High-Precision Half-life Measurements for the Superallowed Fermi β^+ Emitters ^{14}O and ^{18}Ne

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Extracting V_{ud} from Superallowed Fermi β Decays

To first order, β decay *ft* values can be expressed as:

$$ft = \frac{K}{g^2 |M_{fi}|^2}$$

phase space (Q-value) → *ft*

half-life, branching ratio → *ft*

constants → K

matrix element → $|M_{fi}|^2$

Weak coupling strength → g^2

For the special case of $0^+ \rightarrow 0^+$ (pure Fermi) β decays between isobaric analogue states (superallowed) the matrix element is that of an isospin ladder operator:

$$|M_{fi}|^2 = (T - T_Z)(T + T_Z + 1) = 2 \quad \text{(for } T = 1\text{)}$$

Strategy: Measure superallowed *ft*-values, deduce G_V and V_{ud}

Vector coupling constant → $G_V^2 = \frac{K}{2ft}$

$|V_{ud}| = G_V / G_F$ ← Fermi coupling constant

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Superallowed Fermi β Emitters have been used to:

- Confirm the CVC hypothesis to better than 2 parts in 10^4
- Provide the most precise experimental measure for V_{ud}
- Test extensions of the Standard Model

For the … c

analog … n

ladder

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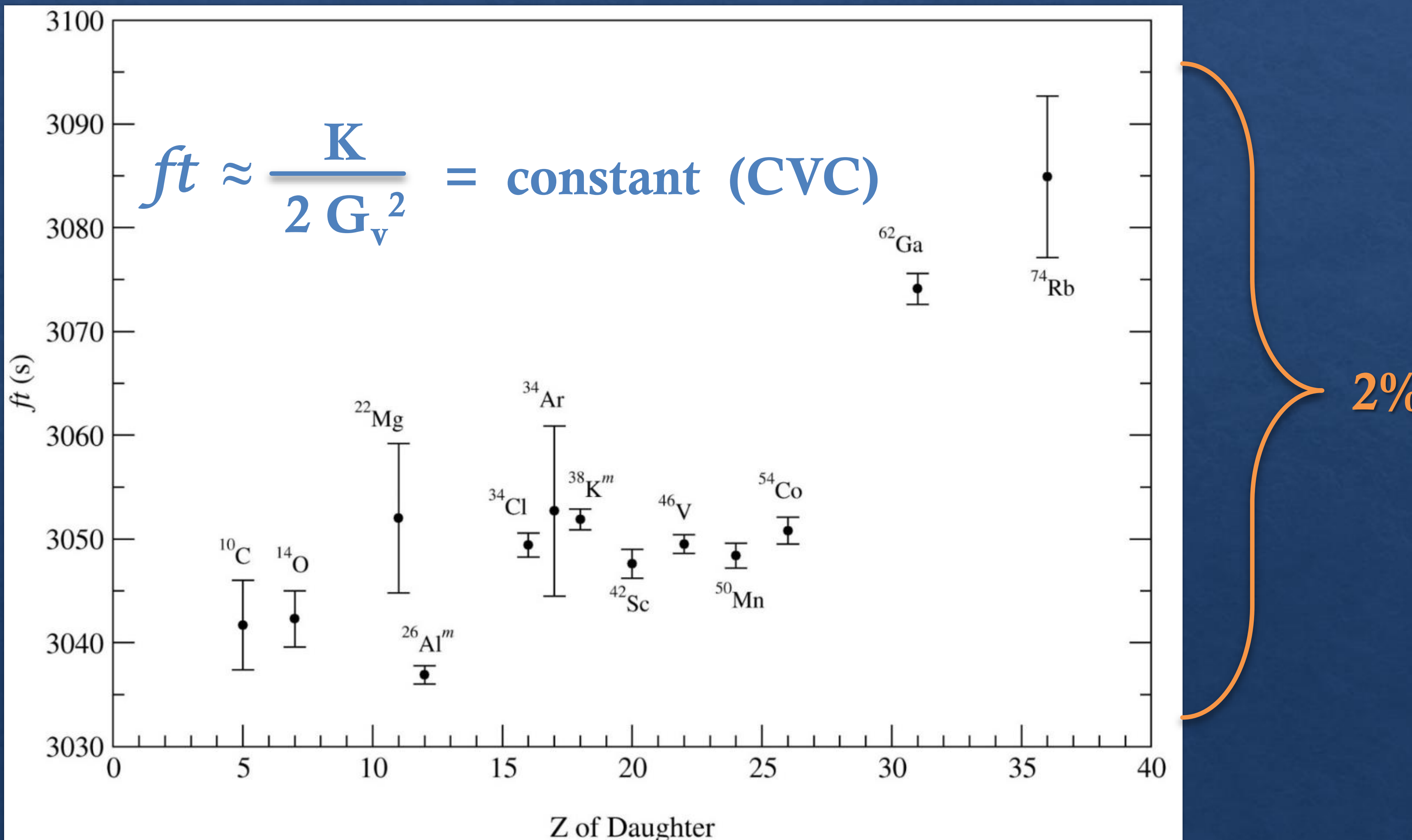
Superallowed *ft* Values



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

Superallowed Fermi β Decay: Corrections

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

"Corrected" ft value

Experiment
- Half-life
- Q-value
- Branching Ratio

Calculated corrections (~1%)
(nucleus dependent)

Inner radiative correction (~2.4%)
(nucleus independent)

CVC Hypothesis

Δ_R = nucleus independent inner radiative correction: 2.361(38)%

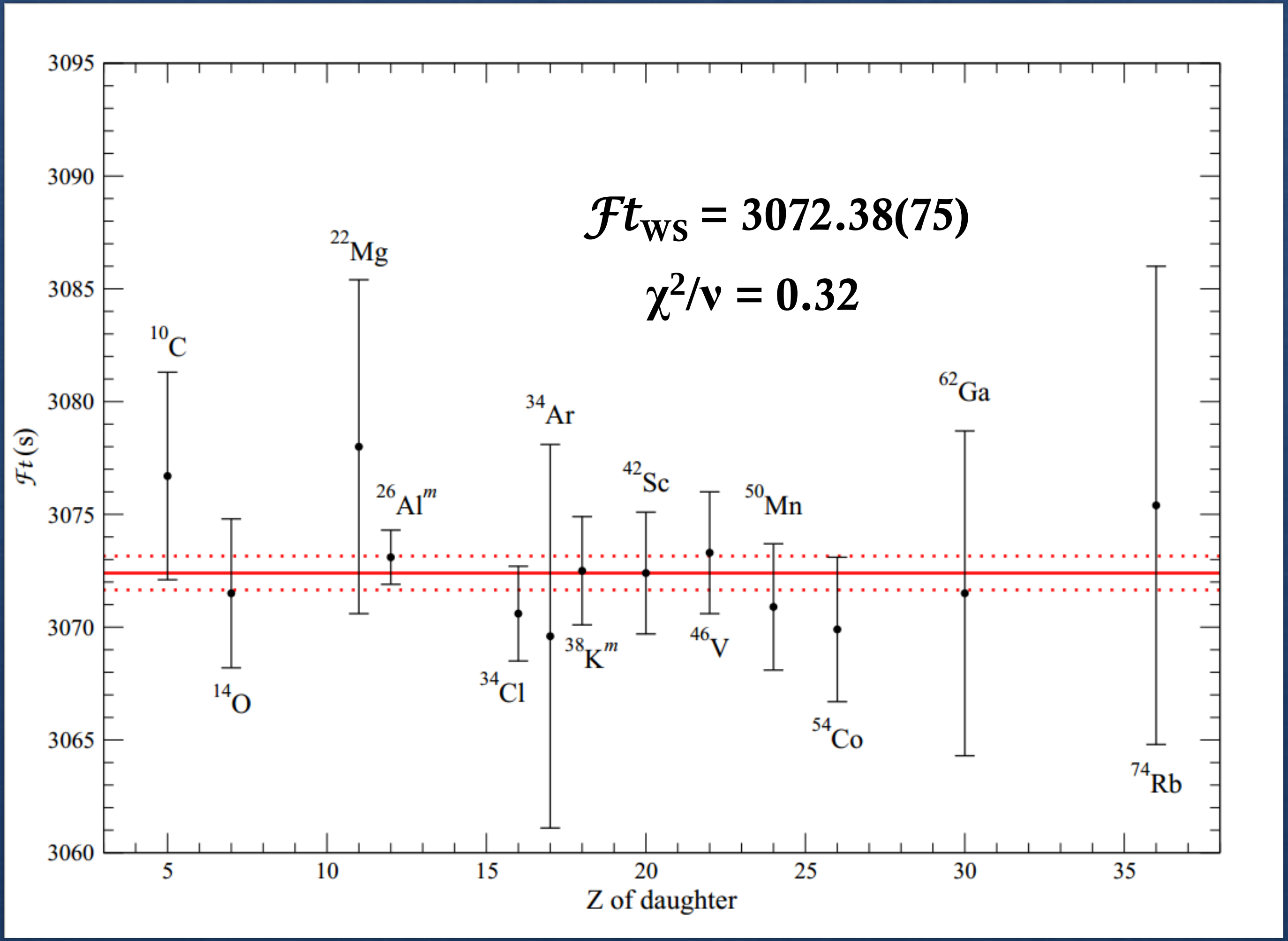
δ_R = nucleus dependent radiative correction to order $Z^2\alpha^3$: ~1.4%
- depends on electron's energy and Z of nucleus

δ_{NS} = nuclear structure dependent radiative correction: -0.3% to 0.03%

δ_C = nucleus dependent isospin-symmetry-breaking (ISB) correction: 0.2% to 1.5%
- strong nuclear structure dependence (radial overlap)

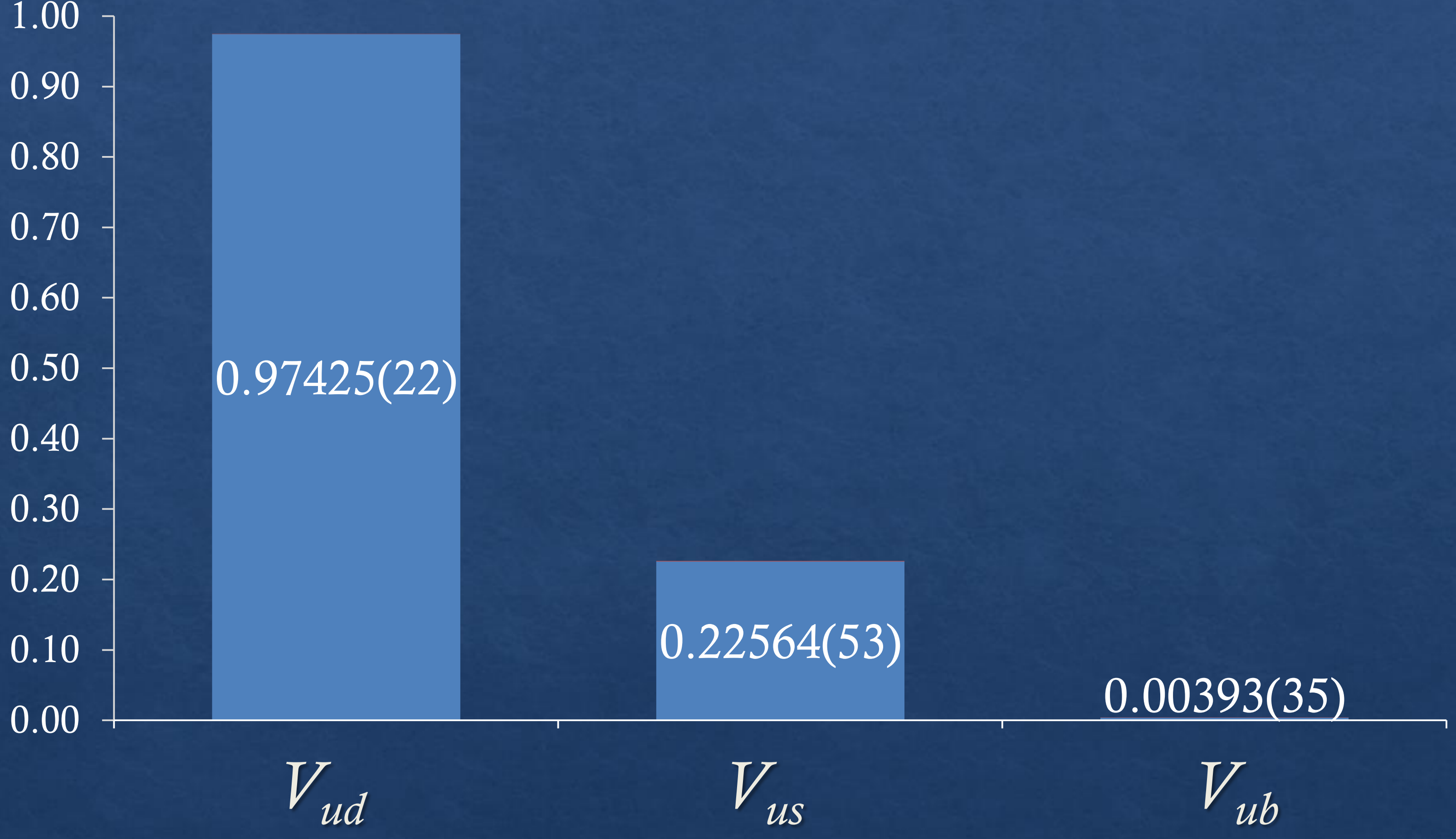
Note: This is one of several approaches for making the necessary theoretical corrections. Although others exist, the procedure of Towner & Hardy are highlighted here.

Corrected $\mathcal{F}t$ Values



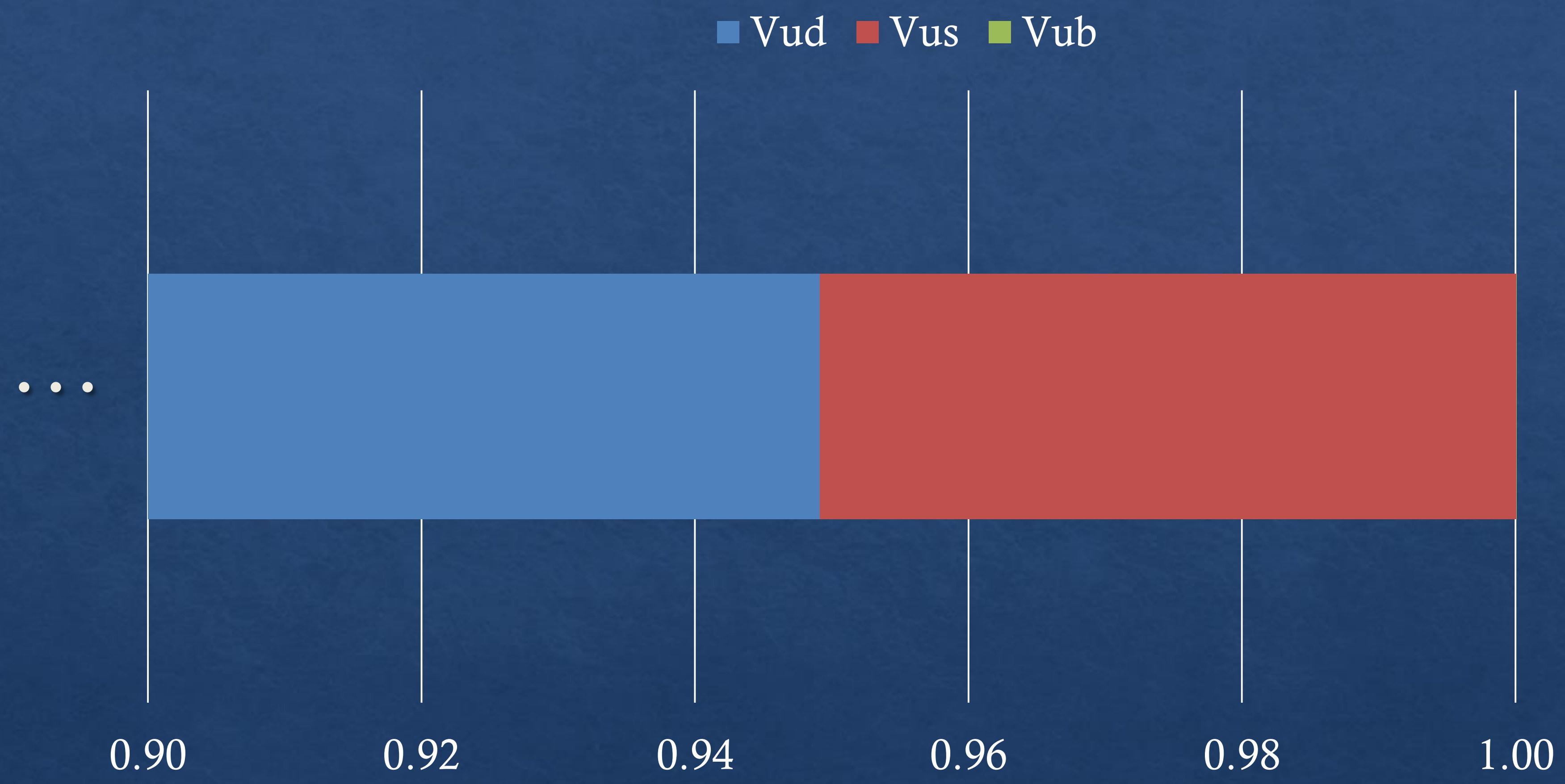
P. Finlay, *et al.*, Phys. Rev. Lett. **106**, 032501 (2011)
R. Dunlop, *et al.*, Phys. Rev. C **88**, 045501 (2013)

CKM Unitarity



J.C. Hardy and I.S. Towner, Phys. Rev. C **79**, 055502 (2009)
R.J. Dowdall *et al.*, Phys. Rev. D **88**, 074504 (2013)
Particle Data Group J. Beringer *et al.*, Phys Rev D **86**, 010001 (2012)

CKM Unitarity



$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1.00009(43)_{Vud}(24)_{Vus}$$

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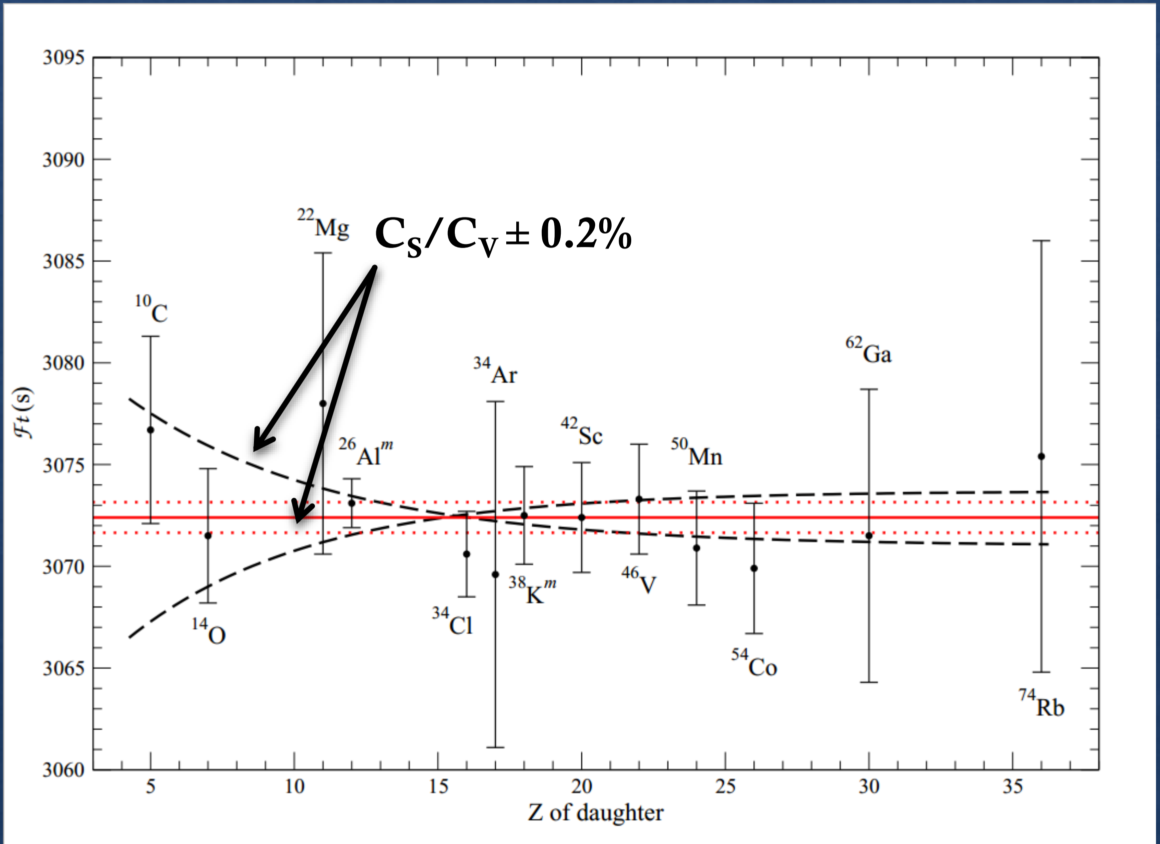
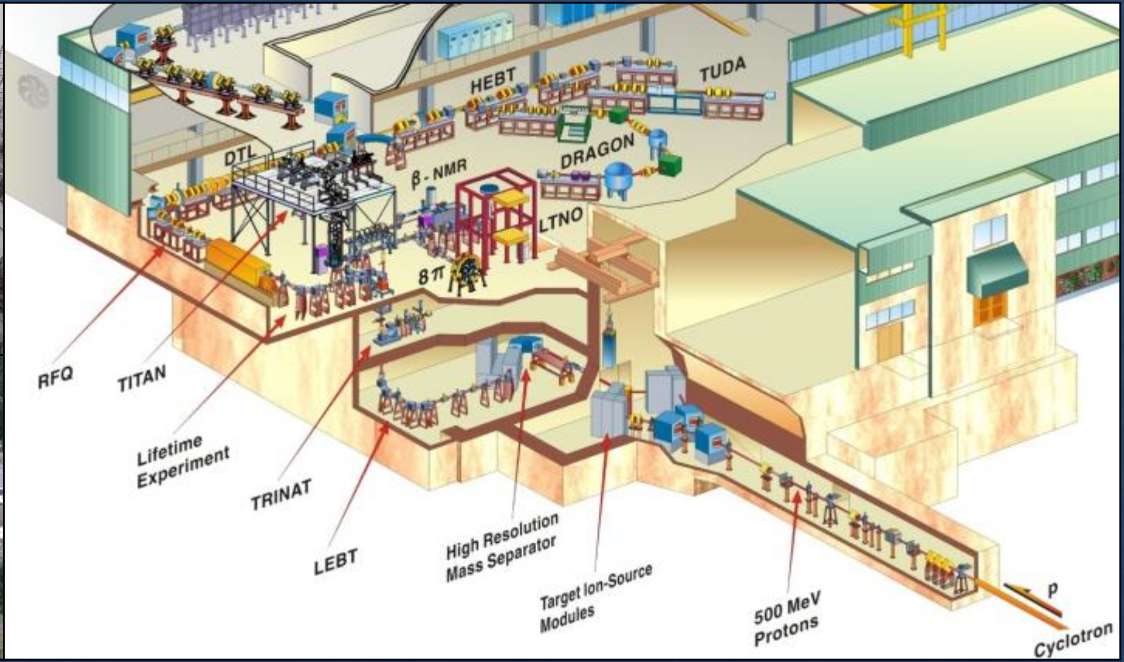
Testing Extensions of the SM

Set sensitive limits on the existence of scalar currents in nuclear β decay

- $\mathcal{F}t$ values for ^{10}C, ^{14}O, and ^{18}Ne are the most important
- Complementary to measurements of β-ν angular correlation coefficients "*a*"
- Resolving trivial sources of systematic uncertainty in superallowed data are essential

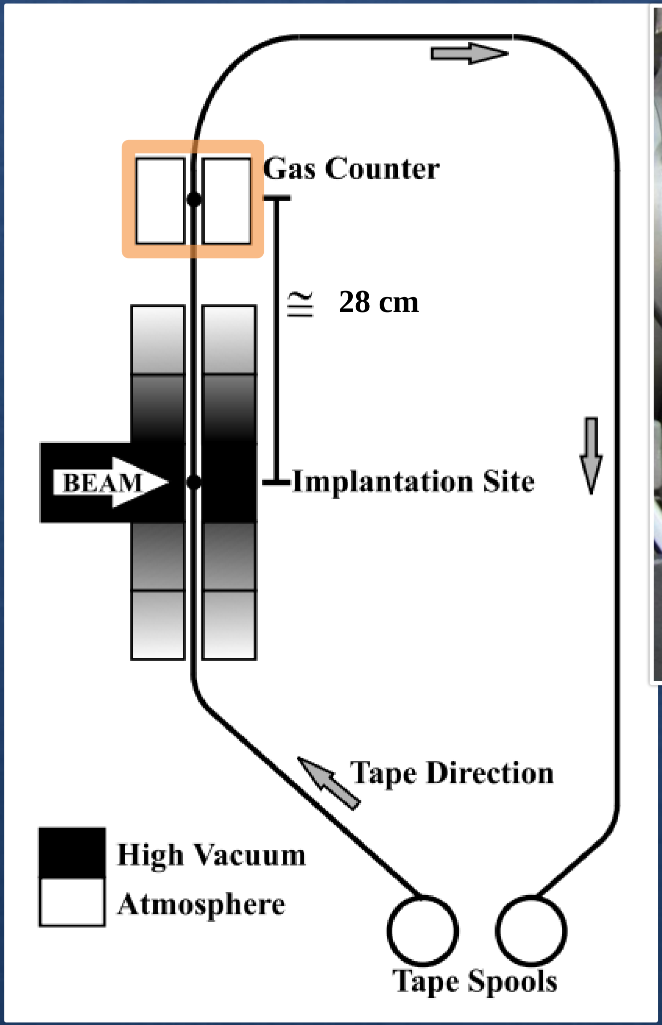


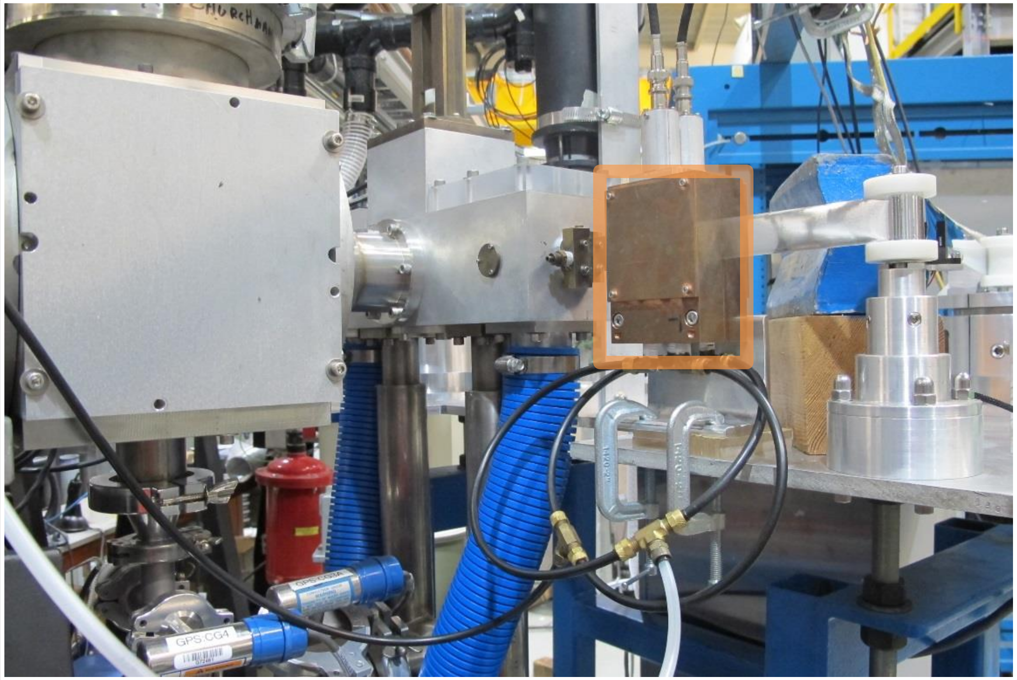
TRIUMF–ISAC



Up to 100 μA, 500 MeV proton beams from the TRIUMF main cyclotron produce high-intensity secondary beams of many of the superallowed emitters by the ISOL technique.

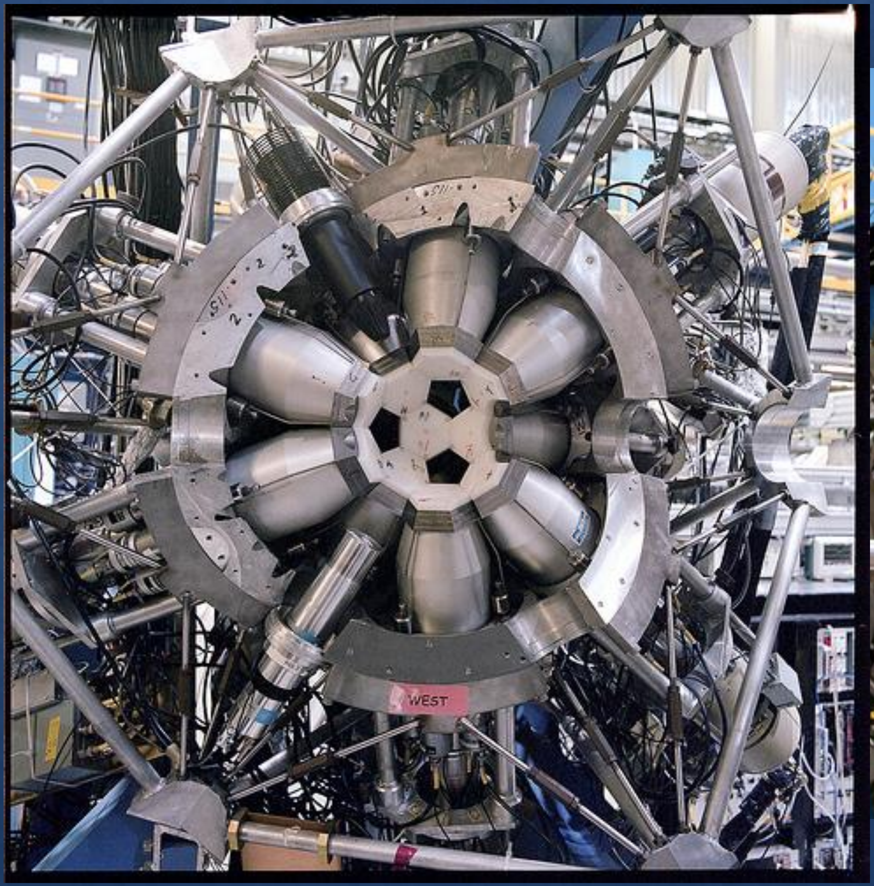
4π Gas Counter

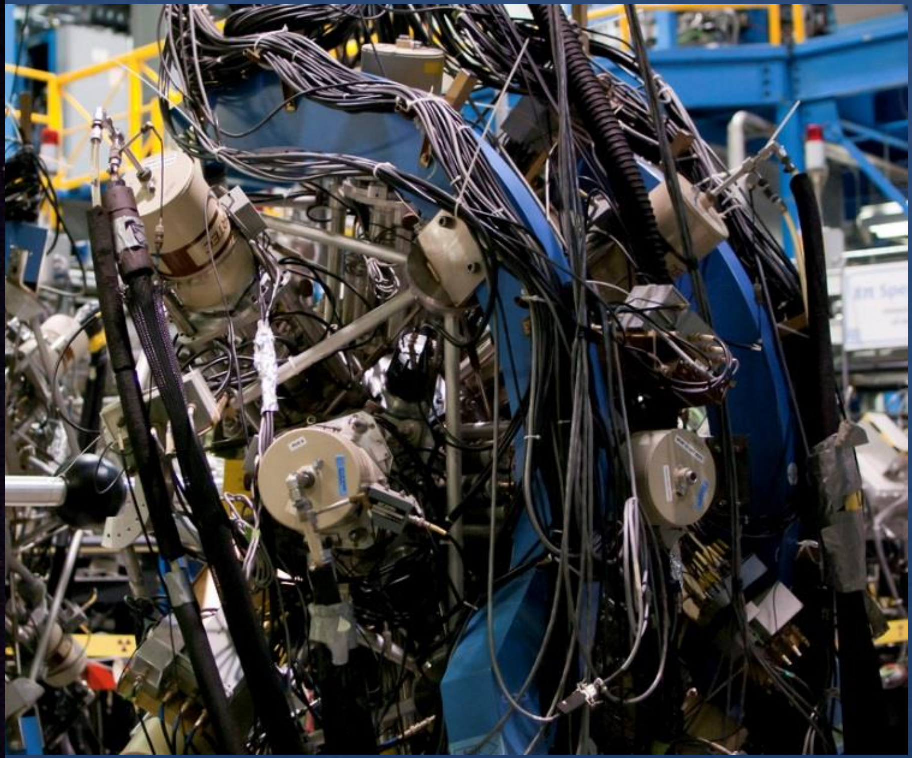




- 4π continuous-flow gas-proportional counter and tape transport system
- Uses methane (CH_4) gas
- 100% efficient β counter
- Very low background rates
- Insensitive to γ-rays

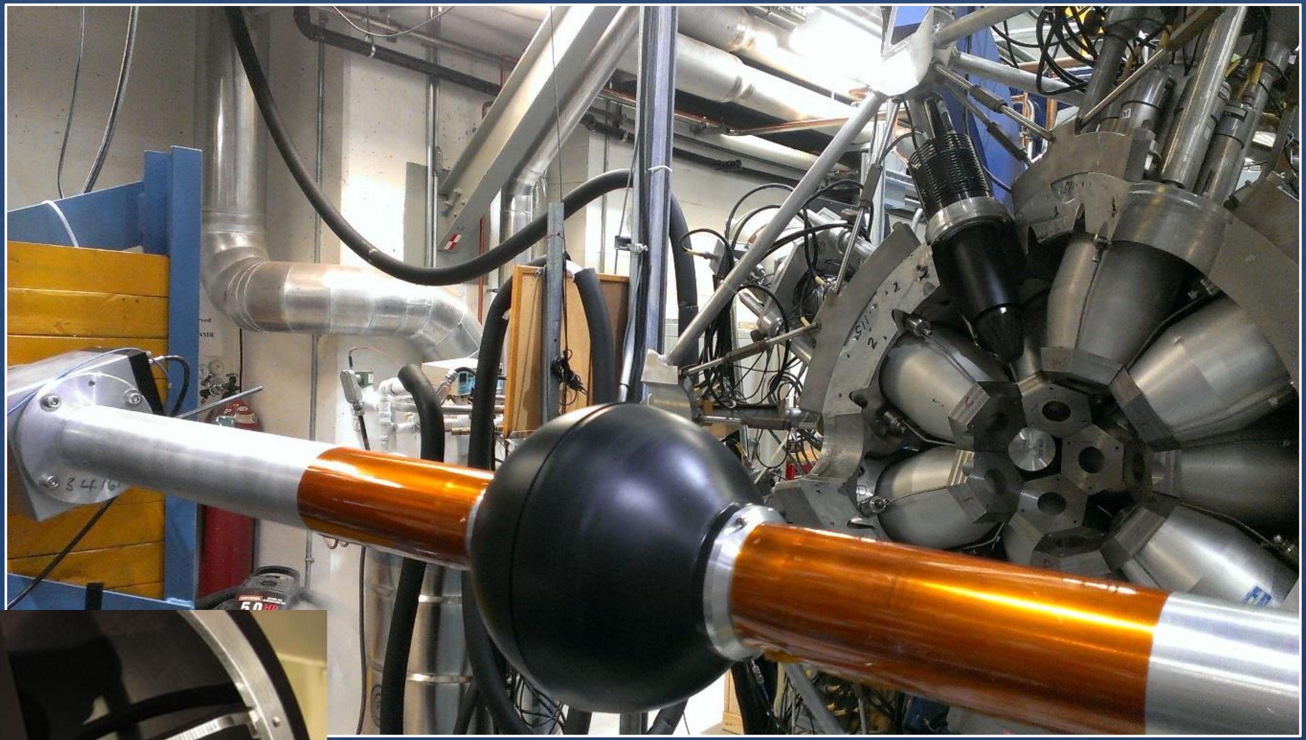
8π γ-Ray Spectrometer

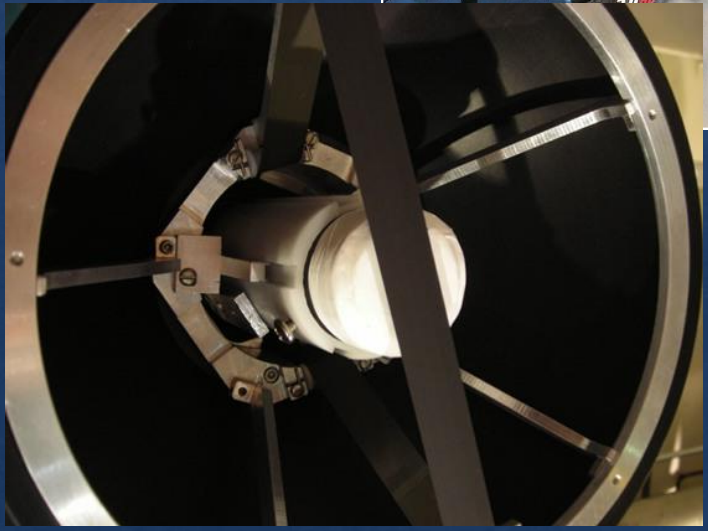




- Spherical array of 20 BGO Compton suppressed HPGe detectors
- ~1% photopeak efficiency
- Works with an array of ancillary detectors

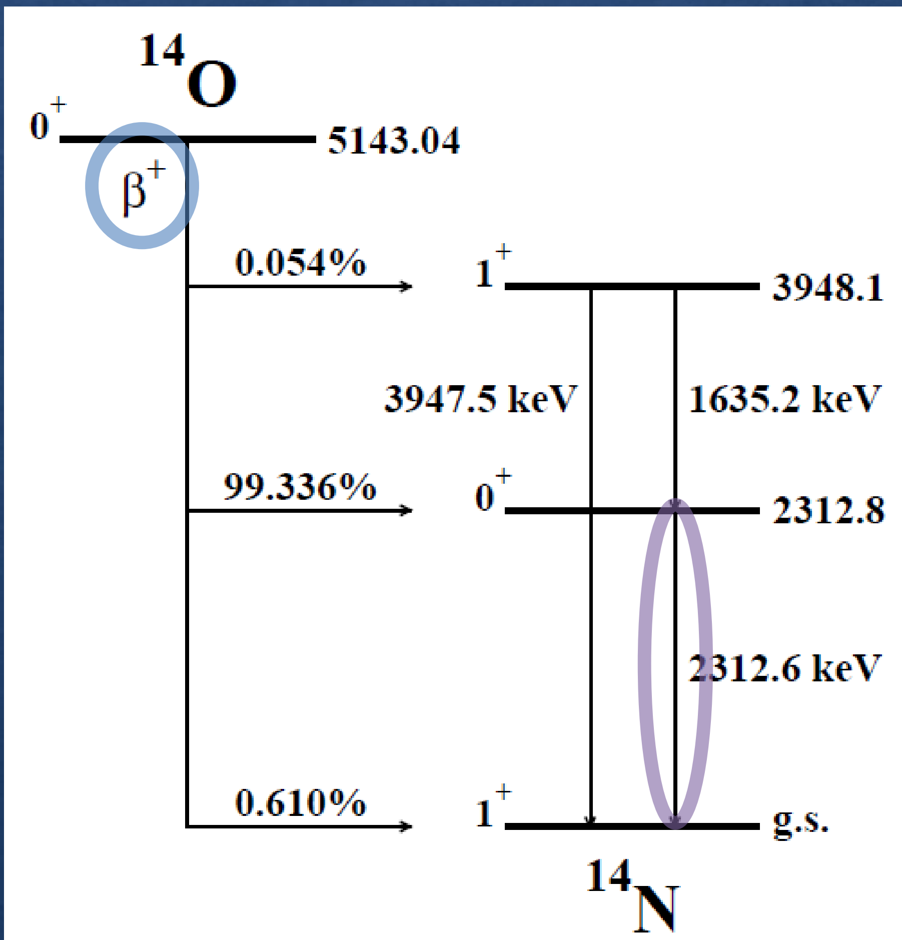
Zero Degree Scintillator (ZDS)





- A fast plastic scintillator used for β counting
- Covers ~20% of the solid angle
- Impose fixed non-extendible dead-times

^{14}O Half-Life Measurement



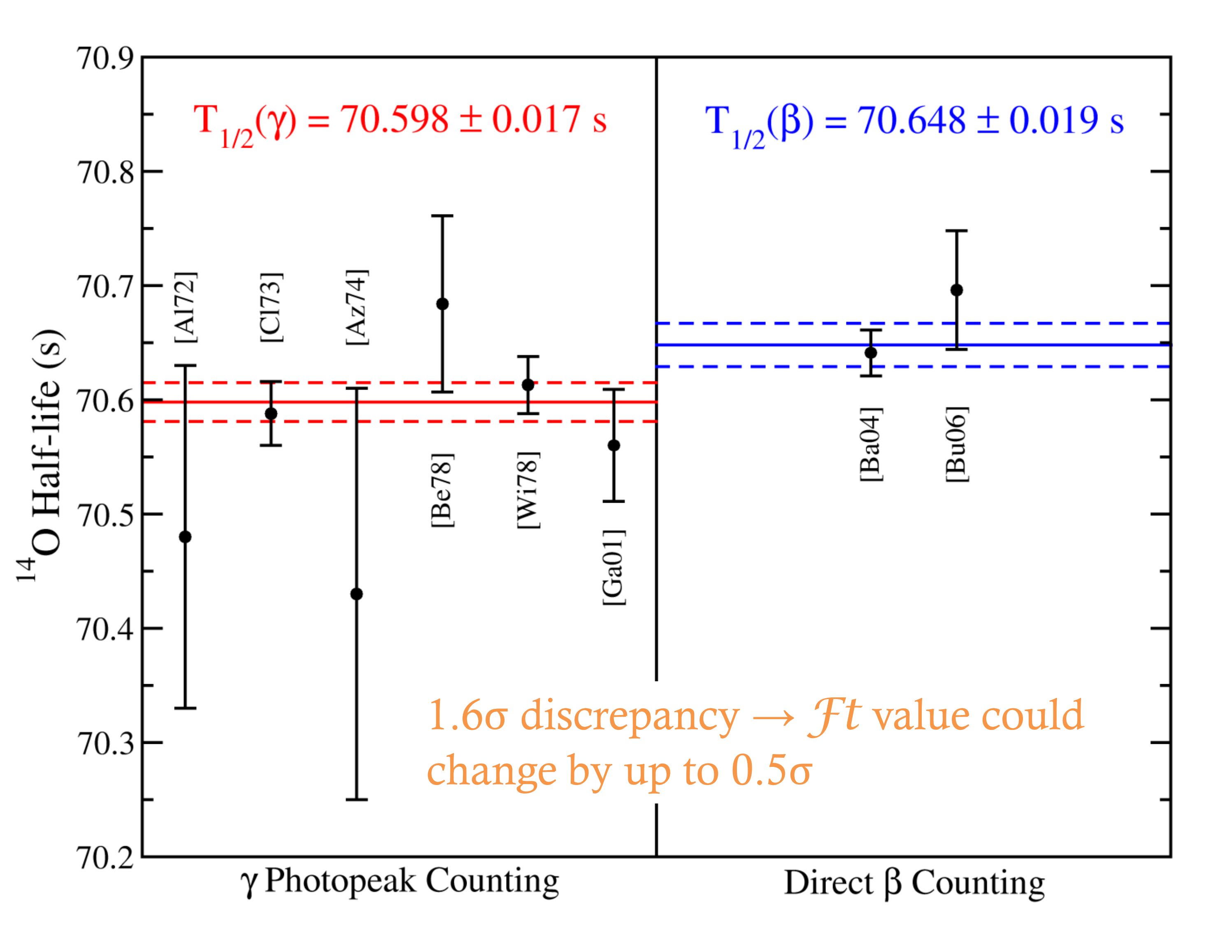
Simultaneous independent direct β and γ-ray counting experiments using the 8π spectrometer and the Zero-Degree Scintillator.

γ Counting:
-Decay Selective
-Slow & Inefficient

β Counting:
-Fast & Efficient
-Not Decay Selective

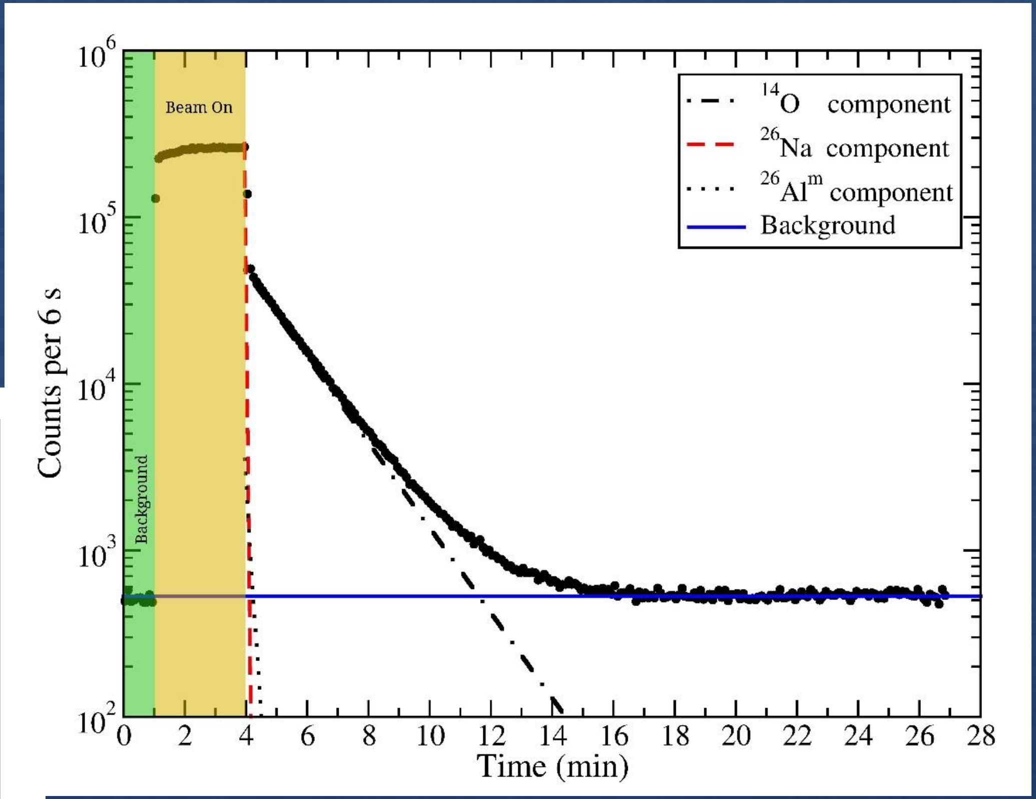
Previous measurements reveal a systematic discrepancy between detection method

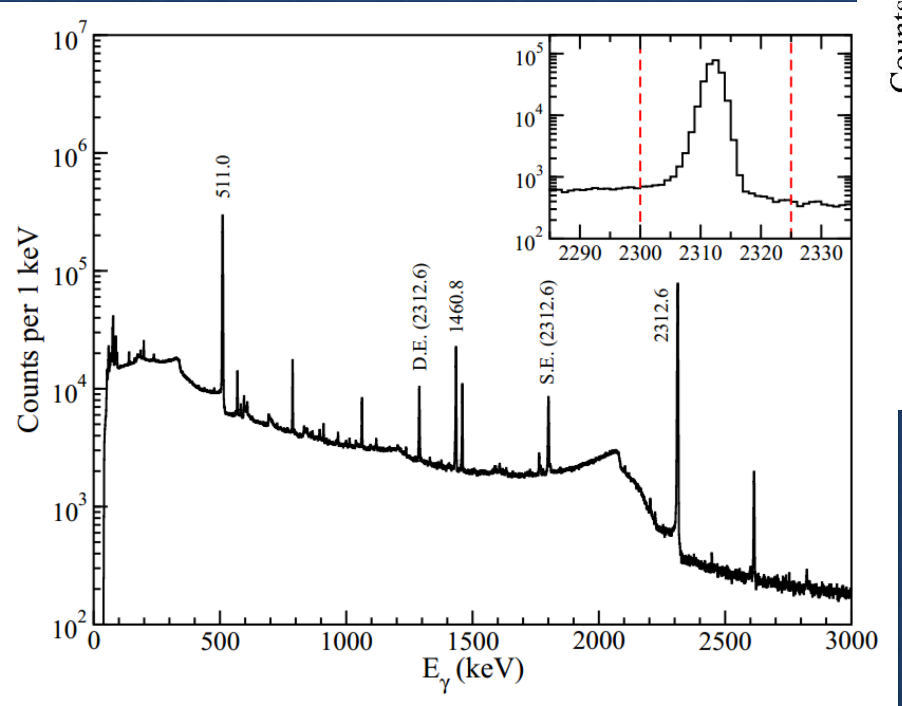
Detection Method Discrepancy



^{14}O Half-Life Measurement

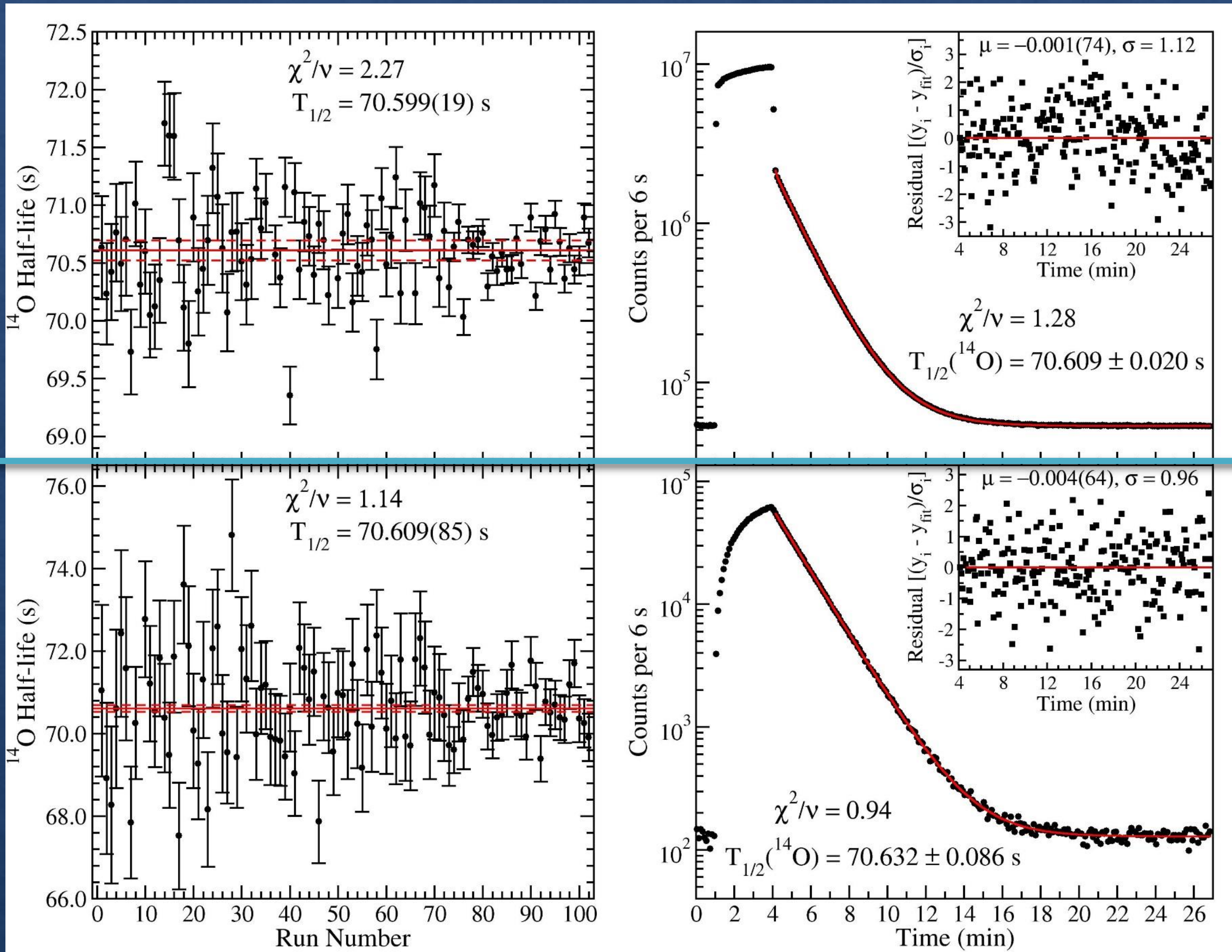
Beam
- ^{12}C-^{14}O: $T_{1/2} = 70.620$ s
- ^{26}Al^{m}: $T_{1/2} = 6.3465$ s
- ^{26}Na: $T_{1/2} = 1.072$ s





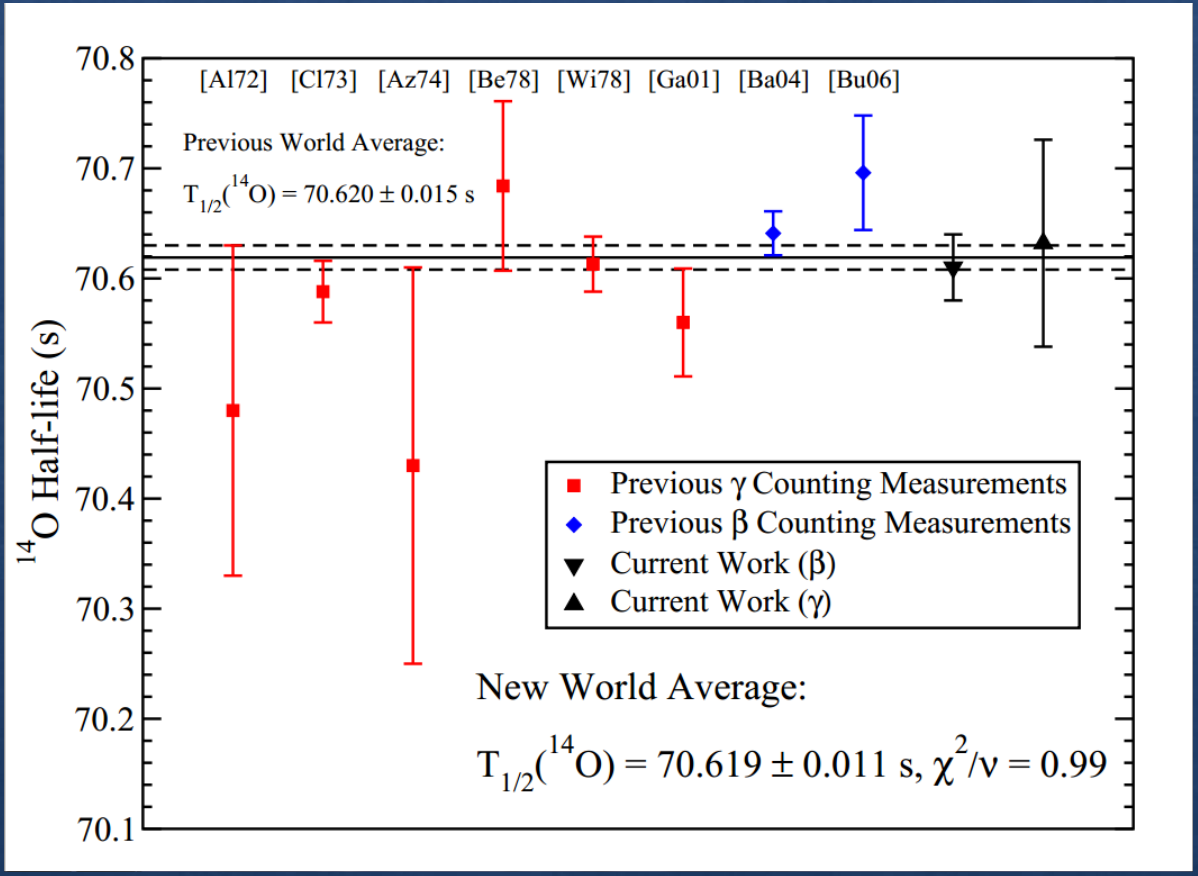
β

γ



$\chi^2/\nu = 2.27$
$T_{1/2} = 70.599(19)$ s
^{14}O Half-life (s)
Counts per 6 s
$\mu = -0.001(74)$, $\sigma = 1.12$
Residual $[(y_i - y_{fit})/\sigma_i]$
Time (min)
$\chi^2/\nu = 1.28$
$T_{1/2}(^{14}O) = 70.609 \pm 0.020$ s
$\chi^2/\nu = 1.14$
$T_{1/2} = 70.609(85)$ s
^{14}O Half-life (s)
Run Number
Counts per 6 s
$\mu = -0.004(64)$, $\sigma = 0.96$
Residual $[(y_i - y_{fit})/\sigma_i]$
Time (min)
$\chi^2/\nu = 0.94$
$T_{1/2}(^{14}O) = 70.632 \pm 0.086$ s
Time (min)

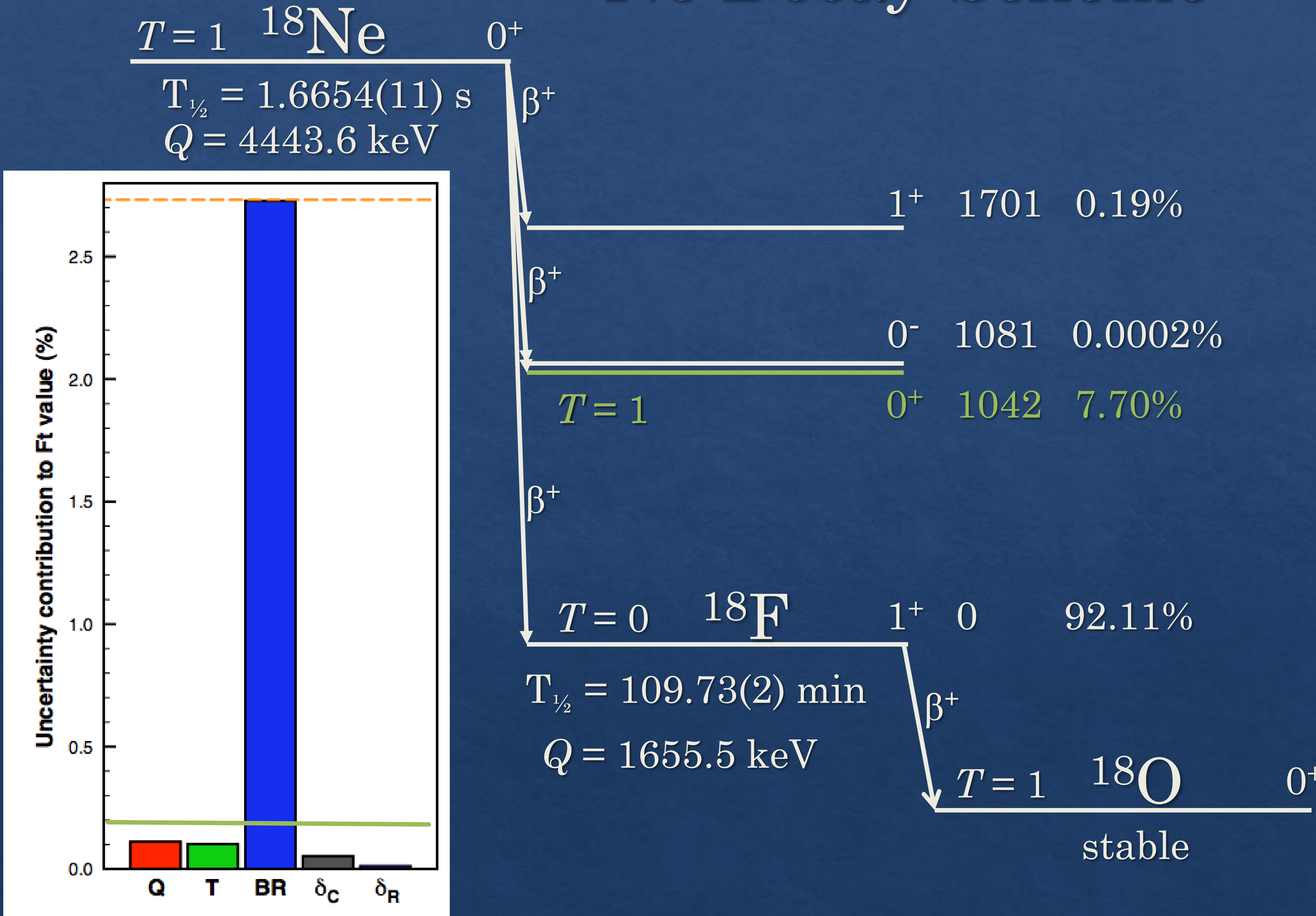
Status of ^{14}O Half-Life



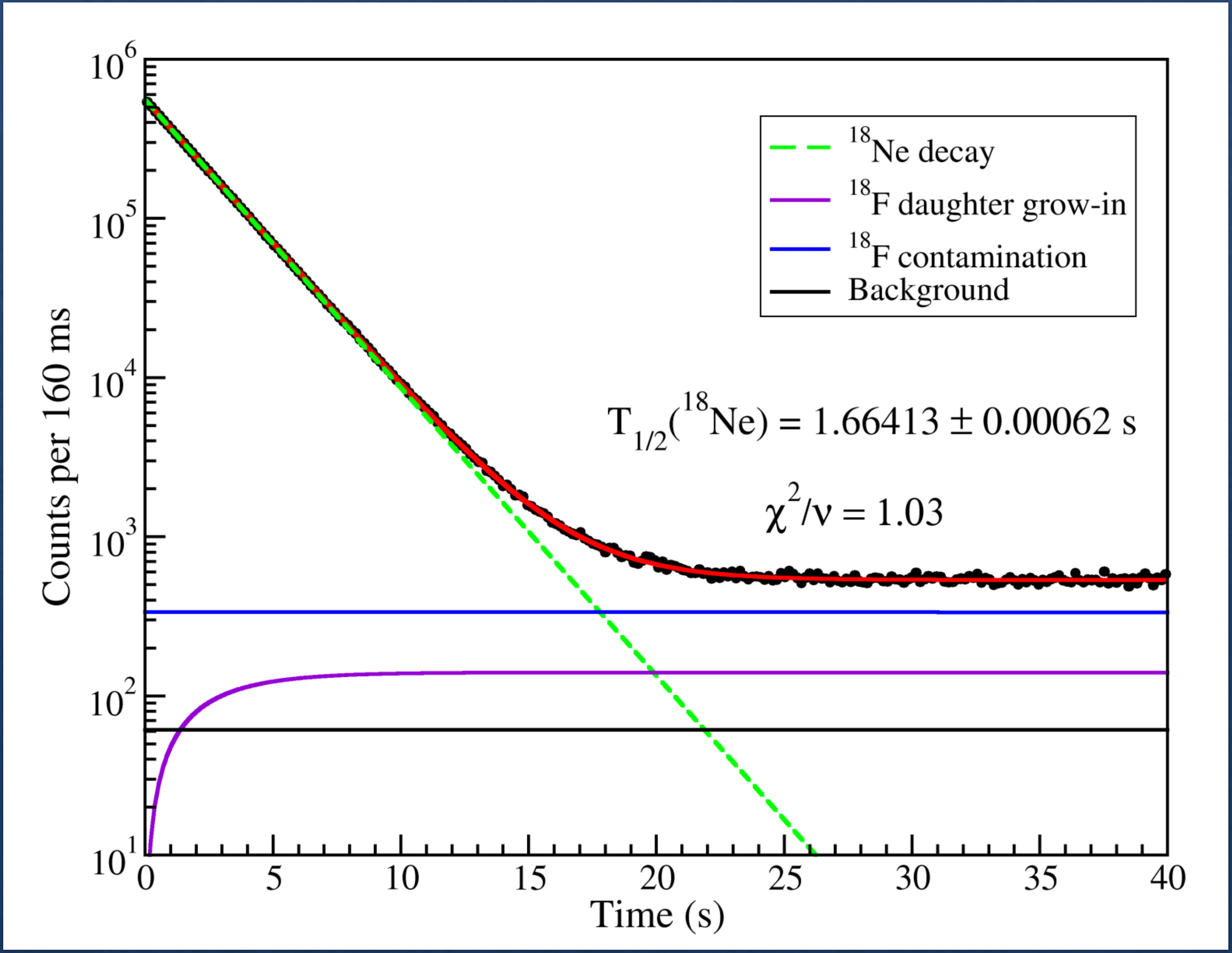
A.T. Laffoley *et al.*, Phys. Rev. C **88**, 015501 (2013)

- Performing simultaneous β and γ half-life measurements for ^{14}O will help address the current systematic discrepancy.
- A follow-up experiment is scheduled for July to push below 0.03% precision.
- Precision *ft* determination of light superallowed Fermi β emitters will help push the limits of scalar currents in the Weak interaction.

^{18}Ne Decay Scheme



Sample Data – Gas Counter



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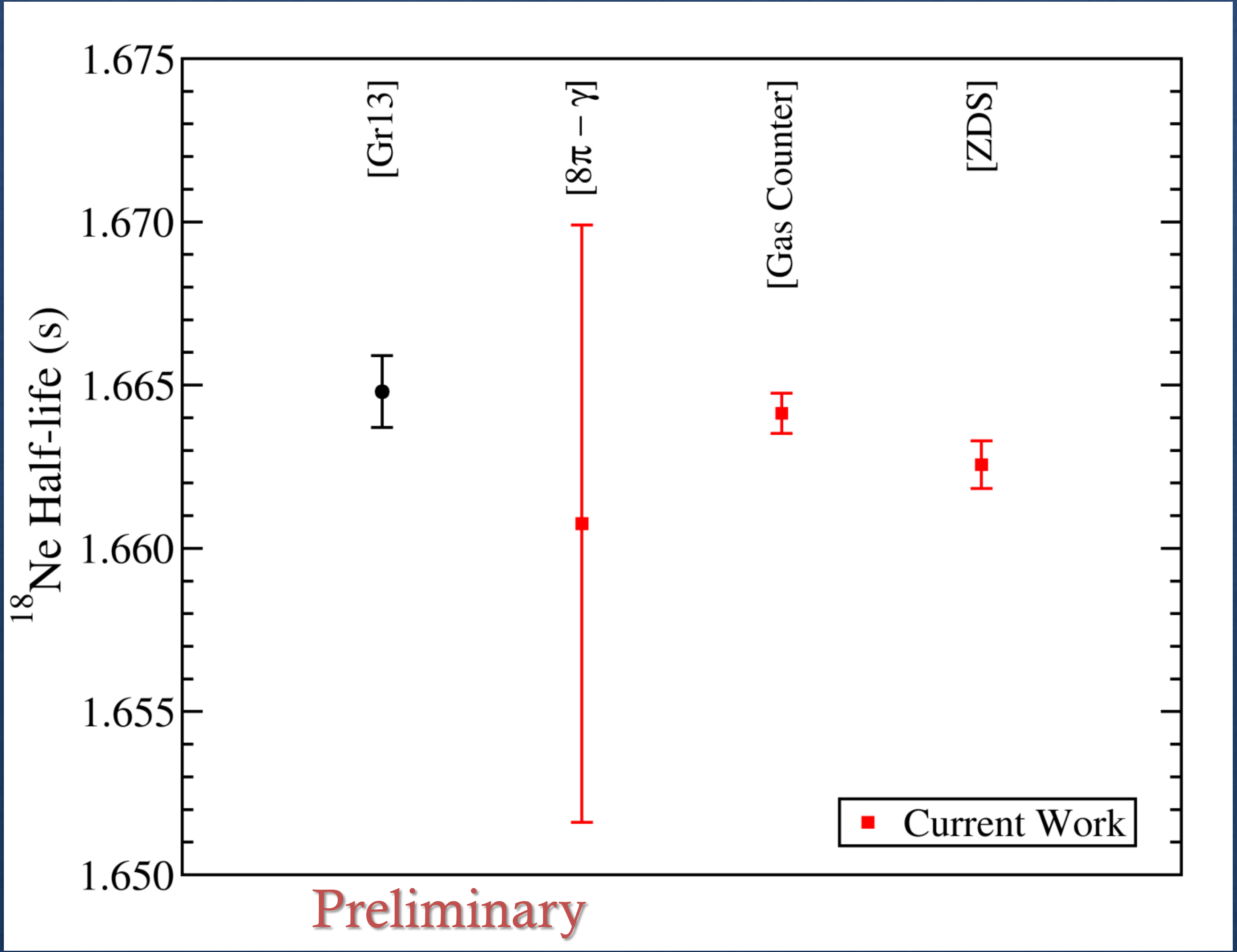

Conclusions

- The systematic difference between half-life detection method has been resolved
- An upcoming ^{14}O experiment, using the 4π gas counter, will push the precision below 0.03%

- We measured the half-life of ^{18}Ne to ±0.025%, a factor of 3 times improvement over previous measurements
- In combination with recent BR measurement performed at GANIL, the *ft* value of superallowed Fermi β^+ emitter ^{18}Ne will now be among the set of high-precision cases

- These high-precision half-life measurements are important in setting limits on scalar currents in the Weak interaction
- Improving the precision of the *ft* measurements for superallowed Fermi emitters will reduce the uncertainty for V_{ud}
- Will be used to help differentiate between theoretical models for the δ_C (isospin-symmetry-breaking) correction

Thank You!

UNIVERSITY of GUELPH

V. Bildstein
G. Deng
A. Diaz Varela
M. Dunlop
R. Dunlop
Z. Fairchild
P. Finlay
P. E. Garrett
B. Hadinia
D. S. Jamieson
B. Jigmeddorj
A. Radich
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