PROCEEDINGS OF SCIENCE

Data analysis of the NUCLEUS experiment with the Diana framework

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The analysis of cryogenic detector data is known to be challenging for any experiment. The main difficulty resides in the background rejection since they suffer from the presence of several different pulse shapes which need to be discriminated down to very low signal-to-noise ratio.

Background reduction is particularly important for the NUCLEUS experiment [1] whose aim is to produce ultra-low threshold (around 20 eV) cryogenic detectors to measure coherent elastic neutrino-nucleus scattering at the Chooz nuclear power plant. The low threshold is necessary due to the low nuclear recoil signal produced which is below 1 keV.

In this poster the data analysis procedure performed for the NUCLEUS experiment with the DIANA analysis framework [2] is presented along with several software upgrades implemented.

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1. Introduction

Analysing data from cryogenic detectors poses significant challenges, particularly in dealing with background rejection due to various pulse shapes, especially under low signal-to-noise ratio (SNR) conditions. This is especially true for the NUCLEUS experiment [1], due to the ultra-low threshold cryogenic calorimeters (around 20 eV) developed for measuring coherent elastic neutrino-nucleus scattering. Therefore, it is important to have a robust analysis protocol along with a user friendly framework in order to exploit the full potential of the NUCLEUS detectors. In this proceeding a brief overview on the analysis pipeline used in the Diana framework [2] for the NUCLEUS data is presented. A short summary of the new features added to the framework since the first implementation for the CUORE [3] experiment are show as well.

2. PyDiana: Combining C++/ROOT and Python in a single framework for cryogenic detectors

The ideal features for any analysis software are: robustness, speed, low memory usage, richness in ready to use algorithms, easy data handling and visualization. The classical Diana C++/ROOT [4] structure is not sufficient to ensure all the above criteria, while it does satisfy most of them, it does not allow for easy data handling and visualization. This is the reason why *PyDiana* was created as a versatile python front-end to a robust C++/ROOT back-end.

PyDiana is based on the new *PyROOT* [4] interface that allows to seamlessly integrate C++ code and ROOT classes into a python framework ensuring a complete interoperability of both the data and the software. An example of this combination is provided in the following section.

3. Analysis Pipeline

In this section the analysis pipeline developed in Diana for NUCLEUS is presented using as an example the analysis performed for the observation of a nuclear recoil peak in $CaWO_4$ due to neutron capture[5].

The protocol is divided into two main steps, the first one is the analysis of the raw waveforms and makes use of the C++ back-end and the second is a more high level step where the distributions of the various measured quantities are studied to extract the main features from the data using *PyDiana*.

3.1 Raw Waveform Analysis

The first step of the data analysis of cryogenic detectors is the study of the raw waveforms recorded from the sensors in order to extract the properties of the data.

In the case of NUCLEUS, the data from the transition edge-sensors (TESs) is recorded in a continuous stream and needs triggering, which is done in two steps. The first trigger, based on a band pass filter, is used in order to have a quick look at the data for the extraction of a signal template and a description of the noise. After these quantities are extracted one can build a matched filter (see [2]) and use it to achieve an optimal SNR on the data stream for a lower triggering threshold (Figure 1).

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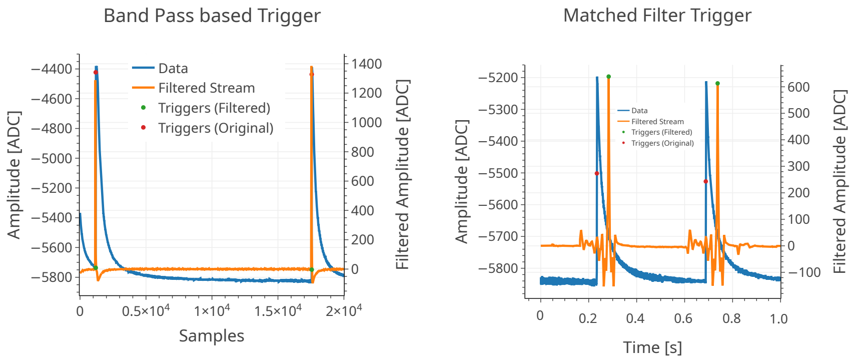

Figure 1: Triggering algorithms in NUCLEUS: on the left the band pass trigger used for first look at the data, on the right a matched filter based trigger to get the optimal triggering threshold.

After the data is triggered some basic pulse shape quantities are calculated and used to apply quality cuts. In particular, some strong data selection is used in order to select clean sets of signal traces and noise traces. The signal set is then averaged in order to build a signal template, while the noise traces are used to build the noise power spectral density. Aside from describing the detector's response, these two quantities are required in order to build a new matched filter and in general for precise amplitude reconstruction.

In NUCLEUS there are two main ways to accurately measure the signal amplitude (proxy for the energy). In order to deal with detector saturation a fit of the signal template to the waveform under analysis is performed using only the points in the linear response region. Since the fit only works at fairly high SNR, in order to go down to threshold the matched filter is used. Once the data is filtered the point with the maximum amplitude present in the waveform corresponds both in position and amplitude to the signal. Moreover, on the matched filtered waveform three additional pulse quantities based on the difference with respect to the template signal are calculated in order to exploit the optimal SNR for better background rejection down to threshold.

3.2 Distribution Analysis

Once all the raw waveform analysis is performed the more high level step of the analysis of the distributions is performed. The first part of the procedure consists in selecting events that are suitable for the high level analysis, this is done by cutting on several pulse shape quantities, in particular the low SNR parameters calculated in the matched filtering stage.

Once the data is cleaned it is necessary to calibrate the response of the detectors. In NUCLEUS there are several ways to do this, one is the use of X-ray sources the most common being ^{55}Fe source. A second way of calibrating is through the exploitation of the photostatistics of light bursts generated from an LED (see Figure 2 and [6]), which also has the advantage of allowing the evaluation of several non-linearities and systematics (not used in [5]). The third way is by inducing a nuclear recoil peak through neutron capture [5] (see Figure 3). Once the data is cleaned and calibrated then one can proceed to plot the final energy spectrum in order to search for features. In Figure 3, the peak of the neutron recoil peak induced by neutron capture is visible with a 3σ significance near the expected energy of 112 eV (see [5]) along with the two peaks produced from a ^{55}Fe source.

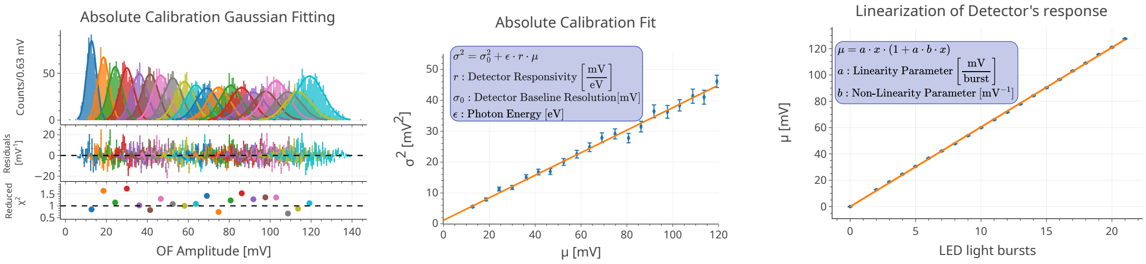

Figure 2: Energy Calibration using photostatistics generated by LED light bursts.

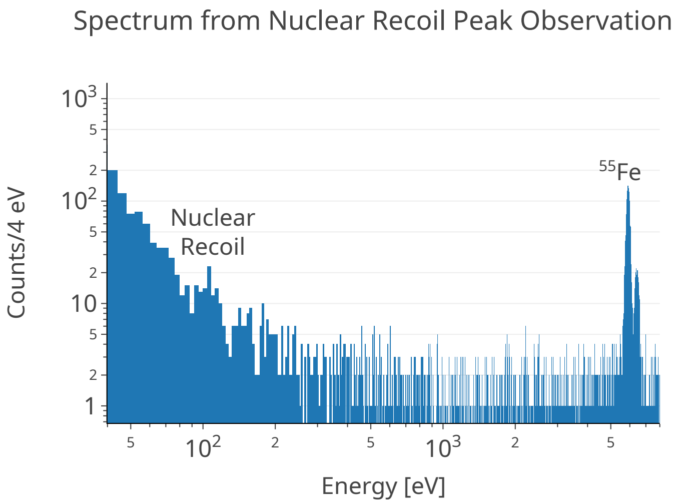

Figure 3: Energy Spectrum from the analysis presented in [5] with the nuclear recoil the ^{55}Fe peaks present.

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