., Phys. Lett. B 690, 346 (2010).
M. L. Bissell et al., Phys. Rev. Lett. 113, 052502 (2014)

previously discussed case

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motivation I

- qualitatively expected behavior
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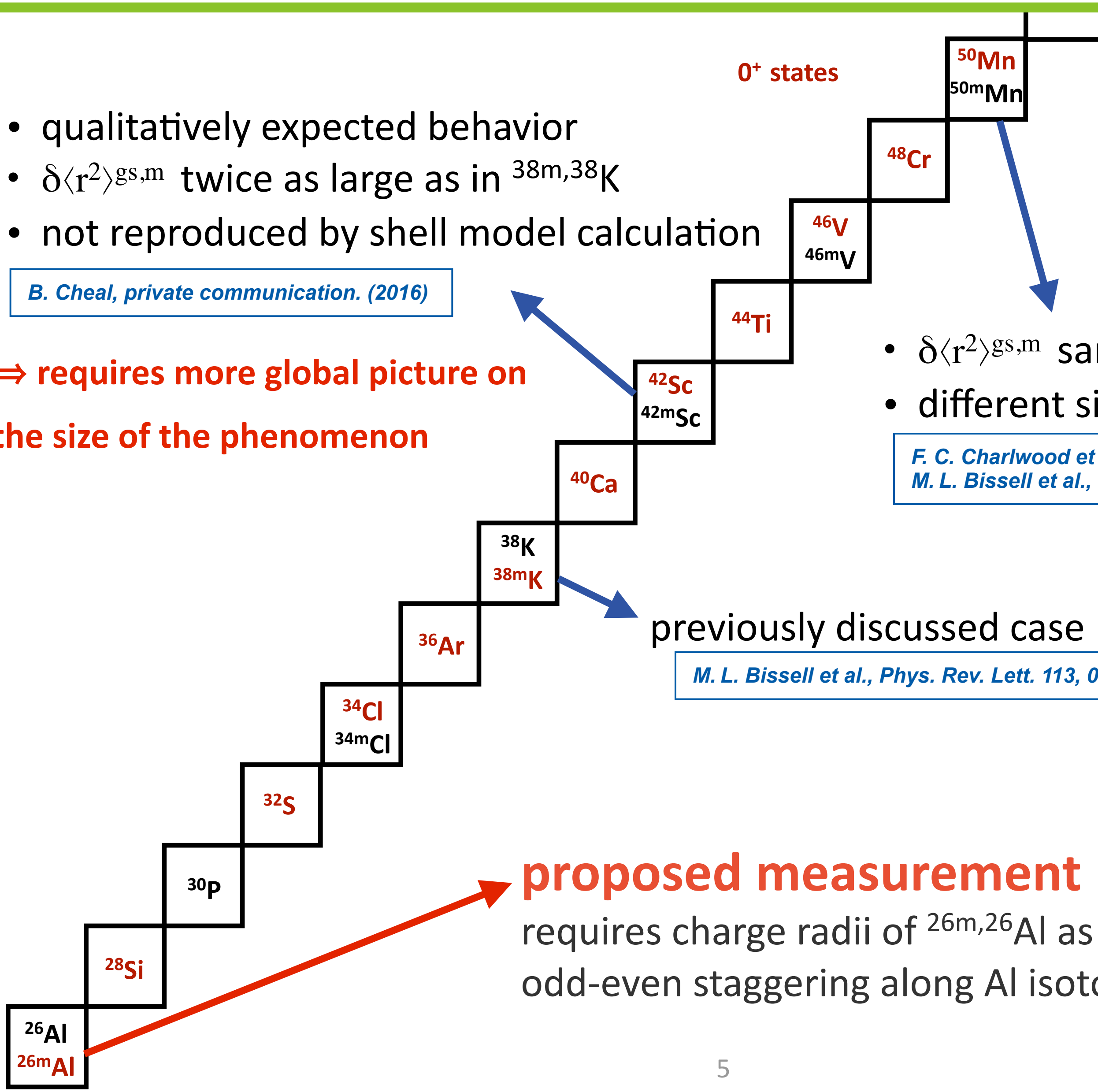
⇒ requires more global picture on the size of the phenomenon



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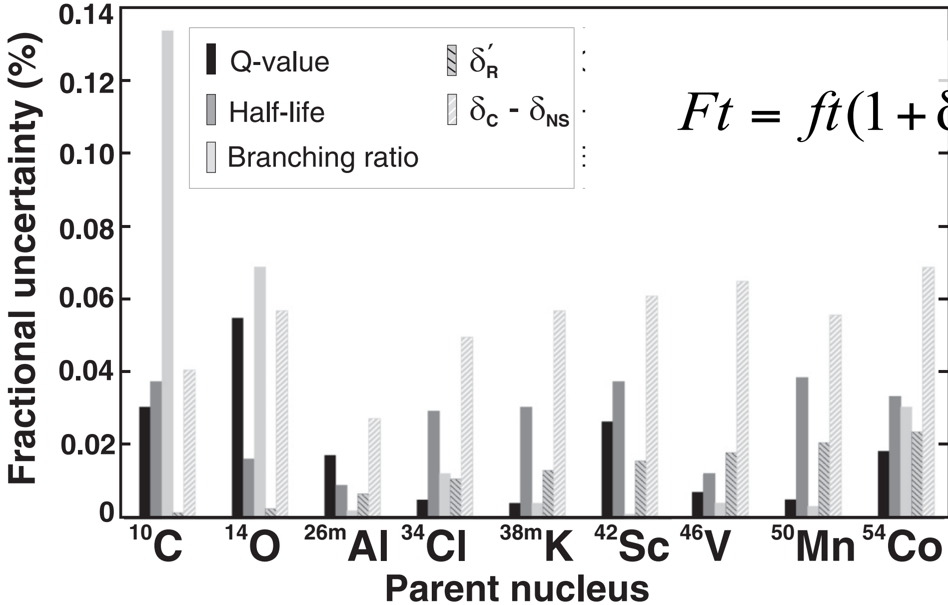
proposed measurement

requires charge radii of ^{26m,26}Al as well as odd-even staggering along Al isotopic chain

Superallowed β decays, V_{ud} & ^{26m}Al's charge radius

motivation II



J. C. Hardy and I. S. Towner, Phys. Rev. C 91, 025501 (2015)

$$\mathcal{F}t = ft(1+\delta_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

$$\boxed{|V_{ud}| = \frac{G_V}{G_F}}$$

(details see previous talk)

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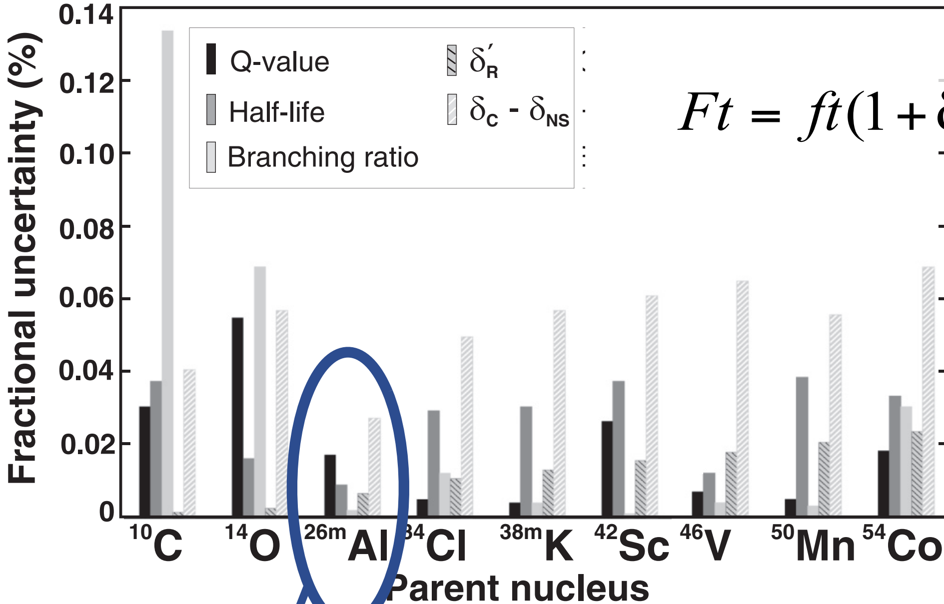

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- most precisely studied superallowed β emitter
- rivals precision of all other 13 cases combined

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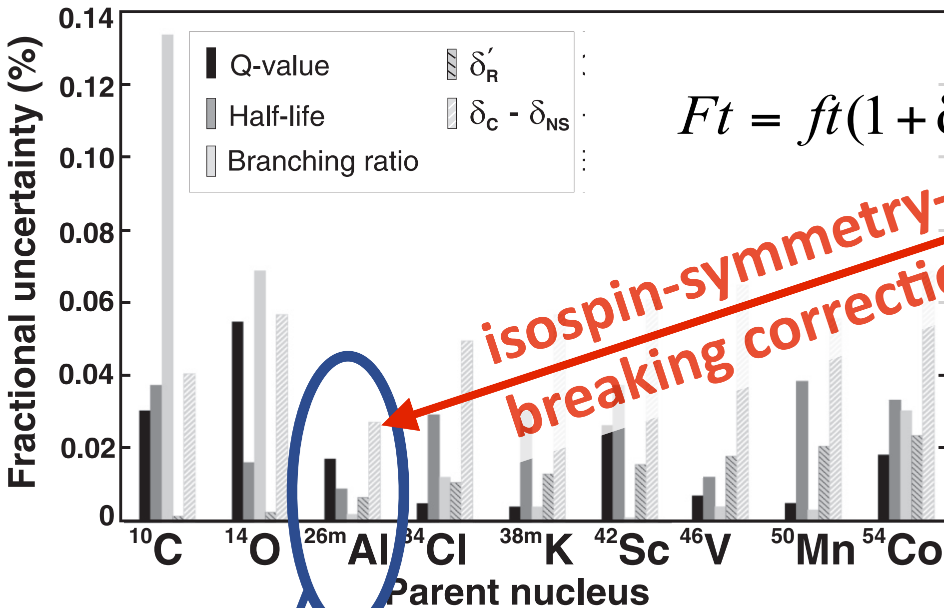

J. C. Hardy and I. S. Towner, Phys. Rev. C 91, 025501 (2015)

isospin-symmetry-breaking corrections

$$Ft = ft(1+\delta_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

$$\boxed{\left|V_{ud}\right| = \frac{G_V}{G_F}}$$

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ISB corrections δ_c

$$\delta_C = \delta_{C1} + \delta_{C2}$$

configuration mixing within the restricted shell model space

radial overlap correction

^{26m}Al

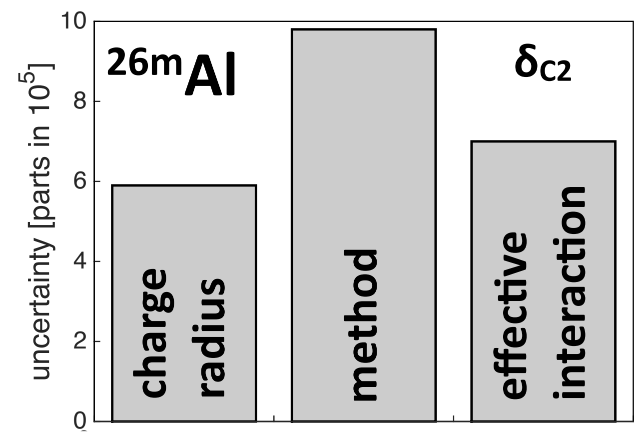
δ_{C1} = 0.030(10) %
δ_{C2} = 0.280(15) %

δ_{C2}: shell model based on Saxon-Woods radial functions

$$\begin{aligned} V_C(r) &= Ze^2/r, \quad \text{for} \quad r \geqslant R_c, \\ &= \frac{Ze^2}{2R_c}\left(3 - \frac{r^2}{R_c^2}\right), \quad \text{for} \quad r < R_c, \end{aligned}$$

- nuclear charge radius enters here
- often not known experimentally (e.g. ^{26m}Al)

⇒extrapolation based on stable isotopes (and inflated uncertainties)



I. S. Towner private communications (2016).

I. S. Towner and J. C. Hardy, PRC 66, 035501 (2002).
I. S. Towner and J. C. Hardy, PC 77, 025501 (2008).

motivation II

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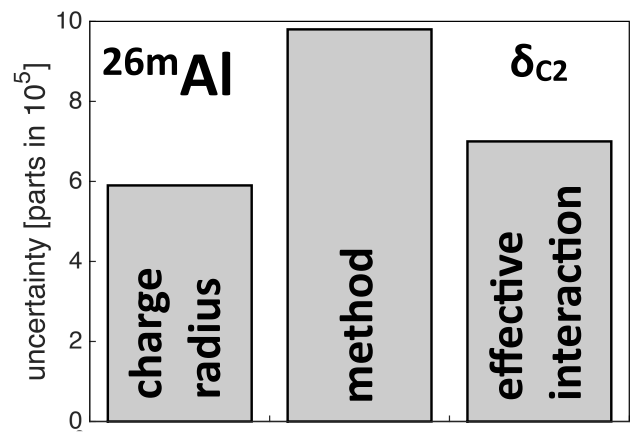


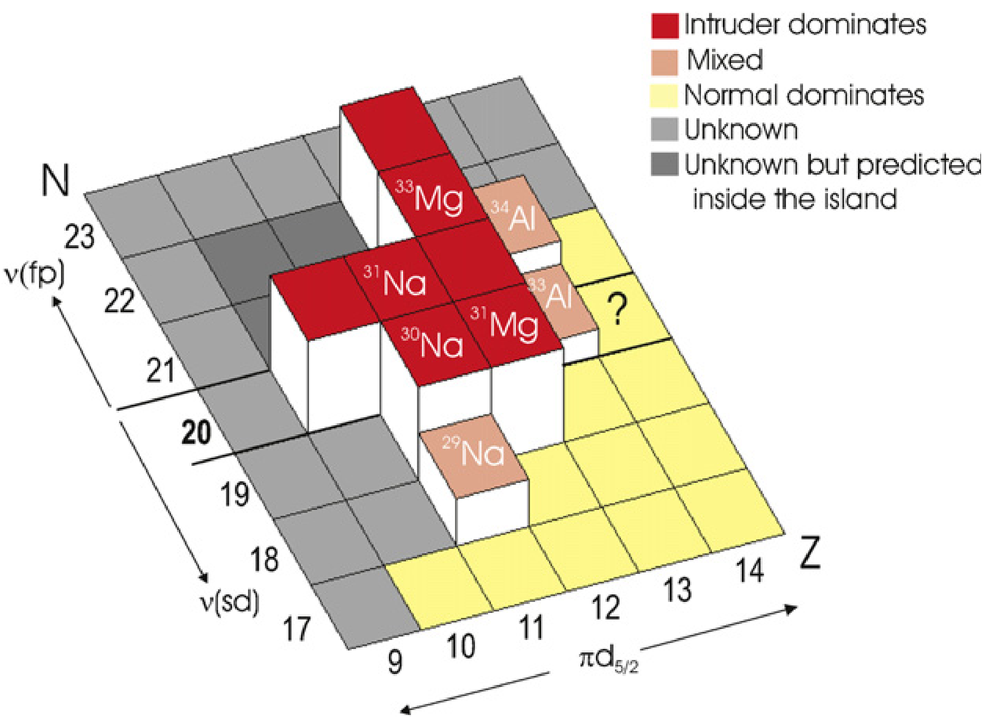
I. S. Towner private communications (2016).

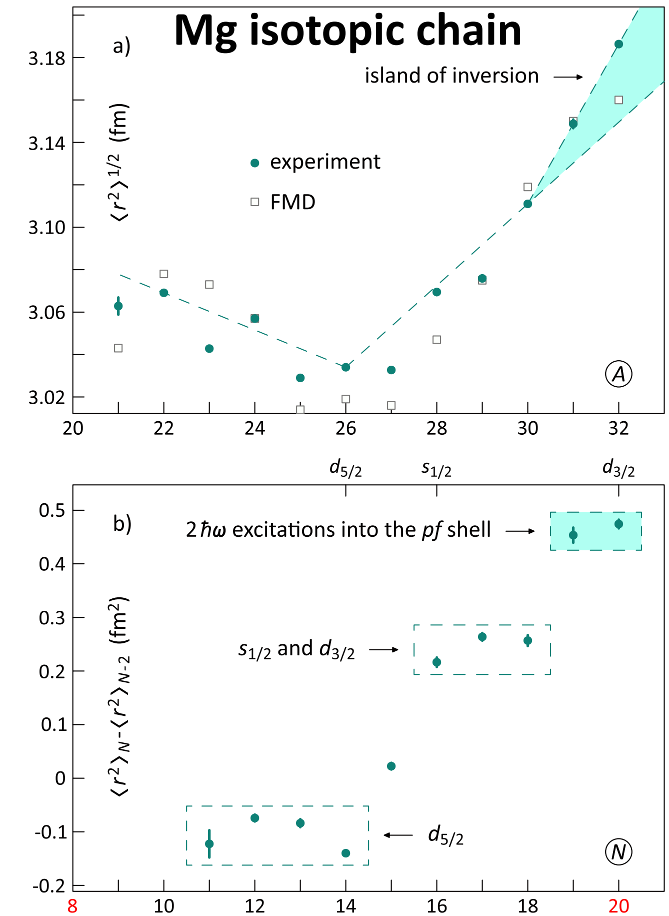
proposed measurement will place $\langle r^2 \rangle$ on solid experimental grounds

and reduce uncertainty on δ_{C2}

charge radii & the island of inversion

motivation III





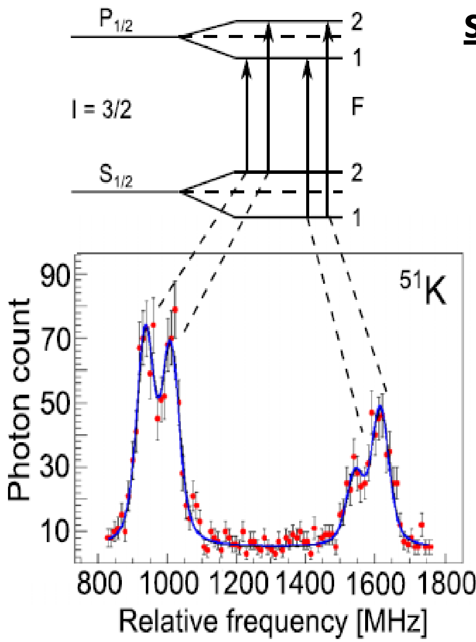
^{33,34}Al: intruder admixtures in the ground state (μ and Q)

P. Himpe et al., Physics Letters B 643, 257 (2006)
P. Himpe et al., Physics Letters B 658, 203 (2008)
K. Shimada et al., Physics Letters B 714, 246 (2012)

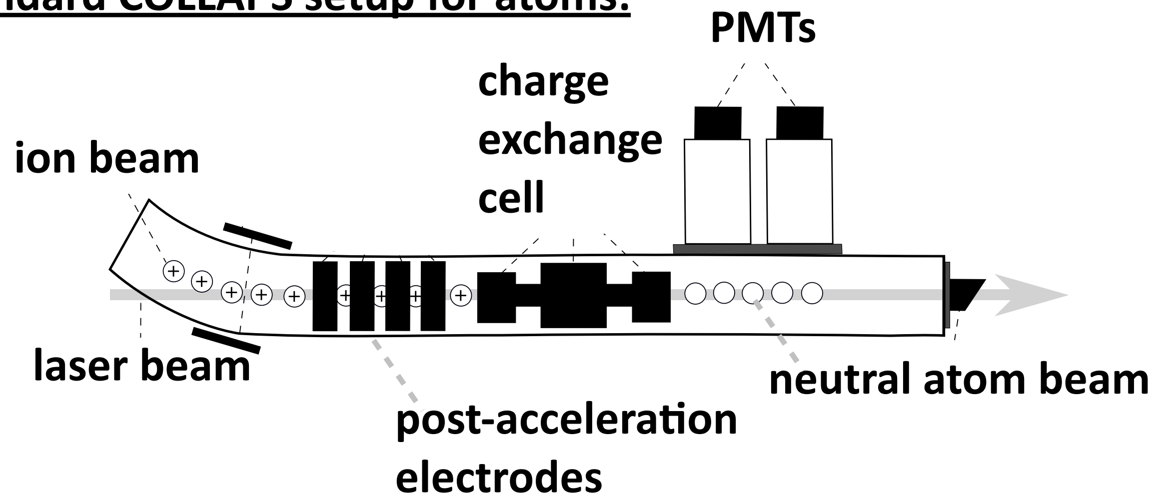
D. T. Yordanov et al., Phys. Rev. Lett. 108, 042504 (2012)

signature of admixture in charge radius of ^{33}Al?

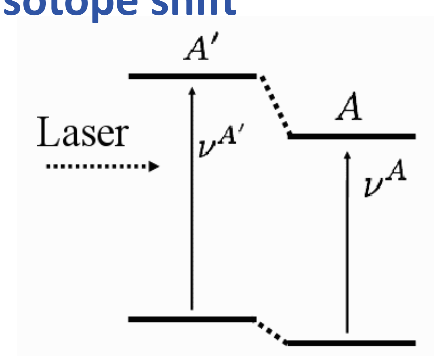
Measurement



standard COLLAPS setup for atoms:



isotope shift



$$\delta\nu^{A,A'} = M\frac{A'-A}{A\cdot A'} + F\delta\langle r^2\rangle^{A,A'}$$

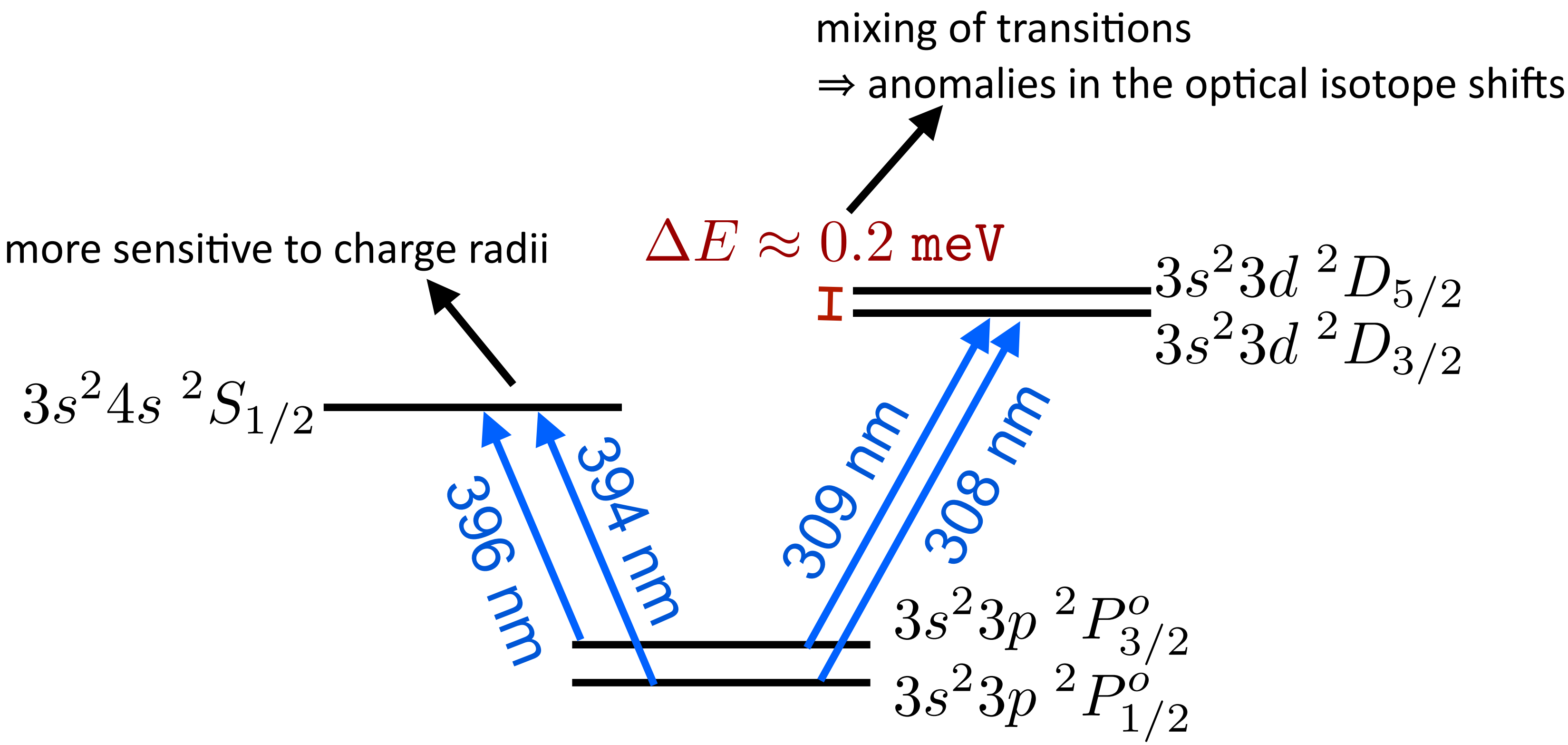
difference in rms charge radii

mass and field shift factors from atomic physics calculation

calculations ongoing within collaboration

L. Filippin and M. Godefroid

atomic transitions



<u>Preferred transition: 396 nm</u>

- larger transition strength
- sensitive to quadrupole moments (not known for ^{24,29,30}Al)

ISOLDE yields and requested shifts

nuclide	spin^{parity}	half-life	μ [μ_N]	Q [b]	yield [ions/μC]	shifts (target)
^{24}Al	4^+	2.1 s	2.99(9)	?	4.5E+03 ^{a}	4*
^{25}Al	$5/2^+$	7.2 s	3.6455(12)	0.24(2)	not listed	2
^{26}Al	5^+	7.2E+5 y	2.804(4)	0.27(3)	not listed	2
^{26m}Al	0^+	6.3 s	-	-	6.8E+04	2
^{27}Al	$5/2^+$	stable	3.6415069(7)	0.1466		
^{28}Al	3^+	2.2 min	3.242(5)	0.175(14)	4.0E+07	1
^{29}Al	$5/2^+$	6.6 min	?	?	4.5E+07	1
^{30}Al	3^+	3.6 s	3.010(7)	?	2.5E+06	1
^{31}Al	$5/2^+$	640 ms	3.830(5)	0.1340(16)	2.5E+05	2
^{32}Al	1^+	33 ms	1.959(9)	0.024(2)	not listed	2
^{33}Al	$5/2^+$	42 ms	4.088(5)	0.132(16)	1 - 4E4^b	4

^{a}Yield measured at ISOLDE-SC with a UCx target;
^{b}Estimate based on recent yield measurements on ^{34}Al [31], which are not listed in the yield database.

21 shifts: (2 for setup and 19 for online measurements of $^{24-33}$Al split into two separate beamtimes)

ISOLDE yields and requested shifts

^{24}Al yield at ISOLDE-PSB likely lower: calculated estimate 9E2 /μC

J. P. Ramos and T. Stora, private communications, 2016.

⇒ request yield test with UCx at the end of first run

⇒ 2nd run may require lighter target and/or LIST for suppression of Na contamination

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Summary

- proposal to measure charge radii of $^{24-33}$Al with laser spectroscopy at COLLAPS
- <u>**3 science motivations:**</u>
- study np pairing in self-conjugate nucleus ^{26m,26}Al
  - in analogy to ^{38m,38}K
  - to provide more global picture on the size of the phenomenon
  - requires measurement of odd-even staggering of r along isotopic chain
- superallowed β decays, V_{ud} & ^{26m}Al's charge radius
  - provide accurate&precise input parameter for calculation of ISB corrections
  - currently based on extrapolation of stable isotopes
- Al charge radii at the border of the island of version
- <u>**request 21 shifts**</u>
  - 2 for setup
  - 19 for online measurements of $^{24-33}$Al
  - split in 2 beamtimes

Collaboration

H. Heylen[1], S. Malbrunot-Ettenauer[2], M.L. Bissell[3], K. Blaum[4], B. Cheal[5], L. Filippin[6], R.F. Garcia Ruiz[3], W. Gins[1], M. Godefroid[6], C. Gorges[7], S. Kaufmann[7], Á. Koszorús[1], J. Krämer[7], M. Kowalska[2], G. Neyens[1], R. Neugart[4,8], W. Nörtershäuser[7], R. Sánchez[9], Z.Y. Xu[1], X.F. Yang[1], D.T. Yordanov[10].

[1] *KU Leuven, Instituut voor Kern- en Stralingsfysica, 3001 Leuven, Belgium*
[2] *Experimental Physics Department, CERN, CH-1211 Geneva 23, Switzerland*
[3] *School of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL, UK*
[4] *Max-Plank-Institut für Kernphysik, D-69117 Heidelberg, Germany*
[5] *Oliver Lodge Laboratory, Oxford Street, University of Liverpool, L69 7ZE, United Kingdom*
[6] *Université libre de Bruxelles, B 1050 Brussels, Belgium*
[7] *Institut für Kernphysik, TU Darmstadt, D-64289 Darmstadt, Germany*
[8] *Institut für Kernchemie, Universität Mainz, D-55128 Mainz, Germany*
[9] *GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany*
[10] *Institut de Physique Nucléaire Orsay, IN2P3/CNRS, 91405 Orsay Cedex, France*