Energy Calibration and Measurement using Signal Amplitude for various Germanium detectors

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Introduction

To study neutrino electromagnetic properties to investigate the anomalous properties of neutrino and neutrino interactions with matter can probe new physics beyond the Standard Model (SM). In addition to this neutrino coherent scattering with nucleus is a fundamental SM prediction which has never been observed. Similarly search of suitable dart matter candidate is also highly motivated with models but still not observed. In this case, the WIMP elastic recoils off nucleus are the favored channel in direct dark matter candidate search experiments. In this direction, use of nuclear power reactors is common due to almost free low energy neutrinos and additional shielding. Typical recoil energy spectra to various neutrino physics using Kou-Sheng Nuclear Power Plant in Taiwan is shown in Figure 1. To study the above mentioned physics detector sensitivities and dynamic ranges of several associated components must be significantly enhanced especially in terms of lower energy reach of signal detection i.e. the physics threshold of detector can be extended. This motivate us to characterize detector specially germanium, behaviour and to devise optimal analysis methods in the energy region of interest where the signal amplitude is comparable to those due to fluctuations of pedestal electronic noise.

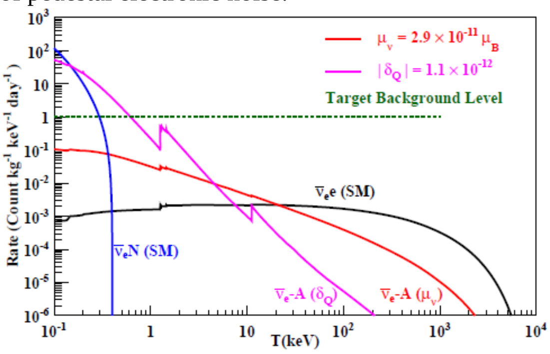

Fig. 1: The observed spectra due to reactor-electron antineutrino interactions on Ge target with neutrino flux $10^{13}cm^{-2}s^{-1}$, neutrino magnetic moment and neutrino milli-charge fraction at the current bounds from direct experimental searches. Overlaid are the SM anti-ν_e–e and coherent scattering anti-ν_e–N.

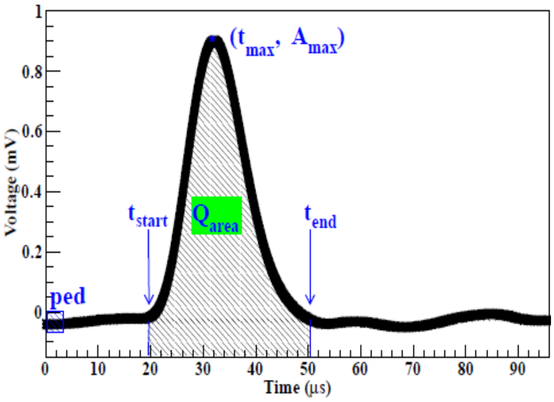

Fig. 2: Typical (SA_6) shaping amplifier with 6 μs shaping time pulse from germanium detector. The various DAQ related parameters for data analysis and energy calibration purposes are marked.

Varity of germanium detectors have been studied. Performance of the detector basically based on the linearity with deposited energy in the detector. We studied the performance of detectors based on the energy measurement especially in the energy region at and below the noise edge.

Energy Measurement

As shown in Figure 2, A_{max} and Q_{area} are the maximum amplitude and integrated area within the time window of t_{start} and t_{end}, respectively. The averaged pedestal value is an offset and is subtracted in the analysis. The pedestal electronic noises are characterized by Noise-Amplitude-RMS (σ_A) and Noise-Area-RMS (σ_Q), derived from random trigger events. For quick and valid comparison of the various detectors performances σ_A and σ_Q are measured in calibrated energy unit. Both parameters have been adopted for the measurement of the energy of an event. As the signal size becomes comparable to the electronic noise in low energy region required further investigations.

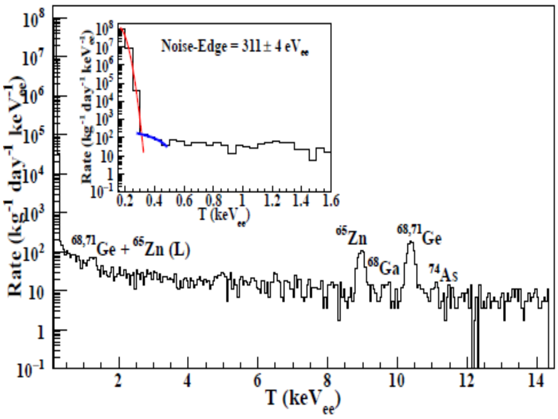

Fig. 3: Typical pPCGe spectrum is showing x-ray peaks and noise edge. Peaks are used in energy calibration. The peaks are due to electron capture of cosmogenic activated isotopes producing x-rays inside the detectors. In the inset, noise edge is illustrated.

Energy Calibration

We measured spectra of the three types of Ge detector and only showing pPCGe spectrum in Figure 3. Details of all detectors are mentioned in Ref. [#]. In all spectra, no physics structure is observed below 1 KeV and for energy calibration purpose test-pulser is used. The energy scale of the pulser is defined by matching to the known γ–peaks at high energy. We observed that the response of the detector is linear to a range below the electronic noise edge.

Energy Response

Deviation from linearity can be expected when the pulse amplitude is comparable to the pedestal noise fluctuations as shown in Figure 4(a). This is a consequence to the choice of the pulse amplitude as the energy estimator; even random sampling of the pedestal noise would give finite amplitude.

From Figure 4(b), it can be seen that the response is non-linear only at $A_{max} < 6\sigma_A$ for both detectors. In the physics region above the electronic noise edge of 7.3 (7.6) σ_A for pPCGe (nPCGe) and the response is linear to better than 4 eV that is justifying the validity of the amplitude measurement.

Results and Outlook

The present adopted scheme of energy measurement with the amplitude of SA_6 is therefore applicable to the entire detector fiducial volume for all type of high purity germanium detectors. It is robust and well behaved in the energy range of interest where physics is extracted. At this stage we are realizing the limitations of the detector and adopted software tools. Therefore, to push the physics threshold lower the optimizations of hardware configurations, the JFET and ASIC electronic components are necessary. Study on the novel idea of internal amplification in germanium ionization detectors seems to be useful.

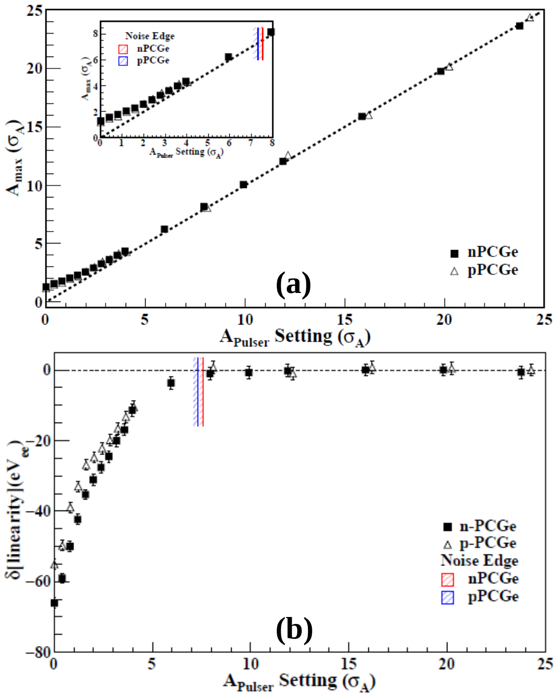

Fig. 4: (a) Response of the pPCGe and nPCGe detectors versus energy when the test pulser amplitude is comparable to pedestal noise fluctuation. A_{max} in σ_A unit, showing non-linear behaviour as energy approaches to zero, (b) deviations in eV unit from linearity.

Acknowledgments

This work is fully supported by the Academia Sinica and the Ministry of Science and Technology, Taiwan. Authors are grateful to the TEXONO Collaboration.

Reference

[1] H. B. Li et al., Phys. Rev. Lett. **110**, 261301 (2013).
[2] H. B. Li et al., Astopart. Phys. **56**, 1 (2014).