HIGH-PRECISION HALF-LIFE MEASUREMENT OF ^{14}O

Winter Nuclear & Particle Physics Conference

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University of Regina

Department of Physics

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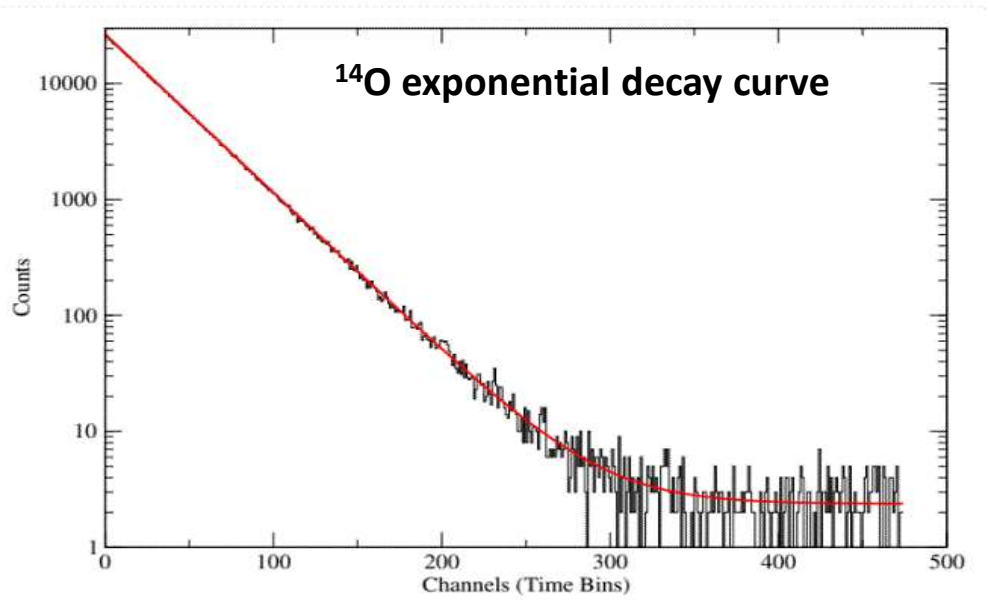
TRIUMF

On behalf of the TRIUMF GPS and GRIFFIN Collaborations

Outline

- Introduction to “Super Allowed Fermi Beta Decay”
- Key quantities to be measured
- *ft* values for Beta Decay
- Experimental facility
- Data analysis and new ^{14}O half-life measurement
- Comparison to previous results
- Conclusion and future work



Gas filled proportional counter

TRIUMF

Beta Decay

- **Two Types: Beta Minus Decay, Beta Plus Decay**
- **Beta Plus Decay: Conversion of a proton into neutron**

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}W_{N+1} + e^{+} + \nu_e $$

- **Beta Minus Decay: Conversion of neutron into proton**

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1} + e^{-} + \bar{\nu}_e $$

“Super allowed Fermi Beta Decay”

- Beta Decay from parent nuclei can populate several daughter states
- Momentum conservation & selection rules

$$\vec{J}_P = \vec{J}_D + \vec{L} + \vec{S} \qquad \pi_P = \pi_D(-1)^L$$

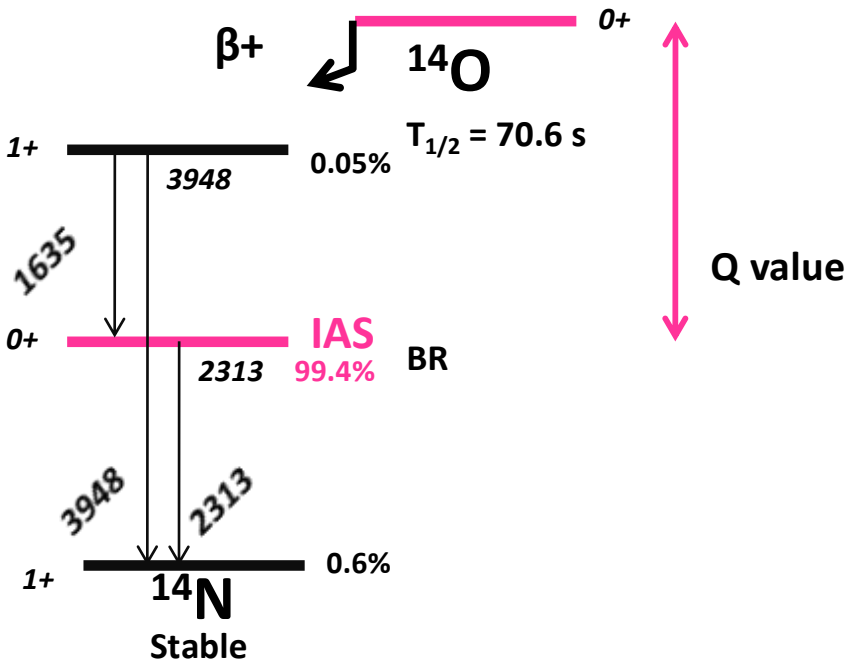
- Allowed decays (L=0)
- Forbidden decays (L=1,2,3,…)

- Fermi decays (S=0)
- Gamow-Teller decays (S=1)

- If decay occurs between “*isobaric analogue states*” → Super
  - States with identical wave functions except p is replaced with n (isospin symmetry)

Key quantities to be measured

- Total transition energy Q value
- Half life $T_{1/2}$ of the parent state
- Branching ratio (BR) to the transition of interest

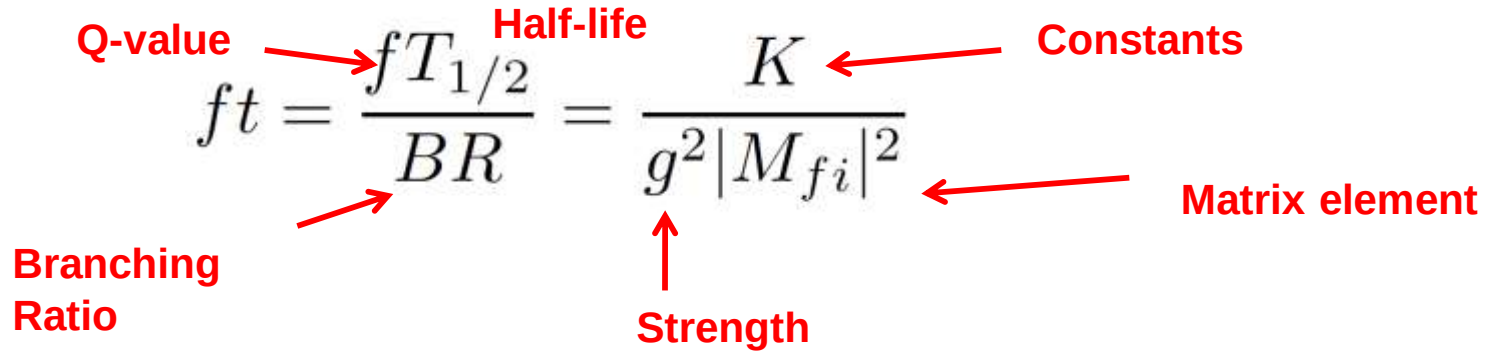


These quantities are combined into the *ft* value of the beta transition

- *f* = statistical rate function , depends on Q value
- *t* = partial half life , depends on $T_{1/2}$ and BR

ft values for Beta Decay

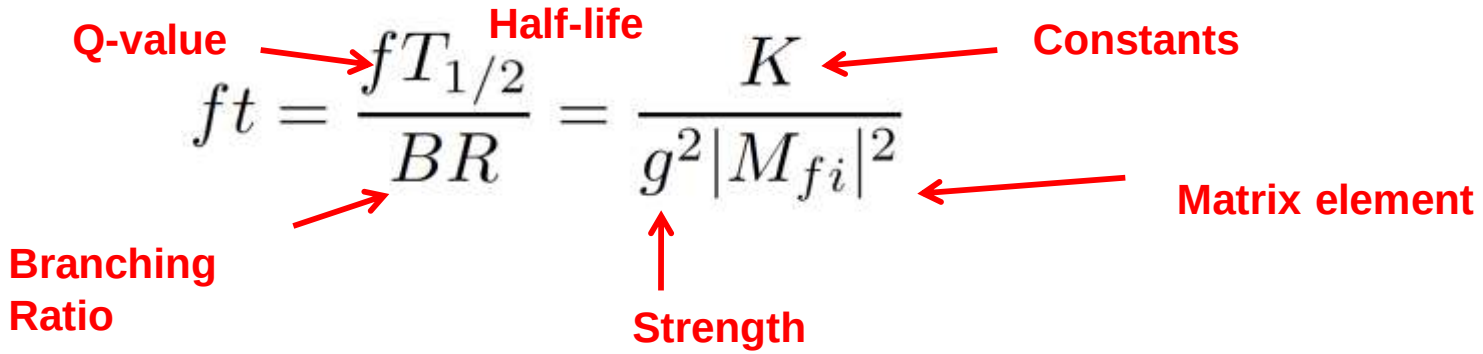
- **From Fermi Theory of Beta Decay :**



- **M_{fi} is the nuclear matrix element connecting final and initial states**
- **g is a quantity that defines the strength of the (weak) interaction**

ft values for Beta Decay

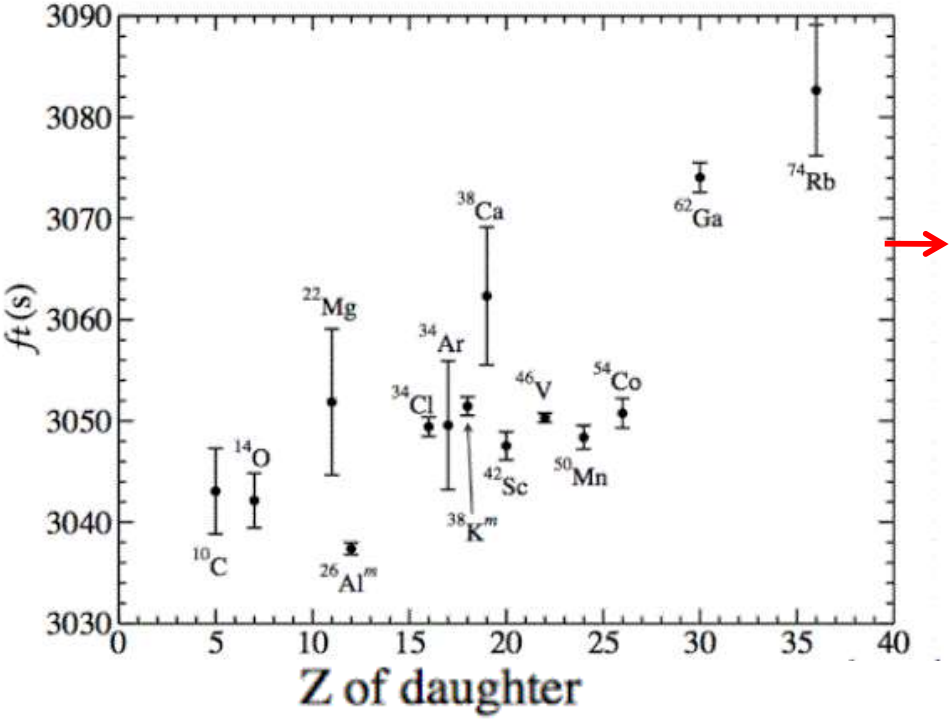
- **From Fermi Theory of Beta Decay :**



- **For the special case of (isospin T=1) super-allowed Fermi transitions**
  - **M_{fi} = √2 (isospin symmetry)**
  - **g = G_v Vector Coupling constant (CVC hypothesis)**

$$ft = \frac{fT_{1/2}}{BR} = \frac{K}{2{G_V}^2} = \text{constant}$$

Graph between *ft* and Z of daughter

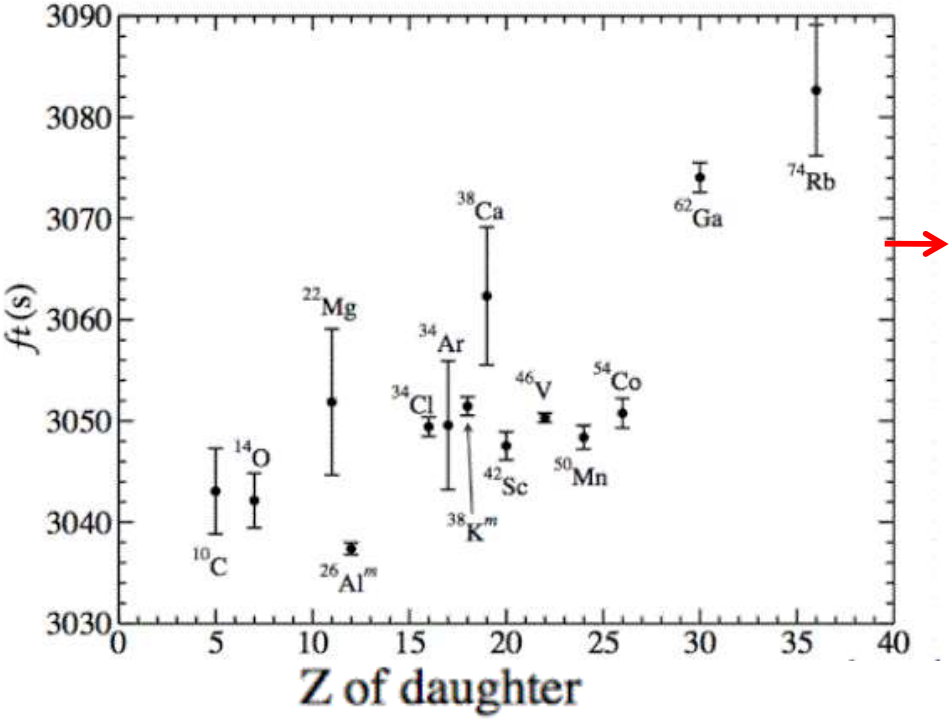


Values are constant to within ~2%

➢ **Isospin symmetry is broken and other small effects**

Figures from: A.T. Laffoley PhD Thesis, U of Guelph, 2015

Graph between *ft* and Z of daughter

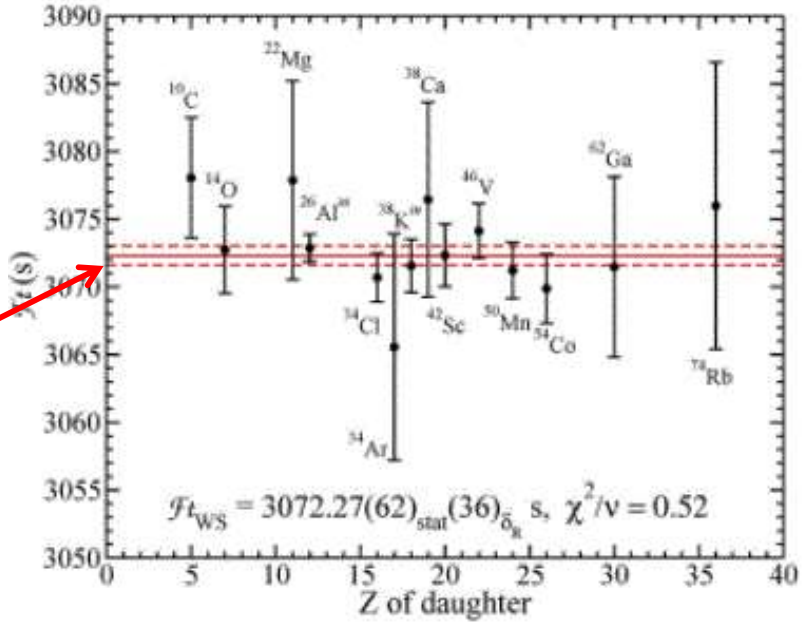


Values are constant to within ~2%

➢ **Isospin symmetry is broken and other small effects**

After doing theoretical corrections

Now constant to ±0.02%!



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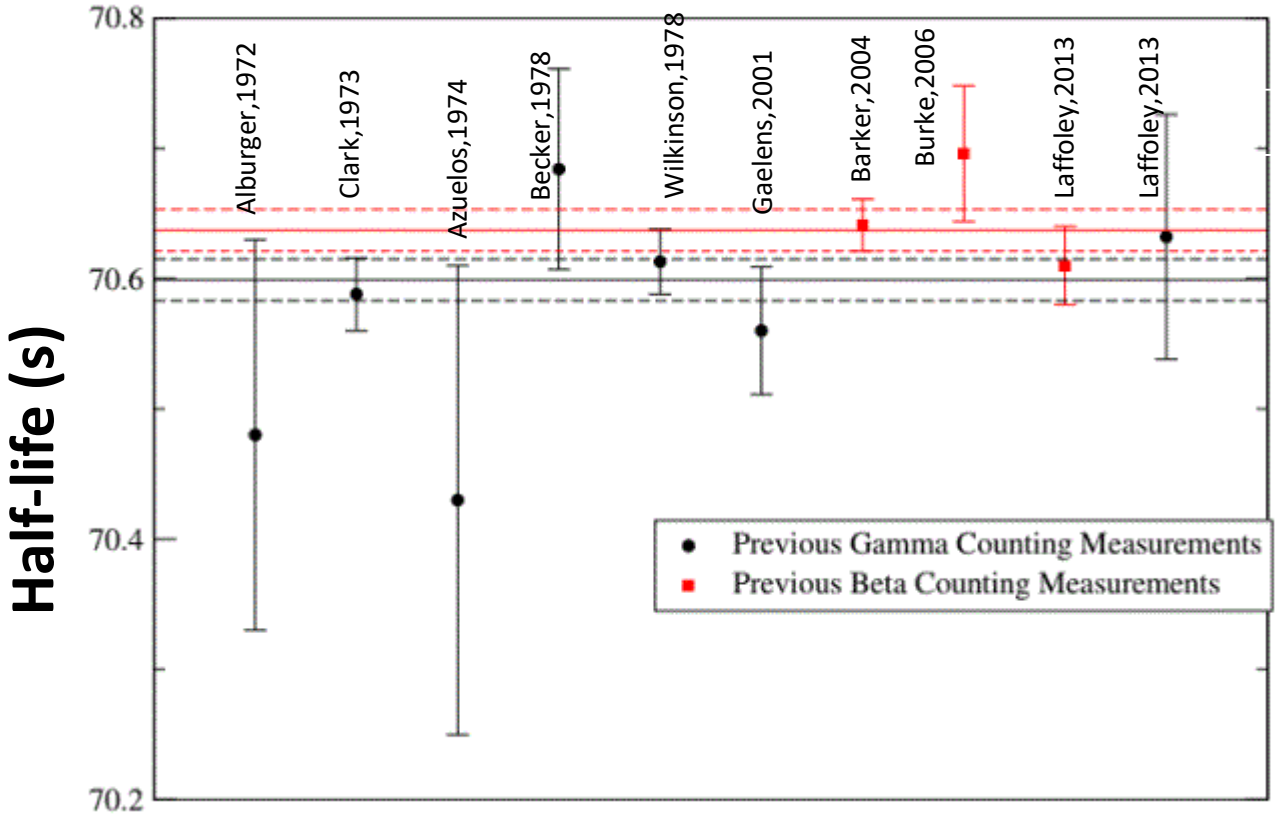
Possible discrepancy in ^{14}O Half-Life measurements



$T_{1/2}$ = 70.637 ± 0.016 s

$T_{1/2}$ = 70.599 ± 0.016 s

- **Goal:** To provide the highest - precision half-life measurement for ^{14}O that can potentially resolve this discrepancy – TRIUMF ISAC

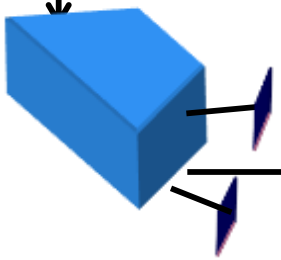
TRIUMF ISAC (Isotope Separator and Accelerator)

TRIUMF 500 MeV
Cyclotron 100 µA

proton beam

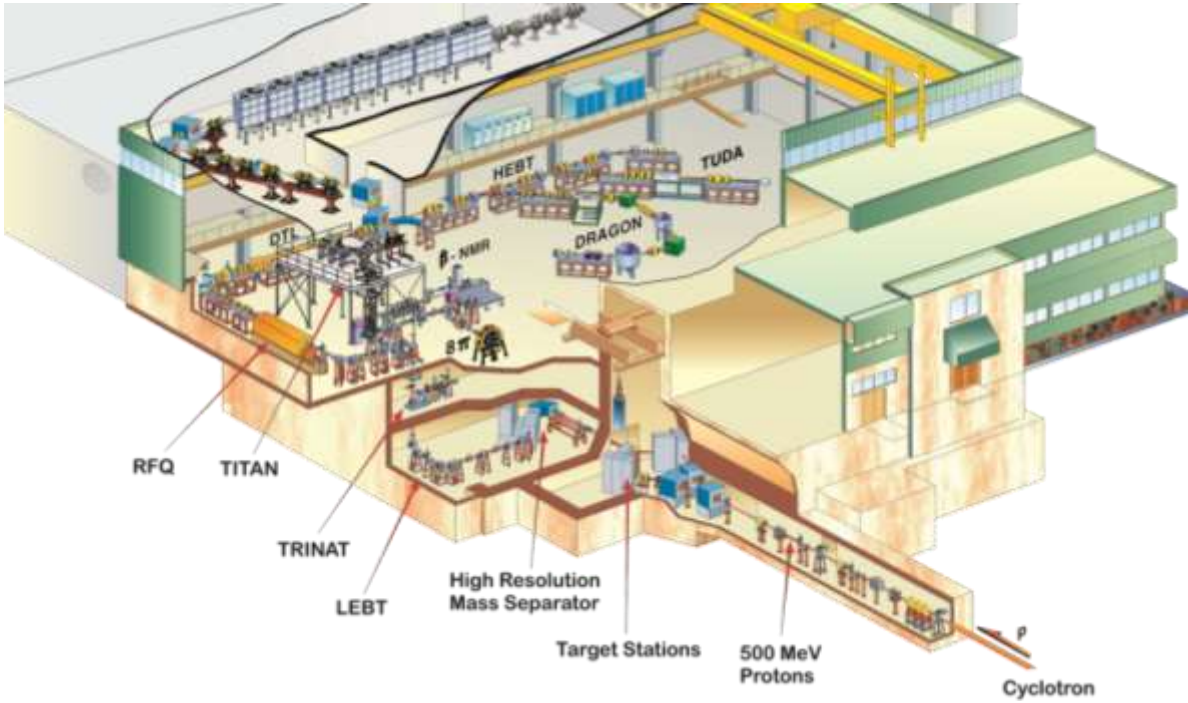
production target

ion source



mass separator

~40 keV beam



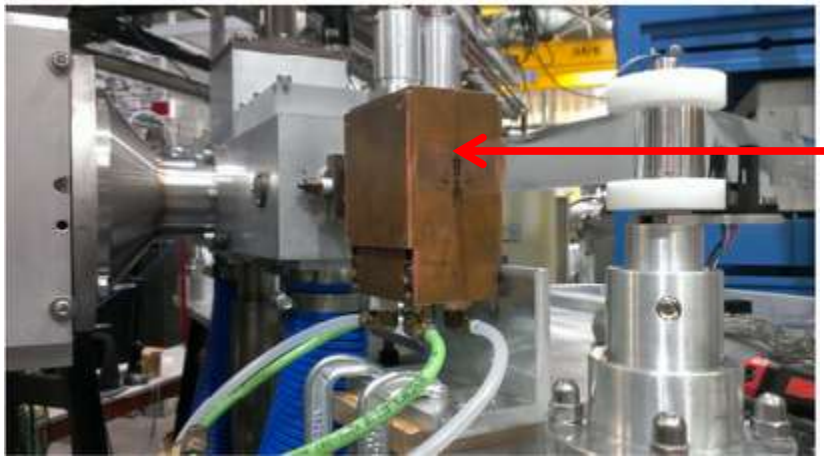
experimental area

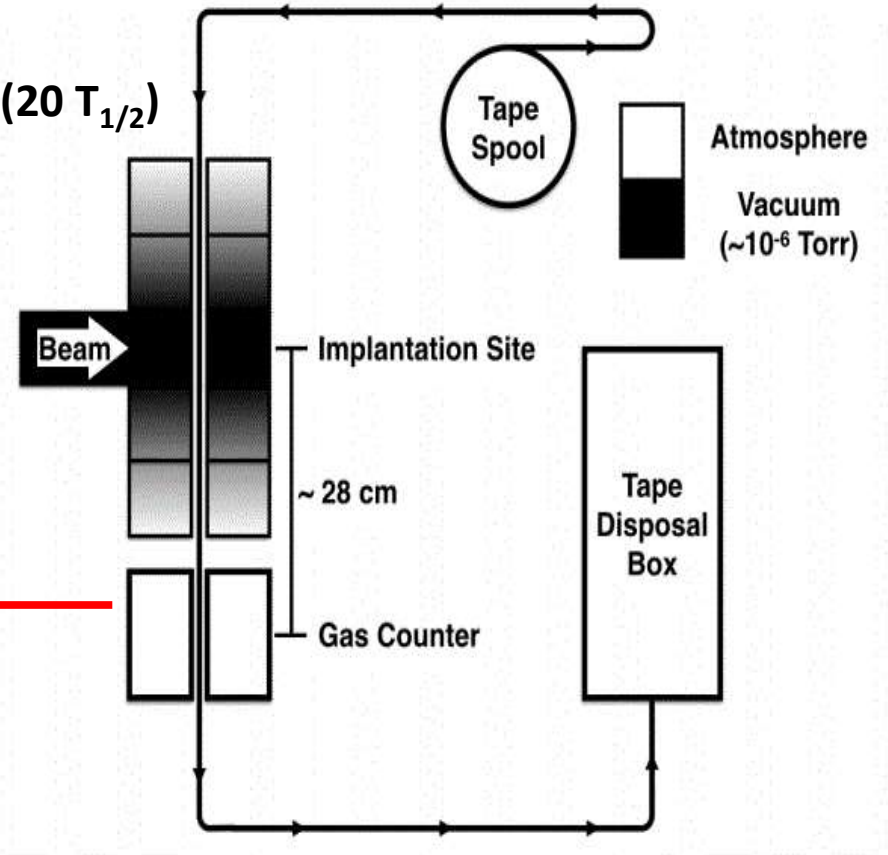
$^{12}C^{14}O$ beam at ~10^5 ions/s

4π Proportional Gas counter and Fast Tape System

Gas filled proportional counter (detects beta particles)

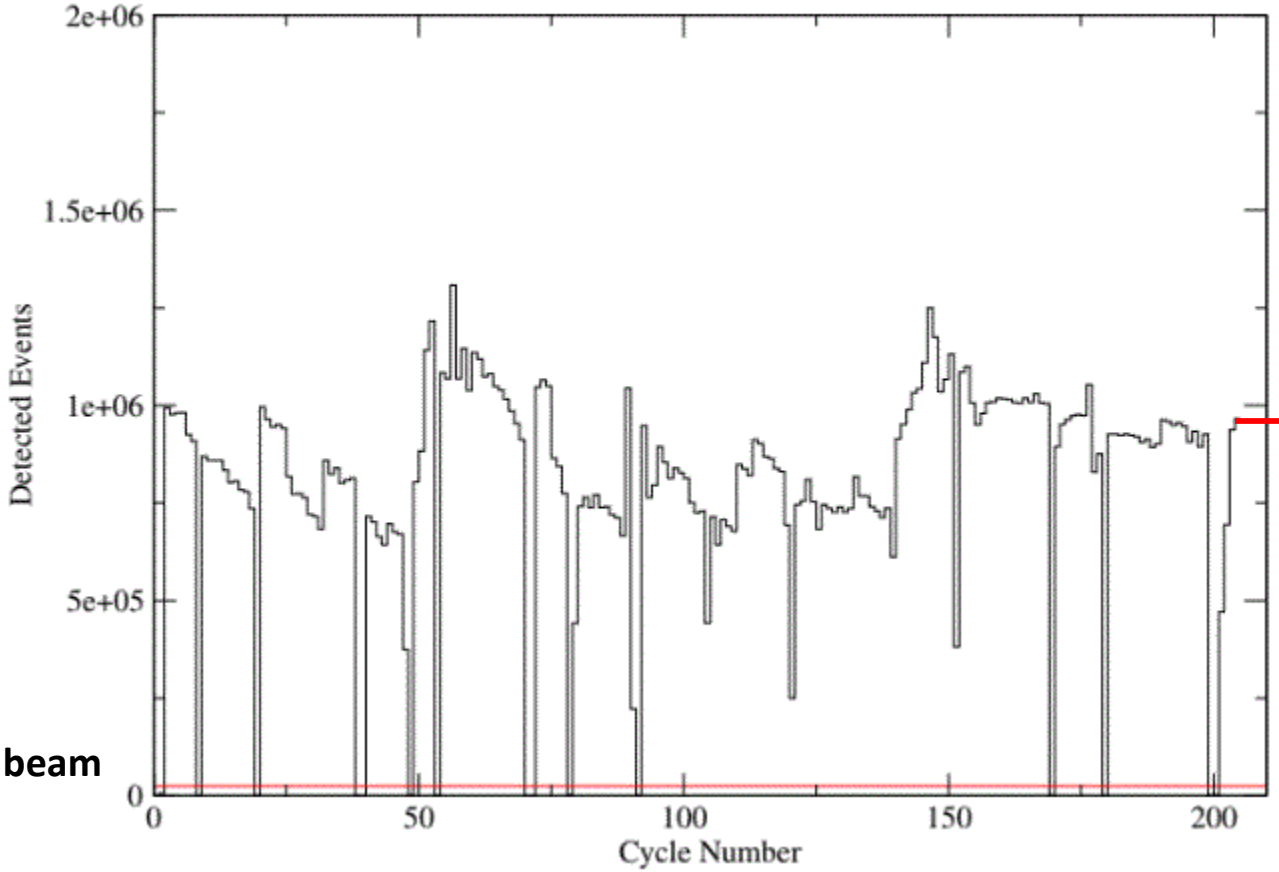
- **Beam is implanted onto tape (1 to 3 min)**
- **Sample is moved to centre of counter (~1 s)**
- **Count exponential decay activity for ~24 min (20 $T_{1/2}$)**
- **Cycle repeated (200 total cycles, 5 days)**





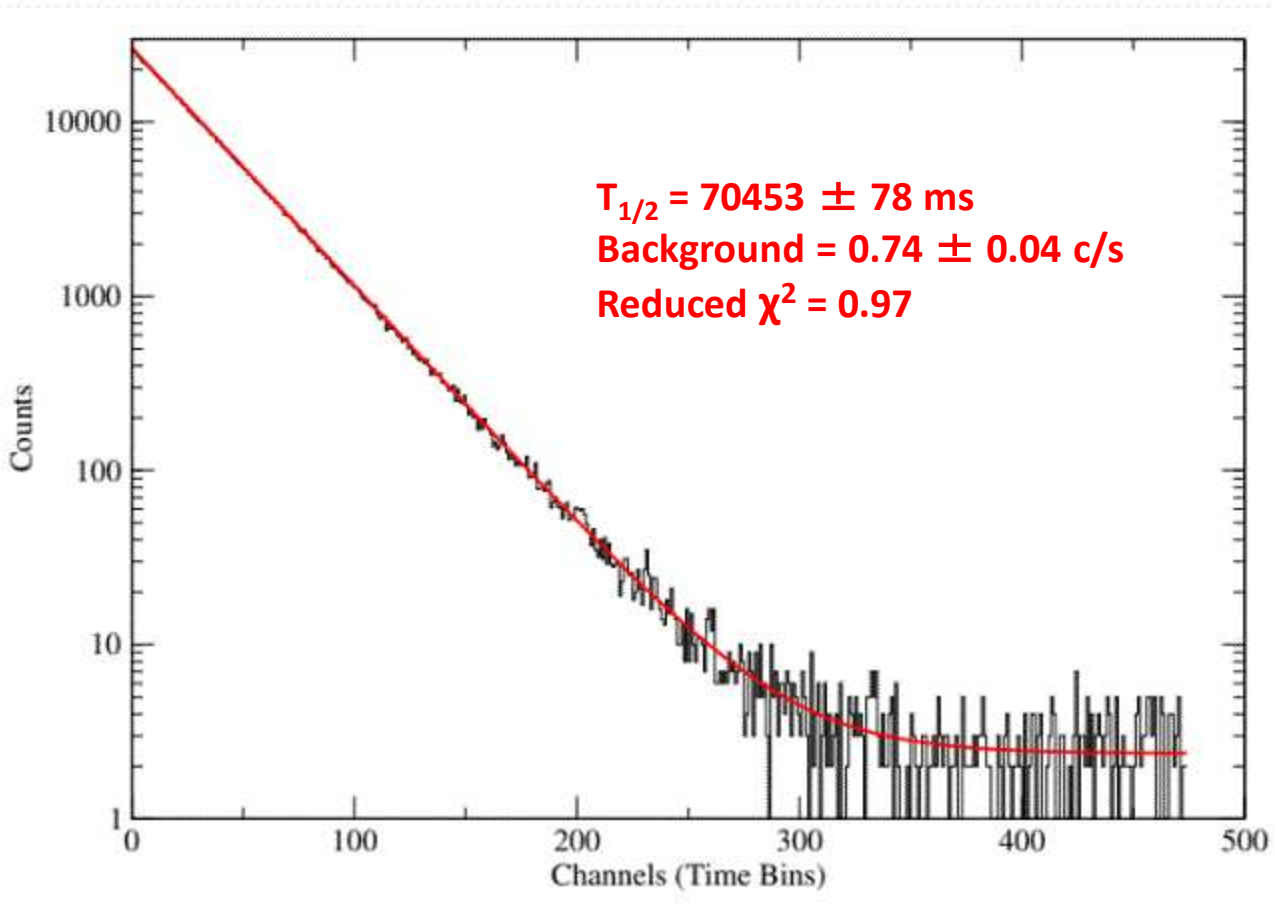
Data Selection

- **Removed cycles with very low statistics (cyclotron interruption)**



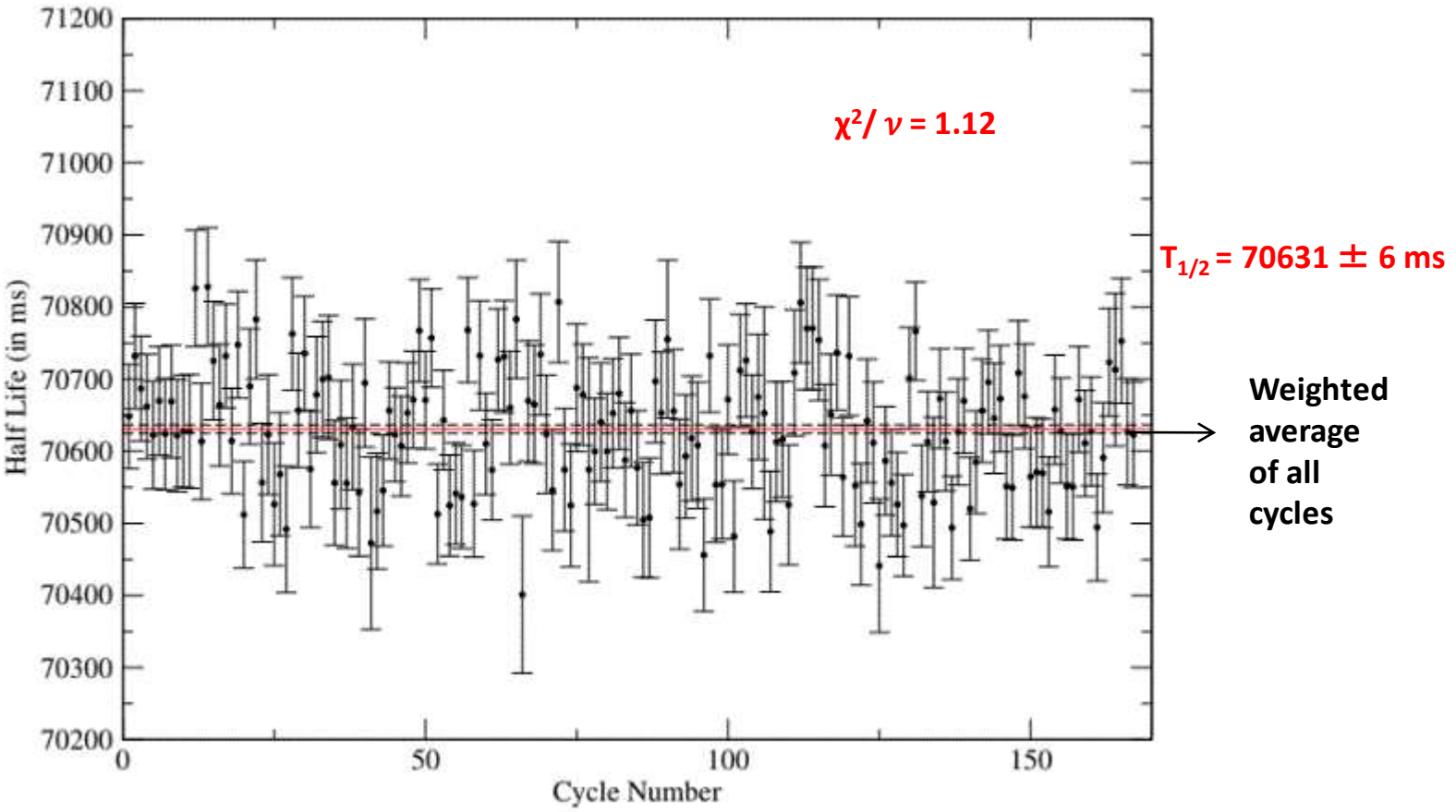
Decay Curve Fitting

- Data were fit to the exponential decay curve
- Slope on log scale will give the value of decay constant (half life)



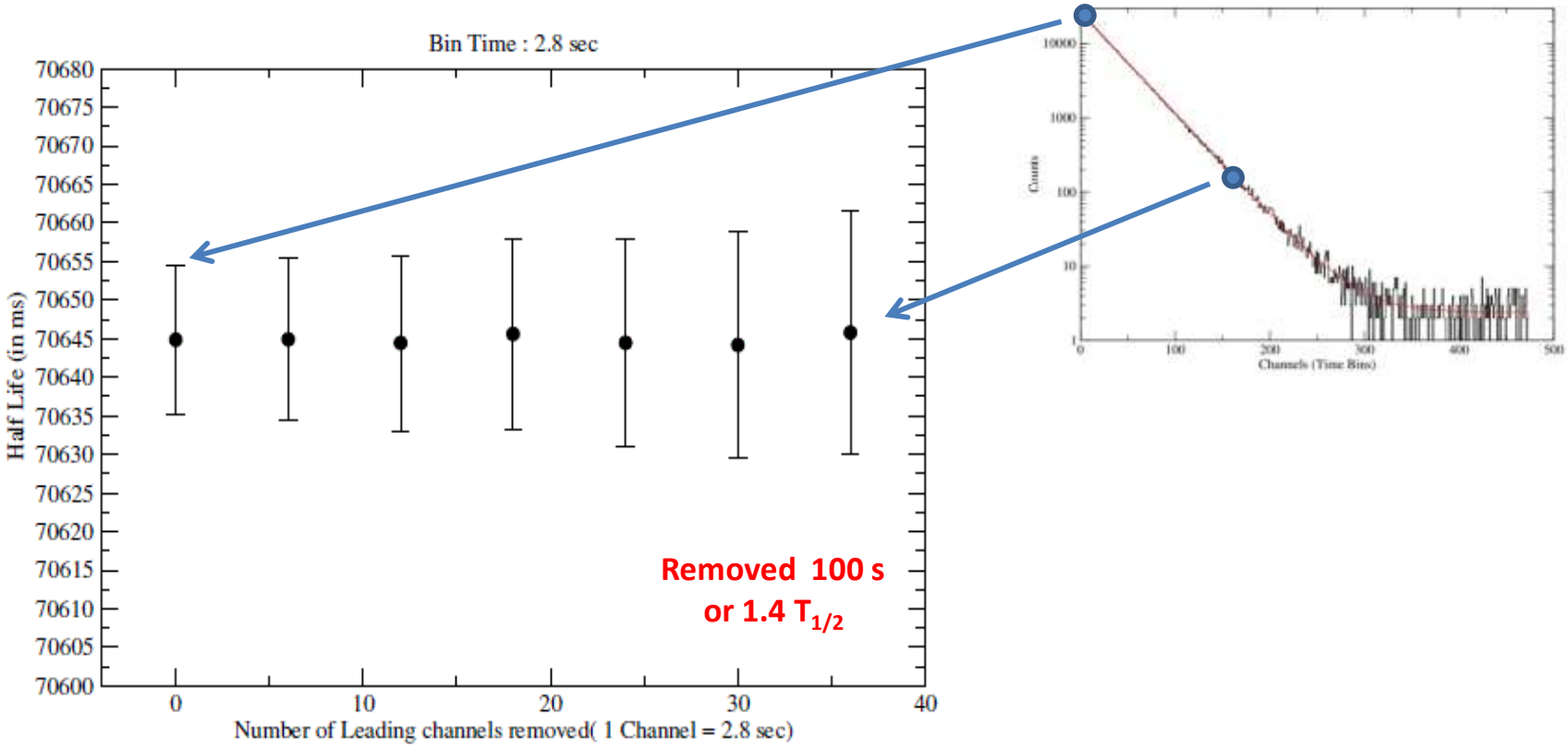
Deduced Half life of Selected Cycles

- Total of 183 cycles (statistical precision ±6 ms or ± 0.008%)

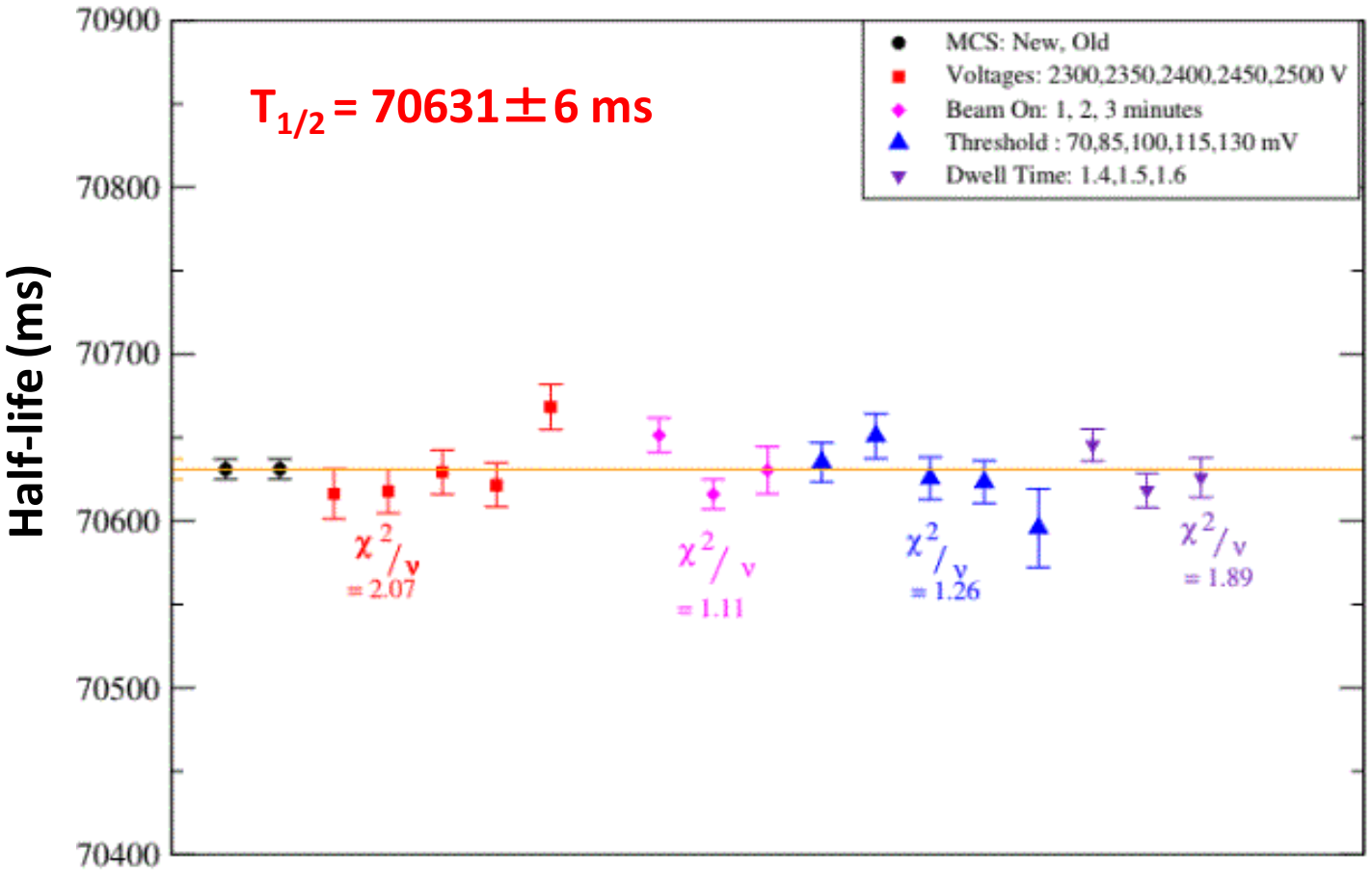


Leading Channel Removal Plots

- In order to search for rate dependent effects, leading channels are removed
- Refit to determine the half life as a function of rate



Tests For Possible Systematic Uncertainties



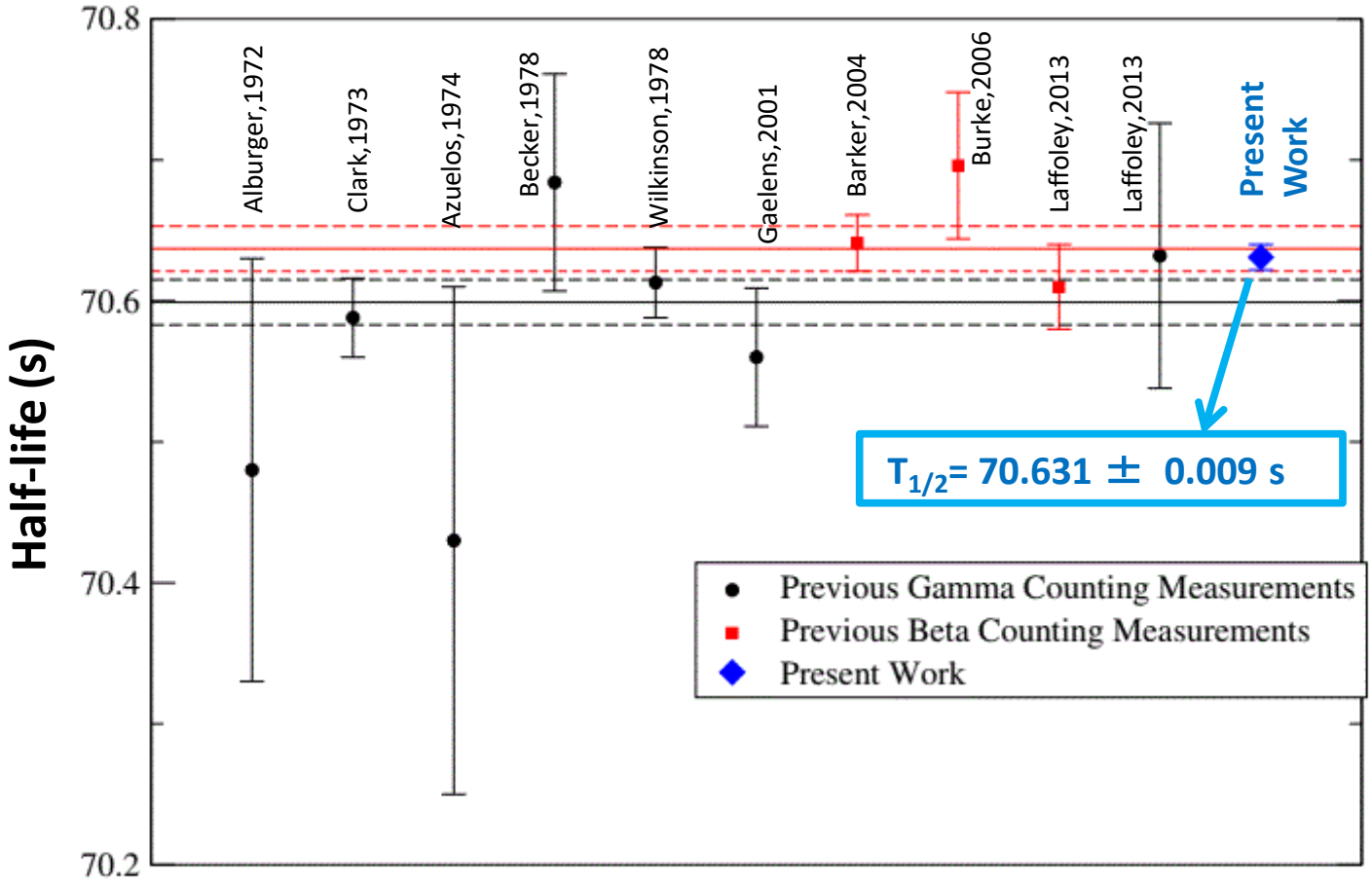
Uncertainty Budget and Final Result

Parameters	Uncertainty (ms)
Half Life (statistical)	6.0
Voltage setting	6.0
Dead time uncertainty	1.0
Contaminant (Na)	0.8
Contaminant (Al)	0.5
Total (quadrature sum)	8.6

Final Result: $T_{1/2}$ (^{14}O) = 70631 ± 9 ms

Comparison to previous measurements

- **Half life of all the previous 10 measurements along with the present work**



Conclusion

- Most precise ^{14}O half life ever measured !!

Final Result: $T_{1/2}$ (^{14}O) = 70631 ± 9 ms

- Current measurement more precise than previous world average (±0.013%)

- Future Work→ Measuring half life with GRIFFIN (gamma decay)
  - GRIFFIN described in next talk from Andrew MacLean

Thank You!

- G.F.Grinyer[1], G.C.Ball[2], J.R.Leslie[3], C.E.Svensson[4], F.A.Ali[4], C.Andreoiu[5], N.Bernier[2], S.S.Bhattacharjee[2], V.Bildstein[4], M.Bowry[2], C.Burbadge[4], R.Caballero-Folch[2], R.Coleman[4], A. Diaz Varela[4], M.R.Dunlop[4], R.Dunlop[4], A.B.Garnsworthy[2], G.M.Huber[1], B.Jigmeddorj[4], K.Kapoor[1], A.T.Laffoley[4], K.G.Leach[6], J.Long[7], A.D.MacLean[4], C.Natzke[6], B.Olaizola[2], A.J.Radich[4], N.Saei[1], J.Smallcombe[2], A.Talebitaher[1], K.Whitmore[5] and T.Zidar[4]
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