First results of the KM3NeT/ARCA detector

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Abstract. The KM3NeT collaboration started to build a multi-km\(^3\) neutrino telescope in the Mediterranean Sea. The telescope is composed of two parts: the ARCA detector, optimised for searches for high energy neutrino sources in the Universe, and ORCA, for the determination of the mass hierarchy of neutrinos. ARCA is under construction at the Capo Passero site, Italy, 80 km offshore at a depth of 3500 m while ORCA is located in the Toulon area, France, 40 km offshore at a depth of 2500 m. The basic detection element of the KM3NeT detector is the Digital Optical Module. The module is a pressure resistant glass sphere, containing 31 photo-multiplier tubes. Eighteen modules are arranged in the detection unit, a vertical structure anchored on the sea floor. The detection units are deployed on the sea bed to form a three-dimensional array of optical modules to detect Cherenkov light produced by neutrino-induced muons. In these proceedings preliminary results obtained with the first two detection units of ARCA are presented. The capability to select and reconstruct atmospheric muons is discussed. The dependence of the muon flux with the sea depth is derived, showing that the detector is well calibrated and the systematics are kept under control.

1. Introduction

KM3NeT (km\(^3\)-scale Neutrino Telescope) \[1\] is a research infrastructure in the Mediterranean Sea which will host two neutrino detectors: ORCA (Oscillation Research with Cosmics in the Abyss), located in the Toulon area, France, 40 km offshore at a depth of 2500 m, with the main objective of neutrino mass hierarchy determination \[2\] and ARCA (Astroparticle Research with Cosmics in the Abyss) optimised for searches for high energy neutrino sources in the Universe. The ARCA neutrino telescope is under construction at the Capo Passero site, Italy, about 90 km offshore at a depth of 3500 m and it will reach a volume of cubic kilometre scale. The first two ARCA-DUs were deployed in December 2015 and in May 2016. The detector was taking data continuously from December 2015 up to April 2017. In the first period of data taking the finalization of data acquisition system has been carried on and on-line trigger algorithms have been optimized. The calibration procedures allow to obtain sub-nanosecond accuracy for the timing of PMTs and uniform tuning for their high voltages.

The basic detection element of the detector is the Digital Optical Module (DOM) \[3\], a pressure resistant glass sphere of 43 cm diameter, containing 31 3” photo-multipliers tubes. 18 DOMs are arranged with an interspace of 36 m in the Detection Unit (DU), a vertical string anchored on the sea floor. The DUs are 700 m tall and are deployed on the sea bed to form a three-dimensional array of DOMs. The DUs are connected to submarine Junction Boxes and through them to shore for power feed and data transmission.
The events of interest for a neutrino telescope are the upward-going cosmic neutrinos in the energy range $10^2 \div 10^8$ GeV. The neutrinos interact weakly with matter, producing detectable secondary particles. Muon neutrinos are considered the best candidates for a neutrino telescope. Neutrino-induced muons, in fact, can travel in water over distances of the order of kilometers and can be tracked with high accuracy. At energies $E \geq 1$ TeV the muon direction is almost collinear with the generating neutrino, it is therefore possible to infer the neutrino direction allowing for neutrino astronomy. The detection of high energy muons is done exploiting the Cherenkov effect, which consists of a coherent radiation emitted by charged particles when cross a medium with a velocity greater than the speed of light in that medium. A large volume of a natural medium optically transparent (water or ice) is instrumented with optical sensors to detect the Cherenkov radiation.

A neutrino telescope has three main components of background: the optical background, due to the decay of $^{40}$K in the sea water, the atmospheric muons and the atmospheric neutrinos, produced by the interactions of cosmic rays in the atmosphere. The optical background is responsible for uncorrelate signals on PMTs. It can be reduced looking for time-space correlation between PMTs in the same DOMs. The atmospheric muon and neutrino fluxes produce detectable events like cosmic neutrinos. The background of atmospheric muon can be reduced applying cuts on the reconstructed zenith angle and on quality parameters. For point-like source search, the contribution of cosmic neutrinos over the atmospheric neutrino background is investigated searching for a statistical excess of events around the source position in the sky.

In the next sections the preliminary results obtained with the first two detection units of ARCA are presented. The capability to select and reconstruct atmospheric muons is discussed and the dependence of the muon flux with the sea depth is derived.

2. Study of atmospheric muons and data-MonteCarlo comparison

The multi-PMT DOM structure of the ARCA telescope allows for selecting atmospheric muons over the optical background looking for local coincidences between PMTs. In the KM3NeT framework, a local coincidences (L1) is defined as a signal of two PMTs in the same DOM in a time window less than 25 ns. The PMT multiplicity ($m$) is the number of PMTs in the same DOM with a L1 local coincidence.

The study of the detector response to the optical and atmospheric muon backgrounds is done through MonteCarlo (MC) simulations. MC simulations of the uncorrelated optical background have been performed in order to simulate the decay of $^{40}$K in sea water, the light production and signals on PMT. The Atmospheric muons are simulated through the muon generation and propagation in the sea water, the emission of Cherenkov light and the generation of PMT signals. Data-MC comparison of the rates of local coincidences in a time window of 25 ns, for the lowest and the highest DOMs of the two ARCA-DUs, are shown in Fig. 1. It can be seen that low PMT multiplicities are related with optical background. Atmospheric muon events produce local coincidences on a great number of PMTs in the same DOM, with a consequent high PMT multiplicity. The data-MC comparison shows that the MC well reproduces the data and indicates that for a multiplicity $m \geq 8$ the coincidences rate due to optical background from $^{40}$K decay is negligible [4]. Cuts on PMT multiplicity allows to selects atmospheric muons over the optical background.

3. Atmospheric muon flux dependence with the sea depth

The stability of the PMTs and the homogeneity of the ARCA detector performances can be verified through the dependence of atmospheric muon flux rate with the sea depth. For the study of the atmospheric muon flux dependence a data sample corresponding to a detector livetime of $\sim 10$ day has been considered. A full MC simulation, with the PMT efficiencies equal to 1, has been produced. Then the same trigger algorithms have been applied both for data
Figure 1. Rate of multiple coincidences for the DOM1 of ARCA-DU1 and DOM18 of ARCA-DU2 as a function of PMT multiplicity. Data are reported as blue circles and red squares. The MC simulations of the atmospheric muon background are represented by full areas. The sum of the atmospheric muons and optical background are indicated by full lines. For a multiplicity $m \geq 8$ the coincidences rate due to optical background is negligible.

and MC. To obtain a pure atmospheric muon sample, events with more than $m > 7$-fold local coincidences have been selected. In Fig. 2 the multiplicity rates in single DOM induced by muon flux as a function of the sea depth is shown. The coincidence rate shows an exponential decrease of the PMT rates according to the decrease of atmospheric muon flux with the depth both for data and MC. From the analysis of the $^{40}$K coincidences, a relative efficiency of each PMT has been obtained and include in a new MC production (blue square in Fig. 2). The MC simulation with the relative efficiencies of PMTs well reproduces the characteristics of the selected data [4], indicating that the detector is well calibrated and the systematics are kept under control.

4. Data reconstruction

The KM3NeT/ARCA telescope allows for the reconstruction of muons trajectories looking for time-space correlation among the PMT signals of different DOMs. The reconstruction procedure consists of different steps. At first, a track reconstruction algorithm [5] performs a scan over the full solid angle, selecting PMT signals correlated with candidate reconstructed tracks. After that, a likelihood-maximisation procedure, based on multi-dimensional probability distribution of the arrival times of the Cherenkov light from events, is applied. Finally, the track with the best likelihood is chosen as the reconstructed track. To investigate the quality of the reconstruction procedure a data sample corresponding to a detector livetime of $\sim 20$ days has been selected. For this analysis only the MC simulation of atmospheric muons has been considered. In Fig. 3 the rate of events as a function of the reconstructed zenith angle is presented both for data and MC. The data and MC comparison shows a good agreement, proving the reliability of MC simulation codes and that the detector is well calibrated in time. Even if a small fraction of downward-going atmospheric muons is wrongly reconstructed as upward-going events, they overcome the atmospheric neutrino flux. In Fig. 3 the data-MC ratio is also reported. An excess of data over the MC event has been found in the rage of reconstructed zenith angle of very upward-going tracks. Further studies of this excess of upward-going tracks found in the data are ongoing in order to search for neutrino-induced events.
Figure 2. Comparison between data (triangle), MC with uniform PMTs efficiencies (dotted line) and MC with relative PMTs efficiencies (blue square) of the rates of $m \geq 8$ PMT coincidences in the DOMs as a function of depth for ARCA-DU1 and ARCA-DU2. DOM1 is the lowermost DOM of ARCA-DU1 (3390 m), DOM18 is the uppermost DOM of ARCA-DU2 (2750 m), see Fig. 1

Figure 3. Comparison between the rate of reconstructed events for data and MC as a function of the cosine of the reconstructed zenith angle. In the bottom, the data-MC ratio is shown. No quality cuts are applied to the data sample. Only atmospheric muons are simulated.

5. Conclusion
In these proceedings preliminary results obtained with the first two ARCA-DUs have been presented. The capability of the ARCA telescope for selecting atmospheric muons over the optical background has been verified. The detector performances have been investigated by means of the study of the atmospheric muon flux dependence with the sea depth. Finally, the data-MC comparison of the rate of events as a function of the reconstructed zenith angle demonstrates that the simulation fits well with the data and shows the reconstruction algorithm performances.

References
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