PROCEEDINGS OF SCIENCE

Hands on CUORE ABSuRD: Characterisation of a Silicon Photomultiplier at Low Temperatures

PoS(GSSI14)024

Ritoban Basu Thakur[*]
University of Illinois at Urbana Champaign, &
Fermilab Center for Particle Astrophysics
E-mail: ritoban@fnal.gov

Johannes Rothe[†]
Princeton University
E-mail: jrothe@astro.princeton.edu

Carlo Bucci
Laboratori Nazionali del Gran Sasso
E-mail: carlo.bucci@lngs.infn.it

Lucia Canonica
Laboratori Nazionali del Gran Sasso
E-mail: lucia.canonica@lngs.infn.it

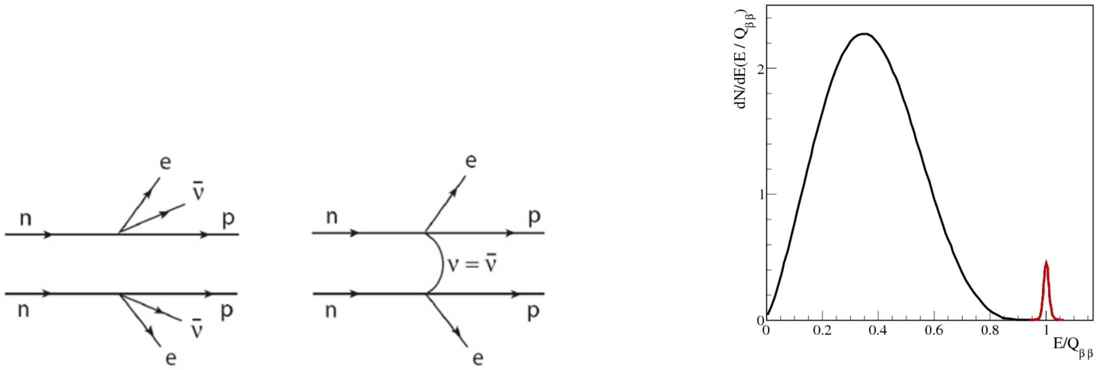
The expected main background contribution in the CUORE experiment is attributed to detector surface contamination with alpha-emitters. To suppress this background, a rejection mechanism employing scintillator foils (the ABSuRD detector) is under development. The optimal operation temperature for a Silicon photomultiplier to characterize candidate scintillator materials was determined and noise sources were characterized.

Gran Sasso Summer Institute 2014 Hands-On Experimental Underground Physics at LNGS - GSSI14,
22 September - 03 October 2014
INFN - Laboratori Nazionali del Gran Sasso, Assergi, Italy

---

[*] Speaker.
[†] Speaker.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence.



(a) Double beta decay processes

(b) Double beta decay spectrum.

Figure 1: Double beta decay channels and expected rates. Subplot (a) shows the two processes contributing to double beta decay. In (b) we show the combined-energy spectrum for all two-electron events. The overwhelming rate of double-beta events from the two neutrino process (first diagram from (a)) is shown in black, the neutrinoless decay (second diagram from (a)) spectrum is the peak shown in red. For CUORE, this peak is expected at 2527 keV.

1. Introduction

1.1 Physics motivation

Neutrinos are a leading gateway into exploring physics beyond the standard model. It is essential to understand whether they are Majorana particles and what their mass-scales are. If neutrinos are Majorana fermions then a double beta decay process is possible, where by weak mediator symmetry no neutrinos are emitted. This results in an effective two-body decay and the beta-spectrum (of the total energy of the two emitted electrons) has a peak as opposed to a continuum. If in neutrinoless double-beta decay ($0\nu\beta\beta$) searches, such a peak is observed we not only understand neutrinos as a fundamental Majorana particle, but can also determine the fundamental neutrino mass from the event rate and nuclear matrix elements. Fig. 1 shows diagrams for the double-beta decay processes and their energy spectrum.

The Cryogenic Underground Observatory for Rare Events (CUORE) experiment aims to measure this $0\nu\beta\beta$ peak by employing ton-scale cryogenic bolometers in a very low background environment. The characteristic time-constant for this process is $\gtrsim 10^{25}$ years, and is hence a very rare process. This necessitates maintaining extremely low backgrounds, particularly given the abundance of recoils from ordinary beta-decays with neutrino emission which form a continuum spectrum. Secondly even if the background is sufficiently moderated, to discern the peak from the continuum tail one needs detectors with extremely high resolution (very low σ/μ). Here, the strengths of ultra cold TeO_2 bolometers can be made use of. At a base temperature of $\sim$10 mK, thermal phonon modes are typically frozen out and atomic recoils may be measured very precisely by exciting these phonon modes. Thus for CUORE, critical development has been pursued on both these fronts of background reduction and detector resolution [1, 2, 3]. In this proceeding we discuss

PoS(GSSI14)024

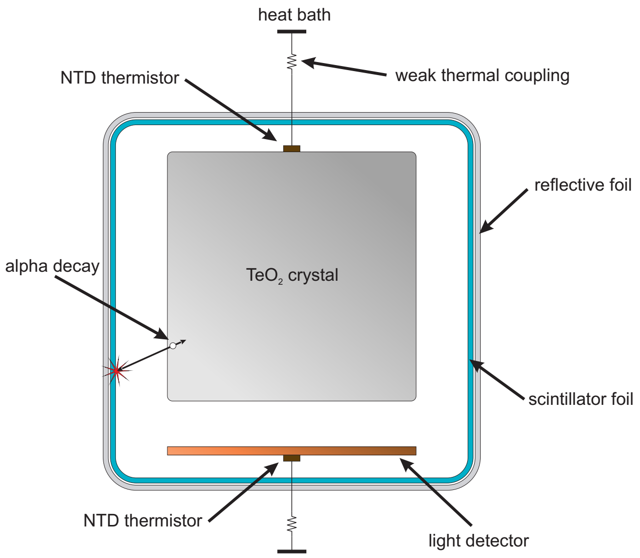


Figure 2: ABSuRD configuration on a CUORE TeO_2 crystal bolometer

a new active veto system intended for tagging backgrounds from surface contaminations.

1.2 Detector Geometry and Introduction to Surface Vetos

Fig. 2 is a schematic of a future upgraded CUORE detector, specifically a single TeO_2 crystal bolometer is shown in the center. The recoil energy from beta decays are measured via thermal phonons with a germanium thermistor (NTD) glued on the TeO_2 crystal. Fig. 2 also shows a surface event generated by α recoil. Such events are a generic problem to most rare event search experiments. Radon from the experimental environment can deposit on to the detector housing, and over time undergo various Pb^{210} α decays, which provide a major background limitation to the experiment.

The crux of an active surface veto is to cover all passive material with scintillating and reflecting foils. Thus for surface events energy is measured as deposited in the main crystal, and also scintillation photons from the foil are read by the light-detector shown in Fig. 2 at the wafer in the bottom. In the CUORE framework this concept is being tested as the “A Background Surface Rejection Detector” (ABSuRD) and will be the focus of this proceeding.

2. The ABSuRD R&D project

The initial tests for ABSuRD require characterizing scintillating material and corresponding photodetectors at very low temperatures. To do this a two stage cryostat was used with one stage held at 50 K and the other at 10 K via a two-stage Gifford-McMahon cooler. The goal is to have silicon photo multiplier (SiPM) photo sensors on one stage and various scintillators with LED sources on the other stage. The schematic of this two-stage housing is shown in Fig. 3.

PoS(GSSI14)024

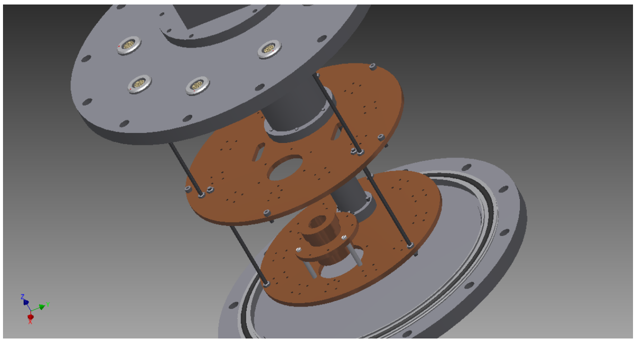


Figure 3: Cryostat for characterizing scintillating materials at low temperature with SiPMs.

During the 2014 Gran Sasso Summer Institute we performed the characterisation of the SiPM response with varying temperature and voltage-current settings.

3. Optimal Operation Temperature for a Silicon Photomultiplier

SiPMs prefer an intermediate range of operating temperatures. At high temperature ($\gtrsim 200$ K), the dark count rate becomes prohibitively large, while at low temperature (below 100 K) after-pulsing is the dominant noise source. Dark counts arise from thermal excitations in the photodiode which trigger an avalanche without presence of a photon. After-pulsing is the delayed initiation of secondary avalanches after a real event, and is favored at low temperatures by increased trap-lifetimes. Trapped states excited by the photoelectron and the first avalanche can decay later and mimic a second photon event. The impact of these effects can be qualitatively seen in Fig. 4, which shows example pulse shapes obtained with a SiPM in the ABSuRD lab at different temperatures. At 300 K we can see a continuous background of counts, the signal never decays to the true baseline level. At 80 K we get strong after-pulsing, visible as multiple peaks riding on the slow decay of a photon event.

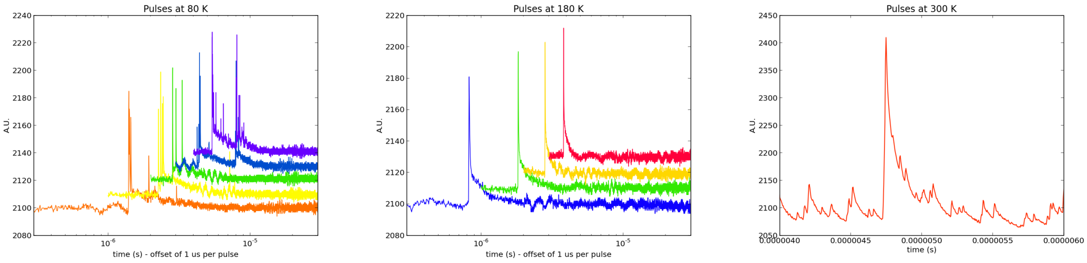


Figure 4: SiPM pulses at 80 K, 180 K and 300 K, notice degradation at low and high temperatures.

In Fig. 5, we show the rates of these events as a function of temperature. We calculate the total rate by triggering in software after acquisition of data. We average over a small window (~ 10 ns) in time and trigger on the peaks using a threshold chosen so that we are not susceptible to noise but also not losing many signal pulses. We can remove the after-pulsing counts from our total rate by “blinding” the software trigger for an interval of a few tens of microseconds, so that the artificial dead time removes the extra counts. We can see that this simple measure of subtracting

PoS(GSSI14)024

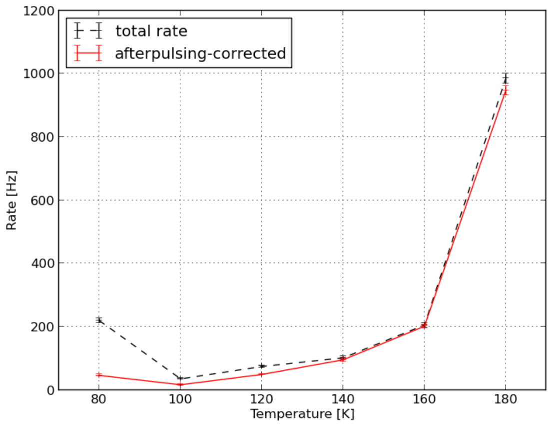


Figure 5: SiPM dark event rates split into contributions by dark counts and afterpulsing

after-pulsing is sufficient to show us the temperature dependence of this noise source. The graph of total counts versus temperature obtained without a light source has a *U-shape*, where after-pulsing is responsible for the rise at low temperatures, and dark counts cause the very high rates closer to room temperature.

Obviously the operating temperature should be chosen in the intermediate range. The exact optimum can best be determined from the contrast in photon-counting diagrams, which is a direct measure of SiPM performance in real operation.

4. Photon counting with the Silicon Photomultipliers

In a SiPM the number of avalanche photo diodes which trigger is proportional to the number of incident photons. Choosing a suitable integration window, the pulse areas should exhibit quantization which shows up as “fingers” in a histogram, however some smearing occurs from temperature dependencies discussed earlier. In Fig. 6 we show such histograms obtained from the data already used above for rate determinations. Although the different photoelectron peaks are visible even at 100 K, the contrast clearly increases towards higher temperatures.

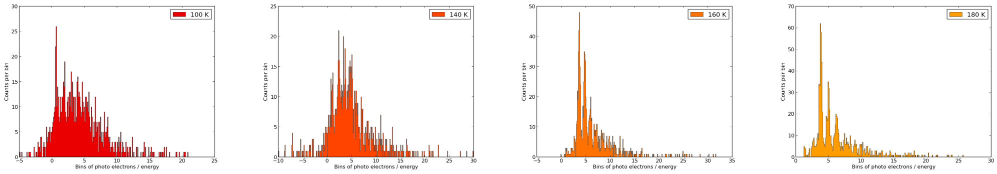


Figure 6: SiPM pulse strength histograms showing photon-counting diagrams at varying temperature.

Fig. 7 shows how the histogram changes for different integration windows (the window boundaries are given in units of 4 ns, the ADC sampling time, relative to the trigger event). We see that a small window of only 32 ns duration yields the best photon-counting results.

PoS(GSSI14)024

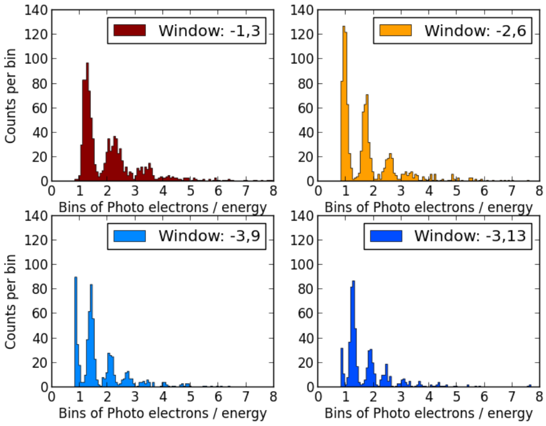


Figure 7: SiPM pulse strength histograms showing photon-counting capability at 180 K

5. Conclusions

In two weeks of experimental work, we verified the photon counting capability of a silicon photomultiplier, located its optimal operating temperature range, characterized the temperature dependence of the noise sources defining this optimum (160-180 K), and created analysis tools that allow fast visualization. Following this work the ABSuRD R&D effort will now focus on the completion of the scintillator characterization setup.

References

[1] E. Fiorini. CUORE: a cryogenic underground observatory for rare events. *Physics Reports*, 307:309–317, December 1998.

[2] C. Bucci, P. Gorla, and W. Seidel. Rejection of Surface Background in Thermal Detectors. *ArXiv e-prints*, March 2011.

[3] F. Alessandria, R. Ardito, D. R. Artusa, F. T. Avignone, III, O. Azzolini, M. Balata, T. I. Banks, G. Bari, J. Beeman, F. Bellini, A. Bersani, M. Biassoni, T. Bloxham, C. Brofferio, C. Bucci, X. Z. Cai, L. Canonica, S. Capelli, L. Carbone, L. Cardani, M. Carrettoni, N. Casali, N. Chott, M. Clemenza, C. Cosmelli, O. Cremonesi, R. J. Creswick, I. Dafinei, A. Dally, V. Datskov, A. De Biasi, M. M. Deninno, S. Di Domizio, M. L. di Vacri, L. Ejzak, R. Faccini, D. Q. Fang, H. A. Farach, E. Ferri, F. Ferroni, E. Fiorini, M. A. Franceschi, S. J. Freedman, B. K. Fujikawa, A. Giachero, L. Gironi, A. Giuliani, J. Goett, A. Goodsell, P. Gorla, C. Gotti, E. Guardincerri, T. D. Gutierrez, E. E. Haller, K. Han, K. M. Heeger, H. Z. Huang, R. Kadel, K. Kazkaz, G. Keppel, L. Kogler, Y. G. Kolomensky, D. Lenz, Y. L. Li, C. Ligi, X. Liu, Y. G. Ma, C. Maiano, M. Maino, M. Martinez, R. H. Maruyama, Y. Mei, N. Moggi, S. Morganti, T. Napolitano, S. Newman, S. Nisi, C. Nones, E. B. Norman, A. Nucciotti, F. Orio, D. Orlandi, J. L. Ouellet, M. Pallavicini, V. Palmieri, L. Pattavina, M. Pavan, M. Pedretti, G. Pessina, S. Pirro, E. Previtali, V. Rampazzo, R. Reil, F. Rimondi, C. Rosenfeld, C. Rusconi, S. Sangiorgio, N. D. Scielzo, M. Sisti, A. R. Smith, L. Sparks, F. Stivanello, L. Taffarello, M. Tenconi, W. D. Tian, C. Tomei, S. Trentalange, G. Ventura, M. Vignati, B. S. Wang, H. W. Wang, C. A. Whitten, Jr., T. Wise, A. Woodcraft, L. Zanotti, C. Zarra, B. X. Zhu, and S. Zucchelli. Validation of techniques to mitigate copper surface contamination in CUORE. *Astroparticle Physics*, 45:13–22, May 2013.

PoS(GSSI14)024