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HIGH ENERGY NEUTRINO TELESCOPES

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We review the status of the four Deep Underwater/Underice High Energy Neutrino Detectors. The BAIKAL and AMANDA collaborations have protoypes in permanent operation. DUMAND–II and NESTOR are expected to start operating in 1–2 years. Experience with the current arrays is essential to optimize the design of the next generation telescope with sensitive detector area of $\sim 1\,\mathrm{km}^2$.

1 Introduction

High energy neutrino telescopes currently under construction are deep underwater/underice Cerenkov detectors, designed for ν_μ–detection via muons originating from charged current interactions $\nu_\mu N \rightarrow \mu X$. Large sensitive detector areas ($\geq 10^3\,\mathrm{m}^2$), exceeding those of underground detectors like MACRO and Kamiokande, are obtained by sparsely instrumenting large natural water/ice volumes with PMTs. Sensitivity is rising with E_{ν_μ} due to larger ν_μ–cross section as well as μ–range.

Main aim of these telescopes is to search for astrophysical sources of high energy ν's. Their detection would allow to study sites and nature of highest energy cosmic accelerators. Candidate sources, as e.g. active galactic nuclei, are discussed in[1] and ref. therein. Calculations show, that sensitive detector areas of up to $1\,\mathrm{km}^2$ are needed to detect the predicted sources.

Other physics topics to be investigated with these telescopes are ν–oscillations (atmospheric or long-baseline), indirect WIMP–searches, detection of low energy ν's from supernova collapses, search for GUT-magnetic monopoles, muon-astronomy, ν_τ–interactions, as well as standard cosmic ray physics[1,2,3,10,11].

2 The Experiments

The four experiments currently under construction follow the same basic design: about 200 PMTs, arranged along vertical strings (one central, the other at the circumference of a circle), with horizontal and vertical spacings governed by the absorption and scattering lengths, L_{abs} and L_{scat}, of the medium, or by mechanical constraints, respectively. The experiments are different concerning the actual geometry, the optical properties of the medium, the dominant background sources and are complementary with respect to details and complexity of the technological implementation.

The muon trajectory is spatially reconstructed from the Cerenkov light arrival times, measured with some nanoseconds precision. Amplitude measurements, with worse resolution compared to timing, is used for muon energy determination and fake event rejection. Pattern recognition is thus very different from Cerenkov detectors like Kamiokande, where many, closely packed PMTs are providing the event information.

Neutrino events are defined as upward reconstructed muons, thus spatial misreconstruction of events is a major performance limitation. Sources of time patterns faking upward muons are true atmospheric muon triggers ($10^{4..6}$ times more abundant than atmospheric ν's) and noise triggers. The first case could be important for shallower detectors (BAIKAL/AMANDA), the second for high dark noise environments (DUMAND/NESTOR).

Effective areas for muons are of the order of $10^3 - 10^4\,\mathrm{m}^2$ for the current detector projects.

2.1 BAIKAL

Site: Lake Baikal in Siberia, 4 km offshore, depth=1.1 km, L_{abs} ~20 m. Array access during the 6 weeks winter ice cover for upgrading and maintenance.

Layout: Neutrino Telescope NT-200 will consist of 196 PMTs at 8 strings carried by a fixed mechanical frame with radius r=21 m, and vertical spacings d_{vert}=5/7.5 m. PMTs are arranged in pairs and switched in coincidence, yielding local background rates of a few hundred Hz only. This is essential for pattern recognition, since a simple majority trigger (≥ 5 PMTs) yields noise–free muon events. To calibrate the array with downgoing muons, currently half of the PMT pairs are pointing upwards.

Status: In 1993, the collaboration deployed the first deep underwater multistring detector, the 36 PMT array NT–36. This array[4], being the first part of NT–200, was operated until its upgrade in 1995 to 72 PMTs. Intensity and angular dependence of the underwater muon flux were measured after successful track reconstruction. As a major result, a suppression rate of 10^5 for the downgoing muons faking ν's was achieved, in agreement with MC–expectations. With a separate trigger system, limits for GUT–monopole fluxes have been obtained[5].

In spring 1996, the array will be upgraded to at least 96 PMTs. With improved reliability of electronic components, a first separation of atmospheric neutrinos is expected.

2.2 AMANDA

Site: South pole, clear and sterile antarctic ice, depth=800–2000 m.
Layout: Independent vertical strings of 20 PMTs, frozen into hotwater-drilled ice holes. String positions are not limited by mechanical constraints. PMTs are operated at high gain, directly driving a coaxial cable. With all electronic components above the ice, this approach is non-hierarchical, with flexibility for upgrades of trigger and front-end electronic.
Status: Deployment of 80 PMTs on 4 strings at 800–1000 m depth in austral summer 93/94 proved the drilling technology is under control. Ice shows extraordinary low absorption ($L_{abs} \geq 200\,m$)[6,9]. However, scattering at residual air bubbles at these low depths washs out the Cerenkov time pattern. The collaboration has demonstrated muon angular reconstrution capability, is investigating a special trigger for high energy ν_e–interactions and analyzed coincidence events with with the air–shower array SPASE situated above AMANDA. A trigger system for MeV ν's from SN collapses is in operation. Reliability of the optical modules is excellent[6].

During the 1995/96 season, 120 PMTs at 6 strings will be deployed at 1500–1900m, where scattering at air bubbles should disappear.

2.3 DUMAND

Site: Pacific Ocean, Hawaii, Big Island, 36 km offshore, depth=4500 m, $L_{abs} \sim 47$ m. Deployment with special vessel and submarine.
Layout: 216 PMTs at 9 independent vertical strings, connected by a junction-box at sea bottom, r=30 m, d_{vert}=10 m.
Status: A successful prototype string test in 1987, measuring the atmospheric muon flux up to 4 km depth, was followed by a big effort to develop the sophisticated underwater equipment. Fall 1993, the 36 km underwater fiber cable and the junction box have been installed. A first string with 24 PMTs was operated for a few hours and recovered after a leakage of a central electronics module. For 1995/96, ocean tests with assembled strings are planned, as well as submarine driven repairs of the junction box at the site. With appropriate funding, deployment of 3 strings ("TRIAD") will be done in 1996/97[7,10].

2.4 NESTOR

Site: Mediterranian, Pylos/Greece, 20 km offshore, depth=3500 m, $L_{abs} \sim$ 55m. Calm sea for deployment.
Layout: A tower with 168 PMTs at 12 rigid hexagonal floors each with 14 PMTs (pairwise up-down looking) at r=16 m, d_{vert}=20 m. The denser array geometry could give lower ν_μ–energy thresholds and ν_e–detection capability. A search for atmospheric ν–oscillation and a long baseline ν–oscillation experiment with a CERN beam are discussed. Advanced analog PMT-data transmission via fiber cables is under investigation.
Status: Site studies, including optical measurements, have been done. Assembling and testing of optical modules, design of the DAQ and front–end–electronics and in–situ tests of the components are in progress. The first full tower will be deployed in 1997[8,11].

3 Conclusions

Substantial progress has been made since 1993, with two prototype arrays in operation and close to interesting upgrades, and the two other detectors soon to follow.

With the currently rising interest towards construction of a next stage detector with effective area $\sim 1\,\mathrm{km}^2$, it should be noted, however, that still experimental input is needed for some key issues of these new ν–detectors:

- experimental verification of the ν–detection capability (with atmospheric ν's) and investigation of the various background sources
- capability to reconstruct energy and track parameters for very high energy muons ($E_\mu \geq$10 TeV),
- influence of light scattering and absorption on the detector performance (including long-term in-situ monitoring of their magnitude and variation),
- balance between design simplicity and maximal performance properties.

Once the current arrays are sufficiently studied, the effort should be concentrated on building a huge km^2–size detector, with sufficient sensitvity to scan the high energy neutrino sky for the predicted astrophysical sources.

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