Neutrino Physics and Astrophysics with IceCube In-fills

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1 Introduction

A conclusive test of many low mass dark matter scenarios, a more precise study of atmospheric oscillation parameters, and an enhanced sensitivity towards supernova burst neutrinos would require a very large neutrino detector with a low energy threshold. Such a detector could be constructed in two phases at the geographic South Pole, making use of the excellent infrastructure, good optical properties of the naturally occurring detector medium and support structure and benefit from the IceCube detector to veto atmospheric muons. A vision to construct a multi-mega-ton ring-imaging ice-cherenkov detector capable of detecting 100 MeV events with numerous scientific applications is described in this document.

2 Path Towards a Large Detector

We propose the construction of a multi-mega-ton ring-imaging detector in two stages. The first stage (PINGU – Phased IceCube Next Generation Upgrade) would consist of an upgrade to the IceCube–DeepCore detector [1] using existing technology complimented with some new optical modules and calibration devices. Physics results are guaranteed by relying on proven IceCube sensors, while the performance of new technologies towards stage 2 can be evaluated. For the first stage 1 we envision the deployment of 18-20 string during two seasons. We aim at achieving an energy threshold of a few GeV for this multi-mega-ton detector.

A stage 2 detector, consisting on the order of 100 strings, using a technology choice based on the performance of the stage 1 array would then aim at constructing a large ring-imaging ice-cherenkov detector. We envision to reconstruct individual events above a threshold on the order of 100MeV and use collective event information to detect supernova burst neutrinos. The targeted detector volume is about five mega-tons with a photo coverage on the order of 10% for the central region of the detector.

3 Physics Motivation

The primary physics driver behind a large ring-imaging ice-cherenkov detector are dark matter searches, neutrino oscillation studies, and increased sensitivity towards supernova burst neutrinos. Extensions reaching proton decay could possibly be contemplated. Other physics topics include, but are not limited to: Sterile neutrinos, Galactic plane neutrinos, neutrinos with soft spectra from Galactic sources, and long-baseline accelerator neutrino oscillation studies [2].

Dark matter scenarios motivated by DAMAs annual modulation signal [3] and isospin-violating scenarios [4] motivated by DAMA and CoGeNT signals could be tested by a mega-ton scale detector with an energy threshold in the GeV range [5].

An energy threshold of a few GeV combined with a good angular and energy resolution, will allow to map out multiple oscillation maxima and minima in the muon neutrino disappearance distribution to perform measurements of Δm^2 and $\sin^2(2\Theta)$. A favorable value of Θ_{13}, as indicated by recent measurements [6], opens up the possibility to determine the neutrino mass hierarchy [7].

A multi-mega-ton detector is necessary to allow for potential detections of supernova burst neutrinos from beyond the Milky Way [8]. Not only would such a detector increase the chances of supernova

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observations, but detections of multiple photons from the same neutrino interaction made possible through a dense sensor spacing potentially allows to reconstruct neutrino burst energy spectra. Besides testing of core-collapse models through the acquired energy spectra and precise timing [9, 10], further science justification lies in the capability to observe neutrinos from collapses that are optically dark and to study neutrino accompanied optically bright events which are not core-collapses.

4 Detector Medium and Technology

The deep ice at the geographic South Pole possesses good optical properties below 2100 m and a high radiopurity. The absorption length at 400 nm is about $\lambda_{\mathrm{abs}} \approx 155$ m and effective scattering length is on the order of $\lambda_{\mathrm{scat}}^{\mathrm{eff}} \approx 47$ m. Uranium (^{238}U) and Thorium (^{232}Th) contaminations are very low at 10^{-4} ppb and Potassium at 0.1 ppb in the Antarctic ice [11]. The combination of low installation costs and the ability to build a contiguous detector not limited in size, makes the South Pole an ideal site. However, the maximum density of instrumentation is determined by the installation procedure and will ultimately determine what photo coverage can be achieved. While the stage 1 detector can rely on the existing hot-water drilling technology, which is well tested for IceCube, for the stage 2 detector there are likely modifications necessary. Nevertheless drilling and deployment costs are expected to be below 10% of the total costs of the array, making the "excavation cost" component a minor one for this array.

IceCube digital optical modules (DOMs) [12] are functioning extremely well, which is undermined by the fact that the number of DOMs that fail commissioning is at a percent level and the number of lost DOMs after successful freeze-in and commissioning is a fraction of a percent. The IceCube detector is operating very stable and shows detector uptimes of about 99%. DeepCore utilizes 252 mm diameter Hamamatsu R7081MOD (super bialkali photocathodes), which are identical to the standard IceCube PMTs (R7081-02), but with a quantum efficiency that is increased 40% at $\lambda = 390$ nm. While, the physics goals of the stage one detector are achievable with the existing DeepCore sensors, we intend to utilize also new photon detection technology, with the goal to demonstrate the potential for reconstructing Cherenkov ring fragments. Developed for KM3NeT [13], multi-PMT optical modules, could be adapted for the use in the ice. A possible design would feature 64 3" PMTs in a cylindrical deployment vessel of similar diameter to an IceCube DOM. The sensor coverage would be the equivalent of approximately two DeepCore 10" PMTs and achieve a pixelization of the detector and a more isotropic light acceptance. Other optical devices utilizing wavelength shifter techniques to increase the photo sensitive area in a cost effective manner are also under consideration.

5 Conclusions

The construction of a large (multi-mega-ton) ring-imaging neutrino detector at the geographic South Pole seems very feasible. A detailed design and physics capabilities study is underway.

References

[1] R. Abbasi *et al.* [IceCube Collaboration], "The Design and Performance of IceCube DeepCore," [arXiv:1109.6096 [astro-ph.IM]].

[2] J. Tang and W. Winter, arXiv:1110.5908 [hep-ph].

[3] C. Savage, G. Gelmini, P. Gondolo, K. Freese, JCAP **0904**, 010 (2009). [arXiv:0808.3607 [astro-ph]].

[4] J. L. Feng, J. Kumar, D. Marfatia, D. Sanford, Phys. Lett. **B703**, 124-127 (2011). [arXiv:1102.4331 [hep-ph]].

[5] C. Rott, T. Tanaka, Y. Itow, JCAP **1109**, 029 (2011). [arXiv:1107.3182 [astro-ph.HE]].

[6] K. Abe *et al.* [T2K Collaboration], Phys. Rev. Lett. **107**, 041801 (2011). [arXiv:1106.2822 [hep-ex]].

[7] O. Mena, I. Mocioiu, S. Razzaque, Phys. Rev. **D78**, 093003 (2008). [arXiv:0803.3044 [hep-ph]].

[8] M. D. Kistler, H. Yuksel, S. 'i. Ando, J. F. Beacom, Y. Suzuki, Phys. Rev. **D83**, 123008 (2011). [arXiv:0810.1959 [astro-ph]].

[9] R. Abbasi *et al.* [IceCube Collaboration], [arXiv:1108.0171 [astro-ph.HE]].

[10] L. Demiroers, M. Ribordy and M. Salathe, arXiv:1106.1937 [astro-ph.IM].

[11] J. Cherwinka, R. Co, D. F. Cowen, D. Grant, F. Halzen, K. M. Heeger, L. Hsu, A. Karle *et al.*, [arXiv:1106.1156 [astro-ph.HE]].

[12] R. Abbasi *et al.* [The IceCube Collaboration], Nucl. Instrum. Meth. **A618**, 139-152 (2010). [arXiv:1002.2442 [astro-ph.IM]].

[13] KM3NeT homepage available at http://www.km3net.org