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The combined AMANDA and IceCube Neutrino Telescope

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Abstract: The IceCube Neutrino Telescope is currently under construction at the geographic South Pole and will eventually instrument a volume of one cubic kilometer by 2011. It currently consists of 22 strings with 60 Digital Optical Modules each. Additionally the AMANDA detector has been fully integrated into IceCube operation. This includes hardware synchronisation, combined triggering, common event building and a combined data analysis strategy. Monte Carlo simulations of a combined AMANDA + IceCube detector will be presented. The results of the simulations were used to implement an online filtering on data provided by the Joint Event Builder collecting data from both detectors. Data taken synchronously from both detectors serve for Monte Carlo verification. We discuss the impact of the AMANDA integration on the effective area, track reconstruction and event selection for the muon neutrino detection channel. In particular, we study fully and partially contained events at low energy. An online filter marks candidates for contained events using peripheral optical modules as a veto against atmospheric muons. The effective interaction volume for this filter is presented.

Introduction

In its 2007 configuration, IceCube consists of 22 strings in operation with 60 digital optical modules each. For details on its performance see [1]. With the deployment of 13 additional strings in the 2006/07 polar summer, the detector surrounds now its predecessor AMANDA. Since IceCube has a wide string spacing of 125 m, optimized for muon tracks above a few TeV, the integration of AMANDA with its denser array adds an important part to the low energy reach of the combined detector.

The implementation of a new DAQ system to the AMANDA detector [2] in the years 2003-2005 allowed for a reduction of the multiplicity trigger threshold. By this the energy threshold of AMANDA has been lowered below 50 GeV. Hence it is capable to complement IceCube at low energies and consequently, the AMANDA detector has been fully integrated into the IceCube detector. This includes a common run control, triggering, event building and online filtering. Every time the AMANDA detector is triggered, a readout request is sent to the IceCube detector. Since the energy threshold of AMANDA is lower, no triggering requests from IceCube to AMANDA are needed. As shown in Fig. 1, the Joint Event Builder (JEB) receives data from both detectors, merges events on a time coincidence base and provides the data to the online filtering. The online filtering selects events of interest for physics analyses and transfers the selected data to the Northern Hemisphere. With this filtering the relevant physics data can be quickly analyzed despite the constraints of limited satellite bandwidth available for data transfer from the South Pole.

Monte Carlo (MC) studies of the performance of the combined detector in muon neutrino channel are presented in this paper. The combined detector provides an improved performance at low energies: the IceCube strings directly adjacent to AMANDA

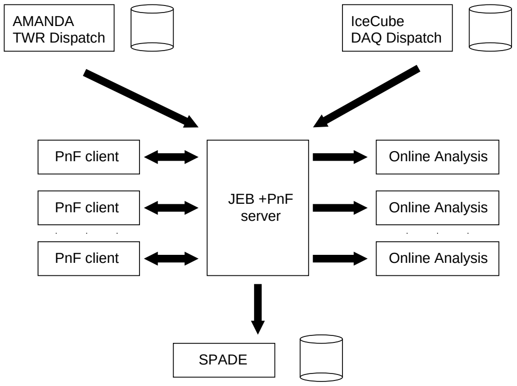

Figure 1: Data flow in the combined AMANDA and IceCube neutrino telescopes using the JEB. The processing and filtering (PnF) clients reconstruct the combined events within a few seconds of data acquisition. Online analysis is then performed before the data is transferred to the SPADE system for satellite transmission and tape archiving.

enlarge the densely instrumented region, provide a longer lever arm and thus improve the angular resolution. This reduces the background for low energy neutrinos from point-like sources compared to previous AMANDA analyses [3]. Since AMANDA is now completely embedded into the IceCube array, the identification of starting and contained tracks becomes possible using IceCube as a veto. The identification of contained events allows a better measurement of the energy. Additionally, with this technique, the rejection of down-going atmospheric muons is possible and thus, the detector is sensitive to sources in the southern sky. Furthermore, analyses for different neutrino flavors will use the combined detector as well to improve the low-energy performance.

Low energy physics with the combined detector

With its enhanced performance at low energies the combined detector will have an improved sensitivity to WIMPs (see [4]) and sources with steep energy spectra or cut-offs below 10 TeV like the Crab nebula [5]. In particular, the search for time-variable sources will profit from this enhancement since their localization in space and time significantly reduces the number of background events. An example for such a source is LS I+61 303 emitting TeV photons periodically with a power law index of -2.6 [6]. Another region of high interest is the Galactic Center which contains a TeV gamma-ray source [7]. As it lies in the southern sky it was not accessible for AMANDA up to now. But also the analysis of atmospheric neutrinos will benefit and might even allow the detection of neutrino oscillation effects in the energy range 10 – 100 GeV and test for non-standard oscillation scenarios.

Online filtering and data analysis

Two filtering strategies make use of the combined detectors. The first strategy aims for an improved performance for up-going muon tracks, by adding a low energy online filter for combined data to the standard IceCube filter for up-going muons. Additionally, a filter using the veto strategy identifies events contained in the AMANDA array and opens a sensitivity window to the southern sky. In addition to the integration of AMANDA, the implementation of a string trigger improves the detection of vertical low energy tracks with IceCube.

The up-going muon filter

The low energy up-going muon track filter uses all hits from both detectors to reach a decision. It is complementary to an up-going muon track filter defined on IceCube hits only. The JAMS reconstruction[1] was chosen for the low energy filter. Events with a reconstructed zenith angle larger than 75° are selected. The combination with the IceCube only filter allows to constrain the use of this relatively slow algorithm to events with hits in the AMANDA detector not passing the IceCube filter and having less than 20 hits in IceCube. For events with more hits, the additional information from AMANDA does not result in a significantly better filtering efficiency.

The effective area for muon neutrinos of the combined detectors using the combined online filter is

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[1] JAMS is based on a cluster search in the abstract space spanned by the distance of the hit to the track and the time residual. The time residual is the difference of the measured hit time and the passing time of the Cherenkov cone for an assumed track.

shown in Fig. 2 in comparison to the IceCube only filter. Figure 3 shows the resulting expected rate of atmospheric neutrinos [8]. It is worth noting that the combined detector detects atmospheric neutrinos over four orders of magnitude in energy between 10 GeV and 100 TeV.

The neutrino signal efficiency of the combined filter is above 90% over the wide energy range from 10 GeV to 100 PeV. The rejection of the atmospheric muon background is above 95%, where less than 0.5% of all events are passing the JAMS filter on combined events. That demonstrates that the background of atmospheric muons is not significantly increased by the AMANDA integration.

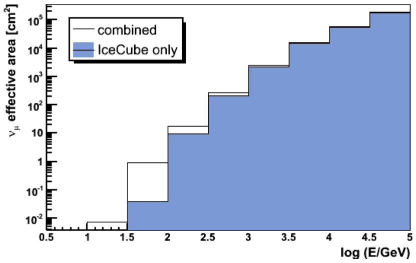

Figure 2: Effective area of the combined detectors in comparison to IceCube only at online filter level.

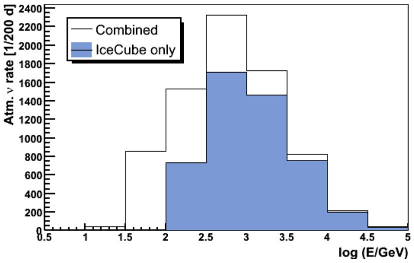

Figure 3: Atmospheric neutrino rate at online filter level for a generic run period of 200 days.

A first study of the angular resolution in the low energy regime ($E < 10$ TeV) was conducted. For this study, events triggering both detectors separately have been selected and a full likelihood reconstruction [9] has been applied. As shown in Fig. 4, a slight improvement was found.

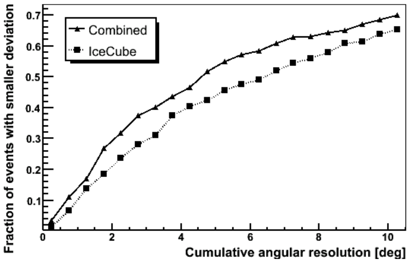

Figure 4: Cumulative distribution of the angle between simulated and reconstructed track for the combined detectors and IceCube only.

A filter for low-energy contained events

As IceCube surrounds the AMANDA detector its outer strings and top-layers can be used to veto through-going tracks and especially study low energy (100 GeV – 1 TeV) fully or partially contained tracks with 4π sensitivity. Figure 5 shows the effective volume for these events at filter level. The combined AMANDA-IceCube detector is used to reconstruct tracks and point them back to their origin. Reconstructed tracks that deposite no light in one or more peripheral strings despite of a high probability to do so assuming a through-going track, are more likely to be due to muon neutrino interactions rather than atmospheric muon background. Furthermore, the charged current interaction of the muon neutrino in the detector produces a cascade with a track attached to it. This topologically differs from a through-going muon track and can be studied in the recorded waveforms and leading edge times. A dedicated reconstruction algorithm is currently under development.

A string trigger for vertical low-energy events in IceCube

We are currently implementing a new string trigger for IceCube that requires 5 DOMs to be hit out of a sequence of 7 DOMs on a single string. The upper most part of the string isd excluded to reduce the trigger rate on down-going muons. In comparison to the standard IceCube trigger requiring 8 DOMs to be hit, for energies below 100 GeV an improvement by more than a factor of 10 is obtained. Figure 6 shows the string trigger efficiency as a function of the muon neutrino energy and zenith angle.

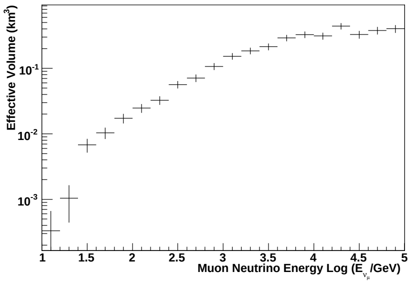

Figure 5: Effective interaction volume of the contained event filter.

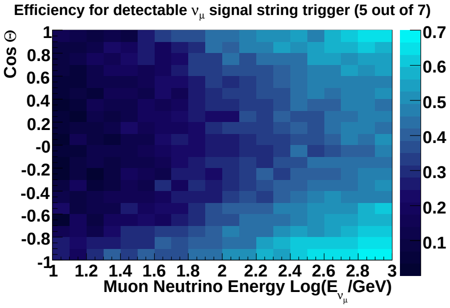

Figure 6: String trigger efficiency for muon neutrinos that produce at least one hit in the detector as a function of muon neutrino energy and zenith angle.

The good performance for vertical tracks allows to compare the fluxes of up- and down-going atmospheric neutrinos and the analysis of WIMP annihilations at the center of the Earth.

Verification of MC simulations

In order to check the viability of the MC simulation for the combined detector, we have compared the distributions of various quantities between data and simulation. The data for this comparison has been acquired in a a regular integrated run in 2007. As an example Fig. 7 shows the comparison of the reconstructed zenith angle spectrum for data and MC. Other distributions, including that of the trigger rate and the number of hit channel were also found to be in good agreement.

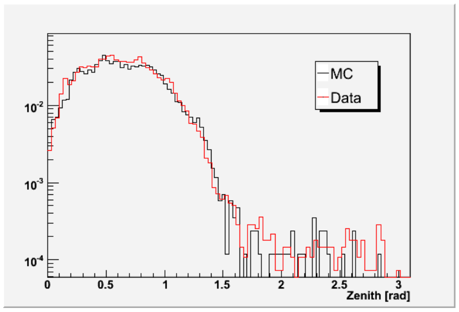

Figure 7: JAMS zenith spectrum from integrated AMANDA-IceCube runs in 2007.

Conclusions

According to the preliminary results presented here, the combined IceCube and AMANDA detector in its current configuration provides a significantly improved performance in the low energy regime. The effective area for up-going muon neutrinos and the effective interaction volume for contained down-going events at online filter level provide improved possibilities to investigate atmospheric neutrinos as well as possible astrophysical sources emitting neutrinos with energies below 10 TeV. For the first time, the Galactic Center can be examined with a neutrino telescope on the Southern Hemisphere.

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