High-Precision Branching Ratio Measurement for the Superallowed β^+ Emitter ^{74}Rb

Ryan Dunlop

Physics Dept. University of Guelph

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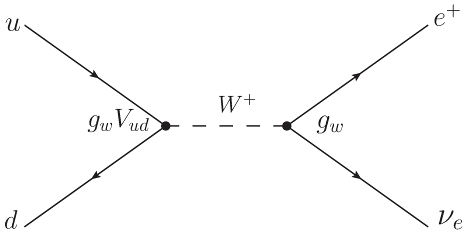
Quark-Mixing and the CKM Matrix

- Weak Eigenstates $\neq$ Mass Eigenstates
- Cabibbo-Kobayashi-Maskawa matrix quantifies mixing of eigenstates
- **Must** be Unitary in Standard Model (Important!)
- β^+-decay: $p \rightarrow n = u\boldsymbol{u}d \rightarrow u\boldsymbol{d}d$

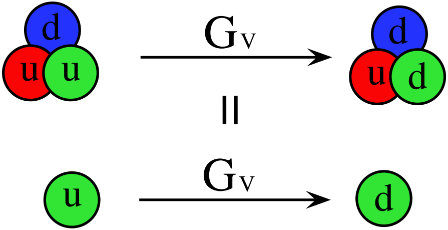
$$\begin{pmatrix} \boxed{V_{ud}} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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



Conserved-Vector-Current Hypothesis

- Motivated by similarity of Weak-vector current with Electromagnetic-vector current
- A nucleus with Z protons has the same electric charge as Z free protons
- Likewise, other interactions do not appear to influence weak vector-current (unlike axial current)



- $G_V = const.$

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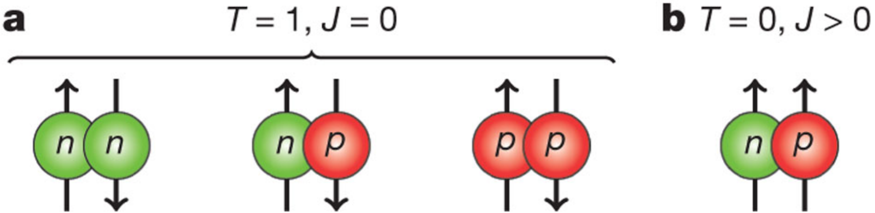
Isospin



- Protons and neutrons are different projections of the same particle
- Convention: n has $T_3 = \frac{1}{2}$, p has $T_3 = -\frac{1}{2}$
- Fermi Decay: $p \rightarrow n$ can be represented by the isospin raising operator $\hat{\tau}^+$
- Only couples states with the same total isospin T called isobaric analogues

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Superallowed-Fermi-β decay

Superallowed-Fermi-β decay:

- Decay between isobaric analogue states
- Same total isospin, same nuclear wavefunctions
- $J^\pi : 0^+ \rightarrow 0^+$ which forbids axial vector contribution $\rightarrow G_V$ Test

^{74}Rb$\rightarrow^{74}$Kr is a decay between states with:

- $T = 1 \rightarrow T = 1$
- $T_3 = 0 \rightarrow T_3 = 1$
- $J^\pi = 0^+ \rightarrow J^\pi = 0^+$

Superallowed-Fermi-β-Decay Rate

Fermi's Golden Rule

$$f(Q, Z_D)t = \frac{const.}{\left|\overline{M}_{fi}\right|^2 g^2} \xrightarrow[T=1]{\text{superallowed}} \frac{const.}{2G_V^2}$$

- $\left|\overline{M}_{fi}\right| = \sqrt{2}$ from the SU(2) symmetry of isospin
- CVC Hypothesis $\rightarrow$ ft should be "CONSTANT"
- Can extract G_V and V_{ud} since $(G_V = G_F V_{ud})$

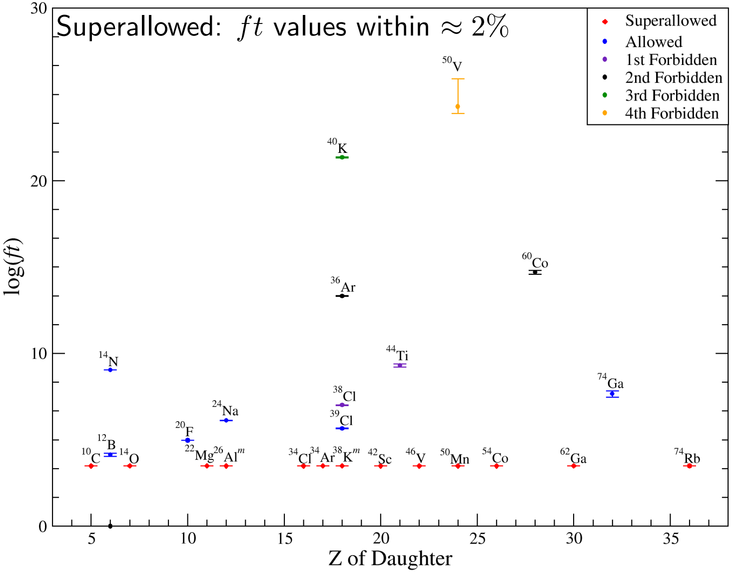
$t \equiv$ Partial half-life (includes **branching ratio**)

$f \equiv$ Statisitcal rate function

$Z_D \equiv$ Charge of Daughter Nucleus

$Q \equiv$ Difference in mass of mother and daughter

ft Values



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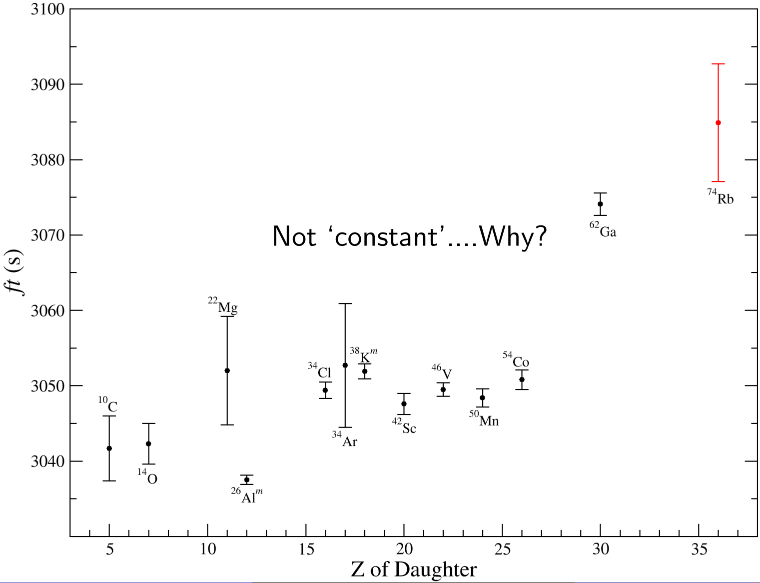
ft Values


3100
3090
3080
3070
3060
3050
3040
ft (s)
5
10
15
20
25
30
35
Z of Daughter
10C
14O
22Mg
26Alm
34Cl
34Ar
38Km
42Sc
46V
50Mn
54Co
62Ga
74Rb
Not 'constant'....Why?

Corrected ft

- Must consider QED, QCD effects

$\mathcal{F}t$ Correction

$$\mathcal{F}t = ft(1+\delta_R)(1-\delta_c) = \frac{const.}{2G_V^2(1+\Delta_R)}$$

Nucleus Independent:

$\Delta_R \equiv$ Radiative Correction $(2.361 \pm 0.038)\%$

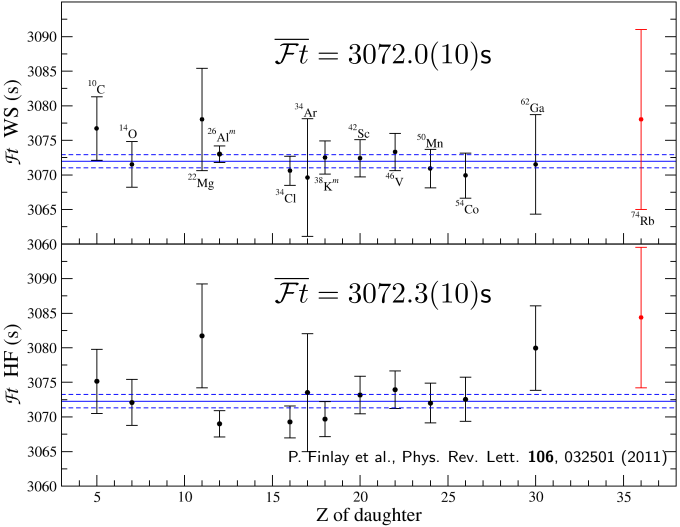
Nucleus Dependent:

$\delta_R \equiv$ Radiative Correction $(1.4 - 1.5)\%$

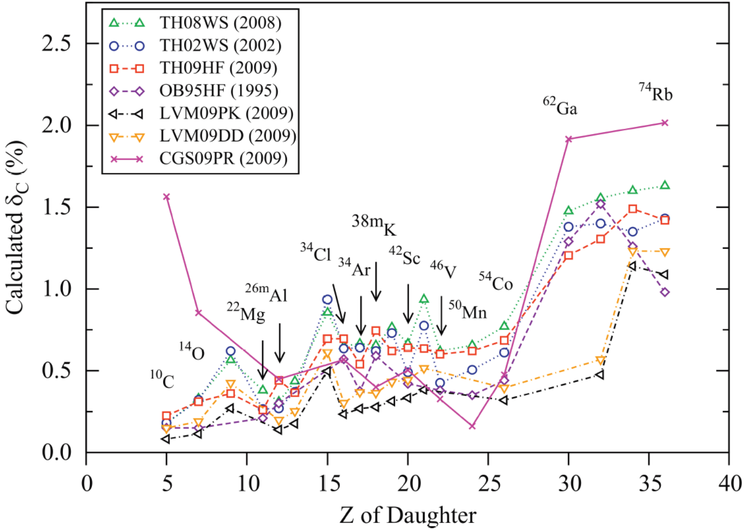
$\delta_c \equiv$ Isospin Symmetry Breaking Correction $(0.25 - 1.5)\%$

World $\mathcal{F}t$ Values

CVC verified to 0.013%



Isospin-Symmetry-Breaking Corrections



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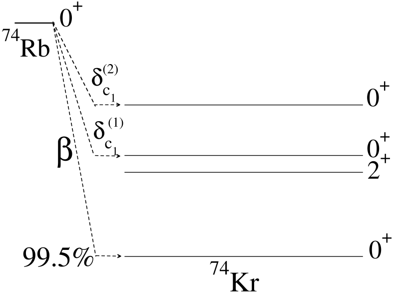
Measurement of the δ_{c_1} Component

$$\delta_c \approx \delta_{c_1} + \delta_{c_2}$$

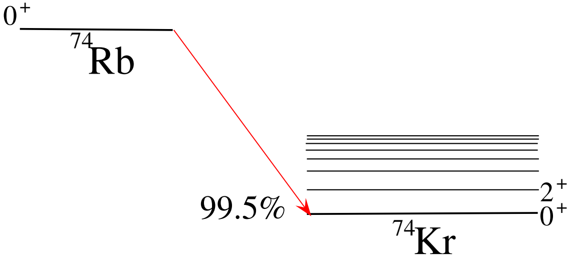
- δ_{c_1} is from configuration mixing between mother and daughter
- δ_{c_2} is caused by imperfect radial overlap between initial and final states

$$\delta_{c_1} = \sum_{i=1}^{\infty} \delta_{c_1}^{(i)}$$

$$\delta_{c_1}^{(i)} = BR_i \left(\frac{f_0}{f_i} \right)$$



Pandemonium - Why ^{74}Rb is Hard



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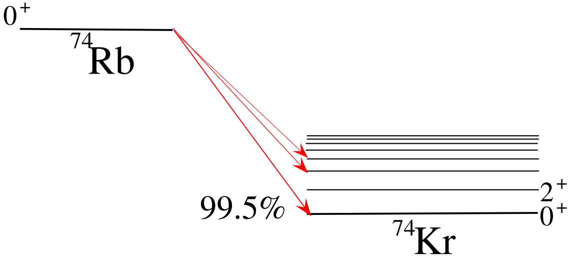

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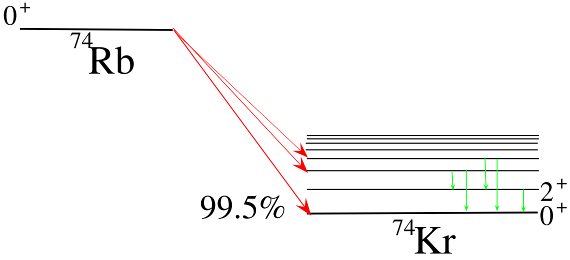

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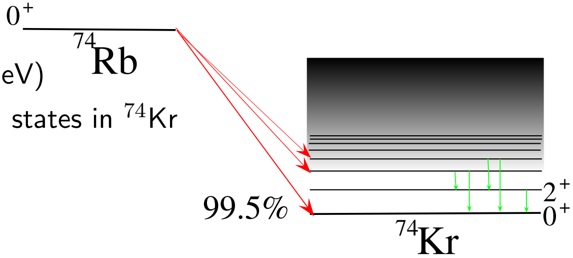
Pandemonium - Why ^{74}Rb is Hard

- High Q-Value (10.4 MeV)
- More than 400 excited states in ^{74}Kr



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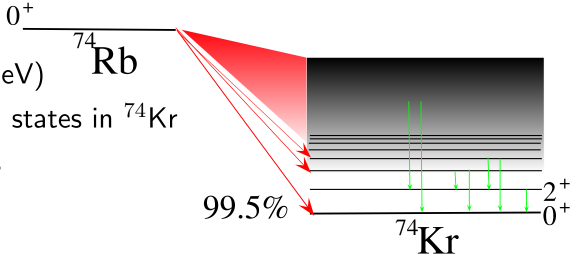

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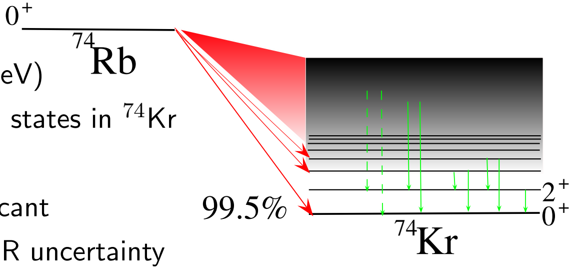
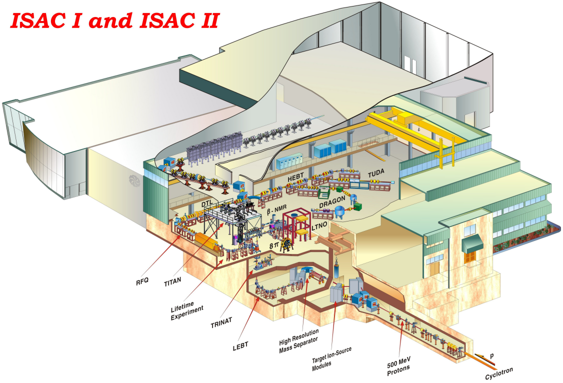


- High Q-Value (10.4 MeV)
- More than 400 excited states in ^{74}Kr
- Many weak transitions
- Unobserved but significant
- Currently dominates BR uncertainty
- Determining BR to some of these states will reduce uncertainty
- Important 2^+ *collector states*

Experimental Setup

Experiment performed at TRIUMF in November 2010.

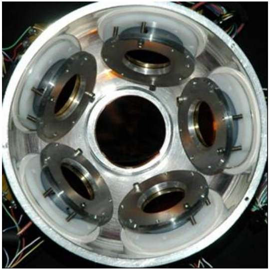


- Collided 500 MeV protons onto a ^{nat}Nb target
- TRIUMF Delivered 6500 ions/s ^{74}Rb

Experimental Setup - 8π

- Implanted RIB of ^{74}Rb inside of a 20 Compton-Suppressed HPGe close-packed-detector array (8π)

- Included 5 Si(Li) detectors (PACES) for measuring conversion electrons



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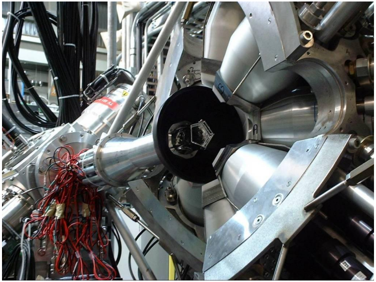
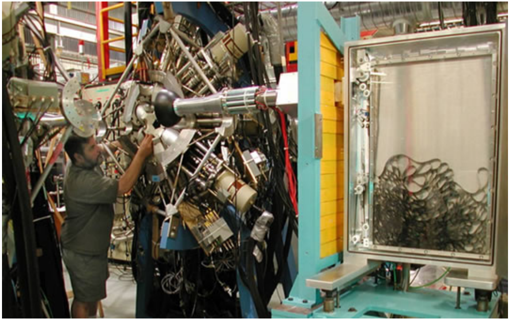
Experimental Setup - 8π



- Included 10 plastic scintillators (SCEPTAR) for detecting β particles

- Tape system to limit long-lived contaminants



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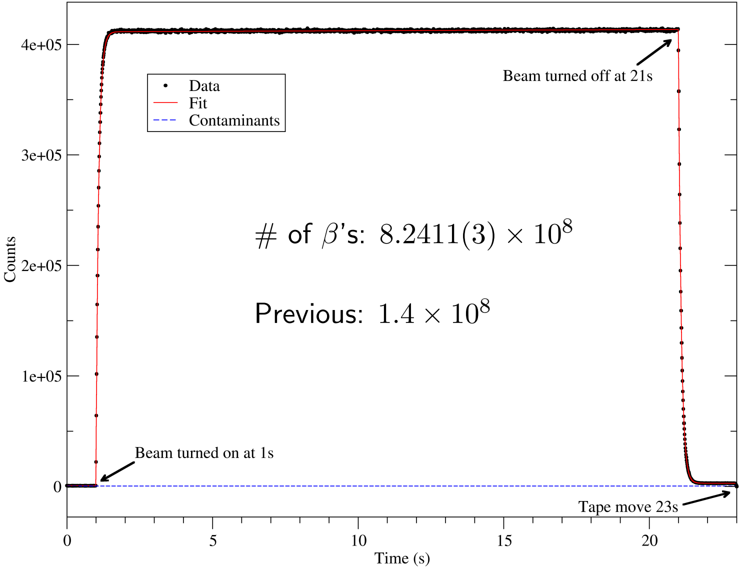
Counting β's



of β's: $8.2411(3) \times 10^8$

Previous: 1.4×10^8

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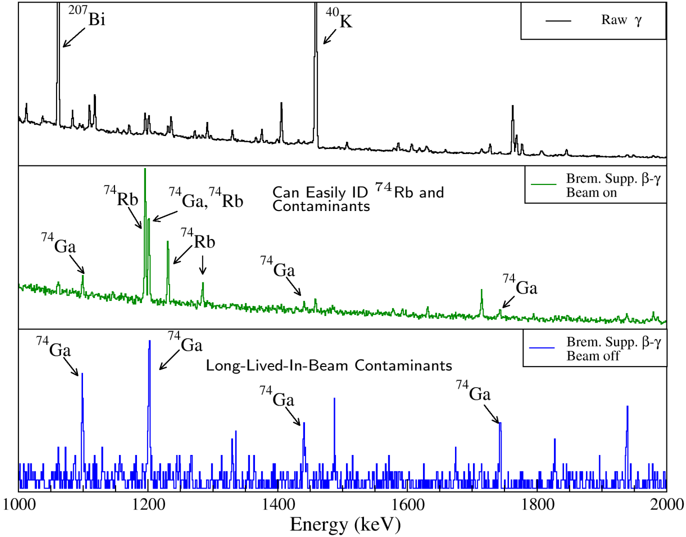
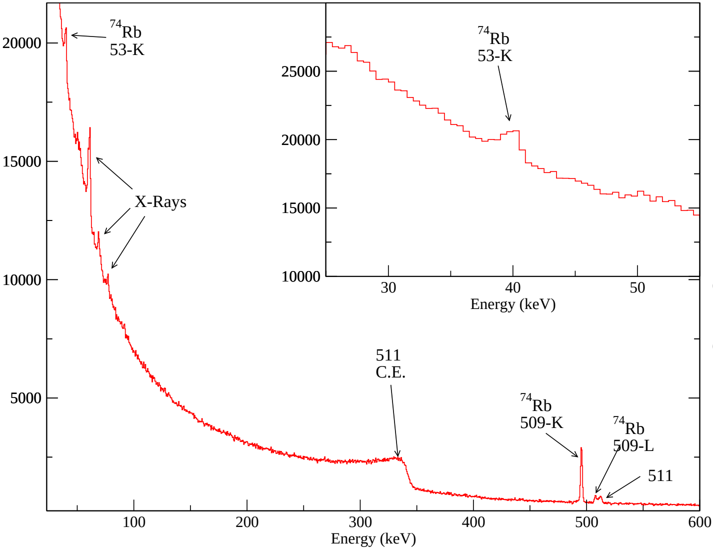
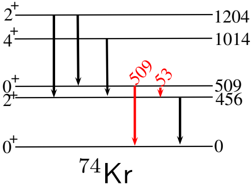
Identifying ^{74}Rb Transitions



PACES Spectrum





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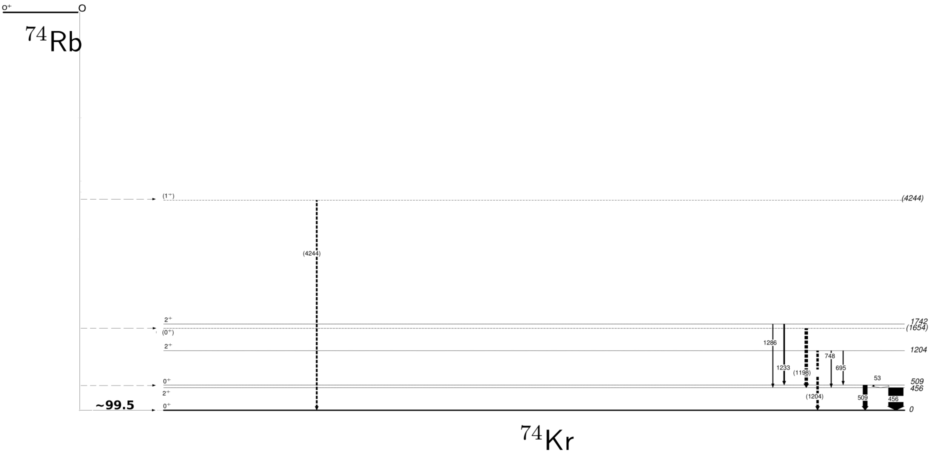
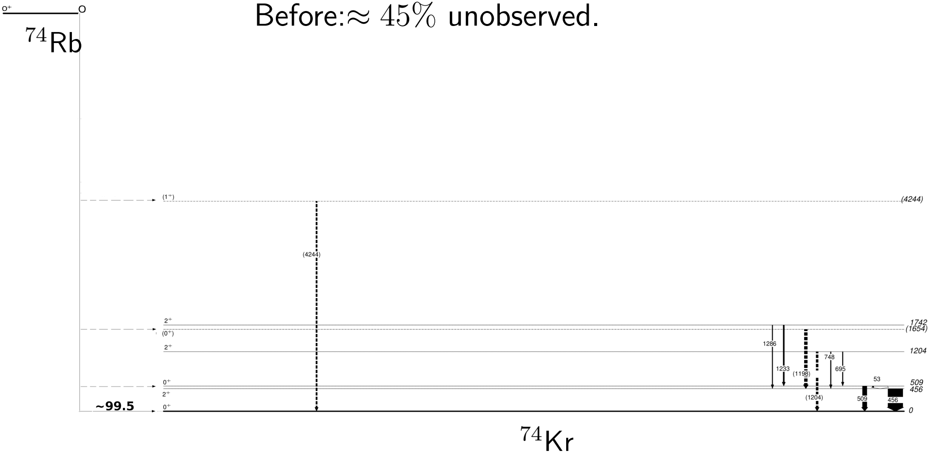
^{74}Kr Level Scheme



^{74}Kr Level Scheme

Before:$\approx 45\%$ unobserved.



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^{74}Kr Level Scheme

Before: $\approx 45\%$ unobserved.

Now: $\approx 20\%$ unobserved.

How is Theory Doing?

β-decay to the 1st excited 0^+ state at 509 kev:

$$BR_1 \leq 0.030\% \qquad \frac{f_0}{f_1} = 1.3$$

Conclusion

How is Theory Doing?

β-decay to the 1st excited 0^+ state at 509 kev:

$$BR_1 \leq 0.030\% \qquad \frac{f_0}{f_1} = 1.3$$

$$\delta_{C_1}^{(1)} = BR_1 \frac{f_0}{f_1} \leq 0.039\% \qquad \text{Theory} = 0.05\%$$

Conclusion

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How is Theory Doing?

β-decay to the 1st excited 0^+ state at 509 kev:

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$$\delta_{C_1}^{(1)} = BR_1 \frac{f_0}{f_1} \leq 0.039\% \qquad \text{Theory} = 0.05\%$$

Conclusion

Theory is overestimating the configuration mixing! (^{62}Ga, ^{74}Rb)

Summary

- Currently have identified 22 excited states and 54 γ-ray transitions
- $\approx 30\%$ improvement in superallowed branching ratio uncertainty
- Theory is overestimating configuration mixing of isospin
- Result will guide corrections for precision tests of the Standard Model (CVC, CKM)

Acknowledgements

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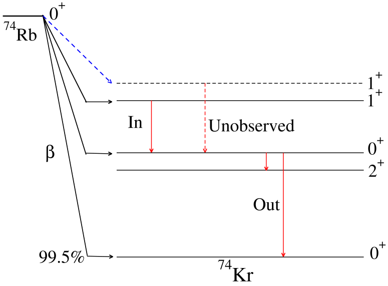
BR Determination

- Determine γ-ray(conversion e^-)-BR's

- Determine nonsuperallowed β-BR's

- Determine superallowed β-BR



$$BR(\beta)_{superallowed} = 1 - \sum BR(\beta)_{nonsuperallowed}$$

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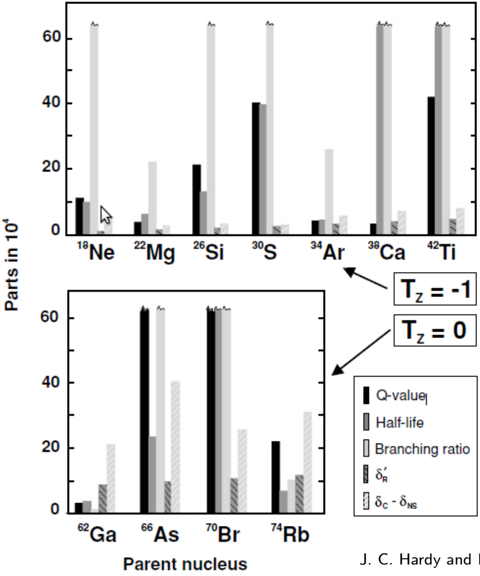
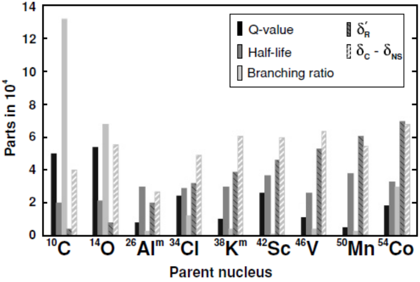
Fractional Uncertainties





J. C. Hardy and I. S. Towner, Phys. Rev. C **79**, 05502 (2009)

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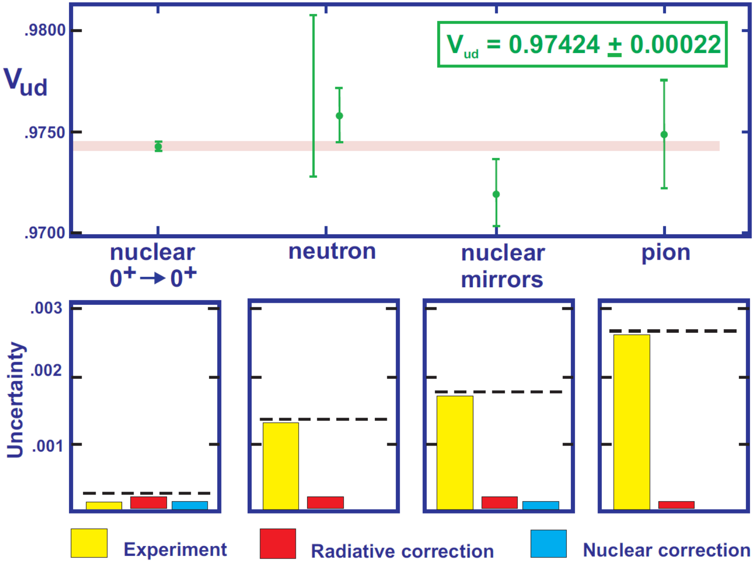
V_{ud} Precision



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Determination of Matrix Element via Isospin

Assuming isospin is a perfect symmetry, β^+ decay from analogue($T = T'$) $0^+ \rightarrow 0^+$ gives:

$$\begin{aligned} \left|\overline{M}_{fi}(F)\right|^2 &= \left|\langle T, T_3 - 1|\, \hat{\tau}^- \,|T, T_3\rangle\right|^2 \\ &= (T + T_3)(T - T_3 + 1) \end{aligned}$$

if we use a $T = 1$ isotriplette and $T_3 = 0 \rightarrow T_3 = -1$

$$\left|\overline{M}_{fi}(F)\right|^2 = 2$$

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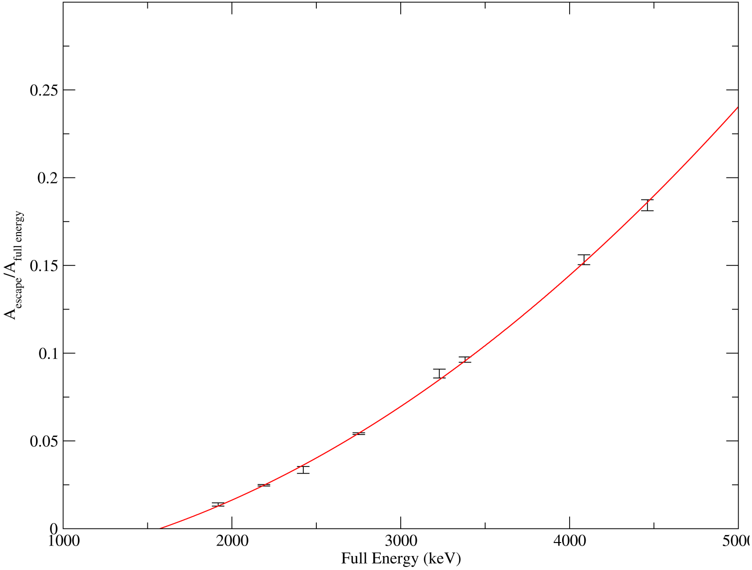
Escape-peak Calibration



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