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The Recent Status of the HUNT Prototypes: 2025

Q.C. Yin,[a,b,c] **Z.K. Zeng,**[a,b] **B. Gao,**[a,b] **C. Liu,**[a,b] **T.Q. Huang**[a,b,*] **and M.J. Chen**[a,b]

[a] *Key Laboratory of Particle Astrophyics & Experimental Physics Division & Computing Center, Institute of High Energy Physics, Chinese Academy of Sciences, 100049 Beijing, China*

[b] *TIANFU Cosmic Ray Research Center, 1500 Kezhi Road, Xinglong Street, Shuangliu District, Chengdu, Sichuan, China*

[c] *Ocean University of China, No. 238 Songling Road, Laoshan District, Qingdao City, Shandong Province, China.*

E-mail: zengzk@ihep.ac.cn,gaob@ihep.ac.cn,liuc@ihep.ac.cn

High Energy Underwater Neutrino Telescope(HUNT) is a next-generation neutrino telescope planned to be constructed in the South China Sea or Baikal Lake. We have almost finished the development of a super-large Optical Module (OM) with a 20-inch PMT and an LED calibration module. Since 2024, we have successfully deployed some prototypes in Lake Baikal and the South China Sea. This report will present the designs of the OM and the LED module, and present initial operational results from these prototype deployments.

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*Speaker

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1. Introduction

High-energy neutrinos are believed to be closely associated with the acceleration sources of cosmic rays, such as active galactic nuclei, gamma-ray bursts, and supernova remnants. By detecting and analyzing these neutrinos, researchers can trace the origins of cosmic rays and reveal the physical mechanisms behind their acceleration and propagation. The Large High-Altitude Air Shower Observatory (LHAASO) has successfully discovered a large number of petaelectronvolt (PeV) cosmic ray candidates in the Milky Way [1]. Whether they have a hadronic origin urgently awaits direct confirmation by neutrino signals, a quest underscored by the current limited significance of neutrino point sources in the Galactic plane [2].

HUNT covers an energy range of 100 TeV to 100 PeV, with an effective telescope volume of 30 km^3. HUNT is planned to be constructed as a 3×3 detection array composed of 9 independent clusters, with a spacing of 10 km between clusters, allowing the detection of a greater number of low-energy muon events. Each cluster is designed as a cylinder with a radius of 800 meters and a height of 1,880 meters. Each cluster consists of 128 strings of OMs, with each string containing 48 OMs at a spacing of 40 meters, resulting in a single-string cumulative length of 1,880 meters. The entire HUNT array will cover a sea area of 400 km^2, utilizing a total of 55,296 OMs, as shown in Figure 1 [3, 4].

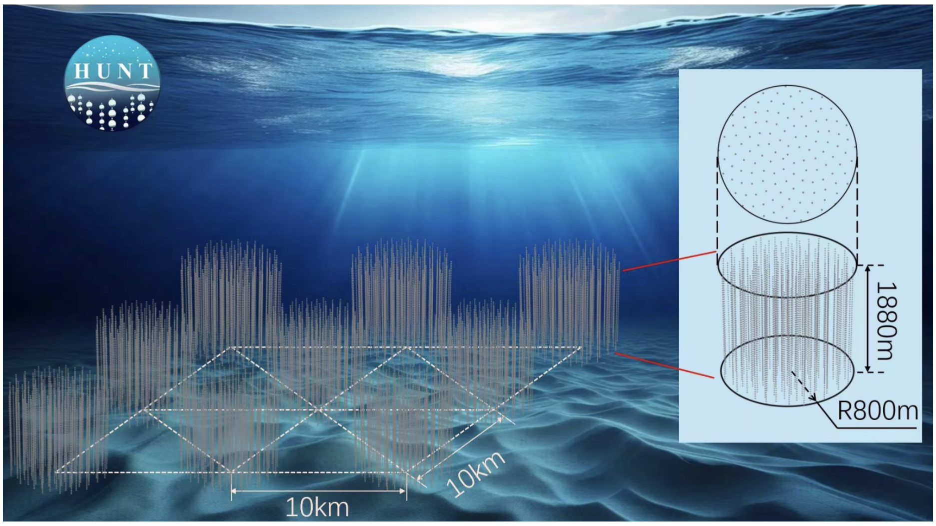


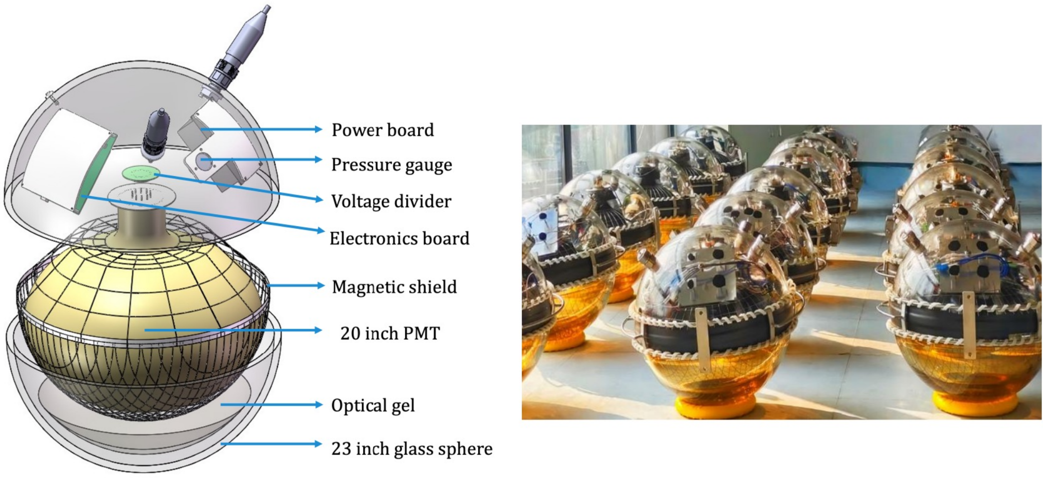
Figure 1: The layout of the HUNT telescope is composed of 9 clusters.

Lake Baikal and the South China Sea were selected as deployment sites due to their unique characteristics. Lake Baikal, renowned for its stable underwater environment and the convenience of construction and installation during winter when the lake freezes, provides an ideal laboratory for the preliminary testing and verification of detector technologies [13]. In March 2024, a prototype detector string containing 12 OMs and 4 LED calibration balls was deployed in Lake Baikal. The primary objective of this deployment was to validate the operational reliability of the detector units, with factors that influenced the status of the MCP, the design of electronics, the waterproof design, etc. The aim was to expose as many risks as possible in the design of the first prototype. Through long-term monitoring, we determined that the noise rate variation of unit detectors over a period of a month was less than 10%.

The deployment of the HUNT project in the South China Sea will achieve the dual functionality of detecting cosmic extreme events and monitoring marine environmental biochemical processes, realizing "one device, multiple outputs" and promoting innovative paradigms for interdisciplinary collaboration and resource sharing. In January 2025, a prototype string equipped with 4 OMs was deployed. The focus of this deployment was to measure the detector's charge spectrum and marine background noise rate: understanding the characteristics and components of marine background noise is crucial for reconstruction algorithm optimization, which helps develop more effective signal processing techniques to distinguish neutrino-induced signals from background noise.

This paper reports on the in-situ performance of two key innovations of the HUNT project: the super-large Optical Module and the multi-wavelength LED calibration system, as demonstrated by the first prototype deployments in Lake Baikal and the South China Sea.

2. Optical modules and LED calibration modules

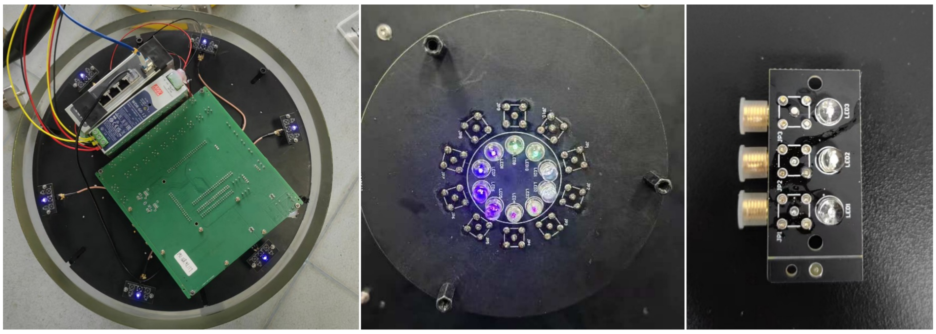


(a) (b)

Figure 2: Left:Schematic diagram of OM composition;Right: OM after laboratory testing.

The optical module is the core component of the entire HUNT detector array, responsible for detecting high-energy neutrinos. It is mainly composed of a 20-inch photomultiplier tube (PMT) [6], a 23-inch sealed glass sphere housing, magnetic shielding mesh, optical coupling silicone gel,and associated electronics,as shown in Figure 2. The 20-inch PMT offers significant advantages: its photocathode area is 40 times larger than that of a 3-inch PMT, which significantly enhances the detection sensitivity to weak neutrino-induced Cherenkov light signals. Meanwhile, the large photosensitive area allows for a larger spacing between detector units, reducing the number of detectors per unit volume. Therefore, the use of 20-inch PMT can substantially reduce the costs of PMT and electronics [5].

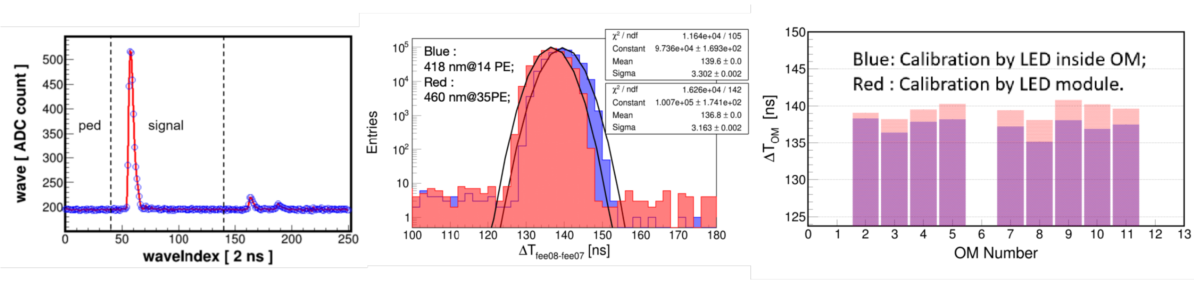
The calibration module includes two types of calibration devices: an LED calibration module integrated into the optical module and an independent LED calibration module in a 17-inch glass sphere. HUNT time calibration is implemented based on multi-wavelength LEDs: the main light source is a 465 nm blue LED, and other LEDs with peak wavelengths ranging from 385 to 525 nm are used for the measurement of the optical parameters of water, as shown in Figure 3 [10].



(a) (b) (c)

Figure 3: (a):Top view of the independent LED module;(b):Bottom view of the independent LED module;(c):LED array in the optical module.

3. Prototype in Lake Baikal



(a) (b) (c)

Figure 4: (a):Detector electronic waveform sampling; (b):The time delay between fee08 and fee07;(c):Time delay distribution by LED calibration modules.

In March 2024, we deployed the first string of detector prototypes in Lake Baikal, which included 12 optical modules and 4 LED calibration balls. The space between OMs is 30 m. The electronics achieves a dynamic range of 1 PE to 2,000 PEs through a dual-range acquisition scheme. It incorporates Q/T waveform storage functionality, as illustrated in Figure 4 (a), which allows detailed offline analysis of signals within a sampled waveform window of 512 nanoseconds. As demonstrated in the accompanying waveform plot, each recorded pulse is digitized at a resolution of 2 ns per sample, providing a high-fidelity representation of signal morphology. For each recorded hit, the system stores the unique identifier (id), integrated charge (Q), and precise timestamp (T), facilitating advanced event reconstruction and noise rejection during data analysis. A key feature of the system is the inclusion of a 100-nanosecond pre-trigger buffer, which captures the baseline region (ped, short for 'pedestal') prior to the signal threshold crossing. This allows for accurate baseline subtraction and improved amplitude and timing measurements.

LEDs can be used to calibrate the time delays between OMs caused by spatial distances. Figure 4(b,c) shows the time delays at different wavelengths between adjacent OMs 7 and 8 and presents the time calibration results obtained using different LED calibration modules. As observed from the calibration results, the time delays correspond to the spatial distances. In the future, LED signals of different wavelengths will be applied to the calibration and monitoring of water quality. When the LEDs in the LED calibration balls are activated, the emitted LED signal is simultaneously detected by both the Baikal-GVD array and the first prototype string of HUNT. We calibrated the relative time delay between the two arrays using regular LED signals, with the calibration achieved by matching LED characteristic events [13].

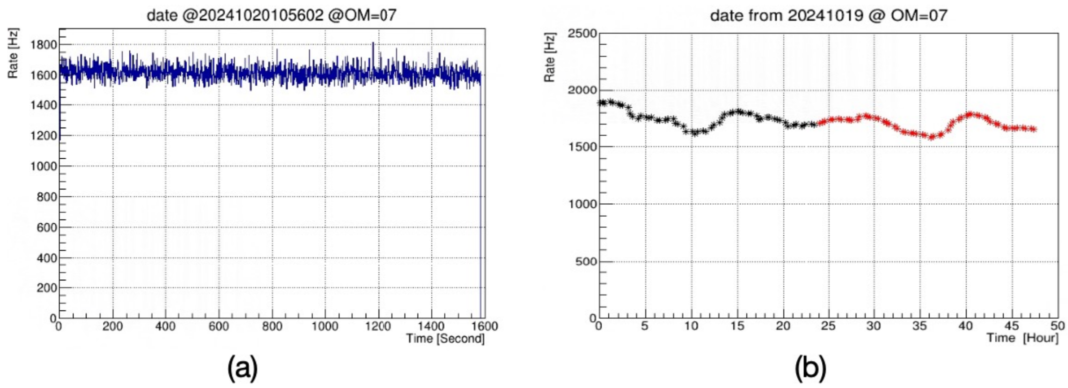


Figure 5: Left: Second-level noise rate monitoring for OM7;Right: Hour-level noise rate monitoring for OM7.

A 35 - day monitoring period was carried out with detectors kept at the same threshold and high voltage. The results, as shown in Figure 5, show that the change in noise rate is about 2% on the second scale, about 4% on the hour scale and about 10% on the month scale. Monitoring the noise rate is essential for understanding the background environment of the detection system and improving data quality [14].

The logic diagram of the trigger algorithm for the HUNT 1st string is shown in Figure6(a), which uses a time window of 300 ns and 2 hit judgments as signal trigger. When the trigger condition is met, an event is saved with trigger time T0 (±(- 850, 1500) ns), and the hit number (nHit) is calculated. The trigger flow diagram and schematic diagram help to understand the logic of event triggering, which is crucial for distinguishing valid physical events from background noise. A down - going event with nHit = 9 as shown in Figure 6(b). After being triggered, different trigger events (down - going and up - going) are analyzed in terms of the number of hits (nHit), arrival time of signals at different OMs. However, with only one string, it is difficult to perform accurate direction reconstruction. As shown in 6(c),preliminary data analysis shows that down - going events are more than up - going events. When the hit number is greater than 5, only down - going events are observed, which may be mostly triggered by atmospheric muons. It is concluded that when nhit > 5, muon - like events occur about 10 per day.

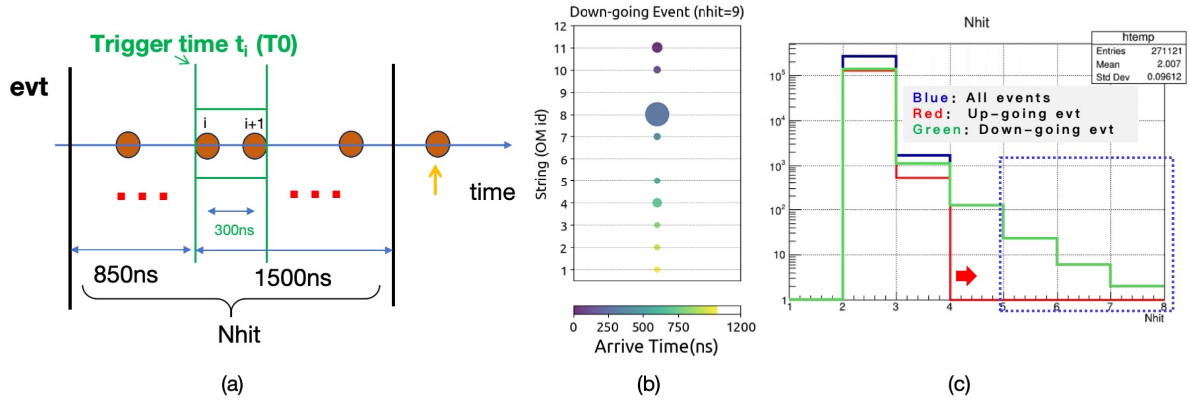


Figure 6: (a): Schematic diagram of the trigger algorithm;(b): A perfect down-going event(nHit=9); (c): Distribution of hit numbers(nHit) for trigger events(3 days raw data.)

4. Prototype in the South China Sea

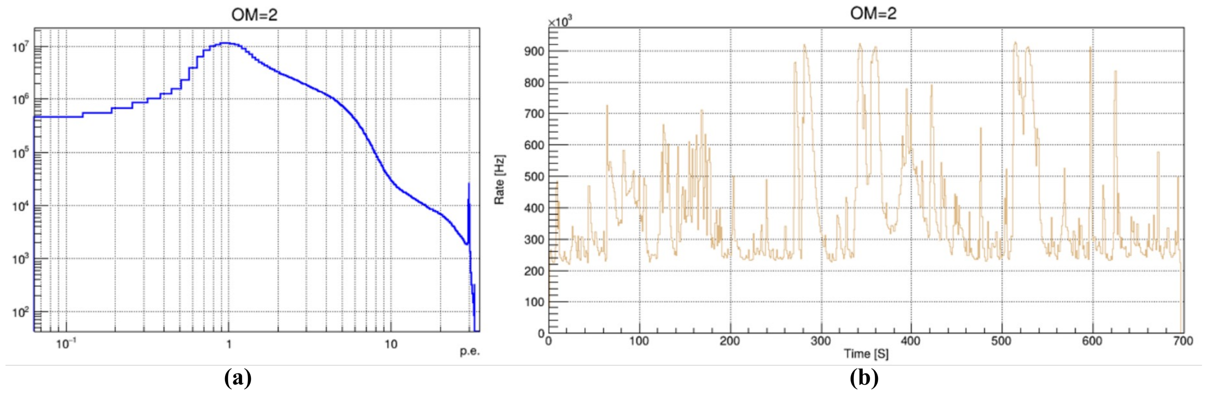


Figure 7: (a):The charge spectrum; (b):The background rate of the OM2 under the threshold of 0.5 pe.

In January 2025, we deployed a detector string in the South China Sea, consisting of four optical modules and one LED calibration module. The upper two optical modules face upward, while the lower two face downward. The distance between optical modules is set at 10 m. During the measurement of detector charge spectra in Figure 7 (a) and the background noise rates of the ocean, we found that the underwater environment of the South China Sea differs significantly from that of Lake Baikal, as shown in Figure 7(b) [12]. In the China South Sea, the single counting rate test covers two types of signals: background radiation and bioluminescence. Experimental results show that the background radiation counting rate exhibits good stability. Under the detection condition of a 20-inch PMT, the counting rate is stably maintained in the range of 200 kHz to 300 kHz, corresponding to 1 to 10 photons. In sharp contrast, bioluminescence signals show significant instability, with counting rates fluctuating from kHz to tens of MHz and durations varying from 1 second to hundreds of seconds. These detailed test data lay a solid foundation for the optimization of subsequent signal discrimination algorithms and the improvement of overall system performance, which is of great significance for accurately distinguishing effective signals from noise interference

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and enhancing the system's detection accuracy. Next, we plan to deploy seven strings of detector prototypes in the South China Sea, focusing on aspects such as array trigger modes, deep-water operations, ocean currents, seabed geology, electricity, and data transmission, in preparation for the future Technology Design Report.

5. Conclusions

This paper reports the progress of the HUNT project in 2025, with its prototypes deployed in Lake Baikal and the South China Sea respectively. The core technologies include 20-inch photomultiplier tubes (with a larger photosensitive area, enhancing the ability to detect weak signals) and multi-wavelength LED calibration modules (with a time precision of 3 nanoseconds, used for measuring optical parameters of water). Tests in Lake Baikal have confirmed the stability of the detector's noise performance (with a fluctuation range of approximately 2%–10%), while deployments in the South China Sea have revealed the unique background noise environment of the ocean. The effective operation verification of the prototypes has provided first-hand data for the subsequent optimization and simulation reconstruction of the HUNT project's detectors.

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