Comments on "A Dark Matter Search with MALBEK"

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CoGeNT and MALBEK use p-type point contact germanium detectors to search for low-mass dark matter particles. Both detectors enjoy identical intrinsic noise characteristics. However, MALBEK’s data acquisition electronics severely degrade the ability to separate signals originating in the bulk of the germanium crystal from surface backgrounds, through a measurement of the preamplifier pulse rise-time in the sub-keVee energy range of interest. The physical meaning of the parameter $W_{\text{par}}$ developed by the MAJORANA collaboration to compensate for this limitation is clarified here. It is shown that this parameter does not correlate to rise-time at low energy, and is presently unable to distinguish between surface and bulk events below $\sim 1$ keVee. This leads to a sizable overstatement of MALBEK’s sensitivity to low-mass dark matter particles, when employing aggressive $W_{\text{par}}$ cuts.

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This brief note intends to clarify the important differences in performance at low-energy between the CoGeNT and MALBEK detectors. Strong limitations in both hardware and methodology affecting MALBEK are hard to derive from the discussion offered in [1]. Both detectors are very similar in their intrinsic characteristics (noise, background, capacitance, design, etc. [2]), with low-background cryostat parts and inner shielding for MALBEK being provided by the CoGeNT collaboration. The MALBEK detector is by design a replica of the CoGeNT detector, and as such it displays the same intrinsic electronic noise ($\sim 160$ eV FWHM). However, the MALBEK data acquisition system, intended for future use in the MAJORANA Demonstrator array, severely curtails this performance by injecting a dominant level of electronic noise (Fig. 1). This problem persisted even following attempts to ameliorate the polling noise from a Struck SIS3302 VME digitizer through software modifications [2].

As is acknowledged in [2], this additional source of electronic noise makes it impossible to adequately measure the rise-time ($t_{10-90}$) of preamplifier pulses below $\sim 4$ keVee in MALBEK (Fig. 2, top panel). This rise-time is the parameter that enables the separation between bulk (small $t_{10-90}$) signals like those expected from hypothetical dark matter particles, and surface (large $t_{10-90}$) backgrounds within CoGeNT. Rise-time is physically correlated to the intensity of the electric field in these two regions, through its effect on charge mobility [3–5]. To compensate for this limitation, MALBEK adopts a parameter ($W_{\text{par}}$) derived from wavelet analysis of preamplifier traces, to attempt a discrimination between surface and bulk events. This parameter is formally defined as $W_{\text{par}} = \max(\left|c_D^{(i)}(n = 0)\right|^2/E^2)$, or roughly equivalent to a “smoothed out derivative normalized by the square of the energy ($E$) of the event” [2]. The coefficients $c_D^{(i)}(n = 0)$ are the so-called detail coefficients corresponding to the first iteration ($n = 0$) of a stationary wavelet transform (SWT), where the index ($i$) corresponds to each sampled datapoint in the preamplifier pulse trace. This prima facie rather obscure definition of $W_{\text{par}}$ will be further clarified below. $W_{\text{par}}$ and the rise-time of preamplifier traces are observed to correlate in MALBEK for calibration events induced by a low-energy $^{241}$Am source,
Taking advantage of the ability to extract rise-time values down to 0.5 keVee in CoGeNT, it is possible to cast light on the opaque meaning of $W_{\text{par}}$ by applying both estimators to a recently released CoGeNT dataset. The physical meaning of $W_{\text{par}}$ can be best understood by observing the behavior of the detail coefficients $c_D^{(i)}(n = 0)$, on which it depends. Fig. 4 shows these coefficients around the position of the preamplifier rising edge ($i \sim 6325$), for three well-formed CoGeNT events of 6.8 keVee, large enough not to be much affected by electronic noise. For sharp pulses with $t_{10-90} \sim 0.3\mu$s (bulk events), a distinct maximum value of $c_D^{(i)}(n = 0)$, to which $W_{\text{par}}$...
FIG. 3: Distributions of $t_{10-90}$ for CoGeNT (left column) and $W_{\text{par}}$ in MALBEK (right column), for several energy regions, labelled within left column panels. Bulk pulses are observed as a peak concentrated to the left (right) of CoGeNT (MALBEK) distributions. MALBEK distributions are obtained from the digitization of DS3a and DS3b data (221 days) in [2]. The 221 day subset of CoGeNT data shown here was selected to start 637 days from its installation underground, so as to establish a fair comparison to these MALBEK datasets (i.e., a similar level of remaining long-lived cosmogenic activation). A fairly constant separation between bulk events (red in bottom panel) and surface events (blue) is maintained for CoGeNT data all the way down to its 0.5 keVee threshold [5, 9, 12]. In contrast to this, these two distributions are observed to merge together at MALBEK’s 0.6 keVee threshold, due to the rapid broadening and migration towards smaller values of $<W_{\text{par}}>$ for fast events of decreasing energy (see text). Surface MALBEK events were observed to populate the range $\sim 1000 <W_{\text{par}}< \sim 3000$ next to its threshold, during early runs previous to the removal of internal surface contaminants [2].
is proportional by definition, can be easily identified. However, as the rising edge softens (larger $t_{10-90}$, surface events), the maximum absolute $c_D^{(i)}(n=0)$ becomes just a random value like that of detail coefficients far from the position of the rising edge in the preamplifier trace. As the energy decreases, pulses are proportionally more affected by electronic noise, and no value of the rise-time, regardless of how small, is able to generate a distinct $\max(|c_D^{(i)}(n=0)|)$ above these random fluctuations (Fig. 5). In other words, $W_{par}$ is a simple indicator of how well the SWT is able to reveal the presence of a rising-edge in a preamplifier trace: for large energy pulses well-above the electronic noise of the preamplifier baseline, bulk events return a $\max(|c_D^{(i)}(n=0)|)$ distinct from random fluctuations in these detail coefficients. However, for the present level of electronic noise affecting CoGeNT and MALBEK PPCs, the presence of a rising edge cannot be identified below $\sim 1$ keVee through the first iteration of a SWT, regardless of how sharp the transition (how small the rise-time) of a pulse might be: the rising edge is not sufficiently well-defined for the $W_{par}$ estimator to indicate its presence, and all events look like surface events under $W_{par}$ examination. The behavior displayed in Fig. 5 illuminates the origin of the rapid merger of MALBEK’s bulk events into the surface event distribution at low energy, already pointed at in Figs. 2, 3.

FIG. 4: Detail coefficients from the first iteration of the stationary wavelet transform (SWT) around the rising edge ($i \sim 6325$, 50ns per sample) of three 6.8 keVee CoGeNT events, each with a different value for the rise-time (see text).

FIG. 5: Top: rise-time distributions for events from a 3.2 year CoGeNT exposure, showing two distinct populations down to threshold. Bottom: Maximum absolute value of the detail coefficients for these events ($W_{par} = \max(|c_D^{(i)}(n=0)|^2)/E^2$). The inset is a zoom-in of the same, extracted from the high-gain CoGeNT channel. $W_{par}$ does not correlate to rise-time at the lowest energies. It is instead a simple measure of how well the SWT can identify the presence of a rising edge in a preamplifier trace, which breaks down below $\sim 1$ keVee for the present level of noise affecting both CoGeNT and MALBEK detectors, regardless of rise-time value. The merger of low-energy bulk events into the surface event distribution affecting MALBEK when using $W_{par}$ as a discriminator is made evident in this figure (see text).

The possible annual modulation observed in CoGeNT data below $\sim 2$ keVee is a subtle effect, amounting to $\sim 5\%$ oscillations of the overall (bulk plus surface) signal rate. It is therefore of the utmost importance to accomplish the best possible separation between surface backgrounds and bulk signals, if a modulation of such a small magnitude stands a chance of being noticed. This is specially true when surface and bulk event rates are seen to be comparable, as is the case for both CoGeNT and MALBEK (Fig. 3), and when taking into consideration the statistics of small numbers involved in a modulation analysis for detectors this modest in mass. In view of the poor to non-existent surface/bulk discrimination ability accomplished within MALBEK in the energy region of interest below 1 keVee, it would be hard to assign any value to a MALBEK search for an annual modulation, if performed by means of a $W_{par}$ analysis.

In conclusion, a careful inspection of the physical meaning of the parameter $W_{par}$ reveals a lack of correlation, even indirect, to preamplifier pulse rise-time $t_{10-90}$.
below $\sim 1$ keVee. With decreasing energy, $W_{\text{par}}$ is observed to rapidly collapse to values assigned to surface events, for all events. As a result, the majority of pulses in the energy region of interest for low-mass dark matter searches are erroneously identified as surface events in a recent MALBEK analysis [1]. When applying aggressive $W_{\text{par}}$ cuts, this leads to an unwarranted decrease of the bulk event rate in MALBEK’s low energy spectrum, and to an artificially enhanced sensitivity to low-mass dark matter particles.

A similar concern can be expressed of a recent analysis of data from another PPC [11], where a dramatic reduction in low-energy background is claimed from use of a method involving extrapolations to low-energy from observations derived using high-energy gamma source calibrations. A straightforward validation of bulk event signal acceptance in the crucially relevant energy region near threshold, obtained through the use of an electronic pulser, is notoriously absent from [11]. While PPCs offer the possibility to discern surface from bulk events, it is easy to overestimate or underestimate the magnitude of the irreducible spectrum next to detector threshold. The only solution to this riddle is a further hardware improvement to the PPC electronic noise. This has been accomplished in a next-generation CoGeNT detector, to be described in an upcoming publication.

An exponential excess of low-energy bulk events remains present in an upcoming analysis [12] of a high-statistics 3.4 year CoGeNT dataset [9]. This excess is identifiable through a direct measurement of rise-time, the physically-relevant quantity when separating surface from bulk events in PPC detectors. The significance of this excess is however observed to depend on the choice of input to the analysis (use of electronic pulser calibrations, or instead of simulated pulses, when defining the characteristics of bulk events [12]). Such an excess is difficult to explain based on known backgrounds [2], and is similar in magnitude and spectral shape to one recently found in the electron recoil band of superCDMS germanium detectors [13]. The possibility of this spectral feature to originate in nuclear recoils seems now remote in view of the most recent superCDMS germanium results [14], but its origin and possible association to the low-significance modulation found in [9] remain unknown.

The shortcomings of the work presented in [1] can be used to illustrate that the performance of a state-of-the-art low-noise detector needs to be matched by its data acquisition system, and other associated electronics. The choices made in this respect within MALBEK can limit the promising performance of a PPC-based MAJORANA Demonstrator as a low-mass dark matter detector [15].

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[3] C.E. Aalseth et al., Phys. Rev. Lett. 106 (2011) 131301.
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[5] C.E. Aalseth et al., Phys. Rev. D88 (2013) 012002.
[6] P.J. Fox et al., Phys. Rev. D85 (2012) 036008; C. Kelso, D. Hooper, M.R. Buckley, Phys. Rev. D85 (2012) 043515.
[7] Notice the change in arbitrary normalization for $W_{\text{par}}$ units between [1] and [2]. The present discussion makes reference to $W_{\text{par}}$ units as in [2].
[8] A dispersion in the value of $t_{10-90}$ is expected from the position-dependence of bulk events within the PPC crystal, which affects the charge collection time through variations in electric field intensity and path length to the collecting electrodes. When combined with the poor to non-existent surface/bulk discrimination power of $W_{\text{par}}$ at the lowest energies explored, a large fraction of actual bulk events near threshold can be assigned significantly smaller (surface-like) values of $W_{\text{par}}$ than what is suggested by the use of a fixed $t_{10-90}$ electronic pulser.
[9] C.E. Aalseth et al., arXiv:1401.3295.
[10] While we have recently improved the choice of rise-time cuts leading to an irreducible bulk event spectrum for CoGeNT [9], the algorithms used for rise-time measurement have remained unchanged since [2], i.e., the optimal CoGeNT surface/bulk discrimination discussed here is due to the noise levels originally achieved by the detector and associated electronics, and not to any later improvements in the data analysis.
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[13] R. Agnese et al., arXiv:1309.3259
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