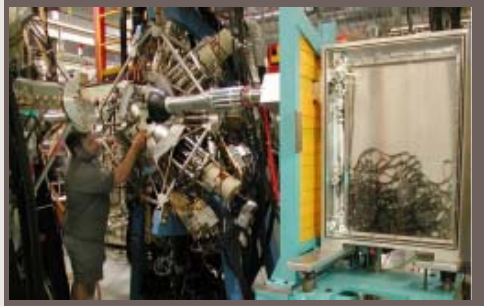
Recent Superallowed Fermi β-Decay Studies at ISAC

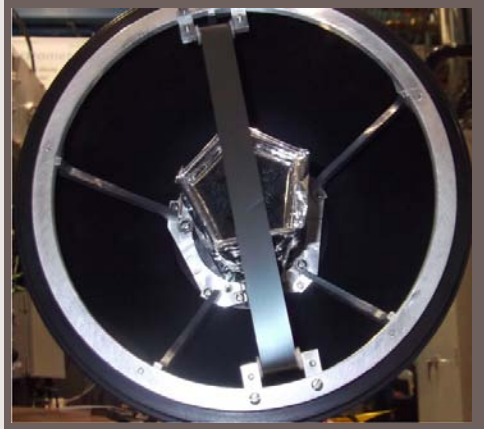
^{14}O (S1140) and ^{74}Rb (S823)

ISCA Science Forum

February 15, 2012

Gordon Ball TRIUMF





Nobel 2008

Unitarity of the Cabbibo, Kobayashi, Maskawa Matrix

Weak eigenstates $\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$ Mass eigenstates

V_{ud} (nuclear β-decay) = 0.97425(22)
V_{us} (kaon-decay) = 0.2253(19)
V_{ub} (B meson decay) = 0.00339(44)

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

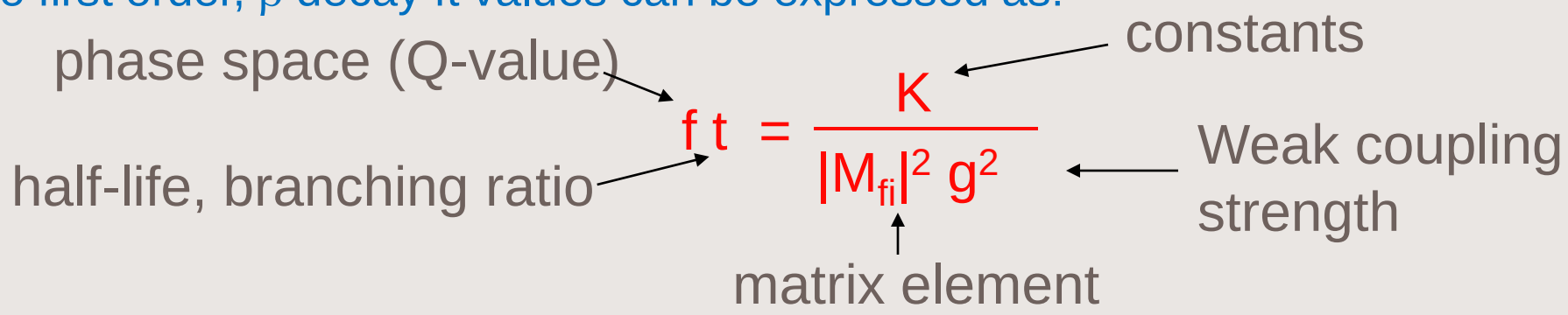
I.S. Towner & J.C. Hardy arXiv:1108.2516v1

⇒unitarity is satisfied to a precision of 0.06%.

V_{ud} can be determined from high-precision measurements of the ft values for superallowed $0^+ \rightarrow 0^+$ Fermi β-decays

V_{ud} : The Responsibility of Low-Energy Nuclear Physics

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



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:

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

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

Vector coupling constant → $G_V^2 = \frac{K}{2\,ft}$ $\qquad |V_{ud}| = G_V / G_F$ ← Fermi coupling constant

Thirteen well-known Superallowed β-emitters

$$Ft = ft(1+\delta_R)(1-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R)} = \text{constant}$$

Experiment

Calculated corrections (~1%) (nucleus dependent)

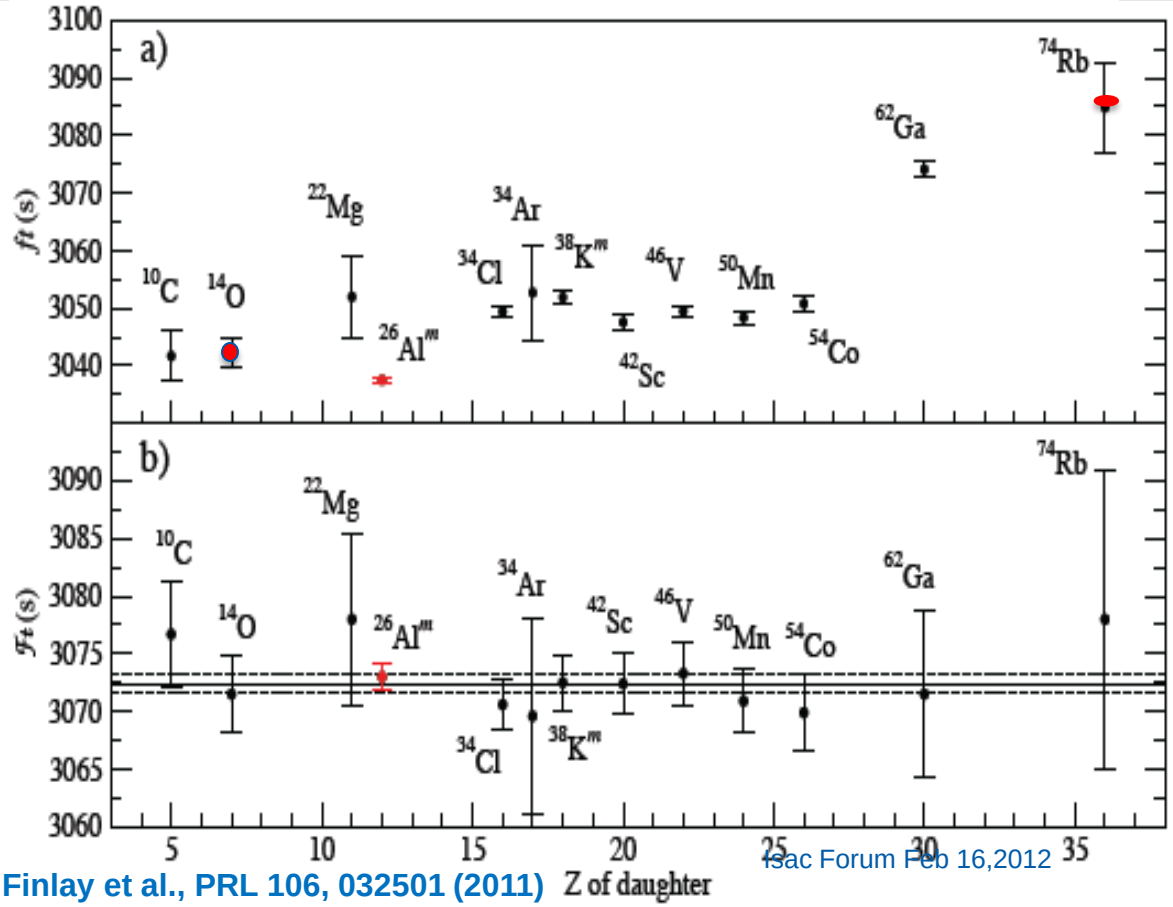
Inner radiative correction (~2.4%) (nucleus independent)

CVC Hypothesis

$\overline{Ft} = 3072.08 \pm 0.79$ s

CVC ~1.3 x 10^{-4}

Towner and Hardy PRC 82(2010)065501

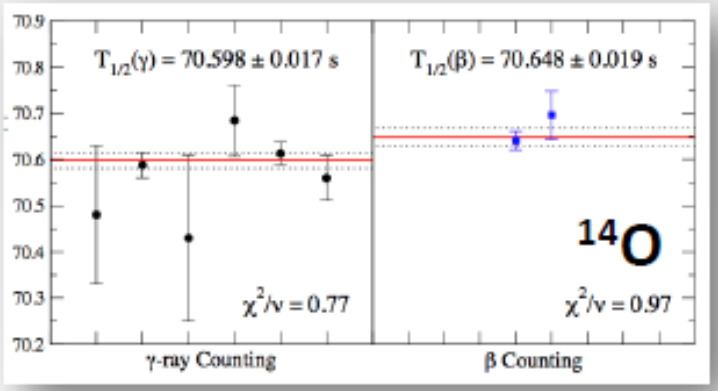


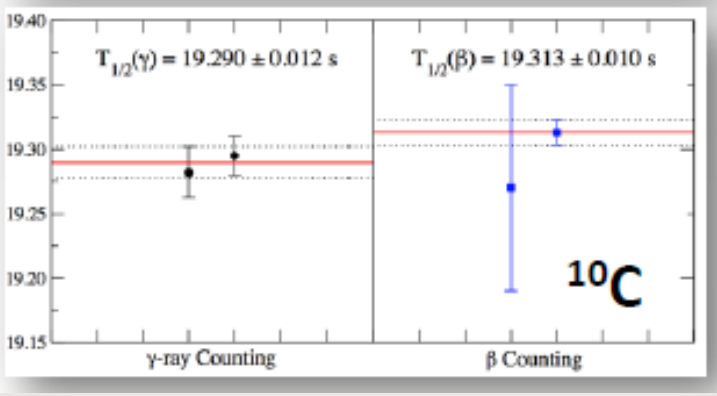
P. Finlay et al., PRL 106, 032501 (2011)

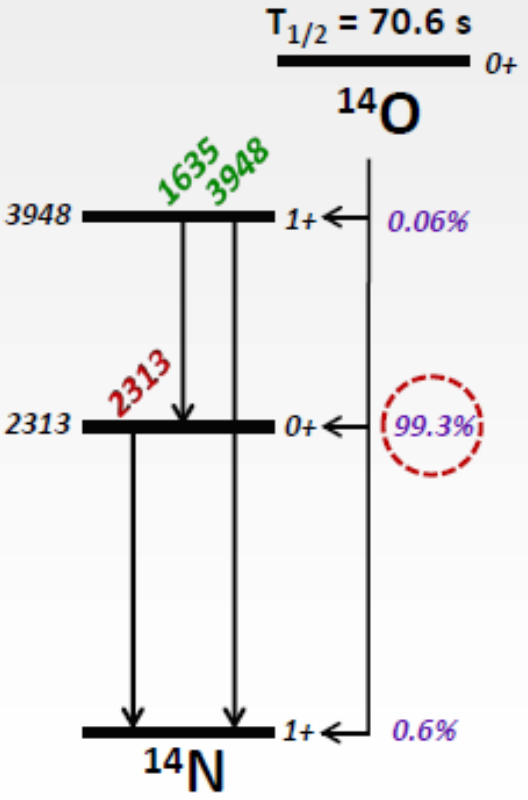
- uncertainty in the weighed average Ft value is dominated by theoretical uncertainties in the nuclear-structure dependent Isospin Symmetry Breaking (ISB) corrections
- new high-precision measurements designed specifically to test the ISB corrections from a variety of theoretical approaches
- there are also remaining cases in which potential systematic errors in the experimental data must be addressed

Half-life of ^{14}O (S1140): *Grinyer et al*

- Systematic difference in ^{14}O (and ^{10}C) half-life related to counting method
  - Direct β counting - fast ✓ efficient ✓ no pile up ✓ not selective ✗
  - Gated γ-ray counting - slow ✗ inefficent ✗ pile up ✗ decay selective ✓

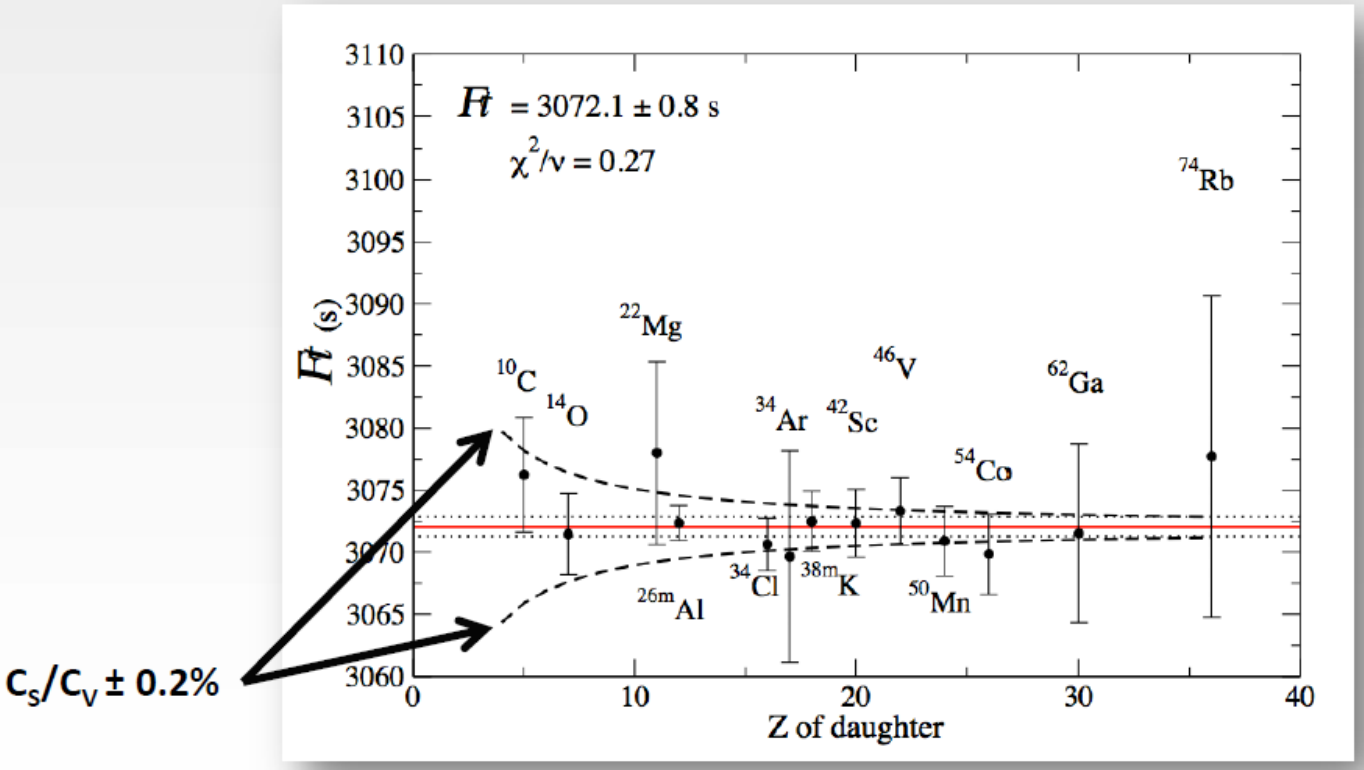






Superallowed *Ft* values and Scalar Currents

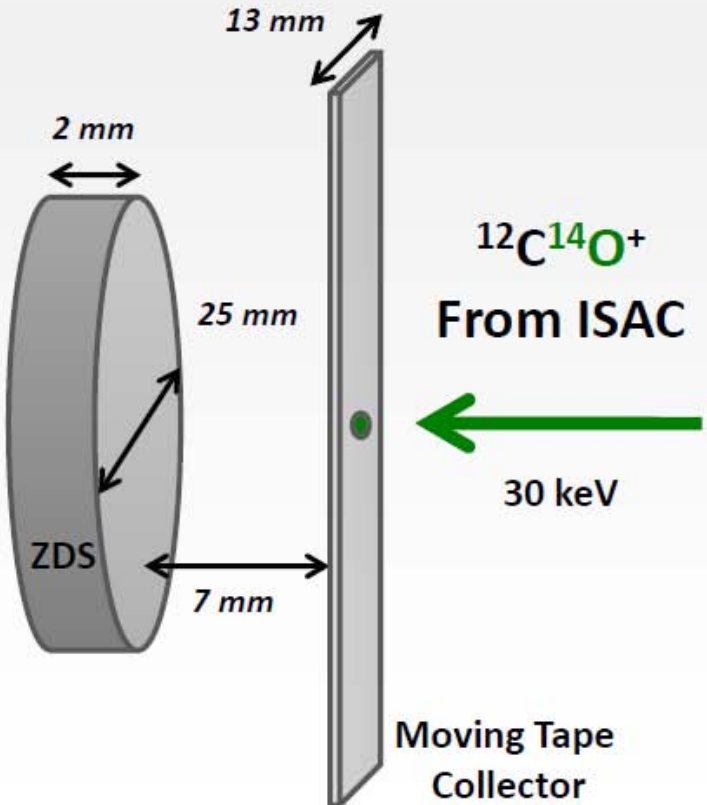
- Limits on scalar interactions derived from deviations to *Ft* = constant
  - *Ft* values for ^{10}C, ^{14}O are the most sensitive
  - Resolving the systematics associated with the half-life is essential

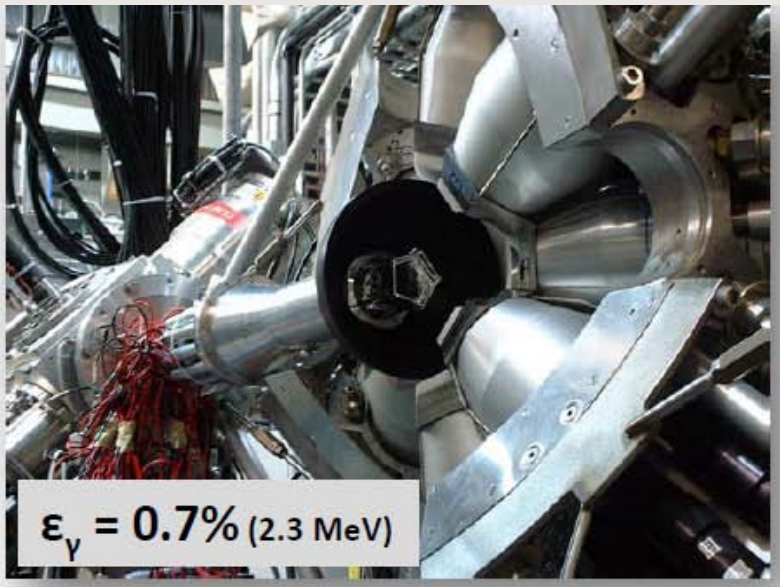


TRIUMF

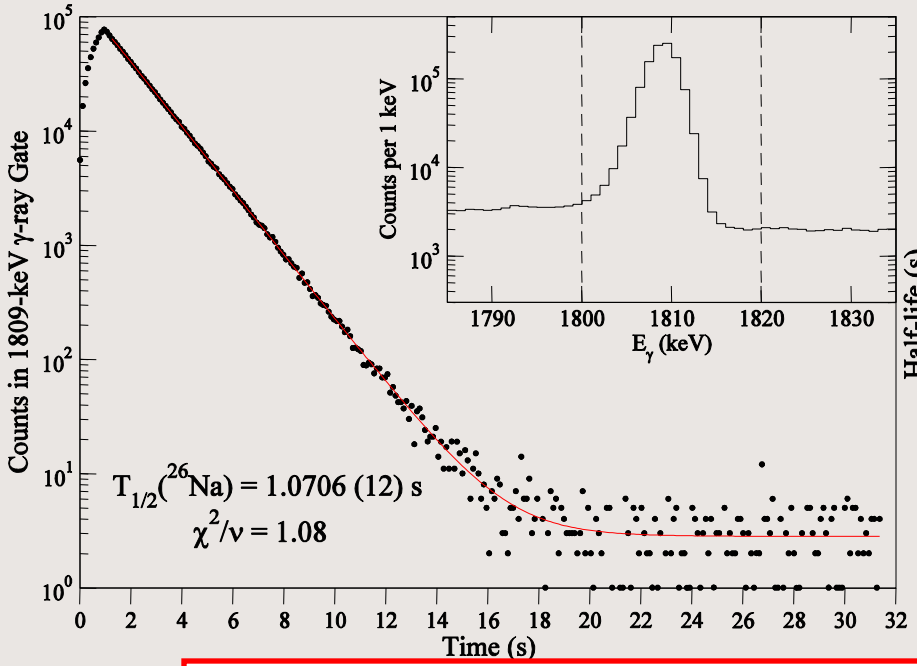
High-precision half-life measurement for ^{14}O

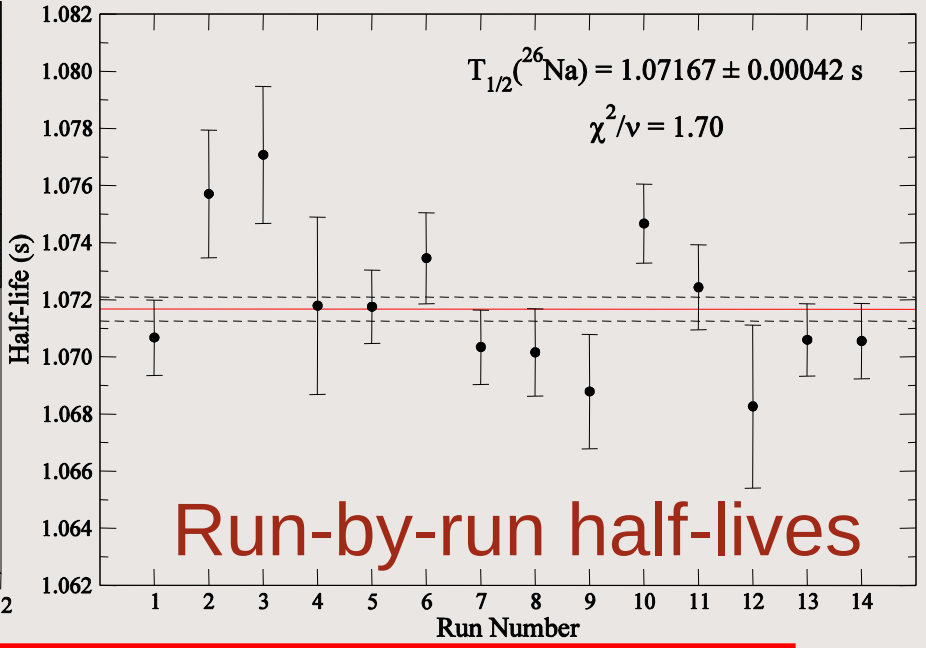
- Simultaneous β and γ-ray counting
  - 8π spectrometer 20 HPGe (γ-ray counting)
  - Zero Degree Scintillator (β counting)
- System test in November 2011





Half-life of ^{26}Na via γ-ray counting





Demonstrates the feasibility of high-precision (0.05%) half-life measurements via γ-ray photopeak counting

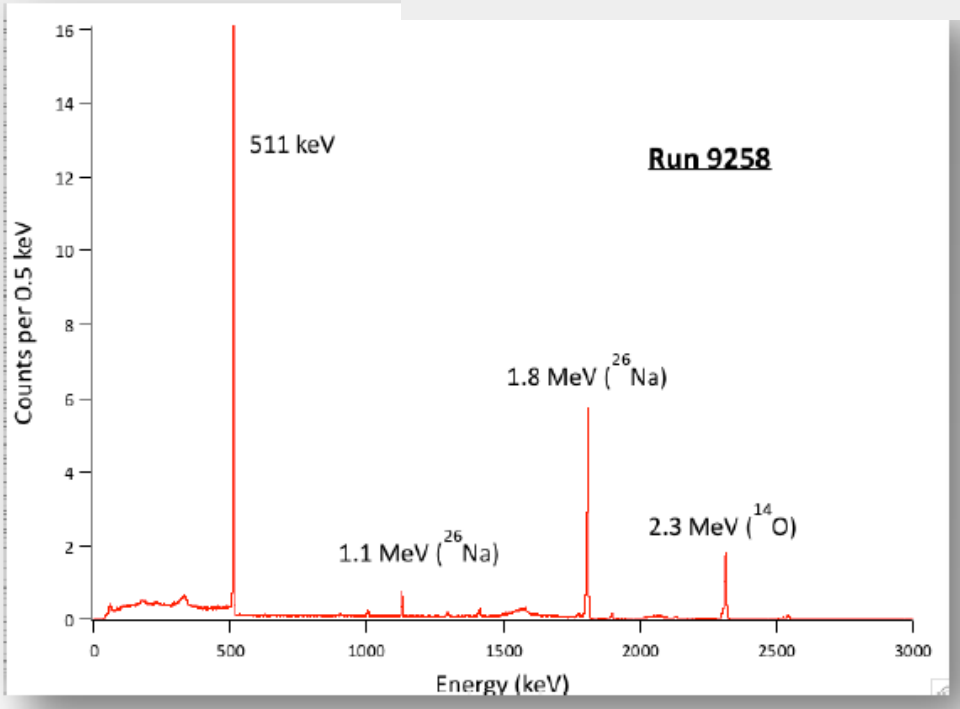
Ha… β C…				…e to β …ing
1.07128(25)	No Correction	1.08174(37)		+28.2σ
	PU Correction	1.07167(55)	-27.2σ	< 1σ

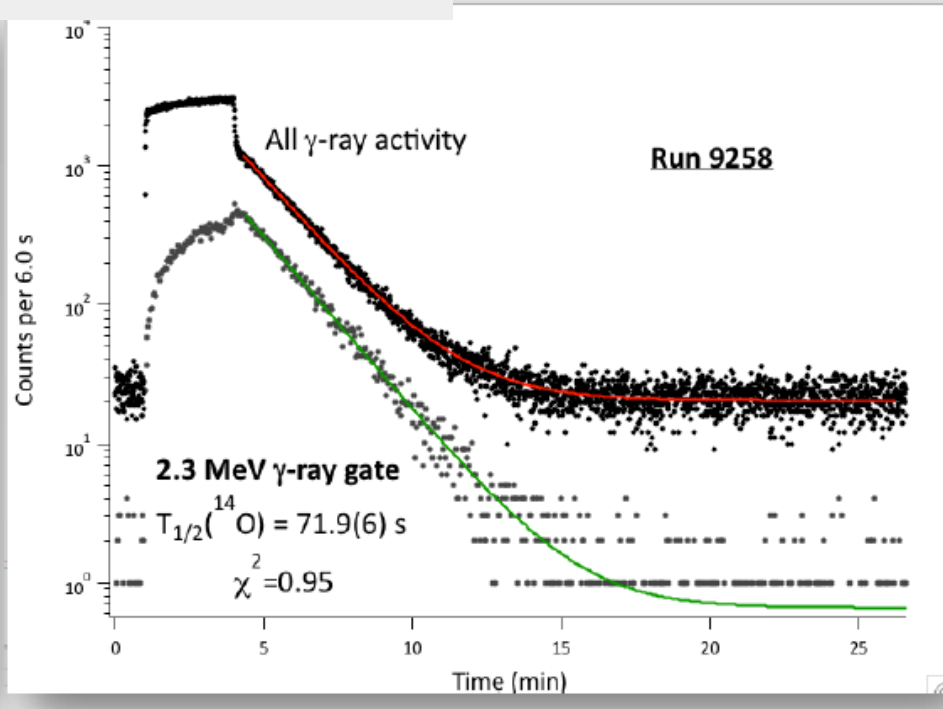
G.F. Grinyer et al. NIM A 579 1005 (2007)

High precision Half-life measurement of ^{14}O: Proof of principle November 2011

γ-counting

- Half-life measurements with 8π
  - No contaminant in 2.3 MeV γ gate
  - Statistical precision (1 run) ~ 0.8%



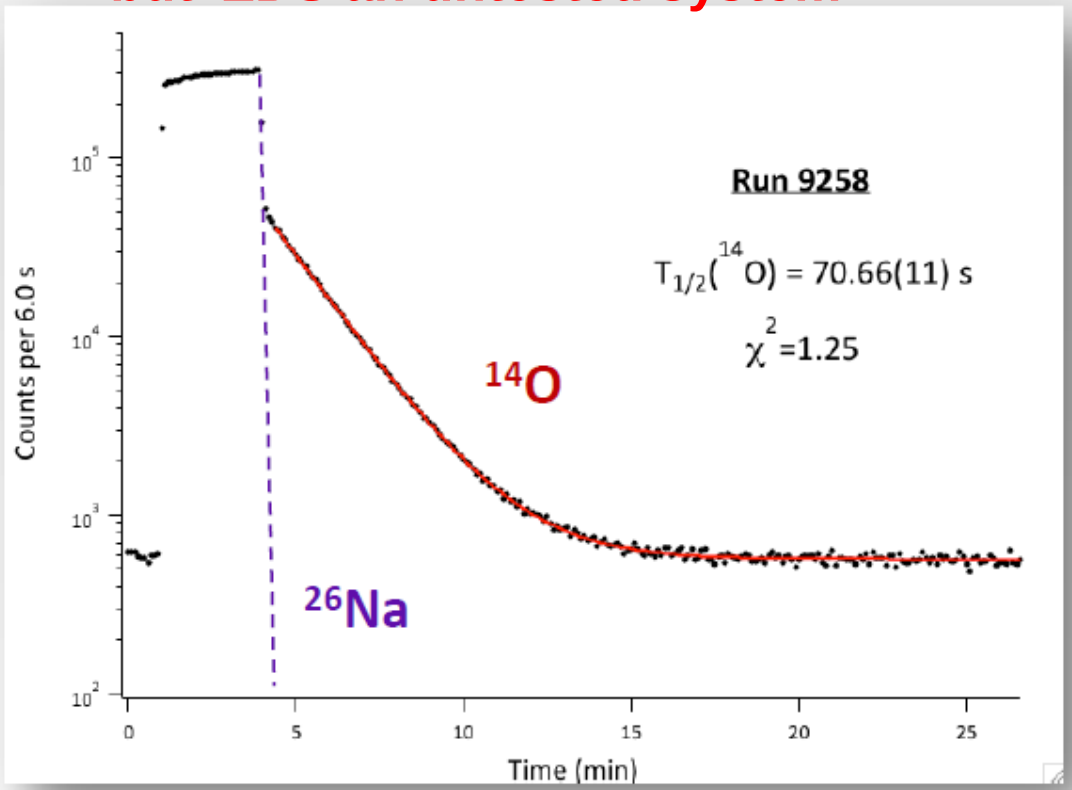


Proof of principle November 2011

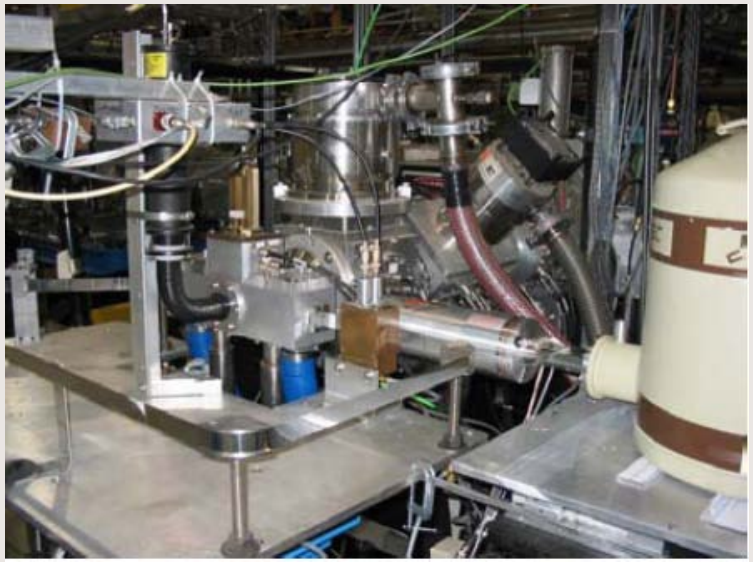
β-counting

- Half-life measurement with ZDS
  - ^{26}Na contaminant ($T_{1/2}$ = 1.07 s)
  - Statistical precision (1 run) ~ 0.2%

but ZDS an untested system

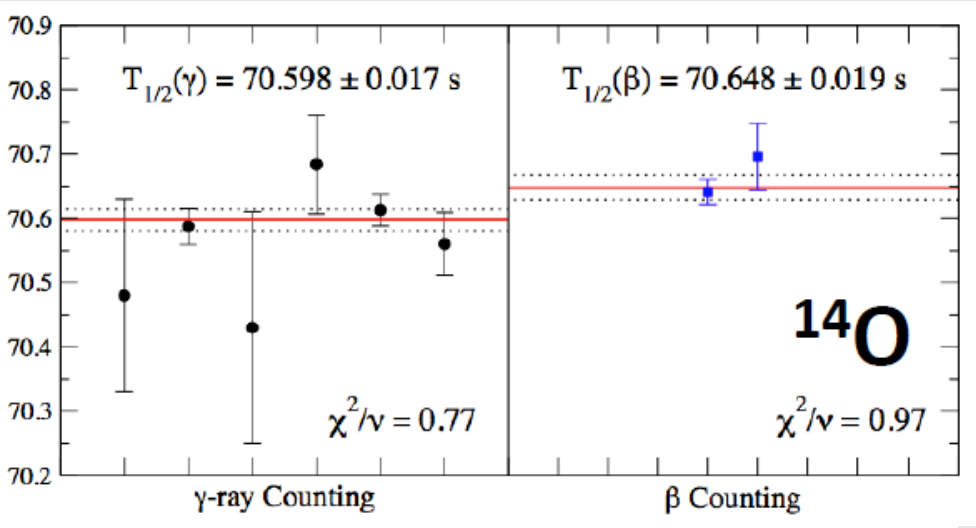


- original plan was to use the 4π gas counter system for β-counting
- diffusion of gaseous elements in aluminized mylar tape
- new thick Al tape system being designed to eliminate this effect



Statistical uncertainties in t ½ for ^{14}O obtained from fits to simulated data for β and γ counting

An overall precision of <0.05% is required to test the systematic differences observed in the world average data between t ½ measurements performed by either γ-ray photopeak or direct β-counting



Nuclide	Beam on (s)	Beam off (s)	Total Cycles (14 shifts)	Beam Rate (ions/s)	Total Precision (s)	(%)
β-counting						
^{14}O	245	1500	312	10^3	0.0249	0.035
	105		339	10^4	0.0065	0.009
	11		360	10^5	0.0049	0.007
γ-counting						
^{14}O	245	800	520	10^3	0.306	0.408
				10^4	0.063	0.084
				10^5	0.016	0.022

S1140 Collaboration

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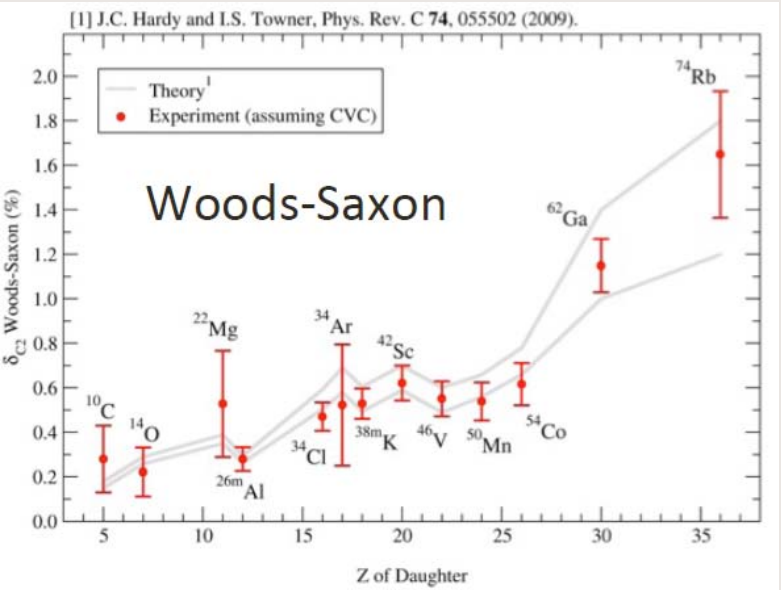
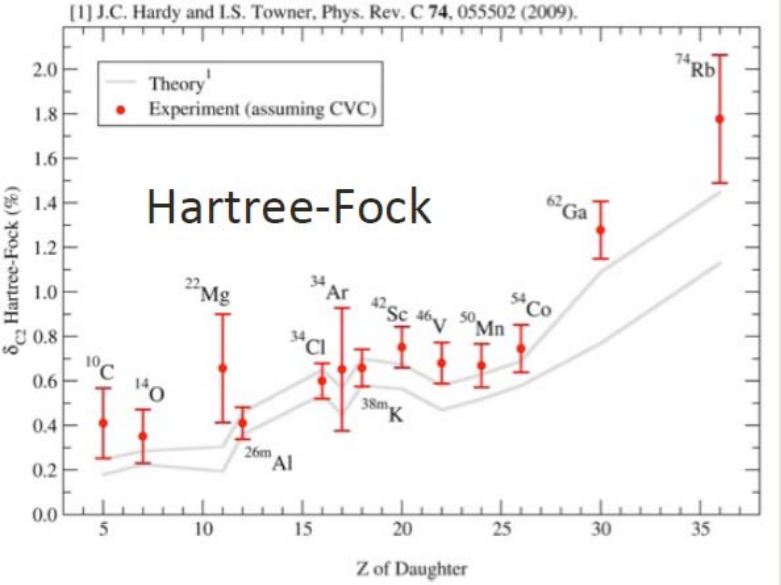
Studies of superallowed β-emitter ^{74}Rb





November 2010

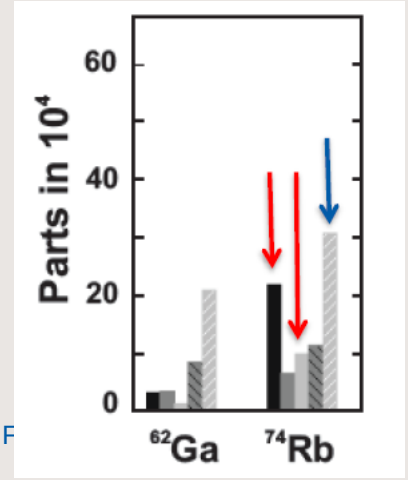
100μA of 500 MeV protons on high-power Nb foil target

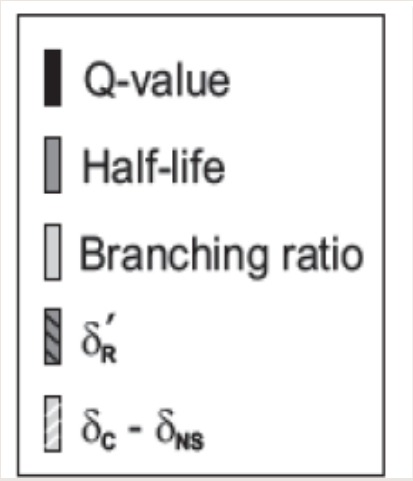
Three experiments focused on the study of the superallowed β-emitter ^{74}Rb (69 ms)

- a high precision branching ratio measurement using the 8π spectrometer

- a high precision measurement of the mass of ^{74}Rb^{8+} with TITAN: RFQ, EBIT and MPET

- a measurement of the charge radius of ^{74}Rb using collinear laser spectroscopy: to reduce the theoretical uncertainty in the nuclear structure correction δC





Superallowed Branching ratios for A > 54 β-emitters and the Pandemonium Effect

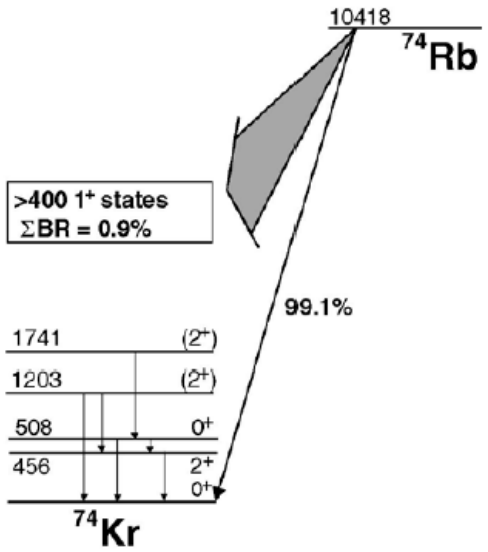
VOLUME 88, NUMBER 25 PHYSICAL REVIEW LETTERS 24 JUNE 2002

Superallowed Beta Decay of Nuclei with $A \geq 62$: The Limiting Effect of Weak Gamow-Teller Branches

J. C. Hardy and I. S. Towner*
Cyclotron Institute, Texas A & M University, College Station, Texas 77843
(Received 16 January 2002; published 6 June 2002)

The most precise value of V_{ud}, which is obtained from superallowed nuclear β decay, leads to a violation of Cabibbo-Kobayashi-Maskawa unitarity by 2.2σ. Experiments are underway on two continents to test and improve this result through decay studies of odd-odd $N = Z$ nuclei with $A \geq 62$. We show, in a series of illustrative shell-model calculations, that numerous weak Gamow-Teller branches are expected to compete with the superallowed branch in each of these nuclei. Though the total Gamow-Teller strength is significant, many of the individual branches will be unobservably weak. Thus, new techniques must be developed if reliable ft values are to be obtained with 0.1% precision for the superallowed branches.

DOI: 10.1103/PhysRevLett.88.252501 PACS numbers: 23.40.Hc, 21.60.Cs, 27.50.+e



For large Q-value β decays, there are generally many weak β branches to the large number of daughter states within the Q-value window.

In the subsequent γ decay, many individual γ-rays may be too weak to identify.

The sum of these unobserved γ intensities will, however, generally be sufficient to prevent precision determination of β decay branching ratios through γ-ray spectroscopy.

High-precision branching ratio measurement for ^{62}Ga: controlling pandemonium via "2+ collector" states

$I_{gs} = 0.1338(26)\ \%$

Unobserved γ feeding of lowest three 2^+ levels

$I'_{2+} = 205 \pm 29$ ppm

$B_{gs} = I'_{gs} / (I'_{gs} + I'_{2+})$

Shell Model: $B_{gs} = 0.20$

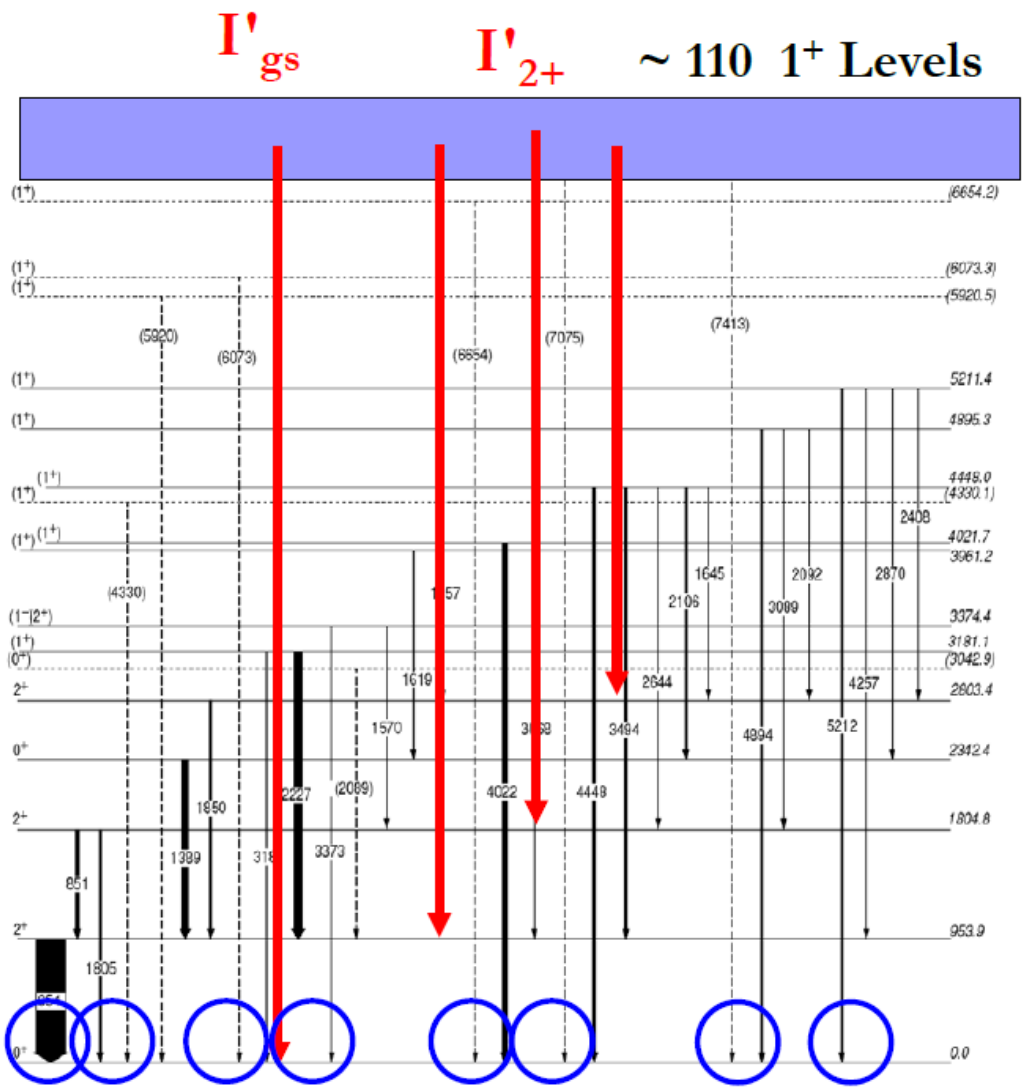
Adopt ±100% uncertainty:

$B_{gs} = 0.0 - 0.40$

$I'_{gs} = 80 \pm 80$ ppm

Superallowed Branching Ratio:

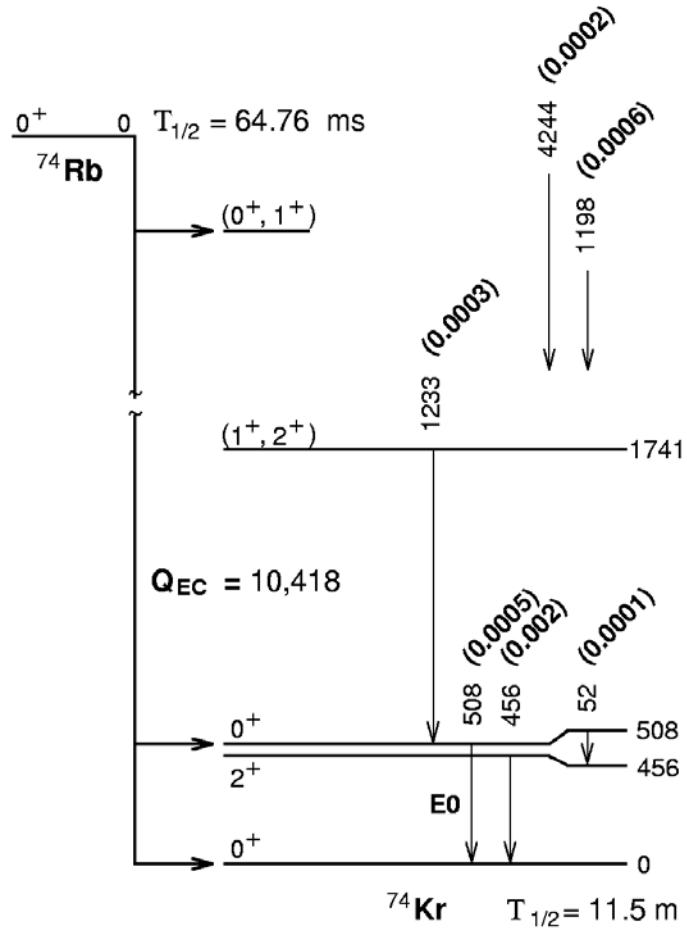
99.858 ± 0.008 %



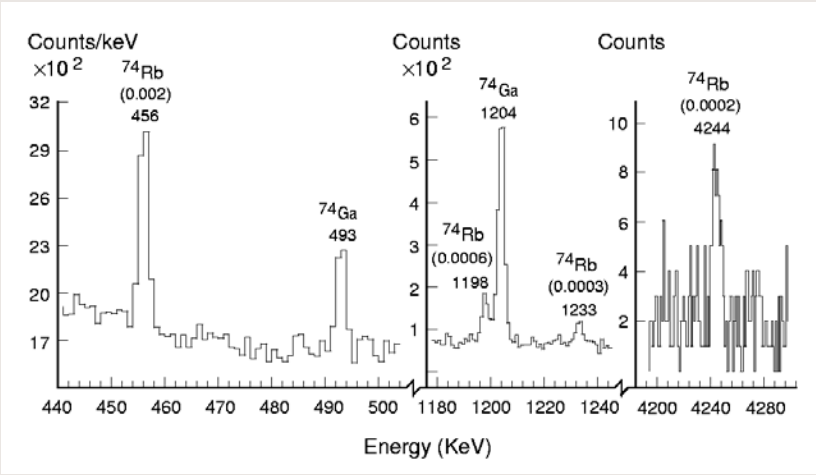
P. Finlay *et al.*, PRC 78 025502 (2008)

^{74}Rb Superallowed Fermi Beta Decay

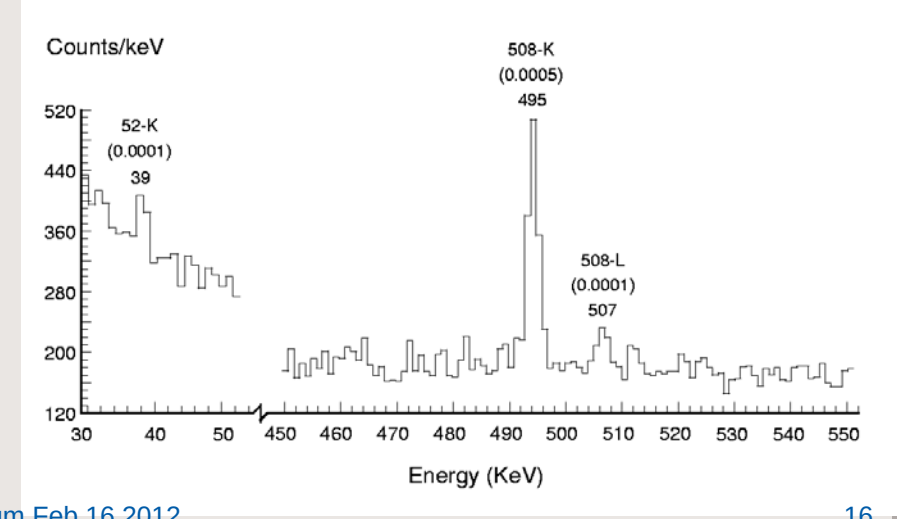
Original BR measurement at ISAC



Gamma-Ray Spectrum (1 HPGe detector)



Conversion Electron Spectrum



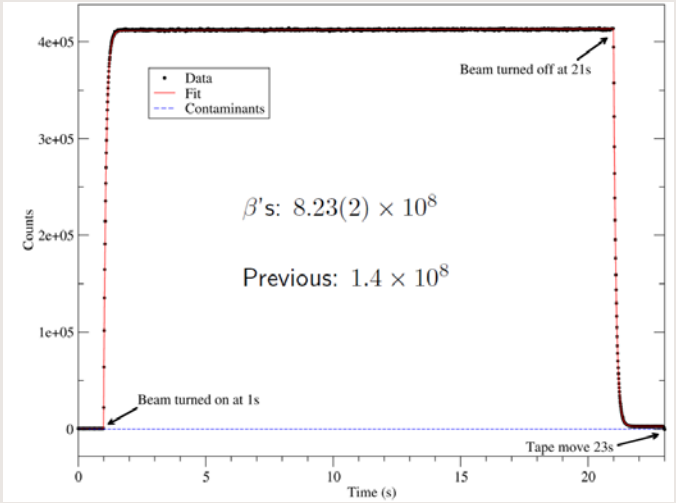
BR = 99.5(1)% Piechaczek *et al* Phys Rev C67 052305(R) 2003

^{74}Rb Branching ratio Measurement using the 8π spectrometer with Sceptar and PACES (S823) Ryan Dunlop *et al*

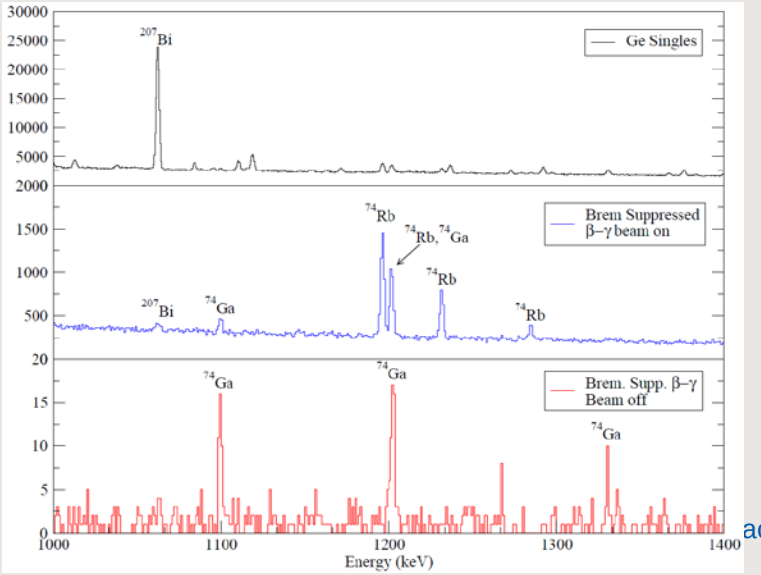
Goal: reduce uncertainty in BR by factor of 3

- previous value 99.5 +/- 0.1 % obtained using only one HPGe detector and two Si(Li) counters

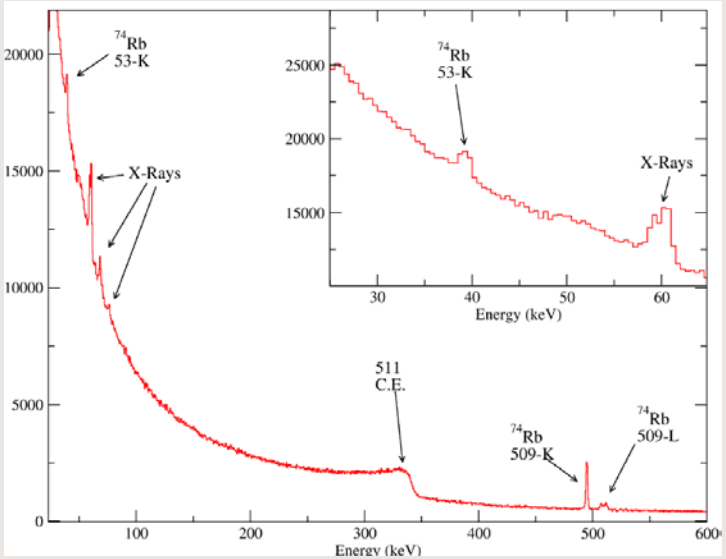
Data obtained in Nov2010 with HP Ta and 100uA
- ~ 10000/s ^{74}Rb
- ^{74}Rb/^{74}Ga ratio increased by ~ 150



beta-coincident gamma-ray spectra

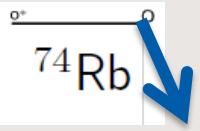


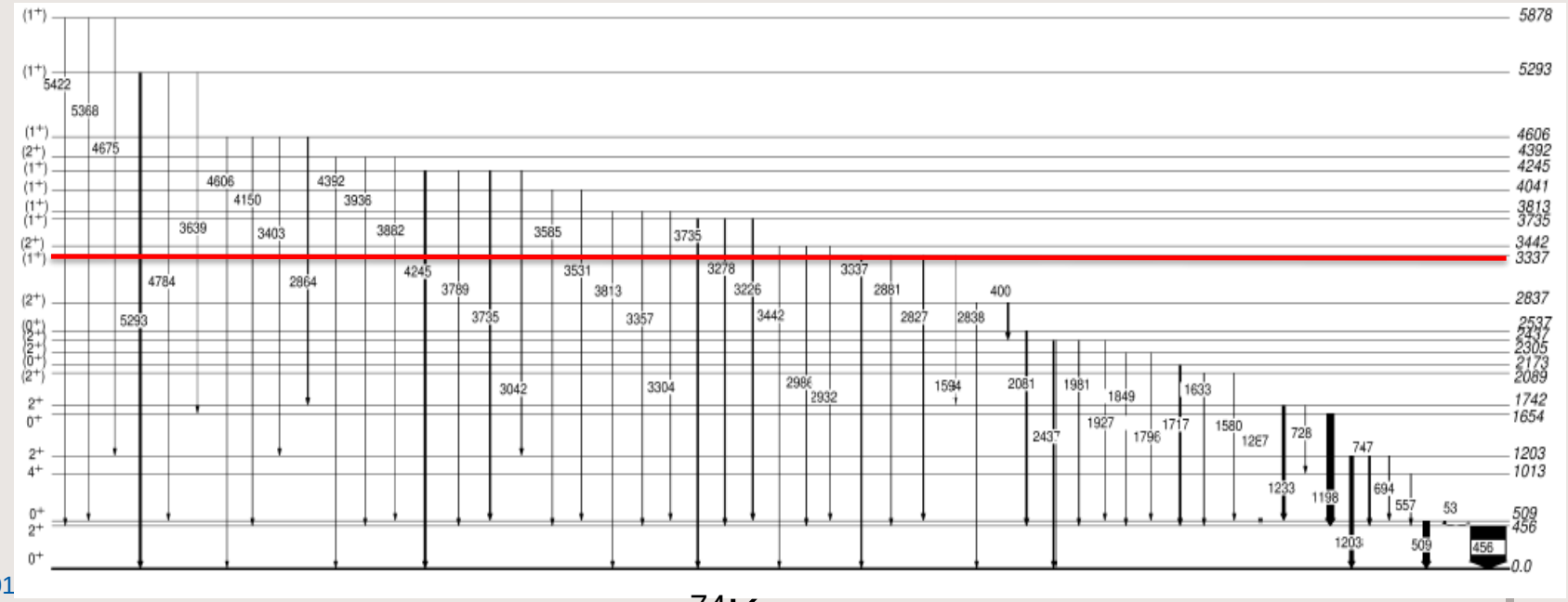
beta-coincident Si(Li) spectrum



^{74}Rb Branching ratio Measurement using the 8π spectrometer

- High Q-value leads to feeding of many high-lying 1+ levels
- The low-lying 2+ and 0+ levels act as collector states and enable a measure of total decay strength
- Present experiment confirmed previous decay scheme
- 47 new transitions and 14 new levels were identified. Lowest 1+ observed at 3.337 MeV
- comparison with theory for estimate of unobserved gs decay strength should lead to 0.03% uncertainty in branching ratio





^{74}Kr

S823 Collaboration

A special thanks to the targets and ion source group and ISAC operations

Thank you!

Merci!

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's Simon Fraser | Toronto | Victoria | York

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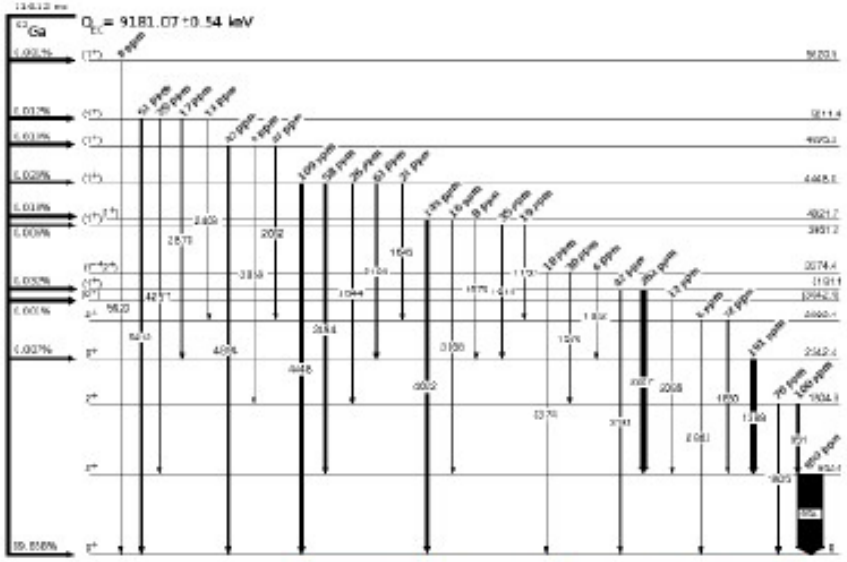
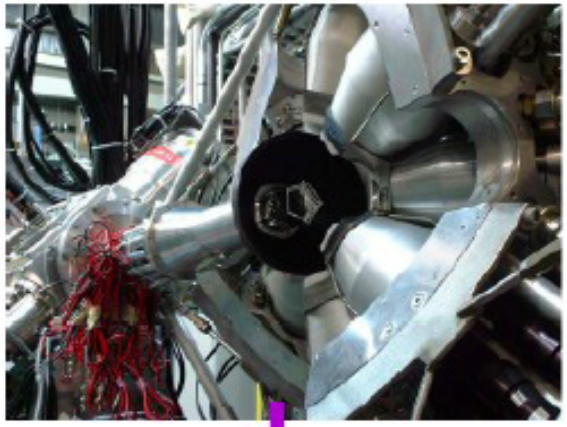
Simulated Performance

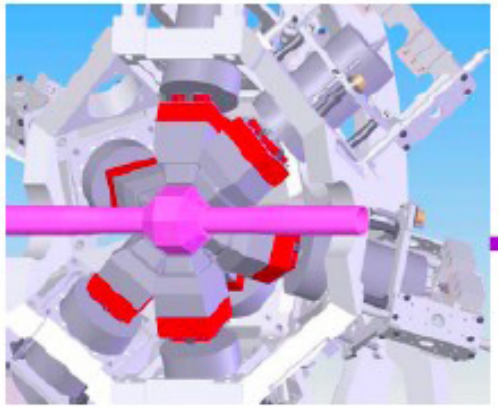
Example: ^{62}Ga Superallowed Fermi β Decay

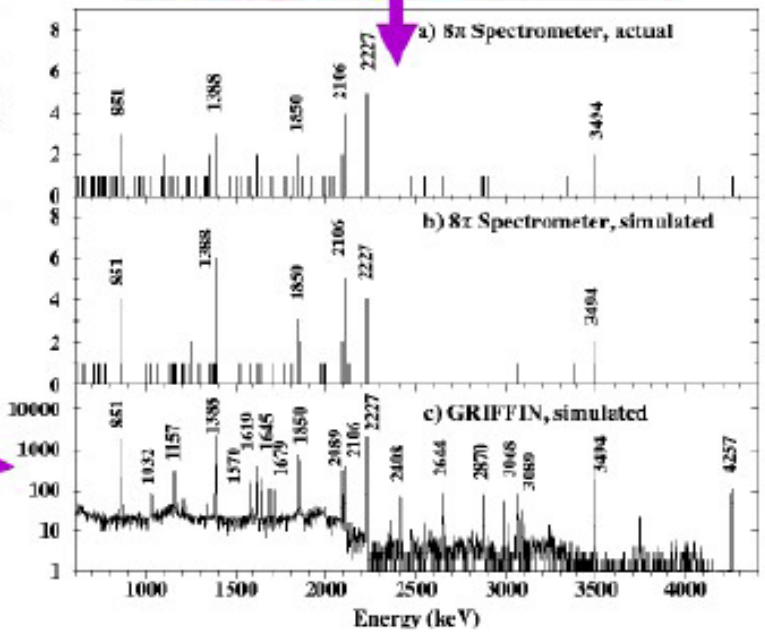
^{62}Ga 600 million decays





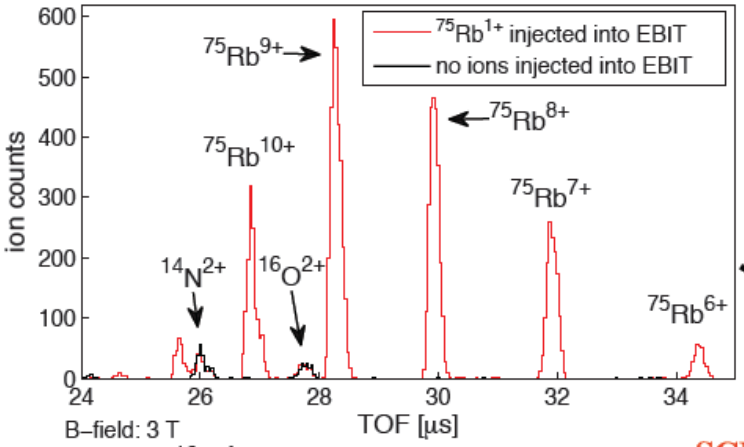
GRIFFIN

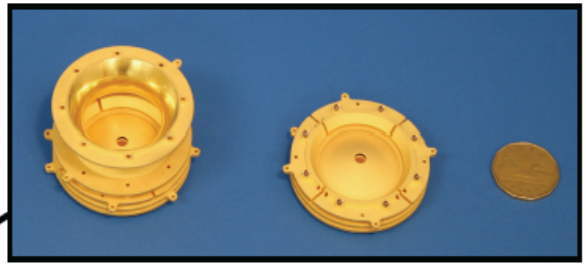


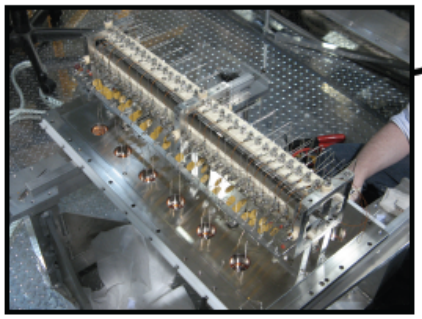


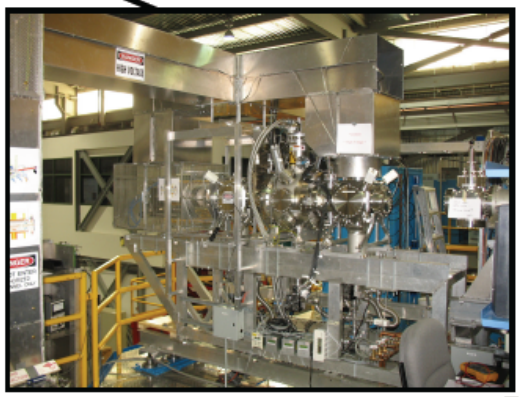
P. Finlay et al., PRC 78, 025502 (2008)

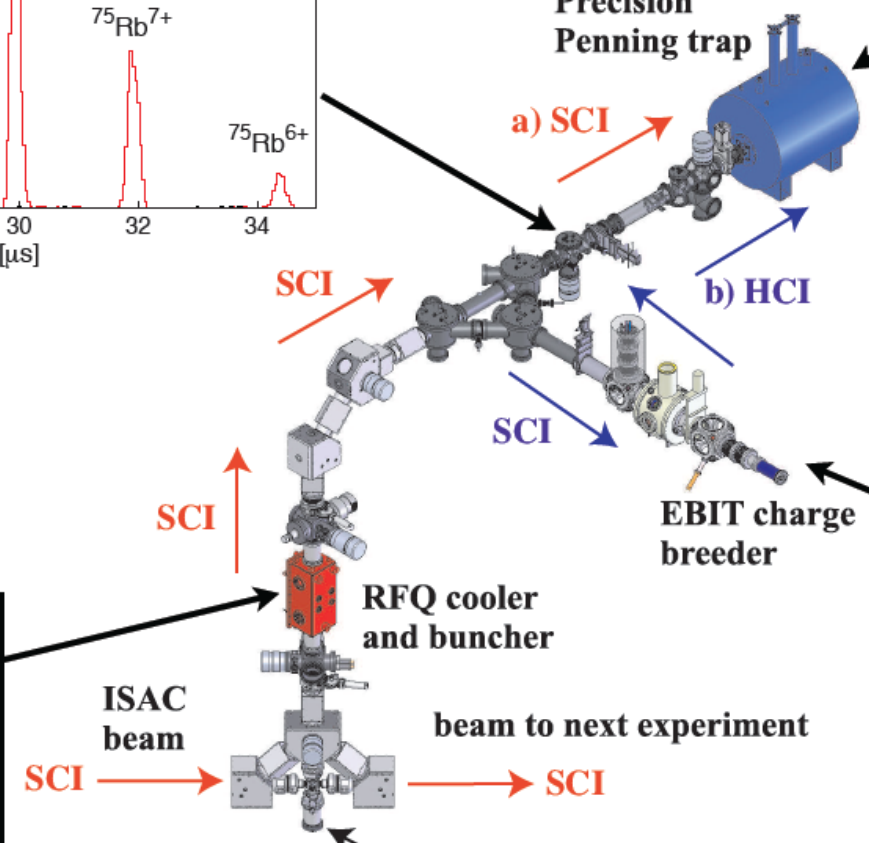
TITAN @ TRIUMF





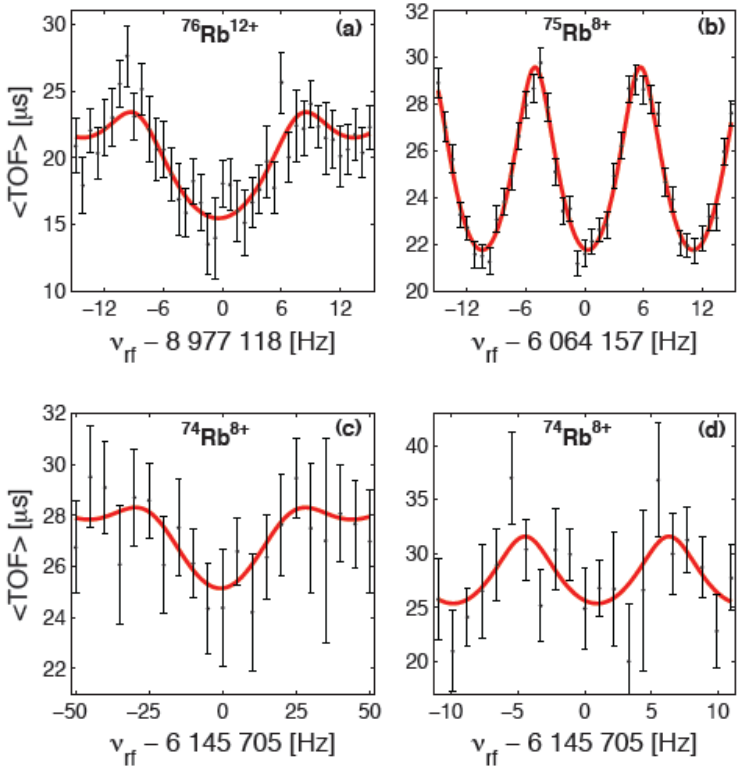


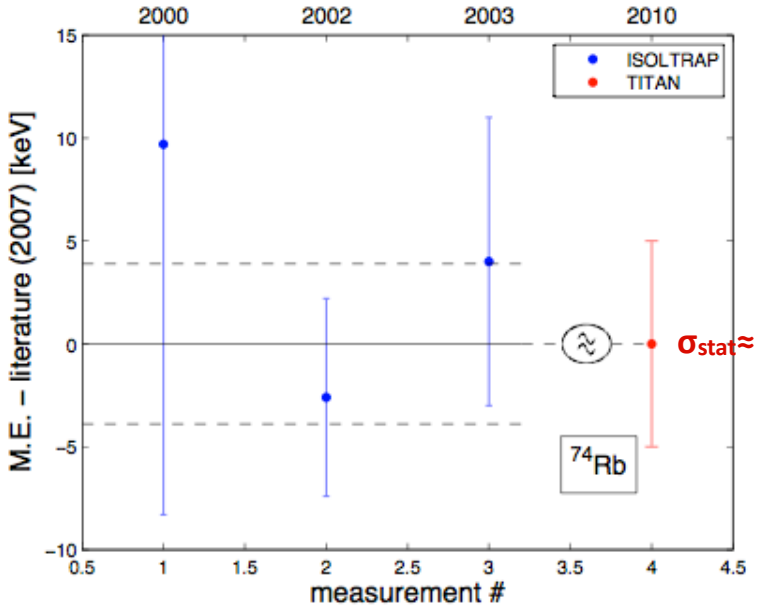




$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{BTN^{1/2}}$$

mass measurement of $^{74\text{-}76}Rb^{8\text{-}12+}$





$\sigma_{stat} \approx 4.1$ keV

Factor of 100 increase in precision possible

HCI

during this beamtime demonstrated up to q=12+

Ramsey excitation:

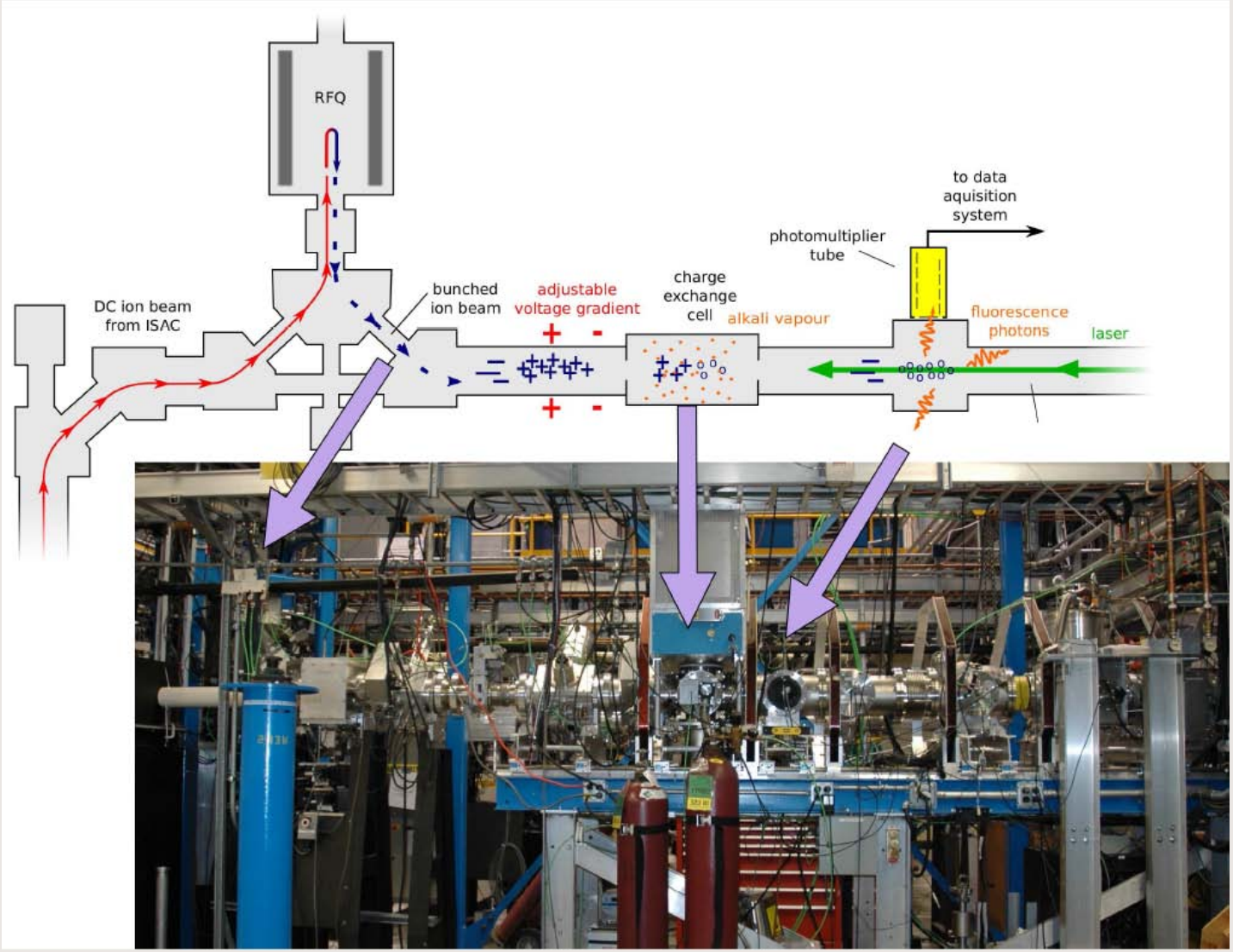
- 2 excitation pulses
- improves precision by a factor 2 - 3

$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{BTN^{1/2}}$$

compared to conventional method: improvement by factor >24

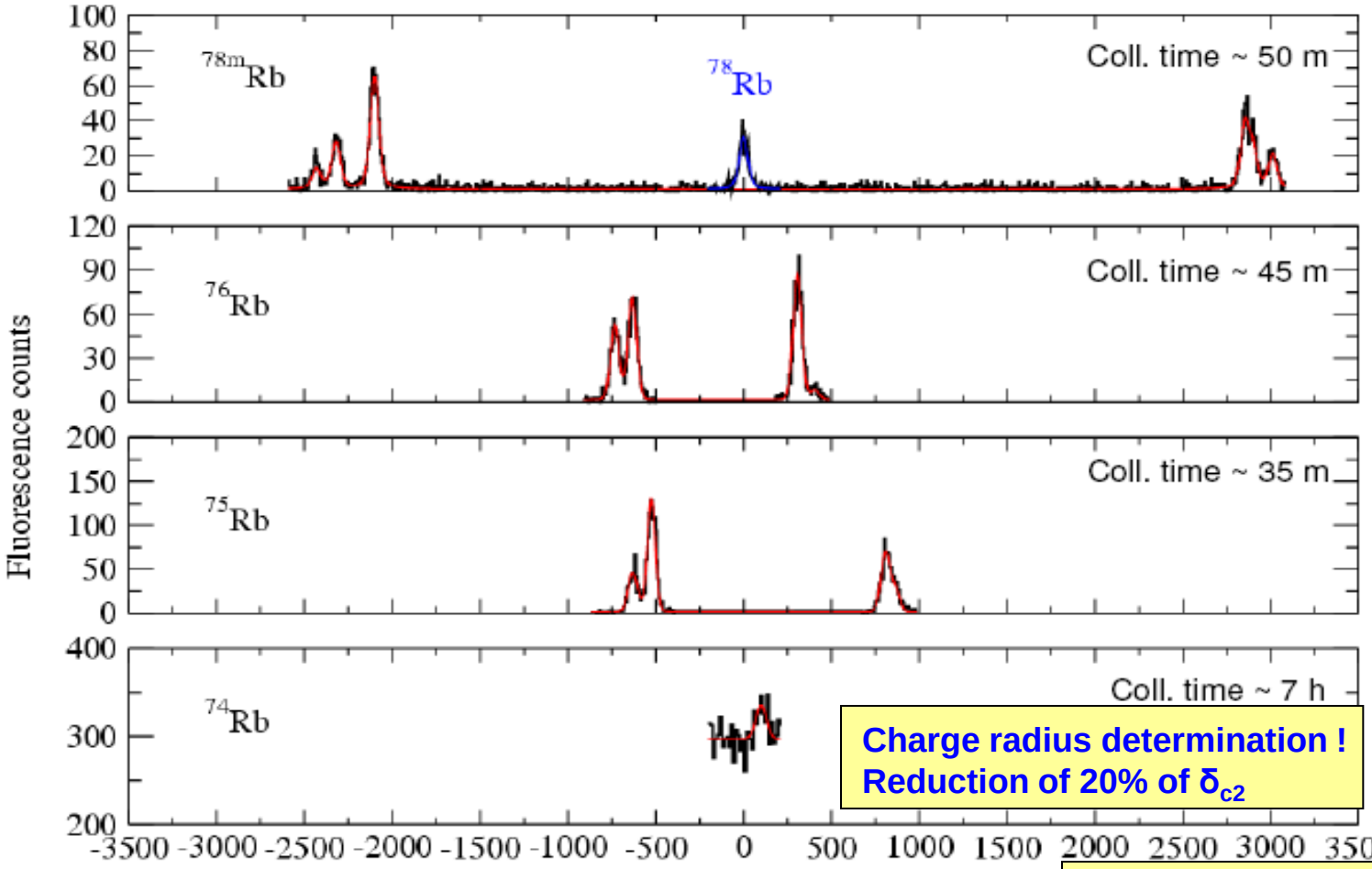
S. Ettenauer et al., accepted for publication in PRL arXiv:1109.3494

Collinear Laser Spectroscopy with cooled bunched beams



Determination of the charge radius of ^{74}Rb through collinear laser spectroscopy of cooled bunched beams

TITAN/Laser-spectroscopy: TRIUMF, McGill, Manchester UK



Yields

^{74}Rb - 1.7e4/s

^{75}Rb – 2.1e6/s

^{76}Rb – 9e7/s

^{78}Rb - 2.1e9/s

^{78m}Rb - 4.4e9/s

Charge radius determination !
Reduction of 20% of δ_{c2}

E. Mane et al. accepted at PRL