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HIGH-STATISTICS β-DECAY MEASUREMENTS AT TRIUMF-ISAC AND THE TRANSITION FROM THE 8π SPECTROMETER TO GRIFFIN*

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Over a 12 year period, the 8π γ-ray spectrometer at the TRIUMF-ISAC facility was a world unique device for β-decay studies. Equipped with a variety of auxiliary devices, it was used in studies of Fermi superallowed β^+ emitters, and nuclear structure studies far from stability and those employing high-statistics measurements. In the present contribution, this latter use is highlighted with examples of recent data obtained in the decay of ^{122}Cs to ^{122}Xe. The 8π spectrometer was replaced with the much more powerful GRIFFIN facility in 2014, ensuring world-leading capability for γ-ray spectroscopy following β decay at TRIUMF-ISAC for the next generation. Examples that highlight GRIFFIN's capabilities are given.

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1. Introduction

The 8π spectrometer was designed and constructed in the early-to-mid 1980s as a device for high-spin studies, and following the closure of the Chalk River TASCC facility and a campaign at Lawrence Berkeley Laboratory, it was repatriated to Canada in 2000. Reconfigured for use as a dedicated spectrometer for β decay, auxiliary detectors were added such as the SCEPTAR array of plastic scintillators for tagging on β particles, the PACES array of Si(Li) detectors for conversion electron studies, and $LaBr_3$ detectors for fast timing measurements. Details of the spectrometer and its auxiliary detector systems, data acquisition, and capabilities are given in, *e.g.*, Ref. [1]. While the 8π enjoyed a unique place in the world of γ-ray spectrometers, the clear obsolescence of the HPGe detectors (the original detectors that were obtained and used in the 1980s) behooved the collaboration to seek a new device that would incorporate modern germanium detectors. The Gamma-Ray Infrastructure For Fundamental Investigations in Nuclei (GRIFFIN) [2] represents this replacement. Using large-volume clover HPGE detectors, at 1 MeV γ-ray energy GRIFFIN can achieve a factor of nearly 17 increase in absolute γ-ray photopeak efficiency *versus* the 8π spectrometer [2, 3]. The Phase I implementation of GRIFFIN kept the original configurations of the 8π auxiliary detectors SCEPTAR and PACES, used the same Moving Tape Collector, and also permitted the incorporation of up to 8 $LaBr_3$ scintillation detectors for fast-timing measurements. The Phase II implementation of GRIFFIN, to be completed in 2018, will see the addition of BGO Compton-suppression shields for both the clover HPGe detectors as well as for the $LaBr_3$ detectors. A very powerful additional capability offered by GRIFFIN is that it can be coupled to the DEuterated SCintillator Array for Neutron Tagging (DESCANT) [4] enabling neutron–γ coincidence studies of β-delayed neutron emitters.

2. High-statistics measurements with the 8π spectrometer

One of the main directions of the many-faceted research programme carried out with the 8π spectrometer concentrated on very high-statistics measurements of β-decaying nuclei that enabled detailed studies of nuclear structure related to the development of collectivity. This programme of study involves performing systematic measurements across an isotopic chain in an attempt to elucidate the evolution of collective states. Some examples of nuclei studied to date are ^{94,98}Zr [5], ^{110,112}Cd [6–11], and ^{122,124,126}Xe [12–15]. Many of these nuclei listed are stable and have a wealth of complementary information, especially that obtained from Coulomb excitation or $(n, n'\gamma)$ reactions that provide level lifetimes.

Examples of data from the measurement of the β decay of ^{122}Cs to ^{122}Xe are shown to demonstrate the capabilities of the 8π spectrometer. The measurement employed a beam consisting of 1.1×10^7 ions/s of $I^\pi = 1^+$, $t_{1/2} = 21.2$ s ^{122}Cs ground state, and 2.1×10^6 ions/s of the $I^\pi = 8^{(-)}$, $t_{1/2} = 3.7$ min ^{122}Cs isomer. Two different beam dwell times/tape cycles were used; the shorter cycle consisting of 20 s beam on followed by 20 s of decay optimized for observation of the ground state decay, and the longer cycle of 7.5 min beam on followed by 7.5 min decay optimized for observation of the high-spin isomer decay.

Shown in Fig. 1 is an example of the γ–γ coincidences obtained following the ^{122}Cs→^{122}Xe decay. The spectrum shown (left panel) results from a coincidence gate taken on the 818 keV $0_2^+ \to 2_1^+$ transition (partial decay scheme shown in the right panel) and clearly shows the presence of a 345 keV γ ray that is assigned as the in-band $2_3^+ \to 0_2^+$ transition. In order to firmly establish the spin of the 1495 keV 2_3^+ level, the γ–γ angular correlation of the 1164 keV and 331 keV transitions are shown in Fig. 2. The angular correlation data (left panel) are shown together with curves representing the minimum χ^2 for each of the spin cascades labelled, and clearly favour a spin of 2 for the 1495 keV level. The χ^2 analysis is shown in the right panel, clearly indicates not only a spin of 2 for the 1495 keV state, but also that the 1164 keV transition is predominately E2 in nature.

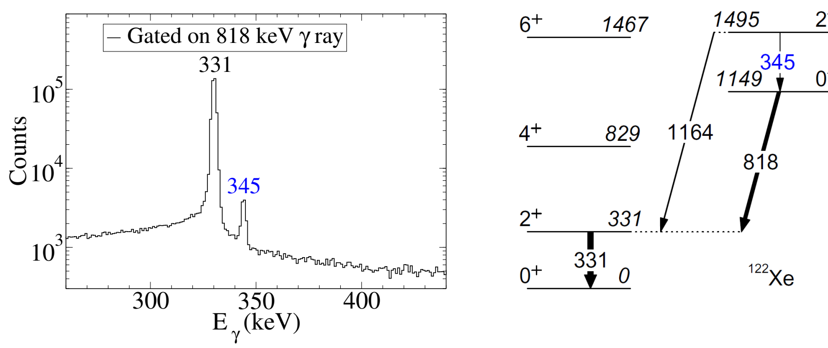

Fig. 1. Data obtained in the decay of ^{122}Cs→^{122}Xe with the 8π spectrometer. The spectrum shown (left) is a result of a γ-ray coincidence condition placed on the 818 keV $0_2^+ \to 2_1^+$ γ-ray decay. The 345 keV γ ray is clearly visible and represents the in-band $2_3^+ \to 0_2^+$ transition, thus firmly establishing the 2^+ band member. The partial level scheme of ^{122}Xe is shown on the right.

One of the main goals of the study of the decay of ^{122}Cs was to locate and firmly establish additional 0^+ states. In the study [15] of ^{124}Xe following the decay of ^{124}Cs, the precise γ-ray branching ratios obtained, combined with the previous knowledge of the level lifetimes (or B(E2) values from Coulomb

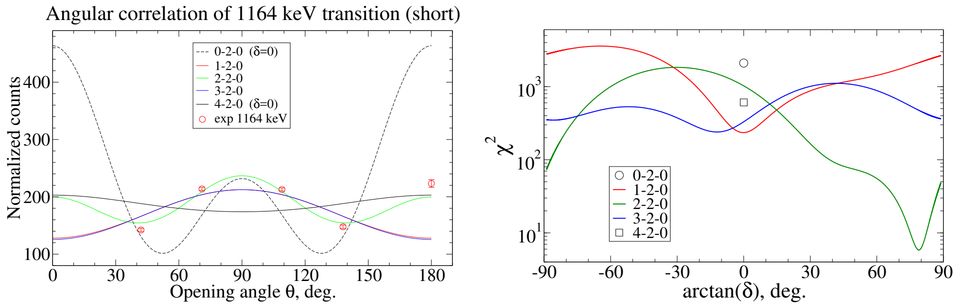

Fig. 2. The angular correlation obtained for the 1164 keV and 331 keV γ-ray cascade. The data (left) obtained for the 5 distinct angles of the 8π spectrometer are obtained from the relative intensities of the γ–γ coincidences. The right panel displays the χ^2 for the different spin assumptions for the 1495 keV level as a function of the mixing ratio δ for the 1164 keV transition. The legends in the figures indicate the spins of the levels considered in the cascade, arranged from initial to final.

excitation), enabled precise $B(\mathrm{E2})$ values to be determined that could then be used in the formation of rotational invariant quantities via the Kumar–Cline sum rules [15]. The ^{124}Xe study revealed that the 0^+_3 state, suggested to be the main fragment of the proton pairing vibration [15], possessed a $\langle Q^2 \rangle$ value nearly identical to that of the ground state. While the data for ^{122}Xe is not nearly as extensive as those for ^{124}Xe, the energy systematics of the 0^+_3 level are strongly suggestive that it could be associated with the 0^+_3 level in ^{124}Xe. The establishment of the rotational band based on the 0^+_3 level is thus highly desirable. Figure 3 displays the γ-ray coincidence spectrum (left) showing the presence of a 350 keV γ ray assigned as the in-band $2^+_4 \to 0^+_3$ transition. This is the first firm assignment of the spin-2 band member of the 0^+_3 state.

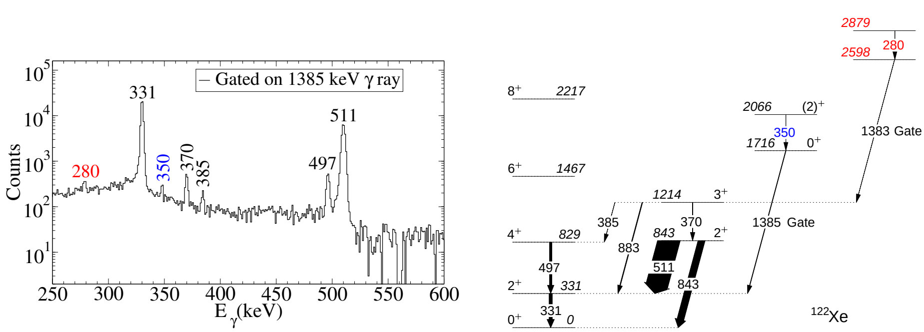

Fig. 3. The coincidence spectrum (left) obtained following the decay of ^{122}Cs using a short tape cycle and with a coincidence gate taken on the 1385 keV $0^+ \to 2^+_1$ transition. The 350 keV γ ray is assigned as the in-band $2^+_4 \to 0^+_3$ transition. A partial level scheme of ^{122}Xe is displayed in the right panel.

3. The GRIFFIN spectrometer

In early 2014, the 8π spectrometer was decommissioned and construction of the new GRIFFIN spectrometer was initiated with commissioning of the device in September 2014. GRIFFIN replaced the γ-ray detection capability of the 8π, based on single-crystal HPGe detectors with approximately 25% relative efficiency, with large-volume clover-style detectors that can reach approximately 220% relative efficiency in add-back mode [3], ultimately leading to a γ-ray photopeak efficiency that is a factor of ≈ 17 larger than that of the 8π at 1 MeV. Figure 4 is a photograph of one hemisphere of the new GRIFFIN array coupled to one hemisphere of DESCANT. GRIFFIN maintains the 8π detection capabilities for β-particle tagging and conversion electron detection with the SCEPTAR and PACES arrays, but also provides capabilities with DESCANT for neutron–γ coincidence measurements [4].

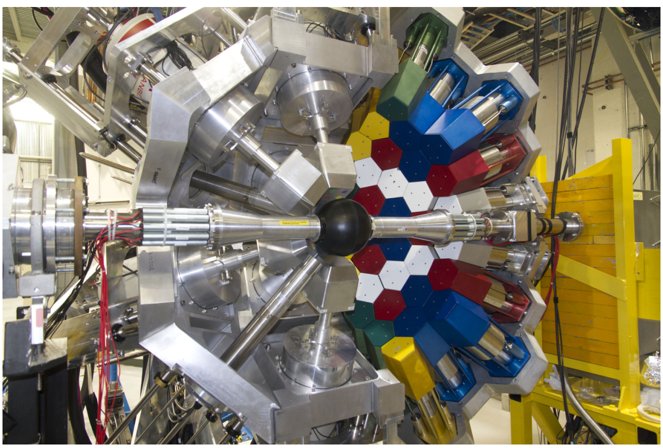

Fig. 4. Photograph of one hemisphere of the GRIFFIN spectrometer [2] coupled with the DESCANT neutron detector array [4].

To demonstrate the improved capabilities of the GRIFFIN spectrometer, Fig. 5 displays γ-ray spectra in coincidence with the 954 keV transition in ^{62}Zn obtained with the 8π (right top) and GRIFFIN (right bottom) spectrometers following the β decay of ^{62}Ga. The total number of ^{62}Ga decays observed in the 8π measurement was approximately a factor of 1.5 that of the GRIFFIN measurement. A future goal, taking advantage of the vastly improved statistics observed with GRIFFIN, is to extract γ–γ angular correlations since recent work [16] casts doubt on the spin of the 2342 keV level. Such an angular correlation analysis would have been impossible with the efficiency of the 8π spectrometer for the beam rates available for ^{62}Ga, but within reach for GRIFFIN.

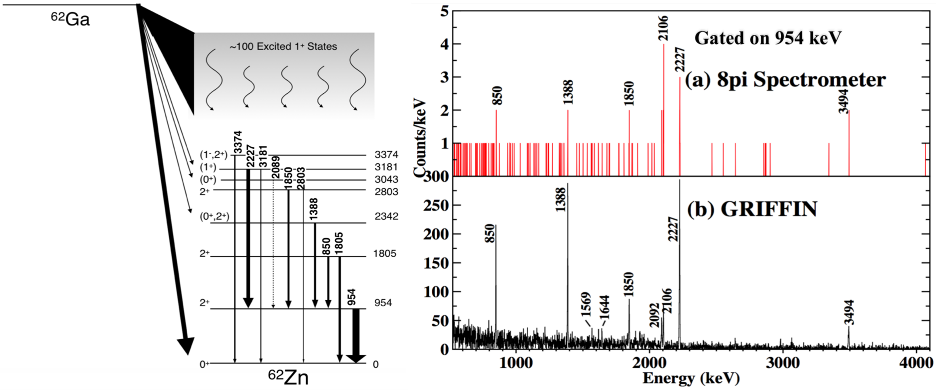

Fig. 5. A comparison of the γ-ray coincidence spectra (right) obtained in experiments examining the decay of ^{62}Ga with the 8π spectrometer (top) and GRIFFIN spectrometer (bottom). The coincidence gate is taken on the 954 keV $2^+ \rightarrow 0^+$ transition in ^{64}Zn. A partial level scheme is shown on the left.

REFERENCES

[1] P.E. Garrett *et al.*, *J. Phys.: Conf. Ser.* **639**, 012006 (2015).

[2] C.E. Svensson, A.B. Garnsworthy, *Hyperfine Interact.* **225**, 127 (2014).

[3] U. Rizwan *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **820**, 126 (2016).

[4] P.E. Garrett, *Hyperfine Interact.* **225**, 137 (2014).

[5] A. Chakraborty *et al.*, *Phys. Rev. Lett.* **110**, 022504 (2012).

[6] P.E. Garrett *et al.*, *Phys. Rev. C* **86**, 044304 (2012).

[7] A. Diaz Varela *et al.*, *EPJ Web Confs.* **66**, 02029 (2014).

[8] B. Jigmeddorj *et al.*, *JPS Conf. Proc.* **6**, 030014 (2015).

[9] B. Jigmeddorj *et al.*, *Eur. Phys. J. A* **52**, 36 (2016).

[10] P.E. Garrett *et al.*, *EPJ Web Confs.* **123**, 02005 (2016).

[11] P.E. Garrett *et al.*, *Acta Phys. Pol. B* **42**, 799 (2011).

[12] B. Jigmeddorj *et al.*, *EPJ Web Confs.* **107**, 03014 (2016).

[13] P.E. Garrett, *EPJ Web Confs.* **93**, 01003 (2015).

[14] A.J. Radich *et al.*, *JPS Conf. Proc.* **6**, 030015 (2015).

[15] A.J. Radich *et al.*, *Phys. Rev. C* **91**, 044320 (2015).

[16] K.G. Leach *et al.*, *Phys. Rev. C* **87**, 064306(R) (2013).