High-Precision Branching Ratio Measurement for the Superallowed Fermi β Emitter ^{22}Mg

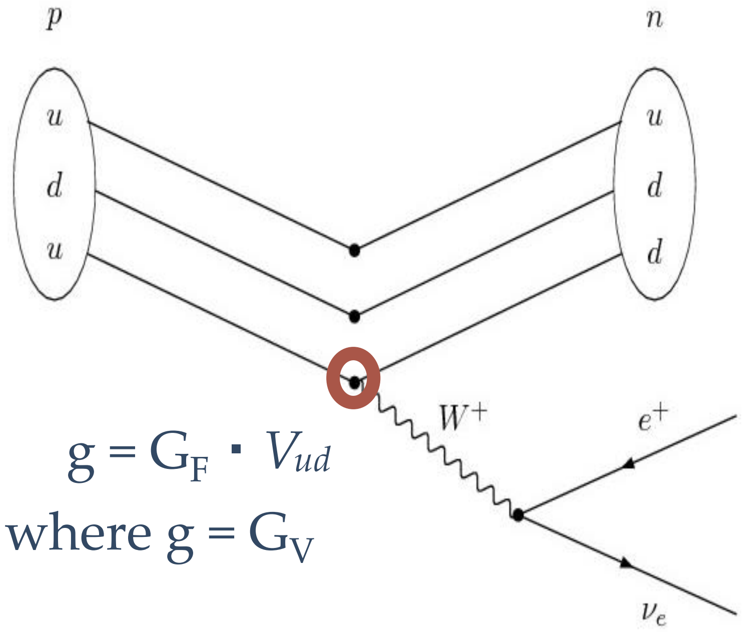
UNIVERSITY of GUELPH

A.T. Laffoley – University of Guelph

CAP Congress, June 13th 2018

Superallowed Fermi Beta Emitters

Precision measurements of the *ft* values for superallowed $0^+ \rightarrow 0^+$ Fermi β decays between isobaric analogue states provide demanding tests of the Standard Model description of electroweak interactions.



$g = G_F \cdot V_{ud}$

where $g = G_V$

From Fermi's Golden Rule:

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

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

Cabibbo-Kobayashi-Maskawa quark mixing matric

Impacts of studying T=1 superallowed Fermi β Emitters

Most precise determination of V_{ud}

$|V_{ud}| = 0.97420(21)$

Test of conserved vector current (CVC) hypothesis

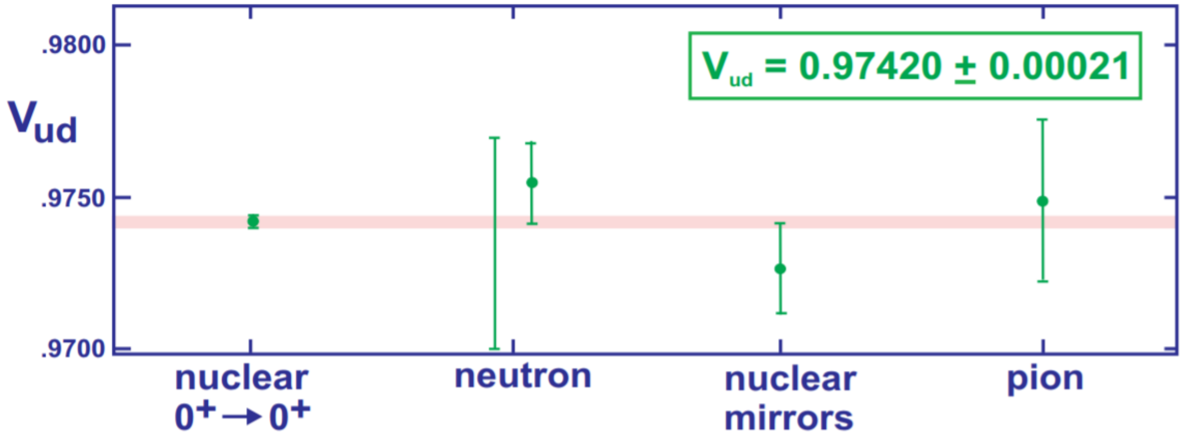
confirmed to better than 12 parts in 10^5

Tests of CKM unitarity

$1 - |V_{ud}|^2 - |V_{us}|^2 - |V_{ub}|^2 = 0.00038(49)$

World survey consists of some 220 individual measurements

CURRENT STATUS OF V_{ud}



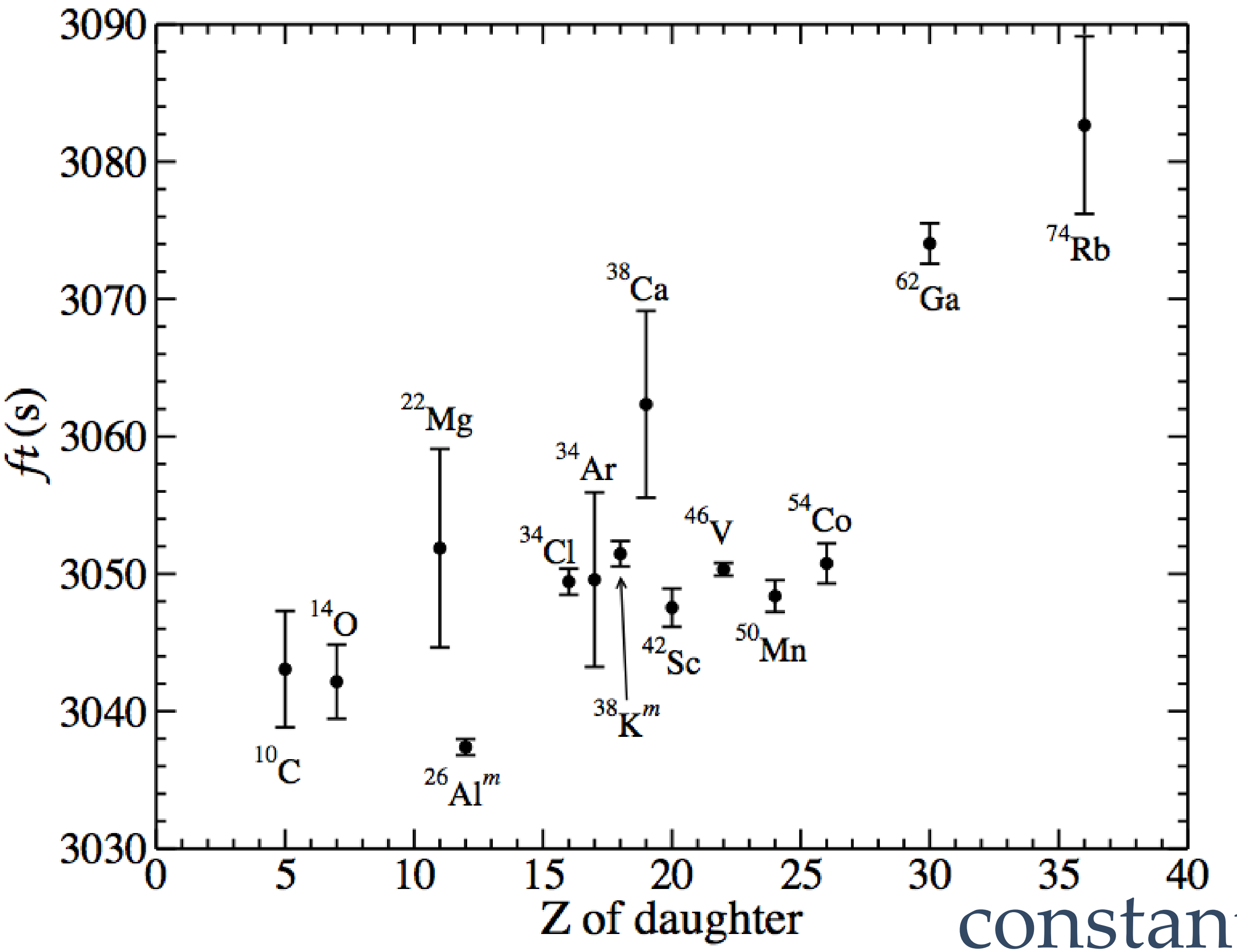
Search for physics beyond the Standard Model

Fundamental or induced scalar currents in Weak interaction

ft values for superallowed transitions

$$ft = \frac{2\pi^3 \hbar^7 \ln 2}{2G_V^2 m_e^5 c^4} = \text{constant}$$

experimentally measured *Q* value, parent half-life ($T_{1/2}$), and branching ratio *(BR)* to superallowed state



constant to within 1.5%

Superallowed Fermi Beta Emitters

$$\mathcal{F}t = ft(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)} = \text{constant}$$

- $\mathcal{F}t$: Corrected *ft* value
- ft: Experiment
- δ'_R, δ_{NS}, δ_C: Calculated corrections (~1%) (nucleus dependent)
- Δ_R^V: Inner radiative correction (~2.4%) (nucleus independent)
- constant: CVC Hypothesis

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

δ'_R = nucleus dependent radiative correction to order $Z^2\alpha^3$: ~1.4%

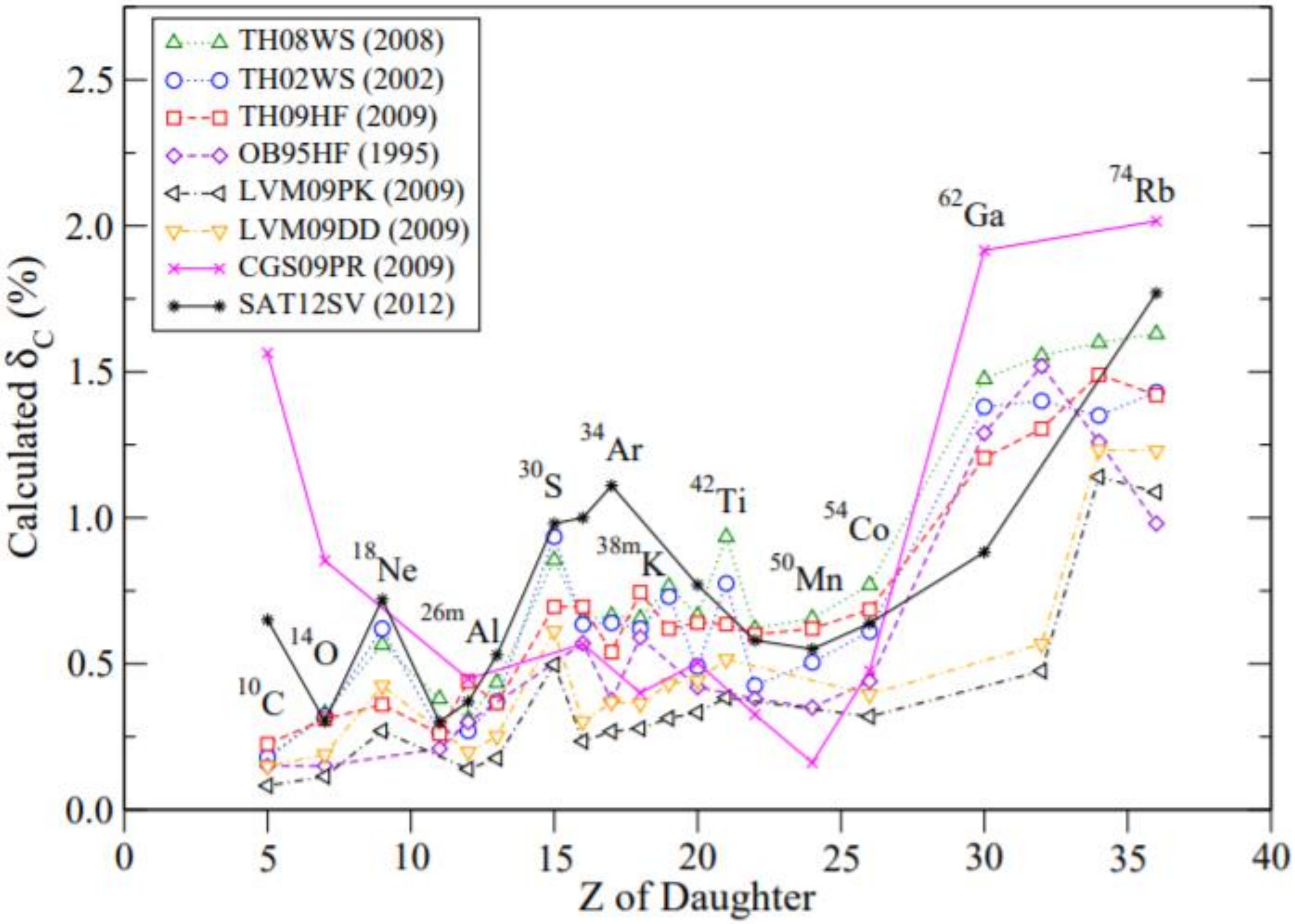
↳ depends on electron's energy and Z of nucleus

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

δ_C = nucleus dependent isospin-symmetry-breaking correction: 0.2% – 1.5%

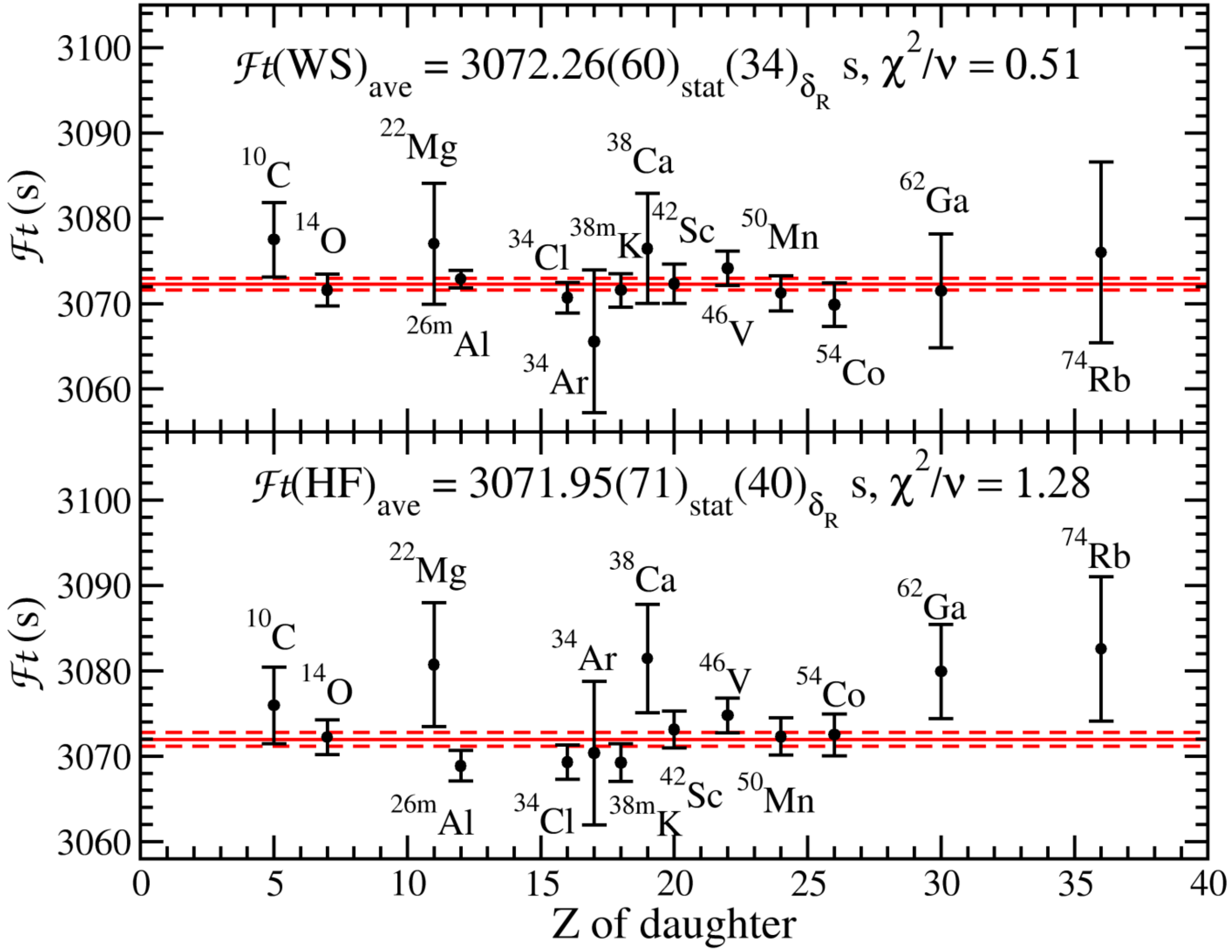
↳ strong nuclear structure dependence

Isospin-symmetry breaking corrections



- Not all models have been equally constrained by experimental data (e.g. nuclear charge radii, separation energies, IMME)
- The Woods-Saxon and Hartree-Fock calculations have been favoured in the previous world surveys

Corrected *ft* values

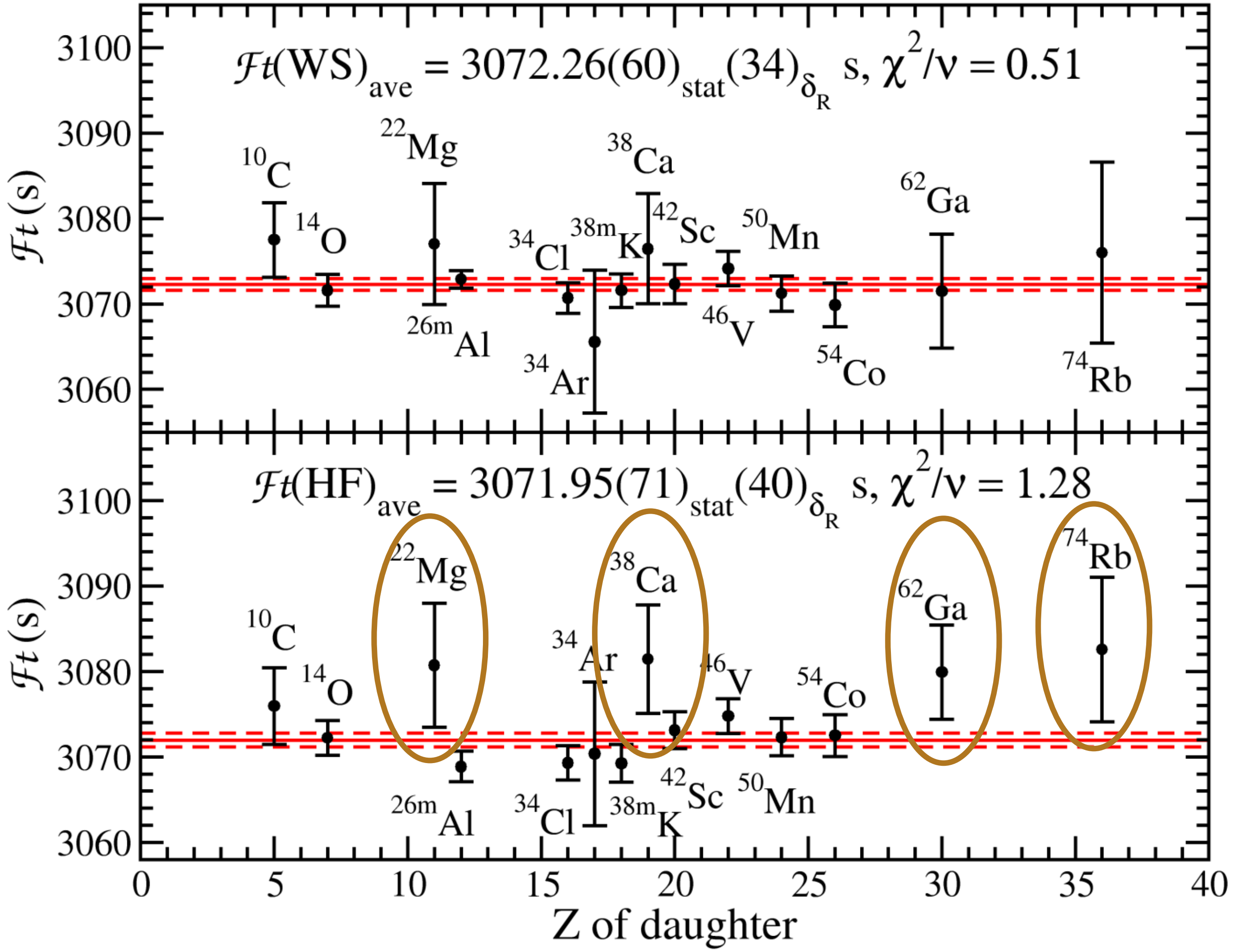


$$\mathcal{F}t = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

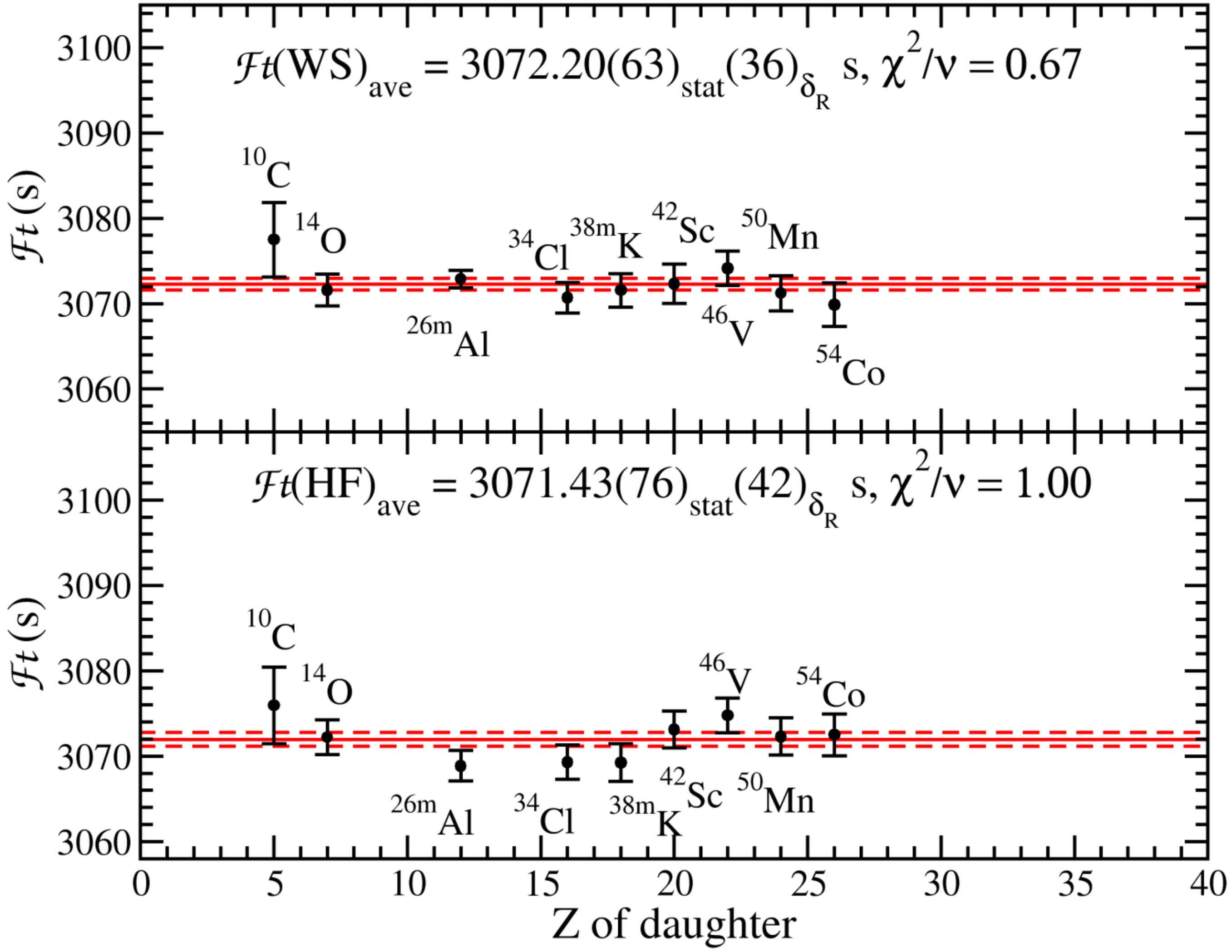
Confirmation of CVC

Estimate theoretical model-dependent uncertainty with difference of values

Corrected *ft* values



Corrected *ft* values



Keeping only transitions where $\mathcal{F}t$ is determined to ±0.15% or better, "constancy" argument fails

Experiment

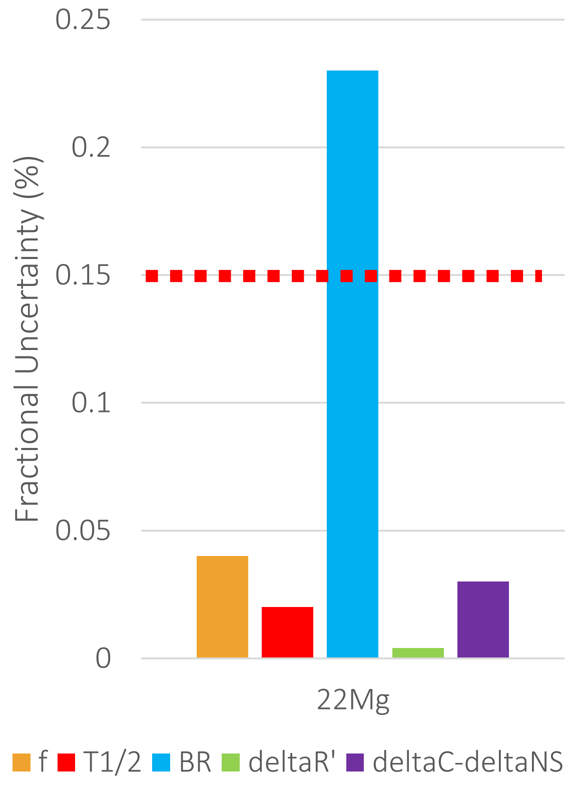
Status of ^{22}Mg *ft* value:

Q-value recently measured @ TITAN – *M.P. Reiter, K.G. Leach et al., PRC 96 052501 (2017)*

Half-life recently measured @ ISAC – *M.R. Dunlop et al., PRC 96 045502 (2017)*

Branching Ratio has only been measured once to high-precision – *J.C. Hardy et al., PRL 082501 (2003)*

Goal: To improve the ^{22}Mg branching ratio measurement to the ±0.15% level

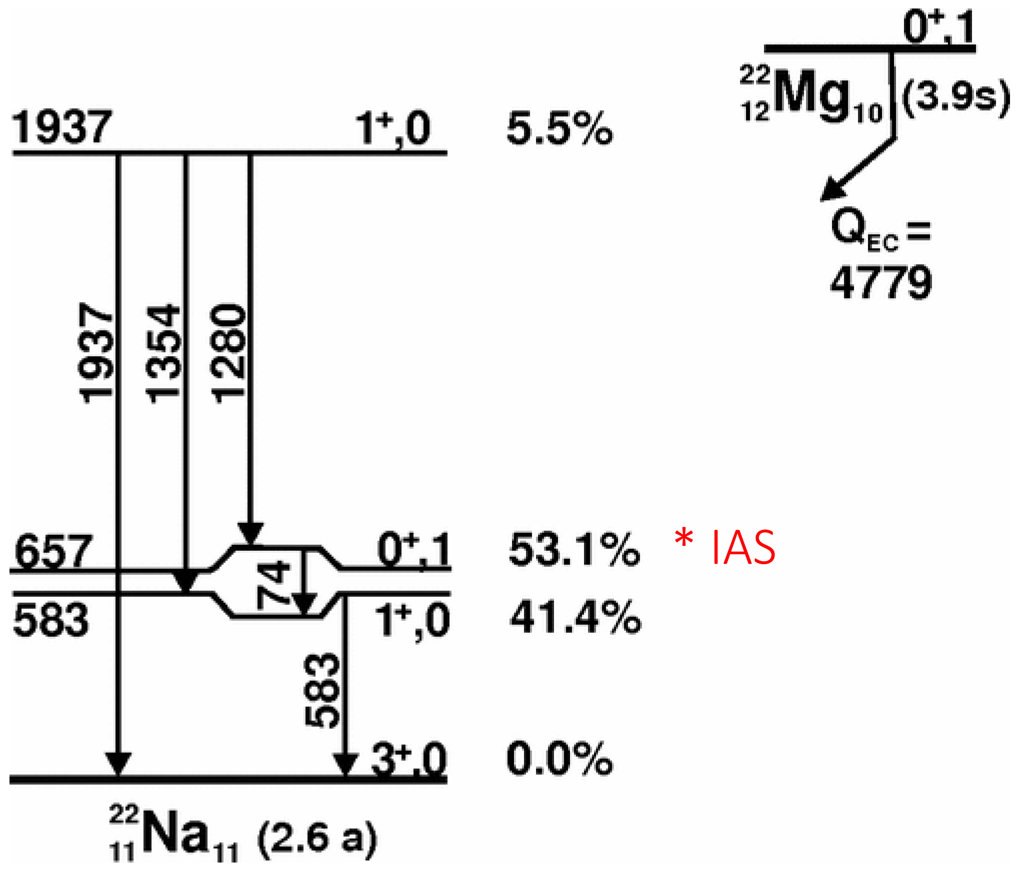


Measuring the ^{22}Mg Branching Ratio

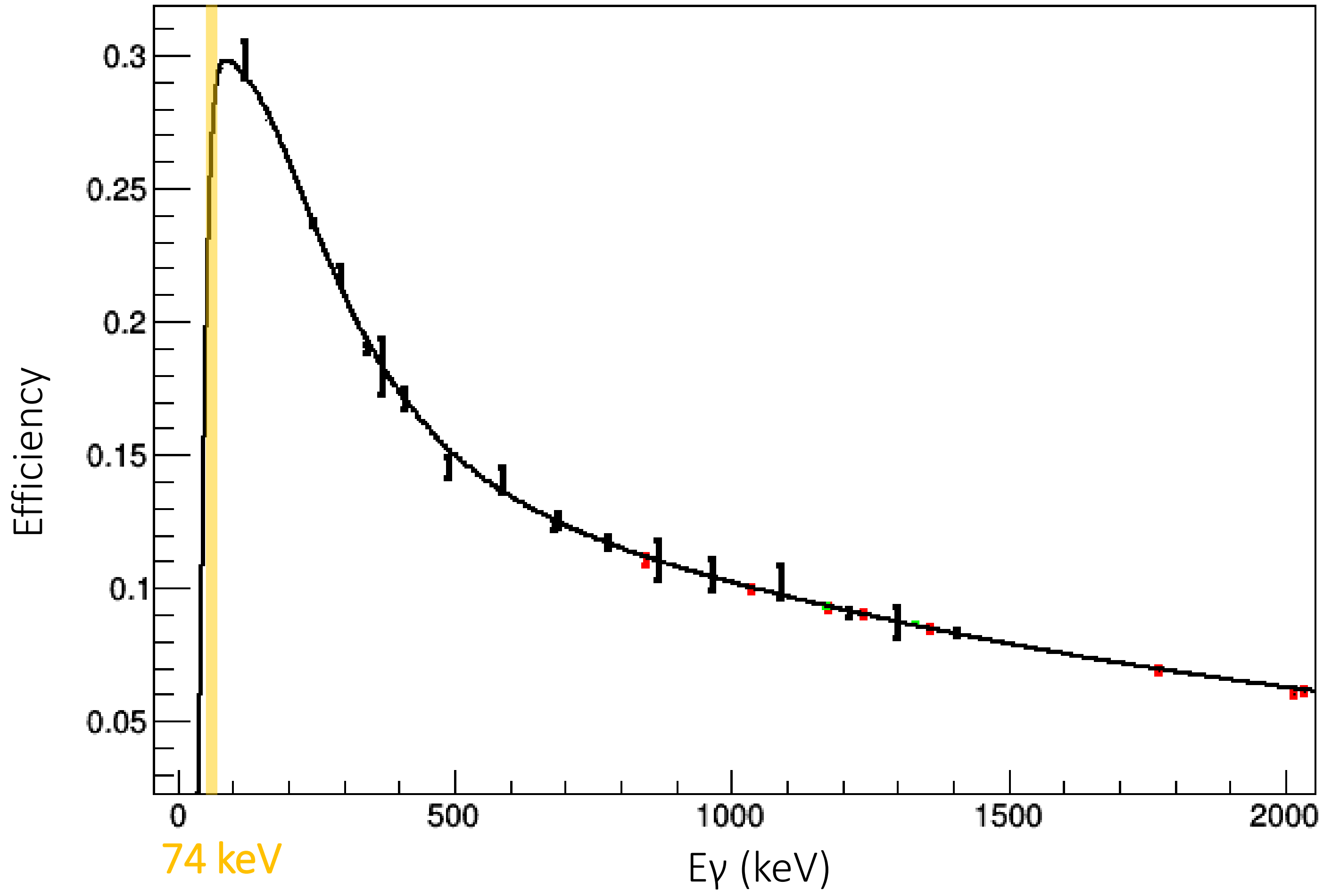
Second-forbidden decay to ground state → all β decays are accompanied by γ-rays

To measure the BR to ±0.15%, we need to measure ε_γ to ±0.1%

This is particularly challenging at 74 keV

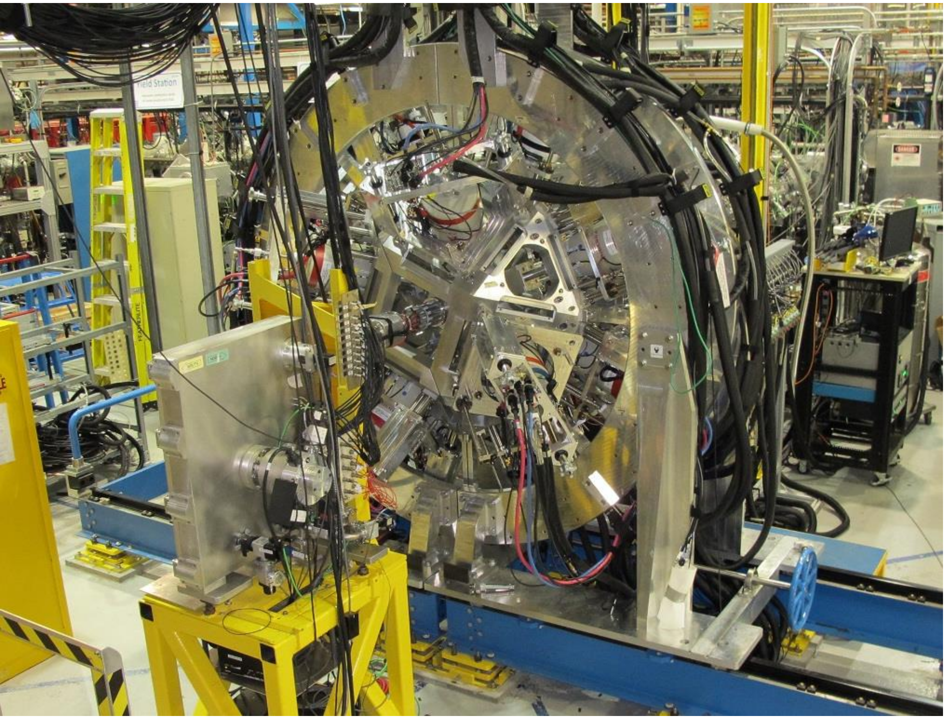


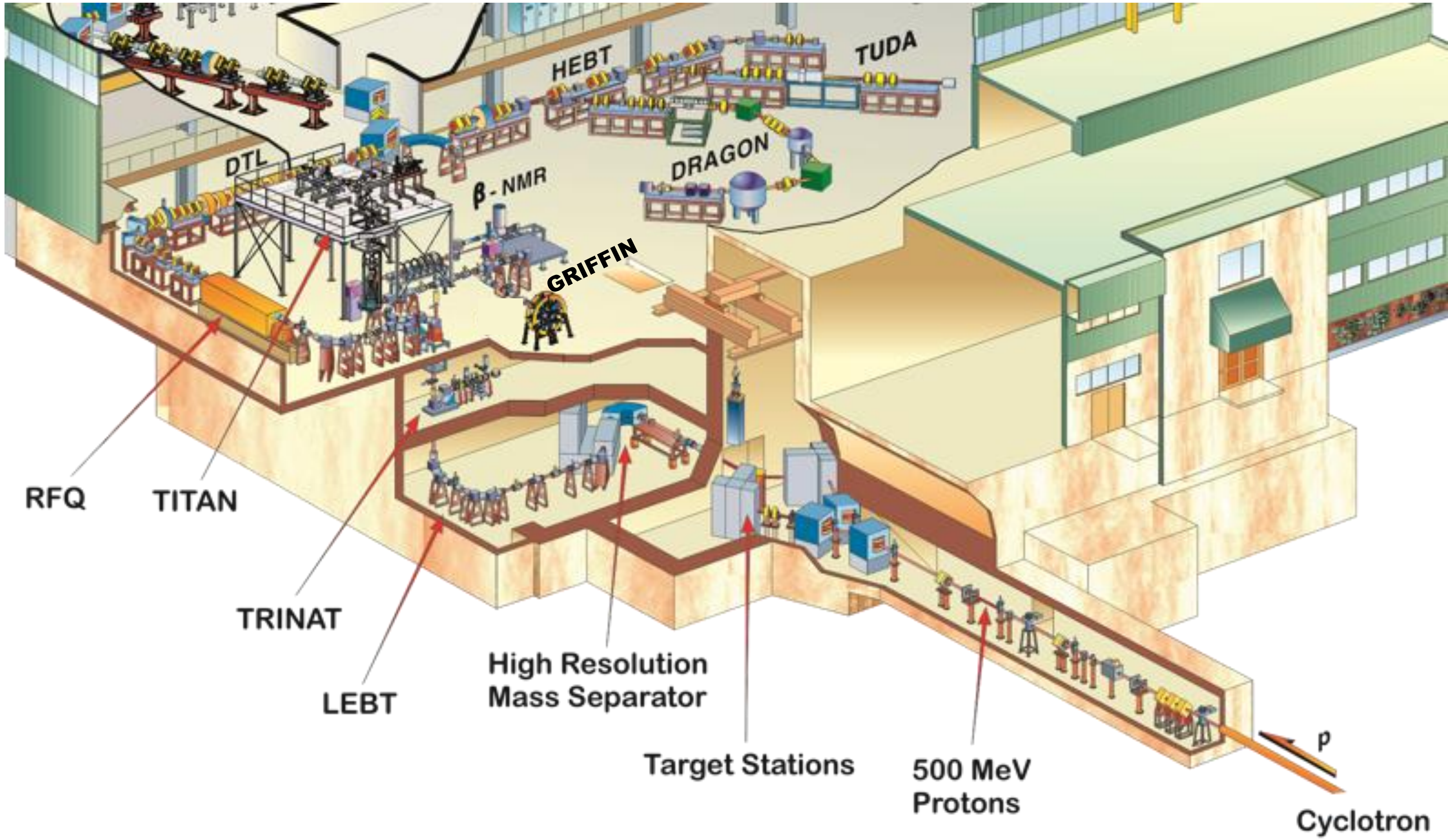
GRIFFIN Efficiency



ε_γ changes quickly at low energies, so a well-calibrated efficiency curve is crucial

GRIFFIN @ ISAC





IGLIS instrumental in suppressing long-lived ^{22}Na ($T_{1/2}$ = 2.6 y) contaminant by 10^7

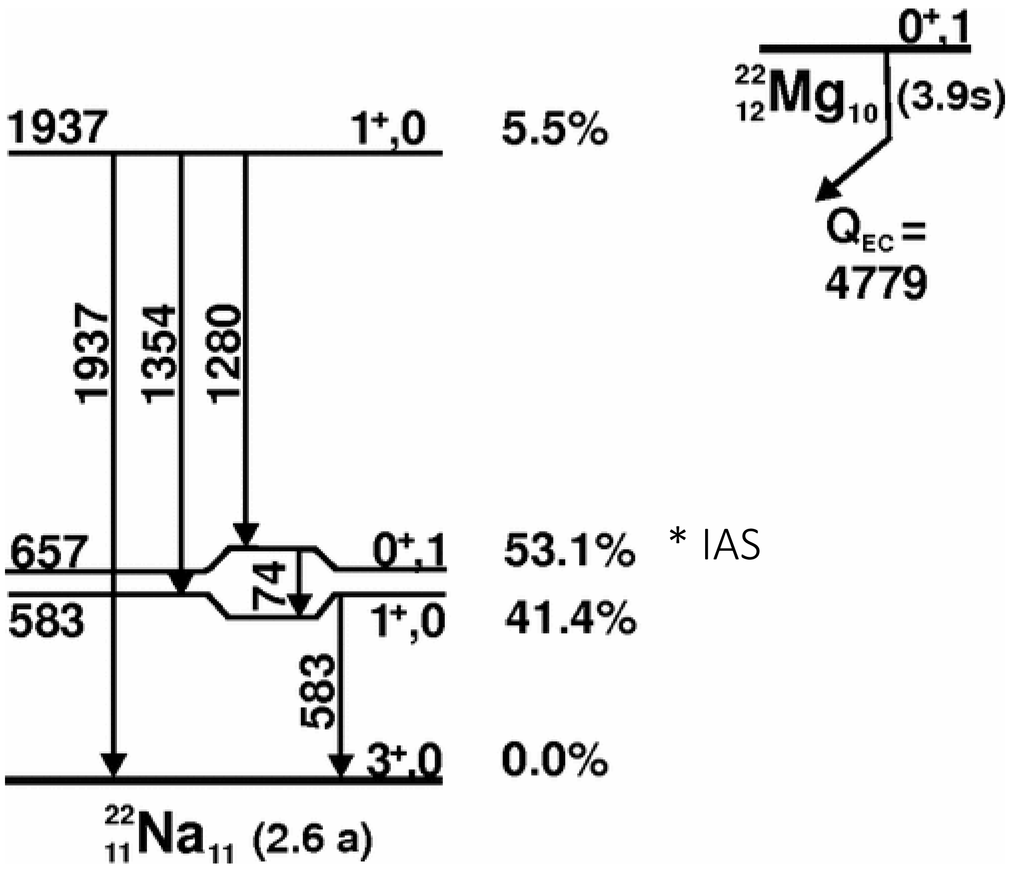
Novel γ-Coincidence Method

The 74 and 583 keV cascade are in 1:1 following the emission of a 1280 keV γ

Can measure $\varepsilon_{583}/\varepsilon_{74}$ *in situ* via coincidence with 1280 keV

The 583 keV excited state has a lifetime of ~250 ns.

Requires large event-build and coincidence gate



Summary of Data

In coincidence with 1280 (for ratio of efficiencies):

74 keV: 5.2×10^{6} counts

583 keV: 2.2×10^{6} counts

Statistical precision <0.1%

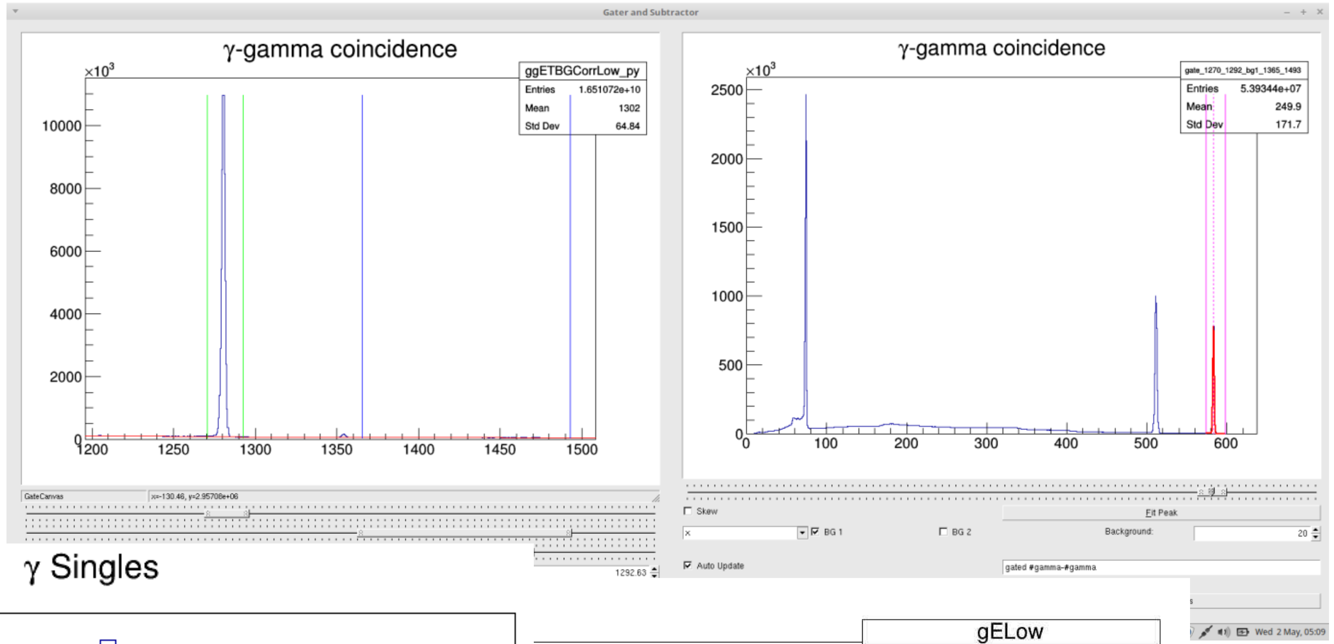
In singles:

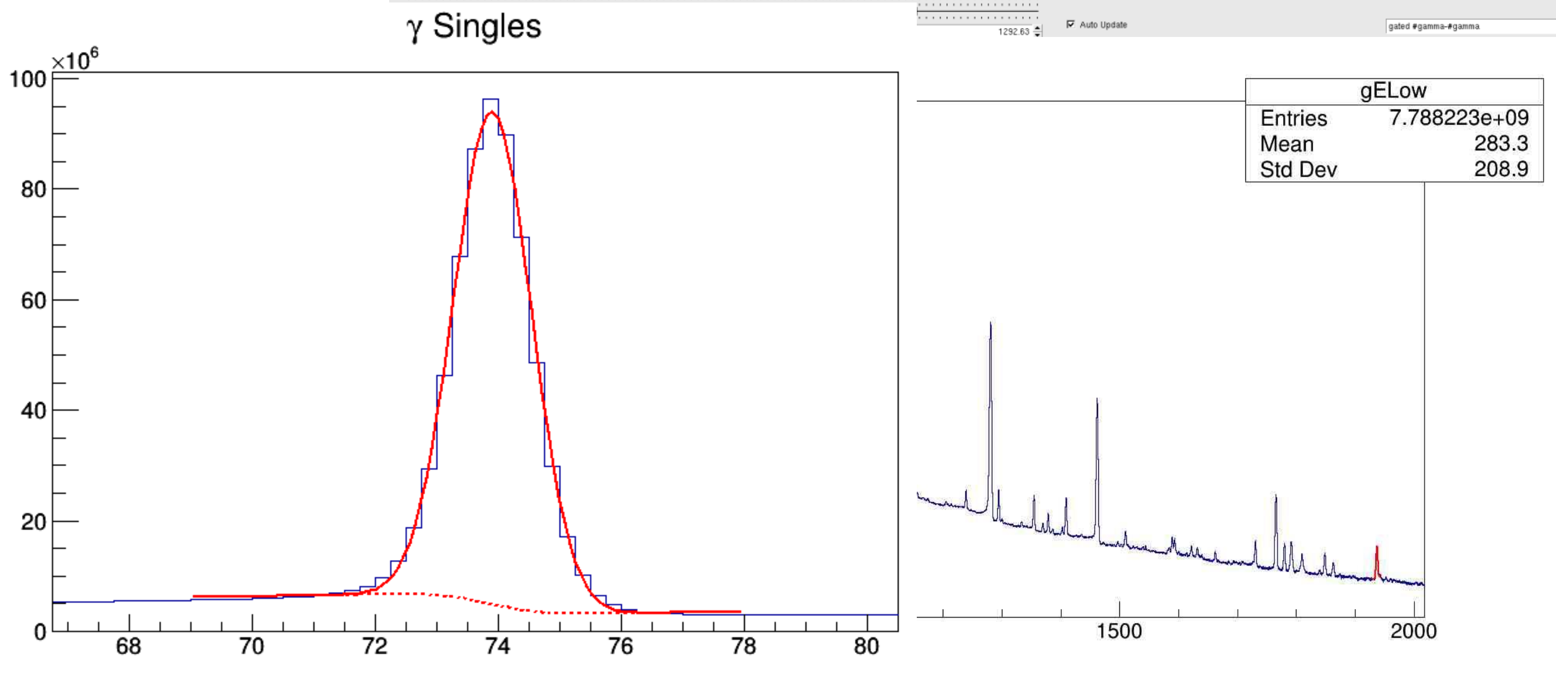
74 keV: 5.8×10^{8} counts

583 keV: 4.2×10^{8} counts

1280 keV: 1.4×10^{7} counts

1937 keV: 6×10^{4} counts





Where does this leave us?

- ❑ All 3 experimental quantities required to calculate *ft* (Q-value, half-life, and branching ratio) for ^{22}Mg have been recently performed at TRIUMF
- ❑ Branching ratio analysis is still ongoing
- ❑ As in all precision measurements, a dedicated systematics investigation is being completed to ensure no biases are introduced.
- ❑ Any conclusions that affect the central value or uncertainty of the world-average $\mathcal{F}t$ value will have implications for both the CVC and CKM unitarity

Thank you for your attention

Simon Fraser University: C. Andreoiu

TRIUMF: G. C. Ball; N. Bernier; M. Bowry; R. Caballero-Folch; A. B. Garnsworthy; G. Hackman; J. Measures; B. Olaizola; Y. Saito

Queen’s University: J. R. Leslie

University of Guelph: H. Bidaman; V. Bildstein; C. Burbadge; A. Diaz Varela; M. R. Dunlop; R. Dunlop; P. E. Garrett; B. Jigmeddorj; A. D. MacLean; C. E. Svensson; J. Turko; T. Zidar

Colorado School of Mines: K. G. Leach; C. Natzke

Reed College: J. K. Smith

NSERC
CRSNG

NRC·CNRC