PreSOBEN

Investigating the origins of the kink in charge radii at N=28

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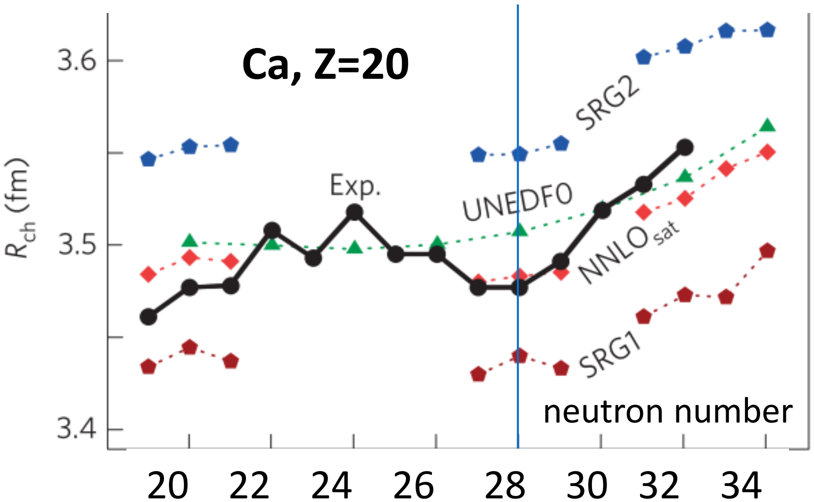
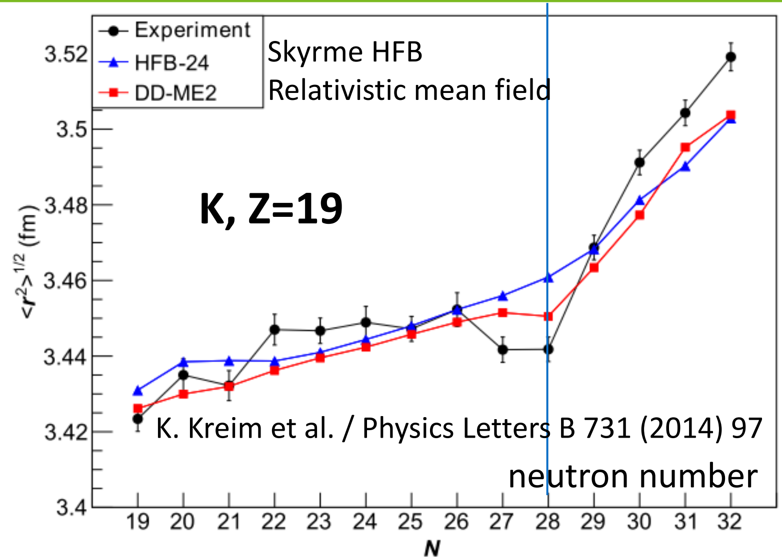
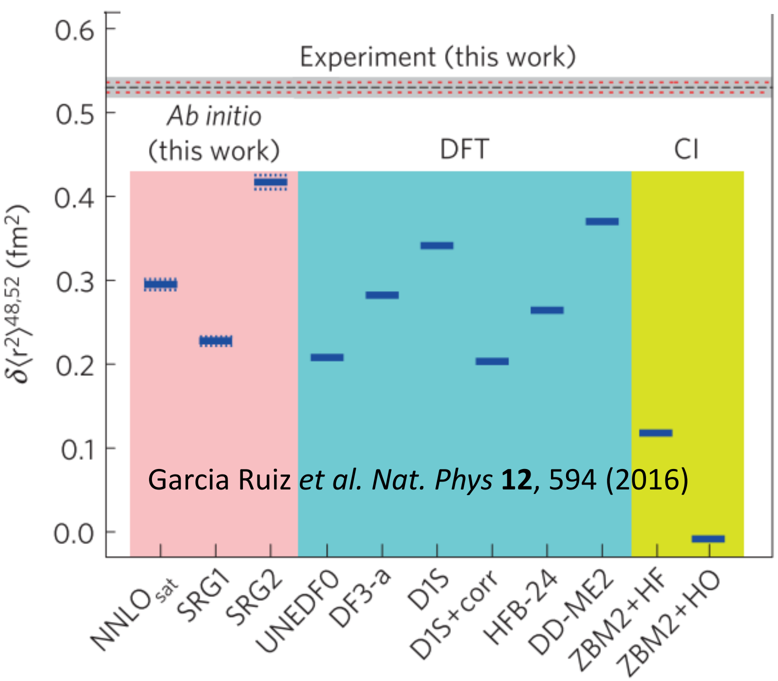
Spokespersons: M. L. Bissell, M. Kowalska
Contact person: M. L. Bissell

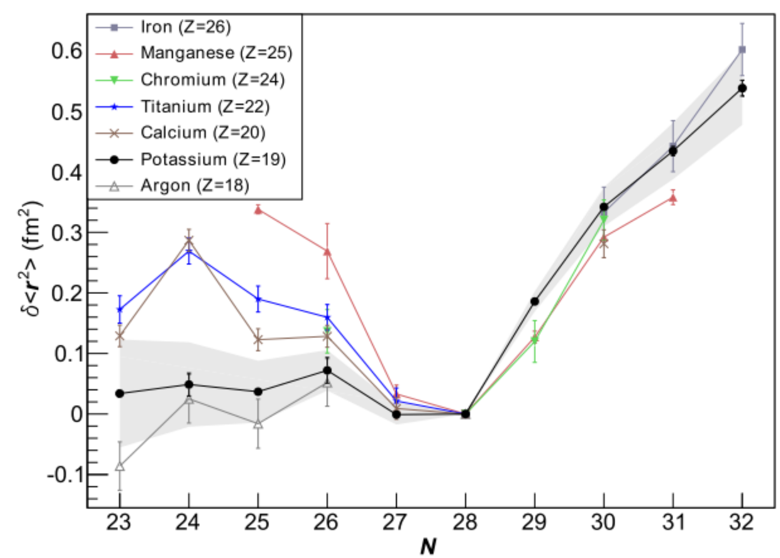
Topic of PhD thesis of Anu Nagpal, U York

Motivation: ‘kink’ in charge radii at N = 28









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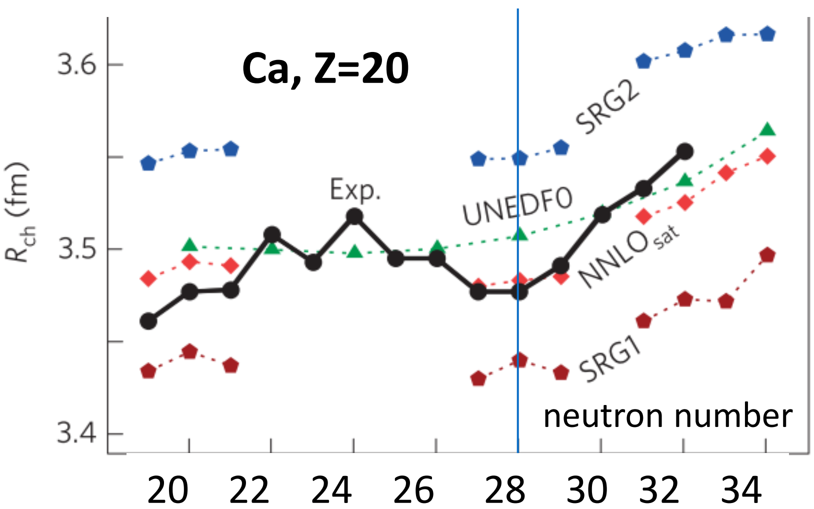
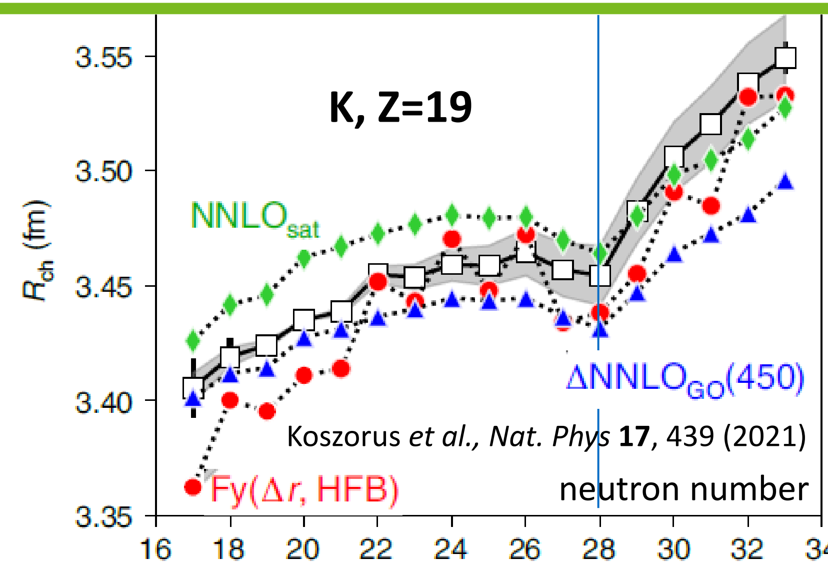
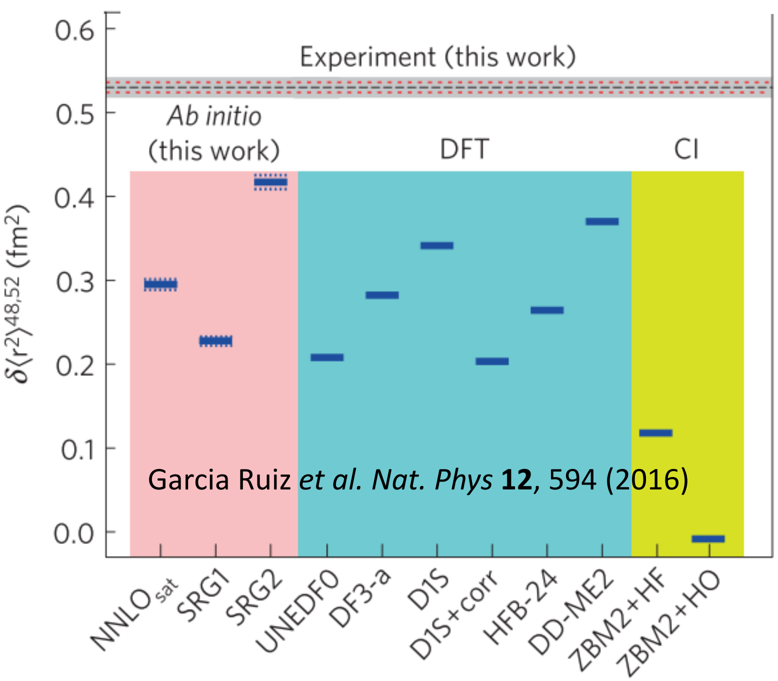
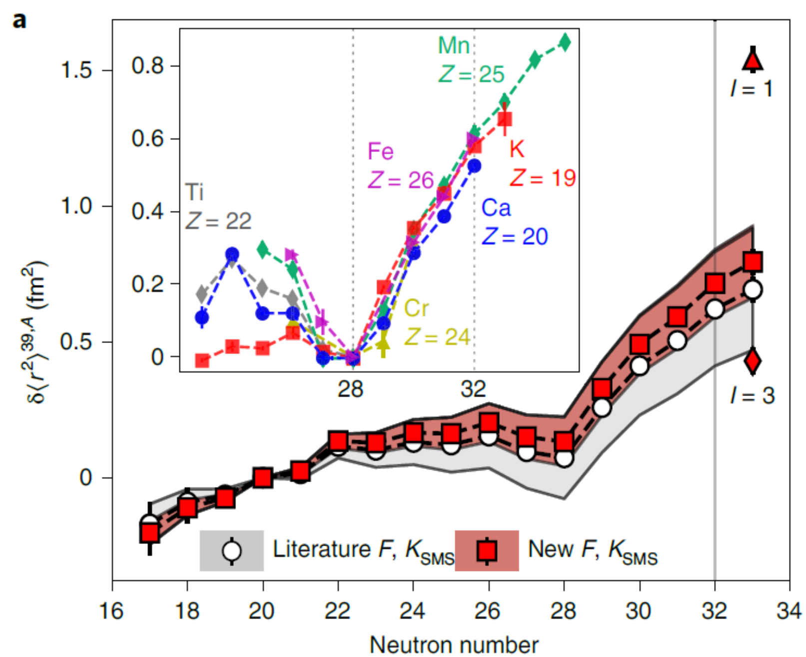


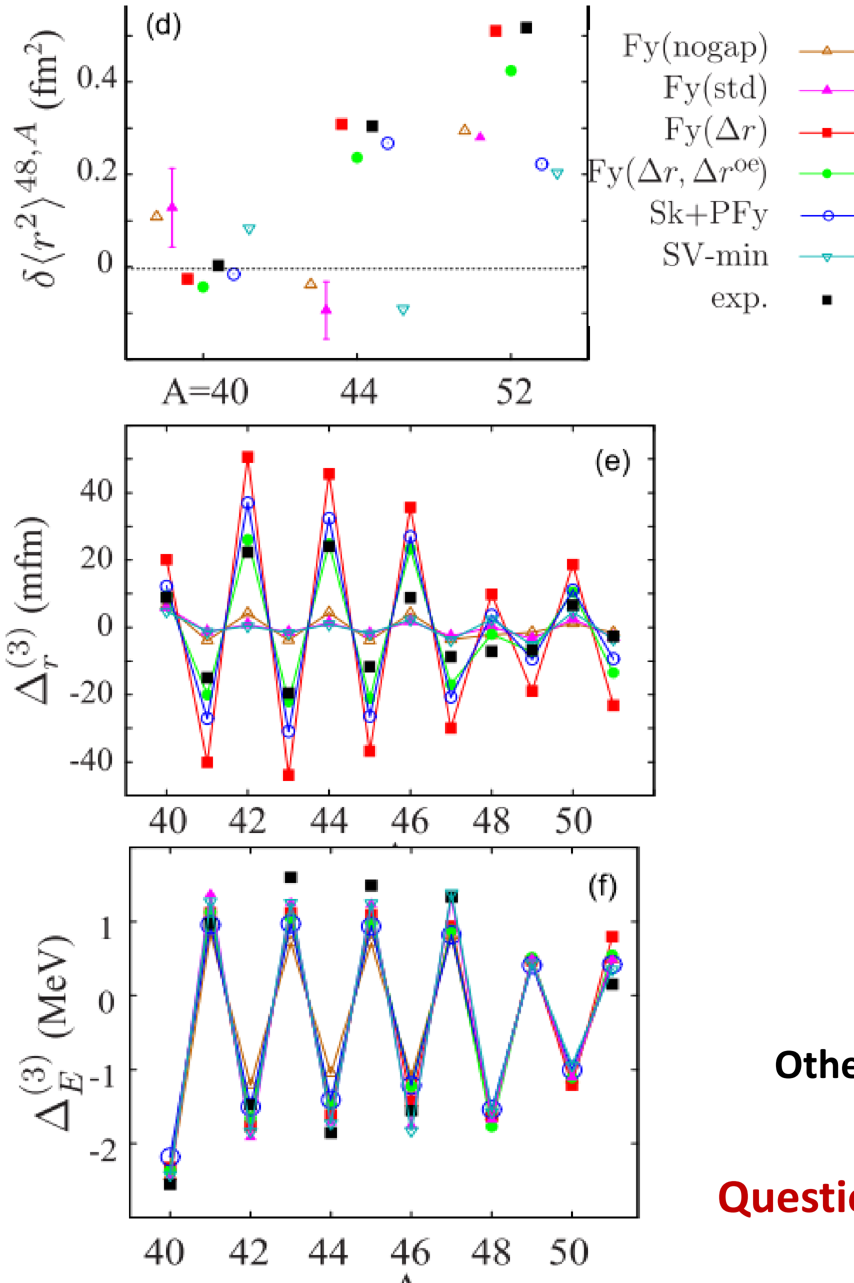






Different theoretical approaches faced challenges in reproducing slope of the kink

Theoretical attempts to reproduce and explain the kink



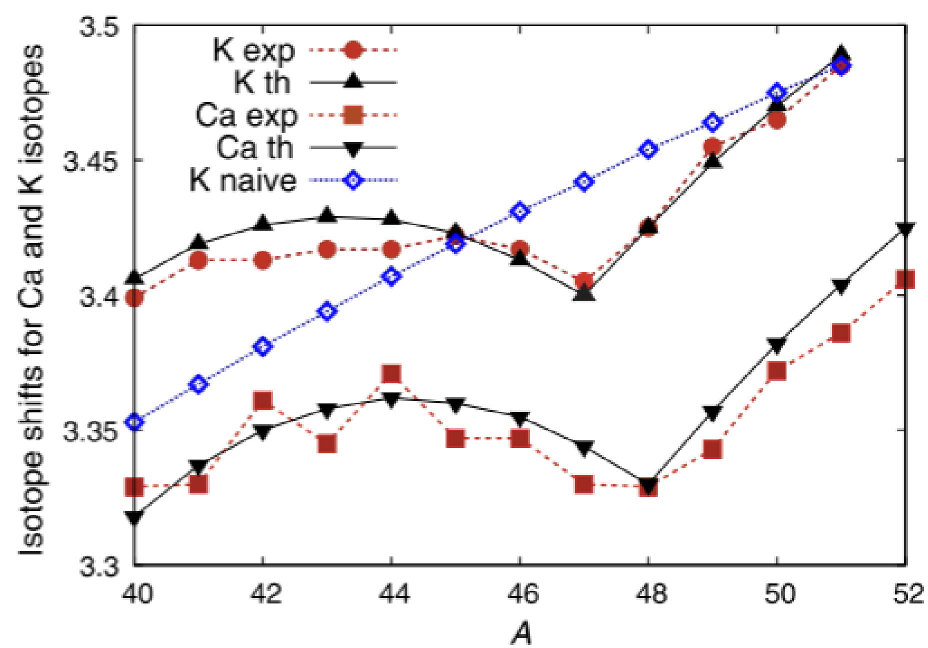
DFT: modified Fayans functional

Reproduces either charge radii or their odd-even staggering

Reinhard, Nazarewicz, Phys. Rev. C **95**, 064328 (2017)

Shell model: "Halo orbits": extended rms charge radius due to neutrons filling "**the *huge* p3/2 orbit**"

Bonnard, Lenzi, Zuker, Phys. Rev. Lett. **116**, 212501 (2016)



Other attempts (relativistic mean field) evoke **deformation**

R. An *et al., Chinese Phys. C* **46,** 054101 (2022)

Question still open: what drives the kink in charge radii at N=28: large neutron orbits or deformation ?

Approach to address the question: hyperfine anomaly

- Magnetic hyperfine anomaly (Bohr Weisskopf effect): $\epsilon = \epsilon_\pi + \epsilon_\nu$
- Spin and orbital contributions to magnetic moment + their radial distributions:

$$-\epsilon_\pi \approx \sum_{i=1}^{3} \left[\alpha_{S\pi} b_{2i,S} \langle R^{2i} \rangle_{S\pi} + \alpha_{L\pi} b_{2i,L} \langle R^{2i} \rangle_{L\pi} + \alpha_{S\pi} (b_{2i,S} - b_{2i,L}) \langle Z R^{2i} \rangle_{S\pi} \right]$$

$$-\epsilon_\nu \approx \sum_{i=1}^{3} \left[\alpha_{S\nu} b_{2i,S} \langle R^{2i} \rangle_{S\nu} + \alpha_{L\nu} b_{2i,L} \langle R^{2i} \rangle_{L\nu} + \alpha_{S\nu} (b_{2i,S} - b_{2i,L}) \langle Z R^{2i} \rangle_{S\nu} \right]$$

(red circle) atomic factors determined from electronic wave functions in nuclear vicinity (atomic theory)

(blue box) spin and orbital contributions to magnetic moment μ

(green box) spin and orbital radial distributions; ‘magnetisation radii’

➡ **Information about nuclear structure complementary to other observables**

- Differential hyperfine anomaly between isotopes A&B in 1 isotopic chain (+ 1 atomic state):

$$^{A}\Delta^{B} \approx \epsilon_A - \epsilon_B \approx \underbrace{(\epsilon_{A\pi} - \epsilon_{B\pi})}_{} + \underbrace{(\epsilon_{A\nu} - \epsilon_{B\nu})}_{}$$

Difference **in π spin and orbital ‘magnetisation** radii’ and/or in **spin and orbital contribution to μ**

Difference in ν **spin and orbital ‘magnetisation radii’** and/or in **spin and orbital contribution to μ**

➡ **Information about changes in nuclear structure along isotopic chain complementary to other observables and probing other aspects of nuclear models**

Proof-of-principle: hyperfine anomaly of ^{47}K vs ^{39}K

- Experiment: liquid beta-NMR at VITO (+ HFS from literature, COLLAPS)
- Atomic theory: relativistic all-orders correlation potential approach (J. Ginges, B. Roberts, Brisbane)
- Nuclear theory: not simplified distribution (ball, single-particle orbit), but 1st time DFT calculation (J. Dobaczewski, York; M. Kortelainen, Jyvaskyla, et al)

Paired neutrons
$^{47}\Delta^{39}$ = 0.37(1)%, mostly due to unpaired proton

M. Bissell et al., to be submitted

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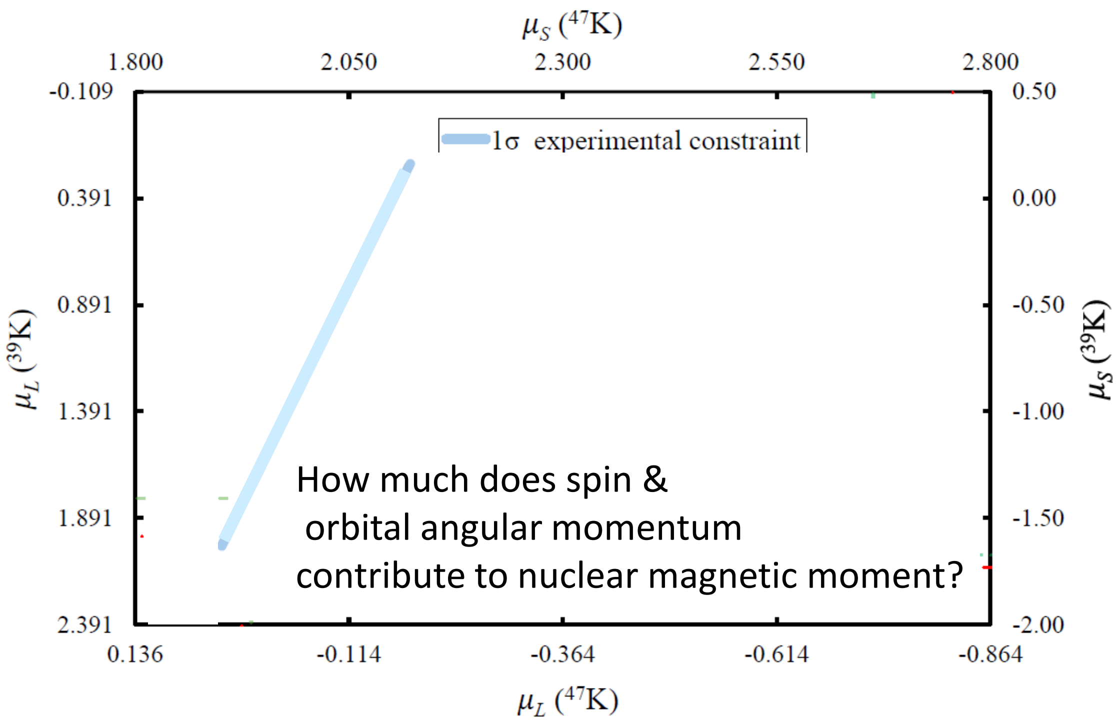

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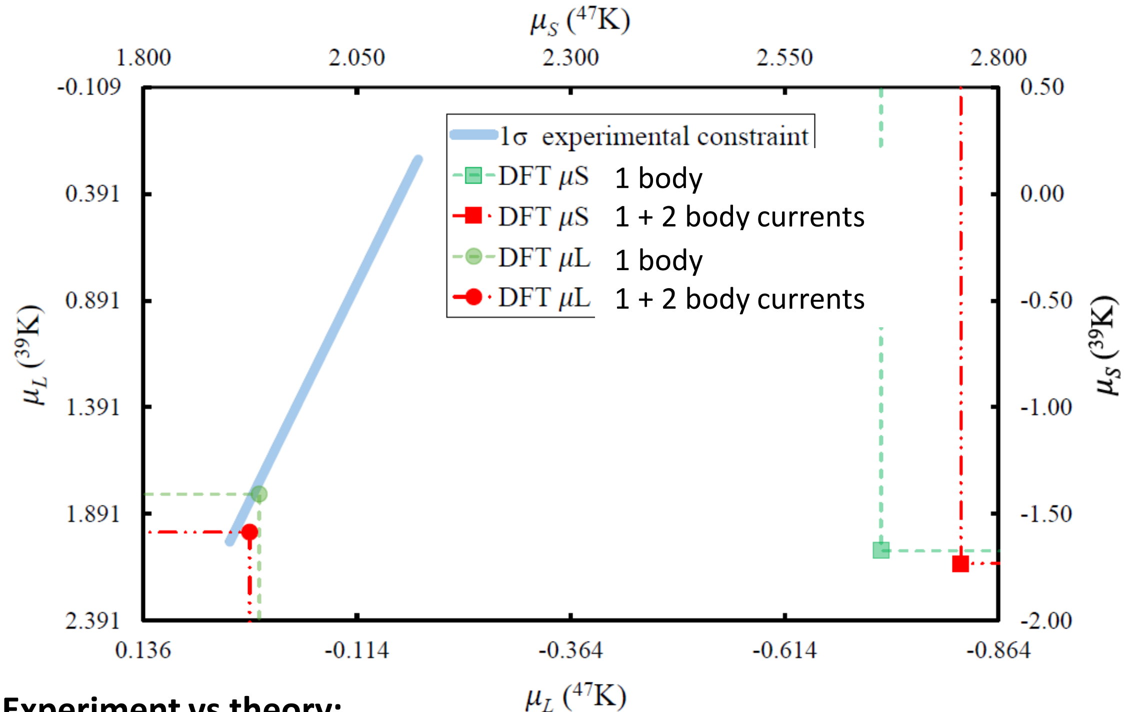

Experiment vs theory:

-> Agreement with μ's + HA only when spin contribution scaled to 75-85%, orbital - unchanged

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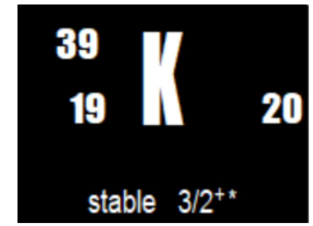

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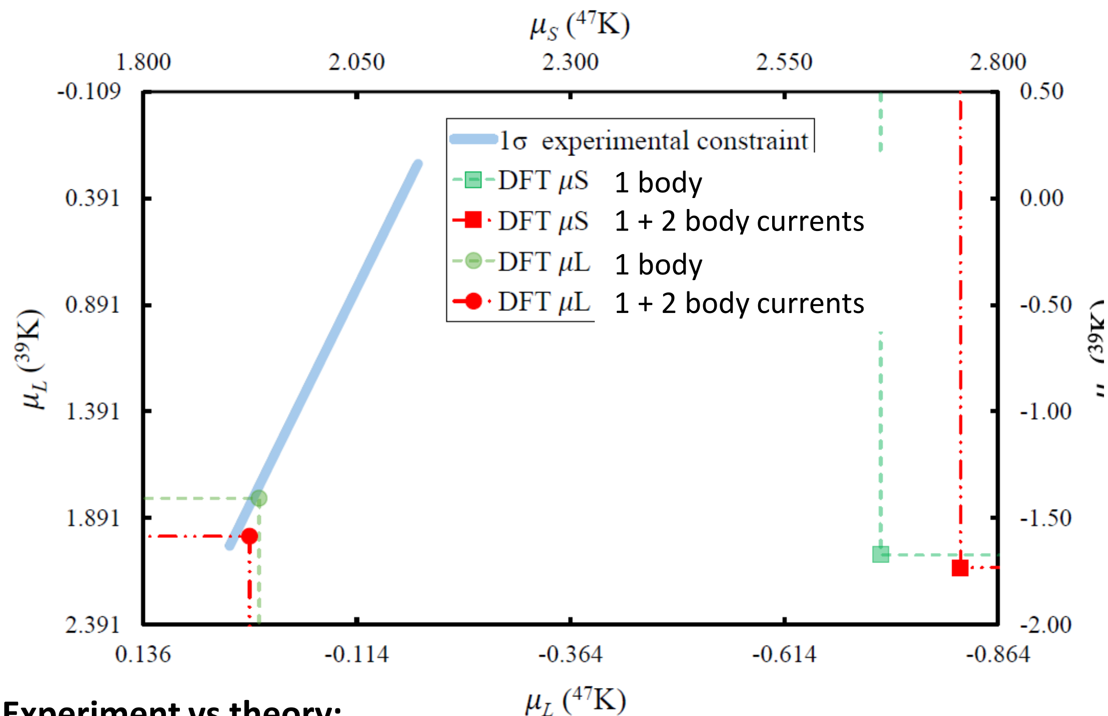
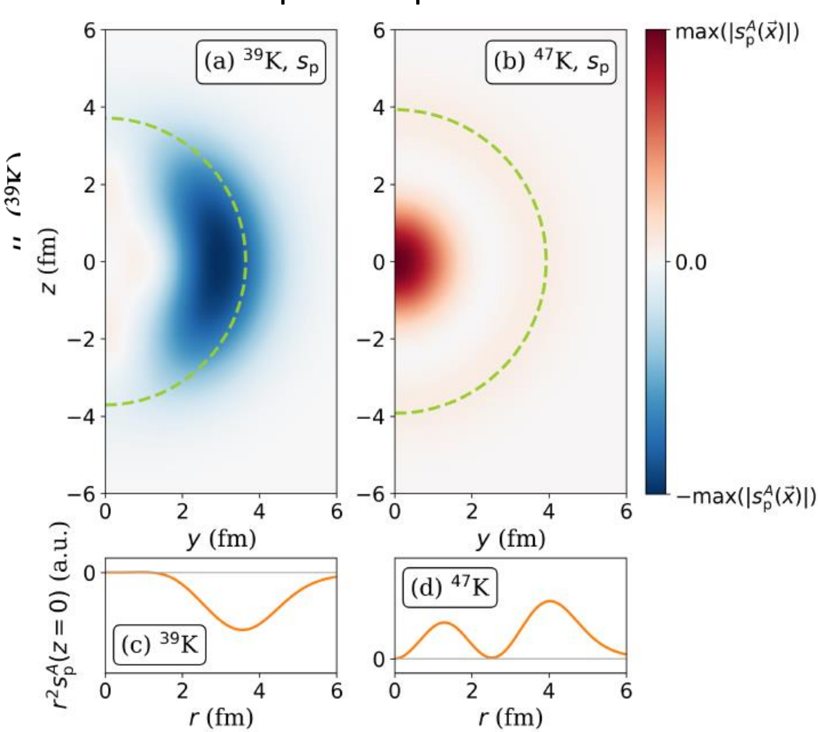


⇒ Proton 'Magnetisation radii' shown: proton spin distribution



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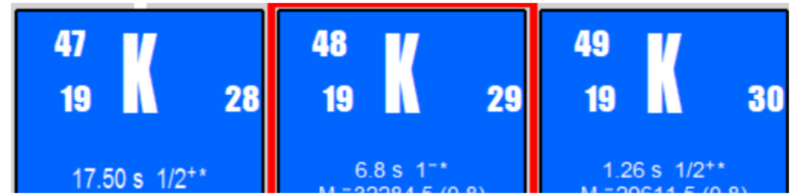
M. Bissell et al., to be submitted

Proposal: 'magnetisation radii' and deformation at N=28

- **' magnetisation radius' across N=28:**

Differential hyperfine anomaly for ^{47,48,49}K

$$^{A}\Delta^{B} \approx \epsilon_A - \epsilon_B \approx (\epsilon_{A\pi} - \epsilon_{B\pi}) + (\epsilon_{A\nu} - \epsilon_{B\nu})$$



ε_{48} – mostly due to unpaired proton at Z=19 and neutron at N=29

ε_{47}, ε_{49} – mostly due to unpaired proton at Z=19 only

=> $^{47}\Delta^{48}$ and $^{48}\Delta^{49}$: single out valence-neutron 'magnetisation radius'

=> constraints on the radial extent of the neutron p3/2 orbit

$$^{A}\Delta^{B} = \frac{g_B\, A_A}{g_A\, A_B} - 1$$

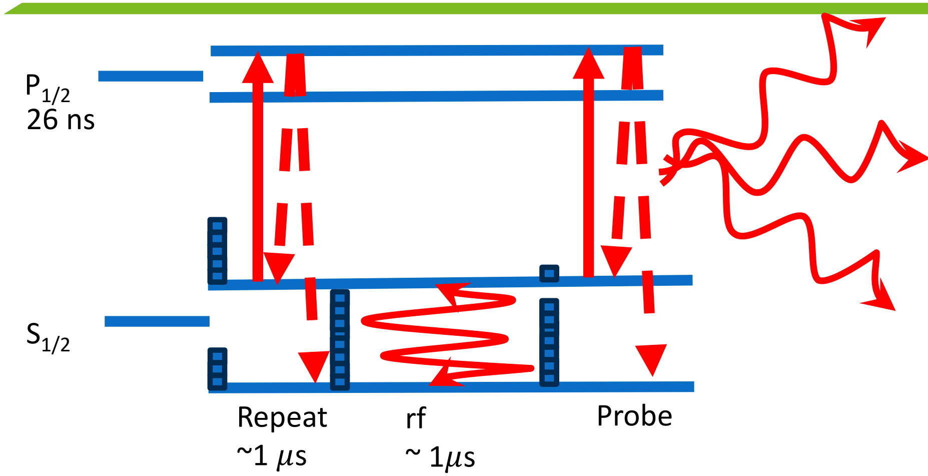
	I^π	μ (μ_N)	A (MHz)	ε_{theo} (%)	$^{48}\Delta^{x}_{theo}$ (%)
^{47}K	½$^+$	+1.9292 (2) [58]	+3413.2 (3)	-0.126	0.085
^{48}K	1$^-$	-0.8997 (3) [45]	-795.9 (3)	-0.211	-
^{49}K	½$^+$	+1.3386 (8) [40]	+2368.2 (14)	-0.121	0.090

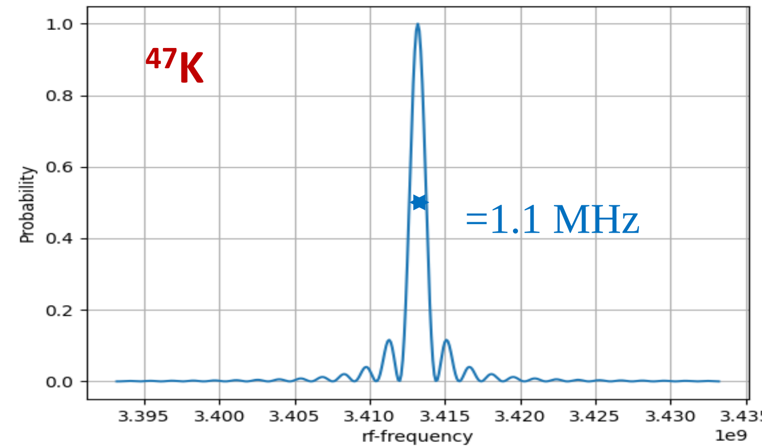
$^{47}\Delta^{39}$ = 0.37(1)%

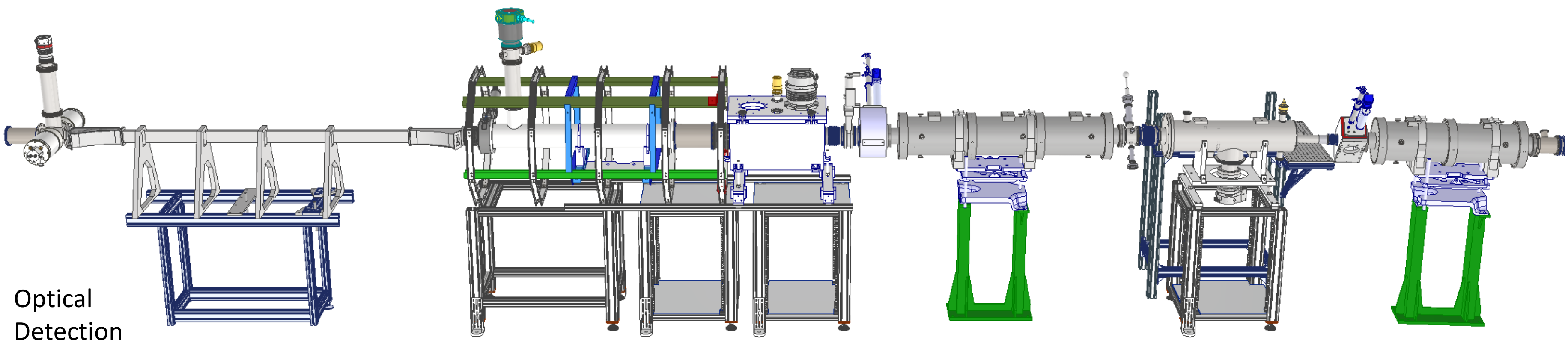
- Experimental determination at VITO beamline:
  - **Precise magnetic moment & g-factor**: liquid beta-NMR: similar setup as for ^{47}K & for battery project
  - **Precise hyperfine structure constant A**: rf laser double resonance spectroscopy: being developed within ERC Grant PreSOBEN

- **deformation across N=28: Quadrupole moment of ^{48}K**
  - Determined using beta-NMR/NQR in crystal with known electric-field gradient (potassium di-hydrogen phosphate (KH2PO4) or KDP single crystal)

Rf-laser double resonance setup



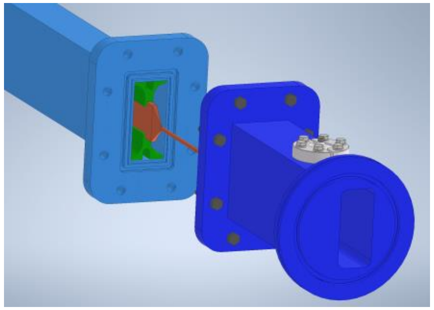


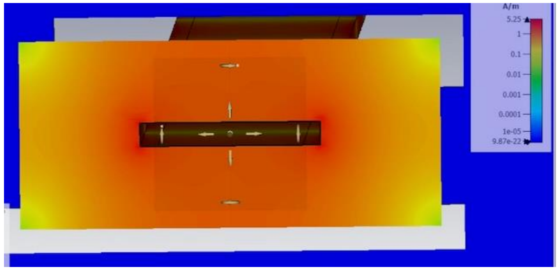


Optical Detection

rf excitation

Optical pumping





N. Azaryan, D. Havranek, PhD thesis of A. Nagpal

Expected yields and beamtime request

- UCx target, HRS, ISCOOL in bunched tune and bunched mode
  - ➢ Yields based on our 47,49K beamtimes

$>10^6\ \mu C^{-1}$ $1.3\times10^6\ \mu C^{-1}$ $2.7\times10^5\ \mu C^{-1}$

- Beamtime request:

	^{39}K	^{47}K	^{48}K	^{49}K
Beta-NMR: 12 RIB shifts				
Optimise spin-polarisation (laser beam overlap, laser power change) +HFS scan	-	0.5	0.5	0.5
Determine Larmor frequency in KCl crystal	-	0.5	0.5	0.5
Measure precise Larmor frequency in EMIM-DCA ionic liquid	-	1	2	2
Measure quadrupole splitting in non-cubic crystal			4	
Rf-laser spectroscopy: 9 stable + 9 RIB shifts				
Optimisation of: transmission, rf-beam overlap, rf power, experimental steps	9	1	-	-
optimise optical pumping and minimise photon background		1	-	-
Rf scans around HFS resonance		2	2	3

Total: **21** Online shifts split over two beamtimes + **9** shifts offline