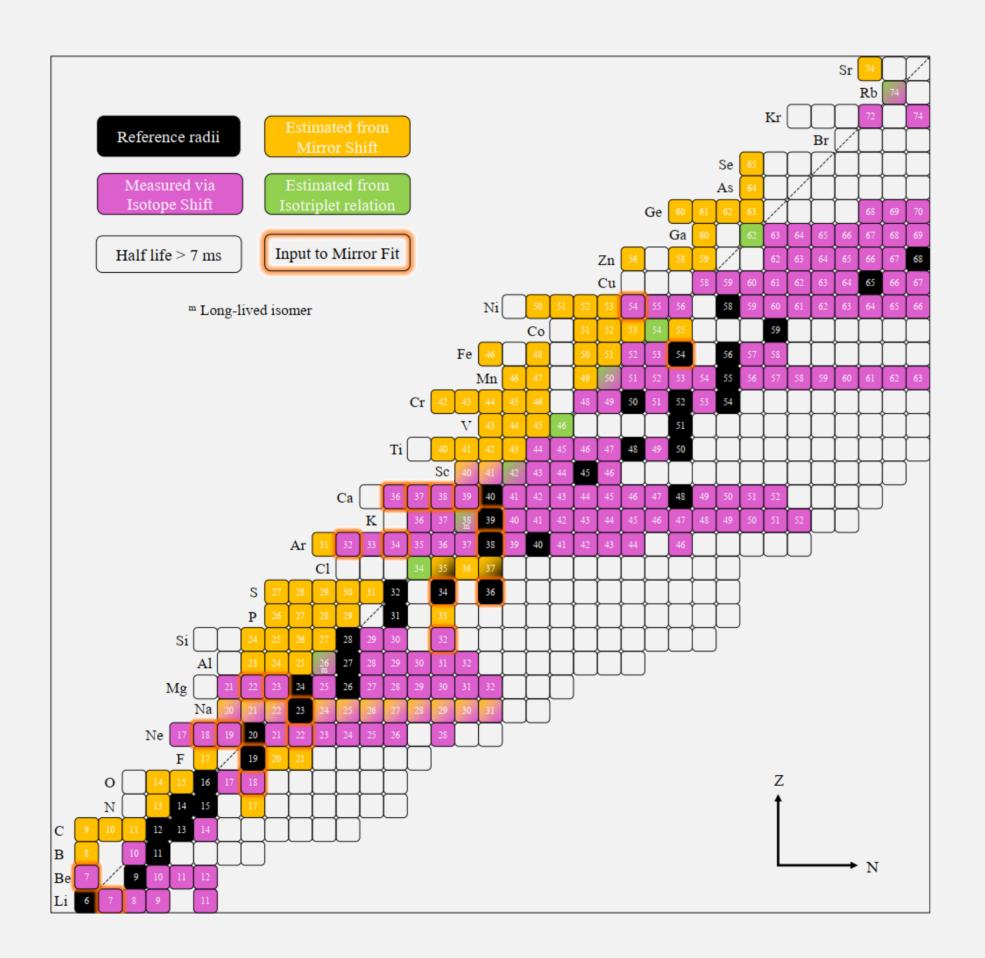
arXiv:2409.08193



Ben Ohayon | Technion IIT | boahyon@technion.ac.il Workshop on V_{ud} from pion, neutron and nuclear beta decay, GANIL November, 5-6, 2024

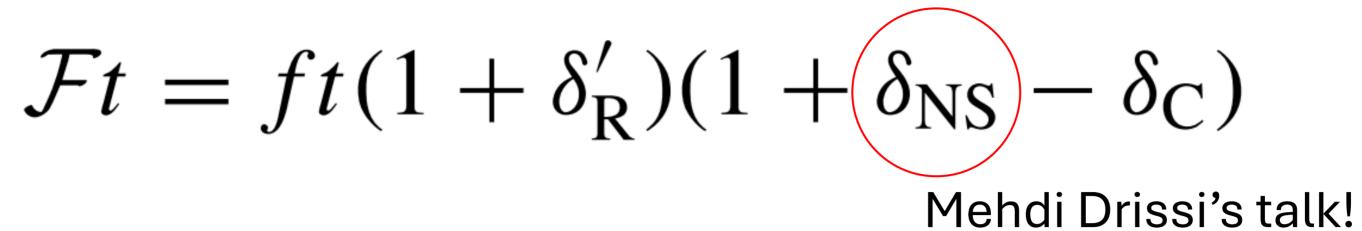
Radii for V_{UD}

This talk: Overview of charge radii for V_{ud}

$$|V_{ud}|_{0^{+}}^{2} = \frac{\pi^{3} \ln 2}{G_{F}^{2} m_{e}^{5} \mathcal{F}t \left(1 + \Delta_{R}^{V}\right)}$$

Next talk by Michael Heines: focus radii extraction from muonic atoms

$\mathcal{F}t = ft(1 + \delta'_{\rm R})(1 + \delta_{\rm NS} - \delta_{\rm C})$



 δ_{C}

Modification of the Fermi Matrix element from its isospin limit value.

 $\mathcal{F}t = ft(1 + \delta'_{\rm R})(1 + \delta_{\rm NS} - \delta_{\rm C})$

 $\delta_{\rm C}$

Modification of the Fermi Matrix element from its isospin limit value.

In the Hardy & Towner approach (PRC 77, 025501), it depends on the charge distribution of the parent nucleus

 $\mathcal{F}t = ft(1 + \delta'_{\rm R})(1 + \delta_{\rm NS} - \delta_{\rm C})$



Modification of the Fermi Matrix element from its isospin limit value.

In the Hardy & Towner approach (PRC 77, 025501), it depends on the charge distribution of the parent nucleus

Example from recent measurement of R(26mAl):

g	u	e
\mathbf{U}		

	guesstimated	(Plattner <i>et al</i> . PRL 131, 222502)
Quantity	Previous value	This Letter
R_c	3.040(20) fm [27]	3.130(15) fm
δ_{C2}	0.280(15)% [10]	0.310(14)%
$\mathcal{F}t(^{26m}Al)$	3072.4(1.1) s [10]	3071.4(1.0) s

 $\mathcal{F}t = ft(1 + \delta'_{\rm R})(1 + (\delta_{\rm NS}) - (\delta_{\rm C}))$



Modification of the Fermi Matrix element from its isospin limit value.

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$\mathcal{F}t(^{26m}Al)$	3072.4(1.1) s [10]	3071.4(1.0) s

To obtain Ft(26mAl) to 0.01%, accuracy of 0.03 fm is enough Need some measurement, but not accurate measurement

 $\mathcal{F}t = ft(1 + \delta'_{\rm R})(1 + \delta_{\rm NS}) - (\delta_{\rm NS}) - ($ $(\delta_{\rm C})$

Towner & Hardy:

Charge radii play a minor role in V_{ud} determination from nuclear Beta decay

Towner & Hardy:

Seng & Gorchtein: Radii play a major role

Charge radii play a minor role in V_{ud} determination from nuclear Beta decay





$\mathcal{F}t = ft(1 + \delta'_{R})$

Seng & Gorchtein PRC 109, 045501 (2024)

$$\delta'_{\rm R}$$
) $(1 + \delta_{\rm NS} - \delta_{\rm C})$

 $\mathcal{F}t = ft(1 +$

Seng & Gorchtein PRC **109**, 045501 (2024)

$$\delta'_{\rm R}$$
)(1 + $\delta_{\rm NS}$ – $\delta_{\rm C}$)

Statistical rate function $f = m_e^{-5} \int_{m_e}^{E_0} \mathbf{p} E(E_0 - E)^2 F(E) C(E) Q(E) R(E) r(E) dE,$

$$\mathcal{F}t = ft(1 +$$

1. Fermi function accounts for Coulomb interaction between outgoing positron and daughter nucleus - Solved numerically given an (EM) charge distribution

Seng & Gorchtein PRC **109**, 045501 (2024)

$$\delta'_{\rm R}$$
)(1 + $\delta_{\rm NS}$ – $\delta_{\rm C}$)

Statistical rate function $f = m_e^{-5} \int_m^{E_0} \mathbf{p} E(E_0 - E)^2 F(E) C(E) Q(E) R(E) r(E) dE$,

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Statistical rate function $f = m_e^{-5} \int_m^{E_0} \mathbf{p} E(E_0 - E)^2 F(E) C(E) Q(E) R(E) r(E) dE$,

- Solved numerically given an (EM) charge distribution

Seng & Gorchtein PRC **109**, 045501 (2024)

$$\delta'_{\rm R}$$
)(1 + $\delta_{\rm NS}$ - $\delta_{\rm C}$)

1. Fermi function accounts for Coulomb interaction between outgoing positron and daughter nucleus

2. Shape factor accounts for the influence of beta-decay form factor – needs weak charge distribution

$$\mathcal{F}t = ft(1 +$$

Statistical rate function $f = m_e^{-5} \int_m^{E_0} \mathbf{p} E(E_0 - E)^2 F(E) C(E) Q(E) R(E) r(E) dE$,

1. Fermi function accounts for Coulomb interaction between outgoing positron and daughter nucleus - Solved numerically given an (EM) charge distribution 2. Shape factor accounts for the influence of beta-decay form factor – needs weak charge distribution

Isospin symmetry connect weak (hard to measure) and EM charge distributions:

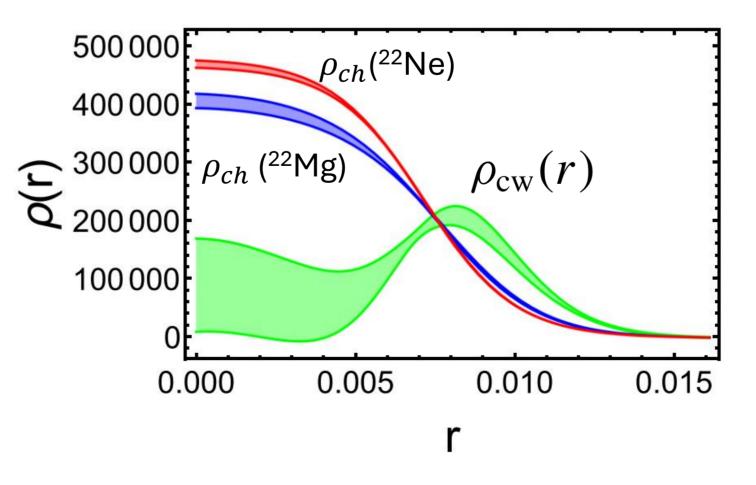
$$\rho_{\rm cw}(r) = \rho_{\rm ch,1}(r) + Z_0[\rho_{\rm ch,0}(r) - \rho_{\rm ch,1}(r)]$$

= $\rho_{\rm ch,1}(r) + \frac{Z_{-1}}{2}[\rho_{\rm ch,-1}(r) - \rho_{\rm ch,1}(r)].$

(need two out-of-three)

Seng & Gorchtein PRC **109**, 045501 (2024)

$$\delta'_{\rm R}$$
)(1 + $\delta_{\rm NS}$ - $\delta_{\rm C}$)



$$\mathcal{F}t = ft(1 +$$

 $f = m_e^{-5} \int_{w}^{E_0} \mathbf{p} E(E_0 - E)^2 F(E) C(E) Q(E) R(E) r(E) dE,$ Statistical rate function

1. Fermi function accounts for Coulomb interaction between outgoing positron and daughter nucleus - Solved numerically given an (EM) charge distribution

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$$\rho_{\rm cw}(r) = \rho_{\rm ch,1}(r) + Z_0[\rho_{\rm ch,0}(r) - \rho_{\rm ch,1}(r)]$$

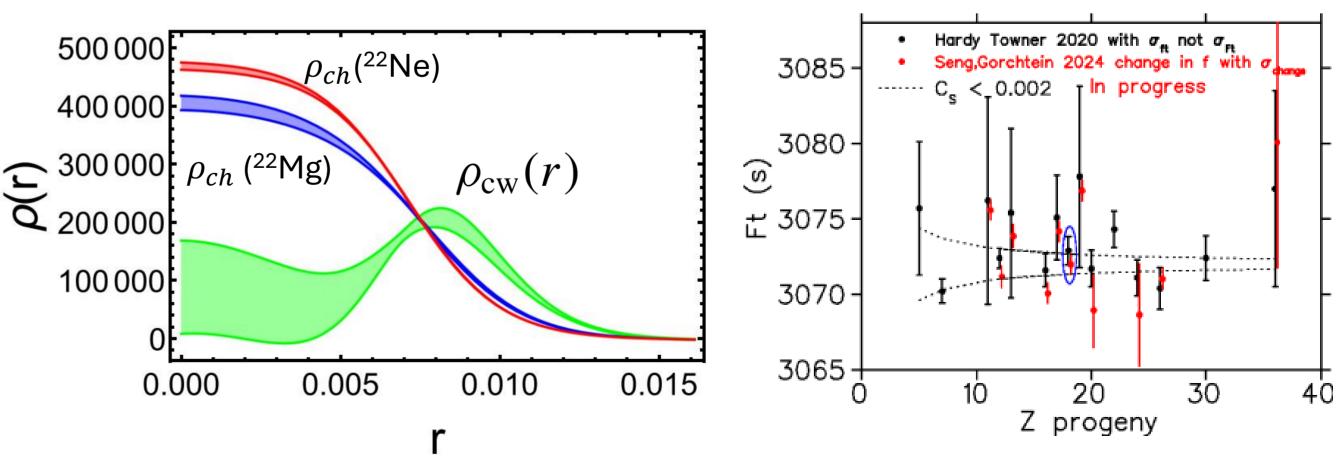
= $\rho_{\rm ch,1}(r) + \frac{Z_{-1}}{2}[\rho_{\rm ch,-1}(r) - \rho_{\rm ch,1}(r)].$

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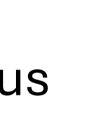
Seng & Gorchtein PRC **109**, 045501 (2024)

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2. Shape factor accounts for the influence of beta-decay form factor – needs weak charge distribution







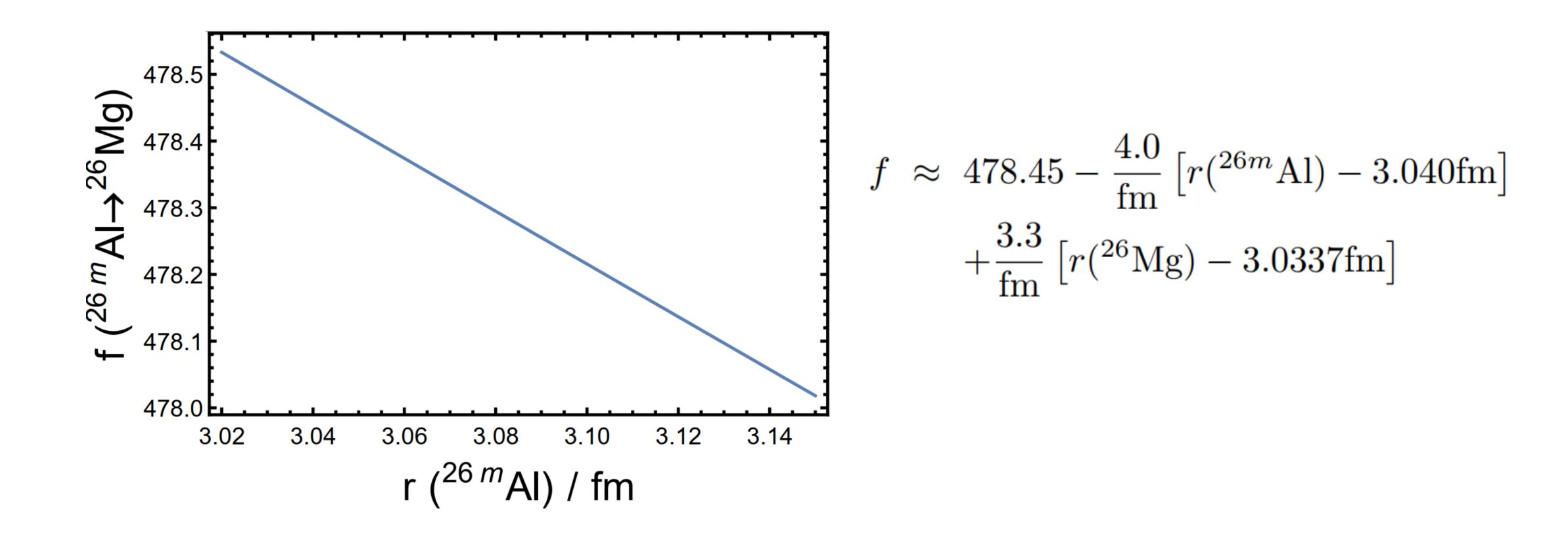




How large is the effect?

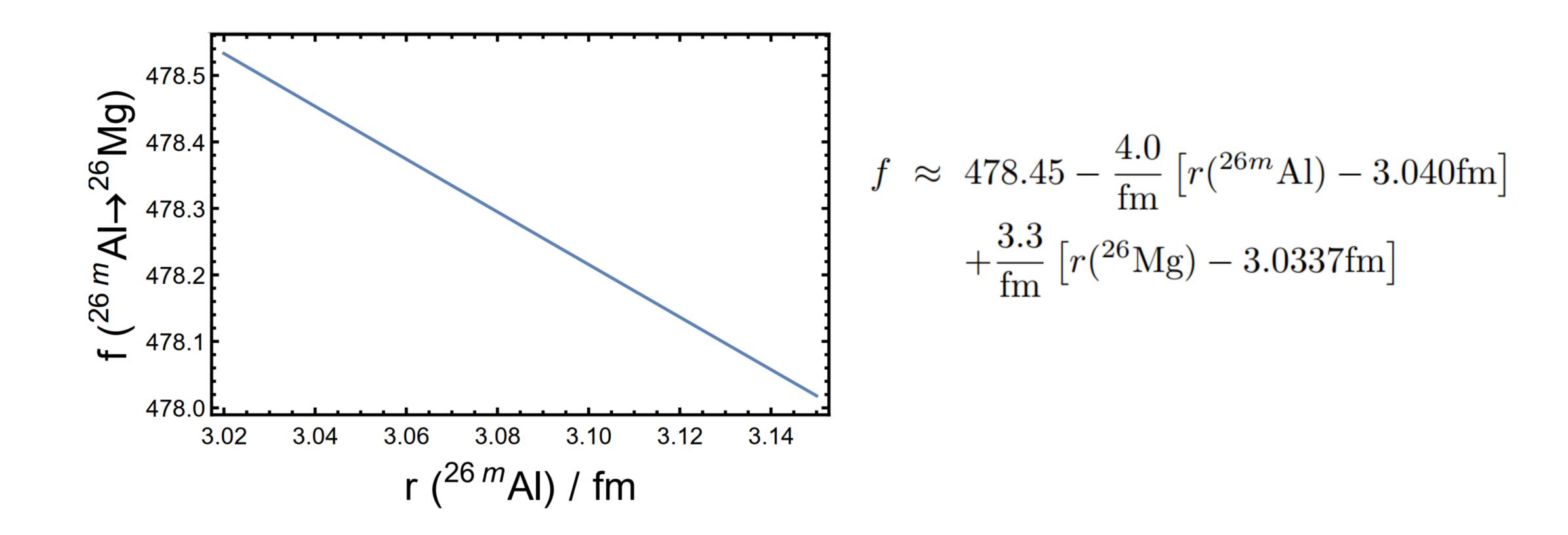
How large is the effect? Example (26mAl):

Ongoing work (with Seng, Gorchtein and Sahoo)



How large is the effect? Example (26mAl):

Ongoing work (with Seng, Gorchtein and Sahoo)



To obtain f(26mAl) to within 0.01%, accuracy of 0.01 fm is needed ! (three times the effect on δ_c)

What else can charge radii do?

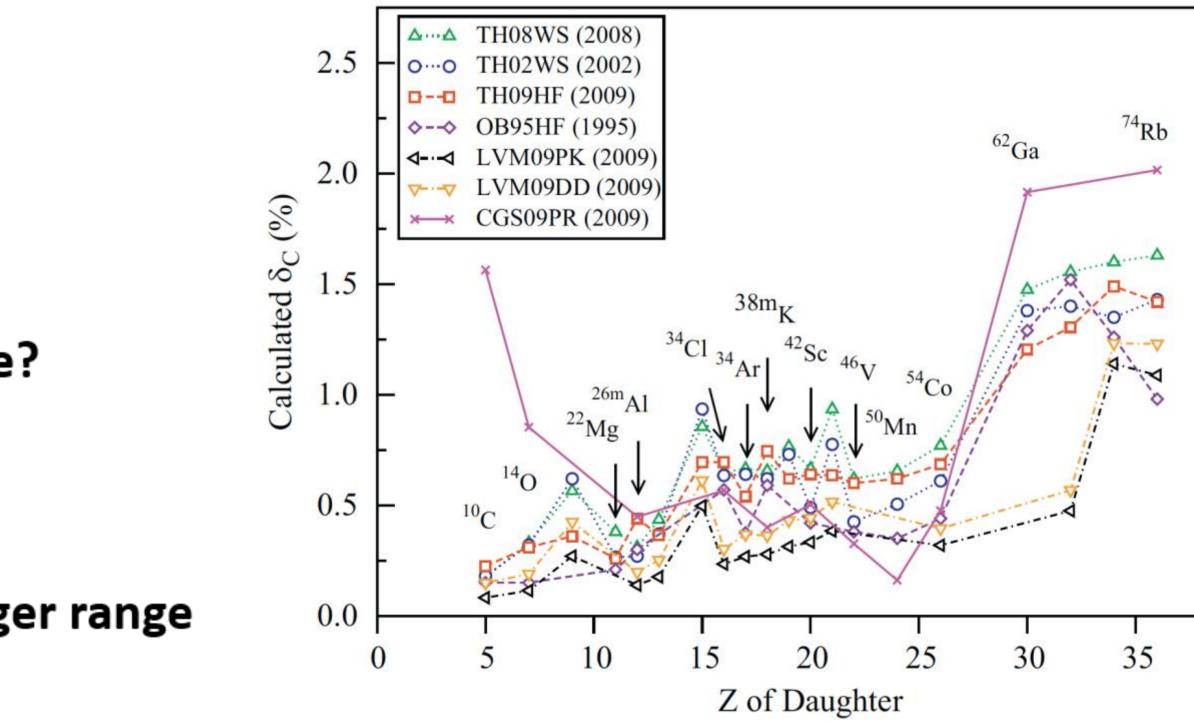
What else can charge radii do?

Bertram Blank's conclusion:

What is the conclusion ?

- V_{us} seems to be stable
- Ft is stable, but depends on δ_{c} correction
- what can we do from the experimental side?
 - measure specific data
 - values where $\delta_{\rm c}$ values differ a lot
 - heavier nuclei to test CVC on a larger range
 - get improved $\delta_{\rm c}$ corrections

Which model to choose?



Grinyer et al., NIMA 622 (2010) 236



3. Testing ISB corrections: Seng & Gorchtein PLB 838 (2023) 137654

What we want to know

Transitions	δ _C (%)											
	WS	DFT	HF	RPA	Micro							
26m Al $\rightarrow ^{26}$ Mg	0.310	0.329	0.30	0.139	0.08							
$^{34}Cl \rightarrow ^{34}S$	0.613	0.75	0.57	0.234	0.13							
38m K \rightarrow 38 Ar	0.628	1.7	0.59	0.278	0.15							
$^{42}Sc \rightarrow ^{42}Ca$	0.690	0.77	0.42	0.333	0.18							
$^{46}V \rightarrow ^{46}Ti$	0.620	0.563	0.38	/	0.21							
50 Mn \rightarrow 50 Cr	0.660	0.476	0.35	/	0.24							
54 Co \rightarrow ⁵⁴ Fe	0.770	0.586	0.44	0.319	0.28							

O

3. Testing ISB corrections: Seng & Gorchtein PLB 838 (2023) 137654

What we want to know

Transitions	δ _C (%)					Transitions	$\Delta M_B^{(1)}$	$\Delta M_B^{(1)} \ (\mathrm{fm}^2)$					
	WS	DFT	HF	RPA	Micro		WS	DFT	HF	RPA	Micro		
26m Al $\rightarrow ^{26}$ Mg	0.310	0.329	0.30	0.139	0.08	26m Al \rightarrow 26 Mg	-0.12	-0.12	-0.11	-0.05	-0.03		
$^{34}Cl \rightarrow ^{34}S$	0.613	0.75	0.57	0.234	0.13	$^{34}Cl \rightarrow ^{34}S$	-0.17	-0.21	-0.16	-0.06	-0.04		
38m K \rightarrow 38 Ar	0.628	1.7	0.59	0.278	0.15	38m K \rightarrow 38 Ar	-0.15	-0.42	-0.15	-0.07	-0.04		
$^{42}Sc \rightarrow ^{42}Ca$	0.690	0.77	0.42	0.333	0.18	$^{42}Sc \rightarrow ^{42}Ca$	-0.15	-0.17	-0.09	-0.07	-0.04		
$^{46}V \rightarrow ^{46}Ti$	0.620	0.563	0.38	1	0.21	$^{46}V \rightarrow ^{46}Ti$	-0.12	-0.11	-0.08	/	-0.04		
50 Mn \rightarrow 50 Cr	0.660	0.476	0.35	1	0.24	50 Mn \rightarrow 50 Cr	-0.12	-0.09	-0.06	1	-0.04		
54 Co \rightarrow ⁵⁴ Fe	0.770	0.586	0.44	0.319	0.28	54 Co \rightarrow ⁵⁴ Fe	-0.13	-0.10	-0.07	-0.05	-0.05		

$$\Delta M_B^{(1)} \equiv \frac{1}{2} \left(Z_1 R_{p,1}^2 + \right.$$

What we can measure

T	• •	•	
Iran	C11		nc
Tran	211	10	115

 $+ Z_{-1}R_{p,-1}^2 - Z_0R_{p,0}^2$

3. Testing ISB corrections: Seng & Gorchtein PLB 838 (2023) 137654

What we want to know

Transitions	δ _C (%)					Trai	nsitions	$\Delta M_B^{(1)} \ (\mathrm{fm}^2)$					
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38m K \rightarrow 38 Ar	0.628	1.7	0.59	0.278	0.15	38 <i>m</i>	$K \rightarrow {}^{38}Ar$	-0.15	-0.42	-0.15	-0.07	-0.04	
$^{42}Sc \rightarrow ^{42}Ca$	0.690	0.77	0.42	0.333	0.18	⁴² So	$c \rightarrow ^{42} Ca$	-0.15	-0.17	-0.09	-0.07	-0.04	
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54 Co \rightarrow ⁵⁴ Fe	0.770	0.586	0.44	0.319	0.28	⁵⁴ C	$0 \rightarrow {}^{54}$ Fe	-0.13	-0.10	-0.07	-0.05	-0.05	

The <u>only</u> example:

 $\Delta M_B^{(1)} \equiv \frac{1}{2} \left(Z_1 R_{p,1}^2 + A_{p,1}^2 \right)$ ³⁸Ar

What we can measure

$$(Z_{-1}R_{p,-1}^2) - Z_0R_{p,0}^2 = 0.1 \pm 1.0 \text{ fm}^2$$

 \uparrow
 ^{38}Ca
 ^{38}K

3. Testing ISB corrections: Seng & Gorchtein PLB 838 (2023) 137654

What we want to know

Transitions	δ _C (%)					Transitions	$\Delta M_B^{(1)} \ (\mathrm{fm}^2)$					
	WS	DFT	HF	RPA	Micro		WS	DFT	HF	RPA	Micro	
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The <u>only</u> example:

 $\Delta M_B^{(1)} \equiv \frac{1}{2} \left(Z_1 R_{p,1}^2 + \frac{1}{2} \right) \left(Z_1 R_{p,$ ³⁸Ar

Very high accuracy needed to distinguish models !

What we can measure

$$(Z_{-1}R_{p,-1}^2) - Z_0R_{p,0}^2 = 0.1 \pm 1.0 \text{ fm}^2$$

 \uparrow
 ^{38}Ca
 ^{38}K

What can charge radii do for us?

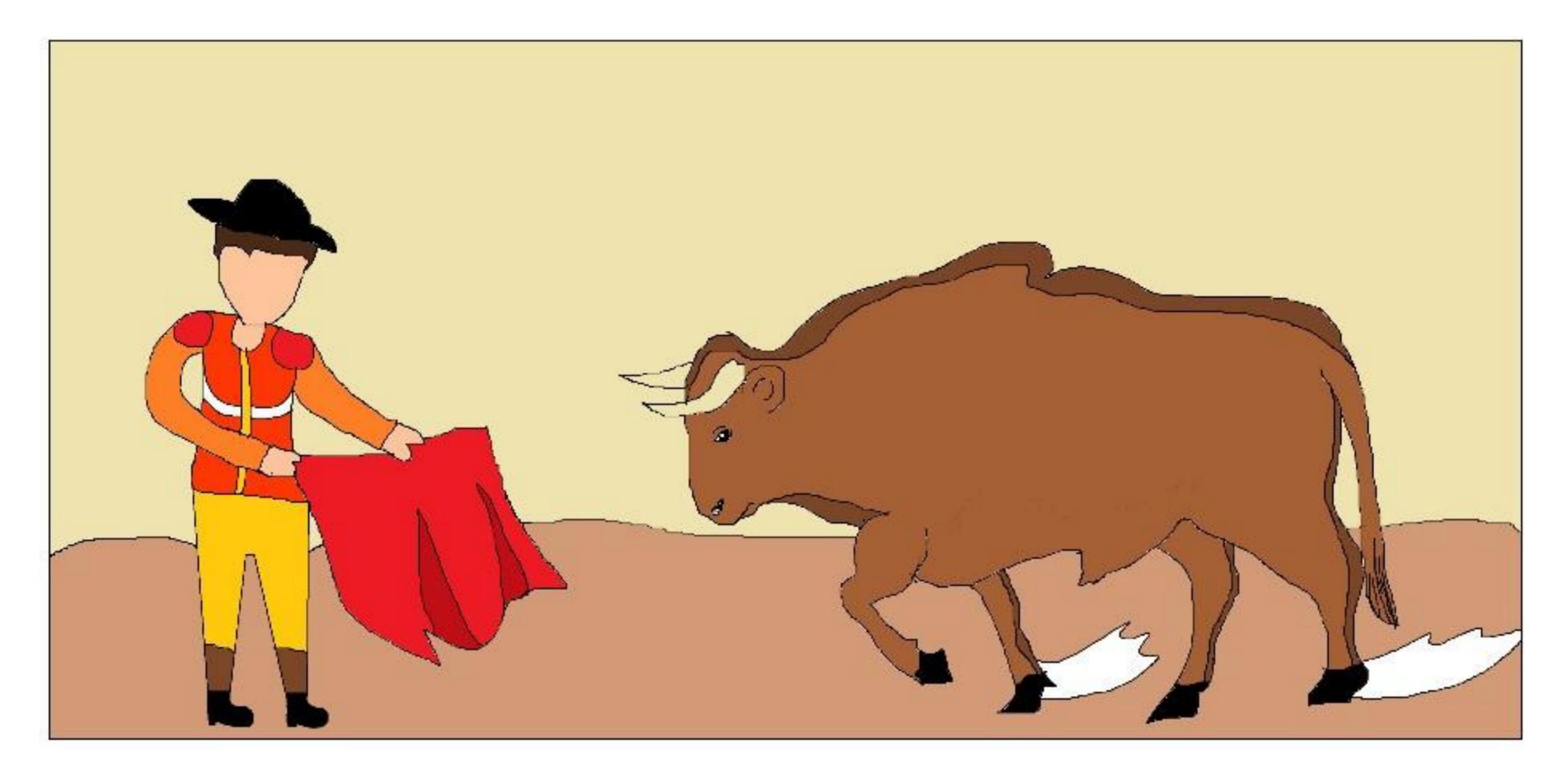
Nucleus of Use: interest: Father 1. Within model, calculate δ_c 2. Calculate fFather, Daughter 3. Benchmark δ_c Isotriplet

Needed accuracy

Poor

Medium-high

Very high !



Ecosystem of charge radii determinations Radius of $r_{\chi}^2 = r_{ref}^2 + \delta r_{a,\chi}^2$

Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus

Review

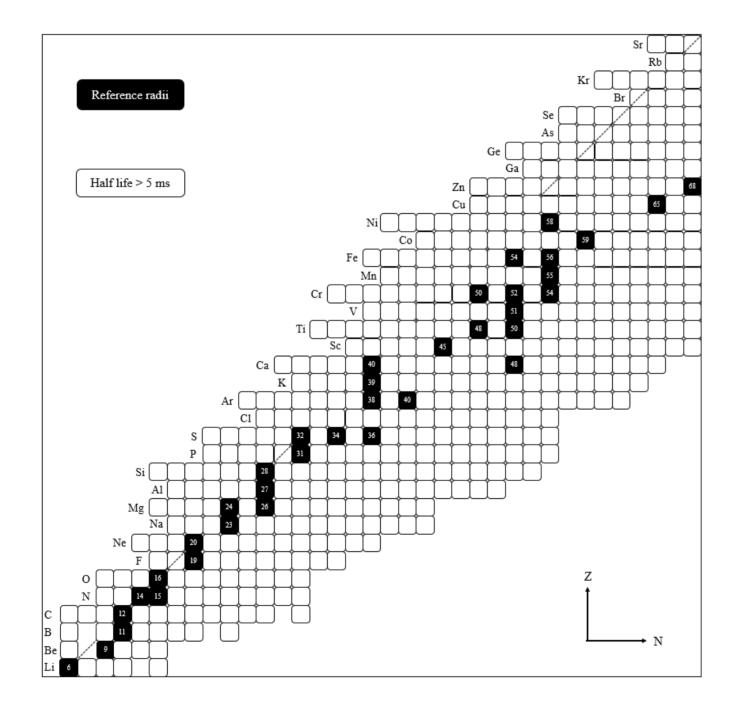
Reference radius (mostly) from **Muonic atoms**

Differential radii (mostly) from radioactive electronic atoms

Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus

Review

Reference radius (mostly) from **Muonic atoms**

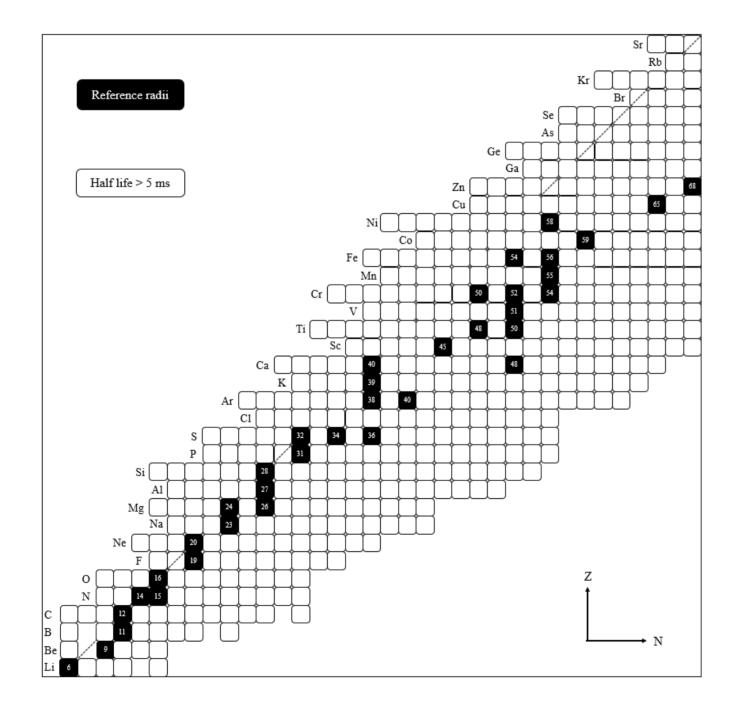


Differential radii (mostly) from radioactive electronic atoms

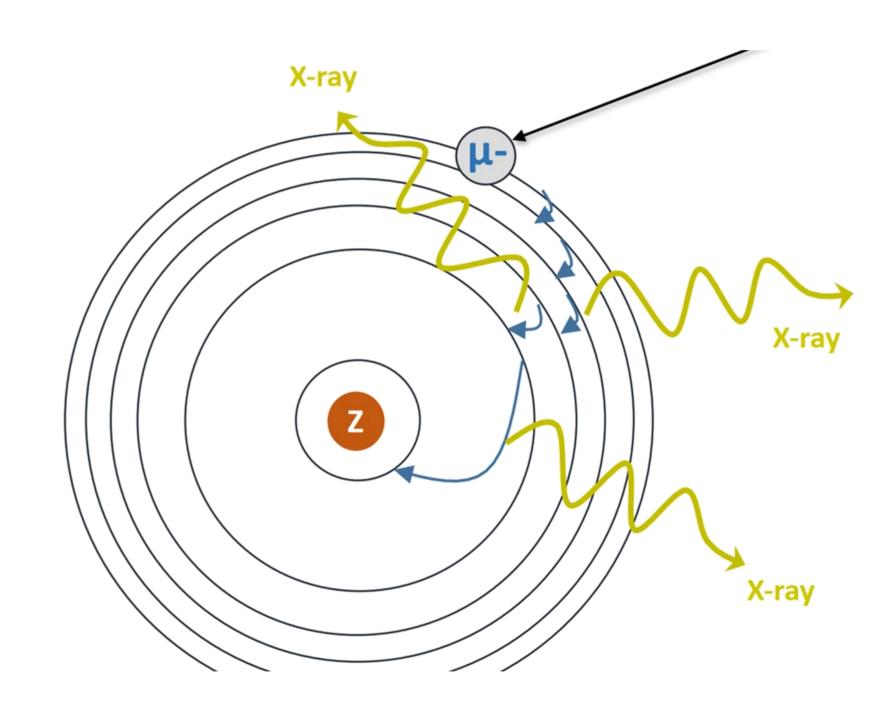
Ecosystem of charge radii determinations Radius of $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$

Review

Reference radius (mostly) from **Muonic atoms**



Differential radii (mostly) from radioactive electronic atoms

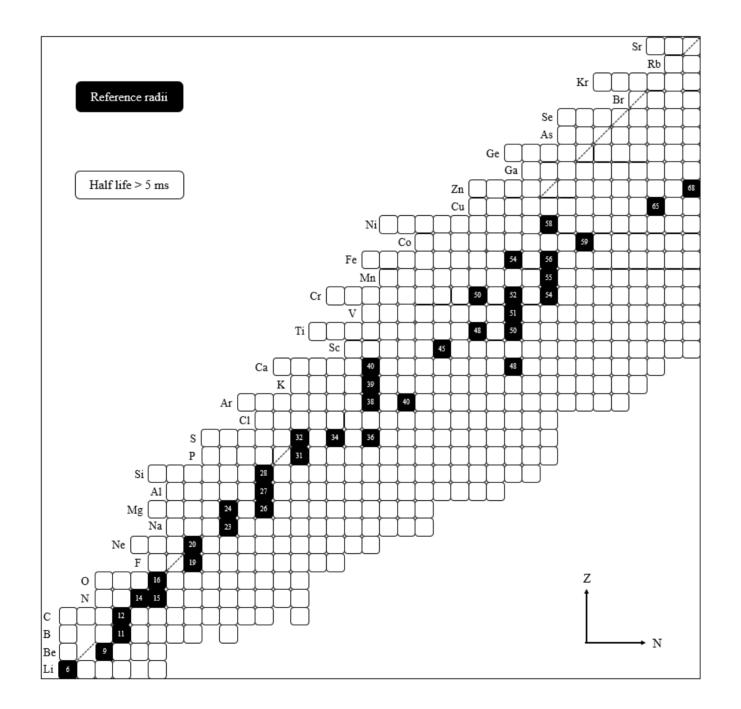


See next talk!

Ecosystem of charge radii determinations Radius of $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$

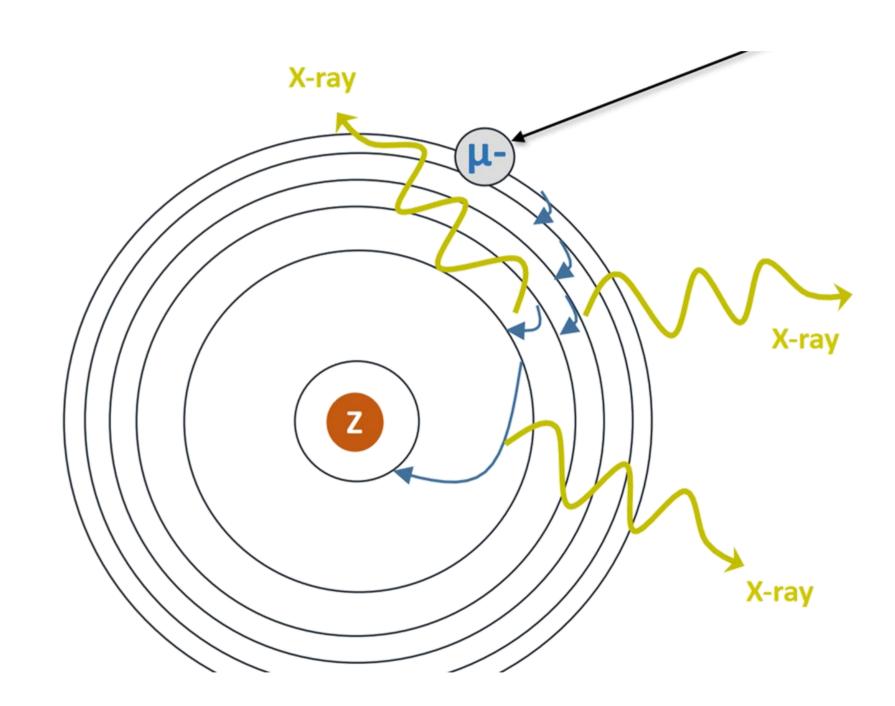
Review

Reference radius (mostly) from **Muonic atoms**



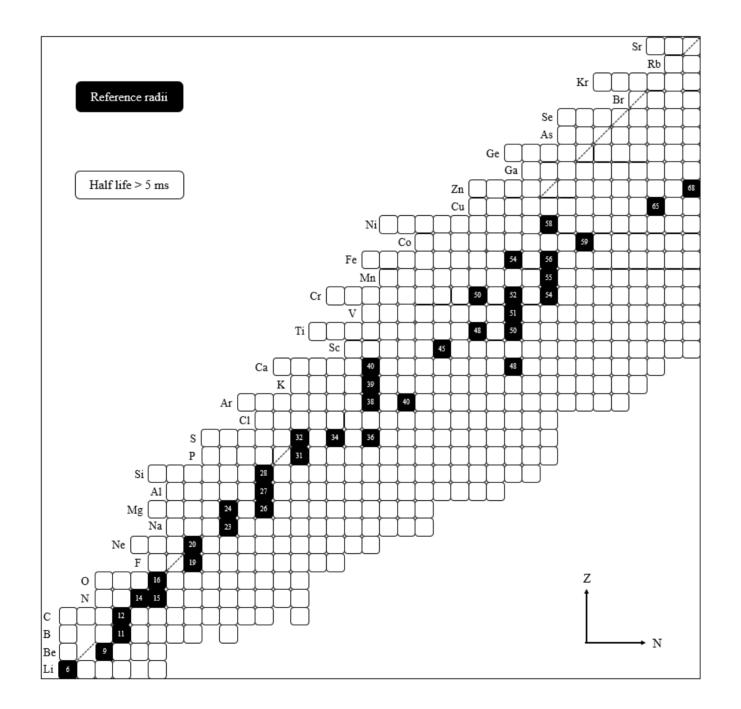
What is in the literature?

Differential radii (mostly) from radioactive electronic atoms



Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus

Reference radius (mostly) from **Muonic atoms**



Differential radii (mostly) from radioactive **electronic atoms**

Table of experimental nuclear ground state charge radii: An update

I. Angeli^a, K.P. Marinova^{b,*}

Review

^a Institute of Experimental Physics, University of Debrecen, H-4010 Debrecen Pf. 105, Hungary ^b Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia

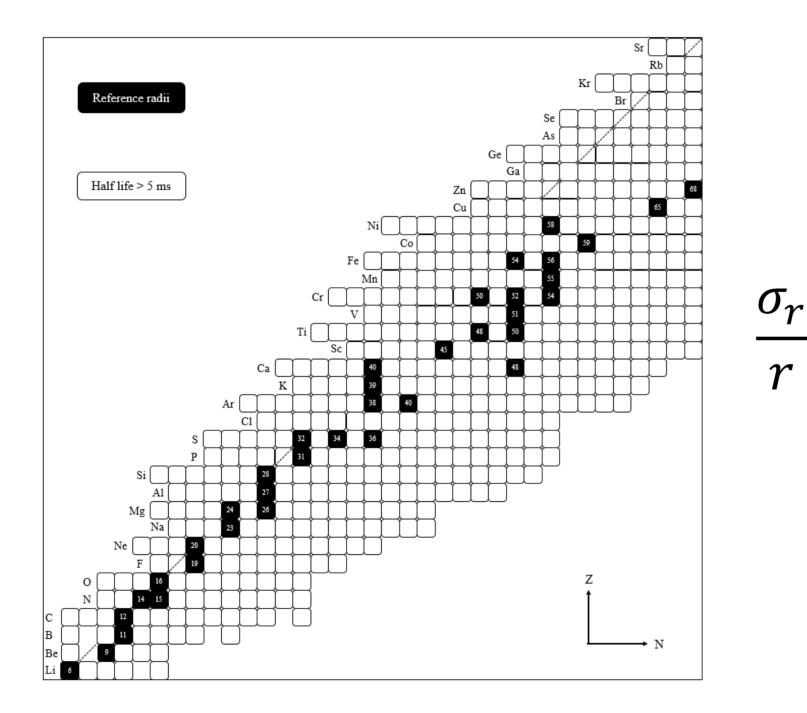


What is in the literature?

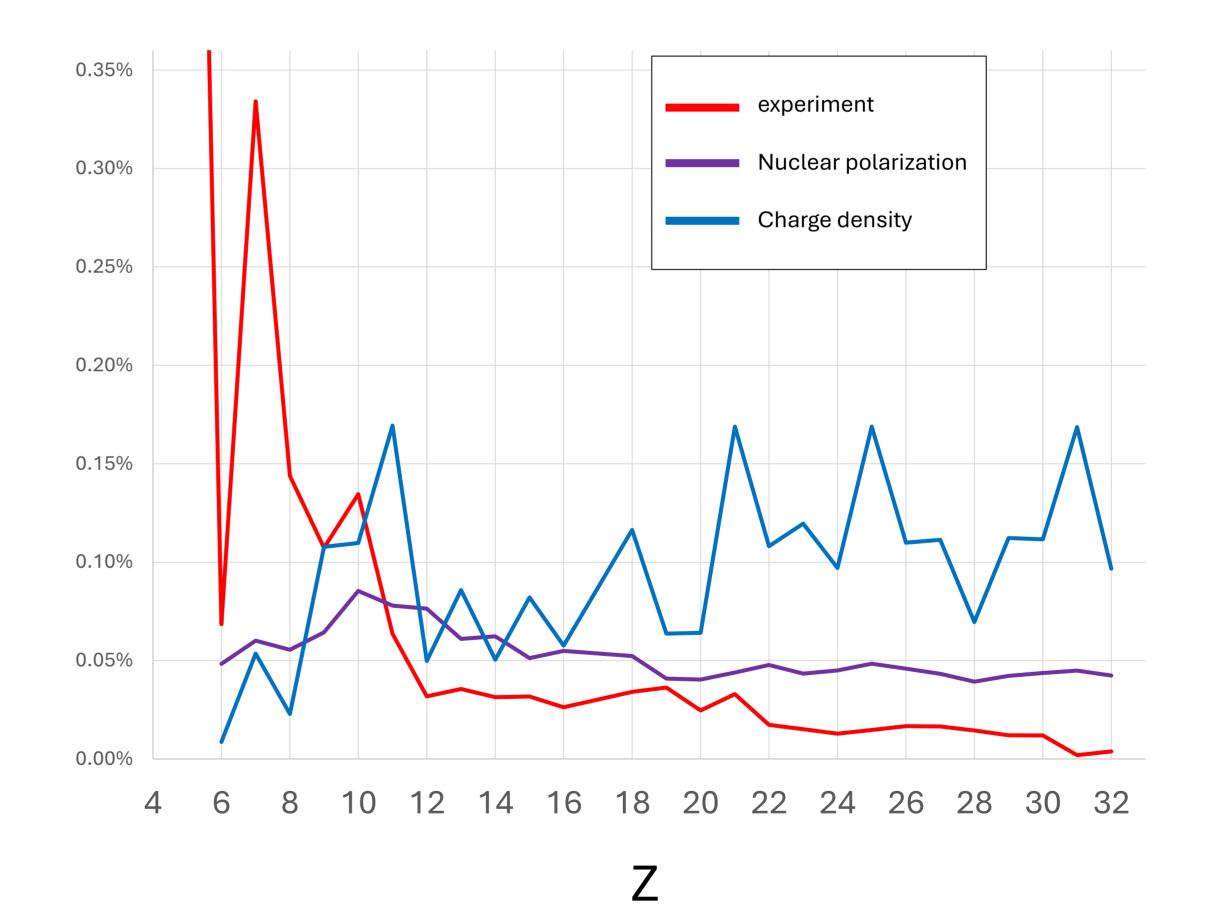
Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus

Review

Reference radius (mostly) from **Muonic atoms**



Differential radii (mostly) from radioactive electronic atoms



New review of reference radii with recalculated values and uncertainties



Transparent tabulation of ref. radii

Table 2

 ν factors of Tab. 1

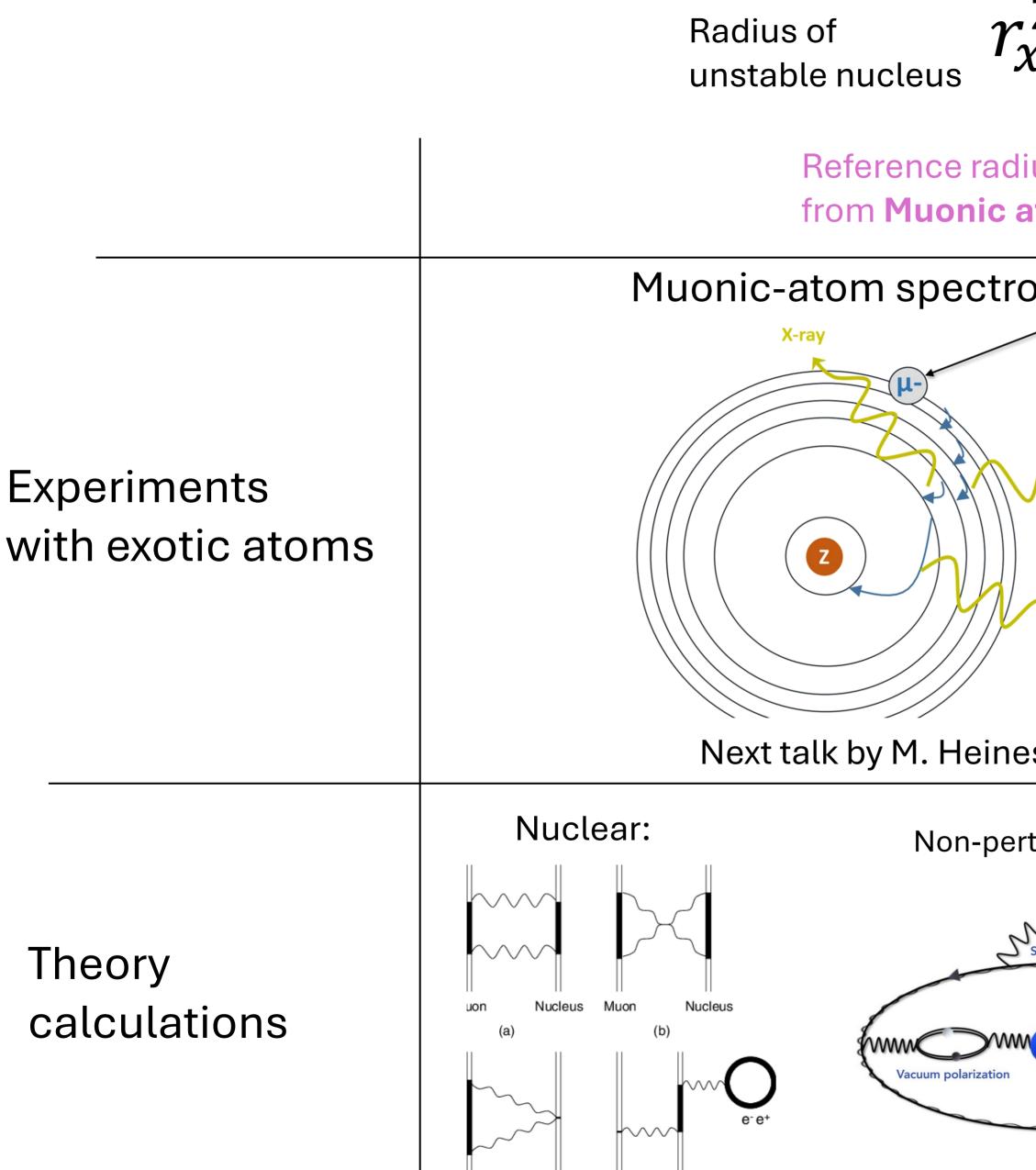
el.	Z	А	$r_{\rm ch}$	$\sigma_{\rm exp}$	$\sigma_{ m NP}$	$\sigma_{ m CD}$	$\sigma_{ m tot}$	Note
Li	3	6	2.589	0.039			0.039	А
Be	4	9	2.519	0.012		0.030	0.032	в
в	5	11	2.411	0.021			0.021	\mathbf{C}
С	6	12	2.483	0.002	0.001	0.000	0.002	D
Ν	7	14	2.556	0.009	0.002	0.001	0.009	
	7	15	2.612	0.009			0.009	Е
0	8	16	2.701	0.004	0.001	0.001	0.004	F
F	9	19	2.902	0.003	0.002	0.003	0.005	†
Ne	10	20	3.001	0.004	0.003	0.003	0.006	t
Na	11	23	2.992	0.002	0.002	0.005	0.006	t
Mg	12	24	3.056	0.001	0.002	0.002	0.003	t
	12	26	3.030	0.001	0.002	0.002	0.003	t
Al	13	27	3.061	0.001	0.002	0.003	0.003	†G
Si	14	28	3.123	0.001	0.002	0.002	0.003	t
Р	15	31	3.190	0.001	0.002	0.002	0.003	
s	16	32	3.262	0.001	0.002	0.003	0.003	
	16	34	3.284	0.001	0.002	0.003	0.004	
	16	36	3.298	0.001	0.001	0.003	0.004	
Cl	17	35	3.388	0.015			0.015	Н
Cl	17	37	3.384	0.015			0.015	Н
Ar	18	38	3.402	0.002	0.003	0.005	0.006	
	18	40	3.427	0.001	0.002	0.003	0.004	
К	19	39	3.435	0.001	0.001	0.003	0.004	
Ca	20	40	3.481	0.001	0.001	0.004	0.004	
	20	48	3.475	0.001	0.001	0.002	0.002	
Sc	21	45	3.548	0.001	0.002	0.006	0.007	

arXiv:2409.08193

Reference radii used in this work. Unless stated otherwise in the note, they are determined via Eq. 1 and 2 with the $2P_{3/2} - 1S$ Barret radii given in [4] and the v factors from tab. 1. Uncertainties are denoted by σ and correspond to statistics and energy calibration (exp), nuclear polarization (NP), and charge distribution (CD) as resulting from the

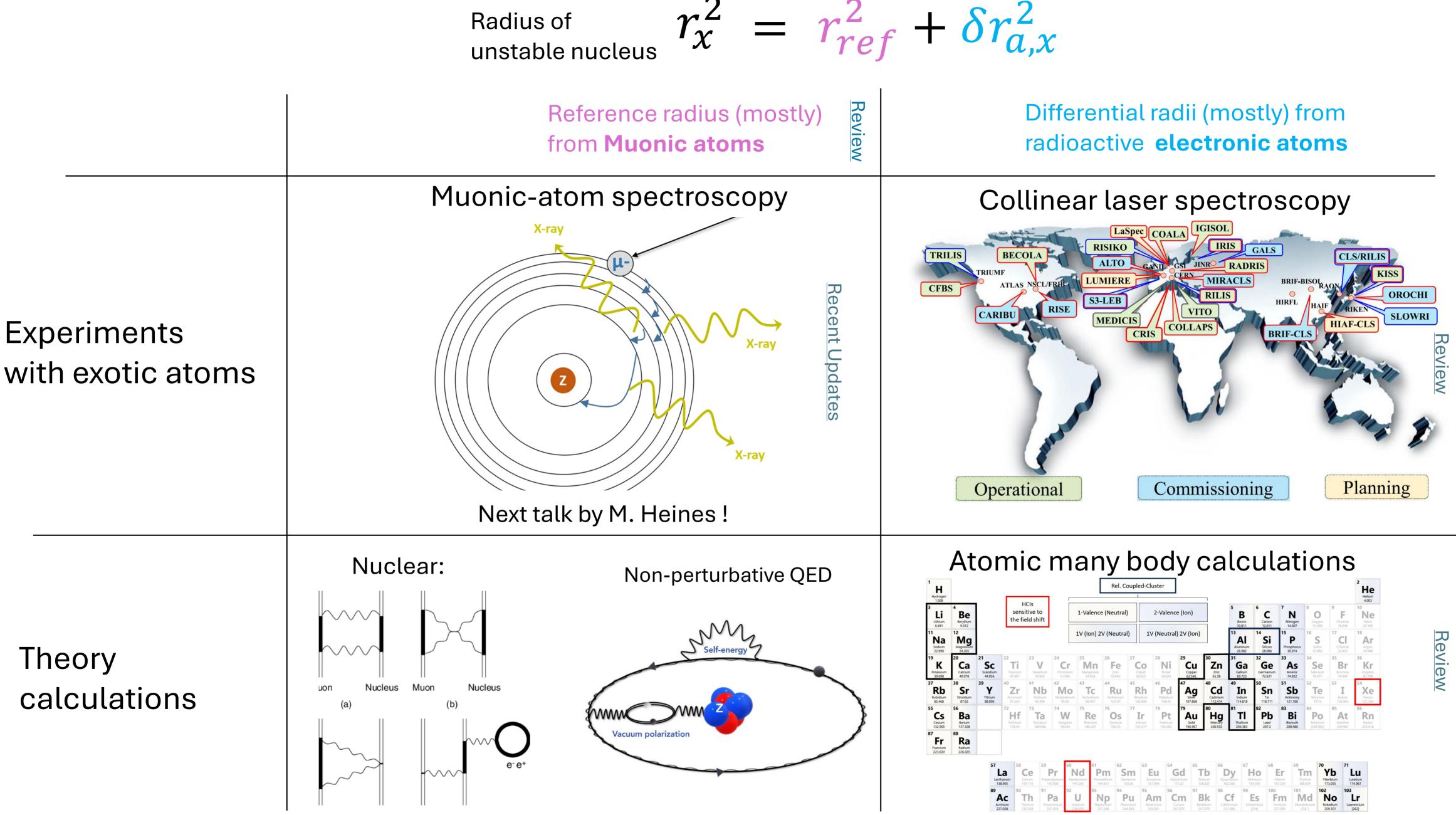


Ecosystem of charge radii determinations Radius of $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$

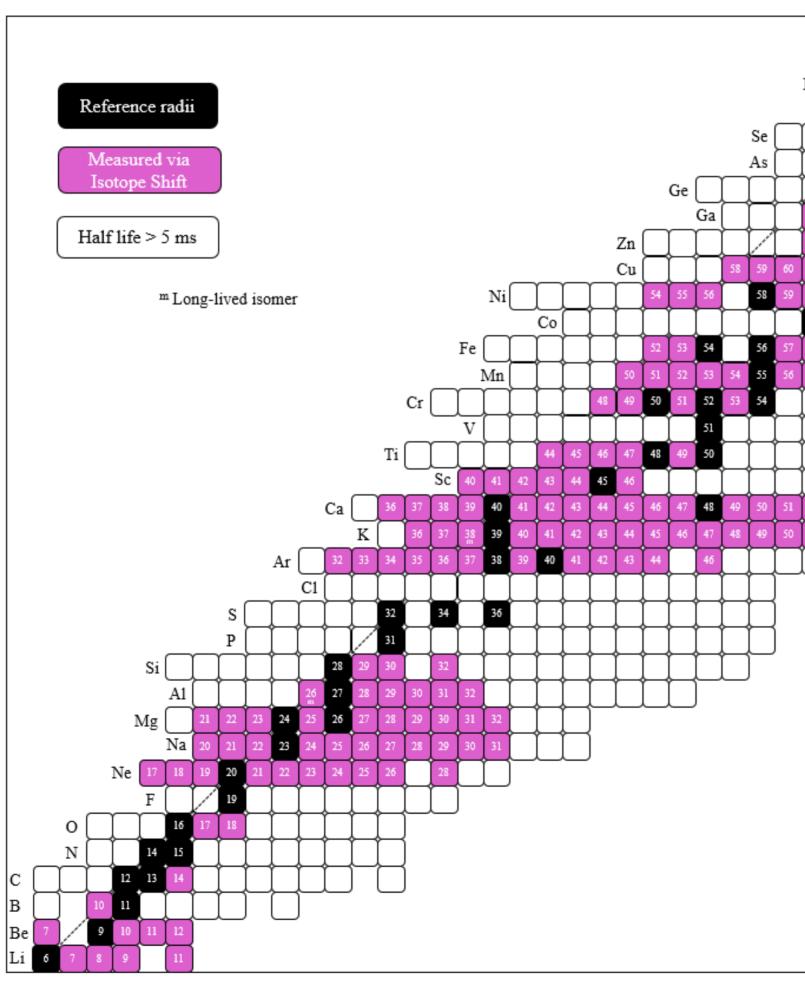


us (mostly)	Differential radii (mostly) from radioactive electronic atoms
oscopy	
Recent Updates	
s!	
turbative QED	
Self-energy	

Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus



Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus Review Reference radius (mostly) Differential radii (mostly) from radioactive electronic atoms from **Muonic atoms** Collinear laser spectroscopy LaSpec COALA IGISOL IRIS GALS RISIKO TRILIS BECOLA **CLS/RILIS** Reference radii RADRIS ALTO JINR MIRACLS LUMIERE CFBS OROCHI Measured via S3-LEB otope Shift RISE CARIBU **SLOWRI** MEDICIS COLLAPS CRIS **BRIF-CI** Review Half life > 5 msm Long-lived isomer Operational Commissioning Planning



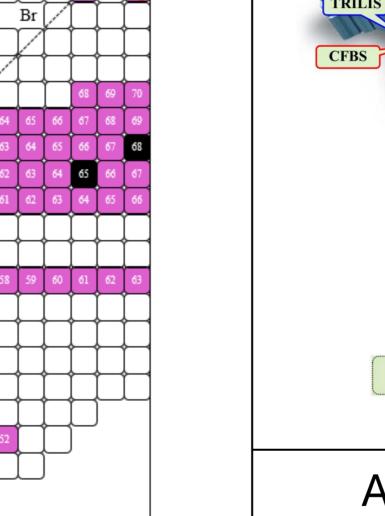
Atomic many body calculations

3 Lithium 6.941	4 Be Beryllium 9.012	Beryllium the field shift				1-Valence	e (Neutral	(Neutral) 2-Valence (Ion)					6 C Carbon 12.011	7 N Nitrogen 14.007	8 Oxygen 15.999	9 Fluorine 18.998	10 Neon 20.180
Na Sodium 22.990	12 Mg Magnesium 24.305					1V (lon) 2	V (Neutra	I) :	1V (Neutral) 2V (Ion)		13 Aluminum 26.982	14 Si Silicon 28.086	15 Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Argon 39.948
Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Gallium 69.723	32 Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Krypto 83.798
B Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112,414	49 In Indium 114.818	50 Sn 118.711	51 Sb Antimony 121.760	52 Telurium 127.6	53 I Iodine 126.904	54 Xeor 131.29
Cs Cesium 132.905	56 Ba Barium 137.328		72 Hf Hafnium 178,49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Irr Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 TI Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rr Rador 222.01
Francium 223.020	88 Ra Radium 226.025																
		Lant	thanum C	erium Prase	odymium Neod	lymium Prom	ethium Sam	arium E	uropium Gad	olinium Ter	bium Dysp	rosium Ho	Imium E	rbium Th	ulium Y	tterbium L	Lu utetium 174.967
		89	90	91	Pa 92	93	94	95	96	97	98	99	100	101	102		

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Ecosystem of charge radii determinations $r_x^2 = r_{ref}^2 + \delta r_{a,x}^2$ Radius of unstable nucleus Review Reference radius (mostly) Differential radii (mostly) from radioactive electronic atoms from **Muonic atoms** Collinear laser spectroscopy LaSpec COALA IGISOL IRIS GALS RISIKO TRILIS BECOLA **CLS/RILIS** Reference radii RADRIS ALTO JINR MIRACLS LUMIERE CFBS OROCHI Measured via S3-LEB Isotope Shift RISE CARIBU **SLOWRI** MEDICIS

Many opportunities for laser spec.: (@GANIL?) Half life > 5 ms¹⁰C m Long-lived isomer ^{14}O ²⁶Si ⁴²Ti ⁴⁶Cr ⁵⁰Fe . . . Ζ



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 88
 Ra

 Francium
 Radium
 223.020
 226.025

87

	Ope	eratio	onal				Со	mm	iss	ioni	ing				No.	ning	
1 Hudrogen	tor	nic	c m	ar	-	bupled-C		уc	ca	lc	ul	at	io	ns	2 He Helium		
1.008 3 4 Libium 6.941 11 12 Na Sodium	lg		sensitive to the field shift		1-Valence (Neutral) 1V (Ion) 2V (Neutral)			2-Valence (Ion) 1V (Neutral) 2V (Ion)			5 6 7 B Carbon Nitroge 10.811 12.011 Nitroge 13 14 15 Aluminum Silicon Phosphon 28.982 58.060 79.010				8 9 10 0 F No 15.99 F No 16 17 18 Suffur Choirine Argon 32.060 35.453 39.346		
19 20 K Potassium 39.098 Cala 37 Rb Rb Stror 85.468 Stror 55 S6 Cesium Bar	a 21 Sc Sc Scandium 44.956 Sr Y Yttrium 88.906	47.867 40 Zr Zirconium 91.224 72 Hafnium	V anadium 50.942 Crromium 51.996 42 Molybdenur 95.95	25 Mnganese 54.938 43 TC Technetium 98.907 75 Re Rhenium 186.207	26 Fe Iron 55.845 44 Ruthenium 101.07 76 OS Osmium 190.23	27 Cobat 58.933 45 Rhadium 102.906 77 Ir Liidium 192.217	28 Nickel 58.093 46 Pdd Palladium 106.42 78 Pt Platinum 195.085	29 Cu Copper 63.546 47 Ag Silver 107.868 79 Au Gold 196.967	30 Zn Zinc 65.38 48 Cd Cadmium 112.414 80 Hg Mercury 200.592	26.982 31 Gallium 69.723 49 In Indium 114.818 81 TI Thallium 204.383	28.086 32 Germanium 72.631 50 Sn Tin 118.711 82 Pb Lead 207.2	30.974 33 Arsenic 74.922 51 Sbb Antimony 121.760 83 Bi Bismuth 208.980	32.066 34 Se Selenium 73.971 52 Tellurium 127.6 84 Polonium [208.982]	35.453 35 Bromine 79.904 53 I Iodine 126.904 85 At Astatine 209.987	39.948 36 Kr Krypton 83.798 54 Xenon 131.294 86 Rn Radon 222.018		

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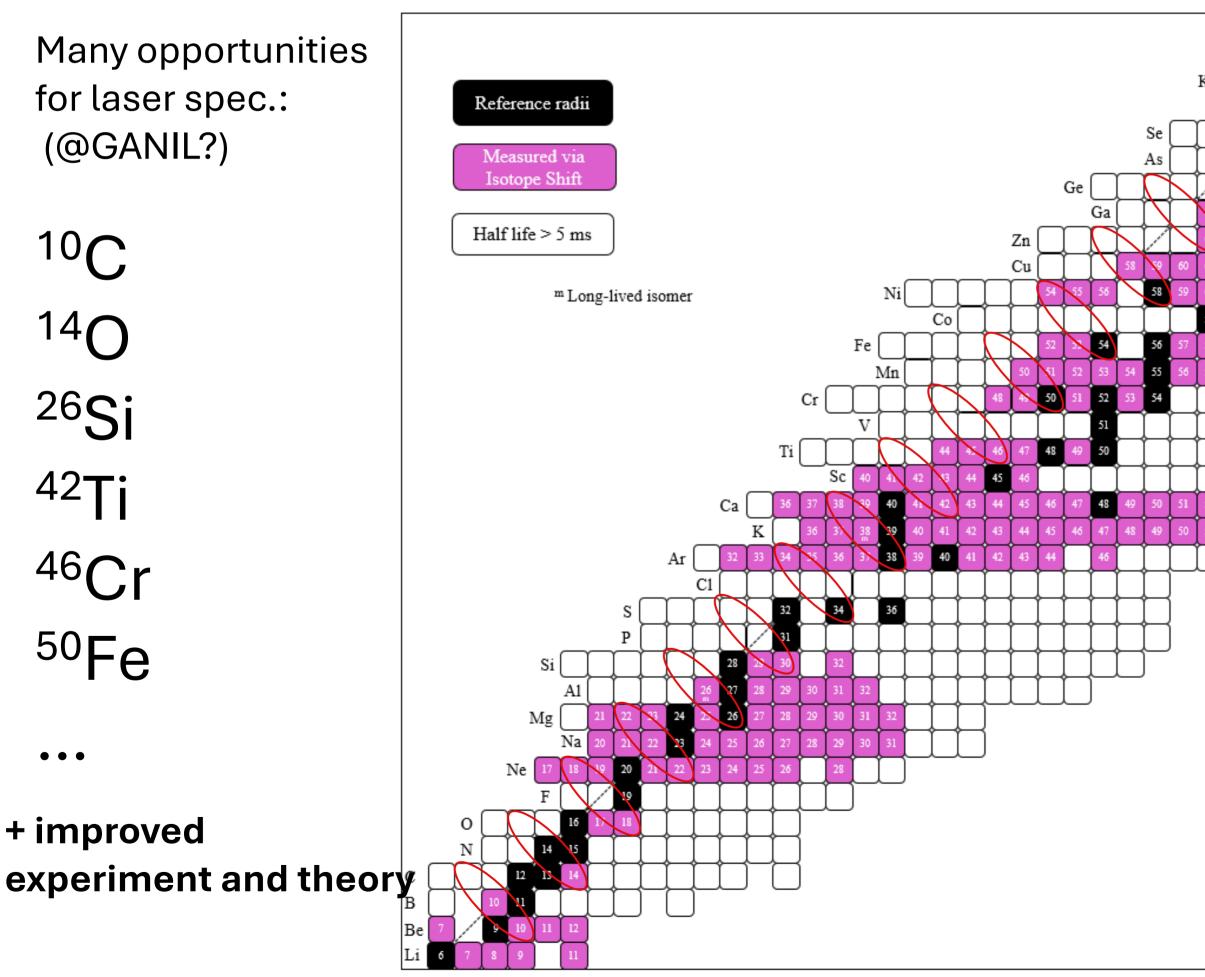
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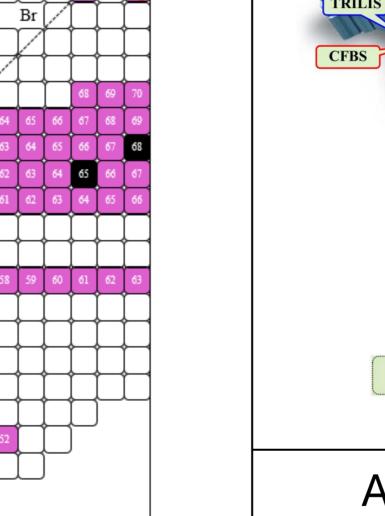
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Lanthanum 138.905	Cerium 140.116	Praseodymium 140.908	Neodymium 144.243	Promethium 144.913	Samarium 150.36	Europium 151.964	Gadolinium 157.25	Terbium 158.925	Dysprosium 162.500	Holmium 164.930	Erbium 167.259	Thulium 168.934	Ytterbium 173.055	Lutetium 174.967
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
Actinium 227.028	Thorium 232.038	Protactinium 231.036	Uranium 238.029	Neptunium 237.048	Plutonium 244.064	Americium 243.061	Curium 247.070	Berkelium 247.070	Californium 251.080	Einsteinium [254]	Fermium 257.095	Mendelevium 258.1	Nobelium 259.101	Lawrencium [262]

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Review

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4 Be Beryllium	sens	ICIs itive to eld shift		1-Valence	e (Neutral)	2-Valence (Ion)			5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 Fluorine	Helium 4.003 10 Neo			
9.012 12 Mg				1V (lon) 2	V (Neutra	l) :	1V (Neutra) 2V <mark>(</mark> lon)		10.811 13 Aluminum 26.982	12.011 14 Si Silicon 28.086	14.007 15 Phosphorus 30.974	15.999	18.998	20.180 18 Argon 39.948			
Magnesium	22	23 V	24 Cr Chromium	25 Mn Manganese	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Gallium 69.723	32 Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	39.946 36 Krypton 83.798			
Magnesitirm 24.305 20 21 Ca Calcium 40.078 44.956	m Titanium	Vanadium 50.942	51.996	54.938					10									
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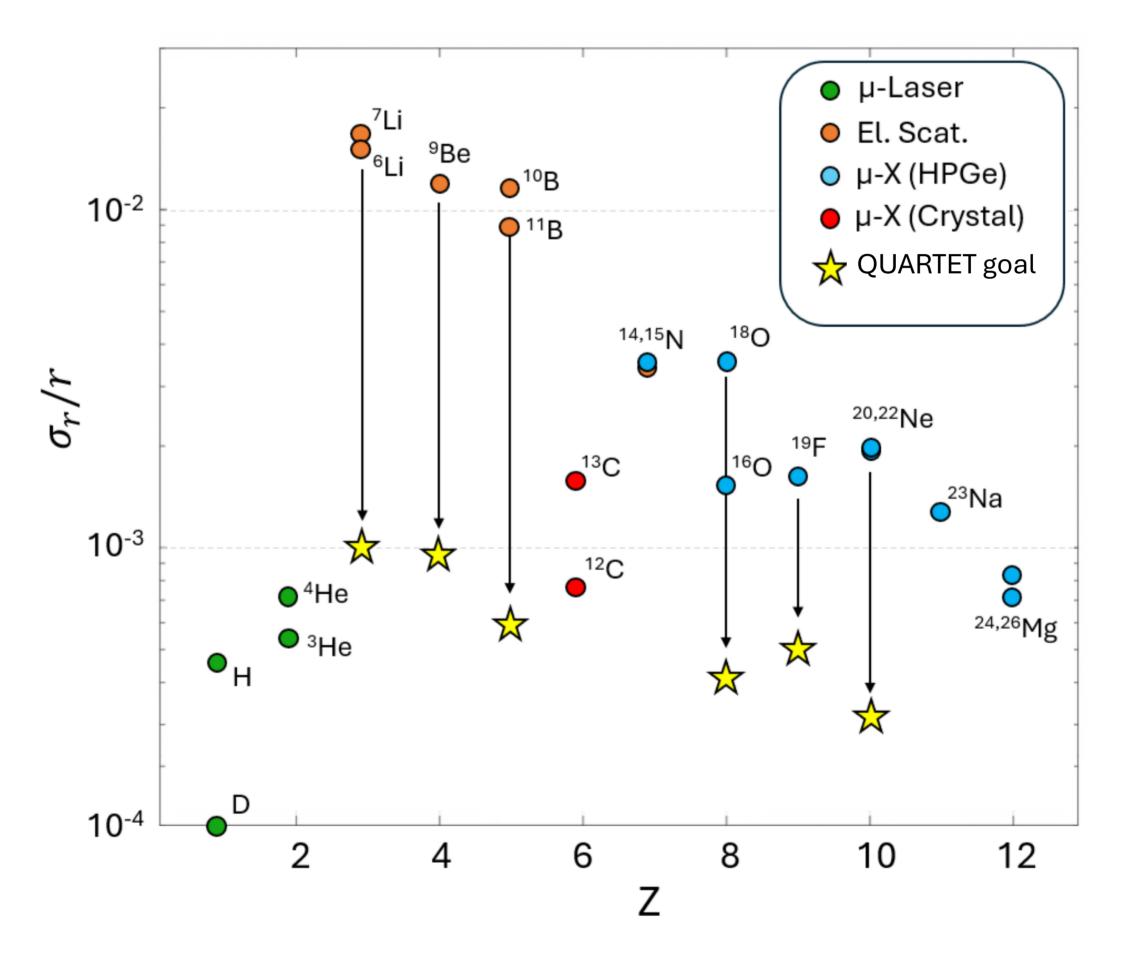
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Review

Role of radii beyond Superallowed?

 Radius affect spectrum shapes (e.g. in ²⁰F), how well do we need to daughter radius?



For more information about QUARTET See <u>here</u>, and next talk.

rallowed? (e.g. in ²⁰F), r radius?

Summary

Nuclear charge radii important for V_{ud}

- 1. Within model, calculate δ_c (need R_{father} to 1%)
- 2. Calculate f(need $R_{father} + R_{daughter}$ to few 0.1%)
- 3. Benchmark δ_c models (need R of triplet to <0.1%)

Ecosystem of charge radii determinations

