High Precision Half Life Measurement of ^{26}Na with GRIFFIN

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GRIFFIN

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Outline

High-Precision Half-Life Measurements

Motivation

- Our goal is to provide a half-life measurement of ^{26}Na as a first experimental test of GRIFFIN for high-precision work (eg. superallowed decay studies).
- The GRIFFIN result can be compared to a previously published high-precision measurement (Grinyer, 2005).
- $\sim 99\%$ of all β decays yield the 1809 keV γ-ray (Grinyer, 2008).

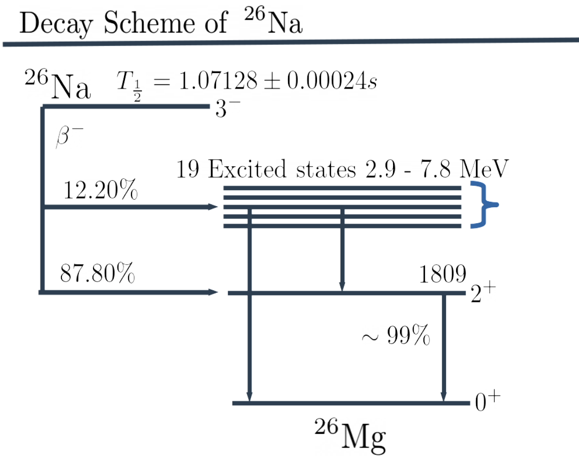
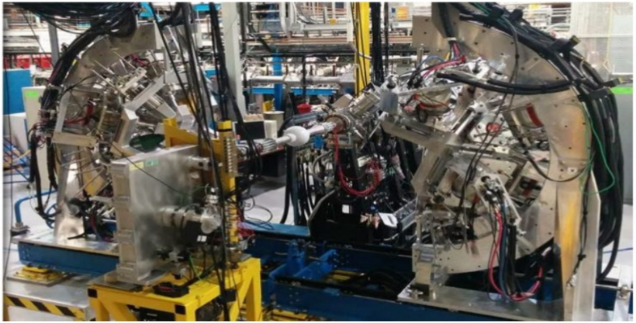


Figure 1: A simplifed ^{26}Na β^- decay scheme to the stable daughter ^{26}Mg.

γ Counting — The GRIFFIN Spectrometer



Both hemispheres of the GRIFFIN array showing the beamline and central vacuum chamber encased in a white 20 mm plastic delrin absorber.

- The **S1140 Experiment** was performed in November, 2017.
- **Spherical array of 16 Clover detectors each consists of 4 HPGe Crystals**
- **~9.1% photopeak efficiency at 1.3 MeV**

Data were Collected in Cycles

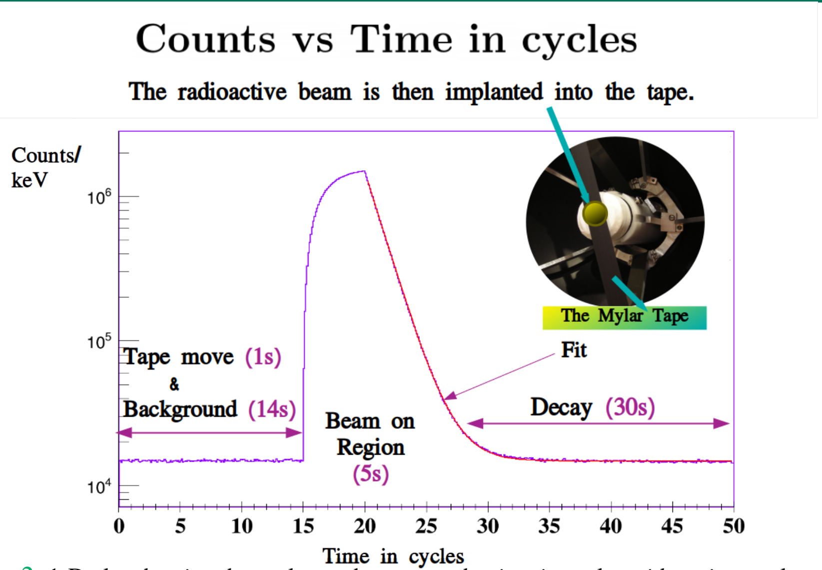


Figure 2: 1-D plot showing the cycle number versus the time in cycles without incomplete cycle.

^{26}Na Energy Spectrum

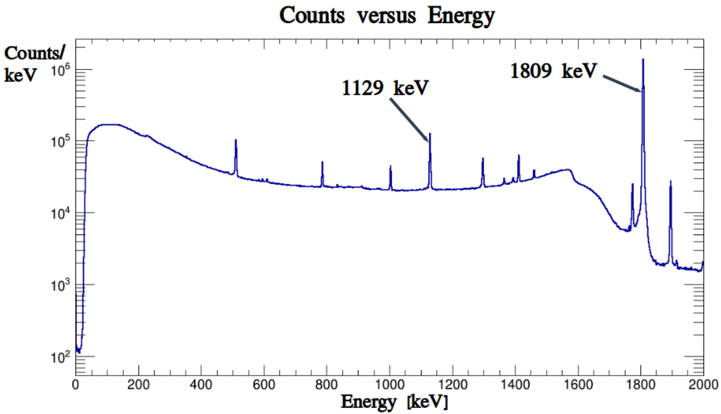


Figure 3: γ-ray singles spectrum for ^{26}Na with all the trigger events for a single run (40 mins).

Finding the peak to Gate 1809 [keV]

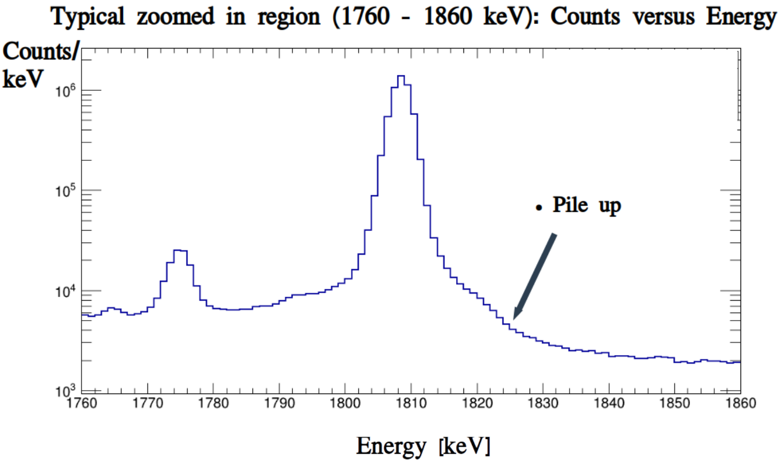


Figure 4: Typical zoomed in region (1760 - 1860 keV) from the γ-ray singles spectrum of ^{26}Na. The region due to pile up is clearly shown.

Data Selection Criteria

Selection Criteria Utilized

1

Decay data for the Na-26 experiment were collected in cycles(**1, 14, 5, 30 s**).★

- The first selection criterion: **REJECT those cycles that had very few, or even zero, total counts recorded during the decay measurement.**

2

Apply an energy gate on the 1809-keV transition in 26-Mg

3

Remove Pile Up Events using a gate on the K-Values

★ The precise values of the tape move, background, beam-on time and decay measurement were varied on a **run-by-run basis.**

Dead-time and Detector Pulse Pile-up Corrections

Dead time is the total period of time during which hit detections cannot be processed even if they are present.

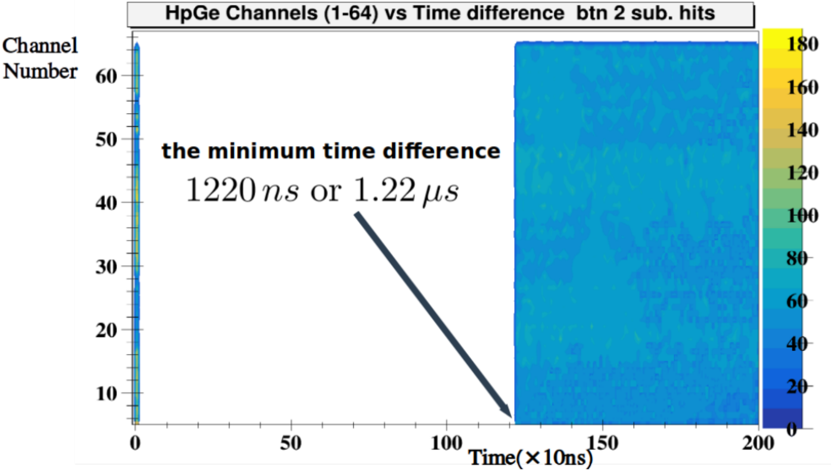
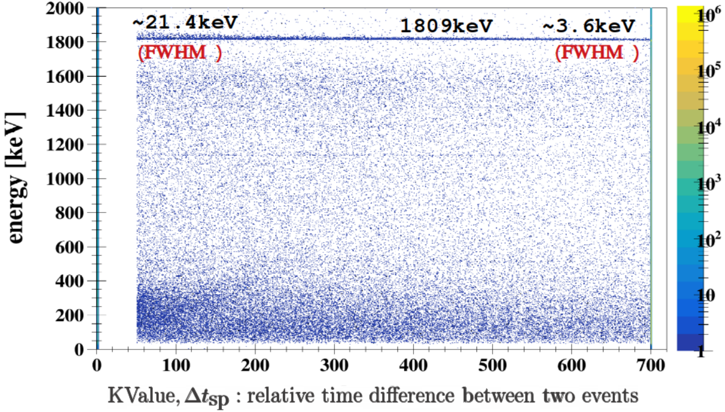


Figure 5: The dead time of the GRIFFIN DAQ shown by plotting the time interval of two consecutive γ-rays for each crystal.

Dead-time and Detector Pulse Pile-up Corrections

Signal pile-up occurs when more than one energy deposition from different physics events is present in a detector element during the processing time of the initial interaction.



One can clearly see the dependence of the energy resolution on the k-value. The energy resolution worsens with decreasing integration length as expected and vice versa.

Looking at the Pile Up and Single Events Spectra

Single Events (blue) KValue == 700 & Pile up Events Kvalue < 700

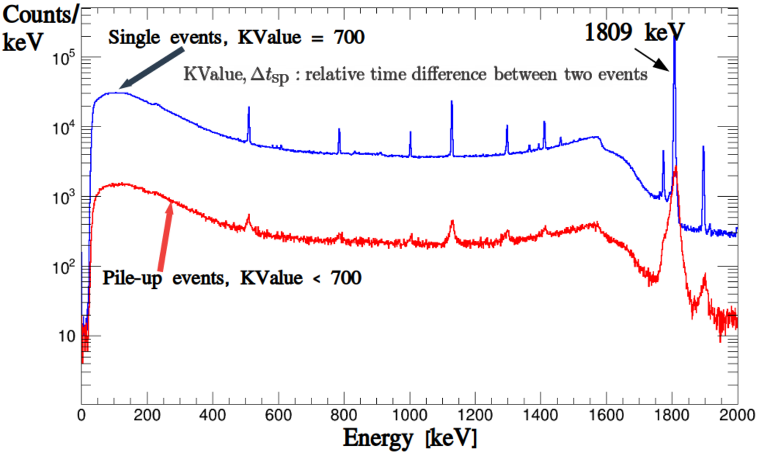


Figure 6: ^{26}Na Energy spectra to distinguish between single and pile-up events.

Dead-time and Detector Pulse Pile-up Corrections

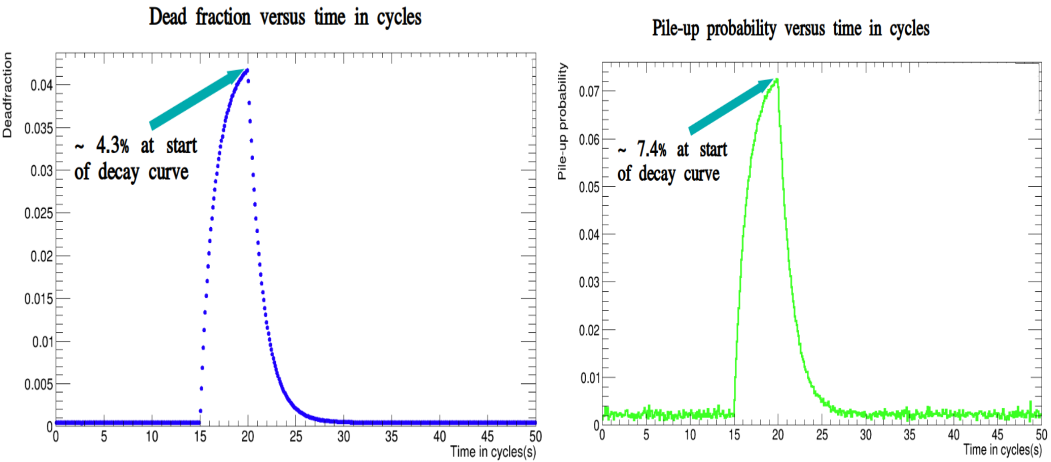
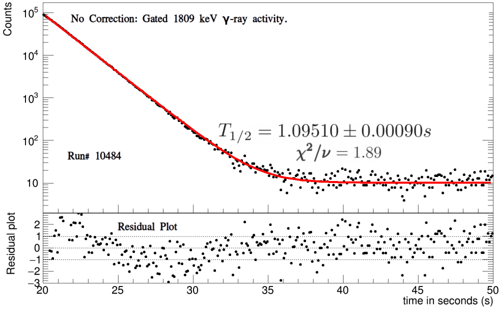


Figure 7: Left: the bin-by-bin dead fraction vs. time in cycles(s) for all events and right: the bin-by-bin pile-up probability vs. time in cycles(s) for all events.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

^{26}Na Gated 1809keV Activity with total decay time of 30s.

Uncorrected Data



1st order pile-up + dt correction

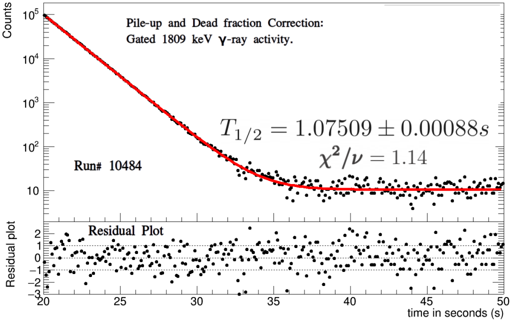


Figure 8: Non-corrected decay curve (left) and 1st order pile-up and dead-time (dt) correction decay curve(right) obtained from a single run following a gate on the 1809-keV transition in ^{26}Mg.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

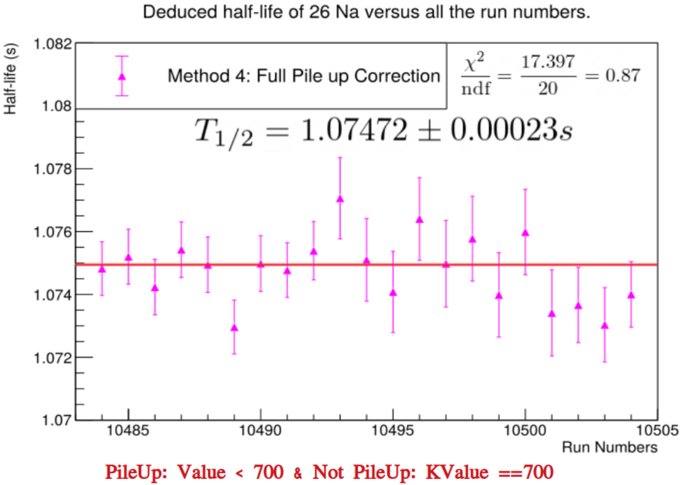


Figure 9: ^{26}Na: Deduced Half life versus run number (right). A weighted average of $T_{\frac{1}{2}} = 1.07472 \pm 0.00023$ s is deduced from these data where the uncertainty is statistical.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

Leading-Channel Removal Plots

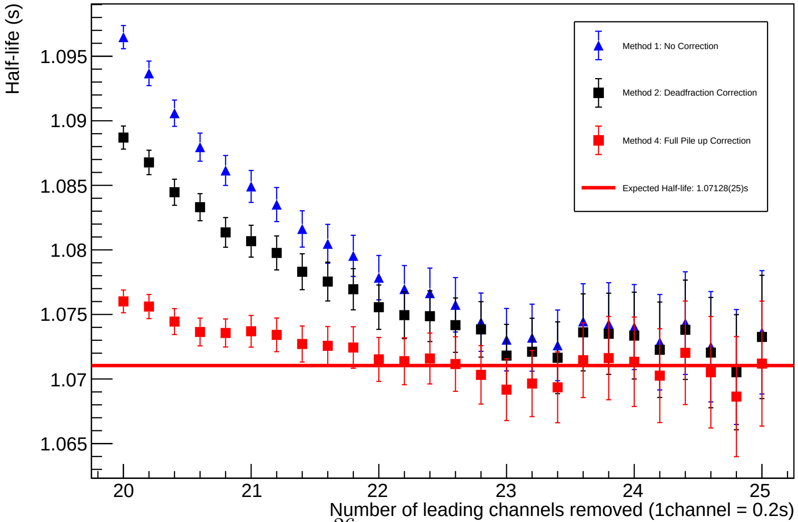


Figure 10: Deduced half-life of ^{26}Na vs. number of leading channels removed.

Rate-Dependent Refinements

- **Pile-up Time Resolution**
  - Corrects for pile-up events not resolved (in time) by the pile-up circuitry.
- **Trigger-Energy Threshold**
  - Corrects for pile-up caused by sub threshold energy events.
- **Pile-up Detection Energy Threshold**
  - Corrects for low energy pile-up events missed by the pile-up circuitry.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

Introduction

Motivation

Experiment

Data Selection Criteria

Analysis

Results and Discussion

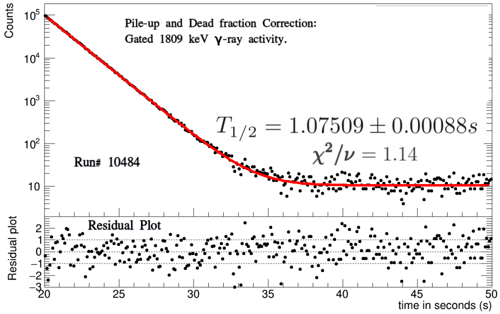
Half-Life Analysis: ^{26}Na Gated 1809keV Activity

Summary and Future Work

Future Plans

Comparing 1st order pile-up correction to Higher order pile-up correction

1st order pile-up correction



Higher order pile-up correction

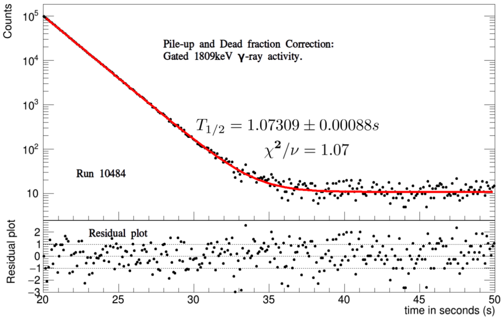
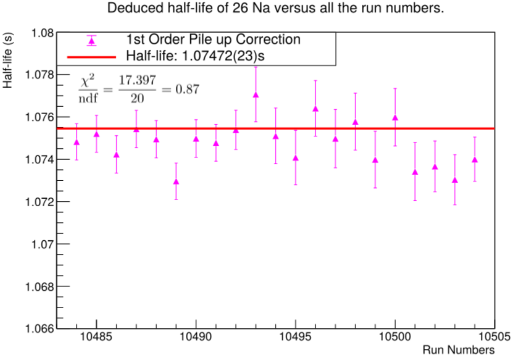


Figure 11: 1st order pile-up correction (left) and Higher order pile-up correction decay curve(right) obtained from a single run following a gate on the 1809-keV transition in ^{26}Mg.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

^{26}Na Deduced Half life vs Run numbers

1st order pile-up correction



Higher order pile-up correction

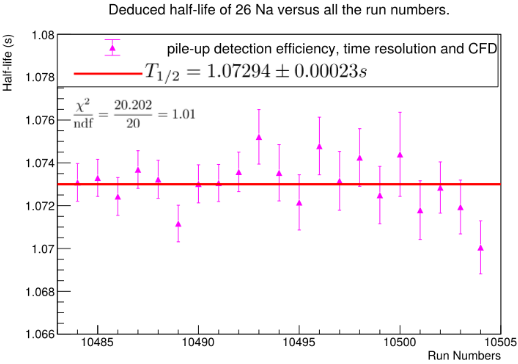


Figure 12: ^{26}Na: 1st order pile-up correction (left) and Higher order pile-up correction (right) of the deduced Half life versus run number.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

Leading-Channel Removal Plots

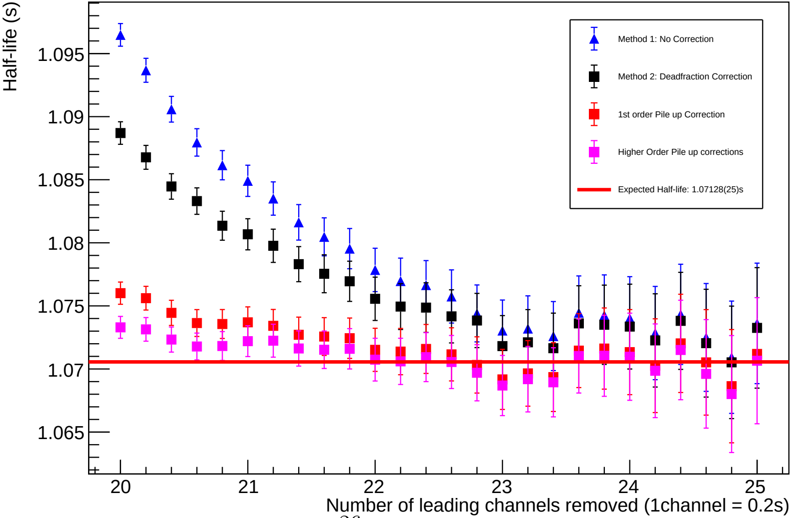


Figure 13: Deduced half-life of ^{26}Na vs. number of leading channels removed.

Summary and Future Work

1. The Half life for the 1809keV activity from ^{26}Na has been determined and was found to be $T_{\frac{1}{2}}$(avg) = 1.07294 ± 0.00023s.

2. The results from the **higher order pile-up corrections** looks promising.

3. Grinyer et al. (2005) measured the high-precision half-life of ^{26}Na via β-counting. The half-life of ^{26}Na was determined to be $T_{\frac{1}{2}} = 1.07128 \pm 0.00025$ s.

4. There is still work to do ($\sim 6\,\sigma$) on refining the pile-up correction and systematic uncertainties. Also need to explore summing effects in GRIFFIN.

5. Analysis of ^{14}O superallowed beta decay

Collaborators & References

COLLABORATORS Thank you very much for your support !

S. Sharma[1], G.F. Grinyer[1a], G.C. Ball[2], J.R. Leslie[3], C.E. Svensson[4], F.A. Ali[4b], C. Andreoiu[5], N. Bernier[2,6c], S.S. Bhattacharjee[2], V. Bildstein[4], 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], E. Gyabeng Fuakye[1], G.M. Huber[1], B. Jigmeddorj[4], K. Kapoor[1], A.T. Laffoley[4], K.G. Leach[7], J. Long[8], A.D. MacLean[4], C.R. Natzke[2,7], B. Olaizola[2d], A.J. Radich[4], N. Saei[1], J.T. Smallcombe[2e], A. Talebitaher[1], K. Whitmore[5], and T. Zidar[4]

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1. Grinyer, G. (2008). High-precision half-life measurements for superallowed Fermi β decays (Doctoral dissertation).
2. Grinyer, G. F., Svensson, C. E., Andreoiu, C., Andreyev, A. N., Austin, R. A. E., Ball, G. C., ... & Zganjar, E. F. (2005). High precision measurements of Na 26 β- decay. Physical Review C, 71(4), 044309.
3. Zidar, T. (2019). Beta decay of neutron-rich 33Mg (Doctoral dissertation).
4. Svensson, C. E., & Garnsworthy, A. B. (2014). The GRIFFIN spectrometer. Hyperfine Interactions, 225(1), 127-132.)
5. Grinyer, G. F., Svensson, C. E., Andreoiu, C., Andreyev, A. N., Austin, R. A. E., Ball, G. C., ... & Zganjar, E. F. (2007). Pile-up corrections for high-precision superallowed β decay half-life measurements via γ-ray photopeak counting. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 579(3), 1005-1033.

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GRIFFIN

A.B. Garnsworthy et al.,

Regina GRIFFIN Group

Photo Credit: Shafakat Arifeen

L to R: J. Liu, Dr. Grinyer, N. Saei, D. Shah, E. Gyabeng Fuakye (me!)

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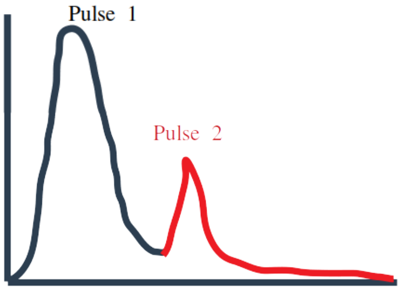
Any Questions ?

Backup Slides

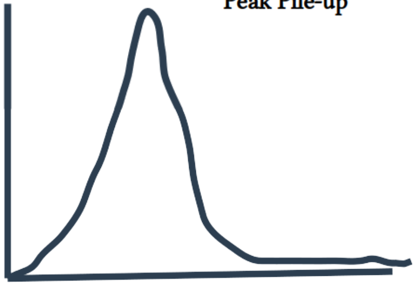
Detector Pulse pile-up

Tail Pile-up



First order pulse pile-up where **pulse 2 is riding on the tail of pulse 1.**

Peak Pile-up



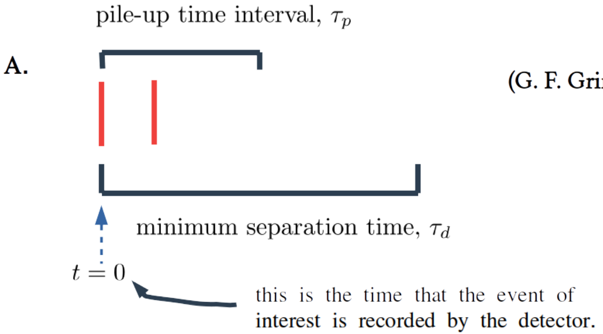
If the pulses **are very close in time**, the system will simply record the two pulses as a single event with a **combined pulse amplitude**.

- The number of pile-up events depend strongly on the count rate of the system.

Common types of Pile-up

Post-piled-up

- Post pile-up is defined as the probability that the pile-up is caused by events arriving after the events of interest has been recorded.

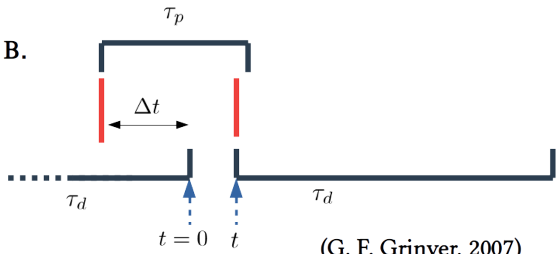


(G. F. Grinyer, 2007)

Common Types of Pile-up

II. Pre-piled-up

- The possibility that the event of interest is piled-up by an event that came before, in a process defined as "pre-pile-up"



(G. F. Grinyer, 2007)

Rejecting those Cycles with few or zero Counts

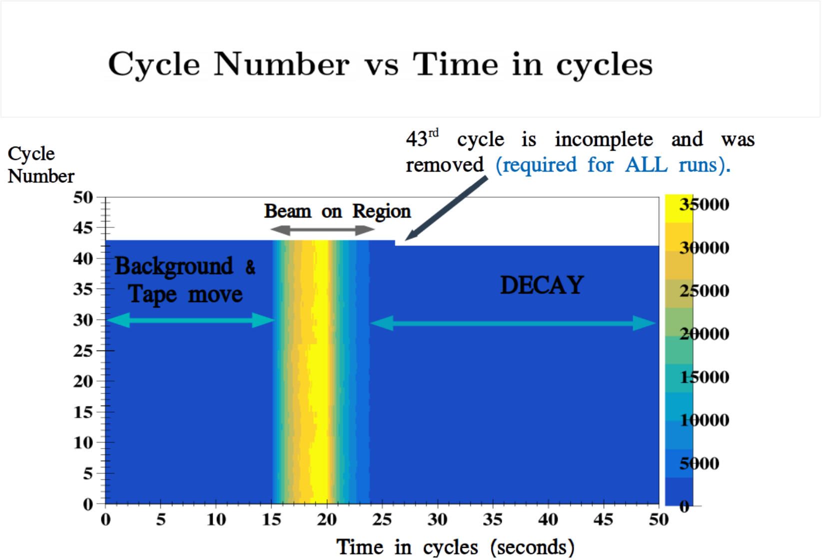


Figure 14: 2-D plot showing the cycle number versus the time in cycles, incomplete cycles were removed for all runs.

Higher Order Pile-up Corrections

Analytical Expressions by (G. F. Grinyer, 2007)

$$P = 1 - e^{-(2-a_4)x}\left[e^{a_4 x} + (1-a_4)x\right] \quad 1$$

$$P = 1 - e^{-2x}(1 + \alpha x) \quad 2$$

$$P = \epsilon_p\left[1 - e^{-2x}(1 + x)\right] \quad 3$$

The probability of pile up with a **non zero time resolution**, **CFD** and **detection efficiency** in 1, 2 and 3 respectively.

$$P_{\text{fit-total}} = a_6\left(1 - e^{-(2-a_4)x}\left[e^{a_4 x} + a_5(1-a_4)x\right]\right) \quad 4$$

Bin-by-bin pile-up correction

1. Deadfraction Correction

$$D_i = \text{Dead fraction}$$

$$N_i' = \frac{N_i}{1 - D_i}$$

Deadtime is the total period of time during which hit detection cannot be processed even if they are present.

2. Higher Order Pile-up Corrections

RATE DEPENDENT CORRECTIONS

$$N_i'' = \frac{N_i}{(1 - D_i) \times (1 - P_{\text{fit-total}})}$$

Higher Order Pile-up Corrections

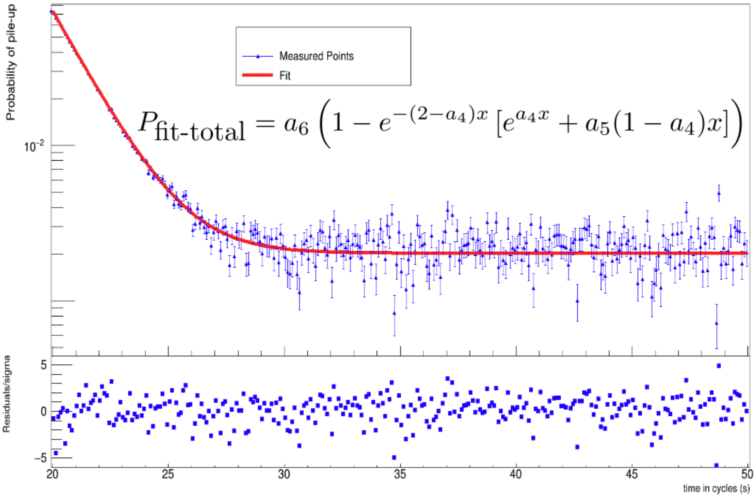
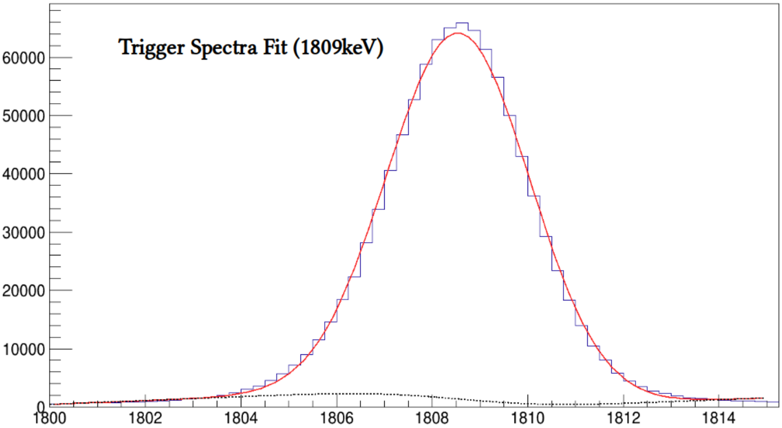


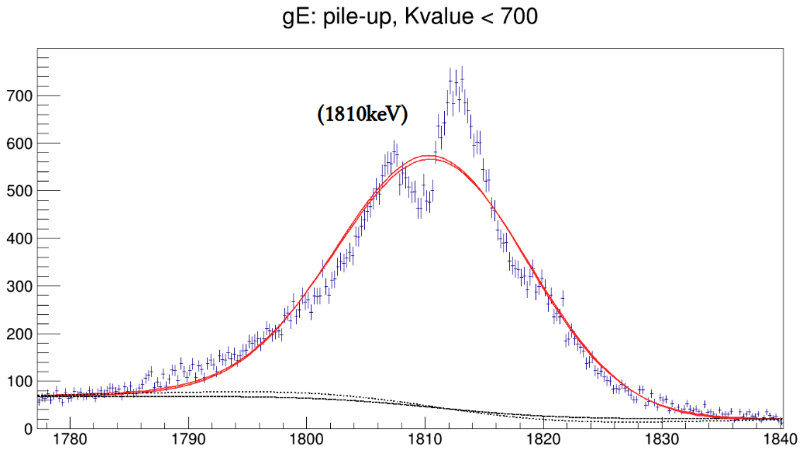
Figure 15: The fit of the probability of pile up with a non zero time resolution, trigger energy threshold and detection efficiency.

Detector Pulse pile-up



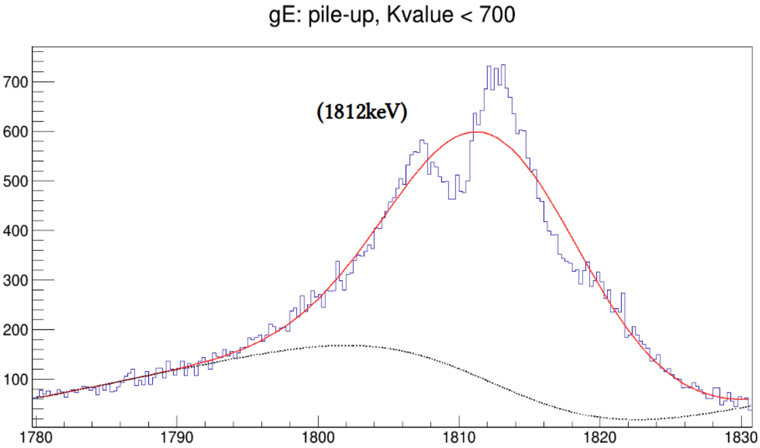
Name: Chan1807_1799_to_1814
Centroid: 1808.560286 +/- 0.002099
Area: 942457.486746 +/- 1071.417292
FWHM: 3.521101 +/- 0.003560

Detector Pulse pile-up



Name: Chan1809_1769_to_1849
Centroid: 1810.898453 +/- 0.074145
Area: 42637.835757 +/- 267.536881
FWHM: 19.244808 +/- 0.121344

Detector Pulse pile-up



Name: Chan1805_1780_to_1830
Centroid: 1812.317813 +/- 0.098190
Area: 33952.185520 +/- 461.208716
FWHM: 15.985993 +/- 0.166816

1st Order Pile-up Corrections

Step-by-Step Correction

1. Deadfraction Correction

$$N_i' = \frac{N_i}{1 - D_i}$$

$$D_i = \text{Dead fraction}$$

Deadtime is the total period of time during which hit detection cannot be processed even if they are present.

2. 1st Order Pile-up Correction

$$N_i'' = \frac{N_i'}{1 - P_i}$$

$$P_i = \frac{\text{Pile-up Events}}{\text{All Events}}$$

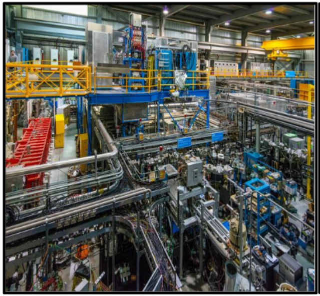
$$N_i'' = \frac{N_i}{(1 - D_i) \times (1 - P_i)}$$

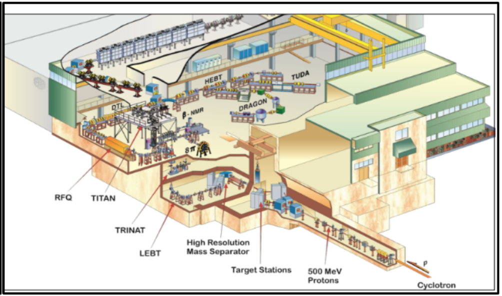
★ RATE DEPENDENT CORRECTIONS

TRIUMF-ISAC Facility

TRIUMF-ISAC

TRIUMF TRIUMF

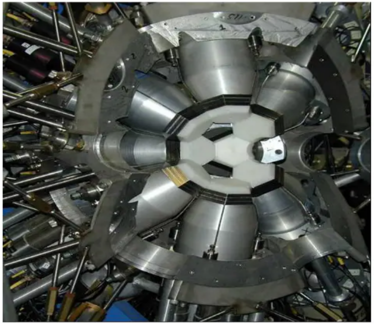




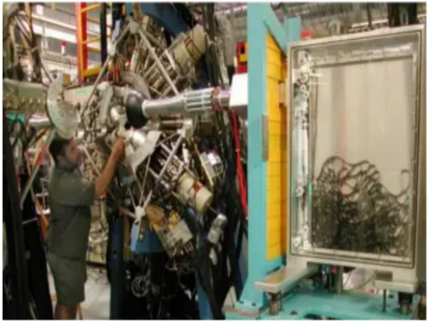
- Up to 100 μA, 500 MeV protons from TRIUMF's main cyclotron are accelerated onto targets which produce high-intensity secondary radioactive ion beams by the ISOL technique.

γ Counting — The 8π Spectrometer

γ Counting — The 8π Spectrometer



One hemisphere of the 8pi Gamma-Ray Spectrometer at ISAC-I.



The collection box and lead shielding wall (yellow) for the moving tape collector system of the 8pi Spectrometer.

- **Spherical array of 20 BGO Compton suppressed HPGe detectors**
  - **~1% photopeak efficiency at 1.3 MeV**

After a decade of operation at ISAC-I, the 8pi Spectrometer was decommissioned in January 2014 to make way for the new high-efficiency GRIFFIN spectrometer.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

^{26}Na Deduced Half life vs Run numbers

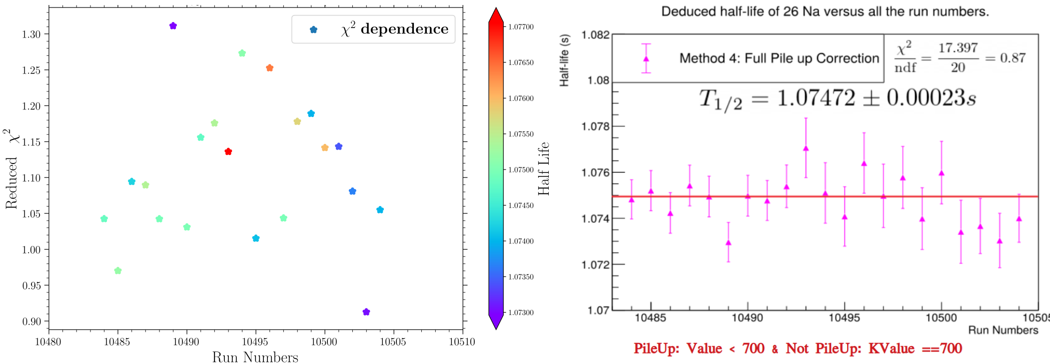


Figure 16: ^{26}Na: Reduced χ^2 vs run numbers(left) and deduced Half life versus run number (right). A weighted average of $T_{\frac{1}{2}}$ = 1.07472 ± 0.00023 s is deduced from these data where the uncertainty is statistical.

Half-Life Analysis: ^{26}Na Gated 1809keV Activity

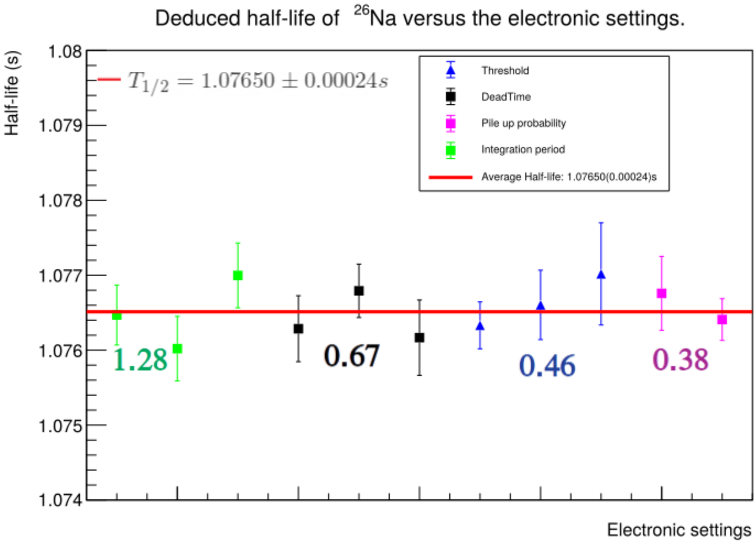


Figure 17: Run 10485: Deduced half-life of ^{26}Na vs. electronic settings

Exploring pile-up options

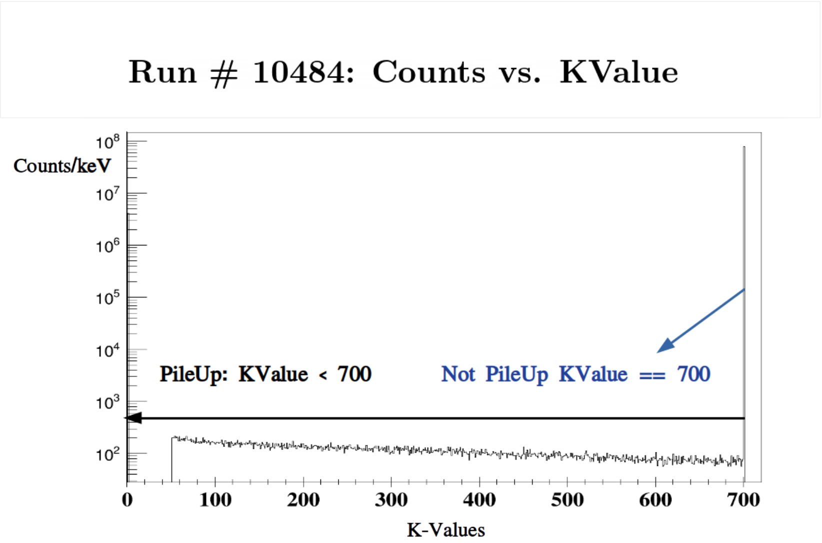


Figure 18: Pile option used: 1-D plot showing the counts versus the integration length.