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The GRIFFIN spectrometer

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Abstract Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei (GRIFFIN) is an advanced new high-efficiency γ-ray spectrometer being developed for use in decay spectroscopy experiments with low-energy radioactive ion beams provided by TRIUMF's Isotope Separator and Accelerator (ISAC-I) radioactive ion beam facility. GRIFFIN will be comprised of sixteen large-volume clover-type high-purity germanium (HPGe) γ-ray detectors coupled to custom digital signal processing electronics and used in conjunction with a suite of auxiliary detection systems. This article provides an overview of the GRIFFIN spectrometer and its expected performance characteristics.

Keywords Gamma-Ray spectrometer · HPGe clover detectors · Radioactive ion beams · Digital electronics

1 Introduction

The Isotope Separator and Accelerator (ISAC) facility [1] at TRIUMF in Vancouver, Canada produces high-quality beams of radioactive ions via the isotope separation on-line (ISOL) technique with primary production targets driven by a 500 MeV proton beam from TRIUMF's main cyclotron with a current up to 100 μA. In addition to ISAC's post-acceleration capabilities [2], low-energy (~30 keV) beams of radioactive isotopes with masses up to $A = 238$ can be transported directly to a variety of experimental facilities, including the 8π γ-ray spectrometer [3, 4] and its

ISAC and ARIEL: The TRIUMF Radioactive Beam Facilities and the Scientific Program.

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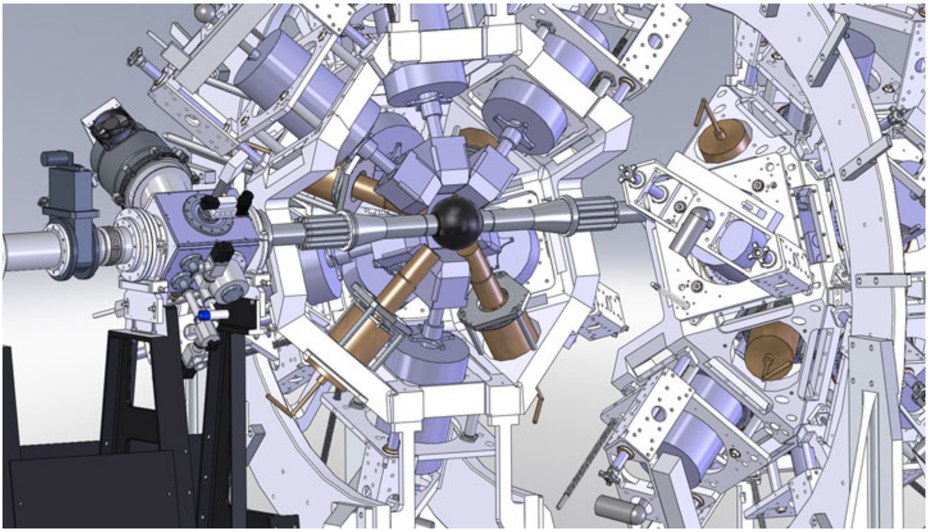

Fig. 1 SolidWorks design of the GRIFFIN spectrometer on its low-energy beamline at ISAC-I. One hemisphere of GRIFFIN is withdrawn to reveal the inner vacuum chamber, which will accommodate a number of GRIFFIN auxiliary detection systems

auxiliary detection systems, which have served as the primary decay spectroscopy facility at ISAC-I for the past decade. The Advanced Rare IsotopE Laboratory (ARIEL) [5] project is currently under construction at TRIUMF and will provide both a simultaneous multi-user radioactive beam capability at ISAC and access to unprecedented intensities of neutron-rich radioactive beams through actinide production targets driven by both a new superconducting electron linear accelerator and a second high-intensity proton beam. In order to fully exploit the new opportunities for nuclear structure, nuclear astrophysics, and fundamental symmetries research that will be provided by ARIEL, the current 8π facility for decay spectroscopy research at ISAC-I will be replaced by the advanced new high-efficiency GRIFFIN spectrometer described in this article.

2 GRIFFIN detector and spectrometer design

GRIFFIN will consist of sixteen clover-type detectors, each comprised of four 90 mm long, ~40 % relative efficiency, n-type high-purity germanium (HPGe) crystals packed in a four-leaf clover geometry. The mechanical dimensions of the GRIFFIN HPGe crystals and clover detectors have been designed to be identical to those used in the TIGRESS [6, 7] array at ISAC-II and, as in TIGRESS, the outer edges of the HPGe crystals will be tapered at 22.5 degrees over the first 30 mm of their length to enable close-packing of neighbouring clover detectors in the GRIFFIN array. The segmentation of the outer electrical contacts of the TIGRESS detectors [8, 9] used for γ-ray Doppler shift corrections in experiments with accelerated radioactive beams, however, will not be present in the GRIFFIN detectors, which will be used in decay spectroscopy experiments with stopped low-energy beams.

As shown in Fig. 1, the GRIFFIN HPGe detectors will be close-packed to fill 16 of the 18 square faces of a rhombicuboctahedral geometry. One of the remaining square faces will be used for the entry of the low-energy radioactive ion beam from ISAC-I, which will be implanted at the center of the array in the same in-vacuum moving tape collector system currently used with the 8π Spectrometer [4]. The other square face will be used for the exit of the in-vacuum tape, allowing long-lived daughter and contaminant activities to be moved into a collection box shielded from the HPGe detectors by a lead wall. As shown in Fig. 1, the 8 triangular faces of the rhombicuboctahedron will also be available for mounting GRIFFIN auxiliary detection systems, including the BaF_2 and $LaBr_3$ fast-timing γ-ray detectors currently used with the 8π Spectrometer [4], or 8π HPGe detectors themselves, which have 0.5 mm Be entrance windows and can efficiently trigger on photons below 10 keV in those experiments for which low-energy detection efficiency is crucial.

In the close-packed geometry, the front faces of the GRIFFIN HPGe detectors will be located 110 mm from the center of the array, comfortably accommodating the existing central vacuum chamber of the 8π Spectrometer, which has an outer radius of 89.4 mm. The existing in-vacuum auxiliary detection systems of the 8π [4], including the 20 plastic scintillator β detectors of the 4π Scintillating Electron Positron Tagging Array (SCEPTAR), the 5 liquid nitrogen cooled Si(Li) conversion electron detectors of the Pentagonal Array of Conversion Electron Spectrometers (PACES), which also serve as α particle and proton detectors, and the 1π zero degree scintillator (ZDS) β detector for fast timing experiments, will all be immediately available for use in GRIFFIN experiments. The gap between the inner vacuum chamber and the GRIFFIN HPGe detectors can optionally be filled by spherical shells of Delrin with thicknesses up to 20 mm in order to stop energetic β particle from directly hitting the HPGe detectors, while minimizing bremsstrahlung production through the use of a low-Z stopping material. By removing the 4 downstream HPGe clover detectors, it will also be possible to couple the new 70-element Deuterated Scintillator Array for Neutron Tagging (DESCANT) [10] neutron detector array to GRIFFIN, providing a powerful β-delayed n-γ coincidence detection capability. Finally, the mechanical support structure for GRIFFIN shown in Fig. 1 has been designed for full compatibility with the future addition of modular bismuth germanate (BGO) Compton suppression shields of a similar design to those used in the TIGRESS array [11].

3 GRIFFIN data acquisition system

The data acquisition (DAQ) system for GRIFFIN will take advantage of state-of-the-art digital electronics based on the TIGRESS DAQ System [12]. The main design aims for the system are to facilitate the requirements of the two themes of the physics program for nuclear structure and precision fundamental symmetries measurements; to operate at high data throughput with each HPGe crystal operating at rates up to 50 kHz, and to achieve a level of accountability and deadtime/event traceability consistent with half-life and branching ratio measurements with precisions better than 0.05 %. Signal processing will be performed with digitizers designed and built at the Université de Montréal and TRIUMF. The front-end digitizers will use 14-bit precision operating at 100 MHz for HPGe, Si(Li), BaF_2 and $LaBr_3$ energy signals and at 1 GHz for SCEPTAR/ZDS and DESCANT. The fast coincident timing for the BaF_2 and $LaBr_3$ scintillators will be performed in conventional analogue

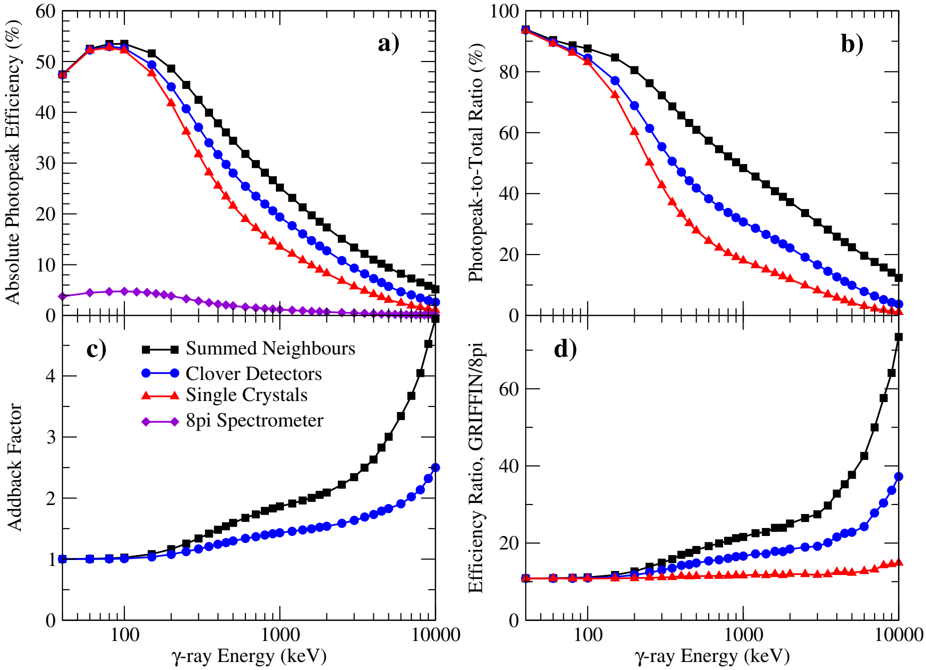

Fig. 2 GEANT4 simulations of GRIFFIN performance metrics: **a** absolute photopeak efficiency, **b** photopeak-to-total ratio, **c** addback factor, and **d** ratio of photopeak efficiency to that of the current 8π Spectrometer, as a function of γ-ray energy. GRIFFIN results are shown treating individual HPGe crystals as separate detectors (*triangles*), summing the energies deposited in the four crystals within a clover detector (*circles*), and summing energies deposited in neighbouring clover detectors (*squares*), while the photopeak efficiencies of the 8π Spectrometer are indicated by diamonds in panel **a**

electronics and the output signal of the TAC modules digitized to be considered in filtering decisions. All events will be pushed to filtering logic where user-selectable coincidence conditions must be satisfied before the data is committed to storage.

4 GRIFFIN performance simulations

Detailed Monte Carlo studies of GRIFFIN performance have been carried out with the GEANT4 simulation package. Figure 2 shows results as a function of γ-ray energy treating the individual HPGe crystals as separate detectors (triangles), summing the energies deposited in the crystals of each clover detector (circles), and summing energies deposited in neighbouring clover detectors in the close-packed array (squares). As shown in Fig. 2a, the absolute photopeak efficiency of GRIFFIN exceeds 50 % in the 50–150 keV energy range, in the "clover" mode is 19 % at 1 MeV and 2.6 % at 10 MeV, while in the "summed neighbour" mode is 25 % at 1 MeV and remains 5.1 % at 10 MeV. The large gains in photopeak efficiency achieved by adding the γ-ray energies deposited in neighbouring crystals, either within the same clover detector or in neighbouring detectors, are displayed in Fig. 2c as the "addback" factors, which are the clover and summed neighbour photopeak efficiencies divided by those of the single crystal mode. For the clover detectors, the addback factor is 1.43 at 1 MeV and 2.5 at 10 MeV, while for the summed neighbour mode it is 1.86 at 1 MeV and 4.9 at 10 MeV, indicating that the close packing of the GRIFFIN detectors, with their flush tapered outer edges over the first 30 mm of HPGe crystal depth, effectively provides an additional addback factor in low γ-ray multiplicity β decay experiments that equals the usual clover addback factor for 1 MeV γ rays and significantly exceeds it for γ rays above 5 MeV.

The photopeak-to-total ratios for GRIFFIN are shown in Fig. 2b and for 1 MeV γ rays increase from 18 % for single crystals, to 31 % for the clover detectors, and 48 % for the summed neighbour mode. Finally, Fig. 2d displays the ratios of the GRIFFIN photopeak efficiencies to those of the current 8π Spectrometer at ISAC-I (shown as diamonds in Fig. 2a for reference). For low-energy γ rays, GRIFFIN is a factor of 11 more efficient than the 8π Spectrometer due to the increased solid angle coverage by HPGe, and this factor is relatively constant in the single crystal mode, increasing to a factor of 15 for 10 MeV γ rays. The addback factors of the clover and summed neighbour modes, however, provide large gains with increasing γ-ray energy. The GRIFFIN clover mode is predicted to be 17 times more efficient than the 8π Spectrometer at 1 MeV and 37 times more efficient at 10 MeV, while the summed neighbour mode is 22 times more efficient at 1 MeV and more than 70 times more efficient than the 8π Spectrometer for 10 MeV γ rays. In addition to these very large efficiency gains for high-energy γ rays, it is also important to note that many GRIFFIN experiments will be carried out in γ-γ coincidence mode, for which the relevant figure of merit is the square of the photopeak efficiency. For typical γ-ray energies in the 1–2 MeV range, the clover mode of GRIFFIN will thus provide approximately 300 times the γ-γ coincidence efficiency of the current 8π Spectrometer, while the summed neighbour mode of GRIFFIN will have almost 500 times the γ-γ efficiency of the 8π. These enormous gains in high-energy and γ-γ coincidence efficiency provided by GRIFFIN will enable both high-precision branching ratio measurements for complex high Q-value β decays and detailed spectroscopic studies of the most exotic beams produced by the new ARIEL facility with intensities below 0.01 ions/s.

5 Summary and outlook

GRIFFIN has been designed to provide the excellent γ-ray energy resolution characteristic of HPGe detectors, the very high photopeak detection efficiency required for experiments with the most exotic radioactive beams, high rate capabilities for experiments with intense radioactive beams closer to stability, and the rigorous control of electronic deadtimes required for high-precision fundamental symmetries measurements, such as the RnEDM experiment [13]. First experiments with $\sim$10 GRIFFIN HPGe clover detectors at ISAC-I are planned for 2014, while the full 16-detector GRIFFIN spectrometer will be operational in 2015. As is the case with the current 8π Spectrometer, GRIFFIN will operate in conjunction with a suite of auxiliary detection systems, including β, conversion electron, neutron, low-energy photon, and fast-timing γ-ray detectors. The combination of the state-of-the-art GRIFFIN spectrometer, this powerful suite of auxiliary detectors, and the intense beams of radioactive ions from ISAC, and its major upgrade to ARIEL, will provide a wide range of new opportunities for nuclear structure, nuclear astrophysics, and fundamental symmetries research.

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References

1. Dilling, J., Krücken, R., Ball, G.C.: The experimental facilities at ISAC. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0886-6
2. Laxdal, R., Marchetto, M.: The ISAC post-accelerator. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0884-8
3. Svensson, C.E., et al.: Radioactive beam experiments with large Gamma-Ray detector arrays. Nucl. Instrum. Meth. Phys. Res. B **204**, 660–665 (2003)
4. Garnsworthy, A.B., Garrett, P.E.: The 8π Spectrometer. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0888-4
5. Dilling, J., Krücken, R., Merminga, L.: ARIEL overview. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0906-6
6. Svensson, C.E., et al.: TIGRESS: TRIUMF-ISAC Gamma-Ray escape-suppressed spectrometer. J. Phys. G **31**, S1663–1668 (2005)
7. Hackman, G., Svensson, C.E.: The TRIUMF-ISAC Gamma-Ray escape suppressed spectrometer, TIGRESS. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0905-7
8. Scraggs, H.C., et al.: TIGRESS highly segmented high-purity Germanium clover detector. Nucl. Instrum. Meth. Phys. Res. A **543**, 431–440 (2005)
9. Svensson, C.E., et al.: Position sensitivity of the TIGRESS 32-Fold segmented HPGe detector. Nucl. Instrum. Meth. Phys. Res. A **540**, 348–360 (2005)
10. Garrett, P.E.: DESCANT—the deuterated scintillator array for neutron tagging. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0891-9
11. Schumaker, M.A., et al.: Measured and simulated performance of compton-suppressed TIGRESS HPGe clover detectors. Nucl. Instrum. Meth. Phys. Res. A **570**, 437–445 (2007)
12. Martin, J.-P., et al.: The TIGRESS DAQ/Trigger system. IEEE Trans. Nucl. Sci. **55**, 84–90 (2008)
13. Tardiff, E.R., et al.: The Radon EDM apparatus. Hyperfine Interact. (2013). doi:10.1007/s10751-013-0898-2