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The Trigger and Data Acquisition System (TriDAS) of the KM3NeT experiment

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Summary. — Starting from 2015, the new generation underwater high energy neutrino telescope, KM3NeT, is being installed in the Mediterranean Sea. During Phase 1, 32 Detection Units (8 tower-like and 24 string-like) will be deployed in the Ionian Sea, about 100 km offshore Portopalo di Capo Passero, Sicily, and 7 string-like DUs will be deployed in the MEUST site, offshore Toulon in France. During Phase 2, several hundreds of DUs will be added to the Phase 1 detector, reaching an effective detection volume of some cubic kilometres. In this contribution the Trigger and Data Acquisition System (TriDAS) of the string-based detector is described. The TriDAS is designed to scale with the detector size, allowing the read-out and the on-line trigger of data from both Phase 1 and Phase 2, whose continuous throughputs are expected to be about 10 Gbps and more than 250 Gbps, respectively.

1. – Introduction

KM3NeT [1] is the new generation underwater high-energy-neutrino telescope and will be installed in two sites in the Mediterranean Sea: off Toulon, France, the ORCA (Oscillation Research with Cosmics in the Abyss) detector will study the neutrino mass hierarchy, using 115 string-like [2] Detection Units (DUs); off Portopalo di Capo Passero, Sicily, the ARCA (Astronomy Research with Cosmics in the Abyss) detector will study ultra high energy neutrinos expected by astrophysical and cosmologic cosmic rays sources. ARCA will be made by about 230 string-like and 8 tower-like [3] DUs arranged in a ~ 100 meters-spaced grid. Each string is made of 18 Digital Optical Modules (DOMs) [4], which are vertically separated by 6 and 36 meters in ORCA and ARCA, respectively. Each DOM is made of a 17$''$ diameter glass sphere which hosts 31 3$''$ photomultiplier tubes. The detection principle is based on the collection of the Cherenkov light of charged particles produced by neutrino interactions in the detector vicinity.

Due to the optical background caused by radioactive β decay of ^{40}K and bioluminescence phenomena in sea water, an on-line trigger is needed. In order to minimise the complexity of the underwater electronics, no hardware trigger is present and the all-data-to-shore approach is used: all detected optical signals are sent to shore via a computer network which includes both the shore-station and the detector. In the final configuration of the experiment, the expected data throughput from both sites is above 250 Gbps.

2. – Architecture of the TriDAS

The KM3NeT Trigger and Data Acquisition System [5] (TriDAS) is the software and computing infrastructure deputed to the read-out, aggregation and filtering of all the detector data. All TriDAS components are connected to a 10 GbE network which extends to the underwater detector. Indeed, the DOMs are all connected to the shore-station via a White Rabbit [6] switching infrastructure, which also provides for proper time synchronisation.

Each DOM digitises the signals from the 31 PMTs as photon hits — defined by the integrated electric charge of the PMT signal over a certain threshold, the crossing time and the duration of the signal over the threshold — and collects them into data frames. Once a data frame is completed, the DOM sends it to shore through UDP/IP protocol.

The first data processing stage is represented by the DataQueue (DQ) farm which is in charge of the aggregation of unfiltered hits and of their distribution to the computers dedicated to the trigger, namely DataFilters (DFs). Each DQ is responsible for data from a sector (*i.e.* a subset of DOMs) of the detector. Each DF receives from all the DQs a bunch of data which belongs to a precise time interval called Time Slice (TS). The duration of a TS is fixed, typically 100 ms. In this way, each DF has a complete snapshot, limited to the TS duration, of the status of the whole detector. Triggered data coming out from the DFs are sent to the DataWriter (DW) that collects them on permanent storage as ROOT [7] files.

The ControlUnit (CU), which represents the user interface to the detector, aims at coordinating the TriDAS and operating the DOMs through a dedicated SlowControl (SC) protocol.

3. – Trigger system

The DF is the central core of the trigger facilities of the TriDAS. Two different levels of filters are implemented: the L1 filters apply very simple conditions, mainly devoted to reject as much uncorrelated background signal as possible; the L2 algorithms validate the events selected by the L1, using more complex topological and temporal conditions.

Every hit that satisfies one of the L1 trigger conditions is marked as a trigger seed and a L1 Event (L1E) is built around it with the hits occurred in a customizable time window, tipically of ± 3 μs. If different L1Es overlap they are merged in a single L1E with an extended time window.

The L1 filters are:

- simple coincidence: one or more hits on different PMTs in the same DOM within a coincidence window of 5 ns;
- charge excess: hits which charge exceeds 3 photo-electrons.

A detailed description of the L2 filters follows.

3˙1. *T-Triggers*. – The three T-Triggers are defined as coincidence conditions on L1 Events. The T1 condition is satisfied when two L1Es occur on the same DOM within a coincidence window of 55 ns. The T2 requires two L1Es occurring on adjacent DOMs of the same DU within a time window of 200 ns. The T3 is satisfied when at least two L1Es occur in adjacent and next-to-adjacent DOMs of the same DU in 200 ns.

3˙2. *Simple causality filter*. – The simple causality filter searches for coincidences of a predefined number of L1 Events within a time window which is determined by the effective position between the involved PMTs. Moreover, the trigger seeds must obey the following causality condition:

$$|t_i - t_j| \leq |\vec{r_i} - \vec{r_j}|\frac{n}{c}, \tag{1}$$

where t is the time of the hit, $\vec{r}$ is the position of the PMT and c/n is the speed of light in water.

3˙3. *Sky scan trigger*. – As for the simple causality filter, the Sky scan trigger is applied only if the number of L1Es within a time window determined by the position of the involved PMTs is greater then a certain threshold. A predefined number of directions isotropically distributed is initially generated. For each of them, the detector is rotated by aligning the z axis with the chosen direction. The following condition is tested:

$$|\,(t_i - t_j)\,c - (z_i - z_j)\,| \leq \tan\theta_c\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \tag{2}$$

where θ_c is the Cherenkov angle in water. If the number of L1 Events satisfying eq. (2) is greater than a predefined threshold the event is validated.

3˙4. *Tracking trigger*. – The Tracking trigger is a derived directly from the Sky scan trigger. Instead of doing a survey of the whole sky, the directions are obtained calculating the position of a set of interesting astrophysical objects at the time of data. The detector is then rotated as in the Sky scan trigger and the condition in eq. (2) is used. The trigger is satisfied when the surface density of the hits in the plane orthogonal to the considered direction exceeds a predefined threshold.

3˙5. *Vertex splitting trigger*. – The Vertex splitting trigger allows to discriminate between spherical- and track-shaped events, corresponding to cascade and muon events, respectively. The hits of each event are divided in two groups, according to their time of occurrence and the geometrical centre for each group is calculated. Moreover, the inertia tensor is computed as

$$I^{j,k} = \sum_i A_i\left(\delta^{j,k}\vec{r}_i^{\,2} - r_i^j \cdot r_i^k\right), \tag{3}$$

where, $k, j = x, y, z$, $\vec{r_i}$ and A_i are the position with respect to the determined centre and the number of hits of the i-th DOM, respectively.

To determine the shape of the event, the ratio between the minimum of the eigenvalues of the inertia tensor and their sum is calculated:

$$T = \frac{\min(I_1, I_2, I_3)}{I_1 + I_2 + I_3}. \tag{4}$$

If $T \approx 1/3$ the event is considered spherical, while if $T \approx 1$ the event is considered as a track.

3˙6. *External trigger*. – The external trigger is an alert message from another experiment, such as a GRB event detected by a satellite. When it occurs, each DF writes a file containing all unfiltered hits recorded in the last minutes, making them available for further off-line analysis. The required data buffer is constrained by the data rate and by the time needed to deliver the alert through the Internet, typically few minutes.

4. – Conclusions

In the next months, the first 9 DUs (8 towers and 1 string) for ARCA and the first DU for ORCA will be deployed in the abyssal sites of Capo Passero and Toulon, respectively. The on-line Trigger and Data Acquisition System will be continuously running in the corresponding shore-station for each site. The implemented filter algorithms will allow to efficiently reduce the optical background, maximising the signal-to-noise ratio.

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