Methods to improve the performance of the SAGE spectrometer

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Abstract

The SAGE spectrometer is capable of simultaneous gamma ray and conversion electron measurements. The system has been tested and the basic operational principles proven to be sound. However there is always room for improvement. Some of these improvements are presented and the effect on the performance is discussed.

1 Basics of SAGE spectrometer

Experiments to study heavy elements are often plagued by internal conversion which causes the low-energy transitions to be lost in gamma-ray spectra. In order to gain more detailed knowledge about these transitions a powerful HPGe gamma ray spectrometer JUROGAM2 was married to an electromagnetic solenoid and a Si detector thus creating the SAGE spectrometer. The main parts of the spectrometer are shown in figure 1. Primary beam travels trough the magnetic coils which are at angle of 3° to the beam axis. Prompt gamma rays are detected by JUROGAM2 around the target chamber and electrons travel to the Si detector guided by the magnetic field. The basic operating principle is illustrated in figure 2. More detailed description can be found in Refs. [1, 2, 3].

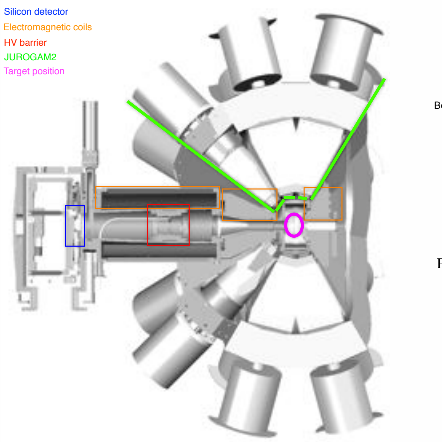


Figure 1: A sidecut image of the SAGE spectrometer. Primary beam enters the spectrometer from left and RITU is on the right side of the JUROGAM2.

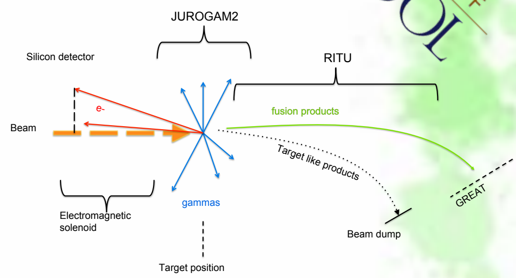


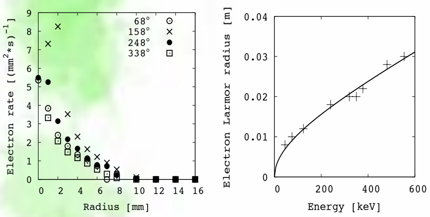
Figure 2: The basic operational principle of the SAGE spectrometer.

2 Radial filtering

The electrons transported through SAGE move according to known electromagnetic laws. These laws can be harnessed to provide a simple selection rule to filter out scattered electrons that have reached the Si detector. The natural starting point for the filter development is the relativistic form of the Larmor radius shown in equation 1.

$$R_e(E) = \frac{m_e c\sqrt{\gamma_0^2 - 1}}{eB} = \frac{m_e c\sqrt{(1+\frac{E}{m_e c^2})^2 - 1}}{eB} \qquad (1)$$

Basis of the equation 1 is the general momentum form of the Larmor radius and the relativistic substitutions used are presented, for example, in [4]. An example of the measured electron distribution with a clearly observable maximum radius is shown in figure 3a.



(a) Radial distribution of 45 keV electrons over the Si detector.

(b) Fitted relativistic Larmor curve.

Figure 3: Steps towards the radial filtering.

The relativistic Larmor function is then fitted to the points obtained from ^{133}Ba and ^{207}Bi transition energies. As shown in figure 3b the measured points correspond nicely to the shape of the theoretical Larmor curve. The radial filter is then implemented by demanding that observed radius of the electron is less than or equal to $R_e(E)$. Resulting spectra have up to 10% less background compared to unfiltered cases. An example of the effect of the filtering is shown in the figure 4. The radial filtering and the following electron add-back method will be discussed in detail in Ref. [5].

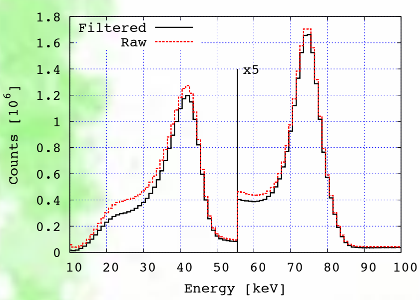


Figure 4: Effect of the radial filtering on low energy part of ^{133}Ba spectrum.

3 Electron add-back

The SAGE silicon detector is highly segmented in order to normalize the count rates. This has a drawback when the goal is to observe high energy electrons. The dimensions of the electron interaction volume become so large that a significant number of the electrons arriving at the Si detector either punch through or deposit energy in more than one pixel. Those electrons that deposit energy in two adjacent pixels can be recovered by demanding coincidence and close proximity on the detector and summing the individual energies. Figure 5 shows the raw singles spectrum of detected "double hit" events together with a reconstructed spectrum.

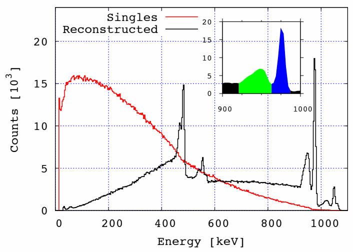


Figure 5: Detected double hit singles and resulting reconstructed spectrum. *Inset:* The typical peak shape in the reconstructed spectrum. Full energy peak in blue, escape peak in green.

The electron add-back generates peaks with a very distinctive signature. This is thought to arise from events where an electron interacts with two pixels and then escapes. A theoretical explanation for the peak shape and relative intensities can be found from Ref. [6]. The effect of electron add-back grows significantly for electron energies above 1 MeV. For example, the detection efficiency of 1682 keV electron from a ^{207}Bi source grows 50% as a result of add-back. If the resulting escape peak is taken account the efficiency grows more that 100% as shown in figure 6. Tests conducted with a ^{133}Ba source have shown that the add-back method is very clean in a sense that summing with full energy events is negligible.

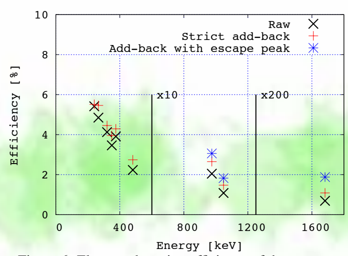


Figure 6: Electron detection efficiency of the system.

4 Technical modifications

During the first experimental campaigns a need for minor technical improvements has arisen. Minor improvements to the HV barrier circuit were made to optimise its performance. The electron distribution was off-centre about 1 cm and was shifted by modifying the magnetic field distribution (detailed description in [3]). The most significant change is the possibility to install the carbon foils that separate the HV volume from RITU in such a way that the foils are not in the direct sight of the HPGe detectors, in order to reduce the gamma-ray background level. The difference between these two setups is shown in figure 7. Maximum usable beam current with the new pumping system is expected to be slightly lower due to the thermal conditions of the target. With the modified pumping system, it may be possible to use higher beam intensities than in the first campaign, but one possible drawback is that the target will not be cooled as efficiently as it is no longer in the volume containing He at 1 mbar. These effects remain to be investigated.

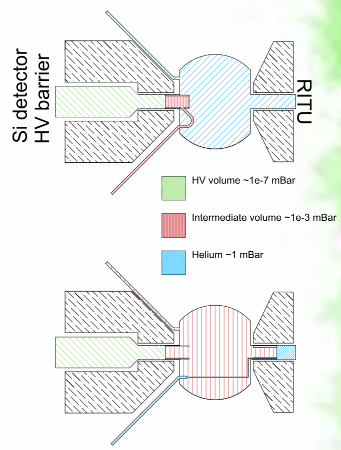


Figure 7: Difference between the different pumping methods. Original setup (upper) has both C-foils attached in single unit between target and the detector. In the modified system (lower) the other C-foil is moved to behind the target within the downstream beam tube.

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