The β Decay of ^{38}Ca: Sensitive Test of Isospin Symmetry-Breaking Corrections from Mirror Superallowed $0^+ \to 0^+$ transitions

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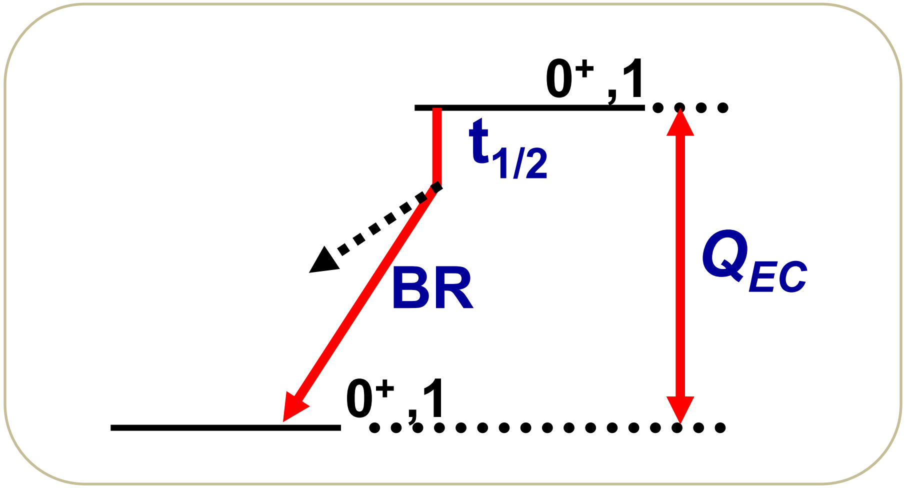
Superallowed $0^+ \rightarrow 0^+$ nuclear β decay

$$ft = \frac{K}{G_V^2 \langle M_F \rangle^2}$$

f = statistical rate function $f(Z, Q_{EC})$
t = partial half-life $f(t_{1/2}, \mathrm{BR})$
G_V = vector coupling constant
M_F = Fermi matrix element



Including corrections

$$\mathcal{F}t = ft(1+\delta_R')[1-(\delta_C-\delta_{NS})] = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

δ_C = isospin-symmetry breaking correction
δ'_R, δ_{NS} = radiative correction (transition dependent)
Δ_R = radiative correction (transition independent)

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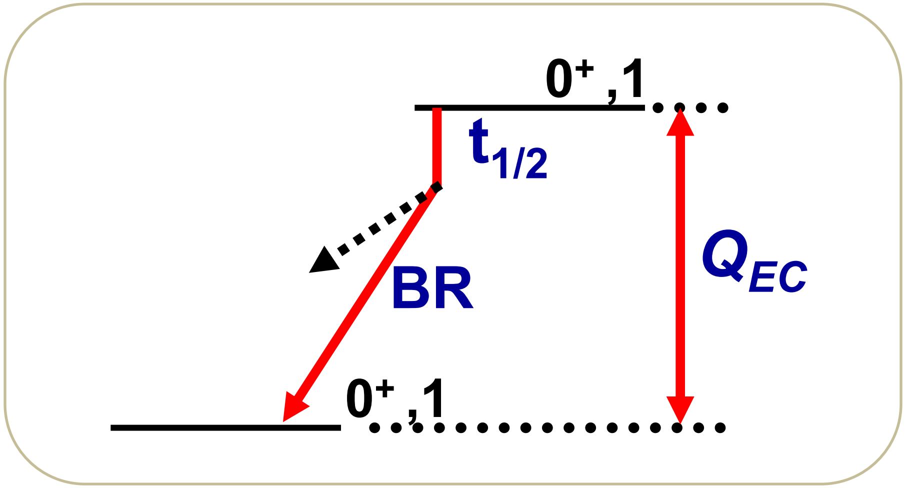


Including corrections

$$\mathcal{F}t = ft(1+\delta_R')[1-(\delta_C - \delta_{NS})] = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

$f(Z, Q_{EC})$
~ 1.5%

f(nuclear structure)
0.3 - 1.5%

f(interactions)
~ 2.4%

World data for superallowed $0^+ \rightarrow 0^+$ β decay (2009)

- **Approximately 150 individual measurements made contributions with compatible precision.**

- **The 13 best-known transitions: the ft values for 10 cases have been measured to 0.1% precision or better; 3 more cases to <0.3% precision.**

- **Results:**

G_V constant

– verified to ±0.013%

$|V_{ud}| = G_V / G_\mu$

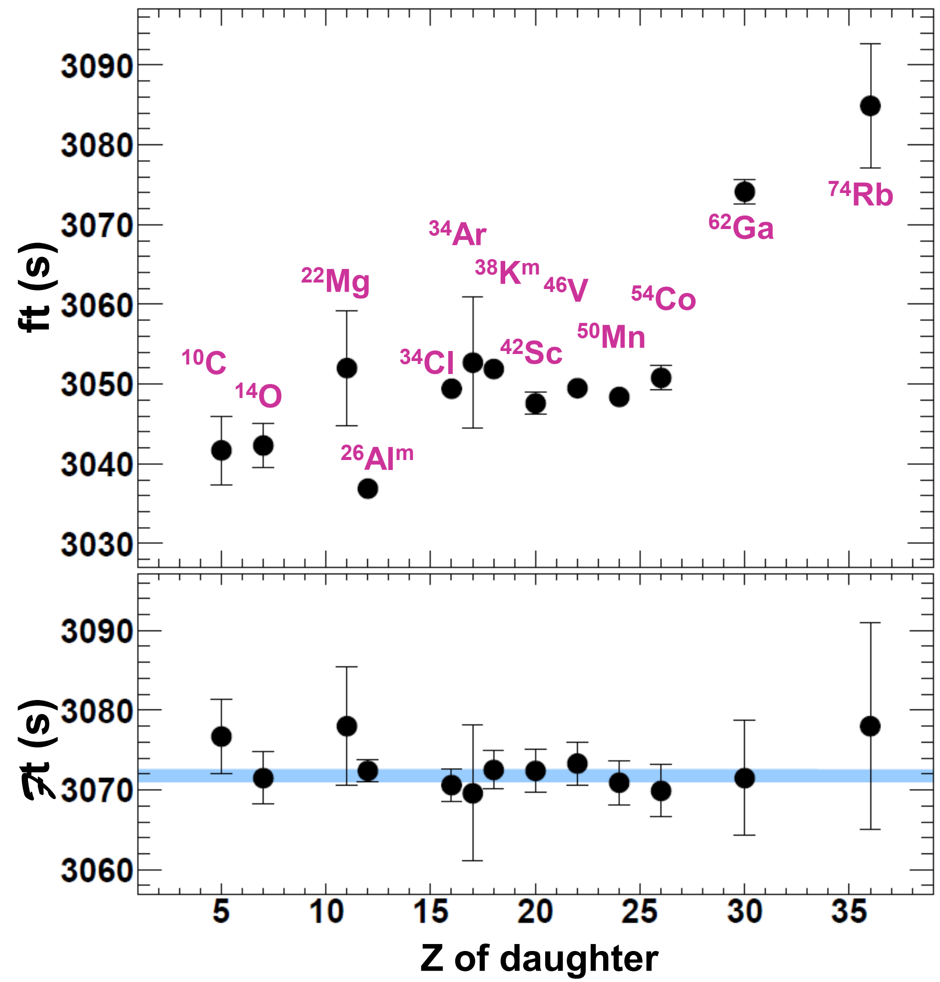
$= 0.97425 \pm 0.00022$

CKM unitarity

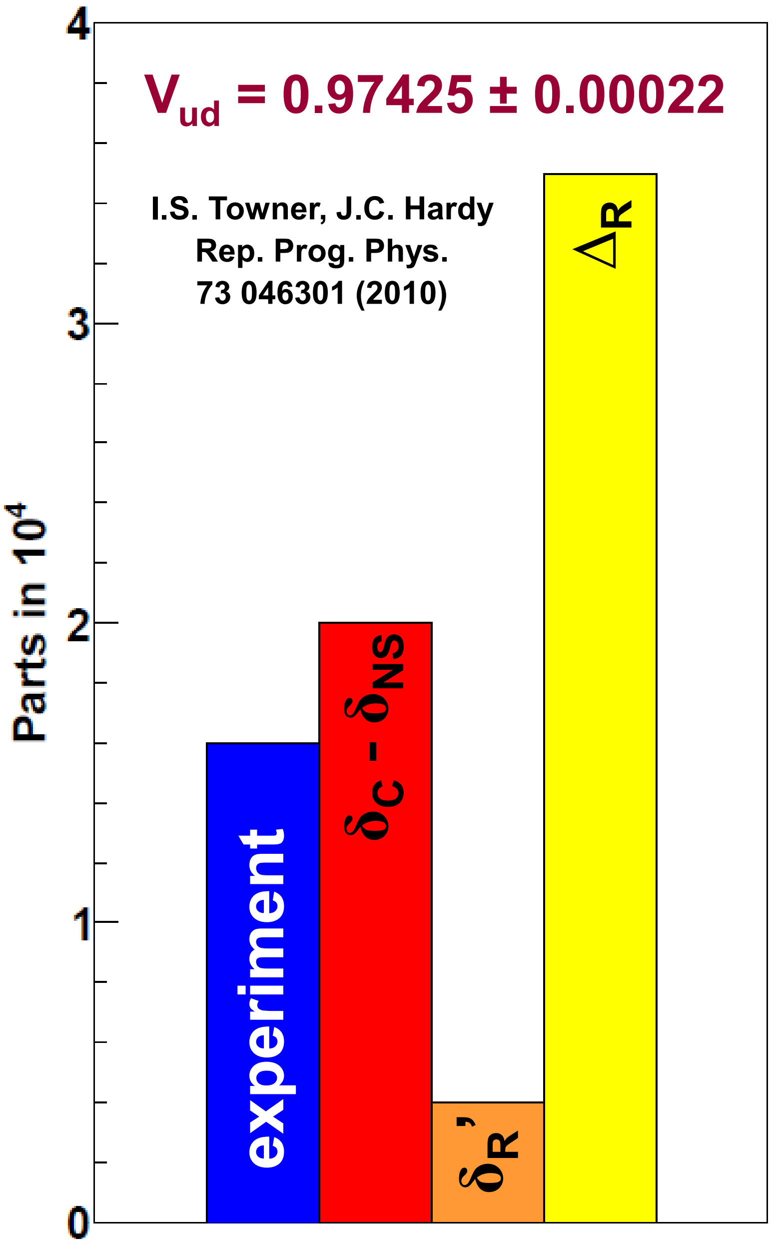
– satisfied at ±0.06%

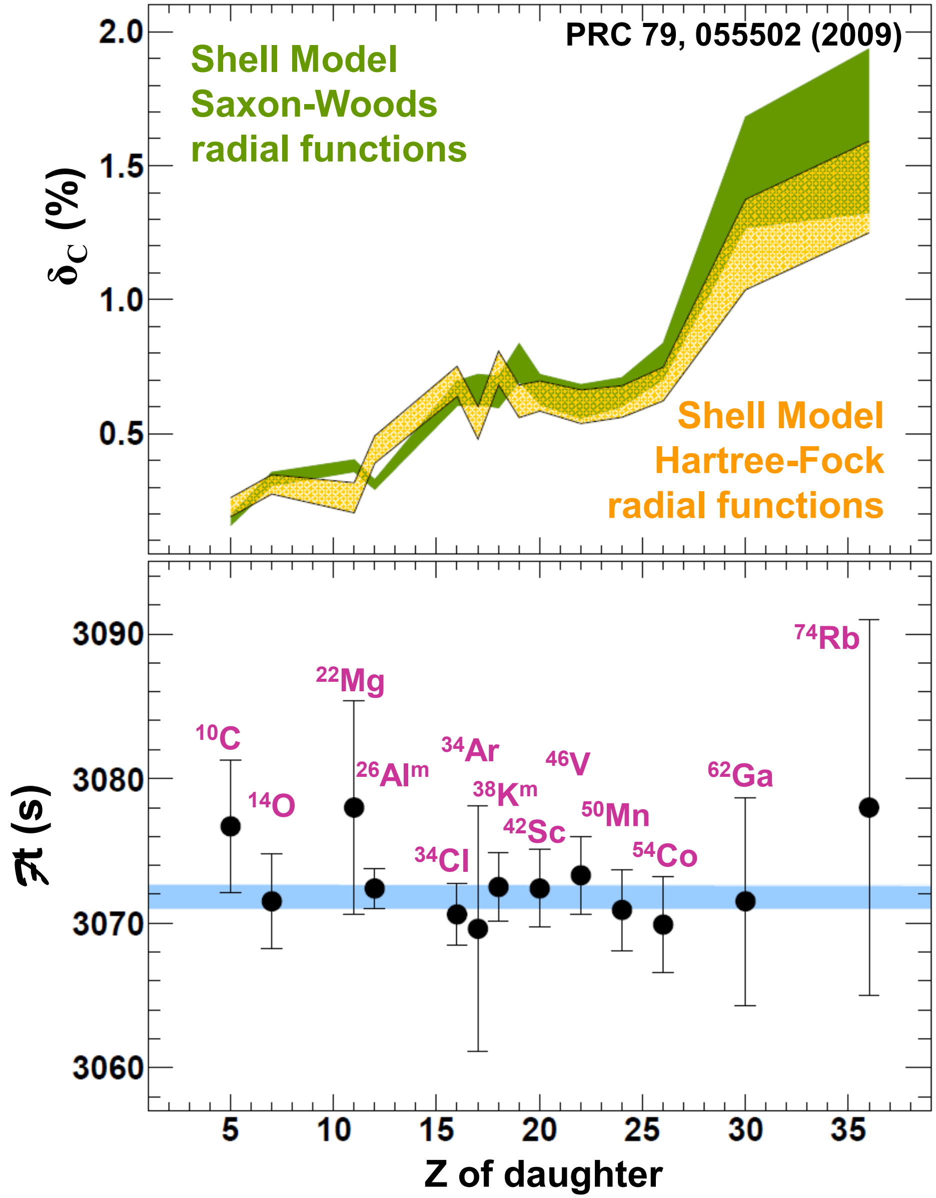
$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.99990 \pm 0.00060$

J.C. Hardy and I.S. Towner
Phys. Rev. C 79, 055502 (2009)



Error budget for V_{ud} determined from $0^+ \rightarrow 0^+$ decays





Testing δ_C calculations by experiment

Our strategy is to compare the ft values from a pair of mirror superallowed decays.

Accepting CVC is valid :

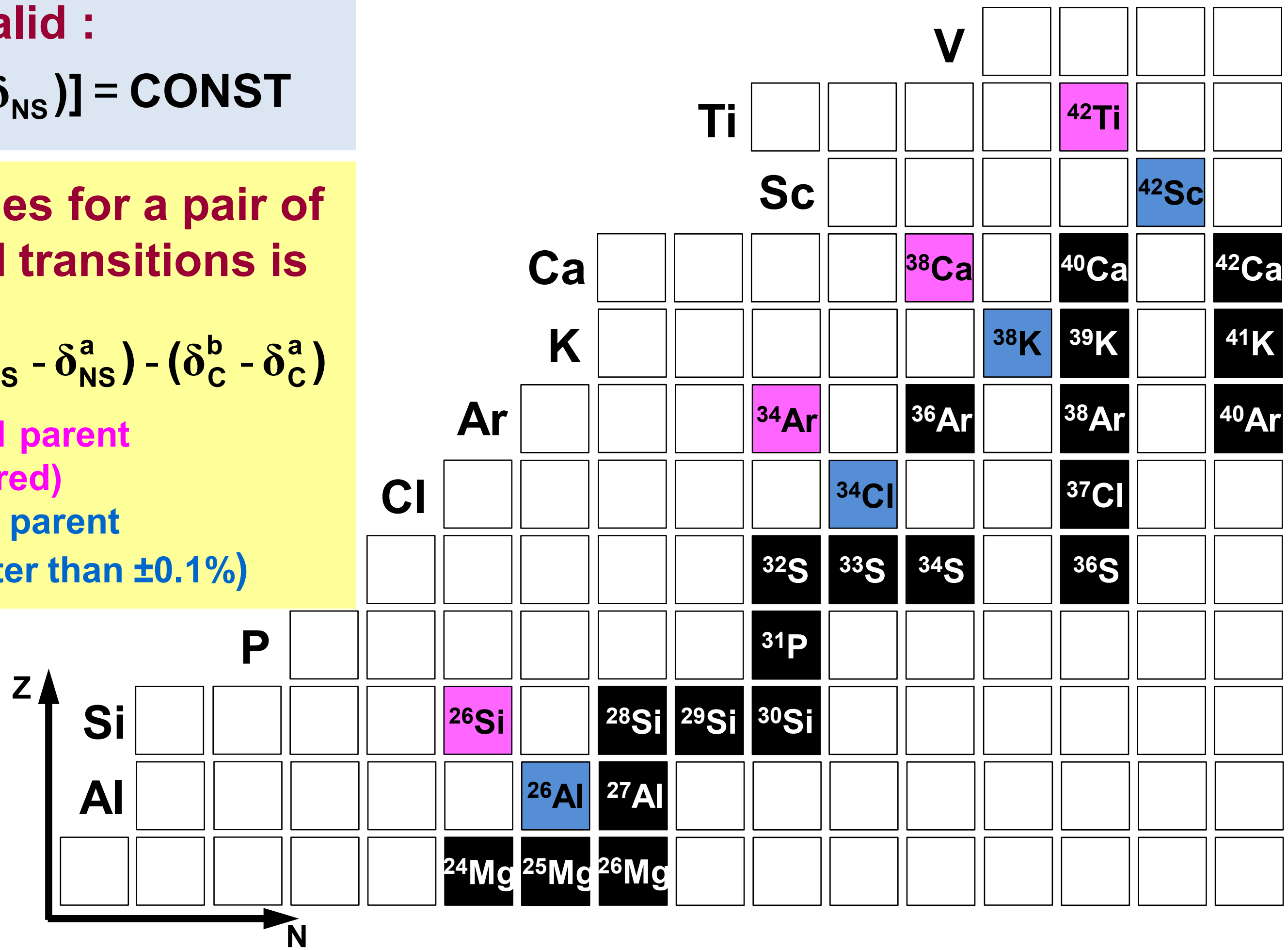
$$\mathcal{F}t = ft(1+\delta'_R)[1-(\delta_C-\delta_{NS})] = \mathrm{CONST}$$

Then, ratio of ft values for a pair of mirror superallowed transitions is

$$\frac{ft^a}{ft^b} = 1 + (\delta'^b_R - \delta'^a_R) + (\delta^b_{NS} - \delta^a_{NS}) - (\delta^b_C - \delta^a_C)$$

a: decay of the $T_Z = -1$ parent
(need to be measured)

b: decay of the $T_Z = 0$ parent
(well-known to better than ±0.1%)



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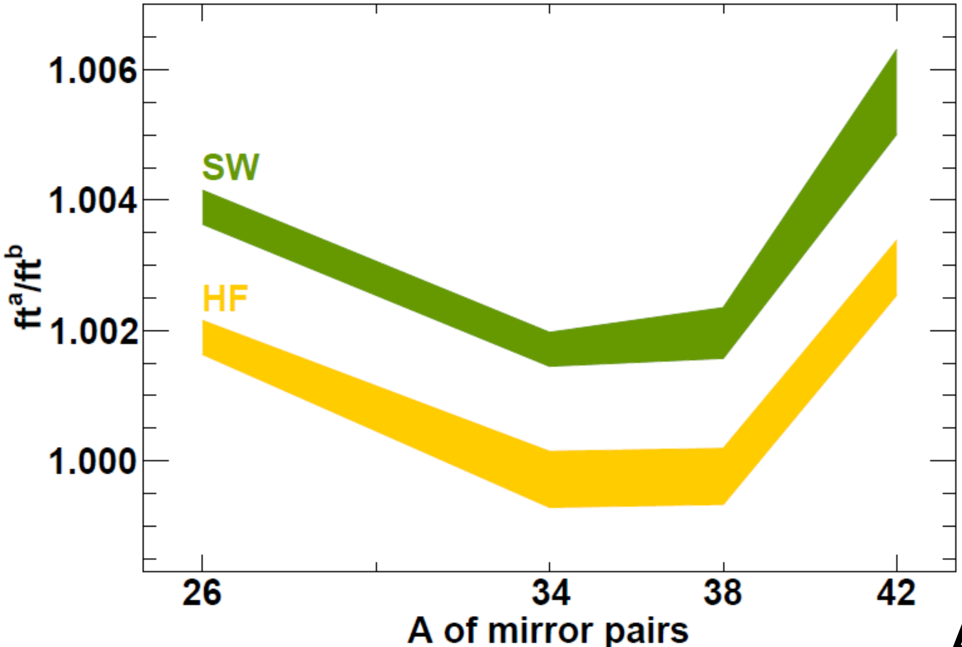
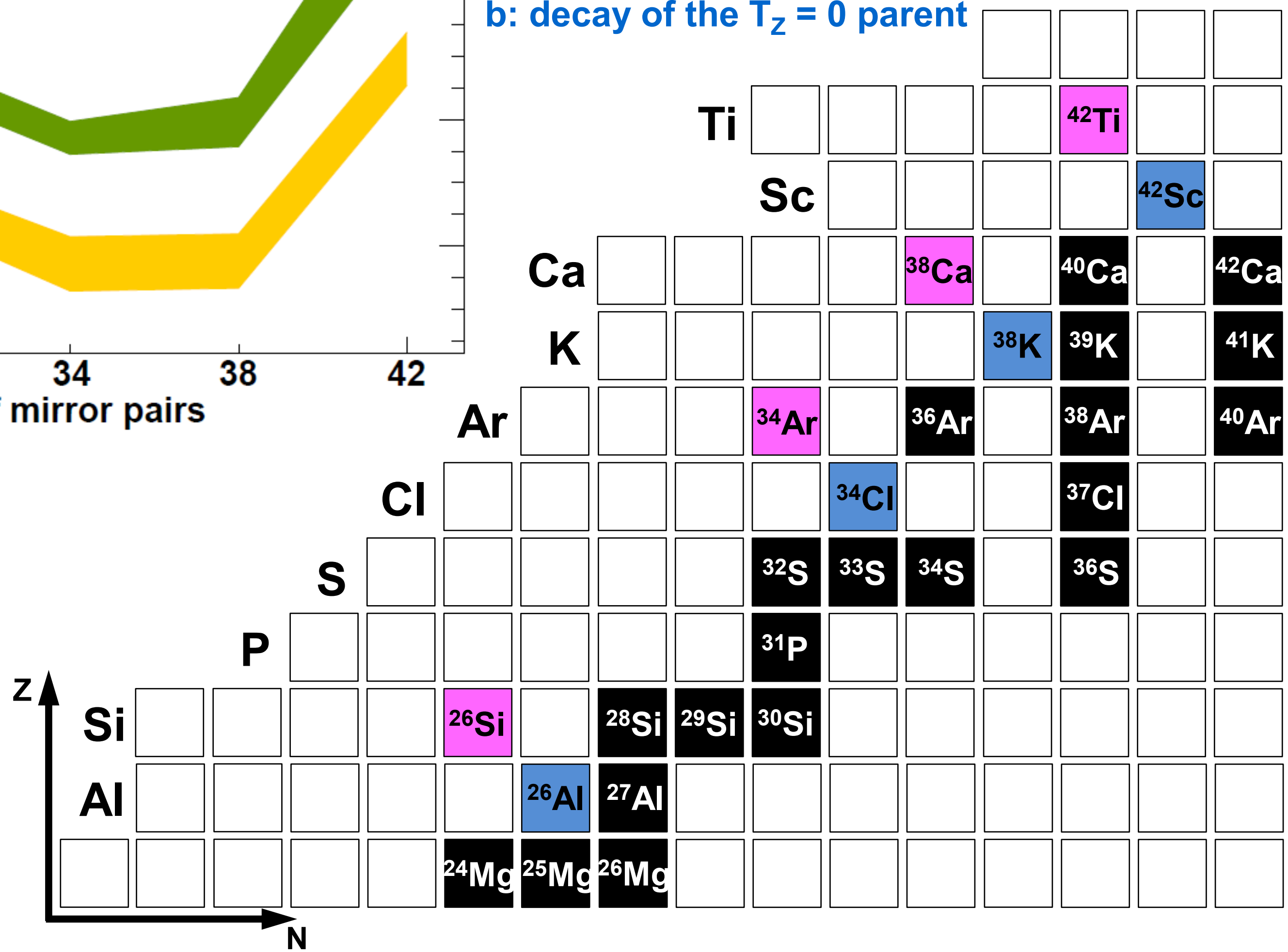
Testing δ_C calculations by experiment



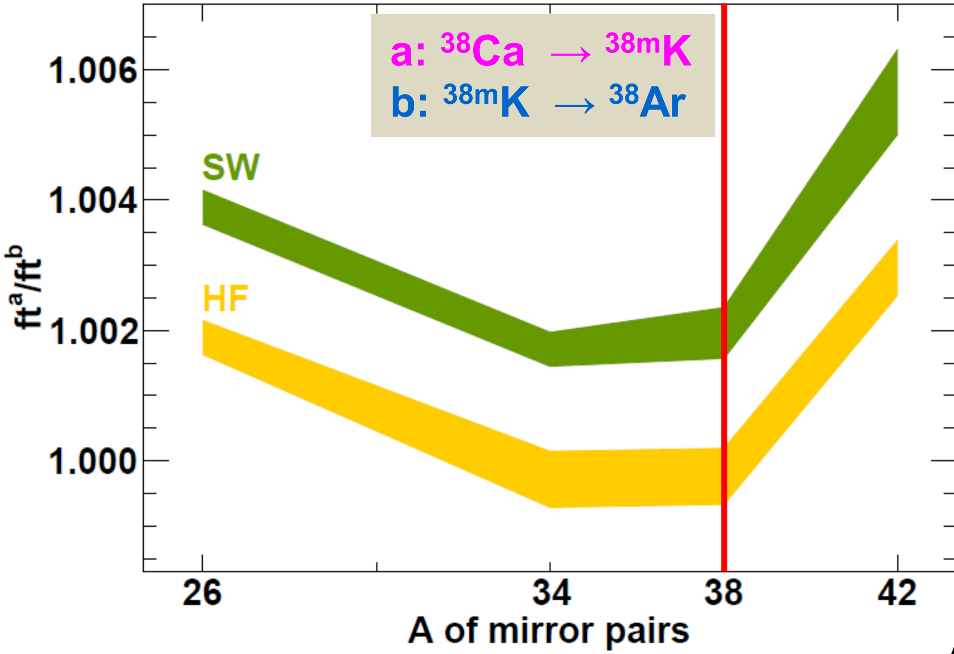
$$\frac{ft^a}{ft^b} = 1 + (\delta_R'^b - \delta_R'^a) + (\delta_{NS}^b - \delta_{NS}^a) - (\delta_C^b - \delta_C^a)$$

a: decay of the T_Z = -1 parent

b: decay of the T_Z = 0 parent



Testing δ_C calculations by experiment



$$\frac{ft^a}{ft^b} = 1 + (\delta_R'^b - \delta_R'^a) + (\delta_{NS}^b - \delta_{NS}^a) - (\delta_C^b - \delta_C^a)$$

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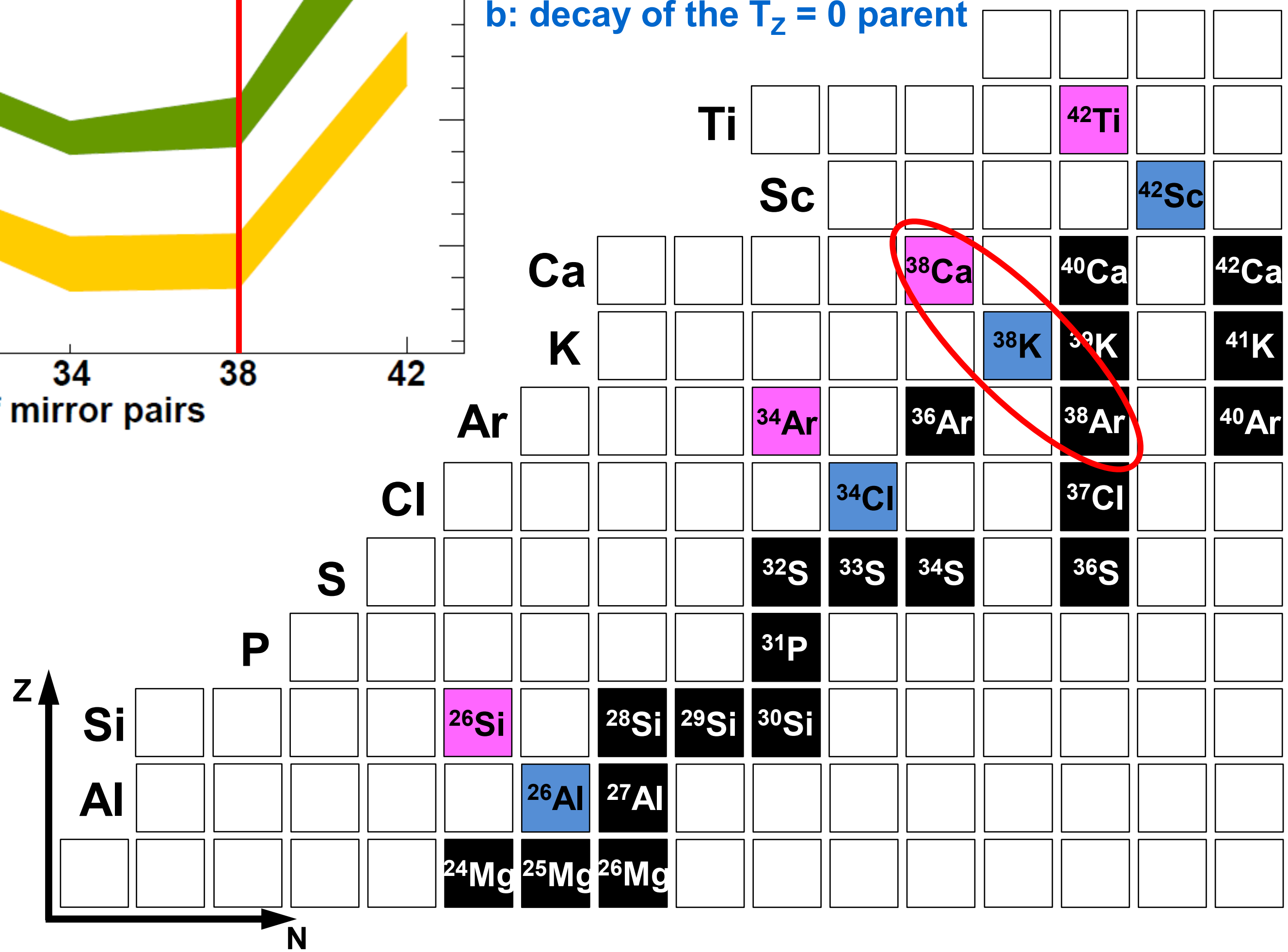
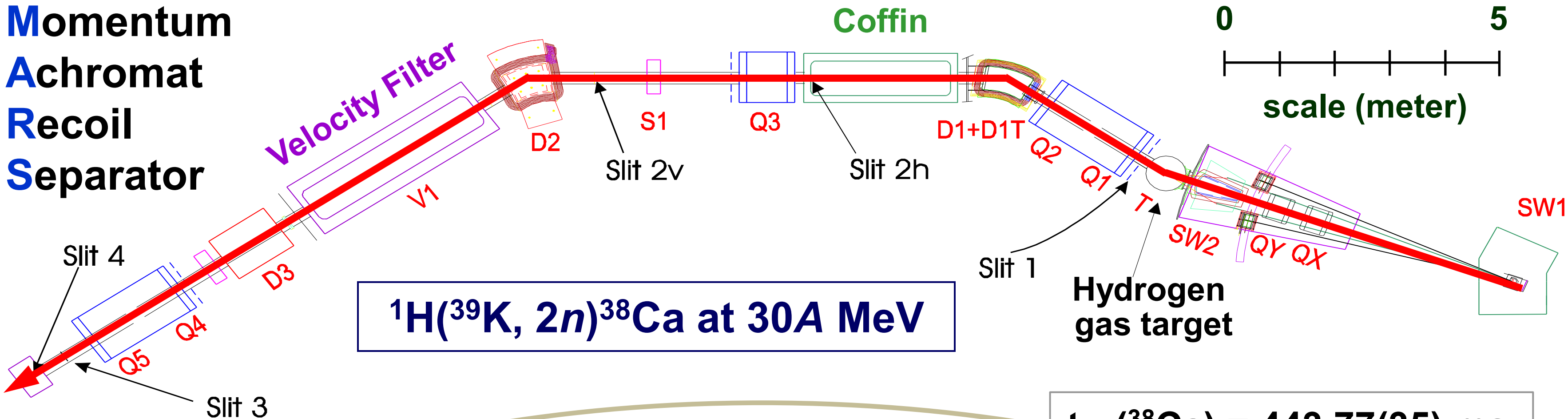


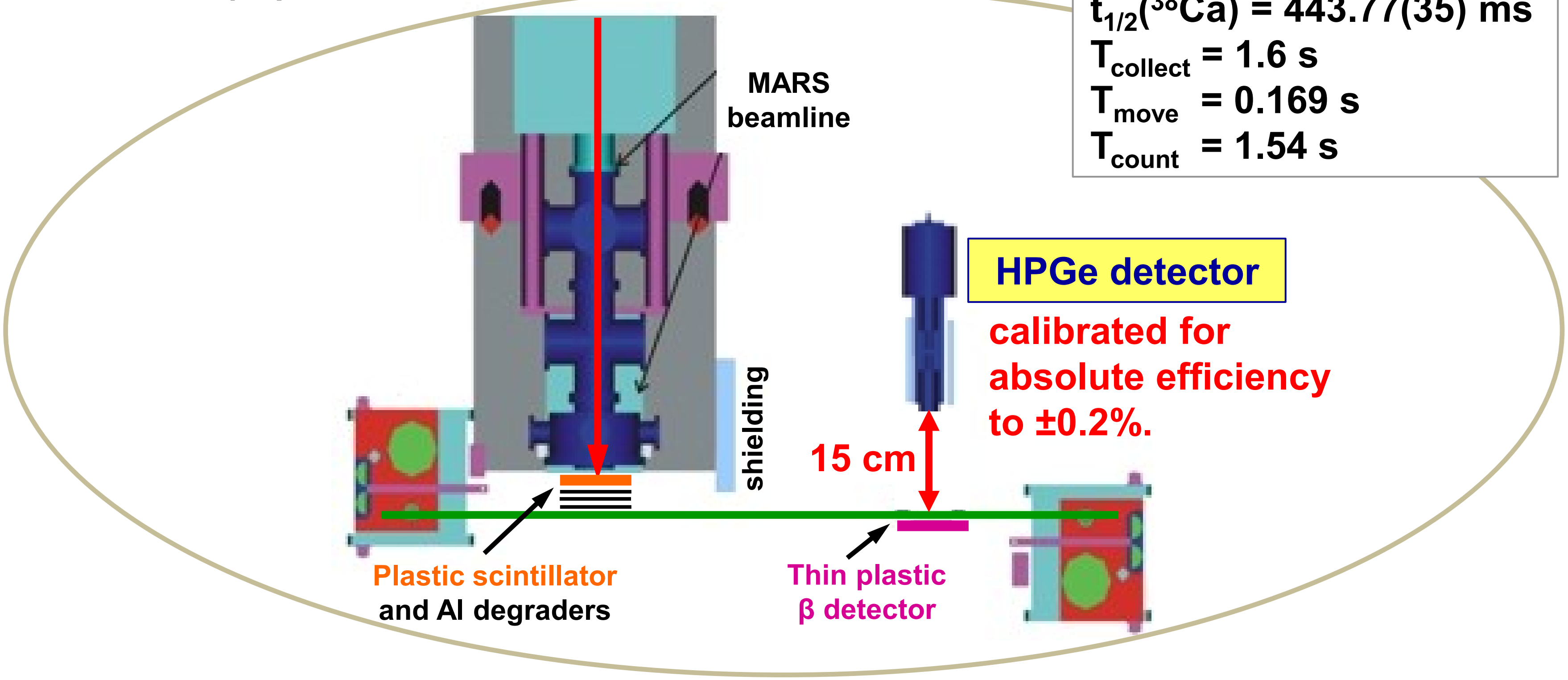
Experimental set-up for branching-ratio measurement

Momentum
Achromat
Recoil
Separator



$^{1}H(^{39}K, 2n)^{38}Ca$ at 30*A* MeV

$t_{1/2}(^{38}Ca)$ = 443.77(35) ms
$T_{collect}$ = 1.6 s
T_{move} = 0.169 s
T_{count} = 1.54 s



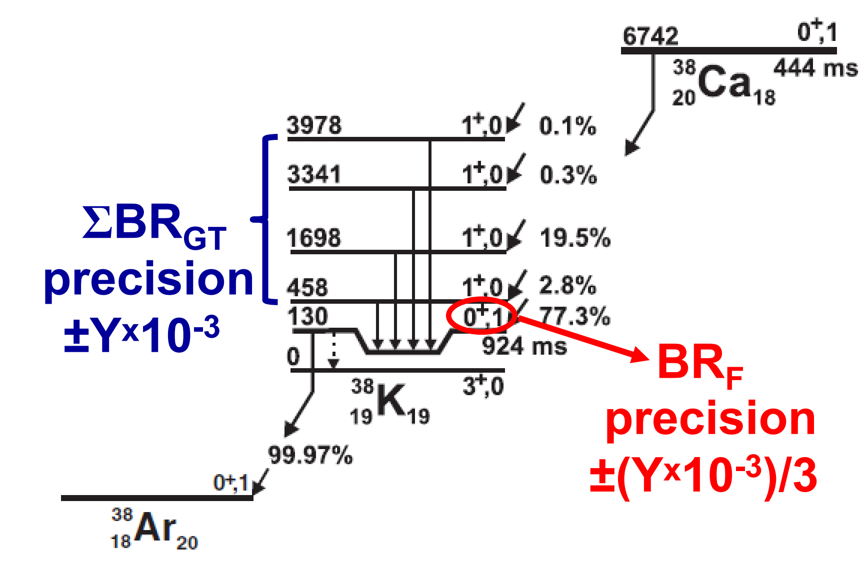
calibrated for absolute efficiency to ±0.2%.

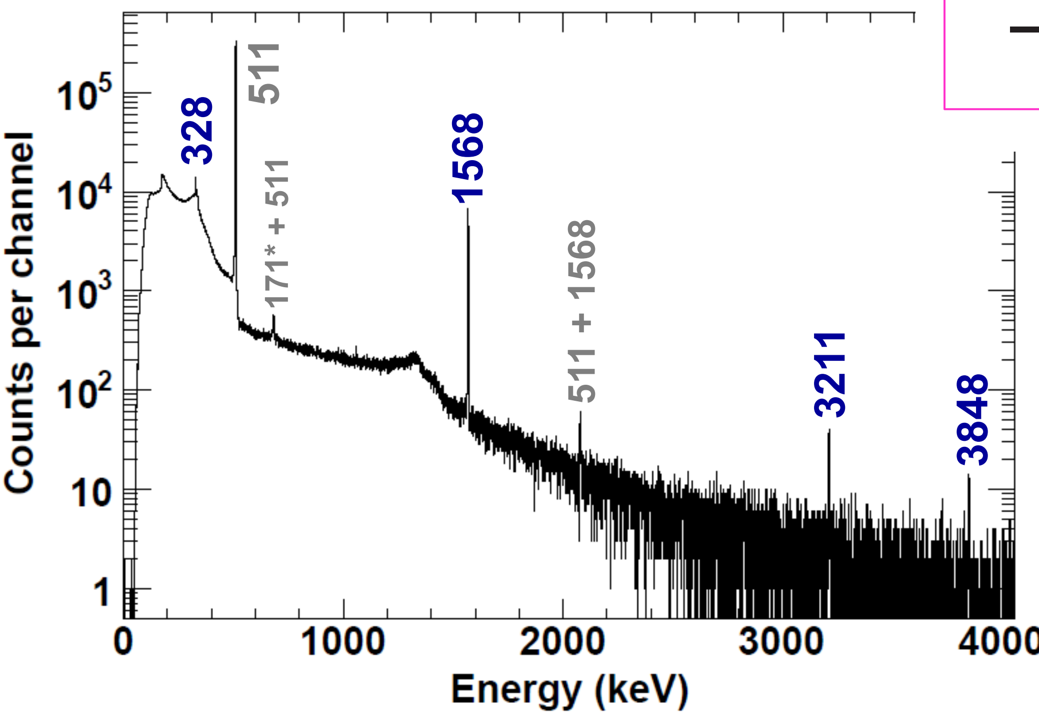
Challenges for the decay of ^{38}Ca

Complex decays require direct branching-ratio measurements approaching ±0.1%.

Our approach: $BR_F = 1 - \Sigma BR_{GT}$

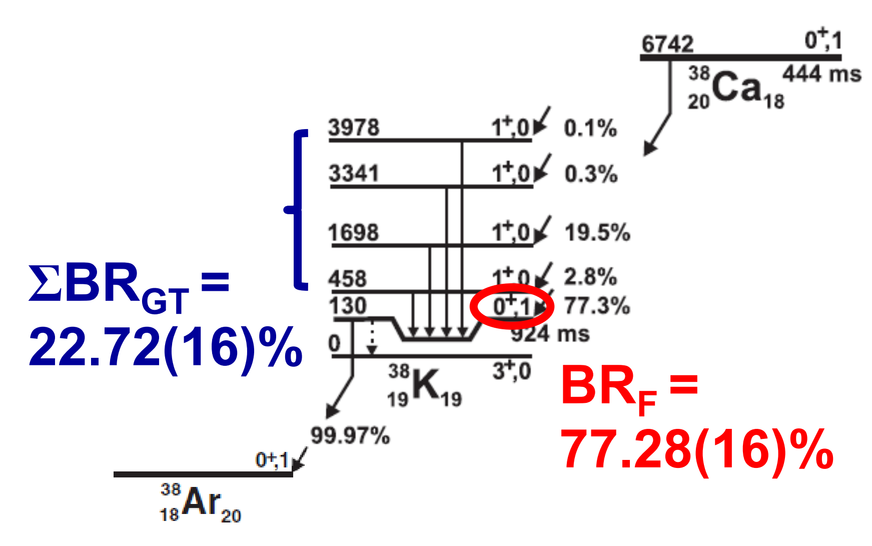
$$R_i = \frac{N_{\beta\gamma_i}}{N_\beta \, \varepsilon_{\gamma_i}} \, \frac{\varepsilon_\beta}{\varepsilon_{\beta_i}} \, k$$





Experimental corrections	
Real-coincidence summing	+2.6(3)%
Dead time + pile-up	+1.37(1)%
Energy dependence of β-detection efficiency	+0.38(4)%
γ detection in β detector	-0.043(4)%

Results for the beta-decay branching of ^{38}Ca



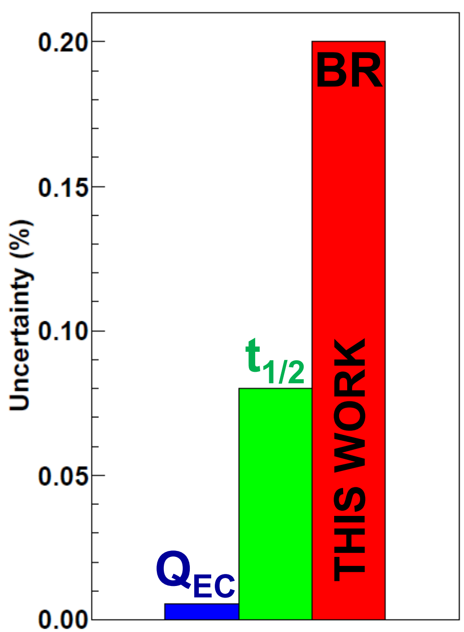
This completes the data required for a precise *ft*-value result for ^{38}Ca to the determination of V_{ud}.

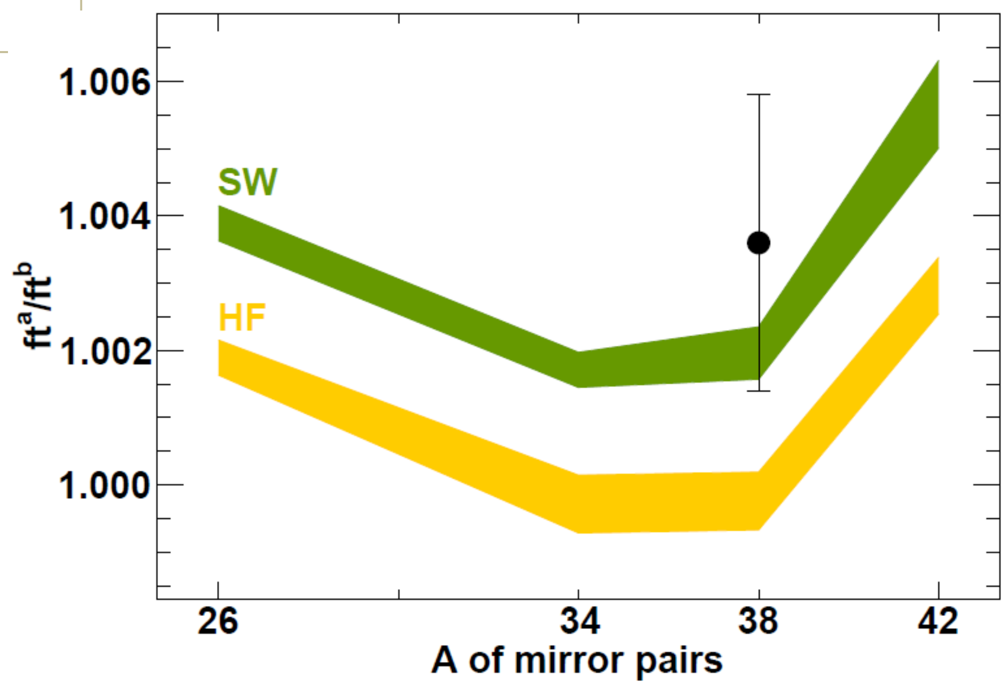
$ft^a(^{38}Ca \rightarrow ^{38m}K)$ = 3062.3 ± 6.8 s

$ft^b(^{38m}K \rightarrow ^{38}Ar)$ = 3051.5 ± 0.9 s

ft^a/ft^b = 1.0036 ± 0.0022

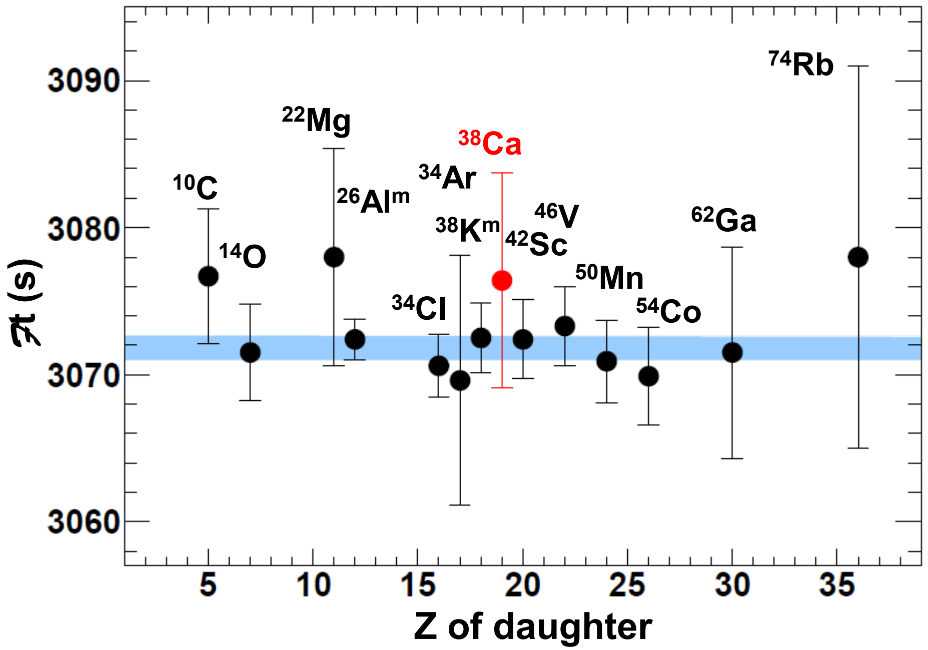
Since 2009

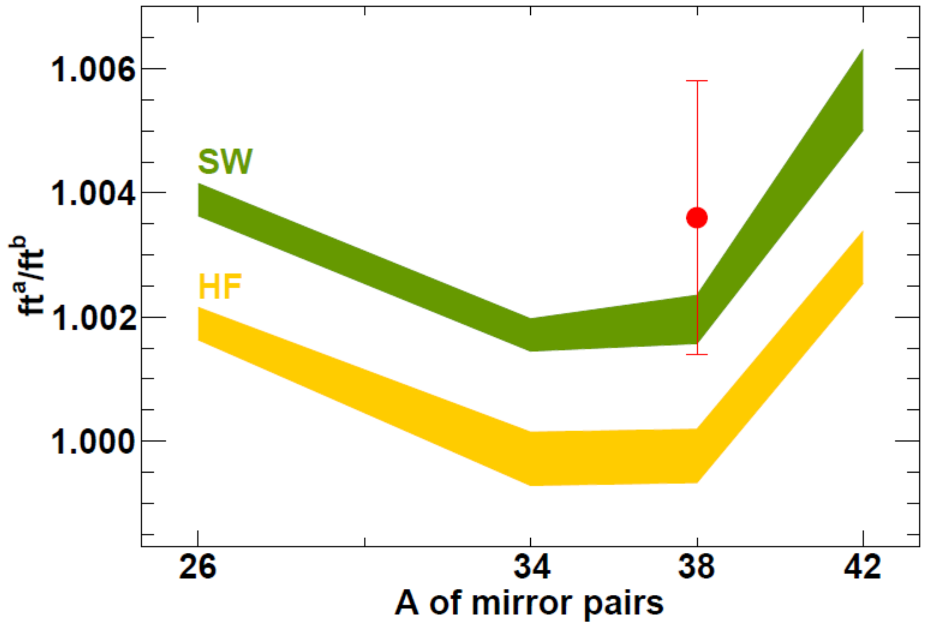


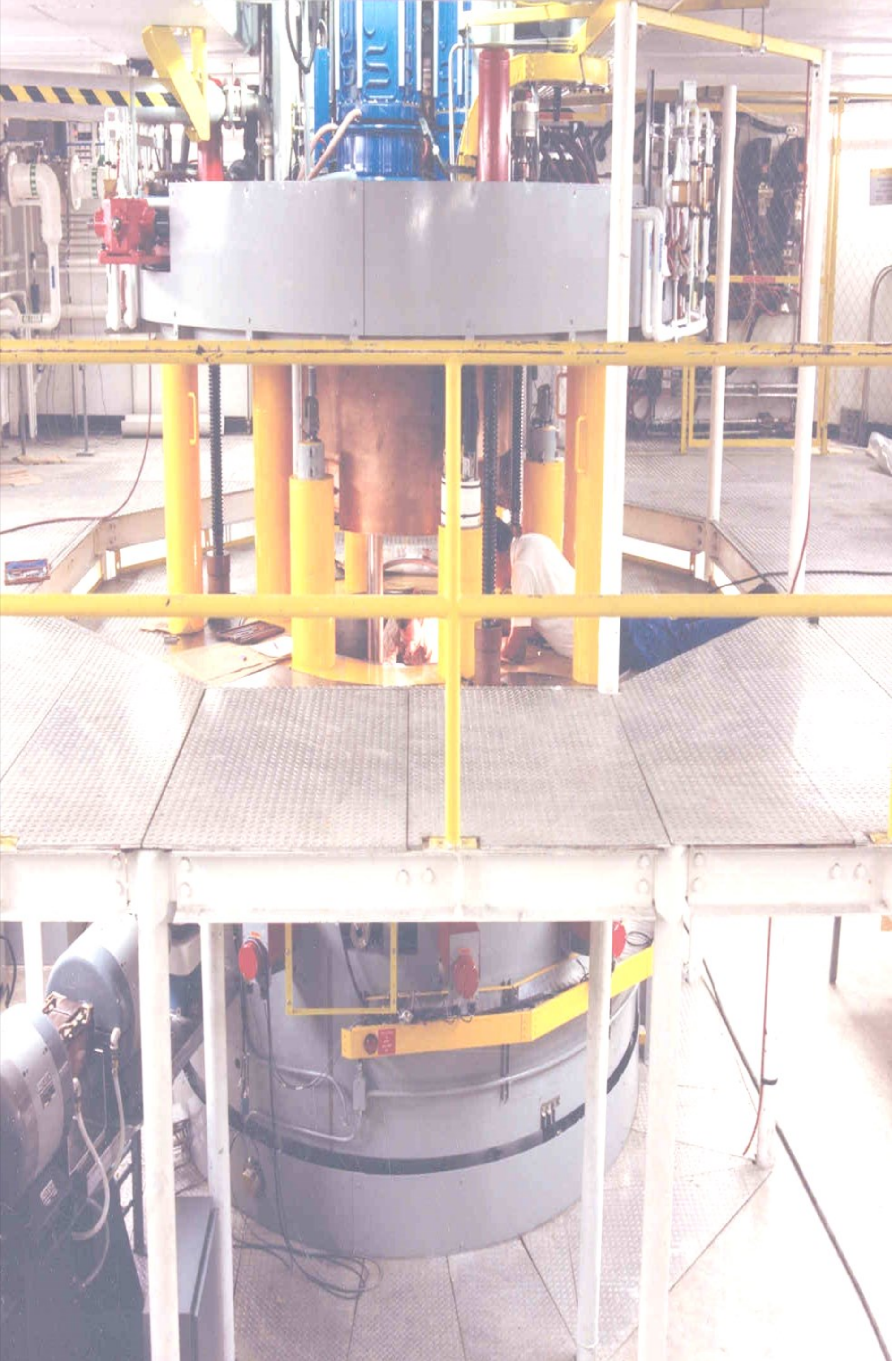


Summary

- The branching ratio for the superallowed transition of ^{38}Ca has been measured to ±0.2% precision for the first time.
- This is the first addition to the set of well-known superallowed transitions in nearly a decade.
- Isospin-symmetry-breaking correction is experimentally tested by measurements of ^{38}Ca.
- It can be further tested and improved by adding new transitions from T_Z = -1 parents with a higher experimental precision.







Collaborators at TAMU

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