

# Pacific Ocean Neutrino Experiment first string trigger and data acquisition systems

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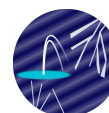
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The Pacific Ocean Neutrino Experiment (P-ONE) is set to deploy its first detection string in the Cascadia Basin off the coast of British Columbia, Canada. As a next-generation Cherenkov neutrino telescope, P-ONE will be sensitive to ultra-high-energy neutrinos ( $10^3$ – $10$  GeV) from astrophysical sources. To effectively capture these rare physics signatures, the experiment's trigger system must operate in a high-background environment dominated by K40 decay and bioluminescence. This poster presents the design and integration of the P-ONE trigger system, which spans multiple levels of data acquisition (DAQ). The trigger must seamlessly interface with both the slow detector controlling Maximum Integrated Data Acquisition System (MIDAS) and the back-end fastDAQ system to select and preliminarily cluster events. The trigger system operates in a hierarchical fashion: first, an initial firmware (LO) trigger identifies candidate events, which are then refined by a physics trigger that requests additional waveform data from neighboring modules. Onshore, these waveform packets and timing information are assembled into full events for storage and analysis. This talk will detail the trigger chain, with a focus on bioluminescence mitigation and physics-driven event selection, as well as its integration with the DAQ and Run Control systems.

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## 1. Overview of Pacific Ocean Neutrino Experiment

The Pacific Ocean Neutrino Experiment (P-ONE) is a next-generation [Mar14] ocean Cherenkov neutrino telescope [Rob+77] designed to detect ultra-high-energy neutrinos ( $10^3$ - $10^8$  GeV) from astrophysical sources. P-ONE will be deployed in the Cascadia Basin, a deep-sea environment off the coast of British Columbia, Canada [Ago+20]. The experiment aims to capture rare astrophysical neutrino events while operating in a challenging background environment dominated by K40 decay and bioluminescence [Hol+24]. The P-ONE detector consists of multiple integrated strings, each equipped with a series of optical modules that detect Cherenkov radiation produced by neutrino interactions in the water. The first string deployment will serve as a proof-of-concept for the full-scale detector, allowing for the testing and validation of the trigger and data acquisition systems [Bai+21].

The trigger system is a critical component of the P-ONE experiment, designed to efficiently identify and select relevant events from the high background noise environment. It operates in a hierarchical manner, with multiple levels of processing to ensure that only significant events are recorded for further analysis. The trigger system must seamlessly interface with both the high-level Maximum Integrated Data Acquisition System (MIDAS) [RAO97] and the low-level fastDAQ system to select and preliminarily cluster events.

The P-ONE detector is designed to operate in a high-background environment, where bioluminescence and K40 decay can significantly interfere with the detection of astrophysical neutrinos. As evident from the pathfinder STRAW-B mission [Hol+24], the trigger system must effectively mitigate these background sources while capturing the rare physics signatures of interest. This poster will detail the design and integration of the P-ONE trigger system, with a focus on bioluminescence mitigation and physics-driven event selection, as well as its integration with the DAQ and Run Control systems.

## 2. Data acquisition system

The data acquisition (DAQ) system for the P-ONE detector is designed to efficiently collect, process, and store data from the optical modules deployed in the Cascadia Basin. The DAQ architecture consisting of two layers that work together to ensure reliable data collection and event selection. The key components of the DAQ system include the Maximum Integrated Data Acquisition System (MIDAS), the fastDAQ system, and various trigger systems that operate at different levels. The DAQ system also allows integration with the calibration system, which is essential for ensuring the accuracy and reliability of the data collected from the detector modules for triggering [Ago+20].

### 2.1 MIDAS and fastDAQ systems

The data acquisition system for the P-ONE detector is built around two key components: the Maximum Integrated Data Acquisition System (MIDAS) and the fastDAQ system. These systems work in tandem to ensure efficient and reliable data collection from the detector modules. The MIDAS framework provides a frequent-operation interface for managing the overall data acquisition process, while the fastDAQ system is responsible for low-level data handling, real-time processing,

and providing support for the trigger. The purpose of using two interfaces is to allow for one to handle the general acquisition of real-time data (fastDAQ), and the other for detector-wide control (MIDAS).

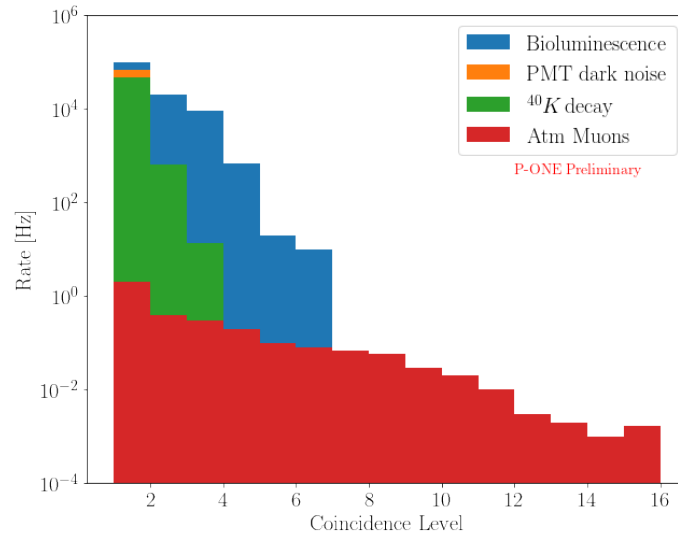
MIDAS serves as the high-level DAQ framework, providing a versatile and scalable platform for managing data flow, experiment control, and monitoring. It is responsible for coordinating the overall operation of the detector, including the integration of triggers, data storage, and run control. MIDAS offers a user-friendly interface for configuring and monitoring the experiment, making it an essential tool for both online and offline operations.

The fastDAQ system, on the other hand, operates at a lower level and is optimized for high-speed data handling. It is designed to process raw data streams from the detector modules in real-time, applying initial filtering and compression to reduce the data volume. The fastDAQ system interfaces directly with the detector hardware, ensuring minimal latency and efficient data transfer to the higher-level MIDAS framework.

Together, these systems form a hierarchical DAQ architecture that balances the need for real-time processing with the flexibility required for complex event selection and analysis. The integration of MIDAS and fastDAQ ensures that the P-ONE detector can handle the high data rates and challenging environmental conditions of the Cascadia Basin, enabling the capture of rare astrophysical neutrino events.

### 3. Trigger systems

The trigger system for the P-ONE detector is a critical component of the data acquisition architecture, designed to efficiently identify and select relevant events from the high background noise environment as depicted in Figure 1.



**Figure 1:** Rate versus coincidence of different light sources in the deep-water ocean.

It is split into three systems: physics, bioluminescent, and minimum bias. The bioluminescent trigger algorithm is responsible for capturing bioluminescent events and providing information

about the time and location of these events. The minimum bias trigger is a short-burst collection trigger to take total rate of the detector. This rate is dominated by a stochastic K40 decay, and helps provide an understanding of K40 decay in water and its effects on the detector system. The physics trigger's algorithm is responsible for capturing and clustering physics events; in the case of P-ONE-1, that is cosmic ray muons. Background to these physics events will be accepted in the trigger, but with the use of the minimum bias and bioluminescent trigger, these backgrounds can be estimated and removed at analysis level.

### 3.1 Physics trigger for first-string deployment

The trigger operates in a hierarchical manner, with multiple levels of processing to ensure that only significant events are recorded for further analysis.

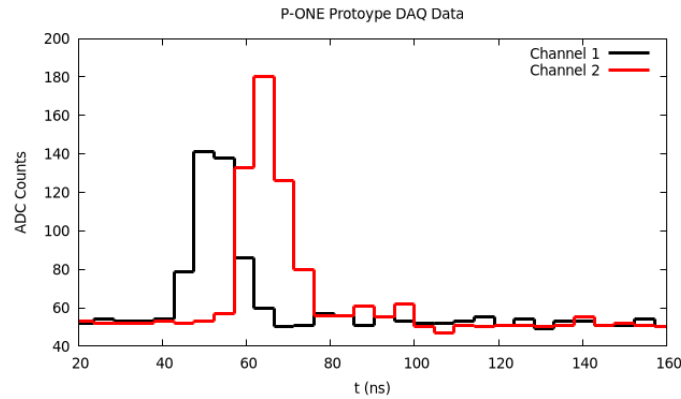
**Level 0** The first level of the trigger system is the firmware-based Level 0 (L0) trigger, which is implemented directly in the detector hardware. This trigger is responsible for quickly identifying candidate events based on predefined criteria, such as signal amplitude and timing. The L0 trigger operates in real-time, allowing it to filter out a significant portion of the background noise before the data is sent to higher-level processing. This trigger interfaces with the fastDAQ system most directly, ensuring that only relevant data is passed to the shore for further triggering.

**Level 1** The second level of the trigger system is the physics trigger. This trigger refines the initial event selection made by the L0 trigger by requesting additional waveform data from neighboring modules. The physics at this level trigger employs the light cone algorithm to select neighboring modules based on their spatial and temporal proximity to the initial candidate event. The light cone algorithm is based on the equation for the time difference  $\Delta t$  between signals detected by two modules:

$$\Delta t = \frac{d}{c} \pm \frac{\sigma}{c},$$

where  $d$  is the distance between the modules,  $c$  is the speed of light in the medium, and  $\sigma$  accounts for timing uncertainties. A module is considered within the light cone if its signal timing satisfies this condition relative to the initial candidate event. This algorithm uses the time differences between detected signals to determine whether a module lies within the expected light cone of the event. Modules that fall within the light cone are requested to provide the waveform information at the requested time-stamp, which is then analyzed to confirm the event's validity and characteristics. After the event is characterized by pulses in the detector, the waveforms read out are unfolded and represented by hit count over time (Figure 2). Waveform unfolding is the process in which the photomultiplier tube (PMT) signals are characterized as some linear combination of single photo-electron waveforms.

This event clustering trigger approach ensures that the trigger system captures events with high precision while minimizing false positives caused by random background noise. By leveraging the additional data from neighboring modules, the physics trigger can significantly improve the signal-to-noise ratio and enhance the overall event selection process. However, noise will still be accepted as signal at this level. Therefore, further background rejection methods must be applied at analysis-level to account for these background pulses.



**Figure 2:** Unfolded waveform representation showing hit counts over time for a candidate event.

### 3.2 Bioluminescence trigger for first-string deployment

In addition to the physics trigger, the P-ONE detector employs a bioluminescence trigger to both study the effects of bioluminescent as it contributes to background noise, and provide data for marine biologists interested in bioluminescent organisms within the Cascadia Basin. This trigger is designed to identify and filter out events caused by bioluminescence, which can significantly interfere with the detection of astrophysical neutrinos. Currently, the bioluminescence trigger is applied at offline-level. PMT hit counts are read continuously from module to shore, stored in i3 files, and saved for offline analysis to determine bioluminescent events. The timing of these events can be applied to the physics analyses to further refine event selection and reduce background noise.

### 3.3 Minimum bias trigger for first-string deployment

The minimum bias trigger is a crucial component of the P-ONE detector’s data acquisition system, designed to capture a wide range of events without specific selection criteria. This trigger is critical for understanding all other types of background noise aside from bioluminescent organisms such as K40 decay, and other environmental factors. The minimum bias trigger operates by continuously monitoring the detector’s data streams and recording all events in short time-windows to avoid oversaturating the bandwidth of the detector. This approach ensures that a comprehensive dataset is collected, allowing for detailed analysis of the detector’s performance and the background environment, particularly dominated by K40 decay. It is understood that this background is stochastic, but its exact impact on the DAQ system, waveform unfolding, and by extension, analyses, will not be understood unless captured. The trigger chains combined make for robust detector-wide data collection to capture physics, background, and bioluminescent events.

## 4. Acknowledgments

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