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KM3NeT
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Studies for the evaluation of the performance of the Time over Threshold technique for the digitization of the signal of a Very Large Volume Neutrino Telescope

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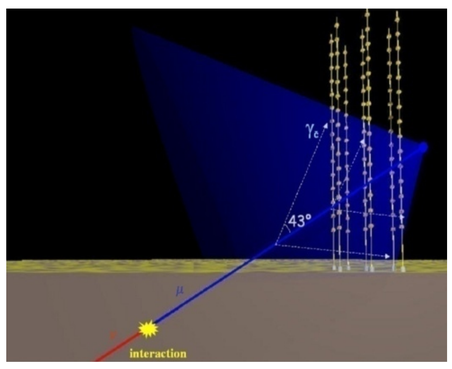
On behalf of the KM3NeT Consortium

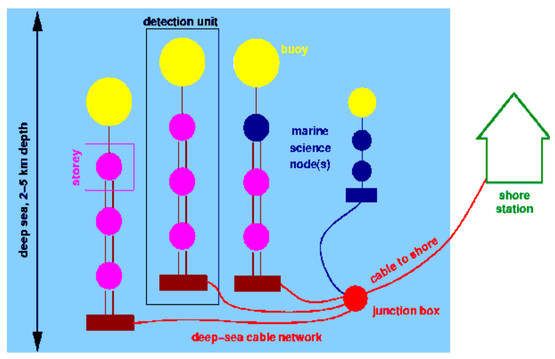
KM3NeT (km³ Neutrino Telescope) will be one of the world's largest particle detectors, built at the bottom of the Mediterranean Sea. It will provide a research infrastructure for a rich and diverse deep-sea scientific program.

KM3NeT is in its preparatory phase and is building on experience from 3 current Mediterranean projects: ANTARES, NEMO and NESTOR [1].



The proposed deep-sea infrastructure will serve as a platform for instrumentation of ocean sciences: Oceanology, Marine Biology, Environmental Science, Geology and Geophysics.

The weak nature of neutrino interactions preserves their energy and directionality potentially allowing them to illuminate parts of the Universe opaque to charged particles and EM radiation. In order to observe the predicted fluxes one must instrument km³s of material sensitive to the resulting secondary radiation. The deep Mediterranean permits observation of Cherenkov photons with attenuation lengths of up to 50m.

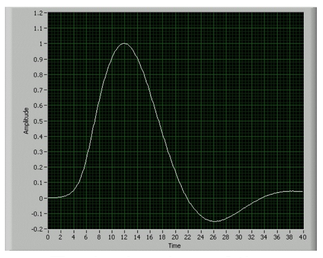


KM3NeT is composed of a number of vertical structures (the Detection Units), which carry photo-sensors and devices for calibration and environmental measurements, arranged vertically on "Storeys". The basic photo-sensor unit is an "Digital Optical Module (DOM)" housing several photomultiplier (PMT) tubes, their high-voltage bases and their interfaces to the data acquisition system with nanosecond timing precision.

The DOM consists of 31 3" PMTs (~30% maximum QE) inside a 17" glass sphere with 31 bases (total consumption of ~6.5W) and includes a cooling shield and stem. The photocathode area per DOM is 1260 cm². The first full prototype is under extended testing in NIKHEF. For the following analysis pulses from the candidate ET Enterprise Ltd. D783FL PMT are used (Q.Dorosti Hasankiadeh in VLVnT11 proceedings)

The DOM prototype

The front-end electronics are based on the SCOTT (Sampler of Comparators Output with Time Tagging) read-out ASIC, which implements the Time over Threshold (ToT) technique. The Time over Threshold (ToT) technique is based on the use of a time to digital converter (TDC) that performs time-tagging of the leading and trailing edge of the PMT signal above a number of thresholds. For the KM3NeT one threshold will be utilized. The ToT technique offers the advantage of significantly reduced amount of data to be transferred to shore, while it does not require complex electronics for its implementation.



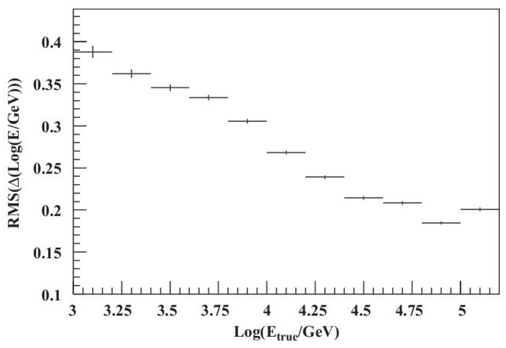
Typical pulse of the studied PMT

Muon track reconstruction & energy estimation

The muon track reconstruction is based on the arrival **times** of the pulses. The energy estimation is based on the deposited charge on each DOM. The charge probability distribution function, P, (that depends on the muon energy E, the distance from the track D, and the PMT orientation with respect to the wavefront θ of the emitted Cherenkov photons) is estimated via simulation. The following Likelihood function is formed

$$L(E)=\ln\left(\prod_{i=1}^{N_{hit}} P(Q_{i,data};E,D,\theta)\prod_{i=1}^{N_{nohit}} P(0;E,D,\theta)\right)$$

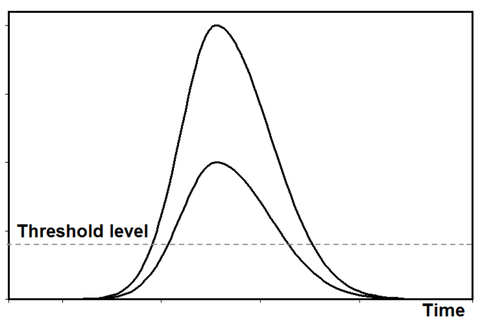
and maximized with respect to the muon energy.



Energy Resolution

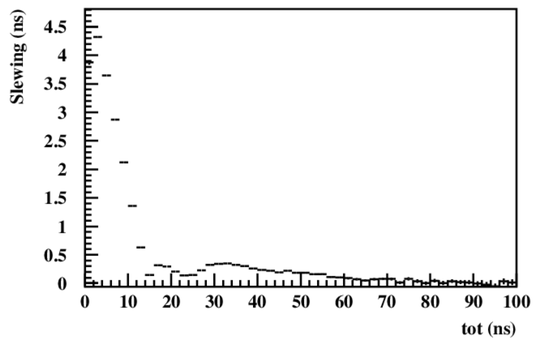
Slewing correction estimation

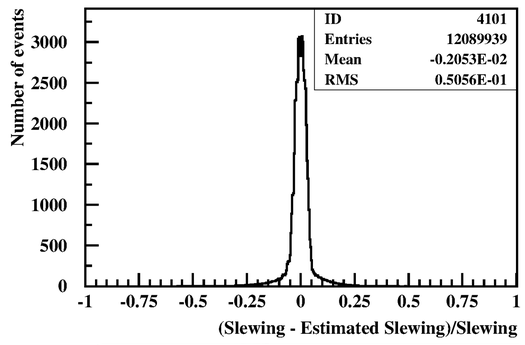
For the timing of the signals, using the ToT technique, the time of the crossing of the lower threshold is utilized. This results in a bias of the timing of the pulses (slewing), which depends on the pulse amplitude. The timing of the pulses is corrected for the slewing effect, by developing parametrizations of the slewing and the error of the slewing estimation as a function of the time over threshold (tot) values.



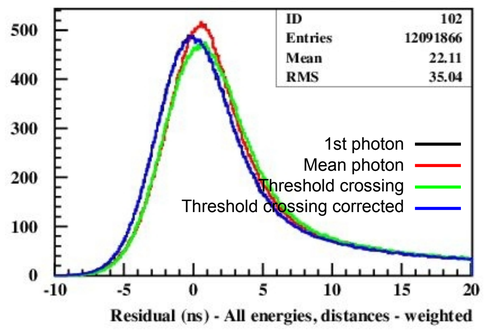
The slewing effect

Simulated pulses have been generated for muons of energy 1TeV – 100TeV, with an E^{-2} spectrum at isotropical directions and uniform distances from the DOM, using the HOURS (Hellenic Open University Reconstruction & Simulation) software package [2]. The results of the analysis, using a threshold of 0.3pe, show that the slewing can be estimated with a resolution of ~5%.



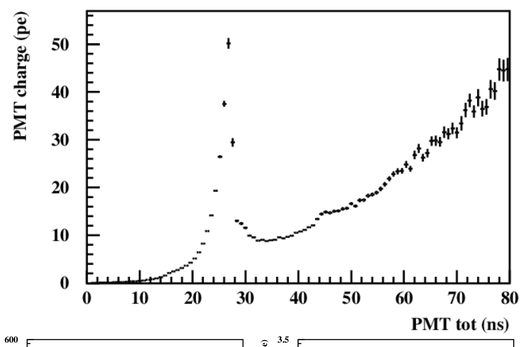


The use of the slewing parametrizations does not increase the statistical error in estimating the arrival time of the pulses. This is evident if the expected arrival times of the photons is compared, with the true (simulated) arrival times of the photons, the arrival times estimated by the threshold crossing and the arrival times estimated by the threshold crossing corrected for the slewing effect.

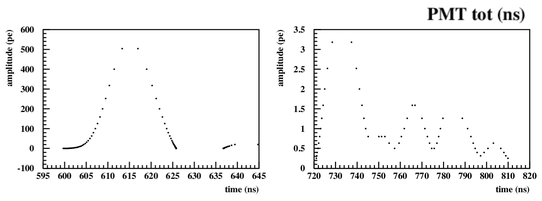


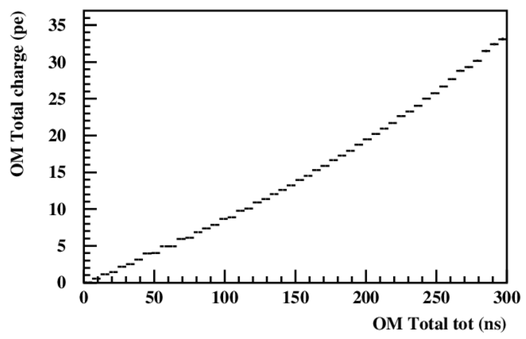
PMT & OM charge estimation

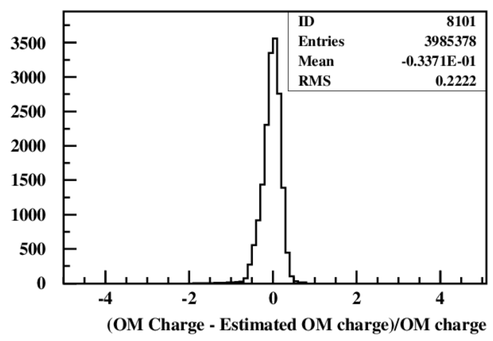
The use of the ToT technique with only one threshold, does not allow the parametrization of the charge of each PMT with a good resolution (>50%). This is due to the non standard shape of the PMT pulses. For multiple thresholds the resolution improves significantly, e.g. for six thresholds it drops to around 8% [3]. The peak at around 25ns corresponds to large number of photons arriving almost synchronously at the PMT. For these pulses the tot values do not vary more than 5ns, while the charge can reach more than 50pe.



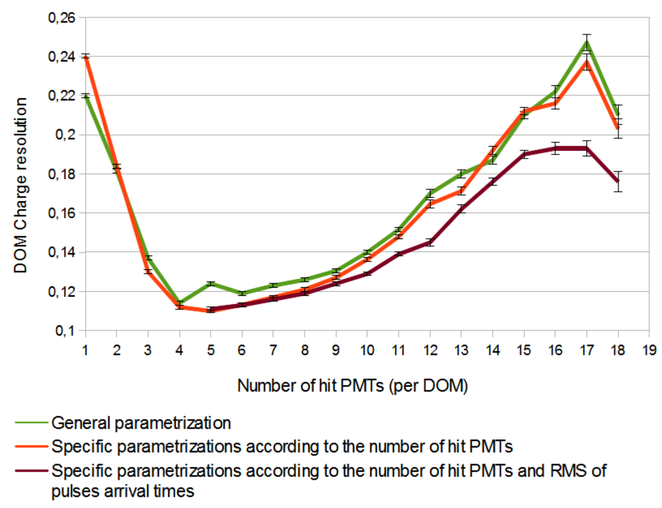
However, if the DOM total charge is parametrized as a function of the sum of the tot values of the PMTs, the DOM total charge can be estimated with a resolution of ~20%.







Further improvement can be achieved for the DOM charge estimation if the number of hit PMTs and the correlations between the arrival times of the pulses at each hit PMT of the DOM are taken into account. Thus, the pulses of different shape are categorized according to the number of hit PMTs and the RMS of the arrival times of the pulses of the PMTs. Then, different parametrizations of the DOM total charge are used.



Conclusions

The ToT technique implemented on the SCOTT ASIC does not add significantly to the statistical error of the timing of the pulses, while the slewing effect can be estimated with a resolution of 5%.

The DOM charge can be estimated using the ToT technique with only one threshold with a resolution of 20%, which is adequate for the energy reconstruction. Studies are ongoing for the improvement of the DOM charge resolution, based on the correlations of the arrival times of the PMTs of each DOM.

References

[1] www.km3net.org

[2] HOU Reconstruction & Simulation (HOURS): A complete simulation and reconstruction package for Very Large Volume underwater neutrino Telescopes, A. G. Tsirigotis, et al. Nucl. Instr. and Meth. A. (http://dx.doi.org/10.1016/j.nima.2010.06.258)

[3] Use of the Multi-Time over Threshold electronics to digitize signals from VLVnT, G. Bourlis, A.Leisos, A. G. Tsirigotis, S.E.Tzamarias, to appear in Nucl. Instr. and Meth. A. (http://dx.doi.org/10.1016/j.nima.2010.04.153)