Astroparticle Physics 78 (2016) 43–51

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

Time calibration with atmospheric muon tracks in the ANTARES neutrino telescope

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http://dx.doi.org/10.1016/j.astropartphys.2016.02.001
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ARTICLE INFO

Article history:
Received 15 July 2015
Revised 1 February 2016
Accepted 4 February 2016
Available online 10 February 2016

PACS:
95.55.Vj

Keywords:
Time calibration
Neutrino Telescopes
ANTARES
Atmospheric muon tracks

ABSTRACT

The ANTARES experiment consists of an array of photomultipliers distributed along 12 lines and located deep underwater in the Mediterranean Sea. It searches for astrophysical neutrinos collecting the Cherenkov light induced by the charged particles, mainly muons, produced in neutrino interactions around the detector. Since at energies of ~10 TeV the muon and the incident neutrino are almost collinear, it is possible to use the ANTARES detector as a neutrino telescope and identify a source of neutrinos in the sky starting from a precise reconstruction of the muon trajectory. To get this result, the arrival times of the Cherenkov photons must be accurately measured. A to perform time calibrations with the precision required to have optimal performances of the instrument is described. The reconstructed tracks of the atmospheric muons in the ANTARES detector are used to determine the relative time offsets between photomultipliers. Currently, this method is used to obtain the time calibration constants for photomultipliers on different lines at a precision level of 0.5 ns. It has also been validated for calibrating photomultipliers on the same line, using a system of LEDs and laser light devices.

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1. Introduction

The ANTARES neutrino telescope [1] aims at the exploration of the high-energy Universe by using neutrinos as cosmic probes. One of the main goals of the experiment is the discovery of point-like sources of cosmic neutrinos. Typically, searches for sources of neutrinos are performed using the reconstructed directions of selected events. In this sense, a good angular resolution, i.e., the angle between the direction of the reconstructed muon track and of the neutrino, is of great importance for searches of point and extended neutrino sources to better discriminate between the signal of cosmic neutrinos and the background of atmospheric muons and atmospheric neutrinos. At energies ~10 TeV the median value of the angular resolution in the ANTARES detector, as determined with simulations, is ~0.4° [2].

In the energy range of interest, the angular resolution is driven by the reconstruction accuracy. Since the reconstruction algorithm depends on the precise measurement of the photon arrival times on the photomultipliers (PMTs), an accurate detector time calibration is crucial to guarantee the best performance of the telescope. In particular, the precision in the measurement of the relative PMT timings is required to be ~1 ns [3].

In this paper, the methods to perform the time calibration of the detector at this level of accuracy and to determine the calibration constants used in the physics analyses of the ANTARES collaboration are presented. The method is based on the reconstructed trajectories of the down going atmospheric muons, which are the main source of physical triggers for a neutrino telescope. This calibration method does not require the physics data acquisition to be stopped and does not rely on additional electronic devices. It was initially implemented for the first ANTARES point-source analysis [4].

The paper is structured as follows. In Section 2 a brief description of the ANTARES detector is presented. The calibration method is introduced in Section 3. In the fourth section the reconstruction method used in the point-like source search, and in the majority of the physics analyses in ANTARES, is described. In Sections 5 and 6 the derivation of the calibration constants is described in detail. In Section 7 the results are discussed and compared to the results obtained with an independent system of calibration that uses an array of optical beacons [5]. A summary and the conclusions are given in Section 8.

2. The ANTARES detector

ANTARES is the first deep-sea neutrino telescope in operation in the world. Anchored at a depth of 2475 m in the Mediterranean Sea, 40 km off the coast of Toulon (France), the detector comprises 885 PMTs distributed on a three-dimensional array made up by 12 flexible lines, each of them 480 m long, which are arranged on an octagonal layout with an interline separation of 60–75 m. Each line holds triplets of PMTs and the control electronics boards needed for the power supply and data control at this level, at 25 vertical positions (storeys). The first storey of each line is placed 100 m above the seabed and the distance between adjacent storeys is 14.5 m. Each PMT (10" photocathode, model R7081-20 of Hamamatsu [6]), hosted in a high-pressure-resistant glass sphere together with high-voltage power supplies and internal calibration tools, constitutes an optical module (OM) [7]. A scheme of the detector can be seen in Fig. 1.

The electronics boards are enclosed in a titanium container, the local control module. The main electronic components are the analogue ring sampler (ARS) circuits [8], which perform the digitisation of the electronic signals produced in the PMTs,

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