PHYSICS RESULTS AND PERSPECTIVES OF THE BAIKAL NEUTRINO PROJECT

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The Neutrino Telescope NT200 is operated since 1998 and was upgraded to the 10 Mton detector NT200+ in 2005. The preparation towards a km3-scale (Gigaton volume) detector in Lake Baikal is currently a central activity. As an important milestone, a km3-prototype string, based on completely new technology, has been installed and was operating together with NT200+ since April 2008. Also selected astroparticle physics results from the long-term operation of NT200 are presented.

1 Introduction

The Baikal Neutrino Telescope NT200 is operating in Lake Baikal at a depth of 1.1 km and is taking data since 1998. Since 2005, the upgraded 10-Mton scale detector NT200+ is in operation. Detector configuration and performance have been described elsewhere [1,2]. The most recent milestone of the ongoing km3-telescope research and development work (R&D) was the installation of a "new technology" prototype string in spring 2008, as a part of NT200+. Fig.1 (left plot) gives a sketch of the current status of the telescope NT200+, including the km3-prototype string.

In this paper we review selected astroparticle physics results from long-term operation of NT200, in particular, an improved limit on a diffuse astrophysical neutrino flux, upper limits on the muon flux from annihilations of hypothetical weakly interacting massive particles (WIMPs) in the Earth and the Sun, and we also discuss the R&D activities towards a km3-scale Baikal telescope. Other results, also on related science and new acoustic technology tests, can be found in [3].

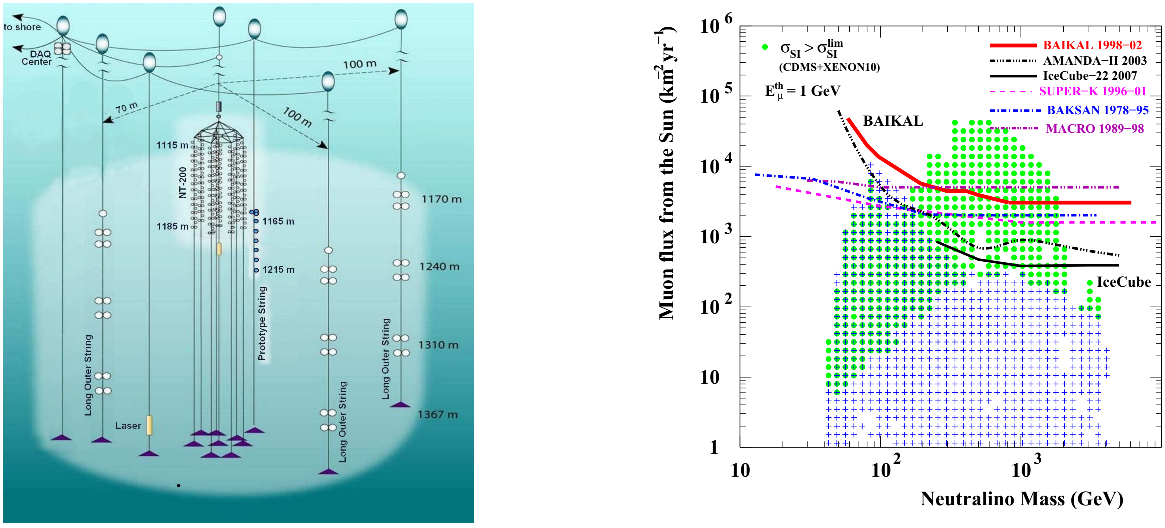

Figure 1: The Lake Baikal neutrino telescope: the compact NT200 (center), 3 long outer strings and the new technology km3-prototype string. Right panel: The NT200 upper limits at 90% c.l. on muon flux from WIMP annihilation in the Sun versus WIMP mass (see text).

2 Selected physics results from NT200

2.1 A search for neutrinos from WIMPs in the Earth and in the Sun

A possible signal from dark matter WIMP annihilations in the Earth and in the Sun would reveal as an excess of upward going muons over atmospheric neutrinos arriving either from near vertical or from the direction of the Sun, respectively. We have used the experimental data of NT200 taken between April, 1998 and March, 2003. In case of the Earth signal, event selection relies on a series of quality cuts which are tailored to the response of the telescope to nearly vertically upward going muons. The energy threshold is about $E_{thr} \sim 10$ GeV in this analysis. We have selected 48 neutrino events for 1038 live days, compared to 56.6 events expected from atmospheric neutrinos with oscillation parameters of Super-Kamiokande results [4], and 73.1 events without oscillations. With no evidence for an excess above the atmospheric neutrino expectation, the upper limit at 90% confidence level (c.l.) on the muon flux from the center of the Earth was determined as $F < 3.7 \cdot 10^{-15}$ cm^{-2}s^{-1} (for WIMP masses greater than 100 GeV, and normalized to $E_{thr} = 1$ GeV).

In case of the Sun we have applied two sorts of quality cuts according to two angular resolutions $\delta\Theta = 3.9°$ and $\delta\Theta = 5.3°$. Respectively, we have selected 510 and 2376 upward going muons in two data samples for 1007 live days. For both samples the distributions of correlation angles between these muons and the Sun were compared to the corresponding off-source background expectation. No indication for excess muons were found. The obtained upper limits at 90% c.l. on an additional muon flux from the Sun are shown in Fig.1 (right) as function of the WIMP mass. In Fig.1 (right), adapted from [5], also gives results from other neutrino telescopes: Baksan, MACRO, Super-Kamiokande, AMANDA-II, IceCube (22 strings), and also minimal supersymmetric neutralino model predictions (see ref. [5]).

2.2 A search for extraterrestrial high-energy neutrinos

The BAIKAL survey for high energy neutrinos searches for bright cascades produced at the neutrino interaction vertex in a large volume around the telescope. A full cascade reconstruction algorithm (for vertex, direction, energy) was applied to the data[6]. Cuts were then placed on this

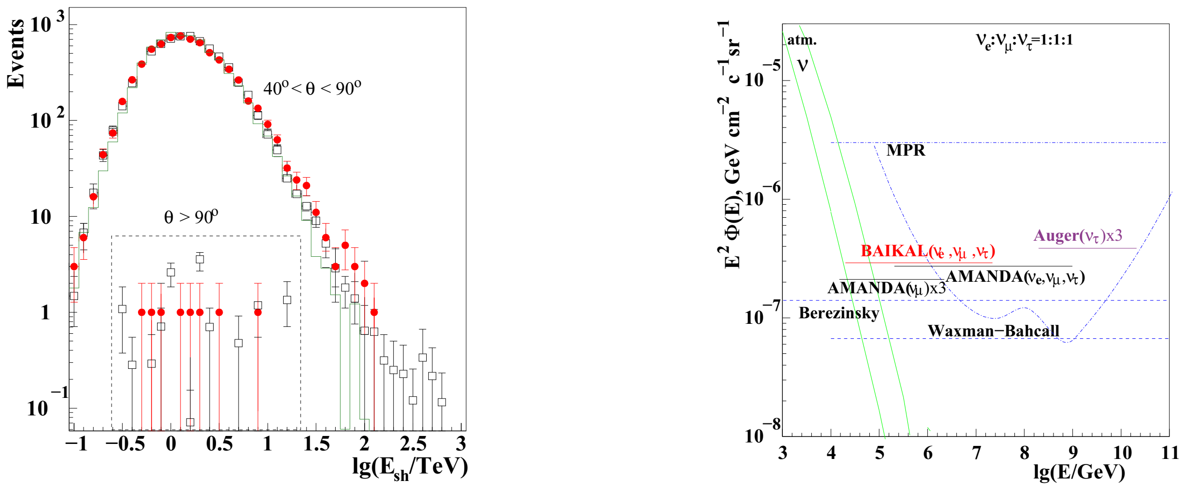

Figure 2: Left panel: Reconstructed cascade energy distribution for data (red dots) and for MC-generated atmospheric muons (boxes); true MC energy distribution given as histogram. Right panel: All-flavor neutrino flux limits and theoretical bounds (see text).

reconstructed cascade energy to select neutrino events. The reconstructed energy distribution of data is shown in Fig.2 (left panel: dots). Eight events were reconstructed as upward going cascades (zenith angle $\theta > 90^\circ$, distribution in dashed box in Fig.2). Also the MC-generated (histogram) and reconstructed (boxes) energy distributions from simulated atmospheric muons are shown in Fig.2 (left panel); 12 upward reconstructed cascade-like events are expected. As seen from Fig.2, within systematic and statistical uncertainties there is no significant excess above the background from atmospheric muons. We introduce the following final neutrino signal cuts on the cascade energy: E_{sh} >130 TeV and E_{sh} >10 TeV for downward and upward going cascades, respectively. With zero observed events and 2.3±1.2 expected background events, a 90% confidence level upper limit on the number of signal events of $n_{90\%}$ =2.4 is obtained. For an E^{-2} behaviour of the neutrino spectrum and a flavor ratio $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$, the 90% C.L. upper limit on the neutrino flux of all flavors obtained with the Baikal neutrino telescope NT200 is: $E^2\Phi < 2.9 \times 10^{-7}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}$, for 20 TeV < E_ν < 20 PeV. Fig. 2 (right panel) shows our upper limit on the all-flavor E^{-2} diffuse flux, which is a significant improvement of the earlier obtained limit [7]. Also shown are the limits obtained by AMANDA [8,9] and Pierre Auger Observatory [10], theoretical bounds obtained by Berezinsky [11], by Waxman and Bahcall [12], by Mannheim et al.(MPR) [13], as well as the atmospheric conventional neutrino fluxes [14].

3 Towards a km3 detector in Lake Baikal: the new technology string

The Baikal collaboration pursues since several years a R&D program for a km3-scale neutrino telescope in Lake Baikal. The construction of NT200+ was a first step in this direction. The existing NT200+ is a natural laboratory to verify many new key elements and design principles of the new telescope. A Baikal km3-detector could be made of building blocks similar to NT200+, but with NT200 replaced by a single string, still allowing separation of high-energy neutrino induced cascades from background. It will contain a total of 1700–2300 optical modules (OMs), arranged at 90–100 strings with 16–24 OMs each, and an instrumented length of 350–460m. Interstring distances will be ∼100 m. The effective volume for cascades events above 100 TeV is 0.5–0.8 km^3, the threshold for muons is 10–30 TeV. The most recent km3-milestone was the construction and installation of a new technology prototype string in spring 2008. This string is operating as an integral part of NT200+. Prototype string design and first results are described in detail in [15]. First calibration and verification tests have been successful. MC-optimization for the km3-detector design is going on, as well as studies for optimal trigger technologies.

4 Conclusion

The Baikal neutrino telescope NT200 is working since April 1998. On the road towards a km3-scale neutrino telescope in Lake Baikal, significant upgrades of the detector have been done in spring 2005. Up to now the NT200+ telescope of 5 Mton enclosed volume is in operation, together with a km3-prototype string installed in spring 2008. An analysis of the NT200 data samples for the 1998-2002 seasons has been carried out. With an improved method, based on reconstructed cascade energy, a significantly lowered upper limit for a diffuse astrophysical $(\nu_e + \nu_\mu + \nu_\tau)$ E^{-2}-fluxes has been obtained. The same data samples were analyzed for neutrinos from WIMP annihilation in both the Sun and the Earth. No excess signals were found, therefore upper limits on an additional muon flux from the Sun and the Earth in dependence on the WIMP mass have been set. The results are comparable with other searches.

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