Track Reconstruction and Point Source Searches with Antares

Heijboer, A.J.

Publication date
2004

Summary

High energy cosmic rays consist mostly of protons which are thought to be accelerated in astrophysical shock waves and which can initiate neutrino production by interactions with photon or matter fields in the accelerating region. Decay of the charged pions produced in these interactions leads to the production of high energy neutrinos. The detection of high energy cosmic neutrinos would therefore shed light on the question on the origin of high energy cosmic rays

The ANTARES collaboration is building a detector for high energy cosmic neutrinos in the Mediterranean Sea. The detector will consist of 900 photomultiplier tubes, which are enclosed in pressure resistant glass spheres and which are positioned along 12 flexible, upright strings with a length of 400 m. This instrument will detect the Cherenkov light produced by muons that result from charged current interactions of muon-neutrinos.

The direction of muons is closely correlated to the neutrino direction, which allows for good angular resolution, provided that the direction of the muon is accurately reconstructed. This reconstruction relies on accurate information on the arrival times of the Cherenkov photons on the photomultipliers. The timing resolution of the detector is expected to be about 1.3 ns. Analysis of data obtained during tests of a prototype detector in the laboratory has confirmed this value.

In order to estimate the performance of the detector, simulations have been performed of the charged current neutrino-nucleon interactions, the propagation of the resulting muons from the interaction point to the detector, the production and propagation of the Cherenkov light through the instrumented volume and the response of the detector.

The algorithm for reconstructing muon tracks consists of several subsequent fitting procedures, which provide increasingly accurate estimates of the track parameters, but which also require increasingly accurate starting points. The final procedure is a maximum likelihood fit. The probability density function of the hit times used in the final fit takes into account the background photons, which are due to decaying ^{40}K and bioluminescence.

After the application of a set of quality criteria to select well reconstructed events, the obtained angular resolution is dominated by the scattering angle between the neutrino and the muon for neutrino energies below 10 TeV. At higher energies, the pointing resolution is dominated by the error on the muon direction and is typically smaller than 0.2°.

The background caused by down-going atmospheric muons that are reconstructed as up-going is rejected to the level of about one event per day by the selection criteria. The remaining background is dominated by atmospheric neutrinos, which account for 10 selected events per day.

A method was developed to search for point-like sources of neutrinos in the background of atmospheric neutrinos. The method is based on a likelihood ratio test. In contrast to

more widely used methods, this method takes into account all available information on the reconstructed direction of the neutrinos, the reconstructed energy and the error estimates provided by the reconstruction. Moreover, the loss of information due to binning effects is minimised.

The performance of the likelihood ratio method was evaluated for a full sky search for a point source of neutrinos with an energy spectrum proportional to E^{-2}. In order to discover the neutrino source at 3(5) σ confidence level after one year of data taking, a flux of $1(1.4) \times 10^{-3}\ E^{-2}$ GeV $m^{-2}\ s^{-1}$ is needed, if the position of the source in the sky if favourable. This flux is about 35% smaller than the flux needed when using a method which relies only on binning of the reconstructed celestial coordinates of the events. The likelihood ratio method thus results in significant increase in the discovery potential.

The search method can also be used to set an upper limit on the flux from a particular direction. The average expected 90% confidence level upper limit that can be set by ANTARES after one year is between 5×10^{-4} and $2 \times 10^{-3}\ E^{-2}$ GeV $m^{-2}\ s^{-1}$, depending on declination. This is an order of magnitude smaller than the present limits for sources in the southern hemisphere. According to model predictions of neutrino fluxes, ANTARES will be sensitive to the most intense sources after about one year of data taking.